The QCD Critical Point: Are We There Yet?

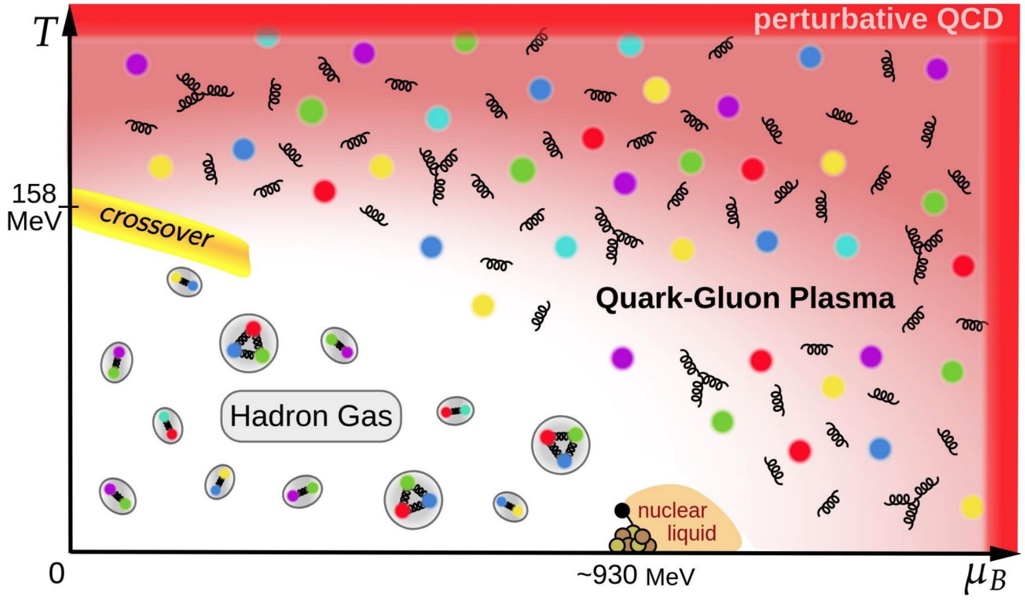
INT Workshop
Lower Order fluctuations
(EXP)

Motivation

- Correlations of transverse momentum, p_T, have been proposed as a measure of thermalization and as a probe for the critical point of quantum chromodynamics (QCD). (STAR, Phys.Rev.C 99 (2019) 4, 044918)

- It is important to note, that observation of a large magnitude of fluctuations would not by itself constitute the signal of the critical point.

- There are many possible contributions to the fluctuations, which are difficult to estimate. The distinct signature of the critical point is the non-monotonous behavior of fluctuation observables. (M. Stephanov,2005 J. Phys.Conf. Ser. 27 144)



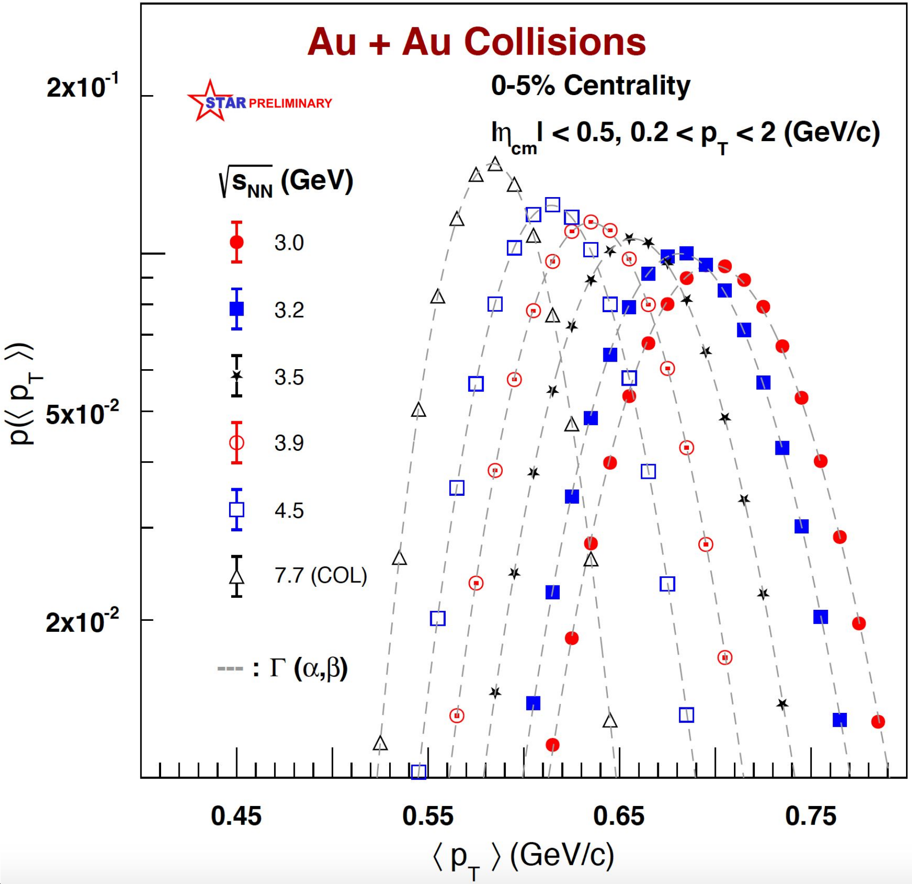
STAR, Phys.Rev.C 99, 2019
CERES, Nucl.Phys.A811:179-196,2008
ALICE, Eur. Phys. J. C 74, 2014

Distribution of Mean Transverse Momentum

- ❖ Decrease of mean to lower collision energies.
- ❖ Increase in width of distribution to lower collision energies.
- ❖ Well described by Gamma distributions.

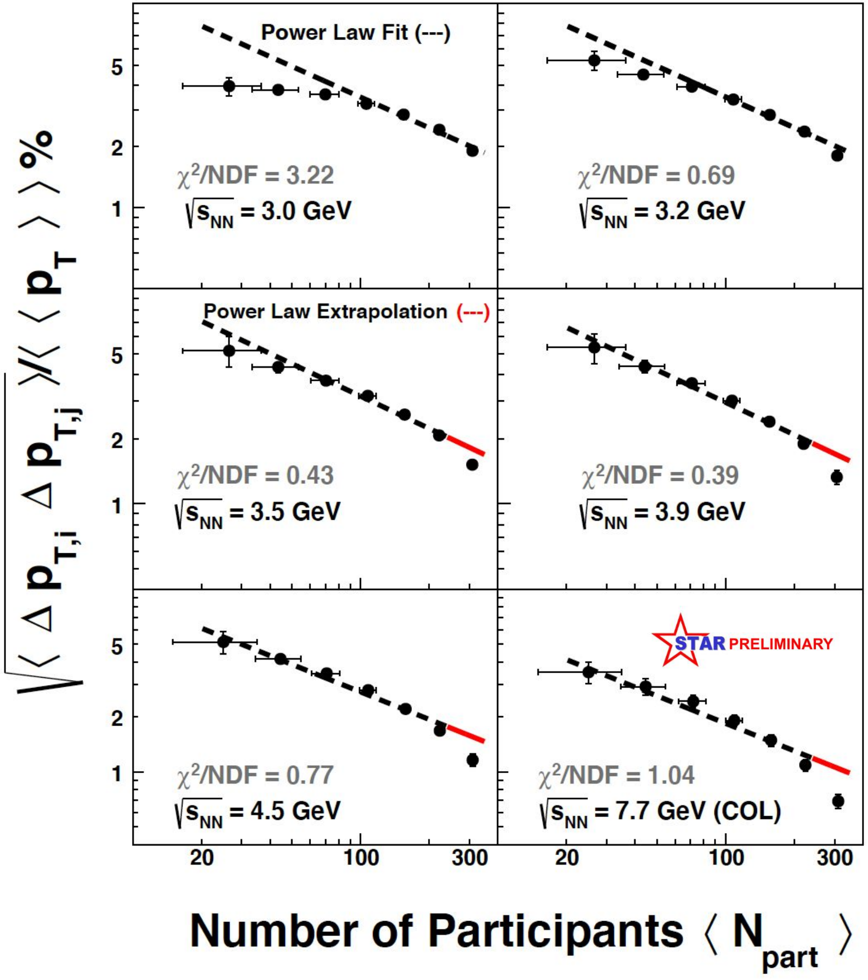
M.J.Tannenbaum Phys.Lett.B 498, 2001

- ❖ Well behaved with collision energy



Correlator Vs Centrality

- If particles are produced via clusters and the relative contribution of such clusters remains constant across centrality intervals, the magnitude of fluctuations should scale inversely with the number of clusters and thus with multiplicity (N_{part}).
- Black dashed lines represent a power law fit given by :$\mathbf{A(\sqrt{s_{NN}})*1/(N_{part})^{0.5}}$, upto N_{part} ~ 240
- Red dashed line is an extrapolation to show deviation from IS behaviour.
- Deviations from this scaling behavior may signal the onset of collective effects, such as a phase transition, or critical phenomena that depend on particle density.



Correlator Vs Collision Energy (Snn)

- First Non-monotonous dependence of pt-pt correlators as a function of collision energy

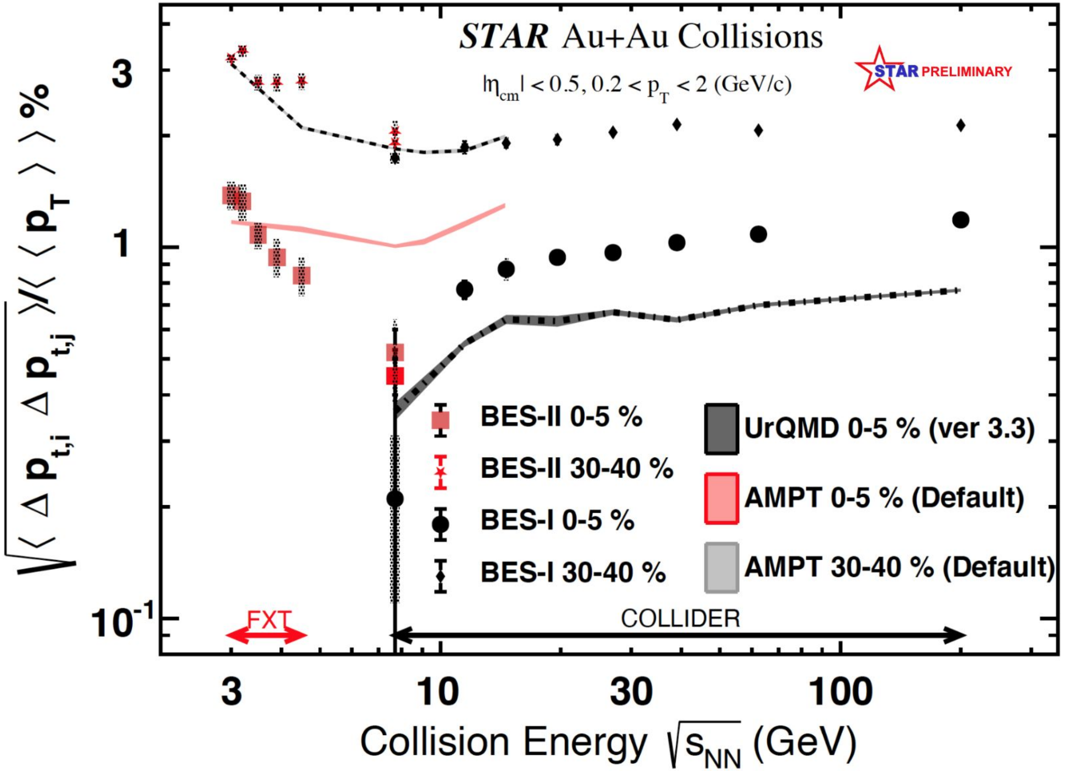
- Transverse momentum fluctuations should be sensitive to temperature and energy fluctuations.

  L. Stodolsky, Temperature fluctuations in multiparticle production, Phys. Rev. Lett. 75, 1044

- These in turn provide a measure of the heat capacity of the system. Since the QCD phase transition is associated with a maximum of the specific heat, the temperature fluctuations should exhibit a minimum in the excitation function.

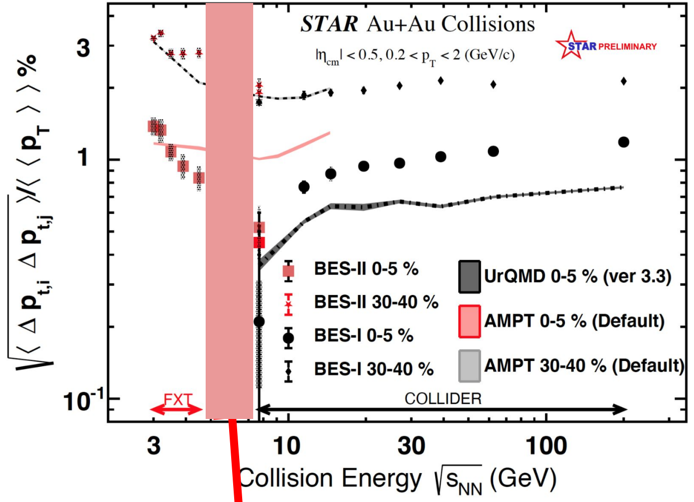
  E. Shuryak, Event-by-event analysis of heavy ion collisions and thermodynamical fluctuations, Physics Letters B 423, 9–14 (1998)

- The significance of non-monotonicity was quantified and found to be **6.6 sigma** for STAR 0-5% centrality and **1.2 sigma** for AMPT 0-5%

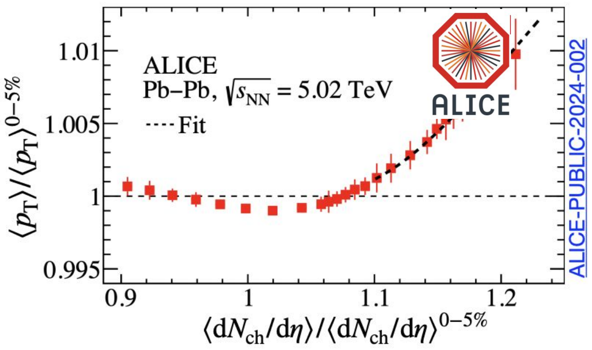


Conclusions

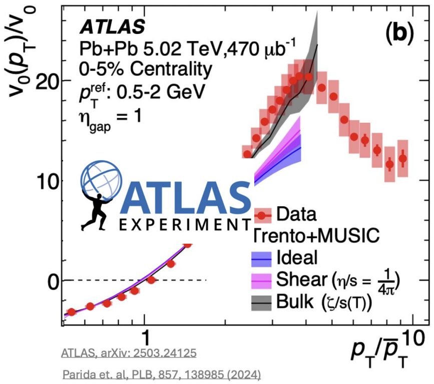
- Non-Monotonic observation of p_T-p_T correlators in central collisions.
- Possibly narrow down/converge on an energy range for CP in accordance with various other theoretical estimates.
- Multiple collaborations investigating transverse momentum dynamics.

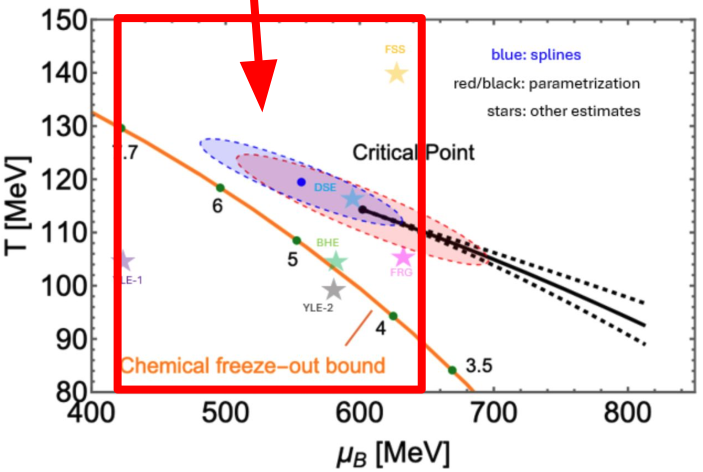


Extract speed of sound of medium



Extract bulk viscosity of medium



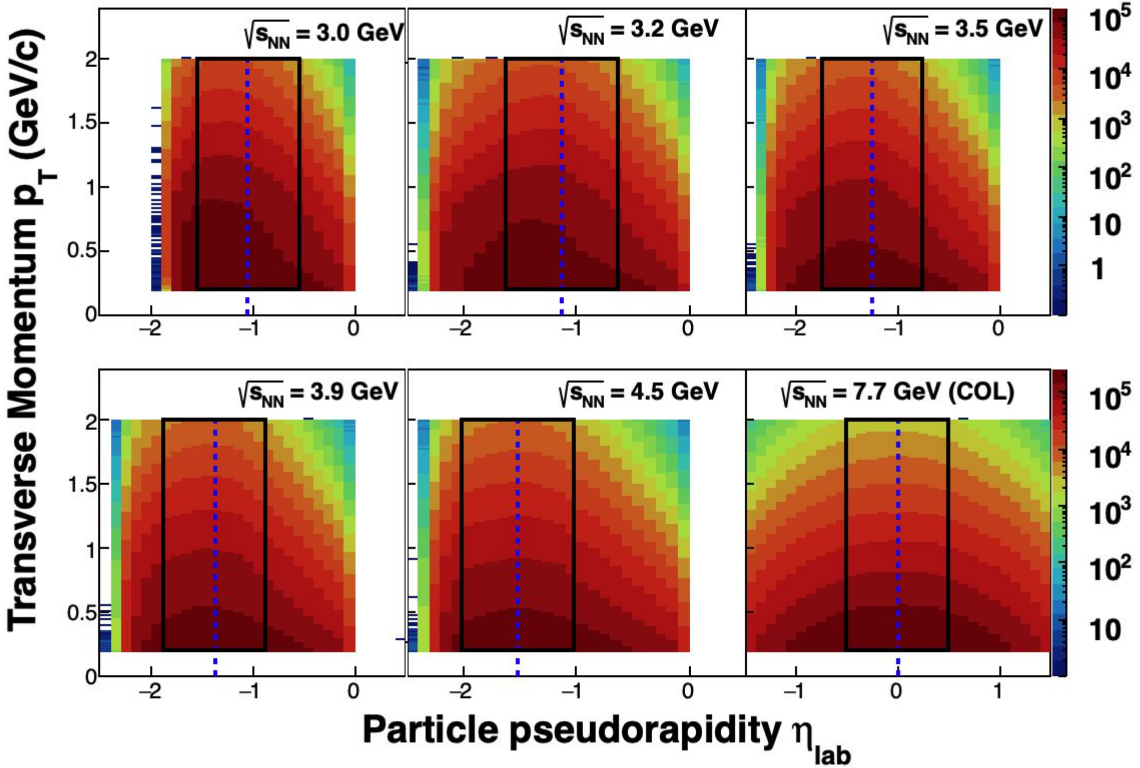


BACKUP

2 particle correlator

All charged particle within a common acceptance window

- p_T : [0.2,2.0] GeV/c
- η_{com} : [-0.5,0.5]
- $\eta_{com} = \eta_{lab} - \eta_{mid}$
- Mid pseudorapidity (dashed blue lines):

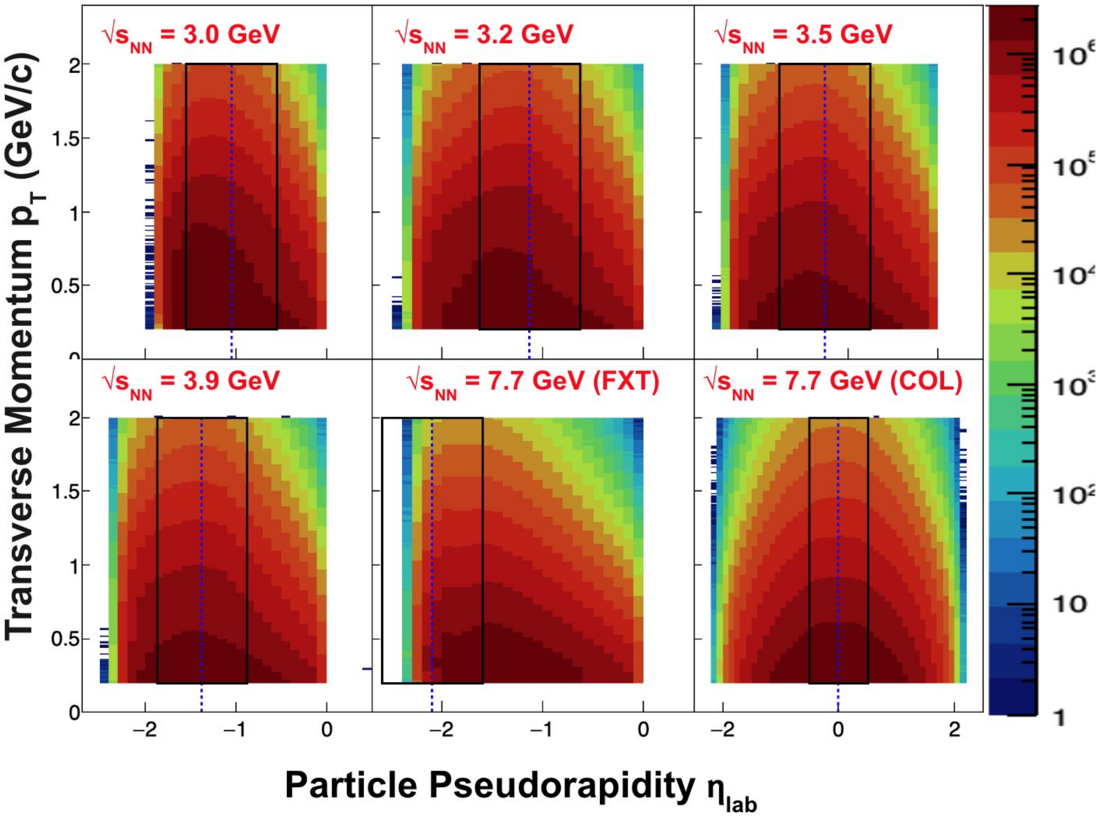


$$C_m = \langle \Delta p_{t,i} , \Delta p_{t,j} \rangle$$

$$\langle (p_{t,i} - \langle p_t \rangle)(p_{t,j} - \langle p_t \rangle) \rangle$$

$$i \neq j$$

Kinematic Acceptances



1. We select particles for the measurements within the black box:
   a. $-0.5<\boldsymbol{\eta}_{com}<0.5$
   b. p_T :[0.2,2.0]
2. Midrapidity is shown in blue dashed lines
3. Only TPC used

Cross Check

To understand if the frame of reference affects our measurements, we did a study in UrQMD (ver. 3.4) Collider mode (COM frame) and Fixed Target mode (Lab frame) @ $\sqrt{s_{NN}}$ = 7.7 GeV

Boosting to lab frame

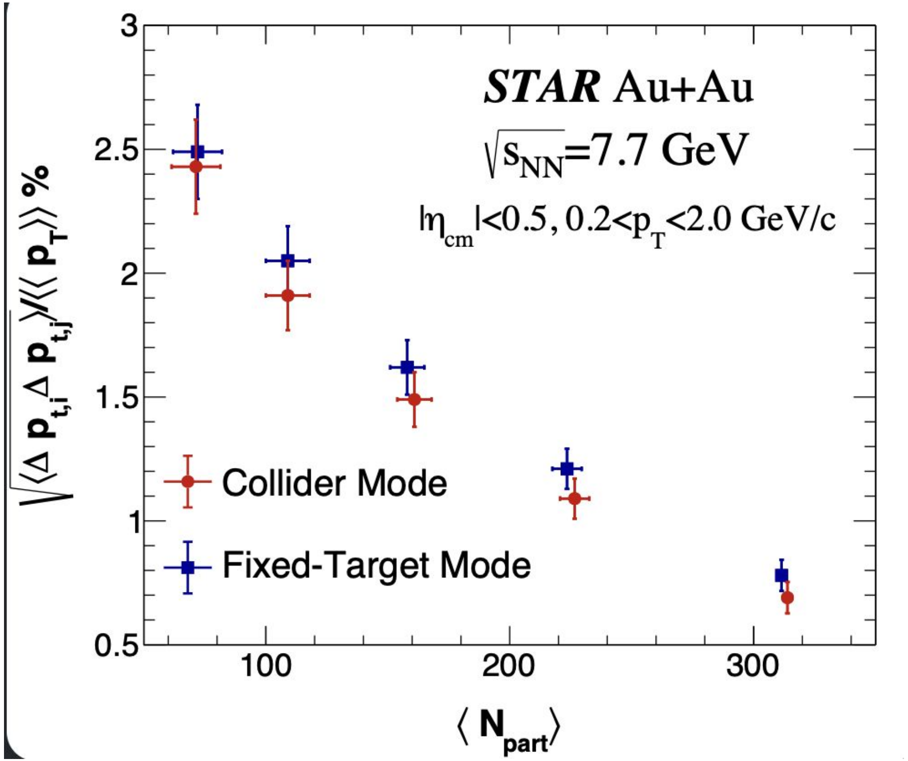
UrQMD data is generated in collider mode (COM),to mimic Lab frame we boost each particle.

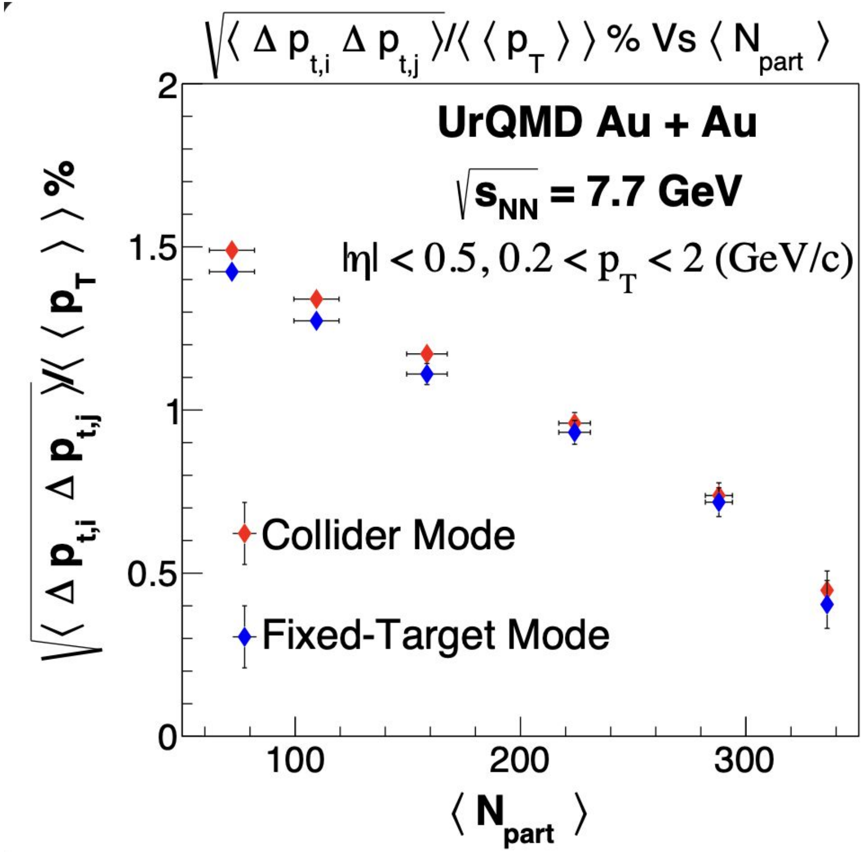
Rapidity is additive hence we boost in rapidity and then perform the respective pseudorapidity cuts, this way we mimic fixed target setup.

- Boosting of COM frame:
  - $y_{lab} = y + y_{mid}$
  - $y_{mid} = -2.1$
  - Calculate eta from y and then apply cut

$$\eta = \frac{1}{2} ln \left[\frac{\sqrt{m_T^2 \ cosh^2 \ y - m^2} + m_T \ sinh \ y}{\sqrt{m_T^2 \ cosh^2 \ y - m^2} - m_T \ sinh \ y} \right]$$

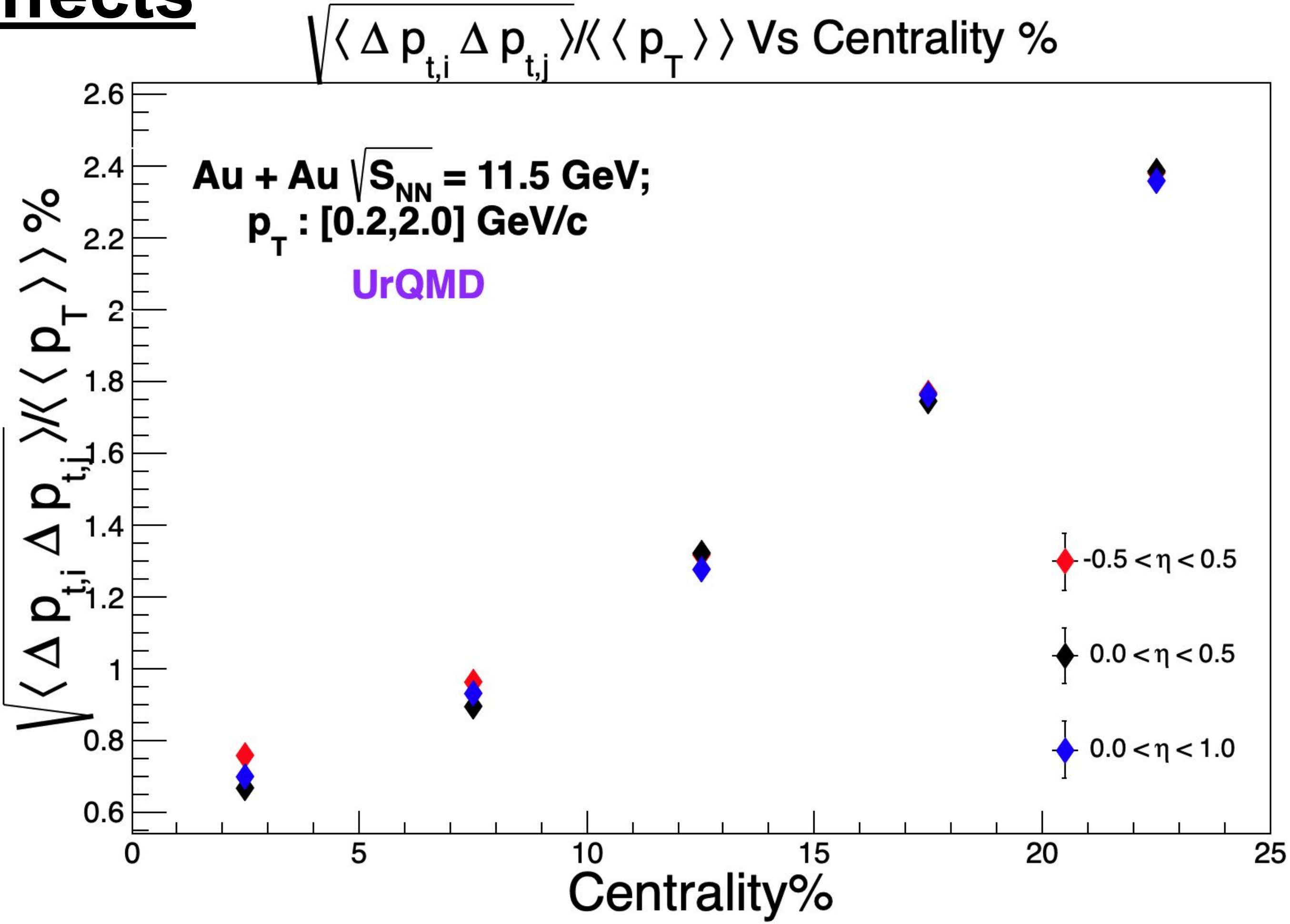
Frame of measurement





Acceptance effects

Asymmetric, half and standard are same within uncertainties.

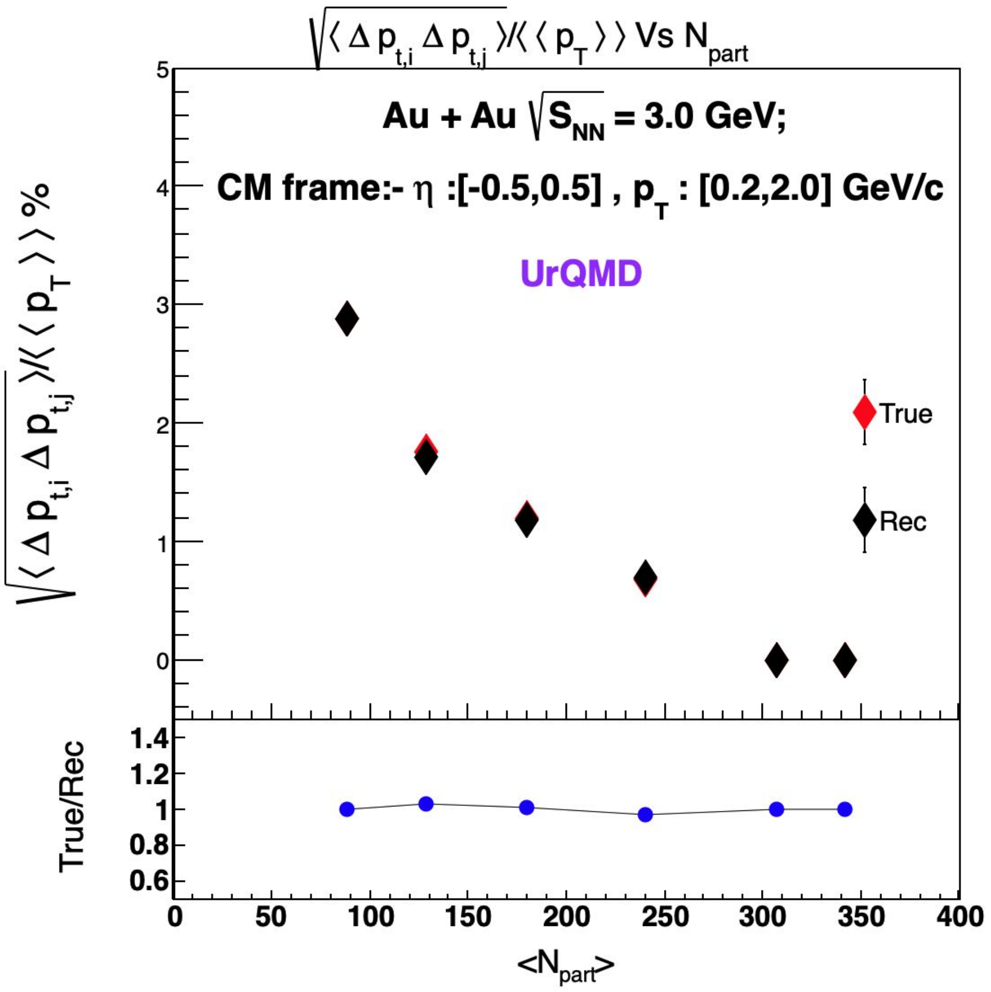


Efficiency effects

Reconstructed Analysis:

1. In UrQMD, we know p_T and η of the particle, calculate corresponding efficiency from curves ($\varepsilon(p_T,\eta)$) .
2. Randomly generate a value between [0,1] (r) for the particle.
3. If $r < \varepsilon$ keep the particle, else discard it.

On an average we simulate the detector effects.



Flow Effects

Collective flow builds as more of the particles encountered by the test particle are moving radially outward. We expect this effect to be most important in central collisions, since the system lives longer and particles have more time to interact.

$$\langle p_t \rangle_e \propto \left(\frac{1+v}{1-v}\right)^{1/2} \qquad \text{and} \qquad \langle \delta p_{t1} \delta p_{t2} \rangle_e \propto \left(\frac{1+v}{1-v}\right).$$

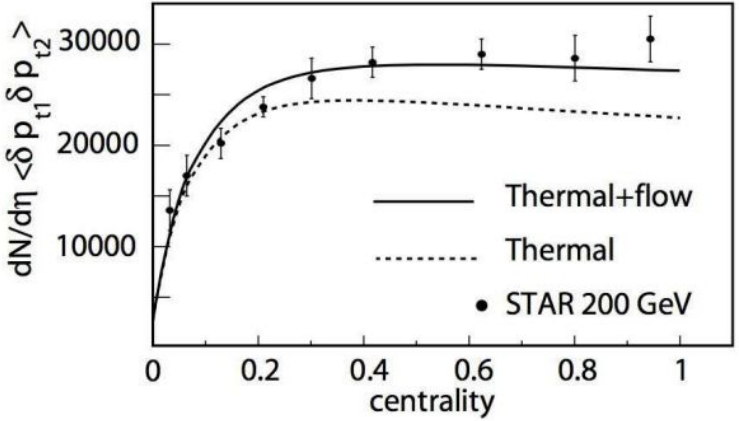


Figure 3. Centrality dependence of p_t fluctuations with radial flow included.

Ref: Probing quark gluon liquid using transverse momentum fluctuations - Sean Gavin, Abdel-Aziz

https://arxiv.org/pdf/nucl-th/0510011

Correlator Vs Centrality (ALICE)

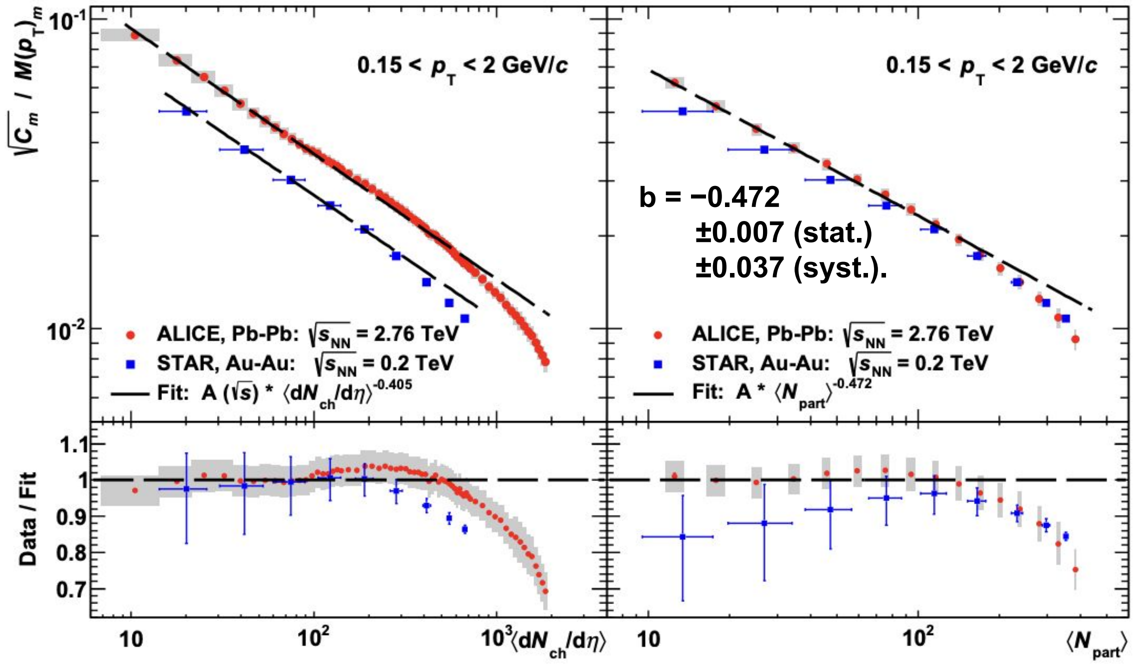


Fig. 7: Left: Relative dynamical fluctuation $\sqrt{C_m}/M(p_\mathrm{T})_m$ as a function of $\langle \mathrm{d}N_\mathrm{ch}/\mathrm{d}\eta \rangle$ in Pb–Pb collisions at $\sqrt{s_\mathrm{NN}} = 2.76$ TeV from ALICE compared to results from STAR in Au–Au collisions at $\sqrt{s_\mathrm{NN}} = 200$ GeV [18]. Also shown as dashed lines are results from power-law fits to the data (see text). Right: same data as a function of $\langle N_\mathrm{part} \rangle$.