Charge Asymmetry Correlations to Search for the Chiral Magnetic Effect from Beam Energy Scan by STAR

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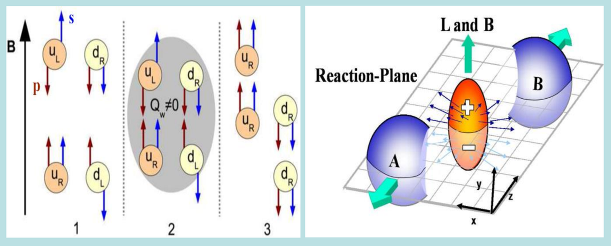
Abstract

STAR has reported the measurement of charge asymmetry correlations with respect to the event plane in search for the Chiral Magnetic Effect [1]. The charge separation parameter Δ after model independent subtraction of elliptic flow (v_2) background, was measured to be $1.3 \pm 1.4(\text{stat.})^{+4.0}_{-1.0}(\text{syst.}) \times 10^{-5}$ for 20− 40% Au+Au collisions at 200GeV, consistent with zero. In this talk we report results obtained with higher statistics data. A statistically significant finite signal is observed. The improved statistical precision allows systematic studies of the charge separation and investigation of possible additional physics backgrounds. It is found that the charge separation parameter Δ increases with decreasing centrality, but shows a weak beam energy dependence. We also report the application of a multi-particle correlation method [2] for the measurement of charge separation with model-independent background subtraction by the mixed-event technique. By comparing correlation functions along and perpendicular to the event plane, upper limits are set on the charge separation parameter in the high statistics 200 GeV Au+Au data. These results will be discussed in terms of the possible Chiral Magnetic Effect and/or physics background.

[1] L. Adamczyk et al. (STAR Collaboration) Phys. Rev. C **89**, 044908 (2014). [2] N. N. Ajitanand, R. A. Lacey, A. Taranenko, and J. M.Alexander, Phys. Rev. C **83**, 011901(R) (2011)

Motivation

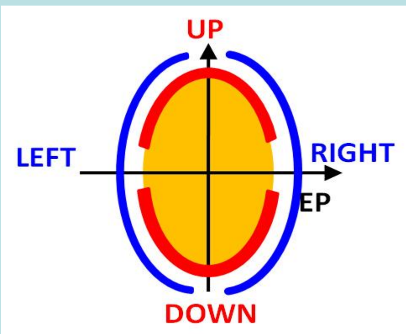


Nuclear Physics A 803.3 (2008)

- **Color Deconfinement** "free" quarks
- **Topological charge** $Q_w = \frac{g^2}{32\pi^2}\int d^4x F^{\alpha}_{\mu\nu} F^{\mu\nu}_{\alpha}$
- **Q_w<0**: LH→RH, **Q_w>0**: RH→LH **Sign of Q_w is random, and $\langle Q_w \rangle$=0**
- A large magnetic field **Charge Separation (*Chiral Magnetic Effect*)**
- **It is across the Reaction-Plane (xz-plane)**

Analysis method

Multiplicity asymmetry method[1]



Charge Multiplicity Asymmetries

$$A_{\pm,UD} = \frac{N_{\pm,up} - N_{\pm,down}}{N_{\pm,up} + N_{\pm,down}}$$

$$A_{\pm,LR} = \frac{N_{\pm,left} - N_{\pm,right}}{N_{\pm,left} + N_{\pm,right}}$$

Average dynamical variance

$$\delta\langle A^2_{UD}\rangle = \left(\delta\langle A^2_{+,UD}\rangle + \delta\langle A^2_{-,UD}\rangle\right)/2$$
$$\delta\langle A^2_{LR}\rangle = \left(\delta\langle A^2_{+,LR}\rangle + \delta\langle A^2_{-,LR}\rangle\right)/2$$

Covariance

$$\delta\langle A_+A_-\rangle_{UD} = \langle A_+A_-\rangle_{UD} - \langle A_+A_-\rangle_{UD,stat+det}$$
$$\delta\langle A_+A_-\rangle_{LR} = \langle A_+A_-\rangle_{LR} - \langle A_+A_-\rangle_{LR,stat+det}$$

The difference between UD and LR measurements

$$\Delta\langle A^2\rangle = \delta\langle A^2_{UD}\rangle - \delta\langle A^2_{LR}\rangle$$
$$\Delta\langle A_+A_-\rangle = \delta\langle A_+A_-\rangle_{UD} - \delta\langle A_+A_-\rangle_{LR}$$

Charge separation can be quantified by

$$\Delta = \Delta\langle A^2\rangle - \Delta\langle A_+A_-\rangle$$

Δ > 0 would indicate a charge separation effect consistent with CME (however, see caveat in [Wang, Koch,[1]]).

Phys. Rev. C **81**, 064902 (2010)
Phys. Rev. C **81**, 031901(R) (2010)

Multi-particle correlation method[2]

$S = \sin(\Delta\phi)$ $\quad \Delta\phi = \phi - \Psi_{RP}$

$\langle S^{h+}_p\rangle$ and $\langle S^{h-}_n\rangle$ = average S over the positively and negatively charged hadrons in the same event
$\langle S^{h\pm}_p\rangle$ and $\langle S^{h\mp}_n\rangle$ = average S over randomly chosen hadrons and remaining hadrons in the mixed event

Construct multi-particle correlator C_p $\quad C_p(\Delta S) = \frac{N(\langle S^{h+}_p\rangle - \langle S^{h-}_n\rangle)}{N(\langle S^{h\pm}_p\rangle - \langle S^{h\mp}_n\rangle)}$, $\Delta S = \langle S_p\rangle - \langle S_n\rangle$

Data analysis procedure:

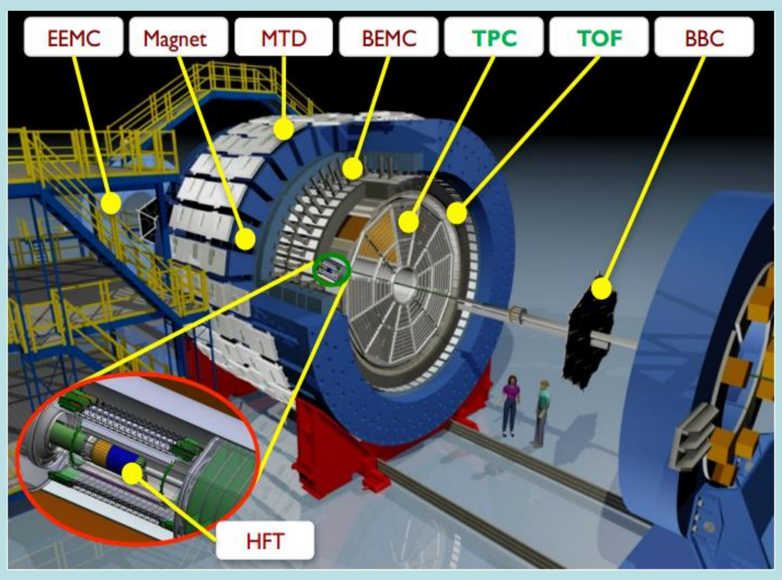
a) For data: Construct correlators C_p and C_{p_prep} using Ψ_2 and ($\Psi_2 + \pi/2$) respectively.
b) For simulations: Re-assign azimuths of data particles using flow function and obtain correlators C_p and C_{p_prep}.

$$\frac{dN_\pm}{d\phi} \propto 1 + 2v_1\cos(\Delta\phi) + 2v_2\cos(2\Delta\phi) + \cdots + 2\boldsymbol{a}_{1,\pm}\sin(\Delta\phi) + \cdots, \Delta\phi = \phi - \Psi_{RP}$$

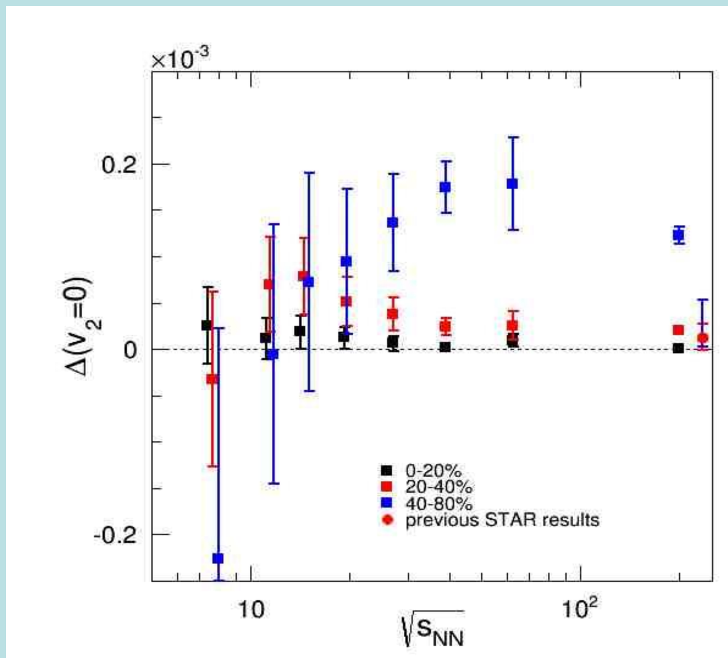
c) Compare shapes of C_p/C_{p_prep} for Data and Simulation.

The Solenoidal Tracker at RHIC (STAR) and Data sets

- Event selection
  |Vz|<30cm: 11.5,14.5,19.6,27,39,62.4,200GeV
  |Vz|<50cm: 7.7GeV
  |Vz-vpdVz|<3cm : 62.4,200GeV
  |Vr|<2cm: 7.7,11.5,14.5,19.6,27,39,62.4,200GeV
- Track selection
  Pseudo-rapidity $|\eta|<1$
  Number of TPC hits nfit>20
  $0.15<p_T<2.0$GeV/c
  DCA<2cm
  Ratio of nfit to maximum fit points rfit>0.52



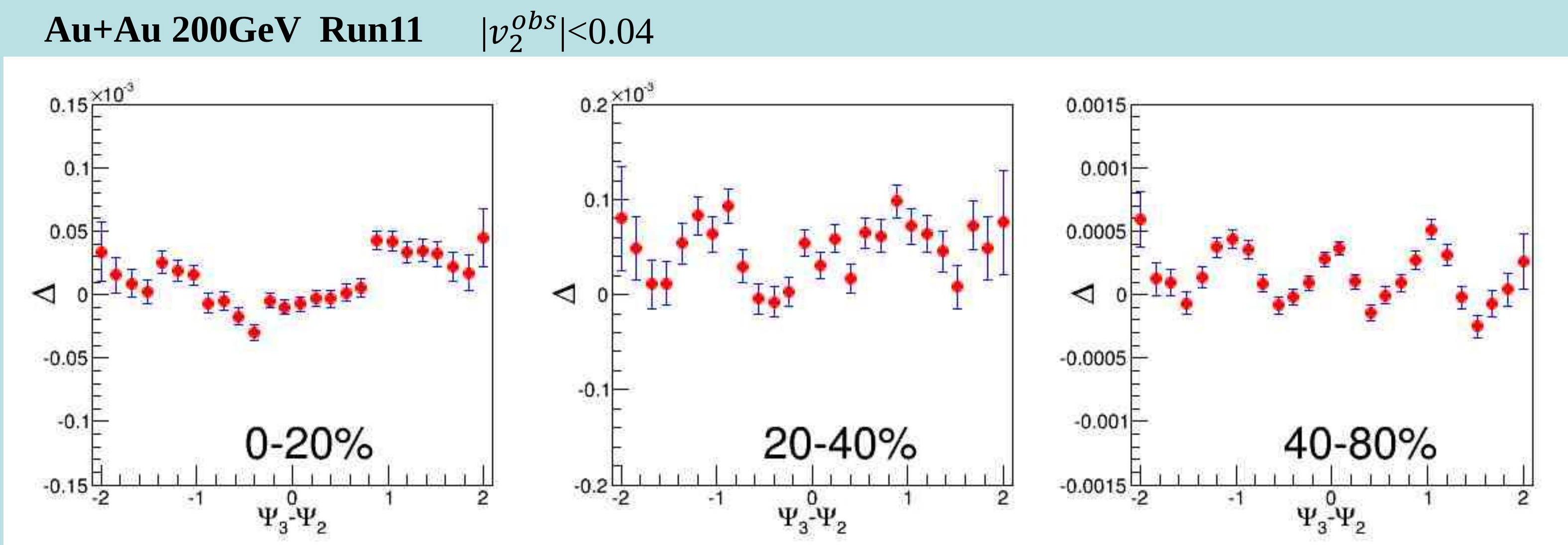
Energy dependence



- In central collisions, the values of Δ are consistent with zero, but larger than zero in middle and peripheral collisions at $\sqrt{s_{NN}} > 20GeV$. Event plane corrections have not applied yet.
- Charge separation has a weak energy dependence in middle central collisions
- Higher statistics needed for $\sqrt{s_{NN}} < 20GeV$

Additional physics background from event shape?

Au+Au 200GeV Run11 $\quad |v_2^{obs}|$<0.04

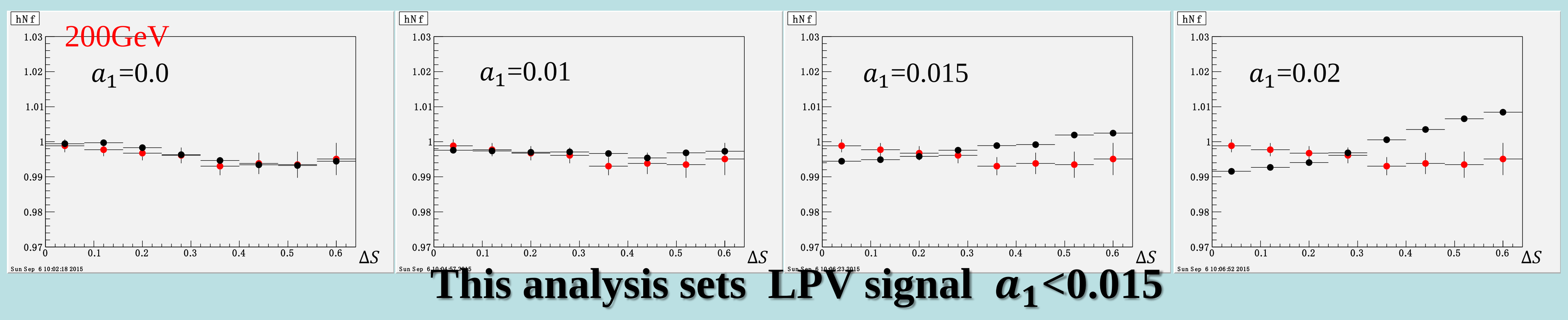


- Δ oscillates with $\Psi_3 - \Psi_2$.
- Need further investigation.

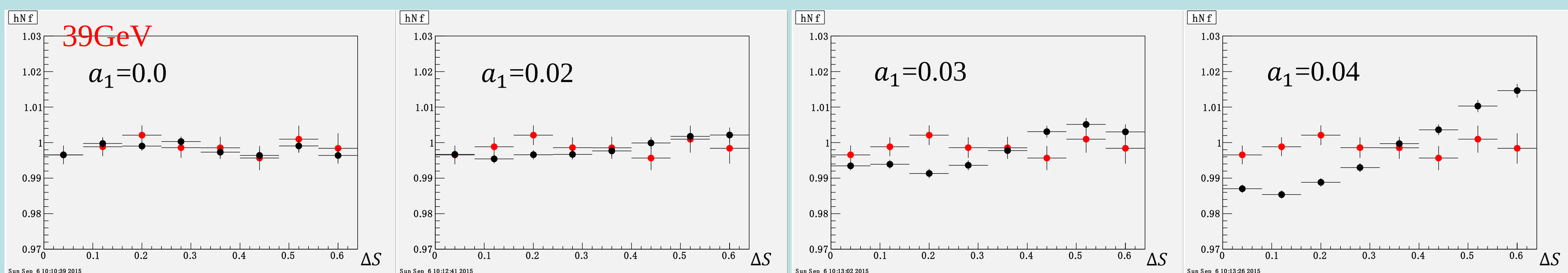
C_p/C_{p_perp}

Au+Au, 30%-50%, $1.0<p_T<2.0$

SIM : Black symbols
Data : Red Symbols



This analysis sets LPV signal a_1<0.015

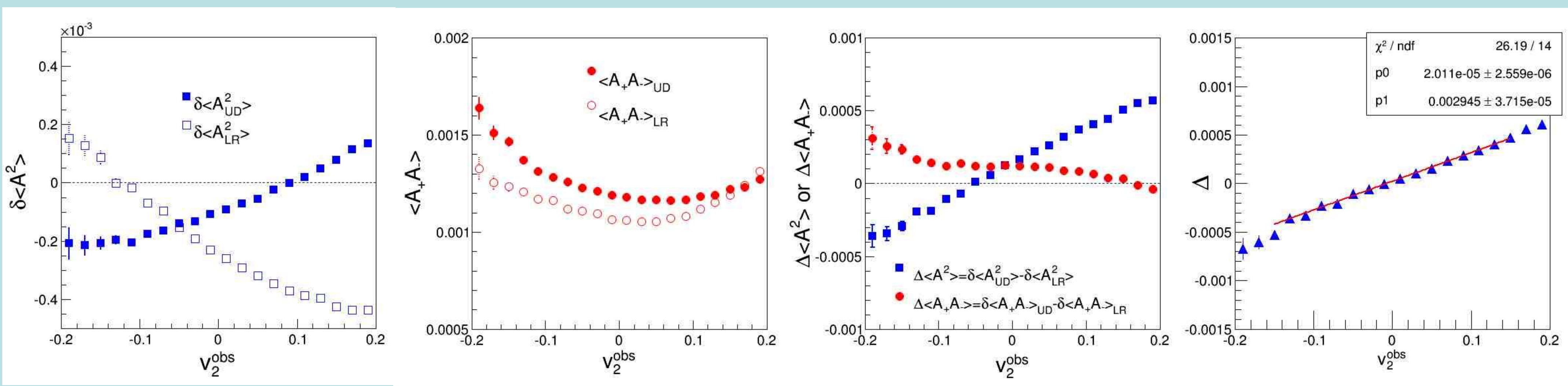


This analysis sets LPV signal a_1<0.03

- By comparing the shapes of the correlation function along and perpendicular to the reaction plane one can remove most of the effects not connected to the parity violating signal 'a_1'.
- **For $\langle p_T \rangle$>=1.3 in 30-50% centrality this method sets an upper limit of 1.5 (3.0)% on the value of a_1 for 200(39) GeV Au+Au collisions.**

v_n background

Dependence of event-by-event v_2 **Au+Au 200GeV 20-40%**



$v_2^{obs} = \langle\cos 2(\phi - \psi_{EP})\rangle$ $\quad$ **$0.15<p_T<2$GeV/c**

- Δ have a strong linear dependence on v_2. Need to **remove v_2 background.**
- $\Delta(v_2^{obs}=0) = 2.0 \pm 0.3(stat.) \times 10^{-5}$ consistent with previous STAR results[1] $\Delta = 1.3 \pm 1.4(stat.)^{+4.0}_{-1.0}(syst.) \times 10^{-5}$.
- no v_3 and v_4 dependence is observed, suggesting no v_3, v_4 background.

Summary

- Charge separation is contaminated by v_2. Model independent removal of effects from v_2, effectively a background to this analysis.
- Finite positive charge separation is observed in mid-central collisions at beam energies above 20 GeV. More statistics are needed for lower energies.
- Charge separation increases with decreasing centrality, but shows a weak beam energy dependence. Event plane corrections have not applied yet.
- Charge separation shows oscillating behavior with the third relative to the second harmonic plane angle, suggesting additional physics backgrounds from the events shape.
- Most of the effects not connected to the parity violating signal 'a_1' can be removed by comparing the shapes of the correlation function along and perpendicular to the reaction plane.
- In 30-50% centrality, multi-particle correlation method sets an upper limit of 1.5 (3.0)% on the value of a_1 for 200(39)GeV Au+Au collisions.

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

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