MEASUREMENT OF NEUTRINO OSCILLATIONS IN MACRO EXPERIMENT

The MACRO Collaboration

Paper presented by J. Musser

ABSTRACT: We consider the possibility of investigating neutrino oscillations in the proposed MACRO experiment. We calculate its sensitivity taking into account the theoretical uncertainties coming from flux calculations, geomagnetic effects and propagation through matter, as well as the experimental limitations.

1. The use of atmospheric cosmic ray neutrinos in underground experiments for investigating neutrino oscillations could in principle allow to explore a region of parameter space beyond that accessible in reactor or accelerator experiments.

Unfortunately, many limitations prevent to reach the nominal high sensitivity deriving from the long oscillation path (i.e. the Earth diameter $D \sim 10^4 Km.$)

First, the low statistics ineherent in this kind of experiments makes small mixing angles not accessible. Furthermore, an average over the neutrino energy spectrum and neutrino directions, i.e. over oscillation lengths, is unavoidable: in particular, the effect of averaging over directions is much larger than the averaging over source dimensions.

The last limitation arises because of the matter. The different indices of refraction in matter for ν_μ and ν_e, generated by the charged current contributions to elastic $\nu_e - e$ scattering, lead to a decoherence of the ν_μ and ν_e components after a characteristic length of $\sim 9000\ Km$ in the earth.

2. Considering only two neutrino flavours, namely ν_μ and ν_e, an underground experiment can record the disappearence of ν_μ or the variation of the ratio ν_μ/ν_e. The disappearence method needs the knowledge of the expected flux and hence is affected by uncertainties of the order of $10-20\%$, as confirmed also from results of large nucleon decay experiments.

The influence of the Earth magnetic field, as well as that of solar wind, adds further uncertainties to the calculation of the low energy part of the spectrum.

The angular distribution of the muons produced by ν in the surrounding rock and the ratio ν_μ/ν_e are however less sensitive to systematic uncertainties. In fact, the energy of parent neutrino for muons traversing an underground apparatus is high enough ($E_\nu \geq 10\,GeV$) to allow neglecting geomagnetic effects, and the comparison between different path lengths makes unnecessary an absolute monitor on the flux, provided the angular distribution is known with sufficient accuracy.

The ratio ν_μ/ν_e is obviously less dependent on theoretical uncertainties.

Two final remarks on experimental possibilities are in order.

A direct comparison of the downward and upward neutrino fluxes using muons produced in the rock is difficult, since, at the deepness of the existing and proposed large underground detectors the cosmic muon background is too high even near the horizontal direction.

In addition, the energy of neutrinos that produce muonic events contained in a detector of reasonable size is very low, so the angle between the produced muon and the parent neutrino is large, making less efficient the distinction between up and down directed neutrinos.

3. We evaluated the sensitivity of MACRO [1] using a complete Montecarlo computation, including generation, transport and tracking of leptons. The ν_μ flux is taken from ref. [2], assuming equal contribution for ν_μ and $\overline{\nu}_\mu$ and $\Phi(\nu_e) = 0.2 \times \Phi(\nu_\mu)$. The interaction cross section includes quasielastic, Δ and inelastic channels. The survival probability for ν_μ is :

$$P(\nu_\mu \rightarrow \nu_\mu) = 1 - (1-\rho) sin^2(2\theta) sin^2(\pi L/l_v) \qquad (1)$$

in vacuum, and

$$P(\nu_\mu \rightarrow \nu_\mu) = 1 - (1-\rho) sin^2(2\theta)(l_m/l_v)^2 sin^2(\pi L/l_m) \qquad (2)$$

in matter.

In the above formulas, θ is the vacuum mixing angle, ρ the ratio ν_e/ν_μ, $l_v = 2.5E/(m_1^2 - m_2^2)$ (oscillation length in vacuum), $l_0 = 2\pi/GN_e = 9 \times 10^3\ Km$ and

$$l_m = l_v(1 + (l_v/l_0)^2 \mp 2l_v/l_0 cos2\theta)^{-1/2} \quad (3)$$

is the oscillation length in matter [3]. The signs refer to neutrino and antineutrino respectively.

A μ produced inside the detector must be fully contained to cut the background of the entering stopping muons, and its verse of motion cannot be identified. Thus we consider only the total number of contained events.

The maximum flux reduction for oscillations in such case is 20% requiring a knowledge of the expected flux better than the present.

A μ produced in the rock must traverse the detector with a minimum track length to allow the determination of the verse of motion by time-of- flight measurement. The median energy of parent neutrinos is, in this case, $\sim 60GeV$ and the mean $\nu - \mu$ angle is $\sim 3.5^o$.

The modulation factor, defined as the ratio between the measured and the expected angular distribution of the detected muons, is shown, for various Δm^2 and at maximum mixing, in Fig.1 and 2.

Matter effects reduce the sensitivity in Δm^2 by about an order of magnitude.

The error bars indicated in Fig.2 correspond to about 3 years of exposure and show that a 3 σ lower limit of $\Delta m^2 = 5 \times 10^{-3}$ is achievable. For $\Delta m^2 > 5 \times 10^{-2}$ the modulation factor becomes again nearly flat, giving the upper limit for this experiment.

REFERENCES

[1] See paper HE 6.1 - 4 in these proceedings.

[2] L.V. Volkova, Sov.J.Nucl.Phys. **31**, 784 (1980)

[3] L. Wolfenstein, Phys. Rev. **D17**, 2369, (1978)

Figure Captions

1) Modulation factor at MACRO, only vacuum oscillations.

2) Modulation factor with matter effects taken into account. Error bars refer to 3 years of data taking.

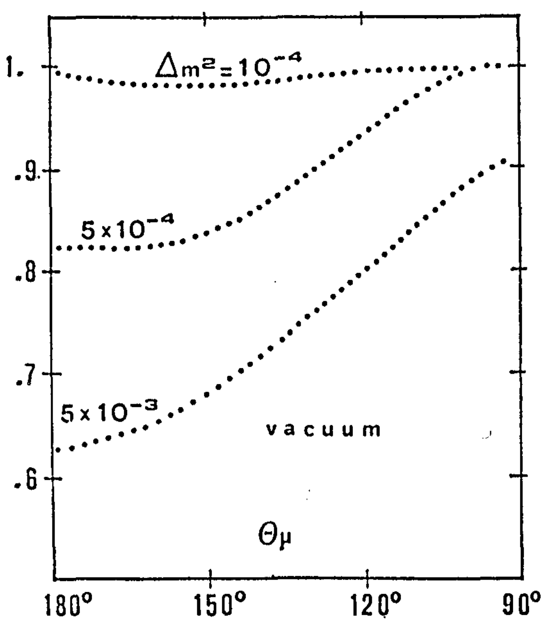

fig. 1

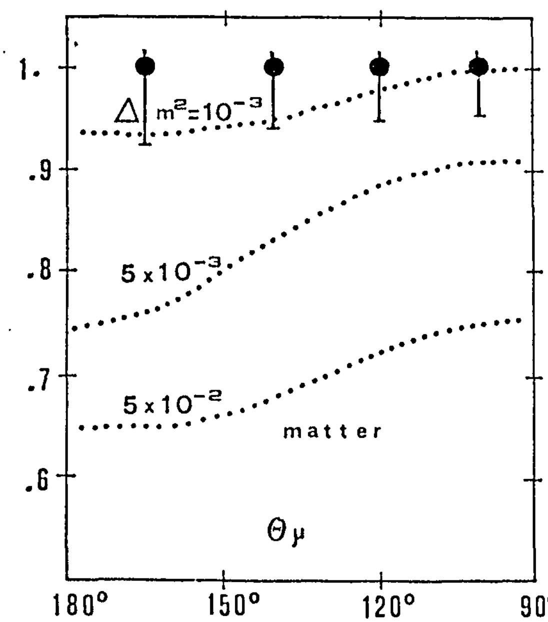

fig. 2