Event-by-Event Fluctuations at 40, 80, and 158 AGeV/c in Pb+Au Collisions

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Abstract. Event-by-event fluctuations of mean $p_T$ and net charge in 40, 80, and 158 AGeV/c Pb+Au collisions are presented. The observed dynamical mean $p_T$ fluctuations in central events of about 1% are very similar to results from RHIC. The centrality dependence of mean $p_T$ fluctuations at 158 AGeV/c shows a peculiar non-monotonic pattern with respect to the extrapolation from the fluctuations measured in p+p collisions. Dynamical net charge fluctuations smaller than the charge conservation limit are observed. After correction for charge conservation, the measured fluctuation signal in central events is comparable to RHIC results.

1. Introduction

Event-by-event fluctuations of mean $p_T$ have been proposed as a possible probe to search for the phase transition, especially the QCD critical point via their non-monotonic variation with control parameters such as beam energy and centrality [1]. On the other hand, the fluctuations can be used to evaluate the extent of thermal equilibrium by comparison with the extrapolated fluctuations from nucleon-nucleon collisions. Suppressed net charge fluctuations have been proposed as a possible signal for the formation of a QGP, due to the smaller charge units of deconfined (anti-) quarks compared to those of confined hadrons [2, 3]. Comparisons with cascade models may clarify whether the observed fluctuations are described by resonance gas models.

A detailed description of CERES experiment at the CERN-SPS can be found elsewhere [4, 5]. For the present analysis, momenta of charged particle tracks produced in Pb+Au collisions at 40, 80, and 158 AGeV/c have been measured with a cylindrical Time Projection Chamber. The data set comprises a wide range of collision centrality. The acceptance of the TPC is around mid-rapidity ($2.0 < \eta < 2.9$) and covers $2\pi$ in azimuth (at 40 AGeV/c only $1.3\pi$, see also [5]).

2. Mean $p_T$ Fluctuations

Two measures are used to evaluate mean $p_T$ fluctuations. The $\Sigma_{p_T}$ measures the dynamical fluctuation normalized with mean $p_T$ [5]. This measure is proportional to
mean covariance of all charged particle pairs per event [6]. Another measure $F_{pt}$ [8] is defined as a deviation from 1 of the ratio of the r.m.s. of the event-by-event mean $p_T$ distribution in real events to that in mixed events. The $F_{pt}$ is approximately proportional to $\langle N \rangle \Sigma^2_{pt}$, where $\langle N \rangle$ is the mean charged particle multiplicity in the acceptance. In Fig. 1, $\Sigma_{pt}$ has a saturation tendency at the pseudo-rapidity interval ($\Delta \eta$) more than 0.4, whereas $F_{pt}$ steadily increases. We therefore use $\Sigma_{pt}$ to compare CERES results ($\Delta \eta = 0.5$) with RHIC results ($\Delta \eta = 0.7 \sim 2$).

Fig. 2 shows $\Sigma_{pt}$ as a function of nucleon-nucleon center of mass energy ($\sqrt{s_{NN}}$) at $2.2 < \eta < 2.7$ and $0.1 < p_T < 2$ GeV/c in 6.5 % central events, compared to RHIC data at $\sqrt{s_{NN}} = 130$ GeV [9, 10], and 200 GeV [8]. For comparison to RHIC data, the CERES data are not corrected for short range momentum correlations. The observed fluctuations at SPS and at RHIC are similarly about 1 %. No indication for non-monotonic variation or enhanced fluctuations is observed. Note that a predicted fluctuation at the critical point is $\sim 2\%$ [1], far above the measured values.

Fig. 3 shows fluctuations corrected for short range momentum correlations at 158 AGeV/c as a function of the number of participants ($N_{part}$). The fluctuations between the minimum-bias data set and the central data set are consistent. As a baseline (dashed lines) reflecting the superposition of individual nucleon-nucleon collisions, we employ the formula $\Sigma_{pt}^{AA} = 12\% \cdot (\langle N_{part} \rangle/2)^{-1/2}$, where the 12 % is a measured fluctuation in p+p collisions at ISR [7], which corresponds to $F_{pt} \approx 1.4 \%$ in the CERES acceptance. Significant deviations from the baseline are observed in semi-central events, whereas in peripheral events (centrality $\geq 66\%$) and in central events (centrality $\leq 20\%$), the fluctuations are consistent with the baseline. The maximum of $F_{pt}$ is about 2.8 % at $N_{part}$ of 50 $\sim$ 100, corresponding to 25 $\sim$ 50 % central events. The observed centrality dependence as well as the increase of $F_{pt}$ with the upper $p_T$ cut is similar to the observations by NA49 [11], PHENIX [8], and STAR [10].

In Fig. 4, $F_{pt}$ of RQMD and UrQMD without rescattering is consistent with the
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3. Net charge fluctuations

As a measure of net charge fluctuations, we use $\nu_{\text{dyn}}$, representing dynamical fluctuations of the difference between normalized multiplicity of positive particles and that of negative particles [12]. The measure is advantageous since the correction for the global charge conservation is additive, and no efficiency correction is necessary.

Fig. 5 shows $\nu_{\text{dyn}}$ multiplied with mean charged particle multiplicity within the acceptance $\langle N \rangle$ as a function of $N_{\text{part}}$ at the three beam energies. The dashed lines show the charge conservation limit, defined as $-4\langle N \rangle / \langle N \rangle_{4\pi}$, where $\langle N \rangle_{4\pi}$ is the total charged particle multiplicity which is assumed to scale with $\langle N \rangle$. The $\langle N \rangle_{4\pi}$ is estimated based on the NA49 measurements [13]. The observed fluctuations are lower than the charge conservation limit. Since the fluctuations are much above the QGP model predictions of $\sim -3.5$ [2, 3], no indication for the formation of a deconfined phase is found. Decreasing tendencies of $\langle N \rangle \nu_{\text{dyn}}$ with $N_{\text{part}}$ are observed at the three beam energies. Whether this is due to a deviation of the charge conservation limit from the multiplicity scaling, or due to a real deviation of the fluctuations from the multiplicity scaling, is under investigation.

Fig. 6 shows, as a function of $\sqrt{s_{NN}}$, a compilation of CERES, STAR [14, 15], and PHENIX results [16] for $\nu_{\text{dyn}}$ corrected for charge conservation ($\tilde{\nu}_{\text{dyn}}$). A decrease of $\tilde{\nu}_{\text{dyn}}$ is observed at SPS energies, while a decrease is tiny from SPS top energy to RHIC energies. Both RQMD and UrQMD are in reasonable agreement with the CERES data.
4. Conclusions

Dynamical mean $p_T$ fluctuations of $\sim 1\%$ in central events are observed, which are similar to the fluctuations measured at RHIC. The $F_{pT}$ shows non-monotonic centrality dependence with a maximum of $\sim 2.8\%$ in semi-central events, which is about a factor of 2 enhanced over the p+p extrapolation. A similar tendency is observed also by NA49, PHENIX, and STAR. RQMD qualitatively reproduces both enhancement of fluctuations in semi-central events and increase of mean $p_T$ as a function of centrality.

The observed dynamical net charge fluctuations are smaller than the charge conservation limit. The $\langle N \rangle \nu_{dyn}$ slightly decreases from peripheral to central events. The $\tilde{\nu}_{dyn}$ decreases at SPS energies but varies little from the SPS top energy to RHIC energies. UrQMD and RQMD reproduce the observed fluctuations at SPS.

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