Dynamical higher cumulant ratios of net and total proton at STAR

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- STAR detector and data sample
- Results and discussions
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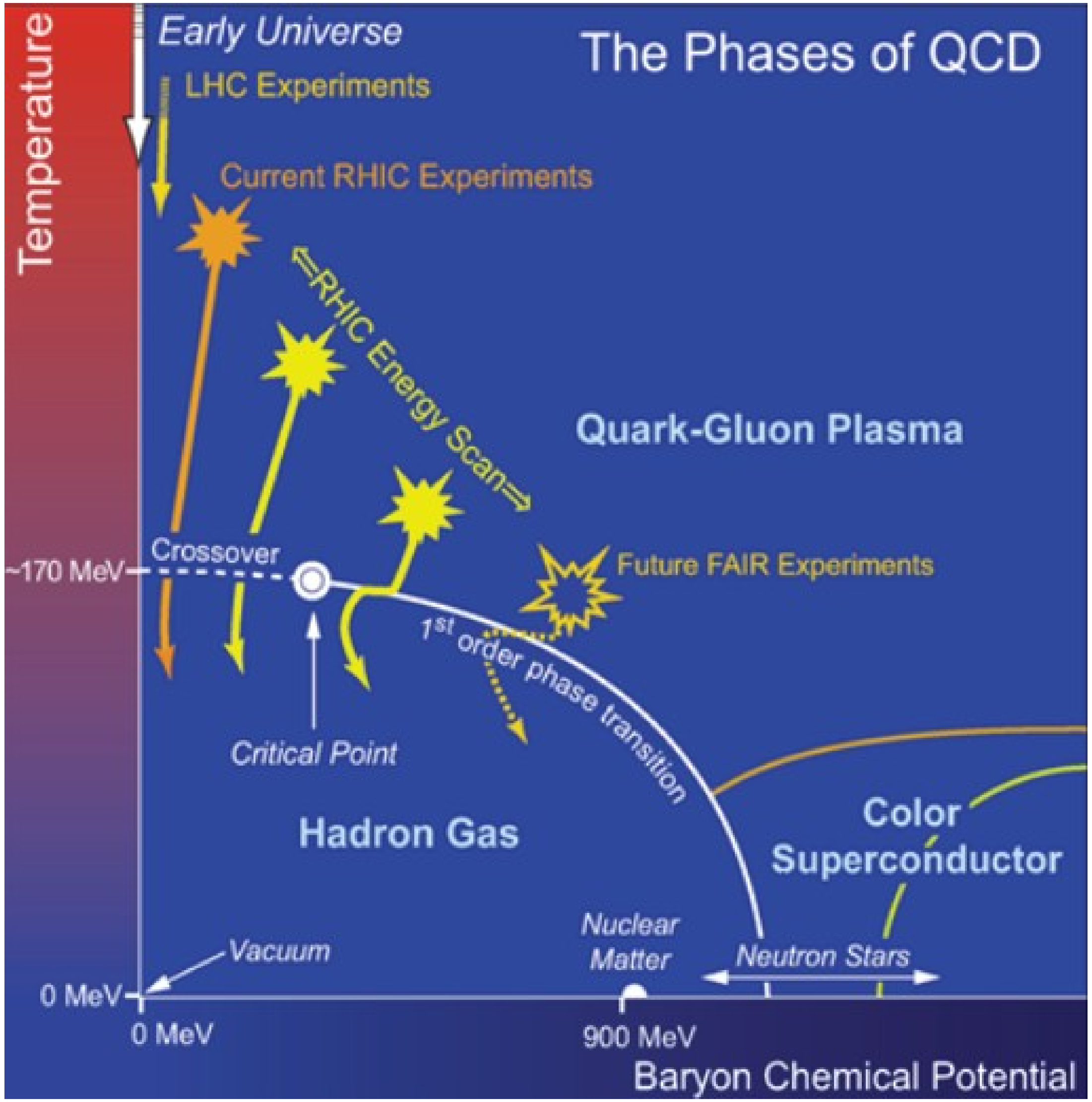
Motivation



◆ At $\mu_B = 0$, lattice QCD predict a crossover transition.

Y. Aoki et al., Nature 443, 675 (2006).

◆ QCD-based models indicate a first-order phase transition at large μ_B .

S. Ejiri et al., Phy. Rev. D 78, 074507 (2008).

◆ QCD critical point (QCP): The end point of the first-order phase transition boundary.

M. Stephanov, Prog. Theor. Phys. Suppl. 153, 139 (2004).
Z. Fodor et al., J. High Energy Phys. 050 (2004).

Experimental exploring:

RHIC Beam Energy Scan Program to search for the signatures of the QCP.

M. Aggarwal et al. (STAR Coll.), arXiv: 1007.2613.

Measurement

◆ Sensitive observables of critical fluctuations: Higher cumulants of baryon distribution

Standard deviation: $\sigma = \sqrt{\left\langle \left(N - \langle N \rangle \right)^2 \right\rangle}$

M. Stephanov, Phys. Rev. Lett. 102, 032301 (2009).
C. Athanasiou et al. Phys. Rev. D 82, 074008 (2010).

Kurtosis: $\kappa = \frac{\left\langle \left(N - \langle N \rangle \right)^4 \right\rangle}{\sigma^4} - 3$

N: the net or total proton number in an event

$\langle \cdots \rangle$: the average over the event sample

◆ **Dynamical cumulant ratios**:

Dynamical kurtosis = measured kurtosis – Poisson statistical part

Lizhu Chen, et al., J. Phys. G: Nucl. Part. Phys. 38, 115004 (2011).
M. Stephanov, arXiv: 1104.1627; Phys. Rev. Lett. 107, 052301(2011).
C. Athanasiou, K. Rajagopal, and M. Stephanov, arXiv:1006.4636.

◆ Poisson statistical parts:

● For net-proton, the ratios of Skellam distribution:

$$\kappa_{stat} = \frac{1}{\langle N_p \rangle + \langle N_{\bar{p}} \rangle},$$

● For total-proton, the ratios of Poisson distribution:

$$\kappa_{stat} = \frac{1}{\langle N_p \rangle + \langle N_{\bar{p}} \rangle}$$

Expected critical behavior

By describing fluctuations of the order parameter field σ near the critical point, the calculations of the Sigma model predicts that:

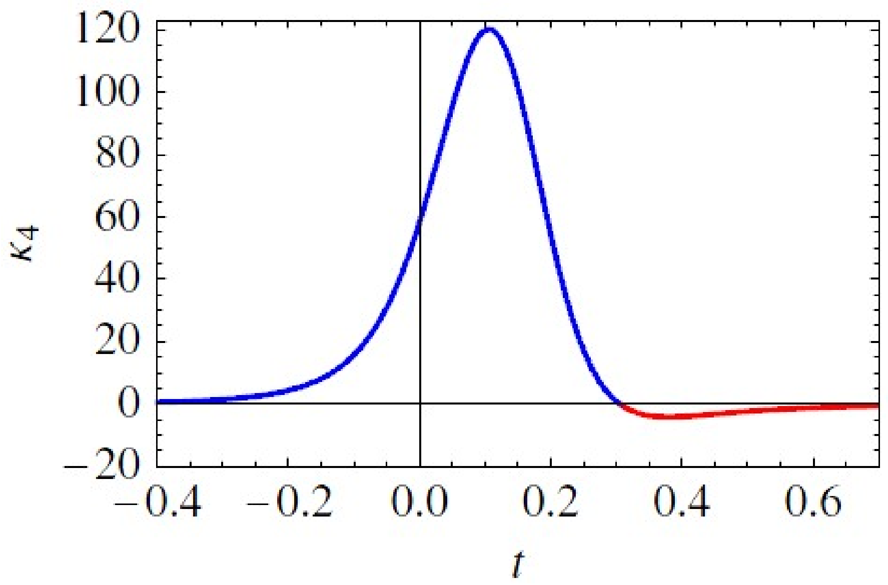
M. Stephanov, Phys. Rev. Lett. 107, 052301 (2011).
M. Stephanov, Phys. Rev. Lett. 102, 032301 (2009).

- Dynamical kurtosis is universally negative when the critical point is approached from the crossover side of the phase separation line.

critical contribution of the cumulant in the σ field

$$\langle(\delta N)^4\rangle_c = \langle N\rangle + \langle\sigma_V^4\rangle_c\left(\frac{gd}{T}\int_p \frac{n_p}{\gamma_p}\right)^4 + \cdots$$

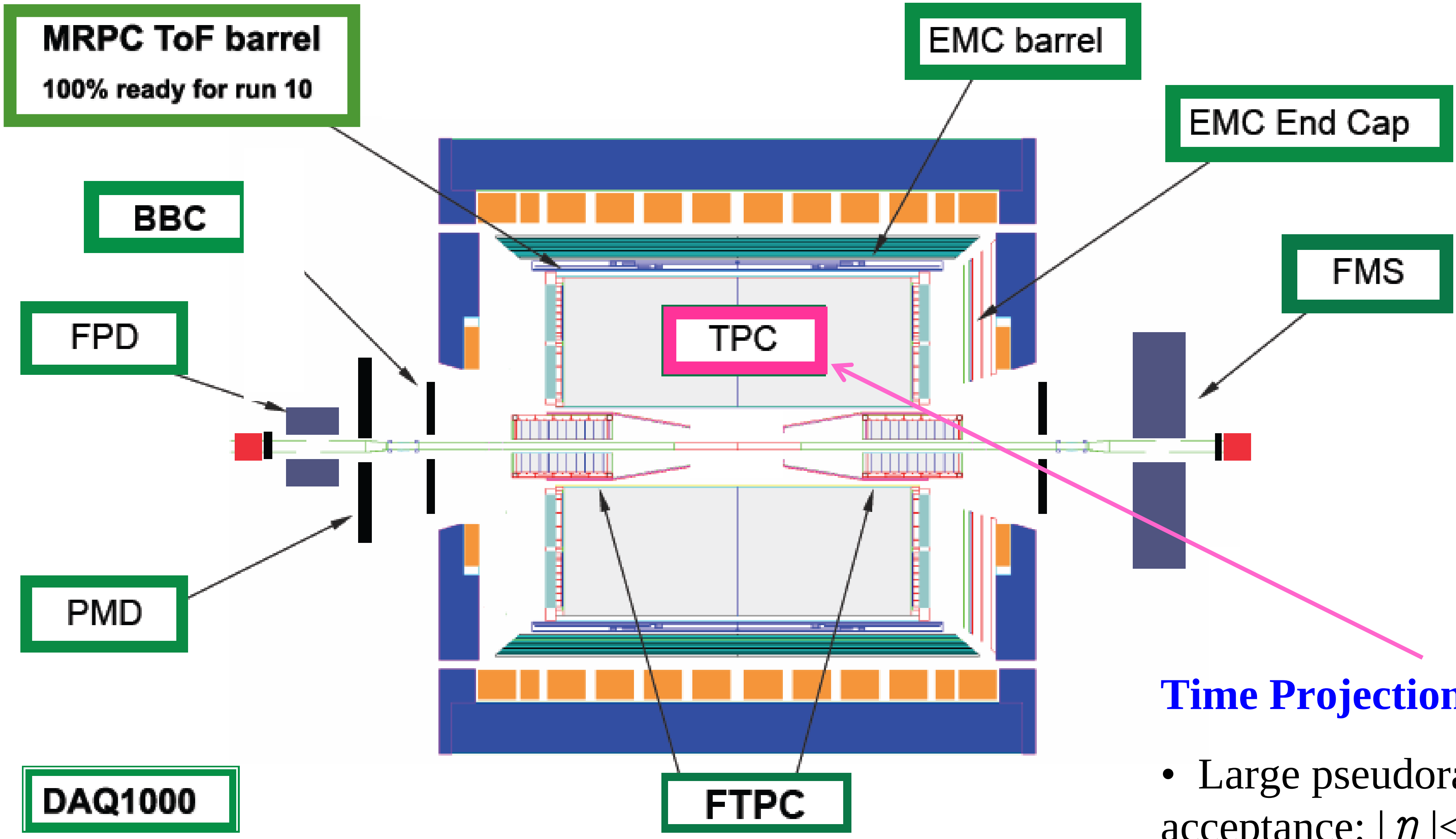
measured cumulant
Poisson contribution



- The negative kurtosis should be firstly observed in more peripheral collisions, and/or sign change at low incident energy.

$t = \frac{T - T_c}{T_c}$ is the reduced temperature

STAR detector



Full azimuthal particle identification!

Time Projection Chamber

- Large pseudorapidity acceptance: $|\eta|<1$
- PID: Ionization Energy Loss (dE/dx).

Data sample

Au+Au collisions from 7.7 to 200 GeV
at RHIC/BES of year 2010 and 2011

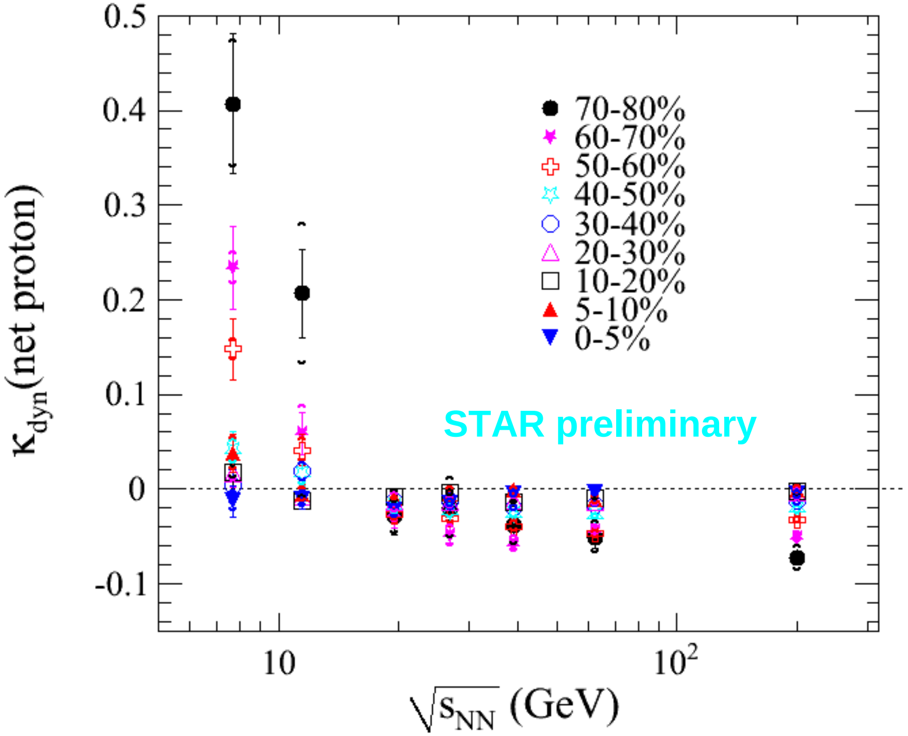
- Particle Identification with Time Projection Chamber:
  Protons/antiprotons are identified by ionization energy loss measured in
  $|y|<0.5$, $0.4<p_T<0.8$ GeV/c.
- Centrality definition:
  Use the multiplicity in $|\eta|<0.5$, but excluding the protons/antiprotons to avoid auto-correlations.
- Statistical error estimation:
  Delta theorem method

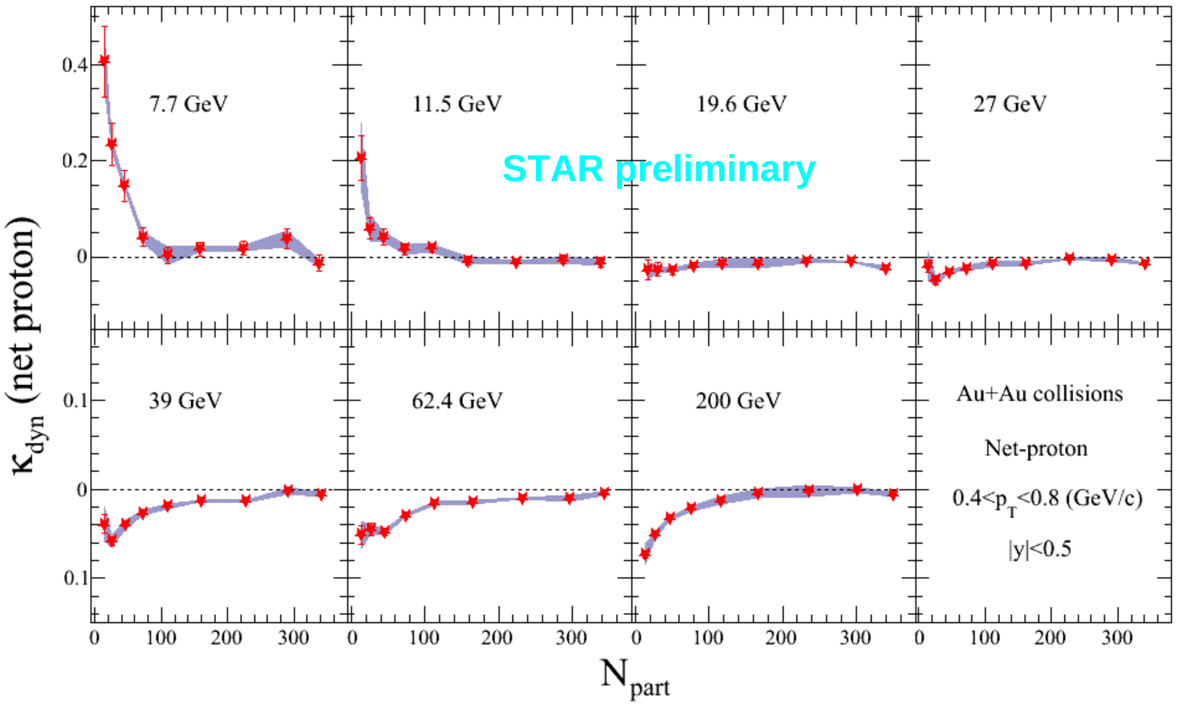
X. Luo, J. Phys. G 39, 025008 (2012) [arXiv: 1109.0593].

Used statistics

$\sqrt{s_{NN}}$ (GeV)	No. of Events (0-80%)
7.7	~2M
11.5	~7M
19.6	~15M
27	~30M
39	~87M
62.4	~47M
200	~242M

Results and discussions: Dynamical kurtosis of net-proton

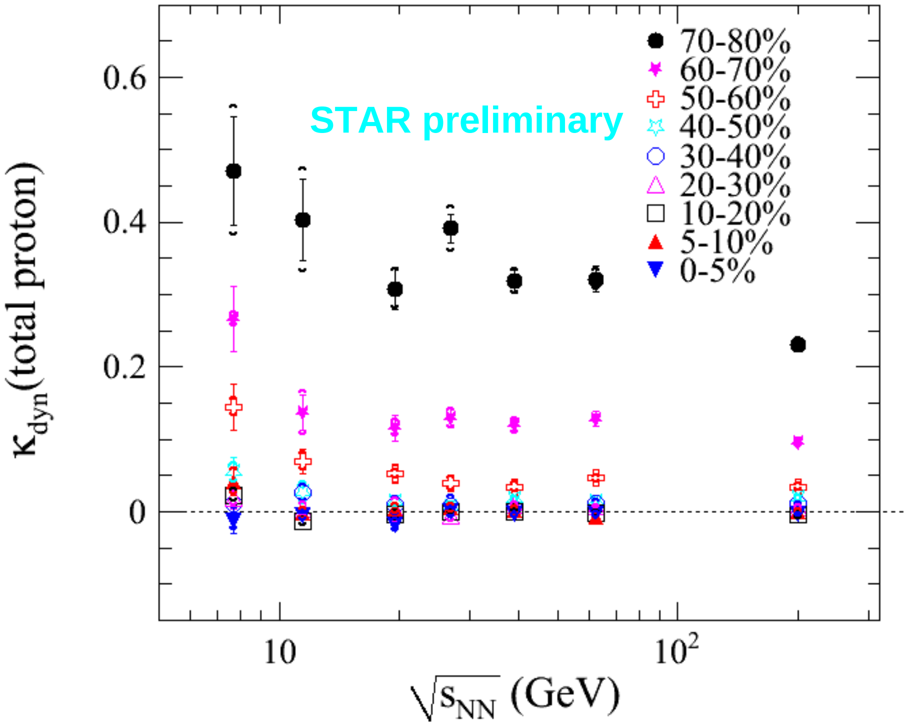


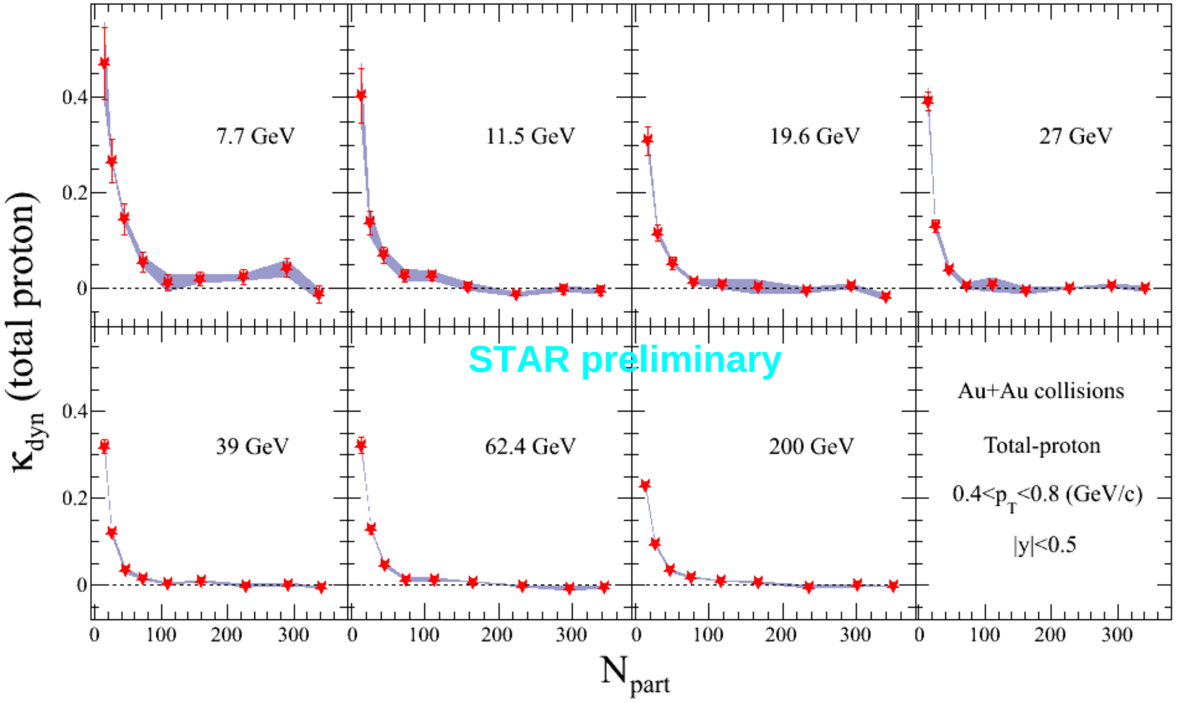


- Below 19.6 GeV, the dynamical kurtosis is positive in peripheral collisions, and increase towards more peripheral collisions.
- Above 19.6 GeV, the dynamical kurtosis turns to be negative in peripheral collisions.

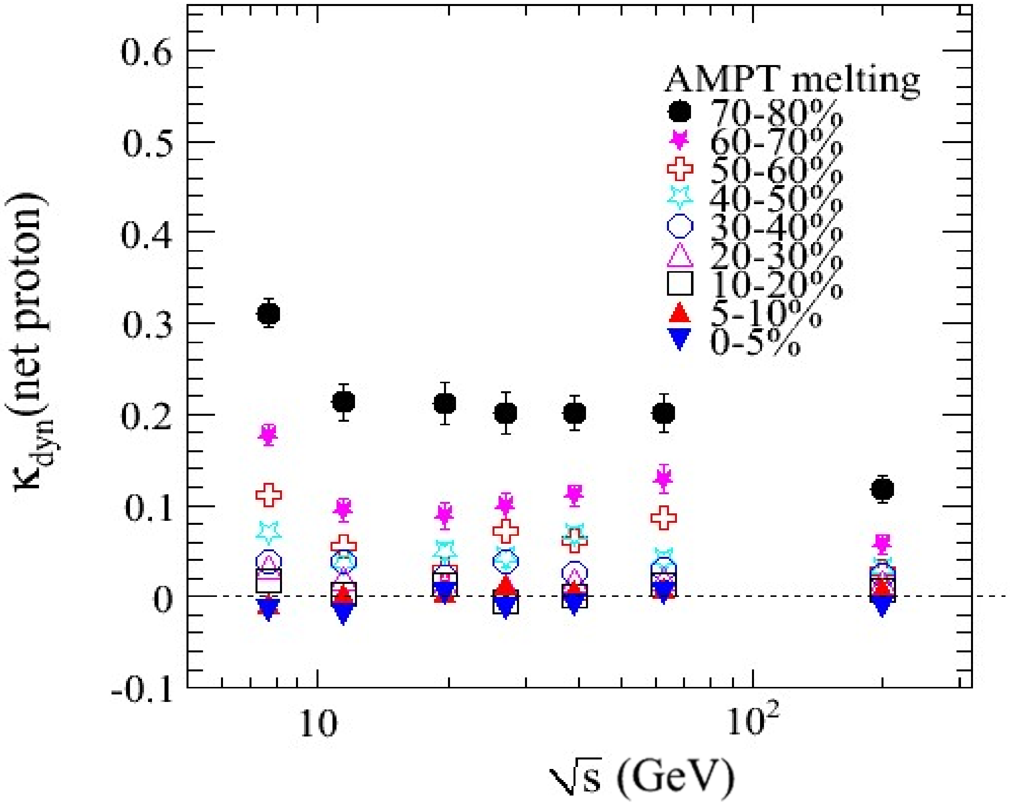
M. Stephanov, Phys. Rev. Lett. 107, 052301 (2011).

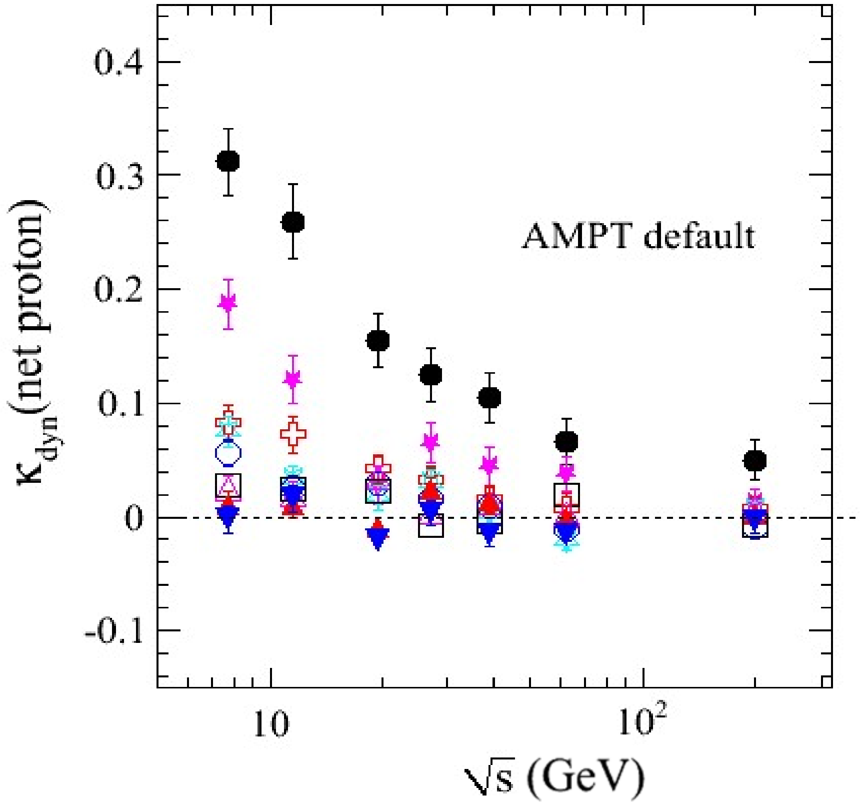
Results and discussions: Dynamical kurtosis of total-proton





- We observe a positive dynamical kurtosis for peripheral collisions at all energies.
- In central collisions, the dynamical kurtosis is around zero at all incident energies.
- In contrary to net-proton we do NOT observe a sign change for total-proton.





- The dynamical kurtosis is positive in non-central collisions at all incident energies.
- No sign change is observed for two settings of the AMPT model.

Summary

- In peripheral collisions, the sign of dynamical kurtosis of net-proton changes from negative to positive when incident energy decreases.
- In the contrary, the sign of dynamical kurtosis of total-proton in peripheral collisions keeps positive at all incident energies.
- From AMPT model calculations where no critical behavior is included, the dynamic kurtosis for net-proton is found to be positive in non-central collisions for all energies.

Thank you!