Charge dependent azimuthal correlations of K-π pairs at STAR

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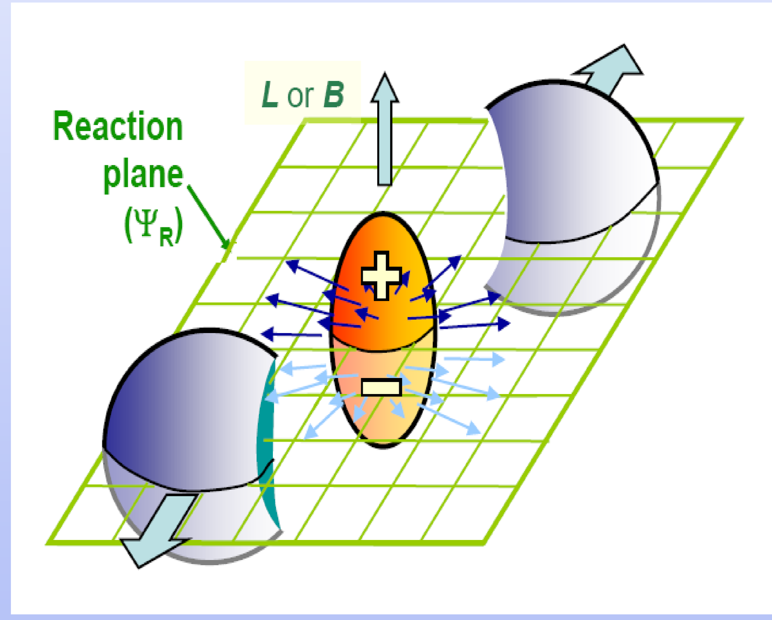
1. Local Parity Violation in Heavy-ion Collisions



Charge dependent azimuthal correlations have been used to probe for local parity violation (LPV) in the quark-gluon plasma (QGP) believed to be formed during Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV at the BNL Relativistic Heavy Ion Collider (RHIC) [1]. It was suggested [2] that P- and CP-odd domains form in the hot dense QCD matter created **during the initial stages of the collisions**, where the chiral magnetic effect (CME) would act as the driving force behind a separation of charges across the reaction plane (RP).

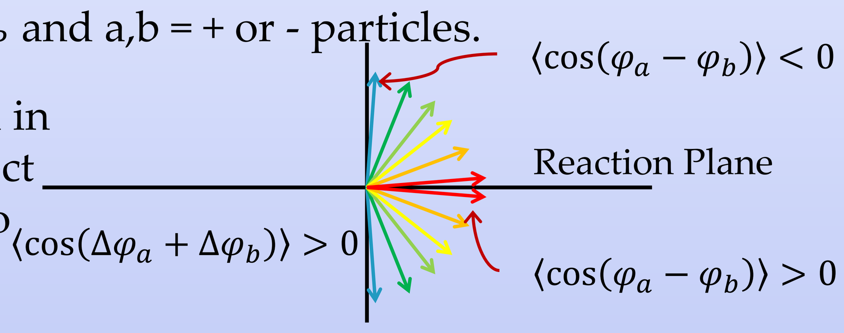
This electric dipole moment will be either parallel or anti-parallel to the strong magnetic field produced in the collision, meaning its expectation value over many events would vanish, however, **the variance should reflect the fact that parity is broken event-by-event.**

2. Measuring the Charge Separation

- Charge dependent azimuthal correlations were proposed [3] as a P-even observable that can detect these dipole fluctuations:

$$\gamma = \langle\cos(\Delta\varphi_a + \Delta\varphi_b)\rangle = \langle\cos\Delta\varphi_a \cos\Delta\varphi_b\rangle - \langle\sin\Delta\varphi_a \sin\Delta\varphi_b\rangle,$$

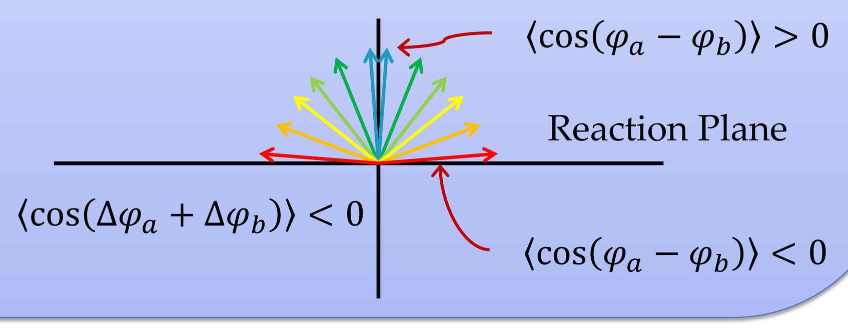
where $\Delta\varphi = \varphi - \Psi_{RP}$ and a,b = + or - particles.



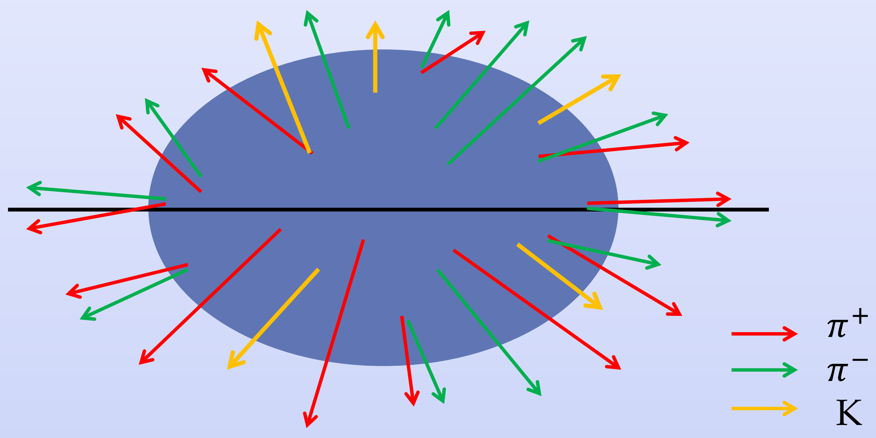
- γ looks at whether charges are emitted in same or opposite directions with respect to one another while taking the RP into account
- Another useful correlator:

$$\delta = \langle\cos(\varphi_a - \varphi_b)\rangle$$

- δ represents the tendency for two particles to be emitted in the same direction (positive) or in opposite directions (negative)

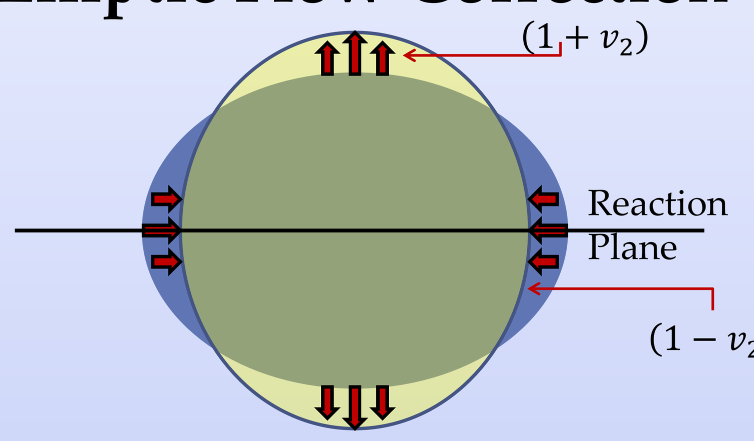


3. Kaon-Pion Pairs and an Elliptic Flow Correction



Kaon-Pion pairs

- There may be a tendency for π^+-π^- pairs to be created during the later stages of hadronization, after elliptic flow is established [4]
  - Implies many **pion pairs will be emitted at small angles with respect to one another,** obscuring the LPV signal
- It is expected that K-π pairs should suppress this effect



Modifying according to flow

- We apply a first-order correction to compensate for the elliptic flow

$$\gamma = \langle\cos(\Delta\varphi_a + \Delta\varphi_b)\rangle$$
$$= \langle\cos\Delta\varphi_a \cos\Delta\varphi_b\rangle$$
$$- \langle\sin\Delta\varphi_a \sin\Delta\varphi_b\rangle$$

Applying a correction:

$$\langle\cos\Delta\varphi_a \cos\Delta\varphi_b\rangle(1 - v_2)$$
$$- \langle\sin\Delta\varphi_a \sin\Delta\varphi_b\rangle(1 + v_2)$$
$$= \gamma - \delta v_2,$$

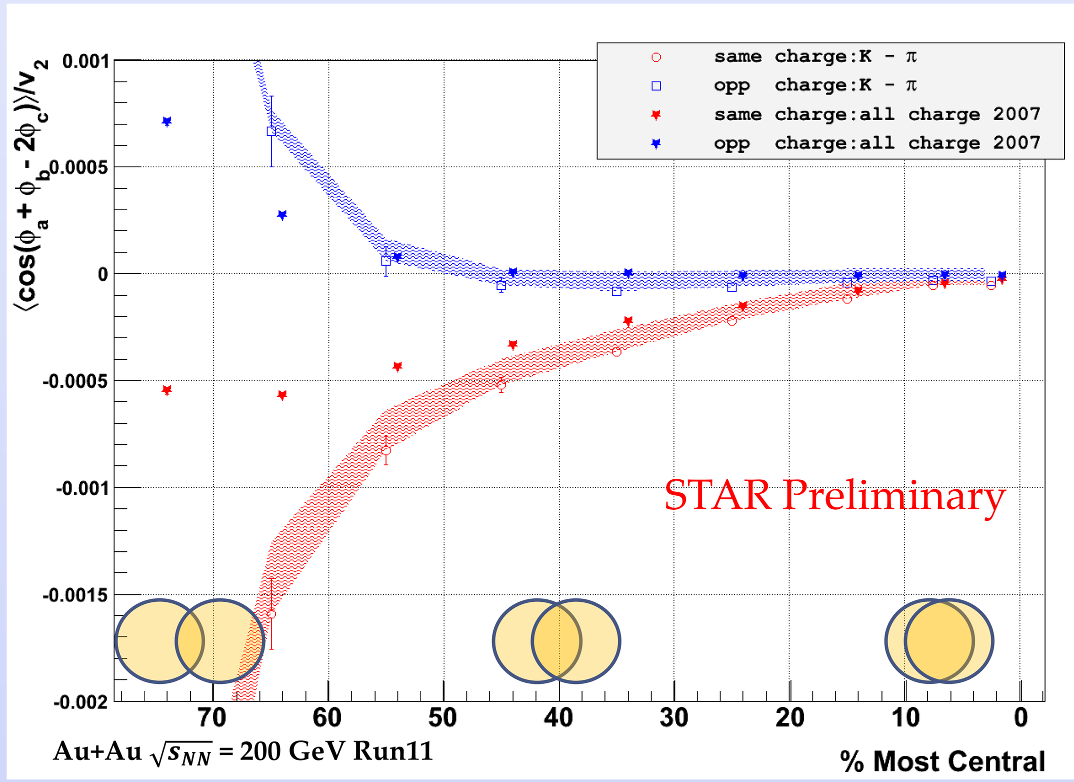
where v_2 is the elliptic flow

3. Experimental Details

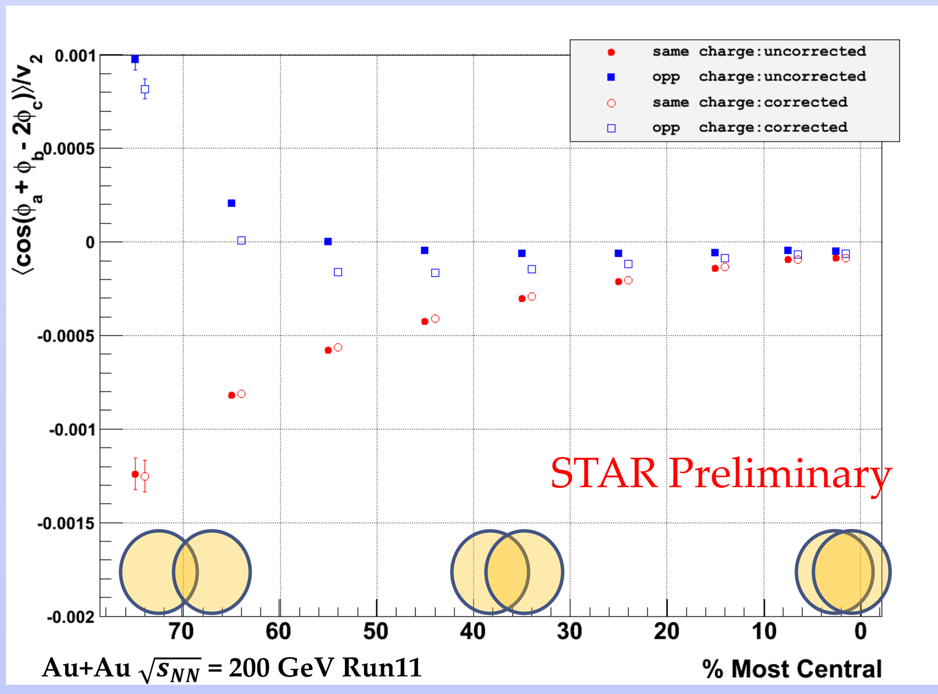
- The Time Projection Chamber (TPC) is used to track charged particles having a 2π azimuthal coverage
- Particles were analyzed within a pseudo-rapidity range $|\eta| < 1.0$ and transverse momentum range $0.2 < p_t < 2.0$ GeV/c
- Particles were identified using the Tim-Of-Flight (TOF) detector using a mass squared cut: $0.001 < m^2 < 0.1$(GeV/c^2)^2 for pions, $0.2 < m^2 < 0.3$(GeV/c^2)^2 for kaons
  - TOF identified particles then had to pass a TPC cut: $n_{\sigma\pi} < 2.0$ for pions, $n_{\sigma K} < 2.0$ for kaons

5. 2011 Data of $\sqrt{s_{NN}}$ = 200 GeV Au+Au Collisions

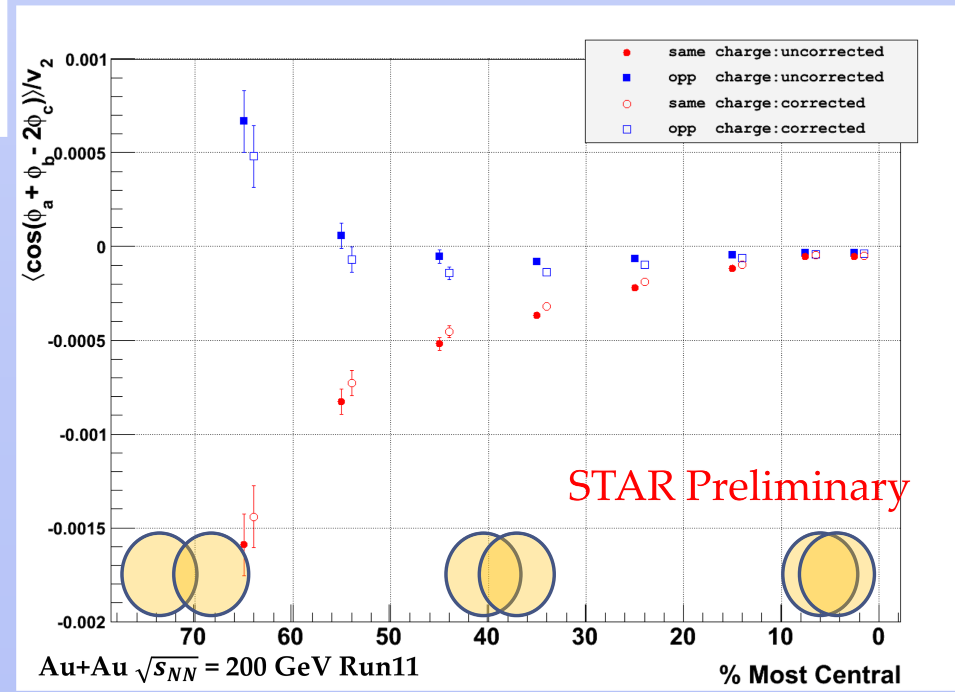
- Three-particle correlator (= $v_2\gamma$) uses a third particle, c (of any type and charge), to take the role of the RP
- The **difference between the opposite-sign and same-sign can be taken to be a charge separation signal**



- Comparing γ using all charged particles (i.e. mostly pions) from 2007 [5] and pairing K-π (2011)
- The shaded region represents systematic errors of data from 2011 compared with 2007, the error bars are statistical
- Charge separation signal is larger in K-π correlations for more peripheral bins – one cause is that selected kaons have higher transverse momentum



- Comparing γ (of all charge pairs, 2011) before and after applying an elliptic flow correction
- Opposite-sign correlations are pulled more negative while same-sign correlations are largely unaffected – a slight reduction in the signal
- Changes in signal reflects δ for all charge correlations



- Comparing γ (of K-π pairs) before and after applying an elliptic flow correction
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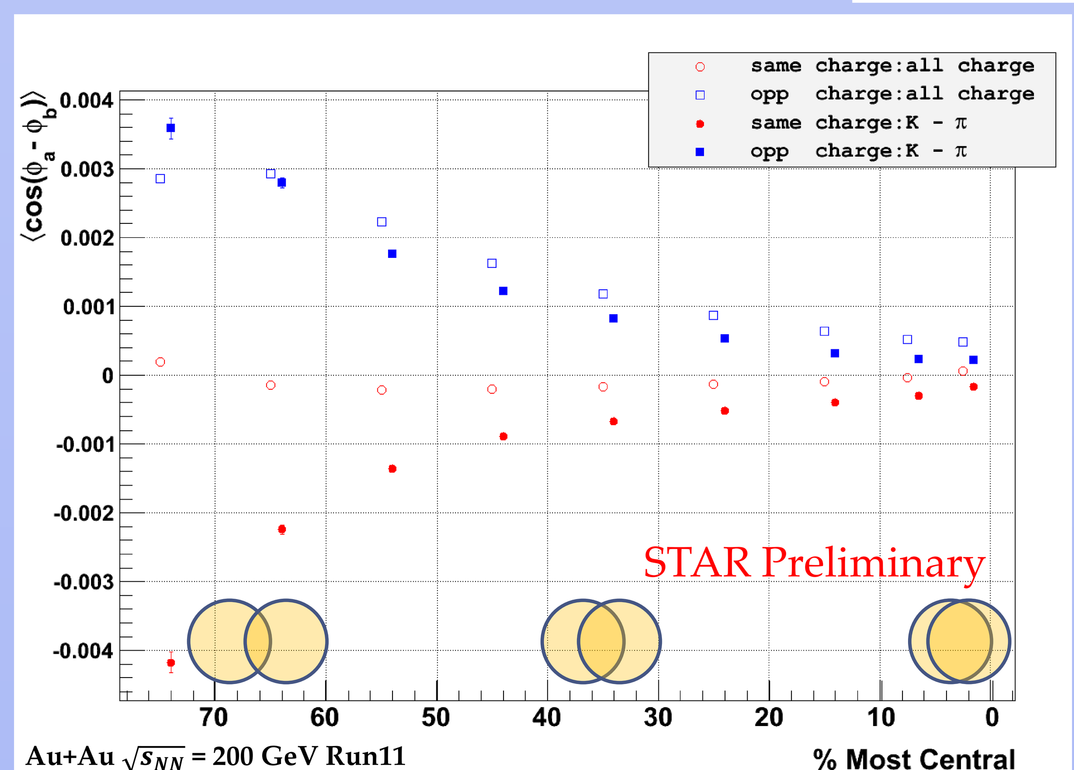

- Comparing δ using all charged particles (i.e. mostly pions) from 2011 with K-π pairs
- Opposite-sign correlations are pulled more negative in K-π correlations since these will be experiencing significant contributions from late stage creation of pions
- The difference in same-sign correlations is intriguing

6. Conclusion

- Charge separation effect similar to, if not greater than, previous methods using all charged pairings.
- **Looking at K-π pairs and applying flow corrections help suppress possible P-even sources**, further refining previously published results[1].
- Data indicates signal may be more due to particle emission preferentially occurring in the vicinity of in-plane more than out.
  - In fact, one has to consider the possibilities of jets and other strong-interaction backgrounds which may dominate the CME signal.
- NB: K* resonances may contribute to opposite-sign K-π correlations, however, preliminary simulation results show they have little effect on the signal.
- The use of balance functions as a means to explain these results as a consequence of a combination of the blast-wave model and charge conservation are also being studied - see Hui Wang's poster

[1] B. I. Abelev *et al.* (STAR Collaboration), Phys. Rev. Lett. **103,** 251601 (2009)
[2] D. E. Kharzeev, L. D. McLerran, and H. J. Warringa, Nucl. Phys. **A803,** 227 (2008)
[3] S. A. Voloshin, Phys. Rev. C **70,** 057901 (2004)
[4] S. Pratt (2012) arXiv:1109.3647v3 [nucl-th]
[5] D. Gangadharan (STAR Collaboration), J. Phys. G: Nucl. Part. Phys. **38,** 124166 (2011)

The STAR Collaboration: http://drupal.star.bnl.gov/STAR/presentations

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