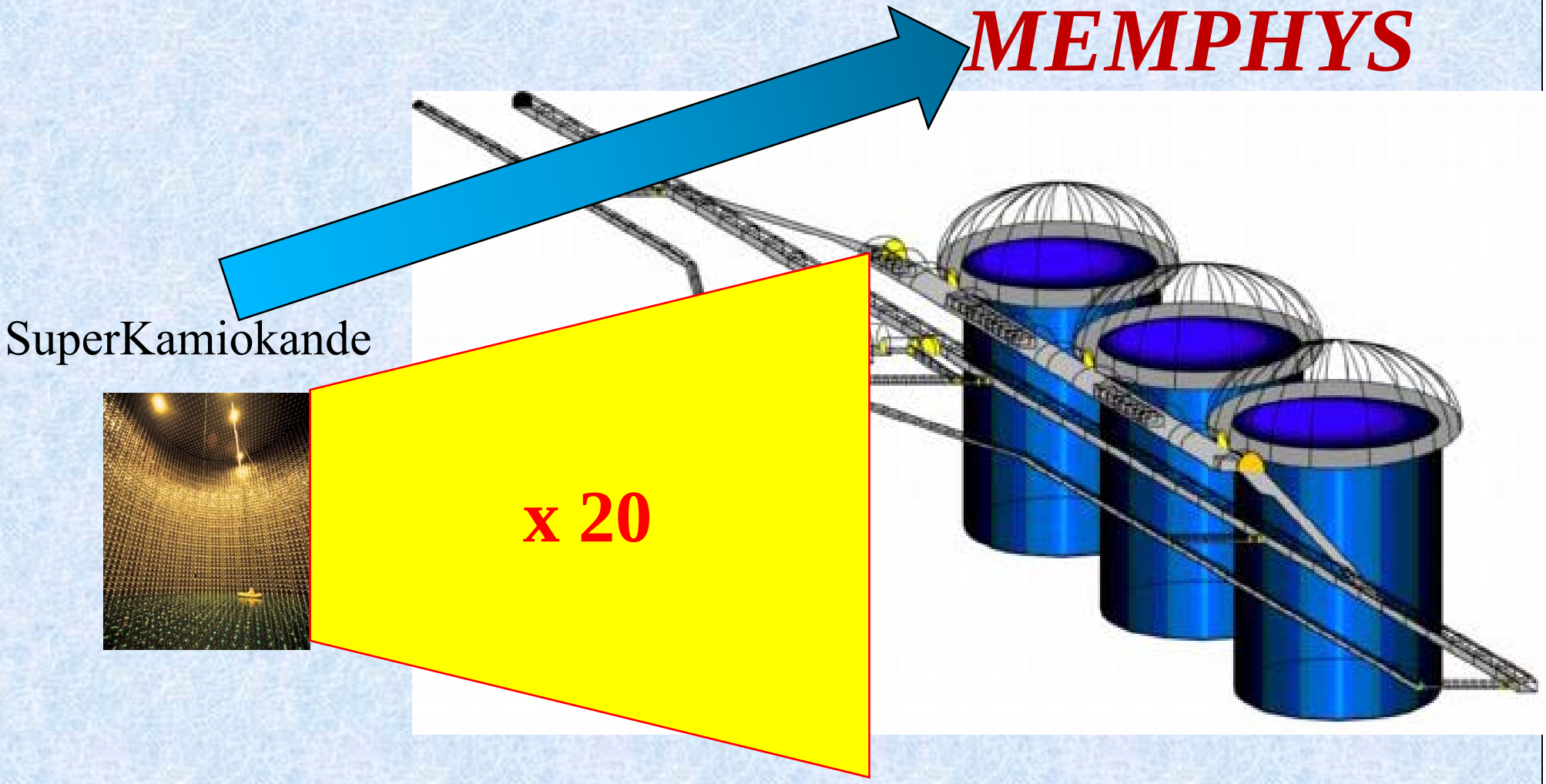
# Studies towards a large scale Water Cherenkov detector in Europe



# LAGUNA:

**L**arge **A**pparatus for **G**rand **U**nification and **N**eutrino **A**strophysics

Consensus among physicists:

**High-energy accelerators like the LHC or the planned ILC cannot directly answer these fundamental questions about Nature.**

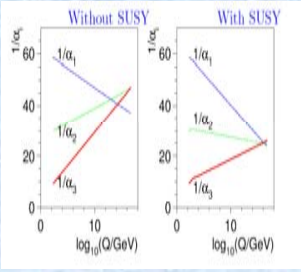
**This was also recognized in the CERN European roadmap for particle physics :**

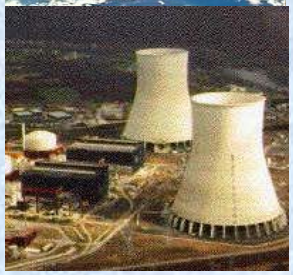
***"A range of very important non-accelerator experiments take place at the overlap between particle and astroparticle physics exploring otherwise inaccessible phenomena. Council will seek to work with ApPEC to develop a coordinated strategy in these areas of mutual interest."***

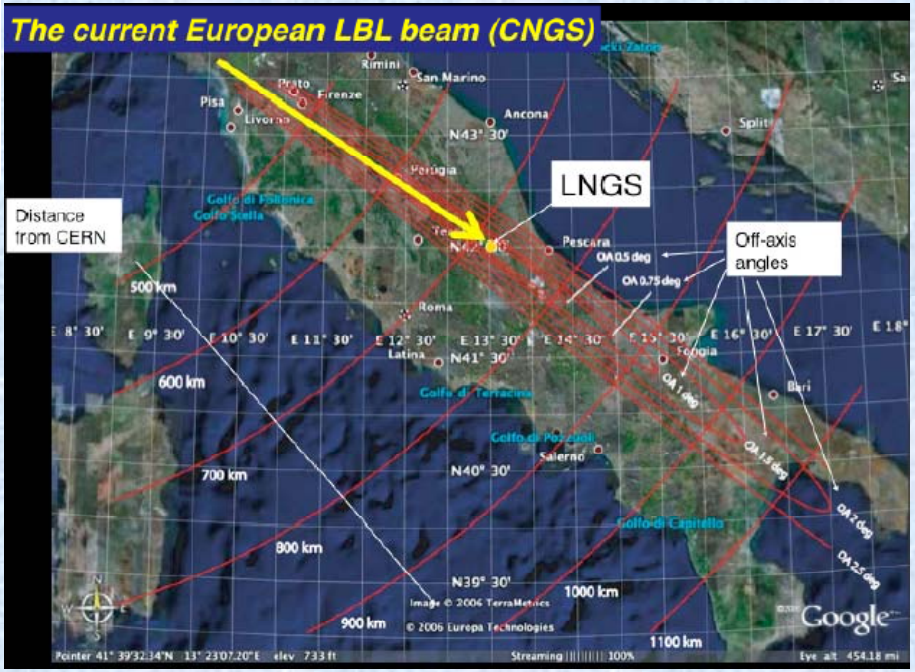
**New megatonne class, multipurpose detectors will allow to study these fundamental questions**

## Particle physics

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

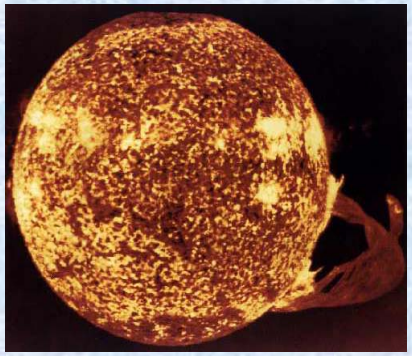


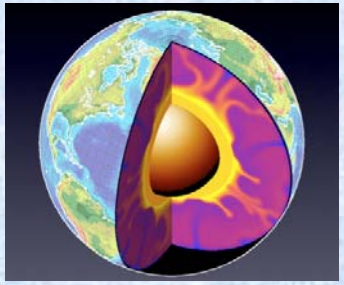





## Neutrino astronomy

**Supernova neutrinos**
**Diffuse SN neutrinos**
**Solar neutrinos**
**Dark matter annihilation**
**Geo-neutrinos**





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

***We recommend that a new large European infrastructure is put forward, as a future international multi-purpose facility on the $10^5$-$10^6$ ton scale for improved studies of***
***proton decay and of***
***low-energy neutrinos from astrophysical origin.***
***The three detection techniques being studied for such large detectors in Europe,***
***Water-Cherenkov,***
***Liquid Scintillator and***
***Liquid Argon,***
***should be evaluated in the context of a common design study which should also address the underground infrastructure and the possibility of an eventual detection of future accelerator neutrino beams.***

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

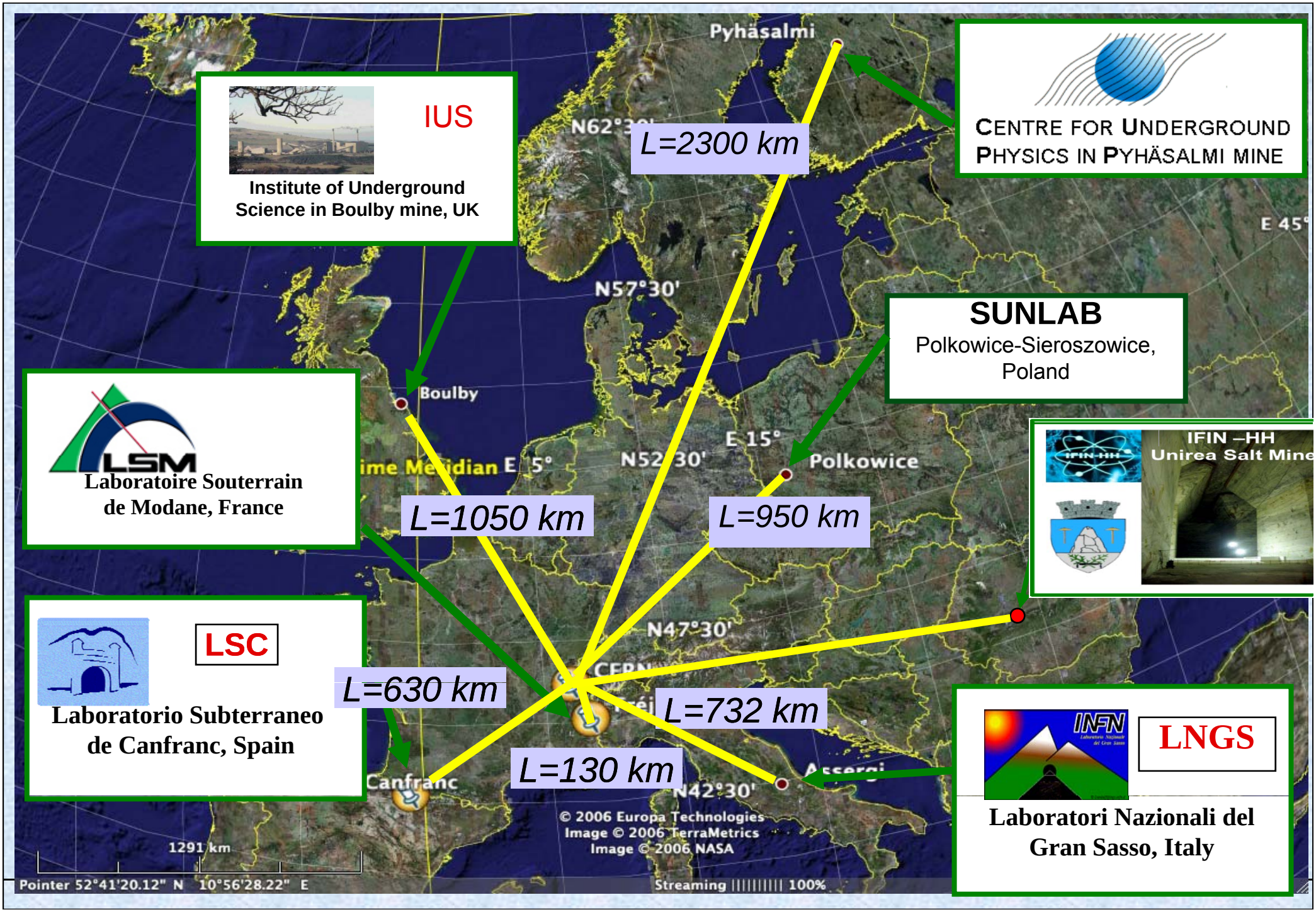
The Design Study programme for the **LAGUNA** project
has been **approved as a whole by the European Commission** (EC)

Nevertheless for the EC it was impossible to allocate
the full amount asked by LAGUNA (≈ 5 M€) : so the EC decided
to mainly support the part of the programme which is more difficult
to be founded on a national (regional) basis :

**1.7 M€** to be mainly devoted
to **the sites infrastructure studies**

From : ***Status and Perspectives of Astroparticle Physics in Europe***
***Christian Spiering***
***Received February 2008 Published online 2008***

**« The present prominent European projects under study are MEMPHYS,**
**a Megaton-scale water detector (de Bellefon et al. 2006), LENA (Wurm et al. 2007),**
**a 30-70 kiloton liquid scintillator detector, and GLACIER (Rubbia 2004),**
**a 50-100 kiloton liquid argon detector.**
**The European LAGUNA consortium (Autiero et al. 2007) has been awarded**
**a FP7 Design Study grant in order :**
**a) to explore and compare the capabilities of the three methods and**
**b) to evaluate the possibilities of excavation of deep large cavities and the**
**accompanying infrastructures.**
**The design study should converge, on a time scale of 2010, to a common proposal.**
**The total cost depends on the method and the actual size and is estimated to be**
**between 400 and 800 MEuro.**
**Civil engineering may start in 2013.**
**The cost would be shared internationally for such a Mega project. »**


IUS
Institute of Underground Science in Boulby mine, UK
Pyhäsalmi
CENTRE FOR UNDERGROUND PHYSICS IN PYHÄSALMI MINE
L=2300 km
N62°30'
N57°30'
E 45°
SUNLAB
Polkowice-Sieroszowice, Poland
Boulby
E 15°
N52°30'
Polkowice
E 5°
L=1050 km
L=950 km
LSM
Laboratoire Souterrain de Modane, France
IFIN –HH
Unirea Salt Mine
N47°30'
LSC
Laboratorio Subterraneo de Canfranc, Spain
L=630 km
L=732 km
L=130 km
Canfranc
N42°30'
LNGS
Laboratori Nazionali del Gran Sasso, Italy
© 2006 Europa Technologies
Image © 2006 TerraMetrics
Image © 2006 NASA
1291 km
Pointer 52°41'20.12" N 10°56'28.22" E
Streaming 100%

# Beneficiaries

- Consortium composed of 21 beneficiaries
  - 9 higher education entities (ETHZ, U-Bern, U-Jyväskylä, UOULU, TUM, UAM, UDUR, USFD, UA)
  - 8 research organizations (CEA, IN2P3, MPG, IPJ PAN, KGHM CUPRUM, GSMiE PAN, LSC, IFIN-HH)
  - 4 SMEs (Rockplan, Technodyne, AGT, Lombardi)
- Additional higher education participants (IPJ Warsaw, U-Silesia, U-Wroclaw, U-Granada)

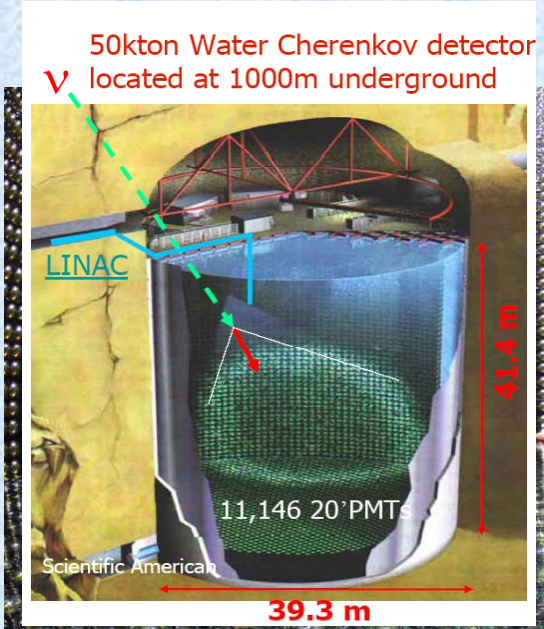
# Work package list

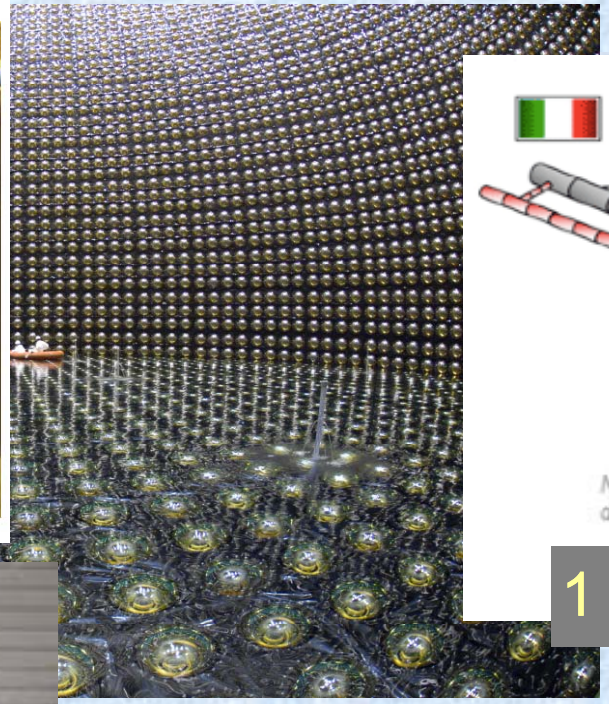
| Work package no. | Work package title | Type of activity | Lead beneficiary no. | Person-months | Start month | End month |
|---|---|---|---|---|---|---|
| WP1 | Management, coordination and assessment | MGT | ETHZ | 26.5 | 1 | 24 |
| WP2 | Underground Infrastructures and Engineering | RTD | U-Oulu | 160 | 1 | 24 |
| WP3 | Safety, environmental and socio-economic issues | RTD | U-Sheffield | 42 | 1 | 24 |
| WP4 | Science Impact and Outreach | RTD | IFJ PAN | 47.5 | 1 | 24 |
| | **TOTAL** | | | **276** | | |

# WP2: Underground infrastructures

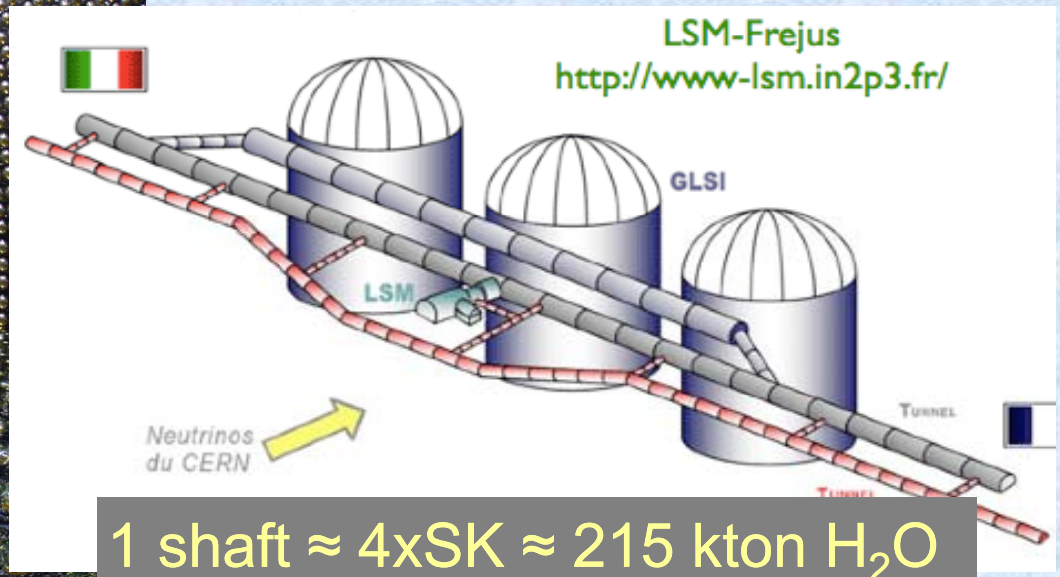
- Led by TUM
- Objectives:
  - To assess the feasibility of large underground caverns in seven potential European sites to host large volume detectors.
  - To provide the technical information, including cost estimates, needed for potential construction decision and site selection.
  - To assess the site impact of the construction of underground tanks on the facility and estimate time of underground realization
- Description of work:
  - The technical issues of the construction of large-scale underground cavities are studied, including general geological studies of the sites, preliminary designs for the cavities, simulations of rock mechanics, analyses of local rocks, planning of the cavity construction and cost optimization.

# MEgaton Mass Physics: MEMPHYS

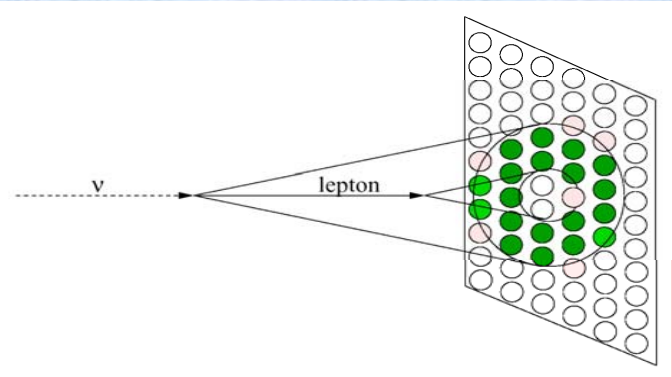


Up to 400 kton fiducial mass




1 shaft ≈ 4xSK ≈ 215 kton $H_2O$




About 170 γ/cm in 350 < λ < 500 nm
With 40% PMT coverage, Q.E.≈20%
Relativistic particle produces
®≈14 photoelectrons / cm
®≈7 p.e. per MeV

# MEMPHYS :
# A large scale water Čerenkov detector at Fréjus

arXiv:hep-ex/0607026v1 17 Jul 2006

A. de Bellefon[1], J. Bouchez[1][2], J. Busto[3], J.-E. Campagne[4],
C. Cavata[2], J. Dolbeau[1], J. Dumarchez[5], P. Gorodetzky[1], S. Katsanevas[1],
M. Mezzetto[6], L. Mosca[2], T. Patzak[1], P. Salin[1], A. Tonazzo[1], C. Volpe[7]

[1] *APC Paris*
[2] *DAPNIA-CEA Saclay*
[3] *CPP Marseille*
[4] *LAL Orsay*
[5] *LPNHE Paris*
[6] *INFN Padova*
[7] *IPN Orsay*

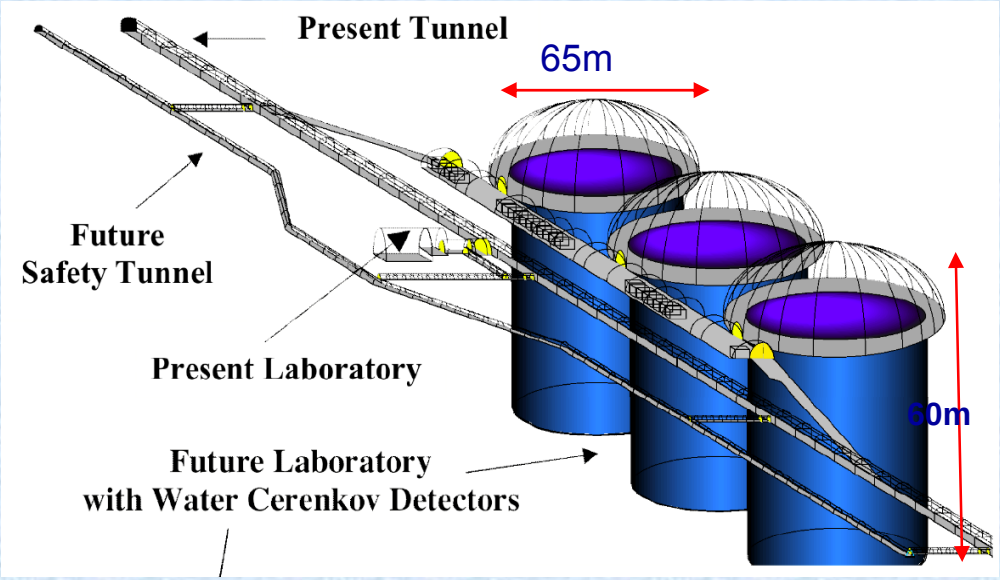
**Abstract**

A water Čerenkov detector project, of megaton scale, to be installed in the Fréjus underground site and dedicated to nucleon decay, neutrinos from supernovae, solar and atmospheric neutrinos, as well as neutrinos from a super-beam and/or a beta-beam coming from CERN, is presented and compared with competitor projects in Japan and in the USA. The performances of the European project are discussed, including the possibility to measure the mixing angle $\theta_{13}$ and the CP-violating phase $\delta$.

# MEMPHYS : MEgaton Mass PHYSics

*a brief reminder*

- water Cherenkov ("cheap and stable")
- total fiducial mass: 440 kt
- 3 cylindrical modules 65 x 65 m
  - size limited by light attenuation length (λ~80m) and pressure on PMTs
  - readout : ~3 x 81k 12" PMTs, 30% geom. cover
  - PMT R&D + detailed study on excavation @Fréjus existing & ongoing




physics goals :

- proton decay searches
- superNovae core collapse and diffuse neutrinos
- precision measurement of neutrino oscillations with beams and solar neutrinos

# Participation to European D.S.

- **LAGUNA** [cfr talk by Th. Patzak, contact person for France] Started

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

  - Several institutions participating to WP2-Underground Infrastructures and Engineering and WP4-Science Impact and Outreach

- **EUROnu** (ranked 1st among FP7 Insfrastructure proposals !) Started

  A High Intensity Neutrino Oscillation Facility in Europe Study

  - Physics performance of Water Cherenkov detector to measure neutrino oscillation parameters with SuperBeam and BetaBeam, including detailed response and backgrounds
  - APC-Paris (A.Tonazzo: contact for WP5-France), LAL_Orsay, LAPP-Annecy, etc.

- **DevDet ?** Submitted

  Detector Development Infrastructures for Particle Physics Experiments

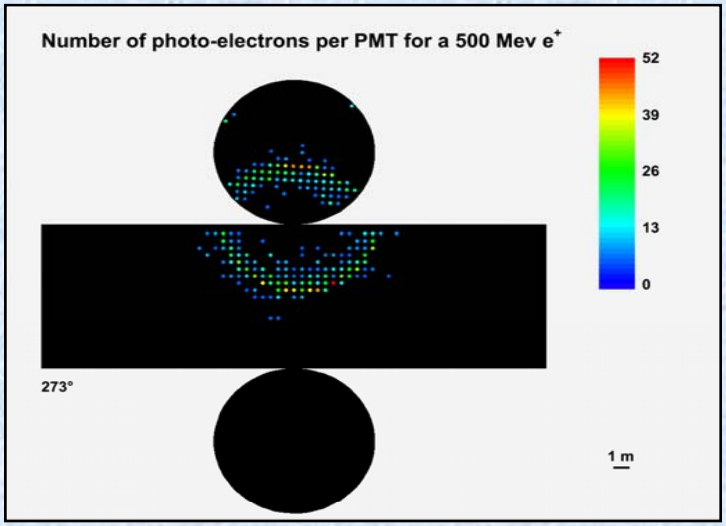
  - Installation of MEMPHYNO prototype on CERN test-beam proposed

# Simulations

- Event Generator:
  - NUANCE for ν beam, ν Atmospheric & Proton Decay
- Simulation:
  - Version 0:
    - adapted by J.E.Campagne from Geant 4 code used by M. Fechner et al. for T2K-WC-2km. The simulation was x-checked using SK & K2K data.

      includes Water & PMT & wall reflectivity optical parameters
  - Current version 7:
    - Interface with the OpenScientist v16r0 framework (G. Barrand@LAL)
    - 3 modes of running in the same framework:
      - Interactive Viewing, Batch processing, AIDA_ROOT analysis
    - Event info from MC
    - Primary + non-Optical photons track infos
    - Hits: each PM maintain a list of arrival time of optical photons detected (i.e photo-cathod efficiency)
- Future developments: (work in progress at APC, LAL, LAPP)
  - Code review to improve the geometry implementation, clean up the patches used to adapt the code from T2K-WC to MEMPHYS use case, improve flexibility
  - Implement the electronics simulation
  - Implement a Data Model to be able to do “replay” event-display

# Simulations




» Visualisation "à la SK" developed

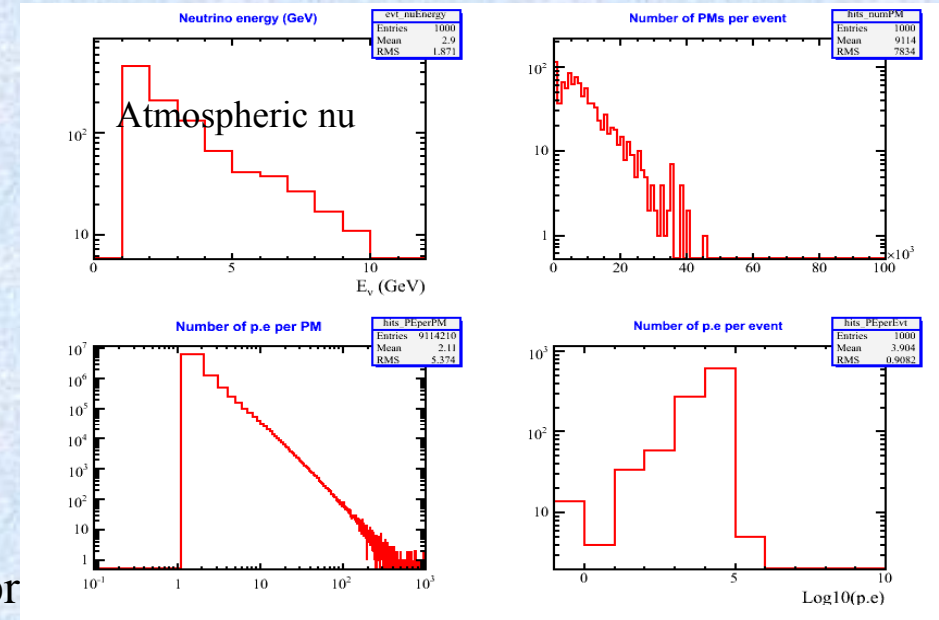
[E.Richard - APC]

Studies of

light collection,

vertex reconstruction

[J.E.Campagne, N.Vassilopoulos]




Dedicated code adapted for MEMPHYNO pr

# Simulations

Ongoing and future work:

- Optimisation of test tank for PMm2 and MEMPHYNO prototype
- Comparison with MEMPHYNO data
- Studies for MEMPHYS
  - different cavity geometries
  - optimal overburden
  - different types of photodetectors
  - use of reflective or WLS paintings .....

  ⇒ define realistic detector performance
  ⇒ detailed simulation of signals and backgrounds

⇒ use all this for **physics reach studies**
- on beta/super beam [in the context of EuroNu
  = France's responsibility: APC+LAPP]
- on p-decay and SN-nu, complementarity to LAr and Sci [in LAGUNA]

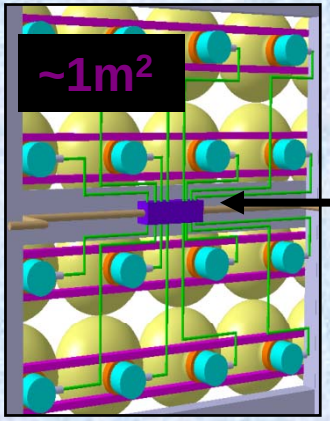
# R&D : PMm2

contact: J.E.Campagne
campagne@lal.in2p3.fr

- 500k€/3yrs funded by French National Research Agency (ANR) for 2007-2010
- Participating: LAL-Orsay, IPN-Orsay, LAPP-Annecy, Photonis

**PMm2 philosophy for large detectors:**

Replace large PMTs (20”) by groups of smaller ones (eg.12”) originally proposed by Photonis Co. at NNN05




x16

**“Local”**

**FE-ASIC** | **Monitoring** | **HV**

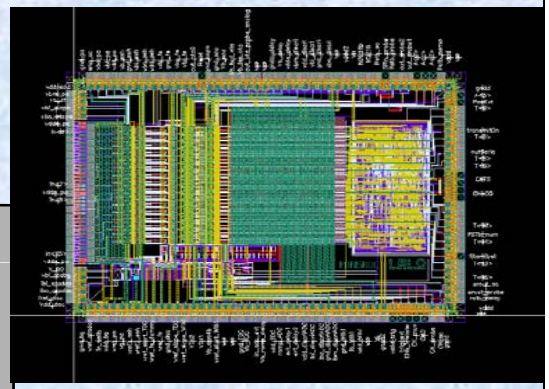
**FPGA + µC**

**Network Controller**

**“No possible local coincidence”**
**(low energy event 10PMs/MeV over 81000 PMs)**

⇓

**TRIGGER LESS DAQ**



**Twisted pairs cables for Clock sync. - Digitized Data - Power**

**“Outside”**

**Ethernet switches + server**

**DAQ**

**GPS receiver**

***: MEMPHYS ~ 3 x 81,000 PMTs; LENA & GLACIER ~ 20,000 ÷ 30,000 PMTs**

# R&D : MEMPHYNO

## A small scale prototype of MEMPHYS

- ~10t of water (+Gd?)
- 2x2x2m$^3$ HDPE tank
- Matrix of 16 12" PMTs (from PMm2 R&D) and/or other photodetectors (e.g.: X-HPX)
- muon hodoscope
  2+2 planes of OPERA-like scintillator bars

APC-Paris
LAL-Orsay
LAPP-Annecy

# R&D : MEMPHYNO

Goals:

1. full test of electronics and acquisition chain with actual physics events
2. trigger threshold studies
3. self-trigger mode
4. Track reconstruction performances
5. Gd doping: feasibility and performance (if studies still needed...)

Test bench for photodetection solutions for large detectors

Plan:

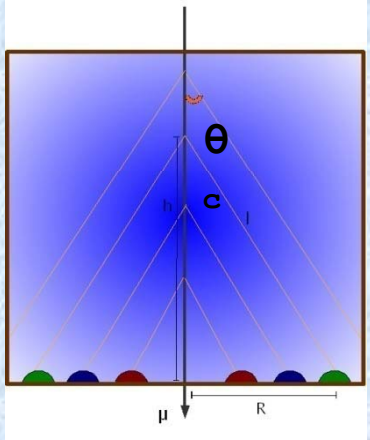
1. Install at APC lab ("hall de montage") => cosmic muon data
   - direction selected with hodoscope
   - test timing, track reconstruction
2. Transport to Fréjus LSM lab
   - Measure backgrounds at underground site
   - Test trigger and thresholds
3. Expose to CERN beam [with DevDet European program]
   - Check electron vertex reconstruction and e/pi separation
4. Back to APC
   - Test Gd-doping

- for DSN detection in MEMPHYS
- for non-proliferation studies :

  MEMPHYNO is a "small-scale", "portable" detector, easy to install near reactor power plants

Memphyno

# Prototype MEMPHYNO:



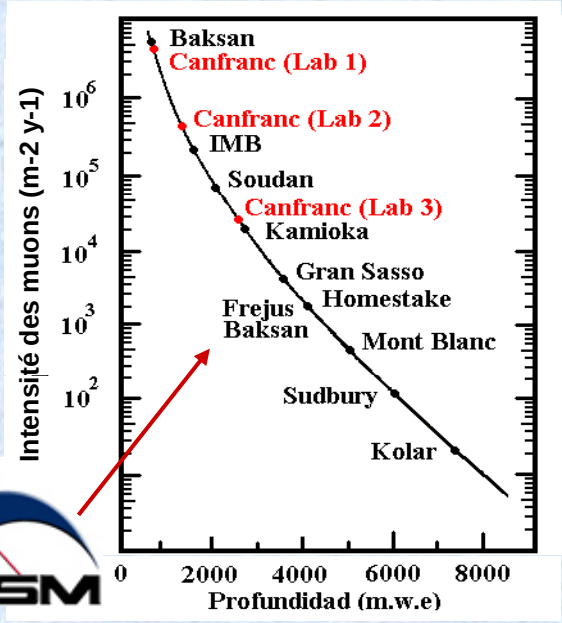

Letter of Intent

for the installation at LSM of a prototype water-Cherenkov

Detector: MEMPHYNO

Contact person: Thomas Patzak, APC Laboratory, Paris, patzak@apc.univ-paris7.fr

**Abstract** We plan to install at the LSM a 10-tons water Cerenkov test facility instrumented with a 16 photomultipliers units with integrated electronics. The objective of this water Cerenkov prototype is to use an "upstream research" for the realisation of large detectors using thousands of photomultipliers, with very large surfaces segmented in macro pixels connected to an innovative autonomous electronics. The whole chain from the signal induced by the Cerenkov photons, the front-end electronics, the DAQ and triggering system will be tested in the site which will most likely provide the final location for a Megaton-scale water Cerenkov detector.




Laboratoire Souterrain de Modane

LSM

# Very recent stuff:

Large amount of money goes to the photo detector (true for the 3 projects)

## Find a NEW photo detector….

1. Development by J. Busto et al. (CPP Marseille) on large highly efficient PMT's (QE = 40%)

X-HPD

Present status :

Photonis have made 2 8'' prototypes to test 'internal' photocathode deposition

No crystal: metal disk to measure photocurrent
Not optimised electrostatically (disk not at sphere centre)

2. New proposal to French funding agencies from a transversal group of members from the physics department of Paris Diderot-Paris7:

"APC" lab + "Matière et Phénomènes Quantiques" lab + Thales Research + Startup

Concept based on new solid state detectors à la "solar panels" with HV bias and integrated optics.

# Summary and outlook

Human resources (25 physicists) :

- work on simulation, mechanical design, PMT R&D is already ongoing at APC, LAL, LAPP (march 2008)
- 1 PhD thesis @APC (2008-2011) is funded by IN2P3-P2I (Michela Marafini)
- 1 Postdoc funded by EURONU @ APC

- Europe is active towards a megaton-scale Water-Cherenkov detector: MEMPHYS
- Envisaged installation site: LSM lab @ Fréjus
  Excavation feasibility pre-study done
- Participation in European D.S.: LAGUNA, EUROnu, (DevDet)
- Ongoing activity on simulation
- Ongoing R&D 1 : PMm2 development of PMTs and their readout
- Ongoing R&D 2 : MEMPHYNO small-scale prototype

**MEMPHYS welcomes new people**

**We hope to start new fruitful collaborations**

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

# Conclusions and outlook

- The LAGUNA proposal is now approved (14 proposals / 54 submitted to FP7)
- The main physics goals are common inside the LAGUNA Cooperation
- The LAGUNA physics programme aims at otherwise inaccessible fundamental phenomena
- The 3 detector approaches appear complementary, but this needs a deeper investigation
- The 7 candidate sites need well coordinated feasibility studies and their basic equipment has to be defined in connection with the 3 proposed detector-types
- The relevant safety requirements must be integrated at all levels of this Design Study
- LAGUNA is an European cooperation, but it is also open for cooperation with the world community !