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.

1. The event-by-event average p_T distribution is not a Gaussian, it's 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:

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

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 M_{p_T} is defined as:

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

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 (NBD) distributed event-by-event multiplicity, with Gamma distributed semi-inclusive p_T spectra. [1] The formula depends on the 4 semi-inclusive

‡ For the full PHENIX Collaboration author list and acknowledgments, see Appendix "Collaborations" of this volume.

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, $\langle p_T \rangle$, σ_{p_T}:

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

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

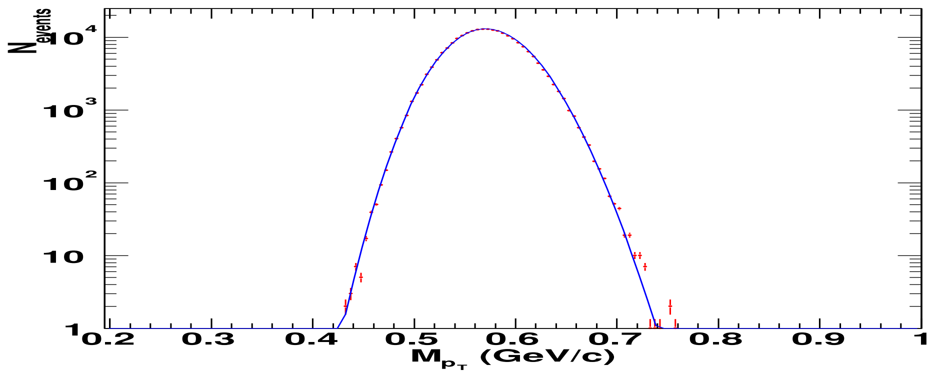

Figure 1. PHENIX mixed-event distribution for the 0-5% centrality class (data points) compared to equation 3 (curve).

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 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 $\sqrt{s_{NN}} =$ 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 percent difference of the standard deviations of M_{p_T} for the data and the mixed-event (random) sample:

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

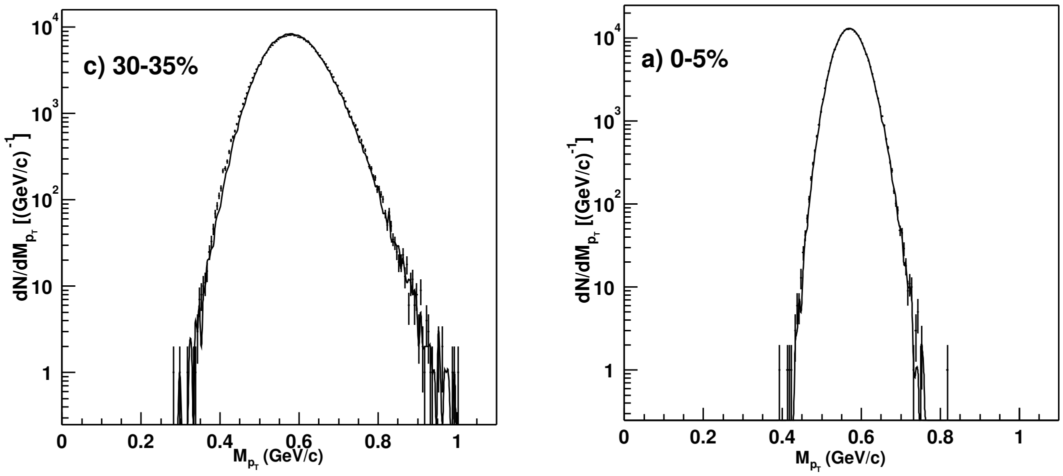

Figure 2. M_{p_T} for 30-35% and 0-5% centrality classes: data (points) mixed-events (histogram).

The results are shown as a function of centrality represented by N_{part} in Figure 3 compared to the previous PHENIX measurement at $\sqrt{s_{NN}} = 130$ GeV. [2] The errors

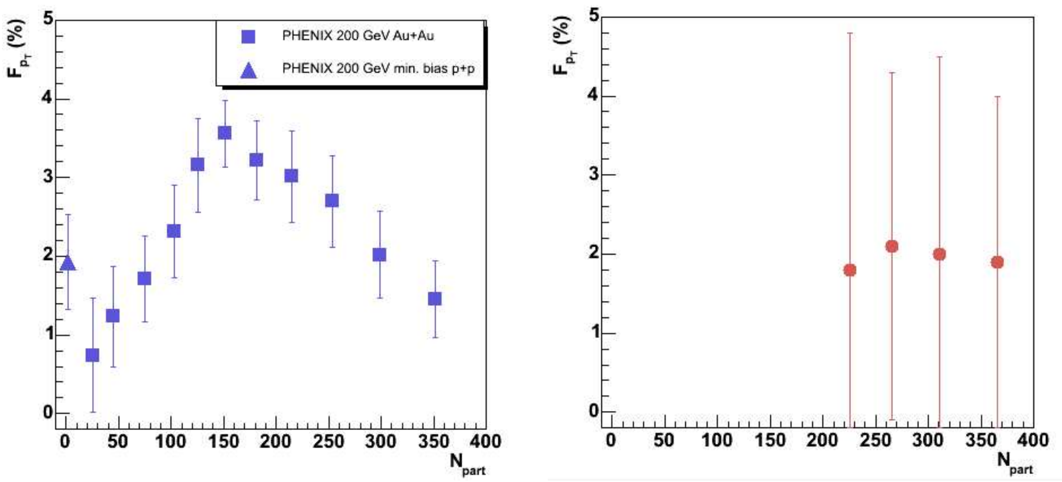

Figure 3. F_{p_T} in % :(left) Au+Au, p+p, $\sqrt{s_{NN}} = 200$ GeV, (right) Au+Au 130 GeV

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 10 independent subsets of the data. The improvement over the $\sqrt{s_{NN}} = 130$ GeV data is due to 3 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 $\leq p_T \leq p_T^{\max}$ (Figure 4), where $p_T^{\max} = 2.0$ 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

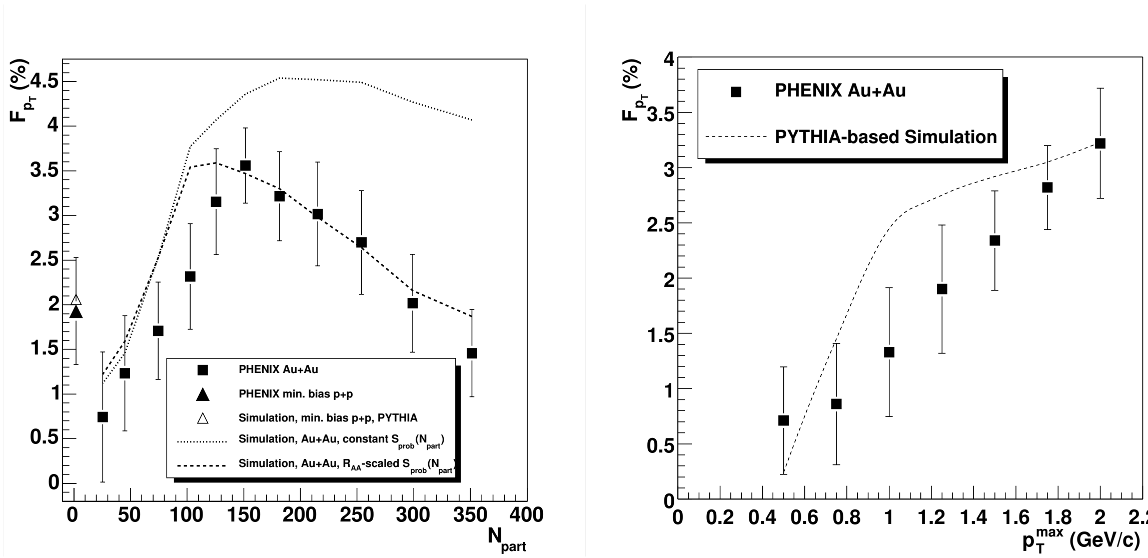

Figure 4. F_{p_T} vs centrality and $p_T^{\max}$ compared to simulations.

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, $S_{prob}(N_{part})$] p-p hard-scattering events from the PYTHIA event generator into simulated 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% . $S_{prob}(N_{part})$ was either constant for all centrality classes, or scaled by the measured hard-scattering suppression factor $R_{AA}(N_{part})$ 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 $S_{prob}(N_{part})$ was chosen so that the simulation with $S_{prob}(N_{part}) \times R_{AA}(N_{part})$ agreed with the data at $N_{part} = 182$. 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]

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

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.

References

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