Event-by-event correlations between Λ ($\bar{\Lambda}$) spin polarization and CME observables in Au+Au collisions at $\sqrt{s_{\rm NN}} = 27$ GeV from STAR

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2023 RHIC/AGS ANNUAL USERS' MEETING

CELEBRATING NEW BEGINNINGS AT RHIC and EIC

August 1-4, 2023

Abstract

Phys.Rev.C 108,(2023)014909

Global polarizations (P) of Λ ($\bar{\Lambda}$) hyperons have been observed in non-central heavy-ion collisions. The strong magnetic field primarily created by the spectator protons in such collisions would split the Λ and $\bar{\Lambda}$ global polarizations ($\Delta P = P_\Lambda - P_{\bar{\Lambda}} < 0$). Additionally, quantum chromodynamics (QCD) predicts topological charge fluctuations in vacuum, resulting in a chirality imbalance or parity violation in a local domain. This would give rise to an imbalance ($\Delta n = \frac{N_L - N_R}{\langle N_L + N_R \rangle} \neq 0$) between left- and right-handed Λ ($\bar{\Lambda}$) as well as a charge separation along the magnetic field, referred to as the chiral magnetic effect (CME). This charge separation can be characterized by the parity-even azimuthal correlator ($\Delta\gamma$) and parity-odd azimuthal harmonic observable (Δa_1). Measurements of ΔP, $\Delta\gamma$, and Δa_1 have not led to definitive conclusions concerning the CME or the magnetic field, and Δn has not been measured previously. Correlations among these observables may reveal new insights. This poster reports measurements of correlation between Δn and Δa_1, which is sensitive to chirality fluctuations, and correlation between ΔP and $\Delta\gamma$ sensitive to magnetic field in Au+Au collisions at 27 GeV. For both measurements, no correlations have been observed beyond statistical fluctuations.

1. Chiral Magnetic Effect (CME) and Relevant Observables

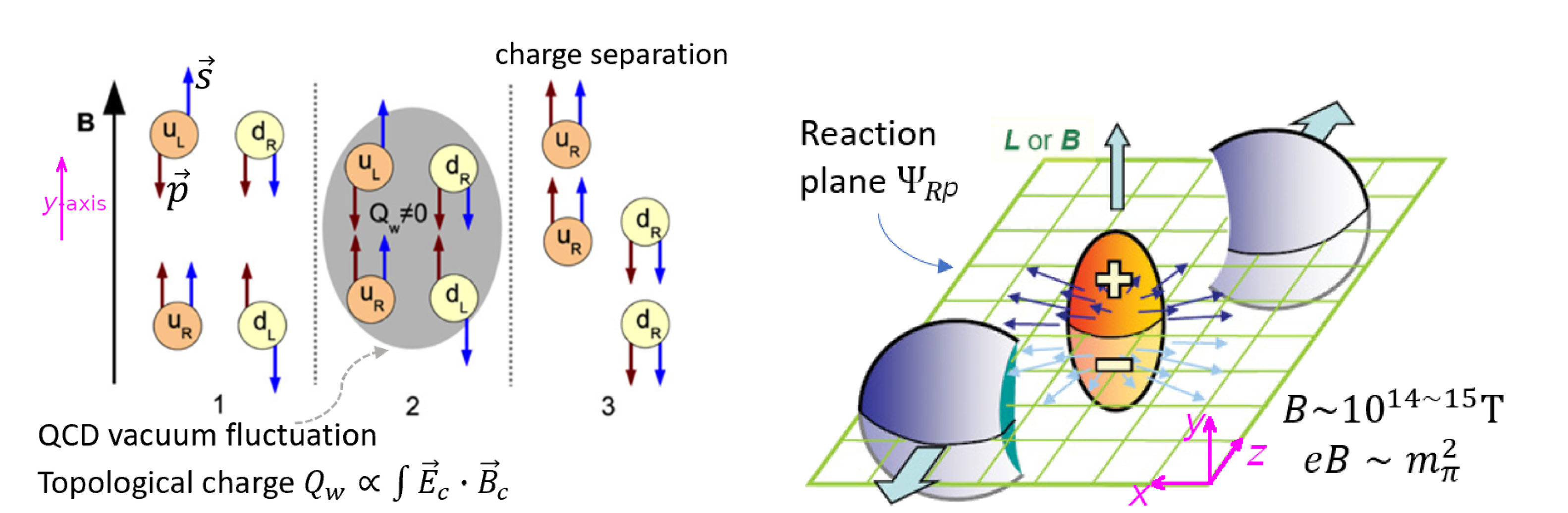

Figure 1: CME schematics [1]

Azimuthal correlators to measure CME

- Parity-odd Δa_1 observable: $\Delta a_1 \equiv \langle \sin(\phi^+ - \Psi_{\rm RP})\rangle - \langle \sin(\phi^- - \Psi_{\rm RP})\rangle$, where the superscripts $\pm$ stand for the charge sign. Random topological charges from event to event $\rightarrow$ $\langle \Delta a_1 \rangle$ vanishes.
- Parity-even $\Delta\gamma$ observable: $\gamma_{\rm OS} \equiv \langle \cos(\phi_\alpha^\pm + \phi_\beta^\mp - 2\Psi_{\rm RP})\rangle$, $\gamma_{\rm SS} \equiv \langle \cos(\phi_\alpha^\pm + \phi_\beta^\pm - 2\Psi_{\rm RP})\rangle$, $\Delta\gamma \equiv \gamma_{\rm OS} - \gamma_{\rm SS}$. The subscript OS stands for opposite-sign pair and SS for same-sign pair. $\Delta\gamma$ contains CME and a major background proportional to v_2.
- "RP" stands for reaction plane, spanned by beam direction and impact parameter. This study use the Event Plane Detector to assess it.

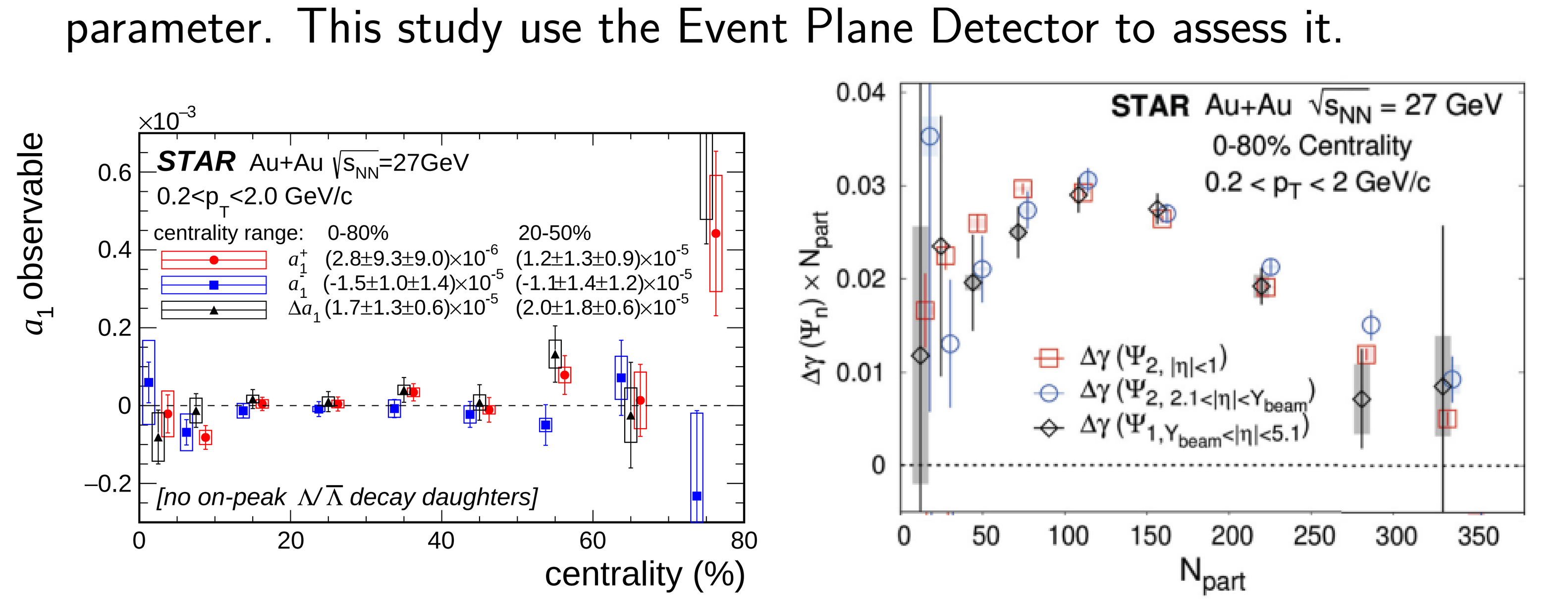

Figure 2: STAR measurements of Δa_1 [2] and $\Delta\gamma$ [3] of Run18 Au+Au 27 GeV.

2. Λ ($\bar{\Lambda}$) Measurements

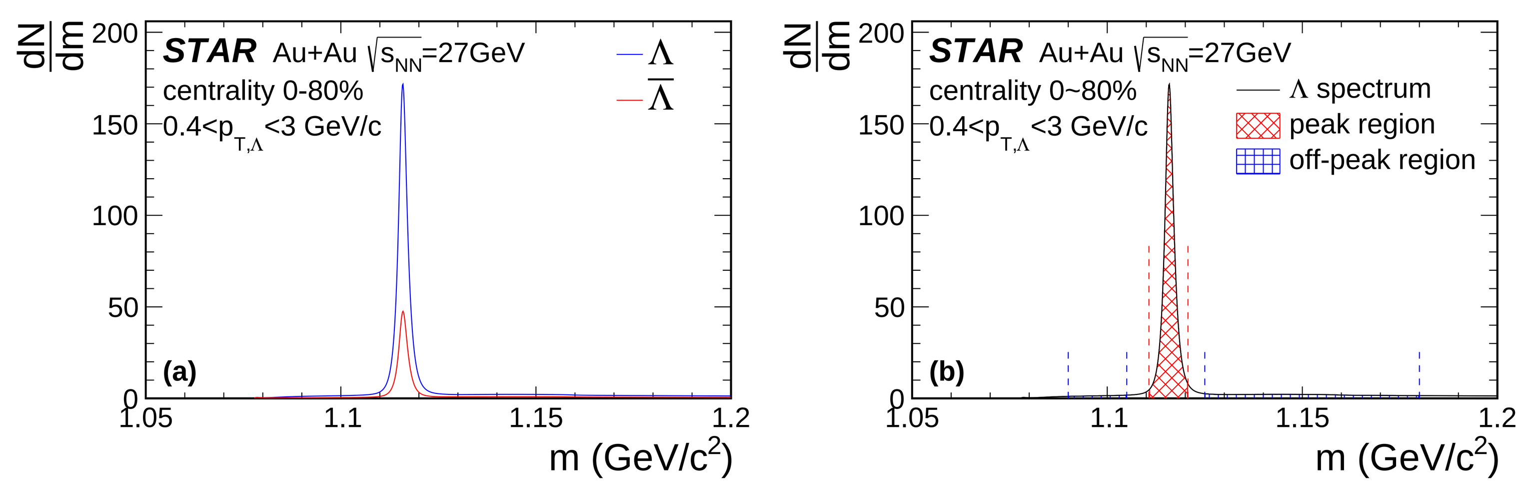

Figure 3: The invariant mass distribution of the reconstructed Λ in Run18 Au+Au 27GeV.

- KFParticle package is used to reconstruct Λ from its decays $\Lambda \rightarrow p\pi^-$.
- The peak region contains residual backgrounds, and the off-peak region is used for background subtraction.

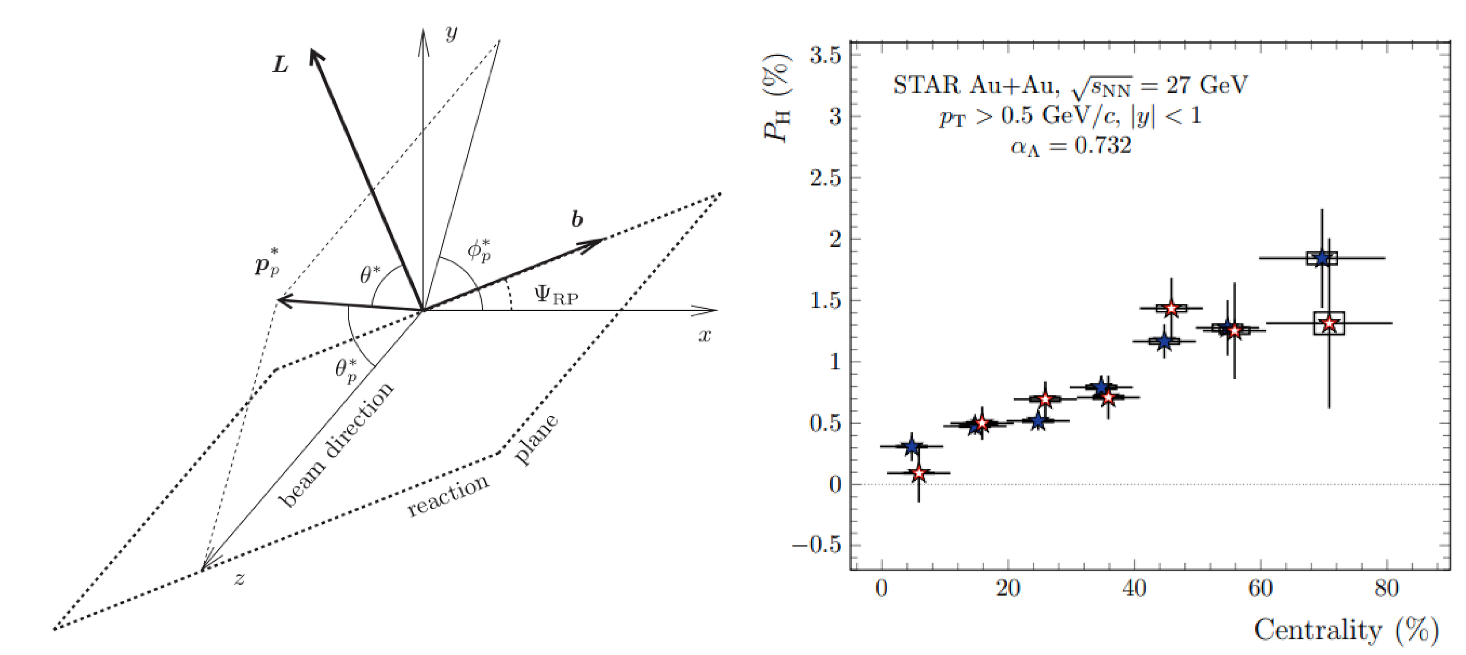

Figure 4: Λ polarization geometry [4] and STAR measurement [5] of Run18 Au+Au 27GeV.

- The polarization of Λ can be measured from the distribution of decay daughter protons w.r.t. RP. $P_\Lambda = \frac{-8}{\pi\alpha_\Lambda}\langle \sin(\phi_p^* - \Psi_{\rm RP})\rangle$, where ϕ_p^* is the decay daughter proton's momentum azimuthal angle in the rest frame of Λ.
- Purity correction (S, B are the signal and background in the peak region) $\langle \sin(\phi_p^* - \Psi_{\rm RP})\rangle = \frac{S+B}{S}\langle \sin(\phi_p^* - \Psi_{\rm RP})\rangle_{\rm peak} - \frac{B}{S}\langle \sin(\phi_p^* - \Psi_{\rm RP})\rangle_{\text{off-peak}}$,

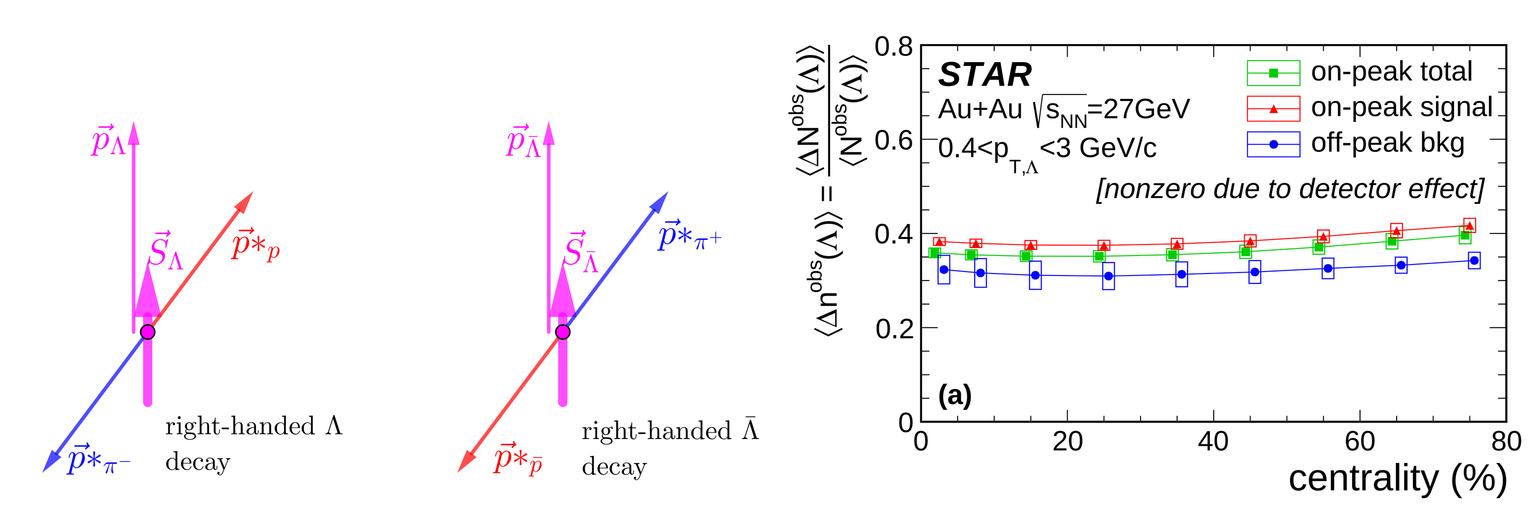

Figure 5: Λ handedness imbalance schematics and measurement of Run18 Au+Au 27GeV.

- $\vec{p}_p^* \cdot \vec{p}_\Lambda < 0 \Rightarrow \Lambda_L$: "left-handed" ; $\vec{p}_p^* \cdot \vec{p}_\Lambda > 0 \Rightarrow \Lambda_R$: "right-handed" . $\vec{p}_{\bar{p}}^* \cdot \vec{p}_{\bar{\Lambda}} < 0 \Rightarrow \bar{\Lambda}_R$: "right-handed" ; $\vec{p}_{\bar{p}}^* \cdot \vec{p}_{\bar{\Lambda}} > 0 \Rightarrow \bar{\Lambda}_L$: "left-handed" .
- The "observed" handedness imbalance is defined $\Delta n^{\rm obs} \equiv \frac{N_L^{\rm obs} - N_R^{\rm obs}}{\langle N_L^{\rm obs} + N_R^{\rm obs}\rangle}$. The nonzero value comes from the detector effect, but does not contribute in correlation measurements. (e.g., $\Lambda_L \Rightarrow \vec{p}_{\pi^-}^* \cdot \vec{p}_\Lambda > 0 \xrightarrow{\rm boost} \vec{p}_{\pi^-} \uparrow \Rightarrow$ eff.$\uparrow$)

3. Event-by-event Correlations

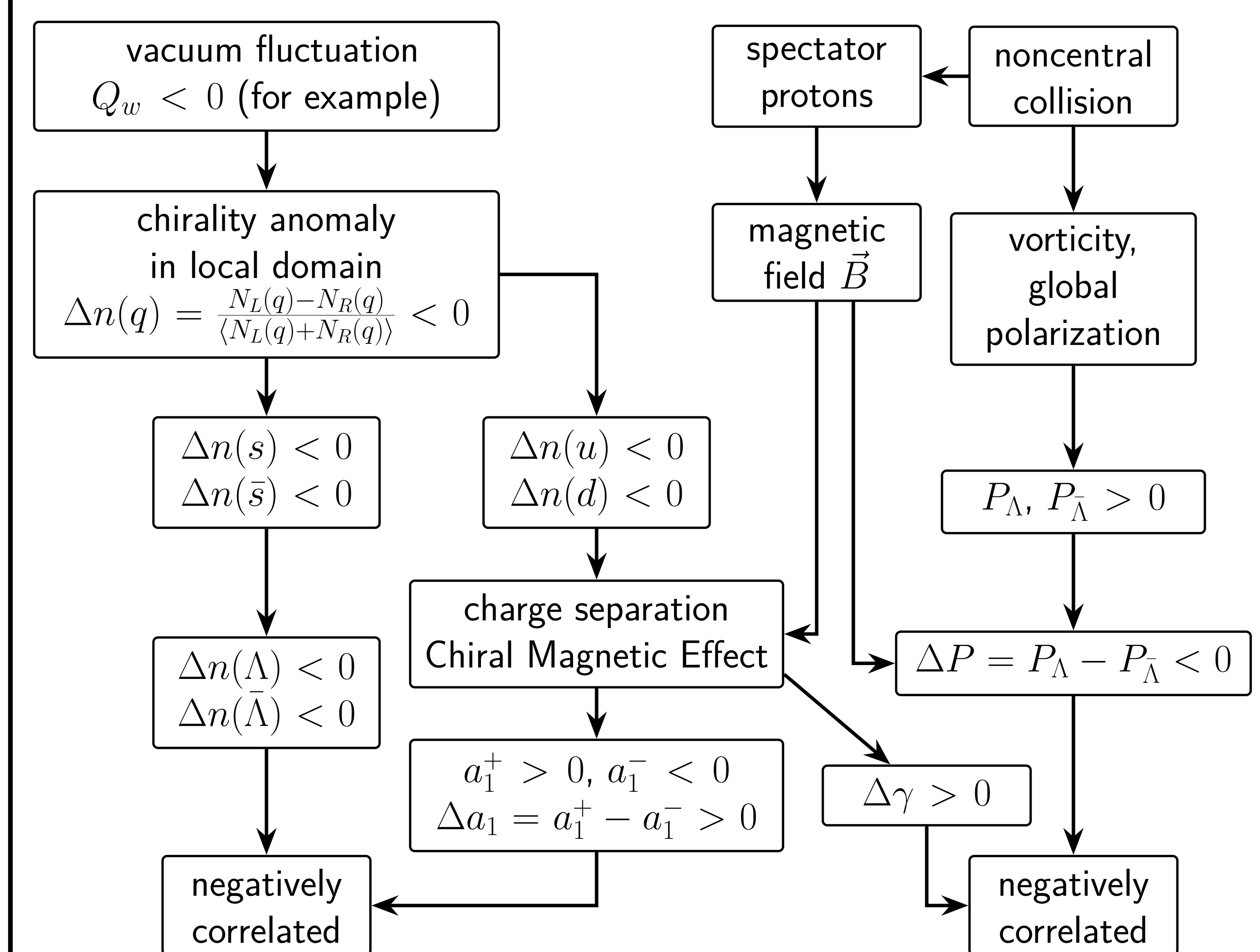

Figure 6: The physics underlying the correlation measurements.

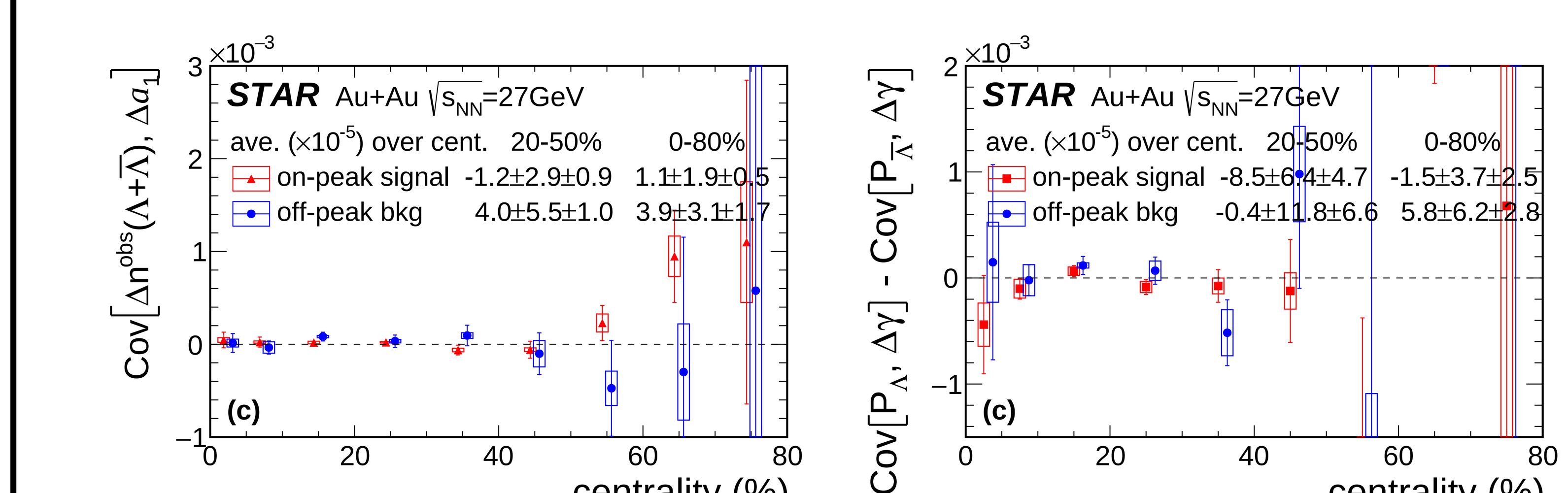

Figure 7: The event-by-even covariance between parity-odd observables Δn vs. Δa_1, and between parity-even observables ΔP vs. $\Delta\gamma$.

Summary

- We calculate those individual quantities ($\Delta\gamma$, Δa_1, ΔP, Δn) from each event, and then use covariances to quantify the correlations $\text{Cov}[X,Y] = \langle (X - \langle X\rangle)(Y - \langle Y\rangle)\rangle = \langle XY\rangle - \langle X\rangle\langle Y\rangle$.
- Though the individual parity-odd quantities (Δn, Δa_1) vanish in event average, their covariance can still be nontrivial.
- Since the backgrounds in different quantities come from uncorrelated sources, they do not contribute to the covariances.
- For both measurements, no correlations have been observed beyond statistical fluctuations.

References

[1] D. E. Kharzeev, L. D. McLerran, and H. J. Warringa, *Nucl. Phys. A*, vol. 803, pp. 227–253, 2008.
[2] M. I. Abdulhamid *et al.*, *Phys. Rev. C*, vol. 108, p. 014 909, 2023. arXiv: 2304.10037 [nucl-ex].
[3] B. Aboona *et al.*, *Phys. Lett. B*, vol. 839, p. 137 779, 2023. arXiv: 2209.03467 [nucl-ex].
[4] B. I. Abelev *et al.*, *Phys. Rev. C*, vol. 76, p. 024 915, 2007. arXiv: 0705.1691 [nucl-ex].
[5] STAR,, 2023. arXiv: 2305.08705 [nucl-ex].

Supported in part by the U.S. DEPARTMENT OF ENERGY Office of Science

The STAR Collaboration, https://drupal.star.bnl.gov/STAR/presentations