THE UNIVERSITY OF ILLINOIS AT CHICAGO

Stony Brook University

STAR

Collision-system Dependence of the Charge Separation Relative to the Event Plane: Implications for Chiral Magnetic Effect Search in STAR

Niseem Magdy and Roy Lacey

niseemm@gmail.com

The 6th International Conference on Chirality, Vorticity and Magnetic Field in Heavy Ion Collisions

Outline

- Motivation
- $R_{\Psi_{2,3}}(\Delta S)$ correlator response
  - ✓ backgrounds only
  - ✓ backgrounds + CME
  - ✓ $R_{\Psi_2}(\Delta S)$ in isobaric collisions
- Results from analysis of isobar data
  - ✓ Data analysis
  - ✓ $R_{\Psi_2}(\Delta S)$ measurments
  - ✓ Ongoing work
- Conclusion

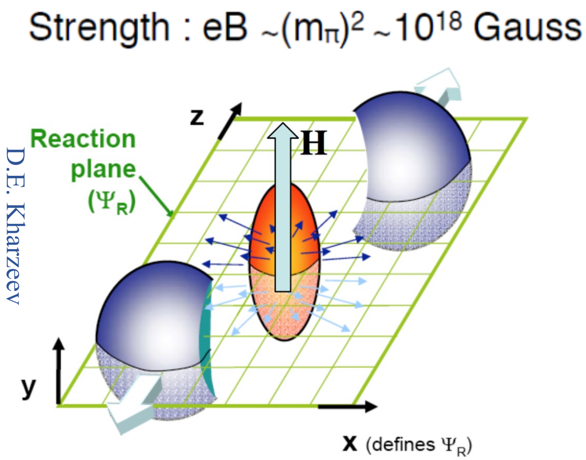
❖ Motivation

➢ Chiral Magnetic Effect (CME)

CME-driven charge separation leads to a dipole term in the azimuthal distribution of the produced charged hadrons:

$$\frac{dN^{ch}}{d\phi} \propto 1 \pm 2\, a_1^{ch} \sin(\phi) + \cdots \qquad a_1^{ch} \propto \mu_5 \vec{B}$$

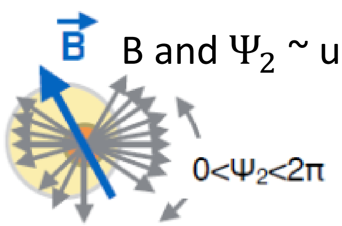
Can we identify & characterize this dipole moment?



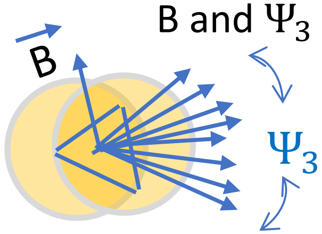
Prog.Part.Nucl.Phys. 75 (2014) 133-151
D.E. Kharzeev

➢ What a good correlator should establish?

✓ Leverage Small systems



✓ Leverage Ψ_3 measurements



✓ Excellent benchmark

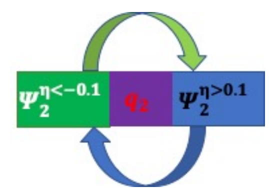
➢ Event-shape selections can constrain the v_2 driven background

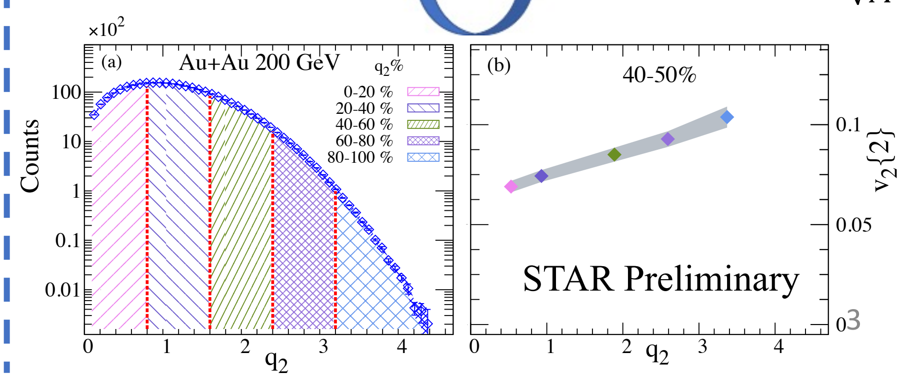
✓ Events are further subdivided into groups with different q_2 magnitude:

$$Q_{2,x} = \sum_{i=1}^{M} \cos(2\,\varphi_i)$$

$$Q_{2,y} = \sum_{i=1}^{M} \sin(2\,\varphi_i)$$

$$q_2 = \frac{\sqrt{Q_{2,x}^2 + Q_{2,y}^2}}{\sqrt{M}}$$





❖ Motivation

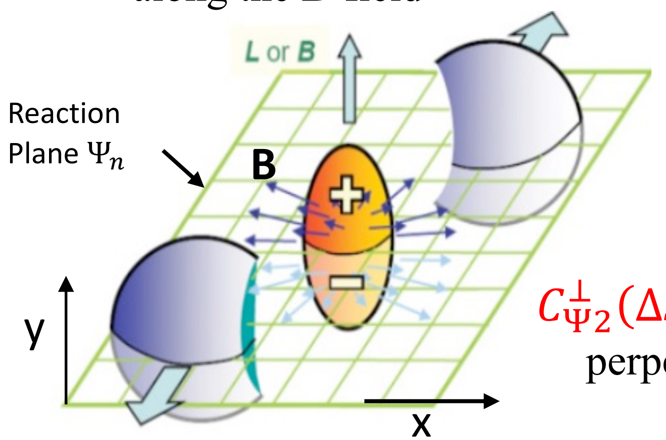
➢ The correlator is constructed for a given event plane Ψ_m via a ratio of two correlation functions

N. Magdy, et al. PRC 97, 061901 (2018)
Piotr Bozek PRC 97 (2018) 3, 034907
Niseem Magdy, et al. PRC 98 (2018) 6, 061902
Yicheng Feng, et al. PRC 98 (2018) 3, 034904
Yifeng Sun, et al. PRC 98 (2018) 1, 014911

$C_{\Psi 2}(\Delta S)$ quantifies charge separation along the B-field

m = 2,3

$$R_{\Psi m}(\Delta S) = \frac{C_{\Psi_m}(\Delta S)}{C^{\perp}_{\Psi_m}(\Delta S)}$$



$C^{\perp}_{\Psi 2}(\Delta S)$ quantifies charge separation perpendicular to the B-field (only background)

The $R_{\Psi 2}(\Delta S)$ correlator measures the magnitude of charge separation parallel to the B-field, relative to that for charge separation perpendicular to the B-field

Note that both $C_{\Psi_3}(\Delta S)$ and $C^{\perp}_{\Psi_3}(\Delta S)$ are insensitive to the CME-driven charge separation (only background)

❖ $R_{\Psi m}(\Delta S)$ Correlator

N. Magdy, et al.
PRC 97, 061901 (2018)

$$R_{\Psi m}(\Delta S) = \frac{C_{\Psi m}(\Delta S)}{C^{\perp}_{\Psi m}(\Delta S)}$$

$$C_{\Psi m}(\Delta S) = \frac{N(\Delta S)}{N(\Delta S_{sh})}$$

$$\Delta\varphi = \varphi - \Psi_{\mathrm{m}}$$

$$C^{\perp}_{\Psi m}(\Delta S) = \frac{N(\Delta S^{\perp})}{N(\Delta S^{\perp}_{sh})}$$

$N(\Delta S)$

$$\langle S^{+}_{\Psi m}\rangle = \frac{\sum_1^p w_p \sin(\frac{m}{2}\,\Delta\varphi)}{\sum_1^p w_p}$$

$$\langle S^{-}_{\Psi m}\rangle = \frac{\sum_1^n w_n \sin(\frac{m}{2}\,\Delta\varphi)}{\sum_1^n w_n}$$

$$\Delta S = \langle S^{+}_{\Psi m}\rangle - \langle S^{-}_{\Psi m}\rangle$$

$N(\Delta S_{Sh})$

$$\Delta S_{Sh} = \langle S^{+}_{\Psi m}\rangle_{Sh} - \langle S^{-}_{\Psi m}\rangle_{Sh}$$

Sensitive to charge separation
(CME and Background)

w_i: charge dependent detector acceptance.

Shuffling of charges within an event breaks the charge separation sensitivity

$N(\Delta S^{\perp})$

$$\langle S^{+}_{\Psi m}\rangle^{\perp} = \frac{\sum_1^p w_p \cos(\frac{m}{2}\,\Delta\varphi)}{\sum_1^p w_p}$$

$$\langle S^{-}_{\Psi m}\rangle^{\perp} = \frac{\sum_1^n w_n \cos(\frac{m}{2}\,\Delta\varphi)}{\sum_1^n w_n}$$

$$\Delta S^{\perp} = \langle S^{+}_{\Psi m}\rangle^{\perp} - \langle S^{-}_{\Psi m}\rangle^{\perp}$$

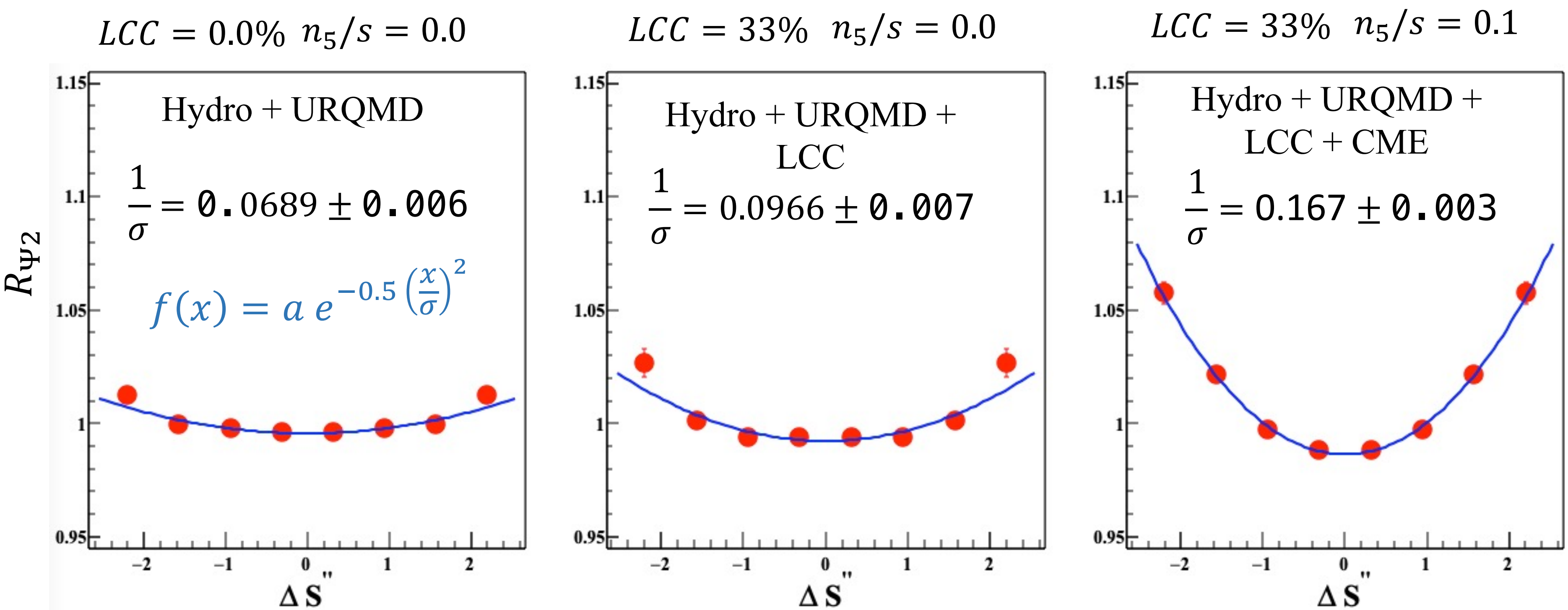
$N(\Delta S^{\perp}_{Sh})$

$$\Delta S^{\perp}_{Sh} = \langle S^{+}_{\Psi m}\rangle^{\perp}_{Sh} - \langle S^{-}_{\Psi m}\rangle^{\perp}_{Sh}$$

➢ We account for both number fluctuations and EP-resolution effect on the width of the $R_{\Psi m}(\Delta S)$

❖ $R_{\Psi_{2,3}}(\Delta S)$ correlator response

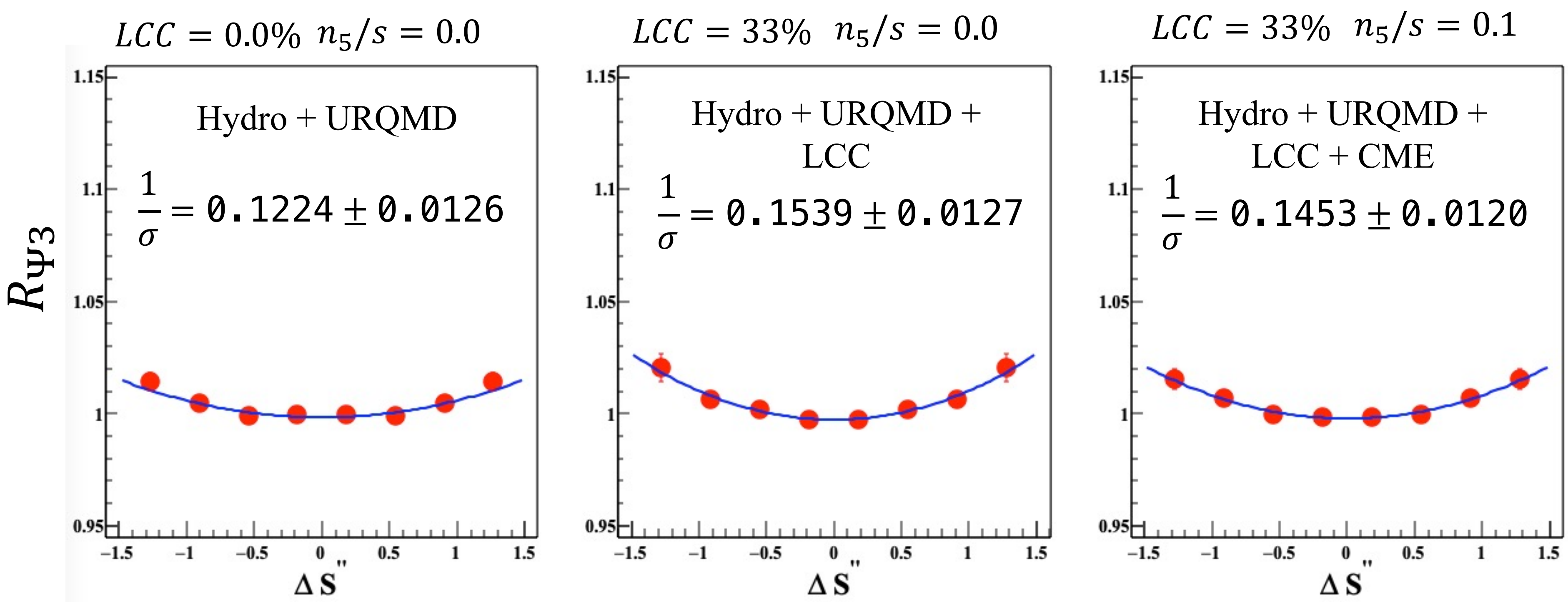
- ➢ $R_{\Psi_2}(\Delta S)$ response in AVFD 30-40 %



- ➢ The magnitudes of the backgrounds and the signal are reflected in the widths of the R_{Ψ_2} distributions

❖ $R_{\Psi_{2,3}}(\Delta S)$ correlator response

➢ $R_{\Psi_3}(\Delta S)$ response in AVFD 30-40 %



➢ The magnitudes of the R_{Ψ_3} distributions:

- ✓ Sensitive to backgrounds
- ✓ Insensitive to CME-driven signal

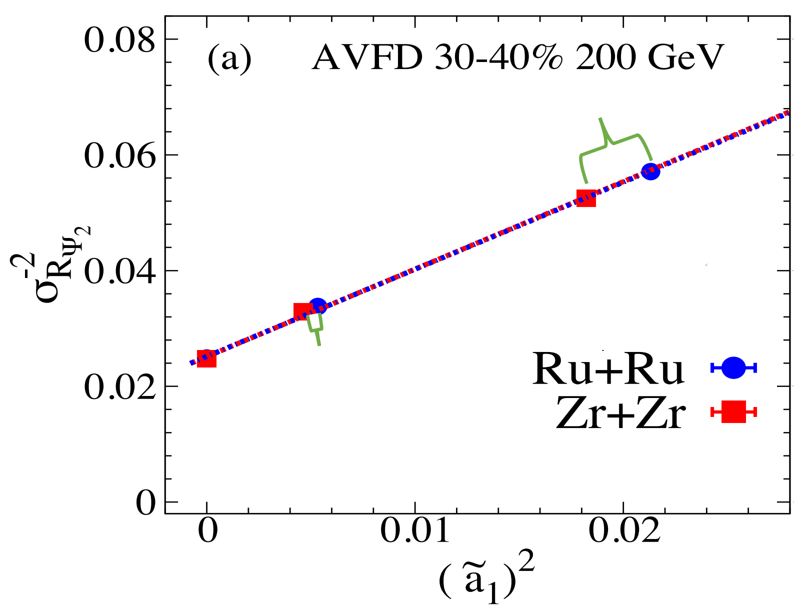
❖ $R_{\Psi_{2,3}}(\Delta S)$ correlator response

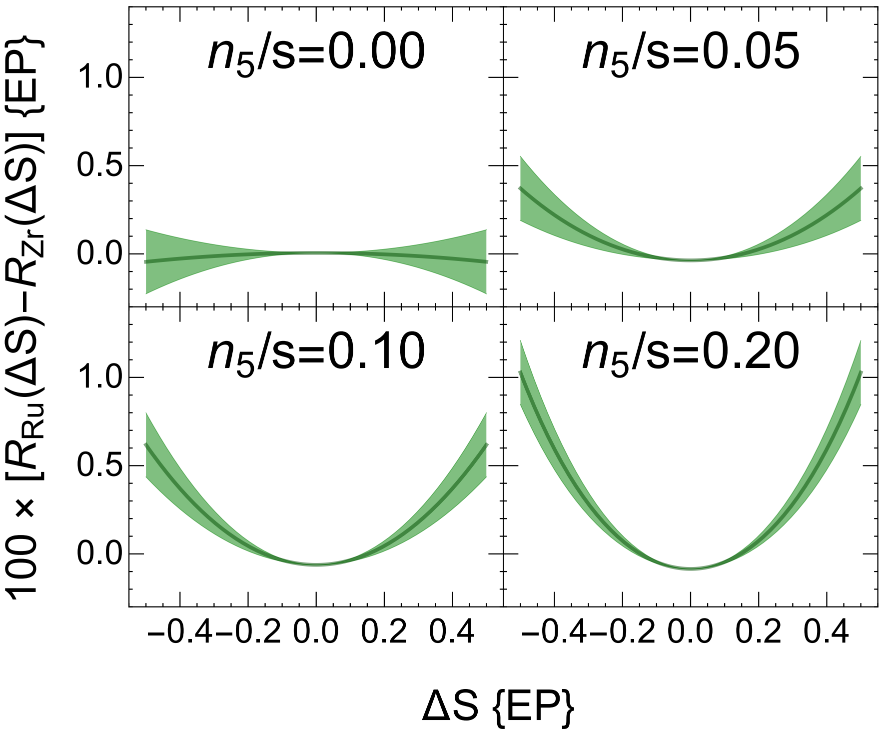
Niseem Magdy, et al.
PRC 98 (2018) 6, 061902

➢ $R_{\Psi_2}(\Delta S)$ in isobaric collisions

✓ If Isobars have same background?

Shuzhe Shi, et al.
PRL 125, 242301 (2020)





Predefined CME signature:

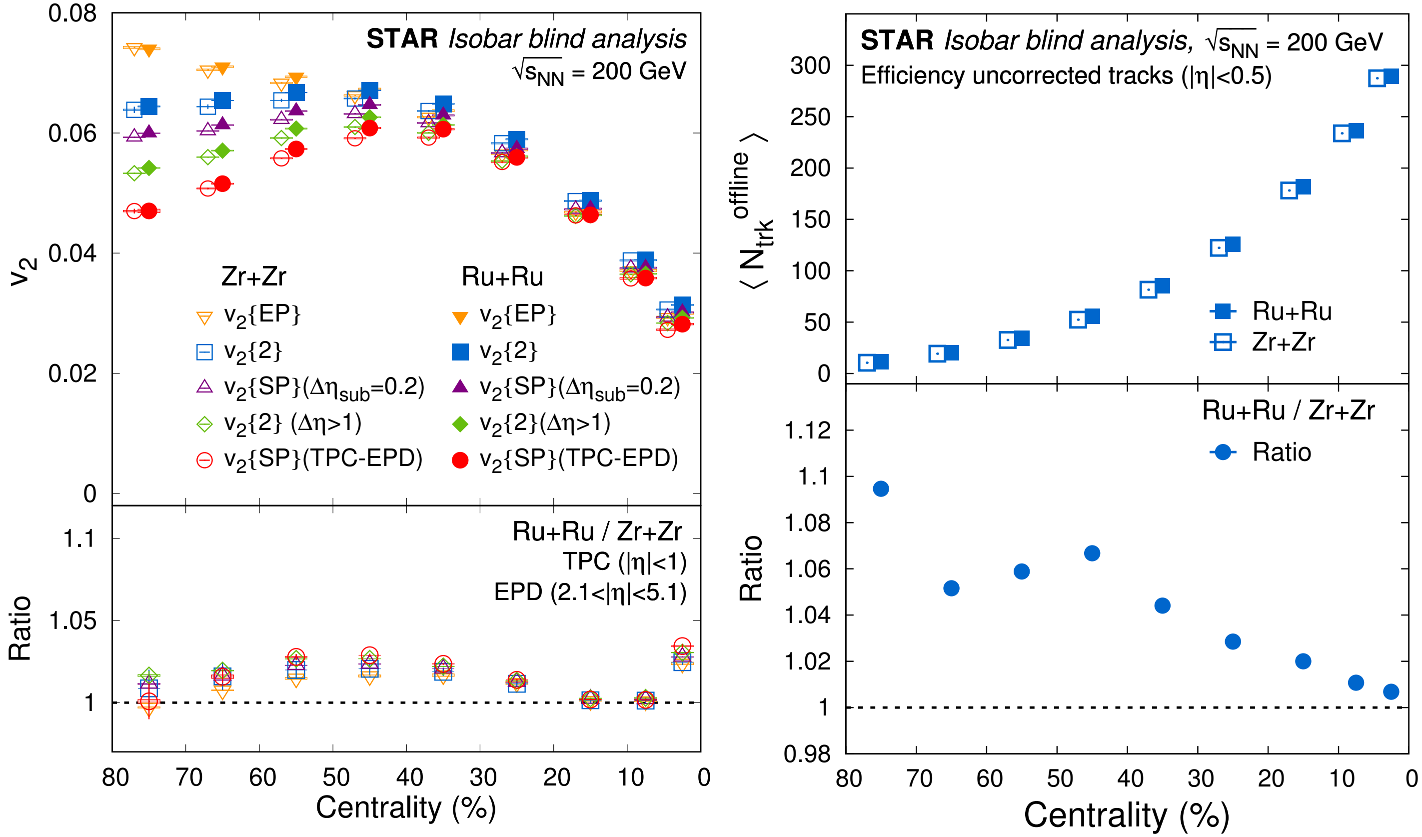
$$1/\sigma_{R_{\Psi_2}}(\mathrm{Ru+Ru}) > 1/\sigma_{R_{\Psi_2}}(\mathrm{Zr+Zr})$$

❖ $R_{\Psi_m}(\Delta S)$ Correlator

➢ $R_{\Psi_m}(\Delta S)$ response in isobaric collisions

✓ Isobaric background are not the same:

STAR Collaboration
arxiv:2109.00131



➢ Observed differences in multiplicity and v_2 for same centrality

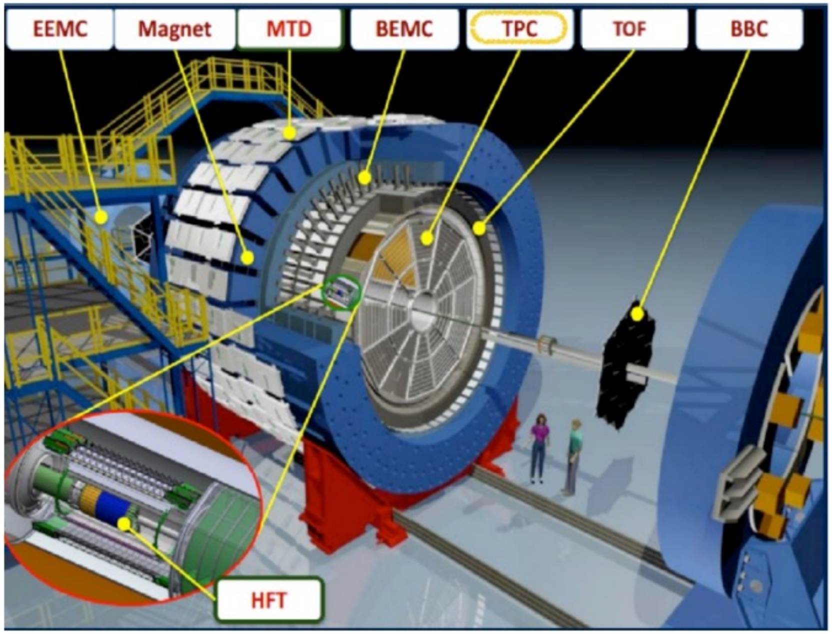
✓ Background differences for the two isobars are more complicated than previously thought

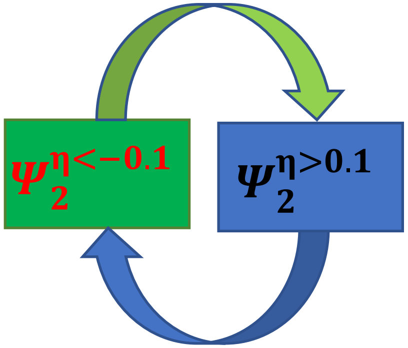
- Results from analysis of isobar data

❖ Data Analysis

The STAR Detector at RHIC

- The TPC detector is used in the current analysis
- Charged hadrons with 0.2 < pT < 2.0 GeV/c used to construct $\Psi_2^{\eta>0.1}$ & $\Psi_2^{\eta<-0.1}$
- Particles with 0.35 < pT < 2.0 GeV/c and $\eta < 0$ analyzed using $\Psi_2^{\eta>0.1}$
- Particles with 0.35 < pT < 2.0 GeV/c and $\eta > 0$ analyzed using $\Psi_2^{\eta<-0.1}$

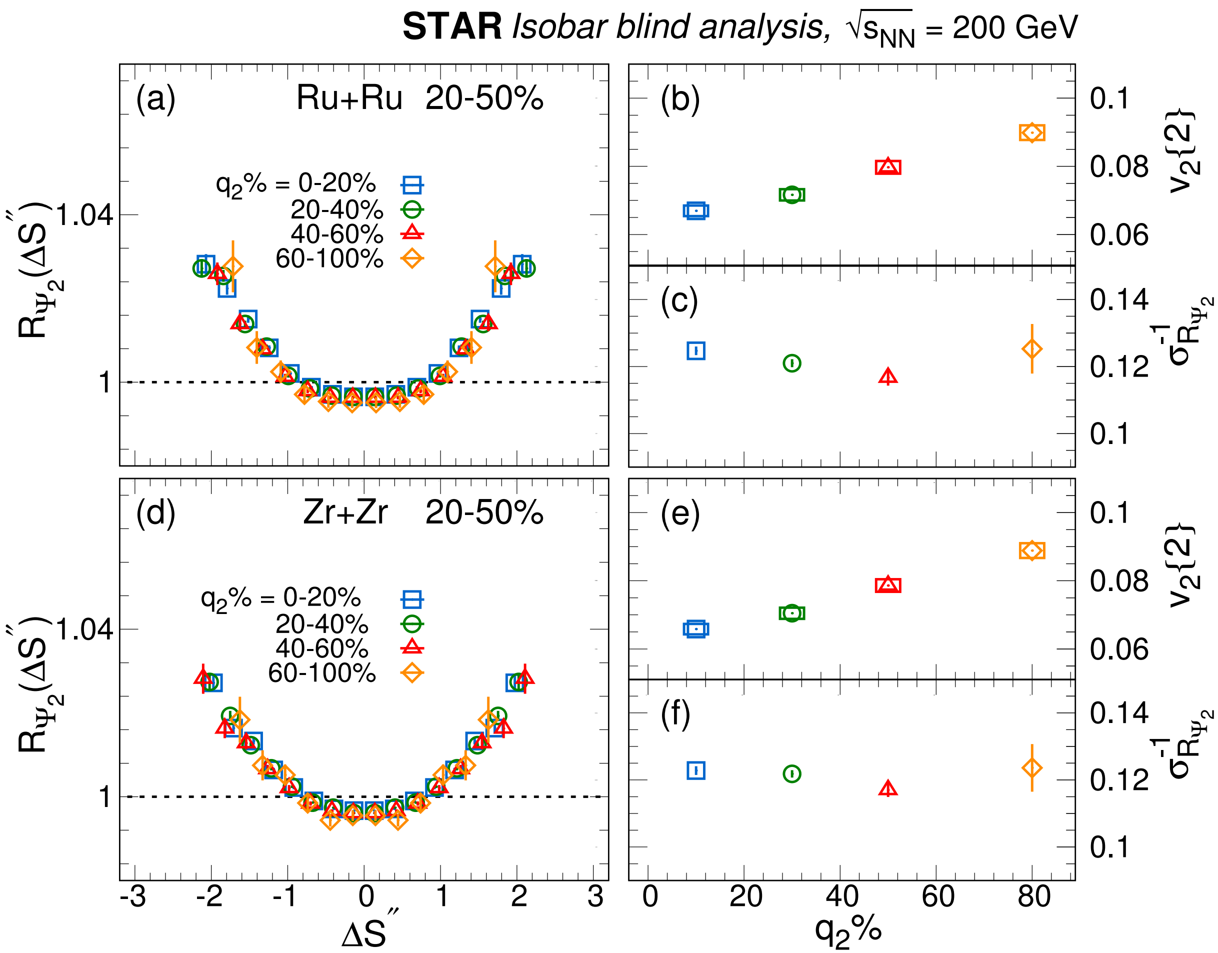




❖ Results

- ➢ $R_{\Psi_2}(\Delta S)$ measurements
  - ✓ Event-shape selections

STAR Collaboration
arxiv:2109.00131



➢ Different q_2 selections indicates that $R_{\Psi_2}(\Delta S'')$ is not strongly influenced by the v_2 background-driven charge separation for ~20% change in v_2.

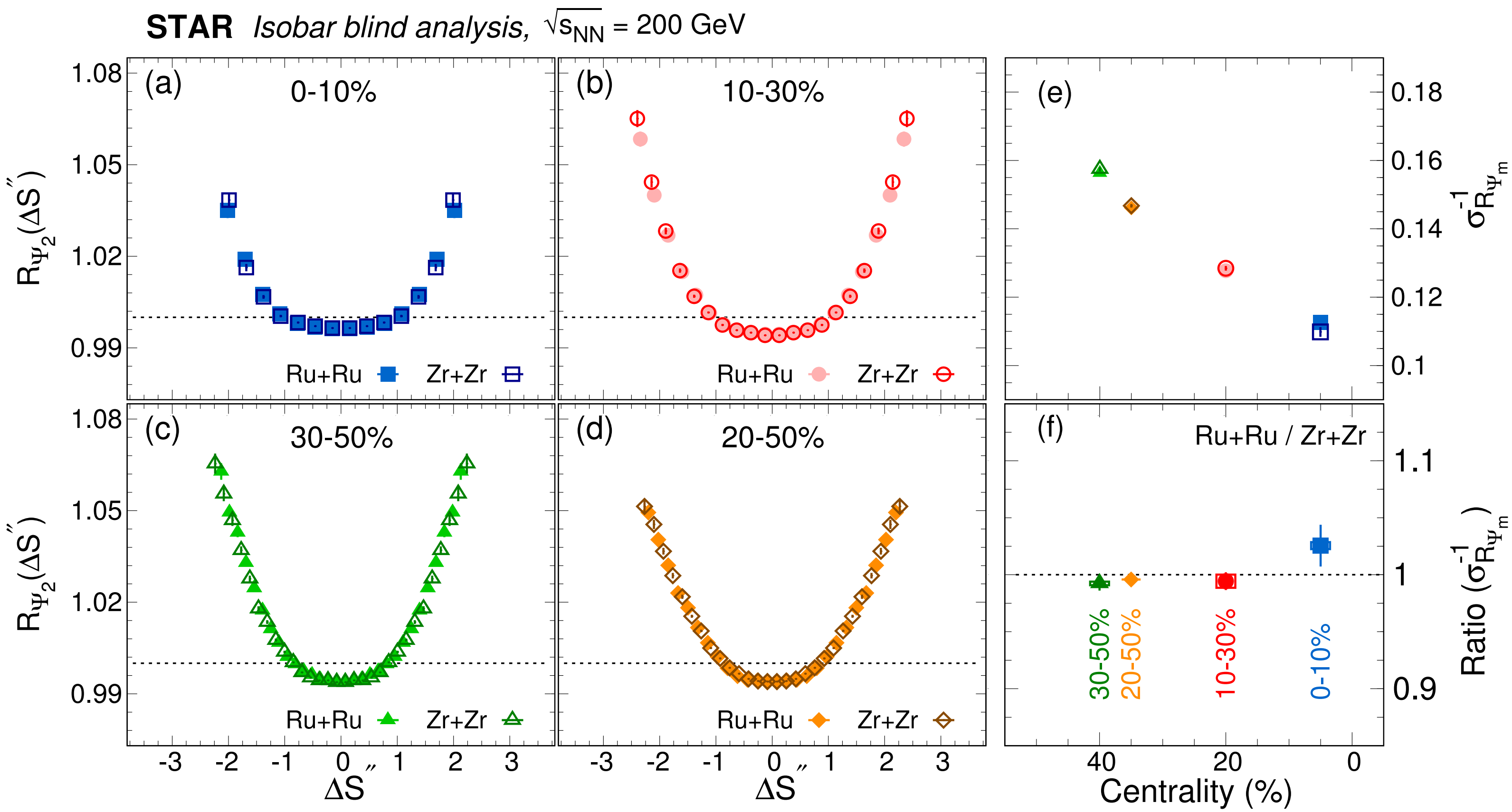
❖ Results

➢ $R_{\Psi_2}(\Delta S)$ measurements

✓ Centrality selections

Predefined CME signature:

$$1/\sigma_{R_{\Psi_2}}(\mathrm{Ru+Ru}) > 1/\sigma_{\mathrm{R}_{\Psi_2}}(\mathrm{Zr+Zr})$$



➢ The $\mathrm{R}_{\Psi_2}(\Delta S'')$ correlators for different collision centrality is similar between the two isobars.

Predefined CME signature not observed

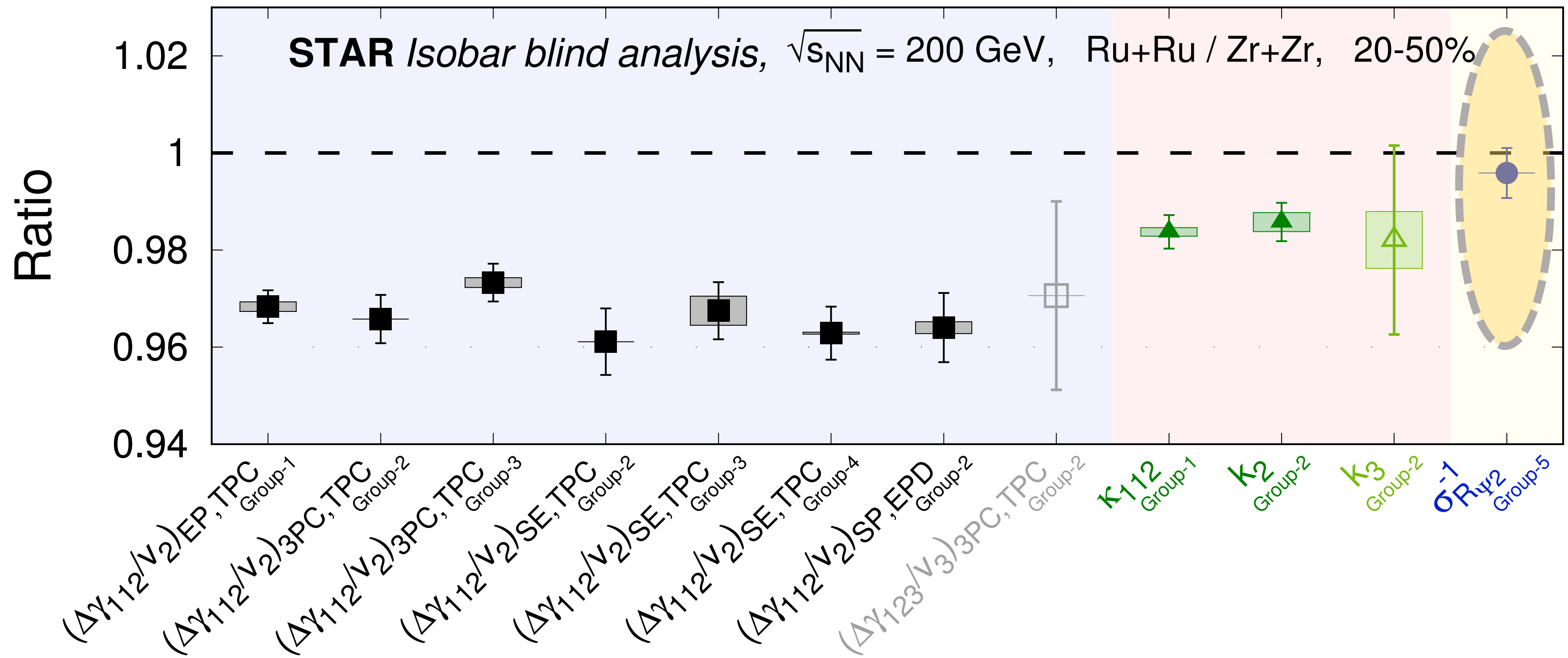
✓ Not an indication for the absence of the CME

❖ Results

➢ $R_{\Psi_2}(\Delta S)$ measurements

Predefined CME signature:

$$1/\sigma_{R_{\Psi_2}}(\mathrm{Ru+Ru}) > 1/\sigma_{\mathrm{R}_{\Psi_2}}(\mathrm{Zr+Zr})$$



Predefined CME signature not observed

✓ Not an indication for the absence of the CME

❖ Ongoing work

- The use of $R_{\Psi_3}(\Delta S)$ to constrain the background difference for the two isobars
- Detailed studies of the nuclear structure effects on the background for the isobars
- Detailed data-model comparisons for isobars

❖ Conclusions

Charge separation calculations with AVFD used to validate the response of the $R_{\Psi_{2,3}}$ correlators:

- ✓ R_{Ψ_2} is sensitive to backgrounds and signal magnitude
- ✓ R_{Ψ_3} is sensitive to backgrounds only

Charge separation measurements performed with R_{Ψ_2} correlator, for isobaric collisions at 200 GeV:

- ✓ R_{Ψ_2} shows concave shape compatible BKG or BKG + CME
- ✓ R_{Ψ_2} shows weak q_2 dependence
- ✓ R_{Ψ_2} distributions are similar for the two isobars

Predefined CME signature not observed

- ✓ Not an indication for the absence of the CME
  - Ongoing work to study the backgrounds

THANK YOU

THANK YOU