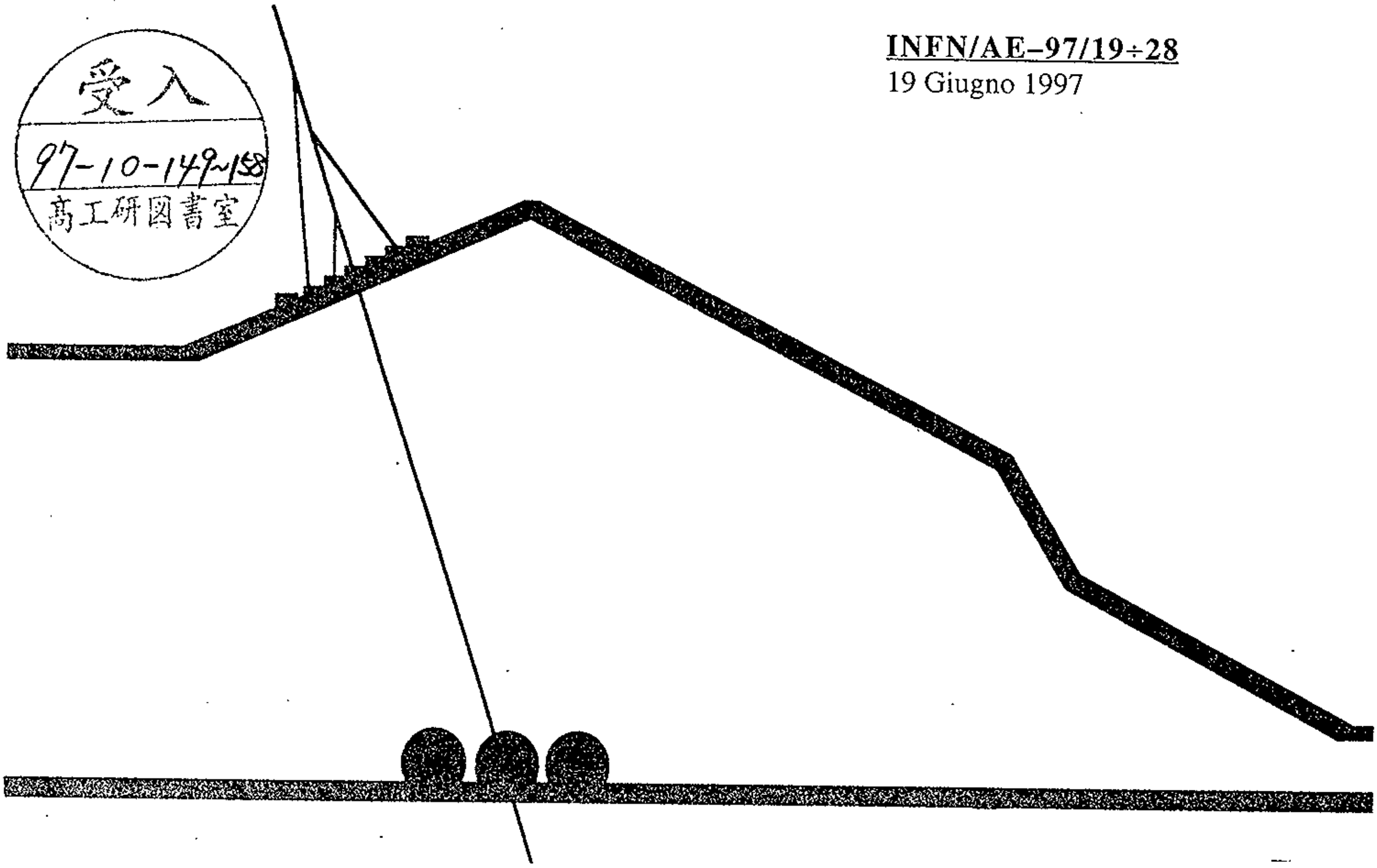
INFN/AE–97/19÷28
19 Giugno 1997



Contributions of the MACRO Collaboration to the 1997 Summer Conferences

INFN – Laboratori Nazionali del Gran Sasso

Published by SIS–Pubblicazioni
dei Laboratori Nazionali di Frascati

The MACRO Collaboration

M. Ambrosio[12], R. Antolini[7], G. Auriemma[14,a], R. Baker[11], A. Baldini[13], G. C. Barbarino[12], B. C. Barish[4], G. Battistoni[6,b], R. Bellotti[1], C. Bemporad[13], P. Bernardini[10], H. Bilokon[6], V. Bisi[16], C. Bloise[6], C. Bower[8], S. Bussino[14], F. Cafagna[1], M. Calicchio[1], D. Campana[12], M. Carboni[6], M. Castellano[1], S. Cecchini[2,c], F. Cei[13,d], P. Celio[14], V. Chiarella[6], A. Corona[14], S. Coutu[11], G. De Cataldo[1], H. Dekhissi[2,e], C. De Marzo[1], I. De Mitri[9], M. De Vincenzi[14,f], A. Di Credico[7], O. Erriquez[1], C. Favuzzi[1], C. Forti[6], P. Fusco[1], G. Giacomelli[2], G. Giannini[13,g], N. Giglietto[1], M. Goretti[4,14], M. Grassi[13], L. Gray[7], A. Grillo[7], F. Guarino[12], P. Guarnaccia[1], C. Gustavino[7], A. Habig[3], K. Hanson[11], A. Hawthorne[8], R. Heinz[8], E. Iarocci[6,h], E. Katsavounidis[4], E. Kearns[3], S. Kyriazopoulou[4], E. Lamanna[14], C. Lane[5], D. S. Levin[11], P. Lipari[14], N. P. Longley[4,m], M. J. Longo[11], F. Maaroufi[2,e], G. Mancarella[10], G. Mandrioli[2], S. Manzoor[2,n], A. Margiotta Neri[2], A. Marini[6], D. Martello[10], A. Marzari-Chiesa[16], M. N. Mazziotta[1], C. Mazzotta[10], D. G. Michael[4], S. Mikheyev[7,i], L. Miller[8], P. Monacelli[9], T. Montaruli[1], M. Monteno[16], S. Mufson[8], J. Musser[8], D. Nicoló[13,d], R. Nolty[4], C. Okada[3], C. Orth[3], G. Osteria[12], O. Palamara[10], S. Parlati[7], V. Patera[6,h], L. Patrizii[2], R. Pazzi[13], C. W. Peck[4], S. Petrera[9,10], P. Pistilli[14,f], V. Popa[2,l], V. Pugliese[14], A. Rainó[1], J. Reynoldson[7], F. Ronga[6], U. Rubizzo[12], A. Sanzgiri[15], C. Satriano[14,a], L. Satta[6,h], E. Scapparone[7], K. Scholberg[3,4], A. Sciubba[6,h], P. Serra-Lugaresi[2], M. Severi[14], M. Sioli[2], M. Sitta[16], P. Spinelli[1], M. Spinetti[6], M. Spurio[2], R. Steinberg[5], J. L. Stone[3], L. R. Sulak[3], A. Surdo[10], G. Tarlé[11], V. Togo[2], C. W. Walter[4] and R. Webb[15]

1. Dipartimento di Fisica dell'Università di Bari and INFN, 70126 Bari, Italy
2. Dipartimento di Fisica dell'Università di Bologna and INFN, 40126 Bologna, Italy
3. Physics Department, Boston University, Boston, MA 02215, USA
4. California Institute of Technology, Pasadena, CA 91125, USA
5. Department of Physics, Drexel University, Philadelphia, PA 19104, USA
6. Laboratori Nazionali di Frascati dell'INFN, 00044 Frascati (Roma), Italy

7. Laboratori Nazionali del Gran Sasso dell'INFN, 67010 Assergi (L'Aquila), Italy
8. Depts. of Physics and of Astronomy, Indiana University, Bloomington, IN 47405, USA
9. Dipartimento di Fisica dell'Università dell'Aquila and INFN, 67100 L'Aquila, Italy
10. Dipartimento di Fisica dell'Università di Lecce and INFN, 73100 Lecce, Italy
11. Department of Physics, University of Michigan, Ann Arbor, MI 48109, USA
12. Dipartimento di Fisica dell'Università di Napoli and INFN, 80125 Napoli, Italy
13. Dipartimento di Fisica dell'Università di Pisa and INFN, 56010 Pisa, Italy
14. Dipartimento di Fisica dell'Università di Roma "La Sapienza" and INFN, 00185 Roma, Italy
15. Physics Department, Texas A&M University, College Station, TX 77843, USA
16. Dipartimento di Fisica Sperimentale dell'Università di Torino and INFN, 10125 Torino, Italy

a Also Università della Basilicata, 85100 Potenza, Italy
b Also INFN Milano, 20133 Milano, Italy
c Also Istituto TESRE/CNR, 40129 Bologna, Italy
d Also Scuola Normale Superiore di Pisa, 56010 Pisa, Italy
e Also Faculty of Sciences, University Mohamed I, B.P. 424 Oujda, Morocco
f Also Dipartimento di Fisica, Università di Roma Tre, Roma, Italy
g Also Università di Trieste and INFN, 34100 Trieste, Italy
h Also Dipartimento di Energetica, Università di Roma, 00185 Roma, Italy
i Also Institute for Nuclear Research, Russian Academy of Science, 117312 Moscow, Russia
l Also Institute for Space Sciences, 76900 Bucharest, Romania
m Swarthmore College, Swarthmore, PA 19081, USA
n RPD, PINSTECH, P.O. Nilore, Islamabad, Pakistan

Acknowledgements.

We gratefully acknowledge the support of the director and of the staff of the Laboratori Nazionali del Gran Sasso and the invaluable assistance of the technical staff of the Institutions participating in the experiment. We thank the Istituto Nazionale di Fisica Nucleare (INFN), the U.S. Department of Energy and the U.S. National Science Foundation for their generous support of the MACRO experiment. We thank INFN, ICTP (Trieste) and NATO for providing fellowships and grants (FAI) for non Italian citizens.

97-10-152

NEUTRINO ASTRONOMY WITH THE MACRO DETECTOR

INFN/AE–97/22
19 Giugno 1997

ABSTRACT

We present the results of a search for neutrino emission from point-like celestial objects and a search for coincidences with gamma ray bursts. For this search we used 605 upward-going muons produced by neutrino interactions in the rock below the MACRO detector in the underground Gran Sasso Laboratory.

INTRODUCTION

High energies neutrinos are expected to be emitted from a wide class of possible celestial objects: X-Ray binary systems, young supernova remnants , active galactic nuclei etc. (Gaisser, 1995). In the range of energies from several GeV to several TeV the detection of neutrinos is based on the observation of upward-going muons produced from neutrino interactions in the rock around the detector. Currently the expected signals are below the sensitivity of existing detectors. Only galactic supernovae are expected to give detectable signals after the supernova explosion. Several authors have also suggested a possible correlation between a gamma ray burst and emission of high energy neutrinos (Halzen, 1996) (Bahcall, 1997).

DATA SELECTION

The MACRO detector (Ahlen et al., 1993) located in the INFN Gran Sasso Laboratory consists of 6 supermodules and has overall dimensions of 12 m x 77 m x 9 m. The bottom half is filled with crushed rock while the top half is open. The detection elements for muons are planes of streamer tubes for tracking and liquid scintillators for fast timing. The angular resolution is better than 0.5°; the time resolution is about 500 psec. The angular resolution was checked with the moon shadow (Ambrosio et al., 1997a). Data for upgoing muons come primarily from three running periods and detector configurations: the lower half of the first supermodule from March 1989 through November 1991, the full lower half of the detector from December 1992 through June 1993 and the full detector from April 1994 until March 1997. Starting from August 1995 the apparatus is running in the final configuration.

The search for upgoing muons crossing the detector is done using the time-of-flight method and is described in detail in (Ambrosio et al.,1997b). In order to maximize the acceptance for this kind of search we do not require a minimum amount of material. Without this requirement we introduce some background due to large angle pions produced from downgoing muons (Ambrosio et al, 1997c) and we also add events with an interaction vertex inside the detector. We also included events which were observed during periods when the detector acceptance was changing with time due to construction work. All of these data can be used for the point source search since the benefit of the greater exposure in setting flux limits offsets the slight increase in the systematic error in the acceptance.

Figure 1 shows the $1/\beta$ distribution for the data set with full MACRO. The measured muon velocity is calculated with the convention that muons going down through the detector are expected to have $1/\beta$ near 1 while muons going up through the detector are expected to have $1/\beta$ near -1. Events with $-1.25 < 1/\beta < -.75$ are defined to be upgoing muon events. There are 605 events which satisfy this definition. Figure 2 shows the number of events as function of the year.

SEARCH FOR POINT LIKE SOURCES

A very important quantity in the search for point sources is the effective angular spread of the detected muon with respect to the neutrino direction. We computed the angle between the neutrino and the detected muon for several neutrino spectral indices γ. We assume a neutrino energy distribution like $dN/dE_\nu = constant \times E^{-\gamma}$ with a full Monte Carlo taking into account the neutrino-nucleon cross

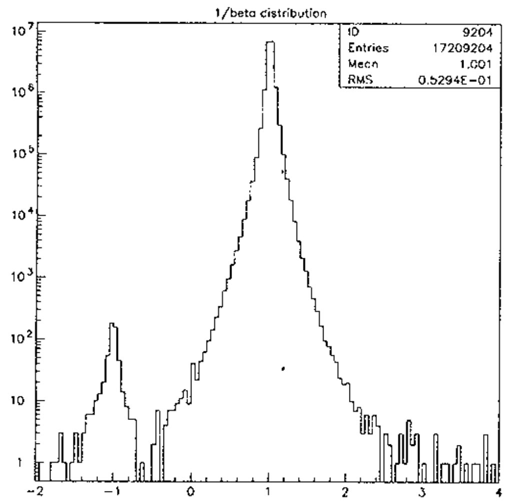


Fig. 1: The 1/β distribution

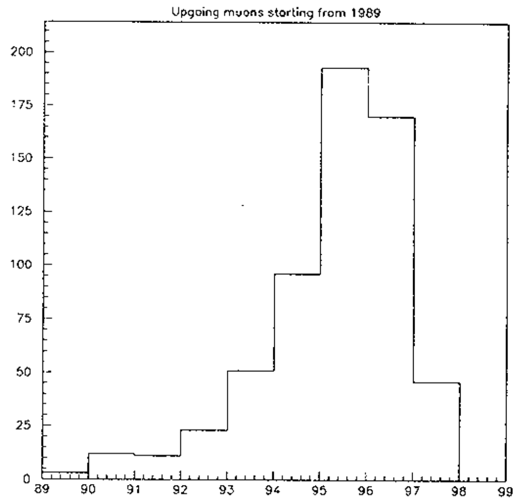


Fig. 2: Upward-going muon events versus year

sections, the muon energy loss in the rock and the detector angular resolution. Table 1 shows the fraction of events in a 3° search cone for two different neutrino spectral indices as a function of zenith angle.

Table 1: Fraction of events accepted in a 3° cone

Cos(Zenith)	$\gamma = 2$	$\gamma = 2.2$
0.15	0.77	0.72
0.35	0.90	0.85
0.55	0.91	0.87
0.75	0.91	0.87
0.95	0.91	0.87

Figure 3 shows the MACRO area as function of the zenith angle and Figure 4 shows the area averaged over 1 day as function of the declination of a possible source (this area includes the geometrical factors and the analysis cuts but does not include the reduction factor due to the search cone). The estimated systematic error is about 8% . In Table 2 are the results for several specific sources. The background was calculated from data itself, counting the events in a declination band of ± 5° around the declination of the source and having different right ascension. The limits were calculated including the reduction factor for a 3° search cone and spectral index $\gamma = 2.1$. The best limit from past experiments was taken from Baksan, IMB, Kamiokande, KGF (Gaisser, 1996). The neutrino flux limits were computed for a neutrino spectral index $\gamma = 2.1$ and with a threshold of 1 GeV on the neutrino energy. The MACRO data which we used are displayed in Figure 5.

To give an idea of the physical implications of those limits we recall that we expect from the supernova remnant Vela Pulsar (Gaisser, 1996) a muon flux of the order of 0.03 x 10^{-14}cm^{-2} s^{-1} (about one order of magnitude lower than the existing limits).

We also looked at the gamma ray sources listed in the Second Egret Catalog (Thompson, 1995). We found no statistically significant excess from any of the sources. We compared the results with the predictions obtained from a Monte Carlo simulation using the events themselves, changing randomly the association between times and angles (zenith, azimuth) and adding a smooth variation to the angles. We have found 5 sources with $\geq$ 2 events in the search cone to be compared to 8.4 sources expected

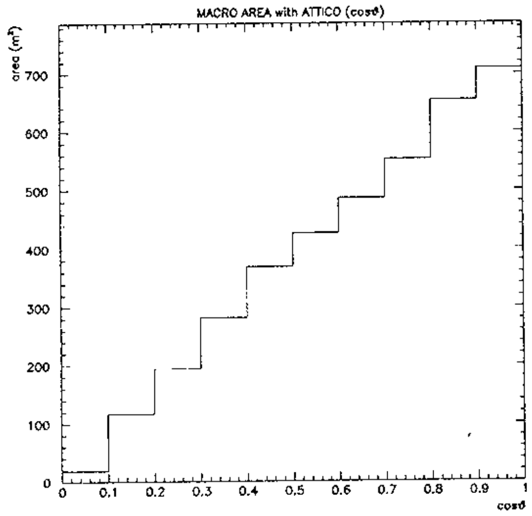


Fig. 3: Area as function of the zenith angle

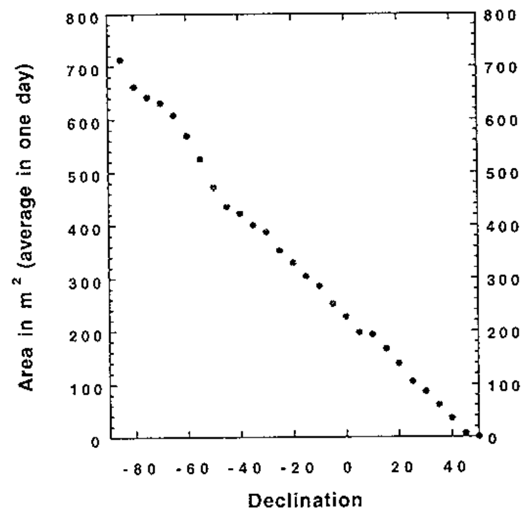


Fig. 4: Area as function of the declination

from the Monte Carlo.

We also looked for possible clusters of events counting the number of events in a 3° cone centered around a given event; we found 22 clusters of $\geq$ 3 events around a given event, to be compared with 21 expected from the Monte Carlo.

SEARCH FOR CORRELATION WITH GAMMA RAY BURSTS

We looked for correlations with the gamma ray bursts in the Batse Catalog 3b (Meegan, 1997) containing 1122 events in the time window between April 21th 1991 and September 19th 1994, overlapping with 143 upward-going muons collected from MACRO during this time. The area for upgoing muon detection in the direction of the bursts averaged over all the bursts in the catalog is $48m^2$; the number is small because MACRO is sensitive to neutrinos in only one hemisphere and because MACRO was not completed in the period between 1991-1994. We found no statistically significant correlation between neutrino events and gamma bursts. We particularly looked in a search cone of 20° around the gamma burst direction (determined from the Batse angular accuracy) and in a time window of $\pm$200 sec: we found no events, compared with 0.33 expected from the background. The expected value was computed with the delayed coincidence technique. The corresponding upper limit at 90% C. L. is 3.9 $\times$ 10^{-9}cm^{-2} upward-going muons per burst. This limit is almost five orders of magnitude lower than the flux of the "extreme" topological defects model reported in (Halzen, 1996).

REFERENCES

Ahlen, S. P. et al., MACRO Collaboration, Nuclear Instruments Methods A324 337 (1993)
Ambrosio, M. et al., MACRO Collaboration, Phys Lett B357, 481 (1995)
Ambrosio, M. et al., MACRO Collaboration, paper HE 3.1.17 at this conference (1997a)
Ambrosio, M. et al., MACRO Collaboration, paper HE 4.1.14 at this conference (1997b)
Ambrosio, M. et al., MACRO Collaboration, paper HE 4.1.13 at this conference (1997c)
Bahcall, J. and Waxman, E., Phys Rev Lett 78 2292 (1997)
Gaisser, T. K., Halzen, F. and Stanev, T. Physics Reports 258 (1995) 173
Gaisser, T. K. Nucl Phys B (Proc Suppl) 48 (1996) 405
Halzen, F. and Jaczko Phys Rev D54 2779 (1996)
Meegan, C. A. et al http://www.batse.msfc.nasa.gov/data/3bcatalog (1997)
Thompson, D.J.et al http://cossc.gsfc.nasa.gov/cossc/egret/egretcatalog and Astr Journ. Suppl. (1995)

Table 2: Limits for Selected Sources at 90% CL. Muon flux limits in unit $10^{-14}cm^{-2}\ s^{-1}$. Neutrino flux limits in unit $10^{-5}cm^{-2}\ s^{-1}$

Source	δ	Events in 3^o	Background	Muon flux limit	Old best limit (muons)	Neutrino flux limit
Cyg X-3	40.8	0	0.06	9.9	4.1 Baksan	5
MRK 421	38.1	0	0.07	9.1	3.3 IMB	4.6
Her X-1	35.4	0	0.14	6.4	4.3 IMB	3.2
Crab Nebula	22	1	0.25	3.8	2.6 Baksan	1.9
Geminga	17.8	0	0.21	2.1	3.1 IMB	1
SS433	5	0	0.34	1.4	1.8 Baksan	0.72
Sco X-1	-15.6	1	0.47	1.57	1.5 Baksan	0.78
Kepler 1604	-21.5	2	0.51	1.92	-	0.96
Galact Cent	-28.8	0	0.5	0.76	0.95 Baksan	0.37
Vela XR-1	-40.5	0	0.65	0.67	0.45 Baksan	0.33
SN 1006	-41.7	1	0.66	1.12	-	0.56
Vela pulsar	-45.3	0	0.76	0.64	0.78 IMB	0.32
CEN XR-3	-60.6	1	1.04	0.84	0.98 IMB	0.42
LMCX-4	-66.4	0	1.15	0.46	0.36 Baksan	0.23
SN1987 A	-69.4	0	1.1	0.46	1.15 Baksan	0.23

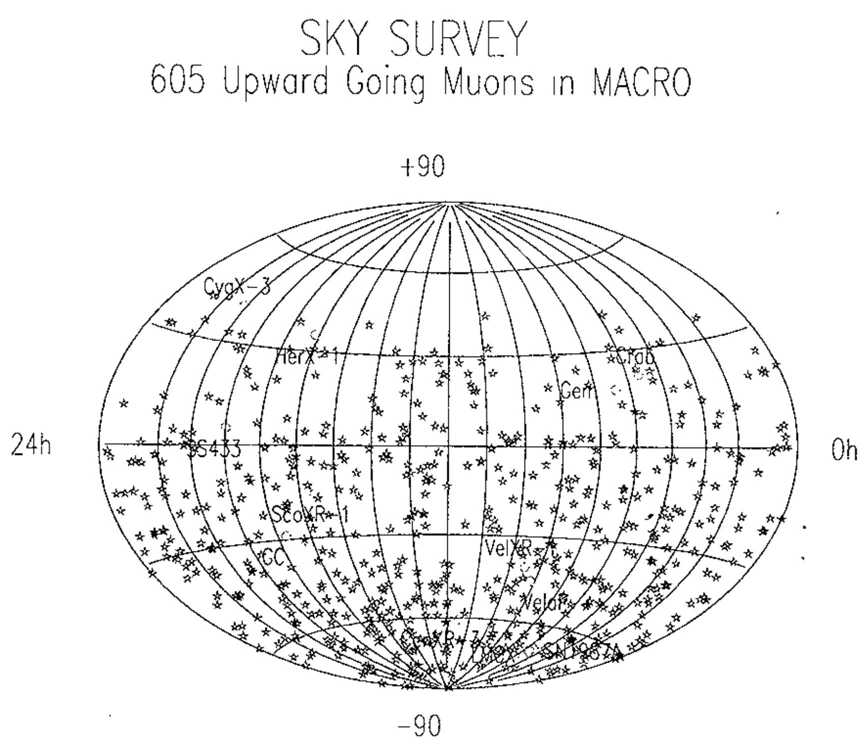


Fig. 5: Upgoing muon distribution in equatorial coordinates.