August 4, 2000

The MONOLITH Project

A. Geiser, Hamburg University
for the MONOLITH Collaboration
(**M**assive **O**bservatory for **N**eutrino **O**scillations or **LI**mits on **TH**eir existence)

Bologna, Bonn, CNR Torino, Columbia, LNF Frascati, Hamburg, Humboldt Berlin, INR Moscow, L'Aquila, LNF Frascati, LNGS Gran Sasso, MEPhI Moscow, Milano, Münster, Napoli, Roma, Torino, Tunis

Abstract

MONOLITH is a proposed massive (34 kt) magnetized tracking calorimeter at the Gran Sasso laboratory in Italy, optimized for the detection of atmospheric muon neutrinos. The main goal is to establish (or reject) the neutrino oscillation hypothesis through an explicit observation of the full first oscillation swing. The Δm^2 sensitivity range for this measurement comfortably covers the complete Super-Kamiokande allowed region. Other measurements include studies of matter effects and the NC/CC and $\bar{\nu}/\nu$ ratio, the study of cosmic ray muons in the multi-TeV range, and auxiliary measurements from the CERN to Gran Sasso neutrino beam. Depending on approval, data taking with part of the detector could start in 2004. The detector and its performance are described, and its potential later use as a neutrino factory detector is addressed.

Contribution to the NuFACT'00 neutrino factory workshop, Monterey, California, USA, May 22-26, 2000

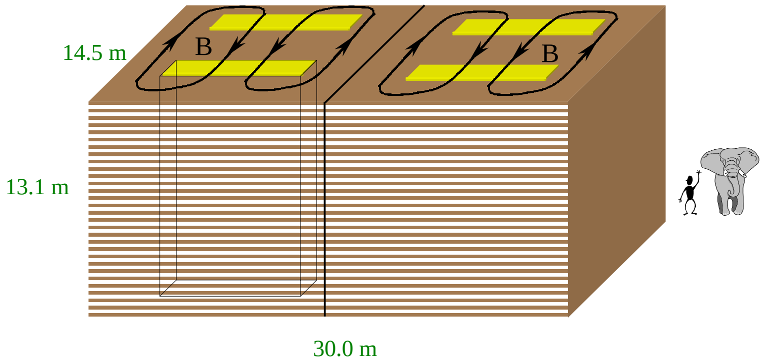

Figure 1: Schematic view of the MONOLITH Detector. The arrangement of the magnetic field is also shown.

1 Introduction

While the cumulative evidence for neutrino oscillations is very striking, the final proof that the observed anomalies are actually due to neutrino oscillations is still outstanding. In particular, the current observations of atmospheric neutrinos [2, 3] are all consistent with the hypothesis of maximal ν_μ oscillations, but do not yet exclude some alternative unconventional explanations [4, 5]. The main physics goal of the MONOLITH experiment [1] is to establish the occurrence of neutrino oscillations in atmospheric neutrinos through the explicit observation of the full first oscillation swing in ν_μ disappearance [6], and to investigate and presumably exclude alternative explanations. This also yields a significantly improved measurement of the oscillation parameters with respect to previous measurements.

The MONOLITH detector will be located at the Gran Sasso Laboratory in Italy, and the measurement of the oscillation pattern can be supplemented by measurements in the CERN to Gran Sasso neutrino beam. A proposal is currently in preparation [1]. If approved promptly, a first part of the detector could be operational towards the end of 2004. The physics results described in the following sections correspond to an exposure of 4 years with the full detector.

2 The MONOLITH detector

The goals quoted above can be achieved with a high-mass tracking calorimeter with a coarse structure and magnetic field. A large modular structure has been chosen for the detector (figure 1). One module consists in a stack of 120 horizontal 8 cm thick iron planes with a surface area of 15×15 m^2, interleaved with 2 cm planes of sensitive elements. The height of the detector is thus 12 meters. Thinner plates, 2 and 4 cm thick, were also considered in the past, however the 8 cm plate thickness resulted to be best compromise between physics result and detector costs. The magnetic field configuration is also shown in figure 1; iron plates are magnetized at a magnetic induction of ≈ 1.3 T. The detector consists of two modules. Optionally, the downstream module could be complemented by an end cap of vertical planes to improve the performance for non-contained muons from the CNGS beam. The total mass of the detector exceeds 34 kt. Glass Spark Counters (resistive plate chambers with glass electrodes) have been chosen as active detector elements. They provide two coordinates with a pitch of 3 cm, and a time resolution of 2 ns. Finally, an external veto made of scintillation counters reduces the background from cosmic ray muons.

3 Observation of neutrino oscillation pattern

In the two flavour approximation, the survival probability for neutrino oscillations in vacuum can be expressed by the well known formula $P(L/E) = 1 - \sin^2(2\Theta)\ \sin^2(1.27\ \Delta m^2\ L/E)$ where L is the distance travelled in km, E is the neutrino energy in GeV, Θ is the neutrino mixing angle, and Δm^2 is the difference of the mass square eigenvalues expressed in eV^2.

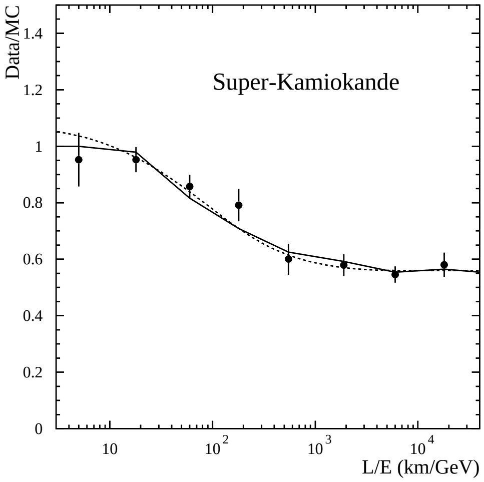

Figure 2: *Left*: L/E distribution from Super-Kamiokande [3] compared to the best fit oscillation hypothesis (continous line), and to a parametrization corresponding to the neutrino decay model of ref. [5] (dashed line). The oscillations are smoothed out by detector resolution. *Right*: L/E distribution to be expected from MONOLITH for $\Delta m^2 = 3 \times 10^{-3}$ eV^2 compared to the best fit oscillation hypothesis (oscillating line) and to the corresponding best fit of the neutrino decay model of ref. [5] (smooth threshold effect).

However, none of the experiments which have yielded indications for neutrino oscillations have so far succeeded to measure an actual sinusoidal oscillation pattern. Figure 2 shows the L/E distribution of Super-Kamiokande [3] compared to the expectation for neutrino oscillations and to a functional form suggested by a recent neutrino decay model [5]. Once the detector resolution is taken into account, the two hypotheses are essentially indistinguishable [5]. Even though the current evidence is very suggestive of neutrino oscillations, a more precise measurement of the oscillation pattern is the only way to actually prove the oscillation hypothesis for atmospheric neutrinos. The crucial issue here is to prove that muon neutrinos do not only disappear, but actually reappear at some larger L/E.

MONOLITH is explicitly designed to fill this gap. Having a similar mass (26 kt fiducial) as Super-Kamiokande, significantly larger acceptance at high neutrino energies and better L/E resolution, the experiment is optimized to observe the full first oscillation swing, including ν_μ "reappearance". Therefore, the oscillation hypothesis can be clearly distinguished from other hypothesis which yield a pure disapperance threshold behaviour (Figure 2).

Furthermore, the sensitivity is almost independent of the oscillation parameters (Fig. 3). This is in contrast to MINOS, which can do a similar measurement at the highest allowed Δm^2 if the low energy beam is used [8], but has a hard time to observe a reappearance signal in the lower Δm^2 range. The good L/E resolution can be used to significantly improve the measurement of the oscillation parameters over the full allowed range (Fig. 4). The systematic error can be reduced by comparing the upward neutrino rate with the corresponding downward rate "mirrored" in L/E (Fig. 3). Finally, if δm^2 is high, measurements of ν_μ disappearance in the CERN to Gran Sasso beam could complement the atmospheric neutrino measurements (Fig. 4) if the systematic error can be suitably controlled.

4 Other physics topics

Provided that the neutrino oscillation hypothesis is confirmed, another goal of the experiment is to further investigate the nature of these oscillations. Depending on the oscillation parameters, oscillations into active (ν_τ) or sterile (ν_s) neutrinos can be distinguished through their different effects on the up/down ratio of neutral current (NC)-like events, and/or through the presence or absence of matter effects yielding a distortion of the observed oscillation pattern as a function of energy and/or muon charge.

Even in the absence of sterile neutrinos, matter effects are present in the case of a small contribution from $\nu_\mu - \nu_e$ oscillations at the "atmospheric" Δm^2. The corresponding MSW resonance might be observable [11] as a localized ν_μ rate suppression either in ν_μ or in $\bar{\nu}_\mu$.

Due to its ability of in situ measurement of the energy of every muon in the multi-TeV range, MONOLITH will also be a unique facility for pioneer investigations of cosmic ray muons in the unexplored 100 TeV energy region. The results of these studies will give information which is relevant for the solution of the problem of the knee in the cosmic ray energy spectrum.

Other potential physics topics include studies of the primary atmospheric neutrino flux, the search for astrophysical point sources, and a search for a neutrino "line" from WIMP annihilation in the center of the earth.

5 MONOLITH at a neutrino factory

Neutrino beams from future muon storage rings [13] (neutrino factories) will be essentially pure beams of either $\nu_\mu + \bar{\nu}_e$ or $\bar{\nu}_\mu + \nu_e$. The occurence of $\nu_e - \nu_\mu$ or $\nu_e - \nu_\tau$ oscillations would therefore manifest itself via the appearance of wrong sign muons. A massive magnetized iron detector like MONOLITH, with good muon charge separation and momentum measurement, could therefore be well suited [14] for the observation of such oscillations. As pointed out in [15, 16] this kind of beam will in particular offer the possibility to measure the θ_{13} mixing angle, currently only constrained by the Super-Kamiokande and CHOOZ results, and the sign of Δm^2 through matter effects. Depending on which of the solar neutrino solutions is correct it might also open the way for the study of CP violation in the neutrino system. Interestingly, the optimization of detectors for the neutrino factory, focusing on wrong sign muon appearance measurements, has yielded a detector [14] whose basic parameters are very similar to those of MONOLITH. This is true in particular when the source is far enough away to impinge at a sizeable angle from below (horizontal geometry of MONOLITH). For instance, a beam from Fermilab (L=7300 km) would impinge at an angle of 35^o, and be almost aligned with the Gran Sasso hall axis, and therefore perpendicular to the magnetic field axis. The results obtained in the physics studies of ref. [12] concerning the measurements of θ_{13}, sign of Δm^2, and CP violation therefore qualitatively apply to MONOLITH used as a neutrino factory detector. Of course the potential timescale of a neutrino factory is quite different from the one of the current atmospheric neutrino program. Nevertheless, it might be interesting to consider that such a facility might become reality within the lifetime of the MONOLITH project, and that its useful life might be extended accordingly.

6 Conclusions

MONOLITH is a 34 kt magnetized iron tracking calorimeter proposed for atmospheric neutrino measurements at the Gran Sasso Laboratory in Italy. Its main goal is the proof of the neutrino oscillation hypothesis through the explicit observation of a sinusoidal oscillation pattern (ν_μ reappearance). Other goals include auxiliary measurements in the CERN to Gran Sasso beam, and the investigation of potential $\nu_\mu - \nu_e$ and $\nu_\mu - \nu_s$ contributions. In the long term, the detector could also be used in a potential neutrino factory beam.

References

[1] MONOLITH Progress Report, LNGS-LOI 20/99, CERN/SPSC 99-24, August 1999; MONOLITH Proposal, LNGS P26/2000, CERN/SPSC 2000-031, August 2000; M. Ambrosio et al., The MONOLITH Prototype, Proceedings of the Bari RPC workshop, October 1999, ftp://netview.ba.infn.it/rpc/proceedings/gustavino.ps, submitted to Nucl. Instr. and Meth.

[2] Super-Kamiokande Collaboration, Y. Fukuda et al., Phys. Rev. Lett. **81** (1998) 1562; Super-Kamiokande Collaboration, Y. Fukuda et al., Phys. Lett. **B 436** (1998) 33; Super-Kamiokande Collaboration, Y. Fukuda et al., Phys. Lett. **B 433** (1998) 9.

[3] H. Sobel (Super-Kamiokande Collaboration), Proceedings of XIX International Conference on Neutrino Physics and Astrophysics (Neutrino 2000), Sudbury, Canada, June 16-21, 2000.

[4] R. Barbieri et al., P. Creminelli, and A. Strumia, IFUP-TH-2000-00, hep-ph/0002199, February 2000; E. Lisi, A. Marrone, and D. Montanino, hep-ph/0002053, February 2000.

[5] V. Barger et al., Phys. Lett. **B 462** (1999) 109.

[6] G. Mannocchi et al., CERN/OPEN-98-004.

[7] A. Curioni et al., hep-ph/9805249;
M. Aglietta et al., LNGS-LOI 15/98, CERN/SPSC 98-28, SPSC/M615, Oct. 1998.

[8] S. Wojcicki, Proceedings of Neutrino '98, Takayama, Japan, June 4-9, 1998.

[9] Kamiokande Collaboration, Y. Fukuda et al., Phys. Lett. **B 335** (1994) 237.

[10] K. Elsener (editor), CERN 98-02 and INFN/AE-98/05, May 1998;
R. Bailey et al., CERN-SL-99-034-DI, June 1999.

[11] A. Geiser, Future Atmospheric Neutrino Detectors, Proceedings of XIX International Conference on Neutrino Physics and Astrophysics (Neutrino 2000), Sudbury, Canada, June 16-21, 2000.

[12] C. Albright et al., FERMILAB-FN-692, May 2000.
V. Barger et al., hep-ph/0003184, March 2000, hep-ph/0004208, April 2000.
A. Cervera et al., hep-ph/0002108, February 2000.
A. Bueno, M. Campanelli, and A. Rubbia, hep-ph/0005007, May 2000.
M. Freund, P. Huber, and M. Lindner, TUM-HEP-373/00, hep-ph/0004085, April 2000.

[13] D. Cline and D. Neuffer, AIP Conf. Proc. **68** (1980) 846; reproduced in AIP Conf. Proc. **352** (1996) 10;
S. Geer, Phys. Rev. **D 57** (1998) 6989; Erratum-ibid. D 59 (1999) 039903.

[14] J.J. Gomez-Cadenas and A. Cervera-Villanueva, talks given at ν-Fact '99, Lyon, 5-9 July 1999.

[15] A. De Rujula, M.B. Gavela and P. Hernandez, Nucl. Phys. **B 547** (1999) 21.

[16] V. Barger, S. Geer and K. Whisnant, hep-ph/9906487.

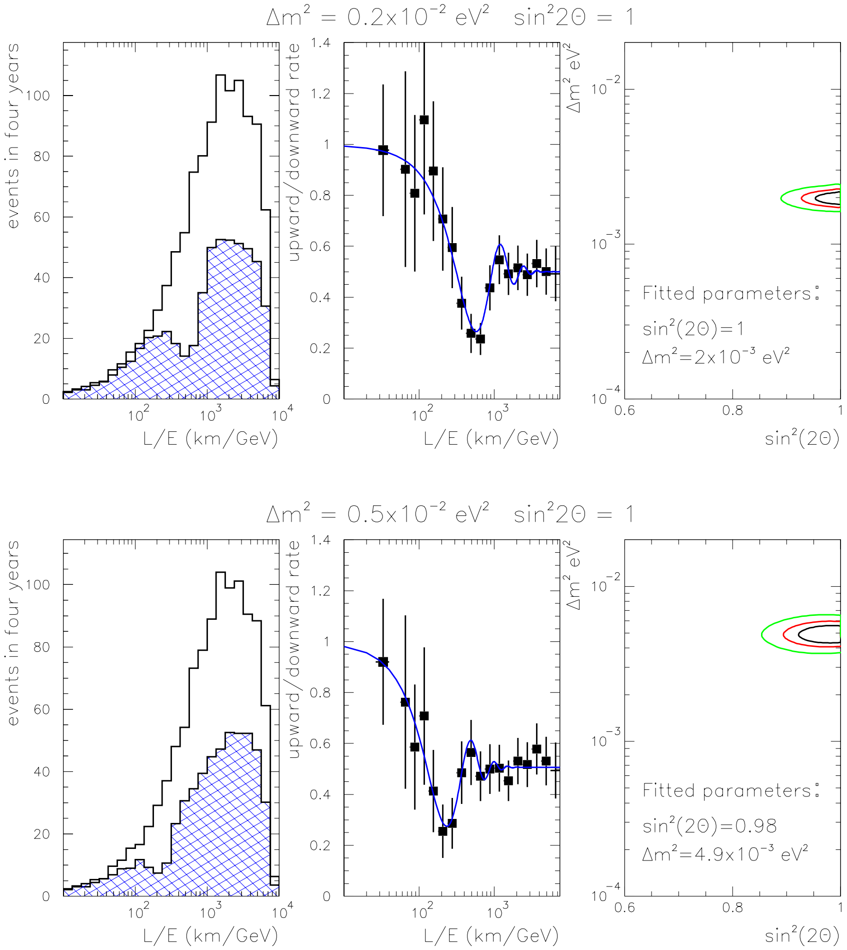

Figure 3: Results of the L/E analysis on a simulated sample in the presence of $\nu_\mu \to \nu_x$ oscillations, with parameters $\Delta m^2 = 2 \times 10^{-3}$ eV^2 and $\sin^2(2\Theta) = 1.0$ (top) and $\Delta m^2 = 5 \times 10^{-3}$ eV^2 and $\sin^2(2\Theta) = 1.0$. The figures show from left to right: the L/E spectrum of upward muon neutrino events (hatched area) and the L/E "mirrored" spectrum of downward muon neutrino events (open area); their ratio with the best-fit superimposed and the result of the fit with the corresponding allowed regions for oscillation parameters at 68%, 90% and 99% C.L.; artist's view of the mirror neutrino path length: downward going neutrinos (zenith angle $\theta < \pi/2$) are assigned the distance they would have travelled if $\theta = \pi - \theta$.

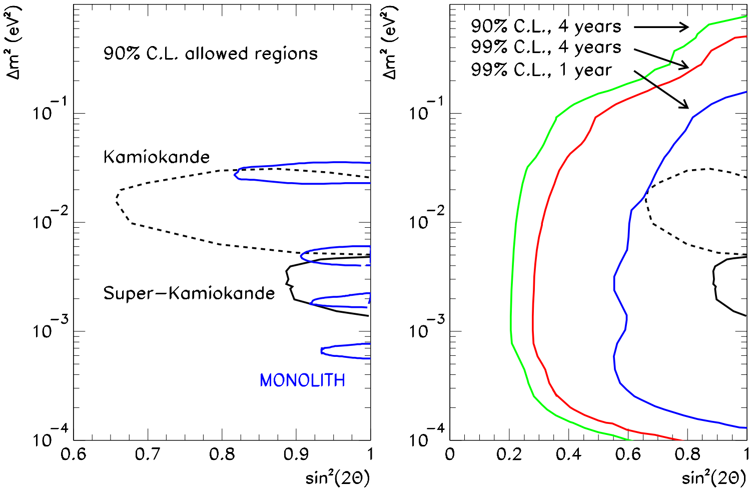

Figure 4: *Left*: Expected allowed regions of $\nu_\mu - \nu_\tau$ oscillation parameters for MONOLITH after four years of atmospheric neutrino exposure. The results of the simulation for $\Delta m^2 = 0.7, 2, 5, 30 \times 10^{-3}$ eV^2 and maximal mixing are shown. *Middle*: MONOLITH exclusion curves at 90% and 99% C.L. after one or 4 years of data taking assuming no oscillations. The full (dashed) black line shows the results of the Super-Kamiokande [3] (Kamiokande [9]) experiment. *Right*: Example for the expected L/E distribution (ν_μ survival probability) in MONOLITH with 2 years of data taking of atmospheric neutrinos and 1 year with the CERN-Gran Sasso neutrino beam for $\Delta m^2 = 5 \times 10^{-3}$ eV^2 (points). Beam neutrinos dominate the L/E region below 10^2 km/GeV. For L/E $> 10^2$ km/GeV only atmospheric neutrinos contribute. Only statistical errors are shown.