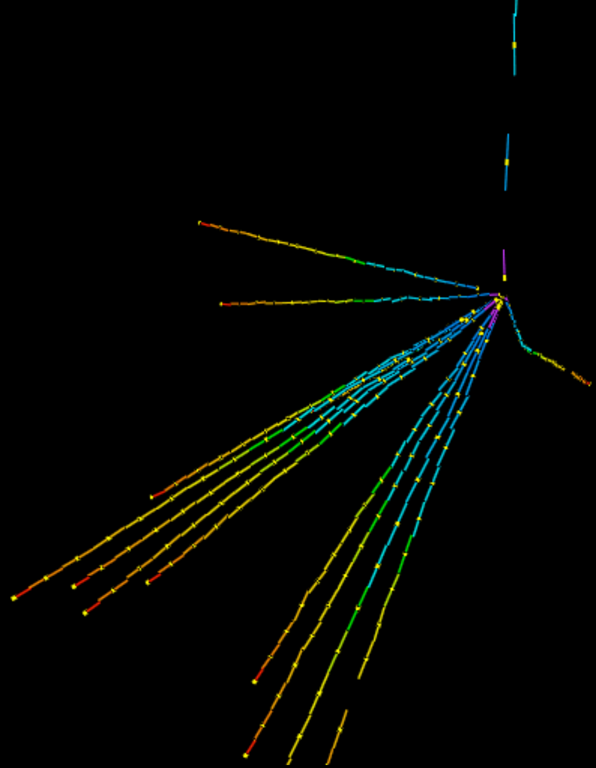
Swiss prospects on neutrino physics



A. Ereditato

A. Einstein Center for Fundamental Physics

LHEP, Bern University

LABORATORIUM FÜR HOCHENERGIEPHYSIK LHEP UNIVERSITÄT BERN

• Neutrino physics is one of the main subjects of modern particle physics, and one of the pillars of the CH particle physics road-map

• Swiss researchers have long-standing esperience in the field

• CH participation in international experiments underway or planned:

1) measurement of neutrino properties (low energy)

2) large-size neutrino observatories (ICECUBE)

3) neutrino oscillation physics

4) active participation in initiatives for future experiments (long term plans, EU programs,..)

• Large visibility of the Swiss groups (detector construction, data analysis and project management)

• Outstanding scientific results near to come under the action of a very motivated community

• The strong support of CH funding agencies is acknowledged for detector construction and conduction (SNF and Universities)

• QUESTION: can we envision an ambitious (although realistic) mid-long term road-map complying with international (and national) financial/manpower constraints and guaranteeing the participation of CH physicists to frontier experiments ?

Experiments with large observatories

Detection of VHE neutrinos with large size detectors

IceCube experiment (EPFL)

Present CH activities centered on three main subjects:

- Neutrino oscillations
- Cosmology
- Multi messengers (rising star)

Important data expected in the next ~5 years. Need to support this line of research, at the time unique and also complementary to other astroparticle physics studies and to other on going and planned neutrino experiments.

Experiments on neutrino properties

Majorana-Dirac nature of the massive neutrinos and mass measurements: $0\nu\beta\beta$-decay

EXO and GERDA experiments (Bern, Zurich)

EXO will soon start: its mid-long term future should be discussed. Interest from Geneva

GERDA has a well established road-map that could bring to high sensitivity measurements (FOLIS)

Reasonable expectation: Swiss researchers will continue their first class involvement in low energy neutrino physics. Activity to be strongly supported by the CHIPP community.

Neutrino oscillation experiments

OPERA, T2K, NA61 experiments are being successfully conducted (Bern, ETHZ, Geneva)

Mid term: prominent R&D activities and scientific initiatives

Far future: MICE, Nufact, Euronu initiatives well on the way

Goal: guarantee continuity in the research, without gaps that would weaken the community and prevent important scientific achievements. Profit of the rather large interest (groups and people) and of the recognized scientific leadership. Define a realistic/ambitious road-map.

Swiss people working on neutrino oscillations

Bern: A. Ariga, T. Ariga, F. Bay, A. Ereditato, E. Frank, F. Juget, J. Knüsel, I. Kreslo, G. Lutter, F. Meisel, M. Messina, U. Moser, C. Pistillo, B. Rossi, K. Pretzl, J.L. Vuilleumier

ETHZ: A. Badertscher, A. Curioni, A. Gendotti, S. Horikawa, L. Knecht, C. Lazzaro, A. Marchionni, G. Natterer, V. Pettinacci, A. Rubbia, C. Strabel, T. Strauss

Geneva: N. Abgrall, J. Argyriades, A. Blondel, A. Bravar, F. Dufour, A. Ferrero, A. Korzenev, S. Murphy, M. Ravonel, R. Schroeter, V. Verguilov, G. Wikstrom

About 40 physicists + engineers, with large scientific contributions, important role and responsibilities:

It is desirable (and realistic) assuming that this community will continue jointly along a coherent line of research

The physics

• 1998 revolution in neutrino physics: discovery of neutrino oscillations with atmospheric neutrinos confirmed by LBL accelerator experiments (Super-Kamiokande, with contributions from Kamiokande, MACRO, SOUDAN2, K2K and MINOS)

• Supported by the observation of neutrino oscillations with solar and reactor neutrinos (Super-Kamiokande, SNO, Kamland, Homestake, GALLEX, SAGE, GNO, CHOOZ, Palo Verde)

• Neutrinos oscillate, hence they are massive particles and mix (analogously to quarks):

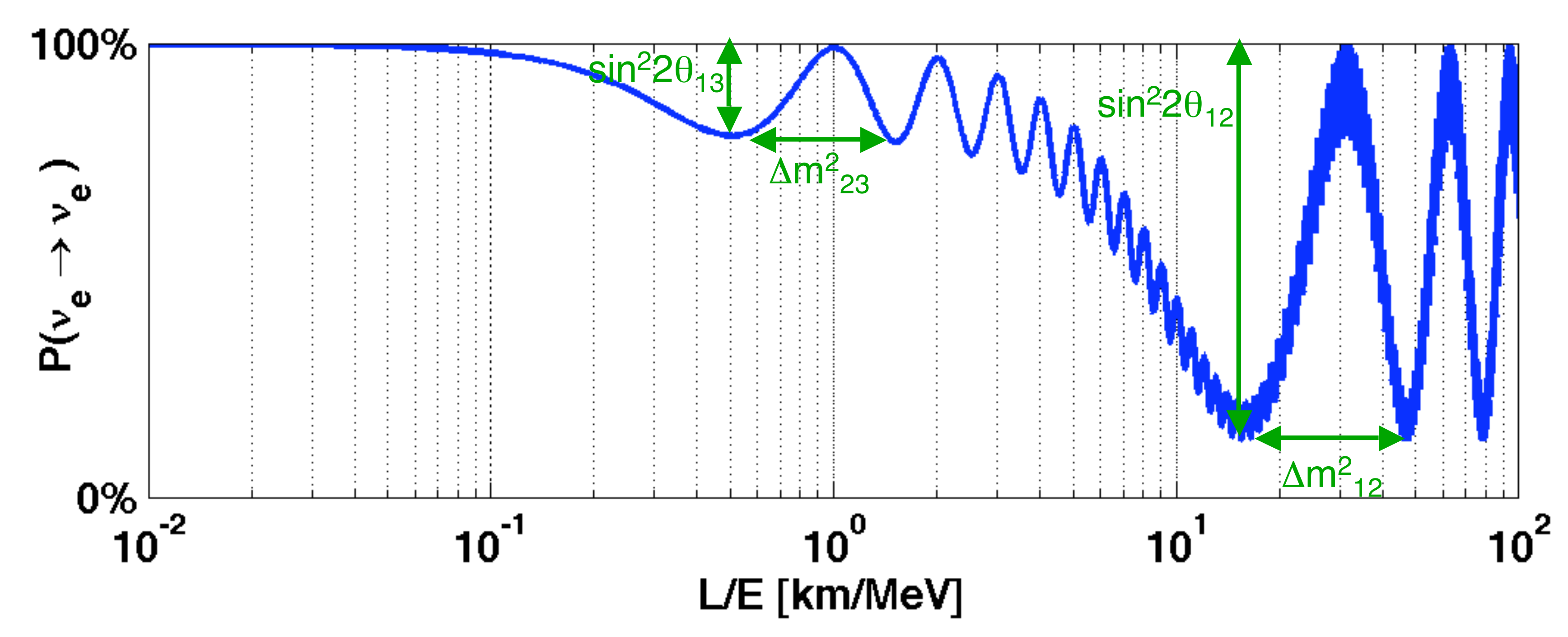
$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix} \begin{pmatrix} e^{i\alpha_1/2}\ \nu_1 \\ e^{i\alpha_2/2}\ \nu_2 \\ \nu_3 \end{pmatrix}$$

$$P(\nu_\ell \to \nu_{\ell'}) = \Big|\sum_i U_{\ell i} U^*_{\ell' i} e^{-i(m_i^2/2E)L}\Big|^2$$

$$= \sum_i |U_{\ell i} U^*_{\ell' i}|^2 + \Re \sum_i \sum_{j \neq i} U_{\ell i} U^*_{\ell' i} U^*_{\ell j} U_{\ell' j} e^{i\frac{|m_i^2 - m_j^2| L}{2E}}$$

PMNS matrix mixing parameters can be determined by measuring specific oscillation channels' probabilities

Example: ν_e survival probability as a function of L/E



Work in progress

Two missing tiles in the neutrino oscillation mosaic:

goals of current accelerator (reactor) LBL ν experiments:

1. Direct observation of the “appearing” neutrino flavor (dedicated OPERA experiment)
2. Measurement of the still unknown θ_{13} mixing angle (T2K experiment, among other projects being realized or planned, such as Double-Chooz, Daya-Bay, NOvA)

OPERA: τ appearance

$$P(\nu_\mu \rightarrow \nu_\tau) \sim \sin^2 2\theta_{23} \cos^4\theta_{13} \sin^2(\Delta m^2_{23} L/4E)$$

T2K: ν_μ disappearance

$$P(\nu_\mu \rightarrow \nu_x) \sim 1 - \cos^4\theta_{13} \sin^2 2\theta_{23} \sin^2(\Delta m^2_{23} L/4E)$$

T2K: ν_e appearance

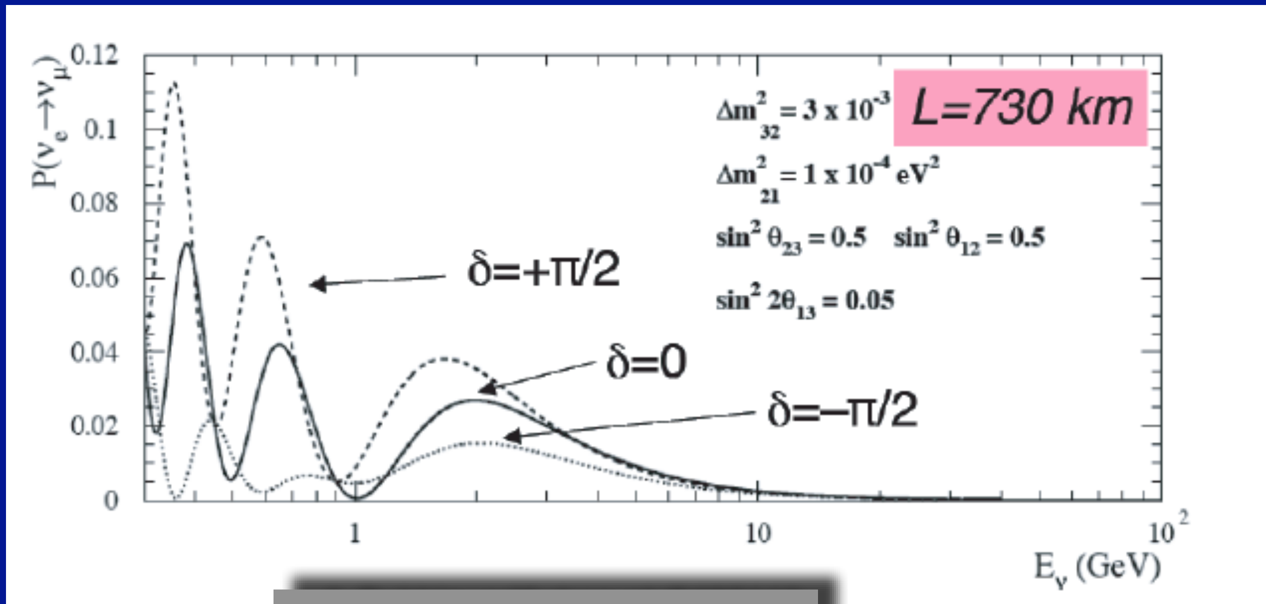
$$P(\nu_\mu \rightarrow \nu_e) \sim \sin^2 2\theta_{13} \sin^2\theta_{23} \sin^2(\Delta m^2_{23} L/4E)$$

The further step will be the discovery of CP violation in the lepton sector, allowed in the PMNS mixing matrix (phase δ), if θ_{13} is not vanishing. This would be a fundamental discovery in particle physics with implications to astrophysics and cosmology.

The phase δ can induce CP violation with different oscillation probabilities for neutrinos and antineutrinos:

$$A_{CP} = \frac{P(\overline{\nu}_e \to \overline{\nu}_\mu) - P(\nu_e \to \nu_\mu)}{P(\overline{\nu}_e \to \overline{\nu}_\mu) + P(\nu_e \to \nu_\mu)} \simeq \frac{\sin 2\theta_{12}}{\sin \theta_{13}} \cdot \sin\delta \cdot \sin \frac{\Delta m^2_{12} L}{4E}$$

Note, however, that matter effects can influence differently the propagation of neutrinos and antineutrinos (on top of the possible effect of δ). Also, energy dependence of the effect:



A. Rubbia, arXiv:hep-ph/0402110

Considerations on a global CH neutrino strategy

We can schematically describe a possible (sound ?) strategy for experimental neutrino oscillation physics for Switzerland with a four-phases' block diagram:

1	2	3	4
OPERA	T2K	Super-Beam + large neutrino detector	Beta-Beam Neutrino-factory
2008-2012	2009-2015	~ 2015-2020	> 2020-2025
ν_τ appearance	$\sin^2 2\theta_{13}$>0.006 (90%) $\sin^2 2\theta_{13}$>0.018 (3σ)	Matter effects, $\not{C}P$	Ultimate sensitivity to $\not{C}P$

Remarks on the detectors

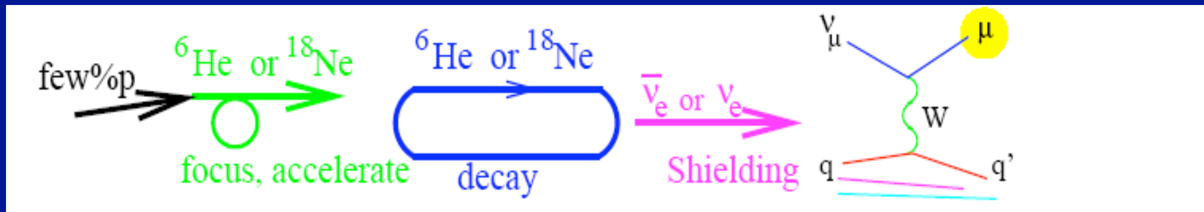
For a phase-3 Super-Beam (ν_μ beam):

Low-energy/short-baseline (<1 GeV/100-200 km): electron detection, event counting, some e/π discrimination and energy resolution, large mass

High-energy/long baseline (~5 GeV/1000-5000 km): richer phenomenology, electron detection, good energy resolution, S/BG discrimination, large mass

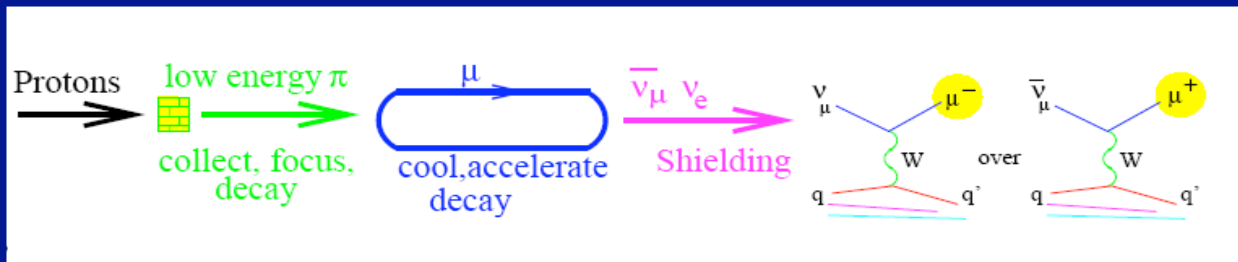
For a phase-4 Beta-Beam (low energy ν_e beam, < 1 GeV):

Muon detection (non magnetized, massive detectors, good event analysis for π BG rejection)



For a phase-4 Nufact (either ν_μ + $\bar{\nu}_e$ or ν_μ + $\bar{\nu}_e$ of high-energy):

Privilege muon detection (magnetized large mass, coarse resolution detector OK ?)



The relevance of a “phase-3” project (1)

• Fill the gap between the present generation of experiments and the “ultimate” Nufact facility: such a multi billion investment should be made on the basis of an adequate understanding of the physics scenario

• Goals of a phase-3 project:

Explore smaller θ_{13} values in the case of negative results from phase-2 experiments

Look for CP violation, following the discovery of θ_{13} from phase-2 experiments

Mass hierarchy (for a sufficiently long baseline experiment)

• Requirements on the beam:

High intensity proton machine to gain a factor ~10 in beam power

Long baseline/short baseline ? Impact on the physics and on the detector design

WBB for multi oscillation peak analysis ?

• Requirements on the detector:

Large mass (sufficient statistics despite the small physics signal and the $1/L^2$ dependence)

Good energy resolution (energy dependence)

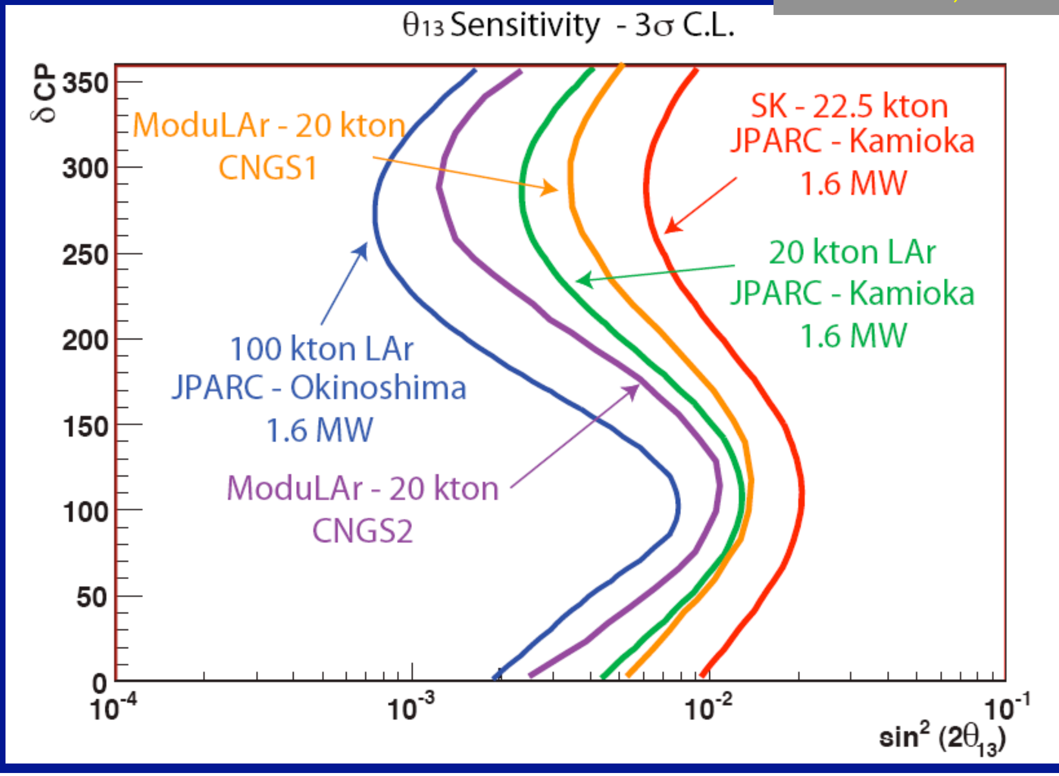
Good BG rejection power

Example:

what can we expect from the next generation high-intensity Super-Beams/detectors?

	J-PARC			CERN SpS			
	design [2]	upgrade [72]	ultimate [2]	CNGS dedicated	+ [61]	1 [73]	2 [73]
Proton energy E_p	30 GeV		40 GeV	400 GeV			
$ppp (\times 10^{13})$	33	67	> 67	4.8	14	4.8	15
T_c (s)	3.64	2	< 2	6	6	6	6
Efficiency	1.0	1.0	1.0	0.55	0.83	0.8	0.8
Running (d/y)	130	130	130	220	220	240	280
N_{pot} / yr ($\times 10^{19}$)	**100**	**380**	**$\simeq 700$**	**7.6**	**33**	**12**	**43.3**
Beam power (MW)	0.6	1.6	4	0.5	1.5	0.5	1.6
$E_p \times N_{pot}$ ($\times 10^{22}$ GeV·pot/yr)	4	11.5	28	3	13.2	4.7	17.3
Relative increase		$\times 3$	$\times 7$	$\times 2$	$\times 7$	$\times 3$	$\times 10$
Timescale	> 2009	2014?	>2014?	> 2008	>2016 ?		

A. Rubbia, arXiv:hep-ph/0908.1286v1



The relevance of a “phase-3” project (2)

• There is a general worldwide interest on this option (CERN, USA, Japan). CH should play (is playing) a role on the 1) **design and optimization of the facility**, as well as on the 2) **detector design and construction**.

• Experience and expertise exist in CH for both above items (Bern, ETHZ, Geneva)

• Funding programs: SINERGIA (A. Blondel, A.E., A.Rubbia, M. Shaposhnikov), FOLIS, LAGUNA

• Detector: the two main options are

“huge” Water Cerenkov (scaling SK up to a ~1 Mton) and/or

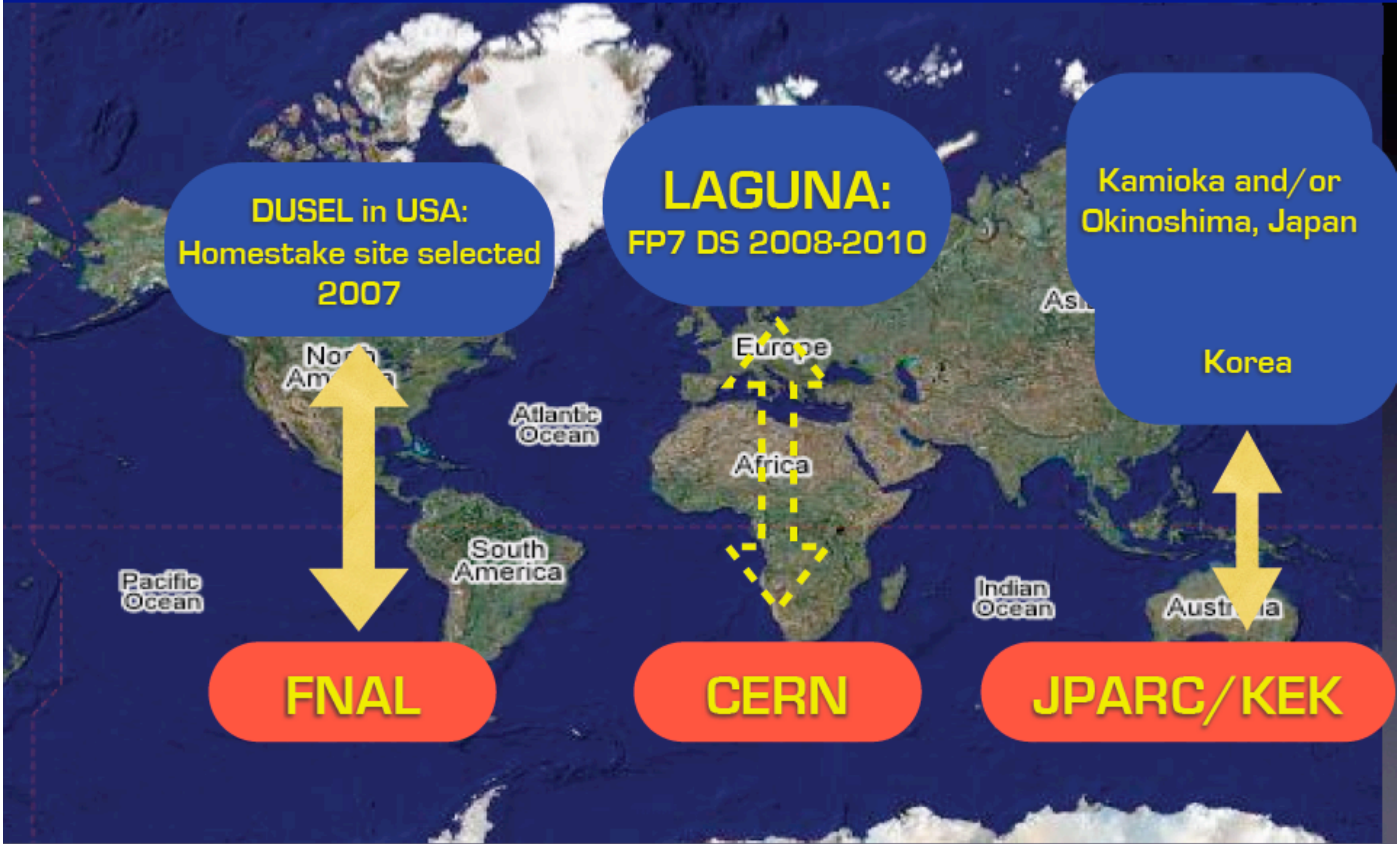
“large” LAr TPC (~100 kton) GLACIER

• The water Cerenkov technique has been so far a “monopoly” of Japan. It is still an option for a future facility (Hyper-K, T2KK). USA are also considering this option (DUSEL).

• As far as CH is concerned: scientific initiative, recognized expertise, ongoing R&D strategy for LAr TPC. Leading CH position (international visibility BE and ETHZ). In parallel, competence for beam studies/design and ancillary devices as near detector components (GE).

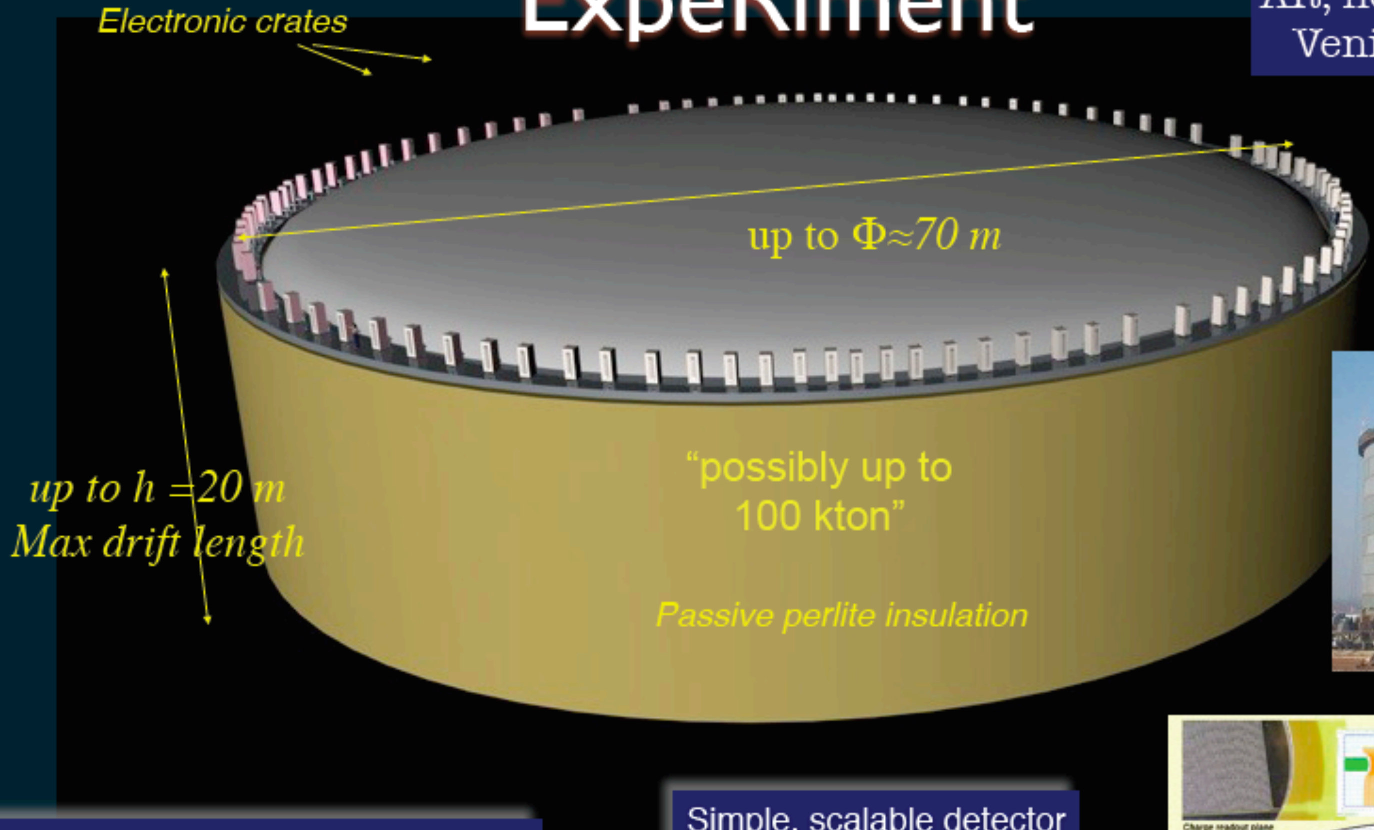
• Natural option: invest in the proposal of a large LAr TPC (likely according to a graded strategy) along a future Super-Beam (from CERN ??). Innovative solution for high performance. Medium risk/ high gain.

• Bonus: a large LAr detector could perfectly act as a next generation underground observatory for astroparticle physics and matter stability searches thanks to the outstanding imaging properties of the technique. This would ensure a rich physics program even in the absence of conclusive discoveries on oscillation physics. Last but not least, such a detector could be ready for phase-4 projects

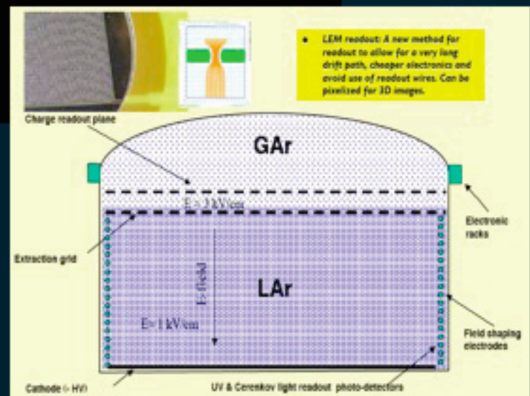

DUSEL in USA:
Homestake site selected
2007
LAGUNA:
FP7 DS 2008-2010
Kamioka and/or
Okinoshima, Japan
Korea
Europe
Africa
Atlantic
Ocean
South
America
Pacific
Ocean
Indian
Ocean
FNAL
CERN
JPARC/KEK

GLACIER: Giant Liquid Ar Charge Imaging ExpeRiment

AR, hep-ph/0402110
Venice, Nov 2003



A scalable design:

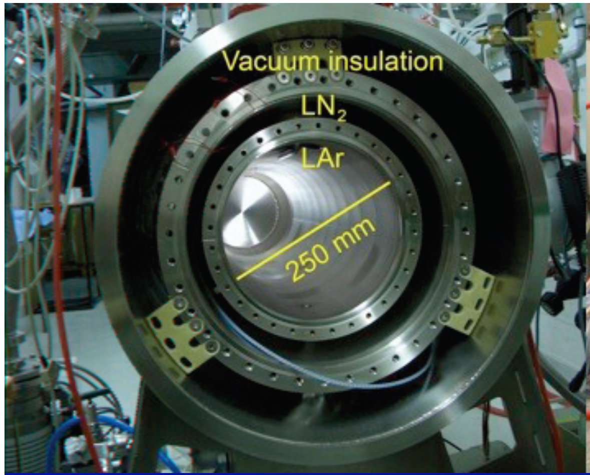


Single module cryo-tank based on industrial LNG technology

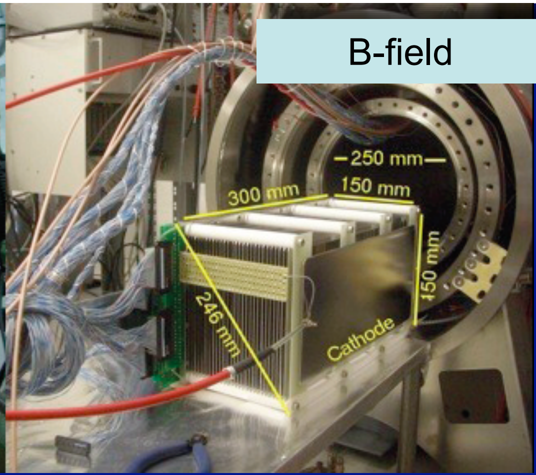
Simple, scalable detector design, possibly up to 100 kton

Modest excavation requirements for "megaton-scale-physics"

Based on LAr LEM-TPC readout

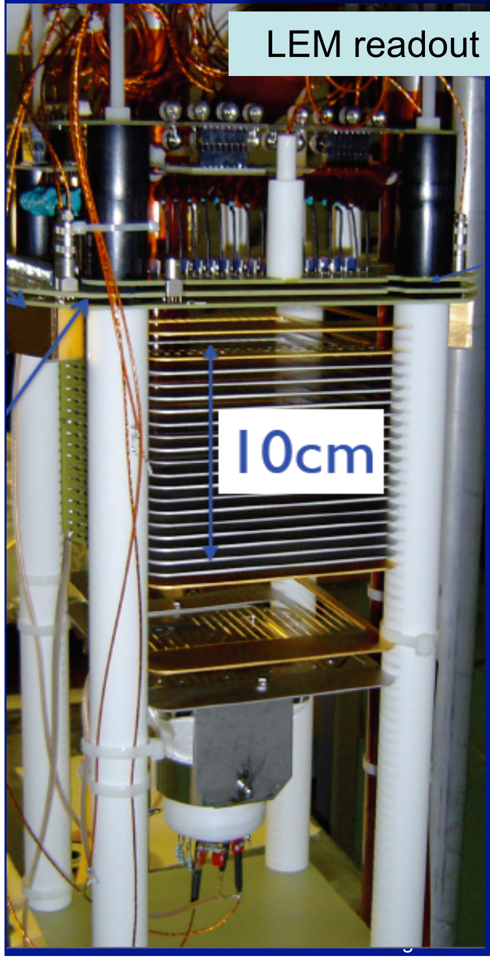


B-field



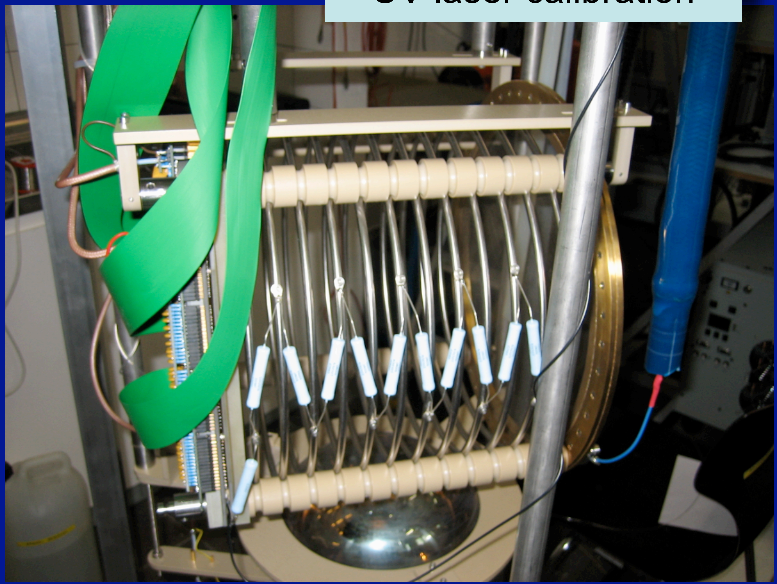
Long drift

LEM readout



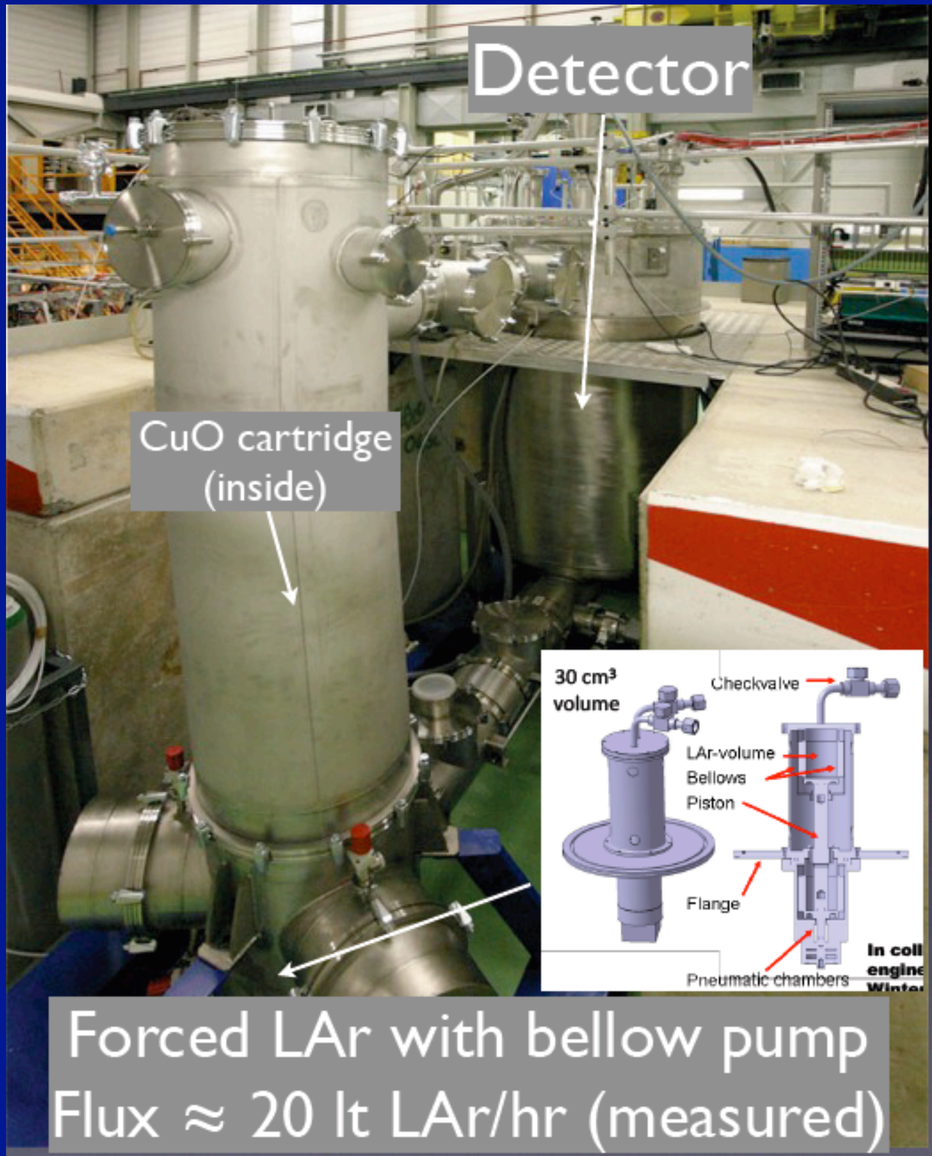
R&D activities: Bern, ETHZ

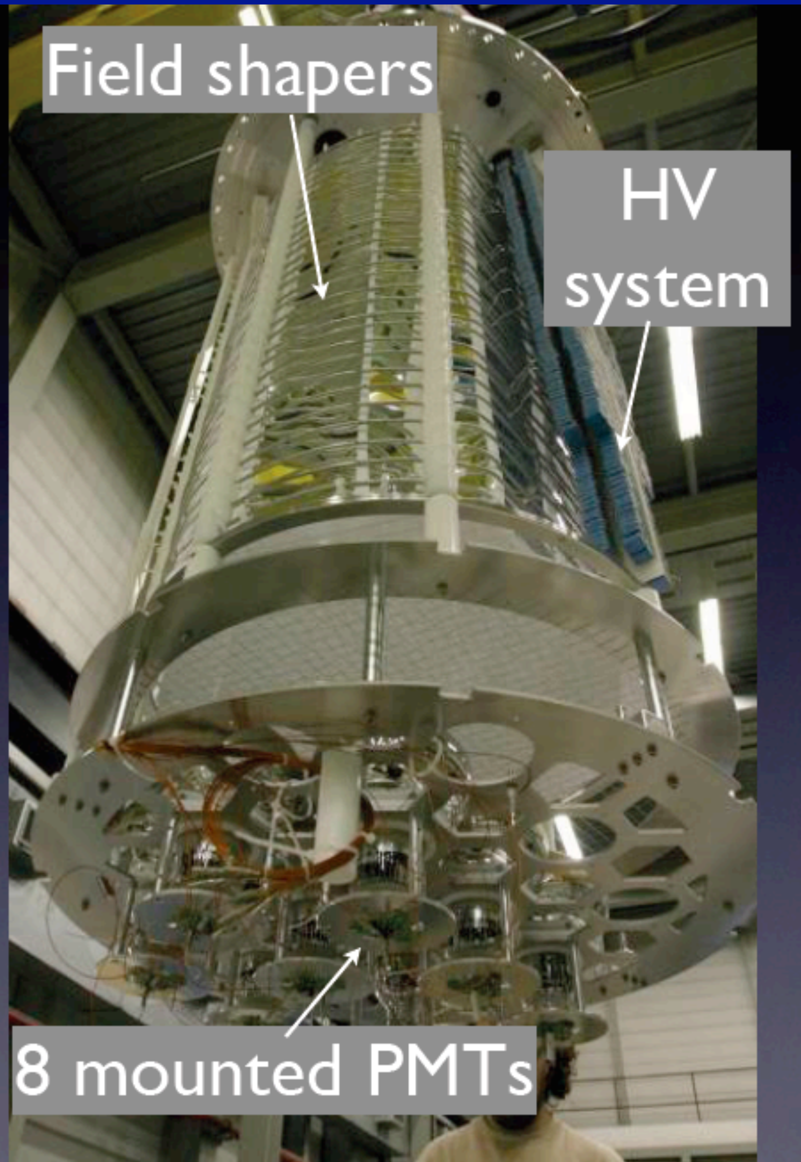
UV laser calibration



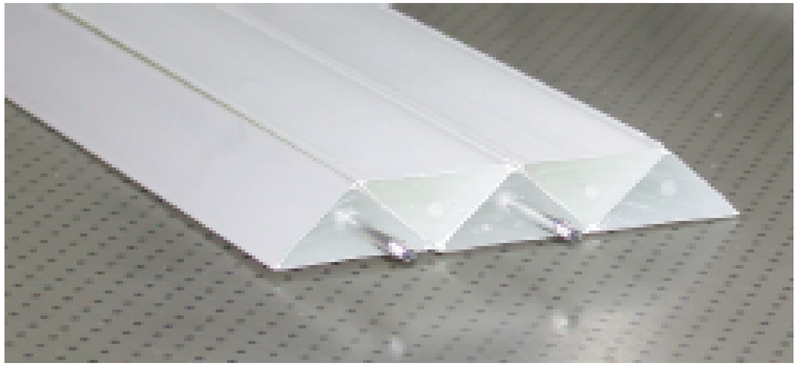
First "medium scale" application:

The ARDM experiment (ETHZ, Zurich)

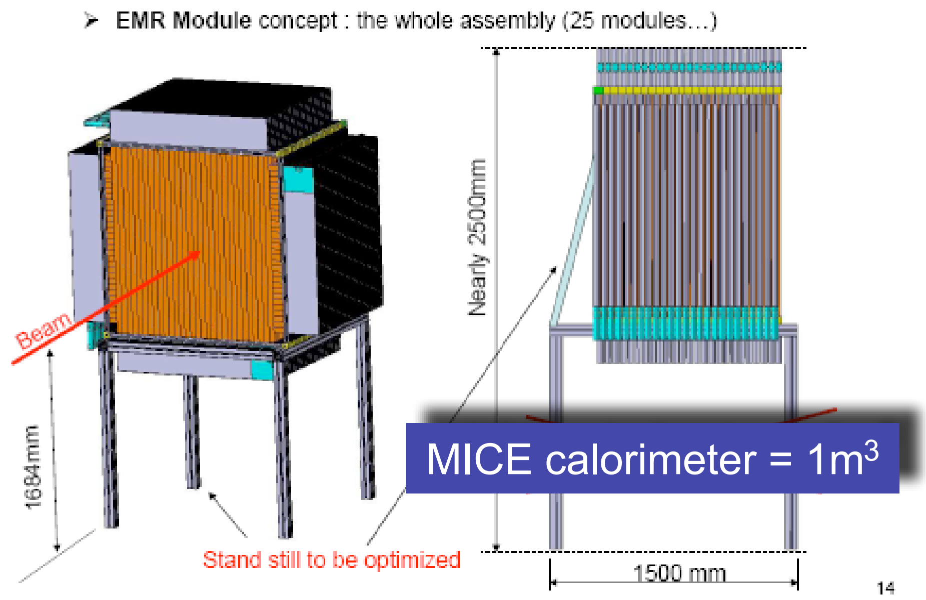




In parallel: Geneva R&D work for neutrino facilities' near detectors

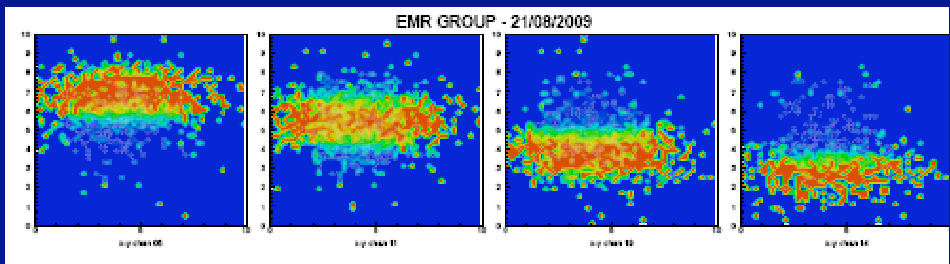


Triangular shaped bars (1.1m long, from Fermilab)



MICE calorimeter = 1m^3

First test in T9 beam last week:



Next: test at CERN in Dipole magnet in H8

Phase-4: long term future of neutrino physics for Switzerland

CH groups are actively involved in the study of long-term, worldwide options for neutrino physics. Given the scale of the projects, extended international collaborations are envisioned.

See e.g. the European initiatives: potential future neutrino projects in Europe beyond the CNGS

- ECFA, for what concerns the accelerator based programs, and
- ApPEC, for large underground (astroparticle physics) detectors,

which are in synergy with the searches for rare processes such as proton decay and detection of neutrinos from supernovae. Two design studies supported by the European FP7 program:

- the EuroNU design study (+NEU2012 network in EUCAD) is dedicated to the assessment and technical development of next generation high-intensity Super-Beams, Beta-Beams and Neutrino Factories (Geneva)

-the LAGUNA design study dedicated to the feasibility of very large underground infrastructure able to host next generation neutrino physics and astroparticle physics and proton decay experiment (Bern, ETHZ)

ADVERTIZING: CERN WS on Future Neutrino Physics at CERN (1-3 October 2009)

CERN Strategy Group

"…..studies of the scientific case for future neutrino facilities and the R&D into associated technologies are required to be in a position to define the optimal neutrino programme based on the information available in around 2012; Council will play an active role in promoting a coordinated European participation in a global neutrino programme"

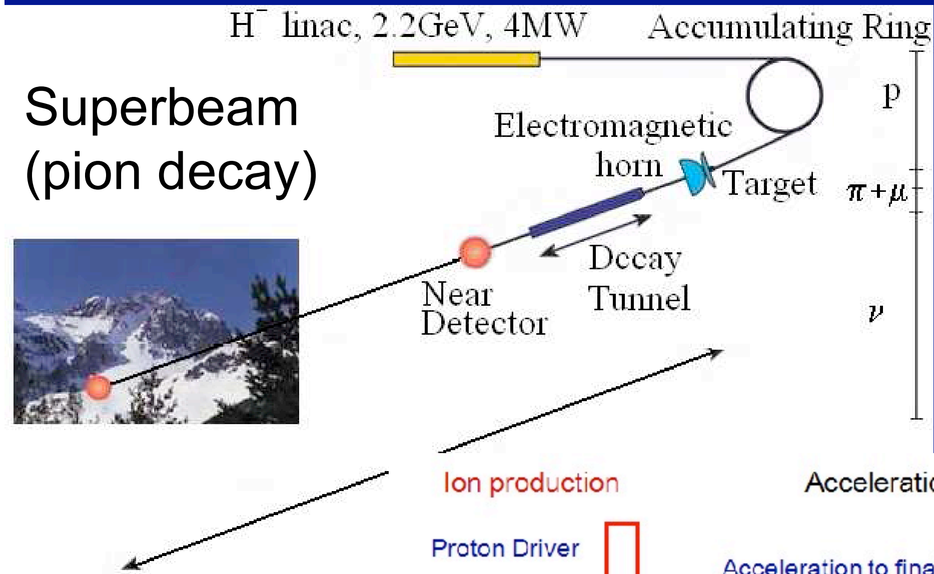
- **Crucial R&D for 2nd generation facilities (post T2K)**
- **Include 3 main European candidates:**
  - **CERN to Frejus Super-Beam**
  - **Neutrino Factory**
  - **Beta-Beam**
- **Performance and "cost" comparison**
- **Present outcome to SG**
- **Done in collaboration, not competition**

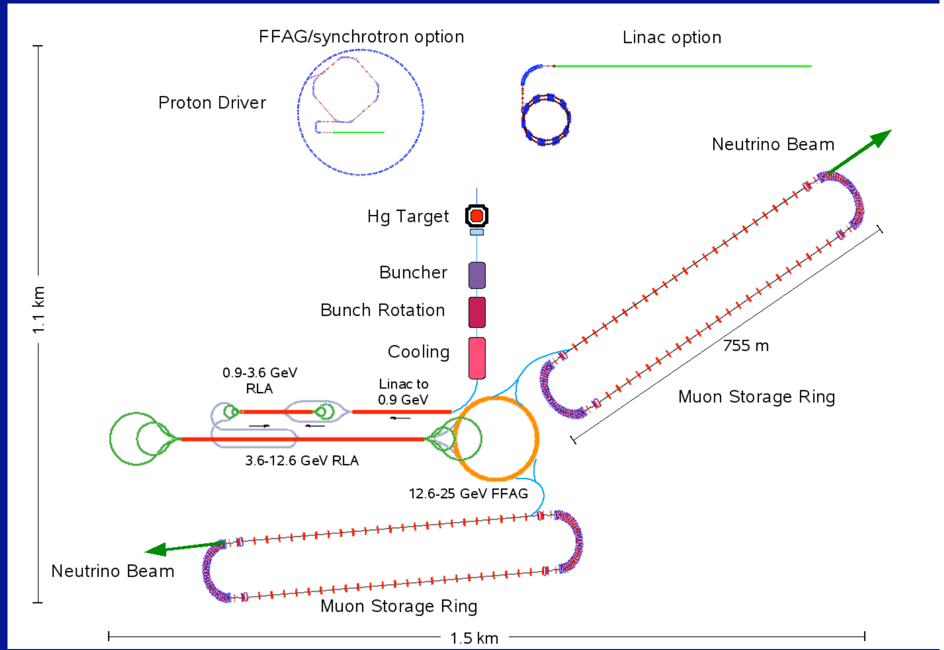
- **Created end 2006**
- **15 partners, coordinator STFC**
- **Submitted proposal: May 07; total cost 14.5M€, EC 4.8M€**
- **Outcome: August 07 – ranked first, negotiate for 4.0M€**
- **Negotiations slow, but complete!**
- **Project started: 1st September**
- **Duration: 4 years – completion in 2012, as required**
- **GA signed**

CH: University of Geneva, Associated Partner (A. Blondel)

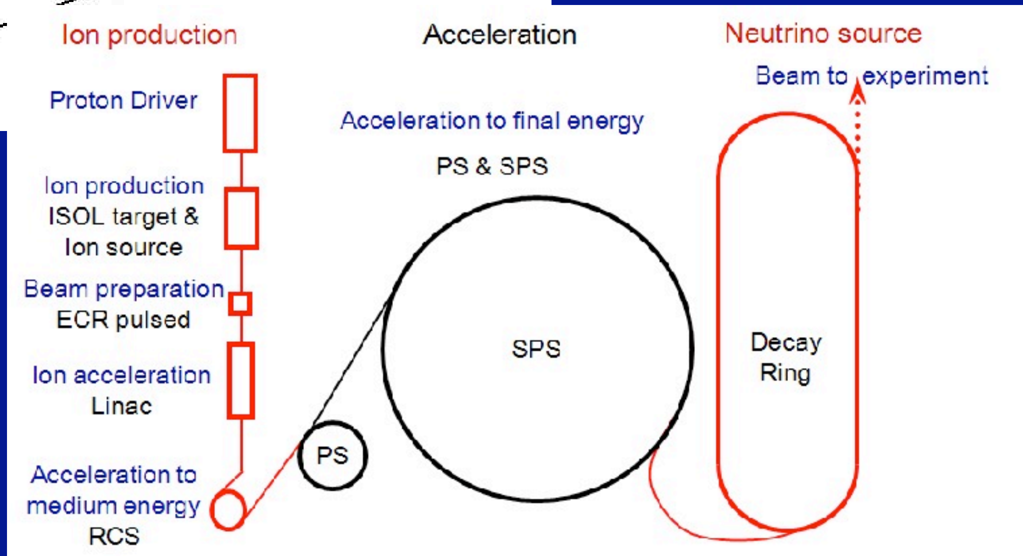
EUROν

Superbeam
(pion decay)





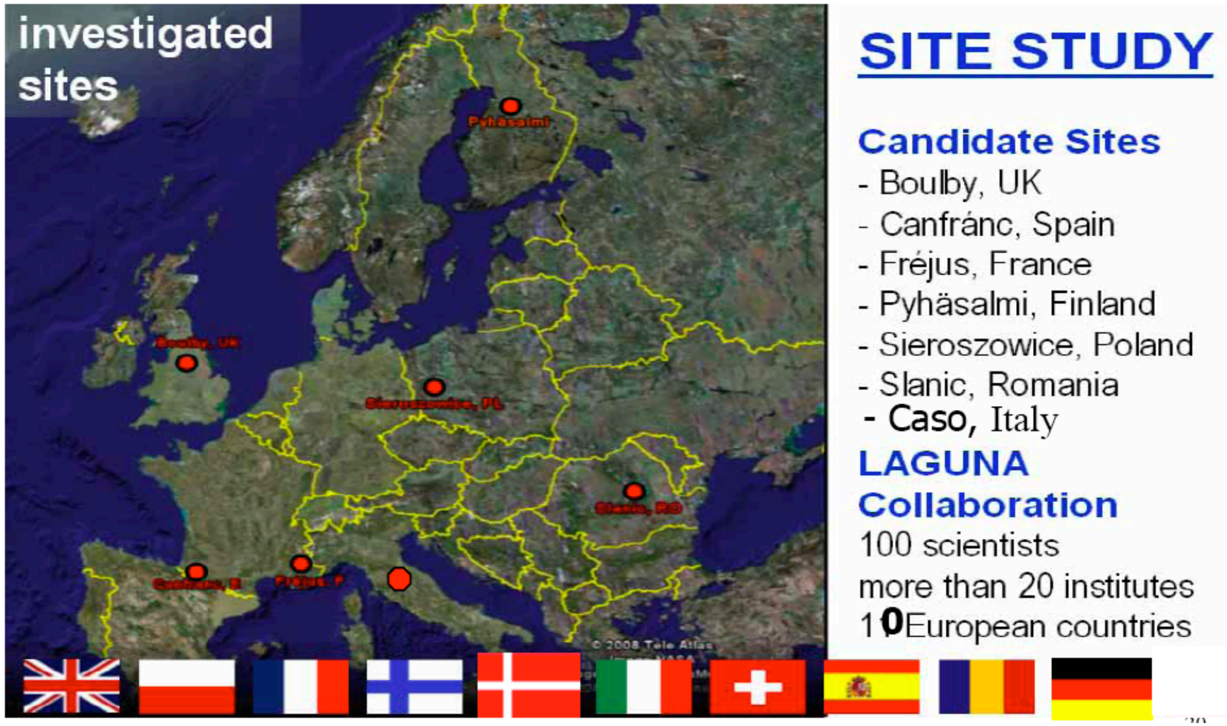
Neutrino-Factory



Beta-Beam

LAGUNA: approved EU FP7, RI design study for site localization of the future European Large Underground Neutrino and Astroparticle Observatory.

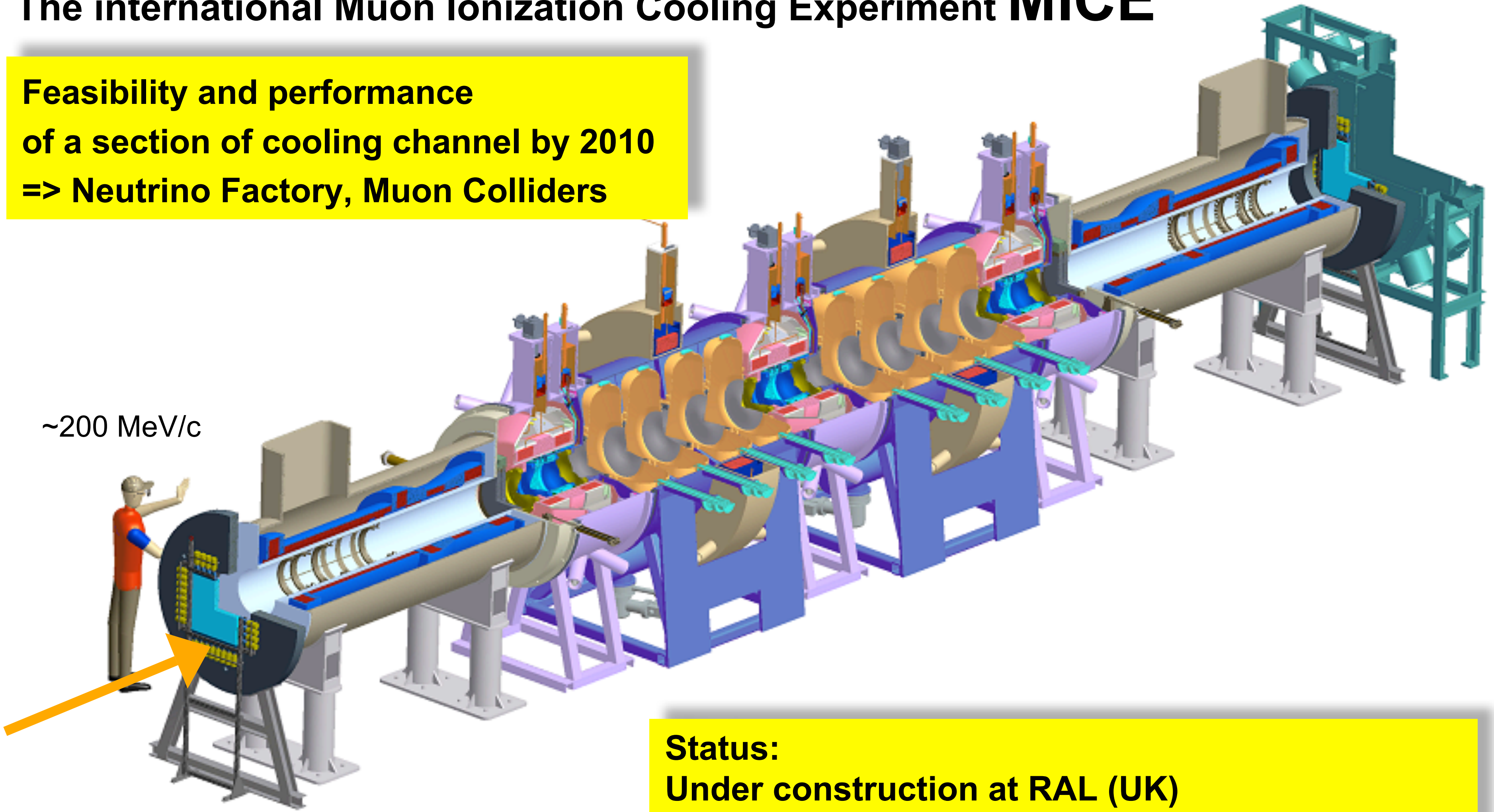
Detector options: LENA (liquid scint.), GLACIER (LAr), MEMPHYS (water Cerenkov)



- Swiss groups: **Bern** and **ETHZ** (~15 CH researchers)
- Scientific interest in promoting the GLACIER option
- Following the current Swiss initiatives in the field of LAr TPC detectors
- **A. Rubbia Project Coordinator**

The international Muon Ionization Cooling Experiment **MICE**

Feasibility and performance
of a section of cooling channel by 2010
=> Neutrino Factory, Muon Colliders



Status:
Under construction at RAL (UK)
First beam: March 2008

CH contributions: TOF, DAQ, Calorimeter
Simulations of RF in magnetic field

Management duties: A. Blondel Spokesperson

Some conclusions…

• Neutrino physics: active research field with strong and visible CH participation, as well as with leading scientific and management role. About 70 active researchers, students and engineers from Bern, EPFL, ETHZ, Geneva, and Zurich involved in frontier experiments (OPERA, T2K, NA61, EXO, GERDA, ICECUBE)

• Important results reasonably expected by the next ~5 years:

Evidence for tau-appearance in neutrino oscillations, Discovery of finite θ_{13} mixing angle or stringent limits, Sensitivity measurements on $0\nu\beta\beta$ decay, High-energy, astrophysical neutrino detection.

• Strong commitment to R&D activities dedicated to neutrino physics (*e.g*. liquid Argon TPCs)

• Swiss researchers will continue working in frontier experiments, with priority to the physics reach potentialities. Need to support the main "pillars":

1) oscillations, 2) low energy, 3) large observatories, with the parallel involvement of neutrino physics theorists.

• We should proceed along graded strategies, complying with financial and manpower constraints, trying to exploit at the best existing resources/expertise and infrastructure.

• As far as neutrino oscillation physics is concerned, a realistic road-map should be depicted as a 4-phases' strategy. Be prepared to start phase-3 and plan accordingly phase-4. Exploit CH competences at the best.

• A lot of work done, a lot to do!

• Side remark/personal opinion: the evolution in the field is such to deserve an update of the current CHIPP road-map.