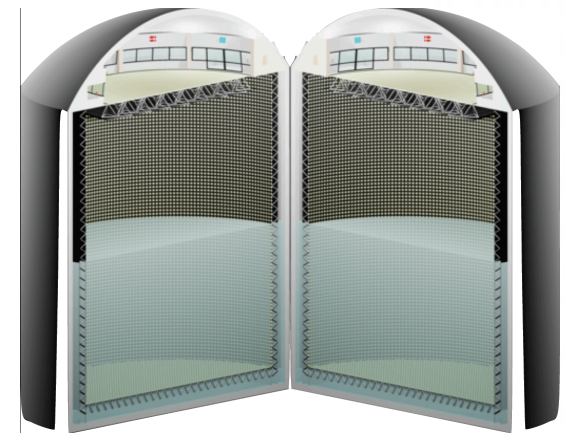


NOW 2012

Neutrino Oscillation Workshop



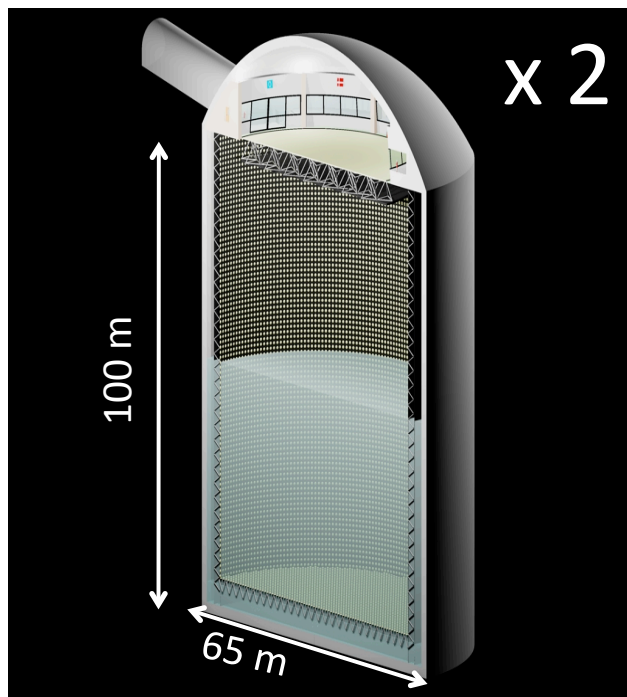
MEMPHYS

Thomas PATZAK
APC - Paris, France



patzak@apc.univ-paris7.fr

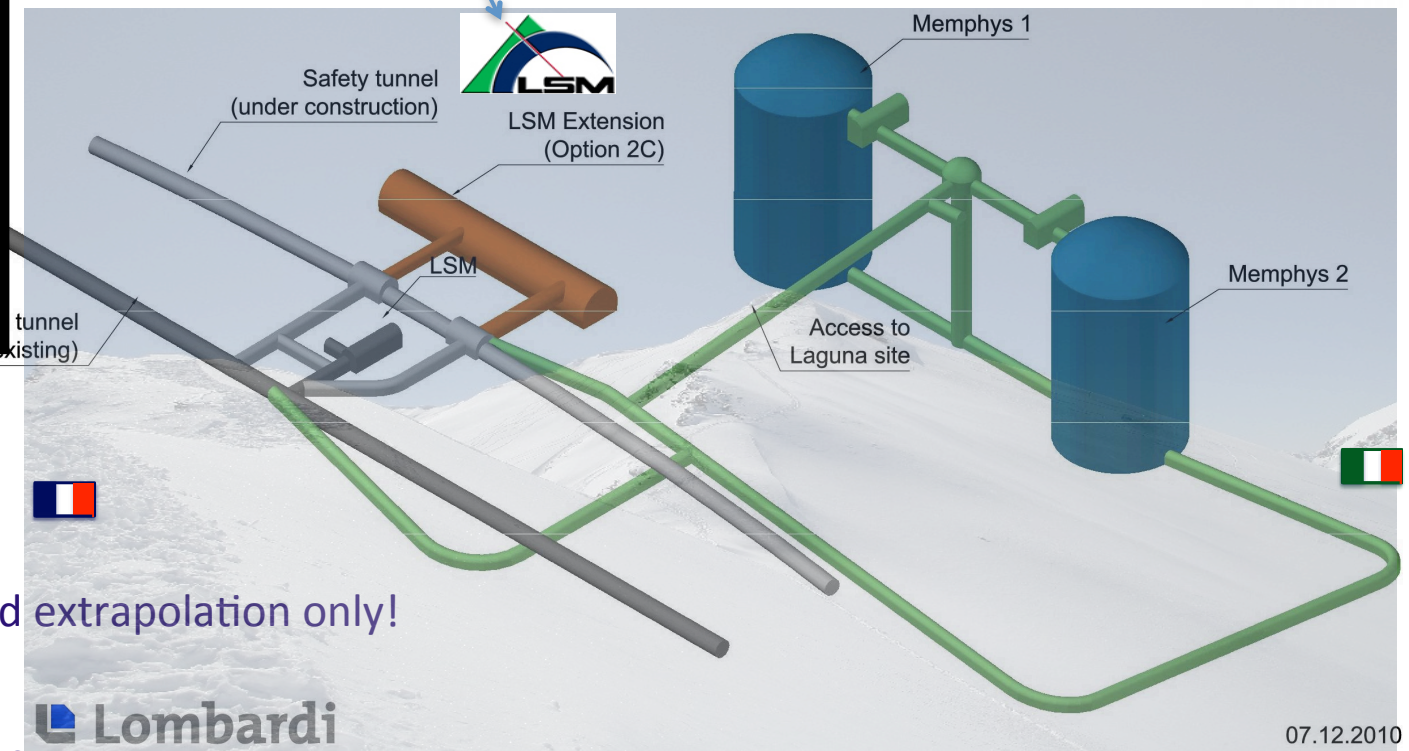
Conca Specchiulla (Otranto, Lecce, Italy), September 9-16, 2012



MEMPHYS (MEgatonMassPHYSics)

Laboratoire Souterrain de Modane - Frejus

- 130 Km from CERN
- 4800 m.w.e.



- Water Cherenkov
 - well proven technology
 - each tank is 6.6 x SK --> mild extrapolation only!
- total fiducial mass: 500 kt
- 2 cylindrical modules 65 x 100 m
 - size limited by light attenuation length ($\lambda \sim 80\text{m}$) and pressure on PMTs
 - readout : ~ 220000 ; 8" PMTs, 30% geom. cover
 - R&D on readout electronics and DAQ + detailed study on excavation @Fréjus existing & ongoing



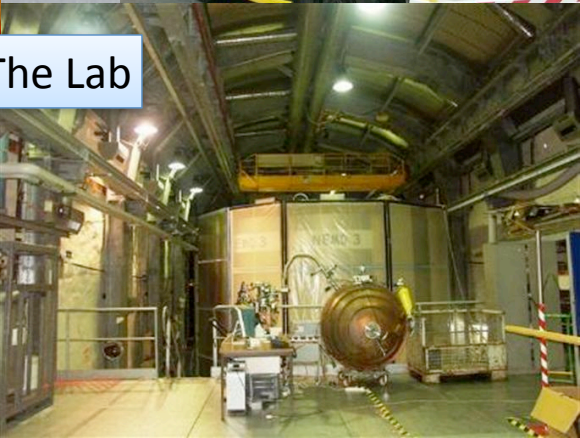
Drive in!

Safety

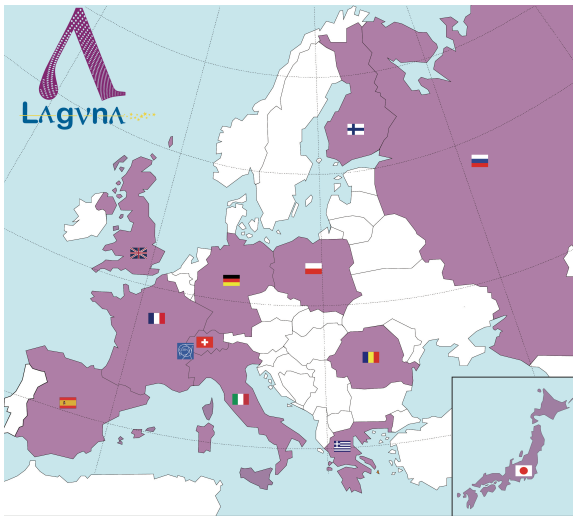


Easy access

The Lab



MEMPHYS is part of the EU FP7 DS LAGUNA-LBNO



LAGUNA-LBNO consortium:
13 countries, 45 institutions, ~300 members
2011 - 2014

France

CEA
 CNRS-IN2P3
 Sofregaz*

Germany

TU Munich
 University Hamburg
 Max-Planck-Gesellschaft
 Aachen(**)
 University Tübingen(**)

Poland

IFJ PAN
 IPJ
 University Silesia
 Wroclaw UT
 KGHM CUPRUM*
 Greece
 Demokritos

Spain

LSC
 UA Madrid
 CSIC/IFIC
 ACCIONA*

United Kingdom

Imperial College London
 Durham
 Oxford
 QMUL
 Liverpool
 Sheffield
 RAL
 Warwick
 Technodyne Ltd*
 Alan Auld Ltd*
 Ryhal Engineering*

Romania

IFIN-HH
 University Bucharest

Denmark

Aahrus(**)

Italy

AGT*

Russia

INR
 PNPI

Japan

KEK

(*=*industrial partners*)
 (**=*associated*)

Switzerland

University Bern
 University Geneva
 ETH Zürich
 Lombardi Engineering*

Finland

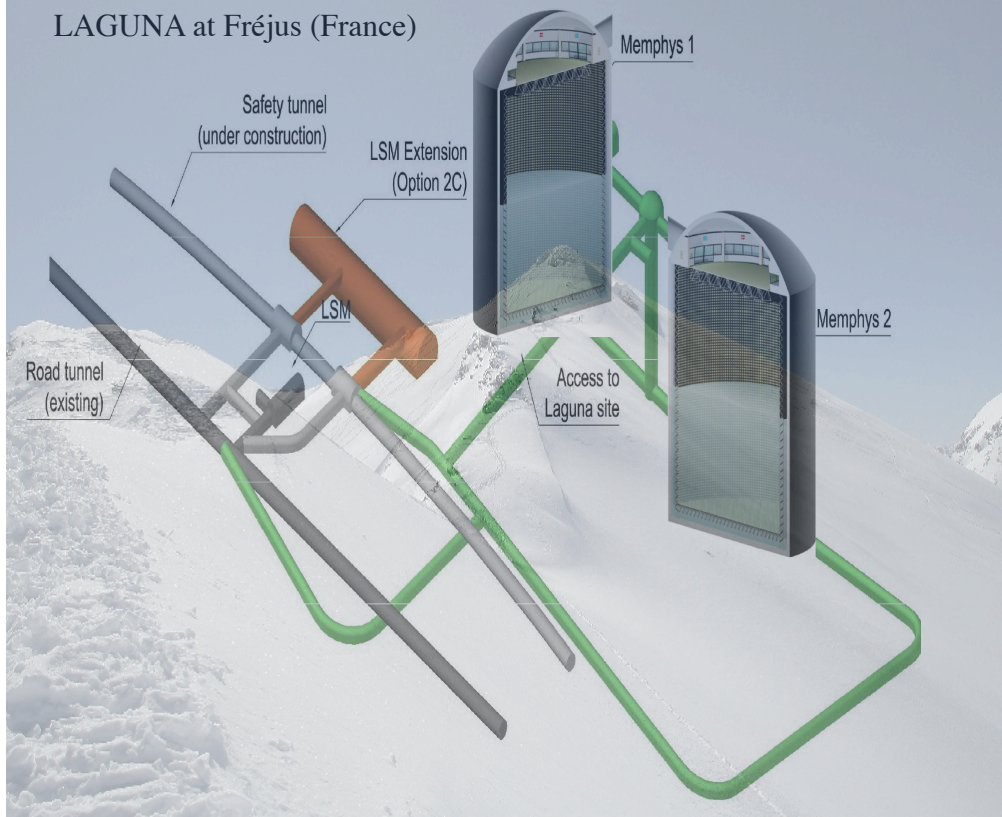
University Jyväskylä
 University Helsinki
 University Oulu
 Rockplan Oy Ltd*

CERN

LAGUNA-LBNO - Cite specific investigations:

1. Shortest baseline (130 km), CERN -> Fréjus: no matter effects; clean measurement of LCPV
2. Longest baseline (2300 km), CERN -> Pyhäsalmi: matter effect; mass hierarchy, LCPV
 - Facility Construction Plan and Costing (WP2)
 - Lifetime Operation (WP3)
 - Baseline Neutrino Beams from CERN (WP4)
 - Science and Impact on Detector Design (WP5)

MEMPHYS is considered as 2nd option



1st Option: LAr + LSc @ Pyhäsalmi

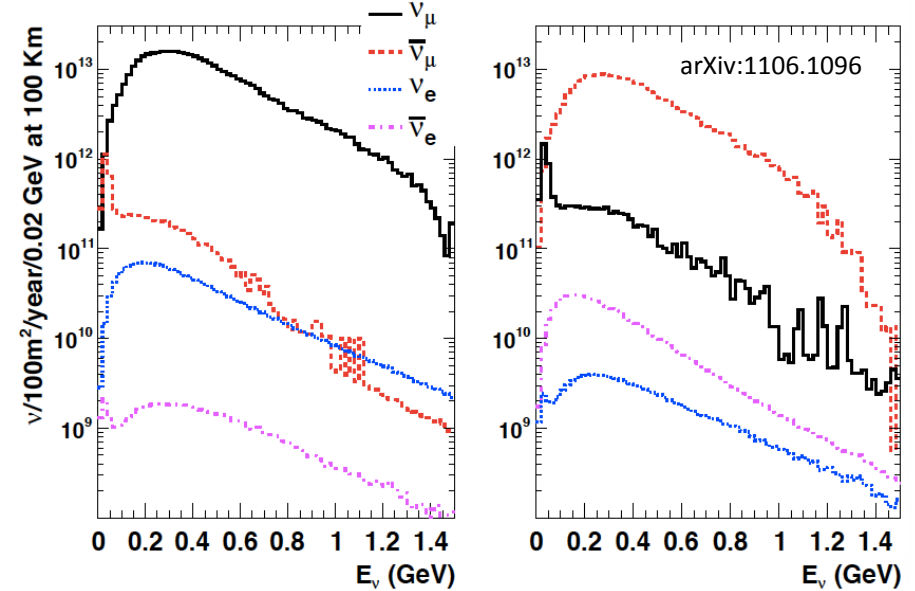
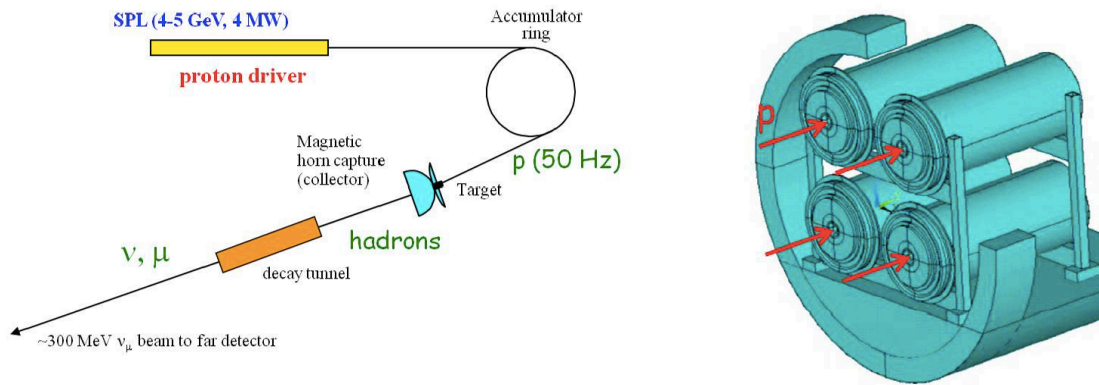


SPSC-EOI-007

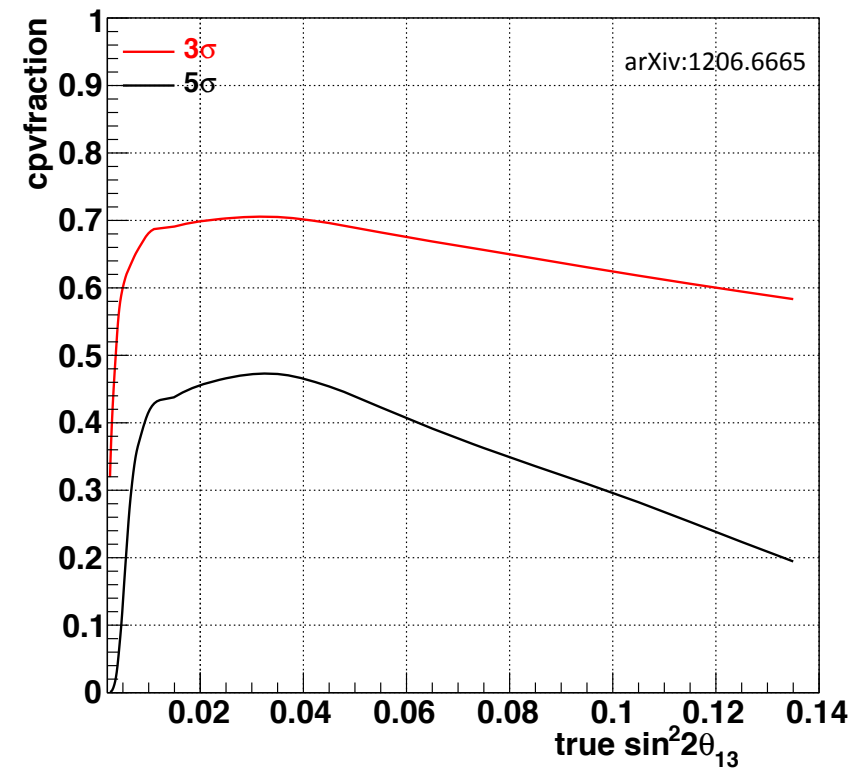
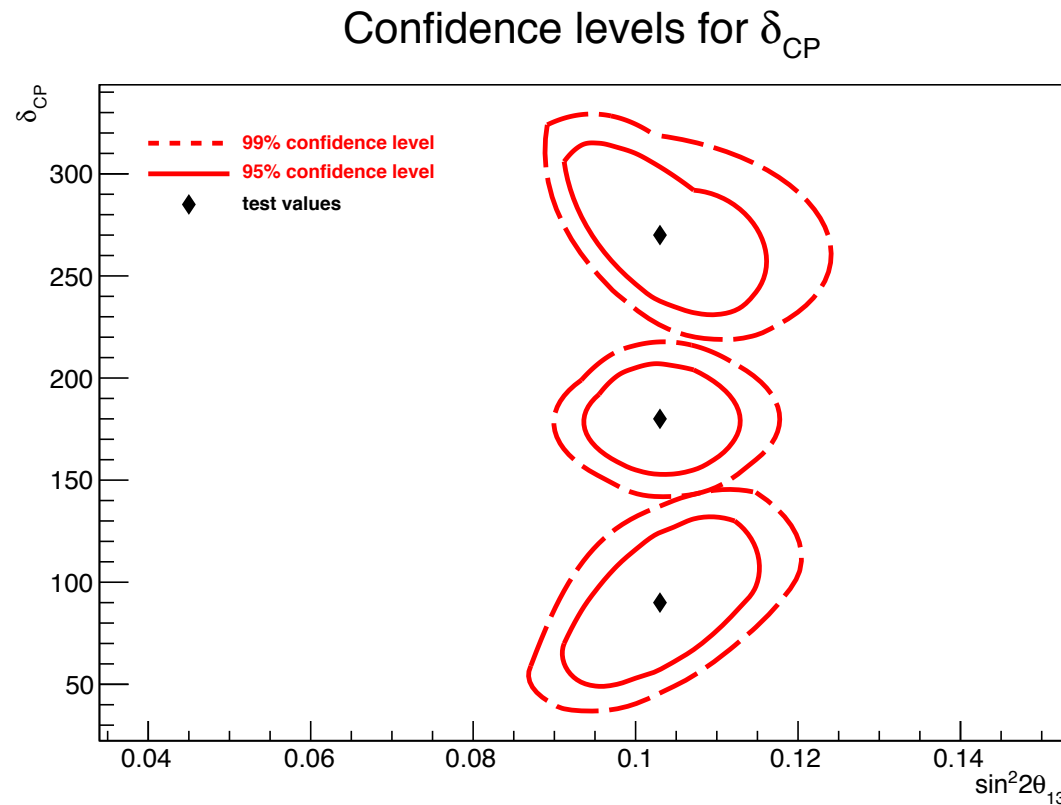
See talk from A. Rubbia
on Saturday



LCPV with MEMPHYS and SPL beam CERN-Frejus [2y (ν) + 8y ($\bar{\nu}$)]

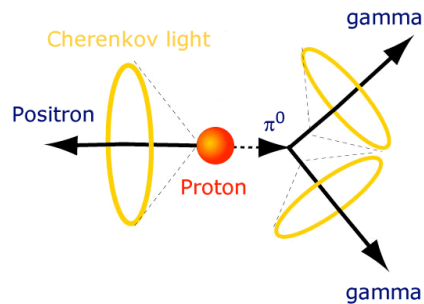


SPL/MEMPHYS 2012: cpv-fraction 5% signal-10% background syst.



MEMPHYS non-accelerator Physics

Proton Decay



Model	Decay Modes	Predictions
Georgi-Glashow	-	ruled out
Type II- $SU(5)$	all	$\tau_p < 2 \times 10^{36}$ yr
Type III- $SU(5)$	$p \rightarrow \pi^0 e^+$	$\approx 10^{35-36}$ yr
Adjoint $SU(5)$	$p \rightarrow \pi^0 e^+$	$\tau_{e+\pi^0} < 10^{35}$ yr
	$p \rightarrow K^+ \bar{\nu}$	$\tau_{K+\bar{\nu}} < 9 \times 10^{36}$ yr
	$p \rightarrow \pi^+ \bar{\nu}$	$\tau_{\pi+\bar{\nu}} < 3 \times 10^{35}$ yr
Non-SUSY $SO(10)$	$p \rightarrow e^+ \pi^0$	$\approx 10^{33-38}$ yr
Minimal SUSY $SU(5)$	$p \rightarrow \bar{\nu} K^+$	$\approx 10^{32-34}$ yr
SUSY $SO(10)$	$p \rightarrow \bar{\nu} K^+$	$\approx 10^{33-36}$ yr

WCD 10 years, 500 kt fiducial:

$p \rightarrow e^+ \pi^0$: $\sim 1.2 \times 10^{35}$ y at 90% C.L.

$p \rightarrow \bar{\nu} K^+$: $\sim 2.4 \times 10^{34}$ y at 90% C.L.

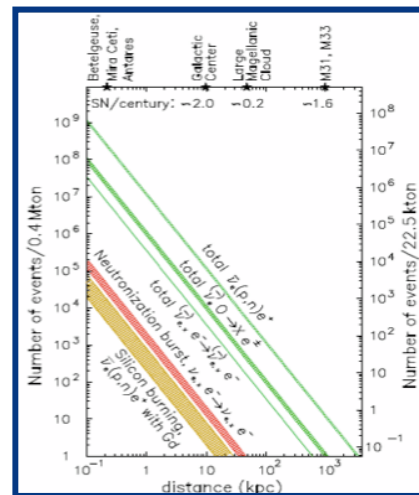
Supernova



Galactic SN: Huge statistics

- SN explosion mechanism: shock waves, neutronization burst
- Neutrino production parameters: rate, spectra
- Neutrino properties

Fogli et al., hep-ph/0412046



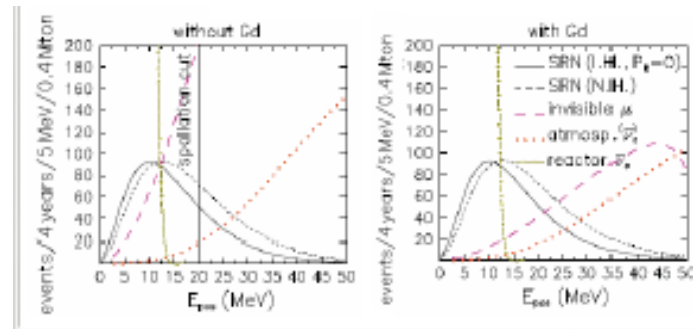
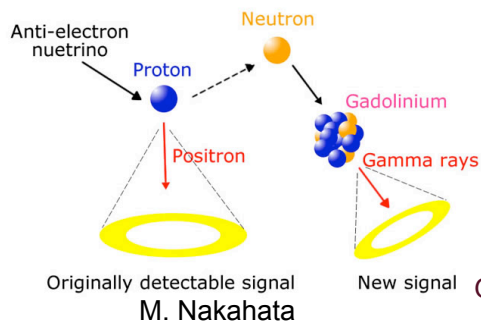
For a galactic Supernova @ 10 kpc:

CC: $\sim 2.5 \times 10^5 \bar{\nu}_e$

ES: $\sim 1.2 \times 10^3 e$

O 10 events @ 1 Mpc

DSN



For 1 tank with Gd (250 kt):

$S/B (5y) = (52 - 132) / 57$

GADZOOKS! Beacom and Vagins, *Phys. Rev. Lett.*, **93**:171101, 2004

MEMPHYS non-accelerator Physics

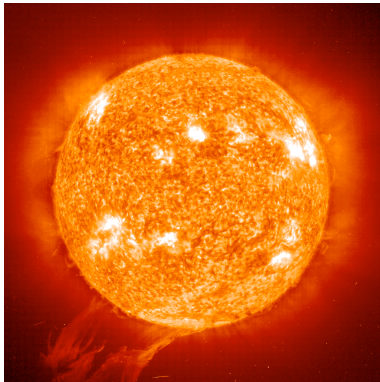
Reactor Neutrinos



1 MEMPHYS tank with Gd 250 kt fiducial @ Fréjus:

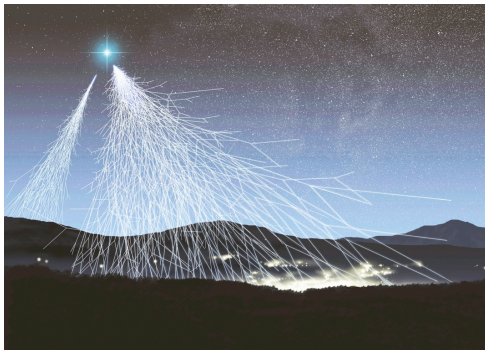
$\sim 2.7 \times 10^4$ per year

Solar Neutrinos



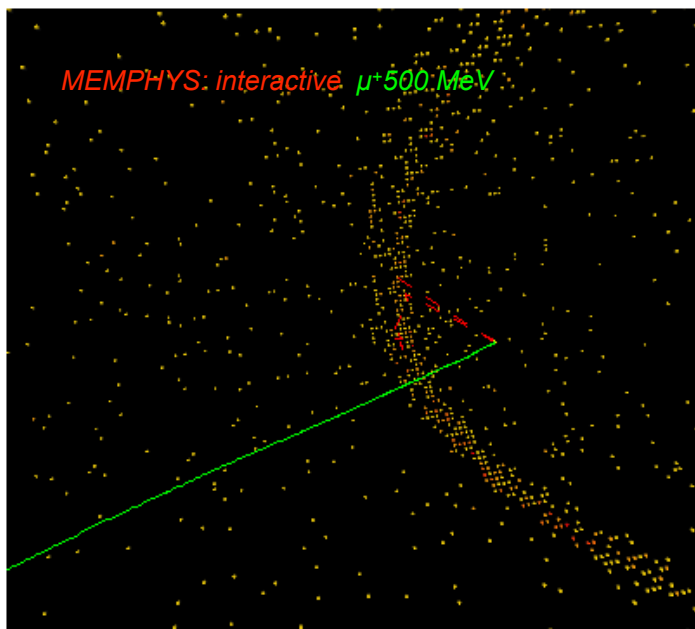
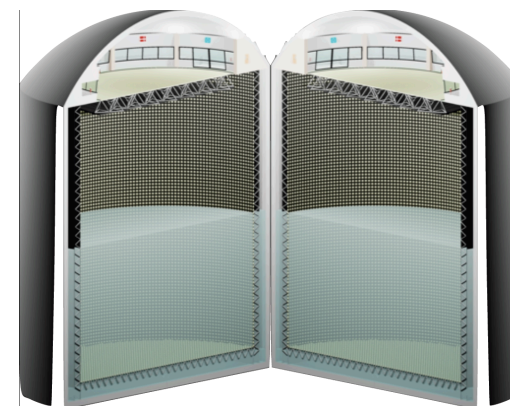
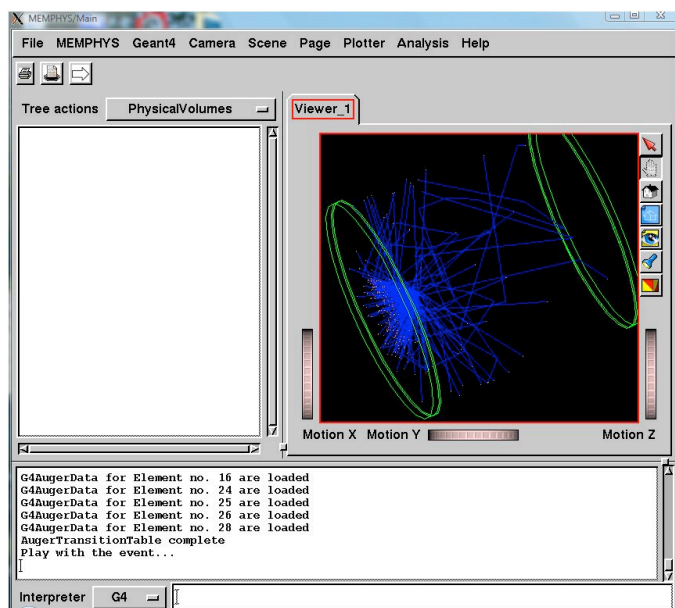
ES $\nu_{8B} \sim 1.3 \times 10^6$ per year

Atmospheric Neutrinos



$\sim 4.8 \times 10^4$ per year

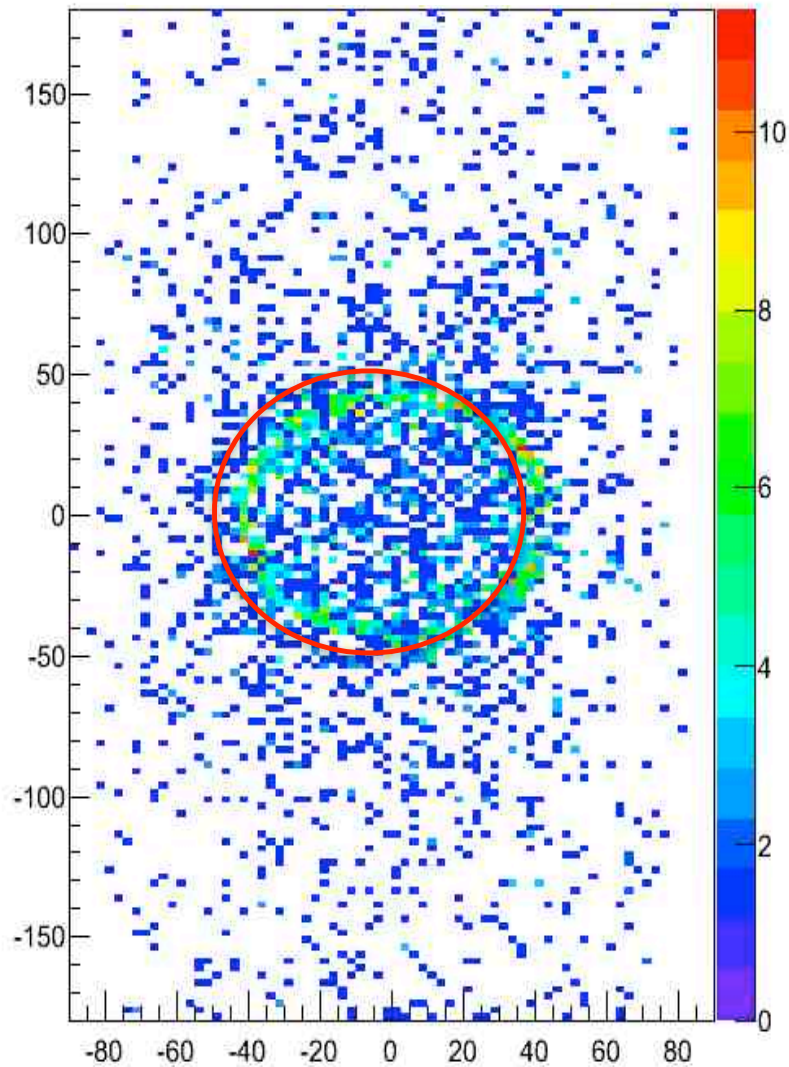
MEMPHYS SIMULATION



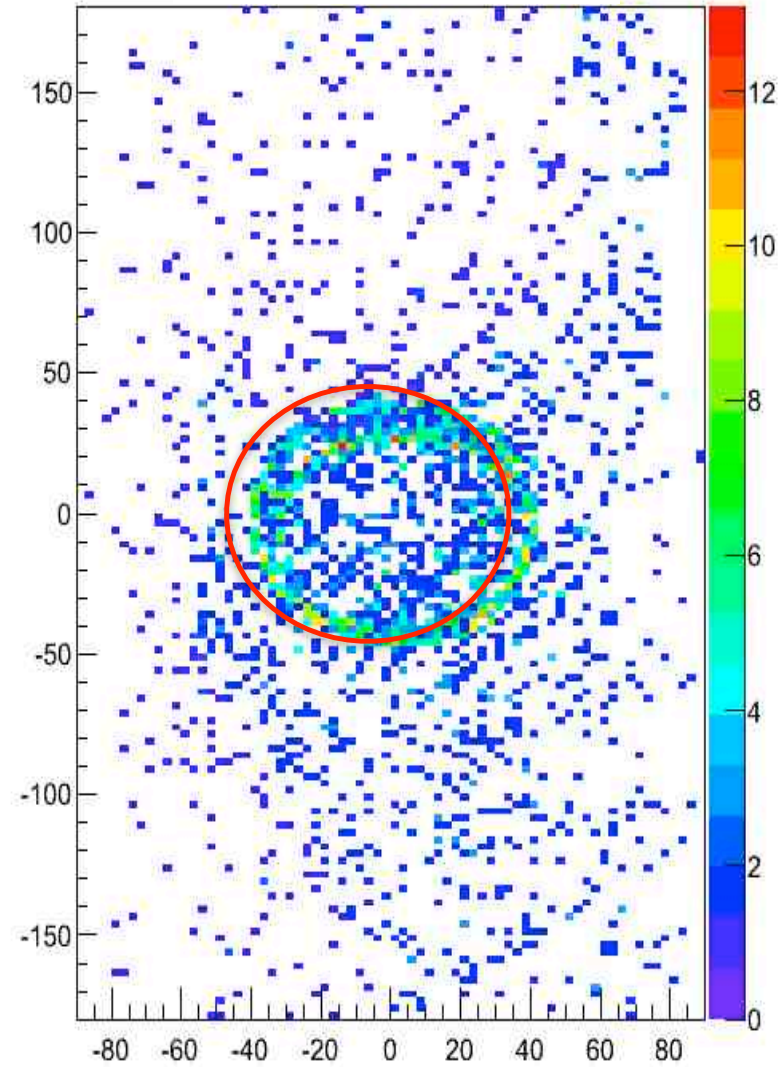
- Full simulation of the MEMPHYS detector
 - originally developed by J.E.Campagne and Guy Barrand at LAL
 - extensively tested and developed by N.Vassilopoulos
 - used to define realistic detector performance – for the first time with a **full simulation** !
 - full and realistic **reconstruction** and analysis algorithms developed
 - extraction of MM is now **done**
 - GLOBES AEDL file is **ready** for potential studies
 - **First potential** studies with new data are done
- Some technical details
 - Neutrino interactions in water simulated with **GENIE**
 - Geant-4 detector simulation, with AIDA and OpenScientists used for ntuple production
 - Detailed detector description, easy to modify. We have implemented the new layout with **65x100 m** tank
 - The detailed simulation of light propagation in water is very **slow**: huge work of scripting for production of large samples

PARTICLE ID

electron: fuzzy ring edge



muon: sharp ring edge

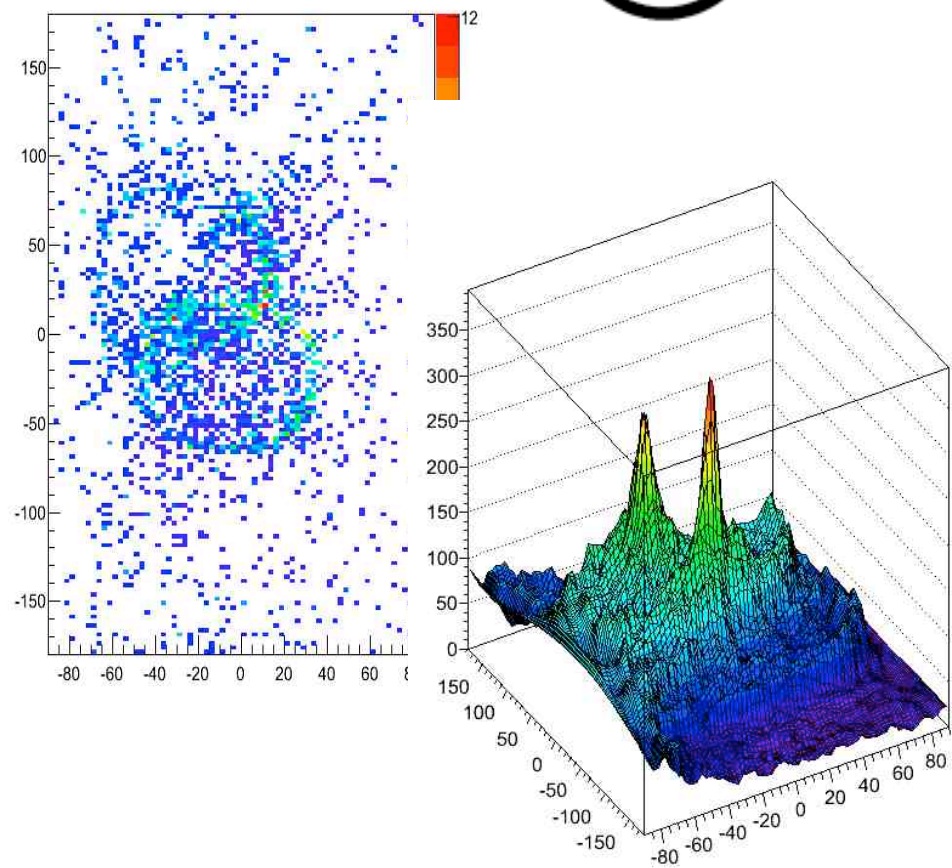
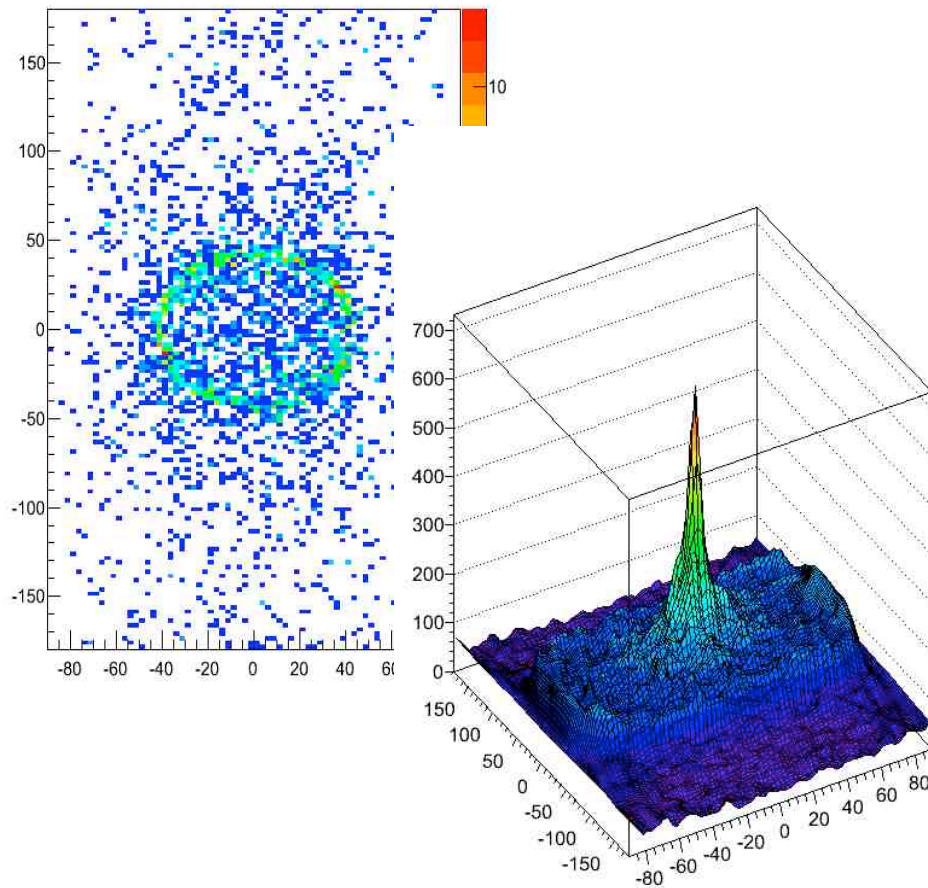
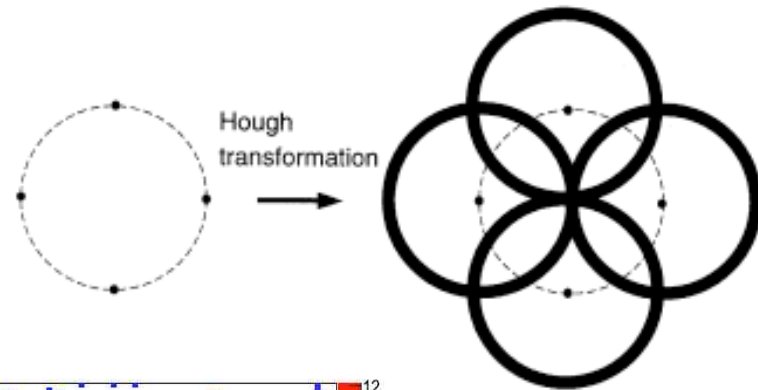


ϕ vs θ , spherical coordinates around fitted vtx and direction
PEs corrected for attenuation length

RING COUNTING

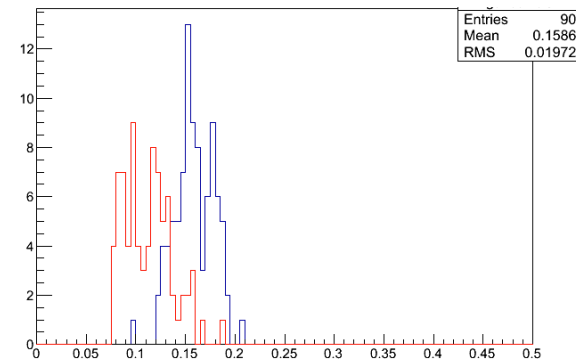
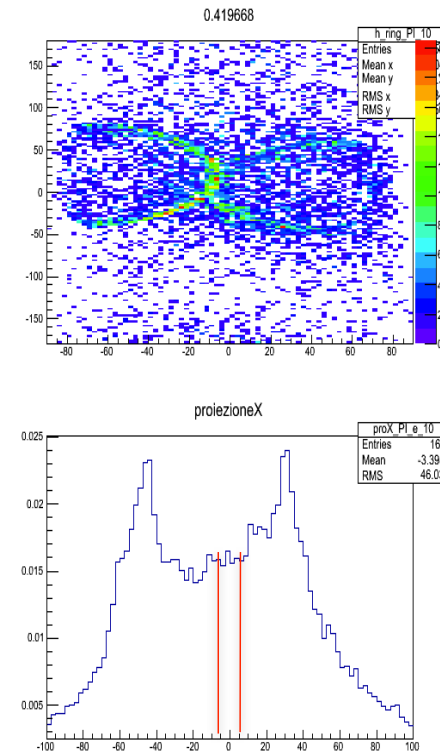
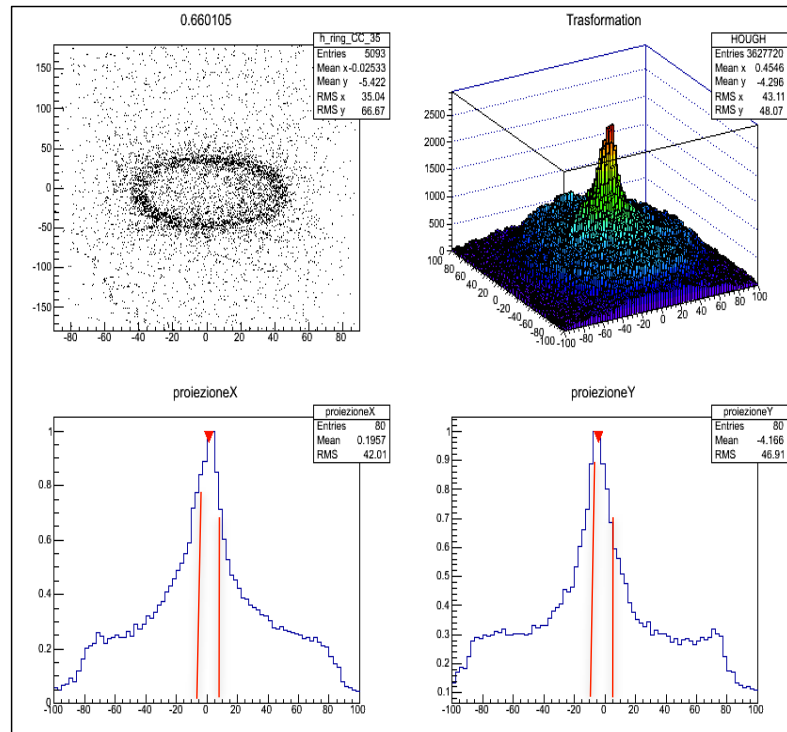
Hough Transformation:

- Turn rings into peaks,
then use peak counting



RING COUNTING

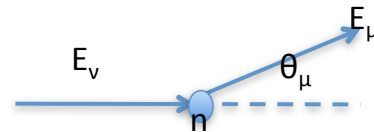
How to count peaks (using projections)



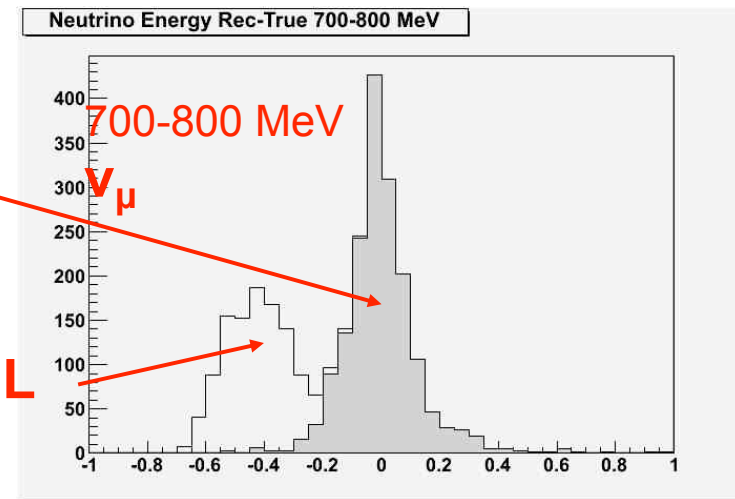
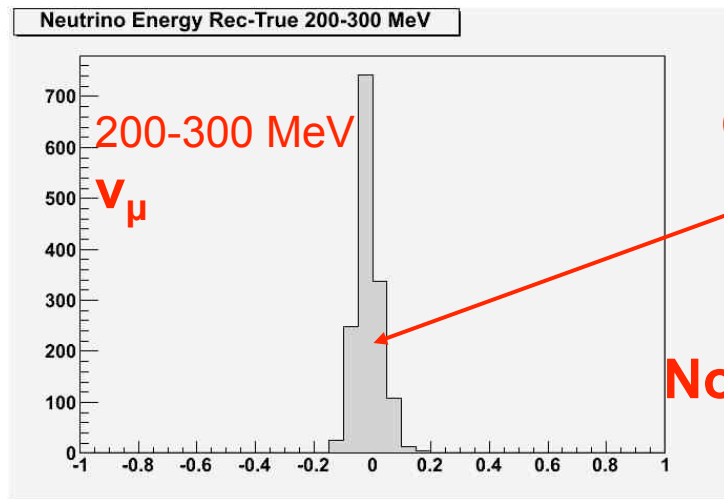
Best estimator:
Area between -5 and +5 bins

ENERGY RECONSTRUCTION

- Neutrino momentum is derived from lepton energy and direction, assuming a 2-body process



$$E_\nu = \frac{m_n E_\mu - m_\mu^2 / 2}{m_n - E_\mu + p_\mu \cos \theta_\mu}$$



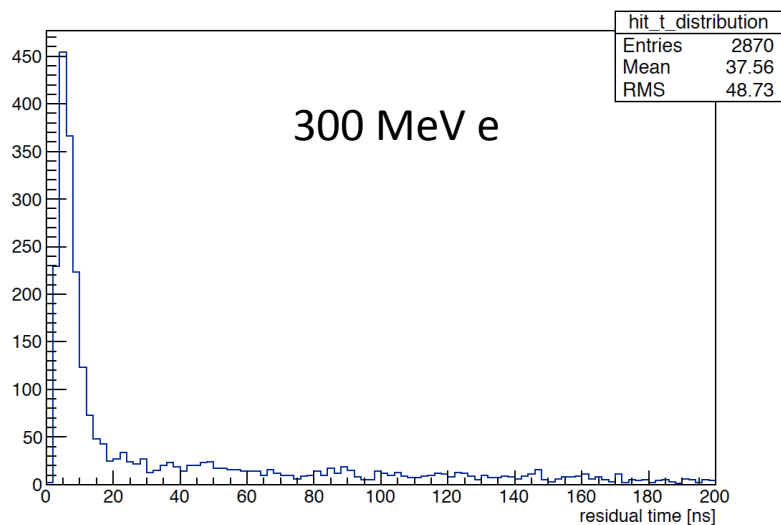
QEL

Non-QEL

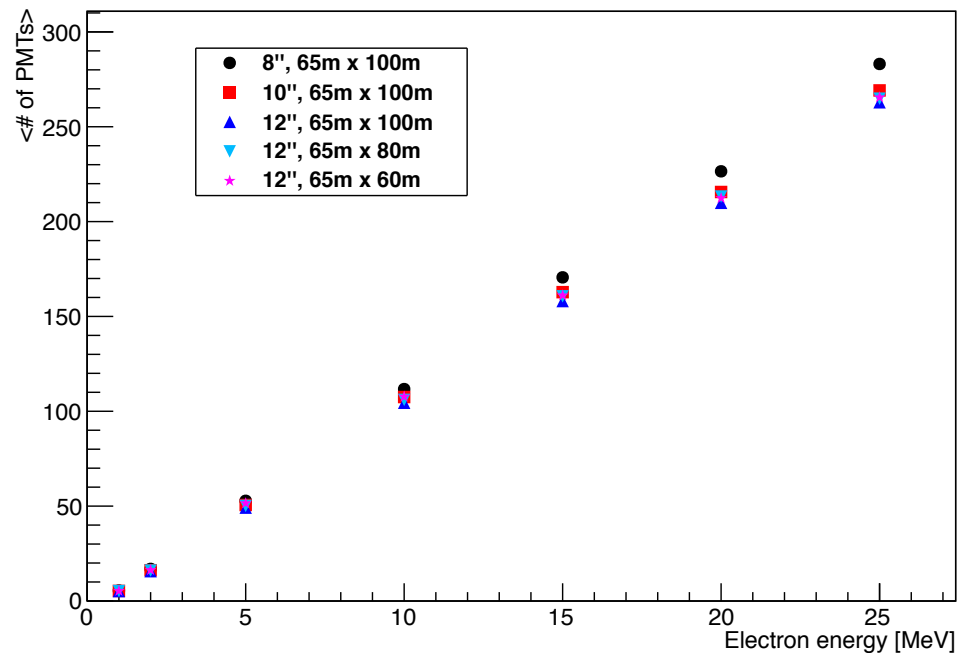
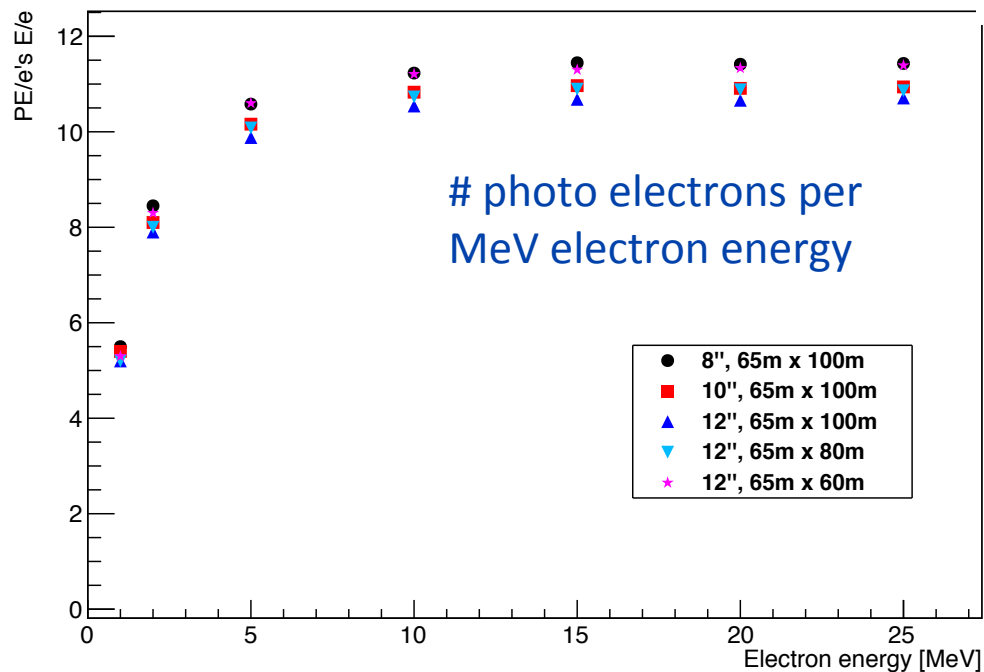
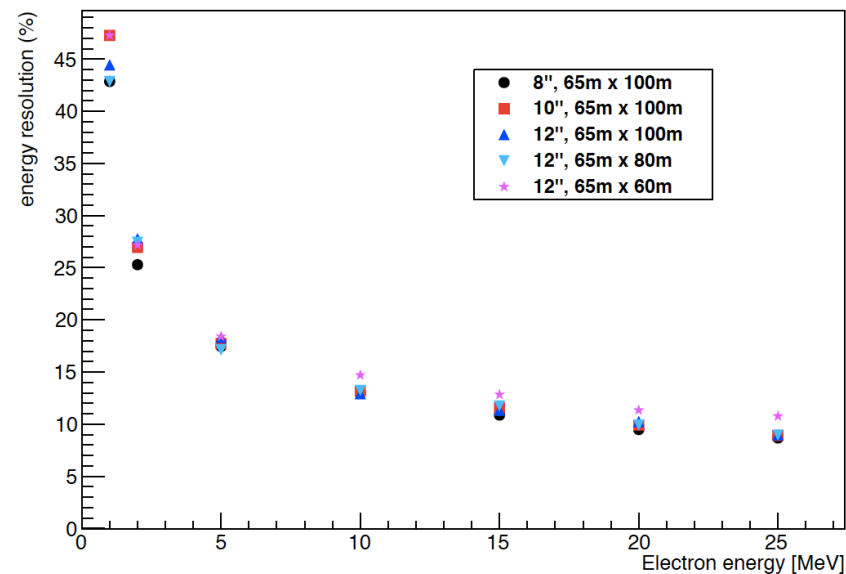
- OK for CC-QEL events, with smearing due to Fermi motion
- in non-QEL, some energy is taken away by other interaction products, whose effect is more important at high energy

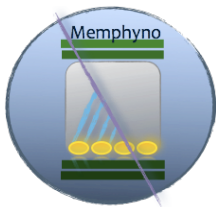
Ongoing detector studies

Residual time for μ 's and e 's



Energy resolution vs PMT size and detector size

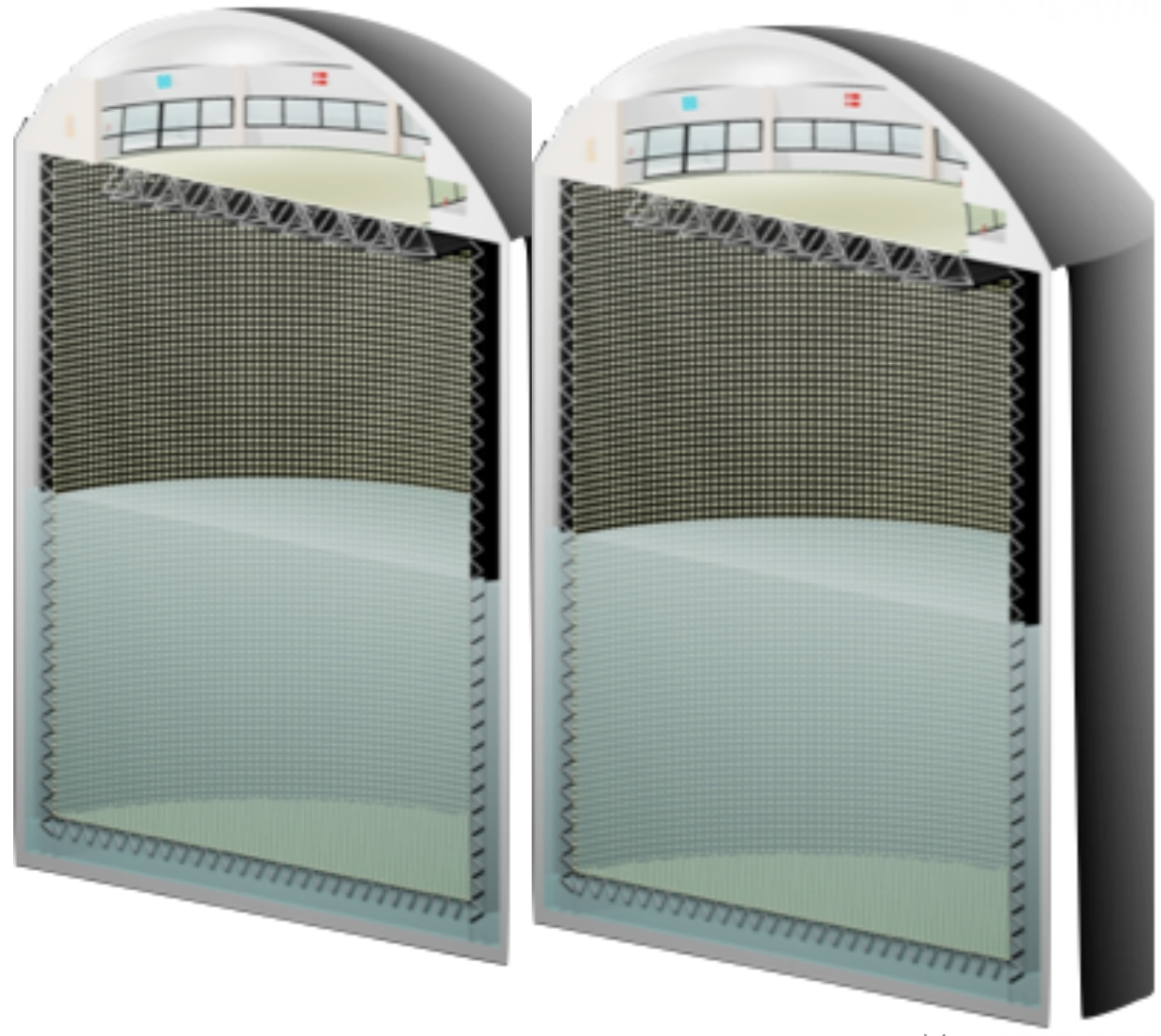
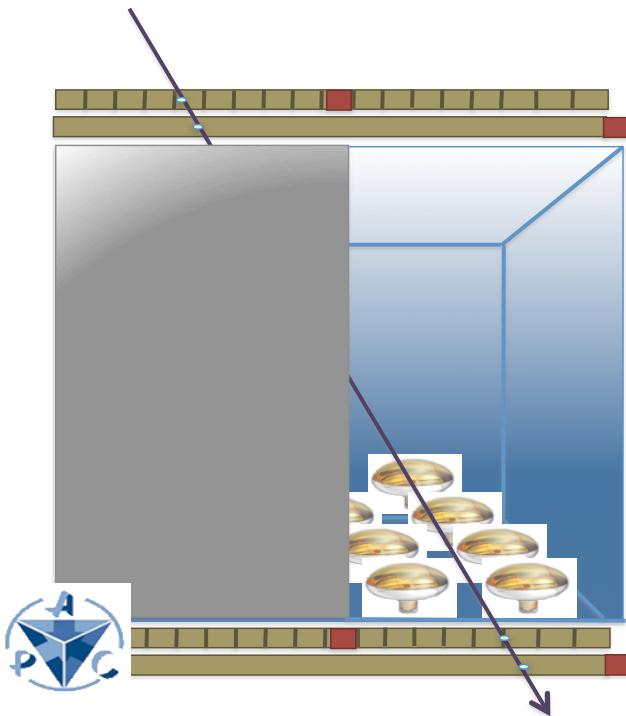




MEMPHYNO THE R&D FOR MEMPHYS

0.7×10^9 liters of water

8×10^3 liters of water





Memphyno:

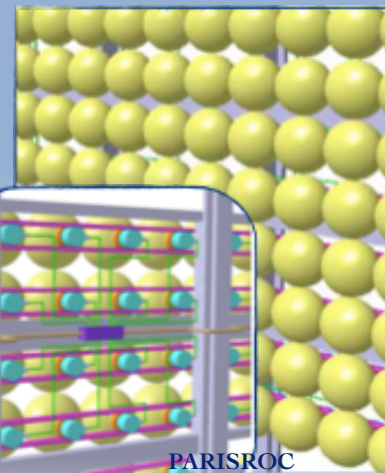
TEST BENCH for photo detection and
electronic solutions for LARGE detectors

<http://pmm2.in2p3.fr>

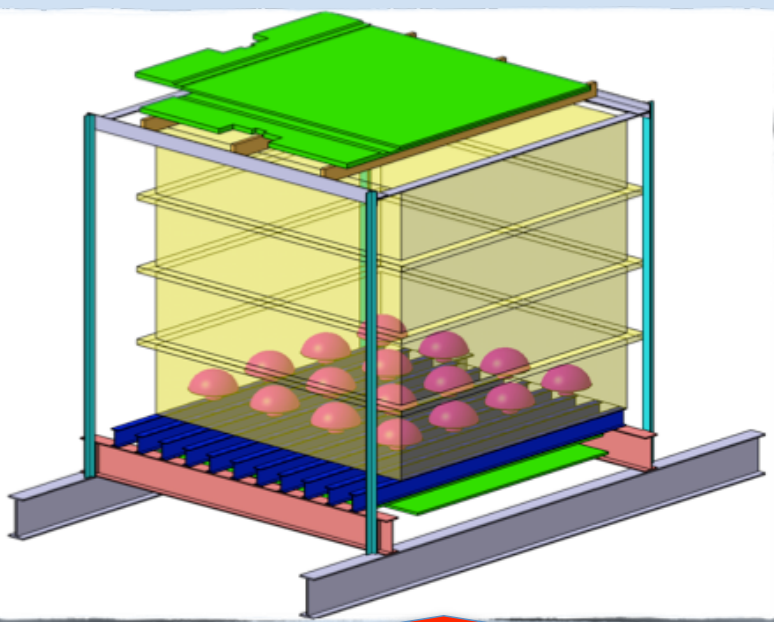
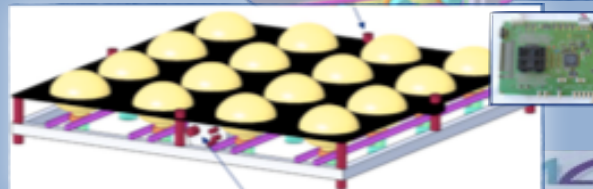
PMm2

- High number of light sensor: need grouped acquisition;

- Common HV
- Common readout
- Common signal digitization



Demonstrator:



~8t of water (+Gd?): $2 \times 2 \times 2 \text{ m}^3$

HDPE tank

- Matrix of 16 PMTs and/or other photodetectors (e.g.: X-HPX)
- **Muon hodoscope:**
 - 2+2 planes of OPERA scintillator bars
 - 4 Pmt multi anodes (64 channels)

220'000 PMT's + 14'000 e-boards

- Full test of the “**electronic and acquisition**” chain
 - Timing between e-boards
 - Trigger **threshold** study
 - Self-trigger mode
- **Track reconstruction** performances;
- Gd doping: flexibility and performance.

ASIC Specs:

- SoC (System on Chip);
- Analog F.E. + charge and time digitization;
- 16 PMTs independent channels;
- 1/3 p.e. 100% trigger efficiency;
- Charge dynamic range 0 to 300p.e. (at PMT gain 10^6);
- 1 ns time stamping resolution;
- Each channel has a variable gain:

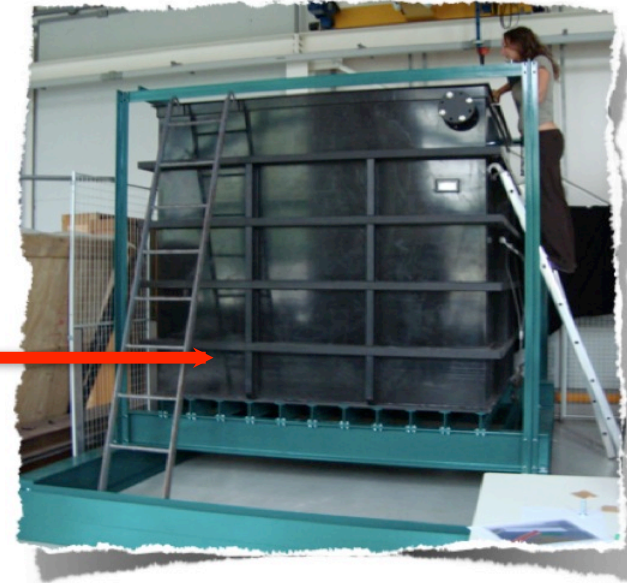
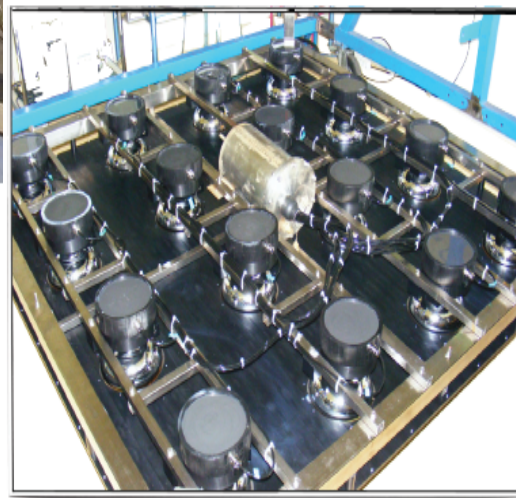
To compensate gain vs HV spread for the 16 PMTs;

- Trigger-less mode:

All the PMTs signals above the threshold (1/3 p.e.)
generate a trigger and are converted in digital data.

Generic approach to meet requirements from different experiments using large quantities of photo sensors

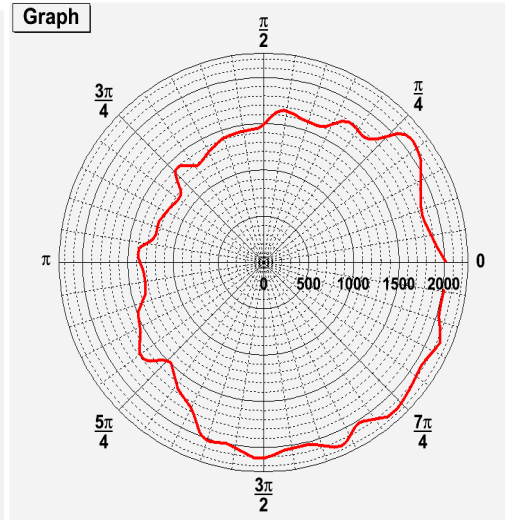
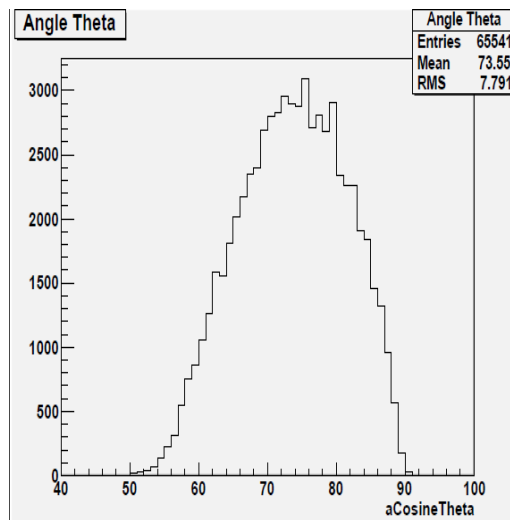
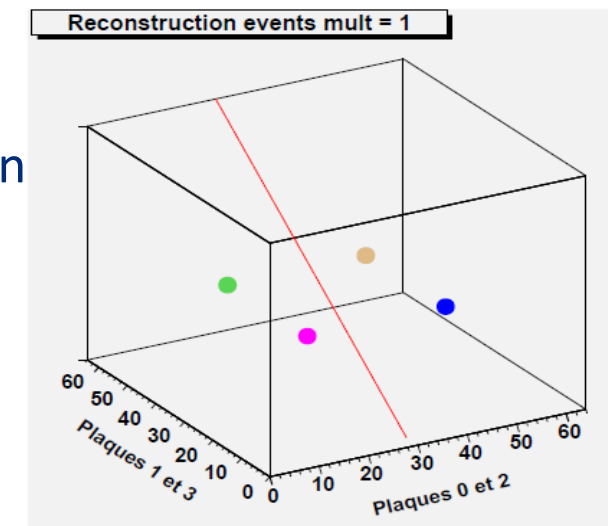
PMm2 MATRIX



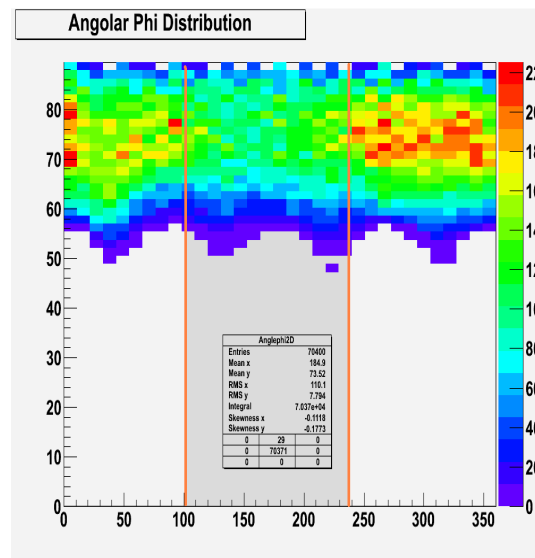
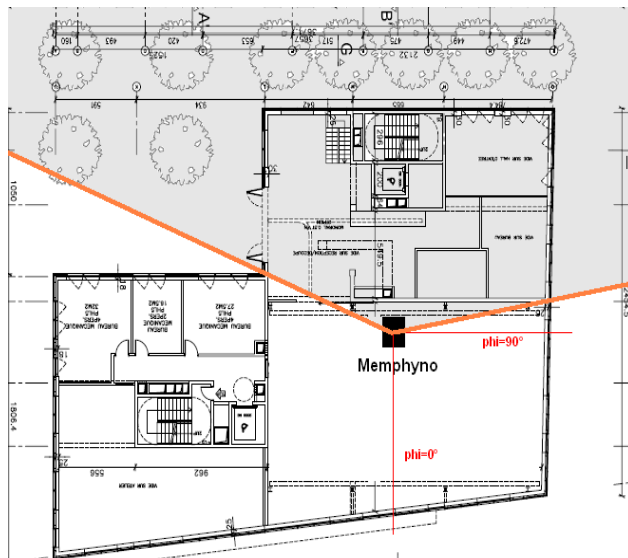


HODOSCOPE

1. Muon track reconstruction



2. Angular distributions



3. Hodoscope as a scanner: μ tomography of the building

Conclusions

- Next generation Neutrino Physics will come from new, megaton scale underground detectors
- Water Cherenkov is a proven technology ready for deployment

Outstanding Physics Potential:

1. Accelerator based:
 - δ_{CP}
 - MSNP precision --> 3 ν or 3+n ?
2. Non-Accelerator based:
 - Proton decay
3. Neutrino Astronomy:
 - Supernova neutrinos
 - Diffuse Supernova Neutrinos (DSN)
 - Solar Neutrinos
 - Atmospheric Neutrinos ---> Mass Hierarchy

- Work on simulation, mechanical design, PMT R&D is ongoing
- Envisaged installation site: @ Fréjus: Excavation feasibility study done
- Participation in European D.S.: LAGUNA, EUROnu, LAGUNA-LBNO
- Ongoing activity on simulation and analysis tools
- Ongoing R&D 1 : Front-end electronics based on PMm2 and DAQ
- Ongoing R&D 2 : MEMPHYNO small-scale prototype



Acknowledgements

We gratefully acknowledge the financial support from EC:

- FP7 Research Infrastructure “Design Studies” LAGUNA (Grant Agreement No. 212343, FP7-INFRA-2007-1)
- FP7 Research Infrastructure “Design Studies” LAGUNA-LBNO (Grant Agreement No. 284518, FP7-INFRA-2011-2.1.1.)
- FP7 Research Infrastructure “Design Studies” EUROnu (Project Number 212372).

And from the French Centre National de la Recherche (CNRS)