

## Energy dependence of fluctuations in central Pb+Pb collisions from NA49 at the CERN SPS

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**Abstract:** The latest NA49 results on fluctuations of multiplicity and average transverse-momentum analyzed on an event-by-event basis are presented for central Pb+Pb interactions over the whole SPS energy range (20A - 158A GeV). The scaled variance of the multiplicity distribution decreases with collision energy whereas the  $\Phi_{p_T}$  measure of  $\langle p_T \rangle$  fluctuations is small and independent of collision energy. Thus in central Pb+Pb collisions these fluctuations do not show an indication of the critical point of strongly interacting matter.

## 1. Introduction

High-energy nucleus-nucleus collisions have been studied over the last two decades. The main goal of these efforts is to understand the properties of strongly interacting matter under extreme conditions of very high energy where the creation of the quark-gluon plasma (QGP) is expected [1, 2]. Various collision characteristics and their energy dependence suggest that a transient state of deconfined matter may be created at collision energies as low as 30 A GeV [3]. Fluctuations in physical observables in heavy-ion collisions have been a topic of particular interest in recent years as they may provide important signals regarding the formation of QGP and the existence of a critical point.

The NA49 detector [4], located at the CERN SPS, offers the unique possibility to study the energy dependence of various collision characteristics on an event-by-event basis. The NA49 energy-scan program obtained results on several kinds of event-by-event fluctuations in central Pb+Pb collision. For example, the observed net-charge fluctuations [5] are close to zero and much larger than expected for an ideal gas of deconfined quarks and gluons. On the other hand the dynamical  $K/\pi$  fluctuations [6] show an increase at low SPS energies, which is qualitatively consistent with the expectation for the onset of deconfinement [7]. Recently it was suggested in [8] that non-monotonic energy dependence of multiplicity and transverse-momentum fluctuations can help to locate the second-order critical end-point. Therefore, the energy-scan program analyzed the event-by-event fluctuations of these observables. In this report the energy dependence of multiplicity and transverse-momentum fluctuations in very central Pb+Pb collisions measured by the NA49 experiment is presented and compared to predictions of the various hadron-gas and string-hadronic models.

## 2. Experiment, Data and Analysis

NA49 [4] is a fixed target experiment located at the CERN SPS which comprises four large-volume Time Projection Chambers (TPC). Two chambers, the Vertex TPCs (VTPC-1 and VTPC-2), are located in the magnetic field of two superconducting dipole magnets (1.5 and 1.1 T), while the two others (MTPC-L and MTPC-R) are positioned downstream of the magnets symmetrically to the beam line. A zero degree calorimeter at the downstream end of the experiment is used to trigger on or select the centrality of the collisions. The data presented here correspond to the most central (1% for the analysis of multiplicity and 7.2% for the analysis of transverse-momentum fluctuations) events for 20A, 30A, 40A, 80A and 158A GeV. The acceptance was restricted in the analysis to the forward hemisphere:  $1 < y_\pi < y_{beam}$  in the case of multiplicity fluctuations and  $1.1 < y_\pi < 2.6^*$  in the case of transverse momentum fluctuations. Note, that the full acceptance of the NA49 detector changes with collision energy.

The scaled variance,  $\omega$ , used in this paper as a measure of multiplicity fluctuations, is defined as  $\omega = \frac{Var(n)}{\langle n \rangle} = \frac{\langle n^2 \rangle - \langle n \rangle^2}{\langle n \rangle}$  where  $Var(n) = \sum_n (n - \langle n \rangle)^2 P(n)$  and  $\langle n \rangle = \sum_n n \cdot P(n)$  are variance and mean of the multiplicity distribution, respectively. Note, that in statistical models [9]  $\omega$  is independent of volume (for large enough volumes). Conservation laws decrease the value of the scaled variance.

\*  $y_\pi$  is the particle rapidity calculated in the center-of-mass reference system, assuming the pion mass for particles.

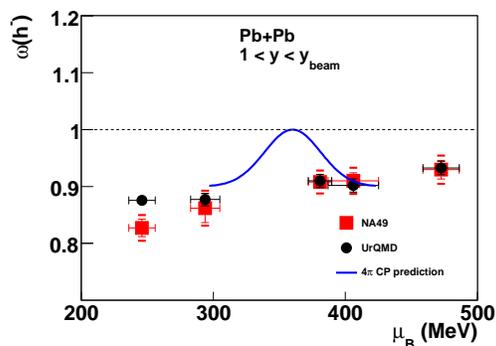
In the NA49 experiment the  $\Phi_{p_T}$  fluctuation/correlation measure, proposed in [10], is used to determine transverse-momentum fluctuations. For a complete definition of  $\Phi_{p_T}$  see [10] and the publication of NA49 [11].  $\Phi_{p_T}$  quantifies the difference between event-by-event fluctuations of transverse momentum in data and the corresponding fluctuations in 'mixed' events. In the latter correlations vanish by construction. There are two important properties of the  $\Phi_{p_T}$  measure. When the system consists of independently emitted particles (no inter-particle correlations)  $\Phi_{p_T}$  assumes a value of zero. On the other hand, if A+A collisions can be treated as an incoherent superposition of independent N+N interactions (superposition model), then  $\Phi_{p_T}$  has a constant value, the same for A+A and N+N interactions.

### 3. Search for the Critical Point

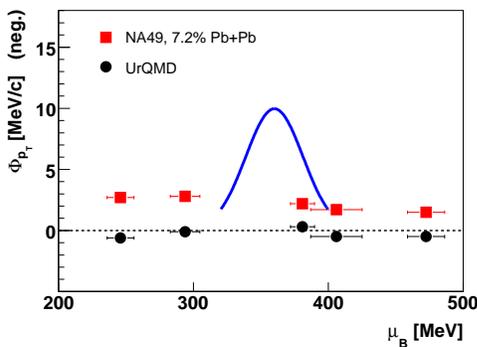
In this section we show results on the energy dependence of multiplicity and transverse-momentum fluctuations, two observables which may be sensitive to the presence of a critical end-point [8].

#### 3.1. Multiplicity Fluctuations

Results on multiplicity fluctuations for negatively charged hadrons are presented for Pb+Pb collisions at 20A, 30A, 40A, 80A and 158A GeV. The measurements are plotted versus the baryo-chemical potential  $\mu_B$  which is derived from hadron-gas model fits to the particle yields obtained by NA49 [12]. In order to minimize the fluctuations in the number of participants, the 1% most central collisions according to the energy of projectile spectators measured in the veto calorimeter are selected. In figure 1 the scaled variance  $\omega(h^-)$  of the multiplicity distribution of negatively charged particles is shown as a function of baryo-chemical potential  $\mu_B$  and compared to the predictions of the UrQMD [13] model. We also show the predicted peak of the scaled variance in  $4\pi$  acceptance in the vicinity of the critical end-point [15, 16, 8]. It is evident from the plot that there is no indication of the critical end-point in the energy dependence of multiplicity fluctuations.



**Figure 1:** (Color online) Scaled variance  $\omega(h^-)$  of the multiplicity distribution of negatively charged hadrons as a function of baryo-chemical potential  $\mu_B$  for the NA49 data (squares) and the UrQMD [13] model (circles). The curve shows the predicted values of the scaled variance in  $4\pi$  acceptance in the vicinity of the critical end-point [15, 16, 8]. The effect of finite acceptance needs to be estimated. See text for details.



**Figure 2:** (Color online)  $\Phi_{p_T}$  measure of transverse-momentum fluctuations calculated for negatively charged hadrons with transverse momenta  $p_T \leq 500$  MeV/c as a function of baryo-chemical potential  $\mu_B$  for the NA49 data (squares) and the UrQMD [13] model (circles). The curve shows the predicted  $\Phi_{p_T}$  values in the vicinity of the critical end-point [8]. See text for details.

### 3.2. Transverse-momentum Fluctuations

Following the suggestion [8] that fluctuations due to the critical point should be dominated by fluctuations of pions with  $p_T \leq 500$  MeV/c we analysed transverse momentum fluctuations for this restricted  $p_T$  range. Figure 2 shows  $\Phi_{p_T}$  values for negatively, positively and all charged particles calculated from NA49 data as a function of baryo-chemical potential  $\mu_B$ . As in the case of multiplicity fluctuations we have also plotted the prediction of the values of  $\Phi_{p_T}$  near the critical point\*. Also for transverse-momentum fluctuations there is no significant energy dependence of the  $\Phi_{p_T}$  measure when low transverse momenta are selected and thus there is no evidence for a critical point.

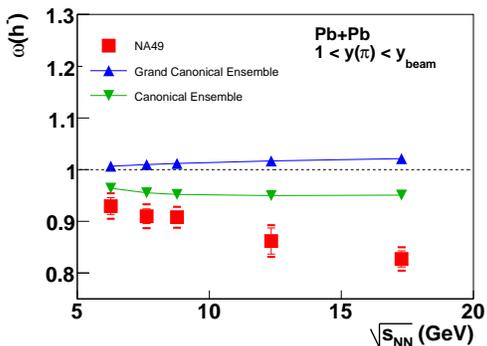
## 4. Comparison to Models

In this section we compare the NA49 data on multiplicity fluctuations to the predictions of hadron-gas models [9] as well as the string hadronic model UrQMD [13]. Note, that the energy dependence of multiplicity fluctuations is also predicted within the HSD model [14], but calculations for the NA49 acceptance are not published.

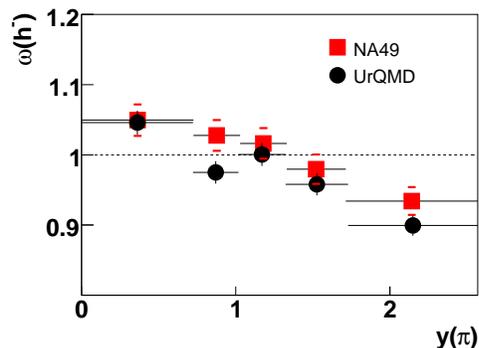
The predictions of the hadron-gas model in its grand-canonical and canonical formulation can be interpolated between full and vanishing acceptance to the experimental acceptance [9], because in these ensembles the particles are essentially uncorrelated in momentum space and the particle momentum distribution is independent of multiplicity. Figure 3 shows that the measured fluctuations disagree with the predictions of the canonical and grand-canonical model in the forward acceptance. For the micro-canonical model no predictions in the limited acceptance are available yet, but smaller fluctuations are expected. The suppression of fluctuations in the experimental data with respect to the grand-canonical model can be explained by charge and energy-momentum conservation [9].

The rapidity dependence of  $\omega$  is shown in figure 4. The width of the  $y$  bins is chosen in such a way that the mean multiplicity in each bin is the same. A decrease of  $\omega$  with increasing rapidity is observed, which is reproduced by the UrQMD model [17]. In terms of a hadron gas model this can be understood as a result of energy and momentum conservation [18].

\* Note that predicted values of  $\Phi_{p_T}$  at the critical point should result in  $\Phi_{p_T} \simeq 20$  MeV/c, however the effect of limited acceptance of NA49 reduces them to  $\Phi_{p_T} \simeq 10$  MeV/c



**Figure 3:** (Color online) Energy dependence of  $\omega(h^-)$  in Pb+Pb collisions in the rapidity interval  $1 < y < y_{beam}$  compared to the predictions of a hadron-gas models [9]. The lines interpolate between the points calculated within the models.



**Figure 4:** (Color online) Rapidity dependence of  $\omega(h^-)$  at 80A GeV compared to UrQMD calculations.

## 5. Conclusions

Our main results from the study of central Pb+Pb collisions are as follows:

- No structure related to the critical point were observed in the energy dependence of multiplicity fluctuations. Statistical models show that conservation laws have an important effect on  $\omega$ . The UrQMD model reproduces the trends observed in the data.
- There is no significant energy dependence of transverse-momentum fluctuations at SPS energies. Thus the energy dependence of  $p_T$  fluctuations shows no evidence of the critical point.
- Net-charge fluctuations are independent of energy and detector acceptance. Their values are close to zero, much above the negative values expected for a QGP.
- Dynamical kaon/pion fluctuations increase towards lower beam energy. Fluctuations are significantly enhanced over hadronic cascade models like UrQMD.

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