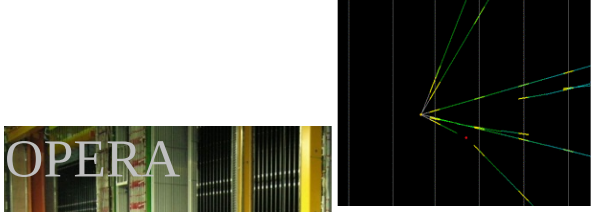
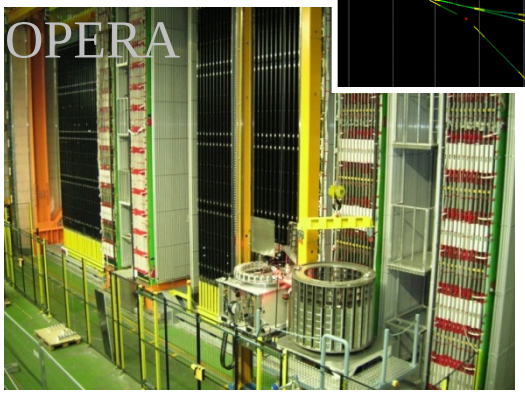
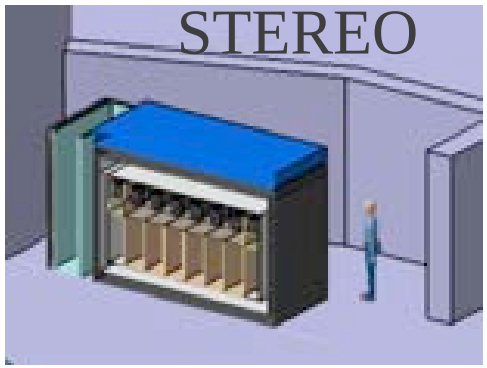
Neutrino physics

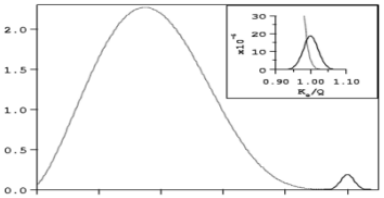
D.Duchesneau

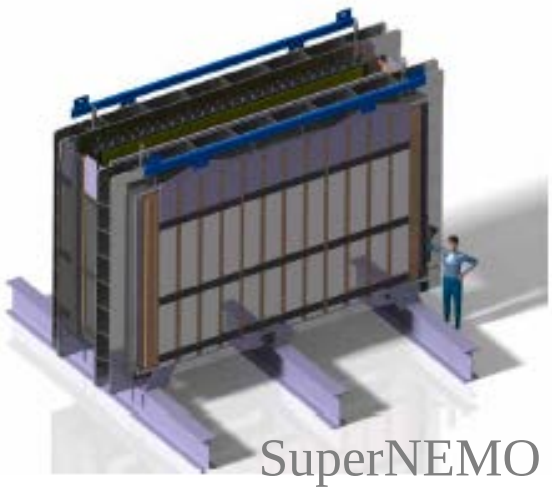
- Introduction
- Research program and status of activities
- Conclusions and prospects

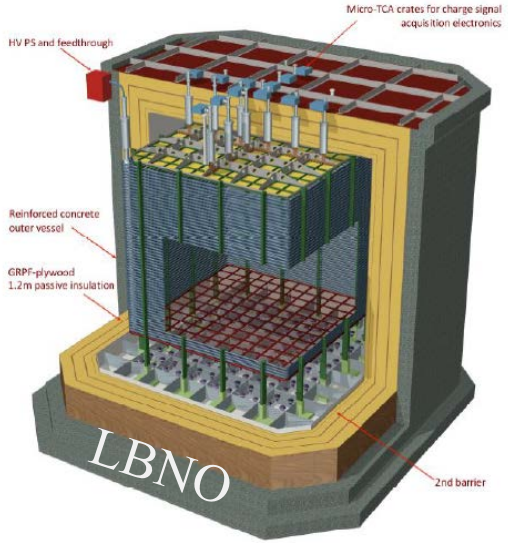


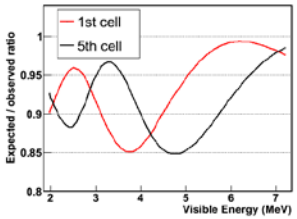












Neutrino Physics:

In 2011 we included Neutrino physics in the Labex program :

1.1. Program description, vision, ambition and scientific strategy (page 3)

Through the LSM as a member of the Labex not only do we want to strengthen the neutrino activity which has recently witnessed fantastic discoveries but we aim at also creating a neutrino pole by gathering physicists of our laboratories and expert visitors around the many facets of the neutrino

At that time LAPP and LSM were involved in neutrino physics independently in 2 main different projects

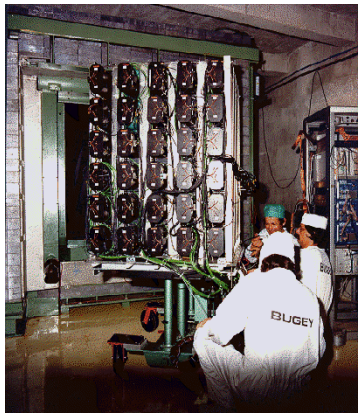
- LAPP: oscillation with accelerator OPERA/CNGS
- LSM: neutrinoless double beta decay NEMO3

Reference to the original Labex document:

At local/regional level, little coordination exists, despite the unique advantage provided by the nearby location of key scientific centres involved in such programmes such as CERN and more particularly LSM and the expertise existing in the laboratories

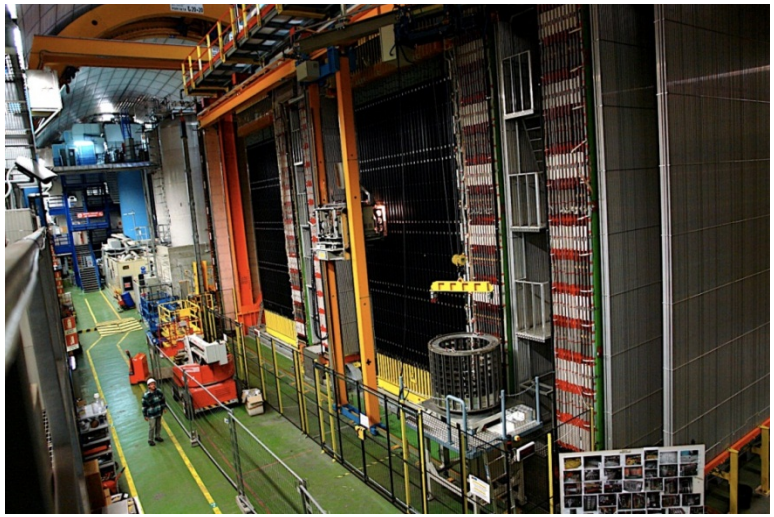
ν experiments at LAPP, LPSC and LSM: long tradition in key experiments

ν oscillations studies at reactors and accelerators



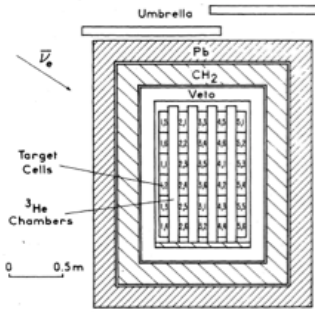
Bugey

Chooz



OPERA (en cours: exploitation / analyse)

Nomad



ILL

ν properties study: magnetic moment, 0 ν double beta decay,

MUNU

NEMO3

The motivations from the remaining fundamental questions and the experience acquired in our labs: decision to develop more the experimental activities within the neutrino physics WP following 3 main research axes.

Enigmass
The enigma of mass

Since 2012 the situation has clearly changed, thanks to the effort put with the Labex:

Concrete actions:

- ✓ LAPP has joined the SuperNemo collaboration and is participating with the LSM to the design and construction of the Demonstrator

- ✓ LPSC and LAPP are participating to the STEREO project at ILL reactor after having answered to an ANR call in 2013 with CEA Irfu.

Neutrino group evolution :

- ➢ 2 postdocs have been hired (1 at LPSC in 2014 and 1 at LAPP in 2013)
- ➢ 1 senior professor (neutrino physicist expert in the US) is going to join for 1 year to work at LSM and LAPP during the demonstrator commissioning

Neutrinos: Why? Here is a brief physics case

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

present

Enigmass
The enigma of mass

- Which is the mass hierarchy?

- Essential for CP violation quest

- Is CP symmetry violated in the leptonic sector?

Future goal

Challenging experimental program: Enigmass can become a 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

SuperNEMO demonstrator (2012-2017)

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

Long baseline project (LBNO type) with large volume LAr detector or Water Cherenkov detector. On a longer term: (2014-2025)

- European Design Study under progress with Laguna-LBNO (2012-2014)
- Detector R&D program on Liquid Argon TPC technology for long baseline neutrino beam

Under definition and discussion with the different Enigmass labs

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 (about 18 people):

- LAPP: I. De Bonis, D. Duchesneau, P. del Amo Sanchez, W. El Kanawati (postdoc ANR Stereo), L. Manzanillas (PhD), H. Pessard, **A. Remoto (postdoc Enigmass)**

- LPSC: S. Kox, J. Lamblin, F. Montanet, J.S Réal, A. Stutz, **postdoc Enigmass under selection**, S. Szlodos (PhD)

- LSM: P. Loaiza, L. Mosca, M. Zampaolo, F. Piquemal

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 could start now with detector R&D and prototyping => worth to initiate some prospective work in the different laboratories to define a common project for the longer term

Conclusions and prospects:

- Neutrino physics within Enigmass: significant growth in the last two years thanks to the support of the labex and the commitment of the various partners laboratories.

- The development of the SuperNEMO project involving experimental groups from LAPP and LSM and the participation in STEREO ANR project of the LPSC and LAPP groups: serious anchors to the creation of the neutrino pole originally thought.

- The momentum given also gives the possibility of extending the research in the neutrino labex for example by developing a joint activity with the theoretical groups in our laboratories

- In the longer term: possibility to define new involvements in future neutrino projects (beyond 2016) involving the interests of the different Enigmas laboratories in the field.

- We have to be careful with strategic choices to maintain the initial momentum and see how to establish the Neutrino regional Pole for a longer term.

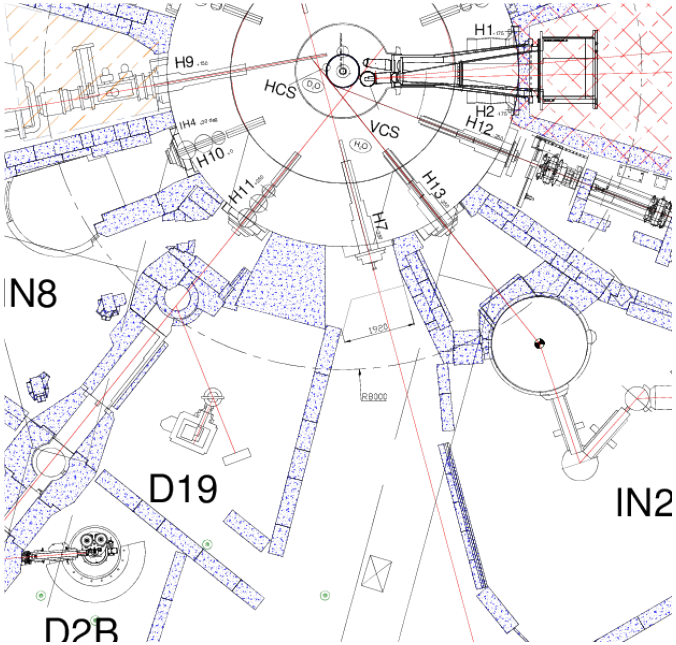
The End

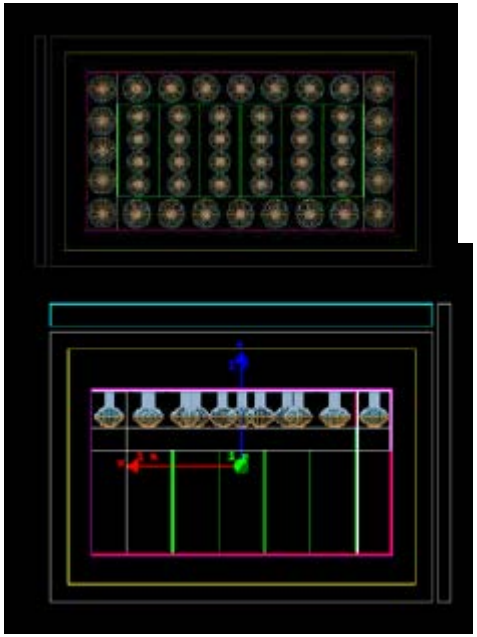
Or if time allows a short overview of the realisations and work within ENIGMASS is available in the next slides

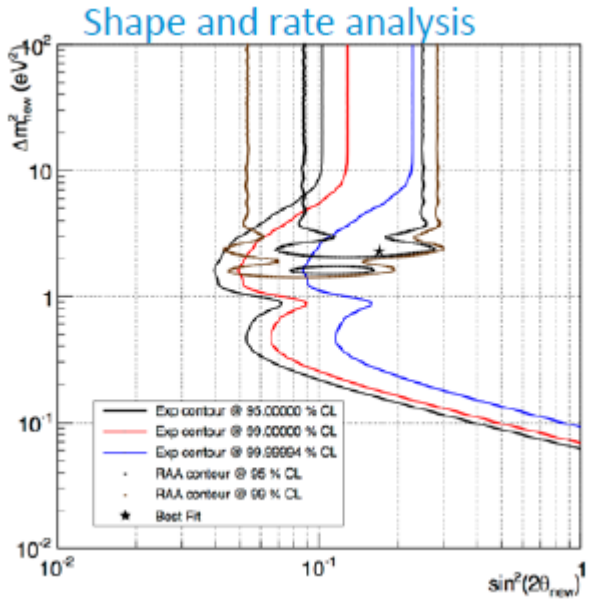
Sterile neutrinos

STEREO at the ILL reactor

ANR grant obtained for 3.5 years







LAPP and LPSC are major actors and have key responsibilities

- Design studies started in summer 2013
- Construction and commissioning by 2015

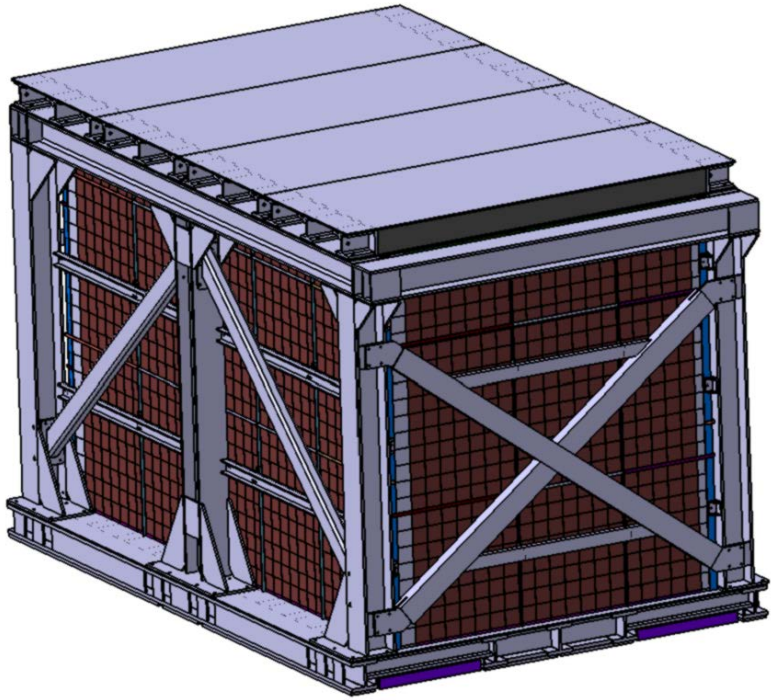
STEREO at LAPP

Pablo Del Amo Sanchez, Jean Favier, Henri Pessard, Wassila El Kanawati (2 yr ANR postdoc since 01/2014), Luis Manzanillas (PhD student since 10/2013)

- LAPP in charge of shielding support structure and automated calibration system.

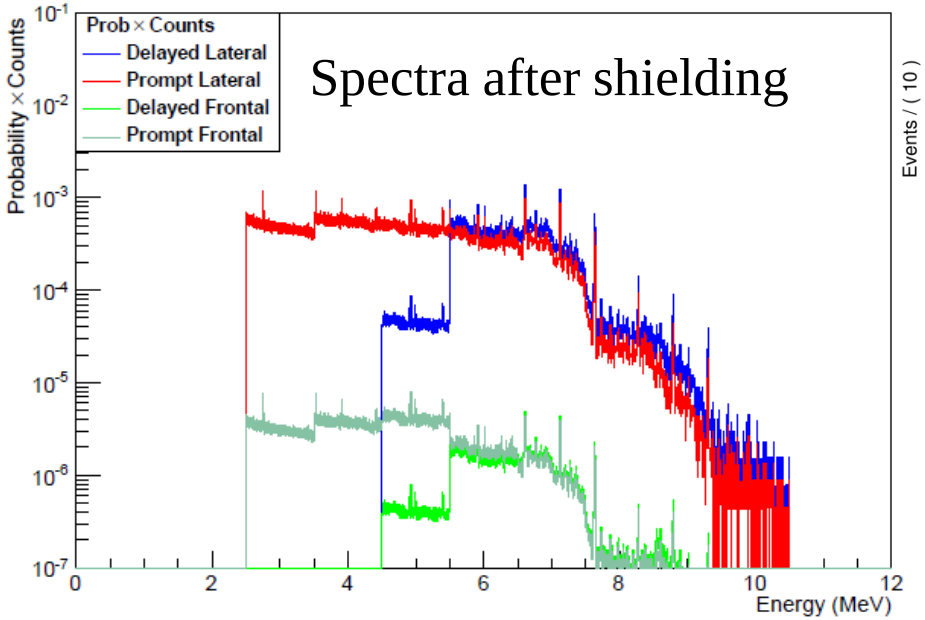
Shielding support must comply with stringent seismic regulations;

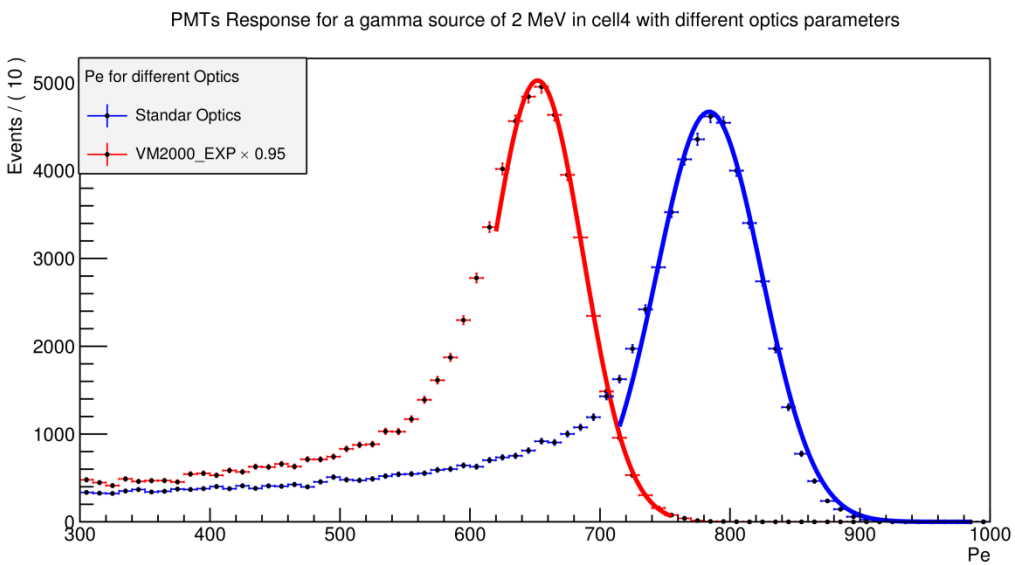
- design well advanced,
- currently looking into possibility of air cushion transport of shielding+detector (80 tons)



STEREO at LAPP

- MC studies of different calibration system concepts and shielding carried out
- First estimation of accidentals background based on gamma & neutron measurements





- Goal of calibration system: ~<2% error on energy scale
- Calibration concept to be frozen soon, details of calibration system waiting for preliminary design of internal detector

STEREO @ LPSC

Responsibilities:

Electronics
DAQ and Monitoring
Cosmic veto counter
Calibration with LED
Coordinationof the simulation

S. Kox, J. Lamblin, F. Montanet, J.S. Réal, A. Stutz
S. Zsoldos (PhD); Postdoc ENIGMASS under selection

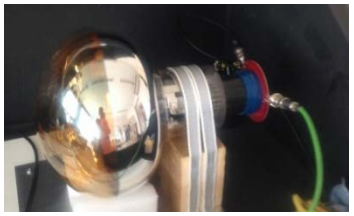
Electronics

Custom front-end + trigger + DAQ electronics based on FPGA

- Signal digitization (14 bits FADC 250 MHz) with signal analysis functions: Qtot, Qtail, full trace readout, timing, etc…
- Trigger and event building
- LED calibration driver

Current prototypes :

- New PMT base design
- Front end board where a part of the FPGA is used to simulate the trigger board
  - → Currently in test with 8'' R5912 Hamamatsu PMT, LEDs and small sample of scintillator
- Currently routing a new prototype based on µTCA technology



Veto counter prototype @ LPSC

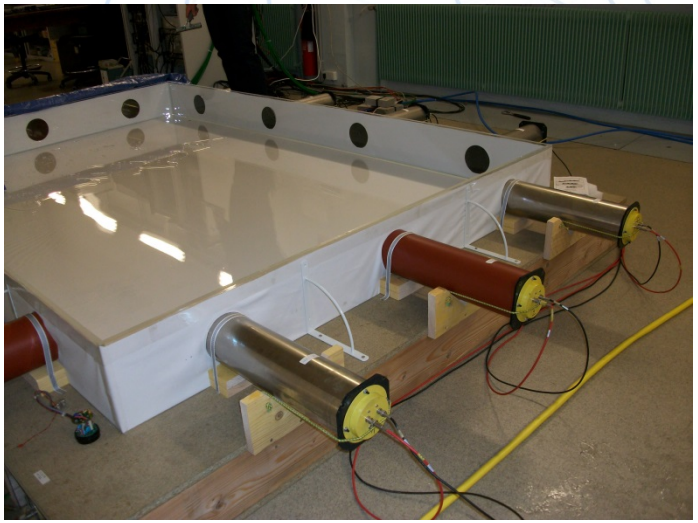
VETO counter:

- Sign cosmic-rays induced background in STEREO i.e. fast neutron induced by muons in shielding
- Large signal from minimum ionizing particle in stereo

Requirements

- Fully efficient to cosmic muons,
- Quasi insensitive to background γ-rays
- Made of non-flammable material

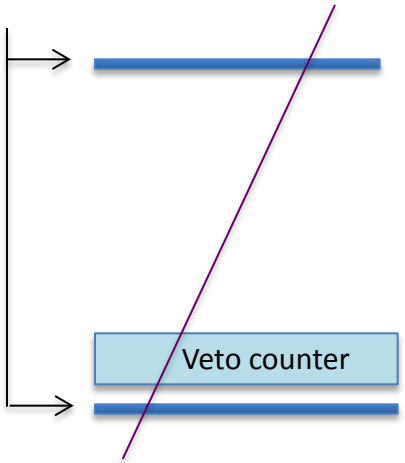
$\rightarrow$Water Cherenkov 3.8 x 2.4 m^2



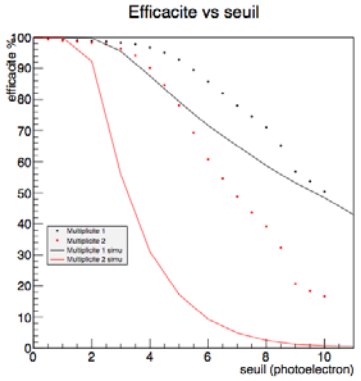
Current prototype :

- Almost full size tank 3 x 2 x 0.25 m^3
- In a big black box with muon telescope
- Optimization of geometry and light collection
  - Purified water
  - Wave Length Shifter (WLS) in water
  - Tyvek diffuser vs TiO2 paint vs VM2000…
  - 14 PMTs (5'' XP4572) on sides
  - Or 12 PMTs (8'' EMI 9345) on top

2x8 Plastic scintillators

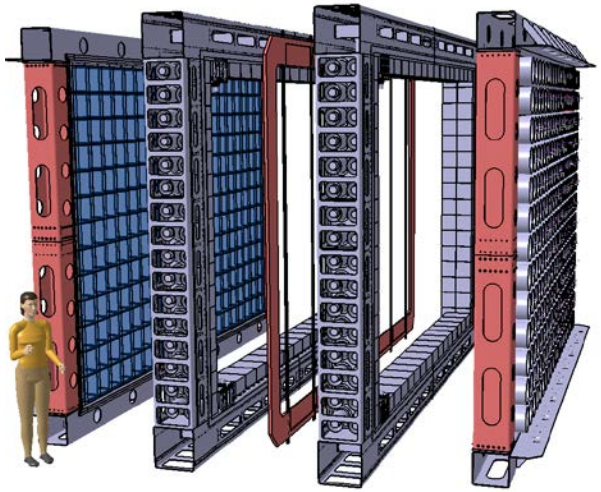


First results with 5'' PMT on sides, no WLS, tyvek diffuser



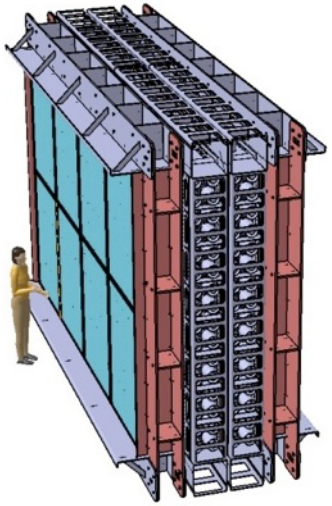
Nature of the neutrino: neutrinoless double beta decay

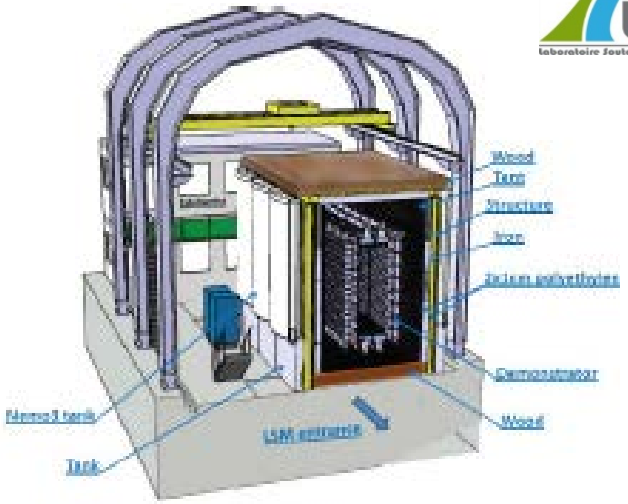
SuperNEMO: Demonstrator module

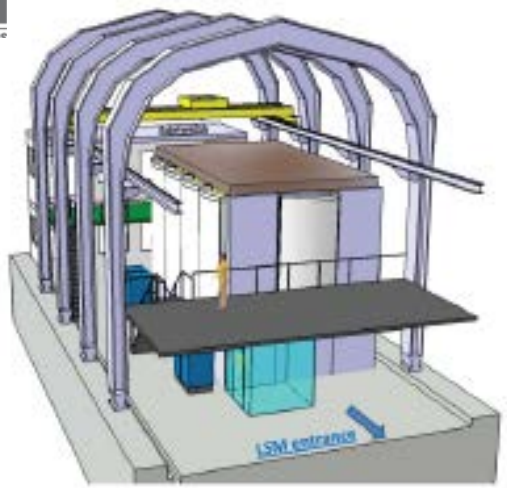


- Construction of some sub detectors already started
- Installation and commissioning (2014 – 2015)at LSM
- Data taking 2016-2017
- Sensitivity after 2 years :

$T_{1/2} > 6.6\ 10^{24}$ y et $\langle m_\nu \rangle < 0.2$ -0.4 eV







SuperNEMO demonstrator

1) R&D and production of ^{82}Se foil source

2) Monte Carlo studies for the foil design optimisation

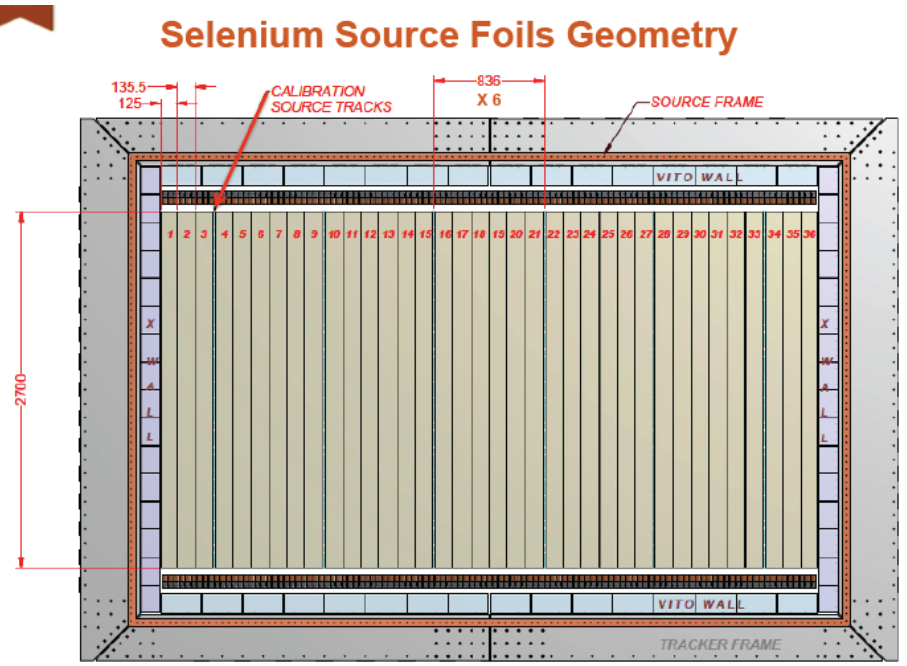
3) Development of the Slow Control system

Started in 2013

Selenium foil source R&D

- 36 strips 3 m long, ~200 um thick (50 mg/cm^2)
- Strong material radio-purity constrain:

^{208}Tl	< 2 µBq/kg
^{214}Bi	< 10 µBq/kg



2 Source Foils 125mm x 2700mm (1&36)
34 Source Foils 135.5mm x 2700mm (2-35)
TOTAL SOURCE SURFACE = 131139cm²

SuperNEMO: source foil R&D

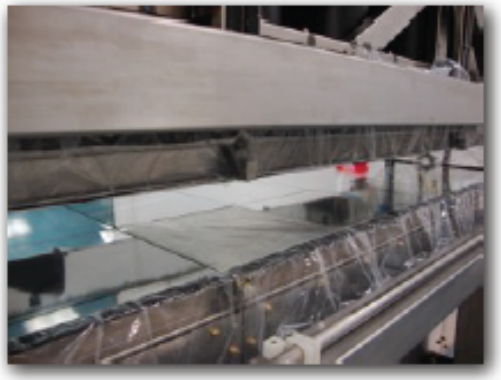
R&D with PVA glue (July - September 2013)

- Defining and training thin foil production technique

Radio-purity measurement

- HGe (LSM): ~1.5 kg PVA powder
- BiPo (LSC): 20 thin foil → 30x30 cm 200 μm thick

	M [g]	T [d]	A(^{208}Tl) [μBq/kg]	A(^{214}Bi) [μBq/kg]
Ge	1485	26	< 120	<350
BiPo	210	71	< 32	no yet
Limit	5 (10) % M_{Se}	—	40 (20)	200 (100)

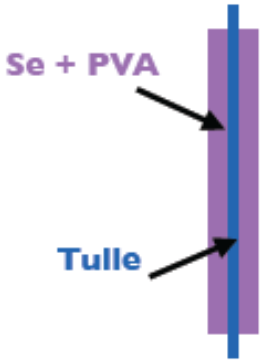


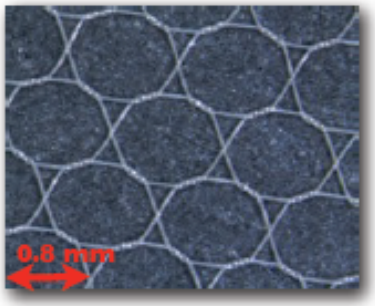
PVA radio-purity is good enough!

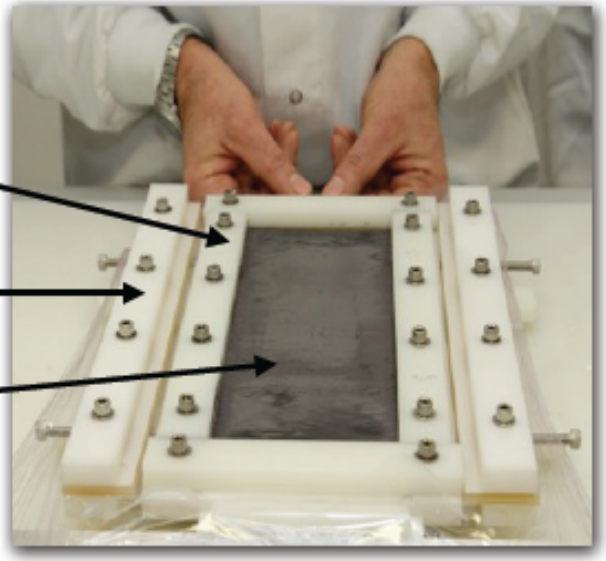
SuperNEMO: R&D source foil

R&D for mechanical support (November 2013 - January 2014)

- Fine mesh fabric (Tulle) as central backbone
- New idea proposed by LAPP:
  - Flexible and resistant foil
  - Small support mass ~ 1 % of Se mass
  - High level of radio-purity is expected
- Preparing samples for radio-purity measurement

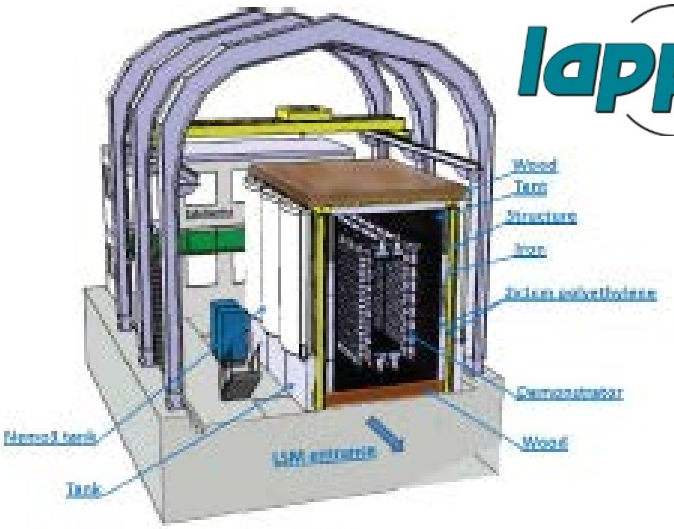






Goal: validating the process, testing the radiopurity and producing by end of 2014

SuperNEMO: Slow Control system



Computing + electronic departments @ LAPP

Develop dedicated software system to:

- **Control/monitor** environmental parameters, detector subsystems (local & remote)
- Operate **heterogeneous** devices including DAQ

Proposed solution:

- Common choice with CTA project → Take advantage of **existing experience**
  - OPC UA **specification** → A standard issued by HW & SW industrial vendors
  - Generic solution **independent** from context (experiments, technical strategy, devices)
- Definition of a **Interface Control Document** (ICD) to collect devices infos/specifications
- First prototype of integrated hardware to be tested next spring
  - From ICD → to web interface management

Implement device & user Interfaces by the end of 2014 / beginning 2015

Oscillation, mass hierarchy and CP violation

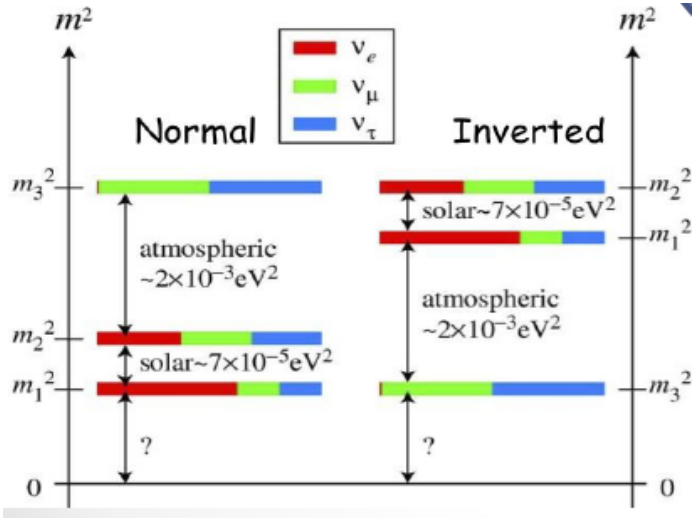
Long baseline project (LBNO type) with large volume LAr detector or Water Cherenkov detector.

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



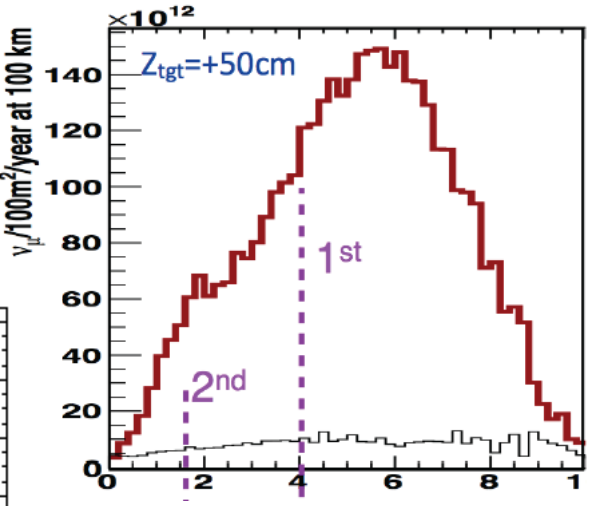
CP Violation:

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

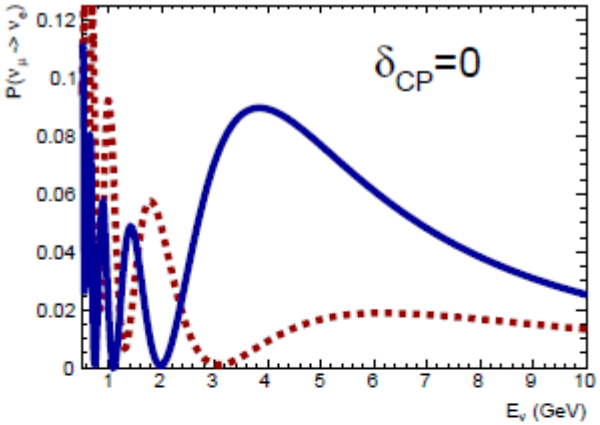
- Long baseline ν beam (>100 km)
  - Europe => LBNO / liquid Argon detector / 2300 et 1300 km?
  - US => LBNE / liquid Argon detector / 1300 km
  - Japan => Water Cerenkov detector / 295 km

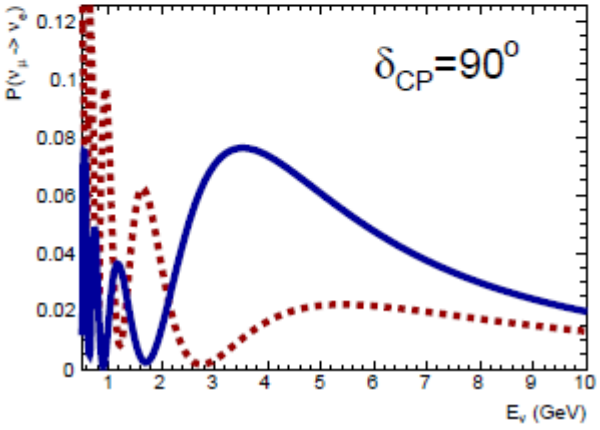
Both questions can be addressed with conventional accelerator neutrino beams by studying $\nu\mu \rightarrow \nu e$ and $\bar{\nu}\,\mu \rightarrow \bar{\nu}\,e$ oscillations

Example: wide band beam with L = 2300 km

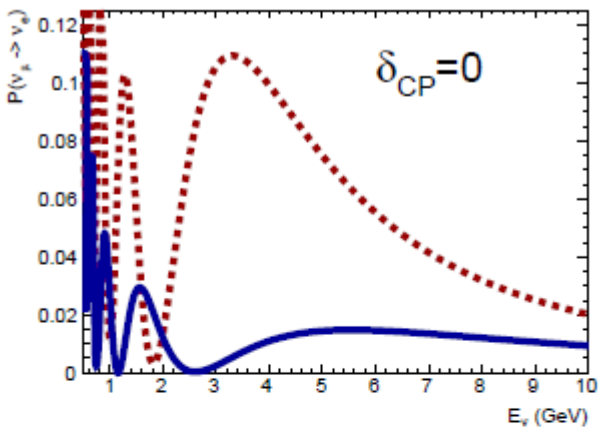


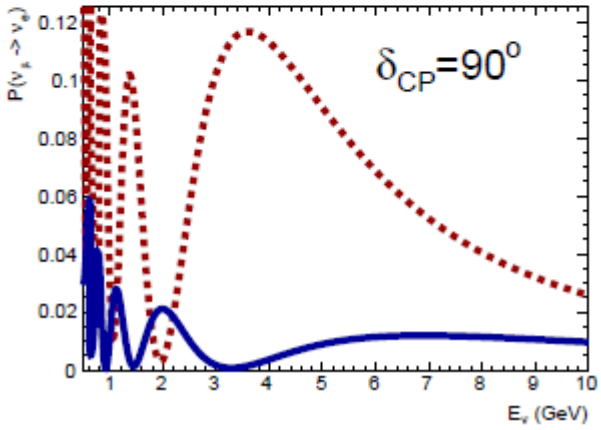
Normal Hierarchy





Inverted Hierarchy





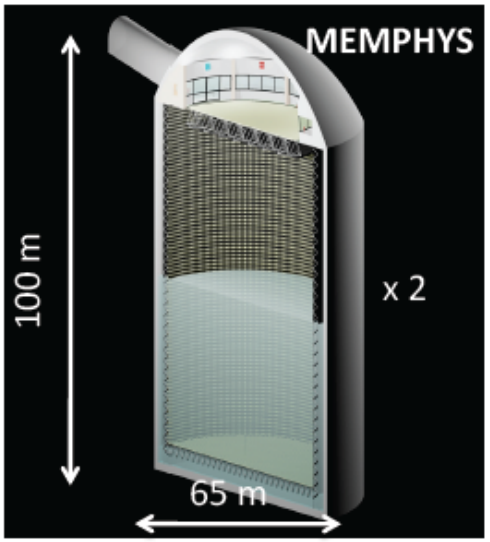
Prob osc. $\nu\mu \to \nu\, e$

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

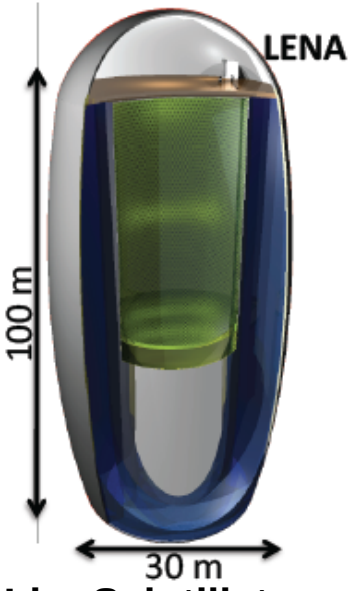
Wide band beam and Liquid Argon detector allow to measure the L/E dependences and possibility to disentangle MH and CPV

Large Underground Detectors: Rich physics program

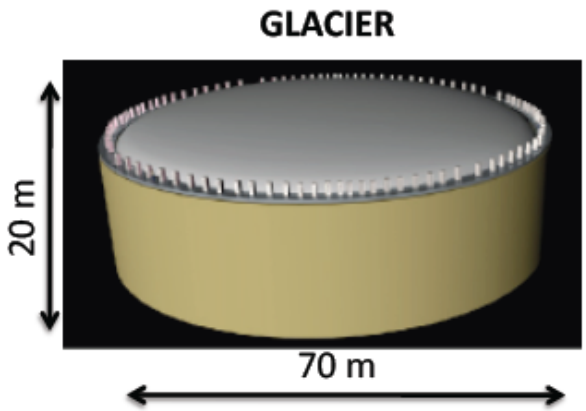
- ν properties(oscillation, mass hierarchy leptonic CP violation: beams, ν atm..)
- Study of astrophysical phenomena linked to ν:
  - ➢Gravitational star collapse (ν from Supernovae)
  - ➢Star formation at the beginning of the universe (SN ν diffuse background)
  - ➢Study of thermonuclear fusion process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



Water Čerenkov 2x 300kT



Liq. Scintillator→50kT



Liq. Argon →100kT