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ABSTRACT

Factorial correlators are studied in 250 GeV/c π^+p and K^+p collisions as a function of the distance in rapidity. The correlators are found to increase with decreasing correlation distance, independently of the rapidity resolution. The increase approximately follows a power law, but the power is considerably larger than expected from a log-normal approximation in the simple α model of intermittency. Also the FRITIOF results are independent of the resolution, but slopes and p_T behaviour cannot be reproduced by this model.

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Intermittency [1] has now been studied in e^+e^- [2,3,4,5], μp [6], νA [7], hadron-hadron [8,9], hadron-nucleus [10,11] and nucleus-nucleus [10,12-15] collisions. Recent reviews are given in [16,17]. The study has been performed in terms of a power law dependence of the scaled factorial moments

$$\langle F_i \rangle = \frac{1}{M} \sum_m \frac{\langle n_m(n_m-1)\ldots(n_m-i+1)\rangle}{\langle n_m \rangle^i} \quad , \tag{1}$$

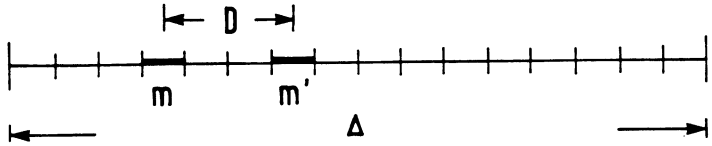
where M is the number of phase-space bins of size $\delta = \Delta/M$ into which an original region Δ is subdivided, n_m is the multiplicity in bin m ($m = 1, ..., M$). The averages under the sum are over the events in the sample.

While in the early stage of the analysis the interest mainly arose from the difficulties of currently used models to reproduce the effect, a number of alternative interpretations is available now. These range from conventional short range correlations and Bose-Einstein interference, via pencil jets and extended parton cascades, to a possible signal for quark-gluon-plasma. Different data support different interpretations, so that more discriminative information is needed experimentally.

While the moments defined in (1) measure local density fluctuations in phase space, additional information is contained in the correlation between these fluctuations within a given event. This correlation can be extracted by means of the factorial correlators [1]

$$\langle F_{ij}^{mm'} \rangle = \frac{\langle n_m(n_m-1)\ldots(n_m-i+1)\; n_{m'}(n_{m'}-1)\ldots(n_{m'}-j+1)\rangle}{\langle n_m\ldots(n_m-i+1)\rangle\langle n_{m'}\ldots(n_{m'}-j+1)\rangle} \quad , \tag{2}$$

where n_m is the multiplicity in bin m and $n_{m'}$ that in bin m' (see Fig.1). The correlators are calculated at given δ for each combination mm' and then averaged over all combinations with given D, as shown below.



According to the simple intermittency model (α-model) described in [1], the $\langle F_{ij} \rangle$ should depend only on D and not on δ, and the dependence should be according to the power law

$$\langle F_{ij} \rangle \propto (\Delta/D)^{f_{ij}} \quad . \tag{3}$$

For the power f_{ij} (slope in a log-log plot) the following relation has been derived [1]:

$$f_{ij} = f_{i+j} - f_i - f_j = ij f_2 \quad , \tag{4}$$

where the first equal sign is due to the α model, the second to the log-normal approximation. Since according to (4) $f_{11} = f_2$, this can also be written in the form

$$f_{ij} = ij f_{11} \; . \tag{5}$$

Preliminary results for pseudo-rapidity resolution $\delta\eta \geq 0.2$ have been reported by the HELIOS Collaboration [18], where, however, the multiplicities had to be estimated from the transverse energy.

The data presented here come from the NA22 experiment performed at CERN. In this experiment the European Hybrid Spectrometer (EHS) is equipped with the Rapid Cycling Bubble Chamber (RCBC) as a vertex detector and exposed to a 250 GeV/c tagged positive, meson enriched beam. In data taking, a minimum bias interaction trigger is used. The details of the spectrometer and the trigger can be found in previous publications [19,20].

Charged particle tracks are reconstructed from hits in the wire- and drift-chambers of the two lever-arm magnetic spectrometer and from measurements in the bubble chamber. The average momentum resolution $\langle \Delta p/p \rangle$ varies from a maximum of 2.5% at 30 GeV/c to around 1.5% above 100 GeV/c. In the rapidity region Δy under consideration ($-2.0 < y < 2.0$), the experimental resolution varies between 0.01 and 0.05 units.

Events are accepted for the present analysis when measured and reconstructed charge multiplicity are consistent, charge balance is satisfied, no electron is detected among the secondary tracks and the number of badly reconstructed (and therefore rejected) tracks is 0. Elastic events are excluded. Furthermore, an event is called single-diffractive and excluded from the sample if the total charge multiplicity is smaller than 8 and at least one of the positive tracks has $|x| > 0.88$. After these cuts, our "cleaned" inelastic non-single-diffractive sample consists of 59 232 π^+p and K^+p events. The averages in (1) and (2) are normalized to this sample, including events with no track in $-2.0 < y < 2.0$.

For momenta $p_{LAB} < 0.7$ GeV/c, the range in the bubble chamber and/or the change of track curvature is used for proton identification. In addition, a visual ionization scan has been used for $p_{LAB} < 1.2$ GeV/c on the full K^+p and 62% of the π^+p sample. Particles with momenta $p_{LAB} > 1.2$ GeV/c are not identified in the present analysis and are treated as pions.

As mentioned above, no losses due to bad reconstruction are allowed in our sample. It has been checked by a comparison to an event sample with track losses that the slopes f_{ij} are hardly affected by track losses. For further analysis of possible biases see [21].

The $\ln\langle F_{ij} \rangle$ are shown as a function of $-\ln D$ in Fig.1a-d, for four values of δy (corresponding to $M = 10$, 20, 30 and 40), respectively. Statistical errors (estimated from the dispersion of the F_{ij} distribution) are in general smaller than the size of the symbols. While an estimate of $\langle F_{ij} \rangle$ is possible up to third order in i and j for δy=0.4 binning (Fig.1a), we restrict ourselves to first and second order at δy=0.1 (Fig.1d). Since the smallest possible value for D is the bin size δy, Fig.1a) extends to $D = 0.4$ and Fig.1d) to $D = 0.1$. In all cases an increase of $\ln\langle F_{ij} \rangle$ is observed with increasing $-\ln D$.

In Fig.2a) we compare the $\ln\langle F_{ij} \rangle$ at fixed $D = 0.4$ for the four different values of δy. The dashed lines correspond to a horizontal line fit through the points. As expected from the α model, the $\langle F_{ij} \rangle$ indeed do not depend on δy. However, this

property is not unique to the α-model. Fig.2b shows that the δy independence is also reproduced by the FRITIOF model [22] (using a sample of 60 000 events) and is probably common to any model with short-range order. For the particular value of $D = 0.4$ this happens even at very similar values of $\ln\langle F_{ij}\rangle$ as in the data.

For $\langle F_{11}\rangle$, the δy independence can be extracted from the integral over the two-particle density, with two integration domains of size δy separated by D. Using exponential short range order [23], this gives

$$\langle F_{11}\rangle - 1 \quad \propto \quad \frac{1}{a^2} e^{-D/L} \cdot (e^a - 1)(1 - e^{-a}) \tag{6}$$

where L is a correlation length and $a = \delta y/L$. According to (6), $\langle F_{11}\rangle$ becomes independent of δy for $a < 1$. Since $e^{-D/L} \to 1$ with $D \to 0$, this form also leads to the deviations from (3) observed as a bending in Fig.1.

Because of the bending, fitted slopes f_{ij} only will be used as an indication for the increase over a certain range. They are given in table 1 for the fit ranges stated. For two values of δy they are compared to FRITIOF predictions in Fig.3a) and 3b), respectively. As observed earlier for the case of single moments [8], the FRITIOF slopes are too low also for the correlators $\langle F_{ij}\rangle$. This shortcoming of FRITIOF is related [23] to the failure of this model to reproduce two-particle rapidity correlations in our [24] and other data [25]. Future improvements of the model should account for these results simultaneously.

According to (4), the ratio f_{ij}/f_2 is expected to grow with increasing orders i and j like their product ij. In Figs.3c) and 3d) this is tested for δy=0.4 and δy=0.2, respectively. In both cases, the experimental results lie far above the dashed line corresponding to the expected $f_{ij}/f_2 = ij$. Since the dependence of $\ln\langle F_{ij}\rangle$ on $-\ln D$ is not strictly linear, this comparison depends on the range of δy and D used to determine f_2 and f_{ij}. In Fig.3d) we, therefore, compare a number of fits. Slopes are reduced when reducing the upper limit in D, but do not reach the α-model prediction (dashed line).

It can be verified from table 1, that at least for the higher orders the discrepancy with (4) is mainly due to the second equal sign, derived from a log-normal approximation. In a recent paper [26] this approximation has been shown valid only for the cases that the density fluctuations are weak or that the fluctuations of the cascade variable ω have a log-normal distribution. Our data demonstrate that neither of these conditions is fulfilled.

Recently, a transverse momentum dependence of the intermittency effect has been reported in our data [27], with essentially all of the effect being restricted to $p_T < 0.30$ GeV/c. In Fig.4, we therefore compare results for p_T cuts with the full sample in terms of f_{ij}/ij for $\delta y = 0.4$. In the data (Fig.4a), the slopes increase both when restricting to small and to large p_T. On the other hand, FRITIOF gives an increase of the slopes for small p_T, but a decrease for large p_T.

We conclude that the correlators $\langle F_{ij}\rangle$ increase with decreasing correlation length D, but only approximately follow a power law for $D \lesssim 1$. For fixed D the values of $\langle F_{ij}\rangle$ do not depend on resolution δy, a feature expected from the α model, but

also reproduced by FRITIOF and probably common to any model with short range order. The powers f_{ij} increase linearly with the product ij of the orders, but are considerably larger than expected from FRITIOF and from the simple α model. Even though FRITIOF has as strong effect at small p_T, the p_T dependence of the effect is not fully reproduced by the FRITIOF model.

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Table 1. Slopes f_{ij} and f_i from fits in the D region indicated.

ij	δy=0.4 ($0.4\leq D \leq 1.2$)	δy=0.2 ($0.2\leq D \leq 1.0$)	δy=0.133 ($0.13\leq D \leq 0.93$)	δy=0.1 ($0.1\leq D \leq 1.0$)
11	0.096±0.004	0.057±0.002	0.043±0.001	0.042±0.001
21	0.163±0.007	0.102±0.004	0.070±0.003	0.079±0.003
31	0.214±0.016	0.165±0.011	0.066±0.012	0.197±0.004
22	0.283±0.008	0.193±0.005	0.114±0.004	
32	0.397±0.017			
33	0.588±0.025			
i	$0.1\leq \delta y \leq 1.0$			
2	0.008±0.001			
3	0.045±0.004			
4	0.153±0.011			

FIGURE CAPTIONS

Fig.1 $\ln\langle F_{ij}\rangle$ as a function of $-\ln D$ for four values of δy, as indicated. Data in numerical form can be obtained by bitnet from U632007 at HNYKUN11.

Fig.2 Dependence of $\ln\langle F_{ij}\rangle$ on the bin size δy for a correlation distance $D = 0.4$, a) for NA22 data, b) for a sample of 60 000 FRITIOF Monte Carlo events. The dashed lines correspond to horizontal line fits through the points.

Fig.3 a) b) The increase of the slopes f_{ij} with increasing order ij compared to the expectation from FRITIOF, for two values of δy, respectively; c) d) the increase of f_{ij}/f_2 with increasing order ij, compared to that expected from the α model (dashed line), for two values of δy, respectively.

Fig.4 The dependence of f_{ij}/ij on the order ij for the full sample and after p_T cuts as indicated, a) for the experimental data, b) for the FRITIOF sample.

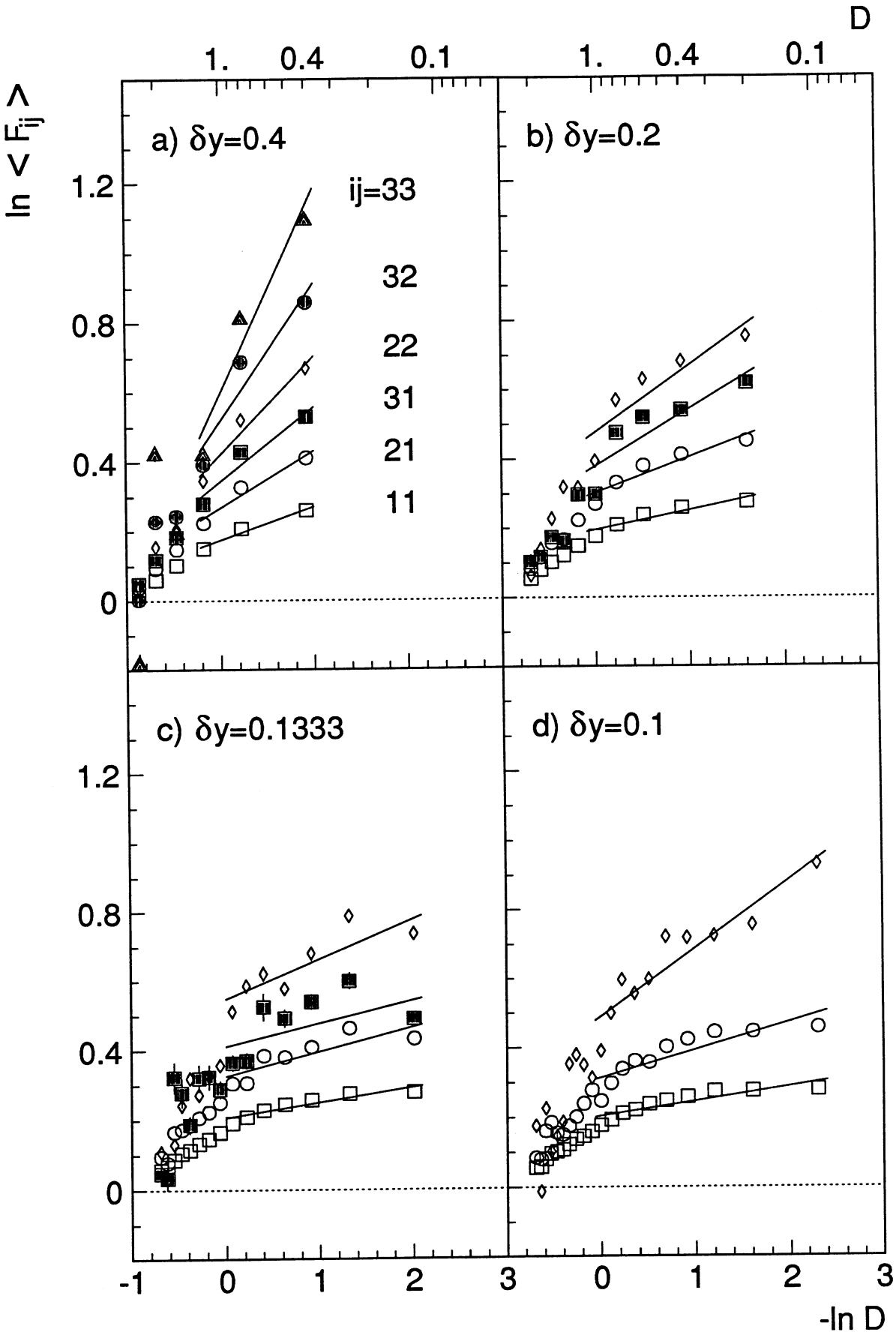
D
1. 0.4 0.1
1. 0.4 0.1
ln Λ V Fij
a) δy=0.4
b) δy=0.2
c) δy=0.1333
d) δy=0.1
ij=33
32
22
31
21
11
1.2
0.8
0.4
0
-1 0 1 2 3
-ln D

Fig. 1

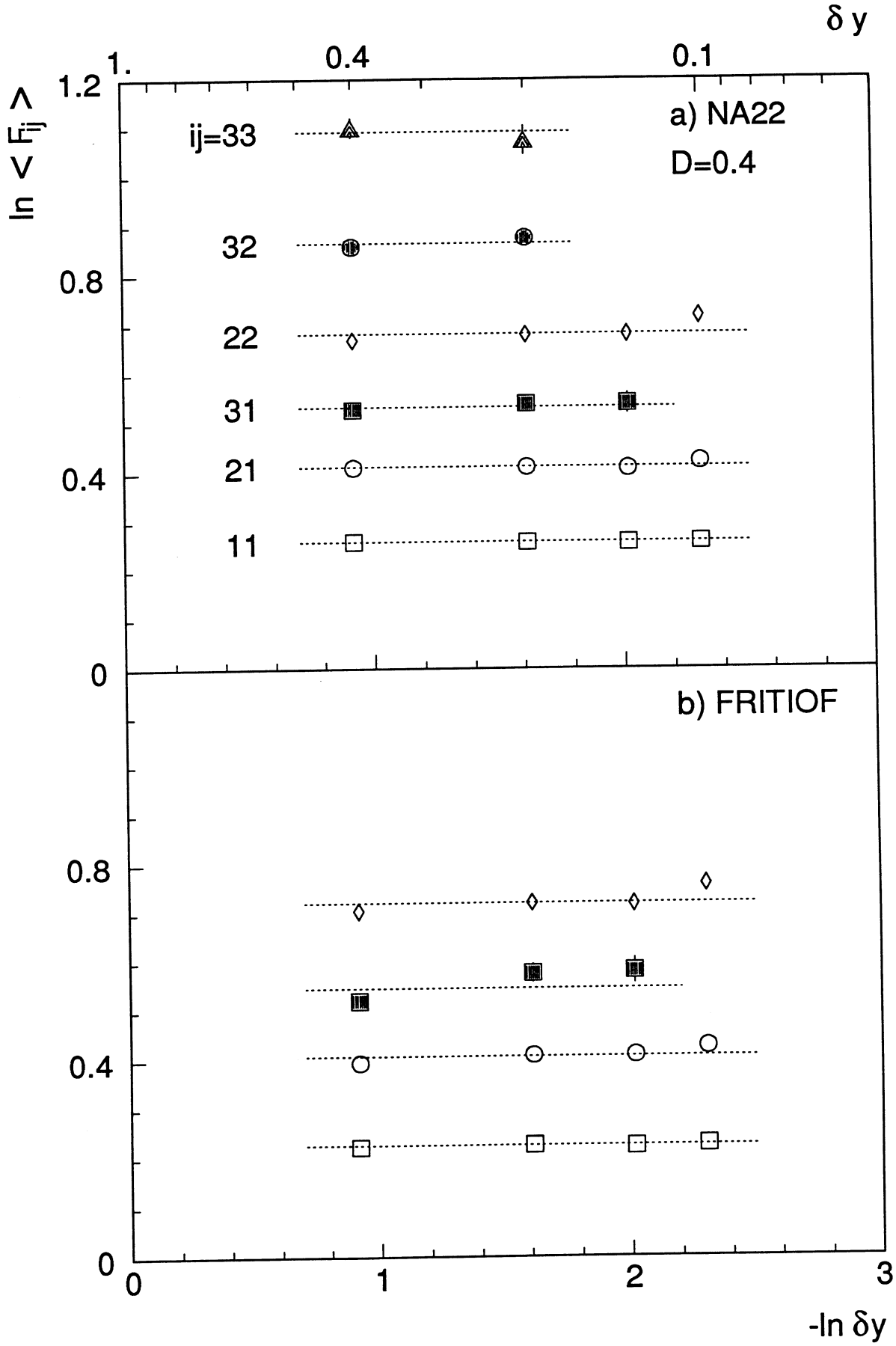
δ y
1.
0.4
0.1
1.2
0.8
0.4
0
Λ
V
Fij
ln
ij=33
32
22
31
21
11
a) NA22
D=0.4
b) FRITIOF
0.8
0.4
0
0
1
2
3
-ln δy

Fig. 2

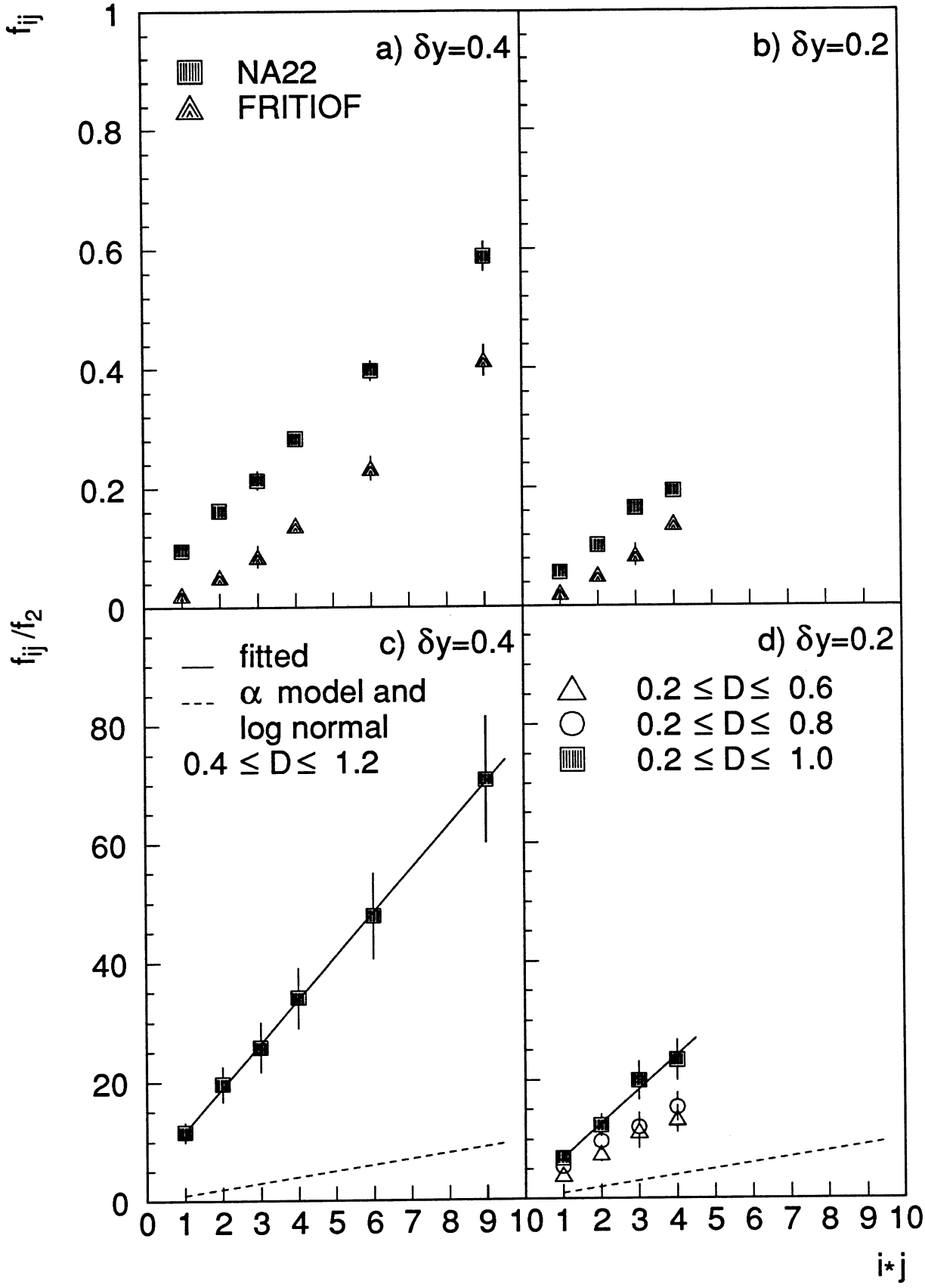
a) δy=0.4
NA22
FRITIOF
b) δy=0.2
c) δy=0.4
fitted
α model and
log normal
0.4 ≤ D≤ 1.2
d) δy=0.2
0.2 ≤ D≤ 0.6
0.2 ≤ D≤ 0.8
0.2 ≤ D≤ 1.0
f_ij
f_ij /f_2
i*j

Fig. 3

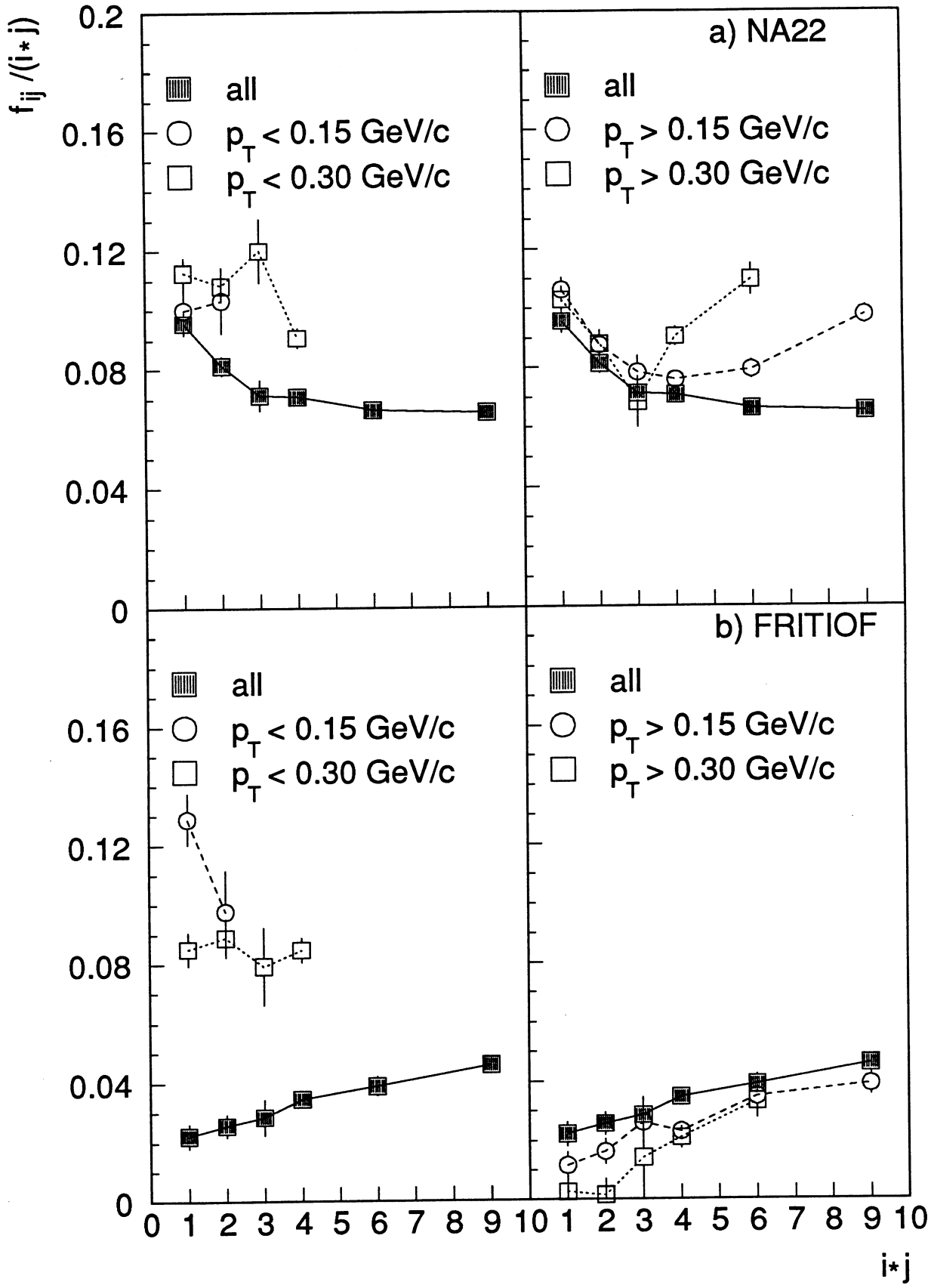
a) NA22
b) FRITIOF
all
p_T < 0.15 GeV/c
p_T < 0.30 GeV/c
p_T > 0.15 GeV/c
p_T > 0.30 GeV/c
$f_{ij}/(i*j)$
i*j
0.2
0.16
0.12
0.08
0.04
0
0 1 2 3 4 5 6 7 8 9 10

Fig. 4