STAR

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Event Plane and Beam Energy Dependence of the Balance Function at RHIC

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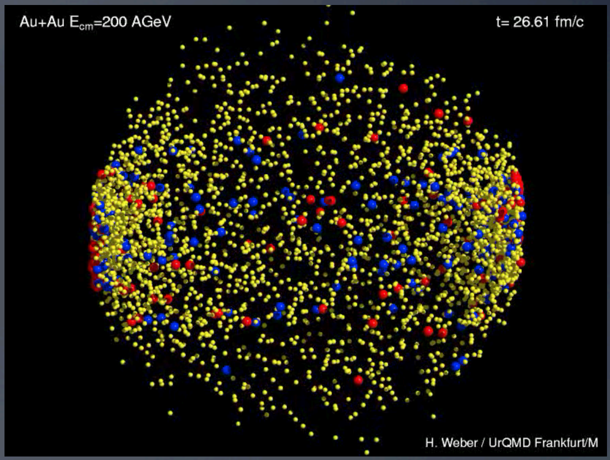
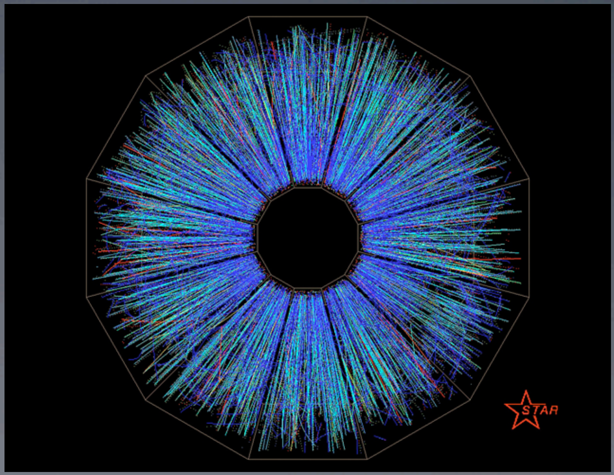
Outline

- Motivation
- Observable
- Balance Function with Respect to the Event Plane
- Beam Energy Dependent Balance Function
- Summary

Motivation

- In heavy ion collisions, most of the detected charge is created during the evolution of the system.
- Charge creation could occur at any time before chemical freeze-out.
- Balance functions are sensitive to charge formation mechanisms and relative diffusion





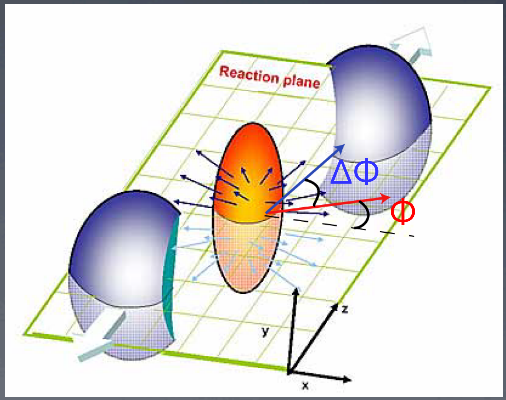
Observable

- The balance function is a conditional probability that a particle *a* in the bin p_1 will be accompanied by a particle *b* of opposite charge in the bin p_2.

$$B(p_2 \mid p_1) = \frac{1}{2}\{\rho(b,p_2 \mid a,p_1) - \rho(b,p_2 \mid b,p_1) + \rho(a,p_2 \mid b,p_1) - \rho(a,p_2 \mid a,p_1)\}$$

- It can be written as

$$B(\Delta\phi) = \frac{1}{2}\{\frac{N_{+-}(\Delta\phi) - N_{++}(\Delta\phi)}{N_+} + \frac{N_{-+}(\Delta\phi) - N_{--}(\Delta\phi)}{N_-}\}$$



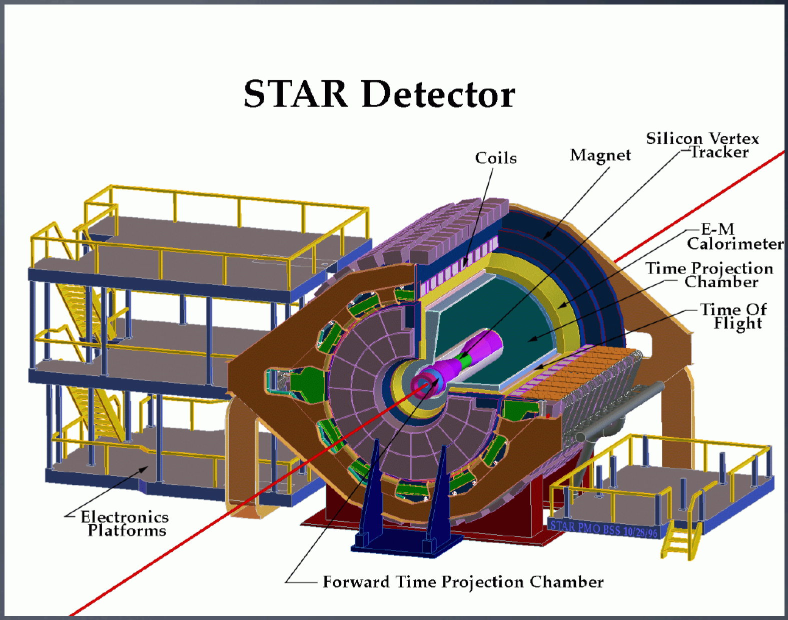
- If we specify first particle's position (azimuth)

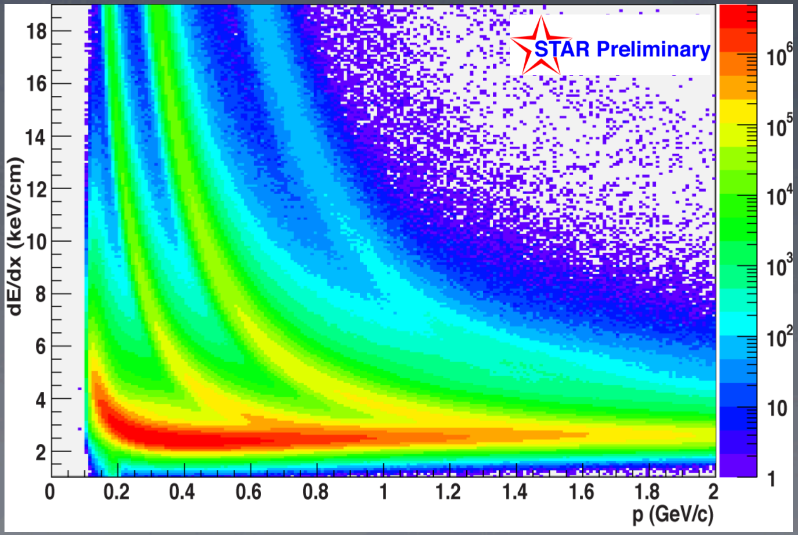
$$B(\phi,\Delta\phi) = \frac{1}{2}\{\frac{N_{+-}(\phi,\Delta\phi) - N_{++}(\phi,\Delta\phi)}{N_+(\phi)} + \frac{N_{-+}(\phi,\Delta\phi) - N_{--}(\phi,\Delta\phi)}{N_-(\phi)}\}$$

The STAR Experiment

- STAR is ideal for balance function study
  - Full azimuthal coverage
  - Large η acceptance
- Particle identification is done using dE/dx from TPC
- TPC event plane is used for balance function calculation

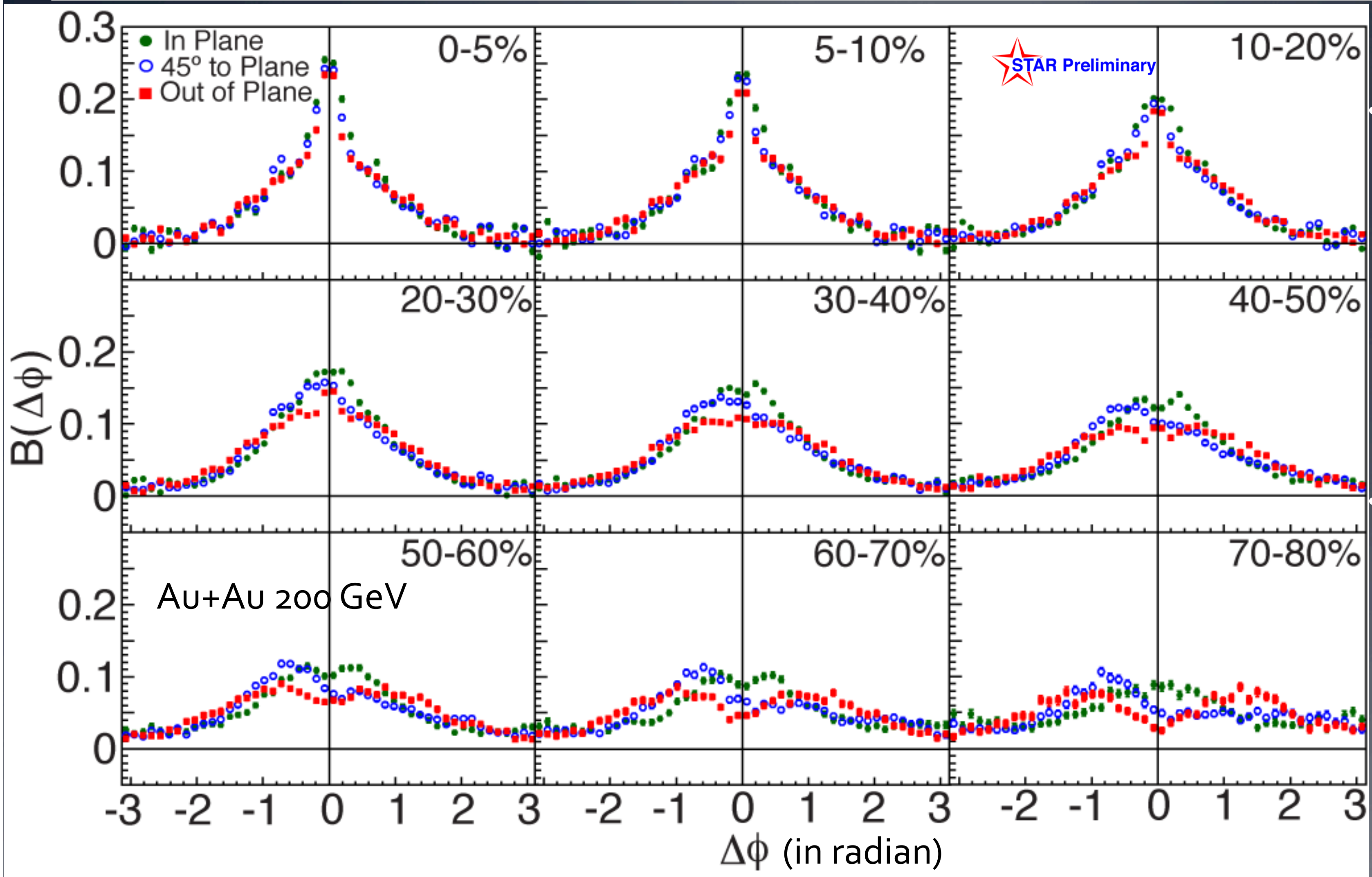
$$\psi_2 = \left(\tan^{-1} \frac{\sum_i w_i \sin(2\phi_i)}{\sum_i w_i \cos(2\phi_i)} \right) / 2$$



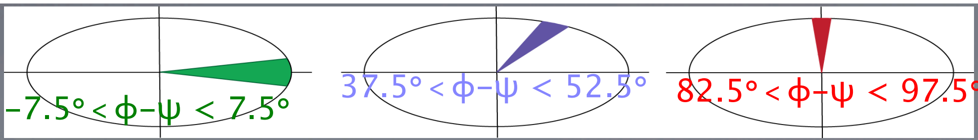


39 GeV dE/dx vs. p

Balance Function

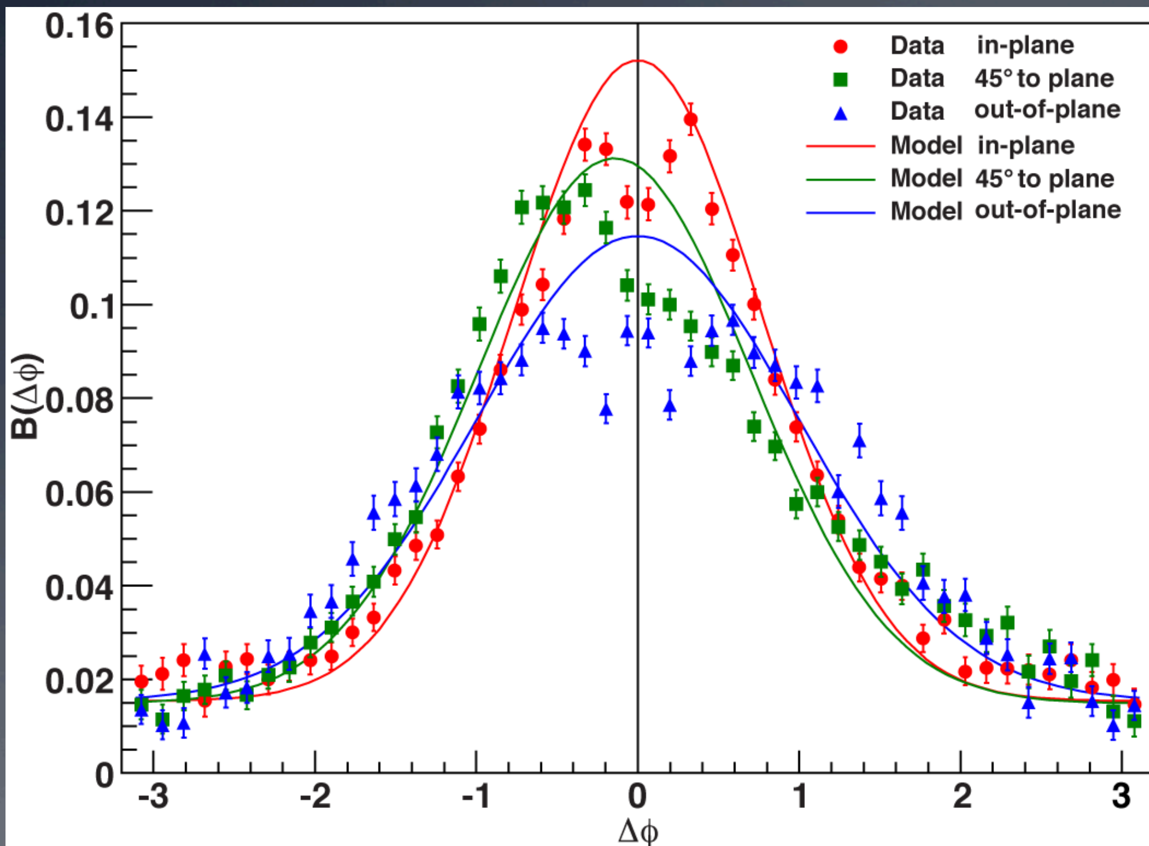


- 45° to event plane balance function is biased toward negative $\Delta\eta$ region
- The out-of-plane balance function is wider than the in-plane balance function



- Balance function narrows in central collision due to collective flow

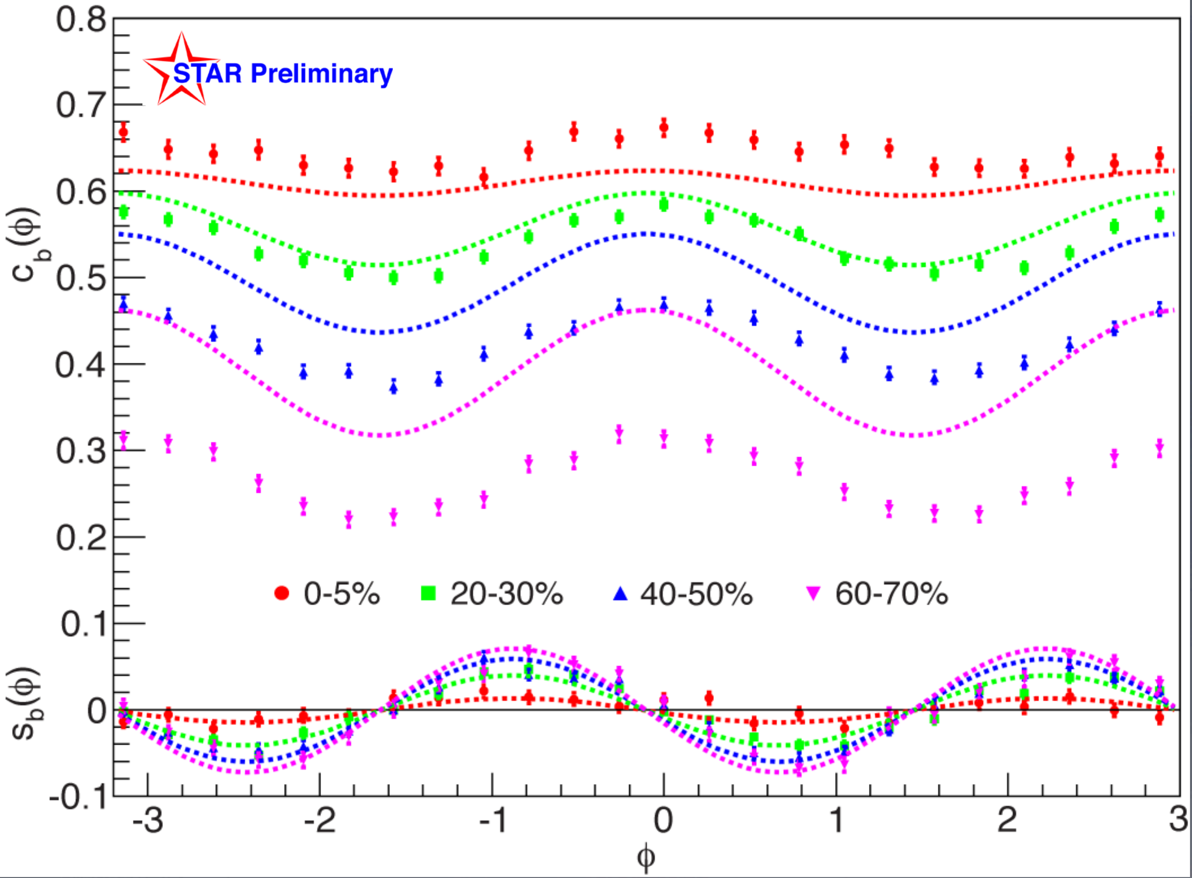
Balance Function



- 40-50% Centrality
- Compare to blast wave model calculations[1]
- HBT/Coulomb effects are observed at ΔΦ close to zero

[1] S. Schlichting and S. Pratt, arXiv:1009.4283v1

Weighted Average

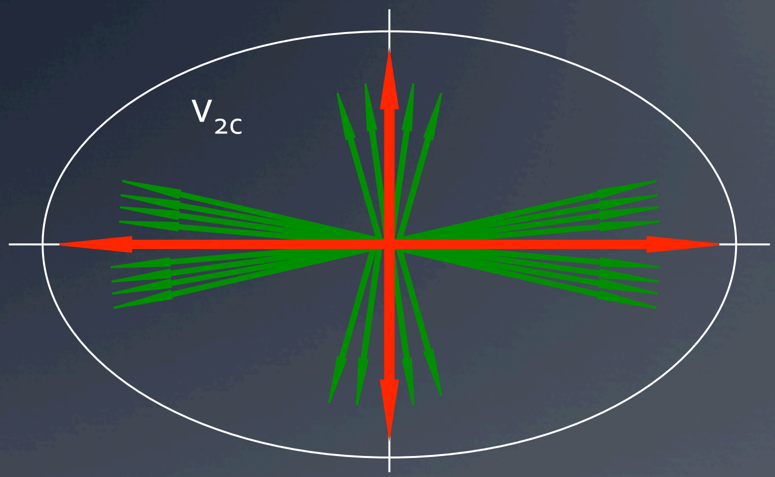


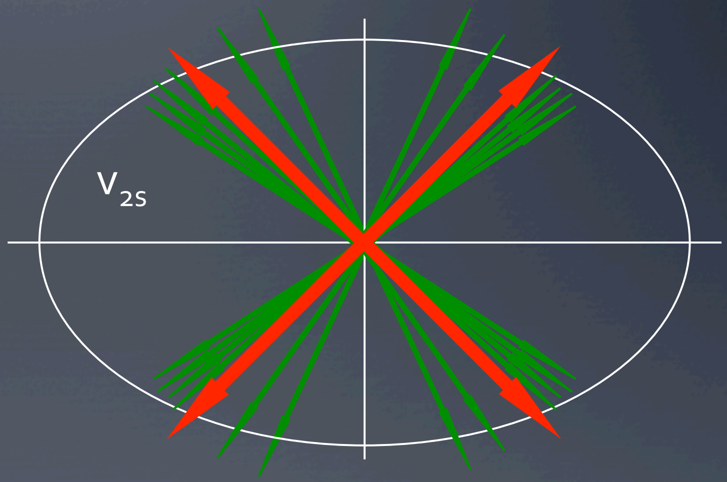
$$c_b(\phi) \equiv \frac{1}{z_b(\phi)} \int d\Delta\phi B(\phi, \Delta\phi) \cos(\Delta\phi)$$

$$s_b(\phi) \equiv \frac{1}{z_b(\phi)} \int d\Delta\phi B(\phi, \Delta\phi) \sin(\Delta\phi) \qquad z_b(\phi) \equiv \int d\Delta\phi B(\phi, \Delta\phi)$$

- Compare to blast wave model calculations
- c_b is related to the balance function width, while s_b can quantify the asymmetry of balance function
- Data show a stronger collective behavior in plane, while the asymmetry is most significant 45° to the reaction plane

Calculate v_{2c} and v_{2s}





- Red arrows are the first particle in balance function calculation
- $v_2 < c_b >$ would be positive if more charges pairs are found in plane
- v_{2c} would be positive if charges are more correlated in plane
- v_{2s} would be negative if charges are more correlated on the in plane side

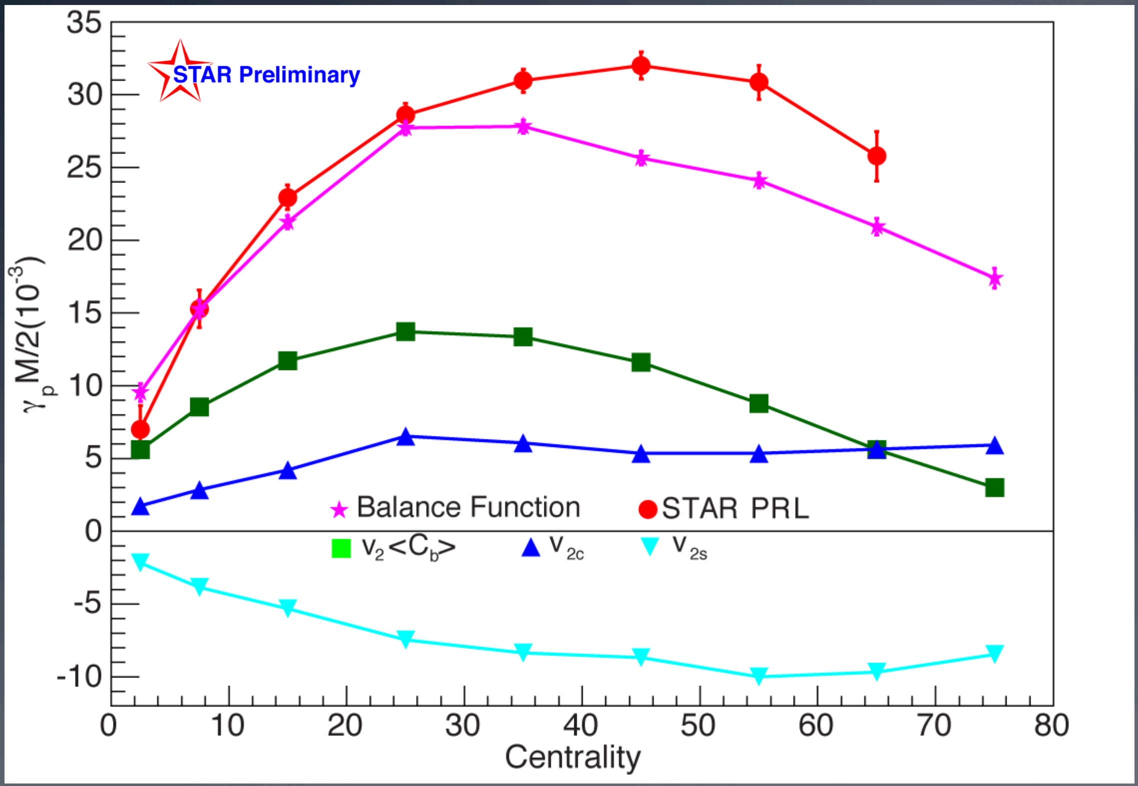
$$v_{2c} \equiv < c_b(\phi)\cos(2\phi) > - v_2 < c_b(\phi) >$$

$$v_{2s} \equiv < s_b(\phi)\sin(2\phi) >$$

$$< f(\phi) > \equiv \frac{1}{M}\int d\phi \frac{dM}{d\phi} z_b(\phi) f(\phi)$$

Explaining Angular Correlations Observed at RHIC with Flow and Local Charge Conservation, Soeren Schlichting, Scott Pratt, arXiv:1005.5341

Parity Observable



- γ_P is the difference between unlike- and like-sign azimuthal correlations
- γ_P scaled by multiplicity can be written as the combination of $v_2 \langle c_b(\Phi) \rangle$, v_{2c} and v_{2s}
- Compare with STAR published data[1]
- The balance function reproduces most of the observed difference between unlike- and like-sign azimuthal correlations

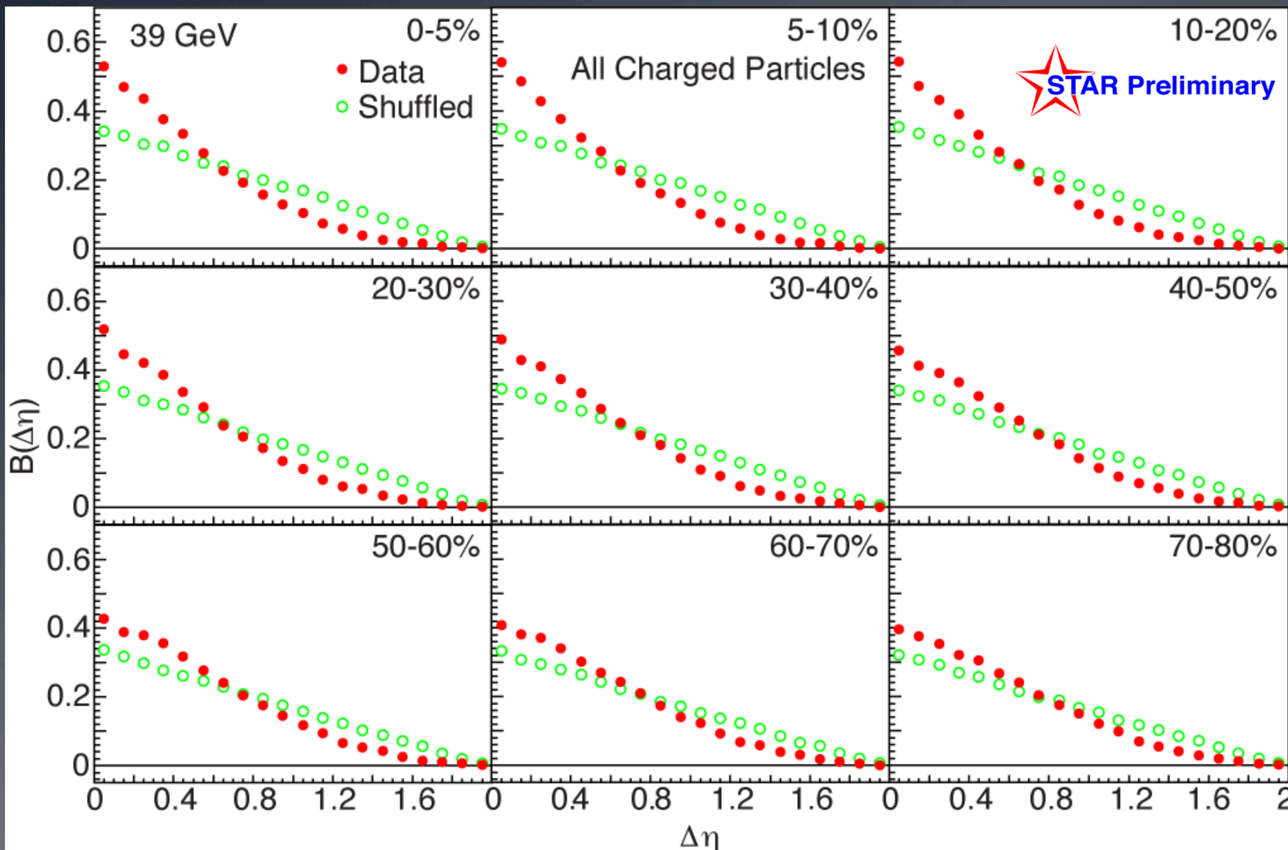
$$\gamma = \langle \cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP}) \rangle$$

$$\gamma_p = \frac{1}{2}(2\gamma_{+-} - \gamma_{++} - \gamma_{--}) = \frac{2}{M}[v_2 \langle c_b(\phi) \rangle + v_{2c} - v_{2s}]$$

[1]10.1103/PhysRevLett.103.251601

Balance Functions Study with RHIC Beam Energy Scan Data

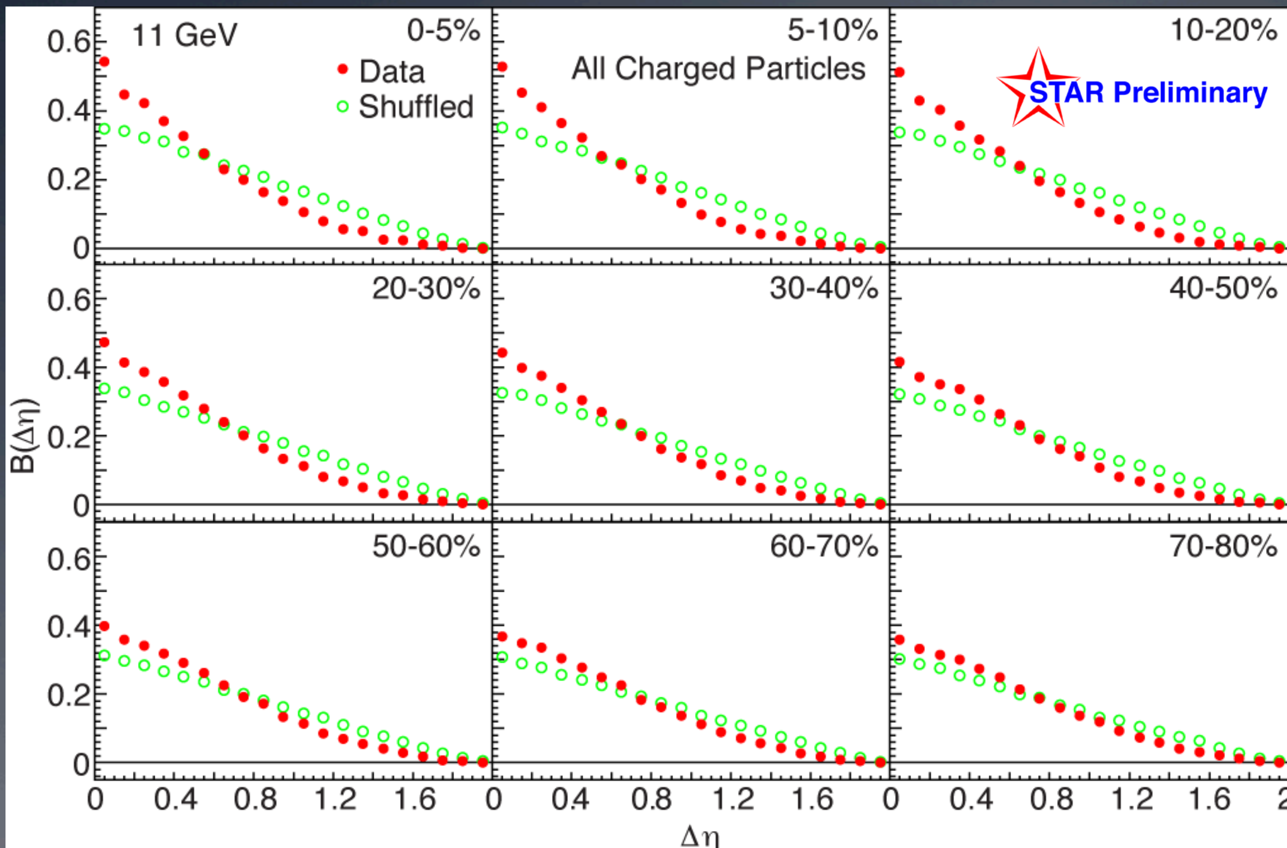
Balance Function for Δη



- 39 GeV
- 9 Centralities
- Data are narrower than shuffled events
- Data narrow in central collisions

$$B(\Delta\eta) = \frac{1}{2}\{\frac{N_{+-}(\Delta\eta) - N_{++}(\Delta\eta)}{N_{+}} + \frac{N_{-+}(\Delta\eta) - N_{--}(\Delta\eta)}{N_{-}}\}$$

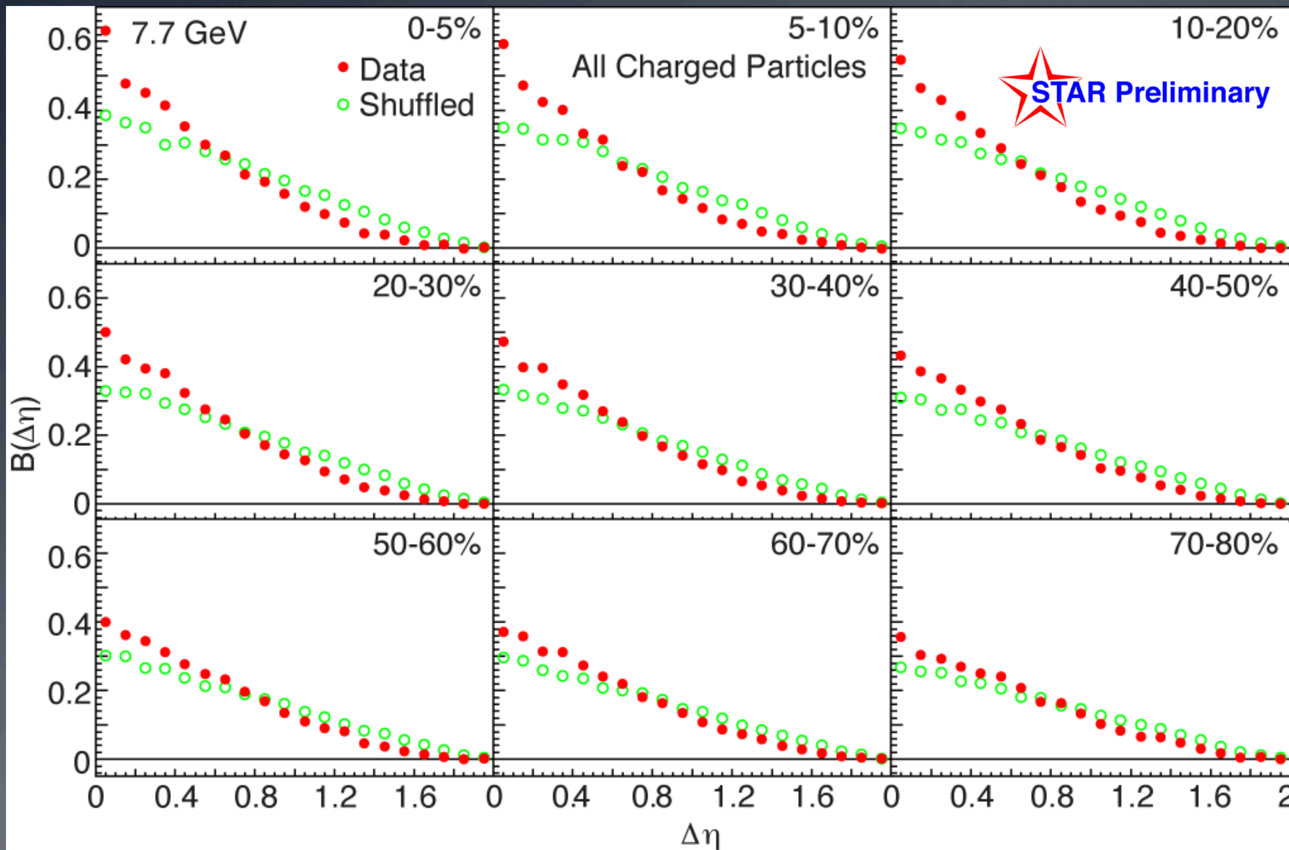
Balance Function for Δη



- 11 GeV
- 9 Centralities
- Data are narrower than shuffled events
- Data narrow in central collisions

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

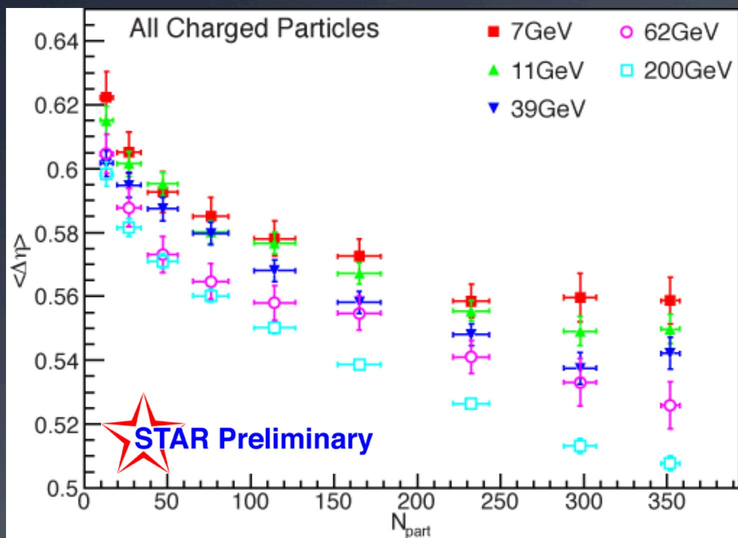
Balance Function for Δη



- 7.7 GeV
- 9 Centralities
- Data are narrower than shuffled events
- Data narrow in central collisions

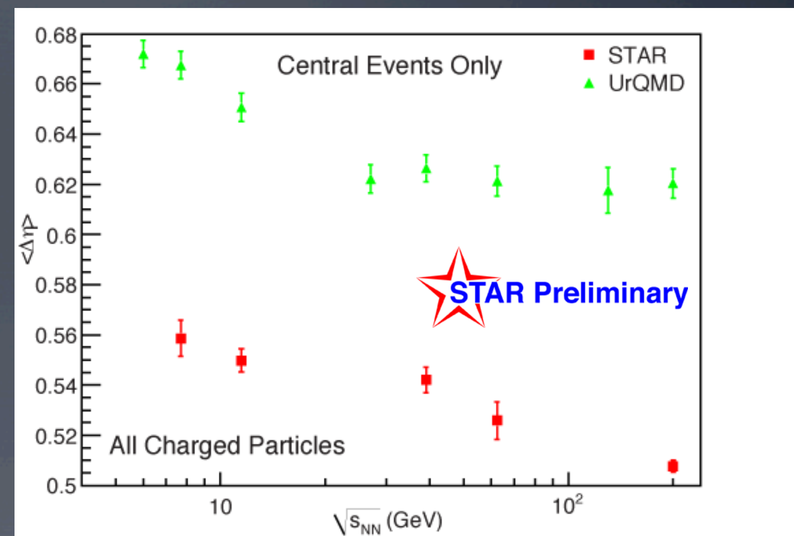
$$B(\Delta\eta) = \frac{1}{2}\{\frac{N_{+-}(\Delta\eta) - N_{++}(\Delta\eta)}{N_{+}} + \frac{N_{-+}(\Delta\eta) - N_{--}(\Delta\eta)}{N_{-}}\}$$

<Δη>



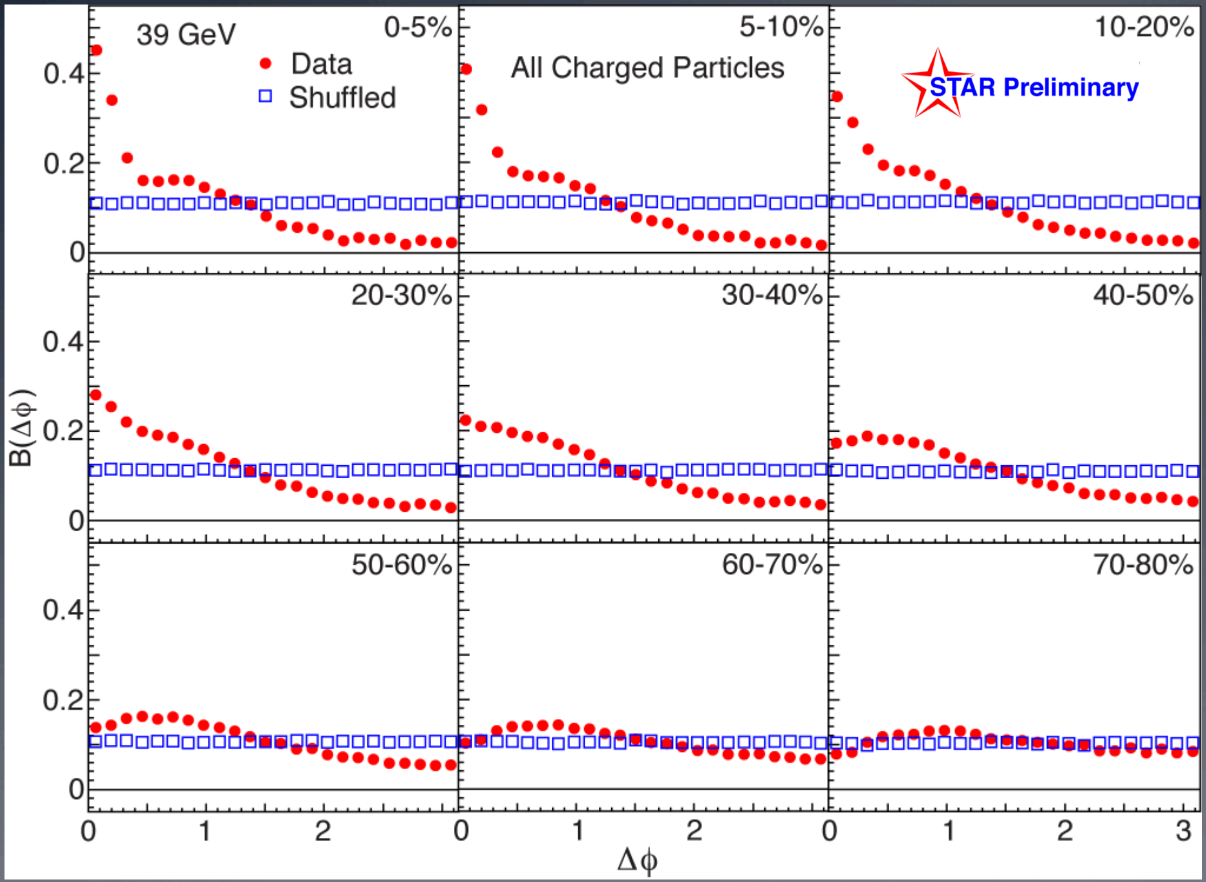
- Narrows in central collision and at higher energy
- Due to later hadronization time and stronger radial flow

$$< \Delta\eta > = \frac{\sum B(\Delta\eta)\Delta\eta}{\sum B(\Delta\eta)}$$



- UrQMD is wider than the data
- UrQMD assumes early charge creation and little flow

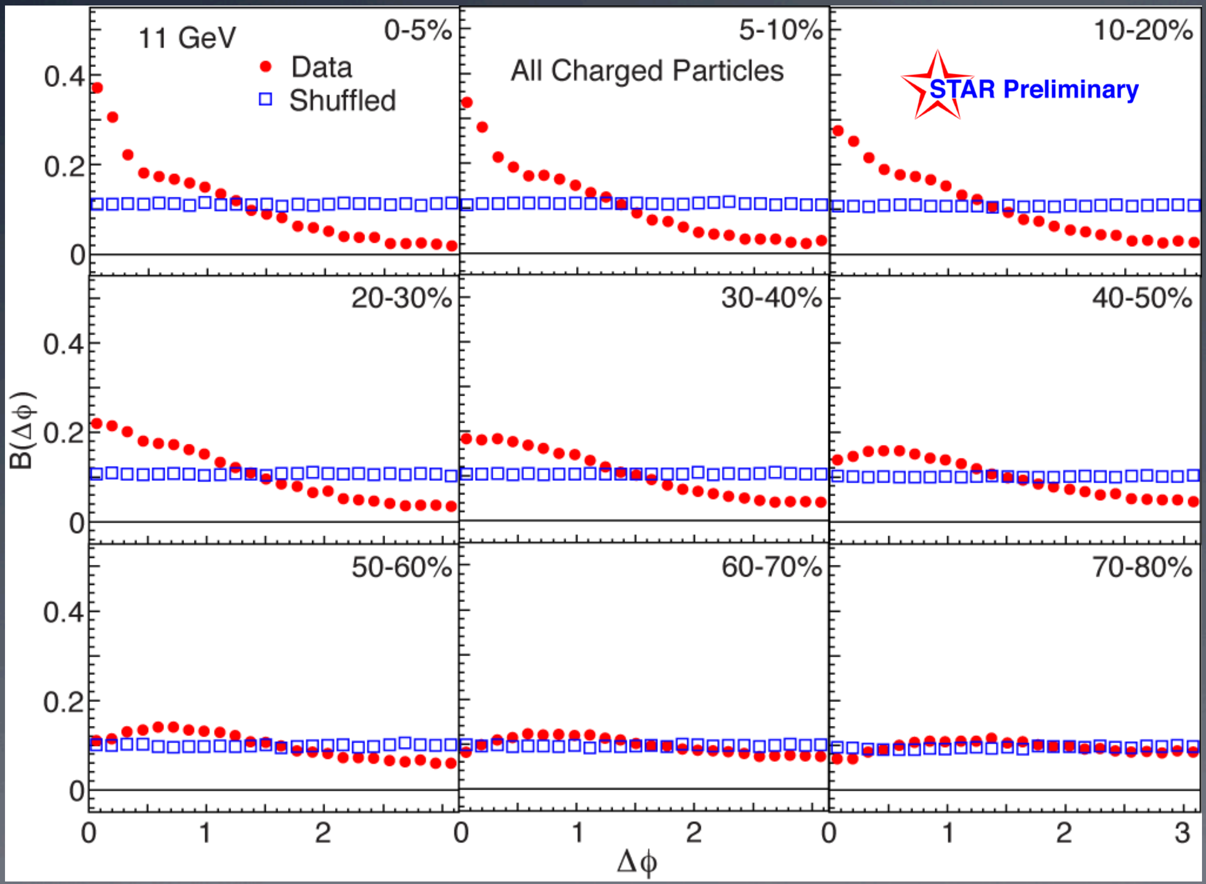
Balance Function for Δϕ



$$B(\Delta\phi) = \frac{1}{2}\{\frac{N_{+-}(\Delta\phi) - N_{++}(\Delta\phi)}{N_{+}} + \frac{N_{-+}(\Delta\phi) - N_{--}(\Delta\phi)}{N_{-}}\}$$

- 39 GeV
- 9 Centralities
- Data show a peak in central collision
- Lowest 3 bins show strong correlation

Balance Function for Δϕ



$$B(\Delta\phi) = \frac{1}{2}\{\frac{N_{+-}(\Delta\phi) - N_{++}(\Delta\phi)}{N_{+}} + \frac{N_{-+}(\Delta\phi) - N_{--}(\Delta\phi)}{N_{-}}\}$$

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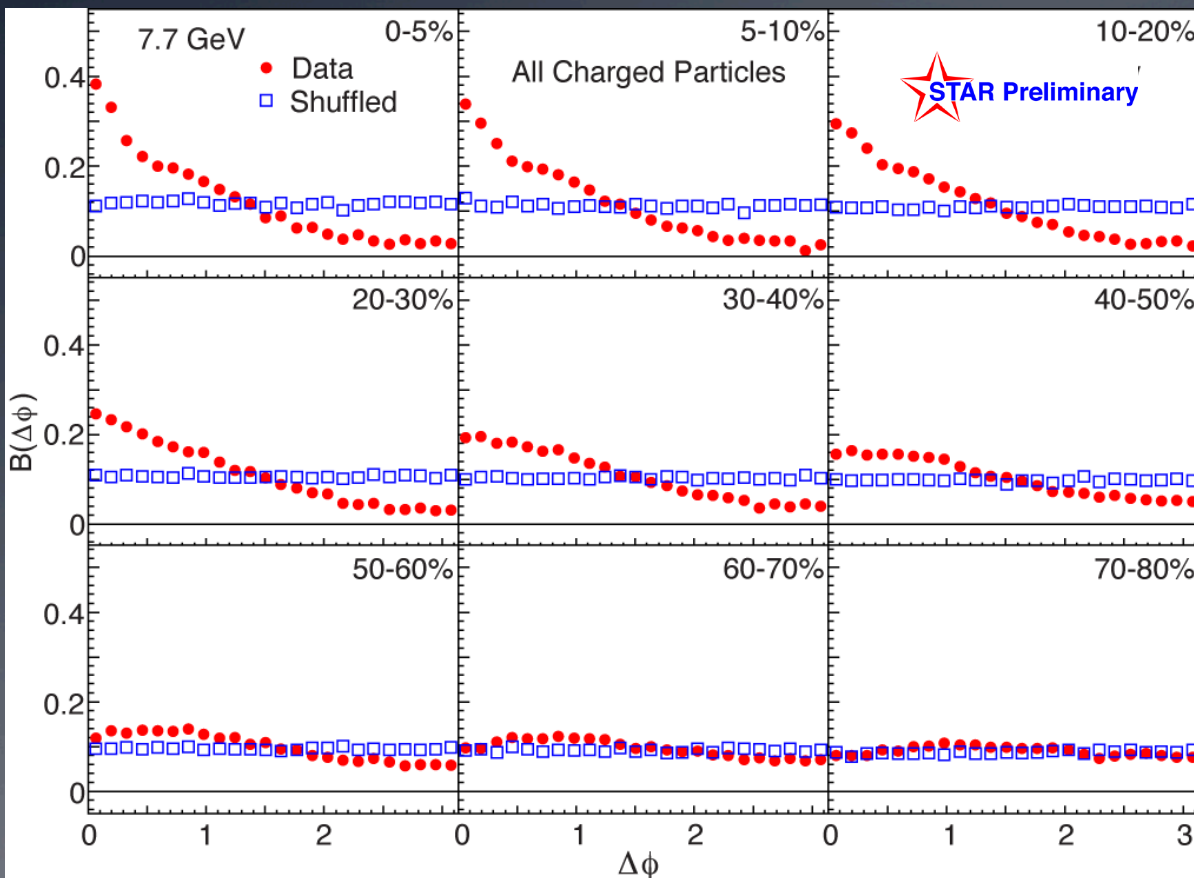
Balance Function for Δϕ



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

- 7.7 GeV
- 9 Centralities
- Data show a peak in central collision
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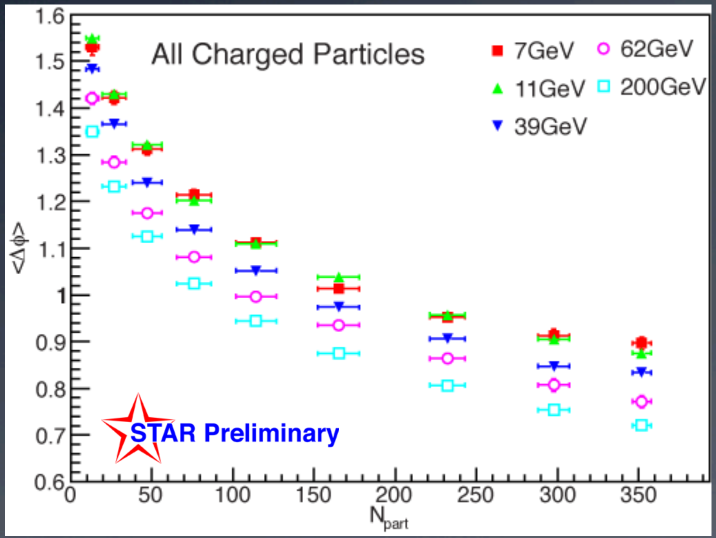
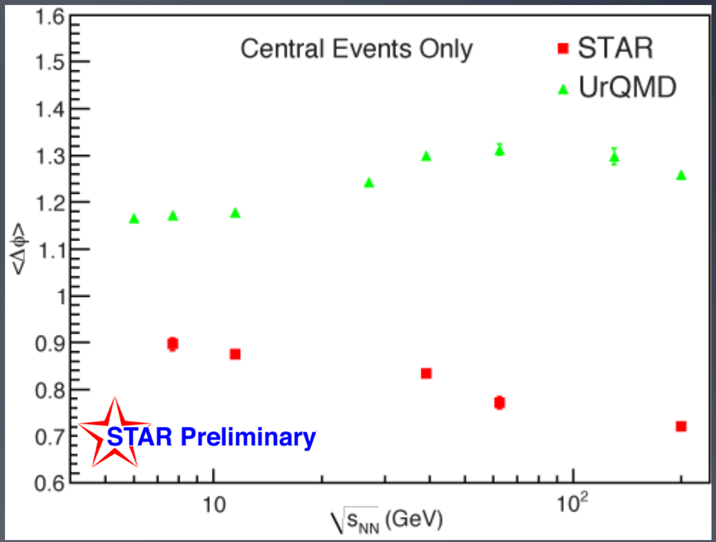
<Δϕ>

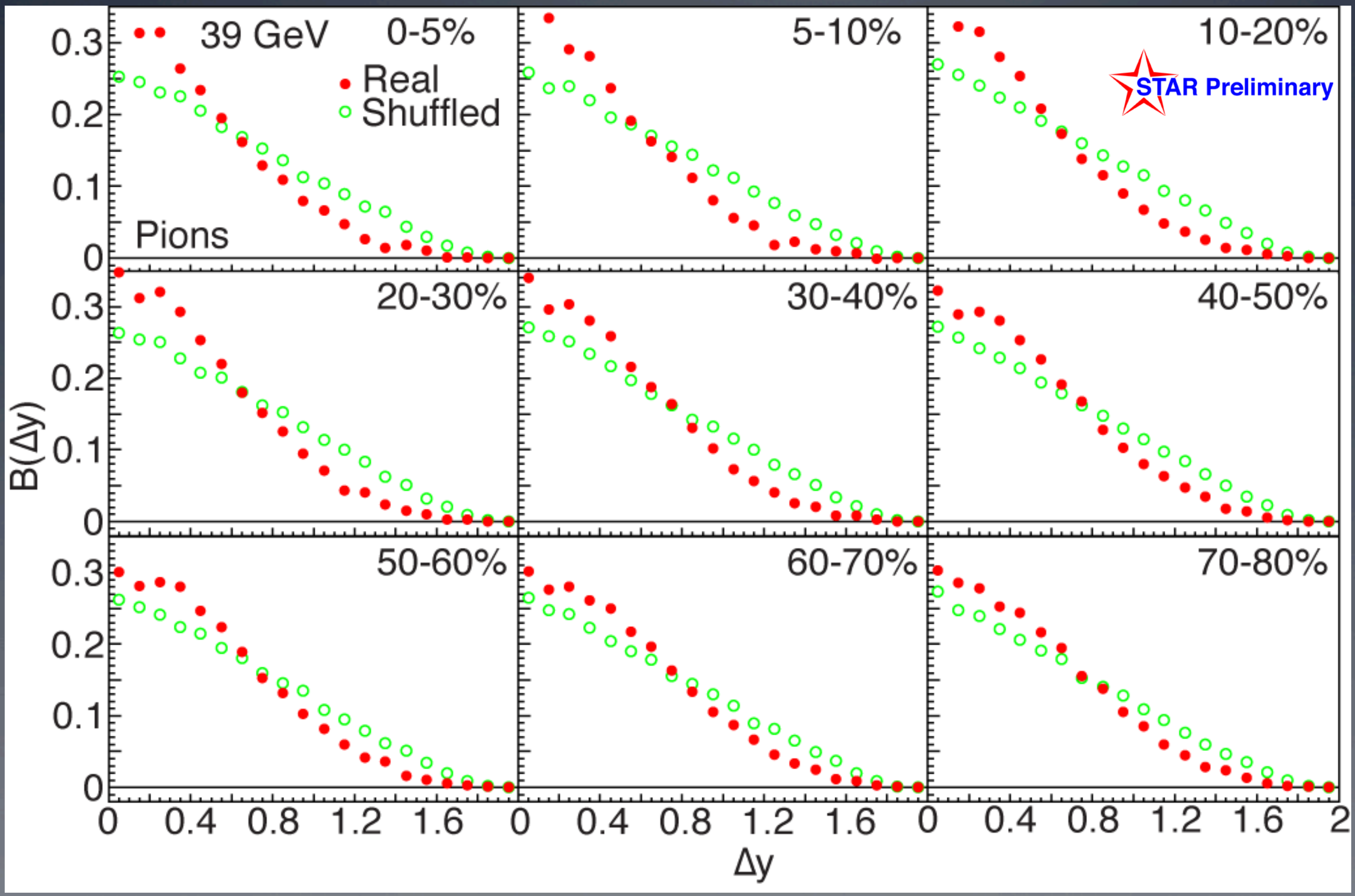


- Narrows in central collision and higher energy
- Due to later hadronization time and stronger radial flow

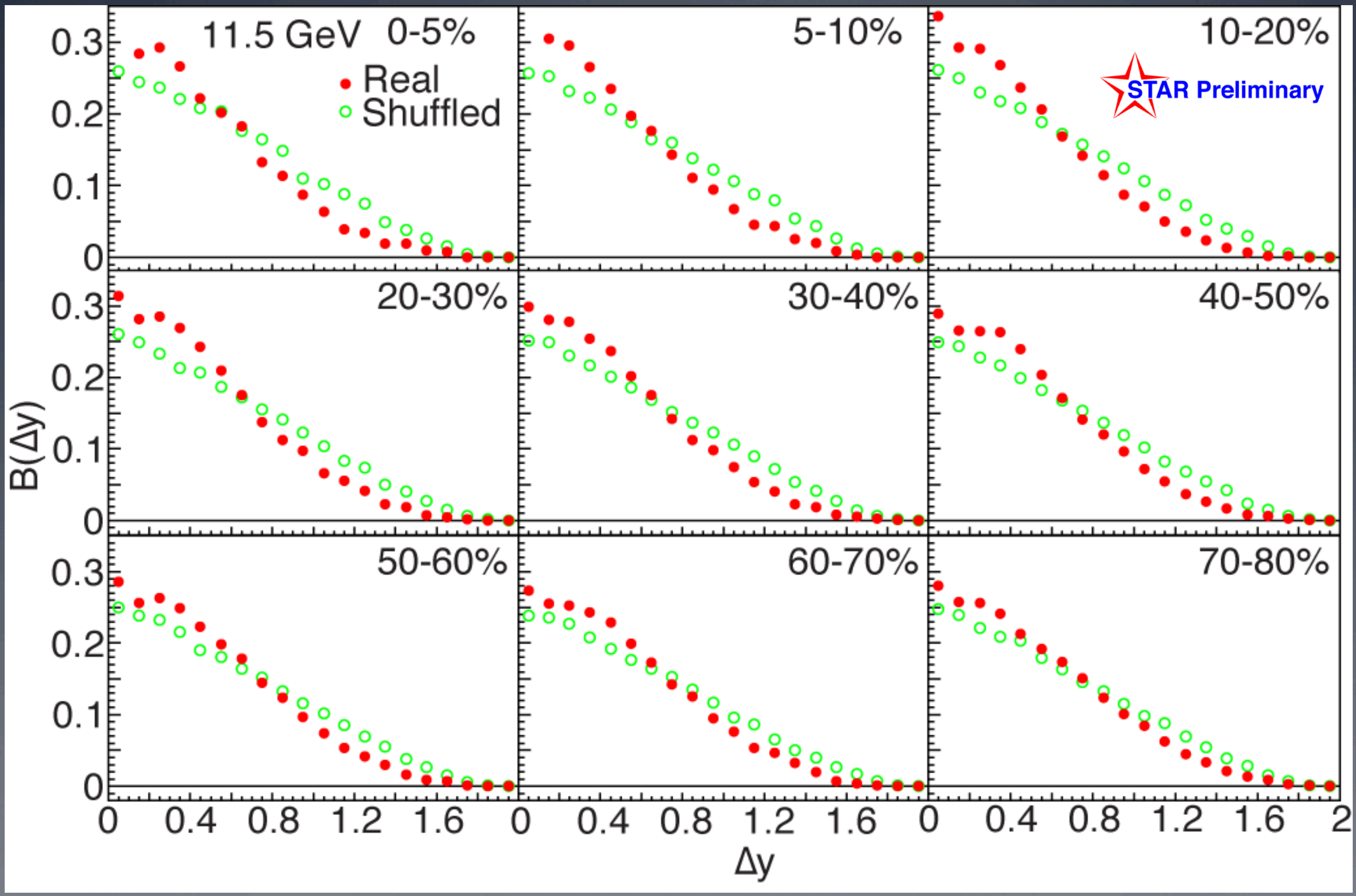


- UrQMD is wider than data
- UrQMD narrows at lower energy

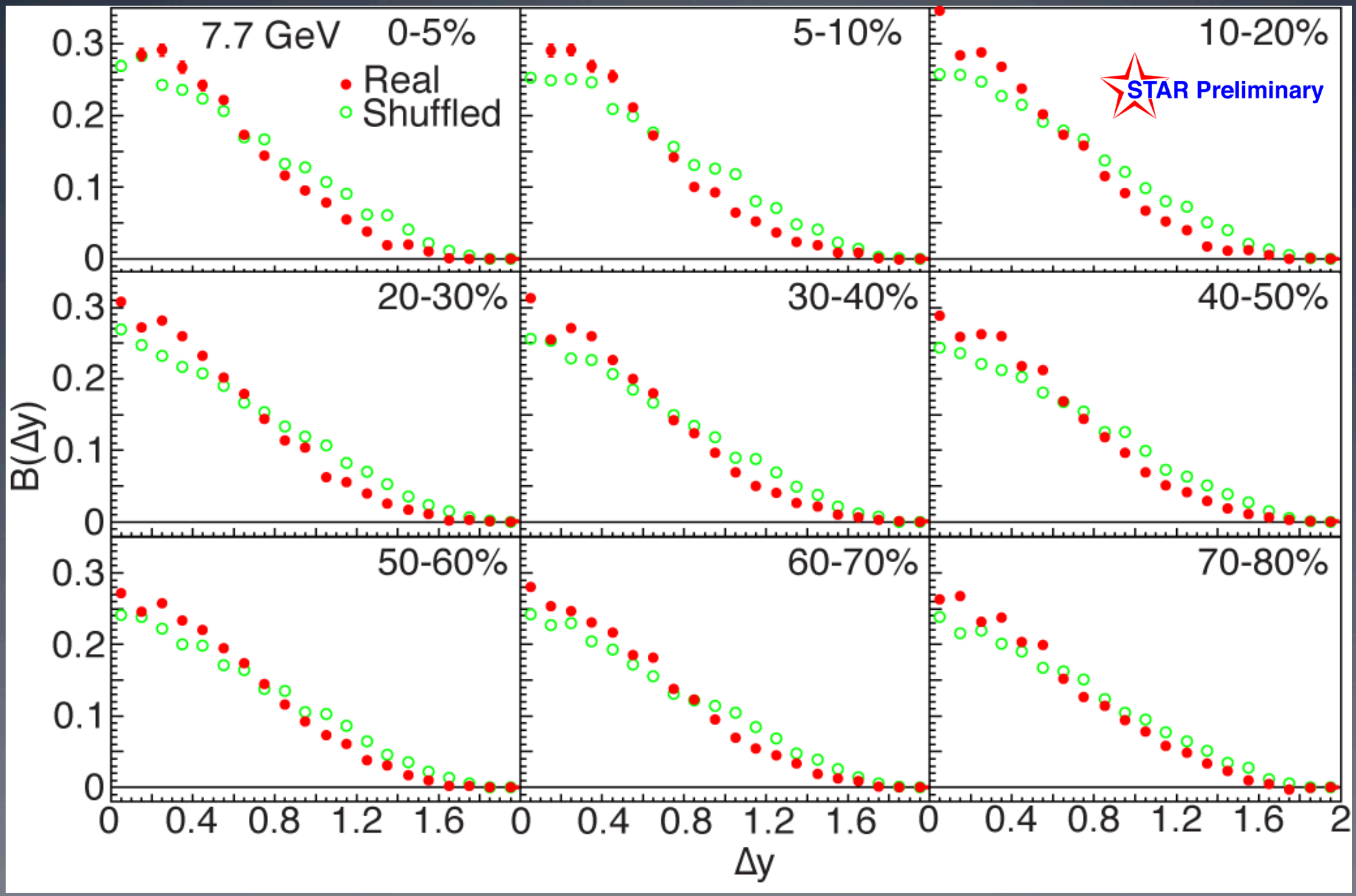
Balance Function for Pions



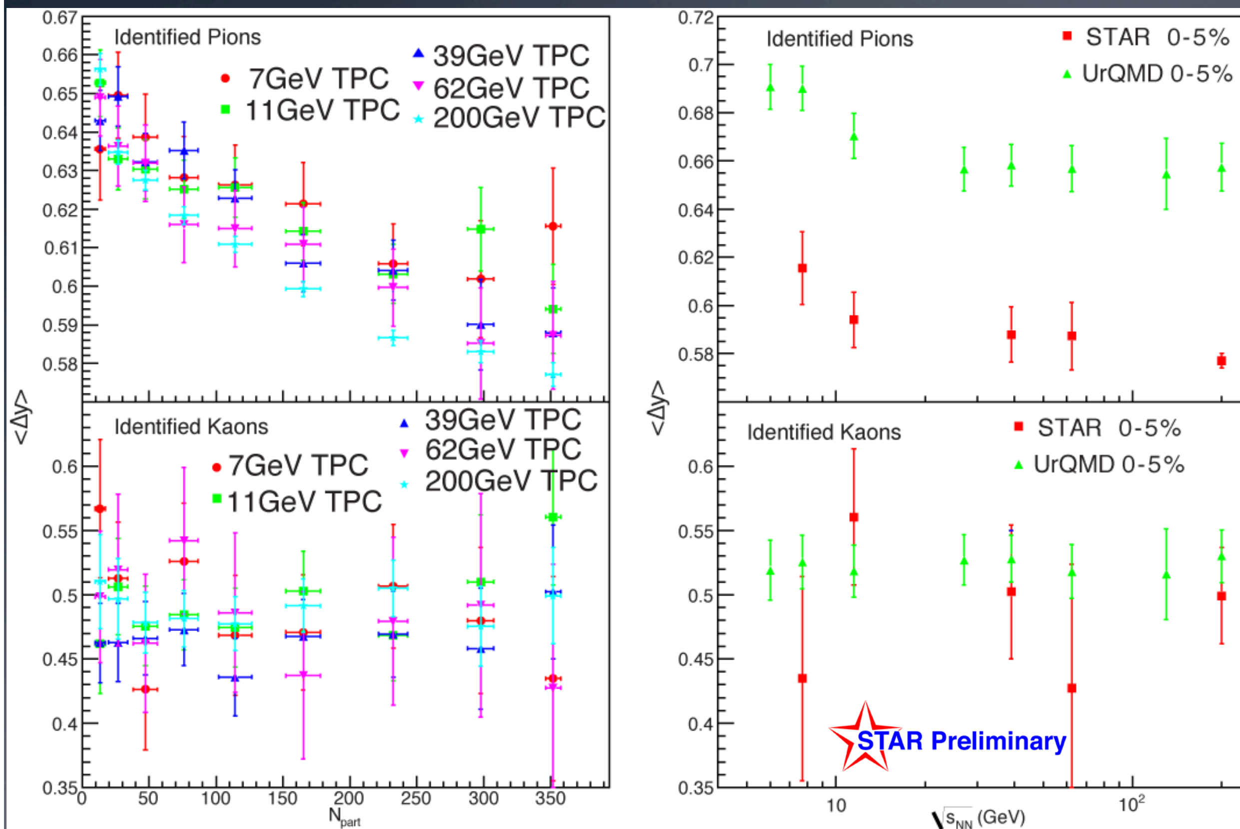
Balance Function for Pions

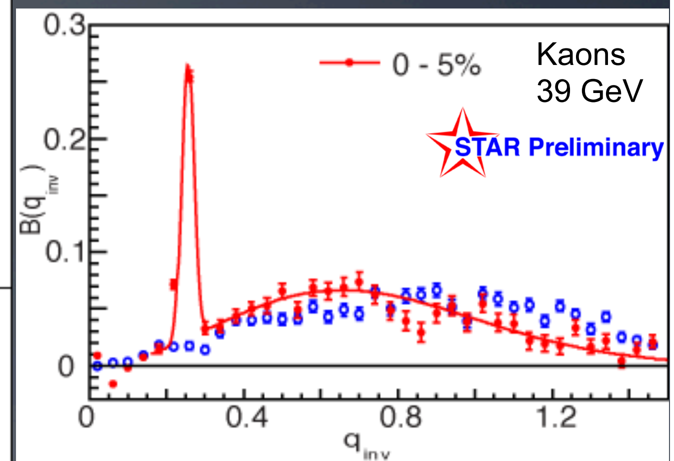


Balance Function for Pions



<Δy>





Kaon balance function is dominated by ϕ *decay*

- Balance functions for pions narrow in central collision and higher energy
- Balance functions for kaons do not narrow

Summary - I

- Balance functions show strong event plane dependence
  - Signature of elliptic flow
- Balance functions can reproduce most of the measured charge-dependent azimuthal correlations
  - Charge conservation
  - Flow effect

Summary - II

- Balance functions narrow in central collisions and at higher collision energies
  - Radial flow effect
  - Later hadronization time

- Balance function for identified Kaons do not narrow
  - Dominated by ϕ decay

Back Up

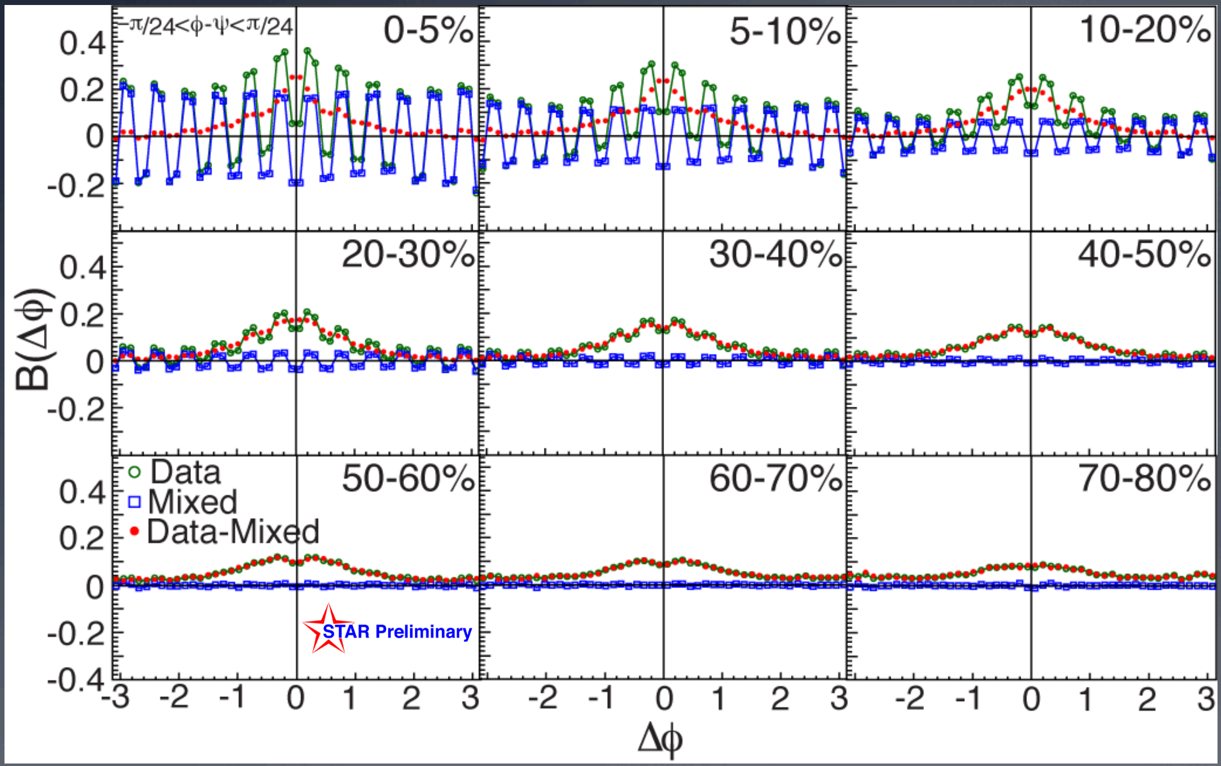
Data Set

Energy (GeV)	Species	Year	Events (M)*	$\lvert V_z \rvert$ cut (cm)
200	Au + Au	Run 7	48	15
62.4	Au + Au	Run 4	4	15
39	Au + Au	Run 10	10	30
11.5	Au + Au	Run 10	12	30
7.7	Au + Au	Run 10	4	70

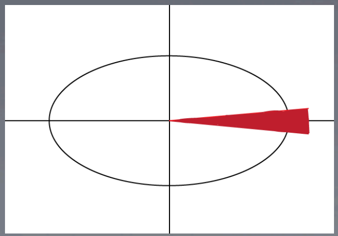
*Number of events used in balance function calculation

- All Charge Particles
  - $|\eta| < 1.0$
  - $0.2 < p_t < 2.0$ GeV/c
- Identified Particles
  - $|\eta| < 1.0$
  - TPC PID
    - π: $n_{\sigma\pi} < 2.0$, $n_{\sigma K} > 2.0$, $0.2 < p_t < 0.6$
    - K: $n_{\sigma\pi} > 2.0$, $n_{\sigma K} < 2.0$, $0.2 < p_t < 0.6$

Sector Boundary Effect

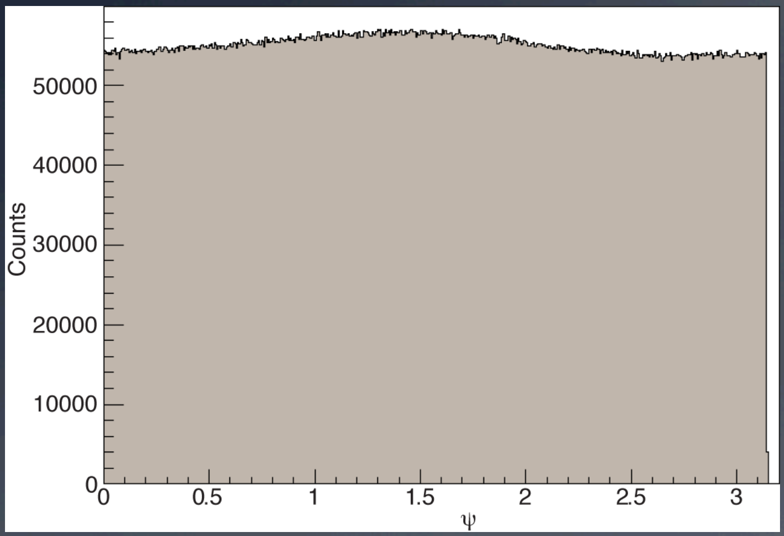


- Au+Au 200 GeV
- In plane balance function
- Mixed events are not zero due to sector boundaries
- Still some residual effects after subtraction



$-7.5° < \phi-\psi < 7.5°$

Event Plane



- Use second harmonic event plane

$$\psi_2 = \left(\tan^{-1} \frac{\sum_i w_i \sin(2\phi_i)}{\sum_i w_i \cos(2\phi_i)} \right) / 2$$

- Apply Φ weight and pt weight

- Φ weight are calculated run by run, centrality by centrality

- Use pt as weight when fill Φ histogram