ESE $\Delta\gamma$ vs. invariant mass in Au+Au collisions at $\sqrt{s_{NN}} = 200GeV$

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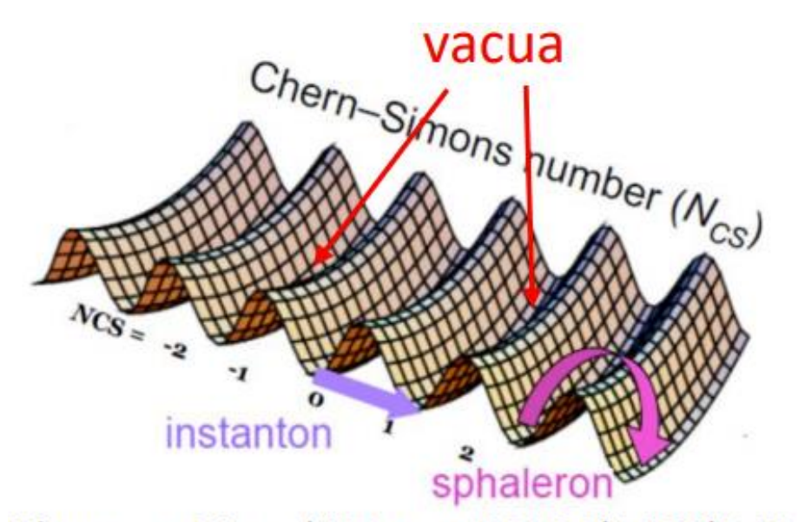
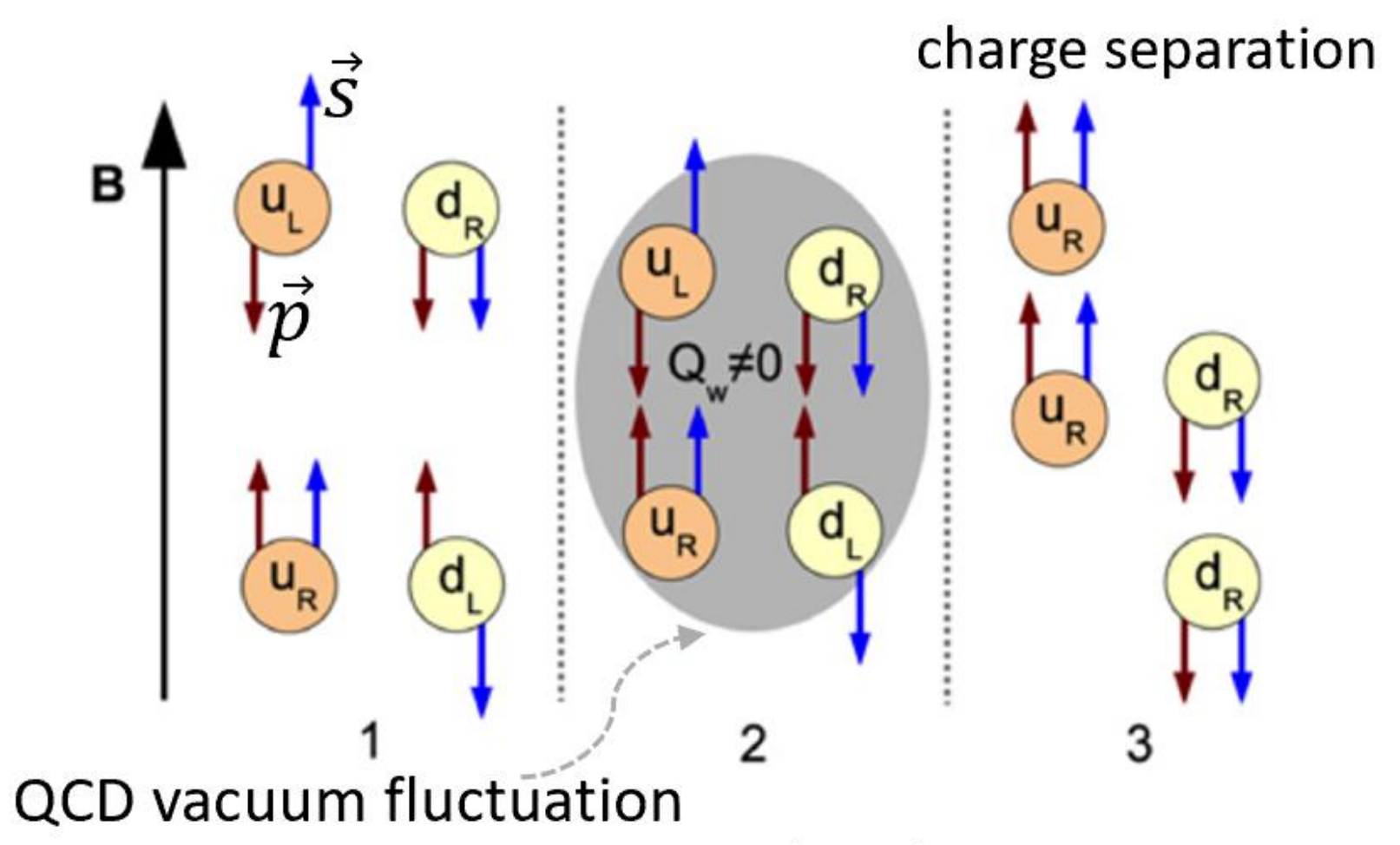
Abstract Chiral Magnetic Effect (CME) is a phenomenon in which electric charge is separated by a strong magnetic field from local domains of chirality imbalance and parity violation in quantum chromodynamics (QCD). The CME-sensitive observable, charge-dependent three-point azimuthal correlator $\Delta\gamma$, 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 2σ 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

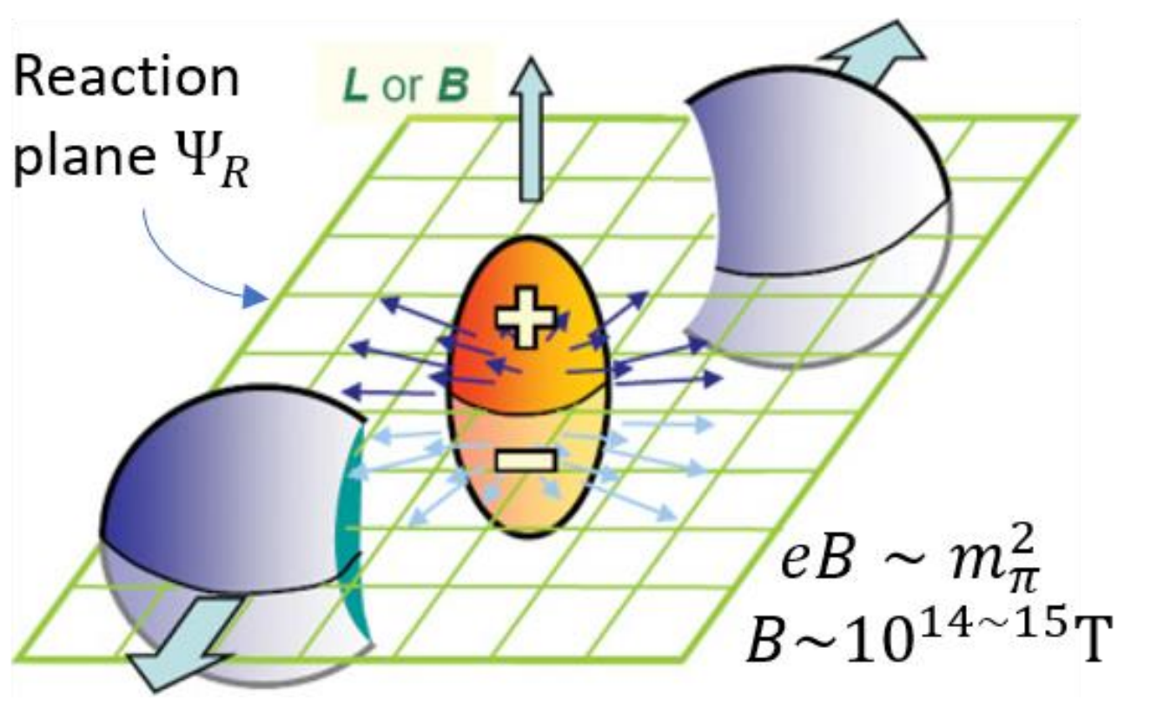


Kharzeev,Pisarski,Tytgat,PRL81(1998)512



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 γ correlator**

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

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

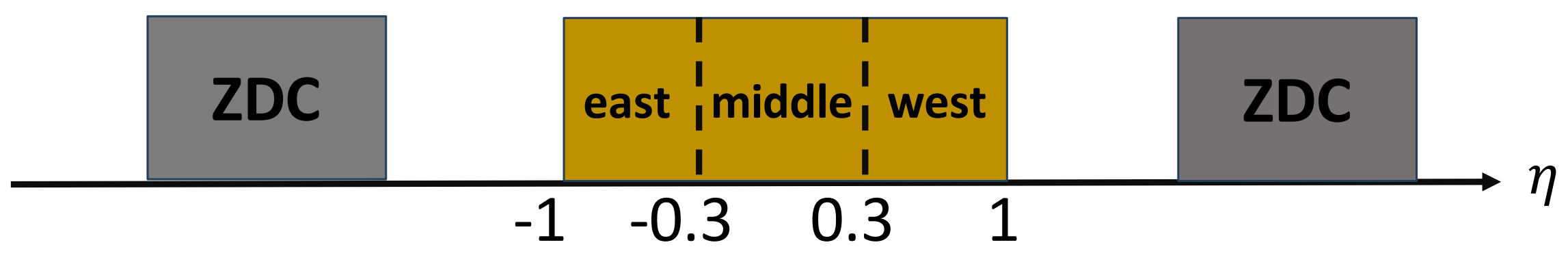
Major flow background in $\Delta\gamma$. Intercept more sensitive to CME.

- ■ **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]. After cuts, we have 2.1 B events.

ESE Analysis procedure

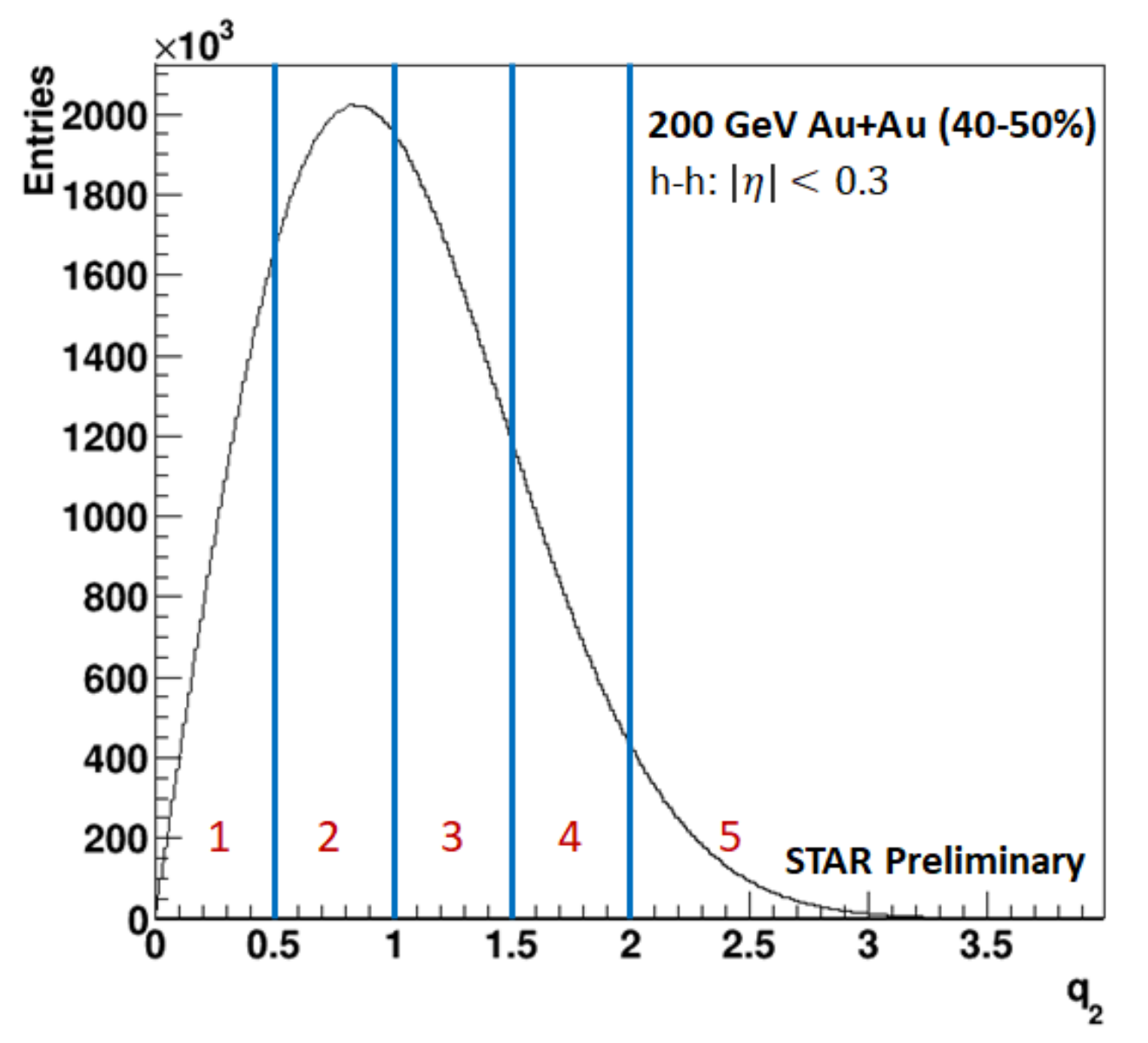
- ■ **Three subevents:** east ($-1 < \eta < -0.3$), middle ($-0.3 < \eta < 0.3$), and west ($0.3 < \eta < 1$)



- ■ **The flow vector**

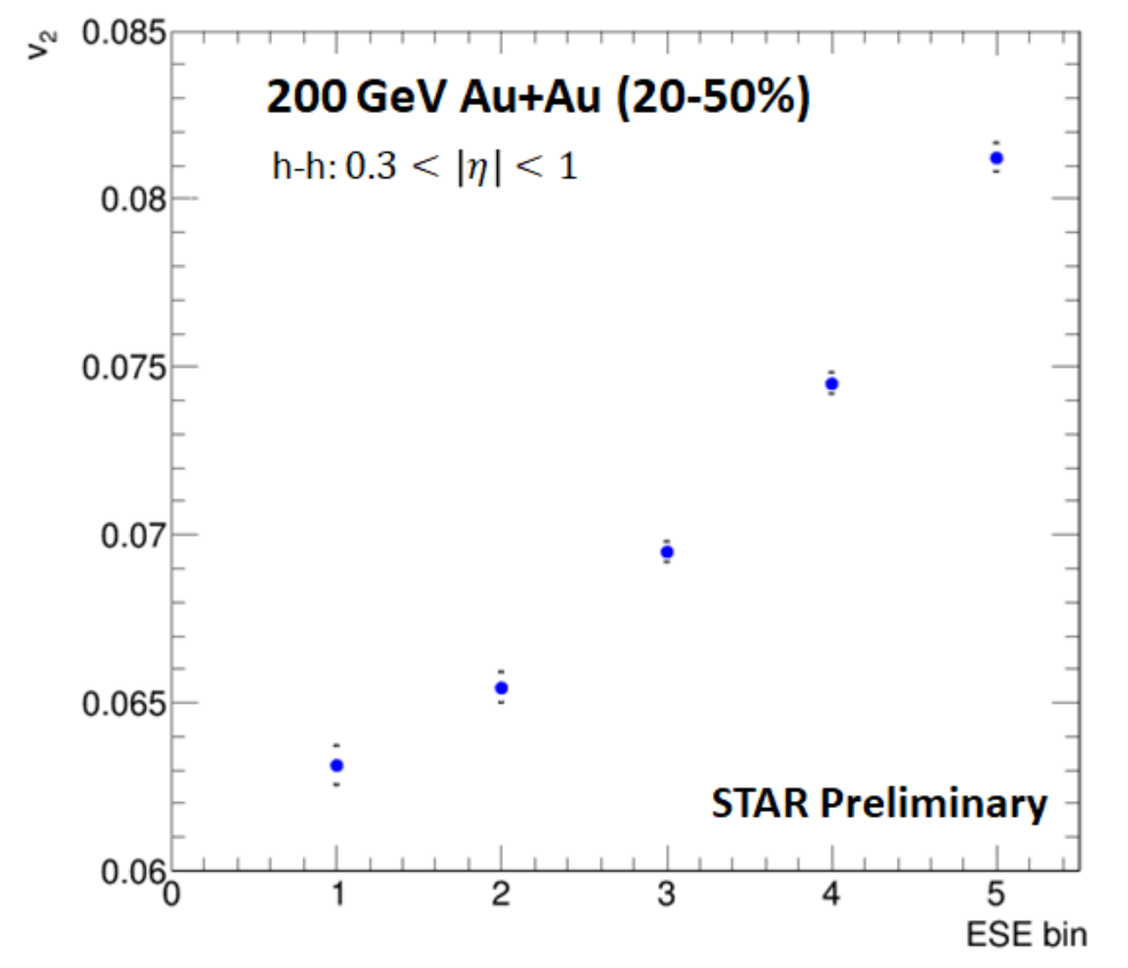
$q_2 = \sqrt{\left[\left(\sum_i^M cos2\phi_i\right)^2 + \left(\sum_i^M sin2\phi_i\right)^2\right]/M}$

calculated from the middle subevent.



- ■ **elliptic anisotropy flow**

$v_2 = \sqrt{\langle cos2(\phi_{c_1} - \phi_{c_2})\rangle}$ (cumulant method)
c_1 from east subevent, c_2 from west subevent

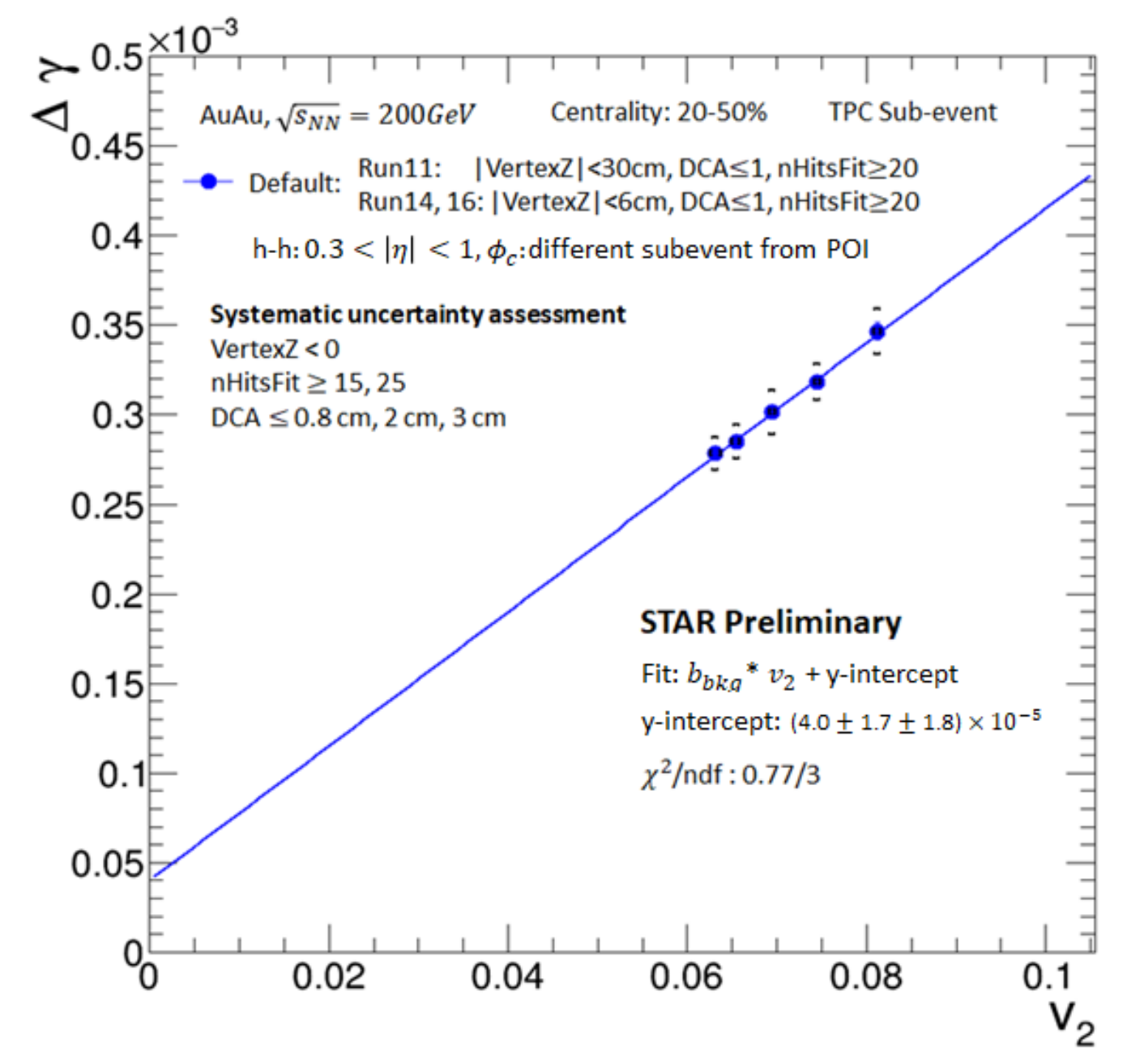


Systematic uncertainty

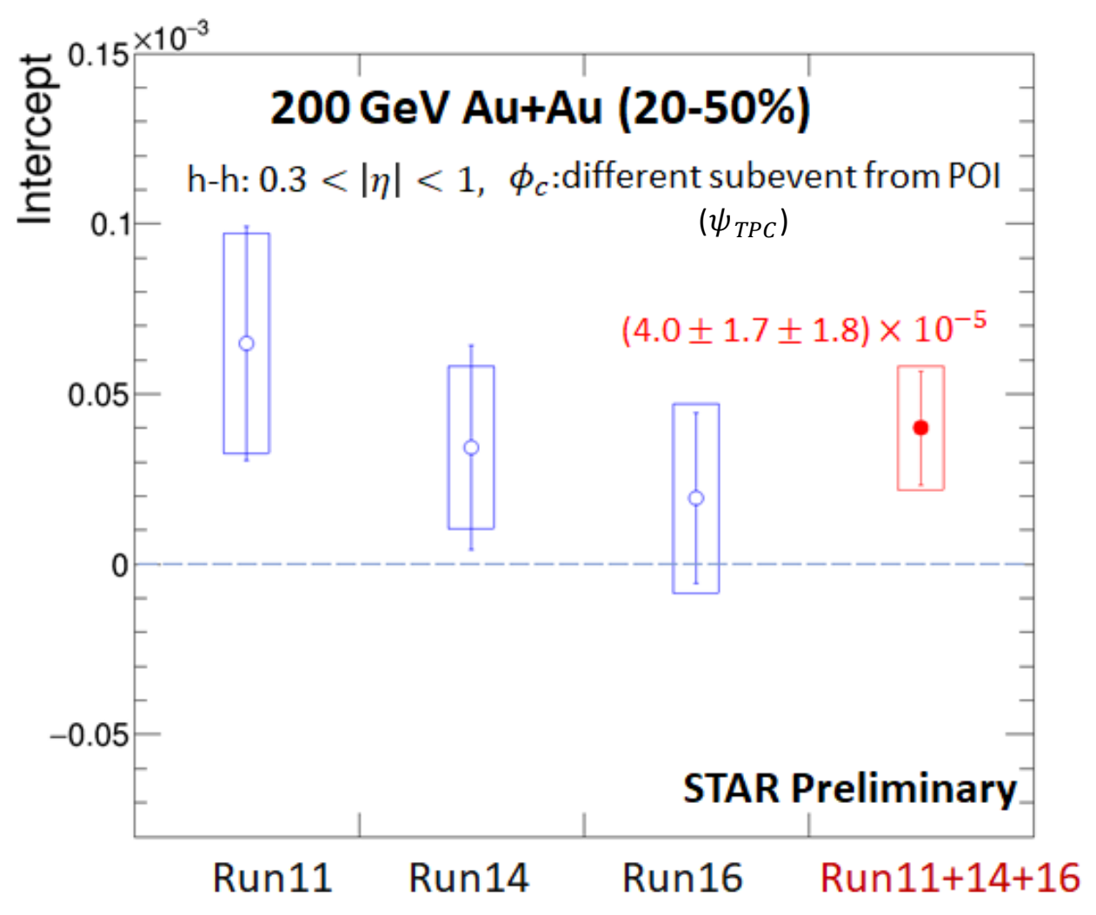
- ■ **Sources of the systematic uncertainty**
  - ☐ Run11:
    |VertexZ| < 30 cm (default), VertexZ< 0
    Run 14, 16:
    |VertexZ| < 6 cm (default), VertexZ< 0
  - ☐ nHitsFit ≥ 20 (default), 15, 25
  - ☐ DCA ≤ 1 cm (default), 0.8 cm, 2 cm, 3 cm
- ■ **The calculation of systematic uncertainty based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

Result

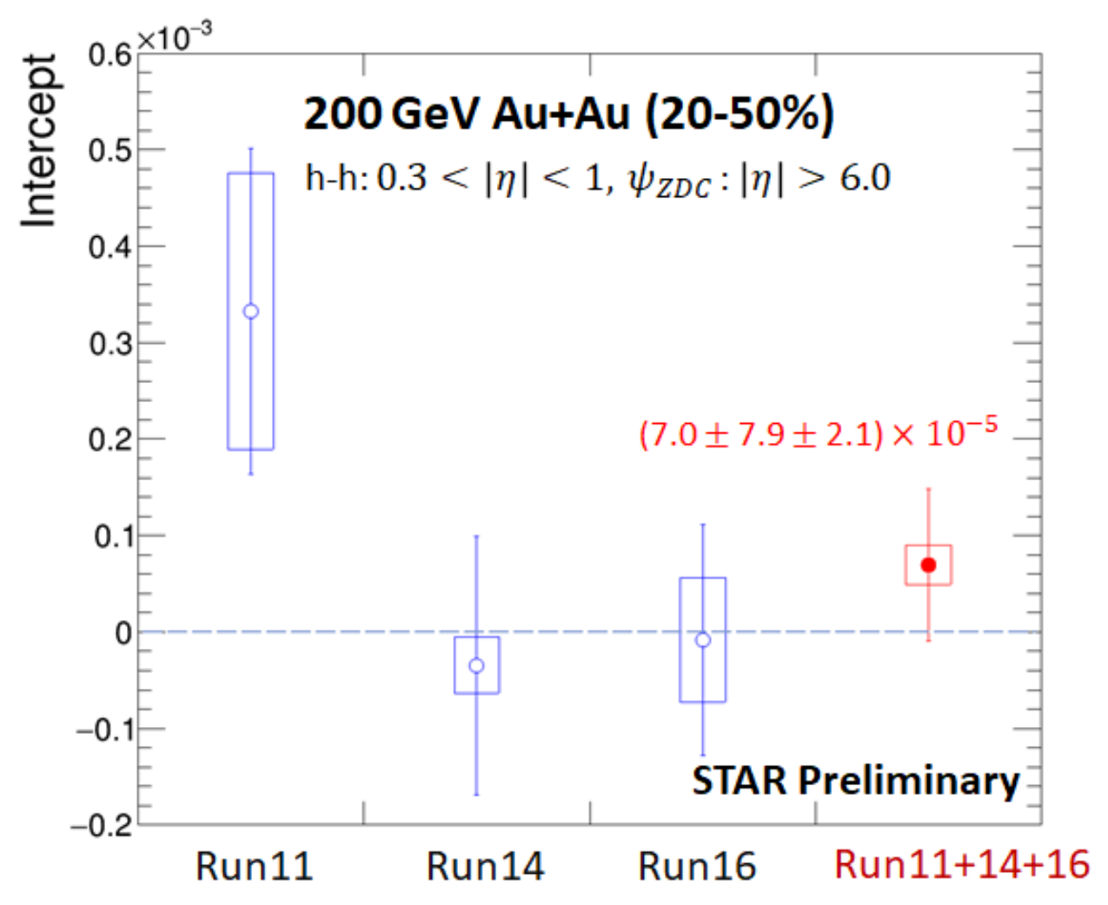
- ■ **$\Delta\gamma$ vs. v_2 using five ESE bins**
  - ☐ $\Delta\gamma = \gamma_{OS} - \gamma_{SS}$
    $\gamma_{OS} = \langle\cos(\phi_\alpha^{\pm} + \phi_\beta^{\mp} - 2\phi_c)\rangle / v_2$
    $\gamma_{SS} = \langle\cos(\phi_\alpha^{\mp} + \phi_\beta^{\mp} - 2\phi_c)\rangle / v_2$
    POI (α, β) from east subevent, c from west subevent; and vice versa.
  - ☐ The intercept is about 1.5σ significance



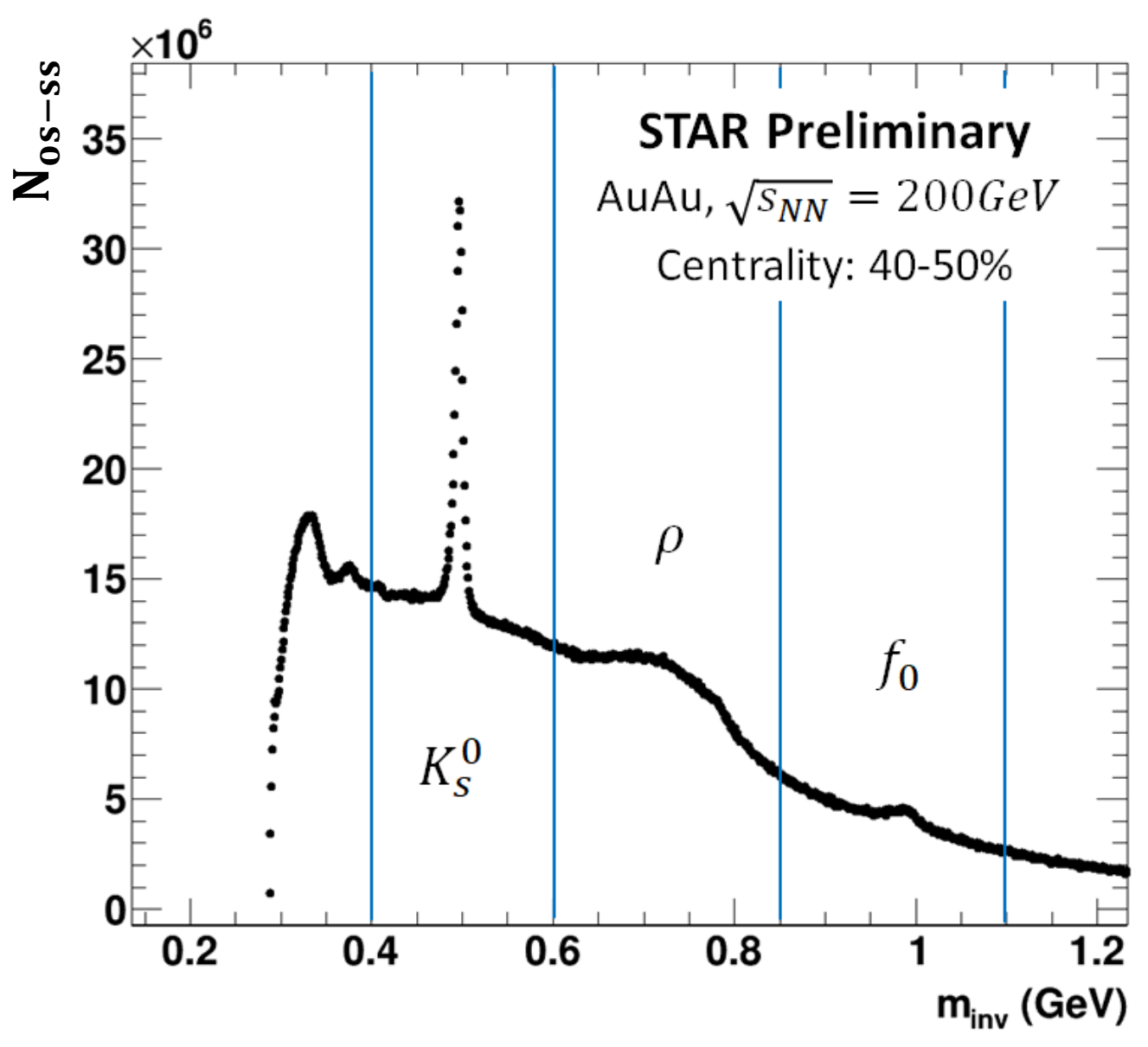
- ■ **POI from one side sub-event, c particle from the other sub-event**



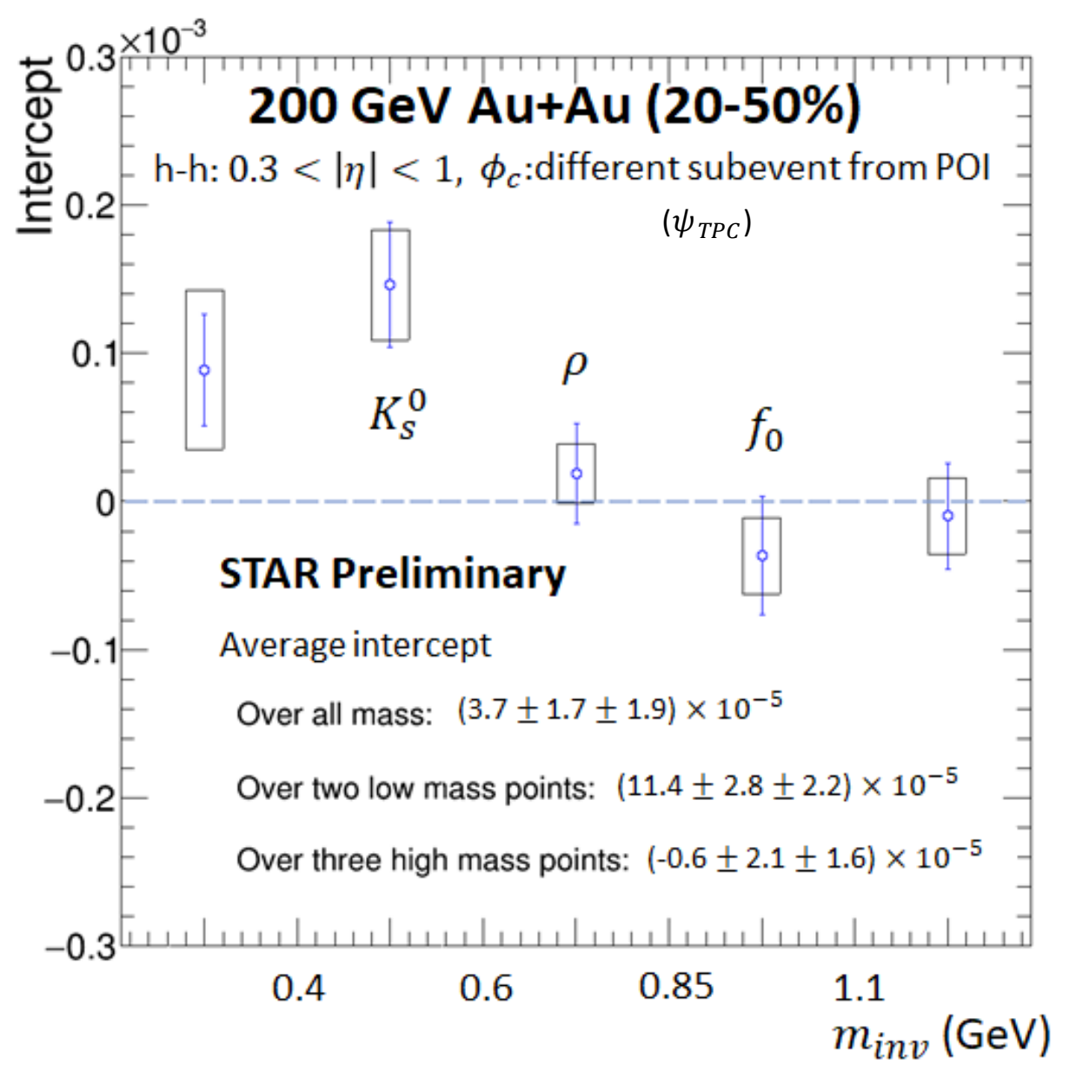
- ■ **POI from one side sub-events, EP from ZDC**
  - ☐ ZDC void of nonflow, but statistics poor



- ■ **Mass windows**
  - ☐ Low mass: mass ($\pi^+\pi^-$) < 0.4
  - ☐ K_s^0 region: 0.4 < mass ($\pi^+\pi^-$) < 0.60
  - ☐ ρ 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 (α,β) pair inv. mass; All other aspects of analysis identical to inclusive ESE.
  - ☐ Low mass region appears to have a larger signal (3σ) than high mass region (consistent with zero)



Conclusion

- ■ ESE studies performed: inclusive and differential in invariant mass (2.1 B Au+Au events)
- ■ Intercept (sensitive to CME) from inclusive data:
  - ☐ TPC sub-event: $(4.0 \pm 1.7 \pm 1.8) \times 10^{-5}$ (1.5σ effect)
  - ☐ ZDC sub-event: $(7.0 \pm 7.9 \pm 2.1) \times 10^{-5}$
- ■ Intercept from low/high mass regions (TPC data):
  - ☐ mass < 0.6 GeV/c^2 (low pt): $(11.4 \pm 2.8 \pm 2.2) \times 10^{-5}$ (3σ effect)
  - ☐ mass > 0.6 GeV/c^2 (high pt): $(-0.6 \pm 2.1 \pm 1.6) \times 10^{-5}$
- ■ To be studied: nonflow effects, q_2 variation of the magnetic field direction

Future steps

- ■ Nonflow effects to be assessed
  - ☐ Non-flow effect in v_2 -> intercept underestimates CME
  - ☐ Three-particle non-flow in $\Delta\gamma$ -> intercept overestimates CME
  - ☐ Use $v_2\{4\}$ where nonflow is negligible. Assuming flow fluctuations proportional to flow magnitude.
- ■ Account for variations over q_2 in determining the magnetic field direction

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, 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, 044908

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