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**INTERMITTENCY PATTERNS IN
 π^+p and K^+p COLLISIONS AT 250 GeV/c**

EHS/NA22 Collaboration

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ABSTRACT

Intermittent behaviour is observed in π^+p and K^+p collisions at 250 GeV/c. It is stronger there than in O^{16} -emulsion, but weaker than in e^+e^- collisions. A jet cascading mechanism is, therefore, the most likely interpretation. Presently used fragmentation models do not (fully) reproduce the effect, suggesting that an improvement of the hadronization picture is needed.

Unusually large density fluctuations in (pseudo)-rapidity have been observed in cosmic ray events [1] as well as in hadron-hadron [2,3], hadron-nucleus and nucleus-nucleus [4] collisions. These fluctuations have led to interpretations in terms of possible evidence for a hadronic phase transition [5], hadronic Cerenkov radiation [6], hadronic hydrodynamics [7] or, simply, a cascading mechanism [8,9].

Before trying to distinguish between the different interpretations in terms of possibly new physics, the density fluctuations have to be shown statistically significant and not reproducible by present fragmentation and hadronization models.

To prove statistical significance, Białas and Peschanski [8] have suggested to study the dependence of the scaled factorial moments of order i (see also Hwa [5] for $i=2$)

$$\langle F_i \rangle = \frac{1}{\langle \bar{n}_m \rangle^i} \left\langle \frac{1}{M} \sum_{m=1}^M n_m (n_m - 1) \cdots (n_m - i + 1) \right\rangle$$

$$\text{with } \langle \bar{n}_m \rangle = \left\langle \frac{1}{M} \sum_{m=1}^M n_m \right\rangle \quad (1)$$

on the size of the rapidity resolution δy . In (1), the original rapidity window Δy (of say 4 units) is divided into M bins of size $\delta y = \Delta y/M$. The multiplicity is n_m in bin m ($m = 1 \dots M$). The average $\langle \rangle$ is over all events in the sample. The authors show the following:

1. Saturation of $\langle F_i \rangle$ with decreasing resolution δy is expected if the fluctuations are purely statistical, or the correlation is of range $d_0 > \delta y$.
2. If non-statistical self similar fluctuations of many different sizes in rapidity exist, the δy dependence follows the power law

$$\langle F_i \rangle \propto (\Delta y / \delta y)^{f_i} \quad \text{with } f_i > 0 \quad (2)$$

This latter effect is referred to as "intermittency". Originally designed for high multiplicity events, the method can in fact be used down to "normal" multiplicities [10].

Using these scaled factorial moments, the authors of [8] show that the JACEE density fluctuations [1] indeed provide indication of being intermittent.

Recent evidence for intermittent behaviour in hadronic *accelerator* experiments comes from the Krakow-Minneapolis-Louisiana Emulsion group for pEm at 200 and 800 GeV as well as for $O^{16}Em$ at 60 and 200 A GeV [11] and from WA80 for 200 A GeV $O^{16}Au$ Collisions [12].

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 has been used. The details can be found in [13]. The statistics available for this study comprises 80 000 π^+p and 34 500 K^+p inelastic events. The rapidity resolution is of the order of 0.1 rapidity units.

In Fig.1a, $\ln\langle F_i \rangle$ is plotted as a function of $-\ln \delta y$ for our combined π^+p and K^+p sample in the rapidity window $\Delta y = 4$ ($-2 < y < 2$). The $\ln\langle F_i \rangle$ are observed to increase with decreasing resolution δy over the whole range of δy . The effect increases with the order i of the moment. Furthermore, within our range of δy , we observe a two slope behaviour with a steep slope for $\delta y > 1$ and a flatter one for $1 > \delta y > 0.1$. Also for the second region the slopes f_i are non-zero for all orders i . The values are given in the first line of table 1, together with χ^2/ND for the fits.

The increase for $\delta y \geq 1$ is exactly what can be expected from conventional short range order correlations. The fact that $\langle F_i \rangle$ does not saturate at smaller resolution, but shows the power behaviour of (2) leads us to the conclusion that intermittency is observed in our data.

The slopes f_i are compared to those obtained by the Emulsion group [11] and WA80 [12] in Fig.2a. There is a clear increase of the slope f_i with increasing order i , for all types of collision. It is interesting to note that the effect is stronger in our data than in the $O^{16}Em$ data at similar energy per nucleon, and still stronger than in central $O^{16}Au$ Collisions.

Whatever the mechanism that causes intermittency in hh , hA and AA collisions, it also seems to be present in e^+e^- collisions. Even though no direct measurements exist, Buschbeck, Lipa and Peschanski [14] have been able to convert small δy negative binomial multiplicity fits of the HRS Collaboration [15] into scaled factorial moments via the relations [16]

$$\langle F_2 \rangle = 1 + 1/k \quad \text{and} \quad \langle F_3 \rangle = 1 + 3/k + 2/k^2 \quad , \quad (3)$$

thus connecting to the cascade picture of Van Hove and Giovannini [17].

Extracting the slopes f_2 and f_3 from the distributions for the 2-jet e^+e^- data and comparing to the hadronic ones in Fig.2a, we conclude that intermittency is at least as strong in the former. If this finding can be confirmed by a direct measurement in e^+e^- , this would mean evidence against the interpretation of intermittency as due to a hadronic reaction mechanism, including hadronic phase transition or hadronic Cerenkov radiation. It is, however, consistent with a cascade type fragmentation.

Can this intermittent behaviour be reproduced by currently used fragmentation and hadronization models? As shown in [14], the e^+e^- slopes at $\sqrt{s}=29$ GeV/c are not reproduced by the cascade like LUND shower model [18]. The behaviour of $\langle F_i \rangle$ with decreasing δy expected from FRITIOF3.0 [19] is shown in Fig.1b. The fitted slopes of the two chain version of DPM [20], FRITIOF2.0 and FRITIOF3.0 are compared to our data in Fig.2b. No intermittency can be expected from DPM, since this uses two (LUND) chains of independent particle and resonance production. Intermittency can, however, be expected in the FRITIOF model from the cascade-like treatment of multi-gluon radiation. It is better reproduced by version 3.0 than 2.0 but the effect is too low even there and something is missing.

A possible candidate for a mechanism increasing the slopes f_i would be the Bose-Einstein effect observed in the same data [21], but not included in FRITIOF. From the flat ϕ distribution of positive as well as negative particles in the NA22 spike event [3] and from the aggregation [17] $1/k$ of negative particles being smaller than

that of all charged particles in the NA22 small δy multiplicity distributions [22], it is unlikely that this mechanism will fully be able to reproduce the observed slopes.

A more likely explanation of the apparent failure of the LUND shower [18] and FRITIOF Monte Carlos seems to be the following. Because of the self-similar character of these cascading models, intermittency is in principle present on the parton level (see also [23]). Due to necessary Q^2 cut-offs and/or resonance decays, the effect is, however, smeared out over the conventional short range order during hadronization. Therefore, an improved hadronization picture seems to be needed and a generalized local parton-hadron duality [24,25] where $1/k$ (and via these $\langle F_i \rangle$) is preserved may be a good candidate.

Another interpretation has been introduced by J. Dias de Deus [7]. In this approach it is suggested to investigate the probability distribution $P(n, \nu)$, where n is the charge multiplicity of an event and ν the maximum number of charged particles inside any small rapidity bin of given size δy in this event. According to the model, $P(n, \nu)$ can be written as a sum of two terms: one corresponding to turbulent and the other to laminar regimes. The turbulent term decreases exponentially with ν while the laminar one increases with $\frac{\nu}{\nu_M}$ and is effectively cut off at large ν (ν_M is the maximal ν for given n and is proportional to n). It follows that the key feature of this intermittency model is the prediction of a two-peak behaviour of the distribution in ν for events with fixed multiplicity n , i.e.

$$P(n, \nu) = P_T(n, \nu) + P_L(n, \nu) \quad . \quad (5)$$

Our results, normalized to the topological cross sections σ_n [13] are given in Fig.3, for the fixed n values indicated. The bin size is $\delta y = 0.1$. Indeed, at large n the shape of the distribution develops a tail at large ν . Although at the much wider bin size $\delta y = 0.5$, a statistically significant widening of $P(n, \nu)$ with ν has recently also been reported in [26].

We conclude that

1. *We observe an increase of the normalized factorial moments with decreasing resolution down to $\delta y = 0.1$ (intermittent behaviour).*
2. *The effect tends to be larger in our data than in nucleus-nucleus collisions, but not larger than in e^+e^- collisions.*
3. *This observation favours jet cascading over a hadronic reaction mechanism as possible interpretation, but presently used cascade models fail to reproduce the effect.*
4. *A flattening at large ν of the $P(n, \nu)$ distribution is observed for large multiplicities n , in qualitative agreement with the intermittency model of Dias de Deus.*

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Table 1. Fitted slopes f_i for the bin size range $1 \geq \delta y \geq 0.1$

	f_2	f_3	f_4	f_5
$\pi^+p + K^+p$	0.0127 ± 0.0008	0.0499 ± 0.0022	0.148 ± 0.007	0.328 ± 0.019
χ^2/ND	0.71	0.82	1.1	2.69
FRITIOF3.0	0.0034 ± 0.0008	0.0070 ± 0.0021	0.037 ± 0.006	0.140 ± 0.020
FRITIOF2.0	0.0024 ± 0.0008	0.0162 ± 0.0020	0.039 ± 0.006	0.070 ± 0.016
DPM (2 chain)	0.0004 ± 0.0006	0.0037 ± 0.0017	0.011 ± 0.005	0.039 ± 0.015

Figure Captions

Fig.1 The $\ln\langle F_i \rangle$ as a function of $-\ln\delta y$ for a) π^+p and K^+p collisions at 250 GeV/c and b) the expectations from FRITIOF3.0.

Fig.2 The slope f_i as a function of the order i for a) the type of collision indicated, b) NA22 events compared to DPM, FRITIOF2.0 and FRITIOF3.0.

Fig.3 The probability distribution $P(n, \nu)$ as a function of ν for $\delta y = 0.1$, for the values of n indicated.

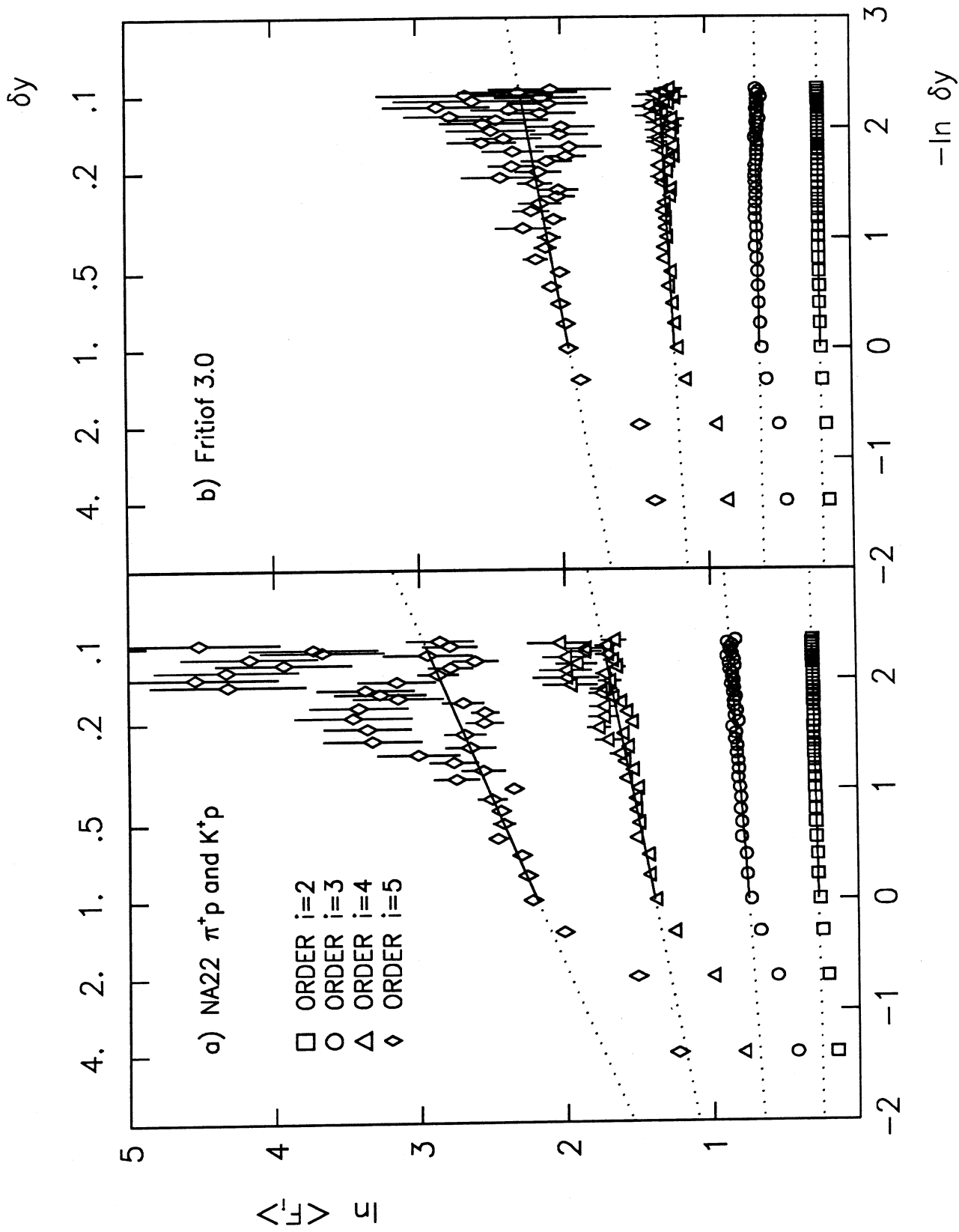


FIG.1

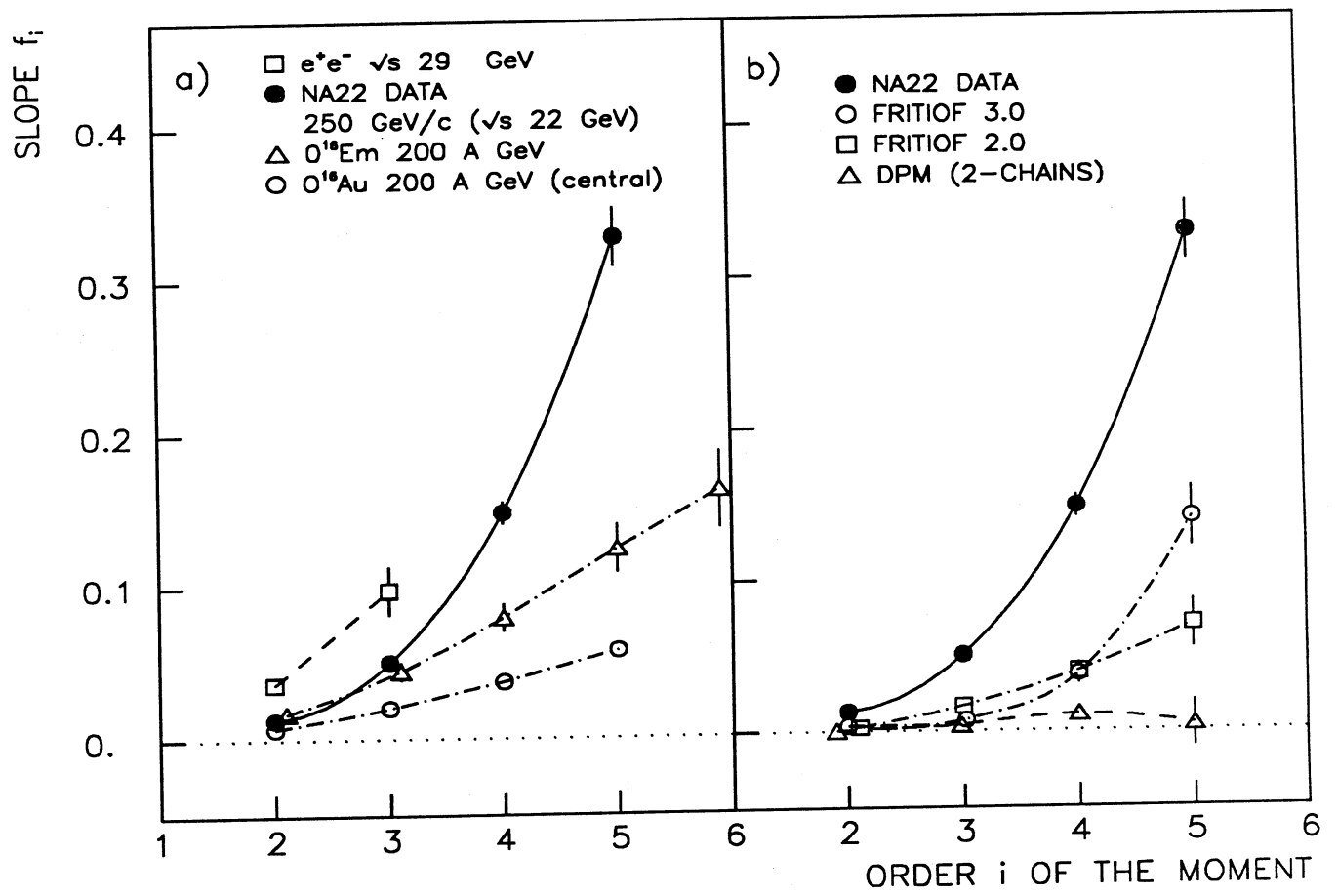


FIG.2

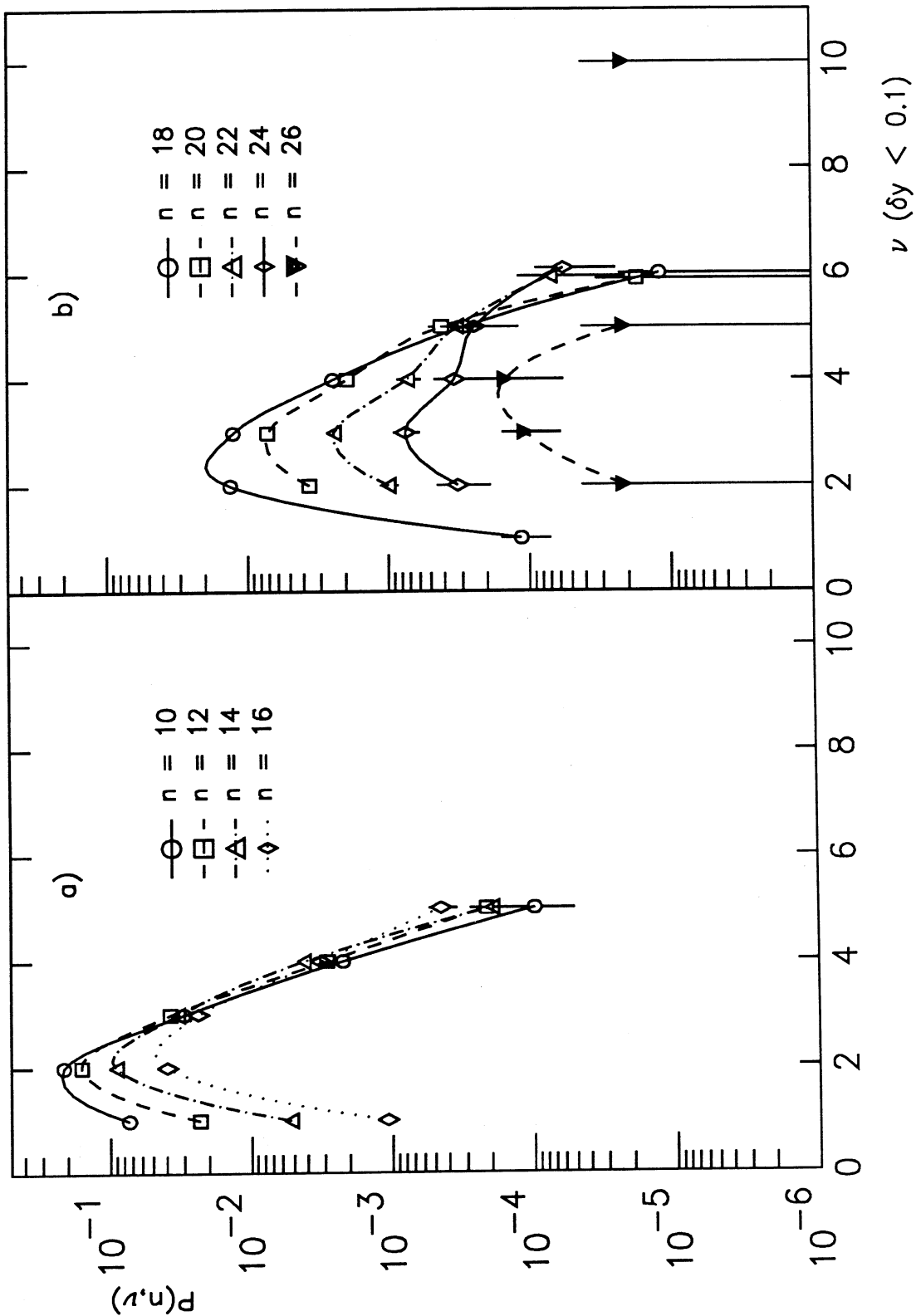


FIG.3