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Time Track Complementarity Test Experiment at EAS-TOP: first results

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Abstract

The Time-Track Complementarity (TTC) approach is based on the selection of the undeviated muons in showers, whose production depth obtained from muon direction is in agreement with that obtained from muon arrival time, allowing the reconstrution of longitudinal production rate. To test the method, an array of Resistive Plate Counters (RPC) has been put into operation under the muon tracking detector of the EAS-TOP array to measure the arrival time of Extensive Air Showers (EAS) muons. Use of muon arrival time and direction together with EAS timing, direction and core location from the e.m. EAS-TOP array allows to test on the field the proposed selection reconstruction procedure. Selection criteria, as well as first results, are presented.

1 Introduction:

The TTC concept has been advocated some time ago by J. Linsley (Linsley 1992, Danilova 1994, Dumora 1996, Ambrosio 1997a) as a tool for investigating the longitudinal developement of EAS through a complete reconstruction of muon tracks in space as well as in time.

The general idea is simple: if muons went straight from the production to detection, also conserving the direction of the parent pions and kaons, measurements of space parameters as well as of the delay with respect to the shower arrival would provide two independent determinations (h_θ and h_t) of their production point (Erlykin 1996, Ambrosio 1997a,b); these determinations should coincide. However, due to the multiple scattering, deviation in geomagnetic field and muon transverse momentum with respect to the parent, $h_\theta \neq h_t$. The TTC concept then advocates using for the analysis only the muons for which the above determinations coincide (within experimental errors), thus providing an unambiguous determination of the production depth. Notice that the effects quoted above *decrease* with increasing energy, so the TTC selection effectively rejects muons of low energy (Ambrosio 1997a).

2 The experimental setup at EAS-TOP:

An experimental apparatus to test such technique has been implemented since 1997 within the EAS-TOP experiment at Campo Imperatore, National Gran Sasso Laboratories (LNGS) (Aglietta 1993, 1997). For the purpose of this paper, we can consider EAS-TOP as built from two independent detectors: an electromagnetic array, providing the space parameters of the shower, and a muon tracker (MHD) which produces the space recontruction of muons (Aglietta 1991). For $N_e \geq 10^5$, used in the present analysis, the shower size, core location and arrival direction are measured with accuracy, respectively: $\frac{\sigma(N_e)}{N_e} \approx 10$ %, $\sigma_r \approx 5$ m and $\sigma_\theta \approx 0.5^o$ (Aglietta 1993).

In order to implement the TTC concept, a layer of 40 m^2 RPC detectors (Ambrosio 1994) has been installed below the EAS-TOP muon tracking detector, to provide the measurement of the relative delay between muons and shower front. These detectors are the same used in the GREX/COVER_PLASTEX experiment (Agnetta 1997) and their use in EAS physics is described elsewhere (Agnetta 1996). The important feature from the point of view of this measure is the time resolution, which is better than 1 ns (Ambrosio 1994). The RPC detectors 1×2 m^2 large are arranged in five rows, each 8 m long and 1 m wide, read-out by 40 independent 0.5×2 m^2 pads.

The experimental setup has been installed in October 1997 and is taking data since January 1998. We have used two basic setups, differing in acquisition scheme and front-end electronics. In the first configuration, readout from RPCs was combined in a single time measurement per row, while presently times are read every 1 m^2 pad. Moreover the readout electronics is now faster and the acquisition logic is different.

This results in a better time resolution for the final configuration (2 ns wrt ≈ 3.5), in the possibility of resolving the ambiguity for multiple muon reconstruction intrinsic in MHD data and in the possibility of using of all the "internal" events of EAS-TOP.

In Grillo 1998 and Aramo 1998 we have presented an analysis of the data taken with the first configuration: this analysis has been important in defining the selection criteria and analysis tool. The results presented here concern data taken in the final configuration.

3 The Data:

The three components of the apparatus (RPC, EM, MHD) collect independent data which are subsequently correlated using event time, as read from atomic clocks. Data are collected when the EAS-TOP e.m. detector issues a trigger to MHD signaling a "internal" event, *i.e.* an event having the maximum of the e.m. density nearby the center of a trigger "circle" internal to the apparatus. Therefore, events are labeled by the corresponding trigger center, which in turn corresponds to a given average muon-axis distance. The measured delay (τ_μ) is thus the delay between the muon arrival time in the RPC counter and the firing time of such central detector near the core location. For the analysis described here events inside a cone of 20^o from the vertical (single muons in the RPC layer, but multiple in MHD) are used.

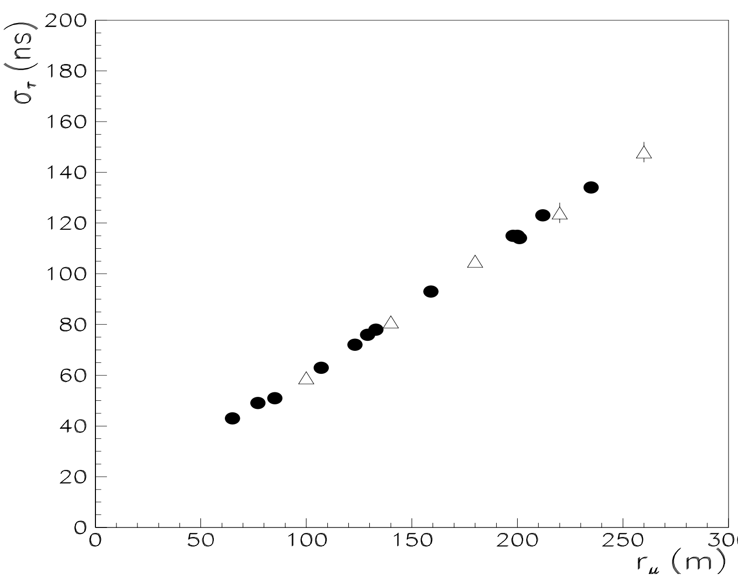

Figure 1: Width of time distribution versus muon-axis distance, compared with Monte Carlo (triangles)

The present analysis regards approximately 1.7 10^6 muons, detected in 5 months of operation. The two cuts described above reduce the sample to 470,000 events. A first measurement concerns the width of the time distribution at various relative μ-axis distances r_μ. It is easy to verify that the main contribution to the width, if the intrinsic experimental time resolution is of the order of nanoseconds, comes from the width of the angular distributions of EAS in the atmosphere; it increases linearly with r_μ and is essentially independent on the μ production height. This distribution is reported in Figure 1, compared with M.C. data (generated with Corsika 5.20, no apparatus simulation).

4 Data Analysis:

For this preliminary analysis we have put emphasys on selecting a sample as clean as possible, in order to understand the systematics of the apparatus: we have therefore applied stringent cuts, with a consequent reduction of the data sample. The unphysical delay introduced by cabling and electronics can be accounted for by a proper data analysis (Grillo 1998), at the price of the introduction of a systematic error. A determination of this delay will follow through measurement. It is convenient to trasform coordinates, angles and times in a reference frame having the z axis coincident with the shower axis; therefore we measure slant heights.
Highly deviated muon tracks are eliminated by requiring that the azimuth angle of the muon points to the shower axis (Aramo 1998). Only events for which the muon-axis distance is larger than 100 m. The final sample consists in $\approx 96,000$ events.

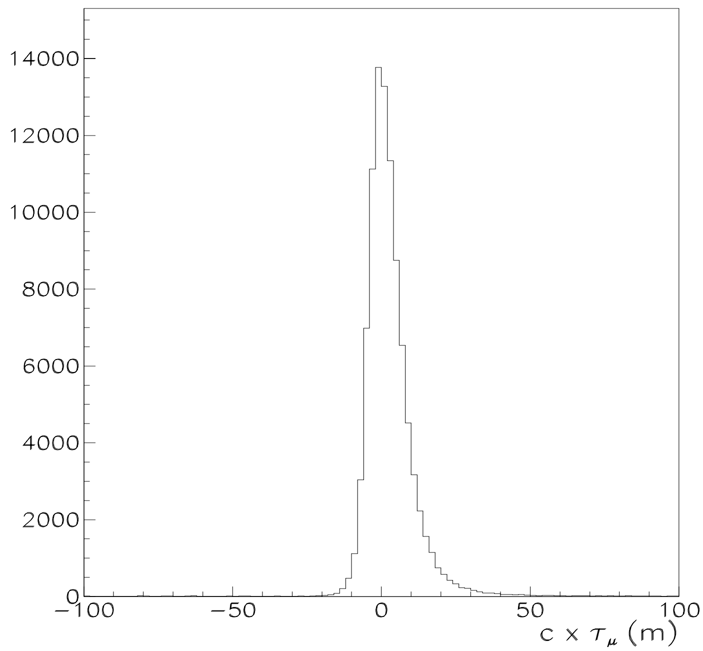

Figure 2: Muon delay $c \times \tau$ (in m)

In the shower frame the width of muon delay distribution respect to the shower front (Figure 2) is intrinsic and due to the production height distribution andinstrumental resolution. From this delay the muon production height h_t can be evaluated (Aramo 1998) and compared with obtained from the muon direction h_θ. Figure 3 shows the correlation between the two indipendent measurements h_t and h_θ: the correlation between them is evident. This correlation suggests to apply the TTC cut defined as the selection of events in a cone around the diagonal of distribution in Figure 3 (inside the two lines superimpose to the graph), where the two determinations coincide within the experimental errors. In total 17,000 events survive this selection and the distribution of the average slant depth (in g/cm^2) $Z_{TTC} = (Z_t + Z_\theta)/2$ is reported in Figure 4.

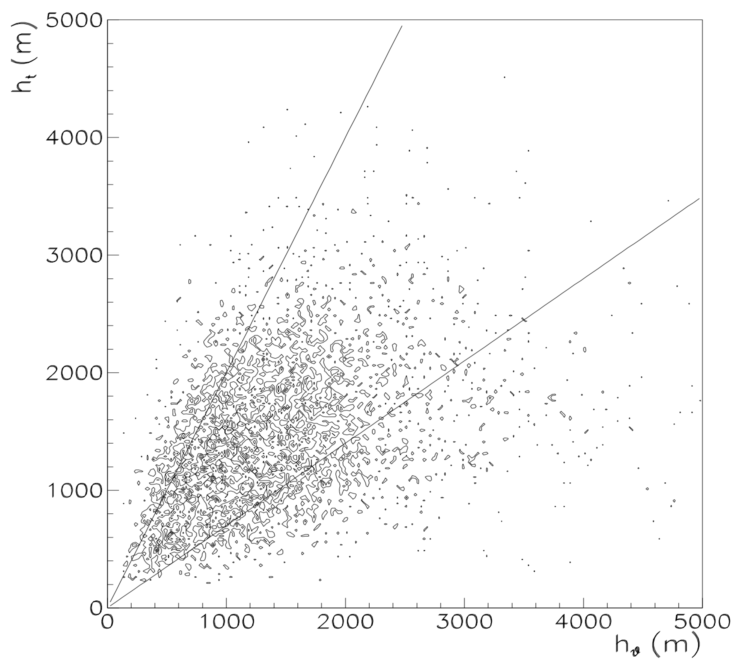

Figure 3: h_t versus h_θ

5 Conclusions

A test to verify the TTC approach to the study of the longitudinal developements of EAS is running at Campo Imperatore (LNGS).
First results of the final configuration of the apparatus suggest that the main basis of the method (*i. e.* coincidence of h_θ and h_t for unscattered muons) are verified. The expected correlation between production depth determinations from muon tracking and timing for the selected muons is found.

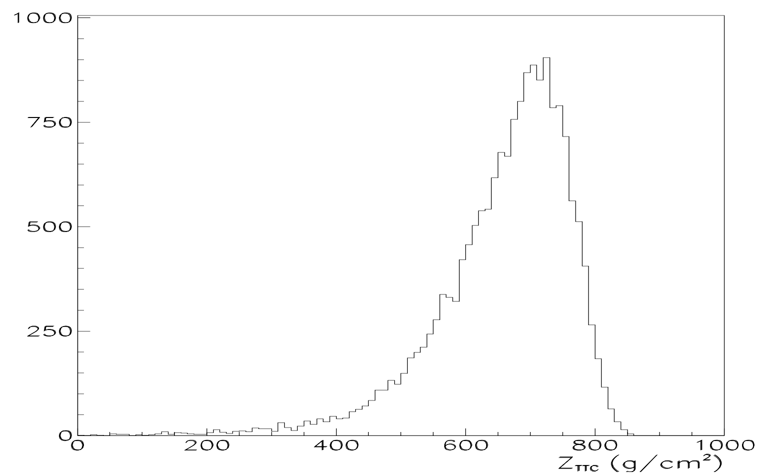

Figure 4: Muon production slant depth Z_{TTC}

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