26th International Symposium on Spin Physics
A Century of Spin

Measurements of Λ, Ξ and Ω Global Polarization in Au+Au collisions at BES-II energies from RHIC-STAR

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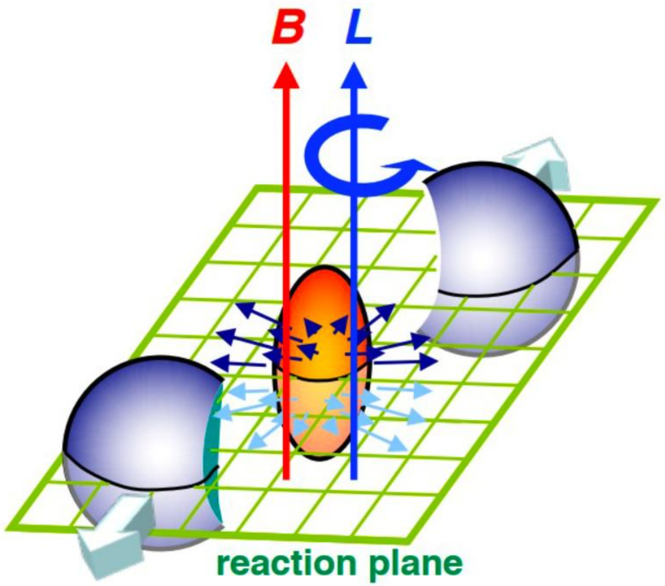
U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

- Introduction
- Global polarization of Λ
  - Energy dependence
  - Splitting between Λ and $\bar{\Lambda}$
- 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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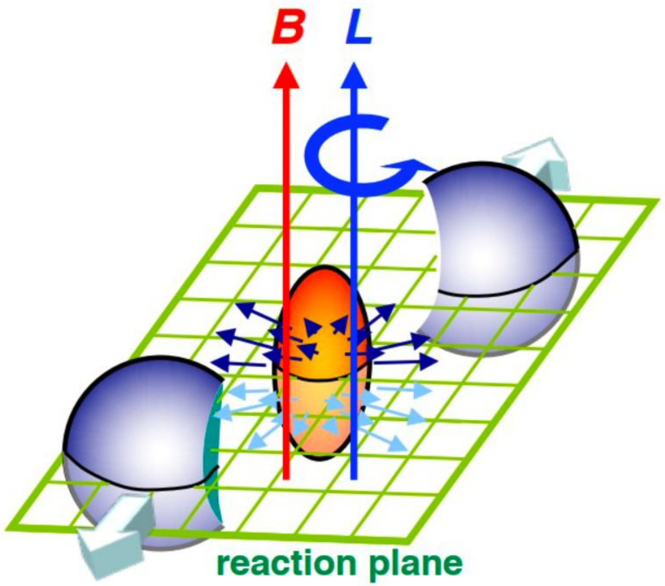
- Polarization of the final-state hadrons

Orbital angular momentum and polarization



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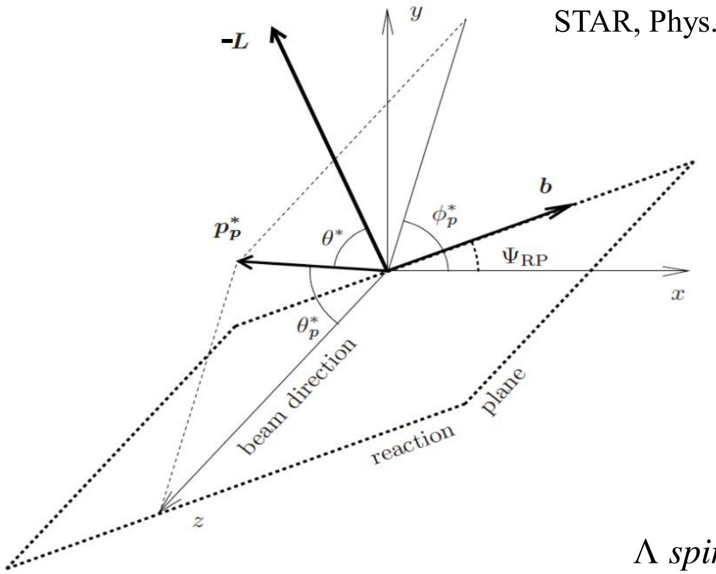
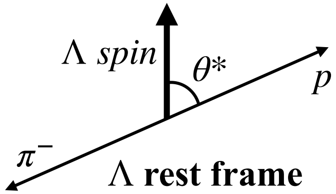
STAR, Phys. Rev. C 76, 024915 (2007)





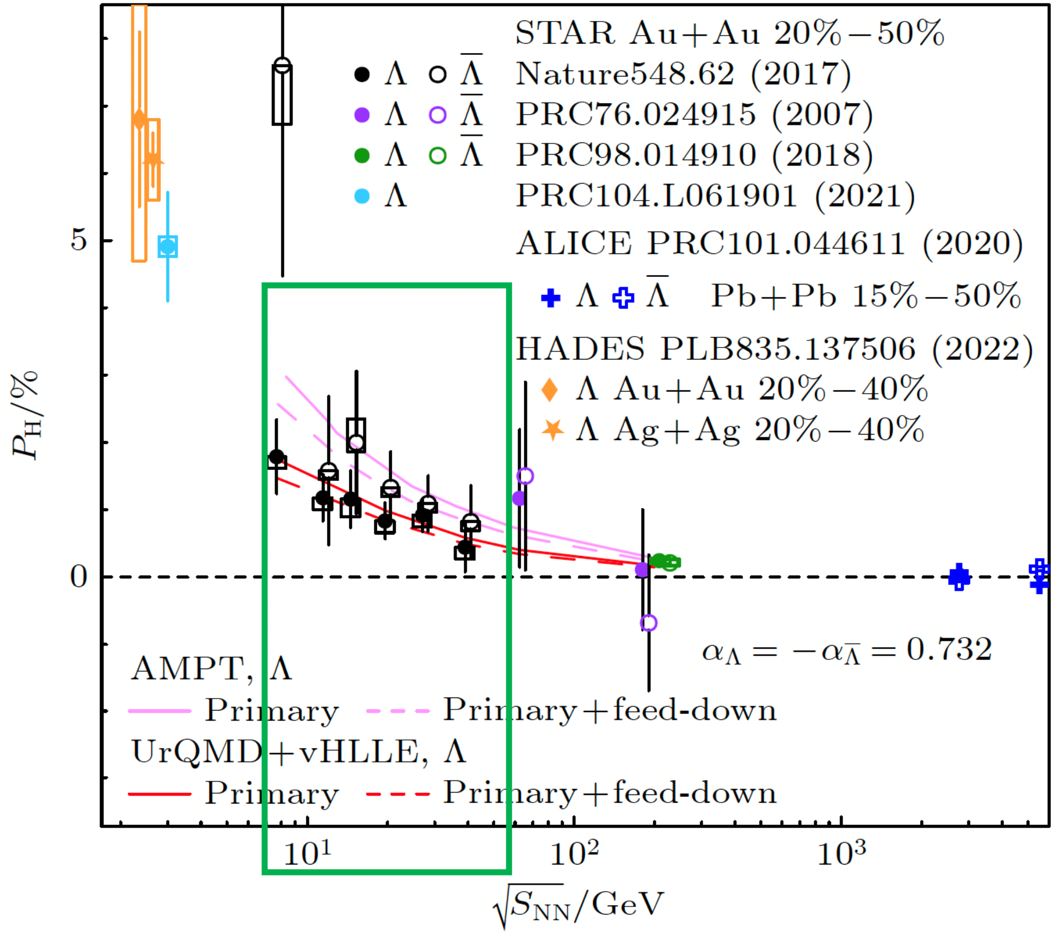
$$\frac{dN}{d\Omega^*} = \frac{1}{4\pi}(1 + \alpha_H P_H \cos\theta^*)$$

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

- 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

Acta Phys. Sin. Vol. 72, No. 7(2023) 072401



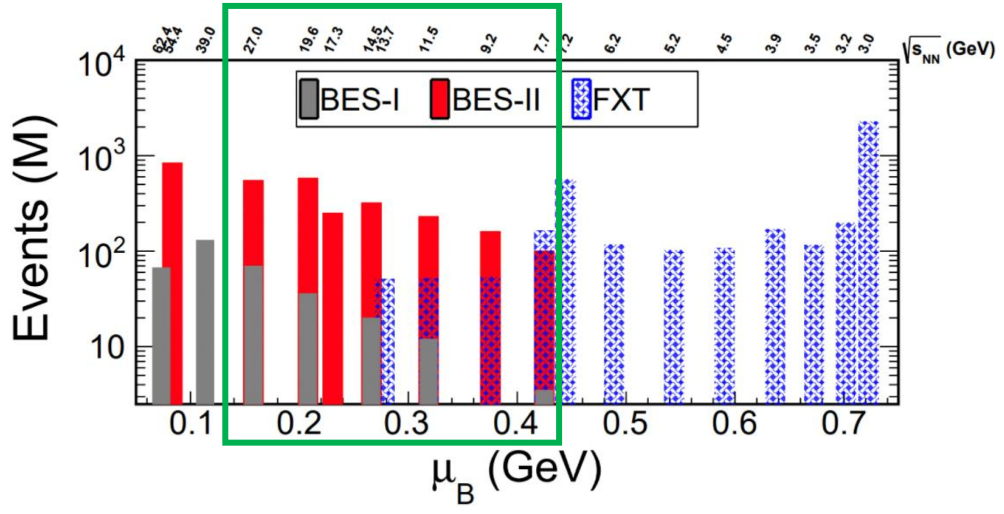
- Strongest vorticity observed in nature

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

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

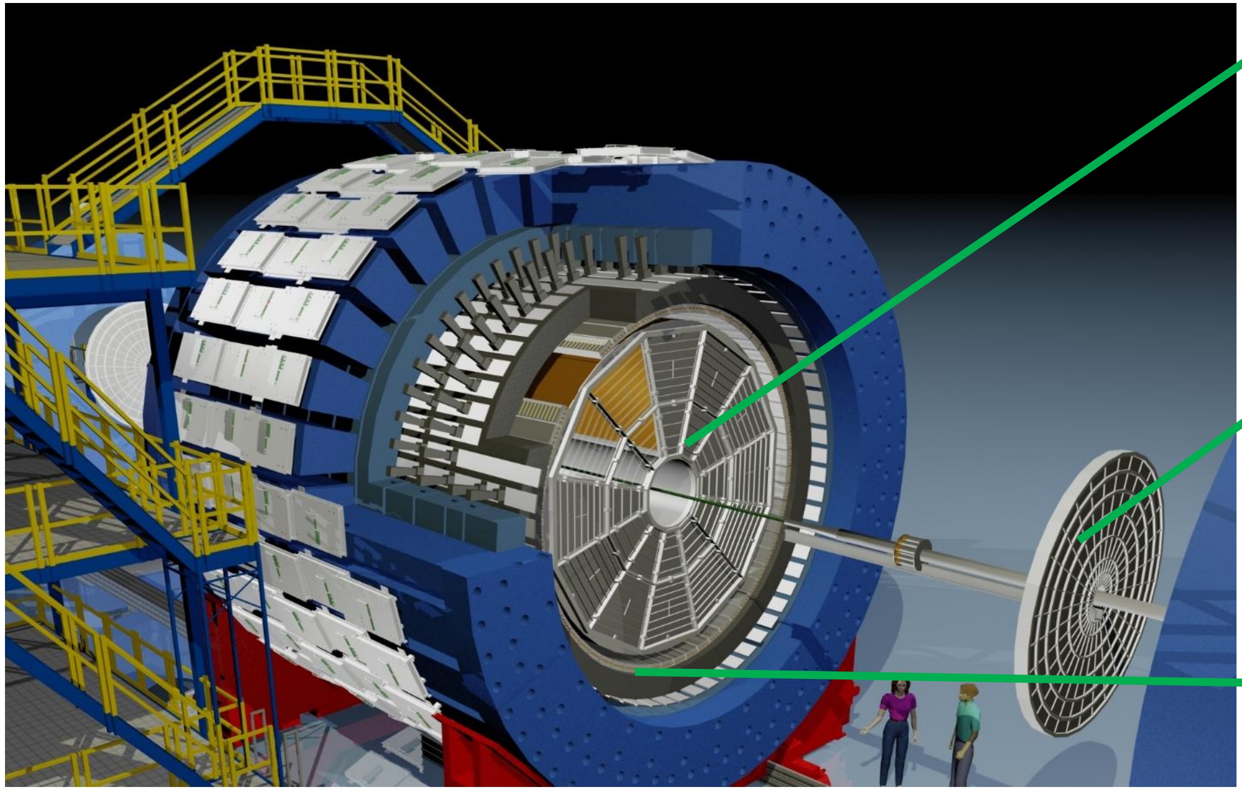
- How does the late-stage magnetic field affect global polarization?

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



- The BES-II by STAR collected an order of magnitude more data compared to BES-I, and collected two additional energy points(9.2, 17.3 GeV)

The STAR detector

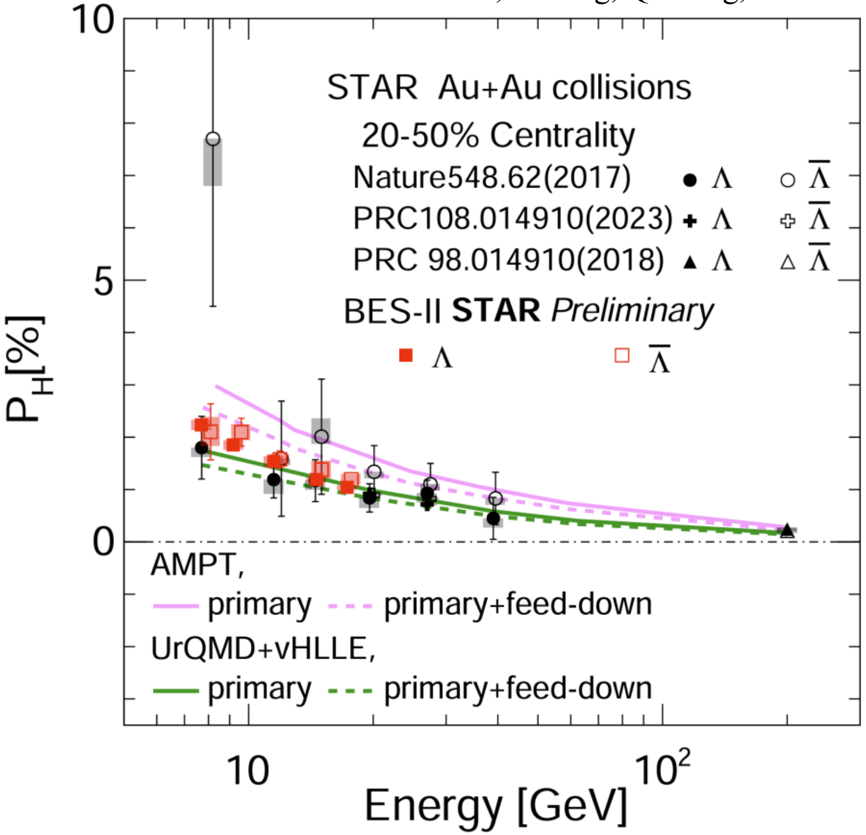


Sub-system relevant to this analysis:

- **Time Projection Chamber**
  - Particle reconstruction
  - The iTPC upgrade extended the pseudo-rapidity coverage from $|\eta| < 1$ to $|\eta| < 1.5$
- **Event Plane Detector**
  - Event plane reconstruction
  - $2.1 < |\eta| < 5.1$
  - Improved the event plane resolution
- **Time Of Flight**
  - PID via particle velocity
  - $|\eta| < 0.9$

Λ global polarization : energy dependence

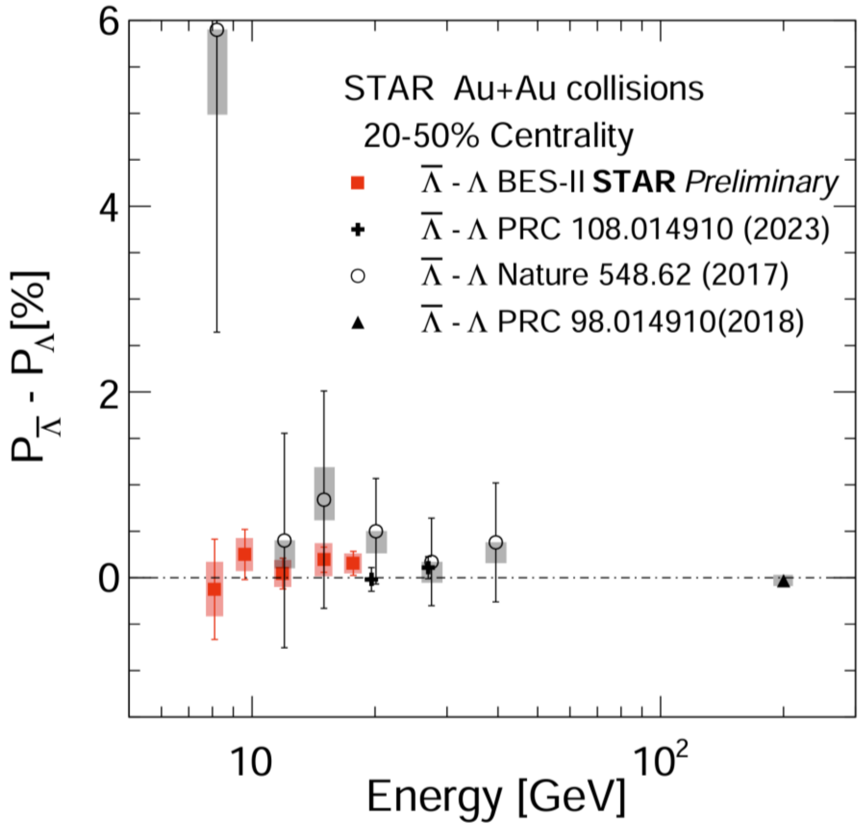
UrQMD+vHLLE : Iu. Karpenko, F. Becattini Eur. Phys. J. C 77, 213 (2017)
AMPT: H. Li , L. Pang, Q. Wang, X. Xia Phys. Rev. C 96, 054908(2017)



- STAR preliminary results at $\sqrt{s_{NN}}$ = 7.7-17.3 GeV from BES-II
- Significant improvement in precision was achieved, collision energy dependence consistent with BES-I
- $P_H = 1.17 \pm 0.40(stat) \pm 0.27(syst)$ % [**BES-I**] ⟹ $1.19 \pm 0.04(stat) \pm 0.05(syst)$% [**BES-II**] at 14.6 GeV

STAR Nature 548.62(2017)

Λ global polarization : splitting of Λ and $\bar{\Lambda}$



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

$$P_{\Lambda} \approx \frac{1}{2}\frac{\omega}{T} + \frac{\mu_{\Lambda} B}{T}$$

$$P_{\bar{\Lambda}} \approx \frac{1}{2}\frac{\omega}{T} - \frac{\mu_{\Lambda} B}{T}$$

$$\Delta P_H = |P_{\bar{\Lambda}} - P_{\Lambda}| \approx \frac{2|\mu_{\Lambda}|B}{T}$$

$T = 150\, MeV, \mu_{\Lambda} = -1.93 \times 10^{-1}\, MeV/T$

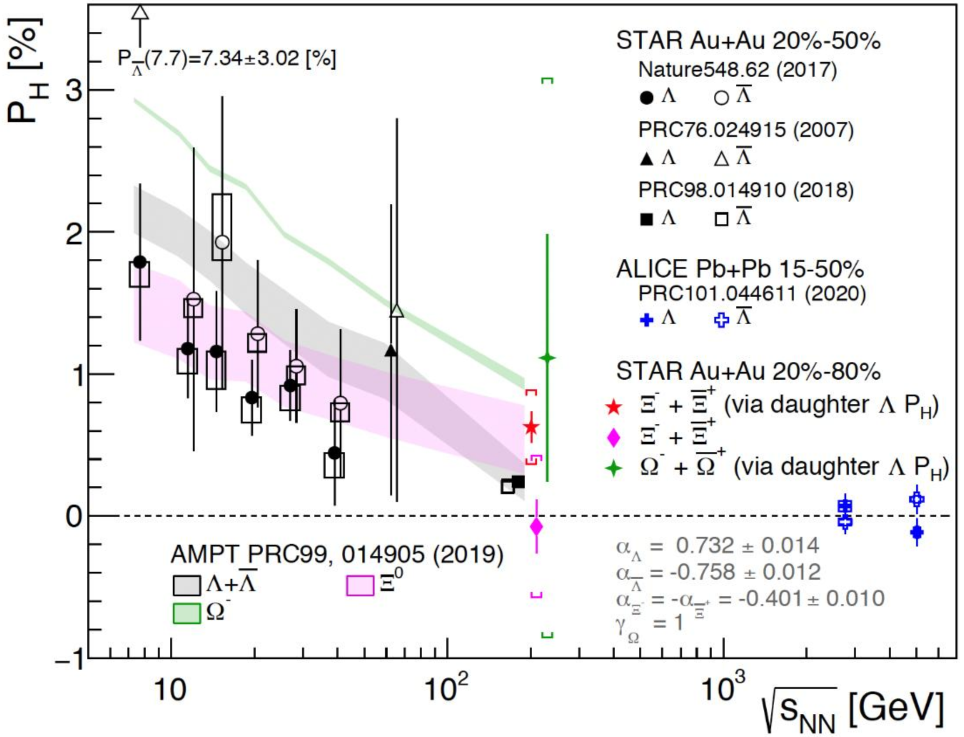
- No obvious splitting between Λ and $\bar{\Lambda}$ global polarization with high precision
- Upper limit on late-stage magnetic field
  - $B \lesssim 10^{13}$ T (95% confidence level) STAR, Phys. Rev. C 108, 014910 (2023)
- Possible explanation: small magnetic field at freeze out

A. Huang, Z. Yuan, M. Huang, Phys. Rev. D 110, 096025 (2024)

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)

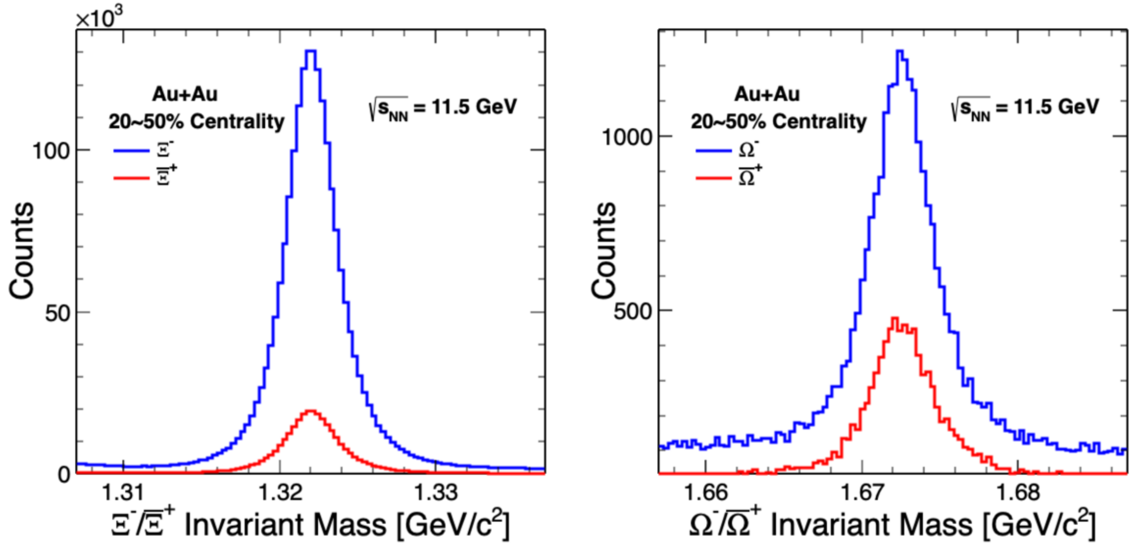


- **Multi-strange hyperons are expected to be polarized in similar way**
- The Ξ polarization is measured to be slightly larger than Λ, but the significance of that is below 1σ. The Ω global polarization shows a hint of being even larger
- Is there a dependence of Ξ and Ω global polarization on collision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

Extraction of Ξ and Ω global polarization

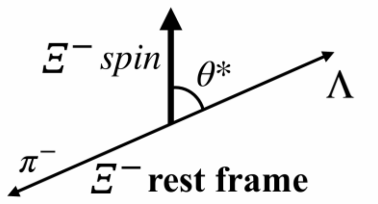
PDG2021

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



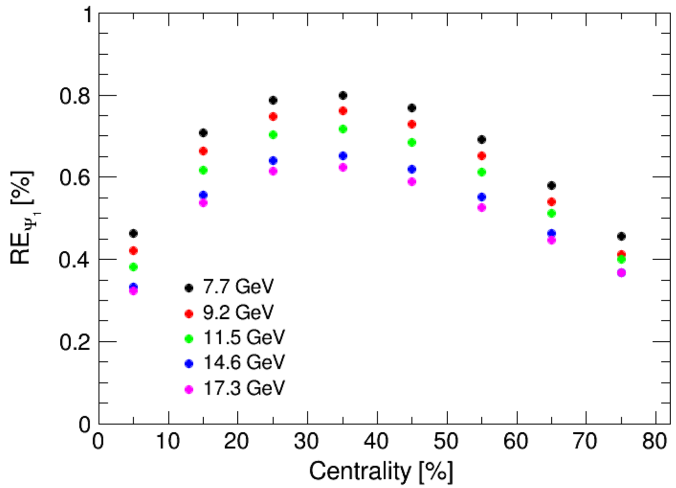
- Two methods for extracting the Ξ and Ω polarization
  - Measured via daughter Λ angle distribution in Ξ rest frame

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



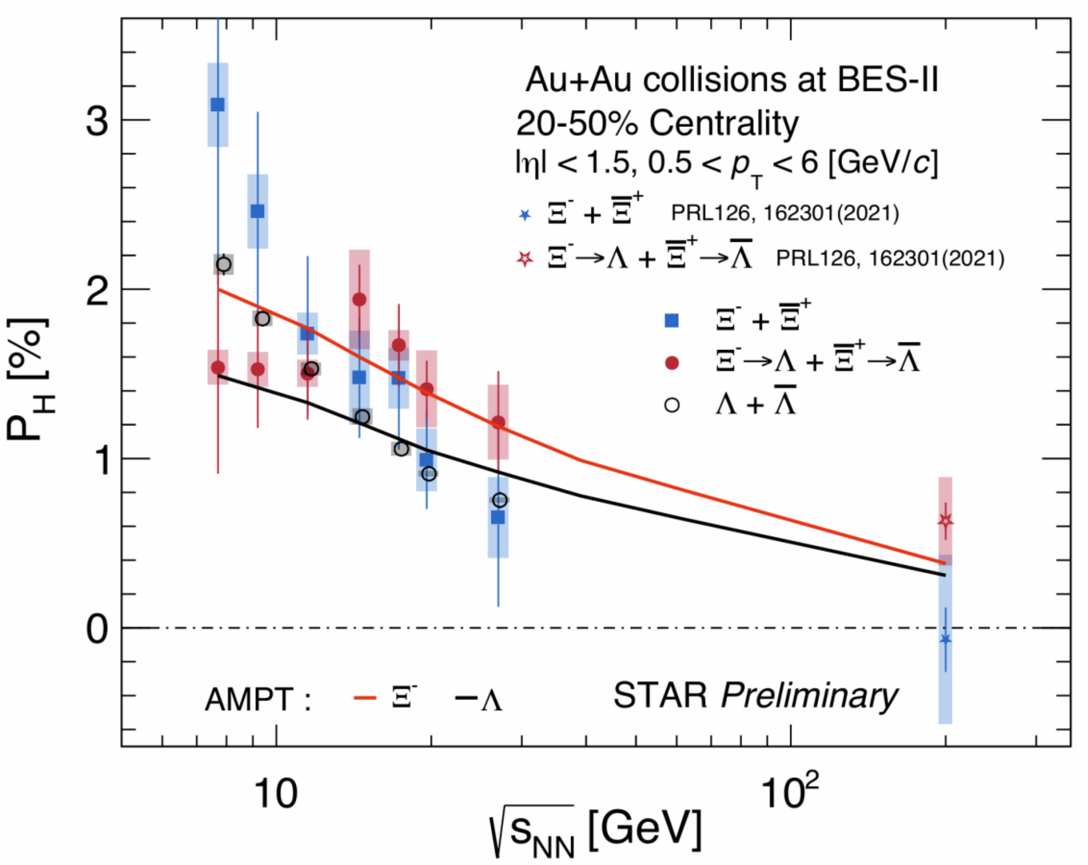
  - via daughter Λ polarization with spin transfer factor ($C_{\Xi^- \rightarrow \Lambda} = 0.944, C_{\Omega^- \rightarrow \Lambda} = 1.0$ is assumed)

- First-order event plane reconstructed by EPD



$\Xi^- + \bar{\Xi}^+$ global polarization

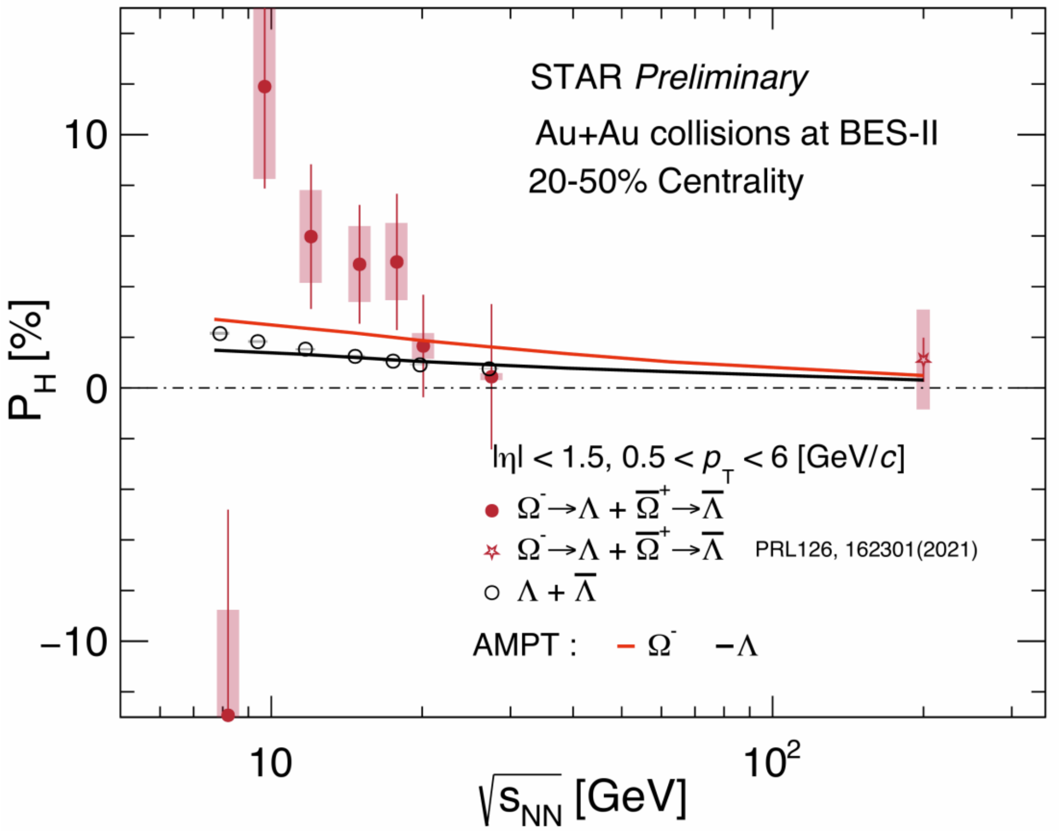
Model calculation:
H. Li, X. Xia, X. G. Huang, H. Z. Huang Phys. Lett. B 827, 136971 (2022)



- For the first time, significant global polarization of $\Xi^- + \bar{\Xi}^+$ has been observed(~ 5 σ)
  - $P_H = 1.940 \pm 0.205(stat.) \pm 0.293(syst.)$ at 14.6 GeV
- Global polarization of $\Xi^- + \bar{\Xi}^+$ decrease with collision energy
- $\Xi^- + \bar{\Xi}^+$ global polarization are consistent between direct and indirect measurement methods
- No obvious difference between $\Lambda + \bar{\Lambda}$ and $\Xi^- + \bar{\Xi}^+$ global polarization within uncertainties

$\Omega^- + \overline{\Omega}^+$ global polarization

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



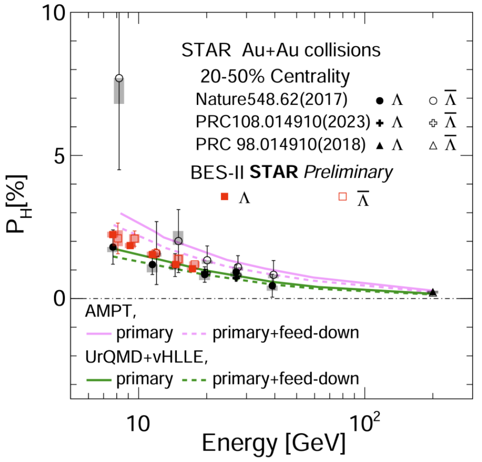
- Global polarization of $\Omega^- + \overline{\Omega}^+$ tend to decrease with collision energy
- A hint of larger $\Omega^- + \overline{\Omega}^+$ polarization than $\Lambda + \overline{\Lambda}$ in lower energies
- Possible **Λ, Ξ, Ω** global polarization difference?

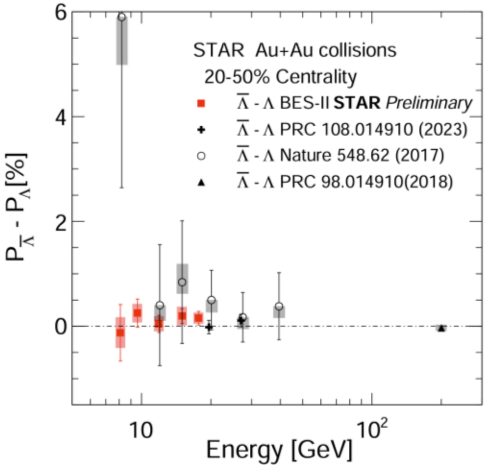
$P_\Lambda \cong P_s$, assuming that $P_{u.d} \sim P_s$ ⟹ $P_\Xi \sim P_\Lambda$, $P_\Omega \sim \frac{5}{3} P_\Lambda$

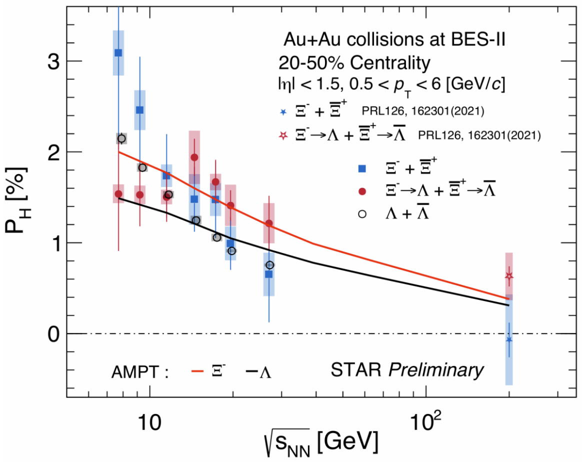
F. Becattini et al., Phys. Rev. C 95.054902(2017)

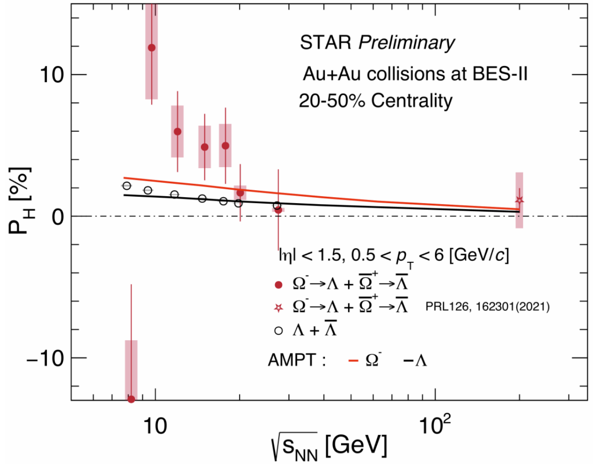
Summary

- High precision measurements of Λ polarization with BES-II, no splitting between P_{Λ} and $P_{\bar{\Lambda}}$ within uncertainties
- A significant $\Xi^{-} + \bar{\Xi}^{+}$ global polarization is observed (~5σ), and also decrease with collision energy.
- Hint of larger $\Omega^{-} + \bar{\Omega}^{+}$ polarization at lower energies









Summary

- High precision measurements of Λ polarization with BES-II, no splitting between P_{Λ} and $P_{\bar{\Lambda}}$ within uncertainties
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- Hint of larger $\Omega^- + \bar{\Omega}^+$ polarization at lower energies

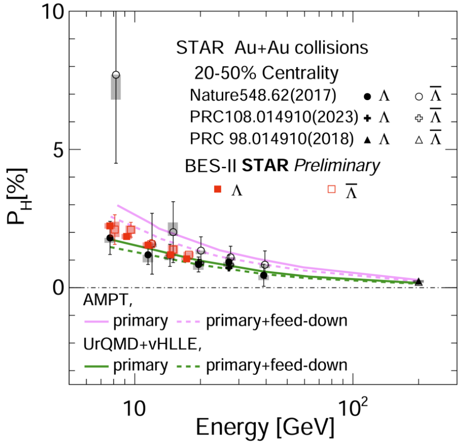
- Outlook: spin correlation of hyperon pair in heavy-ion collision

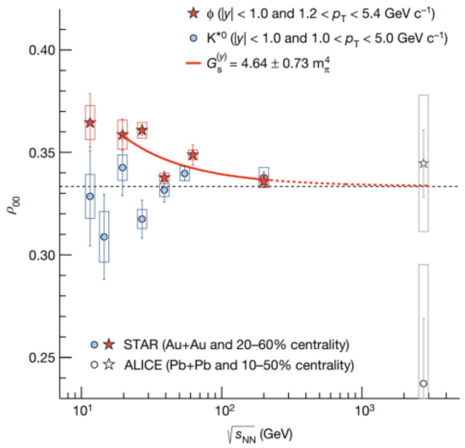
Measurements of hyperon spin correlation in Au+Au collisions at BES-II energies at STAR

Speaker: Xingrui Gou

Session: Spin in heavy-ion collisions

Sep 23, 5:40 PM





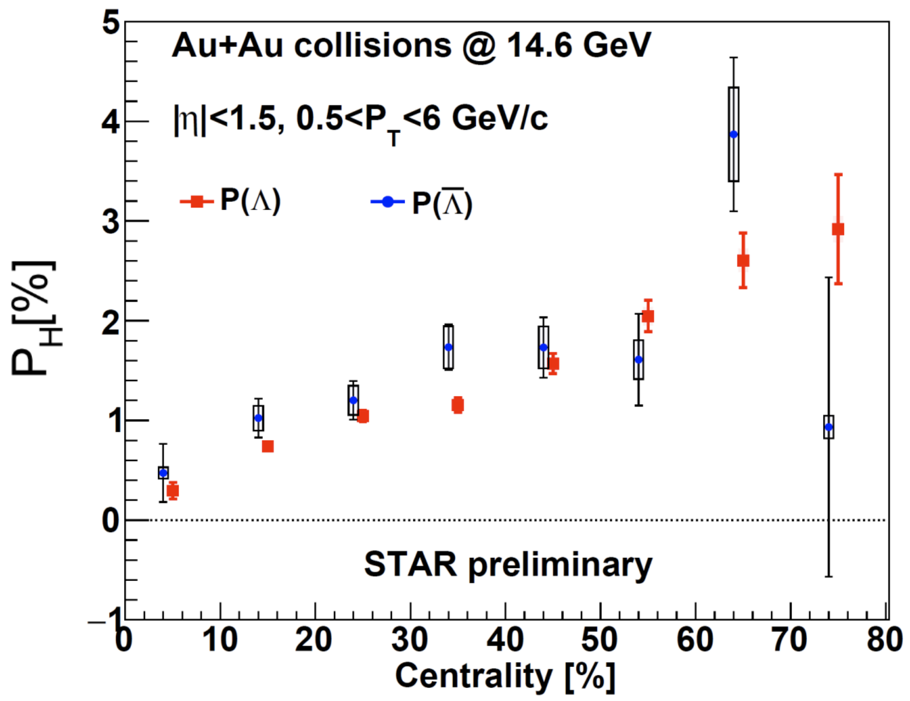
$$\langle P_q P_{\bar{q}} \rangle \neq \langle P_q \rangle \langle P_{\bar{q}} \rangle$$

Hyperon spin correlation in heavy-ion collisions?

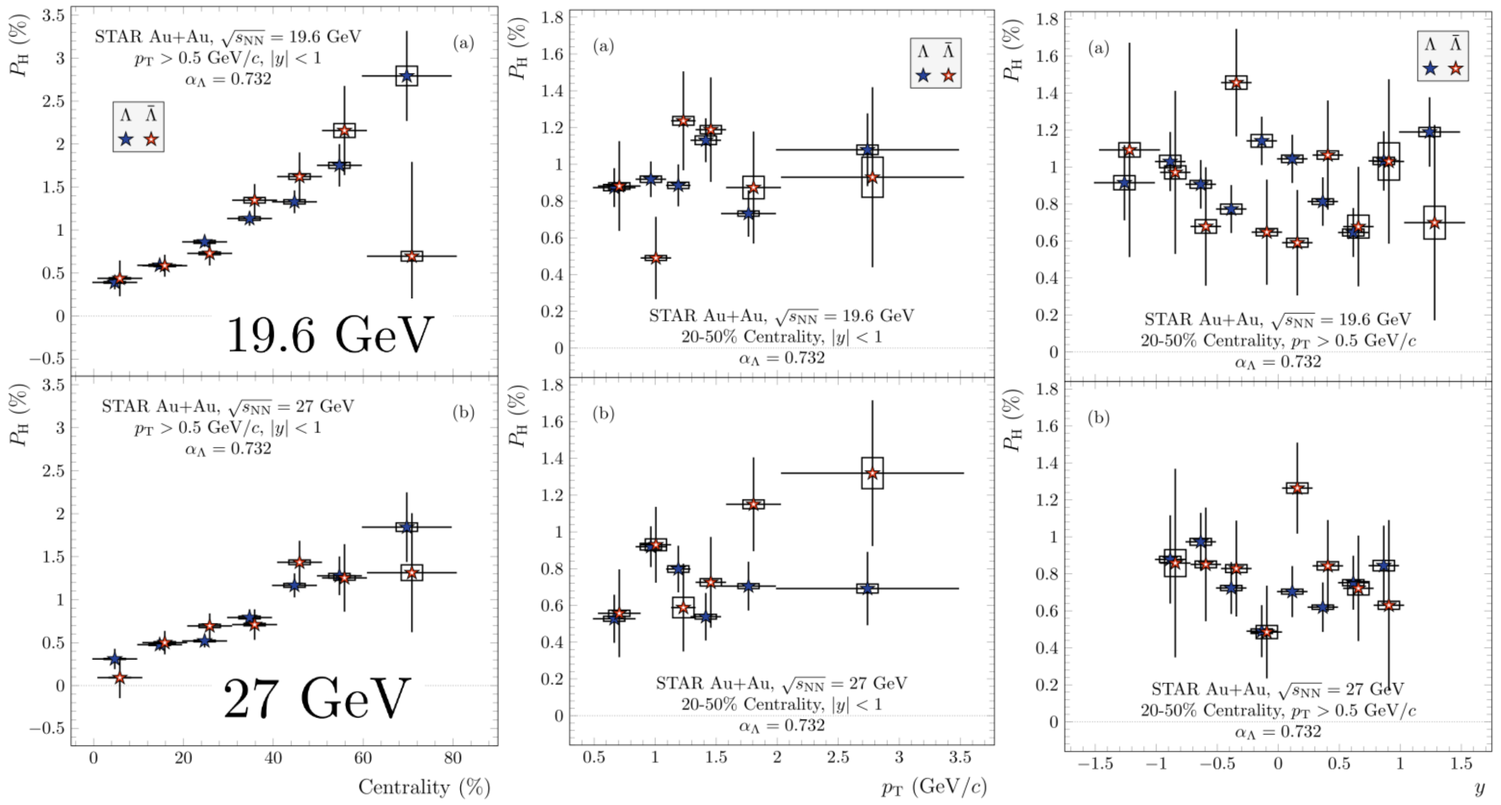
J.-p. Lv, Z.-h. Yu, Z.-t. Liang, Q. Wang, and X.-N. Wang, Phys. Rev. D 109, 114003 (2024)

Back Up

Result of Global Polarization from BES-II



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



- ☐ Clear centrality dependence of Λ and $\bar{\Lambda}$
- ☐ Trend consistent with expectation from vorticity

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 A angular distribution, the angular distribution of the daughter proton is given by:

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

$$\Rightarrow \quad \mathbf{P}_\Lambda = \frac{1}{2(J+1)}[1 + (2J+1)\gamma_\Omega]\mathbf{P}_\Omega \ .$$

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

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