Higher moments measurement of net-Kaon, net-charge and net-proton multiplicity distribution at STAR

Amal Sarkar
(for the **STAR** collaboration)
Indian Institute of Technology Bombay, Mumbai

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STAR

Outline

- **Motivation**

  - QCD phase diagram, Critical Point, Beam Energy Scan
- **Higher Moments**

  - Relation with the correlation length
- **Experimental Setup and Data Analysis**

  - The STAR detector and particle identification
- **Results**

  - Net-Kaon
  - Net-charge
  - Net-proton
- **Summary**

Motivation QCD phase diagram, critical point, BES

- **Smooth crossover at $\mu_B \sim 0$.**

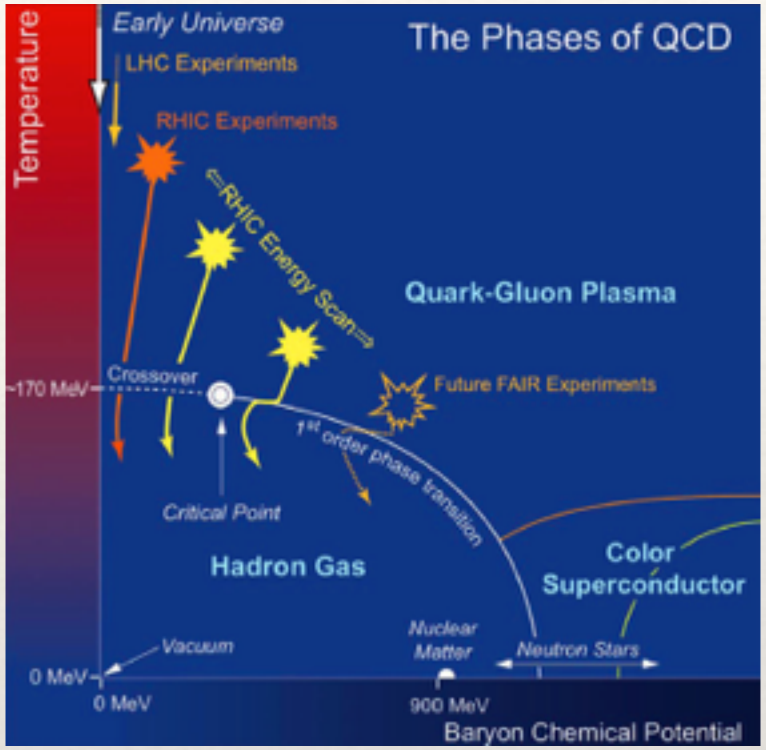
STAR Collaboration, arXiv:1007.2613 (2010), M. Cheng, et al., Phys. Rev. D 79 (2009) 074505

- **1st order transition at large μ_B is expected.**

S. Ejiri, Phys. Rev. D 78,074507 (2008); E.S. Bowmanand J. I. Kapusta, Phys. Rev. C 79, 015202 (2009)

- **End point of the 1st order transition line**
  ➢ **Critical Point(CP)**

M. A. Stephanov, Phys. Rev. Lett. 107, 052301(2011), Phys. Lett. B 695 (2011) 136

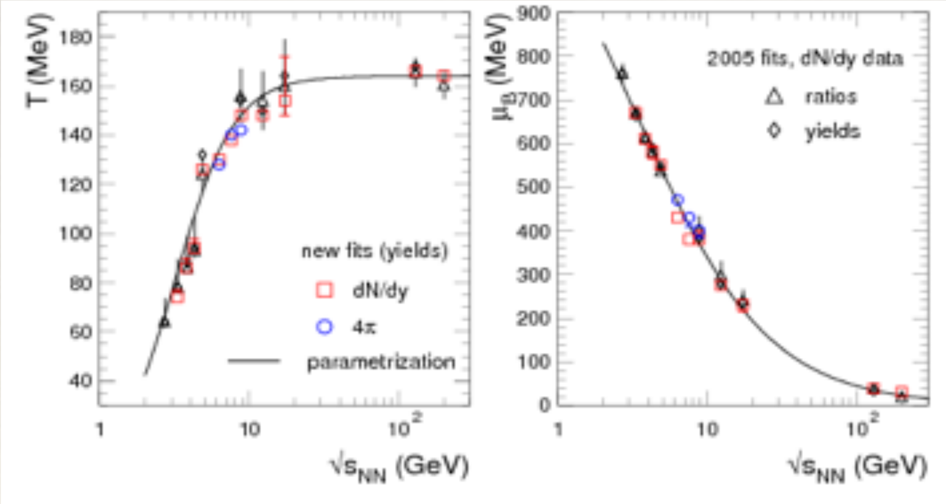


STAR Note 0598

RHIC BES program in STAR

Varying $\sqrt{s_{NN}}$ ➠ vary T and μ_B

QCD phase diagram can be mapped



Adronic et al., Nucl.Phys.A772:167 (2006)

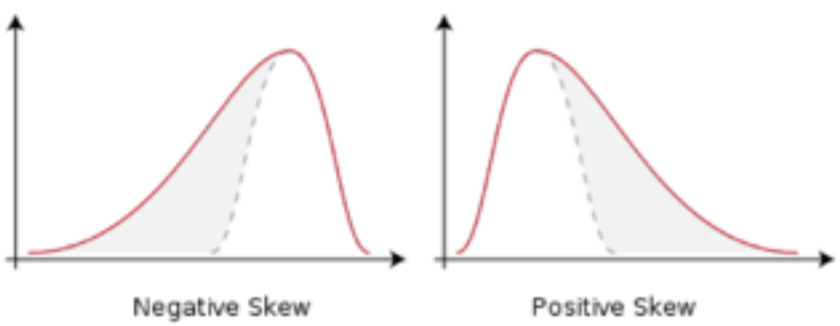
The Beam Energy Scan (BES) program was carried out in the years 2010 & 2011. It extended μ_B range from 20 MeV to 400 MeV.

Higher Moments
Relation with the correlation length

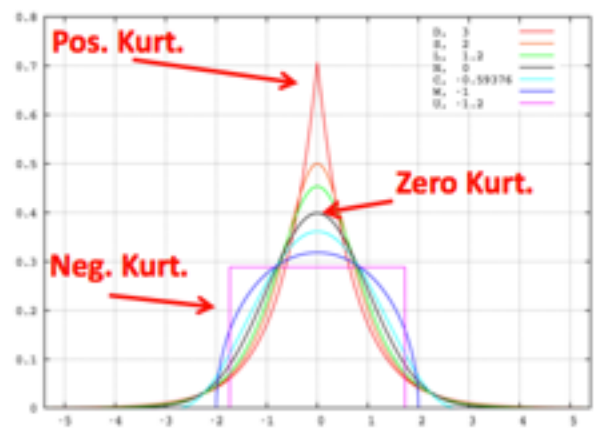
Definition : N: Event by Event Multiplicity Distribution

Mean: $M = \langle N \rangle$ St. Deviation: $\sigma = \sqrt{\langle (N - \langle N \rangle)^2 \rangle}$

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



src: Wikipedia



src: Wikipedia

➢ For Gaussian distribution, the skewness and kurtosis are equal to zero. Ideal probe of the non-Gaussian fluctuations near the QCD Critical Point.

Non-linear sigma model(NLSM)

A strong dependence of experimentally measured moments on the correlation length(ξ)

Athanasiou et al., Phys.Rev. D82 (2010) 074008

$\sigma^2 \sim \xi^2$, $S \sim \xi^{4.5}$, $k \sim \xi^7$

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

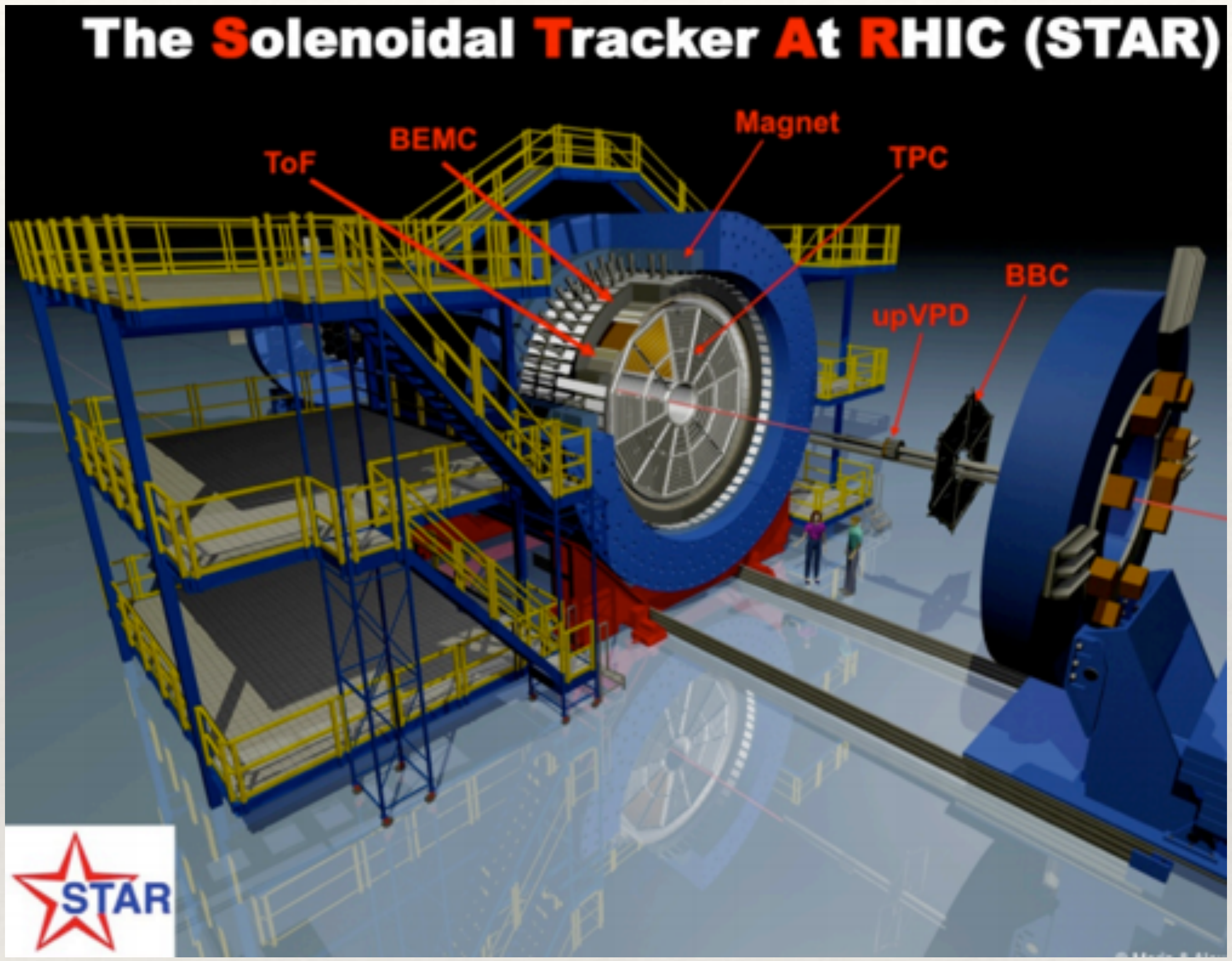
NLSM

Near the critical point ξ diverges. → **Higher order moments of multiplicity distribution** ← Susceptibilities calculated on the lattice.

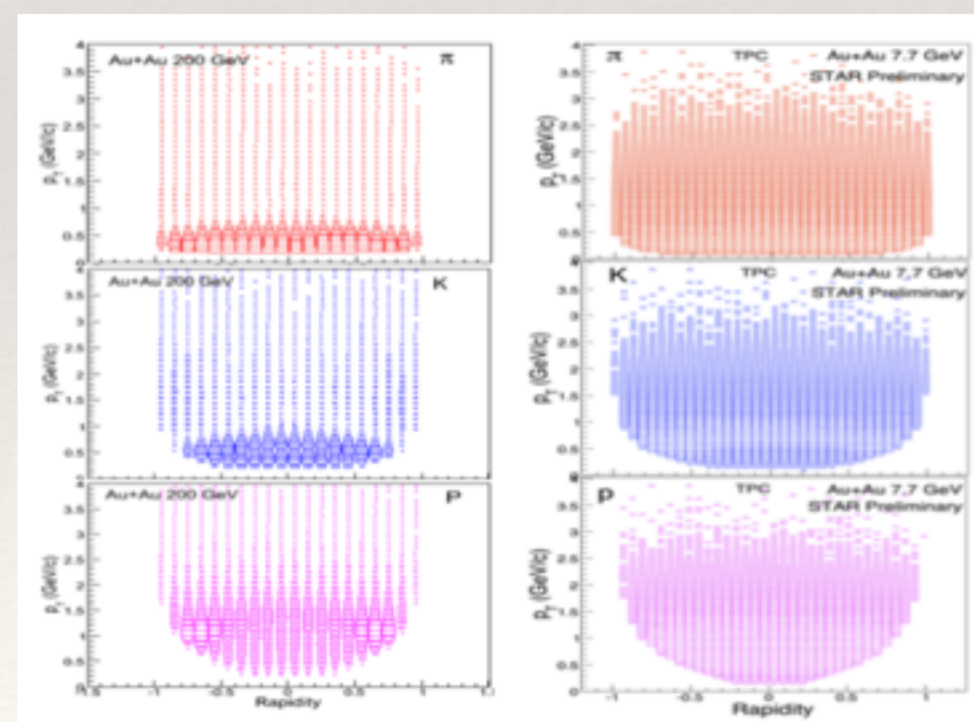
Experimental observable for critical point → Non monotonic variation of moments with center of mass energy

Experimental setup

The STAR detector



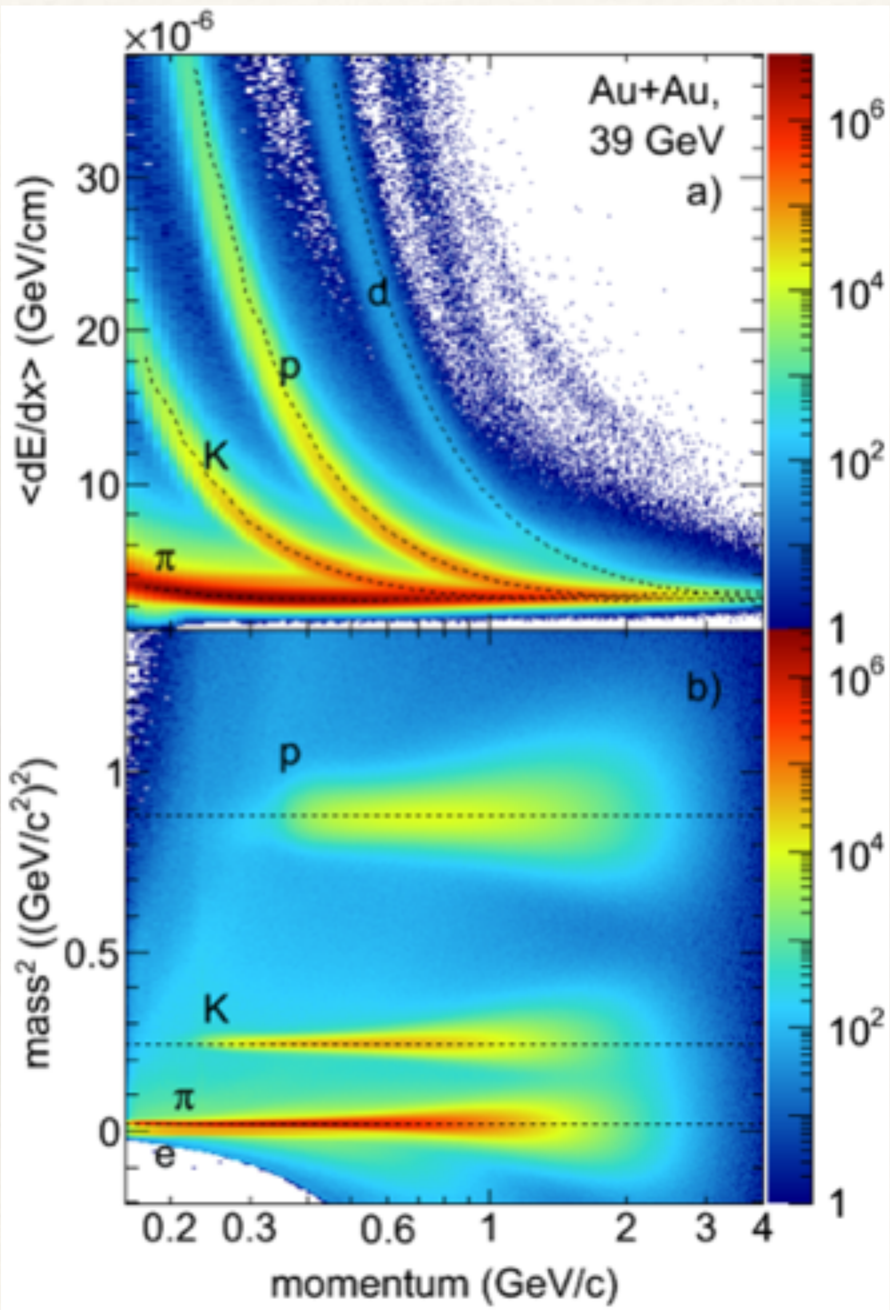
Energy (GeV)	Year	Events (10
7.7	2010	5
11.5	2010	12
19.6	2011	36
27	2011	70
39	2010	130
62.4	2010	67
200	2010	340



STAR detector has full 2π coverage and uniform acceptance at mid-rapidity.

STAR Collaboration, Nucl.Instrum.Meth. A558(2006) 419-429.,
STAR Collaboration, Nuclear Physics A (vol. 774, pp. 956-958,2006).

Data analysis Particle identification and centrality selection



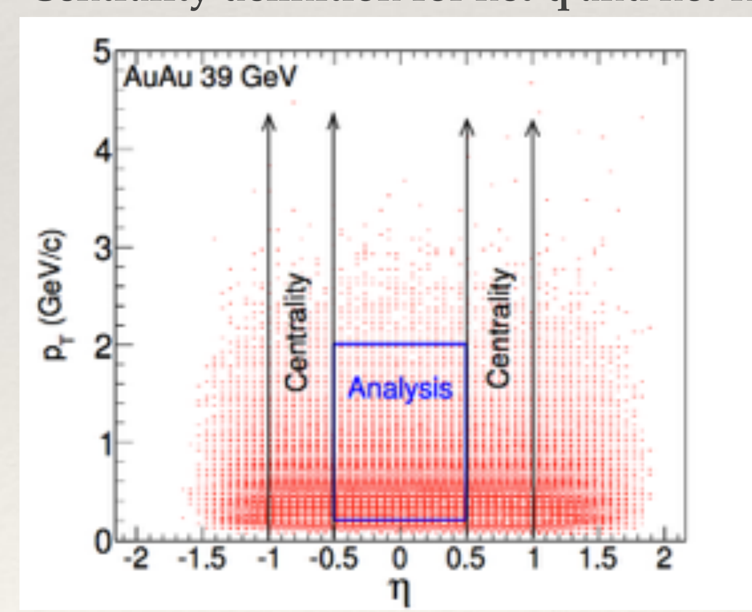
Particle Identification

net-charge	net-proton	net-Kaon
$0.2 < p_T\,(GeV/c) < 2.0$ $\lvert\eta\rvert \leq 0.5$ proton p_T>0.4 (reject spallation)	$0.4 < p_T\,(GeV/c) < 0.8$ $\lvert y\rvert \leq 0.5$	$0.2 < p(GeV/c) < 1.6$, $\lvert\eta\rvert \leq 0.5$ $0.22 < m^2\,(GeV/c^2) < 0.265$

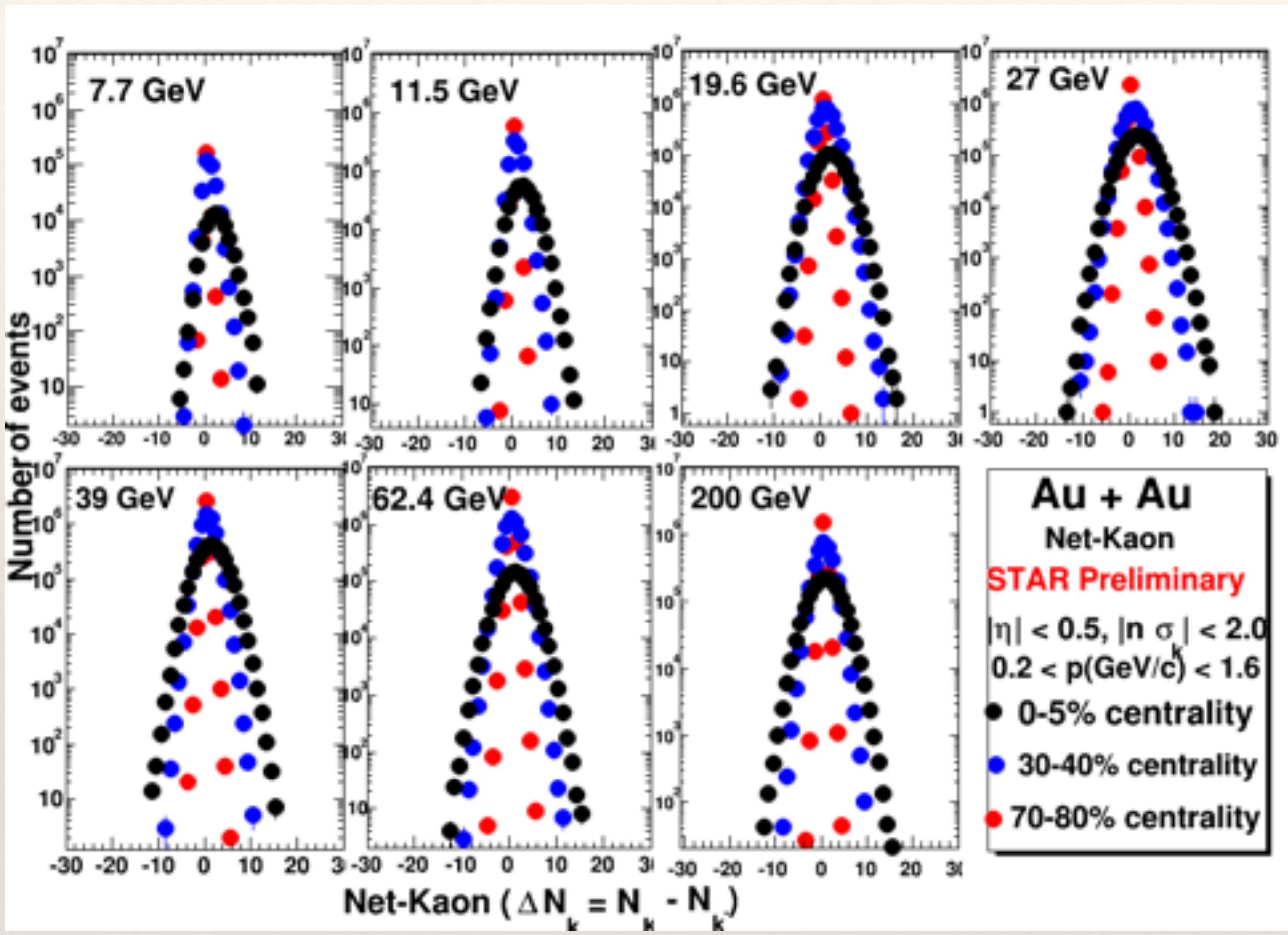
Centrality Selection

The centrality selection utilized the uncorrected charged particle multiplicity measured by the TPC within the pseudo rapidity $0.5 < |\eta| < 1.0$ for net-charge & net-Kaon. Pion and Kaons in $|\eta|<1$ for net-proton.

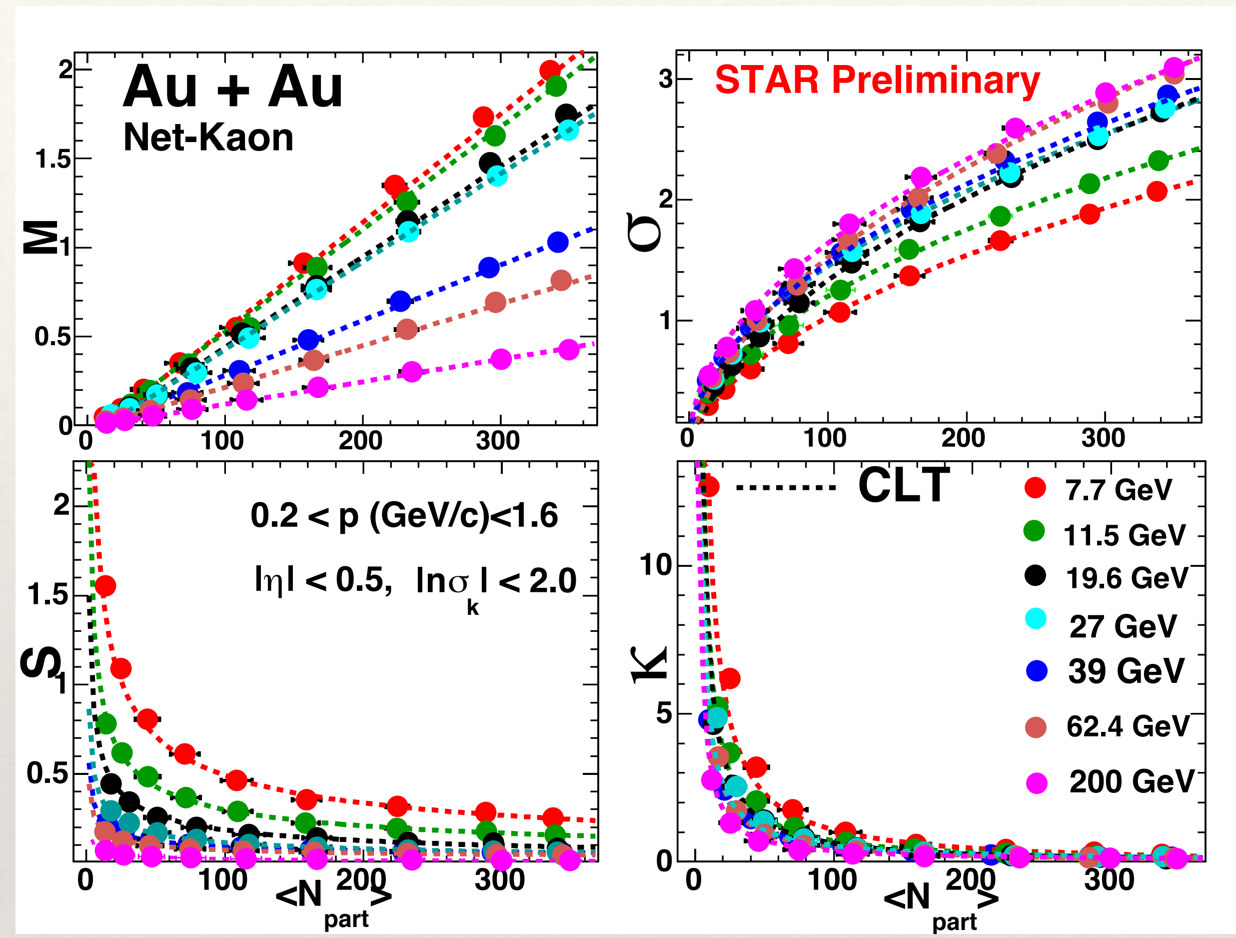
Centrality definition for net-q and net-k



Results Net-Kaon



Event by event net-Kaon

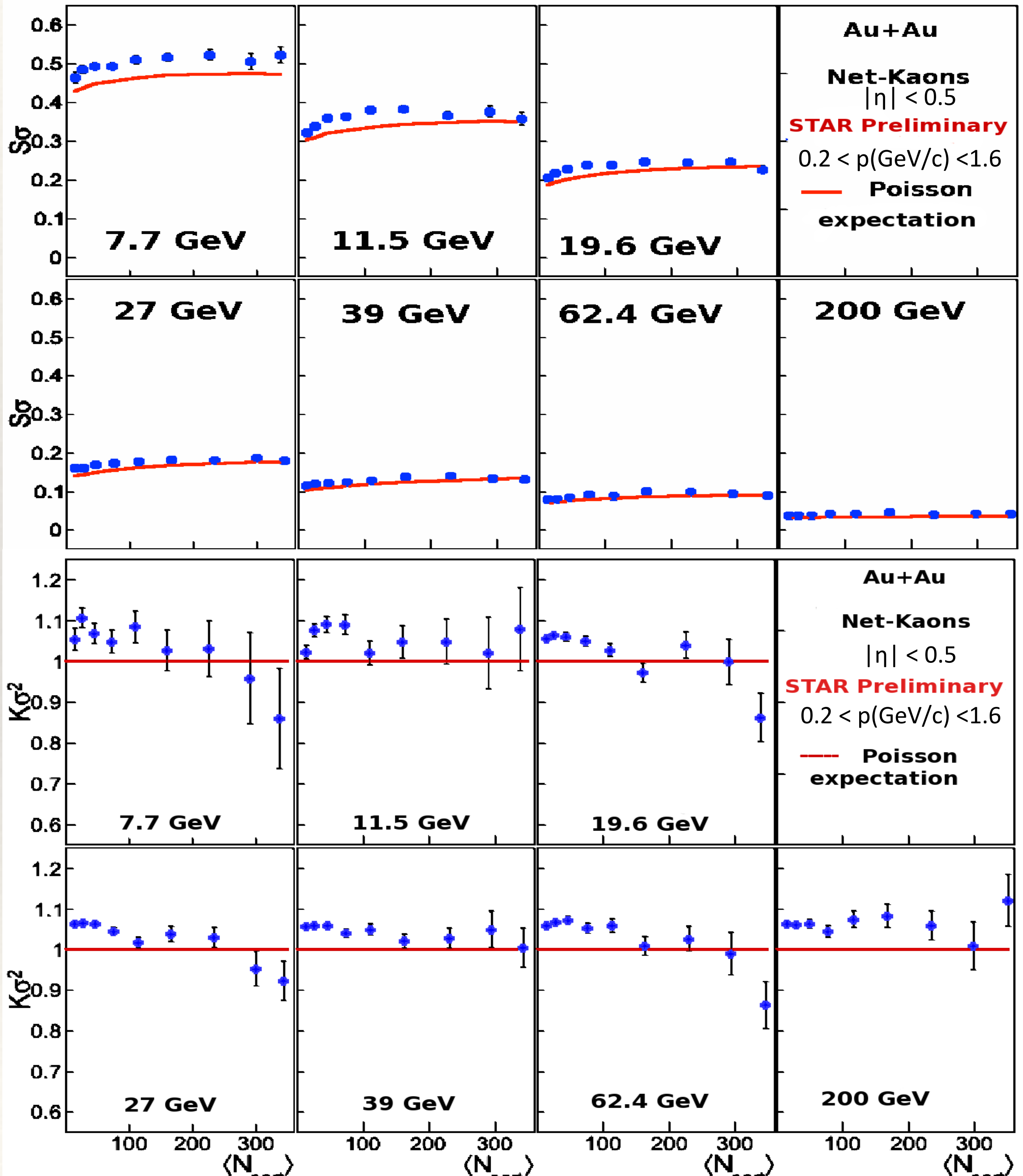


Moments of net-Kaon distribution
Lines are CLT expected

Delta Theorem has been used for error estimation X. Luo, J. Phys. G 39, 025008 (2012)

These results are not efficiency corrected.

Results Net-Kaon



Sσ value is greater than Poisson baseline for beam energy below 200 GeV.

Sσ increase with decreasing collision energies.

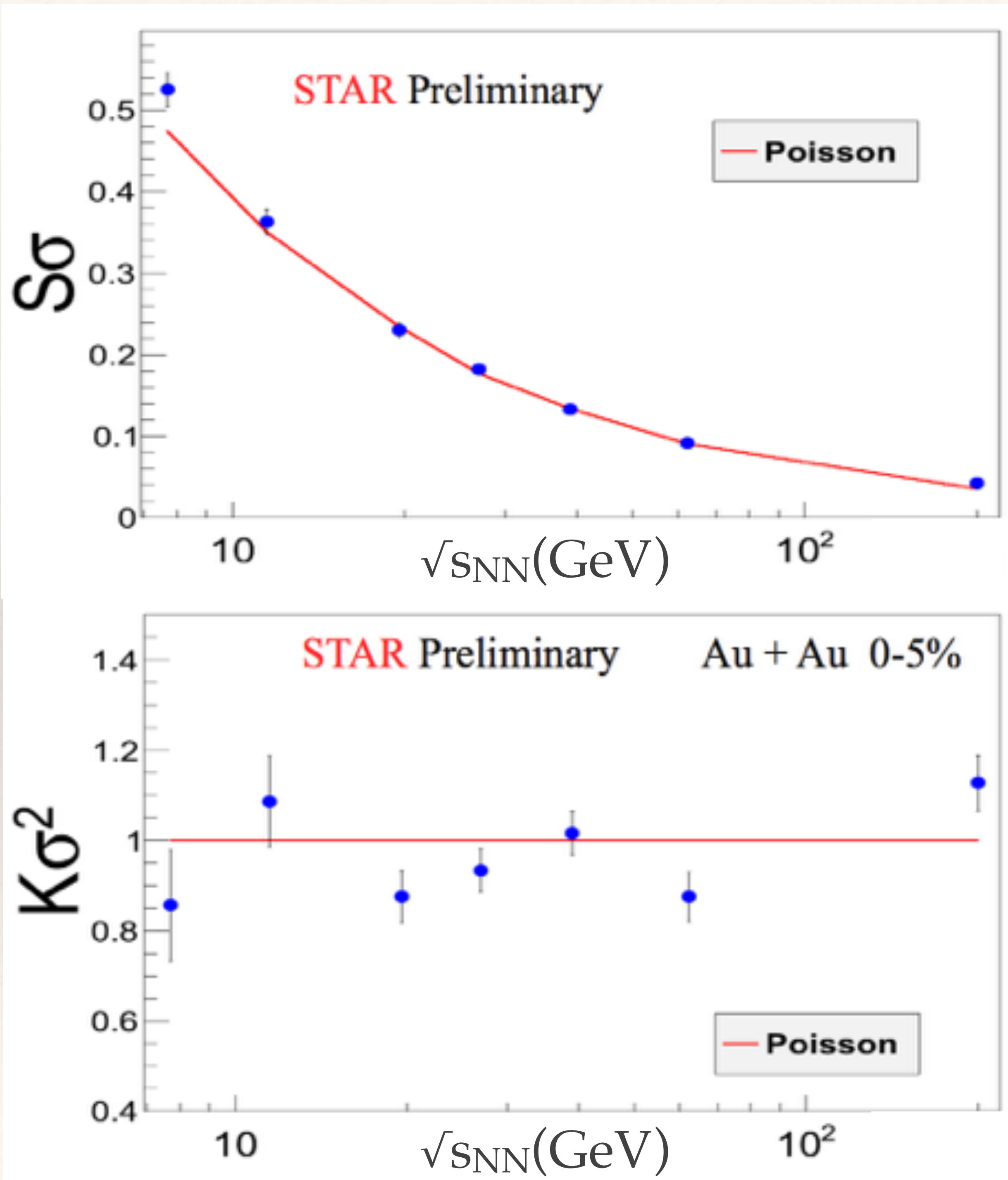
kσ^2 is fairly constant with centrality

These results are not efficiency corrected.

The systematic error study and efficiency correction is ongoing for this analysis.

"Baseline for the energy dependence of higher moments of net-proton multiplicity distribution"
Dr. Xiaofeng Luo

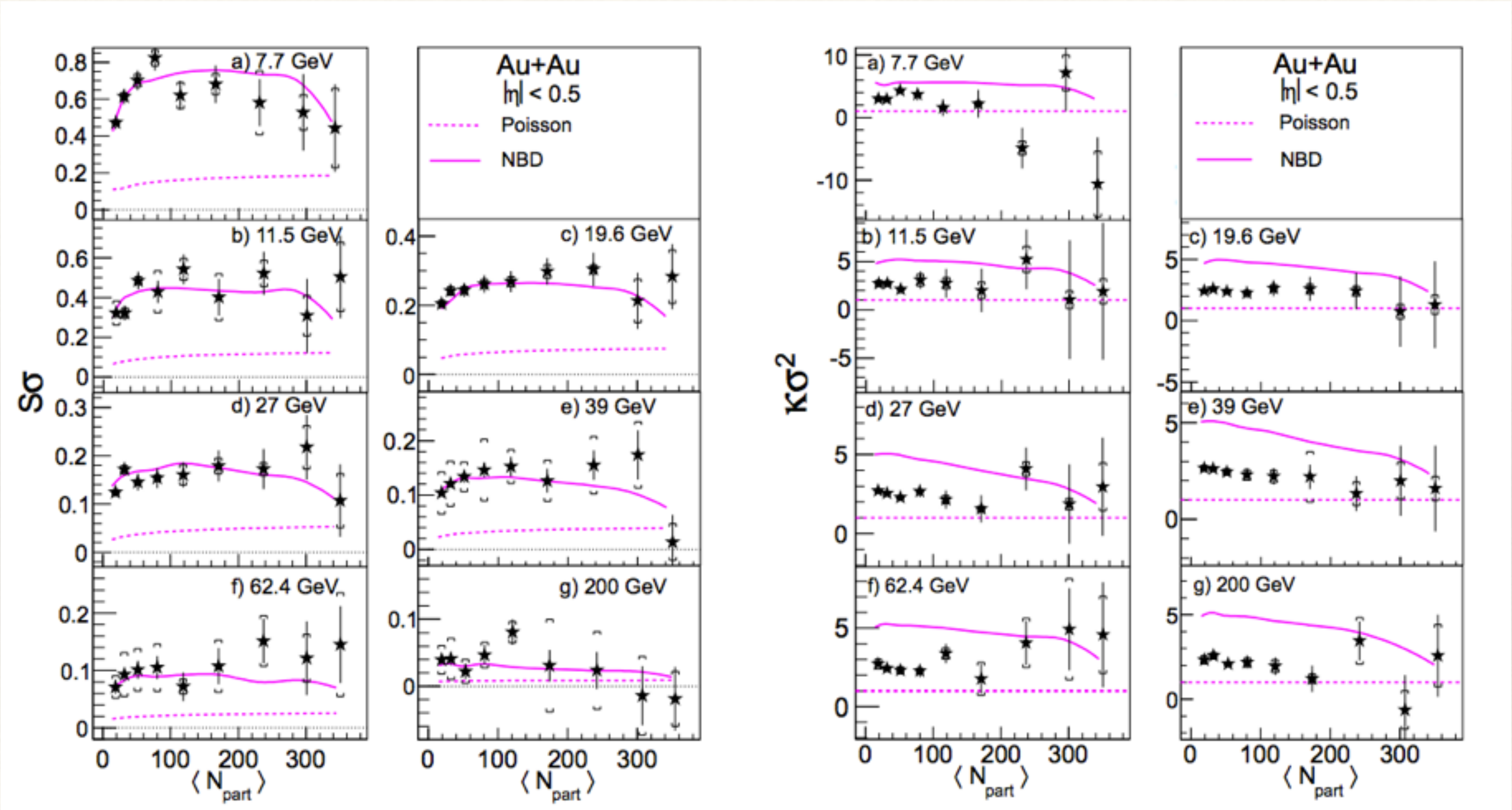
Results Net-Kaon



These results are not efficiency corrected.

The systematic error study and efficiency correction is ongoing for this analysis.

Results Net-charge



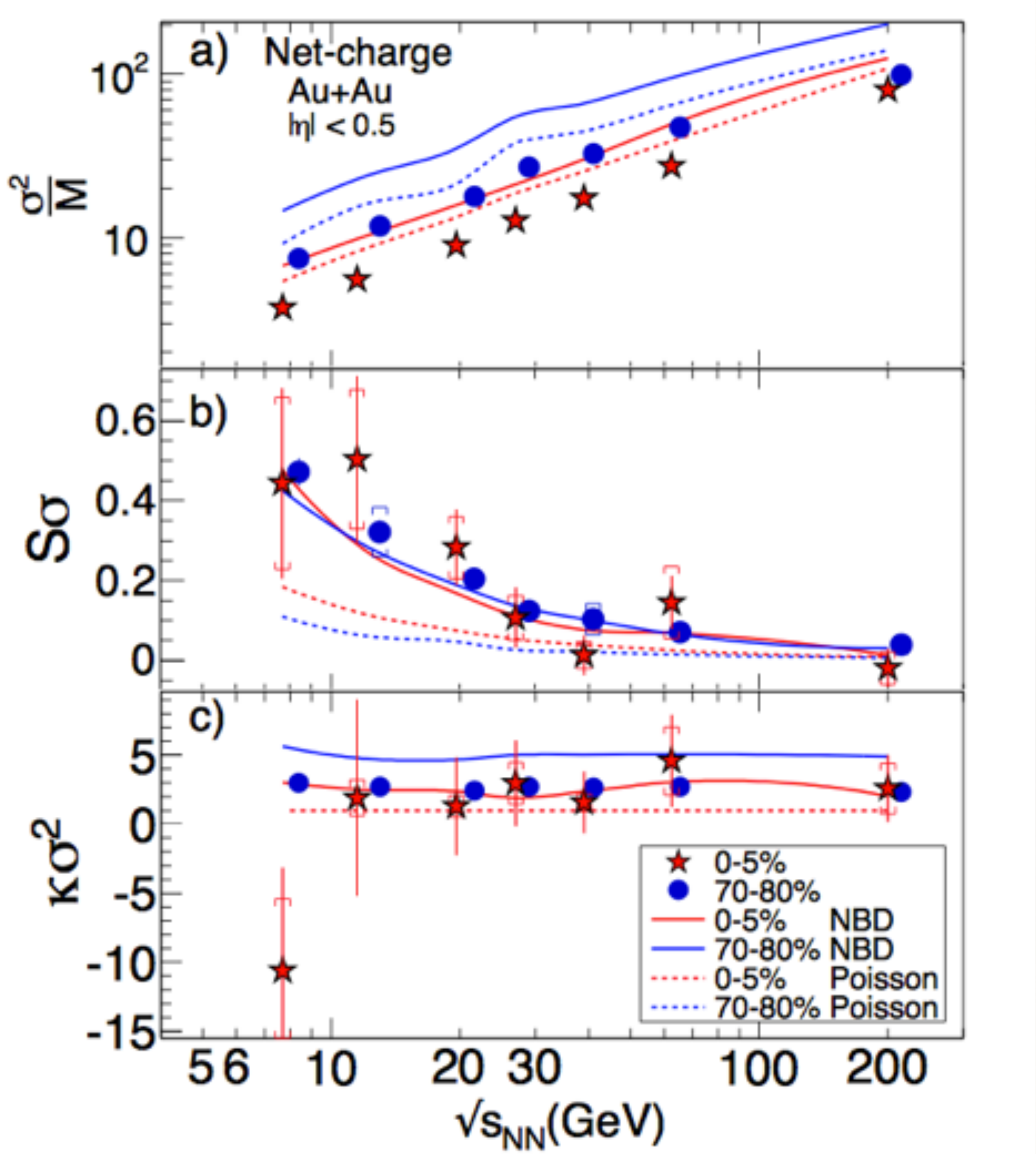
Weak centrality dependence is observed for both Sσ and $\kappa\sigma^2$ at all energies.

All net-charge results are corrected for detector efficiency.

Submitted to **PRL**

arXiv.1402.1558

Results Net-charge



All net-charge results are corrected for detector efficiency.

We observe that the σ^2/M values increase monotonically with increasing beam energy.

The $S\sigma$ values increase with decreasing beam energy. These values deviate from Poisson baseline, but are close to NBD baseline.

The values of $\kappa\sigma^2$ are observed to be within the two baseline distributions.

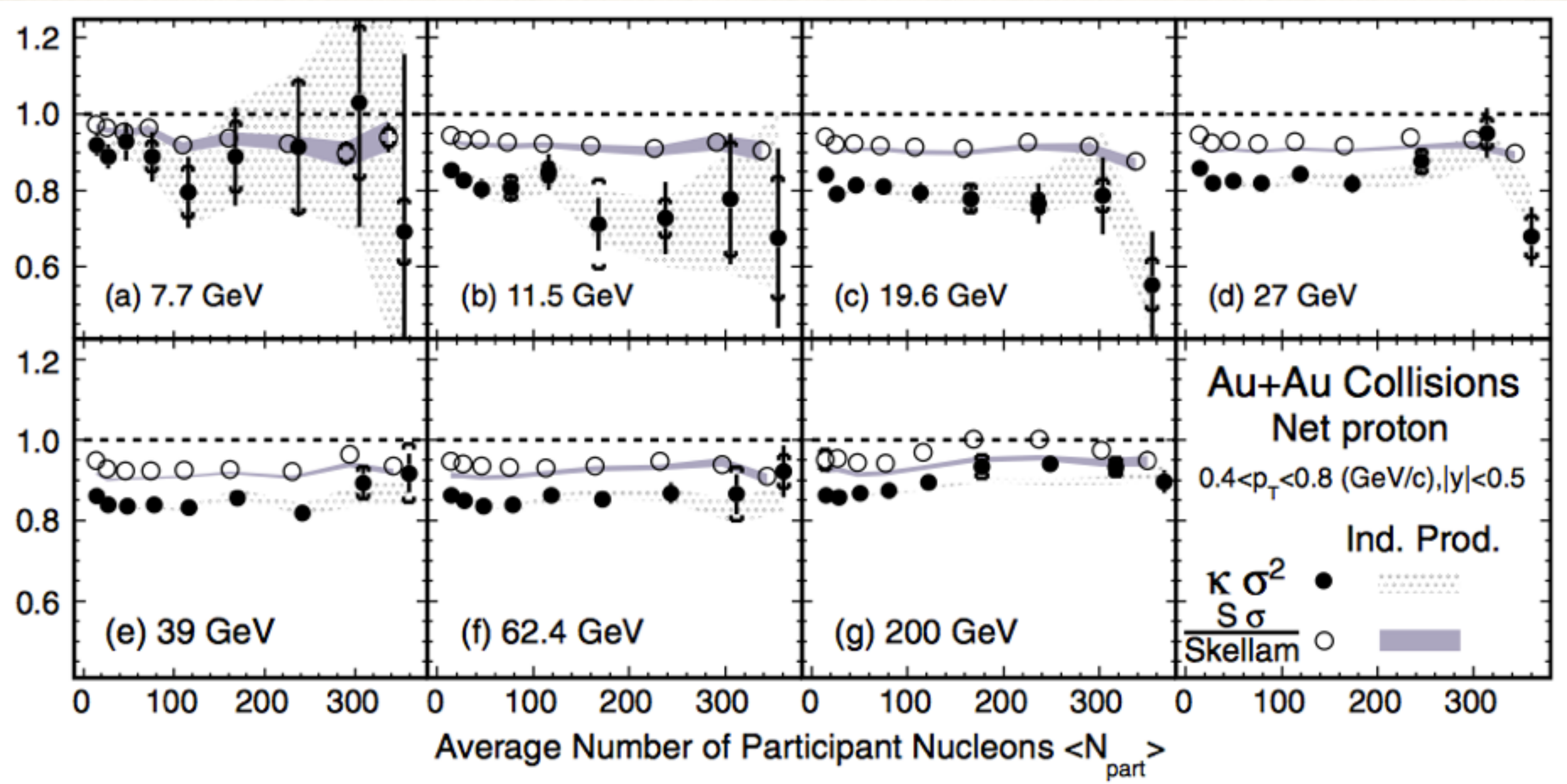
Lattice and HRG analysis of STAR net-charge data for central collisions give a freeze out temperature in the range 135-151 MeV and for μ_B values in the range 326-23 MeV for center of mass energy 7.7-200 GeV.

S. Borsanyi et al., arXiv:1403.4576 [hep-lat]
P. Alba et al., arXiv:1403.4903 [hep-ph]
A. Bazavov et al., PRL 109, 192302 (2012)

Submitted to **PRL**

arXiv1402.1558

Results Net-proton

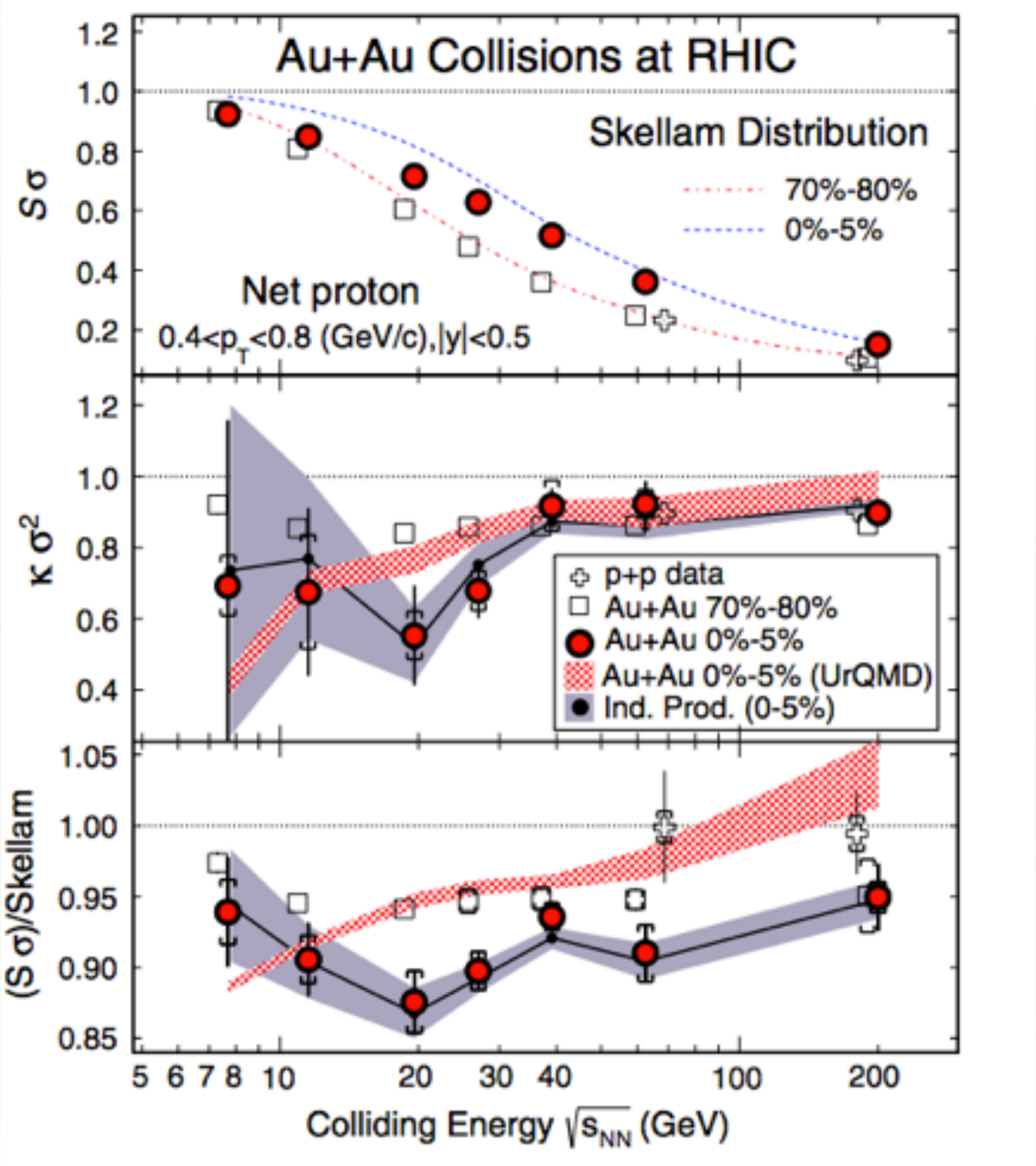


STAR, Phys. Rev. Lett. 112, 032302 (2014).

The results from independent production are found to be in good agreement with the data.

All net-proton results are corrected for detector efficiency.

Results Net-proton



The S**σ** values below 39 GeV, show differences between 0–5% and 70-80% Au + Au collisions. The results are closer to unity for 7.7 GeV.

For the top 0-5% central collisions $\kappa\sigma^2$ show some deviation from Skellam expectation below 39 GeV.

The significance of deviations of 0%–5% Au + Au data from Skellam expectations, are found to be greatest for 19.6 and 27 GeV, with values of 3.2σ and 3.4σ for $\kappa\sigma^2$ and 4.5σ and 5.6σ for Sσ, respectively.

$$\text{deviation} = ((\,|\,\text{data - Skellam}\,|\,)/\sqrt{(err_{stat}^2 + err_{sys}^2)})$$

STAR, Phys. Rev. Lett. 112, 032302 (2014).

All net-proton results are corrected for detector efficiency.

Summary

1. The higher moments of net-charge (ΔN_{ch}), net-Kaon (ΔN_K) and net-proton (ΔN_p) distribution studied for BES energies.

2. Within the uncertainty no non-monotonic behavior has been observed in the product of moments of Net-charge (ΔN_{ch}) distribution as a function of collision energy.

3. The systematic errors study and efficiency correction are going on in net-Kaon (ΔN_K) analysis.

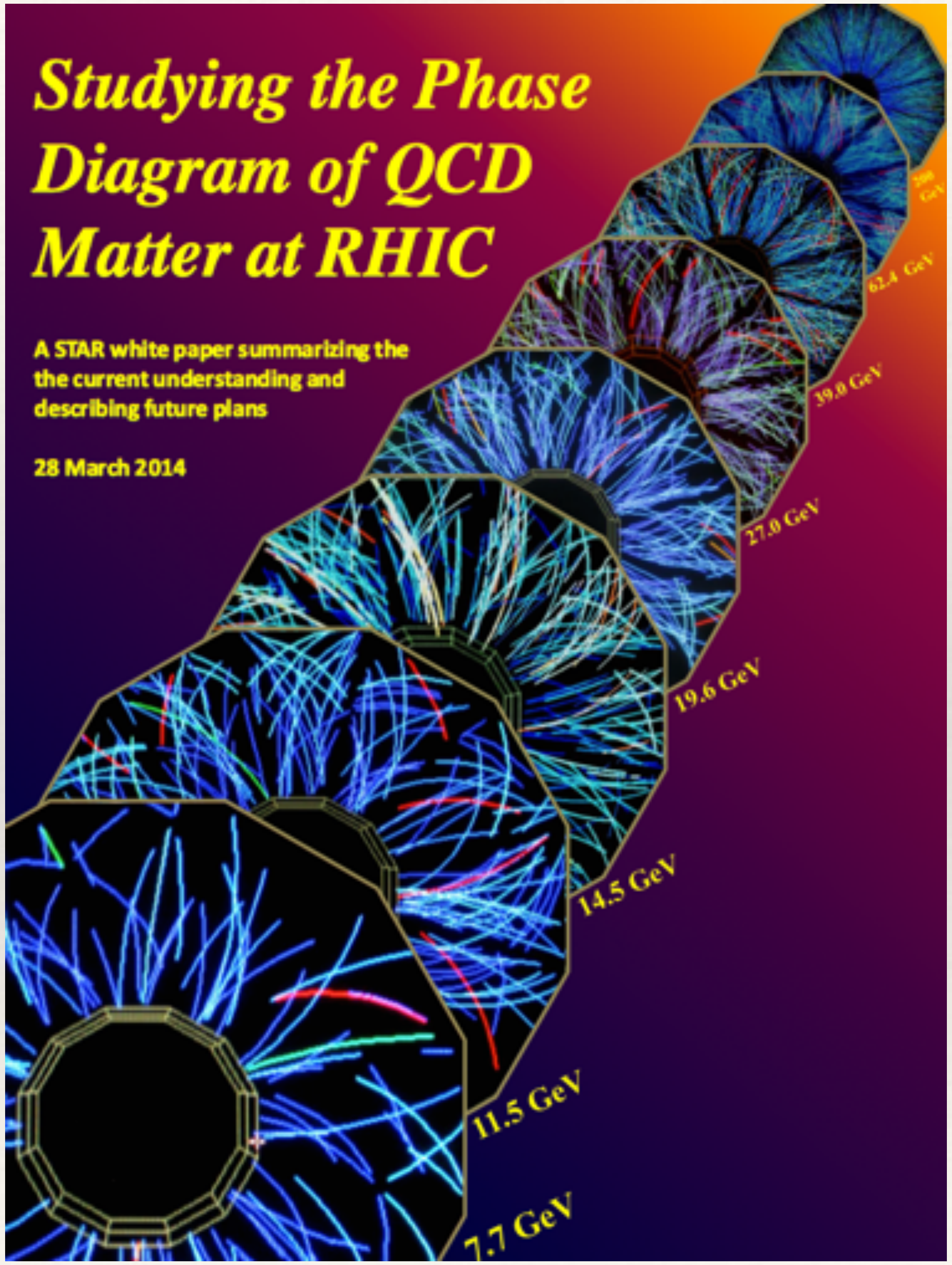
4. Significant deviations of moment products from Skellam expectations, are found in net-proton analysis. The deviation are found to be greatest for 19.6 and 27 GeV.

5. Lattice and HRG analysis of STAR net-charge and net-proton data for central collisions give a freeze out temperature in the range 135-151 MeV and μ_B values in the range 326-23 MeV for center of mass energy 7.7-200 GeV

Looking forward for the BES-II program.

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

Thank you …



Back up

Skellam distribution $f(k;\mu_1,\mu_2) = e^{-(\mu_1+\mu_2)}\left(\frac{\mu_1}{\mu_2}\right)^{k/2} I_{|k|}(2\sqrt{\mu_1\mu_2})$

The Poisson baseline has been calculated from the mean value of the $N_K^{+(}$ (μ_1) and N_K^{-} (μ_2) distribution.

Mean (M) = $\mu_1 - \mu_2$

Variance (σ^2) = $\mu_1 + \mu_2$

Skewness (S) = $(\mu_1 - \mu_2)/(\mu_1 + \mu_2)^{3/2}$

and kurtosis (κ) = $1/(\mu_1 + \mu_2)$

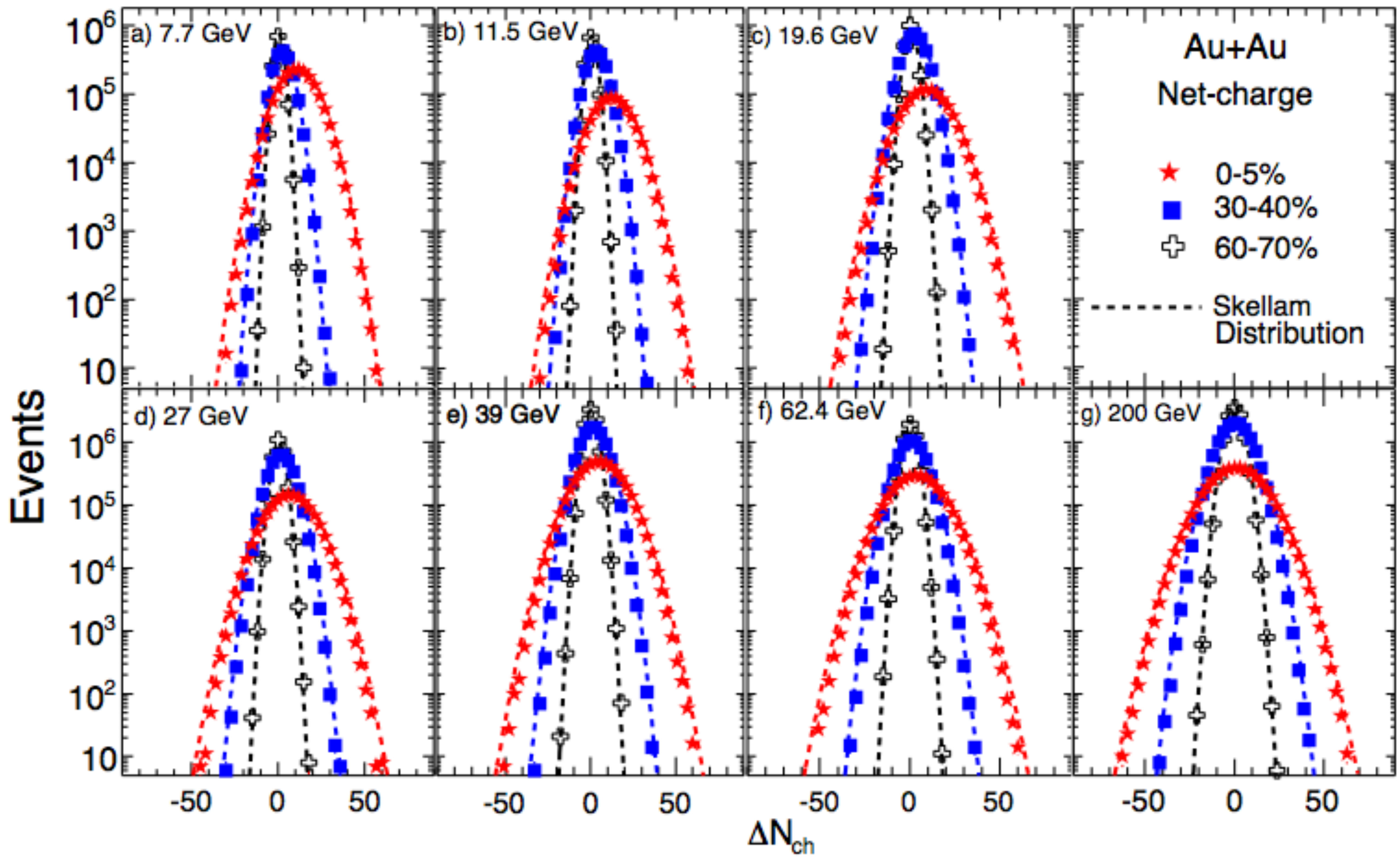
And the volume independent moment products,

$S\sigma = (\mu_1 - \mu_2)/(\mu_1 + \mu_2)$

and $\kappa\sigma^2 = 1$

Results : Net-charge

Net-charge distribution



The mean of net-charge (ΔN_{ch}) distribution shifts towards zero from low to high energies.

Results Net-charge

The four moments (M, σ, S, and k) which describe the shape of the ΔN_{charge} distributions at various collision energies are plotted as a function of average number of participants < N_{part} >. The results are corrected for the finite centrality bin width effects. X. Luo [STAR Collaboration], J. Phys. Conf. Ser.316, 445 012003 (2011).

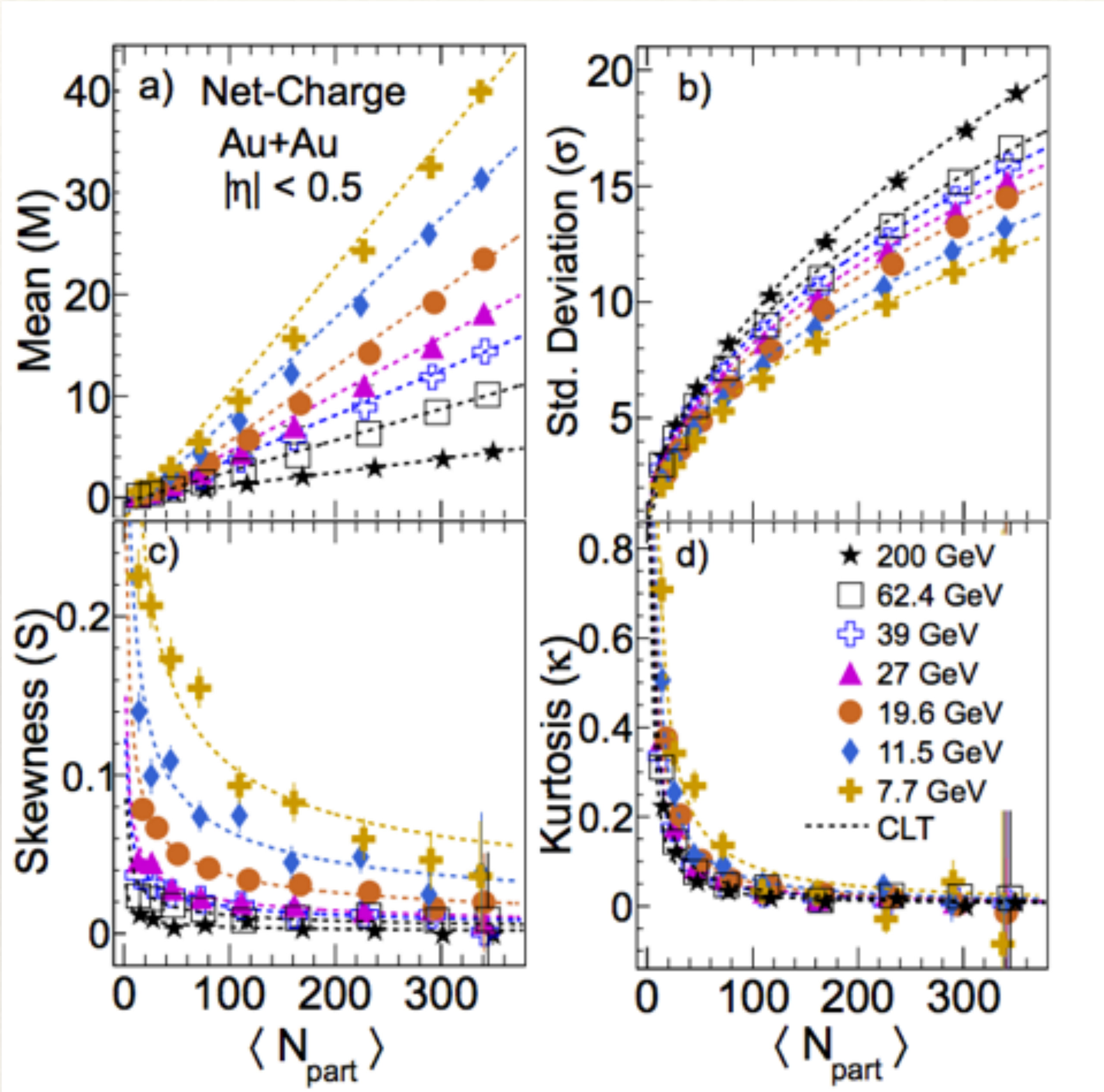
Moments fitted with it's predicted dependence function from Central Limit Theorem (CLT), goes as it's volume's x, √x, 1⁄√x and 1/x respectively (the dotted lines).

The moments follow the CLT well.

All net-charge results are corrected for detector efficiency.

A. Bzdak and V. Koch, Phys. Rev. C 86, 044904 (2012)

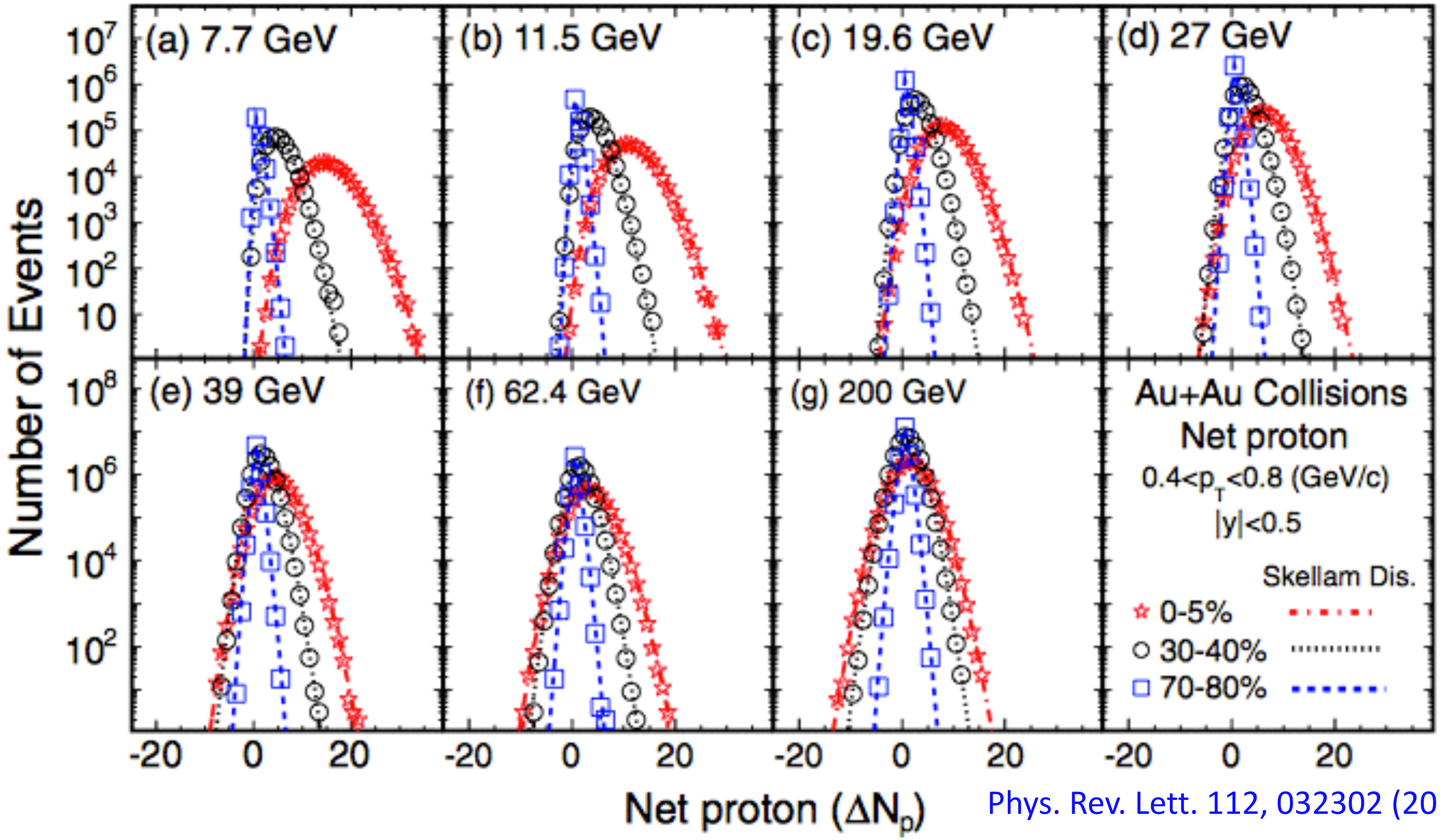
Sangaline at WWND'13



Submitted to **PRL**

arXiv1402.1558

Net-Proton distribution



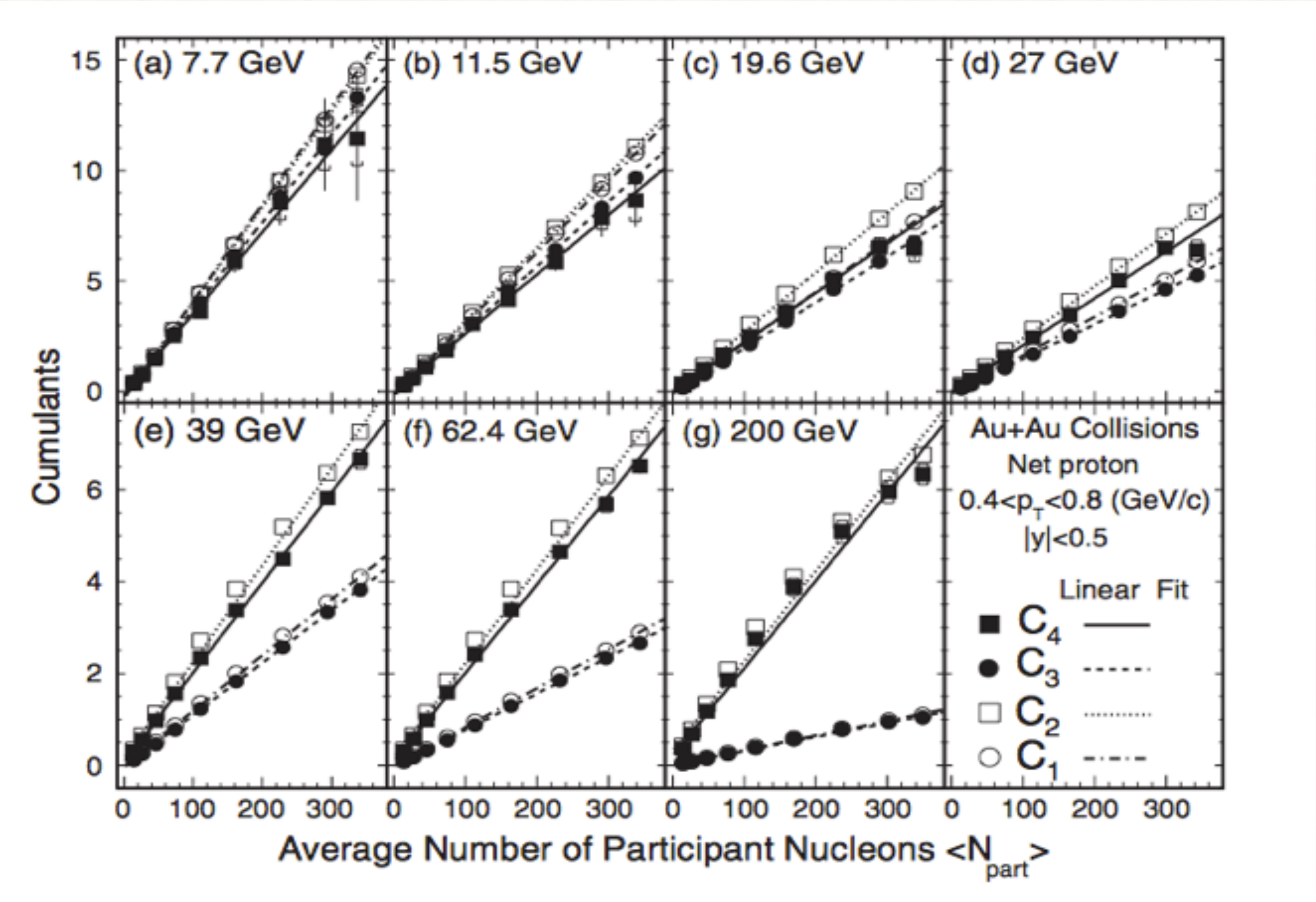
Phys. Rev. Lett. 112, 032302 (2014).

The mean of net-Proton (ΔN_p) distribution shifts towards zero from low to high energies.

Results Net-proton

The four cumulants which describe the shape of the ΔN_p distributions at various collision energies are plotted as a function of average number of participants < N_{part} >. The results are corrected for the finite centrality bin width effects. X. Luo [STAR Collaboration], J. Phys. Conf. Ser.316, 445 012003 (2011).

The cumulants fitted with linear function, (the dotted lines). The cumulants follow linear dependency with average number of participants.



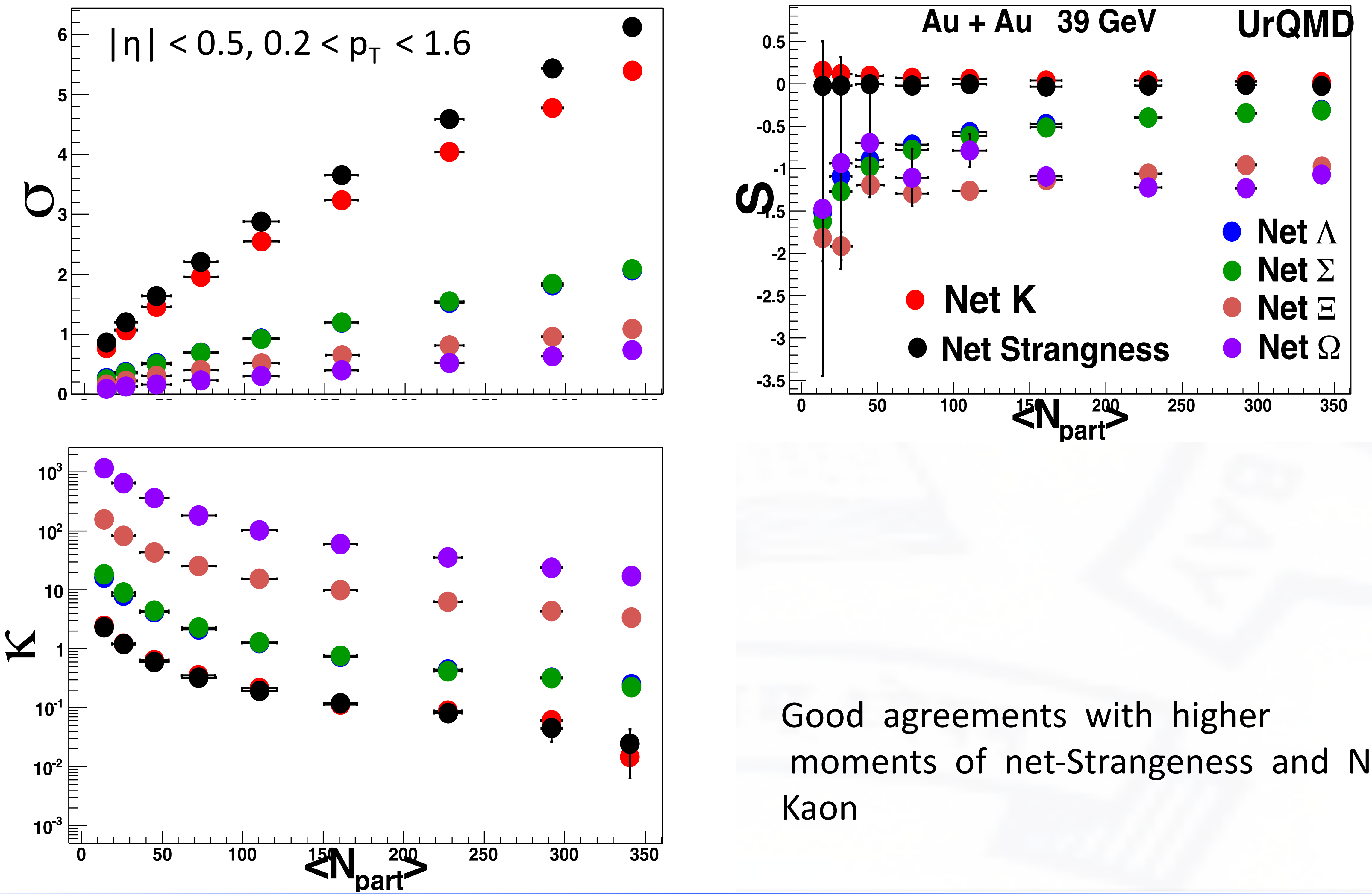
Phys. Rev. Lett. 112, 032302 (2014).

All net-Proton results are corrected for detector efficiency.

Net-Kaons as a proxy for Net-Strangeness in Higher moments calculation

Experimentally, event-by-event net strangeness is very difficult to calculate.

We study : Higher moments of net-Strangeness and net-kaon (From UrQMD model)

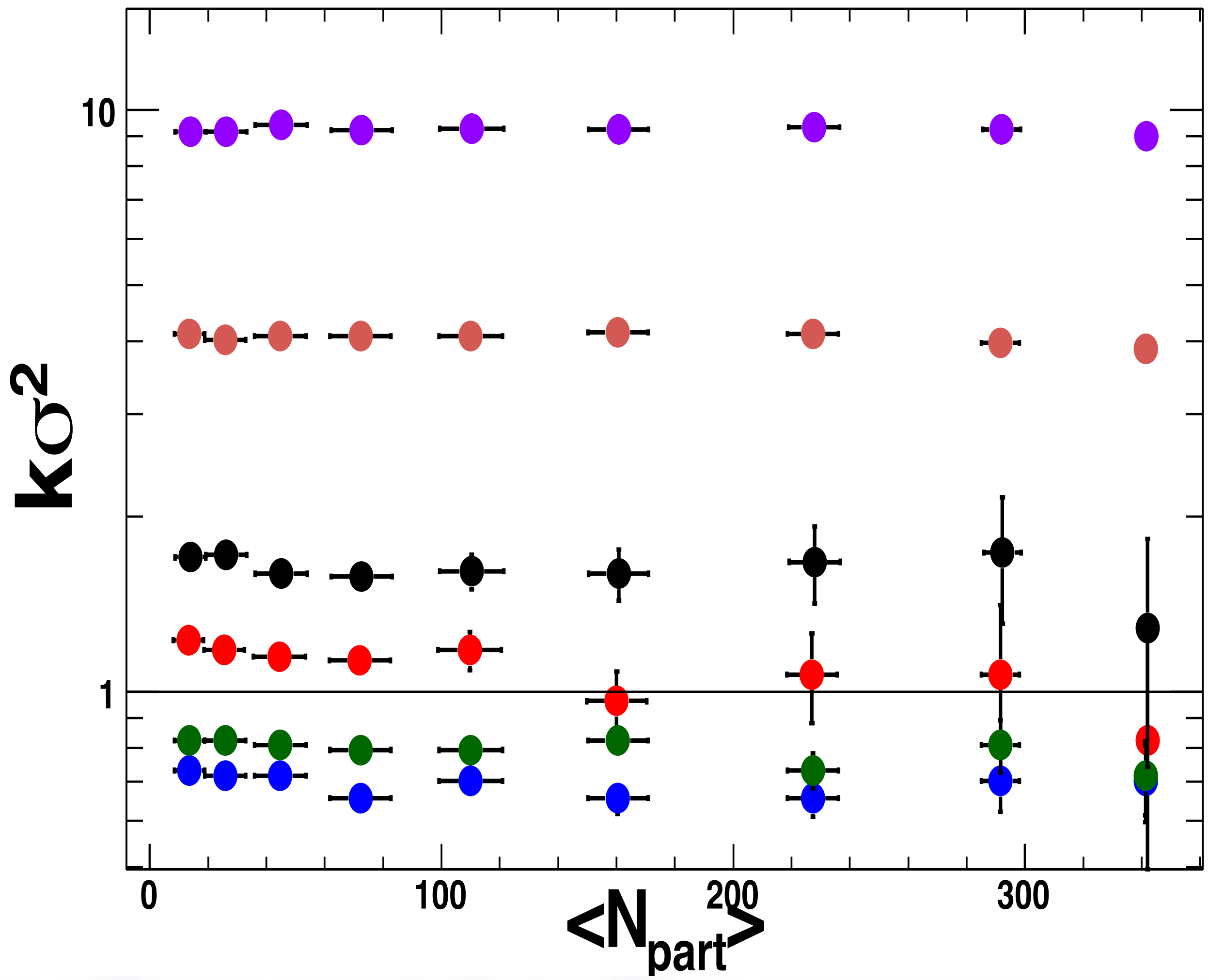


Good agreements with higher moments of net-Strangeness and Net-Kaon

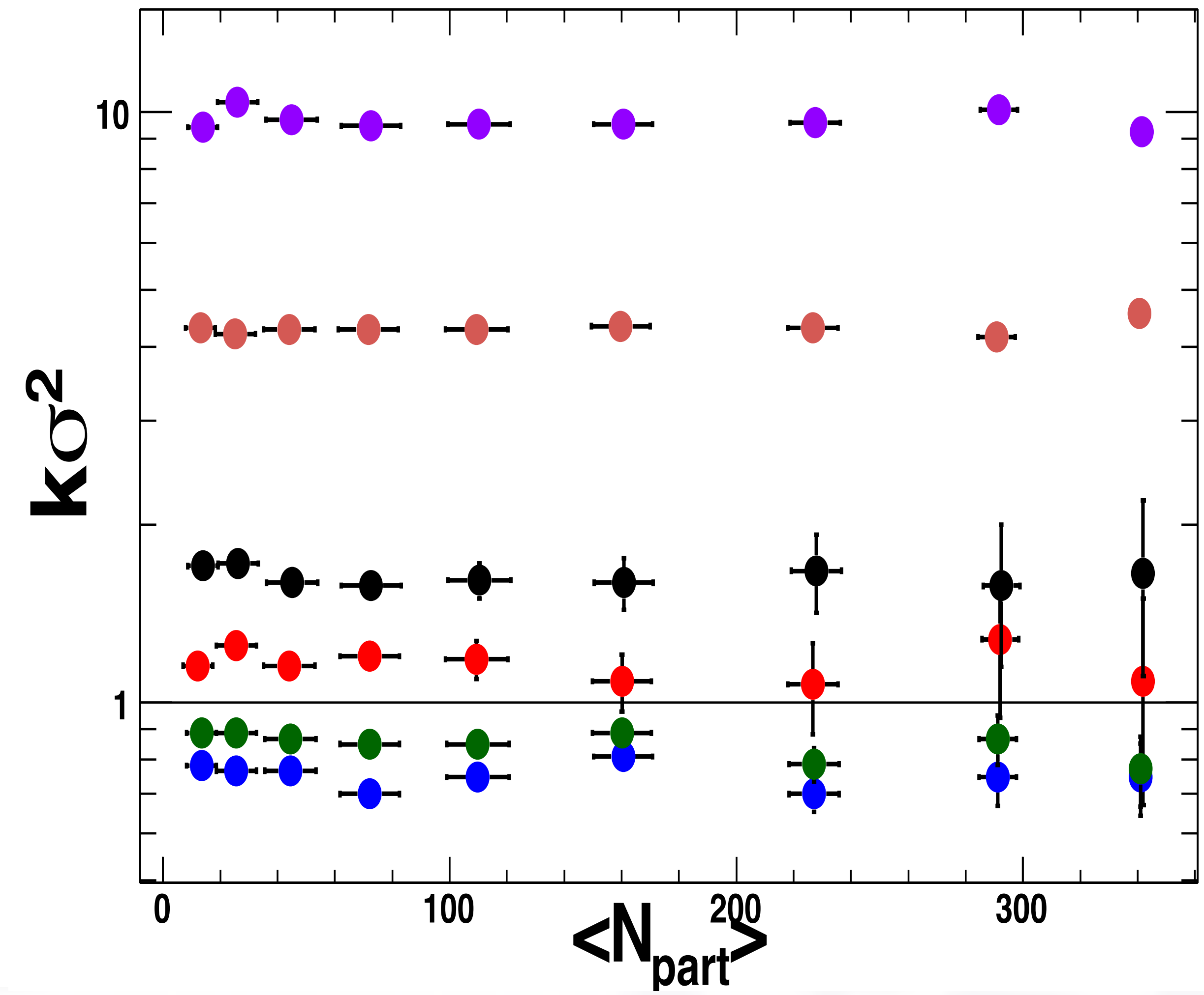
Net-Kaons as a proxy for Net-Strangeness in Higher moments calculation

Standard track cuts applied

$\eta < 0.5$, $0.2 < p_T < 1.6$



Full η used with $p_T < 2.5$



The volume independent moment product kσ2 of net-Strangeness and net-Kaon are also in good agreement with in the statistical uncertainty.

Net-Kaon → **As a proxy of net-strangeness.**