The MEMPHYS Detector @ Fréjus

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on behalf of the **MEMPHYS Collaboration**
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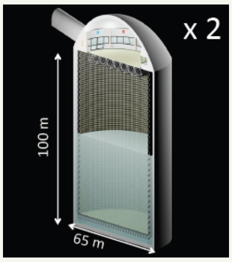
522. WE-Heraeus-Seminar: Exploring the Neutrino Sky and Fundamental Particle Physics on the Megaton Scale

MEMPHYS (MEgaton Mass PHYSics) will be a Megaton scale Water Cherenkov Detector located at Underground Laboratories of Modane (LSM), with a vast physics program: nucleon decay search, neutrinos from supernovae, solar and atmospheric neutrinos, as well as neutrinos from a future Super-Beam or Beta-Beam to measure the δ_{CP} violating phase in the leptonic sector and the mass hierarchy [1]. A full **simulation** of the detector has been performed through the two Montecarlo codes GENIE, simulating neutrino interaction in water, and Geant4, simulating the detector and the particle propagation. A realistic **analysis algorithms** has also been developed. The combination between the simulations and the analysis allows the improvement of the detector design and the evaluation of its performance for beam physics. A study of sensitivity to the **leptonic CP violation phase** using the GLOBES package has been performed [2].

MEMPHYS DETECTOR DESIGN



MEMPHYS is the Water Cherenkov option for the LAGUNA-LBNO project.

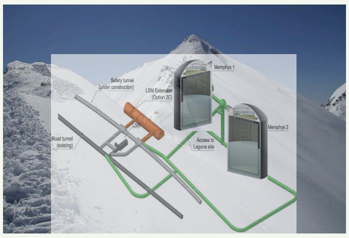
Detector design:

- 2 cylindrical modules **65m x 100m**
- Size limited by light attenuation length (λ~80m) and pressure on PMTs
- Total active mass: **560 kt**
- Readout (2 tanks): 130000, 12" PMTs + light concentrators, 20% geom. coverage (still under study)

Location:

- Laboratoire Souterrain de Modane - Frejus
- **130 km from CERN**
- **4800 m w.e.**

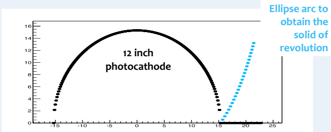
A complete Monte Carlo code (Geant4) allows tests on the detector design



THE OPTION OF LIGHT CONCENTRATORS FOR MEMPHYS

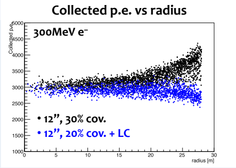
Light Concentrators (ellipsoidal cones) located at the equator of the photocathode, with 60° opening angle

Light Concentrator (LC) Structure: plastic (acrylic) cone + metal coating
Metals for coating: Al, Ag

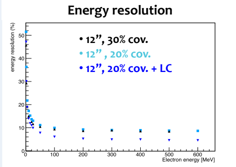


The use of light concentrators has two main advantages:
1. the **reduction of the number of PMTs**: from 30% down to 20% of geometrical coverage
2. a **better energy resolution**, as the number of collected photoelectron is less dependent on the radial position

Collected p.e. vs radius



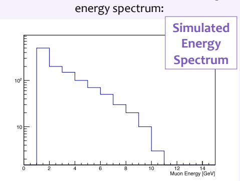
Energy resolution



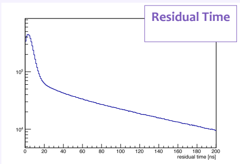
SIMULATION OF ATMOSPHERIC NEUTRINOS

Muons in an energy range between 1 and 10 GeV have been simulated in MEMPHYS. This study allows to estimate the number of collected photoelectron per PMTs, showing a range between 1 and 1000 p.e. This is the requirements for the MEMPHYS electronic readout.

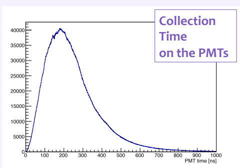
Muons are simulated with the following energy spectrum:



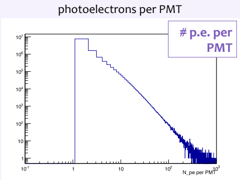
The event time (cluster duration): t_{PMT} – t.o.f



The hit collection time on PMTs



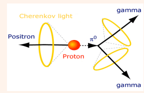
The distribution of the number of collected photoelectrons per PMT



[1] A. de Bellefon et al., *MEMPHYS: A Large scale water Cherenkov detector at Fréjus*, hep-ex/0607026.
[2] L. Agostino et al., *Study of the performance of a large scale water Cherenkov detector (MEMPHYS)*, accepted by JCAP, arXiv:1206.6665v2 (2012).
[3] A. Longhin, *A new design for the CERN-Fréjus neutrino super-beam*, Eur. Phys. J. C (2011) 71:1745

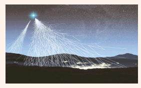
MEMPHYS NON ACCELERATOR PHYSICS

PROTON DECAY



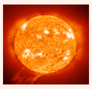
To test the Grand Unification Theory
10 years of data taking in a Water Cherenkov Detector with 500 kt of active volume:
p -> e⁺π⁰: ~1.2 x 10^{35} y @ 90% C.L.
p -> $\bar{\nu}$K⁺: ~ 2.4 x 10^{34} y @ 90% C.L.

ATMOSPHERIC NEUTRINOS



For the mass hierarchy determination and to solve $\sin^2\theta_{23}$ octant degeneracy
Rate ~ 4.8 x 10^4 ν per year

SOLAR NEUTRINOS



For variability analyses of the Sun and to test the Day/Night Asimmetry for ^{8}B neutrinos
Elastic Scattering Rate:
ν_{8B} ~1.3 x 10^6 per year

SUPERNOVA NEUTRINOS

To study the detailed mechanism of supernova explosions and neutrino properties (direct mass?)
For a galactic Supernova @ 10 kpc:
Charged Current: ~ 2.5 x 10^5 ν_e
Elastic Scattering: ~ 1.2 x 10^3 e⁻

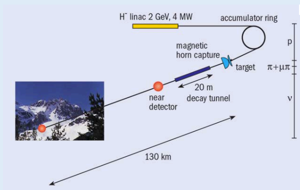
MEMPHYS ACCELERATOR PHYSICS

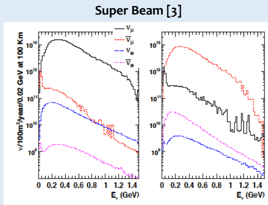
A measure of CP violation effects is given by

$$A_{CP} = \frac{P(\nu_l \to \nu_{l'}) - P(\bar{\nu}_l \to \bar{\nu}_{l'})}{P(\nu_l \to \nu_{l'}) + P(\bar{\nu}_l \to \bar{\nu}_{l'})} \propto J_{CP} \propto \sin\theta_{13} \sin\delta_{CP}$$

We will study the oscillation from **Super-Beam** (ν_μ and $\bar{\nu}_\mu$) and **β-Beam** (ν_e and $\bar{\nu}_e$) from CERN to Fréjus, for a baseline of 130 km.

Super Beam [3]

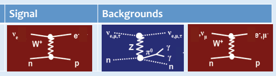


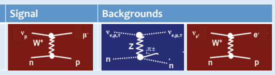


5.6 x 10^{22} p.o.t./year, 4 MW x 10^7 s at 4.5 GeV

For the Super-Beam we look for the oscillation $\nu_\mu \to \nu_e$
For the β-Beam we look for the oscillation $\nu_e \to \nu_\mu$

To distinguish ν_e, ν_m and background interactions it is necessary to identify particles, in particular electrons, muons and π^0

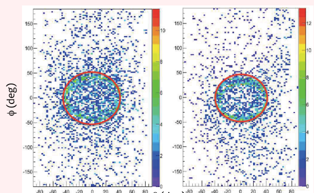
Super Beam	Signal	Backgrounds
ν_e appearance		

β Beam	Signal	Backgrounds
ν_μ appearance		

MEMPHYS RECONSTRUCTION CODE

Particle identification

φ vs θ, spherical coordinates around fitted vertex and direction



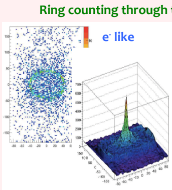
electron: fuzzy ring edge — muon: sharp ring edge

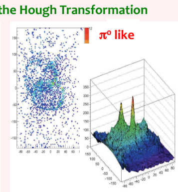
The MC codes simulates: neutrino interaction in water (GENIE) and the particle propagation in the detector (Geant4).
Then an analysis algorithms allows the:

1. Reconstruction of interaction vertex and track direction
2. Ring edge finding
3. Particle identification (e vs μ) from ring "fuzziness"
4. Ring counting (to reject π^0 background) in electron sample
5. Lepton momentum reconstruction
6. Neutrino energy calculation

$$E_\nu = \frac{m_n E_\mu - m_\mu^2/2}{m_n - E_\mu + p_\mu \cos\theta_\mu}$$

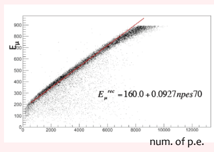
Ring counting through the Hough Transformation





Lepton momentum reconstruction

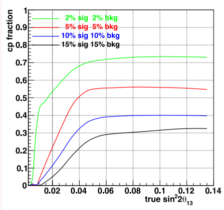
Muon momentum is reconstructed using a linear empirical relation (from simulations) between the real momentum and the number of photoelectrons produced in PMTs

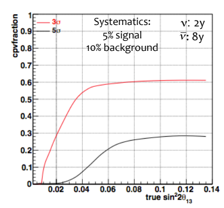


STUDIES OF MEMPHYS PHYSICS POTENTIAL

Simulating the Super-Beam and the β-Beam it is possible to evaluate the **Migration Matrices (MM)** for each channel. MM represent the reconstructed neutrino energy as a function of the true ν energy, summarizing the detector efficiency and the energy resolution. These are fundamental tools for the GLOBES package, allowing to evaluate the MEMPHYS sensitivity to the δ_{CP} and to the Mass Hierarchy.

δ_{CP} fraction for Super Beam





Mass Hierarchy Degeneracy for SuperBeam