

# Measurement of Off-diagonal cumulants between net-proton and net-kaon multiplicity distributions in STAR

Changfeng Li

(For the STAR Collaboration)

Shandong University, Qingdao, China

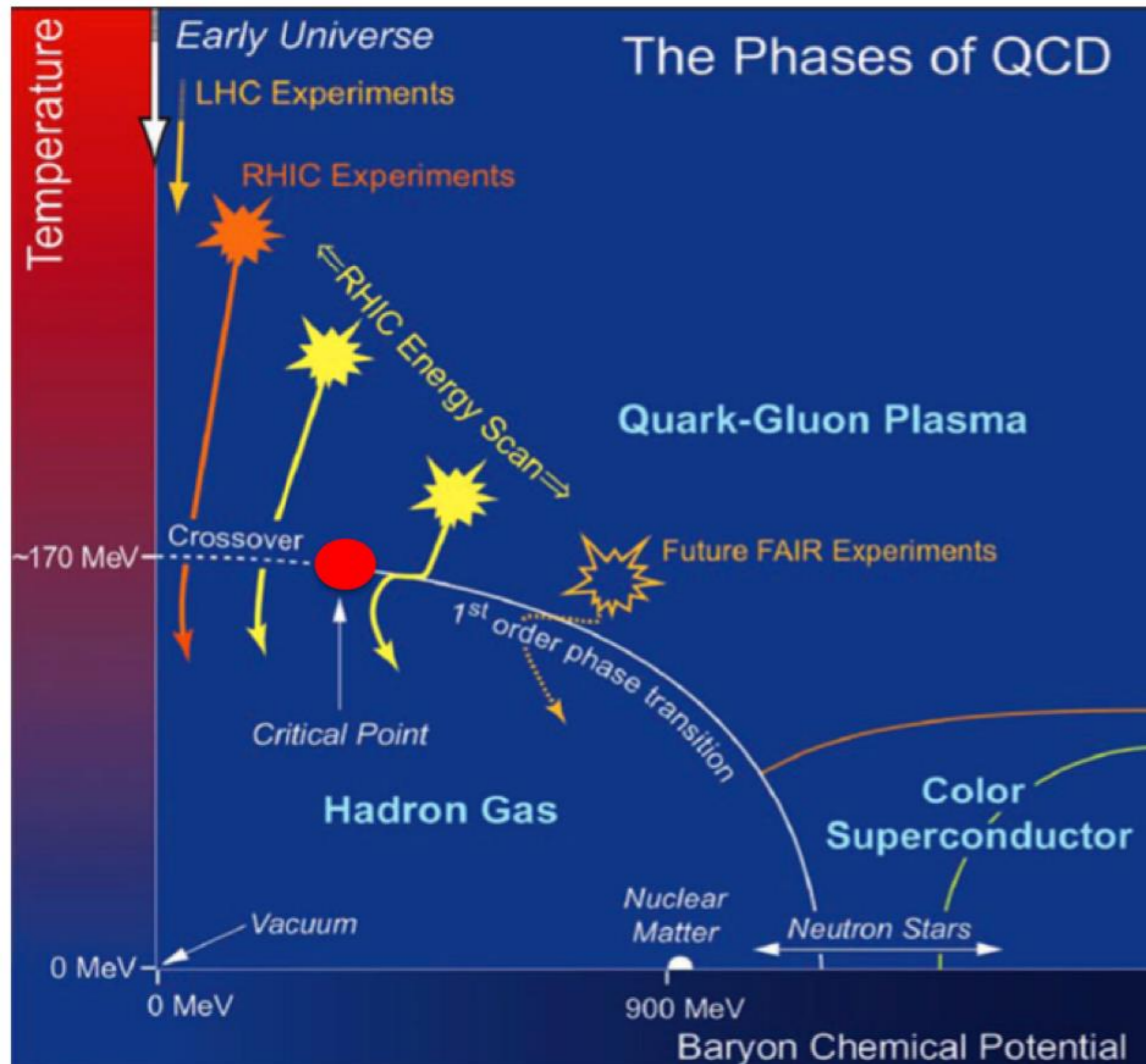
QPT 2021



Changfeng Li, SDU

# QCD Phase Diagram and STAR measurements

## QCD Phase Diagram



Higher order diagonal cumulant measurements to search for the location of QCD Critical Point:

*Net-charge*: PRL 113, 092301 (2014)

*Net-Proton*: PRL 126, 092301 (2021); 112, 32302 (2014)

*Net-Kaon*: Phys. Lett. B 785 (2018) 551

*Net-Lambda*: PRC 102 (2020) 24903

Off-diagonal cumulants:

- Sensitive to the QCD phase transition
- Provide another constraint to determine freeze-out parameters

PRD 73, 014004 (2006); PRL 95, 182301 (2005); PRC 74, 054901 (2006)

RHIC Beam Energy Scan Program goals:

- Study the QCD phase diagram
- Search for the QCD critical point

Recent STAR off-diagonal cumulant measurements:

PRC 100, 014902 (2019)



# Off-diagonal susceptibility

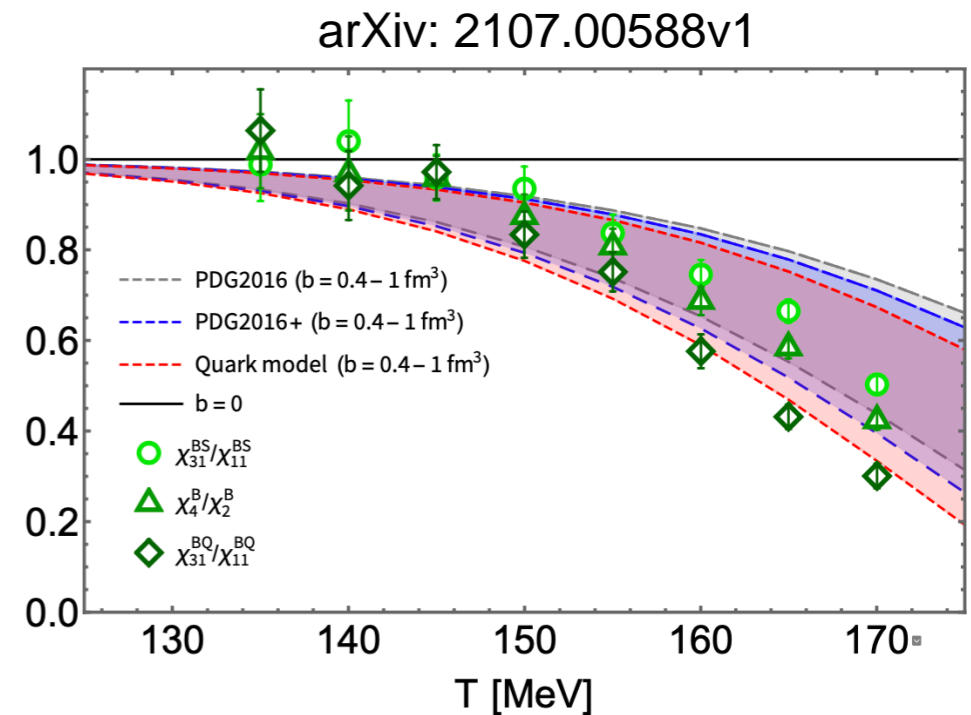
- Correlation between net-p and net-k as a function of  $\sqrt{s}_{NN}$  at different phase space window, provide additional constraint to calculate the freeze-out parameters
- Better understanding of Hadron Resonance Gas (HRG) Model and Lattice QCD

- Provide additional information on undiscovered hadron states in Baryon-strange sector

[ arXiv: 2107.00588v1 ]

Higher order off-diagonal cumulants are sensitive

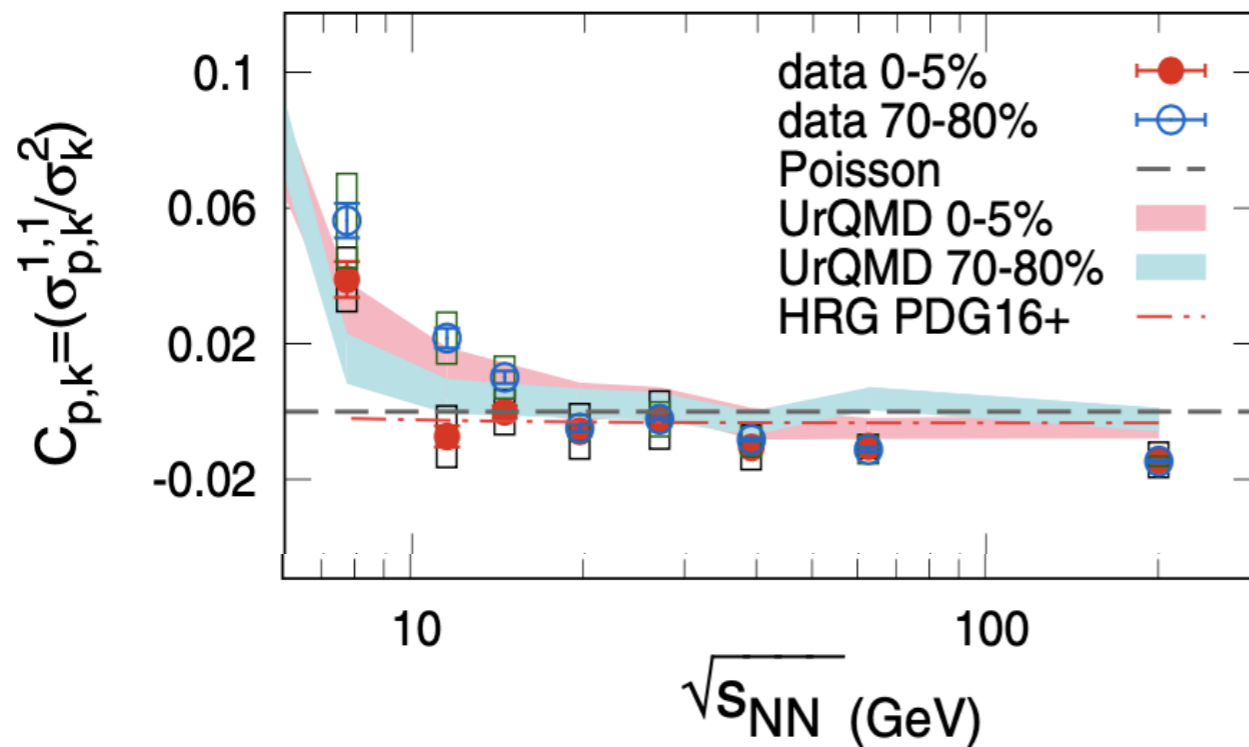
$$\chi_{\alpha}^2 = \frac{1}{VT^3} C_{\alpha}^2, \quad \chi_{\alpha,\beta}^{1,1} = \frac{1}{VT^3} C_{\alpha,\beta}^{1,1}$$



# Off-diagonal cumulants measurement in STAR

Proxy to baryon-strangeness correlation

STAR: PRC 100, 014902 (2019)



Off-diagonal and diagonal matrix elements of 2<sup>nd</sup> order cumulants

$$\sigma = \begin{pmatrix} \sigma_Q^2 & \sigma_{Q,p}^{1,1} & \sigma_{Q,k}^{1,1} \\ \sigma_{p,Q}^{1,1} & \sigma_p^2 & \sigma_{p,k}^{1,1} \\ \sigma_{k,Q}^{1,1} & \sigma_{k,p}^{1,1} & \sigma_k^2 \end{pmatrix}$$

$$\sigma_{X,Y}^{1,1} = \langle (X - \langle X \rangle)(Y - \langle Y \rangle) \rangle$$

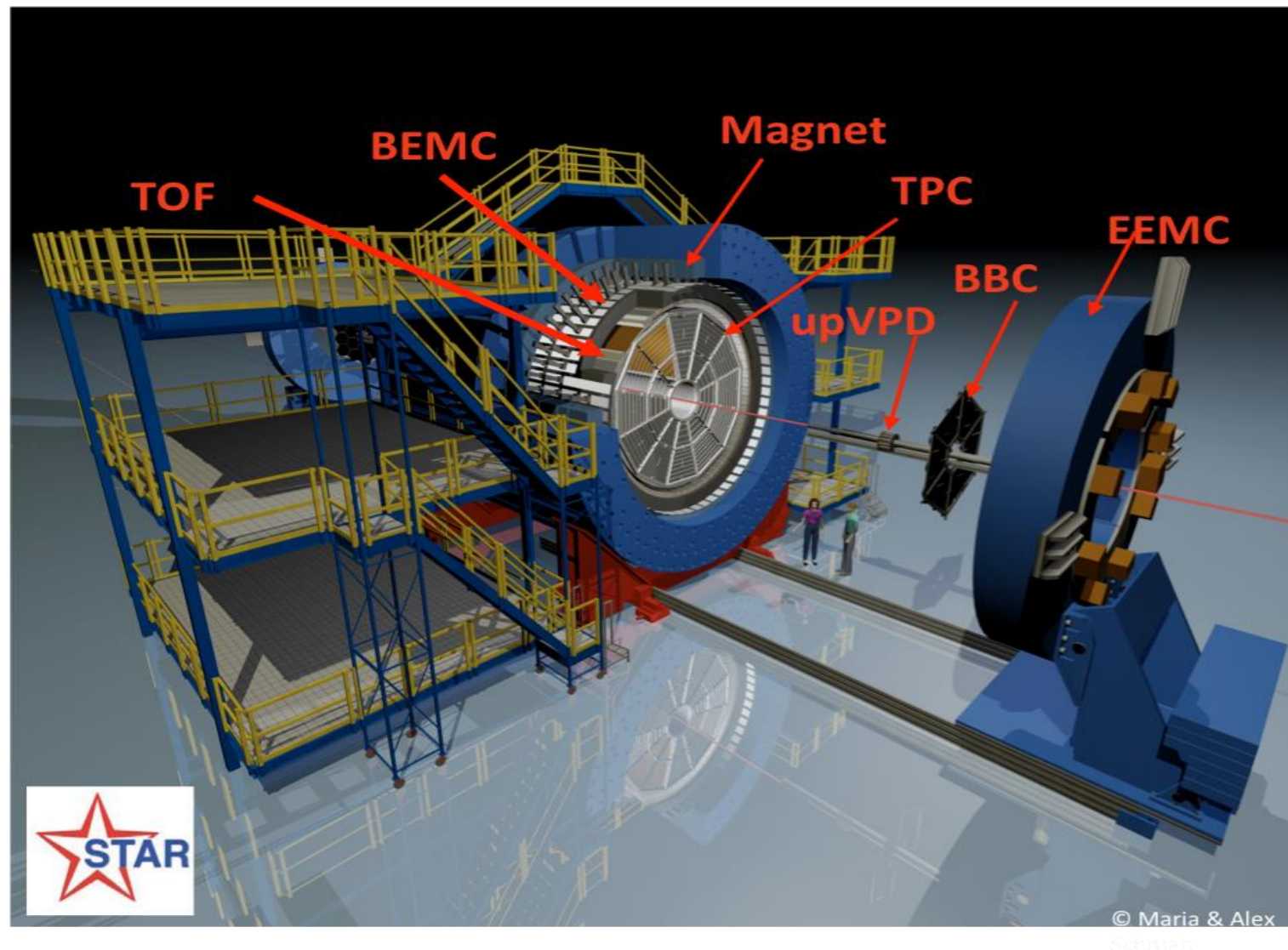
$$\sigma_X^2 = \langle (X - \langle X \rangle)^2 \rangle$$

$$C_{p,k} = \frac{\sigma_{p,k}^{1,1}}{\sigma_k^2} \longrightarrow \text{Correlation between net-proton and net-kaon with respect to net-kaon fluctuations}$$

$C_{p,k}$  is negative at high energy (200 GeV) and positive at low energy (7.7 GeV).



# STAR detector system



Time Projection Chamber (TPC):

- $|\eta| < 1$
- Transverse momentum:  $0.15 \text{ GeV}/c < p_T$
- $2\pi$  azimuthal coverage

Particle identification using both  
TPC and Time of Flight (TOF)

Centrality definition:  
using uncorrected charged particle multiplicity within  $0.5 < |\eta| < 1.0$



# New Au+Au 27 GeV data in STAR

High statistics data taken in year 2018

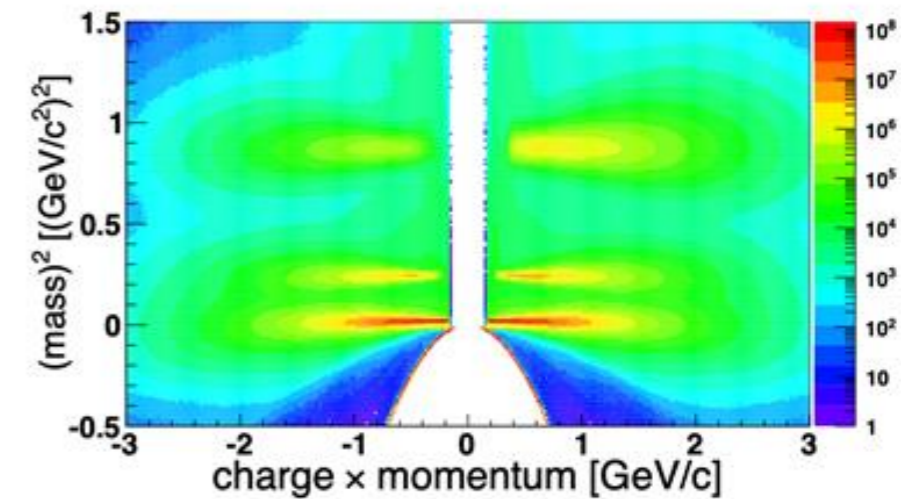
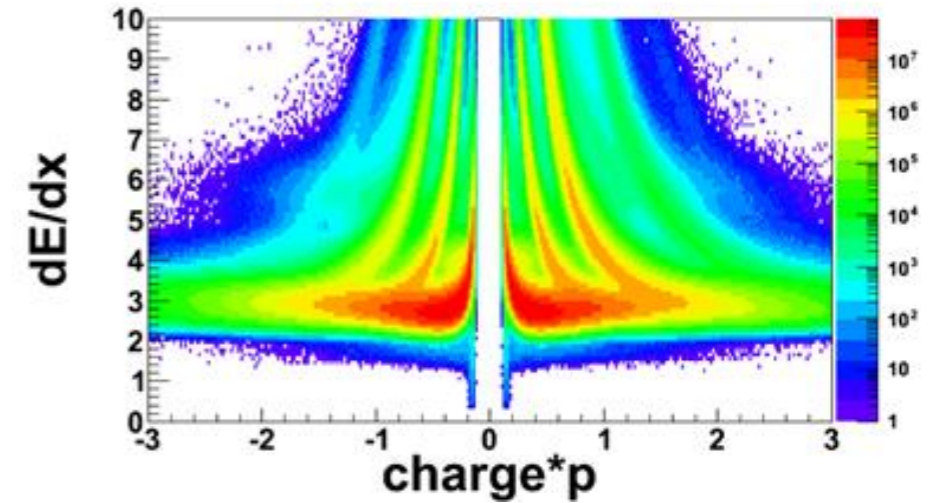
Event selection:

- Primary vertex position along the beam pipe between -30 cm to +30 cm
- Transverse primary vertex position within 2 cm relative to the beam center

- Total minimum bias events: 258 Million

Charged Track selection:

$p_T$  range: 0.4 to 1.6 GeV/c and  $|\eta| < 0.5$



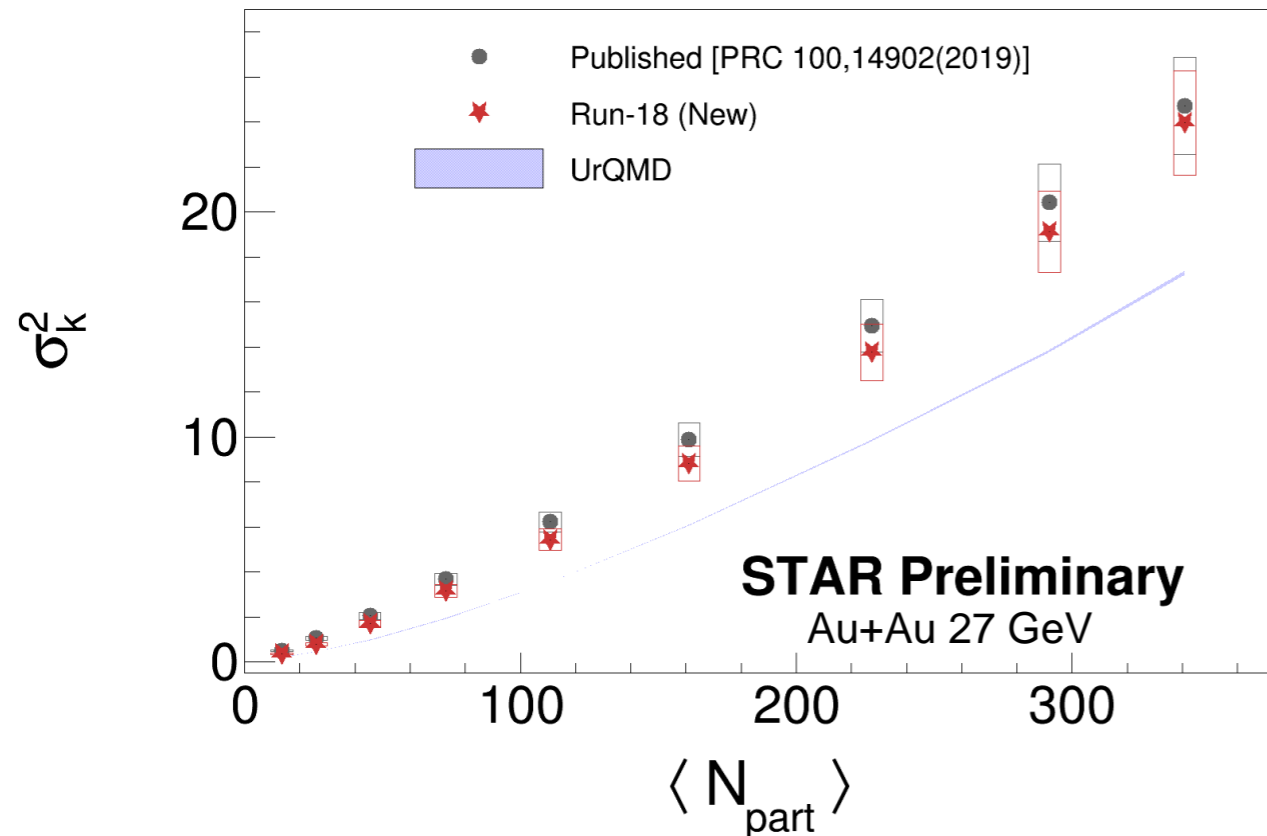
Particle	TPC	TPC+TOF
$p(\bar{p})$	$0.4 < p_T < 0.8(\text{GeV}/c)$ $ \text{n}\sigma_p  < 2$	$0.8 < p_T < 1.6(\text{GeV}/c)$ $0.6 < m^2 < 1.2[(\text{GeV}/c^2)^2]$
$k^+(k^-)$	$ \text{n}\sigma_K  < 2,  \text{n}\sigma_\pi  > 2$	$0.4 < p_T < 1.6(\text{GeV}/c)$ $0.15 < m^2 < 0.4[(\text{GeV}/c^2)^2]$



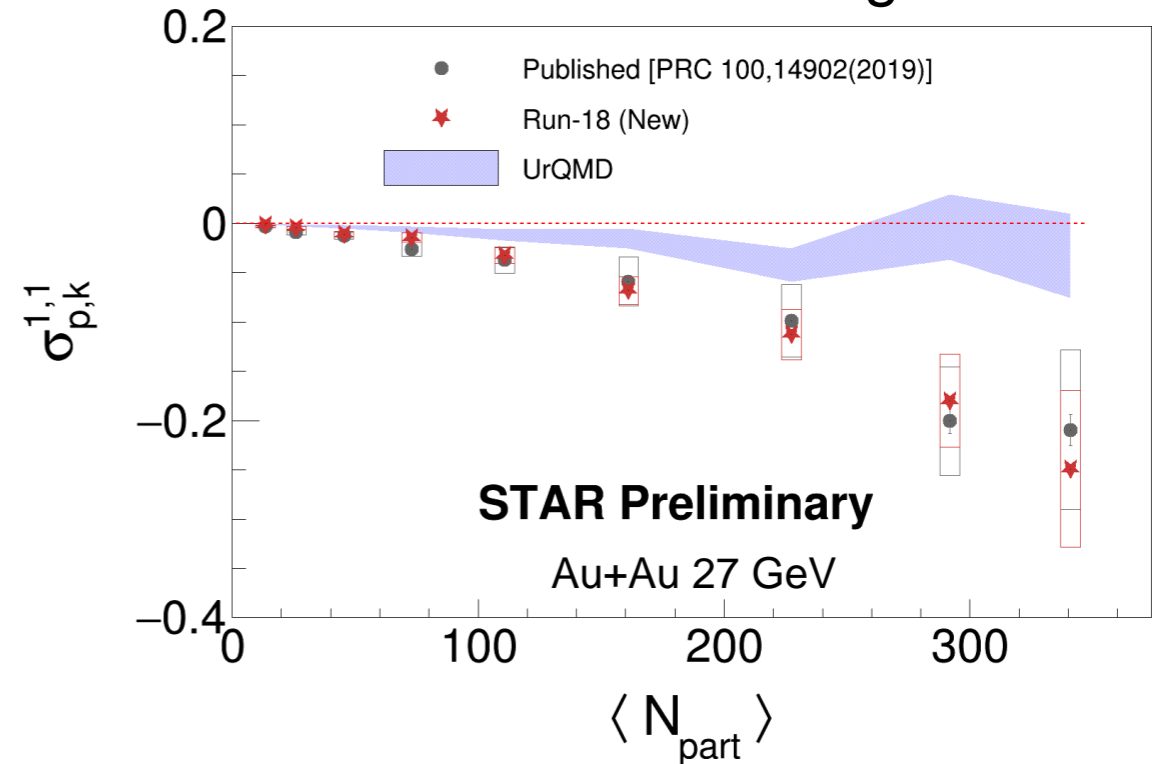
# Centrality dependence of diagonal and off-diagonal cumulants

Au+Au 27 GeV

Net-kaon: 2<sup>nd</sup> order diagonal



Net-proton and net-kaon:  
2<sup>nd</sup> order off-diagonal

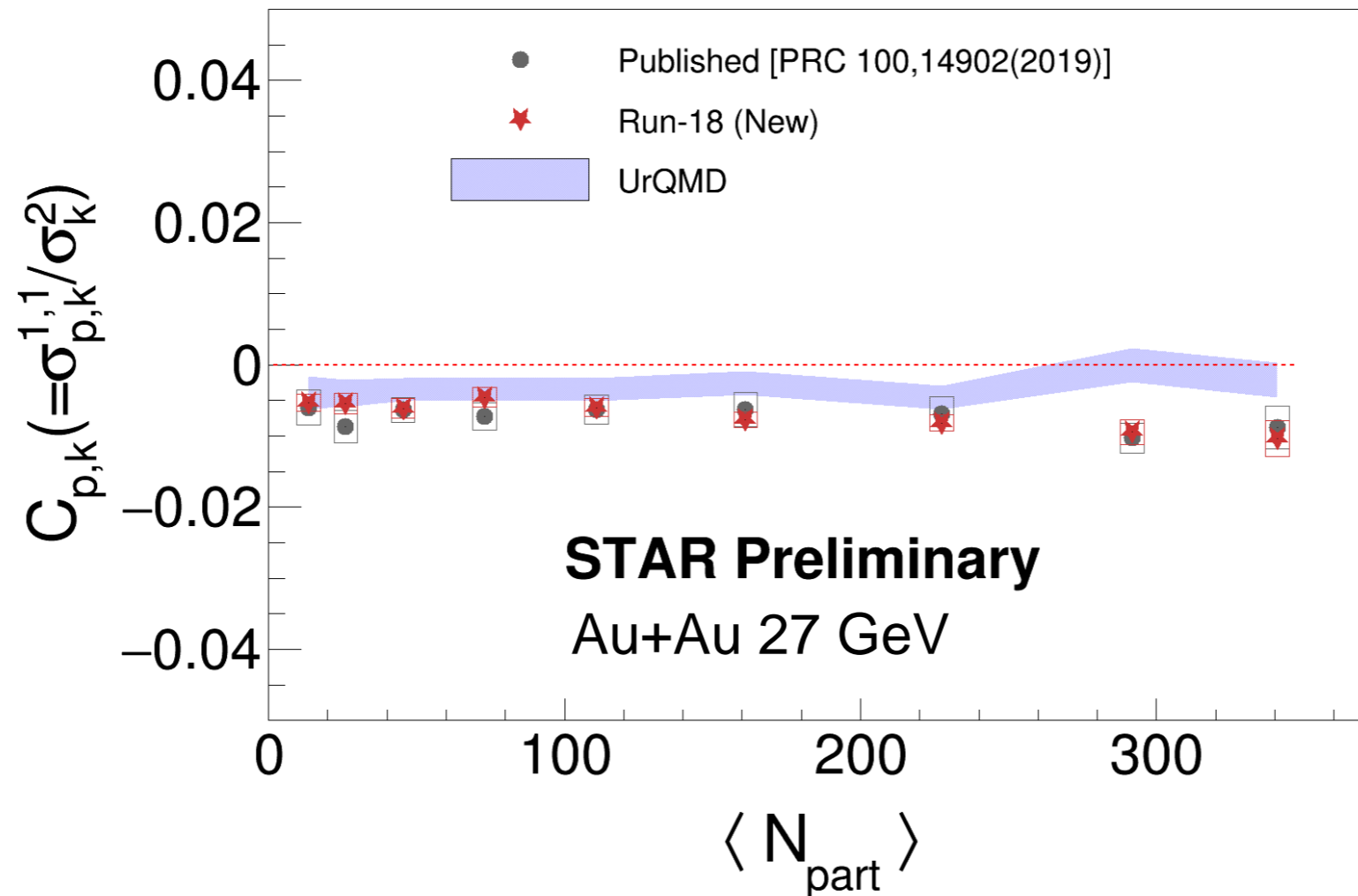


- New results (Run-18) are consistent with the published result (Run11).
- Net-kaon and net-proton are highly anti-correlated at central events
- Run18 dataset provides better statistical precision



# Centrality dependence of ratio between diagonal and off-diagonal cumulants

Proxy to baryon-strangeness correlation with respect to strangeness fluctuation



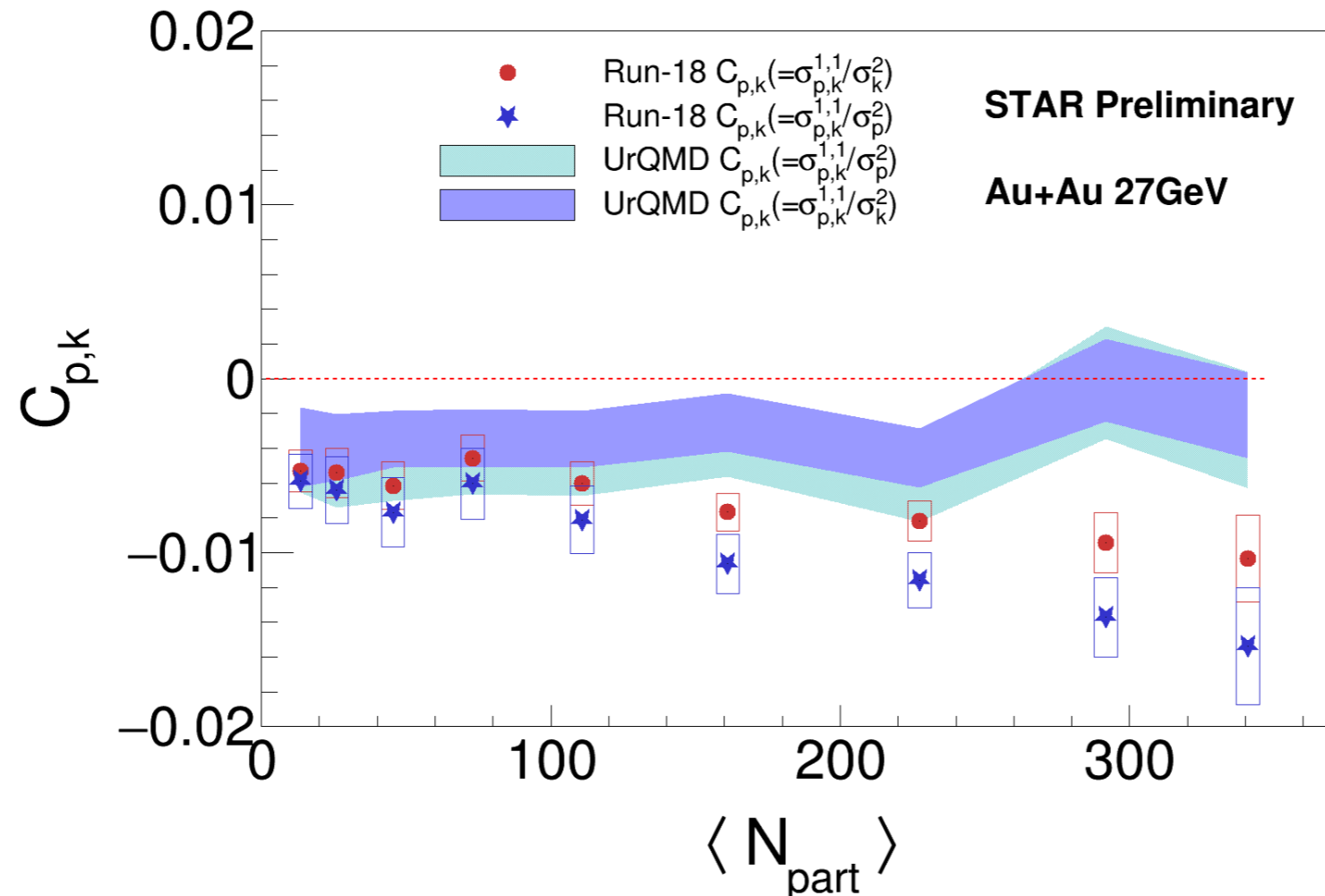
- New results (Run-18) results are consistent with the published result (Run11).
- Correlation between net-kaon and net-proton with respect to net-kaon fluctuations is negative at all centralities
- Run18 dataset provides better statistical precision





# Ratio between diagonal and off-diagonal cumulants

Proxy to baryon-strangeness correlation with respect to strangeness and baryon fluctuations



The values of  $\sigma_{p,k}^{1,1}/\sigma_p^2$  and  $\sigma_{p,k}^{1,1}/\sigma_k^2$  are different.

This difference is not seen in UrQMD model, within uncertainty.  
These results are used to estimate freeze-out parameters.



# Summary and outlook

- We analyzed Au+Au 27 GeV dataset taken in the year 2018
- New results are consistent with the published results providing better statistical precision
- Observations:
  - Correlation between net-kaon and net-proton with respect to net-kaon fluctuations is negative at all centralities
  - Correlation between net-kaon and net-proton with respect to net-proton and net-kaon fluctuations are different
  - UrQMD qualitatively explains the data
- These results provide additional constraint to calculate the freeze-out parameters
- We plan to work on higher order off-diagonal cumulants in STAR using BES-II dataset

