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FIRST RESULTS FROM THE MACRO DETECTOR AT THE GRAN SASSO LABORATORY

The MACRO Collaboration

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The first supermodule (SΩ~800 m^{2}sr) of MACRO had its initial data run from February 23 to May 28,1989. About 245,000 muon triggers were recorded. Preliminary results are here presented.

Vertical muon flux . A subsample of 84000 single muons which crossed the apparatus from top to bottom were selected. Using an elevation map of the Gran Sasso area these events have been divided into bins of equal rock thickness (50 hg cm^{-2}). For each bin, several values of zenith and azimuth contribute which correspond to different acceptance values of the detector. The contributions have been adjusted to the vertical flux by multiplying the bin contents by the cosine of the zenith angle and adding. The vertical flux of muons as a function of rock thickness is shown in Fig. 1. An exponential fit of the data to $[I(h)\cos(q)] = I_0 e^{-hk_0}$, provides $I_0 = (7.29 \pm 0.02) \times 10^{-7}$ cm^{-2} s^{-1} sr^{-1} and $k_0 = (3.31 \pm 0.02)\ 10^{-3}$ m^{-1} (2.68 g cm^{-3} is an average value of the rock density). Both parameters are in agreement with those found by other underground experiments (1).

MACRO as a Muon Telescope One of the physics aims of MACRO is the search for point sources of high energy cosmic rays, through the analysis of the arrival direction of deep underground muons, either downward directed, and therefore presumably produced by the interaction of primaries in the atmosphere, or upward directed, originating from high energy muon neutrinos interacting in the rock surrounding the detector. The distribution of these events in galactic equatorial coordinates shows that they are coming from the nothern hemispere. The data have been searched for narrow anisotropies using bins 3^o x 3^o in declinaton and in right ascension. No deviation has been found in excess of 3.5 s; this leads to a limit on the flux from point sources of < 7.6 x 10^{-12} cm^{-2} s^{-1} (90% C.L.).

A search has also been made for excess muons coming from the direction of the X-ray binary Cyg X-3. In the past there have been observations of a periodic underground muon signal from the direction of Cyg X-3 (2,3). Other experiments with similar or larger collecting area have not seen a signal (4). For this purpose the arrival times in a 10° by 10° window were separated into bins of width 0.1 in phase using the most recent X-ray ephemeris (2). In Fig. 2 the results of this analysis are shown as a solid line together with background (°) estimated from events at the same declination. Using the bin in the phase plot with the largest excess, we obtain, for a modulated signal, an upper limit of 4.3 x 10^{-12} cm^{-2} s^{-1} (90% C.L.).

Search for upward-going muons. Upward-going muons are generated from interactions in the rock below MACRO by muon neutrinos traversing upward through the earth. These neutrinos originate from cosmic ray interactions in the atmosphere or could be also due to neutrinos of extra-terrestrial origin. The flux of upward-going muons is roughly 5 orders of magnitude lower than the flux of ordinary downward muons. Therefore, a large rejection factor is necessary to select this type of event. Our primary discrimination comes from accurate measurement of the time-of-flight in the scintillators associated with a track seen by the streamer tubes.

Multiple Muons. The relative flux of events with different muon multiplicities and the lateral spread of muons within a single bundle, constitute indirect methods for determining the primary cosmic ray composition in the energy range between 10^{13} - 10^{16} eV. The spatial resolution (~1.2 cm) and the size of the supermodule (effectively ~120 m^2) allows for the collection of a sample of multi-muon events that is not heavily biased by the detector finite size and resolution. Fig. 3 shows a multi-muon event .

Figure 4 shows a preliminary multiplicity distribution obtained from a bundle algorithm and by visually scanning events with multiplicity greater than 6. In Fig.5, the experimental distribution is shown for a sample of about 3000 three-muon events together with the expected distribution obtained from the calculated characteristic muon lateral spread of r_0 = 2.3 m (5).

Search for GUT magnetic monopoles. A preliminary search for monopoles was performed using a variety of triggers, mostly based on the scintillator system. We established a 90% upper limit on the monopole flux of 4 x 10^{-14} cm^{-2}sr^{-1}s^{-1} for singly charged GUT monopoles with velocity larger than 2.5 x 10^{-4}c.

Search for electron antineutrinos from stellar collapses. The ν_e are detected in the liquid scintillator tanks via the reaction ν_e+p ---> e$^+$ +n.The antineutrinos average 10 MeV.

The positrons produced in the interaction on free protons peak at about 12 MeV. In order to detect the largest possible fraction of these interactions we have set the positron energy threshold as low as allowed by trigger and acquisition rate constraints (~5 MeV). The radioactivity background spectrum (mostly due to low energy photons) is a very steep function of energy with a slope dependent on the energy resolution of the detector and on the resolving time to eliminate multiple radioactive events. The liquid scintillator system has been optimized to

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provide excellent resolution for both position and energy measurements. Good event localization and energy resolution yield a background rate distribution that fall steeply versus energy, resulting in low background levels. This will allow the possibility of detecting bursts of small multiplicity.

The reaction $\nu_e + p \rightarrow e^+ + n$ leads to the appearance of a delayed (t=170 μs) 2.2 MeV photon produced by the subsequent neutron capture. These photons can be detected lowering, within 80 ns, the energy thresholds from the 5 MeV applied to the primary event to 1 MeV for the secondary event occurring in the same or in adjacent counters for a duration of 500 μs following the primary energy deposition. The delayed photon detection efficiency has been estimated by Monte Carlo simulation to be ~40% with a 1 m distance cut.

We have searched for event clustering within sliding 2 s bins and found no events in three months of running time with more than 4 counts. A gravitational collapse at the center of our galaxy would have given ~8 events in a 2 s interval.

Conclusions. The first run of the first supermodule of MACRO gave operational experience as well as interesting preliminary results. We are now confident that MACRO will accomplish its physics aims.

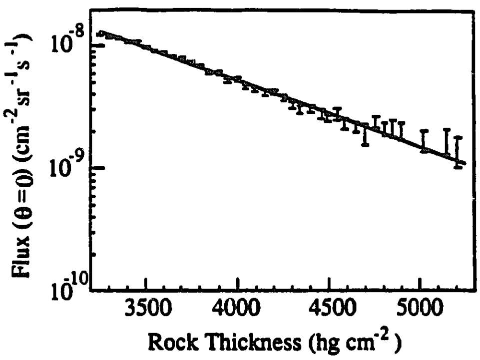

Figure 1. Measured vertical flux for single muons crossing 10 planes in the MACRO detector as a function of rock thickness. The line represents an exponential fit of the data.

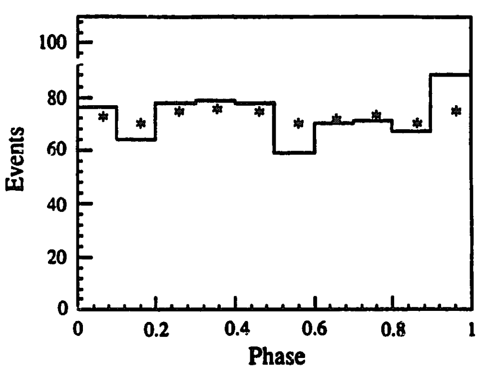

Figure 2. Phase plot of muons in a 10° by 10° window centered on Cyg X-3. Symbols (*) are computed background.

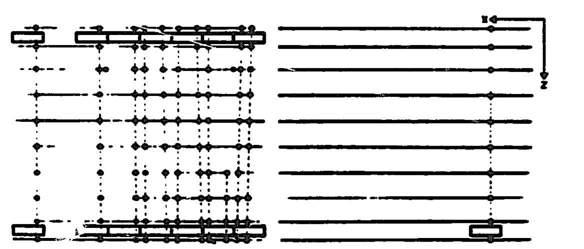

Figure 3. A multi-muon event as seen in one projection view in the on-line display of the supermodule. The two frames shown are the left and right halves of one 12 m side of the detector.

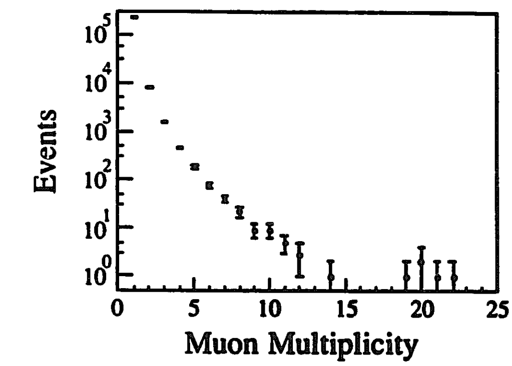

Figure 4. Measured muon multiplicity distribution.

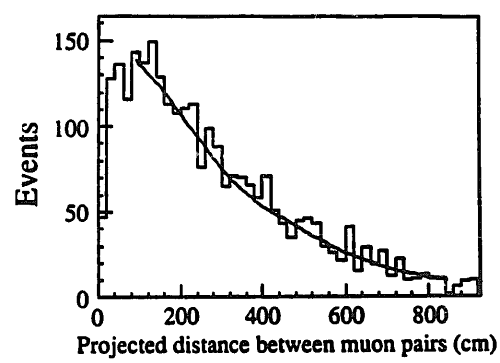

Figure 5. Projected lateral spread distribution for 3-muon events. The solid line represents a theoretical prediction (5).

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