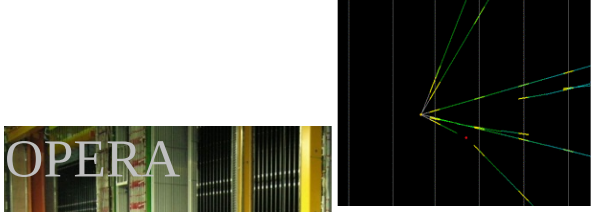
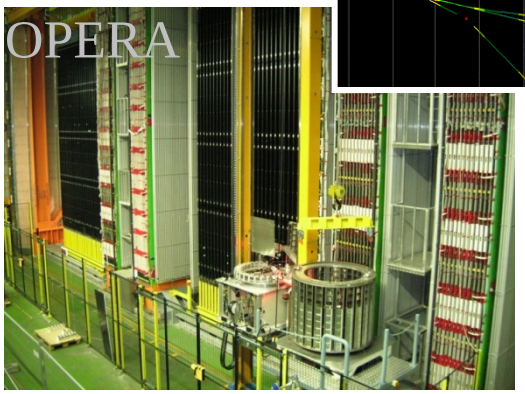
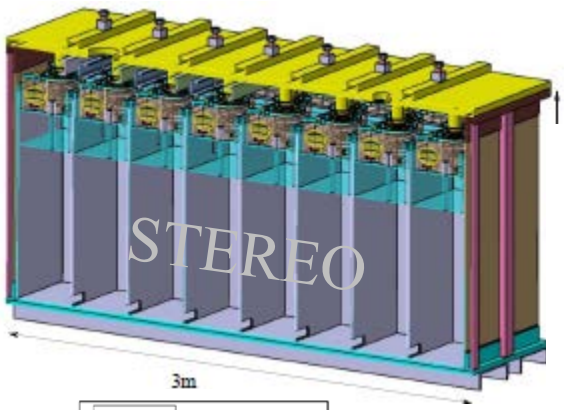
Neutrino physics

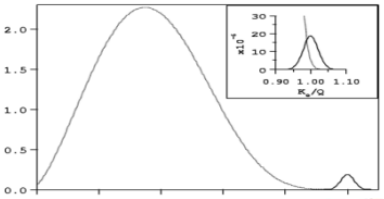
D.Duchesneau

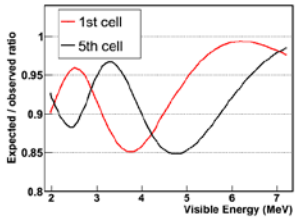
- Research activities: present and foreseen
- Conclusions

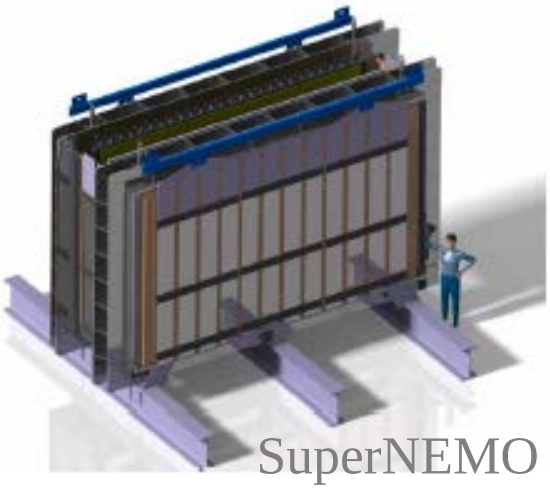


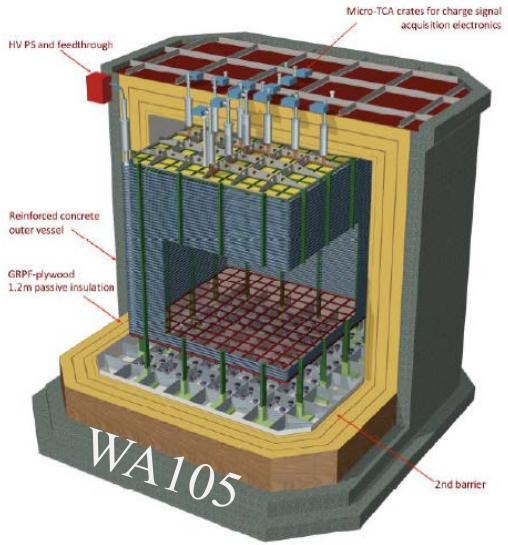












Neutrinos:

Despite major experimental progress these last years, their properties are less well tested than for quarks and charged leptons and several unknown still exist.

still several fundamental questions to answer:

- what is the absolute mass scale?

- fundamental for cosmology and unification scheme of interactions

- are neutrinos their own antiparticles (Majorana) or not (Dirac) ?

- if Majorana => leptonic number violation, theoretical consequence (leptogenesis, GUT)

- Are there more than 3 mass eigenstates?

- Some experimental data prefer sterile neutrino(s) with mass close to 1 eV/c^2

- Which is the mass hierarchy?

- Essential for CP violation quest

- Is CP symmetry violated in the leptonic sector?

Challenging experimental program: Enigmass is an major actor

Experimental activities in this framework:

STEREO project (2013-2017)

(ANR ‘programme blanc’ grant)

- Radioactive source calibration system
- Shieldings: mechanics, realisation
- Acquisition electronics + μ veto
- Intallation and commissioning at ILL reactor
- Running and data analysis

Talk from V. Hélaine

SuperNEMO demonstrator (2013-2017)

- development of the double beta source foils
- development of the detector ‘Slow control’
- Installation and commissioning at LSM
- Running and data analysis

Talk from A. Remoto

« technical participation» of LPSC: software for metadata management

Experimental activities in this framework:

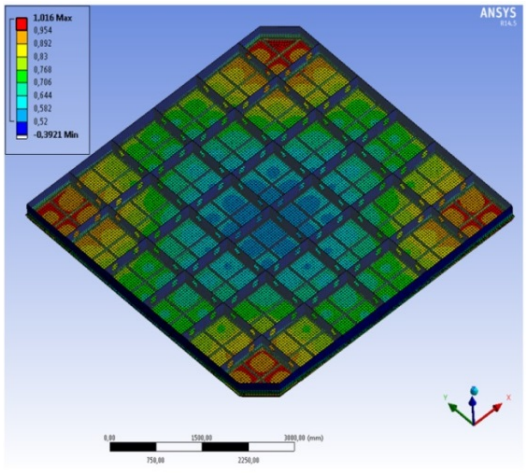
Long baseline project with large volume LAr. On a longer term: (2014-2025)

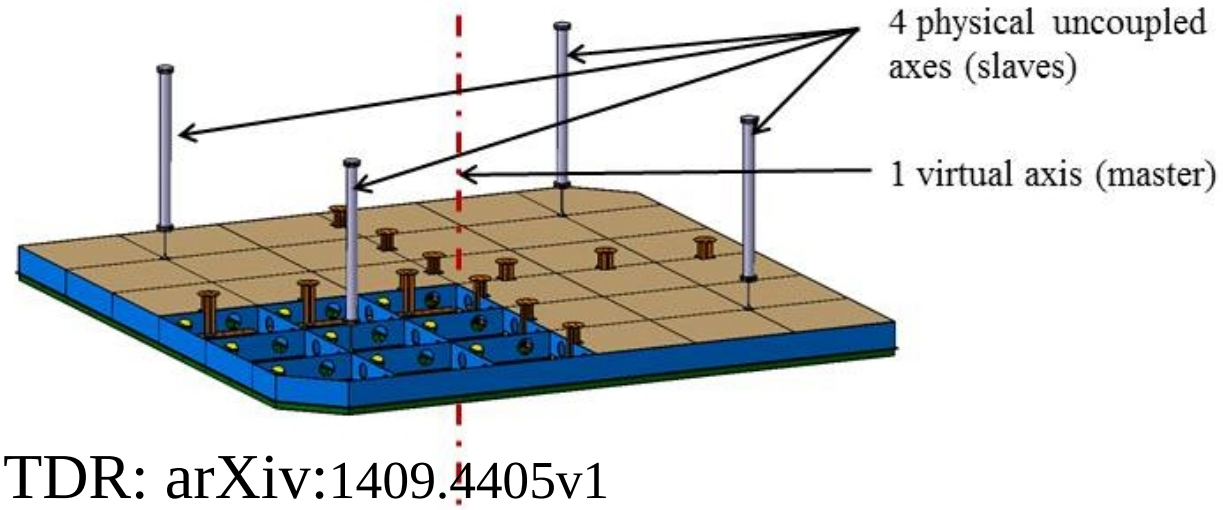
- European Design Study Laguna-LBNO has ended (2012-2014)
- Detector R&D program on Liquid Argon TPC technology for long baseline neutrino beam => WA105 and the CERN Neutrino Platform

discussion with Enigmass labs foreseen to target additional participation for longer term project

WA105

- Anode deck suspension and position control system
- Participation to the photomultiplier electronic readout chain
- Simulation and study of the scintillation light production in liquid argon





TDR: arXiv:1409.4405v1

Neutrino Pole in ENIGMASS

Collaboration: LAPP, LPSC, LSM et LAPTh

The scientific program covers most of the present fundamental research topics in neutrino physics

- Oscillation, mass hierarchy and CP violation
- Neutrino nature
- Sterile neutrinos

This program is in adequacy with the national and international roadmaps. It will be performed using close infrastructures : CERN, ILL, LSM

Potential support from theoretical groups of LAPTh and LPSC expected

Experimental teams:

- LAPP: I. De Bonis, D. Duchesneau, P. del Amo Sanchez, W. El Kanawati, T. Le Noblet (PhD), L. Manzanillas (PhD), H. Pessard, **A. Remoto (postdoc Enigmass)**
- LPSC: S. Kox, J. Lamblin, F. Montanet, J.S Réal, A. Stutz, **V. Hélaine (postdoc Enigmass)**, T. Salagnac (PhD), S. Szlodos (PhD)
- LSM: P. Loaiza, L. Mosca, M. Zampaolo, G. Warot, F. Piquemal

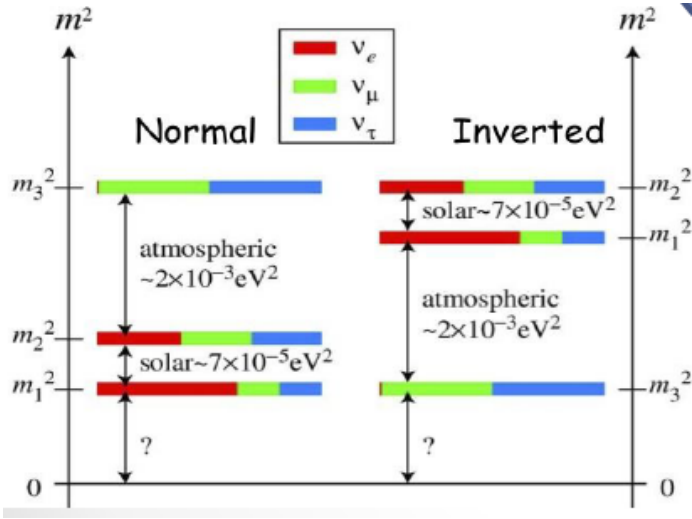
About long baseline projects

Physics case: neutrino mass hierarchy and CP violation

Worldwide effort

Mass hierarchy:

- atmospheric (ex: Pingu, Orca…studies)
- Reactors (ex: JUNO, RENO-50 (20kton LSc, 60 km)
- Long baseline ν beam (> 1000 km)
  - Europe => LBNO with liquid Argon detector
  - US => LBNE with liquid Argon detector



In the process of giving birth to ELBNF

CP Violation:

$$U_{PMNS} = U_{\theta_{23}} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} U_{\theta_{12}}$$

- Long baseline ν beam (>100 km)
  - Europe => LBNO / liquid Argon detector / 2300 and 1300 km?
  - US => LBNE / liquid Argon detector / 1300 km
  - Japan => Water Cerenkov detector / 295 km

Both questions can be addressed with conventional accelerator neutrino beams by studying $\nu\mu \rightarrow \nu e$ and $\bar{\nu}\,\mu \rightarrow \bar{\nu}\,e$ oscillations

Long Baseline European Project: Design Study completed

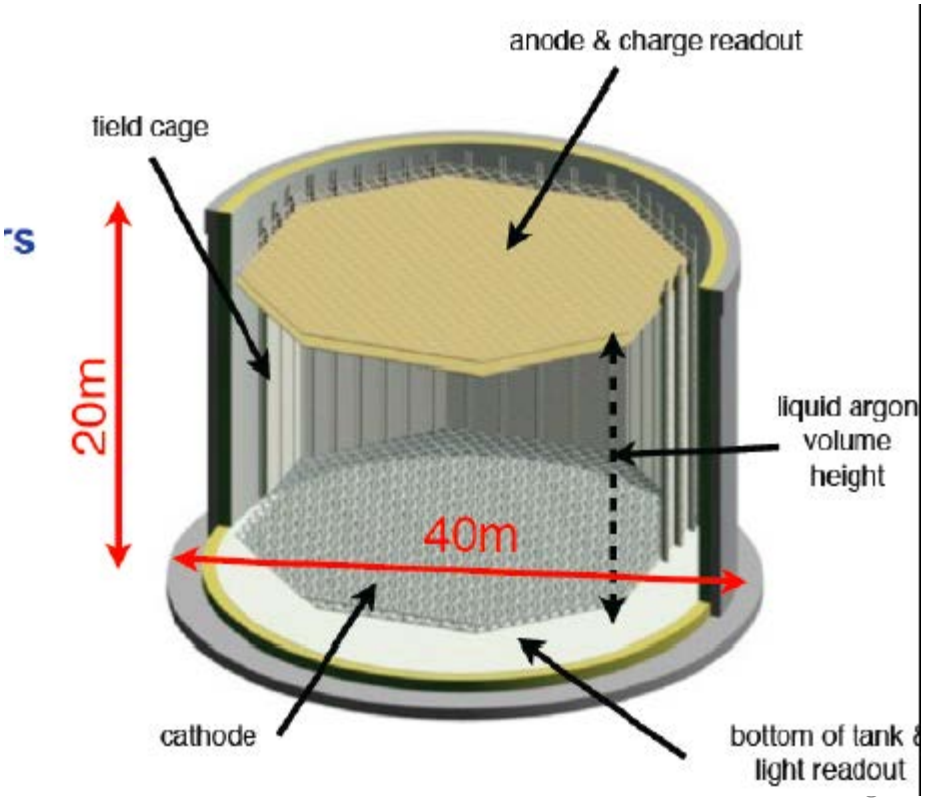
From the LAGUNA and LAGUNA-LBNO design studies

CERN-Pyhäsalmi (2300 km)

GLACIER (20 kton) + MIND (35 ktons)

Sequential approach

20kton => 50 kton LAr

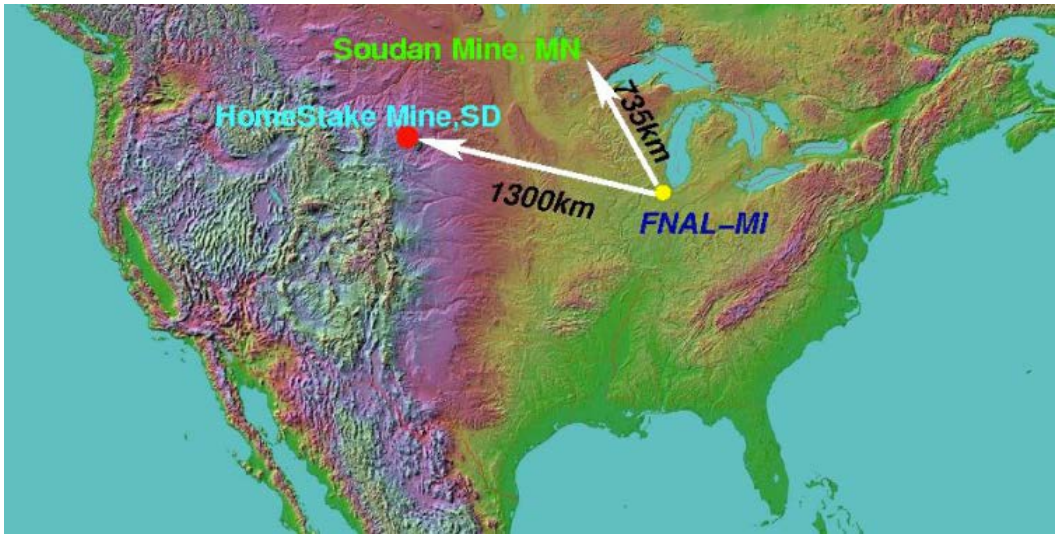


Latest developments on the international level:

Towards a new international collaboration exploiting Fermilab neutrino beam

LBNF:

US plan to propose to provide a facility with a neutrino beam from Fermilab + underground far site to the community.



Opportunities for developping an international collaboration based on the LBNO and LBNE expertise and projects for a LAr experiment.

Everybody interested in those future projects can manifest their support to the initiative=> LoI to be presented on Dec 5th and 12th

Goal: define a collaboration by 2015 and work on a CDR in 2015

Conclusions and prospects:

- Neutrino physics is a very active and exciting field with several experimental challenges ahead

- The ENIGMASS Labex allows to develop a neutrino physics program covering key subjects with scientific output guaranteed in a medium term.

- We have an experimental activity with teams from the different laboratories along three main research paths for the coming years
  - Sterile neutrinos and anomalies (STEREO)
  - Double beta decay search (SuperNemo)
  - Neutrino oscillations: Neutrino beam experiments and future underground projects for neutrino oscillations and astrophysics (OPERA and LBNO)

The long baseline neutrino project is a main item for the future of neutrino physics. A progressive involvement in this project starts now with detector R&D and prototyping.
=> We should follow closely the LBNF effort and be actor in the process.

Discussion with the different Enigmass labs about interest in future neutrino projects should take place in the coming months.

The End

MNSP Matrix and 3 ν oscillation

(MNSP: Maki-Nakagawa-Sakata-Pontecorvo)

$$\nu_\alpha = \sum_{j=1}^{3} U_{\alpha j}\,\nu_j$$

$U_{\alpha j}$ matrix element

Formalism

Mixing matrix

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Theoretical framework well consolidated since 15 years

Δm^2_{31} Δm^2_{21}

$$U = \begin{pmatrix} 1 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & e^{-i\delta}s_{13} \\ 0 & 1 & 0 \\ -e^{i\delta}s_{13} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

atmos+LBL(dis) Reactor + LBL (app) solar+KamLAND

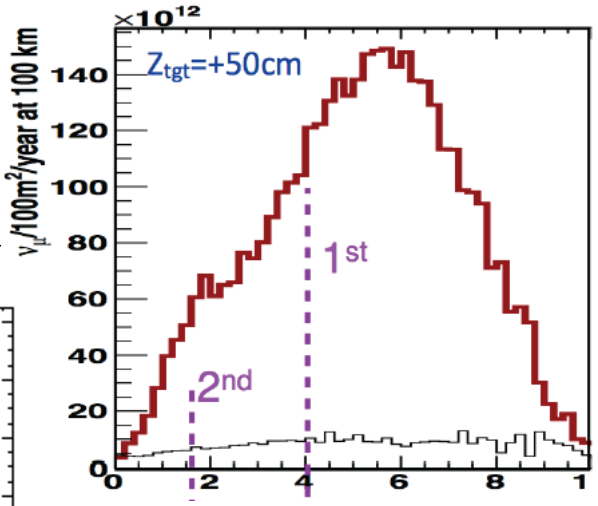
Oscillation probability

$$P_{\nu_\alpha \to \nu_\beta} = \sum_{ij} U_{\alpha j} U^*_{\beta j} U^*_{\alpha i} U_{\beta i} e^{-i\frac{\Delta m^2_{ij} L}{2E}} \approx \sin^2 2\theta_{ij} \sin^2\left(\frac{\Delta m^2_{ij} L}{4E}\right)$$

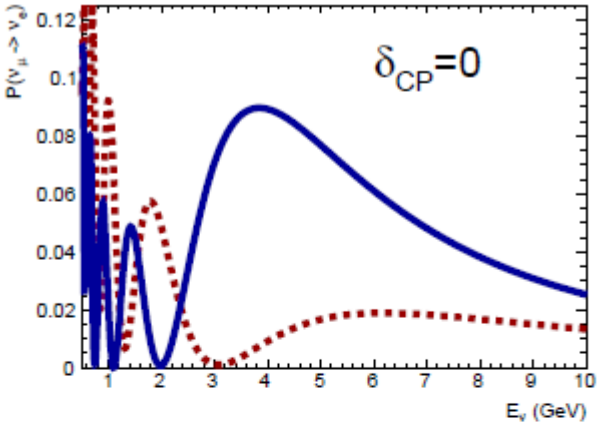
6 parameters to determine:

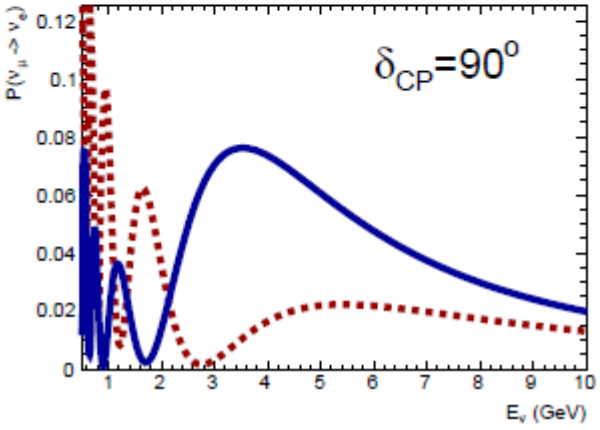
- 3 angles, 2 mass differences,
- 1 CP violation phase

Example: wide band beam with L = 2300 km

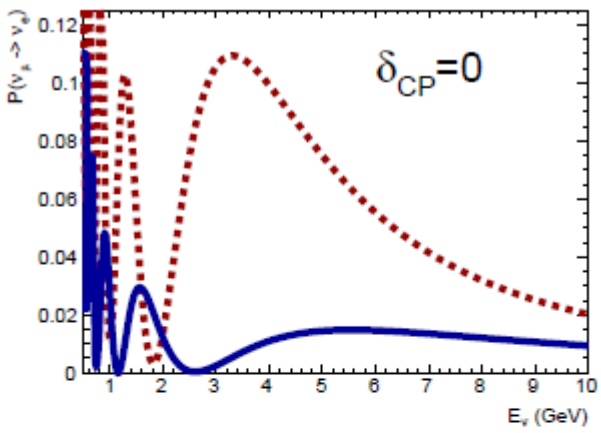


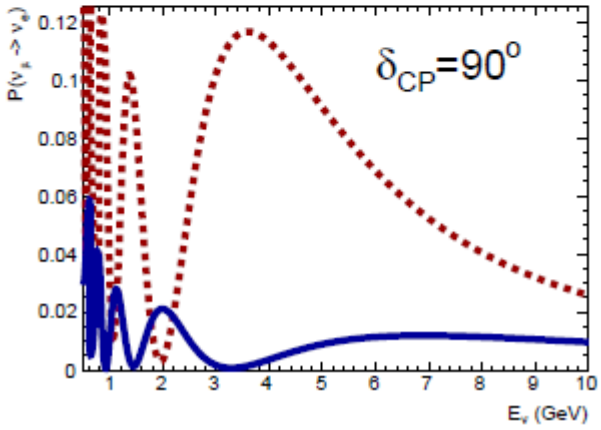
Normal Hierarchy





Inverted Hierarchy





Prob osc. $\nu\mu \to \nu\, e$

Prob osc. $\bar{\nu}\mu \to \bar{\nu}e$

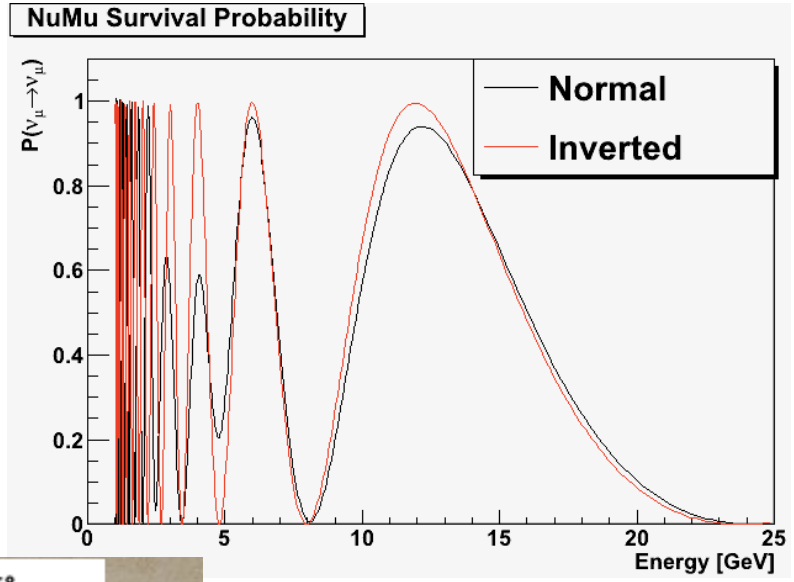
Wide band beam and Liquid Argon detector allow to measure the L/E dependences and possibility to disentangle MH and CPV

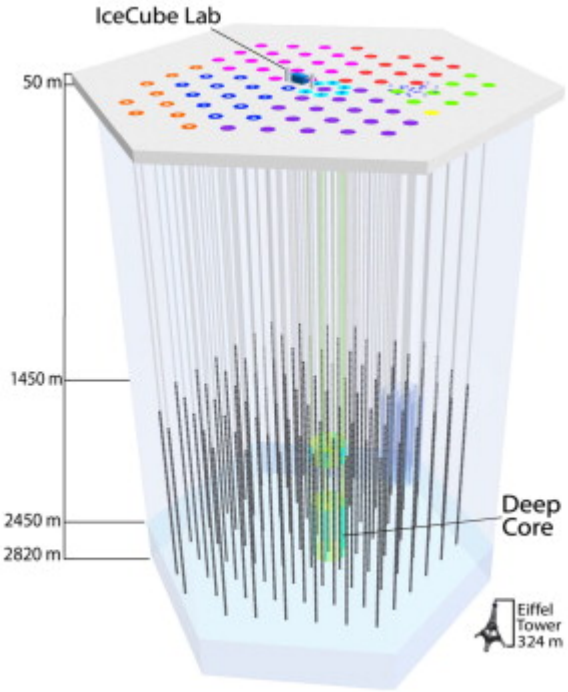
Mass hierarchy:

Other investigation techniques:

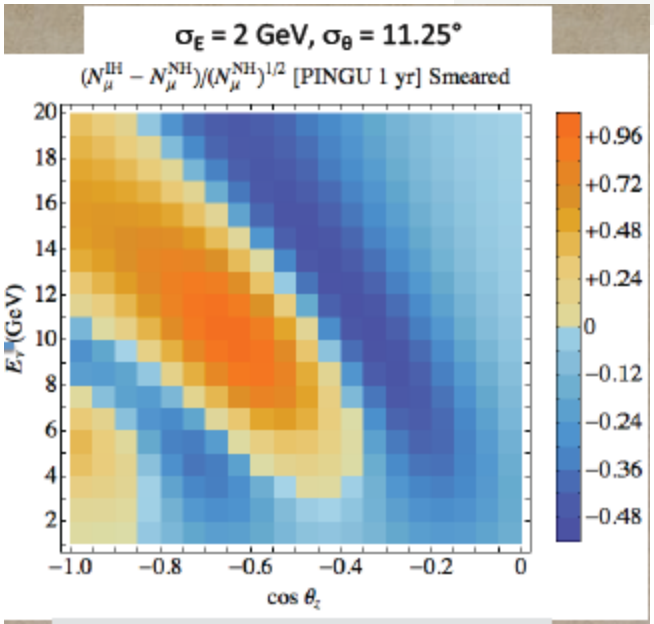
Atmospheric neutrinos: looking at the effect of matter effect in the νμ rate

<10% effect





PINGU



Also

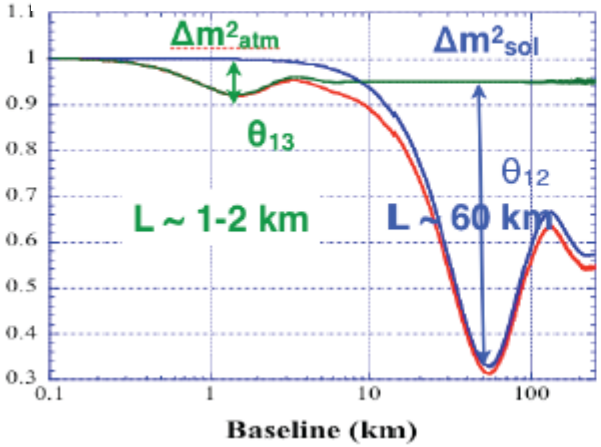
INO: 50 kton iron-RPC calorimeter

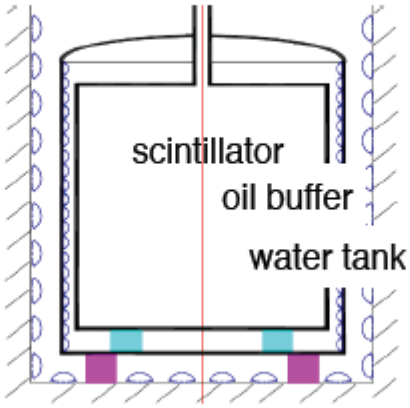
HyperK in Japan

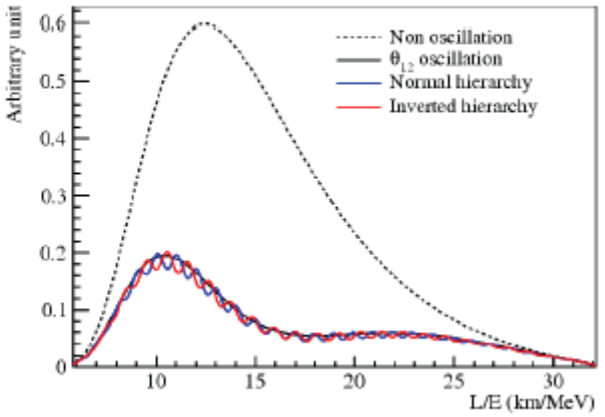
Mass hierarchy:

JUNO

Long Baseline reactor with large detector

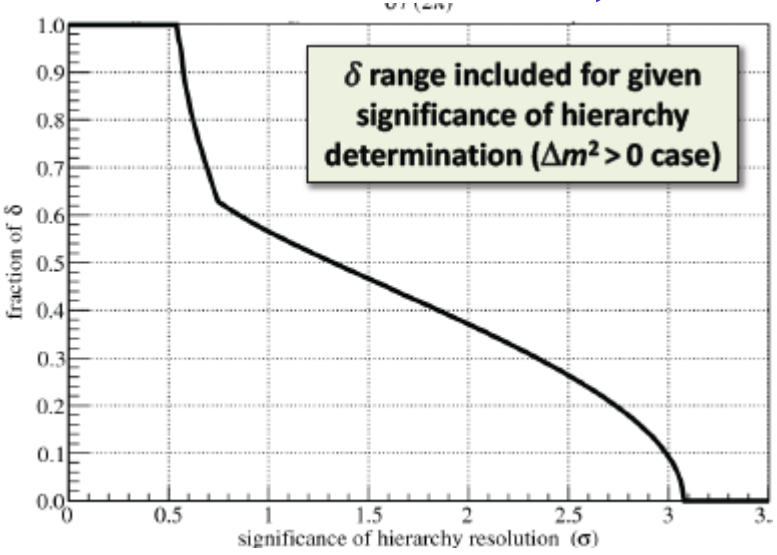






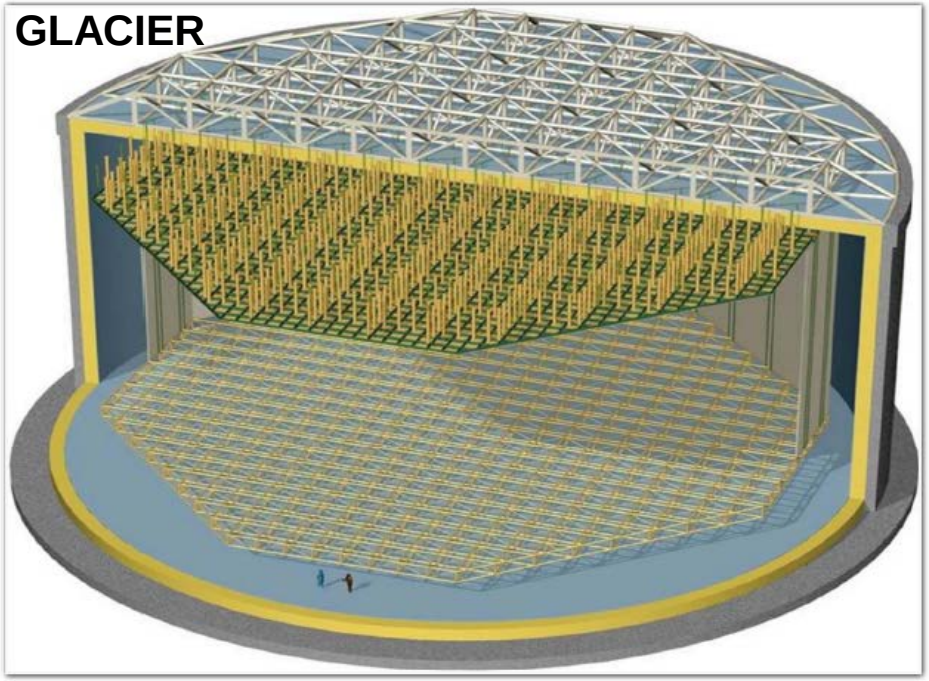
- 20-50 kton LS detector
- 2-3 % energy resolution
- Rich physics possibilities
  - ⇨Mass hierarchy
  - ⇨Precision measurement of 4 mixing parameters
  - ⇨Supernovae neutrino
  - ⇨Geoneutrino
  - ⇨Sterile neutrino
  - ⇨Atmospheric neutrinos
  - ⇨Exotic searches

Accelerator: Nova, T2K



Large Underground Detectors: Rich physics program

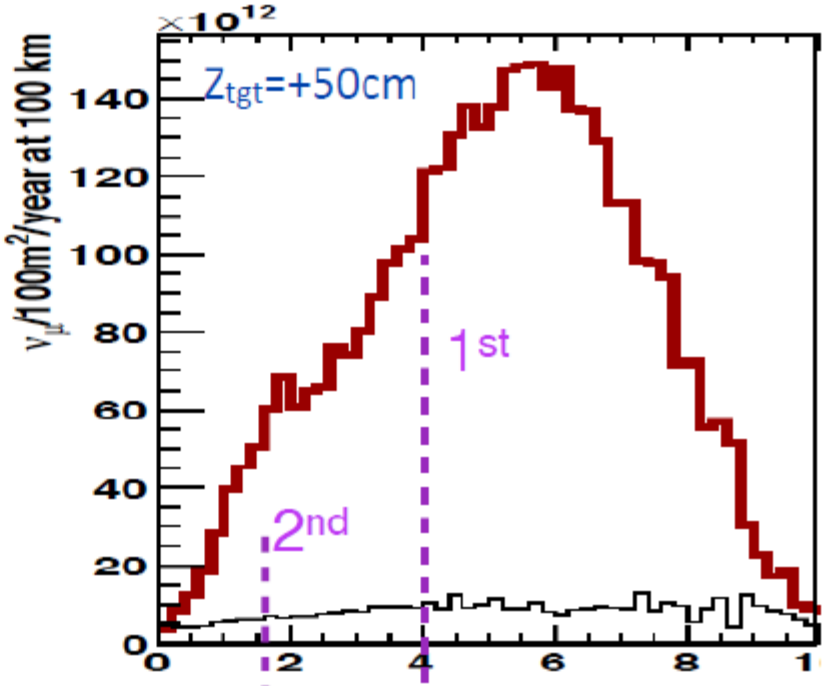
- ν properties(oscillation, mass hierarchy leptonic CP violation: beams, ν atm..)
- Study of astrophysical phenomena linked to ν:
  - ➢Gravitational star collapse (ν from Supernovae)
  - ➢Star formation at the beginning of the universe (SN ν diffuse background)
  - ➢Study of thermonuclear fusion process (solar ν)
- Test of geophysical mode of the earth (Geo - ν , U, Th - ν)
- Nucleon decay



Liq. Argon →100kT

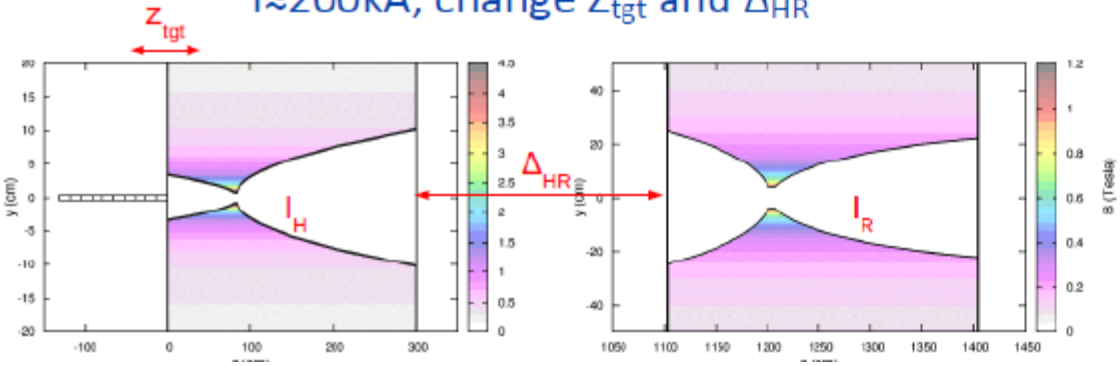
LBNO baseline beam optimisation

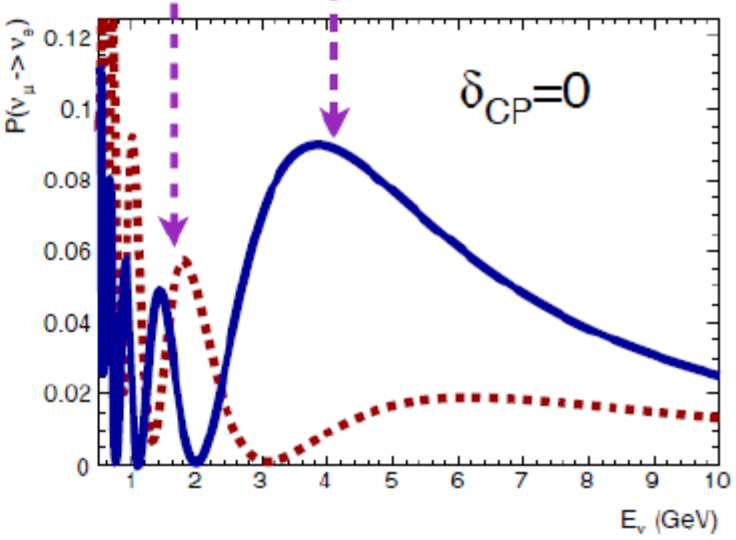
- Conventional beam, horn focused
- Medium energy to cover at $E_\nu \approx 4$ GeV (1st max) and $E_\nu \approx 1.5$ GeV (2nd max)
- Wide band covering 1st and 2nd maximum
- Small tail at high energy
- Positive and negative focus (ν and anti-ν modes)
- High beam power (initially 700 kW then 2MW)
- Angle 10deg dip angle (distance = 2300km)
- Muon monitors
- Magnetised near neutrino detector



Focusing optimisation (preliminary)

Graphite target (r=4mm), Horn shapes fixed, I≈200kA, change Z_{tgt} and Δ_{HR}



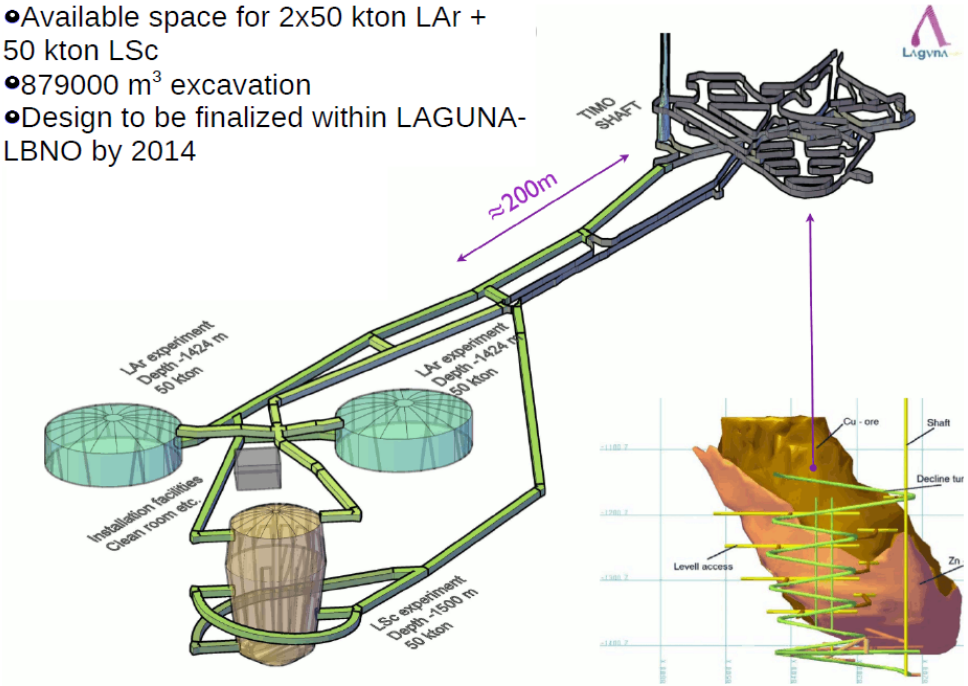


Future Long Baseline Projects

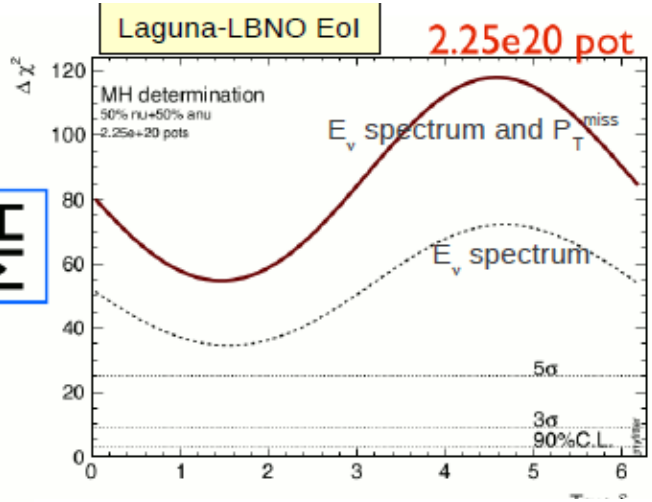
CERN beam to Pyhäsalmi in Finland (2300 km)

high energy wide band beam (neutrinos >1 GeV) => 1st and 2nd maxima

- Available space for 2x50 kton LAr + 50 kton LSc
- 879000 m^3 excavation
- Design to be finalized within LAGUNA-LBNO by 2014

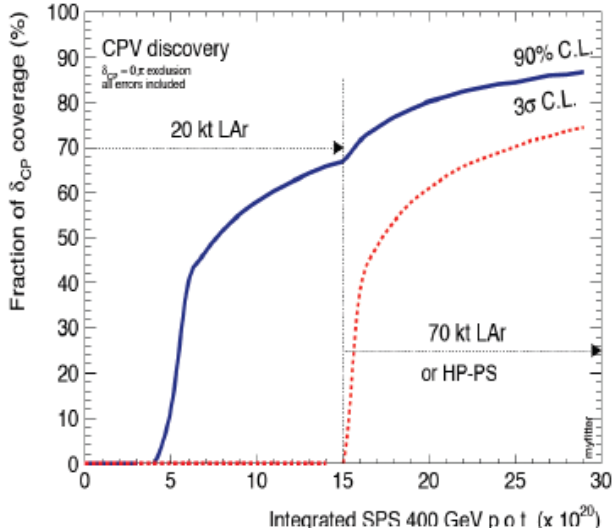


MH

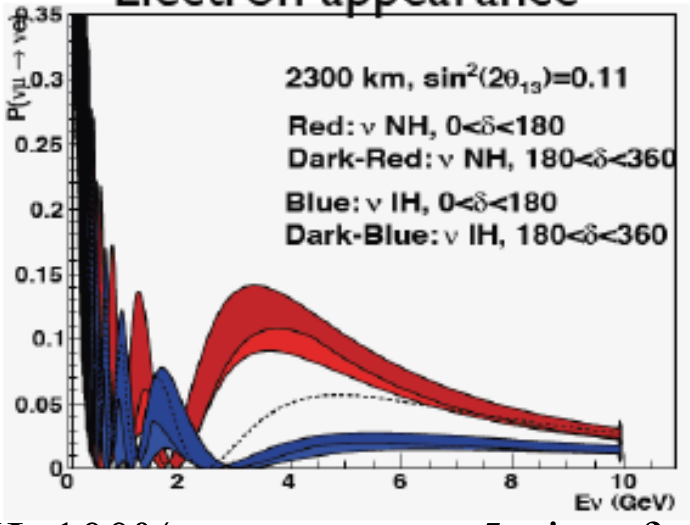


Incremental approach with conventional beams

CPV



Electron appearance



MH: 100% coverage at >5σ in a few years

CPV: ≈60% coverage and evidence for maximal CP ($\pi/2$, $3\pi/2$) at ~3σ in 10y

Liquid Argon TPC

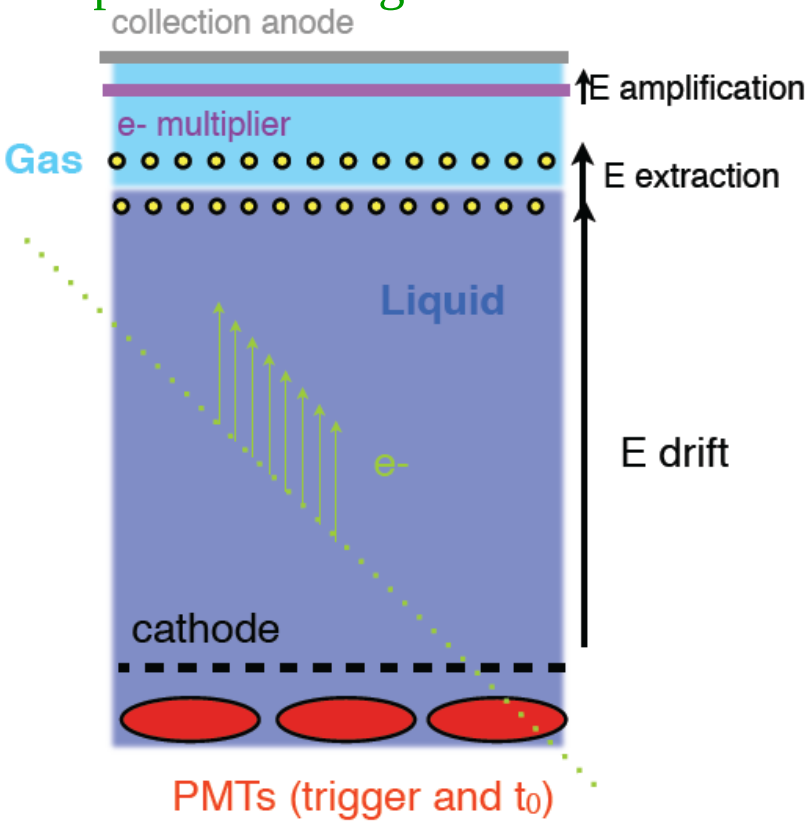
Homogeneous massive target and ionization detector

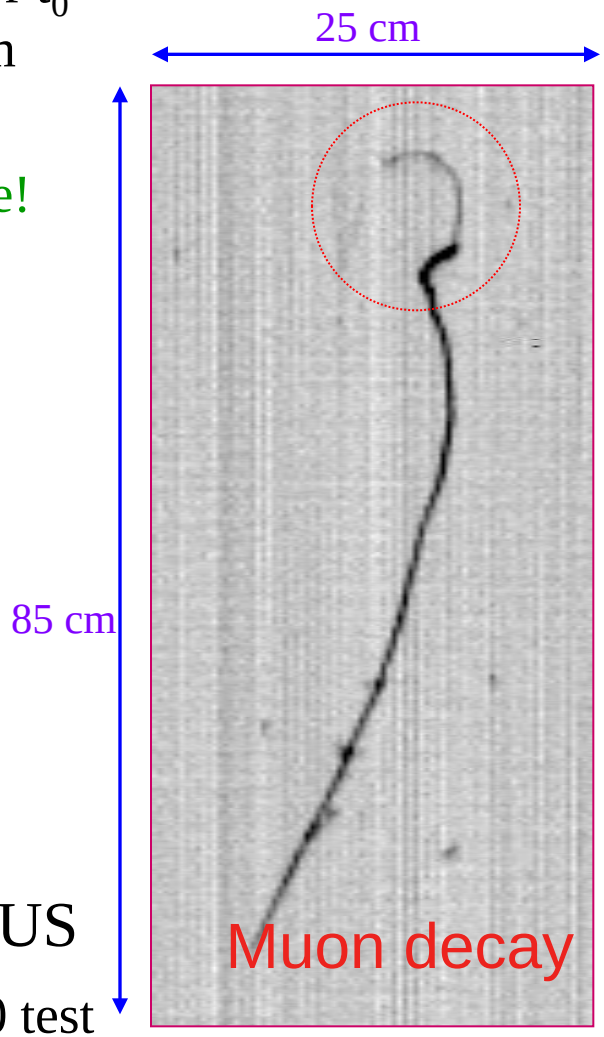
Principle: 3D imaging in a large volume Liquid Argon TPC

- very pure LAr (<0.1ppb) → electrons can drift over large distances (>1.5 m)
- UV scintillation light (5000 photons/mm @128 nm) for t_0
- Primary ionization in LAr: 1 m.i.p ~ 20000 e- on 3 mm
  - → 3D reconstruction with ~1 mm resolution

Double phase: signal readout on 2 view collection anode!

Signal amplified in the gas





ICARUS

T600 test

Run 960, Event 4 Collection Left

Prototyping is needed for the very large LAr detector

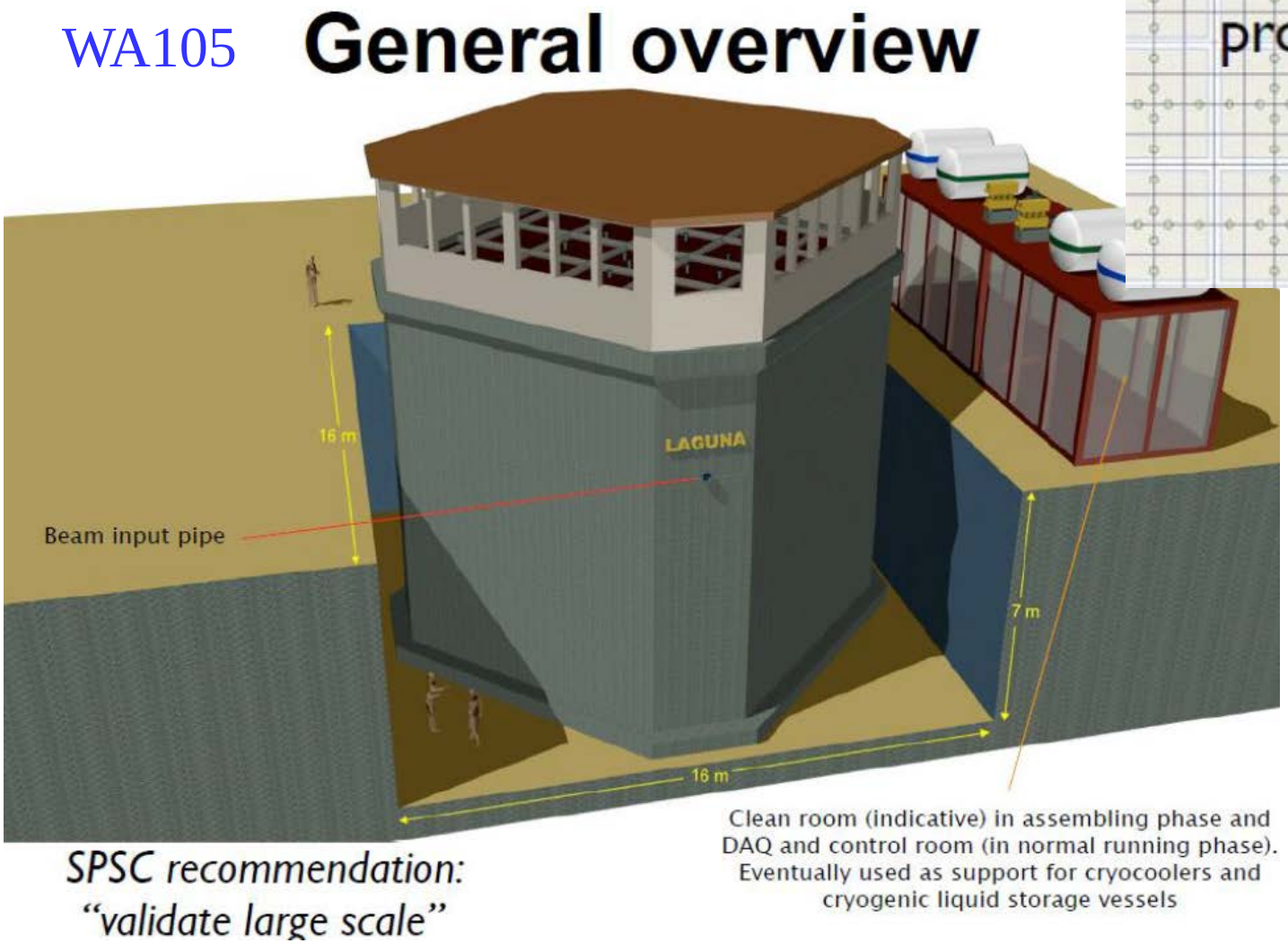
Principle: double phase Argon (liquid / gaz) readout after drift distances up to 20m

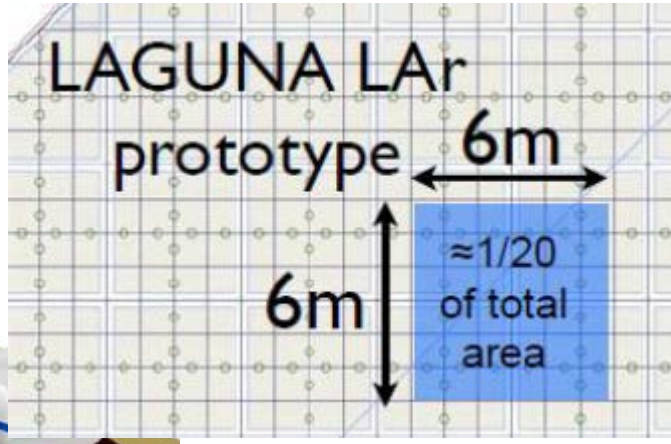
Several technical items have to be validated with a large scale prototype

- LNG tank construction technique
- Purity in non evacuated membrane tank
- Long electron drift distance
- High voltage system for the cage field 300-600 KV
- Double phase readout
- Cold front end electronic
- Interaction reconstruction in the TPC

Large scale 300 t LAr Prototype at CERN

WA105





To install in CERN North Area

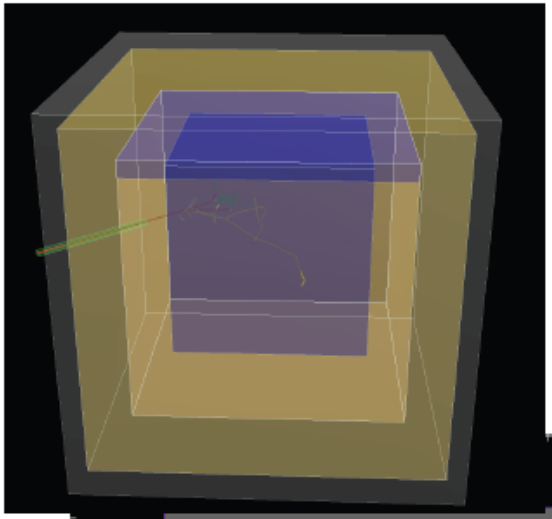
With charged particle beam

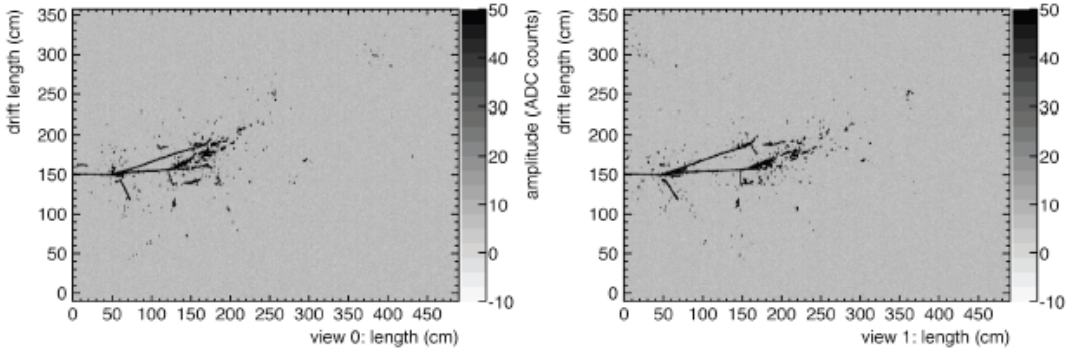
6x6x6m3 active volume LAr TPC detector with double phase + charge amplification + 2-D collection readout PCB anode.
Exposure to charged hadrons beam (1-20 GeV/c)

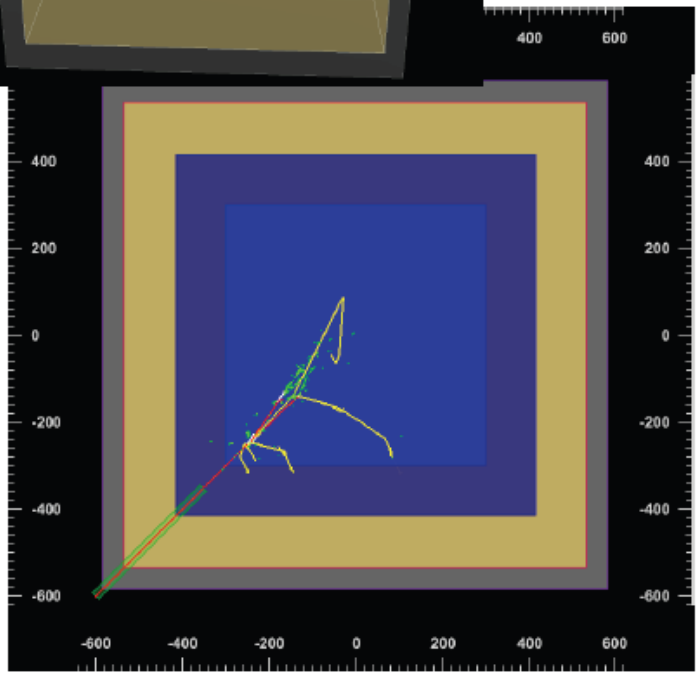
Large scale 300 t LAr Prototype at CERN

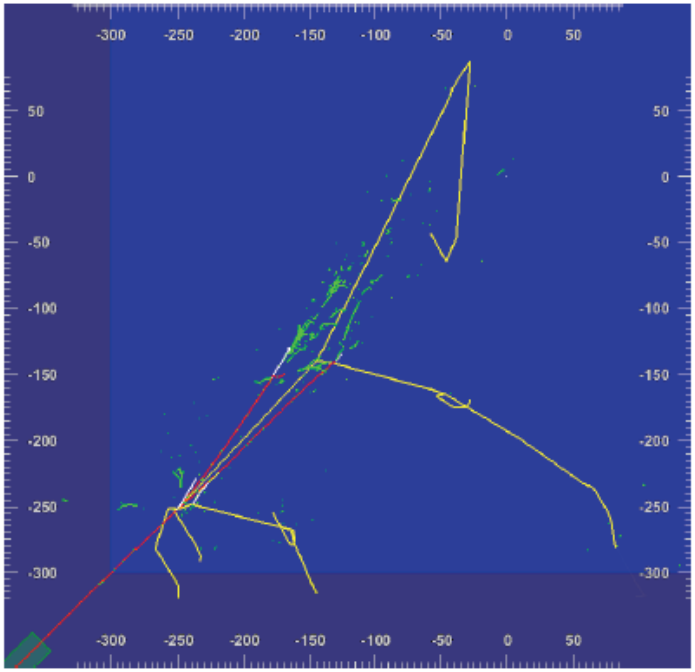
WA105

5 GeV π^+ simulation in $6x6x6m^3$



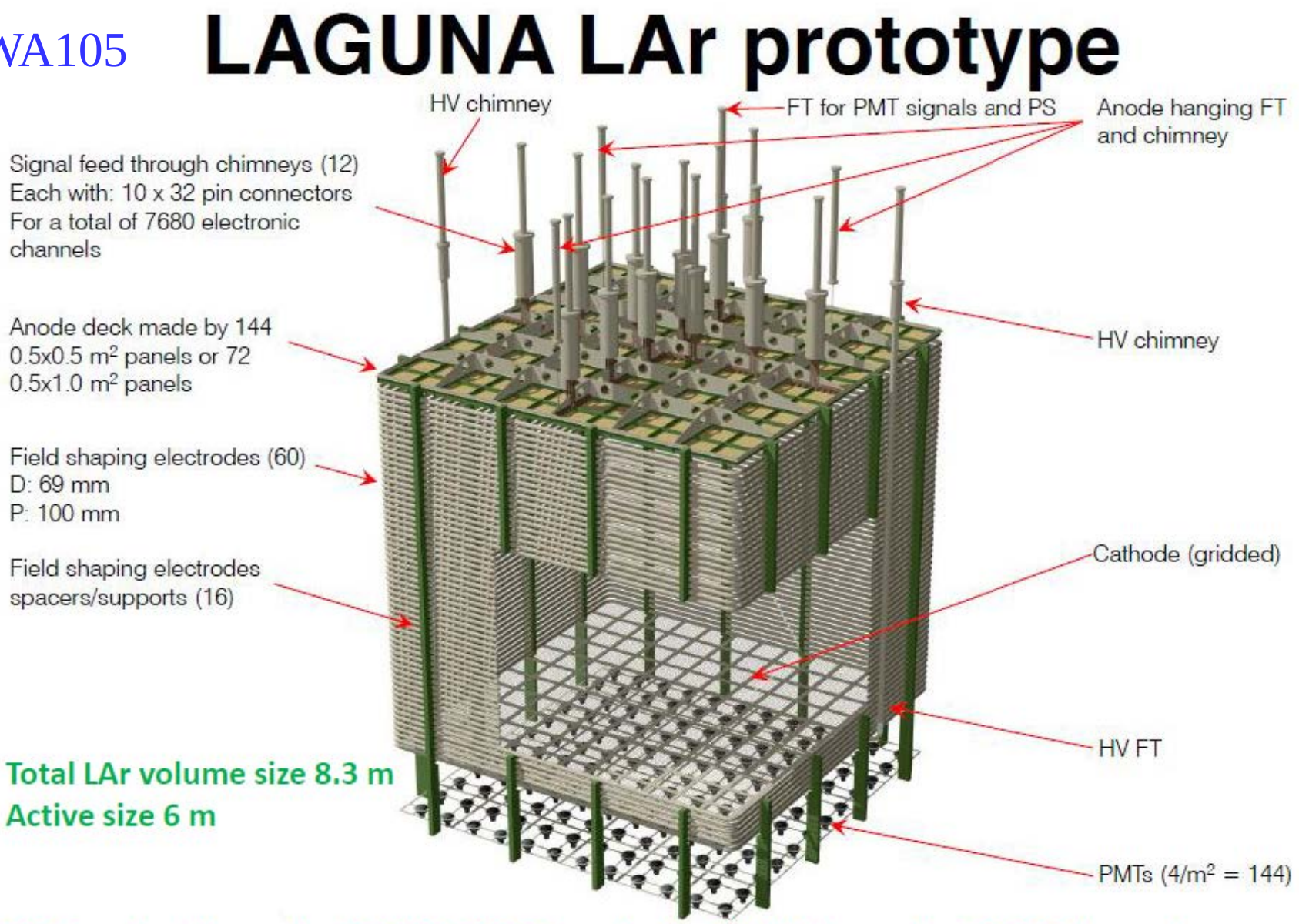






Large scale 300 t LAr Prototype at CERN

WA105



7680 readout channels, ICARUS T600 for a similar fiducial mass had 27000 channels