HE 5.3-12

HIGH ENERGY NEUTRINO ASTRONOMY WITH MACRO

The MACRO Collaboration

Paper presented by G. Auriemma*

ABSTRACT

A large area underground detector with accurate muon tracking and directionality can be used for the search of extraterrestrial sources of high energy neutrinos. The sensitivity of the MACRO detector to possible sources of neutrinos was evaluated with a Monte-Carlo simulation of the neutrino interaction in the rock and of the detection in the real apparatus.

Two categories of possible neutrino sources are discussed in comparison with the detector sensitivity. Promising candidate objects for this search appear to be the two binary X-ray sources in the southern sky Vela X1 and LMC X4, which are known to emit γ-rays up to the 10^4 *TeV* region .

A large flat underground muon detector can be used as a neutrino telescope because the horizontal and upward going muons are generated only by neutrino interactions in the rock $^{1,2)}$. The MACRO apparatus $^{3)}$ in the Gran Sasso Laboratory is particularly well suited to this application due to its intrinsically very high tracking accuracy ($\Delta\theta \leq 1°$), its large area ($\sim 1000\ m^2$) and its time-of-flight resolution ($\sim 1\ nsec$). The depth of the Laboratory ($\sim 4000\ m.w.e.$) assures a good filtering of the downward muons generated by the cosmic ray interactions above the Gran Sasso mountain. The omnidirectional measured muon flux in the Laboratory $^{4)}$ is $\sim 1\ \mu\ m^{-2}\ hour^{-1}$. Therefore the time of flight measurement given by the scintillator counters can distinguish the upward-going component of the muon flux with negligible contamination. Under this circumstances the background to the detection of extraterrestrial neutrino sources is given by the conversion of atmospheric neutrinos. The estimated rate of this background $^{5)}$ is $\sim 1\ \mu\ day^{-1}$ over the entire MACRO apparatus.

An analytical computation of the response of underground detectors to extraterrestrial neutrinos was reported by Gaisser & Stanev $^{6)}$. This computation has shown that the detection efficiency for neutrinos is a fast rising function of the neutrino energy. Therefore the detectability of extraterrestrial neutrinos is related to the hardness of the spectrum of the source.

We have computed the response of MACRO to extraterrestrial neutrino sources with a Monte-Carlo program in order to derive that parameters , such as detection efficiency and the angular spread of the muons respect to the neutrinos direction, which cannot be easily deduced from analitycal computations.

The rate of muons in the MACRO apparatus can be factorized as follows :

$$N_\mu = A(\alpha, \delta) \times \epsilon \times \int_{E_T}^{\infty} F_\nu \times P_\nu \quad dE_\nu \tag{1}$$

where $A(\alpha, \delta)$ is the time averaged exposed area for the point in the sky with equatorial coordinates α, δ, ϵ the detection efficiency in the apparatus, E_T the minimum energy of the muon which can be detected in the apparatus, P_ν the probability that a neutrino produces an upward muon at the

---

* I.N.F.N. Sezione di Roma and Dipartimento di Fisica ,Università di Roma "La Sapienza", Rome, Italy

detector (see Gaisser & Stanev [6]) and F_ν is the spectral distribution of the neutrinos. Assuming , as costumary for astronomical high energy sources, a power-law spectral distribution for the neutrinos:

$$F_\nu = K_\nu \times E_\nu^{-\gamma} \tag{2}$$

we have estimated both the efficiency and the average neutrino conversion probability $\overline{P}_\nu$, defined :

$$\overline{P}_\nu = \frac{\int_{E_T}^{\infty} F_\nu \times P_\nu \, dE_\nu}{\int_{E_T}^{\infty} F_\nu \times dE_\nu} \tag{3}$$

and the average energy $\overline{E}_\nu$ of the neutrinos which have originated a muon detected in the apparatus:

$$\overline{E}_\nu = \frac{\int_{E_T}^{\infty} E_\nu \times F_\nu \times P_\nu \, dE_\nu}{\int_{E_T}^{\infty} F_\nu \times P_\nu \, dE_\nu} \tag{4}$$

In addition from the Montecarlo we have obtained also the angular point-spread function of the muons. Detailed description and results of the Montecarlo will be reported elsewhere [7]. We summarize in Table I the results obtained for spectral index from -2 to -3.8. We have included in the Monte-Carlo code the angular spread originated by the neutrino-nucleus interaction as well as the effect of transport in the rock. The differential cross-section of neutrino-nucleus scattering used takes into account both the effect of the mass of the W boson and the nucleon structure functions according to Duke & Owens parametrization [8]. In the transport section of the program we have included only the multiple Coulomb scattering of the muon . The distribution of the angle θ between the muon in the apparatus and the neutrino original direction shows a central dominating gaussian core and a tail corresponding to relatively rare large angle scatterings.We have therefore quoted two angular parameters in Table I. The one reported in column 6 is the r.m.s. angle wich is dominated by the Coulomb scattering and the one reported in column 5 is the angle wich includes 90 % of the total muons. Comparison between the two angular parameters shows that steeper spectra can be easily identified by the larger angular spread.

TABLE I. Summary of Montecarlo results

γ	$\overline{E}_\nu$ (TeV)	ϵ	$\overline{P}_\nu$ $E_T = 1GeV$	$\theta_{90\%}$	$\theta_{R.M.S}$	M.D.F. $(ergs\ cm^{-2}\ s^{-1})$
2.0	23.3	.75	$6. \times 10^{-9}$	$\leq 1^\circ$	$.47^\circ$	$2. \times 10^{-8}$
2.2	7.8	.68	$1. \times 10^{-9}$	1°	$.61^\circ$	$1. \times 10^{-7}$
2.6	.86	.56	$7. \times 10^{-11}$	$2^\circ.25$	$1^\circ.2$	$1. \times 10^{-6}$
3.0	.095	.39	1.2×10^{-11}	$6^\circ.0$	$2^\circ.0$	$1. \times 10^{-5}$
3.8	.01	.14	3.2×10^{-12}	$11^\circ.5$	$4^\circ.6$	1.7×10^{-4}

The detection of extraterrestrial neutrino sources with MACRO is limited by the sensitivity of the experiment itself and not by the atmospheric background . Infact the resolution of the telescope for hard neutrino sources ($i.e.$sources with spectral index $\gamma \sim -2$) is better then 1 degree. Therefore the expected atmospheric background is ~ .05 μ *year*$^{-1}$. The detection of neutrino emission from an identified celestial object can be unambiguously proved by the clustering of a small number of muons in a cone of aperture ~ 1° around its direction. Therefore the minimum detectable flux (MDF) from a source, reported in Table I corresponds to the neutrino flux which gives 10 muons in a cone of 1° aperture in five years of exposure of the apparatus. The intrinsic neutrino luminosity of a source detectable with MACRO is :

$$L_\nu \geq (M.D.F.) \times 4\pi D^2 \tag{5}$$

where D is the distance of the source.

The localization of the Gran Sasso Laboratory at $38°N$ makes the MACRO experiment suitable for the survey of the southern celestial emisphere. Infact the time averaged exposure area in formula (1) is a function of the source celestial declination. We have reported in Fig. 1 a plot of the equal exposure contours in a galactic coordinates plot. The sensitivity given in table 1 corresponds to the maximum exposure in the direction of the celestial southern pole. For a given source the MDF reported in Table I must be scaled to the actual exposed area

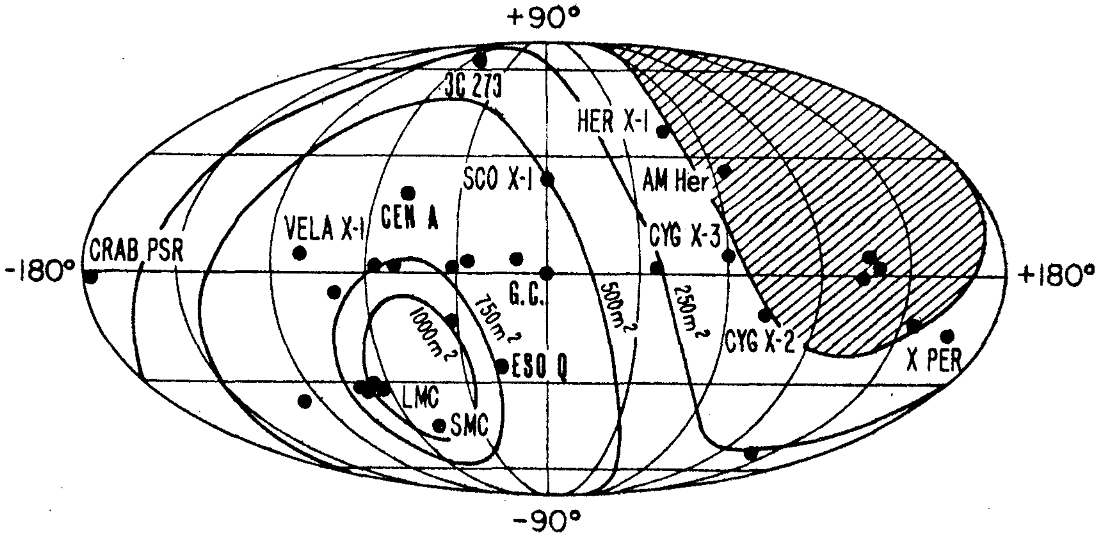

Fig. 1 MACRO field-of-view in Galactic coordinates.Contours represent equal time-averaged exposed area. The shaded region in the northern emisphere is inaccessible to MACRO survey.

It was shown that the MACRO survey will be sensitive mainly to high energy neutrinos. Several classes of objects were proposed as strong neutrino sources [9]. We will discuss briefly the detectability with MACRO of two interesting classes of objects.

a) U.H.E. binaries

Recently U.H.E. γ-rays ($E_\gamma \geq 10^4$ *TeV*) emission was observed from the well known X-ray binaries Cyg X3,Vela X1 and LMC X4 [10,11,12,13]. Very reasonable models of this objects suggest that hard neutrino emission is expected [14] in the *TeV* region, if the U.H.E. γ emission is originated from hadronic interaction of accelerated protons (or nuclei) on the non-degenerate companion star. The spectral index of the neutrinos is predicted to be $\gamma \leq 2$ from the observed γ-ray spectrum. In

Fig. 1 we observe that two of this sources (*viz.* Vela X1 and LMC X4) are in a very good position for the MACRO apparatus.In particular the source in the Large Magellanic cloud is predicted to have a neutrino luminosity well above the detectability of MACRO.

b)Active Galactic Nuclei

Radio and X-ray observations of the compact nuclei of several peculiar galaxies (*viz.* Seyfert's type I galaxies, BL-Lac objects and Quasars) indicate that extreme non-thermal emission originate the huge luminosity of these objects. Neutrino emission could be associated to this non-thermal emission 15,16). In particular the neutrino radiation could be extremely relevant in the case of continous re-acceleration of particles in the source. Recently high quality observations of the X-ray spectra have shown that the non-thermal emission of a large sample of objects can be fitted with an "universal" power law distribution17). This could be the evidence that in all these sources the particle spectrum has a spectral index $\gamma \sim 2.3$. In principle we can expect that the neutrino spectral index would be the same. To be detectable with MACRO a source with spectral index -2.3 should have an intrinsic neutrino luminosity of $L_\nu \geq 10^{45} \times D^2_{Gpc}\ ergs\ cm^{-2}\ s^{-1}$. This neutrino luminosity is anyway too much high also for these type of objects, according to the current estimates.

We are gratefull to T. Gaisser, T. Stanev and V. Stenger for very helpfull discussions.

References

1. K. Lande *Ann. Rev. Nucl. Part. Scie.* **29**, 395–410,(1979)
2. J.C. van der Velde in J. Stone (edt) *"Monopole 83"*, Ann Arbor, Michigan, October 1983
3. B. Barish *Talk given to this Conference.*
4. A. Zichichi in G.Ciapetti,F.Massa & S.Stipcich (edts.) *"Physics and Astrophysics with Underground Track Detector"*, Rome, October 29-31,1981
5. A.F. Grillo & V.Valente *Talk given to this Conference.*
6. T. Gaisser & T. Stanev *Phys. Rev.* **D31**,June 1985 to be published
7. G.Auriemma,A.F. Grillo,J.Musser & G.Tarlé *in preparation.*
8. D.W. Duke & J.F. Owens *Phys. Rev.* **D30**,49,(1984)
9. V.J. Stenger *Astrophys. J.* **284**, 810,(1984)
10. M. Samorsky & W. Stamm *Astrophys. J. Lett.* **268**, L17–L22,(1983)
11. J. Lloyd-Evans *et al.Nature* **305**, 784–787, (1983)
12. R.J. Protheroe, R.W. Clay & P.R. Gerhardy *Astrophys. J. Lett.* **280**,L47–L50,(1984)
13. R.J. Protheroe & R.W. Clay *Nature* **315**, 205–207,(1985)
14. G. Auriemma, H. Bilokon & A.F. Grillo in *"Underground Physics 85"*, April 25-28, St. Vincent,Italy *in press.*
15. D. Eichler *Astrophys. J.* **232**,106–112,(1979)
16. V.S. Berezinsky & V.L. Ginzburg *Mon. Not. R. astr. Soc.* **294**,3–14,(1981)
17. R. Petre, R.F. Mushotzky, J.H. Krolik & S.S. Holt *Astrophys. J.* **280**,499–515,(1984)