Search for the Chiral Magnetic Effect from STAR Beam Energy Scan-II data

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Abstract

The Chiral Magnetic Effect (CME) manifestly violates local P and CP symmetry, and it describes the induction of an electric charge separation along $\vec{B}$ direction. In this work, we measure a correlation observable $\Delta\gamma^{112}$ between two charged mesons to detect the charge separation. The data were taken from Au+Au collisions during the RHIC Beam Energy Scan phase II and at the top RHIC energy. To mitigate the background induced by elliptic flow, we adopt a novel event shape selection (ESS) approach that classifies events based on their shape and determines $\Delta\gamma^{112}$ at the zero-flow limit, which we denote as $\Delta\gamma^{112}_{\rm ESS}$. The value of $\Delta\gamma^{112}_{\rm ESS}$ is reduced from the inclusive $\Delta\gamma^{112}$ by more than five-fold. The measured $\Delta\gamma^{112}_{\rm ESS}$ value in the 20%–50% centrality range is positive finite with a 3σ significance at each of the center-of-mass energies $\sqrt{s_{NN}}$ =11.5, 14.6, and 19.6 GeV.

Chiral Magnetic Effect (CME)

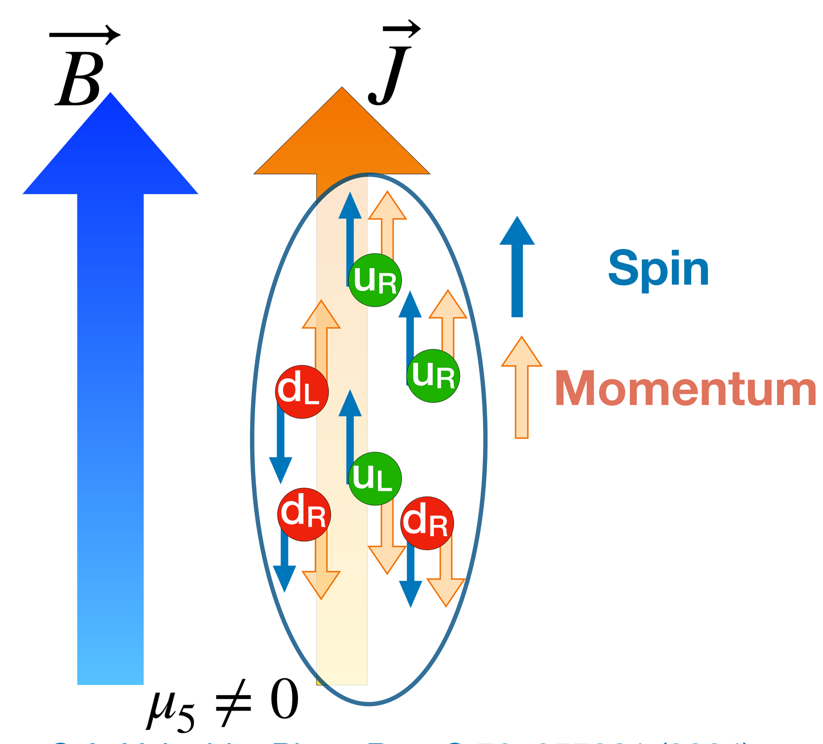
Magnetic field (B) can induce charge separation (current J) for quarks at chirality imbalance ($\mu_5 \neq 0$).

$\vec{J} \propto \mu_5 \vec{B}$ **Manifestly violate local P and CP symmetry.**

odd parity even parity

3 conditions of CME:

- **Chiral Symmetry Restoration**
- **Topological Vacuum Transition**
- **A strong B field**



S.A. Voloshin, Phys. Rev. C,70, 057901 (2004)

Observe CME in Heavy Ion Collisions

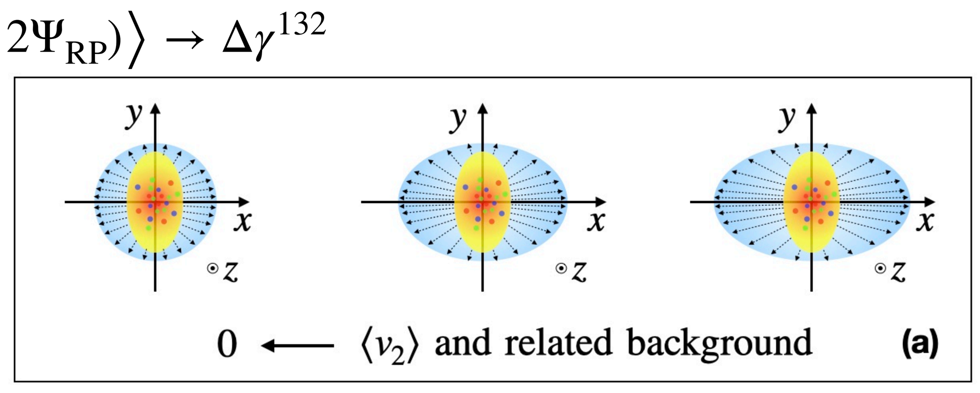
$$\frac{dN_\pm}{d\phi} \propto 1 + \sum_{n=1}^{\infty} 2v_n \cos(n\phi - n\Psi_{\rm RP}) + 2a_1^\pm \sin(\phi - \Psi_{\rm RP})$$

We focus on: $\gamma^{112} = \langle \cos(\phi_1 + \phi_2 - 2\psi_{\rm RP})\rangle = \langle v_1 v_1\rangle - \langle a_1 a_1\rangle + {\rm BG}(v_2^{\rm cl})$

CME signal: $\boxed{\Delta\gamma^{\rm CME} = \gamma^{\rm OS} - \gamma^{\rm SS} > 0}$

BKG indicator: $\gamma^{132} = \langle \cos(\varphi_1 - 3\varphi_2 + 2\Psi_{\rm RP})\rangle \rightarrow \Delta\gamma^{132}$

Event Shape Selection (ESS):



1. Categorize events with event-shape variable

Z. Xu et al, PLB 848(2024)138367

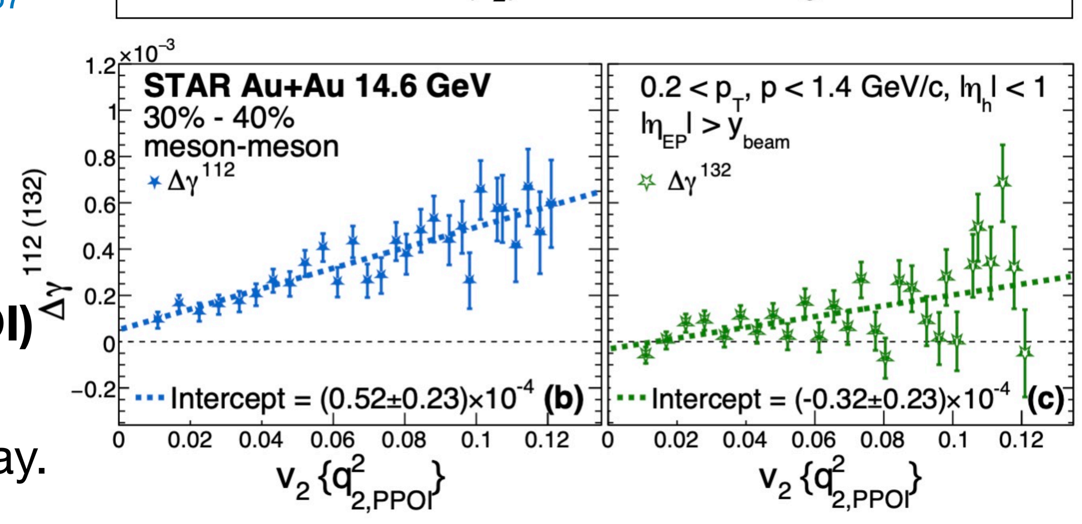
$$q_2^2 = \frac{(\sum_{i=1}^{N} \sin 2\varphi_i)^2 + (\sum_{i=1}^{N} \cos 2\varphi_i)^2}{N(1+N\langle v_2\rangle)}$$

2. Measure the Δγ & v₂

Optimal Solution

pair q_2 (PPOI) .... single v_2 (POI)

- Adding momenta of pair POI (PPOI) to mimic resonance decay.



3. Plot Δγ against v_2 to extrapolate intercept $\Delta\gamma^{112}_{\rm ESS}$

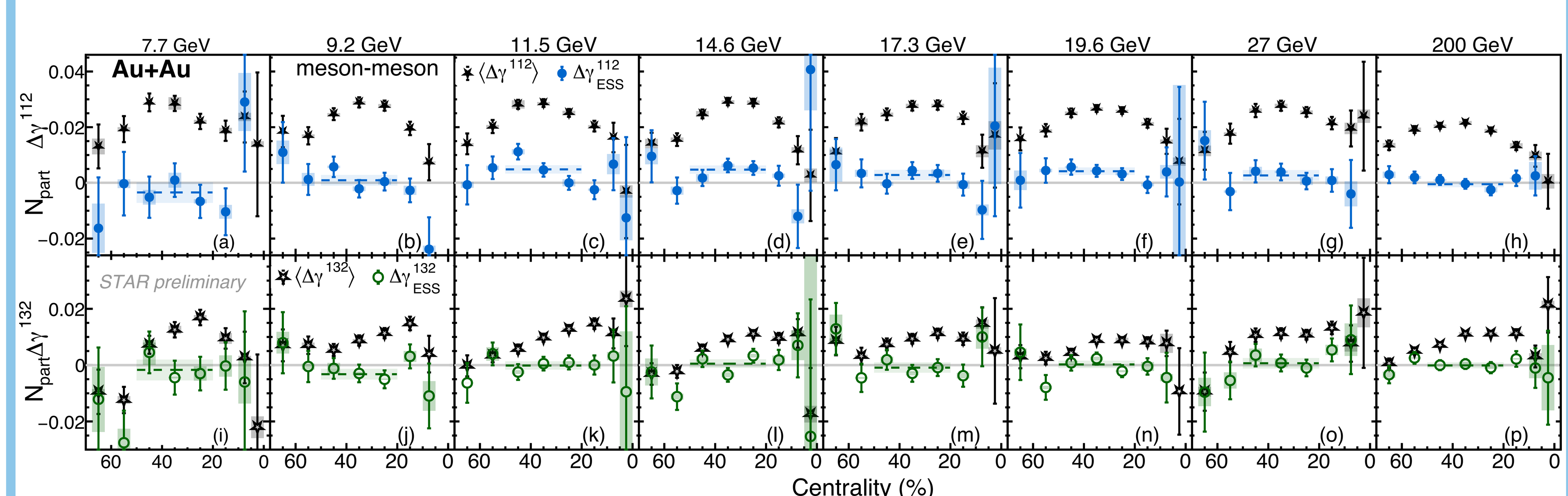
Event Shape Selection **Spectator Ψ_1**

$$\Delta\gamma^{112} = \underbrace{\Delta\gamma^{\rm CME}}_{\text{Signal}} + \underbrace{\cancel{k\frac{v_2}{N}}}_{\text{Background}} + \cancel{\Delta\gamma^{\rm nonflow}}$$

$\boxed{\Delta\gamma^{112}_{\rm ESS} = Intercept \times (1-v_2)^2}$ *Non-interdependent Flow, Z.Xu et al Phys. Rev. C 107, L061902*

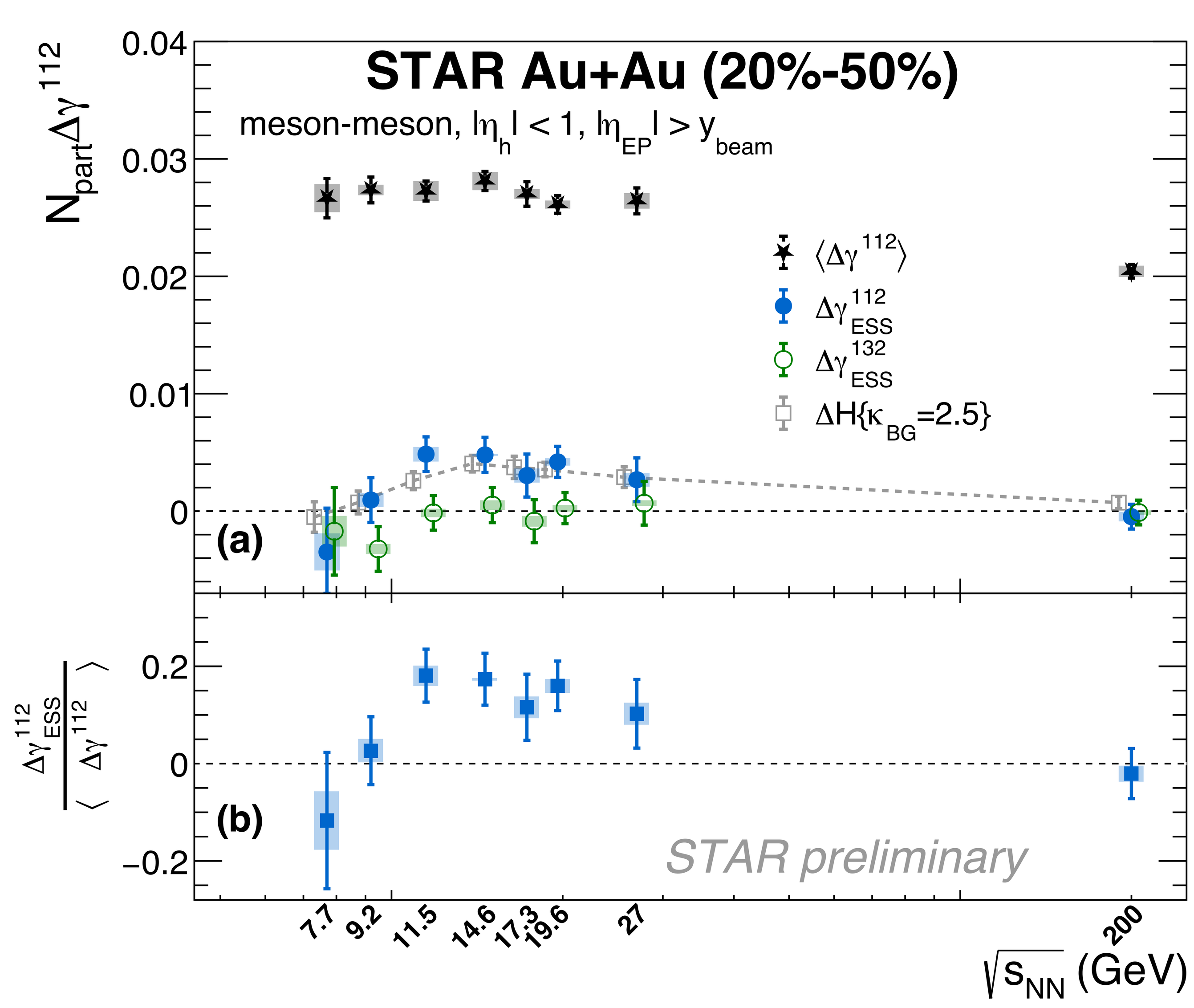
- Nonflow background removal: spectator Ψ_1
  - Short range nonflow: large eta gap between TPC POI and spectators
  - Momentum conservation: using spectators from west and east sides.
- Flow background removal: The ESS technique extrapolates an observable to isotropic emission, characterized by zero elliptic flow (v_2).

Beam Energy Scan-II results



- $\Delta\gamma^{132}_{\rm ESS}$ is consistent with zero at all energies. —> effectiveness of flow background suppression with ESS and nonflow background removal with the spectator plane.
- Combining points between 10-20 GeV, $N_{part}\Delta\gamma^{112}_{\rm ESS}$ is [4.26±0.71(stat.)±0.21(syst.)]×10⁻³, with **5.7σ** significance (assuming similar physics conditions between 10 and 20 GeV).
- The ESS method identifies that at least 80% of $<\Delta\gamma^{112}>$ is from the flow-related background.

√sNN (GeV)	Significance
7.7	Consistent with 0
9.2	Consistent with 0
11.5	3σ
14.6	3.1σ
17.3	1.6σ
19.6	3.5σ
27	1.3σ
200	Consistent with 0



Summary

- The search for the CME in heavy-ion collision probes the intrinsic properties of QCD.
- STAR latest CME searches use the novel Event Shape Selection to effectively suppress flow-related backgrounds.
  - Below $\sqrt{s_{NN}}$ = 10 GeV and at 200 GeV, the charge separation is consistent with zero.
  - At each of 11.5, 14.6 and 19.6 GeV, a positively finite $\Delta\gamma^{112}_{\rm ESS}$ (>3σ) is observed at mid-centrality where we expect a magnetic field.

Acknowledgements

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