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Probing the Quark-Gluon Phase Transition with Correlations and Fluctuations in Heavy Ion Collisions from the STAR Experiment

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for the STAR Collaboration

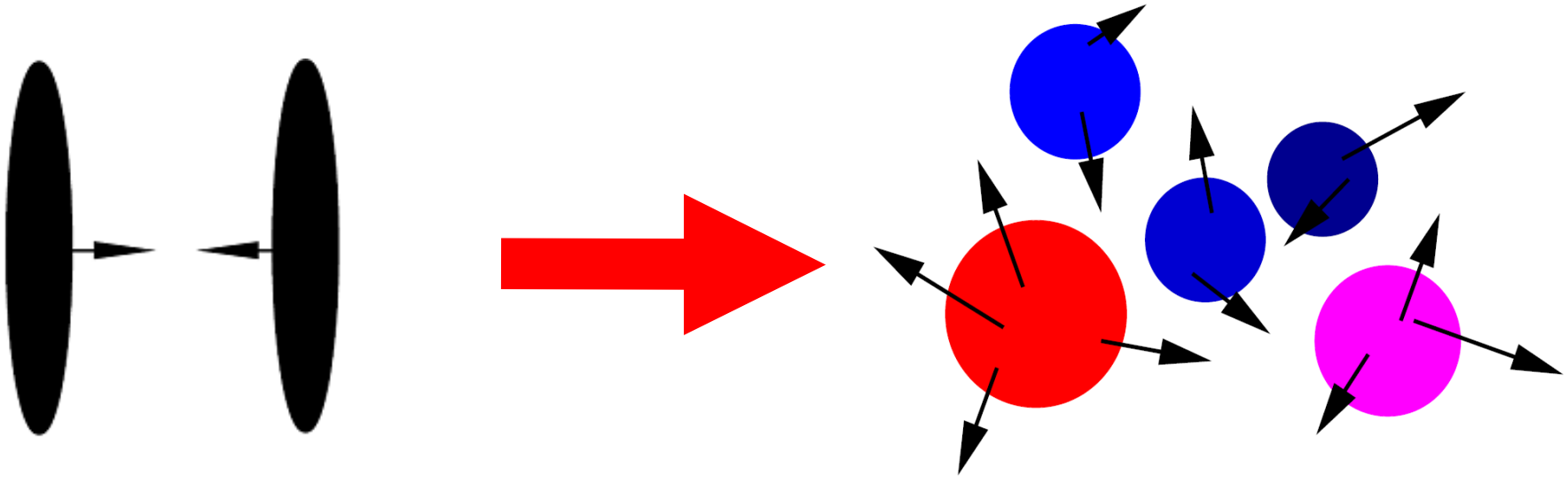
July 28, 2009

Outline

- Motivation
- Experimental Method
- Results
- Future Plans
- Summary

Study of Correlations and Fluctuations

- Expectation that correlations reflect features of multi-particle production.
  - e.g. Bose-Einstein/HBT (source size).
- Forward-backward correlations in (pseudo)rapidity characterize formation and decay of possible clusters.
  - Number of sources.
  - Size of sources.
- Changes in particle number fluctuations (π, K, p) expected near a phase transition.



F-B Multiplicity Correlations

- Predicted in context of Dual Parton Model [DPM] (and Color Glass Condensate [CGC]).
- Test of multiple elementary [partonic] scattering.
- Linear expression relating N_b and N_f (forward and backward multiplicity), found in hadron-hadron experiments (ex. UA5),

$$< N_b > (N_f) = a + bN_f$$

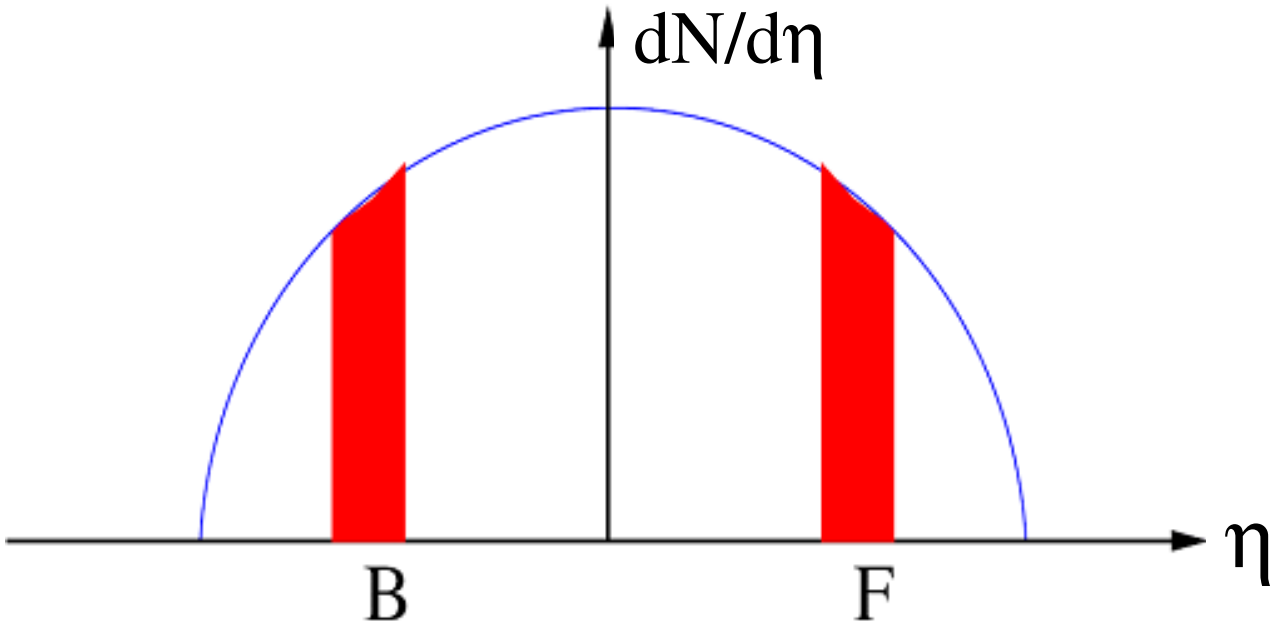
N = # of hadrons

- "b" is correlation strength.
  - Function of √s and A.
  - Coefficient can be expressed as,

$$b = \frac{< N_f N_b > - < N_f >< N_b >}{< N_f^2 > - < N_f >^2} = \frac{D_{bf}^2}{D_{ff}^2}$$

Short- and Long-Range Correlations

$$b = \frac{< n_f n_b > - < n_f >< n_b >}{< n_f^2 > - < n_f >^2} = \frac{D_{bf}^2}{D_{ff}^2}$$



- $(D_{ff})^2$ characterizes short range correlations, related to the number of emitted particles per cluster.
- $(D_{bf})^2$ is related to the number of sources.

- Long-range is taken as a separation in η of forward-backward windows by > 1.0.

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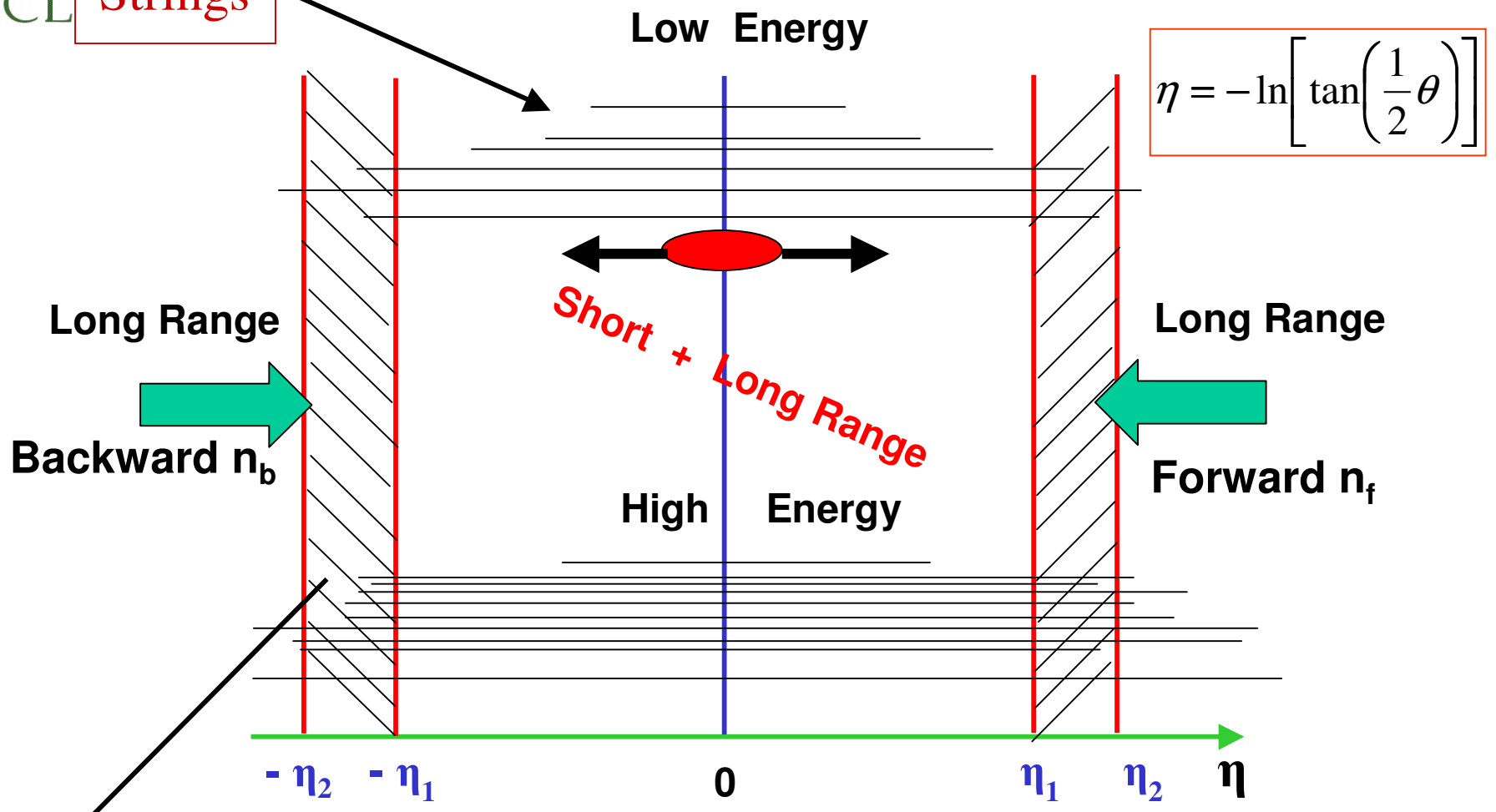
Strings



Pseudorapidity Gap

Pseudorapidity interval

Probes **longitudinal** characteristics of the system.

Short and Long-Range FB Multiplicity Correlations

- Working definitions:
  - Short-range correlations (SRC):
    - SRC is defined as correlation for $|\Delta\eta| < 1.0$.
  - Long-range correlations (LRC):
    - LRC is defined as correlations for $|\Delta\eta| > 1.0$.

Energy Dependence: pp Min Bias

- Comparing correlation as function of $\sqrt{s_{NN}}$.
- 200 and 400 GeV in close agreement:
  - Larger SRC at 400 GeV
  - Plateau at same value of *b* at large Δη as 200 GeV.
- 62.4 GeV goes smoothly to $b = 0$.
  - Not even a small LRC.

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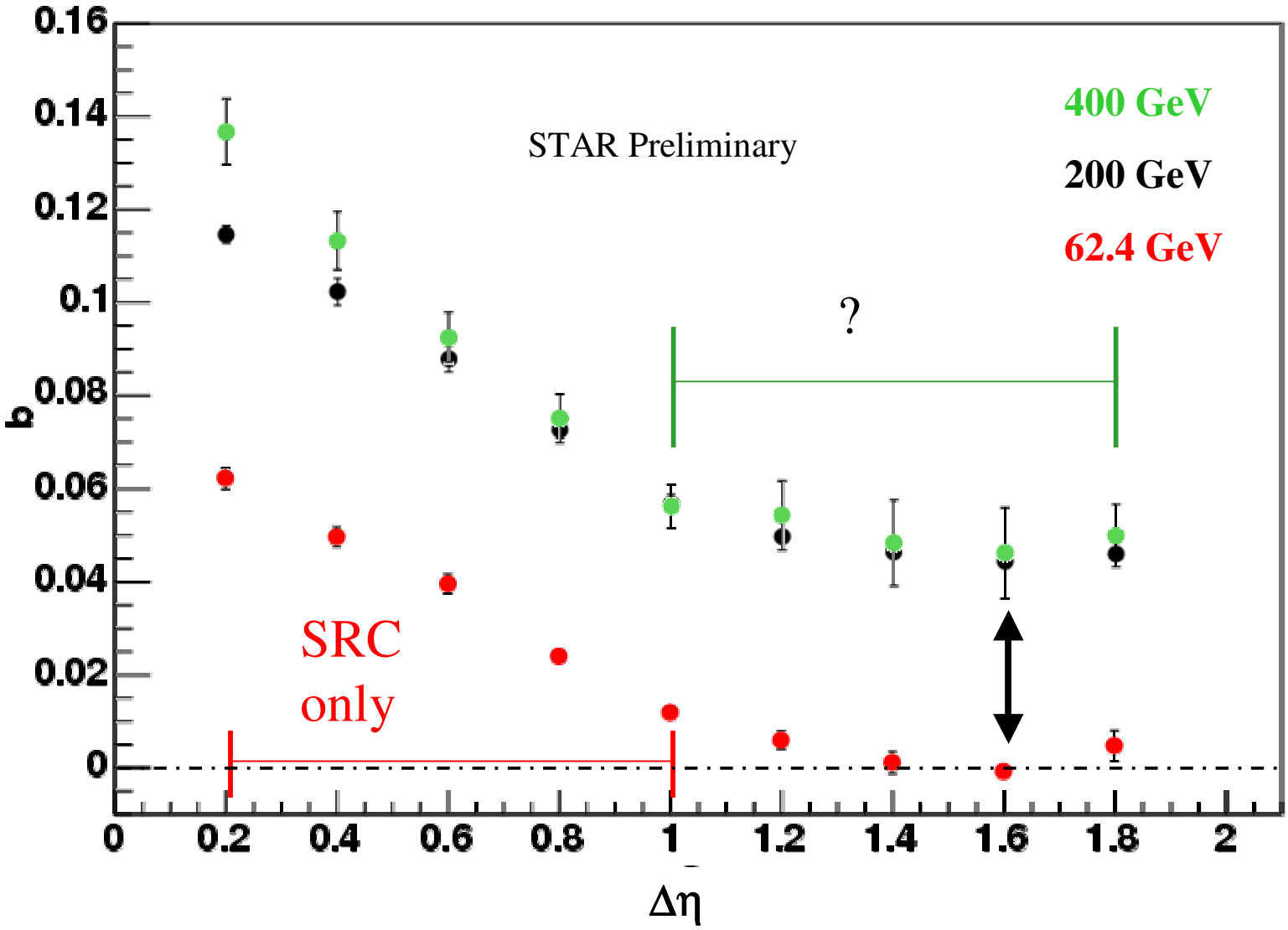
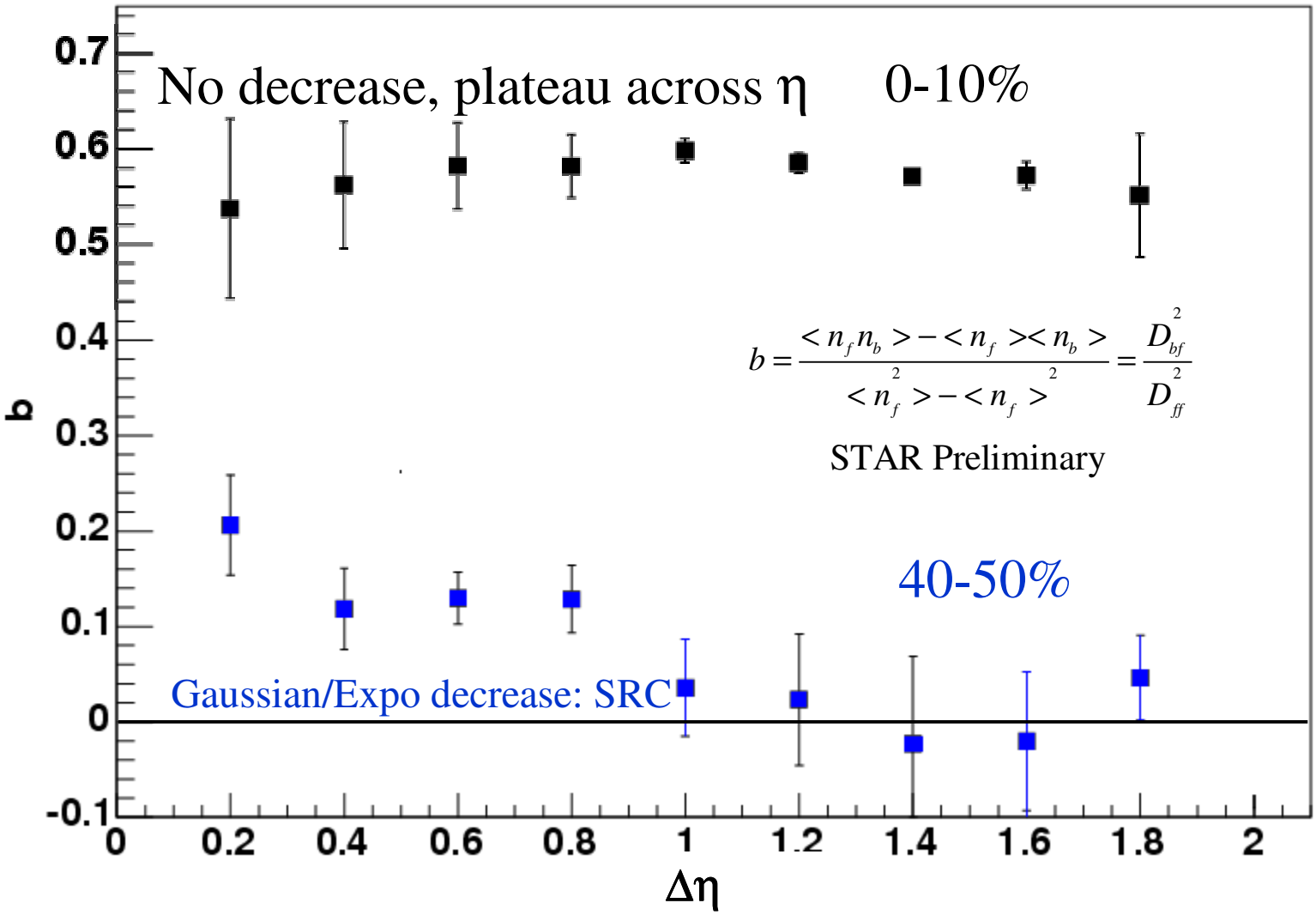


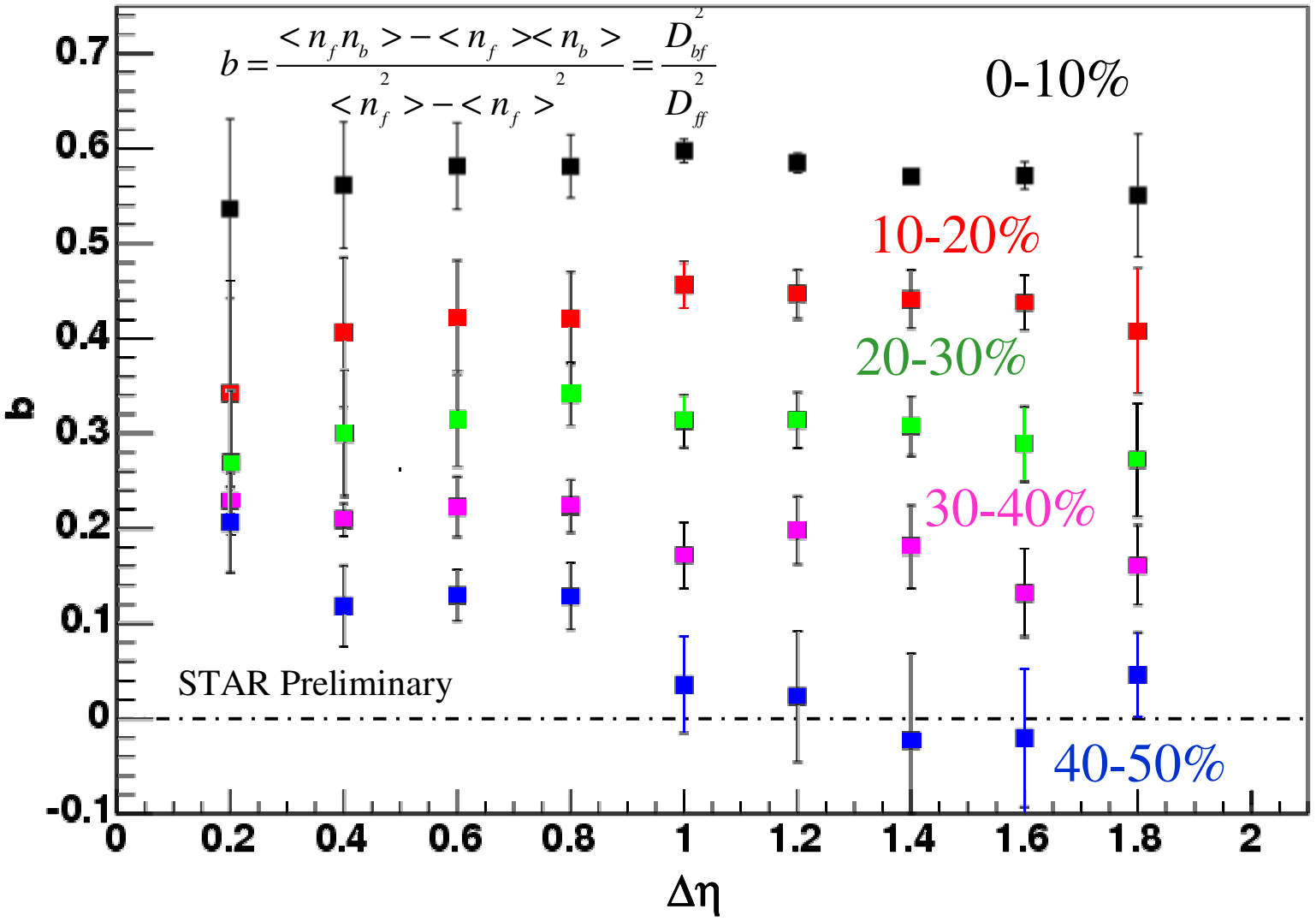
Centrality Dependence: Au+Au at 200 GeV



- Central collisions demonstrate a strong, LRC.

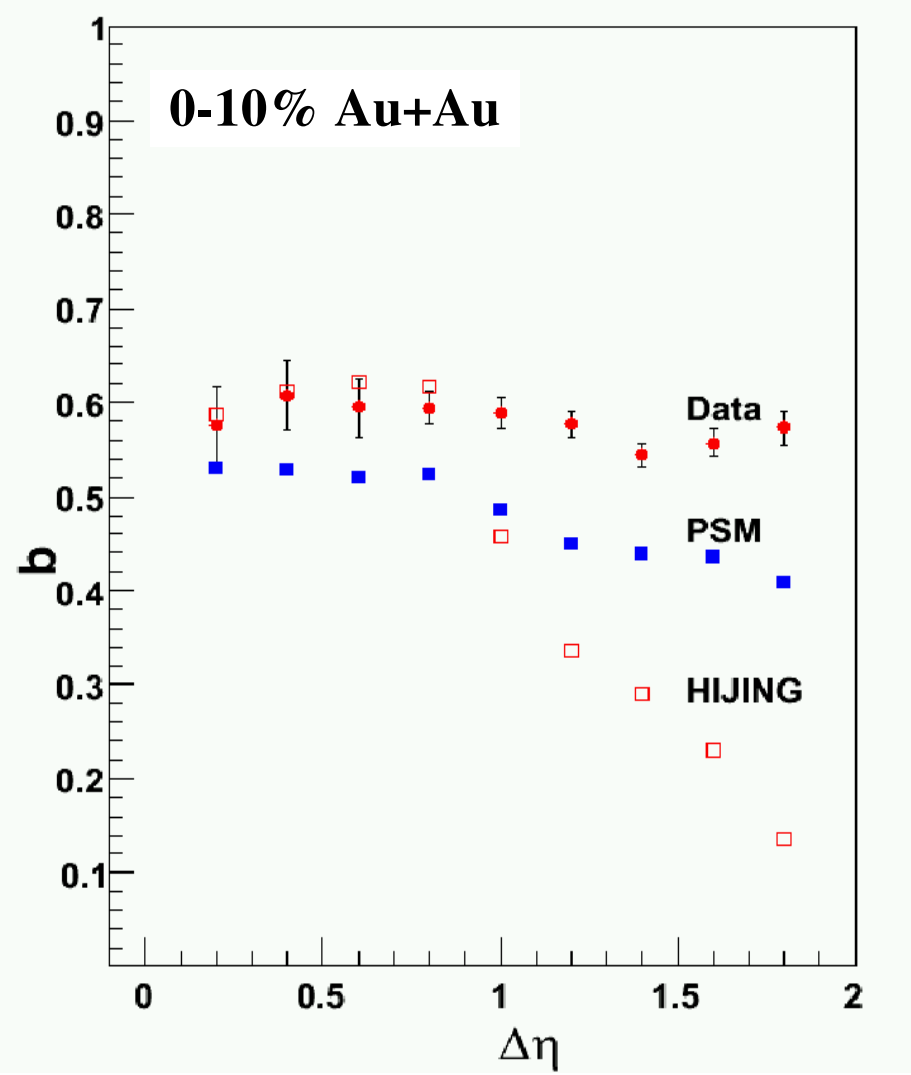
- For mid-peripheral collisions:
  - LRC is absent.

Centrality Dependence: 200 GeV Au+Au



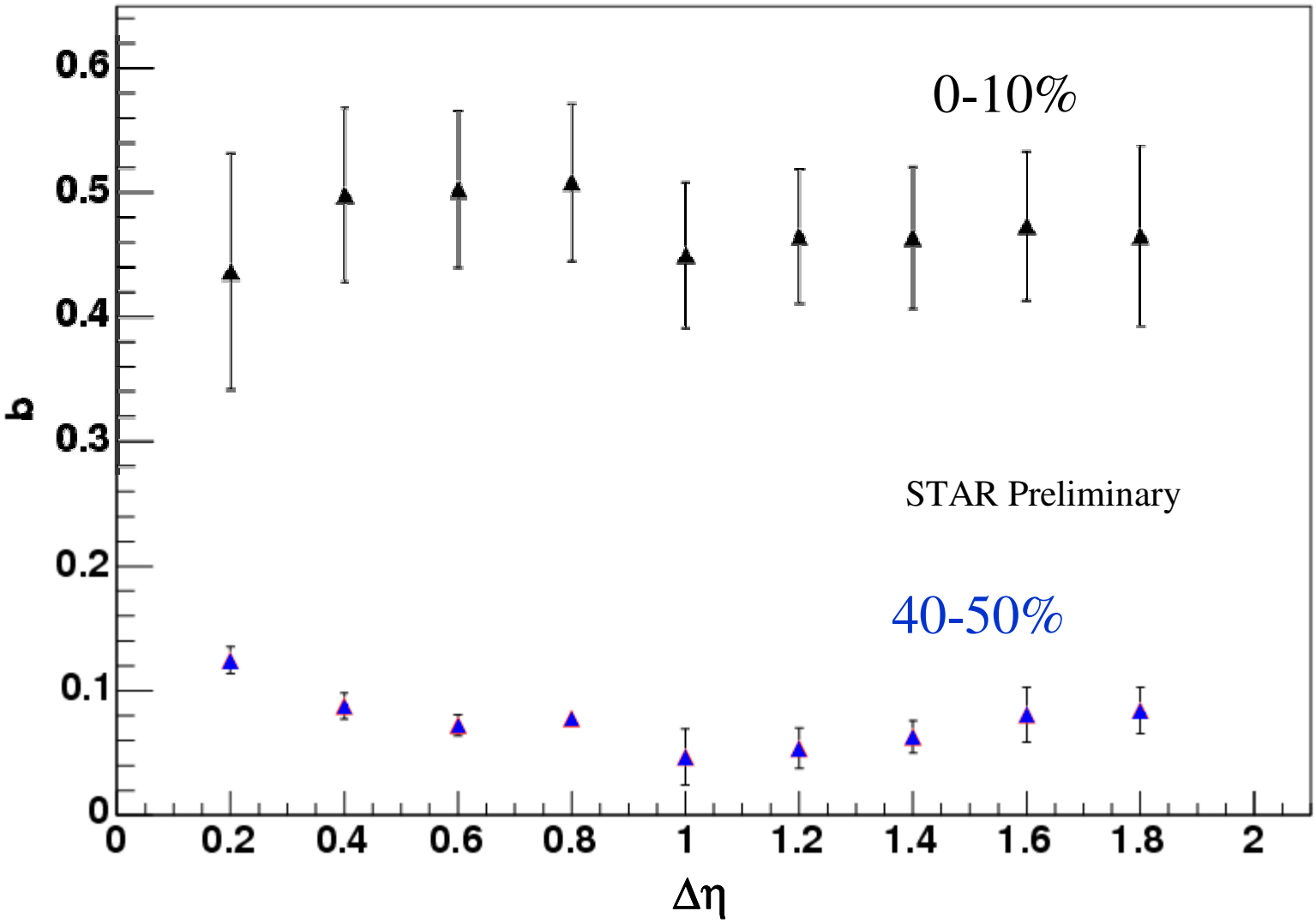
Comparison to Parton String Model (PSM) and HIJING

- 2 Monte Carlo models: PSM (DPM) and HIJING.
  - HIJING does not have long strings in η.
  - PSM has these included.
- PSM shows qualitative agreement w/ data.
- HIJING agrees well w/ the short-range component.



Centrality Dependence:
40-50% Cu+Cu at 200 GeV

- As in mid-peripheral Au+Au:
  - LRC absent.
  - Approx same evolution w/ $\Delta\eta$.



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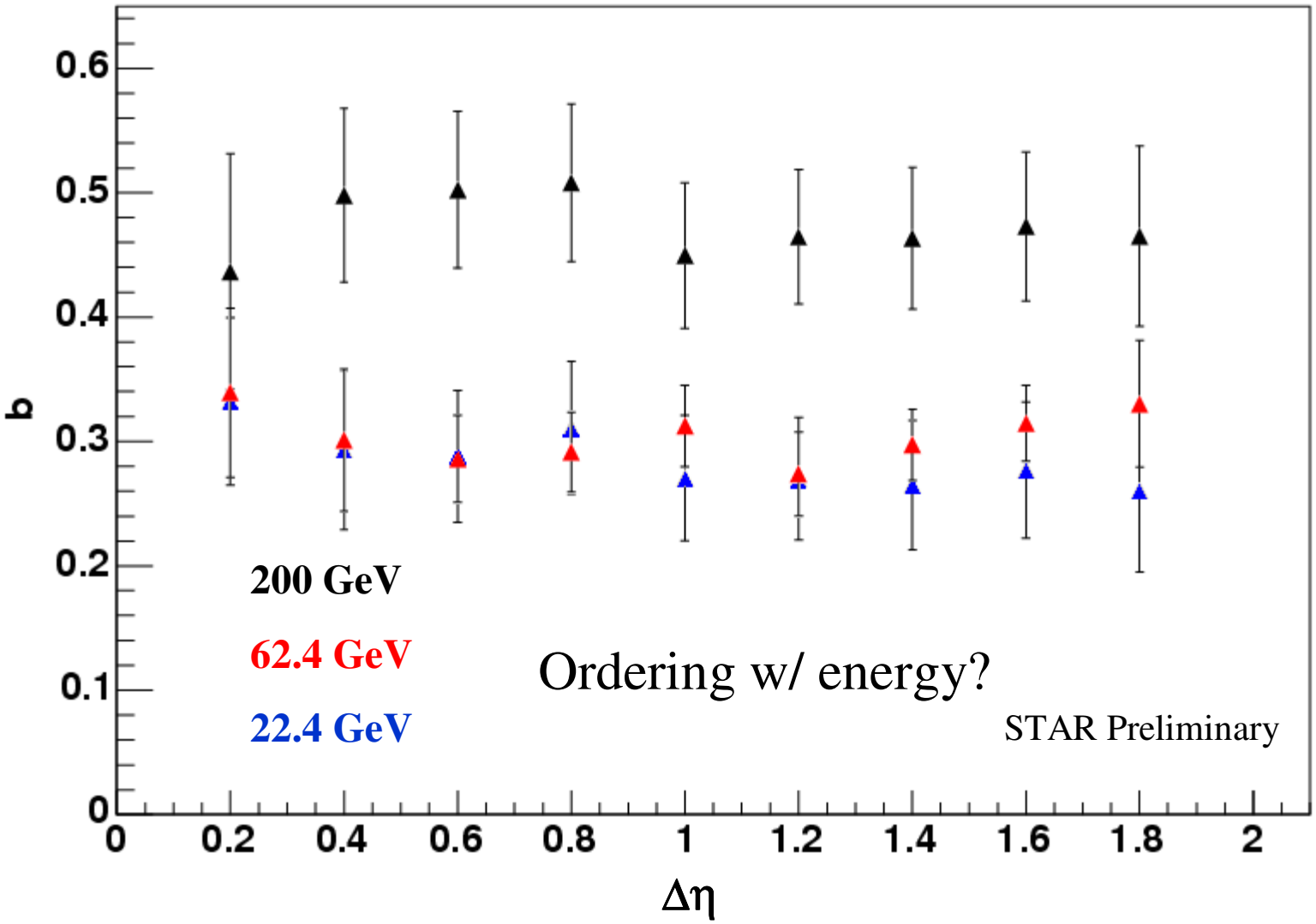
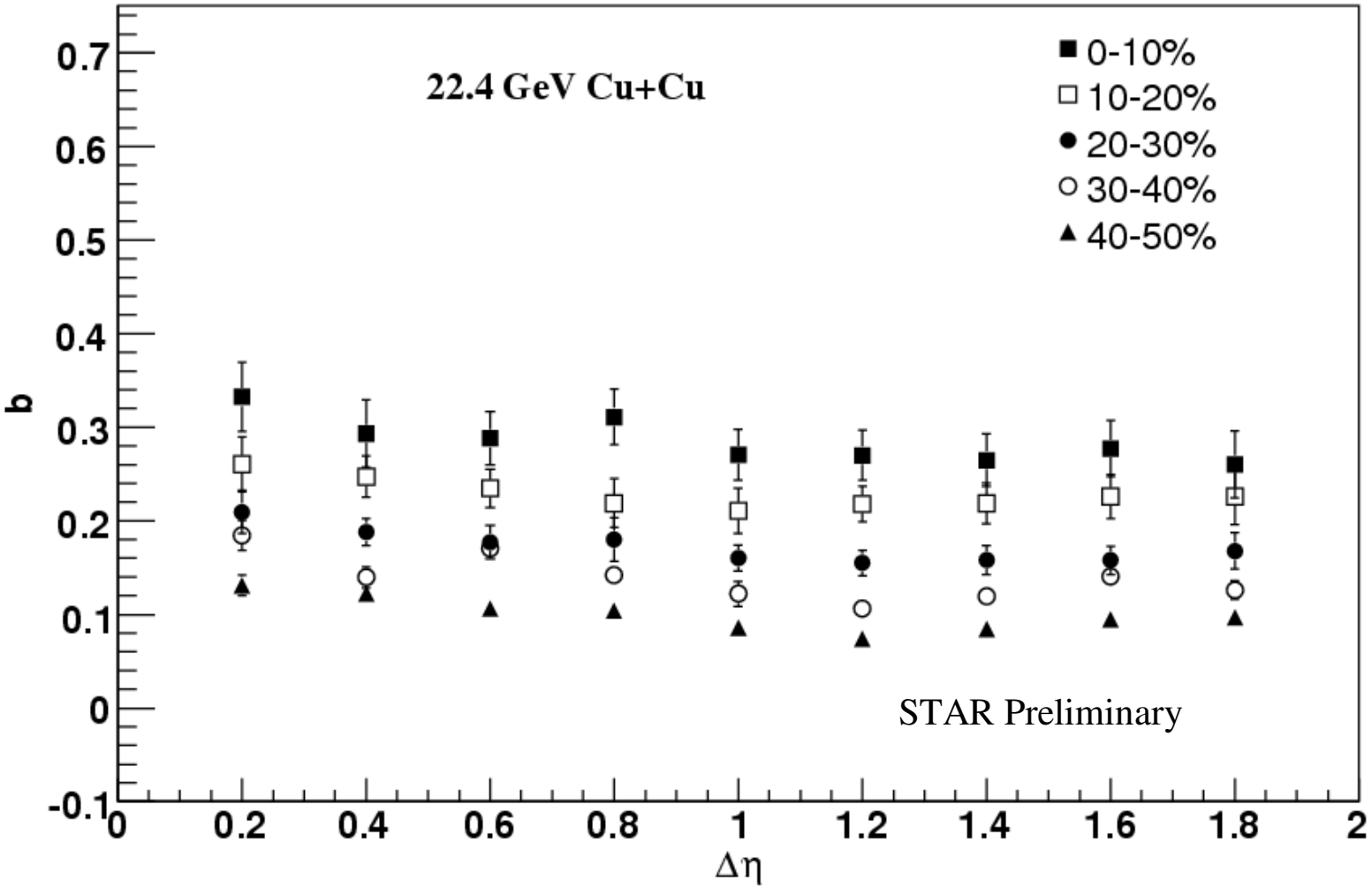
Search for the QCD Critical Point

- Proposal for future running at RHIC to consist of an "energy scan" to search for predicted QCD critical point.
- Fluctuations and correlations (particle ratios, multiplicity, p_T, etc.) and behavior of flow (directed and elliptic) in vicinity of the critical point are expected to be primary signatures.
- F-B correlations and K/π, p/π fluctuations can be measured at all energies.

Energy Dependence: Central 0-10% Cu+Cu



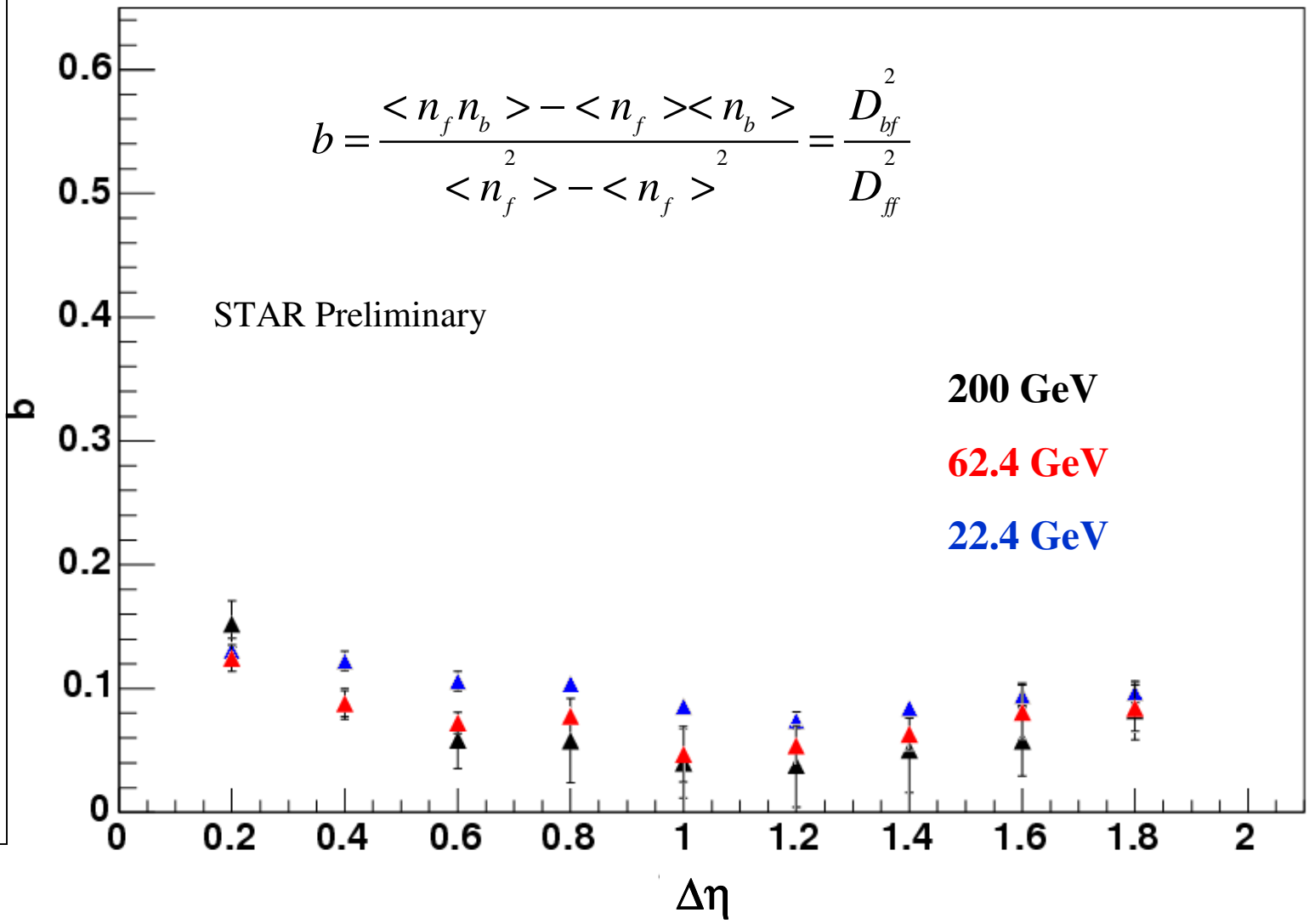
Centrality Evolution: 22 GeV Cu+Cu



Energy Dependence: 40-50% Cu+Cu

- For mid-peripheral collisions:
  - LRC is absent at all energies.
  - All energies show approx. same evolution w/ η.

$$b = \frac{< n_f n_b > - < n_f >< n_b >}{< n_f^2 > - < n_f >^2} = \frac{D_{bf}^2}{D_{ff}^2}$$



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Particle Ratio Fluctuations

K/π and p/π

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}

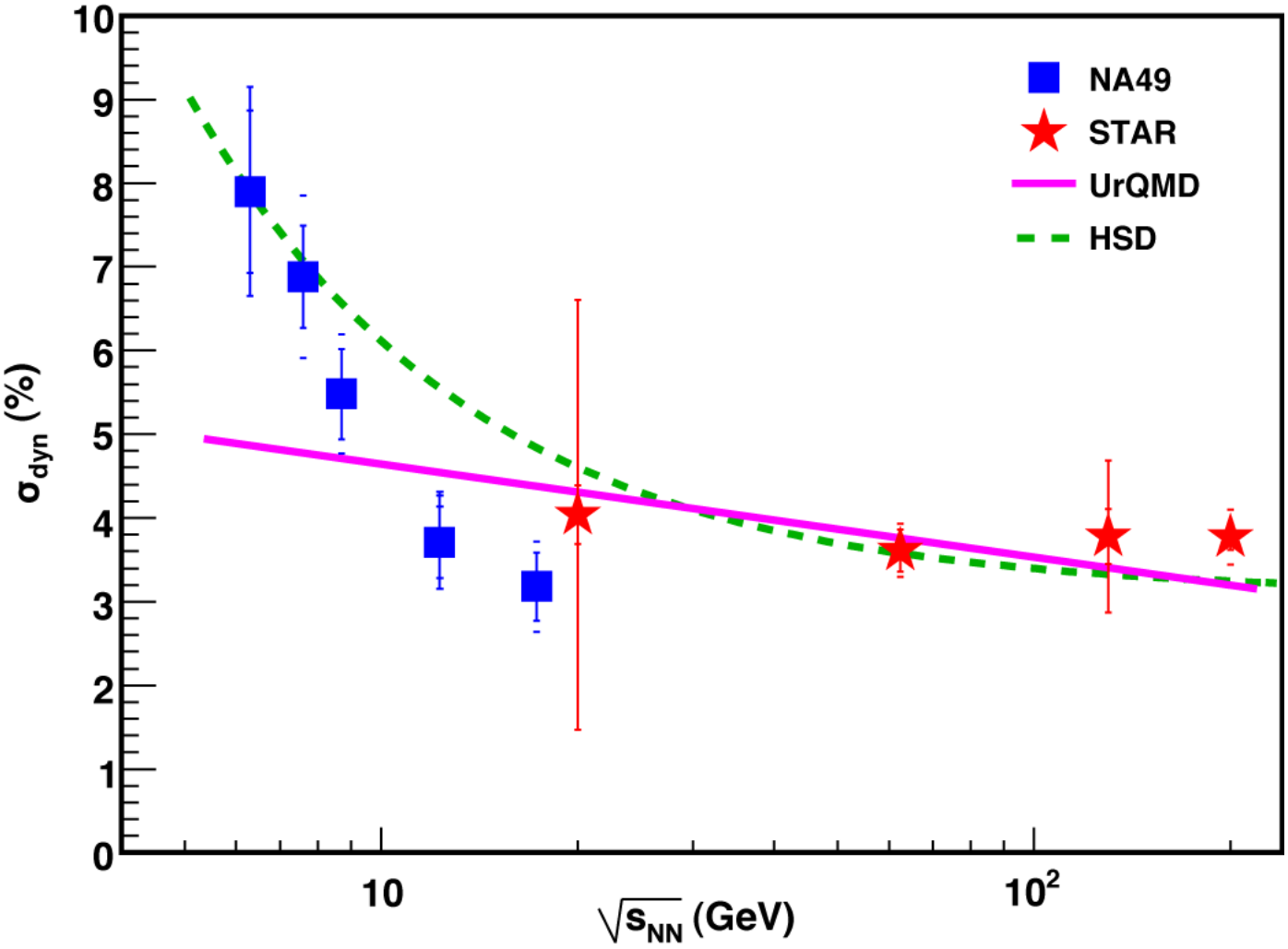
$$\nu_{\mathrm{dyn},K\pi} = \frac{\left\langle N_K\left(N_K - 1\right)\right\rangle}{\left\langle N_K\right\rangle^2} + \frac{\left\langle N_\pi\left(N_\pi - 1\right)\right\rangle}{\left\langle N_\pi\right\rangle^2} - 2\frac{\left\langle N_K N_\pi\right\rangle}{\left\langle N_K\right\rangle\left\langle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

- It has been demonstrated that,

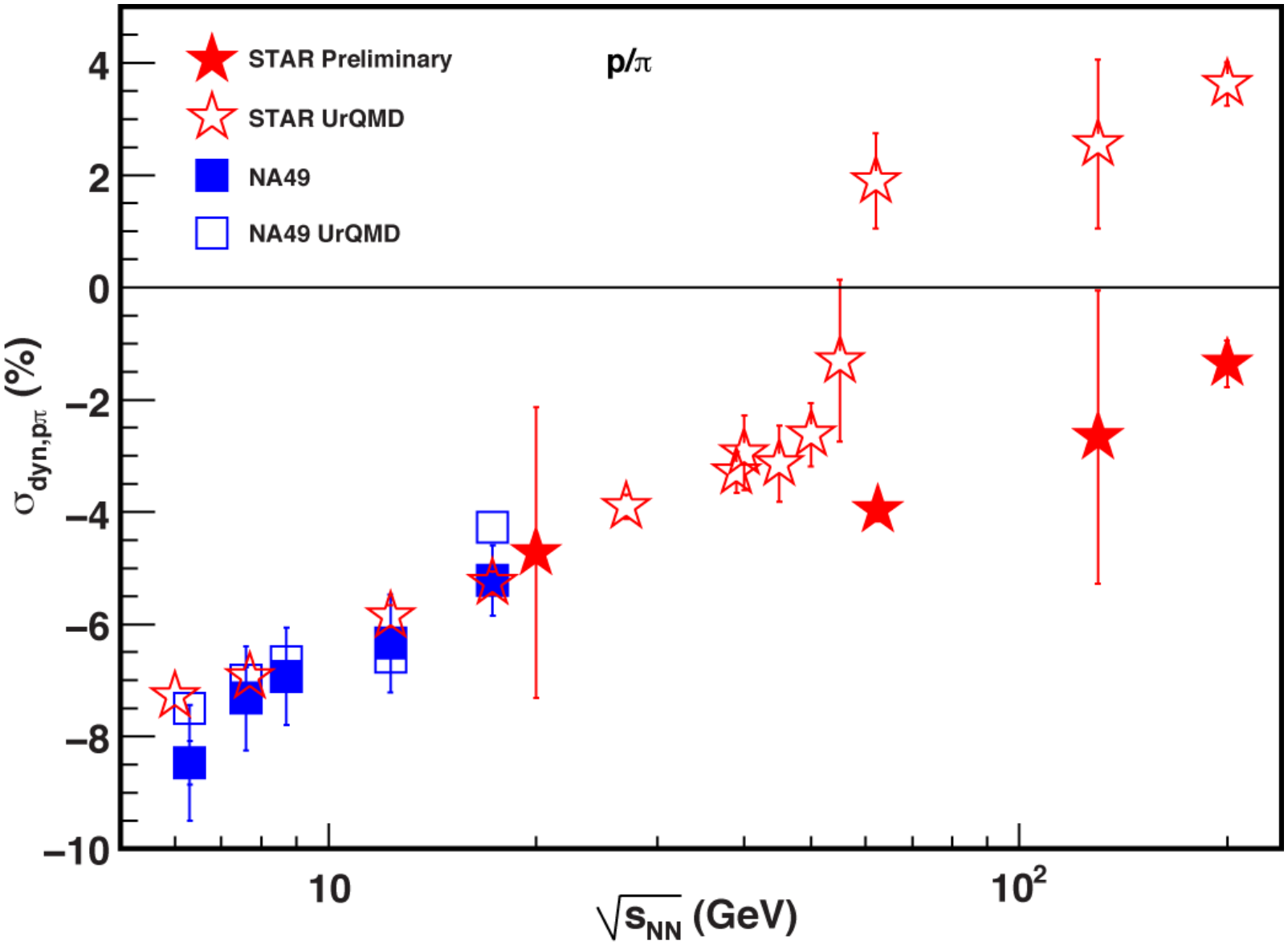
$$\sigma^2_{\mathrm{dyn}} = \nu_{\mathrm{dyn}}$$

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

- Compare STAR results for central Au+Au collisions with SPS results for central Pb+Pb collisions

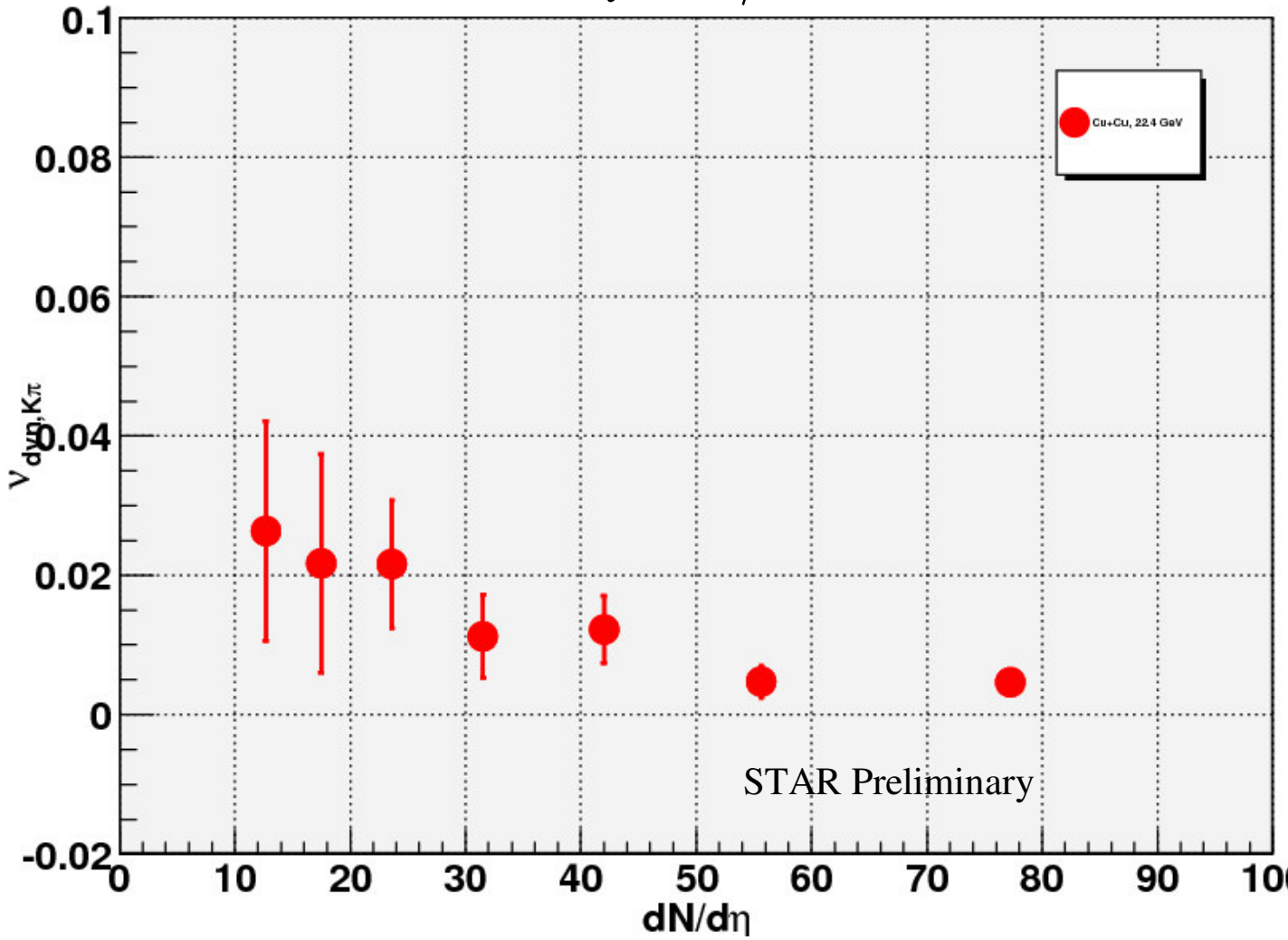


Excitation Function for $\sigma_{dyn,p\pi}$



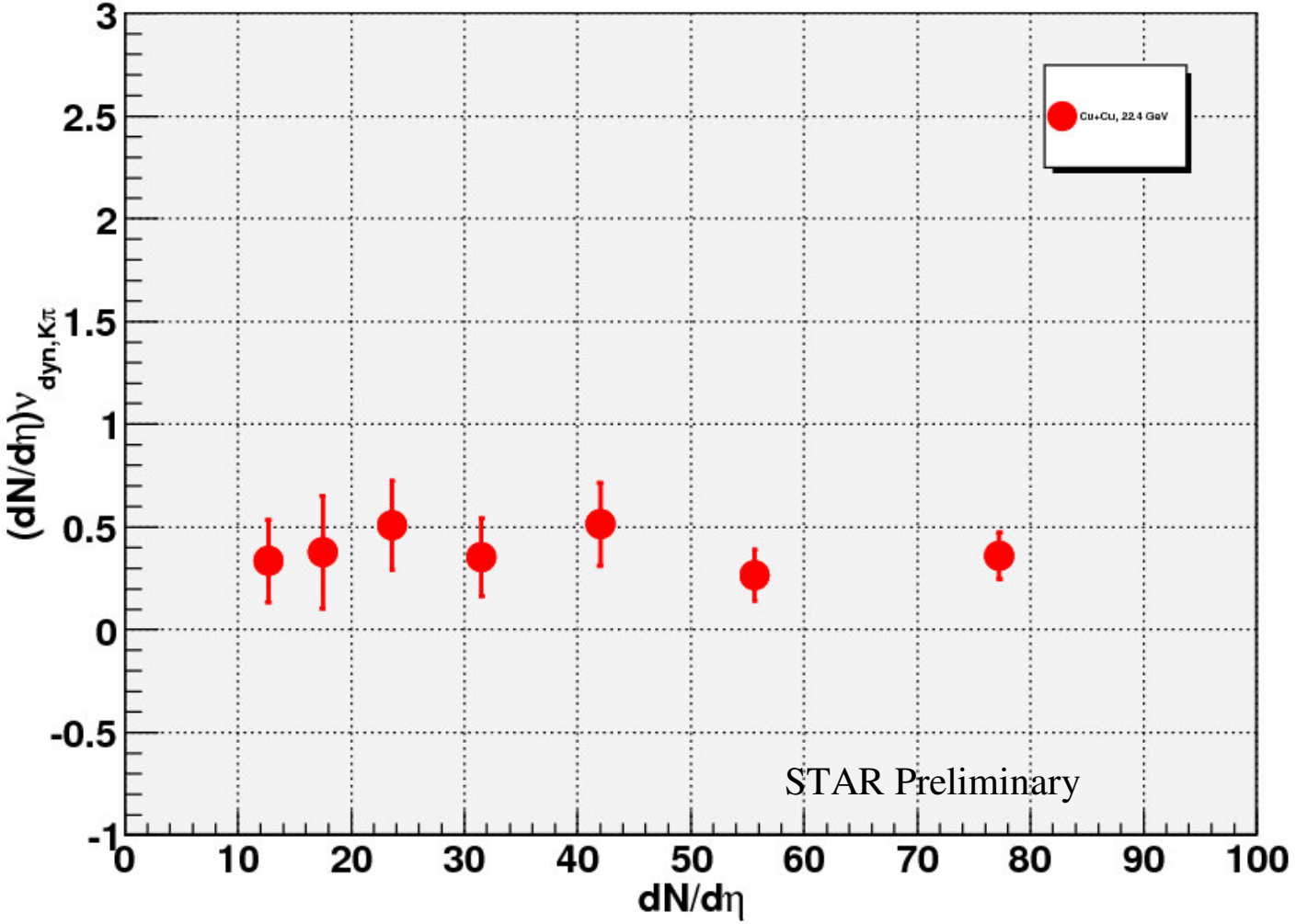
Cu+Cu 22.4 GeV

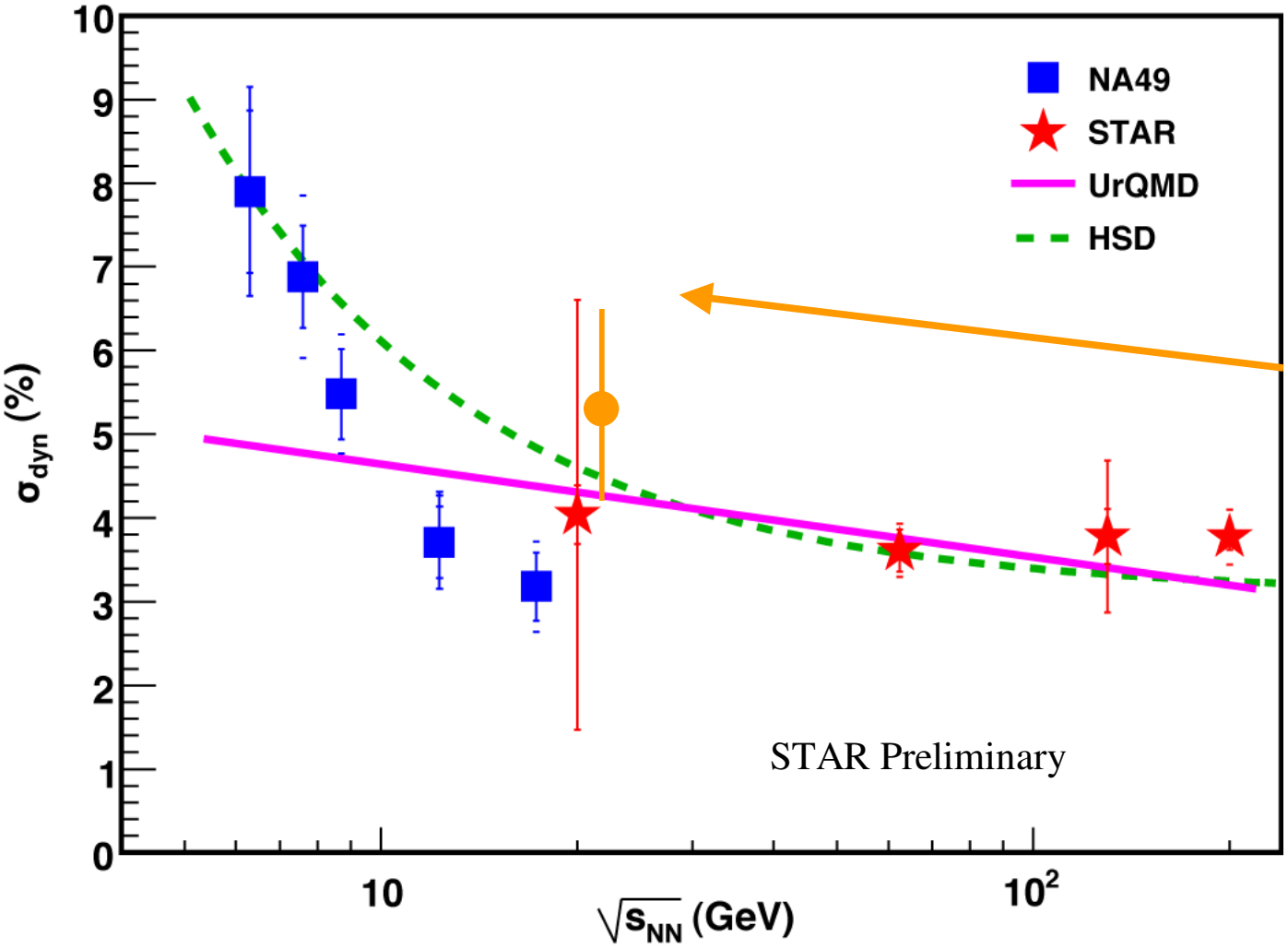
$\nu_{dyn,K/\pi}$



Cu+Cu 22.4 GeV

$(dN/d\eta)v_{dyn,K/\pi}$





01-% Cu+Cu
22.4 GeV

Statistical error only.

Summary I

- Centrality Dependence:
  - At 200 GeV, central A+A collisions exhibit a strong, long-range correlation.
  - For mid-peripheral collisions, correlation coefficient shows similar behavior at all energies and systems.
    - Dominated by SRC.
    - LRC is consistently absent.
- System Size Dependence:
  - Similar LRC at 200 GeV in Au+Au and Cu+Cu.
  - Correlation in pp at 200 GeV resembles that of mid-peripheral A+A.
- Energy Dependence:
  - For central collisions, correlation coefficient seems to depend more on energy than system size.
  - Differences in correlation in pp 200/400 vs. 62 GeV could indicate small LRC.
  - Jet contribution?

Summary II

- Preliminary look at $\nu_{dyn,K/\pi}$ for Cu+Cu at 22.4 GeV.
  - More track quality cuts to be investigated.
- For $\nu_{dyn,p/\pi}$ models show a transition effect.
  - Acceptance in HSD…?
  - Not acceptance in UrQMD. What is it?
- Study of fluctuations and correlations well established, will be an important part of QCD critical point search.