Investigating the Chiral Magnetic Wave at RHIC-STAR

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- Methodology
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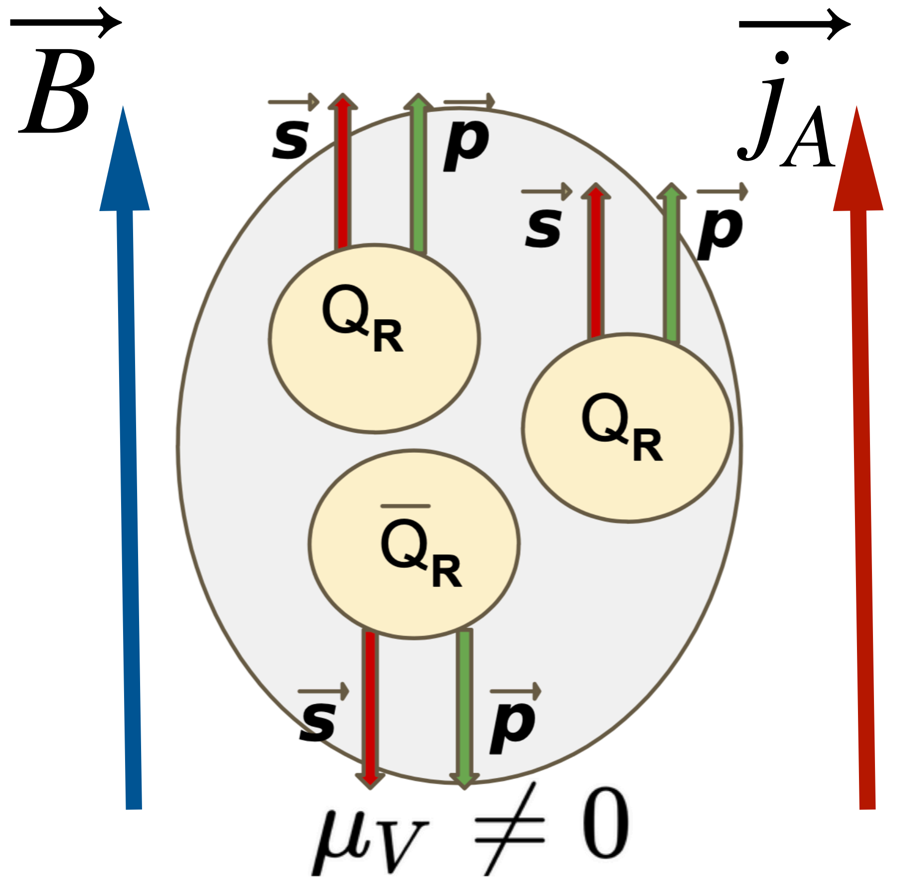
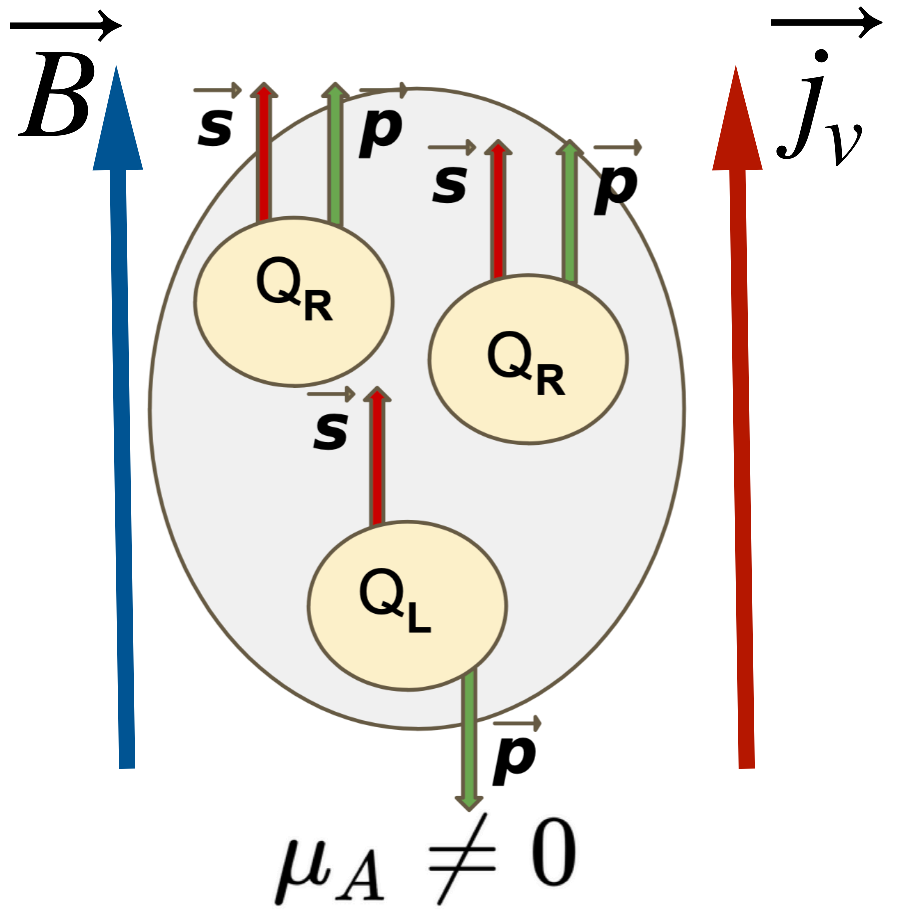
Introduction

Chiral Separation Effect (CSE)



CSE: With chirality imbalance, net electric charge current emerges along magnetic field.

Chiral Magnetic Effect (CME)



CME: With charge imbalance, net axial current emerges along magnetic field.

CSE + CME = CMW

$$\vec{j}_A = \frac{N_C e}{2\pi^2}\mu_\nu \vec{B} \qquad \vec{j}_\nu = \frac{N_C e}{2\pi^2}\mu_A \vec{B}$$

Y. Burnier, D. E. Kharzeev, J. Liao and H-U Yee, Phys. Rev. Lett. 107, 052303 (2011).

- Chiral Magnetic Wave (CMW): Charge and axial density fluctuations mutually induce each other through the CME and CSE.
- CMW evolution results in formation of electric charge quadrupole in the QGP medium, where positive charges accumulate at the poles and negative charges at the equator of the nuclear overlap region. This results in charge-dependent elliptic flow asymmetry.

Motivation

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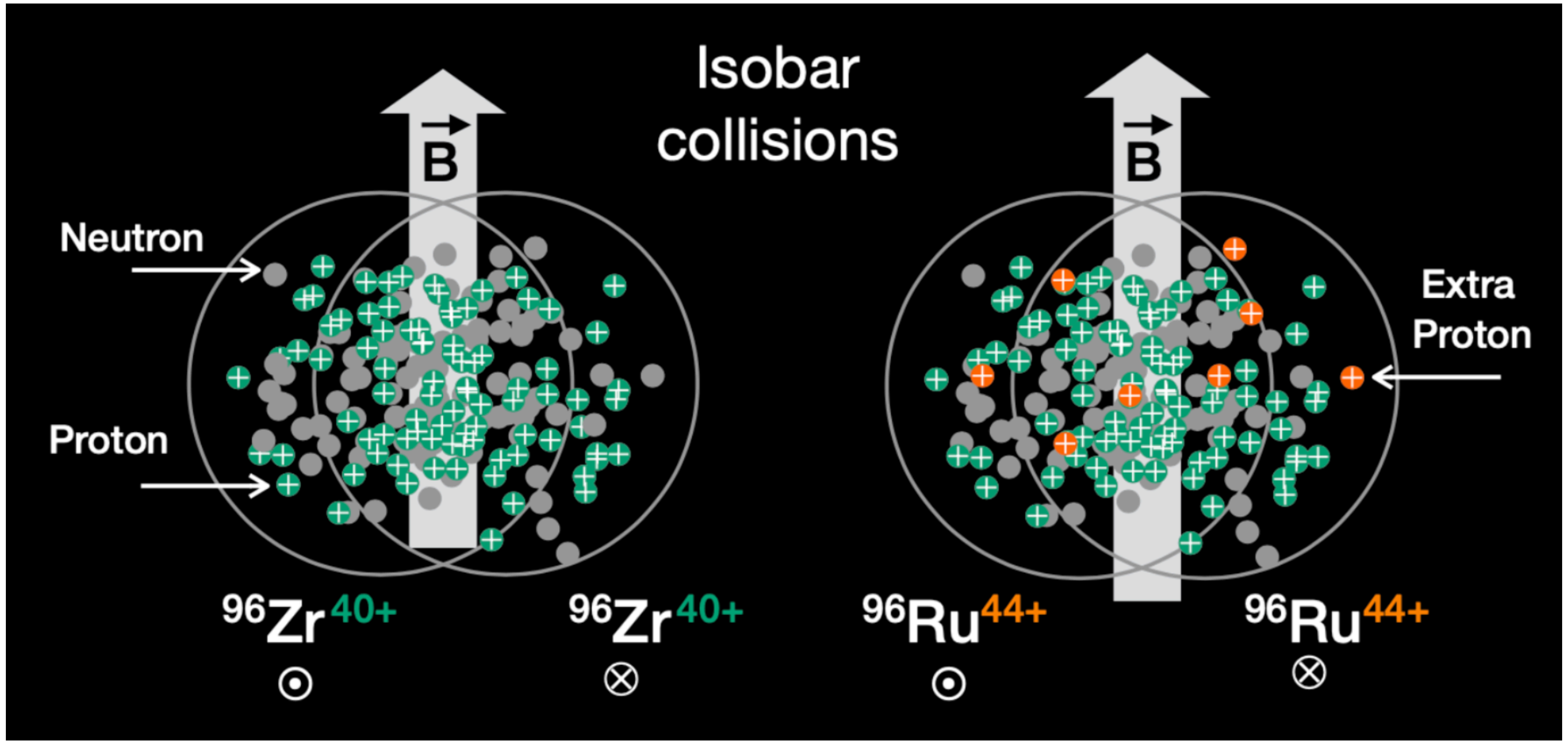
Isobar Collisions

- The magnetic field is ~10-18% larger in Ru+Ru collisions than Zr+Zr collisions due to the presence of 4 extra protons in Ru than Zr.
- Enhanced magnetic fields in Ru+Ru collisions are expected to give rise to larger CMW signal in Ru+Ru collisions.



P. Tribedy, Free meson seminar, TIFR, Oct 7th, 2021

Methodology

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- Electric quadrupole moment induced by CMW leads to difference in elliptic flow (v_2) of positive and negative charge particles, predicted to be proportional to charge asymmetry (A).

$$v_2^{\pm} - v_{2,base}^{\pm} = \mp \frac{r}{2} A \longrightarrow \Delta v_2 = v_2^- - v_2^+ \approx rA$$

$$A = \frac{N_+ - N_-}{N_+ + N_-}$$

- Experimentally, r is measured by slope of v_2 vs A.

- Another observable that can be used is covariance of $v_2^{\pm}$ and A (3-point correlator or 3-particle correlator):

$$\langle v_2^{\pm} A \rangle - \langle A \rangle \langle v_2^{\pm} \rangle \approx \mp r(\langle A^2 \rangle - \langle A \rangle^2)/2 \approx \mp r\sigma_A^2/2$$

- Δ Integral Correlator :

$$\Delta IC = \langle v_2^- A \rangle - \langle A \rangle \langle v_2^- \rangle - (\langle v_2^+ A \rangle - \langle A \rangle \langle v_2^+ \rangle) \approx r\sigma_A^2$$

** Phys. Rev. C 93 (2016) 044903*

** arXiv:2308.16123v1 [nucl-ex]*

Anisotropic Flow Calculation

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The two-particle Q-cumulant method :

$$Q_n = \sum_{j=1}^{M} e^{in\phi_j}, \qquad p_n = \sum_{j=1}^{m_p} e^{in\phi_j}$$

Reference Particles (REF) Particle of Interest (POI)

Sub-Event	REF $p_T < 2.0$ GeV/c	POI $p_T < 0.5$ GeV/c
A	**-1 < η < -0.3**	**0 < η < 1**
B	**0.3 < η < 1**	**-1 < η < 0**

The reference two particle cumulant is : $C_n\{2\} = \frac{Q_n^A \cdot Q_n^{B*}}{M_A\ M_B}$

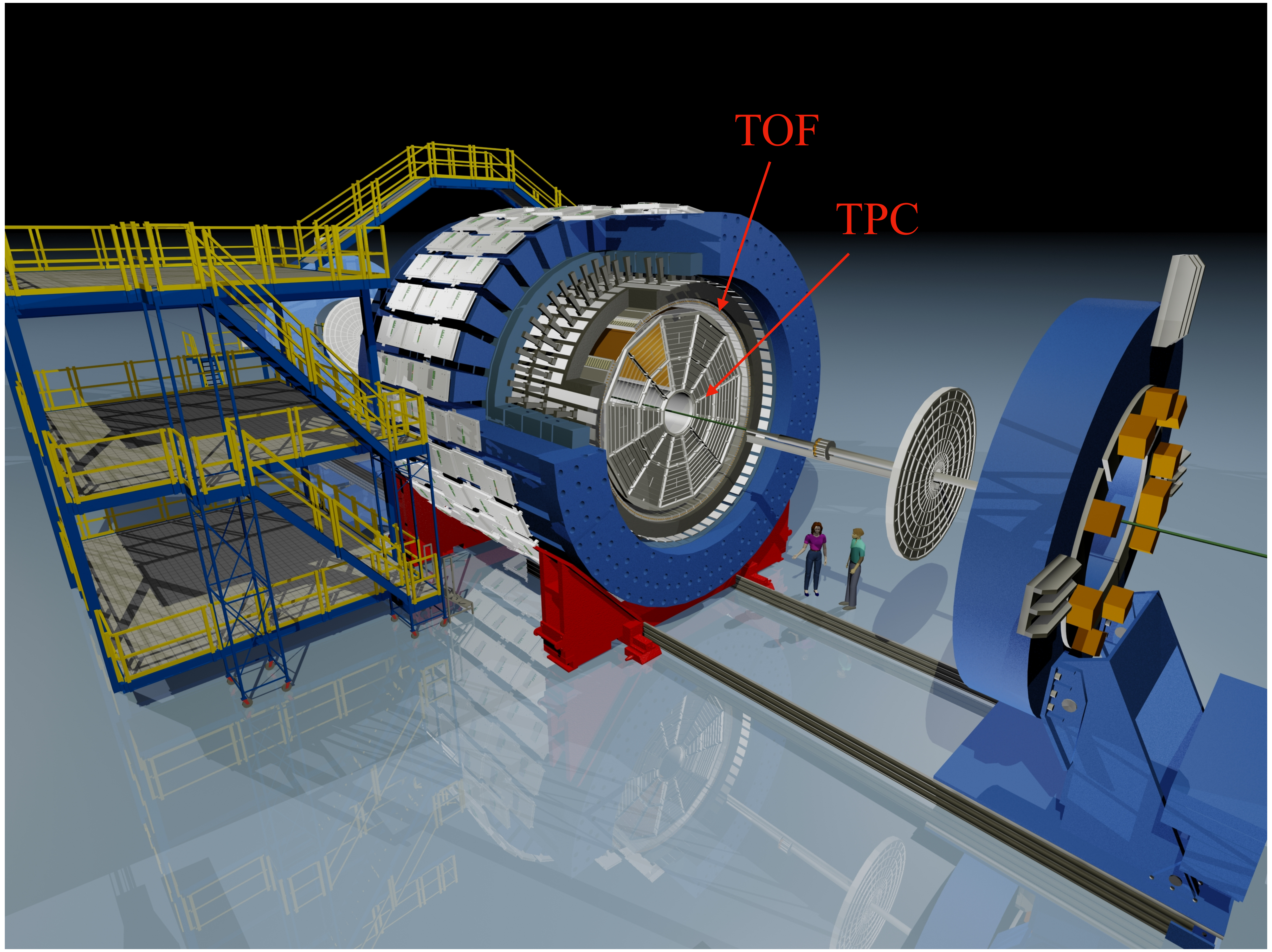
here Q_n^A and Q_n^B are flow vectors calculated from reference particles for sub-event A and B. M_A and M_B are multiplicities of these two sub-events.

The two-particle cumulant is calculated as $\langle 2' \rangle^A = \frac{p_n^A \cdot Q_n^{A*}}{m_p^A\ M_A}$, $\langle 2' \rangle^B = \frac{p_n^B \cdot Q_n^{B*}}{m_p^B\ M_B}$, $d_n\{2\} = \langle\langle 2' \rangle\rangle$

With all charged hadrons (h) as REF, the anisotropic flow of $h^\pm$: $v_n^{h^\pm}\{2\} = d_n\{2; h^\pm - REF\}/\sqrt{C_n\{2\}}$

A. Bilandzic, R. Snellings and S. Voloshin, Phys. Rev. C 83, 044913 (2011)

STAR Detector



Solenoid Tracker At RHIC (STAR).

- Time Projection Chamber (TPC)
  - Track reconstruction
  - Energy loss calculation
- Time Of Flight detector (TOF)
  - Particle identification
  - Pile-up rejection

Data Set

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★Run 18

★Collision Type: Zr+Zr @ 200 GeV (~ 1.6B Events after cuts)
Ru+Ru @ 200 GeV (~ 1.6B Events after cuts)

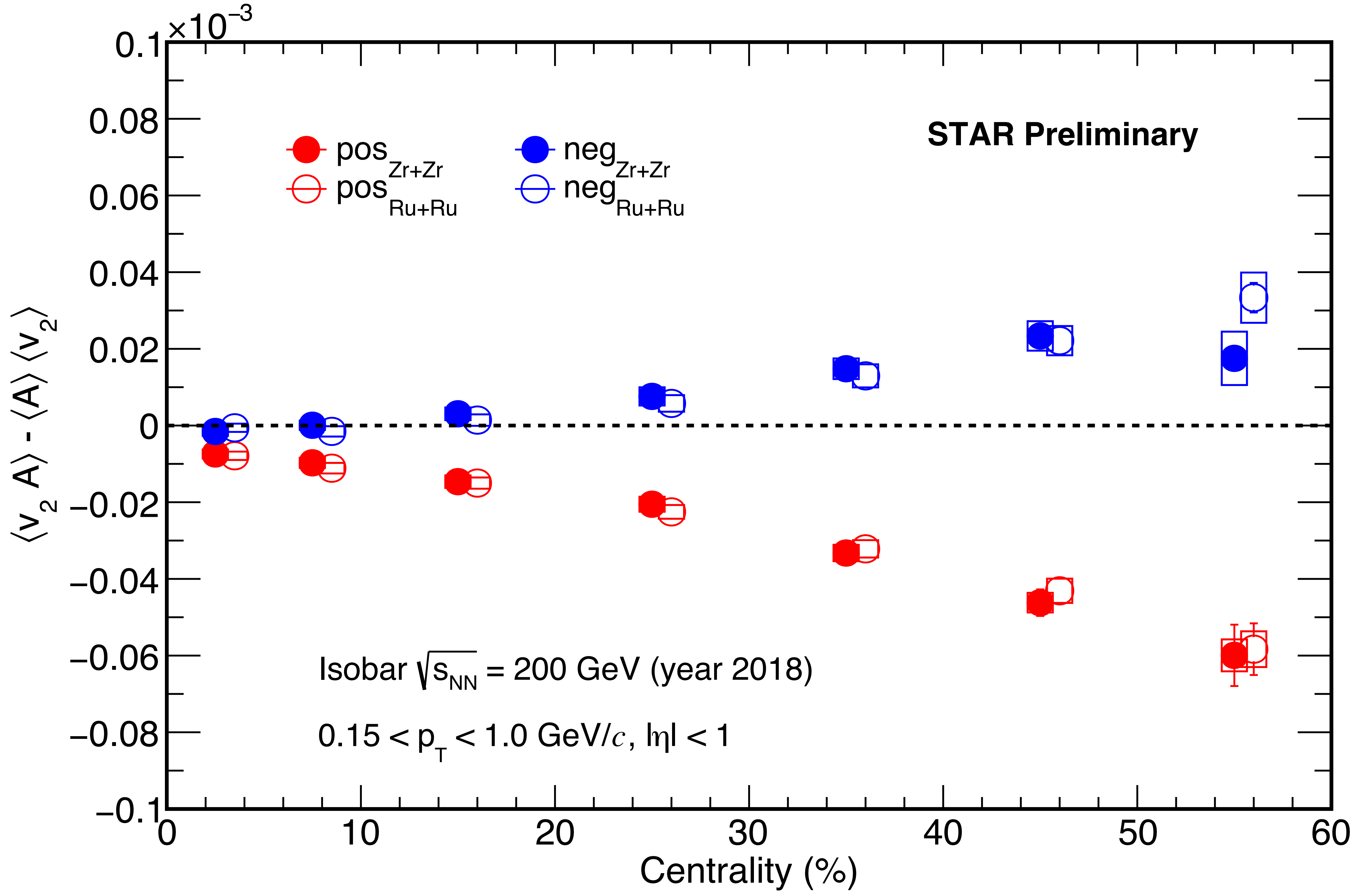
Event Cuts

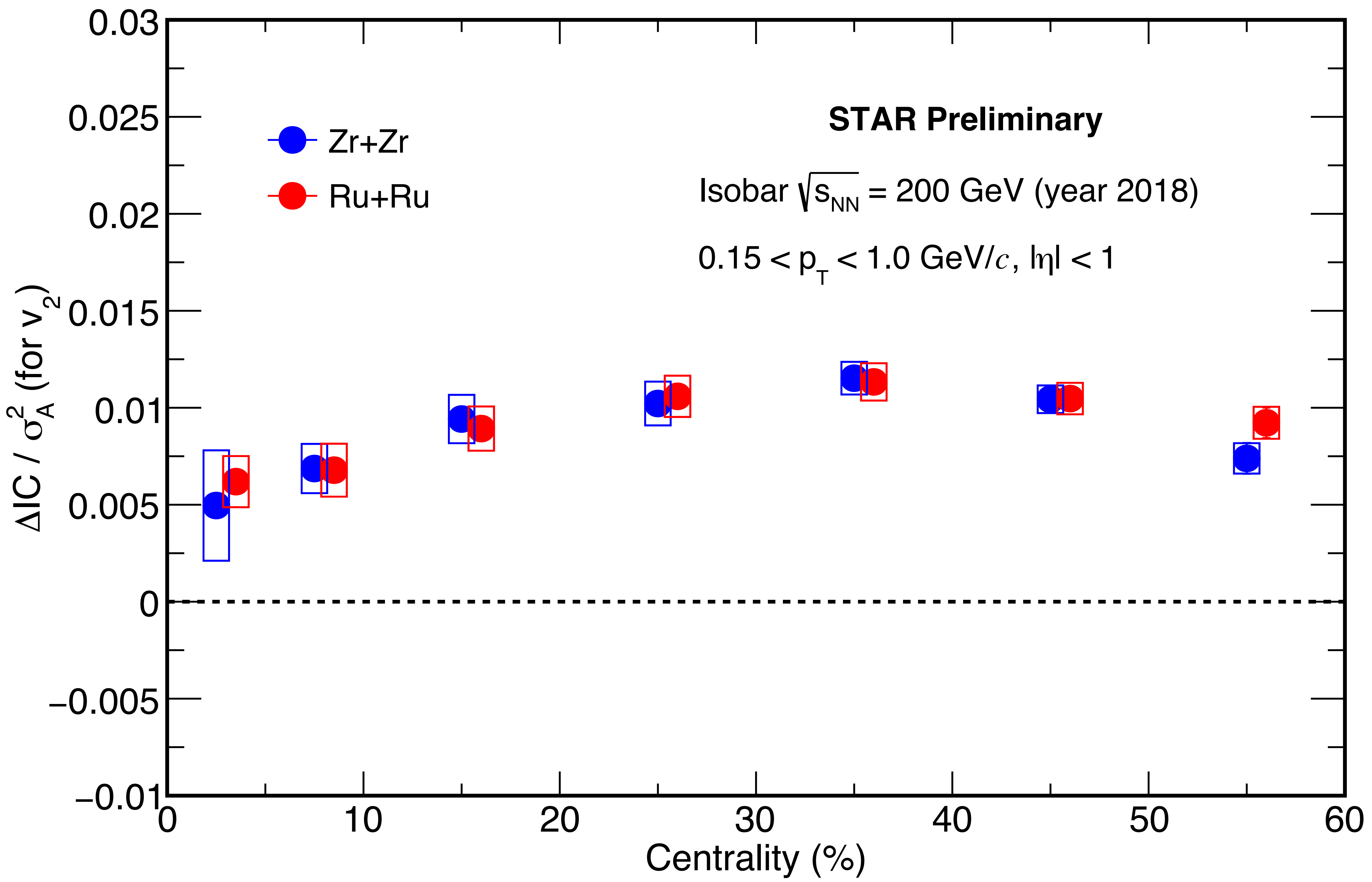
- Minimum bias Trigger (600001, 600011, 600021, 600031)
- $| V_{z,TPC} - V_{z,VPD} | < 5$ cm
- $V_r < 2$ cm
- Vertex cut: $-35 < V_Z < 25$ cm

Track Cuts

- $N_{Hits} > 15$
- $N_{Hits}/N_{HitsPoss} > 0.52$
- DCA < 3 cm
- $0.15 < p_T < 2$ GeV/c
- $|\eta| < 1$

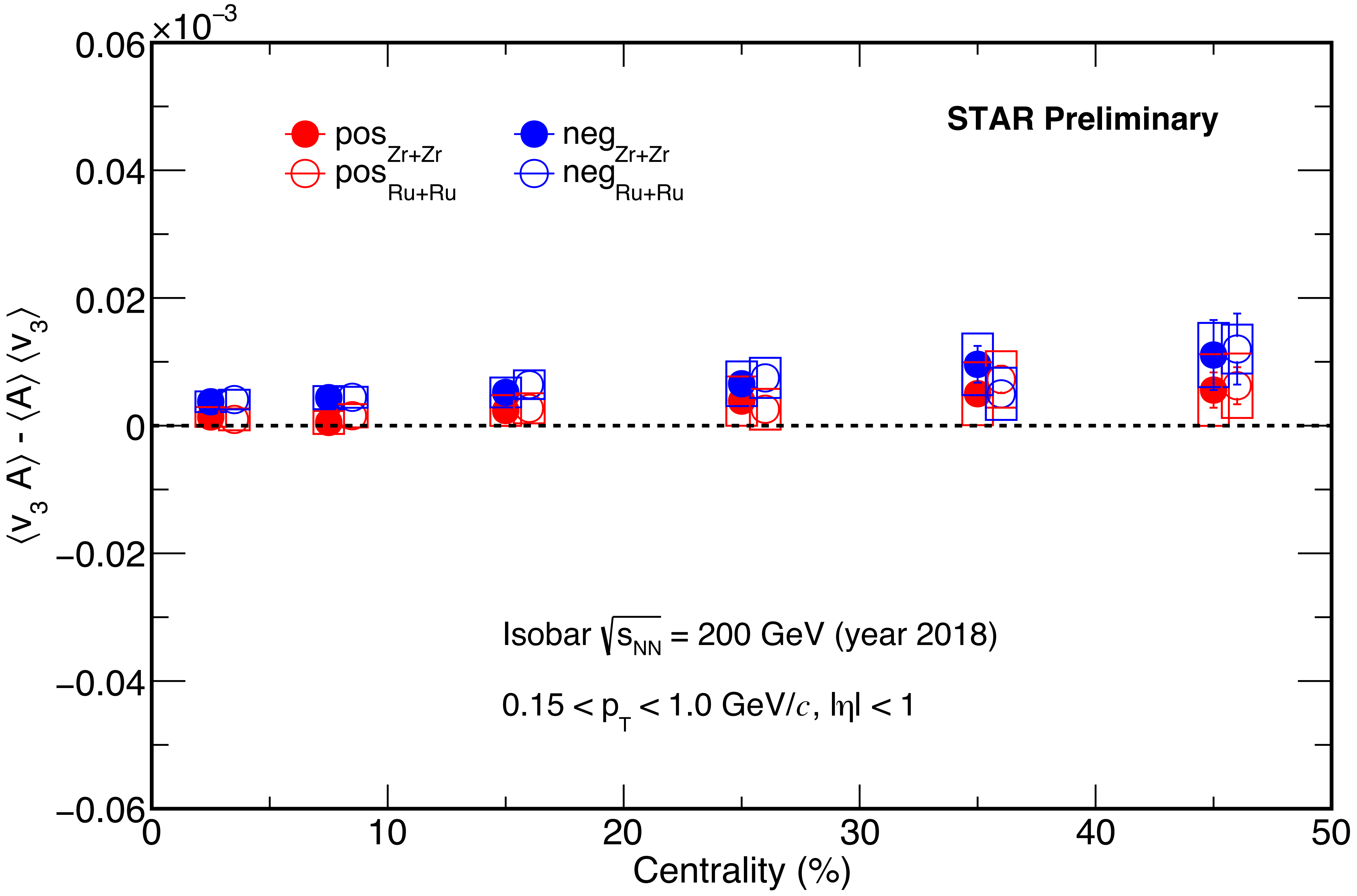
Covariance of v_2 and A

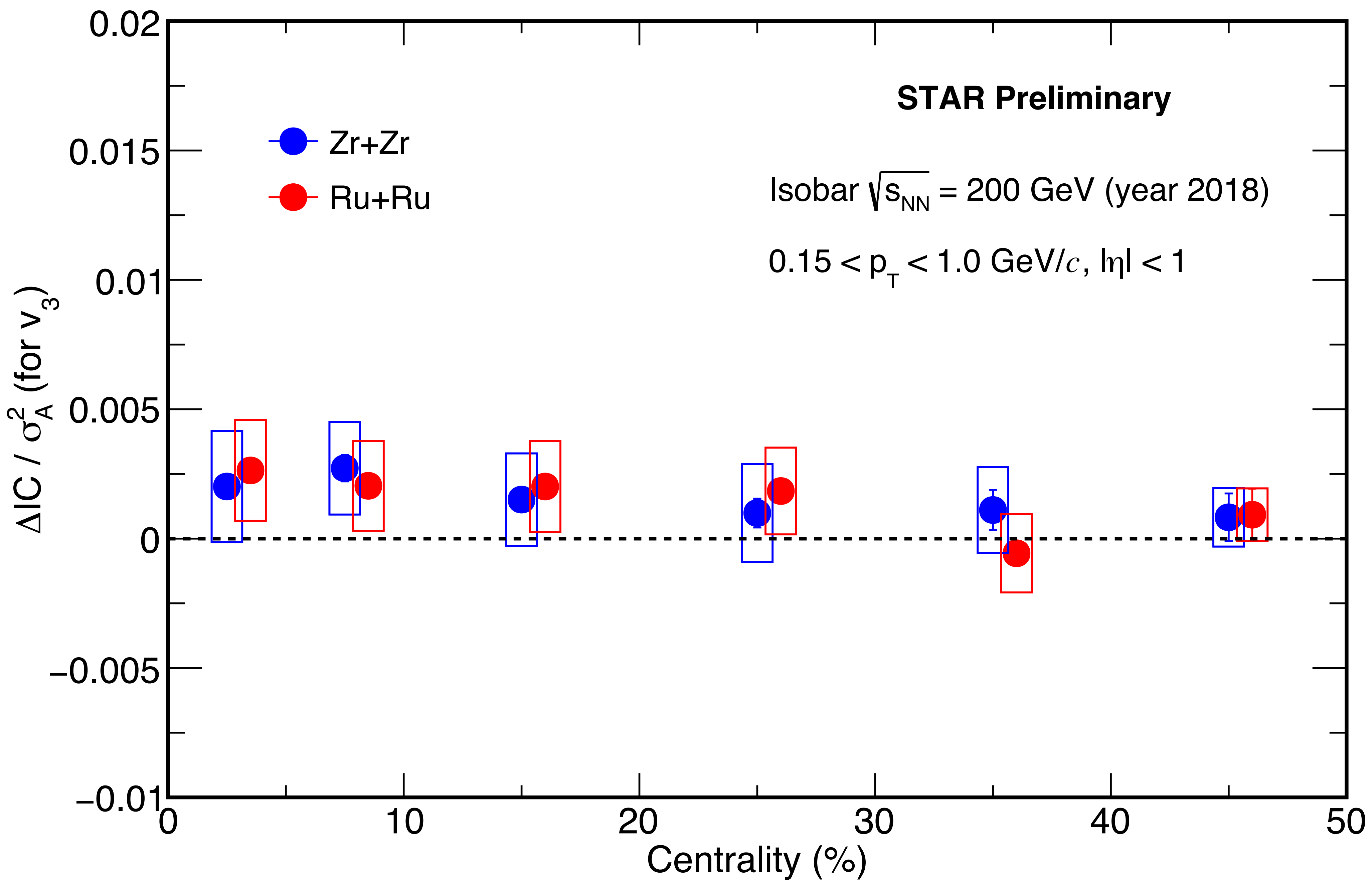




- Both Ru+Ru and Zr+Zr show charge dependent splitting of covariance between v_2 and A.
- Both Collision systems shows similar values of $\Delta IC/\sigma_A^2$ (for v_2).

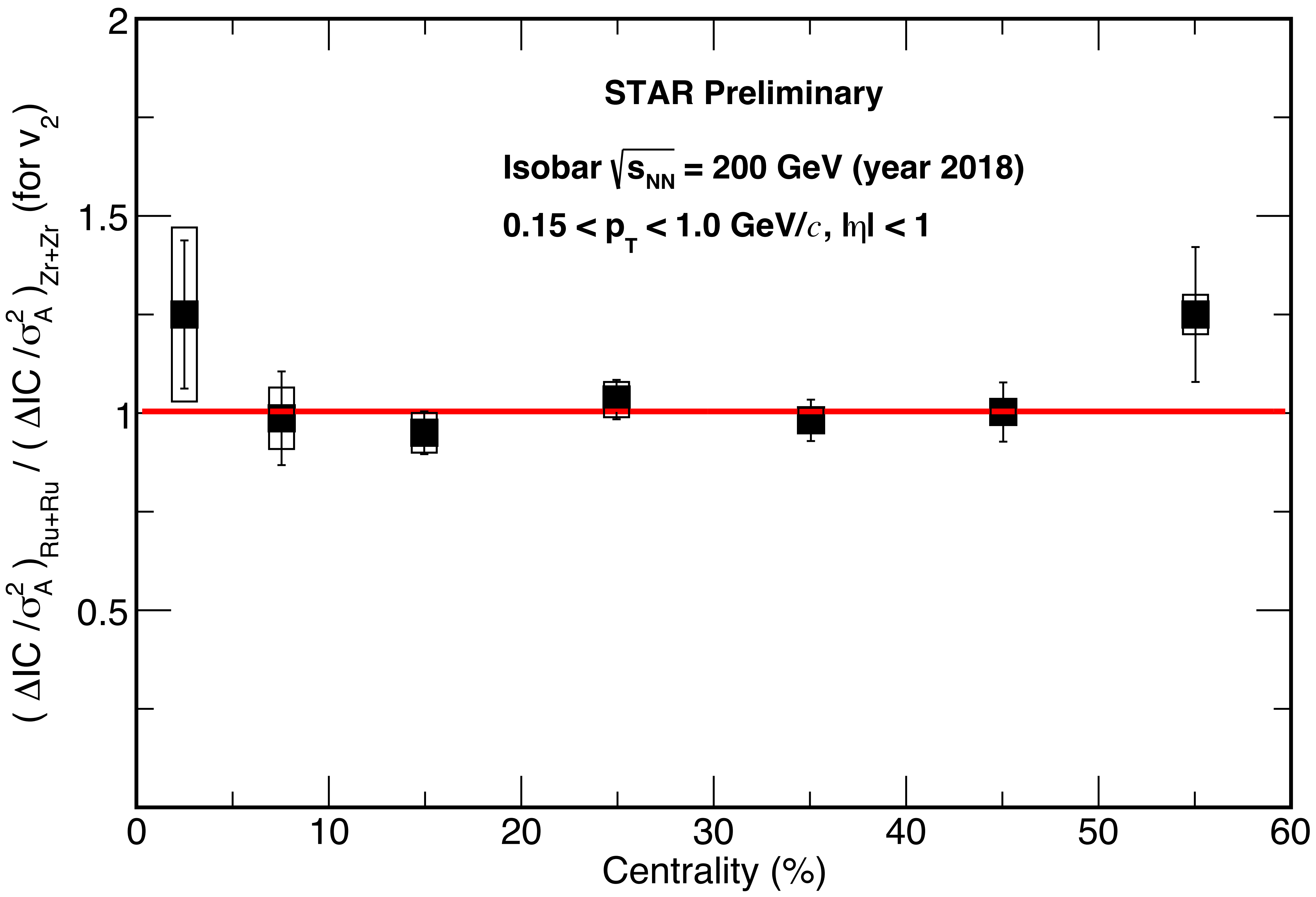
Covariance of v_3 and A





- Both Ru+Ru and Zr+Zr shows no splitting of covariance between v_3 and A.
- The values of $\Delta IC/\sigma_A^2$ (for v_3) are similar for both collision systems with the uncertainties.

Ratio



- No enhancement is observed in $\Delta IC/\sigma_A^2$ for Ru+Ru collisions compared to Zr+Zr collisions, despite the Ru having 4 more protons than the Zr.
- pol0 fit value is 1.0042 +/- 0.0265.

Summary

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- Both Ru+Ru and Zr+Zr shows similar splitting of integral correlator for positive and negative charged particles.
- Integral covariance of v_3 and **A** for positive and negative charged particle agrees within errors.
- No enhanced splitting is observed in the Ru+Ru compared to the Zr+Zr, despite the Ru having 4 more protons than the Zr.

Outlook

- Comparison of results with other collision systems to study system size dependence.
- To determine f_{CMW} using Event Shape Engineering (ESE) technique.

Thank you for your Attention !