Vol. B20 (1989) ACTA PHYSICA POLONICA No 5

INTERMITTENCY, A COMPARISON OF HADRON-HADRON TO e^+e^- AND NUCLEUS-NUCLEUS COLLISIONS*

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(*Received October 21, 1988*)

Intermittency is observed in all types of collision. It tends to be strongest in e^+e^- and weakest in nucleus-nucleus collisions. Jet-cascading is the most likely interpretation of the effect. Presently used cascading models are, however, too weak to reproduce it and a new hadronization picture may be needed.

PACS numbers: 13.85.–t

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

Before trying to distinguish between the different interpretations in terms of possibly new physics, two questions need to be answered:

1. Are the fluctuations statistically significant?
2. Can they be reproduced by present fragmentation and hadronization models?

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

$$\langle F_i \rangle = \frac{1}{M} \sum_{m=1}^{M} \frac{\langle n_m(n_m-1) \dots (n_m-i+1) \rangle}{\langle n/M \rangle^i} \tag{1}$$

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 in n in Δy and n_m in bin $m(m = 1 \dots M)$. The average $\langle\ \rangle$ is over all events in the sample, the normalized sum runs over all bins. The authors show that

* Presented at the XXVIII Cracow School of Theoretical Physics, Zakopane, Poland, May 31 — June 10, 1988.

i) saturation of $\langle F_i \rangle$ with decreasing δy is observed if the fluctuations are purely statistical (or the correlation is of range $d_0 > \delta y$);

ii) the δy dependence follows the power law

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

if fluctuations of many different sizes (intermittency) in rapidity exist;

iii) the powers f_i are related by

$$f_{i+1} - f_i = i f_2 \tag{3}$$

if the number of steps in a cascade is large and the Gaussian approximation [8b] can be applied;

iv) furthermore, originally designed for high multiplicity events, the method can in fact be used down to "normal" multiplicities [10].

Using these factorial moments, the JACEE density fluctuations [1] could be shown [8] to be non-statistical and intermittent.

Recent evidence for intermittent behaviour in hadronic *accelerator* experiments comes from the Krakow-Minneapolis-Louisiana Emulsion group [11] for pEm at 200

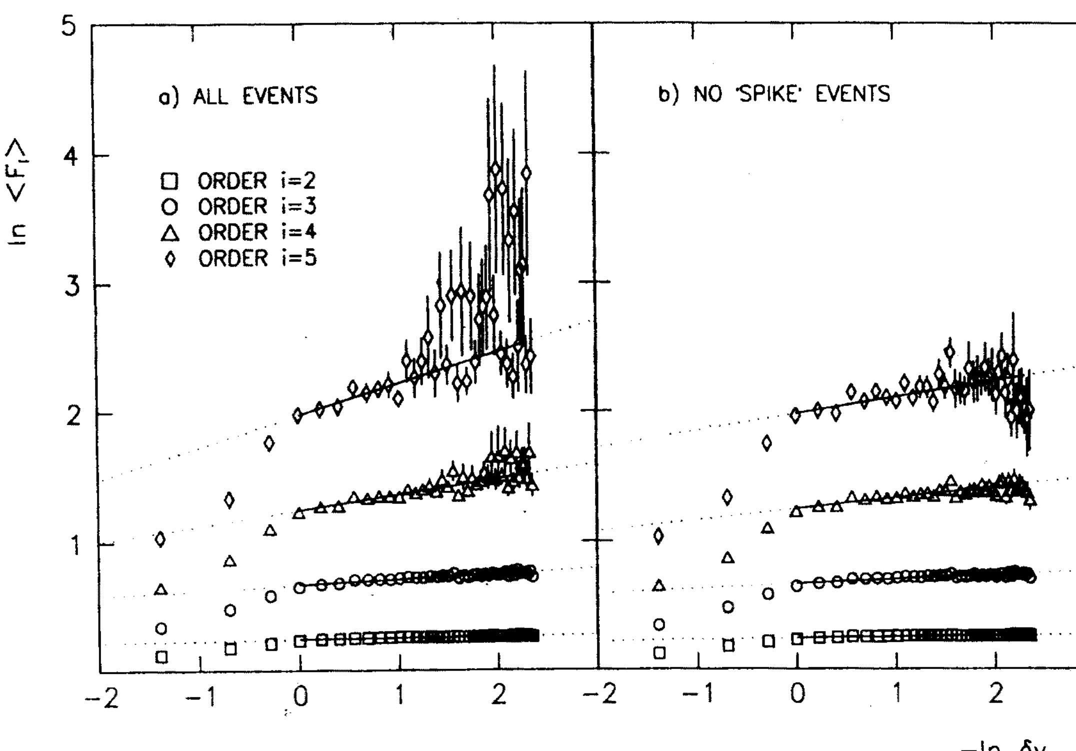

Fig. 1. The ln $\langle F_i \rangle$ as a function of $-\ln \delta y$ for K^+p and π^+p collisions at 250 GeV/c: a) all events, b) after exclusion of "spike" events [12]

and 800 GeV as well as for O^{16} Em at 60 and 200 GeV and from NA22 [12]. As a typical example, ln $\langle F_i \rangle$ is plotted as a function of $-\ln \delta y$ in Fig. 1 for NA22. All events as well as all except the obvious "spike" events (at least 5 particles leading to a local density $\delta n/\delta y > 100$) are plotted. For large bin-sizes ($-1.4 < -\ln \delta y < 0$), $\langle F_i \rangle$ increases fast with decreasing interval size (i.e. increasing $-\ln \delta y$). This is exactly what is expected from conventional short range order. What is not expected from this, however, is the continued linear rise of ln $\langle F_i \rangle$ at smaller resolution (i.e. intermittency), even after exclusion of "spike" events.

The slopes f_i (straight lines in Fig. 1) are compared to those obtained by the Emulsion group [11] in Fig. 2a. There is a clear increase of the slope f_i with increasing order i, for all experiments. This positively anwers the first question, i.e. statistically significant density fluctuations exist down to at least $\delta y = 0.1$, and they exist in hadron-hadron, hadron--nucleus and nucleus-nucleus collisions. It is interesting to note that the effect is stronger in NA22 than in O^{16} Em.

Can this intermittent behaviour be reproduced by currently used fragmentation and hadronization models? To answer this question, the NA22 dependence of f_i on i is compared in Fig. 2b to the slopes expected from the two chain version of DPM [13] and from FRITIOF2.0 [14b]. The slopes obtained for all NA22 events as well as those obtained after exclusion of obvious "spike" events are given. No intermittency can be expected from DPM, since this uses two (LUND) chains of independent particle and resonance production. Intermittency can be expected in the FRITIOF2.0 model from the cascade-like treat-

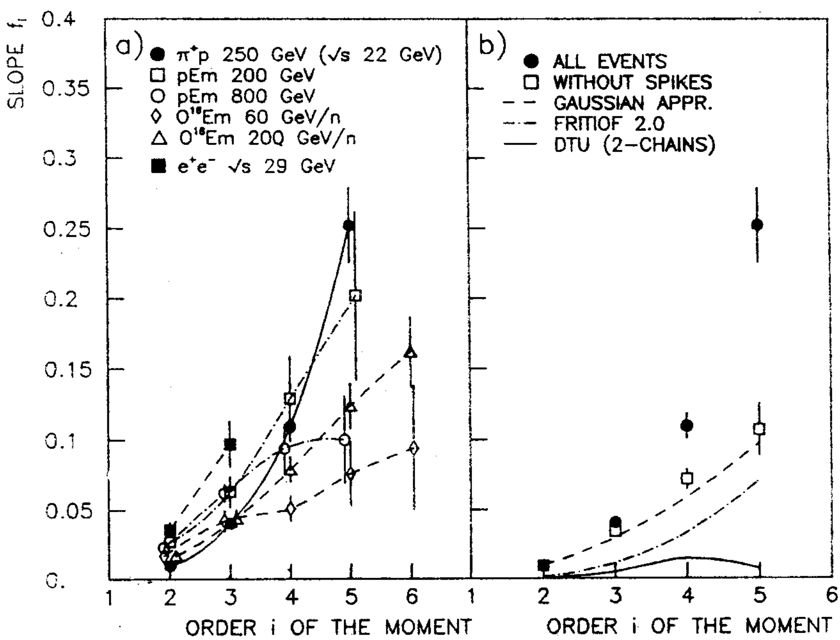

Fig. 2. The slope f_i as a function of i for a) the type of collision indicated; b) NA22 events compared to DPM, FRITIOF and the Gaussian approximation

ment of multi-gluon radiation. The effect is too low, however, and something else is needed.

Furthermore, when all events are included, the slope f_i grows faster with i than expected from the simple Gaussian approximation of [8]. As can be seen from the open squares in Fig. 2b, this deviation only vanishes when obvious spike events are excluded.

What is it? An obvious candidate for a mechanism increasing the slopes f_i would be the Bose-Einstein effect observed in the same data [15], 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 [16] $1/k$ of negative particles being smaller than that of all charged particles in the NA22 small δy multiplicity distributions [17], it is unlikely that this mechanism will fully be able to reproduce the observed slopes. Nevertheless, the Bose-Einstein effect has to be included in FRITIOF and a future comparison in two dimensions (y and ϕ) as suggested by Ochs and Wosiek [9] will be able to tell.

There is one important conclusion we can draw already at this stage, however. 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 [18] have been able to convert small δy negative binomial multiplicity fits of the HRS Collaboration [19] into factorial moments via the relations

$$\langle F_2 \rangle = 1 + 1/k \quad \text{and} \quad \langle F_3 \rangle = 1 + 3/k + 2/k^2, \tag{4}$$

thus connecting to the cascade picture of Van Hove and Giovannini [16].

The results are shown in Fig. 3. Also there, $\langle F_2 \rangle$ and $\langle F_3 \rangle$ continue to increase for δy down to 0.2 units. The slopes f_2 and f_3 are compared to those of the hadronic collisions in Fig. 2a and are even *larger* than these. The authors, furthermore, show that the effect is stronger for the "two-jet" sample than for the fully inclusive sample. If this finding can be confirmed by a direct measurement of the $\langle F_i \rangle$, it would mean that the mechanism is strongest in the cleanest case of 2-jet e^+e^- events and weakest in the case of nucleus--nucleus collisions.

Among the suggested interpretations, the above conclusion is in favour of a cascading mechanism. From the failure of the LUND shower model [29] in Fig. 3 (both via negative binomial fits and direct calculation) and the observation for FRITIOF in Fig. 2b, one can conclude that it is necessary but not sufficient that the cascade is present at the parton lewel (see also [21]). The effect is smeared out over the conventional short range order during hadronization. A new hadronization picture is needed and a generalized local parton--hadron duality [22, 23], where $1/k$ (and via this also $\langle F_i \rangle$ is preserved may be a good candidate.

We conclude that

i) intermittency is observed in all types of collision, but tends to be stronger in e^+e^- collisions than in nucleus-nucleus collisions;

ii) jet-cascading, therefore, is the most likely interpretation of the effect;

iii) presently used cascade models are too weak to reproduce the effect, however, and a new hadronization picture may be needed.

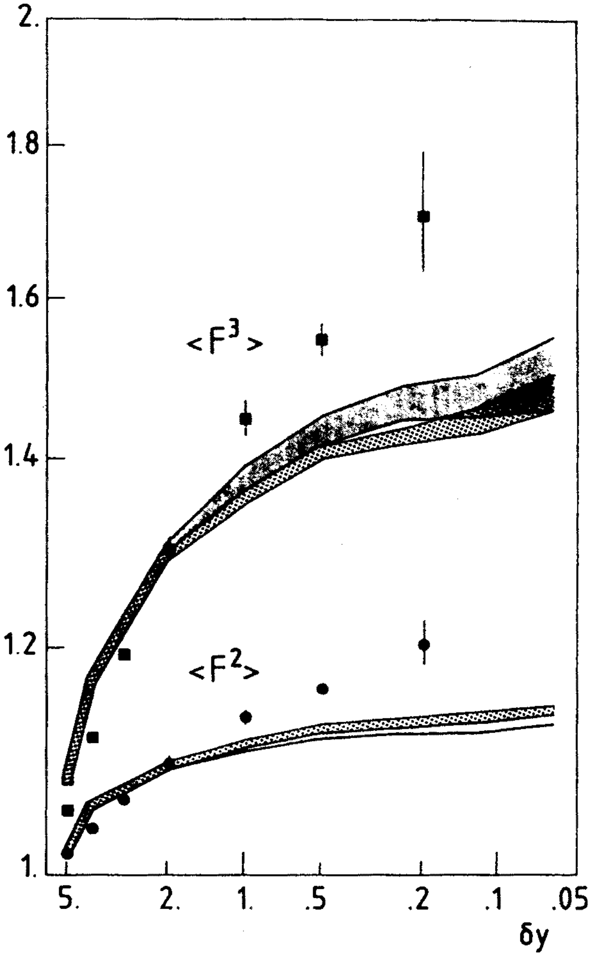

Fig. 3. The factorial moments $\langle F_2 \rangle$ and $\langle F_3 \rangle$ in the two-jet e^+e^- data at $\sqrt{s} = 29$ GeV obtained from the $1/k$ parameter of negative binomial fits of [19]. The shaded region corresponds th the Lund Shower Monte Carlo [20] according to (1), the dotted region is obtained from $1/k$ of NB fits to the multiplicity distributions from the same model according to (4) [18]

I am obliged to my colleagues from the NA22 Collaboration, in particular T. Haupt and E. Markhorst for their work on the NA22 data and to A. Białas, B. Buschbeck, P. Lipa and L. Van Hove for clarifying discussions.

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