Search for the chiral magnetic effect with spectator and participant planes in STAR

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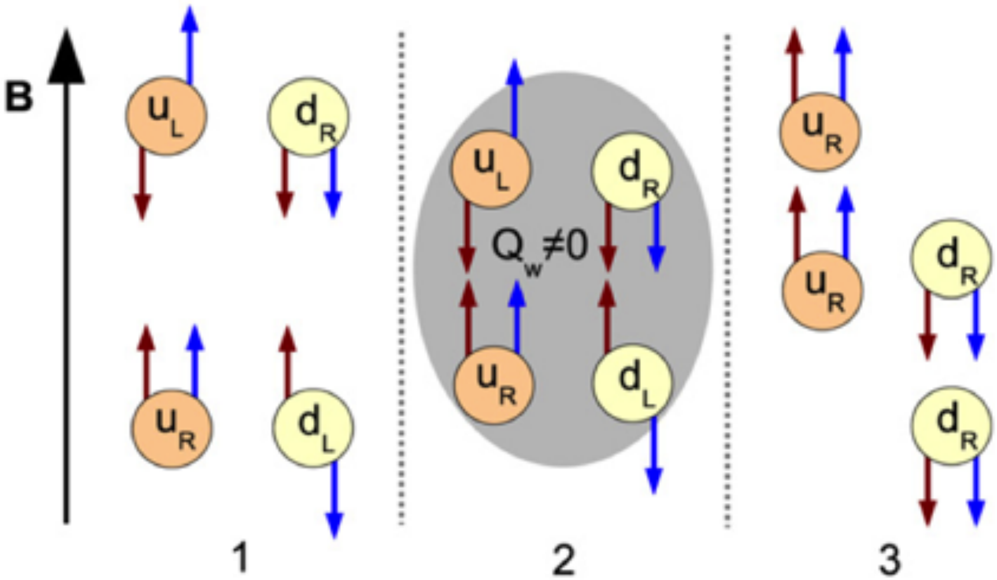
Outline

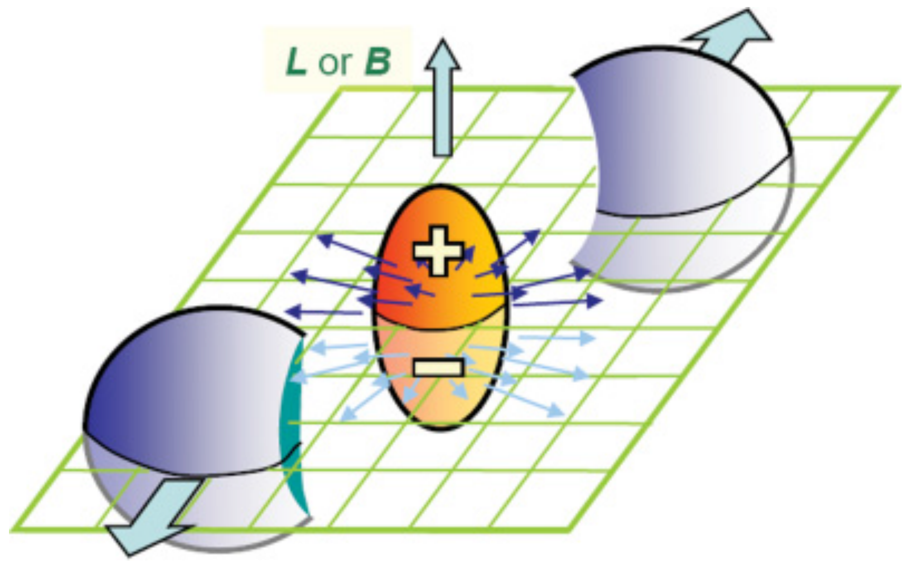
- Chiral Magnetic Effect (CME)
- RHIC-STAR experiment
- Measurements with respect to Ψ_{RP} and Ψ_{PP}
- Summary

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

Chiral Magnetic Effect (CME)

Kharzeev, *et al*. NPA 803, 227 (2008)
Voloshin, PRC 70, 057901 (2004)

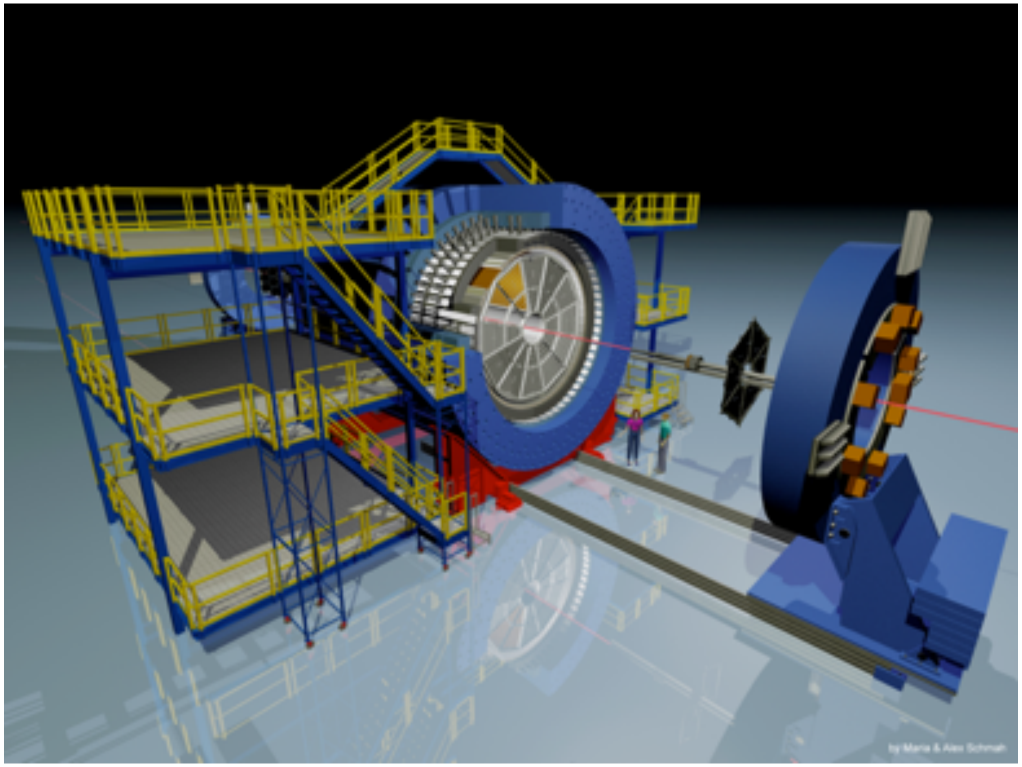


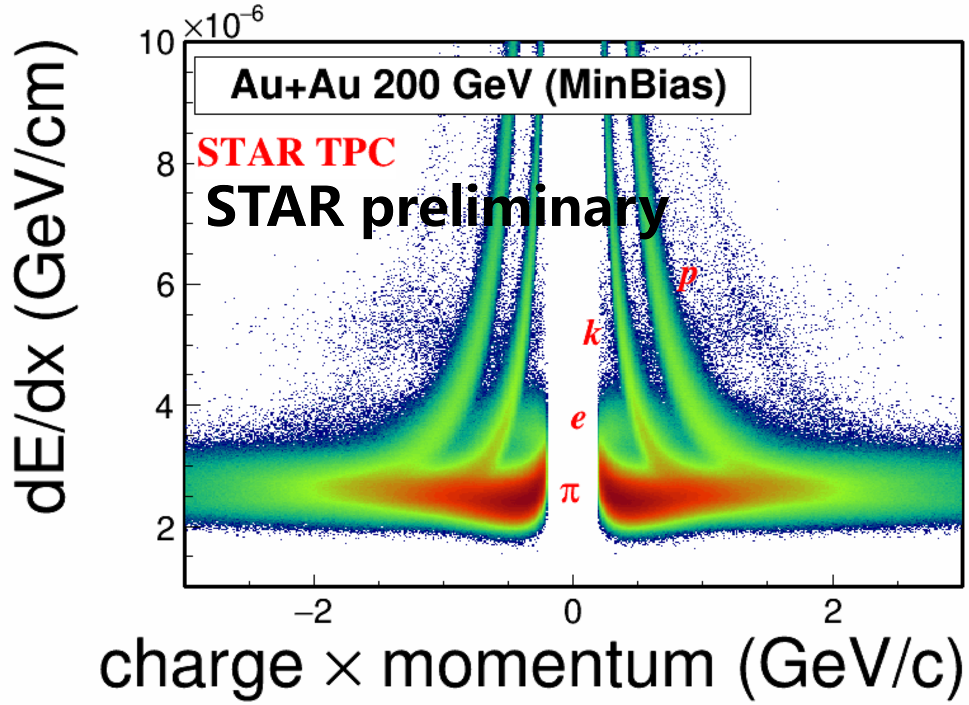


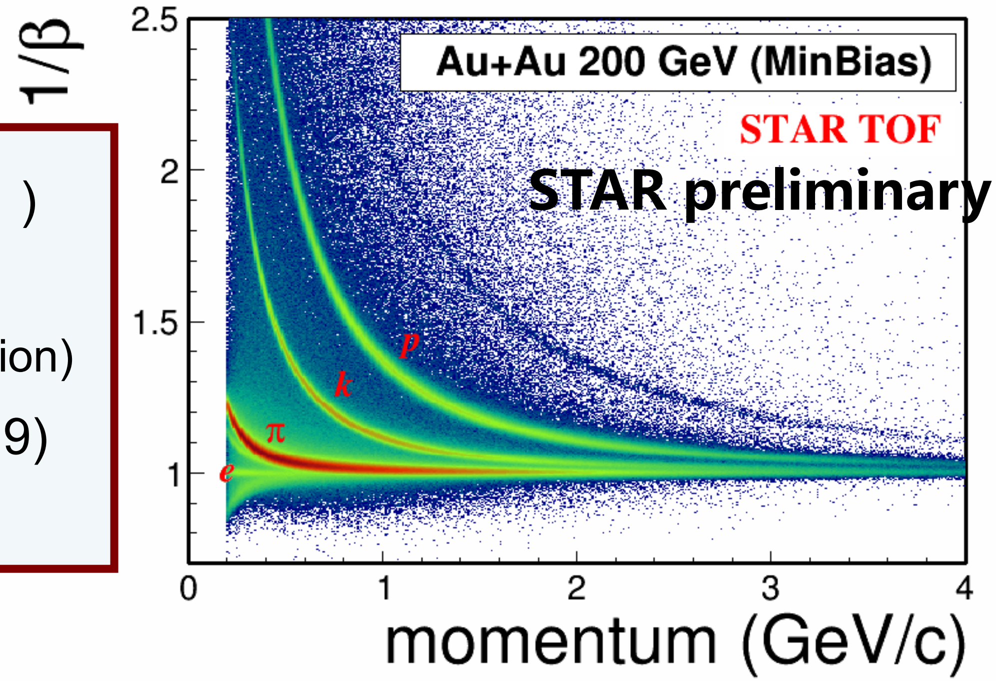
$j_V = \frac{N_c e}{2\pi^2}\mu_A B,$ ⇨ electric charge separation along the B field

- 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, $\boxed{\gamma = \cos(\phi_\alpha + \phi_\beta - 2\psi_{RP})}$ used to search for the CME

The STAR detector





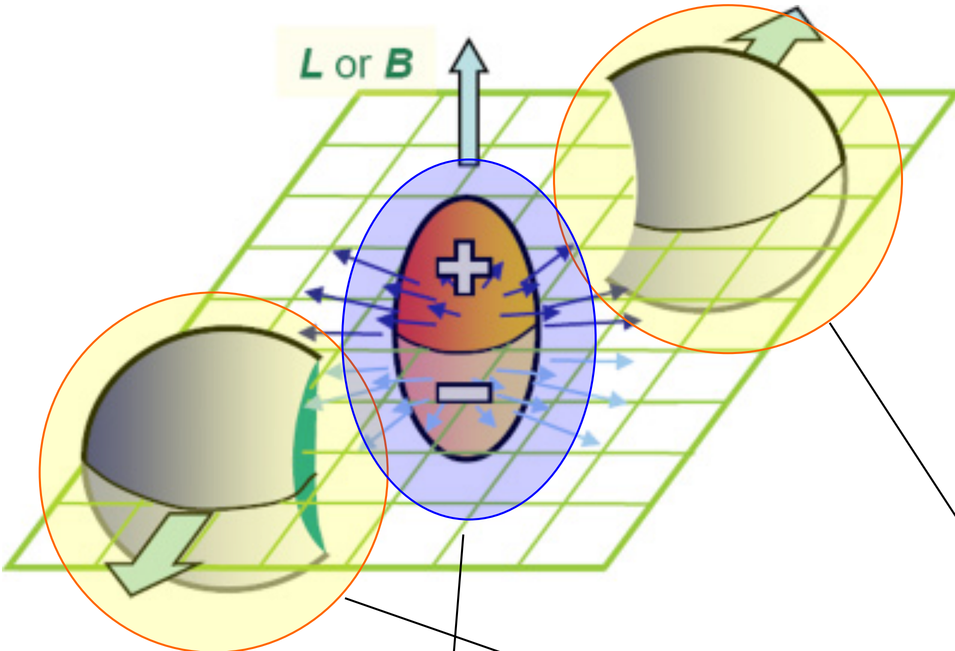


- **Time Projection Chamber** (ϕ=0-2π, $|\eta|<1$)
  - Tracking - momentum
  - Ionization energy loss - dE/dx (particle identification)
- **Time Of Flight detector** (ϕ=0-2π, $|\eta|<0.9$)
  - Timing resolution <100ps - PID improvement

Ψ_{PP} & Ψ_{RP} to resolve CME & Bkg

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

B. Alver *et al.* (PHOBOS) , PRL **98**, 242302 (2007).



- **Ψ_{PP}** maximizes v_2,
  ➔ v_2 background
- **Ψ_{RP}** maximizes the magnetic field (B),
  ➔ CME signal
- **Ψ_{PP}** and **Ψ_{RP}** are correlated, but not identical due to geometry fluctuations

$$a \equiv \langle \cos 2(\psi_{PP} - \psi_{RP}) \rangle$$

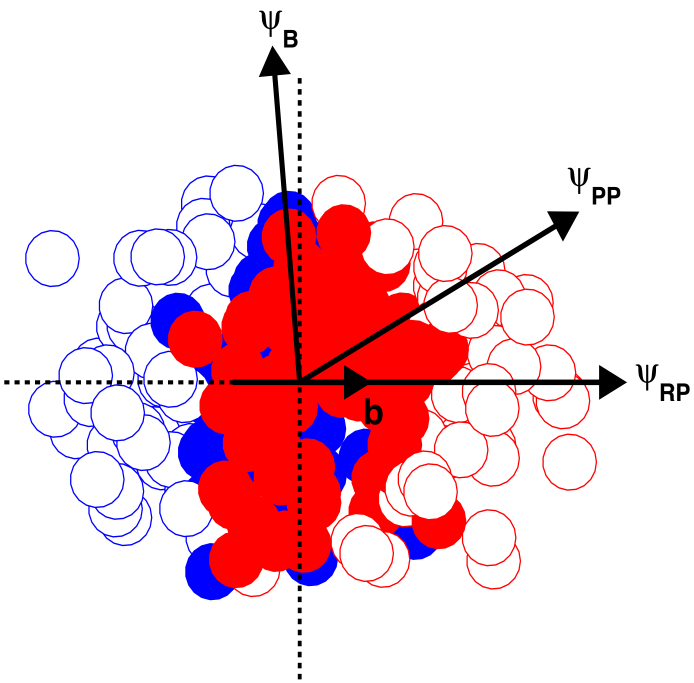
- $\Delta\gamma$ w.r.t. TPC Ψ_{EP} (proxy of Ψ_{PP}) and ZDC Ψ_1 (proxy of Ψ_{RP}) contain different fractions of CME and background (Bkg)

Ψ_{PP} & Ψ_{RP} to resolve CME & Bkg

- Ψ_{PP} maximizes flow, ➔ flow background
- Ψ_{RP} maximizes the magnetic field (B), ➔ CME signal

$\Delta\gamma$ 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



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

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

Two-component assumption

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

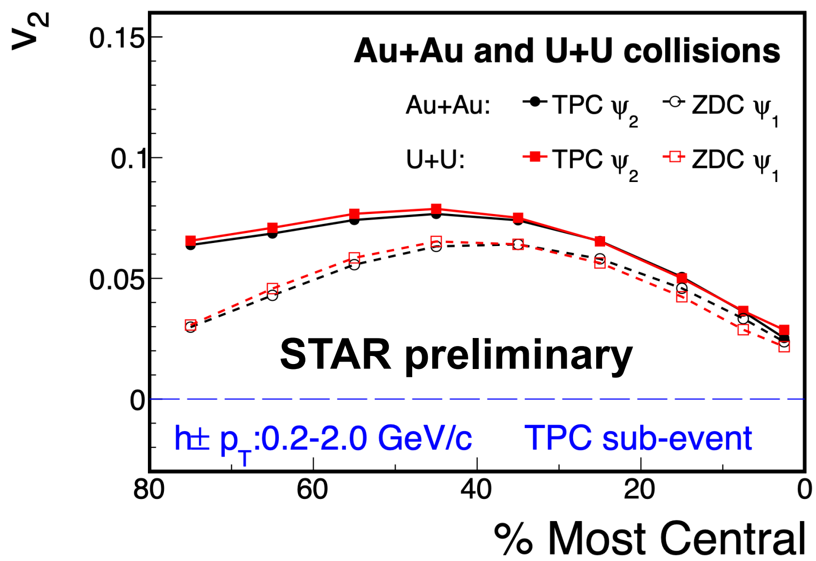
assume $\mathrm{Bkg} \propto v_2$

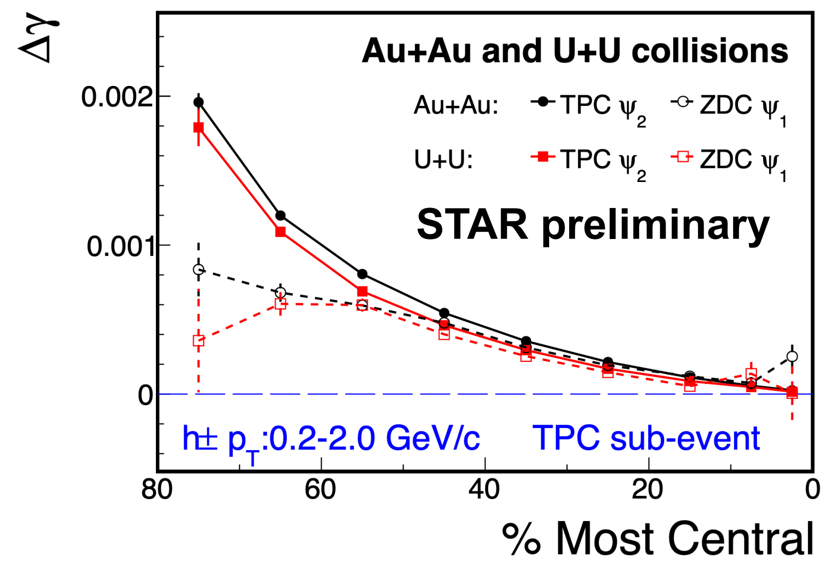
$$a = v_2\{\psi_{\mathrm{ZDC}}\} / v_2\{\psi_{\mathrm{TPC}}\},\ A = \Delta\gamma\{\psi_{\mathrm{ZDC}}\} / \Delta\gamma\{\psi_{\mathrm{TPC}}\}$$

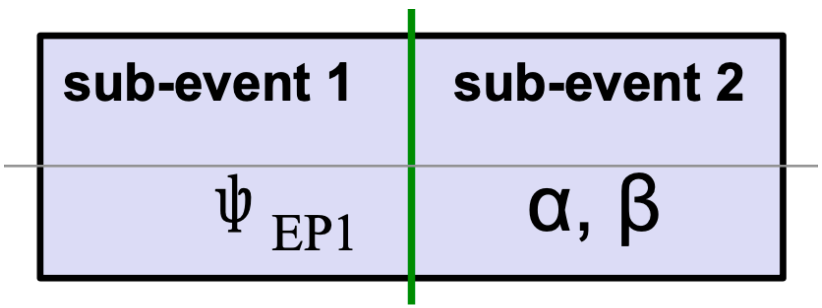
Both are experimental measurements

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

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







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

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

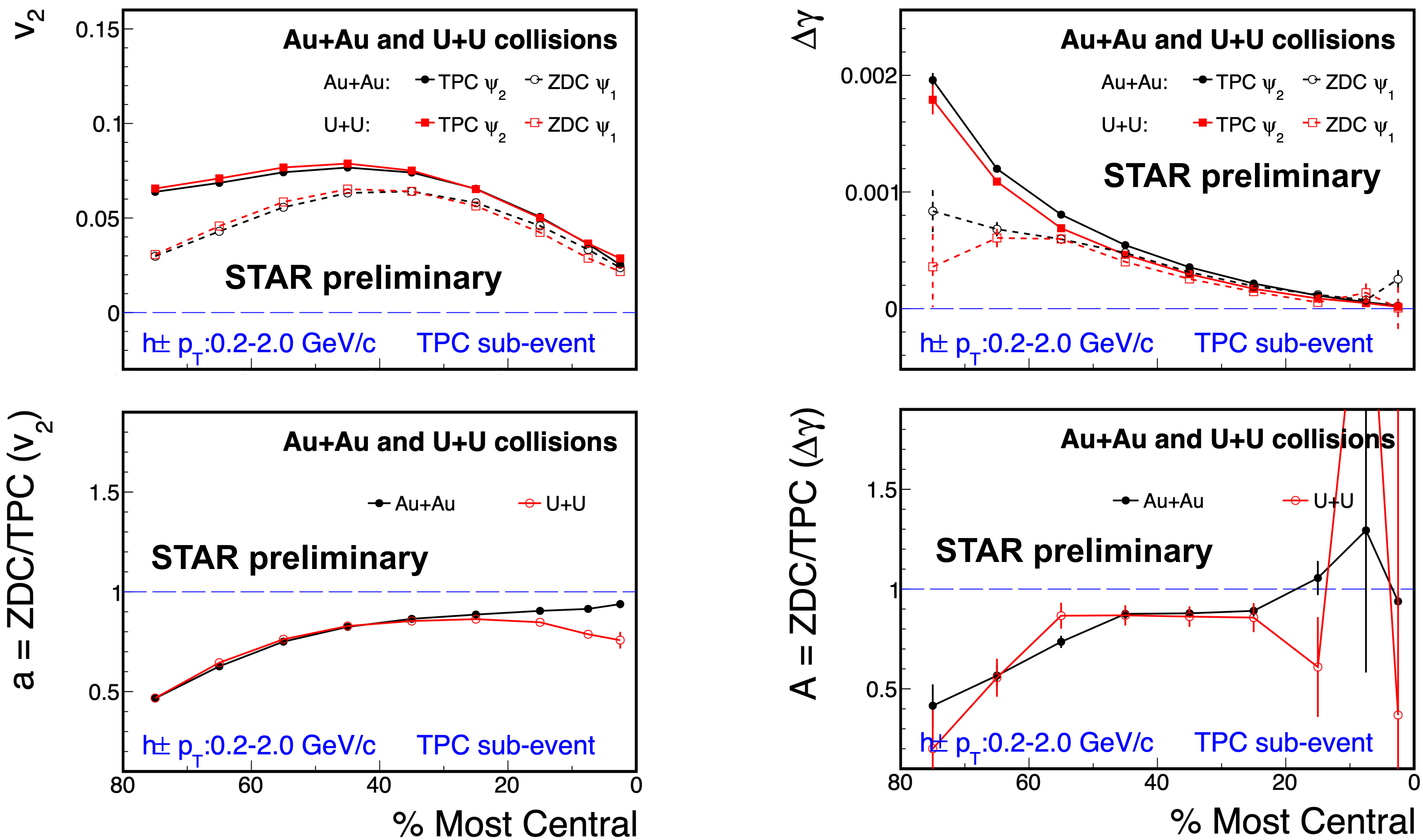
$\Delta\gamma = \gamma_{OS} - \gamma_{SS}$

OS (opposite-sign) and SS (same-sign) represent the charge combinations of α and β particles

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

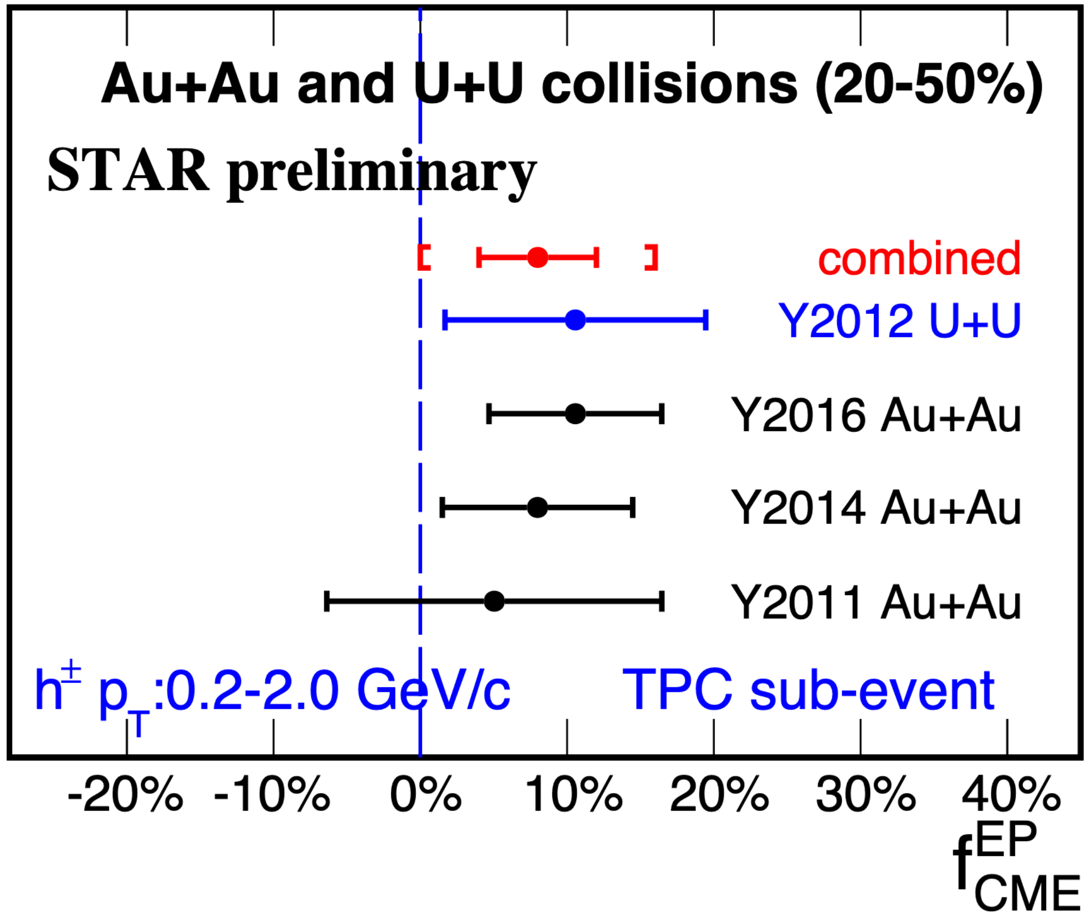


- Data indicate difference in v_2 between central U+U and Au+Au
- "a" and "A" similar trend and magnitude, indicate bkg. dominant

CME fraction by Ψ_{PP} & Ψ_{RP} in U+U & Au+Au

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

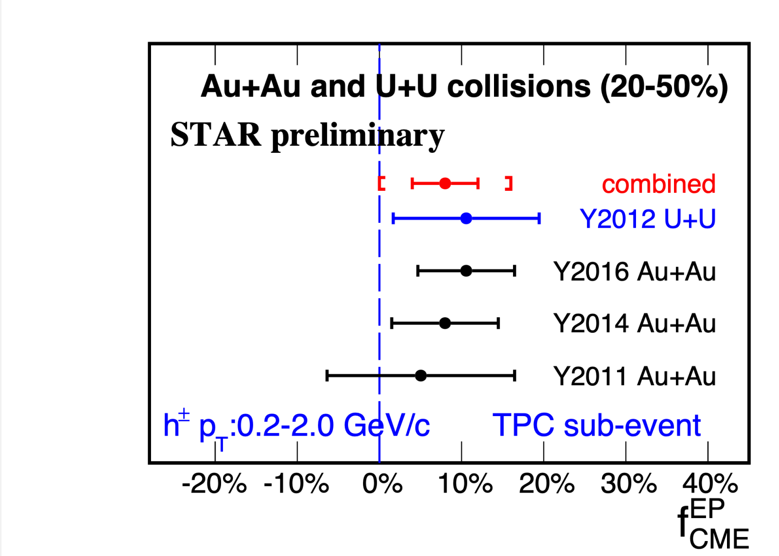
$$\begin{aligned} & f_{EP}(\mathrm{CME}) \\ & = \mathrm{CME}\{\psi_{TPC}\} / \Delta\gamma\{\psi_{TPC}\} \\ & = (A/a-1)/(1/a^2-1) \end{aligned}$$



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

Summary

- $\Delta\gamma$ 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:

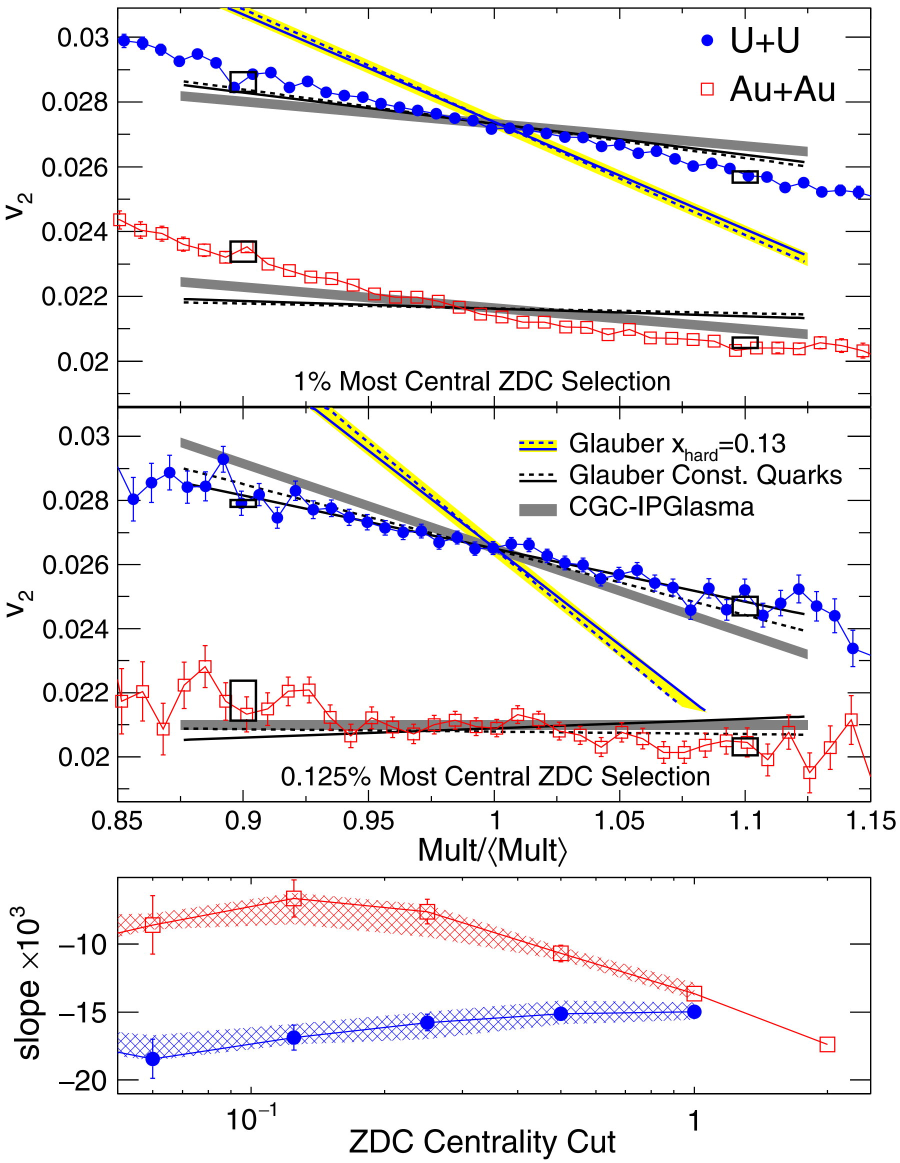


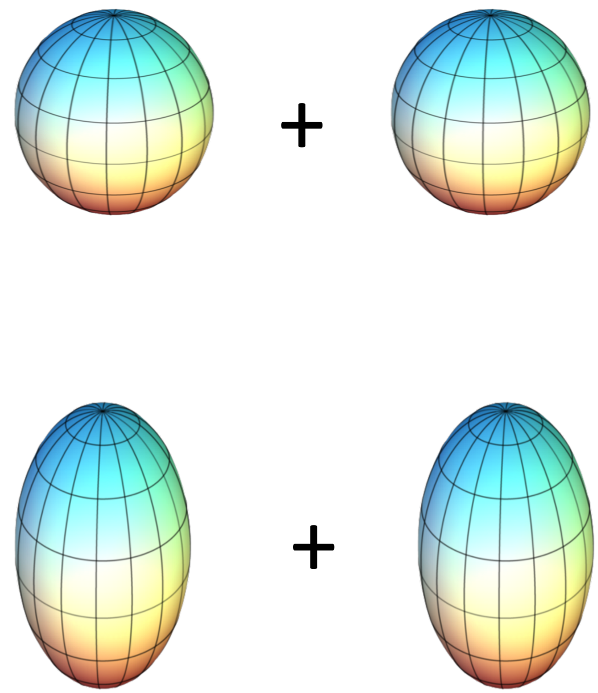
possible CME signal is **(8±4±8)%** of the inclusive $\Delta\gamma$

Work in progress: studies to reduce systematic uncertainties.

Shape difference in Au+Au & U+U

STAR, PRL 115, 222301 (2015)





Au+Au

U+U
Body-body

- 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.