Cumulant measurement of net-kaon distributions in Au+Au collisions at $\sqrt{s_{NN}}$ = 27 GeV from BES-II program at RHIC

Ashish Pandav(for the STAR Collaboration)
NISER, HBNI

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4. Analysis
5. Results
6. Summary

DAE-BRNS High Energy Physics (HEP) Symposium,
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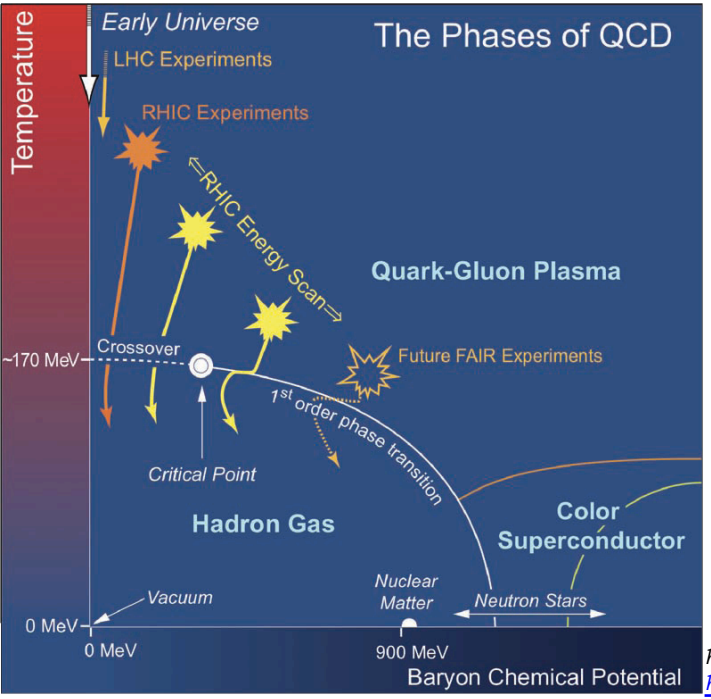
Introduction: QCD Phase Diagram



https://drupal.star.bnl.gov/STAR/starnotes/public/sn0493
https://drupal.star.bnl.gov/STAR/files/BES_WPII_ver6.9_Cover.pdf

Event Statistics in BES-I

√s (GeV)	Statistics (millions)	Year
7.7	~4	2010
11.5	~12	2010
14.5	~ 20	2014
19.6	~36	2011
27	~70	2011
39	~130	2010
54.4	~1200	2017
62.4	~67	2010
200	~350	2010

Goal: Study the phase diagram of QCD.
BES: Varying beam energy varies Temperature (T) and Baryon Chemical Potential (μ_B).
Fluctuations in various observables are sensitive to phase transition and critical point.

Results from high statistics Au+Au collisions at $\sqrt{s_{NN}}$ = 27 GeV from BES-II (taken in 2018)

Observables

- Higher moments or cumulants of net-particle distributions (B, Q, S).

$$C_1 = < N >$$
$$C_2 = < (\delta N)^2 >$$
$$C_3 = < (\delta N)^3 >$$
$$C_4 = < (\delta N)^4 > -3 < (\delta N)^2 >^2$$

$$\frac{C_2}{C_1} = \frac{\sigma^2}{M} \qquad \frac{C_3}{C_2} = S\sigma \qquad \frac{C_4}{C_2} = \kappa\sigma^2$$

- Higher order cumulants of conserved number distributions are sensitive observables.* Related to the correlation length and susceptibilities.

$C_2 \sim \xi^2$ $\quad C_4 \sim \xi^7$ *Quantitative numbers - Model dependent

$$\frac{\chi_q^{(4)}}{\chi_q^{(2)}} = \kappa\sigma^2 = \frac{C_{4,q}}{C_{2,q}} \qquad \frac{\chi_q^{(3)}}{\chi_q^{(2)}} = S\sigma = \frac{C_{3,q}}{C_{2,q}}$$

M. A. Stephanov, Phys.Rev.Lett. 107 (2011) 052301
M.A Stephanov, Phys.Rev.Lett. 102 (2009) 032301
Y. Hatta et al, Phys.Rev.Lett. 91 (2003) 102003

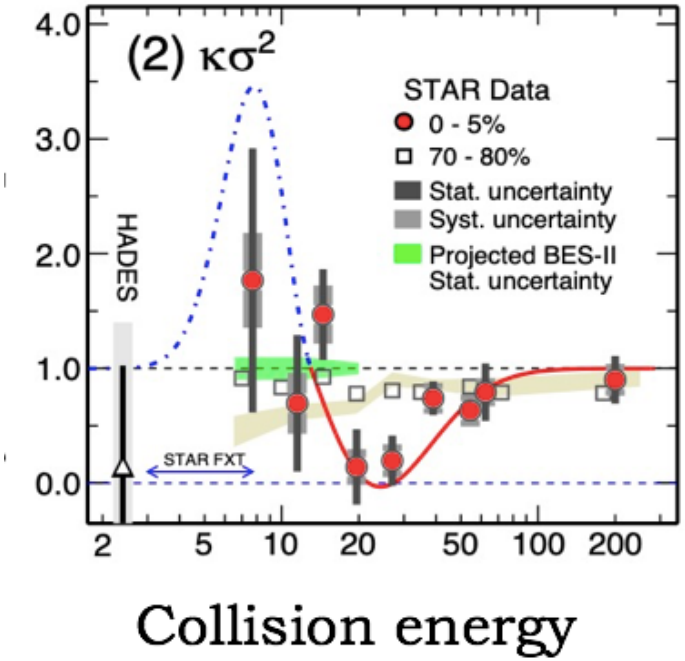
M.A Stephanov et al, Phys.Rev.Lett. 81 (1998) 4816-4819
M. A. Stephanov et al, Phys.Rev. D82 (2010) 074008
B. Berdnikov et al, Phys.Rev. D61 (2000) 105017
M. Asakawa et al, Phys.Rev.Lett. 103 (2009) 262301

Net-kaon and QCD CP

Higher moments of conserved quantity – sensitivity to QCD CP physics

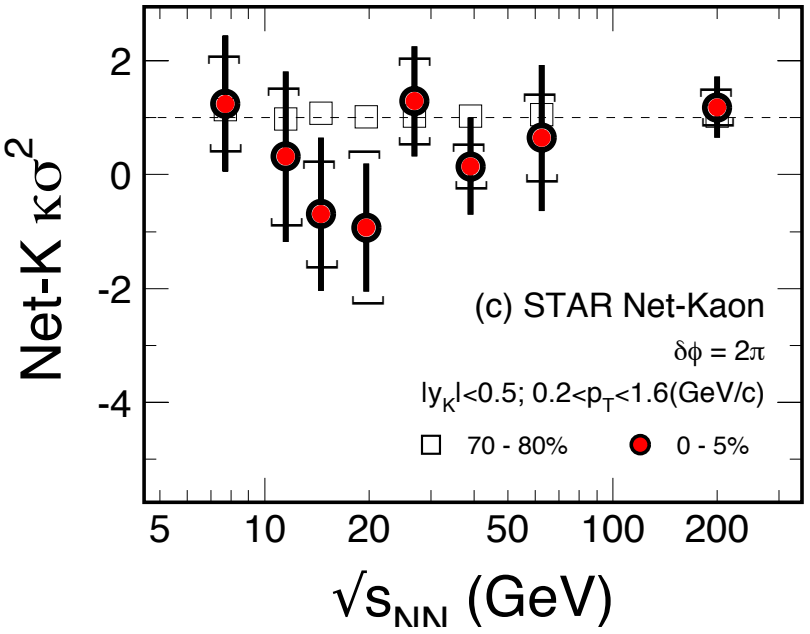
STAR: arXiv: 2001.02852

Net-proton
Observation



Phys.Lett.B 785 (2018) 551-560

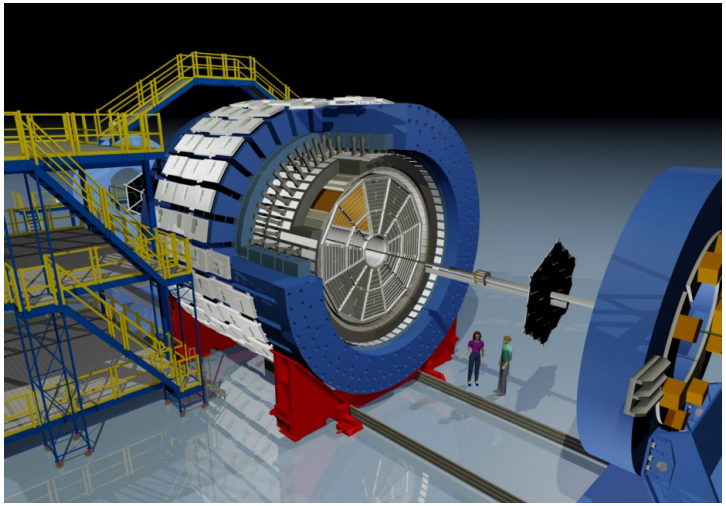
Net-kaon

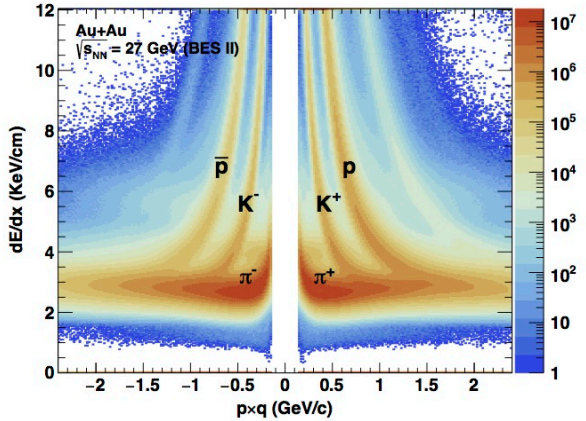


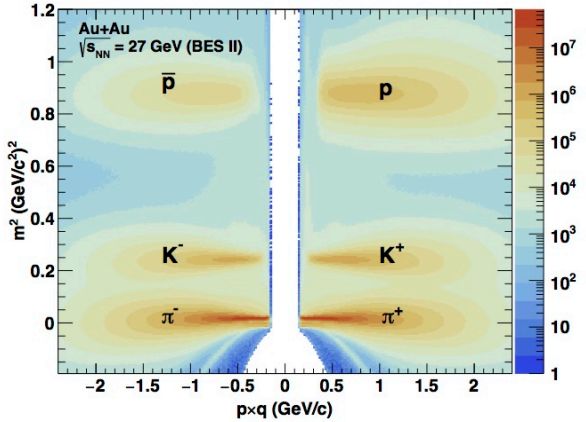
Inconclusive:
Large stat.errors

Precision measurement in BES-II important

The STAR Detector







Main Detectors: Time Projection Chamber and Time-of-Flight. **Full azimuthal angle coverage.**
$|\eta|<1$ coverage.
Uniform acceptance in p_T vs. rapidity at midrapidity for all particles.

K. H. Ackermann et al. Nucl. Instrum. Meth. A 499, 624 (2003)

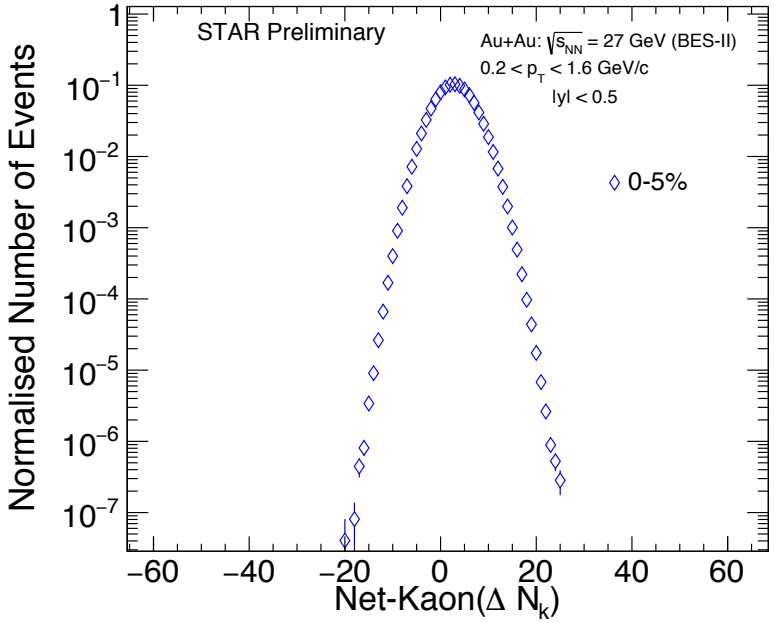
Data Set

Collision system and energy	Au+Au at $\sqrt{s_{NN}}$ = 27 GeV
Baryon Chemical Potential	~ 147 MeV
No. of events	~ 400 Millions with |Vz|< 50 cm and Vr < 2 cm
Collision centrality	0-5%
Centrality	Using charged particle multiplicity avoiding self-correlation effect
Z Vertex	+/- 50 cm
Vertex radial position	2 cm
Detectors for PID	Time Projection Chamber and Time-of-Flight

Analysis	Particle Type	Transverse Momentum Range (p_T)	Rapidity (y)
Net-kaon	Kaons (K^+ & K^-)	0.2 to 1.6 GeV/c	|y| < 0.5

p_T Range	PID by TPC	PID by TOF
0.2 to 0.4 GeV/c	$\|n\sigma_{kaon}\|$ < 2	-
0.4 to 1.6 GeV/c	$\|n\sigma_{kaon}\|$ < 2	0.15 < m^2 < 0.4 (GeV$^2/c^4$)

Event-by-Event Raw Net-Kaon Distributions



- Raw net-kaon distribution shown for 0-5% centrality.
- The distribution is uncorrected for detector efficiency.
- Statistical uncertainty on the cumulants: $err(C_r) \propto \frac{\sigma^r}{\sqrt{N_{evts}}}$

Analysis Techniques (Corrections And Uncertainties)

- Reconstruction efficiency correction - binomial model

- Centrality bin width correction

$C_n = \sum_r w_r C_{n,r}$ where $w_r = n_r / \sum_r n_r$
n=2,3,4…
Here, n_r is no. of events in r^{th} multiplicity bin

- Statistical uncertainties

1) Boot strap method.
2) Delta theorem method.
Results from both methods are consistent.

- Systematic uncertainties

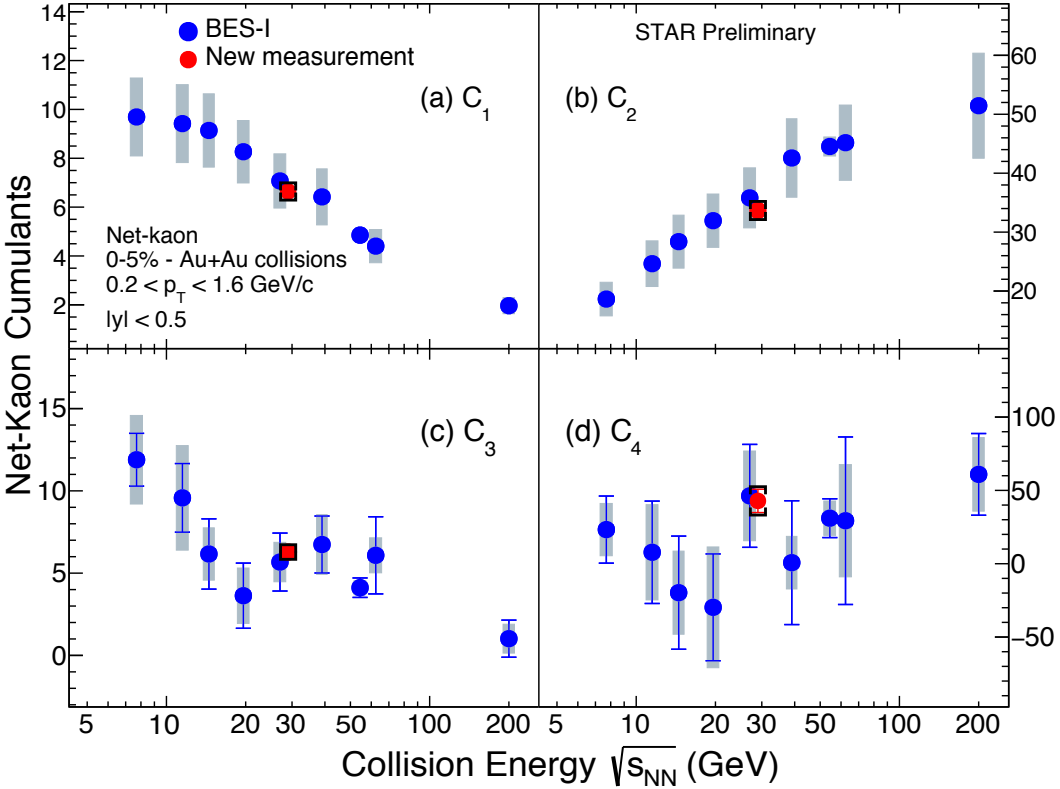
Sources:
Particle Identification
Background Estimates (DCA)
Track Quality Cuts
Efficiency variation

Net-kaon Cumulants: 27 GeV

Cumulant	σ_{stat} (0-5%)	σ_{sys} (0-5%)
C_1	0.03%	5.3%
C_2	0.07%	5%
C_3	7%	7%
C_4	19%	23%

X. Luo , Phys. Rev. C 91, (2015) 034907
T. Nonaka et al, Phys. Rev. C 95, (2017) 064912
X. Luo et al, J.Phys. G 40, 105104 (2013)
X. Luo, J. Phys. G 39, 025008 (2012)
X.Luo et al, Phys.Rev. C99 (2019) no.4, 044917
A.Pandav et al, Nucl. Phys. A 991, (2019)121608

Energy Dependence of Net-Kaon Cumulants(0-5% centrality)



Bars are for statistical uncertainty

Shaded band and caps represent systematic uncertainty

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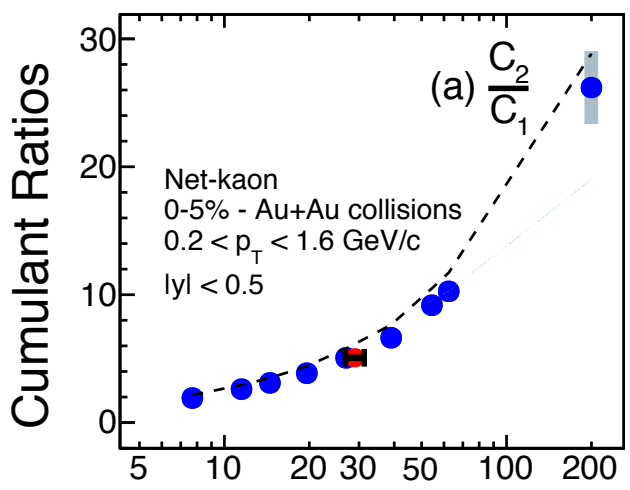
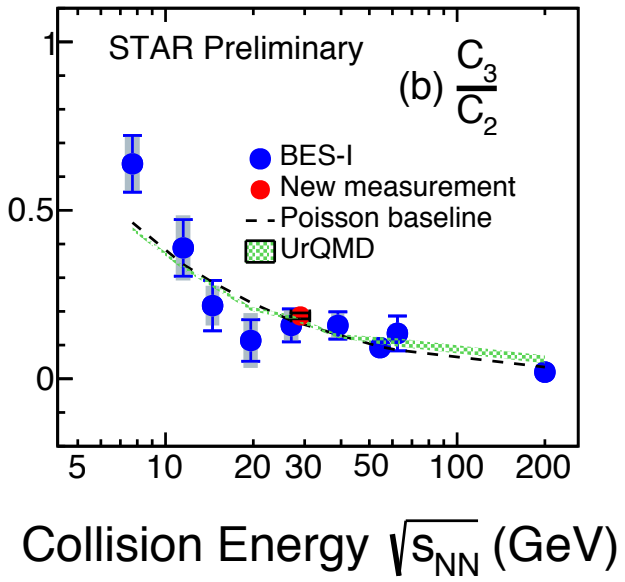
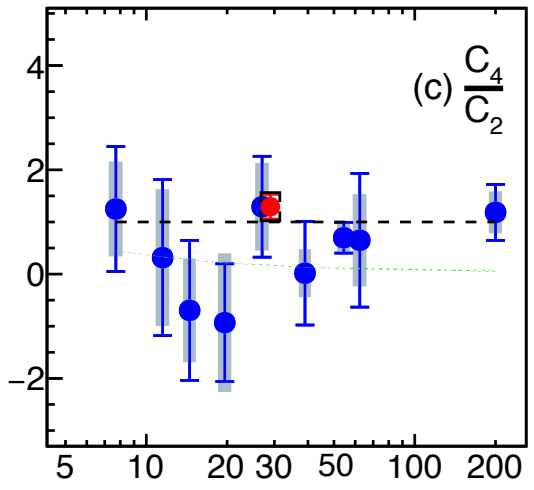
- C_1, C_3 decreases and C_2 increases with increasing collision enrgy.
- C_4 shows weak collision energy dependence.
- New measurement at 27 GeV consistent with with previous measurement at 27 GeV in BES-I and follows the BES-I trend.

Energy Dependence of Net-Kaon Cumulant Ratios(0-5% centrality)







New measurement at 27 GeV(red marker) and 54.4 GeV are STAR preliminary
Other BES-I data, published in *Phys.Lett.B 785 (2018) 551-560*

- C_2/C_1 increases with increasing collision energy whereas C_3/C_2 shows decreasing trend.
- C_4/C_2 shows weak collision energy dependence.
- New measurement at 27 GeV is consistent with BES-I measurement's trend.
- UrQMD model and Poisson baseline qualitatively describe the observed collision energy dependence.

Summary

- The first measurements of net-kaon cumulants (up to the fourth order) for 0-5% central Au+Au collisions at $\sqrt{s_{NN}}$ = 27 GeV at BES-II are presented.

- The cumulant and cumulant ratios of net-kaon:
  - C_1, C_2, C_3 and ratios C_2/C_1, C_3/C_2 show strong collision energy dependence.
  - C_4 and C_4/C_2 exhibit weak collision energy dependence.

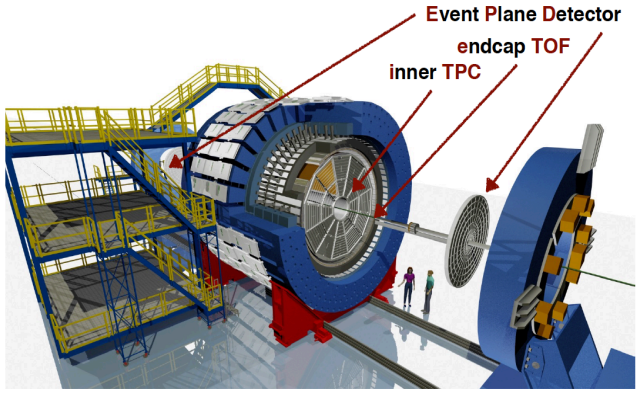
- The new measurement of cumulants of net-kaon distribution and their ratios at BES-II are consistent with those at 27 GeV in BES-I and follows the BES-I energy dependence.

- The collision energy dependence of cumulant ratios is only qualitatively reproduced by the UrQMD model and Poisson baseline.

Outlook:.

- Perform fluctuation measurements with high statistics Au+Au collision data at other energies from BES-II program at RHIC.

Outlook: Ongoing Beam Energy Scan Phase – II at RHIC



Collider Mode

√s (GeV)	Statistics (Millions) – BES-I	Statistics (Millions) – BES-II
7.7	~4 (year: 2010)	**~100**
9.1	~0.003(2008)	**~160**
11.5	~12(2010)	**~230**
14.5	~ 20(2014)	**~300**
19.6	~36(2011)	**~400**

FXT Mode

√s (GeV)	Statistics (Millions)-BES-II
7.7	**~160**
6.2	**~120**
5.2	**~100**
4.5	**~100**
3.9	**~120**
3.5	**~120**
3.2	**~200**
3.0	**~260**

iTPC	EPD	eTOF
Larger rapidity coverage $\|\eta\| < 1.5$	$2.1 < \|\eta\| < 5.1$	$-1.6 < \eta < 1.0$
Better dE/dx resolution	Centrality determination at forward rapidity	PID extended to forward rapidity
Lower momentum acceptance > 0.1 GeV/c	Better event plane resolution	Better particle identification

BES-II Program will allow:

→ Precision measurement to study the QCD phase diagram.

→ Extend the μ_B coverage up-to ~720 MeV (FXT program)

https://drupal.star.bnl.gov/STAR/starnotes/public/sn0598

THANK YOU