# Search for the Chiral Magnetic Effect by Event Shape Engineering Differentially in Invariant Mass in Au+Au Collisions at $\sqrt{s_{NN}} = 200 GeV$ from STAR


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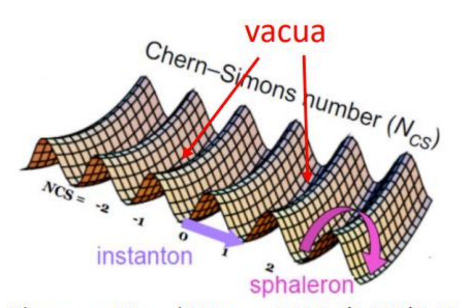
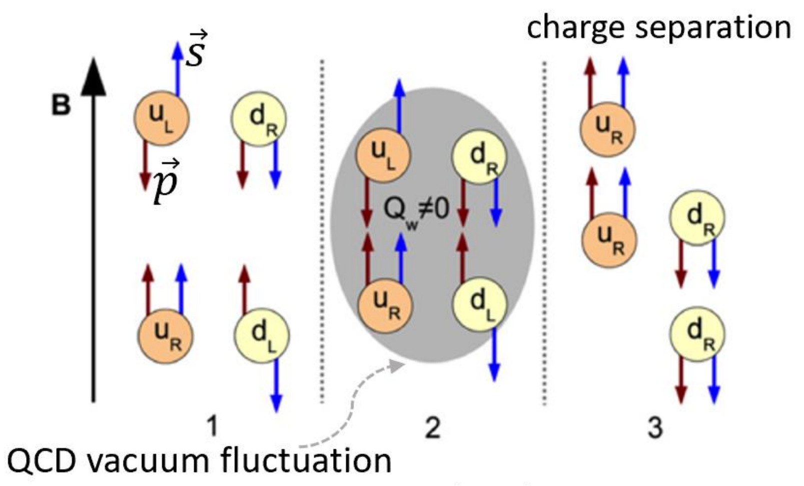
**Abstract** Chiral Magnetic Effect (CME) is a phenomenon in which electric charge is separated by a strong magnetic field from local domains of chirality imbalance and parity violation in quantum chromodynamics (QCD). The CME-sensitive observable, charge-dependent three-point azimuthal correlator $\Delta\gamma$, is contaminated by a major physics background proportional to the particle elliptic anisotropy ($v_2$). In this contribution, we report a fresh investigation of charge separation in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV with the STAR detector using the Event Shape Engineering (ESE) approach [1]. Our approach has several novel aspects, such as using three subevents to identify dynamical fluctuations of $v_2$ by using subevent different from particles of interest for the ESE selection. Since the CME is a low-$p_T$ phenomenon, we further apply the ESE differentially to the $\Delta\gamma$ as a function of the pair invariant mass ($m_{inv}$), particularly at lower $m_{inv}$, which is dominated by a larger fraction of low- $p_T$ pions. We extract the signal as the intercept by projecting $\Delta\gamma$ to zero $v_2$, both integrated over inclusive mass and at low mass. Our results suggest non-zero intercept with an approximately $2\sigma$ significance, which we compare to the published results from the spectator/participant measurement [2]. The extracted signals, highly sensitive to the CME, may still be contaminated by residual flow as well as nonflow contributions in the $v_2$ measurement and in the three-particle correlator [3]. We investigate these contaminations in the ESE measurement, and report measurement using the zero-degree calorimeter (ZDC) that largely suppresses the nonflow contamination.


## The Chiral Magnetic Effect (CME)

- **The CME**
  - Non-zero topological charge → Chirality imbalance of fermions
  - Strong magnetic field → Spin separation according to charge -> Charge separation
- **Importance of the CME**
  - Approximate chiral symmetry restoration
  - Local P/CP-violation in strong interaction
  - It may resolve the strong CP problem of matter–antimatter asymmetry



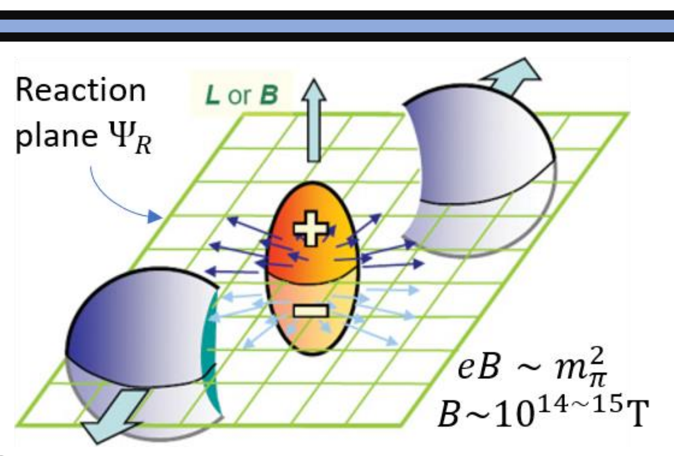

Kharzeev,Pisarski,Tytgat,PRL81(1998)512




QCD vacuum fluctuation

Topological charge $Q_w \propto \int \vec{E}_c \cdot \vec{B}_c$

## Observables




- **Heavy ion collisions**
  - Deconfined quarks and gluons
  - Strong magnetic field
- **The $\gamma$ correlator**

$\gamma_{\alpha\beta} = \langle \cos(\phi_\alpha + \phi_\beta - 2\psi) \rangle = \langle \cos(\phi_\alpha + \phi_\beta - 2\phi_c) \rangle / v_{2,c}$

POI ($\alpha, \beta$) from east subevent, c from west subevent

$\Delta\gamma = \gamma_{OS} - \gamma_{SS} \approx b_{bkg} * v_2 + CME$

Major flow background in $\Delta\gamma$. Intercept more sensitive to CME.

- **Event-shape engineering (ESE)**

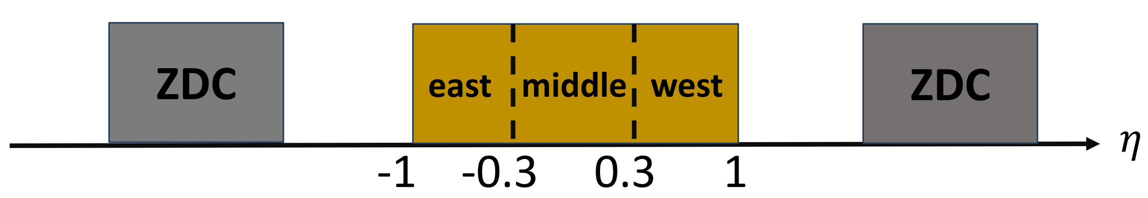
Selects events within narrow centrality bins according to the flow vector $q_2$ in phase space apart from POI's. Select events on dynamical fluctuations of $v_2$, in contrast to statistical fluctuations [4, 5]. After cuts, we have 2.1 B events.

- **CME a non-perturbative (low-$p_T$) phenomenon**

Looking differentially in $m_{inv}$ may yield additional insights

## ESE Analysis procedure

- **Three subevents:** east ($-1 < \eta < -0.3$), middle ($-0.3 < \eta < 0.3$), and west ($0.3 < \eta < 1$)




- **The flow vector**

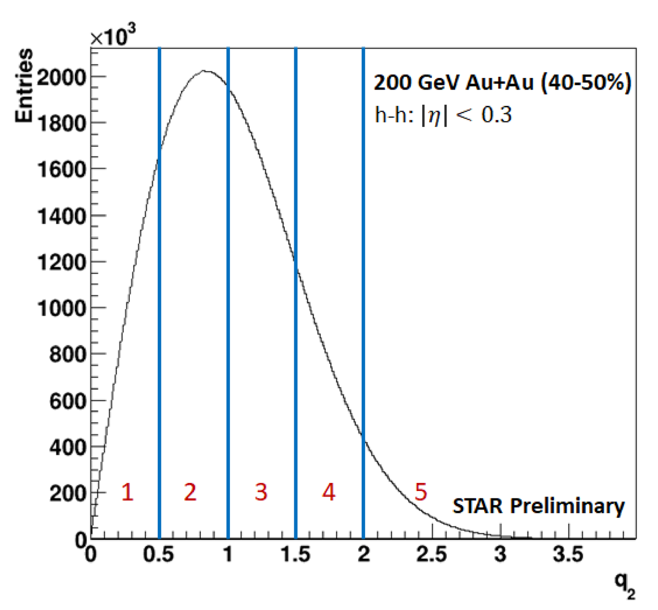
$q_2 = \sqrt{\left[\left(\sum_i^M \cos 2\phi_i\right)^2 + \left(\sum_i^M \sin 2\phi_i\right)^2\right] / M}$

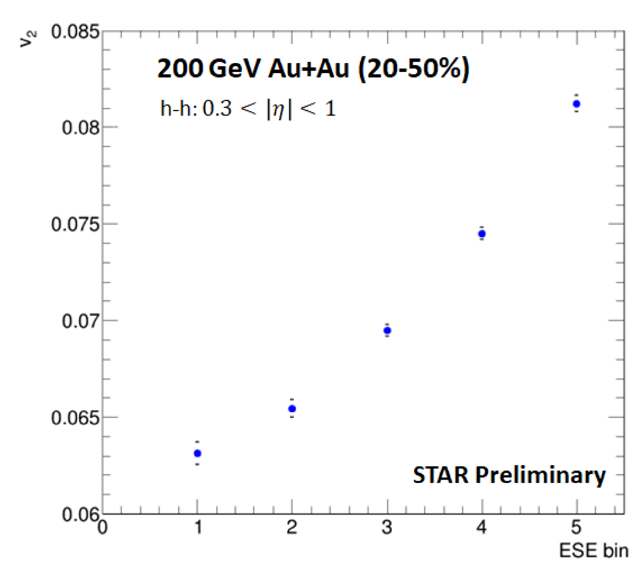
calculated from the middle subevent.

- **elliptic anisotropy flow**

$v_2 = \sqrt{\langle \cos 2(\phi_{c_1} - \phi_{c_2}) \rangle}$ (cumulant method)

$c_1$ from east subevent, $c_2$ from west subevent



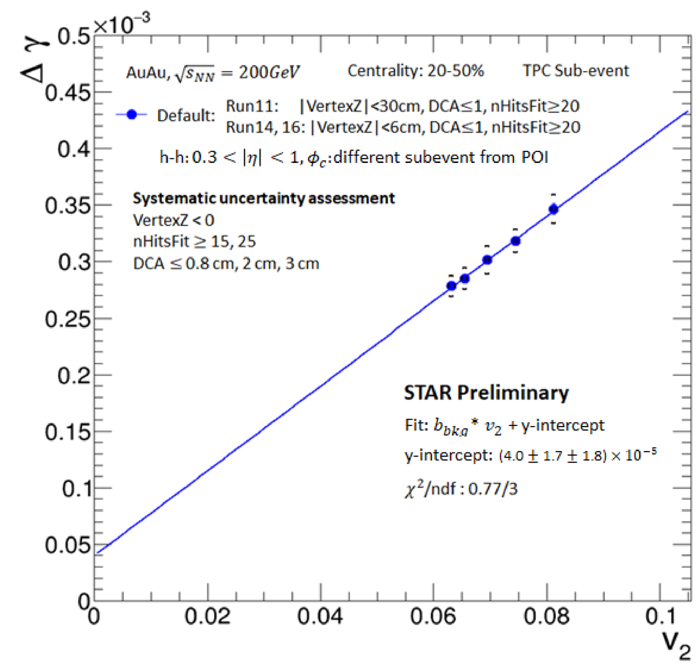




## Systematic uncertainty

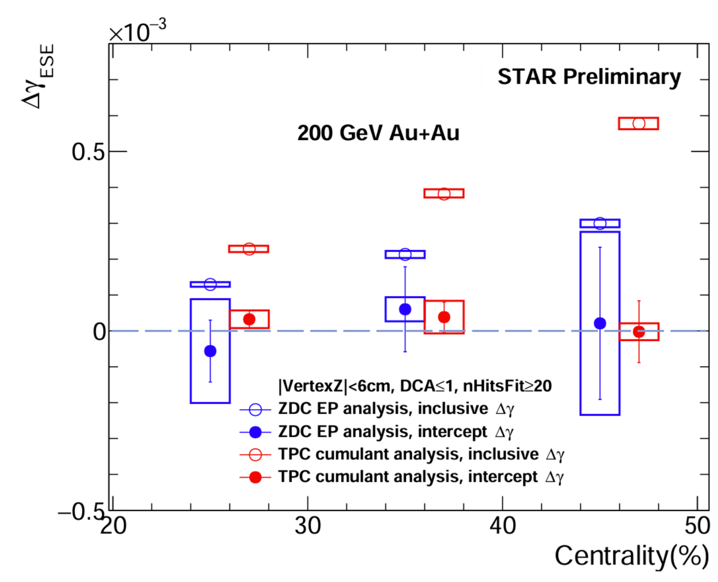
- **Sources of the systematic uncertainty**
  - Run11:
    |VertexZ| < 30 cm (default), VertexZ< 0
    Run 14, 16:
    |VertexZ| < 6 cm (default), VertexZ< 0
  - nHitsFit ≥ 20 (default), 15, 25
  - DCA ≤ 1 cm (default), 0.8 cm, 2 cm, 3 cm
- **The calculation of systematic uncertainty based on the Barlow prescription**

## Result

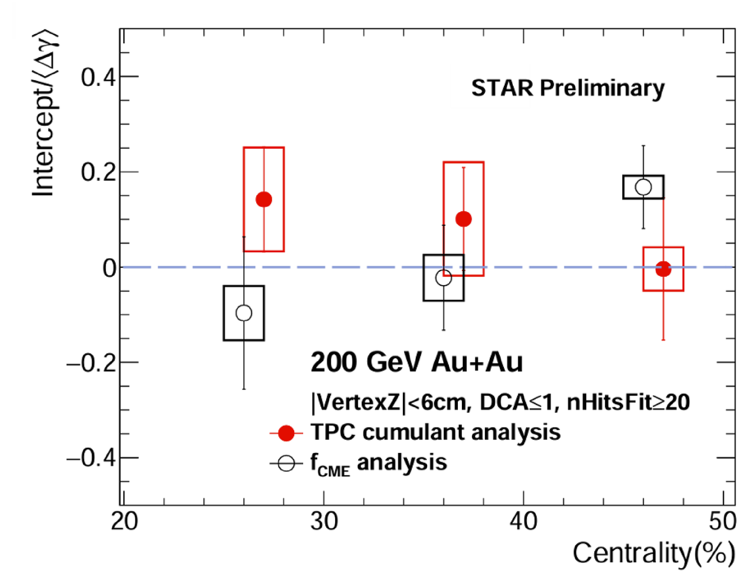
- **$\Delta\gamma$ vs. $v_2$ using five ESE bins**
  - The intercept is consistent with zero within $1.5\sigma$



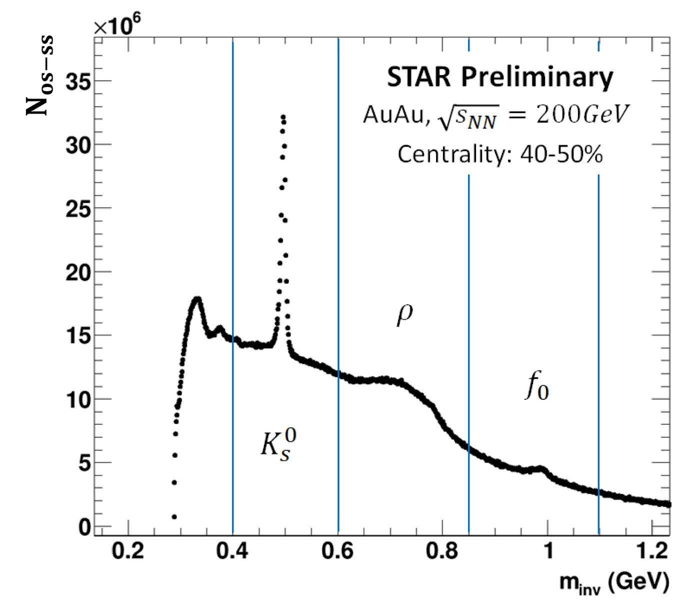

- **intercept vs. centrality**



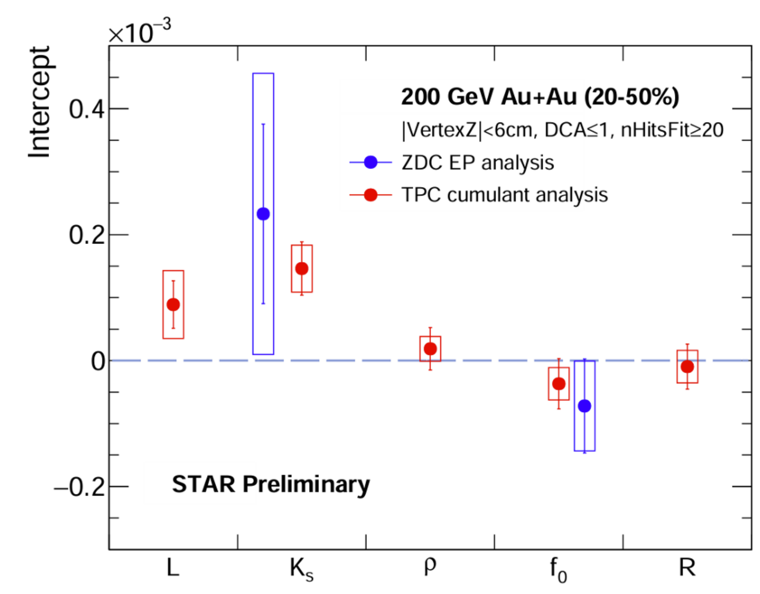

- **Ratio vs. centrality**




- **Mass windows**
  - Low mass: mass ($\pi^+\pi^-$) < 0.4
  - $K_S^0$ region: 0.4 < mass ($\pi^+\pi^-$) < 0.60
  - $\rho$ region: 0.6 < mass ($\pi^+\pi^-$) < 0.85
  - $f_0$ region: 0.85 <mass ($\pi^+\pi^-$) < 1.1
  - High mass: 1.1 < mass ($\pi^+\pi^-$)




- **The intercept vs. invariant mass**
  - Data binned in POI ($\alpha$,$\beta$) pair inv. mass; All other aspects of analysis identical to inclusive ESE.
  - Possible mass dependence is under investigation.




## Conclusion

- ESE studies performed: inclusive and differential in invariant mass (2.1 B Au+Au events)
- Intercept (sensitive to CME) from inclusive data:
  - TPC cumulant measurement: $(4.0 \pm 1.7 \pm 1.8) \times 10^{-5}$
  - ZDC EP measurement: $(7.0 \pm 7.9 \pm 2.1) \times 10^{-5}$
- Intercept from low/high mass regions:
  - Possible mass dependence is under investigation

## Future steps

- Nonflow effects to be assessed
  - Non-flow effect in $v_2$ -> estimate by a data driven fitting method
  - Three-particle non-flow in $\Delta\gamma$ -> estimate by Hijing simulations
  - Investigate the non-flow effects as a function of $q_2$ selections

## Reference


[1] J. Schukraft, A. Timmins, and S.A. Voloshin, Phys. Lett. B719 (2013) 394.
[2] M.S. Abdallah et al. (STAR Collaboration), Phys. Rev. Lett. 128 (2022), 092301.
[3] Y. Feng, J. Zhao, H. Li, H.-j. Xu, and F. Wang, Phys. Rev. C105 (2022) 024913.
[4] L. Adamczyk et al. (STAR Collaboration), Phys. Rev. C 89 (2014), 044908.
[5] STAR Collaboration, arXiv:2506.00278 (2025), arXiv:2506.00275 (2025)



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