



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

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Critical Point and Onset of Deconfinement 2010

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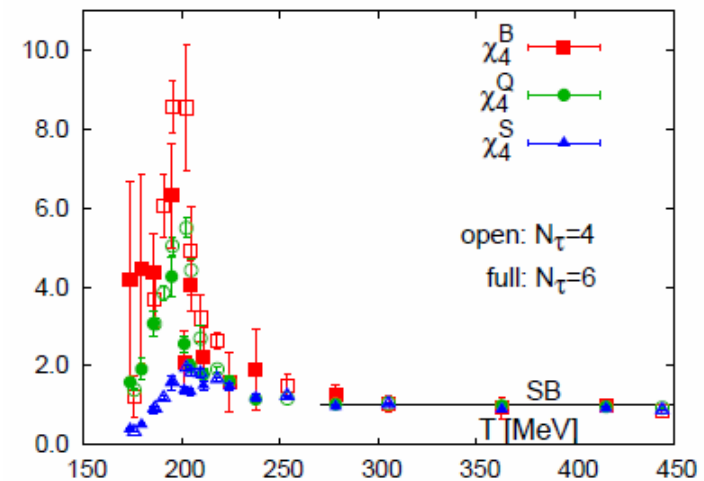
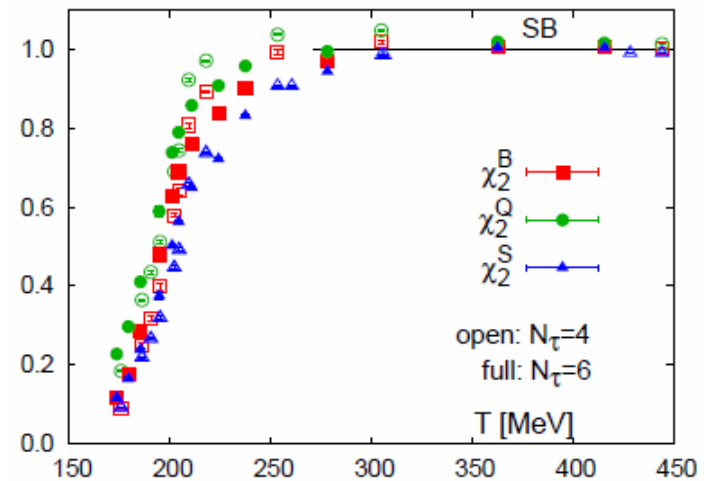
Motivation Behind Correlations and Fluctuations

- 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.





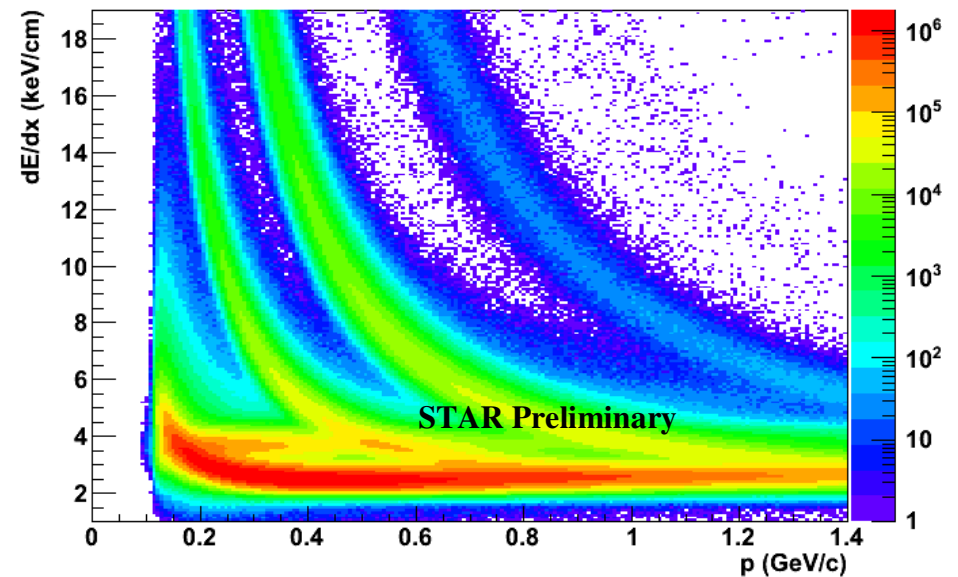
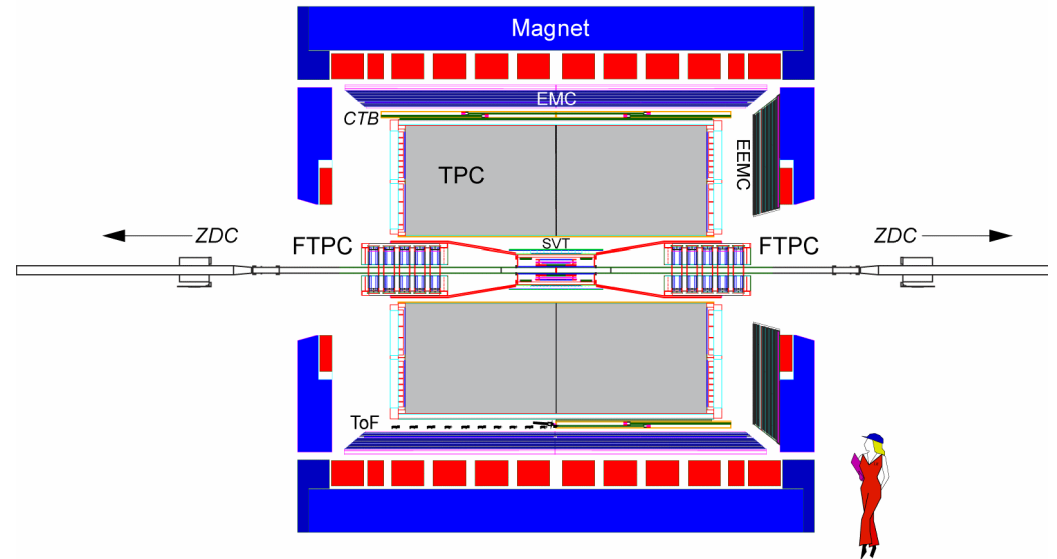
RHIC “Energy Scan”

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



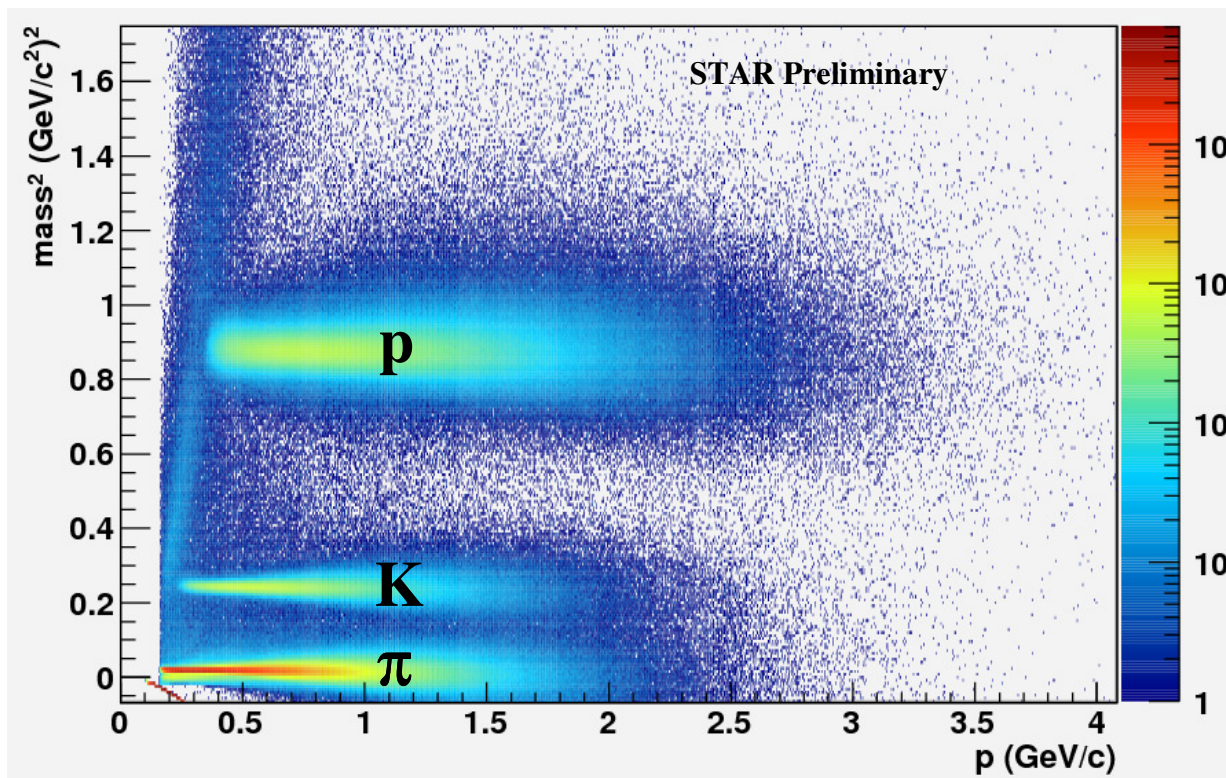
STAR Detector

- 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.





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}

$$\sigma_{\text{dyn}} = \text{sign}(\sigma_{\text{data}}^2 - \sigma_{\text{mixed}}^2) \sqrt{|\sigma_{\text{data}}^2 - \sigma_{\text{mixed}}^2|}$$

σ is relative width of K / π distribution

- Measure deviation from Poisson behavior using V_{dyn}

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

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

$$\sigma_{\text{dyn}}^2 \approx V_{\text{dyn}}$$



Particle Ratio Fluctuations

$$K/\pi$$

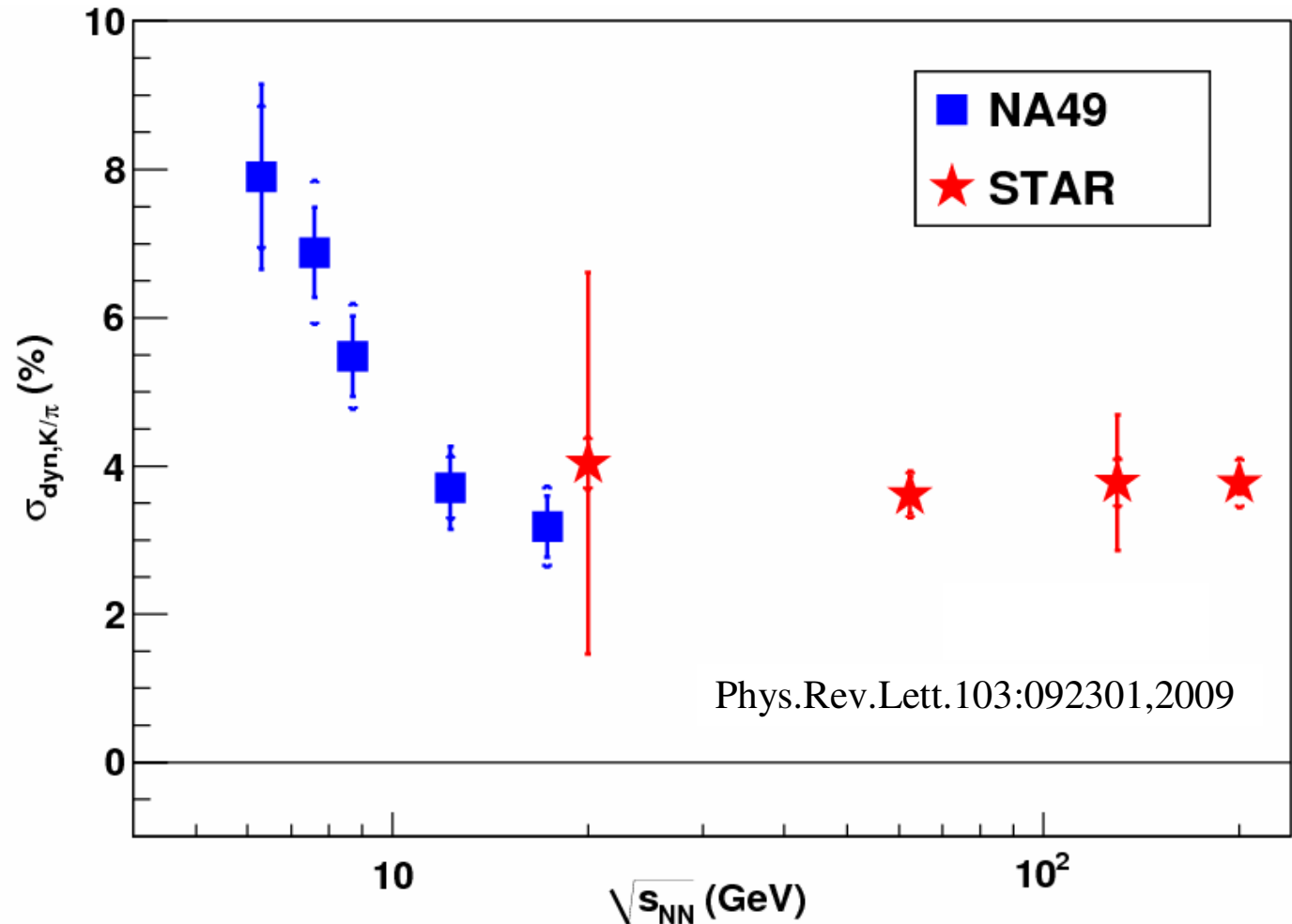
$$(K^+ + K^-)/(\pi^+ + \pi^-)$$



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

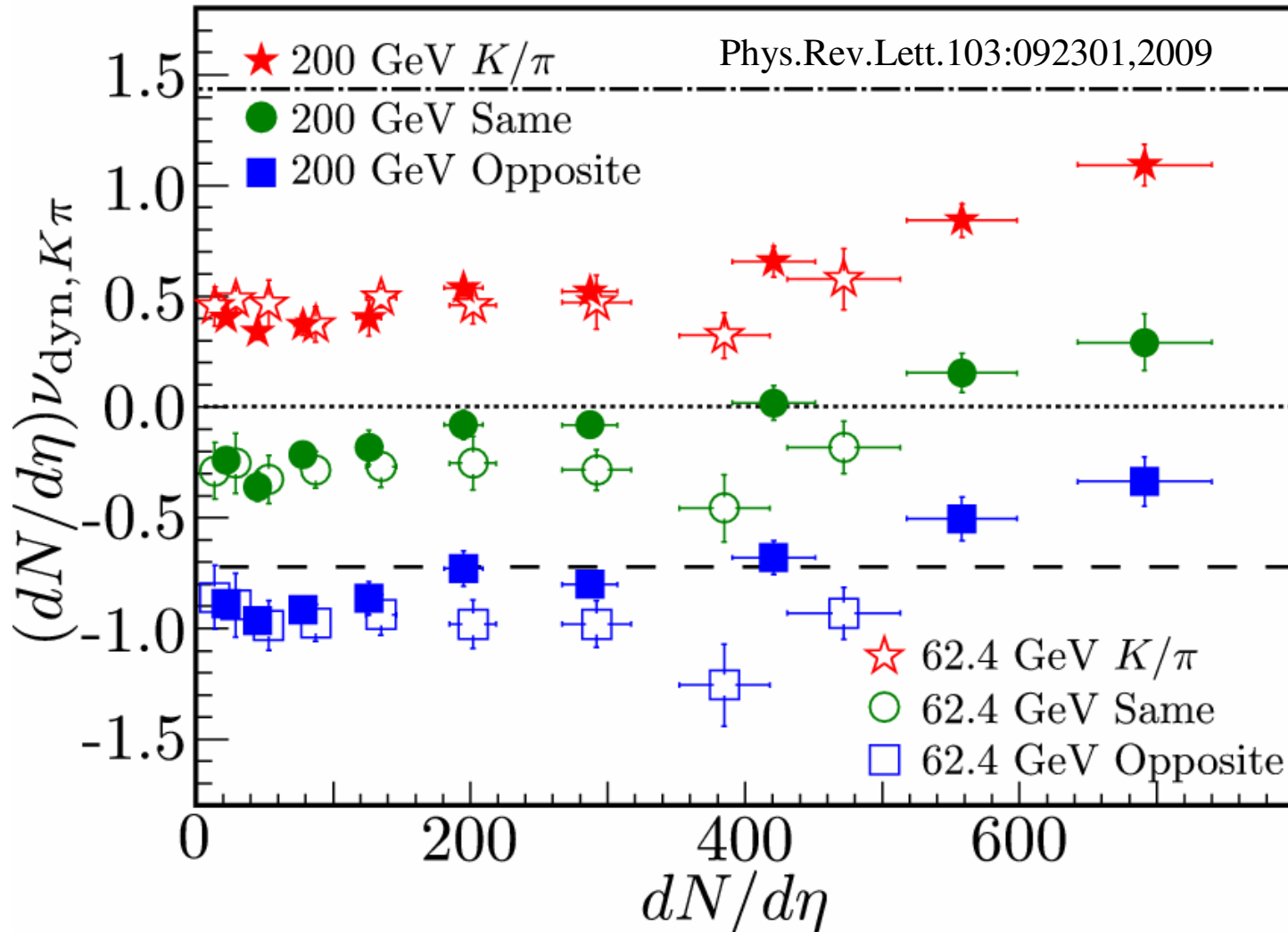
STAR central Au+Au (0-5%) collisions with SPS central Pb+Pb collisions (0-3.5%).

- 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/ $dN/d\eta$ in Au+Au

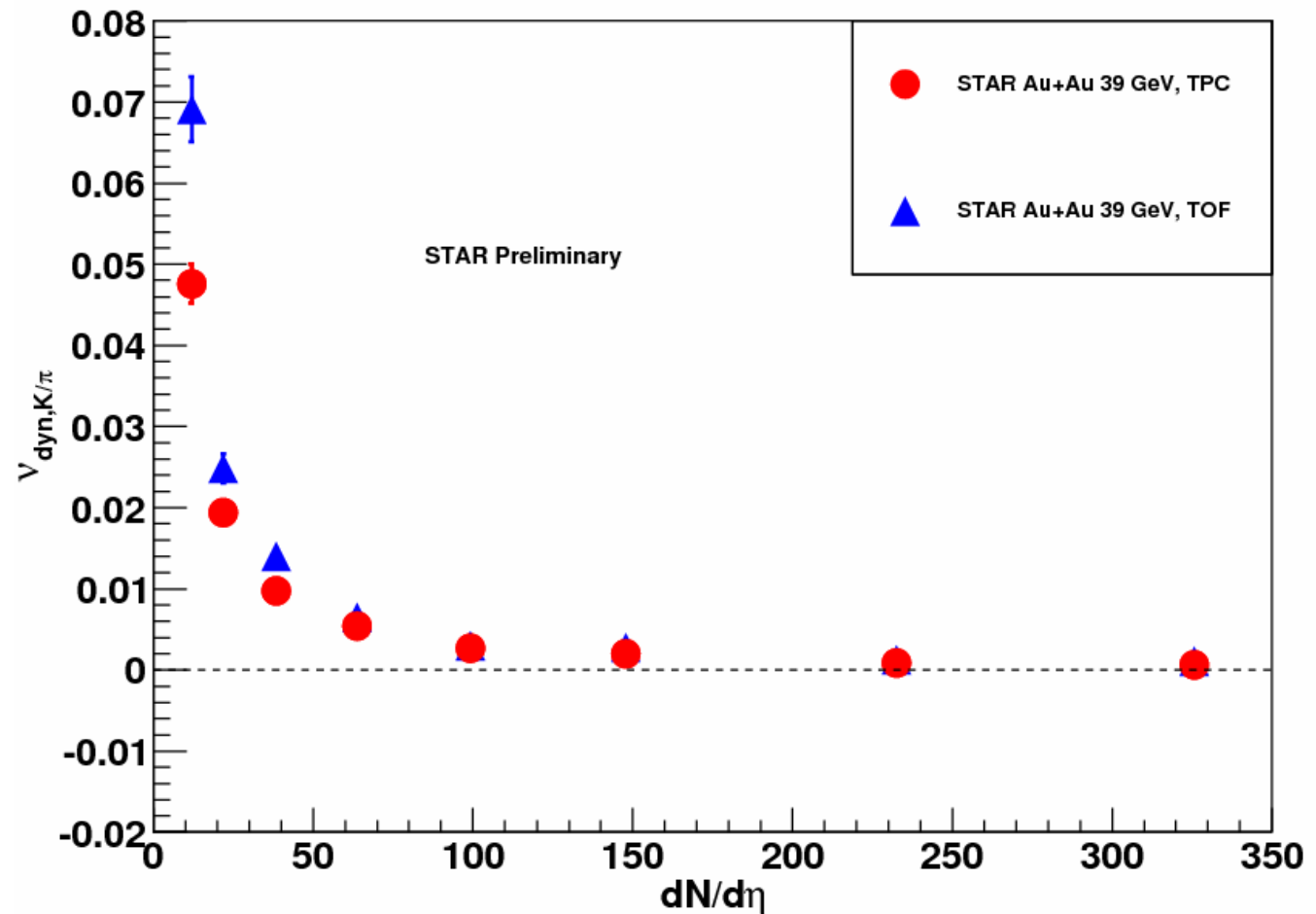


- Charge dependent and independent
- $v_{dyn,K/\pi}$ was found to scale linearly with $dN/d\eta$ (at small $dn/d\eta$) in Au+Au at 200 and 62.4 GeV



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

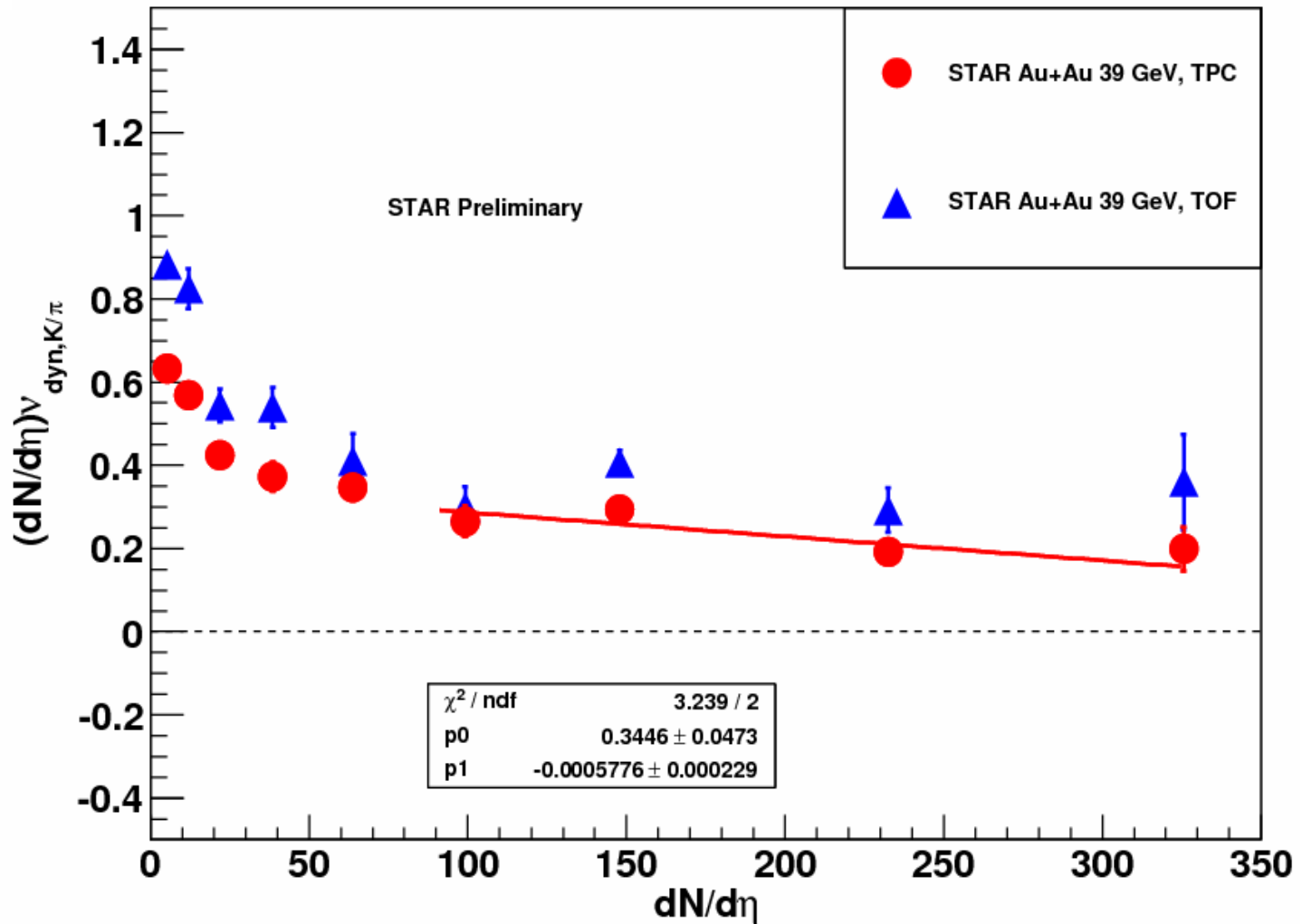
- Can see general $1/N_{\text{ch}}$ dependence.
- Data from TPC and TOF is in good agreement for central collisions.
- Errors are statistical.
- Values of $dN/d\eta$ are uncorrected.





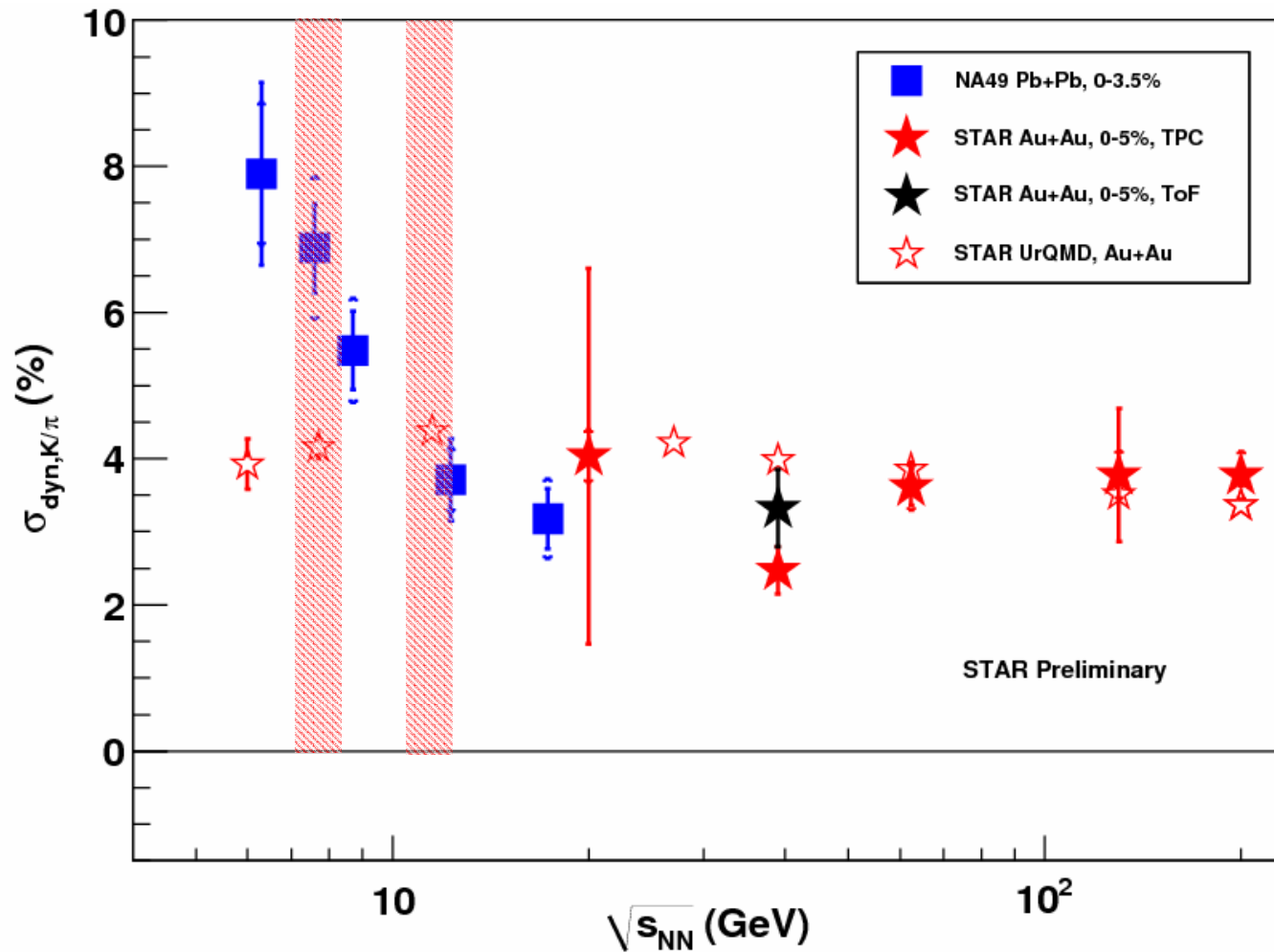
Au+Au 39 GeV, $(dN/d\eta)v_{\text{dyn},K/\pi}$

- If similar to other energies, expect $v_{\text{dyn},K/\pi}$ to scale linearly w/ $dN/d\eta$.
- Extrapolated value is near to mid-peripheral 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 ($1/N_{\text{ch}}$ dependence of v_{dyn}).





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





Particle Ratio Fluctuations

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

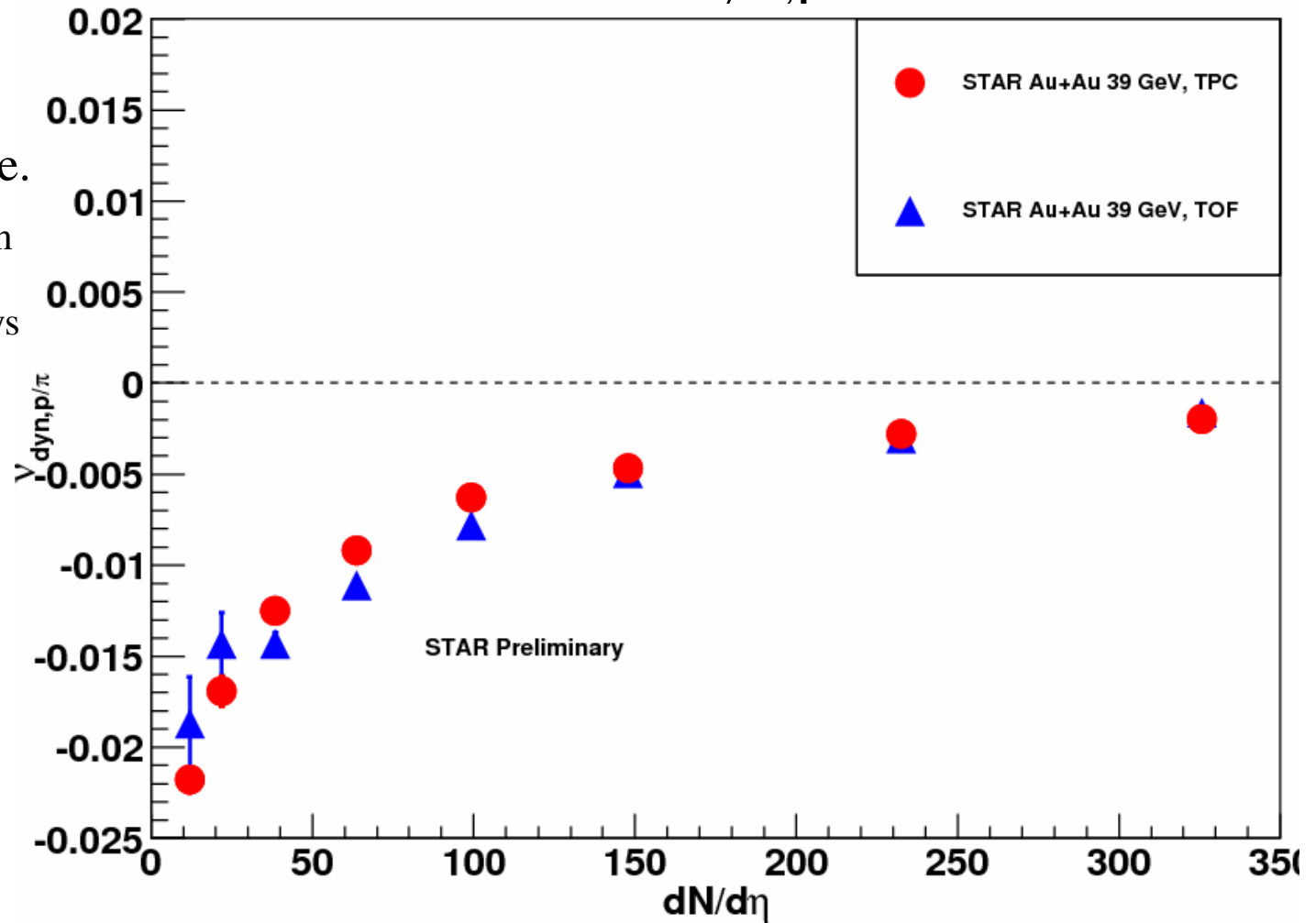


Au+Au 39 GeV, $v_{\text{dyn},p/\pi}$

• Total charge particle
 $v_{\text{dyn},p/\pi}$ for Au+Au 39
GeV is always negative.

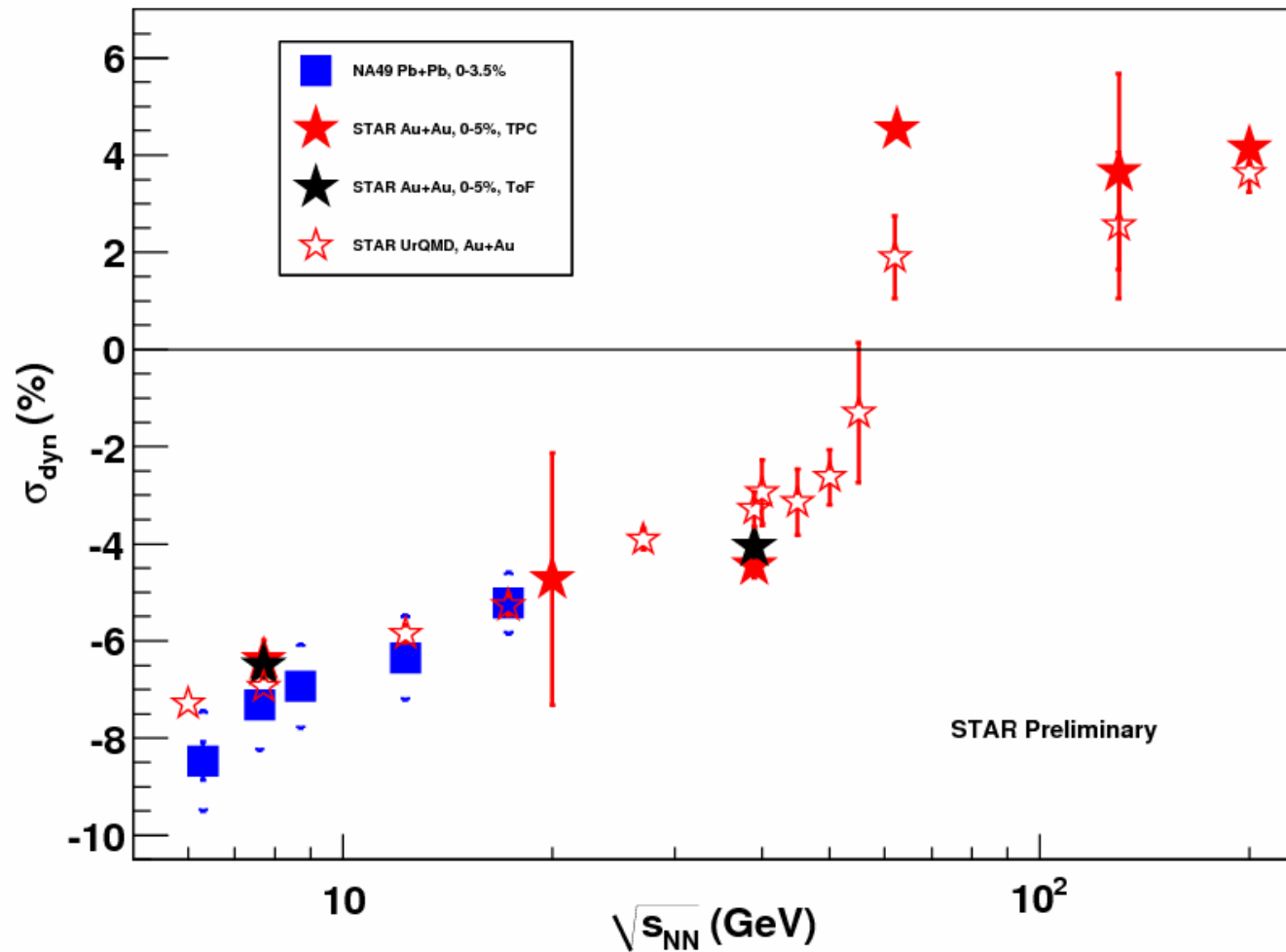
- Correlated production
from resonances (e.g
 Δ 's) and particle decays
(e.g Λ^0).

- Seen in Au+Au
(STAR) and Pb+Pb
(NA49) collisions as
well.





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





System Size Dependence

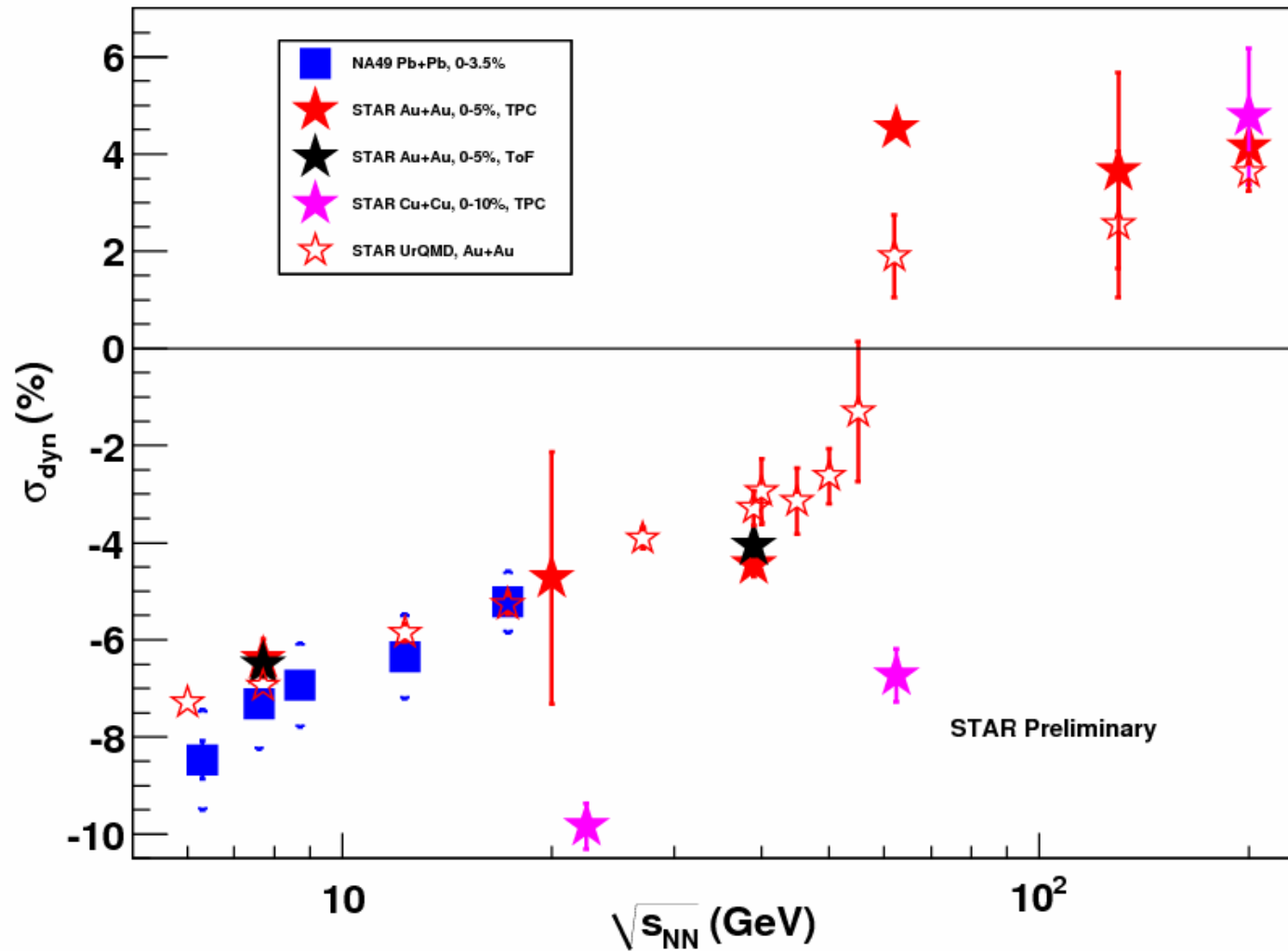


Why Cu+Cu?

- 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 \rightarrow Au+Au.
- Complete systematic checks.



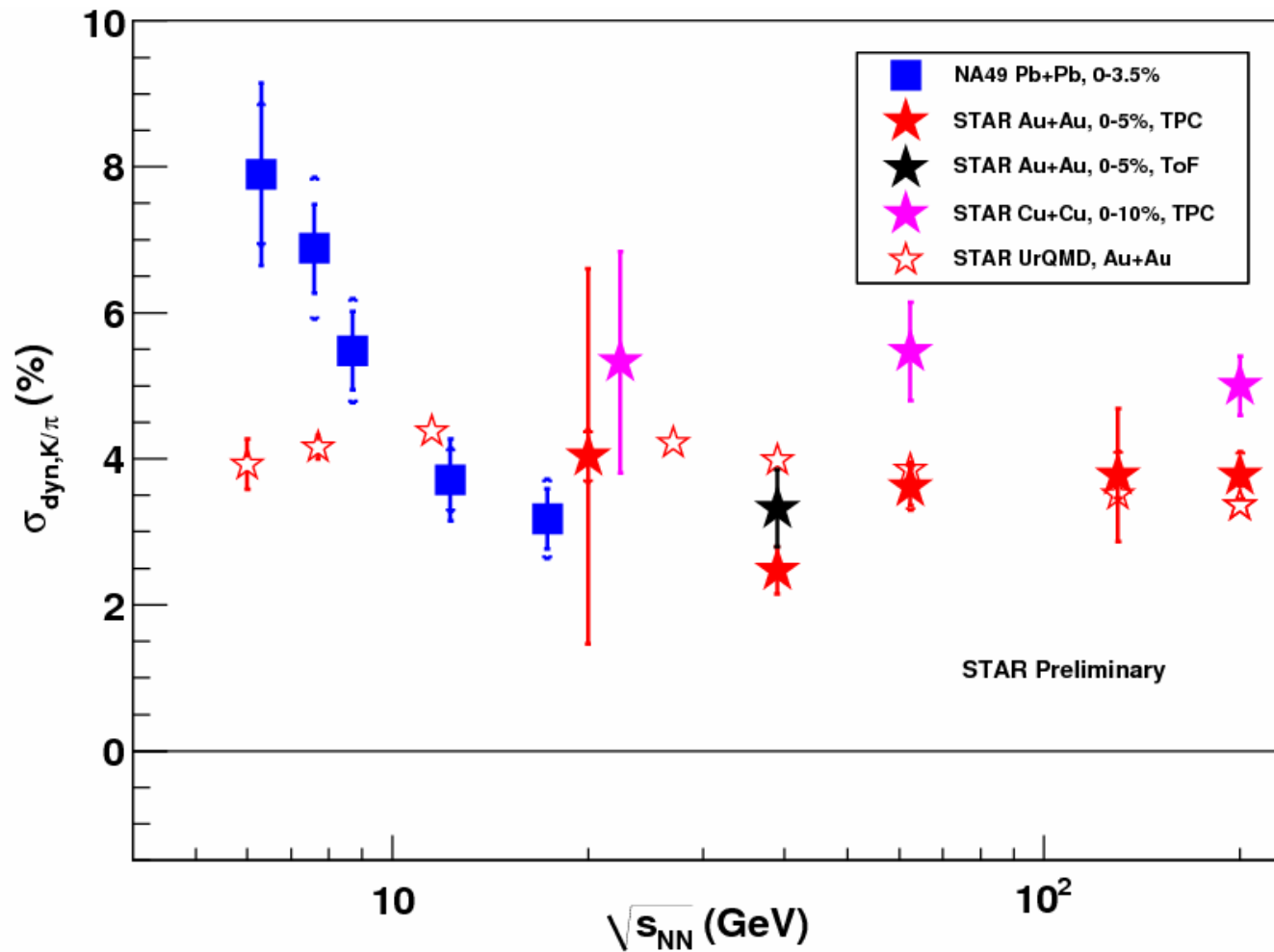
Excitation Function for $\sigma_{\text{dyn},p/\pi}$ Current Landscape





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

Current Landscape





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.
 - 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 $T-\mu_B$ phase space at the same facility.