Search for the Chiral Magnetic Effect with Forced Match of Multiplicity and Elliptic Flow in Isobar Collisions at STAR

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γ-correlator

By utilizing the azimuthal correlation:

$$\gamma_{112} = \langle \cos(\phi_\alpha - \phi_\beta - 2\Psi_{RP}) \rangle$$

$$\Delta\gamma_{112} = \gamma_{112}^{OS} - \gamma_{112}^{SS}$$

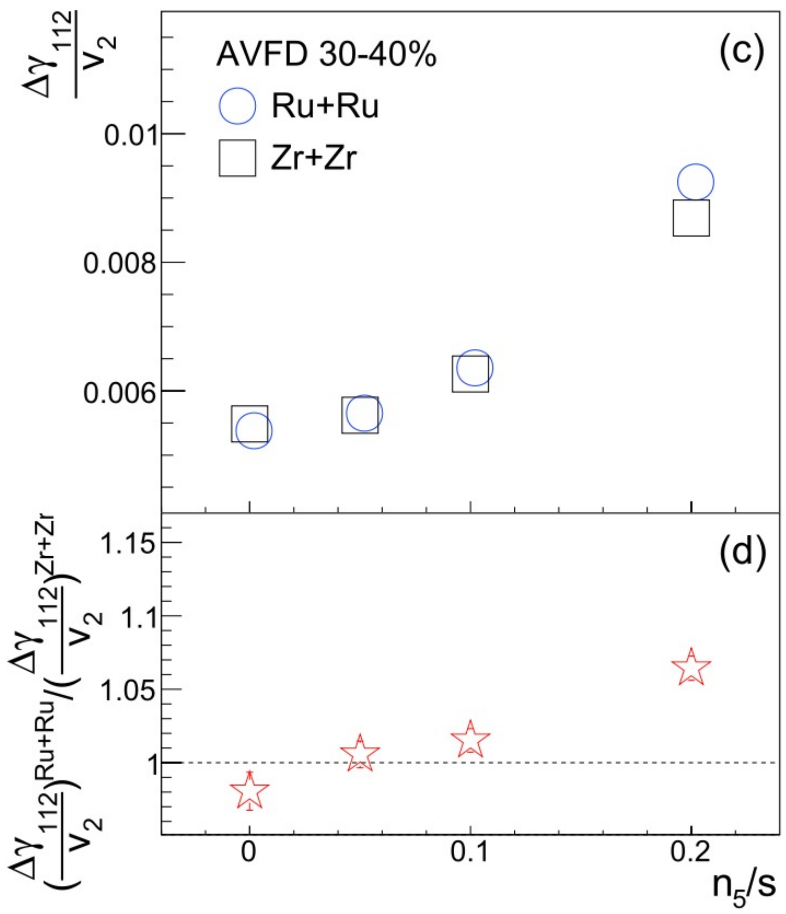
The normalized quantity:

$$\frac{\Delta\gamma_{112}}{v_2}$$

To account for the trivial scaling from the v_2 contribution.

n_5/s, Initial axial charge density, control chirality imbalance, hence CME strength.

Sergei A. Voloshin, RC 70, 057901 (2004)
S. Choudhury, et al., Chin. Phys. C 46, 014101 (2022)

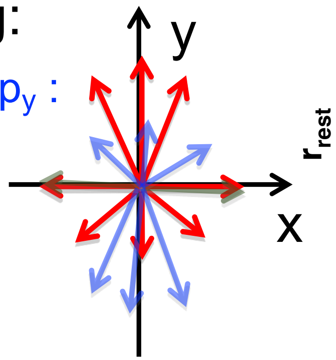


The $\frac{\Delta\gamma_{112}}{v_2}$ is sensitive to CME and can be clearly observed in AVFD events.

Signed Balance Function(SBF)

A.H. Tang, Chin. Phys. C 44, 054101 (2020)
S. Choudhury, et al., Chin. Phys. C 46, 014101 (2022)

By accounting momentum ordering:



1) Count pair's momentum ordering in p_y :

$$B_{P,y}(S_y) = \frac{N_{+-}(S_y) - N_{++}(S_y)}{N_+},$$

$$B_{N,y}(S_y) = \frac{N_{-+}(S_y) - N_{--}(S_y)}{N_-}$$

2) Count net-ordering (e.g. excess of pos. leading neg.) for each event :

$$\delta B_y(\pm 1) = B_{P,y}(\pm 1) - B_{N,y}(\pm 1),$$

$$\Delta B_y(\pm 1) = \delta B_y(+1) - \delta B_y(-1)$$

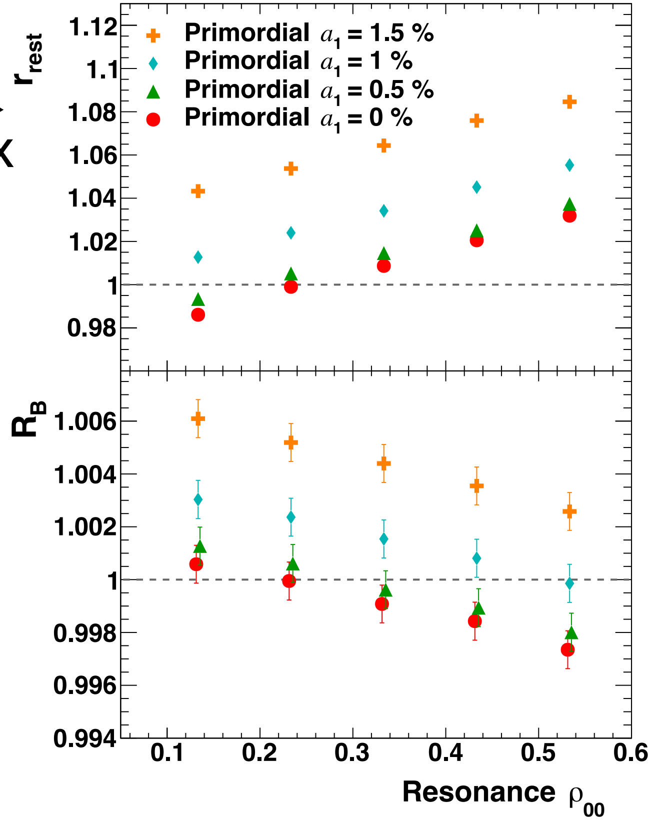
$$= \frac{N_+ + N_-}{N_+ N_-}\left[N_{y(+-)} - N_{y(-+)}\right]$$

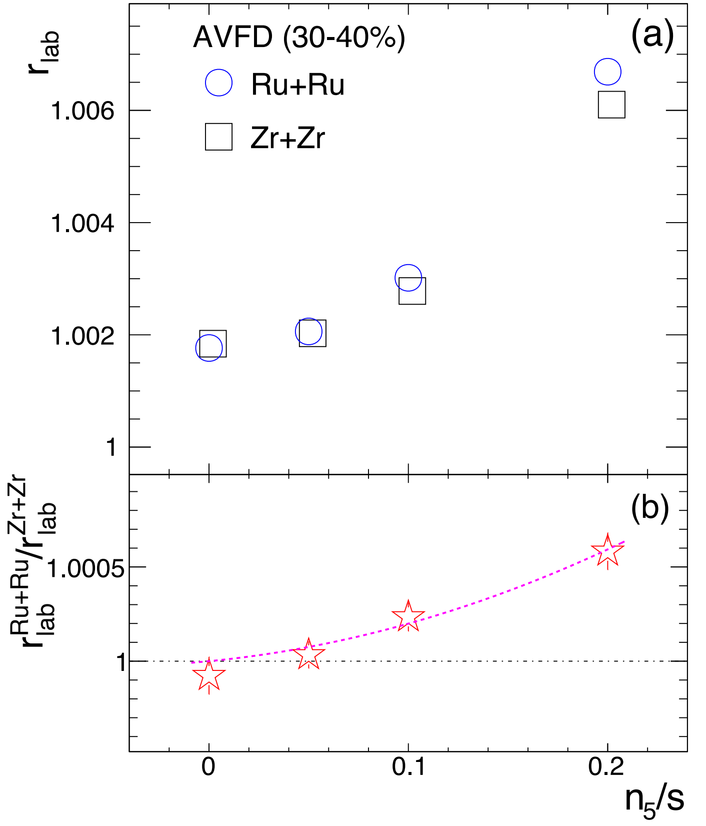
3) Look for enhanced event-by-event fluctuation of net ordering in y direction.

$$r = \frac{\sigma_{\Delta B_y}}{\sigma_{\Delta B_x}} \qquad R_B = \frac{r_{rest}}{r_{lab}}$$

Where y is the direction of the magnetic field, r_{lab} and r_{rest} are the r calculate in laboratory frame and pair rest frame separatly.

Toy model: ρ_{00} + v_2 + CME

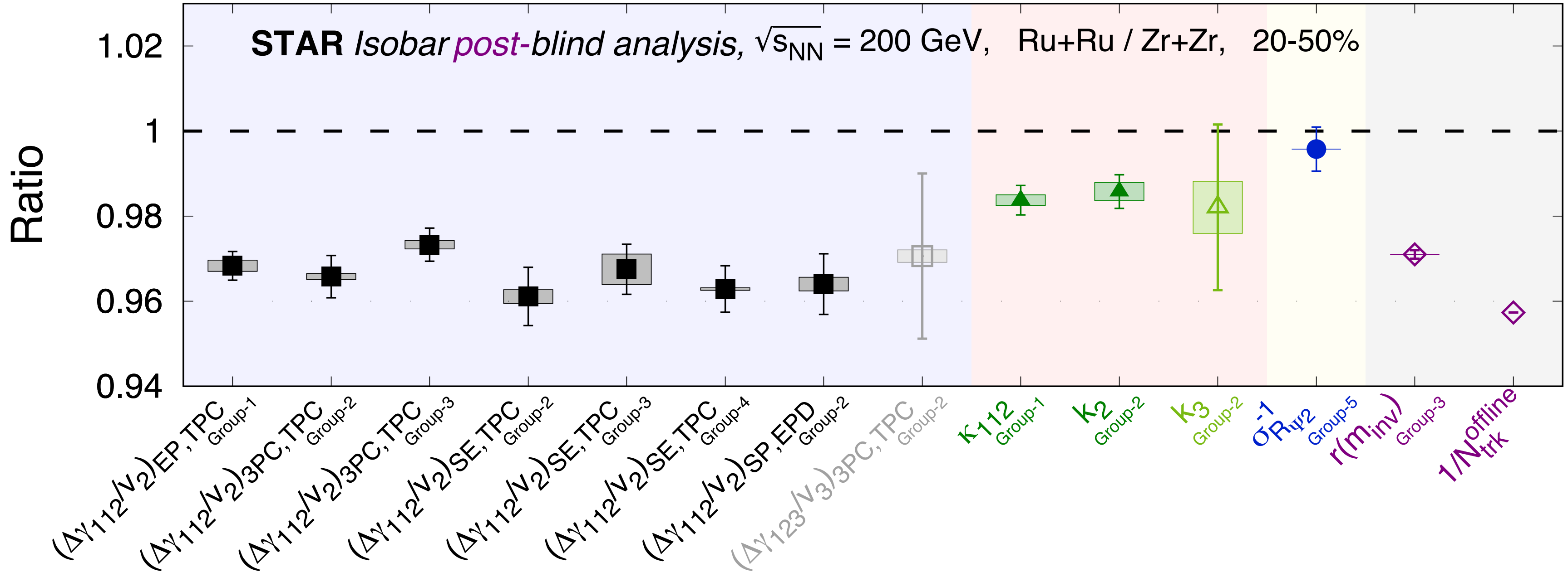




The r_{lab} and R_B are sensitive to the CME signal and the differences between isobars system two systems can observed in models.

Isobar blind analysis at STAR

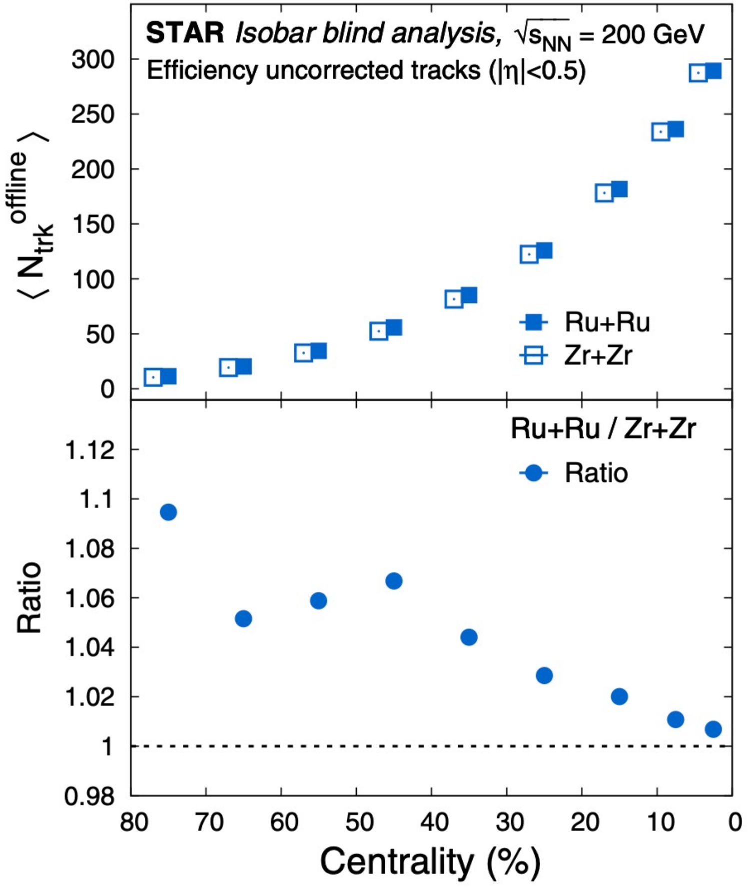
STAR Isobar blind analysis, PRC 105, 014901 (2022)

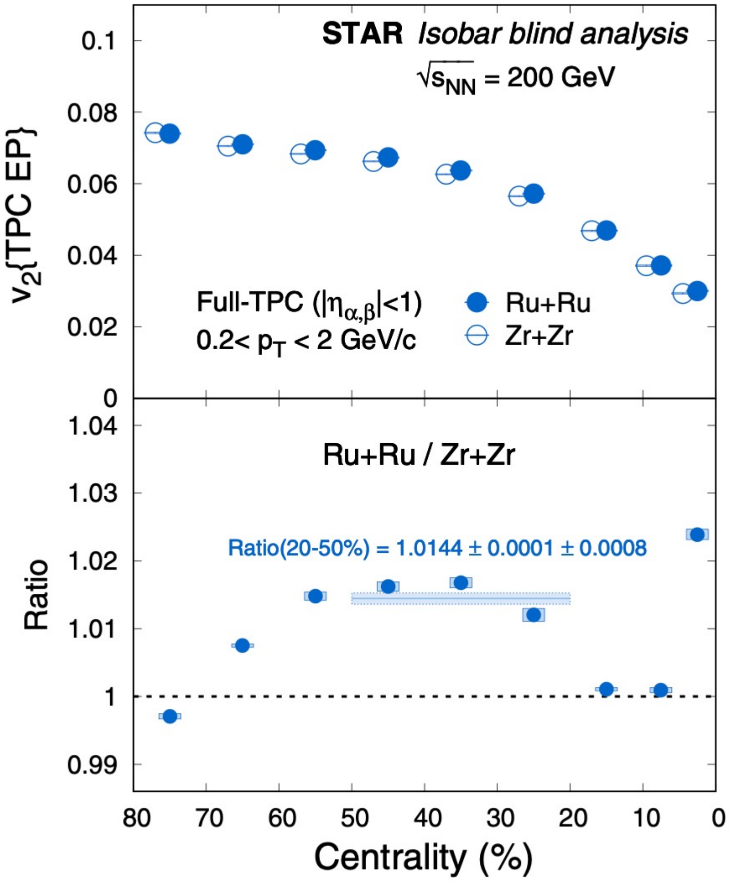


❖ No pre-defined signature ($Ratio > 1$) of CME is observed in isobar collisions.

Isobar blind analysis at STAR

STAR Isobar blind analysis, PRC 105, 014901 (2022)

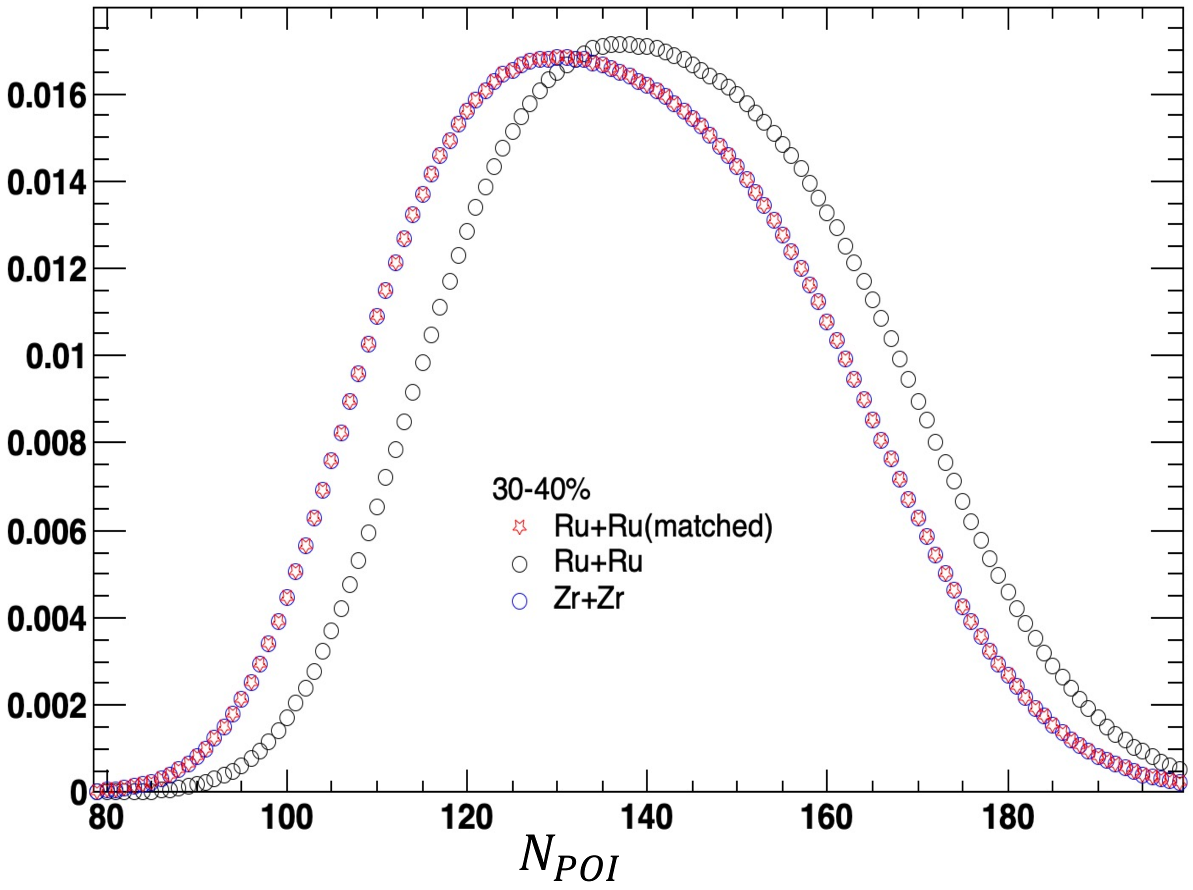




Differences in the multiplicity and v_2 is observed between the two species.

This analysis: forced match is employed to remove these differences.

Forced match



Keep the Zr+Zr original and then match the Ru+Ru Distribution to Zr+Zr.

$$f_{w,bin} = N_{bin(Zr)} \,/\, N_{bin(Ru)}$$

$$S_O \mathrel{+}= O_{bin(Ru)} \cdot N_{bin(Ru)} \cdot f_{w,bin}$$

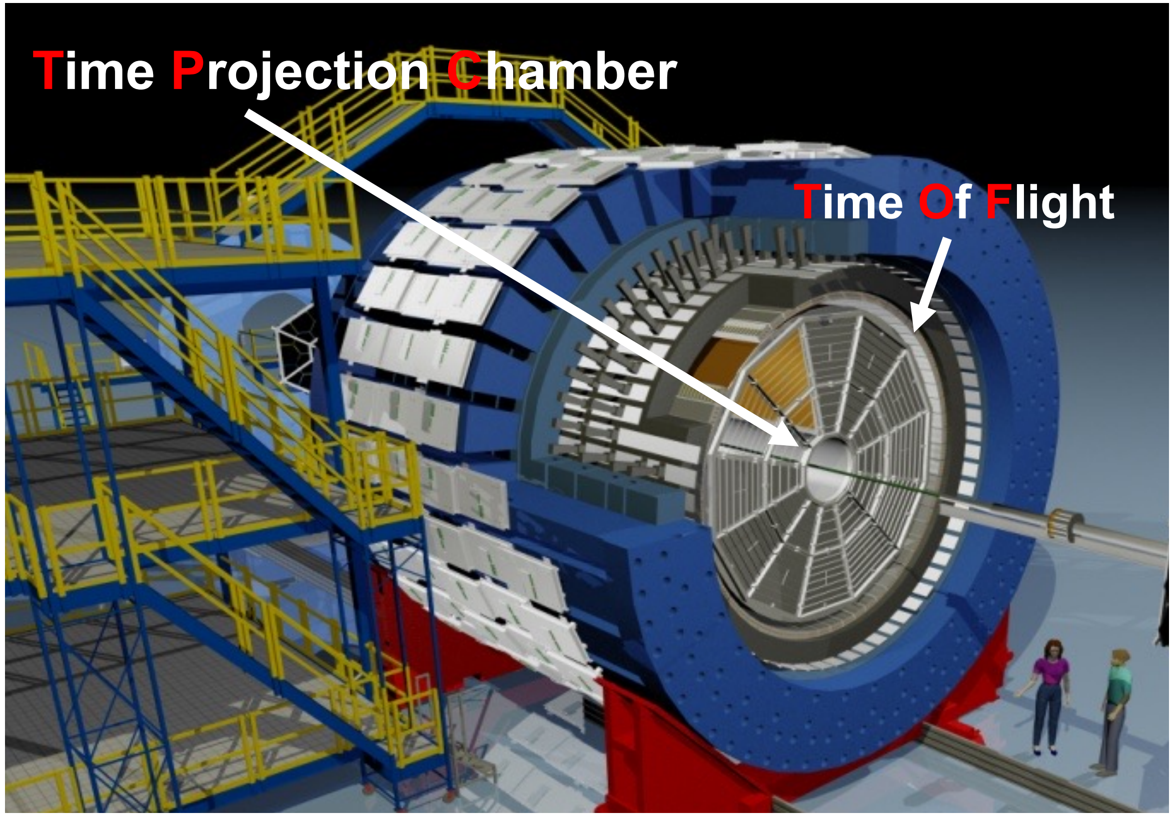
$$S_w \mathrel{+}= N_{bin(Ru)} \cdot f_{w,bin}$$

$$\boldsymbol{O_{Ru(matched)} = S_O \,/\, S_w}$$

N_{bin}: number of events
$f_{w,bin}$: weight factor
O_{bin} : observables
S_O and S_w are the sum of the observable and weight entries in total, respectively.

In this way, the CME related backgrounds are tuned to be exactly the same, making the interpretation on the ratio between isobar systems straightforward.

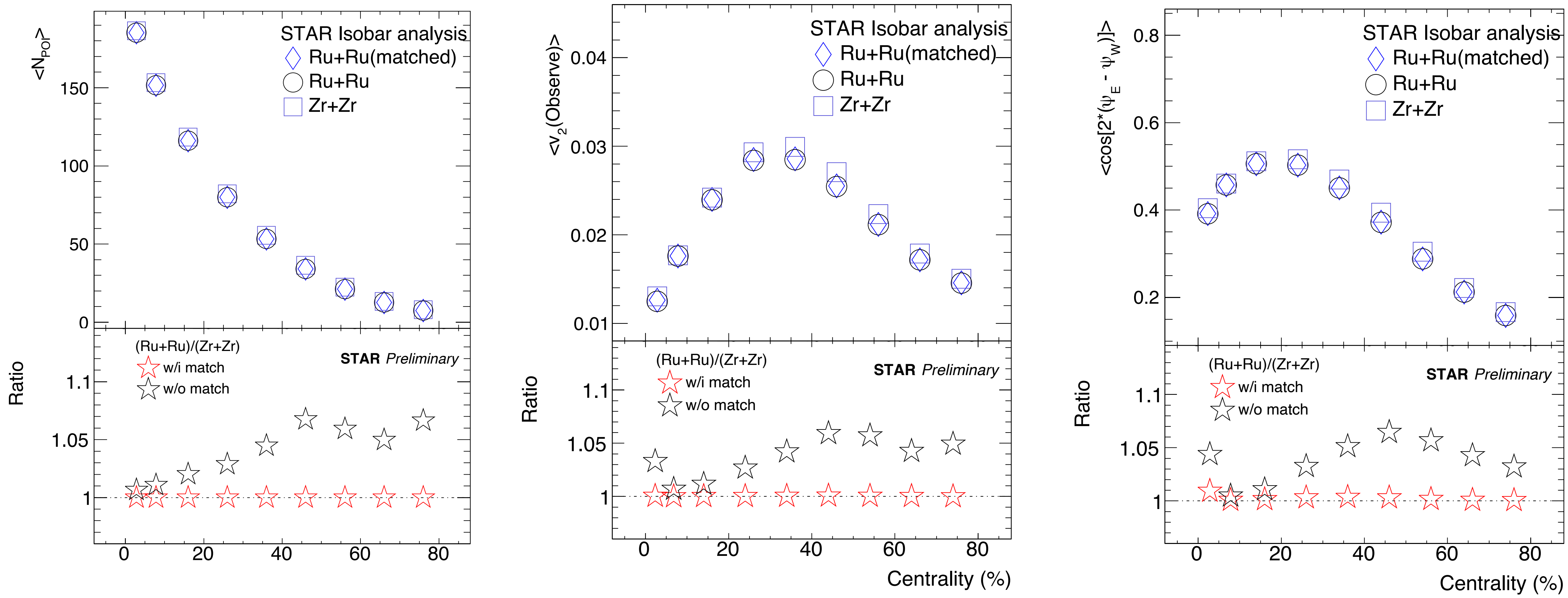
STAR detectors and analysis details



- ➢ Uniform acceptance, full azimuthal coverage, excellent PID capability
- ➢ TPC: tracking, centrality
- ➢ TPC+TOF: particle identification

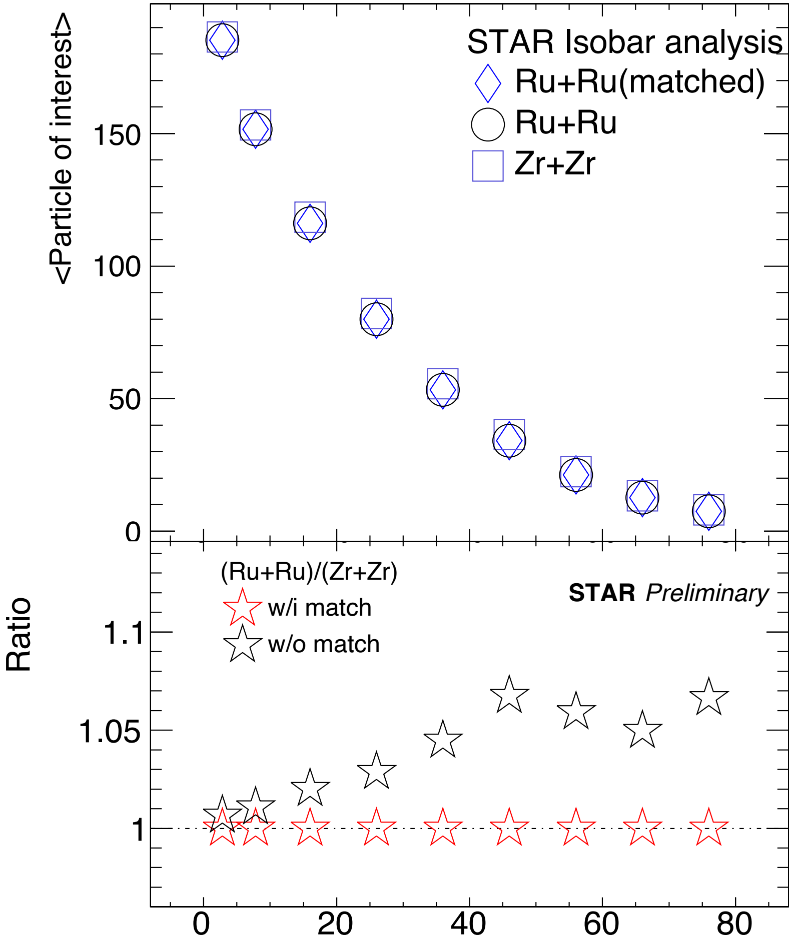
✓ Data sets: Run18 Isobar 200 GeV, minibias trigger.

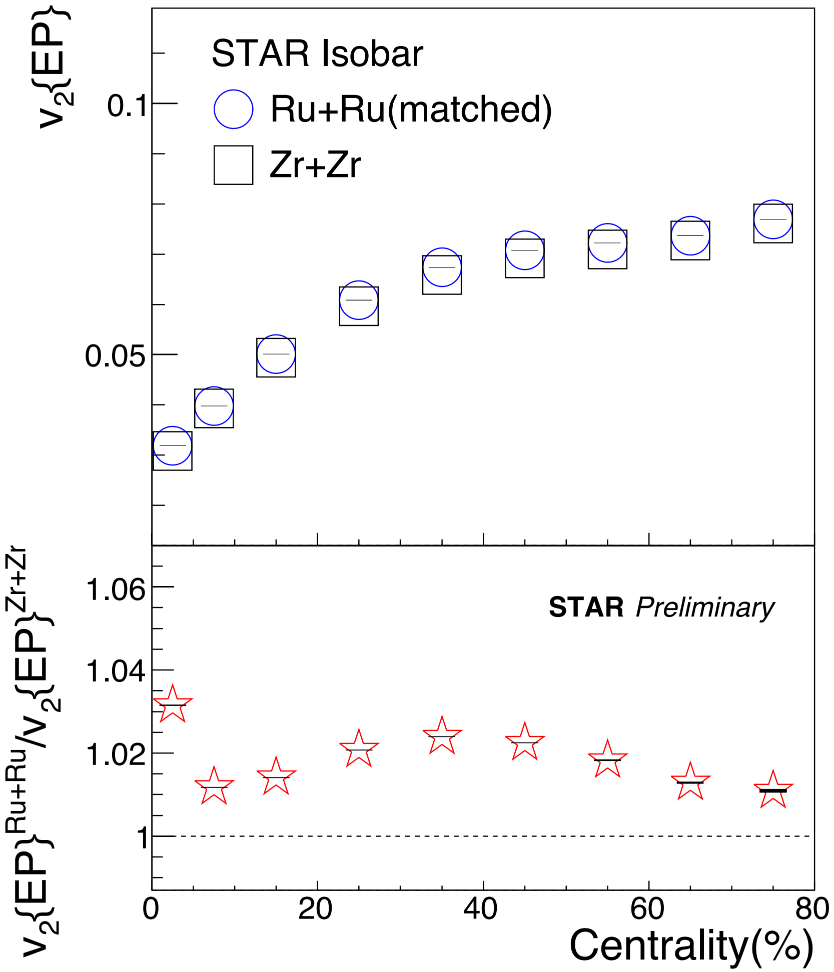
Matching check



- **γ**-correlator： Only the N_{POI} as the matching dimension.
- SBF: N_{POI}, $v_2(observe)$ and $cos[2(\Psi_E - \Psi_W)]$ all as the matching dimensions.
- The difference in N_{POI}, $v_2(observe)$ and $cos[2(\Psi_E - \Psi_W)]$ are removed with match.

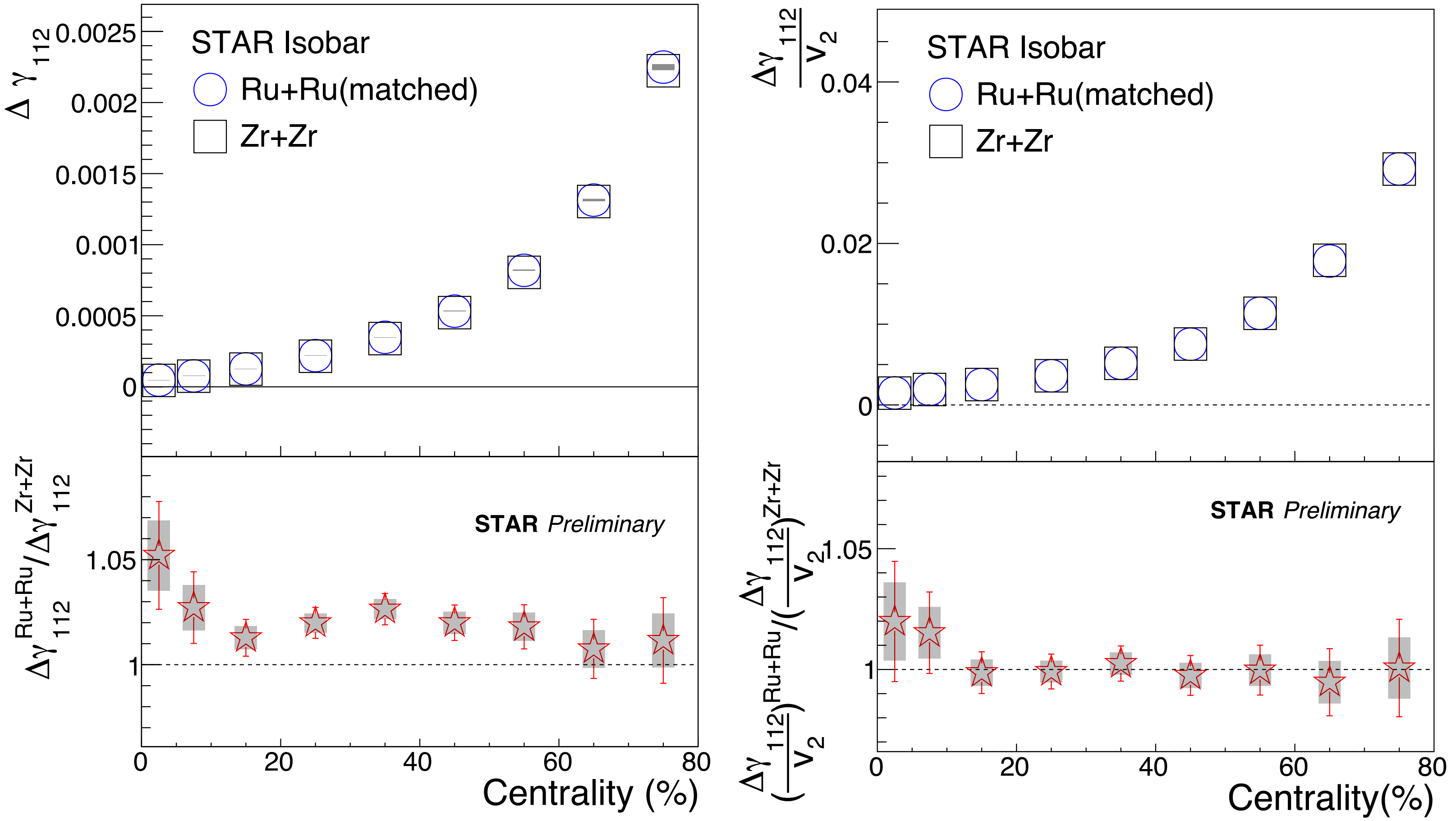
Analysis results: γ





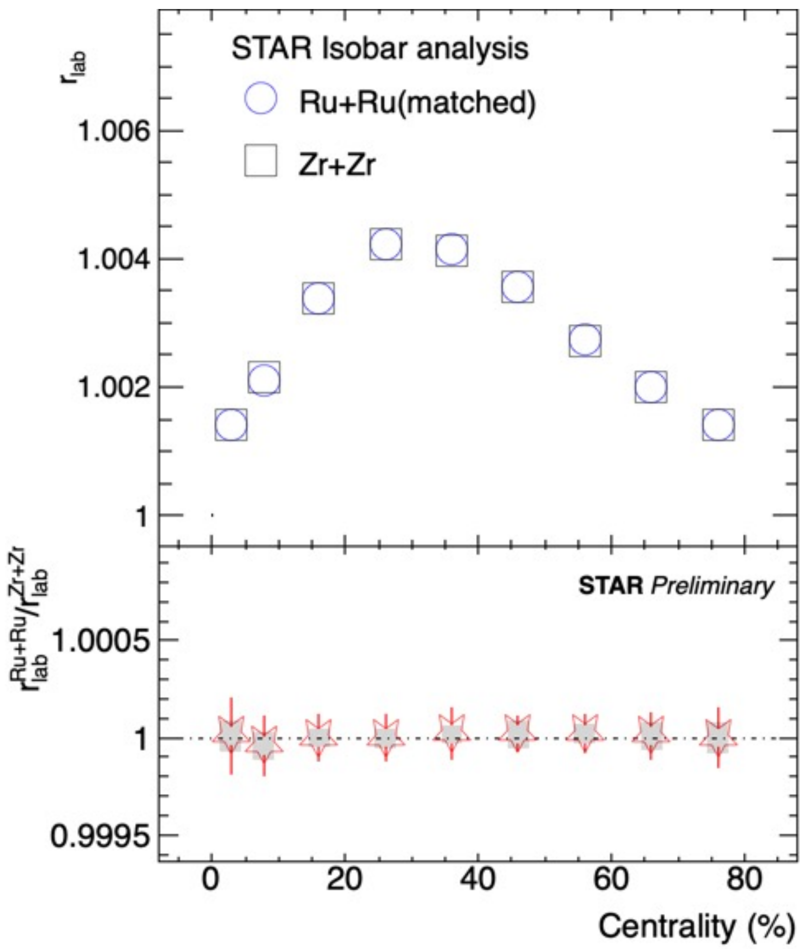
- The difference in N_{POI} is removed with N_{POI} match.
- The ratio of v_2 are above 1 with N_{POI} match.

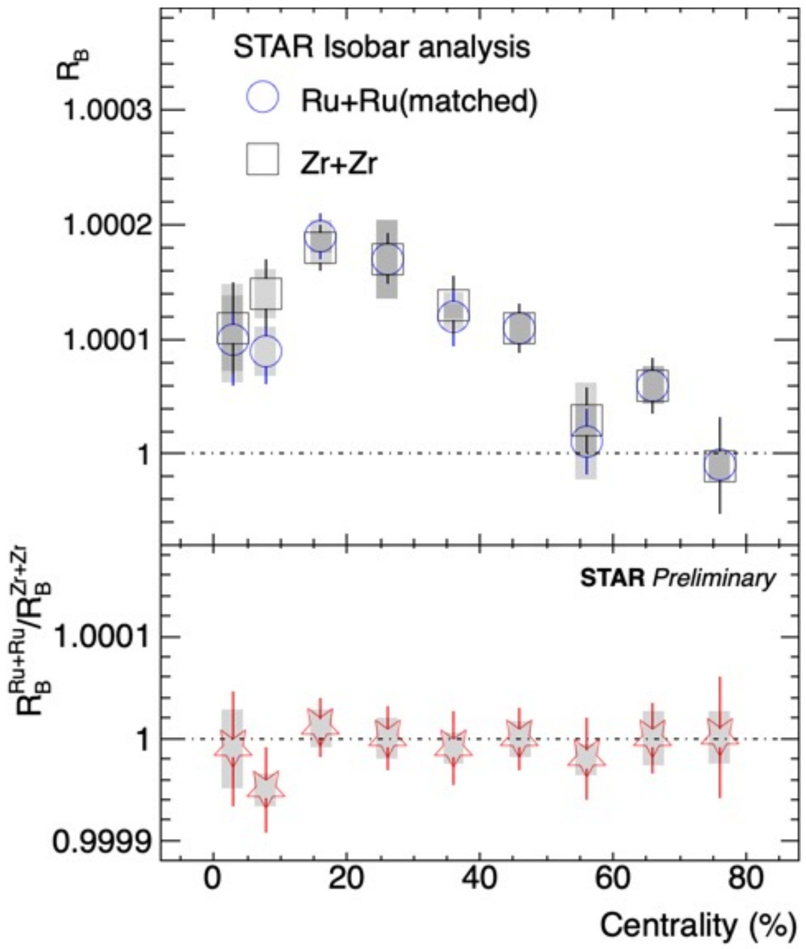
Analysis results: γ



- The ratio $\frac{\Delta\gamma_{112}}{v_2} \approx 1$ with N_{POI} match.

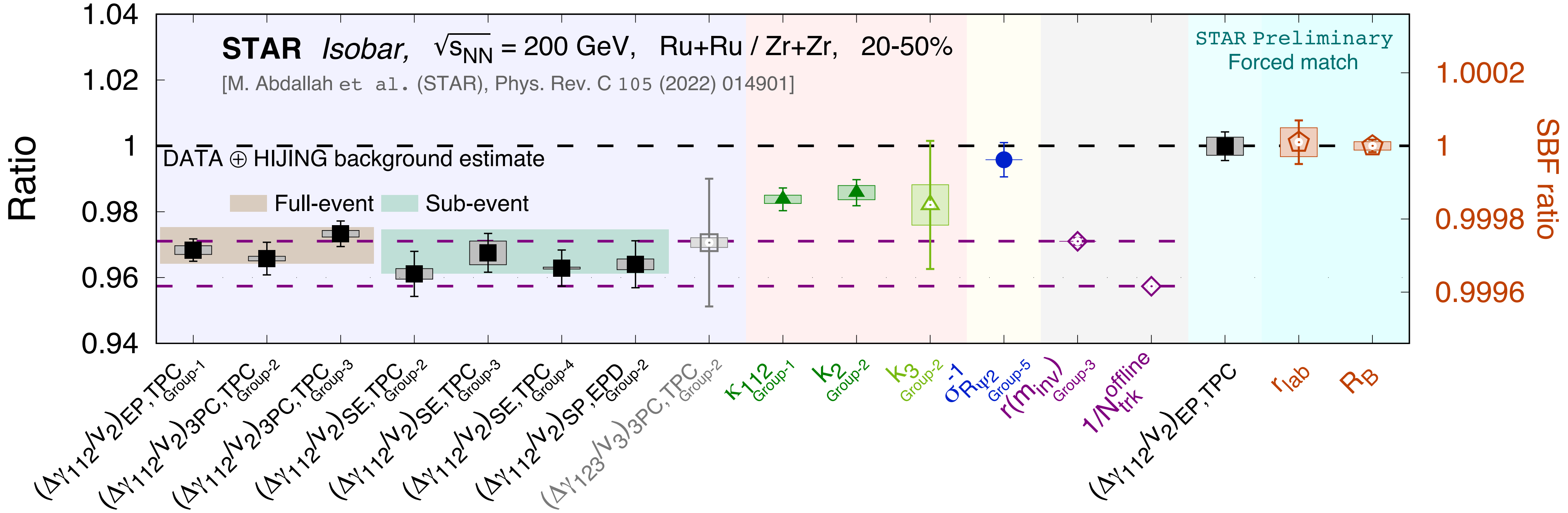
Analysis results: SBF





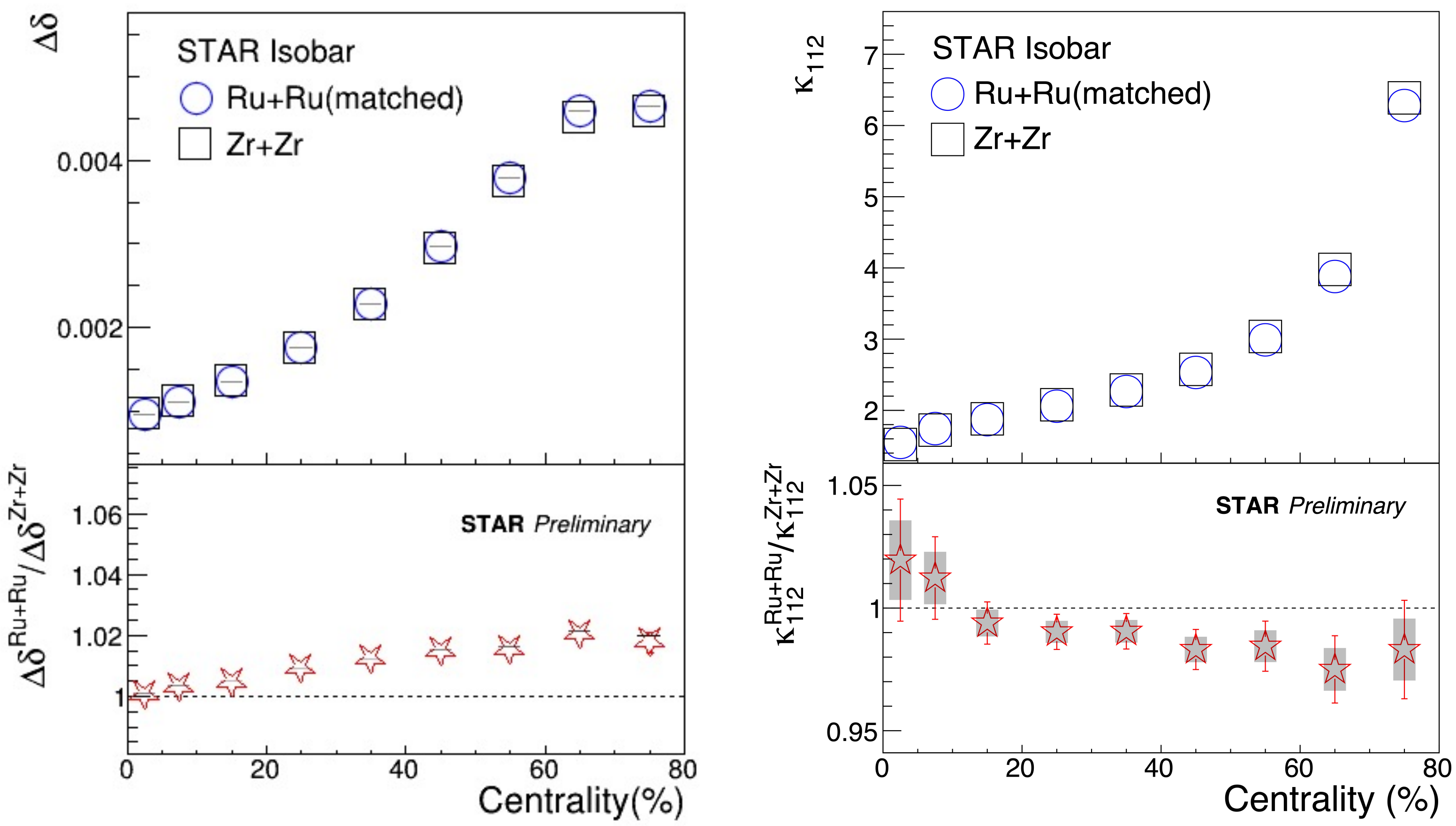
- Both the ratio of r_{lab} and R_B are consistent with 1 with forced match.

Summary and discussions



No obvious CME signal has been observed either in balance function method or γ correlator method when the differences of the multiplicity and v_2 have been removed with forced match.

Backup: Analysis results



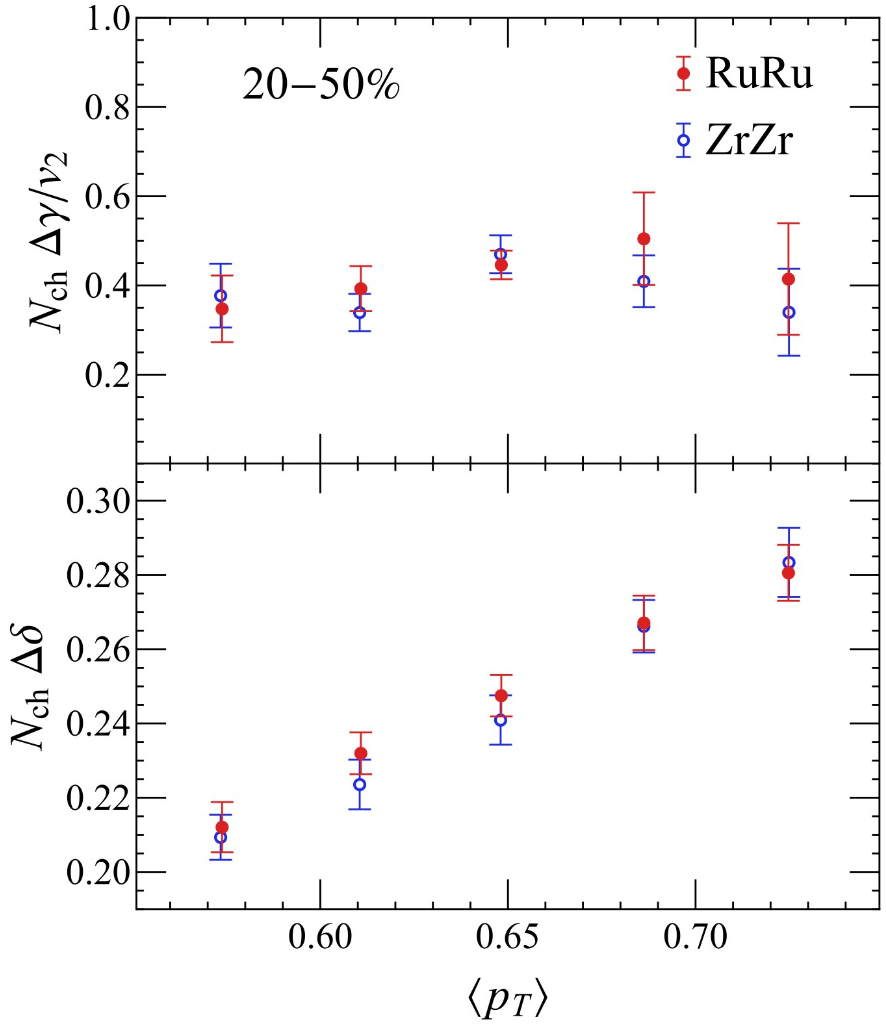
$$\kappa_{112} = \frac{\Delta\gamma_{112}}{v_2 \cdot \Delta\delta}$$

The ratio of $\Delta\delta < 1$ and $\kappa_{112} > 1$ with CME signal.

- The ratio $\Delta\delta$ is larger than even after N_{POI} match;
- κ_{112} is below 1 with N_{POI} match.

Backup: Why not $\Delta\delta$ and κ_{112}

Dmitri E. Kharzeev , Jinfeng Liao ,
and Shuzhe Shi, PRC 106, L051903 (2022)

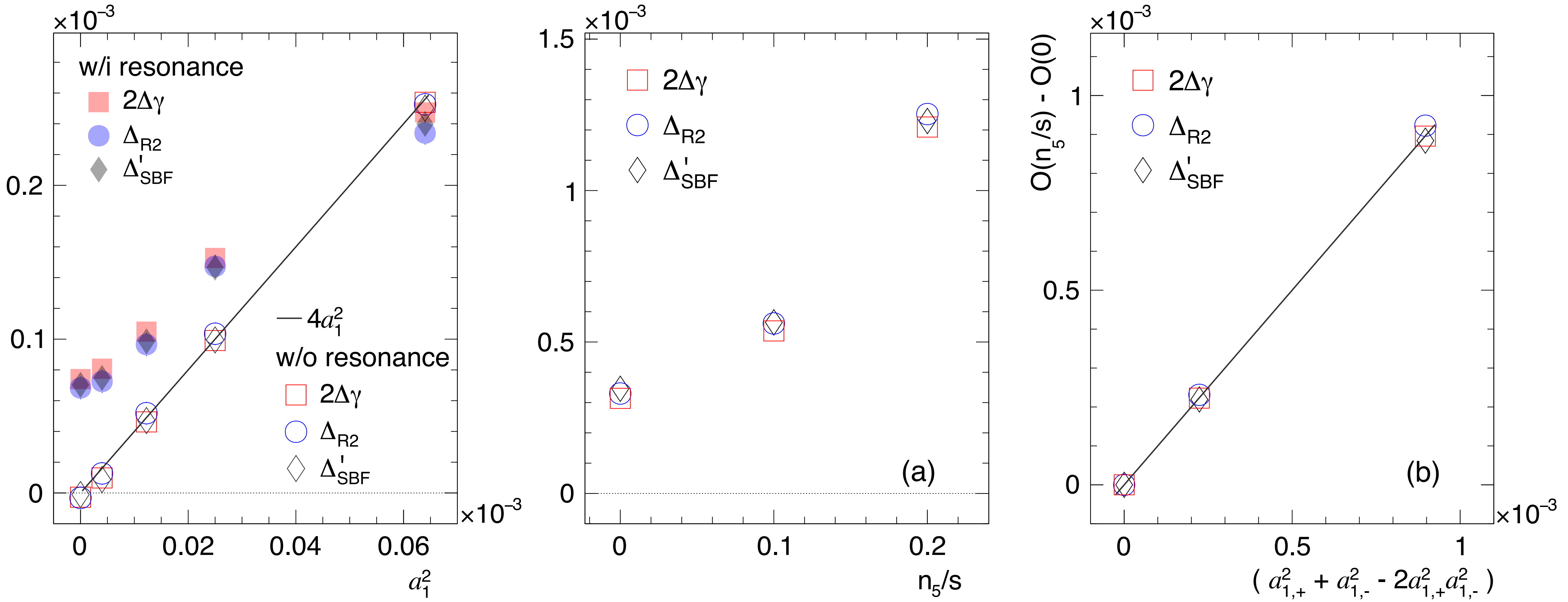


To demonstrate the impact of this effect on the δ and γ correlators, we bin the (20–50)% simulation events based on $\langle p_T \rangle$ and compute the corresponding correlators in each bin. The results, plotted in Fig. 3, clearly show a linear increase of $N_{ch} \times \Delta\delta$ with $\langle p_T \rangle$. The $N_{ch} \times \Delta\gamma/v_2$, on the other hand, appears to be relatively insensitive to the $\langle p_T \rangle$. We also note that hydrodynamic simulations performed in [71] and in our calculations demonstrate that the RuRu events have a larger $\langle p_T \rangle$ than ZrZr events in the same centrality class.

Backup: Connect between γ and signed balance function

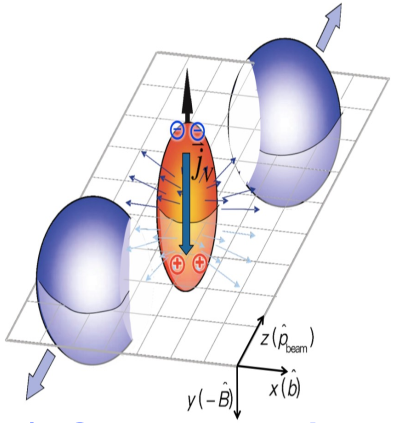
S. Choudhury, et al., Chin. Phys. C 46, 014101 (2022)

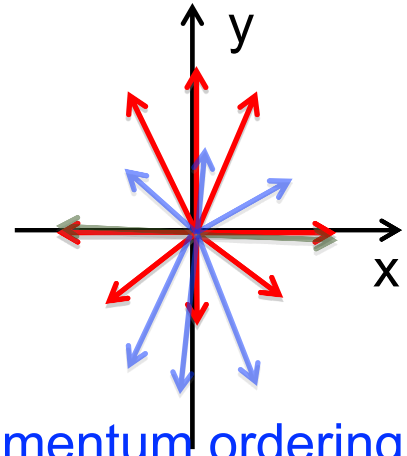
$$\Delta_{\mathrm{SBF}} \equiv \sigma^2(\Delta B_y) - \sigma^2(\Delta B_x)$$
$$\approx \frac{128M^2}{\pi^4}\left(\Delta\gamma_{112} - \frac{4}{3}v_2\Delta\delta\right)$$



$2\Delta\gamma_{112}$, Δ_{R2} and $\Delta'_{\mathrm{SBF}} \equiv \left(\frac{\pi^4}{64M^2}\Delta_{\mathrm{SBF}} + \frac{8}{3}v_2\Delta\delta\right)$

Backup: SBF





1) Count pair's momentum ordering in p_y :

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$$B_{N,y}(S_y) = \frac{N_{-+}(S_y) - N_{--}(S_y)}{N_-}$$

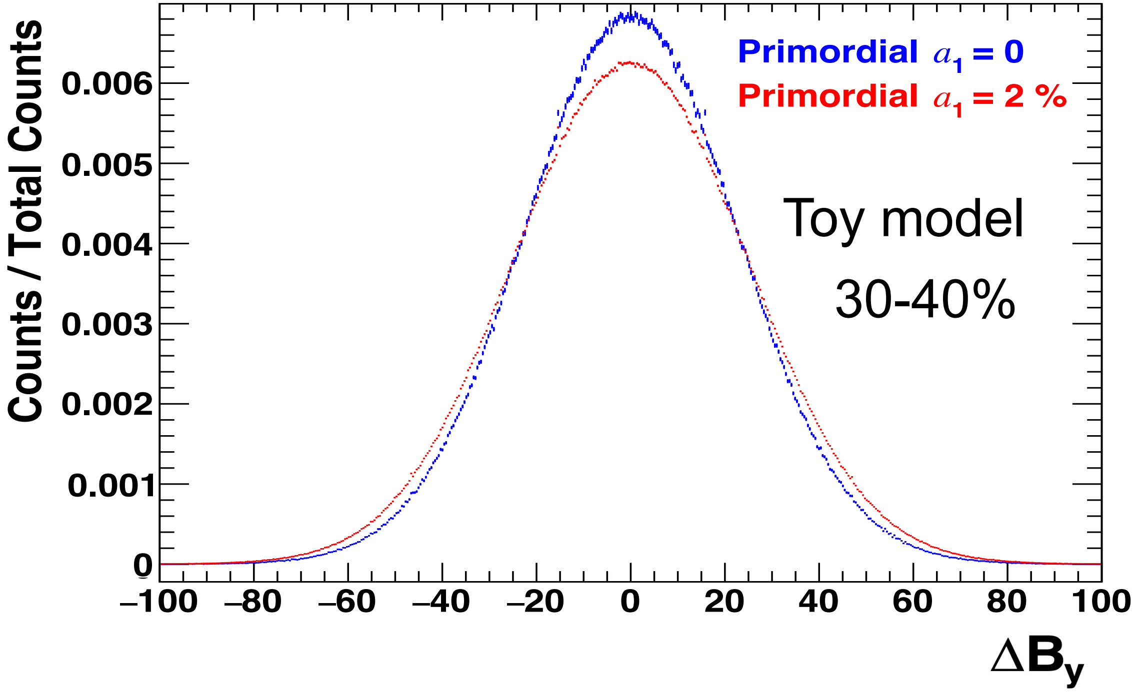
2) Count net-ordering (e.g. excess of pos. leading neg.) for each event :

$$\delta B_y(\pm 1) = B_{P,y}(\pm 1) - B_{N,y}(\pm 1)$$

$$\Delta B_y = \delta B_y(+1) - \delta B_y(-1)$$

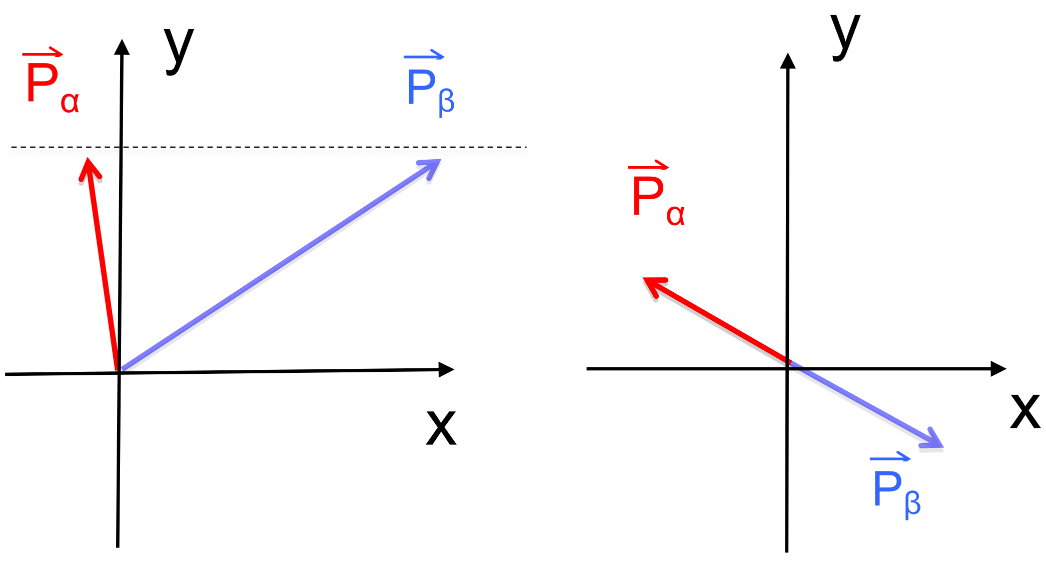
where $N_{\alpha\beta}$ denotes the number of positive -negative pairs with a sign of Sy in an event. S_y is labeled as +1 if $p^{\alpha}_y > p^{\beta}_y$, and -1 if vice versa.

3) Look for enhanced event-by-event fluctuation of net ordering in y direction.



$$r = \frac{\sigma_{\Delta B_y}}{\sigma_{\Delta B_x}}$$ (>1 with CME)

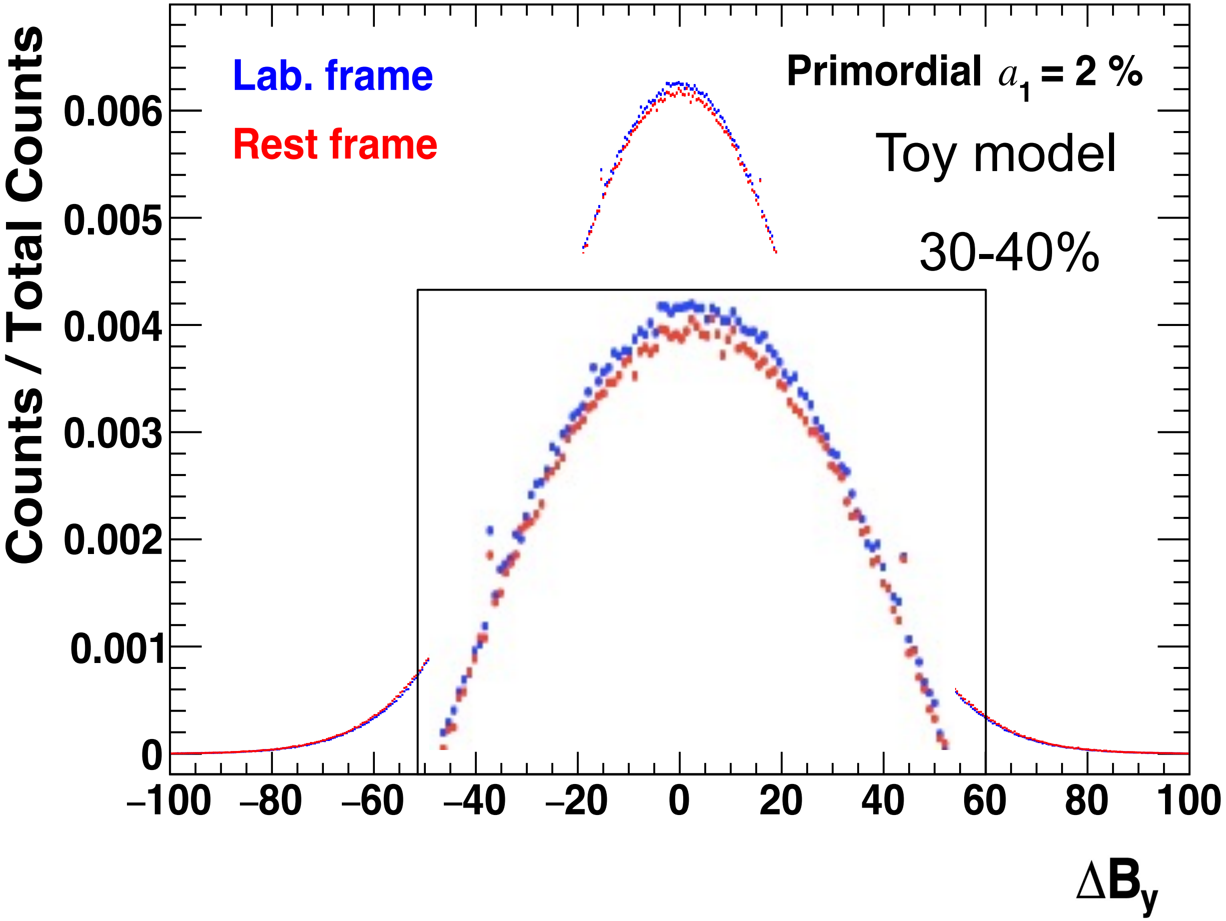
Backup: SBF



Lab frame view
($p_y^\alpha = p_y^\beta$)

Rest frame view
($p_y^\alpha > p_y^\beta$)

Rest frame has the best sensitivity to momentum ordering.



$$R_B = \frac{r_{rest}}{r_{lab}}$$ (>1 with CME)