


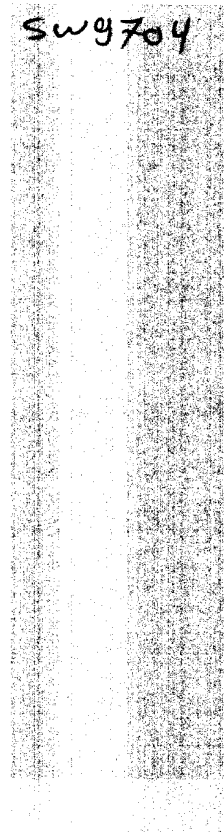
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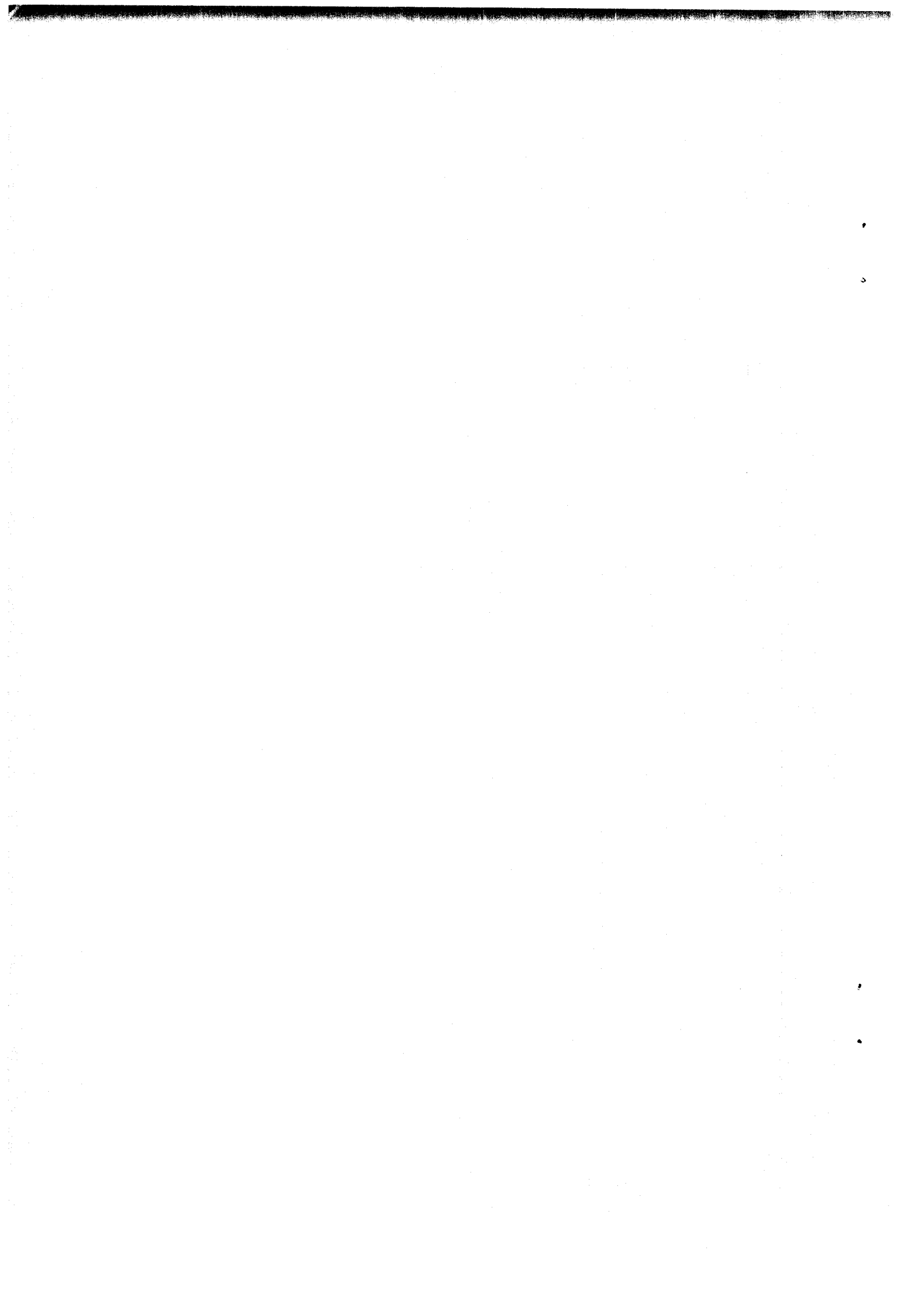
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 $\pi^+p$  and  $K^+p$  collisions at 250 GeV/c**

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# Factorial moments and correlations in transverse momentum in $\pi^+$ p and $K^+$ p collisions at 250 GeV/c

EHS/NA22 Collaboration

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**Abstract:** We have measured the factorial moments up to fifth order, as well as the second-order normalized differential factorial moments, both as a function of the difference of transverse momentum ( $\Delta p_T$ ) in  $\pi^+$ p and  $K^+$ p collisions at 250 GeV/c. The second-order differential factorial moments for like-charged pairs reveal a strong increase with decreasing  $\Delta p_T$ . In a small central rapidity window, this increase is described by a simple power law. If interpreted as originating from Bose-Einstein correlations, such a behavior indicates a power-law structure of the transverse spatial distribution of the particle source.

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# 1 Introduction

Power-law scaling of multiparticle correlations [1] has become a central issue in the field of multiparticle dynamics. Approximate power-law behavior is observed for all types of collisions, from  $e^+e^-$  to AA, in the bin-size dependence of normalized factorial and cumulant moments in rapidity, azimuthal angle, transverse momentum, as well as in four-momentum distance of the particles involved.

In the present paper, a search for power-law behavior is described in the transverse-position distribution of the particle source in  $\pi^+p$  and  $K^+p$  collisions at 250 GeV/ $c$ . To be precise, we searched for a cross-section dependence on the transverse position  $r_T$  of the emitted particle following the form

$$\frac{d\sigma}{d^2r_T} \sim r_T^{-2+\gamma}. \quad (1)$$

Such power law can lead to a rise of the factorial moments with decreasing distance in transverse momentum between the emitted particles. The exact shape of the transverse-position cross-section is related to the Bose-Einstein correlation of identical particles [2] as measured in the transverse-momentum difference. Since the latter is the square of the Fourier transform of the source distribution, a transverse-position cross-section of the form (1) implies that the correlation depends on the absolute value of the transverse-momentum difference  $\Delta p_T$  as  $\Delta p_T^{-2\gamma}$ . Due to cut-offs in the cross-section (1) necessary for its normalization, this power-law behavior of the correlation is restricted to a certain region in  $\Delta p_T$  [3].

As an example, it has recently been shown by Białas and Peschanski [4] that the cross section for the emission of color dipoles in high-energy onium-onium scattering [5] would reveal such a power law in transverse position of the emitted dipole.

The data collection in this experiment is briefly discussed in Sect. 2, the method is recalled in Sect. 3. The results are presented in Sect. 4 and conclusions are summarized in Sect. 5.

## 2 The data

For this CERN experiment, the European Hybrid Spectrometer (EHS) was equipped with the Rapid Cycling Bubble Chamber (RCBC) as an active vertex detector and exposed to a 250 GeV/ $c$  tagged positive, meson-enriched beam. In data taking, a minimum-bias interaction trigger was used. The details of the spectrometer and the trigger can be found in previous publications [6, 7].

Charged-particle tracks are reconstructed from hits in the wire- and drift-chambers of the two lever-arm magnetic spectrometer and from measurements in the bubble chamber. The average momentum resolution  $\langle \Delta p/p \rangle$  varies from a maximum of 2.5% at 30 GeV/ $c$  to around 1.5% above 100 GeV/ $c$ .

Events are accepted for the analysis when measured and reconstructed charge multiplicity is the same, charge balance is satisfied, no electron is detected among the secondary tracks and the number of badly reconstructed (and therefore rejected) tracks is 0. The loss of events during measurement and reconstruction is corrected for by means of the topological cross section data [6]. Elastic events are excluded. Furthermore, an event is called single-diffractive and excluded from the sample if the total charge multiplicity is smaller than 8 and at least one of the positive tracks has  $|x_F| > 0.88$ . After these cuts, the inelastic non-single-diffractive sample consists of 59 200  $\pi^+p$  and  $K^+p$  events.

For laboratory momenta  $p_{LAB} < 0.7$  GeV/ $c$ , the range in the bubble chamber and/or the change of track curvature was used for proton identification. In addition, a visual ionization

scan was used for  $p_{\text{LAB}} < 1.2 \text{ GeV}/c$  on the full  $K^+p$  and 62% of the  $\pi^+p$  sample. Positive particles with  $p_{\text{LAB}} > 150 \text{ GeV}/c$  were given the identity of the beam particle. Other particles with momenta  $p_{\text{LAB}} > 1.2 \text{ GeV}/c$  were not identified in the present analysis and are treated as pions.

In spite of the electron rejection mentioned above, residual Dalitz decay and  $\gamma$  conversion near the vertex still contribute to the two-particle correlations. Their influence on our results has been investigated in detail in [8].

### 3 Measured quantities

We measure the normalized factorial moments

$$F_q(\Delta p_T) = \frac{f_q(\Delta p_T)}{\xi_q^{\text{norm}}(\Delta p_T)} \quad (2)$$

evaluated by the star integration [9]

$$f_q(\Delta p_T) = \int \rho_q(\mathbf{p}_1, \dots, \mathbf{p}_q) \Theta_{12} \Theta_{13} \dots \Theta_{1q} d^3 \mathbf{p}_1 \dots d^3 \mathbf{p}_q, \quad (3)$$

where  $\rho_q$  is the  $q$ -particle density, and the  $\Theta_{1j}$  are defined by the Heaviside unit-step function

$$\Theta_{1j} \equiv \Theta(\Delta p_T - |\mathbf{p}_{T1} - \mathbf{p}_{Tj}|) \quad (4)$$

The latter restrict all  $q - 1$  transverse momenta  $\mathbf{p}_{Tj}$  to lie within the distance  $\Delta p_T$  from  $\mathbf{p}_{T1}$ . The moments  $f_q(\Delta p_T)$  are normalized by the integrals

$$\xi_q^{\text{norm}}(\Delta p_T) = \int \rho_1(\mathbf{p}_1) \dots \rho_1(\mathbf{p}_q) \Theta_{12} \Theta_{13} \dots \Theta_{1q} d^3 \mathbf{p}_1 \dots d^3 \mathbf{p}_q \quad (5)$$

evaluated with particles  $j$  taken randomly from different events (“event mixing”). The property of unbiased estimators for the moments and their normalization is demonstrated in [10]. The non-trivial modifications needed for events with non-uniform weights are derived in [11].

For measuring the two-particle correlations, we also used the differential form of the density integrals [12]

$$DF_2(\Delta p_T) = \frac{1}{N_{cc}} \frac{Df_2(\Delta p_T)}{D\xi_2^{\text{norm}}(\Delta p_T)} \quad (6)$$

with

$$Df_2(\Delta p_T) = \int \rho_2(\mathbf{p}_1, \mathbf{p}_2) \delta_{12} d^3 \mathbf{p}_1 d^3 \mathbf{p}_2 \quad (7)$$

and  $\delta_{12}$  defined to be 1 when  $|\mathbf{p}_{T1} - \mathbf{p}_{T2}|$  lies within a certain bin around  $\Delta p_T$  and 0 otherwise.  $D\xi_2^{\text{norm}}$  is defined as:

$$D\xi_2^{\text{norm}}(\Delta p_T) = \int \rho_1(\mathbf{p}_1) \rho_1(\mathbf{p}_2) \delta_{12} d^3 \mathbf{p}_1 d^3 \mathbf{p}_2. \quad (8)$$

The normalization factor  $N_{cc}$  depends on the charge combination of the measured pairs:  $N_{cc} = \langle n(n-1) \rangle / \langle n \rangle^2$ ,  $N_{+-} = \langle n_+ n_- \rangle / \langle n_+ \rangle \langle n_- \rangle$ ,  $N_{--} = \langle n_-(n_- - 1) \rangle / \langle n_- \rangle^2$ ,  $N_{++} = \langle n_+(n_+ - 1) \rangle / \langle n_+ \rangle^2$  for all pairs, unlike-charge pairs, negative-negative, and positive-positive pairs, respectively. The symbols  $n$ ,  $n_-$ , and  $n_+$  stand for the numbers of total, negative, and positive particles, respectively, and  $\langle \rangle$  stands for averaging over all events in the data sample used. Differential factorial moments normalized by the factor  $N_{cc}$  are equal to 1 when there is no correlation between the particles.

On the other hand, the normalized differential factorial moments are equivalent to the disconnected correlation function measured at a given value of  $\Delta p_T$ , but integrated over the difference in the longitudinal momentum.

While discussing the data, we plot logarithms of the factorial and differential factorial moments as a function of  $-\ln(\Delta p_T/(\text{GeV}/c))$ .

## 4 Results

In Fig. 1 we show plots of the normalized factorial moments  $F_q$  obtained with the full data sample, but centre-of-mass rapidity restricted to  $|y| < 2$  corresponding to the width of the central plateau at our collision energy. The plots are obtained for (from left to right) all charge combinations, for the combinations of the negative particles and of the positive ones. A rise of the factorial moments with decreasing  $\Delta p_T$  can be seen in all the plots for  $\Delta p_T$  less than  $\sim 1 \text{ GeV}/c$ . The slope of the rise grows systematically with rising order  $q$  of the factorial moment.

In Fig. 2 we show plots of the second-order differential factorial moments  $DF_2$  obtained according to (6) for the negative-negative (--) pairs and for the positive-positive (++) ones. They are plotted for four different rapidity intervals:  $|y| < 0.5$ , 1, 1.5 and 2.

The increase of  $DF_2$  with decreasing  $-\ln(\Delta p_T/(\text{GeV}/c))$  for all rapidity cuts and both charge combinations in the region of  $\Delta p_T$  larger than  $\sim 1 \text{ GeV}/c$  (negative  $-\ln \Delta p_T$ ) can be attributed to the conservation of transverse momentum: a particle of so large a  $\mathbf{p}_T$  is usually accompanied by a number of particles of the opposite transverse momentum, so that these particles differ from the former one by large  $\Delta p_T$ . Such pairs contribute to the large correlation observed.

The fast rise of  $DF_2$  with decreasing  $\Delta p_T$  (i.e. increasing  $-\ln(\Delta p_T/(\text{GeV}/c))$ ) in the region of  $\Delta p_T \leq 1 \text{ GeV}/c$  ( $-\ln(\Delta p_T) > 0$ ) corresponds to what is usually assumed to be due to Bose-Einstein correlations in pion interferometry (for a review see e.g [13]). If the observed correlation is indeed purely due to the Bose-Einstein effect and if the source of the particles is fully incoherent, then the disconnected correlation function can be expressed by the Fourier transform of the spatial density of the source:

$$C_2(\Delta p) = 1 + |\tilde{\rho}(\Delta p)|^2. \quad (9)$$

If the transverse part of the source distribution  $\rho_T(\mathbf{r}_T)$  follows a power law  $r_T^{-2+\gamma}$  in some region of  $r_T$ , then the square of its Fourier transform is governed by the power law  $\Delta p_T^{-2\gamma}$  in the corresponding region of the conjugate variable  $\Delta p_T$ . Hence [3], we can expect a similar power-law behavior of  $DF_2$ :

$$DF_2 = 1 + a(\Delta p_T)^{-\phi}. \quad (10)$$

In Fig. 2 we show the fits of the data with (10) as solid lines. The  $\Delta p_T$  region in which momentum conservation has a substantial influence on the correlation is excluded from the fit. So, only data with  $\Delta p_T < 1 \text{ GeV}/c$  ( $-\ln \Delta p_T > 0$ ) are used. The parameters obtained in the fits are given in Table 1. The following observations can be made.

1. In general, the quality of the fit is better for the smaller than for the bigger  $y$ -intervals.
2. The parameter  $a$  governing the overall strength of the correlation rises with decreasing size of the rapidity window.

We have verified that the above observations do not significantly depend on the particular fit range chosen. Both observations are consistent with the Bose-Einstein interpretation of the correlations: For a finite longitudinal size of the source the Bose-Einstein correlation increases when the distance between the particles in longitudinal momentum decreases. In the case of

a broad rapidity range, the Bose-Einstein correlations are partly washed out due to the large difference possible in longitudinal momentum.

The value of  $\phi = 0.79 \pm 0.08$  obtained as an average over the  $(++)$  and  $(--)$  charge combinations in the narrowest rapidity window, translates into a power of the transverse-position cross-section (1) of  $\gamma = 0.40 \pm 0.04$ . To our surprise, this value agrees with that of  $\gamma_M \approx 0.37$  obtained by Białas and Peschanski in [4] for the case of color-dipole emission in the onium-onium collisions.

## 5 Conclusions

We have measured the factorial moments  $F_q$  up to fifth order and the second-order differential factorial moments  $DF_2$  in the difference of the transverse momentum  $\Delta p_T$  in multiparticle production at 250 GeV/c. Both  $F_q$  and  $DF_2$  rise with decreasing  $\Delta p_T$  for like-sign particle combinations. For narrow rapidity windows the  $\Delta p_T$  dependence of  $DF_2$  is fitted well by a simple power law. If the rise of  $DF_2$  is assumed to occur due to Bose-Einstein correlation, this relationship indicates a power-law structure in the transverse-size distribution of the source. Surprisingly, the slope of that power-law dependence is in agreement with the value predicted in [4] for the emission of color dipoles in onium-onium collisions.

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Table 1. Comparison of parameters of the fit of the dependence of  $DF_2$  on  $\Delta p_T$  by (10) for various rapidity windows, in the range indicated by the full line in Fig. 2.

charge combination: --			
rapidity cut	$\phi$	$a \times 10^2$	$\chi^2/NDF$
$ y  < 0.5$	$0.83 \pm 0.12$	$4.6 \pm 1.2$	11.6/13
$< 1.0$	$0.87 \pm 0.10$	$2.8 \pm 0.6$	21.7/13
$< 1.5$	$0.92 \pm 0.10$	$1.9 \pm 0.4$	27.7/13
$< 2.0$	$0.92 \pm 0.10$	$1.5 \pm 0.4$	34.0/13
charge combination: ++			
rapidity cut	$\phi$	$a \times 10^2$	$\chi^2/NDF$
$ y  < 0.5$	$0.75 \pm 0.10$	$4.7 \pm 0.9$	22.9/13
$< 1.0$	$0.84 \pm 0.09$	$2.4 \pm 0.5$	15.7/13
$< 1.5$	$0.95 \pm 0.12$	$1.3 \pm 0.4$	18.1/13
$< 2.0$	$0.93 \pm 0.16$	$1.0 \pm 0.4$	23.6/13

## Figure captions

Fig. 1  $\ln F_q$  as a function of  $-\ln(\Delta p_T/(\text{GeV}/c))$  for all charged, negative and positive particles, the order  $q$  varying from 2 to 5. The data sample in the rapidity window  $|y| < 2$  is used.

Fig. 2 Logarithm of the second-order differential factorial moment  $DF_2$  as a function of  $-\ln(\Delta p_T/(\text{GeV}/c))$  for four different rapidity cuts. The bottom plots correspond to the full data sample used in Fig. 1. The solid lines represent the fit by (10).

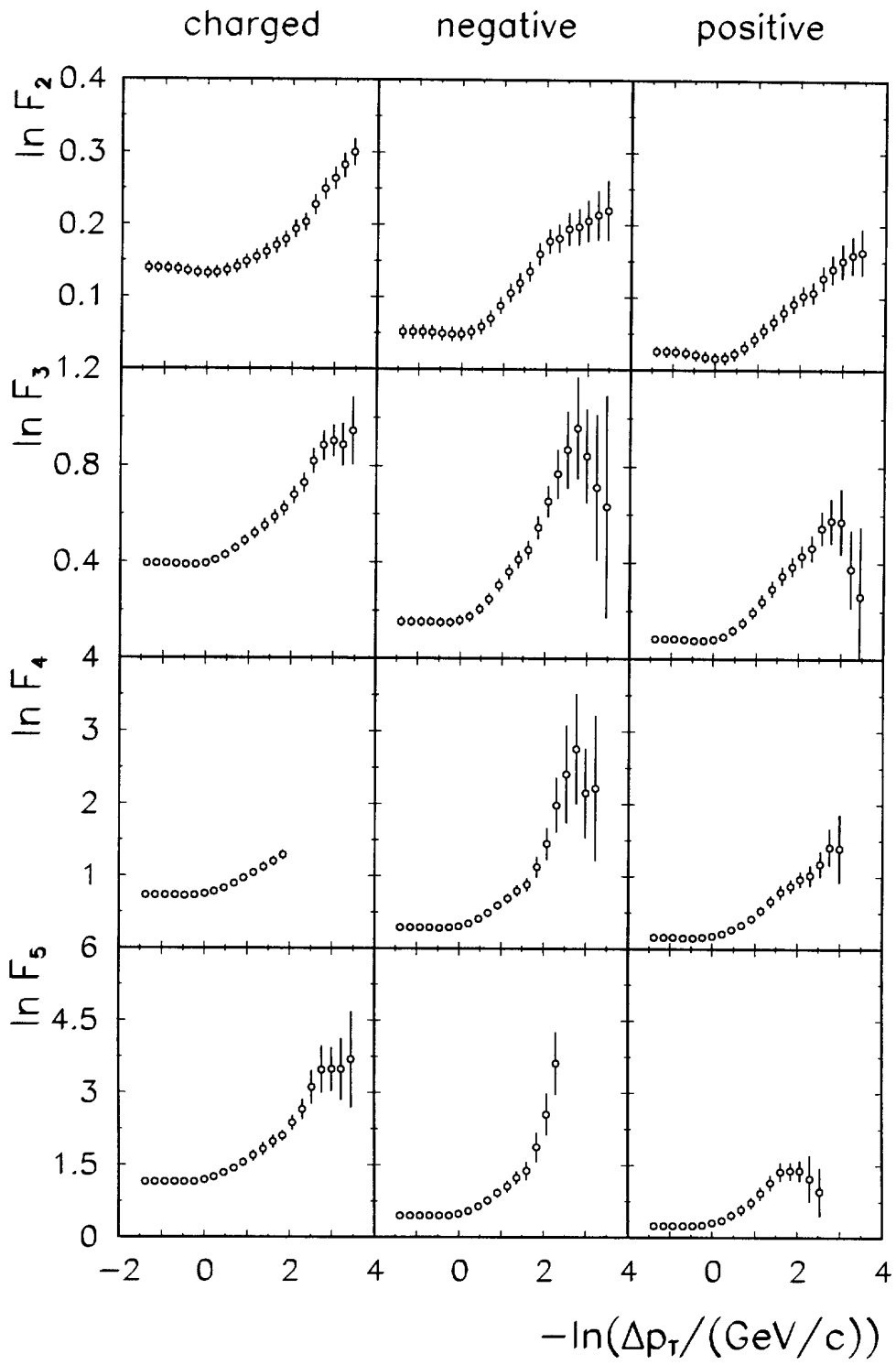


Fig.1

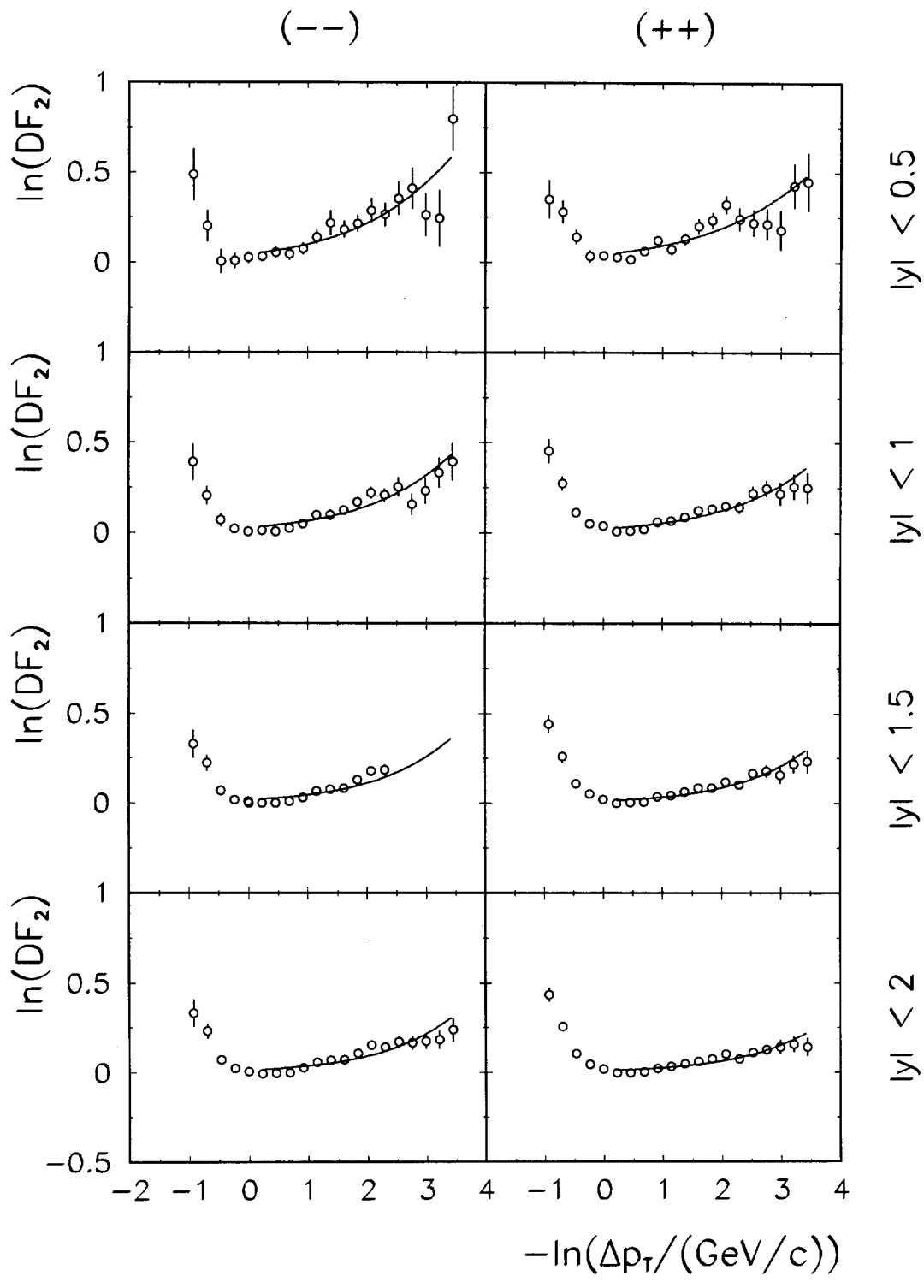


Fig.2