Local Parity Violation or Local Charge Conservation/Flow?

A Reaction-Plane-Dependent Balance Function Study

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Abstract

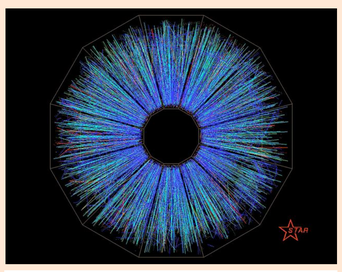
STAR has recently reported charge-dependent azimuthal correlations that are sensitive to the charge separation effect in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV [1]. Qualitatively, these results agree with some of the theoretical predictions for local parity violation in heavy-ion collisions. However, a study using reaction-plane-dependent balance functions shows an alternative origin of this signal. The balance function, which measures the correlation between oppositely charged pairs, is sensitive to the mechanisms of charge formation and the subsequent relative diffusion of the balancing charges. The reaction-plane dependent balance function measurements can be related to STAR's charge-dependent azimuthal correlations. We report reaction-plane-dependent balance functions for Au+Au collisions at $\sqrt{s_{NN}}$ = 200 , 62.4, 39, 11.5, and 7.7 GeV using the STAR detector. The model of Schlicting and Pratt [2] incorporating local charge conservation and elliptic flow reproduces most of the three-particle azimuthal correlation results at 200 GeV. The experimental charge-dependent azimuthal charge correlations observed at 200 GeV can be explained in terms of local charge conservation and elliptic flow.

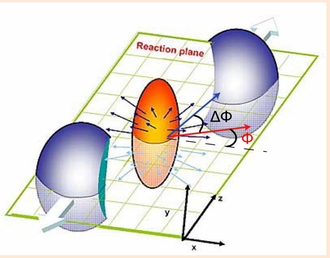
Motivation

- In heavy ion collisions, most of the detected charge is created during the evolution of the system
- Balance functions are sensitive to charge formation mechanisms and relative diffusion
- STAR has proposed a three point correlator [1] to measure the possible Chiral Magnetic Effect

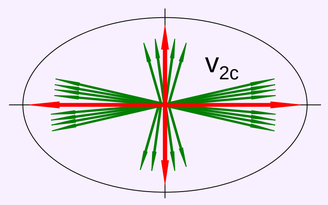
$$\left\langle \cos\left(\varphi_a + \varphi_b - 2\Psi_{EP}\right)\right\rangle$$

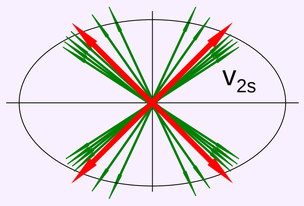
$$B(\phi,\Delta\phi) = \frac{1}{2}\{\frac{N_{+-}(\phi,\Delta\phi) - N_{++}(\phi,\Delta\phi)}{N_{+}(\phi)} + \frac{N_{-+}(\phi,\Delta\phi) - N_{--}(\phi,\Delta\phi)}{N_{-}(\phi)}\}$$





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





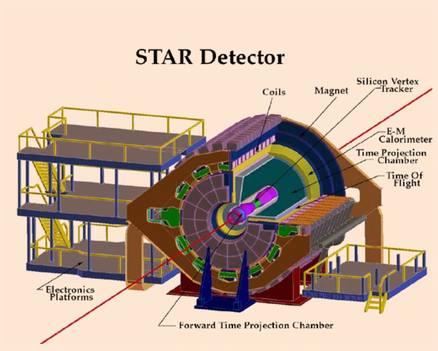
- Red arrows are the first particle in balance function calculation, while green ones are its opposite sign charge pairs
- $v_2<c_b>$ would be positive if more charges pairs are found in plane
- v_{2c} would be positive if charges are more correlated in plane
- v_{2s} would be negative if charges are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

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

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

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

Data Set

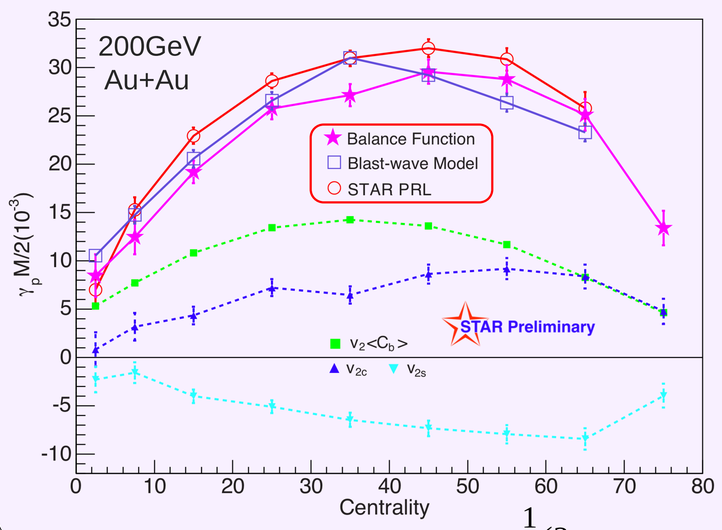


Energy (GeV)	Species	Year	Events (M)*
200	Au + Au	Run 4	14
62.4	Au + Au	Run 4	8
39	Au + Au	Run 10	10
11.5	Au + Au	Run 10	16
7.7	Au + Au	Run 10	4

*Number of events used in balance function calculation

- All charged particles
  - $|\eta| < 1.0$
  - $0.2 < p_t < 2.0$ GeV/c
  - Full azimuthal acceptance
  - Electrons are suppressed

Parity Observable

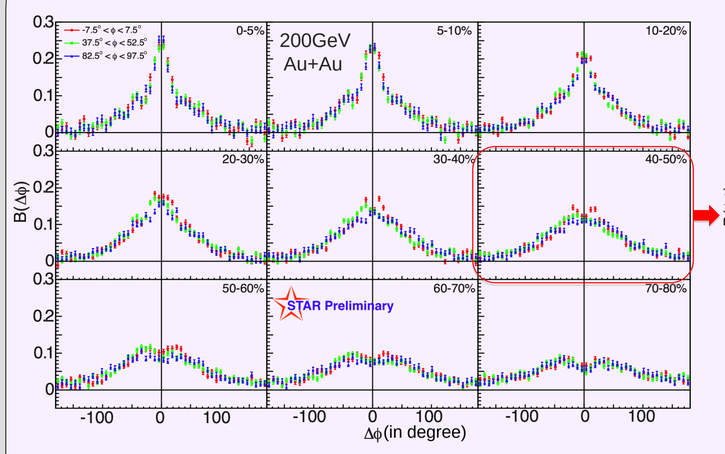


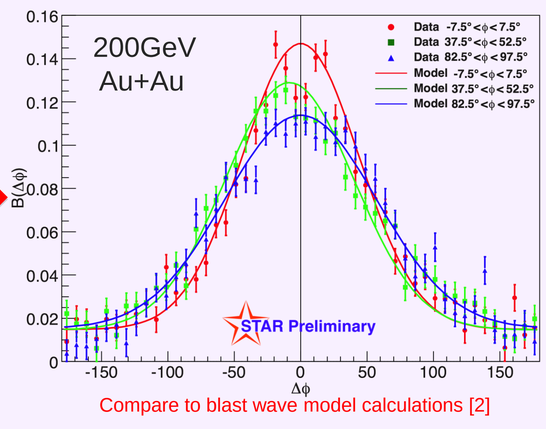
- γ_P is the difference between unlike- and like-sign three point correlators
- γ_P scaled by multiplicity can be written as the combination of $v_2<c_b(\Phi)>$, v_{2c} and v_{2s}
- Compare with STAR published data [1] and blast-wave model [2]
- The blast wave model reproduces the observed difference between unlike- and like-sign azimuthal correlations

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

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

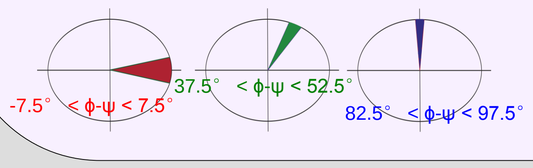
Balance Function





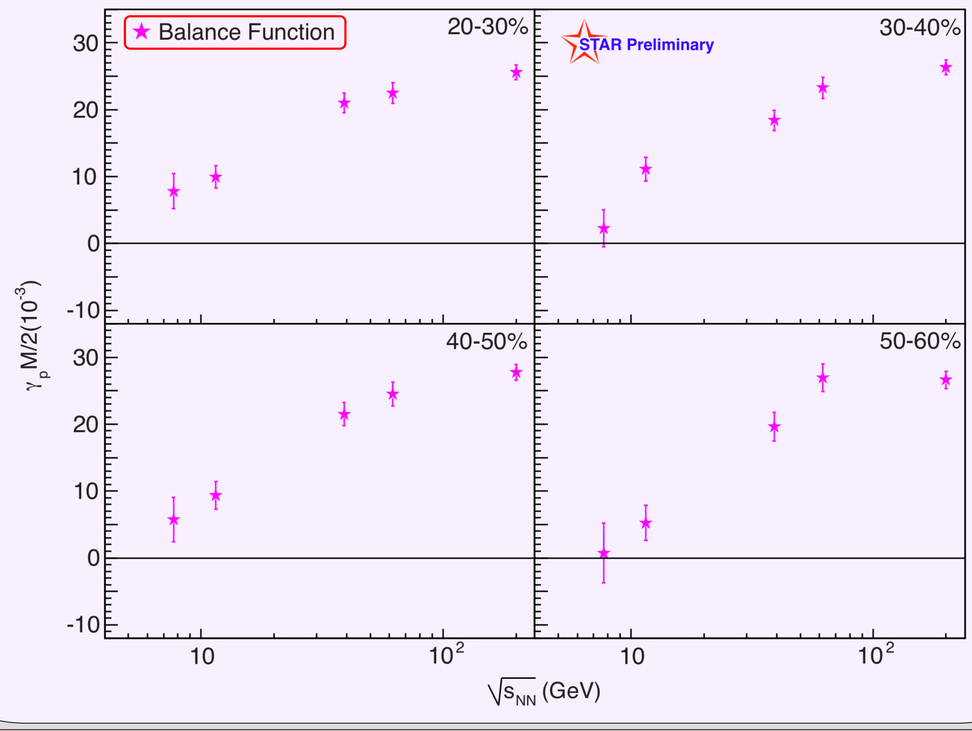
Compare to blast wave model calculations [2]

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

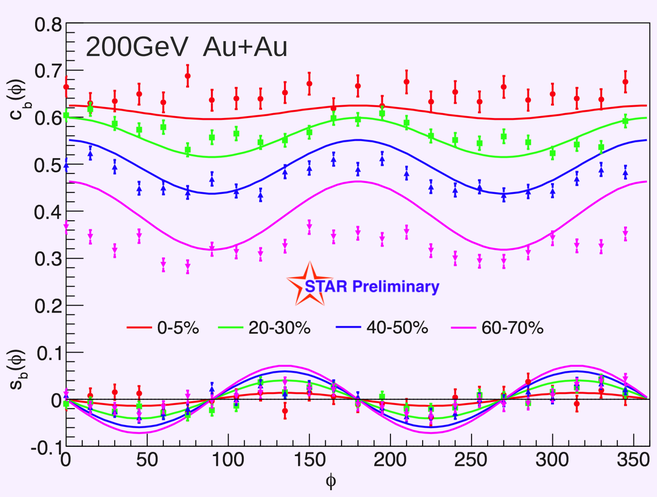


- Balance function narrows in central collision due to collective flow
- 45° to event plane balance function is biased toward negative ΔΦ region
- The out-of-plane balance function is wider than the in-plane balance function

Beam Energy Dependence



Weighted Average



- Compare data (points) with blast wave model calculations(solid lines)
- Data is not corrected for event plane resolution (differences between data and model)
- 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

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

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

$$z_b(\phi) \equiv \int d\Delta\phi B(\phi,\Delta\phi)$$

Summary

- Balance functions can reproduce the difference between unlike- and like-sign charge-dependent azimuthal correlations
  - Charge conservation
  - Flow effect
- γ_P scaled by multiplicity shows a smooth decrease with energy
  - Turn-off of signal at low energies?

References

[1] B. I. Abelev et al. [STAR Collaboration], Phys. Rev. Lett. 103, 251601 (2009) and B. I. Abelev, et al. [STAR Collaboration], Phys. Rev. C 81, 054908 (2010).

[2] S. Schlichting and S. Pratt, Phys. Rev. C 83, 014913 (2011).

See also: Quan Wang (STAR Collaboration): "**Measurement of Charge Multiplicity Asymmetry Correlations to Search for Chiral Magnetic Effect in Heavy Ion Collisions**" (Poster 583)