TIME & SPACE FINE STRUCTURE OF EXTENSIVE AIR SHOWER FRONT

G. AGNETTA(1), M. AMBROSIO(2), J. BEAMAN(3), G.C. BARBARINO (2)(4), B. BIONDO(1)(2), D. CAMPANA(2), O. CATALANO(1)(2), G. DALÌ(1)(5), A. ERLYKIN(2)(6), F. GUARINO(2)(4), A. LAURO(2), J. LINSLEY(1), J. LLOYD-EVANS(3), A. MANGANO(1)(2), G. OSTERIA(2), L. SCARSI(1)(2)(5), A. A. WATSON(3).

(1) Istituto di Fisica Cosmica e Applicazioni dell'Informatica - CNR di Palermo.
(2) Istituto Nazionale di Fisica Nucleare - Sezione di Napoli.
(3) Physics Department, Leeds University, Leeds, UK.
(4) Dipartimento di Scienze Fisiche - Università di Napoli.
(5) Dipartimento di Energetica e Applicazioni di Fisica - Università di Palermo.
(6) P. N. Lebedev Physical Institute - Moscow, Russia.

Abstract

The time & space fine structure of EAS front has been measured for the first time with a high statistics in a core distance range from 0 to 150 m by the GREX/COVER_PLASTEX array. Arrival times of shower particles have been measured with ns-accuracy. A disk thickness of 5 ns in the EAS core has been found.

1. Introduction

The space-time structure of E.A.S. front detected at ground level reflects the nature of primary particle and its interactions with the atmosphere nuclei. The cascade induced by cosmic rays with energy > 10^{14} eV at sea level covers a large area and produces mainly electrons. In hadron induced showers also muons and secondary hadrons are generated.

The measurement of EAS front thickness was first attempted by B. Rossi [Rossi 1953] who compared the arrival times of particles in two nearby scintillators of an array. This method was followed by other authors [Linsley 1962, Woidneck 1975, Linsley 1986] who measured the time spread of shower front. As regards to the shower front curvature, its knowledge is important to link times measured by remote detectors. Usually in such measurements low statistics is obtained.

The COVER_PLASTEX esperiment [Agnetta 1993] has measured the space-time fine structure in a new and original way, using resistive plate counter detectors (RPC) [Ambrosio 1994] for direct time measurements of the arrival time of each particle crossing the detector. The sampling area was 8 m^2 and a high statistics has been obtained. Data was taken at a core distance from 0 to 150 m.

2. The experimental apparatus

The GREX array (fig. 1) in Haverah Park was built for γ-ray astronomy [Brooke 1985]. A good time resolution of scintillators allows a precision $< 1°$ on the shower axis recostruction. Core position is measured with a precision of ~ 6 m in the inner part of the array and ~ 9 m at the periphery. Inside GREX a subarray of five tracking telescopes was installed (PLASTEX - fig. 1) with the aim to track particles and to reconstruct their height of production [Agnetta 1990]. Telescopes consist of six layers of limited streamer tubes (fig. 2) separated by a layer of a dense material. This thin absorber aims to separate electrons, photons and muons in the shower front. Telescope dimensions are ~ 6 m^2 and each plane is read by 1 cm wide x-strips and 1.2 cm wide y-strips. The first two telescopes, named stacks A&B are near the center of the array, while the other three, named C, D and E, are at the periphery, 150 m away from the center (fig. 1).

On the top of telescopes A, B, C and D we have installed a layer of 4 m^2 RPC, equipped with 24 x 24 cm^2 pads read by a front-end tracking and timing electronics able to detect the fired pads and to measure the arrival time of signals from each pad with the time resolution of 2 ns [Agnetta 1994]. By this way for each tracking telescope 64 time channels are allowed, which permit to combine the tracking information with timing measurements.

For each event triggered by the GREX array a big amount of information is obtained. The array measures the axis direction, the core position, and estimates the primary energy: the PLASTEX telescopes track the incoming particles and the RPCs measure arrival times of each pad fired.

3. Data analysis

To measure the front profile and thickness we have analyzed 250.000 events taken with only stacks A&B running jointly with the GREX array. Up to 128 time measurements in the single event are allowed, corresponding to 128 pads covering two stacks. The delay of each particle from the earliest incoming particle is measured as a function of the core distance from the stacks. A requirement of almost 5 fired pads cuts low density events, and a requirement of no more than 80 pads fired reduces the possibility to have more than one particle per pad. Times are corrected for the shower axis inclination. Only showers with zenith angle less than 25° are processed. Only 60.000 events survive to these requirements.

The distributions presented in fig. 3 show the delay time of all particles in the shower front from the earliest particle arriving for three core distance intervals. To avoid tail effects distributions are fitted by a Γ-function according the relation:

$$d(t) = a\, t^b\, e^{-ct} \qquad (1)$$

The curve fit is shown superimposed on the distributions. The agreement between the fit and the distributions is better than 10^{-4}. Fig. 4 shows how arrival time distributions change with the core distance in the range 0 - 150 m. The shape of the shower front is clearly visible.

The curve fit permits to evaluate the front thickness as a function of the core distance. Fig. 5 shows the σ of distributions for core distance intervals of 10 m from 0 to 150 m.

This $\sigma(r)$ dependence can be approximated by:

$$\sigma(r) = m_1 + m_2 \left(\frac{r}{r_0}\right)^{m_3} \qquad (2)$$

where r = core distance, $r_0 = 79$ m (Molier radius), $m_1 = 4.99$, $m_2 = 3.65$, $m_3 = 2.20$. This figure shows that the front disk has a thickness of 5 ns in the core and 21 ns at 150 m.

The thickness dependence from the particle multiplicity has also been investigated. Fig. 6 shows σ measured for various multiplicity intervals, compared with the previous curve for all multiplicities. No significant difference can be seen.

4. Conclusions

The front thickness of EAS detected by the GREX array has been measured with a large statistics in the range from 0 to 150 m of the core distance. A σ ranging from 5 ns in the core up to 21 ns at 150 m has been measured. Precise measurements of the shower front parameters at small core distances were made for the first time. No correlation between σ and particle density has been observed. Arrival time distributions are in good agreement with a Γ function in this core distance interval.

5. Acknowledgment

We are grateful to the graduating students C. Aramo and L. Colesanti for their careful work in data tacking and analysis.

References

Bassi, P., Clark, C., Rossi, B.: 1953, Phys. Rev. vol **92**, N. 2, oct. 15.
Linsley, J., Scarsi, L.: 1962, Phys. Rev. vol **128**, N. 9, dec. 1.
Woidneck, C. P., Böhm, E.: 1975, J. Phys. A: Math. gen. vol **8**, N. 6.
Linsley, J.: 1986, J. Phys. 6: Nucl. Phys. **12**, p. 51.
Agnetta, G. et al.: 1993, Proc. of XXIII ICRC - Calgary, **HE 3.3.1**, p. 270.
Ambrosio, M. et al.: 1994, NIM **A 334**, p. 350.
Brooke, G. et al.: 1985, Proc. of XIX ICRC, La Jolla, **3**, p. 426.
Agnetta, G. et al.: 1990, Il Nuovo Cimento, **13 C**, p. 391.
Agnetta, G. et al.: 1994, NIM **A 337**, p. 521.

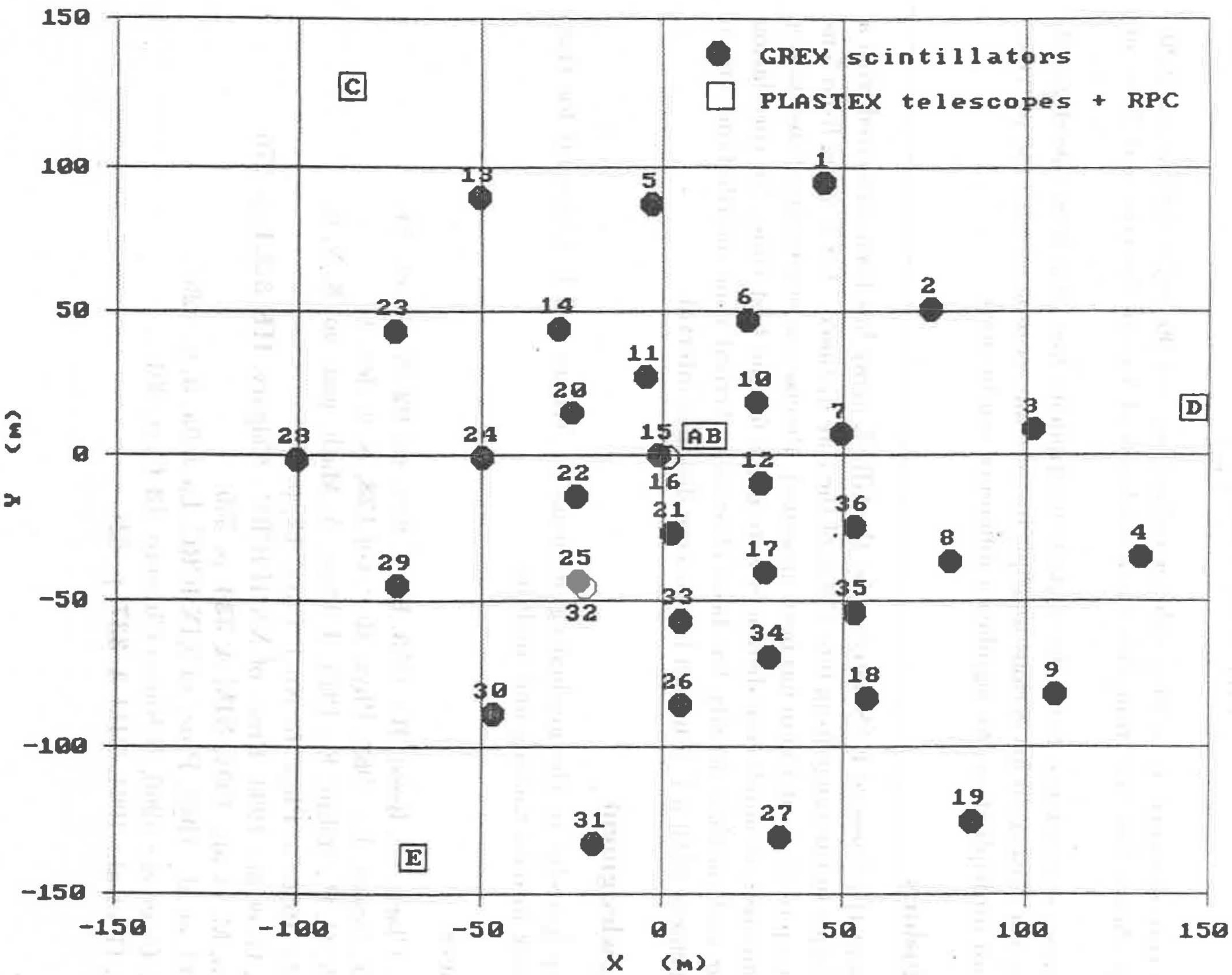
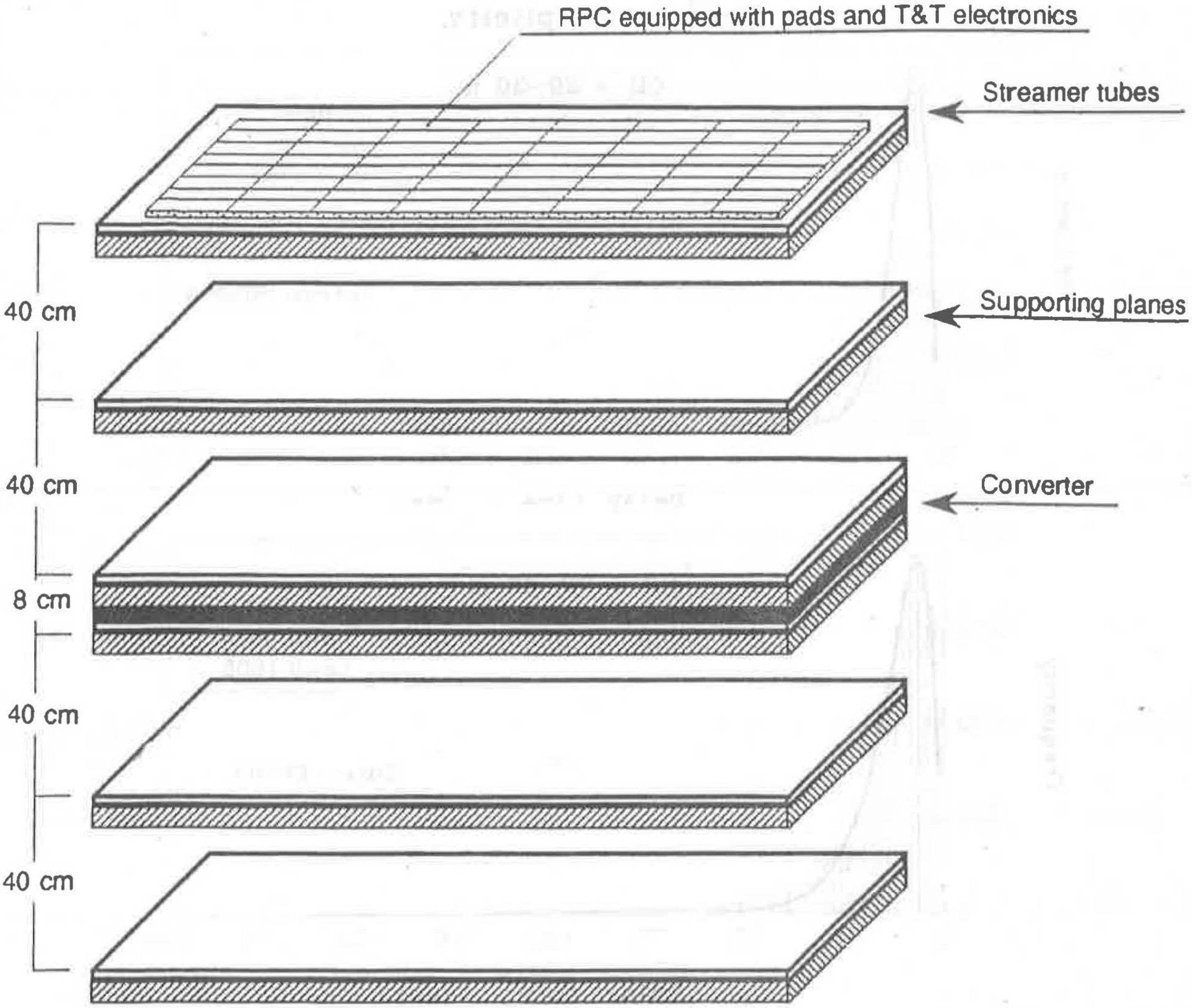


Fig. 1 - The GREX array and the COVER_PLASTEX experiment at Haverah Park.



Converter:	0.9 cm Pb = 1.6 X_0	stack A&B
	3 cm Fe + 1.1 cm Pb = 3.65 X_0	stack C, D & E
Dimensions:	(2.5 x 2.36) m^2	stack A&B
	(2.0 x 2.35) m^2	stack C, D &E

Supporting planes: low density plastic styro-foam

Fig. 2 - Layout of PLASTEX telescopes covered by RPCs.

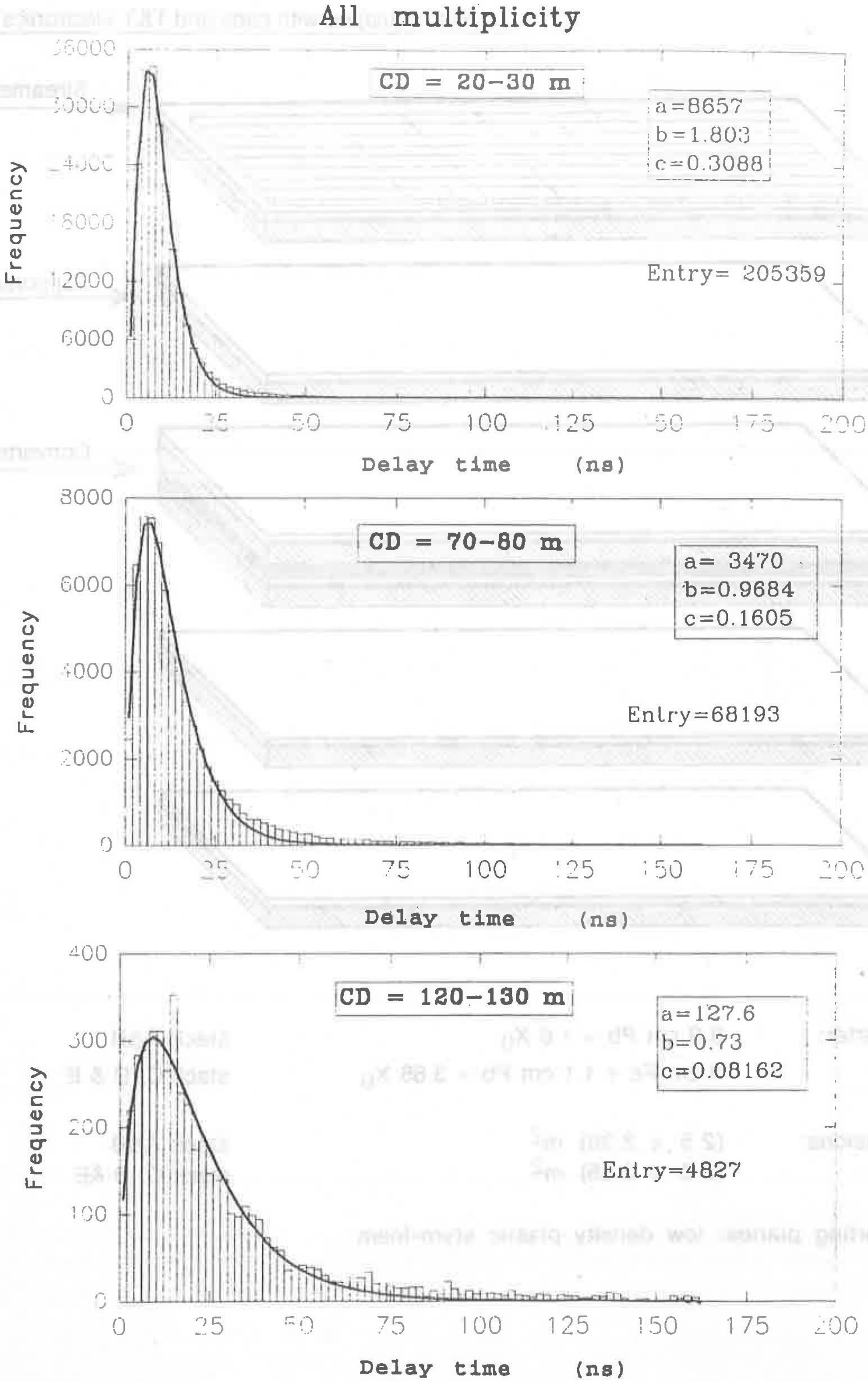


Fig. 3 - Delay time of particles in the shower front from the earliest particle arriving for three core distance intervals.

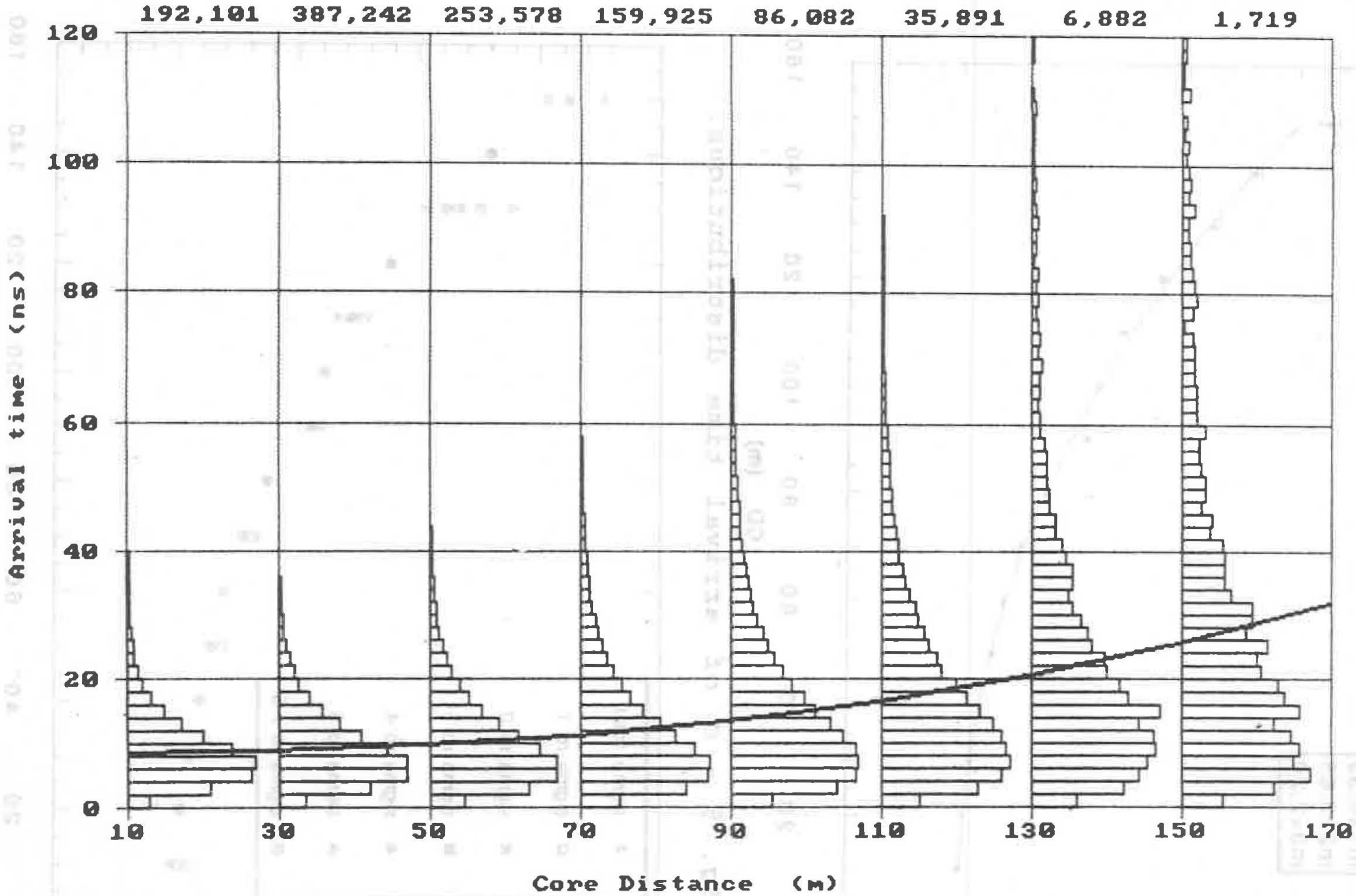


Fig. 4 - Arrival time distributions of particles in the shower front at different core distances. The superimposed curve gives the average arrival time. Plot entries are reported on the top of the graph. Each distribution is normalized to its maximum value.

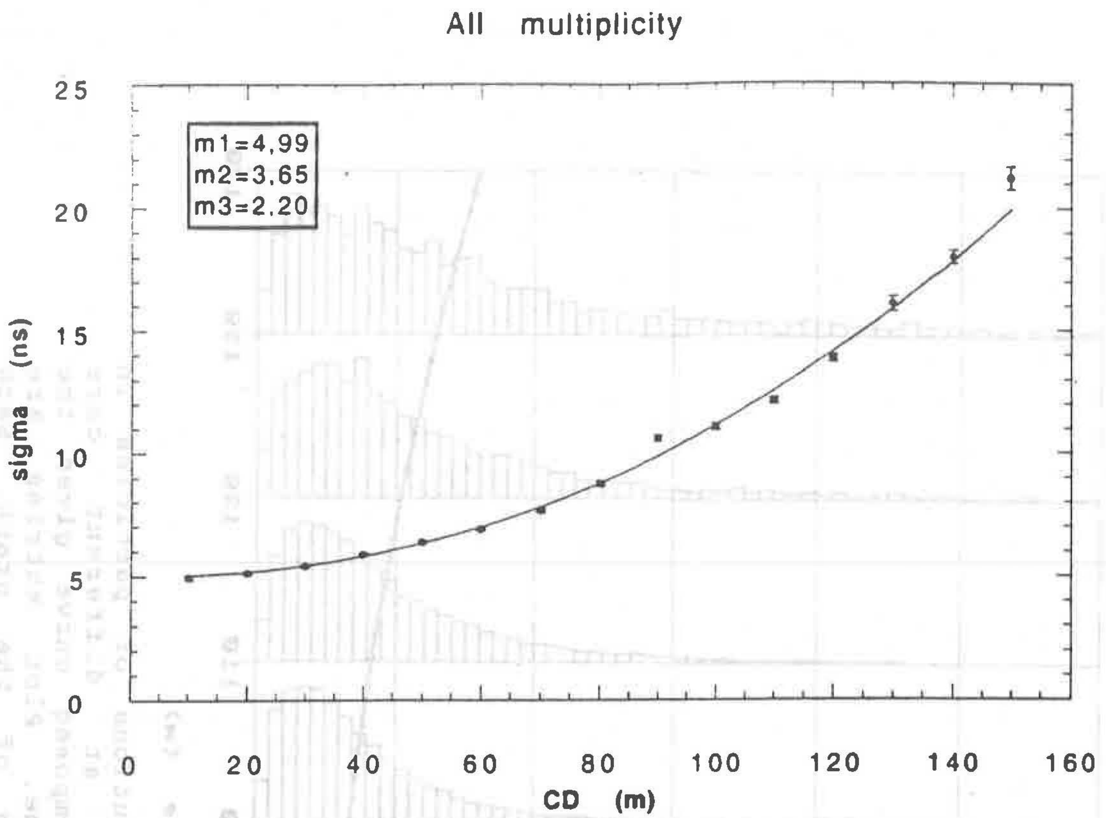


Fig. 5 - σ of arrival time distributions.

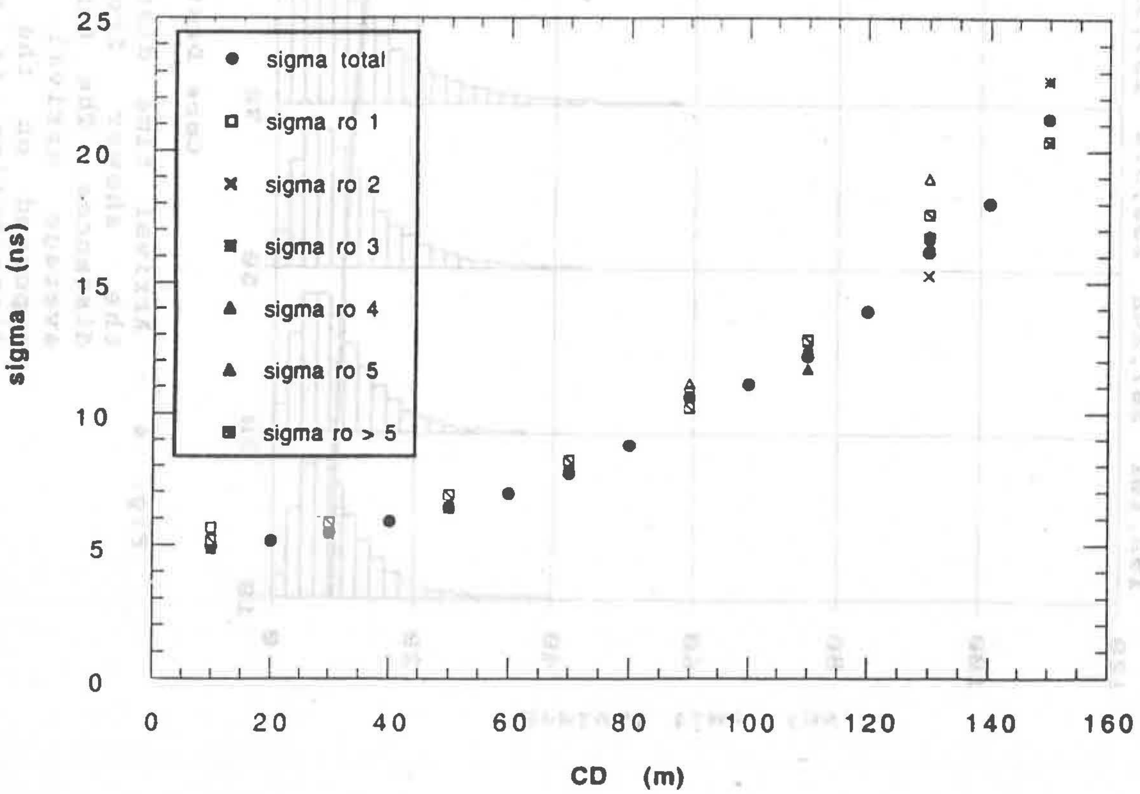


Fig. 6 - σ of arrival time distributions for different multiplicity intervals.