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Event-by-event fluctuations of average transverse momentum in central Pb+Pb collisions at 158 GeV per Nucleon

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We present first data on event-by-event fluctuations in the average transverse momentum of charged particles produced in Pb+Pb collisions at the CERN SPS. This measurement provides previously unavailable information allowing sensitive tests of microscopic and thermodynamic collision models and to search for fluctuations expected to occur in the vicinity of the predicted QCD phase transition. We find that the observed variance of the event-by-event average transverse momentum is consistent with independent particle production modified by the known two-particle correlations due to quantum statistics and final state interactions and folded with the resolution of the NA49 apparatus. For two specific models of non-statistical fluctuations in transverse momentum limits are derived in terms of fluctuation amplitude. We show that a significant part of the parameter space for a model of isospin fluctuations predicted as a consequence of chiral symmetry restoration in a non-equilibrium scenario is excluded by our measurement.

I. INTRODUCTION

The ultimate goal in the study of collisions of heavy ions at the highest available energies is the production and characterization of an extended volume of deconfined quarks and gluons, the quark gluon plasma (QGP)

[1]. Due to the high multiplicities in central Pb+Pb collisions at 158 GeV per Nucleon, recorded in the NA49 large acceptance spectrometer, a statistically significant determination of momentum space distributions and particle ratios can be performed for single events, allowing for a study of event-by-event fluctuations [2,3]. In this paper we will focus on fluctuations in the average transverse momentum of individually measured charged particles from event to event.

One expects that the fluctuation patterns are altered in the vicinity of the QCD phase transition [2,4]. This conjecture is supported by recent calculations in an effective model of the strong interaction [5,6], which suggest that near a tri-critical point in the QCD phase diagram the event-by-event fluctuation pattern in transverse momentum should change significantly.

A precise measurement of event-by-event fluctuations allows for a test of the hypothesis of thermal equilibrium [7] and the extraction of thermodynamical properties of the system in a model comparison. Model studies [8] have shown that non-equilibrium models of nuclear collisions based purely on initial state scattering can be tested by measurements of transverse momentum fluctuations. Model calculations on transverse momentum fluctuations have been performed in many of the commonly used microscopic models of nuclear collisions [9–11], in particular focussing on the question of how the fluctuations change when going from nucleon-nucleon to nucleus-nucleus collisions.

It has also been suggested that for a thermodynamical picture of the strongly interacting system formed in the collision, the strength of fluctuations is directly related to fundamental properties of the system like the specific heat [12,13] and matter compressibility [14]. A detailed discussion of transverse momentum fluctuations in a resonance gas model can be found in [6].

One of the most intensely discussed topics related to fluctuations at the QCD phase transition is the formation of so-called disoriented chiral condensates (DCCs) [15,16] as a consequence of the transient restoration of chiral symmetry, which may lead to a production of pions with much larger fluctuations of the charged-to-neutral pion ratio than expected from Poisson-statistics. The sensitivity of our measurement to these fluctuations is discussed.

NA49 is currently pursuing two different, but complementary approaches to the characterization of the single events. In the approach presented here we characterize the event by global observables like the mean transverse momentum of individually detected charged particles in the event, averaging over a large interval in momentum space. Global quantities in general also include contributions from particle correlations occuring at smaller scales, i.e. smaller intervals in momentum space. NA49 is also studying a system of differential measures of event morphology which aim at a multiscale characterization of the correlation content of single events, which should eventually provide a decomposition of the global fluctuations as a function of scale [17].

II. EXPERIMENTAL SETUP AND DATA SELECTION

The setup of the NA49 experiment is described in [18]. We used a data set of central Pb+Pb collisions that where selected by a trigger on the energy deposited in the NA49 forward calorimeter. The trigger accepted only the 5% most central events, corresponding to an impact parameter range of $b < 3.5$ fm. The event vertex was reconstructed using information from beam position detectors and the fit of the measured particle trajectories. Only events uniquely reconstructed at the known target position were used. The NA49 large acceptance hadron spectrometer allows the detection of more than 1000 individual charged particles for a single central Pb+Pb collision. In this analysis particles were selected that had a measured track length of more than 2 m in one of the two Main Time Projection Chambers (MTPC) outside the magnectic field and were also observed in at least one of the Vertex TPC's inside the superconducting magnets. We studied particles in a region of $0.005 < p_T < 1.5$ GeV/c and rapidity $4 < y_\pi < 5.5$. A cut on the extrapolated impact parameter of the particle track at the primary vertex was used to reduce the contribution of non-vertex particles originating from weak decays and secondary interactions. We estimate that about 60 % of such particles are rejected by the vertex cuts. From a full simulation of our apparatus using a GEANT [19] based Monte-Carlo code and a parametrization of the detector response we obtained an average reconstruction efficiency of 90%. The average resolution in transverse momentum for the particles used here is around 3 MeV/c, dominated by multiple Coulomb scattering. The two-track resolution was determined using both the simulation and a mixed-event technique. For particles selected by the track cuts the pair detection efficiency drops from around 80% at an average distance in the Main TPC of $d = 2.5$ cm to around 20% at an average distance of $d = 1.5$ cm. In table 1 the most important parameters of the inclusive and event-by-event distributions of accepted particles are summarized. Throughout this paper brackets ($\langle x\rangle$) will denote averages over events and bars ($\overline{x}$) will denote inclusive averages over all (accepted) particles and all events.

TABLE I. Measured parameters of the inclusive and event-by-event accepted particle distributions. Errors are statistical only.

No. of events	98426
$\langle N\rangle$	270.13 ± 0.07
$(\langle N^2\rangle - \langle N\rangle^2)^{\frac{1}{2}}$	23.29 ± 0.05
$\overline{p_T}$	376.75 ± 0.06 MeV/c
$(\overline{p_T^2} - \overline{p_T}^2)^{\frac{1}{2}}$	282.2 ± 0.1 MeV/c

III. ANALYSIS AND RESULTS

For each of the events we characterize the observed particle distribution in the acceptance region by calculating the mean of the transverse momentum distribution of the N accepted particles in the event,

$$M(p_T) = 1/N \cdot \sum_{i=1}^{N} p_{Ti}. \tag{1}$$

The resulting distribution of $M(p_T)$ is shown in fig. 1. The distribution of $M(p_T)$ has approximately Gaussian shape. No significant excess of 'anomalous' events outside the main distribution is observed. For the variance of the $M(p_T)$ distribution we get

$$V(M(p_T))/\overline{p_T} = 4.65 \pm 0.01\%.$$

The biggest contribution to the observed variance is expected to come from finite-number statistics. The main task in the remainder of the paper will be to extract possible non-statistical contributions on top of the trivial statistical variation from event to event. A first impression of the possible size of non-statistical contributions can be obtained by a comparison to the same distribution calculated for so-called mixed events (solid line in fig. 1). The mixed events were constructed by combining particles drawn randomly from different events while reproducing the multiplicity distribution of the real events. Only one track of any original event was used in a given mixed event and no further selection was made regarding the impact parameter or multiplicity of the original events. By construction the mixed events have the same single-particle distributions as the real events, but no internal correlations. The variance of the mixed event $M(p_T)$ distribution is therefore determined by finite number statistics, giving

$$(\overline{p_T^2} - \overline{p_T}^2)^{\frac{1}{2}}/(\overline{p_T} \cdot \sqrt{\langle N \rangle}) = 4.6\%.$$

The mixed event distribution resembles, very closely, the single event distribution, thus suggesting that large amplitude non-statistical fluctuations are small and/or rare. To further quantify and study the deviation of the $M(p_T)$ distribution a number of methods has been discussed recently [20–23]. In this analysis we follow the approach suggested in [7]. We define for every particle i

$$z_i = p_{Ti} - \overline{p_T}. \tag{2}$$

For every event we calculate

$$Z = \sum_{i=1}^{N} z_i. \tag{3}$$

With this definitions we use the following measure to quantify the degree of fluctuation in mean transverse momentum from event to event:

$$\Phi_{p_T} = \sqrt{\frac{\langle Z^2 \rangle}{\langle N \rangle}} - \sqrt{\overline{z^2}}. \tag{4}$$

One limiting case for this fluctuation measurement is particle emission according to a parent distribution that remains unchanged for all events, i.e. every single event is just a random sample of finite multiplicity taken from the same parent distribution. Φ_{p_T} was defined such that for this case a value of zero is assumed. This value also corresponds to the fluctuations for an ideal gas of classical particles [24].

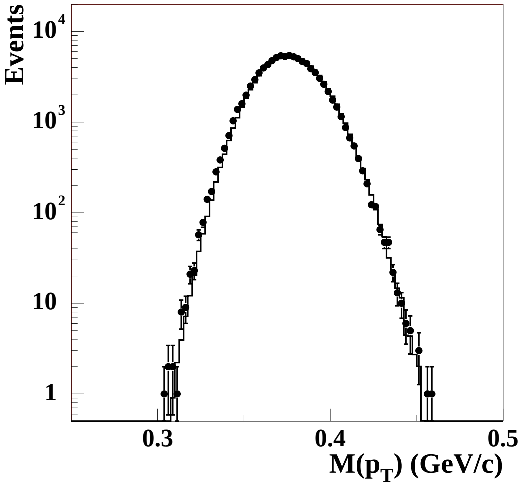

FIG. 1. Event-by-event distribution of the mean transverse momentum $M(p_T)$ of accepted particles in the event (points). For comparison, the solid line shows the $M(p_T)$ distribution for mixed events.

Our goal is to detect or exclude fluctuations that are compatible with changes, event-to-event, in the parent distribution in transverse momentum. Such changes would in general lead to values of $\Phi_{p_T} > 0$. Φ_{p_T}, as we will demonstrate later, is also sensitive to internal correlations or anti-correlations of particles within single events, which result in $\Phi_{p_T} > 0$ or $\Phi_{p_T} < 0$, respectively. In our data set we measure a value of

$$\Phi_{p_T} = 0.6 \pm 1.0 \text{ MeV/c},$$

compatible with zero. The error was estimated by calculating Φ_{p_T} separately on independent subsamples of approximately 10000 events each. Before discussing the implications of the small value measured for Φ_{p_T} for the existence of collective non-statistical fluctuations, we first turn to investigating the sensitivity of this measure to correlations at small scales, which are known to be present in these events.

Previous studies [25] have quantitatively analyzed two-particle correlations in relative momentum, with quantum statistics and Coulomb final state interactions giving the strongest contributions. We have developed an analysis procedure to identify the contribution of these known effects, folded with the NA49 experimental response, to the observed value of Φ_{p_T}. This comparison is done as follows.

1. From the original events we construct a sample of mixed events with the same overall multiplicity distribution as the real events. Without further modifications, the mixed events give a value of $\Phi_{p_T} = -0.2 \pm 0.4$ MeV/c, again consistent with zero.

2. In the second step we model the contributions from particle pair correlations at small relative momenta ('small scales'). The effect of Bose-Einstein or Fermi-Dirac statistics on transverse momentum fluctuations has been discussed in [24].
   The effects of quantum statistics and final-state (Coulomb) interactions partially cancel each other and are further diminished by particles emitted from long-lived resonances, particles originating from weak decays and by including combinations of non-identical particles. A detailed evaluation of two-particle correlations in NA49 is given in [25]. To include the sum of all these effects in the mixed events we use a procedure that was described in [26]. In this procedure the momenta of particles are altered pairwise to introduce the desired form of the two-particle correlation function, making sure that in the mixed events on the average the two-particle correlations as a function of relative momentum closely match those observed in the data, only corrected for the two-track resolution. The analysis of the modified mixed events provides an estimate of the minimal event-by-event $M(p_T)$ fluctuations that we expect as a consequence of the observed average two-particle correlations. The contribution from the two-particle correlation function alone is $\Delta\Phi_{p_T} = 5 \pm 1.5$ MeV/c.

3. In our data set we observe a slight but statistically significant correlation between the multiplicity of the event N and the average transverse momentum $M(p_T)$. The correlation is characterised by a linear correlation coefficient of

   $$\frac{\langle (M(p_T) - \overline{p_T}) \cdot (N - \langle N \rangle \rangle}{V(M(p_T)) \cdot V(N)} = -0.03 \pm 0.01,$$

   where $V(N)$ is the variance of the multiplicty distribution. We therefore observe a slight decrease of $M(p_T)$ with increasing multiplicity within the central collision data set. Introducing this correlation in the mixed events gives a negligible contribution to the width of the $M(p_T)$ distribution ($\Delta\Phi_{p_T} \ll 1$ MeV/c).

4. We then apply an experimental filter on each of the modified mixed events that simulates the influence of the two-track resolution and momentum resolution of the NA49 apparatus. While the contribution from momentum resolution is found to be negligible for the range of fluctuations considered here, the two-track resolution results in an effective anti-correlation between particles in momentum space and gives a contribution of $\Delta\Phi_{p_T} = -4 \pm 0.5$ MeV/c.

Combining all effects, we find that the observed value Φ_{p_T} is compatible with independent particle production: Including both the effects of two-particle correlations in momentum space and the experimental two-track resolution leads to a cancellation resulting in a very small net contribution. Any additional contributions beyond those mentioned above either have to be small or cancel with sufficient accuracy to be compatible with $\Phi_{p_T} = 0.6$ MeV/c.

Here it is worthwhile to note that the effects of two-particle momentum correlations and two-track resolution, as included in our simulations, both are strongly multiplicity-dependent and become negligible for multiplicities comparable to those observed in p+p collisions. This suggests that the physical origin of transverse momentum fluctuations as measured using Φ_{p_T} changes when comparing the value of 0.6 MeV/c for Pb+Pb to the preliminary NA49 measurement of 5 ± 1 MeV/c for p+p collisions [27].

To further study the sensitivity of our measurement we have introduced explicit non-statistical fluctuations in the mixed event sample and studied the response in Φ_{p_T} as a function of the parameters controlling the strength of these fluctuations. By comparing the value obtained for Φ_{p_T} observed in such models with that in the data, we can determine the sensitivity of our measurement to various kinds of fluctuations and eventually derive limits on the amplitude or frequency of occurence for fluctuations in specific models.

In the first model we examine the sensitivity to non-statistical fluctuations introduced by scaling the transverse momentum for all tracks in a given event by a constant factor x. The resulting change in the p_T parent distribution from event to event resembles that of an event by event change in the inverse slope parameter of an exponential transverse momentum distribution. We obtain a random number x for each event distributed according to

$$P(x) = \frac{1}{\sqrt{(2\pi\sigma_{fluc}^2)}} \exp(-(x-1)^2/(2\sigma_{fluc}^2)) \qquad (5)$$

and multiply the transverse momentum of each particle in the event by the same factor x. Here the amplitude of the event by event fluctuation is controlled by the parameter σ_{fluc}. Adding these fluctuations to the mixed events and neglecting two-particle correlations and two-track resolution, Φ_{p_T} increases proportionally to σ_{fluc}^2.

When adding all effects, we find that for this model a fluctuation strength $\sigma_{fluc} = 1.2\%$ corresponds to $\Phi_{p_T} = 7$ MeV/c. Given the definition of Φ_{p_T} in Eq. 4 and net contributions to Φ_{p_T} as observed and simulated in steps 1 to 4 above we can establish an upper limit on $\sigma_{fluc} < 1.2\%$ at 90% confidence level.

While a precise limit for specific models can only be set using a simulation procedure as outlined above, we typically find that for various types of non-statistical fluctuations our measurement is sensitive when the fluctuations lead to an effective non-statistical variation in the mean transverse momentum from event to event of about 1%.

We can also use the simulation procedure to establish limits on fluctuations of amplitude σ_{fluc} that occur only in a fraction F of all events. The resulting exclusion plot is shown in fig. 2, where the relative frequency F of events exhibiting fluctuations of amplitude σ_{fluc} is plotted versus σ_{fluc}. We see that for $F = 1$ fluctuations of a relative amplitude of $\sigma_{fluc} > 1.2\%$ are ruled out at 90% confidence level, whereas fluctuations occuring in 1% of the events can only be ruled out for $\sigma_{fluc} > 10\%$.

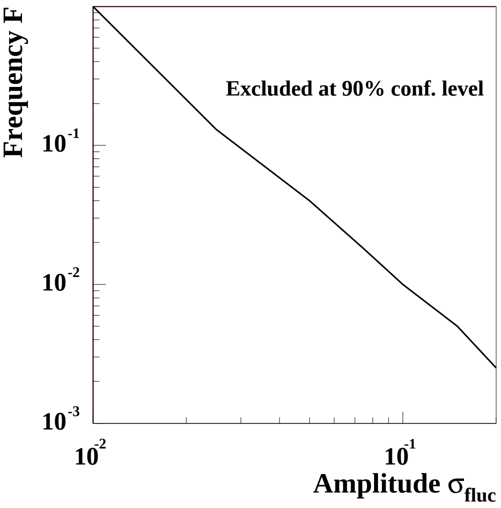

FIG. 2. Limit on the amplitude of fluctuations in the p_T parent distribution as a function of the frequency of events showing the fluctuation.

It is important to note that the measurement of fluctuations in $M(p_T)$ is also relevant for models of processes that lead to non-statistical fluctuations *localized* in transverse momentum. The most widely discussed example of such a process is the formation of disoriented chiral condensates (DCCs) [15,16], which has been postulated as a consequence of the possible restoration of chiral symmetry in non-equilibrium scenarios for heavy-ion collisions. DCC models predict the formation of domains that eventually emit pions where the ratio f of neutral to all pions varies as

$$P(f) = \frac{1}{2\sqrt{f}}. \tag{6}$$

The models also suggest that pions emitted from DCC domains will be preferentially produced at low transverse momenta [15]. This provides for a translation of the number-fluctuations predicted by the DCC models into p_T fluctuations accessible to our experiment. A limit on DCC production has already been set by the WA98 collaboration [28], based on a study of fluctuations in the relative multiplicties of charged and neutral particles near mid-rapidity.

For comparison purposes we used the same DCC model as in [28], where the DCC production is characterized by the probability F to form a single DCC domain in an event and the fraction ξ of pions coming from the DCC. We make the additional assumption that the DCC pions are produced with $p_T < p_T^{max} = m_\pi$. The ratio of neutral to charged pions was chosen randomly according to equ. 6. The isospin fluctuations of pion production from DCCs then lead to multiplicity fluctuations of charged pions at low transverse momenta and therefore to non-statistical fluctuations in $M(p_T)$. For DCCs occuring in every event ($F = 1$) the fluctuations observed in the data rule out DCC sizes of $\xi > 3.5$ %, which is about a factor of 5 smaller than the previous limit set in [28]. This limit could be further improved by restricting the analysis to the region of small transverse momenta.

IV. SUMMARY

In summary, event-by-event fluctuations in the average transverse momentum of charged particles in the forward hemisphere of central Pb+Pb collisions have been measured. The distribution of average transverse momentum per event $M(p_T)$ has an approximately Gaussian shape, with no excess of 'anomalous' events falling out of the distribution. The fluctuation strength in the data is characterized by a value of $\Phi_{p_T} = 0.6 \pm 1$ MeV/c. Using a procedure based on mixed events we find that the fluctuations in $M(p_T)$ from event to event are compatible with independent particle production modified by the known two-particle correlations due to quantum statistics and final state interactions and taking into account the response of the NA49 apparatus, without requiring further variations in the transverse momentum parent distribution from event to event.

For a model of non-statistical fluctuations in average p_T we use a detailed simulation procedure to determine an upper limit on the strength of fluctuations occuring in every event of $\sigma_{fluc} < 1.2\%$ at 90% confidence level.

We also demonstrate that high precision measurements of charged particle transverse momentum fluctuations provide a sensitive test for models predicting the formation of disoriented chiral condensates in heavy-ion collisions. Finally, we have provided the first measurement to compare to predictions of event-by-event transverse momentum fluctuations in thermodynamical descriptions of the strongly interacting system produced in Pb+Pb collisions at the SPS.

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[1] Nucl. Phys. **A638** (1998) , Proceedings of the '97 Quark Matter conference, Tsukuba, Japan.
[2] R. Stock, Proceedings of a NATO Advanced Research Workshop on *Hot Hadronic Matter: Theory and Experiment*, 1994, Divonne, France.
[3] G. Roland, Proc Workshop *QCD Phase Transitions*, Jan 1997, Hirschegg, Austria, ed. H. Feldmeier, J. Knoll, W. Nörenberg and J. Wambach, GSI, Darmstadt, 1997.
[4] St. Mrówczyński, Phys. Lett. **B314** (1993) 118.
[5] M. Stephanov, K. Rajagopal, E. Shuryak, Phys. Rev. Lett. **81** (1998) 4816, K. Rajagopal, hep-th/9808348.
[6] M. Stephanov, K. Rajagopal, E. Shuryak, hep-ph/9903292.
[7] M. Gaździcki, St. Mrówczyński, Z. Phys. **C54** (1992) 127.
[8] M. Gaździcki, A. Leonidov, G. Roland, Eur. Phys. J. **C6**, (1999) 365.
[9] M. Bleicher, M. Belkacem, C. Ernst, H. Weber, L. Gerland, C. Spieles, S. A. Bass, H. Stöcker, W. Greiner, Phys. Lett. **B435** (1998) 9.
[10] F. Liu, A. Tai, M. Gaździcki, R. Stock, hep-ph/9809320, to be published in Eur. Phys. J. C.
[11] A. Capella, E.G. Ferreiro, A.B. Kaidalov, hep-ph/9903338.
[12] L. Stodolsky, Phys. Rev. Lett. **75** (1995) 1044.
[13] E. V. Shuryak, Phys. Lett. **B423** (1998) 9.
[14] St. Mrówczyński Phys. Lett. **B430** (1998) 9.
[15] K. Rajagopal, F. Wilcek, Nucl. Phys. **B399** (1993) 395.
[16] A. Anselm, M. G. Ryskin, Phys. Lett. **B266** (1991) 482.
[17] T. A. Trainor, Proceedings of Workshop on Particle Distributions in Hadronic and Nuclear Collisions, University of Illinois at Chicago, June 1998.
[18] S. Afanasiev et al. (NA49 collab.), CERN-EP/99-001, to be published in NIM.
[19] GEANT 3.21 manual, CERN.
[20] K. Kadija, M. Martinis Z. Phys. **C56** (1992) 437.
[21] A. Bialas, V. Koch, nucl-th/9902063.
[22] W. M. Alberico, A. Lavagno, P. Quarati, nucl-th/9902070.
[23] M. Belkacem, Z. Aouissat, M. Bleicher, H. Stöcker, W. Greiner, nucl-th/9903017.
[24] St. Mrówczyński, Phys. Lett. **B439** (1998) 6.
[25] H. Appelshäuser et al. (NA49 collab.), Eur. Phys. J. **C2** (1998) 661.
[26] K. Kadija, P. Seyboth, Phys. Lett. **B287** (1992) 363.
[27] G. Roland, Proceedings of Workshop on Particle Distributions in Hadronic and Nuclear Collisions, University of Illinois at Chicago, June 1998.
[28] M. M. Aggarval et al. (WA98 collab.), Phys. Lett. **B420** (1998) 169.