# Study of Chiral Magnetic Effect in Isobar ($^{96}_{44}Ru +^{96}_{44} Ru$ and $^{96}_{40}Zr +^{96}_{40} Zr$) collisions at $\sqrt{s_{NN}}$ = 200 GeV at STAR using Sliding Dumbbell Method

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## Abstract

The CME sensitive γ-correlator is investigated in isobaric ($^{96}_{44}Ru +^{96}_{44} Ru$ and $^{96}_{40}Zr +^{96}_{40} Zr$) collisions using the new Sliding Dumbbell Method [1] designed to search for the back-to-back charge separation on event-by-event bases.

## 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). The charge separation effect has been investigated both at RHIC and LHC using the CME sensitive $\gamma$-correlator ($\langle cos(\phi_a + \phi_b - 2\Psi_{RP})\rangle$) [2]. Charge separation measurements in isobaric collisions of $^{96}_{44}Ru +^{96}_{44} Ru$ and $^{96}_{40}Zr +^{96}_{40} Zr$ at $\sqrt{s_{NN}}$= 200 GeV was suggested because of the increased (~10%) magnetic field in Ru+Ru collisions compared to Zr+Zr collisions. This leads to the expectation of an enhanced CME effect in Ru but a similar background in Ru and Zr.

[1] Jagbir Singh, Anjali Attri and Madan M. Aggarwal, DAE Symp.Nucl.Phys. 64 , 830, (2019).
[2] B. I. Abelev *et al.*, STAR Collaboration, Phys. Rev. C 81, 054908 (2010).

# Experimental Setup

The STAR (Solenoidal Tracker at RHIC) detector shown in Fig.1 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 with : $-35 < V_z < 25$ cm, $|\eta| < 1$, $0.2 < p_t < 2.0 GeV/c$ and DCA < 3 cm etc.

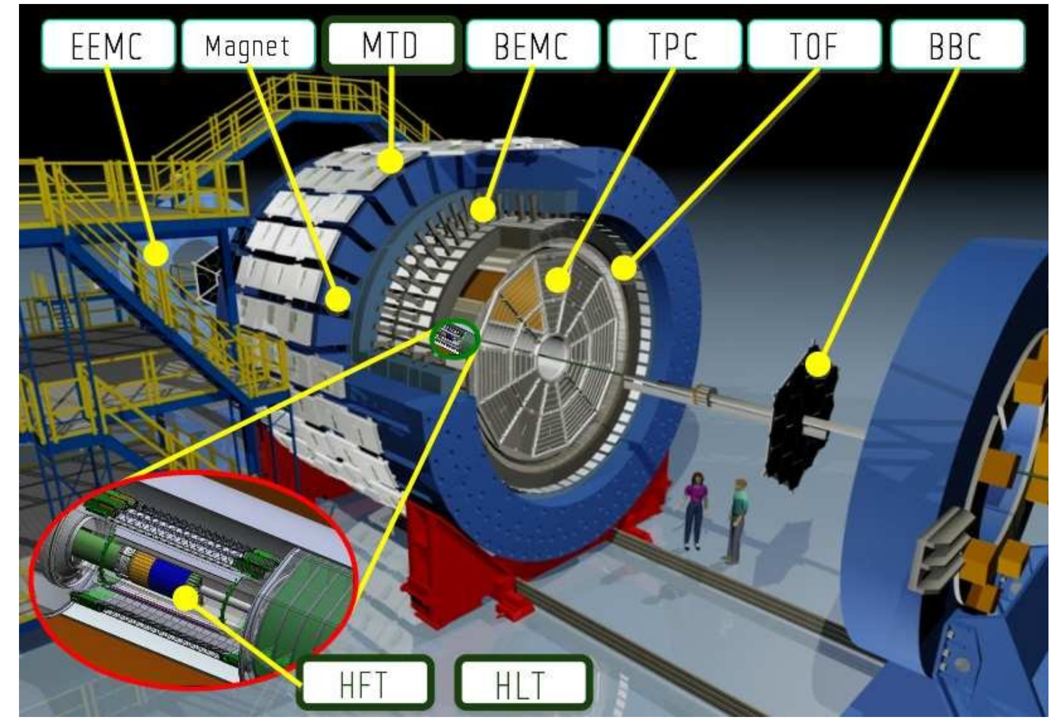



Fig.1: Layout of sub detectors of the STAR experiment.

# Sliding Dumbbell Method

The Sliding Dumbbell Method (SDM) 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 maximum values of $Db_{+-}$ ($Db^{max}_{+-}$) 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* $n^b_-$), number of positive and negative charged particles on "a"("b") side of the dumbbell

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

$$f_{DbCS} = Db^{max}_{+-} - 1$$

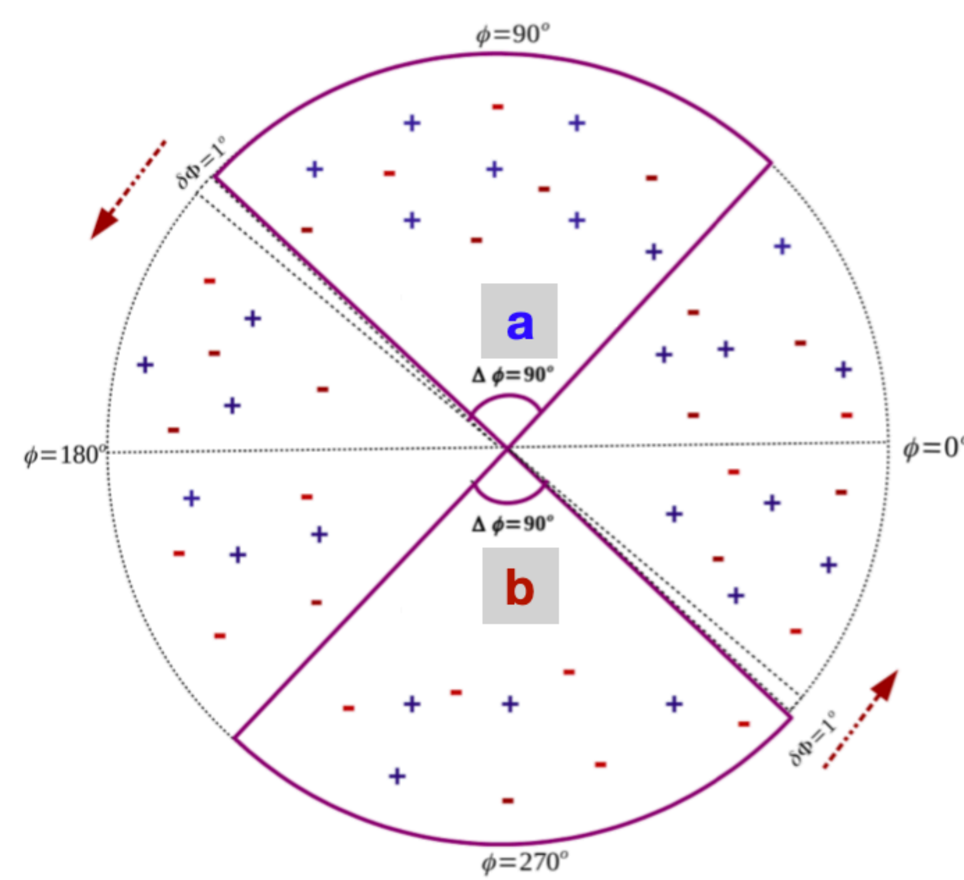



Fig.2 : The Dumbbell of ΔΦ=90°.

# 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 $\theta$ and $\phi$ 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. In order to retrieve correlations amongst particles, we restore the original charges in each event which were shuffled. It is worth mentioning here that shuffling of charges in each event gives rise to $f_{DbCS}$ value which is different from the original real event. There is no correlation between the $f_{DbCS}$ of charge shuffled event and $f_{DbCS}$ of the real event.

# Results

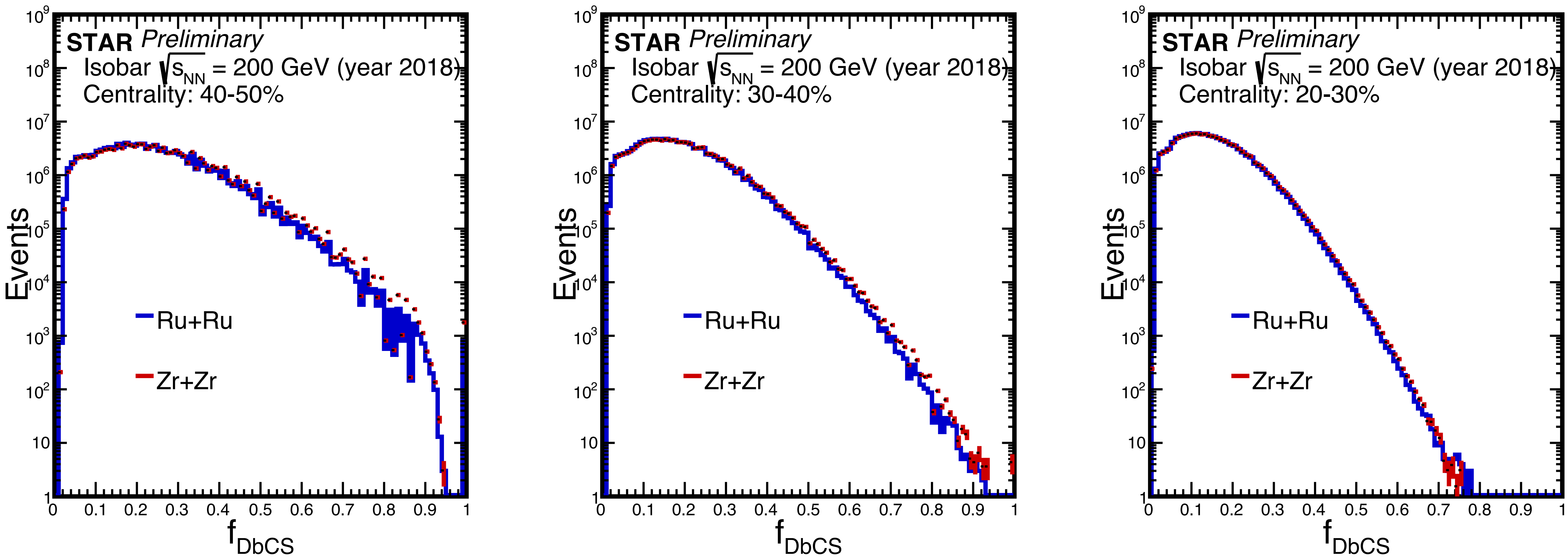



Fig.3 : It is seen that the charge separation ($f_{DbCS}$) distributions extend towards higher $f_{DbCS}$ values with decreasing collision centrality. Also $f_{DbCS}^{Zr}$ distributions extend toward higher charge separation than those of $f_{DbCS}^{Ru}$ with decreasing collision centrality. The charge separation distribution are divided into 10 percentile bins for each centrality - this can be seen as the individual bins in figures 4 through 8.

# Results

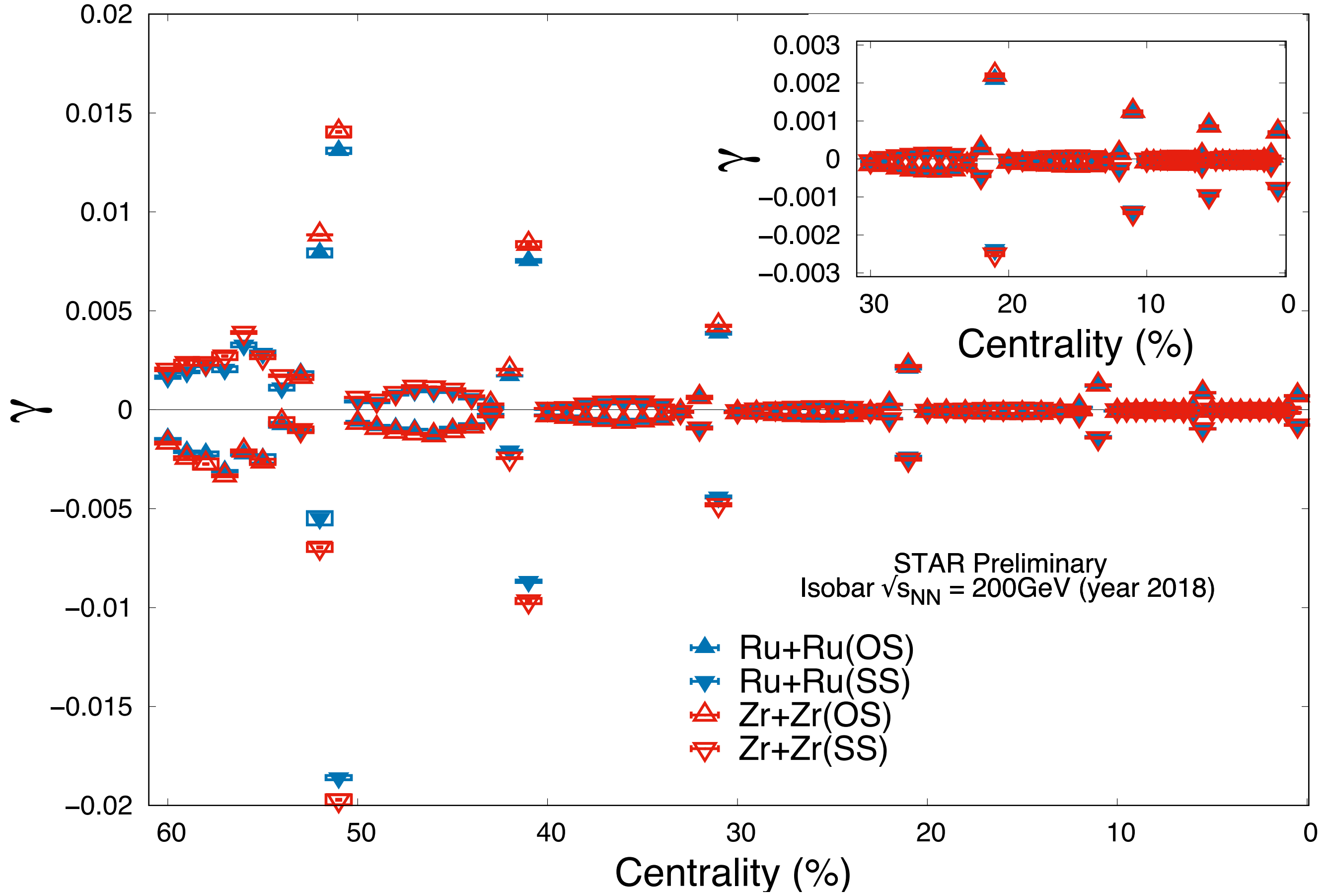
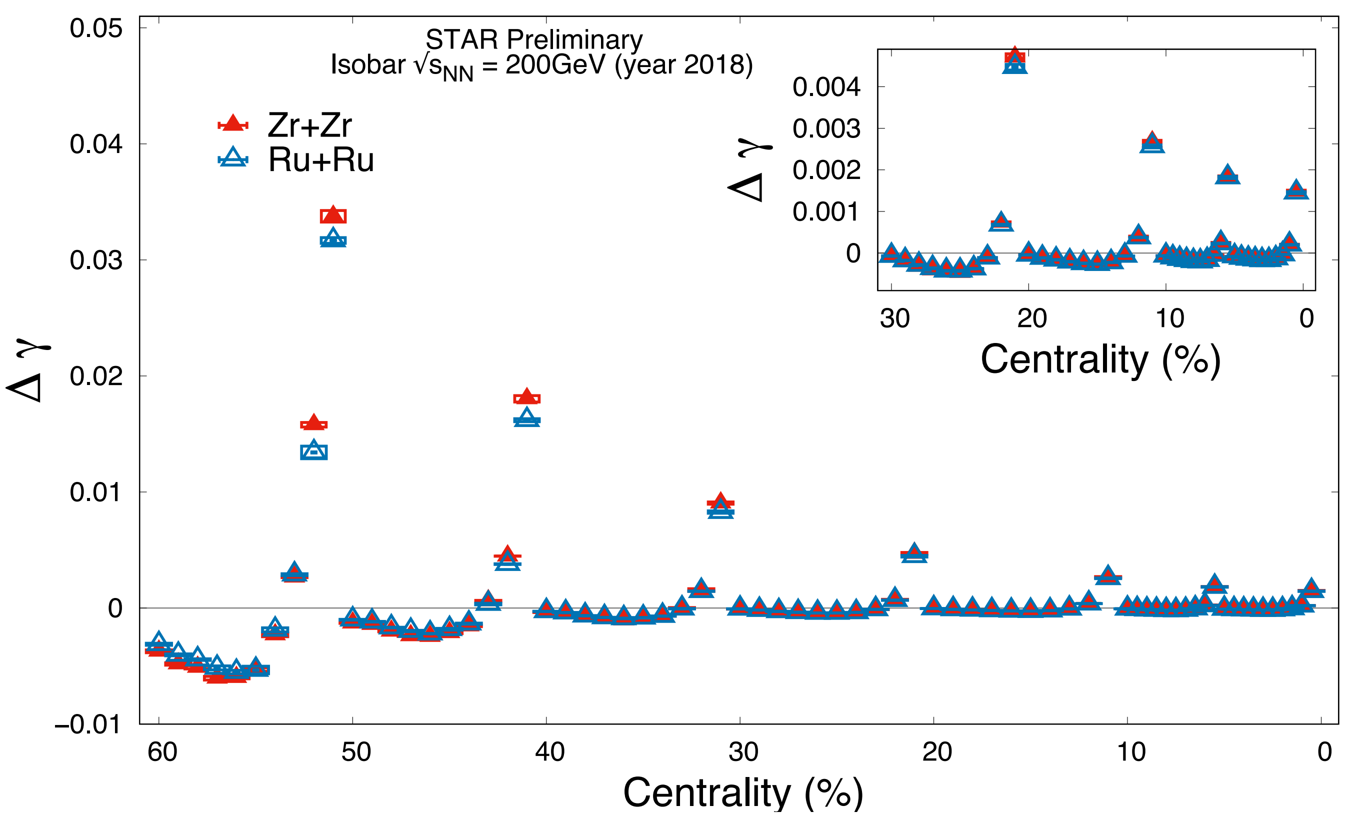



Fig.4 : $\gamma_{OS}$ *and* $\gamma_{SS}$ are plotted as a function of centrality for Ru+Ru and Zr+Zr events. Note that within each 10% centrality bins, the 10 individual bins are bins of charge separation ($f_{DbCS}$), with the most CME-like events (those with largest $f_{DbCS}$ values) being the right-most bins. It is seen that for CME like events, $\gamma_{OS} > 0$ *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.



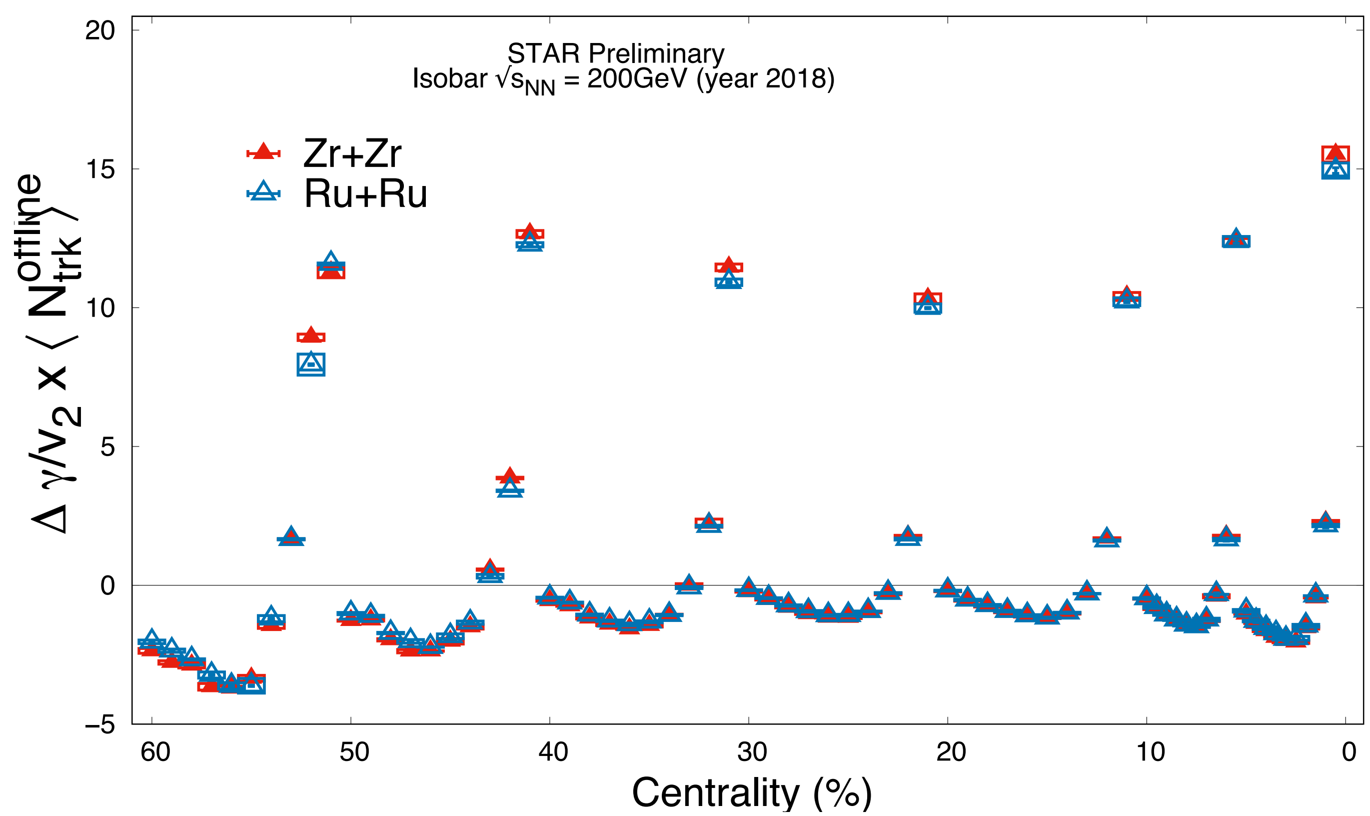
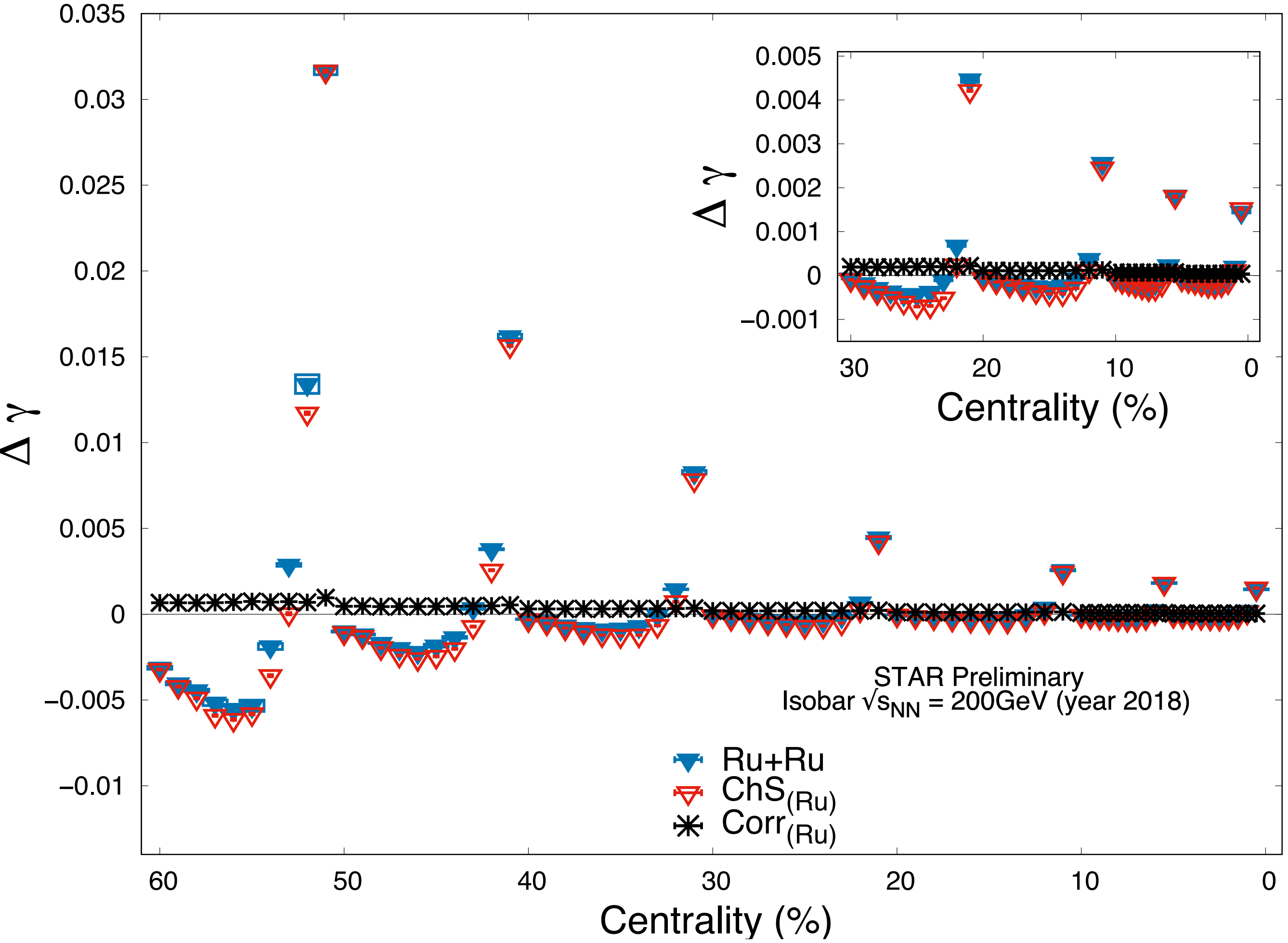




Fig.5 and Fig.6 : $\Delta\gamma$ is positive for the top 20%(30%) $f_{DbCS}$ bins in 0-40%(40-60%) centralities. $\Delta\gamma$ is smaller for Ru than those of Zr for the top 10% (top 20%) $f_{DbCS}$ bins for 20-40% (40-60%) centralities. However, difference between them decreases if $\Delta\gamma$ is scaled with $\langle N_{trk}^{offline} \rangle / v_2$ (where, $\langle N_{trk}^{offline} \rangle$ is uncorrected multiplicity in $|\eta| < 0.5$).

# Results





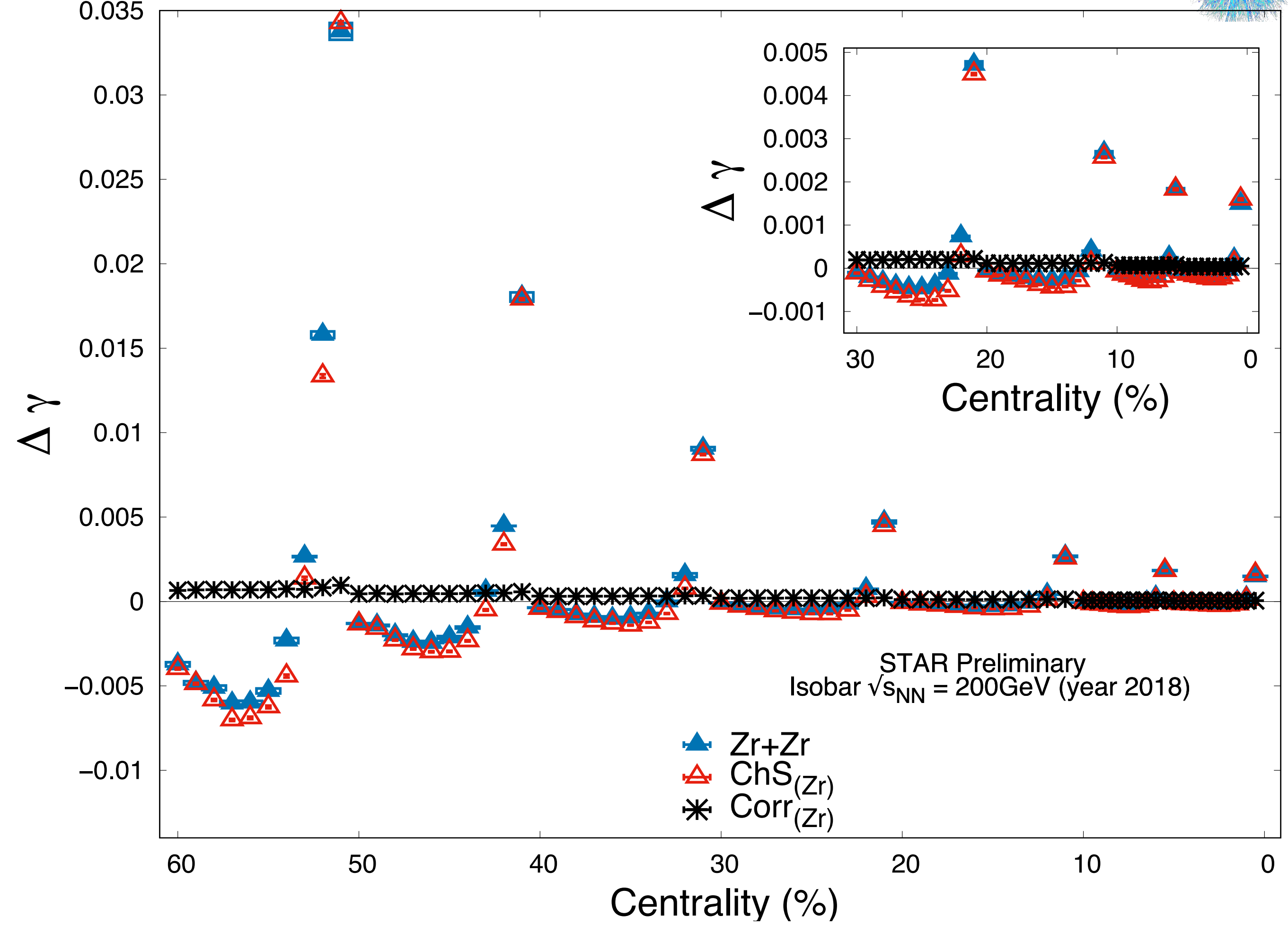




Fig.7 & Fig.8 : $\Delta\gamma$ for Ru+Ru and Zr+Zr are compared with their respective backgrounds (i.e., Charge shuffled (ChS) and Correlated (Corr.) )for 0-60% collision centralities.

# 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, difference between them decreases if Δγ 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 working on the respective backgrounds to get the CME signals in Ru and Zr.