Correlations and Fluctuations in STAR

- Balance Function
- Excitation Function for p_t Fluctuations
- Net Charge Fluctuations
- Discrete Wavelet Analysis

Quark Matter 2004
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The Balance Function

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

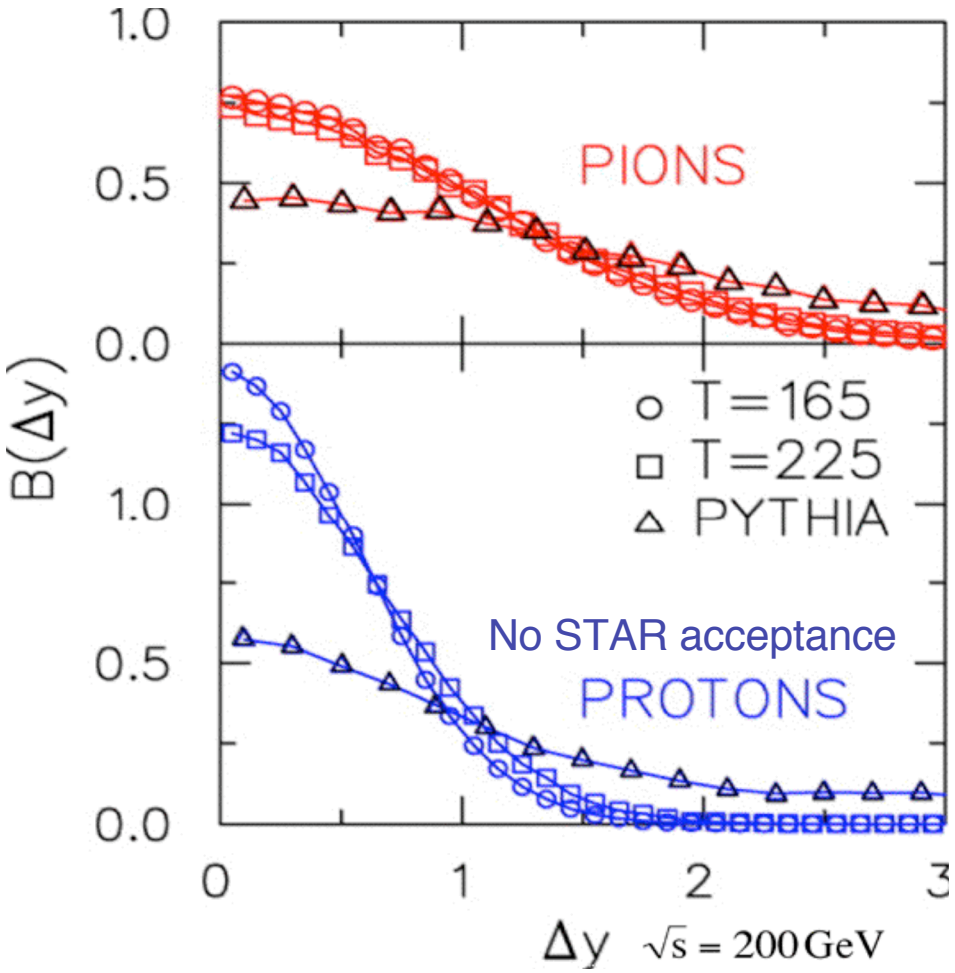
Bass, Danielewicz, and Pratt, PRL **85**, 2689 (2000)

Theoretical expectations for *B(Δy)*

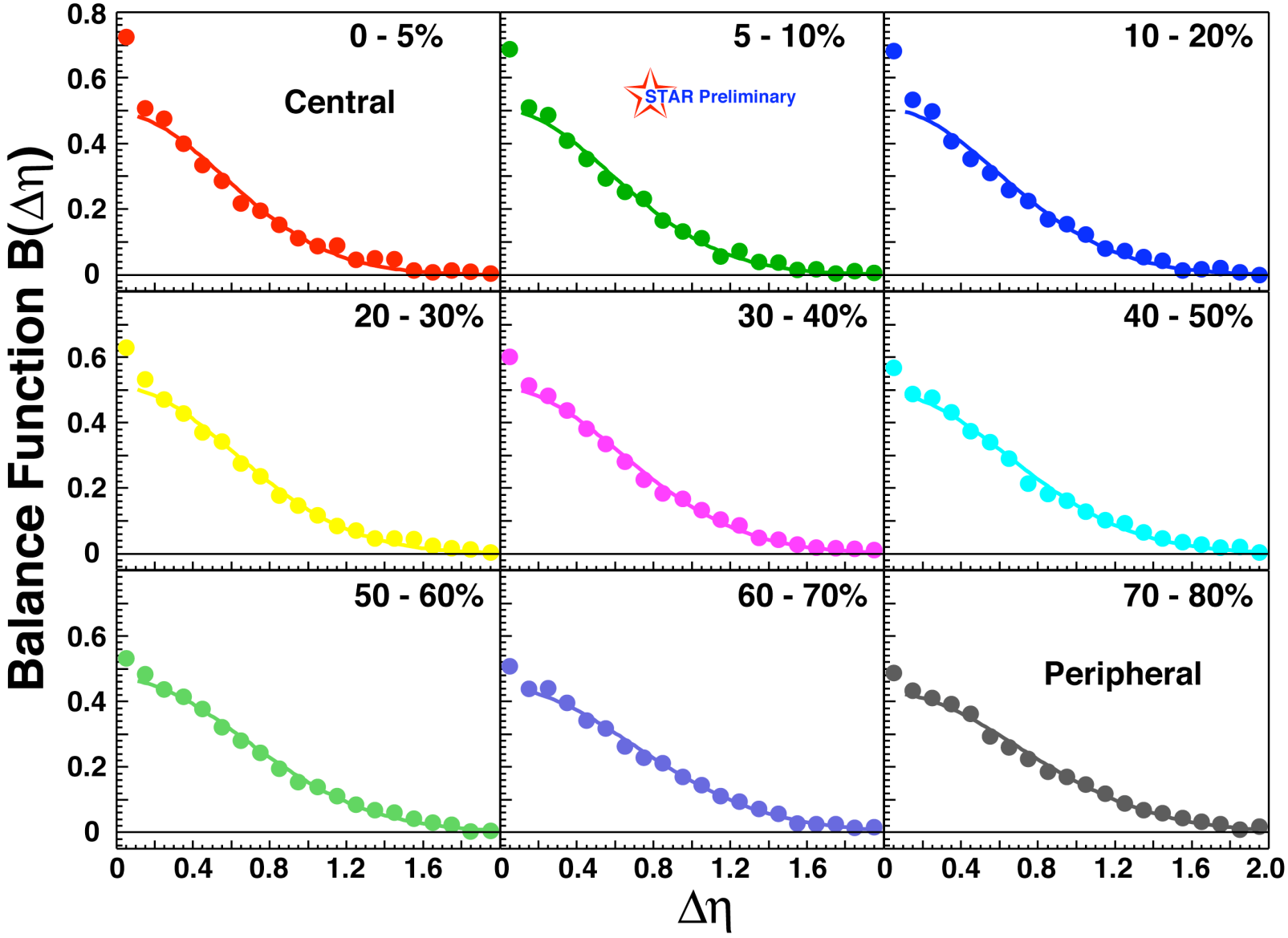
- PYTHIA representing p+p collisions shows a characteristic width of about 1 unit of Δy
- Bjorken thermal model representing delayed hadronization shows narrower balance function width
  - **Nucleon-nucleon → wide**
  - **Delayed hadronization → narrow**

Experimental considerations

- Use $\Delta\eta$ for all charged particles
- We will show centrality dependence for Au+Au and d+Au
- Use all centralities for p+p

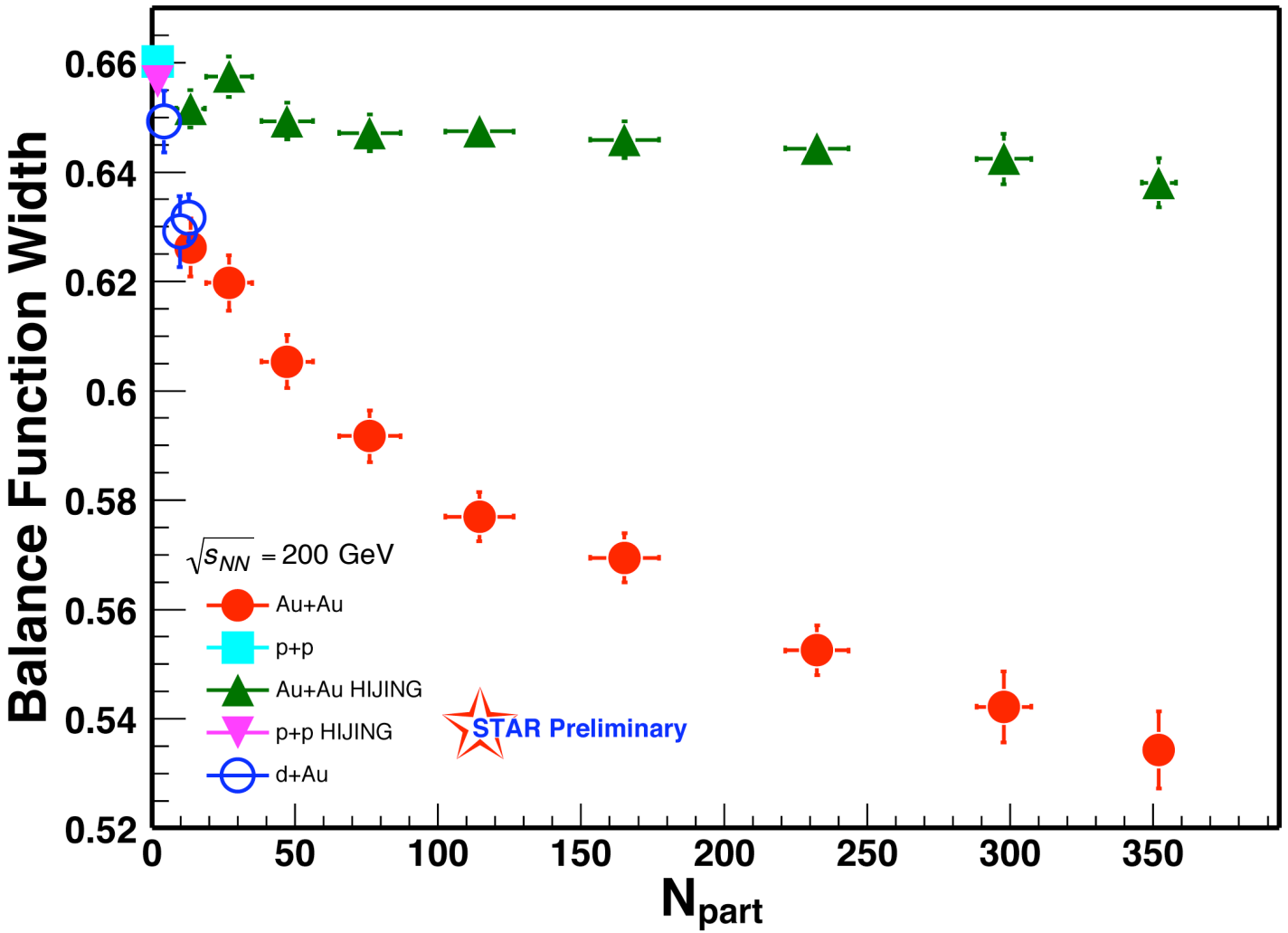


Balance Function for Au+Au at 200 GeV



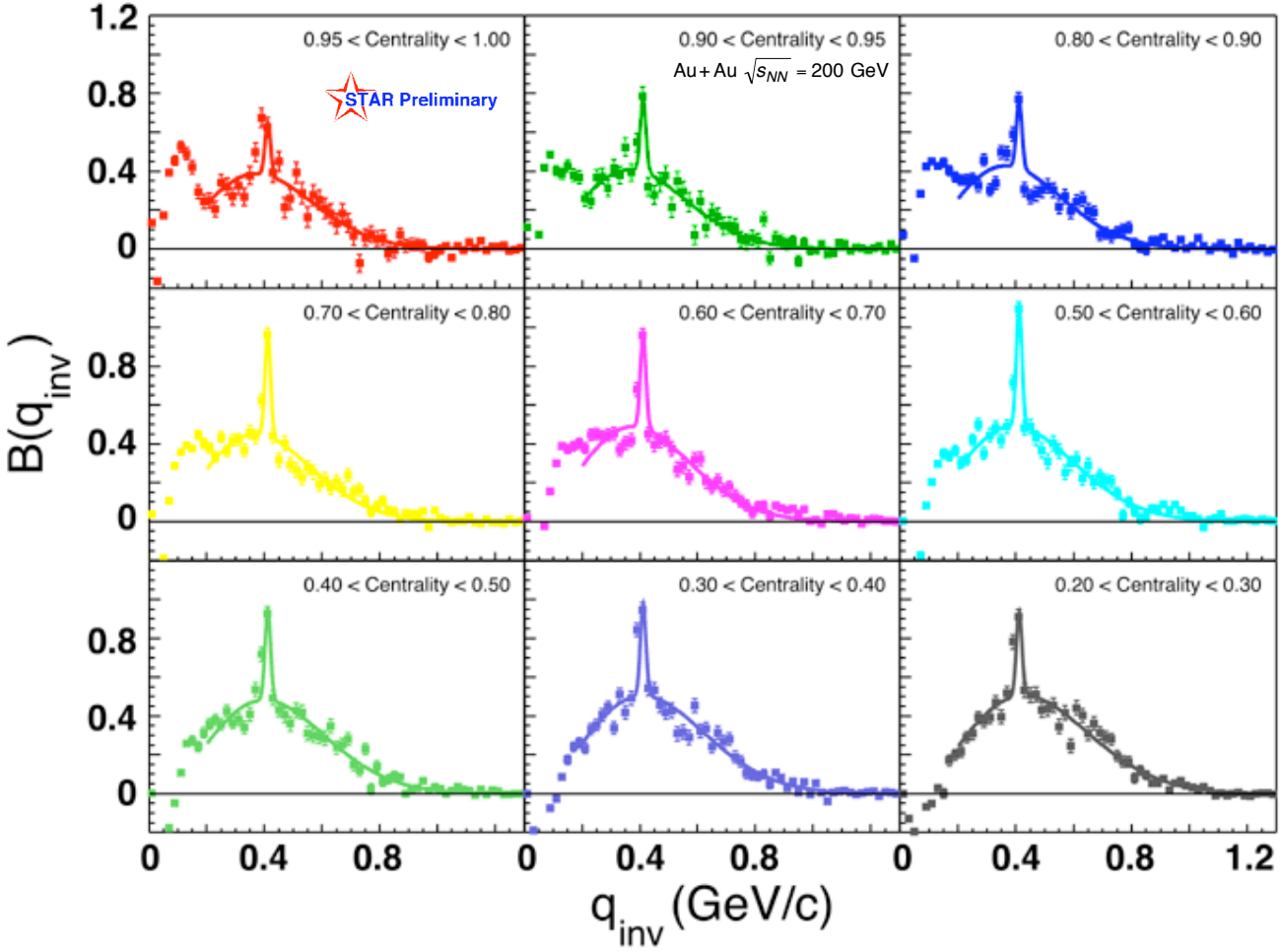
Balance Function Widths

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 q_{inv}



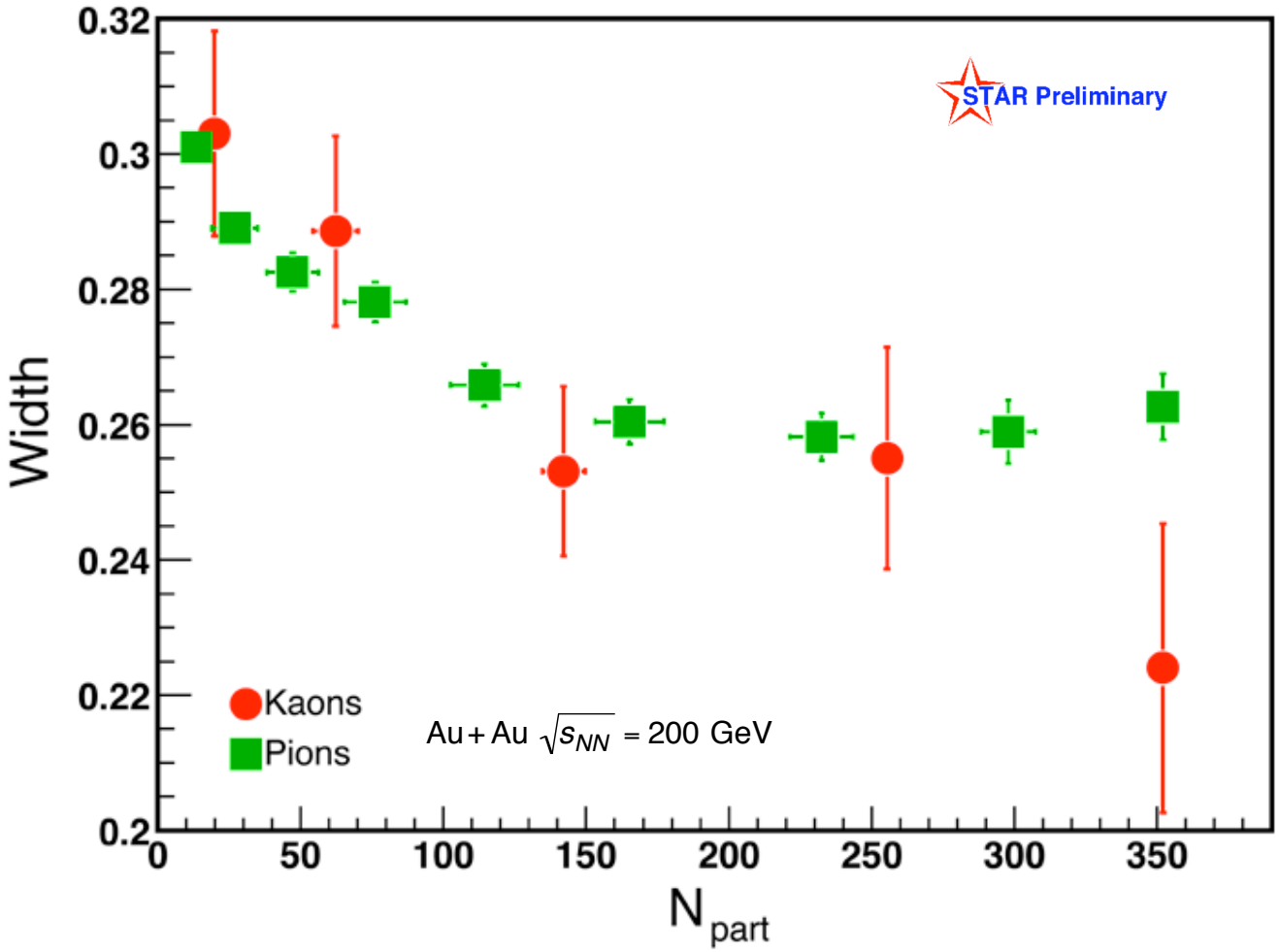
Fits are thermal + K^0 decay

Thermal distribution is

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

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

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

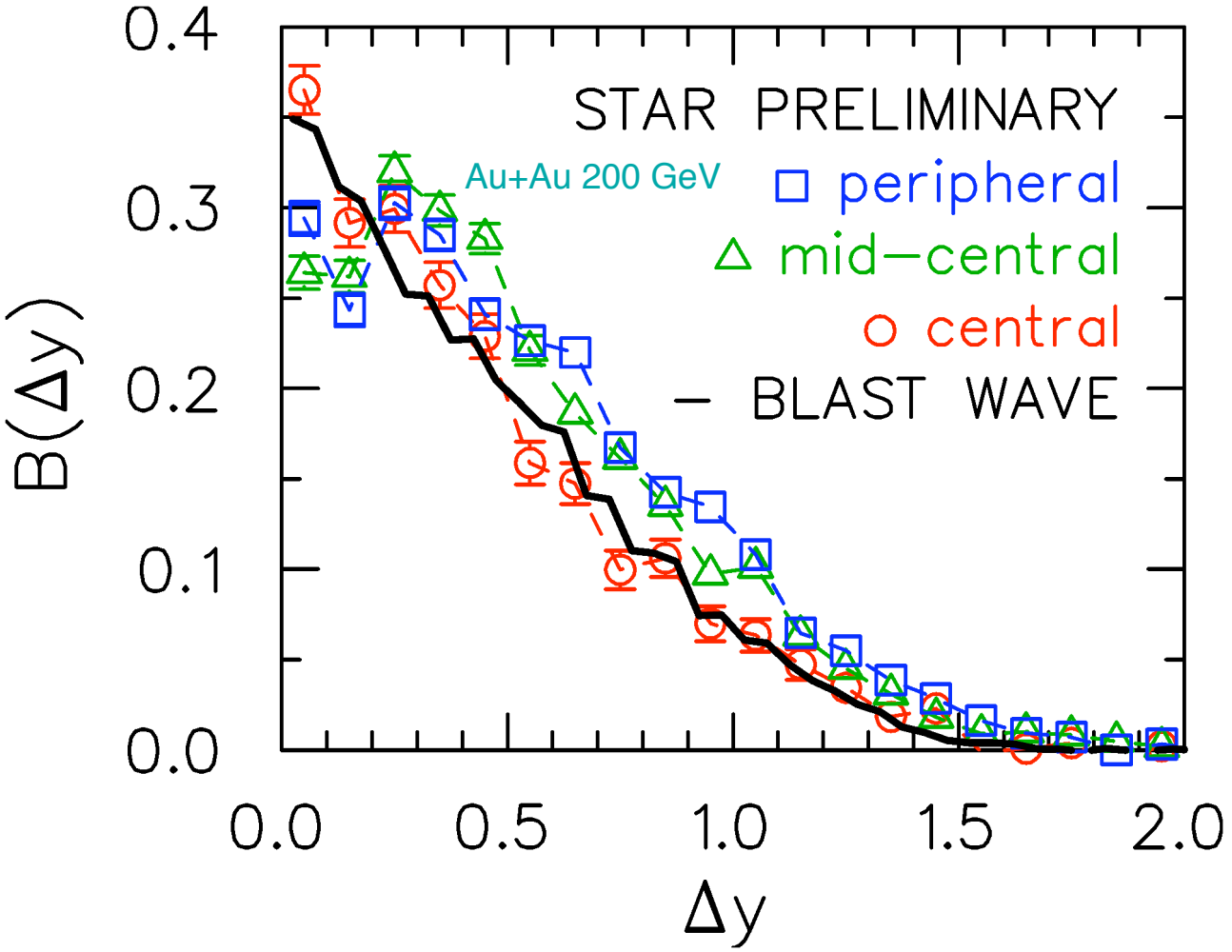
Theoretical Predictions for the Balance Function

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

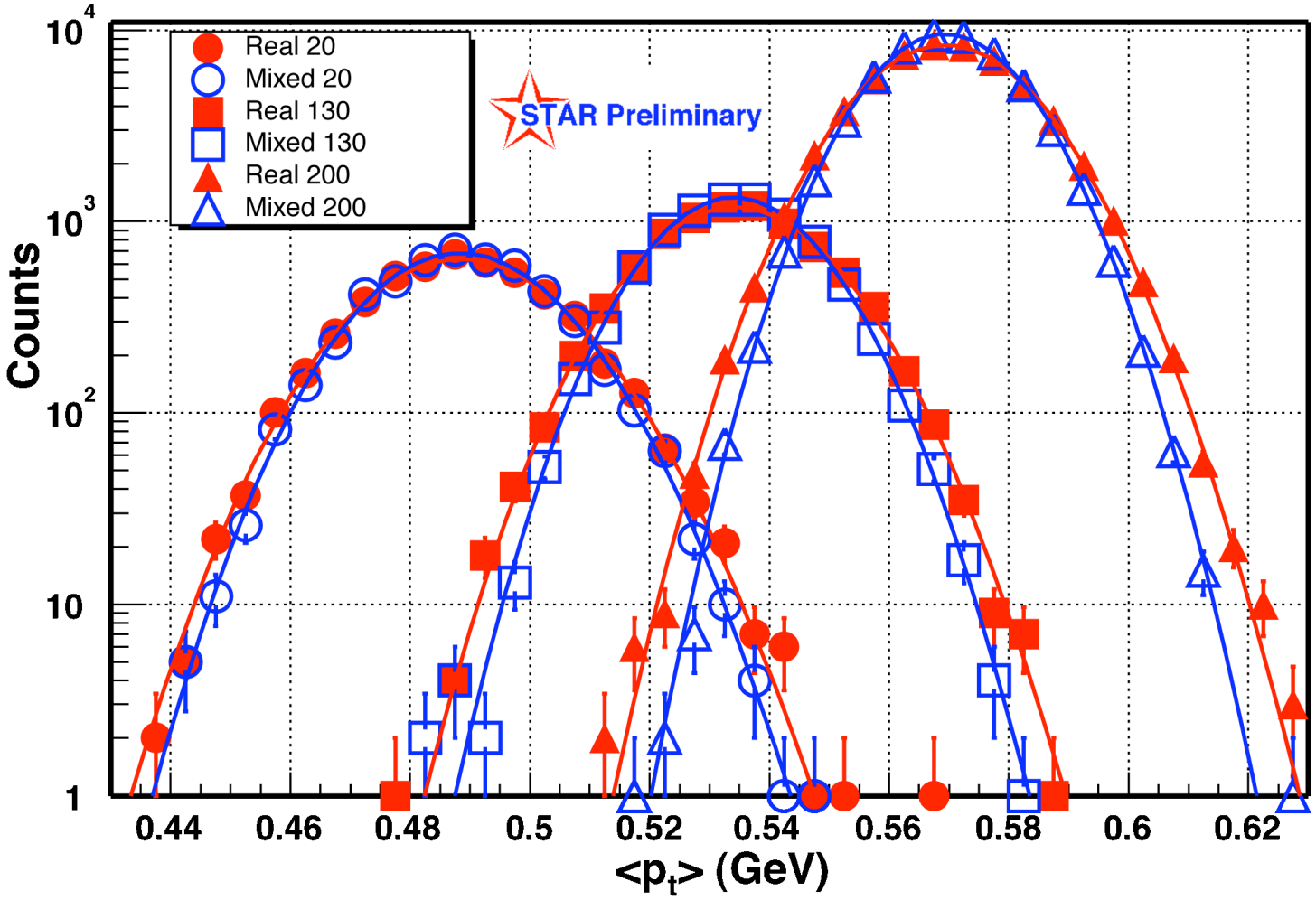
The agreement with the measured narrow balance function in central collisions suggests that charge conservation remains highly localized at breakup



p_t and Net Charge 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 $\langle p_t \rangle$



Au+Au at 20, 130, and 200 GeV

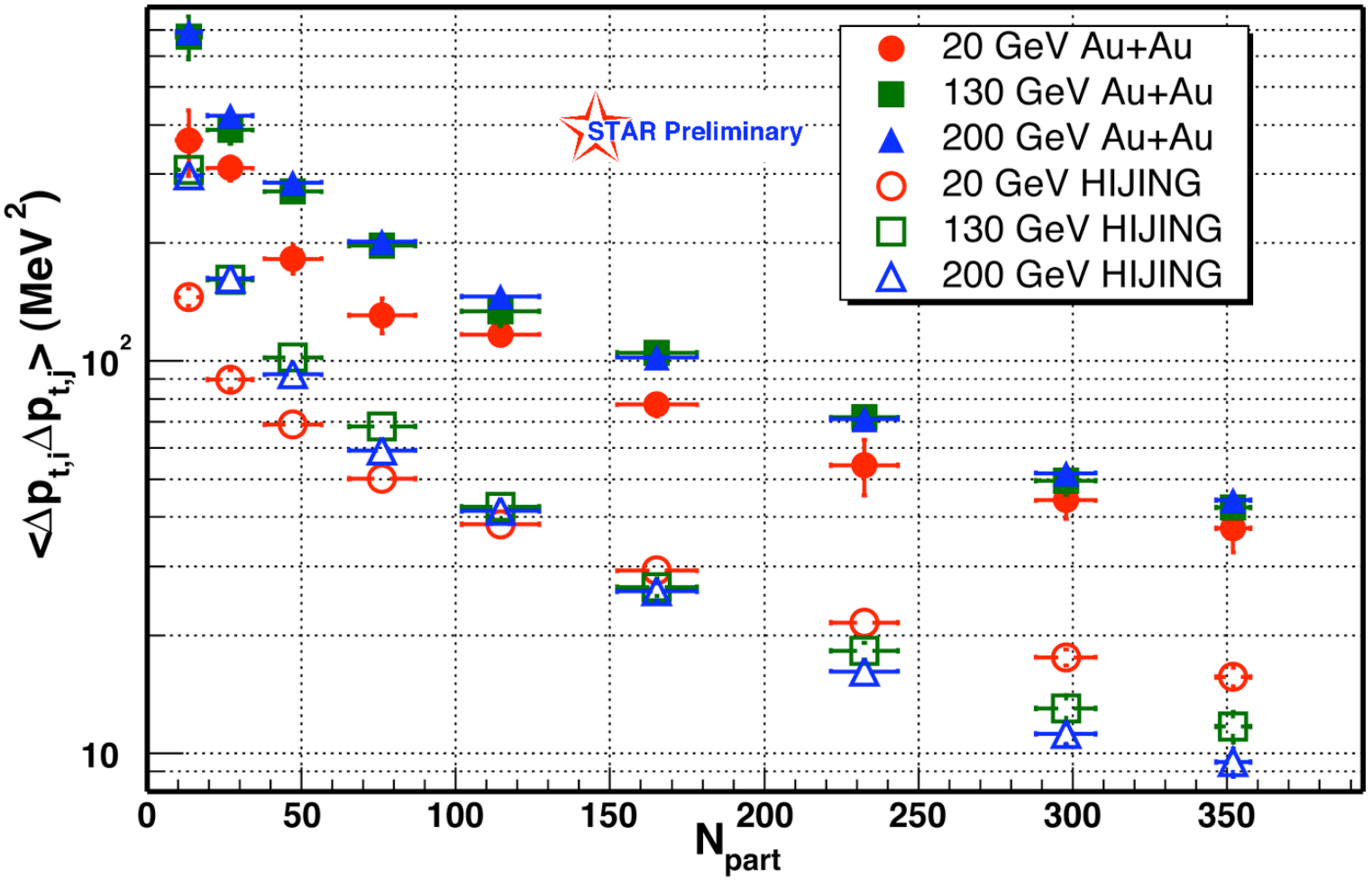
5% most central bin using min bias data, $|\eta| < 1.0$

Real is wider than mixed

→ Dynamical fluctuations

See poster by Claude Pruneau

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



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

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

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

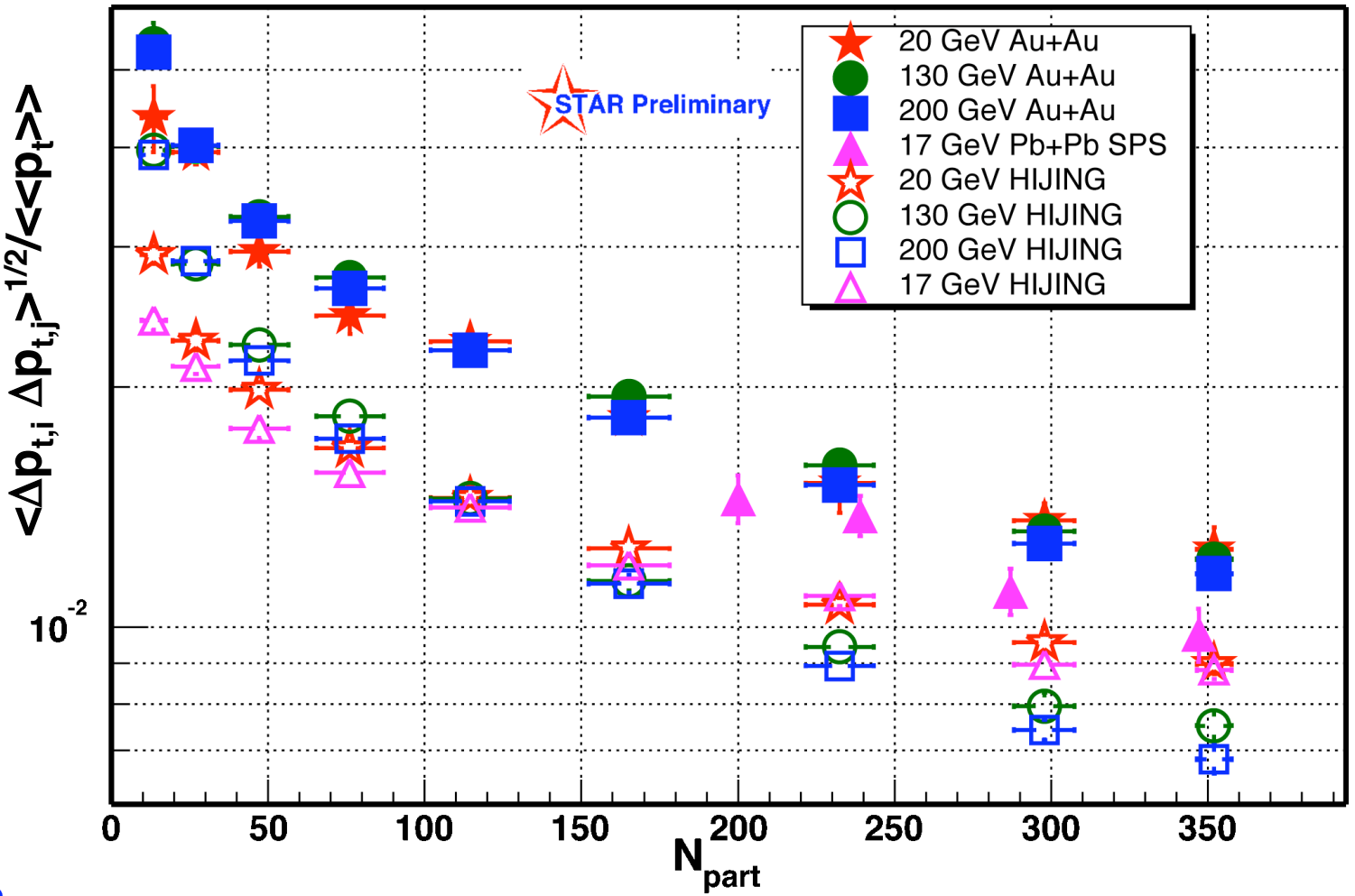
$|\eta| < 1$

Compare with filtered HIJING

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

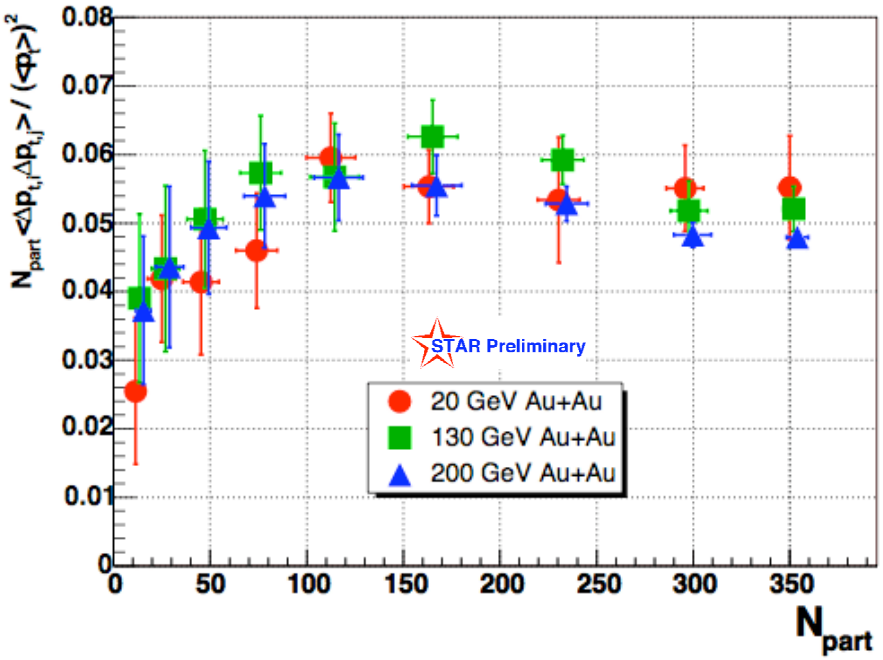
Compare Au+Au at 20, 130, 200 GeV, $|\eta| < 1$

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

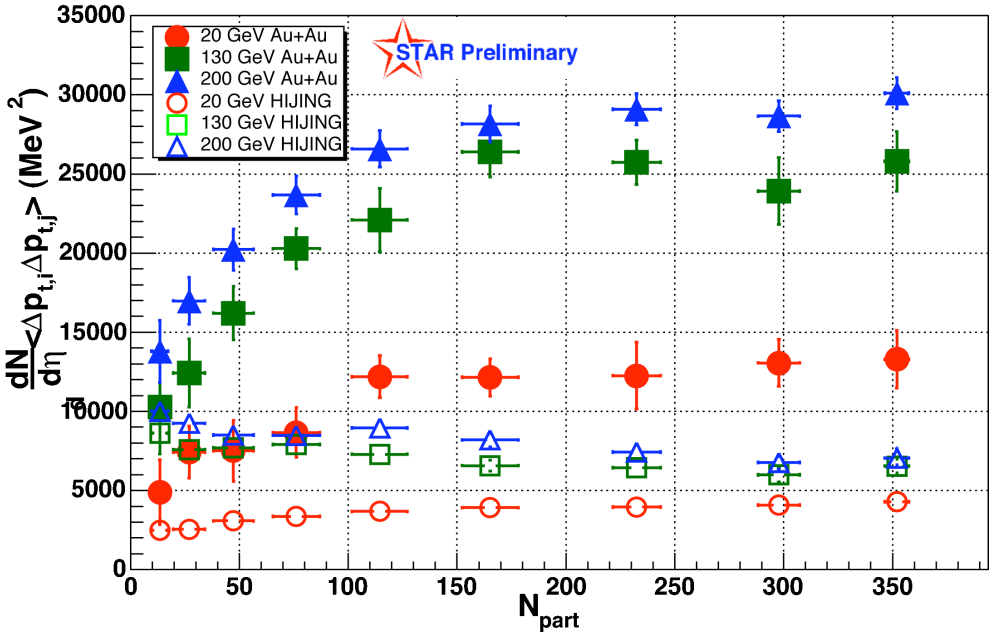


Different Scaling Methods for $\langle \Delta p_{t,i} \Delta p_{t,j} \rangle$

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

Comparison to F_{pt}

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

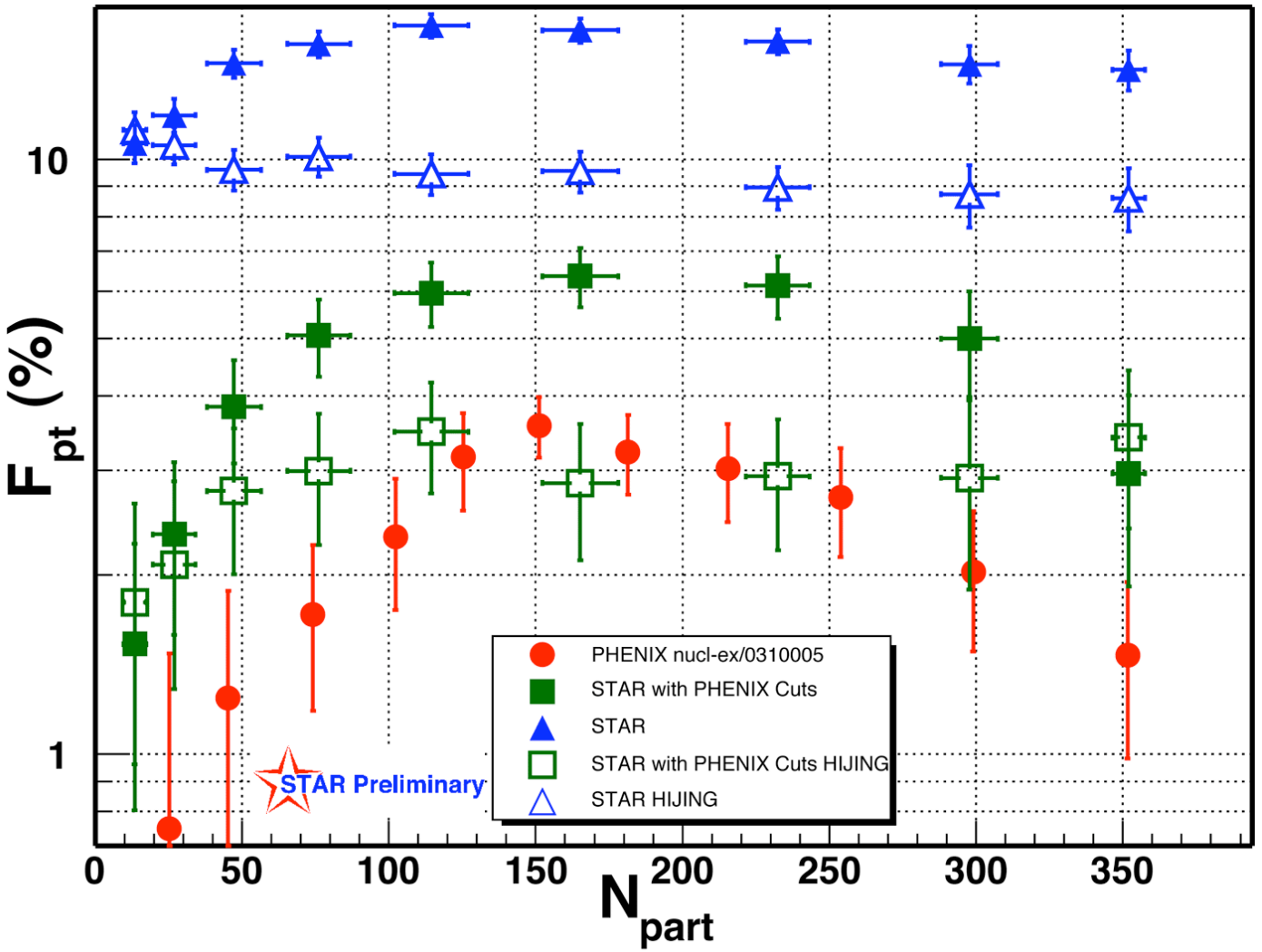
200 GeV Au+Au STAR Cuts

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

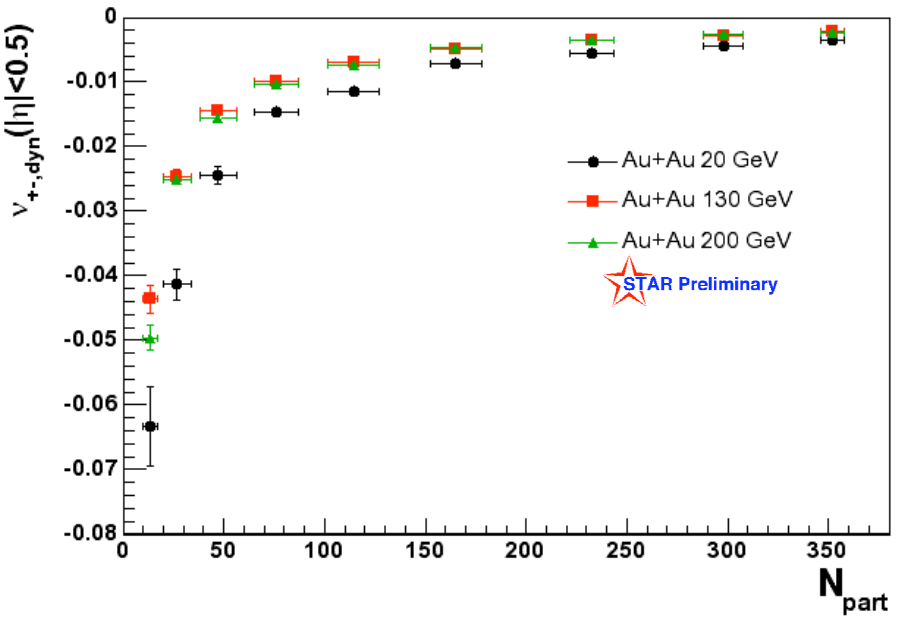
200 GeV Au+Au STAR with PHENIX Cuts

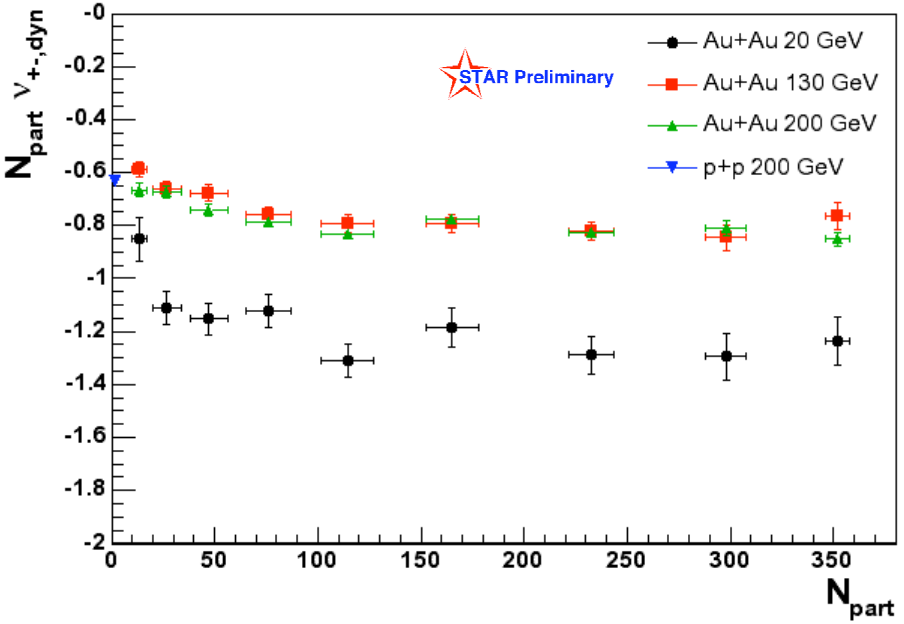
$|\eta| < 0.35$
$\Delta\phi = 2x90°$
$0.2 < p_t < 2$ GeV

Acceptance matters



Net Charge Fluctuations - Centrality Dependence





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

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

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

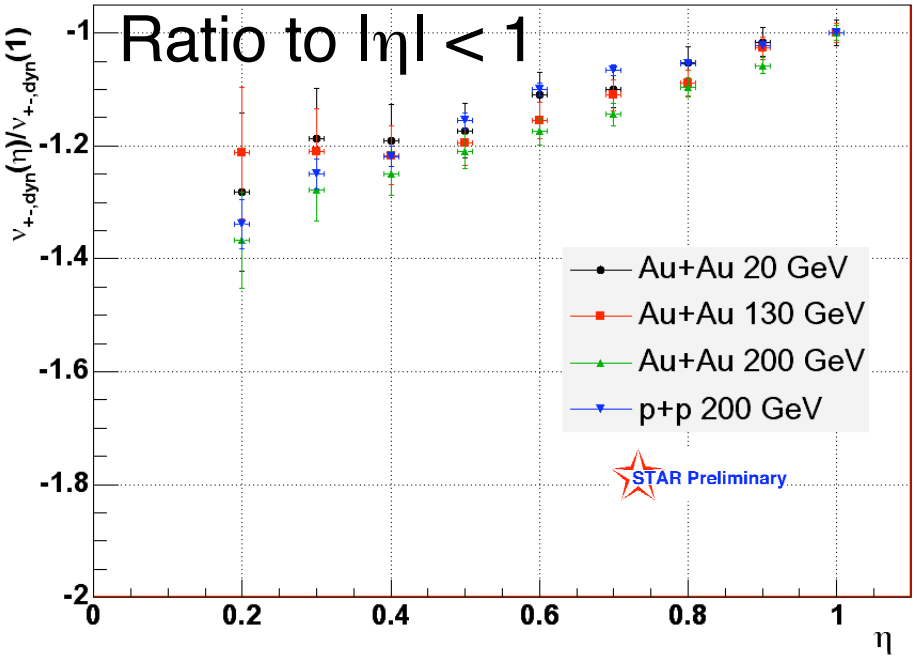
$$\nu_{+-,dyn} = R_{++} + R_{--} - 2R_{+-}$$

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

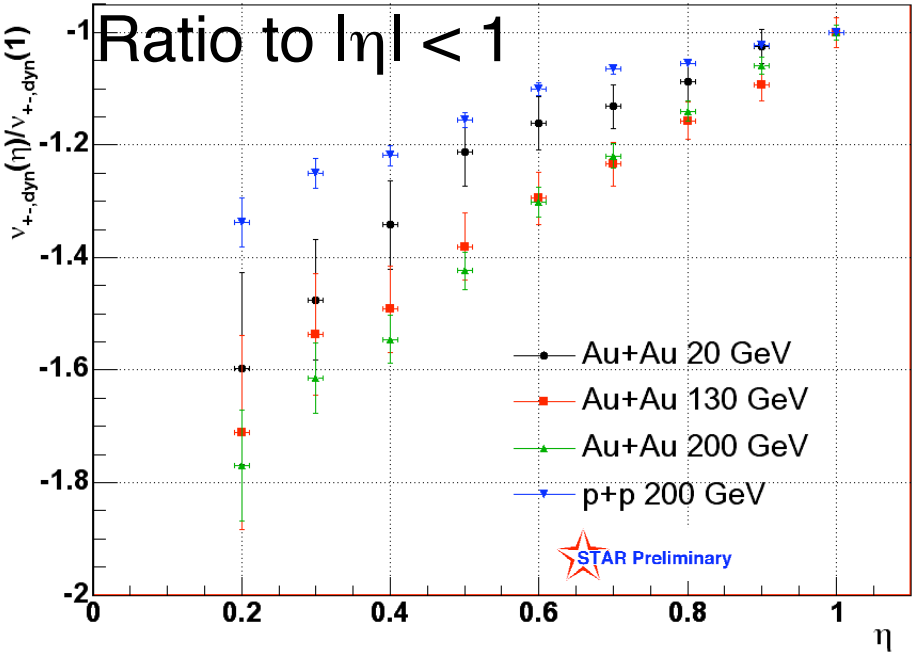
See poster by Claude Pruneau

Net Charge Fluctuations - Dependence on η Acceptance

50-70% Central



0-10% Central

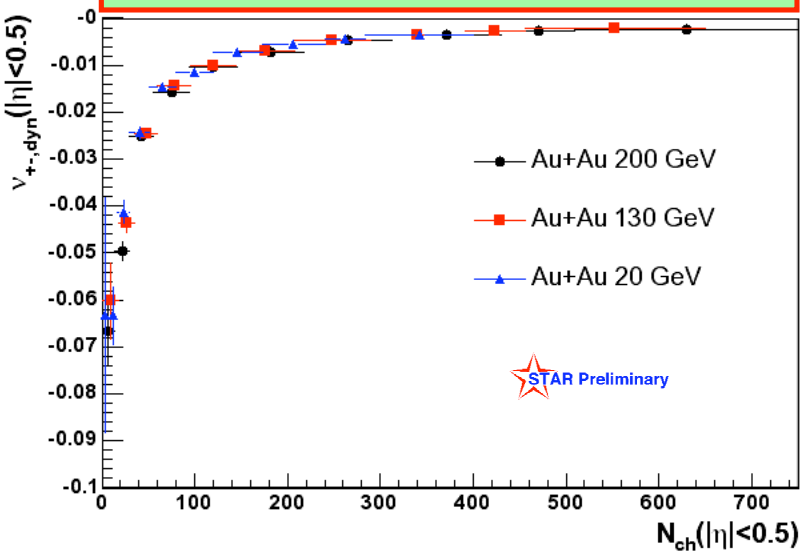


|η| acceptance

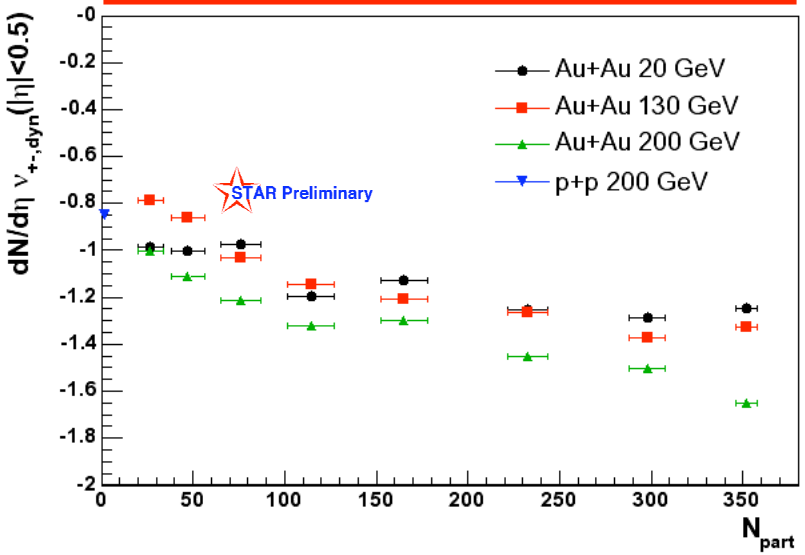
50-70% Au+Au quite similar to p+p
0-10% Monotonic increase of correlation strength with beam energy
Flow is important (sensitivity to velocity profile)

Net Charge Fluctuations - Scaling

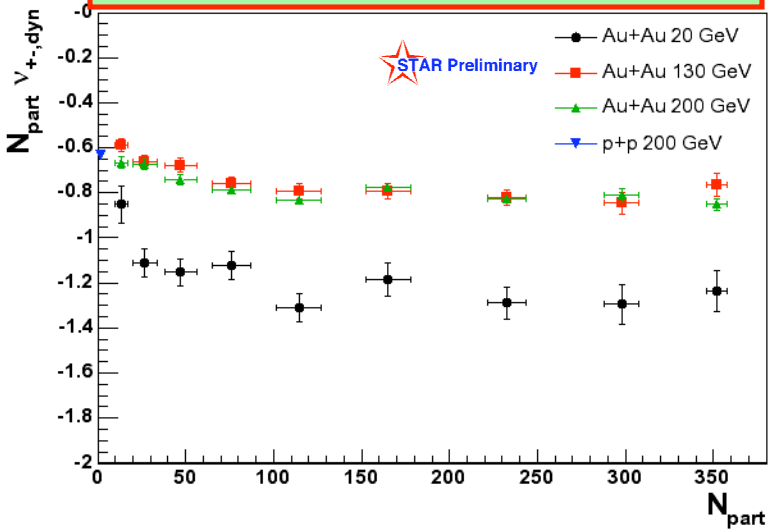
Multiplicity Scaling



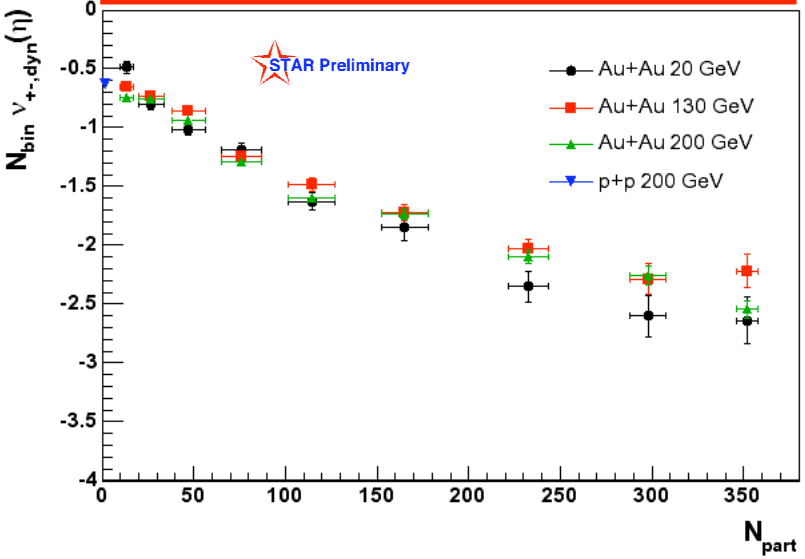
$dN/d\eta$ Scaling



Participant Scaling



Binary Scaling



Discrete Wavelet Analysis

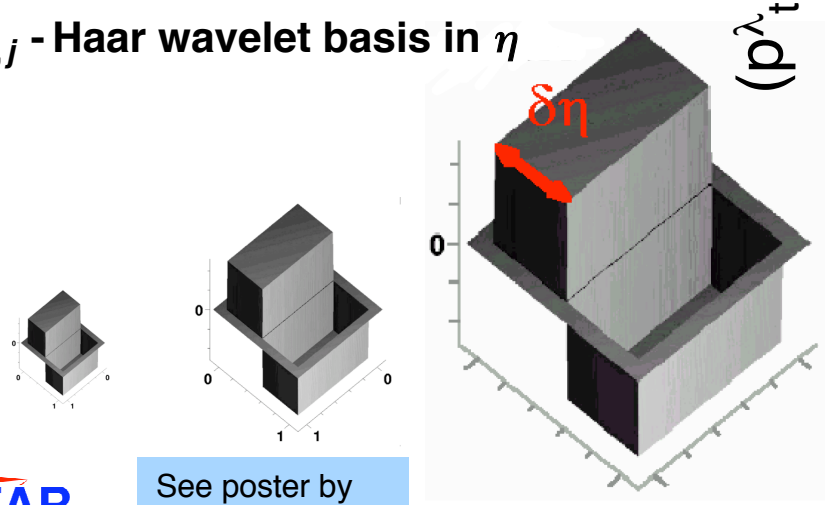
Scale fineness (m), directional modes of sensitivity (λ), track density $\rho(\eta,\phi,pt)$, locations in 2D (i,j). Powers of local fluctuations, mode λ:

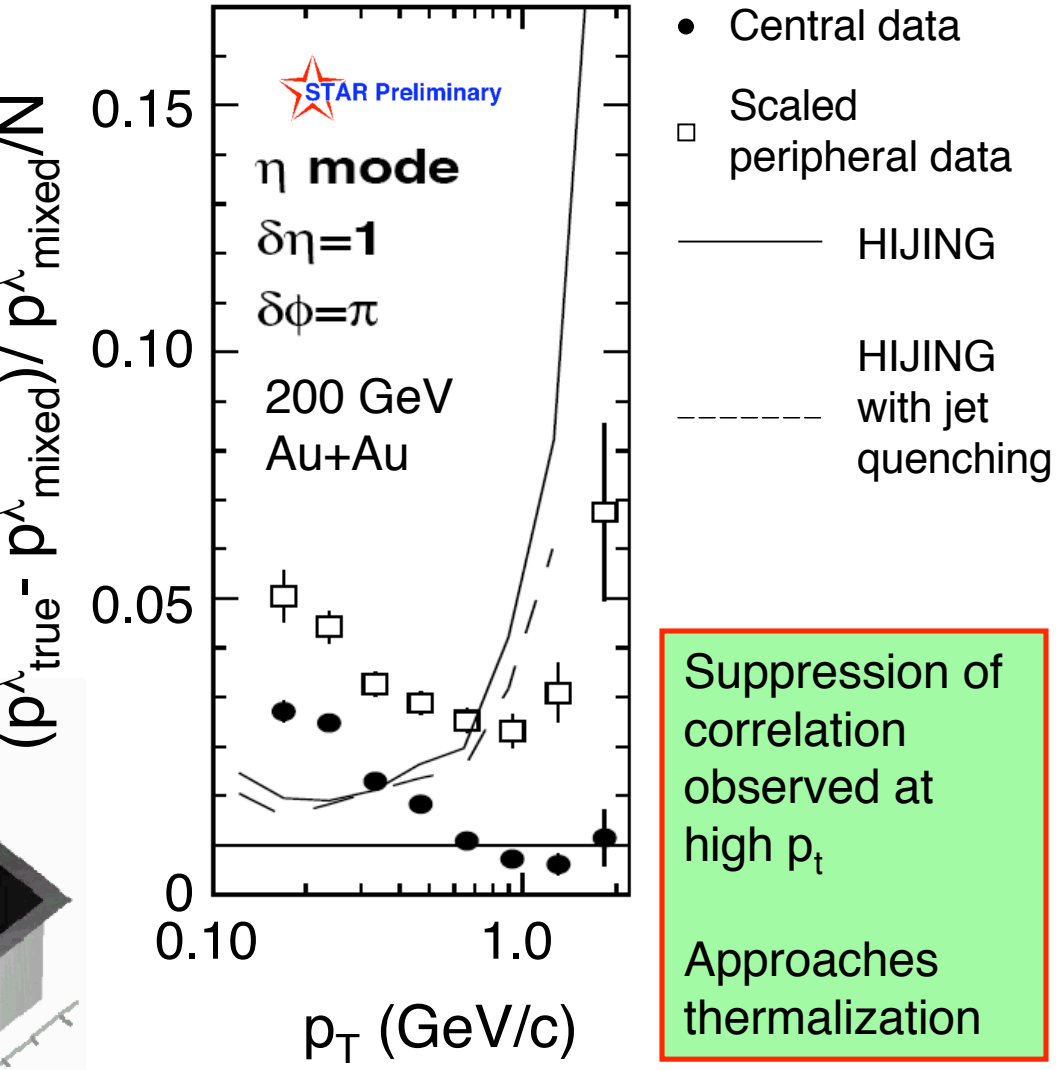
$$P^{\lambda}(m) = \frac{1}{2^{2m}} \sum_{i,j} \left\langle \rho, F^{\lambda}_{m,i,j} \right\rangle^2$$

"Dynamic texture" measure

$$\left(P^{\lambda}(m)_{true} / P^{\lambda}(m)_{mixed} - 1 \right) / N$$

$F^{\lambda}_{m,i,j}$ - **Haar wavelet basis in η**





Suppression of correlation observed at high p_t

Approaches thermalization

See poster by Mikhail Kopytine

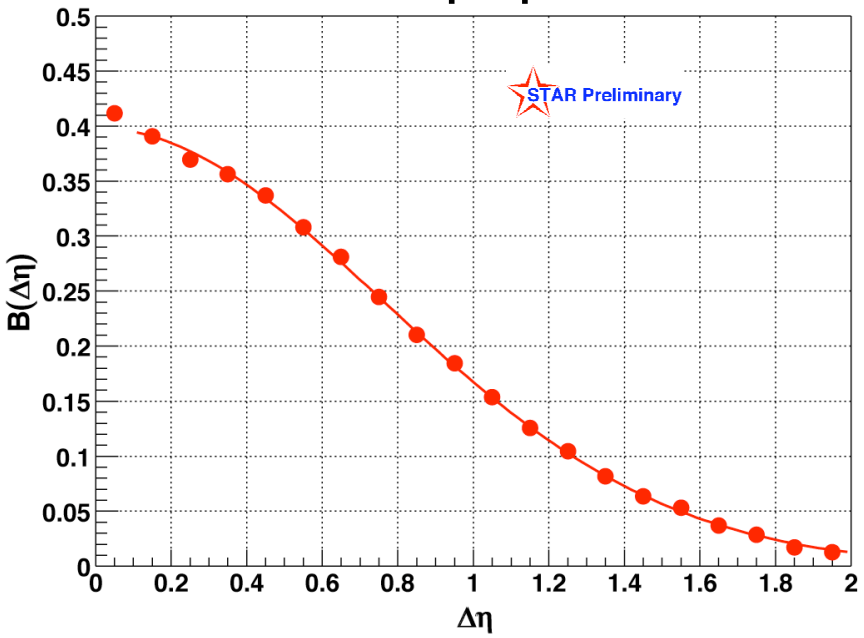
Conclusions

- Balance functions
  - $B(\Delta\eta)$, $B(\Delta y)$, and $B(q_{inv})$ narrow in central Au+Au 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
- Net Charge Fluctuations
  - Larger $|\nu_{+-,dyn}|$ for Au+Au at 20 GeV than 130 and 200 GeV
  - $|\nu_{+-,dyn}|_{Au+Au} \neq N\,|\nu_{+-,dyn}|_{p+p}$
  - N_{bin} scaling observed
- Discrete wavelet analysis
  - Evidence for suppression of jet-like phenomena in central Au+Au collisions in the longitudinal direction

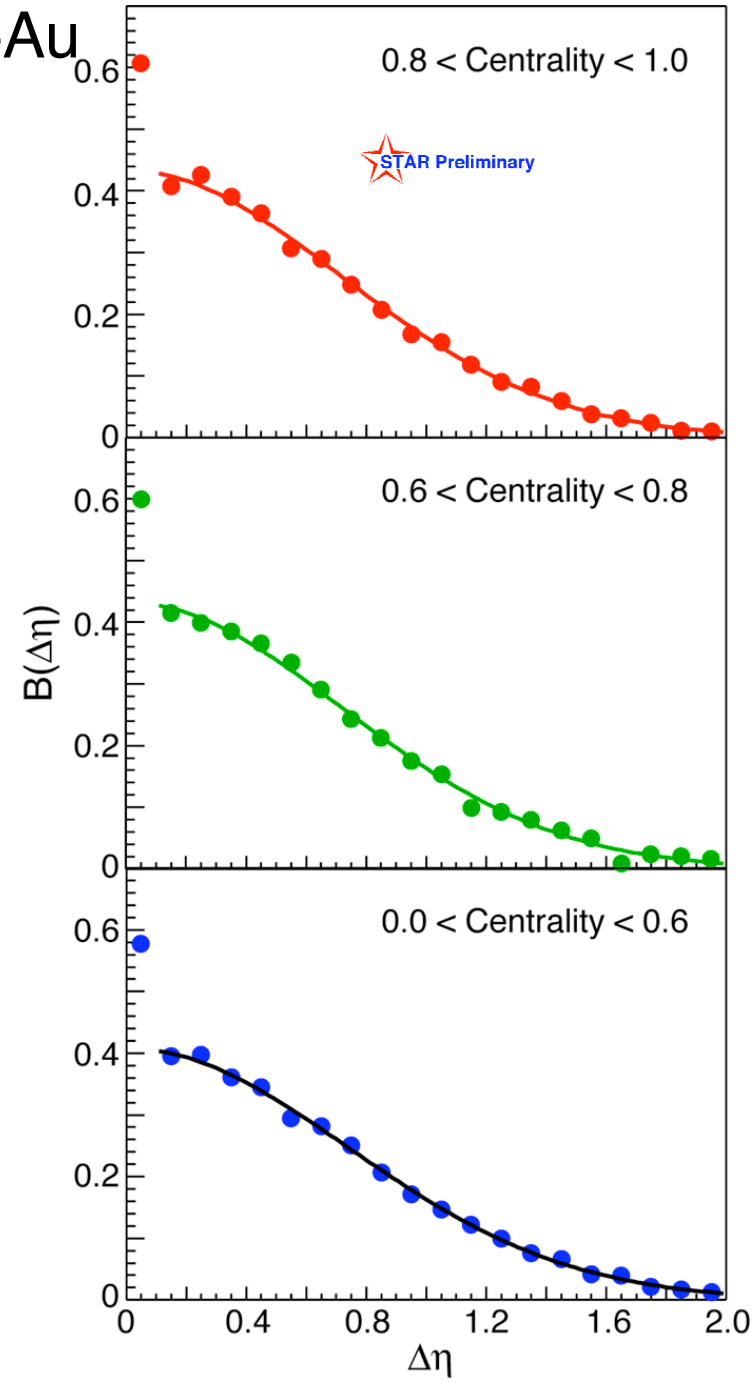
Extra Slides

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

p+p

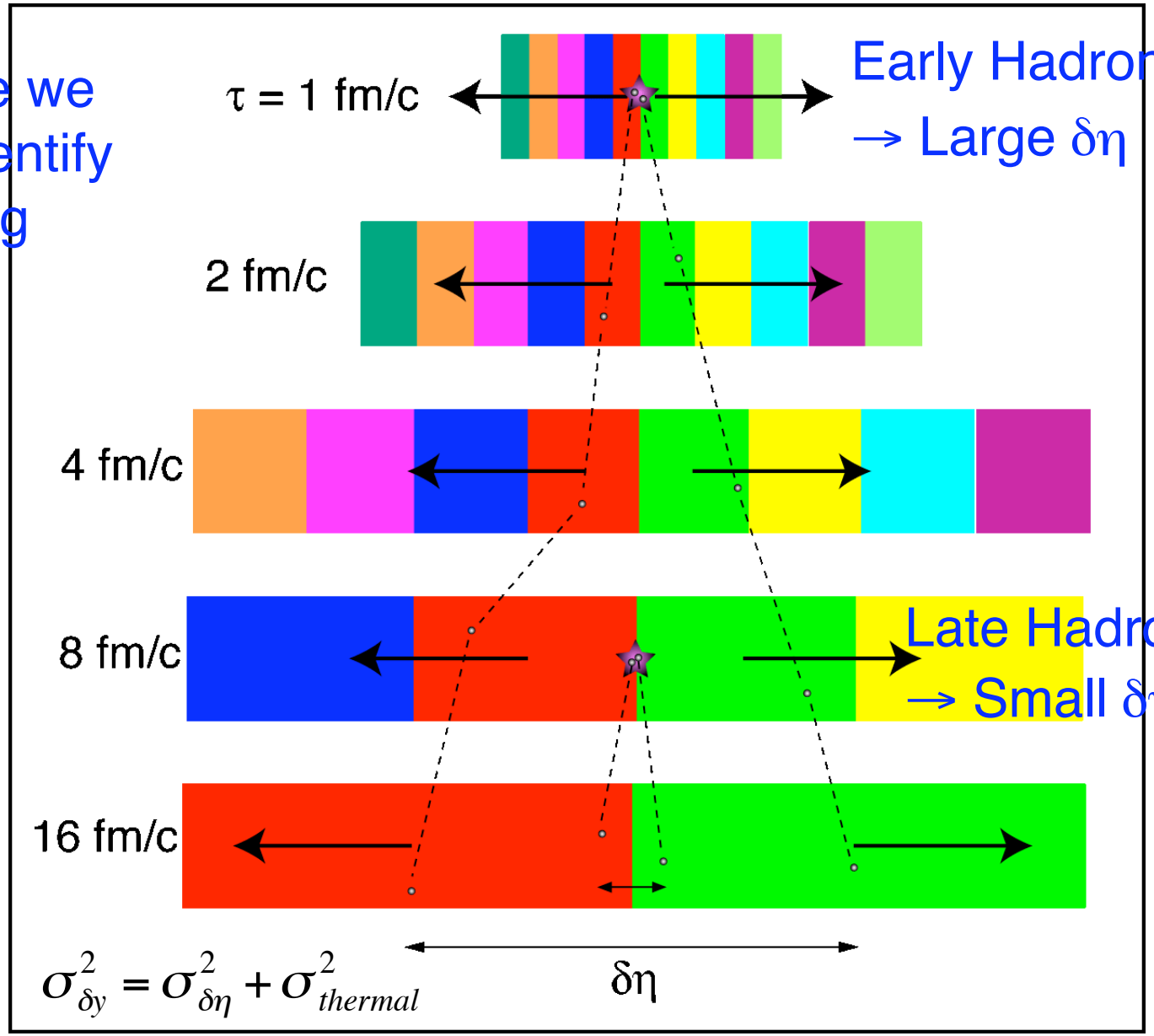


d+Au



Delayed Hadronization

Suppose we could identify balancing charges



After Scott Pratt

Definition of $\langle \Delta p_{t,i} \Delta p_{t,j} \rangle$

As a function of centrality and acceptance

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

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

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

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

Dynamical Net Charge Fluctuations

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

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

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

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

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