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Workshop on

PHYSICS WITH A

MULTI-MW PROTON SOURCE

CERN, Geneva, May 25-27, 2004

Editors: A. Blondel, Y. Blumenfeld, P. Butler, R. Garoby, M. Lindroos, V. Palladino, A. Rubbia
From oral and written contributions by : R. Aymar, J. Ellis, S. Nagamiya, S. Holmes, C. Prior, W.Scandale, H. Haseroth, M. Apollonio, A. C. Mueller, P. Hernandez, L. Mosca, C.K. Jung, K.Nakamura, A. Ereditato, S. Geer, P.Migliozzi, A.Baldini. A. Van der Schaaf, A. Ceccucci, W.Gelletly, F. Gulminelli, K.-L. Kratz, K. Jungmann, J. Aystö, T. Nielsson, H.-J. Kluge, B. Weng, M.Spiro, M. Harakeh, J. Engelen.

Physics with a multi-Megawatt proton source

Summary

The workshop 'Physics with a multi-Megawatt (MMW) Proton Source' was held at CERN on 25-27 May 2004. It was organized by the ECFA/BENE working groups for future neutrino facilities in Europe and by the EURISOL nuclear physics community to explore the physics opportunities offered by a new high intensity proton accelerator. It confirmed the important synergies that exist between these communities. This document summarises the main design choices for the accelerators and experiments involved, the physics possibilities and the most critical R&D that will be necessary. A preliminary baseline road map is delineated.

A strong and diverse physics programme was highlighted.

The leading particle physics case is provided by the study of neutrino oscillations with the ultimate aim of discovery and study of leptonic CP violation. Two main options emerge.
1) A Neutrino Factory based on a high brilliance muon beam would provide high-energy electron neutrinos (up to 20-50 GeV). Aimed at dense magnetic detectors situated ~700 to 4000 km away, this is by far the best tool to perform very precise and unambiguous measurements of oscillation parameters, neutrino mass hierarchy, CP violation and tests of universality in the neutrino sector.
2) A neutrino beta-beam facility would provide a very clean beam of electron (anti) neutrinos from beta decay of high energy radioactive ion beams of characteristics similar to those of EURISOL. The very large detectors that are required are the same as those needed to extend the search for proton decay and astrophysical neutrinos. In combination with a low energy conventional neutrino beam (superbeam), this would provide interesting sensitivity in search for leptonic CP and T violation.

In addition, the near detectors of these facilities offer the possibility to study neutrino interactions with great precision in various energy regimes. The envisaged proton driver offers great flexibility of time structures and would allow cutting edge experiments in low energy muon physics. It will be of great utility for the high intensity operation of the LHC, and will allow higher intensities to be achieved throughout the present CERN complex and fixed target experiments.

A high intensity proton accelerator has been advocated as opening a wide field of new possibilities in nuclear physics as well, with the availability of intense beams of rare radio-isotopes. The detailed study of properties of nuclei at the edges of stability should project decisive light on the fundamental but still largely mysterious question of nuclear matter and its dynamical symmetries. The simultaneous availability of radioactive ion beams and of low energy muon and antiproton beams should allow a new class of experiments to be performed., several of which are critical for the understanding of star formation and supernovae.

The choices that will need to be made in the near future require the critical R&D and studies to be carried out. The list comprises i) the study of high power target, particle collection elements and target stations, ii) the study of beam activations in the proton driver and subsequent accelerators, iii) the demonstration of ionisation cooling, iv) the feasibility study of large underground caverns and v) R&D on the very large detectors that are envisaged.

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1 Foreword: High Energy and High Intensity Frontiers

(R. Aymar, V. Palladino)

In his welcome address, CERN DG Prof. R. Aymar outlined his general view of CERN mission and options for the future.

- CERN is the largest particle physics laboratory in the world, with a history of building and operating accelerators at the high-energy frontier, like the SPS proton/antiproton Collider, LEP and, soon, LHC. Along this logic, CERN is now actively pursuing R & D of CLIC.

- CERN has also a successful tradition of addressing simultaneously diverse physics issues (fixed target experiments, neutrinos, radio-active ions, anti-protons) exploiting at best the capabilities of its accelerator complex. Therefore, the management, with the support of the Council and the Scientific Policy Committee, is willing to plan the future in that respect as well.

He welcomed and thanked all participants for their contribution to the preparation of the meeting organized for that purpose by the CERN SPSC next September in Villars. The CERN management will welcome all help in the definition the optimum changes to be made to the CERN accelerators, so to cover the most ambitious and promising spectrum of physics experiments.

He outlined the two driving scientific motivations of a new vigorous physics program at the high-intensity frontier, and thus for a new MMW proton facility and this Workshop:

- The discovery of neutrino oscillations has opened a new window of exploration, unique in several ways. Measured mass splittings and mixings of neutrinos have been already providing the first experimental data on physics at higher energy scales. Discovery of leptonic CPV promises insight into the most fundamental asymmetries of the universe. The accelerator neutrino community in Europe, now organized also in the BENE network, will do all efforts to maintain a leading role in the sector of accelerator neutrino experiments beyond the CNGS. Its present plans should emerge clearly and in detail.

- The manifestation of the strong and weak interaction in the atomic nucleus can be rigorously investigated through nuclei with anomalous proton/neutron ratio. NuPECC estimates the size of the European community to be over one thousand scientists and has prioritized two second-generation facilities with complementary physics reach: GSI-FAIR, based on the In-Flight separation (IF) method, and EURISOL, based on the Isotope Separator On-Line (ISOL) method. Among the potential sites for hosting a future high-intensity EURISOL facility, CERN has unique possibilities of synergy with a neutrino programme. This workshop should help clarify its extent and determine whether other physics programmes could also benefit

Among the possibilities, a superconducting proton linac (SPL) delivering MegaWatts of beam power at a few GeV has already attracted the interest of the communities interested in radio-active ion beams and in neutrinos. It is clear that such an accelerator could also be beneficial

to the whole CERN accelerator complex, renovating the low energy injectors (Linac 2 and PSB), and increasing drastically their performance.

Rapid cycling synchrotrons delivering MMW proton beams at higher energies deserve also to be considered as alternative or complement to the SPL option. The CERN management would like the help of all communities concerned to refine the specifications of the future CERN proton complex to optimize its interest and potential. Additional extensions should be considered. Comparison with alternative solutions is encouraged. Needless to say, resources are limited, and convergence among requests has to be fostered. A clear outlook of the future must be the task of the workshop.

2 The High Intensity Frontier

(A. Blondel, J. Ellis)

The last few decades in particle physics have seen the extraordinary success of the Standard Model, which explains most observed phenomena in terms of gauge theories. In particular, experiments at the CERN PS and SPS, followed by the $\bar{p}p$ and LEP Colliders, discovered and studied precisely the Neutral Currents and the $W^{\pm}$ and Z bosons. This established the validity of the Standard Model, the quantum theory of particles and their strong and electroweak interactions, to distance scales of ~ 10^{-18}m.

Despite these recent successes, a number of extremely fundamental physics questions remain unanswered. Extensions to the Standard Model are almost certainly required. Among the most important issues, one can mention:

- what is the origin of the widely different masses of elementary particles, and more precisely what is the process that breaks electroweak symmetry;
- what are the origins of the different fundamental forces, and can a unified description of the forces be made;
- is the proton stable;
- what is the origin of matter-antimatter asymmetry in the universe;
- what is the composition of dark matter, and the nature of dark energy in the universe;
- what is the dimensionality of space-time and the role of gravity?

Laboratory exploration in particle physics has traditionally progressed along different and truly complementary lines. The first one is the high-energy frontier, which has been embodied at CERN by the S $p\bar{p}$ S, LEP and will soon advance further with the LHC. There is no doubt that LHC will open a domain of yet unexplored energies and answer a number of these questions, in particular in the domain of the electroweak symmetry breaking, addressing the burning issues of the existence and nature of the Higgs boson and supersymmetric particles.

Many of the other questions require different means of investigations with very detailed studies of the properties of already known particles. This requires well controlled experimental conditions as well as high statistics. In the last few years, the requirements for neutrino physics have led to the study of high intensity neutrino sources, such as the recently published 'CERN/ECFA studies of a European Neutrino Factory Complex' [ECFAreport]. Beyond neutrino oscillation physics, this report emphasized the wide interest of a high-intensity complex based on a multi-Megawatt proton accelerator, for studies of rare decays and precise properties of muons and kaons, deep-inelastic scattering with neutrinos, as well as the longer-term possibility of muon colliders. At the same time, the nuclear-physics community, a long-time user of CERN with ISOLDE, has been stressing the virtues of a high-intensity upgrade of the existing facility, with the EURISOL study [EURISOLe]. The convergence of interest between the particle-physics and nuclear-physics communities is one of the striking aspects of this **high-intensity frontier**. Without going into details that will appear in the following chapters, a foretaste of the physics issues is presented in the following.

The leading possibility for a high-intensity proton accelerator at CERN is the Superconducting Proton Linac (SPL). As shown in Figure 1, it could fit nicely adjacent to the CERN site and feed into the existing CERN infrastructure.

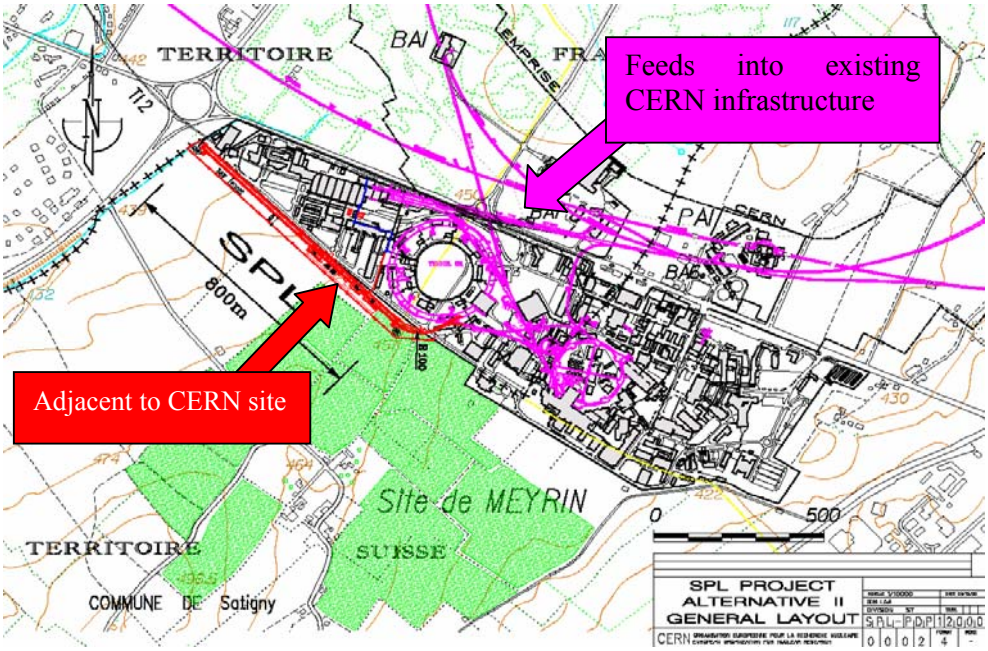

Figure 1 Possible layout of the Superconducting Proton Linac on the CERN site.

As discussed in chapter 4, (see, in particular, Table 2) a survey [HIP_web] has shown that the high-intensity requirements from CERN users cover the CNGS and fixed-target programme, the LHC upgrade, and on a more ambitious scale, the nuclear-physics community, and the high intensity particle physics programme in neutrino, muon and kaon physics in particular.

Clearly, ensuring that the LHC can reach the highest possible luminosity will be of tremendous importance, especially if this can be achieved in a way which is convenient to the experiments (avoiding excessive pile-up of events) while minimizing the integrated radiation dose in the vicinity of the experiments. Although it is not entirely clear at the moment how this can be best achieved, the flexibility offered by a high brilliance proton source with flexible time structure will in all likelihood be very valuable.

2.1 Nuclear physics

As shown in Figure 2, the SPL protons could be served to a new complex of Radioactive Ion Beams (RIB), EURISOL, which is described in detail in section 5.3. The Isotope Separation On-Line (ISOL) technique to produce radioactive beams has clear complementary aspects to the In Flight Fragmentation (IFF) method which will be used at the project FAIR recently approved in GSI (see section 3.3). First-generation ISOL-based facilities have produced their first results and have been convincingly shown to work. EURISOL aims at increasing the variety of radioactive beams and their intensities by orders of magnitude over the ones available at present. As shown in Figure 3, this will offer rich opportunities for various scientific disciplines including fundamental nuclear physics, nuclear astrophysics and the study of fundamental symmetries, as well as a number of other applications (radioactive spies, curing chemical blindness, positron annihilation studies, applications to biomedicine, etc).

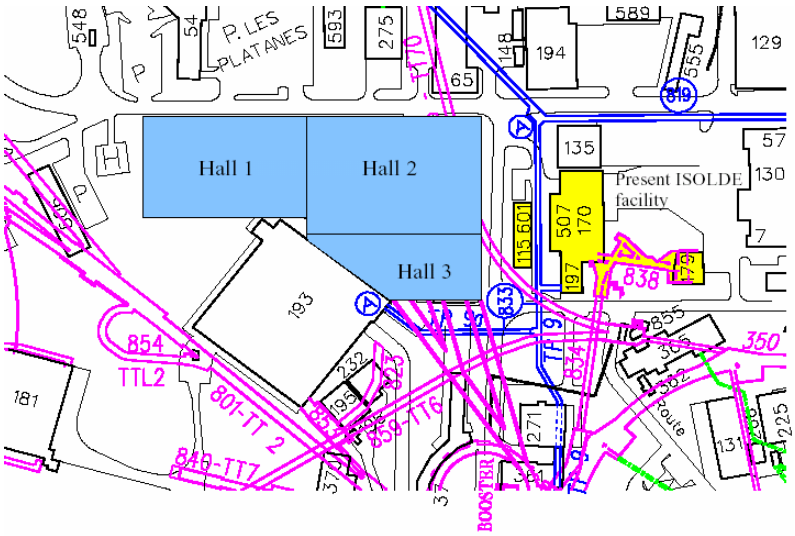

Figure 2 Possible location of the EURISOL complex at CERN.

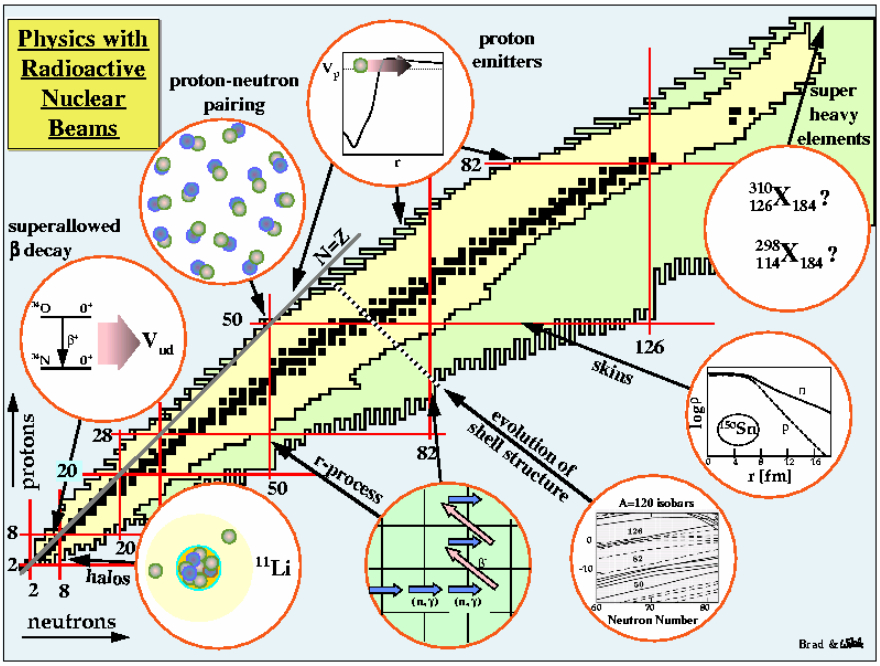

Figure 3 Several aspects of physics with Radioactive Nuclear Beams.

2.1.1 Fundamental nuclear physics.

Although nuclei can be seen as composed of few well known elements bound by a well-known force, the resulting complexity is such that many fundamental questions remain unanswered. In particular it is not clear what are the boundaries of the domain in which nuclei are stable, either at the neutron and proton drip lines, or in the limit of super-heavy elements. Establishing the limit of nuclear existence involves rare reactions and thus will require the very high intensities that EURISOL would allow.

Among other fundamental questions, one can cite the role played by nucleon pairing (nucleonic Cooper pairs), the appearance and behavior of neutron haloes and skins in neutron-

rich nuclei, and more generally the modification of shell closures and magic numbers in the vicinity of the drip-lines (see sections 8.1 and 8.2).

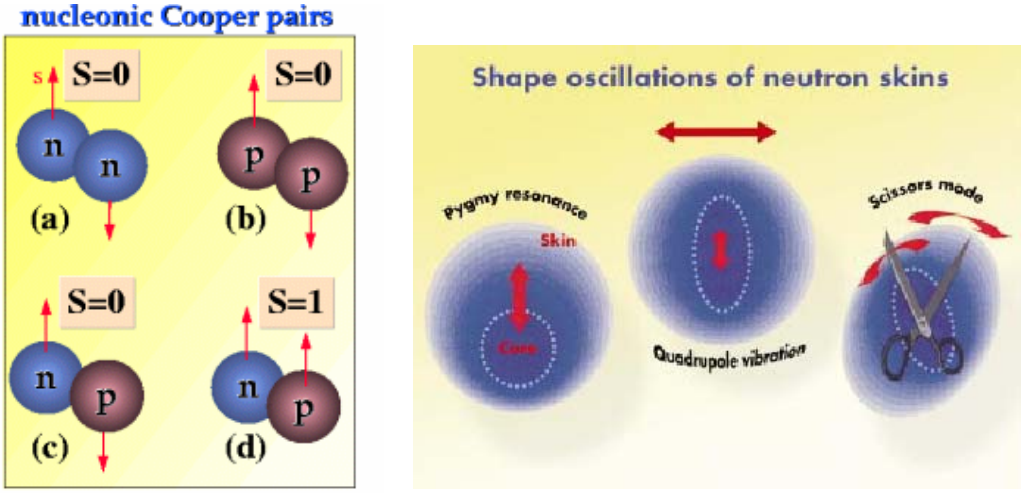

Figure 4: illustration of some fundamental questions in Nuclear Physics; on the left, the formation of bosons in the nucleus ('nucleonic Cooper pairs') is an important ingredient to understand why some nuclei are stable and others not; on the right, the neutron rich nuclei have a 'skin' of neutrons which display shape oscillations in various modes.

2.1.2 Nuclear Physics and Astrophysics

Many phenomena in the universe, such as novae and supernovae, X-ray busts, black hole formation or primordial nucleo-synthesis, represent nuclear experiments on a grand scale, often under conditions that – at least for the time being – cannot be replicated on earth. Nuclear physics is an essential provider of the experimental and theoretical data which are needed to model these phenomena. Figure 5 illustrates this point and describes the path through largely unknown nuclear regions that the nuclear reactions follow to produce the heavier nuclei. The most important parameters needed to be able to improve these calculations are nuclear masses (including n- and p-separation energies) near the proton drip-lines, β-decay half-lives along the process paths and n- and p-capture rates on 'short-lived' nuclei. As discussed in chapter 8.3, many of these data are very poor or completely missing at present and the whole field would benefit considerably from systematic data and understanding of these processes.

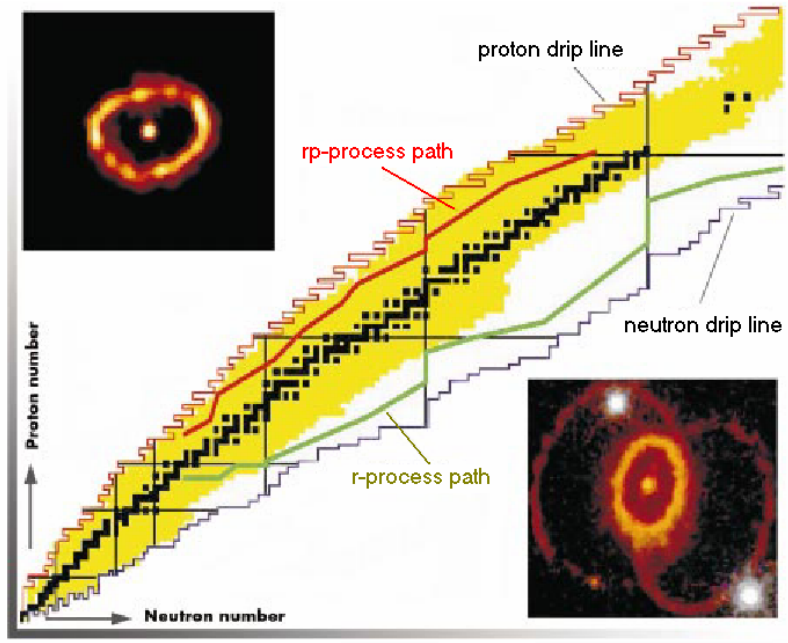

Figure 5 Novae and Supernovae constitute nuclear reactions at a grand scale. The explanation of the energy production in explosive thermonuclear burning probably requires two distinct neutron-capture processes as the origin of heavy nuclei beyond iron.

2.1.3 Other applications

As will be discussed in section 8.4, the availability of intense beams of various nuclei, but also pions and muons should allow very precise search for violations of fundamental symmetries. Among these one could cite the search for neutron and muon electric dipole moment (EDM), search for T violation in beta decay (using reconstruction of final-state momenta and spin polarisation). Also the search and study of rare or forbidden nuclear decays should be of great interest to improve the understanding of nuclear matrix elements, possibly shining some light on those necessary for the interpretation of neutrino-less double beta decay.

The combined availability of intense of radioactive ion beams with intense muon or antiproton sources opens the very interesting possibility of probing nuclear matter with muonic and anti-protonic atoms, in which the nuclei is already rare or unstable. This technique is both a probe of the structure of these nuclei, as well as a means to produce nuclei one or several steps closer to the drip lines (section 8.5).

Finally one cannot close this discussion on nuclear physics without mentioning the industrial applications such as radioactive spies, curing chemical blindness, positron annihilation studies, applications to biomedicine, and material science that benefits from intense beams of radioactive ions, neutrons and muons.

2.2 Particle physics

The leading particle-physics motivation for a high-intensity proton driver is the study of neutrino oscillations, but the facility would also offer great opportunity for the neutrino, muon and kaon physics. Last but not least, a Neutrino Factory would be the first step towards muon colliders.

2.2.1 Neutrino oscillations

The observation of neutrino oscillations has now established beyond doubt that neutrinos have mass and mix. This existence of neutrino masses is in fact the first solid experimental fact requiring physics beyond the Standard Model. It was soon realized that with three families and for a favourable set of parameters, it would be possible to observe experimentally violation of CP or T symmetries in the neutrino oscillation phenomenon [Ruj99]. This observation reinforced the already considerable interest for precision measurements of neutrino oscillation parameters. We know since 2003 and the results from SNO and KAMLAND [SNO02], [Kamland02] that the neutrino parameters belong to the so-called LMA solution which suggests that leptonic CP violation should be large enough to be observed in high-energy neutrino oscillation appearance experiments.

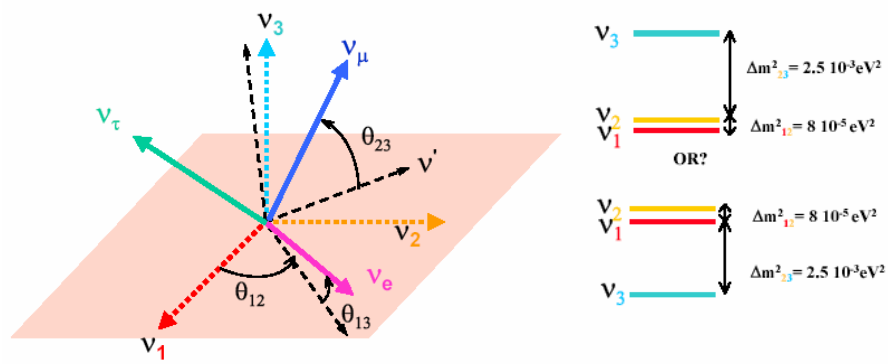

Figure 6 Graphical representation of the present knowledge of the neutrino mixing matrix. The rotations by the successive Euler angles θ_{12}, θ_{13}, θ_{23} that transform the mass eigenstates ν_1 ν_2 ν_3 into the flavour eigenstates ν_e ν_μ ν_τ are shown on the left, while the mass splittings are shown on the right. The best present values are $\theta_{12}=32^0$, $\theta_{23}=45^0$, $\theta_{13}<13^0$, and $\Delta m^2_{12} = +8\ 10^{-5}\ eV^2$, $\Delta m^2_{23} = \pm 2.5\ eV^2$. In addition there is a phase, δ, which generates CP and T violating effects in neutrino oscillations.

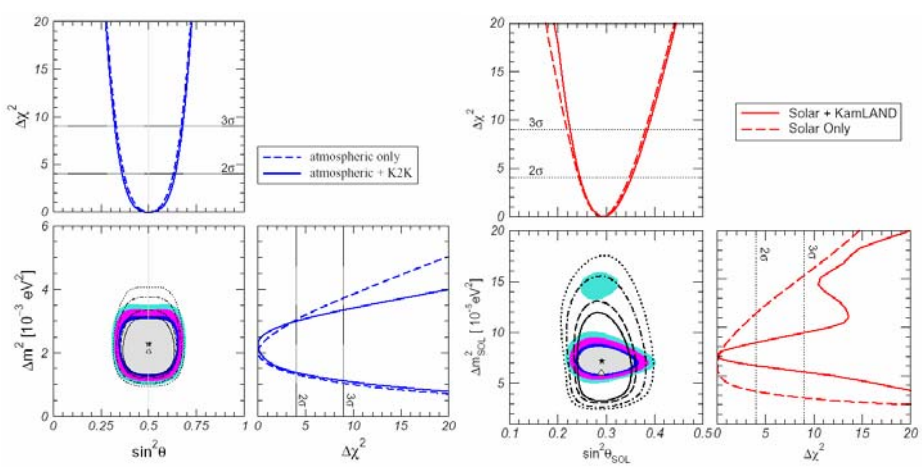

Figure 7 Determination of the neutrino mixing parameters at the time of the workshop. Left: θ_{23} and Δm^2_{23} from atmospheric neutrinos and the K2K experiment; right: θ_{12} and Δm^2_{12} from the solar neutrinos and the KAMLAND experiment [neutrinofits].

The fact that neutrinos have masses that are so much smaller than those of the other known fermions (12 orders of magnitude smaller than the electroweak mass scale or the top quark mass) is a mystery that could open the way to the solution of a number of fundamental questions. One can find a more or less natural explanation in the so called 'See-Saw' mechanism [seesaw]. In this scenario, the neutrinos are very light because the observed light neutrinos are low-lying states of split doublets with heavy neutrinos of a mass scale M which is interestingly similar to the grand unification scale:

$$m_\nu M = v^2 \qquad \text{with } v \approx m_{top} \approx 178 \text{ GeV} \Rightarrow \qquad M \leq O(10^{15}) \text{ GeV}$$

The combination of this scenario with the fact that neutrinos could violate CP symmetry opens the fascinating possibility to explain is simple terms the matter-antimatter asymmetry of the universe [leptogenesis], if for instance the decays of heavy Majorana neutrinos violate CP violation, in a way similar to what happens in K^0_L decays:

$$N \rightarrow \ell^+ X \neq N \rightarrow \ell^- X,$$

with the resulting lepton-antilepton asymmetry propagating later into a baryon-antibaryon asymmetry.

Clearly the study of neutrino properties and in particular the search for leptonic CP violation is a subject of the highest scientific priority.

The tools of choice to search for leptonic CP violation are the oscillations $\nu_e \leftrightarrow \nu_\mu$, and at a later stage $\nu_e \leftrightarrow \nu_\tau$. The search for an asymmetry between neutrino and anti-neutrino oscillations requires dedicated appearance experiments with high statistics and well-defined flux. Solar neutrinos and reactor neutrinos are of too low energy to allow appearance experiments, while atmospheric neutrinos, being an intrinsic mix of neutrinos and anti-neutrinos, are inadequate. Invariably, the requirement of high flux accelerator-generated neutrino beams leads to the need for a high-intensity proton source.

Several possibilities exist for neutrino oscillation experiments. First the CERN to Gran Sasso beam, which is optimized for the search for the $\nu_\mu \rightarrow \nu_\tau$ appearance, would certainly benefit from an increased availability of protons. Then, using more directly the SPL, the following possibilities have been envisaged: the low energy superbeam [Gomez01], beta-beams [Zucchelli], and the Neutrino Factory [Geer98], as sketched on Figure 8.

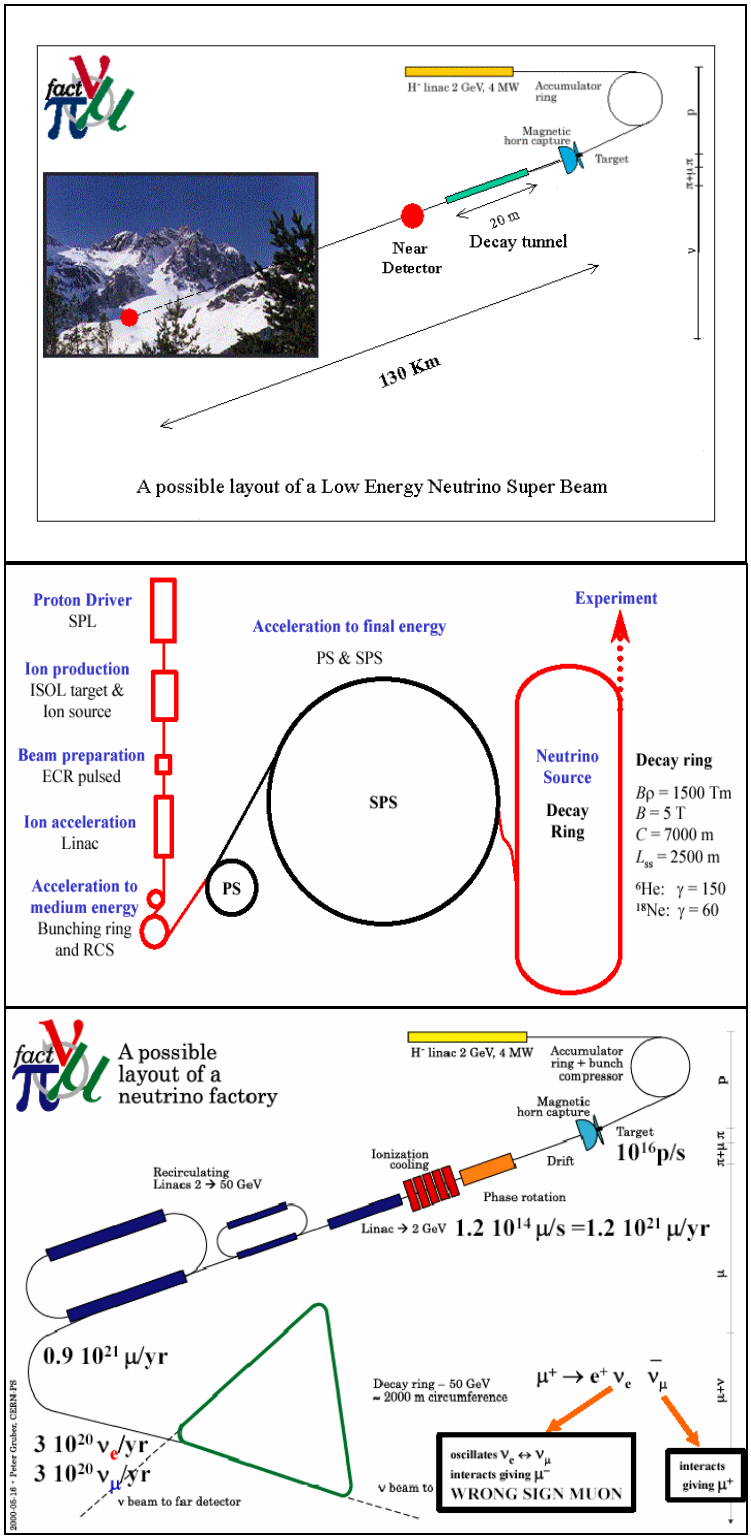

Figure 8 Three possible neutrino facilities based on the same proton driver. Top: a low energy conventional pion decay beam; middle the beta-beam where ^{6}He and ^{18}Ne RIBs are accelerated using the PS and SPS as accelerators; bottom, the Neutrino Factory where muons are accelerated and stored at 20-50 GeV.

The superbeam and beta-beam have the advantage of having similar energies which allows usage of the same far detector that could be located for instance in a new international laboratory in the Fréjus tunnel (see sections 6.2, 6.3 and 6.4). The Neutrino Factory must use its own different detector. A comparison of performances of the three options of Figure 8 is made in Figure 9. All three proposals are superior to existing or planned facilities in the world, but the Neutrino Factory is clearly a much more powerful device. It may, however, be more difficult and expensive than the others. As pointed out in chapter 6.1.3, using a high energy beta-beam could partly compensate the performance deficit of the low-energy one, but the technical and financial implications have not yet been established.

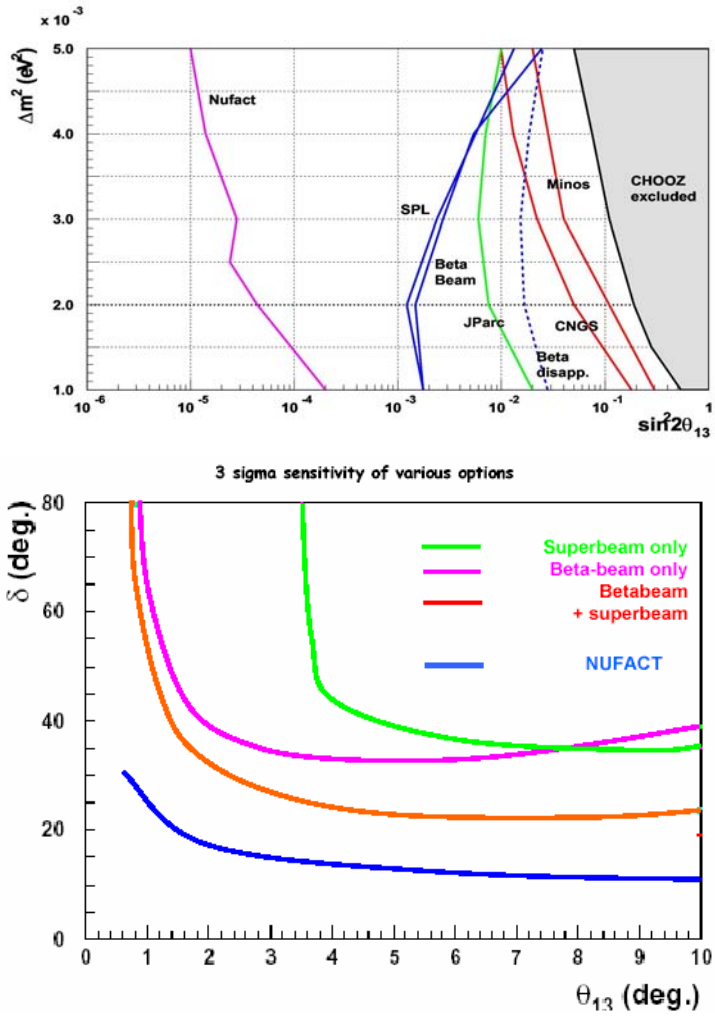

Figure 9 relative sensitivity to θ_{13} (top) and to the CP violating phase δ (bottom), of various options of Figure 8 for future neutrino facilities based on a high intensity proton driver.

2.2.2 High-precision neutrino scattering

As discussed in [Mangano01], [Bigi01], the neutrino beams at the end of the straight section of a Neutrino Factory offer an improvement in flux by several orders of magnitude over conventional beams, allowing several times 10^8 events to be collected per kilogram and per year (Figure 10). This could allow a new generation of neutrino experiments, where very detailed studies of nucleon structure, nuclear effects, spin structure functions and final state

exclusive processes can be made. Also precision tests of the Standard Model could be carried out in neutrino scattering on nucleon or electron target, as well as a precise determination of neutrino cross-sections and flux monitoring with permil accuracy.

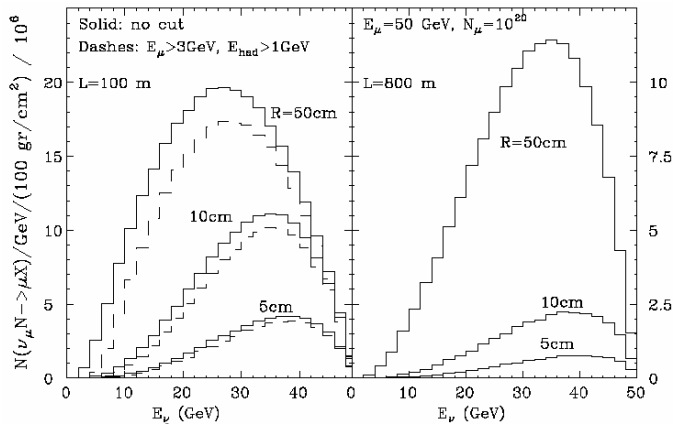

Figure 10 Event rates at the exit of the straight sections in a Neutrino Factory. Note the scale.

As discussed in chapter 7.1, in the case of a superbeam or beta-beam, the study of low-energy neutrino interactions in a near detector is mandatory for the sake of the oscillations analysis. In addition, the understanding of the low-energy transition from elastic reactions to the resonance region and the deep inelastic region is in great need of accurate data.

2.2.3 Muon physics

A high-intensity proton source could certainly produce many low-energy muons and thus, provided the beam and experiments can be designed to do so, provide opportunities to explore rare decays, such as $\mu \to e\,\gamma$, $\mu \to e\,e\,e$, or the muon conversion $\mu\,N \to e\,N$, which are lepton-number-violating processes. While the See-Saw mechanism provides a very appealing explanation of neutrino masses and mixings, its inclusion in supersymmetric models almost invariably leads to predictions in excess or close to the present limits for these processes.

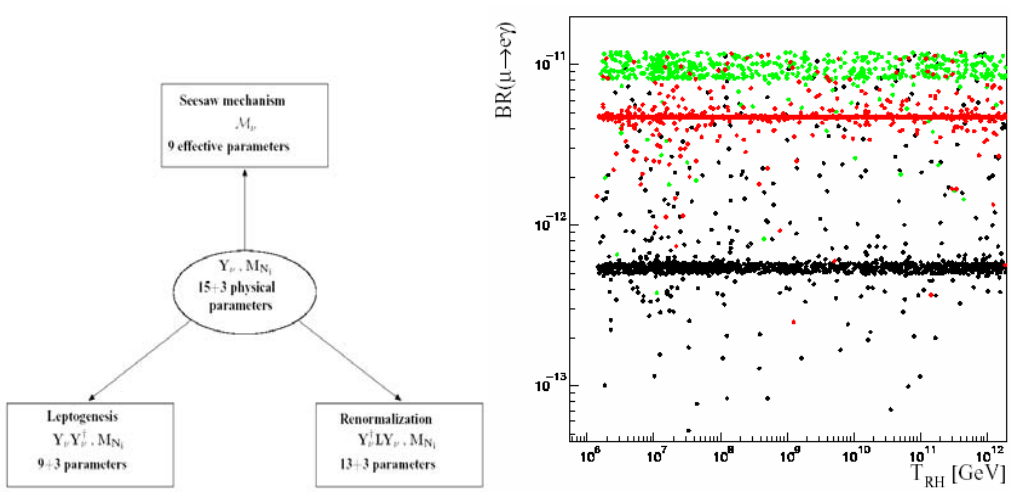

Figure 11 Supersymmetric See-Saw mechanism (left) leads to predictions (right) for the branching ratio $\mu \to e\,\gamma$ that are close to or even beyond the present limits of ~10^{-11} .

It is therefore quite possible that one of these processes will be discovered in the upcoming generation of experiments (MEG at PSI, MECO at BNL) in which case a detailed study would become mandatory. If not, further search with higher sensitivity would be in demand. It should be emphasized that the three processes are actually sensitive to different parameters of these models, and thus complementary from both the experimental and theoretical points of view.

Another fundamental search would clearly be the search for a muon electric dipole moment (EDM), which would require modulation of a transverse electric field for muons situated already at the magic velocity where the magnetic precession and the anomalous (g-2) precession mutually cancel.

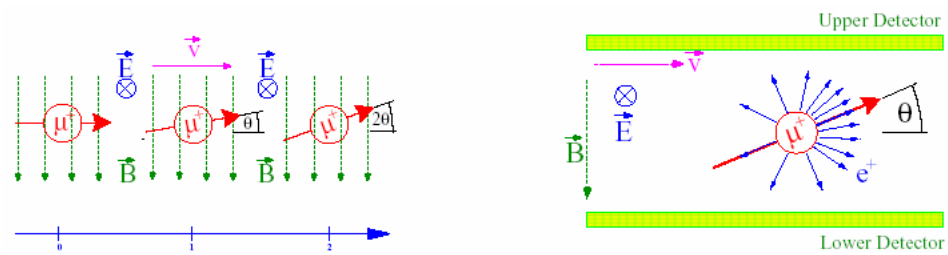

Figure 12 Principle of the measurement of the muon EDM

2.2.4 Kaon physics

Kaons have played a fundamental role in the discovery of both parity violation and CP violation. Despite the great advance due to B factories, there is a growing interest in challenging channels such as $K^+ \to \pi^+ \nu\bar{\nu}$, and $K^0 \to \pi^0 \nu\bar{\nu}$, which is a CP-violating process. Discovery or precision study of these processes constitute further test of our understanding of CP violation in the quark sector.

In addition the search for rare processes such as $K^0 \to \mu\, e$ is a sensitive probe of new physics. As discussed in section 7.3, enhanced performance of the SPS combined with new experimental designs would open these possibilities.

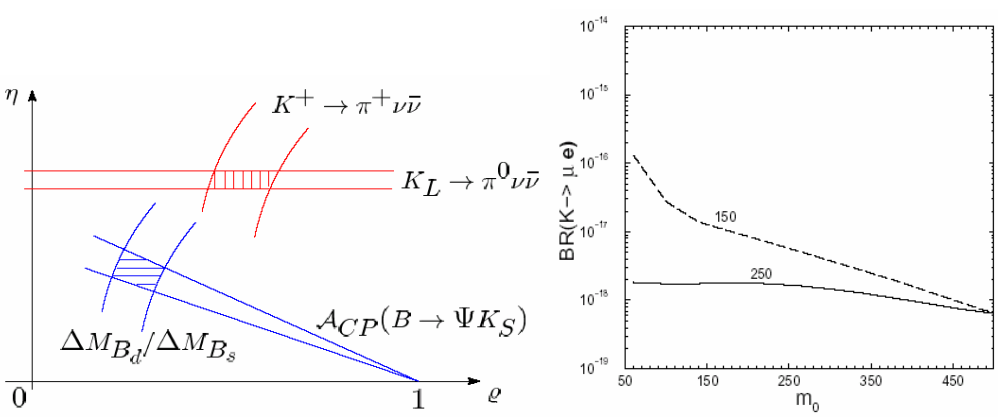

Figure 13 Left, the dependence of the rare decays $K^+ \to \pi^+ \nu\bar{\nu}$, and $K^0 \to \pi^0 \nu\bar{\nu}$ upon the parameters of the unitarity triangle; right, sensitivity of $K^0 \to \mu\, e$ to the Susy mass scale m_0.

2.2.5 Muon Colliders

Finally, although it was not discussed at the workshop, it is worth keeping in mind that the Neutrino Factory is the first step towards muon colliders. As shown in [muoncollider], the relevant characteristics of muons are that, compared to electrons, i) they have a much better defined energy, since they hardly undergo synchrotron radiation or beamstrahlung, ii) their coupling to the Higgs bosons is multiplied by the ratio $(m_\mu/m_e)^2$, thus allowing s-channel production with a useful rate.

These remarkable properties make muon colliders superb tools for the study of Higgs resonances, especially if, as predicted in supersymmetry, there exist a pair H, A of opposite CP quantum numbers which are nearly degenerate in mass. The study of this system is extremely difficult with any other machine and a unique investigation of the possible CP violation in the Higgs system would become possible.

2.3 Conclusions

A proton accelerator of multi-MegaWatt power would offer a very strong physics case with opportunities for a large variety of cutting-edge experiments. It is synergetic with the CERN middle-term programme providing an upgrade of the LHC luminosity as well as the intensity of the fixed-target programme. It allows one to envisage a long-range neutrino-physics programme, with superbeam, beta-beam and/or Neutrino Factory, and a complementary high-intensity muon physics programme, possibly leading to muon colliders. In addition, it is the backbone of the next generation facility for nuclear physics with important consequences for astrophysics and precision tests of the Standard Model. It certainly constitutes an interesting project – and CERN would be a good place for it!

3 Planned High Intensity facilities in the world

3.1 The Japanese Proton Accelerator Reseach Center J-PARC

(S. Nagamiya, V. Palladino)

The physics program and the experience of this facility was presented by its DG, Prof. S. Nagamiya. As the highest power proton facility presently approved and being built, J-PARC [Jparc] represents the natural reference and benchmark for any future high power project. So does the multi-disciplinarity and variety of its program that proved indispensable, and so far unique, to make it possible.

After the groundbreaking ceremony of June 2002, the centre is in advanced state of construction at the JAERI site in Tokai, on the Pacific coast, about 2 hours NE of Tokyo. Once completed, the complex (Figure 14) will comprise a 350 m long Linac, a 1 MW 3 GeV Synchrotron at 25 Hz, and a 0.75 MW 50 GeV Synchrotron. It will be a multipurpose installation serving four different facilities: Materials and Life Science, Nuclear & Particle Physics and Neutrino to Superkamioka [Fukuda98], and Nuclear Transmutation.

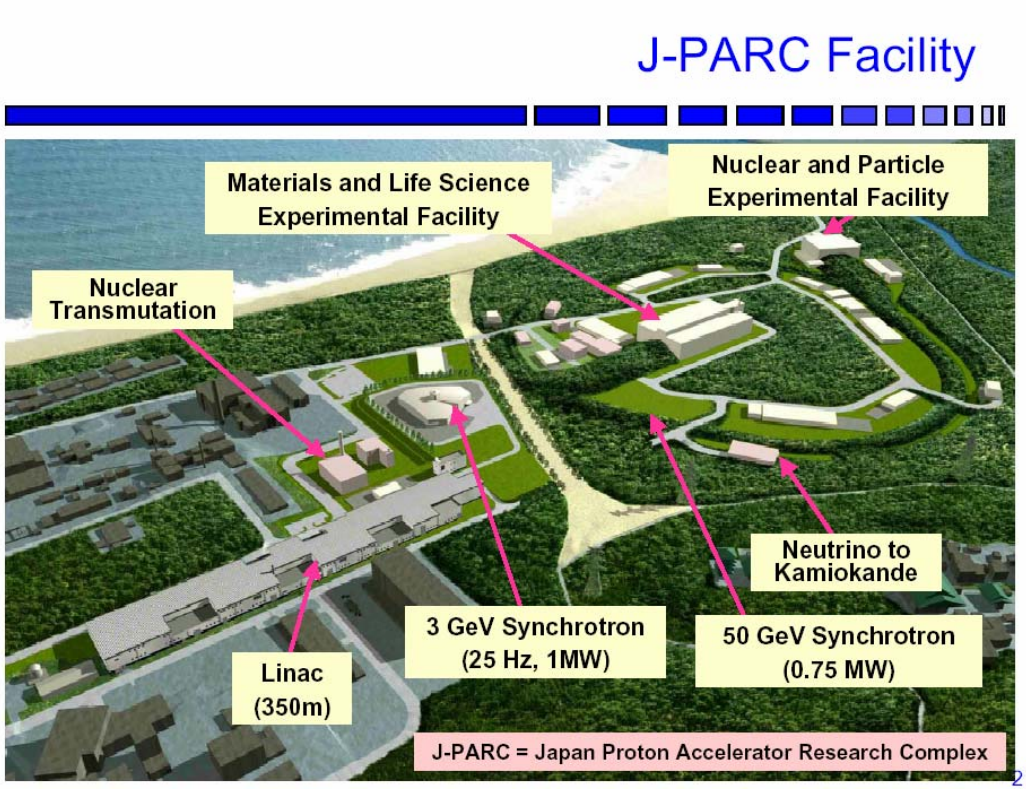

Figure 14 Artistic aerial view of the Japanese Proton Accelerator Reseach Complex J-PARC

The proton beam at 3 Gev will drive a source of the high intensity pulsed Japanese spallation neutron source (JSNS) whose 23 neutron beam lines will be exploited by the Materials and Life Science facility (magnetism, fractals, polymers, structural biology etc). Muon beams from the 3 GeV protons will also be used at the Materials and Life Science facility. The 50 GeV beam 50 will produce 1) hadronic beams (pions, kaons, antiprotons etc) to study mesons

in nuclear matter, rare kaon decays, hyper-nuclei, antimatter 2) a conventional neutrino (super)beam for the study of neutrino oscillations and and 3) in a future stage, high intensity muon beams from pion decay for fundamental and applied muon science. The Nuclear Transmutation facility will operate at 0.6 GeV.

The approved neutrino oscillation program [T2K] is based on a conventional ν_μ superbeam derived from the 50 GeV synchrotron. It has become known as the T2K (Tokai to Kamioka) project (Figure 15), successor of the K2K (KEK to Kamioka) experiment [K2K] that has confirmed, with man made laboratory neutrinos, the phenomena of ν_μ disappearance first observed in the Kamioka detectors with atmospheric neutrinos. The T2K neutrino flux will be about 100 times larger that K2K's. ν_μ disappearance, presumably dominated by the transition into ν_τ , will be studied with superior precision. The compelling search of the subdominant transition into ν_e , that promises the answers to the remaining and most intriguing questions concerning neutrino mixing, will be possible with unprecedented sensitivity.

Figure 15 Layout of theT2K experiment

If transition $\nu_{\mu,}$ to ν_e are discovered in the first phase of T2K and if it will prove possible to run the 50 GeV accelerator at significantly higher power, the project may have a second phase with a 50 times larger Hyper-Kamiokande detector, 1 Megaton or so, aiming at discovery of leptonic CP violation.

Construction of all elements of the complex has started. In spite of different causes of delay, among them the lucky discovery on site of invaluable archeological findings from the Japanese middle ages, accelerator beams are expected to be operating in the spring of 2008 and the experimental facilities will be coming into operations in 2008 and possibly in early 2009, at the latest, when the neutrino superbeam will also start operation. The total capital cost will be 151 GYens, grossly equivalent to 1.5 G$, for the first seven years phase. So far, about 80% of purchase commitments were granted. The cost will rise to 189 GYens, when including its phase II after 2009.

The origin of the J-PARC is rooted in the 1998 negotiations and in 1999 MOU between the Atomic Energy Research Institute (JAERI) and the High Energy Accelerator Research Organization (KEK) agencies. Strongly encouraged in the following years, under the auspices of the newly established fundamental & applied science & technology joint MEXT ministry, the project obtained the construction budget for its first phase in 2001. Notably, however, ideas for a joint large hadron facility project have to be traced, at least back to 1985!

In the area of nuclear and particle physics, a first call in 2002 resulted in 30 LOI [jparclois], signed by 478 physicist, about 2/3 non- Japanese. The call for proposal is expected in 2004-2005. An International Advisory Committee (IAC) has long been in place since its birth of the project.

On October 30, 2003,the LINAC had a successful acceleration of 6 mA at 20 MeV. On November 7, 30 mA was achieved. Among the recent realizations are the ceramic vacuum pipe for the 3 GeV beam and the first RF cavities with extremely high field gradient of 50 kV/meter, dipole and quadrupole magnets for the 50 GeV synchrotron. Impressive progress in construction was manifest from pictures taken at the annual meeting of the IAC in March 2004.

Due to financial difficulties, the energy of the front end LINAC will be initially limited to 200 MeV, but work towards its upgrade to the original 400 MeV will start immediately after. This will result in a delay in the achievement of the target intensity (1 MW at 3 GeV and 0.75 MW at 50 GeV) of the first phase. Achieving higher intensities, up to 4 MW, represents one of the major challenges and unknowns for the successive phases of the facility.

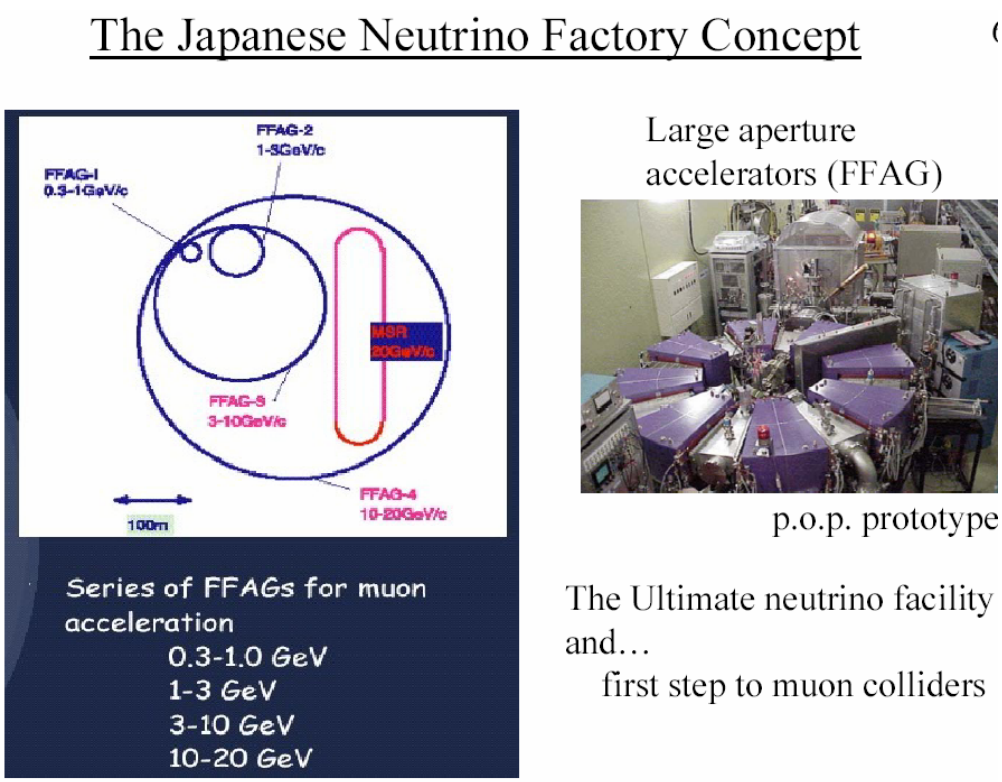

Figure 16 The J-Nufact scheme for a Neutrino Factory, based on a chain of FFAG accelerators

The number of facilities is also expected to evolve. It is worth mentioning, because relevant to the neutrino sector, that preliminary plans have been outlined, following an independent and original Japanese scheme [Jnufact], to use the high intensity muon area as the front end of a Neutrino Factory (Figure 16).

3.2 U.S. Plans for High Power Proton Drivers

(S. Holmes)

3.2.1 Motivations

A "proton driver" is defined as an accelerator capable of delivering beam power in excess of 1 MW onto a target, derived from a proton beam of at least 1 GeV. A broad range of motivations for high intensity proton drivers exist as described by Ellis [Ellis04]. Within the United States both Fermi National Accelerator Laboratory (Fermilab) and Brookhaven National Laboratory (BNL) are developing concepts for proton drivers with 1-2 MW of beam power [Weng03],[Fermi02]. For Fermilab and BNL, with traditions in high energy and nuclear physics, the motivations center around neutrino physics, rare kaon and muon decays, pulsed neutrons, and/or ultimate utilization as an injector into a hadron collider beyond the Large Hadron Collider at CERN.

3.2.2 U.S. Design Concepts

The Fermilab and BNL concepts for 1-2 MW proton drivers have several elements in common:

1. An increase in the repetition rate of an existing accelerator, the Main Injector in the case of Fermilab, and the AGS in the case of Brookhaven.
2. An increase in the injected beam intensity through construction of a new linac (or possibly a synchrotron).
3. A decrease in the filling time of the existing machine. (This is most straightforwardly accomplished by utilizing a linac rather than a synchrotron.)
4. Reliance on previously developed superconducting rf technologies.
5. Upgrade paths are identified that could yield additional factors of 2 to 4.

The BNL concept features a 1.2 GeV superconducting linac as the injector into the upgraded AGS. This configuration would allow the delivery of 1 MW of beam power from the AGS at 28 GeV. Fermilab has two implementations under evaluation, each with the capability of providing high power beams simultaneously at 120 GeV, from the Main Injector, and at 8 GeV. The two possibilities are an 8 GeV synchrotron or an 8 GeV superconducting linac, with the linac preferred.

Performance goals and underlying parameters for the various concepts are shown in Table 1. The columns labelled "Present" represent typical performance with the currently configured accelerator complex.

Table 1 Performance parameters for Fermilab and BNL concepts for Proton Driver upgrades.

	Fermilab Options			Brookhaven		
	Present	Synchrotron	Linac	Present	AGS Upgrade	
Linac						
Kinetic Energy	400	600	**8000**	200	**1200**	MeV
Peak Current	40	50	25	40	30	mA
Pulse Length	90	90	1000	60	720	μsec
Protons/pulse	2.3E+13	2.8E+13	1.6E+14	1.5E+13	1.0E+14	
Repetition Rate	15	15	10	15	2.5	Hz
Average Beam Power	0.02	0.04	**2.00**	0.007	0.05	MW
Booster						
Kinetic Energy (Out)	8	8		1.5		GeV
Protons per Pulse	5.0E+12	2.5E+13		1.5E+13		
Repetition Rate	7.5	15		6.7		Hz
Protons/hour	1.4E+17	1.4E+18		3.6E+17		
Average Beam Power	0.05	**0.5**		0.02		MW
Main Injector				**AGS**		
Kinetic Energy (Out)	120	**120**	**120**	24	**28**	GeV
Protons per Pulse	3.0E+13	1.5E+14	1.6E+14	6.0E+13	9.0E+13	
Repetition Rate	0.54	0.65	0.67	0.33	2.50	Hz
Protons/hour	5.8E+16	3.5E+17	3.8E+17	7.2E+16	8.1E+17	
Average Beam Power	0.3	**1.9**	**2.0**	0.1	**1.0**	MW

3.2.3 The Brookhaven AGS Upgrade

The Brookhaven AGS upgrade is based on the direct injection of approximately 1×10^{14} protons via a 1.0 GeV superconducting extension to the existing 200 MeV drift tube linac. The extension bypasses the existing 1.5 GeV Booster currently used for injection into the AGS. The injector upgrade is accompanied by modifications to the AGS rf and power supply systems to enable 2.5 Hz operations. The net result is a factor of ten increase, to 1.0 MW, in the beam power available at 28 GeV. Subsequent upgrades of either the linac intensity, to 2×10^{14}, and/or the repetition rate, to 5 Hz, would enable additional factors of 2-4 in delivered beam power. A schematic view of the AGS upgrade is given in Figure 17.

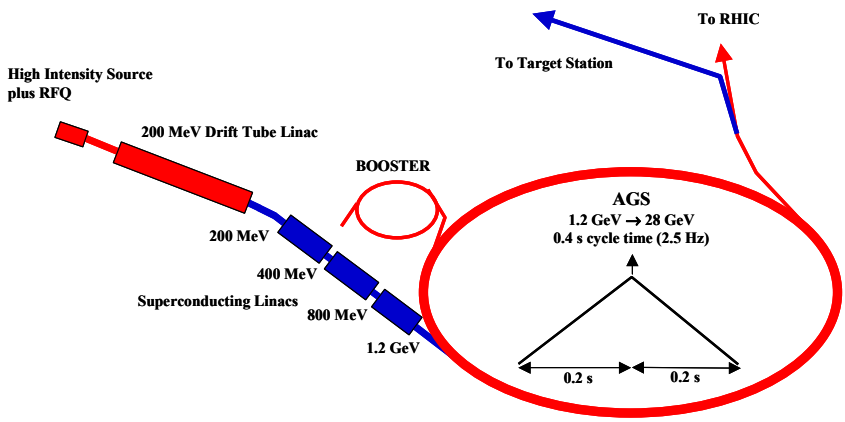

Figure 17 Schematic view of the AGS upgrade concept. Existing accelerators are in red, new facilities are in blue

3.2.4 The Fermilab Proton Driver

The goal of the Fermilab Proton is to increase the intensity delivered to the Main Injector to approximately 1.5×10^{14} protons, allowing full exploitation of the large aperture of the Main Injector and enabling, following relatively modest upgrades to the MI, 2 MW of beam power delivered at 120 GeV. Inspired by the outstanding successes of the TESLA program [Tesla01] the idea has emerged of an 8 GeV superconducting proton linac, injecting H^- directly into the Main Injector. The linac concept is represented schematically in Figure 18. The concept utilizes technologies currently under development for both the RIA and TESLA proposals. A number of variations on this basic scheme are still being explored including: 2.0 MW beam power at 8 GeV, frequencies based on 1207.5 MHz and derivatives thereof, and a warm front end. The key element in the design is the utilization of a "TESLA style" rf distribution system in which 36 cavities are driven from each klystron. Realization of this design configuration is dependent on the development of a ferrite based phase/amplitude controller. In addition, the utilization of such controllers would allow the acceleration of electrons interleaved with proton cycles in the downstream 7 GeV of the linac.

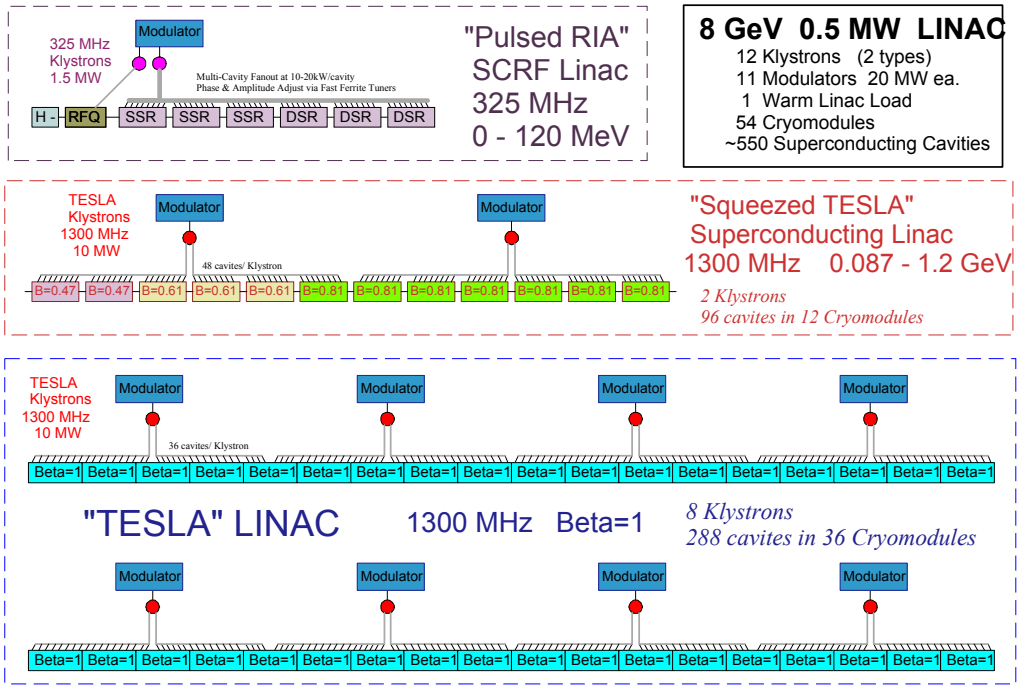

Figure 18 Schematic layout of the superconducting linac based Proton Driver at Fermilab. Linac variants under consideration include higher beam power (2 MW), lower rf frequencies (1207 MHz and its derivatives), and a warm front end.

3.2.5 Summary

Design concepts for Proton Drivers operating in the range 1-2 MW are being developed by both BNL and Fermilab. Both laboratories are motivated by a variety of physics opportunities, with neutrinos in the forefront. Active R&D programs are underway on critical components, aimed at demonstrating technical and cost performance. The recently released Fermilab Long Range Plan [Lrplan04] identifies a 2 MW Proton Driver as the preferred option in the event a linear collider is constructed elsewhere or is delayed. To that end, Fermilab is currently preparing documentation sufficient to support a “statement of mission need”, know as Critical Decision 0 within the U.S. Department of Energy project management system. Brookhaven is preparing a design study that could serve as the basis for a subsequent proposal.

3.3 Fair, the GSI New Facility For Antiproton and ion research

(H.-J. Kluge)

The physics program at the future international facility FAIR at Darmstadt (Facility for Antiproton and Ion Research) addresses a broad research spectrum: In hadron and nuclear physics, it ranges from studies of the sub-nuclear degrees of freedom, of the origin of the nuclear force and the quark-gluon structure of extended nuclear matter, to the exploration of the structure of nuclei, the nuclear many-body system, far from stability. Furthermore, other fields of physics will be exploited such as quantum electrodynamics in extreme electromagnetic fields, atomic physics and fundamental tests by use of antiprotons, the physics of dense plasmas or materials science and biophysics.

The tools for the FAIR research program are intense primary and secondary ion beams, including beams of antiprotons. These beams are generated in the FAIR facility (Figure 19) which makes use of the existing Unilac-SIS18 accelerator as injector. For antiproton production, a linear proton injector and accelerator will be added. The double-ring synchrotrons SIS100/300 will provide a major step in primary and, thus, in secondary ion beam intensities and, for certain demands, also in beam energy. Since the present synchrotron SIS18 is already at its space charge limit of about 10^{10} ions per second with beams of highly stripped uranium U^{73+}, two steps are foreseen to increase the intensity by two orders of magnitude: a faster cycling of the injector (from 0.3 Hz to 3 Hz) and the use of a lower charge states as, for example, q = 28+ for the case of uranium.

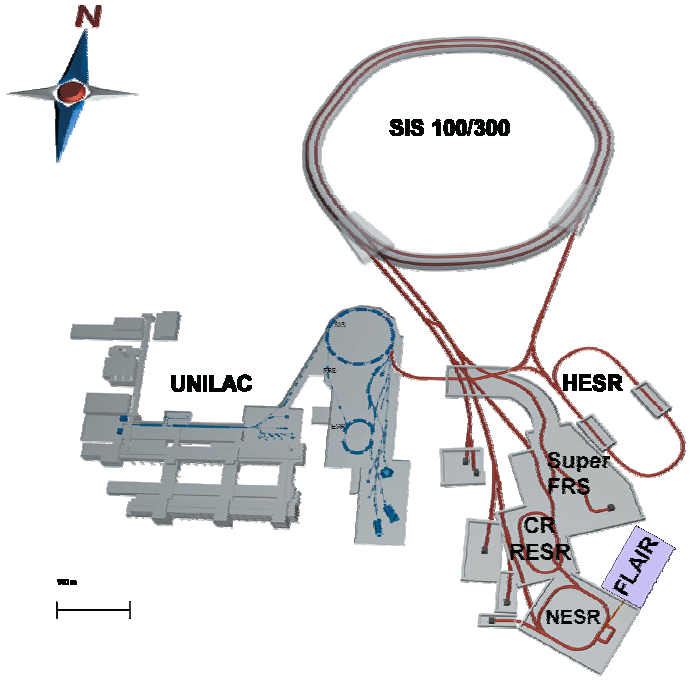

Figure 19 Schematic layout for the Facility for Antiproton and Ion Research, FAIR, at GSI. Details are given in the CDR [CDRFair].

To achieve 1.5 to 2.0 GeV per nucleon for the secondary radioactive beams, an accelerator ring with correspondingly higher magnetic rigidity (≈ 100 Tm) is required. The SIS100 synchrotron will also provide 30 GeV protons, the optimum energy for antiproton production. The second ring, SIS300, serves as a stretcher for slow extraction with high duty cycle and for high charge-state heavy ions and provides energies up to 35 GeV per nucleon at somewhat lower intensities for nucleus-nucleus collisions.

The science case has been worked out in detail in the Conceptual Design Report (CDR) for the facility [CDRFair]. Within the context of this workshop, discussing a high-power proton driver, there is an overlap of FAIR with such a MEGAWATT Facility in the case of research programs with beams of short-lived nuclei. Therefore, the following discussion will be focused on the production and on experiments with radioactive beams (RIB).

Figure 20 presents the layout of the facility for RIB production, separation, and experiments with such beams. The central instrument is the large-acceptance high-resolution spectrometer for exotic nuclei, a two-stage super-conducting fragment separator, called Super-FRS, plus three areas for experiments with stopped (or slowed-down), with fast, and with stored and cooled beams. A key requirement for obtaining uncontaminated secondary beams is the high energy of the primary heavy-ion beam.

Figure 21 shows existing or planned facilities for in-flight production and separation of RIB and indicates at what energy per nucleon the secondary products are fully stripped from electrons that leads to a clean m/q = m/Z separation. The benefit of primary heavy-ion beams well above 1 GeV/nucleon is evident. Important features of in-flight production of RIB are that the radionuclides are available for experiments irrespective of their chemical properties, and that the half-lives of the accessible radionuclides are only limited by their time of flight from the production target to the detector. For relativistic RIB, this time span is of the order of microseconds.

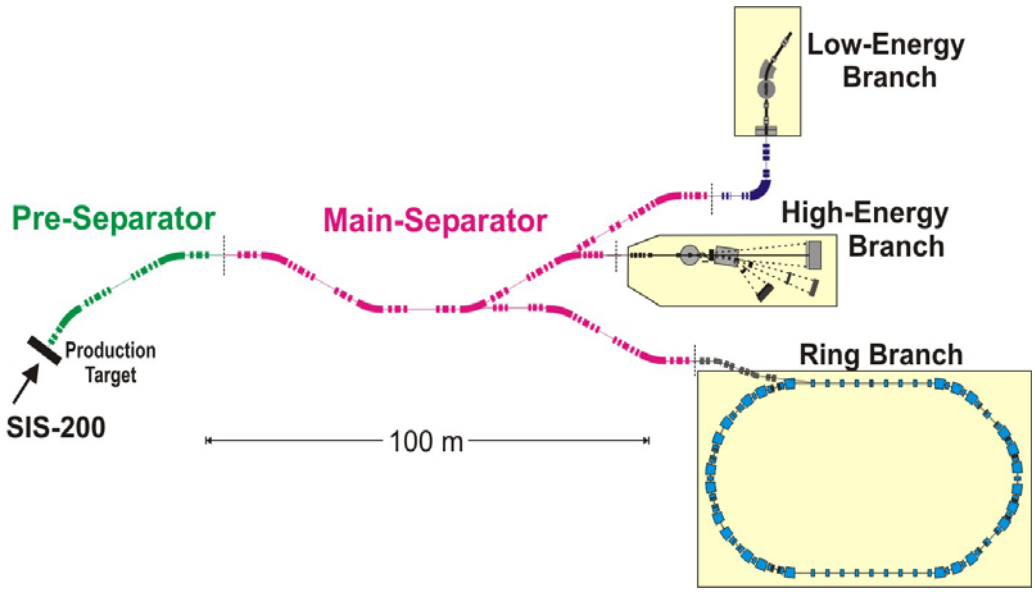

Figure 20 The Superconducting Fragment Separator (Super-FRS) at the FAIR facility.

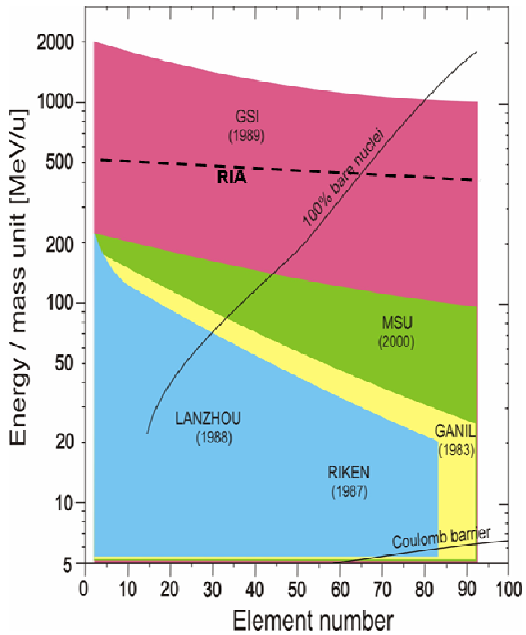

Figure 21 In-flight radioactive beam facilities and yields of fully stripped ions as a function of energy.

An example for production and identification of RIB is shown in Figure 22. In this case, a 1 GeV/u uranium beam impinged on a hydrogen target of the present fragment separator FRS at GSI. Over 1000 reaction products could be separated and identified. This fast and universal production mechanism is complementary to the isotope separator on-line (ISOL) approach which has the advantage of higher production yields, as compared to the in-flight technique, for longer-lived radio-nuclides of volatile elements which are released quickly from the target matrix.

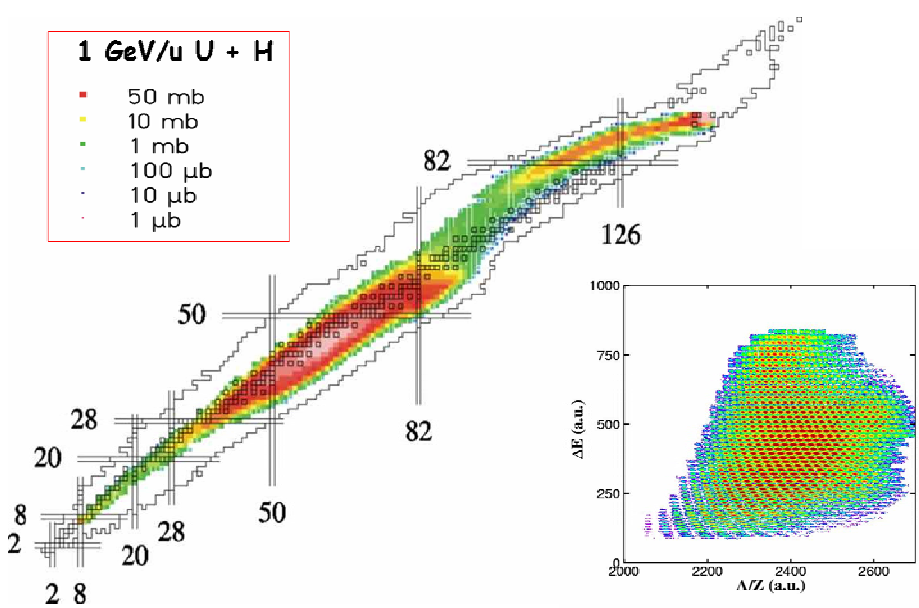

Figure 22 Production of secondary beams by 1 GeV/u uranium ions impinging on a hydrogen target. Over 1000 products were identified by the fragment separator FRS at GSI.

A second key feature of FAIR is cooling and storage. This technology is going to play an important role at the future facility, for radioactive ion beams as well as for high-energy anti-protons. Beam storage and cooling for high-energy heavy-ion beams has evolved at the present GSI facility as a technology with novel applications and research opportunities [STORI02].

Presently, nuclear physics experiments by use of the Experimental Storage Ring, ESR, at GSI concern mainly mass spectrometry and lifetime measurements. In the future, reaction experiments in inverse kinematics will play a major role. Here, stored and cooled highly-charged radioactive ions react with the atoms of the gas jet target installed in the storage ring. In this context, it should be noted that acceleration by synchrotrons and, in this way, production of *pulsed* beams of radionuclides are perfectly tailored for highly efficient injection into storage rings. Storing and cooling of radionuclides are effective means to increase the luminosity for reaction experiments by many orders of magnitude since one gains by the factor of the revolution frequency (typically 1 MHz) and the extremely small diameter of the cooled circulating ion beams.

Therefore, also nuclei very far from stability, which are produced with very low yields at FAIR, will become accessible to experimental investigation. The yields expected at the FAIR facility are shown graphically in the chart of nuclei of Figure 23. Here, the known isotopes are enclosed by a black line. The red lines indicate possible routes of the r-process. High yields of up to 10^6 will be available for more detailed studies of presently known nuclei over nearly the whole chart of nuclei. It is evident that highly efficient detection techniques are required to expand our knowledge to shorter-lived nuclei farther away from stability.

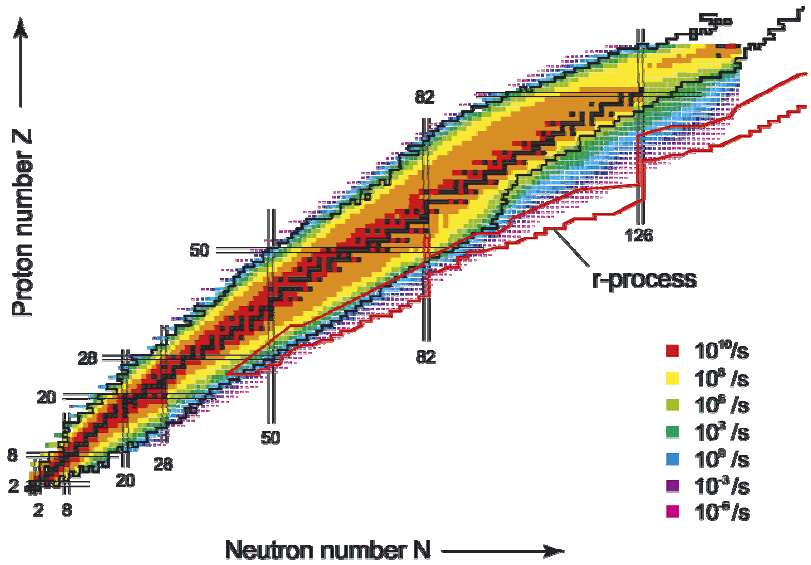

Figure 23: Expected yields at the Super Fragment Separator at FAIR.

4 High Intensity Proton Source

4.1 The future of proton accelerators at CERN

(R. Garoby, W. Scandale)

The Large Hadron Collider will be filled through a set of high performance proton accelerators providing the high brightness beam needed to reach the foreseen luminosity. Although this difficult project has top priority and uses most of the CERN resources, it is nevertheless time investigating improvements of the proton accelerator complex for physical cases beyond the LHC expectations. The needs of multiple physics communities have to be taken into account, as well as the necessity of consolidating the installations while keeping high reliability. This paper starts from the analysis and proposals made by the "High Intensity Proton" (HIP) working group [Hip_web], [Benedikt04] to improve the performances of the PS and the SPS complex and better match the users requests in a staged scenario at short and medium term, and complement it, addressing the main possibilities beyond that horizon.

4.1.1 Outcome of the High Intensity Protons Working Group

The HIP working group, mandated by the direction of the AB department, has recently established a list of requests from the physics teams already working at CERN and recommended a path for the upgrade of the proton accelerators [Hip_web], [Benedikt04]. The needs of LHC, COMPASS, neutrino and radio-active ion beam physics have been taken into account. For the other present users, i.e. AD, PS East area and nToF, the assumption has been that their requirements do not significantly influence the choice, and that every upgrade scenario would be compatible. In terms of schedule and resources, the requests fall into three main categories: (i) the short term, "low" (ideally zero) cost demands, which match the present commitments of CERN and belong to the approved physics programme, (ii) the medium term, "medium" cost requests, which correspond to modest and progressive increases of performance for the present experiments, (iii) the long term, "high" cost wishes, which are linked to major equipment upgrades and to new experiments suggested for integration inside the future physics programme of CERN. These are summarised in Table 2.

Table 2 Main users' requests

User	CERN commitment*	Users' wishes	
	Short term	Medium term [~asap!]	Long term [> 2014]
LHC	Nominal luminosity 10^{34} cm^{-2}s^{-1}	Ultimate luminosity 2.6×10^{34} cm^{-2}s^{-1}	Luminosity upgrade (tenfold)
SFT (COMPASS)	4.3×10^{5} spills/year?	7.2×10^{5} spills/year	
CNGS	4.5×10^{19} p/year	Upgrade ~ × 2	
ISOLDE	1.92 μA**	Upgrade ~ × 5	
Future ν beams			> 2 GeV, 4 MW
EURISOL			> 1-2 GeV, 5 MW

* Reference value for analysis. ** 1350 pulses/hour – 3.210^{13} protons per pulse (ppp).

The Linac2, PSB, PS and SPS have been built more than 35 years ago. Although a significant fraction of their equipment has been renovated, the most expensive ones are the oldest and show weaknesses. This has been aggravated by the reduction or even by the suppression of preventive maintenance due to the lack of resources during the past years. Therefore consolidation is essential in the near future and, in the medium term, the replacement of these accelerators deserves serious consideration. Moreover, the reduction of beam losses is a major issue in order to minimize the material irradiation for improved reliability and, even more important, the dose taken by the personnel during maintenance.

The analysis of the proton flux available to the users starts in 2007, corresponding to the first year of LHC operation, under the following assumptions:

- **Accelerators operating time per year**

PS: 5400 h (without setting-up)
SPS/LHC: 4700 h (without setting-up)
SPS in LHC filling mode: 15% (5%) of the time
SPS in LHC pilot mode: 35% (10%) of the time
SPS in CNGS&SFT mode: 50% (85%) of the time

- **Availability**

PS & PSB: 90%
SPS : 80%

- **Beam intensities**

SPS for CNGS: 4.4×10^{13} and 7×10^{13} ppp
PS for CNGS: 3×10^{13} and 4×10^{13} ppp.

The LHC pilot beam is a "safety beam" to be used to establish circulating beam. The following supercycles have been assumed:

- **LHC filling super-cycle:**
  1 LHC filling (flat porch for 4 PS injections), nominal length ≥ 21.6 s
- **LHC pilot super-cycle:**
  1 LHC pilot + 2 CNGS, nominal length: 22.8 s

- **CNGS&SFT super-cycle:**
  3 CNGS + 1 SFT + 1 MD (Machine Development), nominal length: 34.8 s.

Without any improvement, the basic requests cannot be met, especially for the ISOLDE and SPS users (Table 3 illustrates a case where priority is given to CNGS, resulting in a low flux for COMPASS). Moreover, the large level of beam loss associated with the CNGS operation in the PS will cause irradiation of PS equipment with detrimental consequences on reliability and maintenance.

Table 3 Proton flux in 2007 without improvement to the accelerators ("pot" stands for protons on target).

	Available flux	Basic user's requests	
CNGS flux	4.4	4.5	10^{19} pot/year
COMPASS spills	1.9	7.2	10^{5} /year
ISOLDE flux	1.75 [1215]	1.9 [1350]	(μA) [pulses/hour]
PS East area spills	1.5	1.3	10^{6} /year
nToF flux	1.7	1.5	10^{19} pot/year

Having considered the possible solutions, the following recommendations are made:

- In the short term, define in 2004 and start in 2005 three projects: (i) a new multi-turn PS extraction, to reduce beam loss and activation, (ii) an increased intensity in SPS for CNGS (implications in all machines), (iii) the reduction from 1.2 s to 0.9 s of the PSB minimum repetition time.
- In the medium term, design of a new linac ("Linac4" [Garoby04]) for the replacement of Linac2, with the goal of preparing for a decision of construction at the end of 2006.
- In the long term, prepare for a decision concerning the optimum future accelerators by pursuing the study of a Superconducting Proton Linac [Spl_web], [Vretenar00] and by exploring alternative scenario for the LHC upgrade.
-

The estimated performance resulting from the implementation of the short and medium term measures is shown in Table 4. Numbers without parenthesis can be obtained by giving the highest prioritys to CNGS. Conversely, the numbers in parenthesis are achieved by giving priority to COMPASS and limiting CNGS to its basic request. These improvements, and especially Linac4, should allow reaching the "ultimate" luminosity presently foreseen in the LHC by providing a proton beam with the "ultimate" characteristics.

Table 4 Proton flux in 2010 after implementation of the improvements recommended by the HIP WG.

	Estimated flux	Basic user's request	
CNGS flux	7.5 (4.5)	4.5	10^{19} pot/year
COMPASS spills	3.3 (5.6)	7.2	10^{5} /year
ISOLDE flux	6.4 [2240]	1.9 [1350]	(μA) [pulses/hour]
PS East area spills	1.5	1.3	10^{6} /year
nToF flux	1.6	1.5	10^{19} pot/year

4.1.2 Long term possibilities

Decisions for the long term (beyond 2010) have to take into account (i) the need to replace the aging accelerators, (ii) the plans for upgrading the LHC and (iii) the future physics programmes. Some scenarios have already been proposed for the LHC upgrade, and, for example, the interest of a new 1 TeV injector replacing the SPS has been mentioned [Bruning02] which would probably have to be coupled with a new 50 GeV synchrotron replacing the PS. However, a detailed study is still needed to compare the different possibilities and draw all conclusions.

Concerning the future physics programmes, the HIP working group has already identified a number of possibilities envisaged by nuclear and neutrino physicists that could be satisfied with a multi-MW/ few GeV proton driver like the SPL. Since then, requests for physics with kaons and muons have shown the potential interest of a multi-MW proton source at 30-50 GeV. Although, in principle, all these requirements can be simultaneously satisfied, the needed resources are rather large and the consequences so important for the complex that priorities have to be established, at least to plan for a staged realization.

Assuming that accelerators are replaced not only to improve reliability but also the characteristics of the beam (energy, intensity, brightness…), the replacement of a given machine should be coupled with the change of its injector(s). Therefore the decision process begins at the low energy end and progressively covers all the energy range. The possibilities and the benefits for the different families of users are shown in Table 5. The comments and numbers are indicative and subject to evolution. The various schemes will require further and detailed studies before realistic proposals can be made.

Table 5 Possible improvement to the accelerator complex

("RCS"=Rapid Cycling Synchrotron, "HEP"=High Energy Physics, "mMW"=multi-MW, "SC"=Superconducting)

Present accelerator	Replacement accelerator	Improvement	INTEREST FOR			
			LHC upgrade	Neutrino physics beyond CNGS	Radio-active ion beams beyond ISOLDE	Physics with kaons and muons
Linac2	Linac4	50 → 160 MeV H+ → H-	+	0 (if alone)	0 (if alone)	0 (if alone)
PSB	2.2 GeV RCS for HEP	1.4 → 2.2 GeV 10 → 250 kW Brightness ×2	+	0 (if alone)	+	0 (if alone)
	2.2 GeV/mMW RCS	1.4 → 2.2 GeV 0.01 → 4 MW Brightness ×2	+	+++ for super-beam and beta-beam	+ (too short beam pulse)	0 (if alone)
	2.2 GeV/50 Hz SPL	1.4 → 2.2 GeV 0.01 → 4 MW Brightness ×2	+	+++ for super-beam and beta-beam	+++	0 (if alone)
PS	50 GeV SC PS for HEP	26 → 50 GeV Intensity ×2 Brightness ×2	++	0 (if alone)	0	+
	50 GeV/5 Hz RCS	26 → 50 GeV 0.1 → 4 MW Brightness ×2	++	++	0	+++
SPS	1 TeV SC Synchrotron	0.45 → 1 TeV Intensity ×2 Brightness ×2	+++	?	0	+++

Linac2

Linac4 is a necessary first step, whatever the choices for the other machines, because it is designed to be compatible with the most demanding applications. For the higher energy accelerators, the choice is more open and depends upon the physics programmes.

PSB

If a second generation ISOL-type facility has to be hosted at CERN, the SPL is the ideal solution, which can also be used for all scenarios of neutrino physics (super-beam, beta-beam and Neutrino Factory). The SPL would also be an outstanding replacement of the PSB for the following accelerators serving high energy physics experiments. Once the precise goals of such a multi-MW/ few GeV driver are defined, the possibility of an RCS-based solution should be analysed and compared with the SPL.

If no experimental programme is approved that needs such a beam power at a few GeV, the most economical solution is to build a small size RCS able to fill the PS or its successor in 4 or 8 pulses. Most beam pulses would be available for other users, which could be of interest

for radio-active ion production, although not at the level required by EURISOL (~ 200 kW of beam power instead of 4 MW) [EURISOL_web].

PS

The low energy of the PS beam presently limits the SPS performance and the situation will be worse if the SPS is replaced with a superconducting synchrotron reaching 1 TeV. The present estimate is that the successor of the PS should deliver beam at approximately 50 GeV. If a multi-MW beam power is needed at that energy, a Rapid Cycling Synchrotron has to be considered. It would be a very challenging machine, surpassing the most ambitious synchrotron presently in construction in Japan [Jparc_web]. Moreover, it would probably lack the flexibility of the present PS which would then have to be maintained in operation for the needs of heavy ions for LHC and slow ejection to the East area.

If multi-MW of beam power at 50 GeV is not needed, a synchrotron using superconducting magnets could replace the PS. The key technological item for such a synchrotron will be a fast pulsing superconducting dipole reaching a field of 4 to 6 Tesla in 2 to 3 seconds. The magnets in development for the needs of SIS100 at GSI would be of interest for that application [Fair]. The new process of multi-turn ejection which minimizes beam loss should be used.

SPS

Injection at 1 TeV in the LHC would drastically ease operation with the present magnets, open some interesting possibilities for upgrading the luminosity beyond the ultimate value, and would even be necessary for an energy upgrade [Bruning02]. Other users could also be interested, provided the new machine is capable of slow ejection. The developments taking place in GSI for the superconducting magnets of SIS300 could be exploited [Fair].

LHC

Extracted proton beams at 7 TeV are a potential field of investigation. The physics case should however be properly analysed.

4.2 The Superconducting Proton Linac (SPL) and its potential

(R. Garoby)

4.2.1 Description

The SPL is a multi-GeV, multi-MW (typically 2.2 GeV/4 MW) linear proton accelerator. The basic characteristics of the first Conceptual Design [Spl_web], [Vretenar00] are summarized in Table 6. Operating at 50 Hz, it will be used both as a high-performance injector for the PS, replacing the PSB, and as a high-power proton driver for other physics applications, possibly complemented with an accumulator and a compressor rings.

Table 6 Main SPL parameters (CDR 1)

Type of ion	H^-	
Kinetic energy	2.2	GeV
Mean current during the pulse	13	mA
Beam duty cycle	14.0	%
Mean beam power	4	MW
Pulse frequency	50	Hz
Pulse duration	2.80	ms
Number of H^- per pulse	2.27	$\times 10^{14}$
Bunch frequency	352.2	MHz
Chopping duty cycle	61.6	%
Successive bunches/No. of buckets	5/8	
Norm. r.m.s. transverse emittance	0.4	π mm mrad
Longitudinal r.m.s. emittance	0.3	π deg MeV

The low energy part, up to 160 MeV kinetic energy, is equipped with room temperature accelerating structures and makes extensive use of LEP RF equipment at 352 MHz. It is called Linac4 because it is proposed to be first employed to replace the present Linac2 [Garoby04]. Its characteristics in both modes of operation are outlined in Table 6.

In the initial design of the SPL, based on the quasi-exclusive use of LEP RF hardware, acceleration beyond 160 MeV took place in a 550 m long superconducting linac section which brought the beam kinetic energy up to 2.2 GeV. The schematic layout of this version of the SPL is presented in Figure 24 A second Conceptual Design is in preparation and will be published in 2005. It will take into account the results from the HARP experiments and the outcome of recent developments in superconducting RF. Instead of the 352 MHz LEP cavities, new bulk Niobium cavities will be used at 704 MHz. For the same beam power and cost, the machine will be more compact or, if a higher energy is necessary, it could fit inside the same footprint.

Table 7 Linac 4 specifications.

	Phase 1 (PSB)	Phase 2 (SPL)	
Maximum repetition rate	2	50	Hz
Source current	50	30	mA
RFQ current	40	21	mA
Chopper beam-on factor	75	62	%
Current after chopper	30	13	mA
Pulse length (max.)	0.5	2.8	ms
Average current	15	1820	μA
Max. beam duty cycle	0.1	14	%
Number of particles per pulse	0.9	2.3	$\times 10^{14}$
Transv. emittance (rms, norm.)	0.28	0.28	π mm mrad
Longitudinal emittance (rms)	0.15	0.15	π deg MeV

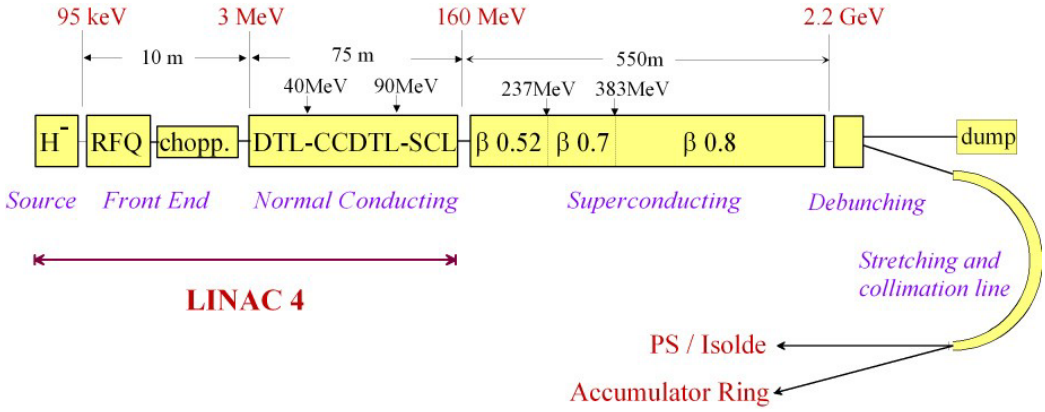

Figure 24 : SPL schematic layout (CDR 1 design for the superconducting part).

4.2.2 Applications

The SPL is ideal as a proton driver for a second generation ISOL facility ("EURISOL") [EURISOL_web] and for all scenarios of neutrino physics (super-beam, beta-beam and Neutrino Factory) [Muons_web]. It would also be a top class replacement for the PSB. For the superbeam option an accumulator ring is needed to shorten the beam pulse from 2.8 ms to 3 μs. For a Neutrino Factory, a second synchrotron has to be built to reduce bunch length to 1 ns rms. In the proposed layout on the Meyrin site, these rings are placed inside the ISR building and connection with the existing machines re-uses existing tunnels (Figure 25).

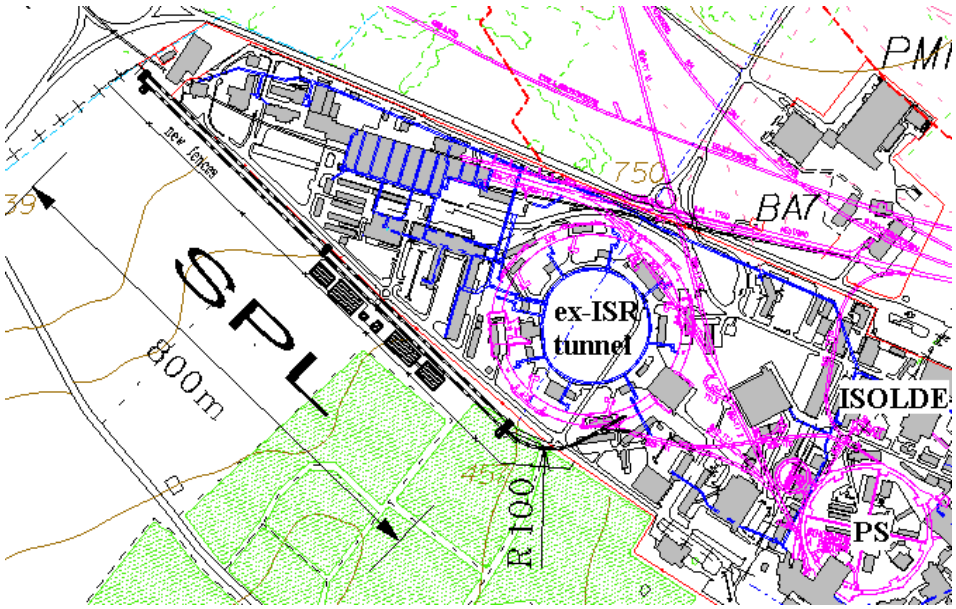

Figure 25 : Proton driver complex on the CERN site.

4.2.3 Other benefits

With the SPL replacing the PSB, the LHC will benefit from:

- the increased brightness of the PS beam that will be welcome for the luminosity upgrade (the space charge limit in the PS is raised to the equivalent of 4×10^{11} protons per LHC bunch within the nominal emittances).
- an extended flexibility in the choice of bunch spacing,
- the simplification of the LHC filling scheme and the "comfortable" performance margin that should increase reliability and integrated luminosity.

Limited profit is expected in terms of intensity per pulse from the PS and SPS, because these machines will already be close to their ultimate capabilities after the installation of linac4.

Most of the SPL being superconducting, it is conceivable to lengthen the beam pulse and increase the beam power by upgrading the electrical and cooling infrastructure. If necessary more high power users could then be accommodated.

4.2.4 Planning

In a context of renovation of the injector complex, it makes sense to begin with the low accelerators because (i) the low energy machines are the oldest, (ii) beam brighness is defined at low energy and (iii) the following accelerators can be based on a high performance/state of the art injector. The choice of the future machine that will replace the PSB has to be made early.

The realization of the SPL is split in three phases, in increasing order of beam energy, cost and benefits. An indicative planning highlighting the key dates is given in Fig. 3.3.

In the first phase the performance of the pre-injector, up to 3 MeV of kinetic energy, will be investigated. A test stand equipped with an RFQ accelerator has been funded and is presently under preparation, with the goal of operating with beam during the year 2007.

In the second phase, Linac4 will be built to replace Linac2, and increase by a factor of two the intensity and brightness of the PSB beam. Linac4 is a useful first step, whatever the choices for the other machines, because it is designed to be compatible with the most demanding applications. Developments for Linac4 [Hippi_web] are taking place with the support of the European Union and of the International Science and Technology Center (Moscow). CERN management confirmed recently its commitment to decide in 2006, with construction starting in 2007. The setting-up with beam could then take place in 2010 and operation for physics could begin in 2011 with immediate benefits for LHC and ISOLDE.

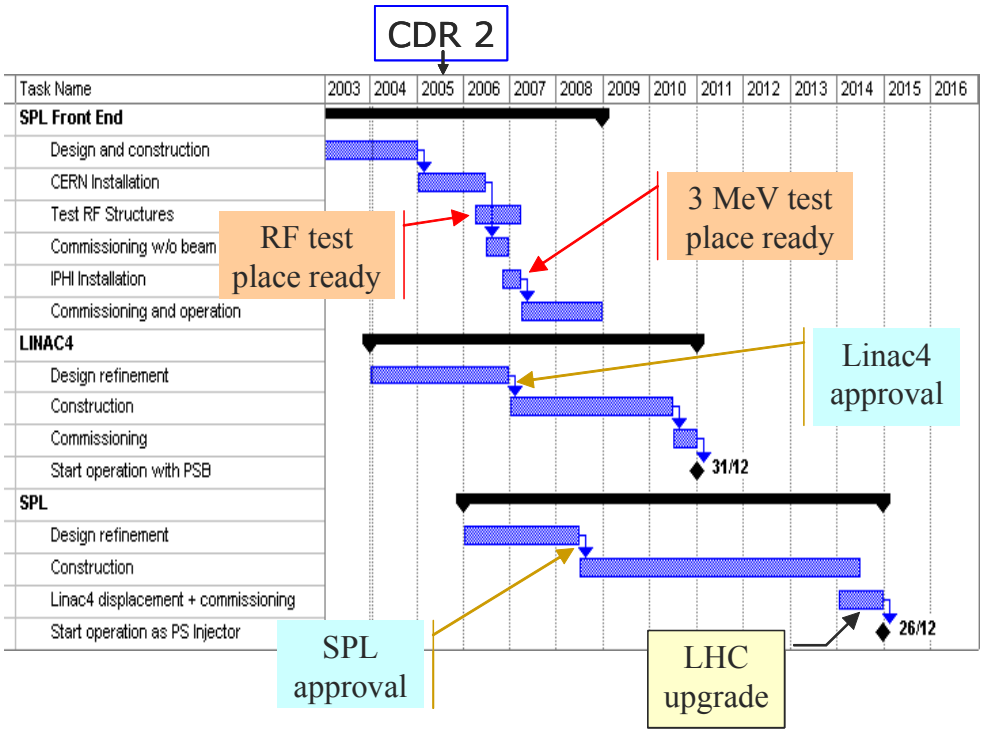

Figure 26: Indicative multi-year planning for the full SPL project.

In the third phase, the full SPL would be built. The decision on its construction will depend upon the future physics programmes at CERN and upon the needs of the LHC upgrade. Considering that finalization and setting-up of the SPL imply interruption of the proton beams for one year, it is logical to plan it during the shutdown for LHC upgrade which is estimated to be in 2014. To match this date, the decision of construction has to be made in 2008.

4.3 The Rapid Cycling Synchrotron options

(C. Prior)

Two criteria have been identified and generally accepted as essential to the definition of the type of machine known as a proton driver:

C1: the need for high beam power, usually within the range 1 to 4MW, possibly achieved via a phased upgrade scheme;

C2: for the Neutrino Factory application, the ability to produce high intensity short bunches of protons, with a representative time duration of 1–2 ns (rms). For a neutrino superbeam, a pulsed beam with a duty factor of 10^{-4} is sufficient.

To put these requirements in context, it is useful to consider the list of existing and proposed proton sources shown in Table 8 and see the extent to which they meet the criteria C1 and C2. The most powerful pulsed machines in operation output approximately 0.15MW and those at the construction phase are generally aimed at ≤ 1MW, with peak power expected to be reached after several years of progressive commissioning and development. Furthermore, not all of these will satisfy the criterion C2 easily. The step to ≥4MW should not be under-estimated, and meeting full proton driver specifications will be an extremely challenging task.

4.3.1 ISIS

Of the machines listed in Table 8, ISIS at the Rutherford Appleton Laboratory (RAL) is the world's most powerful source of pulsed neutrons and is approaching almost 20 years of successful operation. The accelerating system comprises a 70MeV H^- linac injecting via an Al_2O_3 stripping foil into an 800MeV proton synchrotron. Each pulse consists of two bunches of approximately 100 ns duration, directed onto a tantalum target at a repetition rate of 50 Hz, where a variety of experiments are carried out for condensed matter research.

Although far below the levels of performance required in a proton driver, several special features have nevertheless been built into the ISIS accelerators and are of importance for next-generation designs. Injection of H^- is essential in order to build up the required beam intensity within an acceptable transverse emittance. To keep stripping foil temperatures to reasonable levels, phase space painting is included via vertical orbit beam bumps, and to trap and accelerate as many protons as possible, the total RF voltage in the synchrotron is varied according to a prescribed programme during the cycle.

Table 8 Parameters of Existing and Proposed Proton Sources

Machine	Flux ($\times 10^{13}$/pulse)	Rep Rate (Hz)	Energy (GeV)	Power (MW)
Existing:				
RAL ISIS	2.5	50.0	0.8	0.16
BNL AGS	7.0	0.5	24.0	0.13
LANL PSR	2.5	20.0	0.8	0.064
Fermilab MiniBooNE	0.5	7.5	8.0	0.05
Fermilab NuMI	3.0	0.5	120.0	0.3
CERN CNGS	4.8	0.17	400.0	0.5
Under construction:				
ORNL SNS	14.5	60	1.0	1.4
J-PARC 50 GeV	32	0.3	50.0	0.75
J-PARC 3 GeV	8	25	3	1.0
Proposed:				
Chinese SNS	2.5	25	1.0	0.1
Indian SNS	2.4	25	1.0	0.1
Fermilab I	3	15	16	1.2
Fermilab II	2.5	15	8	0.5
BNL	10	2.5	24	1
CERN SPL	23	50	2.2	4
CERN RCS	10	8	30	4
RAL 15 GeV	6.6	25	15	4
RAL 5 GeV	10	50	5	4
ISIS upgrade	~8	50	3–8	1–4
Other studies:				
Europe ESS	46.8	50	1.334	5
Europe CONCERT	234	50	1.334	25
LANL AAA	-	CW	1	100
LANL AHF	3	0.04	50	0.003

Dampig of the head-tail instability can be done by changing the vertical tune during injection, and, indeed, variable tune throughout the cycle is an important feature of ISIS and all high intensity machines. Of more interest is the synchrotron's resistance to the e-p instability thought to be caused by the so-called electron cloud phenomenon. At high intensities, protons can interact with residual gas to release electrons which are first trapped within the bunch and then released from the tail to hit the vacuum chamber walls. Secondary electrons are released that can in turn interact with successive proton bunches, possibly producing a cascade effect leading to severe beam loss. Such behaviour is believed to limit intensity in the Los Alamos Proton Storage Ring (PSR). The absence of any such problem at ISIS is now thought to be due to RF shields built into the dipoles and quadrupoles, which effectively suppress the secondary emission [Bellodi04] . However, this conclusion is still speculative and an intensive R&D programme is in progress to resolve the issue.

Even without the e-p instability, ISIS still shows a loss of about 10% of the beam, generally below 80 MeV, and the bunches of 100 ns duration, while suitable for neutron production, cannot easily be compressed to the 1 ns levels required for a Neutrino Factory . A phased upgrade path to a full proton driver is however under study and is described in §4.3.

4.3.2 SNS and ESS

Many of the ISIS features were incorporated in the design for the European Spallation Source (ESS), which in turn provided a template for the US neutron source SNS. The ESS remains a paper study [ESS03] while the SNS is currently under construction at Oak Ridge, Tennessee. Both have full energy linacs feeding into accumulator rings, producing pulses of the order of 1 μs at their spallation targets. The ESS design also includes a 2 ms long-pulse option. However, both have had to confront the need for a very low loss system, high beam power and high intensity achieved through charge exchange injection and proton accumulation. Elaborate collimation systems are incorporated into the linacs and rings. Special features have been included, such as fast beam choppers in the linacs at energies of 2–3MeV and achromatic arcs in the transfer lines from the linacs to the rings, to facilitate low loss H- injection. Phase space painting during injection is used in both cases, with the ESS also carrying out energy ramping in the linac-ring transfer line and ring RF steering during accumulation. The ESS design also attempts to reduce problems caused by high intensity by splitting the protons between two rings stacked on top of one another.

Neither ESS nor SNS conforms to the strict definition of a proton driver, however. Although both meet the high beam power criterion, bunch compression could only be achieved through the use of an additional ring, where several megavolts of RF would be required.

The enterprising J-PARC project currently under construction at Tokai-mura in Japan, is the first proton driver proper to be built, albeit at the lower end of the beam power range (see Table 8). Based on rapid cycling synchrotrons (RCS), the complex contains a 3 GeV ring producing proton pulses for spallation neutrons and a 50GeV ring in which bunch compression may be carried out. A dedicated Neutrino Factory is being planned with muons, generated from a pion target by the proton driver, being accelerated in a series of fixed-field, alternating gradient (FFAG) rings before decaying to neutrinos in a dedicated storage ring. Further details and a status report of this project are given in chapter 3.1.

4.3.3 Ideas for RCS-based Proton Drivers

Whether the scenario adopted is a full energy linac with accumulator ring (such as SNS) or a synchrotron-based system (such as ISIS or J-PARC), the lessons that have been learnt from the last ten years of study can be summarized as follows:

• To achieve a beam power of several megawatts requires a careful balance of repetition frequency and energy

• Building up the intensity in the ring through H- charge exchange injection is a demanding task. Stripping foil temperatures must be controlled and beam dumps are required for unstripped H- and partially stripped H^0 ions. Studies for the ESS suggest that a suitable choice of the injection beam energy can minimise problems arising from different H^0 excited states [ESS03] . Injection conditions (including orbit bumps, RF voltages and optical Twiss parameters) must be chosen to maintain uncontrolled beam losses below the accepted level of 0.01%. The transverse distribution of the accumulated beam must be as uniform as possible to avoid high peak current and consequential space charge problems.

• The separate operations of compressing the proton bunches to nanosecond (rms) durations and particle accumulation impose entirely different demands on the lattice beam optics. To devise a system which can meet both requirements is extremely diffcult. The CERN solution is to use a separate compressor ring, based on a simple FODO lattice, in which the

accumulated bunches circulate for only ~7 revolutions while being compressed by a total of about 8MV of RF voltage. RCS scenarios attempt to balance the operations of accumulation, acceleration and compression more evenly between systems of rings, and the peak RF requirements can generally be kept lower.

• At such high levels of longitudinal bunch compression, the beam current is high (~1000 A). Space charge will affct the lattice parameters (β-functions, tune, transition energy) and the non-linear optical behaviour needs to be carefully studied.

• Bunch compression is facilitated if the original longitudinal emittance is small. Injection at a lower energy might be preferable for such machines.

4.3.4 Design models

Models developed at the Rutherford Appleton Laboratory extend these ideas. A linac accelerating H^- ions to an energy in the range 150–200MeV provides a suitable combination of parameters to accumulate bunches with a (normalised) longitudinal emittance of about 1 eV.s in a compressor ring. Acceleration to top energy can then be divided between two synchrotrons, the first with a lattice optimised for injection and low-loss particle accumulation and the second designed for final bunch compression before transfer to the target. The RAL designs show a method of doubling mean radii and halving frequencies that reduces the demands on fast cycling dipole magnets and eases the burden on the high gradient RF accelerating cavities.

The models all have a common linac developed from designs originally formulated for the ESS [ESS03] . Through an experimental programme at RAL, positive steps have been taken to devise a high current (50–60 mA) H^- ion source with a lifetime of approximately 10 weeks or longer. This is based on the ISIS Penning source and, after extensive research with the aid of EU support, is probably the best of its kind available today. From the ion source the beam is matched by the Low Energy Beam Transport system (LEBT) into a radio frequency quadrupole (RFQ), bunched and accelerated to 2.5 MeV. The fast beam chopper [Cla02] which follows is a crucial component of the structure, without which low-loss ring accumulation would be impossible. As the frequency of the RFQ is likely to be 234.8MHz, the gap between micro-pulses is of the order of 2–3 ns during which a kicker field has to rise to deflect up to 30% of the micro-pulse train to a beam dump. Operation is at an harmonic multiple of the ring revolution frequency. An intensive R&D programme has been set up aimed at full beam tests within five years (finances permitting). Some support has been obtained from the EU within the Framework Programme 6 (FP6) and the merits of the RAL chopper design will be compared with an alternative model under study at CERN.

Beam passing through the chopper is accelerated in a drift tube linac (DTL) to an energy of 90MeV and undergoes a triple frequency jump to 704.4MHz before being raised to 180MeV in a side-coupled linac (SCL) [Gerigk04] . This work also receives funding from the EU under FP6.

4.3.5 5 GeV, 4MW Model

The HARP experiment (see chapter 5.2.2) will indicate the optimum driver energy for maximum pion yield for a Neutrino Factory. Pending the results, models covering a range of energies have been developed.

The first (Figure 27) has a top energy of 5 GeV and is site-independent. The synchrotron system consists of two stacked booster rings of mean radius 32.5m each taking two bunches of 2.5×10^{13} protons to an energy of 1.2 GeV at a frequency of 50 Hz. The injection period per ring is 0.2 ms and the rings are filled immediately after one another. A simulation of the injection into longitudinal phase space is shown in Figure 6. Although chopped, the beam does not initially fit completely inside the stable phase space bucket, but particles outside are gathered up in the non-adiabatic process as voltages and magnetic fields change and acceleration begins. Momentum ramping and RF steering are used to assist trapping and keep beam loss, which is mainly from scattering in the injection foil, below 0.01%. Over 160 injection turns, the average number of foil traversals per circulating proton is low, keeping temperatures down and probably allowing use of an ISIS-type Al_2O_3 stripping foil, though carbon, with a higher sublimation temperature, would be a safe, alternative choice.

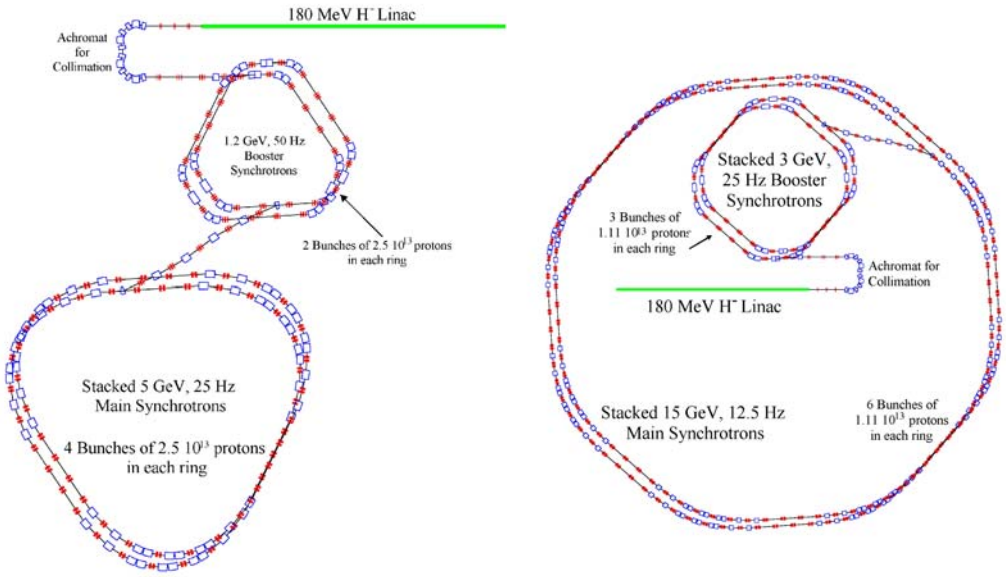

Figure 27 Rapid Cycling Synchrotron models at 5 GeV (left) and 15 GeV (right)

Extraction from both synchrotrons has to be at the same energy, which means on the upward part of the accelerating cycle for the second ring and the downward part for the first. All four bunches - which are 100 ns in duration - are transferred to one of the main synchrotrons, which have twice the radius (65 m) and operate at half the frequency, 25 Hz at harmonic number h = 8.

The beam is accelerated to 5 GeV over 20 ms, during which time the boosters reset and operate again so that as the first main ring is extracted, the second main ring is filled. Extracting alternately in this way restores the 50 Hz cycle. Bunch compression is achieved by choosing the main ring to have $\gamma = 6.5$, only very slightly greater than $\gamma = 6.33$ at top energy. Towards the end of acceleration, the bunches are then almost frozen longitudinally. An additional 500 kV of RF at harmonic number h = 24 are brought into play and this is

sufficient to compress the bunches to 1 ns (rms). The process is accompanied by an increase in momentum spread, which requires non-linear optics to be considered, but a sextupole scheme has been devised to compensate for these high order effects. Further details are given in [Prior00] and [Prior00a] .

4.3.6 15 GeV, 4–6MW Model

A 15 GeV driver has also been designed on the same principles, with the main rings specifically of a size to fit within the CERN ISR tunnel. The booster synchrotrons have mean radius 50 m, h = 3 and output 50 ns bunches at 3 GeV and 25 Hz, after accumulation and acceleration from the 180MeV H- linac. The main rings have radius 150 m, and each compresses 6 bunches to 1 ns (rms) with a peak RF voltage of 1.7MV at harmonic number 36. Space charge tune shifts are of the order of -0.02. Figure 27 shows a possible layout, with the boosters neatly fitted inside the main synchrotrons. For simplicity, all but one of the transfer lines between the rings have been suppressed. The model is nominally designed for 4MW output but is capable of being upgraded to 6MW by increasing the number of bunches.

4.3.7 4.1.3 30 GeV, 4MW Model

Adapting parameters in a different manner, a 30 GeV slow cycling synchrotron at 8 Hz has also been designed for the ISR tunnel [Aut01] . The scenario uses the same 180MeV H- linac and 180 achromat described above, and has a booster accelerating two proton bunches to 2.2 GeV at 50 Hz. Batches of 8 bunches (10^{14} protons in total) are accelerated in the main ring to 30 GeV, which requires a total of 3.8MV of peak RF voltage for the 1 ns rms bunch compression. Such a machine would not only provide an alternative to the CERN SPL but could also inject directly into the CERN SPS above transition energy. It might also be considered as a possible replacement for the elderly CERN PS.

4.3.8 ISIS Upgrades

In its present configuration, the machine is limited by space charge to an intensity of 2.5×10^{13} protons per pulse. A combined h = 2, h = 4 RF system is being installed which, by stretching the stable areas of longitudinal phase space, may allow up to 50% more beam to be injected without any change in the transverse tune effects [Prior93] . The relative phases beween the RF harmonics have to be carefully controlled throughout the cycle but the general principle is well-tried and should provide additional benefits for neutron scatterers for a fairly modest cost. A second target station is also being built, to operate at 10Hz and, by taking one in five pulses from the existing 50 Hz target, will effectively absorb the extra beam power.

The second phase of the upgrade is to replace the ageing ISIS linac with the 180MeV linac described above. At this energy, space charge levels at injection are halved, and initial studies suggest that the synchrotron could output 0.4MW of beam power, which the present target could probably just about withstand.

Beyond this, the only practical method of increasing the power of the facility is by raising the energy through the addition of a second synchrotron. Studies have been carried out to enlarge the 8 GeV ring developed for Fermilab to a mean radius of 78m, three times ISIS's 26 m. This ring could then operate in two modes. Taking ISIS's pulses by a simple bucket-to-bucket transfer, the beam could be accelerated to 3.5GeV to produce 100 ns bunches at an energy suitable for a 1–1.5MW, 50 Hz spallation neutron source. This is a fairly costly project since a new target would be required. In the machine's alternative mode, one in three ISIS pulses

could be accelerated in the main synchrotron to 8 GeV at a frequency of 16.67 Hz (the other two pulses being directed to a beam dump). Experiments of nanosecond bunch compression

could be carried out, studies of lattice and beam behaviour near transition would be possible, and the beam could provide the means for Neutrino Factory pion target tests. Further development would entail the construction of a new booster, effectively replacing the current ISIS accelerator. This could fit inside the 78m ring, thus allowing ISIS to continue operation with relatively little disruption to users. The booster is based on stacked 1.2 GeV, 50 Hz synchrotrons fed by the 180MeV H^- linac via the achromat of Figure 27. The main synchrotron, operating at 25 Hz, would be upgraded to 2.5MW and would provide an enhanced neutron facility at 3 GeV with further scope for Neutrino Factory tests at 6 or 8 GeV.

The final phase of the upgrade programme would be to build a second main synchrotron, stacked on top of he first, so as to recoup the overall 50 Hz frequency as explained above. This would provide a 4–5MW proton driver in the full sense of the term and provide a dual neutron/neutrino facility that would fit comfortably on the RAL site.

4.3.9 Proton Driver R & D

R&D is of course of vital importance, and the following representative (but incomplete) list of topics is adapted from the Snowmass working group's report [PDWG01] .

(1) The requirements from the H^- ion source are a current of 60–75 mA, 6–12% duty cycle, and a normalised rms emittance $\varepsilon_{nrms} \approx 0.2\ \pi$ μrad.m. The lifetime should be at least 2 months. The RAL ISIS ion source is the only source realistically likely to meet these demands in the immediate future.

(2) Work is required on radio frequency quadrupole linacs (RFQ) at frequencies in the range 200 to 400MHz with currents up to 100 mA. 99% transmission efficiency is a goal and the unit must have its higher order modes suppressed.

(3) A fast beam chopper is essential, with rise time<_2 ns. Materials and configurations meeting the thermal demands imposed on the chopper beam dump need to be studied, and a means for handling 5–10kW of beam power should be assessed.

(4) Funnelling may be required to double the linac current, particularly in full-energy linac/accumulator ring systems. The ESS design contains a 20MeV funnel and there are plans to build and test this at RAL at some future date [Prior99] .

(5) R&D is required for high efficiency and high reliability RF sources, such as inductive output tubes (IOT) and multi-beam klystrons.

(6) In the area of linac diagnostics, studies should be carried out on: (a) noninvasive H^- beam profile measurements, using for example laser wire, ionization and fluorescent-based techniques; (b) on-line measurements of beam energy and energy spread; (c) halo monitors, especially in superconducting systems; (d) longitudinal bunch shape measurements.

(7) The EU FP6 HIPPI contract covers work on high-gradient low and intermediate β superconducting cavities and spoke cavities. Much will be learnt from the SNS experience in cryogenics.

(8) There is an active group currently analysing space charge problems, in particular exploring fast accurate codes and devising and carrying out benchmarking tests (see [Prior03b]).

(9) Experimental studies of ring lattices are desirable, for example to explore the higher order dependency of γ_τ on $\Delta p/p$, tune shifts and space charge.

(10) Injection foil lifetime and stripping effciency need to be investigated and experiments on the lifetime of H_0 excited states as a function of magnetic field and beam energy should be carried out. Studies of the efficiency of slow extraction systems would also be of interest.

(11) There is an active international collaboration trying to understand the electron cloud problem. Here too codes are being developed to incorporate an increasing range of physical effects. A benchmarking programme is under way but needs to run in parallel with the experimental programme proposed at ISIS and ongoing studies at the Los Alamos PSR and CERN.

(12) Ring beam loss, collimation and radiation protection issues are of high priority. 3D code development is required, and engineering aspects of collimation and beam dumps should be investigated. The efficiency of beam-in-gap cleaning systems will benefit from SNS experience. Collimation with resonant extraction could, with interest, be explored.

(13) Diagnostics need to be developed to measure beam parameters during ring injection, for example beam position monitors over a large dynamic range for turn by turn measurements, and equipment for fast, accurate, non-invasive tune measurements.

(14) Covering a range of different options, studies of RF in the ring could profitably be carried out to develop: low frequency (~5 MHz), high gradient (~1MV/m) RF systems, some with ~50% duty cycle; (c) high voltage (>100 kV) barrier bucket systems; (d) transient beam loading compensation schemes (e.g. for low-Q magnetic alloy (MA) cavities).

(15) Synchrotron magnets with combinations of different harmonic fields need to be designed and tested. At RAL and Fermilab, for instance, a magnetic field variation

$$B(t) = B_0 - B_1 \cos(2\pi ft) + B_2 \sin(4\pi ft)$$

is proposed with B_2 chosen to help minimise the peak RF voltages needed for acceleration. Suitable power supplies need to be developed, and their cost effectiveness taken into account.

(16) Since most proton driver rings are likely to include inductive inserts to reduce the effects of high space charge levels during bunch compression, a formal R&D programme would be desirable covering aspects of both theory and practice (programmable inserts, inserts with large inductive impedance). An experimental programme is planned for the Fermilab Booster and the J-PARC project.

4.3.10 Conclusions

While there is much work to be done, it appears that there are no insurmountable difficulties to the construction of a successful proton driver. By sharing the challenging aspects over different parts of a machine — chopping in the low energy part of the linac, halo control in intermediate energy stages and the achromat, acceleration and bunch compression in separate rings, and doubling the rings to reduce space charge as necessary — a synchrotron-based

scenario provides a feasible and cost-effective solution for future high power needs. With the support of organisations such as the European Union through Framework 6, good progress is already being made in the design of high intensity linacs with energies up to 200MeV, and further backing will be requested for synchrotron development in the near future. A model has been devised for a slow-cycling replacement for the CERN PS, and the ISIS upgrade plans, which progressively develop an existing facility into a machine for both high energy physics and condensed matter studies, look particularly interesting.

5 Facilities around the intense proton source

5.1 Additional installations for a neutrino physics facility

(A. Blondel, S. Geer, H. Haseroth, A. Rubbia)

5.1.1 Overview

Several neutrino physics facilities have been discussed as shown in Figure 8. The beta-beam is quite different and will be discussed in section 5.4. The Neutrino Factory based on a muon storage ring is being investigated in the US, Japan and Europe since quite a few years. A "Neutrino Superbeam" is a conventional neutrino beam from π decay and is very similar to the front end of the Neutrino Factory. This section concentrates on what is needed behind a proton driver for a Superbeam, then a Neutrino Factory. The overall layout is repeated in Figure 28; as can be seen in Figure 29, a suitable arrangement could be found at CERN.

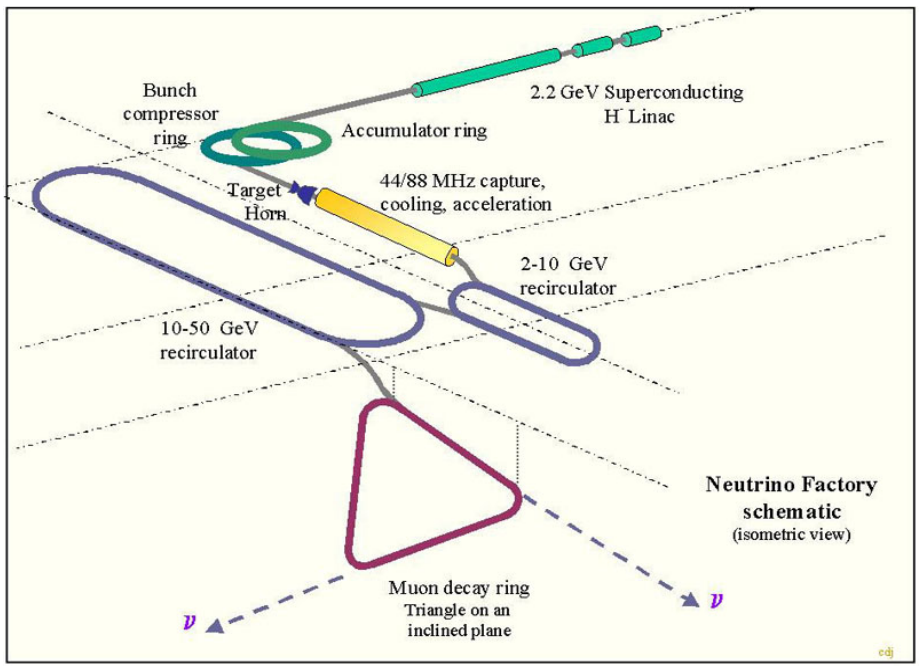

Figure 28 Schematic layout of a Neutrino Factory

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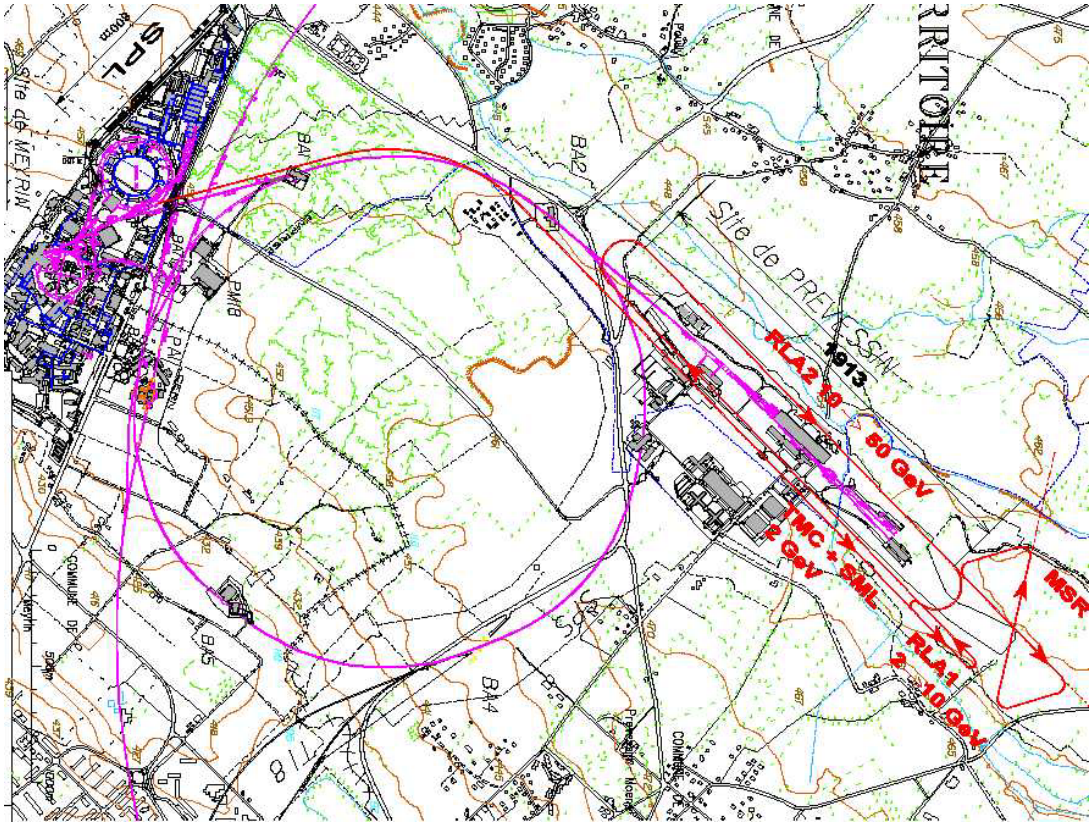

Figure 29 Possible layout of a Neutrino Factory on the CERN site

5.1.2 The Neutrino Factory

New accelerator technologies offer the possibility of building, not too many years in the future, an accelerator complex to produce and capture more than 10^{20} muons per year. It has been proposed to build a *Neutrino Factory* [nufact] by accelerating the muons from this intense source to energies of several GeV, injecting the muons into a storage ring having long straight sections, and exploiting the intense neutrino beams that are produced by muons decaying in the straight sections. The decays: $\mu^+ \to e^+ \nu_e \bar{\nu}_\mu$ and $\mu^- \to e^- \nu_\mu \bar{\nu}_e$ offer exciting possibilities to pursue the study of neutrino oscillations and neutrino interactions with exquisite precision.

To create such an intense muon source, a Neutrino Factory requires an intense multi-GeV proton source capable of producing a primary proton beam with a beam power of 1~MW or more on target. This is just the proton source required in the medium term for Neutrino Superbeams. Hence, there is a natural evolution from Superbeam experiments to Neutrino Factory experiments.

Neutrino Factory designs have been proposed in Europe [Aut99], [Gru02], the US [MuColl] [StudyI][StudyII], and Japan [Japnufact]. Of the three designs, the one in the US is the most developed, and we will use it as a example in general with a few exceptions. The Neutrino Factory consists of the following subsystems:

1. **Proton Driver**. Provides 1-4 MW of protons on a pion production target. For the Neutrino Factory application the energy of the beam is not critical, since it has been

shown that the production of pions is roughly proportional to beam power. In the low energy region, this statement may need to be substantiated with e.g. the Harp measurements (see section 5.2). The time structure of the proton beam has to be matched with the time spread induced by pion decay (1-2 ns); for a linac driver, this requires an additional accumulator and compressor ring. For the superbeam however, the energy of the protons directly impacts on the resulting neutrino beam energy from pion decay which is typically 5 to 10% of that of the incident protons.

2. **Target , Capture and Decay**. A high-power target sits within a 20T superconducting solenoid, which captures the pions. The high magnetic field smoothly decreases to 1.75T downstream of the target, matching into a long solenoid decay channel. A design with horn collection has been proposed at CERN for the Neutrino Factory, with the benefit that it can be also used for a superbeam design. The advantage of the horn that it sign-selects the pions and muons is compensated by the fact that in a Neutrino Factory design one could contemplate to accelerate both signs of muons, thus doubling the available flux.

3. **Bunching and Phase Rotation**. The muons from the decaying pions are bunched using a system of rf cavities with frequencies that vary along the channel. A second series of rf cavities with higher gradients is used to rotate the beam in longitudinal phase-space, reducing the energy spread of the muons.

4. **Cooling.** A solenoid focusing channel with high-gradient 201 MHz rf cavities and either liquid-hydrogen or LiH absorbers is used to reduce the transverse phase-space occupied by the beam. The muons lose, by dE/dx losses, both longitudinal- and transverse-momentum as they pass through the absorbers. The longitudinal momentum is replaced by re-acceleration in the rf cavities.

5. **Acceleration.** The central momentum of the muons exiting the cooling channel is 220 MeV/c. A superconducting linac with solenoid focusing is used to raise the energy to 1.5 GeV. Thereafter, a Recirculating Linear Accelerator raises the energy to 5 GeV, and a pair of Fixed-Field Alternating Gradient rings using quadrupole triplet focusing accelerate the beam to at least 20 GeV.

6. **Storage Ring**. A compact racetrack geometry ring is used, in which 35% of the muons decay in the neutrino beam-forming straight section. If both signs are accelerated, one can inject in two superimposed rings or in two parallel straight sections.

This scheme produces over 2×10^{20} useful muon decays per operational year. The European Neutrino Factory design is similar in general to the US design, but differs in the technologies chosen to implement some of the subsystems. The Japanese design is very different, and uses very large acceptance accelerators rather than a system that reduces the phase-space occupied by the muons so they fit within the more limited acceptance of a more normal acceleration scheme.

5.1.3 The proton Driver

High power of the proton beam is a challenge in terms of beam losses, which can yield undesired activation of the machine components making hands-on maintenance impossible. In the CERN scheme with an H- linac with charge exchange injection into an accumulator ring

the stripping foil needs very close attention. A common problem of all proton drivers is the production of very short bunches in order to reduce finally the energy spread of the muons with a scheme called “debunching” amongst linac experts (“phase rotation” for neutrino people).

5.1.4 The target

For a high power target there are many areas of application in neutrino physics, studies of rare processes initiated by muons, studies of materials with neutron beams from a spallation source, the accelerator production of tritium, accelerator transmutation of waste, accelerator test facilities for fusion reactor materials and many others.

The main problems are the survival of components against melting/vaporization, the survival of components against beam-induced pressure waves (in the case of pulsed proton beams), the survival of components against radiation damage.

Massive solid targets (or rotating-wheel targets), typically water cooled, have been used in most applications with not more than 1-MW beam power. But for beam powers in excess of 1 MW such passive solid targets become very problematic in view of the challenges mentioned above. This has led to consideration of flowing liquid targets: mercury, molten lead, molten Pb/Bi, etc.

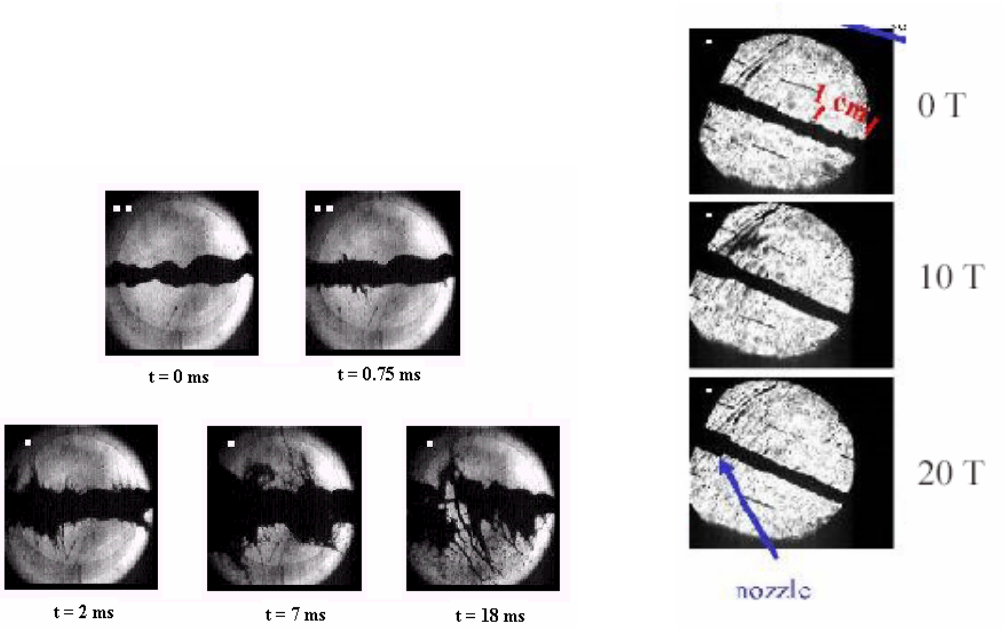

Figure 30 Experiments with liquid mercury jets. On the left is seen a jet exposed to a beam of 4 10^{12} protons of 24 GeV at BNL; the jet explosion begins long enough after the impact. On the right is shown the behaviour of the jet inside a high magnetic field; the jet is able to penetrate the intense magnetic field, and Eddie currents smoothen it.

The usual liquid target systems still require solid-walled containment vessels and beam windows that isolate the target region from the rest of the accelerator complex. An example of such a design within a horn is given in Figure 31. Experience has shown that if a liquid target is confined inside a metal pipe in the region of the interaction with a pulsed proton beam, then the beam-induced pressure waves can cause pitting (associated with cavitation during the

negative-pressure phases of the waves) and possible failure of the solid wall. Such concerns indicate that it would be preferable to have a flowing liquid target in the form of a free jet, at least in the region of interaction with the proton beam. In a recent workshop for "High-Power Targetry for Future Accelerators" in Ronkonkoma it was stated that Targets for 1 MW machines exist (but unproven) and that there is no convincing solution for the 4 MW class machines.

Rotating solid targets, granular targets, liquid metal targets, e.g. Hg have been considered at several labs. Tests with Hg were done at BNL and CERN. Tests with Hg jets injected into high magnetic fields were done by CERN at Grenoble. (Figure 30).

A number of valuable results were obtained, like the measurement of the radial velocity of the dispersal of the Hg jet as a function of the proton beam intensity and the observation that the Hg dispersal is largely transverse to the jet axis and that there is no visible manifestation of jet dispersal before 40 μs. At Grenoble the stabilizing effect of the jet when injected into a magnetic field was observed. There is now a proposal [target-exp] to the Isolde and nToF Committee for an experiment at CERN in the TT2a tunnel using a Hg jet with proton beam AND magnetic field supported by RAL, CERN, KEK, BNL and Princeton University, which would allow very good progress in the understanding of the basic mechanisms important for the design of multi MW targets.

5.1.5 Pion capture

For the pion capture different schemes are proposed. In the US a Solenoid with 10-20 Tesla is being considered (lifetime >>1 year), whereas at CERN the collection with magnetic horns is explored. A magnetic horn would be needed to select either positive or negative pions. Present estimates give a possible lifetime of 6 weeks. HARP results are needed to optimize the proton driver energy, the target and the collection device.

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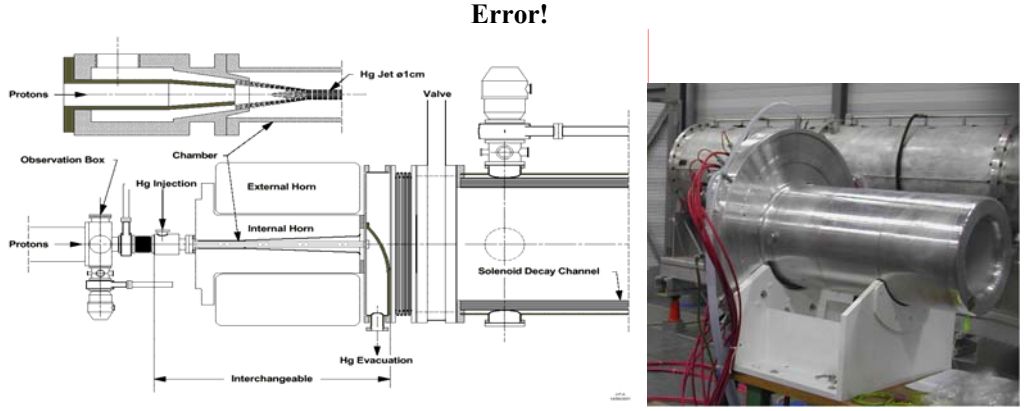


Figure 31 Possible layout of a Hg jet target and a horn. On the right, a prototype horn built at CERN [Gilardoni]

5.1.6 Cooling and phase rotation

Phase rotation in the CERN scheme is achieved with rf cavities operating at 88 MHz [Lombardi]. The American scheme [Study II] was using induction linacs. Now a 200 MHz rf capture system is being worked on. In both cases one lets the muon beam generated via the very short (1 ns rms) proton bunch spread out in the longitudinal direction and use the corresponding time-position correlation to correct the energy of the muons with a time-varying electric field. To perform cooling, the beam is sent through liquid hydrogen

absorbers, reducing the transverse and longitudinal momenta. Subsequent reconstitution of the longitudinal momentum occurs with RF cavities. Basically the cooling channel is a linear accelerator with (liquid hydrogen) absorbers. The cooling channel will be fairly long and expensive, hence the interest in “ring coolers”, where cooling is done over many revolutions.

Ionization cooling involves many new technologies, in particular operation of high gradient RF cavities in high magnetic field, and in the vicinity of hydrogen absorbers. In order to assert the performance that can be achieved in a real channel, the MICE experiment (Figure 32) is being prepared at the RAL (UK). Liquid hydrogen absorber prototypes have been already operated at Fermilab and the first 200 MHz cavities with Be windows is being built in Berkeley, while prototypes of the tracker and detectors are operated in UK, Japan Italy and CERN [MICE].

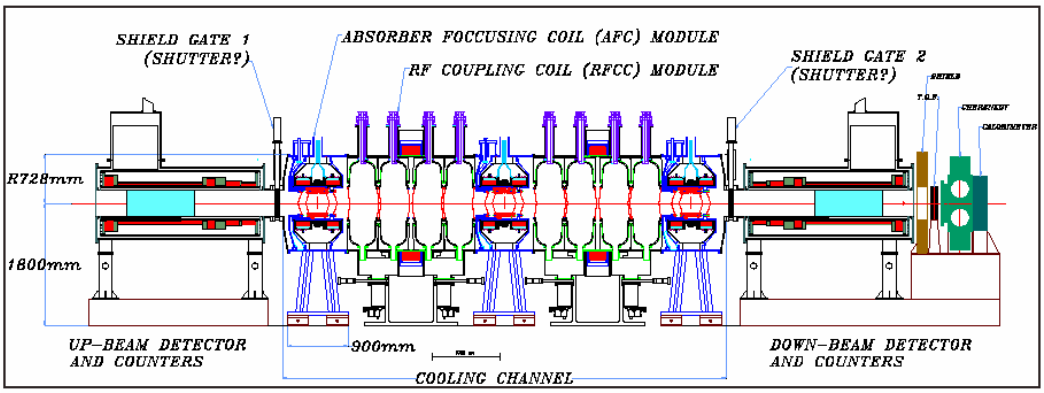


Figure 32 Layout of the MICE experiment.

5.1.7 Acceleration

The acceleration of muons should proceed in several steps and be very fast. After an initial linear accelerator "Recirculating Linear Accelerators" (RLAs) are investigated, as normal synchrotrons are too slow and the decay losses of muons would not be tolerable (the muon’s life time is only 2.2 μs). RLAs are a good compromise between cost and speed. For the acceleration 200 MHz sc cavities, sputtered at CERN, are tested at Cornell.

Another interesting proposal might be mentioned here: the possible use of a rapidly pulsed synchrotron, which seems feasible by making use of the fairly low repetition rate, at least in the US scheme.

The use of FFAGs is also being investigated, after the successful operation of proton FFAGs in Japan. These machines have a large acceptance, both in longitudinal and transverse phase space, hence cooling may not be needed and the acceleration can be fast due to fixed magnetic field. [Keil04]

5.1.8 Decay ring

The decay ring has long straight sections to produce the well directed neutrino beams. The geometry is quite flexible, but in order to achieve high precision on the flux it is best to use a race-track or triangle geometry to ensure muon precession. This allows measurement of the beam energy and energy spread with great precision and ensures that the average polarization is zero. The optics can be designed in such a way as to ensure a beam divergence of less than

0.2/γ, and the necessary diagnostics (at least a beam current monitor, a polarimeter and a measurement of beam angular divergence) can be accommodated. [Keil00], [ECFAreport].

5.1.9 Muon Colliders

Some time ago regarded by some people as science fiction, it must be noted that the advances in cooling theory and technology are so impressive as to consider this type of machine as a real possibility in the future opening the "High Energy Frontier" to leptons.

5.1.10 Progress on Neutrino Factory design

An impressive Neutrino Factory R&D effort has been ongoing in Europe, Japan, and the U.S. over the last few years, and significant progress has been made towards optimizing the design, developing and testing the required accelerator components, and significantly reducing the cost. To illustrate progress in cost reduction, the cost estimate for a recent update of the US design [APS04] is compared in Table 9 with the corresponding cost for the previous "Study II" US design [Study II]. It should be noted that the Study II design cost was based on a significant amount of engineering input to ensure design feasibility and establish a good cost basis. This engineering step has not yet been done for the updated design, but the new cost estimate is based on experience from the Study II work. The conclusion is that the latest design ideas are expected to lead to very significant cost reductions, although more work must be done to establish a reliable new cost estimate.

Neutrino Factory R&D has reached a critical stage in which support is required for two key international experiments (MICE and Targetry) and a third-generation international design study. If this support is forthcoming, a Neutrino Factory could be added to the Neutrino Physics roadmap in less than a decade.

Table 9 Comparison of unloaded Neutrino Factory costs estimates for the US Study II design and for the latest updated US design. Costs are shown including or not including the Proton Driver and Target station in the estimates. The New design cost estimate has not yet benefited from the level of engineering effort included in the Study II work. Table from Ref. [APS04].

	All (M$)	No Proton Driver (M$)	No Proton Driver & No Target station (M$)
Study II	1832	1641	1538
New / Study II (%)	67	63	60

The scientific case for pursuing Neutrino Factory R&D is strong. The encouraging technical progress in Neutrino Factory R&D over the last few years has been matched by progress in building the level of international collaboration needed for the next step, and preparing proposals for the critical R&D experiments. All of this has been accomplished with very limited funding. The next steps require an increase in funding, but to a level which is still modest considering the nature of the enterprise. If a Neutrino Factory is to remain a viable option for the future it is important that MICE, the Targetry experiment, and a third-generation international design study are supported. If this is the case, we have much to look forward to.

5.2 Hadro-production experiments

(M. Apollonio, A. Blondel)

5.2.1 Introduction

The construction of a Neutrino Factory or a superbeam requires optimisation of target material, collection scheme and proton energy. Present studies are based on simulation codes for pion production which show large discrepancies, both in π/K yield and (p_L,p_T) distributions. This reflects the poor experimental data, based on old experiments covering small acceptances, few materials and few incident proton energies, and the lack of a good phenomenological description of low energy hadronic interactions. The situation calls for a new generation of dedicated hadronic experiments as integral part of the neutrino physics programme. The E910 experiment at BNl took data in the late 1990's for proton energies between 6 and 24 GeV and first results were presented recently [BNL91004]. The MIPP experiment at Fermilab [MIPP] is presently being commissioned for proton energies between 15 and 125 GeV. The HARP experiment at CERN is the only one to cover the low energy range of the baseline SPL option (protons of 2.2 GeV kinetic energy (~3 GeV/c momentum) [Vretenar00] where it is crucial to understand the π^+/π^- ratio as well as the rate of $K^\pm$ and K^0 production.

5.2.2 The HARP experiment

HARP [HARP-proposal] was proposed in 1999 as a hadro-production experiment whose goals are:

- The optimisation of the $\pi^+(\pi^-)$ yield in view of a Neutrino Factory or a superbeam
- The calculation of beam fluxes for other experiments, K2K [K2K03] and MiniBooNE [MiniBoone]
- The improvement of the present knowledge about atmospheric neutrino fluxes
- The input for hadronic Monte Carlo generators

The first and second points will be developed in the following.

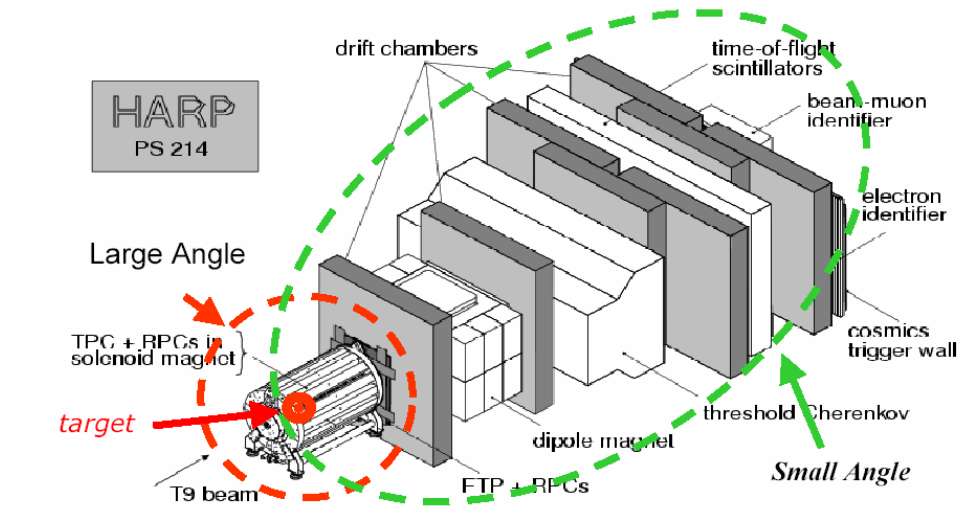


Figure 33 The HARP experiment

Figure 33 shows a layout of HARP; the experiment, located in the PS T9 East Hall at CERN, collected about 420 million events in 2001-2002, with a distribution of beam particle and energy and targets shown in Table 10 at a high DAQ rate (2.5 kHz, ~10^6 events/day). The detector can be ideally decomposed into a Large Angle Region (covered by a TPC and several RPCs inside a 0.7 T solenoidal magnetic field) and a Forward Region (covered by a spectrometer and a series of detectors for particle identification).

Table 10 Summary of the HARP data taking campaign (2001-2002). Many materials have been tested ranging from H to Pb, at proton momenta covering an entire decade (1.5 to 15 GeV/c). Some special targets (like the K2K and MiniBooNE replicas and cryogenic targets) have been thoroughly studied.

	Target material	Target length (λ%)	Beam Momentum (GeV)	#events (millions)
Solid targets	Be	2 (2001) 5 100	±3 ± 5 ± 8 ± 12 ± 15 Negative only 2% and 5%	233.16
	C			
	Al			
	Cu			
	Sn			
	Ta			
	Pb			
K2K	Al	5, 50, 100, replica	+12.9	15.27
MiniBooNE	Be		+8.9	22.56
Cu "button"	Cu		+12.9, +15	1.71
Cu "skew"	Cu	2	+12	1.69
Cryogenic targets	N_2	6 cm	±3 ± 5 ± 8 ± 12 ± 15	58.43
	O_2			
	D_2			
	H_2			
	H_2	18 cm	±3, ±8, ±14.5	13.83
Water	H_20	10, 100	+1.5, 8(10%)	9.6

5.2.3 Optimisation of the Neutrino Factory (and super-beam): large angle

The aim is to reach a precision of 5% in the pion yield (and π^+/π^- ratio). It should be stressed that such measurements will be also extremely useful for a super-beam. At all energies most of the pions are produced at high angles but this is especially true for the low enery of SPL. For this reason the use of Large Angle Detectors (TPC and RPCs) are of paramount importance. Presently the TPC calibration and correction of various distortions and cross-talk is underway. A campaign of calibrations using cosmic rays, radioactive sources (^{83}Kr and ^{55}Fe) and data was pursued [HARP03]. This calibration program allowed:

- The equalisation of gains and mapping of dead pads
- A first evaluation of the correction for cross talk in the readout planes
- The first determination of the dE/dX as a function of p
- An improvement in p_T resolution

Some of these results are summarized in fig. 2 and fig. 3 (left and right). These results will be verified using the well-known elastic scattering processes of protons (pions) on hydrogen target at low momenta (3 GeV/c).

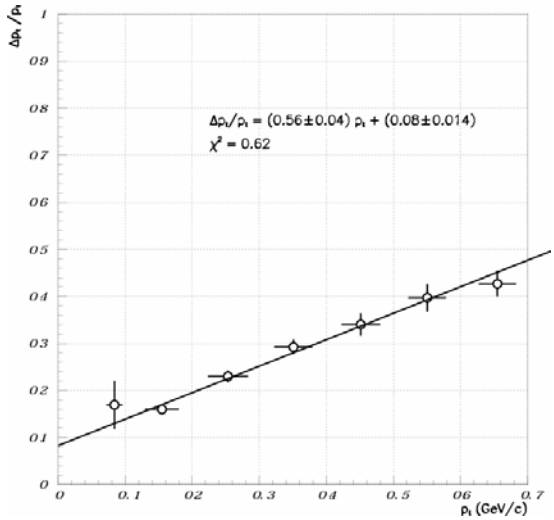


Figure 34 Transversal momentum resolution as a function of p_T, as measured by the TPC.

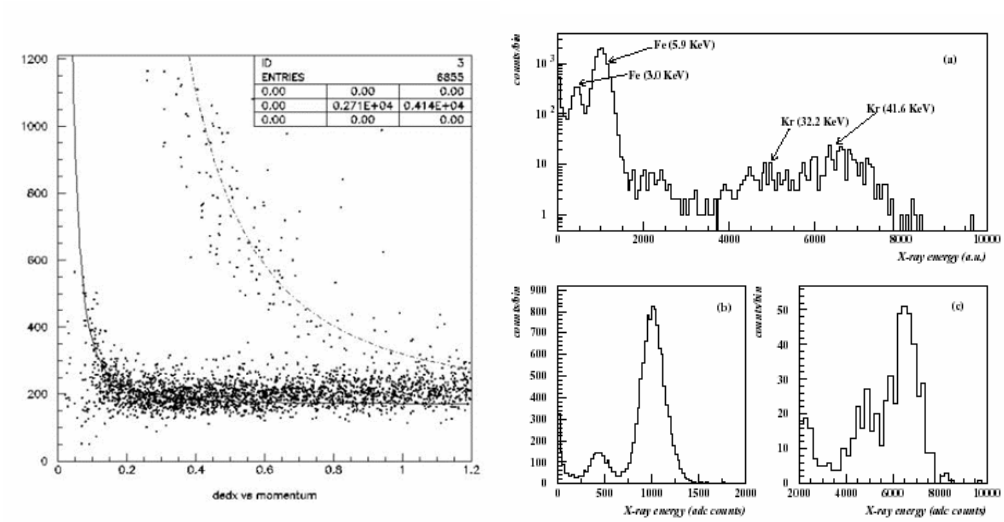


Figure 35 (left) dE/dX as a function of p, showing different particle populations (π,μ and protons); (right) energy peaks for the radioactive sources used to calibrate the detector: (a) overall picture with ^{55}Fe and ^{83}Kr. (b) Fe peaks (at 5.9 and 3.0 keV) and Kr peaks (the main one being at 41.6 keV). This case is obtained using equalised pads.

5.2.4 The K2K and MiniBoone case: the forward analysis

This important physics case has been chosen as the subject of our first analysis. In the K2K experiment [K2K03], one of the largest systematics in the ν oscillation parameters comes from the uncertainty on the far/near ratio, which depends on the π-production model used. The pion flux from KEK can be monitored and checked against simulation of the beam down to neutrino energies of 1 GeV, while for lower energies there is no experimental information. Unfortunately the oscillation effect that K2K is meant to measure takes place somewhere

between 0.5 and 0.75 GeV. This translates into a (p,θ) distribution for parent pions which is well covered by the HARP forward detectors (see fig. 4).

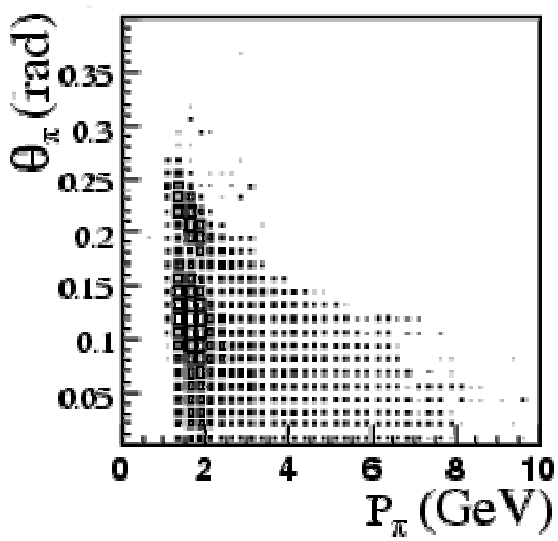


Figure 36 (p,θ) distribution for pions in the K2K case as described in the text. The parameter space is well within the reach of the forward HARP detectors.

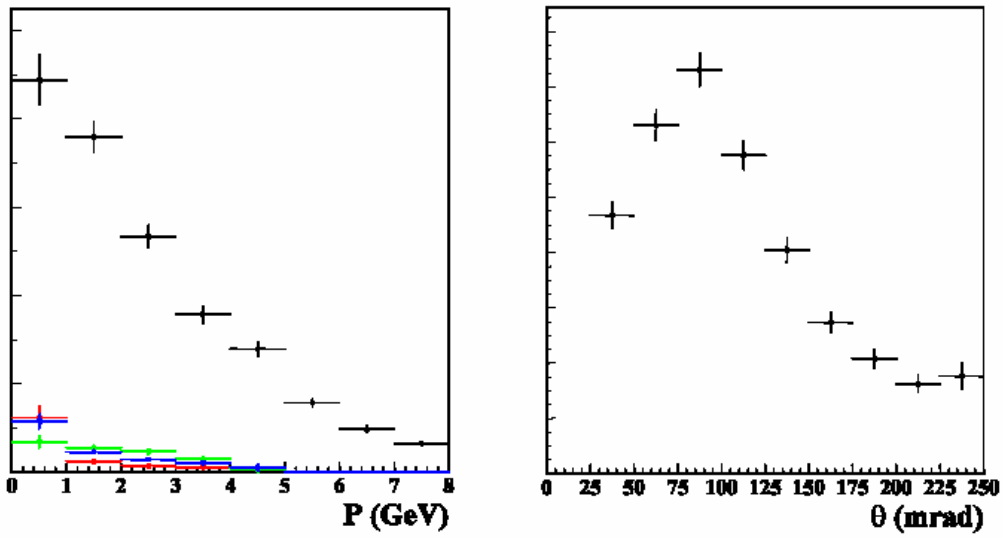


Figure 37 (left) momentum distribution, integrated over θ, for secondary pions from 12.9 GeV/c protons impinging onto a 5% λ Al target. (right) angle distribution, integrated over p, for the same sample. Vertical axis is in arbitrary units [Cervera04].

A special program with an Al K2K replica target has been followed by HARP; at present the collaboration is strongly focussing into this subject, aiming at the calculation of the pion cross section in a range of momenta p_π<8 GeV/c and of emission angles θ_π<300 mrad.

Preliminary results of this analysis, based on an Al thin target at 12.9 GeV/c, have been already made public [Cervera04], and are summarized in Figure 37, in the form of shape distributions for p and θ. Albeit still missing of a real determination for the systematic error they represent our first measurement of the pion yield as a function of momentum and emission angle.

5.2.5 Conclusions

The optimization of future neutrino facilities requires good understanding of pion production by various beams and targets. The HARP experiment was assembled very rapidly and took an extensive data set. The experiment and its analysis require great care, but the experiment should be able to fulfill its goals. The measurement on pion and kaon yields at the low energy of SPL will be important for the decision on this accelerator.

5.3 EURISOL : a new nuclear physics facility

(Y. Blumenfeld, P. Butler, A.C. Mueller)

During the past two decades, progress in nuclear physics has been largely fuelled by the development and improvement of radioactive ion beams. The two main methods used to produce such beams are called projectile fragmentation and ISOL. In the former a high energy heavy ion beam impinges on a thin target and a large array of fragments is produced. The isotopes of interest are selected by a fragment separator and the resulting beam transported to the experimental areas. This method, used at GANIL, GSI, the NSCL/MSU and RIKEN, is particularly efficient for a large variety of species with short lifetimes and delivers high energy beams with relatively modest resolution qualities. The ISOL method, in use at CERN/REX-ISOLDE, GANIL/SPIRAL and TRIUMF, uses a driver accelerator (p, d or heavy ions) and a thick target. The nuclei are produced at rest, diffuse and effuse out of the target before being ionised and then accelerated in a post-accelerator. Beams of high quality but modest energy are produced. The efficiency of such a system depends on the diffusion and effusion times and certain elements, such as the refractory elements, are particularly difficult to produce due to their chemical properties.

Technologies are now being developed, which should allow for improvements of orders of magnitude of the intensities of radioactive beams. A vast physics program has been identified, which is extensively discussed in other talks of this workshop. This led NuPECC to propose the construction of two 'next generation' RIB infrastructures in Europe, i.e. one ISOL and one in-flight facility. The in-flight machine would arise from a major upgrade of the current GSI facility, while EURISOL would constitute the new ISOL facility.

An RTD program, for a preliminary design study of EURISOL, was coordinated by GANIL and J. Vervier, and implemented under the auspices of the EU 5th framework program. The result is a preliminary design report [EURISOL] which outlines a concept for a future EURISOL facility (fig. 1). The driver accelerator would be a super-conducting CW proton LINAC, of energy 1 GeV and power 5 MW, with additional capability of accelerating deuterons and possibly heavier ions with A/Q = 2. Several target stations would be built, including a fission target with a liquid mercury converter allowing for the use of the full 5 MW beam power, and targets receiving directly the approximately 100 KW of proton beam for production of lighter or neutron deficient isotopes. The post accelerator would be a super-conducting heavy-ion LINAC with a maximum energy of 100 MeV/nucleon. The maximum

energy is somewhat arbitrary and for a linac is defined by cost; higher energies could be achieved at CERN by exploiting its existing synchrotron accelerator chain or new accelerators required for the beta-beam facility.

In EURISOL there will be several experimental areas devoted to physics at different energies: fundamental physics, nuclear astrophysics, nuclear structure and nuclear reaction studies. Among the experimental equipment necessary, one can cite ion traps and high precision spectroscopy set ups for very low energy beams (similar to present ISOLDE equipment); a variety of high resolution and/or large acceptance magnetic spectrometers; an innovative gamma-ray tracking array (i.e. the AGATA concept); high granularity charged particle and neutron detectors, a 4Π charged fragment detector, and a fragment separator for production of nuclei very far from stability through secondary fragmentation.

With the wide diversity of scientific disciplines and individual experiments being served by the facility, various multi-user installations (such as at the present ISOLDE) are needed, requiring the design of a beam switchyard that allows parallel operation.

Typical intensities in particles per second would be 10^{13} for ^{132}Sn, 10^{11} ^{56}Ni, 5 10^{13} ^{6}He, and 5 10^{12} for ^{18}Ne.The total cost of such a facility was estimated at 600 M€, including buildings but excluding manpower. The large production of ^{6}He and ^{18}Ne would make EURISOL an attractive source of unstable nuclei for a β-beam installation, as outlined in chapter 5.4.

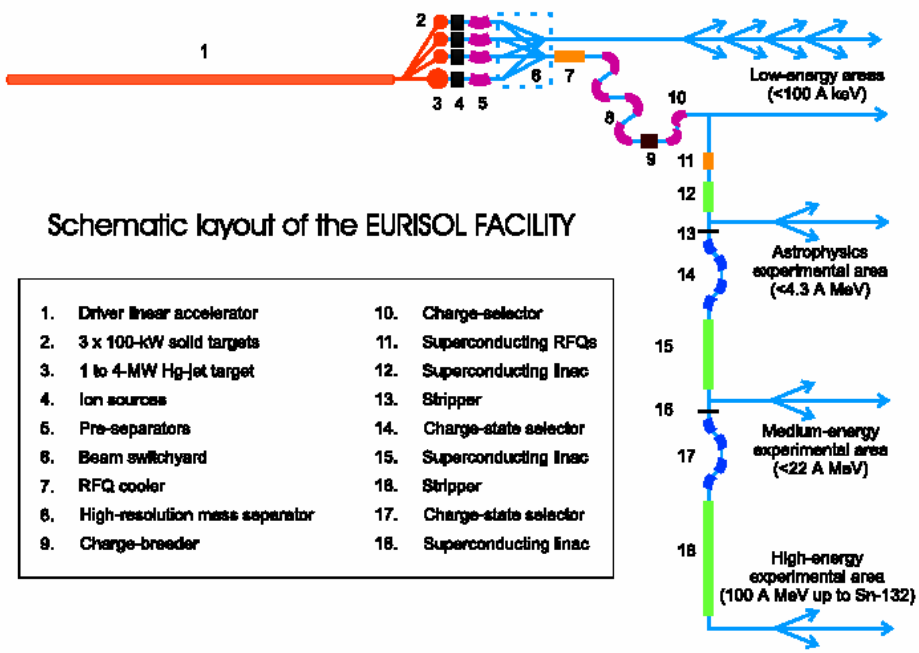


Figure 38 : Conceptual layout of the EURISOL facility.

The roadmap towards EURISOL includes three main aspects:

--The vigorous scientific exploitation of current ISOL facilities : EXCYT, Louvain, REX/ISOLDE, SPIRAL
--The construction of intermediate generation facilities : MAFF, REX upgrade, SPES, SPIRAL2
--The design and prototyping of the most specific and challenging parts of EURISOL in the framework of the EURISOL design study (EURISOL_DS) proposed in the sixth framework program.

In close contact with the nuclear physics and neutrino communities, a design study proposal (EURISOL_DS) was submitted in March 2004, with the aim of performing detailed engineering oriented studies and technical prototyping work for the future EURISOL facility, which would be coordinated by GANIL and G. Fortuna. This design study proposal includes 21 participating institutions from 14 European countries, as well as 21 other contributing laboratories from Europe, North America and Asia who will provide their expertise on specific technical points. The total cost of the design study would be 33 M€, of which 9.16 M€ is requested from the EU, the remainder being provided by the participating institutions.

The work is to be subdivided in 11 tasks (the laboratories leading the tasks are indicated in parentheses) grouped under 4 topical subjects. Several of these tasks include a large effort of technical prototyping as specified:

•Physics, beam intensity and safety
–Physics and instrumentation (Liverpool)
–Beam intensity calculations (GSI)
–Safety and radioprotection (Saclay)
•Accelerators :
–Proton accelerator design (INFN Legnaro)
–Heavy ion accelerator design (GANIL)
–SC cavity development (IPN Orsay): prototyping of SC cavities and multipurpose cryomodule
•Targets and ion sources :
–Multi-MW target station (CERN) : prototyping of mercury converter
–Direct target (CERN) : Several target-ion source prototypes
–Fission target (INFN Legnaro) : prototyping of UC_X target
•Beam properties :
–Beam preparation (Jyväskylä) : prototyping of 60 GHz ECR source
–Beta-beam aspects (CERN)

Several synergies have been identified, in particular with the HIPPI JRA and the BENE network of the CARE Integrated Infrastructure Initiative. This workshop has represented an excellent opportunity to start implementing these synergies.

EURISOL, FAIR and RIA

As outlined in 3.3, the other major "next generation" nuclear facility in Europe, FAIR, will embrace research programmes in hadron and nuclear physics, atomic and plasma physics that are complementary to EURISOL, using intense beams of heavy-ions and anti-protons. In the overlapping area of radioactive ion beam physics EURISOL and FAIR will provide secondary beams in different domains of energy and beam quality, and therefore offer different experimental conditions. The EURISOL facility provides very high secondary-beam intensities for many species and beam properties (continuously variable beam energy of good definition, high purity and small emittance), which are well adapted to highly elaborate

experimental approaches. EURISOL will also provide radioactive ion beams of > 100 MeV/u, that will fragment to the most exotic nuclei. The fragmentation in-flight technique used at FAIR is most interesting for very short-lived nuclei in the vicinity of the drip-lines and/or for RIB production at very high energies. FAIR will also provide cooled, stored beams of longer-lived exotic nuclei.

The American approach is to combine the features of in-flight and ISOL methods into one facility: the Rare Isotope Accelerator (RIA). The primary driver of RIA will be a linac that accelerates protons to 900 MeV and heavy ions to 400 MeV/u. For ISOL its beam power (of the order of 100 KW) is much smaller than EURISOL (5 MW) while its maximum heavy-ion energy is much less than FAIR (1.5 GeV/u). A core element of RIA is the use of gas catcher to stop fragmentation products prior to post-acceleration. This would offer chemistry independent ISOL beams for long-lived (ms) radionuclides but space-charge effects will limit the secondary beam intensity.

5.4 A neutrino beta-beam facility at CERN

(M. Lindroos)

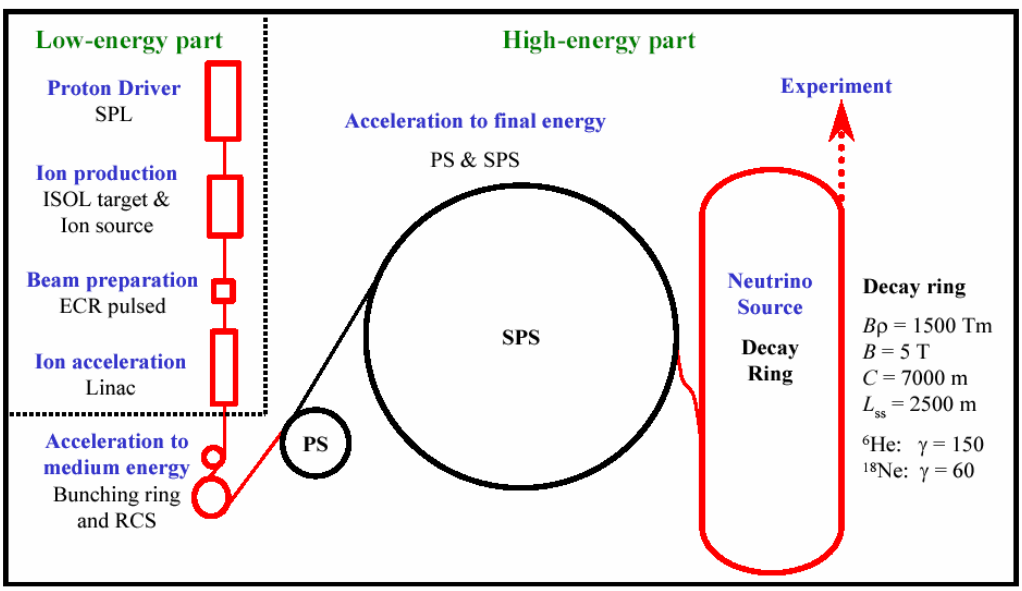


Figure 39 Beta-beam base line design, partially using existing CERN accelerator infrastructure (parts in black).

The proposed beta-beam facility [Zucchelli] can be divided into two parts, a low energy part stretching up to 100 MeV/u and a high-energy part for further acceleration and ion stacking and storage in the decay ring, serving as neutrino source. This division is logical as the low-energy part corresponds to the requirements for an ISOL-type radioactive beam factory as proposed and promoted by the European Nuclear Physics community. The high-energy part, serving the neutrino physics community, would be one of several users of such a radioactive ion beam facility and would consequently share the cost and operation of the low-energy part with other physics applications.

The radioactive ions ^{6}He and ^{18}Ne will be produced in an ISOL system using the proposed Superconducting Proton Linac (SPL) as a driver. Following production, the ions will be fully stripped, bunched and accelerated with a linac to approximately 100 MeV/u. Further bunching will be achieved by multi-turn injection into a Rapid Cycling Synchrotron (RCS), followed by acceleration to 300 MeV/u before injection into the Proton Synchrotron (PS). The beam will then be accelerated in several bunches to PS top energy, transferred to the Super Proton Synchrotron (SPS) and accelerated to the desired top energy. Finally, the ions will be transferred to the decay ring where they will be merged with the already circulating bunches through a longitudinal stacking procedure.

Several bottlenecks exist in this process, not least the bunching at low energy, space-charge limitations in PS and SPS, decay losses along the accelerator chain and the longitudinal stacking procedure at high energy in the decay ring.

5.4.1 Ion production

The flux at the detector depends on the average energy of the neutrinos at rest as this determines the focusing of the neutrino beam. A further constraint is set by the decay losses in the accelerator chain that increase with shorter life-time and another aspect to consider are the decay products that could create long lived contamination in the low-energy part. All constraints together point towards two isotopes of particular interest, ^{6}He to generate electron anti-neutrinos and ^{18}Ne for electron neutrinos.

Both species can be produced in large quantities through the so-called ISOL method. The helium isotope is best produced in a BeO target using a very intense primary proton beam of a few GeV, impinging on a so-called neutron converter. For the neon isotope, spallation in a MgO target with a less intense proton beam, hitting the target material directly, is the method of choice. Due to the use of converter technology typically ten times more helium than neon isotopes can be produced.

5.4.2 Ionization, bunching and pre-acceleration

The ions can be transported away from the ISOL target directly in gas form since the chosen elements are noble gases. Alternatively, a high efficiency (for noble gases) mono-charge ECR source, close to the target, can be used to transport the singly charged ions using classical beam transport. In either case the beam has subsequently to be ionized and bunched for further acceleration in the injector chain.

Efficient bunching (<20 μs pulse length) and full stripping of a high-intensity beam can be achieved using a high-frequency 60 GHz ECR source.

Once fully stripped, the ions are first accelerated in a linac to increase their lifetime. The acceleration of high-intensity radioactive ion beams to ~100 MeV/u using a linac has already been studied within the EU-financed study EURISOL. This study is planned to continue as design study within the 6th EU framework programme.

5.4.3 Stacking

The energy of the beta-beam neutrinos will be in the range of atmospheric neutrinos. As the time structure of the neutrino beam mirrors the one of the ions circulating in the decay ring, the beam has to be concentrated in as few and as short bunches as possible to permit efficient

background suppression in the detector. Four bunches, each 10 ns long, were chosen for the base line design.

A new scheme of longitudinal stacking has been proposed for the beta-beam. It uses asymmetric bunch pair merging, which relies on a dual-harmonic rf system to combine adjacent bunches in longitudinal phase space such that a fresh, dense bunch is embedded in the core of a much larger one with minimal emittance dilution. The fact that only the central part of the residing bunch is affected results in a net increase of the core intensity. The surrounding "older" ions are pushed out, towards the bucket separatrix, where the "oldest" ions will eventually be lost. Asymmetric bunch pair merging has recently been demonstrated in the PS.

5.4.4 Intensity

Starting from the production rates for ^{6}He and ^{18}Ne at the ECR source, and taking into account only beta-decay losses, the beam intensities along the accelerator chain can be calculated. Table 11 quotes the estimated production rates at the source, the beam intensities at extraction from the synchrotrons in the injector chain and the average circulating beam intensities in the decay ring for the beta-beam baseline scenario, assuming 16 Hz operation of the RCS and 8 s cycling time of the SPS and the complete injector chain. The number of batches required to fill the downstream machine is also indicated.

Table 11: Ion intensities for ^{6}He and ^{18}Ne operation along the accelerator chain for the beta-beam base line scenario (only beta-decay losses are taken into account).

Machine	**^{6}He ions**	**^{18}Ne ions**	**Batches**
Source	$\sim 2 \times 10^{13}$ /s	$\sim 8 \times 10^{11}$ /s	dc
RCS	1.0×10^{12}	4.1×10^{10}	16
PS	1.0×10^{13}	5.2×10^{11}	1
SPS	9.5×10^{12}	4.9×10^{11}	∞
Decay Ring	2.0×10^{14}	9.1×10^{12}	-

Experience from operation of high intensity ion beams at CERN suggests that, in addition to the decay losses quoted in Table 11, around 50% of the beam will be lost along the accelerator chain. Applying this rule of thumb shows that in the decay ring typical average ion intensities of 1×10^{14} for ^{6}He and 4.5×10^{12} for ^{18}Ne can be expected.

5.4.5 Decay losses

The most important difference between the acceleration of stable ions and radioactive ions are the beam losses induced by the radioactive decay during the acceleration process, especially at low energies. The isotopes proposed for the beta-beam have been chosen such that no long-lived activity is left to contaminate the accelerator chain.

A first study based on simulation of ion losses in the decay ring for the conceptual design yields that the induced dose rate in the arcs is limited to 2.5 mSv/h after 30 days of operation and 1 day of cooling down time. It was also shown that the induced radioactivity in ground water will have no major impact on public safety. The study demonstrated that the decay

losses in the injector chain will be below the commonly accepted power limit of 1 W/m for hands on maintenance, except for the PS. The analysis of losses in the PS and their consequences clearly deserves more attention. Obviously the losses in the decay ring are much higher and special care will have to be taken in the design to cope with this problem.

5.4.6 Planned R&D

The present design is mainly based on available technology with some conservative extrapolations. The studies of the physics reach of such a facility has shown that it is highly desirable to increase the electron neutrino flux by an increase of number of Neon ions in the decay ring. This could feasibly be achieved by the use of several ISOL targets in tandem making use of the same primary driver beam as only a part of the total beam energy is lost in each individual target unit. Furthermore, the accumulation at low energy can clearly be improved for the longer lived Neon ions (originally optimised for He). Another direction for R&D is driven by the recent discovery that a beta-beam facility at higher neutrino energy (corresponding of a decay ring gamma of approximately 500) has an enlarged physics reach comparable to a Neutrino Factory. The main challenge for such a high gamma facility is the initial acceleration of the ions which today is limited by the maximum magnetic rigidity of the SPS. Beam losses and radiation aspects have clearly been identified as major concerns that will require special attention during the detailed design work.

6 Particle Physics case – neutrino oscillations

6.1 Overview of neutrino oscillation physics

(A. Blondel, S. Geer, P. Hernandez, A. Rubbia)

In recent years exciting experimental discoveries have shown that neutrino flavors oscillate, and hence that neutrinos have nonzero masses and mixings. The Standard Model needs to be modified to accommodate neutrino mass terms, which require either the existence of right-handed neutrinos to create Dirac mass terms, and/or a violation of lepton number conservation to create Majorana mass terms. The observation that neutrino masses and mass-splittings are tiny compared to the masses of any of the other fundamental fermions suggests radically new physics, which perhaps originates at the GUT or Planck Scale, or perhaps indicates the existence of new spatial dimensions. Whatever the origin of the observed neutrino masses and mixings is, it will certainly require a profound extension to our picture of the physical world. The first step towards understanding this new physics is to pin down the measurable parameters, and address the first round of basic questions:

- Are there only three neutrino flavors, or do light sterile neutrinos exist? Are there any other deviations to three-flavor mixing?
- There is one angle θ_{13} in the mixing matrix, which is unmeasured. Is it non-zero?
- We do not know the mass-ordering of the neutrino mass eigenstates. There are two possibilities, the so-called "normal" or "inverted" hierarchies. Which is right?
- There is one complex phase δ in the mixing matrix, which is accessible to neutrino oscillation measurements. If both θ_{13} and $\sin\delta$ are non-zero there will be CP Violation in the lepton sector. Is $\sin\delta$ non-zero ?
- What precisely is the value of the lightest neutrino mass and are neutrino masses generated by Majorana mass terms, Dirac mass terms, or both ?

All of these questions, with the exception of the last one, can in principle be addressed by accelerator-based neutrino oscillation experiments. However, getting all of the answers will not be easy, and will require the right experimental tools. A Neutrino Factory or a beta-beam appear to be the ultimate tools for probing neutrino oscillations. Hence the interest in these new types of neutrino sources.

On the experimental side, a new generation of long baseline oscillation experiments are required that are able to measure the small oscillation probabilities $\nu_e \rightarrow \nu_\mu$ in the atmospheric range. This will require neutrino beams with unprecedented intensity, therefore the need of a new megawatt proton source.

The first step in all the various alternatives that have been proposed would be to use the pions and kaons to produce a conventional neutrino superbeam (SB). The increase in intensity of the proton source cannot be fully exploited however with this type of beams, because systematic errors associated with the irreducible beam background dominate (there is always a poorly known $\nu_e, \bar{\nu}_e$ component in the dominant ν_μ beam. Purer neutrino beams, such as those produced from muons in a Neutrino Factory (NF) [nufact], or boosted heavy ion β

decays as in the β-beam (BB) [Zucchelli],[bbcern], could improve things very significantly. In contrast with a conventional beam, these are essentially pure beams where the fluxes are known with a very good precision since they are essentially fixed from the number of muons/Ions decaying in the decay ring and the well-known kinematics of muon/ion decay.

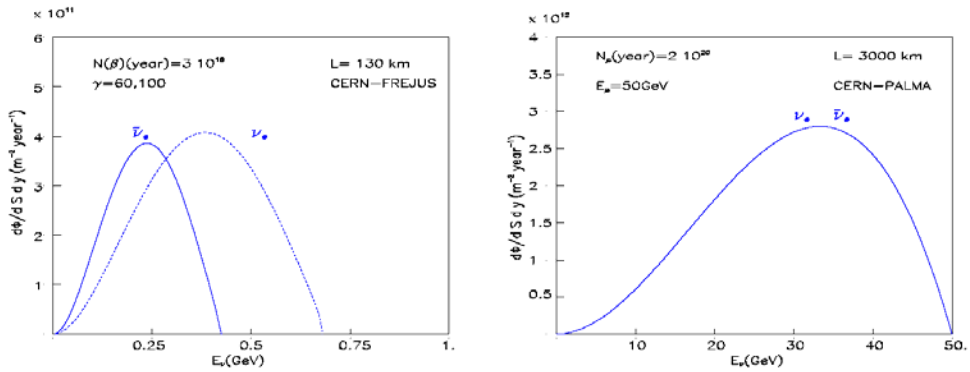


Figure 40 Left: ν_e , $\overline{\nu}_e$ fluxes in the BB from 10^{18} ^{18}Ne and 3 10^{18} 6He ion decays per year at γ=100;60 and L=130 km. Right: ν_e , $\overline{\nu}_e$ fluxes at the NF from 2 10^{20} 50GeV μ^+ , μ^- decays and L=3000 km.

Figure 40 shows the neutrino fluxes as a function of the energy for a typical NF design and the standard BB design.

On the theoretical side, the lightness of the neutrinos seems to point to a new hierarchy problem in the flavour sector: why are neutrinos so much lighter than the remaining leptons ? There is a hint to understand this from the basic symmetries of the SM. All the fermion masses originate from the interaction with the Higgs field, however while for the fermions carrying colour and electromagnetic charge the coupling has to be of the Yukawa type in such a way that masses are proportional to the vacuum expectation value of the Higgs field ($m_f = \lambda_f$ v), for neutrinos another type of coupling is possible:

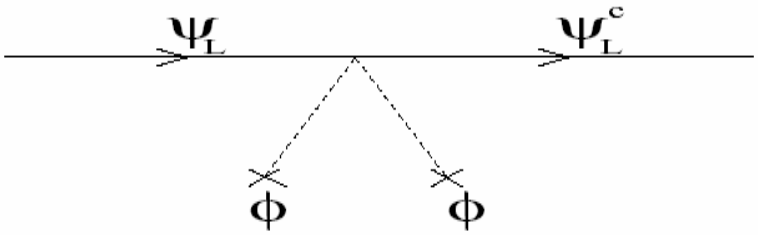


Figure 41 Coupling allowed for neutrinos in the Standard Model, which is not allowed for the other fermions.

This coupling results in Majorana masses for the light neutrinos of the type $m_\nu = \lambda_\nu v^2 /M$, involving necessarily a new unknown physics scale, M, much larger than the electroweak scale v, thus resulting in a natural hierarchy between neutrinos and the remaining leptons. New dynamics should show up at the scale M, which could explain also other mysteries of the SM. The mass M is interestingly close to the Grand Unified scale and is associated with the

breaking of a global symmetry of the SM, the total lepton number. This opens new interesting possibilities to explain the matter-antimatter asymmetry in the Universe.

Unfortunately the scale M is probably too high to be reached in future accelerator experiments, thus the importance of extracting all the information available at low energies where the effects of the scale M are all encoded in the neutrino mass matrices. These matrices contain a number of new physical parameters: besides the three neutrino masses, there are three mixing angles, θ_{12}, θ_{13}, θ_{23}, and CP-violating phases [PMNS]. If neutrinos get masses via Yukawa couplings, there is only one such phase, δ, while in the Majorana case, there are two more phase observable at low energies. In other words, the lepton flavour sector of the SM is at least as rich as the quark sector.

Solar and reactor experiments [Fukuda01],[Apollonio03] have determined the difference between the squared masses of two of the neutrino mass eigenstates, $\Delta m^2_{12} \approx 8\ 10^{-5}\ eV^2$ and one of the mixing angles, $\theta_{12} \approx 32^0$. Atmospheric neutrino experiments [Fukuda98], and the K2K experiment [Ahn03] on the other hand have measured the other mass square difference $\Delta m^2_{23} \approx 2.5\ 10^{-3}\ eV^2$ and the angle θ_{23}, which turns out to be very close to maximal (45^0).

In spite of this impressive experimental progress, we are still far from having the complete picture. Besides the improvement in precision on the parameters that have already been measured (which should for instance answer whether the angle θ_{23} is truly maximal, since this could point to a new fundamental symmetry), it is necessary to establish the three-family mixing picture, which requires the measurement of the third mixing angle θ_{13} presently only bounded to be below $\sim 10^0$).

Very important will also be to establish if there are new phases that violate CP in the lepton sector of the SM and to measure the sign of Δm^2_{23} that determines the type of neutrino spectrum (hierarchical if the neutrinos 1 and 2, which have the highest ν_e content, are lighter than the remaining one or inverse hierarchical if they are heavier. Fortunately all these questions can be addressed in more precise long baseline neutrino oscillation experiments. Other fundamental questions like the determination of the absolute neutrino mass scale and the Majorana nature of light neutrinos requires a new generation of experiments measuring the end-point of Tritium β-decay and searching for rare neutrinoless double β-decay.

6.1.1 Neutrino Factory Physics Program

The possibility of having intense neutrino beams of well-known composition opens the road to a large variety of physics studies. Having a simultaneous beam of electron and muon neutrinos, distinguished by helicity, allows the study of several oscillation processes. If we consider negative muons in the ring, the following transitions can occur:

$\nu_\mu \rightarrow \nu_\mu$ disappearance
$\nu_\mu \rightarrow \nu_e$ appearance
$\nu_\mu \rightarrow \nu_\tau$ appearance
$\bar{\nu}_e \rightarrow \bar{\nu}_e$ disappearance
$\bar{\nu}_e \rightarrow \bar{\nu}_\mu$ appearance
$\bar{\nu}_e \rightarrow \bar{\nu}_\tau$ appearance

An important feature of the Neutrino Factory is the possibility of having opposite muon charges circulating in the ring, therefore allowing also the study of the charged-conjugated processes of those above.

Since measurements can be made with both positive muons or negative muons stored, 12 measured differential spectra can be simultaneously fit to the oscillation parameters. This would provide experiments with a wealth of measurements that, in addition to offering exquisite precision, also offer the flexibility to exploit possible surprises.

The simultaneous presence of both neutrino flavours in the beam poses the problem of separating neutrinos due to oscillations from beam background. A simple identification of the lepton produced in charged-current interactions is not sufficient, since muons, for instance, could come from the antineutrino component of the beam, or from the oscillation $\nu_e \rightarrow \nu_\mu$, or even from the oscillation $\nu_e \rightarrow \nu_\tau$ followed by the decay $\tau \rightarrow \mu$. The obvious way to distinguish neutrinos coming from the beam from those coming from oscillations is to measure the charge of the lepton produced in charged-current events. This can be done readily using a magnetic detector of design similar to that of the CDHS or MINOS experiments, for which by that time one can safely assume that it could be built with a mass of the order of 50 ktons. Many studies have been performed under this hypothesis, where the main discovery channel is the 'wrong sign muon' also called *golden channel* [Cervera00].

The ideal case would be to be able to measure the charge for both electrons and muons, and perhaps find a way also to identify taus. Since the last two requirements are quite difficult to match, we consider as a default case that the detector for the Neutrino Factory will only be able to identify the charge of muons. If also electron identification can be performed, as would be the case in a large liguid argon detector ([Bueno00], see also chapter 6.4) , the detected events can be classified in four classes:

Charged-current electrons,
Right-sign muons,
Wrong-sign muons,
Events with no leptons.

An example of the set of energy spectra for these classes, for positive and negative muons circulating in the ring, is given in Figure 42.

Neutrino factories are also attractive because, when compared with conventional neutrino beams, they yield higher signal rates with lower background fractions and lower systematic uncertainties. These characteristics enable Neutrino Factory experiments to be sensitive to values of θ_{13} that are beyond the reach of any other approach. Studies (see e.g. [Huber03]) have shown that a non-zero value of $\sin^2 2\theta_{13}$ could be measured for values as small as $O(10^{-4})$. In addition, both the neutrino mass hierarchy and CP violation in the lepton sector could be measured over this entire range. Even if $\theta_{13} = 0$ the probability for $\nu_e \leftrightarrow \nu_\mu$ oscillations in a long-baseline experiment is finite, and a Neutrino Factory would still make the first observation of $\nu_e \leftrightarrow \nu_\mu$ transitions in an appearance experiment, and put a sufficiently stringent limit on the magnitude of θ_{13} to suggest perhaps the presence of a new conservation law. For the measurement of the quantities θ_{13} and δ, it has been shown that the *golden* observables are the oscillation probabilities $\nu_e \rightarrow \nu_\mu$ and $\bar{\nu}_e \rightarrow \bar{\nu}_\mu$ at baselines, L, and energies, E_ν, in the atmospheric range $E_\nu / L \approx \Delta m^2_{23}$ while sign(Δm^2_{23}) can also be determined with the same transitions but require sufficiently long baselines and high energies so that Earth matter effects modify the vacuum oscillation probabilities significantly (see Figure 43).

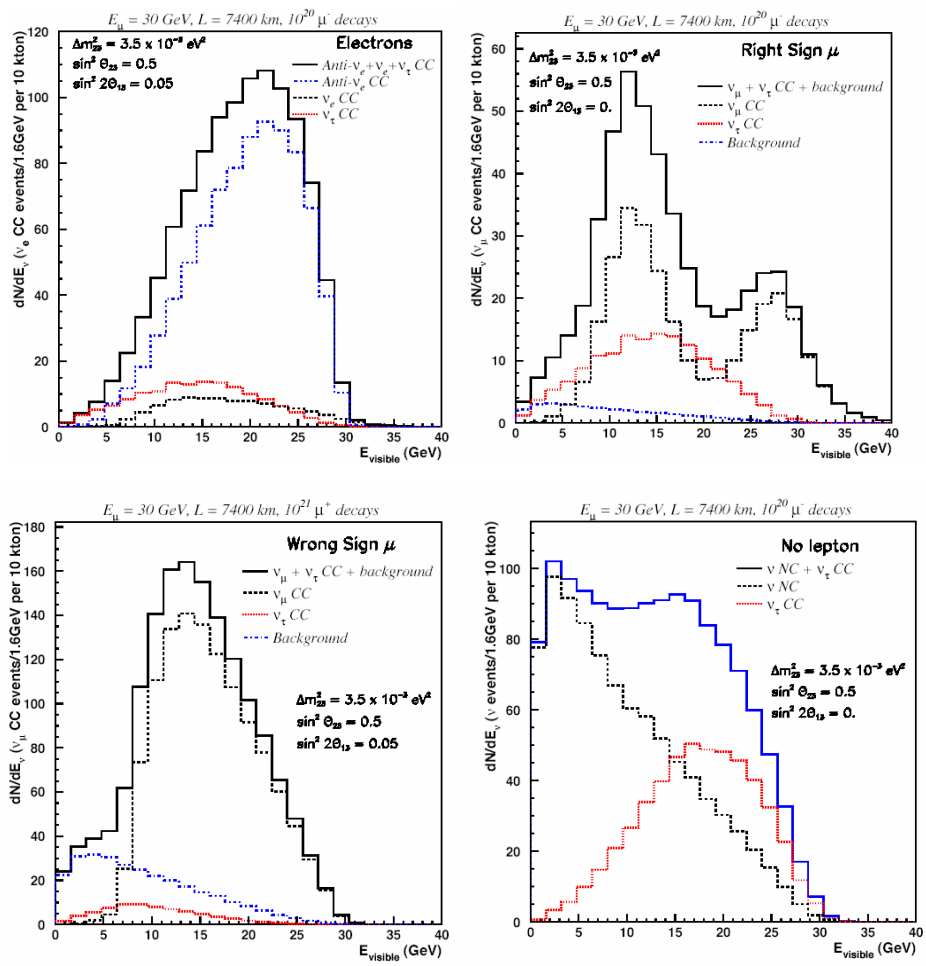


Figure 42 : Four classes of events studied in a liquid argon TPC with muon charge identification. From the top, left to right: events with high-energy electrons, right-sign muons, wrong-sign muons, no charged leptons [Bueno00].

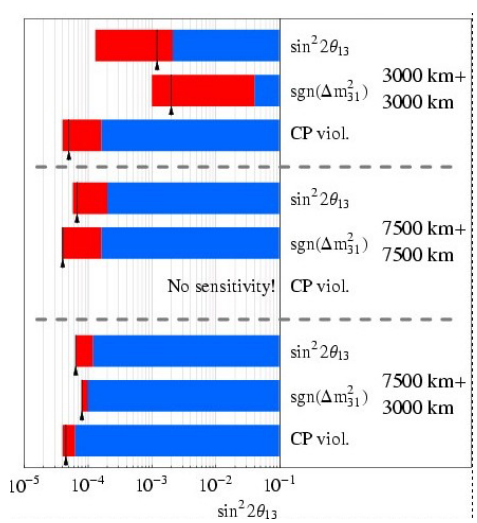


Figure 43 The sensitivity reaches as functions of $\sin^2 2\,\theta_{13}$ for $\sin^2 2\,\theta_{13}$ itself, the neutrino mass hierarchy, and maximal CP Violation ($\delta_{CP} = \pi/2$) for each of the indicated baseline combinations. The bars show the ranges in $\sin^2 2\,\theta_{13}$ where sensitivity to the corresponding quantity can be achieved at the 3σ CL. The dark (red) bars show the variation in the result as Δm^2_{21} is varied within its present uncertainty. Figure from [Huber03].

6.1.2 Physics Program with beta-beams

The physics program of a low energy beta-beam was recently discussed in [Bouchez03].

An ECR source coupled to an EURISOL target would produce $2\cdot10^{13}$ ^{6}He ions per second. Taking into account all decay losses along the accelerator complex, and estimating an overall transfer efficiency of 50%, one estimates that an antineutrino flux aimed at the Fréjus underground laboratory of $2.1\cdot10^{18}$ per standard year (10^{7} s) is possible.

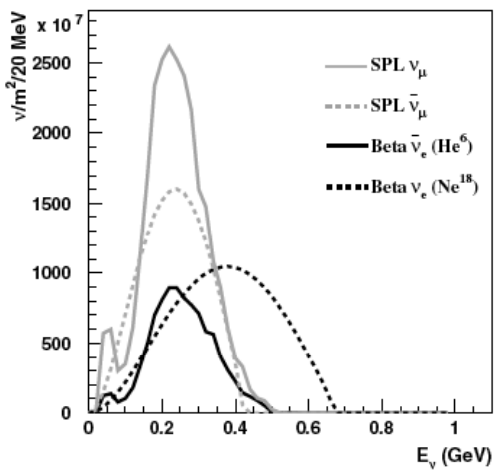
For ^{18}Ne, the yield is expected to be only $8\cdot10^{11}$ ions per second. Due to this smaller yield, which could be certainly improved with some R&D, it was then proposed to use 3 EURISOL targets in sequence connected to the same ECR source. Again taking into account decay losses plus a 50% efficiency, this means that a neutrino flux of $0.35\cdot10^{18}$ per standard year is achievable.

All these numbers are preliminary and need to be refined. They are however based on the present state of the art for the technology, and suppose using the present PS, while the SPS cycle is set at 16 s; a shorter cycle for the SPS would improve the accumulation factor substantially, while a faster PS would increase the intensity of ions making it to the decay ring.

For the present study, it was supposed that the neutrino flux from ^{18}Ne could be increased by a factor 3 over the present conservative estimate, having room for improvements both in the cycle duration of PS and SPS and in the ^{18}Ne production at the targets with a dedicated R&D, while only a 40 % improvement was put on antineutrino fluxes. One assumed that that a UNO-like water Cerenkov detector (440 kt fiducial mass) will be installed in the underground Fréjus laboratory and receive neutrino beams produced at CERN, 130 km away.

The neutrino beam energy depends on the γ of the parent ions in the decay ring. The optimization of this energy, is a compromise between the advantages of the higher γ, as a better focusing, higher cross sections and higher signal efficiency; and the advantages of the lower γ values as the reduced background rates (see the following) and the better match with the probability functions. Given the decay ring constraint: $\gamma(^{6}He)/\gamma(^{18}Ne)=3/5$ the optimal γ values result to be $\gamma(^{6}He)=60$ and $\gamma(^{18}Ne)=100$. A flux of $2.9\cdot10^{18}$ ^{6}He decays/year and $1.1\cdot10^{18}$ ^{18}Ne decays/year, will be assumed. Figure 44 shows the beta-beam neutrino fluxes computed at the 130 Km baseline, together with the SPL Super Beam (SPL-SB).

The mean neutrino energies of the ν_e, ν_e beams are 0.24 GeV and 0.36 GeV respectively. They are well matched with the CERN-Frejus 130 km baseline. On the other hand energy resolution is very poor at these energies, given the influence of Fermi motion and other nuclear effects and in the following all the sensitivities are computed for a counting experiment with no energy cuts.



	Fluxes $\nu/m^2/yr$	$\langle E_\nu \rangle$ (GeV)
$\overline{\nu}_e(\gamma = 60)$	$1.97 \cdot 10^{11}$	0.24
$\nu_e(\gamma = 100)$	$1.88 \cdot 10^{11}$	0.36
ν_μ	$4.78 \cdot 10^{11}$	0.27
$\overline{\nu}_\mu$	$3.33 \cdot 10^{11}$	0.25

Figure 44 : Beta-beam fluxes at the Fréjus location (130 km baseline). Also the SPL Super Beam ν_μ and ν_μ fluxes are shown in the plot [Bouchez03].

The signal in a beta-beam looking for $\nu_e \rightarrow \nu_\mu$ oscillations would be the appearance of ν_μ charged-current events, mainly via quasi-elastic interactions. These events are selected by requiring a single-ring event, the track identified as a muon using the standard Super-Kamiokande identification algorithms (tightening the cut on the pid likelihood value), and the detection of the muon decay into an electron. Background rates and signal efficiency have been studied in a full simulation, using the NUANCE code, reconstructing events in a Super-Kamiokande-like detector.

The beta-beam is intrinsically free from contamination by any different flavor of neutrino. However, background can be generated by inefficiencies in particle identification, such as mis-identification of pions produced in neutral current single-pion resonant interactions, electrons (positrons) mis-identified as muons, or by external sources such as atmospheric neutrino interactions.

The pion background has a threshold at neutrino energies of about 450 MeV, and is highly suppressed at the beta-beam energies. The electron background is almost completely suppressed by the request of the detection of a delayed Michel electron following the muon track. The atmospheric neutrino background can be reduced mainly by timing the parent ion bunches. For a decay ring straight sections of 2.5 km and a bunch length of 10 ns, which seems feasible, this background becomes negligible. Moreover, out-of-spill neutrino interactions can be used to normalize this background to the 1% accuracy level.

Signal and background rates for a 4400 kt-yr exposure to ^{6}He and ^{18}Ne beams, together with the SPL SuperBeam (SPL-SB) fluxes, are reported in Table 12.

Table 12 : Event rates for a 4400 kt-y exposure. The signals are computed for $\theta_{13}=3^\circ$, $\delta=90^\circ$ $sign(\Delta m^2)=+1$. "δ-oscillated" events indicates the difference between the oscillated events computed with $\delta=90^\circ$ and with $\delta=0$. "Oscillated at the Chooz limit" events are computed for $\sin^2 2\theta_{13}=0.12$, $\delta=0$.

	beta-beam		SPL-SB	
	$^6He(\gamma=60)$	$^{18}Ne(\gamma=100)$	ν_μ(2 yrs)	ν_μ(8 yrs)
CC events (no osc, no cut)	19710	144784	36698	23320
Oscillated at the Chooz limit	612	5130	1279	774
Total oscillated ($\delta=90^\circ$, $\theta_{13}=3^\circ$)	44	529	93	82
δ oscillated	-9	57	-20	12
Beam background	0	0	140	101
Detector backgrounds	1	397	37	50

A facility where the neutrino fluxes are known with great precision is the ideal place where to measure neutrino cross sections. In the beta-beam the neutrino fluxes are completely defined by the parent ions beta decay properties and by the number of ions in the decay ring. A close detector of ~1 kton placed at a distance of about 1 km from the decay ring could then measure the relevant neutrino cross sections. Furthermore the γ factor of the accelerated ions can be varied. In particular a scan can be initiated below the background production threshold, allowing a precise measurement of the cross sections for resonant processes. It is estimated that a residual systematic error of 2% will be the final precision with which both the signal and the backgrounds can be evaluated.

The θ_{13} and δ sensitivities are computed taking into account a 10% error on the solar δm^2 and $\sin^2 2\theta$, already reached after the recent SNO-salt results and a 5% and 1% error on δm^2_{23} and $\sin^2 2\theta_{23}$ respectively, as expected from the J-Parc neutrino experiment. Only the diagonal contributions of these errors are considered. In the following the default values for the oscillation parameters will be $\sin^2 2\theta_{23}=1$, $\delta m^2_{23}=2.5\cdot 10^{-3} eV^2$, $\sin^2 2\theta_{12}=0.8$, $\delta m^2_{12}=7.1\cdot 10^{-5} eV^2$, $\mathrm{sign}(\Delta m^2)=+1$.

The θ_{13} angle can be independently explored both with ν_e and ν_e disappearance measurements. We note that the comparison of the ν_e and ν_e disappearance experiments could set limits to CPT violation effects. Sensitivities to θ_{13}, computed for a 5 yr run and for systematic errors equal to 2%, 1% and 0.5% are shown Figure 45left). For comparison sake, shown in the same plot are the sensitivities reachable with the appearance channels, computed for $\delta=0$.

Indeed θ_{13} and δ are so tightly coupled in the appearance channels that the sensitivity expressed for $\delta=0$ is purely indicative. A better understanding of the sensitivity of the beta-beam is expressed in the (θ_{13},δ) plane, having fixed all the other parameters ($\delta m^2_{23}=2.5\cdot 10^{-3}$ eV^2), as shown in Figure 45 right). In the same plot the sensitivity of the SPL-SB computed for a 5 yrs ν_μ run is displayed. It can be noted the very large variation of the SPL-SB

sensitivity for the different values of δ, characteristic of the single flavour run. The beta-beam, having both CP neutrino states in the same run, exhibits a much more favourable dependence to the CP phase δ.

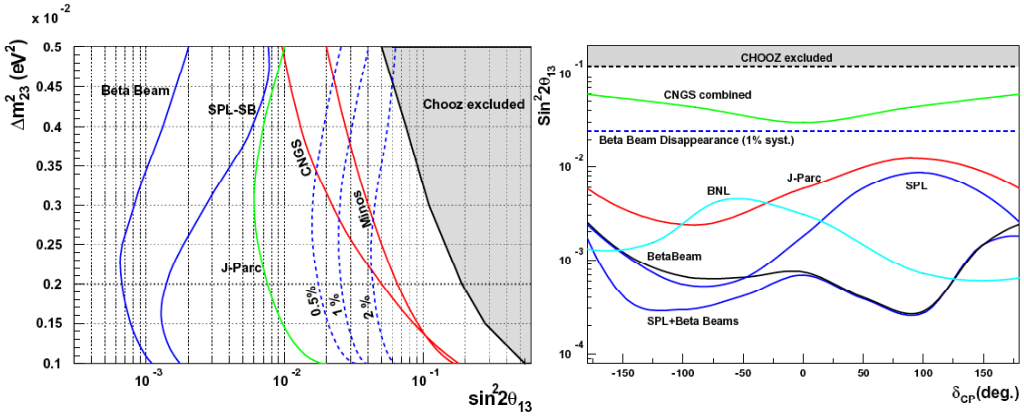


Figure 45 : Left: 90%CL sensitivity of the disappearance channel to θ_{13} in a 5 yrs run drawn as dotted lines. The labels 0.5%, 1% and 2% indicate the systematic errors with which are computed. Also shown are the appearance sensitivities of beta- and SPL beams, computed for δ=0, sign(Δm^2)=+1. Right: 90%CL sensitivity expressed as function of δ for $\delta m^2_{23}=2.5\cdot10^{-3} eV^2$. All the appearance sensitivities are computed for $sign(\Delta m^2)$=+1.

A search for leptonic CP violation can be performed running the beta-beam with ^{18}Ne and ^{6}He, and fitting the number of muon-like events to the $p(\nu_e \rightarrow \nu_\mu)$ and to the $p(\nu_e \rightarrow \nu_\mu)$ probabilities. Event rates are summarized in Table 12. The region of 99% CL sensitivity to maximal CP violation (δ=90°) in the δm^2_{12} and θ_{13} parameter space is plotted in Figure 46.

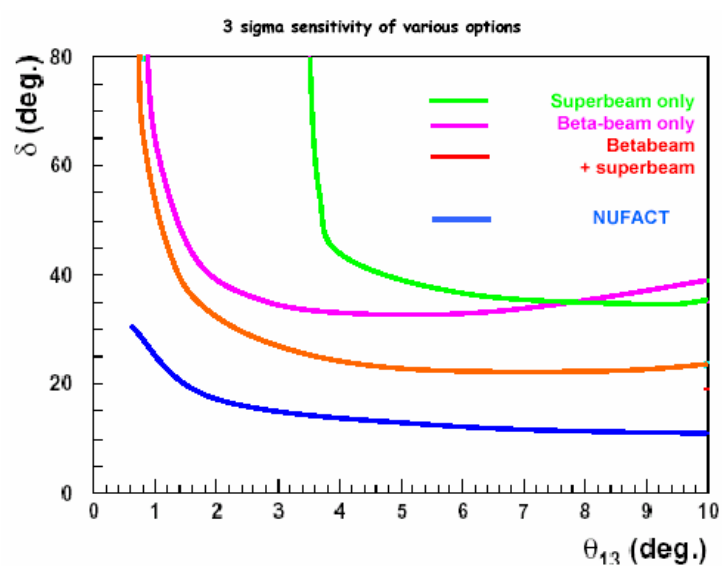


Figure 46 : 99%CL δ sensitivity of the beta-beam, of the SPL-SuperBeam, and of their combination, see text. Dotted line is the combined Superbeam+beta-beam sensitivity computed for sign(Δm^2)=-1. Sensitivities are compared with a 50 GeV Neutrino Factory producing $2\cdot10^{20}\mu$ decays/straight section/year, and two 40 kton detectors at 3000 and 7000 km

6.1.3 Potential improvements in the physics program optimization

Performing measurements at potential neutrino factories or beta-beams will certainly face several difficulties. On the theoretical side, the existence of correlations and degeneracies in parameter space [Cervera00],[Burguet01],[Minakata01],[Barger02] make the simultaneous determination of all the unknowns rather difficult. The importance of having good neutrino energy resolution or combining the measurements of the *golden* oscillation probabilities at several experiments with different $< E_\nu /L >$ (or different matter effects) have been proposed to overcome this problem [Burguet01],[Barger02], [Burguet02]. Alternatively the measurement of the *silver* channels [Donini02] $\nu_e \rightarrow \nu_\tau$ $\bar{\nu}_e \rightarrow \bar{\nu}_\tau$ besides the *golden* one, although it is experimentally more challenging, is extremely powerful in reducing these correlations. The *silver* channel also provides a test of unitarity of the Neutrino mixing matrix! In fact, it has been shown that while the combination of beta-beam and SuperBeam could not help in solving the degeneracies, the combination of one of them with the Neutrino Factory Golden and Silver channel can, instead, be used to solve completely the eightfold degeneracy.

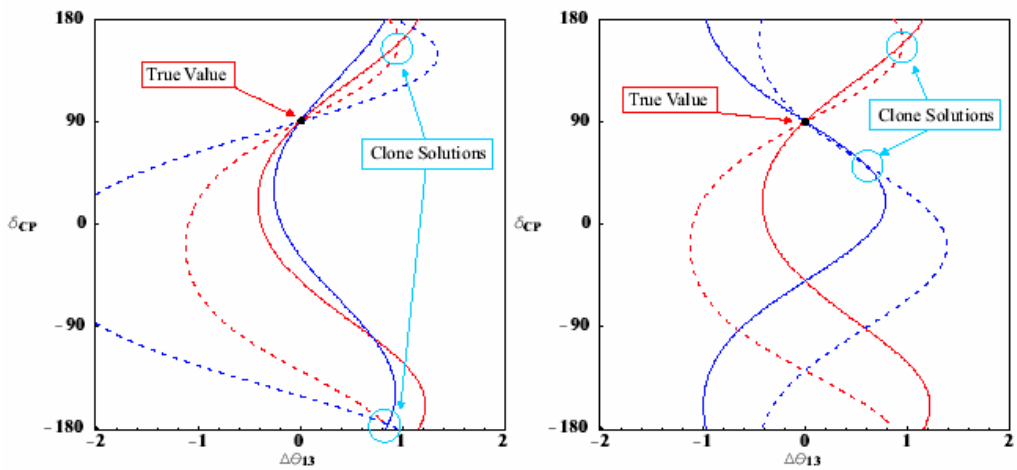


Figure 47 Solving degeneracies (from [Rigolin04]). The parameter space shown is the variation $\{\Delta\theta_{13}, \delta_{CP}\}$ around the true solution in the $\{\theta_{13}, \delta_{CP}\}$ plane. The lines show the locus where the same number of events would be observed. Full lines, neutrino exposure; dashed lines antineutrino exposure. On the left, the red and blue lines show two different base lines (730 and 3500 km) while on the right the red and blue lines show the golden and silver channel.

Typically both in the NF and BB designs, the energy of the parent muon/ion (which is proportional to the average neutrino energy) can be optimized within a rather large range, since this is fixed by the acceleration scheme that is part of the machine design. Once the energy is fixed, the baseline is also fixed by the atmospheric oscillation length. This optimization is however a complex problem because there are often contradicting requirements in the maximization of the intensity, the minimization of backgrounds, having useful spectral information, measuring the *silver* channel besides the *golden* one, having sizeable matter effects, etc.

This optimisation was done for the NF some years ago and a muon energy of E_μ =20-50 GeV and a baseline for the *golden* measurement of a few thousand kilometres is considered a reference setup [Cervera00]. The combination of this measurement, using a 40 KTon iron calorimeter [Cervera00a], plus the *silver* one in an Opera-like tau-neutrino detector

[Donini02] results in a great physics potential. The sensitivity to $\sin^2 \theta_{13}$ is below 10^{-4} and there is a 99% CL discovery potential for CP violation if $\delta > 10^0$. In addition, the atmospheric parameters can be determined with a 1% precision and the sign of Δm^2_{23} can be measured in a large range of parameter space.

In contrast the standard CERN-based β-beam design as conceived by P. Zucchelli [Zucchelli] was intended to use much of the CERN infrastructure. In particular the ions, once produced at a new EURISOL-like facility, would be accelerated at the existing SPS up to a $\gamma \sim 150$. An appropriate baseline for this energy was identified in the Fréjus tunnel, 130km from CERN, that is by happenstance also an appropriate baseline for the SPL-based superbeam [splcern]. A megaton water Cherenkov could be located in Frejus to serve both purposes. The sensitivity to the parameters θ_{13} and δ in the BB and BB + superbeam setups would improve considerably that of other superbeams under construction [Mezzetto03],[Bouchez03], such as T2K at JPARC [Itow01] or NUMI [NUMI], as shown in Figure 45, but it is still limited compared to the ultimate sensitivity in the NF, in spite of the fact that the difference in fluxes between the NF and BB of Figure 40 should be essentially compensated by the bigger detector mass considered in the superbeam-BB case.

It has been recently realized that provided a more ambitious acceleration scheme for the ions were possible, there is an enormous gain in the physics potential of the β-beam if the energy could be increased by a factor 5-10 and the baseline accordingly [Burguet03]. As in the NF, the higher energy results in a higher intensity, because of the larger neutrino cross sections, in a better measurement of the neutrino energy, which reduces parameter correlations and degeneracies and finally the longer baseline makes the measurement of the sign of Δm^2_{23} possible.

Higher energy β-beam at CERN would imply accelerating the ions in the LHC or an upgraded SPS, and the corresponding high energy storage rings. Given their promising physics performance, the feasibility of these options needs to be further studied.

6.2 A possible large underground laboratory: status and plans of the Fréjus international laboratory

(L. Mosca)

The most up to date account of Prof. Mosca's presentation is the Letter of Intent, independently addressed to the VILLARS 2004 SPSC workshop, "Discovery potential for a SPL/super beam and beta beam from CERN pointing at a Megaton class detector in the Fréjus area". Its brief description of the site is reproduced here for completeness.

An intense activity of tunnel excavation will take place in the Fréjus area during the next few years; a safety tunnel parallel to the Fréjus road tunnel, at the French-Italian boarder, was approved in December 2001 and its excavation should start at the beginning of the next year (2005). The diameter of this tunnel, with a present nominal value of about 5.5 m, is currently in the final stage of negotiation between the French and Italian Transport authorities . A series of 34 bypasses will connect the safety tunnel to the road tunnel. The end of the construction of the safety tunnel (without the bypasses) is planned around 2008-2009. This situation creates the opportunity to build a very large cavern near the existing laboratory LSM ("Laboratoire Souterrain de Modane") half way, 6.5 km from both the French and the Italian entry of the tunnel. A laboratory at this location has the advantage of double horizontal access, clearly

symmetrical bi-national and European symbolism, large depth (4800 mwe), good quality of the rock (hardness and absence of water problems) and strong support from the local authorities (Regions Rhône-Alpes and Piemonte) and the Fréjus Tunnel Companies. Its major current difficulty is the perception of a possible conflict with the functionality of the safety tunnel on the French Transport Authority side. In the case this is confirmed the transport authorities recommend the excavation of a third separate tunnel to reach the area of the construction of the cavity (and evacuate the rock of the excavation), while the access after the construction could be done through the safety tunnel. This extra tunnel would of course increase the cost of the installation (cavity plus detector) by 10 to 20%. It is also interesting to note that the beam associated and proton decay physics potential are not seriously affected by moving to a shallower region and therefore reducing the extra excavation costs. There is, for instance, at 3km from the French entrance an overburden of 2500 mwe. In conclusion this the preferred site and studies of feasibility and functional compatibilities are in progress.

A more prospective scenario considers the opportunity created by the Lyon-Turin TGV 52 Km long tunnel crossing the Fréjus region. While the tunnels (one for each direction) are planned to enter in an operational phase in 2015-2020, a few reconnaissance galleries have been approved and funded. In particular the Venaus gallery (5.5 m diameter), starting in the SUSA area (Italy) is a 7 km long gallery (possibly extended to 10 km). The end of this gallery is situated near the French/Italian boarder. It will be excavated between the two train tunnels and the end of its construction is expected in 2008. The gallery has a large overburden going from 4800 mwe at around 7 km from the entrance to 7000 mwe at the end of 10 km, making it eventually the deepest laboratory in the world. In this scenario while there is no serious compatibility problems with the train operation and safety according to the tunnel engineers1, one has a single-sided access, posing safety concerns for the laboratory users and also breaking the bi-national symmetry. This option is disfavoured by the INFN for the reasons stated above and also due to possible conflicts with other national scientific policy options.

6.3 A megaton water Cherenkov detector

(C. K. Jung, K. Nakamura, V. Palladino)

C. K. Jung's presented the physics goals and progress in the US towards a very large mass water Cherenkov Underground *Nucleon decay and Neutrino* Observatory (UNO). He stated repeatedly that this US effort [UNO] is, from the start, complementary and synergic with the very similar Hyper-K effort in Japan. They both originate from the one single world wide community that has clustered around Super-K [Fukuda98] and K2K [K2K] and has recently welcome an enthusiastic European component joining them in K2K and soon in the T2K[T2K] project.

A well organized international effort, joining the forces behind the Hyper-K [Hyper-K] project in Japan, the UNO project in USA and the Frejus project in Europe [Mosca], with common physics goals and strong mutual support of each local initiative, can seriously hope to bring a successful experiment somewhere in the world and carry out a far-reaching, comprehensive neutrino physics and nucleon decay program.

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[1] Its main use after completion will be to house a gathering station in case of a severe train accident.

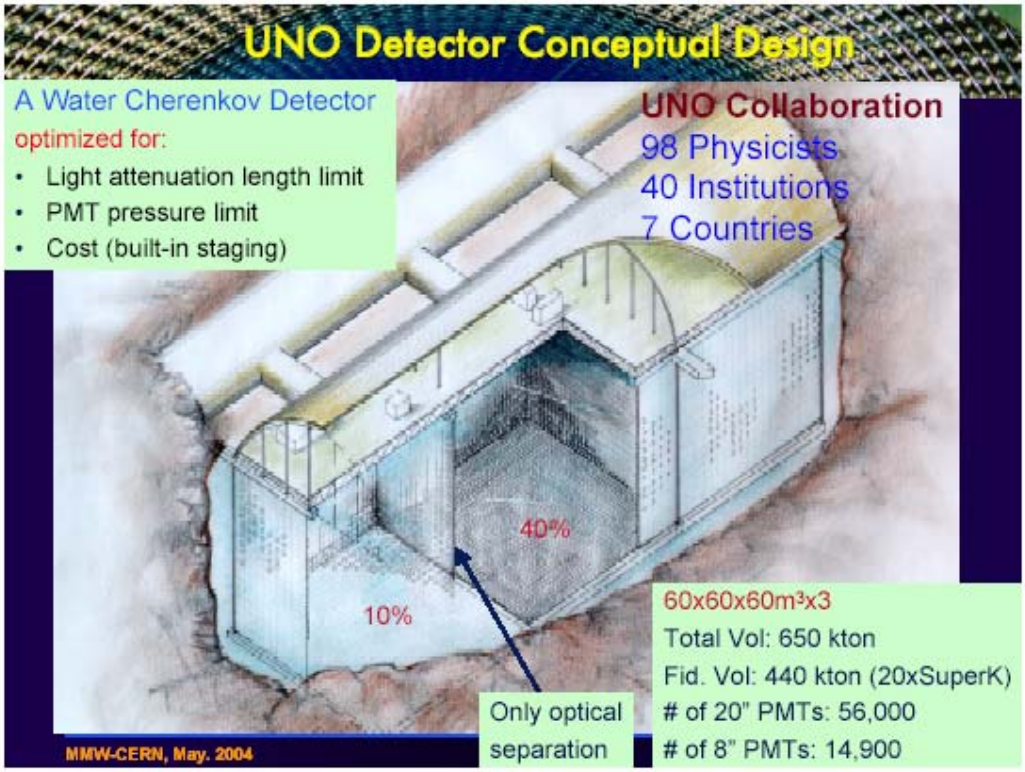

Figure 48 UNO Detector Conceptual Design

A Megaton Water device can rely on a reasonable extrapolation of a proven technology and could be built within a predictable R&D and then construction time. Water is the cheapest detector material. The international community is persuaded that an affordable design, not higher than 500 M$ or so, will be possible and is determined to embark coherently first in a final common R&D phase and then in the construction of such a large detector somewhere in the world, where the realisation of a home underground laboratory, capable to host and operate it, will indeed prove possible. It could do physics 10 years after approval.

The basic design of UNO is (Figure 48) a triplet of adjacent, only optically separated, 60x60x60 m3 water tanks, 650 kton in total, (440 kton fiducial, 20 times SuperK) equipped with 56000 20" PMTs and 14,900 8" PMTs, with surface coverage 40% (as SuperK) in the central tank and 10% in the two wing tanks. The design, optimized to comply with 1) light attenuation length limit 2) PMT water pressure limit 3) cost constraints and built-in staging, involved 98 physicists, from 40 Institutions, in 7 countries. The Hyper-Kamiokande design is very similar (Figure 49). It could be called DUE, as it consists essentially of two independent similar detector units, in two twin cylindrical galleries, each 48m × 50m ×250m, reaching a 1 Mton total mass equipped with 100000 PMTs each.

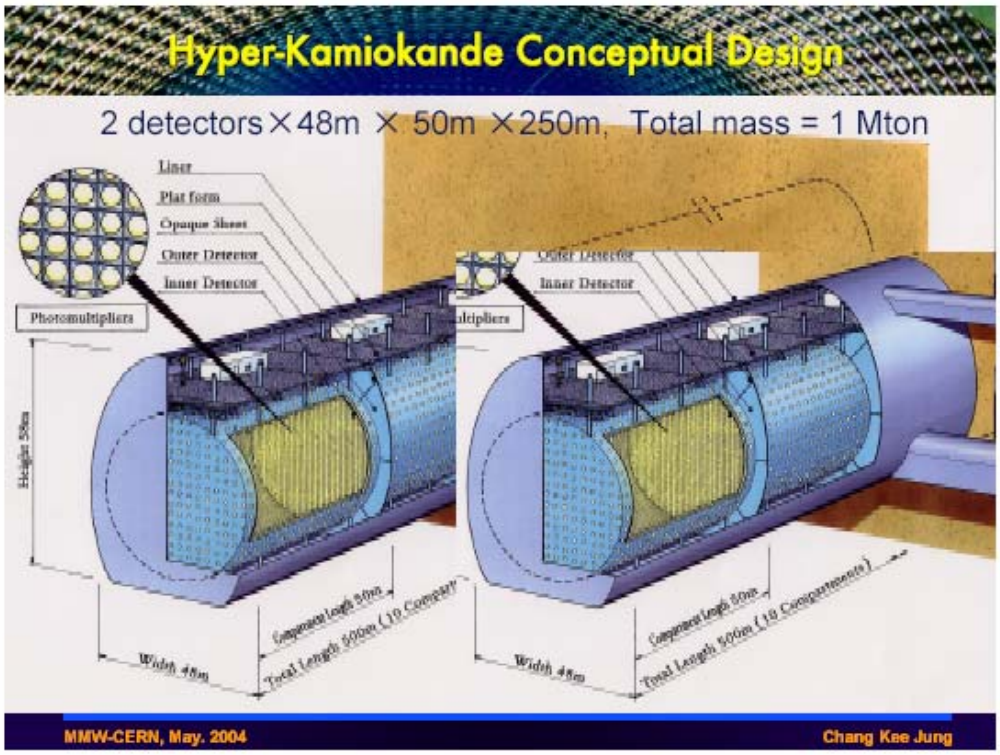

Figure 49 Conceptual Design of Hyper Kamiokande

Multiple smaller detectors appear less convenient. They would 1) be more expensive, the larger surface to volume ratio would require more PMTs 2) provide less total fiducial volume 3) imply more drifts and auxiliary/service space, specially expensive to excavate and finish 4) have smaller energy containment

In addition, for same pmt coverage, the larger detector has a finer effective granularity and therefore better pattern recognition, particle identification, position and angular resolution.

The main challenges to tackle for a Megaton detector appear at the moment

1) to secure an adequate and realistic site
   It should be conveniently located with respect to MMW accelerators. It has to bring no environmental concern. It has to have a vast infrastructure of modern underground technologies The excavation we need has to be half the detector cost, or so. It should be 4000mwe deep or more, to be useful for solar and supernova neutrino studies.
2) to keep the general cost affordable. Cost containment is the key issue.
   About half of the cost is the big PMTs, priced still 2.7 K$ each. 200 K$ or so in total, fully equipped. Their 8 years delivery time dominates construction time. The next coming phase of rigorous professional detector design will have to explore all possible roads to cost reduction. In some areas, photosensors in particular, this implies a serious R&D effort.

Support for the R&D towards UNO, identified as an essential HEP facility, has been repeatedly stated .by major US review panels, from the original statement of the HEPAP sub-panel in 2001 [HEPAP01] to the recent recommendation of the Intra-agency Working Group in April 2004 [Intra04]. NSF is structuring the selection process of a site for the much

recommended multipurpose NUSEL (National Underground Science & Engineering Laboratory). It should take off within 2004 and fund the necessary studies.

6.3.1 Detection of neutrinos

A large UNO type detector, 20 to 40 times bigger than Super-K, appears as an inescapable and natural response to the recent "neutrino revolution", the unequivocal evidence of the existence of neutrino transitions accumulated since 1998.

The Water Cherenkov technique provided the largest share of this evidence [Fukuda98] [K2K] and will, no doubt, still be a main player in the future, at least for detection of low energy below 1 GeV or so.

A new Megaton detector promises a major boost of our observations of atmospheric, solar, Supernova (burst and relic) and astrophysical neutrino phenomena. In conjunction with new superior sources of low energy neutrinos, Superbeams and Beta-beams, it also promises oa similar boost of our experimental knowledge of neutrino mass splitting, mixings and CPV phase. This phase may be the first experimental signal of the type of mechanisms that may have induced primordial leptogenesis and later matter-antimatter asymmetry.

With a Megaton neutrino observatory, detection reach of SuperNova (SN) will extend to the local group of galaxies, to about 1 Mpc. A galactic SN explosion should provide, once every 30 years, a detectable burst of up to 140K neutrino events, with its millisecond timing structure of the flux, resulting in precise observation of explosion process and neutrino mass test <~1eV. SN relic neutrinos could be detected (or all models ruled out) in about 4 years of UNO running at 4000 mwe.

Moving to atmospheric neutrinos, the superior containment of a Megaton device would permit spectacular evidence for a disappearance minimum in L/E of high energy atmospheric muon neutrinos, measuring Δm_{23} to far better than 1%, from 7 years of UNO (enriching the sample of higher energy muons that permit a precise determination of the neutrino path L)

Most relevantly to the Workshop, however, the detector matches beautifully the characteristics of MMW power neutrino conventional (super)beams as well as novel beta-beams. For such neutrino events of 1 GeV or lower, producing little or no pions, one has good efficiency and separated identification of muons , electrons (and photons). This is essential for the study of the subdominant oscillation channel $\nu_\mu \leftrightarrow \nu_e$, , that holds all the remaining secrets of the leptonic mixing and CPV pattern. The megaton mass compensates for the reduced fluxes possible with low energy neutrino beams. Many specific studies have been performed for several combinations of neutrino beam power and baselines (4MW JPARC superbeam to the HyperK site at 300 Km [T2K], 4MW CERN-SPL superbeam and beta-beam to the Fréjus site at 135 Km [ECFAreport], 1 MW BNL-AGS to a Western US site at 2000-4000 Km[BNLnu]). We really ought to make at least one of them reality.

The location of a Western site in the US has generated a significant amount of studies and surveys (Figure 50). The most promising site, offering the largest asset of existing experience and infrastructures (among them the high speed, large and long, conveying shafts system essential for effective evacuation of the excavated rock), appears at the moment the Henderson site, a modern, environment conscious, molybdenum mine in Colorado. This offers a shelter of 5000 mwe, excellent connections and a lively atmosphere, not far from Denver. If favorable geological conditions are confirmed, UNO would require a 116 M$ dedicated large volume excavation.

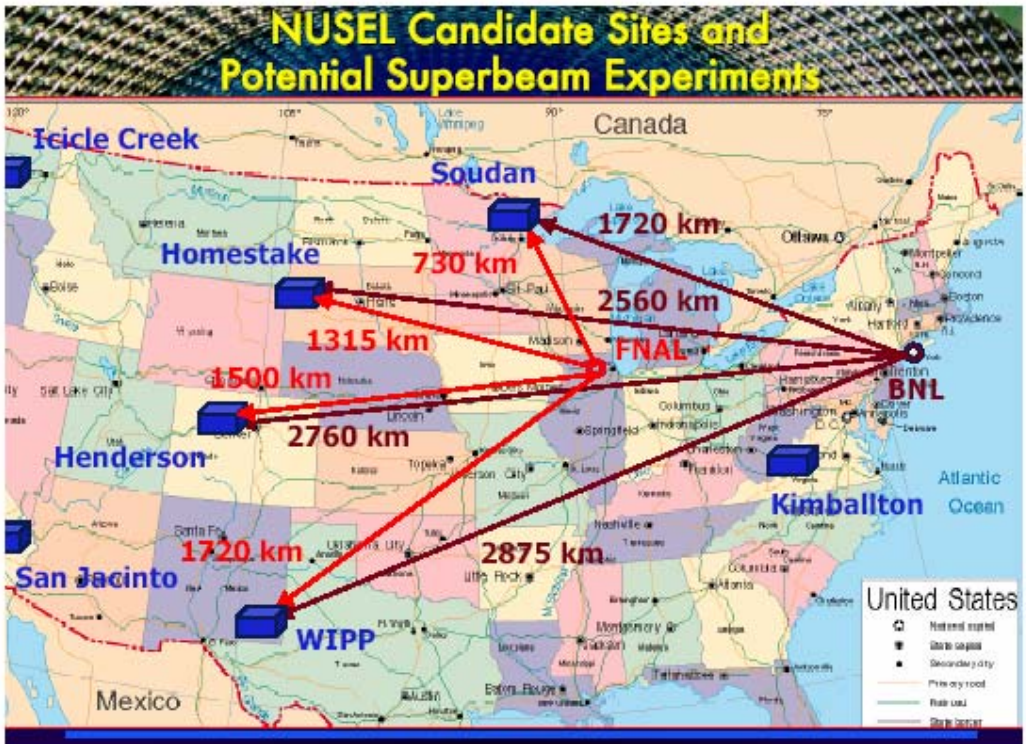

Figure 50 Candidate sites for the US National Underground Science & Engineering Laboratory (NUSEL)

6.3.2 Proton decay

A large UNO type detector has, however, an independent and equally compelling motivation: it appears also as the next natural step to superior sensitivity to nucleon decay and thus to a new mass scale in the GUT region. The minuscule mass splittings measured, by means of the neutrino oscillation wavelength, also favour a new mass scale of GUT nature. This unique scientific and technical synergy between neutrino oscillations and nucleon decay, astro-, nuclear and particle physics, accelerator and non-accelerator physics has been, since 1999, the theme of the NNN (Next Nucleon decay & Neutrino detector) series of Workshops [NNN]. Figure 51 gives a snapshot of the past, present and possible future, both experimental and theoretical, of our understanding of nucleon decay.

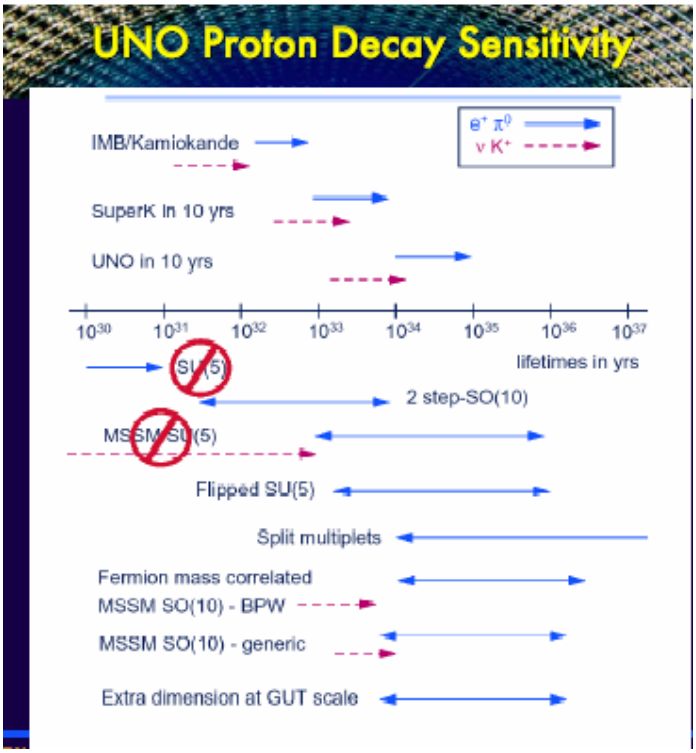

Figure 51 Our past, present and possible future knowledge of nucleon decay.

Candidate events for proton decay to $e\pi^0$ must cluster around zero total reconstructed vector momentum p and total reconstructed invariant mass M around 940 MeV/c^2. Smearing will result from, bound nucleon effects, Fermi momentum and binding energy corrections,. The SuperK sensitivity to partial decay lifetime τ/B (5.7 10^{33} years at 90%CL, for the present 79 Mton-years total exposure) is ultimately limited by an (atmospheric) background rate of fake decay candidates of 2.2 events/Mton year, based on K2K beam data. This is due to the looseness of the 2D cuts, in p and M, affordable while keeping sizeable (43%) detection efficiency. UNO or HyperK will be able to afford much tighter cuts: with still 17% efficiency, selecting essentially only free nucleon decays, the limiting background will reduce to 0.15 fake events/Mton year. With a total UNO exposure larger than 8 years, the sensitivity of a new much larger detector will extend, by more one order of magnitude, to a partial lifetime above 10^{35} years.

The best sensitivity to proton decay to $K\nu$ is obtained with the coincidence method (among the prompt photon emitted when an ^{16}O proton decays and the delayed μ and then electron signals from K decay to $\mu\nu$). This is then slightly enhanced by the K to $\pi\pi^0$ method and the μ spectrum in method in $\mu\nu$ decay . The limiting background is atmospheric ν production of $K\Lambda$ pairs, about 1 event/Mton-year. 10 years of UNO would set a partial lifetime limit larger than 10^{34} years (1.6 $10.^{33}$ presently).

6.3.3 R&D areas. Photosensors.

Detailed geological survey, drillings for final rock characterization, environmental assessment, long term liability issues have to be performed for all serious candidate sites

Solutions for rock surface treatment/water containment are to be understood. Simple geo membrane liners are being weighed against more durable treatment with steel frames and concrete coating with membrane seal.

PMT mounting schemes are being studied, taking into account the pressure limits, unfortunately well know now. PMT cost reduction schemes are to be studied for conventional PMTs, in collaboration with Hamamatsu and possibly other producers. Simpler structures like spherical PMTs are being seriously considered. While PMTs remain the baseline realistic device, alternative photo-sensors are to be investigated too.

In a talk immediately before the Workshop, K. Nakamura described the HyperK program for development of large Hybrid Photo Detectors (HPD) in collaboration with the Hamamatsu Electron Tube Center. It aims at developing high sensitivity at low cost per unit sensitive area. The initial idea of developing a 40 " PMT was abandoned after the SuperK accident and focused on simpler structures like HPDs, that may be cheaper anyway. These replace the traditional chain of dynodes with electron bombardment in silicon, producing e-hole pairs, followed by avalanche multiplication. Noise, traditionally due mostly to the first dynode, is strongly reduced and sensitivity to single photon can be reached. Currently available HPD from Hamamatsu are very small. A 5" prototype was produced and fully characterized: quantum efficiencies and time response data exist. A 13" prototype is now ready (Figure 52). Development of preamp, digital filter and analog memory cards also in progress. Finally, ideas for a 20" spherical HPD are rather advanced, but do need much further study.

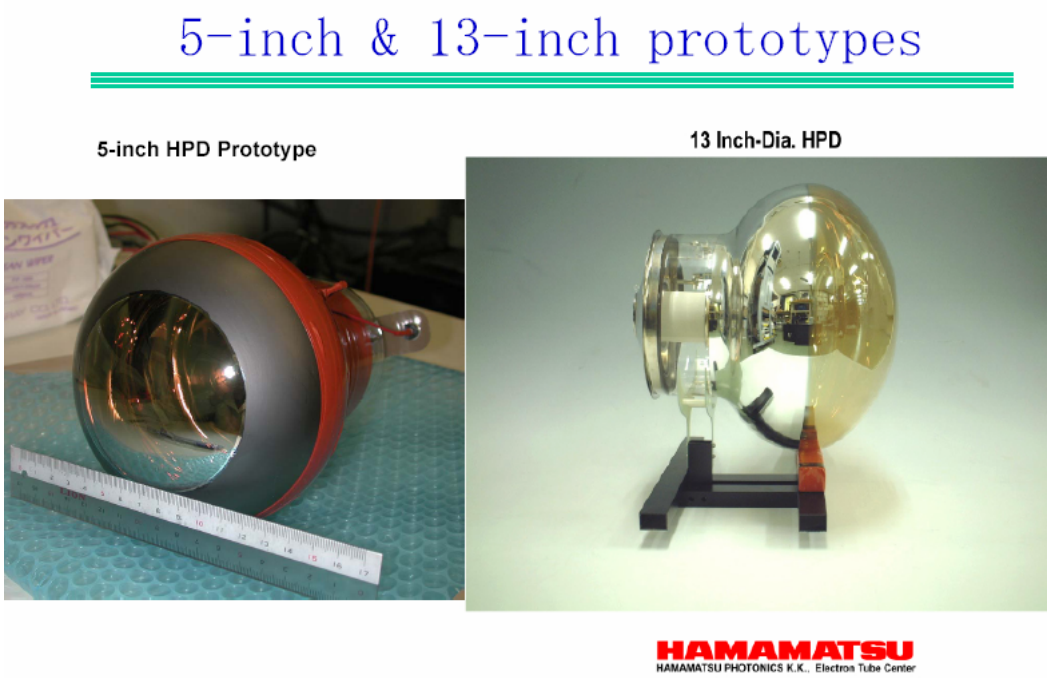

Figure 52 Recent HPD Prototypes from Hamamatsu

Supported by a DOE grant, a Reference Photo-sensor (Figure 53) is being studied at UC Davis, in collaboration with night vision projects. It aims at devices combining optimal light concentration on the photo-cathode with an optimal photo electron collection lens. Large light sensitive surfaces could be covered, honeycomb arrangement of many individual hexagonal devices is suggested.

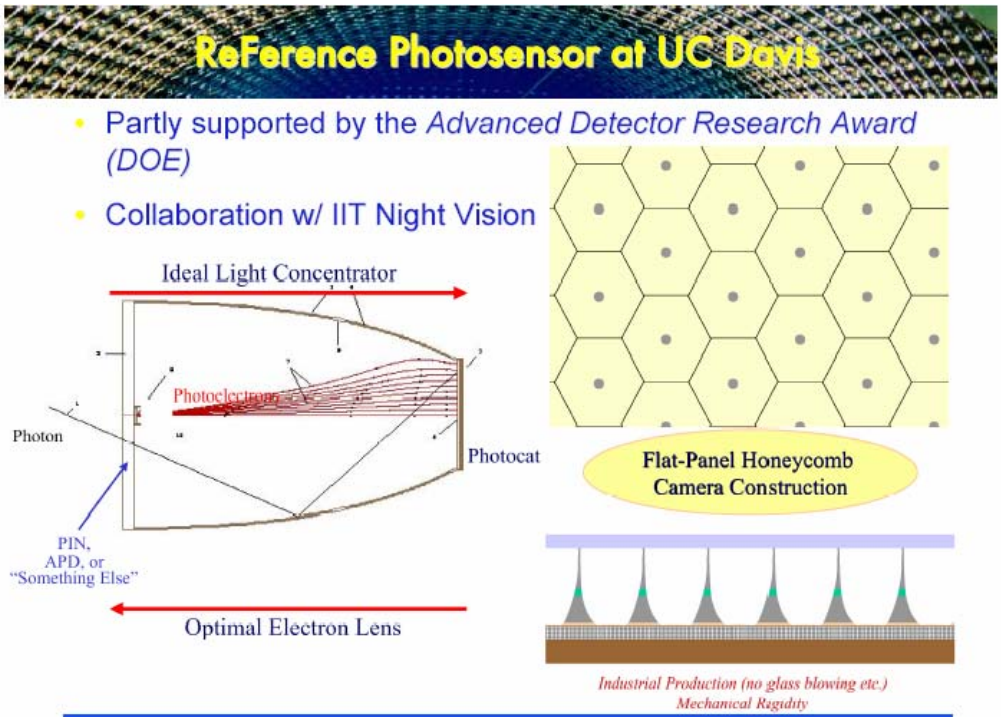

Figure 53 Reference Photosensor R&D in the USA

Further enhancement of performance is being sought could by development of better reconstruction software for Cherenkov rings, based on many years of experience now. More sophisticated electronics, with wave-form digitizers and narrower PMT integration time (to reduce scattered light) is certainly an handle to be exploited.

6.3.4 Conclusions

Based on a proven technology, an underground megaton water Cerenkov detector has a major potential for important discoveries. It would match very well the characteristics of MMW power neutrino conventional beams as well as beta-beams A world wide scientific community, made of collaborating regional collaborations, is looking for one (or more) home sites where to build it and exploit it about 10 years after approval. Collaboration is already being explored on all the non site-specific aspects of the necessary R&D

6.4 Ideas for a next generation liquid Argon TPC detector for neutrino physics and nucleon decay searches

(A. Ereditato, A. Rubbia)

In the late 60's the potentials of liquid noble gases as detection media to realize position sensitive detectors with high spatial resolution was recognized [Doke93] as well as the possibility of using such media for large and performing calorimeters for particle physics experiments [Willis94]. Among the many ideas developed, the Liquid Argon Time Projection Chamber (LAr TPC), conceived and proposed at CERN by C. Rubbia in 1977 [Rubbia77], certainly represented one of the most challenging and appealing designs. The

technology was proposed as a tool for uniform and high accuracy imaging of massive detector volumes.

The feasibility of this technology has been further demonstrated by the extensive ICARUS R&D program, which included studies about proof of principle, LAr purification methods, readout schemes and electronics, as well as studies with several prototypes of increasing mass on purification technology, collection of physics events (also neutrino events), pattern recognition, long duration tests and readout. The realization of the 600 ton ICARUS T600 detector culminated with its full test carried out at surface during the summer 2001 demonstrating that the technique can be operated at the kton scale with a drift length of 1.5 m [Amoruso04, Amoruso04b, Antonello04, Amoruso04b, Arneodo03]. The success of the fully industrial construction of the T600 module and its excellent performance has justified the idea of cloning the detector to reach the 3000 ton mass scale (ICARUS T3000). The T3000 detector represents the largest, practical achievable size by employing a modular approach. On the other hand, modularity was not imposed by the LAr TPC technique but by the boundary conditions of the LNGS laboratory.

Having at disposal the mature technique developed in the context of the ICARUS program, physics is calling today for at least two applications at two different mass scales [Ereditato]. On the one hand, ultimate nucleon decay searches and high statistics astrophysical and accelerator neutrino experiments will require very large detector masses, of the order of 100 kton. On the other hand, future precision studies of neutrino interactions, calorimetry and near stations for long baseline beam experiments will need detectors with masses in the range of 100 ton. There is a high degree of interplay and a strong synergy between small and large mass scale apparatuses, the very large detector needing the small one in order to best exploit the measurements with high statistical precision that will be possible with a large mass. Small and very large LAr detectors could certainly play significant roles in a potential future high-intensity neutrino beam facility. In particular, the conceptual design of a 100 kton LAr TPC detector is in progress together with the identification of an R&D strategy.

The physics potential of the large LAr detector combined with a neutrino Super-Beam has been studied. This application profits from the very good granularity provided by the technique. The optimization of the proton energy and of the baseline will follow from the overall design and upgrades of the future accelerator complex hosting the beam and might be accomplished in stages according to physics advances and/or to the availability of financial resources. The various neutrino beam optimizations will most likely be performed in accordance with the global physics program, which could possibly include nuclear, muon, kaon and neutron physics. However, a 100 kton LAr detector would provide a general purpose detector able to exploit all kinds of neutrino Super-Beams.

The imaging of the events and the high energy resolution in the LAr TPC make the studies with beta-beams very attractive. The possibility to have separately pure electron-neutrinos and antineutrinos, combined with a massive 100 kton detector would be an ideal configuration to study neutrino oscillation parameters, in particular the CP-phase. Optimization studies indicate that the longest possible baseline is required, as long as matter effects are small, in order to benefit from the rise of the (anti)neutrino cross-section and the reduction of momentum smearing introduced by the Fermi motion. The detector must provide good pion/muon discrimination in order to suppress the NC background with a charged leading pion. The combination of imaging (tracking and energy) with the detection of Cerenkov light could provide adequate muon/pion separation.

The physics potential of a magnetized large LAr detector coupled to a Neutrino Factory is also very large. The ideal detector should be capable of identifying and measuring all three charged lepton flavors produced in CC interactions and of measuring their charges to discriminate the incoming neutrino helicity. Embedding the volume of Argon inside a magnetic field would not alter the imaging properties of the detector.

Finally, one should emphasize that the astrophysical neutrino physics program is naturally very rich for a 100 kton LAr observatory [Rubbia04]. One expects 10000 atmospheric neutrino events per year and about 100 tau-neutrino CC events per year from muon-neutrino oscillations. These events are characterized by the excellent imaging capabilities intrinsic to the LAr TPC and will provide an unbiased sample of atmospheric neutrinos with an unprecedented quality and resolution, compared to existing or planned studies based on Cerenkov ring detection. Solar neutrinos provide about 324000 events per year with electron recoil energy above 5 MeV. A galactic SN-II explosion at 10 kpc yields about 20000 events. Sensitivity to extragalactic supernovae should be possible as well as to relic SN neutrinos. A characteristic feature of the LAr TPC is the accessibility to several independent detection channels which have different sensitivities to electron-neutrino, electron-antineutrino and other neutrino flavors. The study of all neutrino flavors from supernova explosion would be performed in great detail by a LAr detector, in an appreciably better way when compared to water Cerenkov detectors, which are mainly focusing on the electron-antineutrino flavor. Last but not least, the physics of the nucleon decay. Direct evidence for baryon number violation represents one of the outstanding goals of particle physics. Nucleon decay searches require very good knowledge of the backgrounds induced by atmospheric neutrinos. A target of 100 kton = 6×10^{34} nucleons yields a sensitivity for protons of $\tau p/Br > 10^{34}$ years $\times$ T(yr)$\times$ ε at the 90% CL in the absence of background. Although the envisioned detector has a mass of 100 kton, its physics program effectively competes with a 1 Megaton water Cerenkov owing to better event reconstruction capabilities provided by the LAr technique.

The possibility to construct and operate a very large LAr TPC is a very complex technical task. However, it can be shown that a 100 kton detector might be technically feasible, economically affordable and able to be safely operated. A single LAr volume is the most attractive solution from the point of view of construction, operation and cryogenics and is to be favored over the modular approach. The basic design features of the detector can be summarized as follows:

1. Single 100 kton boiling cryogenic tanker at atmospheric pressure for a stable and safe equilibrium condition (temperature is constant while Argon is boiling). The evaporation rate is small and is compensated by corresponding refilling of the evaporated Argon volume.

2. Charge imaging, scintillation and Cerenkov light readout for a complete (redundant) event reconstruction. This represents a clear advantage over large mass, alternative detectors operating with only one of these readout modes.

3. Charge amplification to allow for very long drift paths. The detector is running in bi-phase mode. In order to allow for drift lengths as long as 20 m, which provides an economical way to increase the volume of the detector with a constant number of channels, charge attenuation will occur along the drift due to attachment to the remnant impurities present in the LAr. One can compensate this effect with charge amplification near the anodes located in the gas phase.

4. Absence of magnetic field, although this possibility might be considered at a later stage. R&D studies for charge imaging in a magnetic field are on-going and results are expected

soon. Physics studies indicate that a magnetic field is really only necessary when the detector is coupled to a Neutrino Factory.

The cryogenic features of the proposed design are based on the industrial know-how in the storage of liquefied natural gases (LNG), which developed in the last decades, driven by the petrochemical and space rocket industries. The technical problems associated to the design of large cryogenic tankers, their construction and safe operation have already been addressed and engineering problems have been solved by the petrochemical industry. Cryogenic tankers of 200000 cubic meters are in operation and their number in the world is estimated to be about 2000. LNG tankers are of double-wall construction with efficient but non-vacuum insulation between the walls. Large tankers are of low aspect ratio (height to width) and cylindrical in design with a domed roof. Storage pressures in these tankers are very low. Technodyne International Limited, UK , expert in the design of LNG tankers has started a feasibility study in order to understand and clarify the issues related to the operation of a large underground LAr detector.

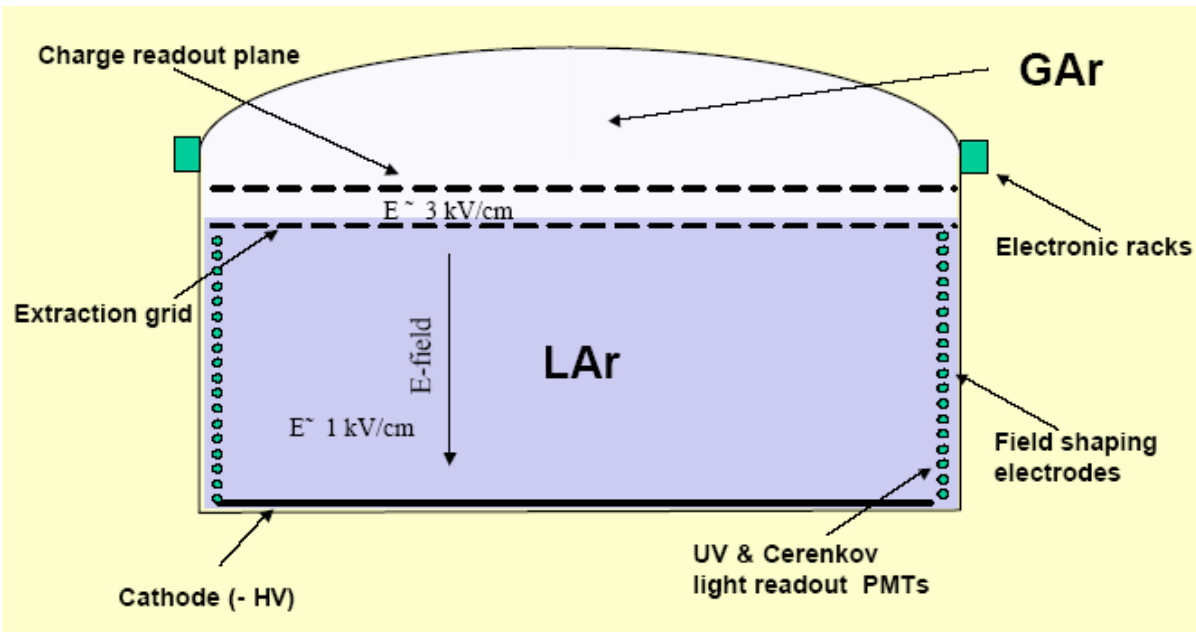

Figure 54: Schematic layout of the inner detector of a future Large Liquid Argon detector

Having in mind the above considerations, a schematic layout of the inner detector is shown in Figure 54, and the full detector is depicted in Figure 55. The detector is characterized by the large fiducial volume of LAr included in a large tanker, with external dimensions of approximately 40 m in height and 70 m in diameter. A cathode located at the bottom of the inner tanker volume creates a drift electric field of 1 kV/cm over a distance of about 20 m. In this field configuration ionization electrons are moving upwards while ions are going downward. The electric field is delimited on the sides of the tanker by field shaping electrodes. The tanker contains both liquid and gas Argon phases at equilibrium. Since purity is a concern for very long drifts of 20 m, one assumes that the inner detector could be operated in bi-phase mode: drift electrons produced in the liquid phase are extracted from the liquid into the gas phase with the help of a suitable electric field and then amplified near the anodes. In order to amplify the extracted charge one can consider various options: amplification near thin readout wires, GEM or LEM. Studies in progress indicate that gain

factors of 100-1000 are achievable in pure Argon. Amplification operates in proportional mode. After a drift of 20 m at 1 kV/cm, the electron cloud diffusion reaches approximately a size of 3 mm, which corresponds to the envisaged readout pitch. If one assumes that the operating electron lifetime is at least 2 ms (as obtained in ICARUS T600 detector during the technical run and better values of up to 10 ms were reached on smaller prototypes during longer runs), one then expects an attenuation of a factor 150 over the distance of 20 m, to be compensated by the proportional gain at the anodes. The expected attenuation factor will not introduce any detection inefficiency, given the nearly 18000 ionization electrons per 3 millimeter produced along a MIP track in LAr. In addition to charge readout, one can place PMTs around the inner surface of the tanker. Scintillation and Cerenkov light can be readout independently. LAr is a very good scintillator with about 50000 /MeV. This light is distributed around a line at 128 nm and, therefore, a PMT WLS coating is required. Cerenkov light from penetrating muon tracks has been successfully within the ICARUS program; this much weaker radiation (about 700 /MeV between 160 nm and 600 nm) can be separately identified with PMTs without WLS coating, since their efficiency for the VUV light is very small.

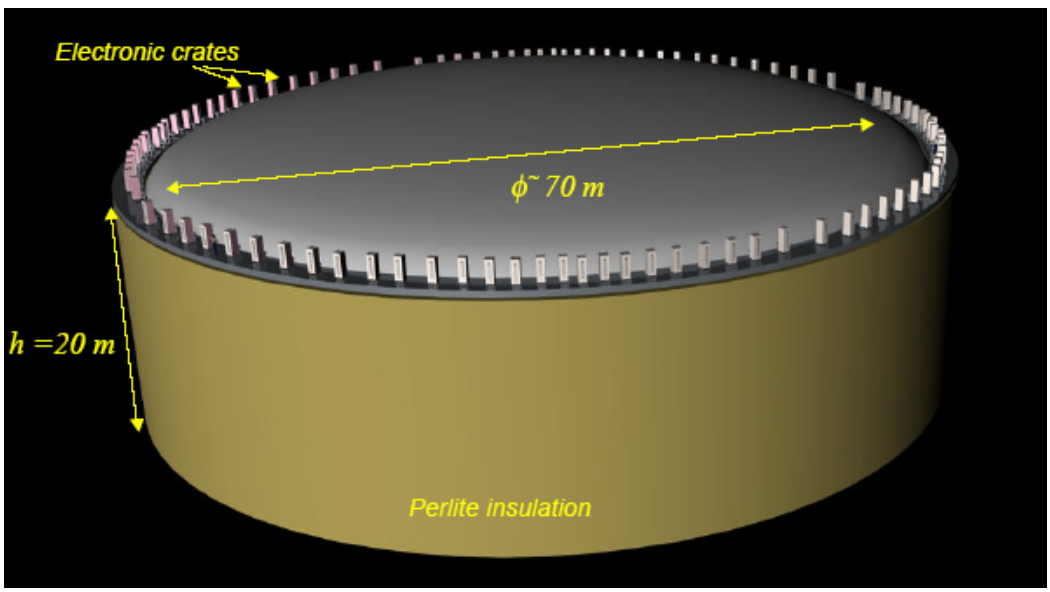

Figure 55 : Artist view of a possible 100 kton liquid argon TPC.

A few studies with the aim of identifying the main issues of the future systematic R&D activities are in progress. Work is being conducted on the study of suitable charge extraction, amplification and imaging devices, on the understanding of charge collection under high pressure as expected for events occurring at the bottom of the cryogenic tanker, on the realization of a 5 m long detector column to simulate very long drift distances of up to about 20 m, on the study of LAr TPC prototypes immersed in magnetic field, on the further development of the industrial design of a large volume tanker able to operate underground, and on the study of logistics, infrastructure and safety issues related to underground sites.

In particular, preliminary investigations are in progress with two generic geographical configurations: a tunnel-access underground laboratory such as for example the planned Frejus laboratories, and with a vertical mine-type-access underground laboratory. Early

considerations show that such sites correspond to interesting complementary options. Concerning the provision of LAr, a dedicated, not underground but nearby, air-liquefaction plant is foreseen. Technodyne International has started investigating the technical requirements and feasibility of such a facility.

Given the extremely appealing physics potential of a large mass liquid Argon astroparticle observatory, nucleon decay and neutrino detector, the community is invited to a deep reflection concerning the feasibility of a next generation 100 kton LAr TPC. In order to start up a complete program of investigations along these lines of thoughts, it has been proposed the creation of an International Network of colleagues and institutions interested in contributing to the development of these ideas, which, if successful, could lead to a submission of Expressions of Interest at a later stage in time.

If CERN will decide to proceed with a high-intensity neutrino facility the realization of a 100 kton LAr detector exploiting these beams could greatly benefit from a strong CERN involvement at the level of the engineering, cryogenics, infrastructure, test beams, and safety aspects, with CERN playing the role of logistic center of gravity of the whole project.

7 Other particle physics opportunities

7.1 Short baseline neutrino physics

(P. Migliozzi)

7.1.1 Introduction

Over the past years there has been a lot of interest in proposing new long baseline (LBL)neutrino oscillation experiments with both conventional (pion and kaon decays) and non-conventional (beta-beams and Neutrino Factories) neutrino beams. In this context the proposal to study the detail of neutrino nucleon/nucleus interactions with short baseline (SBL) experiments has been put forward [Mangano01], [Bigi01], [Flemming04]. The motivations for a SBL program at the future neutrino facilities can be summarized in two main streams: oscillation physics and non oscillation physics. In the following we focus on the aspects relevant to oscillations.

7.1.2 Oscillation physics

The next generation of neutrino oscillation experiments [Apollonio02] aims at the precise measurement of the elements of the neutrino oscillation matrix (PMNS) [PMNS]. There are two experimental techniques two perform this kind of measurements: the appearance and the disappearance experiments.

In an appearance experiment it is important to measure with high accuracy the transition probability between two flavours (i.e. $P(\nu_\mu \rightarrow \nu_x)$). The experimental error on the measured oscillation probability can be written as

$$(\delta P)^2 = \frac{(N_{far} + (\delta B_{far})^2)}{(\phi_{\nu_\mu}\sigma_{\nu_x} M_{far})^2} + (N_{far} - B_{far})\left(\left[\frac{\delta\phi_{\nu_\mu}}{\phi_{\nu_\mu}}\right]^2 + \left[\frac{\delta\sigma_{\nu_x}}{\sigma_{\nu_x}}\right]^2 + \left[\frac{\delta\varepsilon_{\nu_x}}{\varepsilon_{\nu_x}}\right]^2\right)$$

where N_{far} and B_{far} are the number of observed events and the expected background at the far location, respectively; M_{far} is the mass of the detector at the far location; $\Phi_{\nu\mu}$ the expected flux at the far location; $\sigma_{\nu x}$ is the cross-section of the oscillated neutrino ν_x and $\varepsilon_{\nu x}$ its detection ffciency. The variables δX give the error on the corresponding quantities.

The appearance channels that will be exploited at future facilities to search for θ_{13} and non-zero CP phase are the $\nu_e \rightarrow \nu_\mu$ and $\bar{\nu}_e \rightarrow \bar{\nu}_\mu$ oscillations and their CP or T conjugates. Indeed, while for the discovery of a non vanishing θ_{13} it is not mandatory, although highly desirable, to reduce the impact of the intrinsic degeneracy on the sensitivity, to search for CP violation in the leptonic sector one has to measure the oscillation probability for both neutrinos and antineutrinos, and then compare them to search for deviations from zero of the quantity $P(\nu_\mu \rightarrow \nu_e)$ - $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$.

In order to quantify the relative contributions of the different terms to the overall uncertainty on the oscillation probability we refer to the ν_e appearance search performed by the K2K experiment [AhnK2K04]. In K2K, that exploits a conventional neutrino beam whose main component (ν_μ) has an average energy of about 1 GeV, the systematic error is ~30%, but

about 20% comes from the uncertainty on the cross-sections of the background processes (mainly π^0 and $\pi^{\pm}$ production in neutral-current neutrino interactions). This is due to the lack of data on absolute inclusive NC single pion cross-sections as can be seen from Figure 56[Zeller03]. Almost all data on NC single pion production exists in the form of NC/CC ratios and are summarized in Table 13. In some cases the experimental data may differ by as much as factor of two or three. In Table 13[Zeller03] the predictions of the NUANCE Monte Carlo are also shown and are in agreement with at least one of the measurements.

Table 13 Measurements of NC/CC single pion cross-section ratios. The Gargamelle data has been corrected to a free nucleon ratio [Krenz78]. Also quoted are the free nucleons cross-section predictions from NUANCE assuming m_A = 1.032 GeV, m_V = 0.84, and $\sin^2\theta_w$ = 0.2319 in each case. * In their later paper [Derrick81], Derrick et al. remark that while this result is 1.6_ smaller than their previous result [Barish74], the neutron background in this case was better understood. ** The BNL NC π^0 data was later reanalysed after properly taking into account multi-pion backgrounds and found to have a larger fractional cross-section [Nienaber].

Source	Target	NC/CC Ratio	Value
ANL	H_2	$\frac{\sigma(\nu_\mu\, p \to \nu_\mu\, p\, \pi^0)}{\sigma(\nu_\mu p \to \mu^-\, p\, \pi^+)}$	$0.51 \pm 0.25^*$
ANL	H_2	$\frac{\sigma(\nu_\mu\, p \to \nu_\mu\, p\, \pi^0)}{\sigma(\nu_\mu p \to \mu^-\, p\, \pi^+)}$	$0.09 \pm 0.05^*$
NUANCE	free nucleon	$\frac{\sigma(\nu_\mu\, p \to \nu_\mu\, p\, \pi^0)}{\sigma(\nu_\mu p \to \mu^-\, p\, \pi^+)}$	0.20
ANL	H_2	$\frac{\sigma(\nu_\mu\, p \to \nu_\mu\, n\, \pi^+)}{\sigma(\nu_\mu p \to \mu^-\, p\, \pi^+)}$	0.17 ± 0.08
ANL	H_2	$\frac{\sigma(\nu_\mu\, p \to \nu_\mu\, n\, \pi^+)}{\sigma(\nu_\mu p \to \mu^-\, p\, \pi^+)}$	0.12 ± 0.04
NUANCE	free nucleon	$\frac{\sigma(\nu_\mu\, p \to \nu_\mu\, n\, \pi^+)}{\sigma(\nu_\mu p \to \mu^-\, p\, \pi^+)}$	0.17
ANL	D_2	$\frac{\sigma(\nu_\mu\, n \to \nu_\mu\, p\, \pi^-)}{\sigma(\nu_\mu n \to \mu^-\, n\, \pi^+)}$	0.38 ± 0.11
NUANCE	free nucleon	$\frac{\sigma(\nu_\mu\, n \to \nu_\mu\, p\, \pi^-)}{\sigma(\nu_\mu n \to \mu^-\, n\, \pi^+)}$	0.27
Gargamelle	$C_3H_8\ CF_3Br$	$\Sigma_{N=n,p}\ \frac{\sigma(\nu_\mu\, N \to \nu_\mu\, N\, \pi^0)}{2\,\sigma(\nu_\mu n \to \mu^-\, p\, \pi^0)}$	0.45 ± 0.08
CERN PS	Al	$\Sigma_{N=n,p}\ \frac{\sigma(\nu_\mu\, N \to \nu_\mu\, N\, \pi^0)}{2\,\sigma(\nu_\mu n \to \mu^-\, p\, \pi^0)}$	0.40 ± 0.06
BNL	Al	$\Sigma_{N=n,p}\ \frac{\sigma(\nu_\mu\, N \to \nu_\mu\, N\, \pi^0)}{2\,\sigma(\nu_\mu n \to \mu^-\, p\, \pi^0)}$	$0.17 \pm 0.04^{**}$
BNL	Al	$\Sigma_{N=n,p}\ \frac{\sigma(\nu_\mu\, N \to \nu_\mu\, N\, \pi^0)}{2\,\sigma(\nu_\mu n \to \mu^-\, p\, \pi^0)}$	$0.248 \pm 0.085^{**}$
NUANCE	free nucleon	$\Sigma_{N=n,p}\ \frac{\sigma(\nu_\mu\, N \to \nu_\mu\, N\, \pi^0)}{2\,\sigma(\nu_\mu n \to \mu^-\, p\, \pi^0)}$	0.41
ANL	D_2	$\frac{\sigma(\nu_\mu\, n \to \nu_\mu\, p\, \pi^-)}{\sigma(\nu_\mu p \to \mu^-\, p\, \pi^+)}$	0.11 ± 0.022
NUANCE	free nucleon	$\frac{\sigma(\nu_\mu\, n \to \nu_\mu\, p\, \pi^-)}{\sigma(\nu_\mu p \to \mu^-\, p\, \pi^+)}$	0.19

The situation is even more dramatic for antineutrinos where there are almost no data available. For a complete collection of all available data on neutrino and antineutrino cross-sections we refer to [Boone-web].

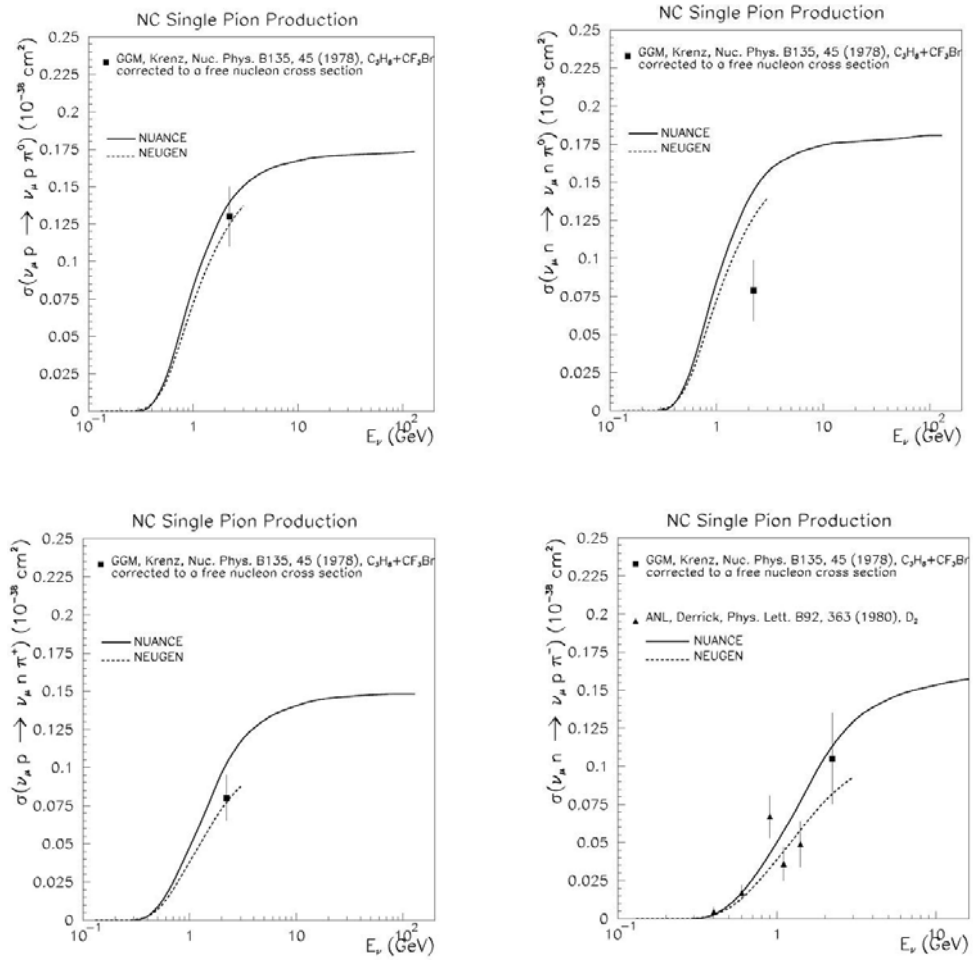

Figure 56 NC 1π cross sections. Top left: (ν_μ p → ν_μ p π^0); top right: (ν_μ n → ν_μ n π^0);; bottom left: (ν_μ p → ν_μ n π^+); bottom right: (ν_μ n → ν_μ p π^-). Shown are the free nucleon cross section predictions from NUANCE [Casper02] and NEUGEN [Gallager02] with m_A = 1.032 GeV, m_V = 0.84 GeV, and $\sin^2\theta_W$ = 0.233.

Therefore, one of the most important issue to be addressed at future facilities is the precise measurement of neutrino and antineutrino cross-sections. In this respect, the most suitable facilities to perform such a measurements are the β-beams and the neutrino factories, where the neutrino flux can be predicted with an accuracy of about 1% and 0.1%, respectively. However, waiting for the construction of these facilities, there is an intense experimental program under way with conventional neutrino beams (Mini-Boone; K2K, MINOS and T2K near detectors; Minerva at NuMI) whose aim, among many others, is to improve the present knowledge of cross-sections.

7.1.3 Conclusion

Detailed study of neutrino interactions is one of the most important topics to be addressed aiming at a precise measurement of the elements of the neutrino oscillation matrix. As an example, the impact of the error on the cross-sections on the determination of the oscillation parameters Δm^2_{23} and θ_{23} within the T2K experiment (JHF→ SK with 5 years data taking) is shown in Figure 57.

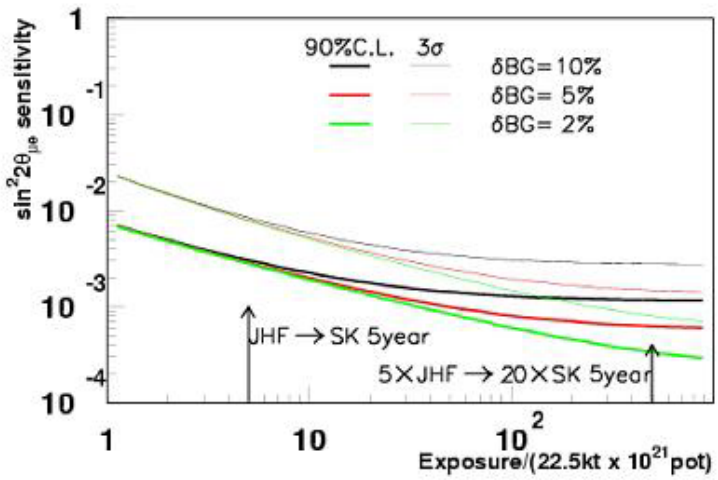

Figure 57 Sensitivity to $\sin^2\theta_{\mu e}$ as a function of the exposure for different estimates of the systematic errors [Itow01].

From the plot shown in the top panel of Figure 58 it is also possible to have a feeling of the impact of the cross-section accuracy on the sensitivity of future experiments (5×JHF→ 20×SK1 with 5 years data taking) foreseen after the generation currently under construction and aiming at the discovery of the CP violation in the leptonic sector. In order to improve the sensitivity, the systematic error should be improved from the 10% foreseen for T2K down to about 2%! Nowadays it is about 30%. This gives an idea of the importance of an accurate determination of neutrino cross-sections.

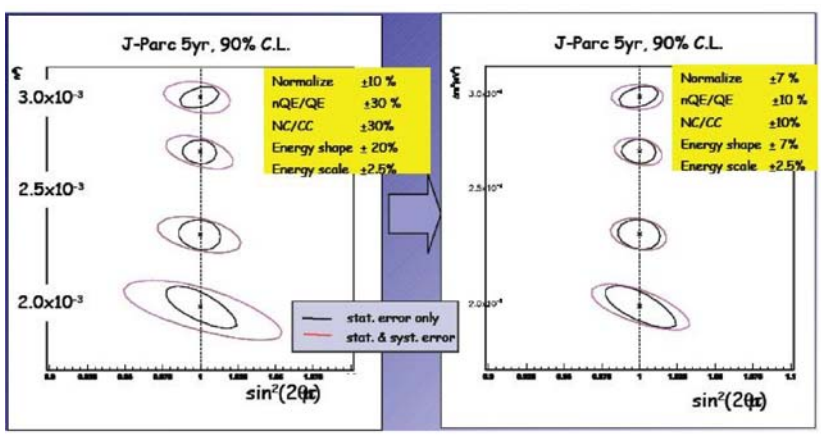

Figure 58 Δm^2 atmospheric and $\sin 2\theta_{23}$ determination at T2K by assuming present systematic errors (left panel) and an improved scenario (right panel), figure taken from [McGrew04].

7.2 High intensity muon physics

(A.Baldini, A. Van der Schaaf)

A community of physicists is proposing or performing experiments with low energy muon beams. Among these items Charged Lepton Flavor Violation (CLFV) searches have a long history reaching back 1948[Hinks48]. The absence of the $\mu \rightarrow e\gamma$ decay has played a fundamental role in the construction of the Standard Model of elementary particles physics. In the past 25 years the sensitivity to this decay was raised by two orders of magnitude. The current best limit was given by the MEGA experiment[Brooks99] which established a 90% C.L. limit of $1.2 10^{-11}$ for the $\mu \rightarrow e\gamma$ branching ratio (*BR*).

Grand unified suspersymmetric (SUSY-GUT) theories, owing to the large top quark mass, predict[Barbieri94] this decay to happen not much below the current experimental limit. Figure 59 shows the SU(5) predictions for the branching ratio as a function of the right handed selectron mass and for several values of *tanβ*, compared with the current experimental limit and the aimed sensitivity of the MEG experiment[MEG] at PSI. Recent indications from the combined LEP experiments favor values of *tanβ* grater than 10. Predictions for SO(10) could be about two orders of magnitude higher than for SU(5).

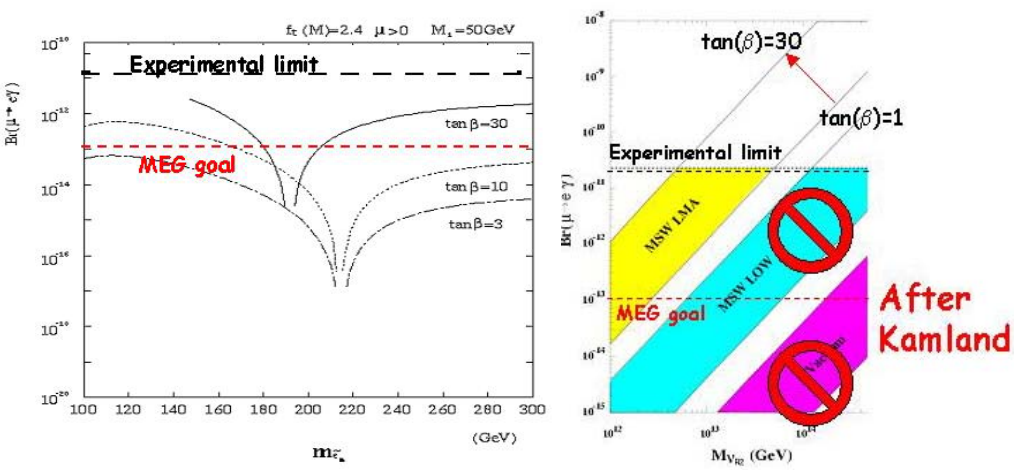

Figure 59 Left: SUSY SU(5) predictions for the $\mu \rightarrow e\gamma$ branching ratio. Right: Predictions from a SUSY model including a see-saw mechanism for neutrino masses generation (see text)

Another, independent, source of CLFV in SYSY-GUT theories might come from neutrino mixing. After the KAMLAND results the large mixing angle solution seems to represent the best solution for the so-called "solar neutrino problem". If a mechanism of the see-saw type is introduced in SUSY-GUT theories to reproduce the pattern of neutrino masses, sizeable contributions (of the same order of magnitude or even higher than the ones discussed above) to the $\mu \rightarrow e\gamma$ process take place[Hisano99] (see Figure 59). These contributions add up to the previous ones, therefore making $\mu \rightarrow e\gamma$ an extremely sensitive probe of SUSY-GUT theories. It must also be remarked that the $\mu \rightarrow e\gamma$ *BR* due to neutrino mixing alone would be completely unobservable ($BR \approx 10^{-54}$). The detection of $\mu \rightarrow e\gamma$ events would thus be a clear, unambiguous sign of physics beyond the standard model, even including neutrino masses.
Experimentally, a beam of positive muons is stopped in a thin target and a search is made for a back to back positron-photon couple with the right momenta and timing. The main background in present experiments comes from the accidental coincidence of independent positrons and photons within the resolutions of the used detectors. The best available

detectors for low energy positrons and photons must therefore be employed. In the MEG experiment at PSI (see Figure 60) a surface muon beam with an intensity grater than 10^7 μ/*s* will be stopped in a thin target. A magnetic spectrometer, composed of a superconducting magnet and drift chambers, will be used for the measurement of the positrons trajectories. Positrons timing will be measured by an array of scintillators. Photons will be detected by an innovative electromagnetic calorimeter in which a total of about 800 photomultipliers will detect the light produced by photons initiated showers in about 800 liters of liquid Xenon. In a recent test at PSI the design energy resolution of 4.5% FWHM was obtained in a 100 l liquid Xenon prototype for 55 MeV photons. The aim of this experiment is to reach a sensitivity down to *BR* of the order of 10^{-13}, with an improvement of two orders of magnitude with respect to the present experimental limit. The start of the data taking is foreseen in 2006.

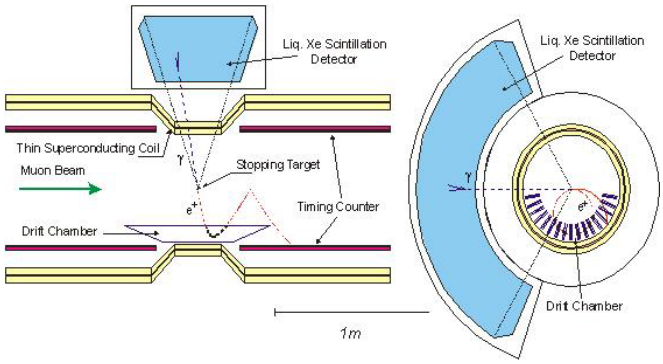

Figure 60 A sketch of the MEG detector

Another channel for CLFV investigation which is not limited by accidental background and can therefore be used to improve the sensitivity to CLFV is muon to electron (μe) conversion in nuclei. The ratio of the rate for this process with respect to μ→eγ has been calculated by several authors, for various nuclei, under assumptions on the relevant matrix elements which are valid in many SUSY models (see Figure 61 [Kitao02]).

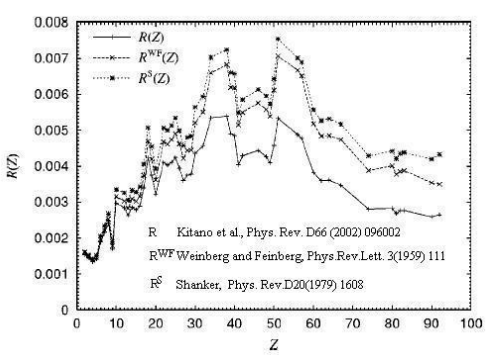

Figure 61 Computed ratio of *BR(*μ*e)/BR(*μ→eγ*)*.

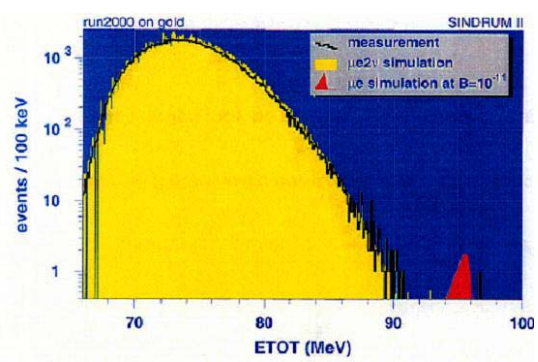

Figure 62 Results of the SINDRUM II experiment

Experimentally, negative muons are brought to stop in a thin target and are subsequently captured around a nucleus. The energy of a possible converted electron would be equal to the rest muon mass minus the muon binding energy (*EB*). Two main sources of background are: i) beam correlated background due mainly to radiative pion capture followed by γ→ *e+e-* conversions and ii) electrons from muon decay in orbit (DIO). The first source of background

can be reduced by timing, the second one is intrinsic; DIO electrons spectrum extends up to the energy region of electrons from μ*e* conversion but with a spectrum proportional to (*E* - *EB*)5. An excellent electron momentum resolution is fundamental in order to keep this background under control.

The best experimental sensitivities to this process were obtained by the SINDRUM experiment at PSI. Pion contamination in the beam was suppressed by means of a moderator which exploited the different ranges of pions and muons. The final result of the SINDRUM II experiment, which used a gold muon stopping target, is shown in Figure 62. The DIO electrons spectrum is well reproduced by simulations. Also shown is the conversion signal for a 10-11*BR*. The momentum resolution at the conversion peak is 2% FWHM. The 90% C.L. limit established by the SINDRUMII experiment is $8 \cdot 10^{-13}$.

The MECO project at BNL (see Figure 63) plans to use a very intense (10^{11} μ/*s*) pulsed muon beam for reaching a sensitivity to μ*e* conversion down to $BR \approx 10^{-16}$. The beam will be obtained by capturing most of the lower energy pions produced in a target placed inside a superconducting solenoid magnet. Muons of suitable momentum (60-120 MeV/c) from pion decays are transported by a curved solenoid to the stopping target and tracking system. The design electron momentum resolution, dominated by interactions in the target is 900KeV FWHM. The pulsed structure of the beam is indispensable to reduce the beam correlated background. A proton extinction factor better than 10^{-9} between two bursts must be obtained in order to reach a sensitivity to $BR \leq 10^{-16}$.

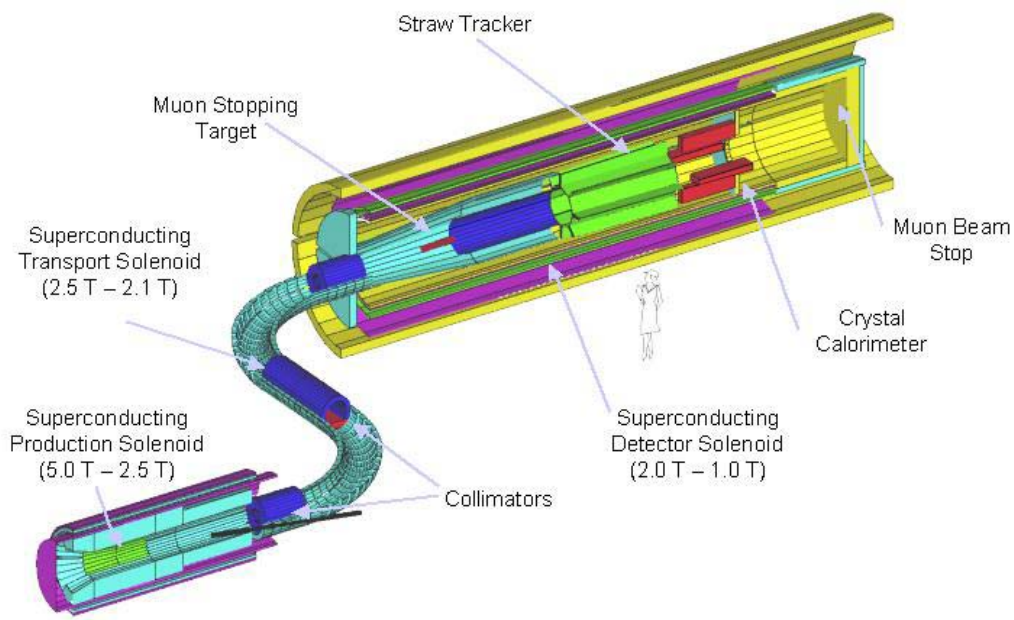

Figure 63 The MECO experiment

In the PRISM/PRIME project at J-PARC the same muon production scheme as MECO is adopted. After pion production in a solenoid the beam is transported in a circular system of magnets and RF cavities (FFAG ring) which acts as a pion decay section (increasing beam cleaning) and reduces the muon energy spread. The features of this beam would be an

extremely high intensity (10^{12} /*s*) of clean muons of low momentum (≈70MeV/c) with a narrow energy spread (few % FWHM). The last feature is essential to stop enough muons in thin targets. If the electron momentum resolution will be kept below 350 KeV/c (FWHM) the experiment will be sensitive to μ*e* conversion down to $BR \leq 10^{-18}$.

The SPL could be used to produce very intense muon beams. Preliminary estimates obtained by suitably scaling MECO calculations indicate that $>10^{12}$ μ/*s* stopped muons and a pulsed structure suitable for performing a very sensitive μe conversion experiment (down to $BR < 10^{-18}$ or better) could be obtained. On the contrary a continuous muon beam seems more difficult to be realized. Other very interesting kinds of experiments, apart from CLFV, could be performed by using a very intense low energy muon beam. These include precise measurements of the muon decay parameters, measurement of the muon anomalous magnetic moment and of the muon electric dipole moment. The muon beams characteristics needed by all the different kinds of experiments were investigated some time ago by the CERN stopped muons working group and are reported in [Aysto01].

7.3 Physics at Higher Intensity PS or SPS at CERN

(A. Ceccucci)

The strategic goals of CERN must include the exploitation of the PS and SPS machines that will be employed as injectors of the LHC just for 15% of the time. It is important to distinguish between two scenarios:

Short to Medium Term: assume the current PS and SPS with adyabatic increase --always welcome!-- of the delivered proton intensities up to a factor of two. As outlined in [Cappi:2001au] bigger gains are unrealistic even with an SPL because large PS and SPS collective effects are the essential limitations.

Longer Term: the path toward higher LHC luminosity is to foresee a new injector chain capable to deliver significant higher intensities at high energy. To employ significantly larger proton intensities at fixed target, the extraction and the targets need to be refurbished as well.

Let us focus here on one example: the opportunity to use the current SPS to perform crucial tests of the Standard Model (SM) by measuring kaon rare decays for which very clean theoretical predictions are available [Buchalla98ba]. The most interesting are:

$K^+ \to \pi^+ \nu\bar{\nu}$, and

$K^0 \to \pi^0 \nu\bar{\nu}$, which is a CP violating process.

The measurement of the Branching Ratio of $K^+ \to \pi^+ \nu\bar{\nu}$ is the cleanest way to measure $|V_{td}|$, while the measurement of $K^0 \to \pi^0 \nu\bar{\nu}$ would provide the cleanest measure of the CP-Violation predicted in the SM. The importance of these decays is that the hadronic matrix elements are well measured from the Kaon semi-leptonic decays. In addition, the remaining uncertainties are largely parametric in nature and will decrease to become negligible once the uncertainties due to other CKM parameters will be reduced.

Experimental progress on $K^+ \to \pi^+ \nu\bar{\nu}$ has been impressive over the past three decades: the BNL experiment 787 has published evidence for two events [Adler01xv], and the subsequent experiment 949 has claimed a third event [Anisimovsky04hr]. These experiments exploit the

large amount of protons available from the 24 GeV AGS to study kaon decays at rest. To test the precise prediction of the SM however, one should aim to collect hundreds of such events, which is extremely difficult with stopped kaon experiments.

Enticed by the quality of the secondary beams prepared for the charged kaon experiment (NA48/2), the NA48 Collaboration has realized that a very competitive programme to study $K^+ \to \pi^+ \nu\bar{\nu}$ can start as soon as the SPS will resume operations after the commissioning of the LHC. The parameters of the possible future beam compared to the present ones are given in Table 14. It is noteworthy that by using the already available 3 10^{12} protons on the T4 target, the experiment would be able to collect 40 times the kaon flux of NA48/2.

Table 14 Comparison between the current NA48/2 beam and the future one. The figures in brackets in the last column refer to increase in rate with respect to the sum of the positive and negative NA48/2 beams

Beam	Present K12 (NA48/2)	New High Intensity K^+ (NA48/3) > 2006	Factor gain w.r.t. 2004
SPS protons per pulse	1×10^{12}	3×10^{12}	3.0
Duty cycle (s / s)	4.8 / 16.8	same	1.0
Beam Acceptance H,V (mrad)	± 0.36	± 2.4, ± 2.0	
Solid Angle (μsterad)	$\simeq 0.40$	$\simeq 16$	40
Average K^+ Momentum $< P_K >$ (GeV/c)	60	75	K^+ : 1.50 π^+ : 1.35 Total: 1.35
Momentum band ΔP_K GeV/c	63-57 = 6	76.1-73.9=2.25	$\simeq 0.375$
Eff.:$\Delta P/P$ (%)	± 5	± 1.5	$\simeq 0.3$
RMS:$\Delta P/P$ (%)	$\simeq 4$	$\simeq 0.95$	$\simeq 0.25$
Beam size (cm)	± 1.5	± 2.5	
Area at KABES (cm^2)	$\simeq 7$	$\simeq 20$	$\simeq 2.8$
Divergence: RMS (mrad)	$\simeq 0.05$	$\simeq 0.1$	$\simeq 2$
Decay fid. length (m)	50	50	
(τ_{K^+})	0.11	0.9	0.8
Beam flux/pulse: p ($\times 10^7$)	0.86	49	
K^+	0.31	15	50 ($\simeq$ 30)
π^+	3.32	150	45 ($\simeq$ 27)
e^+	0.95	35	
Total per pulse ($\times 10^7$)	5.5	250	$\simeq$ 45 ($\simeq$ 27)
Rate (3s eff. spill length) (MHz)	18	800	$\simeq$ 45 ($\simeq$ 27)
Rate @KABES (MHz/cm^2)	2.5	40	$\simeq$ 16 ($\simeq$ 10)
Effective running time/yr (days)	$1/2 \times 120$	$2/3 \times 90$	
(pulses)	3.1×10^5	3.1×10^5	1.0
K^+ decays per year	1.0×10^{11}	4×10^{12}	$\simeq 40$
Events/year (BR= 10^{-10} accept. = 10%)		40	

The study of $K^+ \to \pi^+ \nu\bar{\nu}$ is not limited by the availability of protons from the current SPS. Although the experiment requires a long spill which is in competition with the CNGS programme, this is regarded as a scheduling issue rather than a technical one. A feasibility study for an experiment able to collect at least 50 $K^+ \to \pi^+ \nu\bar{\nu}$ events with a signal to background ratio of ~10:1 in about two years of data taking (NA48/3) has been performed. The two undetectable neutrinos in the final state require the design of an experiment with redundant measurement of the event kinematics and hermetic vetoes to achieve the necessary background rejection. Particular care has to be taken to suppress the two body decays $K^+ \to \pi^+ \pi^0$ and $K^+ \to \mu^+ \nu$ which have Branching Ratios up to 10^{10} times larger than the expected signal. The reconstruction of the two body kinematics cannot be completely exempt from reconstruction tails and backgrounds can originate if photons from $K^+ \to \pi^+ \pi^0$ are not detected or if muons from $K^+ \to \mu^+ \nu$ are mis-identified as pions. To suppress backgrounds from the two body decays, kinematics and particle identification have to be used in conjunction. Only in the absence of correlations the rejection power obtainable applying the two techniques together will equal the product of the single rejection powers. The advantage of using 400 GeV/c protons from the SPS to perform the experiment is two-fold: on the one side, the cross-sections to produce kaons increases as a function of proton energy so that to achieve

the same kaon flux one needs less protons thus reducing the non-kaon-related accidental activity. In addition, the higher kaon energy leads to easier photon detection which simplifies the suppression of the backgrounds originating from $K^+ \to \pi^+ \pi^0$. For example, employing a 75 GeV/c kaon beam and limiting the momentum of the reconstructed π^+ to 40 GeV/c, there are at least 35 GeV of electro-magnetic energy from the π^0 deposited into the photon vetoes. This reduces significantly the probability that both photons are left undetected because of photonuclear reactions.

The disadvantage of employing high energy protons and, consequently, high energy secondary beams, is that the pions and the protons cannot be efficiently separated from kaons. The consequence is that the upstream detectors which measure the momentum and the direction of the kaons are exposed to a particle flux about 17 times larger than the useful (kaon) one. It is important to point out that the detectors placed downstream of the decay region do not suffer from the same limitation because:

- The protons and the undecayed kaons and pions are kept in a vacumm beam-pipe that crosses the downstream detectors.

- The muons from pion decays stay in the beam-pipe without illuminating the drift chambers because of the small transverse momentum released by the pion decay.

In the longer term, a 1 MW and high-energy proton beam would be ideal to consider also a very competitive programme addressing $K^0 \to \pi^0 \nu\bar{\nu}$, the so called *holy grail* of kaon physics. More details can be found in the Expression of Interest [NA48EOI04] submitted by the NA48 Collaboration.

8 Nuclear physics

8.1 The future of nuclear physics studies

(P. Butler, W. Gelletly)

The study of atomic nuclei lies in the mainstream of modern physics. It is closely allied to studies of other finite N, many-body systems such as quantum dots, metallic clusters, grains, fermion condensates etc. Although they are mostly nanostructures and nuclei are femtostructures they have many common features including shell structure, collective modes of motion and pairing. Each of these systems has unique features. Nuclei present a two-fluid(protons and neutrons), strongly interacting system that has many degrees of freedom. It is difficult to study but the tools to do so are well developed.

All of these systems reflect two of the main themes of modern physics, namely "How can such complex systems be built from a few, basic entities?" and "Despite the complexity how do we understand the surprisingly simple excitation patterns and symmetries they exhibit?" Theoretical understanding of each of these systems will impinge strongly on our answers to these questions in all of these systems. Nuclear physics is also closely related to particle physics and astrophysics and has many applications.

There are many specific challenges in nuclear structure physics:

a) Firstly we do not know the limits of nuclear existence. In particular we do not know what is the heaviest element we can make and we have only a vague idea of where the neutron drip-line lies. In the former case we have evidence that there is an island of superheavy nuclei, established by the extra binding from the shell structure. However with stable beams, even with long-lived, radioactive, actinide targets, we can only create species many neutrons away from the epicentre. In the latter case our best estimates of where the neutron drip-line lies are based on mass formulae. These formulae all agree where we have measured masses but disagree by some 20-30 neutrons in where they put the drip-line for an element such as Sn(Z = 50).

b) Secondly we observe dynamical symmetries in nuclei. In terms of the Interacting Boson Model(where pairs of nucleons are treated as bosons) nuclei can be classified in terms of limiting dynamical symmetries corresponding to a spherical vibrator, a gamma soft rotor and an axially symmetric deformed rotor. Almost all even-even nuclei are at these limits or lie between them. Recently Iachello has also introduced the idea of phase transitions between the limits and examples of nuclei close to the critical points have been found. One key question is whether these dynamical symmetries will persist in nuclei far from stability and, in particular, will the new "critical point symmetries" persist there? In addition, in nuclei with a neutron skin will one see dynamical symmetries associated with a two-fluid system consisting of a proton-neutron core and the neutron skin?

c) Pairing is important in nuclei. For example it dictates the fact that ^{4,6,8}He are bound and ^{5,7}He are unbound. In nuclei we are faced with the possibility that we can have isoscalar and isovector pairs of neutrons and protons. This may manifest

itself in terms of either n-p or alpha condensates in N = Z nuclei. This is likely to be the only regime where the isoscalar component manifests itself since elsewhere it will be swamped by like pairs.

d) In nuclei far from stability, particularly in the neutron-rich nuclei, the density will be low near the nuclear surface. One question of considerable importance is how important pairing is in such a low-density environment.

e) Atomic nuclei exhibit a wide variety of types of excitation that range from single and multi-particle excitations to a variety of collective modes. These include rotations, vibrations of various types and so-called giant resonances in which the neutron and proton fluids oscillate relative to one another. Another key question is whether we will observe new types of oscillation far from stability. We might anticipate a scissors –like motion of a deformed core against a neutron skin or even an oscillation of separate neutron and proton fluids relative to the skin. In addition we might expect a pygmy resonance, a simple vibration of core and neutron surface.

f) Underpinning much of our understanding and theoretical interpretation of nuclear structure is the shell structure. This was first seen in atoms and nuclei but , more recently , it has been observed in metallic clusters and quantum dots as well. In simple terms one can define the shell structure as being due to the bunching of levels in the system, which leads to the shell gaps and its consequences. The well known shell gaps in stable nuclei are the result of the poorly understood *l.s* interaction. In recent years it has become apparent that the shell structure is a very flexible concept and that the gaps vary both with rotational frequency and isospin. As we move away from stability on the neutron-rich side the surface density falls since the neutrons lie close to the top of the potential well. As a result we expect the *l.s* interaction to weaken and with it the shell structure. Since the shell structure dictates much of what we see in nuclei it is vital that we are able to map out this underlying structure far from stability. This challenge can be summed up as "How does the shell structure change with a large neutron excess?"

To answer all of these questions we require high quality, intense beams of radioactive ions. We also need new instruments and techniques to allow us to take advantage of the beams. Multi-MW driver accelerators will be vital to create this opportunity and are the key to producing the beams of radioactive nuclei we need.

8.2 Nuclear dynamics and the nuclear equation of state

(F. Gulminelli)

8.2.1 State of the art

Our knowledge on the nuclear Equation of States and nuclear thermodynamics has considerably progressed in the past twenty years. Exclusive analyses of multifragmentation data, measured with low threshold and high granularity second generation 4π detectors, have

been performed. These studies have lead to a consistent bunch of circumstantial evidences of a transition from a bound and ordered liquid-like phase, to an unbound and disordered gas-like phase of light clusters and nucleons. A spectacular scaling of the distribution of fragment sizes has been observed [Elliot02] and a thermodynamically consistent set of critical exponents has been extracted, in agreement with the liquid-gas universality class. A systematic comparison of different thermometers has shown that the multifragmentation phenomenon takes place at a characteristic temperature that has been interpreted as the transition temperature of a nuclear liquid-gas phase transition [Natowitz02]. Large fluctuations of the fragment partitions have been reported [Schrenberg01,D'Agostino04]. that correspond to huge configurational energy fluctuations overcoming the value expected for a canonical ensemble of loosely interacting fermion clusters (Figure 64, left side). If the fragmenting nucleus is close to a thermodynamic equilibrium, this fluctuation signal can be converted into a heat capacity [Dauxois02]. Then, the abnormally large fluctuations would indicate a negative heat capacity between two divergencies, with an amplitude in energy related to the latent heat of the transition (Figure 64, right side). If confirmed, this signal represents a quantitative measurement of the nuclear phase diagram and the first measurement of a negative heat capacity in a mesoscopic system. To confirm the negative heat capacity and settle the finite temperature equation of state, a complete detection on a 4π geometry of the masses and charges of all the reaction products is mandatory. Indeed the limited isotopic resolution of present apparatus induces a dispersion in the calorimetric determination of the deposited excitation energy, which in turn affects the fluctuation measurement with a systematic error which can presently only be estimated through simulations in a model dependent way. Moreover, a full isotopic resolution is necessary to constrain the statistical models and determine the degree of equilibration of the transient nuclear source. A device adapted to nuclear matter studies (FAZIA) has been recently proposed [EURISOLE] and the R&D is taken in charge by the European collaboration AZ4π.

The adequacy of this project has been recognized in the last NuPECC report [NUPECCLRP].

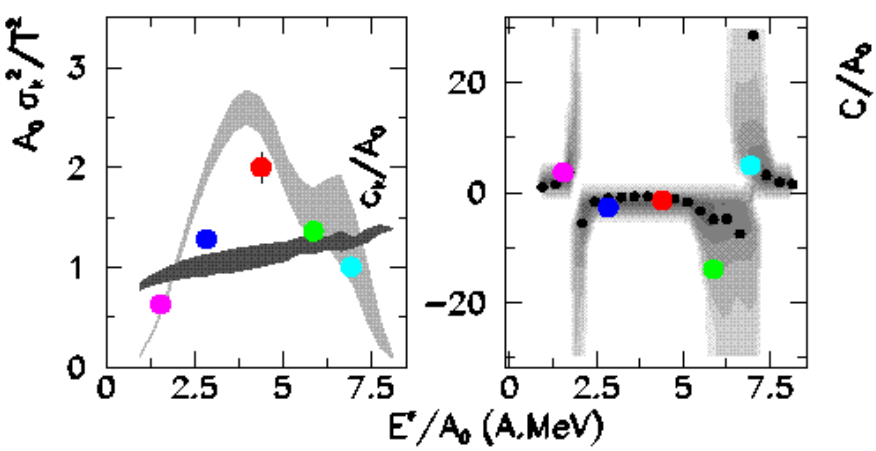

Figure 64 Left side: normalized configurational energy fluctuations and canonical reference (dark grey) measured in peripheral Au+Au collisions at 35 A.MeV (light grey), and central collisions of an Au beam on different targets (symbols). Abnormally high fluctuations are observed in the energy range $2<E^*/A<6.5$. Right side: corresponding heat capacity deduced in the framework of thermodynamic equilibrium. All data are from the Multics-Miniball collaboration [Schrenberg01],[D'Agostino04]

8.2.2 The perspectives of exotic beams

A new high performance RIB facility will offer the possibility to study the role of the isospin (N/Z ratio) in dynamical and statistical de-excitations of hot nuclei. This search will probe the dependence of the nuclear equation of states on the isospin terms under compressed, normal and dilute conditions. The isospin dependent phase diagram of nuclear matter is largely unknown. At zero temperature, the density dependence of the symmetry energy is the subject of numerous theoretical investigations [Greco03]. To constrain the huge theoretical uncertainties on this quantity, isospin diffusion experiments are needed with beam energies in the range 30-100 A.MeV and a large panel of isotopes around A=100] [Tsang04]. At finite temperature, the extra dimension provided by the isospin degree of freedom in the nuclear phase diagram (Figure 65, left part) leads to the expectation of different new phenomena that could be experimentally probed. For the fragmentation of proton rich nuclei, the transition temperature is expected to dramatically decrease approaching the proton drip line [Bonche85], and theory predicts that the first order phase transition should become a cross over due to the Coulomb interaction [Gulminelli03].

The phenomenon of isospin distillation is expected in the fragmentation of neutron rich nuclei [Mueller95], which can be experimentally investigated from the production yield of different isotopes (Figure 65, right side). In both cases beam energies in the range 20-100 A.MeV are needed, as well as a new high resolution 4π device: the FAZIA concept recently proposed in the instrumentation report of the EURISOL Key Experiment Task Group [EURISOLE] (see above).

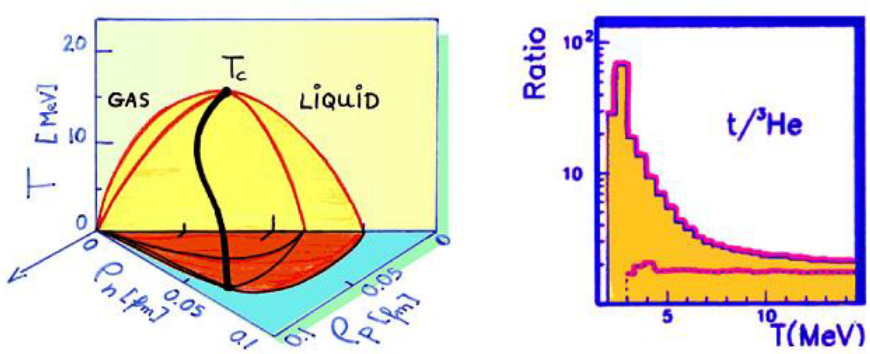

Figure 65 left side: theoretical prediction for the coexistence zone of asymmetric nuclear matter as a function of proton and neutron density from ref. [Mueller95]]. Right side: relative production yield of light isobars (gas phase) as a function of temperature from ref. [Chomaz99]. A neutron enrichment (upper line) is predicted for this neutron rich hot nucleus (160 neutrons and 96 protons) respect to the simple combinatorial expectation (lower line).

8.2.3 Conclusions

The study of the de-excitation pattern of hot nuclei produced in heavy ion collisions constitutes a unique opportunity to probe the interdisciplinary thermodynamics of mesoscopic systems and look for exotic phenomena as negative susceptibility and negative heat capacity [Dauxois02]. If many experimental data already exist on the fragmentation of stable nuclei, almost nothing is experimentally known about the thermodynamics of strongly asymmetric nuclear matter. These studies do not only aim to quantitatively understand the phase diagram

of finite nuclei, but also bear important information on the thermodynamics of dense matter and stars [Glendenning01].

To perform these analyses, exotic beams both on the proton and on the neutron rich side are needed in the energy region of 30-100 A.MeV, as they could be produced by the EURISOL facility.

8.3 Astrophysics with R.I.B.

(K.-L. Kratz)

As outlined in the recent NuPECC report on *'Nuclei in the Universe'* [NUPECCLRP], nuclear astrophysics has developed in the last decades into an important interdisciplinary sub-field of 'applied' nuclear physics. To the nuclear physicist many phenomena in the universe represent nuclear experiments on a grand scale, often under conditions that – at least for the time being - cannot be replicated on earth. To the astrophysicist nuclear physics represents experimental and theoretical sources of data which are needed to model astronomical observations of many astrophysical scenarios. Examples of this dichotomy are the explanation of the energy production in explosive thermonuclear burning and the postulation of two distinct neutron-capture processes as the origin of the heavy nuclei beyond iron.

Among the most interesting applications of explosive nucleosynthesis scenarios in binary systems are novae and X-ray bursters. Novae are in fact thermonuclear explosions on the surface of a white dwarf accreting matter from a companion star. Once the white dwarf's freshly accreted surface layer reaches a critical density and temperature, nuclear reactions trigger a thermonuclear runaway. The explosive burning of hydrogen and the decay of freshly synthesized proton-rich nuclei provide the energy that leads to the observation of a dramatic brightening of the star.

X-ray bursters are believed to be neutron stars accreting material from a low-mass companion star. In regular or irregular intervals of typically 1 hour to 1 day, the accreted layer ignites and a thermonuclear runaway evolves burning hydrogen and helium within tens of seconds. The respective nucleosynthesis process is today known as the rapid proton-capture process, i.e. the rp-process. Provided that a sufficiently high mass-loss out of the gravitational potential of the neutron star is possible, X-ray bursts may contribute to the galactic nucleosynthesis of light (proton-rich) p-nuclei [Wiescher98,Schatz98]

Figure 66 shows the full sequence of nuclear reactions powering a 'normal' X-ray burst, calculated with a one-zone model coupled to a complete reaction network [Schatz01]. The endpoint of the rp-process is expected in the Sn-Sb-Te region, where a reaction cycle is formed as a consequence of low α-binding energies of the proton-rich Te isotopes. This Sn-Sb-Te cycle prevents the synthesis of nuclei heavier than $A \approx 106$ in the rp-process.

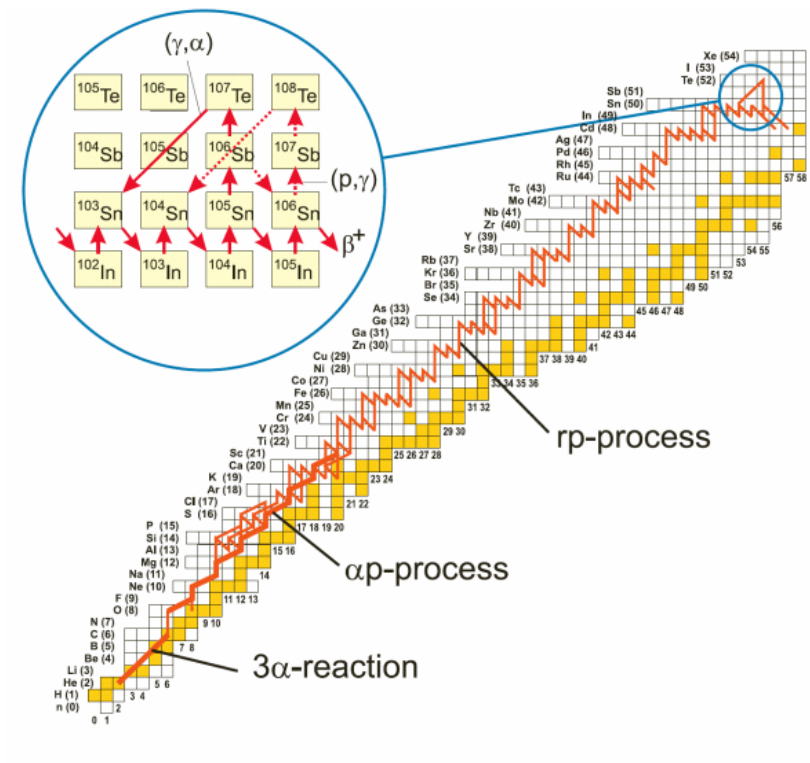

Figure 66 Time integrated reaction flow for a complete X-ray burst. The thermonuclear runaway is triggered by the 3 α-reaction and the break-out reactions of the hot CNO cycle into the αp-process, which provides the seed for the hydrogen burning via the rp-process. The inset shows the Sn-Sb-Te cycle in detail. For more details, see reference [Schatz01].

Summarising the nuclear-data needs for X-ray burst calculations, the most important parameters are nuclear masses (including p-separation energies) near the proton drip-line, β-decay half-lives along the process paths (in some cases including decay from excited and isomeric states) and p-capture rates on 'short-lived' nuclei (in particular those within so-called 2p-capture sequences [Schatz98]).

The understanding that the existence of the heavy elements in nature is due to neutron capture is almost half a century old [Burbidge57, Cameron57, Coryell61] . The abundance features of solar system matter [Anders89, Lodders03] beyond Fe are seen to be correlated with the positions of the neutron shell closures at N=50, 82 and 126. The splitting of the abundance peaks in the mass regions $A \approx 80$, 130 and 195 (see Figure 67) in fact reveals signatures of (at least) two types of neutron-capture processes with quite different astrophysical environments.

1. A process with small neutron densities experiences long neutron-capture time-scales in comparison to β-decays $\tau_\beta < \tau_{\nu,\gamma}$): **slow neutron capture**, the **s-process**, causes abundance peaks in the flow path at nuclei with small neutron-capture cross sections, i.e. stable nuclei with magic neutron numbers [Kappeler98].

2. A process with high neutron densities and temperatures experiences rapid neutron capture and the reverse photodisintegration with $\tau_{\nu,\gamma}$, $\tau_{\nu,n} < \tau_\beta$: the **r-process** causes abundance peaks due to 'long' β-decay half-lives where the flow path comes closest to stability. This occurs again for magic neutron numbers, but for far-unstable nuclei [Kratz00].

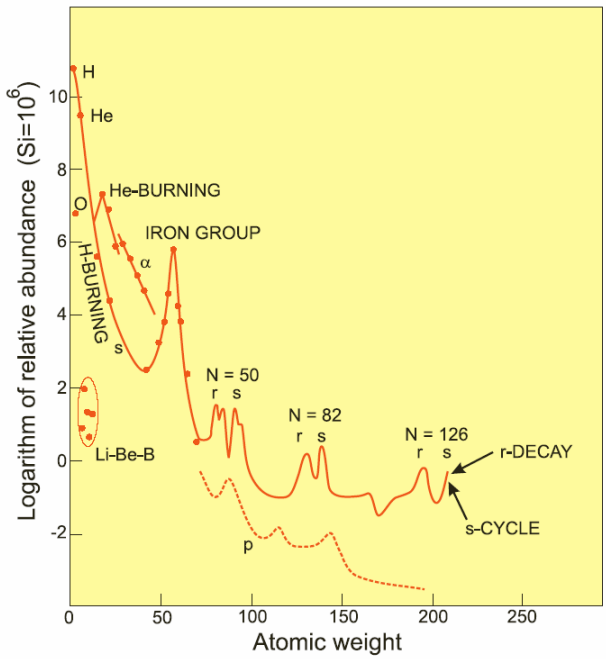

Figure 67 Schematic curve of Solar-System abundances as a function of atomic weight, based on the 1956 data of Suess and Urey] [Suess56].

Approximately half of the nuclear species in nature beyond iron are produced via neutron captures on very short time scales in neutron-rich environments, i.e. the so-called r-process. Only under such conditions is it possible that highly unstable nuclei near the neutron drip-line are produced, also leading – after decay back to stability – to the formation of the heaviest elements in nature like Th, U and Pu. Far from stability, magic neutron numbers are encountered for smaller Z and A numbers than under the low neutron-density s-process conditions in the valley of β-stability. Despite its importance, the exact stellar site where the r-process occurs is still a mystery. However, two astrophysical settings are suggested most frequently, (i) type II supernovae (SN II) with postulated high-entropy ejecta (see, e.g. [Woosley94, Freiburg99]), and (ii) neutron-star mergers or similar events (like axial jets in SN explosions) which eject NS matter with low entropies (see, e.g. [Lattimer77, Rosswog00]). The key to its understanding will probably only be obtained from a close interaction between astronomy, cosmochemistry, nuclear physics and astrophysical modelling of explosive scenarios.

To illustrate the present unsatisfactory situation, with the use of different mass models differences in the main waiting point behaviour around the N=82 closed shell can be deduced, as shown in Figure 68. Using masses from 'unquenched' models such as FRDM or ETFSI-1, the N=82 closed shell is very abrupt and the neutron captures proceed quickly to the N=82 nuclei at low Z. Consequently, very few nuclei with more than 10% abundance in a given isotopic chain are found before reaching the neutron closed-shell N=82 (Figure 68, top left in the circled area). This feature is responsible for the trough (Figure 68, top right) in the fit of the abundance curve of the r-elements at A~120 since very few r-progenitors are found at this mass number.

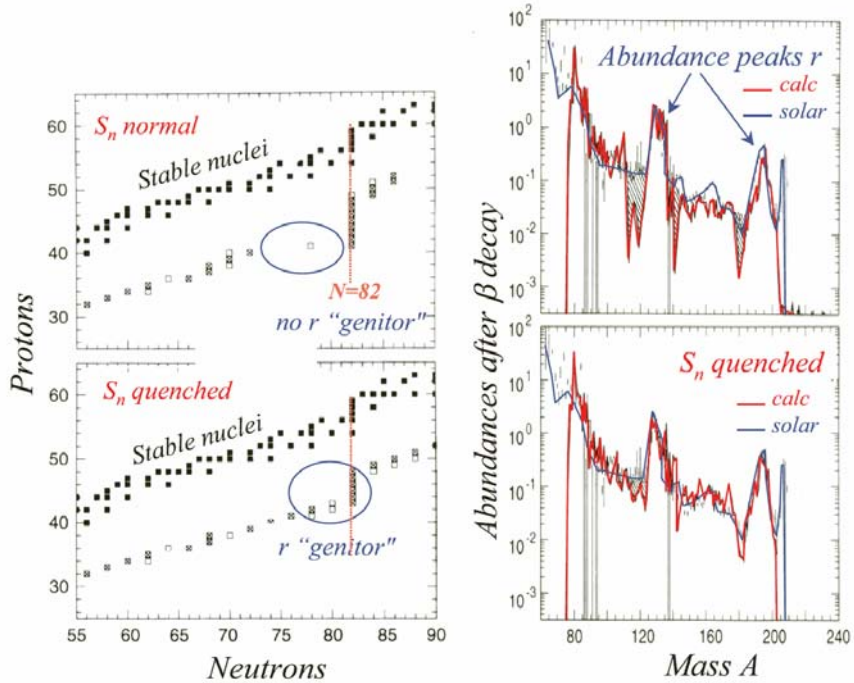

Figure 68 3 (Left:) The r-process waiting points for mass models with strong neutron shell closures (such as FRDM or ETFSI-1) are shown in the vicinity of the neutron shell closure at N=82 for a neutron density of nn=9.5×1020 cm-3 and a temperature of 1.2 □109K. Nuclei with more than 10% of the population of an isotopic chain are represented with an open square. Open squares with a cross indicate waiting-point nuclei with the maximum abundance in an isotopic chain. The nuclei in the valley of stability are displayed as full squares. The bottom part shows the expected waiting points using the masses close to N=82 from models which contain shell quenching (such as HFB/SkP or ETFSI-Q). It is shown that the region within the circle at Z≈40, A≈78 contains more progenitors [Pfeiffer96]. (Right:) Comparison of calculated abundances with the $N_{r,\Theta}$ distribution for 'unquenched' (top) and 'quenched' masses (bottom).

On other hand, calculations performed within the HFB/SkP or the ETFSI-Q models showed that the *N*=82 closed shell is substantially 'quenched' at very neutron-rich heavy nuclei. This creates r-progenitors already before reaching the *N*=82 closed-shell. Using these masses, the *A*~120 trough is filled, in closer agreement with the $N_{r,\Theta}$ curve. This emphasises that a better knowledge of nuclear properties is required when approaching the major closed shells far from stability, for both nuclear physics and astrophysics, in order to see if these shell gaps are, indeed, quenched. For example, if shell quenching far from stability would turn out to be pronounced, the classical *N*=82 shell gap should steadily decrease below doubly-magic ^{132}Sn and eventually vanish at ^{122}Zr. Then, ^{122}Zr would no longer act as an r-process waiting point. Instead, a new (semi-) doubly-magic zirconium isotope with an *N*=70 shell closure, i.e. ^{110}Zr, might be expected (see references [Pfeiffer01, Pfeiffer96]), which then would replace ^{122}Zr as waiting point. Such a change in shell structure would have dramatic consequences on all r-process relevant nuclear physics parameters. For example the (predicted) $T_{1/2}$ and P_n values of ^{110}Zr would change by an order of magnitude from an 'unquenched' deformed to a 'quenched' spherical ground-state shape. Experimental studies of this shell quenching at large *N*/*Z* not only along *N*=82, but also for *N*=50 and *N*=126 are therefore major challenges.

For instance, the study of ^{78}Ni, hitherto produced at a rate of few nuclei per week, constitutes an important landmark for the study of the *N*=50 shell-closure. This will show whether current theoretical approaches as macroscopic-microscopic models, self-consistent

microscopic theories, and relativistic mean-field theories can really predict the influence of the large neutron excesses and the possible modification of shells due to proton-neutron interactions. In the *N*=82 region, mass measurements should extend below *Z*=48 in order to confirm the shell quenching recently observed for ^{130}Cd. [Dillmann04]. Therefore, the study of the refractory elements Pd, Rh and down to Tc or even Zr is of utmost importance (see Figure 69). The study of the *N*=126 closed shell is far from being attainable right now with either existing or future short-term facilities.

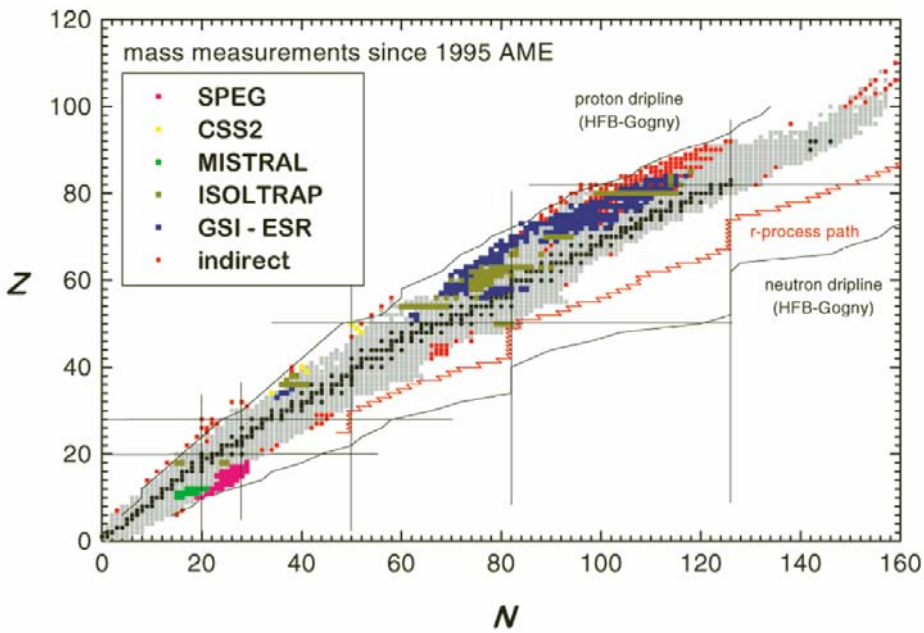

Figure 69 Limits of experimentally determined masses in the neutron-rich closed-shell regions N=50, 82 and 126.

8.4 Fundamental symmetries and interactions

(K. Jungmann)

Symmetries play a key role in physics. Whereas local symmetries correspond to forces, global symmetries are associated with conservation laws. A number of conservation laws exist where an underlying symmetry could not yet be identified and which therefore have no status in modern physics. Among those are the conservation of electric charge, lepton and baryon number, charged lepton number. They are consequently among the not explained features in the Standard model which otherwise is an excellent description of all observations to date in particle physics. Other mysteries remaining in standard theory are the origin of CP violation, the apparent dominance of matter over anti-matter in the universe. Most intriguing is the fact of three particle generations with the observed mass hierarchy. A Multi-Megawatt Proton machine would open up opportunities to conduct experiments to shine light into such fundamental questions in physics.

An international working group charged by NuPECC [NUPECCLRP] has identified the possibilities for contributing to solving urgent scientific questions of fundamental nature using nuclear physics techniques and typical nuclear physics equipment. A large number of these possibilities turned out to be best performed at a high power Proton Driver facility. This

arise from the fact that many experiments performed until today are statistics limited and would enormously benefit from high particle numbers (neutrinos, radioactive isotopes, muons, pions, Kaons , cold neutrons and antiprotons). Some most promising possible experiments to make progress in understanding nature are listed in Table 15. The table gives further the preference for a low (~1 GeV) or high (~30 GeV) energy facility.

In the field of neutrino physics (besides direct searches for a finite mass in non-accelerator spectrometer experiments) the confirmation of oscillations and the search for CP-violation in the lepton sector require long base line experiments. Here intense beams are indispensable. The time before they become available may be well spent exploring novel detector techniques, in particular such using large mass natural salt domes or directional sensitivity at low energies or even air showers.

Time reversal (T) respectively CP violation may relate to the matter-antimatter asymmetry in the universe. The search for permanent electric dipole moments (EDMs) of electrons, nucleons, nuclei, atoms, molecules and second generation particles such as the muon all have an independent potential contribute in a unique way to understanding T and CP symmetry violations. The full nature can only be assessed using several systems. Particular interesting systems are Radium atoms due to both possible atomic enhancement for an electron EDM and nuclear enhancement of a nucleon EDM due to close lying states of opposite parity. A novel scheme using charged relativistic particles in a magnetic storage ring will allow a sensitive muon EDM experiment. The advantage of the muon is apparent in models beyond standard theory with nonlinear mass scaling. Conceptually the muon as a second generation particle may be sensitive to other CP -violating mechanisms than the first generation. A further approach to T-violation is possible through neutrino- β-particle correlations in nuclear β-decay.

For rare and forbidden decays the charged lepton family conservation remains a law without standing in modern physics, as no underlying symmetry has been identified yet. The sensitivity to predictions of speculative models is large, particularly since the experimental detection limits can be lowered significantly with strongly enhanced particle fluxes at a Multi-Megawatt facility.

New weak interaction types (other than V-A) can be searched for in trapped radioactive atom decays. Here both advanced trapping techniques and sufficient nuclei are the key issues. A large number of nuclei is also required for careful systematic studies.

The unitarity of the Cabbibo-Kobayashi-Maskawa matrix is required by standard theory. A deviation may relate to more than three particle generations. At present the most urgent experimental input is required from strange particle (kaon) decay to determine V_{us}. On the long run a renewed pion β-decay experiment would be the cleanest approach towards V_{ud} , because of the by far best understood associated theory of hadron structure as compared to, e.g. nuclear decays.

Table 15 Physics possibilities at a Multi-Megawatt Proton Driver. Most experiments would benefit from a pulsed time structure of the beam.

Physics Topic	**Physics question to address**	**Method**	**Comments**	**Preferred Energy**	
				~ 1GeV	**~30GeV**
The Nature of Neutrinos	Oscillations , CP viol Masses	Long baseline spectrometer	Novel detectors? Salt domes? Only ν_μ	× -	× ×
T and CP Violation	Permanent electric dipole moments D (R) coeff. in β-decays D0- decay	Spin precession in electric fields; Trapping of radioactive atoms	Novel method using rings Radium isotopes Stored radioactive atoms Antii-proton facility	× × 	× × ×
Rare and Forbidden Decays	n-nbar conversion M-Mbar conversion $\mu \to e\gamma$ $\mu \to 3e$ μ N→ N e convers.	Dedicated spectrometers	Ultracold neutrons Novel method possible, unique potential . Unique potential Unique potential Unique potential	× × × × ×	
Correlations in β-decay	Non V-A iṇβ-decay	radioactive nuclear decays	Optically trapped radioactive atoms	×	×
Unitarity of CKM-Matrix	n-decay π–βdecay (super allowed β–decays), K-decays	Lifetimes and transition probabilities	Great potential to test Physics beyond SM, Presently mess in V_{us} ,	× × × -	 ×
CPT Conservation	N p μ	Diurnal Variations of spin dependent quantities	Interaction based models needed	× - ×	 × ×

The conservation of CPT is most fundamentally assumed in most physics models. A severe test is therefore rather important. New models suggest to search for interactions rather than relative numbers in comparing particle and antiparticle properties. Only interactions are relevant in physics. These test come parasitically with muon or antiproton experiments, e.g. through searches for diurnal variations in measured quantities.

Nuclear physics and nuclear techniques offer a variety of possibilities to investigate fundamental symmetries in physics. The advantage of high particle fluxes at a Multi-Megawatt facility allow higher sensitivity to rare processes because of higher statistics and because in part novel experimental approaches are enabled by the combination of particle number and suited time structure of the beam.

8.5 New approaches to the study of the nucleus with muons and antiprotons

(J. Aystö, T. Nielsson)

The trend within nuclear structure physics is to take the many-body system of nucleon that consists the nucleus to its extremes. Here, varying the isospin parameter is a crucial path in deepening our understanding of atomic nuclei. Furthermore, important astrophysical processes often involve nuclei very far from stability. Thus, there is a general consensus [nupec03] that the prime emphasis of future nuclear structure physics will lay on experiments with radioactive beams, and in particular the forthcoming second-generation facilities like the planned facility at GSI [gsi02] and EURISOL [euris03] in Europe. These facilities will be able to deliver several orders of magnitude higher intensities of radioactive beams than today while simultaneously move the experimental frontier several isotopes further toward the driplines. However, there are possibly further synergies that could be exploited at an advanced ISOL-facility since the very intense proton driver beam of several mA will simultaneously be able to produce copious amounts of pions and muons; a physics programme utilizing these has been outlined in [Aysto01].

The processes involved in formation of muonic atoms and decay determine the experimental physics observables; in the capture of a muon in an atomic orbit, the de-excitation process will take place through emission of muonic X-rays that probe the nuclear charge distribution. Subsequently, a sizable part of the muonic atoms will undergo the weak process of muon capture

$$ {}_{Z}X_{N} + \mu \rightarrow {}_{Z-1}Y_{N+1} + \nu_{\mu} $$

This semi-leptonic process has a positive Q-value of ≈100 MeV and thus populates highly excited states in the daughter nucleus, also at high multipoles. For neutron-rich nuclides, it has the additional attractive feature that the resulting system is one step **further away** from the line of stability. The physics that could be addressed by combining RIBs and muons is diverse, and in some cases hard to attain experimentally by other methods. In addition to nuclear structure issues, muon capture involves largely the same matrix elements as in neutrino scattering. Thus, muon capture rates can constrain cross-sections and are of astrophysical interest.

A possible key experiment could be to study highly excited states in the doubly-magic nucleus ^{78}Ni through muon capture on ^{78}Cu. ^{78}Cu can already now be produced with the

intensity of several hundred atoms/s at ISOLDE [turrion03] whereas ^{78}Ni is considerably harder to produce and would need at least 10^3 atoms/s to permit e.g. studies of the lowest excited states through Coulomb excitation. The situation could be much more favorable for muonic atoms; Figure 70 shows an RPA calculation shows that the majority of muonic ^{78}Cu will populate states in ^{78}Ni through muon capture, reaching beyond the neutron separation threshold. Only 14% are lost through muon decay. Combining this with a shell model calculation to estimate the capture rate to bound states yields a branching of 37% to these. It should be noted that this estimate is less robust than the total capture rate since the ground state spin of ^{78}Cu is unknown and the neutron separation energy in ^{78}Ni is taken from systematics. The possibility to tag the muon capture process by observation of gamma transitions in the created nucleus has been used extensively in experiments on stable nuclei; a recent example concerning ^{48}Ca can be found in [fynbo03].

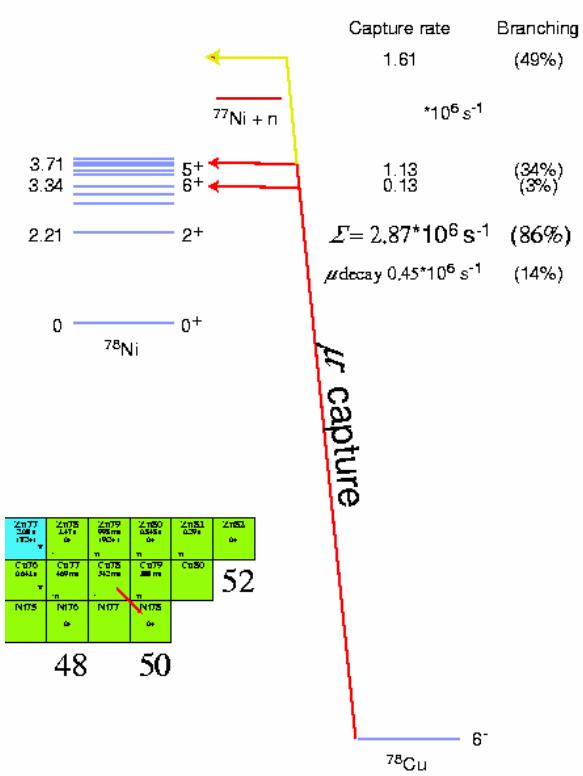

Figure 70 Feeding of excited states in ^{78}Ni by muon capture on muonic ^{78}Cu according to RPA calculations.

Experimentally, it is very challenging to merge the relatively weak intensities of exotic nuclei with the short-lived (τ = 2.2 μs) muons. However, cyclotron traps have been successfully operated to obtain low-energy muon beams [dececco97] at PSI and the recent advances in e.g. formation of anti-hydrogen in traps [gabrielse02] has shown that a nested trap could be a feasible approach provided that sufficient muon and ion densities can be reached. An estimate of the formation rate based on scaling the performance of contemporary devices has been made, leading to the formation of ~(10^1 - 10^2) [jungmann] radioactive muonic atoms/s. (This estimate is based on current PSI cyclotron trap rate for muons, 10^5/s μ^- at 20 - 50 keV scaled by 10^6 for the expected rate using a multi-MW proton driver. By extracting and slowing down

the muons through collisions with H_2 gas in a guiding B-field to v_μ= 1.5 - 30 cm/τ_μ where the cross-section for muon capture exceeds 4x 10^{-17} cm^2 (lower limit from hydrogen muon capture). The ion density in current Penning trap devices can reach $\approx 10^6/cm^3$. The formation rate is then given by $R = N_{ion}\ \sigma_{capture}\ v_\mu$.)

Merging beams of ions and muons in storage rings is a possible approach, however the short muon lifetime limits the number of merging passes. For a possible design of nested storage rings for RIB and exotic probes see [lindroos04]. Currently, the most promising concept involves stopping muons and ions in cryogenic fluids. A concept of thus stopping and subsequent transfer muons in liquid hydrogen and deuterium layers to implanted ions has been developed [strasser99]. Recently, there has been major progress in this approach [strasser04]. The similar concept of stopping and transporting radioactive ions in superfluid helium was recently experimentally demonstrated with good efficiency [huang03].

The 'common knowledge' that the ISOL-method has severe drawbacks due to the decay losses in the target-ion source system when trying to study very short-lived species does not remain valid if beam quality becomes an issue. This is clearly the case for the methods outlined here, where emittance and energy spread become crucial obstacles for the formation of muonic atoms, as well as for existing tools for RIBs like collinear LASER spectroscopy or possible future tools like electron-ion scattering [gsi02] or anti-protonic atoms [euris03]. A high-energy beam from a fragmentation facility needs to be cooled (stochastic and subsequently electron cooling) and possibly decelerated in several time-consuming steps, limiting the experimental scope to half-lives of the order of seconds. The ISOL-method, however, produces a beam which directly from the ion source has good properties, and experience with Penning trap and RFQ coolers show that substantial improvement can be reached in a few tens of milliseconds. Thus, unless alternative methods are shown to work for intense high-energy radioactive beams, the ISOL-method occurs to have the best potential concerning new experimental probes where the beam intensity is crucial. See Figure 72

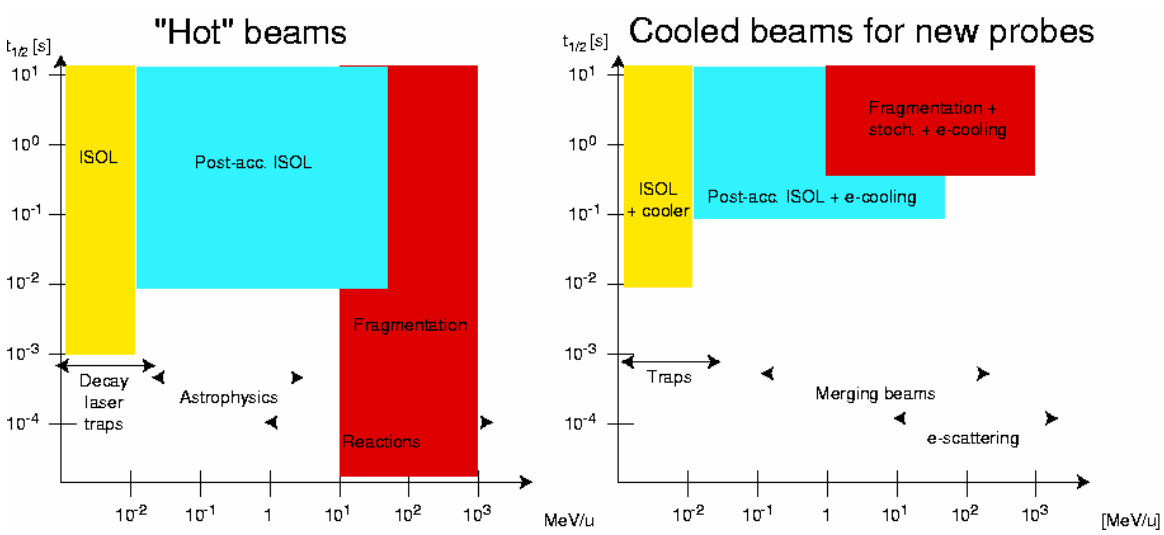

Figure 71 Experimental reach expressed in beam energy and half-lives for ``hot'' (directly following production) and ``cold'' (following improvements of beam properties) beams from ISOL-type and in-flight facilities.

9 Conclusions and outlook

9.1 Accelerators

(B. Weng)

There is a world-wide surge of interest in the design and applications of High Power Proton Accelerators. Their use ranges from neutrino super beam, muon colliders, beta-beam, double beta decay, radioactive ion beam, to spallation neutron sources and accelerator driven systems. They all require a MW-type proton driver system to provide sufficient flux of beams for intended research. This is a timely and well-organized workshop to formulate the strategy of CERN and European's future development in both the facilities and science programs with potential of fundamental discoveries in the post LHC era.

The scientific community of CERN proposes a 4 MW proton driver as an anchor for its future physics program. This facility consists of a front-end system of room temperature linac of 160 MeV, and then a superconducting linac of 2.2 GeV, operating at 50 Hz, delivering 4 MW proton beam power to target. If the end use of secondary beam is of continuous fashion, then there is no need of any other beam compression device. In the case of short bunch beam, a proper accumulation and bunch compression device has to be added. The following is the summary of my comments about the design and implementation of the accelerator complex (Figure 72).

The choice of the Superconducting Linac(SPL) over the Rapid-Cycle-Synchrotron (RCS) configuration is a sound choice in terms of its mature technology, reduced beam losses, and flexibility in meeting the requirements from different physics communities represented in this workshop. The choice of bulk Nb superconducting cavity construction over Copper-Nb composite can provide higher accelerating gradient to provide higher beam energy than 2.2 GeV in the fixed length of the linac, or shorter length of the linac at 2.2 GeV. It is well-known that, the bulk Nb structure is subjected to the Lorentz detuning and micro-phonic vibration which can cause amplitude and phase perturbation without proper compensation. Therefore, it is important to realize that there is no "show stoppers" in the proposed proton driver design, the challenge is in the careful identification and cure of emittance growth mechanism, control of beam losses, beam collimation, radiation shielding, and reliable operation.

The target/horn system is intimately coupled to the specification of the proton driver and the beam characteristics required for physics research. The beam energy, intensity, and bunch structure impact greatly on the selection of target material and its cooling requirements. The physics research requirements dictate the species of secondary beam, its flux and spectrum which couples back to the selection of target material and horn design. It is imperative that the accelerator builders, the target/horn experts and the physicists have close communications and discussions through the design and construction cycle of the facility intended. It is a common believe that the target/horn system is feasible for up to 1 MW beam power and additional R&D and prototyping is required for higher power system from 2 to 4 MW. An active R&D effort in this area is required for the decision on the required performance on the facility in few years time.

The accelerator components and operation personnel can not tolerate excessive beam losses; therefore, realistic analysis of possible beam losses, its collimations and shielding have to be carefully considered for any multi-megawatt facility. Also, considerations and provisions for

reliability, availability, and maintainability have to be designed in from the very beginning. Spares, preventive maintenance and repair procedures have also to be part of the design concerns.

The accelerator facility and physics research programs conceived in this workshop can be further upgraded to higher power, or expanded into many disciplines. For the initial implementation, it is important to clearly define what is in the baseline for both the facility construction and the physics research intended to pin down the cost, schedule, and performance parameters for proper project definition. In the same vane, a well-thought out plan for its future developments in either more power, adding additional facilities, or serving different communities have to be mapped out in the beginning to minimize interference with on-going physics research and waste of components and infrastructures. With both plans in hand, a realistic staged approach can be formulated for long-term development, since both the cost and research requirements prohibit complete construction in one time.

It is apparent that it needs heavy investments in the R&D and prototyping of components to realize the plan outlined in this workshop, which no single institution can afford to complete them alone. Therefore, two conditions are necessary to fulfil this vision. The first is a firm commitment from the CERN management to a steady support of this line of R&D in both manpower and material resources. The second is the formation of an effective international collaboration in this regard. It is my own observation from my participation in the BNL VLBL neutrino proposal and muon collider collaboration in the past few years that, without active participation from CERN, the international collaboration effort will forever remain in the fragmented stage(a case in point is the MICE experiment and the 4 MW liquid mercury target development program). I strongly recommend that CERN management make its firm decision and help to create adequate support in the future R&D in the line of HPPA, as long as the short term core mission of timely completion of LHC is not compromised.

The suggested R&D items for CERN MW facility include ion source, chopper, SRF cavity and cryo-module, target and horn system should be supported with vigour both to ascertain the technical feasibility and provide sufficient base for reliable cost estimate by the LHC completion time. Early implementation of the Linac4 up to 160 MeV in 2006 can benefit both the LHC performance and the existing CERN fixed target program, CNGS and ISOLDE.

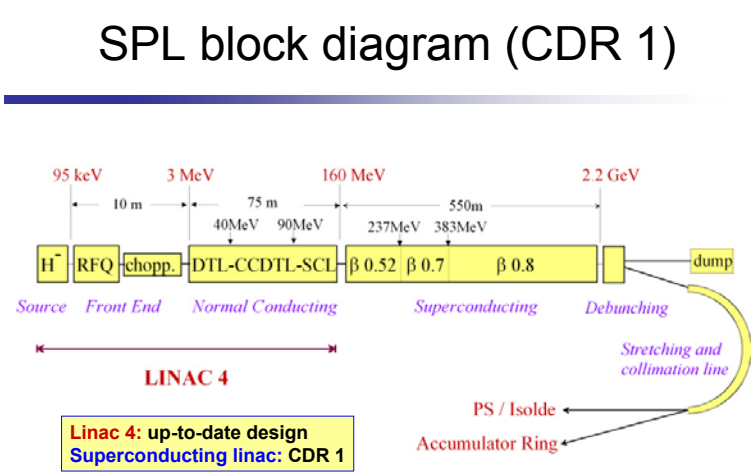

Figure 72 SPL Block diagram

9.2 Nuclear Physics

(P. Butler, M. Harakeh)

The NuPECC Long Range Plan 2004 (NUPECC) describes how research in all fields encompassed by nuclear science, from the smallest scales to the largest ones, has made vigorous strides in the last decade. Many questions have been answered. However, the answers often raised new questions paving the way to new directions in research in our continuing quest for the understanding of our universe from the smallest building blocks, the leptons and quarks and the mesons that carry the forces, to the largest structures in the cosmos. To address these questions new facilities have been proposed or are under construction. NuPECC has recommended as the highest priority (i) the construction of the international "Facility for Antiproton and Ion Research (**FAIR**)" at the GSI Laboratory in Darmstadt and (ii) the construction of the next-generation EURopean ISOL facility (**EURISOL**). These facilities have different time-frames: the planning of FAIR will see it completed about the same time (~ 2013) that the construction phase of EURISOL begins.

FAIR will provide new opportunities for research in the different subfields in nuclear science. The envisaged facility for producing high-intensity radioactive ion beams in In-Flight Fragmentation (IFF) is highly competitive, if not surpassing in certain respects similar facilities either planned or under construction in the U.S. or in Japan. With the experimental equipment available at low and high energy and at the New Experimental Storage Ring (NESR) with its internal targets and electron collider ring, the new facility will provide worldwide leadership in nuclear structure and nuclear astrophysics research. This is in particular true for research performed with short-lived exotic nuclei far from the valley of stability. The high-energy high-intensity stable heavy-ion beams will facilitate the exploration of compressed baryonic matter with new penetrating probes. The high quality cooled antiproton beams in the high-energy storage ring (HESR) in conjunction with the planned detector system PANDA will provide the opportunity to search for new hadron states predicted by QCD and explore the interactions of the charmed hadrons in the nuclear medium. In short, this facility is broadly supported since it will benefit almost all fields of nuclear science with new research opportunities.

The Isotope Separation On-Line (ISOL) technique to produce radioactive beams has clear complementary aspects to the IFF method. First-generation ISOL-based facilities have produced their first results and have convincingly been shown to work. EURISOL aims at increasing the variety of radioactive beams and their intensities by orders of magnitude over the ones available at present for various scientific disciplines including nuclear physics, nuclear astrophysics and fundamental interactions. The presently running project is aimed at completing a design study of the EURISOL facility. Because of this time-line for EURISOL NuPECC supports projects which have intermediate planning and will be realised on a shorter time-scale. These include the second-generation ISOL facilities: **SPIRAL2** (GANIL, Caen), **SPES** (LNL, Legnaro), the upgraded **REX-ISOLDE** (CERN, Geneva) and **MAFF** (München). The technical developments required for these intermediate-scale projects such as high-power proton/deuteron (p/d) superconducting linear accelerators (SPIRAL2, SPES), heavy-ion superconducting postaccelerator (SPIRAL2), or high-power production targets (ISOLDE) are precisely the ones needed for EURISOL. An advanced ISOL facility such as EURISOL will use a high-power (several MW) p/d accelerator. A large number of possible

projects such as Neutrino Factory, antiproton facility, muon factory and neutron spallation source may benefit from the availability of such a p/d driver, and synergies with closely and less closely related fields of science are abundant. Considering the wide interest in such an accelerator NuPECC recommends joining efforts with other interested communities to do the RTD and design work necessary to realize the high-power p/d driver in the near future.

9.3 Particle physics

(A. Blondel, M. Spiro)

Certainly the physics case that was presented in the workshop for a high intensity proton machine in Europe is very strong. The leading case is neutrino physics but the accompanying programs in rare muon and Kaon decays are compelling.

For neutrino physics a number of possibilities have been suggested to explore the $\{\theta_{13}$, sign(Δm^2_{13}), $\delta\}$ paradigm. In many ways the choices or strategy should be made on the basis of the science, and probably on the basis of available funding, synergies, and timing.

The first possibility is that of two low energy beams – the superbeam and the standard beta-beam, that can aim at the same detector, a very large water Cherenkov and/or liquid argon detector situated at a short distance (O (100km)). In this first scenario there is little matter effects and the sensitivity depends on how massive the detector can be, taking account the boundary conditions due to excavation possibilities and cost, while keeping reasonable efficiency and calibration. Operating with 300-600 MeV neutrinos has the advantage of staying in the quasi-elastic region, but the cross-sections are low and poorly known with large differences between i) neutrinos and anti-neutrinos, and ii) muon neutrinos and electron neutrinos. The consequences in terms of systematics on a CP asymmetry remain to be established. On the positive side, the possibility of building both T and CP asymmetries is a remarkable feature of this combination of superbeam and beta-beam. In addition, a very large, non-magnetic detector has an excellent physics programme in its own right, being able to extend considerably the search for proton decay, astrophysical and cosmological neutrinos.

The other possibility that has been studied is the Neutrino Factory. This source of high energy (up to the muon energy, i.e. 20-50 GeV) electron neutrinos allows an even broader and more precise neutrino oscillation programme. The production of taus is allowed (silver channel) and the study of the matter resonance at 12 GeV is possible. Flux, efficiencies and backgrounds can be determined very precisely. The difficulties are twofold: first the accelerator itself is rather innovative, making it mandatory to pursue a vigorous programme of R&D to ascertain the proposed technologies (such as ionisation cooling or FFAGs) and secondly the overall cost is uncertain. The detector must be magnetic, which limits the feasibility of very large masses, and the physics programme, besides that of neutrino oscillations, of a large magnetized detector needs to be investigated. It remains without any doubt that the Neutrino Factory is the most powerful tool to explore CP violation, measure precisely all oscillation parameters relevant to the 'atmospheric oscillation' and test universality. Last but least, it is an important step towards muon colliders.

It will be important that a study of both options on equal footing of physics performance and cost be presented at the time when important decisions will need to be made, and this will require studies and R&D both on accelerator and detectors. In the framework of the

ECFA/BENE study groups, the plan is to monitor these studies on a regular basis and to come up with a recommendation around 2008.

Intense beams of muons have been stressed as a powerful tool to study rare decays and leptonic flavour violation processes, which seem to be a likely outcome of many scenarios of supersymmetry. Other properties of muons (g-2, EDM) have shown to be places of choice to challenge the Standard Model. The details of targets and beam lines need to be studied, but it is clear that an accelerator like the SPL and its accumulator ring would provide great flexibility on the time structure of the beam.

Finally it is obvious that all CERN facilities in fixed target experiments and the LHC itself can only benefit from a source of higher brilliance and intensity.

9.4 General outlook

(J. Engelen, V. Palladino)

9.4.1 Introduction

As discussed by J. Ellis, the physics at the High Intensity Frontier with a new MMW facility is unique and compelling. CERN appears to be a natural, if not the best, laboratory to host it.

The main focus, in the particle physics sector, is the potential offered to neutrino physics by superior neutrino beams, of conventional (superbeam) or novel (beta-beam, Neutrino Factory) nature. Physics motivations are also very solid, in the studies of low energy muons. Mastering high brilliance muon beams holds the key to possible muon colliders.

A remarkable synergy exists with one of the most promising next generation facilities for nuclear physics and astrophysics, EURISOL; the *isotope on line* technique, invented in Europe in the 50's and brought to maturity by ISOLDE at CERN, would see intensities increased by a three orders of magnitude.

The entire program appears to be compatible and synergetic with the CERN core program. It is capable to improve the performance of the LHC, the CNGS and ISOLDE, and of most existing CERN facilities.

9.4.2 Multi-Megawatt facilities in the World

The reference facility is JPARC, which is already in construction. Its initial 0.75 MW program includes the first neutrino conventional superbeam for oscillation searches over the 300 Km baseline from Tokai to Kamioka (T2K). Europe is and will be collaborating with that effort, but we must at the same time explore a possible European longer term program.

Current ideas for a possible evolution of T2K provide a natural benchmark. These include upgrade of the beam power on neutrino target to 4 MW, and a new Water Cerenkov detector of one Megaton (HyperK), similar to, but 50 times bigger than, the present one (SuperK). Following or in place of this, our Japanese colleagues pursue actively an important R&D towards a Neutrino Factory, whose present design is largely based, in the Japanese scheme, on the fixed field alternated gradient (FFAG) accelerators.

Similar MMW plans are under study also in the United States, both at BNL and Fermilab. The BNL concept features a 1.2 GeV SC linac feeding a refurbished AGS. Fermilab has two implementations under evaluation, a synchrotron and a SC linac, both at 8 Gev and capable of both stand-alone operation and of injection into the 120 GeV Main Injector.

Superior conventional neutrino beams from either laboratory could then illuminate neutrino detectors in a new Mton scale national underground science and engineering laboratory (NUSEL), in the Western part of the US, for which several locations are being proposed. The UNO collaboration, complementary and synergic with the HyperK effort, drives the effort towards design and construction of such a neutrino detector.

Beyond conventional superbeams, the US Muon Collaboration has been playing a leading role in the international effort towards a Neutrino Factory. By means of two full rounds of design studies, a complete preliminary design has been performed.

9.4.3 A MMW source for Europe

9.4.3.1 Proton driver

In this international context of ambitious but uncertain plans, Europe and CERN may indeed have an important role to play. Most recent studies and this Workshop have focused particularly on the possibilities that could be open by the availability at CERN of the SPL, a 4 MW few GeV/c 50 Hz superconductive proton linac, proposed as the backbone of a new European high power proton complex. Its original design was that for 3 GeV/c proton momentum but a somewhat larger momentum is possible and may be preferable in the end.

There exist other options for a MMW source of protons. Higher energy would require correspondingly fewer protons. A Rapid Cycling Synchrotron has been considered and would be perfectly suitable for Neutrino Factories. One may even consider the viability of FFAG accelerators. Further study is required to ascertain which is the best option both technically and in terms of optimal physics performance. Light should also be shed by the HARP data.

9.4.3.2 Target and collection

All these possibilities require that we learn to handle MMW proton beams. No existing target system is presently capable to sustain the thermal and mechanical stresses produced by a MMW beam. Radiation issues in the target area need to be tackled. R&D is necessary to establish a convincing design providing a safe and robust solution to this problem. Most promising are liquid jet targets, although other solution are being explored too. If that problem is solved, together with the similar and related problem of designing a MMW collection system (horn or solenoid) for secondary mesons (and muons) emerging from the target, one has created the conditions to have a MMW neutrino conventional superbeam.

9.4.3.3 Neutrino superbeam

Preliminary ideas for a neutrino superbeam have been investigated for a 3 GeV/c SPL: with a relatively short and tuneable 5-30 m pion decay tunnel downstream of the target, it would have a low average energy E, around 300 MeV. Less intense than the T2K beam, it would however be essentially free of intrinsic ν_e background while minimizing also inelastic neutrino interactions responsible for detector backgrounds, resulting in the end in physics performance very close to those of the T2K upgrade. Although such a superbeam could arrive only after several years of operation of T2K and may not be defendable as a stand alone

facility, it would still play an essential role in conjunction with one of the two types of novel neutrino sources, the beta-beam described below.

9.4.3.4 EURISOL and the beta-beams

A proposal of a super-ISOLDE facility, 1000 times more powerful, exists and has become known as EURISOL. Its proponents view CERN as one of the possible sites: this would enrich the panorama of CERN activities with new frontier research in nuclear physics and astrophysics, attracting a large community of new users. Remarkably, its proton driver could very well be the SPL and its high power target station(s) could closely resemble the ones being studied for neutrino applications.

The intense beams of radioactive ions produced to EURISOL, however, carry also the possibility of beta-beams, novel and superior pure ν_e beam obtained from beta decay of the ions. Radioactive ions produced by the ISOL technique would have to be accelerated in the existing CPS and the SPS (or possibly their replacements) and then circulated in a new ion storage ring, whose straight sections would then become powerful sources of neutrinos. The most promising ions are ^{18}Ne and ^{6}He, producing respectively the most copious yield of ν_e and anti-ν_e. Lorentz γ factors of 150 (^{6}He) or 250 (^{18}Ne) are possible with the SPS. The average ν_e energy is then very close to that of the SPL superbeam ν_μ's, few hundred MeV. In order to conduct neutrino oscillation search experiments near the first maximum of oscillation probability, in the L/E variable, detector(s) of few hundred MeV neutrinos must be at a distance L, from the neutrino source at CERN, of about 100 to 150 Km. The fact that the two types of beams can use the same detector is a remarkable coincidence of great benefits.

As it requires only 5 to 10% of the SPL intensity, a beta-beam could run simultaneously with the SPL superbeam. Thanks to the very low Q value of the beta decays, these beams are much more collimated and intense, per decay, than conventional pion decay and available ^{18}Ne and ^{6}He fluxes result in a comparable neutrino flux.

9.4.3.5 Megaton class detectors and experiments

Detection of those low energy, modest intensity, neutrinos from beta-beams and superbeams requires new massive, low density, unprecedentedly large detectors. A Megaton Water Cerenkov detector, of the HyperK or UNO type, is again the natural default option. In Europe, however, an extra card is there to be played, the large Liquid Argon TPCs as described by Ereditato.

In the last few years it has been proposed to excavate a new large European underground laboratory in conjunction with the excavation of the new safety tunnel that will supplement the existing alpine Fréjus road tunnel. We are faced with an opportunity very similar to the one that INFN was able to exploit in the realization of the Gran Sasso Laboratory. The window of opportunity is the year 2008-2009; which sets the date for a necessary decision. While this options remains to be proved truly realistic, it has raised undoubtedly much interest and hopes and must be thoroughly explored.

The physics case for exploitation of a Megaton Water Cerenkov detector in a new Frejus laboratory in conjunction with a beta-beam from CERN has been studied in detail. The discovery potential of leptonic CP violation, by means of simultaneous ν_e and anti-ν_e running, is not very far from the one of a Neutrino Factory, that is still the benchmark ultimate neutrino facility for these studies. The simultaneous use of a SPL conventional superbeam, however, would open the unique opportunity to perform T and CPT violation

searches. Thanks to its superior granularity, patter recognition and detection efficiency, a 0.1 Mton Li-Argon detector can be also envisaged as a detector alternative or complementary to a 5 to 10 times larger Water device.

All these considerations lead to the formulation of the first (of two) global hypothesis, ie explicit proposals for a well matched pair of neutrino source and detector site. In summary, this first possibility implies low energy, moderate flux neutrino beta-beams and superbeams pointing to a very large mass underground detector at 100 Km or so distance from CERN, in some alpine gallery. There is another remarkable synergy with the fact that this experimental approach satisfies also the equally compelling needs of nucleon decay studies and those of a low energy (Supernova) neutrino observatory. The package thus offers a very attractive physics program, as was been discussed by C.K.Jung.

9.4.3.6 Neutrino Factory

The second proposal is a Neutrino Factory. This has the unique virtue of providing electron neutrinos of an energy that is high enough (up to the stored muon energy of >~20 GeV) to allow tau production as well as the crossing of the matter resonance around 12 GeV. The very high neutrino flux can be exploited with smaller -- but magnetic -- detectors, typically in the 50 Kton range. The distance from the neutrino source must be extended to match, in L/E, the multi GeV average energy E of the neutrinos. An existing underground laboratory like Gran Sasso can indeed host such a detector, but a second underground location, further away from CERN, will be needed to fully study both leptonic CP violation and the matter effects that can be used to establish the mass hierarchy of neutrinos. Candidate locations have been suggested in the extreme north of Norway and Finland as well as in a far south European location on one of the Canary islands.

The European scheme for a Neutrino Factory was discussed by H. Haseroth. In addition and downstream of the target and collection complex necessary for a superbeam, it includes sections devoted to the preparation of the muon beam (phase rotation, bunching and ionization cooling), to their acceleration to 20-50 GeV, and a muon storage ring of 2 km or so in circumference. The straight sections of the storage ring are sources of the neutrinos from muon decays.

The detector best suited for a Neutrino Factory is a magnetic detector sensitive to the charge of the muons. The cleanest signature of oscillation is the ν_e transition to a "wrong charge" ν_μ, that has become known as the "golden channel". The ν_e transition to a "wrong charge" ν_τ, that can be studied with an ICARUS- or OPERA-like detector, has instead become known as the "silver channel" and has the merit to suppress ghost solutions in oscillation parameter space as discussed by P. Hernandez.

The physics case for this second global option, a neutrino factor serving a "modest" size magnetized detector, has been studied in detail both in the US and in Europe. It provides the strongest sensitivity to the CP violation phase and to all other relevant neutrino oscillation parameters. It emerges as the superior and ultimate line of approach to the rich phenomenology implied by our present understanding of the oscillation phenomena.

9.4.3.7 Good news

The studies that have been performed so far indicate that a Neutrino can be built now. The real challenge of the Neutrino Factory R&D is cost reduction. Good news were given by S. Geer that a revision of the cost estimates from the second US design study points to a major

reduction of the cost of a Neutrino Factory down to approximately 1.3 G$, a good step closer to being ultimately affordable, and not so different from our first global option.

9.4.3.8 Near detectors and physics of neutrino interactions

On the path of neutrinos to far detectors, it will be essential to have near stations monitoring each of the two types of neutrino beams, i.e. the low energy beta-beam (and superbeam) or the high energy neutrino beam from the factory. This is the only way to keep systematic uncertainties under control. An additional reward of this near detector stations, which will enjoy fluxes several orders of magnitude higher than short baseline neutrino experiments so far, comes from the possibility of using small low mass highly sophisticated jewel detectors that will greatly enhance our knowledge of the physics of neutrino interactions.

9.4.3.9 Making choices

A choice among the two global options discussed above will probably be necessary in the not far future, in the context of consensual international coordination of regional plans and programs. The last point that deserves discussion is therefore international collaboration on the R&D efforts necessary to make one or both these options a reality somewhere in the world. A large amount of R&D is necessary in all areas: high power proton drivers, targetry and collection, muon manipulation (ionisation cooling in particular) and acceleration, neutrino detectors. All of these are in progress with a healthy level of global collaborations. Europe is likely to be able to host in the coming future several aspects of this effort. Among them, a targetry & collection demonstration experiment at the CERN PS, an international muon ionisation cooling experiment (MICE) at RAL and possibly an FFAG development and test program. This R&D effort deserves support. The rate of progress will be slow, delays should be carefully avoided for the few demonstrations that are on the critical path .

9.4.4 Conclusions

The European strategy in neutrino physics, adequately ambitious and aware of the international context, based on a new MMW proton driver and in synergy with nuclear physics and other sectors of particle physics, including either a beta-beam/superbeam complex and/or a Neutrino Factory complex, will receive careful attention from the CERN management and the CERN council.

10 Recommendations

10.1 Recommended accelerator R&D

(R. Garoby, M. Lindroos, A. Blondel, H. Haseroth)

10.1.1 Proton driver

For the linac proton driver solution, provided the on-going support to the development of equipment for Linac4 is steadily maintained, more efforts have to be invested in the following items, as highlighted in section 9.1 of this document:

- The H- ion source, whose characteristics are beyond today's state-of-the-art,
- The chopper driver, for which no adequate solution has yet been found,
- The superconducting RF technology where activity has been almost stopped at CERN.

It is clear that the issue of radioprotection and the management of beam losses are crucial to the operation of a multi-MW machine, which implies strengthening efforts on beam dynamics and on the analysis of measures to limit activation (calculation of activation, selection of materials, design of collimators and beam dumps…).

For the RCS proton driver solution(s), competence and efforts are localised at RAL. For a proper comparison with the SPL option, more resources are necessary, and certainly some at CERN. Obviously, if an RCS based solution is finally selected, the resources initially invested in the SPL would be redirected.

10.1.2 EURISOL and neutrino beta-beam

The EURISOL design study proposal concerning an ISOL and beta-beam facility, submitted to the EU sixth framework program, was favourably evaluated. Contract negotiations between the EU and the institutes and universities participating are scheduled for September 2004. The aim is to get started in January 2004 and work for four years. The technical design work to be undertaken has been described in section 5.3. The study is presently site independent but CERN is listed as a candidate lab to host the facility considering especially the possible construction of SPL at CERN. The design study is strongly supported and the community is encouraged have a full technical design report ready for the present milestone of 2009 for a decision on SPL at CERN.

10.1.3 Superbeam and Neutrino Factory

Because of the high beam power and the resulting safety issues, the engineering design of the target and target area are crucial and challenging. For the needs of all applications, a strongly increased effort has to be invested in these fields, both for the nuclear physics applications (which are covered in the framework of EURISOL) and for the particle physics applications, which are not covered at CERN presently. The target experiment which is being proposed [target-exp] is a remarkable example of international collaboration and should be supported, but it only covers the specific aspect of the beam-target interaction in a magnetic field.

In the case of the neutrino super-beam, the design of a horn that combines neutrino flux optimisation and the capability to survive long enough the mechanical stress and the high level of radiation is a case of concern. The on-going efforts in collaboration between LAL-Orsay and CERN should be encouraged and strengthened.

The above are all necessary both for a superbeam and Neutrino Factory. The accelerator R&Ds specific of a Neutrino Factory are as follows.

- Theoretical development and optimisation of the design for cost/performance optimisation
- For the muon front-end (phase rotation and cooling): demonstration of the gradients under which RF cavities can operate in magnetic fields
- Experimental demonstration of muon ionisation cooling (MICE experiment)
- Design and cost estimate of acceleration with FFAG

A substantial fraction of the theoretical work and the component development for the muon front end are already underway within the auspices of the Neutrino Factory and Muon Collaboration [MuColl], in particular the MUCOOL effort [Mucool].

The MICE experiment at RAL, with strong support from the UK, is an opportunity for Europe to have a major impact on this research. Support from PSI and CERN in the form of refurbished equipment is foreseen. Support and participation from other European laboratories would be highly welcome and desirable.

The R&D on FFAGs is already well underway in Japan, where the PRISM experiment is proceeding. This new technique, which could have many other applications than acceleration or phase rotation of muons, certainly deserves attention and support for the small group approaching it in Europe.

The design and R&D effort leading to a superbeam or Neutrino Factory clearly requires worldwide participation and the community involved is aiming at a world design study to be completed in 2008. This calls for determined participation from several European laboratories in a concerted way, as recommended by the European Muon Coordination Group [EMCOG]. Possibilities to obtain EU funding via a EU FP6 design study or additional JRA's within CARE [CARE] are being investigated.

10.2 Recommended detector R&D

(A. Blondel, V. Palladino, A. Rubbia)

It has been proven since the early days of neutrino detection that assembling adequately large mass detectors will not be an easy task [Strolin]. The time is ripe to face this challenge. In order for the programme to be successful in Europe our recommendations are as follows.

1) In collaboration with the Japanese and US efforts, undertake the design of a Megaton size Water Cerenkov detector, along the lines described in section 6.3. The technique and cost of excavation of very large underground caverns has to be understood. Photosensor development and involvement of European manufacturers appears highly desirable.

2) Support the European R&D towards large mass Li Argon detectors. Its seed is the ICARUS Collaboration, which in the process to implement the technology in its first 3 KTon application at LNGS. Tho design of much larger devices, up to 100 Ktons, and possibly embeded in magnetic fields is undertaken. Non-European participation is being actively sought.

3) Launch a design study and cost optimisation of a ~50 Kton large magnetic detectors (LMD) [Cervera], ideal tool for the *golden channel* at the Neutrino Factory. Options are a Super MINOS detector, 10 times larger than MINOS [MINOS] or a slightly larger implementation of the MONOLITH [Monolith] design type.

4) Given the importance of the *silver channel*, studies of multi-kiloton detectors with kink-finding capabilities, OPERA-like or otherwise, should be investigated.

10.3 Proposed milestones

The ECFA/BENE [BENE] and EURISOL [EURISOL] communities plan to continue their joint effort, assemble the largest possible interest and constituency around a complete MMW physics program. The general "strategy" is to provide the CERN Management with

1) the appropriate documentation to support a proposal to the CERN Council at the end of 2006, consisting of a first set of limited new investments

2) a full conceptual design report for a superior MMW facility, intended to support the proposal, to the CERN Council in the course of 2009, of major new investments in the MMW sector, after LHC and before CLIC.

This schedule implies that we in Europe should continue to push vigorously the necessary R&D, solve the remaining technical challenges, make construction costs affordable and be ready with a complete technical design to start building a complex of MMW particle and nuclear physics facilities as soon as that will be possible.

A more detailed list of upcoming events is as follows:

- 2-3 November 2004, DESY: ECFA/BENE Workshop on 'The future of accelerator based neutrino experiments in Europe', within the general yearly CARE meeting http://care04.desy.de/
- March 2005 (Fréjus) Megaton physics workshop
- June 2005 (Frascati) NUFACT05 : an interim set of BENE recommandations is planned

Further milestones are more tentative, but may possibly be

- End 2006 first limited new investiments at CERN (160 MeV H- linac?)
- June 2008: NUFACT08 will take place again in Europe. This is the planned time for final BENE recommendations based on comparative study of various options and will be the foreseen decision time to excavate Megaton in Fréjus.
- Around 2009 decisions on project at CERN after the LHC

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Workshop Organization, Participants and Programme

Local Organizing Committee:

M. Benedikt (CERN), A. Blondel (Geneva), P.Butler (co-chair), L. Ghilardi (CERN), G. Giudice (CERN), E. Gschwendtner (Geneva), M. Lindroos, V. Palladino (co-chair), M. Vretenar (CERN)

Programme Committee:

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Table 16 List of participants:

ADELMANN	ANDREAS	Paul Scherrer Institut (PSI)	Villigen	Switzerland
ALEKSAN	ROY	CPPMarseille	Marseille	France
AMSLER	CLAUDE	Physik-Institut der Universität Zürich	Geneva	Switzerland
ANGHINOLFI	MARCO	INFN	Genova	Italy
APOLLONIO	MARCO	University of Trieste and INFN	Trieste	Italy
ASLANIDES	ELIE	CPPMarseille	Marseille	France
AYSTO	JUHA	Department of Physics	Jyvaskyla	Finland
BALDINI	ALESSANDRO	INFN - Pisa	Pisa	Italy
BALDO CEOLIN	MILLA	University of Padova, Physics Dept.	Padova	Italy
BENNETT	ROGER	CCLRC	Didcot	UK
BLONDEL	ALAIN	DPNC	Geneve	Switzerland
BLUMENFELD	YORICK	Institut de Physique Nucleaire	Orsay	france
BONESINI	MAURIZIO	INFN - Milano	Milano	Italy
BOOTH	CHRIS	University of Sheffield	Sheffield	UK

BOUCHEZ	JACQUES	CEA/DAPNIA	Gif-sur-Yvette	France
BUTLER	PETER	CERN	Geneva	Switzerland
CALABRETTA	LUCIANO	INFN-LNS	Catania	ITALY
CAMPAGNE	JEAN-ERIC	LAL	Orsay	France
CATANESI	MARIA-GABRIELLA	INFN Bari	Bari	Italy
CAVATA	CHRISTIAN	CEA Saclay	Gif/Yvette	France
CAZES	ANTOIEN	Laboratoire de L'accélérateur Linéaire	Orsay	France
CECCUCCI	AUGUSTO	CERN	Geneva	Switzerland
CERVELLI	FRANCO	INFN pisa	pisa	Italy
CERVERA	ANSELMO	DPNC Uni Geneva	Geneva	Switzerland
CHIHIRO	OHMORI	KEK	Tsukuba	Japan
CHMIELEWSKA	DANKA	Institute for Nuclear Studies (IPJ)	Warsaw	POLAND
CIAVOLA	GIOVANNI	INFN-LNS	Catania	Italy
CORNELL	JOHN	GANIL	CAEN	France
DE BELLEFON	ALAIN	PCC-Collège de France	Paris	France
DEBU	PASCAL	CEA / Saclay	Gif/Yvette	France
DECLAIS	YVES	IPNL	Villeurbanne	France
DECONTO	JEAN-MARIE	LPSC CNRS/IN2P3	Grenoble	France
DENDOOVEN	PETER	KVI	Groningen	Netherlands
D'HOSE	NICOLE	DAPNIA/SPhN	CEA- Saclay	France
DORNAN	PETER	Imperial College	London	UK
DORSIVAL	ALEXANDRE	CERN-SC-RP	Geneva	Switzerland
DOSSELLI	UMBERTO	I.N.F.N. Padova	Padova	Italy
DUCHESNEAU	DOMINIQUE	LAPP, Annecy	Annecy-le-Vieux	France
ENQVIST	TIMO	CUPP - Pyhäsalmi	Pyhäsalmi	Finland
EREDITATO	ANTONIO	INFN Napoli	Napoli	Italy
FACCO	ALBERTO	INFN-LNL	Padova	Italy
FAVIER	JEAN	LAPP	Annecy	France
FELTESSE	JOEL	CEA/DSM/DAPNIA-Saclay	Gif-sur-Yvette	France
FINDLAY	DAVID	RAL- CCLRC	Didcot	United Kingdon
FORTUNA	GRAZIANO	INFN Laboratori Nazionali di Legnaro	Legnaro (PD)	ITALY
FRAILE	LUIS MARIO	CERN	Geneva	Switzerland
FYNBO	HANS O. U.	Department of Physics, Univ. Aarhus	Aarhus C	Denmark
GAROBY	ROLAND	CERN	Geneva	Switzerland
GASTALDI	UGO	INFN-LNL Legnaro	Legnaro (Pd)	Italy
GEER	STEVE	FNAL	Batavia	USA
GELLETLY	WILLIAM	The University of Surrey	Surrey	UK
GERBIER	GILLES	CEA Saclay -DAPNIA/SPP	Gif s Yvette	France
GILARDONI	SIMONE	DPNC Uni Geneva	Geneva	Switzerland
GRÉGOIRE	GHISLAIN	University of Louvain	Louvain-la-Neuve	Belgium
GRIECO	GIOVANNI	CAEN SpA	Viareggio	Italy
GSCHWENDTNER	EDDA	DPNC Uni Geneva	Geneva	Switzerland
GULMINELLI	FRANCESCA	Laboratoire de Physique Corpusculaire	Caen	France
HABS	DIETRICH	LMU München	Munich	Germany
HANCOCK	STEVEN	CERN	Geneva	Switzerland
HANKE	KLAUS	CERN	Geneva	Switzerland
HARAKEH	MUHSIN	Kernfysisch Versneller Instituut	Groningen	the Netherlands
HASEROTH	HELMUT	CERN	Geneve	Switzerland
HERNANDEZ	PILAR	University of Valencia	Valencia	Spain
HILSCHER	DIETRICH	Hahn-Meitner-Institute	Berlin	Germany
HOLMES	STEPHEN	Fermilab	Batavia, IL	USA
HUYSE	MARK	Instituut voor Kern- en Stralingsfysica	Leuven	Belgium
JEPPESEN	HENRIK	Department of Physics and Astronomy	Aarhus	Denmark
JOKINEN	ARI	Department of Physics	Jyvaskyla	Finland

JONSON	BJÖRN	Experimental Physics	Göteborg	Sweden
JUNG	CHANG KEE	Stony Brook University	Stony Brook, NY	USA
JUNGMANN	KLAUS	Kernfysisch Versneller Instituut	Groningen	Netherlands
KALANTAR	NASSER	Kernfysisch Versneller Instituut	Groningen	Netherlands
KATSANEVAS	STAVROS	IN2P3	Paris	France
KAYIS TOPAKSU	AYSEL	CERN and Uni. Cukurova, Adana	Geneva	Switzerland
KESTER	OLIVER	MPU München	Munich	Germany
KIRK	HAROLD	BNL	NY	USA
KLUGE	H.-JÜRGEN	GSI	Darmstadt	Germany
KOJIMA	YASUAKI	Grad. School of Eng., Hiroshima University	Hiroshima	Japan
KÖRNER	GABRIELE-ELISABETH	NuPECC	Garching	Germany
KRATZ	KARL	Institut für Kernchemie Universität Mainz	Mainz	Germany
KUGLER	ANDREJ	Nuclear Physics Institute ASCR	Rez	Czech Republic
KURCEWICZ	WIKTOR	Inst. Exp. Physics, Warsaw University	Warsaw	Poland
LAVAGNO	ANDREA	Politecnico - Dipartimento di Fisica	Torino	Italy
LETTRY	JACQUES	CERN-AB	Geneva	Switzerland
LINDNER	MANFRED	Technical University Munich	Garching	Germany
LINDROOS	MATS	CERN	Geneva	Switzerland
MAMATOV	YASHAR	Samarkand	Samarkand	Uzbekistan
MASULLO	MARIA ROSRIA	Istituto Nazionale di Fisica Nucleare	Napoli	Italy
MÉOT	FRANÇOIS	CEA DAPNIA	Gif sur Yvette	France
MEZZETTO	MAURO	INFN	Padova	Italy
MIGLIOZZI	PASQUALE	INFN Napoli	Napoli	Italy
MORI	YOSHIHARU	KEK	Tsukuba	Japan
MOSCA	LUIGI	CEA-Saclay	Gif-sur-Yvette	France
MOSNIER	ALBAN	CEA/Saclay	Gif-sur-Yvette	FRANCE
MUCIACCIA	MARIATERESA	University & INFN, BARI	Bari	Italy
MUELLER	ALEX C.	CNRS-IN2P3	Orsay	France
MULLER	ANDRÉ	CERN	Geneva	Suisse
MUSSA	ROBERTO	INFN Torino	Torino	Italy
NAGAMIYA	SHOJI	KEK	Tsukuba-shi	Japan
NAKAMURA	KENZO	KEK	Tsukuba	Japan
NAPOLITANO	MARCO	University "Federico II" and INFN	Napoli	Italy
NGUYEN	HOGAN	Fermilab	Batavia	USA
NILSSON	THOMAS	Inst. of Nuclear Physics, TU Darmstadt	Darmstadt	Germany
OTTO	THOMAS	SC-RP, CERN	Geneve	Switzerland
PALLADINO	VITTORIO	University Napoli		Italy
PANMAN	JAAP	CERN	Geneve 23	Switzerland
PAOLUZZI	MAURO	CERN	Meyrin	Switzerland
PEACH	KEN	RAL	Didcot	UK
PIERRE	FRANÇOIS	CEA Saclay	Gif/Yvette	France
REPELLIN	JEAN-PAUL	Laboratoire de l'Accélérateur Linéaire	Orsay	France
RIISAGER	KARSTEN	Department of Physics and Astronomy	Aarhus C	Denmark
ROSSI	CARLO	CERN	Geneva	Switzerland
RUBBIA	ANDRÉ	Institute for Particel Physics of ETHZ	Zurich	Switzerland
RUBBIA	CARLO	ENEA-Univ. Pavia	Geneva	Switzerland
SANDSTRÖM	RIKARD	DPNC Uni Geneva	Geneva	Switzerland
SCHLATTER	DIETER	CERN	Geneva	Switzerland
SCHMELZBACH	PIERRE	Paul Scherrer Institute	Villigen PSI	Switzerland
SCHROEDER	W. UDO	University of Rochester	Rochester	USA
SPIRO	MICHEL	IN2P3	Paris	France
STROLIN	PAOLO	University and INFN, Naples	Napoli	Italy

SUJKOWSKI	ZIEMOWID	Institute for Nuclear Studies	Warsaw	Poland
TENGBLAD	OLOF	IEM-CSIC	Madrid	Spain
TERRANOVA	FRANCESCO	INFN-Frascati	Frascati	Italy
TERRIEN	YVES	Commissariat à l'Energie Atomique	Gif sur Yvette	France
TORTORA	LUDOVICO	INFN - Roma III	Rome	Italy
TRONCI	CESARE	University of Torino	Torino	Italy
TUOMINIEMI	JORMA	Institute of Physics	Helsinki	Finland
VAN DUPPEN	PIET	K.U.Leuven, University of Leuven	Leuven	Belgium
VOLPE	MARIA CRISTINA	Institut de Physique Nucléaire Orsay	Orsay	France
VRETENAR	MAURIZIO	CERN	Geneva	Switzerland
WARK	DAVID	Imperial College London	London	UK
WARNER	DAVID	CCLRC Daresbury Laboratory	Warrington	UK
WENG	B. WU-TSUNG	Brookhaven National Laboratory	Upton	USA
WOODS	PHILIP	University of Edinburgh	Edinburgh	UK

Table 17 Workshop Agenda

Tuesday, May 25, Afternoon			
13:30	**Introductory Session**		
	R. Aymar	Welcome address	10+5'
	J. Ellis	The high intensity frontier	30+5'
	S. Nagamiya	The JPARC program & experience	25+5'
	S. Holmes	US plans for high power proton drivers	25+5'
15:20	**Accelerator Session**		
	R. Garoby	The potential of the SPL at CERN	30+5'
15:55–16:20	**Coffee Break**		
	C. Prior	Rapid Cycling Synchrotron option	20+5'
	H. Haseroth	Additional installations for a neutrino physics facility	25+5'
	M. Apollonio	Defining the energy of the proton driver	15+5'
	A. Mueller	Additional installations for a Nuclear Physics facility	20+5'
	M. Lindroos	A neutrino Beta-beam facility at CERN	20+5'
18:30	**Adjourn**		

Wednesday, May 26, Morning			
9.00	**Particle Physics Session**		
	P. Hernandez	Neutrino oscillation physics from a Mwatt neutrino complex	25+5'
	L. Mosca	The Frejus underground laboratory: status and plans	15+5'
	C. K. Jung	A Megaton Water Cherenkov detector	15+5'
	A. Ereditato	Large Liquid Argon detector	20+5'
10:40 -11:05	**Coffee Break**		
	S. Geer	Neutrino Factory: physics and R&D progress	20+5'
	P. Migliozzi	Physics of Neutrino interactions	15+5'
	A. Van der Schaaf	The Physics of a new high intensity low energy muon source	25+5'
	A. Ceccucci	The Physics of higher intensity PS or SPS (kaons, muons, neutrinos)	15+5'
12:40	**Lunch**		

Wednesday, May 26, Afternoon			
14:00	**Nuclear Physics Session**		
	Y. Blumenfeld (IPN Orsay)	Introduction: The Eurisol DS proposal	15'+5'
	W. Gelletly (Surrey)	The future of nuclear structure studies	30'+10'
	F. Gulminelli (LPC Caen)	Nuclear dynamics and the nuclear equation of state	25'+5'
15:30-16:00	**Coffee break**		
	K.-L. Kratz (Mainz)	Astrophysics with RIB	25'+5'
	K. Jungmann (Groningen)	Fundamental symmetries and interactions (at an intense proton source)	25'+5'
	J. Äystö (Jyväskylä)	New approaches to the study of the nucleus : muons, pbar,…	25'+5'
	H.-J. Kluge (GSI)	FAIR: the GSI New Facility	25'+5'
18:00	**Adjourn**		
19:30	**Workshop dinner**		

Thursday, May 27, Morning			
9.00	**Poster Session**		
10:30	**Coffee**		
11:00	**Outlook Session**		
	B. Weng	Accelerator aspects	25+5'
	M. Spiro	Particle Physics aspects	25+5'
	M. Harakeh	Nuclear Physics	25+5'
	J. Engelen	Concluding remarks	25+5'
13:00	**Lunch Meeting of SAC & PAC : "Towards Cogne"**		