

MEMPHYS: A next generation megaton scale water Cherenkov detector in Europe

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Abstract. Future large underground detectors for neutrino physics are studied in Europe within the FP7 design studies LAGUNA, EUROnu and Laguna-LBNO. In this paper the MEMPHYS detector and its development phases are described. MEMPHYS is a proposed 0.5 Mton scale Water Cherenkov experiment to be performed deep underground. It is dedicated to nucleon decay, neutrinos from supernovæ, solar and atmospheric neutrinos, as well as neutrinos from a future Super-Beam (SB) or β -Beam (β B) to measure the mixing angle θ_{13} , the CP violating phase δ and the mass hierarchy. A small-scale prototype, MEMPHYNO, has been constructed with the purpose of serving as a test bench for new photo detection and data acquisition solutions.

1. Introduction

Neutrinos are messengers from astrophysical objects as well as from the early universe and can give us information on processes, which cannot be studied otherwise. Underground experiments, like SuperKamiokande (SK) [1], have made important discoveries. Next-generation very large volume underground experiments will answer fundamental questions on particle and astroparticle physics. They will search for a possible finite lifetime of the proton with a sensitivity one order of magnitude better than the current limit. With a neutrino beam they will measure with unprecedented sensitivity the last unknown mixing angle (θ_{13}) of neutrinos and unveil through neutrino oscillations the existence of CP violation in the leptonic sector, LCPV, which in turn could provide an explanation of the matter-antimatter asymmetry in the Universe. Moreover they will study astrophysical objects, in particular the Sun and Supernovæ [2]. The construction of a large scale detector devoted to particle and astroparticle physics in Europe is one of the priorities of the ASPERA [3] roadmap (2008). The FP7 Design Studies LAGUNA (2008 - 2011) (Large Apparatus studying Grand Unification and Neutrino Astrophysics) [5] [4] and LAGUNA-LBNO (2011 - 2014) [6] support studies of European research infrastructures in deep underground cavities able to host a very large multipurpose next-generation neutrino observatory - GLACIER (Liquid Argon) [7], LENA (Liquid Scintillator) [8], MEMPHYS (Water Cherenkov) [9] [10]. One of the possible sites is near the LSM (Laboratoire Souterrain de Modane) underground site at Fréjus, the deepest in Europe (4800 m.w.e.). Its distance from CERN adapted for “low energy” neutrino beams (130 km) made this site one of the best candidates for the MEMPHYS experiment especially for a clean measurement of LCPV.

2. The MEMPHYS Detector

One of the most understood techniques for neutrino detection is based on the Cherenkov light emission in water by the final state particles resulting from neutrino interactions. At beam energies below 1 GeV the water Cherenkov technique is well adapted to the physics scope of LAGUNA. Therefore the possibility of building a water Cherenkov detector with a fiducial mass of about 20 times larger than SuperKamiokande is currently investigated by different groups around the world, and for different underground sites. The MEMPHYS project is discussed here with particular interest for deployment in an extended Modane Laboratory (LSM -Fréjus¹), the distance from CERN being optimal for a low energy neutrino beam [12]. Each tank of MEMPHYS is about 10 times SuperKamiokande and therefore only a mild extrapolation from an existing detector is necessary.

For a MEMPHYS detector at the Fréjus site, situated at 130 km from CERN, the first peak of the neutrino oscillation probability occurs at a beam energy between 0.2 – 0.4 GeV. Using both βB and SB we obtain a discovery potential of $\sin^2 2\theta_{13} \sim 5 \cdot 10^{-3} - 3 \cdot 10^{-4}$ (lower–upper limits) at 3σ , irrespective of the actual value of δ_{CP} phase. For certain values of δ_{CP} the sensitivity is significantly improved. For a βB (SPL) alone discovery limits around $\sin^2 2\theta_{13} \sim 3 \cdot 10^{-4}$ to 10^{-3} are obtained for a large fraction of possible values of the δ_{CP} phase. Another important point is the understanding of the neutrino mass hierarchy: MEMPHYS could also determine this parameter with a sensitivity at 2σ CL (with 5 years data) for $\sin^2 2\theta_{13} > 0.025$. This result could be obtained - in a MEMPHYS at Fréjus configuration - combining βB and SB with the measurement of atmospheric neutrinos.

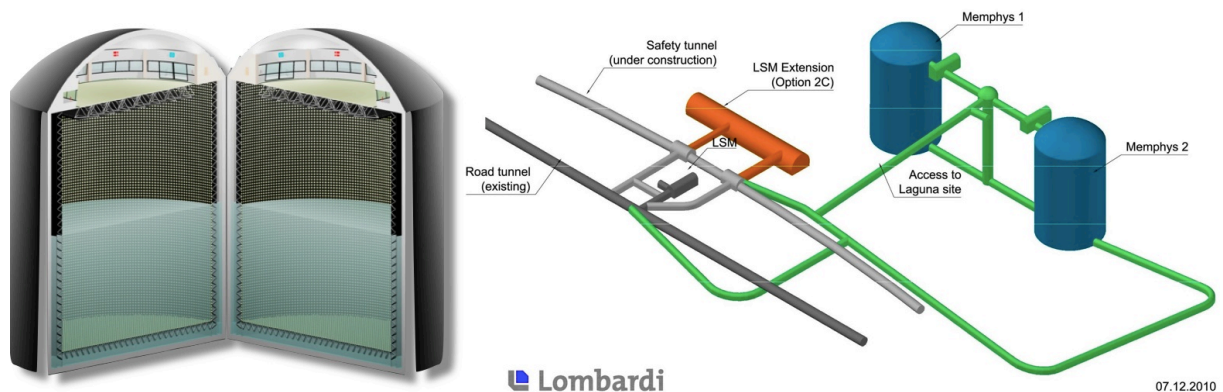


Figure 1. Design of the MEMPHYS detector. On the left the schematic view of a cylinder [11]. On the right one of the possible options for the MEMPHYS detector: two tanks, 64 m in diameter and 103 m high, separated by 140 m from each other.

The project aims at a fiducial mass around half a megaton obtained with 2 cylindrical detector modules of 65 meters in diameter and 103 meters in height. A schematic view is shown in figure 1. It takes into account the need to have a veto volume, 1.5 m thick, plus a minimal distance of about 2 meters between photodetectors and interaction vertices, leaving a sufficient space for ring development and to protect from γ from the PMTs natural radioactivity. The fiducial volume is 530 kilotons. The light sensors choice is to instrument the detector with photomultiplier tubes (PMTs) with a geometrical coverage of 30%. However, a number of technical aspects are under investigation. One of the challenges is the large number of photomultipliers

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required. The baseline design of MEMPHYS uses about 220,000 8" PMTs.

3. Detector simulation and development

The coverage of large area with PMTs at a "low" cost implies a readout integrated electronics circuit (called ASIC) for groups of PMT (matrix of 4x4). The development of such electronics is the aim of a dedicated French R&D program, called PMm² [13]. The circuit under development allows to integrate for each group of PMTs: a high-speed discriminator on the signal photoelectron (ph.e), the digitization of the charge (on 12 bits ADC) to provide numerical signals, the digitization of time (on 12 bits TDC) to provide time information, a channel-to-channel gain adjustment and a common high voltage. All the electronic and acquisition developed in the PMm² program is going to be fully tested with the MEMPHYNO prototype installed at the APC laboratory. MEMPHYNO is a test bench for any kind of light sensor or electronics solution for next generation megaton size experiments. This prototype is realized with a PEHD (Polyethylene) tank of 2 x 2 x 2 m³ filled with water and a hodoscope made by 4 scintillator planes (kindly donated by the OPERA [14] collaboration) - 2 on the top and 2 on the bottom - for the trigger of the incoming cosmic muons. A schematic view of the Memphyno tank with the muon hodoscope (green) and the PMm2 matrix (read dots) is shown in the left part of figure 2. In the same figure (middle and right) the PMT matrix as well as the pressure resistant box for the electronics are shown.

The development on grouped electronics and photosensors is of very high interest for all the three detector options of the Laguna project. In particular the strong synergy with the LENA detector lead to an joint study within a collaborative effort between german and french groups [15].

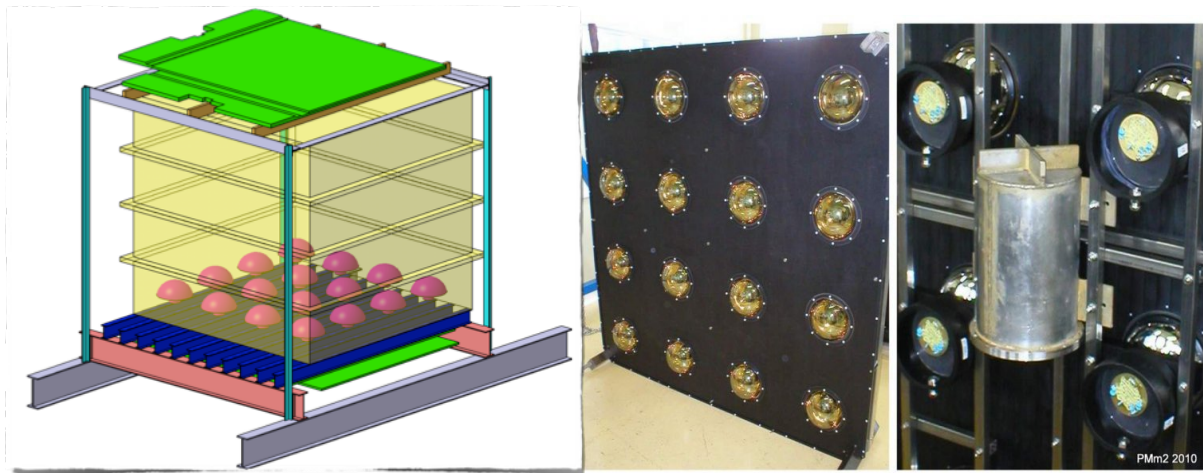


Figure 2. Left: Schematic view of the MEMPHYNO prototype. Middle: Photograph of the PMm2 matrix of 16 8" Hamamatsu PMTs. Right: Backside of the matrix showing the watertight box for the electronics.

In parallel to the development on photosensors and electronics a large effort on the simulation of the detector performance is ongoing.

The neutrino event generator is based on GENIE [16] and the full simulation of the MEMPHYS detector is based on GEANT4 [17]. The code has been developed starting from the SuperKamiokande algorithm and adapted to the new geometry and PMT choice of MEMPHYS. A new event reconstruction algorithm for ring and vertex finding is under development [18] [19].

4. Conclusions

In this paper we have made a summary of the physics potential of a next generation water Cherenkov detector - MEMPHYS. This detector has outstanding potential for the detection of supernova neutrinos, one can expect in the order of 10 events from an explosion at 1 Mpc, and DSN. A unique feature of this detector is the possible combination with a Super-Beam or β -Beam from CERN. This would allow the discovery of $\sin^2 2\theta_{13} \sim 5 \cdot 10^{-3} - 3 \cdot 10^{-4}$ (lower-upper limits) at 3σ , irrespective of the actual value of δ_{CP} phase. MEMPHYS allows the exploration of 75% of the phase space for LCPV.

Water Cherenkov is a proven technology, ready for deployment. A large development effort is undertaken to handle the large number of photo sensors. Its aim is the development of a grouped readout of 16 PMTs underwater, close to the PMTs. A test facility, MEMPHYNO, has been installed at the APC laboratory in Paris to perform tests of the new electronics using cosmic ray muons.

5. Acknowledgment

We are grateful to the European Commission for the financial support of the project through the FP7 Design Studies Laguna, Laguna-LBNO and EUROnu. We thank the french Centre National de Recherche Scientifique for the support of the project in form of the PICS.

6. References

- [1] [Super-Kamiokande Collaboration] S. Fukuda *et al.*, *Nucl. Instrum. Methods* **A501**, 418 (2003).
- [2] K.S. Hirata *et al.*, *Phys. Rev.* **D38**, 448 (1988); W.D. Arnett, J.L. Rosner, *Phys. Rev. Lett.* **58**, 1906 (1987).
- [3] ASPERA webpage: <http://www.aspera-eu.org>
- [4] D. Autiero *et al.*, *JCAP* **11**, 011 (2007).
- [5] Laguna FP7 design study, Grant Agreement No. 212343.
- [6] LAGUNA-LBNO FP7 design study, Grant agreement no: 284518.
- [7] A. Rubbia *et al.*, *J. Phys. Conf. Ser.* **171**, (2009).
- [8] L. Oberauer, F. von Feilitzsch, W. Potzel, *Nucl. Phys. Proc. Suppl.* **138**, 108 (2005).
- [9] A. de Bellefon *et al.*, [arXiv:hep-ex/0607026](https://arxiv.org/abs/hep-ex/0607026).
- [10] MEMPHYS webpage: http://www.apc.univ-paris7.fr/APC_CS/Experiences/MEMPHYS
- [11] J.L. Borne *et al.*, *Acta Physica Polonica B* **41**, (2010).
- [12] J-E. Campagne *et al.*, *JHEP* **04**, (2007).
- [13] PMM² webpage: <http://pmm2.in2p3.fr> (ANR-06-BLAN-0186-02).
- [14] OPERA Proposal, CERN/SPSC 2000-028, SPSC/P318, LNGS P25/2000.
- [15] PICS (Projet international de cooperation scientifique) Grant Agreement No. 5226.
- [16] C. Andreopoulos *et al.*, *Nucl. Instrum. Meth.* **A614** (2010)
- [17] S. Agostinelli *et al.*, *Nucl. Instrum. Meth. A* **506** (2003) 250-303; J. Allison *et al.*, *IEEE Trans. Nucl. Sci.* **53** No. 1 (2006) 270-278.
- [18] Private communication from Alessandra Tonazzo, APC, Paris, France.
- [19] Private communication from N. Vassilopoulos, IRES, Strassbourg, France .