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Event-by-event average p_T fluctuations in $\sqrt{s_{NN}}$ = 200 GeV Au+Au and p+p collisions in PHENIX: measurements and jet contribution simulations

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Abstract

Small, but significant non-random fluctuations in event-by-event average p_T have been observed in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV by the PHENIX Collaboration. These are consistent with being caused by correlations due to jets at large p_T, where the measured suppression must be included to reproduce the centrality dependence of the non-random fluctuations.

(Some figures in this article are in colour only in the electronic version)

1. The event-by-event average p_T distribution is not a Gaussian, it is a Gamma distribution

The single-particle inclusive p_T distribution averaged over all particles in all events in a p–p experiment (inclusive) or in a given centrality class in an A+A experiment (semi-inclusive) is usually written in the form

$$\frac{d\sigma}{p_T\, dp_T} = b^2\, e^{-bp_T} \qquad \text{or} \qquad \frac{d\sigma}{dp_T} = b^2 p_T\, e^{-bp_T}. \tag{1}$$

Equation (1) represents a Gamma distribution with $p = 2$, where $\langle p_T \rangle = p/b, \sigma_{p_T}/\langle p_T \rangle = 1/\sqrt{p}$ and typically $b = 6$ (GeV/c)$^{-1}$ for p–p collisions. The 'inverse slope parameter' $T = 1/b$ is sometimes referred to as the 'temperature parameter'.

For events with n detected charged particles with magnitudes of transverse momenta, p_{T_i}, the event-by-event average p_T, denoted by M_{p_T} is defined as

$$M_{p_T} = \overline{p_T} = \frac{1}{n}\sum_{i=1}^{n} p_{T_i} = \frac{1}{n} E_{Tc}. \tag{2}$$

For the case of statistical independent emission, where the fluctuations are purely random, an analytical formula for the distribution in M_{p_T} can be obtained assuming negative binomial

[1] For the full PHENIX Collaboration author list and acknowledgments, see appendix 'Collaborations' of this volume.

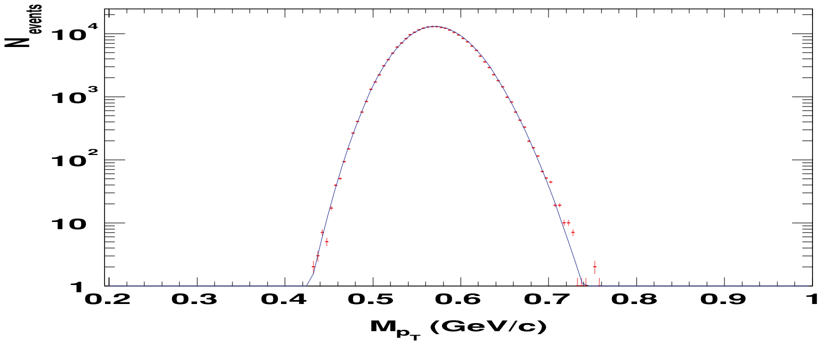

Figure 1. PHENIX mixed-event distribution for the 0–5% centrality class (data points) compared to equation (3) (curve).

(NBD) distributed event-by-event multiplicity, with Gamma distributed semi-inclusive p_T spectra [1]. The formula depends on the four semi-inclusive parameters $\langle n\rangle$, $1/k$, b and p which are derived from the means and standard deviations of the semi-inclusive p_T and multiplicity distributions, $\langle n\rangle$, σ_n, $\langle p_T\rangle$ and σ_{p_T}:

$$f(y) = \sum_{n=n_{\min}}^{n_{\max}} f_{\mathrm{NBD}}(n, 1/k, \langle n\rangle) f_{\Gamma}(y, np, nb), \tag{3}$$

where $y = M_{p_T}$. For fixed n, and purely random fluctuations, the mean and standard deviation of M_{p_T} follow the expected behaviour, $\langle M_{p_T}\rangle = \langle p_T\rangle, \sigma_{M_{p_T}} = \sigma_{p_T}/\sqrt{n}$. In PHENIX, equation (3) is used to confirm the randomness of mixed events (figure 1).

2. Measurement of non-random fluctuations in PHENIX

Mixed events are used to define the baseline for random fluctuations of M_{p_T} in PHENIX [2, 3]. This has the advantage of effectively removing any residual detector-dependent effects. The event-by-event average distributions are very sensitive to the number of tracks in the event (denoted by n or N_{tracks}), so the mixed-event sample is produced with the *identical* N_{tracks} distribution as the data. Additionally, no two tracks from the same data event are placed in the same mixed event in order to remove any intra-event correlations in p_T. Finally, $\langle M_{p_T}\rangle$ must exactly match the semi-inclusive $\langle p_T\rangle$. As noted above, the randomness of M_{p_T} for the mixed-event sample is tested by comparison to equation (3). Figure 1 shows the excellent agreement between the calculation and the mixed-event M_{p_T} distributions for the 0–5% centrality class. The standard deviations, $\sigma_{M_{p_T}}$, differ by less than 0.04%. This represents the maximum error from any effects introduced by the event-mixing procedure.

The measured M_{p_T} distributions for the data in two centrality classes for $\sqrt{s_{\mathrm{NN}}} = 200$ GeV Au+Au collisions in PHENIX are shown in figure 2 (data points) compared to the mixed-event distributions (histograms). The non-Gaussian, Gamma distribution shape of the M_{p_T} distributions is evident. The difference between the data and the mixed-event random baseline distributions is barely visible to the naked eye. The non-random fluctuation is quantified by the per cent difference of the standard deviations of M_{p_T} for the data and the mixed-event (random) sample:

$$F_{p_T} \equiv \frac{\sigma_{M_{p_T},\mathrm{data}} - \sigma_{M_{p_T},\mathrm{mixed}}}{\sigma_{M_{p_T},\mathrm{mixed}}}. \tag{4}$$

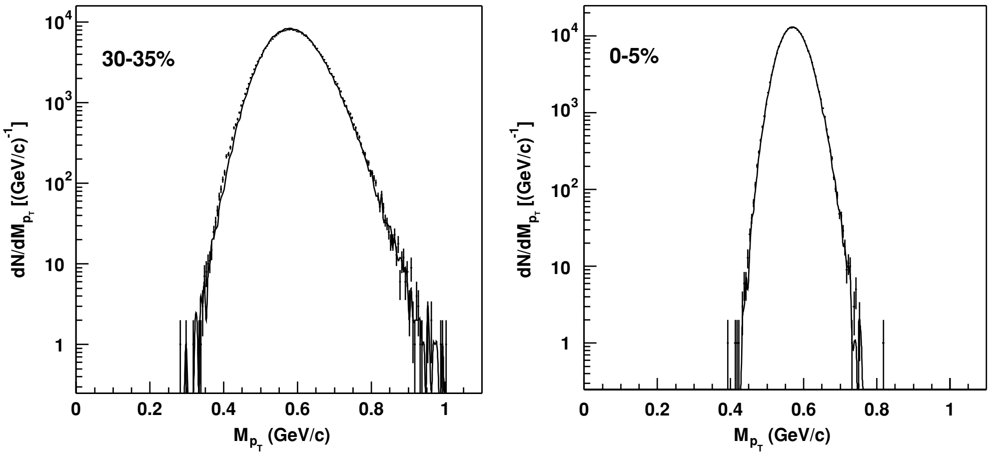

Figure 2. M_{p_T} for 30–35% and 0–5% centrality classes: data (points) mixed events (histogram).

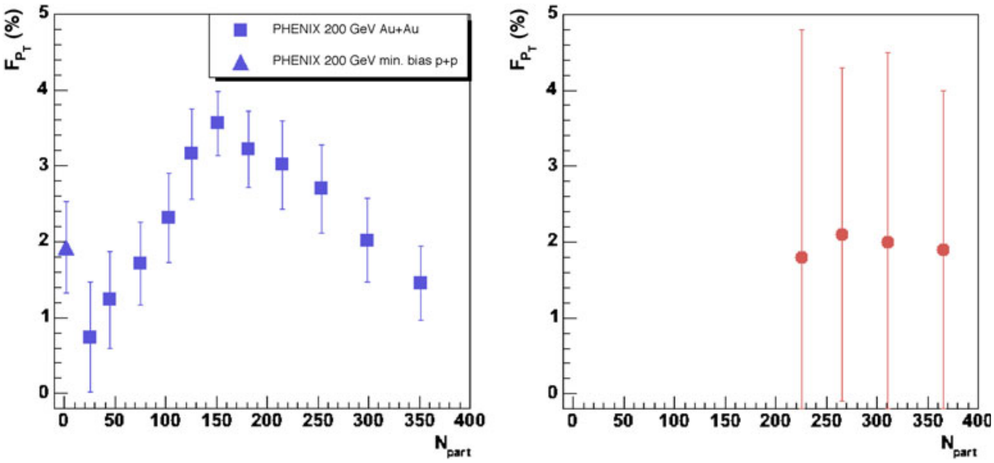

Figure 3. F_{p_T} in %: (left) Au+Au, p+p, $\sqrt{s_{\mathrm{NN}}} = 200$ GeV, (right) Au+Au 130 GeV.

The results are shown as a function of centrality represented by N_{part} in figure 3 compared to the previous PHENIX measurement at $\sqrt{s_{\mathrm{NN}}} = 130$ GeV [2]. The errors shown are systematic errors due to time-dependent detector variations. Comparatively, statistical errors are negligible. The systematic error is calculated from the rms variation of F_{p_T} from ten independent subsets of the data. The improvement over the $\sqrt{s_{\mathrm{NN}}} = 130$ GeV data is due to three times larger solid angle (larger N_{tracks}), better tracking and more statistics [3].

The dependence of F_{p_T} on N_{part} is striking. To further understand this dependence and the source of these non-random fluctuations, F_{p_T} was measured over a varying p_T range, 0.2 GeV/c $\leqslant p_T \leqslant p_T^{\mathrm{max}}$ (figure 4), where $p_T^{\mathrm{max}} = 2.0$ GeV/c for the N_{part} dependence. The increase of F_{p_T} with p_T^{max} suggests elliptic flow or jet origin. This was investigated using a Monte Carlo simulation of correlations due to elliptic flow and jets in the PHENIX acceptance. The flow was significant only in the lowest centrality bin and negligible ($F_{p_T} < 0.1\%$) at higher centralities. Jets were simulated by embedding (at a uniform rate per generated particle, $S_{\mathrm{prob}}(N_{\mathrm{part}})$) p–p hard-scattering events from the PYTHIA event generator into simulated

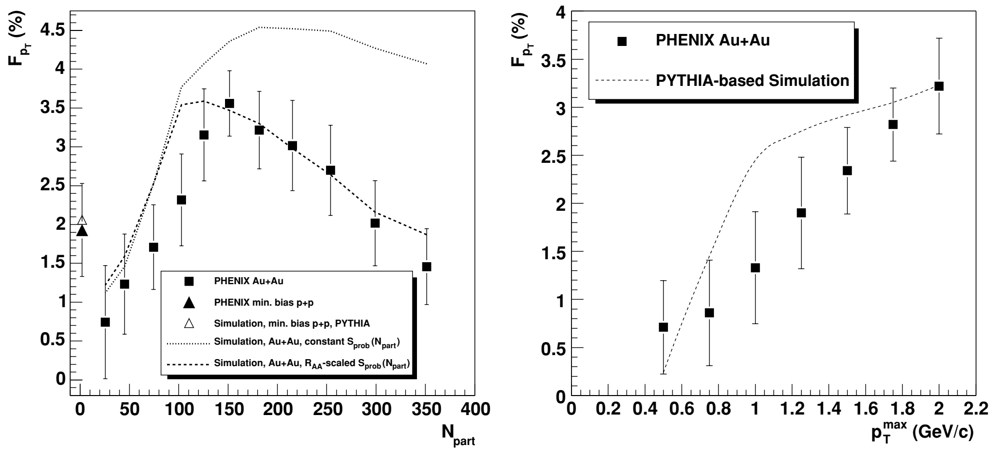

Figure 4. F_{p_T} versus centrality and $p_T^{\max}$ compared to simulations.

Au+Au events assembled at random according to the measured N_{tracks} and semi-inclusive p_T distributions. This changed $\langle p_T \rangle$ and σ_{p_T} by less than 0.1%. $S_{\mathrm{prob}}(N_{\mathrm{part}})$ was either constant for all centrality classes, or scaled by the measured hard-scattering suppression factor $R_{\mathrm{AA}}(N_{\mathrm{part}})$ for $p_T > 4.5$ GeV/c [4]. A value $F_{p_T} = 2.06\%$ for p–p collisions was extracted from pure PYTHIA events in the PHENIX acceptance in agreement with the p–p measurement. The value of $S_{\mathrm{prob}}(N_{\mathrm{part}})$ was chosen so that the simulation with $S_{\mathrm{prob}}(N_{\mathrm{part}}) \times R_{\mathrm{AA}}(N_{\mathrm{part}})$ agreed with the data at $N_{\mathrm{part}} = 182$. The centrality and $p_T^{\max}$ dependences of the measured F_{p_T} match the simulation very well, but only when the R_{AA} scaling is included.

A less experiment-dependent method to compare non-random fluctuations is to assume that the entire F_{p_T} is due to temperature fluctuations of the initial state, with rms variation $\sigma_T/\langle T \rangle$ [5, 2]:

$$F_{p_T} = \frac{(\langle n \rangle - 1)}{2} \frac{\sigma_T^2 / \langle T \rangle^2}{\sigma_{p_T}^2 / \langle p_T \rangle^2} = \frac{p}{2}(\langle n \rangle - 1)\frac{\sigma_T^2}{\langle T \rangle^2}. \tag{5}$$

This yields $\sigma_T/\langle T \rangle = 1.8\%$ for central collisions and 3.7% at the peak of F_{p_T}, which puts severely small limits on the critical fluctuations that were expected.

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