MONOLITH: a next generation experiment for atmospheric neutrinos

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MONOLITH is a massive magnetized tracking calorimeter, optimized for the detection of atmospheric muon neutrinos, proposed at the Gran Sasso laboratory in Italy. The main goal is to establish (or reject) the neutrino oscillation hypothesis through an explicit observation of the full first oscillation swing (the "L/E pattern"). Its performance, status and prospects are briefly reviewed.

1. INTRODUCTION

Although the evidence for neutrino oscillation is growing year after year, the final proof that the observed anomalies are due to oscillation is still outstanding. Alternative models (neutrino decay, potential decoherence effect, influence of large extra-dimensions) to explain the Super-Kamiokande (SK) atmospheric neutrinos results have been proposed. On the experimental side, as pointed out also in recent Neutrino 2000 conclusions "*there is as yet no direct evidence of an oscillation pattern*" [1] and the oscillation parameters in the atmospheric sector are still measured with a poor precision.

The MONOLITH experiment has been designed exactly to reach these physics goals, that is prove ν oscillations through the observation of the oscillation pattern and improve the measurements of parameters affecting the oscillations (if oscillation is the pysical case). The experimental method that is proposed is designed to overcome the limits of current atmospheric neutrino experiments through a systematic free and Monte Carlo independent measurements of the parameters. MONOLITH will also test the (now disfavored) hypothesis of mixing with sterile neutrinos searching for matter induced effects. Further items of research, not discussed here, are the use of the huge sample of events coming from the CNGS beam to complement the atmospheric neutrino sample, the measurement of the cosmic muon spectrum at TeV energies and the use of the detector as a muon charge-ID detector for a beam coming from a ν-factory.

Mass	35 kt
Magnetic Field	1.3 T
Dimensions	(30.0×14.5) m$^2\times13.1$ m
Space resolution	1 cm
Time resolution	1 ns
GSC counters	54000 m^2
External Veto	1500 m^2
p_μ resolution	$\approx 8\%$ (FC), $\approx 20\%$ (PC)
E_h resolution	$90\%/\sqrt{E\ (\mathrm{GeV})} \oplus 30\%$

Table 1
MONOLITH main parameters. FC: fully contained events, PC: partially contained. The External Veto consists of scintillator counters.

2. APPARATUS AND EXPERIMENTAL APPROACH

To explicitly detect an oscillation pattern in the L/E spectrum of atmospheric muon neutrinos, the energy E and direction θ of the incoming neutrino have to be measured in each event. The latter can be estimated from the direction θ_μ of the muon produced from the ν_μ charged-current interaction. The neutrino energy E can be obtained by means of energy measurements of the

*on behalf of the MONOLITH Collaboration muon E_μ and of the hadrons produced in the interaction (E_h). In order to make the oscillation pattern detectable, the L/E ratio has to be measured with a FWHM error smaller than half of the modulation period. The resolution on L/E improves at high energies, mostly because the muon direction gives a better estimate of the neutrino direction. Therefore the ability to measure high momentum muons (in the multi-GeV range) in partially contained events, which is rather limited in the on-going atmospheric neutrino experiments, is particularly rewarding.

A complete description of the detector structure can be found in [2]. The apparatus consists of two modules, a stack of 125 horizontal 8 cm thick iron plates each with a surface of 15.0×14.5 m^2, interleaved with 2.2 cm gaps housing the sensitive elements. The main detector parameters and resolutions are summarized in Table 1. Taking into account needs of such a large area detector and fast mass production, Glass Spark Counters [2], derived from resistive-plate chambers, have been chosen as active elements. The magnetization of iron plates is obtained through a vertical slot crossing all the stack: each field line lays entirely inside an individual plane.

To avoid systematic effects and Monte Carlo dependencies, we use the ratio between the measured down-going neutrino flux as a *near* unoscillated reference flux and the upward neutrinos flux as a *far* oscillated one. Thus we associate for each downward neutrino its *mirror* path-length, as originally proposed in [3]. This method is to a large extent insensitive to uncertainties in the knowledge of atmospheric neutrino fluxes and neutrino cross sections as well detector inefficiencies. It is based on the up/down symmetry of the neutrino fluxes, which holds at typical MONOLITH energies ($E_{th} > 1.5$ GeV). In this framework, the atmospheric neutrinos represent an ideal case for a disappearance experiment.

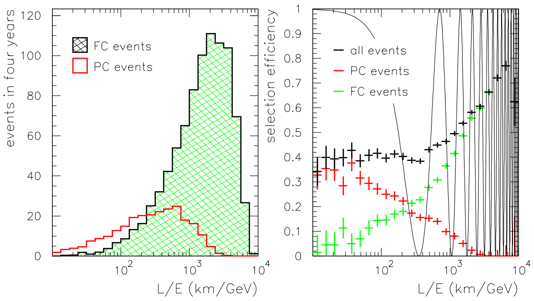

Figure 1. Selected events (*left*) and overall selection efficiency and selection efficiency for FC and PC contained events as a function of L/E (*right*). The ν_μ survival probability using present best-fit value of SK is superimposed.

3. DETECTION OF THE L/E PATTERN

The event selection has been tuned to obtain the L/E resolution required to detect the pattern. Muons are reconstructed or via energy loss in the iron or via magnetic analysis. Minimal requirements have been applied to the reconstructed muon momentum ($p_\mu > 1.5$ GeV) and, for outgoing muons, to the track-length l ($l > 4$ m). Additional cuts (for details see [2]) on combinations of the observables E_μ, E_h and θ_μ are applied to ensure the required L/E resolution and on visible vertex coordinates, muon direction, external veto information to reject the cosmic muon background. With these cuts, we expect in 4 years of data taking (see Fig. 1) to select for physical analysis ≈ 1200 events (80% fully contained and 20% partially contained) of down-going ν_μ (in case of no oscillation this number is the same for up-going).

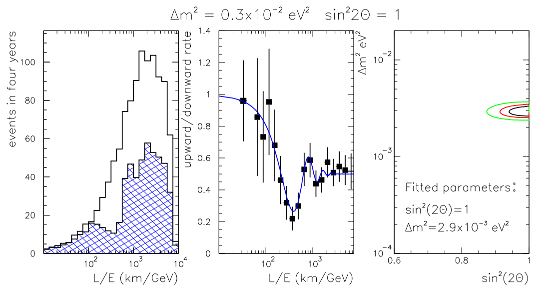

Figure 2. The L/E spectrum of upward muon neutrino events (hatched area) and the L/E "mirrored" spectrum of downward muon neutrino events (open area) (*left*); their ratio with our best-fit superimposed (*center*); results of the fit (68%, 90% and 99% C.L. shown) (*right*).

The gain in acceptance at small values of L/E due to the magnetic field analysis is noteworthy: as shown in Fig. 1 the inclusion of partially contained events increases the MONOLITH selection efficiency by more than a factor two in the region where the first semi-period of the oscillation is expected according to the SK results. The cost of the magnetization, when compared to the whole cost, is around 8%, but, in practice, has an effect similar to that of doubling the total mass.

In Fig. 2 we show, for a particular choice of oscillation parameters, how MONOLITH detects the oscillation pattern using the ratio between up-going and down-going events. Note that around $\Delta m^2 \approx 10^{-3}\mathrm{eV}^2$ MONOLITH can measure the Δm^2 value with 6% precision.

An accurate analysis [2] of the capability of MONOLITH to confirm the oscillation hypothesis with respect to other alternative models has been performed. Around current SK values, MONOLITH is able to reject the decay hypothesis at 95% C.L. or better with 99.5% efficiency. In Fig. 3 the expected allowed regions of the $\nu_\mu \to \nu_\tau$ oscillation parameters after 4 years of data taking with MONOLITH are shown for four different values of Δm^2. It is worthwhile to note that the progress in the knowledge of the Δm^2 expected by MONOLITH with respect to SK, is quantitatively similar to the one done by SK with respect to Kamiokande.

4. STATUS AND PROSPECTS

The MONOLITH Collaboration counts now 85 physicists and 17 institutions. After preliminary detector studies [4,5], a Proposal [2] has been recently submitted to the LNGSC. Cosmic ray and beam tests have been carried out during the last two years at LNGS and CERN/PS to study up/down discrimination and hadronic energy resolution. Assuming approval in early 2001, the first module is foreseen to be operational by the end of 2004 and the detector to be completed by the end of 2006.

The superior L/E resolution of the detector will allow detection of the first oscillation period. MONOLITH will thus prove (or disprove) the oscillation hypothesis. It will also highly improve the measurement of the oscillation parameters. These qualitative and quantitative improvements qualify MONOLITH as a next generation neutrino oscillation detector.

We finally note that the basic parameters of detectors that are proposed for neutrino beams from muon storage rings look very similar to those of MONOLITH (so that the expected performances should roughly apply to MONOLITH). The useful life of the detector might be extended accordingly.

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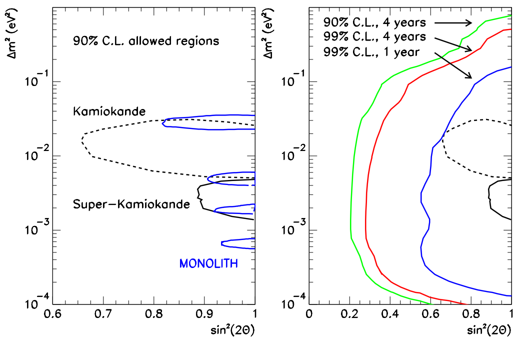

Figure 3. *Left:* expected allowed regions of $\nu_\mu - \nu_\tau$ oscillation parameters for MONOLITH after four years of exposure: the results of the simulation for $\Delta m^2 = 0.7, 2, 5, 30 \times 10^{-3}$ eV^2 and maximal mixing are shown *Right:* exclusion curve assuming no oscillation.