# Probing the QCD Critical Point By Higher Moments of Net-Charge Distribution


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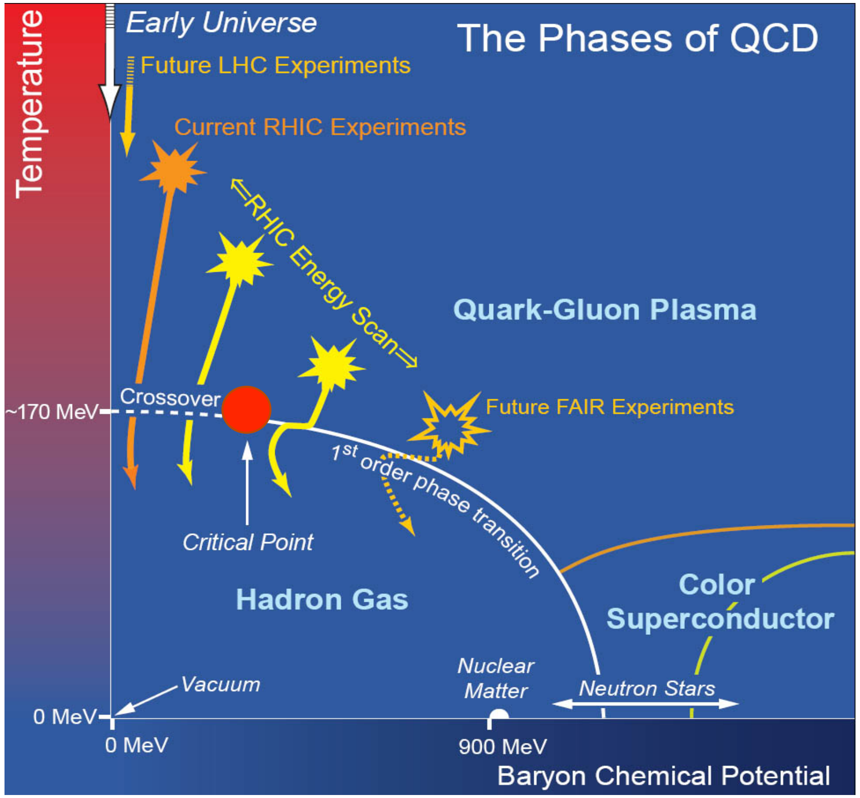
# Contents

# QCD Critical Point

## RHIC Beam Energy Scan Program

| | |
|---|---|
| 2010 | 200, 62.4, 39, 11.5, 7.7 (GeV) |
| 2011 | 27, 18,5 (GeV) |

$\mu_B$ : 20-550 MeV




The Frontiers of Nuclear Science
A Long Range Plan, Dec 2007

In QCD, Hadrons to QGP

Low T and High $\mu_B$ : 1st Order

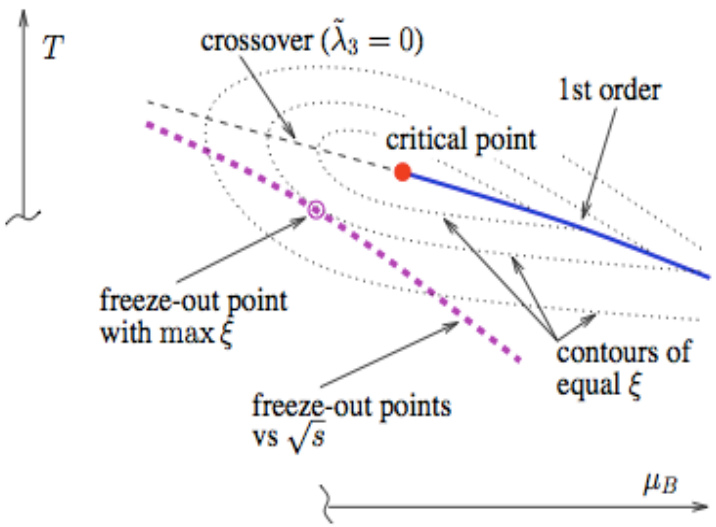
High T and $\mu_B = 0$ : Rapid Cross Over

$\boxed{T_c, \mu_{Bc} = ?}$

# Signature of QCD CP: Theoretical Background

As T approaches $T_c$

- Divergence of correlation length ( $\xi$ )
- Divergence of susceptibility
- Non-Gaussian fluctuation of conserved quantity




**Correlation length : QCD Model**

**At CP (for large $\mu_B$)**

$$<(\delta N)^2>\sim \xi^2, <(\delta N)^3>\sim \xi^{4.5}$$

PRL. 102,032301

$$<(\delta N)^4>-3<(\delta N)^2>^2\sim \xi^7$$

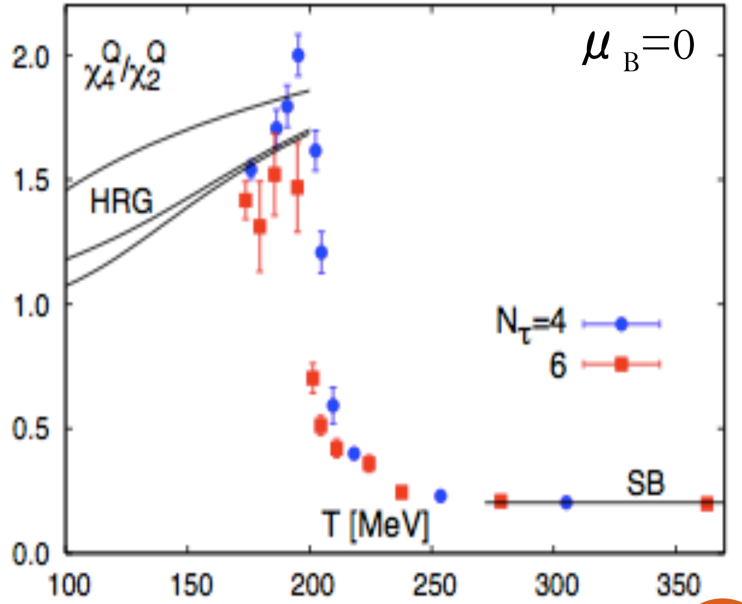
**Susceptibility: Lattice QCD and Hadron Resonance Gas Model**

$$\chi_2^X = \frac{1}{VT^3} < \delta N^2{}_X >$$

X = Q,B,S

$$\chi_4^X = \frac{1}{VT^3}(<\delta N_X{}^4> - 3<\delta N_X{}^2>^2)$$

arXiV:0811.1006




**Near the CP ➡ Non-Gaussian fluctuation**

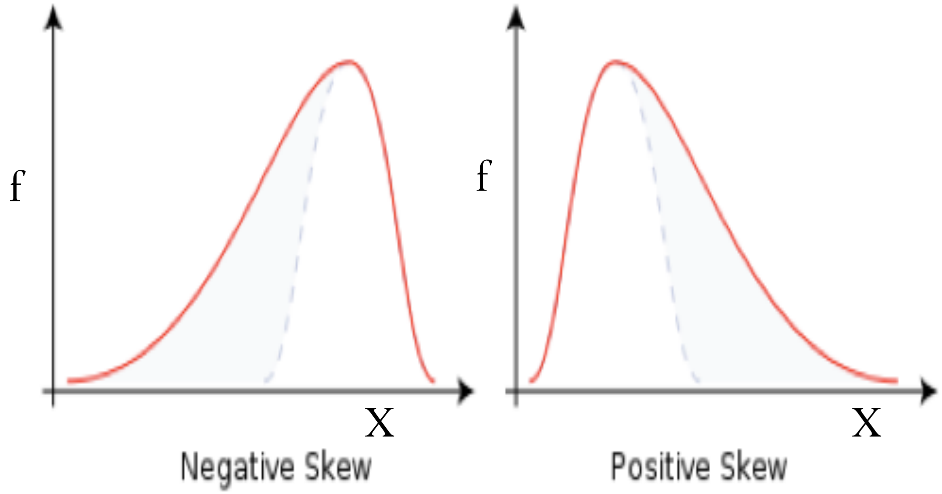
# Introduction to Higher Moments

Mean, $M = \langle N \rangle$

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

Skewness, $S = \dfrac{\langle (N - \langle N \rangle)^3 \rangle}{\sigma^3}$

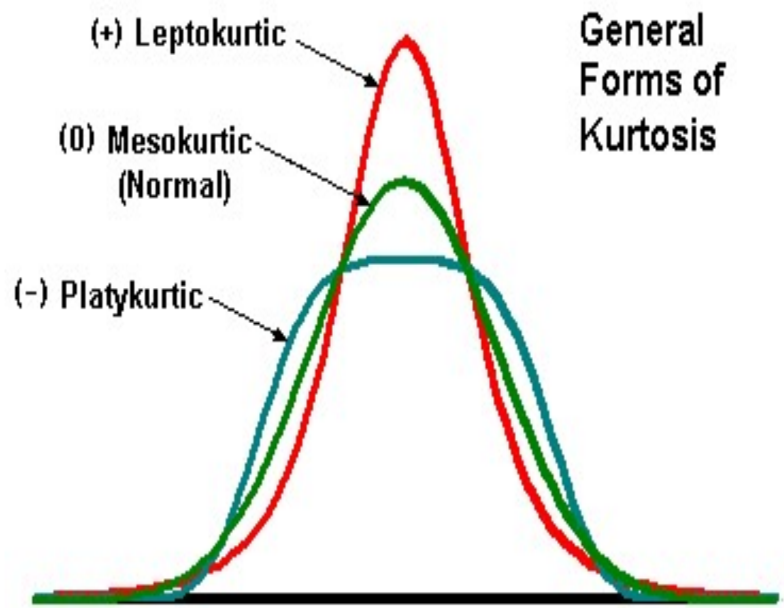
Kurtosis, $K = \dfrac{\langle (N - \langle N \rangle)^4 \rangle}{\sigma^4} - 3$




Skewness represents Asymmetry of the Distribution

Kurtosis represents peakness of the Distribution.

For Gaussian Distribution, Skewness and Kurtosis are zero



# Experimental Methods

**Varying beam energy,**
**Phase Diagram (T, $\mu_B$) can be mapped**

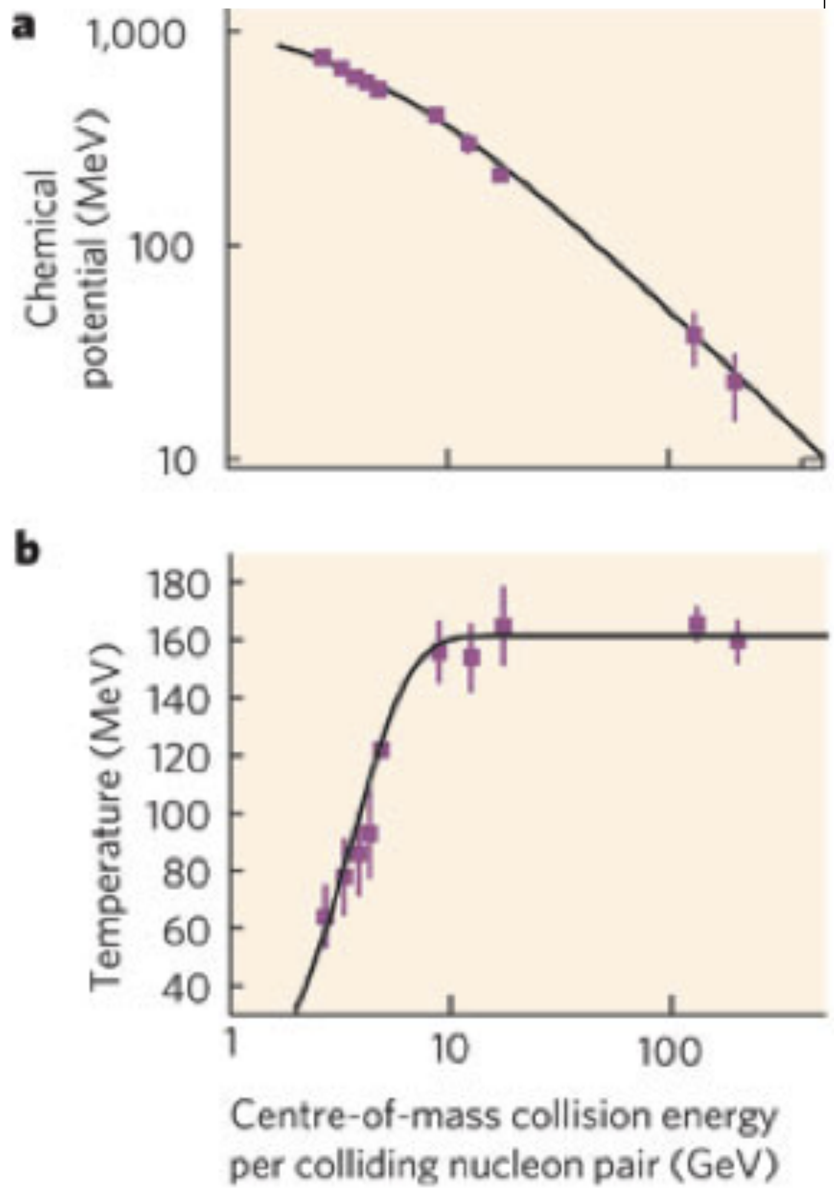
**Aim**

✓ **Vary the Colliding energy ($\sqrt{S}$)**

✓ **Calculate higher moments of conserved quantities (i.e. net-charge, net-baryon and net-strangeness)**

**Non-monotonic behavior**

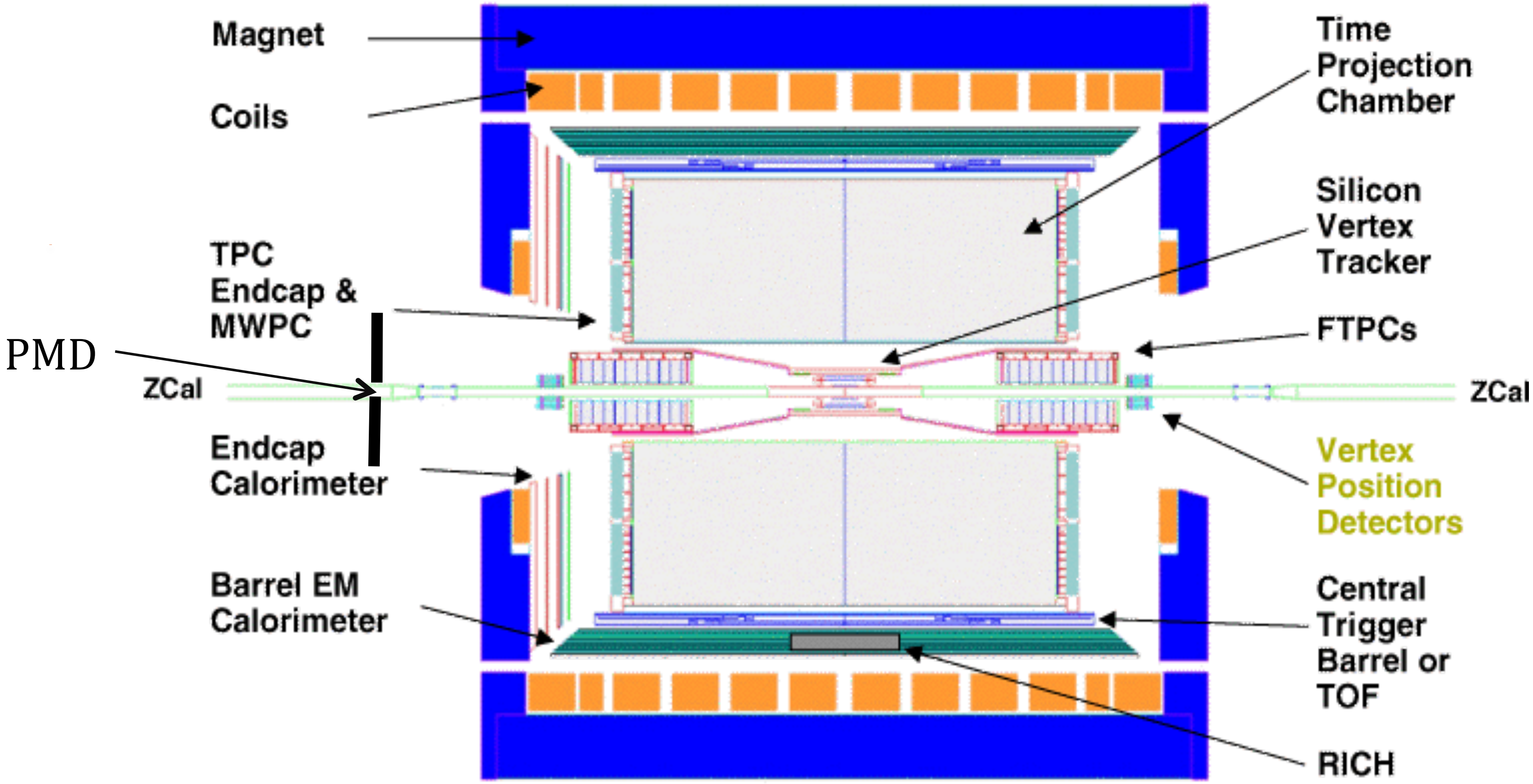
**signal for CP**




arxiv: 0909.4630(2009)

Nature 448, 302-309 (19 July 2007)

# STAR Detector




**STAR Data**

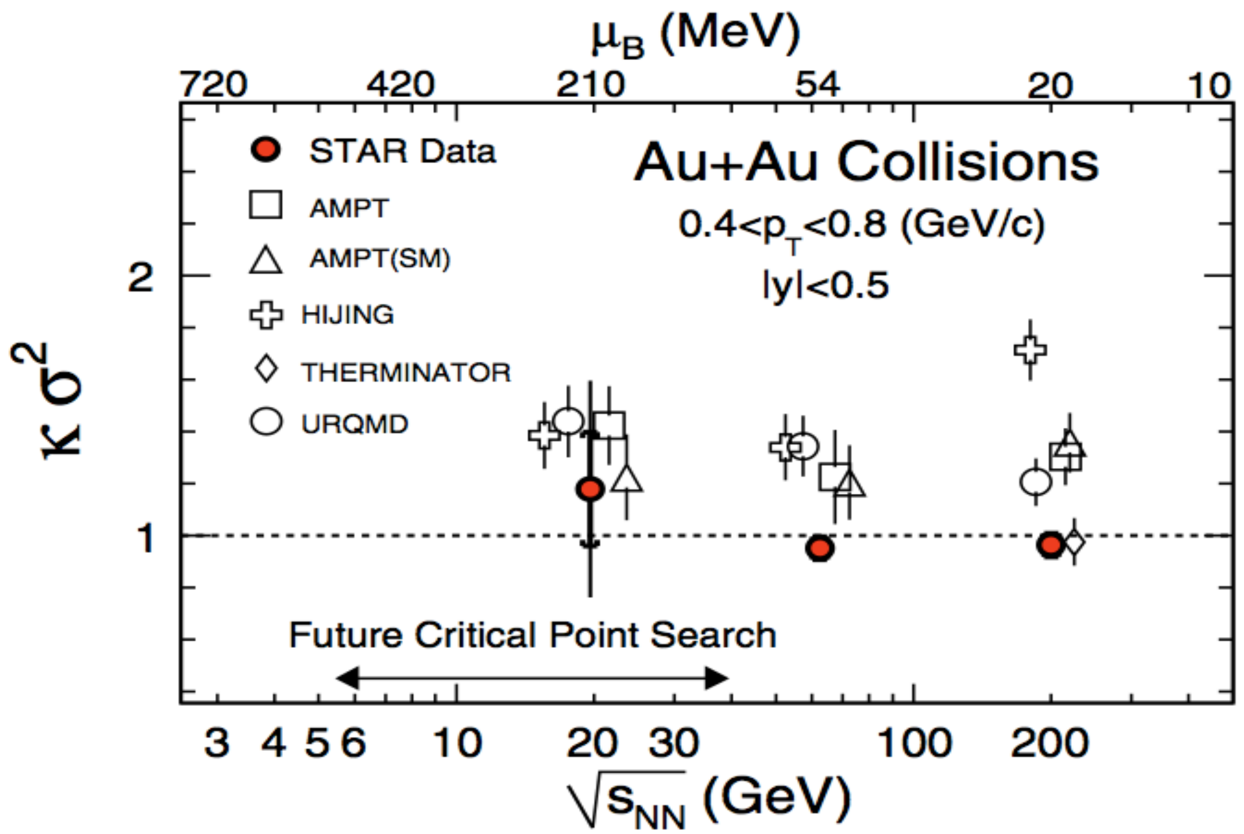
**AuAu 39 GeV ~ 6 M**

**$0.15 < p_T < 1.0$ (GeV/c)**

**$-0.5 < \eta < 0.5$**

Particle identification over $2\pi$ in azimuthal angle and more than two unit in rapidity

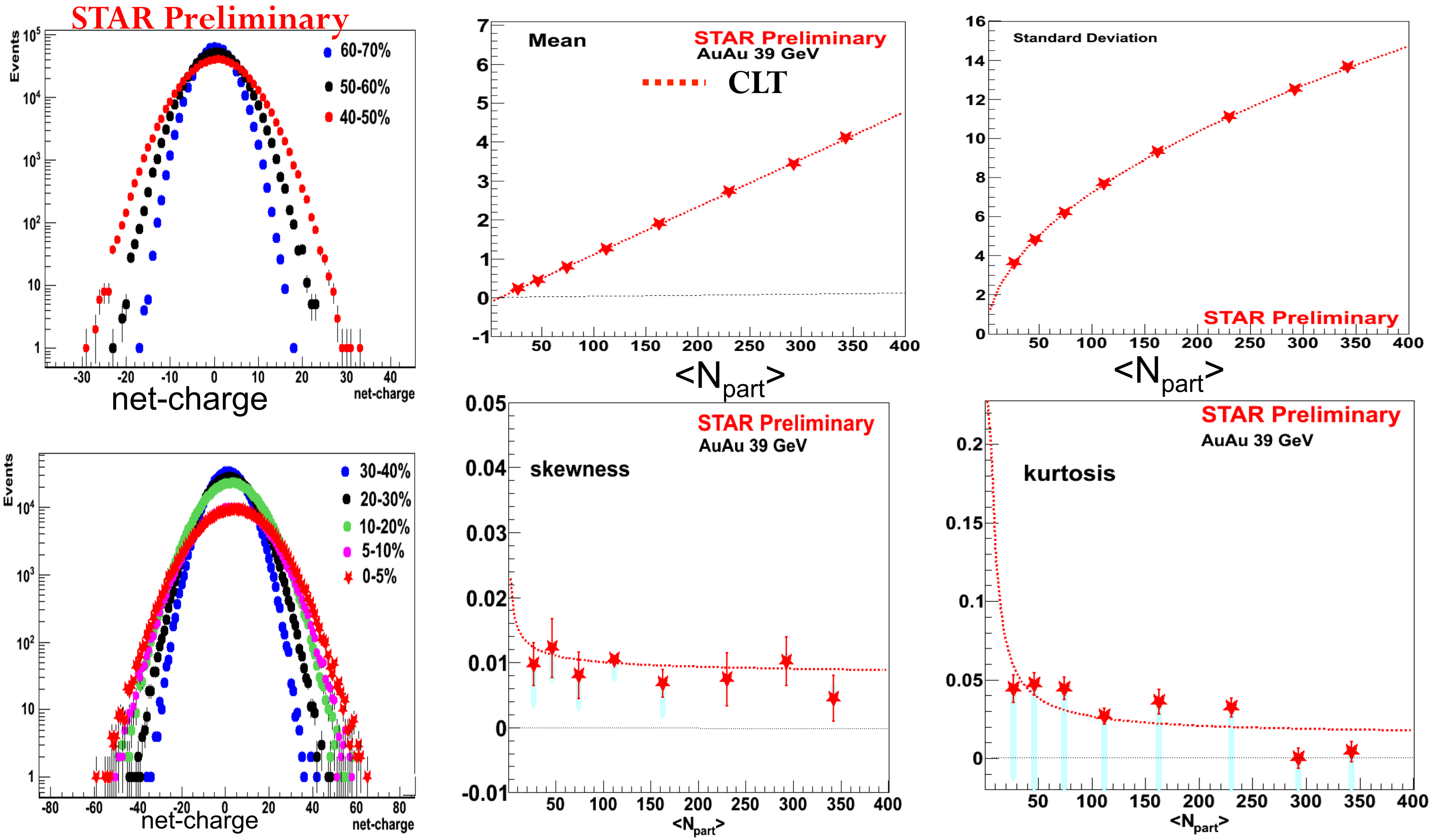
# Recent Results of Net-Proton Fluctuation




**STAR results on net-proton high moments for Au+Au collisions at $\sqrt{s_{NN}}$ = 200, 62.4 and 19.6 GeV**

PRL 105 (2010) 022302

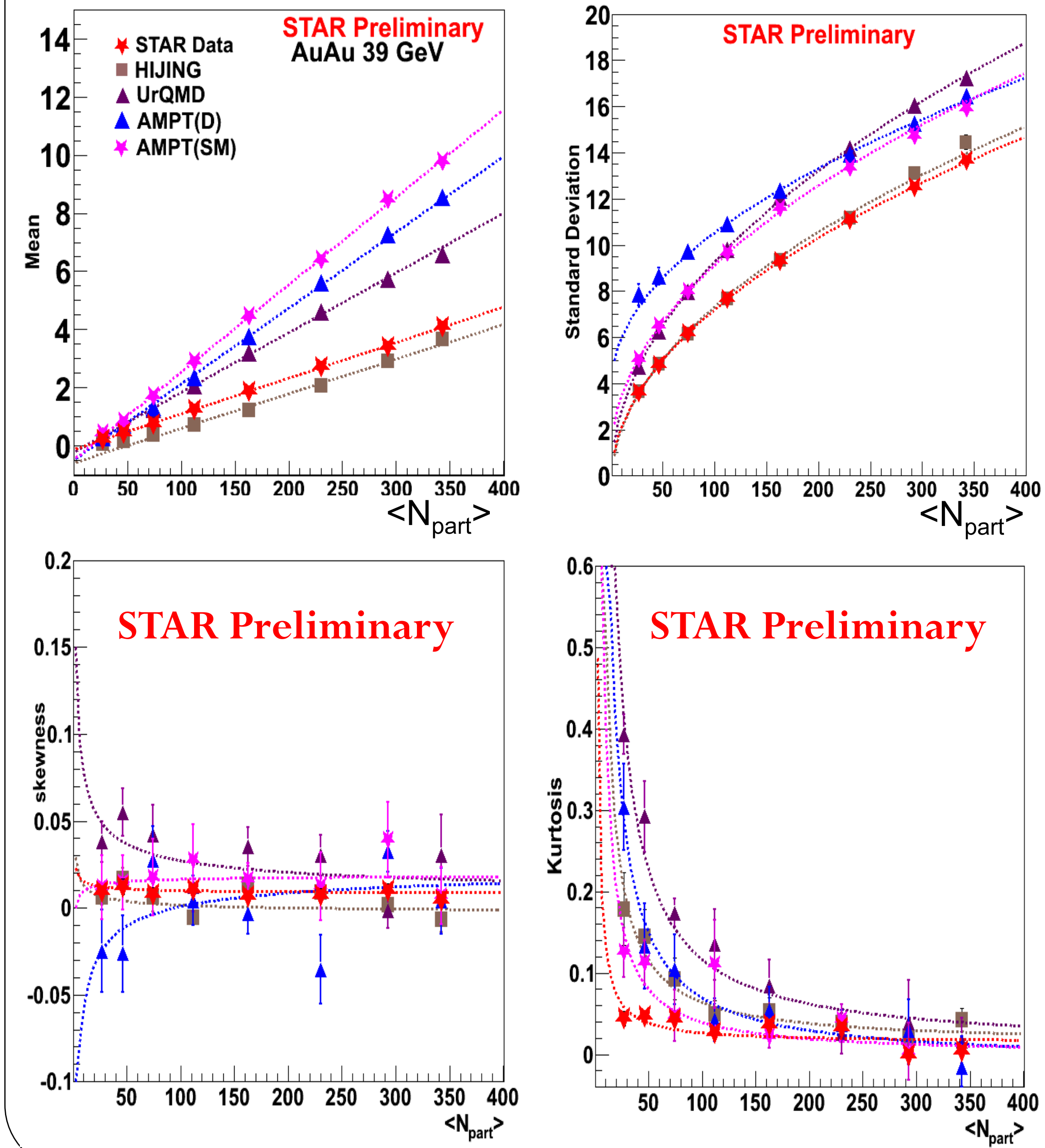
# Higher Moments For Net-charge Distribution




➢Kurtosis does not agree with central limit theorem (CLT) at higher centrality

➢Systematic errors, from bin width effect, has been included

# Comparison With Models




- **AMPT (D) shows negative-skewness at peripheral events**

HIJING: QCD based jet-interaction model

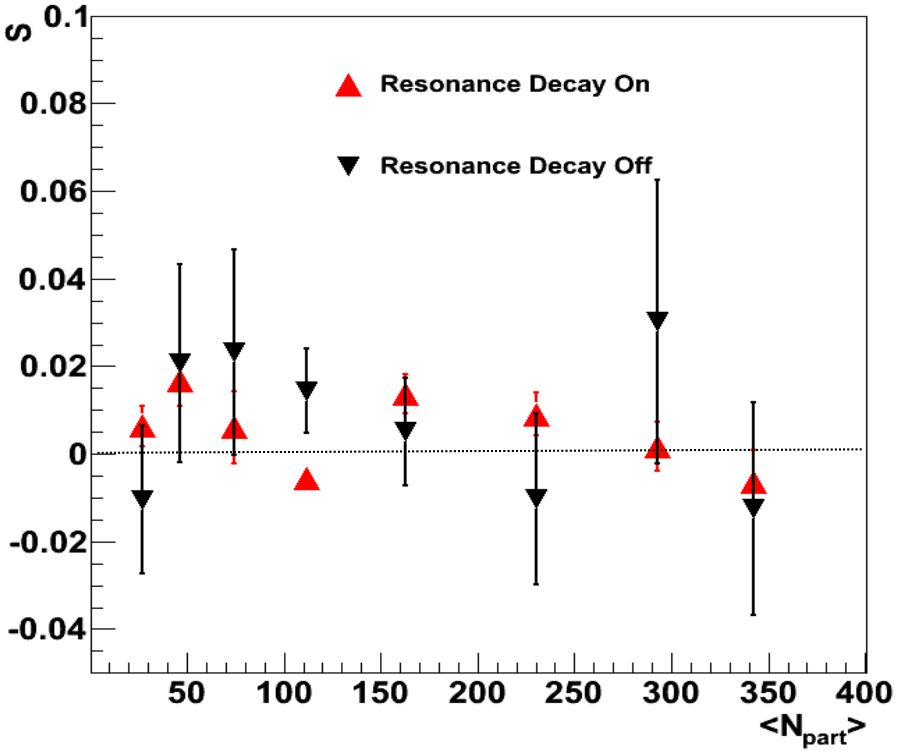
UrQMD: transport model containing resonances, rescattering, etc.

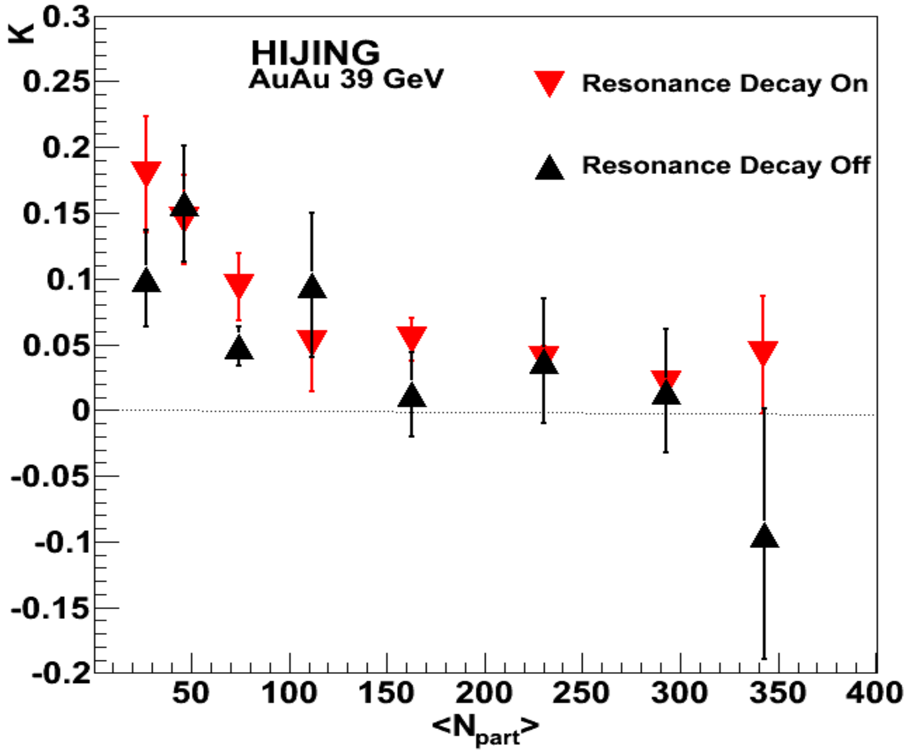
AMPT : multiphase transport model where AMPT(SM) includes coalescence mechanism of particle production

*AMPT(D) => AMPT(Default)

*AMPT(SM)=>AMPT (String Melting)

# Resonance effect on net-charge fluctuation

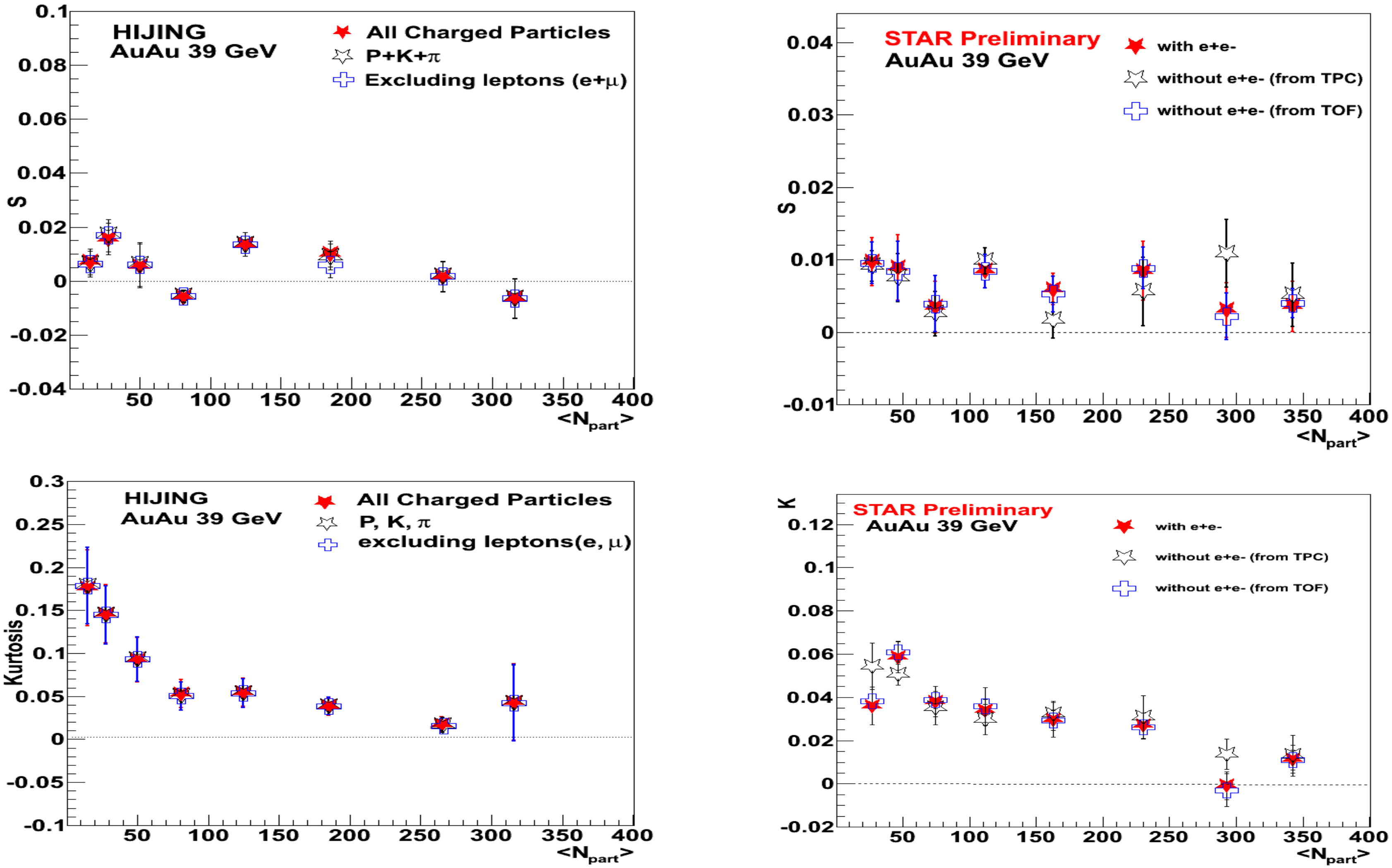



➢**Resonance decay**:

**within error bars, the effect on the skewness is small**

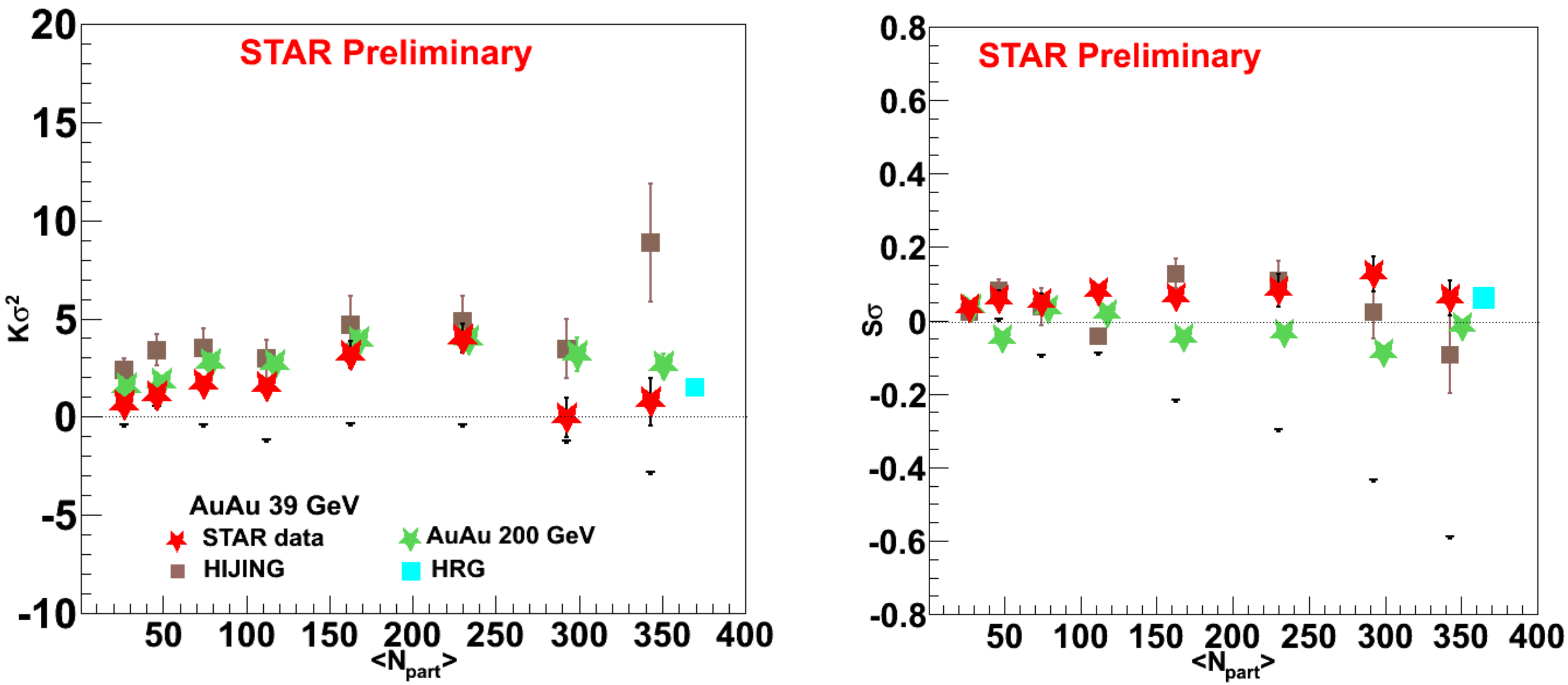
# Leptonic contribution for net-charge fluctuation




➢HIJING : No effects on higher moments for all charged particles and selected ($P+K+\pi$) hadrons

➢HIJING and STAR data : Negligible effects of leptons

# Products Of higher moments For Net-charge Distribution




- **HRG Model : $K\sigma^2$:1.75 to 1.85, $S\sigma$: 0.03 to 0.15**
- **HRG model agree with data**

*HRG : Karsch and Redlich, arxiv:1007.2581

* AuAu 200 GeV : Nucl.Phy.A 830(2009)

# Summary

- Results on higher moments of net-charge distribution from AuAu 200 and 39 GeV collisions have been presented .
- HRG model agrees with data.
- $K\sigma^2$ and $S\sigma$ values are comparable for AuAu 200 and 39 GeV.
- Products of the higher moments of net-proton and net-charge distribution have similar values at AuAu 200 and 39 GeV .

# Outlook

- Systematic study
- Data analysis for other BES energies (7.7,11.5, 62.4 (GeV))
- Run 11 data taking for BES energies ( 27,18 ,5(GeV) )

# THANK YOU

# Back Up

# Central Limit Theorem (CLT)

**Each centrality reflect volume of the system (i.e.,<$N_{part}$>)**

**How moments depend on <$N_{part}$> ?**

$$M_i = CM_x \langle N_{\text{part}} \rangle_i,$$

$$\sigma_i^2 = C\sigma_x^2 \langle N_{\text{part}} \rangle_i,$$

$$S_i = S_x / [\sqrt{C \langle N_{\text{part}} \rangle_i}],$$

$$\kappa_i = \kappa_x / [C \langle N_{\text{part}} \rangle_i].$$

Where $i$ represents each centrality

PRL 105 (2010) 022302

**Agreement between moments and CLT**

**No volume dependence**

**Deviation from CLT → new physics (may be presence of CP)**