Search for the Chiral Magnetic Effect using Sliding Dumbbell Method in Isobar Collisions ($^{44}_{96}Ru + ^{44}_{96}Ru$ and $^{40}_{96}Zr + ^{40}_{96}Zr$) at RHIC

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Introduction

In the hot dense de-confined medium in non-central heavy-ion collisions, the strong magnetic field created by the fast-moving spectator protons causes the charge separation perpendicular to the reaction plane, a phenomenon known as the Chiral Magnetic Effect (CME) [1] as shown in Fig.1. The charge separation effect has been investigated both at RHIC and LHC using the CME sensitive γ-correlator ($\langle cos(\phi_a + \phi_b - 2\Psi_{RP})\rangle$) [2]. It was realized that four more protons in $^{96}_{44}Ru$ than those in $^{96}_{40}Zr$ will result in an increased magnetic field (~10%) in $^{96}_{44}Ru + ^{96}_{44}Ru$ collisions than those in $^{96}_{40}Zr + ^{96}_{40}Zr$ collisions [3].

This led to the expectation of an enhanced CME effect in Ru+Ru collisions than in Zr+Zr collisions both having similar backgrounds. A new technique, Sliding Dumbbell Method [4] is designed to search for potential CME-like events corresponding to the highest back-to-back charge separation.

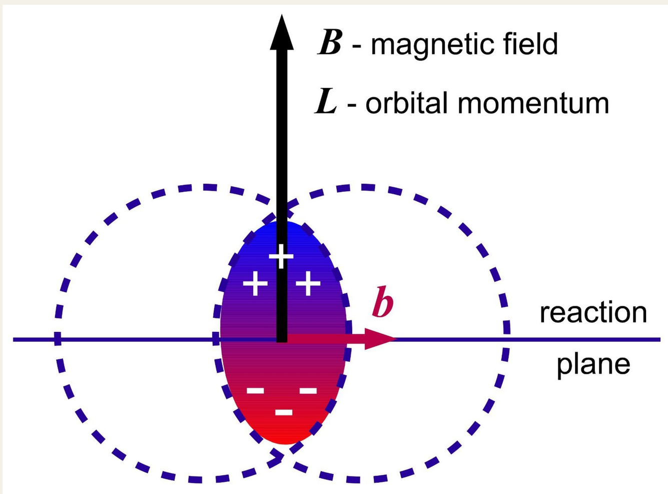


Fig.1: A schematic illustration of charge separation in non-central heavy-ion collision.

Analysis Method: Sliding Dumbbell Method

The Sliding Dumbbell Method (SDM) [3] is designed to search minutely for the back-to-back charge separation on an event-by-event basis (Fig.2). Azimuthal plane in each event is scanned by sliding the dumbbell of 90° in steps of $\delta\phi = 1^\circ$ while calculating, Db_{+-} for each region to obtain the maximum value of Db_{+-} i.e., Db_{+-}^{max} in each event.

$$Db_{+-} = \frac{n_+^a}{(n_+^a + n_-^a)} + \frac{n_-^b}{(n_+^b + n_-^b)}$$

Where, n_+^a *and* n_-^a (n_+^b *and* n^b_-), are the number of positive and negative charged particles on the "a"("b") side of the dumbbell.

- Fractional Charge separation (f_{DbCS}) across the dumbbell in each event is defined as :

$$f_{DbCS} = Db_{+-}^{max} - 1$$

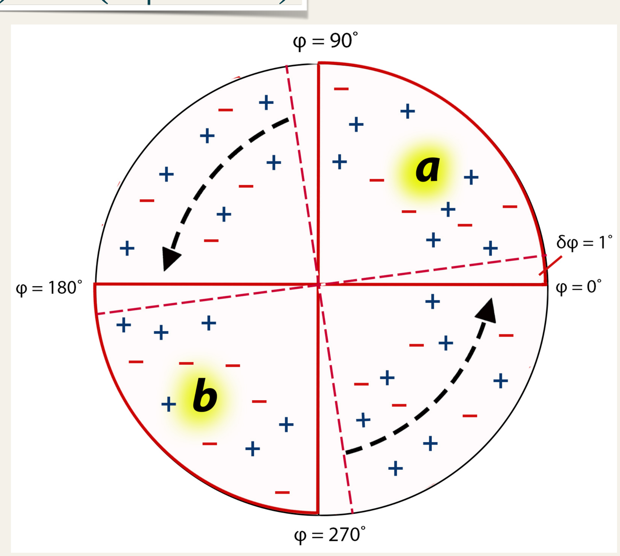


Fig.2: Pictorial depiction of the transverse (azimuthal) plane with hits of positive (+) and negative (-) charge particles in an event.

Experimental Setup

The STAR (Solenoidal Tracker at RHIC) detector shown in Fig.3 at RHIC consists of various sub-detectors. Time Projection Chamber (TPC) and Time of Flight (TOF) are the main sub-detectors, with complementary tracking and particle identification capabilities.

Data Set: Isobaric Collisions (Ru+Ru & Zr+Zr) at 200 GeV (~50% of the available data) .

Event and Track selection cuts are as follows:

- **Vertex Cut**: -35 < V_z < 25 cm
- **Pseudo-rapidity Cut**: $|\eta| < 1$
- **Transverse momentum Cut**: $0.2 < p_t < 2.0 GeV/c$
- **Distance of Closest Approach**: DCA < 3 cm

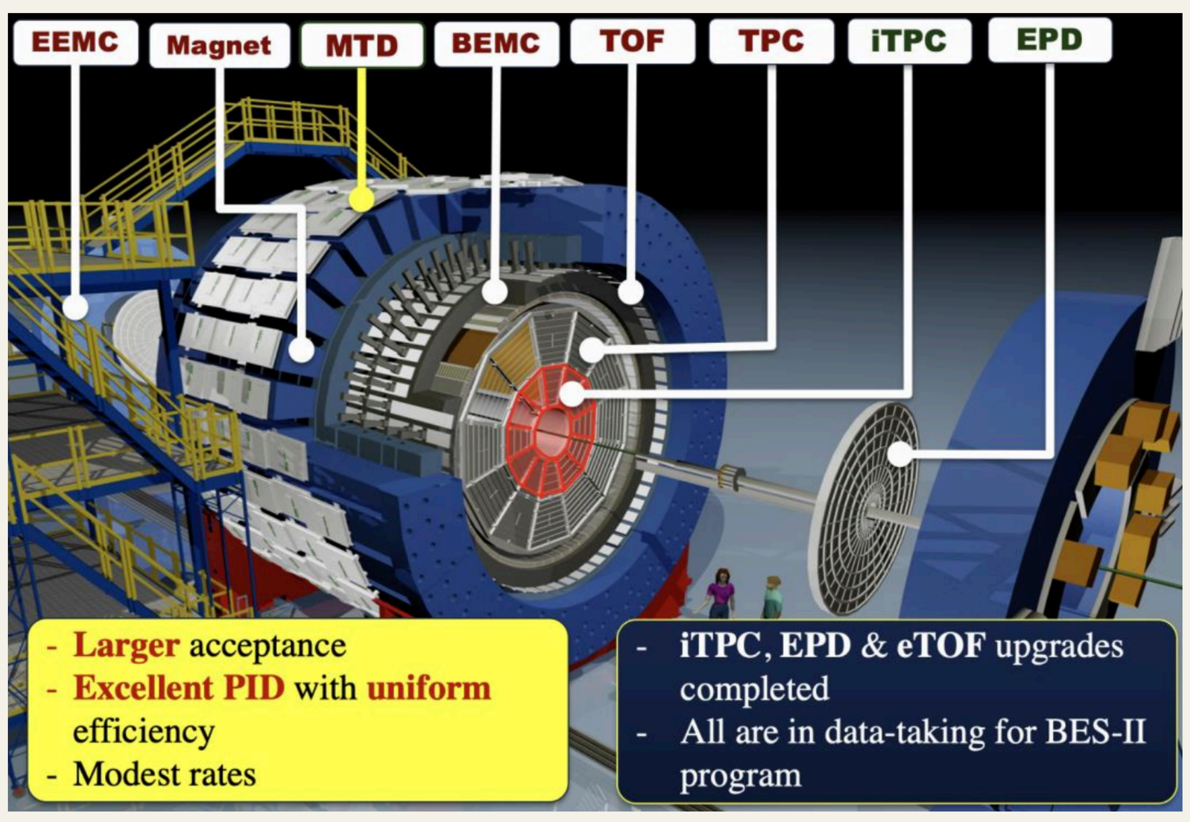


Fig 3:Layout of sub-detectors of the STAR experiment.

Background Estimation

•**Charge Shuffle (ChS)**: The charges of particles in each event are shuffled randomly to destroy the charge-dependent correlations amongst charged particles but keeping θ and ϕ of each particle unchanged in an event.

•**Correlated (Corr.) Background**: The shuffling of charges of particles in an event keeping the flow in, kills not only the CME-like correlations but also correlations amongst produced particles in an event. Correlations amongst particles that were destroyed during charge shuffling were recovered from the corresponding original events in a particular f_{DbCS} bin. This is termed as the correlated background.

Results

Fig.4: It is seen that the charge separation (f_{DbCS}) distributions extend towards higher f_{DbCS} values with decreasing collision centrality. Different f_{DbCS} distributions are divided into ten percentile bins for each centrality.

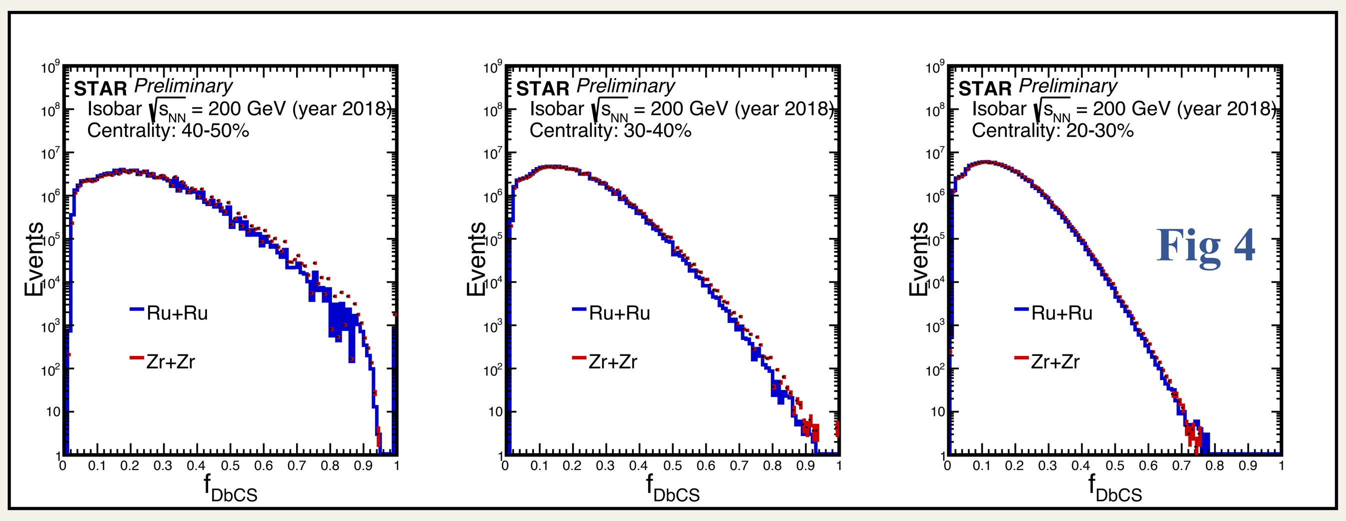
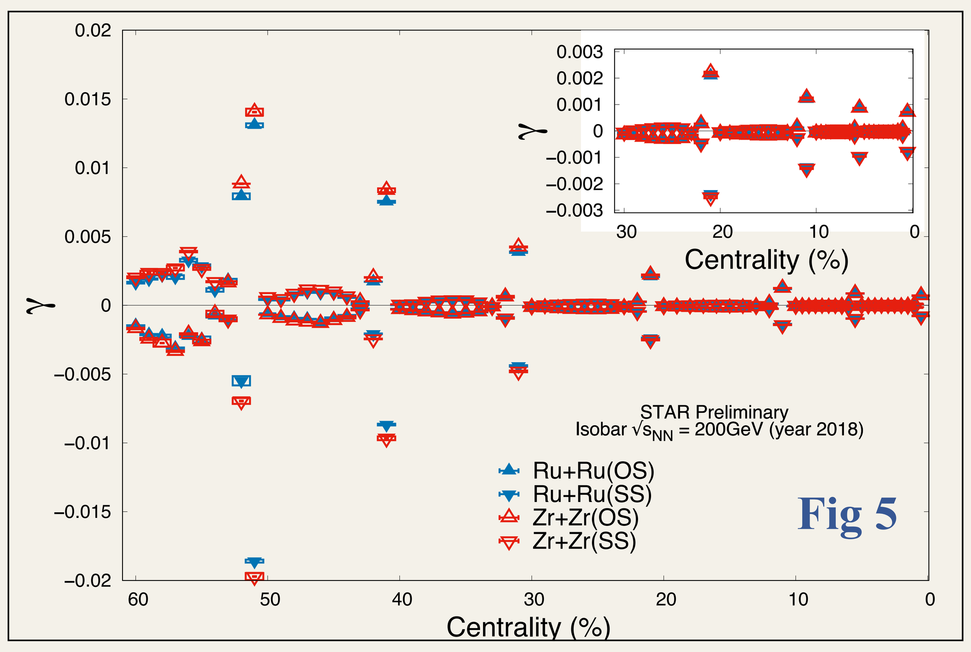


Fig.5: γ_{OS} *and* γ_{SS} are plotted as a function of centrality for Ru+Ru and Zr+Zr collisions along with different charge separation (f_{DbCS}) bins. It is seen that for the highest charge separations, $\gamma_{OS} > 0$ *and* $\gamma_{SS} < 0$ for top 20%(30%) f_{DbCS} bins for 0-40%(40-60%) centralities. Boxes represent systematic uncertainties on the data points whereas statistical errors are smaller than the symbol sizes.



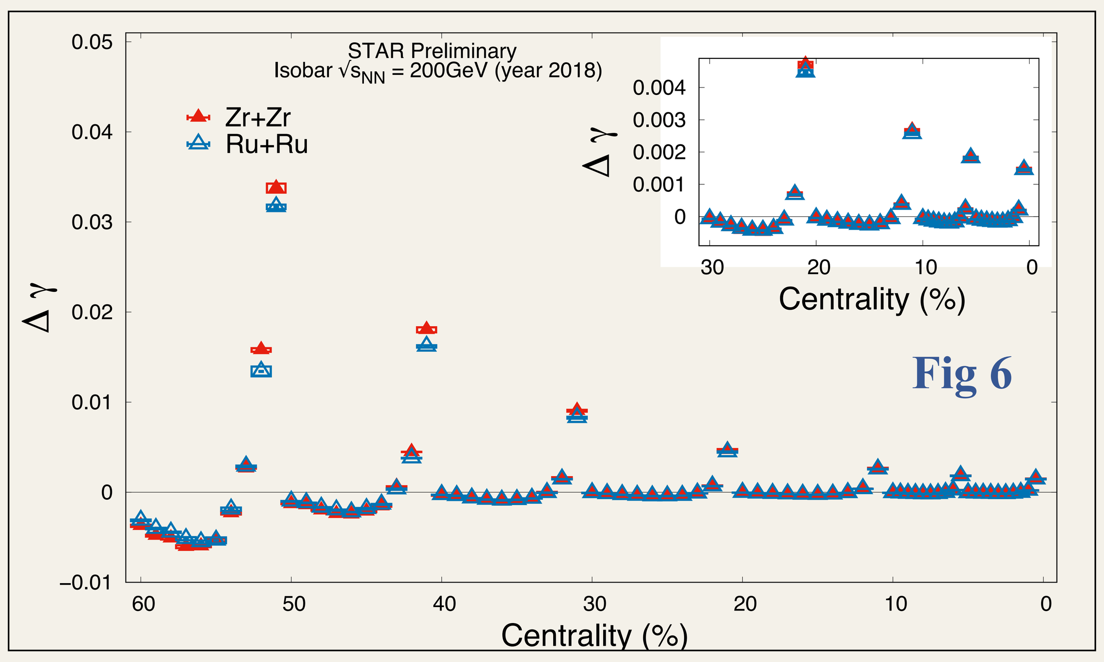


Fig.6: $\Delta\gamma$ is compared for Ru+Ru and Zr+Zr collisions. $\Delta\gamma$ is positive for the top 20%(30%) f_{DbCS} bins in 0-40%(40-60%) centralities. $\Delta\gamma$ is smaller for Ru than those of Zr for the top 10% (top 20%) f_{DbCS} bins for 20-40% (40-60%) centralities.

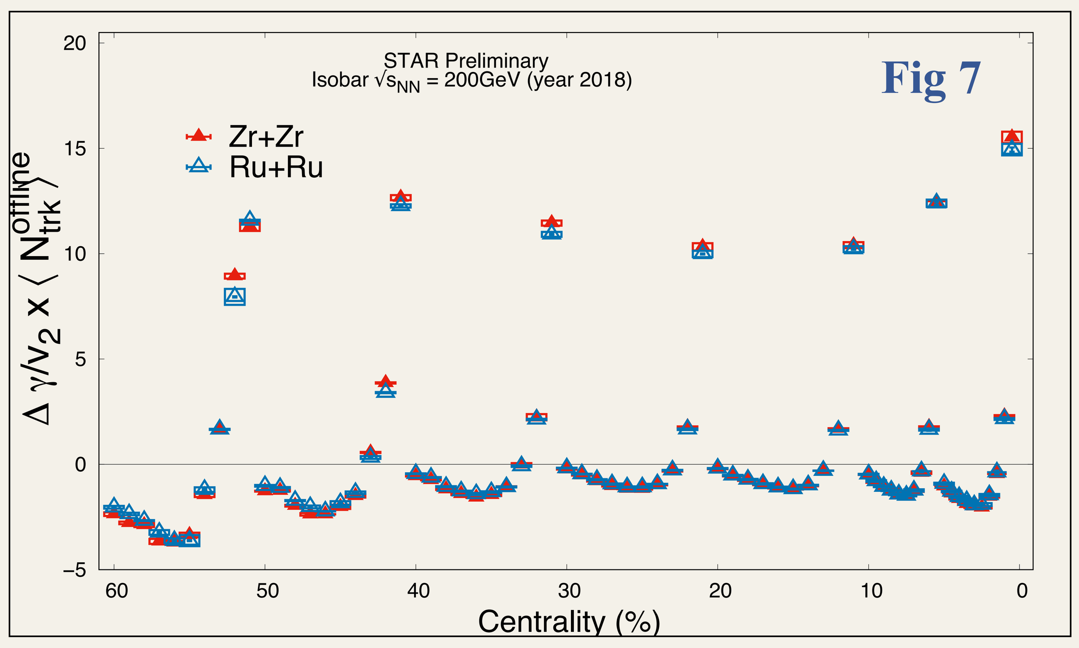
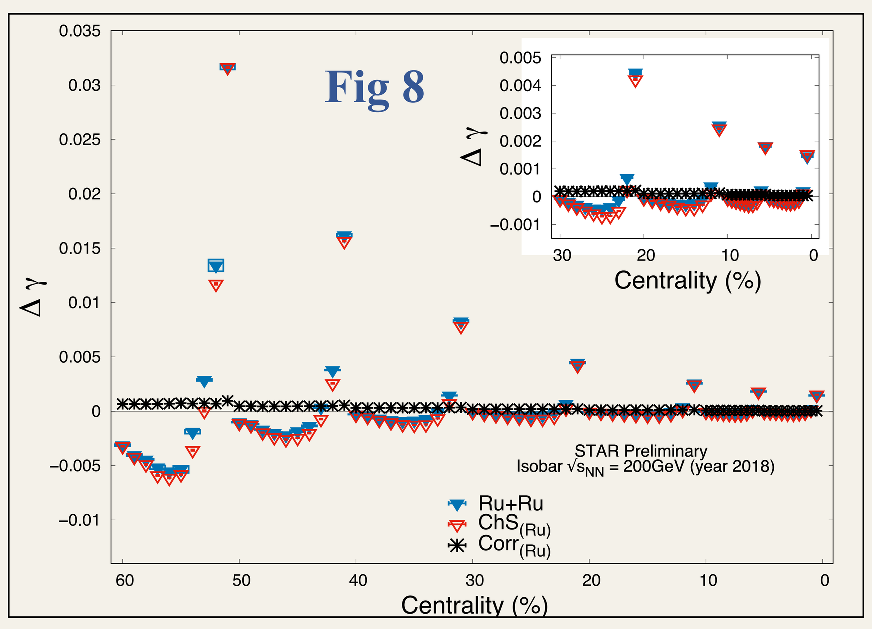


Fig.7: $\Delta\gamma$ is scaled with $\langle N_{trk}^{offline}\rangle/v_2$ (where $\langle N_{trk}^{offline}\rangle$ is multiplicity uncorrected for tracking efficiency in $|\eta| < 0.5$).



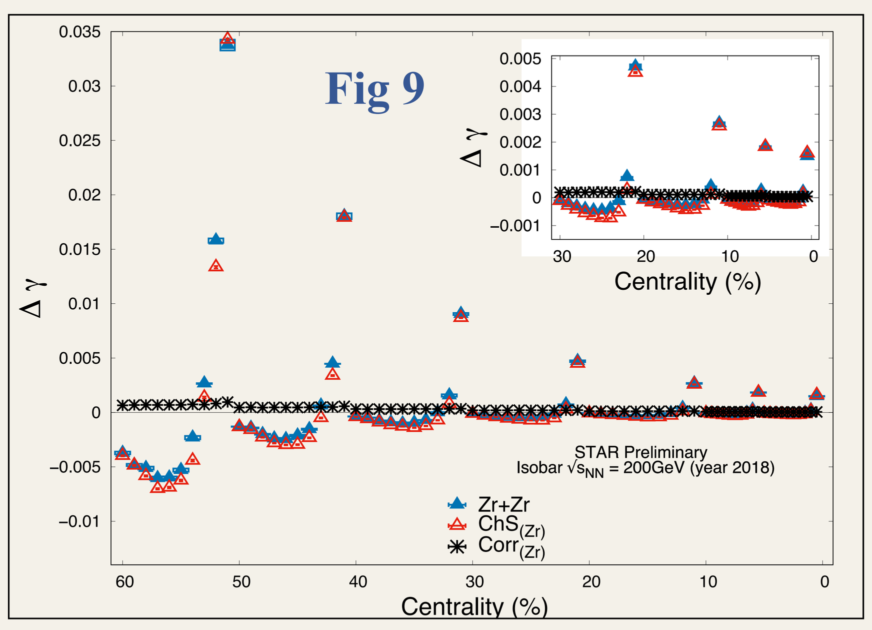


Fig.8 & Fig.9: $\Delta\gamma$ for Ru+Ru and Zr+Zr are compared with their respective backgrounds (i.e., Charge shuffled (ChS) and Correlated (Corr.)) in each f_{DbCS} bin for 0-60% collision centralities.

Summary

- The charge separation (f_{DbCS}) distribution extends towards higher f_{DbCS} values with decreasing collision centrality.
- It is seen that $\gamma_{OS} > 0$ *and* $\gamma_{SS} < 0$ for top 20%(30%) f_{DbCS} bins for 0-40%(40-60%) centralities as expected in CME like events.
- It can be seen that $\Delta\gamma$ are smaller for Ru than those of Zr for the top 10% (top 20%) f_{DbCS} bins for 20-40% (40-60%) centralities. However, the difference between them decreases if $\Delta\gamma$ is scaled with $\langle N_{trk}^{offline}\rangle/v_2$.
- $\Delta\gamma$ for Ru+Ru and Zr+Zr are compared with their respective backgrounds (i.e., Charge shuffled (ChS) and Correlated (Corr.)) for 0-60% collision centralities. We are analyzing the full available data set to get a detailed comparison.

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