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Event-by-event fluctuations of mean transverse momentum in Au+Au collisions in STAR experiment at relativistic heavy-ion collider

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Abstract. We report results on event-by-event fluctuations in mean transverse momentum in Au+Au collisions at $\sqrt{s_{NN}} = 130$ GeV measured by the STAR experiment at RHIC. The dynamical fluctuations, $\sigma_{\langle p_t \rangle,\mathrm{dynam}}$, is found to be about $1.2 \pm 0.2\%$ of the mean transverse momentum for particles in pseudo-rapidity range of $-0.5 < \eta < 0.5$ and for the top 6% central collisions.

Keywords. Mean transverse momentum; fluctuations.

1. Introduction

Event-by-event fluctuations are considered to be one of the important tools to identify quark gluon plasma (QGP) phase transition. A first-order phase transition may lead to large fluctuations in energy density due to the formation of QGP droplets [1,2]. Second-order phase transitions may lead to divergence in the specific heat; it would also increase the fluctuations in energy density. One could observe them as fluctuations in mean transverse momentum if matter freezes out at the critical temperature T_c [3,4].

In this paper we report the preliminary results of event-by-event dynamical fluctuations in mean transverse momentum of charged particles produced in Au+Au collisions at $\sqrt{s_{NN}} = 130$ GeV in pseudo-rapidity region $|\eta| < 0.5$ measured by time projection chamber (TPC) in STAR experiment [5].

2. Results and discussions

A total of 130 K triggered central events and 140 K minimum bias events with a primary vertex position within 75 cm of the center of the TPC have been used in this analysis. Tracks are required to pass within 3 cm of the primary vertex and the ratio of the number of points on a track to the maximum possible number of points is required to be greater than 0.5 in order to avoid double counting of tracks due to track splitting. Also, only tracks within the pseudo-rapidity range $-0.5 < \eta < 0.5$ and transverse momentum $0.150 < p_t < 2.0$ GeV/c are selected for the analysis. Within the pseudo-rapidity and momentum cut used the track reconstruction efficiency is estimated to be constant within

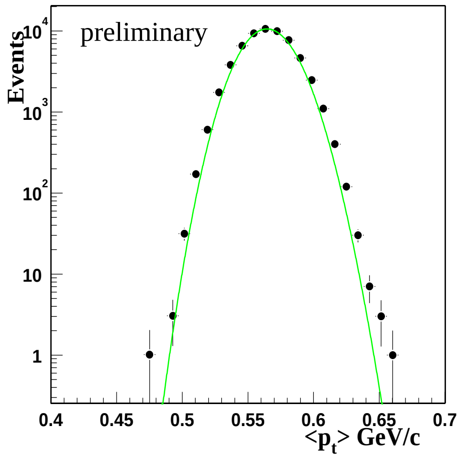

Figure 1. $\langle p_t \rangle$ distribution for most central events. The solid line is the gamma distribution with parameters $\langle M \rangle$, $\bar{p_t}$, and σ_{p_t}, as obtained from the data.

$\pm 10\%$. The centrality of the collision is determined by the total charged particle multiplicity, N_{ch}, measured by the TPC in the pseudo-rapidity region $|\eta| < 0.75$.

The mean transverse momentum of charged particles in each event is calculated by

$$\langle p_t \rangle = \frac{1}{M} \sum_{i=1}^{M} p_{t_i}, \tag{1}$$

where p_{t_i} is the transverse momentum of the ith particle and M the total number of particles. The mean transverse momentum averaged over all events in the event sample is denoted by $\langle\langle p_t \rangle\rangle$. Figure 1 shows the $\langle p_t \rangle$ distribution for the top 6% central events. The $\langle p_t \rangle$ distribution shown in figure 1 is not corrected for track reconstruction inefficiencies. We do not observe any obvious structures in this distribution which would indicate a distinct class of events, and proceed further with the analysis only of the second moment (width) of the distribution. The solid curve, shown in figure 1 for illustrative purposes, represents the gamma distribution [6] and it is a good approximation for event-by-event $\langle p_t \rangle$ distribution under the assumption of independent particle production. The parameters for gamma distribution are the mean event multiplicity, $\langle M \rangle$, and the mean and variance of inclusive transverse momentum distribution, $\bar{p_t}$, σ_{p_t}. With these parameters the variance of the gamma distribution is equal to the variance expected for statistical fluctuations in $\langle p_t \rangle$. The difference in widths indicates dynamical fluctuations.

The non-statistical (dynamical) fluctuations in $\langle p_t \rangle$ is the consequence of the correlation between particle transverse momenta. In this paper we use the notation [7]

$$\sigma^2_{\langle p_t \rangle,\mathrm{dynam}} \equiv \sigma^2_{\langle p_t \rangle} - \sigma^2_{\langle p_t \rangle,\mathrm{stat}} = \langle\langle p_{t,i}\, p_{t,j} \rangle\rangle_{i \neq j} - \langle\langle\ p_t \rangle\rangle^2, \tag{2}$$

with double angle brackets meaning the average over particle pairs in some (pseudo) rapidity and transverse momentum window, and the average over all events from the corresponding event class. The relative fluctuation in mean transverse momentum $\sigma_{\mathrm{dynam}}/\langle\langle p_t \rangle\rangle \approx 1.2 \pm 0.2\%$. The (relative) systematic error in our measurement of $\sigma^2_{\langle p_t \rangle,\mathrm{dynam}}$ is about 5%.

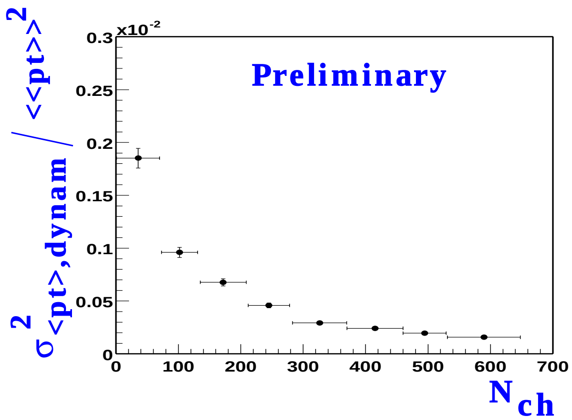

Figure 2. Ratio of $\sigma^2_{\langle p_t\rangle,\mathrm{dynam}}/\langle\langle p_t\rangle\rangle^2$ as a function of centrality.

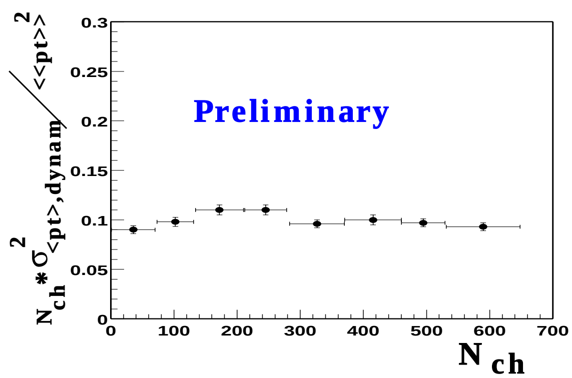

Figure 3. Same as figure 2 scaled with multiplicity.

Figure 2 shows the ratio of dynamical fluctuation to mean transverse momentum as a function of centrality. The relative fluctuations decrease with centrality of the collision approximately inversely proportional to the event multiplicity. It is seen better in figure 3, where the ratio is weighted with the multiplicity. Such dependence is consistent with the correlation due to particle production via individual *NN* collisions, jets, resonances, strings, etc. If relative number of such clusters remains the same for different centralities, then $\sigma^2_{\langle p_t\rangle,\mathrm{dynam}}$ is inversely proportional to the event multiplicity, reflecting the 'statistical dilution' in probability for a given particle to be correlated with another particle.

Event-by-event dynamical fluctuations in Pb+Pb and Pb+Au collisions at CERN SPS have been measured by the NA49 experiment [8] and NA45/CERES collaboration [9] using the so called Φ_{p_t} [10] measure. The NA49 reported [8] $\Phi_{p_t} = 0.6 \pm 1$ MeV/c for the rapidity region $4.0 < y < 5.5$ and 5% most central collisions. The observed fluctuations are very small, but it would be confusing to compare these numbers with STAR measurement, because NA49 results have been obtained in forward rapidity region, while STAR measurements are done at mid-rapidity. The CERES has measured the fluctuations in the central rapidity region. They reported $\Phi_{p_t} = 7.8 \pm 0.9$ MeV/c in central Pb+Au collisions

[9]. For the top 6% central collision we obtain $\Phi_{p_\mathrm{t}} = 25.4 \pm 1.5$ MeV (stat). It is shown in [7] that Φ_{p_t} is related to $\sigma^2_{\langle p_\mathrm{t}\rangle,\mathrm{dynam}}$ via an approximate relation,

$$\Phi_{p_\mathrm{t}} \approx \frac{\sigma^2_{\langle p_\mathrm{t}\rangle,\mathrm{dynam}}\langle M\rangle}{2\sigma_{p_\mathrm{t}}}. \qquad (3)$$

As seen from eq. (3), Φ_{p_t} being directly proportional to the number of reconstructed tracks used for its calculation, strongly depend on acceptance cuts and tracking efficiency. In our analysis we observe an approximately linear dependence of Φ_{p_t} on the number of particles surviving acceptance and track selection cut. It has been checked by randomly discarding a certain fraction of particles for fixed acceptance ($\Delta\eta = 1$) and/or varying the acceptance itself. Due to the above reason, direct comparison of our results to NA49 and CERES is not possible. For a rough comparison one can take into account that CERES multiplicity is close to 130 and their $\langle\langle p_\mathrm{t}\rangle\rangle \approx 420$ GeV/c and $\sigma_{p_\mathrm{t}} \approx 0.270$ GeV/c. Then $\Phi_{p_\mathrm{t}} \approx 8$ MeV corresponds to $\sigma_{\langle p_\mathrm{t}\rangle,\mathrm{dynam}}/\langle\langle p_\mathrm{t}\rangle\rangle \approx 1.2\%$.

To understand the role of (mini)jet production in $\langle p_\mathrm{t}\rangle$ fluctuations, we have performed an analysis of central HIJING [12] events with hard processes switched 'on' or 'off' and with the same cuts as real experimental data. The jets increase the fluctuations by about 10% from $\sigma_{\langle p_\mathrm{t}\rangle,\mathrm{dynam}}/\langle\langle p_\mathrm{t}\rangle\rangle \approx 1\%$ in the case with hard processes switched off to $\sigma_{\langle p_\mathrm{t}\rangle,\mathrm{dynam}}/\langle\langle p_\mathrm{t}\rangle\rangle \approx 1.1\%$ with hard processes switched on. Note that both numbers are very close to the experimentally observed value.

3. Summary and conclusion

We have measured event-by-event dynamical fluctuations in the mean transverse momentum. The relative dynamical fluctuation is about $\sigma_{\langle p_\mathrm{t}\rangle,\mathrm{dynam}}/\langle\langle p_\mathrm{t}\rangle\rangle \approx 1.2 \pm 0.2\%$ for the top 6% central collisions. This value is similar to the preliminary CERES measurements at SPS. HIJING model (no final state rescatterings) gives similar results. The centrality dependence of dynamical fluctuations exhibit rough proportionality to the inverse of the multiplicity density, which is consistent with the particle production via the superposition of individual *N–N* collisions, and/or decays of jets, resonances, strings etc.

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