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Multifractal Structures in Multiparticle Production in $\bar{p}$–p Interactions at $\sqrt{s}$=1800 GeV *

The CDF Collaboration

presented by

Franco Rimondi
University of Bologna and INFN
Bologna, Italy

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MULTIFRACTAL STRUCTURES IN MULTIPARTICLE PRODUCTION IN $\bar{p}-p$ INTERACTIONS AT $\sqrt{s} = 1800$ GeV.

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University of Bologna and INFN Bologna, ITALY.

ABSTRACT

Fractal structure in multiparticle production of $\bar{p}-p$ "minimum-bias" interactions at $\sqrt{s} = 1800$ GeV has been studied using the Collider Detector at Fermilab. Preliminary results are shown and compared with very simple Monte Carlo models.

INTRODUCTION

In multiparticle production large fluctuations of the final state (pseudo)-rapidity density are observed[1-4]. In order to perform quantitative studies of the statistical significance of these fluctuations, Bialas and Peschanski[5-6] have developed a method of analysing the data in terms of scaled (normalised) factorial moments as functions of decreasing rapidity bin width. In the case of non statistical, self-similar density fluctuations those moments are expected to increase according to a power law with decreasing bin width, down to the experimental resolution. Evidence for such behaviour, usually referred to as intermittency, has been shown to exist in ll[7], hh[8], lh[9] and NN[10] interactions.

Intermittency is closely connected with fractal structures. Theoretical approaches to the study of the multifractal structures in multibody production in particle interactions have been proposed[11-13]. The analysis procedure developed in references[12-13] has been applied to minimum bias $\bar{p}-p$ data at $\sqrt{s} = 1800$ GeV. In the following, preliminary results from this analysis are presented. The data have been recorded with the Collider Detector at the Fermilab Tevatron Collider.

* Argonne National Laboratory,Brandeis University,University of Chicago, Fermi National Accelerator Laboratory,Laboratori Nazionali di Frascati, Harvard University, University of Illinois,National Laboratory for High Energy Physics(KEK),Lawrence Berkeley Laboratory,University of Pennsylvania,Istituto Nazionale di Fisica Nucleare Pisa,Purdue University,Rockfeller University,Rutgers University,Texas A&M University, University of Tsukuba,Tufts University,University of Wisconsin.

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THE FRACTAL MOMENTS

In order to allow a quantitative study of the multifractal structure in multiparticle production a set of moments, the fractal moments G_q, are defined. A (pseudo)-rapidity interval $\Delta\eta$ is divided into M bins of width $\delta = \Delta\eta/M$. If k_i denotes the number of particles in the i^{th} bin, the multifractal moments are defined as follows:

$$G_q = \sum_{i=1}^{M} p_i^q \qquad = \sum_{i=1}^{M} (k_i/n)^q \tag{1}$$

where $p_i = k_i/n$, n is the event multiplicity in $\Delta\eta$ and q is a real number. The summation in (1) is carried over the non-empty bins only.

G_q can be determined as a function of δ. The particle production process exhibits self-similar behaviour when there is a range of δ in which:

$$G_q \quad \propto \quad \delta^{\tau(q)} \tag{2}$$

It is the relation (2) which has to be studied and the slope $\tau(q)$ has to be extracted from the data.

It should be noticed that for finite resolution and limited multiplicity n, since in (1) only $k_i > 0$ are taken into account, the behaviour (2) does not necessarly appear for $\delta \to 0$ [13].

In practice the average of G_q over many events has to be considered. This is done by the following procedure. First the average of $\mathrm{Ln}(G_q)$, over all the events of the sample, is computed as a function of ν, where $\nu = \log(M/2)$.

$$< \mathrm{Ln}(G_q) >= 1/N_{ev}(\sum_{j=1}^{Nev} \mathrm{Ln}(G_q)_j) \tag{3}$$

In the plot $< \mathrm{Ln}(G_q) >$ versus ν, a region in ν of approximate linearity should be identified for each q. From those intervals, the mean value of τ (q) can be computed as:

$$< \tau(q) >= (-\Delta < \mathrm{Ln}(G_q) > /\Delta\nu)(1/\mathrm{Ln}(2)) \tag{4}$$

Once $< \tau$ (q)$>$ is determined, the two quantities:

$$\alpha_q = d < \tau(q) > /dq \quad \text{and} \quad f(\alpha_q) = q\alpha_q - \tau(q) \tag{5}$$

can be evaluated, as they come from the theory of multifractals. The function $f(\alpha_q)$ describes the fractal structure of the pseudorapidity distribution. For a discussion of the function $f(\alpha_q)$ and of its properties see references 12-14 and references therein.

THE DATA SAMPLE

Detailed descriptions of the experimental apparatus, as well as of the minimum bias trigger and of the event selection, have been reported elsewhere[15,16]. Here only a few things relevant to the present analysis will be described. A sample of about 140,000 fully reconstructed minimum bias events from the 1988/1989 run has been used. The trajectories of the charged particles were measured by a set of eight time-projection chambers (VTPC) surrounding the beam pipe at the interaction point. The chambers cover a region of about $\pm$ 3 units in η and 2π in azimuth. They provide good η determination, with precision better than 0.07 units of η for $\eta > 3$ and around 0.005 near $\eta = 0$. For about the 25% of the tracks only a poor ϕ measurement is provided and only for about 20% of the tracks it is possible to measure the momenta. The VTPC are segmented azimuthally into octants; track pairs going through the same octant are resolved if they are separated by at least 0.06 units of η, they are unambiguously resolved if they pass through two different azimuthal segments. Charged tracks within the $\Delta\eta$ interval: [-2.9 - -0.1] $\cup$ [0.1 - 2.9] have been selected and only events with multiplicity greater than 5 in the above interval have been kept. The preliminary results presented here are not efficiency corrected. The tracking inefficiency is less than 5%, while the charged particle background from photon conversion, particle decay and secondary hadronic interactions is estimated to be about 4-5% in central region, rising to about 10% at the edge of the interval[16].

RESULTS

In fig.1 the mean values of $\mathrm{Ln}(G_q)$ are plotted as a function of ν for some values of q. Actually $< \mathrm{Ln}(G_q) >$ has been computed for q ranging from -6 to 6 in steps of 0.5, except in the region $-1 < q < 1$ where the q step is 0.1. The range of ν corresponding to the first three points at the lower values of ν have been chosen to extract the mean slope $< \tau\ (q) >$, assuming it is given by the mean slope among those three points as determined by the least squares method. From $< \tau\ (q) >$, α_q and $f(\alpha)$ have been computed according to formulas (2) and (3). The $f(\alpha)$ spectrum is shown in fig. 2. It has a smooth behaviour with a maximum at $\alpha_o \approx 0.89$, corresponding to $q \approx 0$ as expected.

In fig. 2 results from two very simple Monte Carlo models are also shown. In the first model, tracks are generated with a uniform distribution and the event multiplicity is distributed according to the observed multiplicity distribution. In the second one, tracks are generated in clusters of gaussian shape with the following parameters: $\bar{\eta}$ uniformly distributed in $\Delta\eta$, $\sigma_\eta = 0.5$, cluster multiplicity between

1 and 10. The number of clusters per event is determined by the total event multiplicity which is again distributed according to the observed distribution.

The same analysis has been performed dividing the events in classes, containing events with multiplicities in different restricted intervals. In fig. 3 the f(α) spectra for each multiplicity interval are shown. The data in fig. 3 correspond to a range of q from -1 to 1 in steps of 0.1. A clear dependence of the f(α) spectrum on multiplicity is observed: as multiplicity increases, the f(α) spectrum becomes wider.

Comparisons with the two previously discussed models are also shown.

CONCLUSIONS

We are looking at a new analysis method of multiparticle final state processes. It can be complementary to intermittency, but it may be too early to draw physical conclusions. The only other experimental results are the e^+ e^- data presented by K. Sugano at this conference. The ability and reliability of the method to extract useful physical information needs to be tested comparing results from different kind of data from the same experiment and from different experiments as well as from Monte Carlo. The preliminary results presented here encourage further studies.

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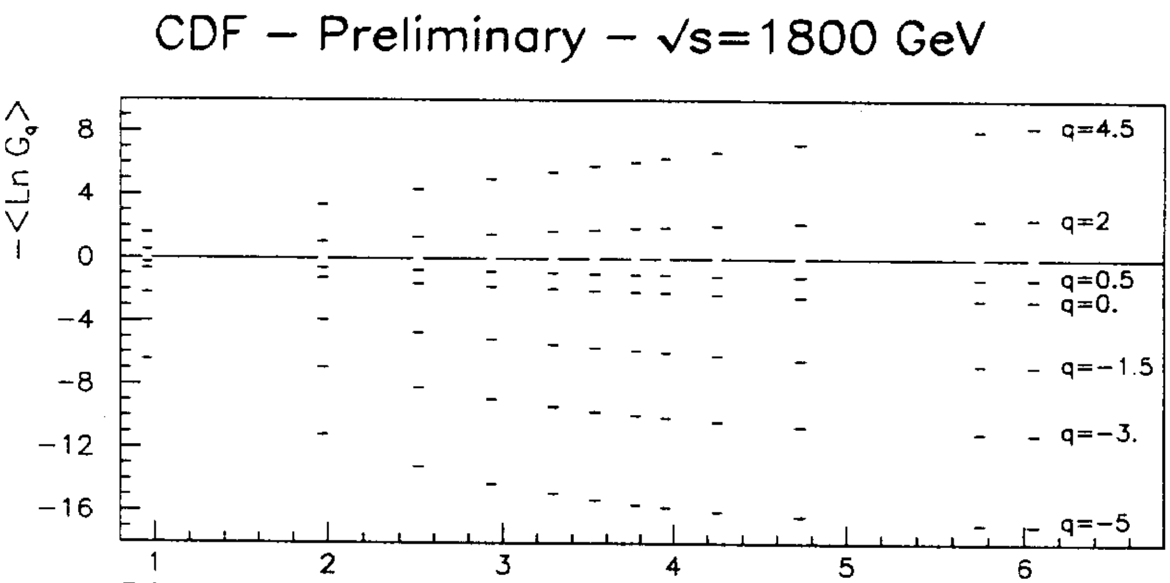

FIG. 1 – Mean value of $Ln(G_q)$ versus ν for different values of q.

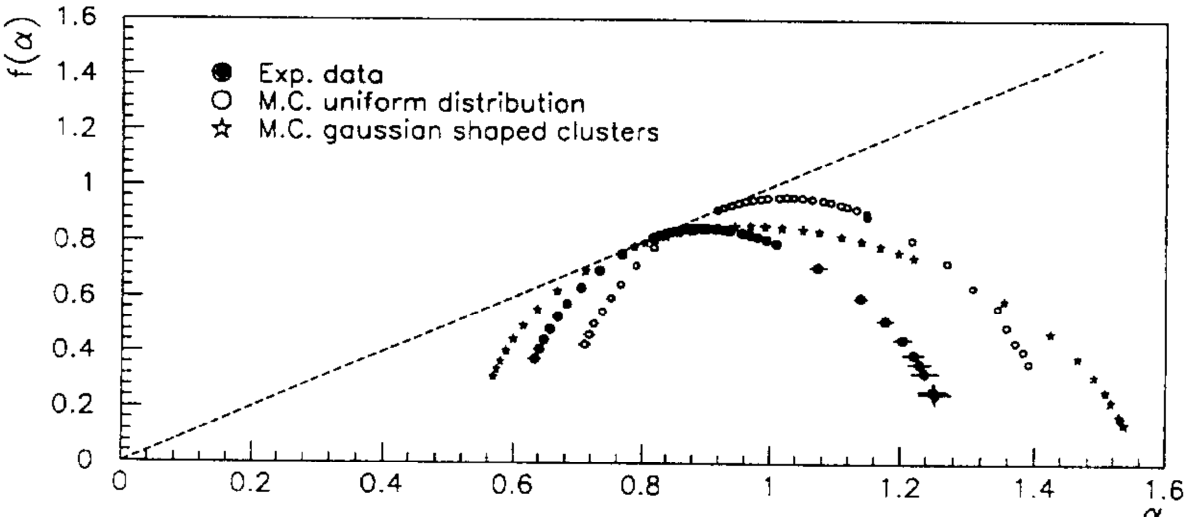

FIG. 2 – The function $f(\alpha)$ versus α for events with multiplicities >5 in $\Delta\eta$ [−2.9 – −0.1]& [0.1 – 2.9]. Results from the two simple Monte Carlo models described in the text are also shown.

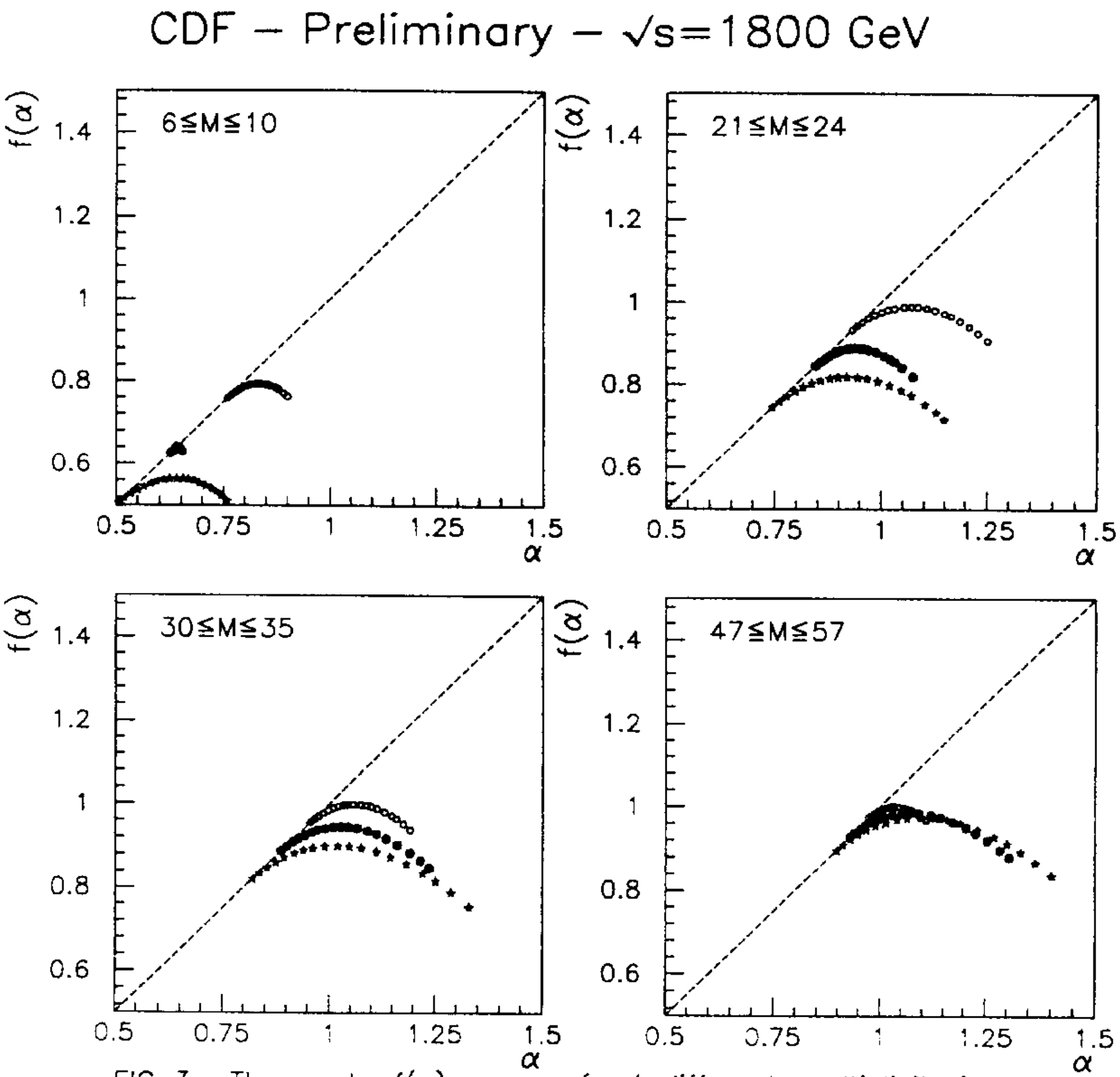

FIG. 3 – The spectra $f(\alpha)$ versus α for 4 different multiplicity intervals. Also shown are the results from the uniform distribution model (O) and the cluster model (☆).