Global Polarization of Hyperons in Au+Au Collisions at RHIC BES-II Energies

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1.Global polarization of Λ, Ξ and Ω hyperons in Au+Au collisions from the RHIC Beam Energy Scan-II (arXiv:2611.03044)
2.Differential measurement of global polarization of Λ, Ξ and Ω hyperons in Au+Au collisions at $\sqrt{s_{NN}} = 7.7 - 27$ GeV from the RHIC Beam Energy Scan-II (arXiv:2611.03237)

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NSFC

Outline

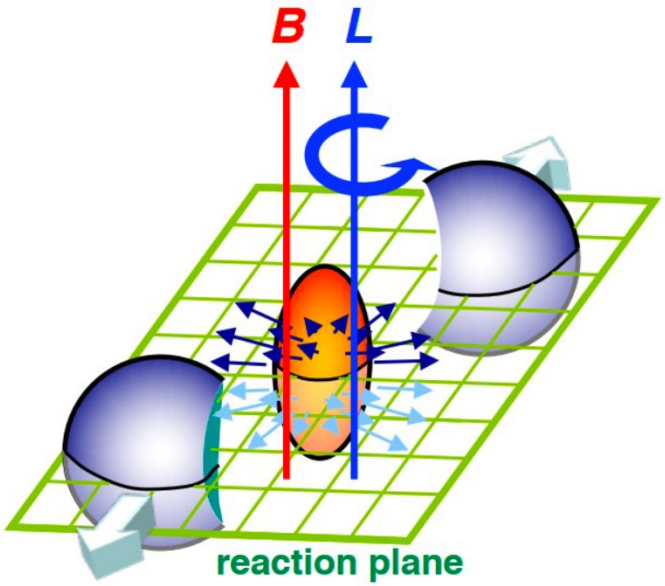
- Introduction

- Global polarization of Λ
  - Energy dependence, and the $\Lambda/\overline{\Lambda}$ splitting
  - Centrality, p_T and rapidity dependence

- Global polarization of Ξ and Ω

- Summary

Orbital angular momentum and polarization



Z.-T. Liang and X.-N. Wang, Phys. Rev. Lett. 94, 102301 (2005)

- Non-central HICs have large initial angular momentum and magnetic field

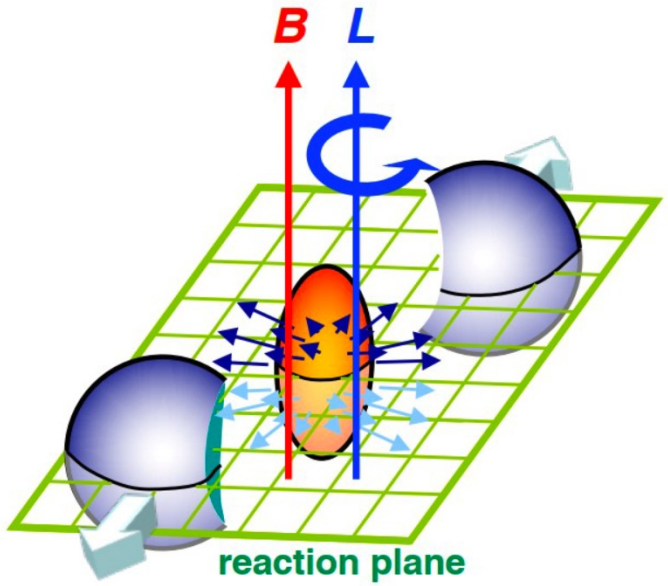
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- Polarize quarks due to "spin-orbit" interaction

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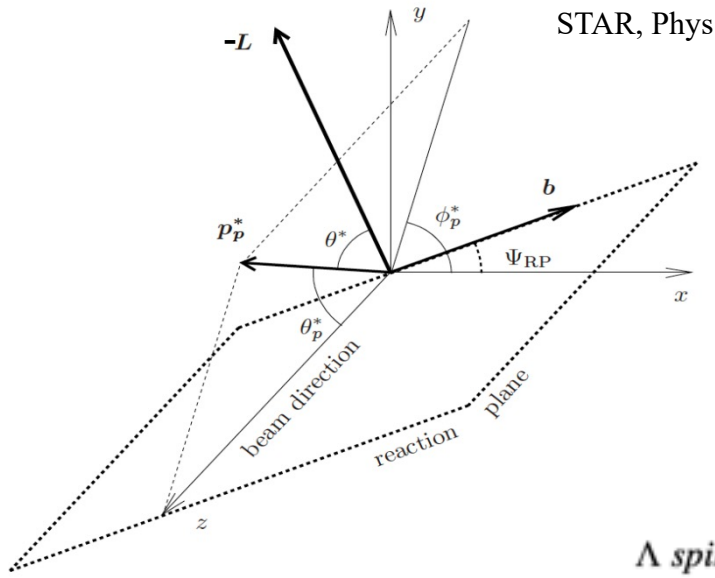
- Polarization of the final-state hadrons

Orbital angular momentum and polarization

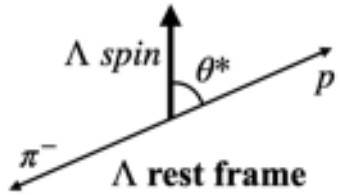


Z.-T. Liang and X.-N. Wang, Phys. Rev. Lett. 94, 102301 (2005)

- Non-central HICs have large initial angular momentum and magnetic field
- Polarize quarks due to "spin-orbit" interaction
- Polarization of the final-state hadrons



STAR, Phys. Rev. C 76, 024915 (2007)

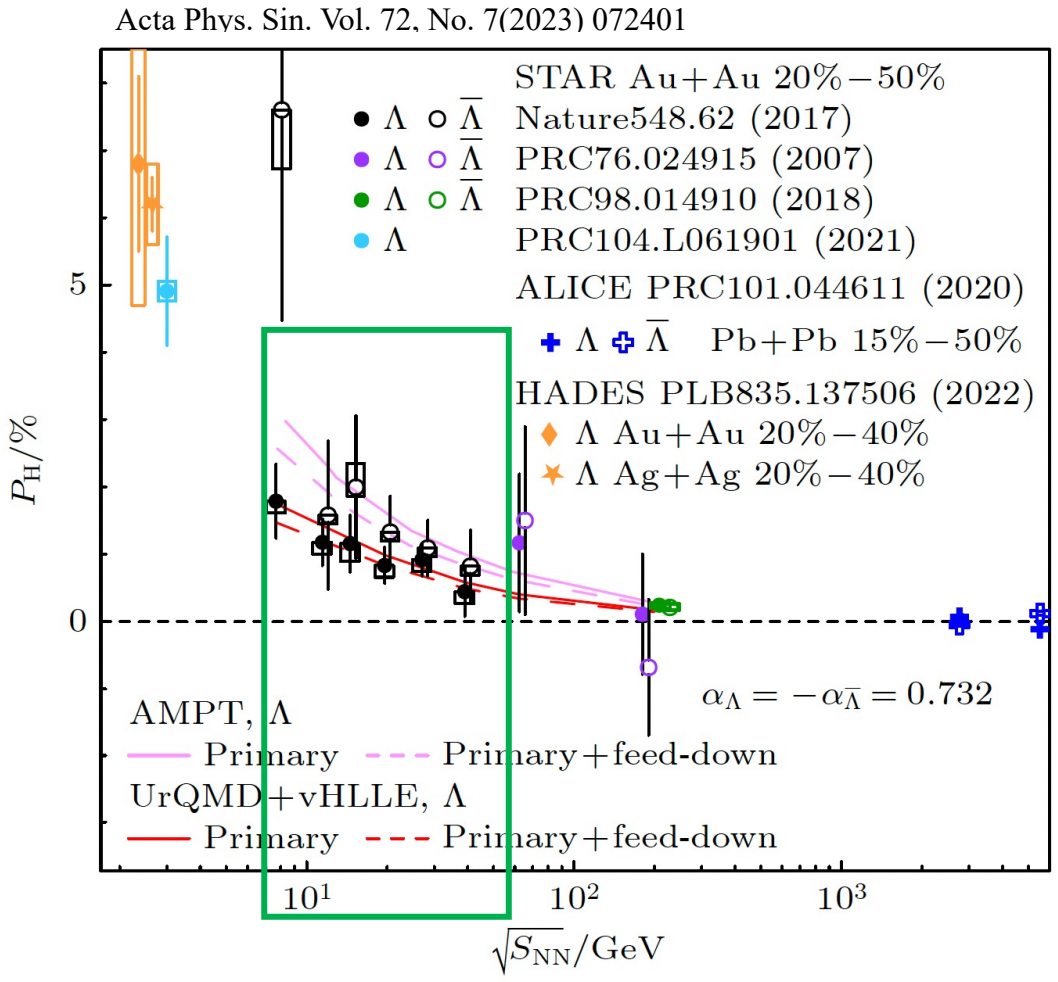


$$\frac{dN}{d\Omega^*} = \frac{1}{4\pi}\left(1 + \alpha_H P_H \cos\theta^*\right)$$

$$P_H = \frac{8}{\alpha\pi}\frac{1}{A_0}\frac{\langle \sin(\Psi_1 - \phi_p^*)\rangle}{Res\left(\Psi_1\right)}$$

- α_H is the hyperon decay parameter, $\alpha_\Lambda = 0.732 \pm 0.014$
- ϕ^* is the azimuthal angle of the daughter proton in Λ rest frame
- A_0 is an acceptance correction factor, $A_0 = \langle \sin\theta_p^* \rangle$

Observation of Λ global polarization



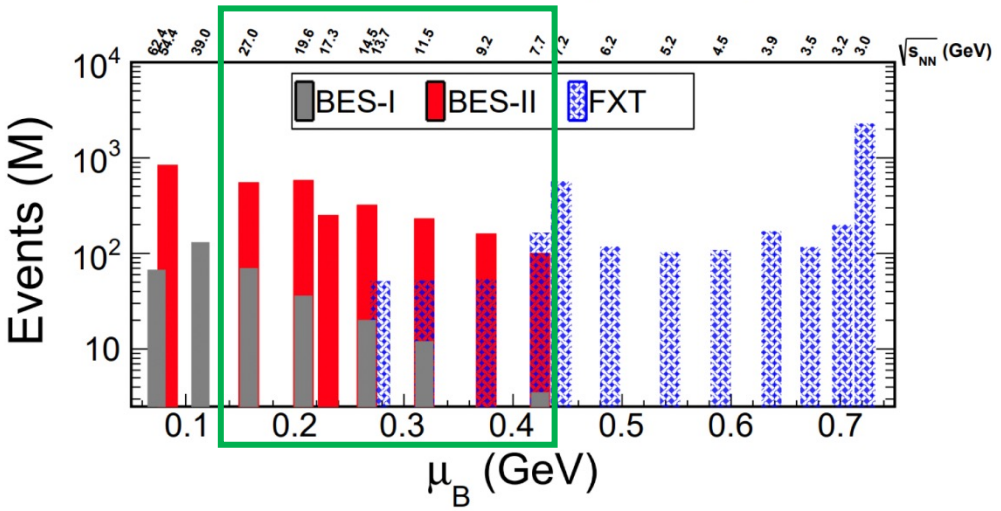
- Strongest vorticity observed in nature

$$\omega \sim 10^{21}\, s^{-1}$$

F. Becattini et al., Phys. Rev. C 95.054902(2017)

- How does the late-stage magnetic field affect global polarization?

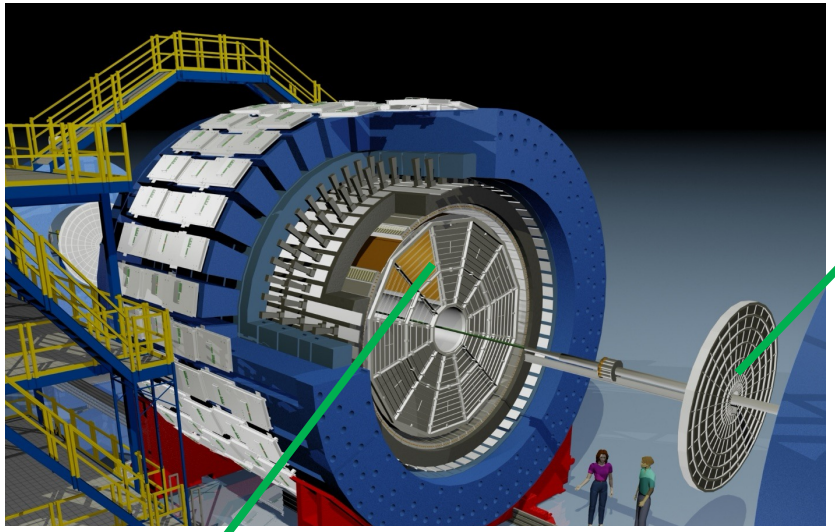
$$|B| \approx \frac{T_s |P_\Lambda - P_{\bar{\Lambda}}|}{2\,|\mu_\Lambda|}$$



- STAR collected about an order of magnitude more data in BES-II than in BES-I, with two additional energies of 9.2 and 17.3 GeV.

The STAR detector

Detector subsystems used in this analysis



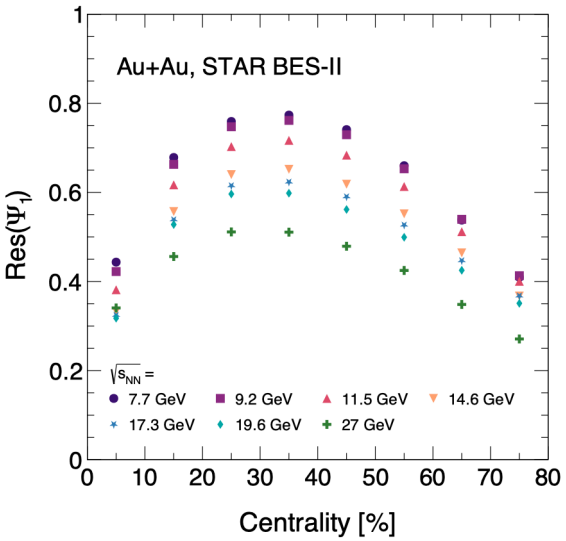
Time Projection Chamber

- Tracking and particle identification
- $|\eta| < 1.5$ at 7.7–19.6 GeV
- 27 GeV: $|\eta| < 1.0$

Event Plane Detector

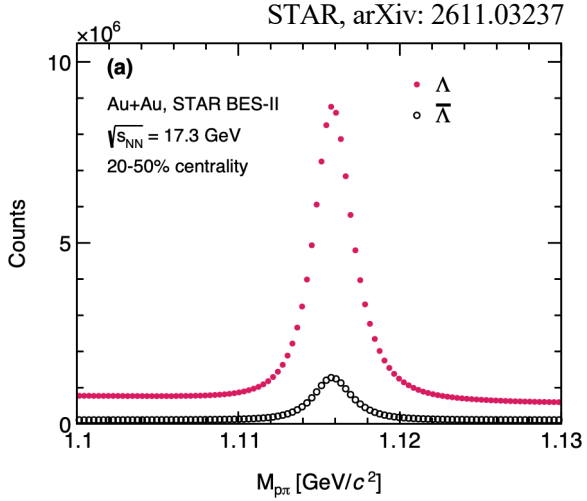
- Event plane reconstruction
- $2.1 < |\eta| < 5.1$
- Improved the event plane resolution

STAR, arXiv: 2611.03237



First-order event plane from the EPD

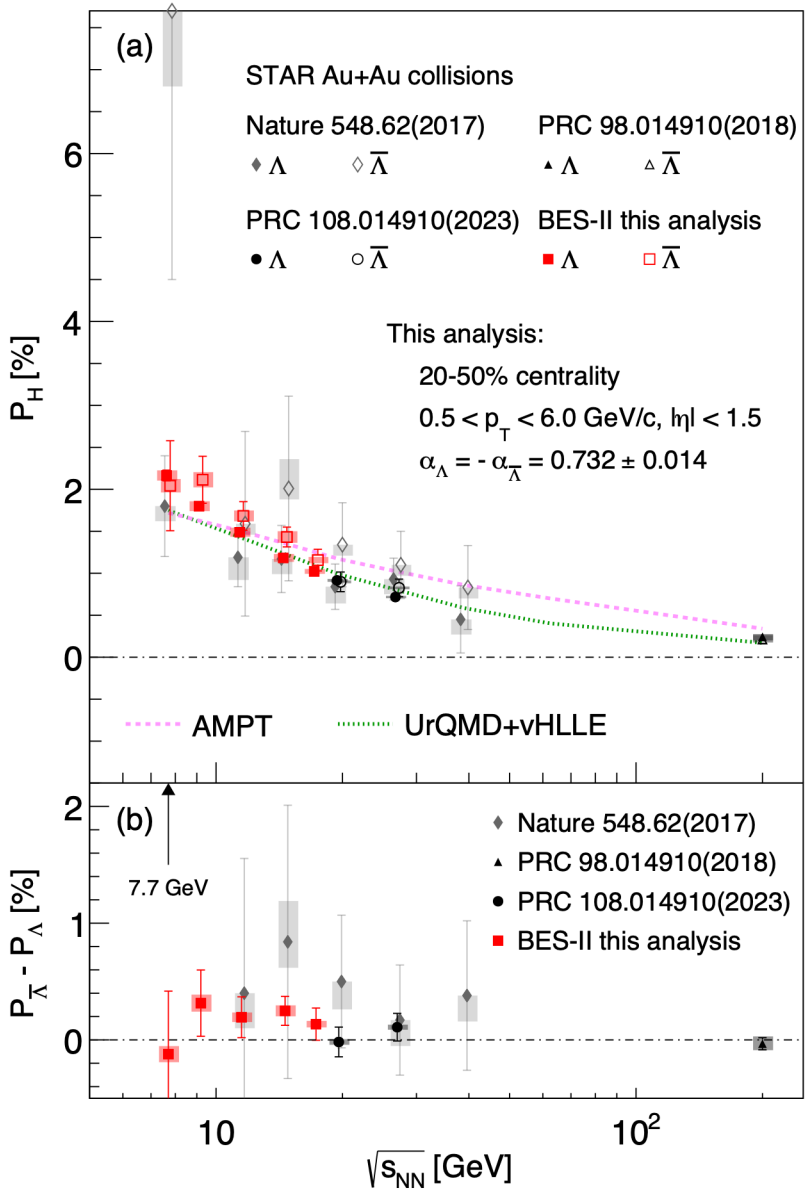
STAR, arXiv: 2611.03237



Mass distributions of Λ and $\bar{\Lambda}$ candidates reconstructed using topological selections.

Λ global polarization : energy dependence

STAR, arXiv: 2611.03044



- BES-II substantially improves the statistical precision of Λ and anti-Λ measurements.
- Global polarization increases toward lower collision energies.
- The Λ–anti-Λ polarization difference remains consistent with zero over 7.7–27 GeV.

F. Becattini et al., Phys. Rev. C 95.054902(2017)

$$|B| \approx \frac{T_s |P_\Lambda - P_{\bar{\Lambda}}|}{2\,|\mu_\Lambda|}$$

$$T_s = 150\ MeV, \mu_\Lambda = -1.93\times10^{-14}\ MeV/T$$

95% C.L. upper limits on the effective magnetic field

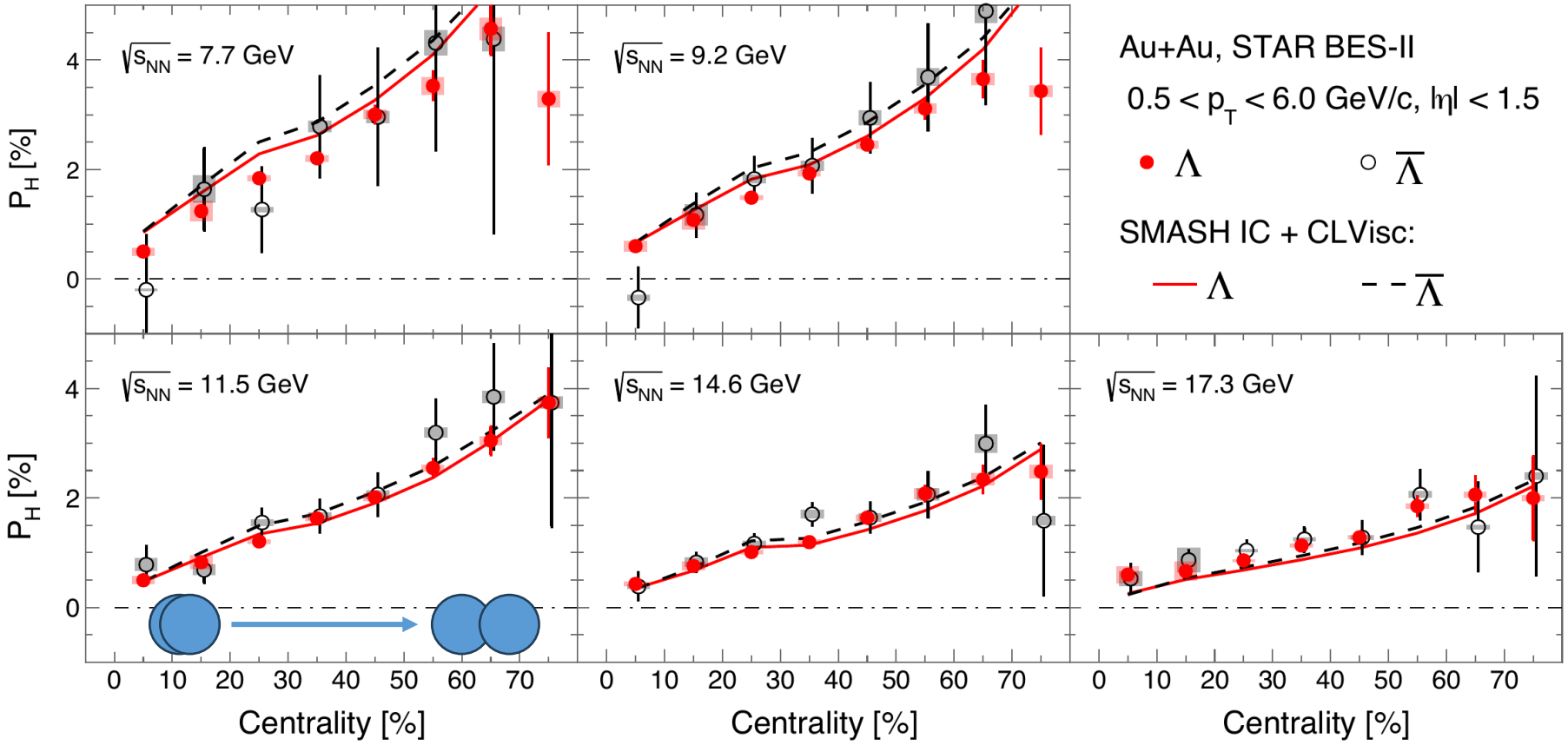
$\sqrt{s_{NN}}$ (GeV)	7.7	9.2	11.5	14.6	17.3	19.6	27
B ($\times10^{13}$ T)	3.8	3.5	2.2	2.0	1.6	0.9	1.4

19.6, 27GeV from STAR, Phys. Rev. C 108, 014910 (2023)

Λ global polarization : centrality dependence

STAR, arXiv: 2611.03237

Model: G.-H. Li, C. Yi, X.-Y. Wu, S. Pu, and G.-Y. Qin, arXiv:2606.10341.

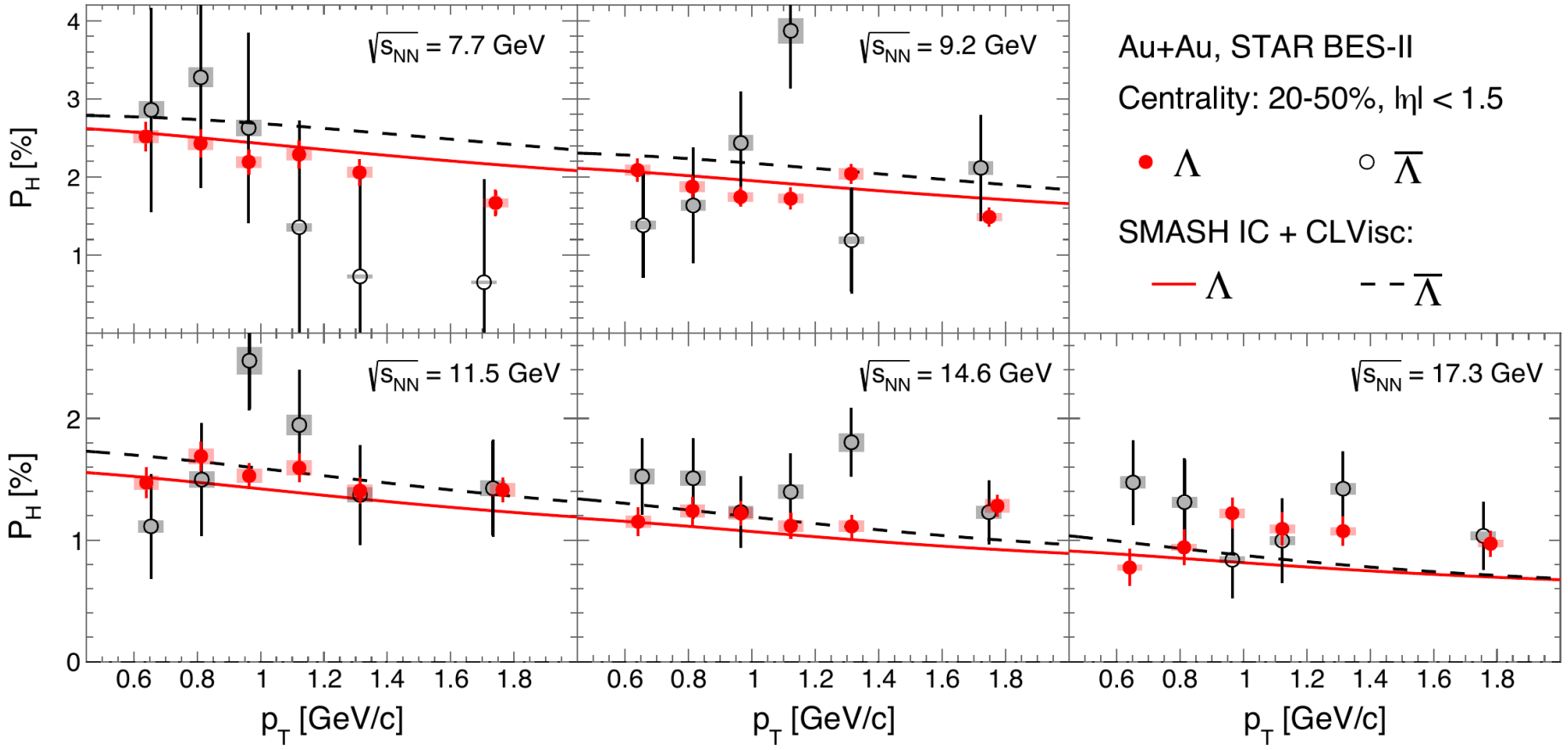


- P_Λ and $P_{\bar{\Lambda}}$ increase towards peripheral collisions;
- SMASH IC + CLVisc calculations qualitatively reproduce the observed centrality dependence. The predicted $\Lambda/\bar{\Lambda}$ polarization splitting is dominated by the chemical-potential-gradient contribution

G.-H. Li, C. Yi, X.-Y. Wu, S. Pu, and G.-Y. Qin, arXiv:2606.10341.

Λ global polarization : transverse-momentum dependence

STAR, arXiv: 2611.03237
Model: G.-H. Li, C. Yi, X.-Y. Wu, S. Pu, and G.-Y. Qin, arXiv:2606.10341.

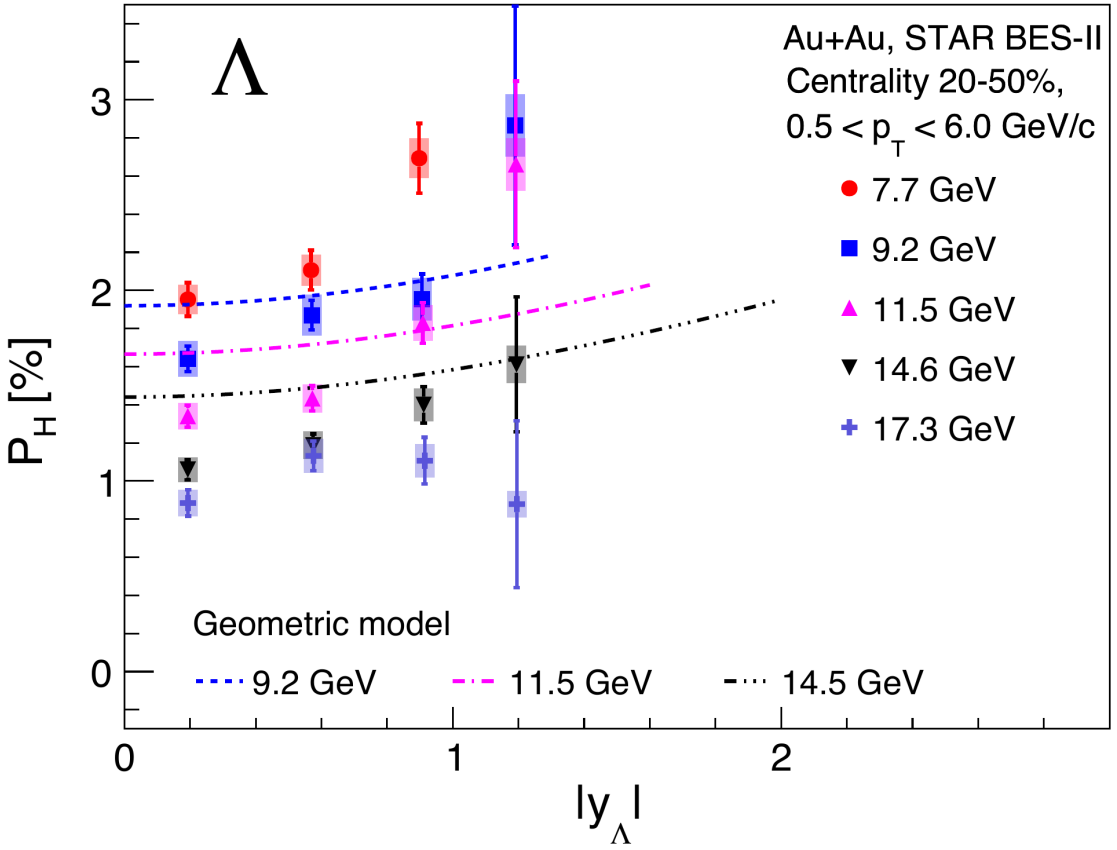


- A clear decreasing trend in p_T is observed at 7.7 GeV, while the p_T dependence is relatively weaker at the other collision energies.
- The data are compatible with the weak dependence predicted by the SMASH IC + CLVisc model.

Λ global polarization : rapidity dependence

STAR, arXiv: 2611.03044

Model : Z.-T. Liang, J. Song et al, Chin. Phys. C 45, 014102 (2021)



- The first evidence for a nonzero rapidity dependence
  - Λ polarization increases with absolute rapidity, more strongly at lower energies.
  - A linear fit uses the combined 7.7–17.3 GeV data.

$$\text{slope} = 0.498 \pm 0.103 \Rightarrow 4.8\sigma$$

The slope uncertainty includes statistical and systematic contributions.

- The geometric model predicts the increasing trend of Λ polarization versus rapidity, but with a weaker rapidity dependence than observed in the data

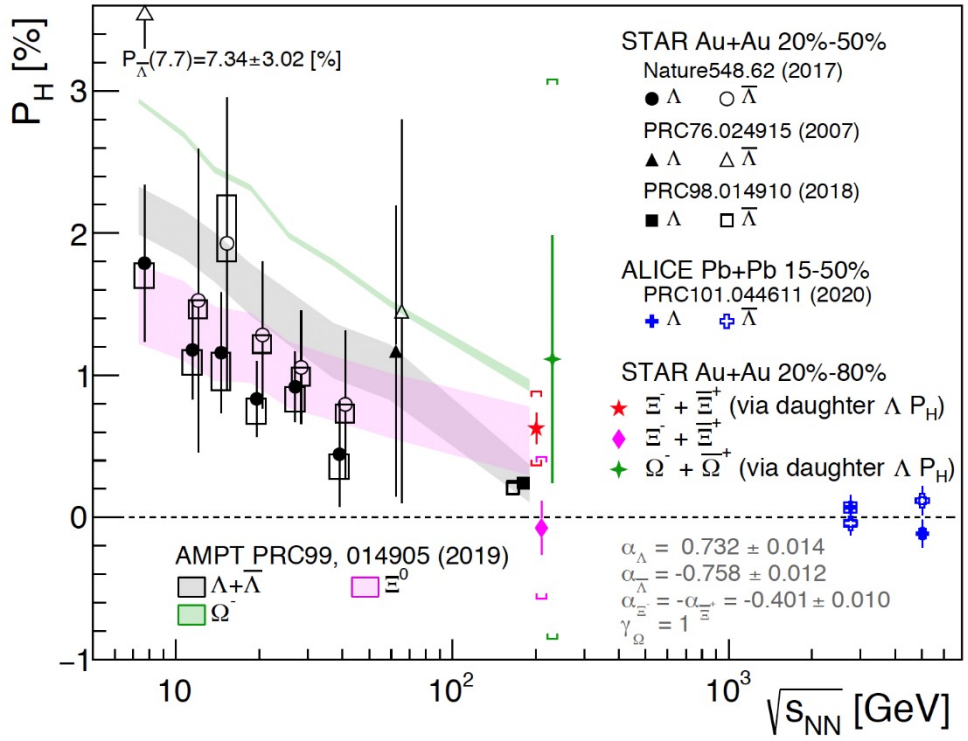
- Different models predict different trends.

Z.-T. Liang, J. Song et al, Chin. Phys. C 45, 014102 (2021)
Y. Sun, C. M. Ko, Phys. Rev. C 96, 024906 (2017)
Y. Xie, D. Wang, L. P. Csernai, Eur. Phys. J. C 80, 39 (2020)
… …

Global polarization of Ξ and Ω

Hyperon	Spin
Λ(uds)	1/2
Ξ^-(dss)	1/2
Ω^-(sss)	3/2

STAR, Phys. Rev. Lett. 126, 162301 (2021)



- **Multi-strange hyperons are expected to be polarized in a similar way**
- The Ξ polarization is measured to be slightly larger than that of Λ, but the significance of that is below 1σ. The Ω global polarization shows a hint of being even larger
- Is there a dependence of Ξ and Ω global polarization on collision energy?

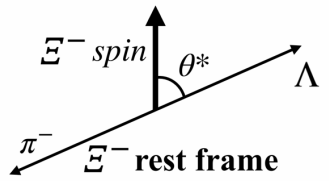
Extraction of Ξ and Ω global polarization

PDG2021

Hyperon	Decay mode	α_H	Spin
Λ(uds)	$\Lambda \to p + \pi^-$	0.732	1/2
Ξ^-(dss)	$\Xi^- \to \Lambda + \pi^-$	-0.401	1/2
Ω^-(sss)	$\Omega^- \to \Lambda + K^-$	0.0157	3/2

- Two methods for extracting the Ξ and Ω polarization
  - Direct measurement: measured via daughter Λ angle distribution in Ξ rest frame

$$P_H = \frac{8}{\alpha\pi}\frac{1}{A_0}\frac{\langle \sin(\Psi_1 - \phi^*)\rangle}{Res\,(\Psi_1)}$$



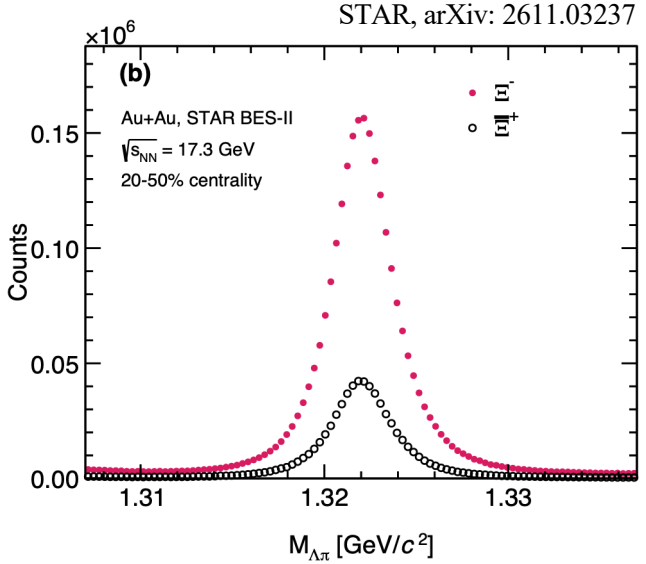
  - Indirect measurement: via daughter Λ polarization with spin transfer factor

($C_{\Xi^-\to\Lambda} = 0.944$, $C_{\Omega^-\to\Lambda}$ is assumed 1.0)

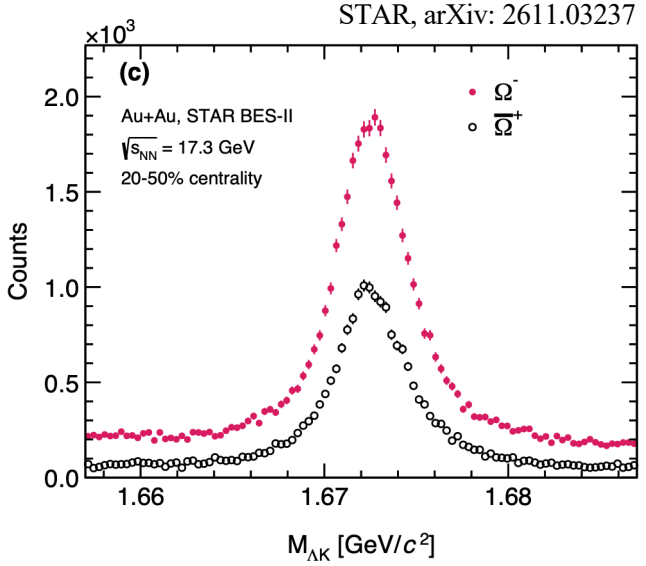
$$\mathbf{P}_\Lambda = \begin{cases} \mathbf{P}_\Omega & \text{if } \gamma_\Omega = 1\ , \\ -0.6\mathbf{P}_\Omega & \text{if } \gamma_\Omega = -1 \end{cases}$$

K. B. Luk et al. Phys. Rev. D 38, 19 (1988)

STAR, arXiv: 2611.03237



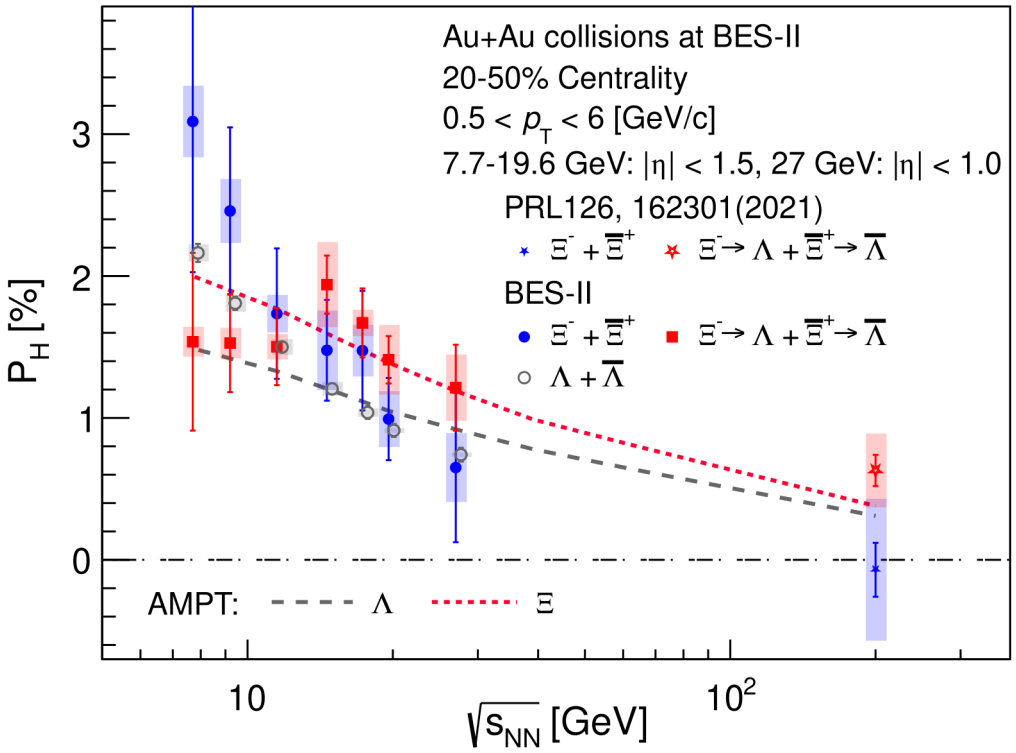
STAR, arXiv: 2611.03237



$\Xi^- + \bar{\Xi}^+$ global polarization : energy dependence

STAR, arXiv: 2611.03044

Model calculation:
H. Li, X. Xia, X. G. Huang, H. Z. Huang Phys. Lett. B 827, 136971 (2022)



- A clear polarization signal of $\Xi^- + \bar{\Xi}^+$ is observed and exhibits a collision energy dependence, rising toward lower energies.

  Energy-combined results (7.7–27 GeV)

  - Direct measurement: 5.2σ

    $[1.389 \pm 0.163\,(\text{stat.}) \pm 0.212\,(\text{syst.})]\%$

  - Indirect measurement: 7.1σ

    $[1.565 \pm 0.094\,(\text{stat.}) \pm 0.200\,(\text{syst.})]\%$

- The two measurements are consistent with each other

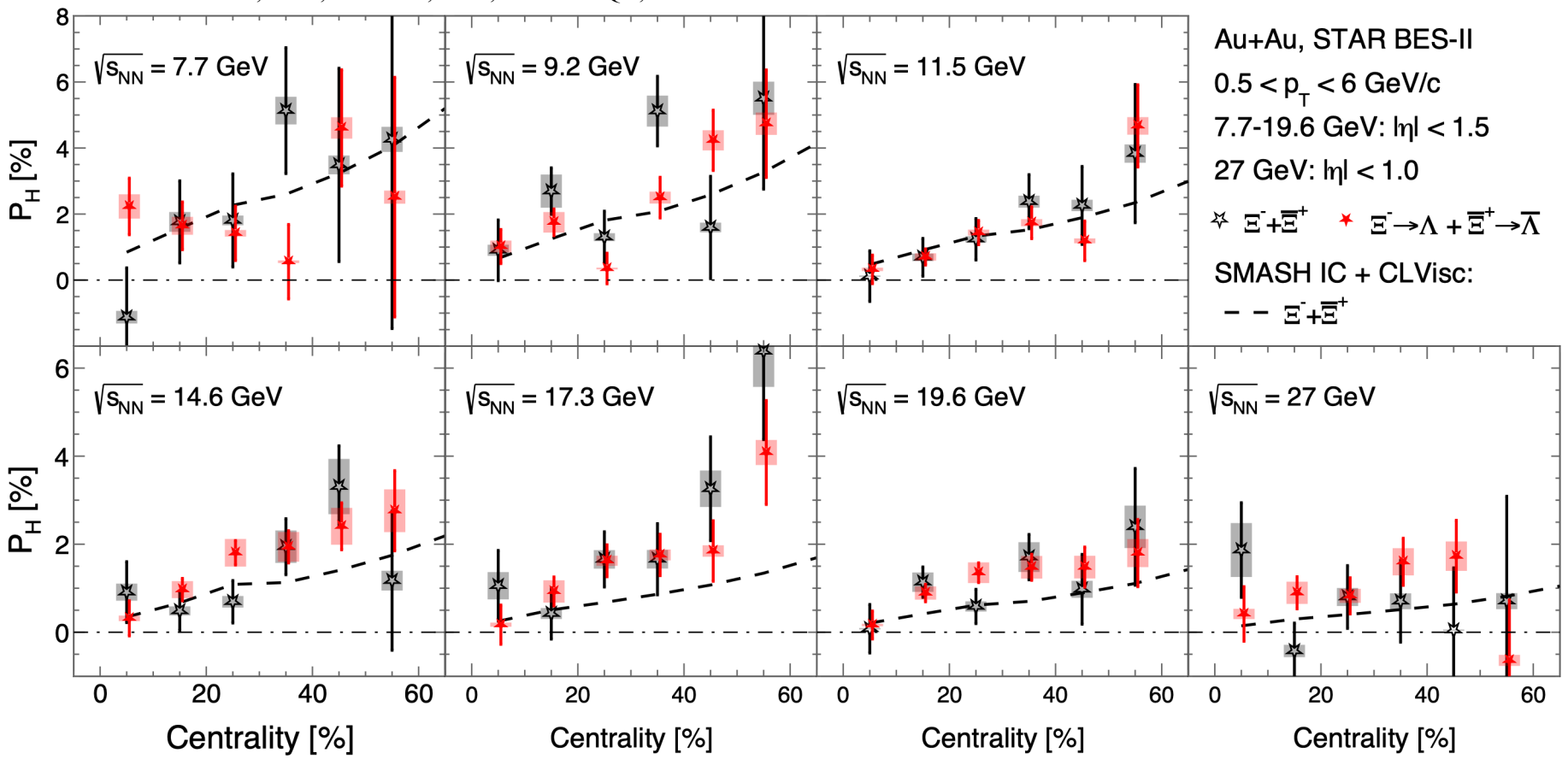
- No significant difference between $\Lambda + \bar{\Lambda}$ and $\Xi^- + \bar{\Xi}^+$ global polarization within uncertainties

- The AMPT calculation can qualitatively describe the measurement.

$\Xi^- + \bar{\Xi}^+$ global polarization : centrality dependence

STAR, arXiv: 2611.03237

Model: G.-H. Li, C. Yi, X.-Y. Wu, S. Pu, and G.-Y. Qin, arXiv:2606.10341.

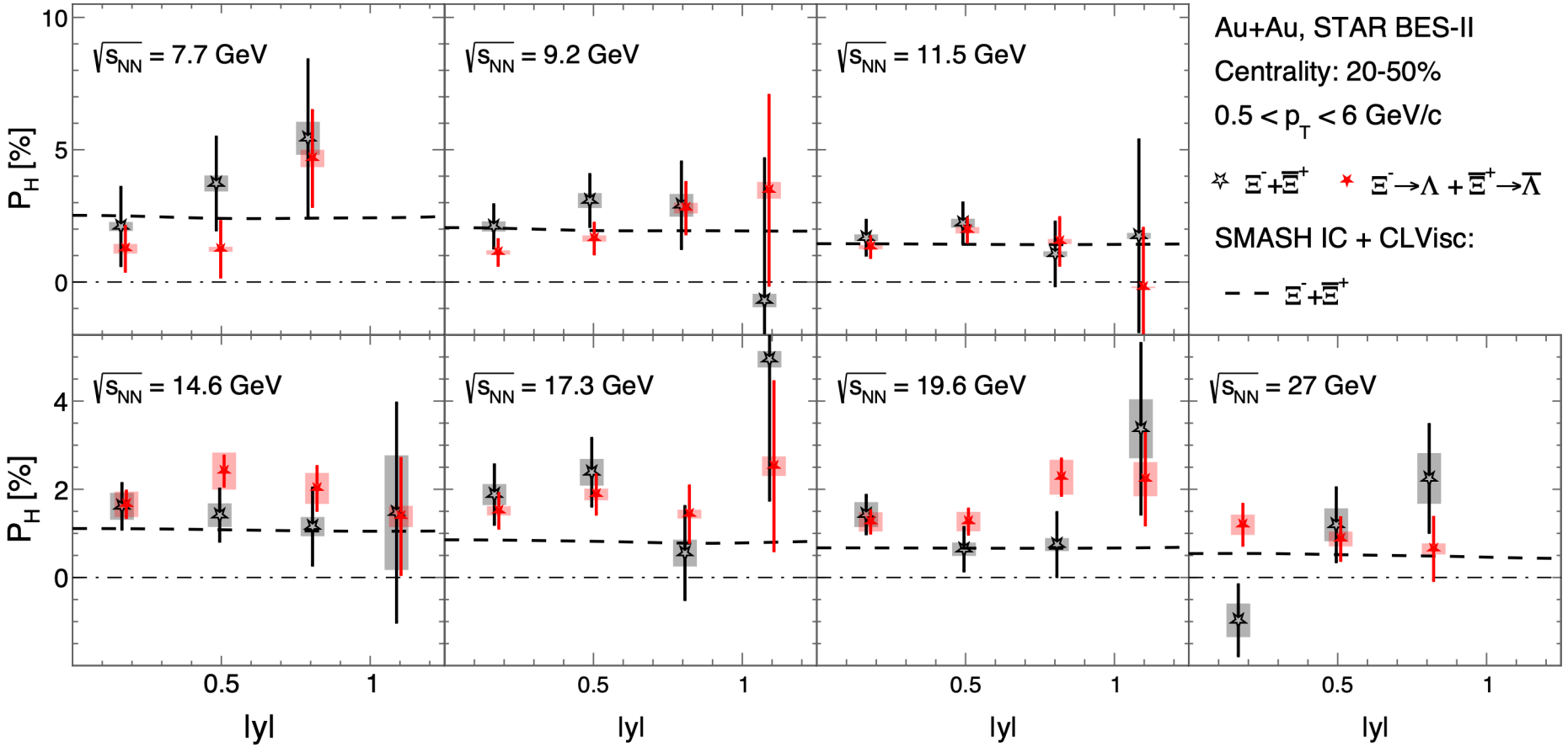


- The Ξ polarization generally increases toward peripheral collisions.
- The model captures the trend qualitatively.

$\Xi^- + \bar{\Xi}^+$ global polarization : rapidity dependence

STAR, arXiv: 2611.03237

Model: G.-H. Li, C. Yi, X.-Y. Wu, S. Pu, and G.-Y. Qin, arXiv:2606.10341.

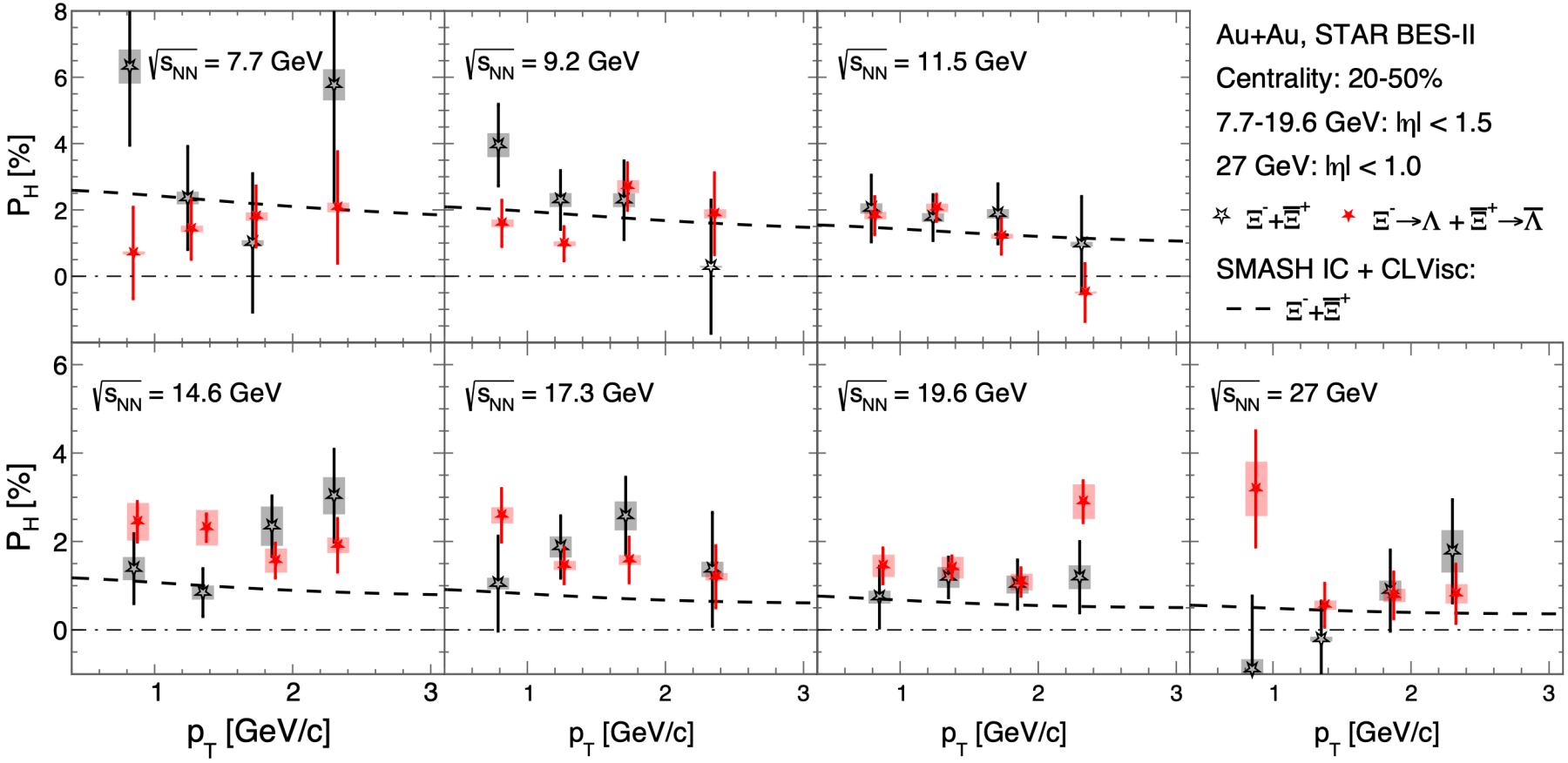


- No significant rapidity dependence is observed for Ξ within current uncertainties.

$\Xi^- + \bar{\Xi}^+$ global polarization : transverse-momentum dependence

STAR, arXiv: 2611.03237

Model: G.-H. Li, C. Yi, X.-Y. Wu, S. Pu, and G.-Y. Qin, arXiv:2606.10341.

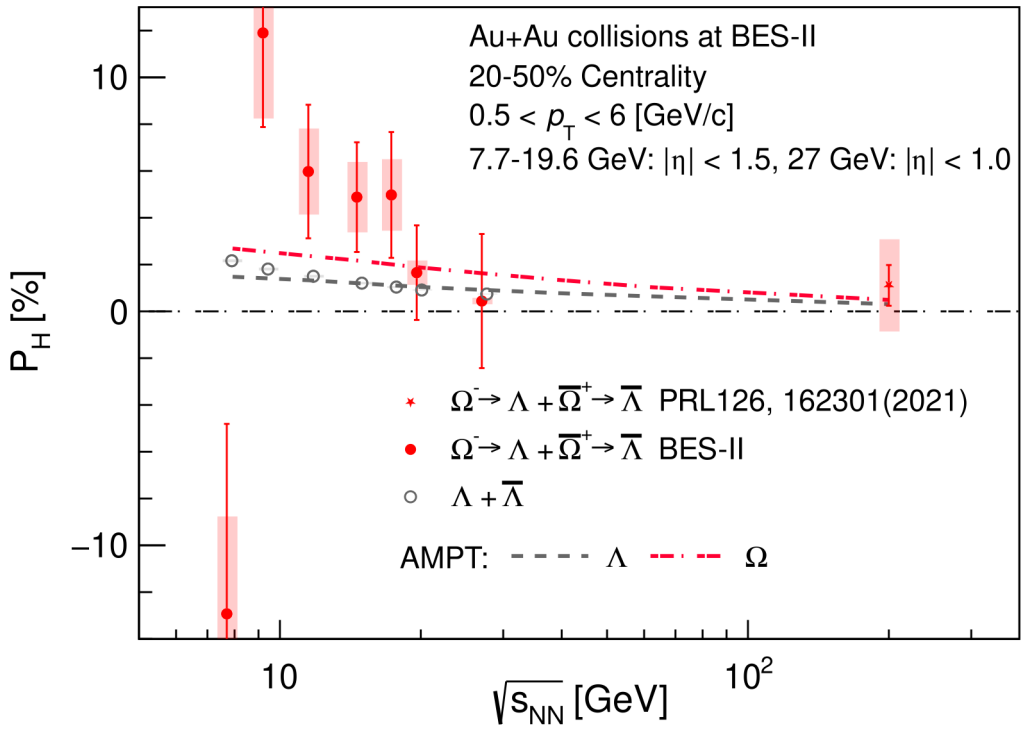


- No significant transverse-momentum dependence is observed for Ξ.

$\Omega^- + \bar{\Omega}^+$ global polarization : energy dependence

STAR, arXiv: 2611.03044

Model calculation:
H. Li, X. Xia, X. G. Huang, H. Z. Huang Phys. Lett. B 827, 136971 (2022)



- The Ω results suggest decreasing polarization with increasing collision energy.
- The data favor the spin-transfer coefficient $C_{\Omega^-\to\Lambda} = 1$. ($C_{\Omega^-\to\Lambda} = -0.6$ would reverse the inferred polarization)
- The hint of larger Ω polarization than inclusive Λ is not statistically conclusive (about 1.5σ).
- Possible **Λ, Ξ, Ω** global polarization difference?

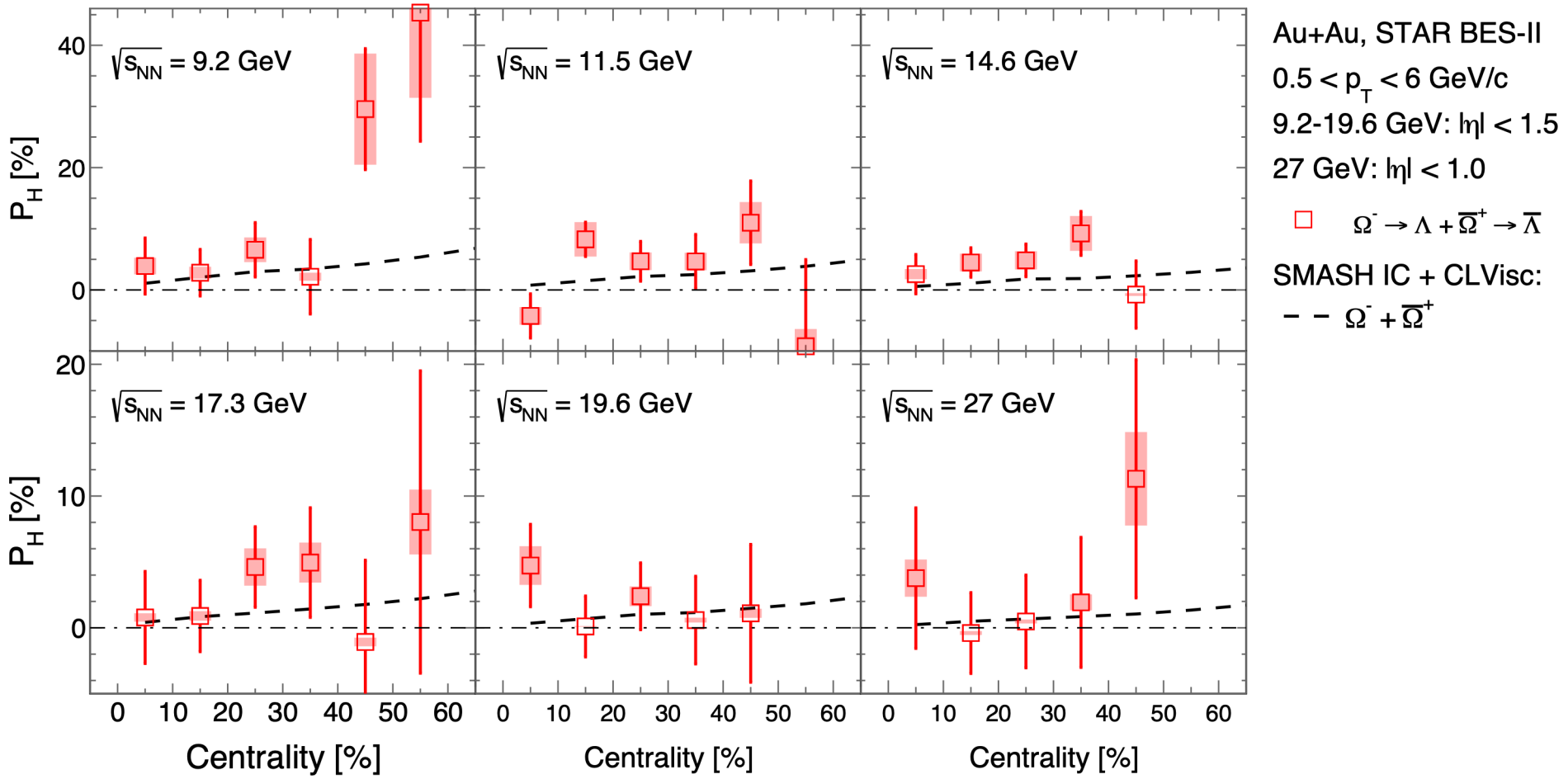
$P_\Lambda \cong P_s$, assuming that $P_{u.d} \sim P_s \Longrightarrow P_\Xi \sim P_\Lambda$, $P_\Omega \sim \frac{5}{3} P_\Lambda$

H. Li, X. Xia, X. G. Huang, H. Z. Huang Phys. Lett. B 827, 136971 (2022)

$\Omega^- + \bar{\Omega}^+$ global polarization : centrality dependence

STAR, arXiv: 2611.03237

Model: G.-H. Li, C. Yi, X.-Y. Wu, S. Pu, and G.-Y. Qin, arXiv:2606.10341.



- The Ω results suggest an increase toward peripheral collisions, with large uncertainties.

Summary

- Λ : Precision BES-II measurements show no significant difference between Λ and $\bar{\Lambda}$ global polarization.
  - Polarization increases toward peripheral collisions.
  - First evidence for increasing Λ global polarization with |y|, with a significance of 4.8σ in the combined 7.7–17.3 GeV data
  - A clear decreasing trend in p_T is observed at 7.7 GeV, while the p_T dependence is relatively weaker at the other collision energies.

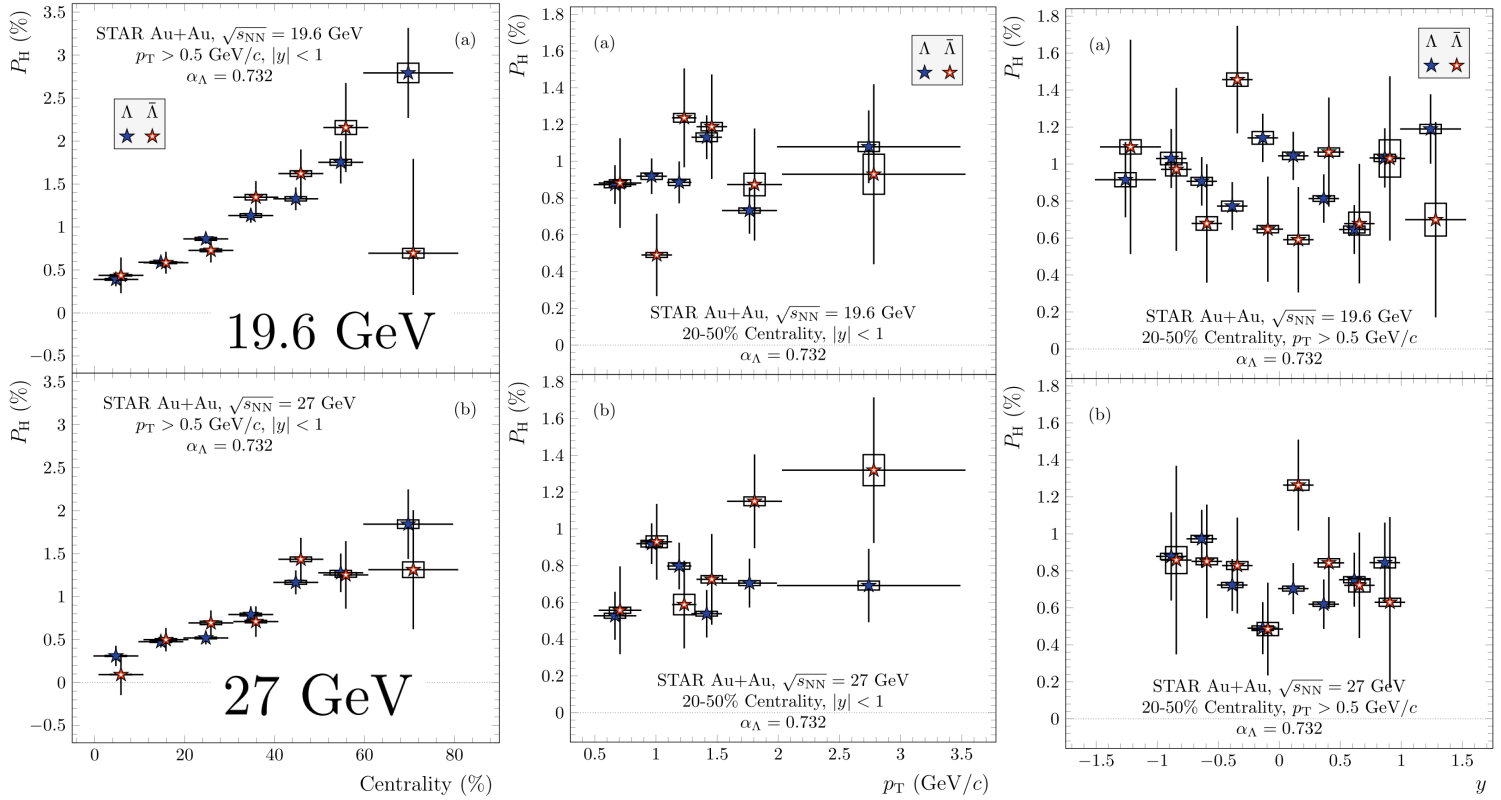
- Ξ: Significant global polarization is observed, with consistent results from direct and indirect measurements.
  - Polarization increases toward lower collision energies.
  - Polarization increases toward peripheral collisions.
  - No significant rapidity or p_T dependence is observed within current uncertainties.

- Ω: Assuming $C_{\Omega^- \to \Lambda} = 1$, the results suggest larger polarization at lower collision energies.
  - An increase toward peripheral collisions is suggested, although uncertainties remain large.

Back Up

Result of Global Polarization from BES-II

STAR, Phys. Rev. C 108, 014910 (2023)



Why $C_{\Omega^-\to\Lambda} = 1.0$

K. B. Luk et al. Phys. Rev. D 38, 19 (1988)

The weak decay $\Omega^- \to \Lambda + K^-$ proceeds to the final states of orbital angular momentum L= 1,2 through the amplitudes A_L. The asymmetry parameters in the decay process can be written as:

$$\alpha = \frac{2\,\mathrm{Re}(A_1^* A_2)}{|A_1|^2 + |A_2|^2}, \quad \beta = \frac{2\,\mathrm{Im}(A_1^* A_2)}{|A_1|^2 + |A_2|^2}, \quad \gamma = \frac{|A_1|^2 - |A_2|^2}{|A_1|^2 + |A_2|^2}, \quad \alpha^2 + \beta^2 + \gamma^2 = 1 .$$

When the joint probability distribution for the decay chain is integrated over the angular distribution, the angular distribution of the daughter proton is given by:

$$\frac{dn}{d\Omega_p} = \frac{1}{4\pi}(1 + \alpha_\Lambda \mathbf{P}_\Lambda \cdot \hat{\mathbf{p}}), \quad \frac{dN}{d\Omega_p} = \frac{1}{4\pi}\left[1 + \frac{\alpha_\Lambda}{2(J+1)}[1 + (2J+1)\gamma_\Omega]\mathbf{P}_\Omega \cdot \hat{\mathbf{p}}\right] . \quad \Rightarrow \quad \mathbf{P}_\Lambda = \frac{1}{2(J+1)}[1 + (2J+1)\gamma_\Omega]\mathbf{P}_\Omega .$$

Using $J = \frac{3}{2}$:

$$\mathbf{P}_\Lambda = \begin{cases} \mathbf{P}_\Omega & \text{if } \gamma_\Omega = 1 , \\ -0.6\mathbf{P}_\Omega & \text{if } \gamma_\Omega = -1 \end{cases}$$