Search for the Chiral Magnetic Effect with Isobar Collisions at 200 GeV using the $R_{\Psi_2}(\Delta S)$ correlator

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

Outline

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- $R_{\Psi_{2,3}}(\Delta S)$ correlator response
  - ✓ backgrounds only
  - ✓ backgrounds + CME
  - ✓ $R_{\Psi_2}(\Delta S)$ in isobaric collisions

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- Analysis and results from isobar data
  - ✓ Data analysis
  - ✓ $R_{\Psi_2}(\Delta S)$ measurments
  - ✓ Ongoing work

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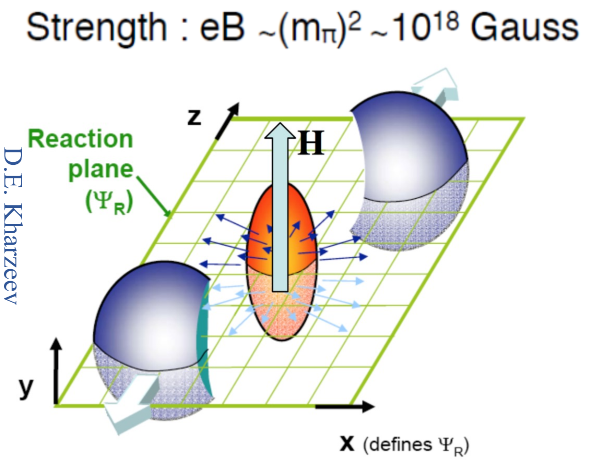
❖ Motivation

➢ 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?



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

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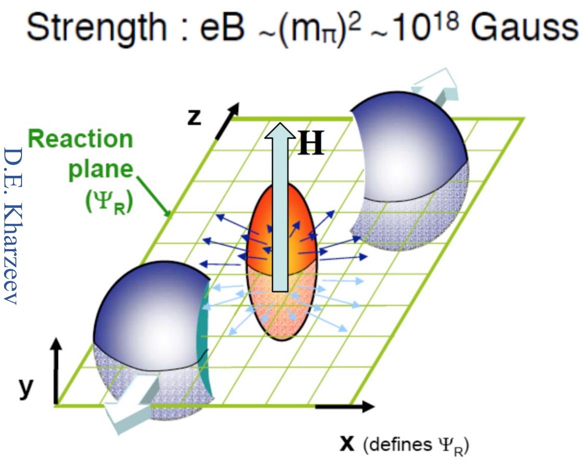

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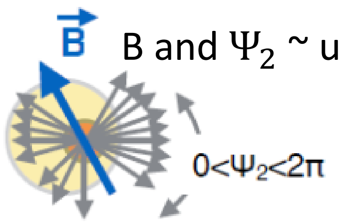
➢ What a good correlator should establish?

✓ Leverage Small systems

B and Ψ_2 ~ uncorrelated



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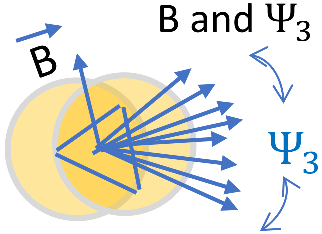

✓ Excellent benchmark

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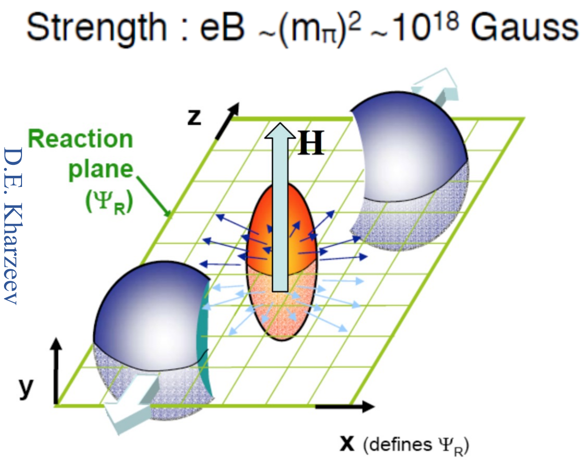

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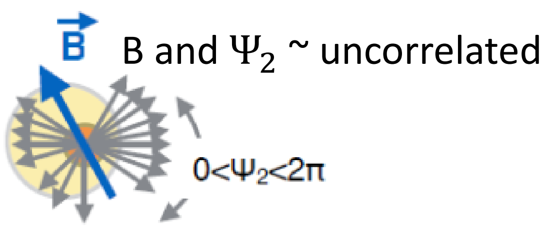

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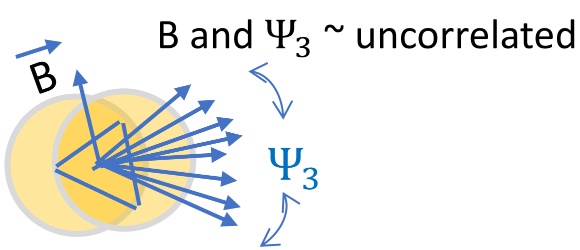


✓ Excellent benchmark

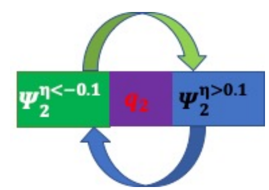
➢ Event-shape selections can constrain the v_2 driven background

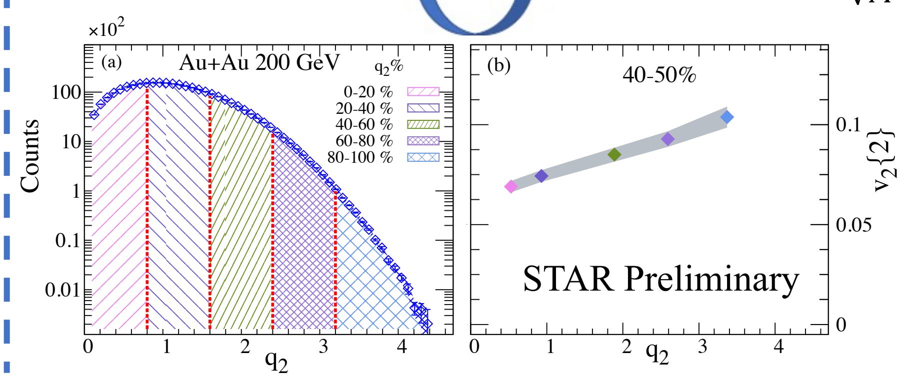
✓ Events are further subdivided into groups with different q_2 magnitude:

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

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

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





❖ 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)
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m = 2,3

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

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

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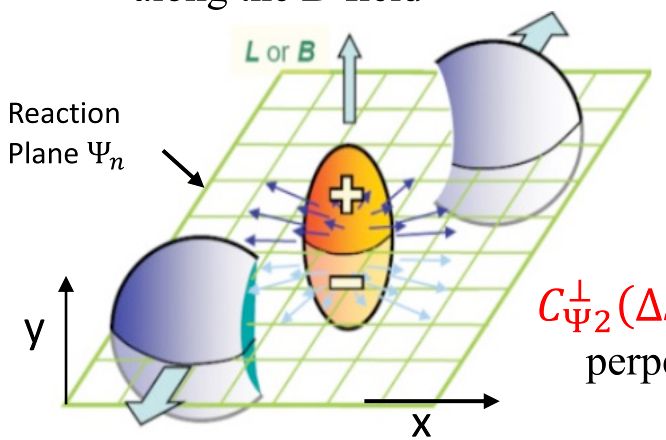

$C^{\perp}_{\Psi 2}(\Delta S)$ quantifies charge separation perpendicular to the B-field (only background)

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

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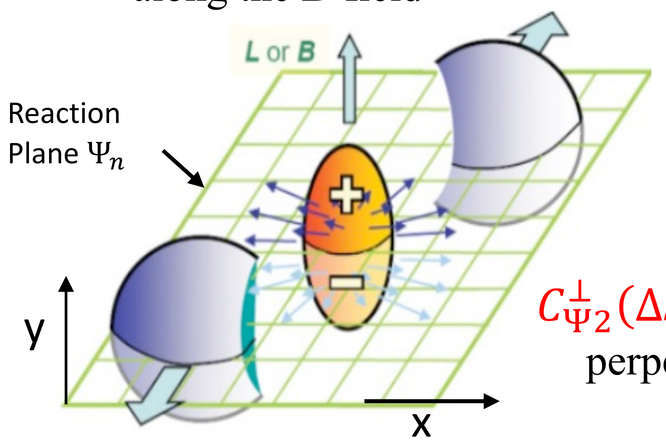

$C^{\perp}_{\Psi_2}(\Delta S)$ quantifies charge separation perpendicular to the B-field (only background)

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)

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

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

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

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

$N(\Delta S)$

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

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

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

Sensitive to charge separation
(CME and Background)

w_i: charge dependent detector acceptance.

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

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

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$N(\Delta S_{Sh})$

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

Shuffling of charges within an event breaks the charge separation sensitivity

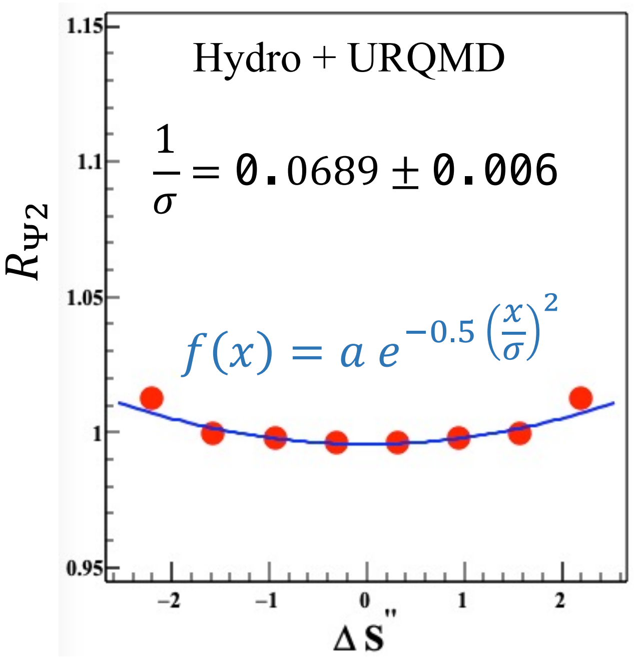
$N(\Delta S_{Sh}^{\perp})$

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

- 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 %

$LCC = 0.0\%$ $n_5/s = 0.0$



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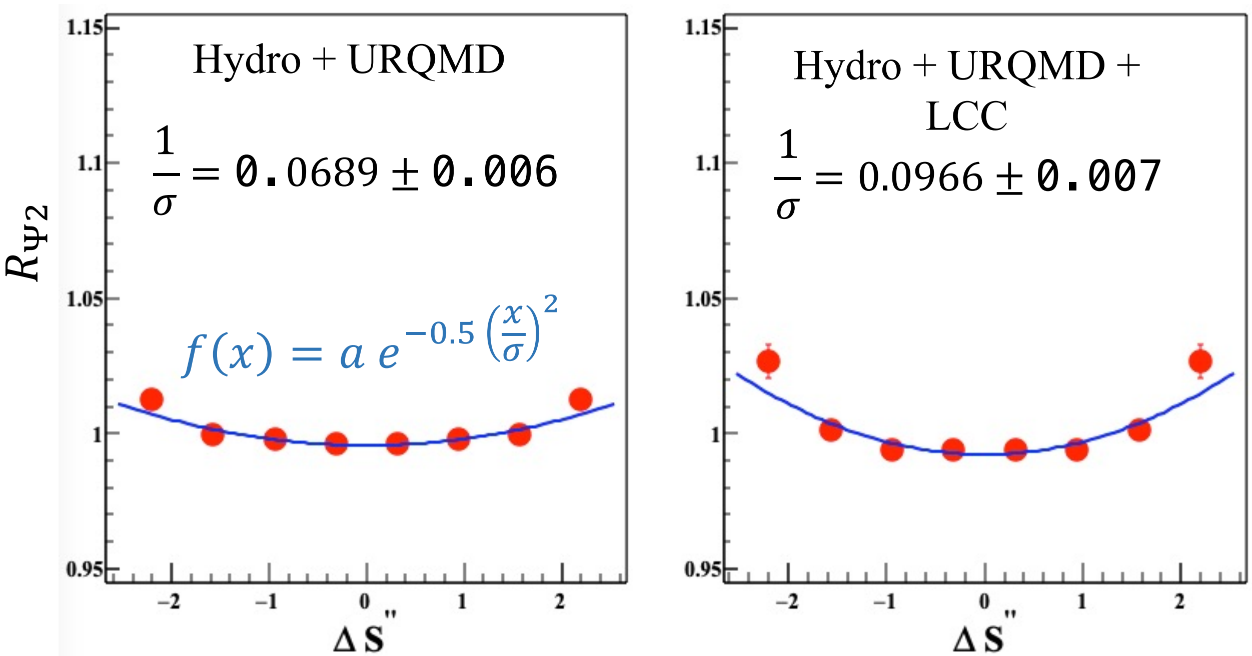

- The magnitudes of the $R_{\Psi 2}$ distributions:
  - ✓ Sensitive to backgrounds

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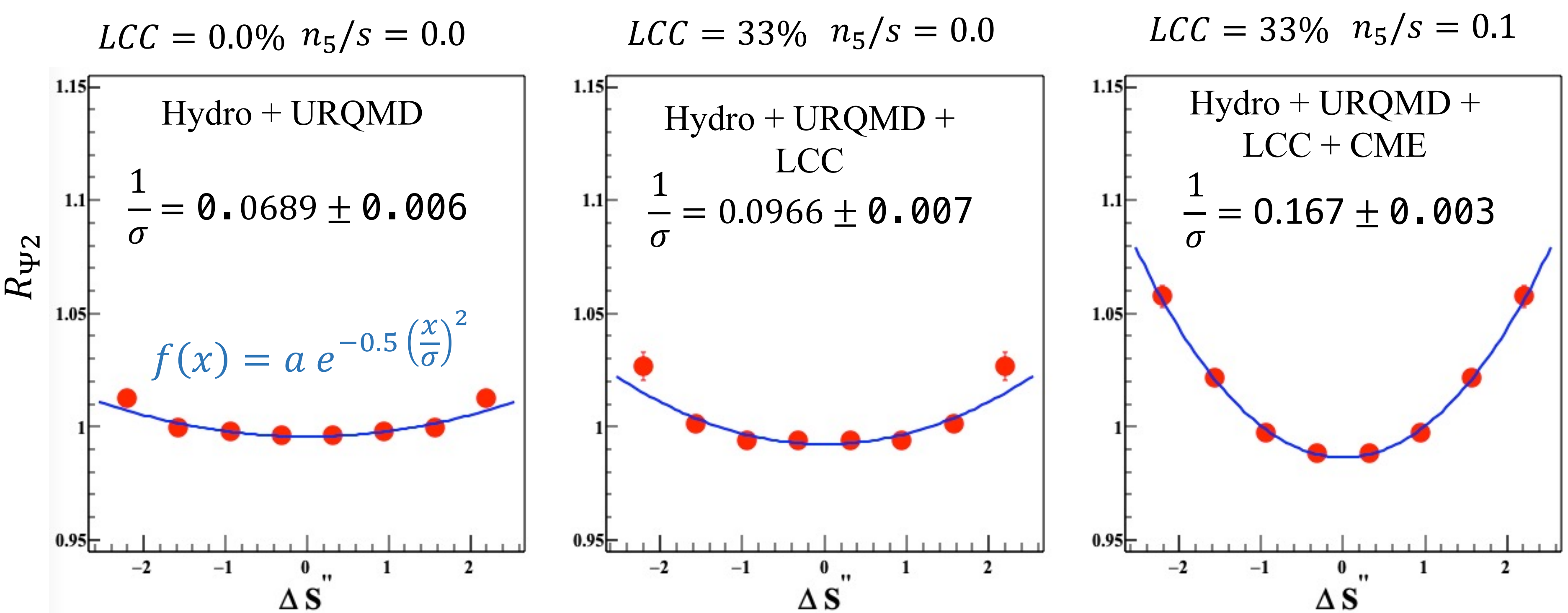

➢ The magnitudes of the R_{Ψ_2} distributions:

✓ Sensitive to backgrounds

✓ Sensitive to CME-driven signal

- $R_{\Psi_{2,3}}(\Delta S)$ correlator response
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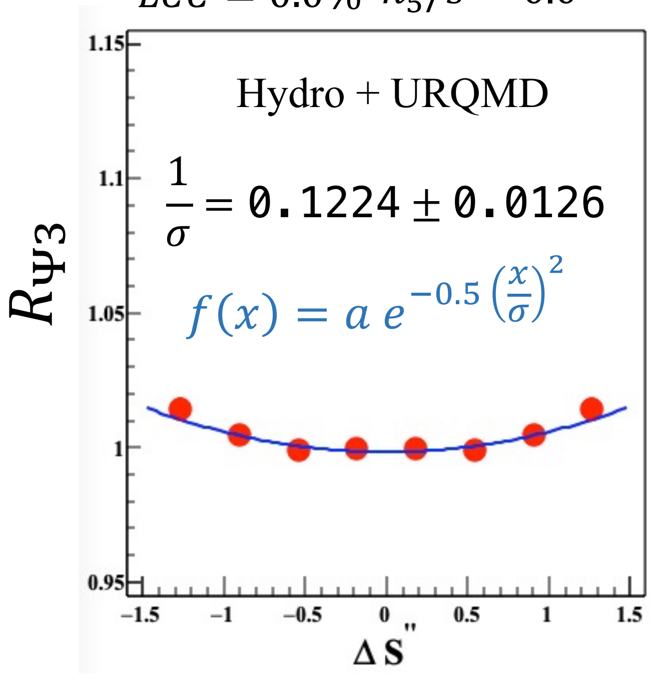
$LCC = 0.0\%\ n_5/s = 0.0$



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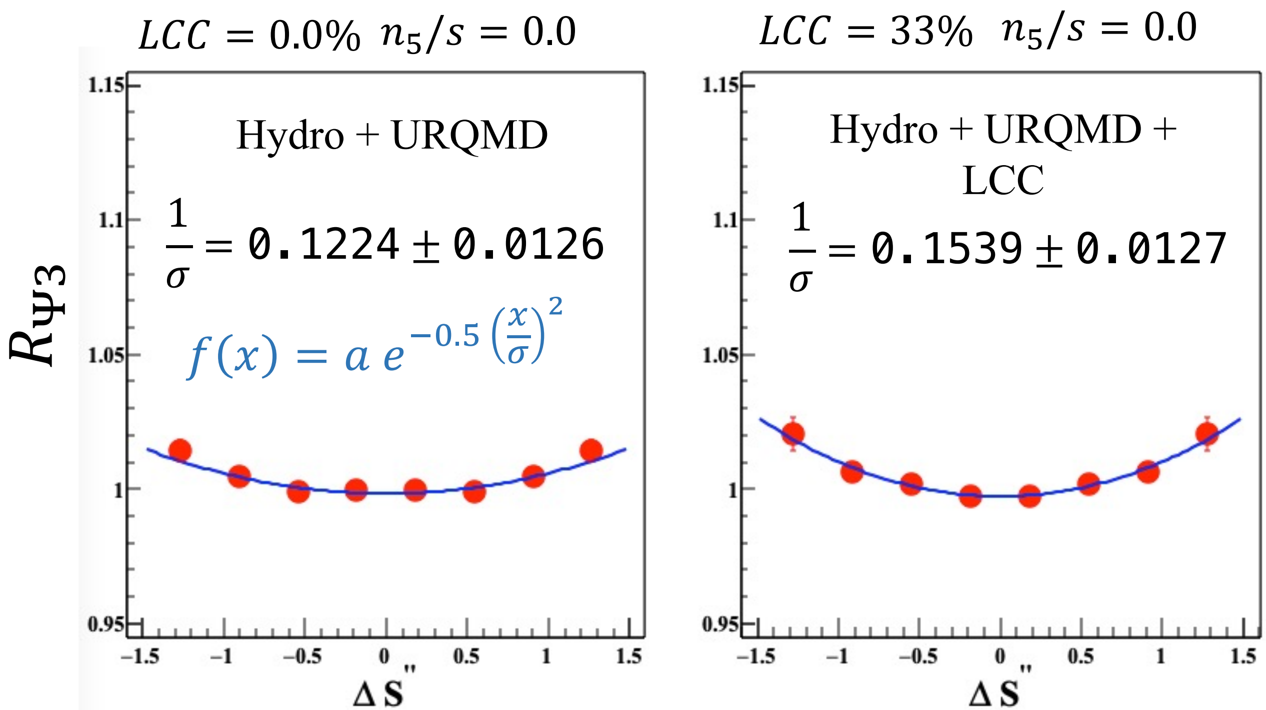

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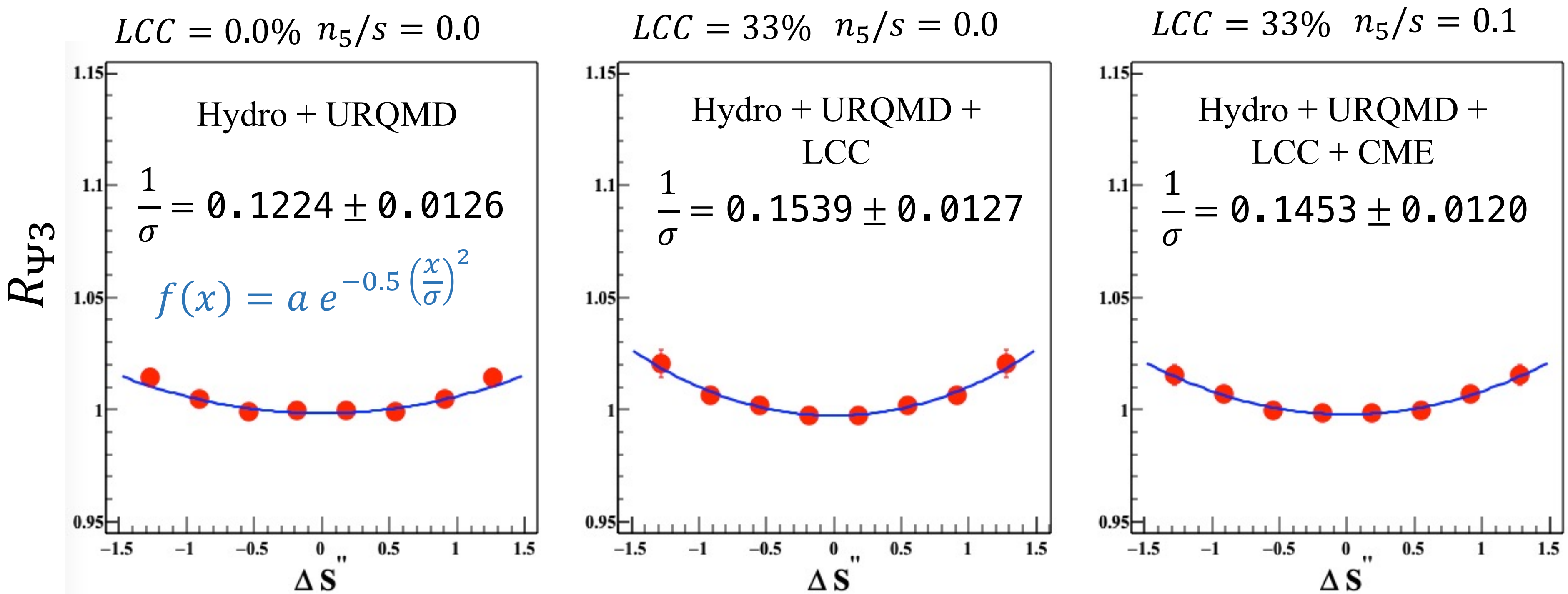


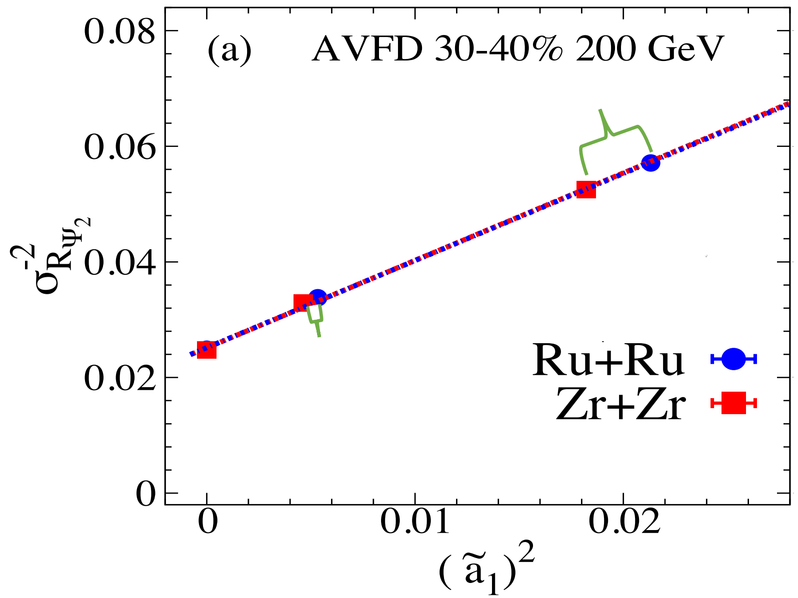
- ➢ The magnitudes of the R_{Ψ_3} distributions:
  - ✓ Sensitive to backgrounds
  - ✓ Insensitive to CME-driven signal

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

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

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

✓ If Isobars have same background?



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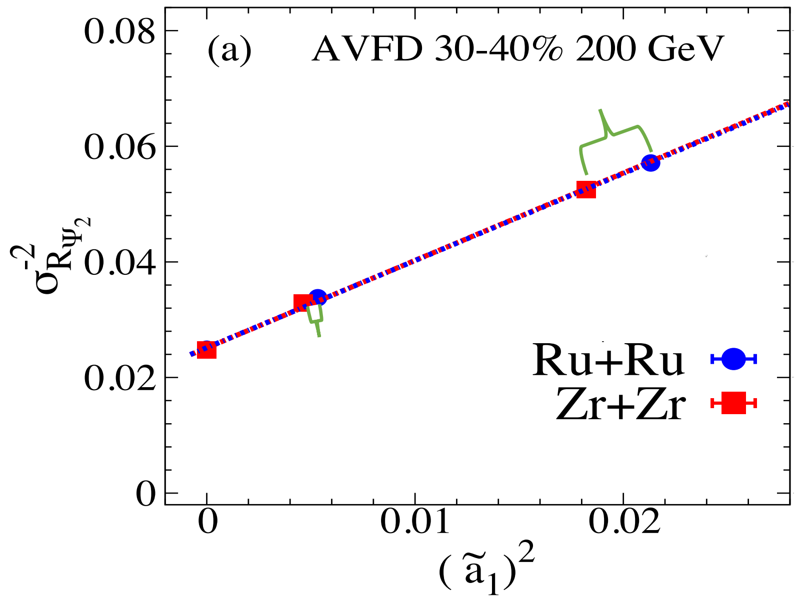
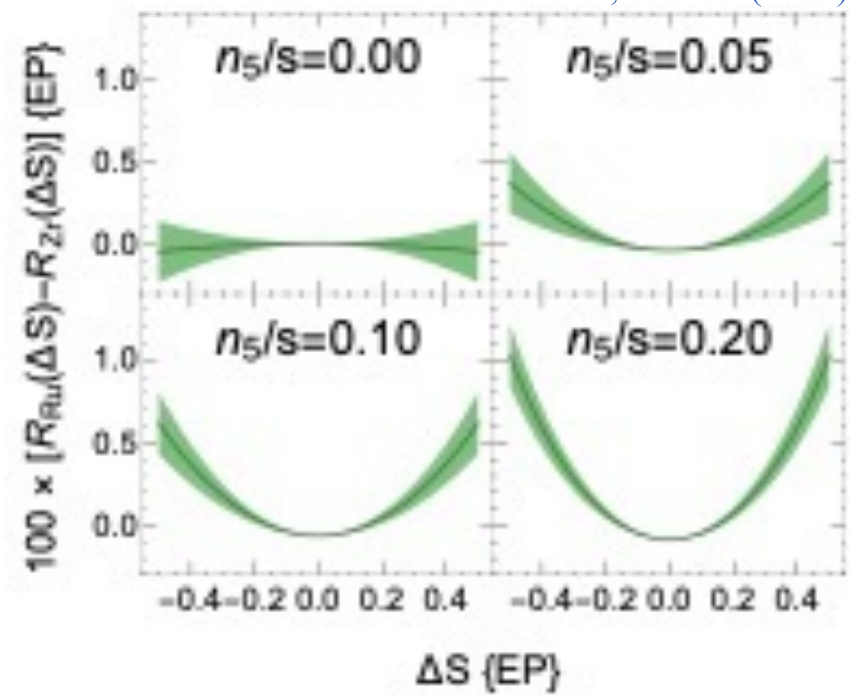
Shuzhe Shi, et al.
PRL 125, 242301 (2020)





Predefined CME signature:

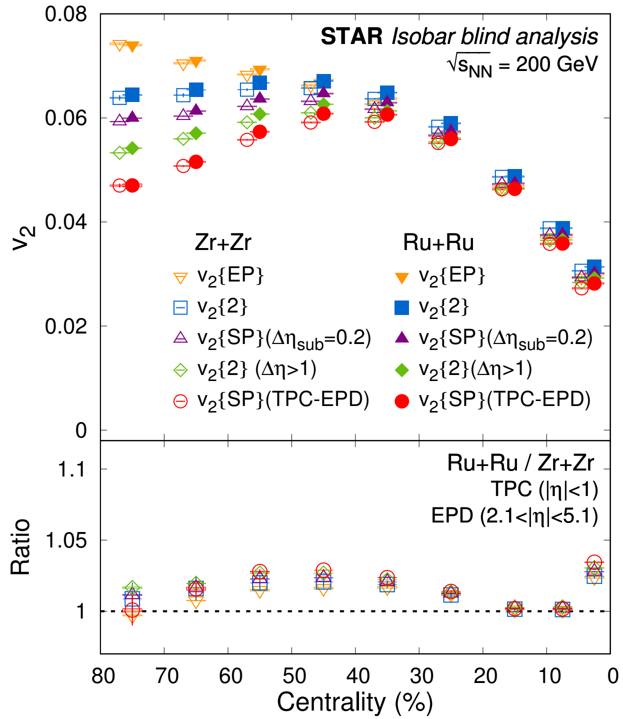
$$1/\sigma_{R_{\Psi_2}}(\mathrm{Ru+Ru}) > 1/\sigma_{\mathrm{R}_{\Psi_2}}(\mathrm{Zr+Zr})$$

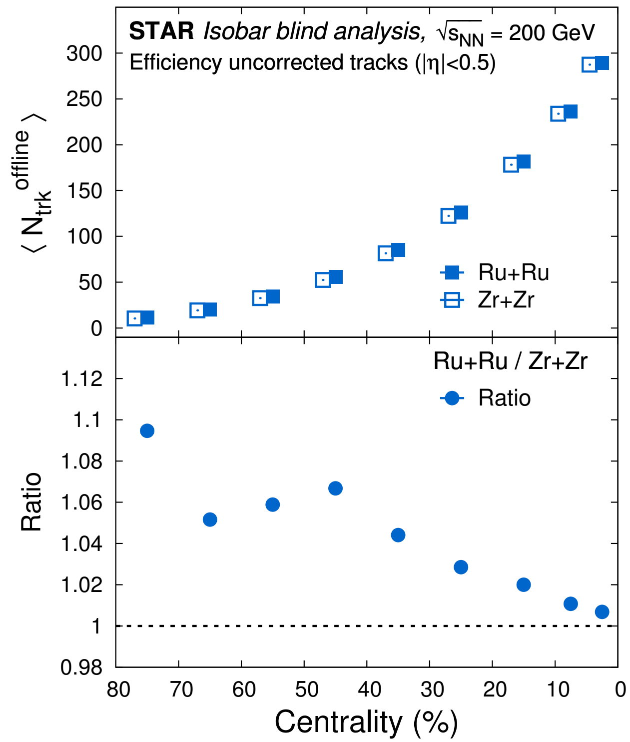
❖ $R_{\Psi_m}(\Delta S)$ Correlator

➢ $R_{\Psi_m}(\Delta S)$ 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

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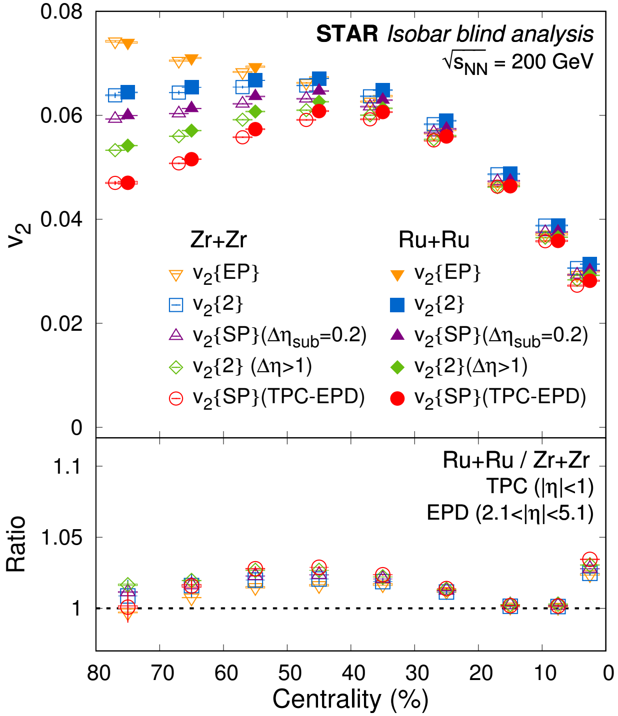

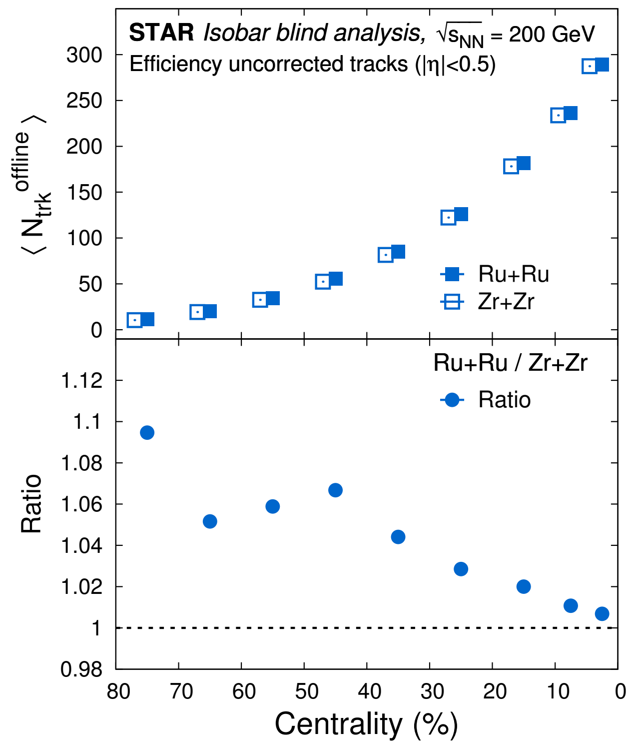

➢ Observed differences in multiplicity and v_2 for same centrality

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

✓ The predefined CME signature could be invalid

- Analysis and results from the 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 $\Psi_2^{\eta>0.1}$
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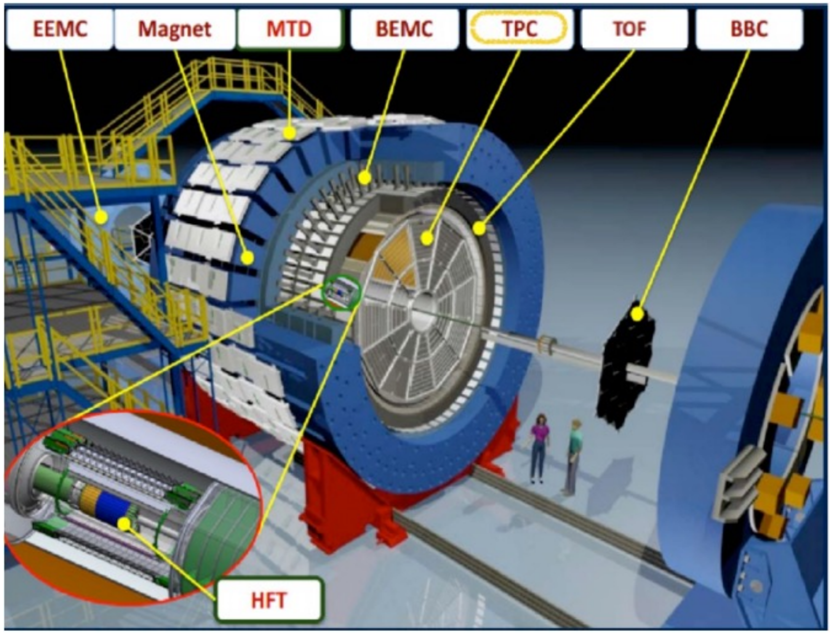

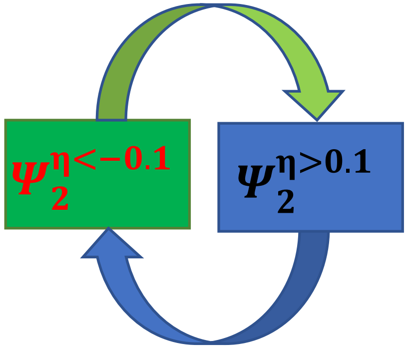

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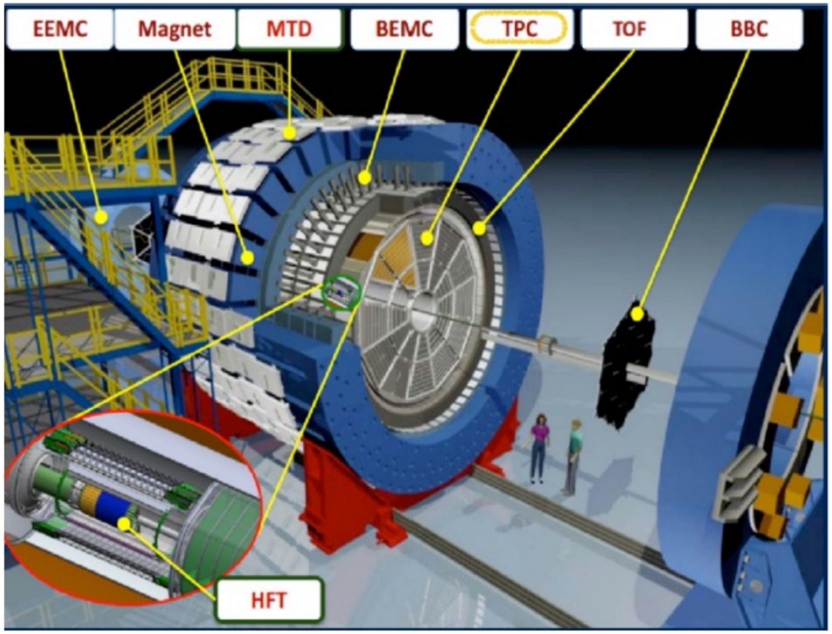
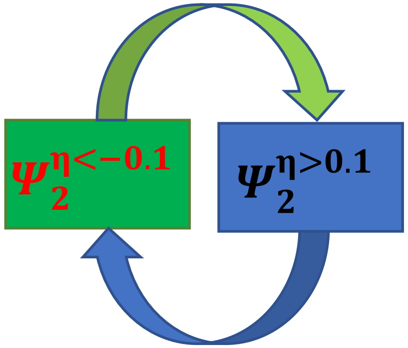
- $R_{\Psi_2}(\Delta S)$ measurements made as a function of:
  - ✓ Centrality
  - ✓ Event shape selection at a given centrality





❖ Results

➢ $R_{\Psi_2}(\Delta S)$ measurements

✓ Event-shape selections

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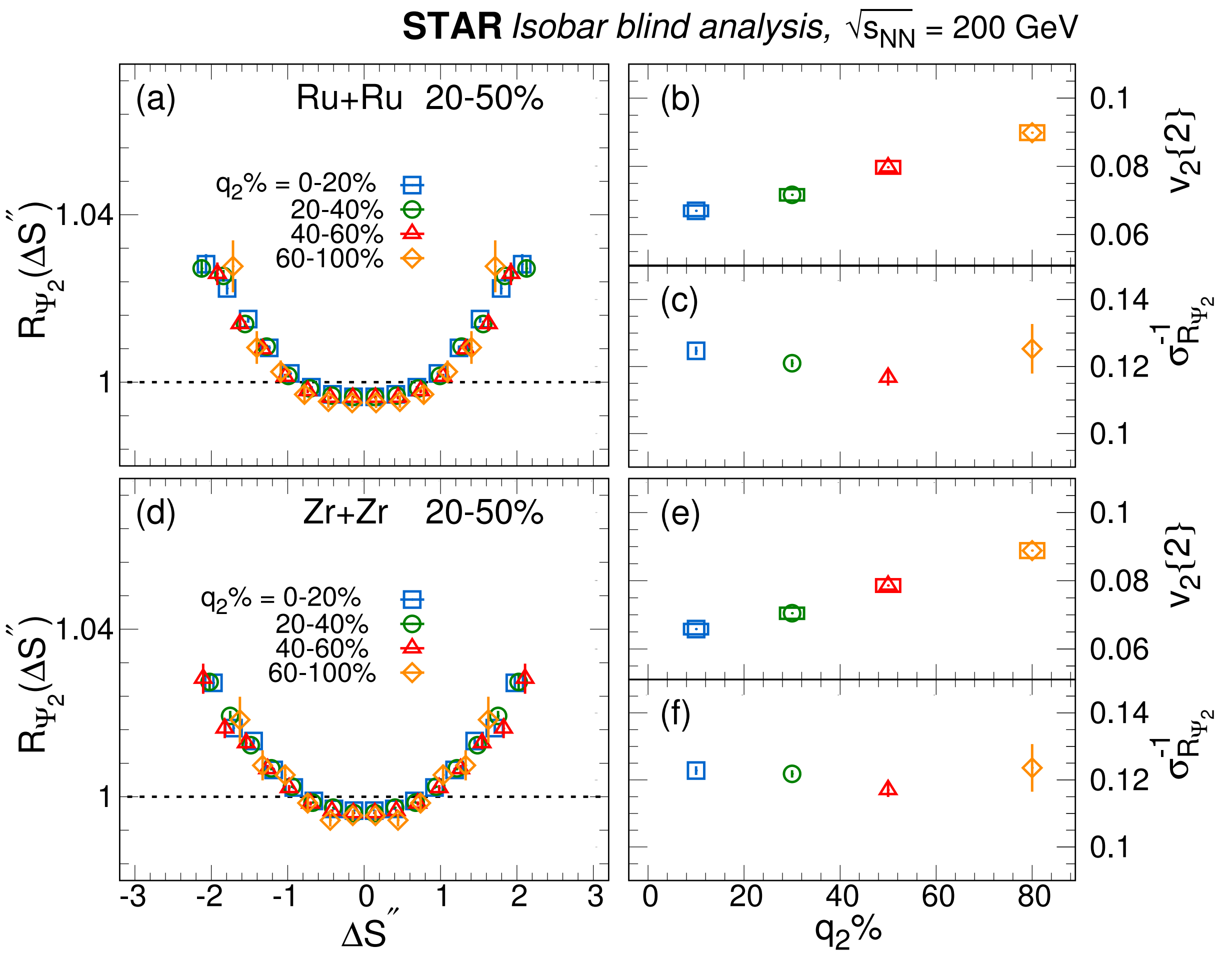

➢ The q_2-selected results indicate that $R_{\Psi_2}(\Delta S^{''})$ is not strongly influenced by the v_2 background-driven charge separation for up to ~30% change in v_2.

❖ Results

➢ $R_{\Psi_2}(\Delta S)$ measurements

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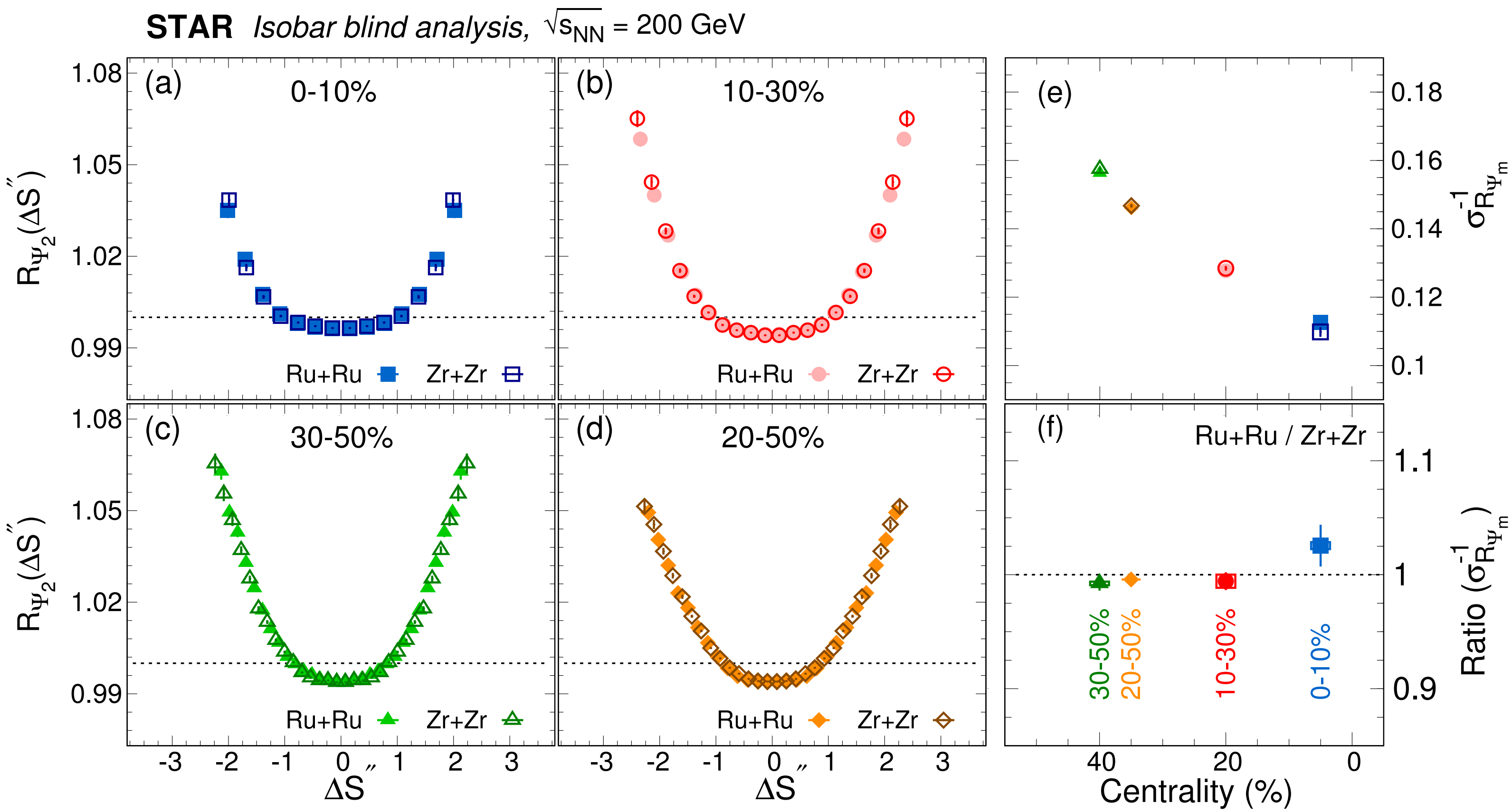

➢ For the same centrality, the $R_{\Psi_2}(\Delta S'')$ correlators for the two isobars are similar.

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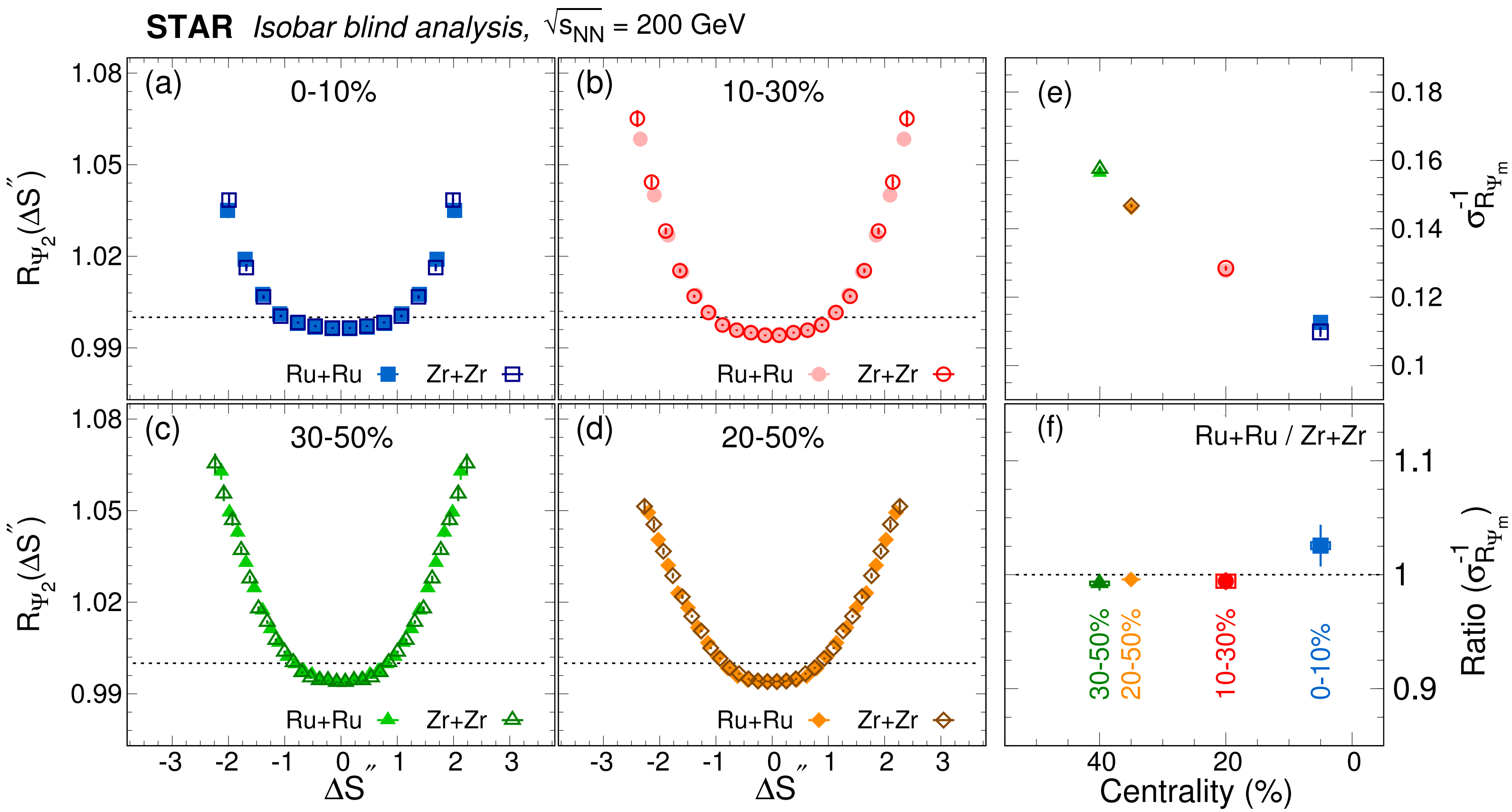

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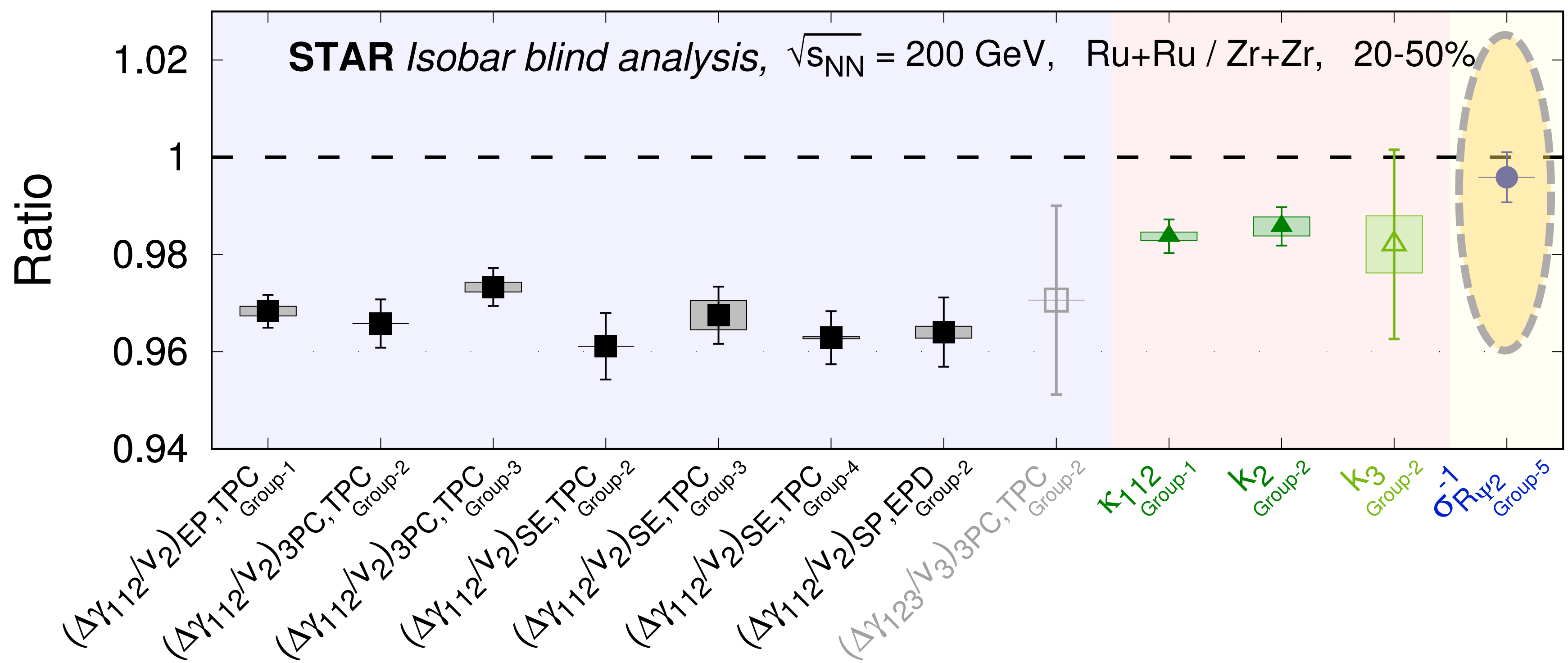

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❖ Ongoing work

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- Detailed studies of possible nuclear structure effects on the background differences for the isobars
- Detailed data-model comparisons for isobars

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

- ✓ R_{Ψ_2} shows concave-shaped distributions compatible with BKG or BKG + CME
- ✓ R_{Ψ_2} shows weak q2 dependence for up to ~30% change in v2
- ✓ R_{Ψ_2} distributions are similar for the two isobars

The predefined CME signature is not observed

- ✓ Not an indication for the absence of the CME in the individual signal
  - Ongoing work to characterize the effects of backgrounds

THANK YOU

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