ARGO-YBJ Experiment: study of extensive air shower structure

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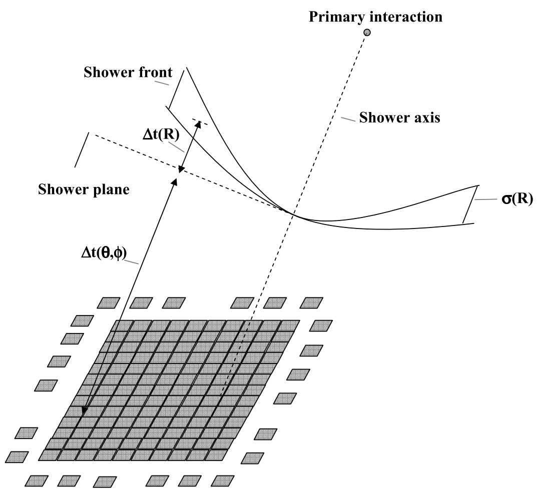

Figure 1. Sketch of shower front geometry and observables.

0.1. Study of shower time structure and morphology

The Lecce group is carring out a detailed study of the time structure and morphology of the front of extensive air showers as detected by ARGO-YBJ [1] (see also [2] and [3] for the analysis details).

The space-time structure of extensive air showers depends on primary mass, energy and arrival direction and on the interaction mechanisms with air nuclei. A flat array like ARGO-YBJ can measure the particles arrival times and their densities at ground. The digital readout allows detecting shower secondary particles down to very low density and the high space-time granularity is able to provide a fine sampling of the shower front close to the core. The time profile of the shower front can be reconstructed by the time of fired pads. Particles within several tens of meters from the shower core are expected to form a curved front which can be well fitted by a cone.

The following observables were investigated in the energy range between 300 GeV and 100 TeV:

- **Curvature** of the shower front as the mean of time residuals with respect to a planar fit ($\Delta t(R)$ see Fig. 1)
- **Thickness** of the shower front as the root mean square (RMS) of time residuals with respect to a conical fit ($\sigma(R)$, see Fig. 1).

The space and time structure of the shower disk has been studied as a function of the distance to shower axis, in intervals of 1 m up to a maximum distance of 80 m. Fig. 2 (top) shows the mean of time residuals with respect to a planar fit for different pad multiplicities. The arrival time delay from planar fit increases with distance giving time delays larger than 10 ns for particles landing further than 50 m from the core. No significant dependence on pad multiplicity is observed. Fig. 2 (bottom) shows the RMS of time residuals with respect to the conical fit as a function of distance to shower axis for different pad multiplicities. The thickness of the shower front increases with distance and it tends to become thinner for increasing multiplicities.

Fig. 3 (top) shows the time residuals with respect to planar fit for data and simulation (see [3] for the details on Monte Carlo simulation), concerning pad multiplicity between 200 and 400. Data and simulation show a very good agreement at the level of this observable. The agreement remains good for higher pad multiplicities and larger zenith angles.

The measured shower thickness has been found to be systematically larger than expected from simulation and this feature doesn't change with multiplicity, even, as shown in Fig. 3 (bottom), for the highest multiplicities at which the quality of reconstruction is enhanced. However, due to temperature and pressure variations occuring in real operating conditions, data suggest a lower time resolution [4] than assumed for this study ($\sim$1 ns). Besides that, the simulation doesn't include the contribution of heavier primaries. These facts may account for part of the observed discrepancy.

Shower by shower fluctuations play a key role

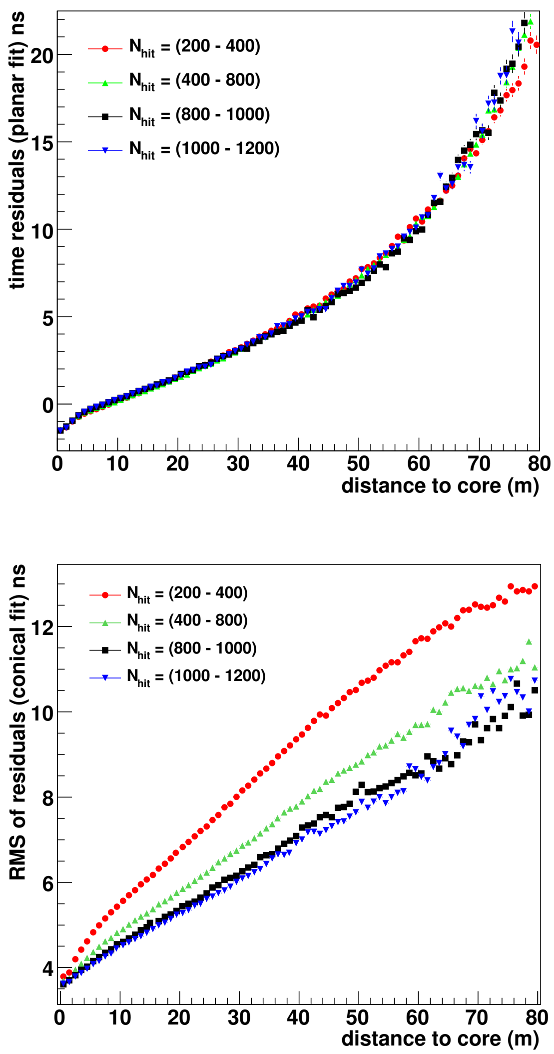

Figure 2. Mean of time residuals with respect to a planar fit (top) and RMS of time residuals with respect to a conical fit (bottom) as a function of distance to the shower axis for different pad multiplicities and for zenith angles less than 15°. Data are shown (statistical uncertainties only).

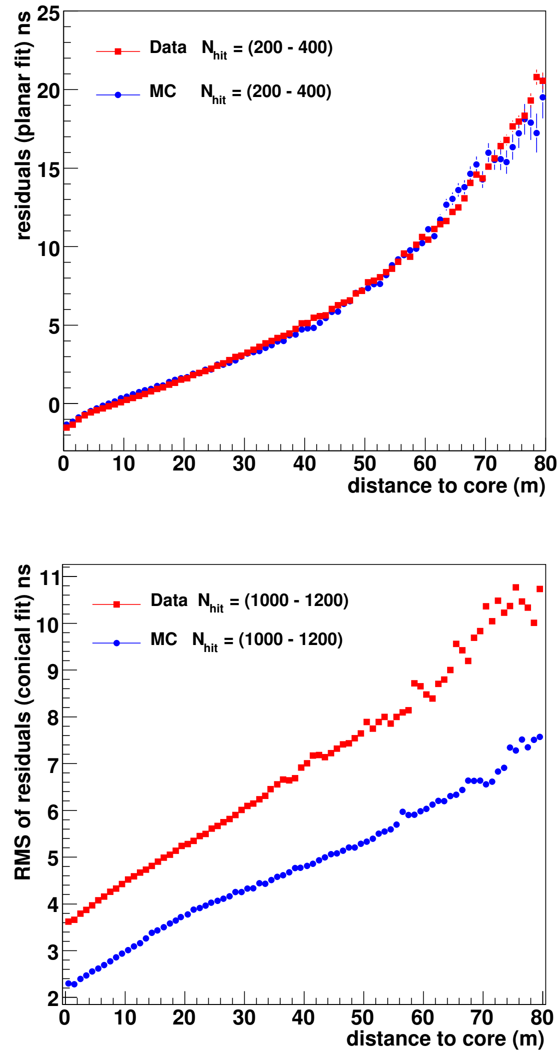

Figure 3. Time residuals with respect to a planar fit (top) and RMS of time residuals with respect to a conical fit (bottom) for data and simulation. Pad multiplicity between 200 and 400 (top) and between 1000 and 1200 (bottom). Zenith angle less than 15° (statistical uncertainties only).

for the understanding of EAS morphology. The design of the ARGO-YBJ detector offers a unique chance to have high-resolution pictures of shower footprints at ground. Each observed event keeps track of the propagation through the atmosphere. This factor can influence the shape of time front and the sequence of arrival times. For showers interacting deeper in the atmosphere, ("young showers"), due to geometrical reasons, the arrival of particles at a given lateral distance is expected to be more delayed compared to showers that have interacted higher in the atmosphere ("old" showers). Young showers will then exhibit a steeper time profile with respect to a planar fit. Additionally, secondary muons, more abundant in hadron-induced showers, originate at even higher altitudes and their contribution further reduces the time delay leading to a flattening of the arrival time profile. A study of the correlation between the conicity parameter α assigned to each reconstructed event and the atmospheric depth at shower maximum stage, Xmax, has been performed using CORSIKA simulations. Results are shown in Fig 4 for proton and photon primaries. More than 10^7 photon-induced CORSIKA showers have been produced with the same hadronic interaction models as for proton and used for this analysis. As shown in Fig. 4, the average value of

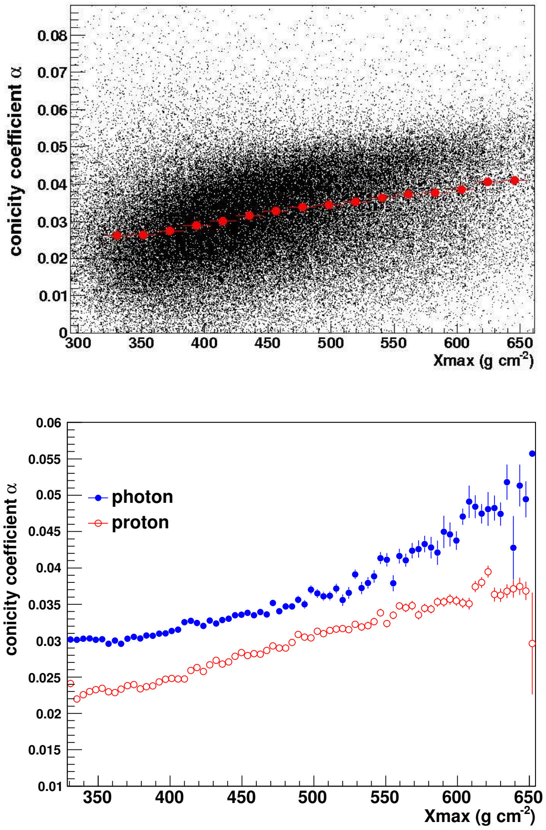

Figure 4. The conicity parameter α as a function of the atmospheric depth at the shower maximum Xmax for proton (top) and compared to photon (bottom) (statistical uncertainties only).

α tends to increase for deeper Xmax. Indeed, on an event by event basis, the true value of Xmax is associated to the reconstructed conicity and a deep Xmax, independently of multiplicity, is expected to give a younger shower with larger α.
Photon-induced showers behave similarly but they have a higher average conicity reflecting their intrinsic structure dominated by a pure electromagnetic component with a much smaller muon content with respect to hadronic showers.
Though very challenging from the experimental point of view, a measured conicity can be correlated with an average Xmax, providing and indication of the stage of shower development. This study is still in progress (i.e heavier primaries have to be added, the impact of detector systematic uncertanties has to be considered) but several analyses, including the calculation of hadronic cross-sections (see [5]), might benefit from a positive outcome of this work.

REFERENCES

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