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D$\bar{D}$ CORRELATIONS IN 360 GeV/c π^-p INTERACTIONS

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ABSTRACT

Correlation properties of $D\bar{D}$ pairs produced in 360 GeV/c π^-p interactions are presented and compared with various models of charm production.

In this letter we investigate the properties of $D\bar{D}$ pairs produced in 360 GeV/c $\pi^- p$ interactions. The NA27 experiment, as described in more detail in [1], uses the high resolution hydrogen bubble chamber, LEBC, and the European Hybrid Spectrometer (EHS) [2]. LEBC provides a resolved bubble diameter of ≤ 20 μm, and has a two track resolution better than 20 μm. Charm decays can be detected efficently with lifetimes down to $\sim 10^{-13}$ s. The EHS provides a momentum precision better than 1%, good gamma/electron identification and measurement, and charged particle identification in the range 5-50 GeV/c.

Using this detector with a minimum bias trigger (98^{+2}_{-3}% efficient for charm production events), 265 000 $\pi^- p$ interactions were collected representing a charm event sensitivity of (15.8 ± 0.8) events/μb.

Details regarding the scanning, the measurements and subsequent geometric and kinematic fitting of these events are described elsewhere [1]. The selected charm event sample consists of 114 events, 69 of which have two decay vertices. For 14 of these 69 pairs, one of the decays is detected because one decay prong only has significant impact parameter, with the decay vertex being embedded in the jet of the primary interaction. We reject these 14 events as being unreliable for the analysis reported here. We also exclude two pairs which are not $D\bar{D}$ but $\Lambda_c \bar{D}$ associated production. After this selection, we are left with 53 charm pairs. We have estimated [1] that the non-charm background is less than 0.1 decay in this sample.

To study correlations between D-meson pairs it is essential that both decays have well defined longitudinal momentum (x_F) and transverse momentum (p_T). A further selection of events was therefore made according to the following strategy discussed in detail in [1, 3]. Kinematic fits to decay channels were performed including the use of particle identification probabilities to resolve ambiguous solutions where possible. Remaining ambiguities were treated by applying a set of simple overall constraints to the event; energy conversation, charm quantum number conservation, a preference for Cabibbo favoured solutions and the selection of single over multiple missing neutral decays.

As the detection/reconstruction efficiency for charm falls rapidly below $x_F = 0$, events were retained only if both D's have $x_F > -0.1$ and the x_F of the pair is positive. This results in a final sample of 12 events: 3 $D^+\bar{D}^o$, 5 $D^o\bar{D}^o$, 3 D^-D^o and 1 D^+D^-. In this sample each D/$\bar{D}$ is assigned two weights [1]: (a) WV, the visibility weight (inverse of the probability of its decay to be visible inside the bubble chamber) and (b) WS, the spectrometer weight (inverse of the probability of successfully reconstructing and hybridising the decay tracks in the spectrometer). Thus the overall weight of a D$\bar{D}$ pair is taken as

$$WT = WS_1 \cdot WS_2 \cdot \mathrm{Min}\ (WV_1, WV_2).$$

The minimum of the two visibility weights is taken because having detected one D the probability of detecting the other at measurement (even if missed in the scan) is high. The sum of weights for the 12 events is 35.6.

These data were used to calculate the effective mass, M, Feynman x, x_F, square of the transverse momentum, p_T^2, and pair rapidity gap, DY, of each D$\bar{D}$ pair. The weighted distributions of these quantities are shown in fig 1.

Another useful variable is ϕ_T, the angle between the D and $\bar{D}$ in the plane transverse to the beam direction. To determine ϕ_T it is sufficient to know only the directions of the charm particles, we therefore use a statistically more significant sample of events than in the above. The transverse distances travelled before decay are generally small and could be affected by scanning losses. We have therefore checked that the observed distribution in ϕ_T is not sensitive to cuts either on the length or the transverse length of the D mesons. The ϕ_T distribution for the 53 double charm decay events is shown in fig. 2. Identified Λ_c events are not included, so that the events plotted are predominantly D$\bar{D}$.

The average values of all D$\bar{D}$ correlation quantities are given in table 1.

To interpret these observations, we first consider a simple phase space calculation modified to include the observed distributions in multiplicity and the single particle inclusive transverse momentum distributions for the D-mesons and additional pions [1,3]. In addition we compare the data with QCD-fusion model calculations and a cluster model.

For the study of uncorrelated $D\bar{D}$ pairs, one could simply take randomly a D from one event and a $\bar{D}$ from another. This pairing, although including the single D and $\bar{D}$ production properties exactly, will not reflect kinematic correlations occuring between the D and $\bar{D}$. This is particularly important in the transverse momentum plane since the D-mesons are produced with a much larger average p_T than the pions and Kaons. We therefore include these kinematic correlations by using the simple phase space model described below.

Phase space events are generated of the type $\pi^- p \rightarrow \pi^- p + D + \bar{D} + \pi^\pm + \ldots + K^\pm + \ldots + \pi^o + \ldots + K^o$ with the charged particle multiplicity distributions reproducing our data. Reasonable assumptions are made about the average π, K and π^o content of each event$^{(*)}$. A matrix element of the form

$$|M|^2 \propto \prod_{i=1}^{N} \exp(-b_i p_{T_i}^2)$$

is introduced, where N is the total number of final state particles. The b_i depend on particle type and are adjusted until the $<p_T^2>$ of the pions, Kaons and D-mesons agree with observation$^{(**)}$. It is found that this peripheral phase space generation, when summed over all final state particle multiplicities, results in an inclusive x_F distribution for the single D-mesons which agrees with the data. In summary, this Peripheral, Inelastic Phase Space model (PIPS) is constrained to reproduce the single $D/\bar{D}$ p_T^2 distribution and includes energy-momentum conservation for the

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(*) The charged particle multiplicity distribution is generated according to a KNO scaling distribution with $<n^\pm> = 10$ ($n^\pm$ excludes the D and $\bar{D}$). We assume that $<n_K^\pm> = <n_K^o> = 0.08\ n^\pm$ and $<n_\pi^o> = 0.5\ n_\pi^\pm$ or $(3.4 + 0.2\ n_\pi^\pm)$ for $n_\pi^\pm \leq 8$ or (≥ 9). $n_K^\pm$, n_K^o and n_π^o are generated according to a Poisson distribution.

(**) The model generates pions, kaons and D-mesons with $<p_T^2> = 0.19$, 0.26 and 1.1 $(\mathrm{GeV}/c)^2$ respectively. This last number corresponds to the measured value for the D-meson sample considered here. It is slightly different from the value given in [1] and which corresponds to a sample obtained with more stringent scanning cuts.

particle multiplicity environment in which the $D\bar{D}$ pairs are produced. Thus the only assumed correlation between D and $\bar{D}$ is a kinematic one.

The predictions obtained with PIPS are given in table 1 and shown as the solid curves in figs 1 and 2. As can be seen from these figures and table 1, these predictions reproduce well the distributions in M, x_F, DY and p_T^2 of the $D\bar{D}$ pairs. The experimental ϕ_T distribution is in good agreement with PIPS apart from the curious structure at $\phi_T \sim 120°$. In general, the PIPS model reproduces the $D\bar{D}$ correlation data reasonably well; however, we emphasize that it is an entirely empirical model which uses known inclusive features of charm events (multiplicity distributions and limited p_T). We next consider models which derive their predictions from perturbative QCD.

For calculating parton fusion predictions we consider $q\bar{q}$ and gluon-gluon fusion according to the standard procedure [4]. The predictions presented here are from a recent calculation [5] taking the mass of the charm quark, m_c, as 1.25 GeV/c^2, structure function parametrizations as given in [6] and a gaussian distribution for the intrinsic transverse momentum (k_T) of the partons with $<k_T^2>$ = 0.64 GeV/c. For this simple calculation, the c and $\bar{c}$ quarks are assumed to hadronise completely independently of each other as well as of the remaining quark and gluon fragments produced in the overall interaction.

For the charm quark hadronisation two forms were tried:

$$f(z) \sim \delta(z_{max} - z)$$

and

$$f(z) \sim \{z\ [1 - 1/z - 0.15/(1 - z)]^2\}^{-1}, \text{ with } z < z_{max}$$

where $z = p_D/p_c$, p_D being the momentum component of the D along the direction of the charm quark c and $z = z_{max}$ corresponding to the condition $E_D = E_c$. The latter form is due to Peterson et al. [7] and has been used successfully to describe $D/\bar{D}$ production in e^+e^- interactions.

Still within the framework of the QCD fusion mechanism, the Lund model [8], gives an alternate form for the charm quark hadronisation. In contrast to the simple fragmentation models discussed above, this model incorporates a colour field interaction between the produced $c/\bar{c}$ quarks and the other hadronic fragments. This leads to leading $D/\bar{D}$ effects, which have been observed experimentally [3].

Averages of the $D\bar{D}$ correlation variables calculated from these fusion models are given in table 1. A more detailed comparison to the data is shown in fig. 1 where the dashed and dotted curves are respectively the δ function and LUND fragmentation schemes. All model predictions are normalized to the observed event sample i.e. we compare the shapes of the differential distributions, not absolute pair cross sections. Within our limited statistics these two fragmentation mechanisms are indistinguishable and both describe the $D\bar{D}$ pair M, x_F and DY distributions fairly well. The fusion model with the fragmentation function of Peterson et al. predicts very narrow M and DY distributions which disagree with the data (for example, see fig. 1(a)).

None of the fusion models explain the observed p_T^2 distribution of the $D\bar{D}$ pair.

The ϕ_T distribution shown in fig. 2 is not very sensitive to the QCD subprocess but is affected by the intrinsic k_T distribution of the colliding partons. We have used a k_T^2 distribution of the form

$$dN/dk_T^2 = \exp(-\ k_T^2/\ \langle k_T^2\rangle)/\langle k_T^2\rangle$$

with $\langle k_T^2\rangle$ chosen to agree with measurements from the hadroproduction of $\mu^+\mu^-$ pairs in π^-p interaction; $\langle k_T^2\rangle = 0.64\ (\mathrm{GeV}/c)^2$ [9]. The fusion model predictions are compared to the ϕ_T data in fig. 2 where, again, the dashed and dotted curves are for the δ function and LUND fragmentation, respectively. Both these fusion calculations fail to predict the peak at ~ 120°; in addition, they both give a poor fit to the remainder of the distribution.

As noted earlier, the ϕ_T distribution agrees well with PIPS except for the peak observed in the range 120–130°. If we take PIPS as a measure of the background then the probability that the peak is a statistical fluctuation is < 1%. Moreover, a peak in the same range was observed in the NA16 data [10] which leads us to conclude that this feature is not a statistical fluctuation.

We have also compared our data to some cluster type models in which both the D and $\bar{D}$ originate from the same cluster [11]. These models predict very narrow $M(D\bar{D})$ and DY distributions which disagree with the data.

To conclude, we report an investigation of $D\bar{D}$ correlations in hadronic interactions. The $D\bar{D}$ mass, Feynman x, rapidity gap and p_T^2 distributions from 360 GeV/c π^-p collisions can be well reproduced by a model which contains only the single $D/\bar{D}$ inclusive spectra and necessary kinematic correlations. However, the transverse angle, ϕ_T, between the D and $\bar{D}$ exhibits a peak near 120° which is not predicted by this model.

Most features of our $D\bar{D}$ data are also reproduced by the fusion model with a hard $c \rightarrow D$ fragmentation ($E_D = E_c$) or with the LUND fragmentation procedure in which the D and $\bar{D}$ are formed by string breaking in colour fields. These models reproduce reasonably well the $D\bar{D}$ mass, Feynman-x, and rapidity gap distributions. They do not however predict the relatively hard p_T ($\langle p_T^2 \rangle = (1.65 \pm 0.40)(\mathrm{GeV/c})^2$) distribution of $D\bar{D}$ pairs or the features of the ϕ_T distribution. The simple fusion model with independent $c/\bar{c}$ fragmentation via the Peterson fragmentation function does not describe our data; neither do cluster type models.

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TABLE 1

Average values of the $D\bar{D}$ correlation variables.

	$\langle M(D\bar{D})\rangle$ (GeV/c^2)	$\langle x_f\ (D\bar{D})\rangle$	$\langle p_T^2\ (D\bar{D})\rangle$ $(GeV/c)^2$	$\langle DY\rangle$	$\langle\phi_T\rangle$ (deg)
Data	4.50 ± .16	0.25 ± .07	1.65 ± .40	0.80 ± .14	115 ± 8
Models:					
PIPS	4.70	0.25	1.39	0.83	115
Fusion/δ function	4.60	0.24	0.63	0.72	129
Fusion/Peterson	4.24	0.21	0.60	0.58	118
Fusion/Lund	4.60	0.25	0.75	0.77	126

FIGURE CAPTIONS

Fig. 1 Weighted distributions of the $D\bar{D}$ correlation variables from the 12 $D\bar{D}$ pairs with kinematically selected decay fits: solid curve is the uncorrelated prediction (PIPS); dashed and dotted curves are, the fusion model predictions with, respectively, δ function and LUND charm quark fragmentation. Fig. 1(a) also shows the Peterson fragmentation prediction.

Fig. 2 Distribution of the angle between the D and $\bar{D}$ in the plane transverse to the beam direction using 53 topologically clear $D\bar{D}$ pairs. The curves are described in fig. 1.

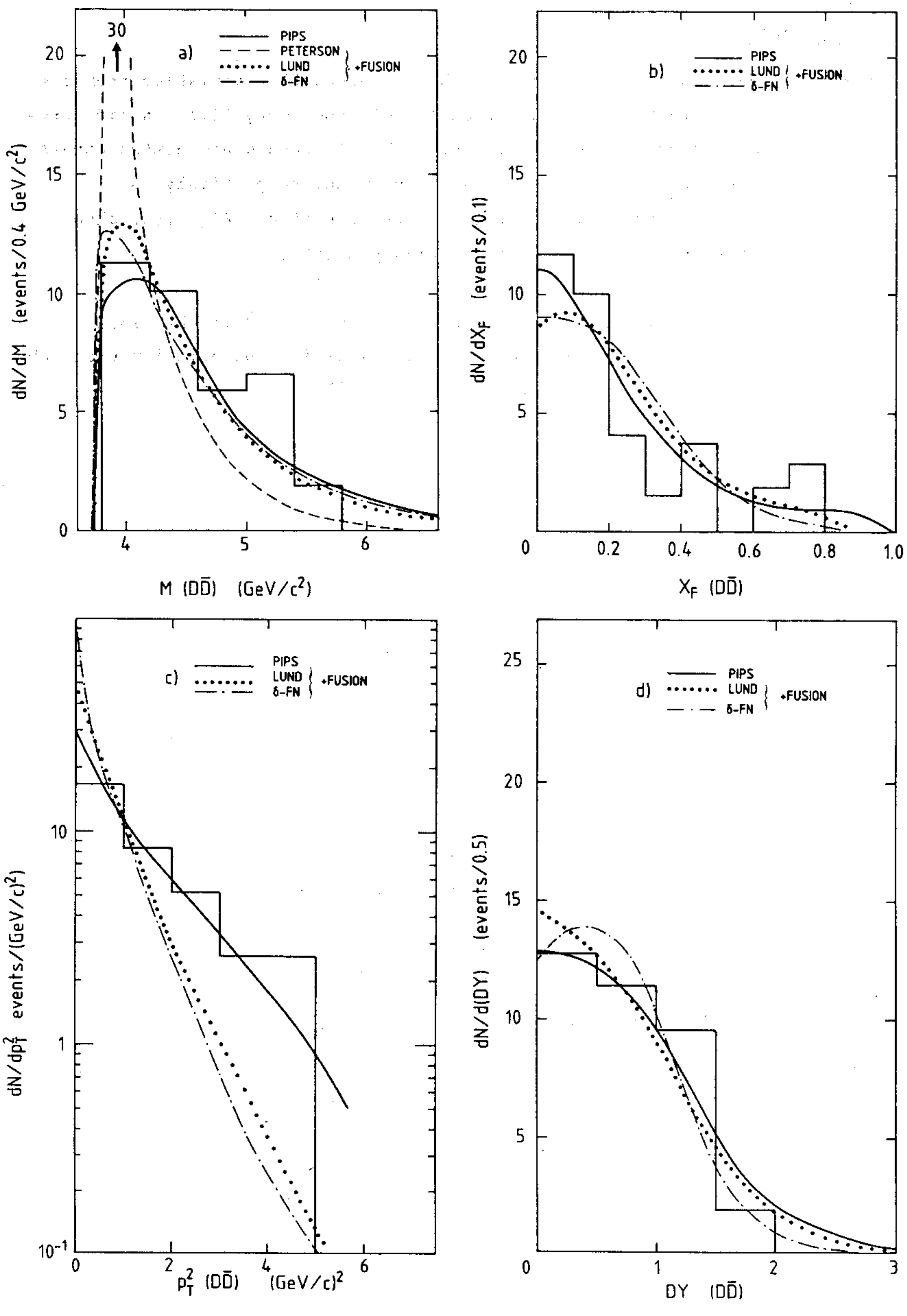
a)
30
PIPS
PETERSON
LUND
δ-FN
+FUSION
dN/dM (events/0.4 GeV/c²)
M (DD̄) (GeV/c²)
0
5
10
15
20
4
5
6
b)
PIPS
LUND
δ-FN
+FUSION
dN/dX_F (events/0.1)
X_F (DD̄)
0
0.2
0.4
0.6
0.8
1.0
5
10
15
20
c)
PIPS
LUND
δ-FN
+FUSION
dN/dp_T² events/(GeV/c)²
p_T² (DD̄) (GeV/c)²
10⁻¹
1
10
0
2
4
6
d)
PIPS
LUND
δ-FN
+FUSION
dN/d(DY) (events/0.5)
DY (DD̄)
0
1
2
3
5
10
15
20
25

Fig. 1

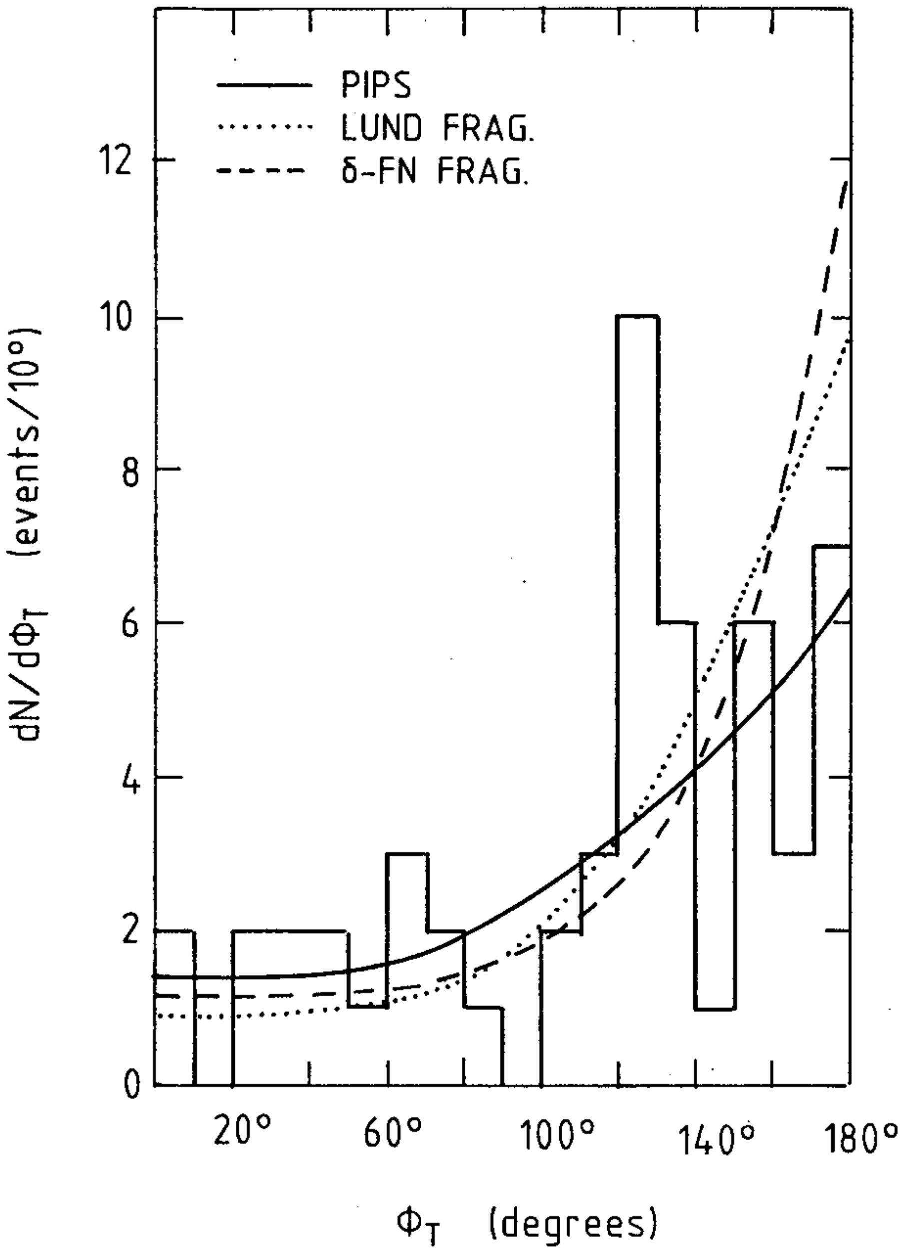
PIPS
LUND FRAG.
δ-FN FRAG.
dN/dΦ_T (events/10°)
0
2
4
6
8
10
12
20°
60°
100°
140°
180°
Φ_T (degrees)

Fig. 2