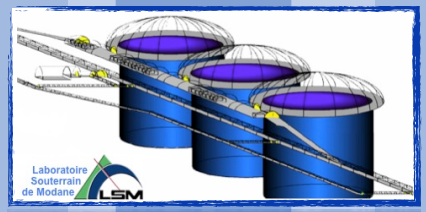
2nd LSM extension workshop - 16th Oct 2009

# UNDERGROUND STUDIES AND R&D TOWARDS MEGATONNE DETECTORS AT LSM

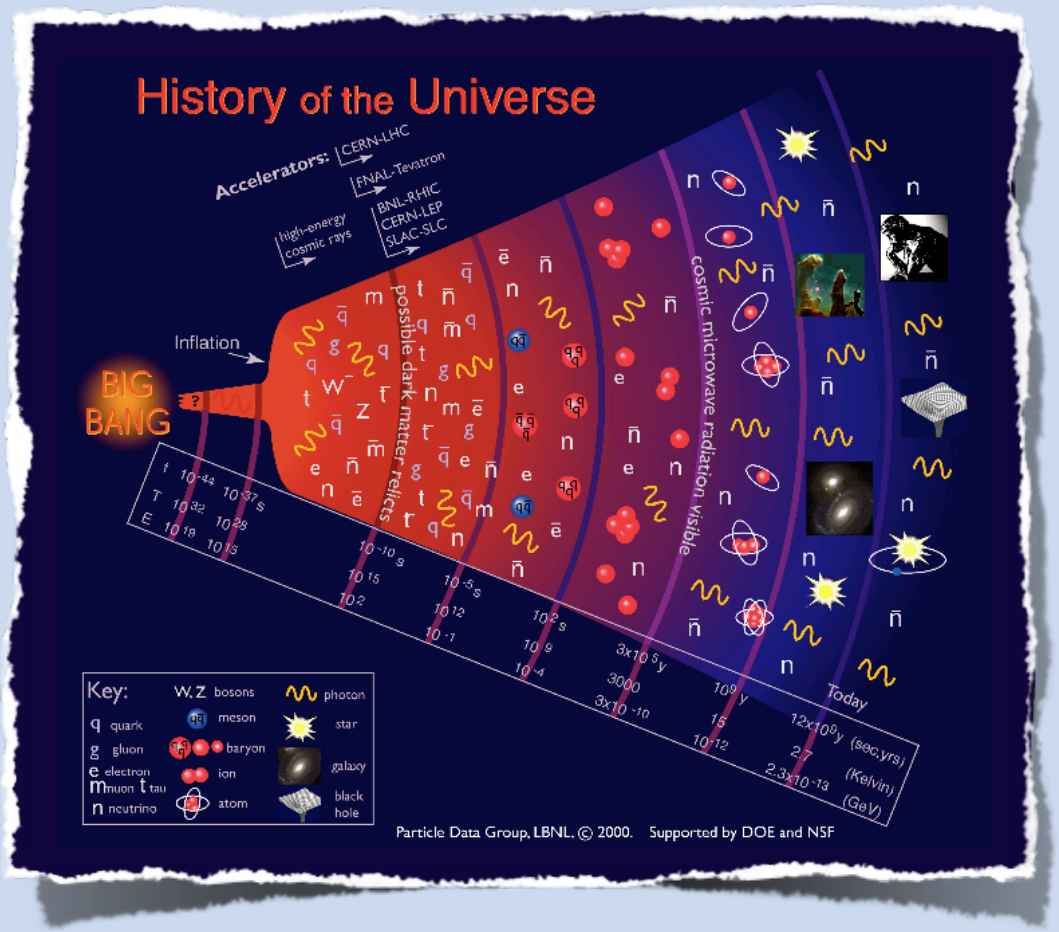
Michela Marafini - APC, Paris

# SUMMARY

- Fundamental questions
- European position
  - LAGUNA sites
  - DETECTORS under study
- MEMPHYS
  - Detector geometry
  - Physic channels
  - Simulation and bkg studies
  - R&D
- Memphyno
  - Idea
  - Design
  - Actual Status




# ..WHY? HOW?..

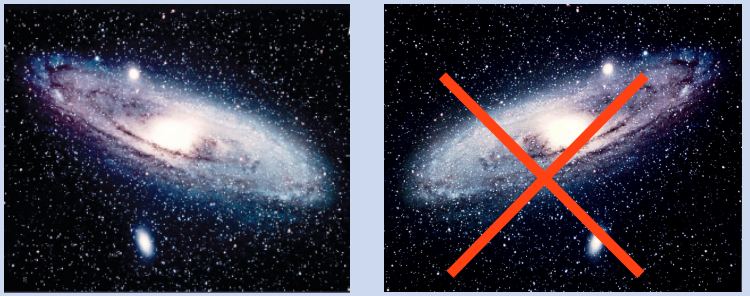



The Big Bang origin of the Universe requires **matter and antimatter to be equally abundant** at the very hot beginning.

## The Great Annihilation

1 particle out of 10 billion pairs of particles and anti-particles left over…

$$\eta = \frac{n_b - n_{\bar{b}}}{n_\gamma} \sim 10^{-10}$$



## Baryogengesis

The **GUT** need a measure of **proton decay** to be proofen

# Lepto-Baryongenesis

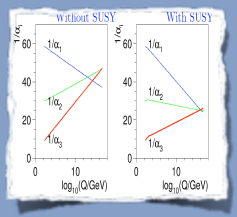
Measured CP baryonic violation is not enough
**=> need a knew type: Lepton CP violation**

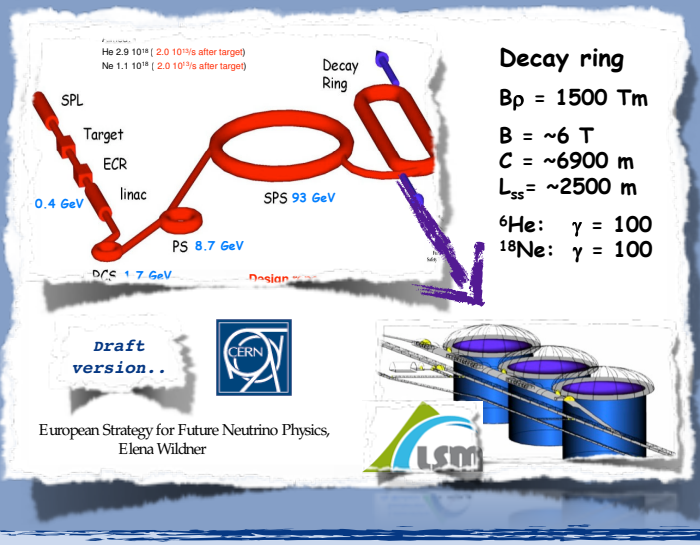
**Interaction conservation of B+L**

# MAY BE ANSWERS..

## Particle Physics

Proton decay
CP-violation in neutrinos
(combination atmospheric, reactors and beam neutrinos)

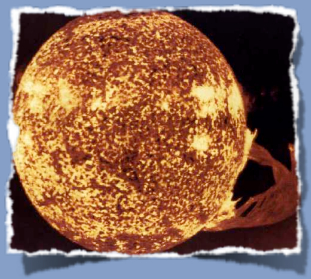


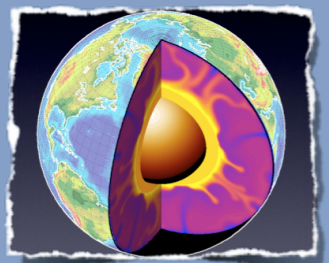




## Neutrino Astronomy

Supernova neutrinos, diffuse SN neutrinos, solar neutrinos, geo-neutrinos, dark matter annihilation..

Supernova 1987A
23 February 1987



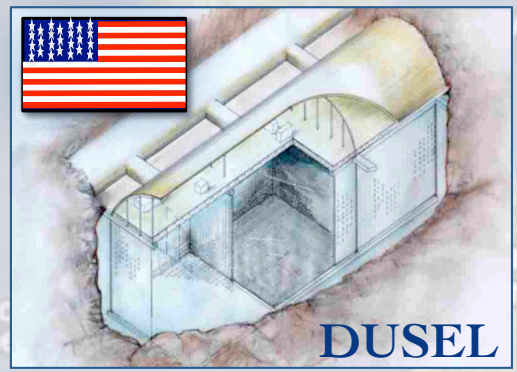


Geo-neutrinos for Earth studies

The ApPEC Steering Committee has mandated the Peer Review Committee to write a Roadmap. ApPEC roadmap recommendation: **large neutrino detectors.**

This design study should take into account worldwide efforts and converge, on a time scale of 2010, to a common proposal.

# EUROPEAN POSITION



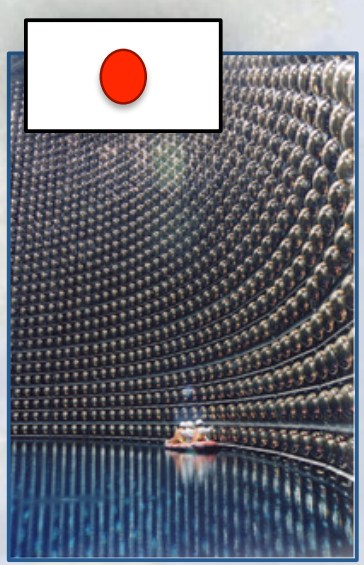

Water Čerenkov
Liq.Arg.

- **LAGUNA**

**Design of a pan-European Infrastructure for Large Apparatus studying Grand Unification and Neutrino Astrophysics.**

- **EUROnu**

**A High Intensity Neutrino Oscillation Facility in Europe Study:** Physics performance of detectors to measure neutrino oscillation parameters with SuperBeam and BetaBeam and Neutrino factory, including detailed response and backgrounds.



HyperKamiokande
Liq.Arg.

... In a

# LAGUNA

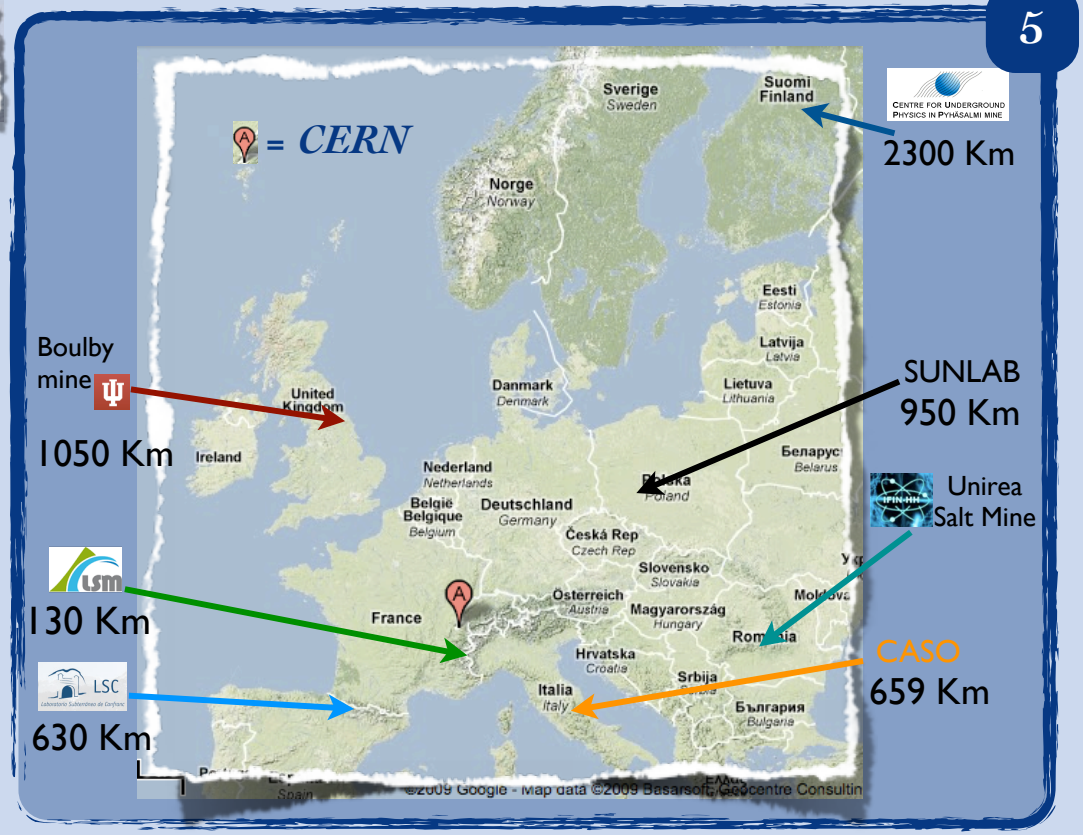
Large Apparatus for Grand Unification and Neutrino Astrophysics

## Proton Decay:

- limit up to $10^{35}$ y

## Neutrino Physics:

- supernovae neutrinos (explosion and relic)
- atmospheric neutrinos
- solar neutrinos
- accelerator neutrinos (Superbeam, BetaBeam, NeutrinoFactory)
- geo-neutrinos

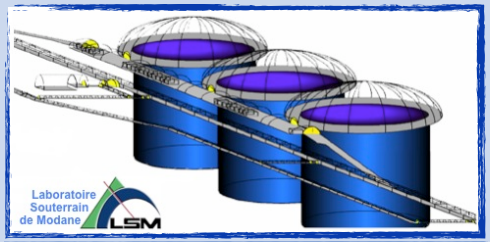



**= > 7 canditate sites:**

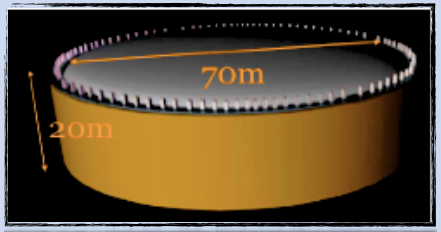
- Boulbu
- Fréjus
- Caso
- LSC
- Pyhäsalmi
- Sunlab
- IFIN-HH

http://laguna.ethz.ch

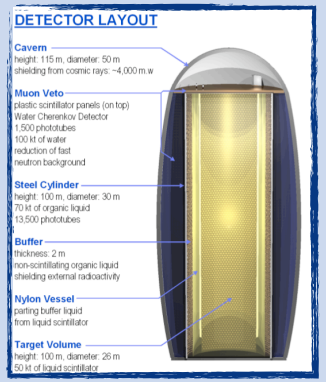
**MEMPHYS:** Water Čerenkov




**GLACIER:** Liquid Argon




**LENA:** Liquid Scint.

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# LAGUNA

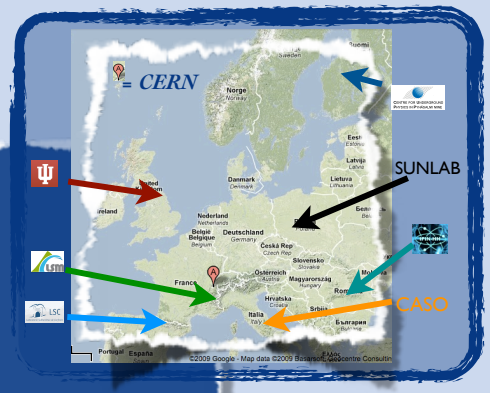
Large Apparatus for Grand Unification and Neutrino Astrophysics

## Proton Decay:

- limit up to 0.4 $10^{35}$ y: $p \rightarrow \bar{\nu} + K^+$

## Neutrino Physics:

- supernovae: ~ 9,3,7 $10^3$ CC, NC, ES
- DSNB: (S/B) 9-110/7 (per 5 y)
- solar: $^8$B (ES:$10^4$, CC:360), $^7$Be:$10^6$, pep:7.7 $10^4$
- geo-neutrinos: ~1000 ev. (per y)




- Boulbu
- Fréjus
- Caso
- LSC
- Pyhäsalmi
- Sunlab
- IFIN-HH

# LENA

## DETECTOR LAYOUT

**Cavern**
height: 115 m, diameter: 50 m
shielding from cosmic rays: ~4,000 m.w

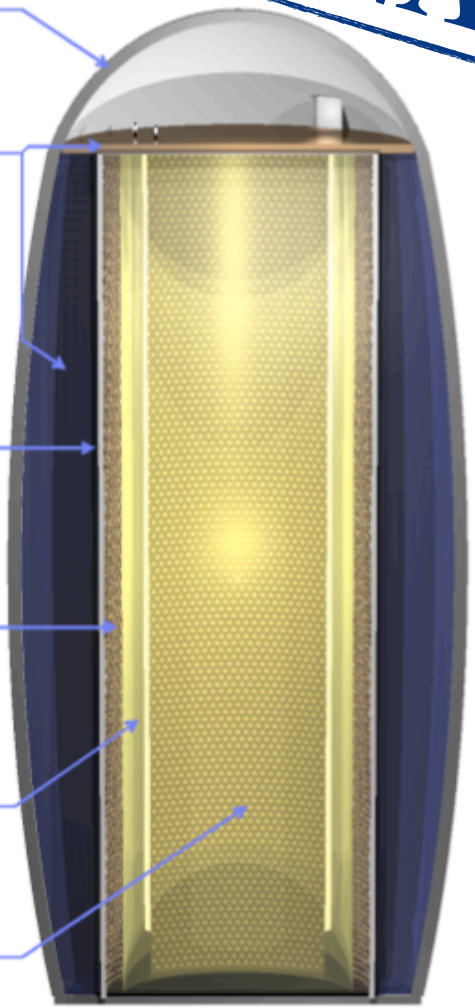
**Muon Veto**
plastic scintillator panels (on top)
Water Cherenkov Detector
1,500 phototubes
100 kt of water
reduction of fast
neutron background

**Steel Cylinder**
height: 100 m, diameter: 30 m
70 kt of organic liquid
13,500 phototubes

**Buffer**
thickness: 2 m
non-scintillating organic liquid
shielding external radioactivity

**Nylon Vessel**
parting buffer liquid
from liquid scintillator

**Target Volume**
height: 100 m, diameter: 26 m
50 kt of liquid scintillator



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http://laguna.ethz.ch

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# LAGUNA

Large Apparatus for Grand Unification and Neutrino Astrophysics

## Proton Decay:

- limit up to $0.4\ 10^{35}$ y: $p \rightarrow \bar{\nu} + K^{+}$

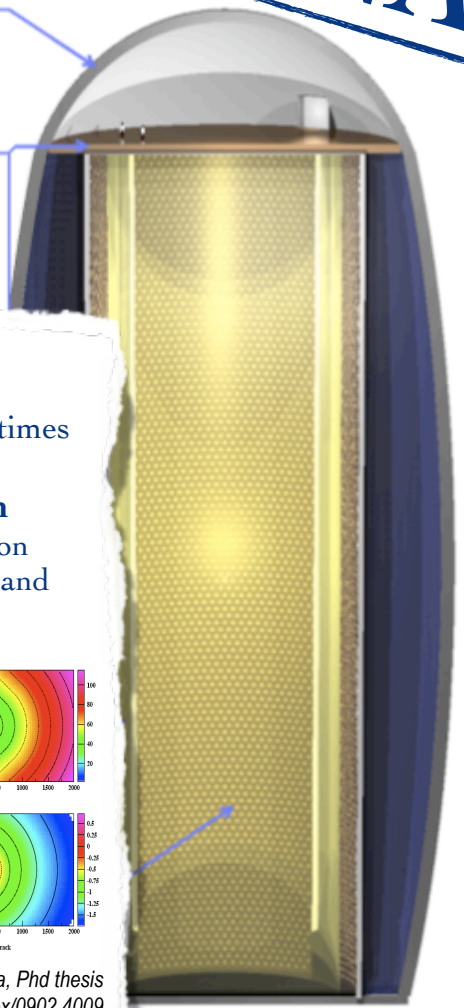
## Neutrino from beams:

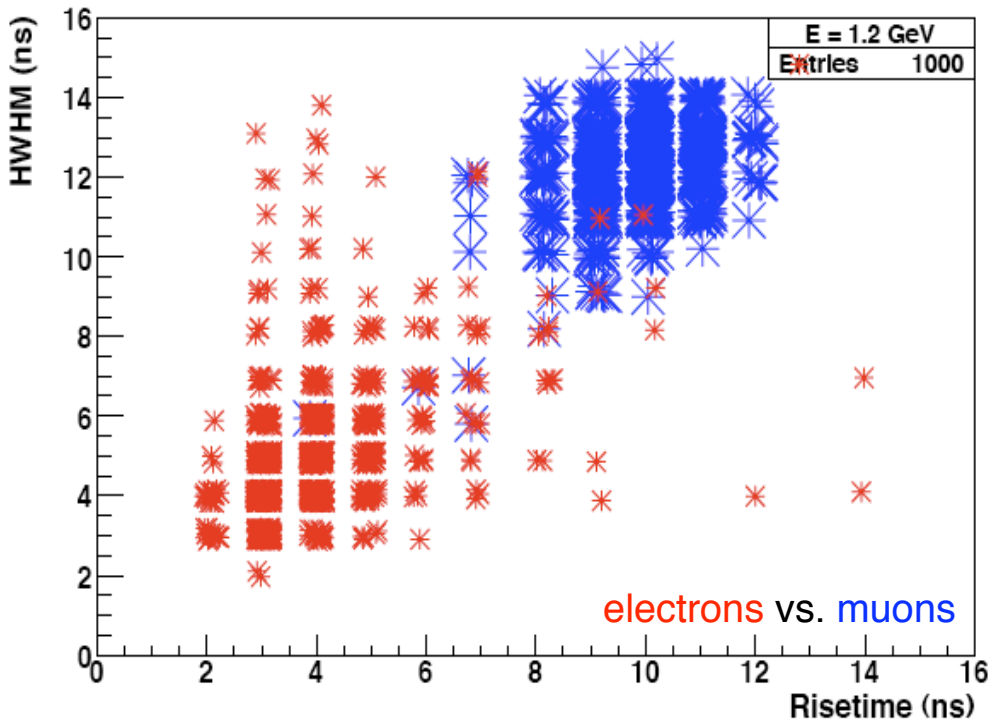
# LENA

## DETECTOR LAYOUT

**Cavern**
height: 115 m, diameter: 50 m
shielding from cosmic rays: ~4,000 m.w

**Muon Veto**
plastic scintillator panels (on top)
Water Cherenkov Detector
1,500 phototubes
100 kt of water





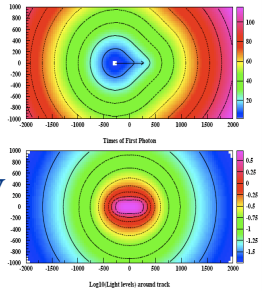

### Tracking Capabilities

- primary photon arrival times
- angular resolution: <1°

### Particle Identification

Particle track-reconstruction using photon arrival times and mean charge distributions.

**Expected energy resolution: ~2.5% @1GeV**



*T. Marrodán Undagoitia, Phd thesis*
*J. G. Learned, hep-ex/0902.4009*
*J. Peltoniemi, arXiv*

... In a

# LAGUNA

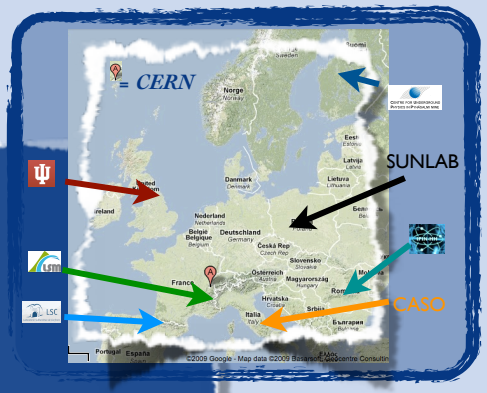
Large Apparatus for Grand Unification and Neutrino Astrophysics

## Proton Decay:

- limit up to 1.1 $10^{35}$ y: $p \rightarrow \bar{\nu} + K^+$
- limit up to 0.5 $10^{35}$ y: $p \rightarrow e^+ + \pi^0$

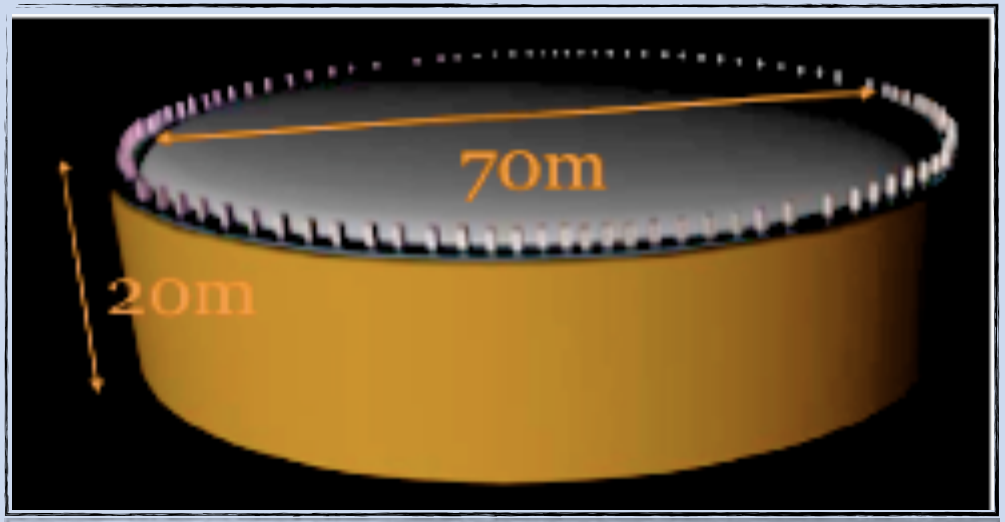
## Neutrino Physics:

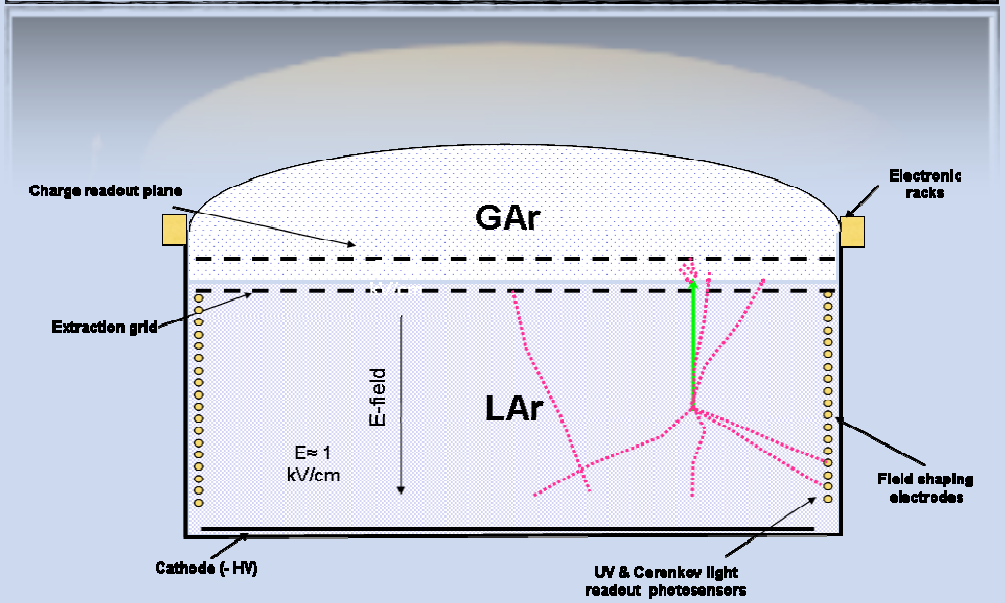
- supernovae: ~2.5,3 $10^4$, CC, NC, $10^3$ ES
- DSNB: (S/B) 40-60/30 (per 5 y)
- solar neutrinos: $^8$B: 4.5 $10^4$ (ES)
- atmospheric: $10^4$ ev. (per y)




- Boulbu
- Fréjus
- Caso
- LSC
- Pyhäsalmi
- Sunlab
- IFIN-HH

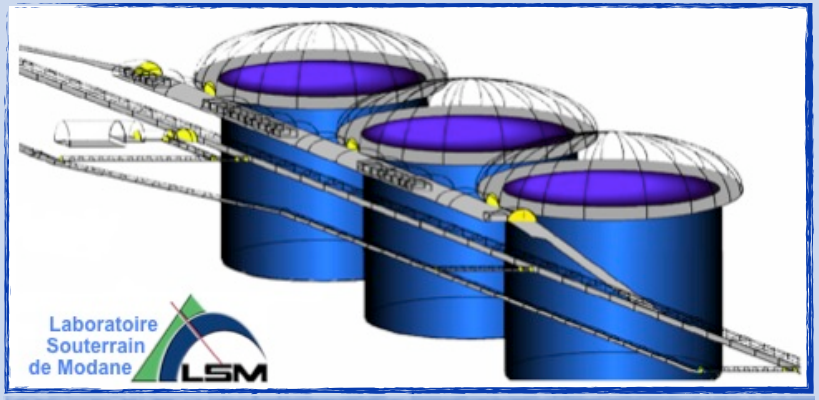
# GLACIER

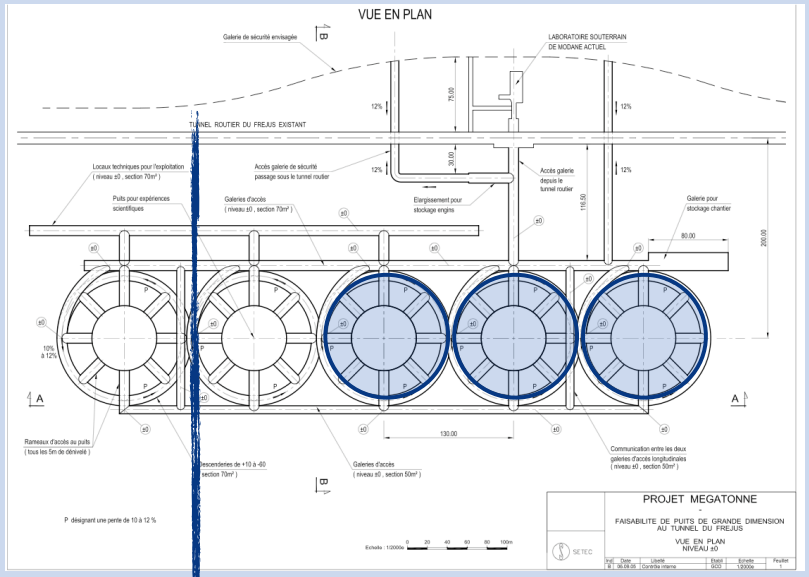


# MEMPHYS

## MEgaton Mass PHYSics




- Water Čerenkov ("cheap and stable")
- Fiducial mass: 440 kt
- Baseline:
  -- 3 (or 5) cylindric modules 60 x 65 m;
  -- Size limited by the attenuation length (λ~80m) and the pressure on the PMTs;
  -- Readout: 12"-10" PMTs, 30% geom. coverage

**Underground site.** Studied in an European program: cavity, rock, infrastructure for the cavern choice.

**http://www.apc.univ-paris7.fr/APC_CS/Experiences/MEMPHYS/**

**arXiv: hep-ex/0607026**

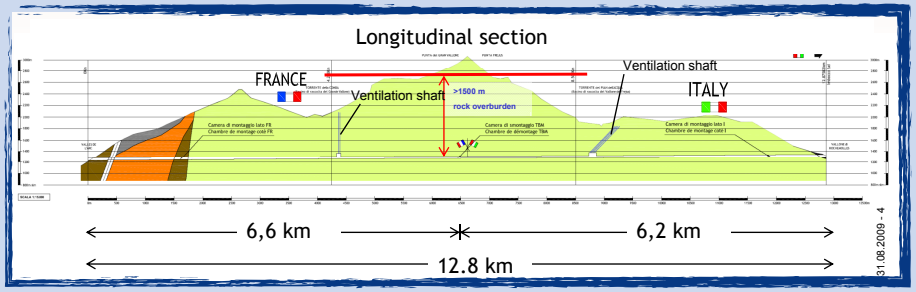
**Detailed study for possible installation in extension of LSM at Fréjus site on going:**

- 130 Km from CERN, ~ 4800 m.w.e.
- **Tank studies** are carried out in Laguna;

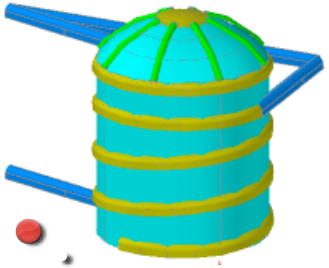
# MEMPHYS

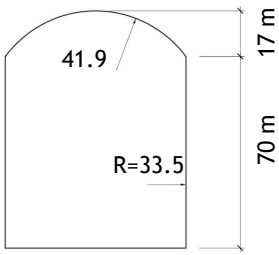
MEgaton Mass PHYSics

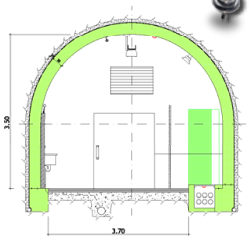
## Possibles Layouts and design at Fréjus



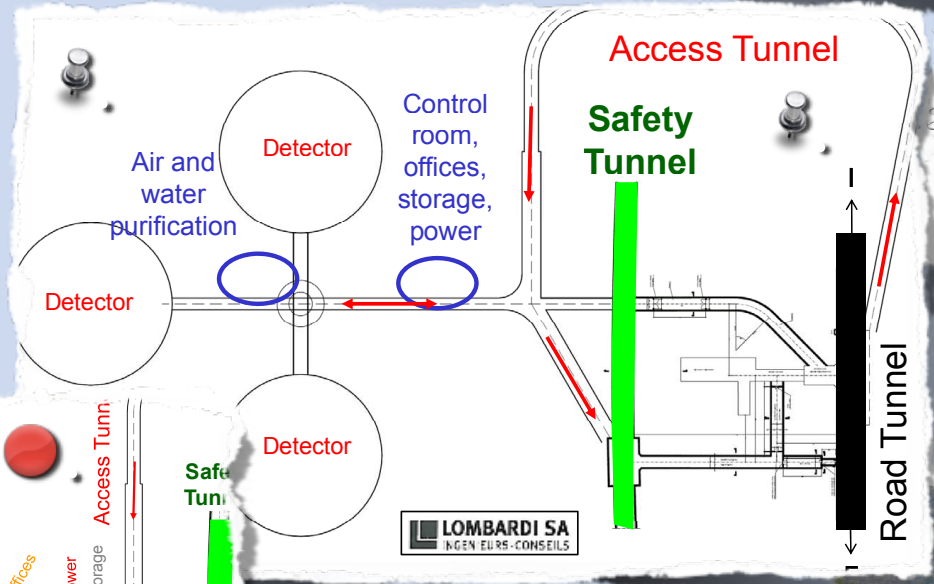

**Proposed cavern excavation and layout for the LAGUNA**

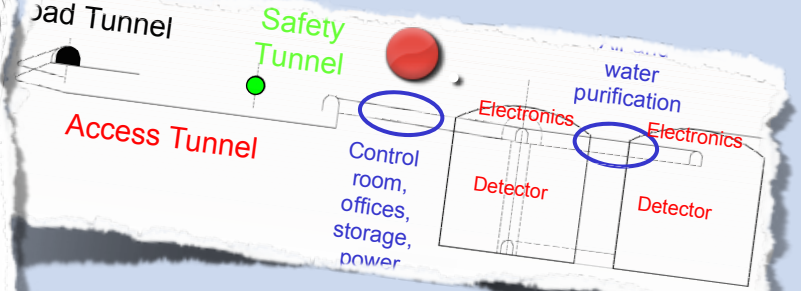


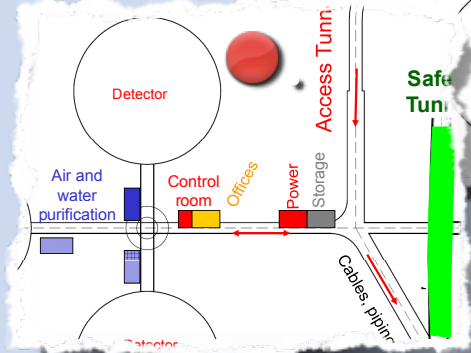


LOMBARDI SA INGEN EURS-CONSEILS

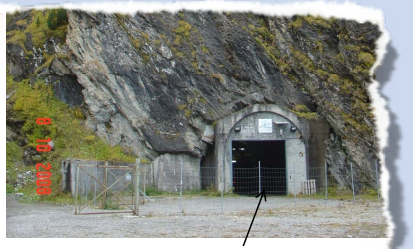



**Draft version.. study in progress**

Fresh water



Shaft access

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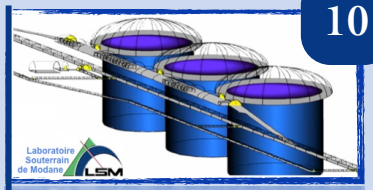
**2nd LSM extension workshop - 16th Oct 2009**

Physics channels@

# MEMPHYS




**Summary of the physics potential of Memphys (440 ktons).** The (*) stands for the case where some Gd is added.

| | |
|---|---|
| **Proton decay** | |
| $e^+ \pi^0$ | $1.0 \times 10^{35}$ |
| anti-$\nu$ $K^+$ | $2 \times 10^{34}$ |
| **SN $\nu$ (10 kpc)** | |
| CC | $2.0 \times 10^5 (\overline{\nu}e)$ |
| ES | $1.0 \times 10^3 (e)$ |
| **DSNB $\nu$** (S/B 5 years) | 43-109/47 (*) |
| **Solar $\nu$** (Evts. 1 year) | |
| $^8$B ES | $1.1 \times 10^5$ |
| **Atm. $\nu$** | $4.0 \times 10^4$ |
| **Geo $\nu$** | need 2 Mev thr. |
| **Reactor $\nu$** (Evts. 1 y) | $6.0 \times 10^4$ (*) |

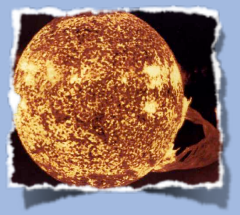
## PROTON DECAY

$$p \rightarrow e^+ + \pi^0$$

## DIFFUSE SUPERNOVA NEUTRINOS

## SUPERNOVA COLLAPSE NEUTRINOS

## ATMOSPHERIC, SOLAR (ES) NEUTRINOS

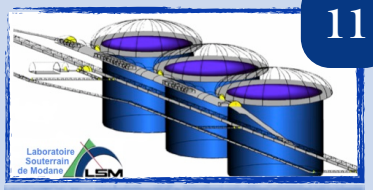


Physics channels@

# MEMPHYS

NEUTRINO BEAMS

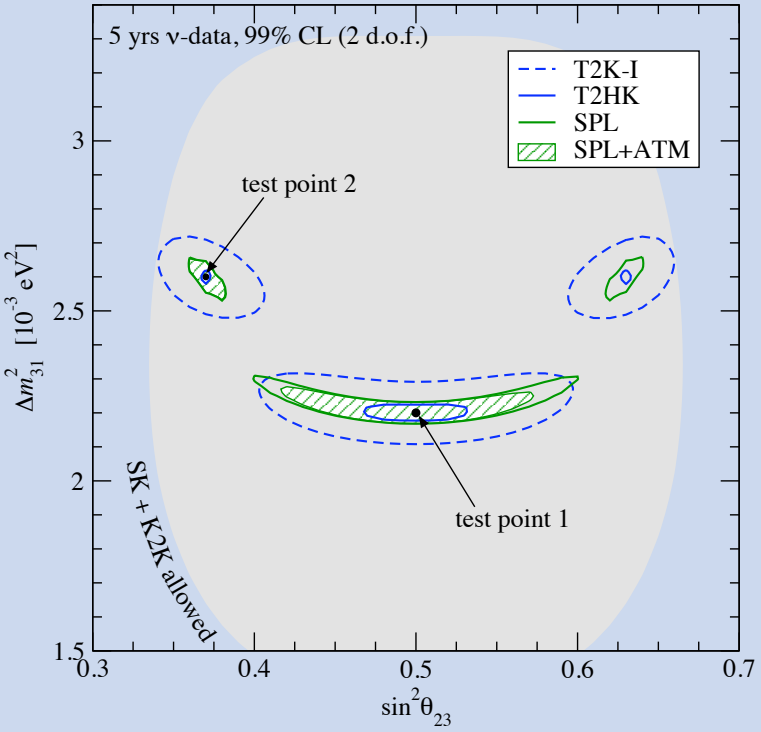
SUPER-BEAMS BETA-BEAMS

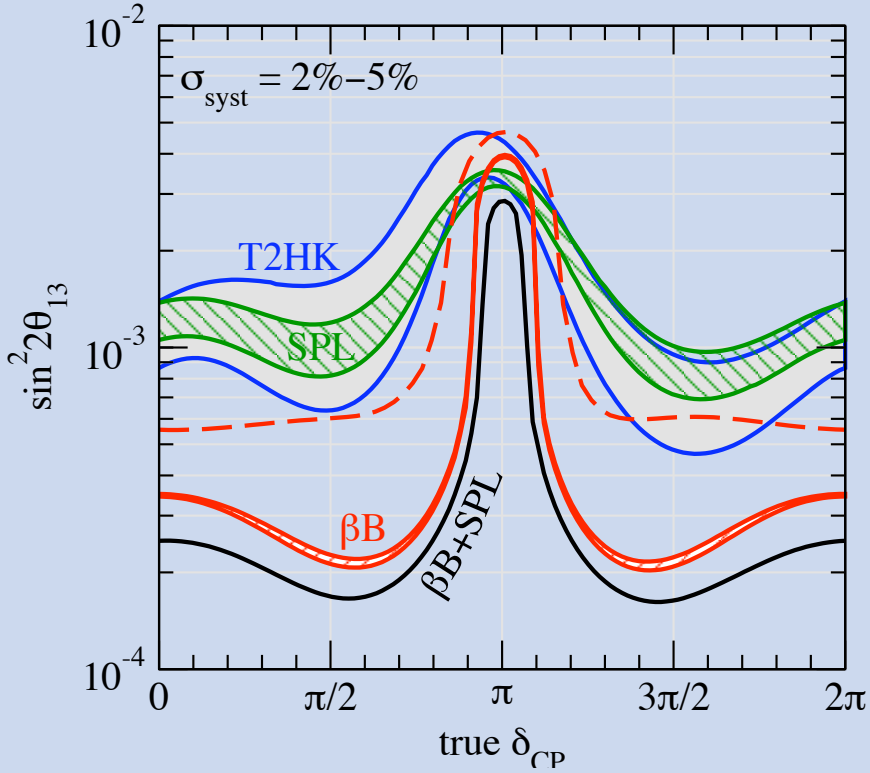



The main goals: search of a non-zero $\theta_{13}$ angle or its measurement; searching for possible leptonic ***CP violation***; determining the **mass hierarchy** and the $\theta_{23}$ ***octant***.

CERN

130 Km CERN-LSM



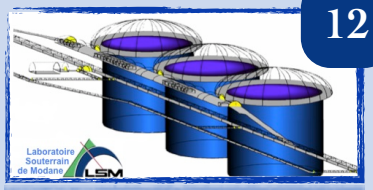




arXiv:hep-ph/0603172v3

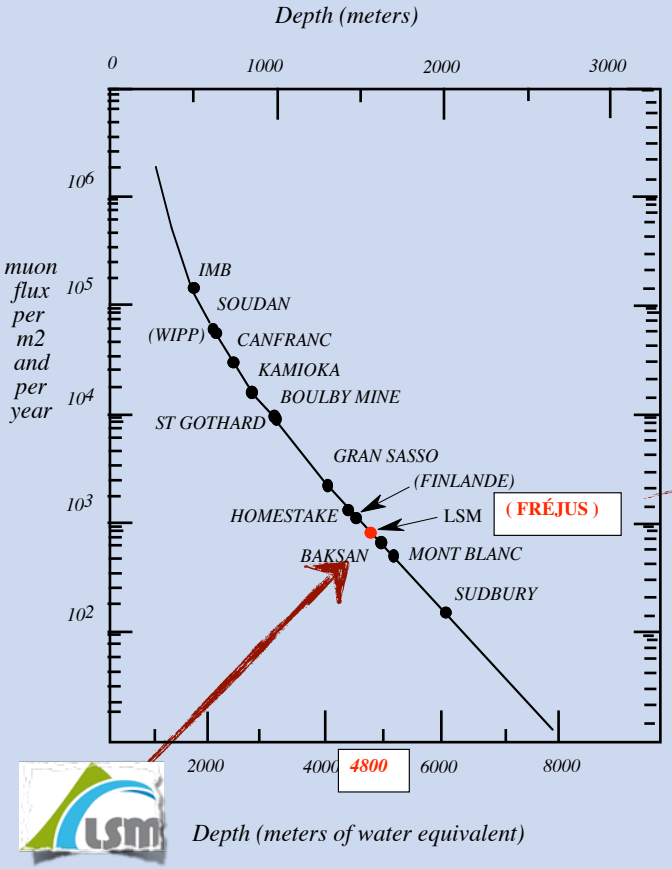
# MEMPHYS

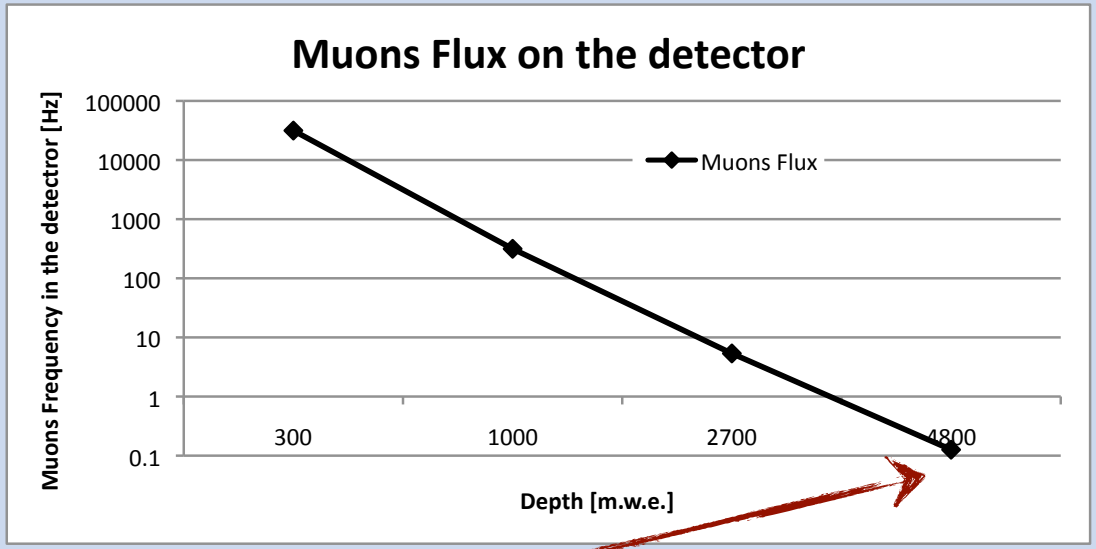
MEgaton Mass PHYSics

## SIMULATIONS AND STUDIES



**Memphys simulation** in Geant4:
NUANCE for ν beam, ν Atmospheric & Proton Decay.
**Future developments:** work in progress at APC, LAL, LAPP.




- **Less background;**
- **Less dead time;**
- **Less muon spallation;**

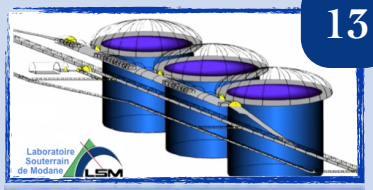
Work in progress for muon interactions in the rock, multiples backgrounds, **depth** and **latitude** studies for **reactor** and **atm** neutrinos bkg and **matter effect in the earth.**

Michela Marafini

# MEMPHYS

MEgaton Mass PHYSics

R&D

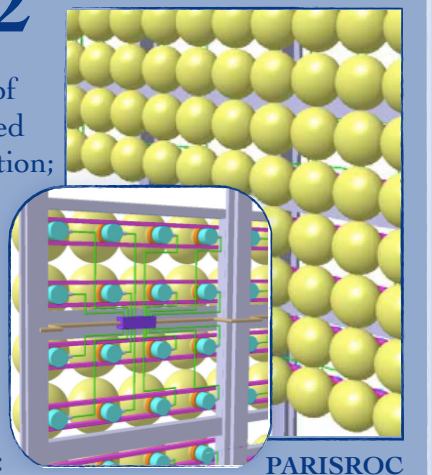



## PMm2

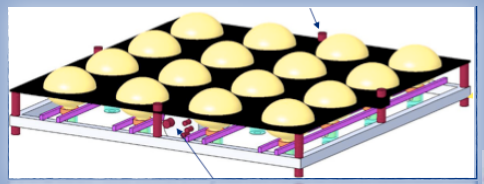
http://pmm2.in2p3.fr

- Hight number of **light sensor**: need grouped acquisition;

- Common HV
- Common readout
- Common signal digitization

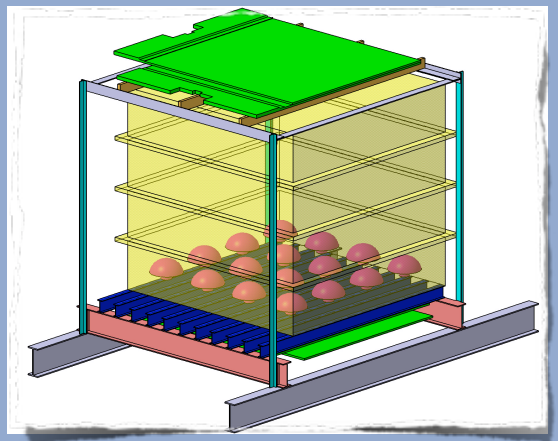


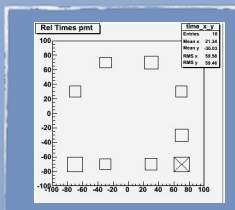
Demonstrator:

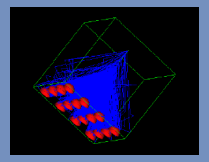


PARISROC

## Memphyno



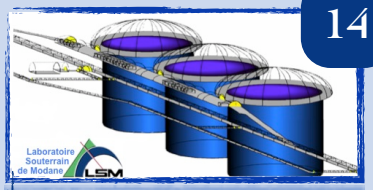


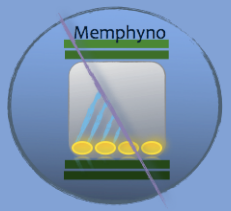
Memphys' Prototype

# MEMPHYNO

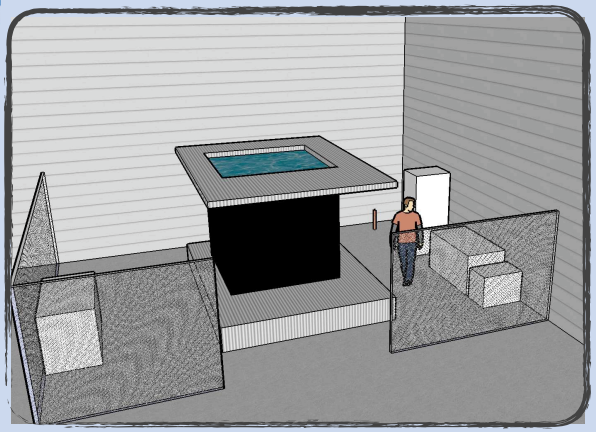
**TEST BENCH for photodetection and electronic solutions for LARGE detectors**




- **~8t of water** (+Gd?)
- 2x2x2m$^3$ HDPE tank
- Matrix of 16 PMTs and/or other photodetectors (e.g.: X-HPX)
- **Muon hodoscope:**
  - 2+2 planes of OPERA-like scintillator bars
  - 4 Pmt(ino) multi anodes (64 channels)

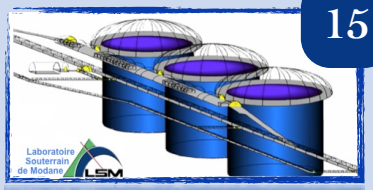



**~ 10 physicists**
**~ 5 engineers and technicists**

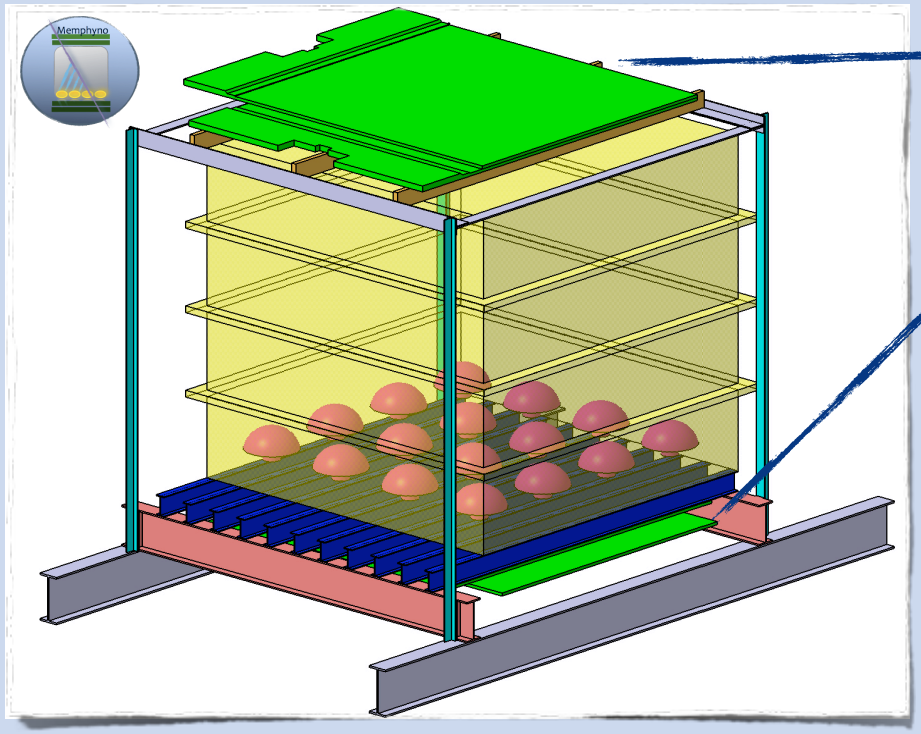


- Full test of the "**electronic and acquisition**" chain;
- Trigger **threshold** study
- Self-trigger mode
- **Track reconstruction** performances;
- Gd doping: flexibility and performance.

# MEMPHYNO




## DESIGN



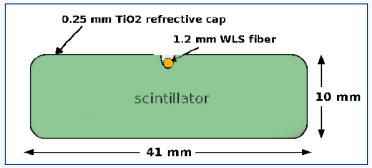

## Muon Hodoscope

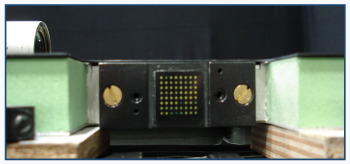
- Position x-y of the incoming muon
- "Four-fold Coincidence" for a trigger

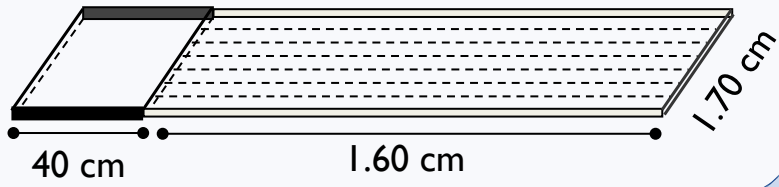
Test with cosmic muons(**Čerenkov light**).

**Spares scintillator plans of OPERA**

Scintillator plans for the **μ Hodoscope**:

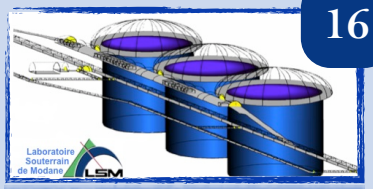


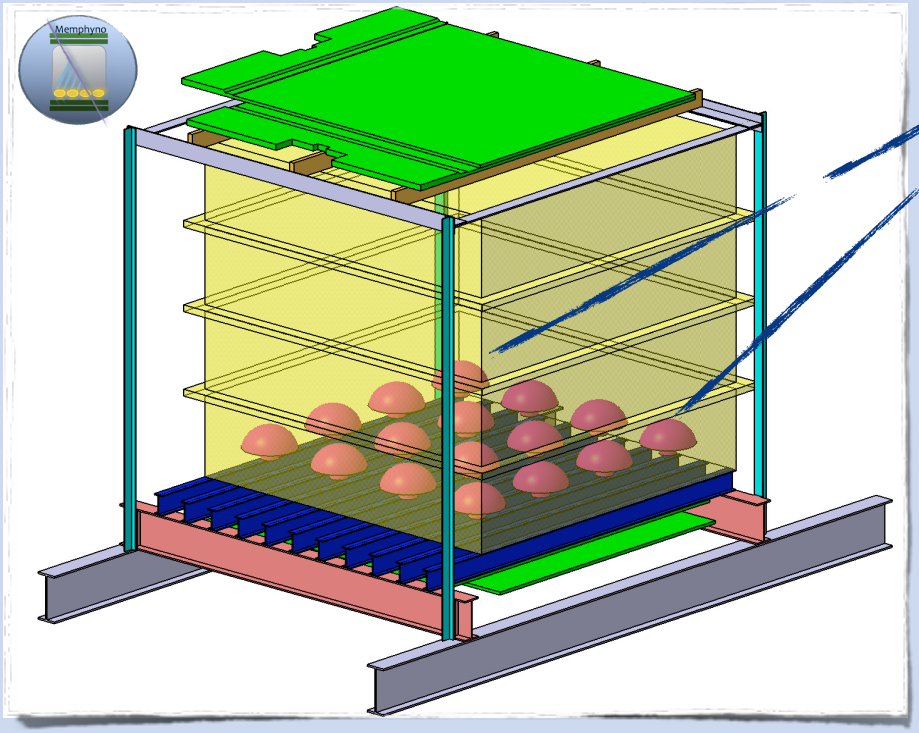





# MEMPHYNO

## DESIGN



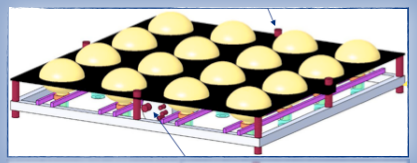




Test with cosmic muons(**Čerenkov light**).
The Hodoscope is the trigger of the signals in the PMTs.

### PMTs used to test the matrix acquisition and electronic

- Position x-y of the incoming muon
- "Four-fold Coincidence" for a trigger

The PMm2 electronic will be tested with real Čerenkov light signals.

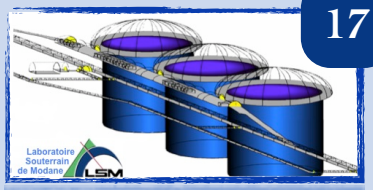


**Track reconstruction performances;**

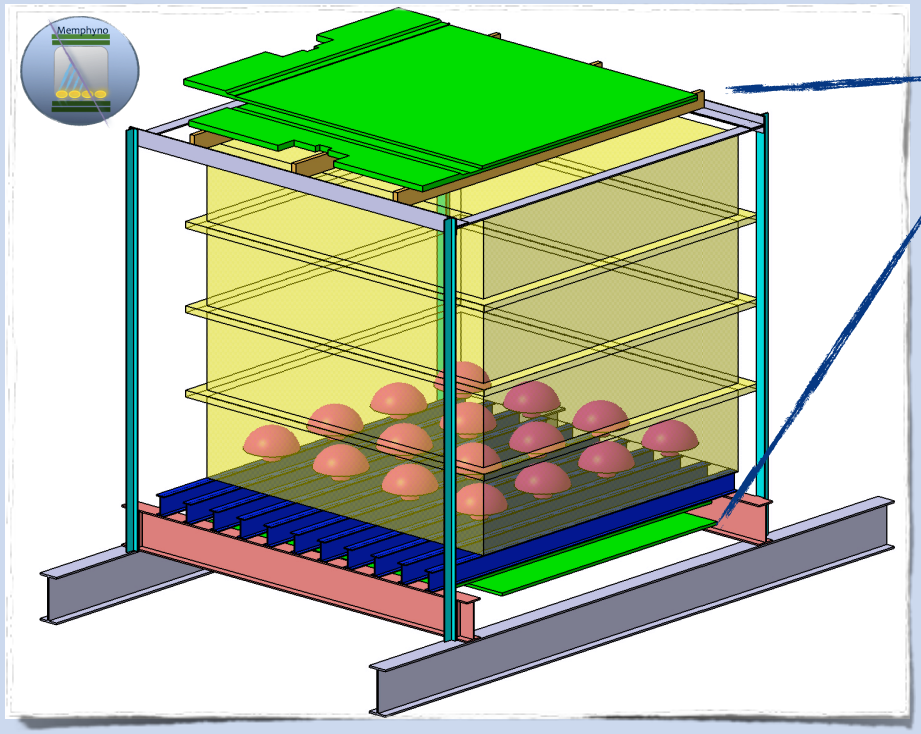
Test one (then more together) electronic board and the all signal transmission.

Start with 4 PMT 8": Borexino to test our DAQ and Hodoscope-PMTs system.

# MEMPHYNO




## DAQ




- Position x-y of the incoming muon
- "Four-fold Coincidence" for a trigger

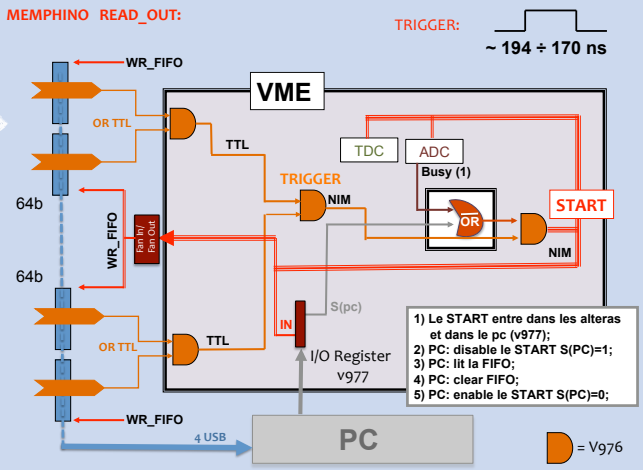
+

PMTs

Test with cosmic muons(**Čerenkov light**).

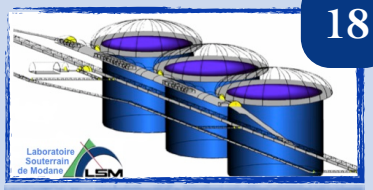
**Common effort with PMm2 to make a easy "plugging and play" structure for the electronic and mechanic systems**

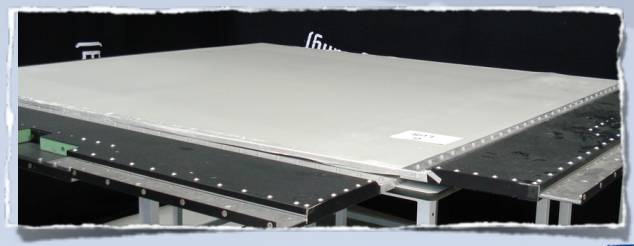
## Memphyno Read-out schema

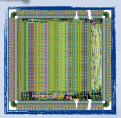


# MEMPHYNO


## STATUS AT PRESENT TIME

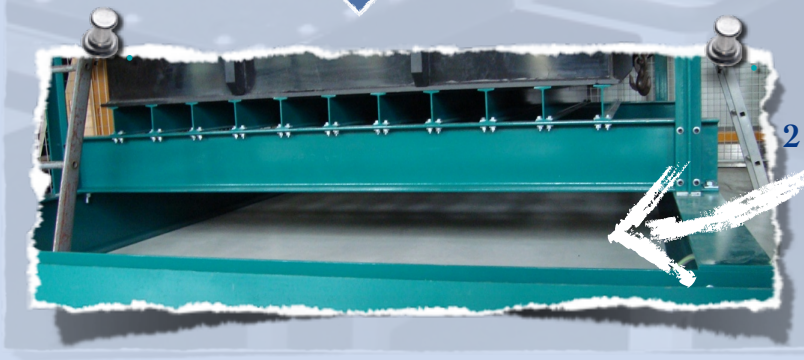




**Hodoscope assembling**

Maroc II + 64multi-anodes

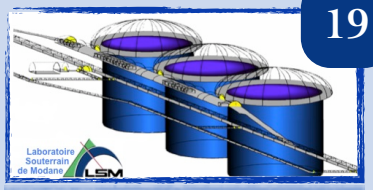


2 plans top
2 plans bottom

..Soon we will start the acquisition..

# MEMPHYNO

## FUTURE

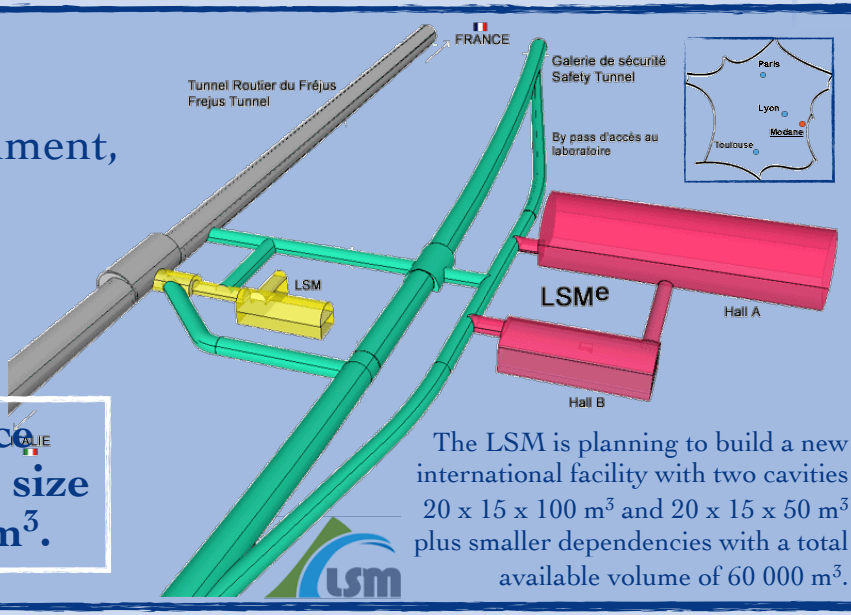



### Measure at Fréjus

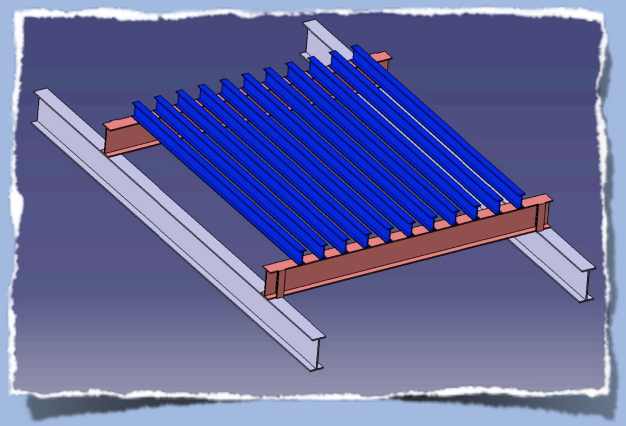
Test in an underground environment, "the same" of the MEMPHYS:

- cosmic muons test
- rocks background test

**The currently available space (3x3x3m$^3$) has determined the size of Memphyno's tank: 2x2x2m$^3$.**




The LSM is planning to build a new international facility with two cavities 20 x 15 x 100 m$^3$ and 20 x 15 x 50 m$^3$ plus smaller dependencies with a total available volume of 60 000 m$^3$.

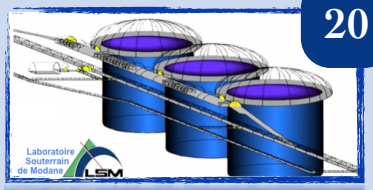



**The support can be completely dissembled ("Ikea style")!**

**The grey IPNs can take out (used just for weight raisons)**

# MEMPHYNO

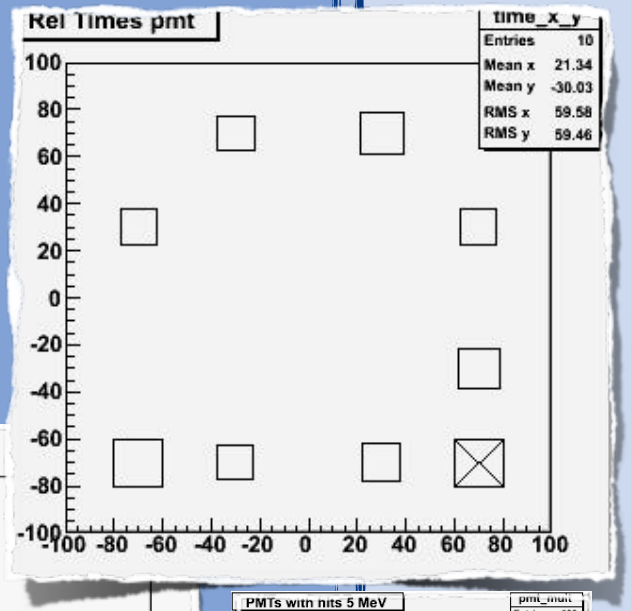
## FUTURE

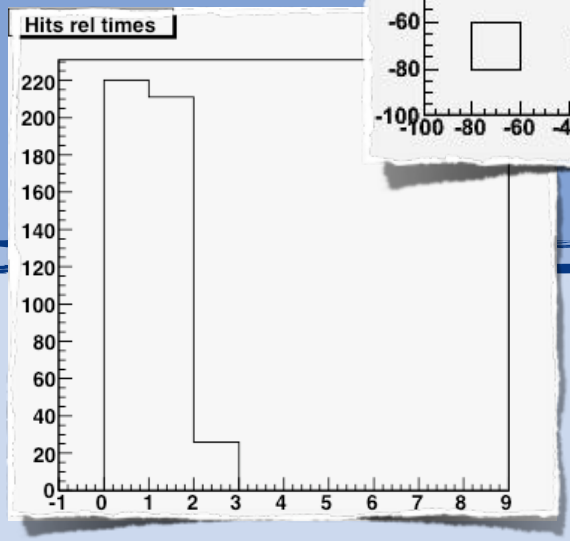


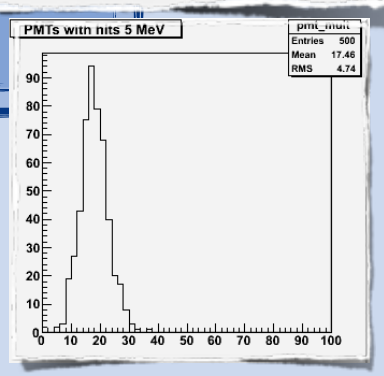

### Measure at beam

***Beam@CERN:*** $e^-$, K and π.
***Beam@LAL:*** electrons

- "beam triggered" test
- vertex reconstruction
- cosmic muons bkg

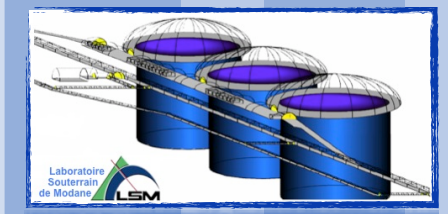


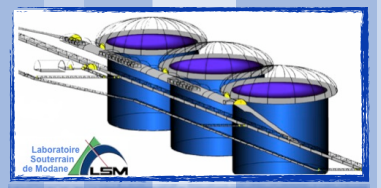




# CONCLUSIONS

- **Europe is active towards a megaton scale water Čerenkov detector: MEMPHYS**
  - Envisaged installation at LSM
  - Physic goals:
    - proton decay
    - supernovae core-collapse and diffuse supernova neutrinos
    - precision measurement of neutrino oscillation parameters on beams: 130 km from CERN, SuperBeam or/and Beta-Beam
  - Participation to european projects: Laguna, Euronu, DevDet, ...
  - Simulation and bkg studies ongoing
  - R&D ongoing..
- Memphyno (Small size prototype)
  - Building@APC right now
  - Starting the acquisition soon
  - Future project:
    - beam test (electron)
    - underground test (bkg)



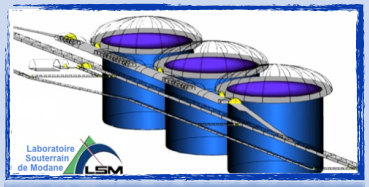

# WATER ČERENKOV R&D IN EUROPE



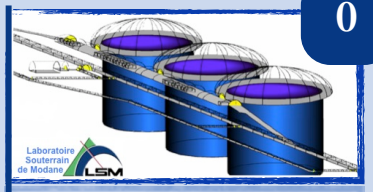

# GRAZIE


Michela Marafini

# BACKUP



# MEMPHYS

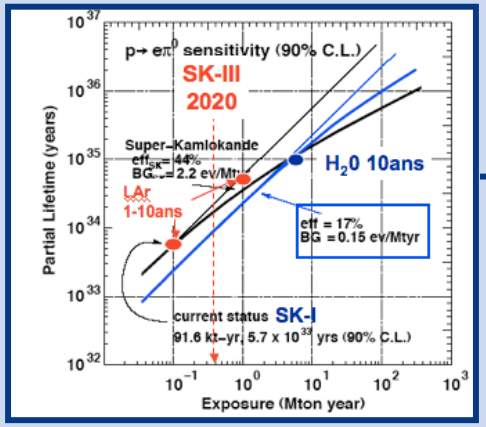



## Physics channels@

$$p \rightarrow e^+ + \pi^0$$

"Golden channels"

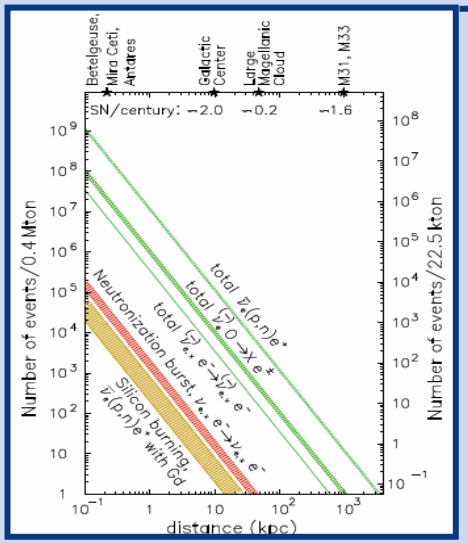
$H_2O$ better then LAr, Scint.




## PROTON DECAY

arXiv:hep-ex/0005046v1

## SUPERNOVA COLLAPSE NEUTRINOS



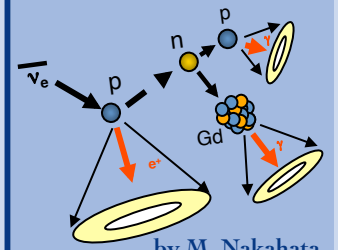

Fogli et al., hep-ph/0412046

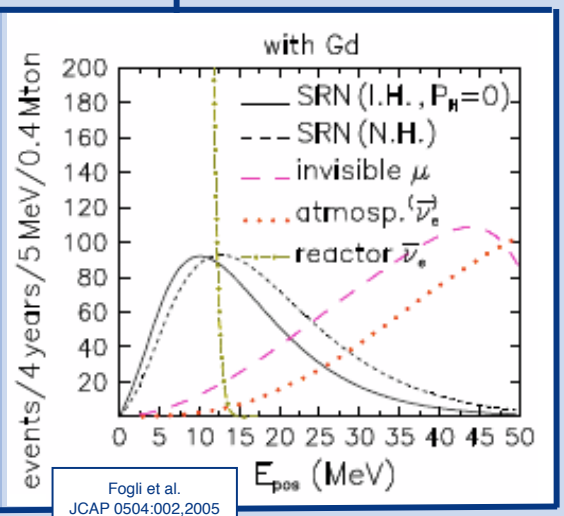
**Evidence up to ~ 1Mpc**

**Galactic SN**: Huge statistics

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

## DIFFUSE SUPERNOVA NEUTRINOS



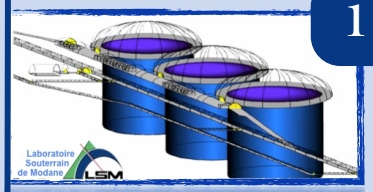

Fogli et al. JCAP 0504:002,2005

## ATMOSPHERIC, SOLAR (ES) NEUTRINOS

Physics channels@

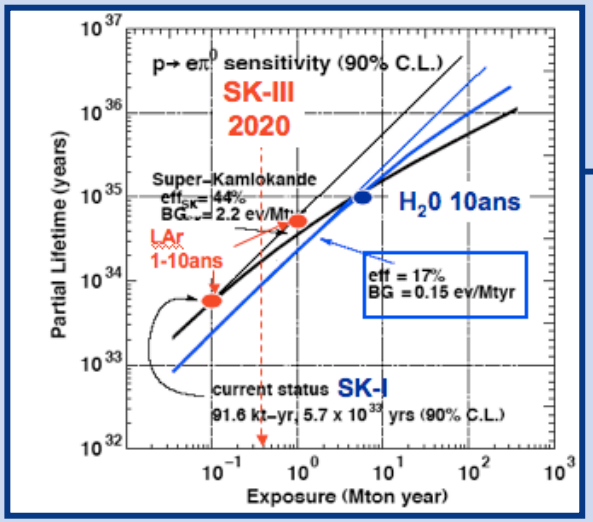
# MEMPHYS

## PROTON DECAY



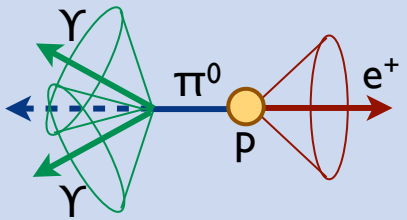

"Golden channels"

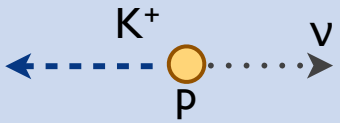
$H_2O$ better then LAr, Scint.

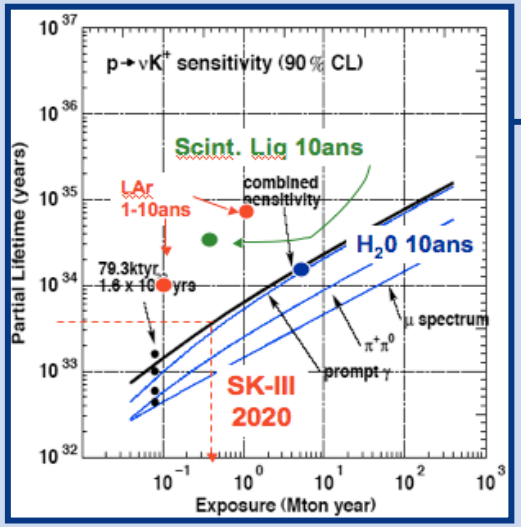



arXiv:hep-ex/0005046v1

$$p \rightarrow e^+ + \pi^0$$



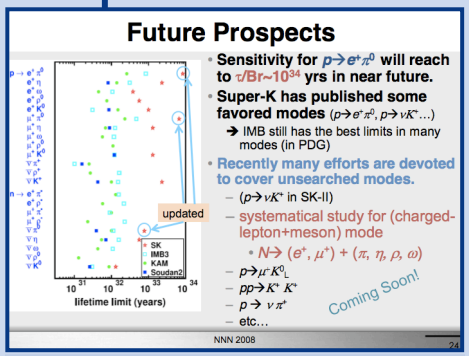




arXiv:hep-ex/0005046v1

$$p \rightarrow \bar{\nu} + K^+$$

LAr, Scin. better then $H_2O$ (K below Č. thr).

At NNN08 SK showed improvement in this channel

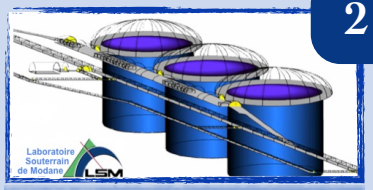


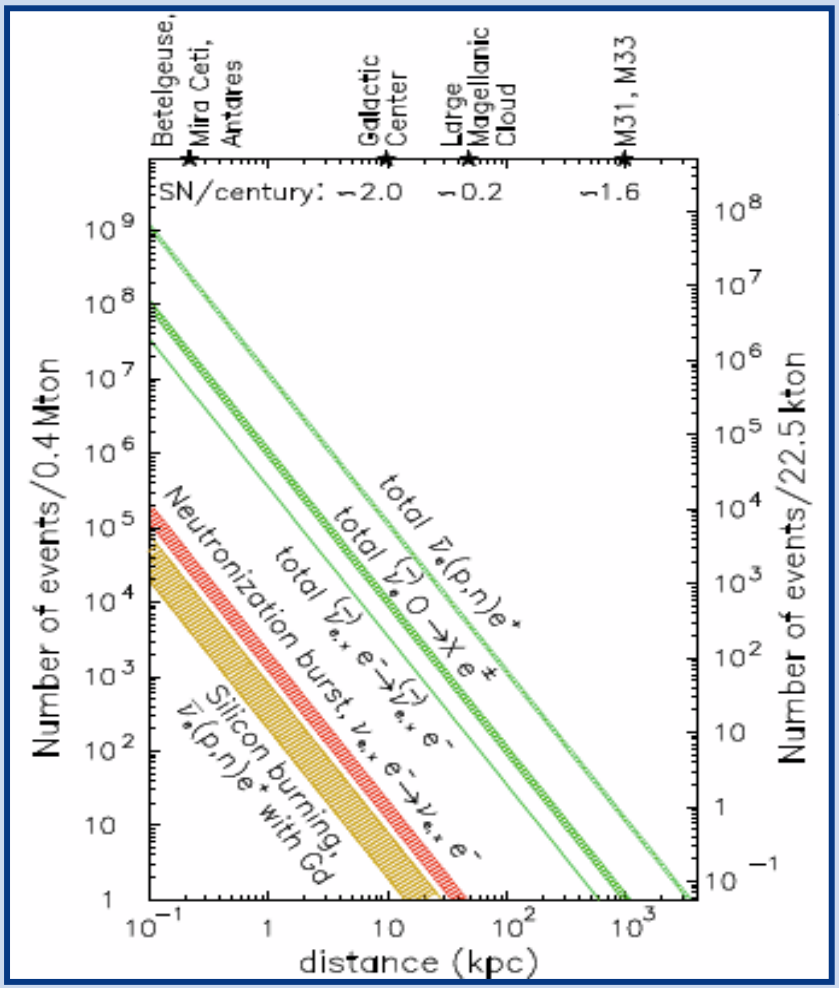

Haruki Nishino (*ICRR, University of Tokyo*)

Physics channels@

# MEMPHYS

## SUPERNOVA COLLAPSE NEUTRINOS




Fogli et al., hep-ph/0412046

Evidence up to ~ 1Mpc

**Galactic SN**: Huge statistics => we can do spectral analysis:

- in time
- in energy
- in flavor composition

Access to =>

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

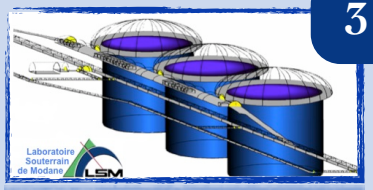
**Possibility of early SN trigger (from event coincidence) up to ~5 Mpc**

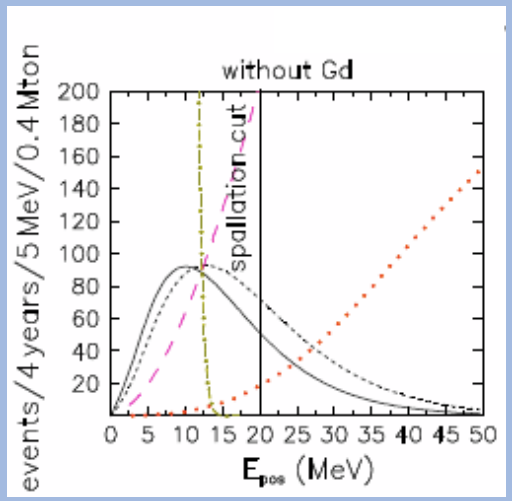
Ando et al., astro-ph/0503321

Physics channels@

# MEMPHYS

## DIFFUSE SUPERNOVA NEUTRINOS



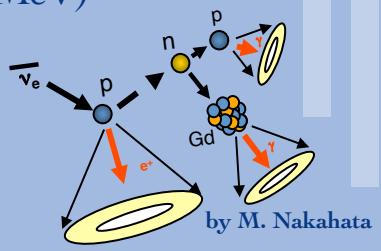


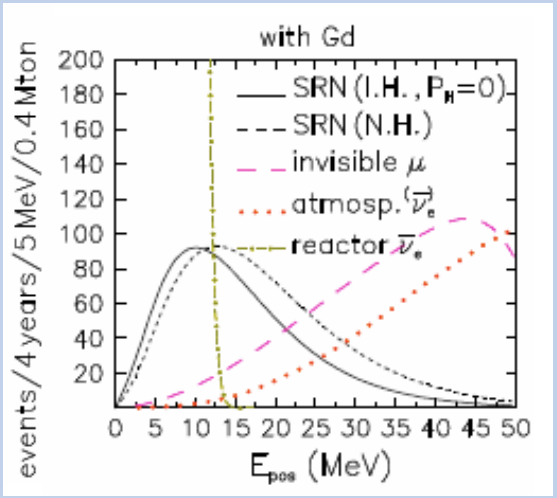

Fogli et al.
JCAP 0504:002,2005

**Small signal** over very large bkg:

- Decay ***e*** from" invisible $\mu$"
- Atmospheric $\nu_e$
- Reactor (E ≤ 10 MeV)

**Adding Gd *...**
..to reject
the not $\bar{\nu}_e$




**MEMPHYS could see the SRN in few years!**

Direct measurement of emission parameters possible.

Yuksel et al.,
astro-ph/0509297

Started **studies for sensitivity** for a 440ktons Water Čerenkov detector (bkg and dead-time) as a function of **latitude and depth** of the underground site in different European locations.

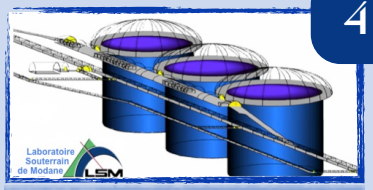
* PRL93, 2004

## Physics channels@

# MEMPHYS

SUPER-BEAMS

BETA-BEAMS

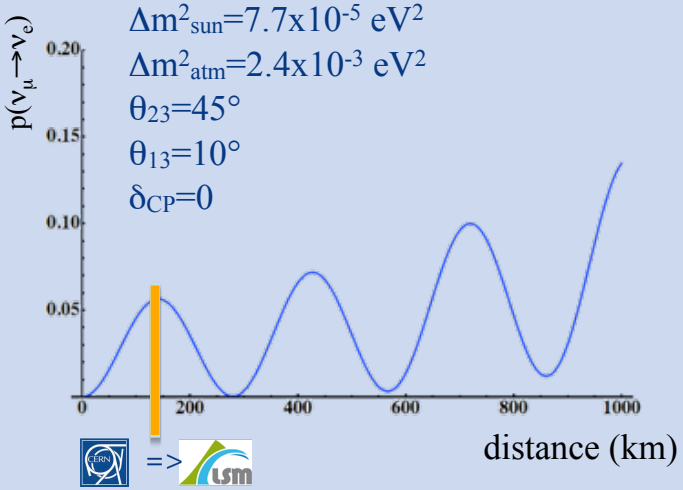



**The main goals:** search of a non-zero $\theta_{13}$ angle or its measurement; searching for possible leptonic CP violation; determining the mass hierarchy and the $\theta_{23}$ octant.

CERN

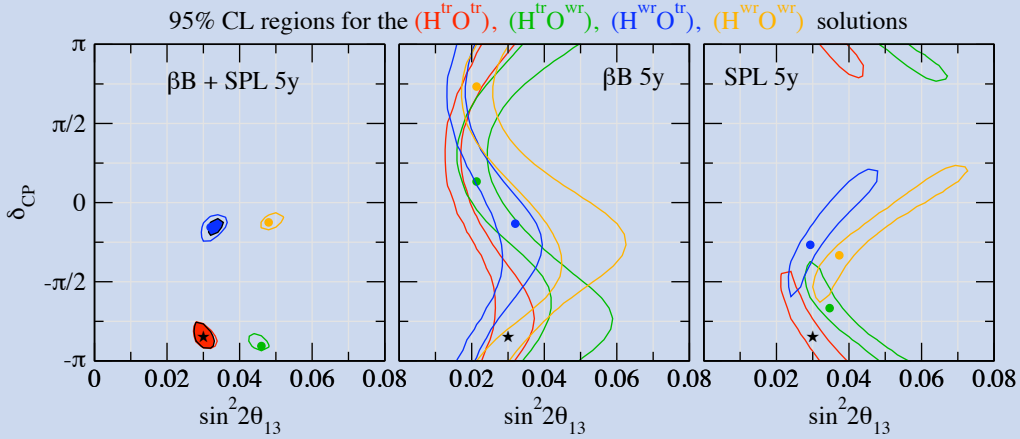
130 Km CERN-LSM

$\Delta m^2_{sun}=7.7\times10^{-5}$ eV$^2$
$\Delta m^2_{atm}=2.4\times10^{-3}$ eV$^2$
$\theta_{23}=45°$
$\theta_{13}=10°$
$\delta_{CP}=0$




SPL proton kinetic energy: ~ 4 GeV
Neutrino Energy: ~ 300 MeV

Marcos Dracos - CERN
Workshop - 1st-3th Oct 2009

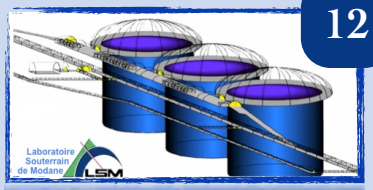



arXiv:0705.0116v2

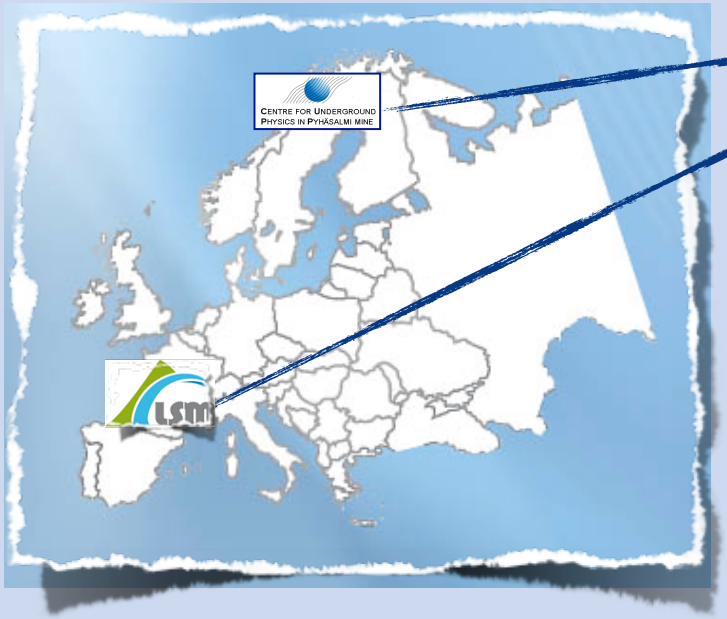
# MEMPHYS

MEgaton Mass PHYSics

# BACKGROUND STUDIES




- **The Atmospheric neutrino flux depends from the latitude.**




**Latitude study for diffuse Supernova neutrino background**

| Site | Latitude (N) | $s_{atm}$ |
|---|---|---|
| *Kamioka*, Japan | 36.27° | 1 |
| *Pyhäsalmi*, Finland | 63.66° | 2.0 |
| *Fréjus*, France | 43.43° | 1.5 |

Dependence of the total atmospheric neutrino flux below 60 MeV on the detector location. The scaling factor $s_{atm}$ compares the flux to the one at the Kamiloka site.

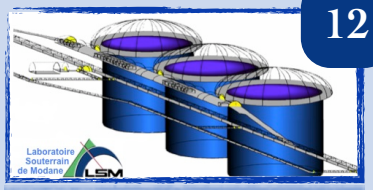
- **less invisible muons;**
- **less electronic anti-neutrinos;**

Work in progress for muon interactions in the rock, multiples backgrounds, **depth** and **latitude** studies for **reactor** and **atm** neutrinos bkg and **matter effect in the earth**.

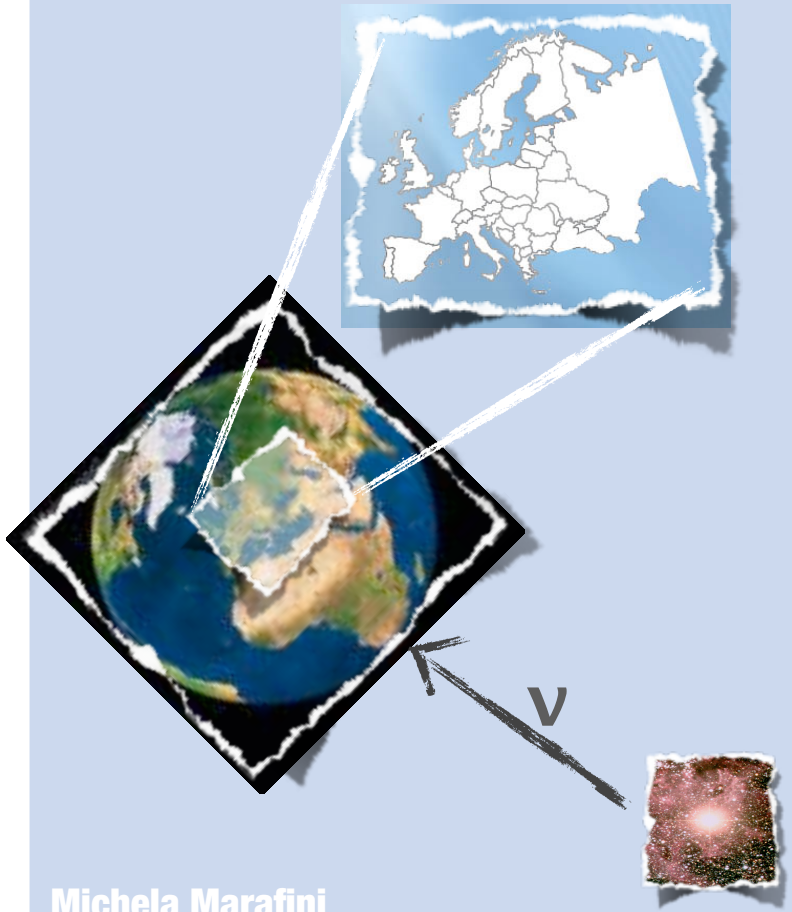
# MEMPHYS

MEgaton Mass PHYSics

# BACKGROUND STUDIES




- **The probability of observe matter effect in the earth with explosion supernova neutrino depends on the latitude.**




| LOCATION | Latitude | Longitude | Sh.Prob. Earth |
|---|---|---|---|
| *Pyhäsalmi*, Finland | 63.66° *N* | 26.04° | 0.581 |
| *Fréjus*, France | 43.43° *N* | 6.73° | 0.568 |
| *Boulby*, England | 54.56° *N* | -0.083° | 0.577 |
| *Kamioka*, Japan | 36.27° *N* | 137.3° | 0.560 |
| *Canfranc*, Spain | 42.7° *N* | -0.52° | 0.568 |
| South Pole | 90° *S* | 0° | 0.414 |

- **the best location is the norther;**
- **the effect is extremely light;**
- **comparison measurements are possible if we take in account a not-showed detector in South Pole and one showed in Europe (Prob ~ 0.5 - 0.4);**

Work in progress for muon interactions in the rock, multiples backgrounds, **depth** and **latitude** studies for **reactor** and **atm** neutrinos bkg and **matter effect in the earth**.