Measuring Dynamical K/π and p/π Fluctuations in Au+Au Collisions from the STAR Experiment

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August 24, 2010

Critical Point and Onset of Deconfinement 2010

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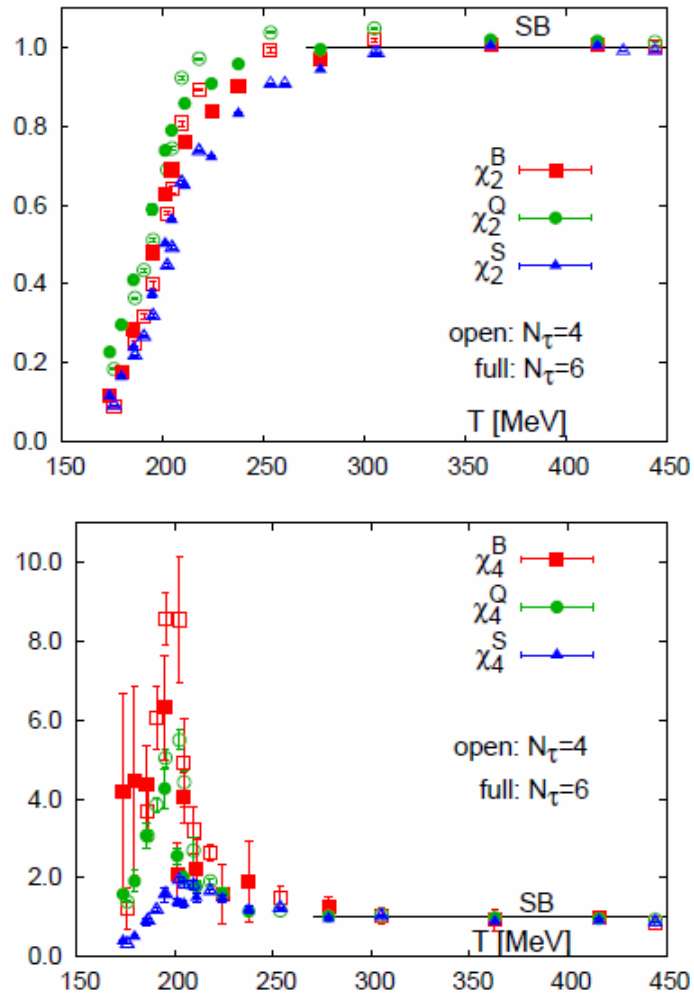
Motivation Behind Correlations and Fluctuations

- Many theoretical predictions that behavior of correlations and fluctuations in a deconfined phase different than that in hadron gas.
- Experimental justification from studies of the thermodynamics of phase transitions.
- Even w/o such guidance, can search for discontinuities in fluctuations and correlations as functions of incident energy and centrality (not an inclusive list):
  - Particle ratio fluctuations (K/π, p/π, K/p).
  - Forward-Backward multiplicity correlations.
  - Balance Functions
  - Net Charge Fluctuations
  - Etc.

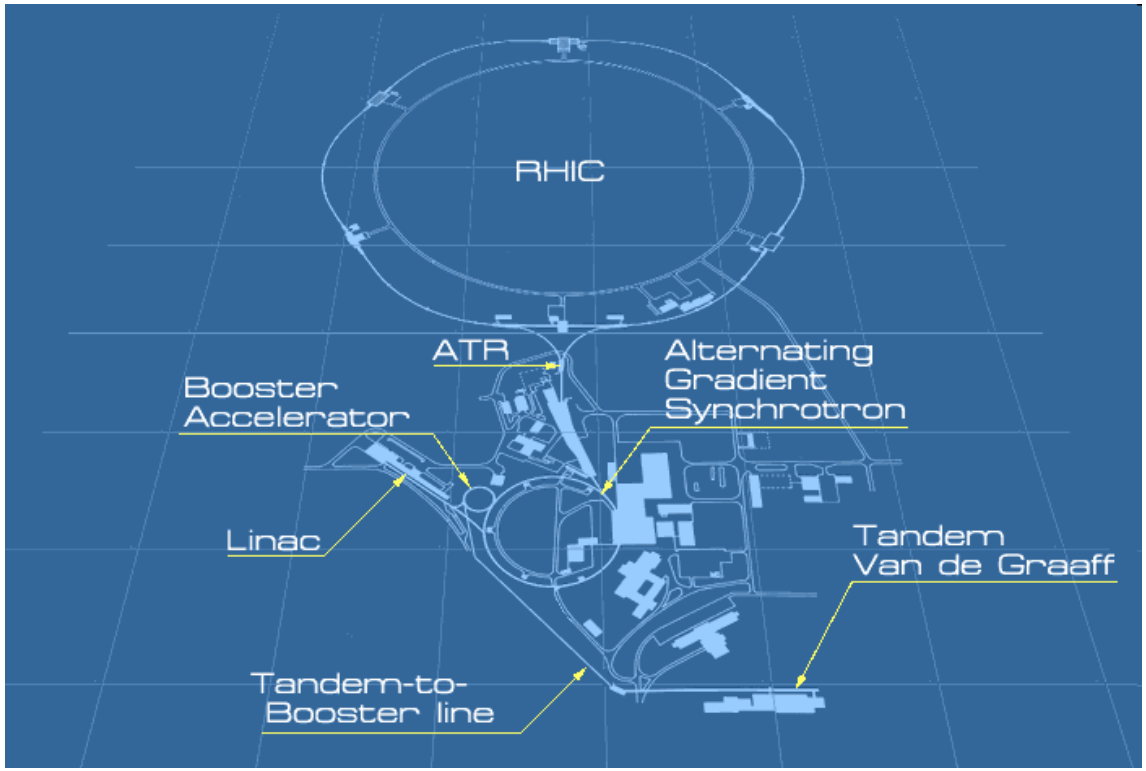
Search for the QCD Critical Point

- 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



RHIC is an extremely versatile machine!

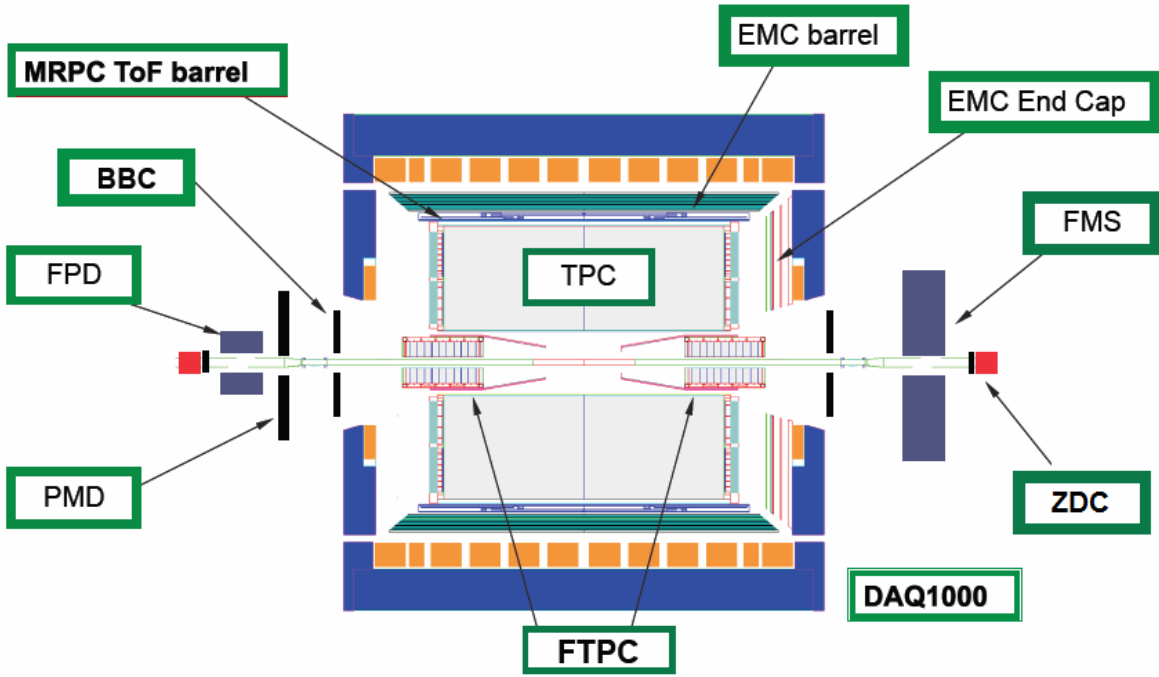
- Intersecting storage ring (ISR) hadron collider.
- 6 intersection points, currently 2 major experiments:
  - PHENIX
  - STAR
- Center-of-mass collision energies
  - $\sqrt{s_{NN}}$ = 20-200 GeV for heavy ions (e.g. Au, Cu).
  - $\sqrt{s_{NN}}$ = 22-500 GeV for polarized protons.
- Two independent, superconducting rings, allow for asymmetric collisions (e.g. d+Au).
- New ion source (EBIS) will allow for U+U collisions.
- New possibilities for heavy ion collisions at CM energies as low as $\sqrt{s_{NN}}$ = 5 GeV.

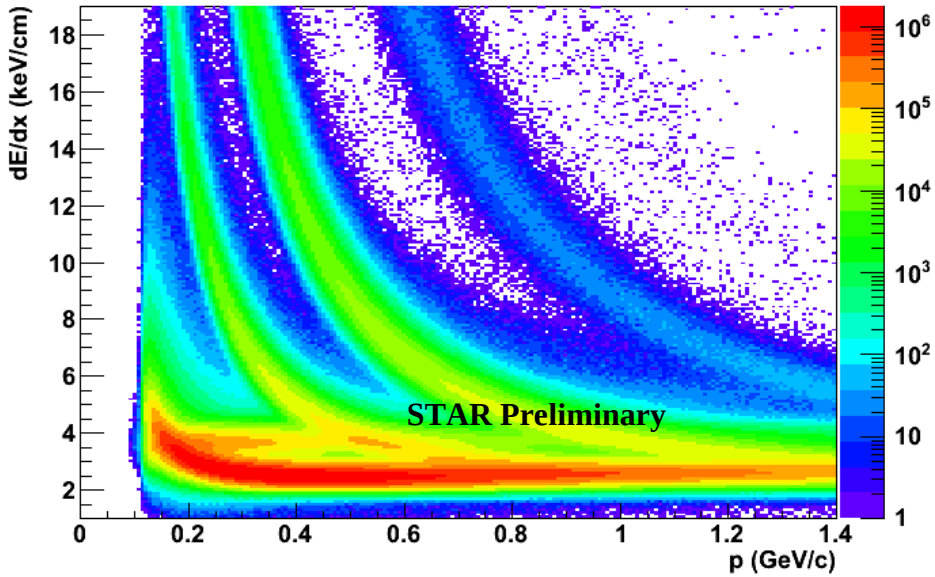
RHIC "Energy Scan"

- Using RHIC to run an "energy scan" to search for predicted QCD critical point.
- For Run 10, we have Au+Au collisions at $\sqrt{s_{NN}}$ = 200, 62.4, 39, 11.5, and 7.7 GeV.
- Can examine our fluctuations observables to look for non-montonic behavior as a function of collision energy.

STAR Detector

- STAR is a large acceptance detector.
  - Good η and φ coverage for measuring fluctuations.
- $|\eta| < 1.0$
- PID:
  - π, K, p ID for $p_T < 1$ GeV.
- ToF upgrade will enhance PID capabilities.





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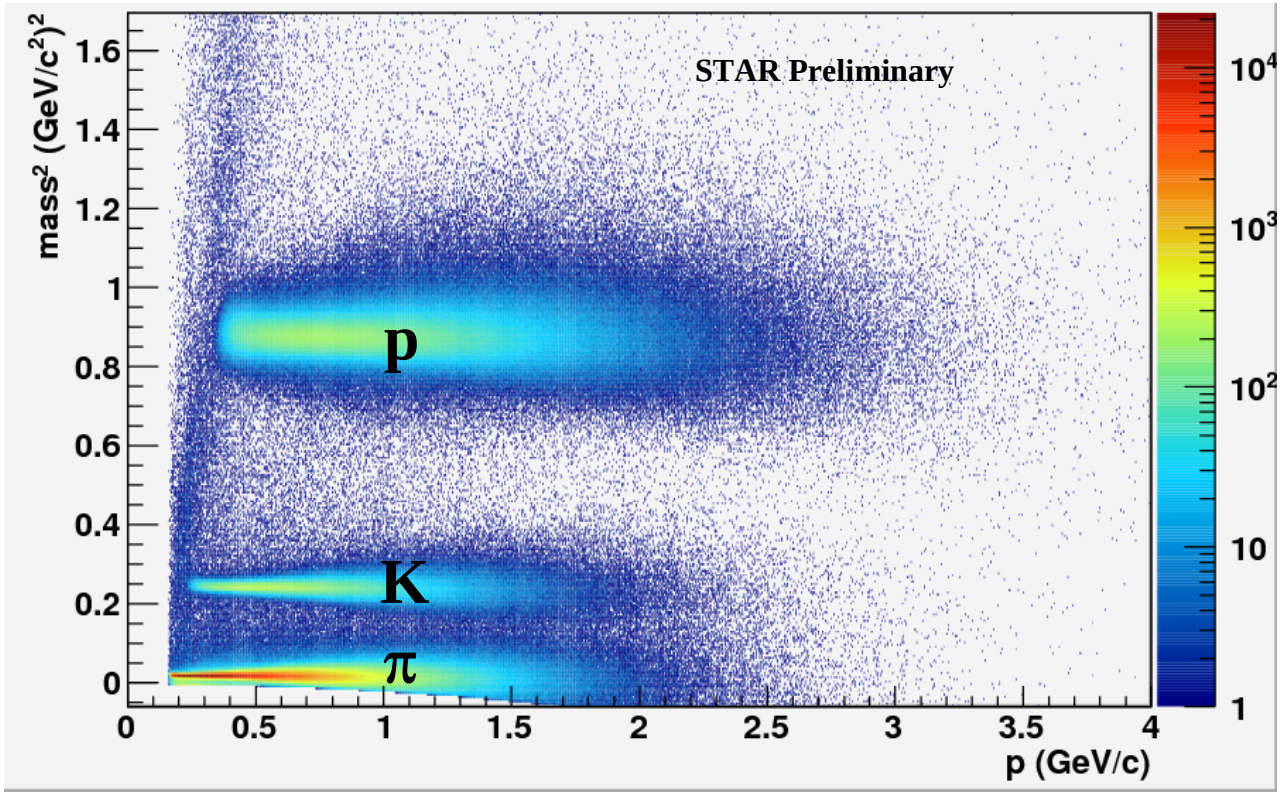
Particle ID Using STAR Time-of-Flight



- Full ToF installed for Run 10. (First stage of energy scan program.)
- Excellent separation in $m^2(p)$ for π, K, p.

Characterize Fluctuations

- NA49 uses the variable σ_{dyn}

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

σ is relative width of K / π distribution

- Measure deviation from Poisson behavior using ν_{dyn}

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

- It has been demonstrated (for K/π and p/π) that,

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

Particle Ratio Fluctuations

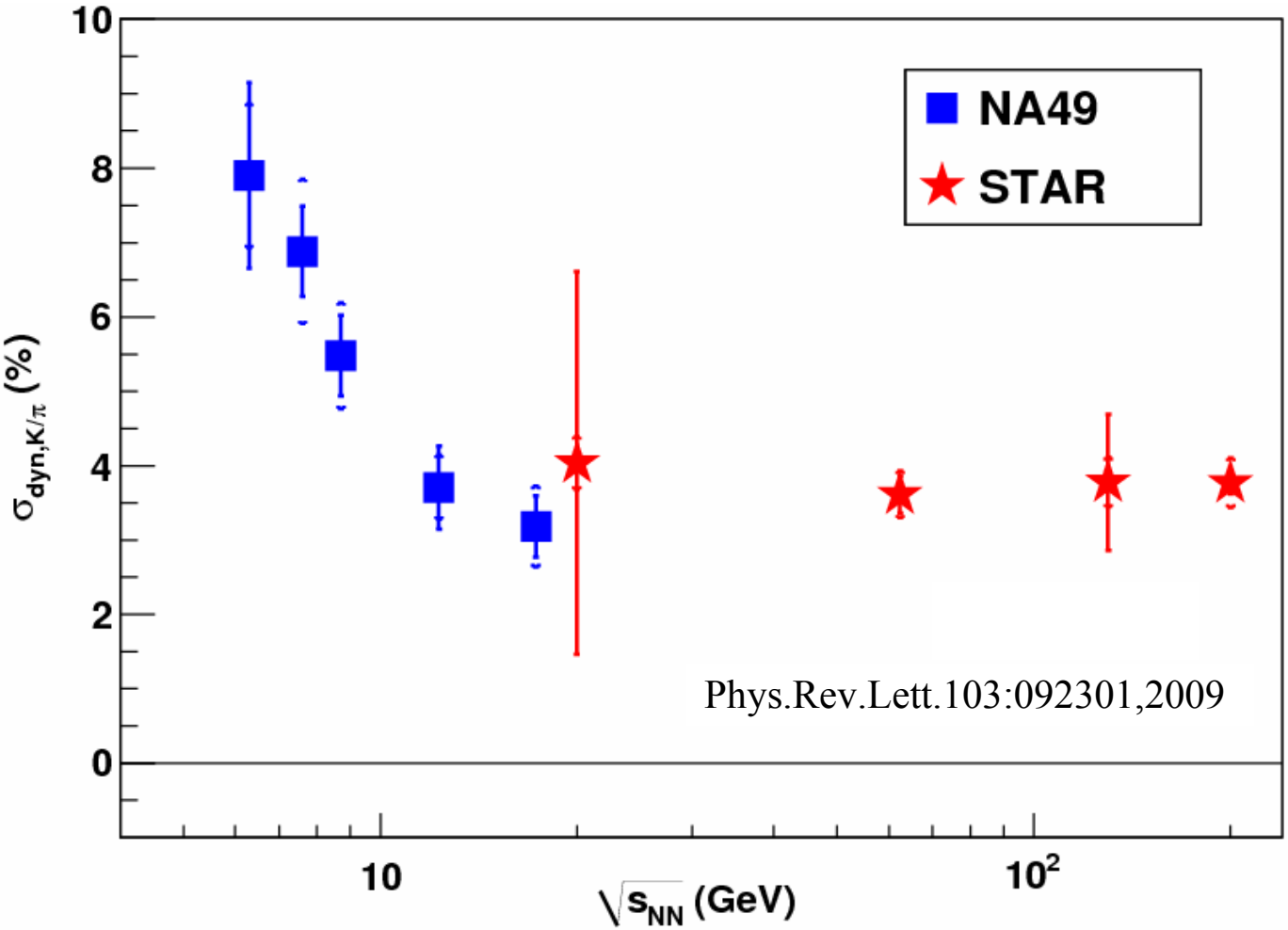
K/π

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

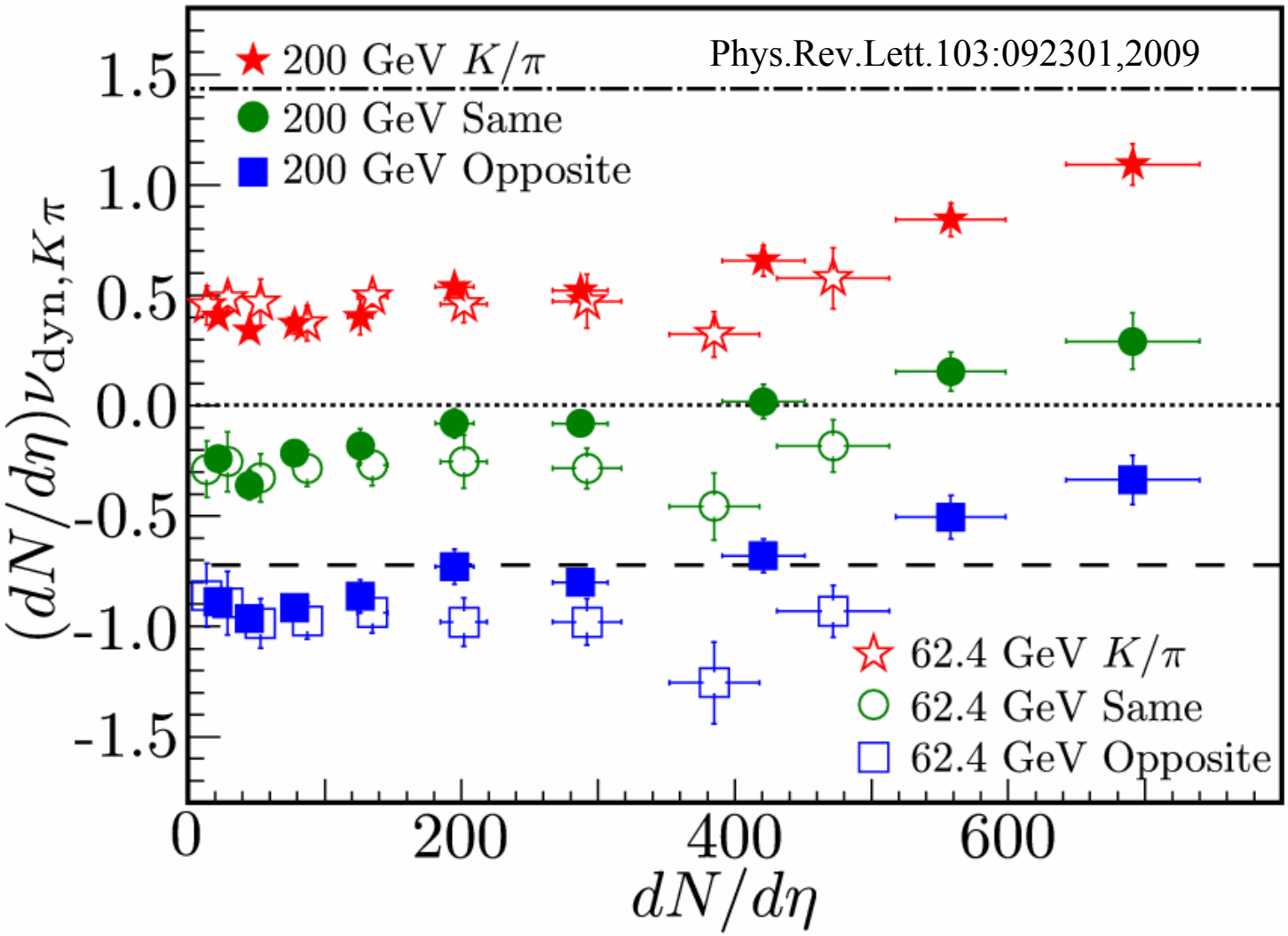
Excitation Function for $\sigma_{dyn,K/\pi}$

STAR central Au+Au (0-5%) collisions with SPS central Pb+Pb collisions (0-3.5%).

- Large decrease in fluctuations as function of energy from NA49.
- Fluctuations measured by STAR approximately constant as function of energy from 19.6-200 GeV.
- $|\eta| < 1.0$
- π, K: $0.2 < p_T < 0.6$ GeV.
- p: $0.4 < p_T < 1.0$ GeV.



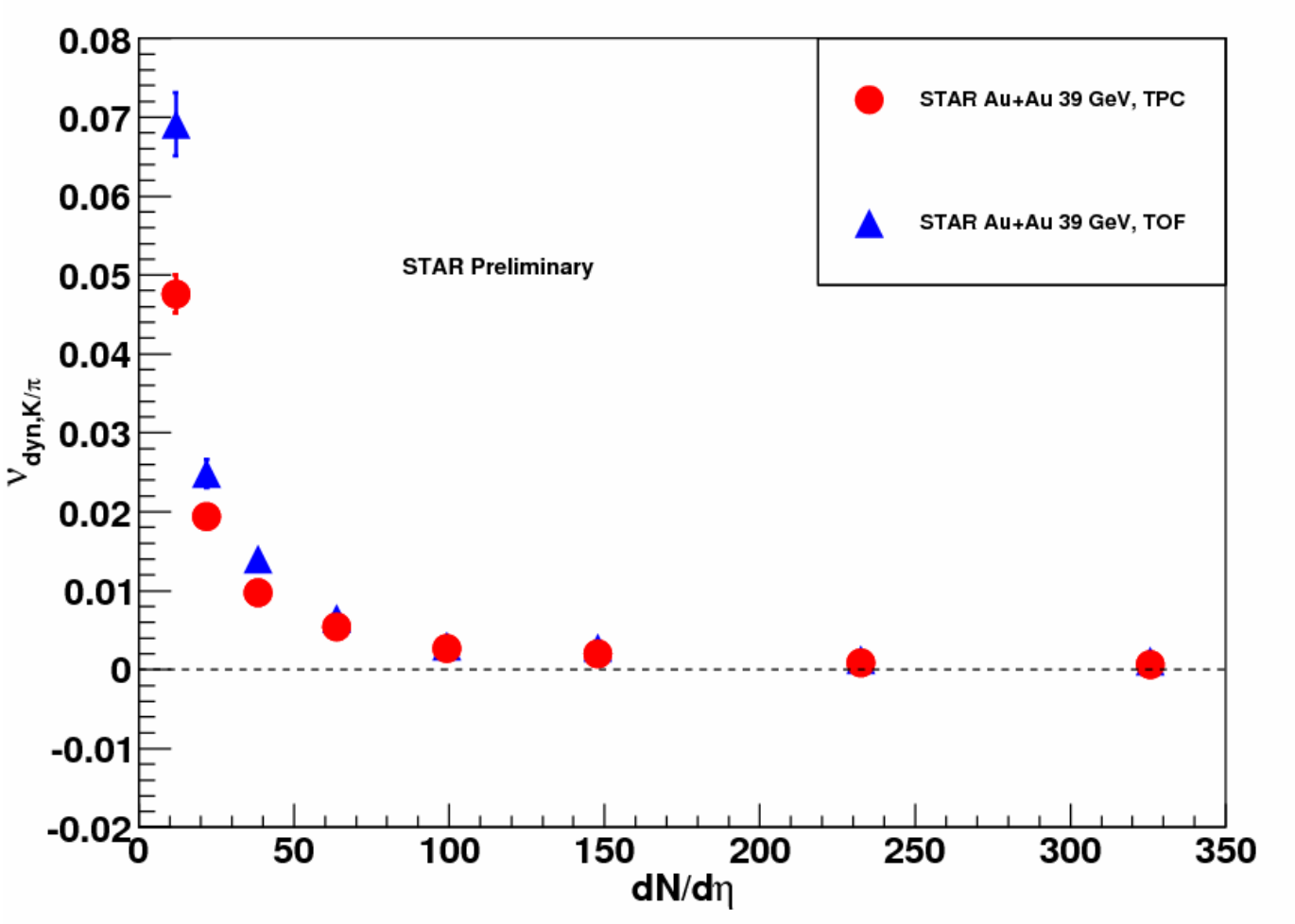
Scaling w/ dN/dη in Au+Au



- Charge dependent and independent $\nu_{dyn,K/\pi}$ was found to scale linearly with dN/dη (at small dn/dη) in Au+Au at 200 and 62.4 GeV

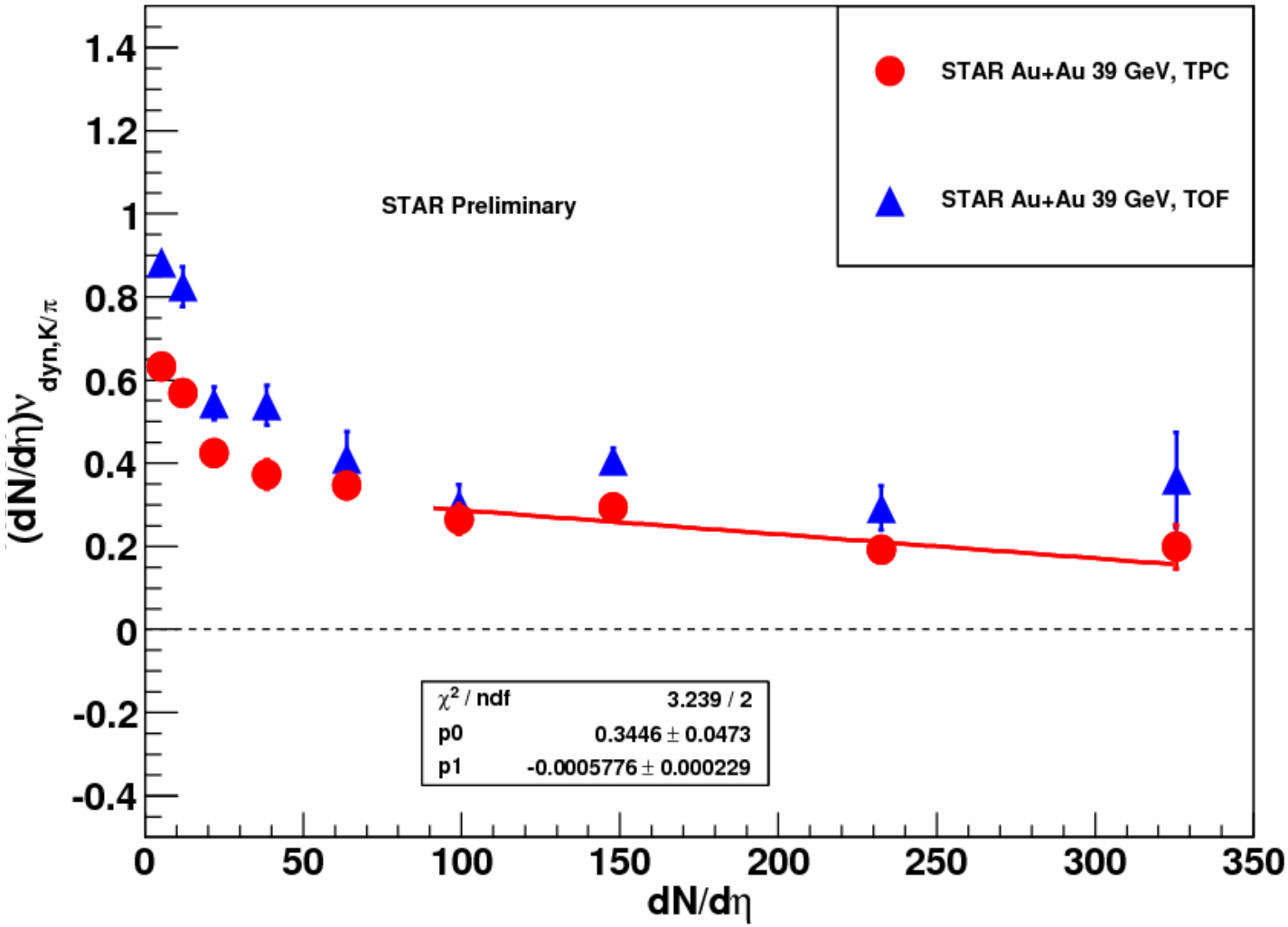
Au+Au 39 GeV, $\nu_{dyn,K/\pi}$

- Can see general $1/N_{ch}$ dependence.
- Data from TPC and TOF is in good agreement for central collisions.
- Errors are statistical.
- Values of dN/dη are uncorrected.

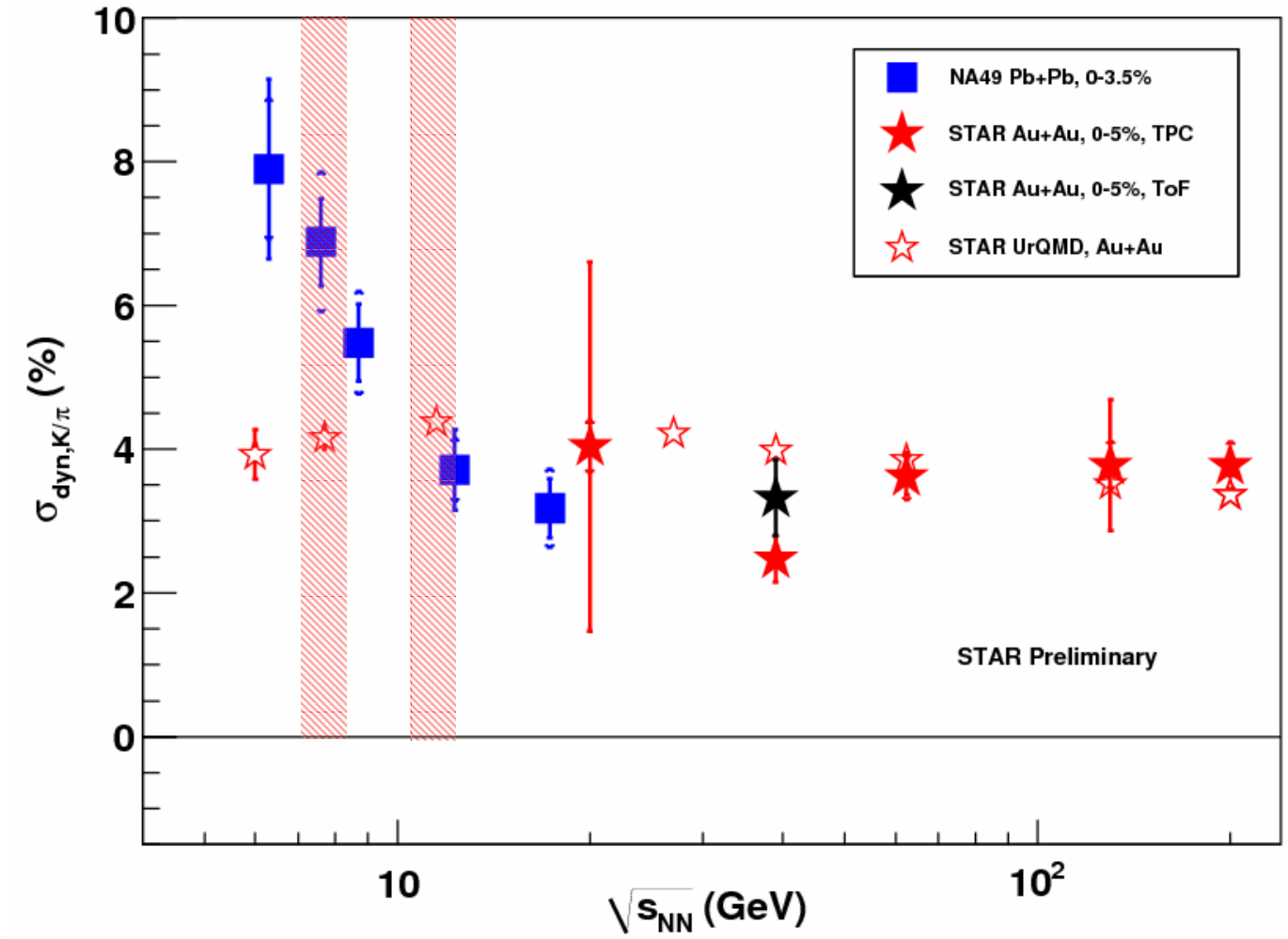


Au+Au 39 GeV, $(dN/d\eta)\nu_{dyn,K/\pi}$

- If similar to other energies, expect $\nu_{dyn,K/\pi}$ to scale linearly w/ $dN/d\eta$.
- Extrapolated value is near to mid-peripherhal Au+Au 200 GeV (0.34).
- More study is needed to determine if linear scaling w/ $dN/d\eta$ is actually broken.
- TOF values are larger than TPC because TOF is subset of TPC data ($1/N_{ch}$ dependence of ν_{dyn}).



Excitation Function for $\sigma_{\mathrm{dyn},K/\pi}$ from STAR Au+Au data



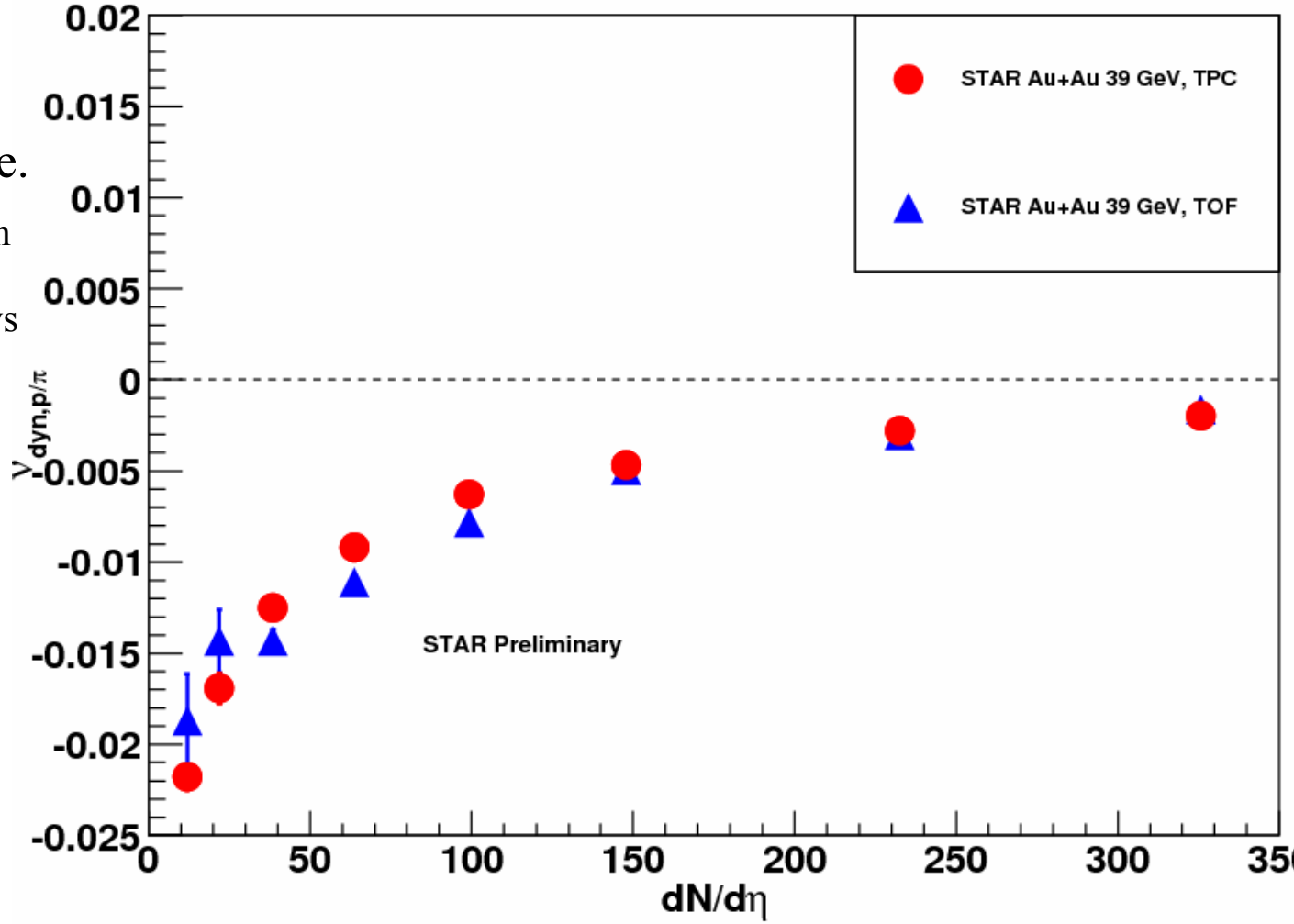
Particle Ratio Fluctuations

p/π

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

Au+Au 39 GeV, $\nu_{dyn,p/\pi}$

- Total charge particle $\nu_{dyn,p/\pi}$ for Au+Au 39 GeV is always negative.
  - Correlated production from resonances (e.g Δ's) and particle decays (e.g Λ^0).
  - Seen in Au+Au (STAR) and Pb+Pb (NA49) collisions as well.



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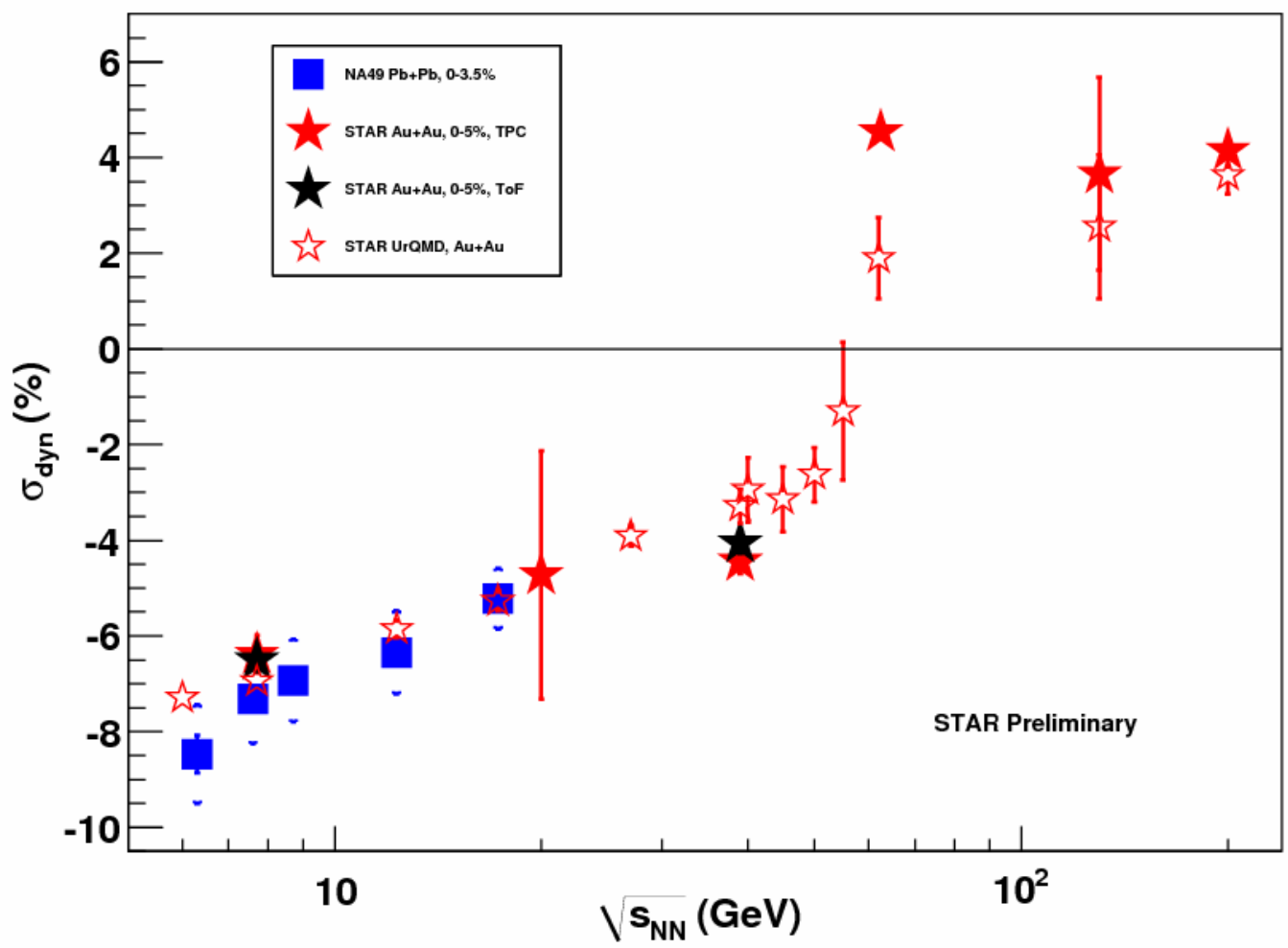
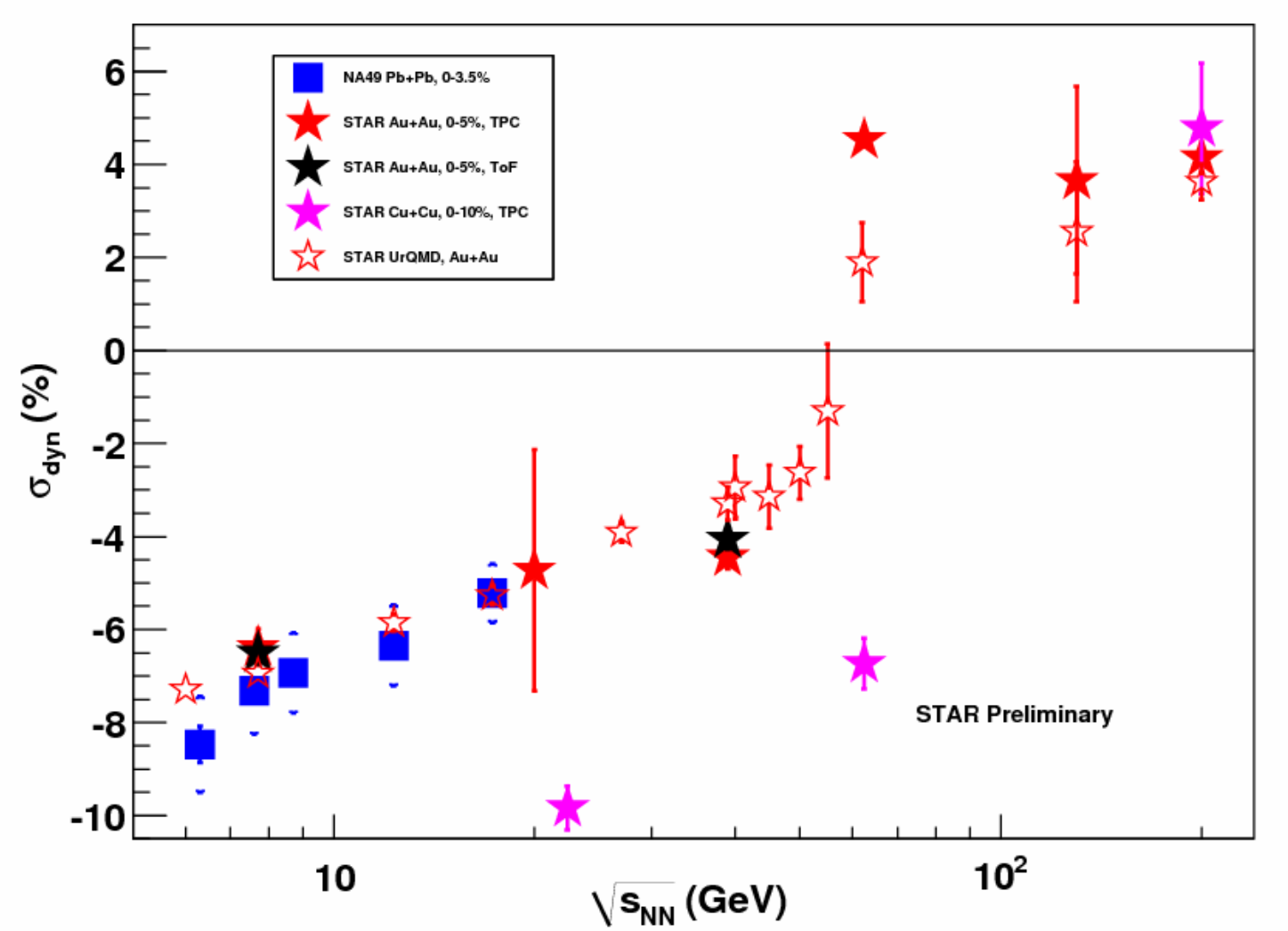


System Size Dependence

Why Cu+Cu?

- Provides different energy density at same μ_B as Au+Au.
  - Look for deviations from behavior in Au+Au.
- Some observables (e.g. v_1, F-B correlations, …) do not scale with N_{part} in Cu+Cu → Au+Au.
- Complete systematic checks.

Excitation Function for $\sigma_{\mathrm{dyn},p/\pi}$ Current Landscape



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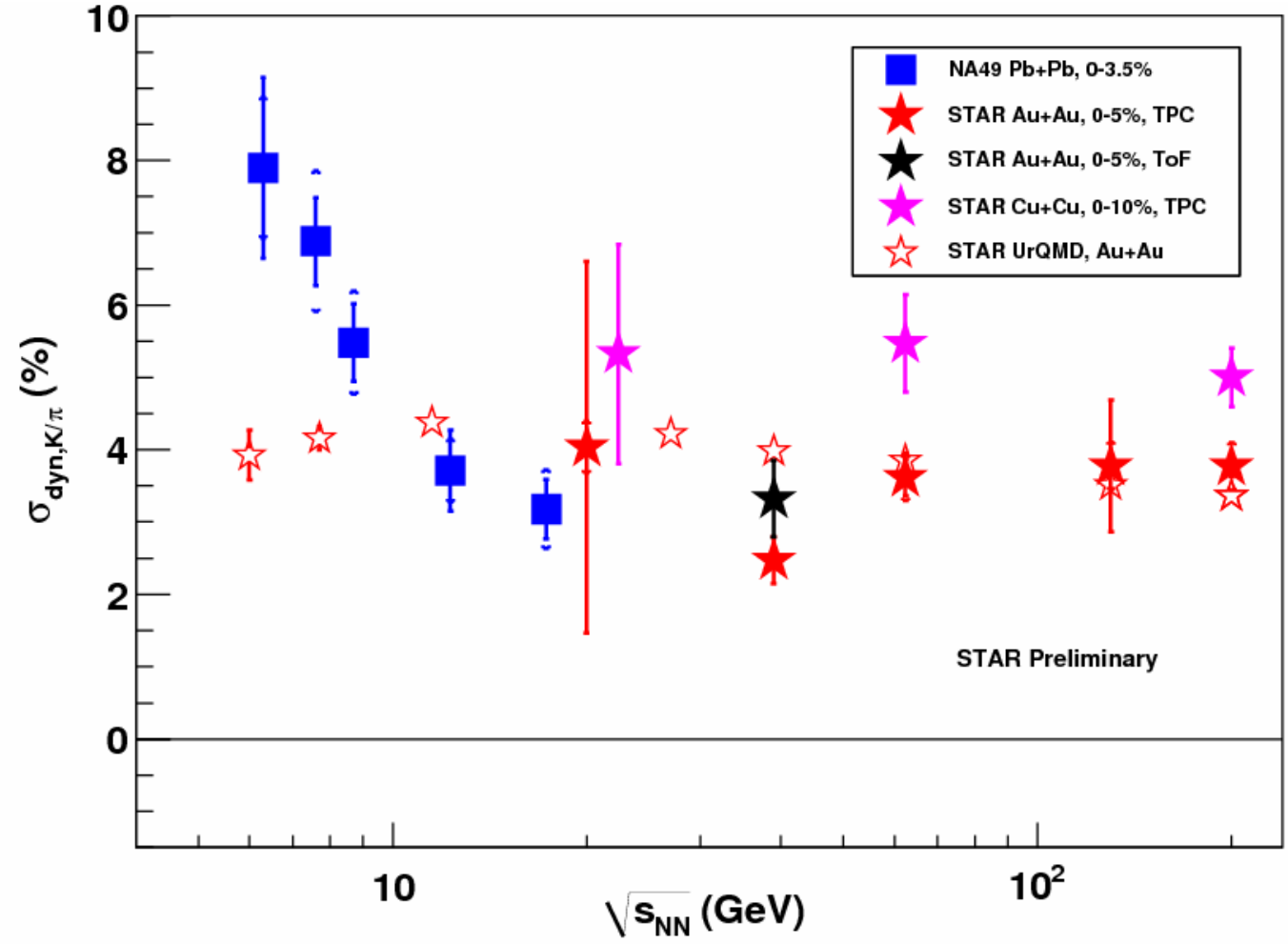

Summary I

- The STAR experiment has results on fluctuations and correlations for several colliding systems and energies that provide new insights into particle production.

- New results from initial data collected during RHIC energy scan to search for QCD critical point.
  - For K/π:
    - First results from $\sqrt{s_{NN}}$ = 39 GeV Au+Au are consistent w/ results from higher energies. Still investigating systematics. Additional data will be forthcoming.
    - Results from $\sqrt{s_{NN}}$ = 7.7 GeV Au+Au under investigation.
  - For p/π:
    - First results from $\sqrt{s_{NN}}$ = 39 and 7.7 GeV Au+Au.
    - At $\sqrt{s_{NN}}$ = 7.7 GeV, good agreement w/ NA49 measurement.
    - Results more stable than K/π fluctuations.
  - Charge separated results following soon.

  - TOF data is consistent fluctuations measured by the TPC.
  - $\sqrt{s_{NN}}$ = 11.5 GeV Au+Au data production is on the horizon.
    - $\sqrt{s_{NN}}$ = 27 and $\sqrt{s_{NN}}$ = 18 GeV Au+Au collisions are scheduled for Run 11.

Summary II

- K/π and p/π fluctuations Cu+Cu are constant from $\sqrt{s_{NN}}$ = 200-22.4 GeV.
  - Cu+Cu 0-10% larger fluctuations than Au+Au 0-5%, consistent with N_{ch} scaling. Better agreement w/ Au+Au 0-5% if comparing Cu+Cu 0-5%.
  - UrQMD (not shown) predicts larger values for Cu+Cu 0-10% than the data shows.

- The RHIC Beam Energy Scan (BES) program is ongoing and is probing new regions of the QCD phase diagram, while revisiting energies studied at fixed target experiments using a mature collider and well understood detector setup.
  - Provide a comprehensive picture of the T-μ_B phase space at the same facility.