An event-shape-engineering method to study charge separation in heavy-ion collisions

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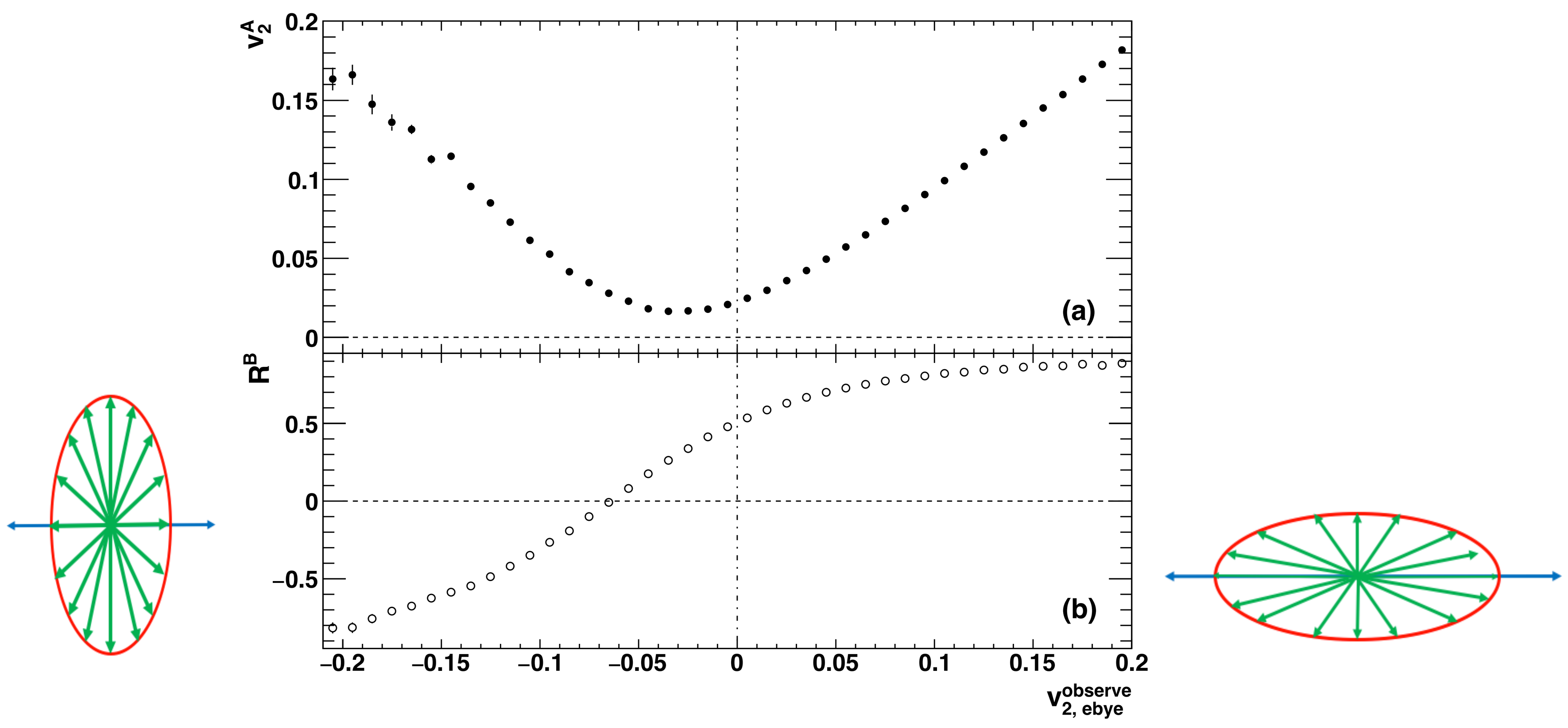
Abstract

Recent measurements of charge-dependent azimuthal correlations in high-energy heavy-ion collisions at RHIC and the LHC have indicated charge-separation signals perpendicular to the reaction plane, and have been related to the chiral magnetic effect (CME) (see a review in Ref [1]). The discovery of this phenomenon in heavy-ion collisions will signify simultaneously three important physics ingredients: the strongest magnetic field ever made by mankind, the chirality imbalance caused by vacuum transition, and the chiral symmetry restoration in the deconfined nuclear matter. However, the correlation signal is contaminated with the background driven by the elliptic flow (v_2) of the collision system [2], and an effective approach is needed to remove the flow background from the correlation. In this poster, we disclose a few shortcomings of a previous attempt of the event shape engineering (ESE) based on the "event-by-event v_2" [3]. We will further present a novel ESE technique [4] utilizing the magnitude of the flow vector to select spherical events in heavy-ion collisions, which leaves the charge separation measurements free of flow contributions. The simplified Monte Carlo simulations and a multi-phase transport model (AMPT) are employed to develop the ESE scheme to reveal the true CME signals from the experimental observation. Caveats regarding artificial effects and extreme conditions in this method will also be discussed.

Why we need event-shape enginnering?

- Searches for chiral effects induced charge separation signal have been a hot topic in recent experimental study of heavy ion collisions
- The widely used observable [5], $\gamma = \left\langle \left\langle \cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP}) \right\rangle_p \right\rangle_E$, is contaminated with the v_2-related background:
  - Decays of resonance
  - Transverse Momentum Conservation (TMC)
  - Local Charge Conservation (LCC)
- Flow-related background can be eliminated by using event-shape engineering to select spherical events or sub-events ($v_2 = 0$).
- A better approach is needed to obtain spherical events rather than using event-by-event v_2.

Why event-by-event v_2 fails?



- Event is split into two sub-events (A and B) to evaluate v_2 and event-plane orientation.
- Simplified Monte Carlo simulations (TMC, LCC and resonance decay not implemented) show the true elliptic flow v_2^A doesn't go to zero as the observed $v_{2,ebye}^{observe}$ vanishes.
- The event-plane resolution R^B becomes negative as the $v_{2,ebye}^{observe}$ goes to negative, which makes $v_2^A = v_{2,ebye}^{observe}/R^B$ invalid.

A better handle on event shape

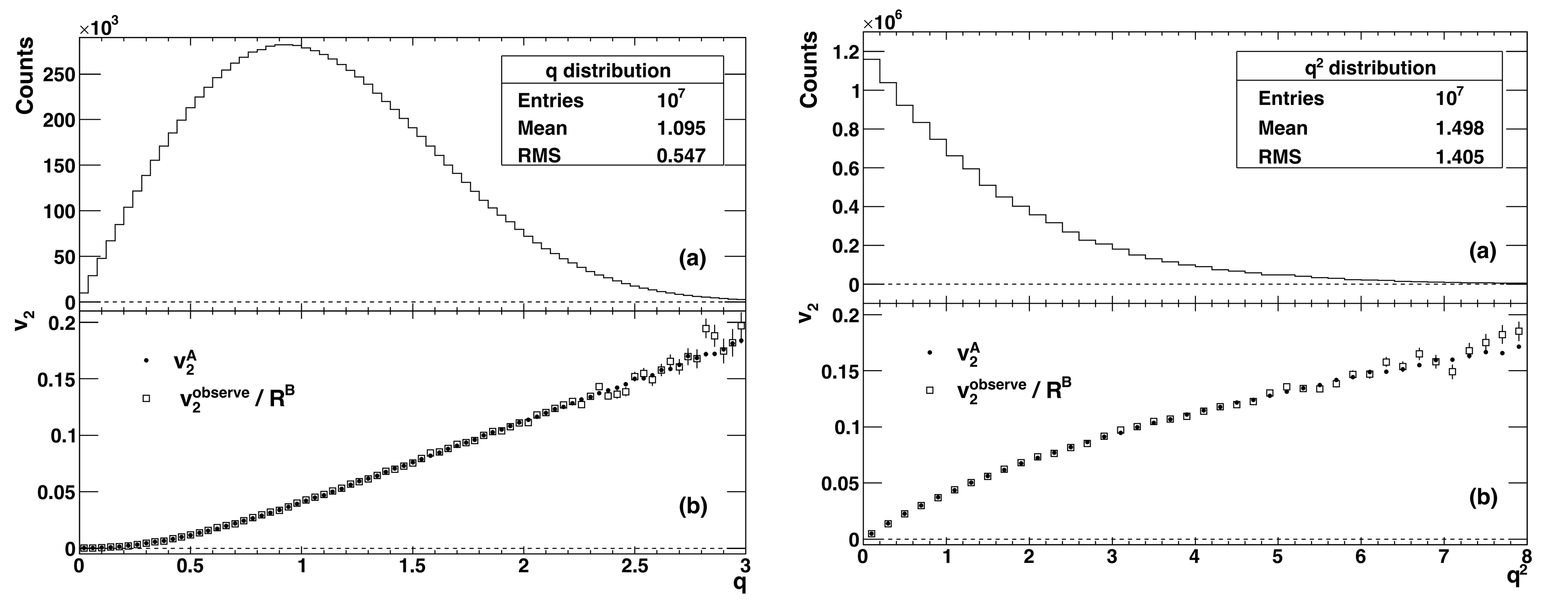
- Criteria of a good handle on event shape:
  - Truly reflect the ellipticity of the particles of interest.
  - Flow background vanishes as the event-shape handle is turned to flow-off mode.
  - No significant artificial background induced in event selection by turning event handle.
- Flow vector $\vec{q} = (q_x, q_y)$:

$$q_x = \frac{1}{\sqrt{N}} \sum_i^N \cos(2\phi_i)$$

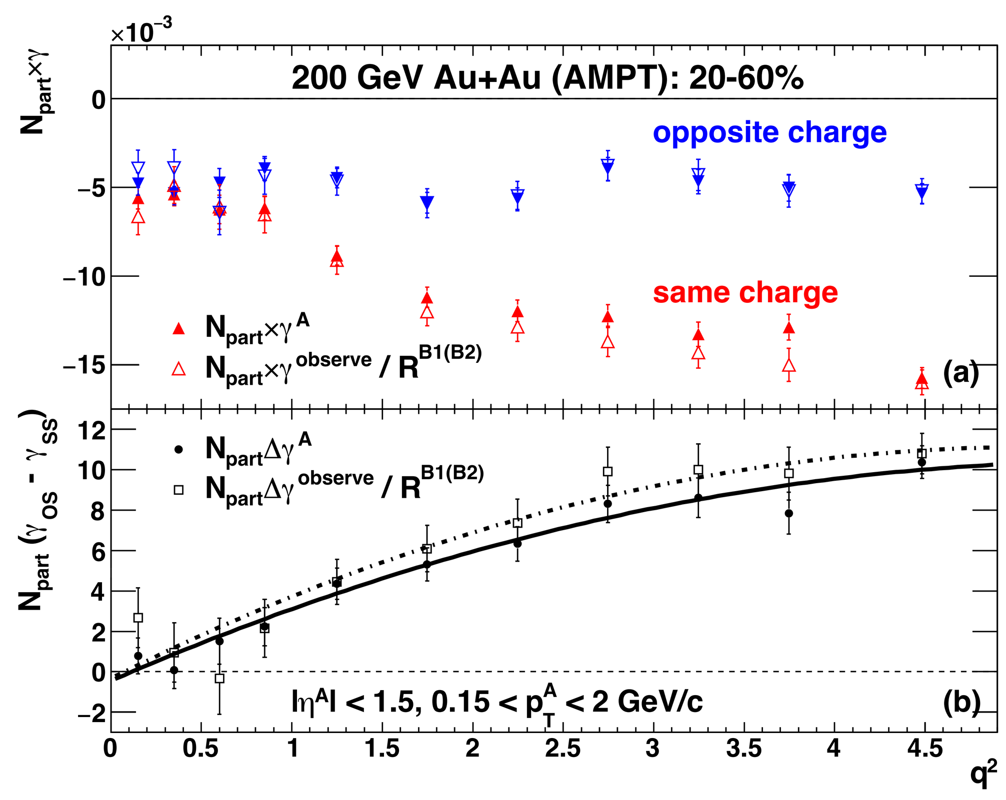
$$q_y = \frac{1}{\sqrt{N}} \sum_i^N \sin(2\phi_i)$$

- The handle of our choice: $q^2 = |\vec{q}|^2$
  - $q^2 = 0$ implies $q = |\vec{q}| = 0$, which makes it capable of selecting spherical sub-events in terms of the second harmonic.

- A close-to-linear relationship between $v_2^{observe}/R^B$ and q^2 is observed in Monte Carlo simulation, which makes it more reliable to project γ to $q^2 = 0$.
- Comparing with q, high statistics in low q^2 makes it more statistically robust to project γ to zero q^2.

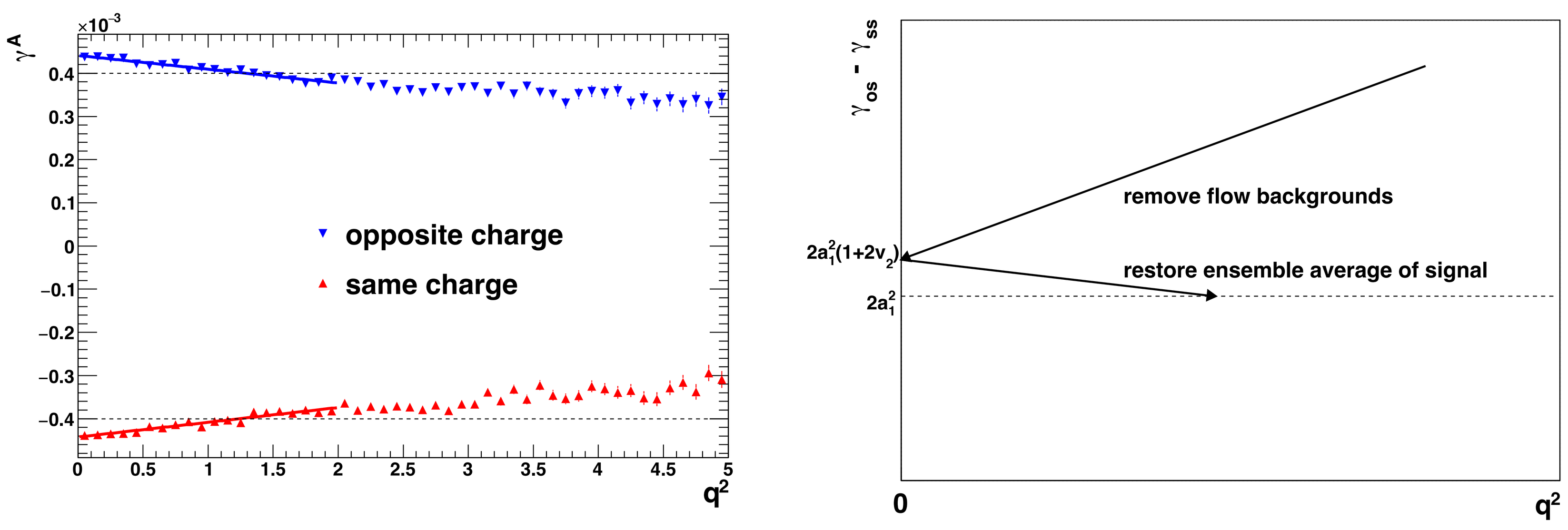


More realistic simulations…



- AMPT[6,7] (a realistic event generator, no CME implemented) is used to generate 200 GeV Au+Au collision events.
- At large q^2, the finite difference between opposite charge and same charge correlators indicates a finite flow-related background.
- The backgroun vanishes as q^2 goes to zero.

How to apply it in experiment data analyses?



- Monte Carlo simulation shows at zero q^2, the projected γ is larger than the input γ by a factor of $2v_2$
- Three steps to experimentally reveal the true CME signal:
  - Compute q^2 handle
  - Remove flow background by projecting signal to zero q^2
  - The event-ensemble-avergaed CME is restored from $\Delta\gamma_{ebye}|_{q^2=0}/(1 + 2v_2)$

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