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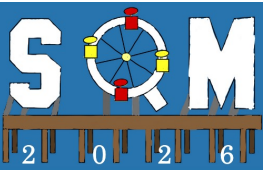

Measurements of Local Polarization of Λ Hyperons with Event Shape Engineering in Au+Au collisions at RHIC-STAR

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for the STAR Collaboration

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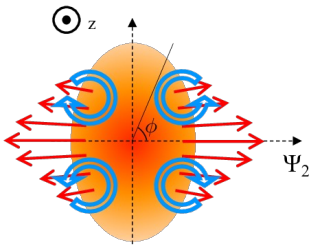
Physics motivation

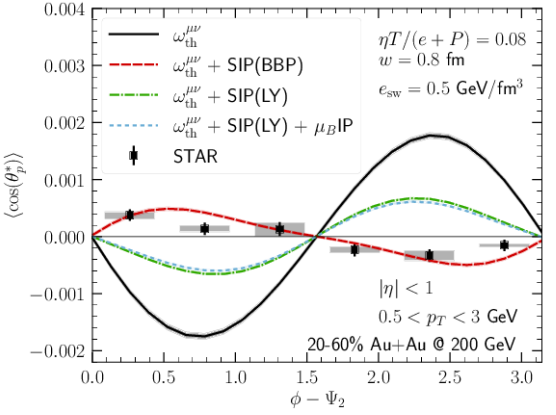
- Local polarization
  - Anisotropic flow is expected to generate local vorticities along the beam direction.
    → Leads to particle polarization



STAR, PRL131, 202301 (2023)

- Spin puzzle
  - Current theoretical models cannot completely explain data observed at RHIC and the LHC.
  - Some models suggest that local polarization may originate from mechanisms other than the kinematic vorticity.

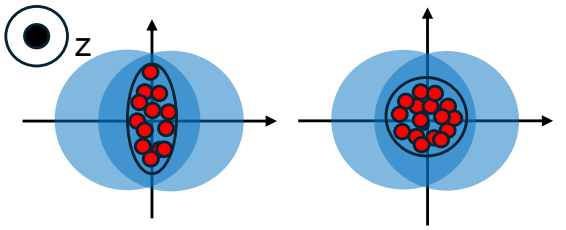
Wu et al., PRR1, 033058 (2019)
Fu et al., PRC103, 024903 (2021)



Alzhrani et al., PRC106, 014905 (2022)

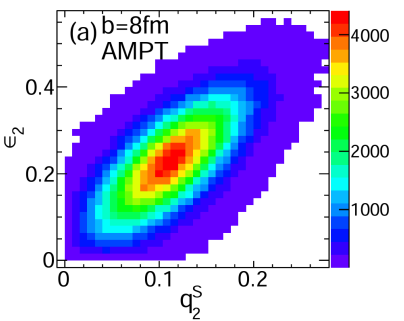
Physics motivation

- Event Shape Engineering (ESE)
  - A method to select events with different magnitudes of final-state flow within a narrow centrality range.
  - Enables separating the difference of initial geometry.

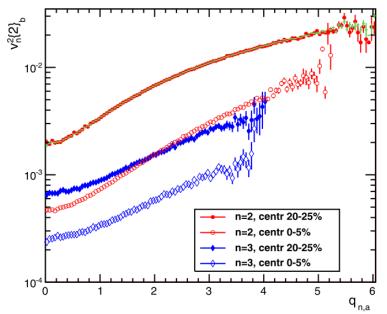


- We measured elliptic flow and local polarization of Λ with ESE in $\sqrt{s_{\mathrm{NN}}}$ = 19.6 GeV Au+Au collisions.
- Our goal is to experimentally reveal the link among the initial geometry, elliptic flow, and local polarization.

Initial eccentricity ϵ_2 or v_2 vs. flow vector q_2

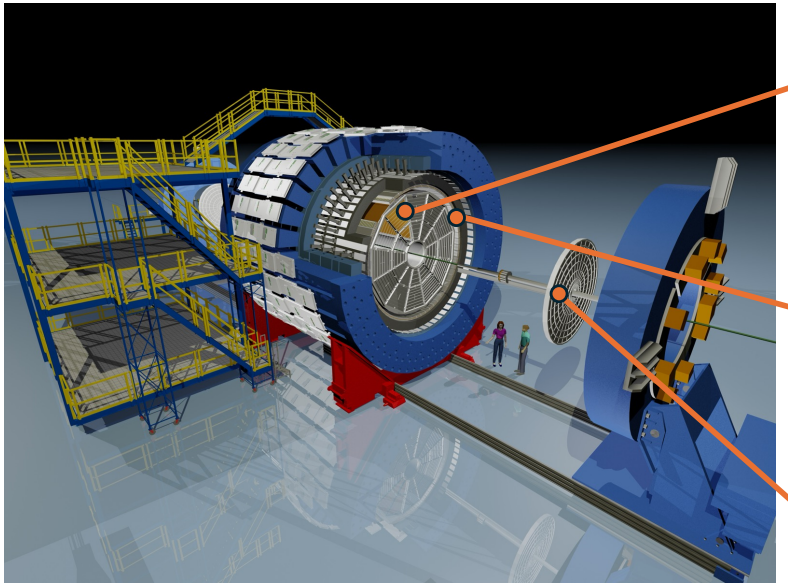


Huo et al., PRC90, 024910 (2014)



Schukraft et al., PLB719, 394 (2013)

The STAR detector



Sub-systems mainly used in this analysis:

Time Projection Chamber

- Reconstruction of charged-particle tracks
- PID utilizing ionization energy loss
- Wider acceptance by the iTPC upgrade ($|\eta| < 1.5$)

Time of Flight Detector

- Improved PID accuracy
- $|\eta| < 0.9$

Event Plane Detector

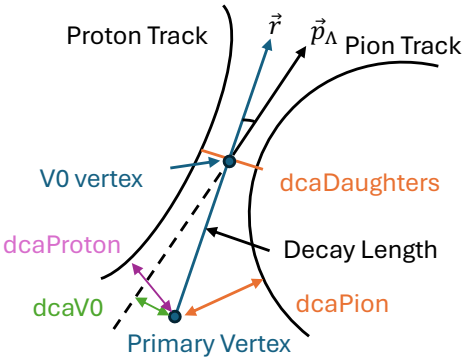
- Event plane determination
- $2.14 < |\eta| < 5.08$

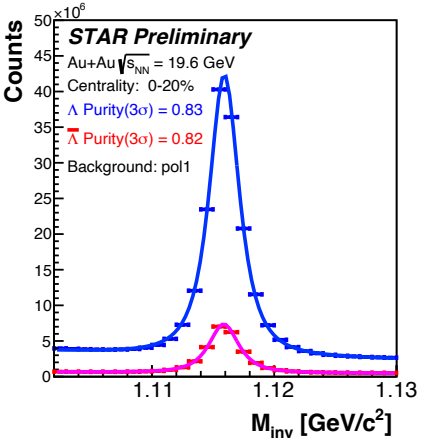
Λ reconstruction

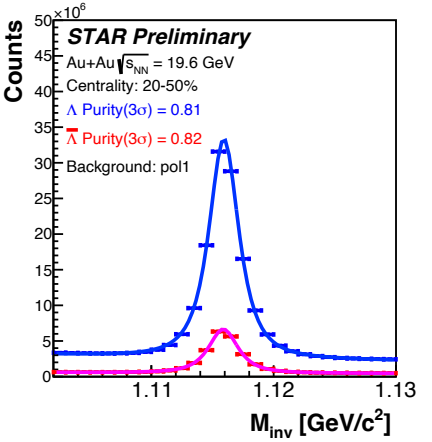
$$\Lambda \rightarrow p + \pi^-$$
$$\overline{\Lambda} \rightarrow \bar{p} + \pi^+$$

- PID using TPC and ToF information
- Λ reconstructed using decay topology
- Kinematic cuts for Λ
  - $|\eta_\Lambda| < 1.5$
  - $0.5 < (p_\Lambda)_T < 10.0$ GeV/c

- Fitted with Student's t-function to estimate purity
- Only daughter pairs within $\pm 3\sigma$ around the mean were selected for further analysis.

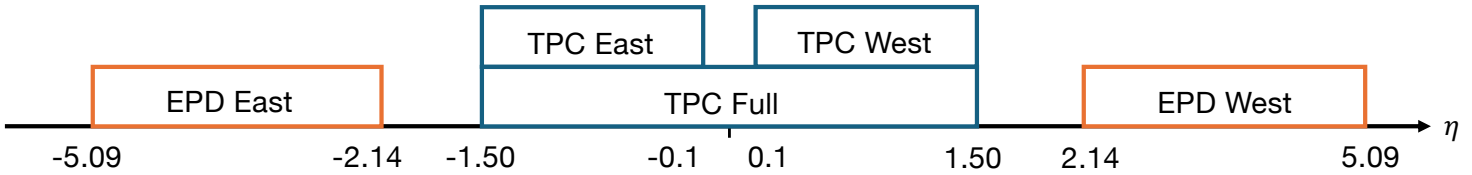






Event plane determination

Sub-events definition in this analysis:



- Track selection for TPC: $0.15 < p_{\mathrm{T}} < 2.0$ GeV/c
- For EPD: nMip ≥ 0.3

- Q-vector

$$Q_2^x = \sum_i \omega_i \cos(2\phi_i), \quad Q_2^y = \sum_i \omega_i \sin(2\phi_i)$$

- Event plane angle

$$\Psi_2 = \frac{1}{2}\arctan\left(\frac{Q_2^y}{Q_2^x}\right) \quad \text{where } \Psi_2 \in \left[-\frac{\pi}{2}, \frac{\pi}{2}\right]$$

nMip: number of minimum ionizing particles
ϕ_i: azimuthal angle of charged particles
$\omega_i = p_{\mathrm{T}}$ (for TPC), nMip (for EPD, if nMip>3, used 3)

Calibration: re-centering and flattening

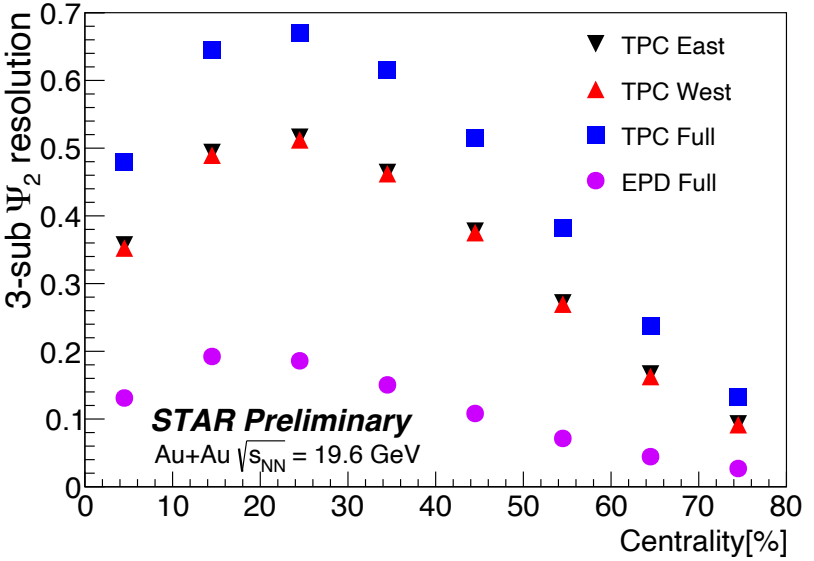
- Performed for each run number, z-vertex range (10 cm steps), and centrality range (10% steps)

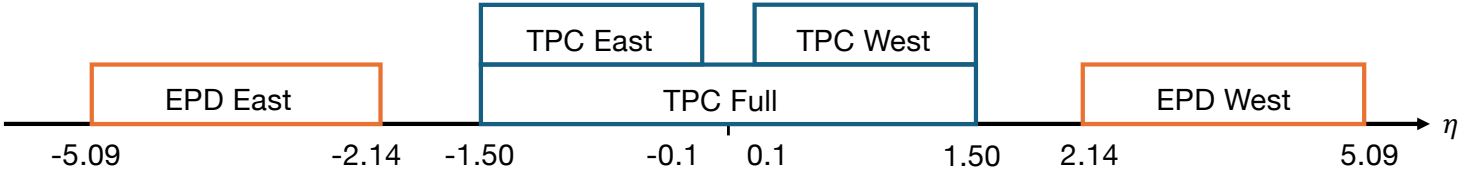
Event plane resolution

Event plane resolution by 3-sub event method:

$$Res\{\Psi_2^A\} = \sqrt{\frac{\langle \cos[2(\Psi_2^B - \Psi_2^A)] \rangle \langle \cos[2(\Psi_2^C - \Psi_2^A)] \rangle}{\langle \cos[2(\Psi_2^B - \Psi_2^C)] \rangle}}$$

A	B	C
TPC Full	EPD East	EPD West
TPC East (West)	EPD East	EPD West
EPD Full	TPC East	TPC West





Event Shape Engineering

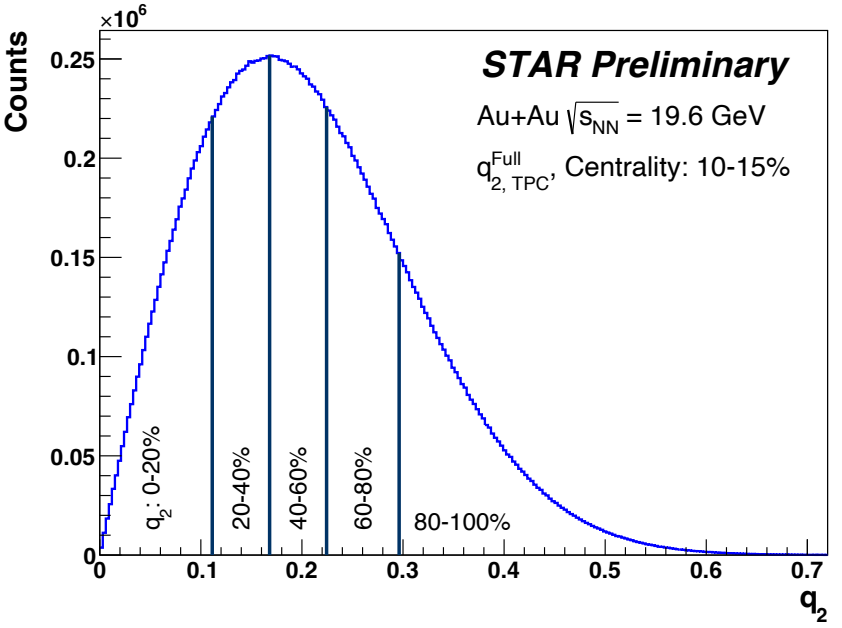
Based on q_2, events were divided into 5 classes with equal number of events (20% each)

Schukraft et al., PLB719, 394 (2013)

$$q_{2\ \mathrm{TPC}} = \frac{|\boldsymbol{Q}_2|}{\sqrt{\sum p_{\mathrm{T}}}}$$

To avoid multiplicity bias in event-shape selection, q_2 selection was performed in narrow centrality (and multiplicity) bins:

- Centrality 10-80%: 5% steps
- For 0-5% and 5-10%: Events were further divided into 4 groups based on measured multiplicity, and then q_2 selection was applied to each group.



Measurements of v_2 and $P_{z,2}$ with ESE

$$v_2 = \frac{\langle \cos[2(\phi_\Lambda - \Psi_2)] \rangle}{Res\{\Psi_2\}}$$

$$\mathrm{P}_{z,2} = \frac{1}{\alpha_\Lambda \langle \cos^2 \theta_p^* \rangle} \frac{\langle \cos\theta_p^* \sin(2(\phi_\Lambda - \Psi_2)) \rangle}{Res\{\Psi_2\}}$$

α_Λ: Λ decay parameter $\alpha_\Lambda = -\alpha_{\bar{\Lambda}} = 0.747 \pm 0.010$
θ_p^*: polar angle of the daughter proton in Λ rest frame
ϕ_Λ: azimuthal angle of Λ particle

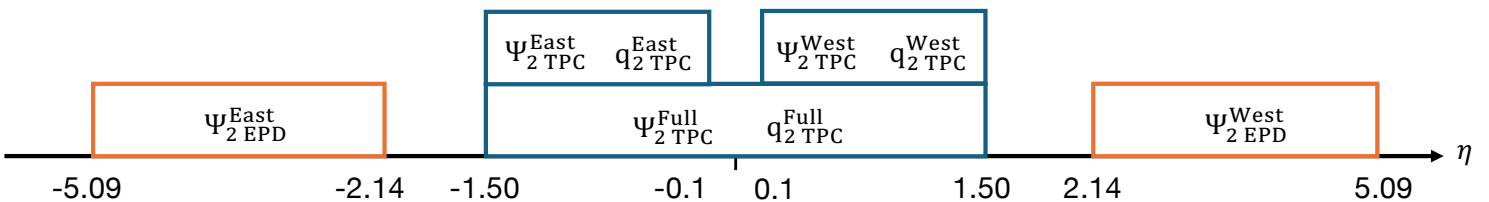
To study possible event bias, v_2 and $P_{z,2}$ of Λ measured with:

1. $\Psi_{2\ \mathrm{TPC}}^{\mathrm{Sub}}$ and $\mathrm{q}_{2\ \mathrm{TPC}}^{\mathrm{Sub}}$ (if $\eta_\Lambda > 0$, used $\Psi_{2\ \mathrm{TPC}}^{\mathrm{East}}$ and $\mathrm{q}_{2\ \mathrm{TPC}}^{\mathrm{East}}$)
2. $\Psi_{2\ \mathrm{TPC}}^{\mathrm{Full}}$ and $\mathrm{q}_{2\ \mathrm{TPC}}^{\mathrm{Full}}$
3. $\Psi_{2\ \mathrm{EPD}}^{\mathrm{Full}}$ and $\mathrm{q}_{2\ \mathrm{TPC}}^{\mathrm{Sub}}$ (if $\eta_\Lambda > 0$, used $\mathrm{q}_{2\ \mathrm{TPC}}^{\mathrm{East}}$)
4. $\Psi_{2\ \mathrm{EPD}}^{\mathrm{Full}}$ and $\mathrm{q}_{2\ \mathrm{TPC}}^{\mathrm{Full}}$

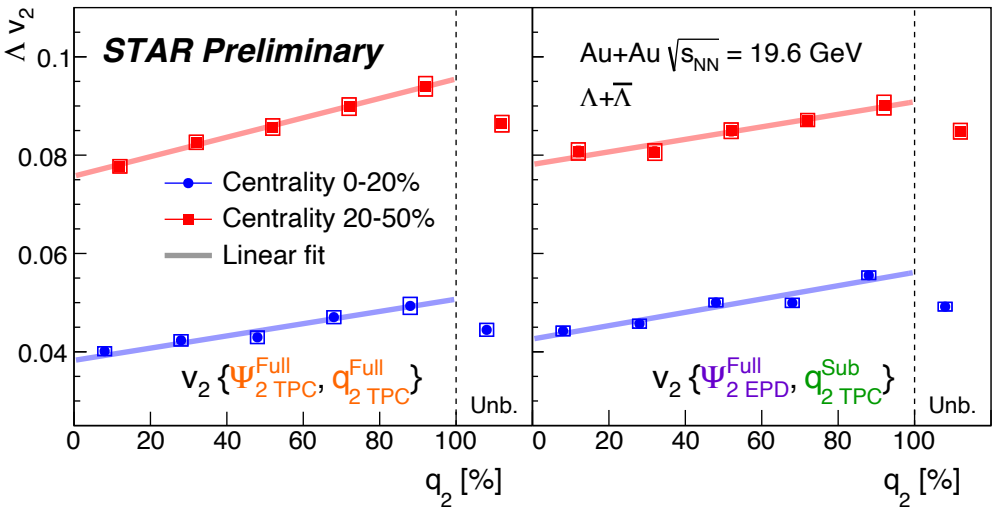
Purity correction

$$v_2^{\mathrm{Obs}} = \mathrm{Purity} \times v_2^{\mathrm{Sig}} + (1 - \mathrm{Purity}) \times v_2^{\mathrm{Bkg}}$$

Daughter tracks were removed from Ψ_2 and q_2 calculations to avoid self-correlation.



q_2 dependence of v_2

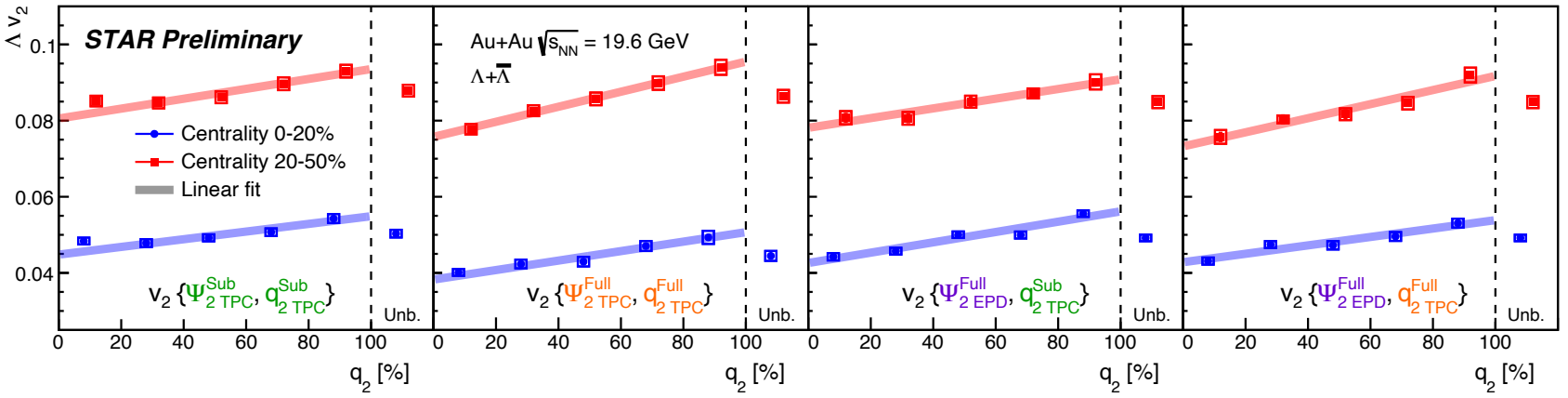


Left: $\Psi^{\mathrm{Full}}_{2\ \mathrm{TPC}}$ and $q^{\mathrm{Full}}_{2\ \mathrm{TPC}}$

Right: $\Psi^{\mathrm{Full}}_{2\ \mathrm{EPD}}$ and $q^{\mathrm{Sub}}_{2\ \mathrm{TPC}}$ (if $\eta_\Lambda > 0$, used $q^{\mathrm{East}}_{2\ \mathrm{TPC}}$)

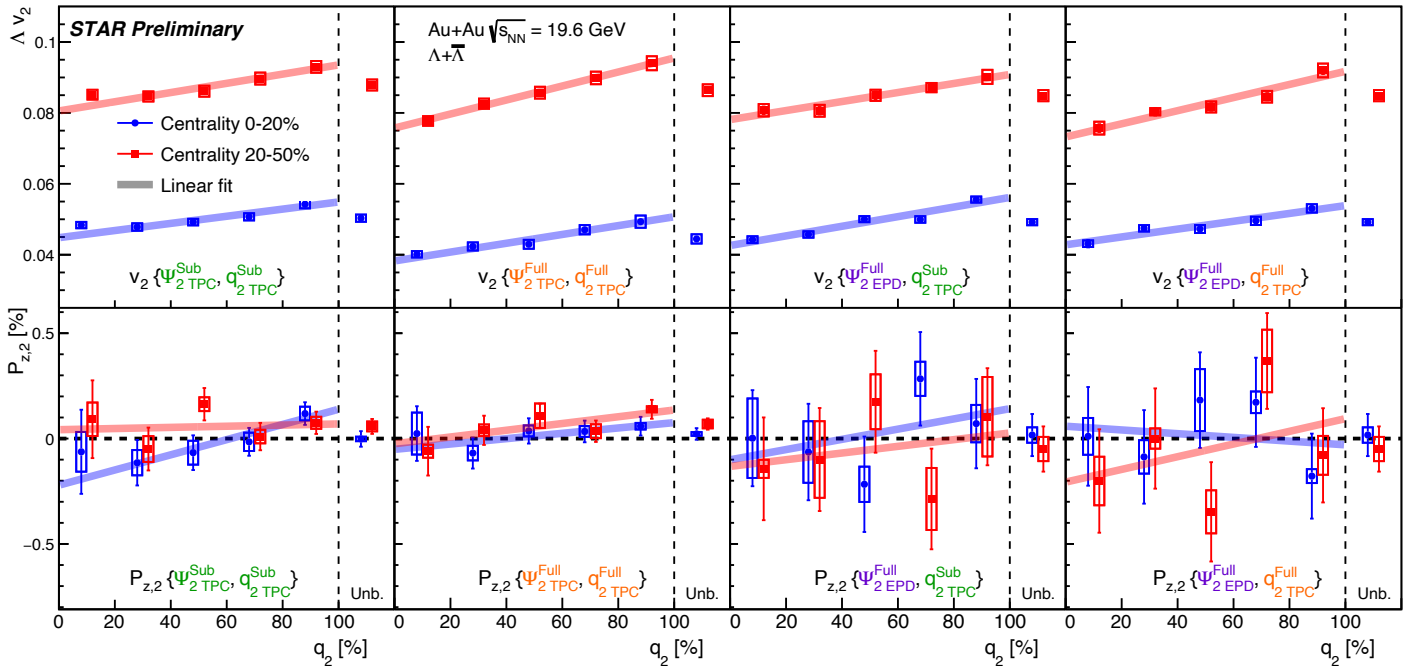
- Λ v_2 changes with q_2 of charged particles by about 20%.
- Specifically ($\Psi^{\mathrm{Full}}_{2\ \mathrm{EPD}}$, $q^{\mathrm{Sub}}_{2\ \mathrm{TPC}}$) is clean combination as it uses separate η regions for Ψ_2 , q_2, and v_2.
- The trends for 2 combinations are consistent with each other
- Note: q_2 event selection and non-flow effect are different for the two cases.

q_2 dependence of v_2



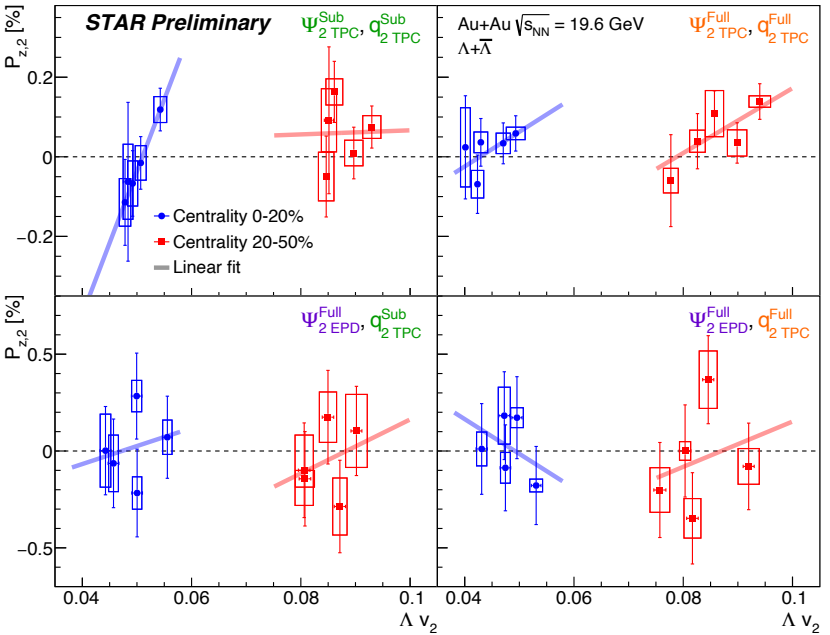
- v_2 shows a clear q_2 dependence for all the (Ψ_2, q_2) combinations.
- The v_2 results are consistent across all combinations.
- Given this consistency, the combination ($\Psi^{\mathrm{Full}}_{2\ \mathrm{TPC}}$, $q^{\mathrm{Full}}_{2\ \mathrm{TPC}}$) is a better measurement owing to its highest Ψ_2 resolution and q_2 sensitivity.

q_2 dependence of v_2 and $P_{z,2}$



- $P_{z,2}\{\Psi^{\mathrm{Sub}}_{2\ \mathrm{TPC}}, q^{\mathrm{Sub}}_{2\ \mathrm{TPC}}\}$ and $P_{z,2}\{\Psi^{\mathrm{Full}}_{2\ \mathrm{TPC}}, q^{\mathrm{Full}}_{2\ \mathrm{TPC}}\}$ indicate a slight dependence on q_2 (~1.5σ effect).
- Measurements with EPD are obscured due to lower resolution.

v_2 vs. $P_{z,2}$



- $P_{z,2}\{\Psi^{\mathrm{Sub}}_{2\ \mathrm{TPC}}, q^{\mathrm{Sub}}_{2\ \mathrm{TPC}}\}$ and $P_{z,2}\{\Psi^{\mathrm{Full}}_{2\ \mathrm{TPC}}, q^{\mathrm{Full}}_{2\ \mathrm{TPC}}\}$ exhibit a slight dependence on v_2 (~2.0σ effect).
- Intercept seems to be negative (~1.5σ effect).
  → Possibly other polarization mechanisms?

Summary

- Elliptic flow and local polarization of $\Lambda + \overline{\Lambda}$ have been studied in Au+Au collisions at 19.6 GeV with ESE.
  → First attempt to measure the relation between v_2 and $P_{z,2}$
- $P_{z,2}\{\Psi_{2\,\mathrm{TPC}}^{\mathrm{Sub}}$ and $\mathrm{q}_{2\,\mathrm{TPC}}^{\mathrm{Sub}}\}$ and $P_{z,2}\{\Psi_{2\,\mathrm{TPC}}^{\mathrm{Full}}$ and $\mathrm{q}_{2\,\mathrm{TPC}}^{\mathrm{Full}}\}$ indicate a slight dependence on q_2 (charged particles) and v_2 (Λ).
- Outlook: measurements in 200 GeV Au+Au collisions