Higher Moments of Net-Kaon Multiplicity Distributions at STAR

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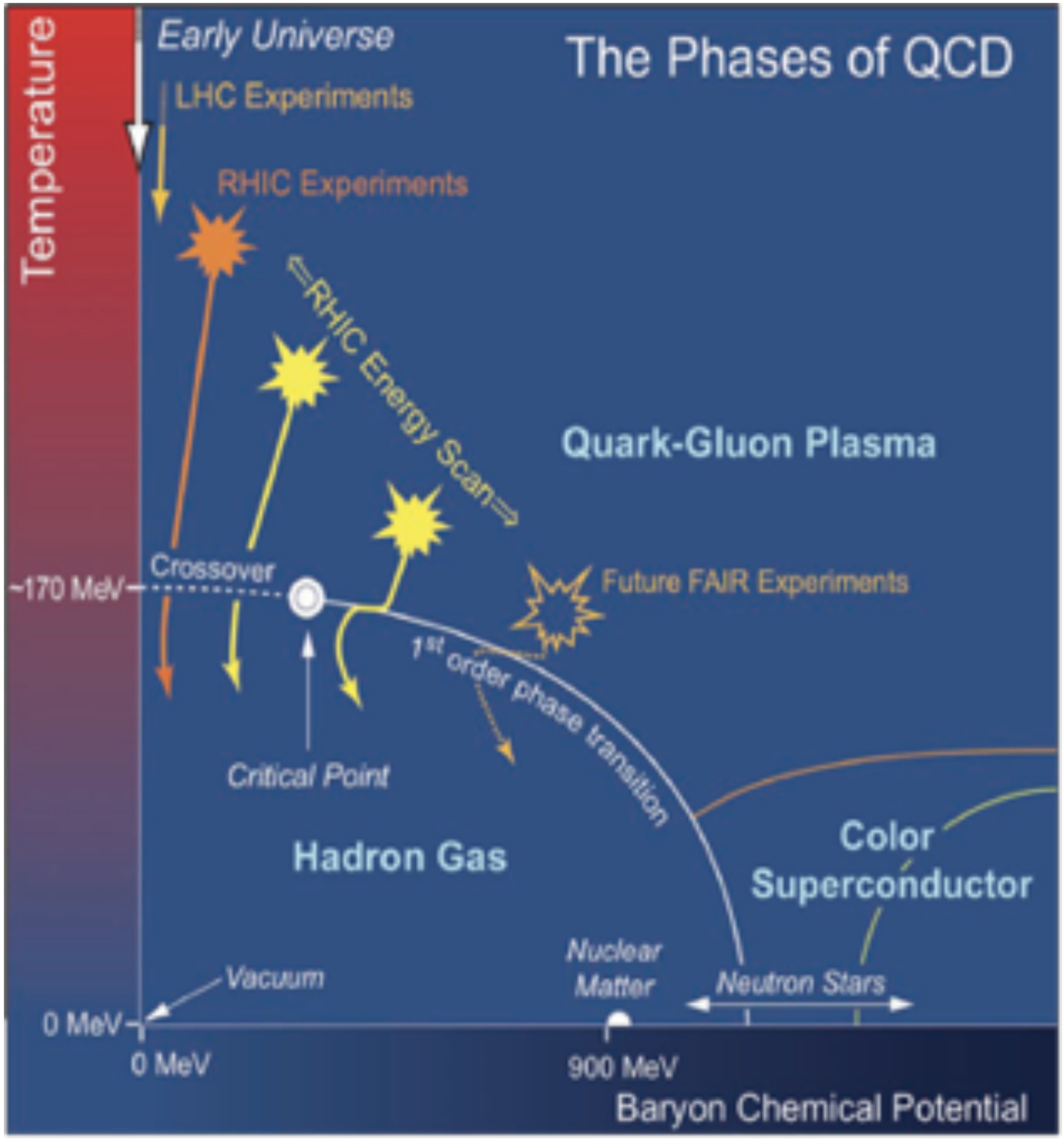
Outline

- Introduction
- Analysis Techniques and Details
- Results
- Summary

QCD Phase Diagram



STAR Note 0598

- Crossover at μ_B=0.
- First order phase transition expected at large μ_B.
- QCD Critical Point: The end point of first order phase transition boundary.
- Where is CP(Critical Point) ?

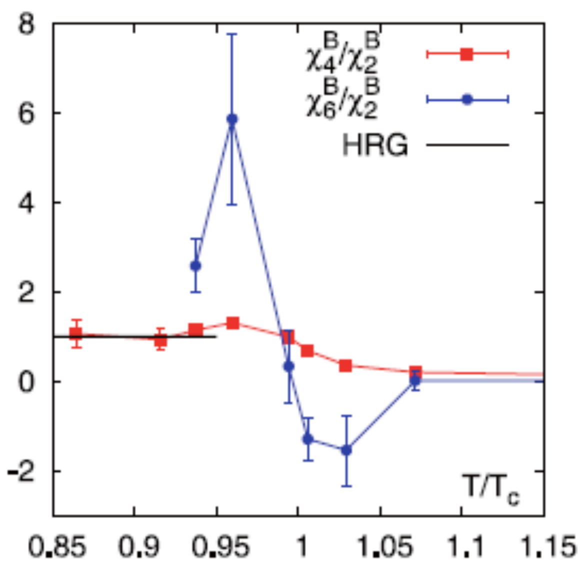
Fluctuations of Conserved Quantities(B,Q,S)

- Sensitive to correlation length (ξ) and probe non-gaussian fluctuations near the Critical Point.

$$\left\langle (\delta N)^2 \right\rangle \sim \xi^2, \left\langle (\delta N)^3 \right\rangle \sim \xi^{4.5}, \left\langle (\delta N)^4 \right\rangle - 3\left\langle (\delta N)^2 \right\rangle^2 \sim \xi^7$$

M. A. Stephanov, Phys. Rev. Lett. 102, 032301 (2009).
M. A. Stephanov, Phys. Rev. Lett. 107, 052301 (2011).
M. Asakawa, S. Ejiri and M. Kitazawa, Phys. Rev. Lett. 103, 262301 (2009).

- Direct connection to the susceptibility of the system.



$$\chi_q^{(n)} = \frac{1}{VT^3} \times C_{n,q} = \frac{\partial^n (p/T^4)}{\partial(\mu_q)^n}, q = B,Q,S$$

S. Ejiri et al, Phys.Lett. B 633 (2006) 275.
Cheng et al, PRD (2009) 074505. B. Friman et al., EPJC 71 (2011) 1694.
F. Karsch and K. Redlich , PLB 695, 136 (2011).
S. Gupta, et al., Science, 332, 1525(2011).
A. Bazavov et al., PRL109, 192302(12) // S. Borsanyi et al., PRL111, 062005(13) // P. Alba et al., arXiv:1403.4903

Higher Moments (fluctuations)

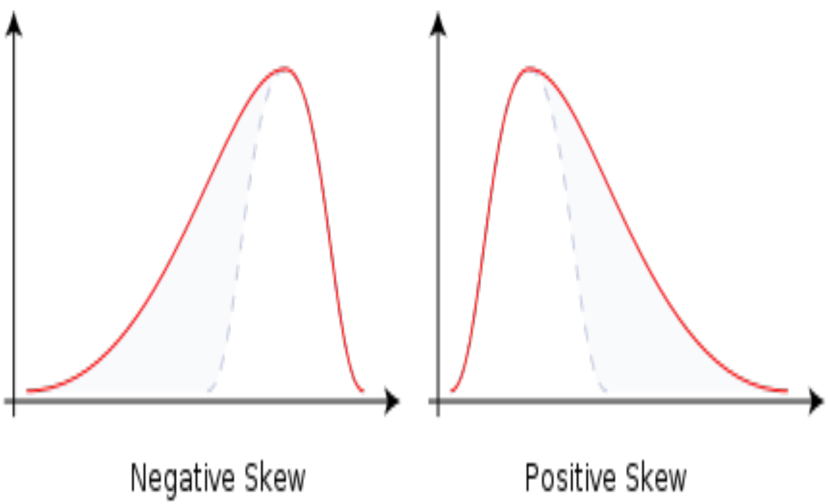
"Shape" of the fluctuations can be measured: non-Gaussian moments (cumulants):

$$C_{1,x} = <x>, C_{2,x} = <(\delta x)^2>,$$

$$C_{3,x} = <(\delta x)^3>, C_{4,x} = <(\delta x)^4> - 3<(\delta x)^2>^2$$

$$S = \frac{C_{3,N}}{(C_{2,N})^{3/2}} = \frac{<(N-<N>)^3>}{\sigma^3}$$

$$\kappa = \frac{C_{4,N}}{(C_{2,N})^2} = \frac{<(N-<N>)^4>}{\sigma^4} - 3$$



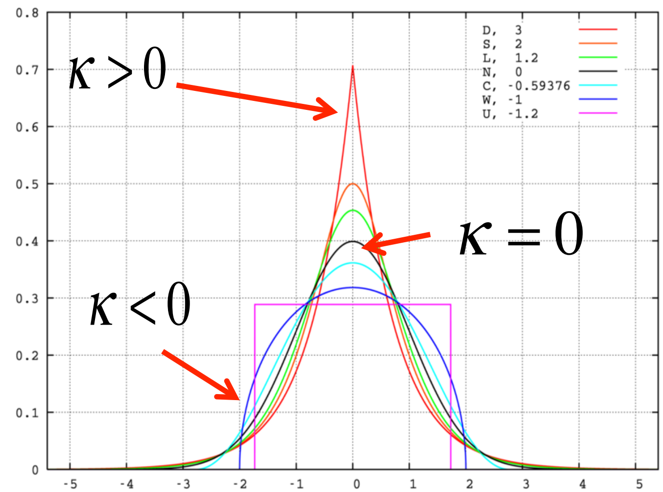


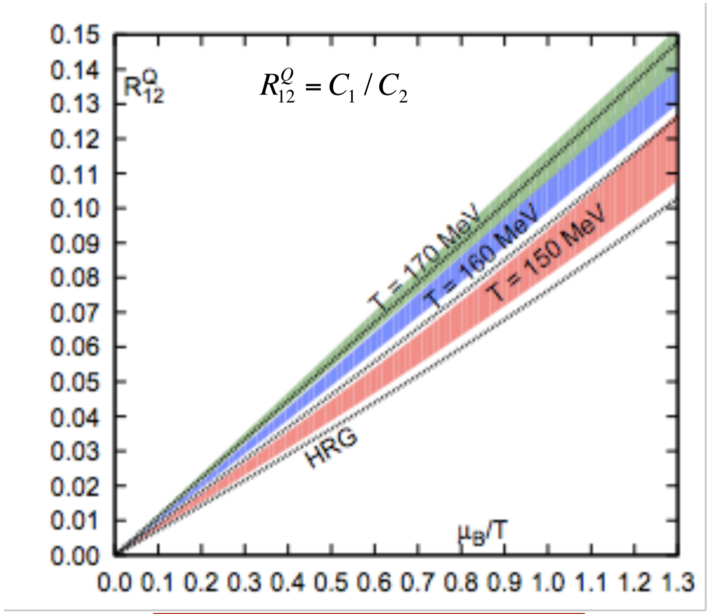
Figure from wikipedia

- **Cumulant Ratios**

$$\kappa\sigma^2 = \frac{C_{4,q}}{C_{2,q}}, \quad S\sigma = \frac{C_{3,q}}{C_{2,q}}$$

Experimental Observables

- We measured the net-particle multiplicity fluctuations: net-charge, net-proton (proxy for net-baryon), net-kaon (proxy for net-strangeness). The main observables are volume independent cumulant ratios.



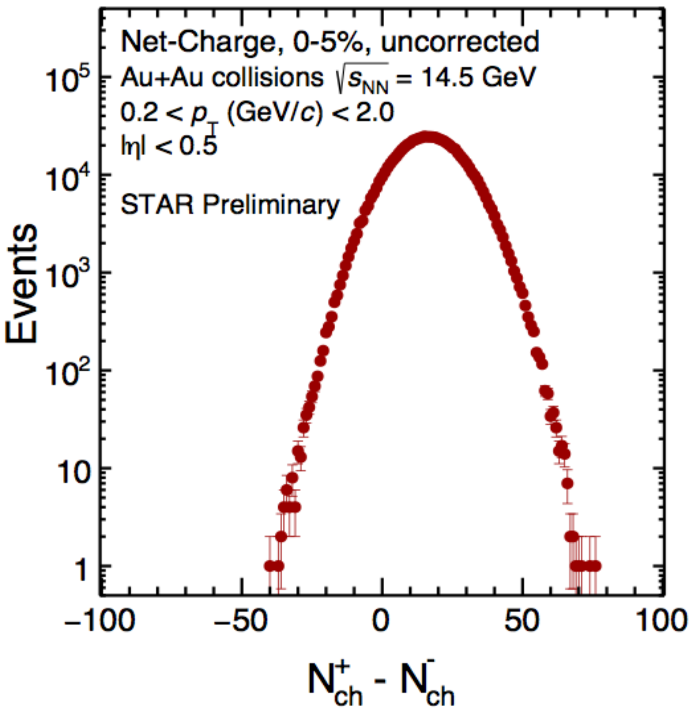
HotQCD, PRL109, 192302 (2012)
WB Group, PRL111, 062005 (2013)

$$\frac{\chi_2^i}{\chi_1^i} = (\sigma^2/M)^i = \frac{c_2^i}{c_1^i}$$

$$\frac{\chi_3^i}{\chi_2^i} = (S\sigma)^i = \frac{c_3^i}{c_2^i}$$

$$\frac{\chi_4^i}{\chi_2^i} = (\kappa\sigma^2)^i = \frac{c_4^i}{c_2^i}$$

$$i = B, Q, S$$



Theory ⟷ **Experiment**

RHIC Beam Energy Scan Phase 1 (BES I)

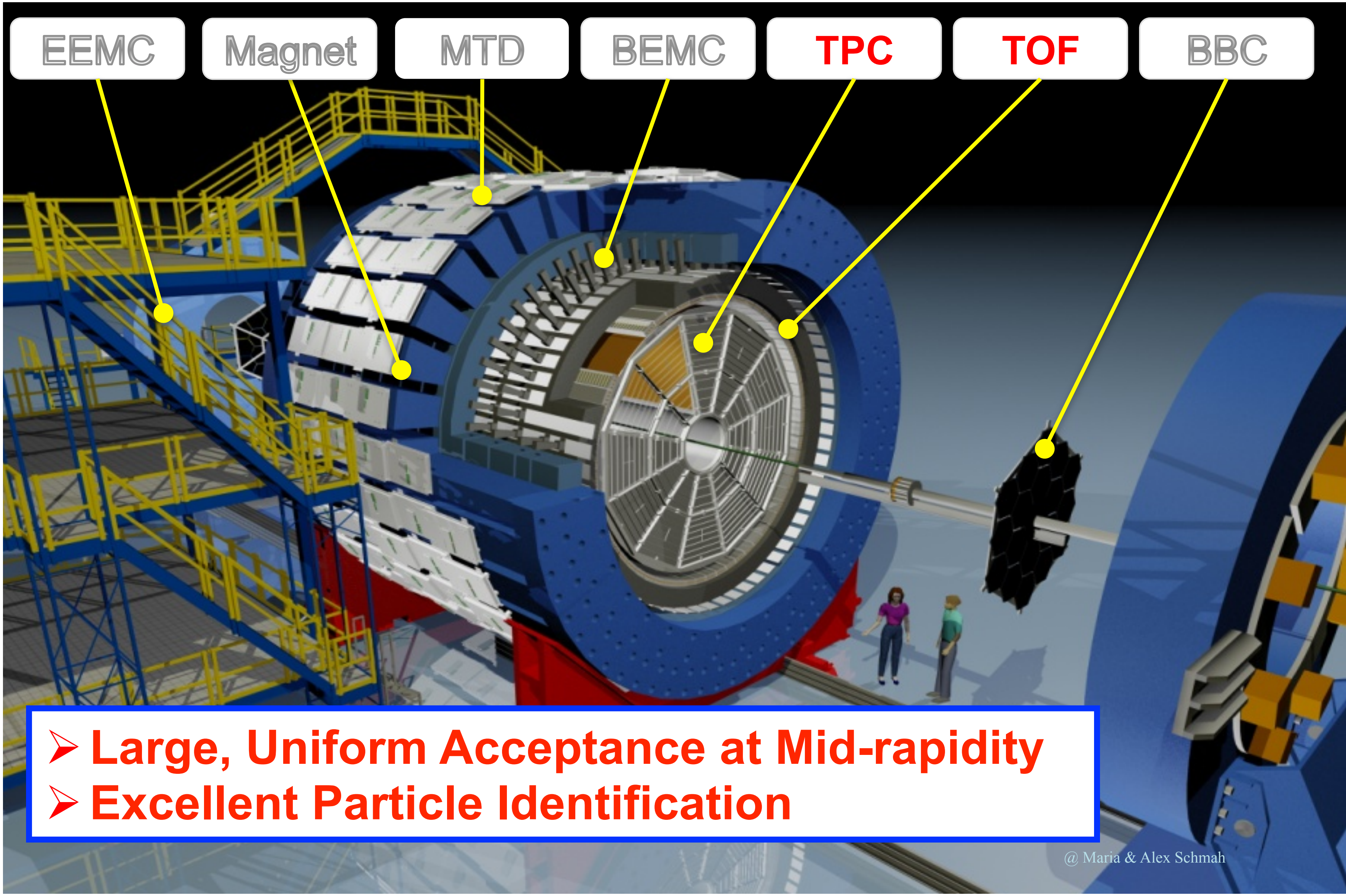
- In the first phase of the Beam Energy Scan (BES) program at RHIC, eight beam energies have already been analyzed from $\sqrt{s_{NN}}$=7.7GeV to 200GeV.

√s (GeV)	Statistics (Millions)	Year	μ_B (MeV)	T (MeV)	μ_B /T
7.7	~4	2010	420	140	3.020
11.5	~12	2010	315	152	2.084
14.5	~ 20	2014	266	156	1.705
19.6	~36	2011	205	160	1.287
27	~70	2011	155	163	0.961
39	~130	2010	115	164	0.684
62.4	~67	2010	70	165	0.439
200	~350	2010	20	166	0.142

μB, T : J. Cleymans et al., PRC 73, 034905 (2006)

Study QCD Phase Structure
- Onset of sQGP
- Phase boundary and **critical point.**

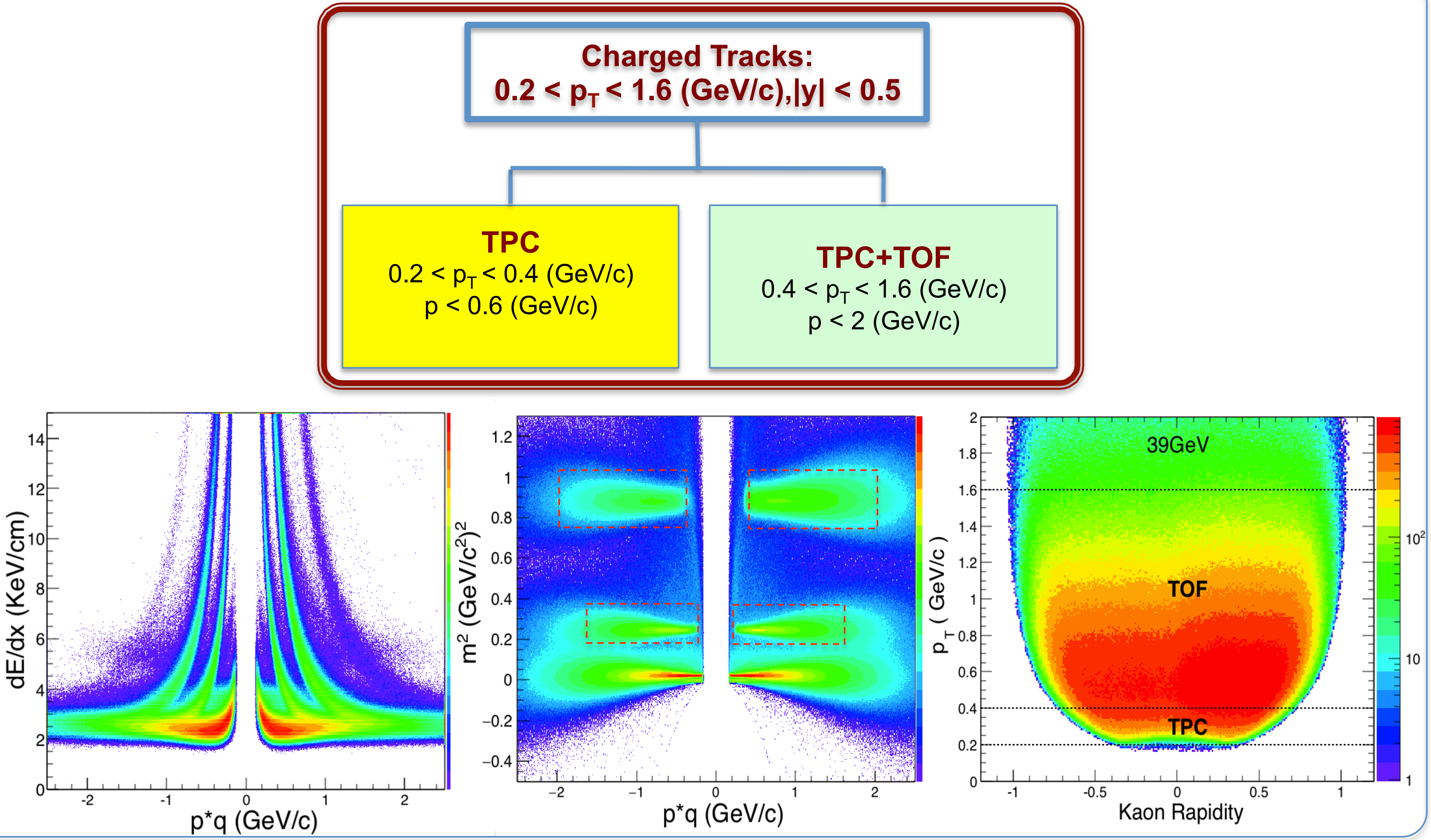
STAR Detector



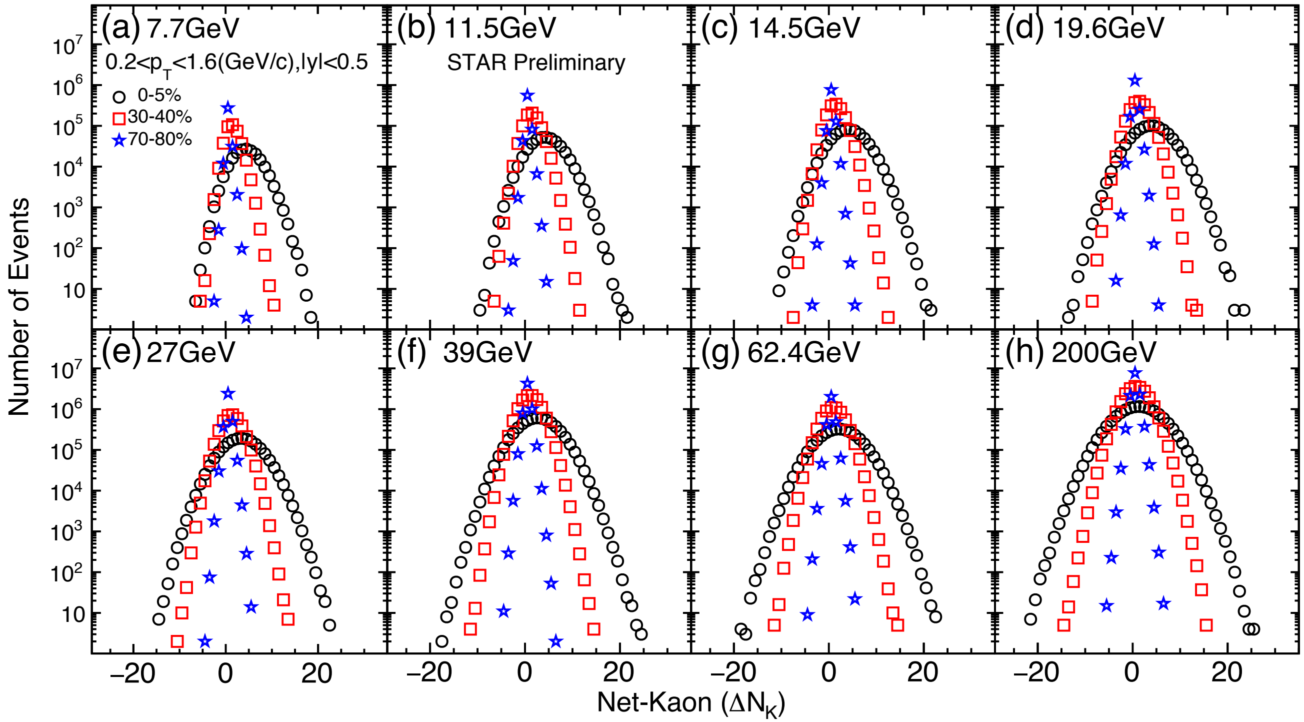
- Large, Uniform Acceptance at Mid-rapidity
- Excellent Particle Identification

Kaon ID with STAR Detectors

- PID: Energy loss (dE/dx) in Time Projection Chamber and mass-squared (m^2) from Time of Flight are used to identify kaons within $0.2<p_T<1.6$ (GeV/c) and at mid-rapidity $|y|<0.5$.



Event by Event Net-kaon Distributions



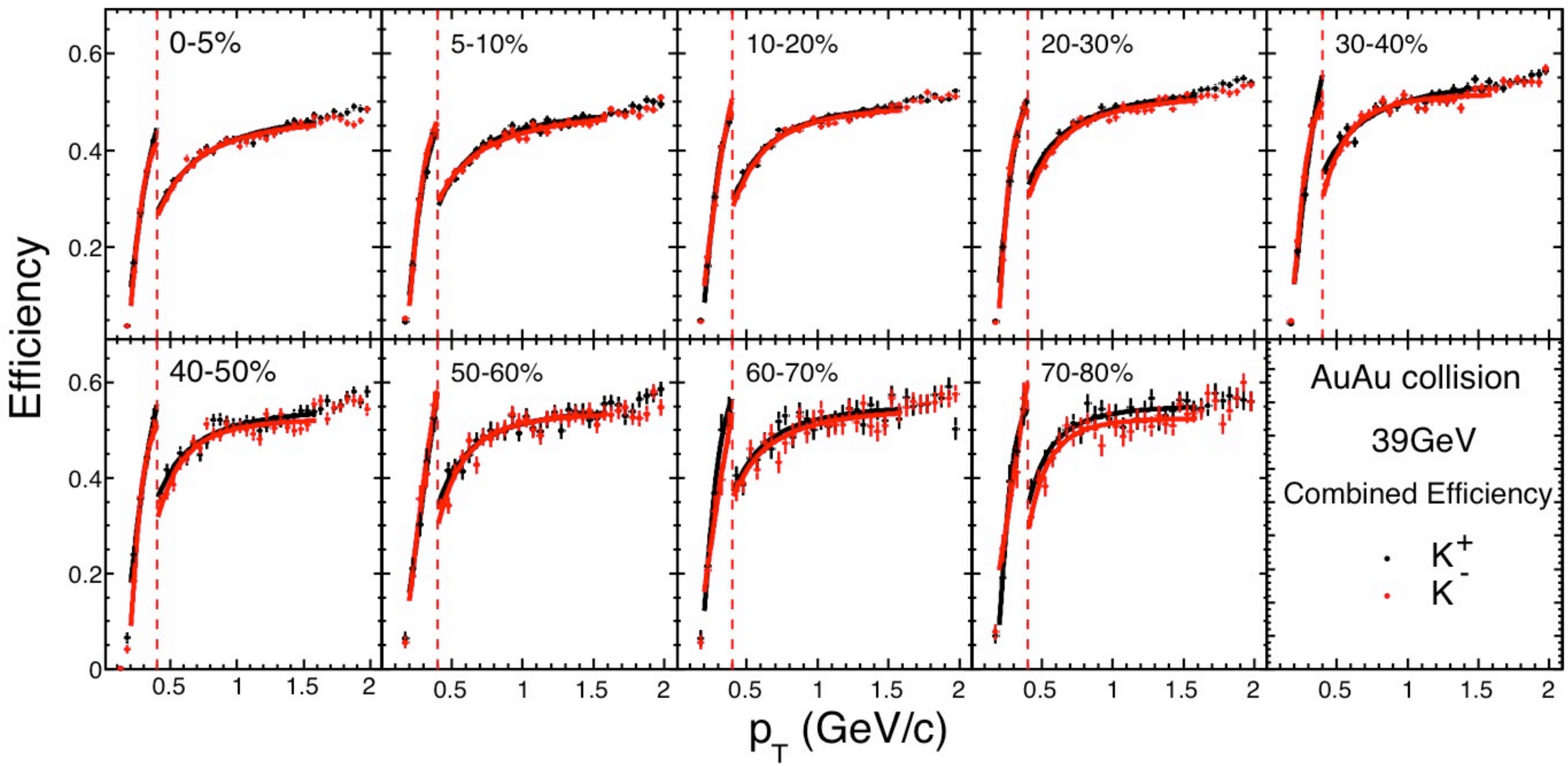
- Most central collisions have a wider distribution compared with peripheral collisions.
- The peak of the net-kaon distributions shift slightly towards the positive direction as the energy decreases.

Effects that need to be addressed to get final moments/cumulants:

1. Auto-correlation effects.
2. Effects of volume fluctuations.
3. Finite detector efficiency .

A. Bzdak, et al. PRC91, 027901 (2015)
X.Luo, Phys. Rev. C 91, 034907 (2015)
X.Luo, et al. J. Phys. G40,105104(2013)

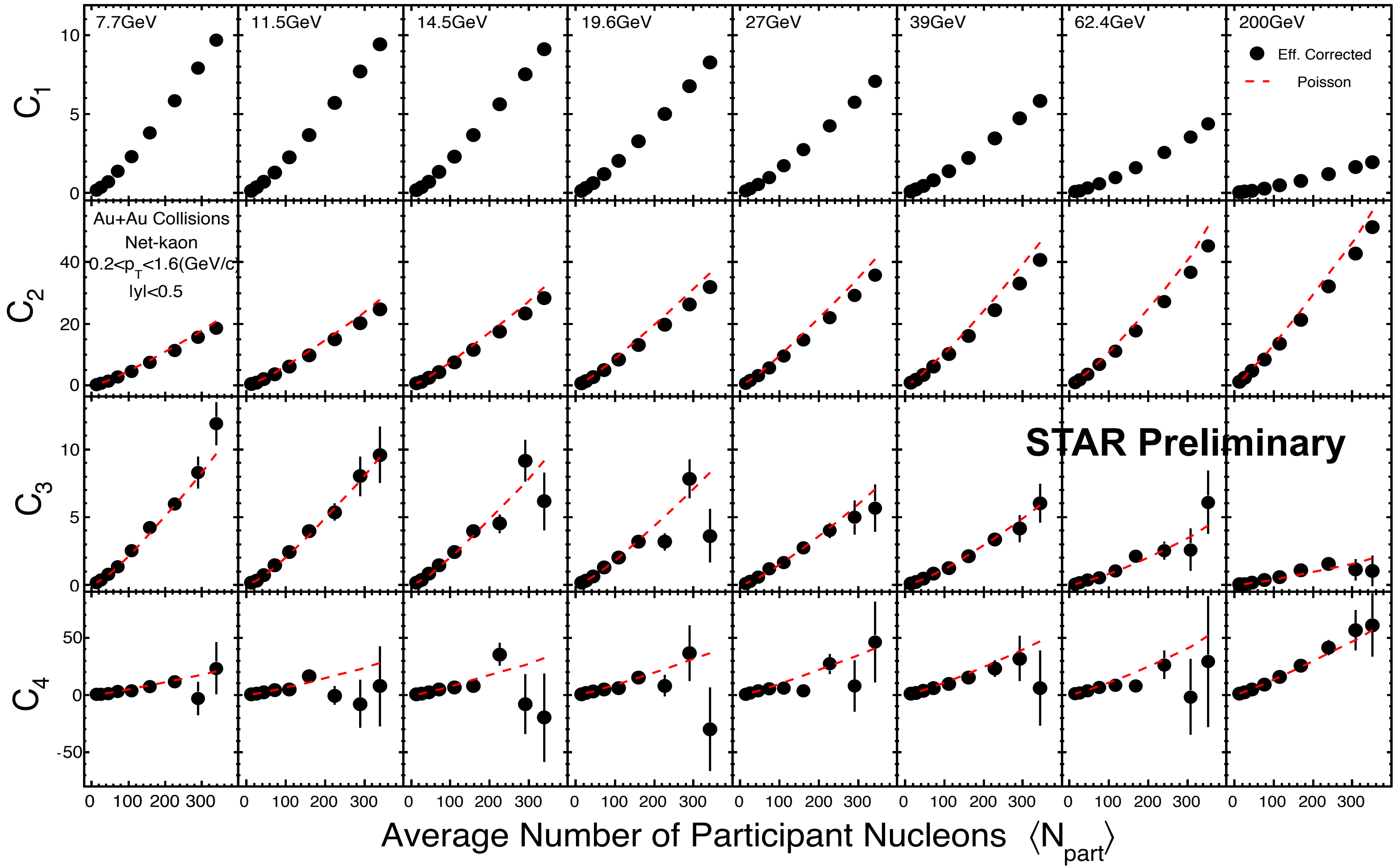
Combined Efficiency for K^+ and K^-



- 0.2< p_T <0.4 (GeV/c), TPC only
- 0.4< p_T <1.6 (GeV/c), TPC+TOF
  Efficiency=Efficiency(Tracking)*Efficiency(TOF match)
- The input number is the p_T weighted average efficiency.

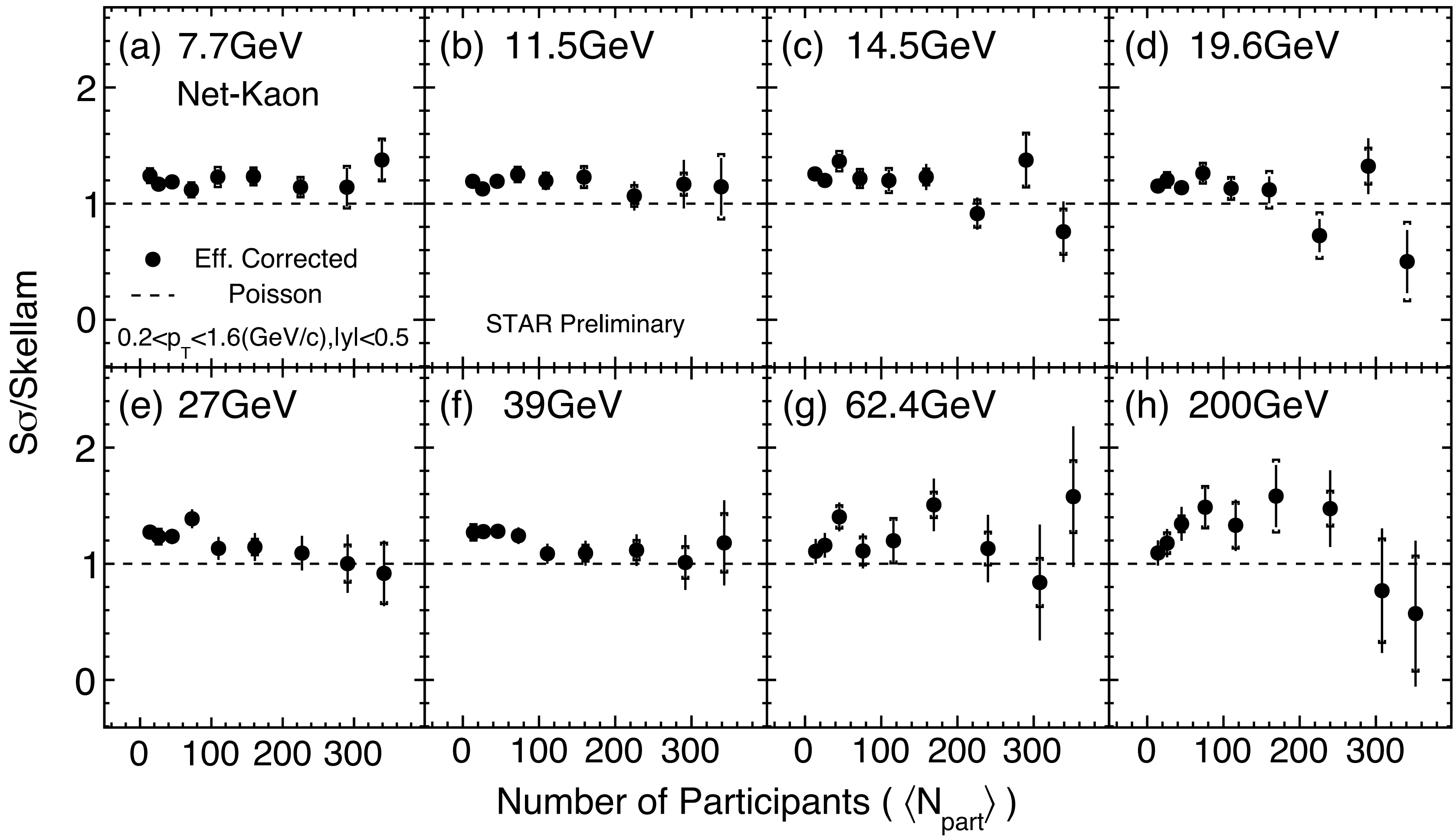
X. Luo, PRC91, 034907 (2015); A. Bzdak and V. Koch, PRC91, 027901 (2015)

Cumulants for Net-Kaon



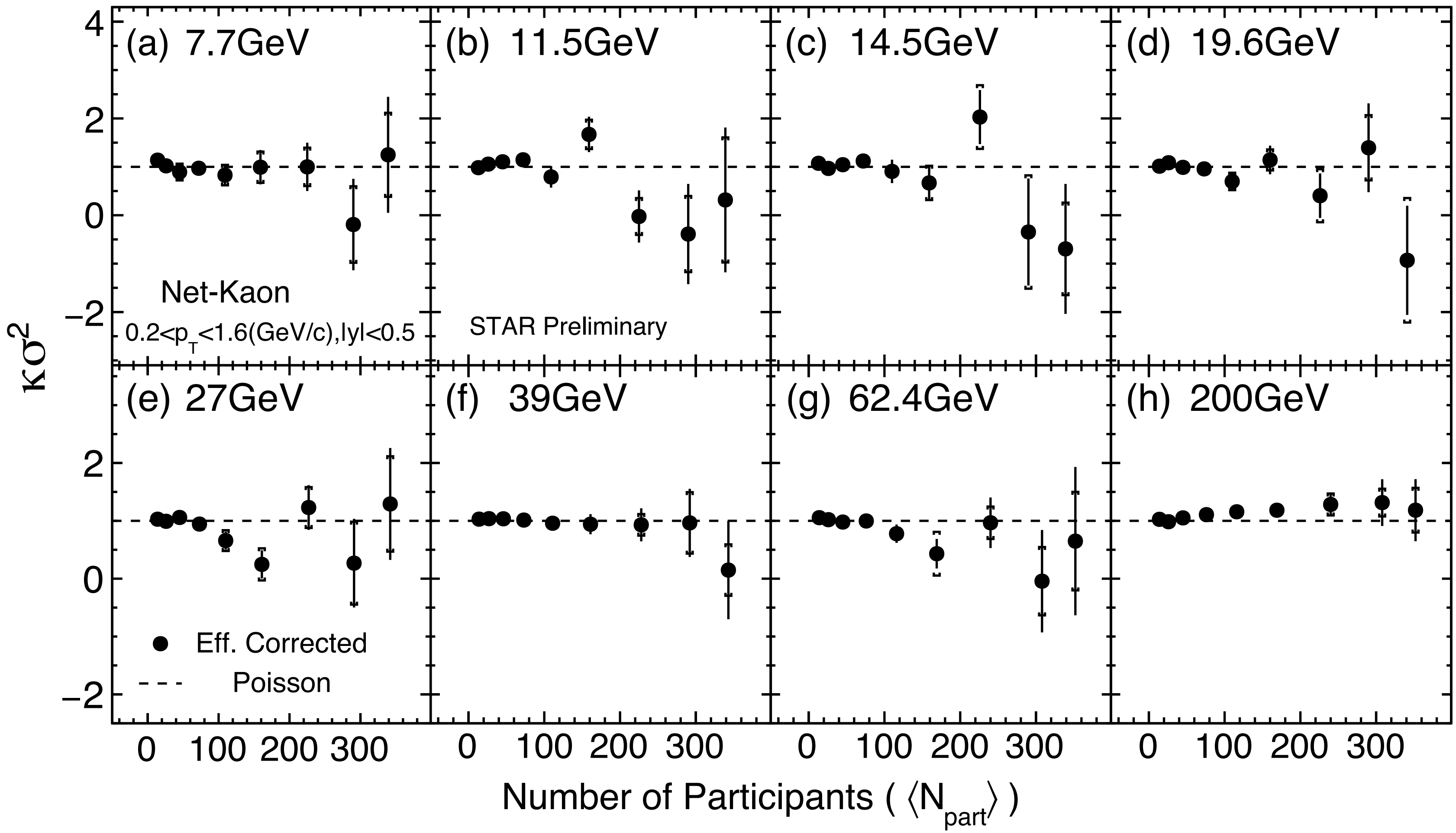
C_3 and C_4 generally consistent with Poisson expectation.

Centrality Dependence of C_3/C_2



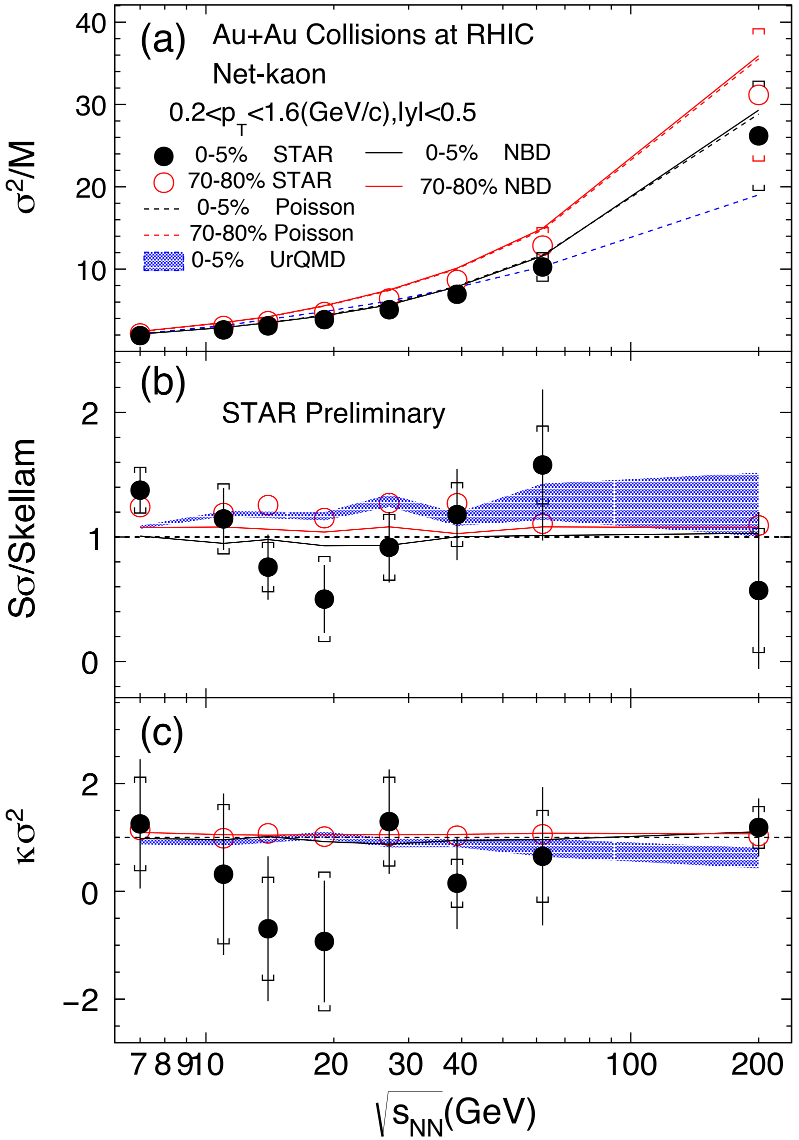
➢ The values of Sσ/Skellam are consistent with unity within uncertainties.

Centrality Dependence of C_4/C_2



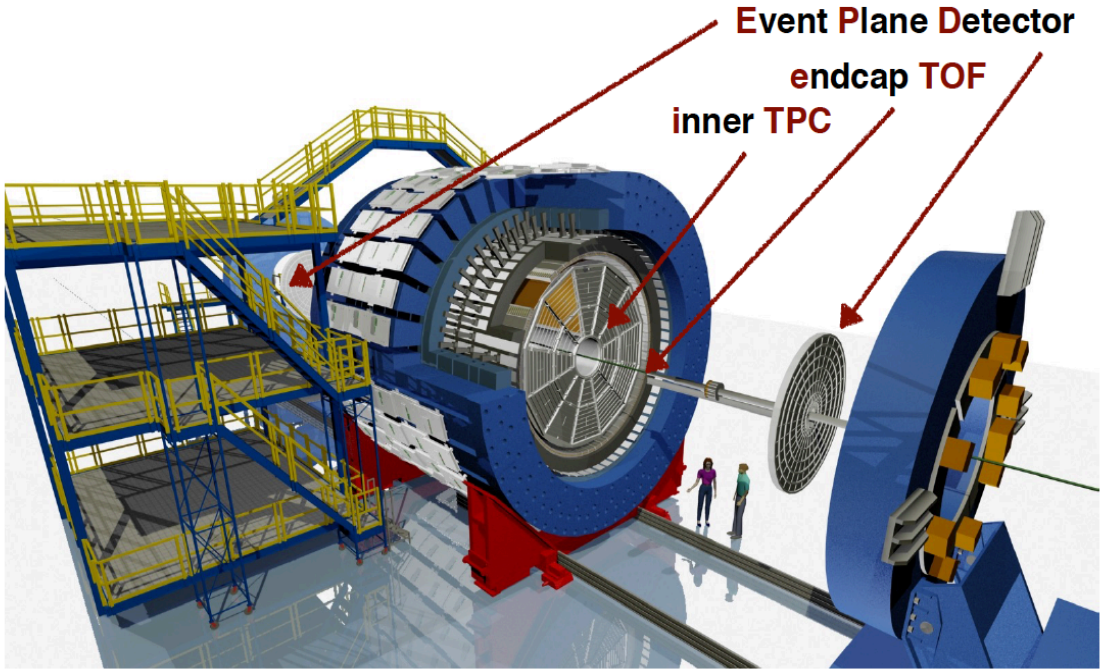
- The values of $\kappa\sigma^2$ are consistent with unity within uncertainties.

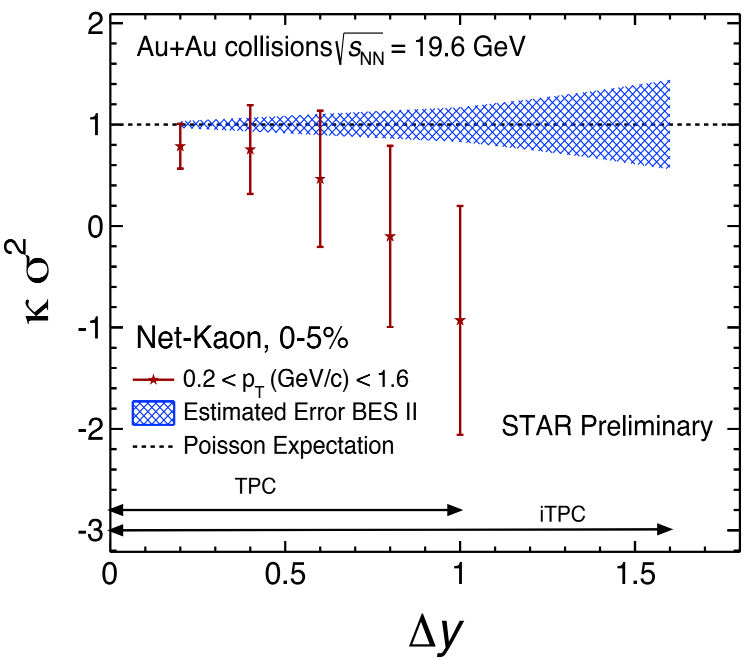
Energy Dependence of Net-kaon



- The values of σ^2/M increase as the energy increases.
- The values of $S\sigma$/Skellam are consistent with poisson and negative binomial distribution baseline within uncertainties.
- The values of $\kappa\sigma^2$ are consistent with poisson and negative binomial distribution baseline within uncertainties.
- UrQMD (no Critical Point), shows no energy dependence for $S\sigma$/Skellam and $\kappa\sigma^2$.

Beam Energy Scan II





iTPC proposal: http://drupal.star.bnl.gov/STAR/starnotes/public/sn0619
BES-II whitepaper: http://drupal.star.bnl.gov/STAR/starnotes/public/sn0598

- Inner TPC(iTPC) upgrade : |η| < 1 to | η |< 1.5, better dE/dx resolution and higher tracking efficiency.
- Event Plane Detector (EPD)： Centrality and Event Plane Determination. 2.1 < |η| < 5.1
- eTOF： Larger rapidity coverage extends PID in forward direction -1.6 < η < -1.1.

More details see talks by Alexander Schmah, Jinlong Zhang, and Chi Yang.

Summary

- STAR new results on collision energy and centrality dependence of net-Kaon cumulants and their ratios, within the kinematic range [$|y| < 0.5$, $0.2 < p_T < 1.6$ (GeV/c))], for Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7, 11.5, 14.5, 19.6, 27, 39, 62.4 and 200 GeV are presented.

- The values of net-Kaon's $\kappa\sigma^2$ and $S\sigma$/Skellam are consistent with poisson and negative binomial distribution baseline within errors.

- BES-II (2019-2020) will improve on Kaon's:
  - rapidity, purity, and efficiency
  - systematic control