V. Palladino
SPSC Closed Session
Villars, 22 Sep 2004

Summary of Multi Mega Watt (MMW) Workshop

See http://proj-bdl-nice.web.cern.ch/proj-bdl-nice/megawatt-summaries/WorkshopSummary-3.71.doc

- Highlights & outlook for MMW physics

  admittedly ν *- centric*

- Rich & debated spectrum of options (**π decay channel, μ & β storage ring….**
  energy, baseline , detector mass & density …

  but consensus on highest priority : **High Power** MMW Drivers
  MMW Targets
  MMW Collectors

- Tentative timeline & recommendations

Workshop on

BENE+EURISOL

PHYSICS

WITH A

MULTI-MW PROTON SOURCE

CERN, Geneva, May 25-27, 2004

The workshop explores both the short- and long-term opportunities for particle and nuclear physics offered by a multi-MW proton source such as a proton linear accelerator or a rapid-cycling synchrotron. This source would provide Muon and Electron Neutrino beams of unprecedented intensity, superior slow Muon and possibly Kaon facilities, as well as a world-leading Radioactive Ion Beam facility for Nuclear, Astro- and fundamental physics.

Scientific Advisory Committee:

J. Äystö (Jyväskylä), R. Aleksan (Saclay)
M. Baldo Ceolin (Padova), J. Bouchez (Saclay)
E. Coccia (G. Sasso), J. Dainton (Liverpool)
J.-P. Delahaye (CERN), C. Detraz (CERN)
R. Eichler (PSI), J. Engelen (CERN)
J. Feltesse (Saclay), E. Fernandez (Barcelona)
G. Fortuna (Legnaro), B. Foster (Oxford)
W. Gelletly (Surrey), D. Goutte (GANIL)
D. Guerreau (IN2P3), M. Harakeh (KVI Groningen)
H. Haseroth (CERN), W. Henning (GSI)
E. Iarocci (INFN), B. Jonson (Göteborg)
K. Jungman (KVI Groningen), B. Kayser (Fermilab)
M. Lindner (TU Munich), A. Muller (IPN Orsay)
S. Nagamiya (JPARC), M. Napolitano (Napoli)
W. Nazarewicz (Oak Ridge), K. Peach (RAL)
R. Petronzio (Roma II), F. Ronga (Frascati)
D. Schlatter (CERN), M. Spiro (IN2P3)
I. Tanihata (RIKEN), C. Wyss (CERN)
J. Zinn-Justin (DAPNIA)

Programme Committee:

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Y. Blumenfeld (IPN Orsay), P. Butler (CERN),
P. Debu (Saclay), R. Edgecock (RAL), J. Ellis (CERN),
R. Garoby (CERN), U. Gastaldi (Legnaro),
M. Lindroos (CERN), V. Palladino (Napoli),
J. Panman (CERN), C. Prior (RAL),
A. Rubbia (ETH Zurich), P. Schmelzbach (PSI)

Local Organizing Committee:

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

http://physicsatmwatt.web.cern.ch/physicsatmwatt/

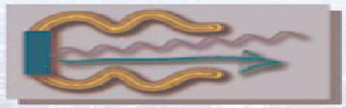
Annual Meeting
CARE

Coordinated **A**ccelerator **R**esearch in **E**urope
supported by the European Community (FP6 Research Infrastructures Action)

Nov. 2-5, 2004, DESY Hamburg, Germany

Progress and Status Reports of Joint Research Activities (JRA)

Superconducting RF



Photoinjectors

HIPPI

High Intensity Pulsed Proton Injection

NED

High Field Magnets R&D

And Networking Activities:

ELAN

Linear Colliders

HEHIHB

Proton Accelerators

BENE

Neutrino Beams

International Program Committee:

R. Aleksan (CEA/DAPNIA and CNRS/IN2P3)
A. Devred (CEA/DAPNIA)
R. Garoby (CERN)
T. Garvey (CNRS/IN2P3)
A. Ghigo (INFN)
O. Napoly (CEA/DAPNIA)
V. Palladino (INFN)
D. Proch (DESY)
F. Richard (CNRS/IN2P3)
W. Scandale (CERN)

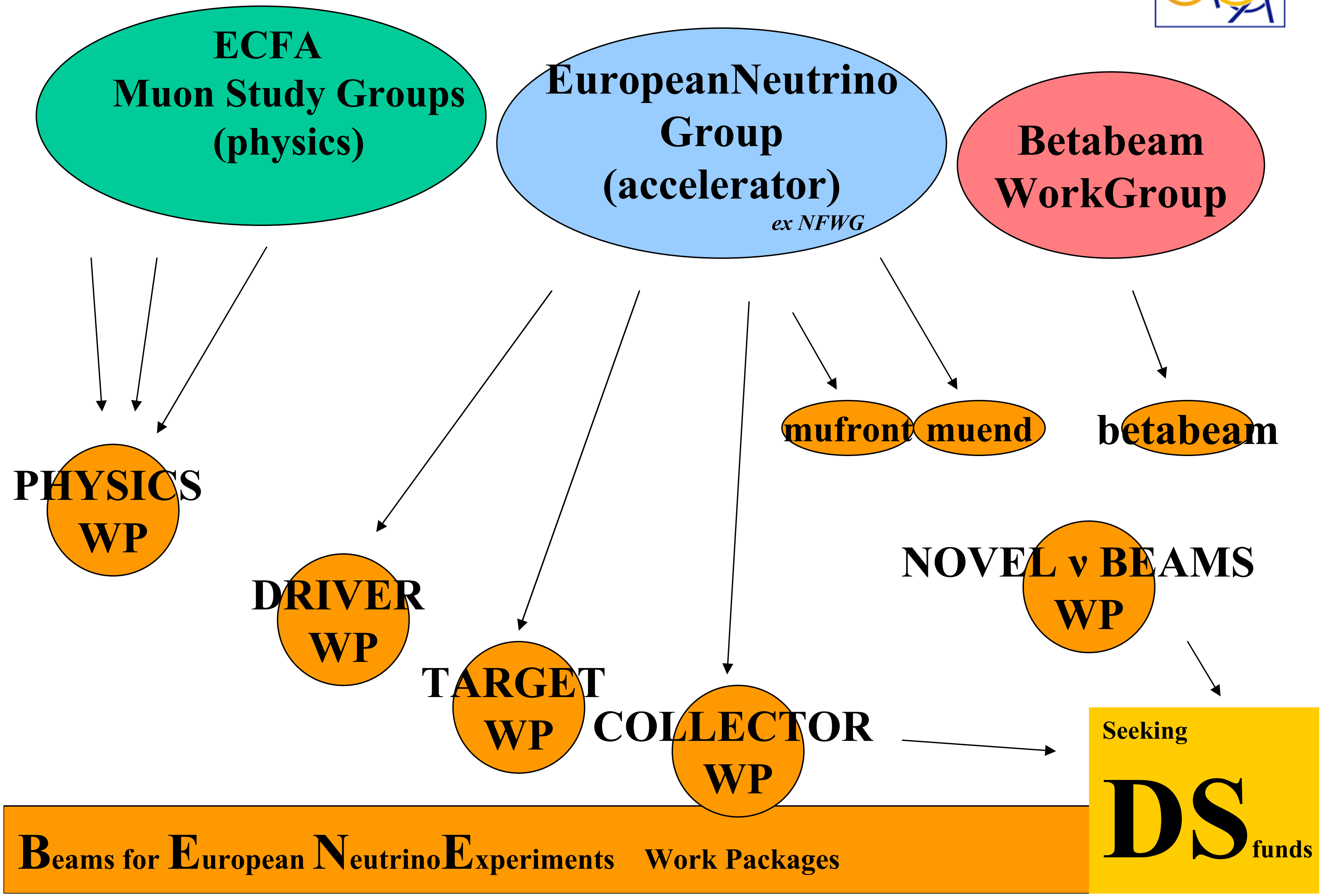
Local Organization:

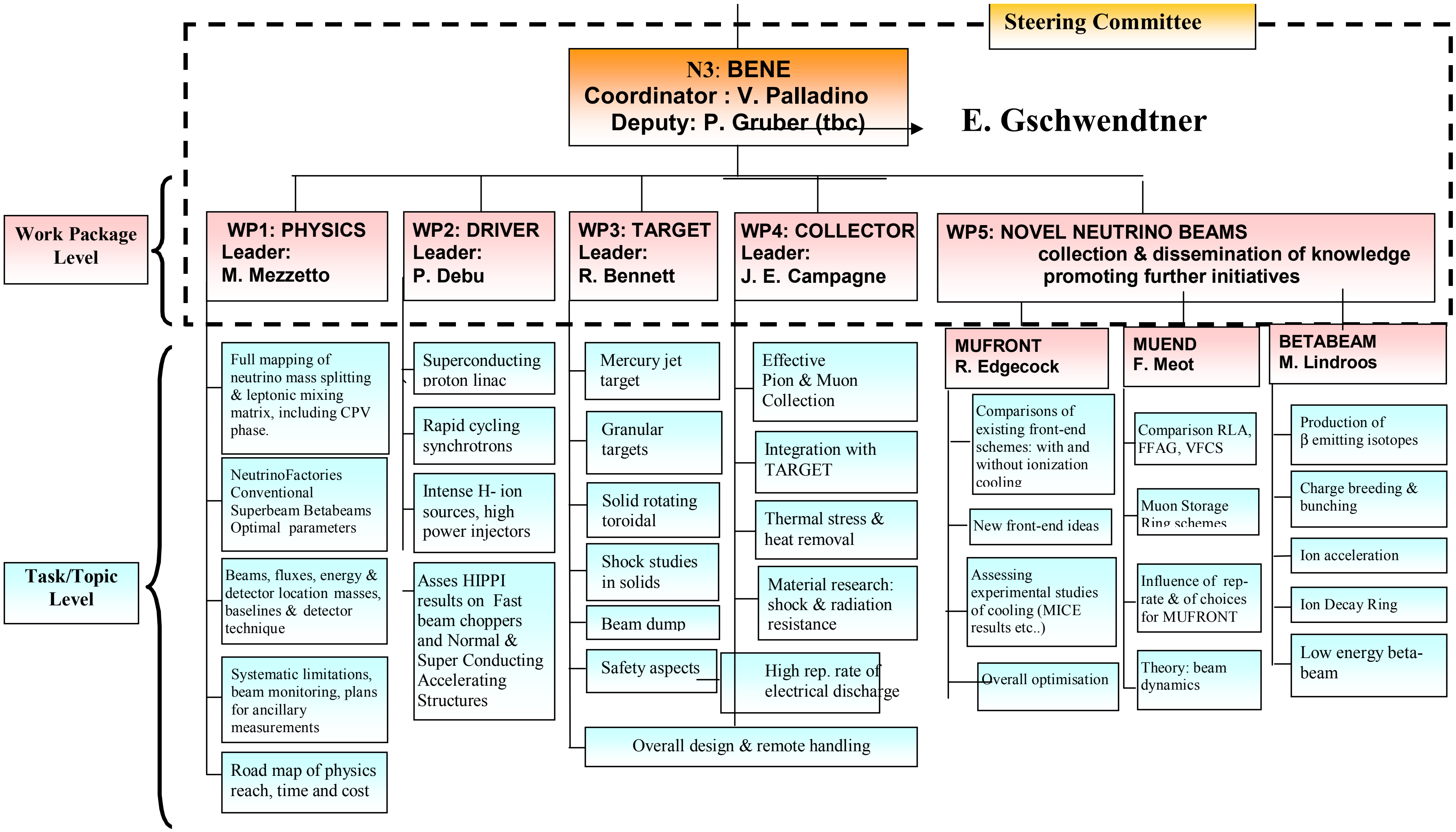
A. Brinkmann
A. Goessel
K. Lando
H. Mais
R. Mayer
S. Mette
W.-D. Moeller
I. Nikodem
D. Proch
D. Reschke

Information and Registration
http://care04.desy.de
Contact: care04@desy.de

On the first two days of the Annual Meeting, Nov. 2 and 3, there will be the
ECFA/BENE Workshop
The Future of Accelerator Neutrino Experiments in Europe
(see http://bene.na.infn.it/Events/20041102/Agenda.html)

BENE as an integrating activity … Joint ECFA/BENE activities





PHYSICS	ENG …. the accelerator sector

… from BENE proposal :
coordinate and integrate the activities of the accelerator and particle physics communities working together, in a worldwide context,

towards **achieving superior neutrino (ν) beam facilities for Europe.**

1) to establish a road map for upgrade of our present facility and the design and construction of new ones

2) to assemble a community capable of sustaining the technical realisation and scientific exploitation of these facilities

220 signatures

3) to foster a sequence of carefully prioritized&coordinated initiatives capable to establish, propose and execute the R&D efforts necessary to achieve these goals.

approval of BENE and HIPPI

recognition of accelerator neutrino physics, CNGS & beyond
and of its need for Mwatt protons
July 03

fruitful confrontation with RIB NUPECC community

EURONS, EURISOL ……. Rad Ion Beams
could work together towards a betabeam
could share a MWatt p-driver
Moriond 03

new management taking office at CERN

→ **MWW Workshop**
first major BENE event

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"		

Physics with Megawatt

- Long-range programme in ν physics:
  superbeam, β beam, ν factory unique and compelling
- Complementary programme in μ physics:
  rare μ decays, μ properties, μ colliders?
- Next-generation facility for nuclear physics
  also tests of SM, nuclear astrophysics
- Synergy with CERN programme:
  LHC, CNGS ν, ISOLDE, heavy ions, β beam

Interesting project – and CERN would be a good place for it

The options we have explored

NB: beam + detector configurations

Conventional beam **π decay channel** ... ν_μ (0.1-1% ν_e)

SuperBeam, if MW power ....

need Very Large Detector (water C, Li-Ar)

the same as p-decay

50-500 Ktons
ie new lab

n o v e l b e a m s

Neutrino Factory **μ storage ring** ..... ν_μ & $\overline{\nu}_e$

manipulate &
accelerate
ν parents !

(& μ accelerator complex!)

needs Large Magnetic Detector

(SuperMINOS, Li-Ar in $\vec{B}$)

30-100 Ktons
LNGS !
new lab ?

BetaBeam **β storage ring** ... pure ν_e

(& EU accelerator complex)

detectors same as SuperBeams

NB : π μ β possible, in all cases, for CP, T & CPT studies

The key to novel neutrino beams

the re- acceleration of the neutrino parent !!!

$$\nu \text{ Flux} \approx (N_{parent}/L^{2)}\,\gamma_{parent}{}^{2}$$ **basic kinematics**

$$\nu \text{ Rate} \approx \gamma_{parent}{}^{3}/L^{2}$$

$$\nu\text{-osc Rate} \approx E^{3}\sin^{2}(L/E)/\,/L^{2}$$

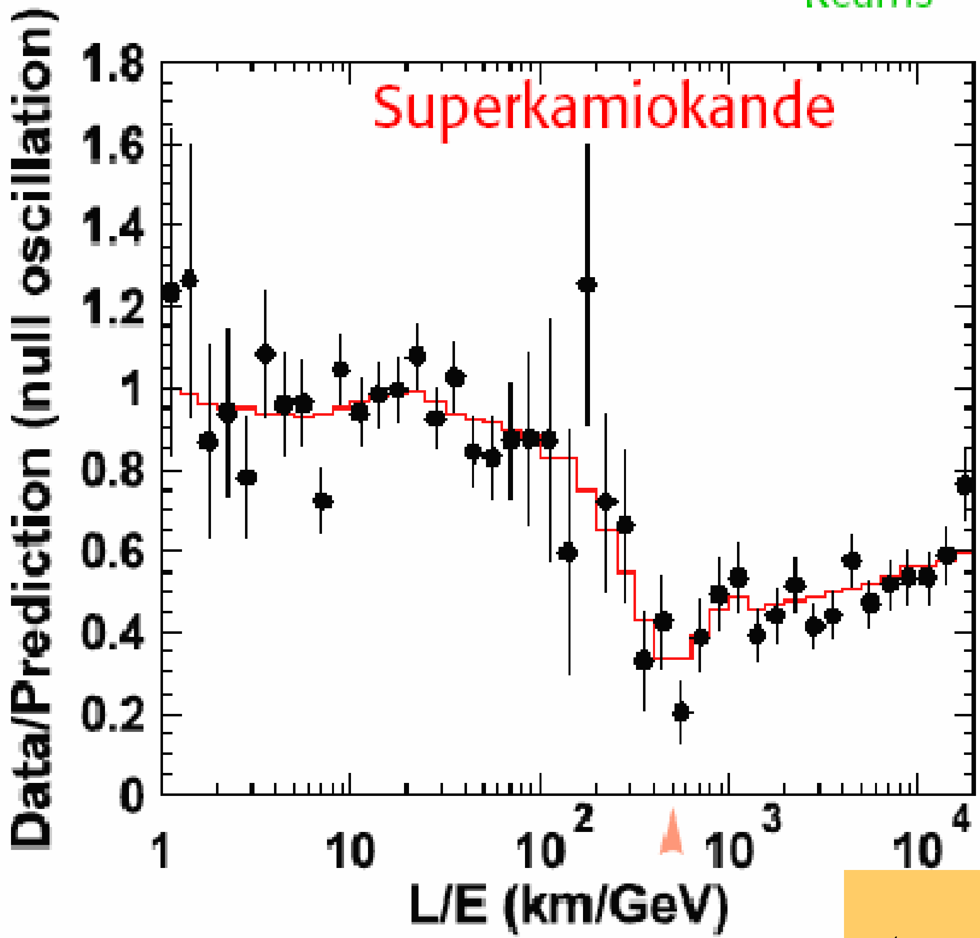
ν/parent grows very rapidly with E_{parent}

NB 1) not necessarily with E_{proton} **N_{parent} !!!**

2) low E may have independent merits **no matter effects ie no fake CP V**

Atmospheric neutrinos: SuperKamiokande L/E analysis

Kearns



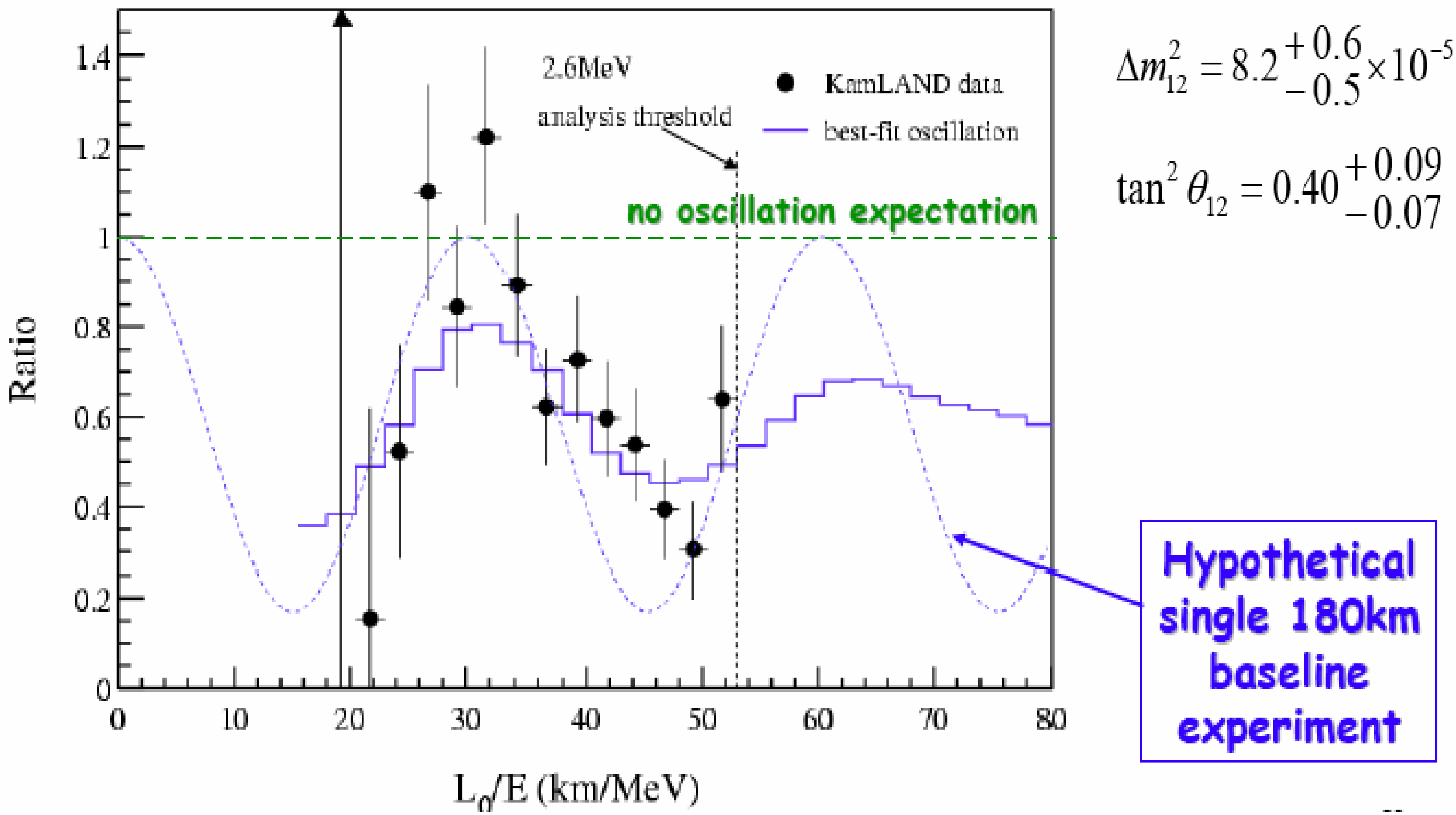
Atmospheric "wavelenght"

oscillation dip seen at ~500 km/GeV

KamLAND "L"/E distribution: direct look at oscillations

Solar "wavelenght" about 30 times longer

Gratta



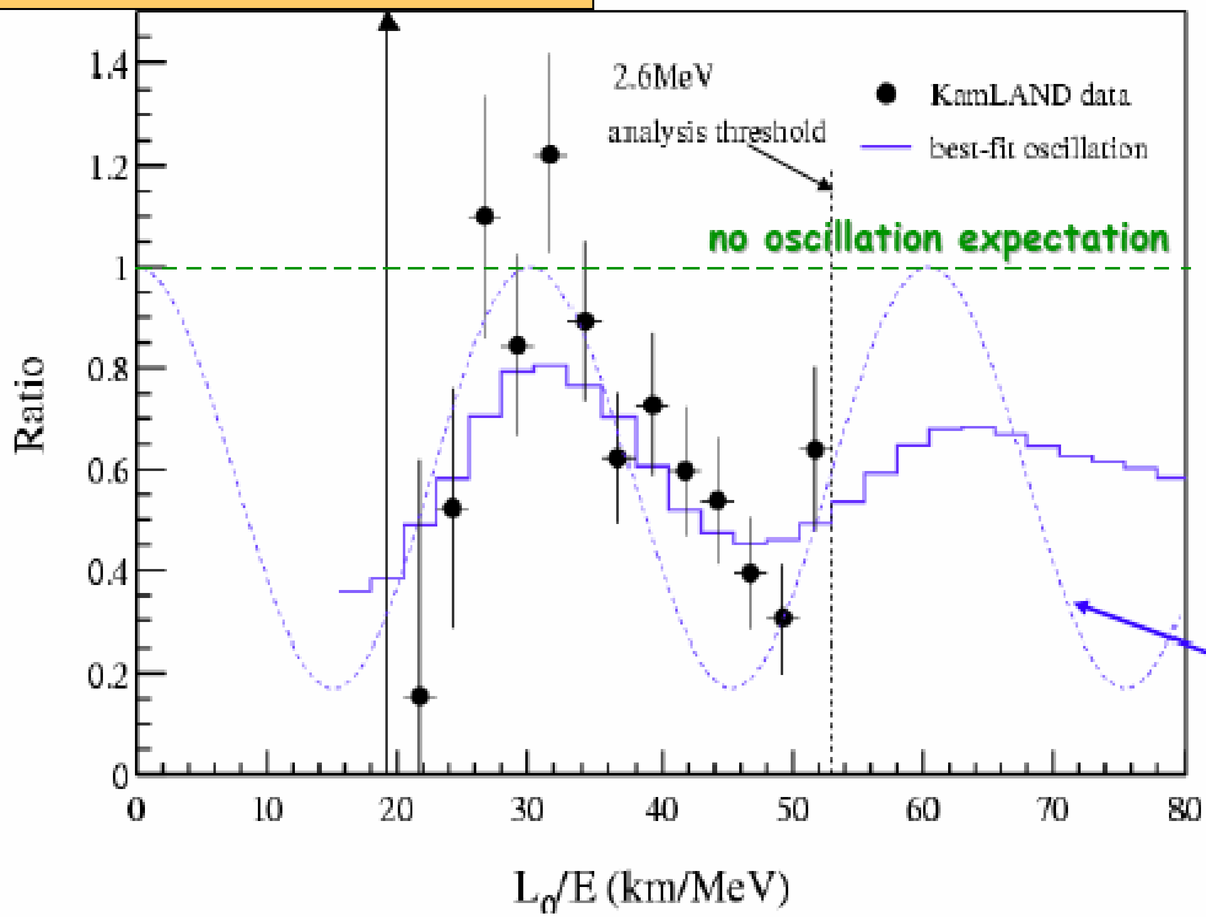
$$\Delta m^2_{12} = 8.2^{+0.6}_{-0.5} \times 10^{-5} eV^2$$

$$\tan^2\theta_{12} = 0.40^{+0.09}_{-0.07}$$

KamLAND "L"/E distribution: direct look at oscillations

Solar "wavelenght" about 30 times longer

Gratta



$$\Delta m^2_{12} = 8.2^{+0.6}_{-0.5} \times 10^{-5}\, eV^2$$

$$\tan^2\theta_{12} = 0.40^{+0.09}_{-0.07}$$

Hypothetical single 180km baseline experiment

λ≈30000 km/GeV

The matrix of neutrino transition probability

P_{ee}=1- …..

$P_{e\mu}$=

$P_{e\tau}$=

$P_{\mu e}$ =

$P_{\mu\mu}$=1- …..

$P_{\mu\tau}$=

$P_{\tau e}$ = …….

$P_{\tau\mu}$= …..

$P_{\tau\tau}$=1- …..

The matrix of neutrino transition probability

P_{ee}=1- …..

$P_{e\mu}$= - 4 Re $J_{e\mu}^{12}\sin^2\Delta_{12}$
- 4 Re $J_{e\mu}^{13}\sin^2\Delta_{13}$
- 4 Re $J_{e\mu}^{23}\sin^2\Delta_{23}$
$\pm$ 8J $\sin\Delta_{12}\sin\Delta_{23}\sin\Delta_{13}$

$P_{e\tau}$= - 4 Re $J_{e\tau}^{12}\sin^2\Delta_{12}$
- 4 Re $J_{e\tau}^{13}\sin^2\Delta_{13}$
- 4 Re $J_{e\tau}^{23}\sin^2\Delta_{23}$
$\pm$ 8J $\sin\Delta_{12}\sin\Delta_{23}\sin\Delta_{13}$

$P_{\mu e}$ = - 4 …
- 4 …
- 4 …
- (± 8J….

$P_{\mu\mu}$=1- …..

$P_{\mu\tau}$= - 4 Re $J_{\mu\tau}^{12}\sin^2\Delta_{12}$
- 4 Re $J_{\mu\tau}^{13}\sin^2\Delta_{13}$
- 4 Re $J_{\mu\tau}^{23}\sin^2\Delta_{23}$
$\pm$ 8J $\sin\Delta_{12}\sin\Delta_{23}\sin\Delta_{13}$

$P_{\tau e}$ = …….

$P_{\tau\mu}$= …..

$P_{\tau\tau}$=1- …..

The matrix of neutrino transition probability

Solar (SuperK,SNO)
LBL Reactors (Kamland)

P_{ee}=1- …..

$P_{e\mu}$= $- 4 \, Re \, J_{e\mu}^{12} \sin^2\Delta_{12}$
$- 4 \, Re \, J_{e\mu}^{13} \sin^2\Delta_{13}$
$- 4 \, Re \, J_{e\mu}^{23} \sin^2\Delta_{23}$
$\pm 8J \sin\Delta_{12} \sin\Delta_{23} \sin\Delta_{13}$

$P_{e\tau}$= $- 4 \, Re \, J_{e\tau}^{12} \sin^2\Delta_{12}$
$- 4 \, Re \, J_{e\tau}^{13} \sin^2\Delta_{13}$
$- 4 \, Re \, J_{e\tau}^{23} \sin^2\Delta_{23}$
$\pm 8J \sin\Delta_{12} \sin\Delta_{23} \sin\Delta_{13}$

$P_{\mu e}$ = - 4 …
- 4 …
- 4 …
- (± 8J….

$P_{\mu\mu}$=1- …..

$P_{\mu\tau}$= $- 4 \, Re \, J_{\mu\tau}^{12} \sin^2\Delta_{12}$
$- 4 \, Re \, J_{\mu\tau}^{13} \sin^2\Delta_{13}$
$- 4 \, Re \, J_{\mu\tau}^{23} \sin^2\Delta_{23}$
$\pm 8J \sin\Delta_{12} \sin\Delta_{23} \sin\Delta_{13}$

Atmo Super-K
K2K, NuMI, CNGS

T & CP violating term $e^{-i\delta}$
universal

$P_{\tau e}$ = …….

$P_{\tau\mu}$= …..

$P_{\tau\tau}$=1- …..

Experiments ahead of us, for decades …..

The matrix of neutrino transition probability

P_{ee}=1- .....

$P_{e\mu}$=
- $- 4 \, Re \, J_{e\mu}^{13} \sin^2\Delta_{13}$
- $- 4 \, Re \, J_{e\mu}^{23} \sin^2\Delta_{23}$
- $\pm 8J \sin\Delta_{12} \sin\Delta_{23} \sin\Delta_{13}$

golden

BetaBeam, NuFact

$P_{e\tau}$= -
- $- 4 \, Re \, J_{e\tau}^{13} \sin^2\Delta_{13}$
- $- 4 \, Re \, J_{e\tau}^{23} \sin^2\Delta_{23}$
- $\pm 8J \sin\Delta_{12} \sin\Delta_{23} \sin\Delta_{13}$

silver

NuFact

$P_{\mu e}$ =
- \- 4 ...
- \- 4 ...
- \- (± 8J....

$P_{\mu\mu}$=1- .....

$P_{\mu\tau}$=
- $- 4 \, Re \, J_{\mu\tau}^{13} \sin^2\Delta_{13}$
- $- 4 \, Re \, J_{\mu\tau}^{23} \sin^2\Delta_{23}$
- $\pm 8J \sin\Delta_{12} \sin\Delta_{23} \sin\Delta_{13}$

SuperBeam, NuFact

$P_{\tau e}$ = ...

$P_{\tau\mu}$= .....

$P_{\tau\tau}$=1- .....

can we exploit them all? what strategy?

What we do not know yet?

θ_{13} < $\pi/20$ **or so … sure smaller, but how much?**

θ_{13} **drives** $\nu_\mu \rightarrow \nu_e$ **subleading transitions** $\Rightarrow$

δ_{CP} no clue, so far

the "holy grail of neutrino science "

an insight into antimatter suppression … CP odd leptogenesis?

Sign Δm^2 ……. hierarchy or degenaracy?

matter effects …. explore the detailed mechanism

All above emphasize subleading transition $\nu_\mu \rightarrow \nu_e$

Sensitivity to δ_{CPV} ....

asymmetries can be sizeable ……….

particularly for subdominant transitions

$\nu_\mu \leftrightarrow \nu_e$ transitions again

$$A_{\not{CP}} = \frac{P_{\not{CP}}}{P_{CP}} = \frac{P_\nu - P_{\bar{\nu}}}{P_\nu + P_{\bar{\nu}}} = \frac{8J \sin\Delta_{12}\sin\Delta_{23}\sin\Delta_{13}}{4\,[\mathrm{Re}\,J_{e\mu} + \mathrm{Re}\,J_{e\mu}{}^{12}]\sin^2\Delta_{23}} =$$

$$= \boxed{5\% \; \frac{0.3}{\sin 2\theta_{13}} \; \frac{\Delta m_{12}{}^2}{10^{-4}\,\mathrm{eV}^2} \; \frac{L}{732\mathrm{Km}} \; \frac{10\ \mathrm{GeV}}{E} \; \sin\delta}$$

possibly even big ……….

NB: L/E behavior

Matter effects : Matter is CP odd (no e^+) …. $\nu_\mu \leftrightarrow \nu_e$ **again**

$tg^2 2\theta^{matter}_{13} = \sin\theta_{13} / (\cos\theta_{13} - A^{matter} / \Delta m_{23})$

BUT $A = A_{CP} + A_{matter}$!

P_ν enhanced if $\Delta m_{23} > 0$

$P_{\bar{\nu}}$ depressed

viceversa if $\Delta m_{23} < 0$

$$A_{matter} \approx 0.7\ 10\text{-}6 \ \frac{\Delta m_{23}^2}{3\ 10\text{-}3\ eV^2} \ \frac{L^2\ (Km^2)}{E\ (GeV)}$$

NB: L^2/E behavior

faster with L than CP

short L, low E CP viable?

Can syst error in the subtraction be controlled?

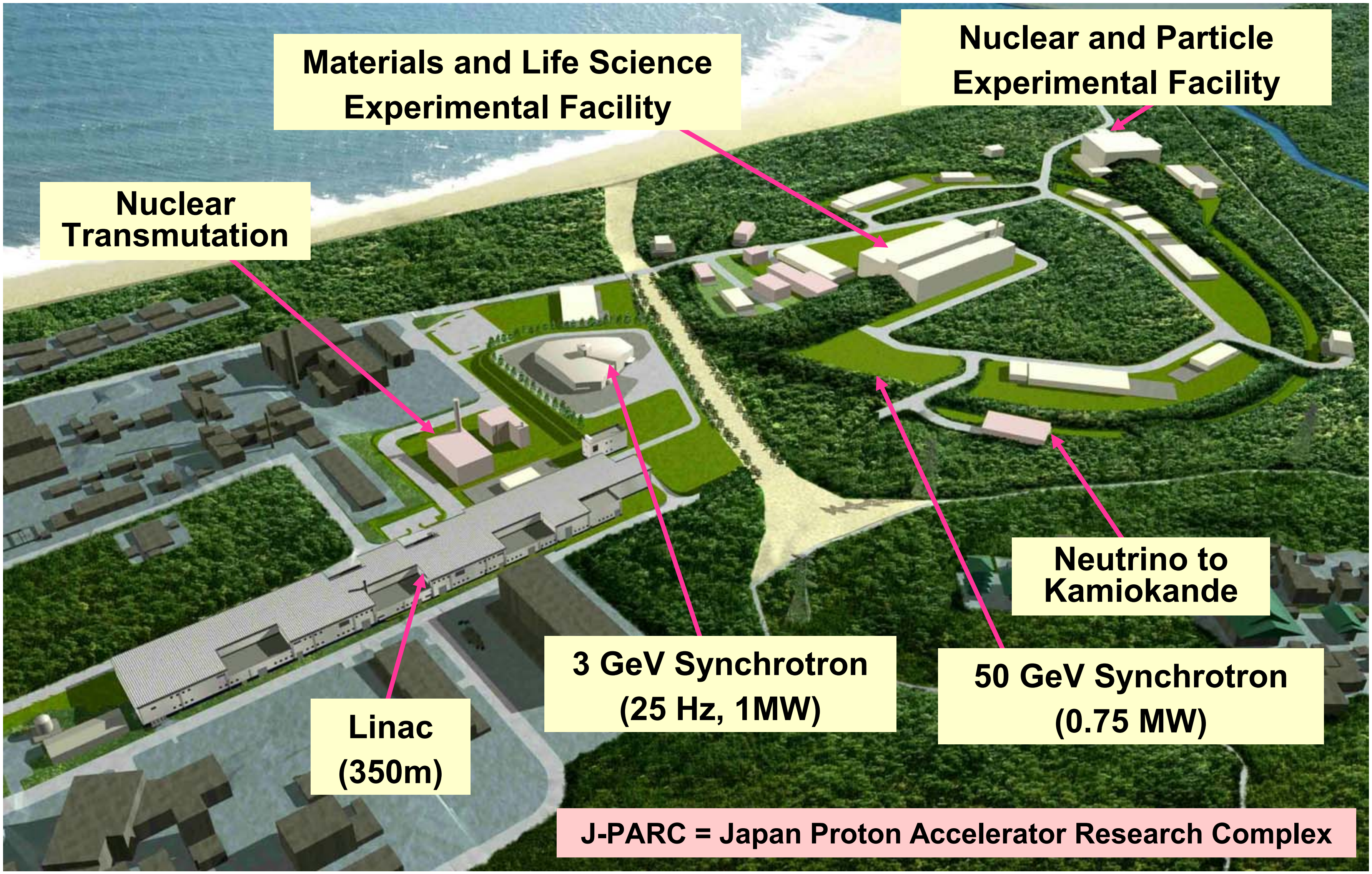
YES! At Nufact 5σ, if $N_\mu * N_{KT} * \varepsilon_{detectors} \approx 6\ 10^{22}\ \mu$ Ktons

$N_\mu \approx 2\ 10^{21}$ /year $N_{KT} \approx$ several 10 Ktons

Mwatts & Mtons !!

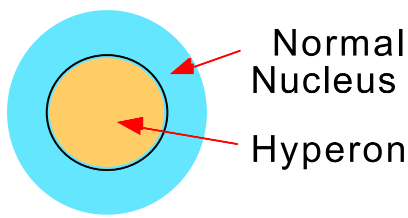
$\varepsilon_{detectors}$

The reference facility: J-PARC
0.75 MW at start, evolving



Nuclear and Particle Physics

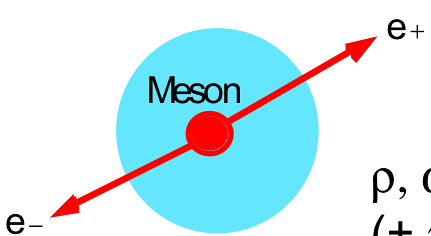
Baryon Implantation



Hypernucleus

- High resolution spectroscopy for S = -1 hypernuclei
- S = -2 hypernuclei

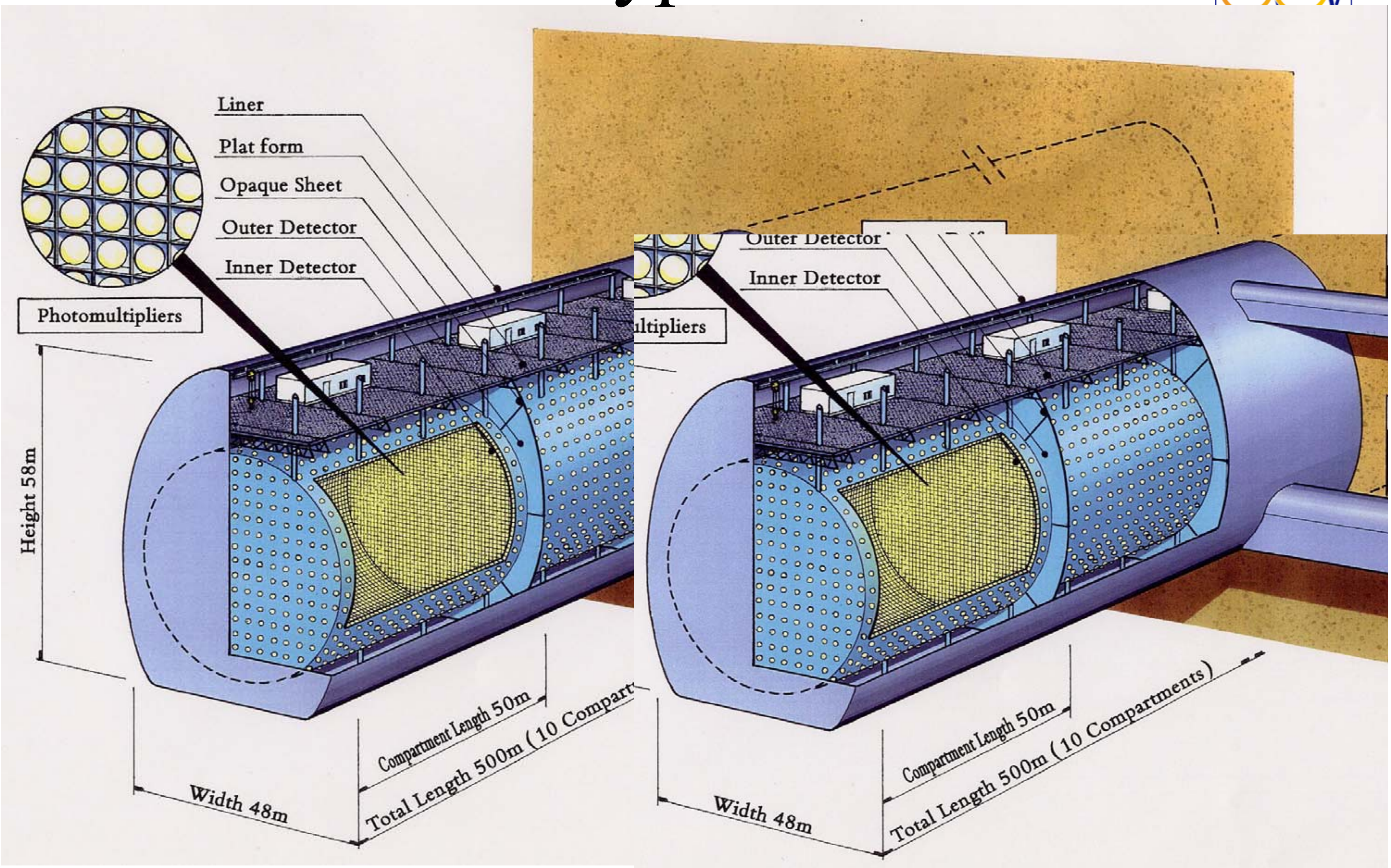
Meson Implantation



ρ, ω, φ, J/Ψ, etc.
(+ π, K, σ, etc.)

Neutrino conventional beam (0.75 MW) ν_e
then multi MW Superbeam + Mton
later Neutrino Factory

2 Detector Hyper-Kamiokande



2 detectors×48m × 50m ×250m, Total mass = 1 Mton

Next phases of EU initiative in neutrino Physics ?

2006 2009 2014 >2014

CNGS

EU-T2K …..

CH, France, Italy, Spain, UK
UA1/NOMAD magnet

T2H (4 MW, 1 Mton) ?

Super Conventional beam

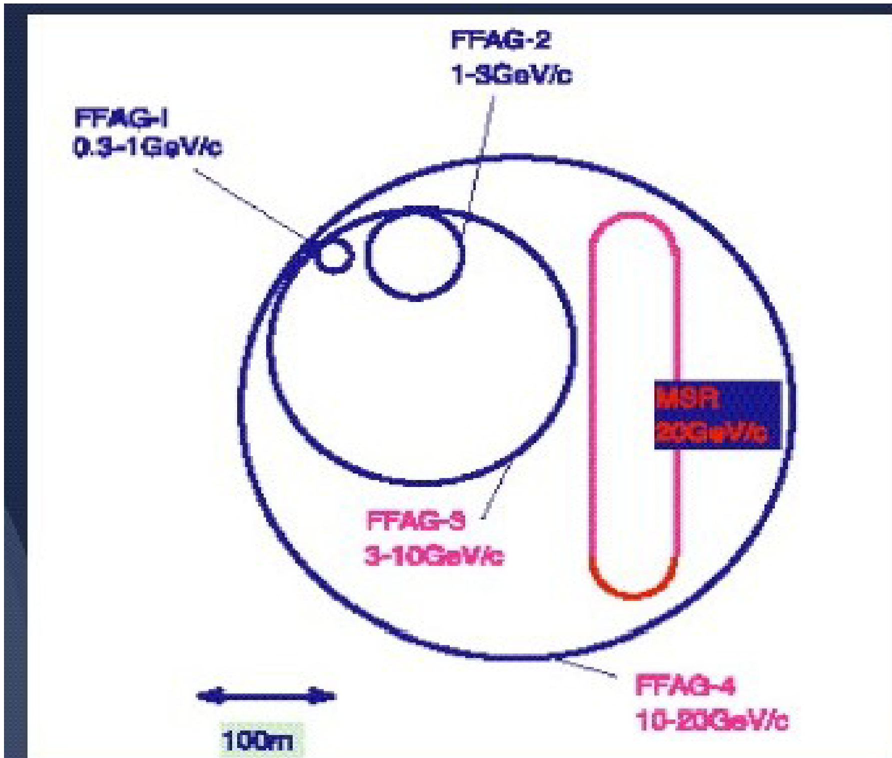
R&D targets, horns

R&D cooling, reacceleration

New EU Neutrino Complex?

Super Conventional beam? (Gilardoni)
Novel beams (Mezzetto, Haseroth, Lindroos, Blondel ..)

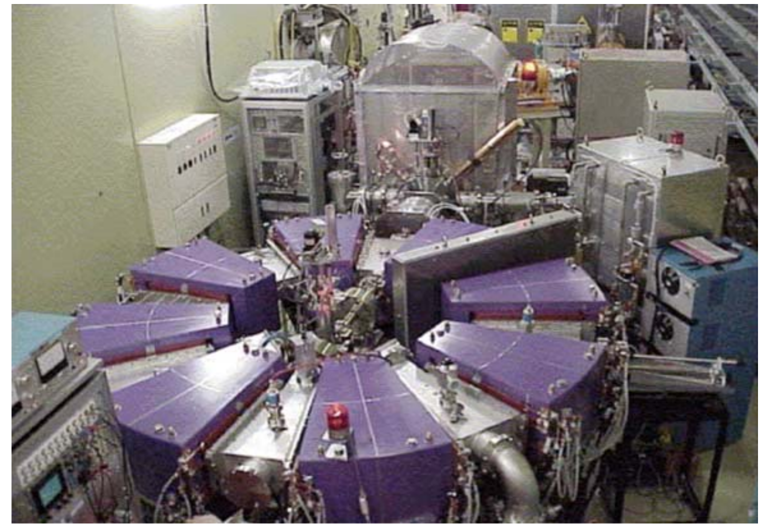
The Japanese Neutrino Factory Concept



Series of FFAGs for muon acceleration

0.3-1.0 GeV
1-3 GeV
3-10 GeV
10-20 GeV

Large aperture accelerators (FFAG)



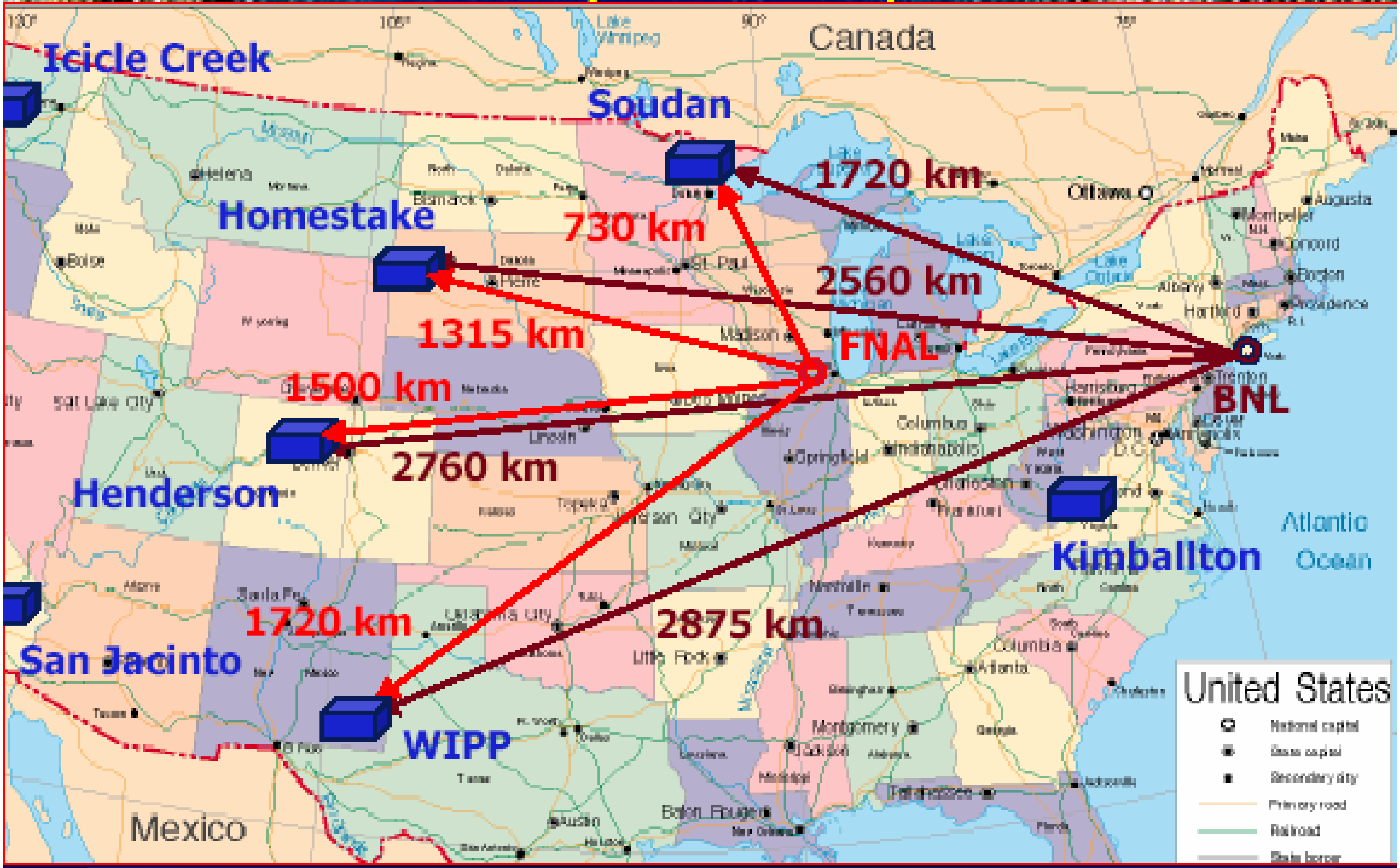
p.o.p. prototype

The ultimate neutrino facility
and…
first step to muon colliders

High Power Proton Drivers
Fermilab and Brookhaven

- Fermilab and Brookhaven concepts have several elements in common:
  - Increase the repetition rate of the existing machine (MI or AGS)
  - Decrease the fill time of the existing machine by using a (sc) linac
  - Increase the injected beam intensity by using a linac (or synchrotron)
  - Rely on previously developed SCRF technologies
- Both conceive of upgrade paths that could go another factor of 2-4
- **The BNL concept features a 1.2 GeV superconducting linac as the injector into the (upgraded) AGS**
- **Fermilab has two implementations under evaluation**, each with capability to inject into the Main Injector and to provide stand-alone 8 GeV beams:
  - **8 GeV synchrotron** (with 600 MeV linac injector)
  - **8 GeV superconducting linac**

NUSEL Candidate Sites and Potential Superbeam Experiments

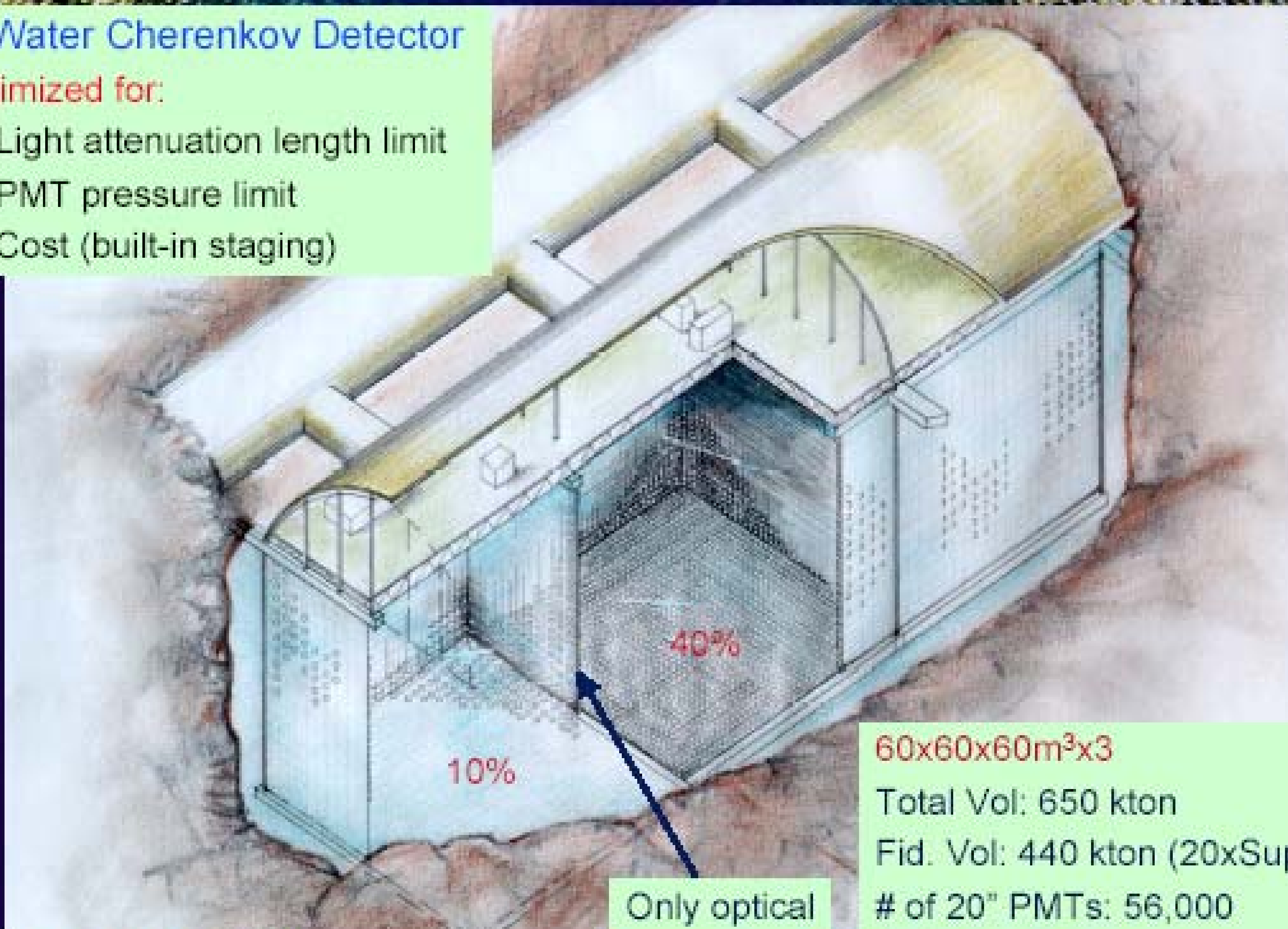


UNO Detector Conceptual Design

A Water Cherenkov Detector

optimized for:

- Light attenuation length limit
- PMT pressure limit
- Cost (built-in staging)



Only optical separation

$60x60x60m^3x3$

Total Vol: 650 kton

Fid. Vol: 440 kton (20xSuperK)

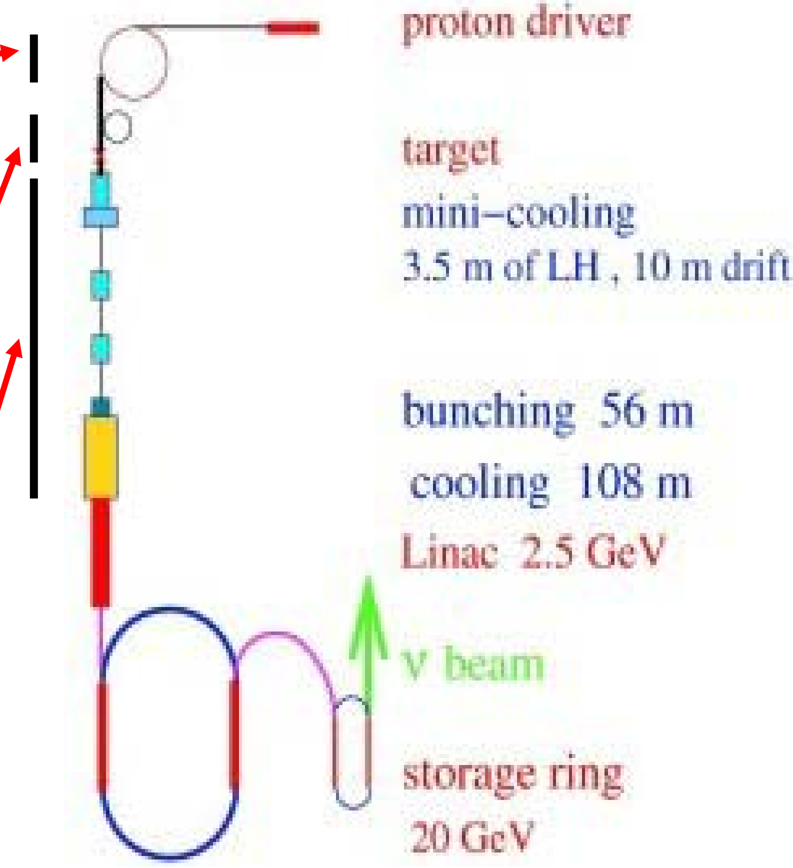
# of 20" PMTs: 56,000

# of 8" PMTs: 14,900

US Neutrino Factory Concept - 1

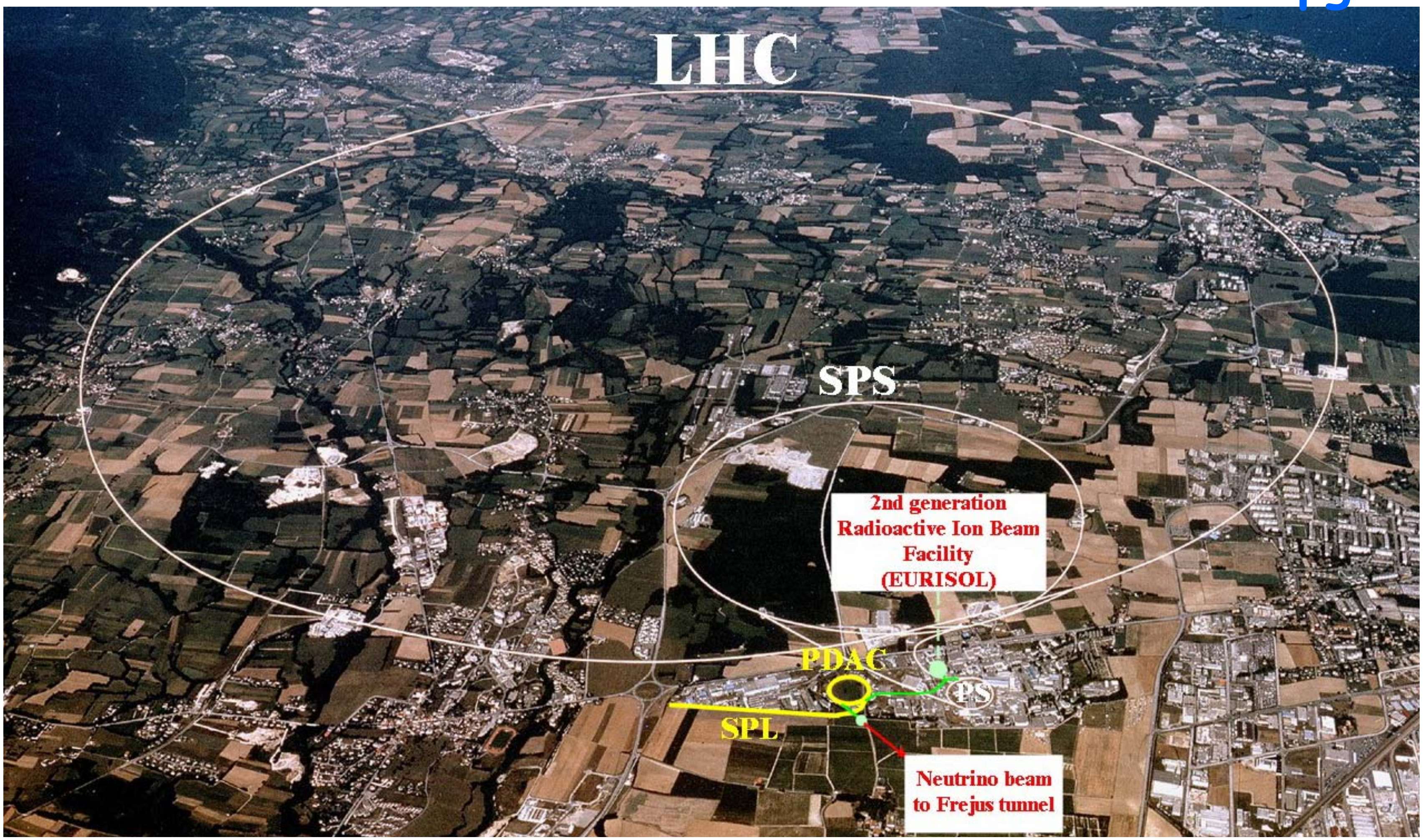
Example: US Design Study 2

1. Make as many charged pions as possible
   ✸ INTENSE PROTON SOURCE
   (In practice this seems to mean one with a beam power of one or a few MW)
2. Capture as many charged pions as possible
   ✸ Low energy pions
   ✸ Good pion capture scheme
3. Capture as many daughter muons as possible within an accelerator
   ✸ Reduce phase-space occupied by the μs
   ✸ Muon cooling – needs to be fast other-wise the muons decay



European MWatt complex:
combination of linac+rings

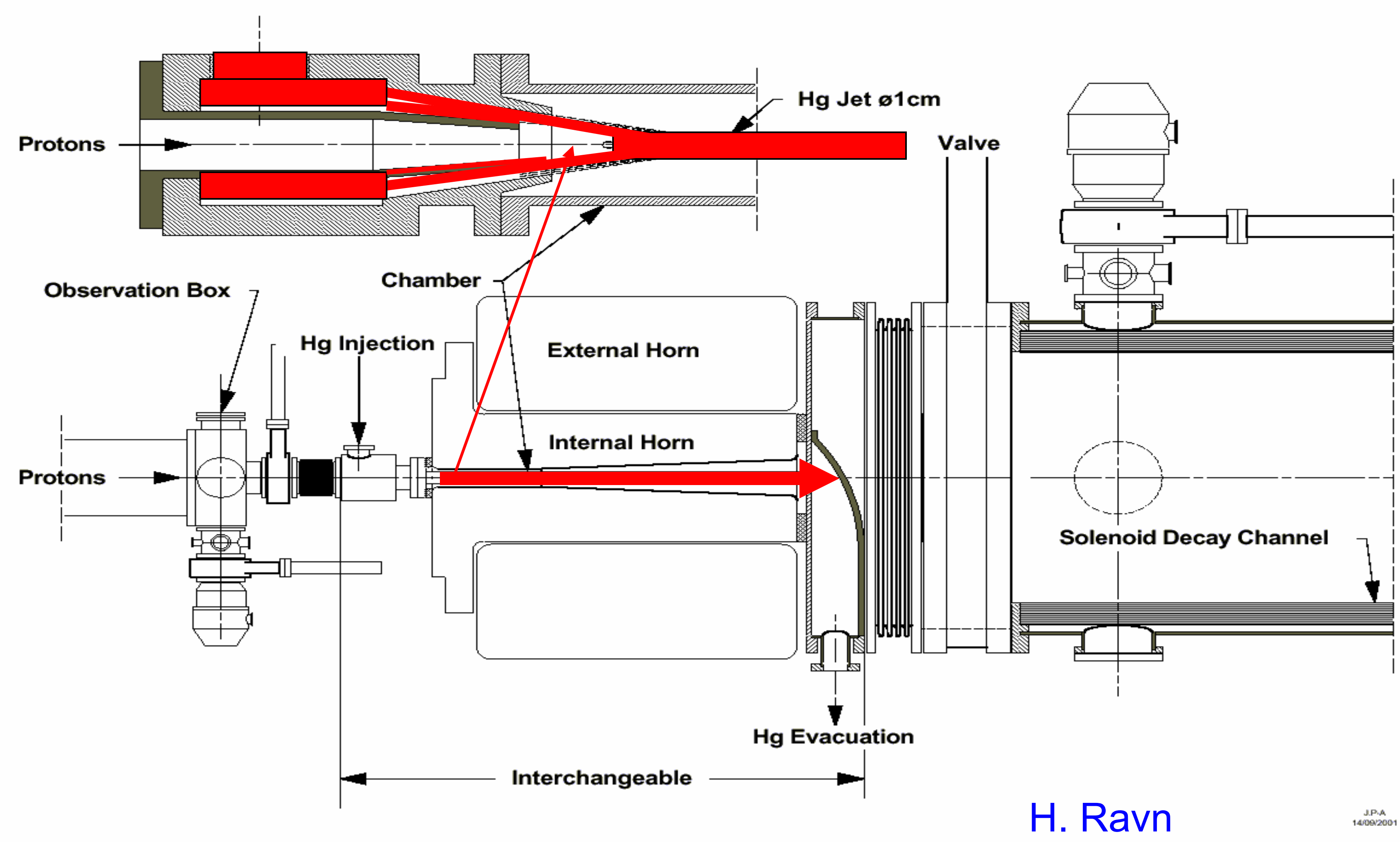
in synergy
with LHC upgrades



Potential of future accelerators

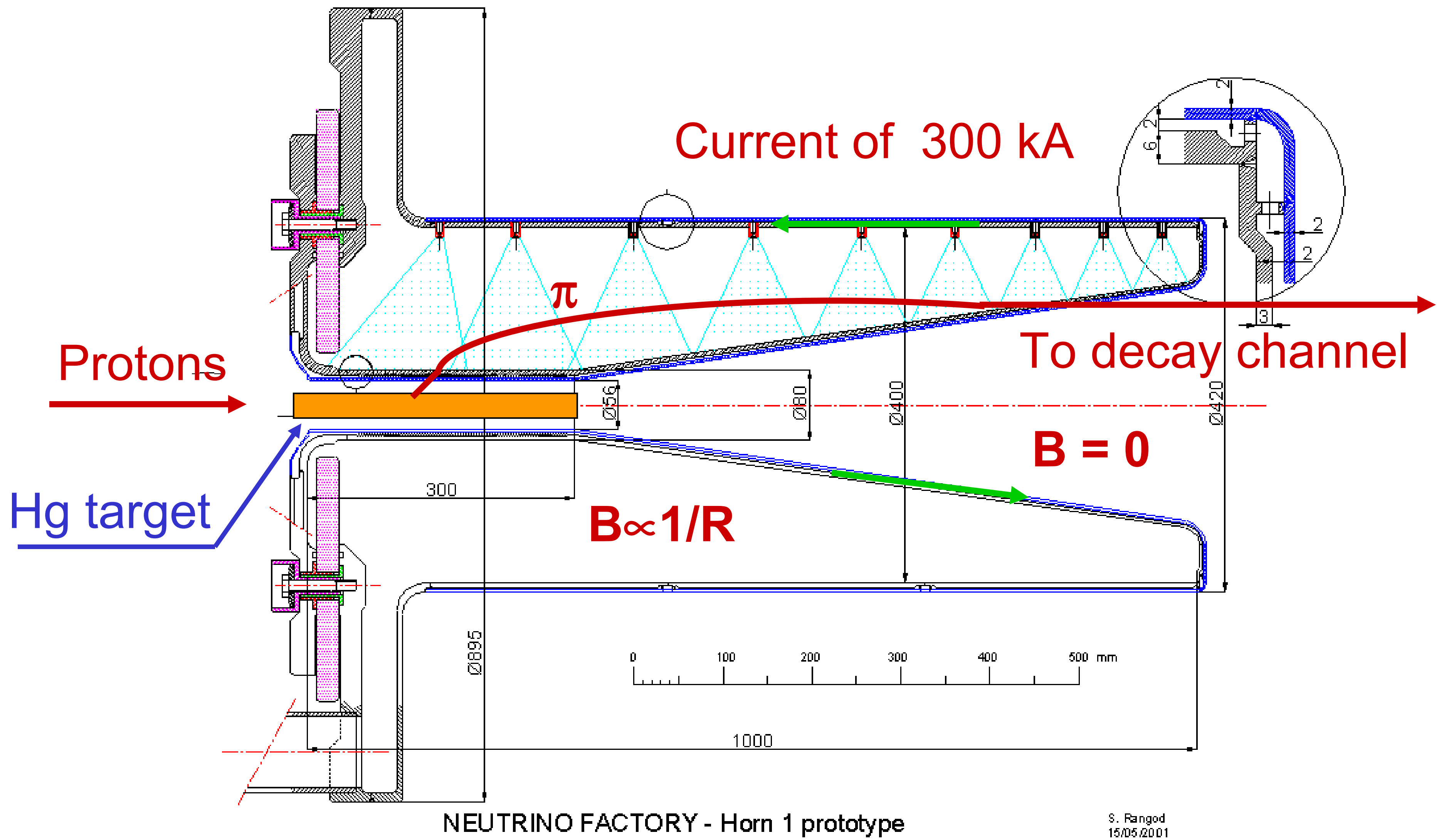
	INTEREST FOR			
	LHC upgrade	Neutrino physics beyond CNGS	Radio-active ion beams (EURISOL)	Others
Low energy 50 Hz RCS (~ 400 MeV / 2.5 GeV)	Valuable	Very interesting for super-beam + beta-beam	No	?
50 Hz SPL (~ 2 GeV)	Valuable	Very interesting for super-beam + beta-beam	Ideal	Spare flux ⇒ possibility to serve more users
High energy 8 Hz RCS (30-50 GeV)	Valuable	Very interesting for neutrino factory	No	Valuable
New PS (30-50 GeV)	Valuable	No	No	Valuable
1 TeV LHC injector	Very interesting for luminosity upgrade. Essential for doubling the LHC energy	No	No	Valuable

MWatt targetry
Ex: Hg-jet p-converter target

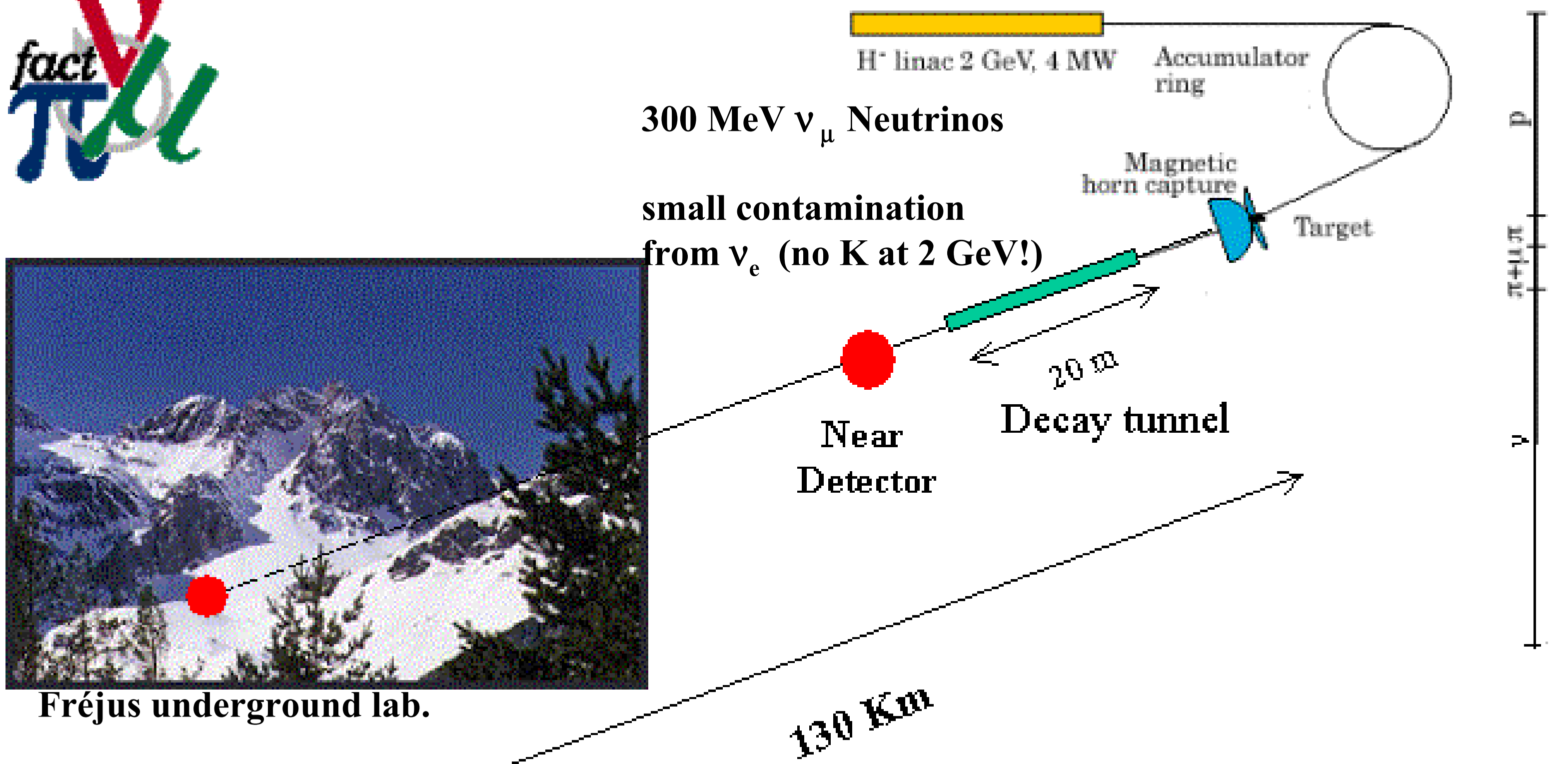


H. Ravn

Mwatt pion/muon collection systems
Ex: Horn focusing system



CERN-SPL-based Neutrino **SUPERBEAM**

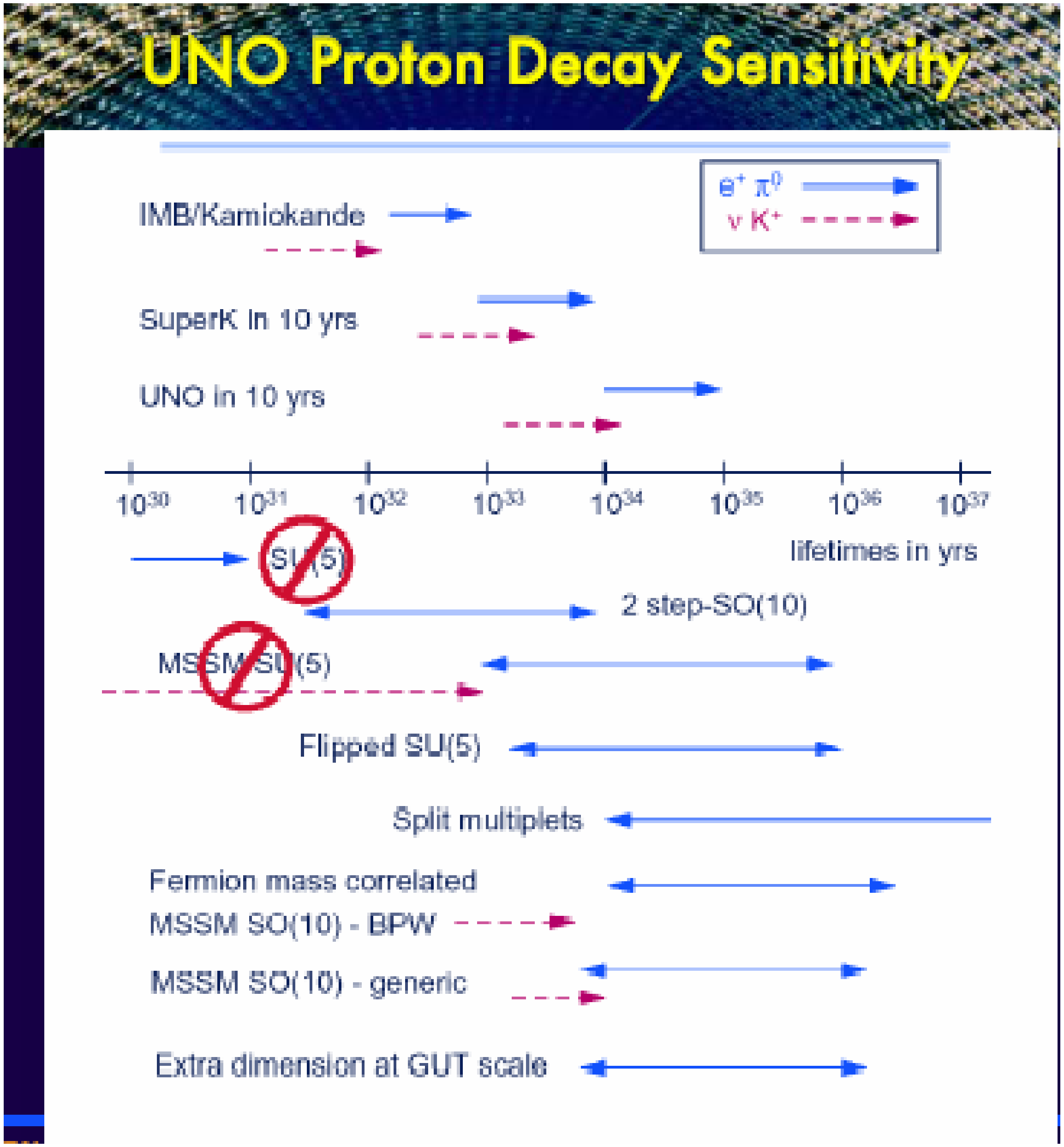


Fréjus underground lab.

A large underground water Cerenkov (400 kton) UNO/HyperK or/and a large L.Arg detector.

also : proton decay search, supernovae events solar and atmospheric neutrinos. Performance similar to J-PARC II

There is a window of opportunity for digging the cavern stating in 2008 (safety tunnel in Frejus)



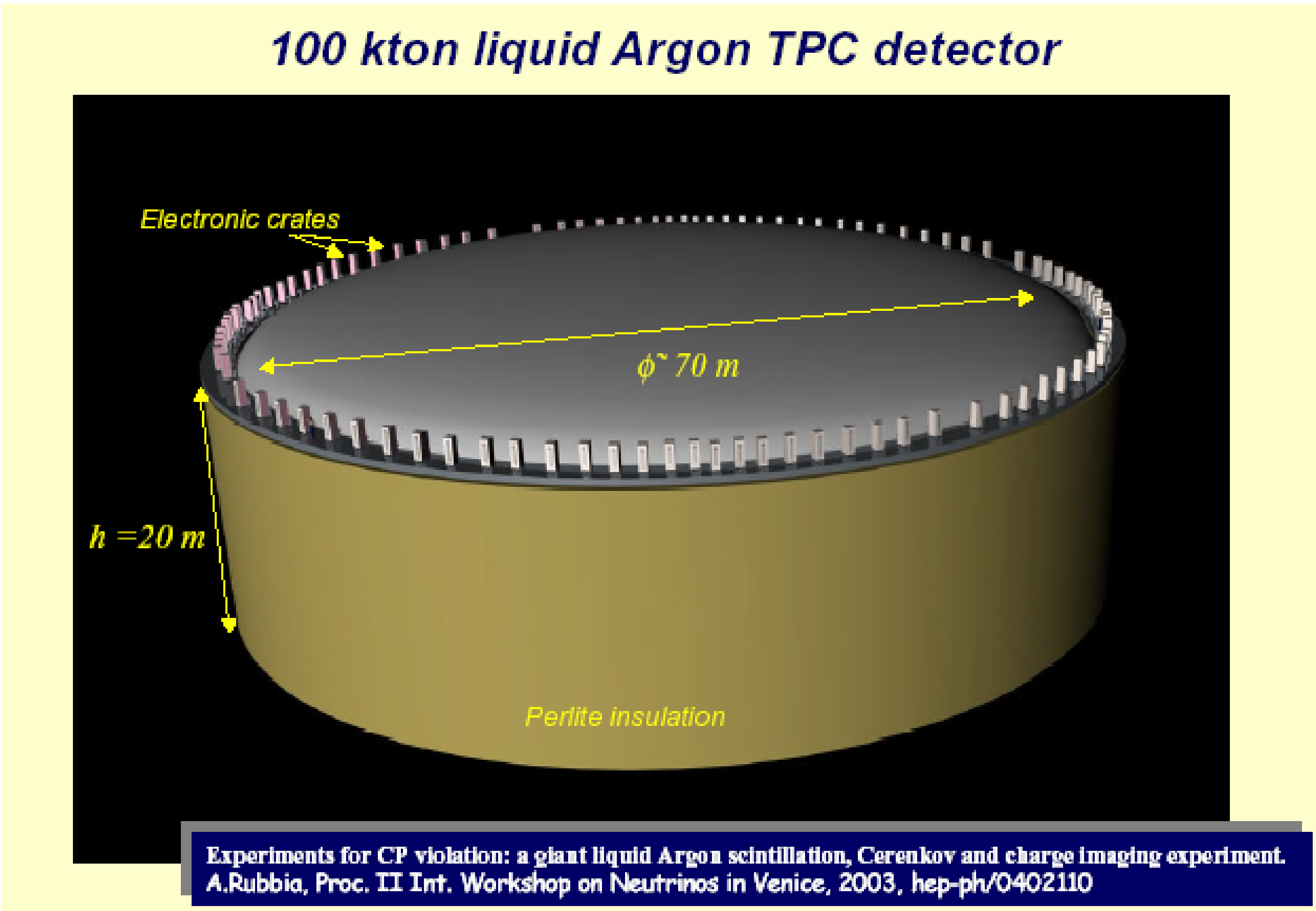
Evident synergy
Astro-particle

NNN 05, March 2005
Aussois

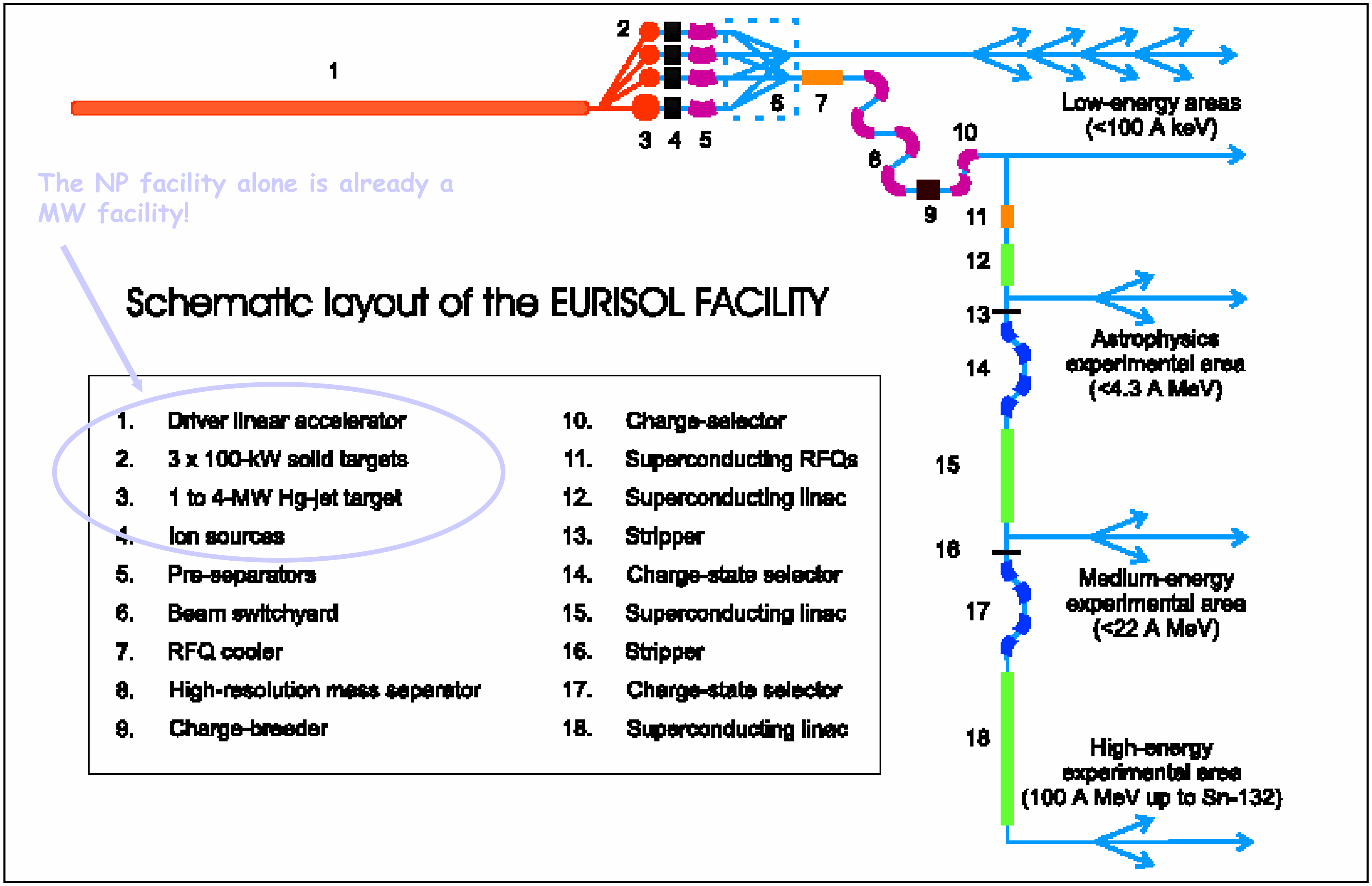
Next
Nucleon Decay &
Neutrino Detector

Detectors ….. again UNO/HyperK

but also



EURISOL Overall Baseline Layout



EURISOL 4 yrs Design Study Approved mid 04
FP6 Contract being prepared Jan 05

WP1

………

G.Fortuna INFN
P. Butler
Y. Blumenfeld
(M. Lindroos)

Flying !!!!!

……….

WP11 Betabeam(Benedikt)

…………

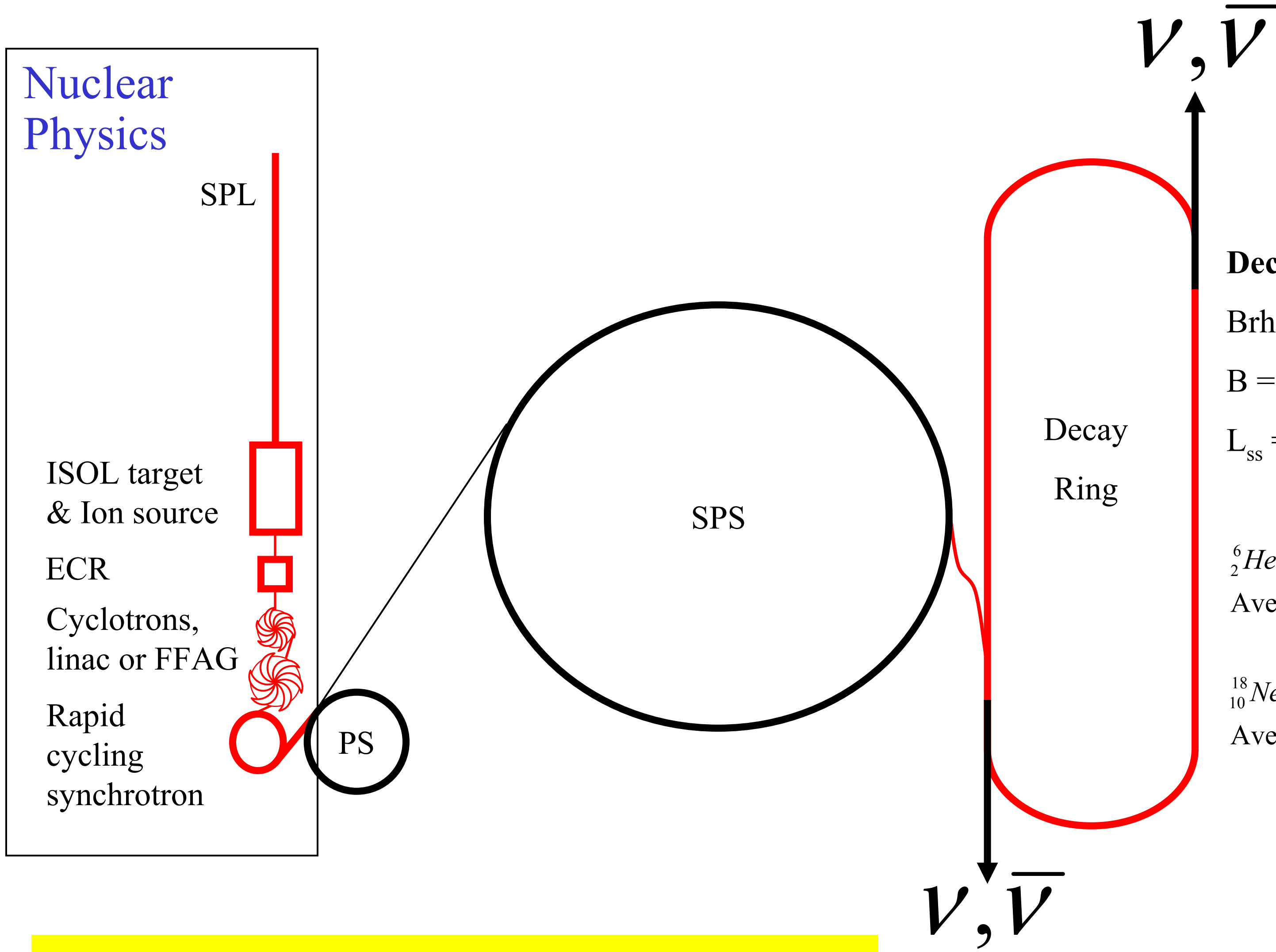
Eurisol Design Study Tasks

- Preparatory meeting for EURISOL design study in Orsay.
- First drafts presented by task coordinators.

1. Proton Accelerator (Alberto Facco, INFN-LNL)
2. Heavy-Ion Accelerator (MH. Moscatello, GANIL)
3. Cryomodule Development (S. Bousson, IPNO)
4. Direct Target/Ion Source (J. Lettry, CERN)
5. Solid Converter-Target/Ion Source (L. Tecchio, INFN-LNL)
6. Liquid-Metal Target/Ion Source (F. Groeschel, PSI)
7. Safety and Radioprotection (D. Ridikas, CEA-Saclay)
8. Beam Preparation (A. Jokinen, JYFL)
9. Physics and Instrumentation (R. Page, U. Liverpool)
10. Beam Intensity Calculations (K.H. Schmidt, GSI)
11. Beta-Beam Aspects (M. Benedikt, CERN)
12. Co-ordination and Layout (Not yet allocated)

CERN: β-beam baseline scenario

EU pride



Decay ring

Brho = 1500 Tm

B = 5 T

L_{ss} = 2500 m

${}^6_2He \to {}^6_3Li\, e^- \bar{\nu}$

Average $E_{cms} = 1.937$ MeV

${}^{18}_{10}Ne \to {}^{18}_9 Fe\, e^+ \nu$

Average $E_{cms} = 1.86$ MeV

Same detectors as Superbeam !

W Workshop

Multiple beta beam regimes

Low energy ……. $\gamma_{ion} \approx 1\text{-}10$ E_{ν_e} few 10 MeV (C. Volpe)
neutrino reactions
nuclear (astro-)physics,
solar , supernovae

Medium energy …. $\gamma_{ion} \approx 100$ E_{ν_e} few 100 MeV (M . Mezzetto)
massive low density detector
very large !!!!

High energy ……… $\gamma_{ion} \gtrsim 500$ E_{ν_e} GeV & multi GeV (P. Hernandez & al.)
denser, smaller, farther detectors
same as NuFact?

NB Main issues are technical !!!
may well be an evolutive process (M. Lindroos)

Electron neutrinos !!!!

(terrestrial) emphasis shifting to subdominant $\nu_e \leftrightarrow \nu_\mu$ transition

$\nu_\mu \rightarrow \nu_e$ Conventional beam, dirtish

$\nu_e \rightarrow \nu_\mu$ Beta beam, clean

$\nu_e \rightarrow \nu_\mu$ NuFact, clean

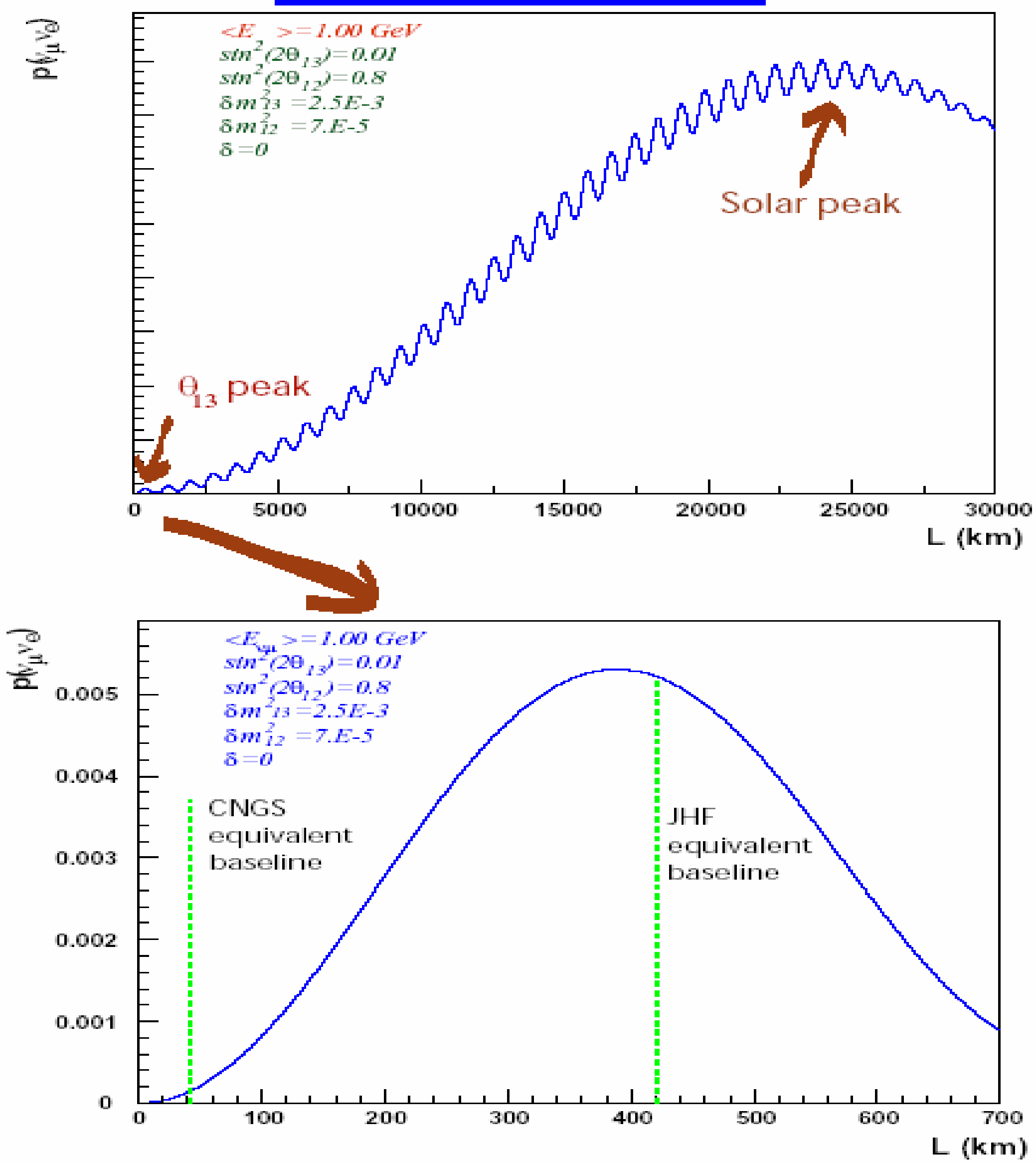
$\nu_e \rightarrow \nu_\tau$

Why subleading?

solar $\nu_e \rightarrow \nu_{active}$

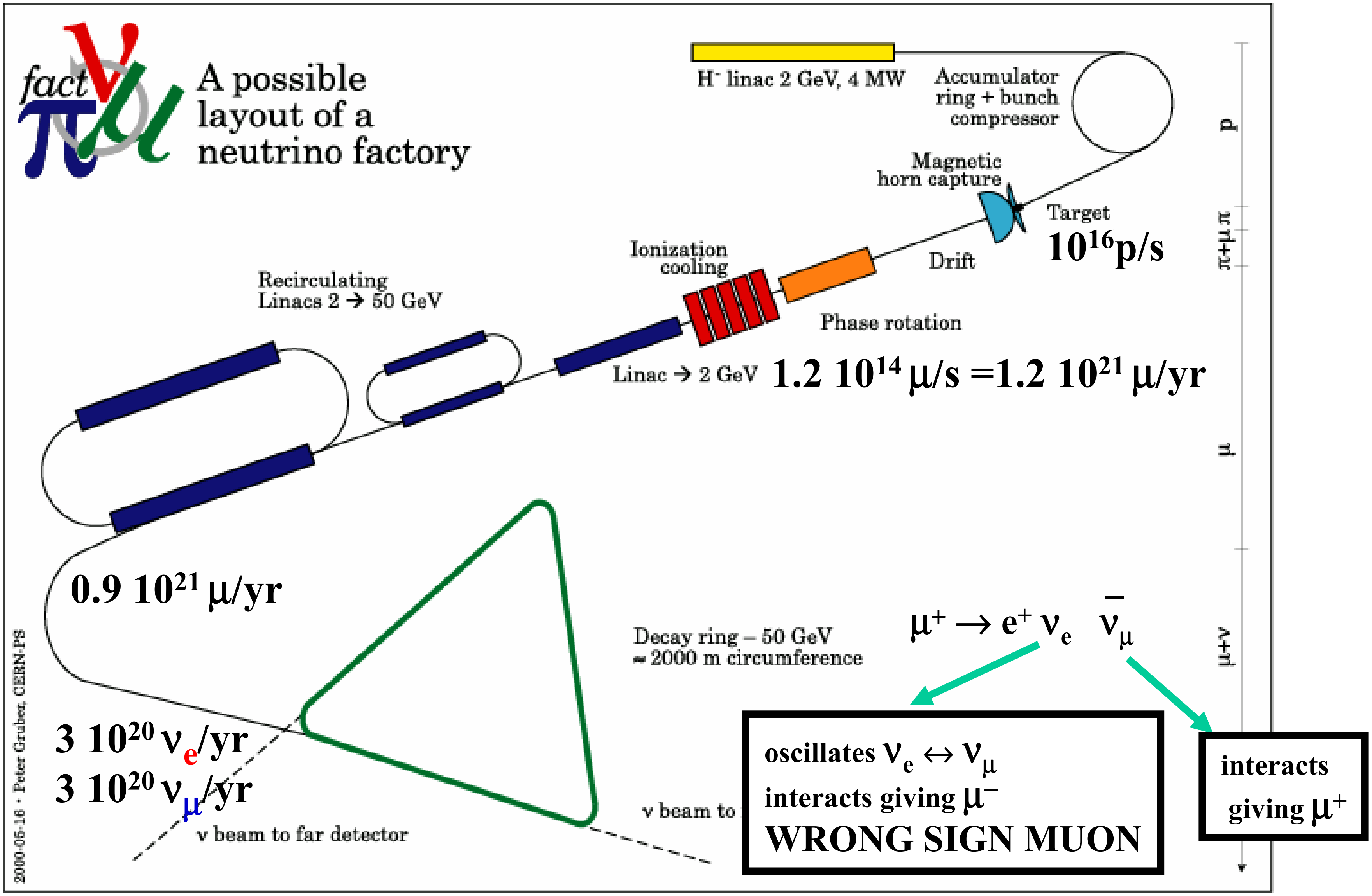
terrestrial $\nu_\mu \leftrightarrow \nu_\tau$

$\leftrightarrow \nu_e$

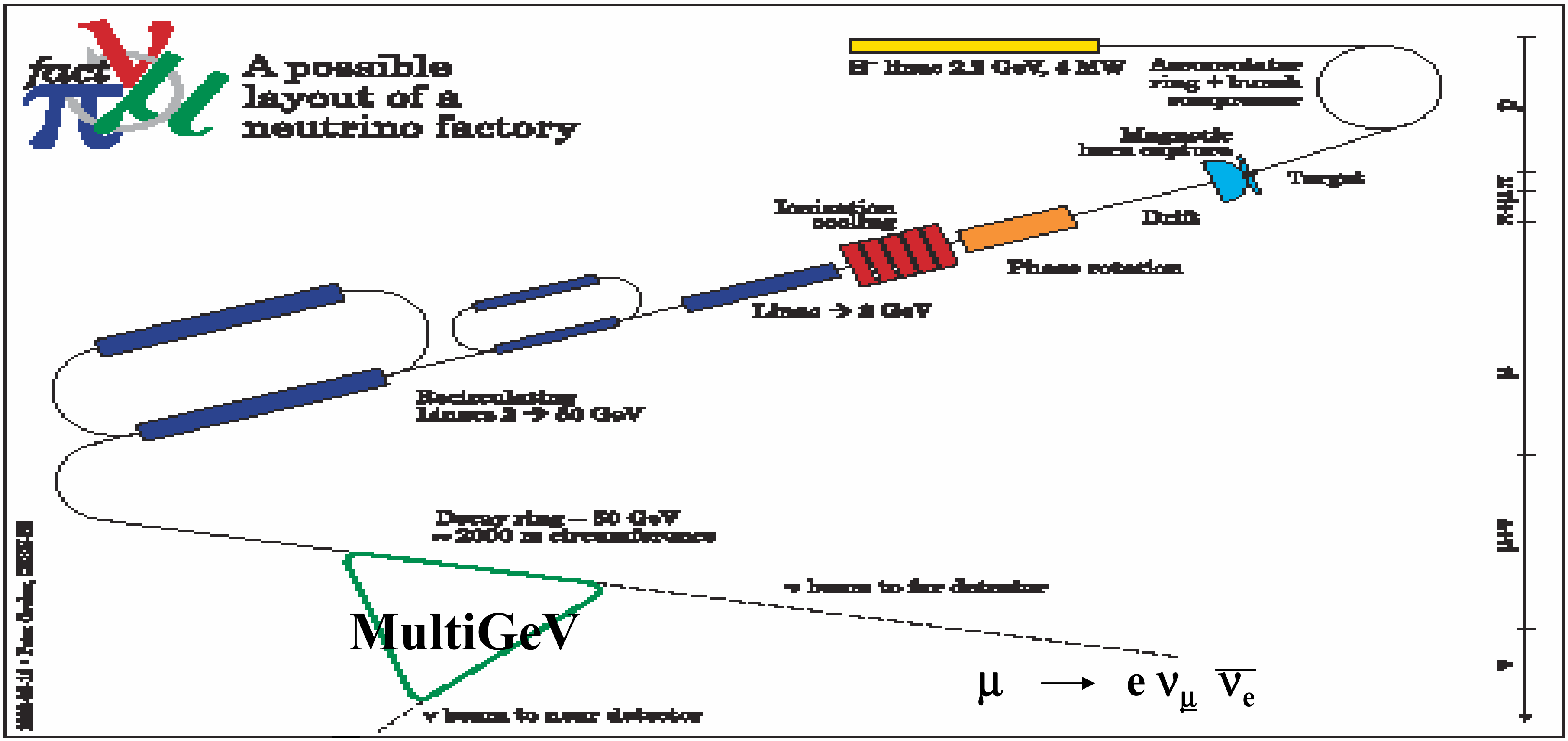


M. Mezzetto, "Introduction to Physics", ENG meeting, CERN, March 26, 2003. . 8

-- Neutrino Factory -- CERN layout



Neutrino Factory: CERN Scheme



$\mu \rightarrow e\, \nu_\mu\, \nu_e$

Disappearance	Appearance	Appearance … Wrong Charge Signature		
$\bar{\nu}_e \rightarrow \bar{e}$ deficit	$\nu_\mu \rightarrow \nu_e \rightarrow e$ excess	$\bar{\nu}_e \rightarrow \bar{\nu}_\mu \rightarrow \bar{\mu}$ excess	Golden	!
Vill: $\nu_\mu \rightarrow \mu$ deficit	$\nu_\tau \rightarrow \tau$ excess	$\bar{\nu}_\tau \rightarrow \bar{\tau}$ excess	Silver	

Magnetic detector

The matrix of neutrino transition probability

P_{ee}=1- …..

$P_{e\mu}$=

- 4 Re $J_{e\mu}^{13}\sin^2\Delta_{13}$
- 4 Re $J_{e\mu}^{23}\sin^2\Delta_{23}$
$\pm$ 8J $\sin\Delta_{12}\sin\Delta_{23}\sin\Delta_{13}$

golden

BetaBeam, NuFact

$P_{e\tau}$= -

- 4 Re $J_{e\tau}^{13}\sin^2\Delta_{13}$
- 4 Re $J_{e\tau}^{23}\sin^2\Delta_{23}$
$\pm$ 8J $\sin\Delta_{12}\sin\Delta_{23}\sin\Delta_{13}$

silver

NuFact

$P_{\mu e}$ =

- 4 …
- 4 …
- ($\pm$ 8J….

$P_{\mu\mu}$=1- …..

$P_{\mu\tau}$=

- 4 Re $J_{\mu\tau}^{13}\sin^2\Delta_{13}$
- 4 Re $J_{\mu\tau}^{23}\sin^2\Delta_{23}$
$\pm$ 8J $\sin\Delta_{12}\sin\Delta_{23}\sin\Delta_{13}$

SuperBeam, NuFact

$P_{\tau e}$ = …….

$P_{\tau\mu}$= …..

$P_{\tau\tau}$=1- …..

NuFact does them all !

The matrix of neutrino transition probability

P_{ee}=1- …..

$P_{e\mu}$=
- $- 4 \text{ Re } J_{e\mu}^{13}\sin^2\Delta_{13}$
- $- 4 \text{ Re } J_{e\mu}^{23}\sin^2\Delta_{23}$
- $\pm 8J \sin\Delta_{12}\sin\Delta_{23}\sin\Delta_{13}$

golden

$P_{e\tau}$= -
- $- 4 \text{ Re } J_{e\tau}^{13}\sin^2\Delta_{13}$
- $- 4 \text{ Re } J_{e\tau}^{23}\sin^2\Delta_{23}$
- $\pm 8J \sin\Delta_{12}\sin\Delta_{23}\sin\Delta_{13}$

silver

BetaBeam, NuFact

$P_{\mu e}$ =
- \- 4 …
- \- 4 …
- \- (± 8J….

$P_{\mu\mu}$=1- …..

$P_{\mu\tau}$=
- $- 4 \text{ Re } J_{\mu\tau}^{13}\sin^2\Delta_{13}$
- $- 4 \text{ Re } J_{\mu\tau}^{23}\sin^2\Delta_{23}$
- $\pm 8J \sin\Delta_{12}\sin\Delta_{23}\sin\Delta_{13}$

SuperBeam, NuFact

$P_{\tau e}$ = …….

$P_{\tau\mu}$= …..

$P_{\tau\tau}$=1- …..

The Neutrino Factory does them all !

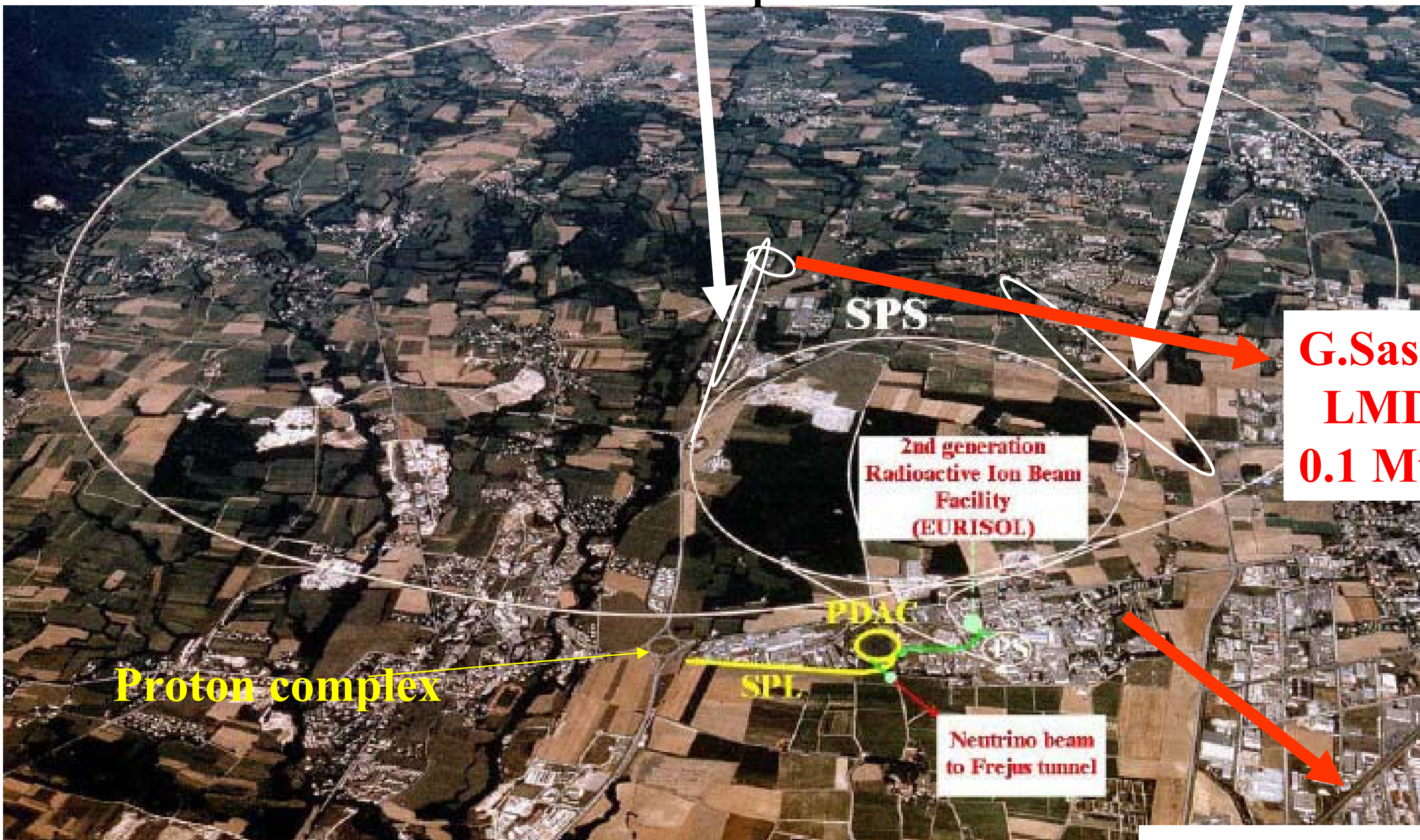
Old and new european underground laboratories

Garoby
Haseroth
Lindroos

EU Neutrino Complex

BetaRing

Muon Complex



G.Sasso
LMD
0.1 Mto

Frejus 1 Mton
Water C

Physics Reach in one plot only (Mezzetto, Blondel)

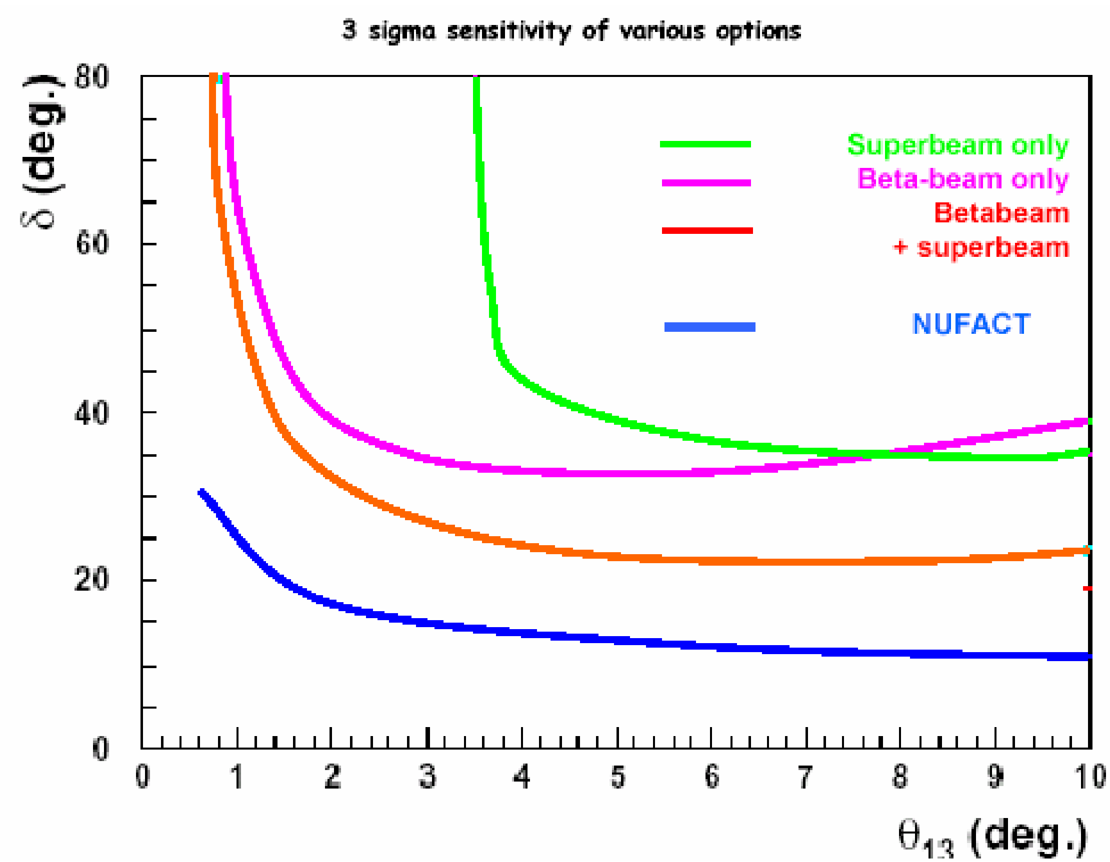


Figure 7 : 99%CL δ sensitivity of the beta-beam, of the SPL-SuperBeam, and of their combination, see text. Dotted line is the combined Superbeam+beta-beam sensitivity computed for sign(Δm_2)=-1. Sensitivities are compared with a 50 GeV Neutrino Factory producing $2\times10_{20}\mu$ decays/straight section/year, and two 40 kton detectors at 3000 and 7000 km

$A_{\not{CP}} = \dfrac{P_\nu - P_{\bar\nu}}{P_\nu + P_{\bar\nu}}$ **$\nu/\bar\nu$ asymmetry**

$\nu_e \rightarrow \nu_\mu$	**at NuFact + Betabeam**
$\nu_\mu \rightarrow \nu_e$	**Superbeam**

$A_{\not{T}} = \quad \longrightarrow \quad \longleftarrow$ **asymmetry …**

$\nu_e \leftrightarrow \nu_\mu$	**at NuFact?**
$\nu_e \leftrightarrow \nu_\mu$	**Betabeam + Superbeam**

$A_{\not{C}PT}$ **both asymmetries**

Betabeam +

Superbeam

All of great interest!

The betabeam/superbeam synergy

CP Searches

- SuperBeam running with ν_μ and $\overline{\nu}_\mu$.
- Beta Beam running with ^{6}He ($\overline{\nu}_e$) and ^{18}Ne (ν_e).

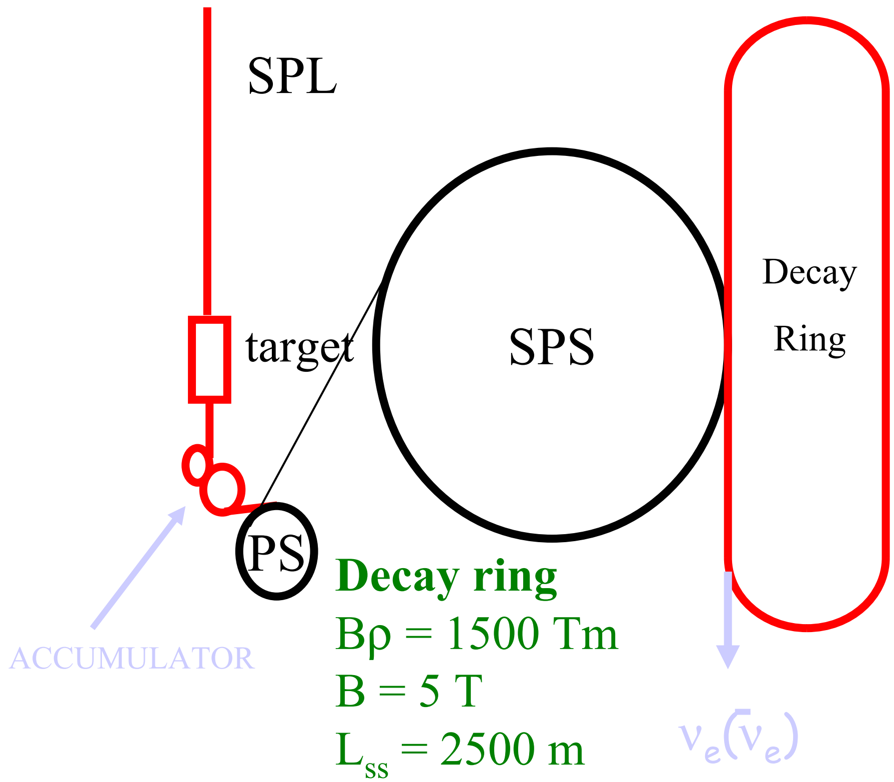
T searches

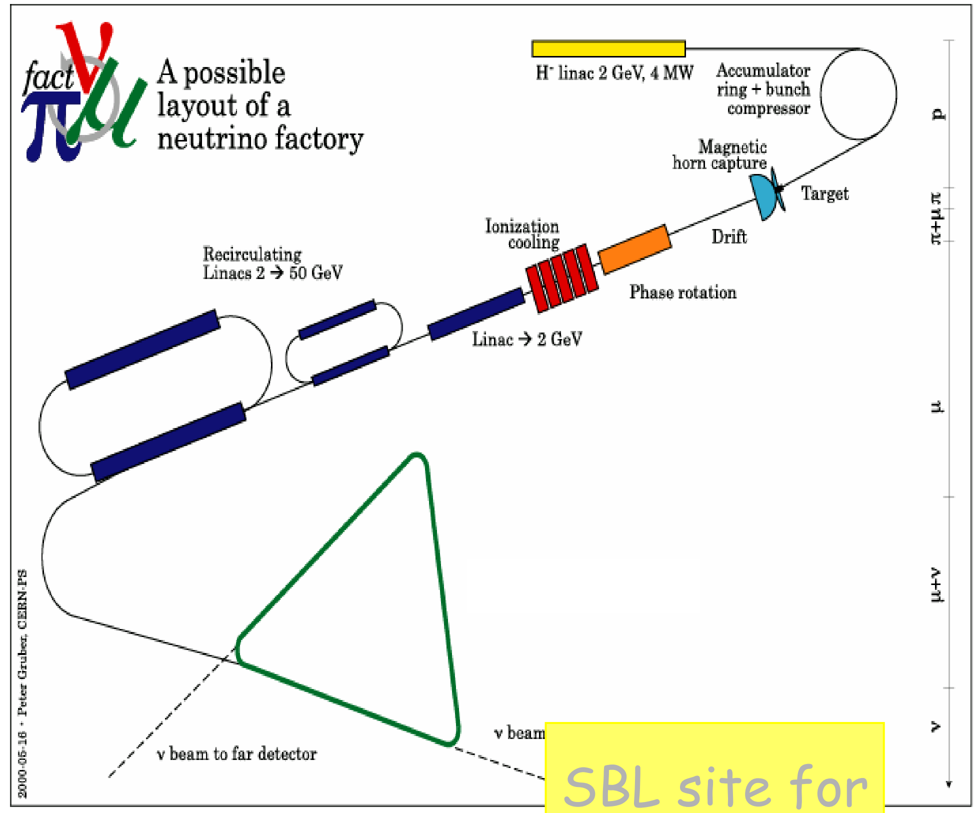
- Compare Super Beam $p(\nu_\mu \rightarrow \nu_e)$ with Beta Beam ^{18}Ne $p(\nu_e \rightarrow \nu_\mu)$
- Compare Super Beam $p(\overline{\nu}_\mu \rightarrow \overline{\nu}_e)$ with Beta Beam ^{6}He $p(\overline{\nu}_e \rightarrow \overline{\nu}_\mu)$.

CPT searches

- Compare Super Beam $p(\nu_\mu \rightarrow \nu_e)$ with Beta Beam ^{6}He $p(\overline{\nu}_e \rightarrow \overline{\nu}_\mu)$.
- Compare Super Beam p($\overline{\nu}_\mu \rightarrow \overline{\nu}_e$) with Beta Beam ^{18}Ne $p(\nu_e \rightarrow \nu_\mu)$

NB: near-detector sites essential





Common near design for both SuperBeam and β-beam?

SBL site for the νFact

International R&D !!!!!

- Intersection of interests from HEP, NP and AP communities; and international community (Japan: Hyper-Kamiokande, Europe: CERN/Fréjus (133 km) initiatives
  - A well organized international effort with a common physics goals and strong mutual support can bring a successful experiment somewhere in the world

MMW-CERN, May. 2004 Chang Kee Jung

Superbeam and Neutrino Factory R&D

Proton driver (and accumulator etc..)

Target area, targetry & collection

Muon Ionization Cooling.

Acceleration.

Detectors

Superbeam/Neutrino factory FP6 design study proposal in preparation for early 2005

--> be ready for decisions in 2010!

NB Nearly all of the accelerator R&D has, from the start, had a healthy level of global collaboration. Examples: MUSCAT, MUCOOL, Targetry, HARP, Design Studies I and II, …

Targetry & Collection: Proposal to test a 10m/s Hg Jet in a 15T Solenoid with an Intense Proton Beam

Note: The solenoid is under construction, and the Hg-jet under development.

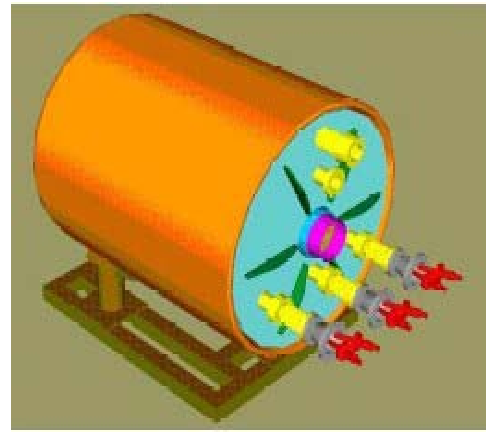
CERN-INTC-2003-033
INTC-I-049
26 April 2004

A Proposal to
the ISOLDE and Neutron Time-of-Flight Experiments Committee

Studies of a Target System for a 4-MW, 24-GeV Proton Beam

J. Roger J. Bennett[1], Luca Bruno[2], Chris J. Densham[1], Paul V. Drumm[1], T. Robert Edgecock[1], Tony A. Gabriel[3], John R. Haines[3], Helmut Haseroth[2], Yoshinari Hayato[4], Steven J. Kahn[5], Jacques Lettry[2], Changguo Lu[6], Hans Ludewig[5], Harold G. Kirk[5], Kirk T. McDonald[6], Robert B. Palmer[5], Yarema Prykarpatskyy[5], Nicholas Simos[5], Roman V. Samulyak[5], Peter H. Thieberger[5], Koji Yoshimura[4]

Spokespersons: H.G. Kirk, K.T. McDonald
Local Contact: H. Haseroth

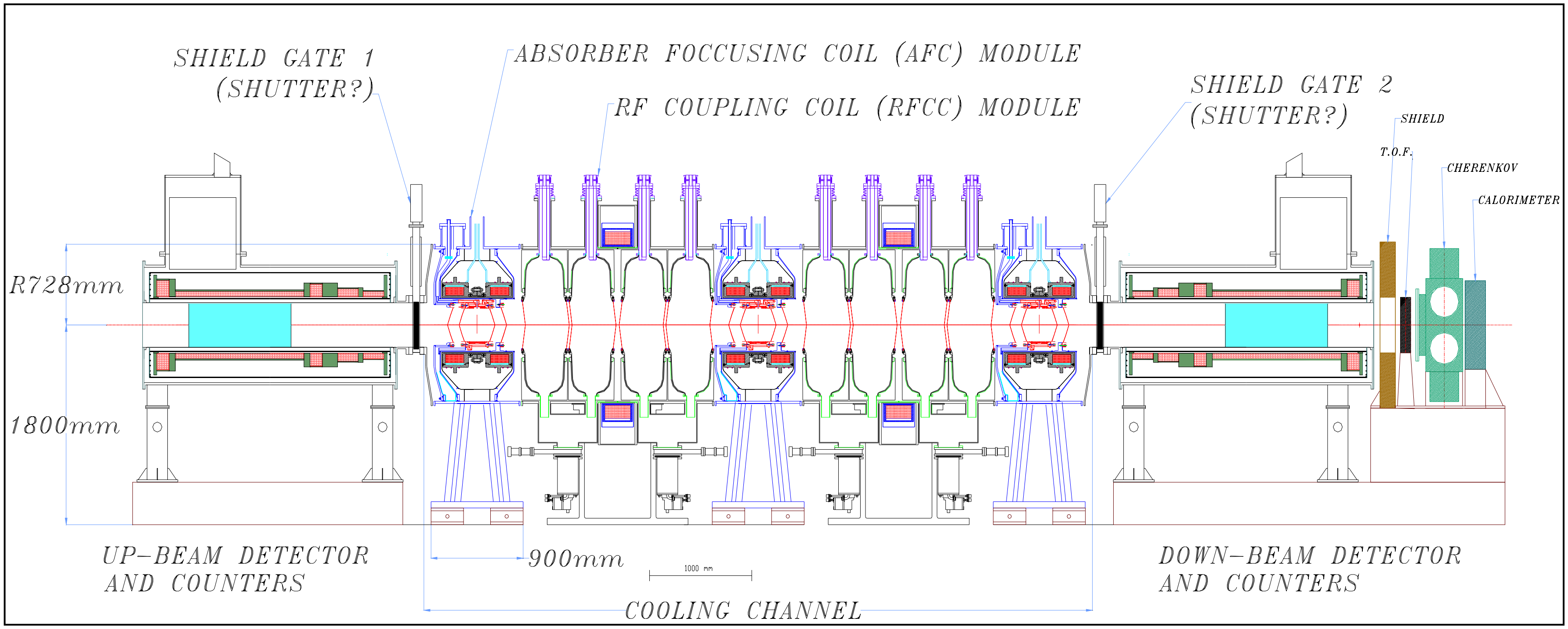


Participating Institutions

1) RAL
2) CERN
3) KEK
4) BNL
5) ORNL
6) Princeton University

MICE – a Global Muon Ionization Cooling Experiment

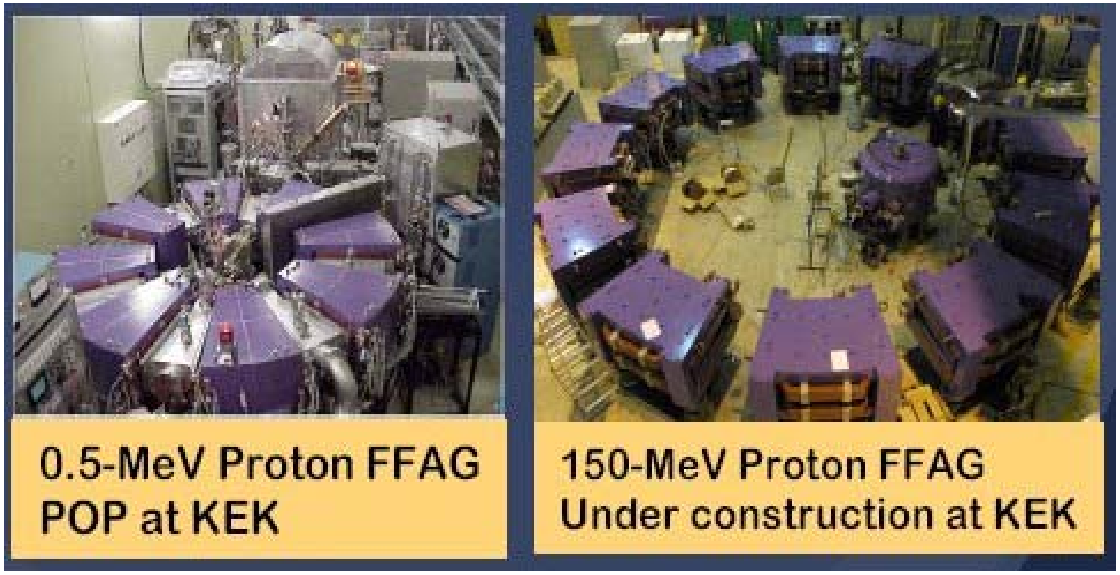
Build & operate a section of a realistic cooling channel & measure its performance in a muon beam (at RAL) for various operation modes & beam conditions.

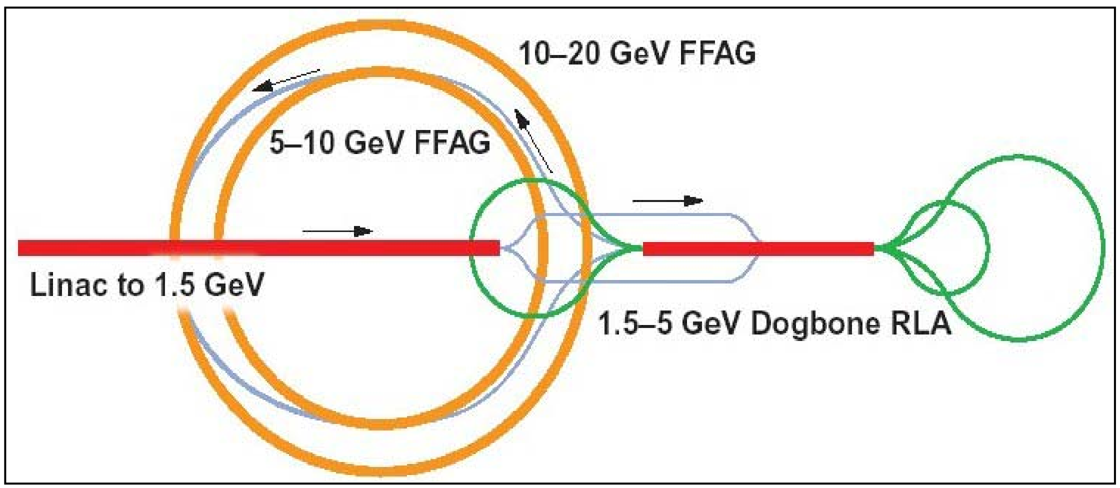


Has Scientific Approval and is seeking funding.

NB US, Europe and Japan !!!!!!!!!

Acceleration





New US Acceleration Scheme … still evolving

Much progress in Japan with the development and demonstration of large acceptance FFAG accelerators.

Latest ideas in US have lead to the invention of a new type of FFAG (so-called non-scaling FFAG) which is interesting for more than just Neutrino Factories & may require a demonstration experiment (plans are developing)

Perhaps US & Japanese concepts are merging to produce something better ??

Neutrino Factory: towards cost reduction

	Study 2	Now	Factor
PHASE ROTATION			
Beam Line (m)	328	166	51 %
Acceleration (m)	269	35	13 %
Acc Type	Induction	Warm RF	
COOLING			
Beam Line (m)	108	51	47 %
Acceleration (m)	74	34	46 %
Absorbers	Liquid Hydrogen	Solid Li or LiH	
ACCELERATION			
Beam Line (m)	3261	$\approx$ 700	$\approx$ 21 %
Tun Length	1494	$\approx$ 700	$\approx$ 47 %
Acc Length	288	$\approx$ 130	$\approx$ 45 %

1.1.10 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 1 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 1 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.

most cheerful news to the friends of the neutrino

Conclusions:

An European strategy, based on a new powerful

in WW context !

<u>MWatt proton Driver</u>

for a new **<u>European Neutrino Complex</u>**

comprising part or all of

Superbeam

Eurisol/Betabeam

Neutrino Factory

deserves careful attention

(at least) one point that does need clarification ....

The richness of options

ν Superbeam
ν Betabeam
ν Factory

and the animated debate on the choice of $<E_\nu>$ & $L_{detector}$

should not obscure the fact that ALL options DO need

a Megawatt Proton Beam
& a Megawatt Target-Collection Complex

This emerges consensually as
the highest priority
for European accelerator ν

In the framework of the yearly general CARE Meeting (DESY, Hamburg Nov 2 –6) we will hold a

ECFA/BENE Workshop

on

The future of accelerator neutrino experiments in Europe

http://people.na.infn.it/~palladin/041102BENE/BENE04PreliminaryAgenda.pdf

Nov 2-3, 2004, DESY, Hamburg

This is the 3rd and last ECFA/BENE meeting in 2004. It will be reviewing the opportunities offered to both neutrino physics and accelerator physics by a vigorous European initiative in the sector of superior conventional & novel neutrino beams beyond the CNGS.

It will include:

1) a theoretical, phenomenological and experimental discussion of beam options, beam energies, baselines, sites and neutrino detectors

2) a review of the technical challenges (proton drivers, targets, collection systems) common to all beam options as well as of those specific of betabeams (production, acceleration and storage of radioactive ions) and of neutrino factories (muon phase rotation, cooling, acceleration & storage).

1.1 Recommended accelerator R&D

1.1.1 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.

1.1.2 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.

1.1.3 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.

Gilardoni
Haseroth
Lindroos

Friday

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.

1.2 Recommended detector R&D

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 **Error! Reference source not found.**. 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.

Blondel, Mezzetto, Mosca

Friday

1.3 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

BENE General plans & Milestones

CARE04 Nov DESY

NNN05 Frejus March

NuFact05 June (Frascati)

Interim Report to EC — Input to first round of discussion at CERN ***Dec 06***

CARE 05 Nov

…………………………

NuFact08 EU again June

Final Report to EC — Input to second round of discussion at CERN ***Dec 09***

CDR for a new MMW ν-Complex