The influence of Bose-Einstein correlations on intermittency in $p\bar{p}$ collisions at $\sqrt{s} = 630$ GeV

UA1-MINIMUM BIAS-Collaboration

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Abstract. The influence of Bose-Einstein correlations on the rise of factorial moments is small in the 1-dimensional phase space given by the pseudorapidity $\eta$, where the 2-body correlation function is dominated by unlike-sign particle correlations. Contrarily, the influence is dominant in the higher dimensional phase space. This is shown by using correlation integrals. They exhibit clear power law dependences on the four-momentum transfer $Q^2$ for all orders investigated ($i=2-5$). When searching for the origin of this behaviour, we found that the Bose-Einstein ratio itself shows a steep rise for $Q^2 \to 0$, compatible with a power law.

1 Introduction

Recent searches for intermittency in the two- and three dimensional phase space show a strong rise of the factorial moments (FM) with decreasing phase space volumes $v$ [1]. This rise is not only seen in hard scattering processes, but also in hadron-hadron reactions [2, 3] and in nuclear collisions [4, 5]. It indicates that a singularity might occur for $v \to 0$ in the two and multiparticle correlation function. In hadron-hadron and nuclear collisions, the question is still open if this behavior can be explained by known effects. One candidate is the Bose-Einstein (BE) effect [6-8]. All investigations of the influence of this effect are rather indirect up to now*. Usually the slopes of the FM measured for all particles ($\phi_{\text{all}}^{2n}$) are compared to those where only like-sign particles contribute ($\phi_{\text{ls}}^{2n}$). However, experimental investigations in the 1-dimensional rapidity space show either no differences between $\phi_{\text{ls}}^{2n}$ and $\phi_{\text{all}}^{2n}$, indicating that the Bose-Einstein effect has no major influence [9] or are not conclusive (see e.g. [1, 10]). Studies of intermittency and multifractality with Monte Carlo models including the BE effect [11] could not explain the experimental results [9]. Perhaps, the implementation has been too crude and so the question is still open.

The aim of this paper is to study the influence of the Bose-Einstein correlations with some new experimental

* We will refer to new investigations which occurred during the preparation of this manuscript in our conclusions.
methods. We cannot distinguish between the quantum statistical symmetrization effect and other short-range correlations of like-sign particles (e.g. from the decay of higher resonances). Therefore, more precisely, we want to study the contribution of the very short-range correlations observed in the correlation function of like-sign particles (when analysed e.g. in $Q^2$) to the rise of the FM. We will call these correlations BE effect throughout this paper.**

The paper is organized as follows: after giving the definitions and the specification of the data sample in Sects. 2 and 3, we present the analysis in Sect. 4. We used three methods: a) comparison of $\phi_i$ with $\phi_i^{all}$, b) the method of "pair subtraction" and c) a detailed study of the two particle correlation function. For our analysis we used two different variables: the pseudorapidity $\eta$ and the four-momentum difference $Q^2$ between pairs. The conclusions of our results are given in Sect. 5.

2 Definitions

We use the usual "vertical" FM of order $i$:

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

$$
= \frac{1}{M} \sum_{m=1}^{M} \frac{1}{\Omega_m} \int \prod_{k=1}^{i} d\eta_k \rho_i(\eta_1, \ldots, \eta_i)
$$

where $\rho_i$ is the inclusive $i$-particle density function. For the computation of the integrals a binning of the original region $\Delta \eta$ into $M$ subintervals of the size $\delta \eta$ is introduced. The number of particles in the $m$-th bin $n_m$ is counted. The integration domain $\Omega_m = \sum_{m=1}^{M} \Omega_m$ thus consists of $M$ $i$-dimensional boxes $\Omega_m$ of edge length $\delta \eta$. The brackets $\langle \rangle$ denote the averages over the event sample.

Selfsimilar density fluctuations at all scales $\delta \eta$ would lead to a power law dependence of $\langle F_i \rangle$ on $\delta \eta$:

$$
\langle F_i \rangle \propto \left( \frac{1}{\delta \eta} \right)^{\zeta_i}
$$

$$
\log \langle F_i \rangle = a_i + \zeta_i \log \left( \frac{1}{\delta \eta} \right).
$$

This behavior is called intermittency [14] and the parameters $\zeta_i$ (slopes of the $\langle F_i \rangle$ in a log-log scale) are called intermittency exponents.

Recently a considerable improvement of the factorial moment method to study correlations has been proposed in [15] with the measurement of the correlation integrals $\langle C_i \rangle$. These quantities are closely related to the $\langle F_i \rangle$. The main difference is that the integration domain $\Omega_m$ is extended to a strip domain $\Omega_S$ which depends only on $\delta \eta$:

$$
\langle C_i(\delta \eta) \rangle = \frac{\int \prod_{k=1}^{i} d\eta_k \rho_i(\eta_1, \ldots, \eta_i)}{\int \prod_{k=1}^{i} d\eta_k \rho_i(\eta_1) \cdots \rho_i(\eta_i)}.
$$

The counting procedure for the correlation integral requires that all $i$-tuples in $[0, \Delta \eta]$ which are separated by a distance less than $\delta \eta$ are counted. In [15] a detailed discussion of the implementation of the $\langle C_i \rangle$ has been given. The method for counting $i$-tuples which is used in this paper is given by the "GHP" integral [16]:

$$
\langle C_i(\delta \eta) \rangle
$$

$$
= \frac{1}{\text{Norm}} \left( \sum_{j_1 < \cdots < j_i} \prod_{k=1}^{i} \Theta(\delta \eta - |\eta_{j_k} - \eta_{j_{k+1}}|) \right)
$$

where $\Theta$ is the usual Heaviside step function and Norm is obtained by "event mixing" [15].

We have verified, that the values of $\langle F_i \rangle$ and $\langle C_i \rangle$ are almost identical in the case of the analysis in $\delta \eta$ [17, 18] (differences are of the order of the statistical errors in our data sample of 160 000 events, see Fig. 1a). One advantage of $\langle C_i \rangle$ is the better statistical accuracy. We use here another advantage: since (4) depends only on differences of phase space variables, we can replace $|\eta_{j_k} - \eta_{j_{k+1}}|$ by $-(p_{j_k} - p_{j_{k+1}})^2$, and $\delta \eta$ by $Q^2$, where $p$ is the four-momentum of a particle. Thus we are able to measure the $\langle C_i \rangle$ as a function of $Q^2$, which is the theoretically preferred variable in jet evolution. In (4) the product extends over all possible pairs of an $i$-tuple. It contributes to $\langle C_i \rangle$ only if all pairs satisfy the condition $|\eta_{j_k} - \eta_{j_{k+1}}| < \delta \eta$. In the case of the $Q^2$-analysis we have modified this condition: only $i$-tuples with $q_1^2 + q_2^2 + \cdots + q_{i-1}^2 < Q^2$, where $q_i^2 = -(p_{j_k} - p_{j_{k+1}})^2$, contribute to $\langle C_i \rangle$ and we obtain:

$$
\langle C_i(Q^2) \rangle
$$

$$
= \frac{1}{\text{Norm}} \left( \sum_{j_1 < \cdots < j_i} \Theta \left( Q^2 - \sum_{k=1}^{i} q_{j_k,j_{k+1}} \right) \right).
$$

In analogy to the usual analysis with FM, we will search for a power law of the $\langle C_i \rangle$ as a function of $Q^2$:

$$
\langle C_i \rangle \propto \left( \frac{1}{Q^2} \right)^{\gamma_i}
$$

Equation (5) is conceptually different from (4) for $i \geq 3$. However, the search for a power law is motivated by the desire to search for selfsimilar dynamics in the production of particles, not knowing a priori in which variable it might show up. The variable $Q^2$ defined above has been proposed in [19] and used in the analysis of higher order Bose-Einstein correlations [13]. In choosing this variable, we are able to demonstrate the close connection between intermittency analysis and the analysis of Bose-Einstein correlations. Moreover, we want to remind the