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MACRO and EAS-TOP Collaboration

# SIMULTANEOUS OBSERVATION OF EXTENSIVE AIR SHOWERS AND UNDERGROUND MUONS AT THE GRAN SASSO LABORATORY

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# SIMULTANEOUS OBSERVATION OF EXTENSIVE AIR SHOWERS AND UNDERGROUND MUONS AT THE GRAN SASSO LABORATORY

MACRO* and EAS-TOP** collaboration

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In this paper we present new combined data from the MACRO underground detector located at the Gran Sasso Laboratory and the EAS-TOP surface array located on top of the mountain above MACRO at a zenith angle of 27.5° and separated by 3100 meters water equivalent (m.w.e.) of rock. Discussed are the method of the event correlation and the characteristics of the reconstructed events.

## 1. INTRODUCTION

At the Gran Sasso Laboratory[1], the MACRO and EAS-TOP experiments are in operation and provide new data on the simultaneous observation of extensive air shower and underground muons with such an acceptance, geometrical resolution, and reconstruction capability that has never been achieved by previous experiments.

The MACRO detector is located in the Hall B of the Gran Sasso Laboratory and sees the EAS-TOP array, located at 2000 m a.s.l., with a solid angle $\Delta\Omega \sim .06$ sr. The relative rock depth ranges from 3100 to 3500 m.w.e. General descriptions of the two apparata are presented in ref[2,3].

In this paper, we report the first results obtained by the joint collaboration. We show the detection features achieved by the two experiments and discuss their capability for reconstruction of cosmic ray events.

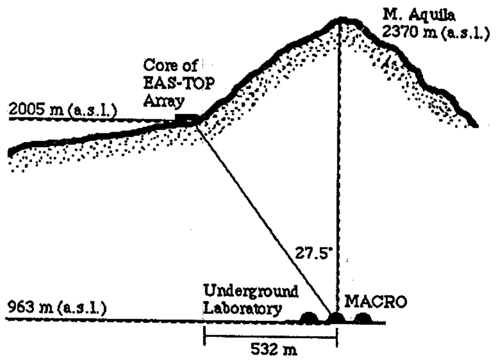


FIG. 1 Locations of the two arrays at the LNGS.

## 2. DATA SELECTION

The two experiments ran simultaneously from March 23 to May 29, 1989, for a total live time of 1107 hours. The correlation of data is established off-line on the basis of the absolute timing and the directional capabilities of the detectors. The absolute Universal Time (UT) is provided by a Rubidium clock with 1 μs precision for MACRO, and by a quartz clock with 100 μs precision for EAS-TOP.

For a sample of 637 hours of data, Fig. 2 shows the distribution of the time difference between the reconstructed events of MACRO and EAS-TOP which had a time coincidence within a 4 ms window and angle $\psi \leq 10°$ between the two reconstructed directions. The correlation peak is well fitted by a gaussian with a $\sigma \sim 90$ μs. The mean value of 3.2 ms is due to a different internal zero-setting of the two clocks.

The area under the correlation peak over the accidental background level, within $\pm 3\sigma$, corresponds to $8.0 \pm 0.7$ correlated events per day, with an estimated accidental contribution of ~4%. This coincidence rate has remained constant during the entire measurement period.

The total number of coincidences found in the whole data sample using this selection is 347.

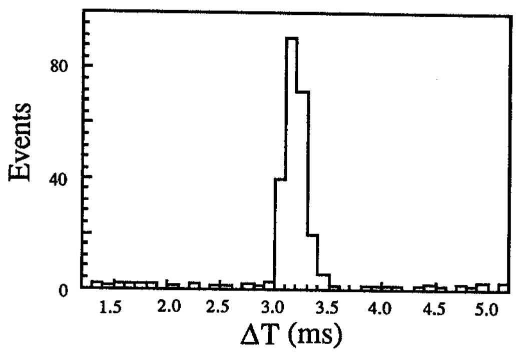


FIG. 2 Time distribution of the reconstructed events of EAS-TOP and Macro in coincidence, within 4 ms. and $\Delta\psi \leq 10°$.

## 3. SPATIAL AND ANGULAR RESOLUTION

The achievable accuracies in event reconstruction depend

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** For the complete list of the collaboration see G.Navarra, these proceedings.

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on physical and instrumental effects. In the case of EAS-TOP, the main physical uncertainty is given by the time and density fluctuations of the particles inside the shower disk. This is more relevant far from the shower axis and at the lower energies (up to a few nanoseconds). From the instrumental point of view, ADCs and TDCs have to be carefully and frequently calibrated. In the case of MACRO, the tracking system gives a high intrinsic accuracy, but the actual limiting factor is the multiple scattering of muons in the rock .

In order to have a first understanding of the reconstruction capabilities of the combined experiments, our selection has been restricted to the "internal trigger" events. These are the events in which the largest number of particles is recorded by an EAS-TOP counter not belonging to the edge of the array. In our whole sample, corresponding to the 1107 hours of running, the number of internal trigger events is 93 out of a total of 347.

To study the angular accuracy of the combined experiments a cut ($\Delta X$, $\Delta Y \leq 60$ m ) has been applied to the difference of the measured core location coordinates. After the cut, 90 events remain out of 93. The measured resolutions and averages on the projected angular difference along X (East-West direction) and Y (South-North direction) are $\sigma_{\theta x} = 1°$ and $\sigma_{\theta y} = 1.2°$, with $< \Delta\theta_x > = -0.04 \pm 0.10°$ and $<\Delta\theta_y> = -0.20 \pm 0.12°$. No appreciable systematic effects are seen. The corresponding accuracy in the relative pointing between the two experiments ($\psi$) is 1.5°. The distribution of the $\psi$ is shown in Fig. 3.

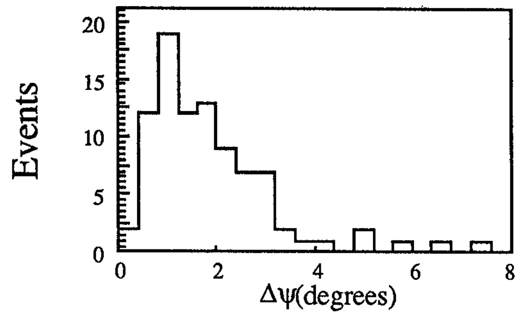


FIG. 3 Distribution of the angles in space between the reconstructed directions.

Selecting only the events for which $\psi \leq 5°$ (87 out of 93), the analysis of the difference in the shower core location by the two experiments, as projected on a plane perpendicular to the direction reconstructed by EAS-TOP, gives a resolution of ~26 m. For the events with shower size $N_e \geq 10^5$ and muon multiplicity $N_\mu \geq 2$, the resolution decreases to ~13 m, which is in agreement with expectations. However, the present data sample is not sufficient to analyze a possible dependence of the geometrical reconstructions on the shower size. As expected, slightly worse resolutions are obtained when edge events are included.

4. MULTIPLICITY DISTRIBUTION

Fig. 4 shows the measured multiplicity distribution for the 87 intewrnal trigger events. It must be compared to the multiplicity distribution measured by MACRO in stand alone operation, which is shown in the same figure normalized to $N\mu = 1$. These data refer to a 1740 hour of effective running time with $\theta < 70°$. The different ratio of multiple to single muons in the two cases is a direct reflection of the higher primary energy threshold in the coincidence experiment.

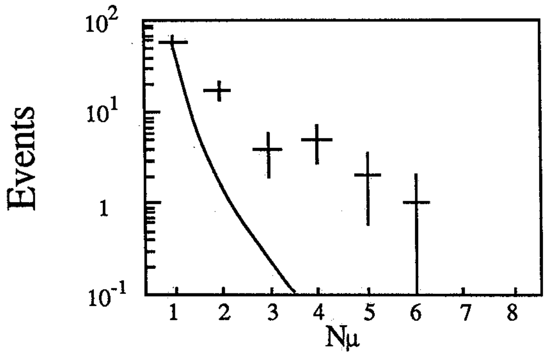


FIG. 4 Muon multiplicity distribution of the observed internal events.

5. CONCLUSION

The results presented here show that the coincidence experiment at the Gran Sasso Laboratory between EAS-TOP and MACRO has achieved good detection and operational efficiency. In particular, the geometrical reconstruction of the events obtained is without systematic effects.

Many improvements are scheduled in the near future. As MACRO puts additional supermodules into operation, its active surface will increase by a factor of 6. EAS-TOP will lower the energy threshold by a factor 3 and increase its sensitivity at high energy. Furthermore, an absolute time resolution of ~1 μs will be achieved. After 3 years of running, an increase in statistics by a factor of 100 is expected, hopefully allowing a quantitative study of the cosmic ray spectrum and composition.

REFERENCES

1.E. Bellotti, 1988, Nucl. Instr. and Meth A264, 1.
2.M. Aglietta et al., 1989, Nucl. Instr. and Meth. A277, 23.
3.M. Calicchio et al., 1988, Nucl. Instr. and. Meth. A264 , 18.
4.T.K. Gaisser and T. Stanev, 1985, Nucl. Instr. and Meth. A235, 183.