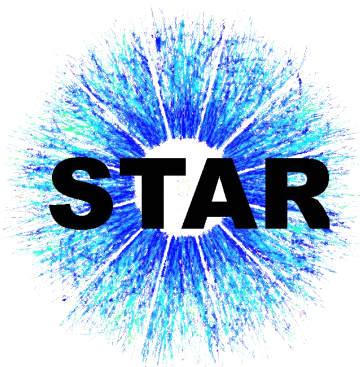




Search for CME in U+U and Au+Au collisions in STAR with different approaches of handling backgrounds

Jie Zhao (for the STAR collaboration)
Nov 5 2019



Purdue University, West Lafayette



In part supported by

U.S. DEPARTMENT OF

ENERGY

Office of
Science

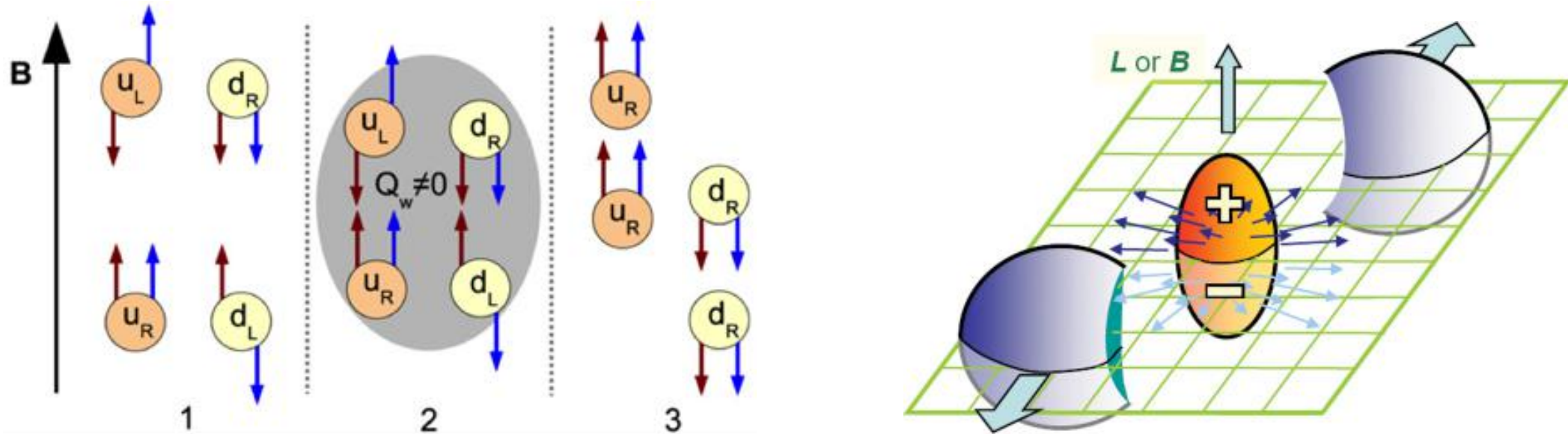
- Chiral Magnetic Effect (CME)
- RHIC-STAR experiment
- Previous measurements
- Mixed-harmonics in Au+Au and U+U
- Measurements with respect to Ψ_{RP} and Ψ_{PP}
- Summary

Ψ_{RP} : reaction plane ; Ψ_{PP} : participant plane

Chiral Magnetic Effect (CME)

Kharzeev, *et al.* NPA 803, 227 (2008)

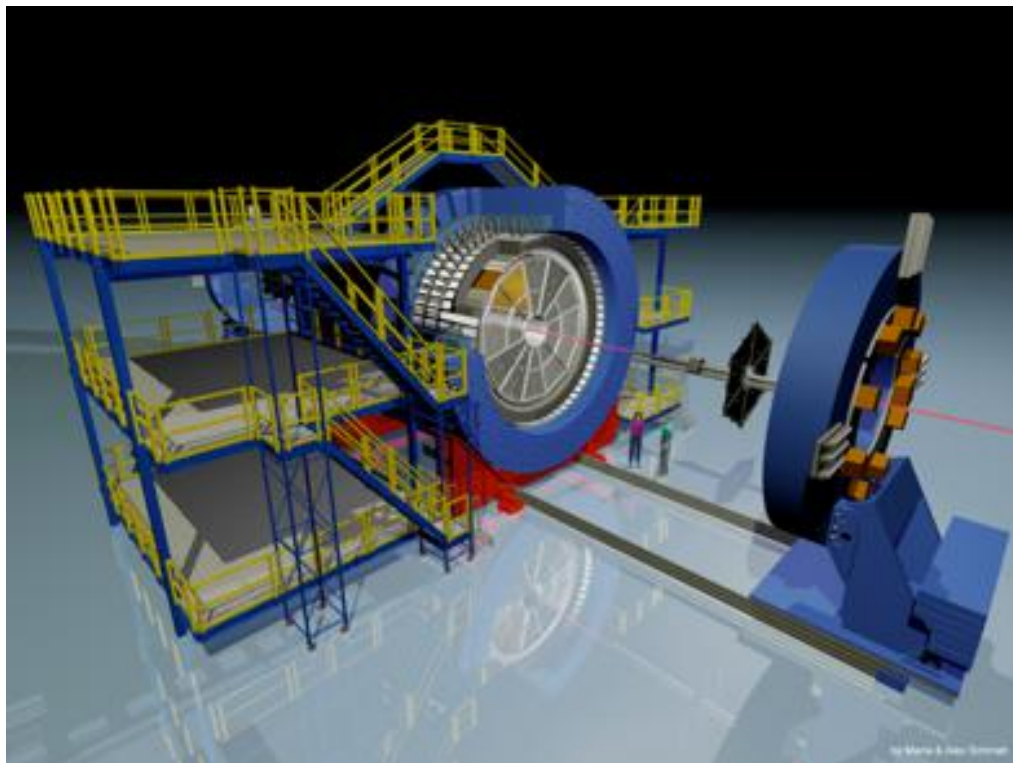
Voloshin, PRC 70, 057901 (2004)



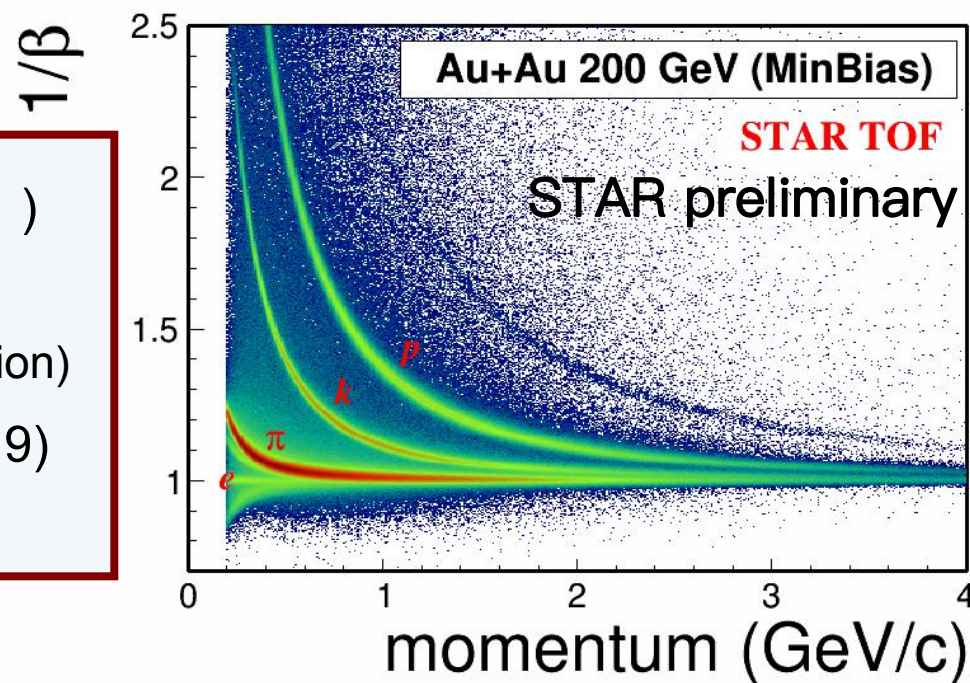
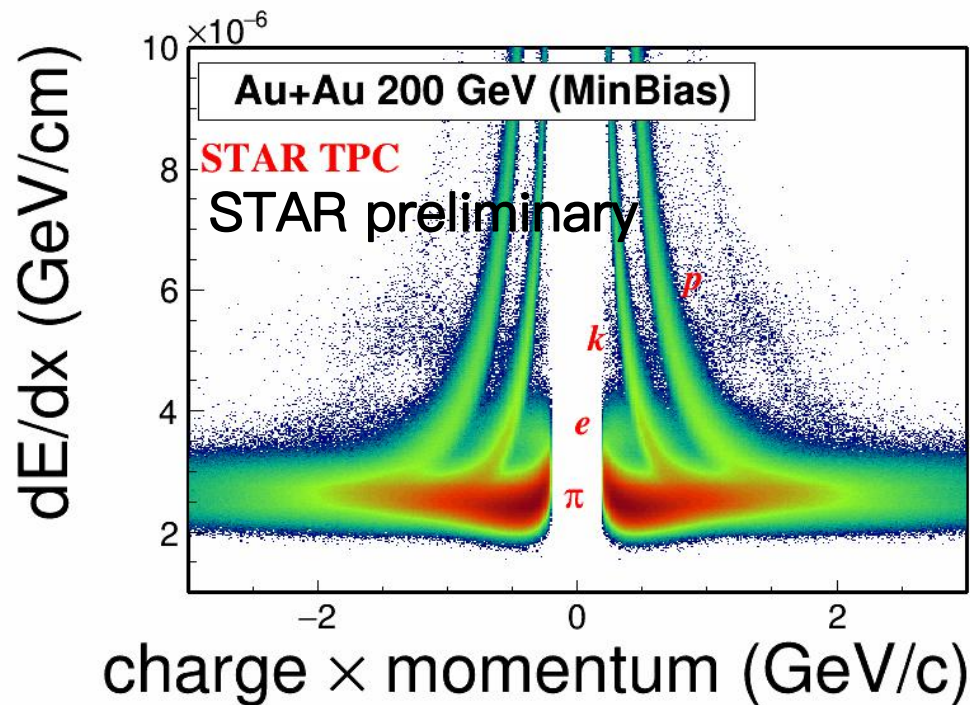
$$j_V = \frac{N_c e}{2\pi^2} \mu_A B, \quad \Rightarrow \text{electric charge separation along the B field}$$

- Gluon configuration with non-zero topological charge (Q_w), generating electric current along B direction, leading to electric charge separation
- Chiral symmetry, strong CP problem, matter-antimatter asymmetry etc.
- Experimentally, $\gamma = \cos(\phi_\alpha + \phi_\beta - 2\psi_{RP})$ used to search for the CME

The STAR detector

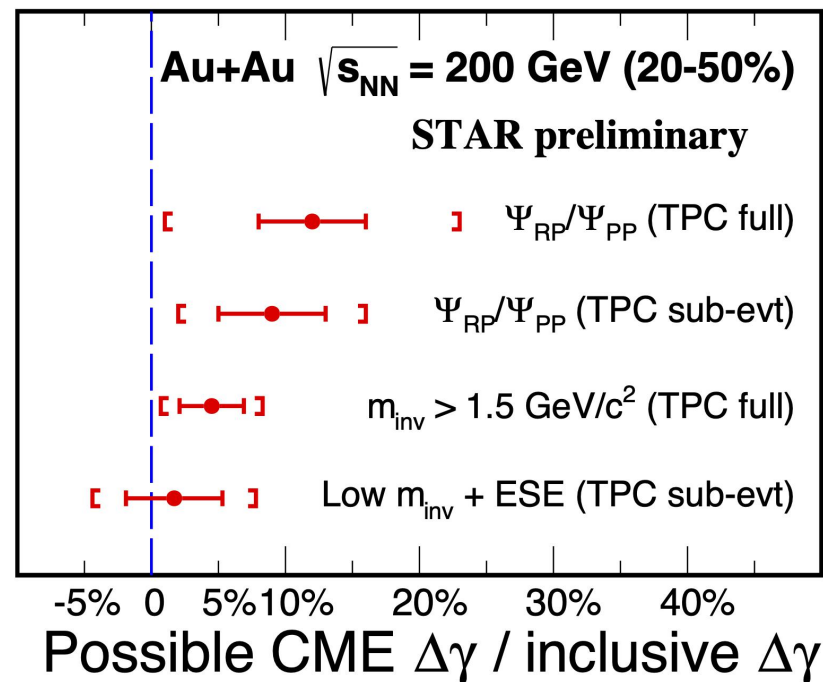
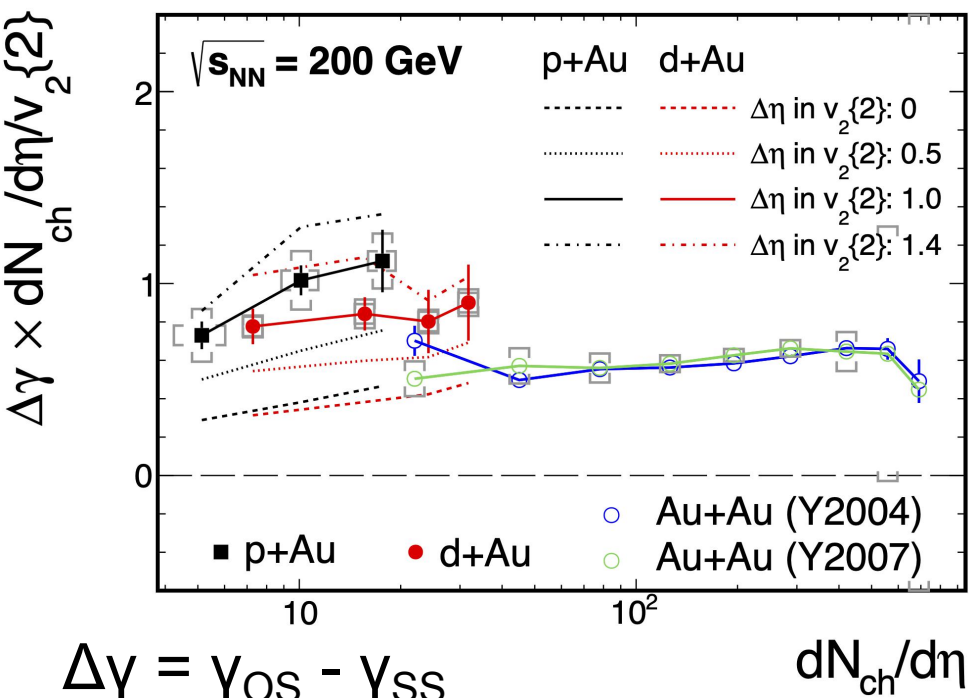


- **Time Projection Chamber** ($\phi=0-2\pi$, $|\eta|<1$)
 - Tracking - momentum
 - Ionization energy loss - dE/dx (particle identification)
- **Time Of Flight detector** ($\phi=0-2\pi$, $|\eta|<0.9$)
 - Timing resolution $<100\text{ps}$ - PID improvement



STAR, PLB 798 (2019) 134975

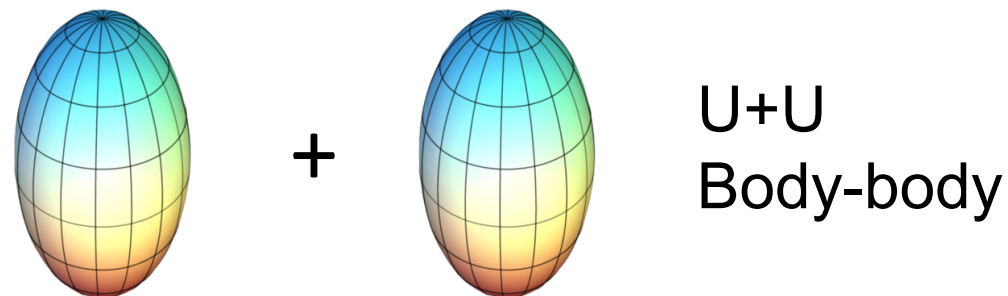
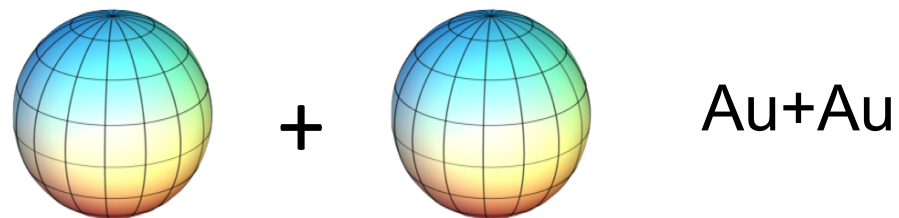
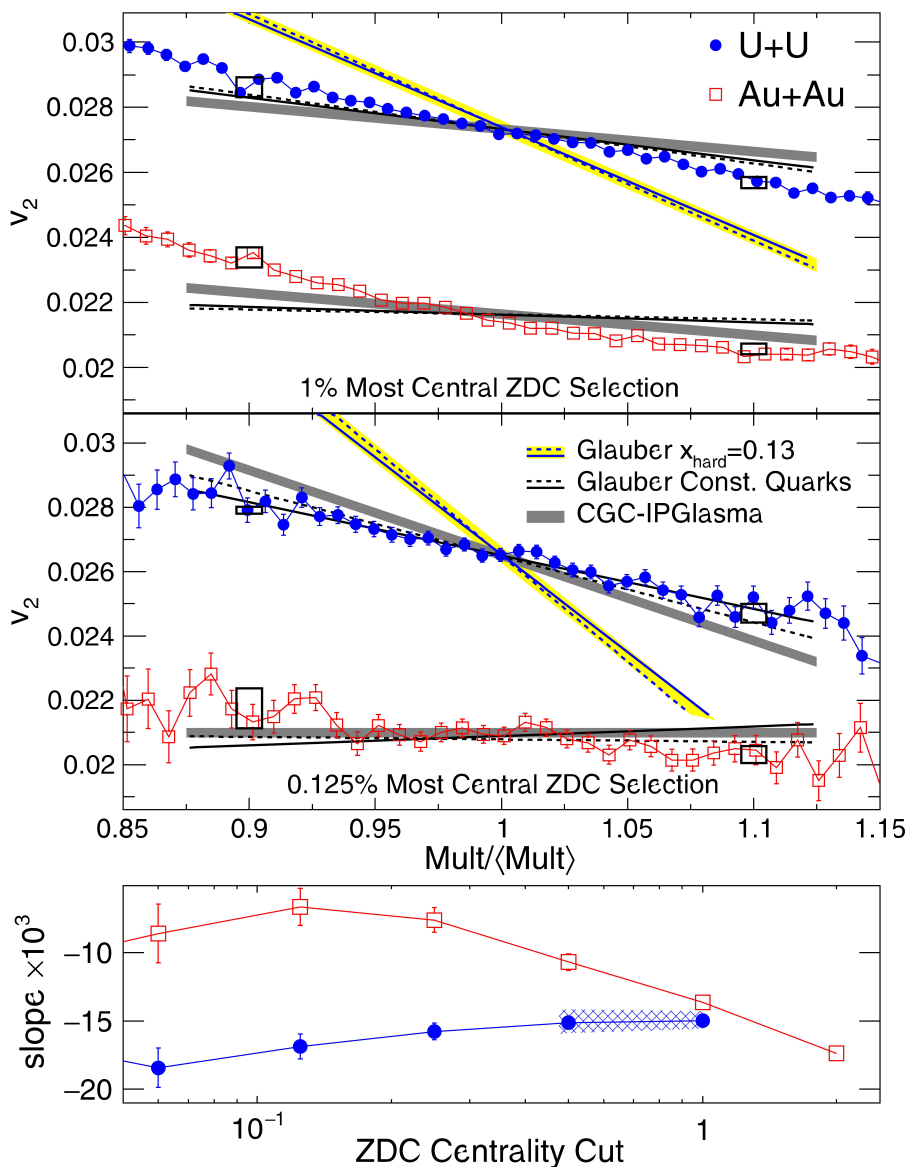
J. Zhao (STAR collaboration). NPA 982 (2019) 535



- First measurements in p +Au and d +Au collisions at 200 GeV, suggesting background dominance in Au+Au collisions.
- Methods based on invariant mass distribution and the Ψ_{RP} and Ψ_{PP} difference are used to extract possible CME fraction. Results indicate that possible CME signal is small, within $1-2\sigma$ from zero.

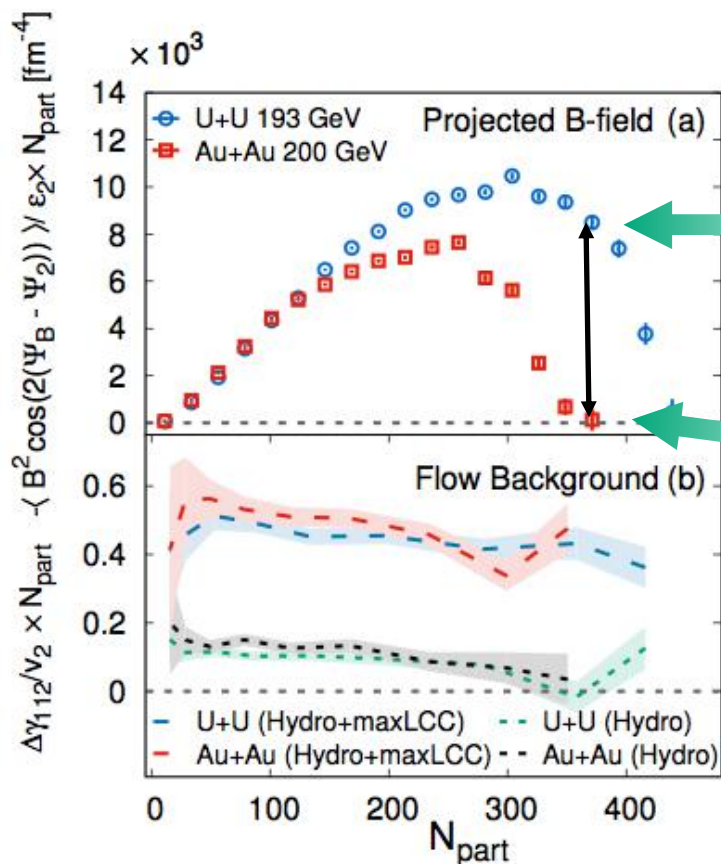
Shape difference in Au+Au & U+U

STAR, PRL 115, 222301 (2015)

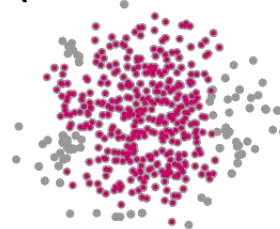


- Event shape difference in U+U and Au+Au, may be sensitive to CME
- Ψ_{PP} and Ψ_{RP} difference might differ between U+U and Au+Au.

Mixed-harmonics in Au+Au & U+U



U+U
($N_{part}=394$)



Au+Au
($N_{part}=394$)

$$Y_{112} = \cos(1\phi_\alpha + 1\phi_\beta - 2\psi_2), \text{ CME + bkg.}$$

$$Y_{123} \sim \cos(1\phi_\alpha + 2\phi_\beta - 3\psi_3), \text{ bkg. only}$$

$$Y_{132} \sim \cos(2\phi_\alpha + 3\phi_\beta - 2\psi_2), \text{ bkg. dominant}$$

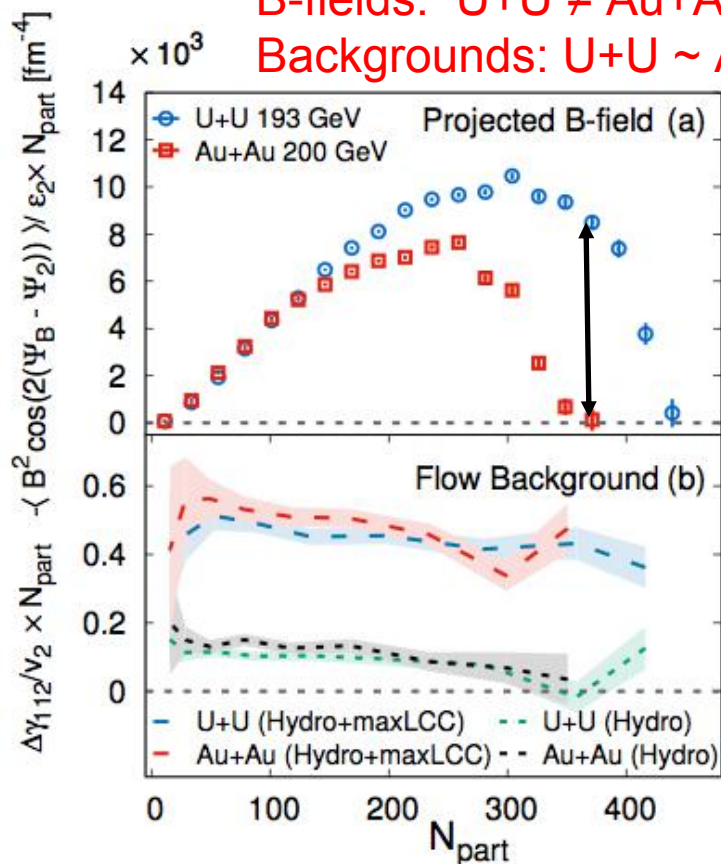
Model expectation:

B-fields: U+U \neq Au+Au

Backgrounds: U+U \sim Au+Au

Mixed-harmonics in Au+Au & U+U

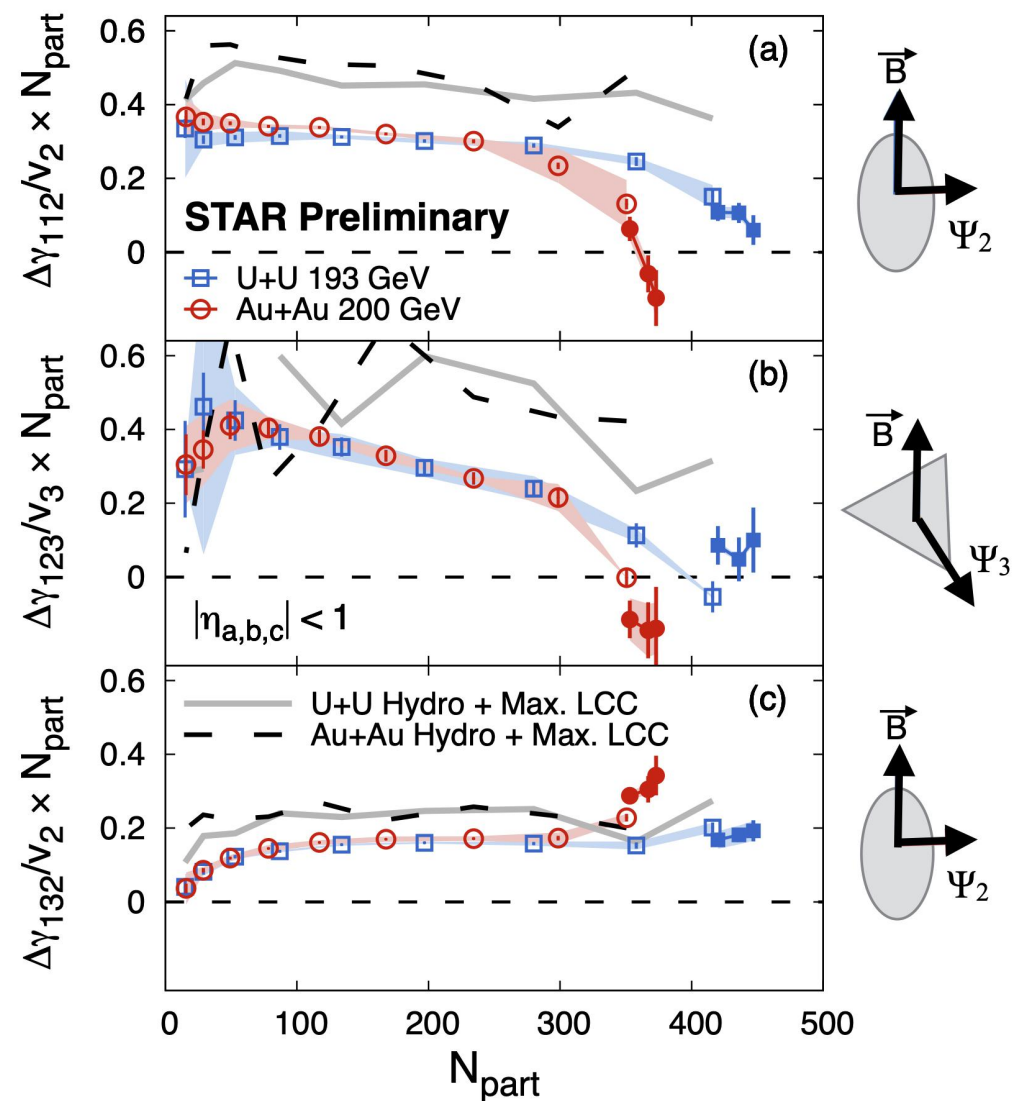
B-fields: U+U \neq Au+Au
 Backgrounds: U+U \sim Au+Au



$$Y_{112} = \cos(1\phi_\alpha + 1\phi_\beta - 2\Psi_2), \text{ CME + bkg.}$$

$$Y_{123} \sim \cos(1\phi_\alpha + 2\phi_\beta - 3\Psi_3), \text{ bkg. only}$$

$$Y_{132} \sim \cos(2\phi_\alpha + 3\phi_\beta - 2\Psi_2), \text{ bkg. dominant}$$

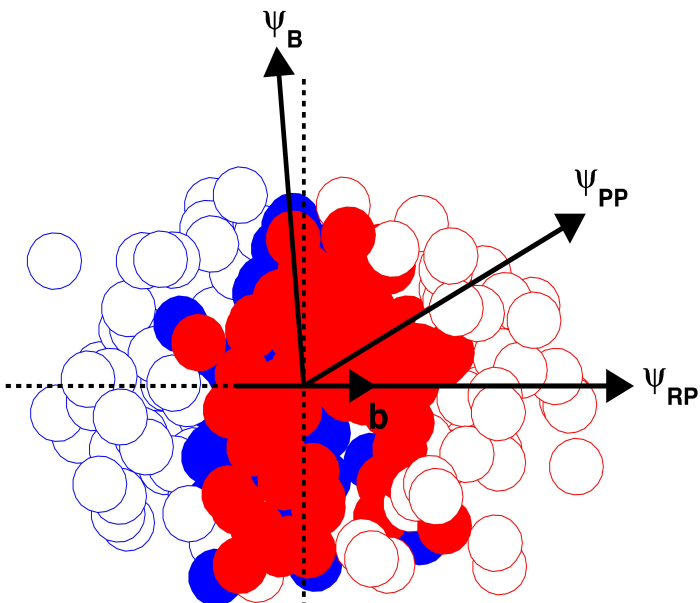


- Charge separation w.r.t. Ψ_2 and Ψ_3 planes investigated in U+U and Au+Au
- Data do not entirely confirm with signal-only or background-only expectations
- Interesting features in ultra-central collisions, need further investigations

Ψ_{PP} & Ψ_{RP} to resolve Bkg & CME

- Ψ_{PP} maximizes flow, → flow background
- Ψ_{RP} maximizes the magnetic field (B), → CME signal
- Ψ_{PP} and Ψ_{RP} are correlated, but not identical due to geometry fluctuations
- $\Delta\gamma$ w.r.t. TPC Ψ_{EP} (proxy of Ψ_{PP}) and ZDC Ψ_1 (proxy of Ψ_{RP}) contain different fractions of CME and Bkg

H-J. Xu, *et al*, CPC 42 (2018) 084103, arXiv:1710.07265



$$\Delta\gamma\{\psi_{\text{TPC}}\} = \text{CME}\{\psi_{\text{TPC}}\} + \text{Bkg}\{\psi_{\text{TPC}}\}$$

$$\Delta\gamma\{\psi_{\text{ZDC}}\} = \text{CME}\{\psi_{\text{ZDC}}\} + \text{Bkg}\{\psi_{\text{ZDC}}\}$$

Two-component assumption

$$\text{CME}\{\psi_{\text{TPC}}\} = a * \text{CME}\{\psi_{\text{ZDC}}\}, \text{Bkg}\{\psi_{\text{ZDC}}\} = a * \text{Bkg}\{\psi_{\text{TPC}}\}$$

assume $\text{Bkg} \propto v_2$

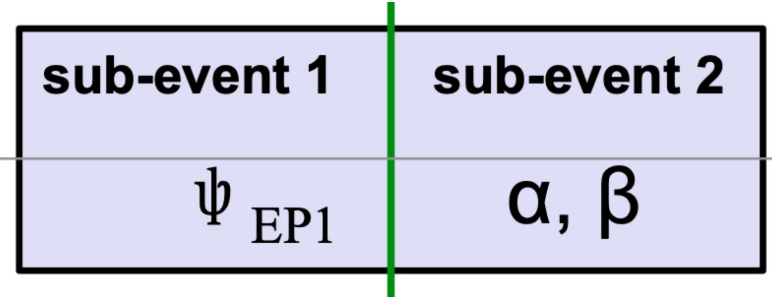
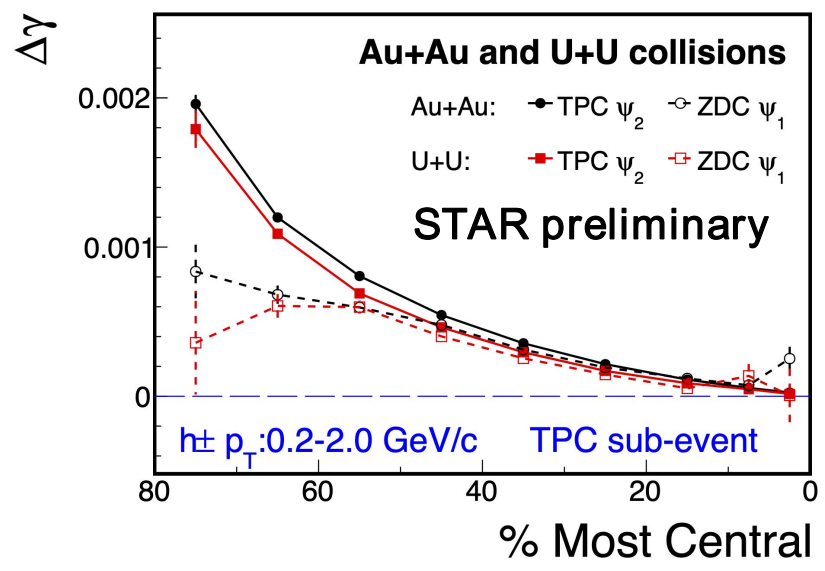
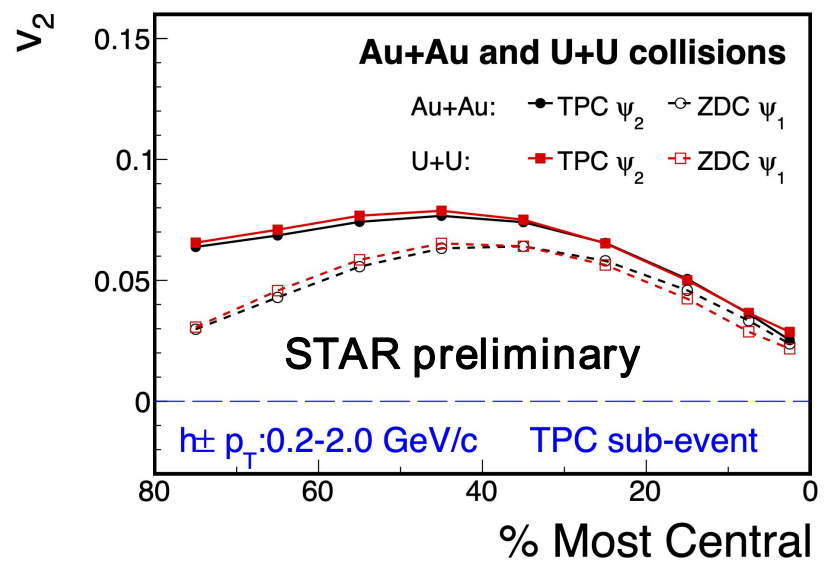
$$a = v_2\{\psi_{\text{ZDC}}\} / v_2\{\psi_{\text{TPC}}\}, A = \Delta\gamma\{\psi_{\text{ZDC}}\} / \Delta\gamma\{\psi_{\text{TPC}}\}$$

Both are experimental measurements

$$f_{\text{EP}}(\text{CME}) = \text{CME}\{\psi_{\text{TPC}}\} / \Delta\gamma\{\psi_{\text{TPC}}\} = (A / a - 1) / (1 / a^2 - 1)$$



$\Delta\gamma_{112}$ w.r.t. Ψ_{PP} & Ψ_{RP} in U+U & Au+Au



$$v_2 = \cos(2\phi - 2\psi)$$

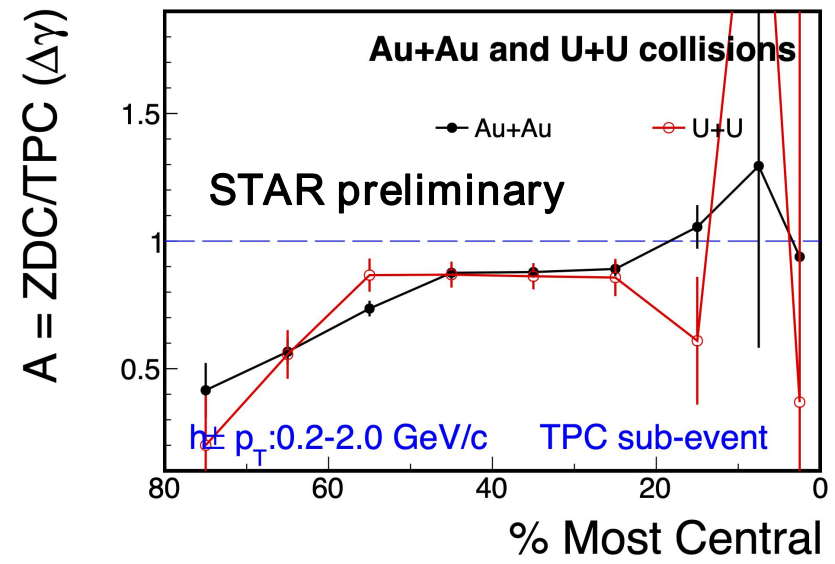
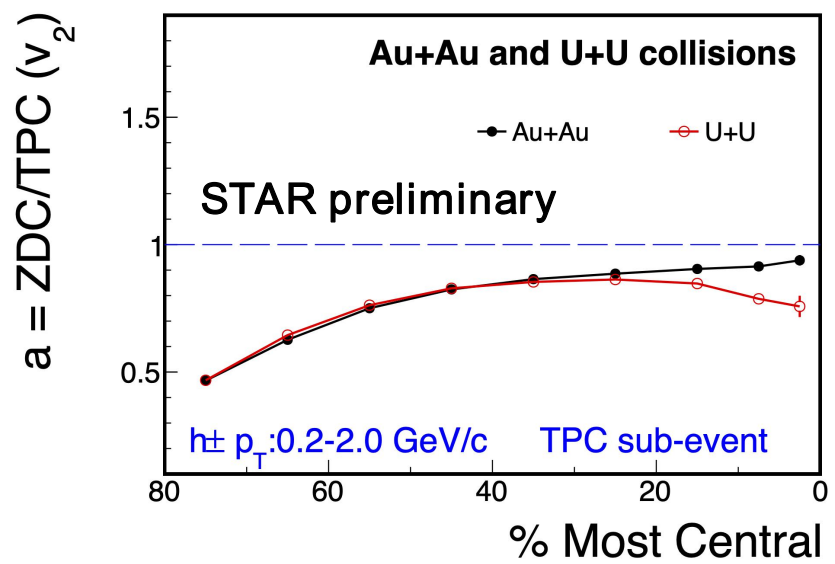
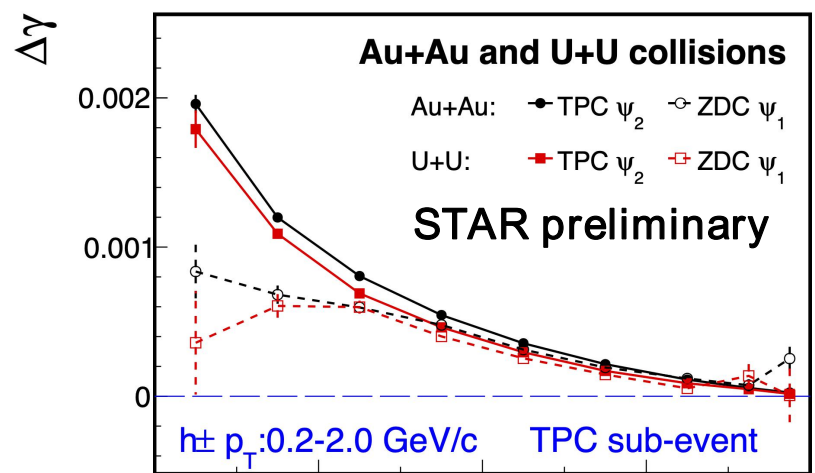
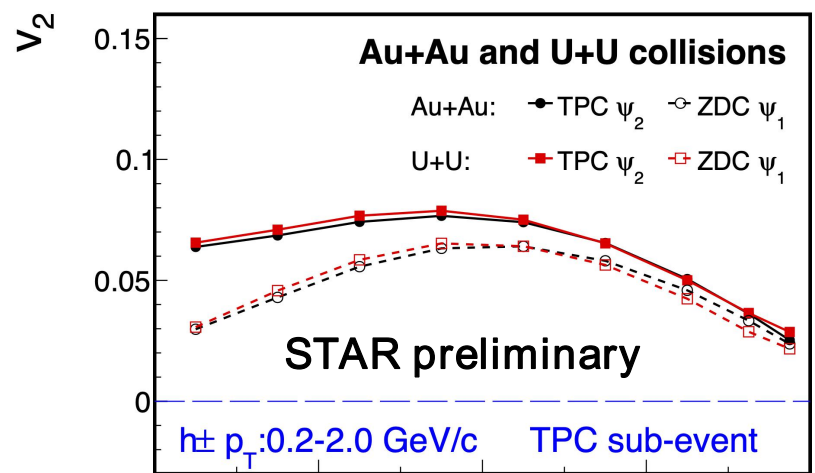
$$\gamma = \cos(\phi_\alpha + \phi_\beta - 2\psi)$$

sub-event method, east ($-1 < \eta < -0.075$) and west ($0.075 < \eta < 1$)

statistical uncertainties only



$\Delta\gamma_{112}$ w.r.t. Ψ_{PP} & Ψ_{RP} in U+U & Au+Au



➤ Data indicate difference in v_2 between central U+U and Au+Au

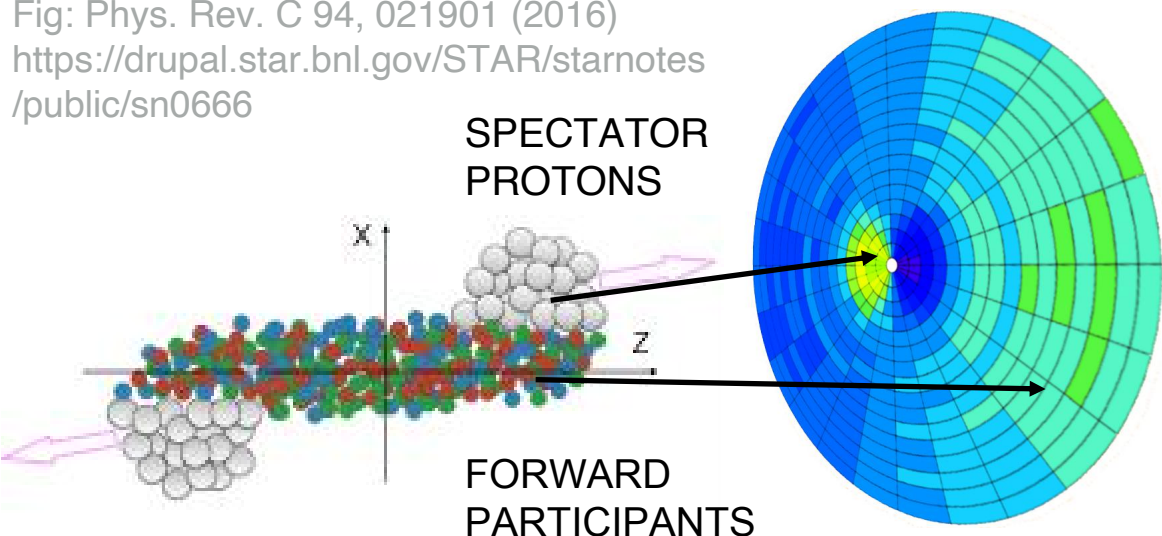
➤ “a” and “A” similar trend and magnitude, indicate bkg. dominant

STAR Event Plane detector acceptance: $2.1 < |\eta| < 5.1$

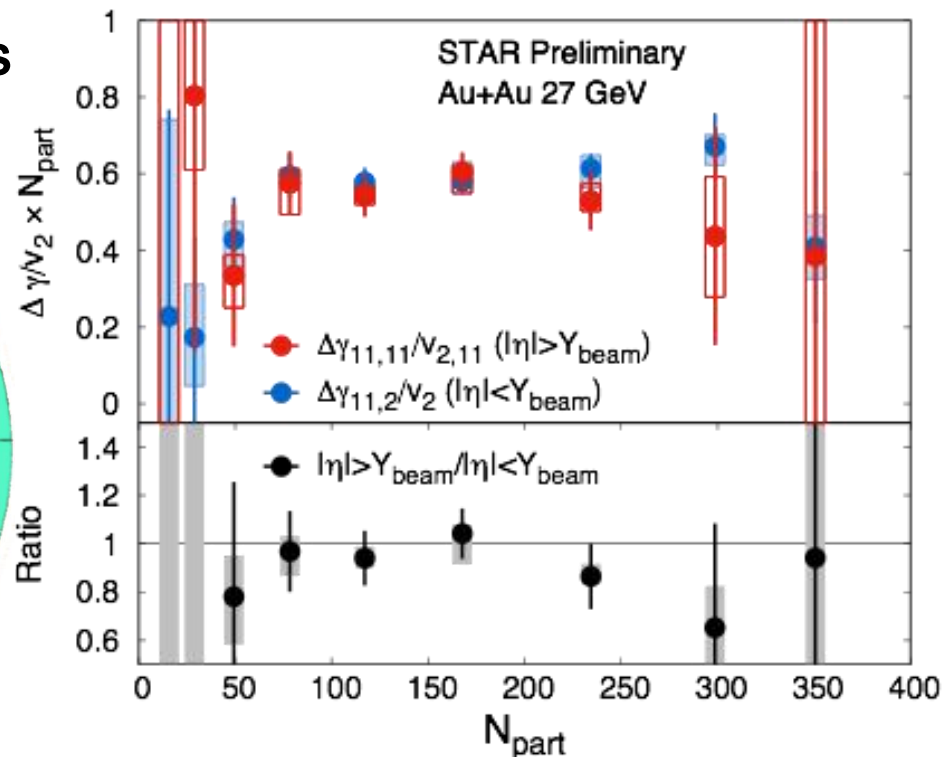
Beam rapidity for Au+Au 27 GeV, $Y_{beam} = 3.4$

EPD detects both participants & spectators

Fig: Phys. Rev. C 94, 021901 (2016)
<https://drupal.star.bnl.gov/STAR/starnotes/public/sn0666>



Poster by S. Choudhury (#735)



w.r.t. planes of the produced particles
 $|\eta| < Y_{beam}$

$$\gamma_{1,1,2}^{\alpha,\beta}(\text{TPC} - \text{EPD}^{\text{outer}}) = \left\langle \cos(\phi_a^\alpha + \phi_b^\beta - 2\Psi_2^{|\eta| < Y_{beam}}) \right\rangle$$

w.r.t. planes of the spectator protons
 $|\eta| > Y_{beam}$

$$\gamma_{1,1,1,1}^{\alpha,\beta}(\text{TPC} - \text{EPD}^{\text{inner}}) = \left\langle \cos(\phi_a^\alpha + \phi_b^\beta - \Psi_1^{\eta > Y_{beam}} - \Psi_1^{-\eta < -Y_{beam}}) \right\rangle$$

> Unique way to search for CME using EPD for both Ψ_{PP} and Ψ_{RP}

> Ratio ~ 1 with large uncertainty, indicating CME fraction consistent with zero. More quantitative result in progress

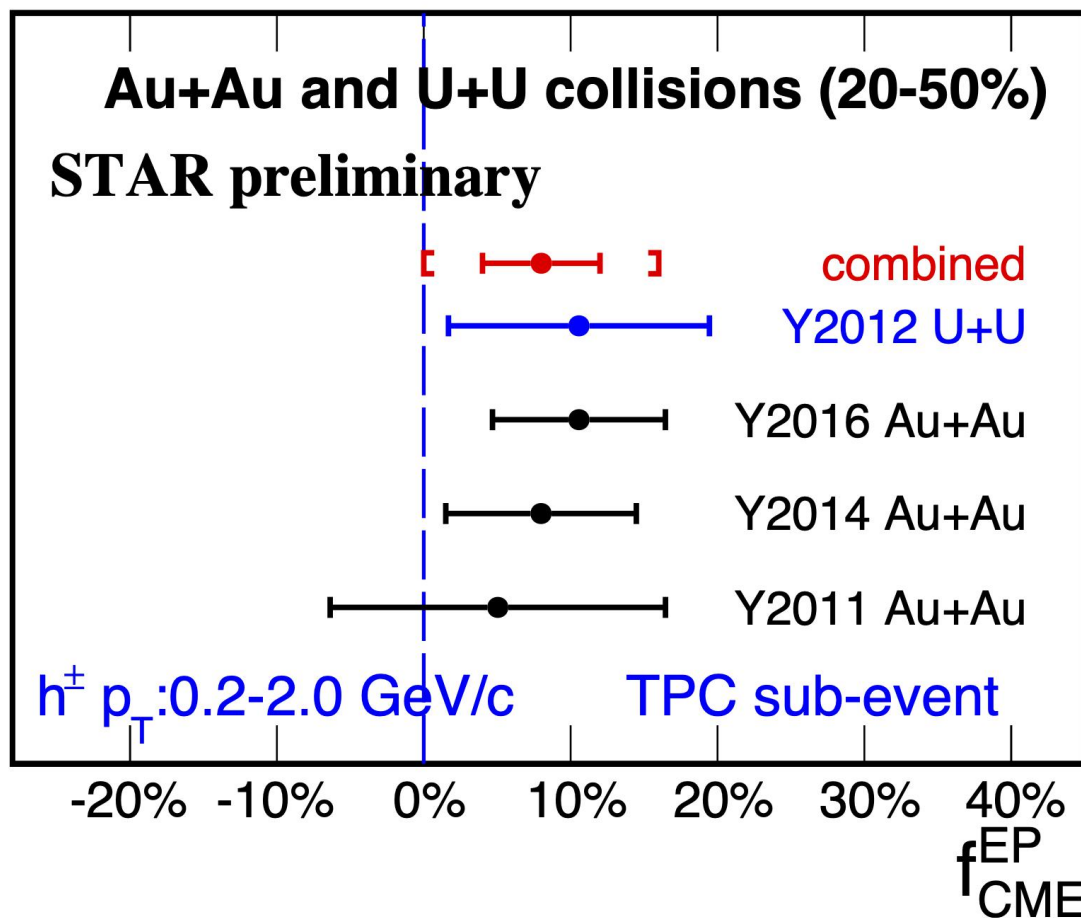
$$a = v_2\{\psi_{ZDC}\} / v_2\{\psi_{TPC}\}$$

$$A = \Delta\gamma\{\psi_{ZDC}\} / \Delta\gamma\{\psi_{TPC}\}$$

$$f_{EP}(\text{CME})$$

$$= \text{CME}\{\psi_{TPC}\} / \Delta\gamma\{\psi_{TPC}\}$$

$$= (A/a - 1) / (1/a^2 - 1)$$



- CME fractions are extracted with $\Delta\gamma$ using Ψ_{PP}/Ψ_{RP} in U+U and Au+Au: the combined result is $(8 \pm 4 \pm 8)\%$, previous results $(9 \pm 4 \pm 7)\%$
- Systematic uncertainties assessed by track quality cuts and η gap

- Mixed-harmonics: background models capture most of the observed trends, further study of ultra-central Au+Au & U+U collisions
- 27 GeV Au+Au data with new detector EPD sensitive to both spectator and participant planes
- $\Delta\gamma$ with respect to Ψ_{PP} and Ψ_{RP} to isolate possible CME from Bkg. Current Au+Au 200 GeV and U+U 193 GeV results indicate that:
 - possible CME signal is $(8 \pm 4 \pm 8)\%$ of the inclusive $\Delta\gamma$

Results indicate possible CME signal fraction is small in $\Delta\gamma$