

# Time structures in shower longitudinal development with ARGO-YBJ detector

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on behalf of  
ARGO-YBJ Collaboration

• (Tibet), 4300 m a.s.l.



**High Altitude Cosmic Ray Laboratory @ YangBaJing**  
(Site Coordinates: longitude  $90^{\circ} 31' 50''$  E, latitude  $30^{\circ} 06' 38''$  N)

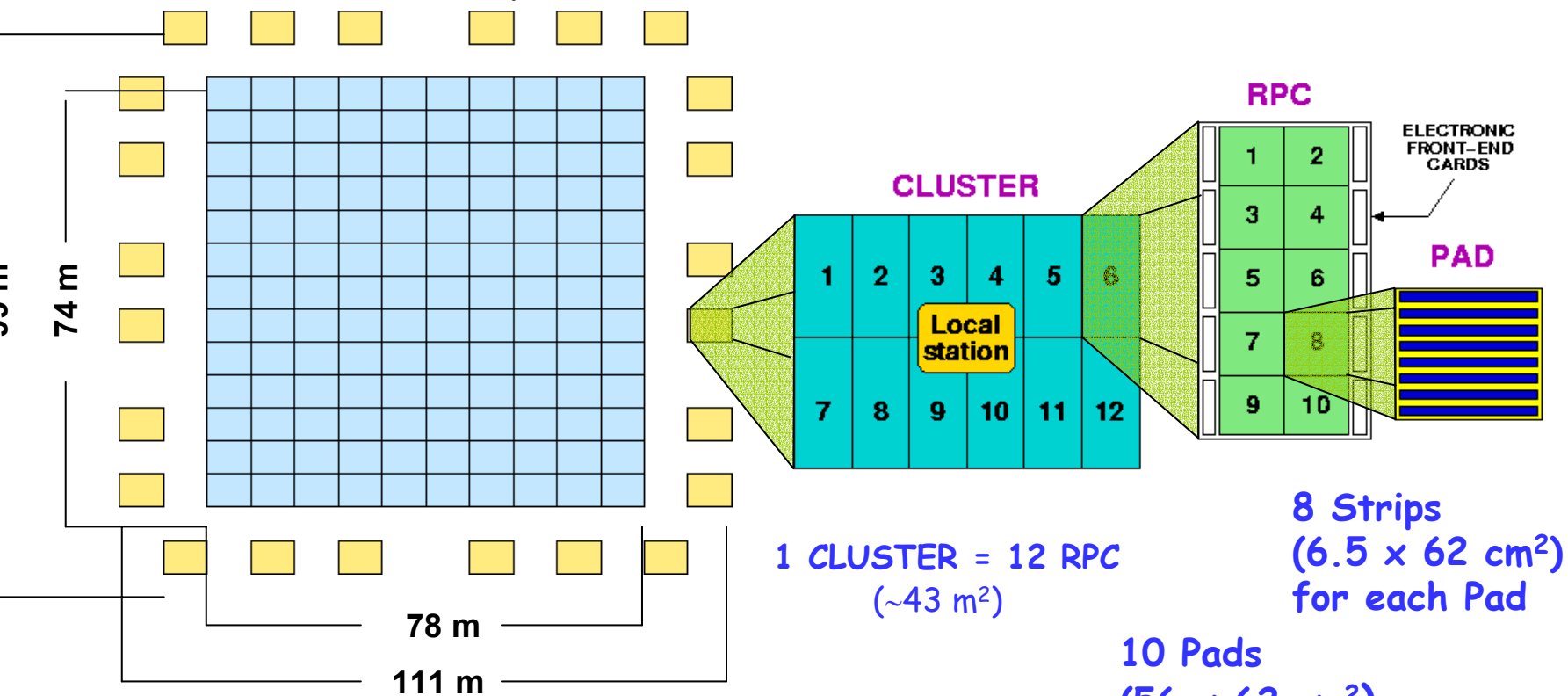


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Tev Particle Astrophysics 2007  
Venezia, Italy

# ARGO-YBJ layout

## Detector layout



1 CLUSTER = 12 RPC  
(~43 m<sup>2</sup>)

8 Strips  
(6.5 x 62 cm<sup>2</sup>)  
for each Pad

10 Pads  
(56 x 62 cm<sup>2</sup>)  
for each RPC

layer (~92% active surface) of  
Resistive Plate Chambers (RPC),  
covering a large area (5600 m<sup>2</sup>)  
+ sampling guard ring  
+ 0.5 cm lead converter

# Main detector features and performances

- ✓ Active element: Resistive Plate Chamber  $\Rightarrow$  time resolution  $\sim 1$  ns
- ✓ Time information from Pad ( $56 \times 62$  cm<sup>2</sup>)
- ✓ Space information from Strip ( $6.5 \times 62$  cm<sup>2</sup>)
- ✓ Full coverage and large area ( $\sim 10,000$  m<sup>2</sup>)
- ✓ High altitude (4300 m a.s.l.)



- good pointing accuracy ( $\leq 0.5^\circ$ )
- detailed space-time image of the shower front
- capability of small shower detection ( $\Rightarrow$  low E threshold)
- large aperture ( $\rightarrow 2\pi$ ) and high "duty-cycle" ( $\rightarrow 100\%$ )

$\Rightarrow$  **continuous monitoring of the sky** ( $-10^\circ < \delta < 70^\circ$ )

# Arrival Direction Reconstruction

In EAS experiments for an event E the time  $t_{EP}$  can be measured on each fired detector unit P, whose position  $(x_P, y_P)$  is well known

Primary direction cosines  $l_E = \sin \theta_E \cos \phi_E$  and  $m_E = \sin \theta_E \sin \phi_E$

$\theta_E$  = zenith angle

$\phi_E$  = azimuth angle

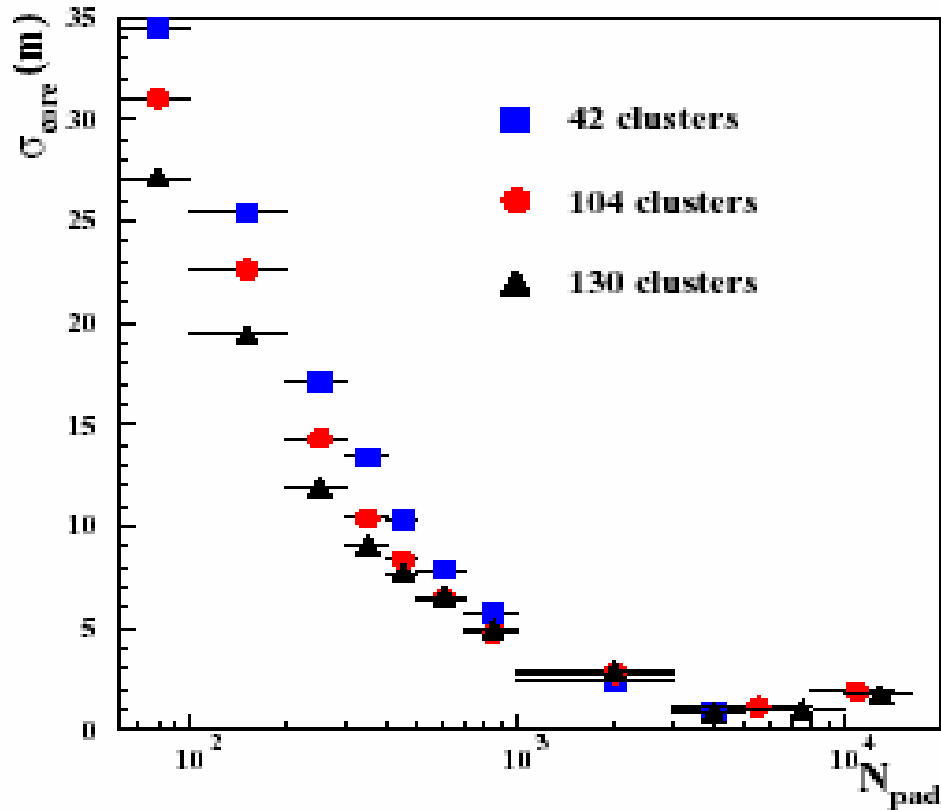
Planar Fit

$$\chi^2 = \sum_P \left( t_P - t_{0E} - \frac{x_P}{c} l_E - \frac{y_P}{c} m_E \right)^2$$

Conical Fit

$$\chi^2 = \sum_P \left( t_P - t_{0E} - \frac{x_P}{c} l_E - \frac{y_P}{c} m_E - \frac{R_P}{c} \alpha \right)^2$$

# Core Reconstruction



Shower core position resolution of internal selected protons as a function of the pad multiplicity for different detector dimensions.

# Timing Calibration

Taking into account the time offset  $\Delta_p$  typical of the detector unit

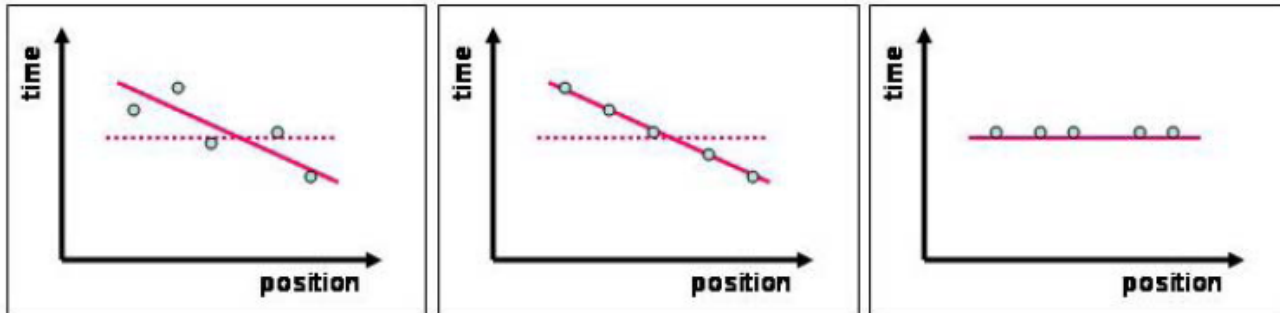
Characteristic Plane-equation

$$c(t_{EP} - \Delta_P - t_{0E}) = l_E x_P + m_E y_P$$

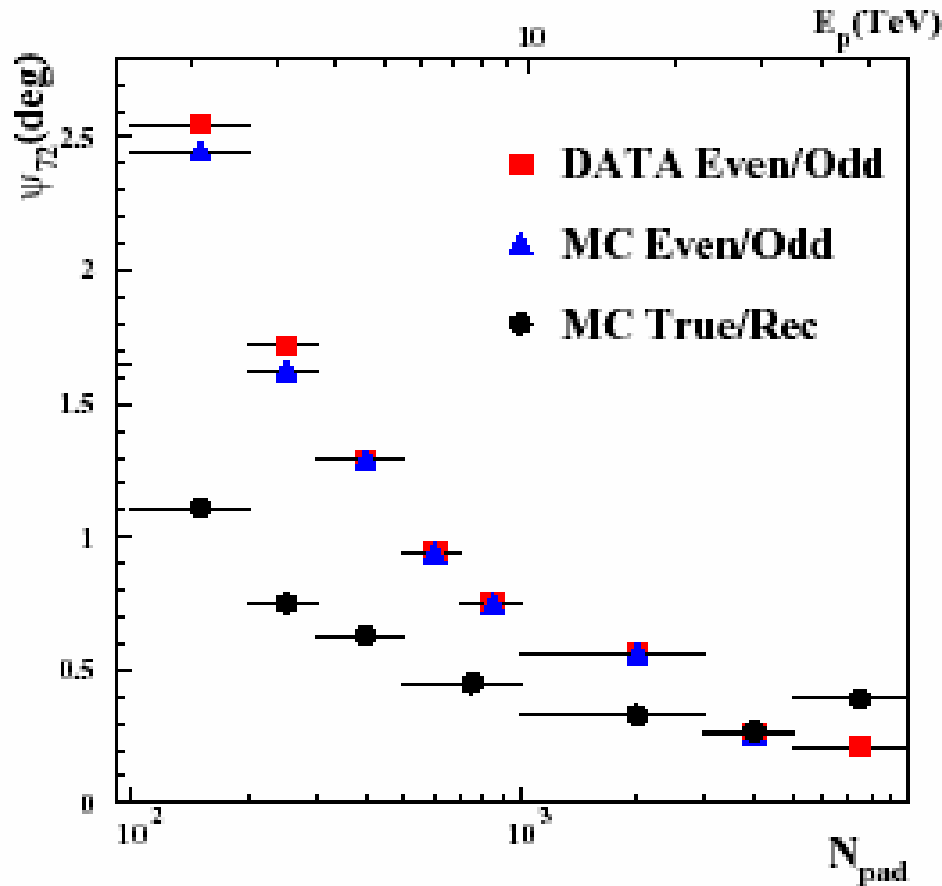
$\Delta_p =$  residual correction + systematic correction

Residuals correction reduces the differences between fit time and measured time

Systematic correction guarantees the removal of the complete offset

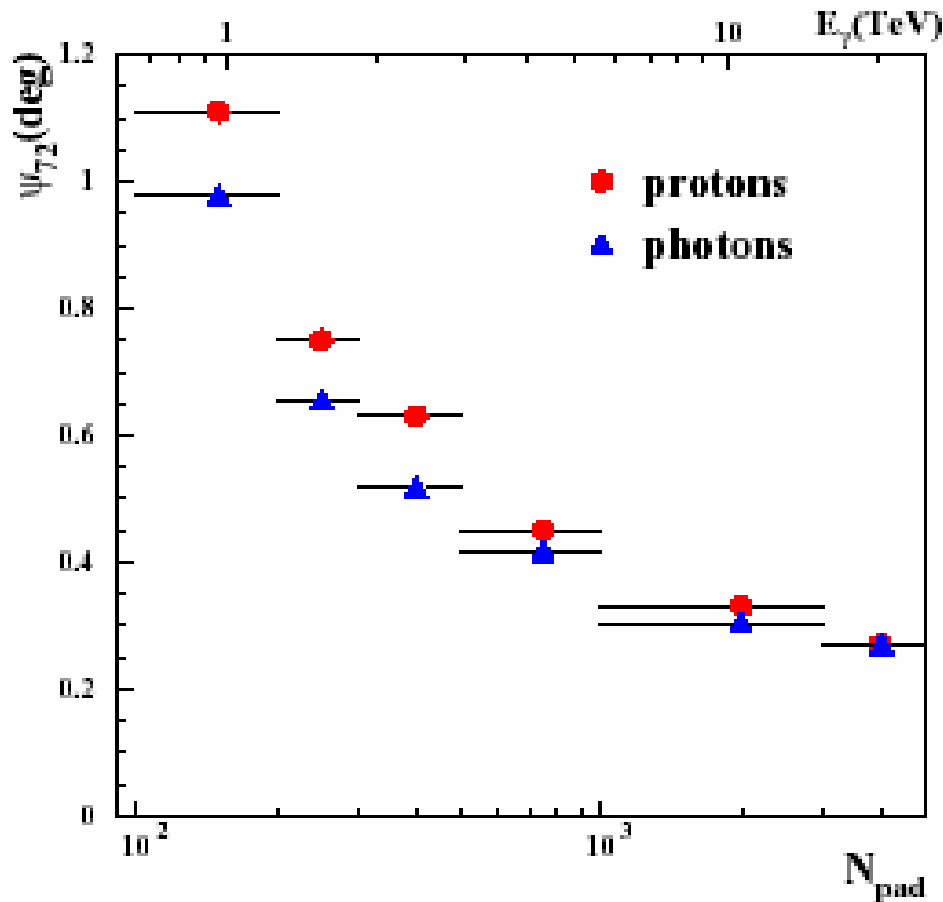


# Angular Resolution



The opening angle  $\psi_{72}$  as a function of pad multiplicity measured with ARGO-130 compared with MC simulations. The upper scale shows the estimated median energy for proton-induced showers. The error bars refer to the width of the pad multiplicity bins.

# Angular Resolution



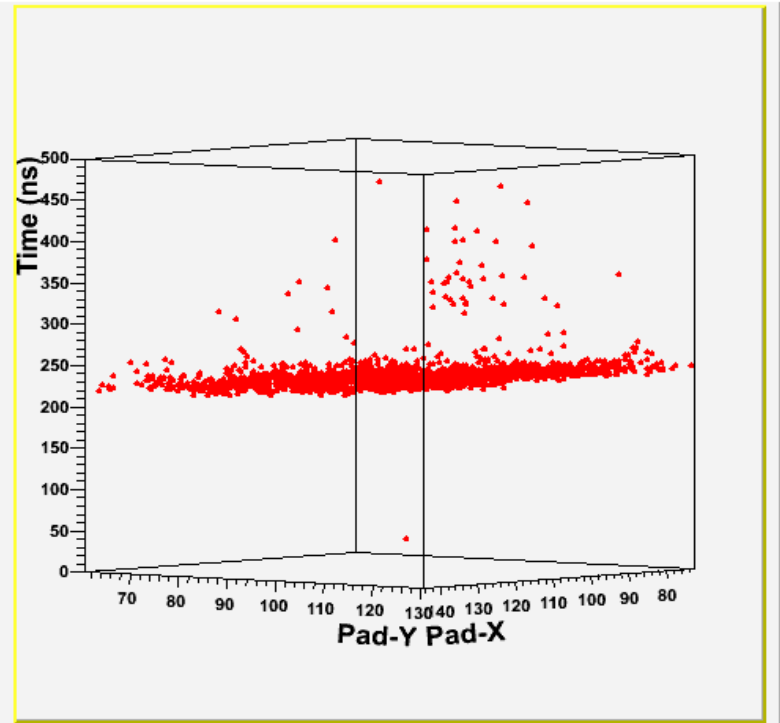
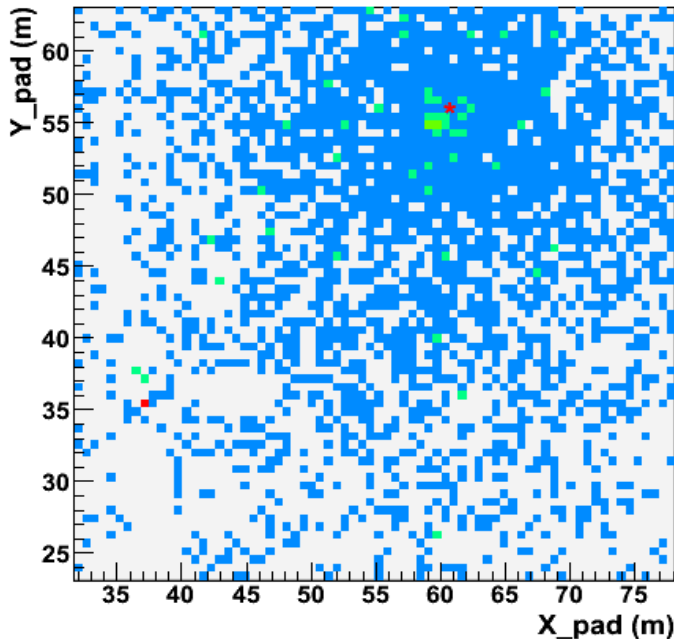
The opening angle  $\psi_{72}$  as a function of pad multiplicity for protons and photons. The error bars refer to the width of the pad multiplicity bins. The upper scale shows the estimated median energy for photon-induced events.

# ARGO-YBJ performance

High space/time granularity of ARGO-YBJ detector

⇒ capability of detecting several kinds of events, characterized by different topologies and time structures. Deeply inspect a wide and possibly unexpected EAS phenomenology.

## A very energetic shower

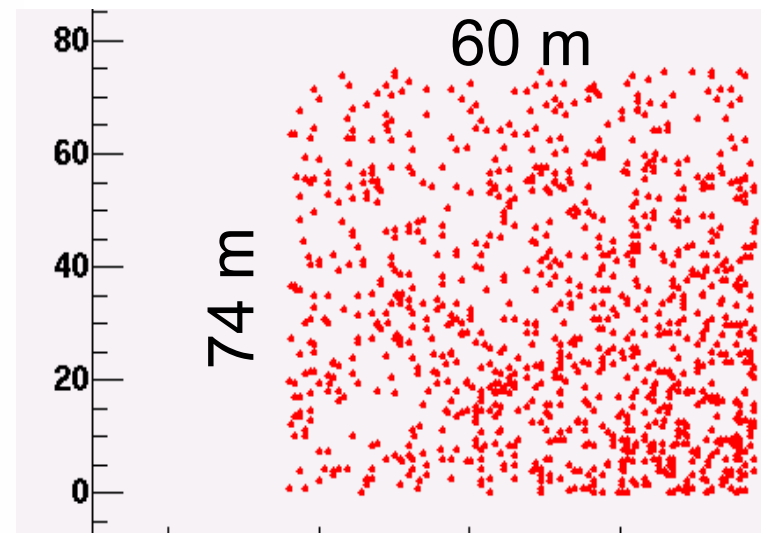
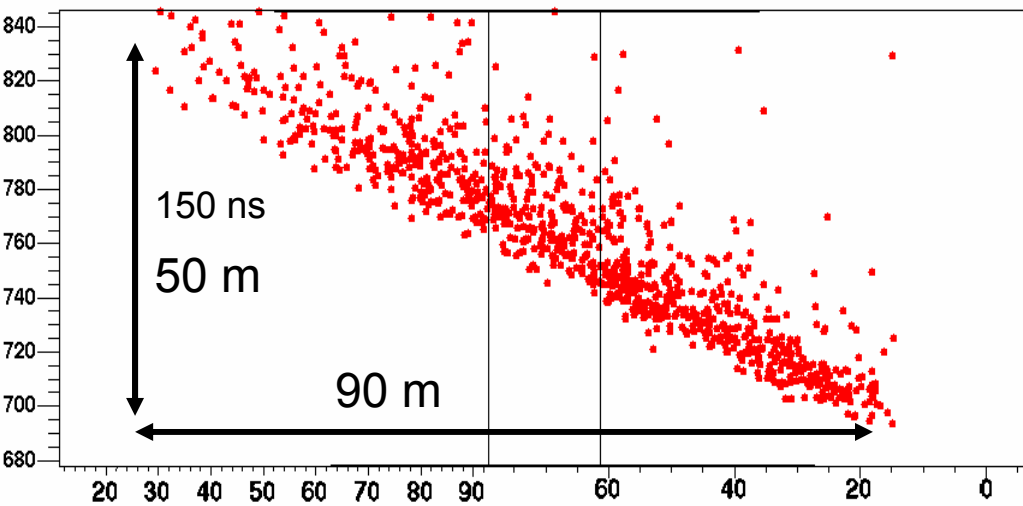
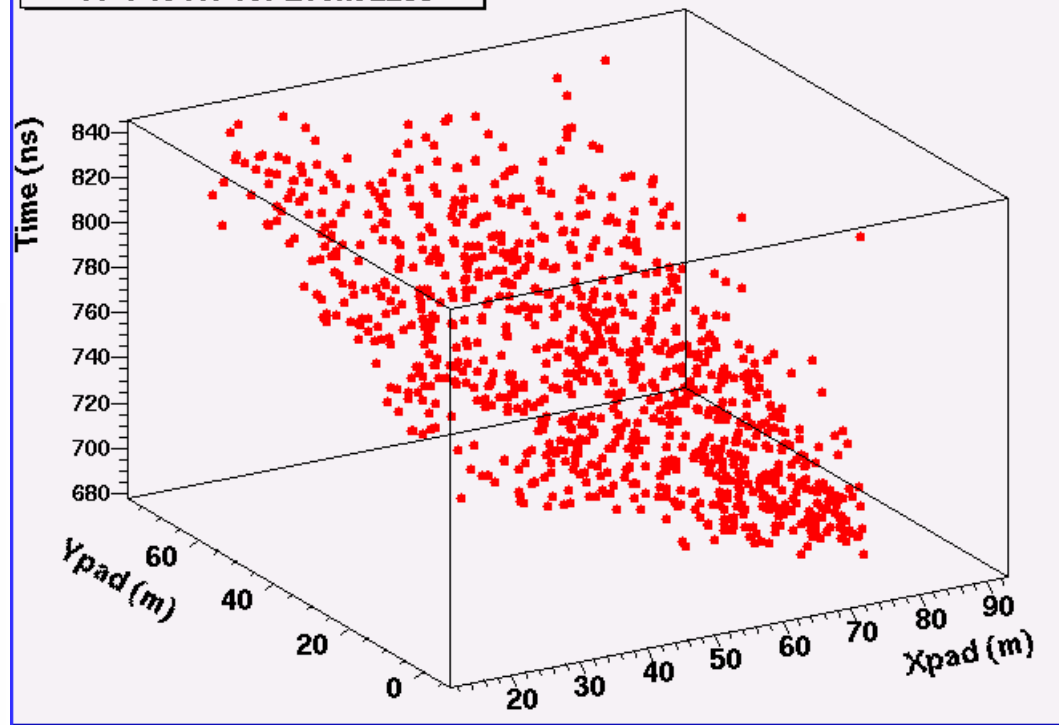


# A unique way to study EAS

Full space-time reconstruction

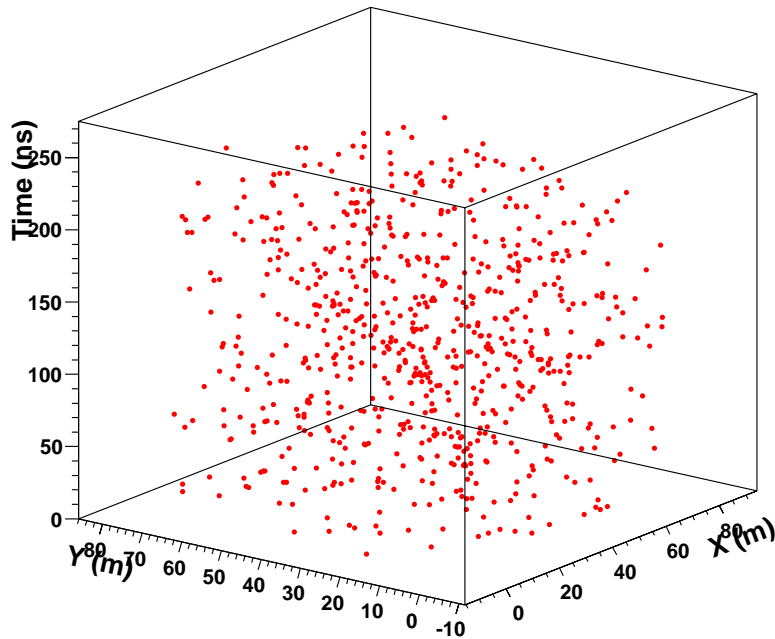
Shower topology

Structure of the shower front

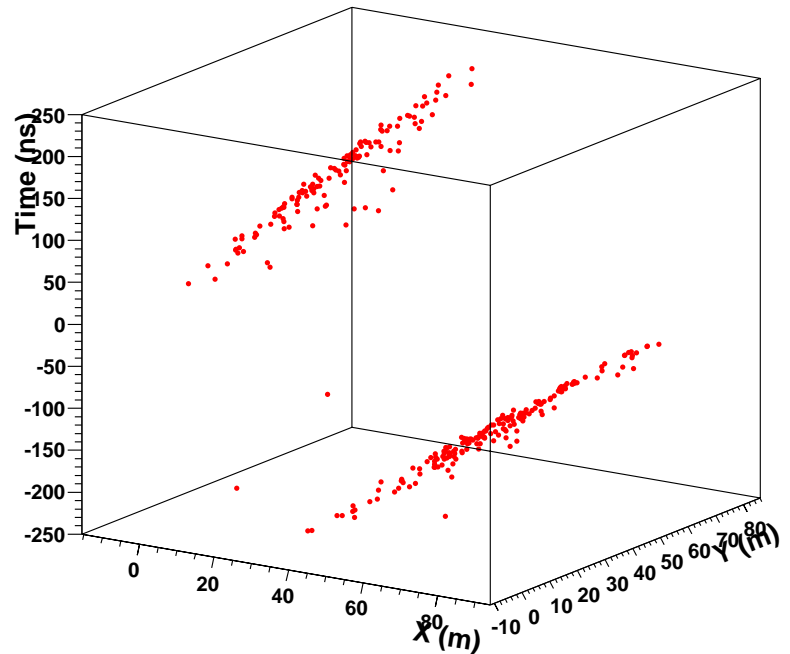


# Time structure of EAS front

ARGO-130



ARGO-130

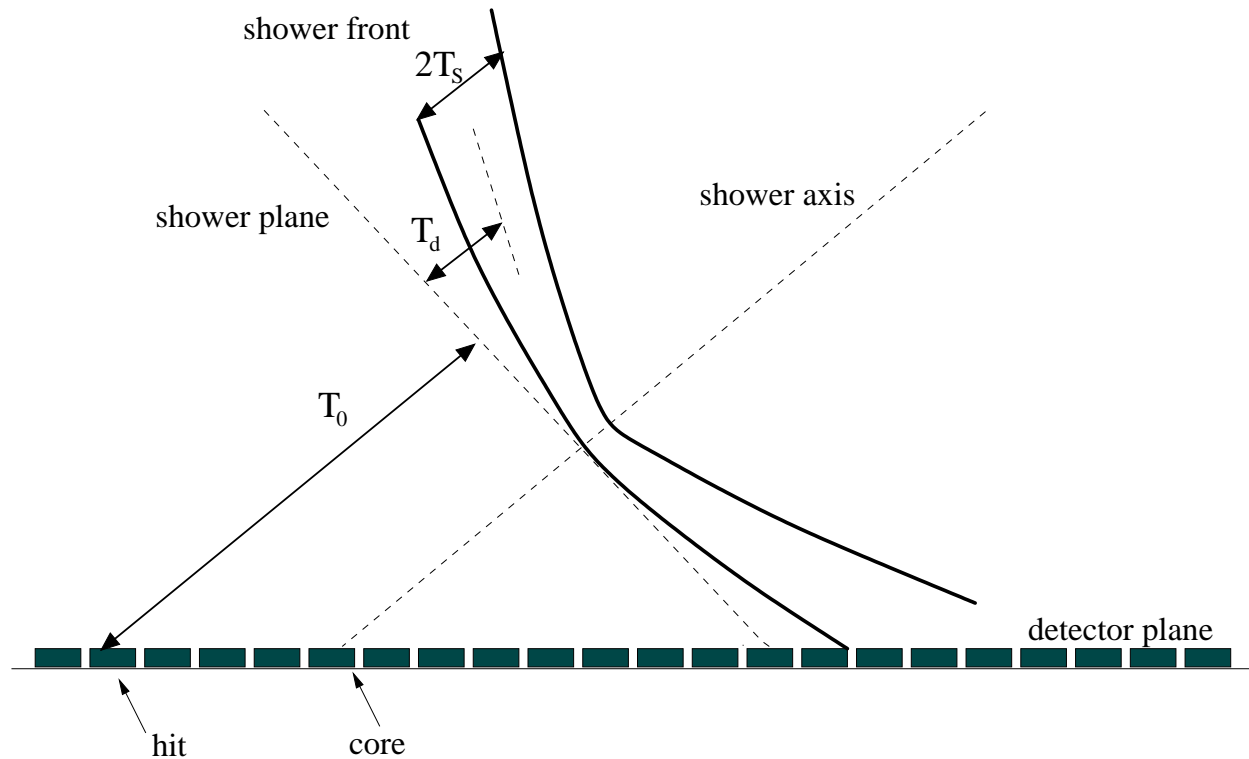


**Events with large rms of time residual respect to a conical fit**

# Time structure of EAS front

- The high space-time granularity of the *ARGOYBJ* detector allows a fine sampling of the shower front close to the core.
- The time structure of the shower disk has been studied as a function of the distance to the shower axis up to 40 m in 1 m bins.
- The curvature and shower thickness have been investigated in the energy range between few TeV up to 20 TeV.

# Time structure of EAS front



❖ The curvature ( $T_d$ ) of the shower front as the mean of time residuals with respect to a planar fit

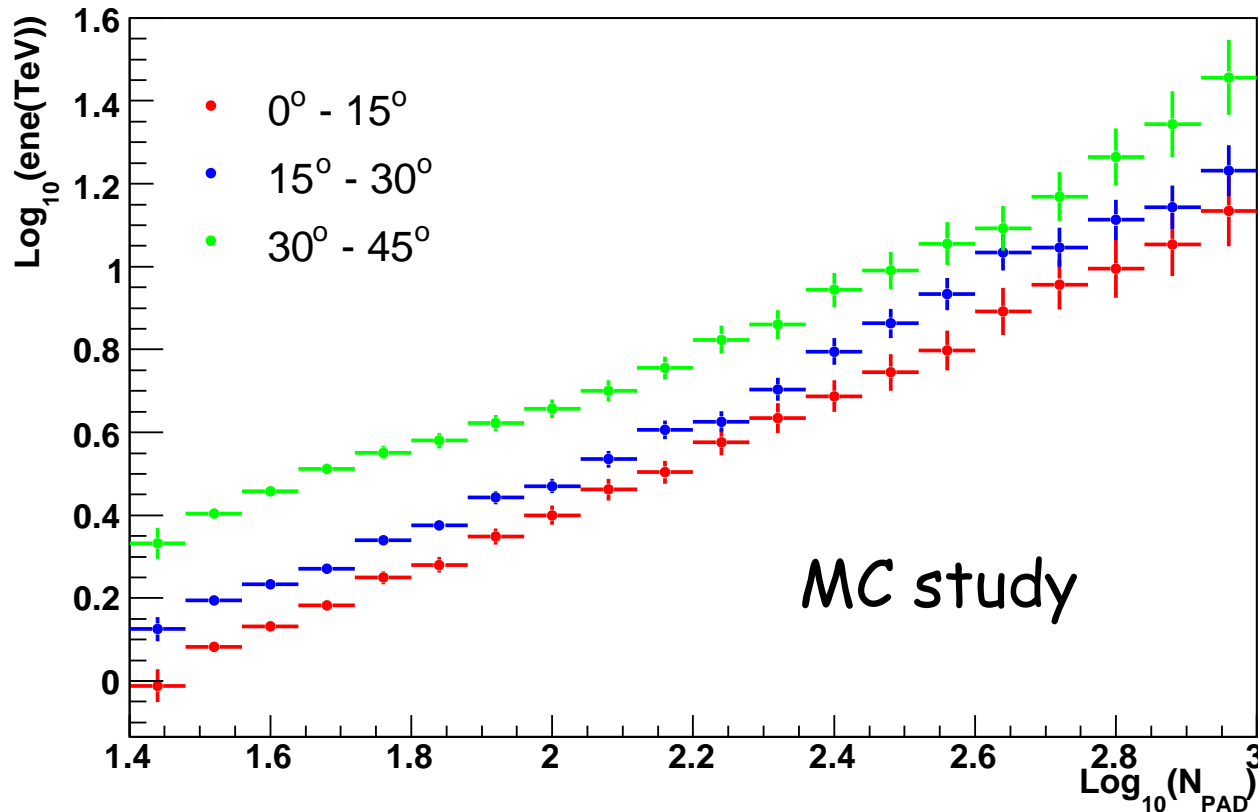
❖ The shower thickness ( $T_s$ ) of the shower front as the root mean square (RMS) of time residuals with respect to a conical fit

# The Sample

- $10^6$  well reconstructed events
- Core in  $20 \times 20 \text{ m}^2$
- Hit multiplicity  $> 200$
- Quality cut on  $\chi^2/\text{ndof}$

# Multiplicity – Energy correlation

Multiplicity  $\rightarrow$  Average primary energy (0-15°)



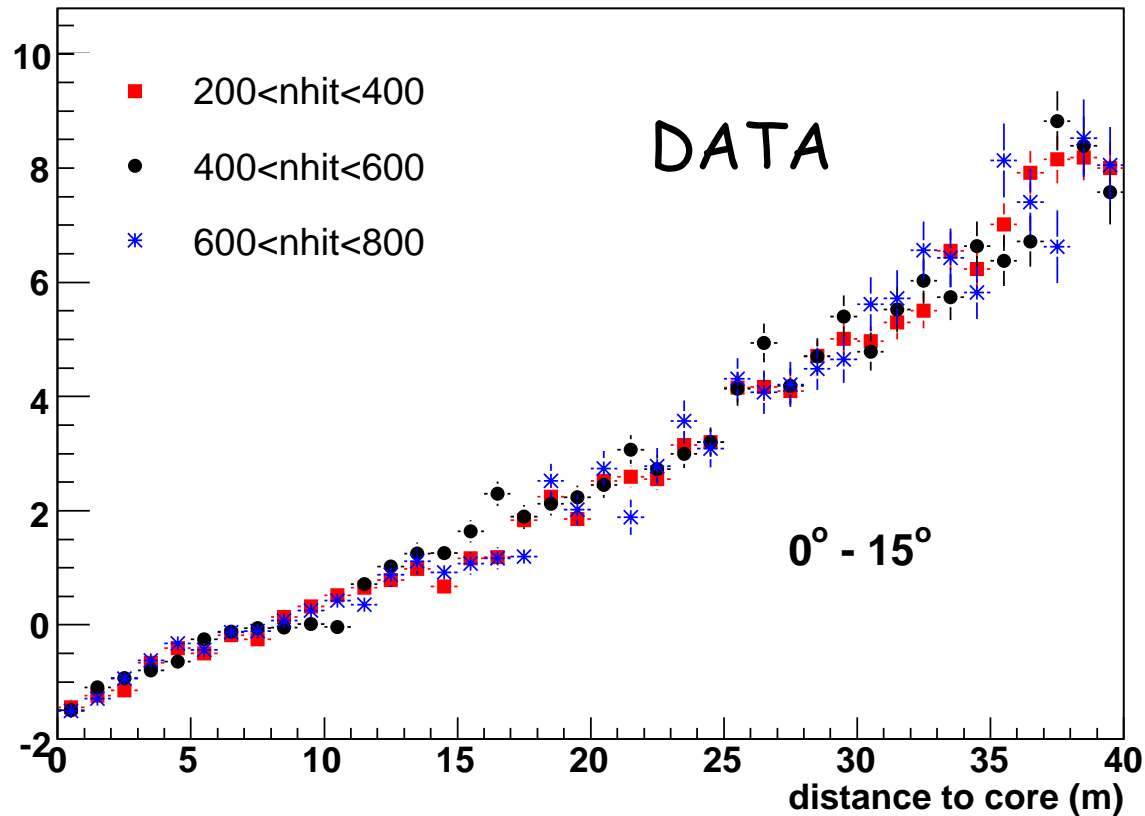
200  $N_{\text{pad}} \rightarrow 4 \text{ TeV}$

400  $N_{\text{pad}} \rightarrow 7 \text{ TeV}$

600  $N_{\text{pad}} \rightarrow 11 \text{ TeV}$

800  $N_{\text{pad}} \rightarrow 15 \text{ TeV}$

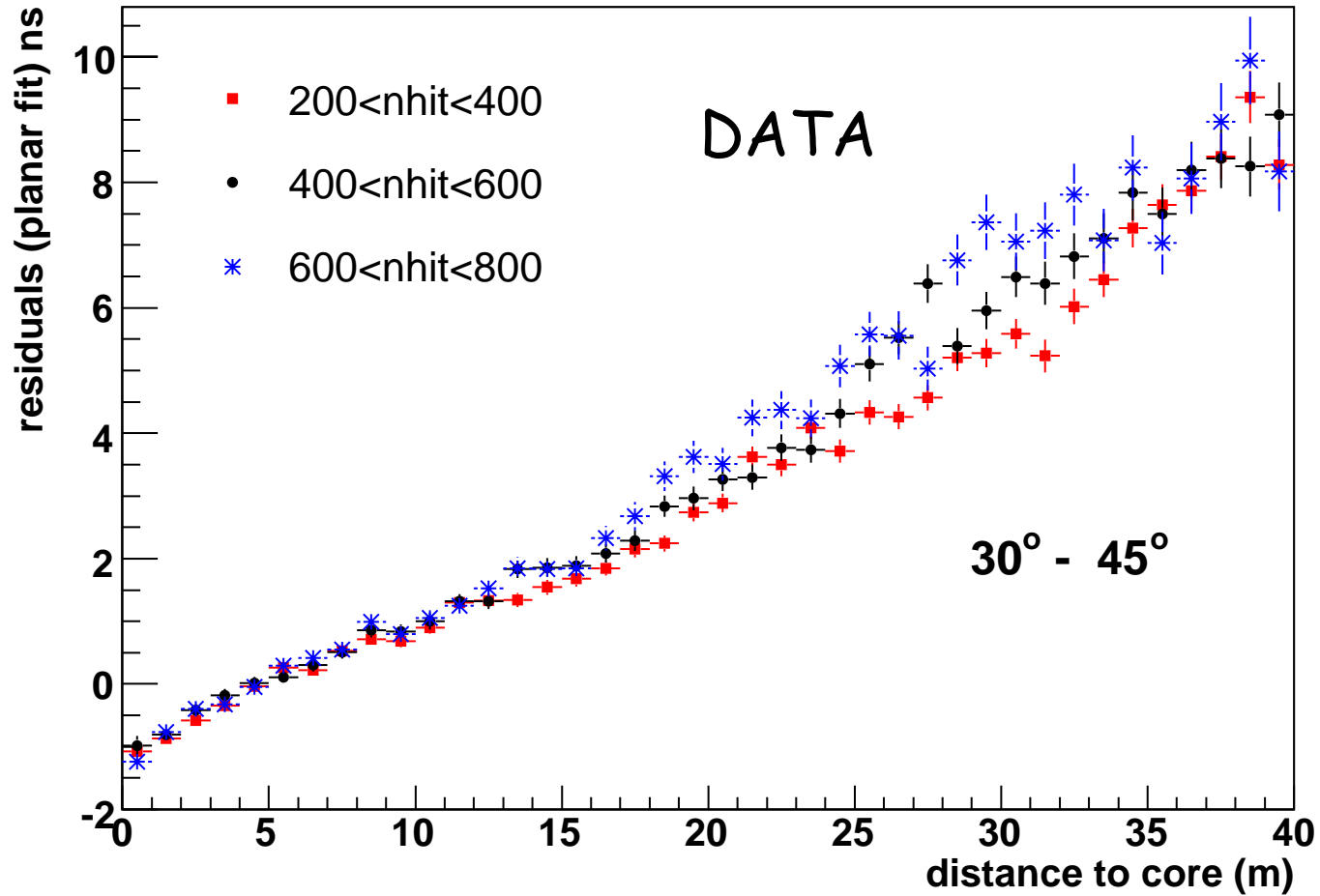
# Curvature



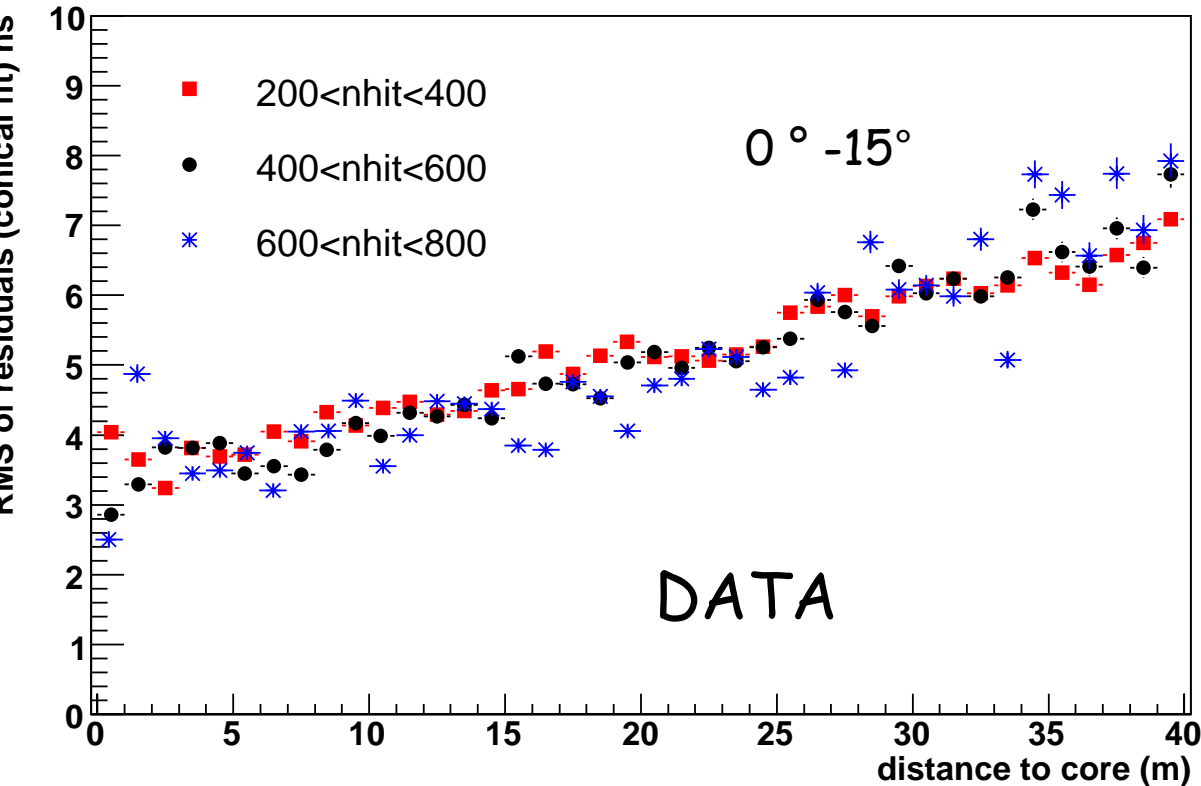
- mean of time residuals with respect to a planar fit as a function of the distance to the shower axis for different pad multiplicities and for zenith angles  $< 15^\circ$ .

- The deviation from a planar fit increases with distance (up to about 8 ns at 40 m) and depends only weakly on hit multiplicity in the considered energy range.

# Curvature



# Thickness of shower front



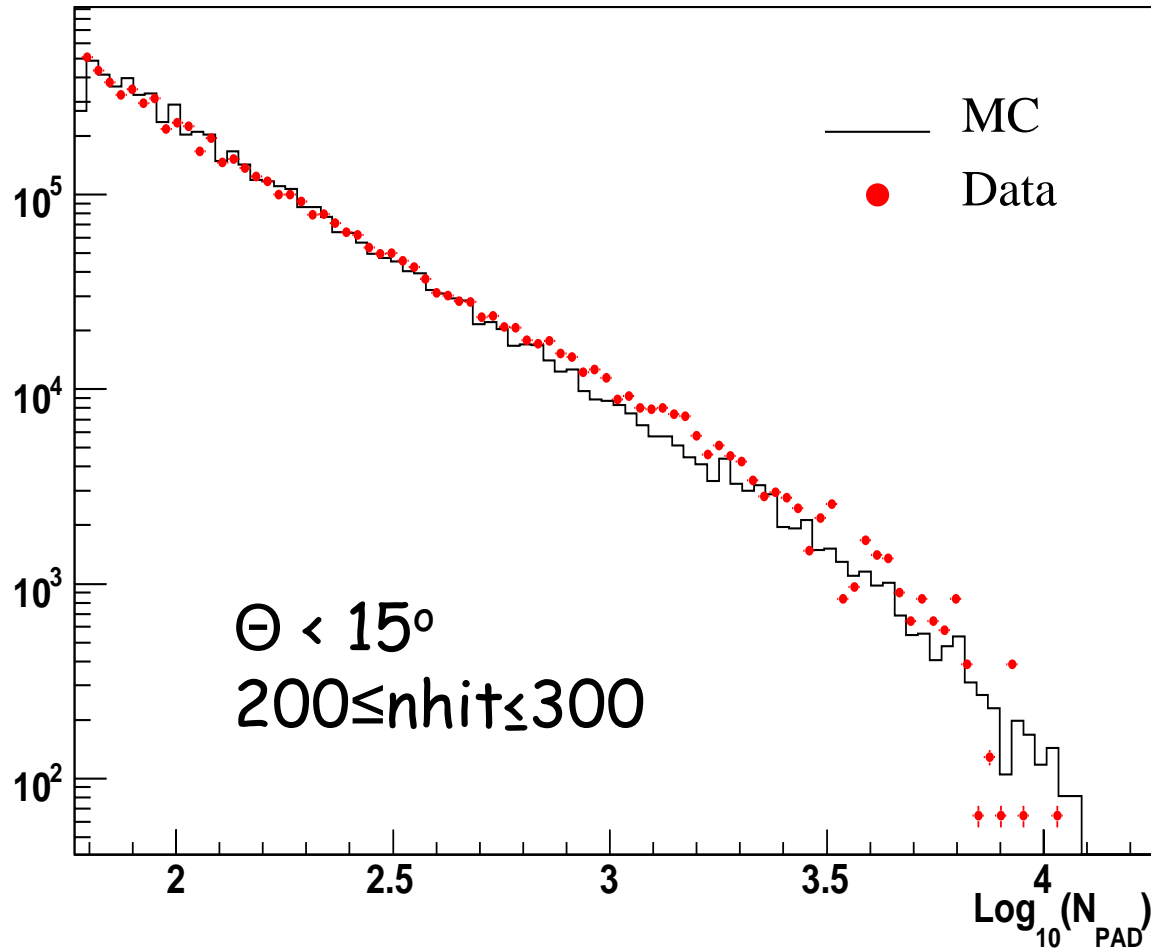
- RMS of time residuals with respect to a conical fit as a function of the distance to the shower axis for different pad multiplicities and for zenith angles  $< 15^\circ$ .

- The thickness of the shower front increases with distance (up to about 7 ns at 40 m) without any significant dependence on hit multiplicity in the considered energy range.

# Comparison of simulation to data

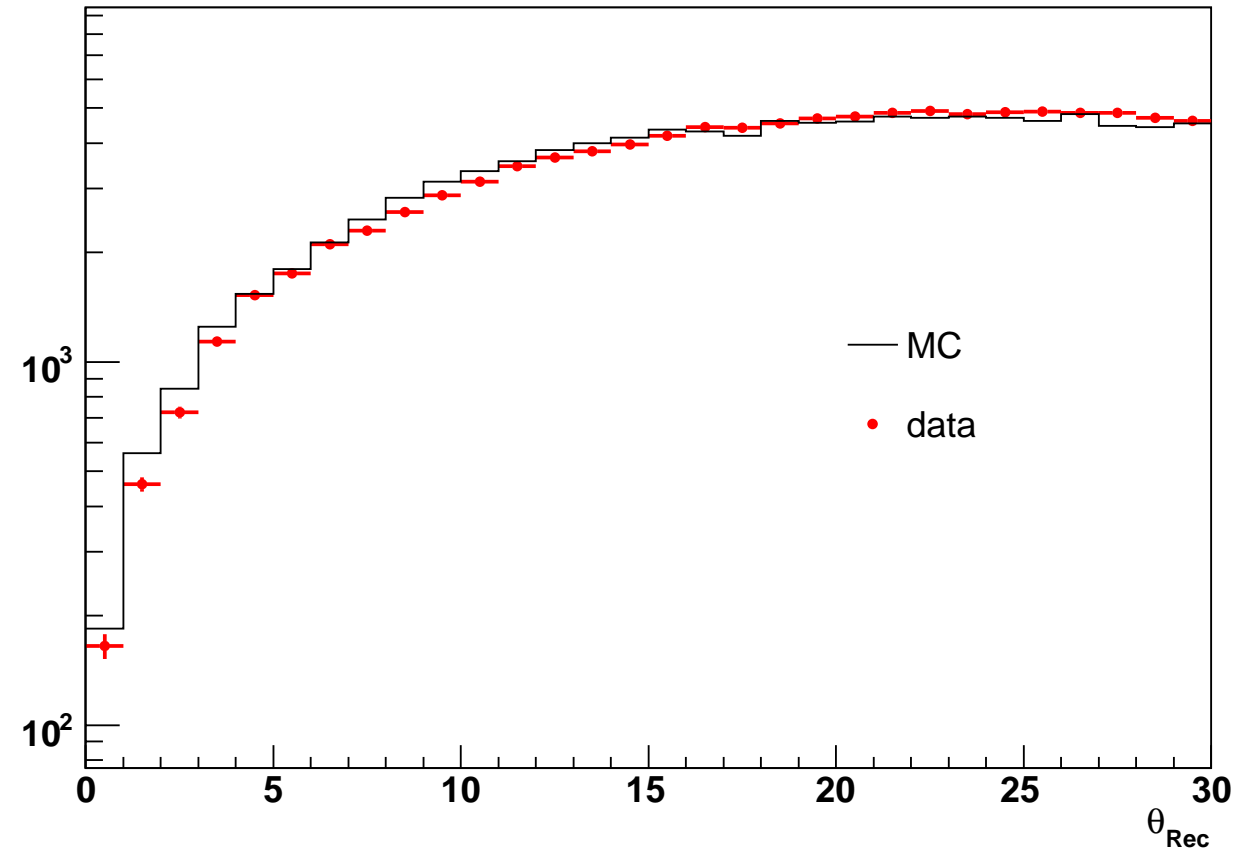
- $6 \times 10^6$  CORSIKA proton showers
- Zenith angle  $< 45^\circ$
- Spectral index  $-2.7$
- Energy range 100 GeV - 1000 TeV
- Detector simulation based on GEANT3

# Pad multiplicity



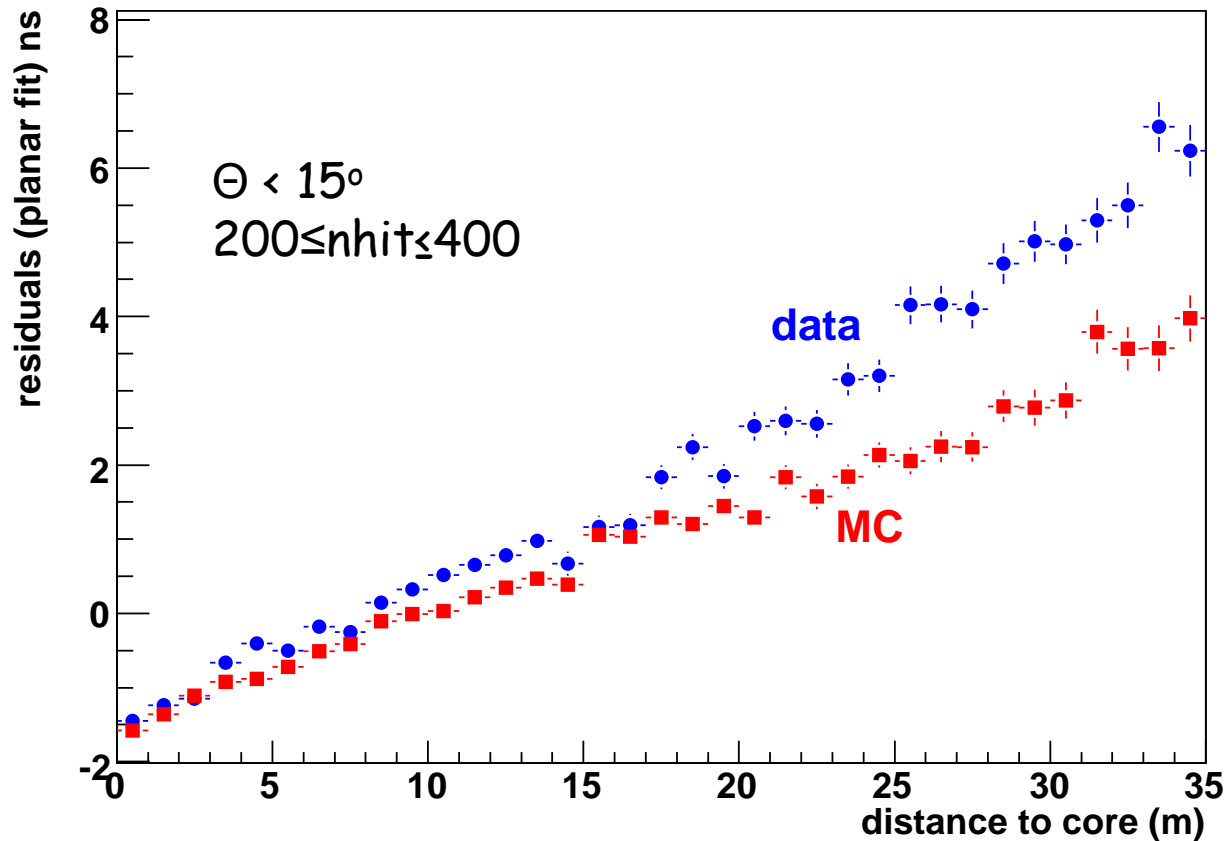
Distribution of pad multiplicity from simulation (solid line) in comparison with data (bullets), for zenith angle  $< 15^\circ$ .

# Reconstructed zenith angle



Distribution of reconstructed  $\theta$  from simulation (solid line) in comparison with data (bullets).

# Curvature



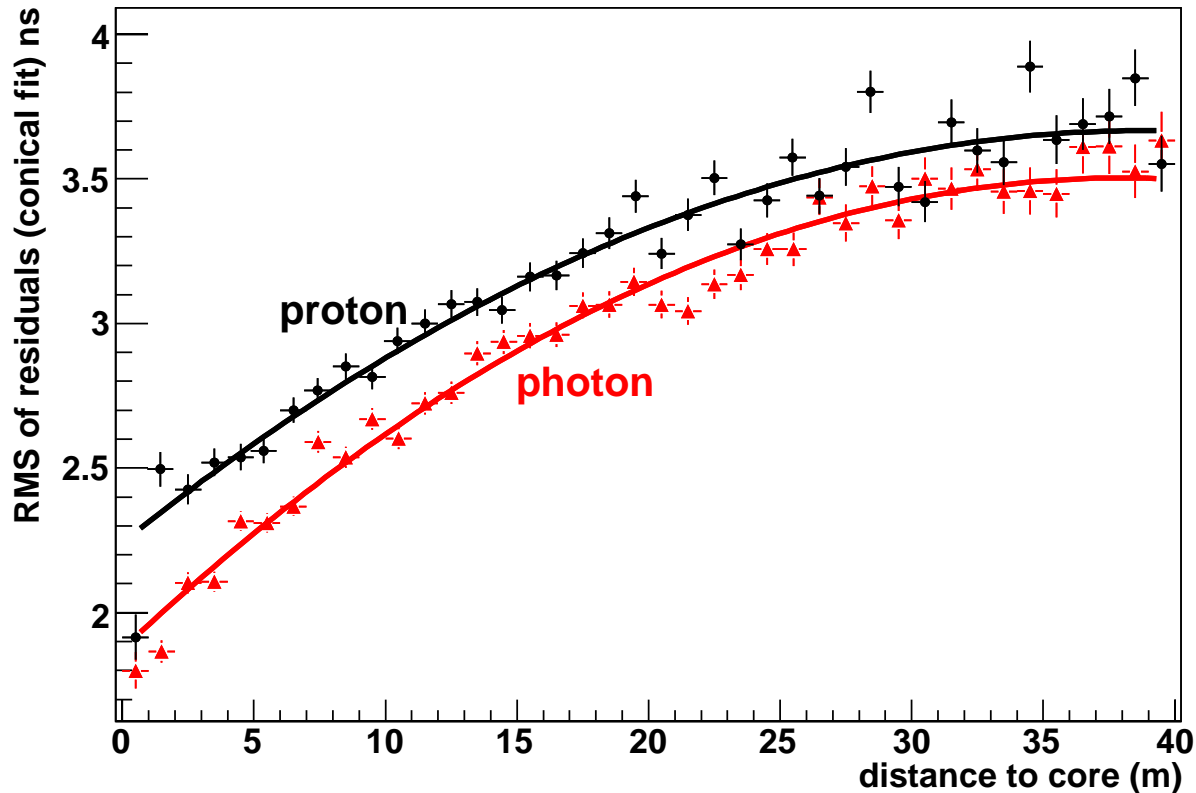
time residuals with respect to a planar fit for data (blue bullets) and simulation (red boxes).

An agreement is found up to a distance of 15 m. At larger distances, the measured front curvature tends to be larger than predicted by simulation.

# Photons and protons comparison

- 5000 photons and 5000 proton showers
- Zenith angle  $< 15^\circ$
- Energy range 3 - 10 TeV
- Core in  $40 \times 40 \text{ m}^2$
- Hit multiplicity  $> 200$

# Thickness of shower front

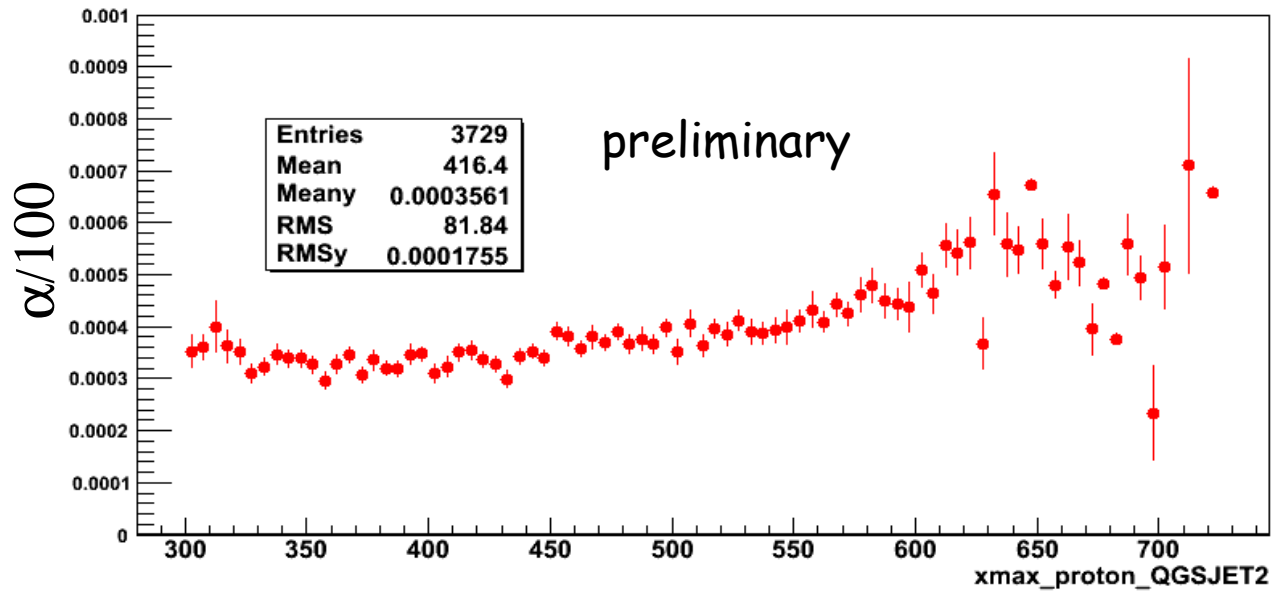


Hint for composition studies

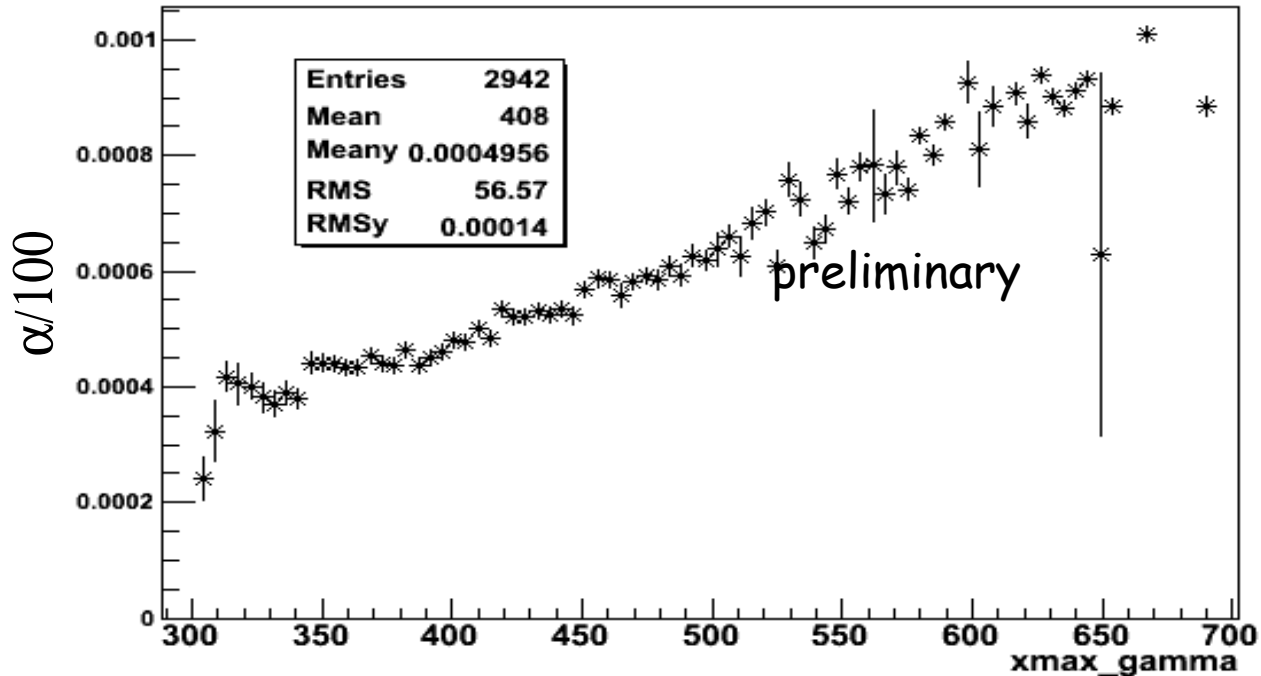
Though the measured difference is very small (at the level of the time resolution of the detector), this observable could be investigated in order to provide, on statistical basis, a clue to  $\gamma$ /hadron separation and mass composition studies.

Further studies and an extended simulation with heavier primaries are planned.

# Conicity vs Xmax



# Conicity vs Xmax



# Conclusions

- Space-time granularity -> powerful tool for the study of time structure in cosmic ray showers
- A measure of the curvature and thickness of the shower front has been presented
- The impact of these observables on mass composition studies has been discussed and the potentialities of the method investigated