R&D towards the MEMPHYS detector

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Abstract

MEMPHYS is a 0.5 Mton scale Water Čerenkov detector proposed for deep a underground installation$^{(\star)}$. Its performance concerning neutrino beams includes the possibility of measuring the mixing angle θ_{13}, the CP violating phase δ_{CP} and the mass hierarchy. In addition, it would have an unprecedented reach for nucleon decay searches and for supernova neutrino detection.One R&D item currently being carried out is *Memphyno*, a small-scale prototype. Its main purpose is to serve as a test bench for new photodetection and data acquisition solutions, such the *grouped readout* and *HV feeding* system (developed in the $PMm2$ project). We present here the aims and status of Memphyno.
$^{(\star)}$*Possible sites are under study in the European FP*7 *project LAGUNA.*

1 Introduction

Neutrinos are messengers from astrophysical objects as well as from the Early Universe and can give us information on processes happening in the Universe, which cannot be studied otherwise. Underground experiments, like SuperKamiokande (SK) [1], have achieved new fundamental results. Next-generation very large volume underground experiments will answer fundamental questions on particle and astroparticle physics: they will search for a possible finite lifetime for the proton with a sensitivity one order of magnitude better then the current limit; they will measure with unprecedented sensitivity the last unknown mixing angle (θ_{13}) in the neutrino oscillations formalism and unveil through neutrino oscillations the existence of CP violation in the leptonic sector, which in turn could provide an explanation of the matter-antimatter asymmetry in the Universe; moreover they will study astrophysical objects, in particular our Sun and Supernovæ [2]. LAGUNA [3] is a European project carrying on underground sites studies and developments in view of such detectors observatories (GLACIER, LENA, MEMPHYS) searching for rare events and studying various terrestrial and extra-terrestrial sources of neutrinos. The construction of a large scale detector devoted to particle and astroparticle physics in Europe is one of the priorities of the ASPERA roadmap, defined in 2008 [4].

2 Brief reminder of MEMPHYS and its physics potential

One of the most reliable and cost effective techniques for neutrino detection is based on the Čerenkov light emission in water by the final state particles resulting from neutrino interactions. The possibility of building a water Čerenkov detector with a fiducial mass of about 20 times larger than SK is currently being investigated by different groups around the world, and for different underground sites. The MEMPHYS project [5] is discussed here with particular interest in deployment in an extended LSM-Fréjus laboratory, which for a low energy neutrino beam, is located at an optimal distance from the CERN accelerator complex [6]. The design of MEMPHYS detector's modules is a rather mild extrapolation

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of the SK detector and relies on the expertise acquired after 20 years of operation. The project aims at a fiducial mass of around half a megaton obtained with 3 cylindrical detector modules, 65 meters in diameter and 60 meters in height (possibly extendable to 80 meters). The design takes into account the necessity to have a veto volume on the edge of the detector, 1 or 2 meters thick, plus a minimal distance of about 2 meters between photodetectors and interaction vertices, leaving a sufficient space for ring development. The light sensors choice is to instrument the detector with photomultipliers tubes (PMTs) with a geometry coverage of about 30%. The coverage of large area with PMTs at a "low" cost implies a readout integrated electronics circuit (called ASIC). This allows to integrate: 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. The development of such electronics is the aim of a dedicated R&D French program, called PMm^2 [7] (ANR-06-BLAN-0186-02). All the electronics and acquisition of PMm^2 is going to be fully tested with the Memphyno prototype (more details in paragraph 3), mainly at the APC laboratory in Paris.

2.1 Physics goals

We summarize the event rate in MEMPHYS detector [3] in the table on the right - neutrinos from supernova explosion (SN), diffuse supernova neutrinos (DSNB), solar, atmospheric and reactor neutrinos (the ($\star$) stands for the case where Gd salt is added to the water) - and we show the proton decay discovery potential. Moreover, concerning an accelerator-based neutrino oscillations study, there are two possible solutions for the neutrino beam: a Super-Beam (SB) and/or a β-Beam (βB) from CERN to the detector [8]. In particular, we are considering a βB with $\gamma = 100$ for the stored ions and a SB based on an optimized SPL with a proton beam energy of 3.5 GeV and a proton beam power on the target of 4 MW.

TOPIC	MEMPHYS (440ktons)
Proton decay:	
$e^+\pi^0$	1.0 x 10^{35} y
$\bar{\nu}K^+$	2 x 10^{34} y
SN ν (10 kpc):	
CC	2.0 x 10^5 ($\bar{\nu}_e$)
NC	1.0 x 10^3 (e)
DSNB ν (S/B 5 y)	$43 - 109/47$ ($\star$)
Solar ν	
^8B ES	1.1 x 10^6 per y
Atm. ν	4.0 x 10^4 per y
Geo ν	need 2 MeV thr.
Reactor ν	6.0 x 10^4 per y ($\star$)

In these studies we consider the MEMPHYS detector at the Fréjus site, located at 130 km from CERN (first peak of the neutrino oscillation probability). The performance obtained with a βB depends on the number of ion decays per year, but for both beams we obtain a guaranteed discovery potential of $sin^2 2\theta_{13} \sim 5 \cdot 10^{-3}$ 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) discovery limits around $sin^2 2\theta_{13} \sim 3\ (10) \cdot 10^{-4}$ are possible for a large fraction of all possible values of δ_{CP} phase. We stress that MEMPHYS could also resolve (even at the Fréjus-CERN distance) the parameter degeneracies with a sensitivity to the mass hierarchy at 2σ CL (with 5 years data dominated by statistic errors) for $sin^2 2\theta_{13} > 0.025$ for βB and SB and the possibility to determine the octant of θ_{23} with the combination of SB with atmospheric data. In the context of the European program Design Study EU-FP7 EUROnu [9] there are many studies focused on a European beam pointed to MEMPHYS in particular in the configuration CERN-Fréjus.

3 Memphyno R&D

The huge size of MEMPHYS and the cost of the light sensors of a such experiment require a careful choice concerning the detection technique and the data acquisition system. As we mentioned before, the project PMm^2 intends to realize a new electronic board dedicated to a grouped acquisition in matrix of 16 PMTs. In the MEMPHYS detector, each matrix of PMTs will have a common board (PARISROC) for the distribution of high voltage and for the signal detection. Such system should be tested with real physical signals and with the same detection technique as MEMPHYS. For this, a small prototype of MEMPHYS, Memphyno, is presently under construction at APC in order to make a full test of the complete chain "electronics and acquisition". Moreover, Memphyno is going to measure the trigger threshold, the track reconstruction performance and the properties of the PMTs. This prototype is realized with a PEHD (Polyethylene) tank of 2 x 2 x 2 m and a hodoscope made by 4 scintillator plans (2 on the top and 2 on the bottom) for the trigger of the incoming cosmic muons. The first 16 PMTs matrix of PMm^2 will be placed in the tank and studied first with cosmic muons (possible tests will be made with Gadolinium salt). Then, Memphyno will be moved to LSM for a background test, then at CERN for electron, pion and kaon beams measurements (an electron beam from the LAL is also possible). The test with electrons will be used to study the collection efficiency of the Čerenkov light from a point-like source and to check the single photoelectron range with the new electronics system.

3.1 Memphyno at APC

At present time, Memphyno is being built at APC and the hodoscope is going to be operational before the end of the year. Waiting for the PMm^2 demonstrator (16 8" PMTs of Hamamatzu), the tank will be cleaned and filled and tests of acquisition system will start with 4 8" PMTs (ETL-Electron Tubes Limited) from Borexino. The aim is to have a running prototype before the next summer and to be ready next september for the 16 PMTs matrix in order to have results on its test before the end of 2010. The DAQ system, the trigger and the mechanical integration of the 16 PMTs matrix from PMm^2 is currently under development in a joint effort from both teams.

3.2 Memphyno at LSM and CERN

The future plan is to move Memphyno to LSM for underground measurements. We must check the response of the new electronics to the rock background and measure in particular the random coincidences. Shortly after, Memphyno will go into the CERN test beam to study the detector response to electrons and pions.

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