Recent Results of Fluctuation and Correlation Studies from the QCD Critical Point Search at RHIC

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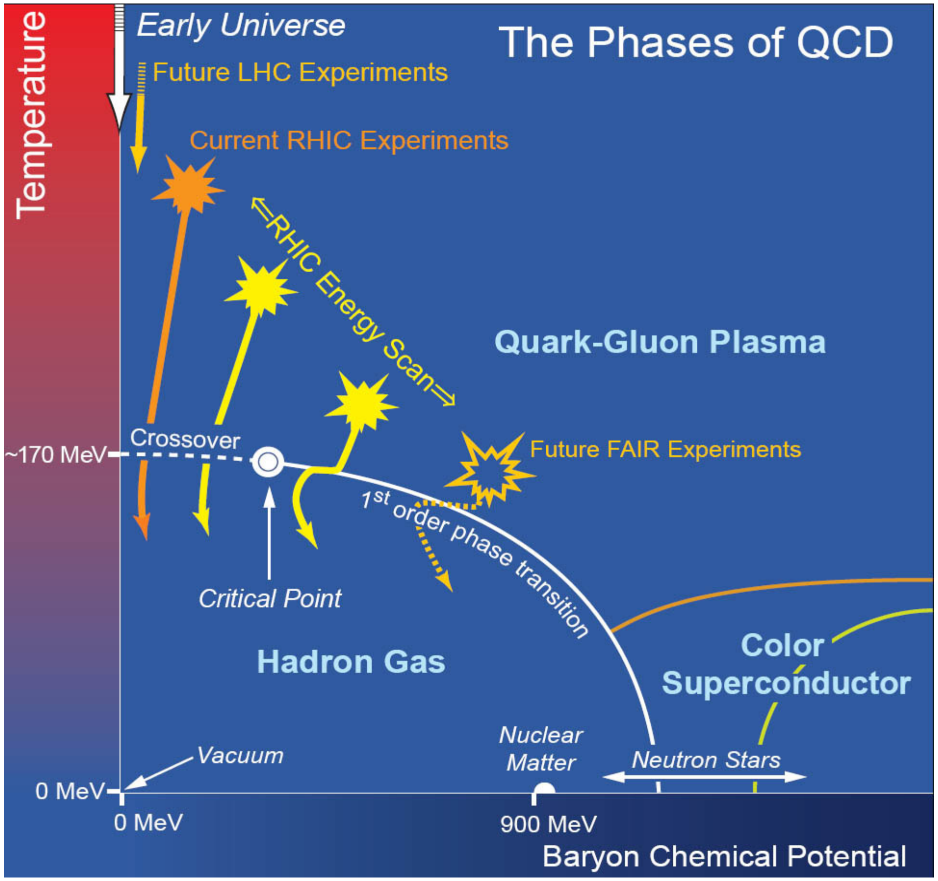
Outline

- Introduction
- Critical Point Search
- Particle Ratio Fluctuations
- Summary

Nuclear Matter

- Finite (charged) nuclear matter occurs at low T and $\mu_B \approx 922$ MeV → energy density (ε) ≈ 0.15 GeV/fm^3.

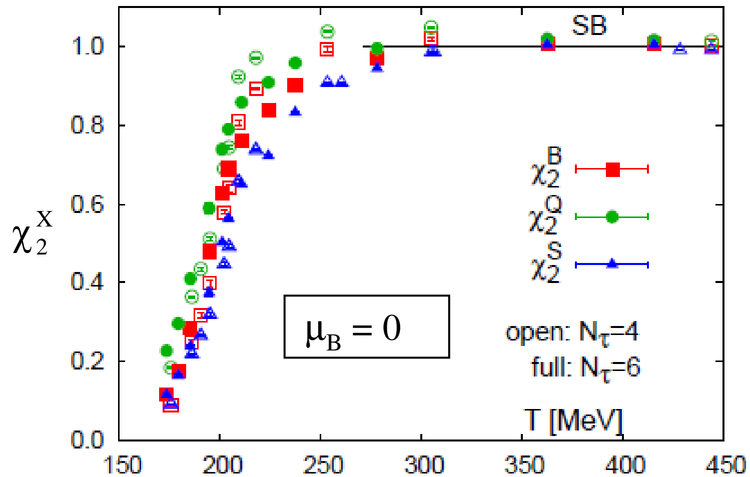


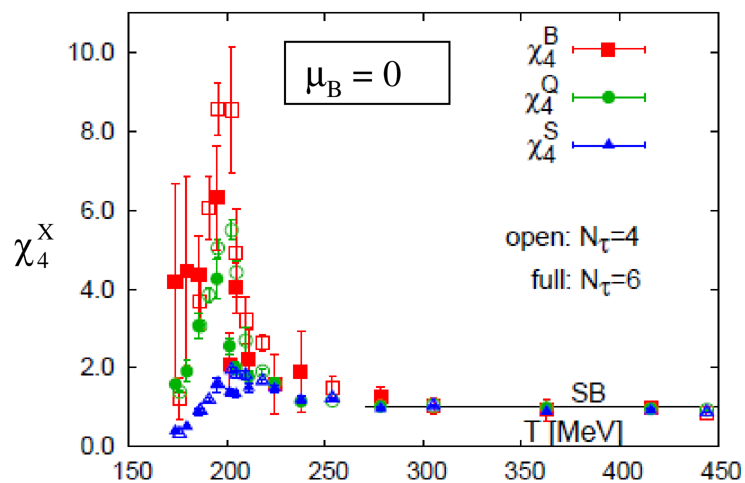
- Lattice QCD:
  - –Transition between hadronic matter and quark-gluon matter predicted at T ≈ 170 MeV.
  - –Critical point predicted.
    - Transition crossover to left, 1st order to right.

Search for the QCD Critical Point

- In a phase transition near a critical point, an increase in non-statistical fluctuations is expected.
- Finite system-size effects may influence fluctuation measurements.
  - Finite-size scaling of fluctuations may indicate existence of critical point.
  - E.g. Change in behavior of quark susceptibilities.

    Aoki, Endrodi, Fodor, Katz, and Szabó *Nature* **443**, 675-678 (2006)
- These may manifest in final-state measurements.





RHIC "Energy Scan"

- Using RHIC to run an "energy scan" to search for predicted QCD critical point.
- For 2010, we had Au+Au collisions at $\sqrt{s_{NN}}$ = 200, 62.4, 39, 11.5, and 7.7 GeV.
  - 2011 added Au+Au collisions at $\sqrt{s_{NN}}$ = 19.6 and 27 GeV.
- Can examine our observables to look for non-monotonic behavior as a function of collision energy.

Particle Ratio Fluctuations

p/π

$(p^{+} + p^{-})/(\pi^{+} + \pi-)$

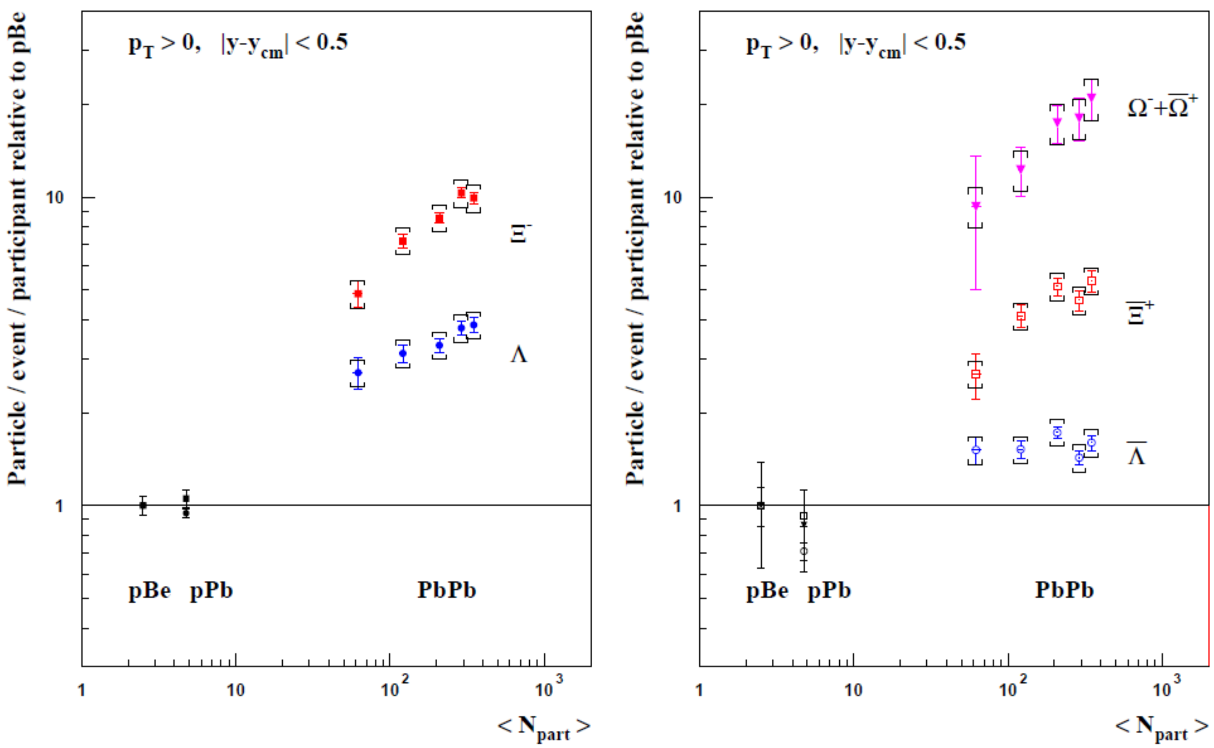
K/π

$(K^{+} + K^{-})/(\pi^{+} + \pi-)$

K/p

$(K^{+} + K^{-})/(p^{+} + p^{-})$

Strangeness Enhancement



A. Dianese [NA57 Collab.] , Nucl. Phys. A 774, 51–58 (2006)

- Suggested that a signature of a QGP would be enhancement in the production of particles containing strange quarks.
  (J. Rafelski and B. Müller, Phys. Rev. Lett. 48, 1066–1069 (1982))
  - Production of strange-anti-strange quark pairs via gluon fusion in a QGP.
- Seen across a wide range of collision energies of A+A and p+A.

Particle Ratios

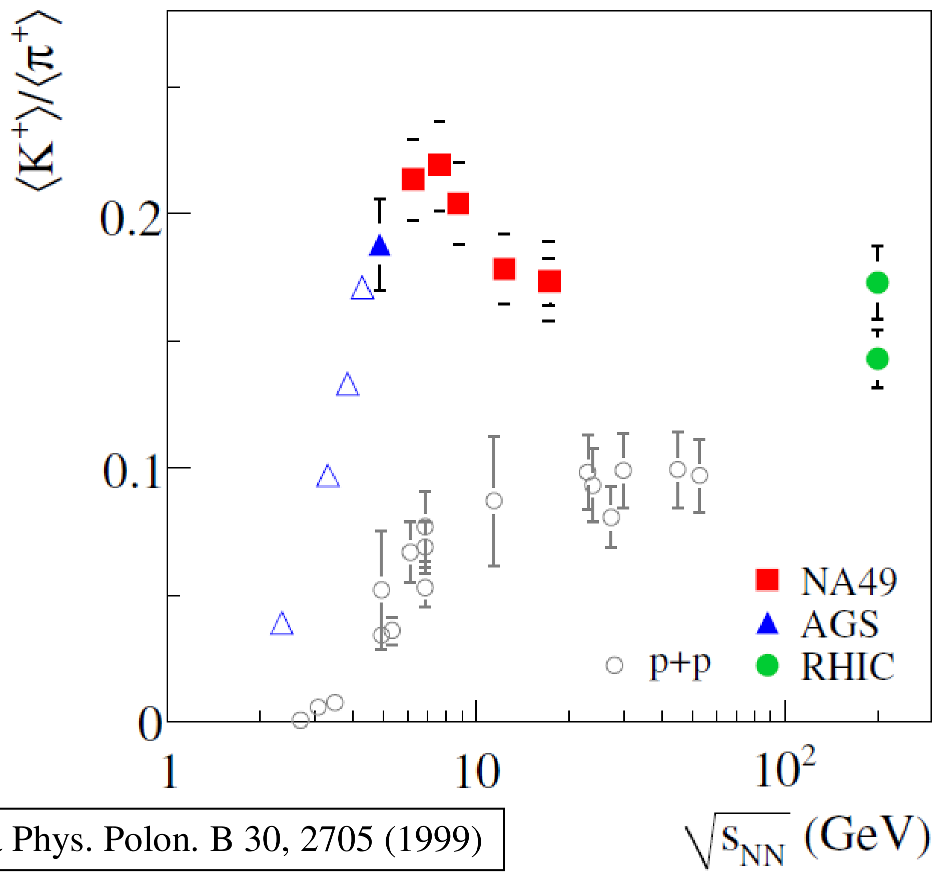
- Conserved quantities:
  - Charge, Strangeness, Baryon #

- K/π : Strangeness/entropy
- p/π : Baryon/entropy
- K/p: Strangeness/baryon

- Particle ratios (ideally) cancel volume fluctuations.

K/π "Horn"

- Maximum observed by NA49 in the K^{+}/π^{+} ratio.
  - Very different compared to K^{-}/π^{-} ratio, which shows no peak.
  - Also much different from pp collisions.
- Ascribed to deconfinement phase transition $\sqrt{s_{NN}}$ ~ 7-8 GeV.



M. Gazdzicki and M. I. Gorenstein, Acta Phys. Polon. B 30, 2705 (1999)

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New State of Matter created at CERN

PR01.00
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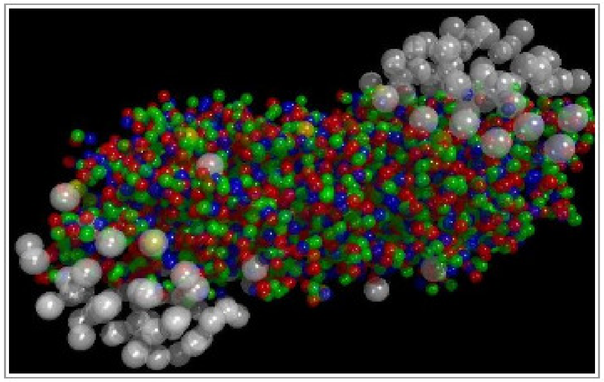
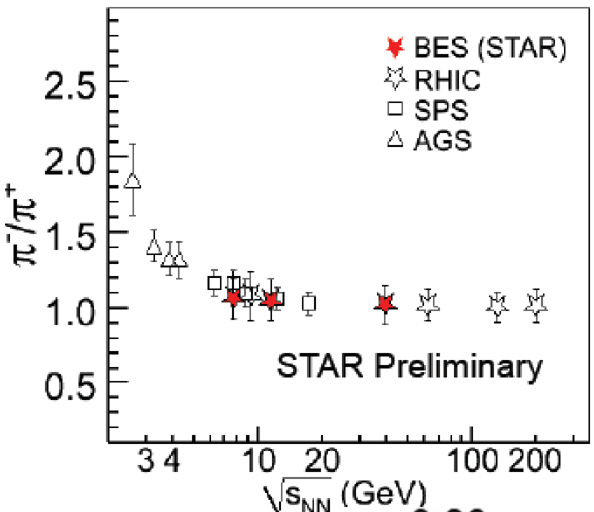
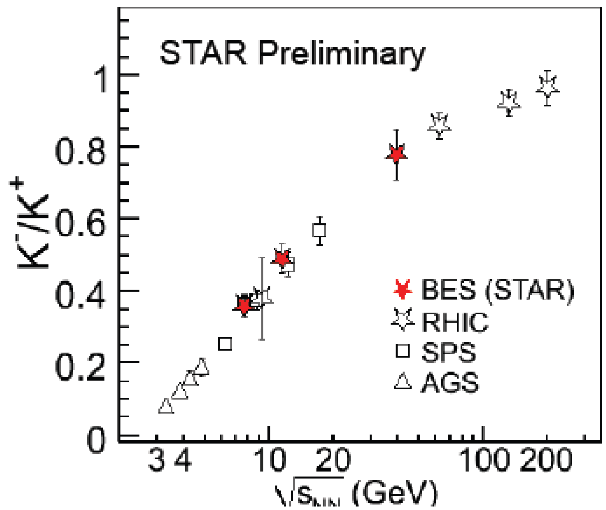


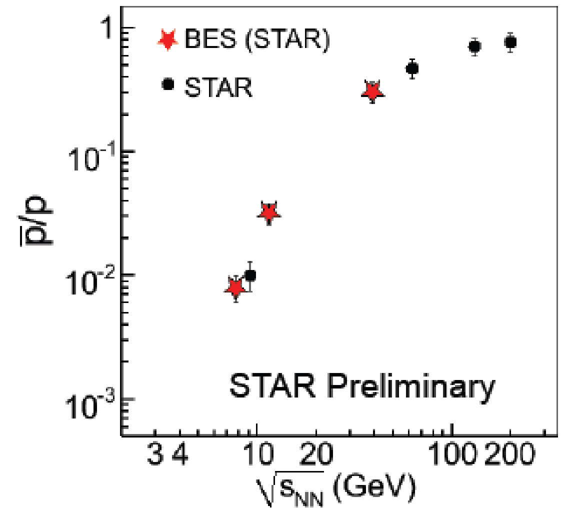
At a special seminar on 10 February, spokespersons from the experiments on CERN* 's Heavy Ion programme presented compelling evidence for the existence of a new state of matter in which quarks, instead of being bound up into more complex particles such as protons and neutrons, are liberated to roam freely.

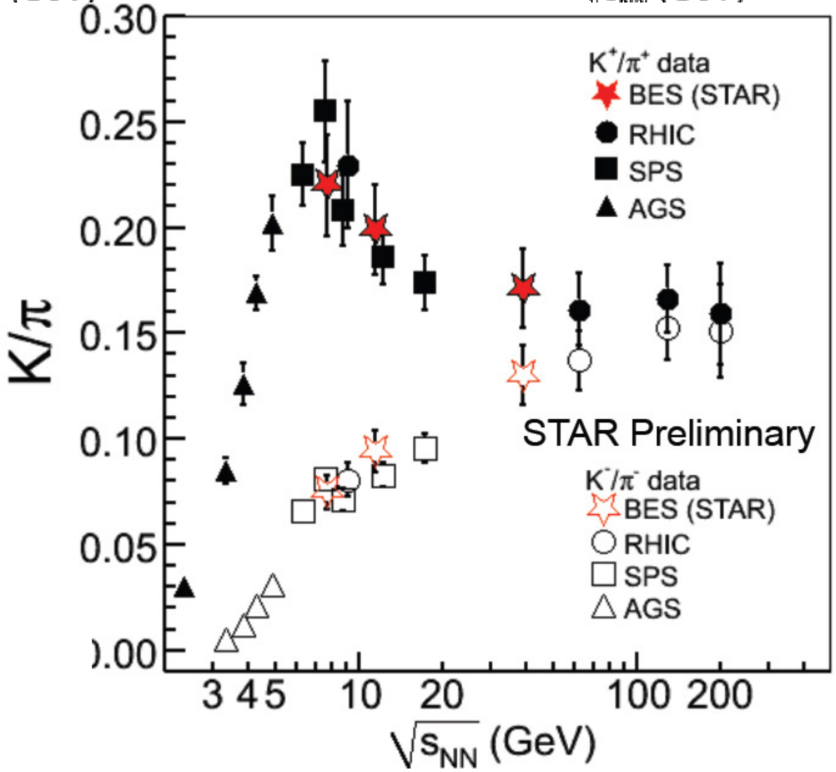
Theory predicts that this state must have existed at about 10 microseconds after the Big Bang, before the formation of matter as we know it today, but until now it had not been confirmed experimentally. Our understanding of how the universe was created, which was previously unverified theory for any point in time before the formation of ordinary atomic nuclei, about three minutes after the Big Bang, has with these results now been experimentally tested back to a point only a few microseconds after the Big Bang.

STAR Particle Yields and Ratios









NA49: PRC 66 (2002) 054902,
PRC 77 (2008) 024903,
PRC 73 (2006) 044910
STAR: PRC 79 (2009) 034909,
arXiv: 0903.4702; PRC 81 (2010) 024911
E802(AGS): PRC 58 (1998) 3523,
PRC 60 (1999) 044904
E877(AGS): PRC 62 (2000) 024901
E895(AGS) : PRC 68 (2003) 054903

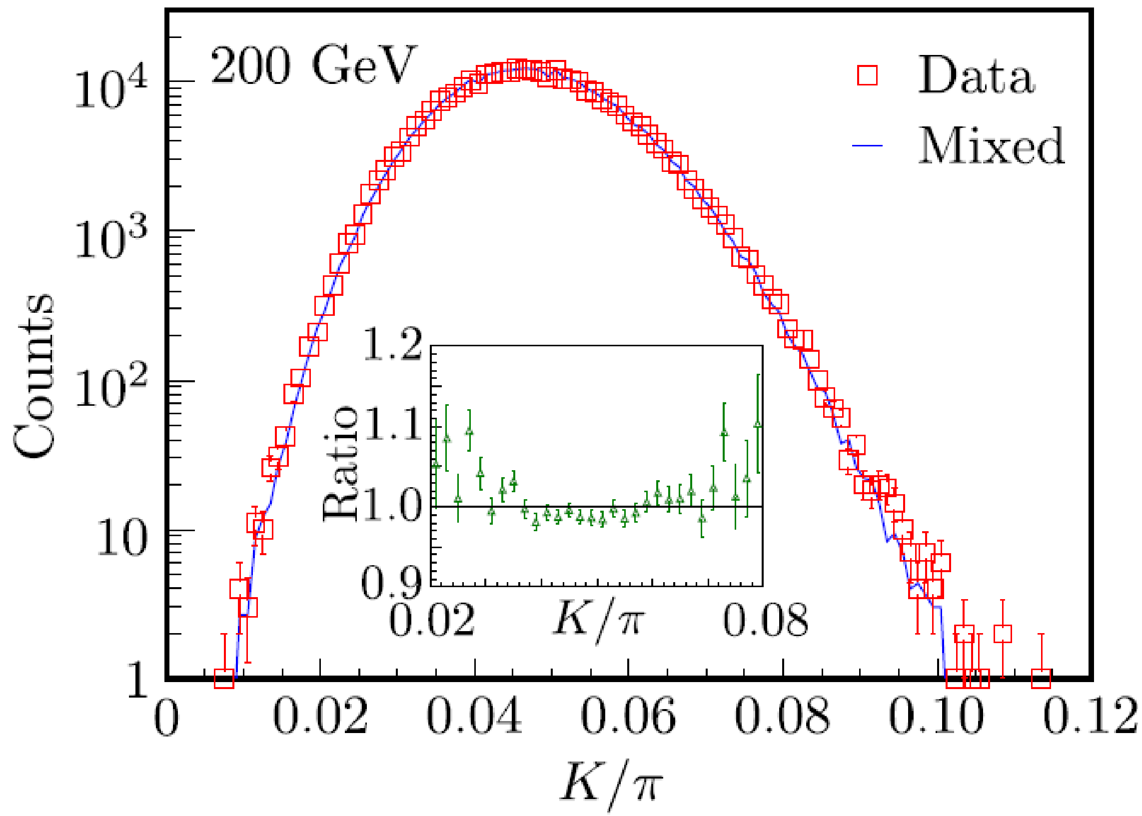
NSCL

Fluctuation Observables, σ_{dyn}

- NA49 uses the variable σ_{dyn}

$$\sigma_{dyn} = sign\left(\sigma^2_{data} - \sigma^2_{mixed}\right)\sqrt{\left|\sigma^2_{data} - \sigma^2_{mixed}\right|}$$

σ is the reduced width of K/π distribution



Fluctuation Observables, ν_{dyn}

- STAR uses a different fluctuation observable, ν_{dyn}.

$$\nu_{\mathrm{dyn},K\pi} = \frac{\langle N_K (N_K - 1) \rangle}{\langle N_K \rangle^2} + \frac{\langle N_\pi (N_\pi - 1) \rangle}{\langle N_\pi \rangle^2} - 2 \frac{\langle N_K N_\pi \rangle}{\langle N_K \rangle \langle N_\pi \rangle}$$

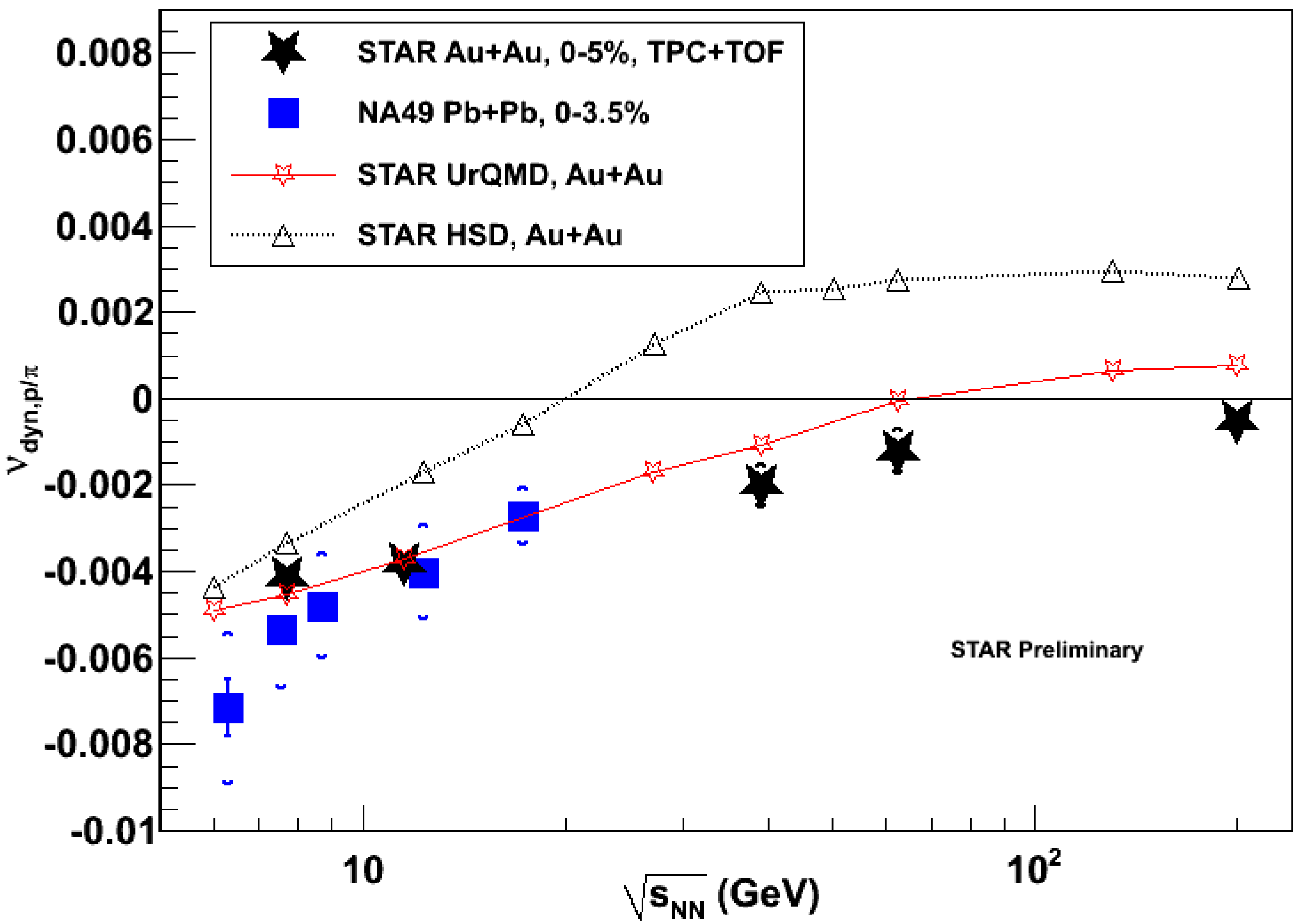
- Introduced to study net-charge fluctuations.

- Measures deviation from Poisson behavior.

- It has been demonstrated that,

$$\sigma^2_{dyn} \approx \nu_{dyn}$$

Excitation Function for $\nu_{dyn,p/\pi}$



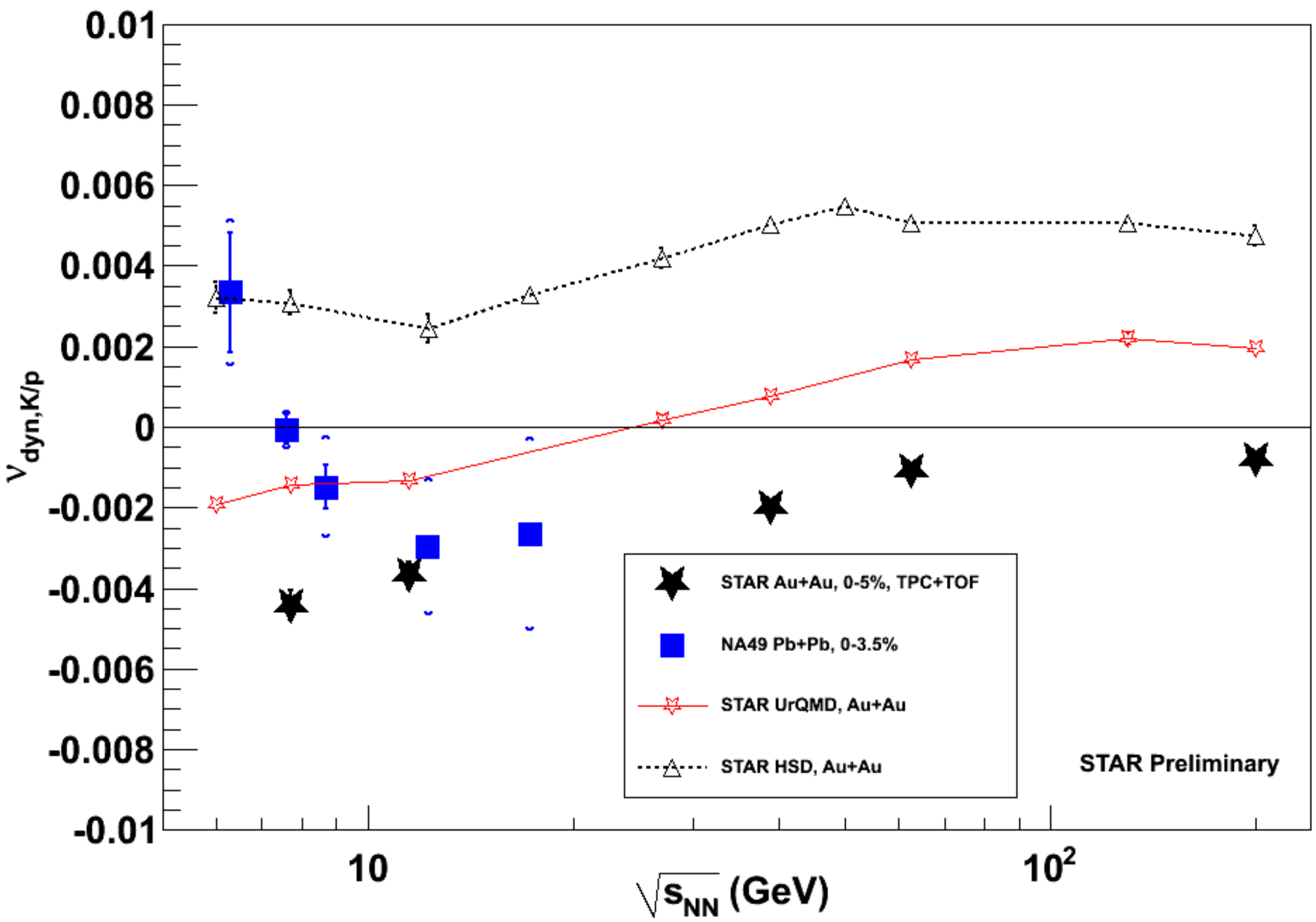
- NA49 $\sigma_{dyn,p/\pi}$ converted to $\nu_{dyn,p/\pi}$.
- TPC+TOF (GeV/c):
  - π : $0.2 < p_T < 1.4$
  - p : $0.4 < p_T < 1.8$
- TPC+TOF includes statistical and systematic errors from electron contamination.
- Agreement with measurements from NA49 at low energies.

(NA49 data from: C. Alt et al. [NA49 Collab.], Phys. Rev. C 79, 044910 (2009)

- UrQMD and HSD predictions both change sign at high energies.

Excitation Function for $\nu_{dyn,K/p}$

- NA49 $\sigma_{dyn,K/p}$ converted to $\nu_{dyn,K/p}$ using $\sigma^2_{dyn} = \nu_{dyn}$.



- TPC+TOF (GeV/c):
  - K : $0.2 < p_T < 1.4$
  - p : $0.4 < p_T < 1.8$

- TPC+TOF includes statistical and systematic errors from electron contamination.

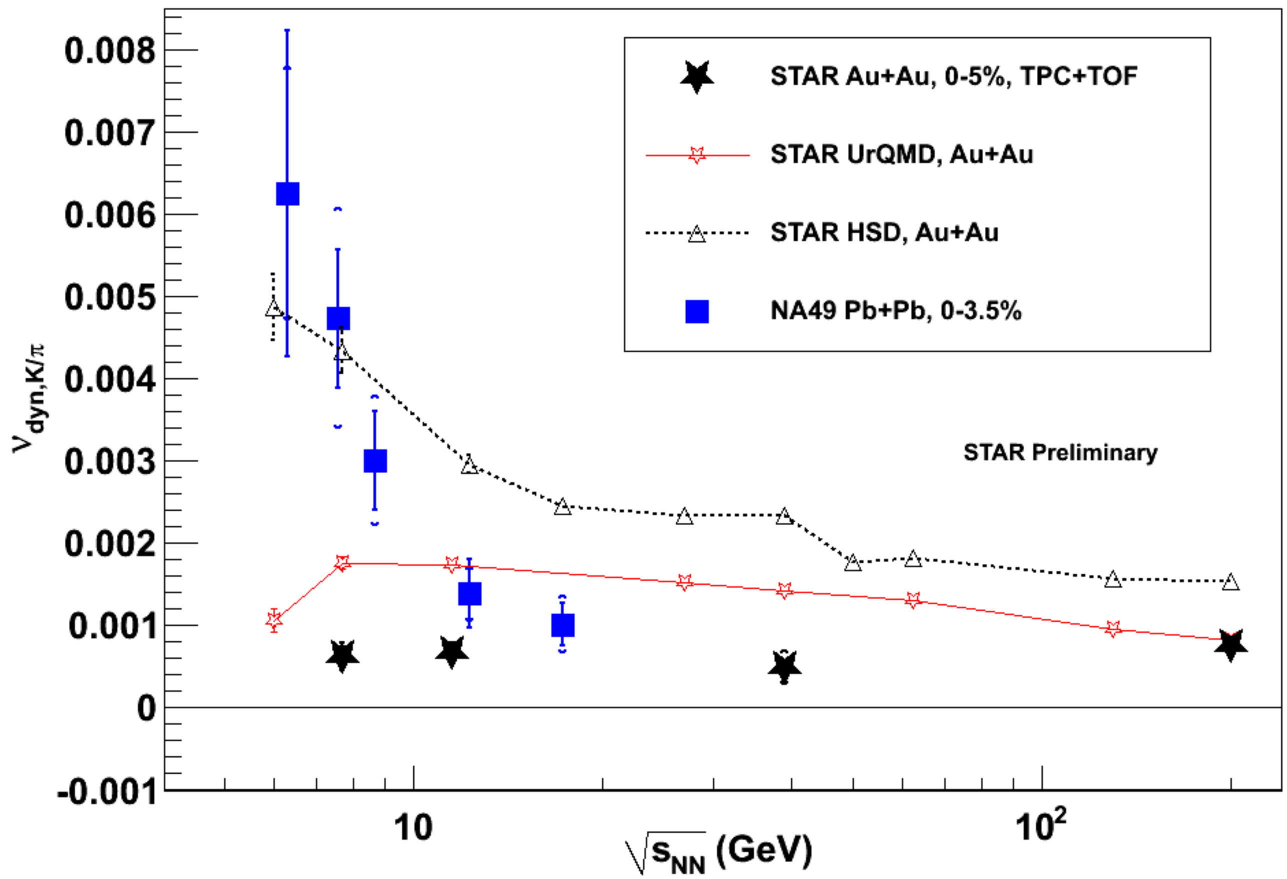
- Large deviation between STAR and NA49 result at $\sqrt{s_{NN}}$ = 7.7 GeV.

(NA49 data from: T. Anticic, et al [NA49 Collab.] arXiv:1101.3250v1 [nucl-ex])

- Models predominantly independent of experimental acceptance.

Excitation Function for $\nu_{dyn,K/\pi}$

- NA49 $\sigma_{dyn,K/\pi}$ converted to $\nu_{dyn,K/\pi}$ using $\sigma^2_{dyn} = \nu_{dyn}$.



- TPC+TOF (GeV/c):
  - π : $0.2 < p_T < 1.4$
  - K : $0.2 < p_T < 1.4$
- TPC+TOF includes statistical and systematic errors from electron contamination.
  - Pion contamination of kaons < 3% using TPC and TOF.
- Difference between STAR and NA49 result below $\sqrt{s_{NN}}$ = 11.5 GeV.

  (NA49 data from C. Alt et al. [NA49 Collab.], Phys. Rev. C 79, 044910 (2009))
- Both models show little acceptance effects.
  - UrQMD predicts little energy dependence.
  - HSD predicts an energy dependence.

Summary

- New results for dynamical particle ratio fluctuations from data collected during first part of the RHIC energy scan to search for QCD critical point.
  - For p/π fluctuations:
    - From $\sqrt{s_{NN}}$ = 7.7-200 GeV, all measured fluctuations are negative.
  - For K/p fluctuations:
    - Similar to p/π, fluctuations measured from $\sqrt{s_{NN}}$ = 7.7-200 GeV are negative.
  - For K/π fluctuations:
    - STAR does not observe any strong energy dependence of K/π fluctuations in central Au+Au collisions.
  - Additional systematics under study.
- There remain many open questions regarding the interpretation of particle ratio fluctuations results.
  - Differences in experimental measurements.
  - Are these variables sensitive to the physics expected to be observed during a phase transition or passing near a critical point?
- Hope to answer some of these questions in the near future and create some new ones!