Laguna: Future Megaton Detectors in Europe

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Abstract. The FP7 Design Study LAGUNA (Large Apparatus studying Grand Unification and Neutrino Astrophysics) supports studies of European research infrastructures in deep underground cavities able to host a very large multipurpose next-generation neutrino observatory dedicated to nucleon decay, neutrinos from supernovæ, solar and atmospheric neutrinos, as well as neutrinos from a future Super-Beam or β-Beam to measure the mixing angle θ_{13}, the CP violating phase δ and the mass hierarchy.

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 for the proton with a sensitivity one order of magnitude better then 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, which 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[1] roadmap (2008). The FP7 Design Study LAGUNA (Large Apparatus studying Grand Unification and Neutrino Astrophysics) [3] support studies of European research infrastructures in deep underground cavities able to host a very large multipurpose next-generation neutrino observatory - GLACIER (Liquid Argon) [4], LENA (Liquid Scintillator) [5], MEMPHYS (Water Cherenkov) [6].

2. Laguna

The FP7 Design Study LAGUNA [3] is a Pan-European effort of 21 beneficiaries, composed of academic institutions from Denmark, Finland, France, Germany, Poland, Spain, Switzerland, United Kingdom, as well as industrial partners specialized in civil and mechanical engineering and rock mechanics, is assessing the feasibility of this Research Infrastructure in Europe.

The LAGUNA consortium is evaluating possible extensions of the existing deep underground laboratories in Europe: Boulby (UK), Canfranc (Spain) and Modane (France) and considers the

[1] ASPERA: http://www.aspera-eu.org

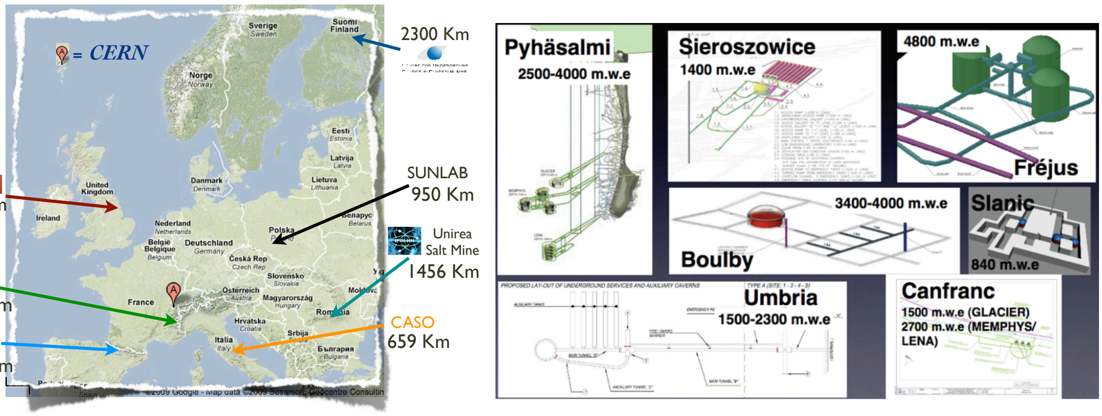

Figure 1. Left: Map of the seven possible underground sites in Europe. Right: Typical example of layouts studied in LAGUNA DS for each site.

creation of new laboratories in the following regions: *Caso* Umbria Region (Italy), *Pyhäsalmi* (Finland), *Sierozsowice* (Poland) and *Slanic* (Romania).
In Europe there are three different proposed detectors, based on different techniques: GLACIER (Liquid Argon), LENA (Liquid Scintillator) and MEMPHYS (Water Cherenkov). For all three detectors there are, in the LAGUNA context, specific studies concerning the construction feasibility, the required depth, the muons and reactor neutrinos flux etc. In figure 1 the seven sites are shown, as well as an example of the construction studies developed in the LAGUNA context by the different beneficiaries.

Location	Type	Envisaged depth m.w.e.	Distance from CERN [km]	Energy 1st osc. max. [GeV]
Fréjus (F)	Road tunnel	$\simeq$ 4800	130	0.26
Canfranc (ES)	Road tunnel	$\simeq$ 2100	630	1.27
Umbria (IT)[a]	Green field	$\simeq$ 1500	665	1.34
Sieroszowice (PL)	Mine	$\simeq$ 2400	950	1.92
Boulby (UK)	Mine	$\simeq$ 2800	1050	2.12
Slanic (RO)	Salt mine	$\simeq$ 600	1570	3.18
Pyhäsalmi (FI)	Mine	up to $\simeq$ 4000	2300	4.65

[a] $\simeq 1.0^\circ$ off axis.

Figure 2. Potential sites being studied with the LAGUNA design study [7].

The design study is dedicated to the comprehensive and coordinated technical assessment of each site (rock studies, external activities compatibility, etc...). Moreover the study must produce a coherent cost estimation. The next generation deep underground neutrino detector in Europe should be coupled to advanced neutrino beams from CERN. Each site has specific depth characteristics and is situated at a specific distance from the CERN complex (see figure 2). This offers a large number of possible "detector-site" combinations and must be considered a benefit and not a disadvantage compared to other countries where there is only one possible scenario. The selection of the optimized configuration involves several aspects (physics performances, technical feasibility, safety and legal aspects, socio-econimic and environmental impact, costs, ...) and this implies a particular attention of LAGUNA to interdisciplinary matter, as both physicists and engineers as well as geo-technical experts are directly involved.

2.1. GLACIER

The GLACIER (Giant Liquid Argon Charge Imaging ExpeRiment) [4] detector is based on a new liquid argon detector concept, scalable to a single unit of mass 100 kton: it relies on a cryogenic storage tank developed by the petrochemical industry (LNG technology) and on a novel method of operation called the LAr LEM-TPC. LAr LEM-TPCs operate in double phase with charge extraction and amplification in the vapor phase. The concept has been very successfully demonstrated on small prototypes: ionization electrons, after drifting in the LAr volume, are extracted by a set of grids into the gas phase and driven into the holes of a double stage Large Electron Multiplier (LEM), where charge amplification occurs.

Figure 3. Design of the Glacier detector [4]. The maximum diameter is 70 m; the height is limited to 20 m by the maximum possible drift length.

Effective extrapolation to the required scale needs concrete R&D. A ton-scale LAr LEM-TPC detector is being operated at CERN in Blg 182 within the CERN RE18 experiment (ArDM). In order to prove the performance for neutrino physics, additional dedicated test beam campaigns are being considered, to test and optimize the readout methods and to assess the calorimetric performance of such detectors. A 1 kton detector can be built assuming the GLACIER design with a 12 m diameter and 10 m vertical drift. From the point of view of the drift path, a mere factor 2 will be needed to extrapolate from the prototype to the 100 kton device. Hence, the prototype will be the real demonstrator for the long drifts. At the same time, the rest of the volume scaling from the 1 kon to the 100 kton achieved by increasing the diameter to about 70 m, can be realized noting that (a) large LNG tanks with similar diameters and aspect ratios already exist (b) the LAr LEM-TPC readout above the liquid will be scaled from an area of 80 m^2 (1 kton) to 3800 m^2 (100 kton). This will not require a fundamental extrapolation of the principle, but rather only pose technical challenges of production, which can be solved in collaboration with industry.

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In addition, researches into neutrino oscillations point to the need to couple the observatory to intense neutrino beams, for instance from CERN, to address the puzzle of the origin of matter excess over antimatter in the Universe (discovery of CP-violation in the Lepton Sector). In such a detector the level of precision in the measurements of the last unknown oscillation angle θ_{13}, the phase of CP violation and the mass hierarchy when combined with a neutrino beam is unprecedented. Several beams can be considered for the GLACIER detector.

2.2. LENA

LENA (Low Energy Neutrino Astronomy) is a proposed large $\sim$ 50ktons liquid scintillator neutrino (LSc) detector for particle-astrophysics, located in a deep underground laboratory. Because of its low energy threshold, LENA would be sensitive to neutrinos from very different sources: the measurement of the diffuse Supernova neutrino background; the precise determination of thermo-nuclear fusion processes and the matter-effects in solar matter by measuring solar neutrinos with high statistics; a measurement of geo-neutrinos probing Earth's models; in case of an actual galactic type II Supernova an accurate measurement of the time development and flavour content of the emitted neutrino burst. Moreover, LENA can search for proton decay, especially $p \to K^+\bar{\nu}$, thus probing grand unified theories. In addition, LENA will be used as a detector for low energy atmospheric neutrinos and may perform an indirect search for Dark Matter.

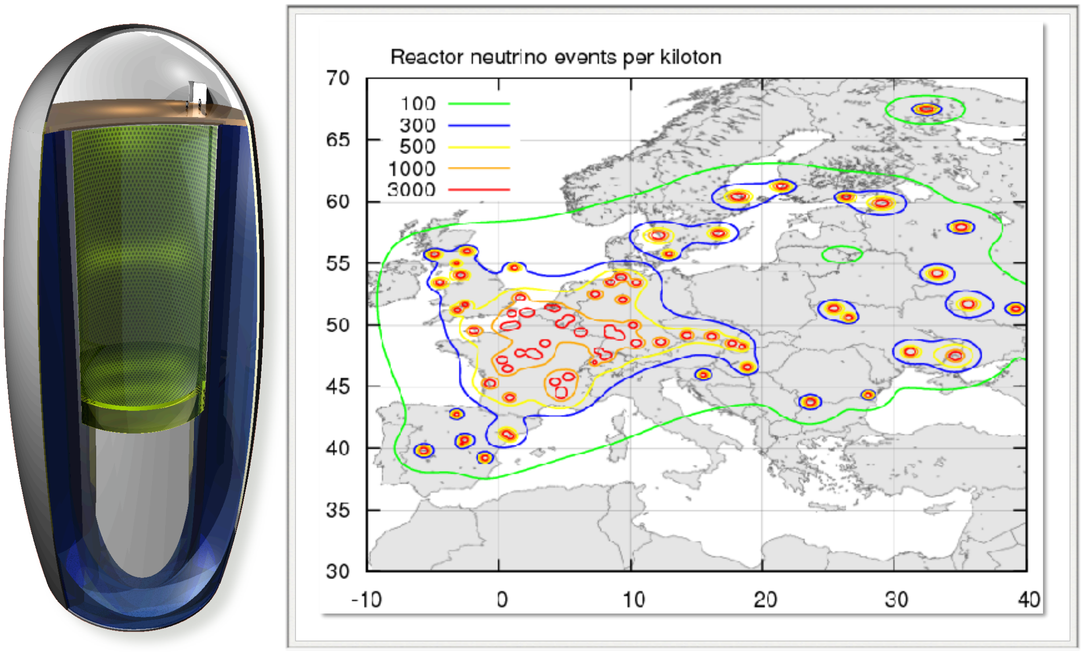

Figure 4. Left: Design of the Lena detector [5]. The tank is 100 m height and includes the water muon veto. Right: Reactor neutrinos background flux in Europe per year and per kiloton.

Recent studies indicate that such a large volume of LSc detector can resolve both momentum and energy of GeV particles [8]. Monte-Carlo simulations have been performed to study the reconstruction capability of a LSc detector for complex event topologies of CC neutrino interactions. If this new approach is feasible it will offer the possibility to complement the already rich low-energy physics program of LENA by long-baseline neutrino oscillation experiments, either from atmospheric neutrinos or an accelerator-produced neutrino beam.

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2.3. MEMPHYS
One of the techniques most understood for neutrino detection is based on the Cherenkov light emission in water by the final state particles resulting from neutrino interactions. Therefore the possibility of building a water Cherenkov detector with a fiducial mass of about 20 times larger than SK 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 -Fréjus), which for a low energy neutrino beam is located at an optimal distance from the CERN accelerator complex [9].

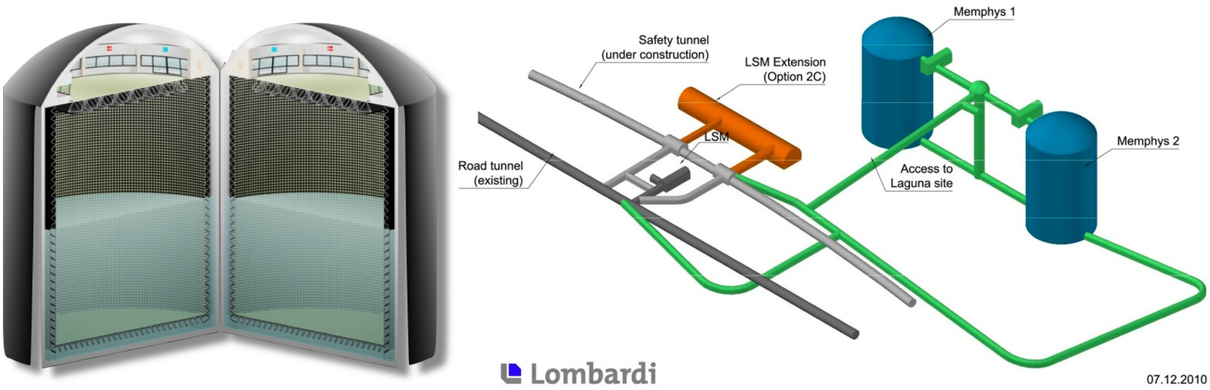

Figure 5. Design of the Memphys detector. On the left the schematic view of a cylinder [10]. On the right one of the possibles option for the MEMPHYS detector: two tanks, 64 m in diameter and 103 m high, separated by 140 m from each other.

The huge size of MEMPHYS and the cost of the light sensors of a such a big experiment require an attentive choice concerning the detection technique and the data acquisition system. The project PMm^2 has realized a new electronics board dedicated to a grouped acquisition in the form of a matrix of 16 PMTs [11]. In the MEMPHYS detector each PMT matrix will have a common board (PARISROC) for the high voltage distribution and for the signal detection. Such a system should be tested with real physical signals and with the same detection technique as MEMPHYS in order to improve and adapt the system to the needs of the megaton scale experiments.

For this purpose a prototype of MEMPHYS, Memphyno, has been constructed at APC in order to make a full test of the complete chain "electronic and acquisition" [10]. The first 16 PMTs matrix of PMm^2 will be placed in the tank and studied first with cosmic muons in water with an option of introducing Gadolinium salt it a later stage. Then Memphyno will be moved to LSM for background tests and later to CERN for electron, pion and kaon beam measurements (an electron beam at the LAL is also possible). The test with electrons will be used to study the collection efficiency of the Cherenkov light from a point-like source and to check the single photoelectron range with the new electronics system.
The Memphyno prototype comprises a tank of $2 \times 2 \times 2$ m^3 filled with water and an Hodoscope made by 4 scintillator planes (2 on the top and 2 on the bottom) to provide the trigger and the direction of crossing cosmic muons.
At the present time, Memphyno has been built at APC and the Hodoscope is operational since May 2010. Whilst waiting for the PMm^2 demonstrator (16 8" Hamamatsu PMTs + PARISROC electronic board) the acquisition system have been performed with 4 8" PMTs (ETL-Electron Tubes Limited) from Borexino.

3. Summary
The Laguna design study allowed to accomplish a very detailed investigation of the different underground locations. It also helped to structure the European neutrino community and define the physics goals of the next generation experiments.

Topics	GLACIER 100 kton	LENA 50 kton	MEMPHYS 440 kton
Proton decay			
$e^+\pi^0$	0.5×10^{35}	—	1.0×10^{35}
$\bar{\nu}K^+$	1.1×10^{35}	0.4×10^{35}	0.2×10^{35}
SN ν (10 kpc)			
CC	$2.5 \times 10^4(\nu_e)$	$9.0 \times 10^3(\bar{\nu}_e)$	$2.0 \times 10^5(\bar{\nu}_e)$
NC	3.0×10^4	3.0×10^3	—
ES	$1.0 \times 10^3(e)$	$7.0 \times 10^3(p)$	$1.0 \times 10^3(e)$
DSNB ν (S/B 5 years)	40-60/30	9-110/7	43-109/47 (*)
Solar ν (Evts. 1 year)			
^{8}B ES	4.5×10^4	1.6×10^4	1.1×10^5
^{8}B CC	—	360	—
^{7}Be	—	2.0×10^6	—
pep	—	7.7×10^4	—
Atmospheric ν (Evts. 1 year)	1.1×10^4	—	4.0×10^4 (1-ring only)
Geo ν (Evts. 1 year)	below threshold	≈ 1000	need 2 MeV threshold
Reactor ν (Evts. 1 year))	—	1.7×10^4	6.0×10^4 (*)
Dark Matter (Evts. 10 years)	3 events ($\sigma_{ES} = 10^{-4}$,$M > 20$ GeV)	—	—

Figure 6. Summary of the physics potential of the proposed detectors for astro-particle. The (*) stands for the case where Gadolinium salt is added in the water of one of the MEMPHYS tanks [3].

In Figure 6 we resume the non-accelerator physics goals of the three detectors. In the framework of the LAGUNA program the detectors have to be considered in their underground sites taking into account the distance from CERN. According to the characteristics of the experiments and of their potential distance from the CERN facility reach different sensitivities to θ_{13} and to the δ CP phase. The synergy with the EUROnu program, that investigates a possible European neutrino beam, is necessary to performed a realistic and competitive experiment.

4. References
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