# Transverse momentum fluctuations in event-by-event viscous hydrodynamics

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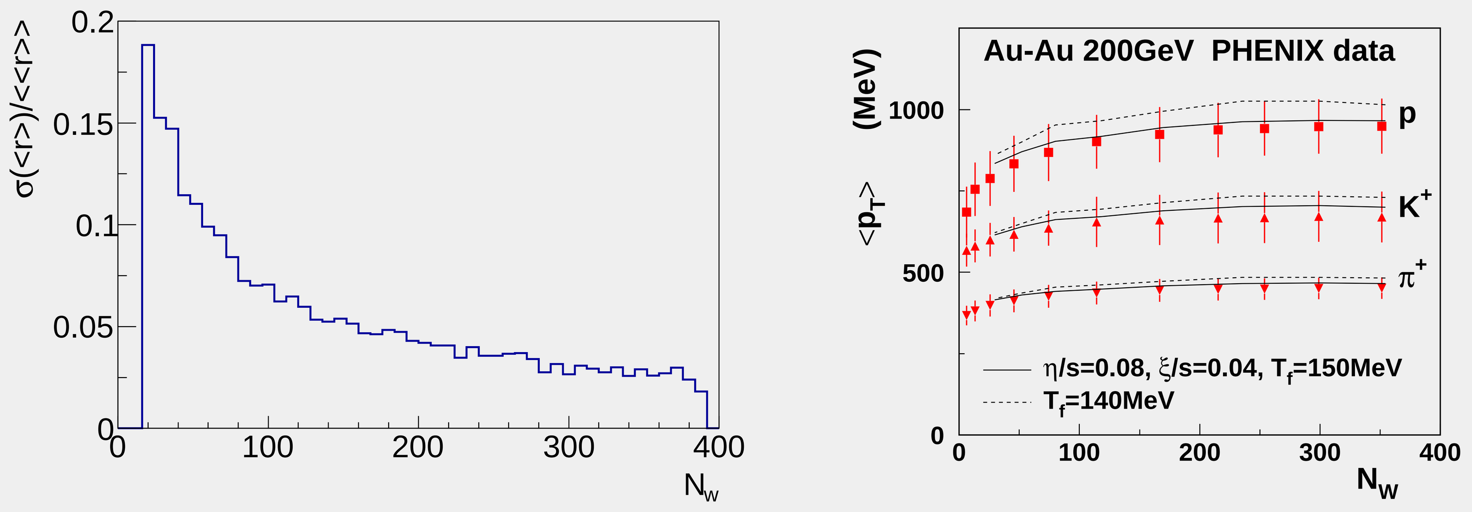
## Abstract

Event-by-event fluctuations of the transverse momentum in relativistic heavy-ion collisions at $\sqrt{s_{NN}} = 200$ GeV are shown to be determined by fluctuations of the size of the initial fireball. Fluctuating Glauber-model initial conditions are evolved using event-by-event $(3+1)$-dimensional viscous hydrodynamics. The scaled fluctuations $\langle \Delta p_{Ti} \Delta p_{Tj} \rangle^{1/2} / \langle\langle p_T \rangle\rangle$ that measure the dynamical fluctuations of the average transverse momentum are well reproduced by the model. The hydrodynamic response relating geometric fluctuations to transverse momentum fluctuations is not modified by core-corona effects, a change in the value of bulk or shear viscosity, freeze-out and numerical details.

## Initial conditions, hydrodynamics

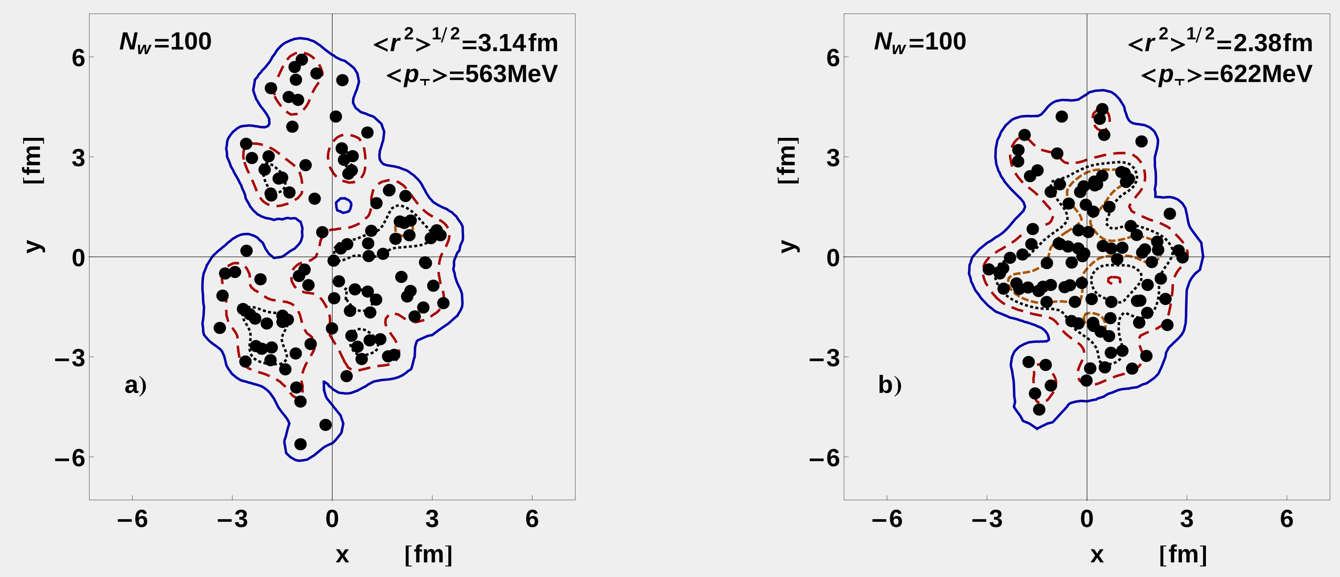
The Monte Carlo Glauber model predicts fluctuations of the shape as well as of the size of the initial fireball. Shape fluctuations are know to be related to the harmonic coefficients of the flow of produced particles [1]. A similar mechanism has been proposed [2], relating the fluctuations of the size of the fireball in the transverse plane to fluctuations of the average transverse momentum.




The expansion of the source is simulated using a $(3+1)$-dimensional viscous hydrodynamic model [3] with shear and bulk viscosities. Simulations are performed event-by-event using sets of initial conditions generated via the Glauber Monte Carlo model. The relative fluctuations of the transverse size of the fireball range from $3\%$ for central to $6\%$ for semi-peripheral collisions (left panel above). The calculation reproduces well the average transverse momentum (right panel above) and the elliptic flow.

## Initial size ↔ average $p_T$

The size of the fireball in the transverse plane fluctuates. In events where the source is "squeezed" (right panel) the acceleration is stronger, and a larger transverse flow is generated; the expansion of a "swollen" source (left panel) gives a smaller transverse flow.




The final transverse momentum is anticorrelated with the initial r.m.s. radius. The deformations of the shape of the initial density are at the origin of non-zero harmonic coefficients of the flow of emitted particles.

## References

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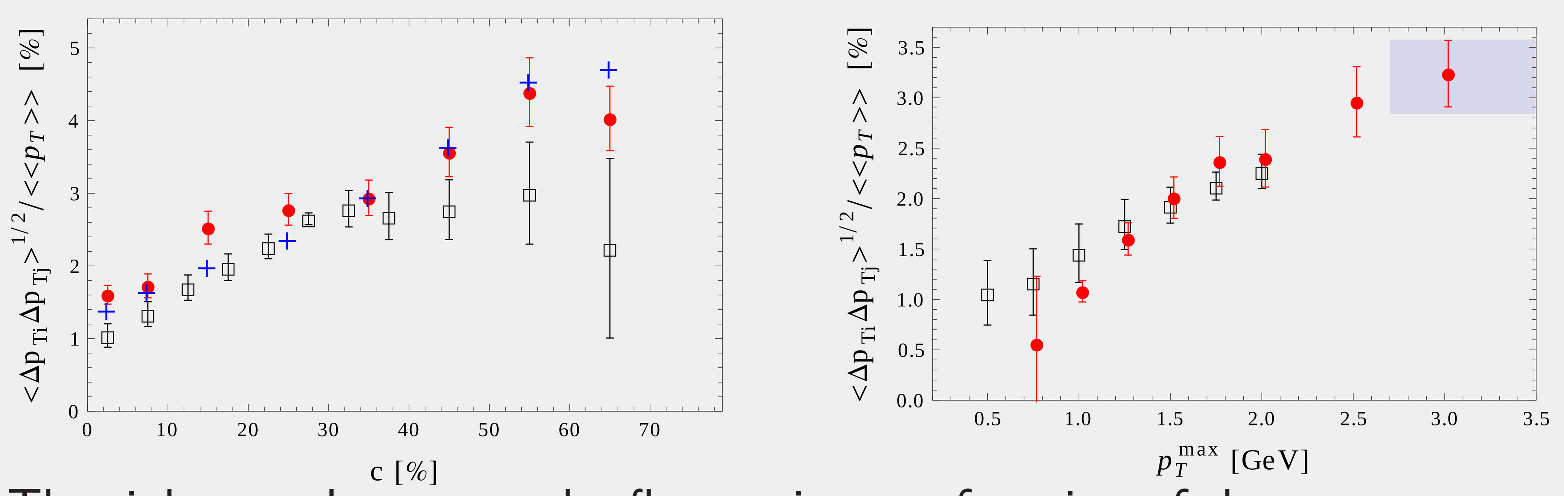
## $p_T$ fluctuations

We are interested in dynamical fluctuations related to fluctuations of the flow in each event. Experimental measures of the transverse flow fluctuations

$$\langle \Delta p_{Ti} \Delta p_{Tj} \rangle \equiv \frac{1}{N_{ev}} \sum_{k=1}^{N_{ev}} \frac{C_k}{N_k(N_k-1)}$$

$$C_k = \sum_{i=1}^{N_k} \sum_{j=1, j\neq i}^{N_k} (p_i - \langle\langle p \rangle\rangle)(p_j - \langle\langle p \rangle\rangle)$$

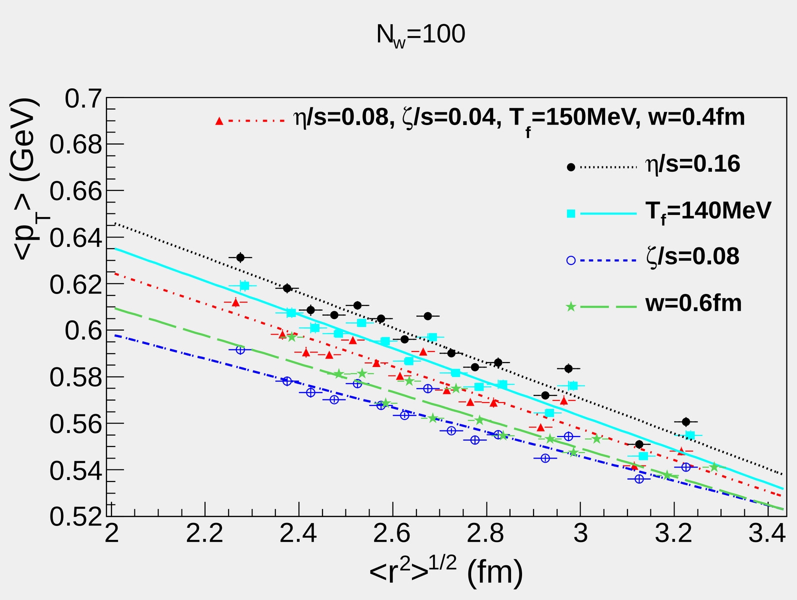
get rid of statistical fluctuations. The definition assures that for an uncorrelated emission of particles the scaled fluctuations vanish. In the hydrodynamic model the fluctuations are generated as fluctuations of the collective transverse flow, whereas the fluctuations of the collective flow originate from variations of the expansion rate for fireballs of different sizes. Event by event simulations of Au-Au collisions at $200$GeV are performed. The resulting fluctuations of the transverse momentum are similar as observed by PHENIX and STAR [5,6] (left panel).




The right panel presents the fluctuations as function of the upper transverse momentum cut-off. It shows that the observed increase of the fluctuations with $p_T$ can be explained by hydrodynamics. Effects of minijets on $p_T$ fluctuations could be observed only above $3$GeV, where the hydrodynamic contribution saturates (shaded band in the right panel).

## Hydrodynamic response

We have checked that the scaled $p_T$ fluctuations do not depend on the details of the model : the freeze-out temperature, the value of bulk and shear viscosity coefficients, the width of the Gaussian function representing the contribution of each participant nucleon to the fireball density, core-corona effects, the way the centrality classes are defined.




The figure shows that when changing the parameters of the model the average transverse momentum $\langle p_T \rangle$ and its dispersion $\Delta \langle p_T \rangle$ change but the scaled fluctuations $\Delta \langle p_T \rangle / \langle p_T \rangle$ do not change.

The hydrodynamic response of $p_T$ fluctuations to size fluctuations takes the form

$$\frac{\Delta \langle p_T \rangle}{\langle p_T \rangle} = 0.3 \frac{\Delta \langle r \rangle}{\langle r \rangle}$$

The value of the coefficient $0.3$ is related to the equation of state of the expanding matter [7].

## Conclusions

We demonstrate using event by event hydrodynamic calculations that the scaled fluctuations of the transverse momentum originate from geometric fluctuations of the size of the initial fireball. We reproduce the centrality and upper transverse momentum dependence of the experimental measure of the dynamical fluctuations of the average transverse momentum.