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# THE USE OF MULTIPLE COULOMB SCATTERING IN THE DETERMINATION OF TRACK FLIGHT DIRECTION IN FINE GRAIN DETECTORS FOR NUCLEON DECAY EXPERIMENTS

G. Battistoni[1], E. Bellotti[2], H. Bilokon[1], G. Bologna[3], P. Campana[1], C. Castagnoli[3], V. Chiarella[1], A. Ciocio[1], D. C. Cundy[4], B. D'Ettorre-Piazzoli[3], E. Fiorini[2], P. Galeotti[3], A. F. Grillo[1], E. Iarocci[1], C. Liguori[2], G. Mannocchi[3], G. Mantovani[5], A. Marini[1], G. P. Murtas[1], P. Negri[2], G. Nicoletti[1], P. Picchi[3], M. Price[4], A. Pullia[2], S. Ragazzi[2], M. Rollier[2], F. Ronga[1], O. Saavedra[3], A. Sarracino[2], L. Satta[1], M. Spinetti[1], P. P. Sverzellati[2], L. Trasatti[1], V. Valente[1] and L. Zanotti[2]

1 - INFN - Laboratori Nazionali di Frascati
2 - Dipartimento di Fisica dell'Università di Milano, and INFN - Sezione di Milano
3 - Istituto di Cosmogeofisica del CNR, and Istituto di Fisica Generale dell'Università di Torino
4 - CERN, Geneva, Switzerland
5 - Università di Perugia, associato LNF

## ABSTRACT

We show that it is possible to determine the orientation of a muon-like track with a good confidence level using multiple coulomb scattering. The calorimeter we have considered uses 1 cm streamer tube planes spaced with 0.5 cm thick iron plates. We have found an efficiency of 90% for muons of 60 degrees of incidence and P = 400 MeV/c. This technique can be used to check the topology of a nucleon decay candidate.

## 1. - INTRODUCTION

As a particle slows down the multiple coulomb scattering angle tends to increase. The track asymmetry created can be used in order to determine the track flight direction.

We discuss this possibility for a one kiloton fine grain calorimeter detector like NUSEX but with improved granularity. The NUSEX detector[1], running under the Mont-Blanc tunnel, consists of one centimeter iron plates interleaved with planes of plastic streamer tubes having $0.9 \times 0.9\ cm^2$ internal cross section. The sensitive planes are 2.7 cm apart. Both coordinates are measured for each plane : one coordinate (x) is given from the hit tubes, the other (y) is given from the induced signal on strips one centimeter wide, 1.2 cm pitch, orthogonal to the tubes. The spatial resolution for both views is of the order of 3 mm. The improved apparatus, being studied for the Gran Sasso tunnel, will have 0.5 centimeter iron plates with a 2.2 centimeter spacing. Of course the method can be used for other detectors.

## 2. - METHOD

In the approximation of gaussian distributions for multiple scattering and measurement errors, the distribution of the measured displacements from the original trajectory can be written:

$$F(y, \ldots\ldots, y) \propto \exp\left(-\frac{1}{2} \sum_{ij} W_{ij} y_i y_j\right) \qquad (1)$$

where $W_{ij}$ is the weight matrix. It is known that the weight matrix is the inverse of the moment matrix:

$$W_{ij} = \langle (y_i - \langle y_i \rangle)(y_j - \langle y_j \rangle) \rangle^{-1} . \qquad (2)$$

For a given incidence angle and a given number of hit planes N, the moment matrix of order N x N has been computed by a Montecarlo method taking into account the energy losses, the Moliere distribution, and the detector geometry. The weight matrix has been obtained applying equation (2).

In order to determine the flight direction two fits with a straight line were made: one with the correct flight direction, the other with the wrong one. The difference :

$$D = \chi^2_{correct} - \chi^2_{wrong} \qquad (3)$$

of the two normalized chisquare is sensitive to the track direction. Both views were take into account. Fig. 1 shows the distribution of D for muons stopping in the Nusex detector taking into account only the last 14 planes (corresponding to P = 320 MeV/c). These muons, all coming from the same direction (from the top) were collected under the Mont-Blanc tunnel. Out of 15 tracks only two have D of the wrong sign. The Mon

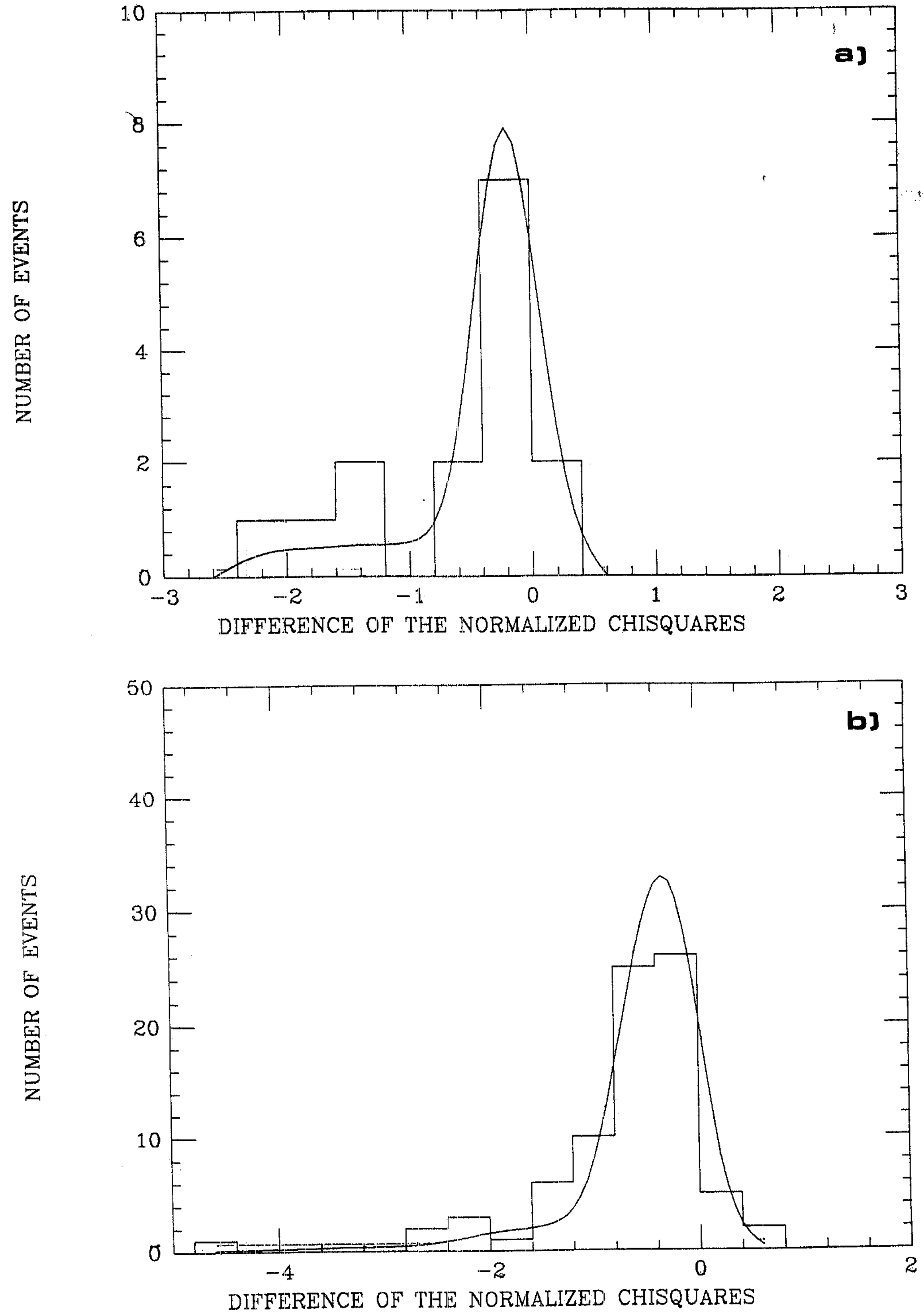


FIG. 1 - Differences between the normalized chisquares of a straight line fit to the correct direction and the wrong direction. The curve is the Montecarlo prediction ($\sigma_x$ equivalent = 3 mm, $\sigma_y$ = 3 mm). The tubes read the x coordinates; the strips read the y coordinates. a) refers to muons stopping in the Nusex apparatus (all coming from the top); b) refers to negative "muon like" pions. In both cases the distance between the tube planes was 2.7 cm and the iron was 1 cm thick.

tecarlo calculation is also shown in the figure. Fig. 1b shows the distribution of D for "muon like" negative pions of 500 MeV/c. Data were collected during a test run in a calorimeter having the same Nusex granularity. Out of 81 tracks 6 have D of wrong sign.

The agreement between data and Montecarlo is good and allows us to extrapolate the results to other situations.

Fig. 2a shows the efficiency, defined as the fraction of times in wich the right direction has been found, calculated for various incidence angles and various momenta of a muon like track and for the apparatus having improved granularity (0.5 cm of Iron and 2.2 cm of sampling)(2). Fig. 2b shows the efficiency with 1 mm resolution in the tube plane. This could possibly be achieved by correcting the coordinates for the drift times. At the most probable incidence angle (60 degrees) the efficiency is better than 86% for track having $P > 300$ MeV/c.

If the track stops before the end point (as would be in the case of an interacting pion) the efficiency goes down (Fig. 3). However the method still gives information about the track orientation. The pions collected during the test run and having more than 4 aligned planes (4 cm of iron) have been analyzed. The efficiency is 71% for $P = 300$ MeV/c and 80% for $P = 500$ MeV/c. Of course this result should be better for the apparatus with improved granularity and spatial resolution.

## 3. - OTHER METHODS

The track position and multiple scattering angles distributions are only approximately gaussian. In particular for small incidence angle the measurement errors are uniformly distributed. So it may be possible to find more efficient tests. Another disadvantage of the D test is that the calculation is complicated. In fact it is necessary to know the weight matrix for a particular track. This can be achieved by initially computing a set of matrices for different incidence angles and using a recurrence formula in order to have matrices of inferior rank(3). This procedure also requires the knowledge of the details of the distributions involved.

Two other empirical tests not requiring the knowledge of the measurement errors have been examined.

The first is based on the scattering angle:

$$\vartheta_{i+2,i+1,i} = (y_{i+2} - 2y_{i+1} + y_i)/\mathrm{STEP}$$

were STEP is the distance between two measurement planes.

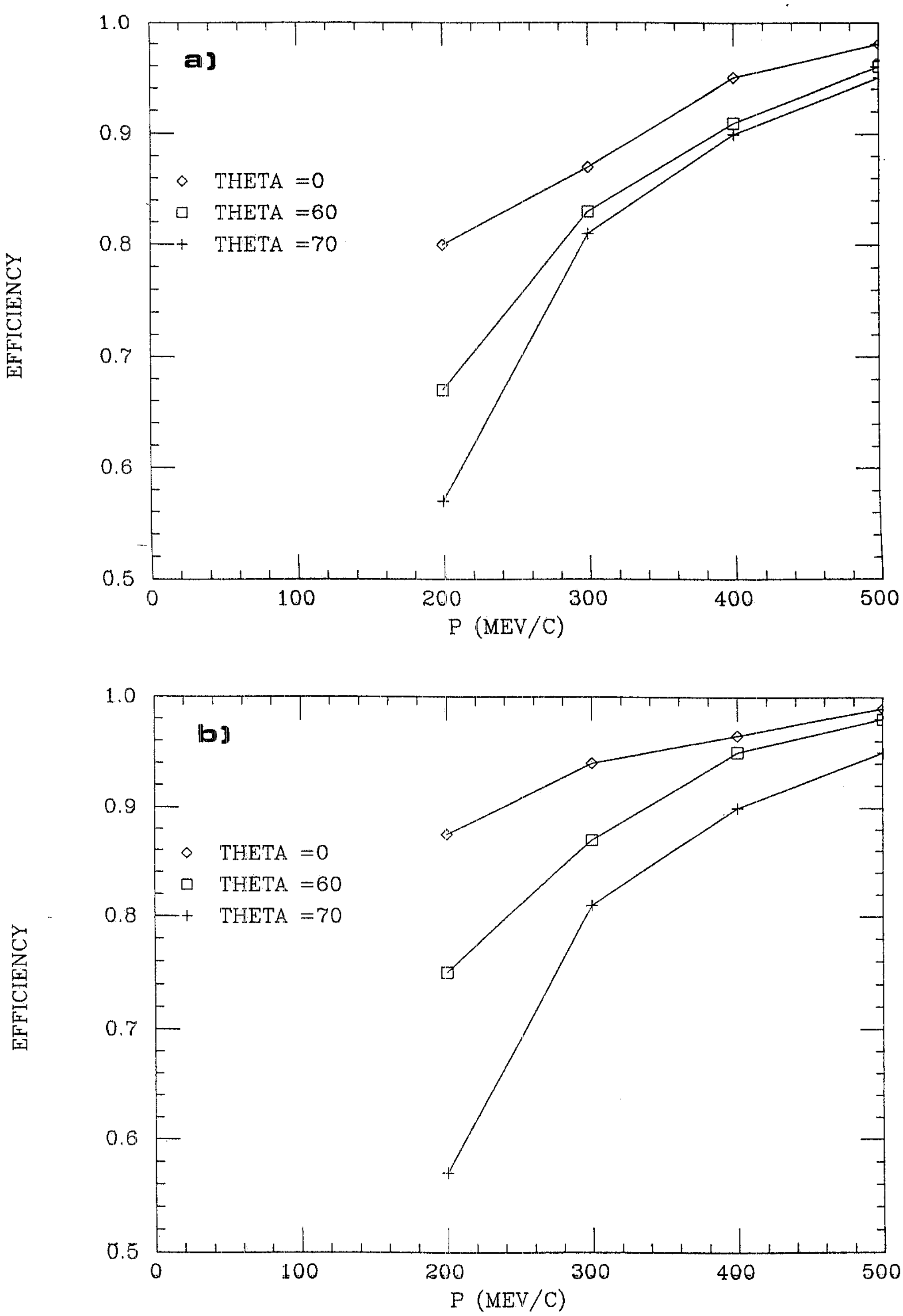


FIG. 2 - Efficiencies for various incidence angles for an apparatus having 0.5 cm of iron and 2.2 cm between the tube planes. The efficiency is the fraction of tracks found with the correct direction. a) refers to $\sigma_x$ equivalent = 3 mm and $\sigma_y$ = 3 mm; b) refers to $\sigma_x$ = 1 mm and $\sigma_y$ = 3 mm.

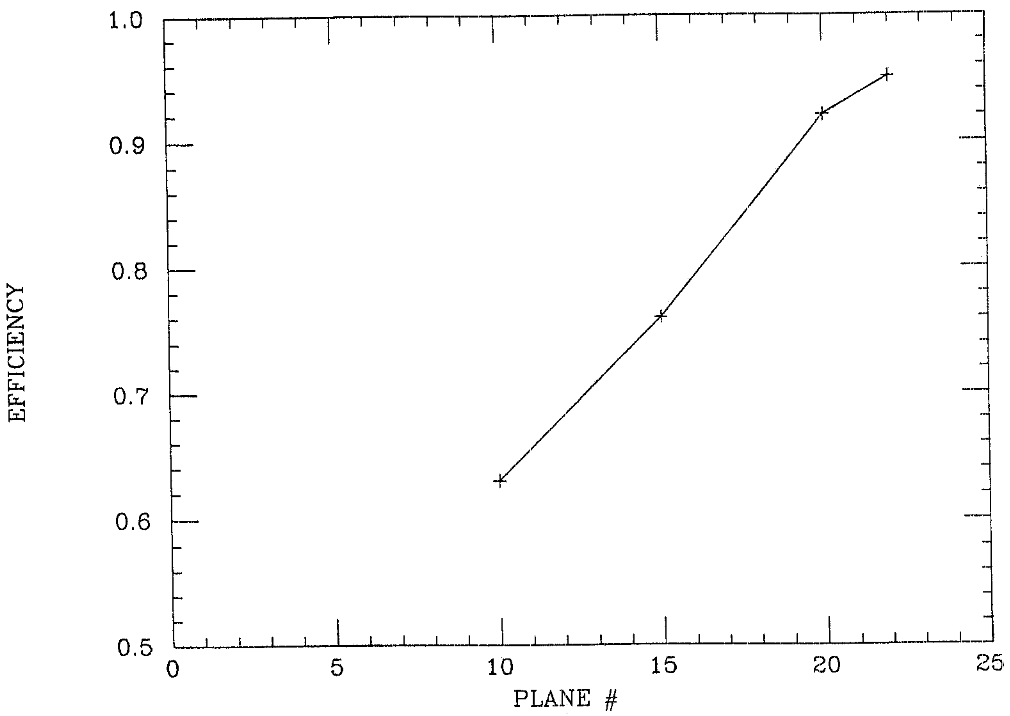


FIG. 3 - Efficiencies for a muon track of P = 400 MeV/c and $60^{0}$ of incidence stopping before the end point. The apparatus had 0.5 cm iron and 2.2 cm between the tube planes and 1 mm of resolution in x, 3 mm in y.

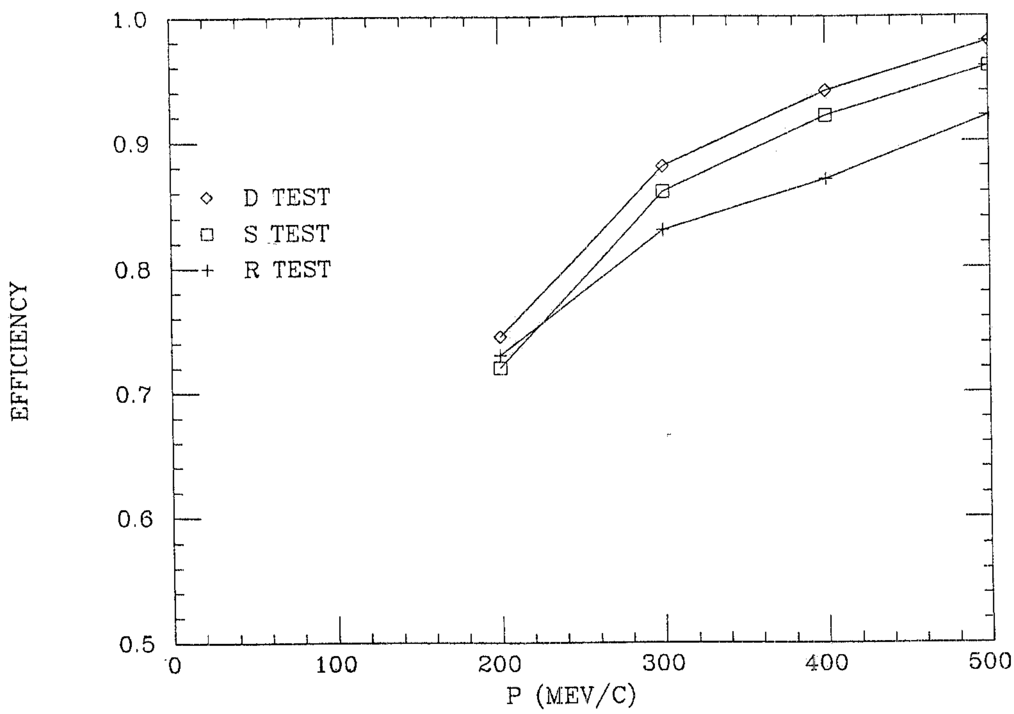


FIG. 4 - Efficiencies for the three different test functions. Apparatus as in Fig. 3.

The test is the slope S of the linear fit of $\vartheta$ as function of the penetration depth. The second is based on the quantity:

$$R = \sum_{i=3}^{N} \left( \sqrt{\delta_{N-i}} - \sqrt{\delta_i} \right) \tag{5}$$

where $\delta_{N-i}$ is the sum of the squares of the residual of the linear fit of the last i points, and $_i$ is relative to the first i points.

For gaussian measurement errors, as $\sigma_x \rightarrow 0$ ($\sigma_x$ is the standard deviation in the tube plane) S and D become 100% efficient (300 MeV/c muons at 0 incidence); R goes to 90% efficiency.

Fig. 4 shows the efficiencies of the different tests in the region of $\sigma_x$ = 1 mm and $\sigma_y$ = 3 mm (as in the improved NUSEX apparatus). R and S were computed from a weighted average of the x and y information.

In this region S is more powerful than R. In the region of $\sigma_x$ = 3 mm and $\sigma_y$ = = 3 mm however R is more efficient than S.

For track having many points (P > 500 MeV/c) probably it is better to use one of these more simple tests instead of D because the efficiency is high in any situation.

## 4. - CONCLUSION

In a fine grained detector information about the track flight direction can be obtained from the $\mu \rightarrow e$ decay (for positive muons) and from the interaction patterns (for electrons and pions). The new method discussed increases inexspensively the possibility of checking the right topology for a nucleon decay candidate.

## REFERENCES AND FOOTNOTES

(1) - G. Battistoni et al., Fully contained events in the Mont-Blanc nucleon decay detector, Frascati preprint LNF-82/81 (1982); submitted to Physics Letters.

(2) - The x coordinate is computed from the average of the hit tubes; so at large incidence angles $\sigma_x$ decreases. Normal distribution is assumed for the y coordinate.

(3) - Weight matrices of order $n < N$ have been computed from the recurrence formula:

$$W_{ij}\,\text{new} = W_{ij}\,\text{old} - W_{ik}\,W_{jk}/W_{kk}$$

where k is the integrating coordinate. This formula has been obtained from the relation:

$$\int_{-\infty}^{+\infty} \exp - (ax^2 + 2bx + c)\,dx = 2\sqrt{\frac{2\pi}{a}}\,\exp\frac{(b^2 - ac)}{a}\,.$$