Balance Function and p_t Fluctuations at RHIC

- Balance Function
  - $B(\Delta\eta)$, $B(\Delta y)$, $B(q_{inv})$, $B(\Delta\phi)$
- p_t Fluctuations
  - Excitation Function of $<\Delta p_{t,i}\, \Delta p_{t,j}>$
    - Au+Au at 20, 130, and 200 GeV
  - F_{pt}

Gary D. Westfall
Michigan State University
For the STAR Collaboration

The Balance Function

$$B(\Delta y) = \frac{1}{2}\left\{\frac{N_{+-}(\Delta y) - N_{++}(\Delta y)}{N_+} + \frac{N_{-+}(\Delta y) - N_{--}(\Delta y)}{N_-}\right\}$$

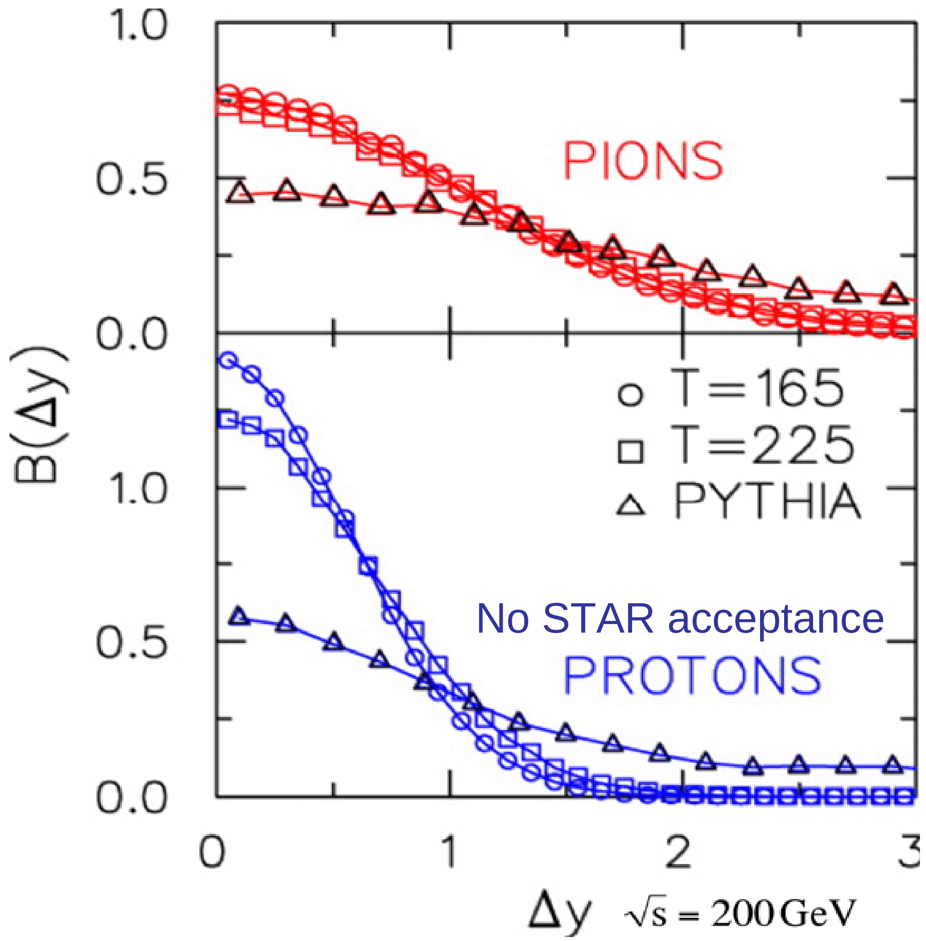
Bass, Danielewicz, and Pratt, PRL **85**, 2689 (2000)

Theoretical expectations for B(Δy)

- PYTHIA representing p+p collisions shows a characteristic width of about 1 unit of Δy
- Bjorken thermal model representing delayed hadronization shows narrower balance function width
  - **Nucleon-nucleon → wide**
  - **Delayed hadronization → narrow**

Experimental considerations

- Use Δη, Δy, q_{inv}, Δφ
- Centrality dependence for Au+Au and d+Au at 200 GeV
- All centralities for p+p at 200 GeV

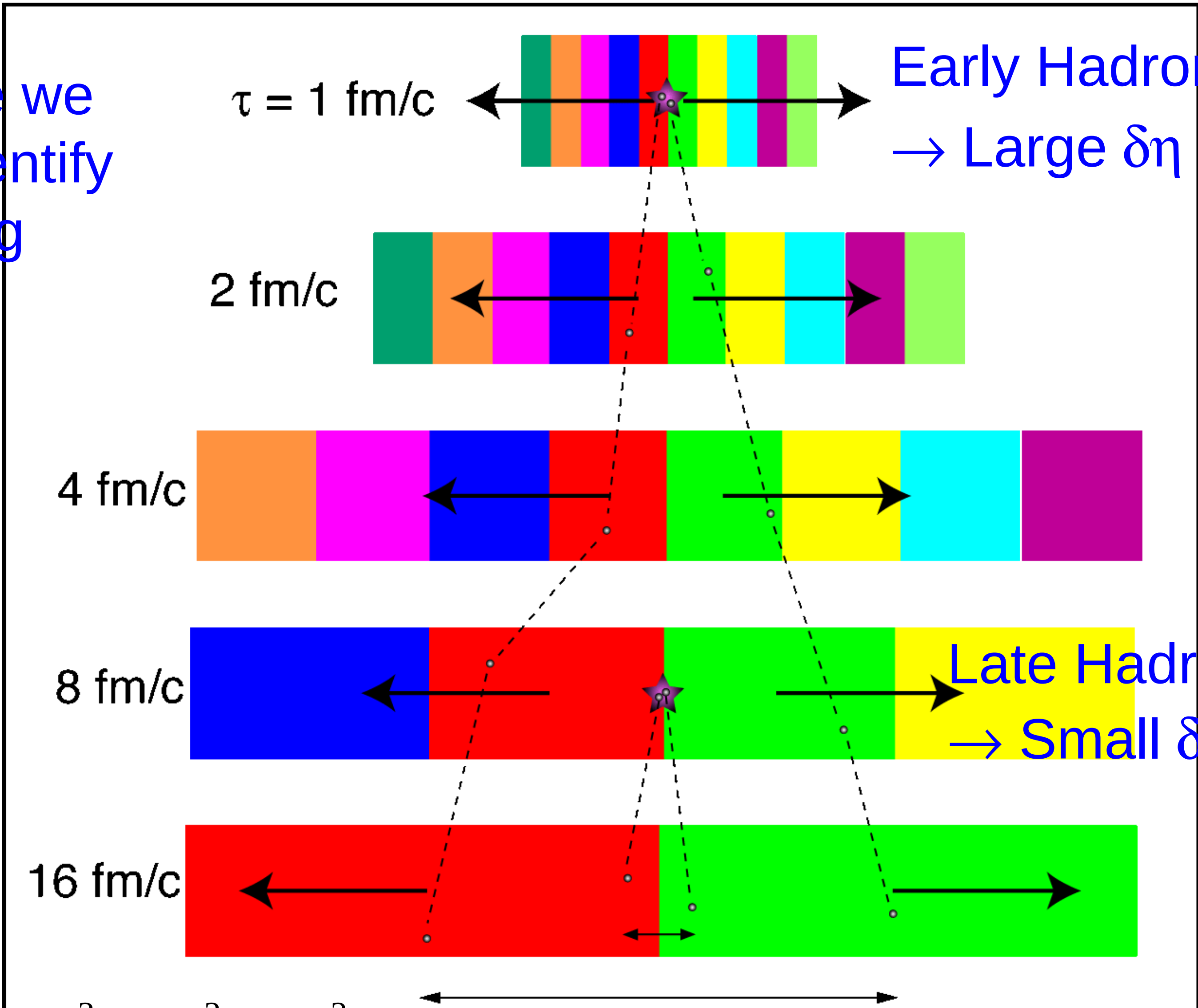


Delayed Hadronization

- A new observable has been proposed by Bass, Danielewicz, and Pratt [Phys. Rev. Lett. **85**, 2689 (2000)] called the **balance function**
- The basic premise is that charge/anti-charge pairs are created close together in space-time
- If these pairs are created early in the collision, they will be pulled apart in rapidity by longitudinal expansion and will suffer scattering for the duration of the collision, losing their correlation in rapidity
- If instead, the system exists in a deconfined phase for a substantial time, and then the pairs are formed at hadronization, they will experience less expansion and fewer collisions, retaining more of their correlation in rapidity

Delayed Hadronization

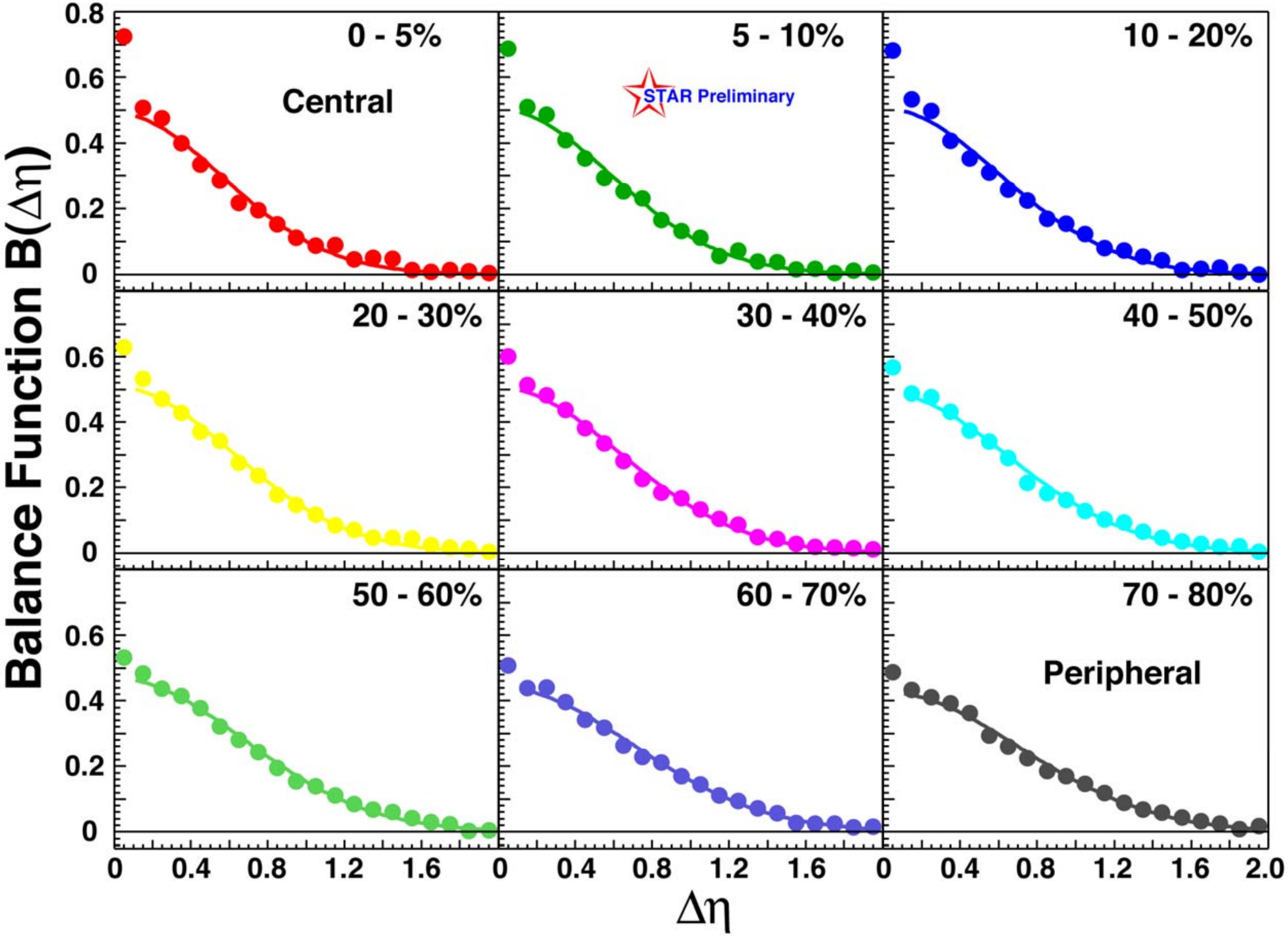
Suppose we could identify balancing charges



$$\sigma_{\delta y}^{2} = \sigma_{\delta\eta}^{2} + \sigma_{thermal}^{2}$$

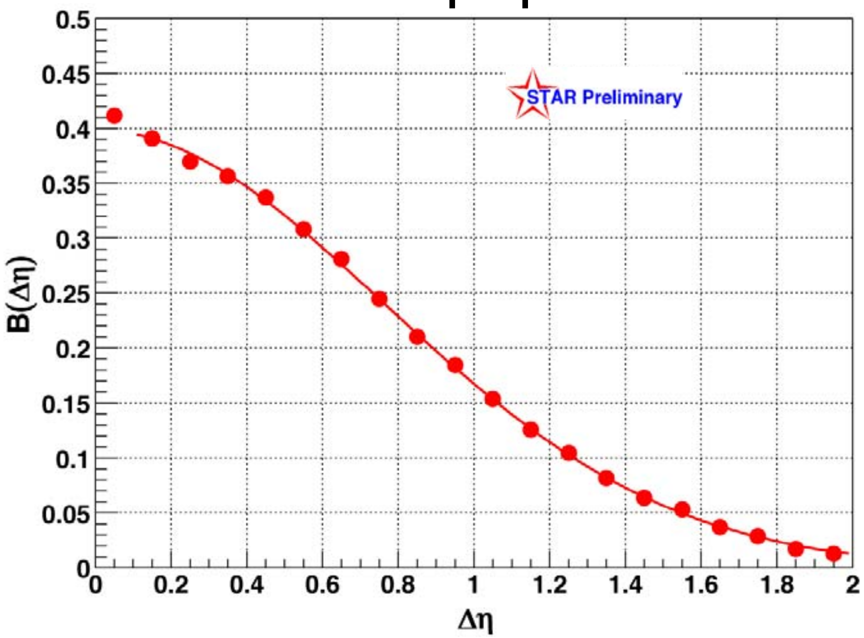
After Scott Pratt

Balance Function for Au+Au at 200 GeV

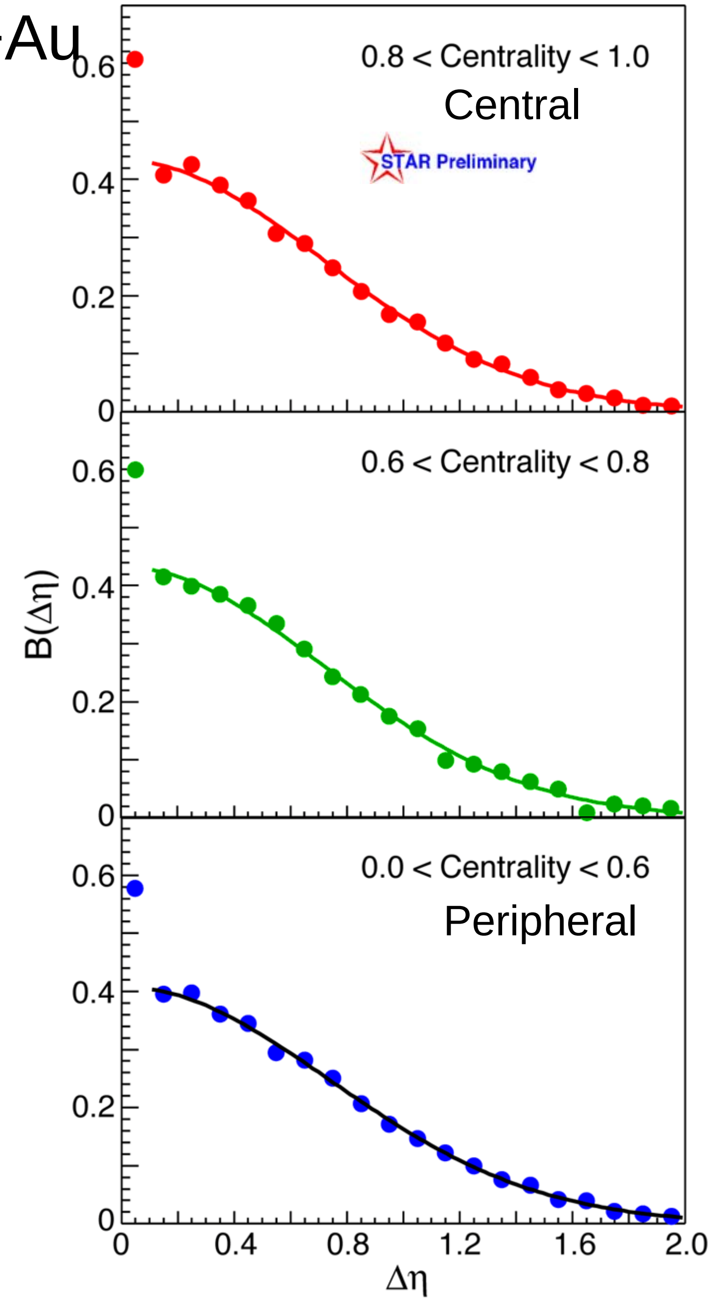


Balance Function for p+p and d+Au at 200 GeV

p+p

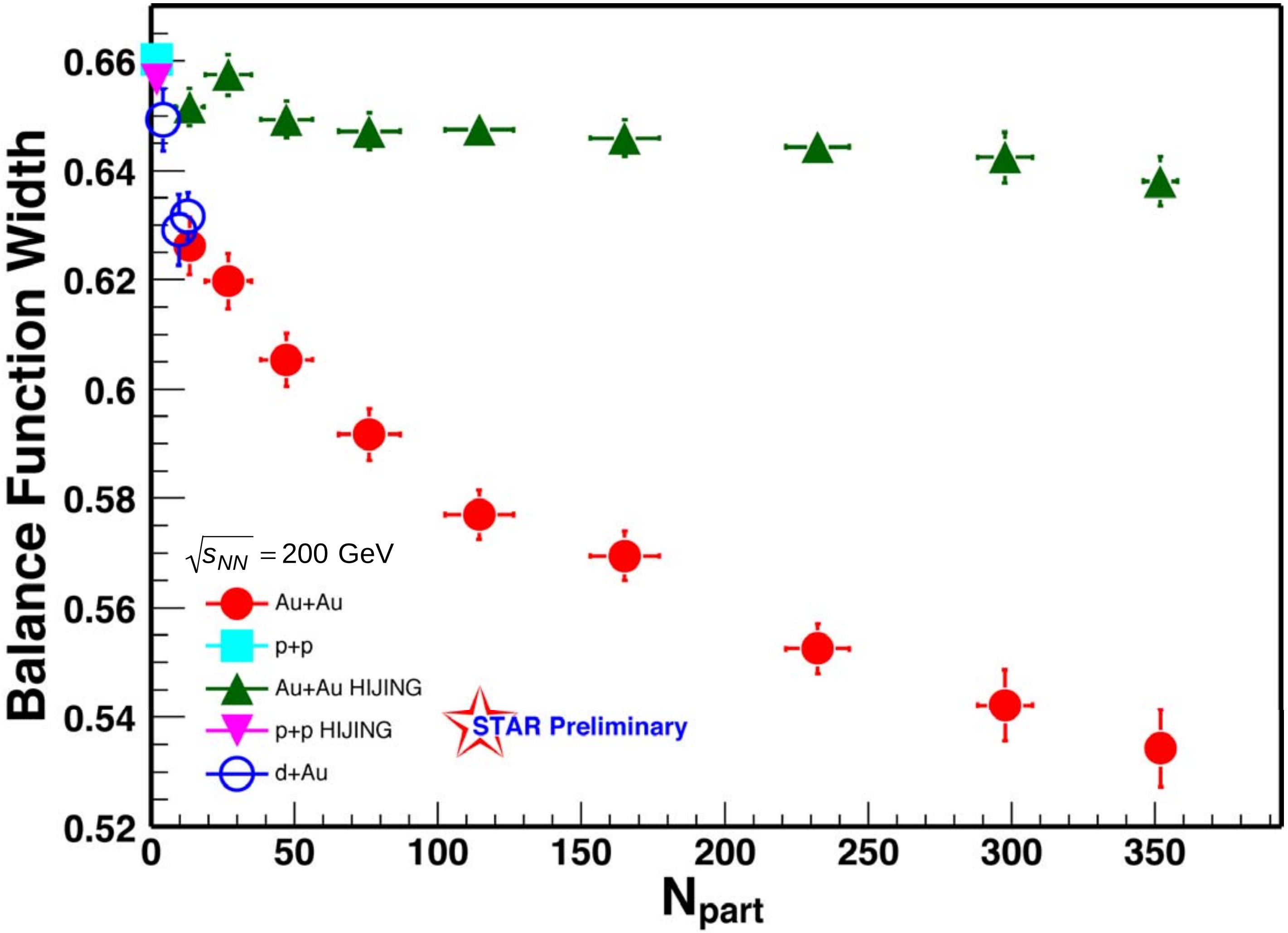


d+Au



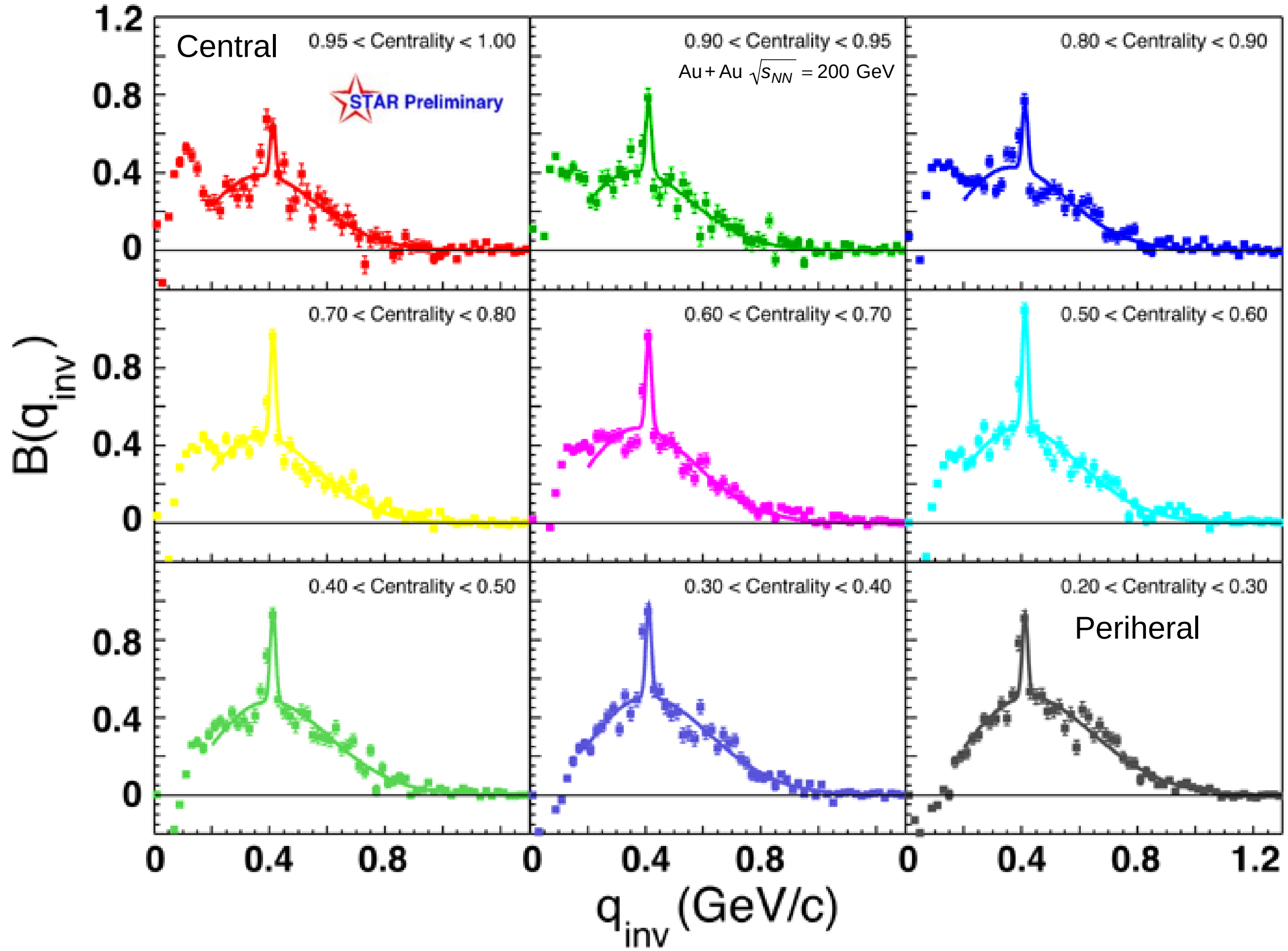
Balance Function Widths

Width is defined as weighted average of $\Delta\eta$ for $0.1 \le \Delta\eta \le 2.0$



Balance function for Au+Au narrows in central collisions
HIJING shows little centrality dependence
Smooth dependence on N_{part}

Balance Function for Pions using q_{inv}



Fits are thermal + K^0 decay

Thermal distribution is

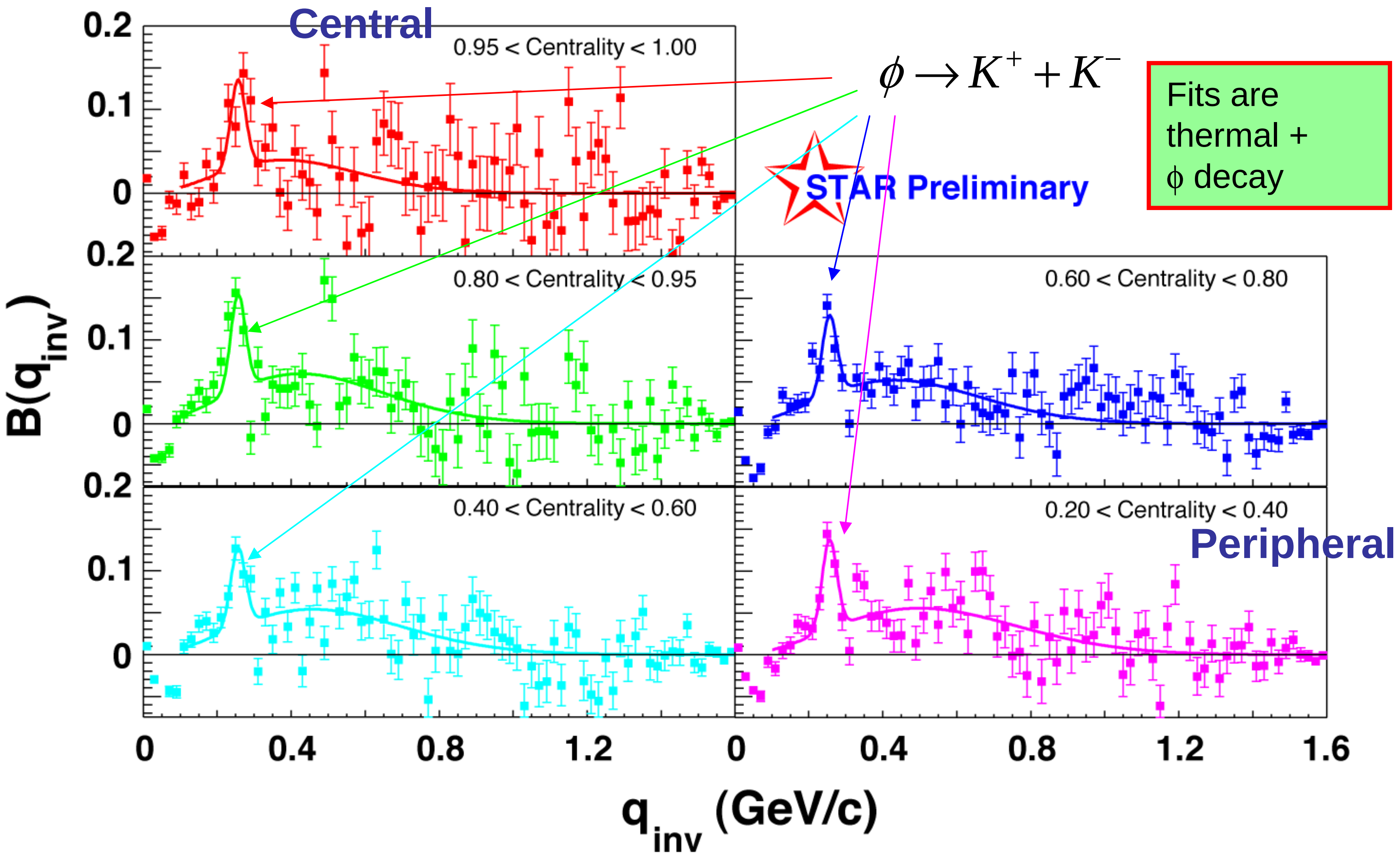
$$\propto q_{inv}^2 e^{-\frac{q_{inv}^2}{2\sigma}}$$

Narrowing of B(Δη) may be caused by transverse flow
Use B(q_{inv}) to remove reference frame dependence
Allow more direct comparison with thermal models

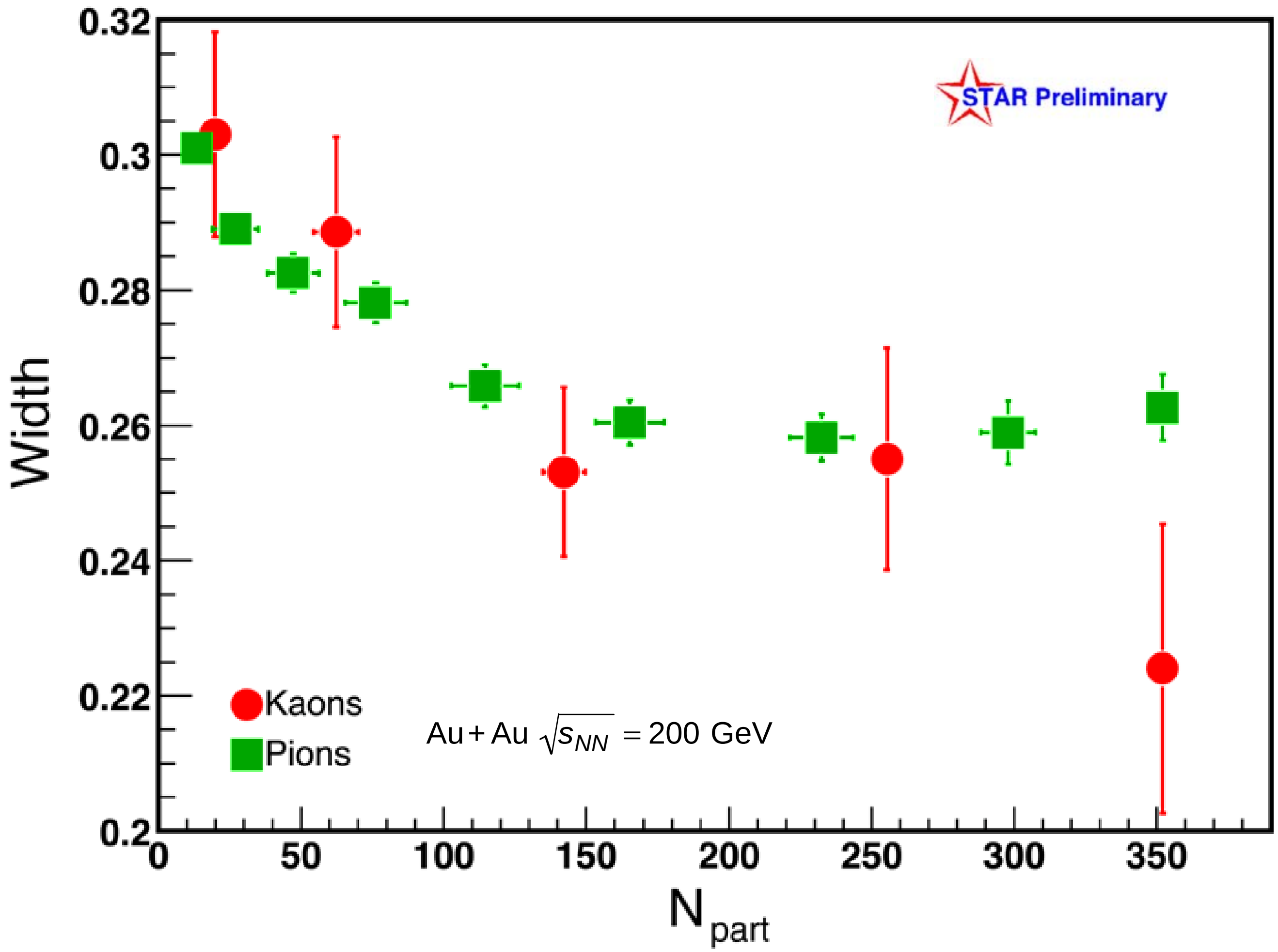
Balance Function for Kaons using q_{inv}

Identified charged kaon pairs (K^+,K^-)

p < 0.8 GeV, no electrons



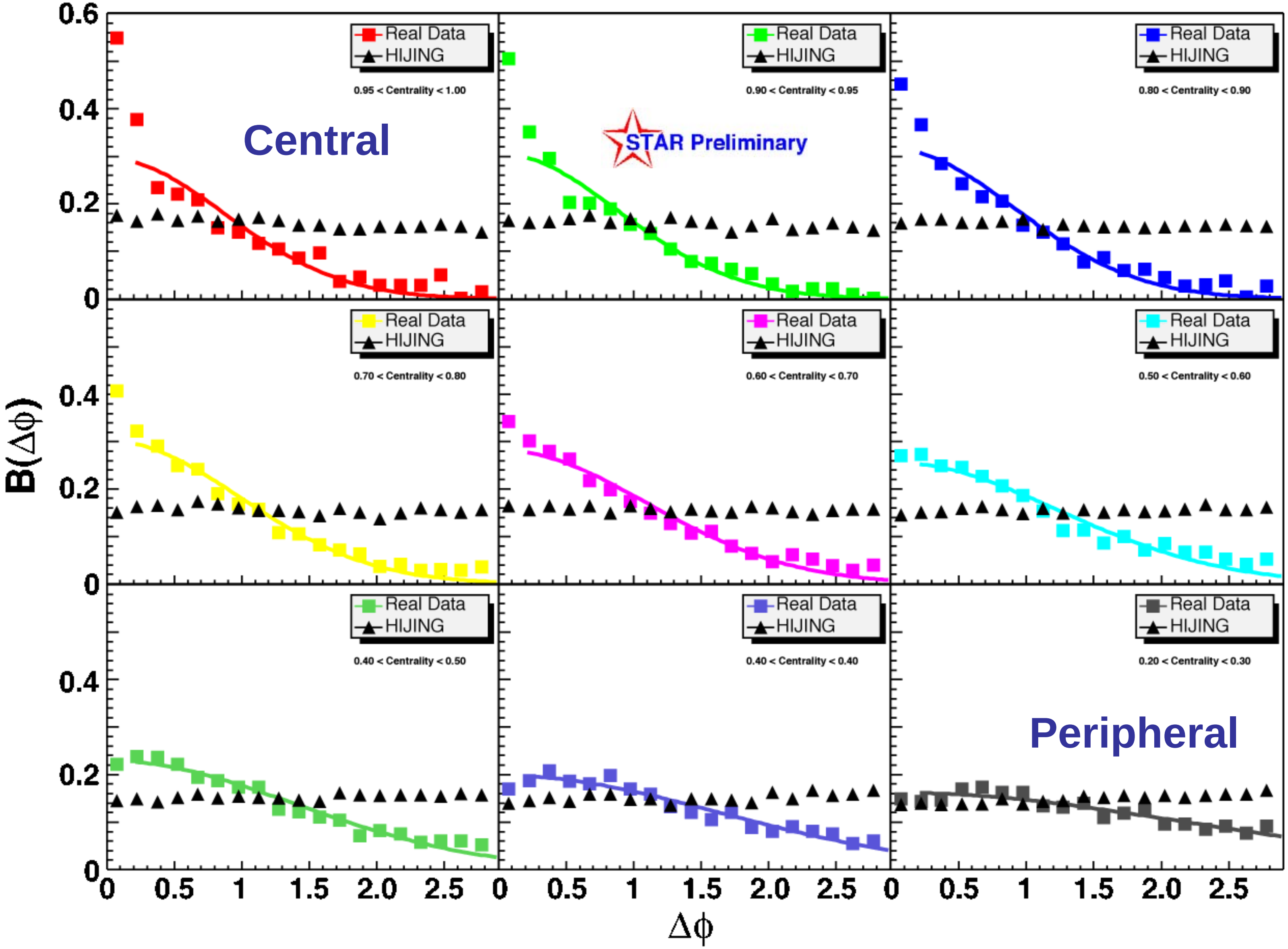
Width of Balance Function using q_{inv}



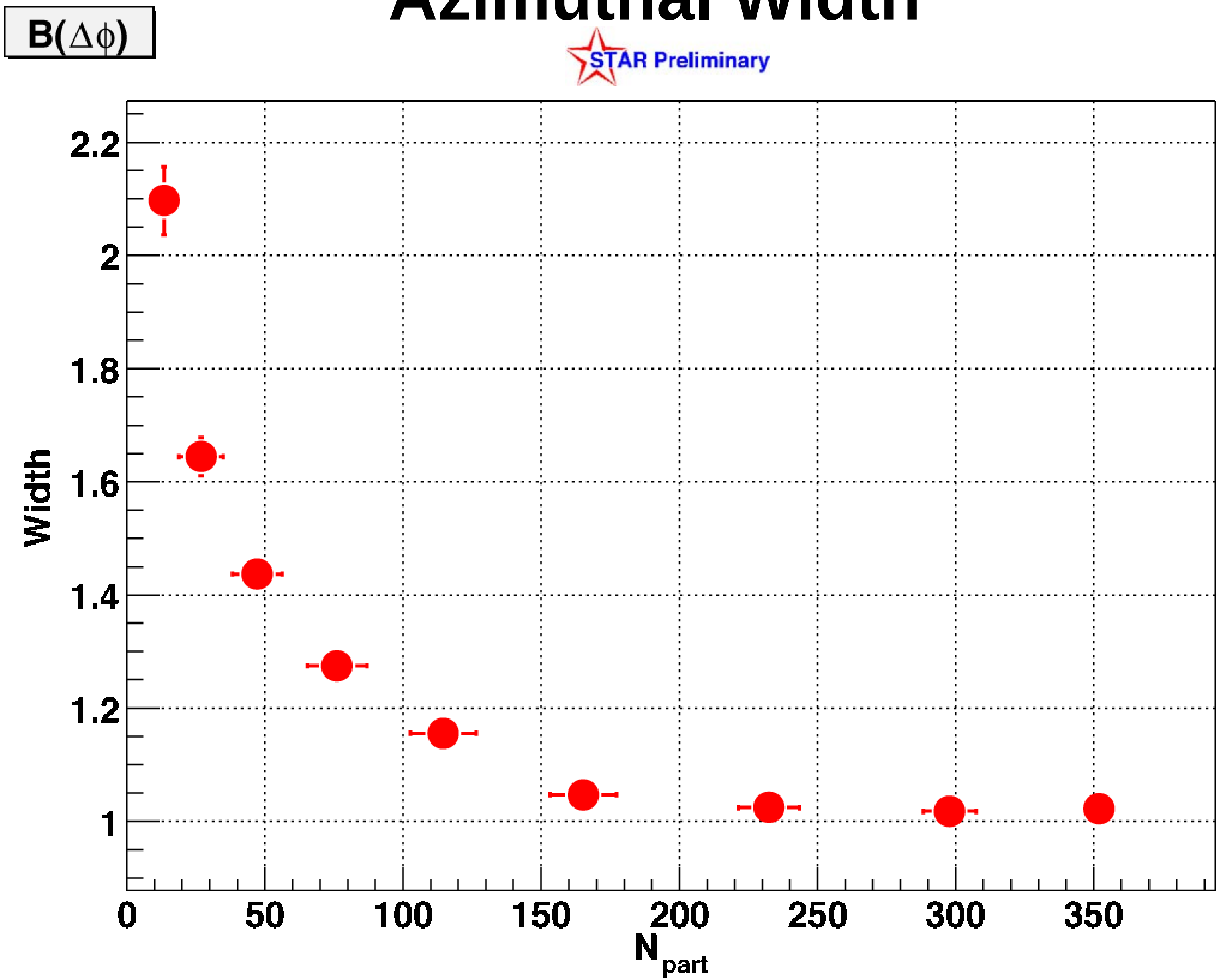
Balance function B(q_{inv}) for pions and kaons narrows in central collisions even when using Lorentz invariant observable

Balance Function for All Charged Particles, B(Δφ)

no electrons

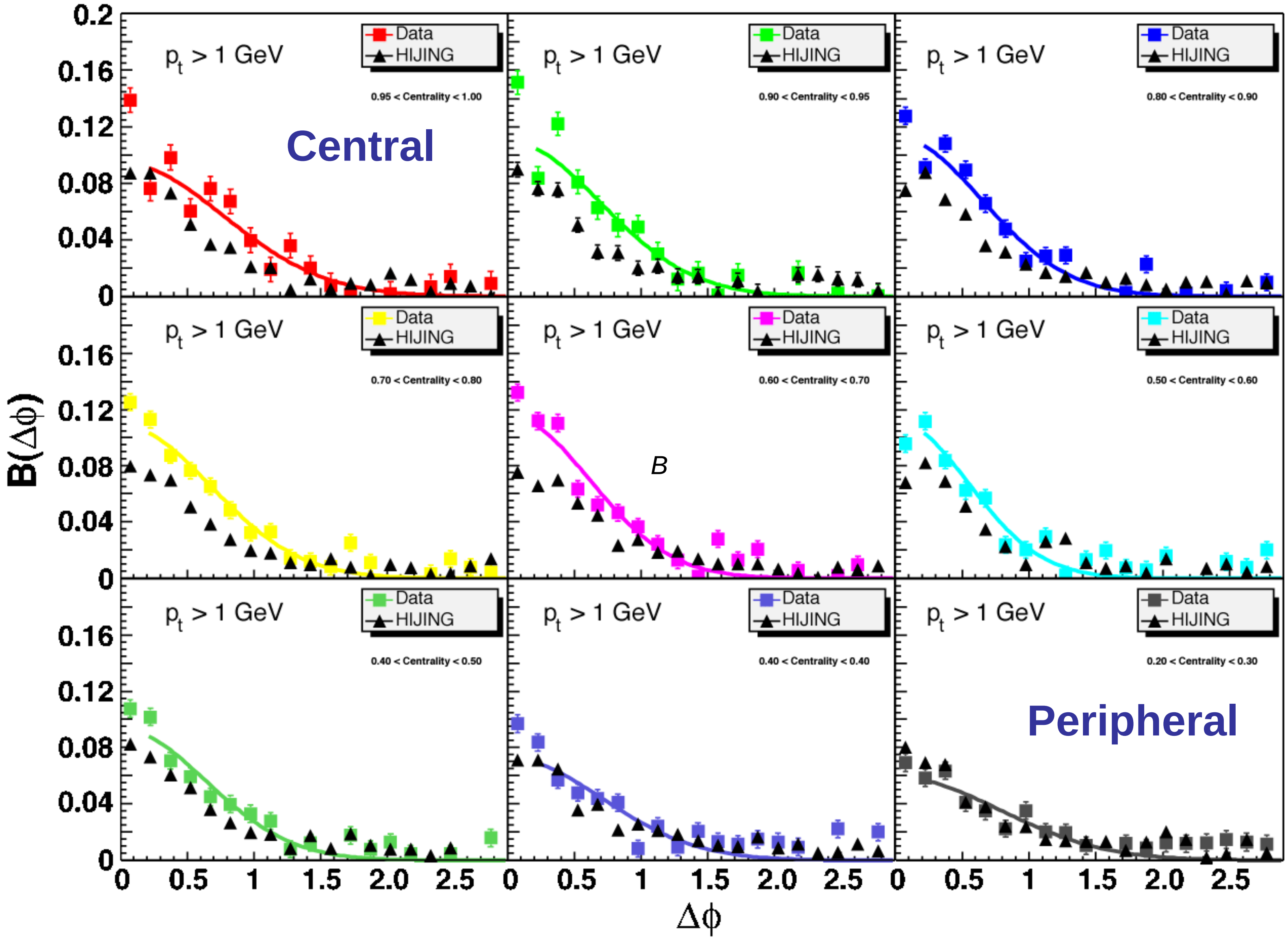


Azimuthal Width



B(Δϕ) at High p_t

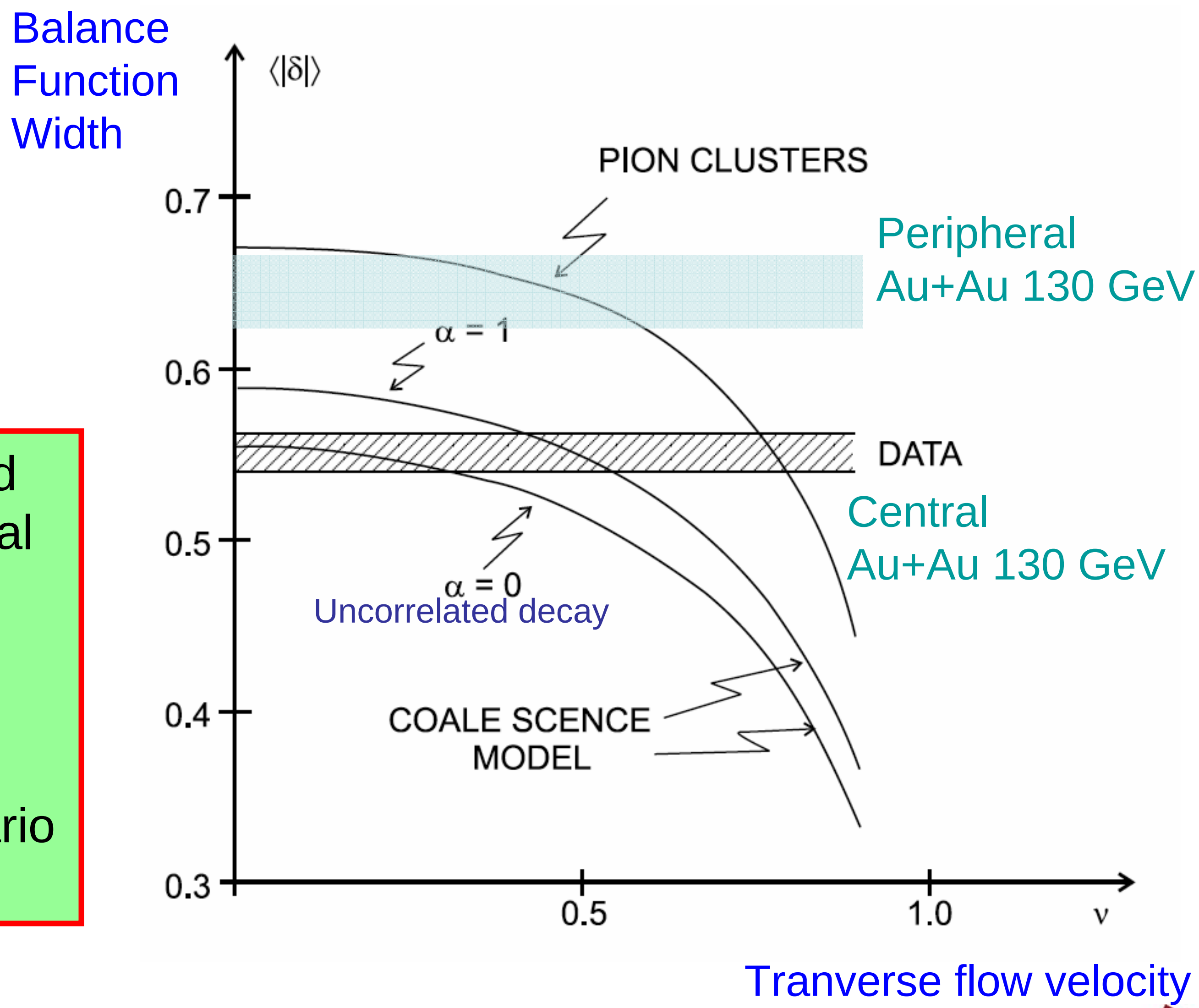
STAR Preliminary



Quark Coalescence Narrows Balance Function

A. Bialas
hep-ph/0308245

Shows that measured narrow width in central collisions can be explained using a quark/antiquark coalescence model while hadronic scenario fails



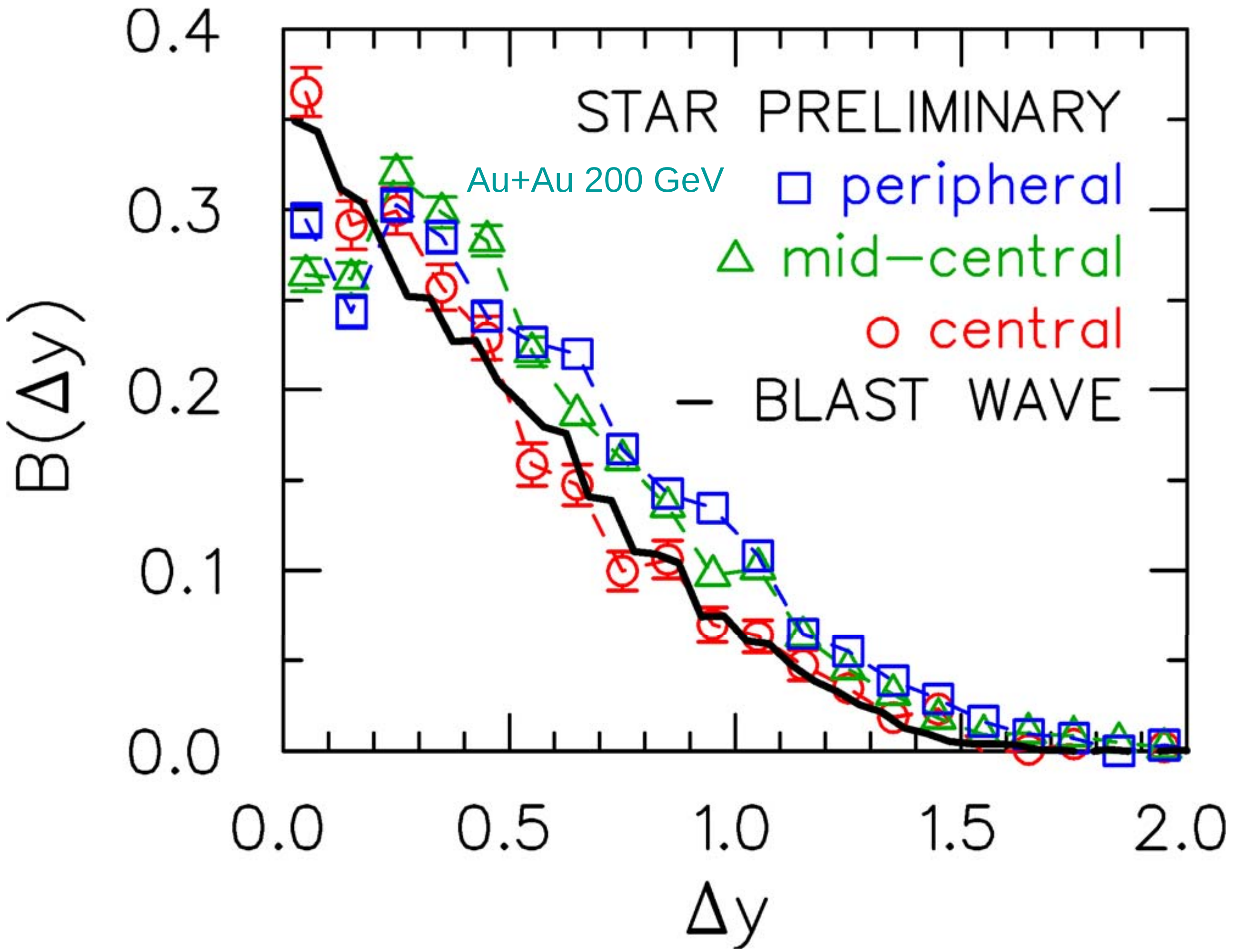
Theoretical Predictions for the Balance Function

Cheng, Petriconi, Pratt, and Skoby, nucl-th/0401008

Includes HBT, Coulomb, resonances, strong interactions, radial flow, conservation of S,Q,B

Uses STAR acceptance filter

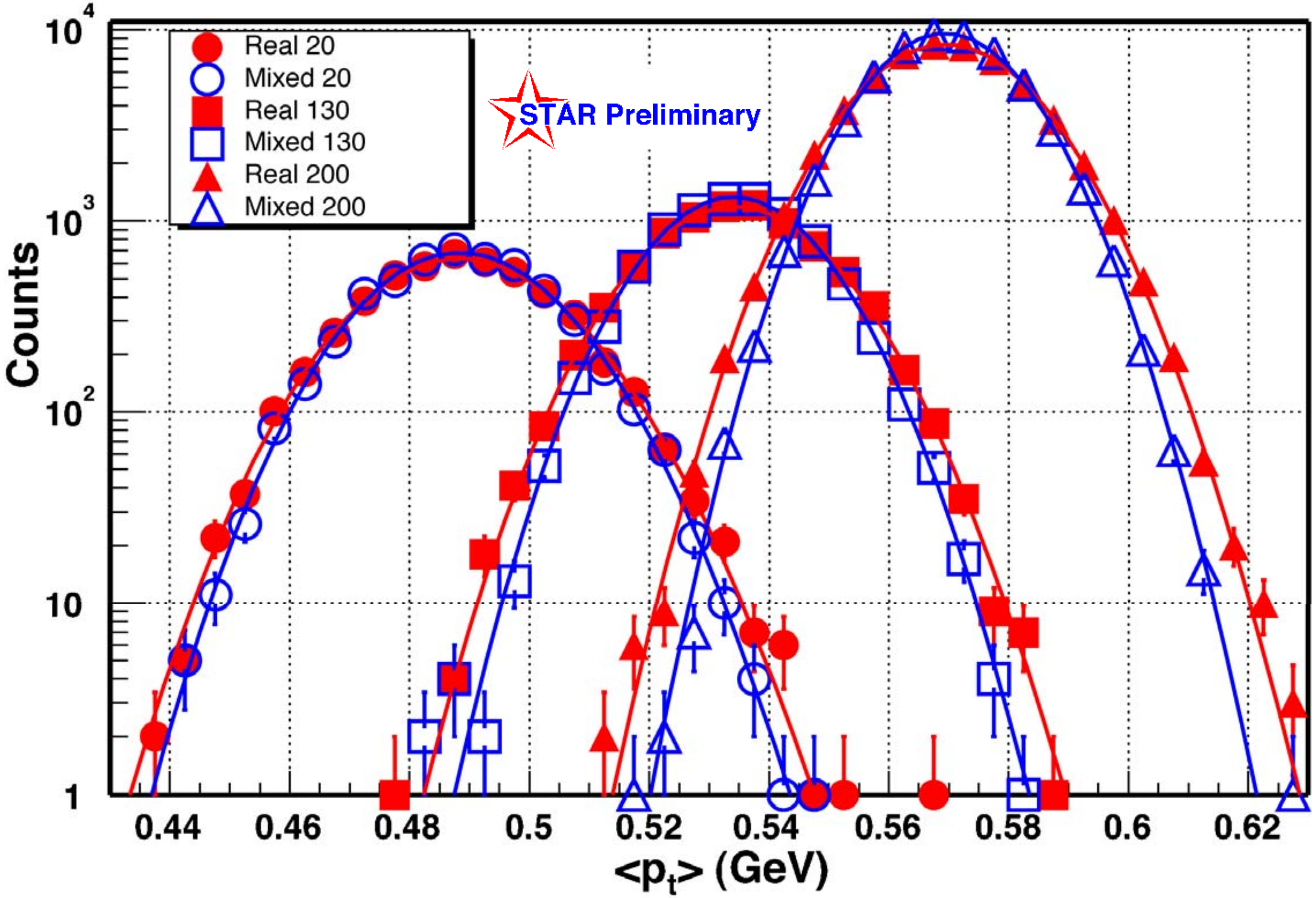
The agreement with the measured narrow balance function in central collisions suggests that charge conservation remains highly localized at breakup



p_t Fluctuations

- Search for dynamical fluctuations motivated by predictions
  - Fluctuations in energy density due to localized deconfinement
  - Increased fluctuations in energy density due to long range correlations
  - Proximity to tri-critical and critical points would lead to changes in fluctuation patterns
  - Production of DCCs
  - Fluctuations from jet production

Histograms of $<p_t>$



Au+Au at 20, 130, and 200 GeV

5% most central bin using min bias data, $|\eta| < 1.0$

Real is wider than mixed

$\rightarrow$ Dynamical fluctuations

Definition of <$\Delta p_{t,i}\, \Delta p_{t,j}$>

As a function of centrality and acceptance

$$\langle\langle p_t \rangle\rangle = \left(\sum_{k=1}^{N_{event}} \langle p_t \rangle_k \right) / N_{event} \quad \text{where} \quad \langle p_t \rangle_k = \left(\sum_{i=1}^{N_k} p_{t,i} \right) / N_k$$

$$\langle \Delta p_{t,i} \Delta p_{t,j} \rangle = \frac{1}{N_{event}} \sum_{k=1}^{N_{event}} \frac{C_k}{N_k (N_k - 1)}$$

$$C_k = \sum_{i=1}^{N_k} \sum_{j=1, i \neq j}^{N_k} \left(p_{t,i} - \langle\langle p_t \rangle\rangle \right)\left(p_{t,j} - \langle\langle p_t \rangle\rangle \right)$$

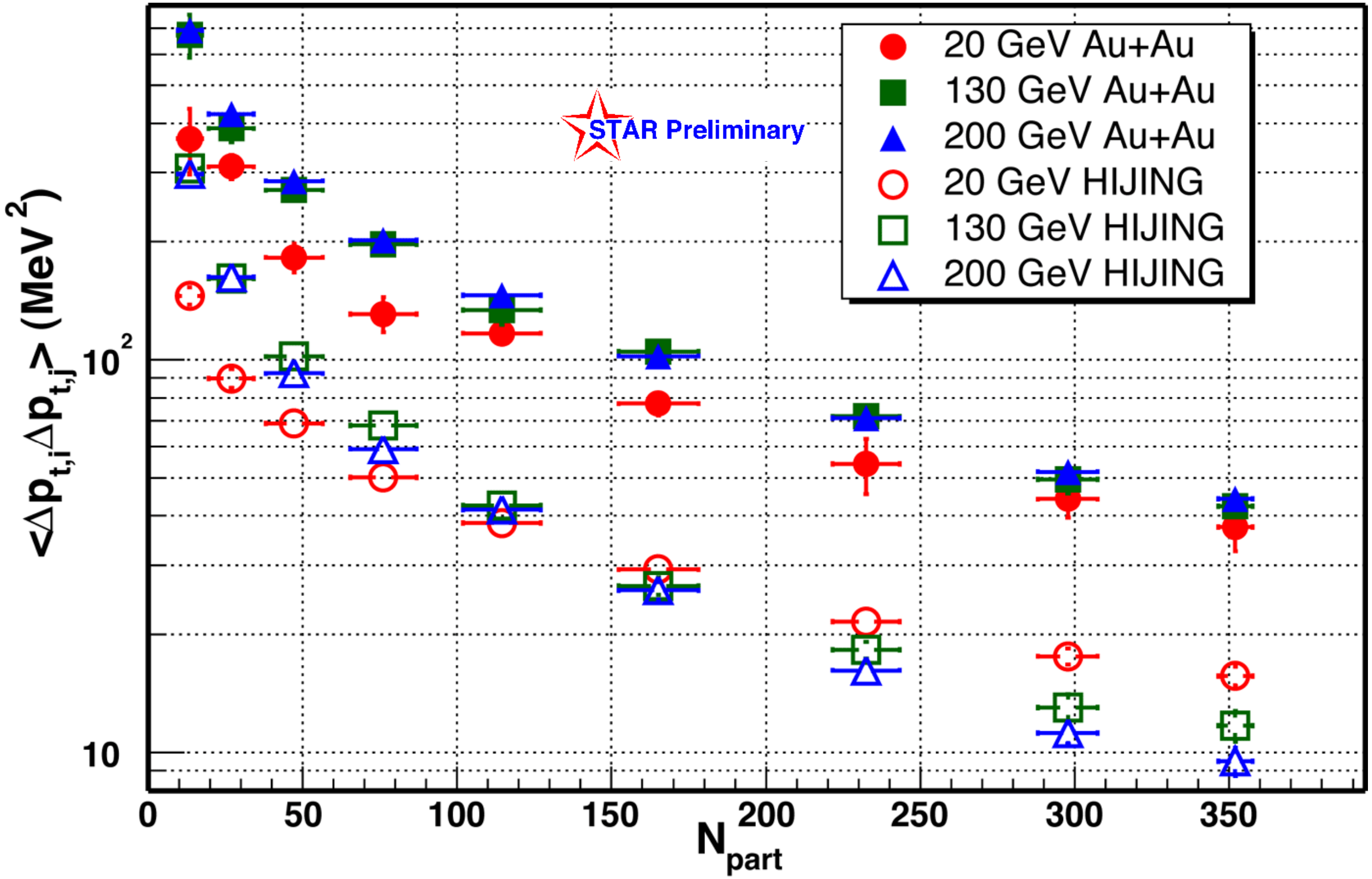
N_{event} = number of events

$\langle p_t \rangle_i$ = average p_t for i^{th} event

N_k = number of tracks for k^{th} event

$p_{t,i}$ = p_t for i^{th} track in event

$<\Delta p_{t,i}\, \Delta p_{t,j}>$ as a Function of Incident Energy



$$\langle \Delta p_{t,i} \Delta p_{t,j} \rangle = \frac{1}{N_{event}} \sum_{k=1}^{N_{event}} \frac{C_k}{N_k (N_k - 1)}$$

$$C_k = \sum_{i=1}^{N_k} \sum_{j=1, i \neq j}^{N_k} (p_{t,i} - \langle\langle p_t \rangle\rangle)(p_{t,j} - \langle\langle p_t \rangle\rangle)$$

Compare Au+Au at 20,130, and 200 GeV

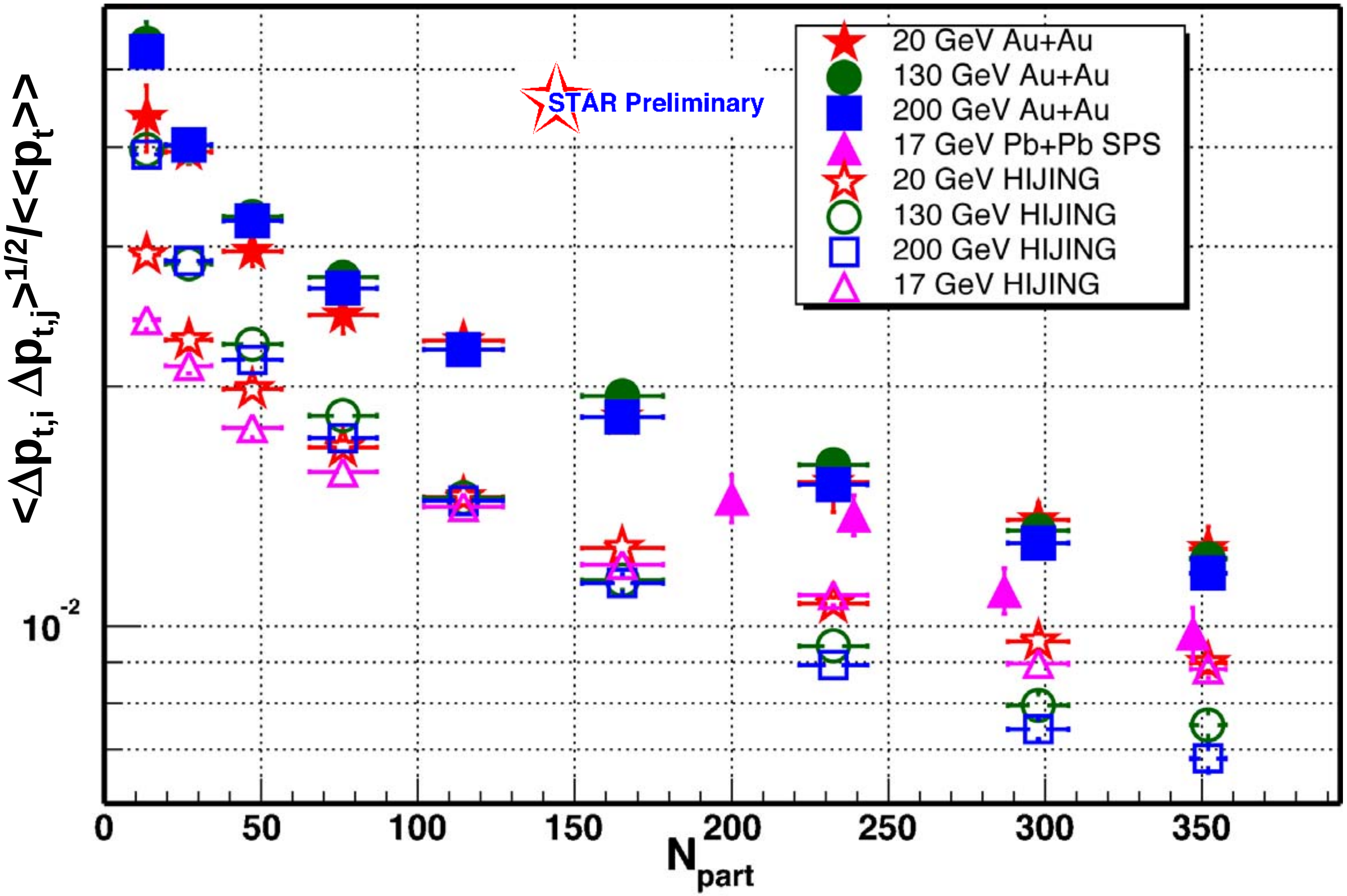
$|\eta| < 1$

Compare with filtered HIJING

$<\Delta p_{t,i}\ \Delta p_{t,j}>^{1/2}/<<p_t>>$ as a Function of Incident Energy

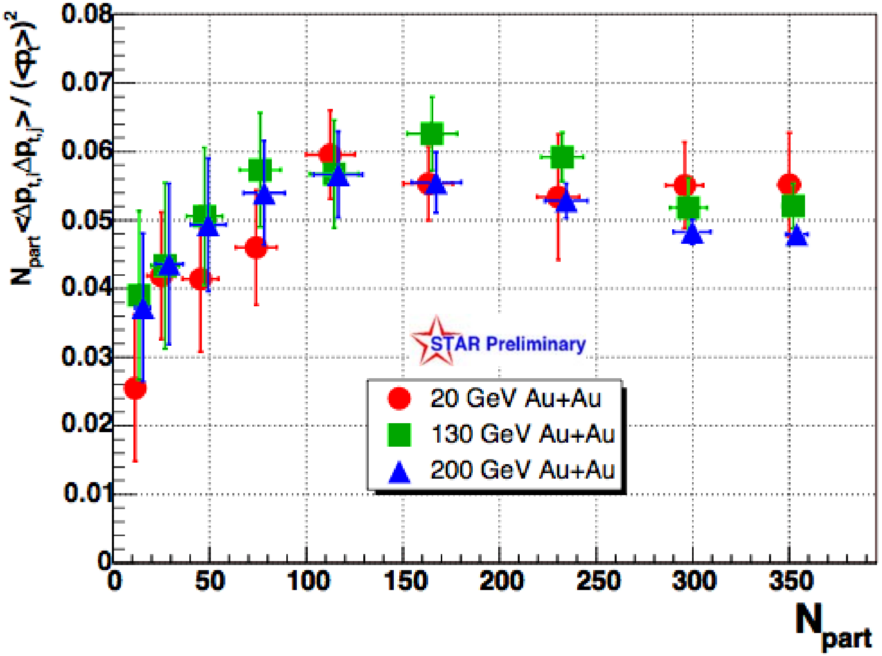
Compare Au+Au at 20, 130, 200 GeV, $|\eta| < 1$

Compare with CERES result from SPS, 17 GeV Pb+Pb

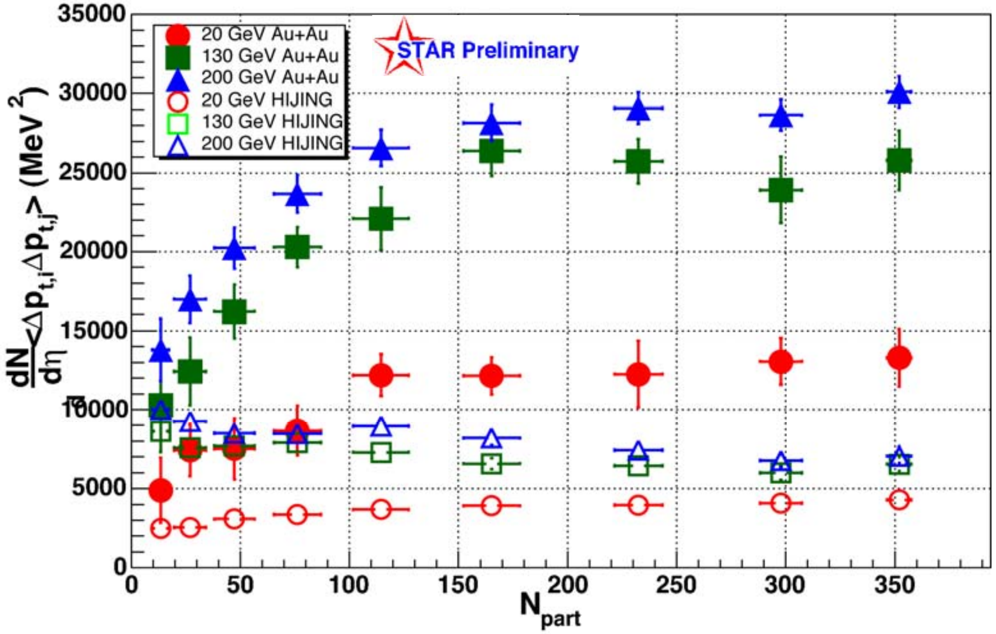


Different Scaling Methods for $<\Delta p_{t,i}\ \Delta p_{t,j}>$

Scale with N_{part}



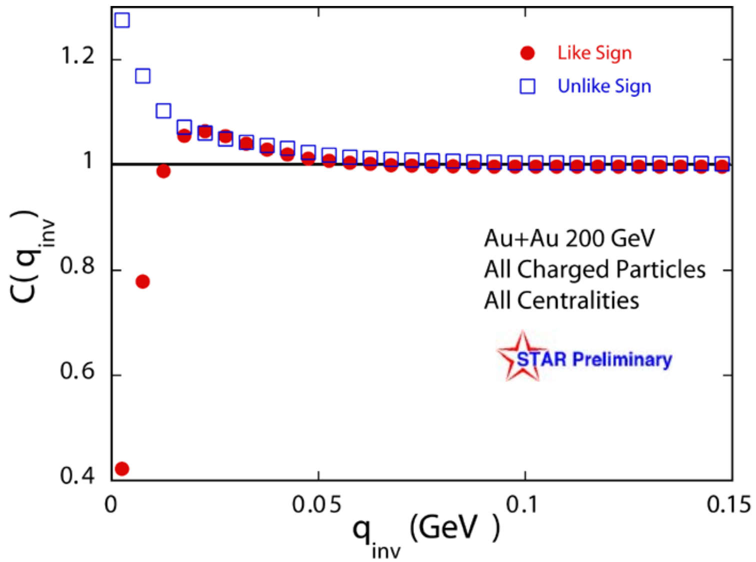
Scale with $dN/d\eta$ - compare to $\Delta\sigma_{pt}$

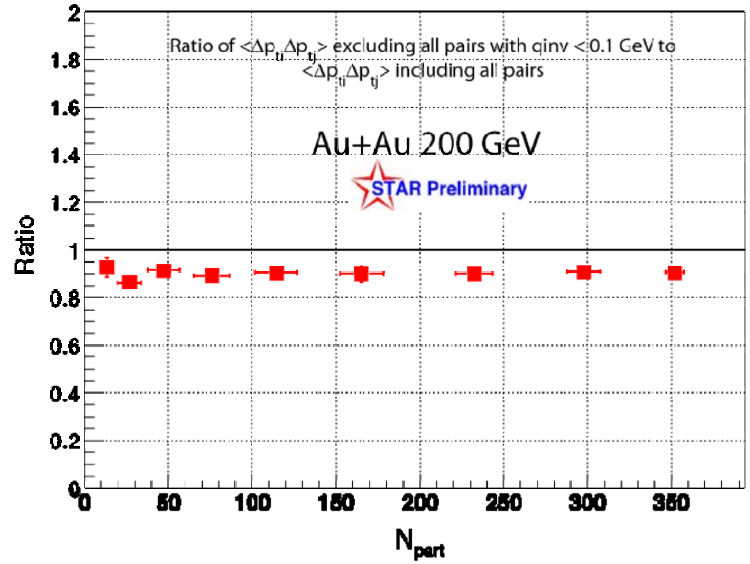


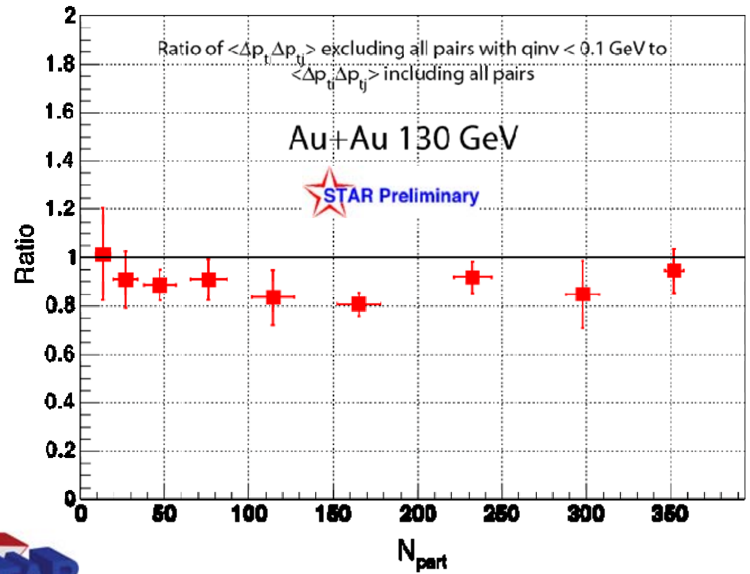
Centrality dependence may be sign of the onset of equilibration in central Au+Au collisions

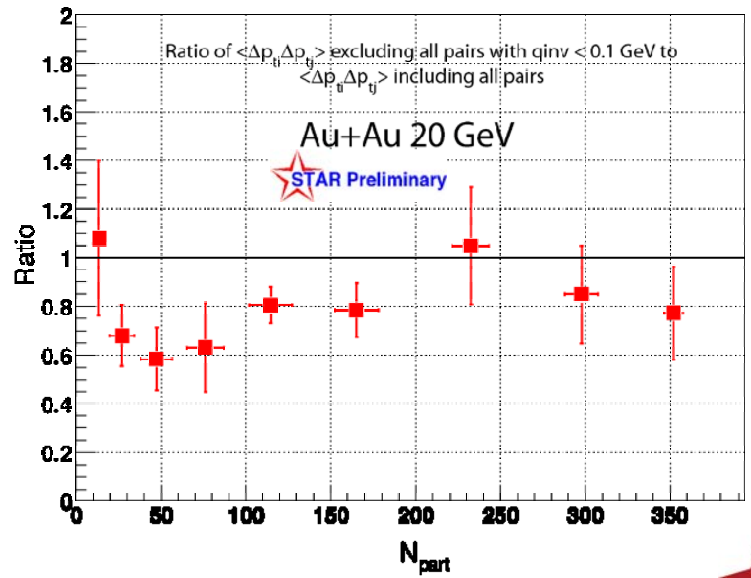
Effects of Short Range Correlations

Ratio of $<\Delta p_{t,i}\ \Delta p_{t,j}>$ using Pairs with q_{inv} < 0.1 GeV to All Pairs



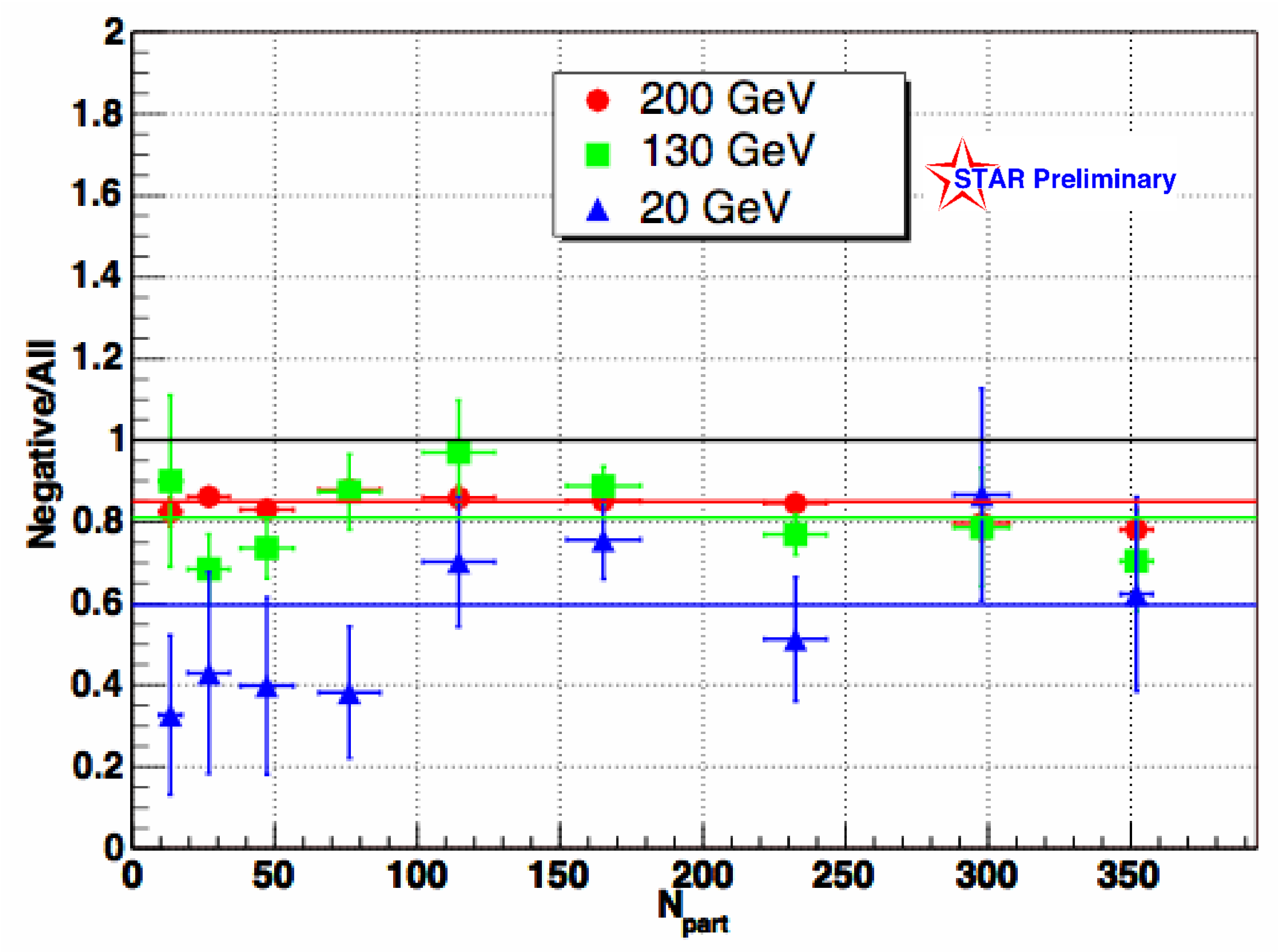






Estimate Contribution of Resonances

Ratio of $<\Delta p_{t,i}\, \Delta p_{t,j}>$ using
Negative Particles Only to All Particles



Comparison to F_{pt} at 200 GeV

$$\omega_T = \frac{\sigma_T}{\mu_T} \quad F_{pt} = \frac{\omega_{T,real} - \omega_{T,mixed}}{\omega_{T,mixed}} = \frac{\sigma_{T,real} - \sigma_{T,mixed}}{\sigma_{T,mixed}}$$

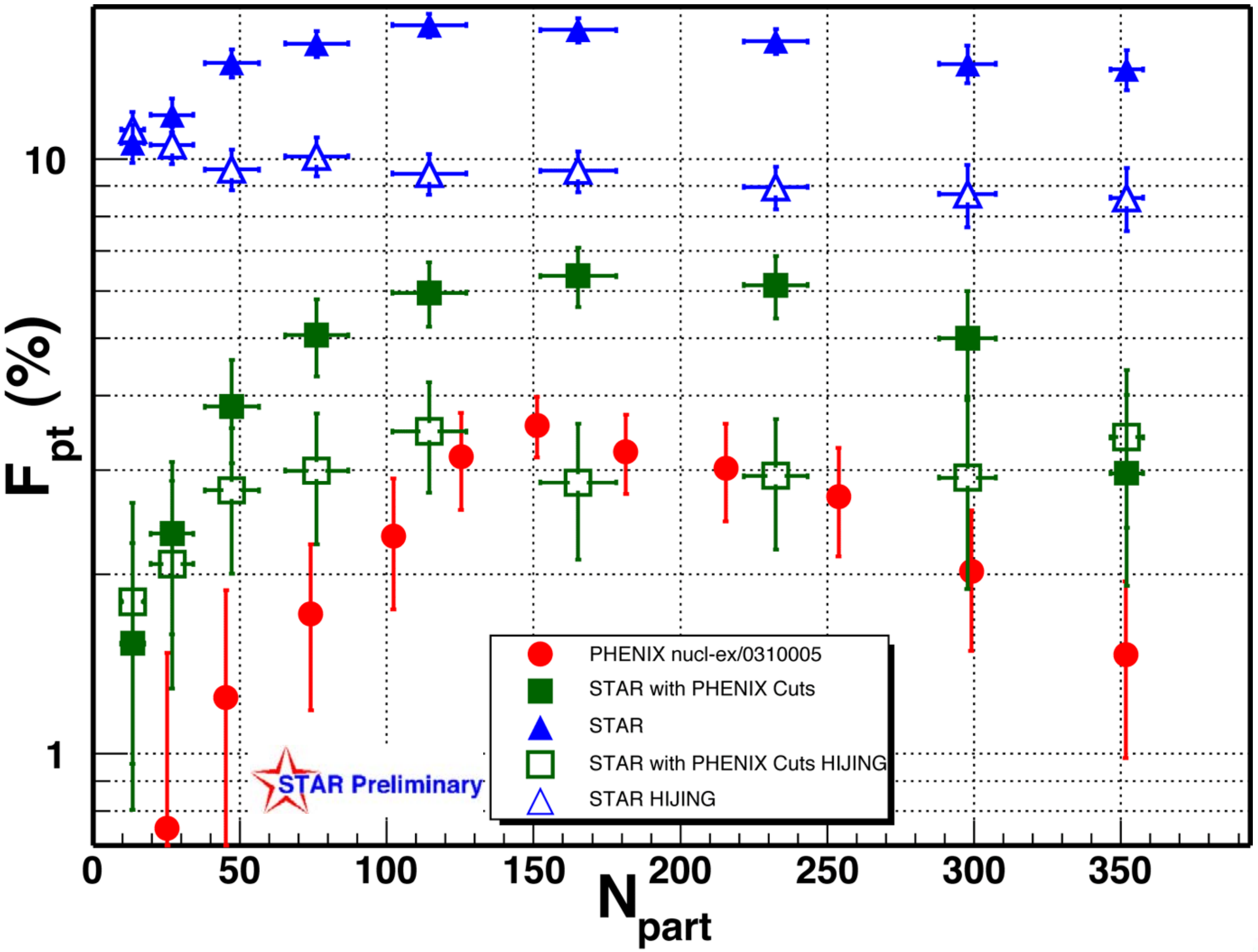
200 GeV Au+Au
STAR Cuts

$|\eta| < 1.0$
$\Delta\phi = 360^\circ$
$0.1 < p_t < 2$ GeV

200 GeV Au+Au
STAR with PHENIX Cuts

$|\eta| < 0.35$
$\Delta\phi = 2x90^\circ$
$0.2 < p_t < 2$ GeV

Acceptance matters

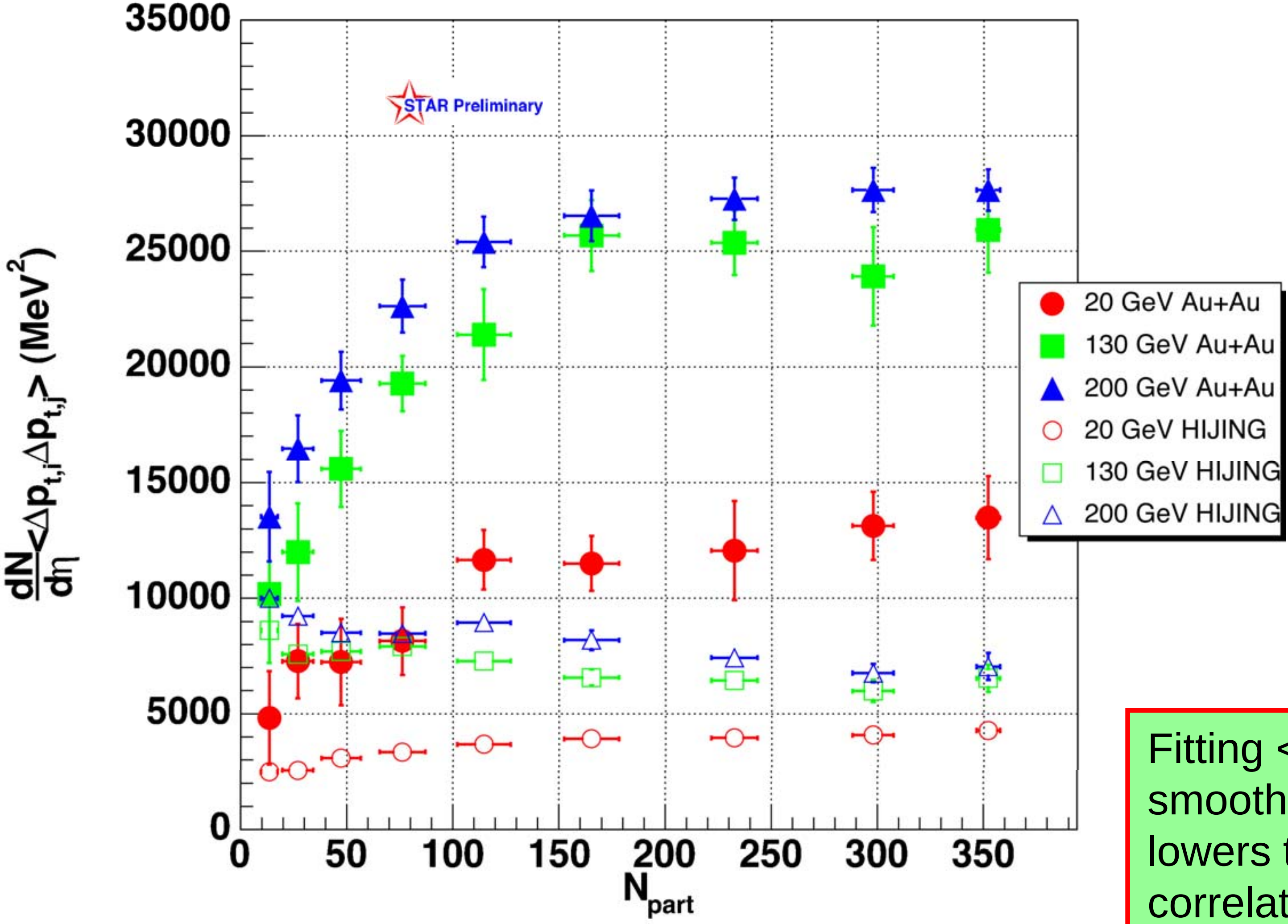


Conclusions

- Balance functions
  - $B(\Delta\eta)$, $B(\Delta y)$, $B(q_{inv})$, and $B(\Delta\phi)$ narrow in central Au+Au collisions
  - Narrowing of $B(\Delta\eta)$ in central collisions consistent with trends of models incorporating late hadronization
- p_t correlations
  - Dynamic correlations observed at Au+Au collisions at 20, 130, and 200 GeV
  - Correlations/particle increase with incident energy
  - Correlations/pair show little incident energy dependence
    - May show onset of equilibration in central Au+Au collisions

Extra Slides

Use Fit Method for <$\Delta p_{t,i}\, \Delta p_{t,j}$>



Fitting <<p_t>> smooths and lowers the correlations

Comparison to F_{pt} at 130 GeV

$$\omega_T = \frac{\sigma_T}{\mu_T} \qquad F_{pt} = \frac{\omega_{T,\mathrm{real}} - \omega_{T,\mathrm{mixed}}}{\omega_{T,\mathrm{mixed}}} = \frac{\sigma_{T,\mathrm{real}} - \sigma_{T,\mathrm{mixed}}}{\sigma_{T,\mathrm{mixed}}}$$

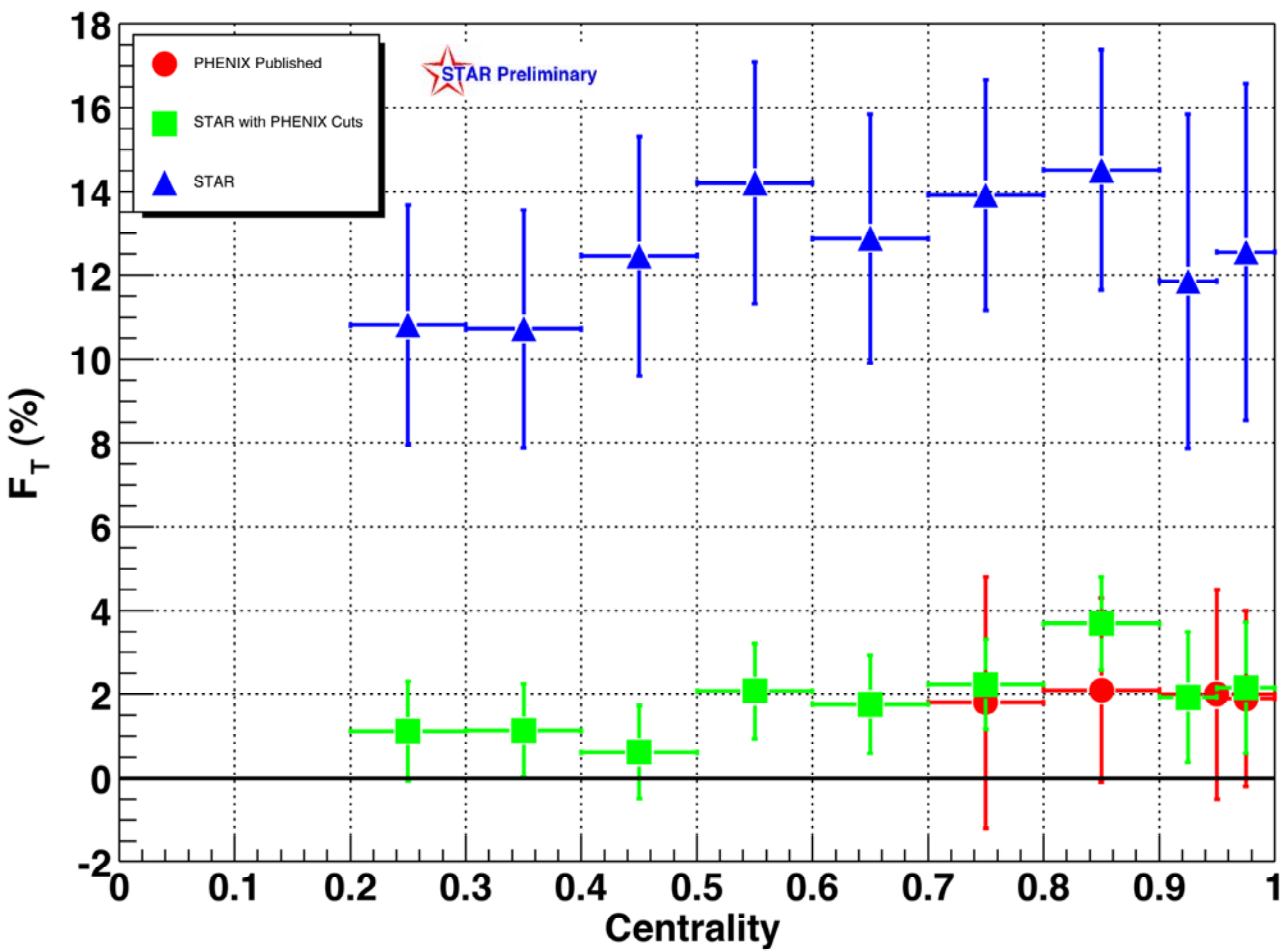
130 GeV Au+Au
STAR Cuts

$|\eta| < 1.0$
$\Delta\phi = 360^\circ$
$0.1 < p_t < 2$ GeV

130 GeV Au+Au
STAR with
PHENIX Cuts

$|\eta| < 0.35$
$\Delta\phi = 90^\circ$
$0.2 < p_t < 2$ GeV

Acceptance
matters more



Dynamical Net Charge Fluctuations

Definition: $$\nu_{+-,dyn} = \nu_{+-} - \nu_{+-,stat}$$

$$\nu_{+-} = \left\langle \left(\frac{N_+}{\langle N_+ \rangle} - \frac{N_-}{\langle N_- \rangle} \right)^2 \right\rangle \xrightarrow{\text{Independent Particle (Poisson) Limit}} \nu_{+-,stat} = \frac{1}{\langle N_+ \rangle} + \frac{1}{\langle N_- \rangle}$$

Measurement: $$\nu_{+-,dyn} = \frac{\langle N_+(N_+ - 1)\rangle}{\langle N_+ \rangle^2} + \frac{\langle N_-(N_- - 1)\rangle}{\langle N_- \rangle^2} - 2\frac{\langle N_+ N_- \rangle}{\langle N_+ \rangle \langle N_- \rangle}$$

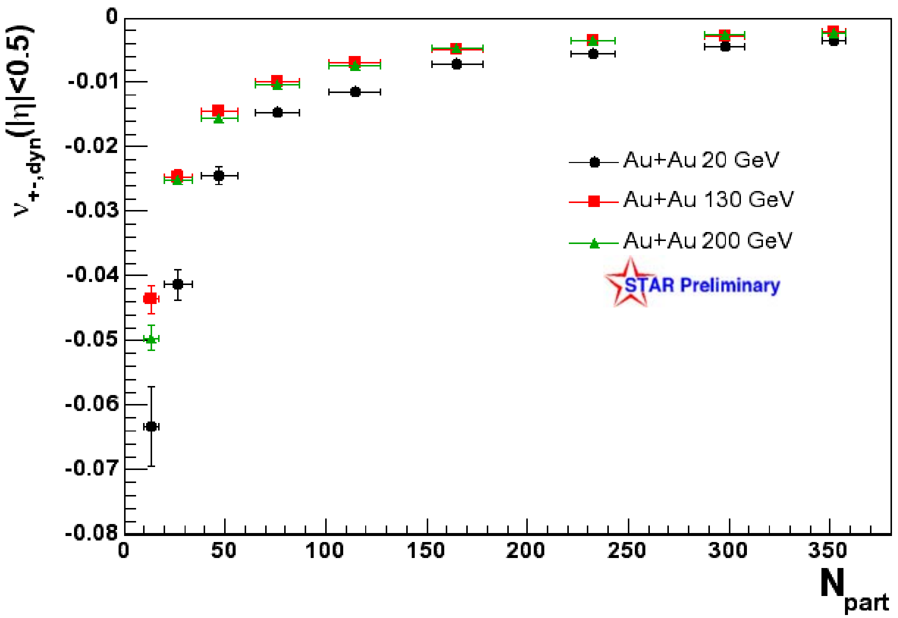
Key Properties:

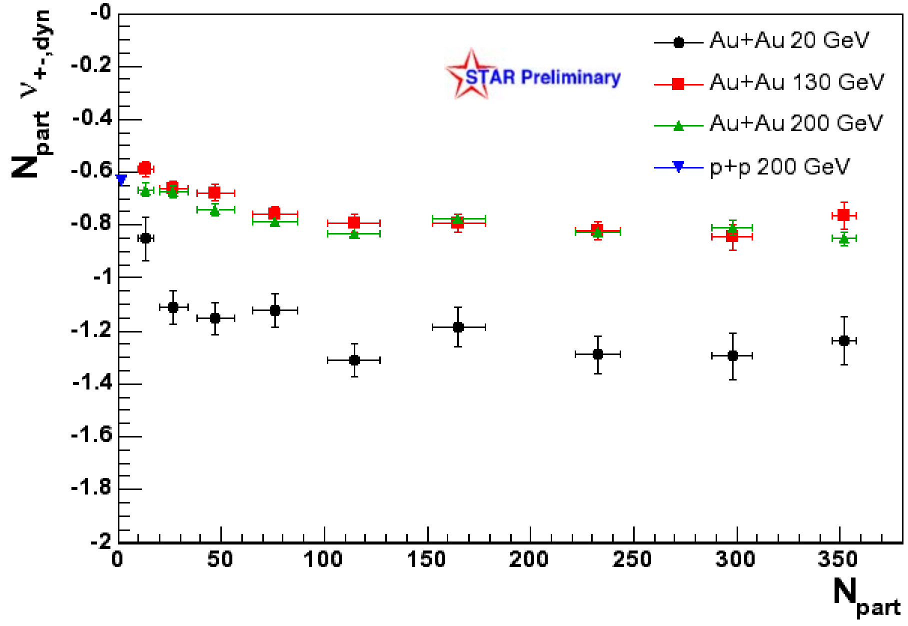
$$\nu_{+-,dyn} = R_{++} + R_{--} - 2R_{+-}$$ Sensitive to two-particle correlations

$$\nu_{+-,dyn} = 0$$ Independent Particle Production

$$N_{sources}(b)\,\nu_{+-,dyn}^{A+A}(b) = \nu_{+-,dyn}^{p+p}$$ Independent N+N Collisions

Net Charge Fluctuations - Centrality Dependence





$$\nu_{+-,dyn} = \nu_{+-} - \nu_{+-,stat}$$

$$\nu_{+-} = \left\langle \left(\frac{N_+}{\langle N_+ \rangle} - \frac{N_-}{\langle N_- \rangle} \right)^2 \right\rangle$$

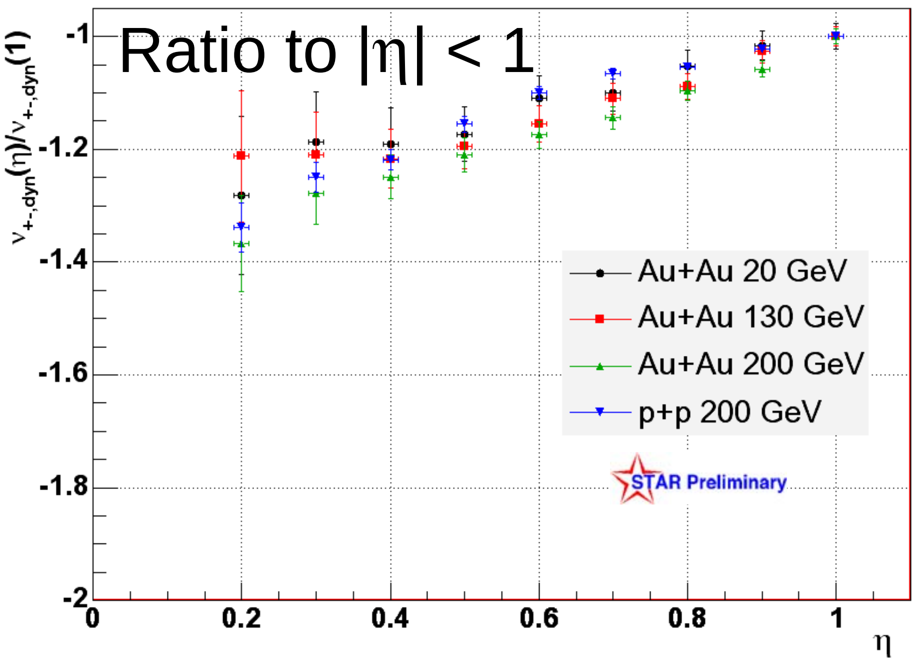
$$\nu_{+-,stat} = \frac{1}{\langle N_+ \rangle} + \frac{1}{\langle N_- \rangle}$$

$$\nu_{+-,dyn} = R_{++} + R_{--} - 2R_{+-}$$

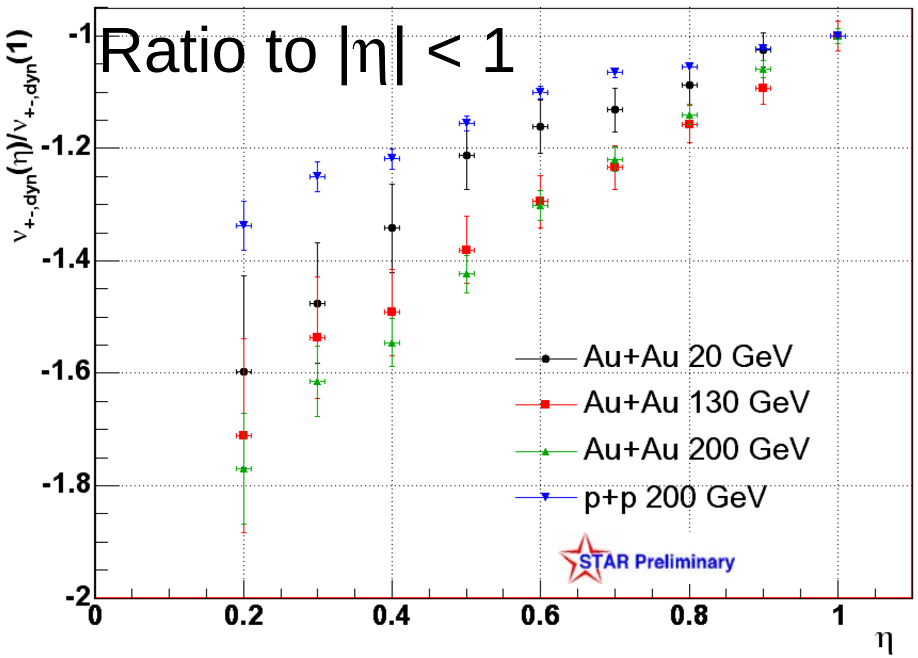
Increased dilution of correlation with increasing N_{part}
$|\nu_{+-,dyn}|$ larger at 20 GeV than 130 and 200 GeV
Peripheral Au+Au in agreement with inclusive p+p
1/N scaling violation

Net Charge Fluctuations - Dependence on η Acceptance

50-70% Central



0-10% Central

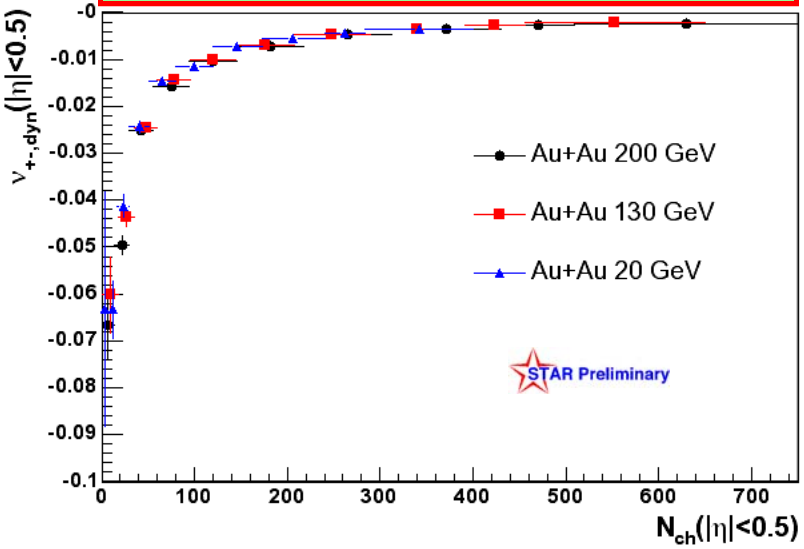


|η| acceptance

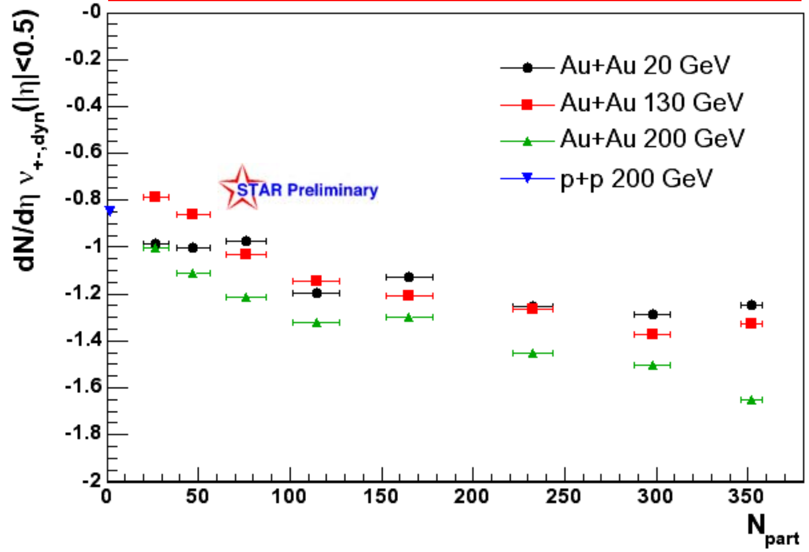
50-70% Au+Au quite similar to p+p
0-10% Monotonic increase of correlation strength with beam energy
Flow is important (sensitivity to velocity profile)

Net Charge Fluctuations - Scaling

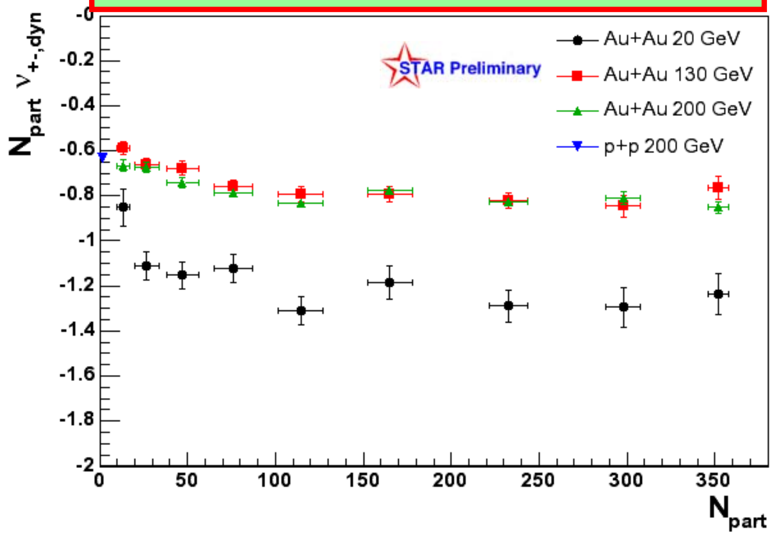
Multiplicity Scaling



dN/dη Scaling



Participant Scaling



Binary Scaling