The Sixth and Fourth Order Cumulants of Net-proton Multiplicity Distribution at STAR

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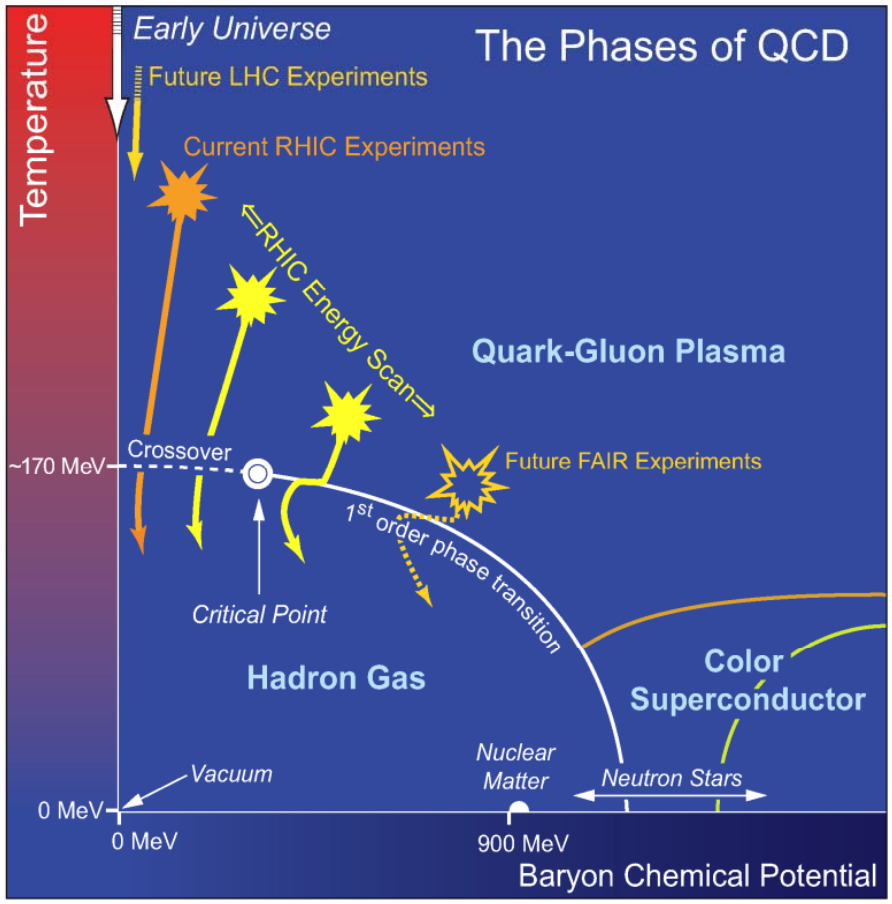
Outline

- **Motivation**
- **STAR Detector**
- **Results and Discussions**
  - Centrality dependence
  - Energy dependence
- **Summary**

Motivation



- Lattice QCD: μ_B=0,Crossover.
  Y. Aoki et al., Nature 443, 675-678(2006).

- QCD based Model,
  T≈0 and larger μ_B, first order transition.
  eg: S. Ejiri, Phys. Rev. D 78, 074507 (2008); H. Saito, et al., (WHOT-QCD Collaboration). hep-lat/1106.0974.

- Experiment approach:

✓RHIC Beam Energy Scan Program: The search for signatures of phase boundary and critical point. *http://drupal.star.bnl.gov/STAR/starnotes/public/sn0493. arXiv: 1007.2613.*

✓High event statistics collected at RHIC top energy.

Important observable: The cumulants ratios of conserved quantities.
Direct connection between theory calculation and experiment.

Ratios of cumulants of net-proton multiplicity

1:The net-proton multiplicity fluctuation can reflect the net-baryon number fluctuation.

Y. Hatta et al,PRL 91, 102003 (2003)

2: Related to the ratios of the susceptibilities directly.

$$\chi_4^B / \chi_2^B \approx \left(\frac{1}{VT^3} C_4\right) / \left(\frac{1}{VT^3} C_2\right) = C_4 / C_2 = \kappa\sigma^2$$

$$\chi_6^B / \chi_2^B \approx \left(\frac{1}{VT^3} C_6\right) / \left(\frac{1}{VT^3} C_2\right) = C_6 / C_2$$

✓ The volume effect is canceled out

$$C_2 = \left\langle \delta N_{p-\bar{p}}^2 \right\rangle$$

$$C_4 = \left\langle \delta N_{p-\bar{p}}^4 \right\rangle - 3\left\langle \delta N_{p-\bar{p}}^2 \right\rangle^2$$

$$C_6 = \left\langle \delta N_{p-\bar{p}}^6 \right\rangle - 15\left\langle \delta N_{p-\bar{p}}^4 \right\rangle \left\langle \delta N_{p-\bar{p}}^2 \right\rangle - 10\left\langle \delta N_{p-\bar{p}}^3 \right\rangle^2 + 30\left\langle \delta N_{p-\bar{p}}^2 \right\rangle^3$$

3: Hadron Resonance Gas (HRG) expectation:

$$C_{2n} / C_2 = 1 \quad (n = 1, 2, 3 \cdots)$$

✓ Independent of collision energy and centrality

F. Karsch and K. Redlich, Phys. Lett. B 695, 136 (2011)

Ratios of cumulants of net-proton multiplicity

4: Sensitive to the correlation length

$$\left\langle \delta N^{k} \right\rangle \sim \xi^{2.5k-3} \Longrightarrow \begin{array}{l} \left\langle \delta N^{3} \right\rangle \sim \xi^{4.5} \\ \left\langle \delta N^{4} \right\rangle - 3\left\langle \delta N^{2} \right\rangle^{2} \sim \xi^{7} \end{array}$$

M. A. Stephanov, Phys. Rev. Lett. 102, 032301 (2009). arXiv:1104.1627

✓ The correlation length away from the CP (Critical Point): $\xi \sim 0.5-1\,fm$

✓Near the CP, due to the critical slowing down:
Magnitude of ξ is limited: $\xi \sim 2-3\,fm$

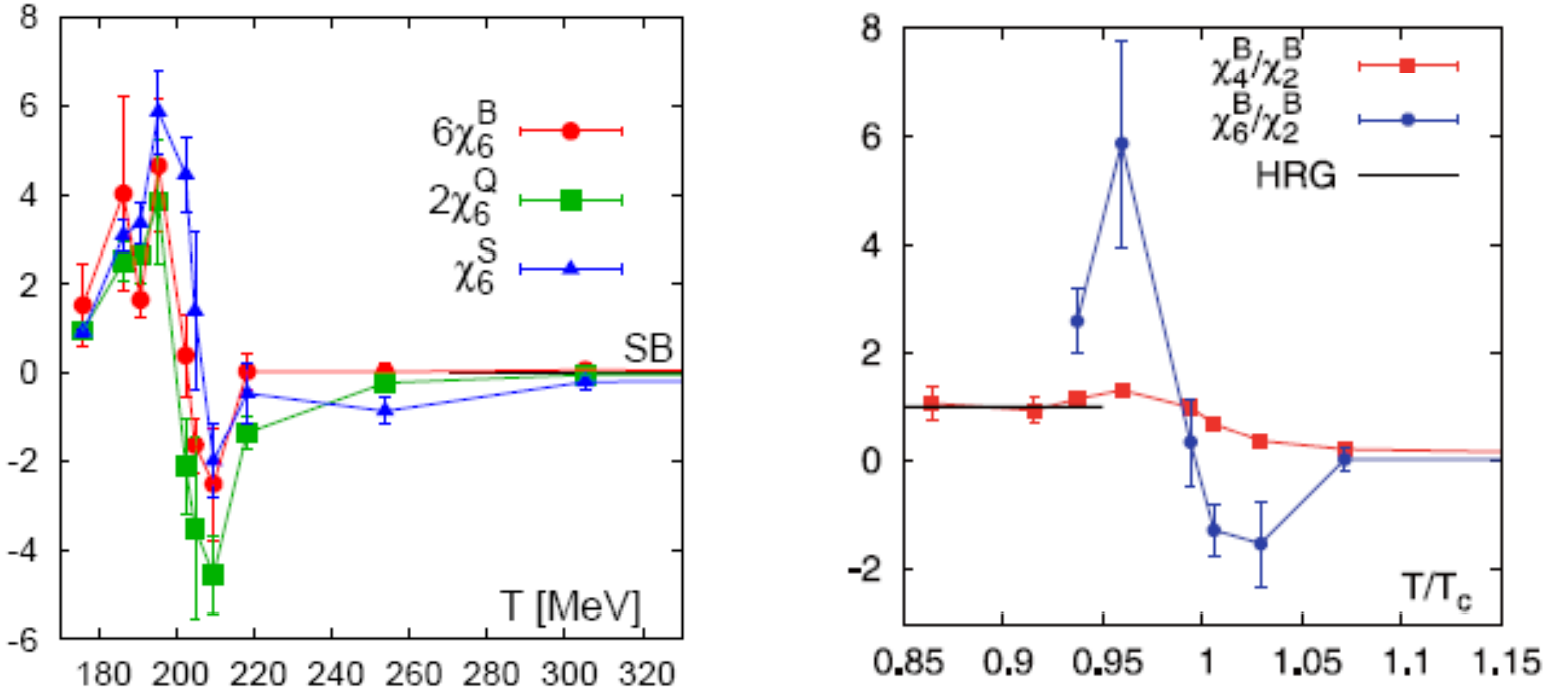
B. Berdnikov, K. Rajagopal, Phys. Rev. D 61, 105017 (2000).

✓Higher moments are more sensitive to the critical point.

✓ Non-monotonic signal as function of energy is expected to be observed near CP.

Ratios of cumulants of net-proton multiplicity

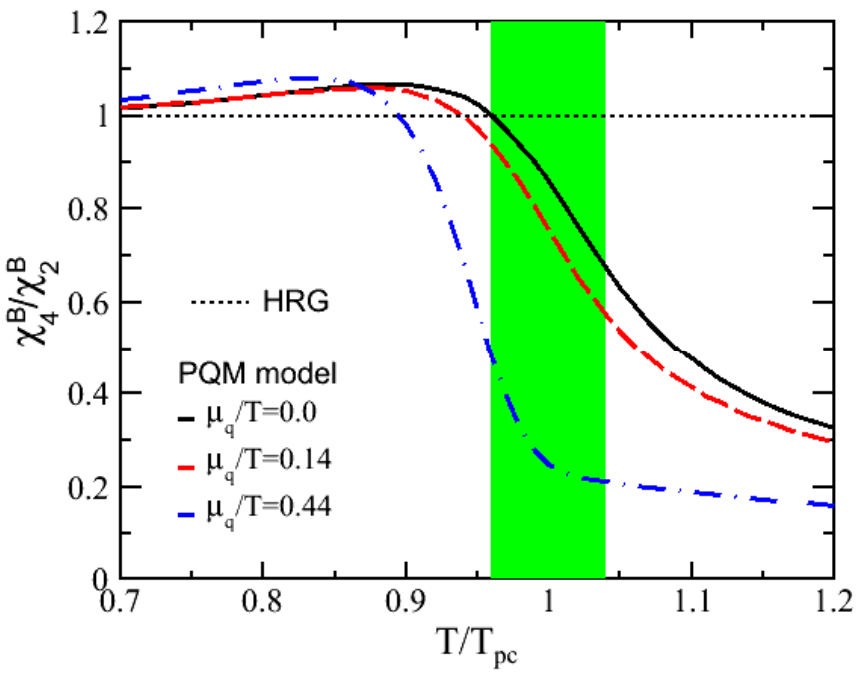
5: Sensitive to the QCD Critical Temperature T_c

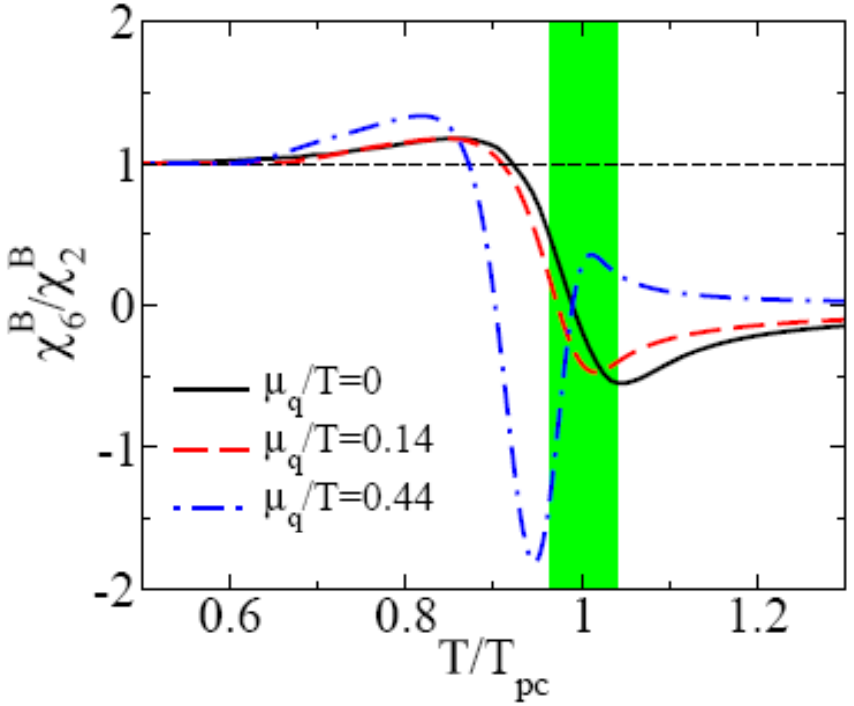


Cheng et al, Phys.Rev. D79 (2009) 074505，Prog.Theor.Phys.Suppl. 186 (2010) 563-566

- Both ratios fluctuate near the T_c.
- The higher order of the cumulants show the stronger fluctuation.
- Lattice prediction: in high energy nuclear collision (e.g. LHC and RHIC), the C_6/C_2 may be negative if the freeze out curve close to phase transition line.

Ratios of cumulants of net-proton multiplicity



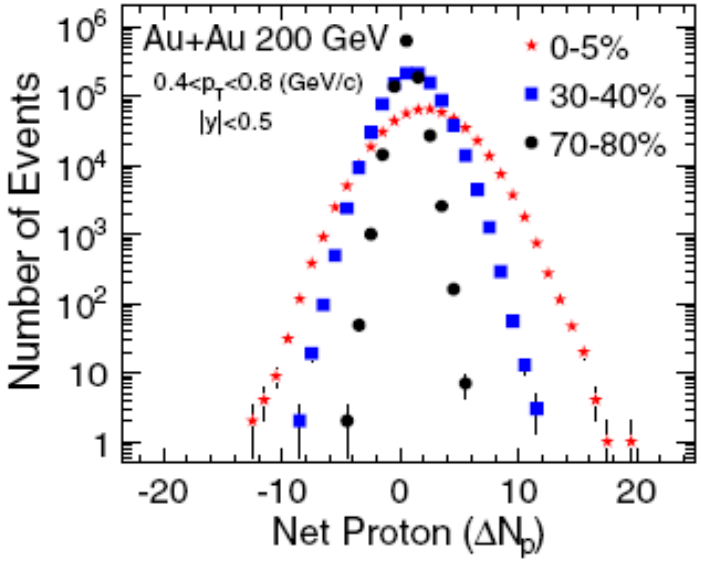


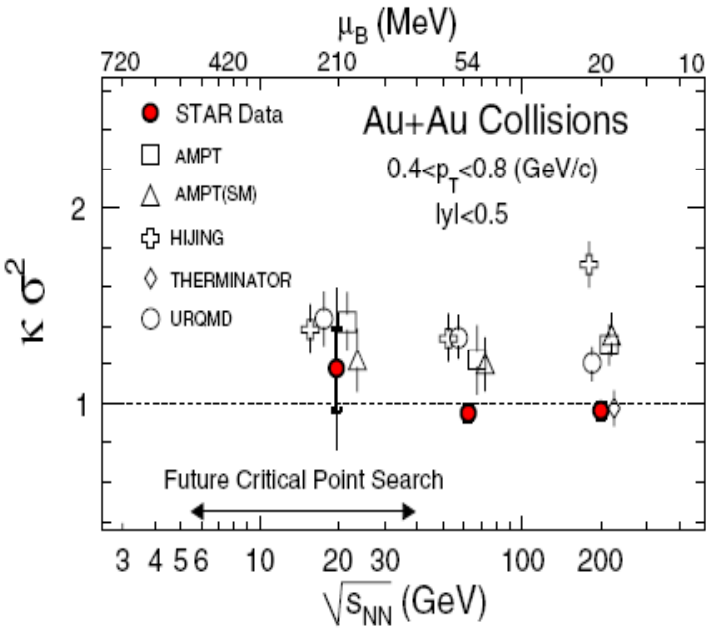
- The PQM model is an effective model to study the thermodynamics near the chiral phase transition.

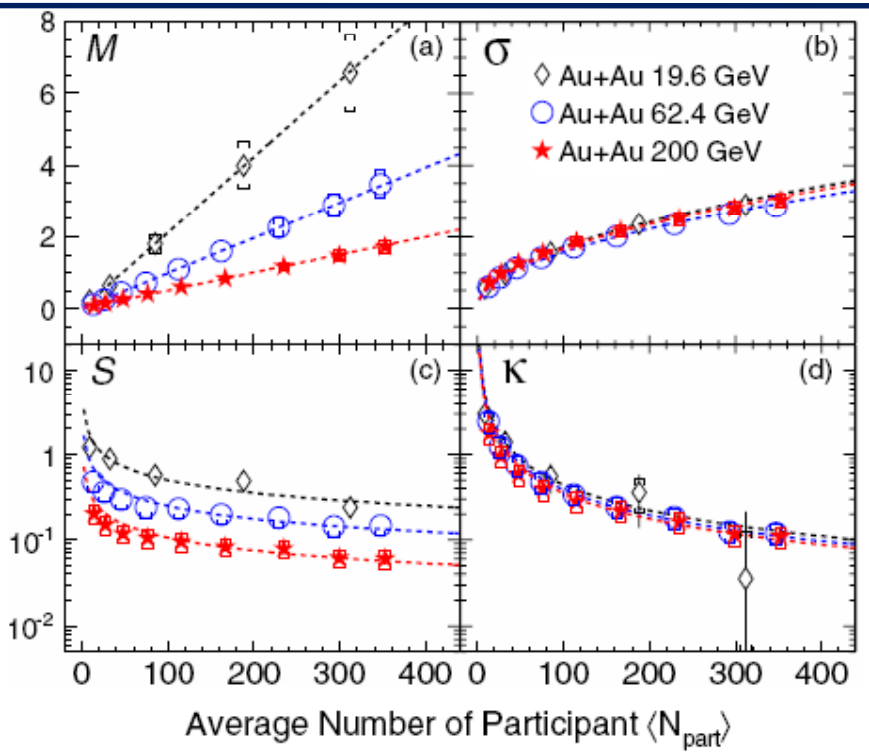
- The structure of the fluctuation in PQM model are similar with Lattice QCD for both ratios.

B. Friman, F. Karsch, K. Redlich and V. Skokov. Eur. Phys. J. C71, 1694 (2011)

First result on higher moments of net-proton



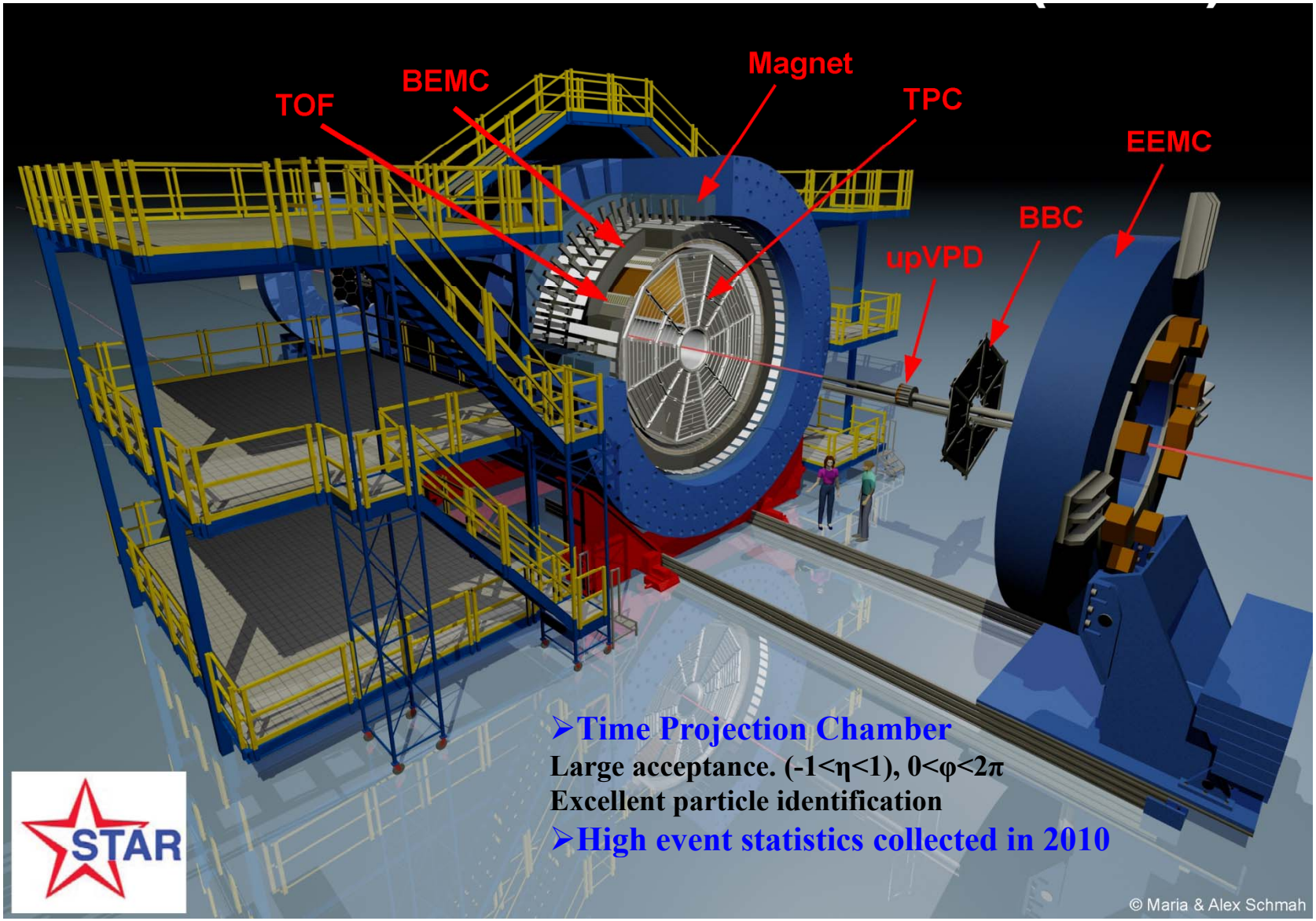




STAR , PRL 105 (2010) 022302.

- STAR first results on higher moments analysis are up to fourth order.
- Using ratios used to establish base line measurements for the QCD critical point search.
- **This talk: C_6/C_2 and C_4/C_2.**

STAR Detector



Analysis Detail

- Data collection
  - ✓ 200 GeV: 404 Million total*
  - ✓ 39 GeV: 125 Million MB

*Central collisions data from both MinBias and central-trigger data-sets.

- Centrality Bin Width Effect

For each centrality, cumulants are calculated in each uncorrected reference multiplicity, then weighted by the number of events in that multiplicity bin.

STAR, arXiv:1106.2926

- Kinematic range for protons:
  - Midrapidity: $|y| < 0.5$
  - p_T : 0.4 - 0.8 GeV/c

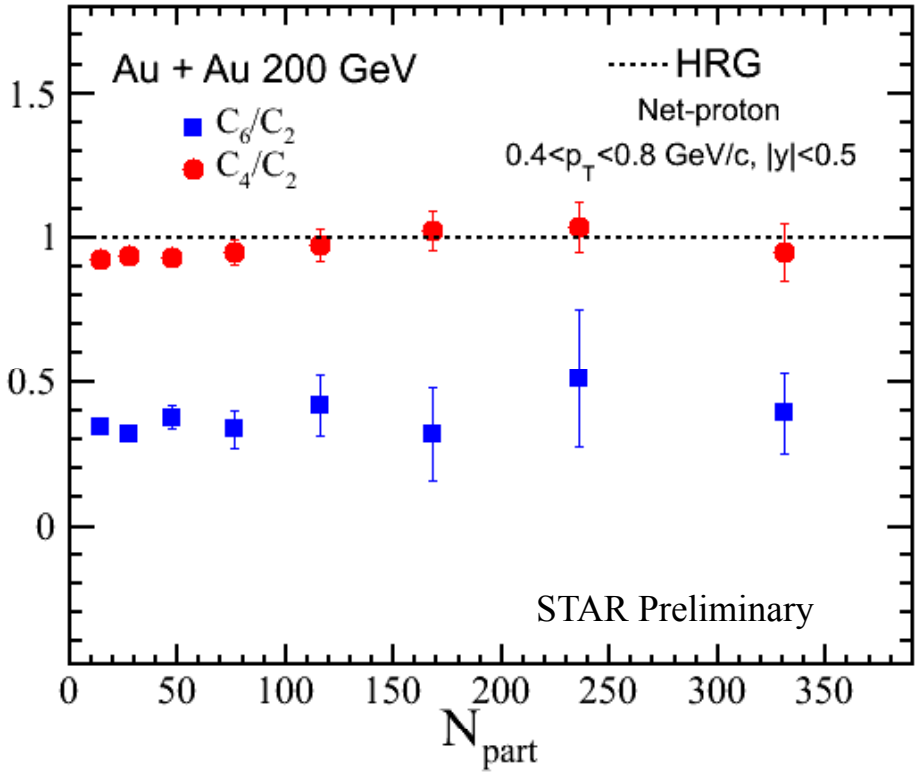
- Statistical error estimate: Bootstrap method.

Bradley Efron,http://www.jstor.org/pss/2030104 .

- Systematic effects:

Auto-correlation between centrality selection , PID method, error estimation are under study.

Results (I): Au + Au 200 GeV

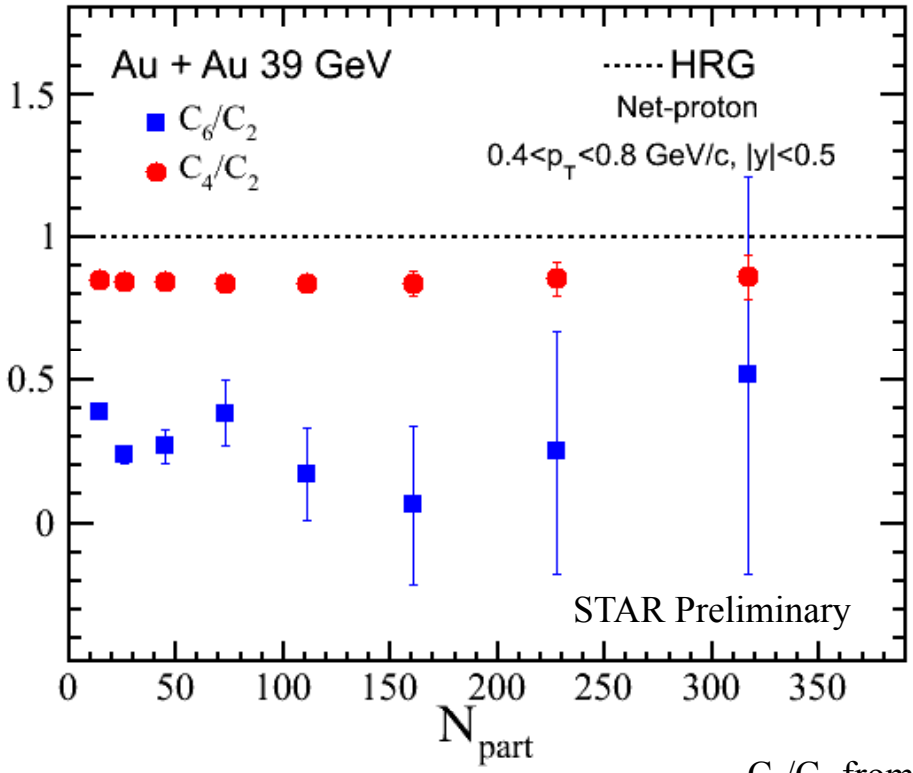


C_4/C_2 are published in STAR, PRL 105 (2010) 022302.

- Central collisions, MinBias trigger and central trigger datasets.

- The centrality dependence is weak.
- C_4/C_2 are consistent with unity for central collisions.
- First results of C_6/C_2.

Results (II): Au + Au 39 GeV

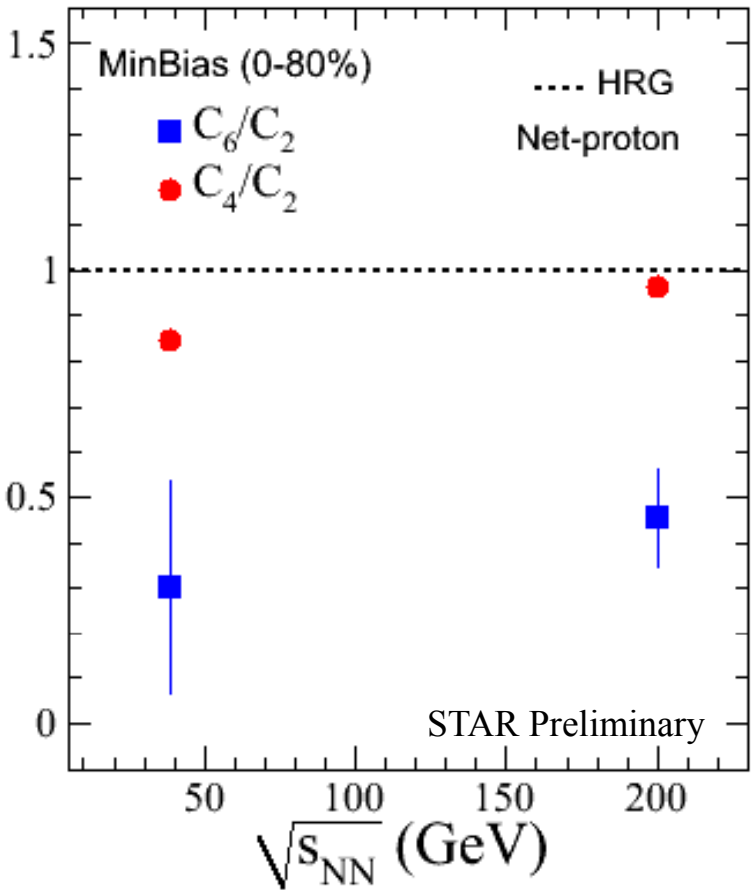


C_4/C_2 from STAR, arXiv:1106.2926

- C_4/C_2 deviate from the unity.

- C_6/C_2 show similar trend as in Au + Au 200 GeV. But larger error in central collisions.

Results (III): Energy dependence



- Data:
  The deviation for C_4/C_2 from HRG at lower energy.

- Theory:
  The deviation from the HRG results grow with increasing energy.

P. Braun-Munzinger, et al. arXiv: 1107.4267

Summary

- The cumulant ratio of conserved quantities provide a direct connection between theory calculation and experiment. It is an important observable for studying the QCD phase diagram.

- We report the first results of net-proton C_6/C_2 in Au + Au collisions at 39 and 200 GeV.

- All observed values are positive at both energies.

- The values of C_6/C_2 are lower than that of C_4/C_2.

- The centrality dependence is weak.

Outlook: Au + Au Collisions at 19.6, 27 and 62.4 GeV data are under analysis.