Measurement of Charge Multiplicity Asymmetry Correlations to Search for Chiral Magnetic Effect in Heavy Ion Collisions

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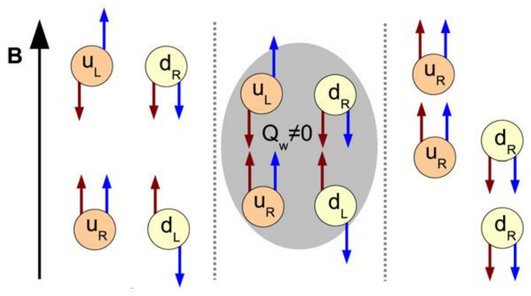
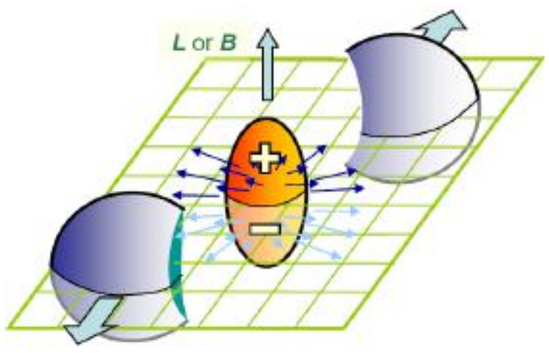
ABSTRACT It has been suggested that local parity violation in QCD would lead to charge separation of quarks by the Chiral Magnetic Effect (CME) in heavy ion collisions. Charge separation could yield a dynamical charge multiplicity asymmetry with respect to the reaction plane. We report results on charge multiplicity asymmetry correlations in $\sqrt{s_{NN}}$ = 200 GeV Au+Au and d+Au collisions by the STAR experiment, as well as from the RHIC beam energy scan. We found that the correlation results could not be explained by CME alone. We study our results as a function of the measured azimuthal angle range as well as the event-by-event anisotropy parameter v_2^{obs}. The results indicate that the charge separation effect appears to be in-plane rather than out-of-plane. We found that the charge separation effect is proportional to the event-by-event v_2^{obs} and consistent with zero in events with $v_2^{obs} \cong 0$. Our studies suggest that the charge separation effect, within the statistical error, may be a net effect of event anisotropy and correlated particle production. Possible upper limit on the CME imposed by our data will be discussed.

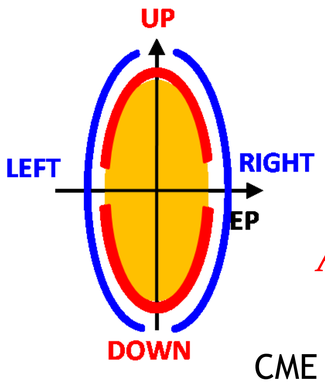
MOTIVATION AND OBSERVABLES

In quantum chromodynamics (QCD), by interacting with fermions, topological charge Q≠0 fields induce parity odd effects. With the presence of large external magnetic field, charge separation is expected.





Chiral Magnetic Effect (CME):
- ➢Quark gluon plasma
- ➢Chiral symmetry restoration
- ➢Local parity violation
- ➢Large magnetic field
- ➢Charge separation

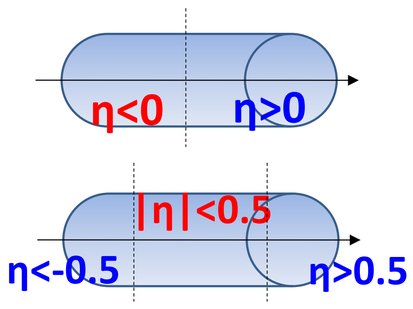


Separate an event into two hemispheres, Up and Down, or Left and Right. Charge Multiplicity Asymmetries are defined as:

$$A_{\pm,UD} = \frac{N_{\pm,up} - N_{\pm,down}}{N_{\pm,up} + N_{\pm,down}} \qquad A_{\pm,LR} = \frac{N_{\pm,left} - N_{\pm,right}}{N_{\pm,left} + N_{\pm,right}}$$

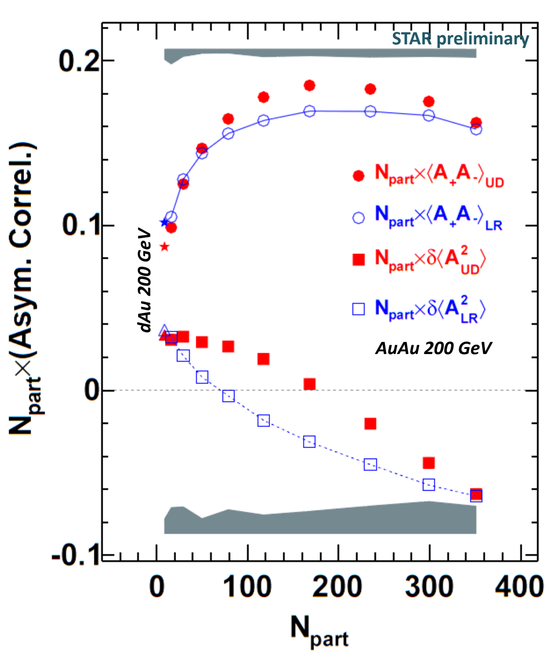
CME Expects:
- ❑ Charge separation across EP. A_{LR} is the null-reference.
- ❑ A_{+UD} and A_{-UD} are anti-correlated ➔ $\langle A_+A_-\rangle_{UD} < \langle A_+A_-\rangle_{LR}$
- ❑ Dynamical fluctuation broadens $A_{\pm UD}$ ➔ $\langle A_\pm^2\rangle_{UD} > \langle A_\pm^2\rangle_{LR}$

Data Set and Analysis Details



- ❑ 2004 Au+Au 200 GeV and 2003 d+Au 200 GeV minimum bias data, Beam Energy Scan data collected from STAR at RHIC.
- ❑ p_T range:
  - ➢ Event plain: 0.15<p_T<2.0 GeV/c
  - ➢ Asymmetry: 0.15<p_T<2.0 GeV/c
- ❑ Separate η to remove self-correlation.

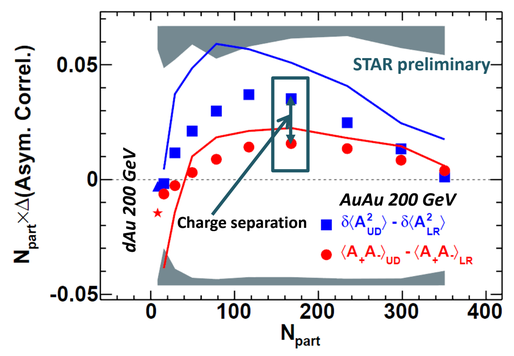
Charge Multiplicity Asymmetry Correlation Results

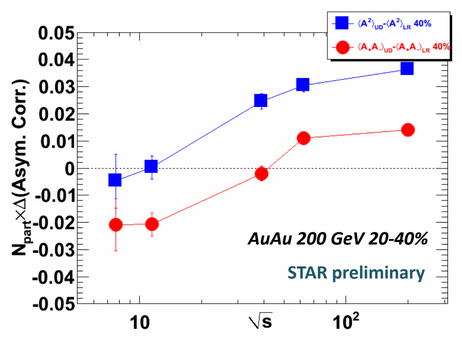


➢ opposite-sign particles are preferentially in same direction, in all centralities.

➢ same-sign particles are preferentially in same direction in peripheral, but in mid-central to central, they prefer back-to-back.

UD-LR Results and Charge Separation



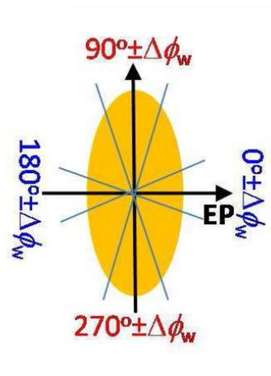


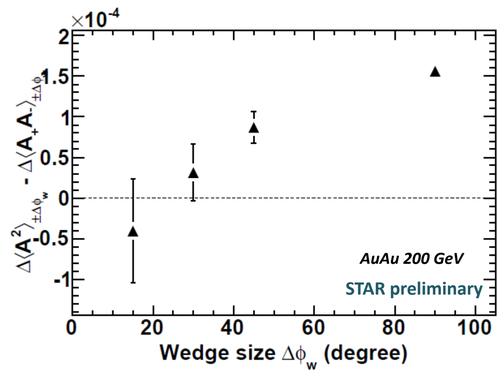
- ➢ Data not corrected by EP resolution, curves(left) are data/resolution.
- ➢ Same- and opposite-sign UD-LR results qualitatively similar at 200 GeV.
- ➢ Same-sign UD-LR is positive, consistent with CME.
- ➢ Opposite-sign UD-LR also positive at 200 GeV, inconsistent with CME alone.

UD-LR difference: same-sign > opposite-sign : **charge separation**.

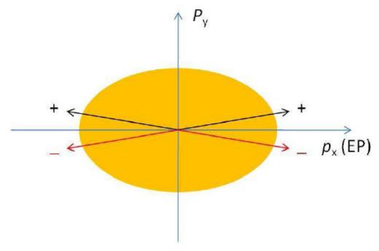
Is the Charge Separation Out-of-plane or In-plane?

➢ If CME yields final-state same-sign pairs preferentially in the orbital angular momentum direction, then the charge separation effect should be larger with smaller wedge size.

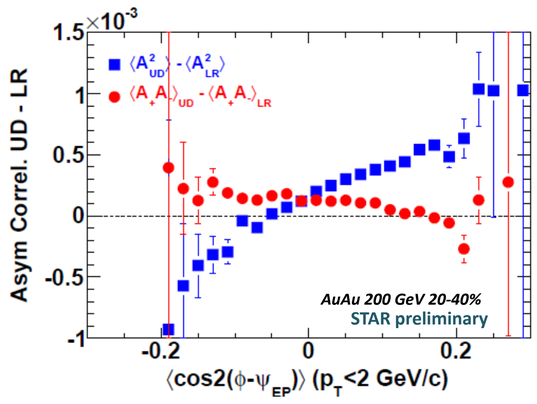




➢ Charge separation is actually smaller for smaller wedge size. Suggest the effect is in-plane: the charge separation across the EP happens in the vicinity of the EP.

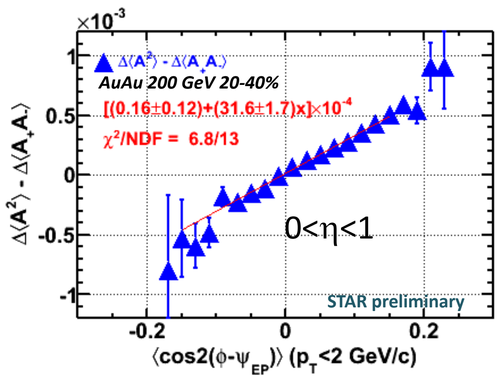


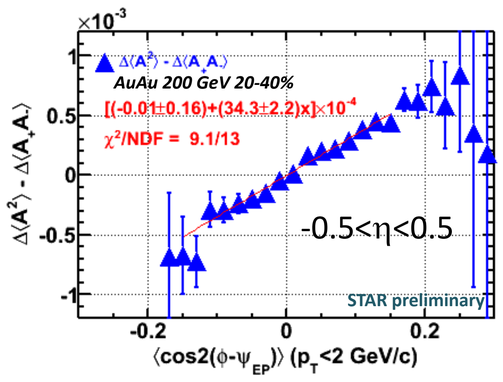
Is the Charge Separation CME or Physics Background?



❑ Charge multiplicity asymmetry correlations as a function of the event-by-event anisotropy (v_2^{obs}) of the measured particles in the 20-40% centrality.

❑ Same-sign and opposite-sign show different trend.





❑ The charge separation effect is proportional to event-by-event anisotropy of measured particles (v_2^{obs}= $\langle\cos2(\phi-\Psi_{EP})\rangle$), suggesting a v_2^{obs}-related background, but interpretation is still under investigation.

❑ Background may be a net effect of anisotropy and particle correlation.

❑ In v_2^{obs}=0 events where such background may be absence, charge separation effect is consistent with 0.

SUMMARY

- ❑ Charge multiplicity asymmetry correlations are reported in 200 GeV Au+Au and d+Au collisions, as well as RHIC energy scan.
- ❑ Results could not be explained by CME alone.
- ❑ The charge separation appears to be in-plane rather than out-of-plane.
- ❑ The charge separation effect is proportional to the event-by-event v_2^{obs}. It may be a net effect of particle anisotropy and correlated production.
- ❑ Upper limit of charge separation in $v_2^{obs} \cong 0$ events: 4×10^{-5} at 98% CL.

Please also refer to ***Hui Wang*** (STAR collaboration) poster 381 "***Local Parity Violation or Local Charge Conservation/Flow?***"