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The EAS-TOP collaboration

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Presented by V.Patera

The simultaneous observation of the electromagnetic and TeV muon components of extensive air showers by the EAS-TOP and MACRO detectors, respectively, is described for a period of 100 days in 1990. The two detectors and their combined resolutions are briefly reviewed and muon multiplicity distributions for various detector configurations are presented. A first analysis of the physical parameters N_μ and N_e related to the study of the primary composition at $E_0 = 10^{14} - 10^{16}$ eV is also presented.

1.INTRODUCTION

The EAS-TOP[1] detectors of the electromagnetic component of extensive air shower (EAS) and the high energy underground muons MACRO[2] detector operate as a multicomponent EAS detector aimed to the study of the primary cosmic ray composition at high energies[3]. These experiments are located at the Gran Sasso Laboratories at altitudes of 2005 and 963 m a.s.l. The angular range of EAS-TOP as seen by MACRO is 25° to 37° in zenith and 160° to 200° in azimuth. The mean slant depth of MACRO in the EAS-TOP direction is 3200 m w.e., corresponding to a muon energy threshold of 1.4 TeV.

At the time of this data taking two supermodules of MACRO ($24\times12\times4.8\ m^3$) were in operation. A detected muon in MACRO is defined as at least 4 aligned hits out of 10 horizontal layers of streamer tubes. A spatial accuracy in tracking ~1 cm is achieved in MACRO, and the resulting accuracy in angular reconstruction in two projected views is better than 0.6°, correspondig to the

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mean angular deviation due to multiple Coulomb scattering in the rock above the detector.

The EAS-TOP[1] detector is an array of 29 modules of scintillation counters, each of area 10 m^2, distributed over an area of 10^5 m^2. The minimum trigger requirements are four contiguous modules firing, corresponding to a primary energy threshold ~50 TeV. For a primary energy $E_0 \geq 200$ TeV ($N_e \geq 3 \times 10^4$) and core inside the edges of the array, the angular reconstruction accuracy is ~ 0.8°, the core location is determined to a few meters and the total shower size to $\Delta N_e/N_e \sim 20\%$. Shower size and core location are obtained by fitting the measured electron densities with the NKG lateral distribution function formula.

In this paper we present the main features of the coincident events gathered between July 18 to December 14, 1990, for a total live time of 100.0 days. We also present a first analysis of the physical parameters N_μ and N_e of 580 events with the core inside the edges of the EAS-TOP array ($A_{int} = 4 \times 10^4\ m^2$, high energy internal events).

2.DATA SELECTION AND COMBINED RECONSTRUCTIONS

For both detectors, the timing of each event was provided by independent rubidium clocks, accurate to 1 μs. The selection of coincident events was performed off-line on the basis of this timing. Relative clock drifts were corrected (also off-line) by using relativistic muons to define the coincidence peak, run by run.

Fig. 1 shows the distribution of time differences between the reconstructed events of EAS-TOP and MACRO. The curve is a gaussian fit with a standard deviation of 0.69 μs. A 3σ cut at ± 2.1 μs was applied to define a coincidence. Accidental coincidences caused a background of 22.6±0.1 events per μs. Overall, 7644 events satisfied the 3σ cut, including an estimated 95.0±0.3 accidental coincidences (1.2%), for a constant trigger rate of 75.5±0.9 real coincidences per day.

Events recorded by EAS-TOP were classified according to the trigger criteria. In what follows, the analysis is restricted to so-called "internal" events, i.e. events

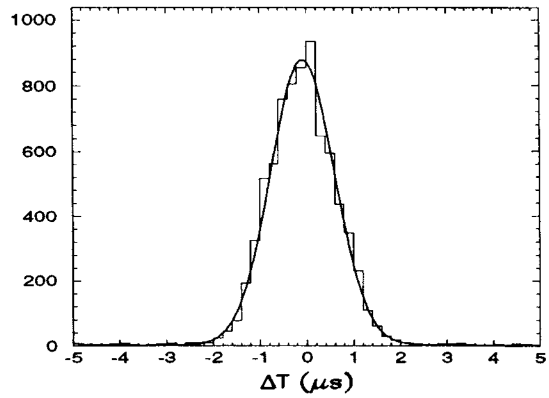

Figure 1: Time difference distribution between EAS-TOP and MACRO events.

for which the core of the shower lies within the boundaries of the array. This category was further divided into high energy and low energy internal events, where a high energy event hit at least 6 contiguous counters, and a low energy event hit at most one counter located on the edges of the array but satisfied the minimum trigger requirement. The corresponding primary energy thresholds were roughly 100 TeV and 50 TeV.

Out of the 7644 coincident events, 582 were high energy internal events. For this trigger configuration, a background of 3.2±0.5 accidental coincidences (0.5%) was expected; out of the 582 events, 2 were eliminated as background by obvious angular mismatches. For 90% of the remaining events, the independent reconstructions agreed to better than 3.9° in absolute direction in space and 55 m in core location, indicative of consistent reconstruction procedures. 434 of the 7644 coincidences were low energy internal events.

The distribution of muon bundle multiplicities N_μ as seen by MACRO for high energy and low energy internal events is shown in Fig. 2. An anticoincident event is defined as a MACRO event pointing back to a small fiducial area of about 10^4 m^2 well within the perimeter of EAS-TOP and which did not trigger the array. This corresponds to a primary energy below the threshold of EAS-TOP. Also plotted on Fig. 2 are the multiplicity distributions for anticoincident events and those coincident events reconstructed by MACRO to point back to

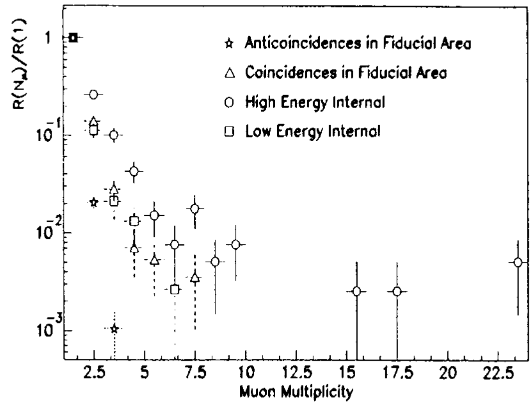

Figure 2: Multiplicity distributions normalized to the rates of single muons for various trigger configurations. For multiplicities without data points, no event had been recorded.

the same fiducial area. There were 2915 anticoincident events recorded, compared with 670 coincident events pointing back to the fiducial area.

3.SIMULATION

We compared the experimental data with the preliminary results of a Monte Carlo simulation. The physics generator was taken from [4] based on a p-p and p-p hadronic interaction model developed according to collider results up to $\sqrt{s} = 900$ GeV. Nucleus interactions were treated in the context of the superposition model. The mean values and fluctuations of Ne were from [5]; the slope of the electromagnetic lateral distribution function was sampled from the experimental distribution.

As a first approach, we have treated shower size and muon multiplicity independently. However there exists an anticorrelation effect as discussed in [5], which affects $\log_{10} N_e$ by at most 10% at 100 TeV, decreasing at higher energy. A simulation describing the full experimental setups for each detector, including trigger scheme and measured fluctuations, was then carried out producing data of the same format as that of real events. Simulated data were then analyzed using the same reconstruction procedures as for real events.

We have simulated pure p and Fe compositions with a statistical sample corresponding to a live time 10 times

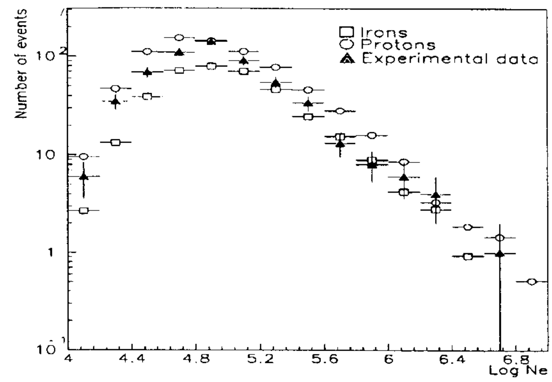

Figure 3: Distributions of $\log_{10}(Ne)$

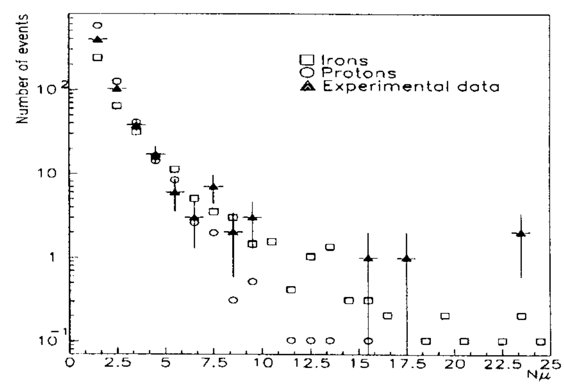

Figure 4: Muon multiplicity distributions

larger than the experimental one, and a particle spectrum compatible with the experimental data of [6, 7], the same for both compositions:

$$F = K \times E^{-\gamma} \quad m^{-2}s^{-1}sr^{-1}GeV^{-1}$$

where $K = 2.7 \times 10^4$ and $\gamma = 2.65$ for energies in the range $50 < E < 2000\ TeV$ and for energies $> 2000\ TeV$ $K = 4.3 \times 10^6$ and $\gamma = 3.00$

4.DATA ANALYSIS

The coincidence rate for simulated events ranges from 3.8 (pure Fe) to 7.7 (pure p) ev/day, to be compared with the experimental one f=5.80$\pm$0.24 ev/day (uncertainties in the primary energy spectrum and interaction model currently affect the simulated data by at most 25%).

A plot of the $\log_{10} N_e$ spectrum for the real coincident

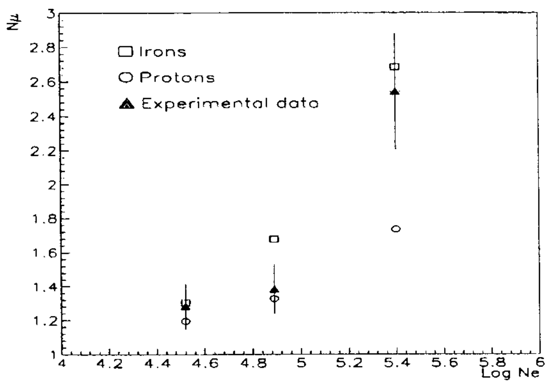

Figure 5: Correlation between N_μ and Ne

events is given in Fig 3, together with the expectations for the extreme pure compositions p and Fe. Simulated data are normalized to the total live time. Fig 4 shows the experimental muon multiplicity spectrum compared with Monte Carlo predictions. The mean experimental N_μ value for three $\log_{10} N_e$ intervals, chosen to give the same statistical sample , is plotted versus $\log_{10} N_e$ in Fig 5. In this plot, which is less sensitive to the primary spectrum, the experimental points lie between the two extreme cases, as expected for a mixed primary composition. This is also the case for the absolute rates and the general trends of the multiplicity distribution.

5.CONCLUSIONS

The coincidence technique based on timing measurements guarantees a high efficiency of operation with extremely low levels of background, which can be identified from the geometrical information.

In the current EAS-TOP trigger configuration, the efficiency for detecting the electromagnetic component of extensive air showers for which the high energy muons point back to the array is good ($\sim$ 19%) and is 100% for $N_\mu \geq 4$.

As is apparent from Fig. 2, the general features of muon multiplicity distributions agree with expectations over a primary energy range from less than 50 TeV up to more than 1000 TeV, namely that with increasing shower size, and thus increasing primary energy, there is an increase in the contribution of high muon multiplicities. The measured coincidence rate, the shower size spectrum and the muon multiplicity distribution, within the experimental fluctuations, are consistent with the expected ones for a mixed composition, showing that the model is adequate and the two experiments have been well simulated.

In spite of this general consistency, a quantitative statement on primary mass abundances is not possible at this time due to limited statistics and the need to further refine the simulation model by making full consistency checks with all the experimental data, thereby reducing systematic uncertainties. Work is in progress to increase the statistical sample by including external events in the analysis.

The next coincident run will start next autumn with a total surface area of 860 m^2 for MACRO and $A_{int} \simeq 6 \times 10^4\ m^2$ for EAS-TOP. In such conditions the statistical errors in the measured parameters will be reduced to 10% in the whole range (including the region above the knee in the primary spectrum) in about 1 year of combined live time.

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