LETTERS TO THE EDITOR

INTERMITTENCY AND QCD JETS*

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(Received April 5, 1989)

Multiplicity distributions in rapidity bins are studied in the Marchesini-Webber model for e^+e^- annihilation. The intermittent, power-like growth of the scaled factorial moments for small rapidity bins is found. Corrections accounting for the rapidity dependence of the single particle density are analyzed and shown to lead to the universal behaviour for various choices of the studied rapidity range.

PACS numbers: 12.38.Aw

Moments of the multiplicity distributions in small rapidity bins have become recently a subject of vigorous experimental and theoretical investigations. Few years ago Białas and Peschanski have predicted a power-like increase of scaled factorial moments with decreasing bin length in a model based on the analogy with the turbulent flow (intermittency) [1]. Such an effect was considered as a possible signal for quark-gluon plasma formation and seemed to be present in cosmic ray data on nucleus-nucleus collisions [2]. Later, experimental investigations have discovered analogous effects in the wide range of energies for nuclear, hadronic and leptonic collisions [3, 4, 5]. On the other hand, commonly used

* Supported by the grants CPBP 01.09 and CPBP 01.03.

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hadronization models (e.g. Dual Parton Model and Lund Monte Carlo-FRITIOF) were shown to disagree with these data revealing much weaker increase of moments or even saturation for small bins [6]. Apparently, one has found a new general feature of multiparticle production not present in standard models of these processes. This has prompted many authors to the construction of new hadronization schemes. Nevertheless, it seems at least as important to analyze more carefully the predictions of the existing models, and to search for the factors influencing the expected dependence of the multiplicity moments on the bin size. This should provide more decisive tests of these models.

In this note we look for the consequences of the Marchesini–Webber model which incorporates the perturbative QCD cascade with coherence effects [7]. Based on the model is the Monte Carlo program which generates complete events resulting from various hard processes [8]. We are using a sample of 750 events from the e^+e^- annihilation at the CM energy of 1000 GeV[1]. For this set of events we compute the rapidity distribution $\varrho(y) = \frac{1}{N_{ev}} \frac{dN}{dy}$, which is shown in Fig. 1a, and the scaled factorial moments

$$F^{(i)} = M^{i-1} \sum_{m=1}^{M} \frac{\langle k_m(k_m-1) \dots (k_m-i+1)\rangle_{ev}}{\langle n \rangle_{ev}^{i}}, \tag{1}$$

where k_m is the number of particles emitted in the m-th bin of rapidity in a given event, and $\langle\rangle_{ev}$ denotes averaging over all events in the sample; n is the multiplicity of the event. M determines the size of the rapidity bin $\delta = \frac{\Delta}{M}$ into which the relevant phase space has been divided. Dependence of the factorial moments, Eq. (1), for $i = 2, 3, 4, 5, 6$, on the bin size δ, are shown in Fig. 1b. Three important points should be noted here. 1) The moments are rising with decreasing bin size, and for the experimentally accessible range $(0.1 < \delta < 1.0)$ the results can be fitted by the straight lines corresponding to the intermittent behaviour found in the data. 2) For large bins $(\delta > 1.0)$ increase of $F^{(i)}(\delta)$ is faster, as also seen in experiments [3, 4, 5], and for the smallest bins $(\delta < 0.1)$ the dependence saturates. 3) The values of slopes obtained from the linear fits in the range $(0.1 < \delta < 1.0)$ are, to a good approximation, rising linearly with the index of the moment, cf. Fig. 3.

At present, there are obviously no data to compare with the results described above. However, the qualitative picture is certainly very similar to the lower energy hadronic data and to the results extracted from fits to the 30 GeV e^+e^- data. Note that the slope values reported here are much bigger than those obtained from the analysis of the e^+e^-, hadron-hadron or nucleus-nucleus collisions. Two effects account for this difference. First, the QCD cascade is weakly developed at $\sqrt{s} = 30$ GeV compared to that at 1000 GeV, and second, slopes for "the simplest" (involving smaller number of jets) processes are expected to be bigger than those for more complicated (e.g. nucleus-nucleus) collisions [9, 10]. Such a regularity was indeed found experimentally [6].

[1] The Monte Carlo data were provided to us by prof. G. Marchesini.

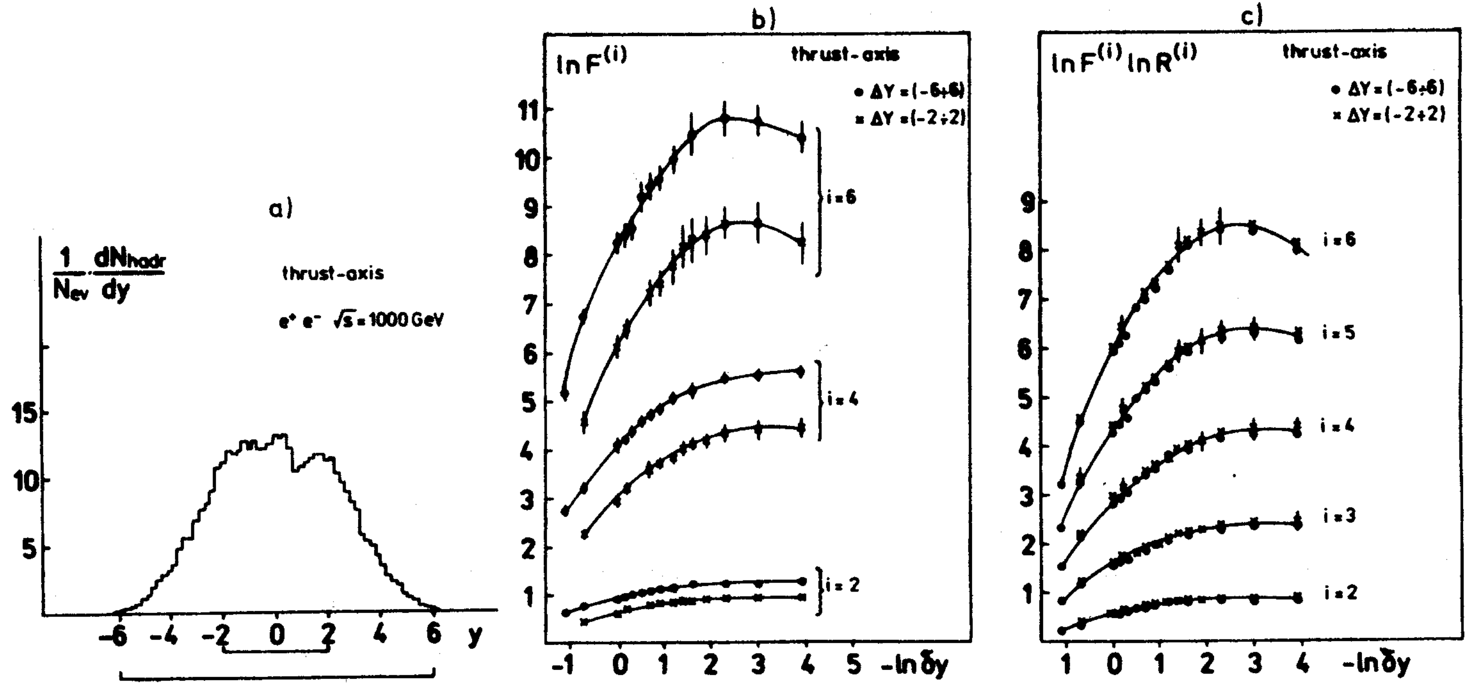

Fig. 1. Results of the Marchesini-Webber Monte Carlo with rapidity defined relative to the thrust axis: a) single-particle distribution, b) uncorrected moments computed for two choices of the rapidity range Δ, c) after correcting with R-factors (see text)

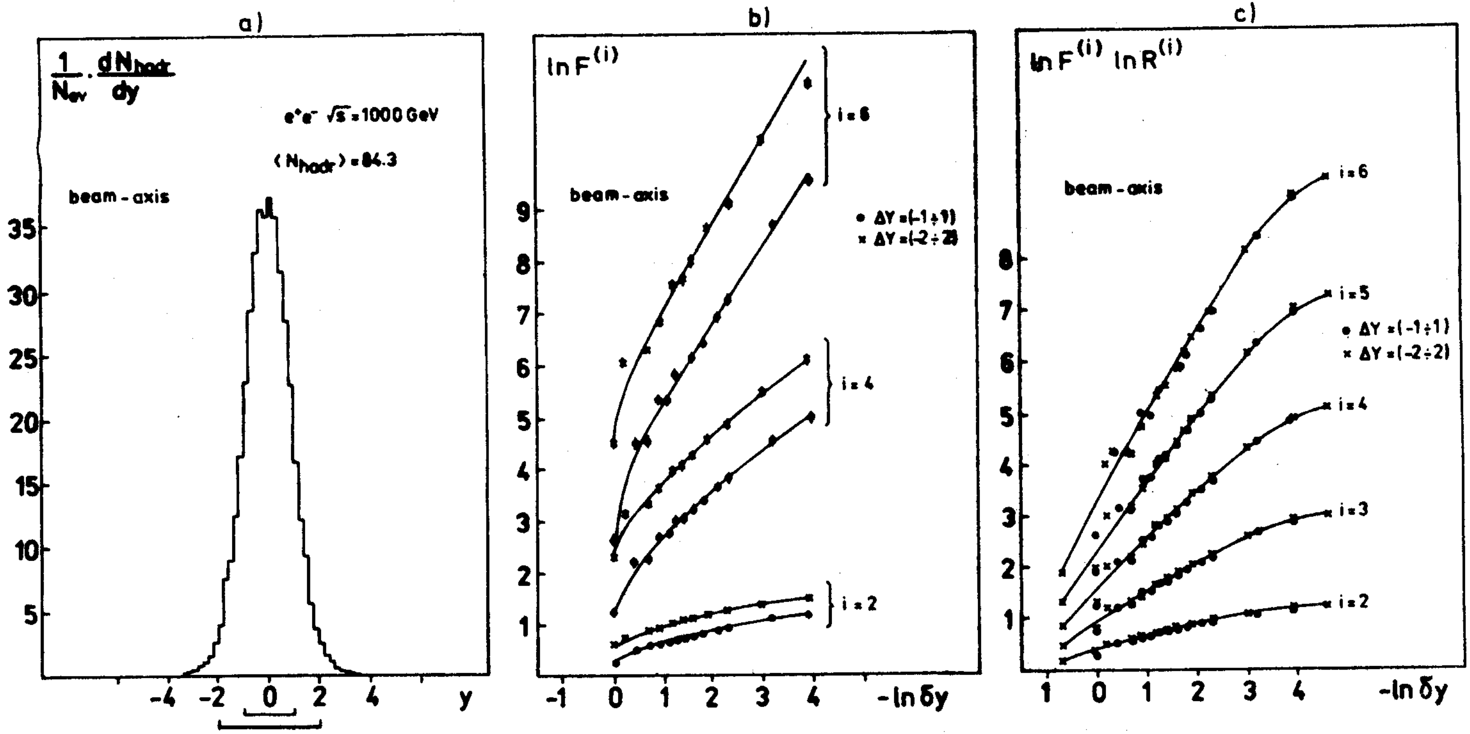

Fig. 2. Same as Fig. 1 but with rapidity defined relative to the beam axis

Since the intermittent behaviour observed in the model is naturally attributed to the branching structure of the QCD jets, it might be interesting to check how the results depend on the angular distribution of jets. To this end we have simply computed, from the same sample, the rapidity distribution and factorial moments using instead of the jet axis the direction of the original e^+e^- pair. The results are shown in Fig. 2. We see that Figs 2b and 1b significantly differ from each other. The moments are generally biggeı and grow faster with $(-\ln\delta)$. This result seems understandable since now, not only the secondary (gluonic) jets, but also primary quark jets may have direction corresponding to one of the rapidity bins within our range. Before considering this further we shall, however, take into account another difference between the two analyses.

Whereas for the jet axis our rapidity range Δ was practically within the plateau, for the beam axis the rapidity distribution is far from being flat. As already noted [11], non-flat rapidity distribution introduces into $F^{(i)}(\delta)$ extra factors

$$R^{(i)} = \frac{\frac{1}{\Delta}\int\limits_{\Delta} \varrho(y)^i dy}{\left(\frac{1}{\Delta}\int\limits_{\Delta} \varrho(y) dy\right)^i} \tag{2}$$

which do not depend on δ. However, we note here that for δ not infinitesimally small this formula should be in fact replaced by

$$R^{(i)}(\delta) = \frac{\frac{1}{M}\sum\limits_{m=1}^{\Delta/\delta}\left(\frac{1}{\delta_m}\int\limits_{\delta_m} \varrho(y) dy\right)^i}{\left(\frac{1}{\Delta}\int\limits_{\Delta} \varrho(y) dy\right)^i} \tag{3}$$

where $\delta_m = \delta$ and $m = 1, \ldots, M$. It is readily seen from Eq. (3) that the dependence of R-factors on δ cannot be neglected as long as $\varrho(y)$ varies appreciably over the interval δ. If we want to compare tests of the multiplicity fluctuations performed on various samples, we should rather divide $F^{(i)}(\delta)$ by $R^{(i)}(\delta)$. The effect of R's in our case is clearly seen from Figs 1b, 1c and Figs 2b, 2c for the jet and beam axis respectively. In Figs 1b and 2b we show factorial moments computed for the two choices of the whole rapidity interval Δ. It is evident that a) variation of the single particle distribution with y strongly enhances F's, and b) these differences are completely cancelled when R's are taken into account (cf. Figs 1c and 2c for the jet and beam axis). The improvement is similar for both the jet and beam axis as the rapidity reference. However in the former case only for $\Delta = (-6, 6)$ the values of R's were substantially different from unity. For smaller range ($\Delta = (-2, 2)$) variation of the rapidity distribution was too weak to produce any effect. To conclude, we recommend presenting the data in the form of $F^{(i)}/R^{(i)}$ vs $(-\ln\delta)$ since this eliminates at least one nonuniversal feature of the various data sets. It turns out that the slopes

TABLE I

Slope values α_i resulting from the fit $\ln(F^{(i)}/R^{(i)}) = \alpha_i(-\ln\delta)+\beta_i$

i	2	3	4	5	6
beam	0.25(1)	0.59(2)	0.97(3)	1.39(4)	1.76(7)
thrust	0.12(2)	0.32(4)	0.57(6)	0.83(10)	1.13(15)

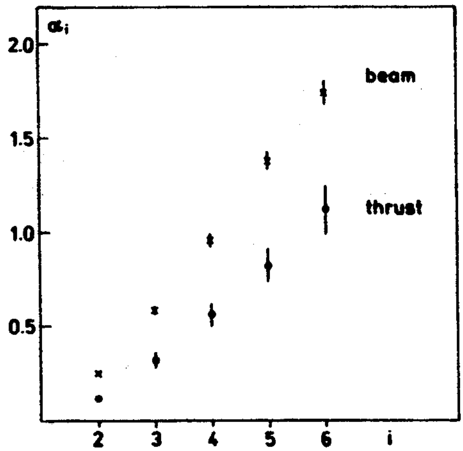

Fig. 3. Slopes of the effective linear dependence of $\ln(F^{(i)}(\delta)/R^{(i)})$ in $(-\ln\delta)$ for $i = 2, 3, 4, 5, 6$

are not much affected by the R-factors. Corrected slopes are within one standard deviation from the uncorrected ones, though the shift is systematically towards lower values.

Table I and Fig. 3 show slopes of the linear fits to the corrected data. Fits were performed in the interval $0.1 < \delta < 1.0$, i.e. in the range where the behaviour is approximately linear.

We see that the differences between the results obtained for the jet axis and the beam axis survive, although the normalization is now more similar. We conclude that the jet angular distribution influences the slope values on the $\ln(F^{(i)}(\delta)/R^{(i)})$ vs $(-\ln\delta)$ plots. Thus, one of the factors enhancing too slow increase of moments in various models may be the transverse momentum, i.e. tilting the jets/strings in hadron-hadron collisions with respect to the collision axis.

To summarize, we have investigated the dependence of the factorial moments on the bin size in the Marchesini–Webber model of e^+e^- annihilation. We have found strong, approximately linear, increase of $\ln F^{(i)}(\delta)$ with the $(-\ln\delta)$ in qualitative agreement with available lower energy data. For quantitative tests we will need Monte Carlo events at lower energy and dedicated analysis of the experimental material.

We would like to thank Professor G. Marchesini who kindly provided us the sample of the Monte Carlo generated events.

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