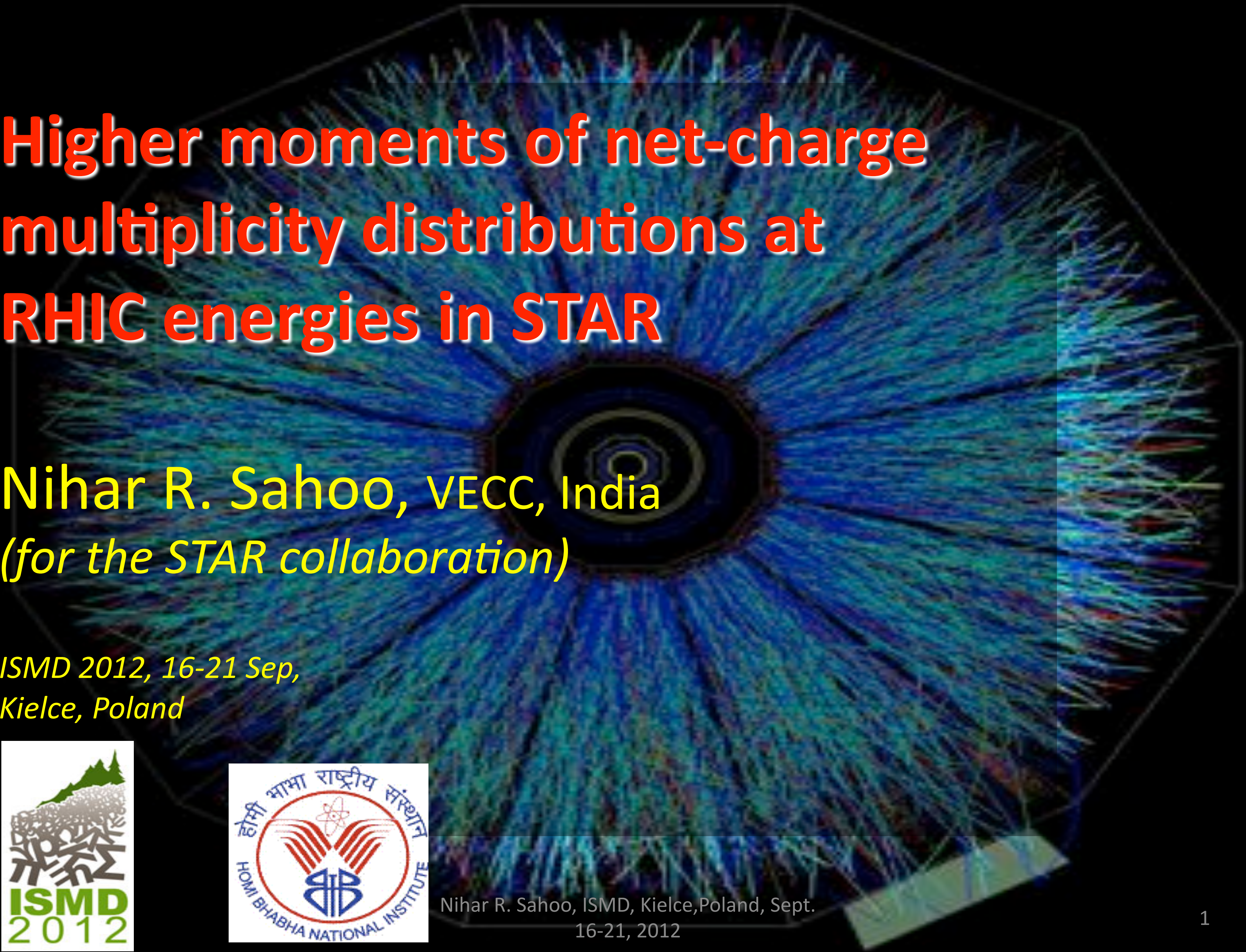
Higher moments of net-charge multiplicity distributions at RHIC energies in STAR



Nihar R. Sahoo, VECC, India

(for the STAR collaboration)

ISMD 2012, 16-21 Sep, Kielce, Poland

Overview

Motivation

- QCD Phase Diagram and Critical Point
- Connection between theory and experiment
- Extraction of the freeze-out parameter

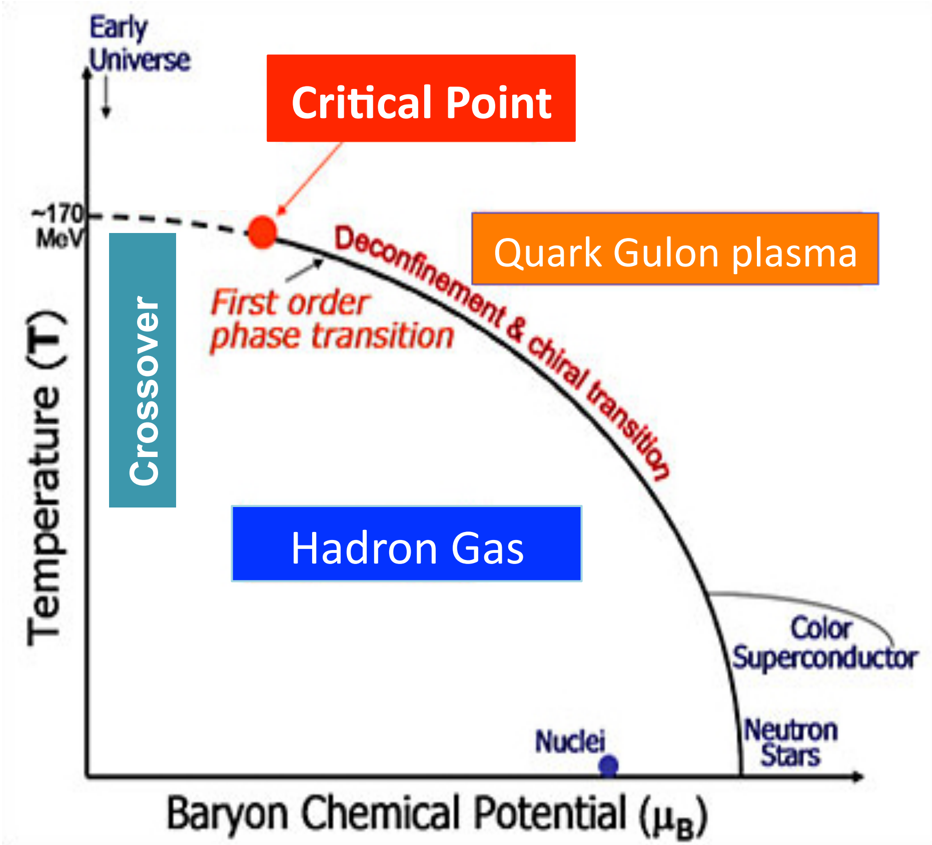
Experiment

- RHIC Beam Energy Scan Program
- STAR detector system
- Analysis details

Results

Summary

QCD Phase Diagram and Critical Point



- ★ At large baryon chemical potential (μ_B): a 1^{st} order phase transition is expected.

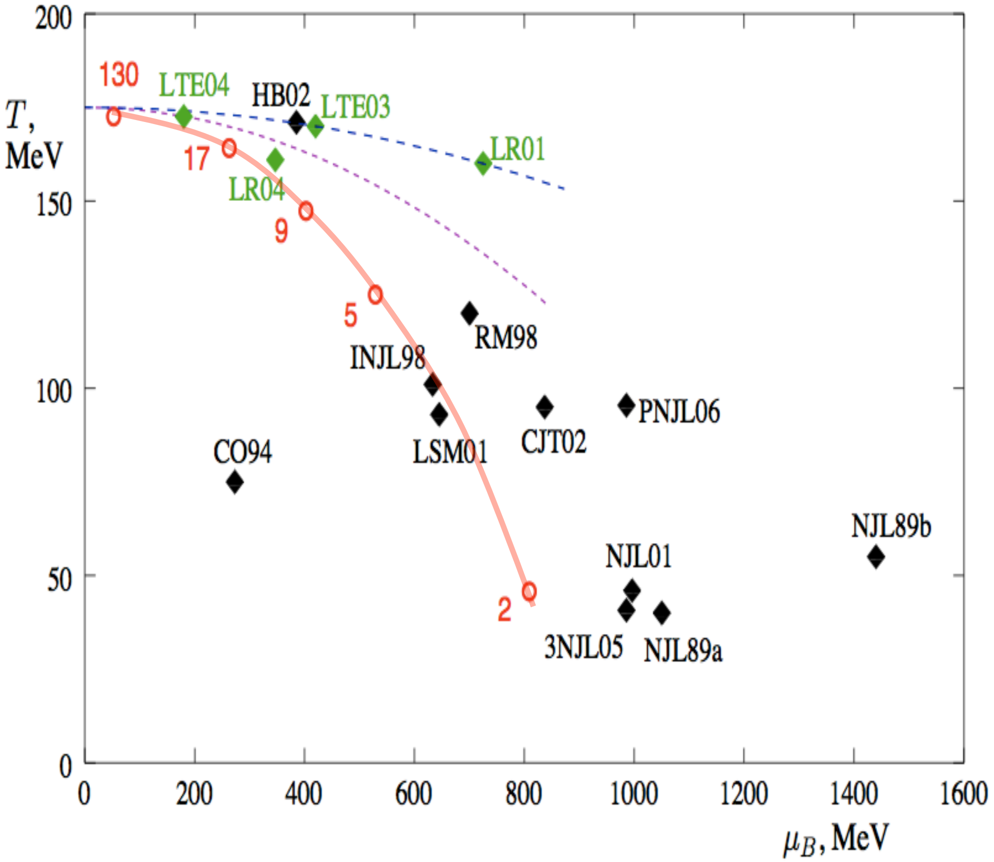
S.Ejiri et al., Phys.Rev.D78, 074507 (2008)

- ★ At $\mu_B = 0$ ➔ crossover.

Aoki et al., Nature 443, 675-678(2006)

- ★ The end point of the 1^{st} order phase transition: **QCD Critical Point (CP).**

Theoretical prediction for critical point



Source	(T, μ_B), MeV	Comments	Label
MIT Bag/QGP	none	*only 1st order, no chiral symmetry*	—
Asakawa,Yazaki '89	(40, 1050)	NJL, CASE I	NJL/I
"	(55, 1440)	NJL, CASE II	NJL/II
Barducci, *et al* '89-94	$(75, 273)_{TCP}$	composite operator	CO
Berges, Rajagopal '98	$(101, 633)_{TCP}$	instanton NJL	NJL/inst
Halasz, *et al* '98	$(120, 700)_{TCP}$	random matrix	RM
Scavenius, *et al* '01	(93,645)	linear σ-model	LSM
"	(46,996)	NJL	NJL
Fodor, Katz '01	(160, 725)	lattice reweighting	
Hatta, Ikeda, '02	(95, 837)	effective potential (CJT)	CJT
Antoniou, Kapoyannis '02	(171, 385)	hadronic bootstrap	HB
Ejiri, *et al* '03	(?,420)	lattice Taylor expansion	

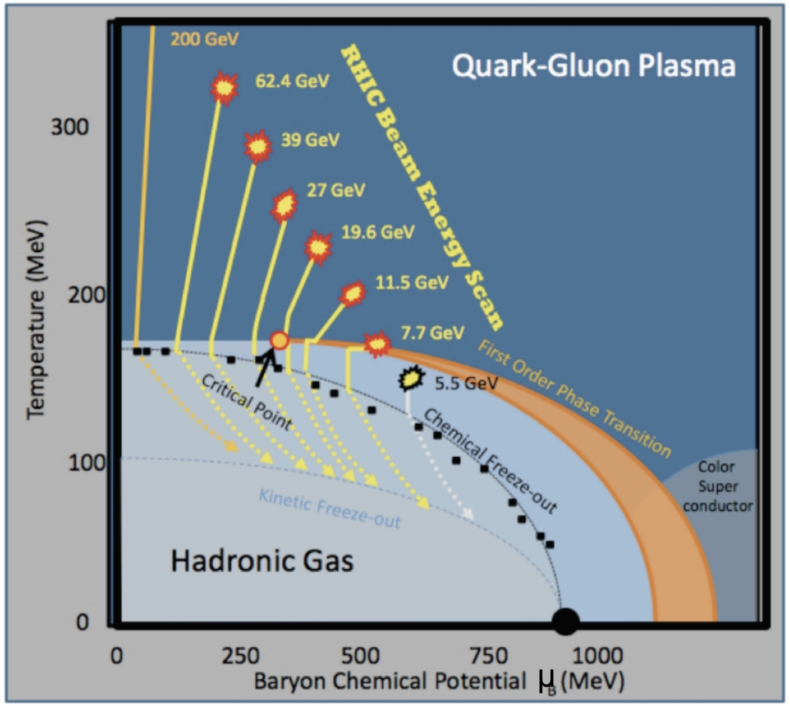
○ Freezout point from Experiment **◆ Model Prediction** **◆ Lattice Prediction**

----- Magnitude of slope $d^2T/d\mu_2$ obtained by lattice Taylor expansion

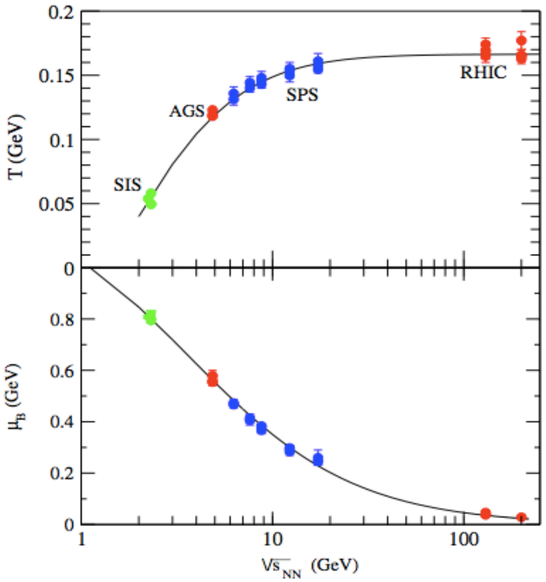
Various theoretical models, predict various location of Critical Point (CP).

STAR Experiment has undertaken beam energy scan program.

RHIC Beam Energy Scan (BES) program



arXiv:1007.2613



J. Cleymans, et. all, PRC 73, 034905 (2006)

- Search for the signature of CP
- locating QCD phase boundary

	$\sqrt{s_{NN}}$ (GeV)	Year
	200	2011
	62.4	2010
BES	39	2010
BES	19.6	2011
BES	27	2011
BES	11.5	2010
BES	7.7	2010

✓ Varying beam energy, one can tune Temperature and Chemical Potential.

✓ QCD phase diagram can be mapped between μ_B values 20 to 450 MeV.

Introduction to Various moments

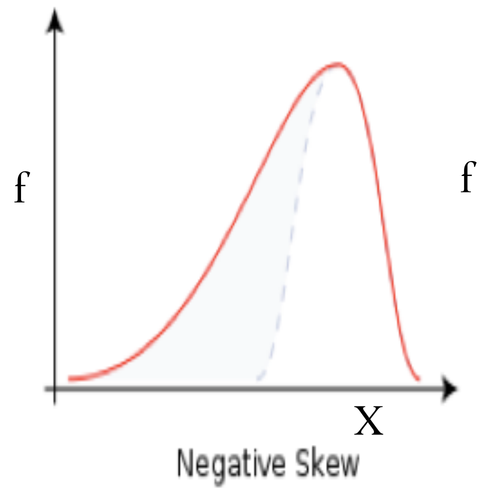
Mean (M) = $C_1 = <N>$

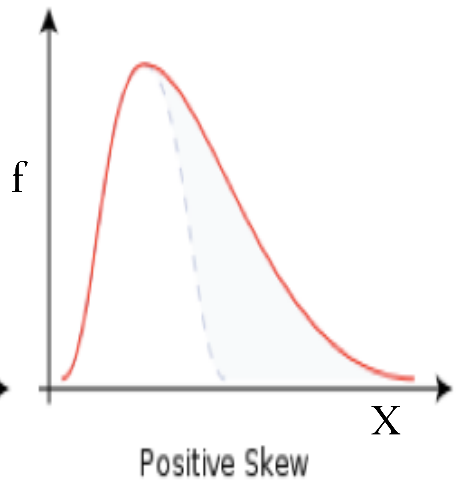
Where, C_n is the nth order cumulant

Standard Deviation (σ) = $C_2 = < (N - <N>)^2 >^{1/2}$

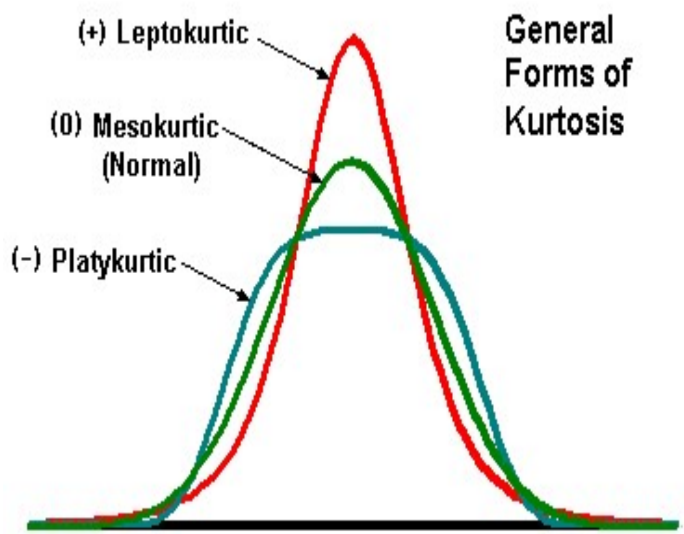
Skewness (S) = $\frac{C_3}{C_2^{3/2}} = \frac{<(N - <N>)^3>}{\sigma^3}$, **Kurtosis** (κ) = $\frac{C_4}{C_2^{2}} = \frac{<(N - <N>)^4>}{\sigma^4} - 3$

- Degree of the asymmetry of the distribution.
- Tail-ness of the distribution.





- Degree of the peakedness of the distribution.



Connection between theory and experiment

★ Signature of Critical Point

•Divergence of the correlation $\chi_n \sim \xi^{5n/2-3}$

•Divergence of the thermodynamic susceptibility (QCD based calculation)

★ Bridge between

Theory and Experiment

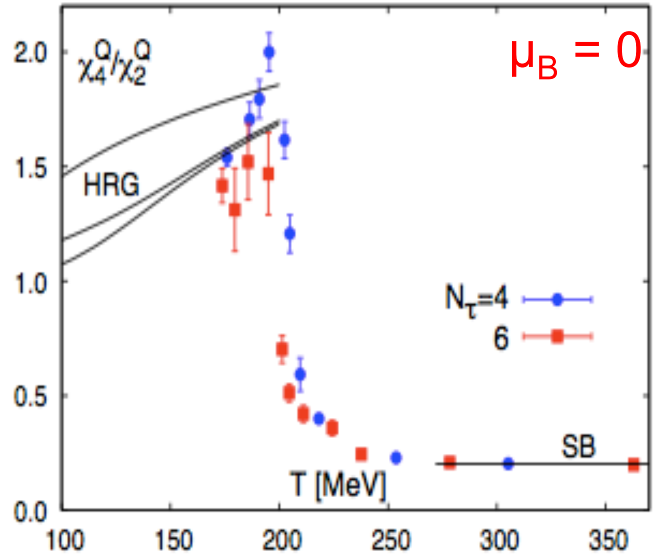
$VT^3\chi_2^Q = <(\delta N_Q)^2>$ (σ)

$VT^3\chi_3^Q = <(\delta N_Q)^3)>$ (S)

$VT^3\chi_4^Q = <(\delta N_Q)^4)> -3 <(\delta N_Q)^2)>^2$ (κ)

Thermodynamic susceptibility ←→ Moments of the conserved charge distribution

(Lattice QCD results)



M. Cheng et al., arXiv:0710.0354
M.A. Stephanov, PRL. 102, 032301 (2009)

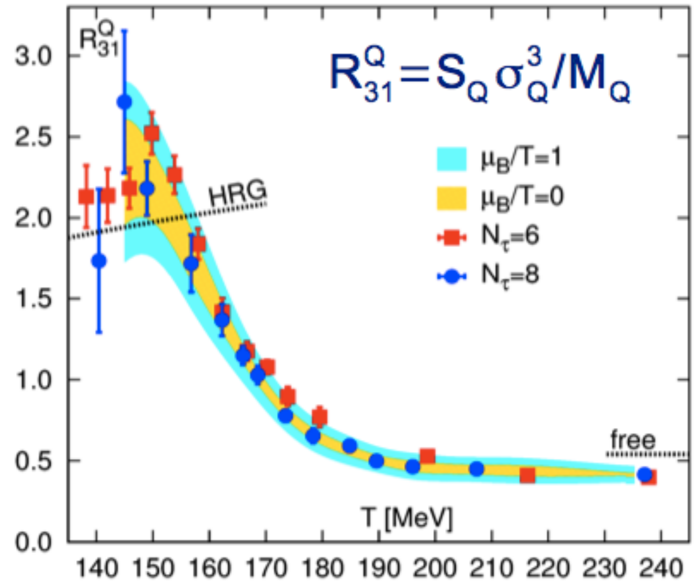
★ To cancel the volume term, product of higher moments are taken.

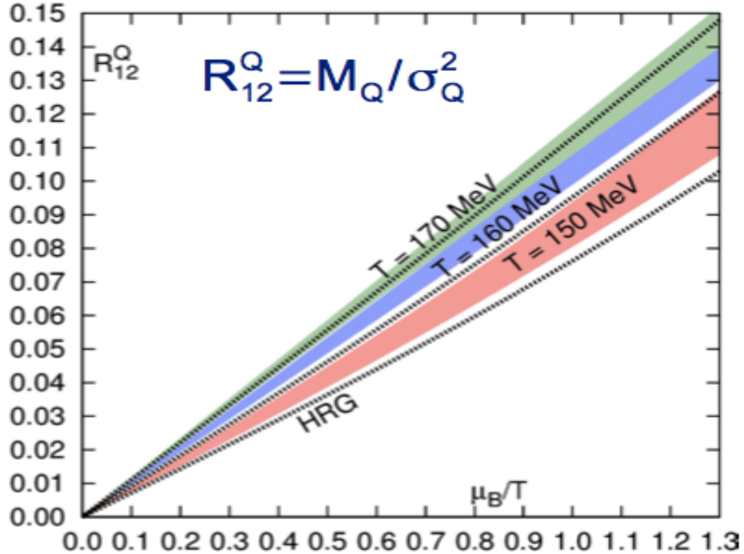
$$\sigma^2/M, S\sigma, \kappa\sigma^2$$

★ **Non-monotonic behavior of the product of higher moments as a function of the beam energy could be signature of the CP.**

Extraction of the freeze-out parameter

QM12: S. Mukherjee
arXiv:1208.1220





Lattice QCD

- ★ Add another dimension to this field.
- ★ Direct connection with experiment (product of net-charge higher moment) to extract freeze-out parameter.

Experiment and Lattice QCD — Freeze-out parameter

(at given $\sqrt{s_{NN}}$) $S\sigma^3/M <--> T$

$M/\sigma^2 <--> \mu_B/T$ (at given T)

$S_Q\sigma^3_Q/M_Q$	T^f [MeV]
$\lesssim 2$	$\lesssim 155$
~ 1.5	~ 160
$\lesssim 1$	$\gtrsim 170$

For T^f = 160 MeV

M_Q/σ^2_Q	μ^f_B/T^f
0.01 – 0.02	0.1 – 0,2
0.03 – 0.04	0.3 – 0.4
0.05 – 0.08	0.5 – 0.7

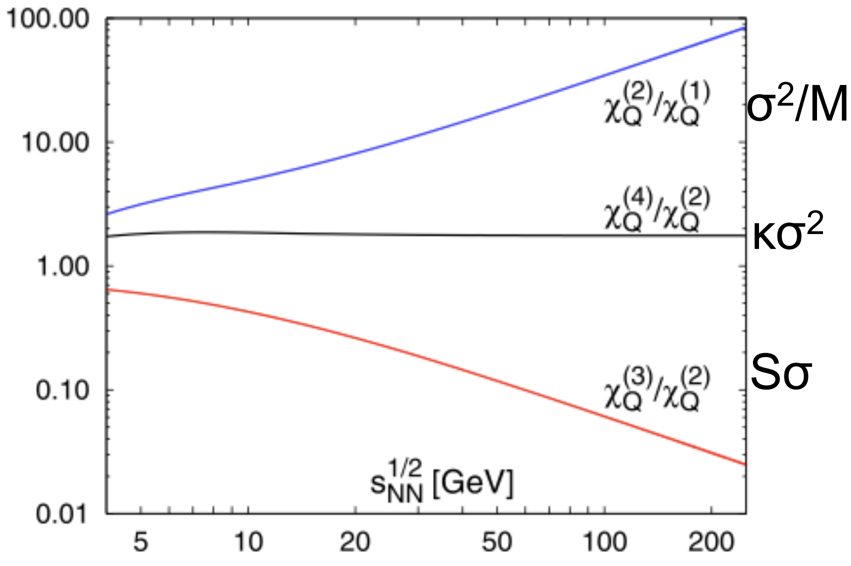
Baseline for net-charge higher moments

⌘ Baseline for Critical Point Search

★ **Hadron Resonance Gas (HRG)**

Non-Critical Point model

F. Karsch et al., PLB 695 (2011)



★ **Poisson baseline**

Assume: positive and negative charged particles distributions as independent Poisson distributions.

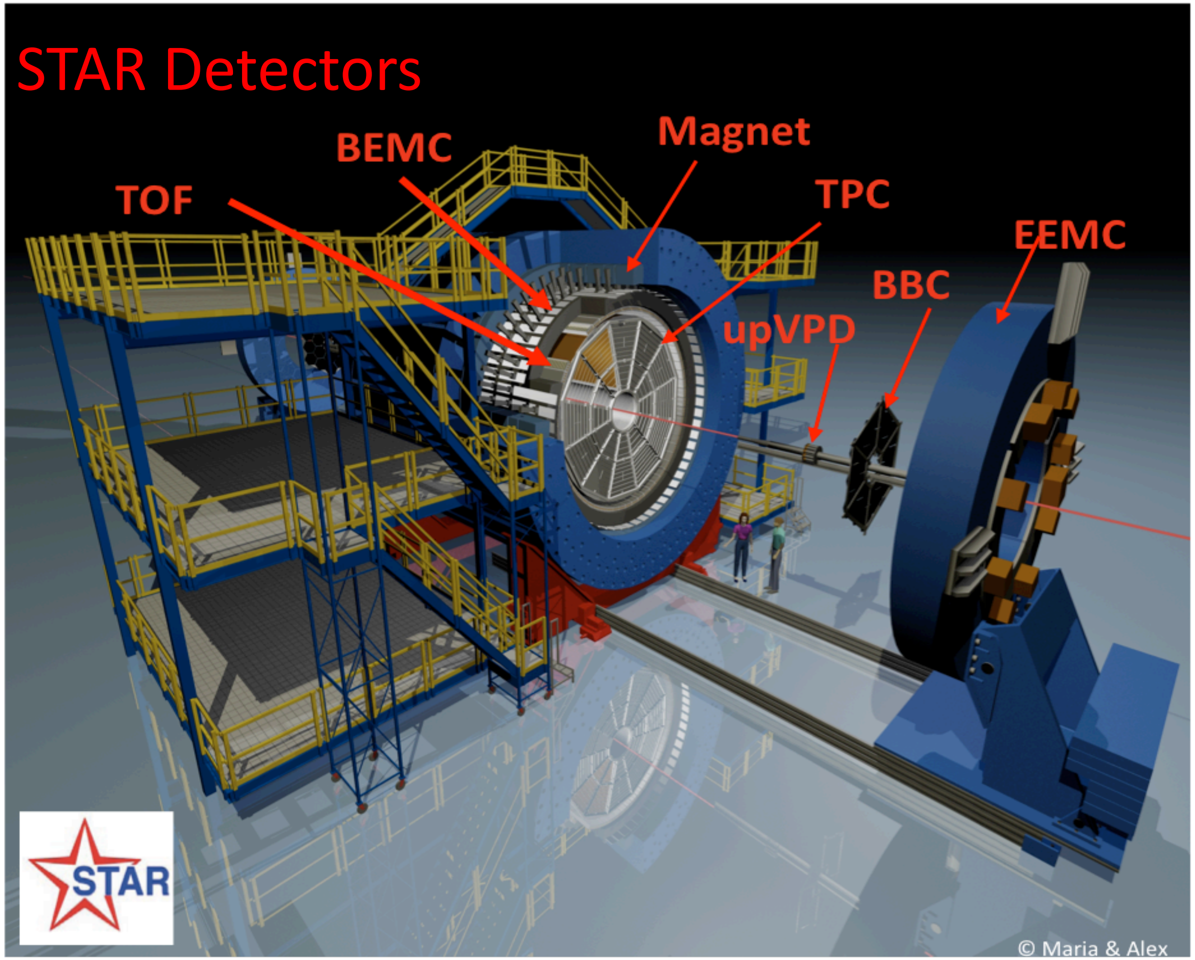
$$\frac{\sigma^2}{M} = \frac{\mu_1 + \mu_2}{\mu_1 - \mu_2} \quad , \quad S\sigma = \frac{\mu_1 - \mu_2}{\mu_1 + \mu_2}$$

Difference of the two Poisson distribution is a Skellam Distribution.

$$\kappa\sigma^2 = 1$$

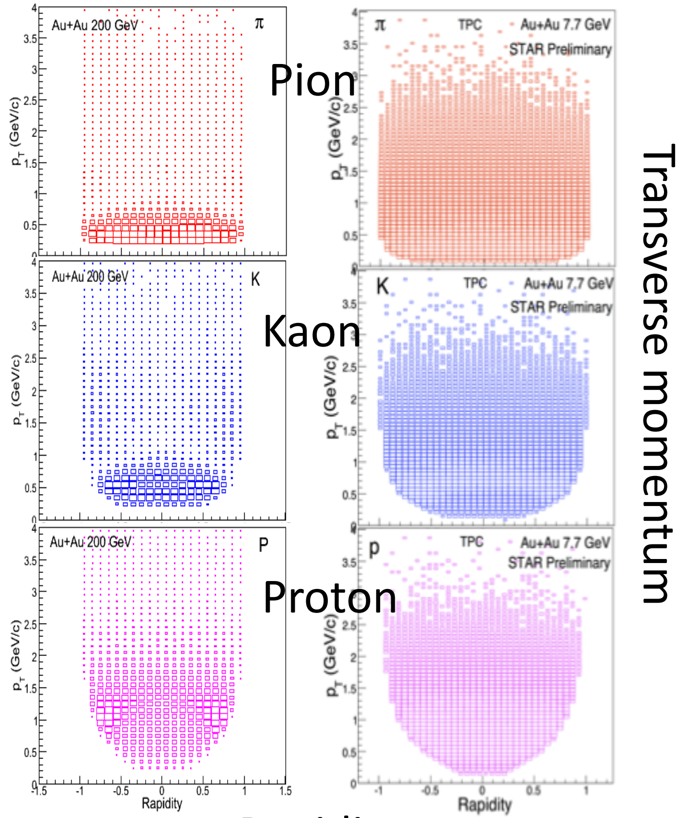
μ_1 and μ_2 mean of positive and negative charge particles distributions respectively.

Experimental details



Uniform Acceptance

AuAu 200 GeV 7.7 GeV



Rapidity

- Uniform pT and rapidity acceptance.
- Full 2π coverage
- Very good particle identification capabilities (TOF and TPC)

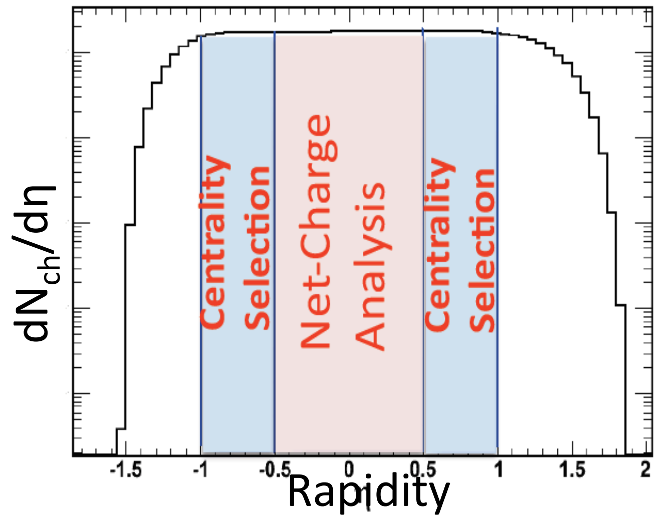
Important tools for any fluctuation analysis

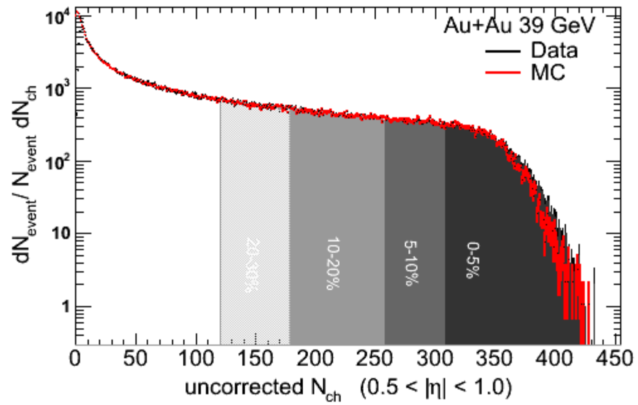
Analysis Details

- **Charged particles selection**
  - By STAR Time Projection Chamber.
  - Transverse momentum range - 0.2 to 2.0 GeV/c .
  - Background protons have been removed transverse momentum below 400 MeV.
  - Pseudo-rapidity range - $|\eta| < 0.5$
- **Centrality selection**
  - To remove auto-correlation effect, centrality selection done outside analysis rapidity region ($|\eta| < 0.5$).
  - Uncorrected charged particles multiplicity within $0.5 < |\eta| < 1.0$.
- **Centrality bin width correction**
  - Reduce the finite bin width effect
- **Statistical error estimation**

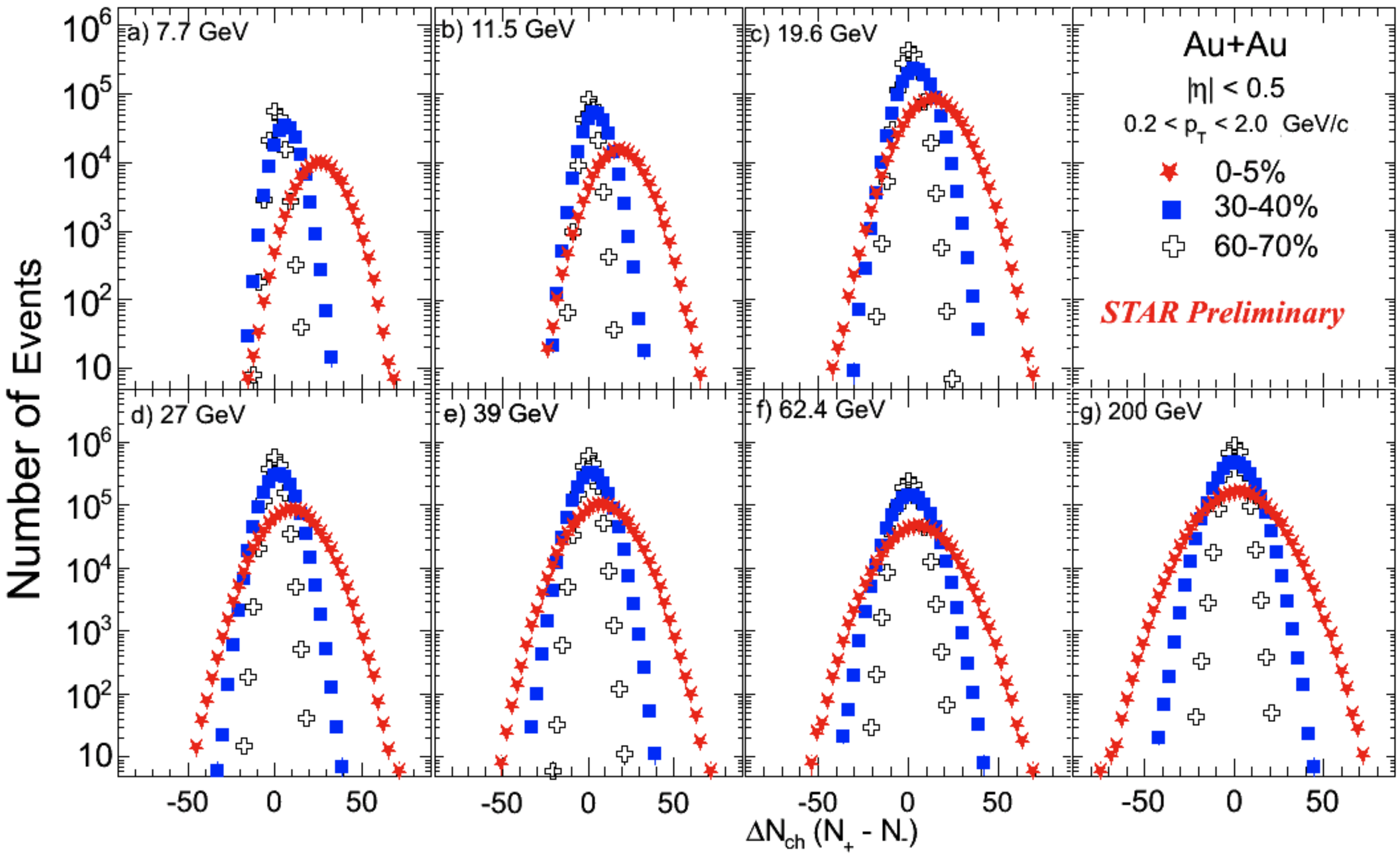
Delta theorem is used.

X. Luo, arXiv: 1109.0593



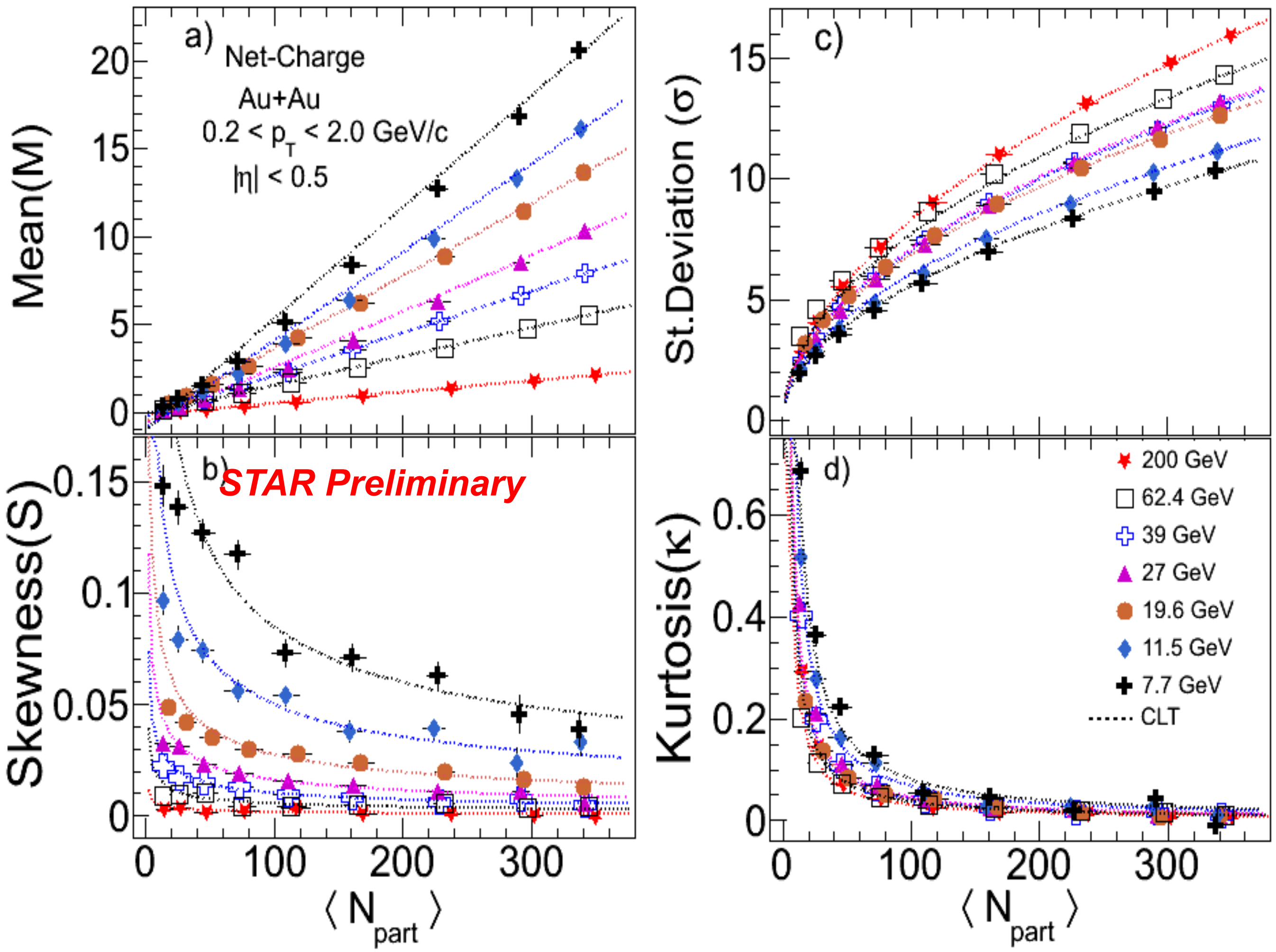


Net-charge distribution



★ The raw net-charge multiplicity distribution shows that with decreasing colliding energy, the distribution shifts towards positive side.

Various moments



Central Limit Theorem (CLT)

$$M(V)\ \alpha\ V$$

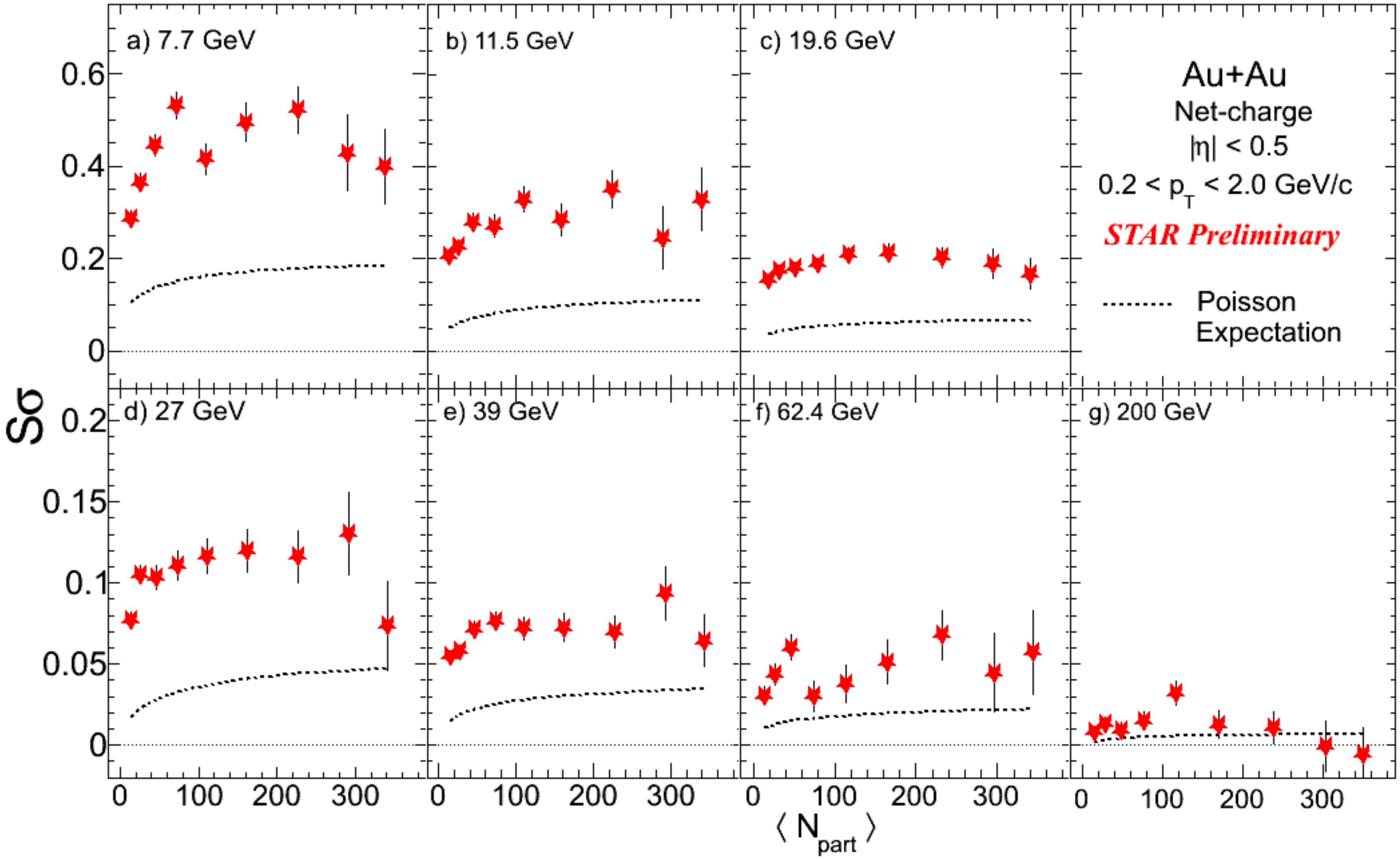
$$\sigma(V)\ \alpha\ \sqrt{V}$$

$$S(V)\ \alpha\ \frac{1}{\sqrt{V}}$$

$$\kappa(V)\ \alpha\ \frac{1}{V}$$

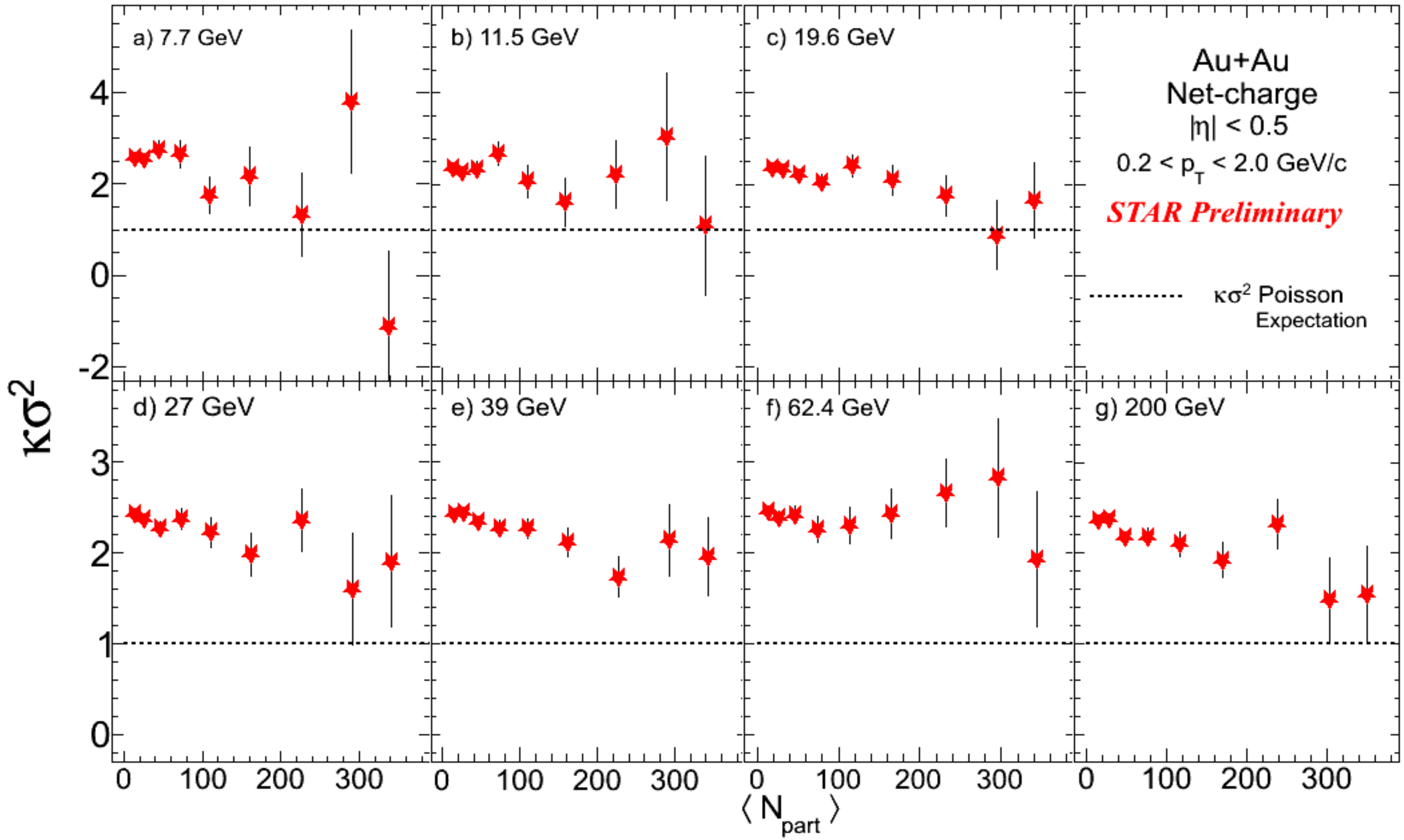
- ★ The number of participant nucleons (proxy of volume (V)) dependence of the moments follows the trends as expected by CLT.

Centrality dependence of product of higher moments



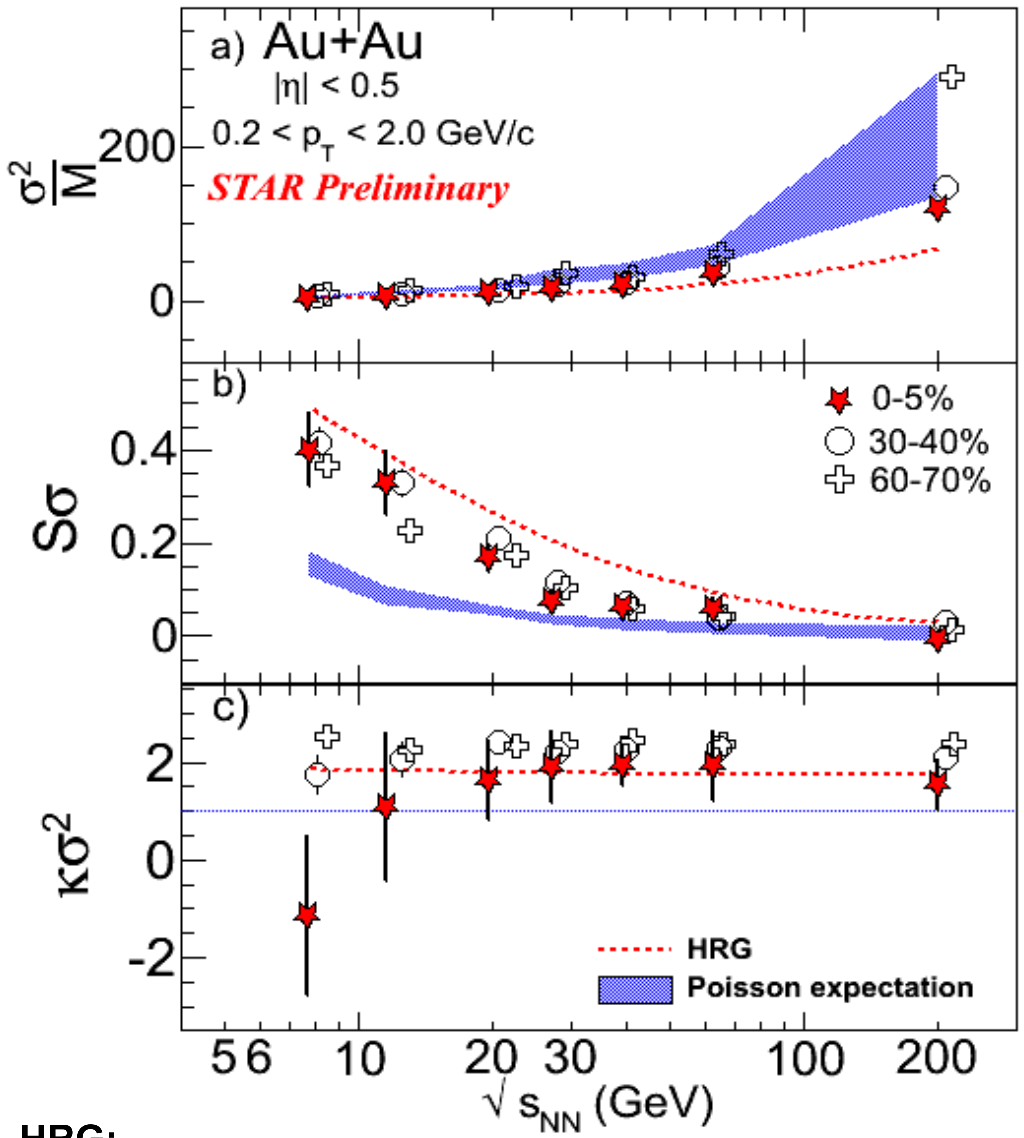
★ Sσ are found to have values that have increasing deviations from Poisson expectations with decreasing in beam energy.

Centrality dependence of product of higher moments



- $\kappa\sigma^2$ shows consistence within all centralities for all beam energies.
- At all energies $\kappa\sigma^2$ shows larger value than unity (Poisson expectation).

Beam energy dependence



★ σ^2/M increases with increase in colliding energy.

★ $S\sigma$ increases with decreasing colliding energies. Below 27 GeV, $S\sigma$ starts to deviate from Poisson expectation. HRG model over-predicts the data.

★ $\kappa\sigma^2$ shows no energy dependence and all the values are above unity, except in top central events at 7.7 GeV with large error bar.

HRG:

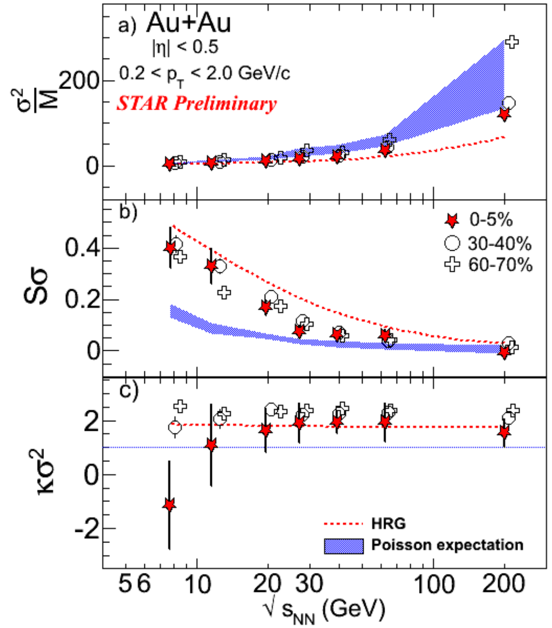
F. Karsch et al., PLB 695 (2011)

Summary

★ Higher moments of the net-charge multiplicity distributions have been measured in Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7 to 200 GeV.

★ The centrality dependence of the moments follows the expectation from the CLT.

★ σ^2/M increases with increase in colliding energy.



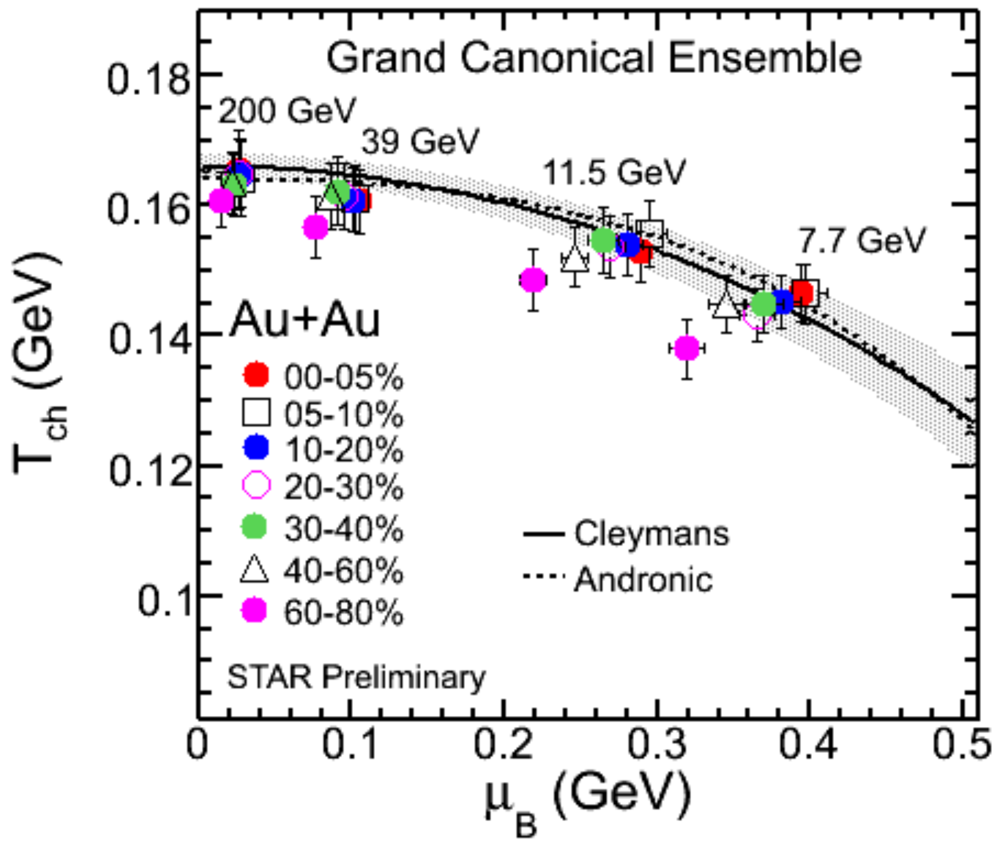
★ Sσ deviates from Poisson expectations below 27 GeV.

★ Within statistical uncertainty, $K\sigma^2$ is seen to be independent of collision energy and no significant enhancement is observed.

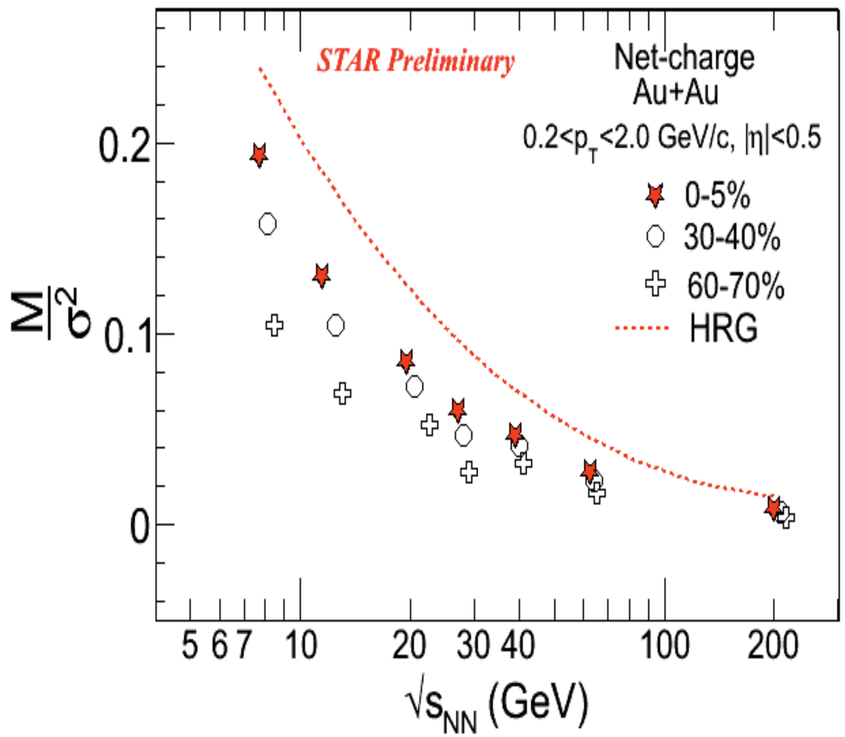
Outlook

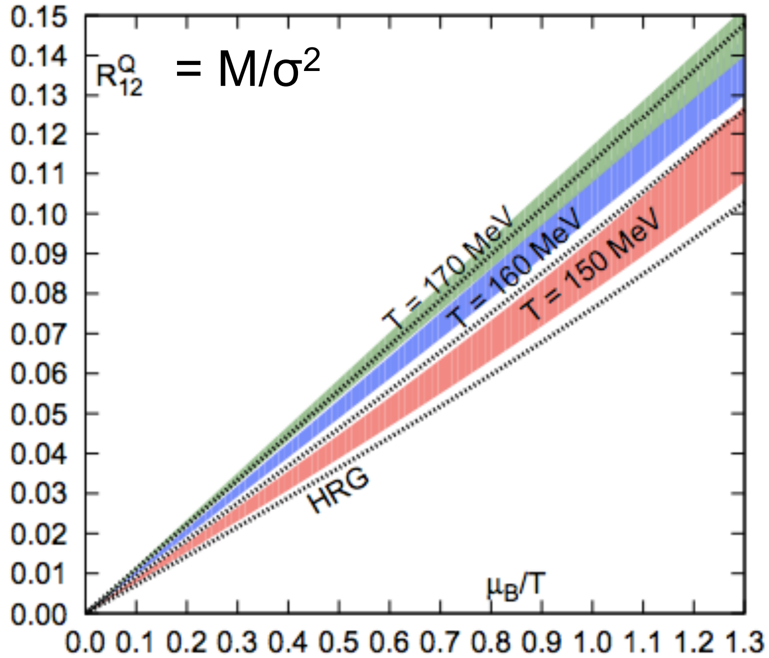
- BES-II may expose intriguing results at low energies.
- More understanding on extraction of freeze-out parameter.

Back Up


Grand Canonical Ensemble
200 GeV
39 GeV
11.5 GeV
7.7 GeV
Au+Au
00-05%
05-10%
10-20%
20-30%
30-40%
40-60%
60-80%
Cleymans
Andronic
STAR Preliminary
T_ch (GeV)
μ_B (GeV)
0.18
0.16
0.14
0.12
0.1
0
0.1
0.2
0.3
0.4
0.5

Lattice and Experiment





QM12: S. Mukherjee
arXiv:1208.1220

Analysis Details

- **Centrality bin width correction**

(To reduce the finite bin width effect)

$$M = \frac{\sum n_i M_i}{\sum n_i} = \sum \omega_i M_i \qquad S = \frac{\sum n_i S_i}{\sum n_i} = \sum \omega_i S_i$$

$$\sigma = \frac{\sum n_i \sigma_i}{\sum n_i} = \sum \omega_i \sigma_i \qquad K = \frac{\sum n_i K_i}{\sum n_i} = \sum \omega_i K_i$$