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**DETECTION OF SMALL SIZE SHOWERS
BY MEANS OF AN RPC's CARPET**

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Abstract

A computer simulation has been carried out to investigate the performances of an RPC's carpet (ARGO proposal). The effective area and the angular resolution of the detector for air showers initiated by $2.5 \div 10 \text{ TeV}$ gamma-rays are studied as a function of the RPC time resolution and of the iron converter thickness.

INTRODUCTION

Recent developments of the atmospheric Čerenkov technique have led to the detection with high statistical significance of a steady flux from the direction of the Crab Nebula^[1,2]. The extragalactic source Mrk 421 has been later on observed at TeV energies by the Whipple Observatory^[3]. However, the same experimental facility failed to detect any positive excess from other potential TeV gamma-ray sources (as binary systems, radio pulsars, plerions, galactic plane, molecular clouds)^[4]. This disappointing result prompts again the need of investigating by means of a detector making use of different approach and free of the traditional limitations of the Čerenkov technology (low duty cycle and small angular acceptance).

The ARGO (Astrophysical Radiation and Gamma Observatory) detector is conceived to operate with high sensitivity in the energy range between $\sim 5 \div 100 \text{ TeV}$, a region marginally accessible to the traditional techniques (Čerenkov telescopes and E.A.S. arrays), providing a systematic and continuous (duty cycle $\geq 90\%$) monitoring of the northern hemisphere sources in the declination band $5^\circ < \delta < 75^\circ$. Moreover, since ARGO is expected to reach a γ/h discrimination better than 10^{-4} , it will represent a unique possibility to investigate the diffuse gamma ray flux from the galactic plane and the high-latitude gamma ray background resulting from the interaction of extragalactic high energy protons ($> 10^{19} \text{ eV}$) with the 3° K fossile radiation.

EXPERIMENTAL SET-UP

A schematic view of the proposed detector is presented in Fig. 1. It consists of an upper single layer $120 \times 120 \text{ m}^2$ of RPC's covered by a thin converter (iron), and a streamer tube system (at least two layers) of the same dimension placed below $\sim 3 \text{ m}$ of rock. The upper RPC plane measures the space-time pattern of the electrons of the shower front. The good time resolution ($\sigma_{RPC} < 2 \text{ ns}$) of this detector should allow a precise measurement of the shower direction.

The streamer tube system, placed below $\sim 3 \text{ m}$ of rock, acting as a μ -filter, measures the muon content of the shower, allowing to select with high discrimination power the e.m. cascades against the hadron induced ones. The whole set-up is installed in a building consisting in an upper hall and in excavated cave. It will be surrounded by an EAS array consisting in ~ 120 RPC stations to recover edge effects and to increase the effective sensitive area. Details are given in Ref. [5].

DETECTOR PERFORMANCES

In order to anchor on the Crab ('the standard candle') and go up into the UHE region, ARGO should operate with an energy threshold in the region $\sim 5 \div 10 \text{ TeV}$. In this range the atmospheric shower are characterized by a very low electron size at ground, as shown in Fig. 2. To overcome this difficulty, ARGO

- i) makes use of a thin layer of iron in which high energy electrons multiply and the γ component (about 8 times more abundant than electrons, Fig. 3) generates an e^+e^- pair,
- ii) measures, by means of pads coupled to the RPC's, the spatial pattern of the shower front with a resolution $12 \times 12 \text{ cm}^2$ and timing with ns accuracy (the information of the pads is OR-ed in order to get the time of the first particle hitting each 1 m^2 'logic pad').

Assuming a rejection power r (the fraction of discarded background events by muon counting) $\sim 88\%$ at 5 TeV [5], we would need $A_{eff} \geq 10^4 \text{ m}^2$ and $\delta\theta(\text{angular resolution}) \leq 0.3^\circ$ in order to detect the Crab Nabula steady flux at a 5σ level in 1 yr of operation.

Calculations of the detector response at energies $5 \div 20 \text{ TeV}$ have been performed by means of the EPAS code [6], to propagate the electromagnetic component throughout the atmosphere up to an elevation of 1200 m a.s.l. and zenith angle 30° (a conservative condition). Additional codes have been written to study the influence of a thin iron converter in front of the RPC layer, to simulate the triggering condition and to reconstruct the primary particle arrival direction. The effect of the iron converter is of increasing the number of fired pads (Fig. 4) and improving the electron time profile (Fig. 5). However, the maximum effect is reached at different thicknesses. As a reasonable compromise we have chosen one radiation length.

Results concerning the effective area and the angular resolution as a function of the energy can be summarized as follows:

Effective area

The effective area has been calculated by a standard procedure, simulating N showers uniformly distributed over a large area A including the detector and selecting those (n)

which satisfy the trigger conditions. Thus $A_{eff} = \frac{n}{N} \cdot A$.

To obtain A_{eff} two independent trigger conditions have been considered: the first subdivides the whole apparatus in $4 \times 4 \text{ m}^2$ logic sub-units, and demands at least a threefold coincidence ($\tau = 500 \text{ ns}$) of these logic sub-units, each having at least two 1 m^2 pads fired in a narrow temporal window ($\tau = 50 \text{ ns}$); the second demands at least four 1 m^2 pads fired within 100 ns in a sub-area of $8 \times 8 \text{ m}^2$. These requirements are easy to realize, and they exploit the low noise ($\leq 0.5 \text{ KHz/m}^2$) and the temporal properties of the RPC's to lower the spurious triggers at a level of $\leq 1 \text{ Hz}$. In Fig. 6 the effective area for 'internal' (core inside the carpet) and 'external' (core on the whole covered area) showers is shown as a function of the energy.

Angular resolution

Only 'internal' events have been considered. In order to get a pseudo-experimental temporal pattern, the arrival time of the electrons in the simulated showers have been smeared out with the detector response described by a gaussian. The pseudo-data obtained in this manner have been processed according to an iterative procedure to remove spurious times due either to accidental hits (on average 10 in 500 ns) or to extreme time fluctuations of shower particles, and to take into account the slope of the shower front (Fig. 7). This procedure consist in the following steps^[7]:

first step:

- determination of the core position from the center-of-gravity of the hits ($\sigma_x \simeq \sigma_y \simeq 4.5 \text{ m}$)
- unweighted plane fit to hits at core distance $\leq 40 \text{ m}$.

The distribution of residuals (Fig. 8) exhibits a long tail due to the time fluctuations and to the curved profile of the shower front.

second step:

- rejection of out-lying points by means of a 4σ cut ($\sim 4 \text{ ns}$)
- cone-like fit by fitting a conical shape to the survived times.

third step:

- symmetrize the distribution of residuals by rejecting negative residuals greater than the largest positive residual
- weighted cone-like fit with $w(r) = \frac{1}{\sigma^2(r)}$, being $\sigma(r)$ the r.m.s. of the distribution of the residuals ($r =$ distance from the core).

As a result about 20% of the times are rejected. The final distribution of residuals is shown in Fig. 9.

This procedure is rather fast ($\sim 5 \div 10 \text{ Hz}$ on a VAX station 4000-60) because makes use only of analytic formulae. No 'a priori' information about shower features is required.

The angular spread in the reconstructed arrival directions is shown in Fig. 10 for $E_\gamma = 10 \text{ TeV}$. From these distributions the angular radius $\psi(70\%)$ of the cone centered around the source direction and containing 70% of the signal is obtained - $\psi(70\%) \sim 1.58\sigma$ for a gaussian point spread function. The dependence of $\psi(70\%)$ on σ_{RPC} is shown in Fig. 11 for three energies ($E_\gamma = 2.5, 5, 10 \text{ TeV}$). It appears that the RPC's response (time resolution, stability, uniformity) represents a crucial parameter in view of obtaining the required pointing accuracy.

CONCLUSIONS

Work to improve the previous algorithms is in progress. However, the present calculations concerning the low energy performances of the RPC's carpet in ARGO look very promising, confirming the possibility of detecting γ -showers at energies $\leq 5 \text{ TeV}$ with a 5σ sensitivity to fluxes not far from the Crab one.

Present simulations indicate that the angular resolution of the detector could be improved by taking into account, in a more appropriate way, the shape of the shower front. In fact, the conicity parameter α is found not constant but linearly dependent on the core distance, suggesting a parabolic shape for the shower profile.

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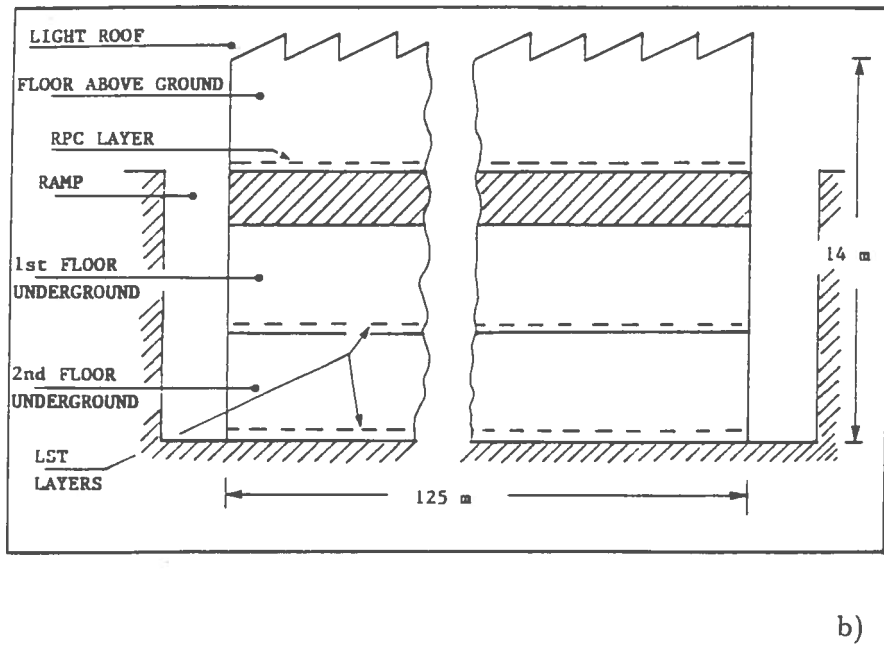
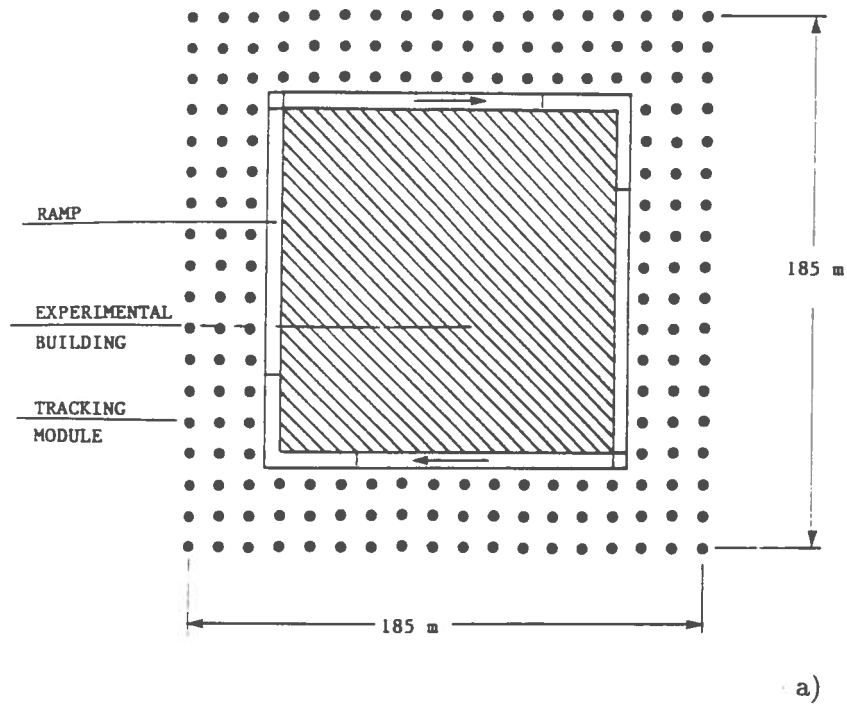


Fig. 1: Schematic view of the telescope: a) top view; b) side view.

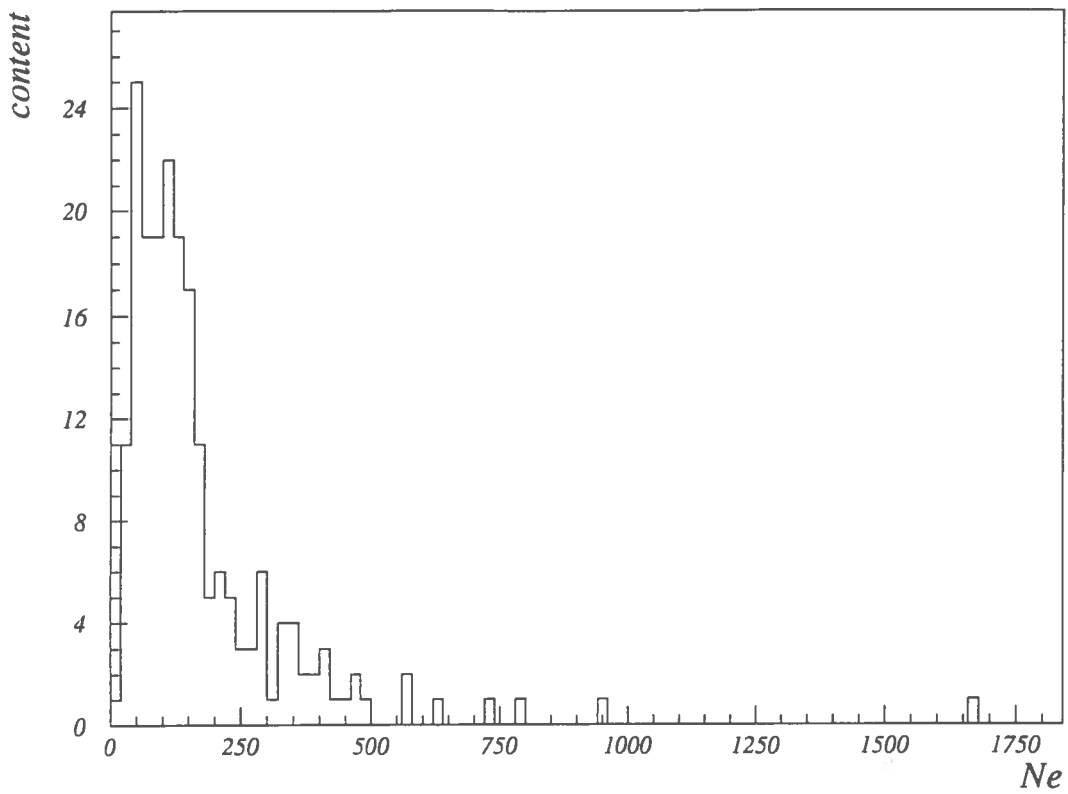


Fig. 2: Electron size distribution at a depth 900 g/cm^2 for γ initiated showers of 10 TeV.

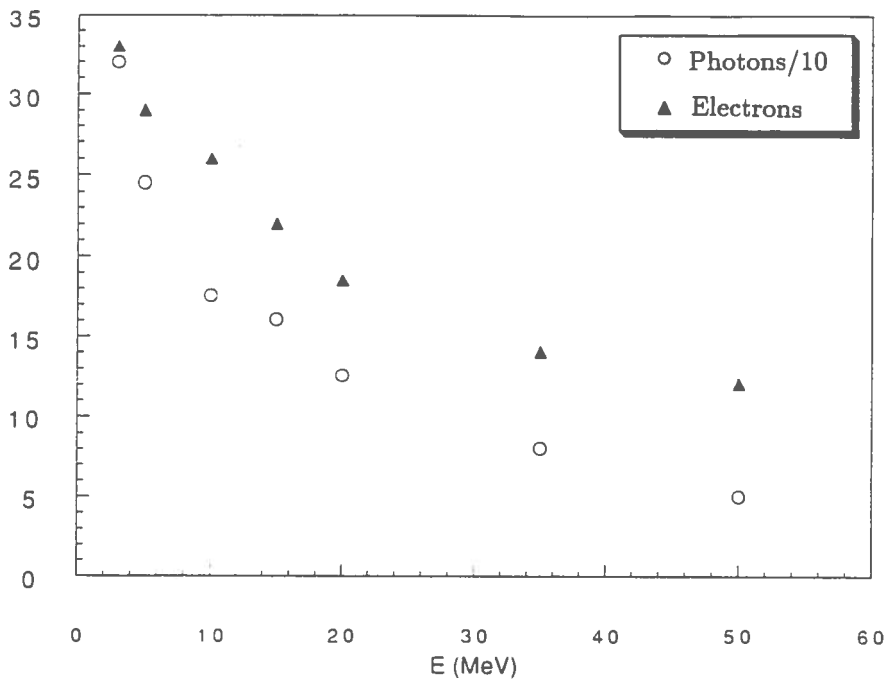


Fig. 3: Integral distribution of the electron and photon components in a shower produced by a 5 TeV γ -primary.

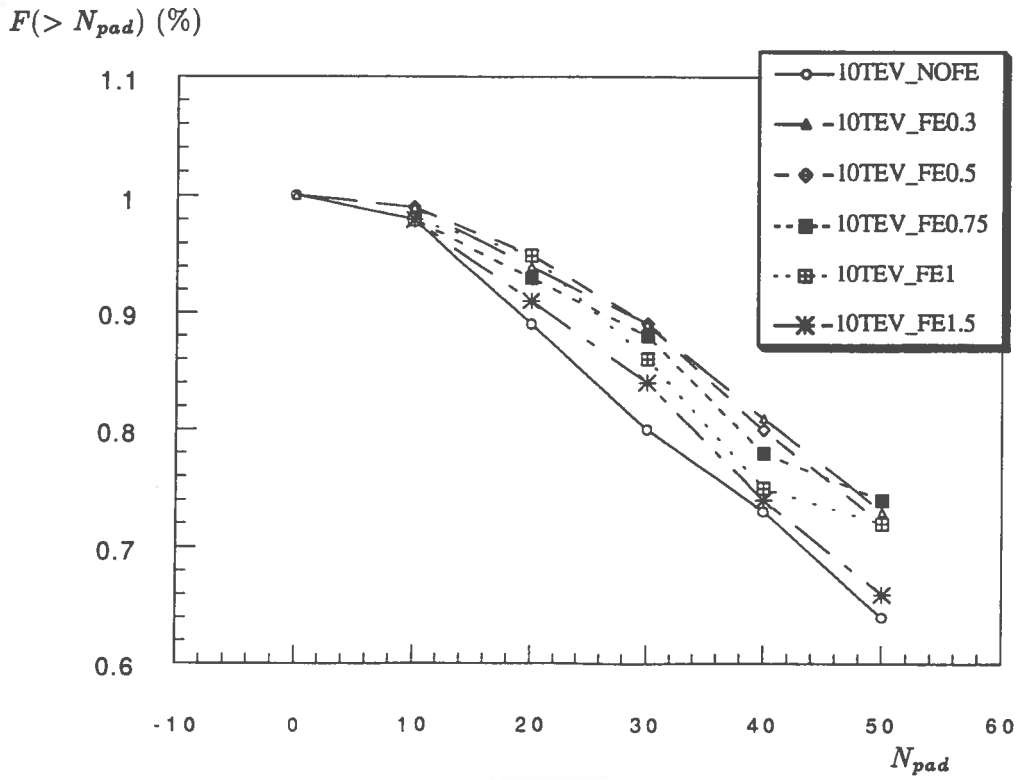


Fig. 4: The number of $1 m^2$ pads fired by 10 TeV showers for different thicknesses of iron (no-iron, iron from 0.3 to 1.5 r.l)

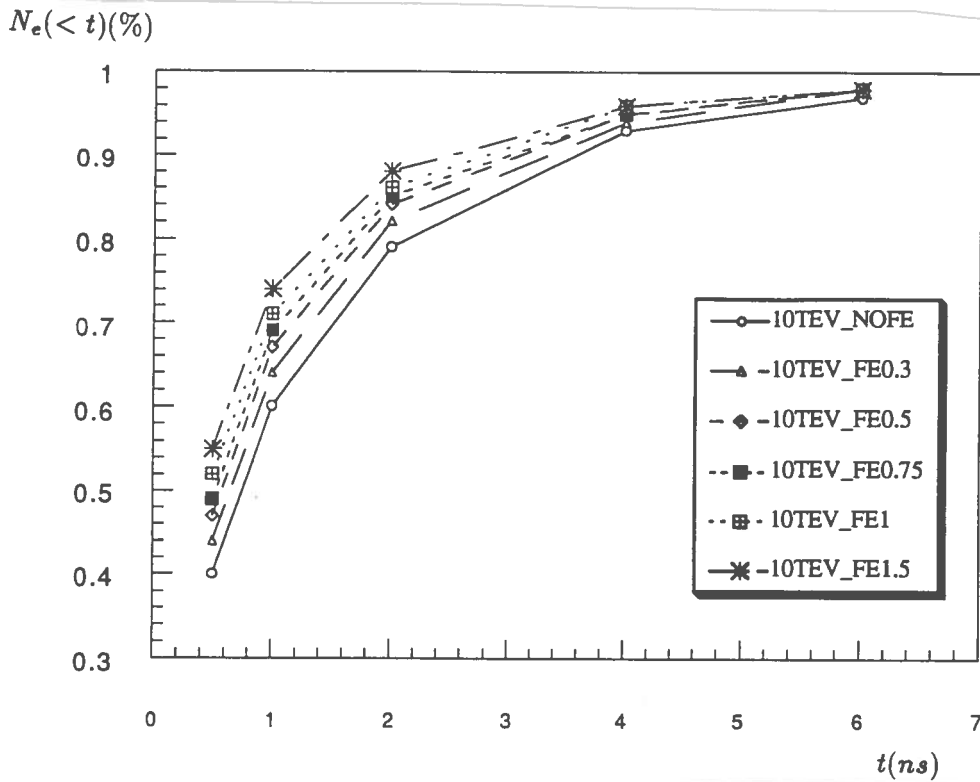


Fig. 5: Integral distribution of the electron arrival time for different thicknesses of iron.

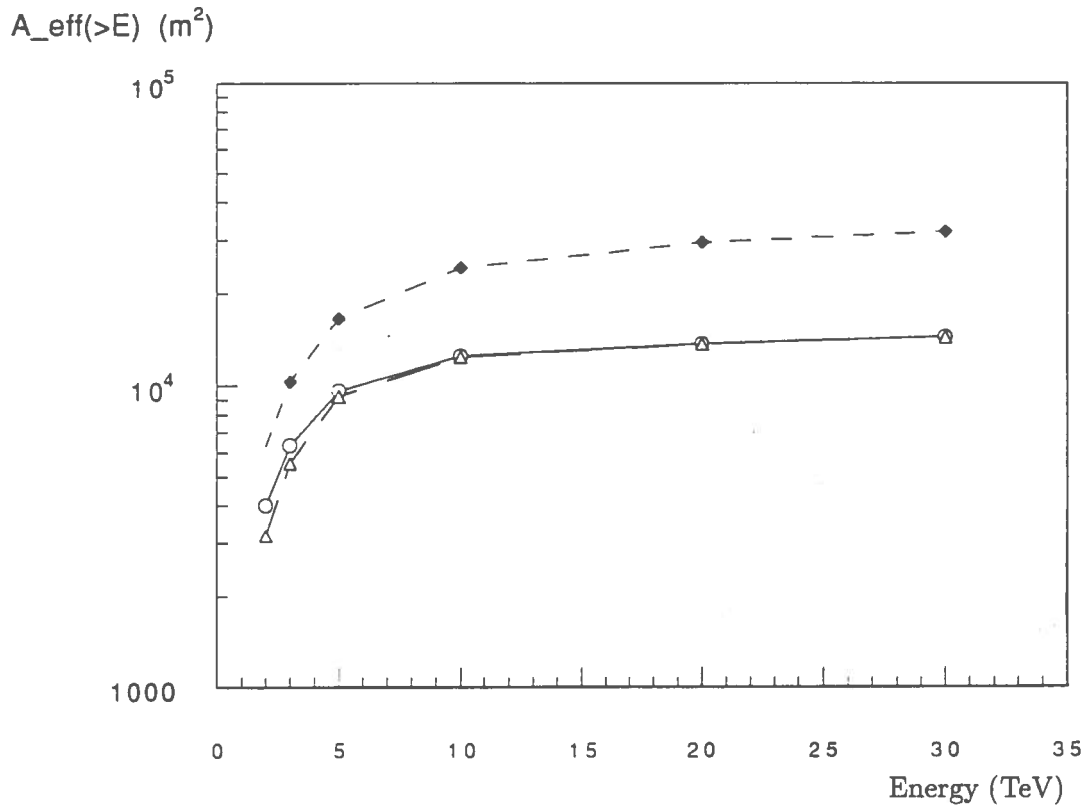


Fig. 6: The effective area for 'internal' (open circle = γ , triangle = protons) and 'external' showers (diamond = γ) (see text).

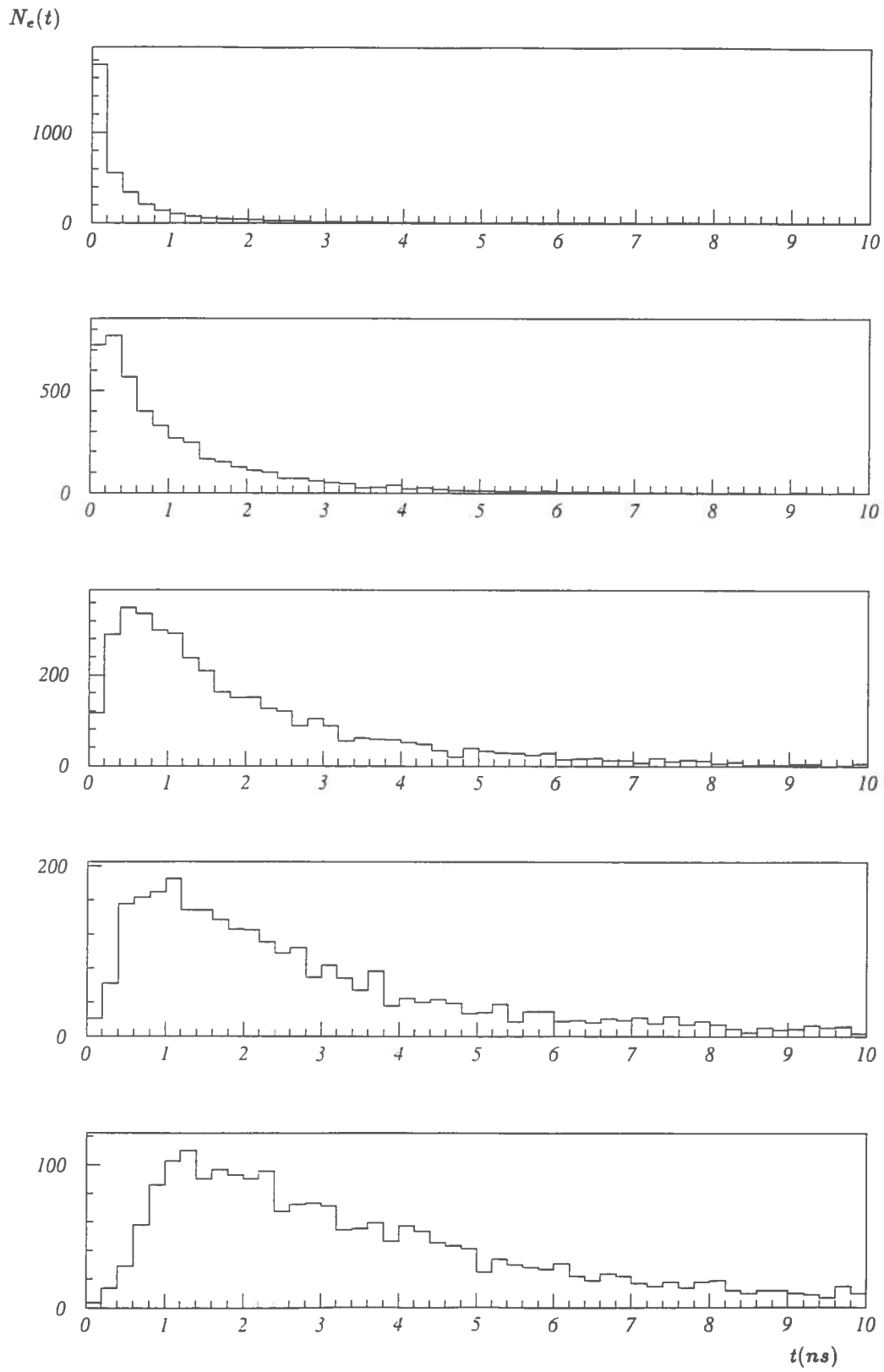


Fig. 7: Arrival time distributions (first electron) at different distances from the shower core ($\Delta R = 0-10, 10-20, 20-30, 30-40, 40-50$ m from the top)

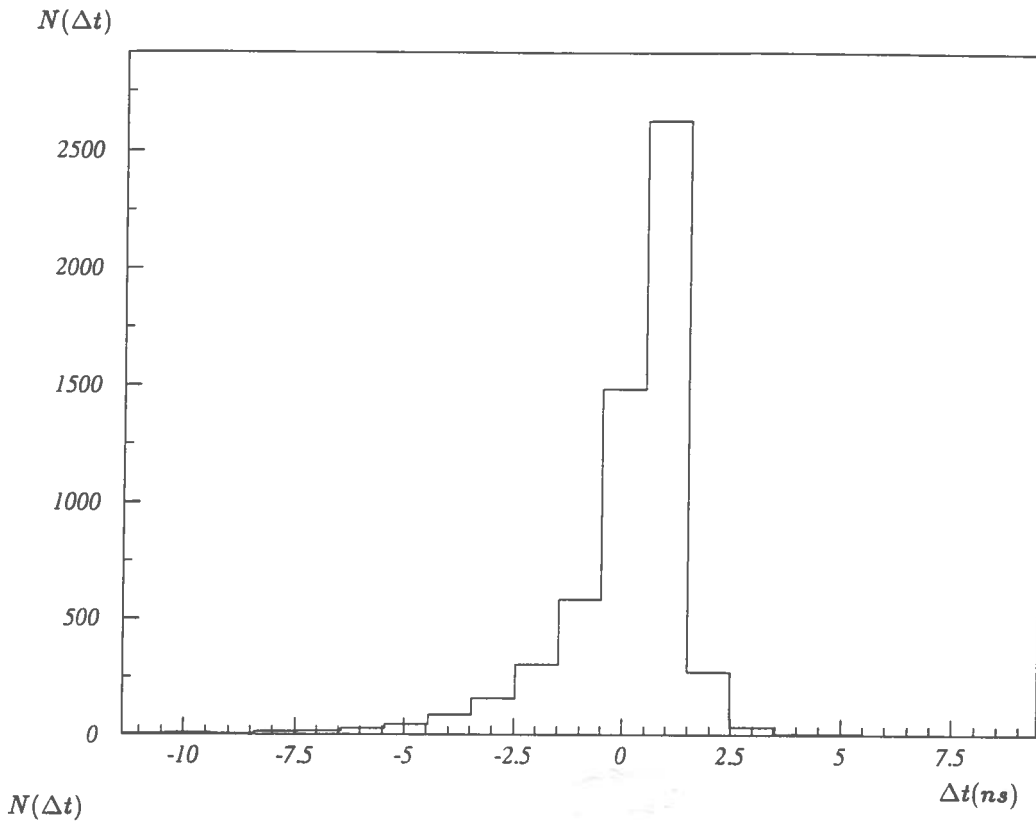


Fig. 8: The distribution of time residuals ($\Delta t = t_{plane} - t_i$) after an unweighted plane fit.

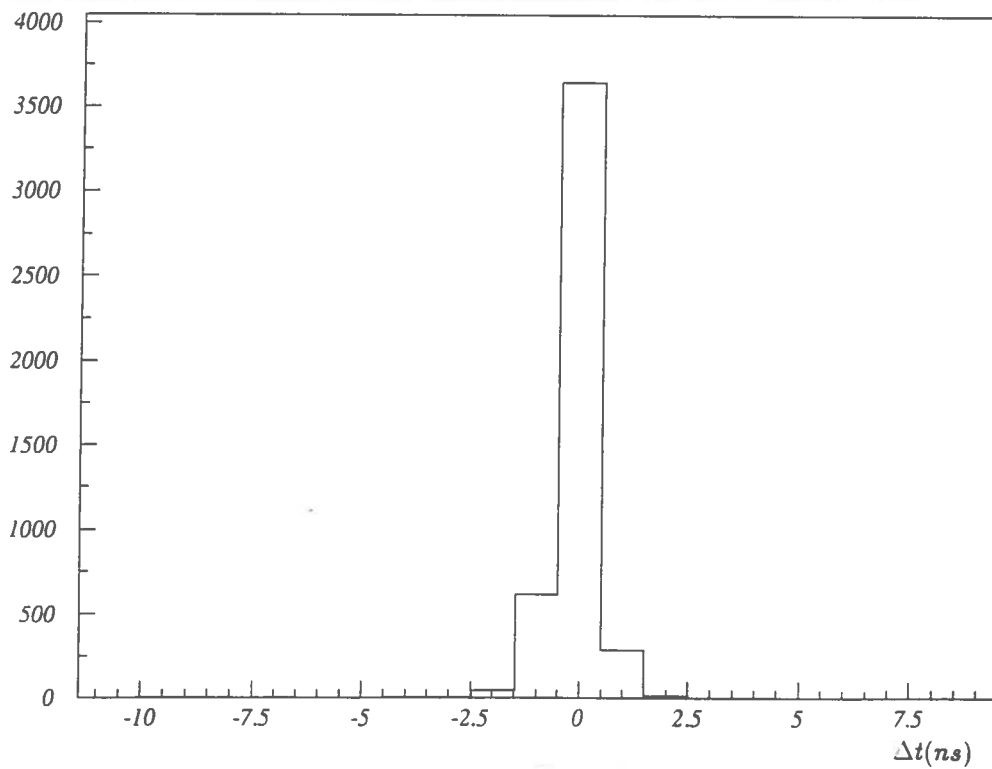


Fig. 9: The final distribution of time residuals ($\Delta t = t_{cone} - t_i$).

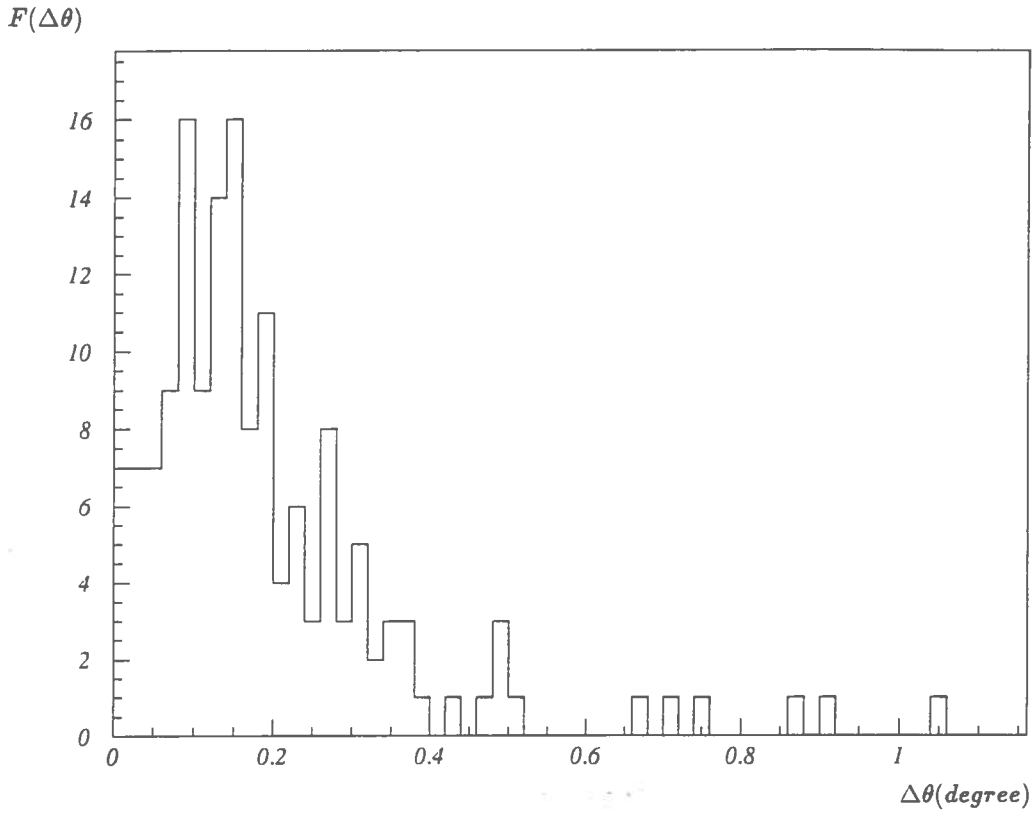


Fig. 10: The angular spread in the reconstructed arrival directions ($E_\gamma = 10$ TeV)

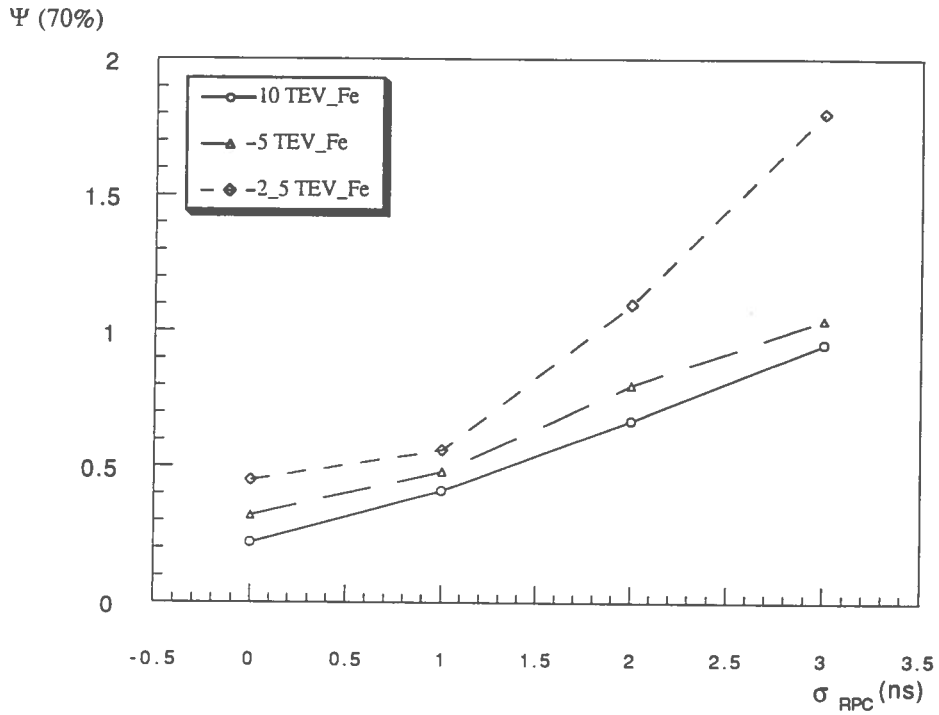


Fig. 11: The dependence of $\psi(70\%)$ on σ_{RPC} for three energies ($E_\gamma = 2.5, 5, 10$ TeV).