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THE MACRO EXPERIMENT AT GRAN SASSO UNDERGROUND LABORATORY

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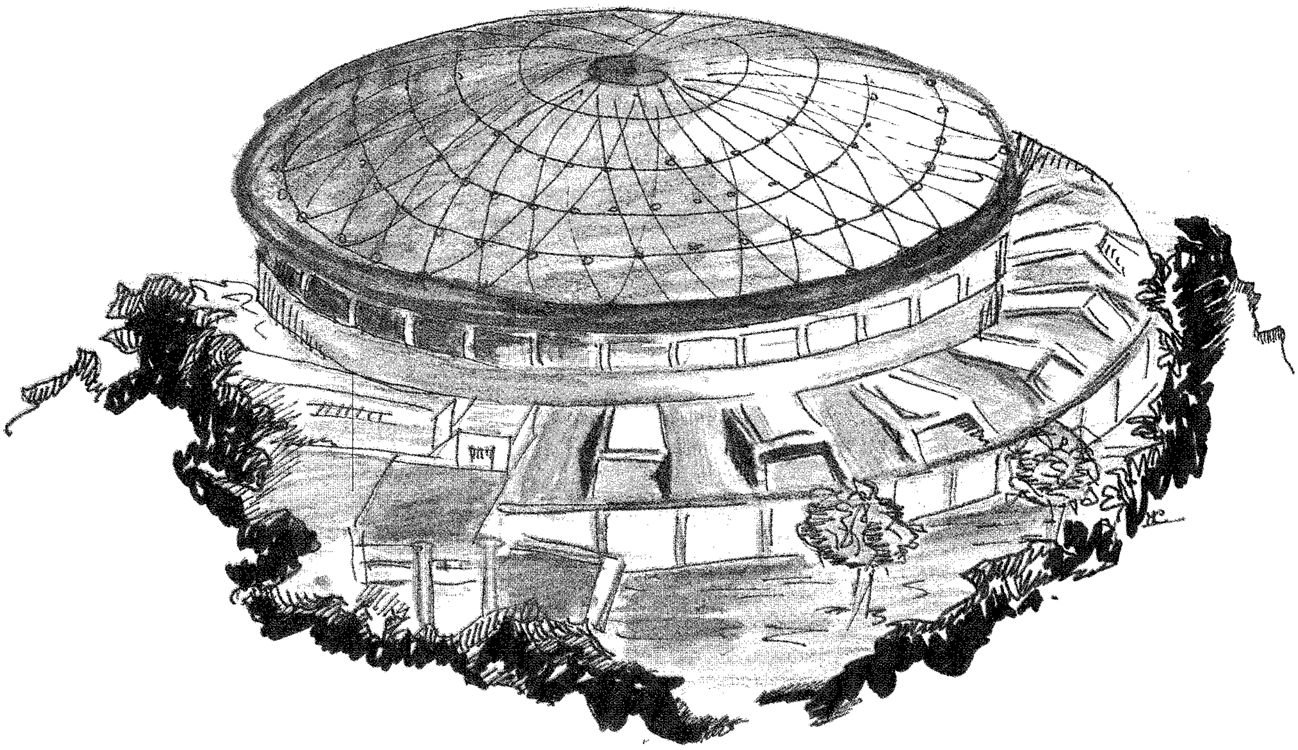

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THE MACRO EXPERIMENT AT GRAN SASSO UNDERGROUND LABORATORY

MACRO Collaboration*

Presented by M. Spinetti
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ABSTRACT

The MACRO experiment, installed in the Gran Sasso Laboratory, has started the data collection with the first supermodule (1200 m^2 sr of acceptance) while the construction of the whole detector is going on. The capabilities of MACRO detector include a sensitive search for massive monopoles, a survey on astrophysical point source candidates, the detection of ν-burst from stellar collapse and a systematic studies on muons and multimuons in the cosmic rays with the new possibility of correlated events with the surface EAS detector. A description of the detector features is also given.

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1. - INTRODUCTION

The MACRO experiment at the Gran Sasso Laboratory has started a first period of data taking at beginning of 1989 with the first supermodule completely installed and tested ($\approx 1200\ m^2$ sr, schematically shown in Fig. 1).

The MACRO experiment belongs to a new generation of large underground detectors, such as allowed by the large halls of the Gran Sasso Laboratory, with a large acceptance ($\approx 10000\ m^2$ sr) for isotropic fluxes of penetrating particles, designed in order to push the sensitivity in the search of rare phenomena in the cosmic radiation.

The primary physics aim of the experiment is to search for GUT massive monopoles (as well as any other slow penetrating particle) with a sensitivity well beyond the astrophysical bounds, measuring both the velocity and the energy loss.

The large acceptance of the detector and its design features will allow also to search with a good sensitivity for point sources, like Cygnus X3, emitting high energy γ's, ν's or other neutral particles, and for ν burst emitted in stellar collapse.

The investigation of the standard penetrating cosmic radiation with high statistics will allow systematic studies on primary composition. In this field a unique perspective is open by the Extensive Air Shower detector (EASTOP), placed on top of the Gran Sasso mountain, looking to the events passing through both detectors: event by event, the primary energy is measured by EASTOP with sufficient accuracy, via the electromagnetic shower size, and the underground high energy (≥ 2 TeV) muon content by MACRO.

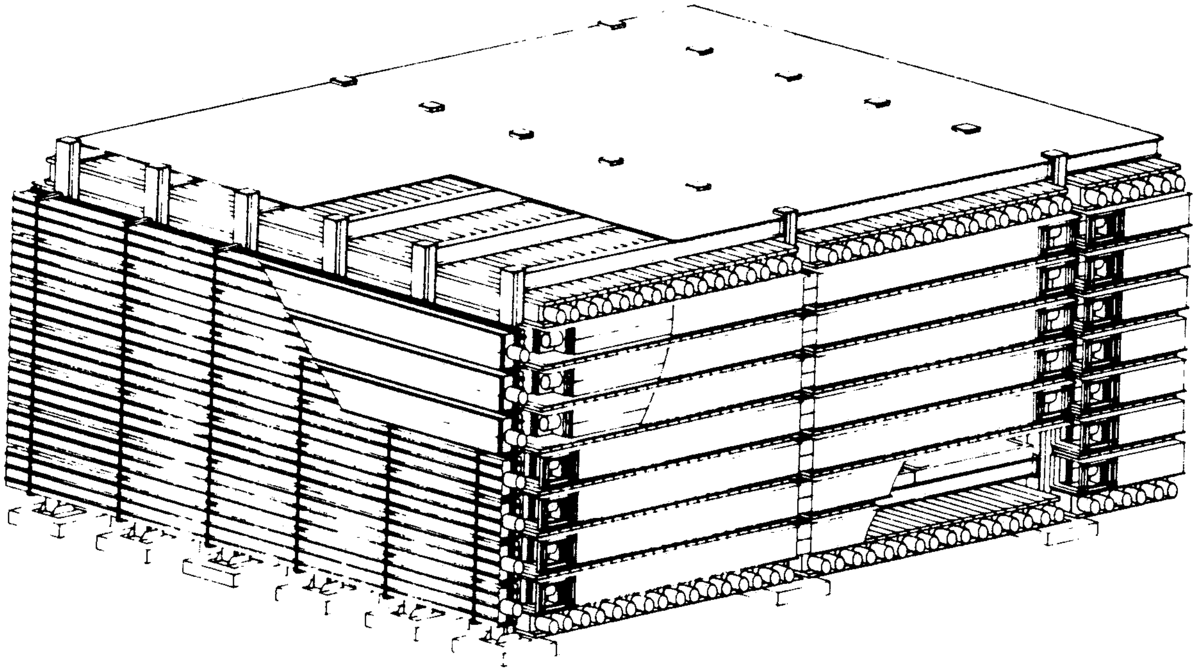

FIG. 1 - Schematic view of one MACRO supermodule ($12\text{x}12\text{x}4.5\text{m}^3$).

2. - THE DETECTOR

The MACRO apparatus has been designed with three different types of detectors in order to have redundant informations for particles with a different energy loss-velocity correlation in a wide range of velocity ($\beta \geq 10^{-4}$). The cross checks between the informations of the three detectors can give a good signature for any monopole candidate.

The detector itself mainly consists of a horizontal sandwich of 3 scintillation counter layers, 18 streamer tube layers and one track-etch layer, interleaved with passive absorbers (iron and $CaCO_3$) in order to set a minimum threshold of ≈1 GeV for crossing muons.

The four vertical sides of the detector are closed with 6 streamer tube layers and one scintillation counter layer .

The whole detector is divided in 12 supermodules, each one with dimensions 12 x 12 x 4.5 m^3 (Fig. 1).

2.1. - The Liquid Scintillation Detector

The liquid scintillator is a mixture of 5% pseudocumene and 95% low paraffin mineral oil, added with antioxidants and wavelength shifters.

A careful selection and test of all the ingredients allowed to reach a remarkable 12 m attenuation length without loosing in light output: this result is particularly important for the geometry of the MACRO counters. These counters are 12 x .75 x .25 m^3 PVC tanks lined with FEP teflon and equipped with two 20 cm Hamamatsu PMT's at each end.

The total mass of the liquid scintillator is about 700 tons distributed in 484 tanks.

A particular effort has been devoted to study the response of the liquid scintillator to slow particles. A neutron beam incident on the scintillator has allowed to measure the light yield of scattered protons whose energies were as low as 50 eV (1). This calibration has a great relevance for a reliable computation of the liquid scintillator energy loss - velocity correlation for the monopoles, the dyons and other slow moving particles (Fig. 2).

A wave form digitizer with 2 μs time acceptance allows a detailed study of the light yield released by a slow particle crossing the counter, from which the particle velocity inside the counter and the energy loss can be deduced.

Tests done on the actual counters have shown that the time resolution is about 1 ns while the energy resolution is about 14 % : these features allow a good rejection power ($\approx 10^{-6}$) between upward going and downward going muons and an accurate velocity measurement for particles crossing two layers of scintillation counters.

2.2. - The Streamer Tube Detector

The streamer tube detector is a system of ≈60000 streamer tubes.

Each tube has a 3x3 cm^2 cross section, a 12m length, a 100 μm anode wire and a graphite cathode; it operates in the limited streamer regime with a gas mixture done with He (57%), CO_2 (28%) and n-pentane (15%).

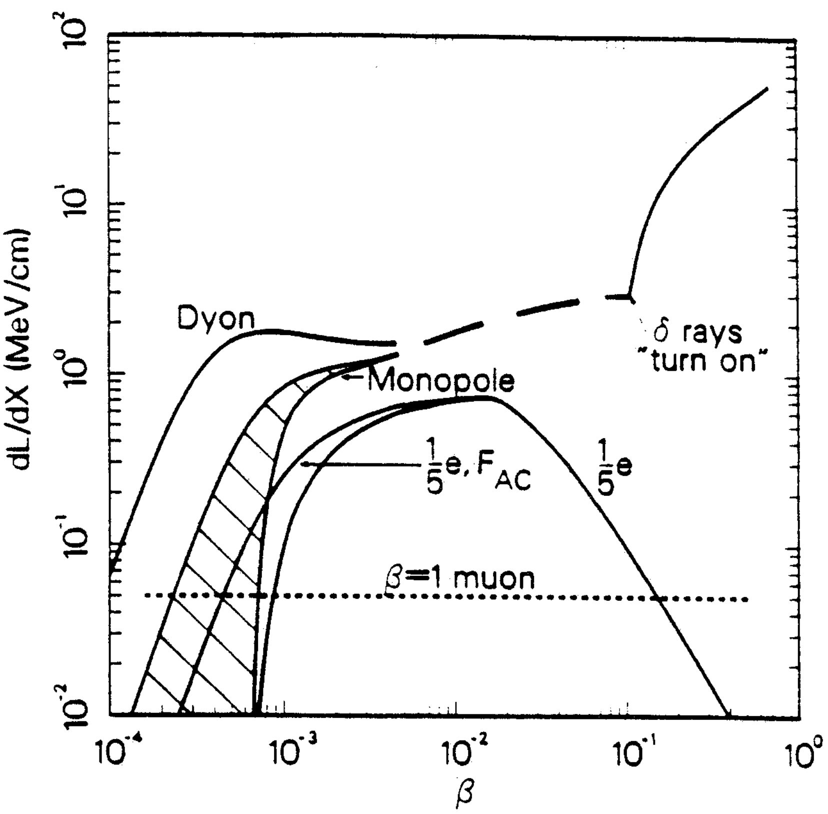

FIG. 2 - Specific light yield for bare GUT monopoles, dyons (monopole-proton pair), and $\frac{1}{5}e$ superstring particles. The allowed regions are shaped. The abrupt increase for monopoles with $\beta>0.1$ is due to production of delta rays whose scintillation emission is not quenched.

The high voltage set allows to lower the streamer threshold down to about 1% of a minimum ionizing particle.

A two dimensional read out is performed picking up signals from anode wires and 26° stereo strips.

Preliminary data taken with the first supermodule have given a spatial resolution of about 1 cm and a streamer tube layer efficiency of 97%.

The timing and the amplitude for each streamer tube layer is recorded in a wide time range (0.5 ms) in order to measure the velocity and the energy loss of slow highly ionizing particles. It is worth to note that the streamer regime is not a completely saturated one. The measurements done with relativistic heavy ions (2) have shown that the streamer charge increases logarithmically with the energy loss (Fig. 3). This feature permits the energy loss measure in the wide range covered by slow monopoles.

The Drell effect (3) in the He of the gas mixture together with the very low threshold allows the detector to have a ß threshold for monopoles down to ≈ 10^{-4} (Fig. 4).

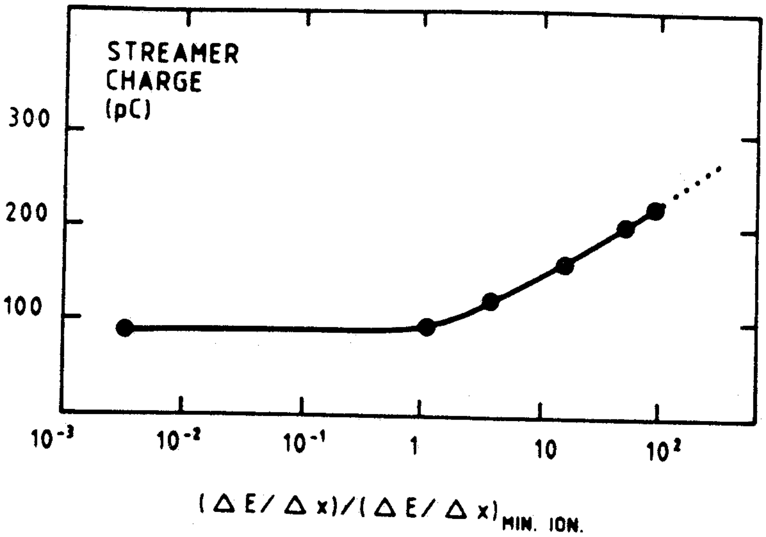

FIG. 3 - Streamer charge response to energy loss obtained with UV rays, muons and relativistic heavy ions.

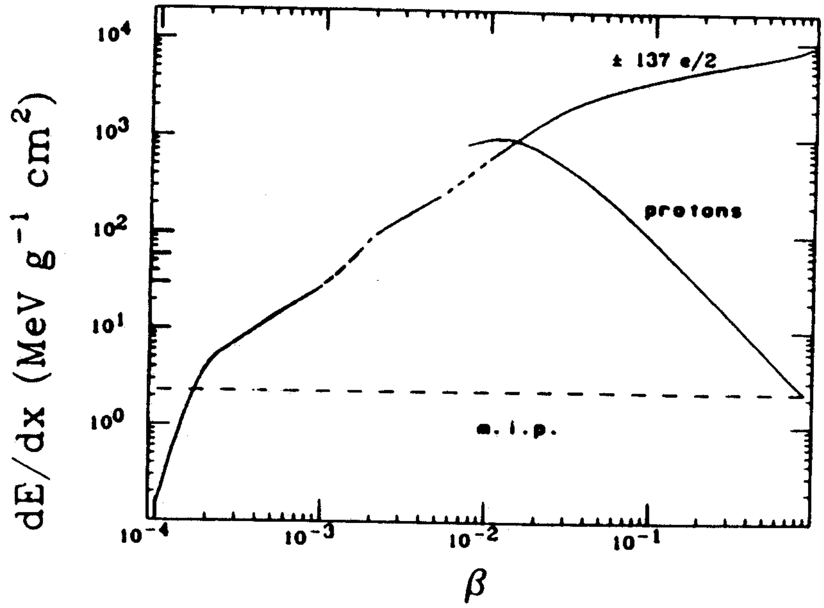

FIG. 4 - Energy loss for a GUT monopole in the gas mixture of streamer tubes, according to the Drell mechanism.

2.3. – The Track-Etch Detector

This detector consists in a horizontal layer of plastic sheets placed in the middle of MACRO.

This layer is divided in 25x25 cm^2 pieces, each one being a sandwich of 5 Lexan layers, 3 CR39 layers and one Al layer (Fig. 5).

The two plastic material cover a large range of sensitivity to the energy losses and moreover the various sheets can be yielded to different strength of chemical attach, extending the sensitivity range. The Al sheet has the role of stopping possible nuclear fragments.

The response of this detector to bare monopoles as well as to other massive particles is reported in Fig. 6.

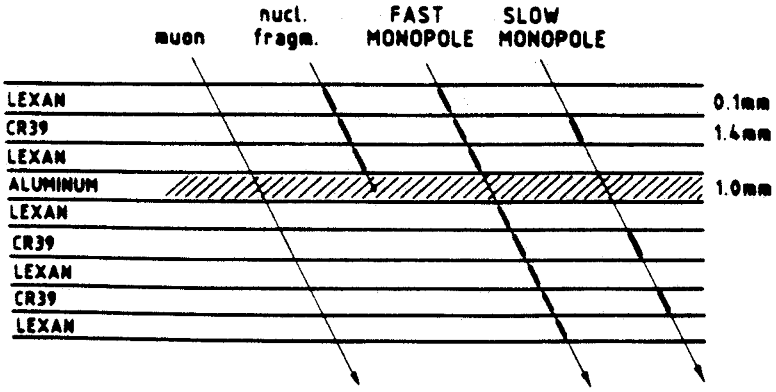

FIG. 5 - Vertical stratigraphy of the track-etch detector, with a schematic description of the response to different particles.

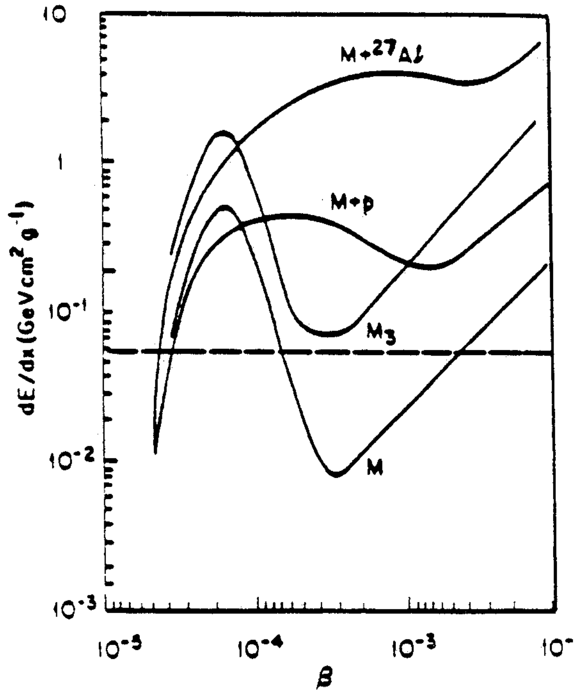

FIG. 6 - Restricted energy losses in CR39 for free monopoles with $g=g_D$ or $g=3g_D$ and for bound monopoles with $g=g_D$.

This detector can be used in two different modes:

– a triggered mode, searching for monopole tracks in a small region (≈ 1 cm^2) around the position expected for the candidates found by the other detectors,

– a purely passive mode, etching and scanning all the sheets looking for candidates not seen by the active detectors.

Several tests have been performed with relativistic heavy ions in order to measure the response of various samples of materials and to calibrate different etching strength.

3. – THE PHYSICS AIMS

3.1. – The GUT Monopoles

Grand Unified Theories (GUT) predicts the existence of magnetic monopoles with masses $\approx 10^{16}$ GeV/c^2 and magnetic charge $g_D = hc/4\pi e$, but no reliable prediction has been done on their abundance.

An upper limit on their flux can only be derived by the survival of the magnetic galactic field: this limit, called Parker limit, is about 10^{-15} cm^{-2} s^{-1} sr^{-1}.

A similar limit can be set considering the limit on the possible dark matter in the Universe due to monopoles.

The flux maximum is expected at the lowest velocities around $\beta \approx 10^{-4}$, where monopoles are trapped in the magnetic field of the Sun; for higher velocities the flux decreases logarithmically. Around $\beta \approx 10^{-3}$ monopoles are trapped in the galactic magnetic field while for $\beta \geq 10^{-2}$ they must be of extragalactic origin.

The Parker limit has not been achieved by active experiments while the indirect mica track-etch experiments have found a lower limit under restrictive assumptions.

MACRO with the three combined detectors covers all the β range where monopoles are expected. For each candidate there will be three energy loss measurements and three velocity measurements: the consistency check between all these informations will give a good signature for any monopole candidate.

If no candidate will be found, in few years of operation MACRO will push the flux limit about 10 times below the Parker limit for GUT monopoles and, more in general, it will put a similar limit for any massive charged penetrating particle.

From this flux limit it can be derived a limit of about 1% on the GUT monopoles as a constituent of the dark matter.

3.2. – Cosmic Ray Physics

The large acceptance of the MACRO detector will permit to collect a large statistics on the underground single ($\approx 10^7$ eV / y) and multiple ($\approx 3 \times 10^5$ eV / y) muons allowing accurate and systematic studies. Moreover the relevance of the large acceptance is that multimuons events will be unbiased since the minimum detector dimension is twice larger than the multimuon average size. This will lead to an increased sensitivity of the multimuon distribution to the primary chemical composition.

The most interesting perspective in this field is open by the possibility of coincidences between MACRO and the extensive air shower detector EASTOP (4), placed on top of the Gran Sasso mountain. This detector is located at 2000 m a.s.l. with a zenith angle $\theta=27.5°$ off the vertical of MACRO for which the corresponding depth is about 3200 hg/cm^2 (Fig. 7).

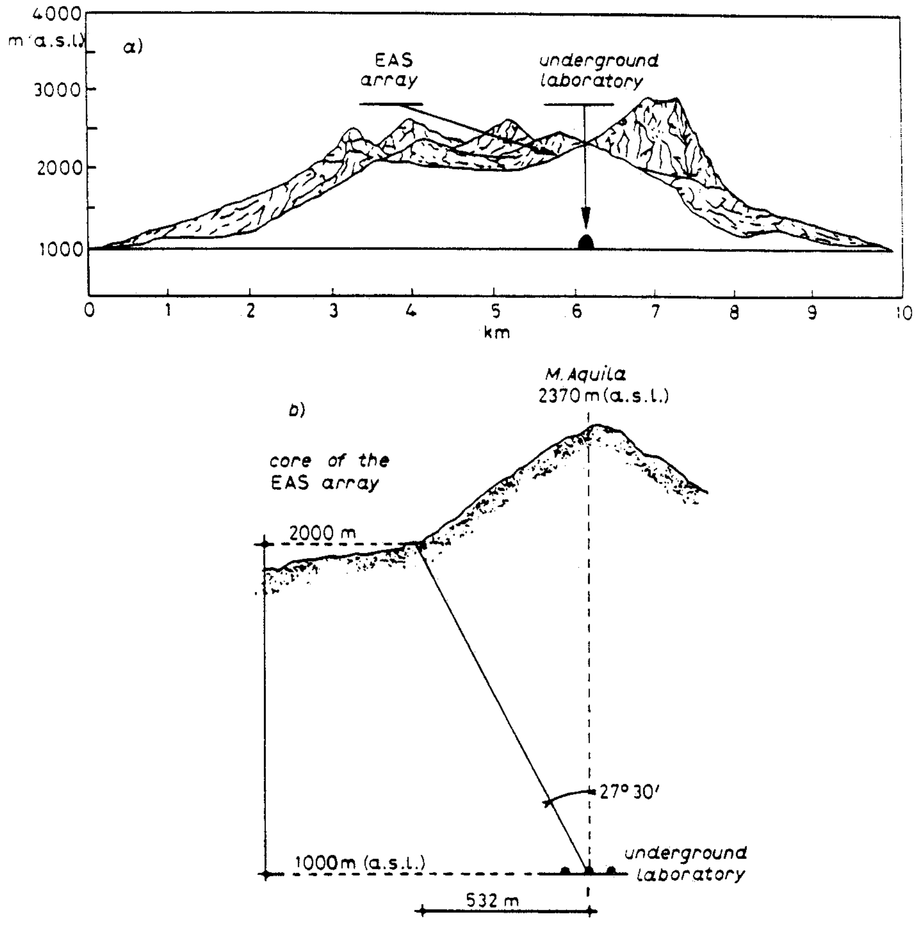

FIG. 7 - Mountain profile and location of the underground laboratory and of EASTOP.

The expected number of correlated events is about 15000 per year and considering the time and the angular resolution, the background is negligible.

The use of these events, which have information about both the energy of the primary and the high energy muon number, will considerably increase the sensitivity to the composition, particularly at the highest energies, since the shower size fixes the primary energy within a factor two, given the difference between the proton or iron initiated showers.

On the contrary multimuon events with a given multiplicity are produced by primaries whose energy covers at least two decades.

3.3. – Astrophysical Point Sources

In recent years, a lot of efforts have been dedicated to the study of point sources such as Cygnus X3, Vela X1, LMC X4. The main interest in studying these objects is that they can explain the origin of cosmic rays, in particular at the highest energies ($\approx 10^{17}$ eV) which cannot be attained by the conventional statistical mechanism.

These sources are binary systems, that is a neutron star rapidly rotating around a large companion star. Protons and ions are presumably accelerated in the strong magnetic field generated by the neutron star and interact with the companion star producing charged and neutral pions decaying in neutrinos and gammas. These gammas, seen from the Earth, are strongly absorbed by the the companion star except when the proton beam grazes its rim.

This mechanism produces a typical peaked phase plot for all the photon emissions while for neutrinos it is expected an observable flux during almost half the period of the binary system.

MACRO will observe the point sources in the northern hemisphere looking to the downward going muons produced in the atmospheric showers. Taking into account the emitted energy spectrum and the experimental indications that the muon content of these showers does not differ from that of the standard hadronic showers (5), about 300 events per year would be detected in MACRO from Cygnus X3. This number is sufficiently larger than the expected background, taking into account a 10% duty cycle in the phase plot and an angular window as narrow as allowed by the muon multiple scattering in the rock (0.6°).

The sources in the southern hemisphere can be revealed looking to neutrino induced upward going muons. At the most probable neutrino energies (above 1 TeV) the muons are aligned within 1° with the neutrino direction. Sources like Vela X1 and LMC X4 can give 5÷10 ev/y in a 1° cone to be compared with a 0.1 ev/y due to atmospheric neutrinos. A lower background results from wrong downward going muons.

3.4. – Gravitational Stellar Collapse

The observation of the SN1987A in the underground detectors has confirmed the standard supernova model and therefore the interest in this search.

A gravitational stellar collapse essentially appears as a burst of positrons which come from the interaction of the anti-ν_e burst with the MACRO liquid scintillator.

A crucial point is the background counting rate whose fluctuations can simulate the anti-ν_e burst. A dedicated electronics has been designed in order to have a hardware reconstruction of the deposited energy independent by the position along the counter so that the threshold is on the true energy. Moreover an on-line filter reduces the double hit radioactivity background. Measurements performed on one counter installed in the first supermodule have given a counting rate as low as about 10^{-3} Hz.

The total MACRO counting rate is expected to be less than few Hertz with a $8 \div 10$ MeV energy threshold. In these conditions, a collapse similar to that of the SN1987A can give a 10 sec burst of about 50 positrons in the total mass of the MACRO liquid scintillator. The probability that a background fluctuation can simulate the anti-ν_e burst is well below 10^{-4} in several years of running.

4. – OPERATION OF THE I° SUPERMODULE

One MACRO supermodule, although a fraction of the whole detector, covers an area of 145 m^2 and has a significant acceptance of 1200 m^2sr comparable with most of the running underground detectors.

As already said, the first supermodule has started a period of run in order to collect a significant sample of data. About 10^5 muon events are planned to be collected at a rate of 2 ev/min. Within these events about 300 coincidences with the surface detector are expected.

The run is done with all the triggers activated in order to check the actual performance of the apparatus in all the physics aims.

An example of a multimuon event is shown in Fig. 8.

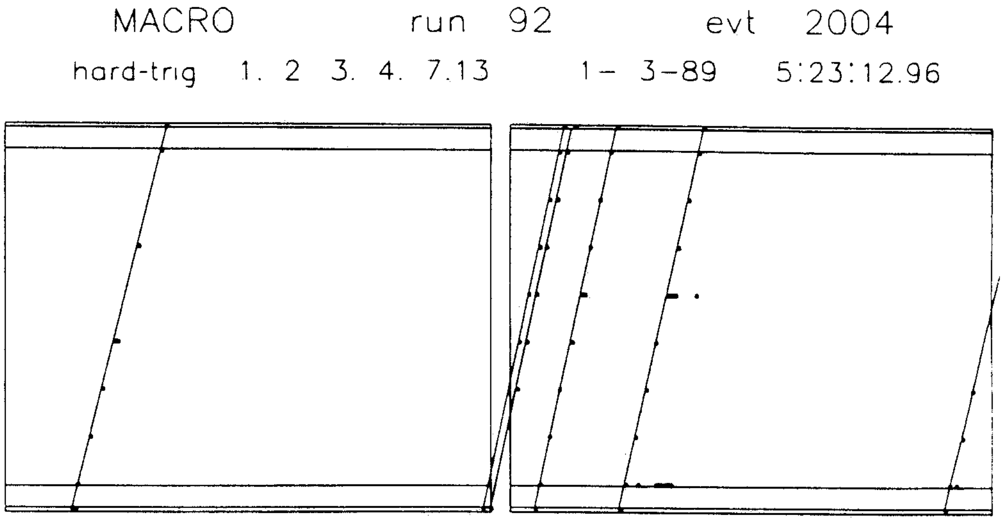

FIG. 8 - The wire view of a multimuon event.

The measured efficiency of a streamer tube layer is 97%, practically being the geometrical one. The measured spatial accuracy is about 1cm which corresponds to an angular accuracy of 0.2°.

From the row data collected up to now the zenithal and azimuthal angle distributions are obtained (Fig. 9a and Fig. 9b): they are close to what is expected from the detector acceptance and the rock thickness.

The MACRO planning foresees that in the next months the second and third supermodules will be fully equipped and ready for data taking.

The construction of the other three supermodules will start in the next months so that in 1990 the data collection will be done with six supermodules and a total acceptance of about 7000 m^2 sr. The full detector will be completed in the next years.

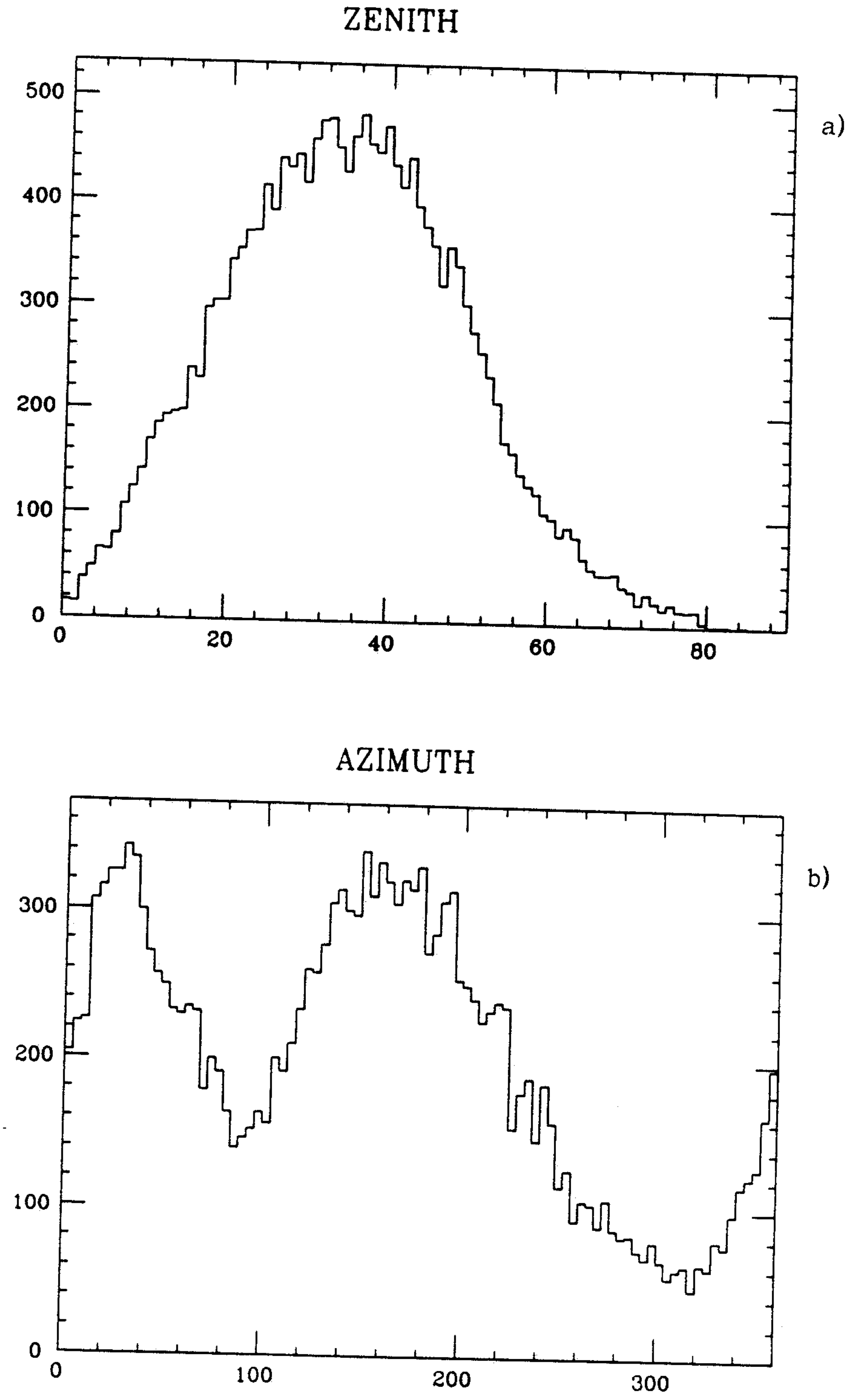

FIG. 9 - The a) zenithal and b) azimuthal angle distributions obtained from row data.

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