Measurements of Hyperons Global Polarization in Heavy Ion Collisions from STAR

荀兴瑞 (for the STAR Collaboration)
山东大学

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暨第十四届全国中高能核物理专题研讨会
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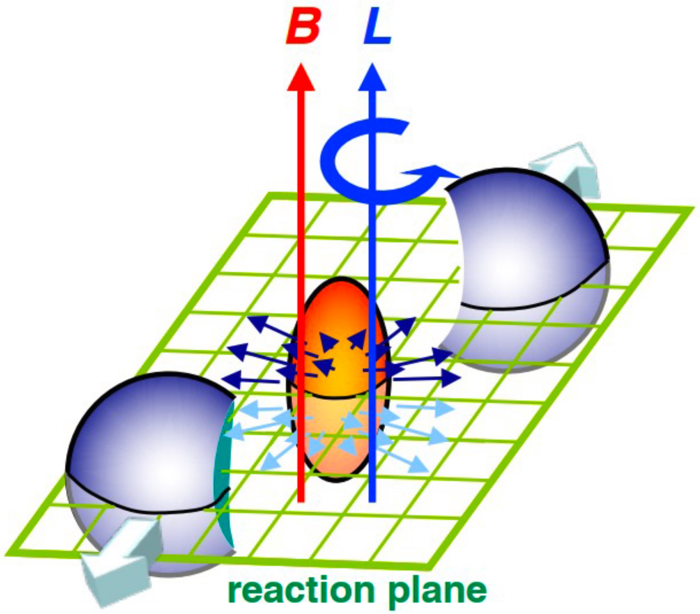
NSFC

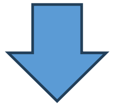
Outline

- Brief introduction on orbital angular momentum and polarization
- Global polarization analysis process
- Recent STAR experiment results
  - Λ global polarization
  - Ξ and Ω global polarization
- Summary

Orbital angular momentum and polarization

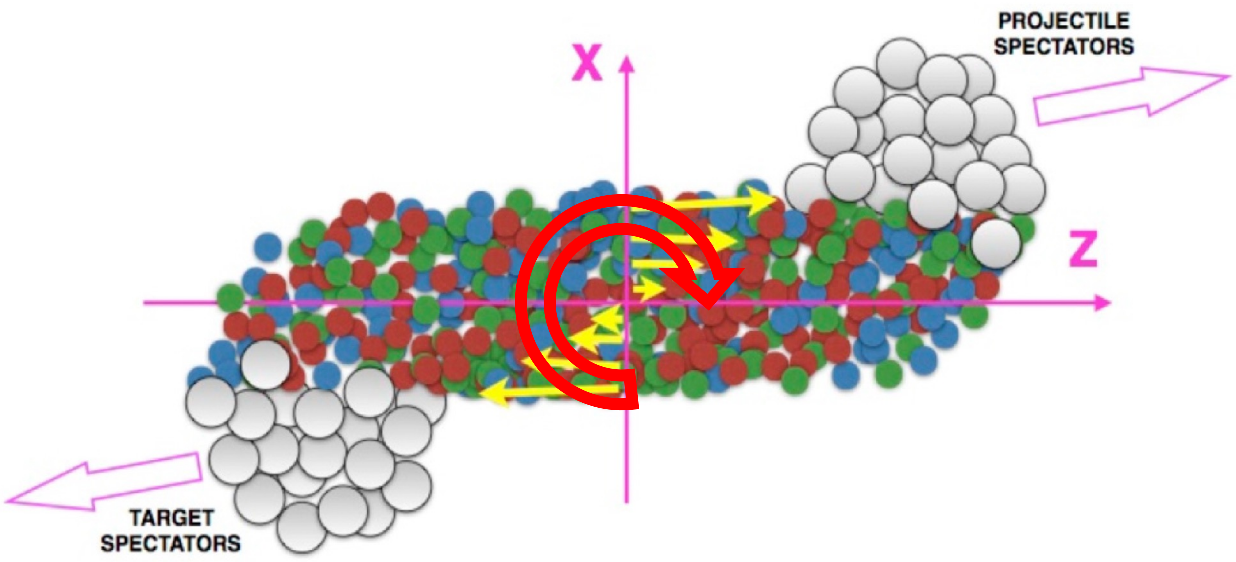


Orbital angular momentum



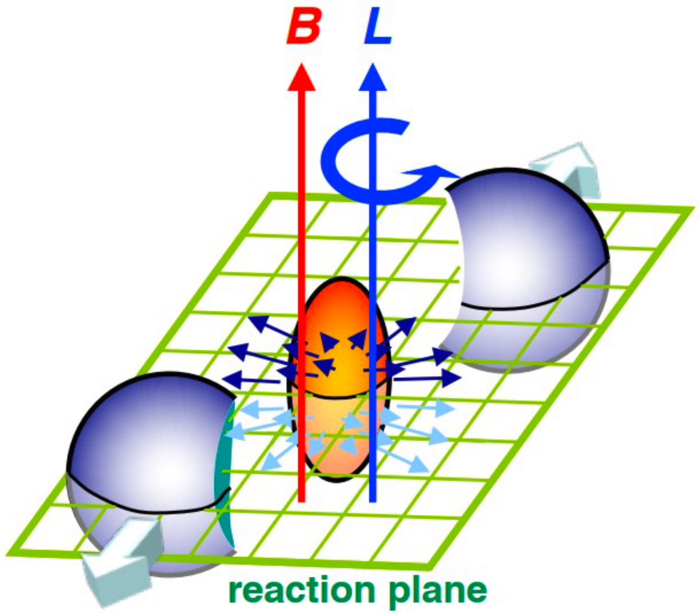
Local fluid vorticity $\omega = \frac{1}{2}\nabla\times v$

The most vortical fluid $\sim 10^{20} - 10^{21} s^{-1}$
(Au+Au@RHIC at ***b***=10 fm)



Z.-T. Liang and X.-N. Wang, PRL 94, 102301 (2005)

Orbital angular momentum and polarization



Orbital angular momentum

Local fluid vorticity $\omega = \frac{1}{2}\nabla\times v$

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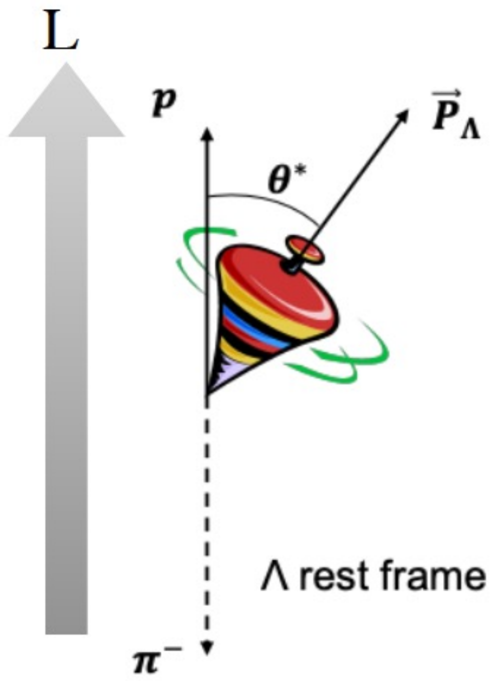
(Au+Au@RHIC at ***b***=10 fm)



Leads to global polarization along ***L*** though spin-orbit coupling

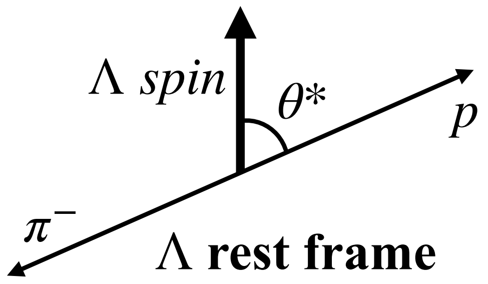
Z.-T. Liang and X.-N. Wang, PRL 94, 102301 (2005)

Global polarization measurement

- “Self-analyzing”, parity-violating weak decay channel of hyperons
  - Daughter baryon is preferentially emitted in the direction of the hyperon spin

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

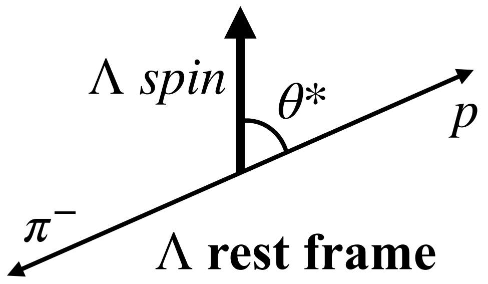
α_H : hyperon decay parameter
P_H : hyperon polarization
θ^* : polarization angle



$\Lambda \rightarrow p + \pi^-$
(BR:63.9%,cτ~7.9cm)

Global polarization measurement

- "Self-analyzing", parity-violating weak decay channel of hyperons
  - Daughter baryon is preferentially emitted in the direction of the hyperon spin
  - Measured via the distribution of the azimuthal angle of the hyperon decay baryon (in the hyperon rest frame) with respect to the reaction plane.

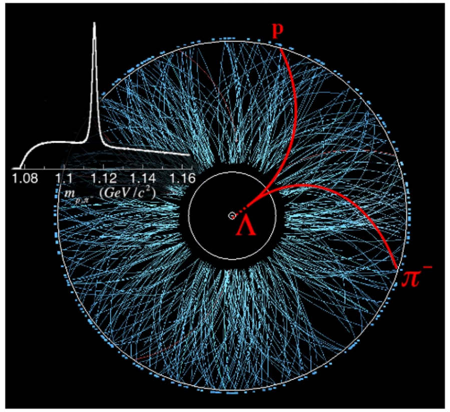


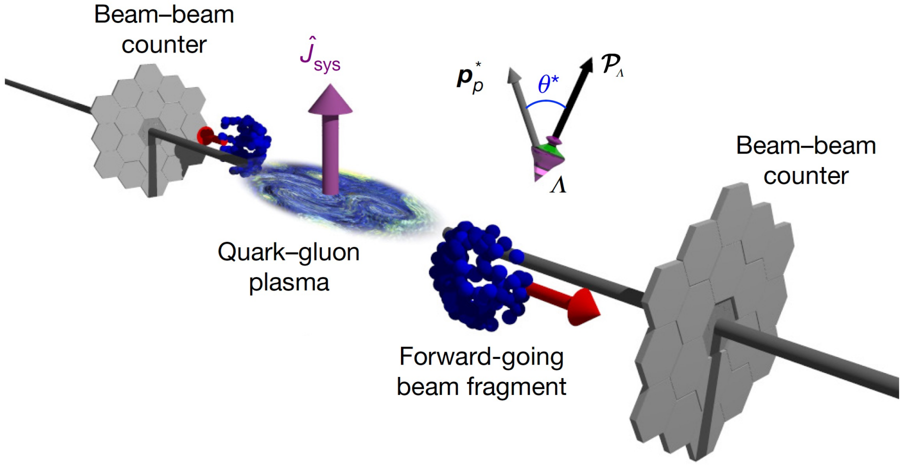
$\Lambda \rightarrow p + \pi^-$
(BR:63.9%,cτ~7.9cm)

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

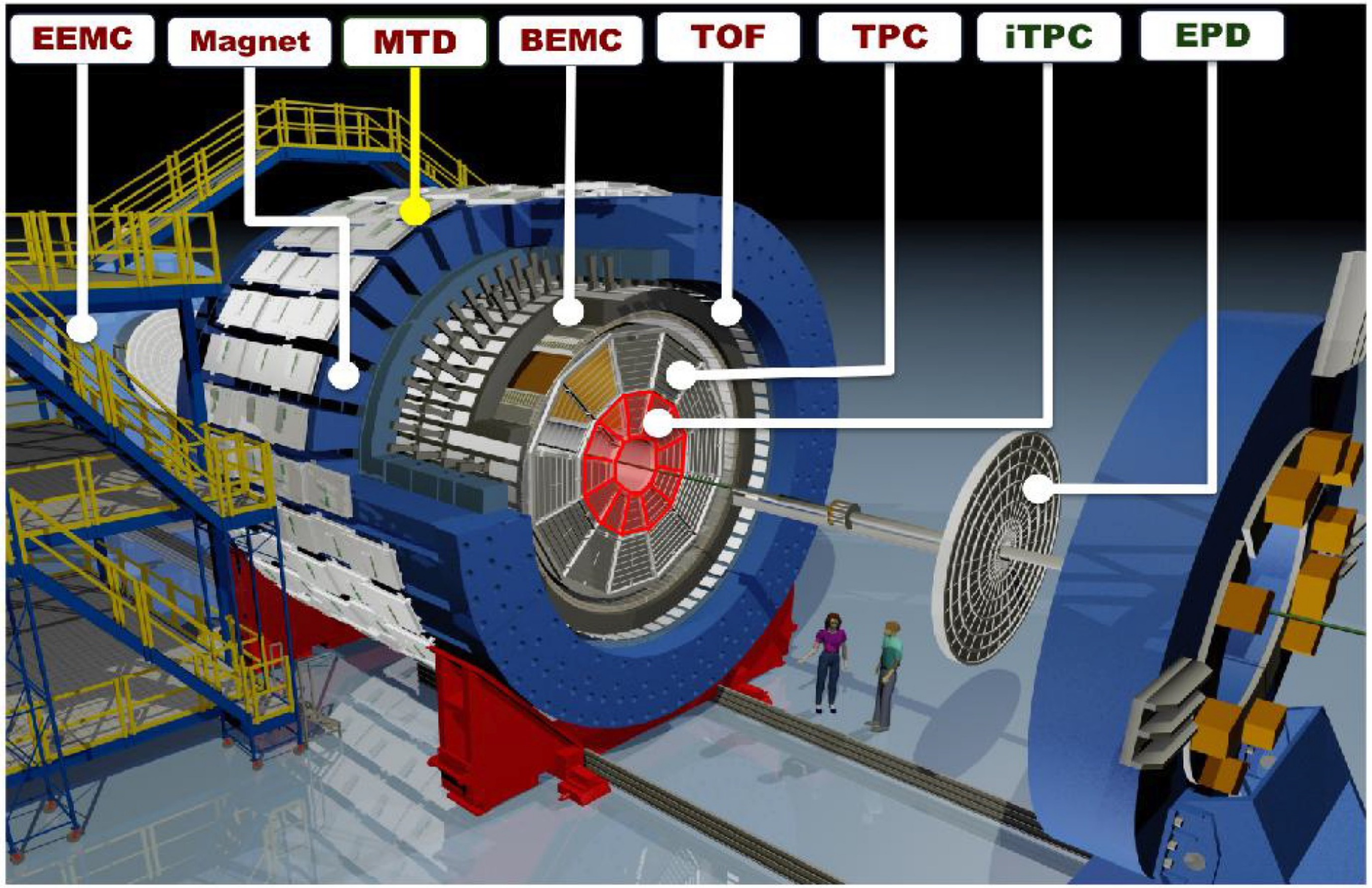
$\alpha_\Lambda = -\alpha_{\bar{\Lambda}} = 0.732 \pm 0.014$
A_0: Acceptance correction factor
Ψ_1: First-order event plane angle
$Res(\Psi_1)$: Event plane resolution

STAR, PRC76, 024915 (2007)



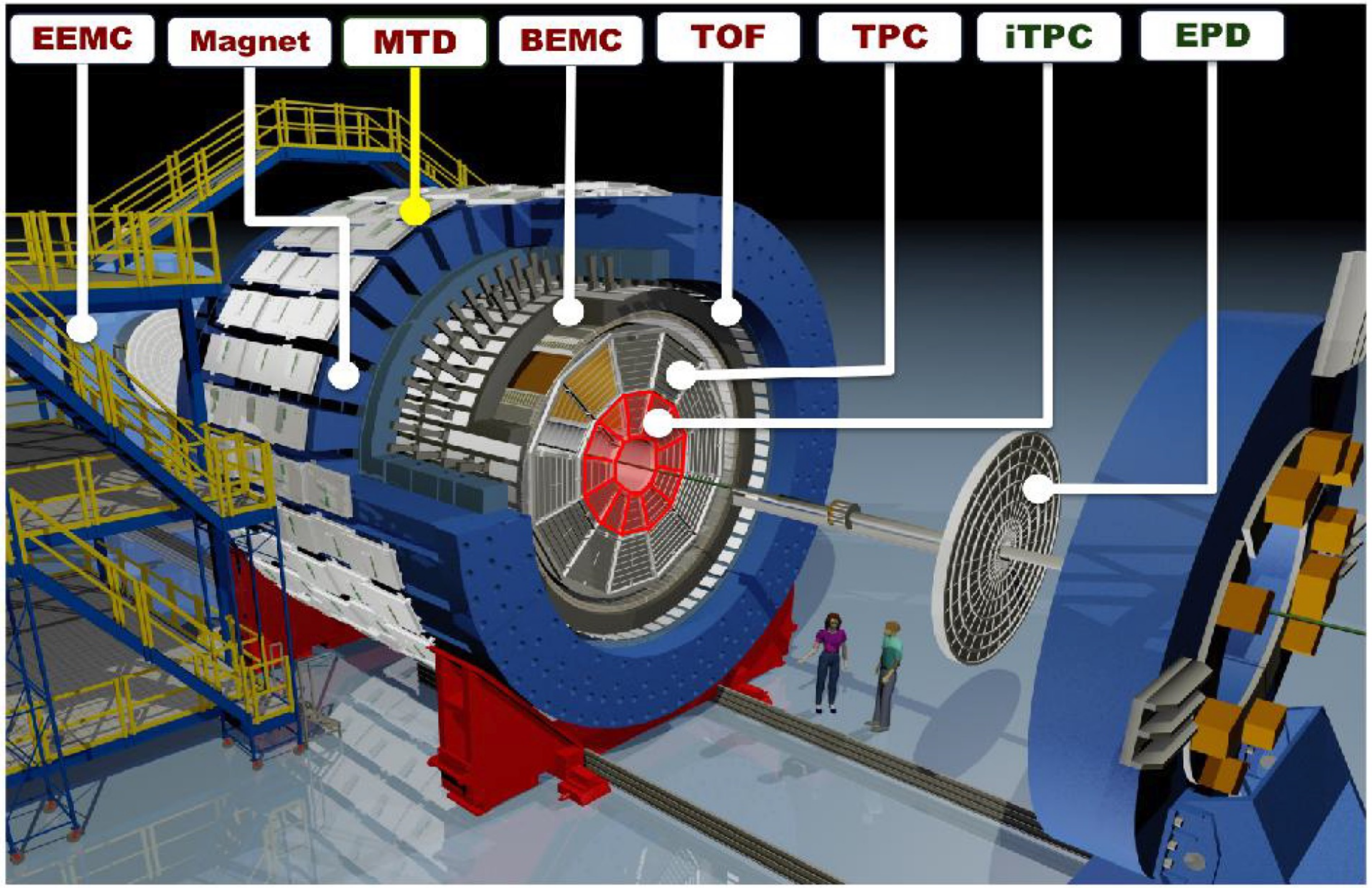


The STAR detector



- **Event Plane Detector**
  - Event plane reconstruction
  - $2.1 < |\eta| < 5.1$
- **Zero Degree Calorimeters**
  - Event plane reconstruction
  - $6.3 < |\eta|$
- **Time Projection Chamber**
  - Upgrade with inner TPC
  - Better track quality
  - Larger acceptance
  - $|\eta| < 1.0 \rightarrow |\eta| < 1.5$
- **Time Of Flight**
  - PID via particle velocity
  - $|\eta| < 0.9$

Event plane reconstruction



- **Event Plane Detector**
  - Event plane reconstruction
  - $2.1 < |\eta| < 5.1$

- **Zero Degree Calorimeters**
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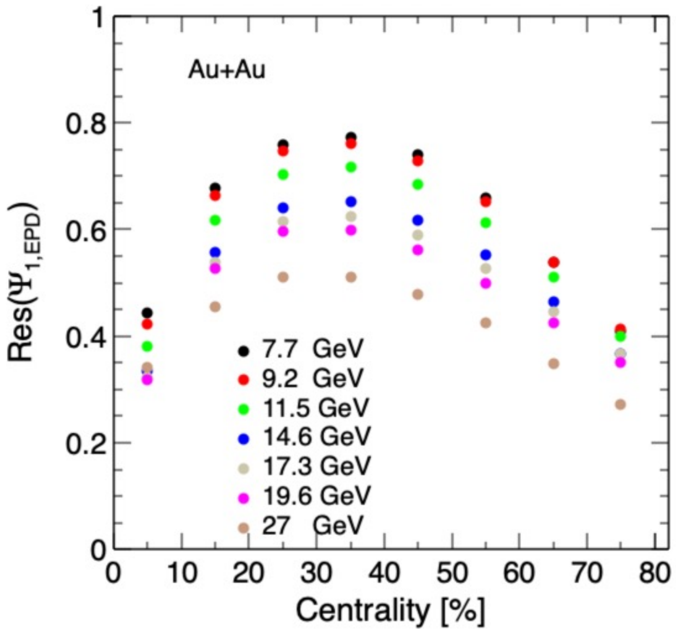
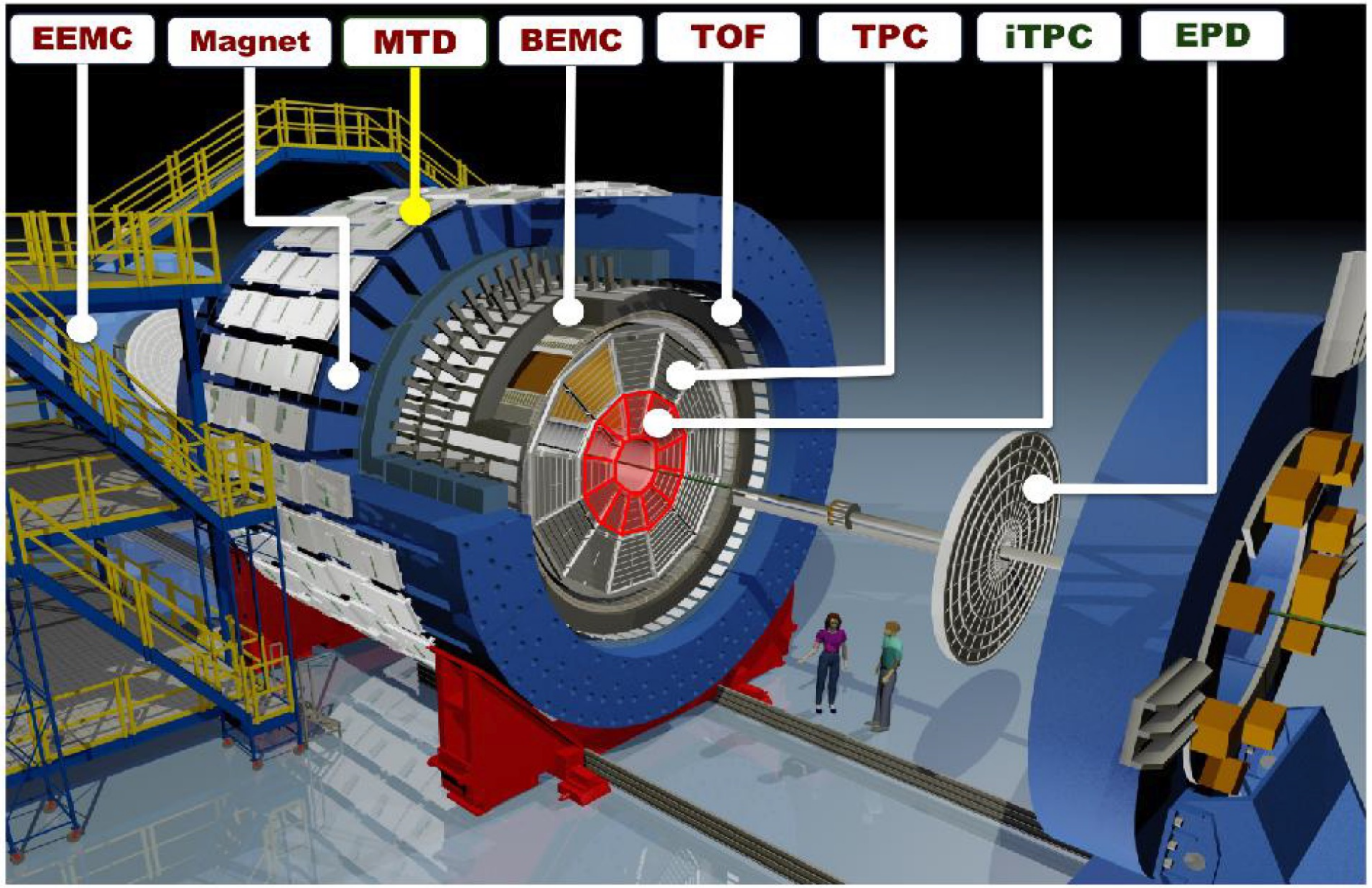
  - $6.3 < |\eta|$

Event plane resolution



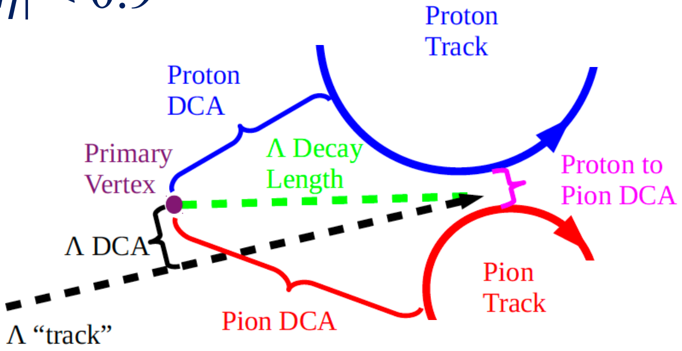
- First-order event plane reconstructed by EPD, ZDC

Hyperons reconstruction



- **Time Projection Chamber**
  - Upgrade with inner TPC
  - Better track quality
  - Larger acceptance
  - $|\eta| < 1.0 \rightarrow |\eta| < 1.5$

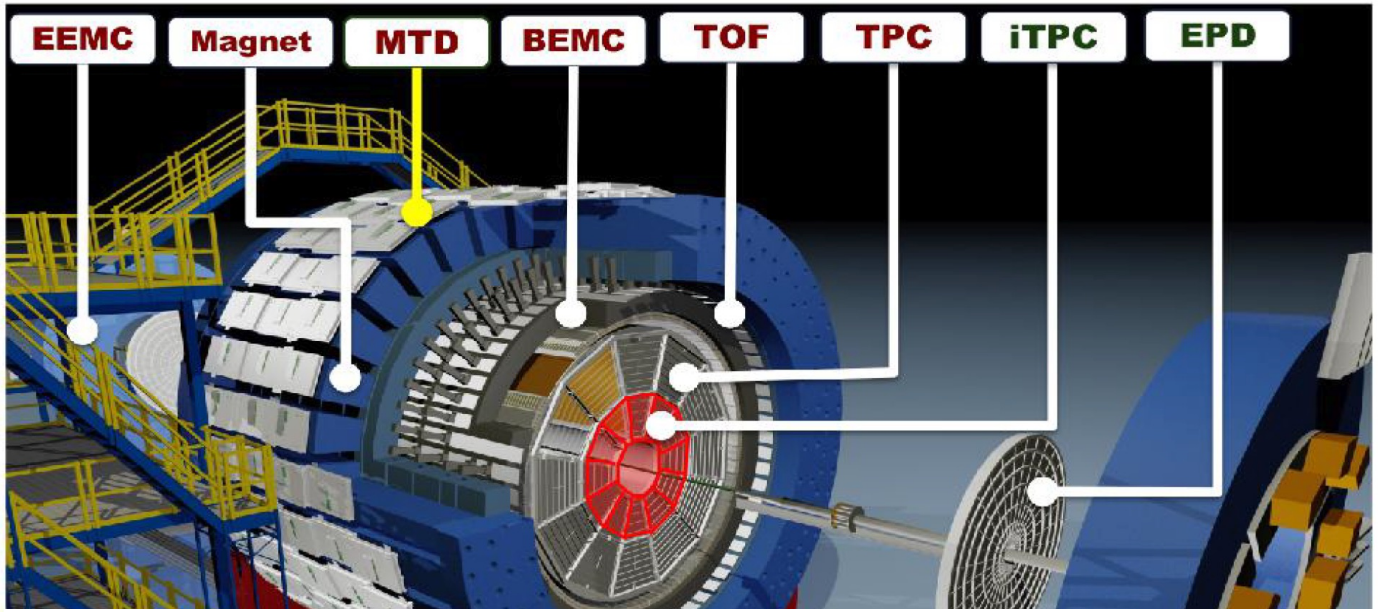
- **Time Of Flight**
  - PID via particle velocity
  - $|\eta| < 0.9$



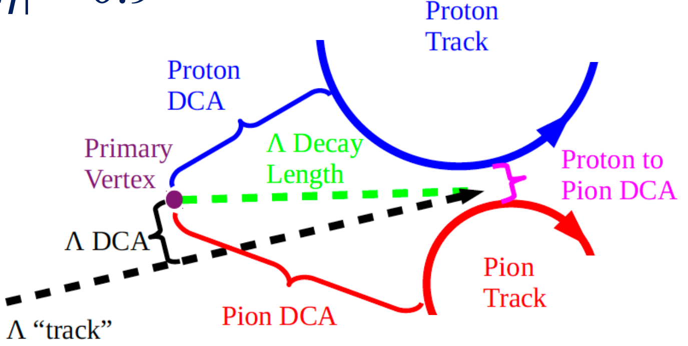
- Hyperons reconstructed using KF Particle package

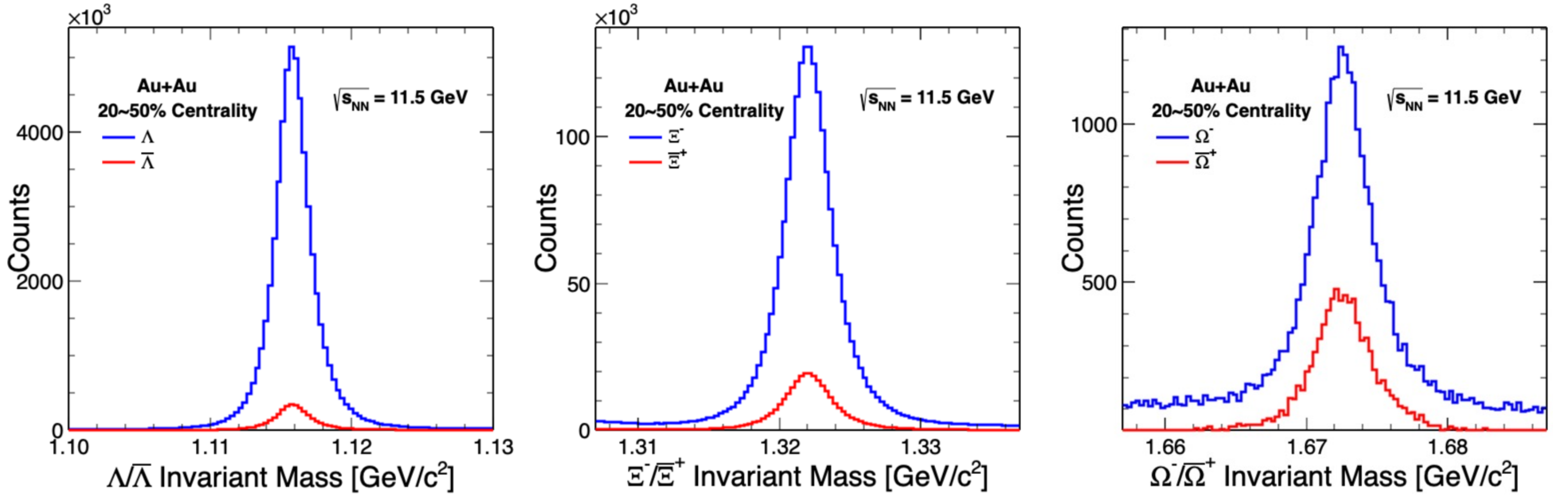
- $\Lambda \rightarrow p + \pi^-$
- $\Xi^- \rightarrow \Lambda + \pi^-$, $\Lambda \rightarrow p + \pi^-$
- $\Omega^- \rightarrow \Lambda + K^-$, $\Lambda \rightarrow p + \pi^-$

Hyperons reconstruction



- **Time Projection Chamber**
  - Upgrade with inner TPC
  - Better track quality
  - Larger acceptance
  - $|\eta| < 1.0 \rightarrow |\eta| < 1.5$
- **Time Of Flight**
  - PID via particle velocity
  - $|\eta| < 0.9$

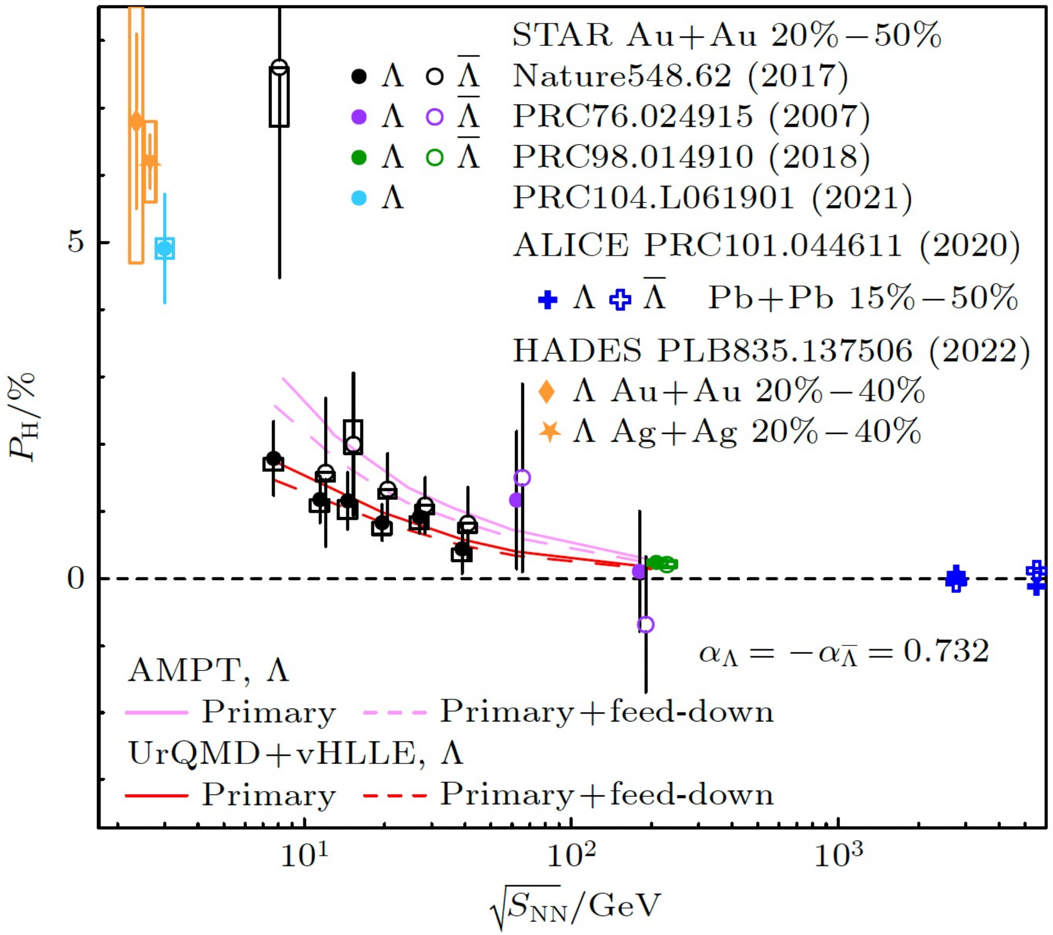




- $\Lambda \rightarrow p + \pi^-$
- $\Xi^- \rightarrow \Lambda + \pi^-$, $\Lambda \rightarrow p + \pi^-$
- $\Omega^- \rightarrow \Lambda + K^-$, $\Lambda \rightarrow p + \pi^-$

Observation of Λ global polarization

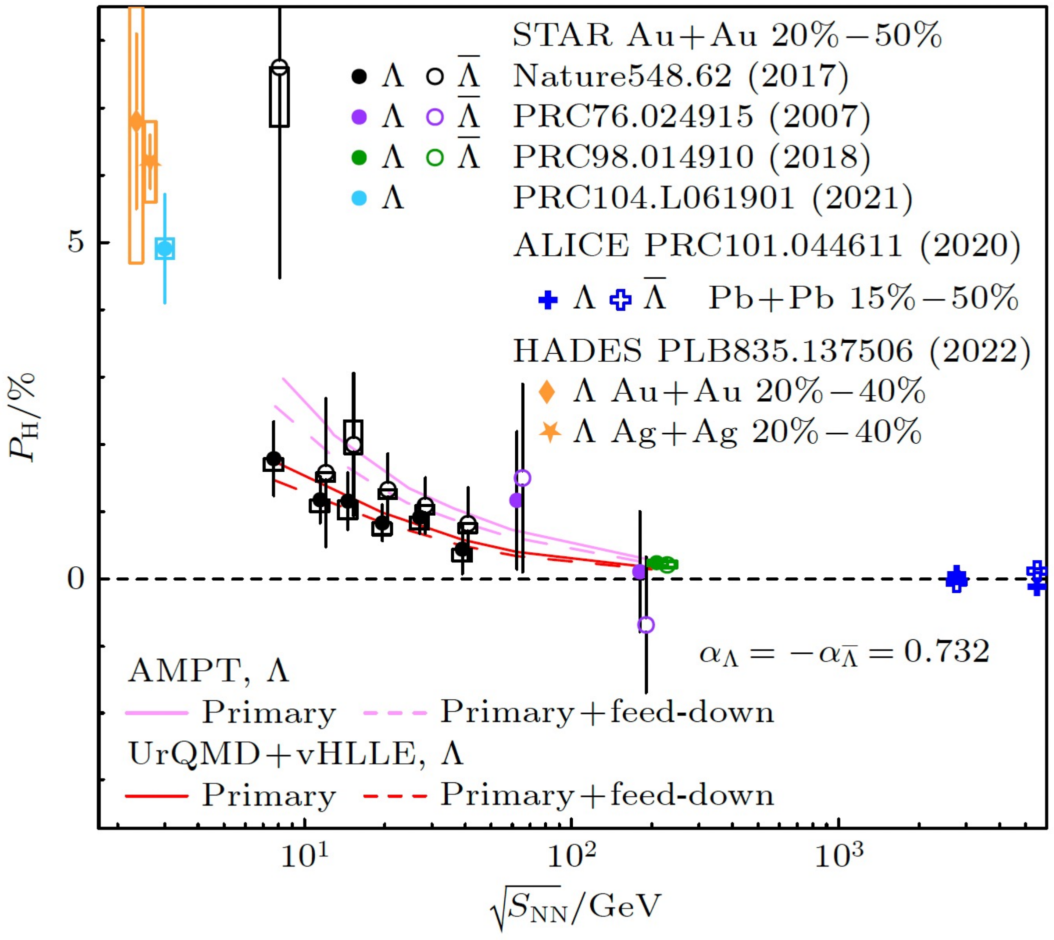
Acta Phys. Sin. Vol. 72, No. 7(2023) 072401



- STAR, first measurement in AuAu 200 GeV, P_H<2%
  PRC 76, 024915 (2007)
- STAR, first observation in BES-I
  Nature 548, 62 (2017)
- STAR, high precise P_H at 200 GeV
  PRC 90, 014910 (2018)
- ALICE, LHC energy region
  PRC 101, 044611 (2020)
- STAR, P_H at 3 GeV
  PRC 104, L061901 (2021)
- HADES energy region, consistent with STAR
  PLB 835,137506(2022)
- STAR, P_H at 19.6 and 27 GeV BES-II
  PRC108,014910(2023)

Energy dependence of Λ global polarization

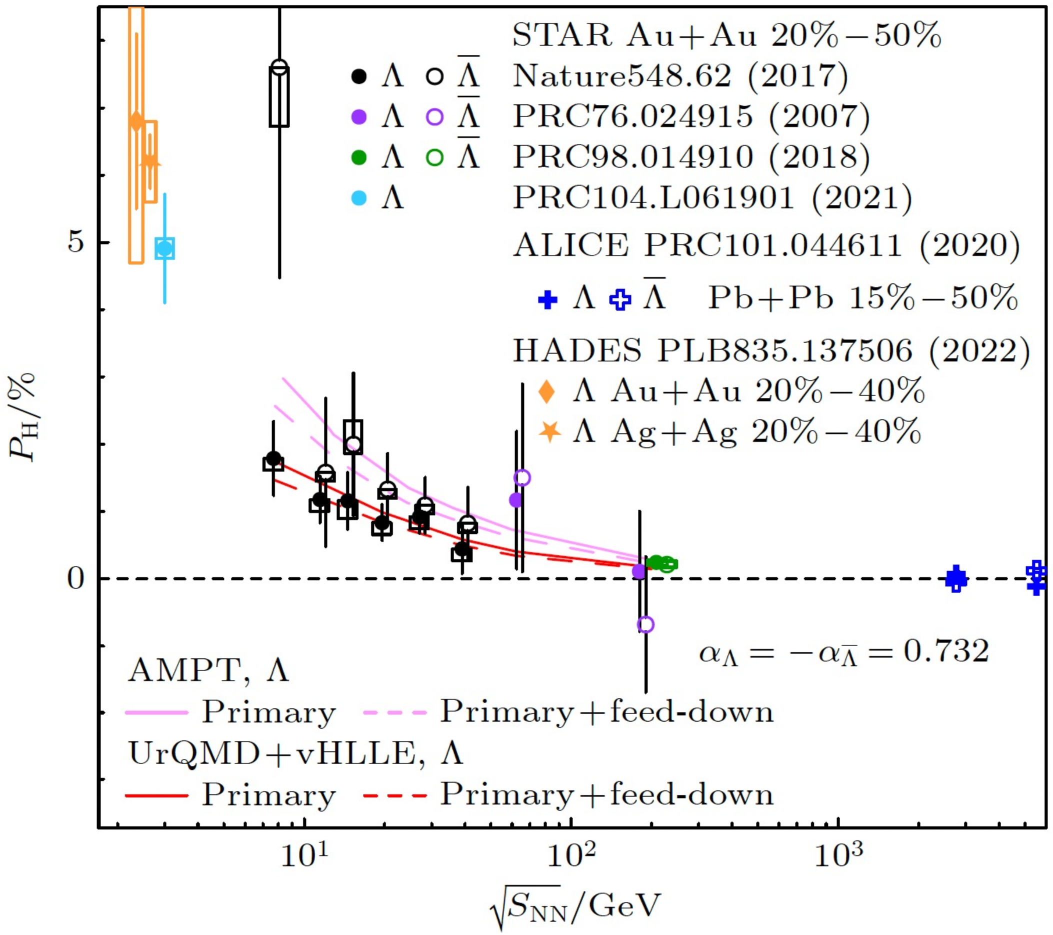
Acta Phys. Sin. Vol. 72, No. 7(2023) 072401



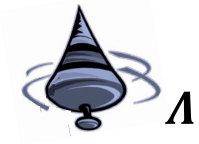
- Significant collision energy dependence, described well by various theoretical models
  - Liang and Wang, PRL 94,102301(2005),
  - Gao, Chen, Deng, Liang, Wang, Wang, PRC 77, 044902(2008)
  - Fang, Pang, Q. Wang, X. Wang, PRC 94, 024904(2016)
  - I. Karpenko and F. Becattini, EPJC(2017)77:213, UrQMD+vHLLE
  - H. Li et al., PRC 96, 054908 (2017), AMPT
  - Becattini, Lisa, Ann. Rev. Nucl. Part. Sci. 70, 395 (2020).
  - Huang, Liao, Wang, Xia, Lect. Notes Phys. 987, 281 (2021).
  - Becattini, Rept. Prog. Phys. 85, No.12, 122301 (2022)
  - Wang, Liang, Ma, ActaPhys. Sin. 72, No. 7 & 11 (2023)
  - Lv, Yu, Liang, Wang, Wang, PRD 109 (2024) 11, 114003
  - Zhang, Lv, Yu, Liang, PRD 110 (2024) 7, 074019
  - Palermo, et al. EPJC 84 9, 920 (2024)
  - Yi, Wu, Zhu, Pu, Qin, PRC 111 4, 044901 (2025)
  - Sun, et al., PRL 134 (2025) 2, 022301 ⋯⋯

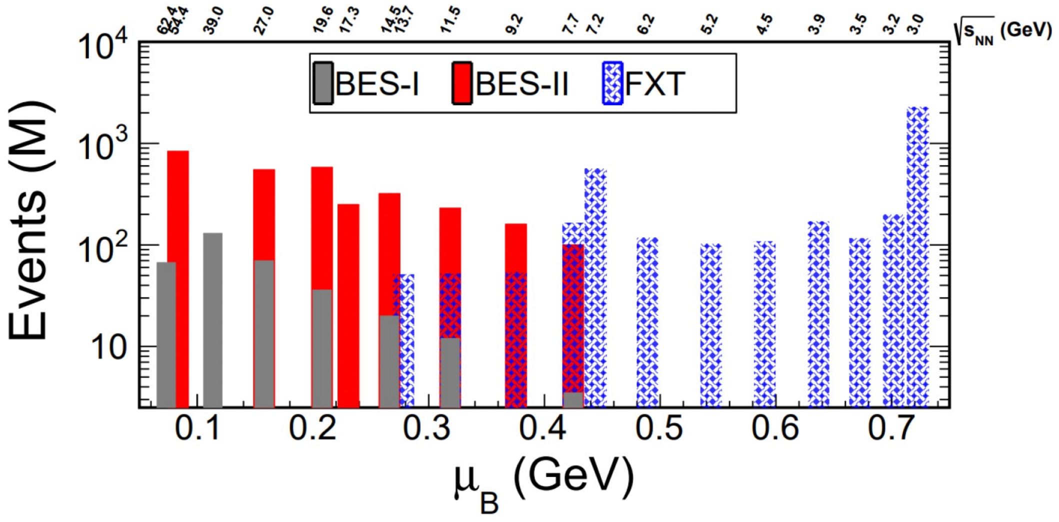
Energy dependence of Λ global polarization

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



$\overline{P_{\bar{\Lambda}}} \parallel \vec{B}$ $\quad$ $\overline{P_{\Lambda}} \parallel -\vec{B}$

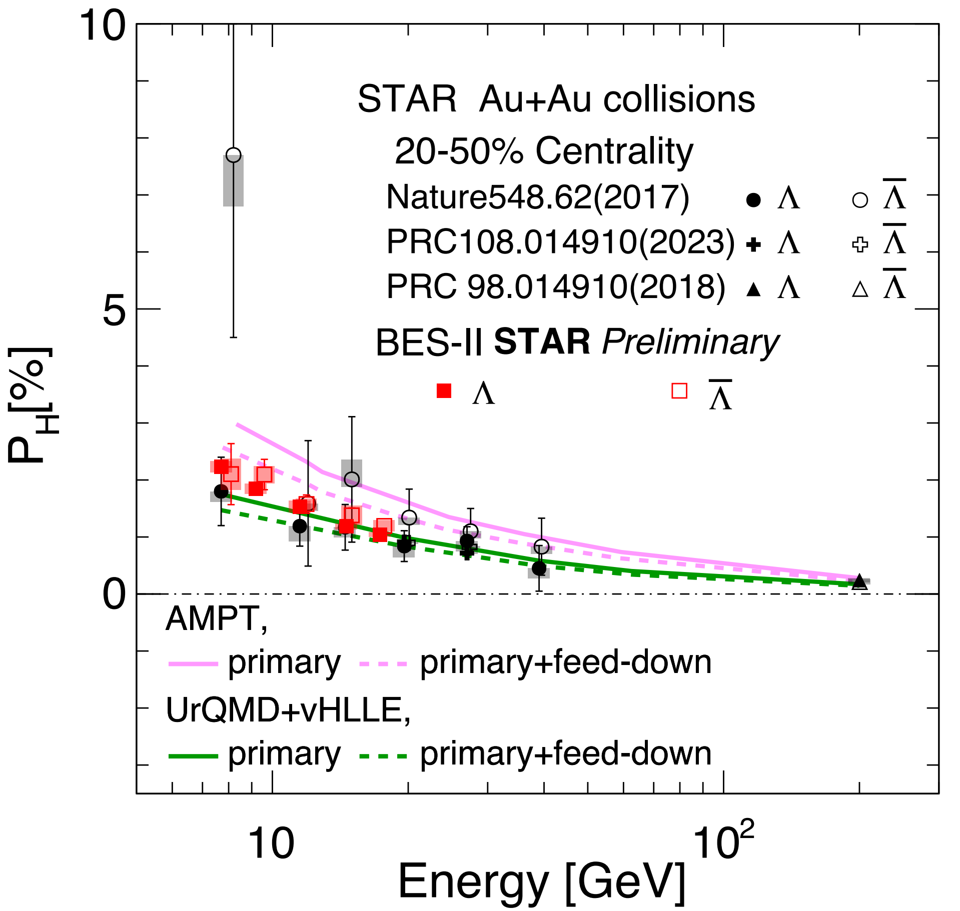




➢ *Possible difference between Λ and $\bar{\Lambda}$ due to magnetic field effect?*

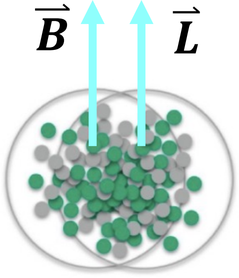
- ❑ STAR, P_H at 19.6 and 27 GeV BES-II, no splitting
  PRC108,014910(2023)
- ❑ Greatly improved precision from Beam Energy Scan phase-II at 7.7, 9.2, 11.5, 14.6, 17.3 GeV
- ❑ STAR, new results
  - Λ, Ξ, Ω global polarization

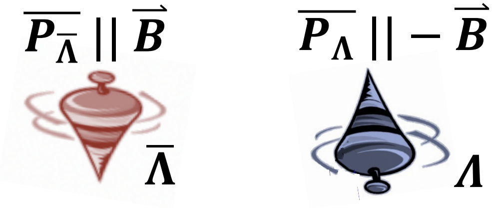
Energy dependence of Λ global polarization : from BES-II

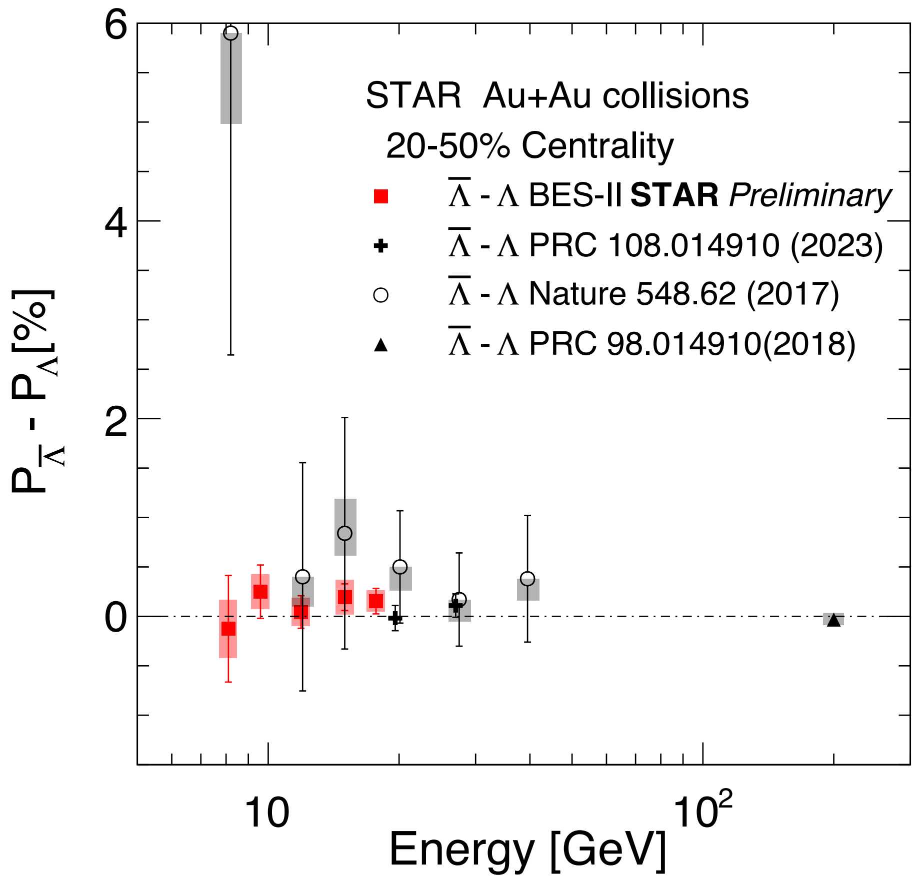


- New STAR preliminary results at $\sqrt{s_{NN}}$ = 7.7-17.3 GeV from BES-II
- Significant improvement in precision was achieved, collision energy dependence consistent with BES-I

Splitting of Λ and $\bar{\Lambda}$ global polarization : from BES-II







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

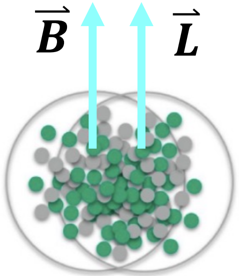
$$P_{\bar{\Lambda}} \approx \frac{1}{2}\frac{\omega}{T} - \frac{\mu_{\Lambda} B}{T}$$

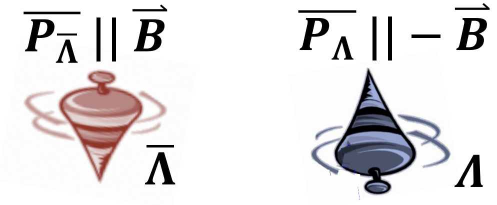
$$\Delta P_H = |P_{\bar{\Lambda}} - P_{\Lambda}| \approx \frac{2|\mu_{\Lambda}|B}{T}$$

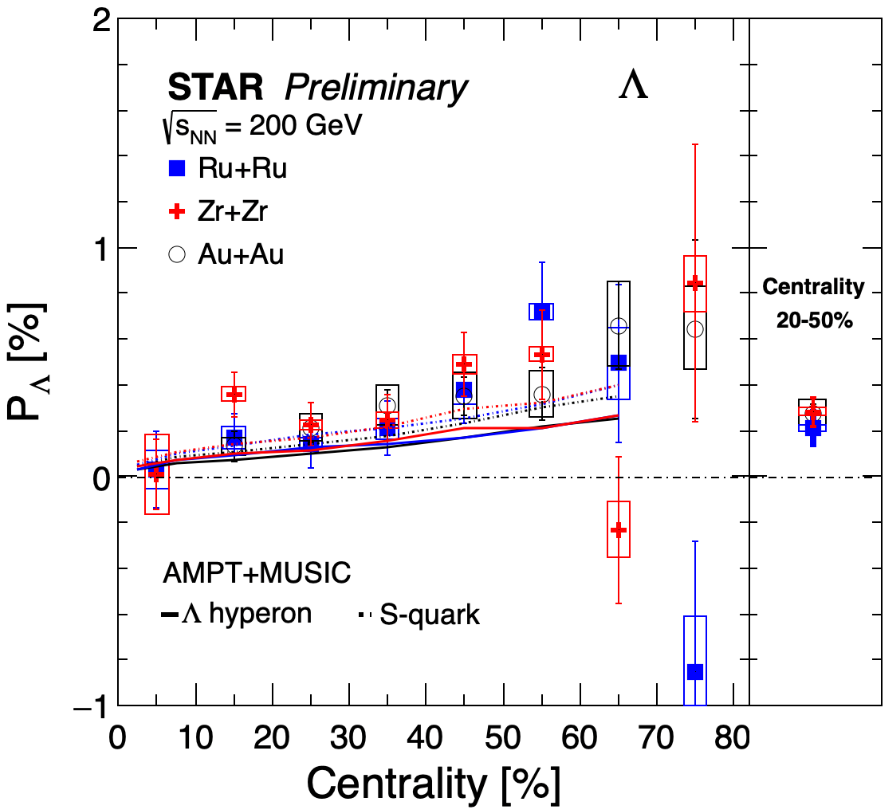
$T = 150\ MeV, \mu_{\Lambda} = -1.93\times 10^{-1}\ MeV/T$

- 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, PRC 108,014910(2023)

Measurements of Λ global polarization in isobar collisions







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

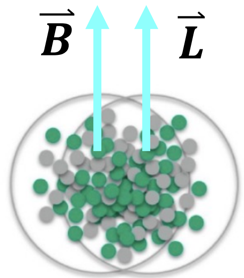
$$P_{\bar{\Lambda}} \approx \frac{1}{2}\frac{\omega}{T} - \frac{\mu_{\Lambda} B}{T}$$

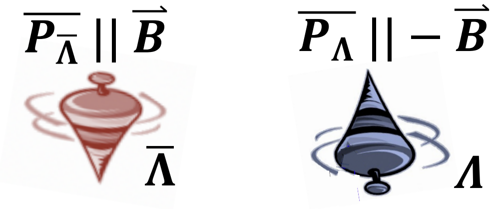
$$\Delta P_H = |P_{\bar{\Lambda}} - P_{\Lambda}| \approx \frac{2|\mu_{\Lambda}|B}{T}$$

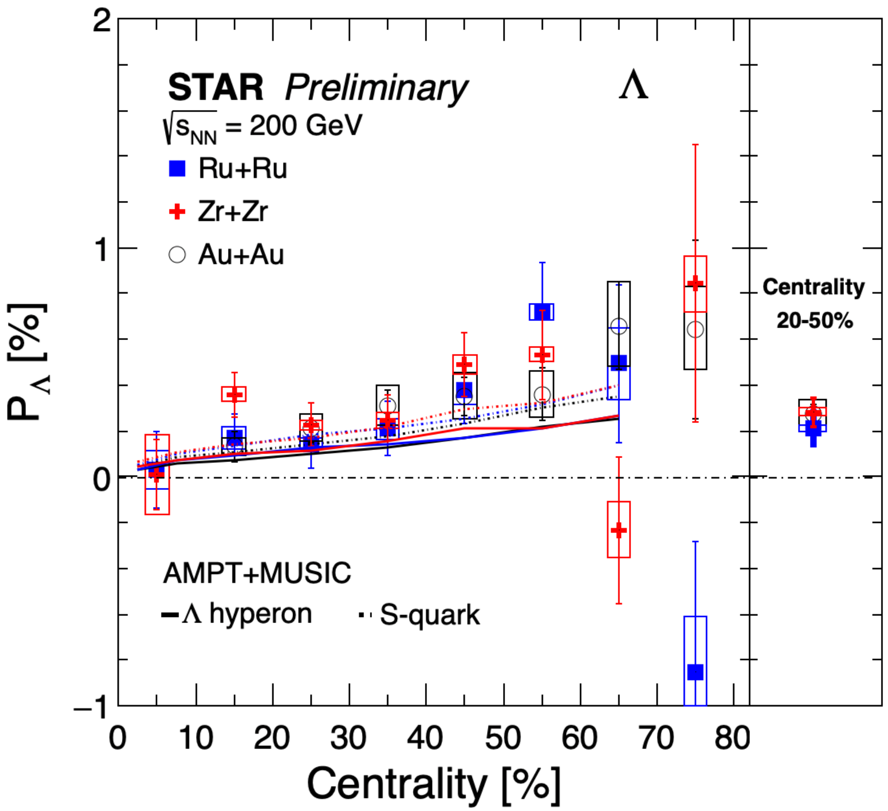
$$T = 150\ MeV, \mu_{\Lambda} = -1.93\times10^{-1}\ MeV/T$$

- Significant global polarization observed in isobar collisions, increase with centrality
- No significant difference of P_{Λ} between ${}^{96}_{44}Ru + {}^{96}_{44}Ru$ and ${}^{96}_{40}Zr + {}^{96}_{40}Zr$ collisions

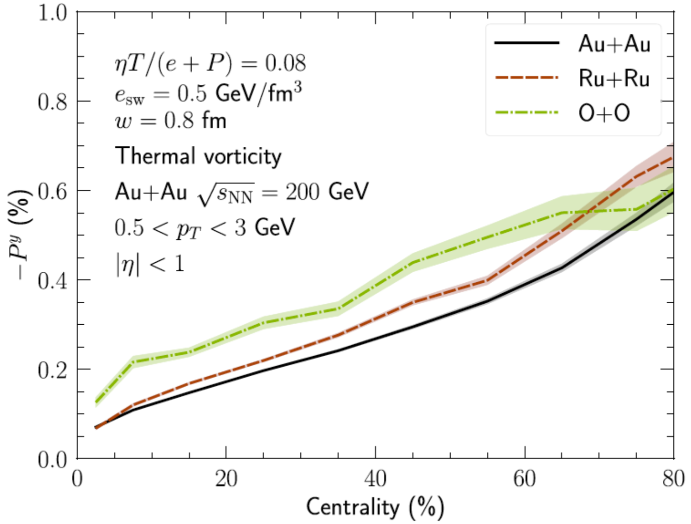
Measurements of Λ global polarization in isobar collisions







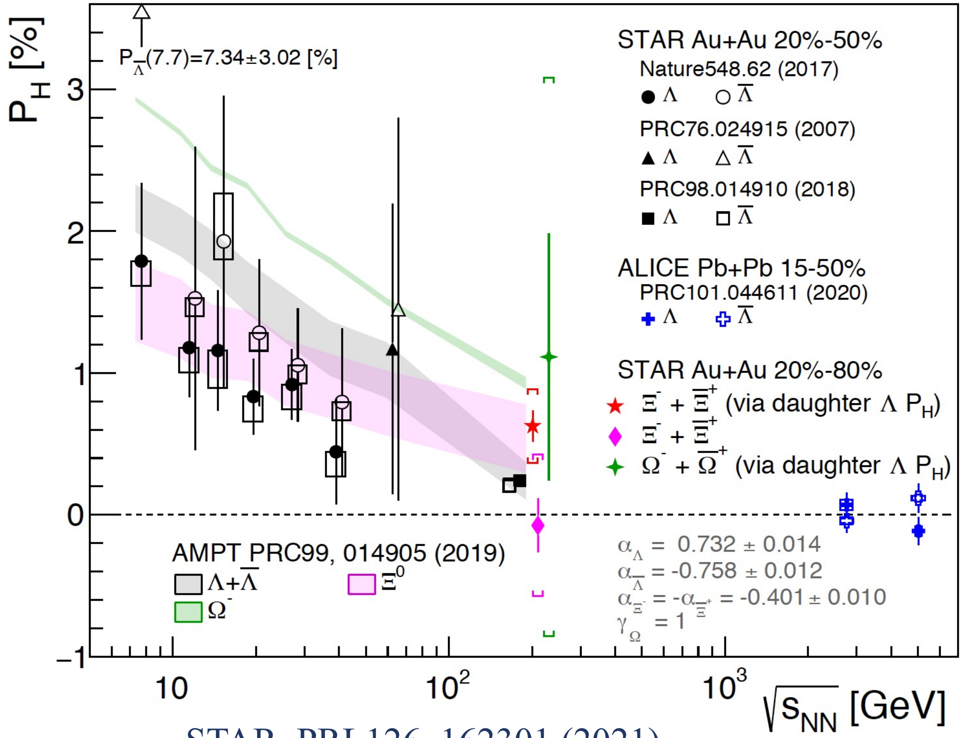
S. Alzhrani et al., PRC 106.014905



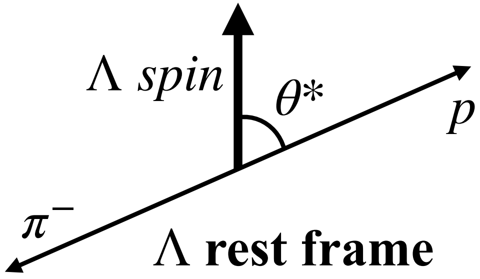
- Significant global polarization observed in isobar collisions, increase with centrality
- No significant difference of P_{Λ} between ${}^{96}_{44}\mathrm{Ru} + {}^{96}_{44}\mathrm{Ru}$ and ${}^{96}_{40}\mathrm{Zr} + {}^{96}_{40}\mathrm{Zr}$ collisions
- No system size dependence between Ru+Ru, Zr+Zr and Au+Au collisions within uncertainty

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

- Possible larger Ξ global polarization than Λ due to earlier production, vorticity evolution or spin quantum number
  - Via daughter Λ angle distribution in Ξ rest frame
  - Via daughter Λ polarization with spin transfer factor($C_{\Xi^- \to \Lambda} = 0.944, C_{\Omega^- \to \Lambda} = 1.0$ is assumed)



STAR, PRL126, 162301 (2021)



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

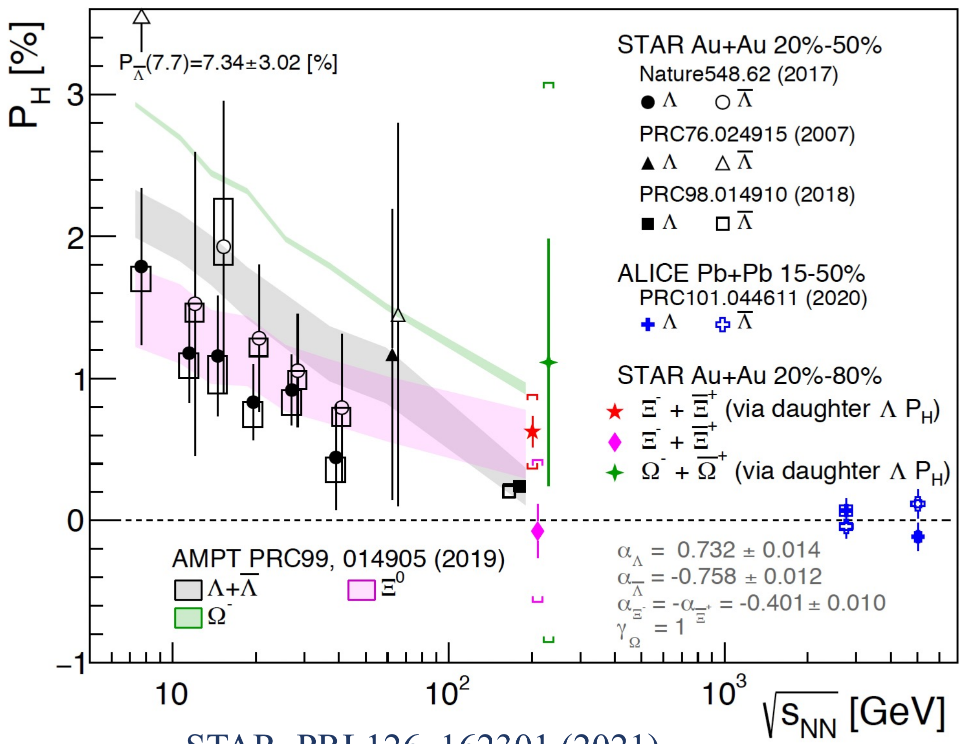
α_H : hyperon decay parameter
P_H : hyperon polarization
θ^* : polarization angle

Hyperon	Deacy 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

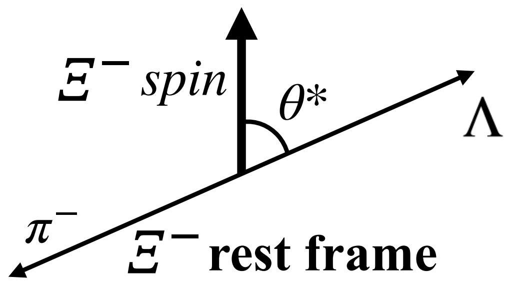
PDG2021

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

- Possible larger Ξ global polarization than Λ due to earlier production, vorticity evolution or spin quantum number
  - Via daughter Λ angle distribution in Ξ rest frame
  - Via daughter Λ polarization with spin transfer factor($C_{\Xi^- \to \Lambda} = 0.944$, $C_{\Omega^- \to \Lambda} = 1.0$ is assumed)



STAR, PRL126, 162301 (2021)



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

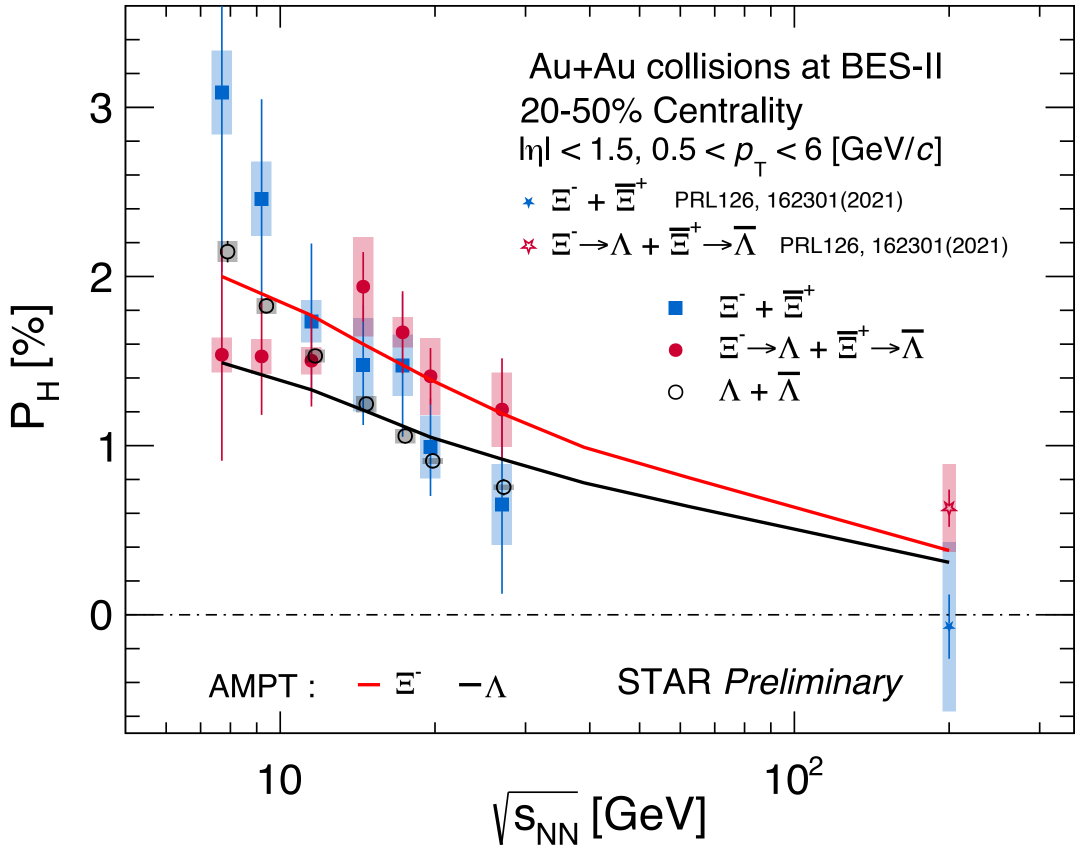
α_H : hyperon decay parameter
P_H : hyperon polarization
θ^* : polarization angle

- **Collision energy, centrality, p_T, η dependence?**
- **Possible Λ, Ξ, Ω global polarization difference?**

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

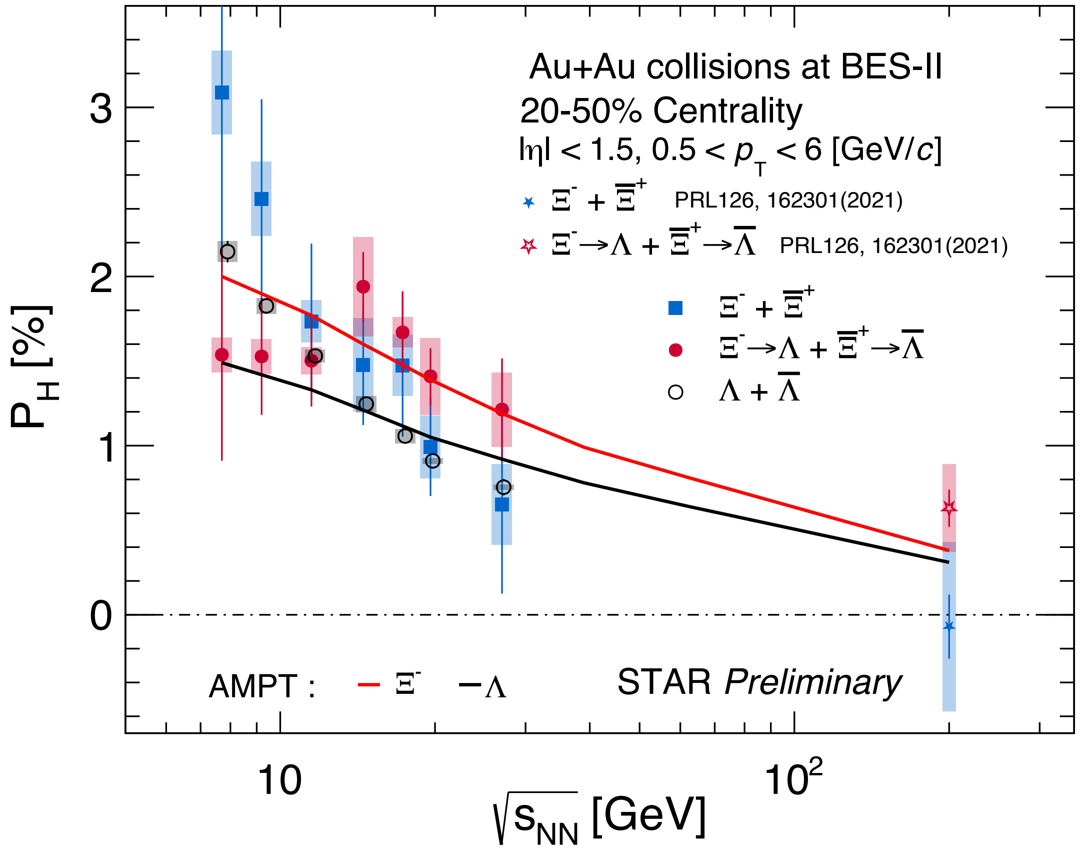
Z.-T. Liang and X.-N. Wang, PRL 94, 102301 (2005)
Hui Li et al., PLB 827, 136971(2022)

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



- Significant $\Xi^- + \bar{\Xi}^+$ global polarization observed (~ 5 σ)
- Global polarization of $\Xi^- + \bar{\Xi}^+$ seems to decrease with increase in collision energy

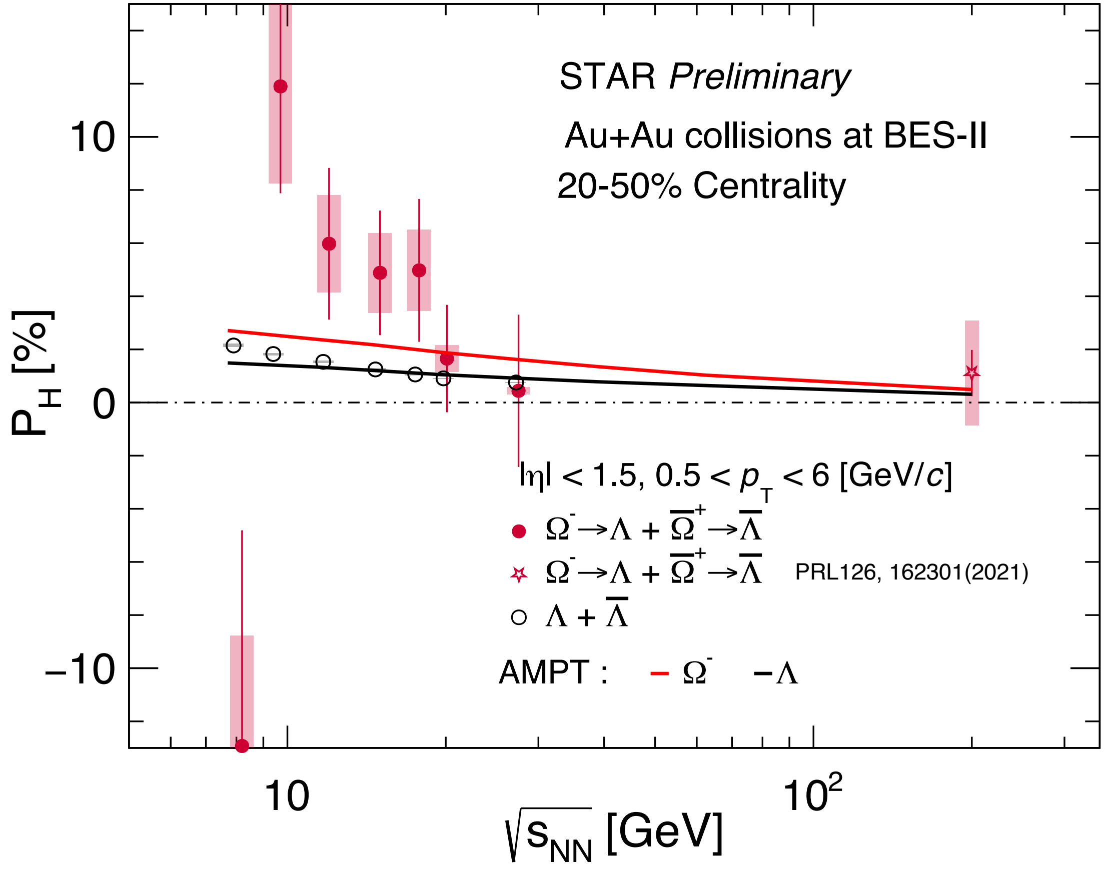
$\Xi^- + \bar{\Xi}^+$ global polarization



- $\Xi^- + \bar{\Xi}^+$ global polarization are consistent between direct and indirect measurement methods
- No significant difference between $\Lambda + \bar{\Lambda}$ and $\Xi^- + \bar{\Xi}^+$ global polarization within uncertainties

Model calculation:
H. Li, X. Xia et al Phys. Lett. B 827, 136971 (2022)

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

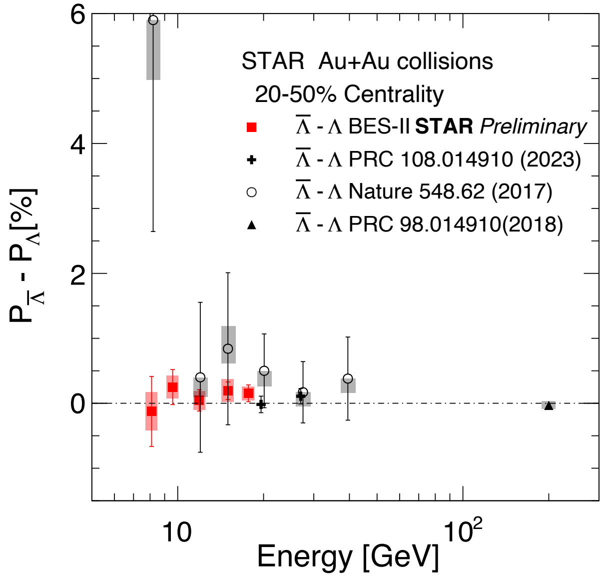


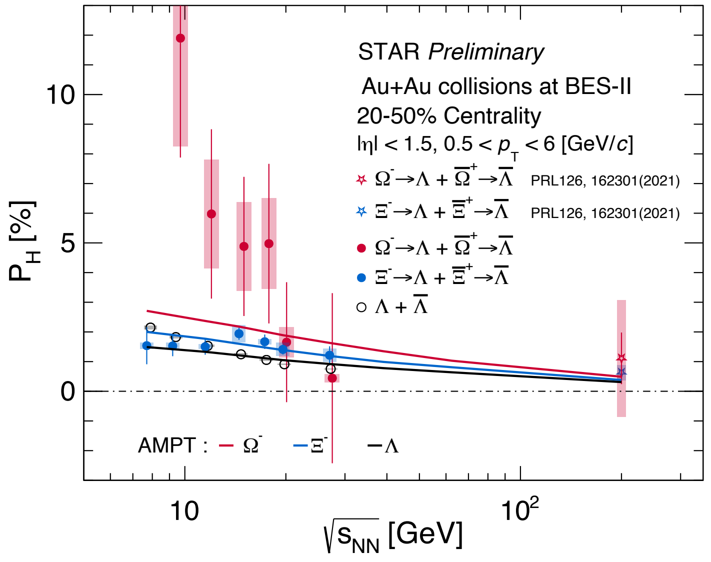
- Global polarization of $\Omega^- + \overline{\Omega}^+$ seems to decrease with increase in collision energy
- A hint of larger $\Omega^- + \overline{\Omega}^+$ polarization than $\Lambda + \overline{\Lambda}$ and $\Xi^- + \overline{\Xi}^+$ in lower energies

Model calculation:
H. Li, X. Xia et al Phys. Lett. B 827, 136971 (2022)

Summary

- No splitting observed between Λ and $\bar{\Lambda}$ global polarization in Au+Au collisions at 7.7 - 27 GeV and ${}^{96}_{44}Ru + {}^{96}_{44}Ru$, ${}^{96}_{40}Zr + {}^{96}_{40}Zr$ collisions at 200 GeV
- The first measurement of $\Xi^- + \bar{\Xi}^+$ and $\Omega^- + \bar{\Omega}^+$ global polarization vs collision energy at $\sqrt{s_{NN}}$ = 7.7, 9.2, 11.5, 14.6, 17.3, 19.6 and 27 GeV
- Global polarization of $\Xi^- + \bar{\Xi}^+$ and $\Omega^- + \bar{\Omega}^+$ seems to decrease with collision energy, with a hint of larger $\Omega^- + \bar{\Omega}^+$ polarization

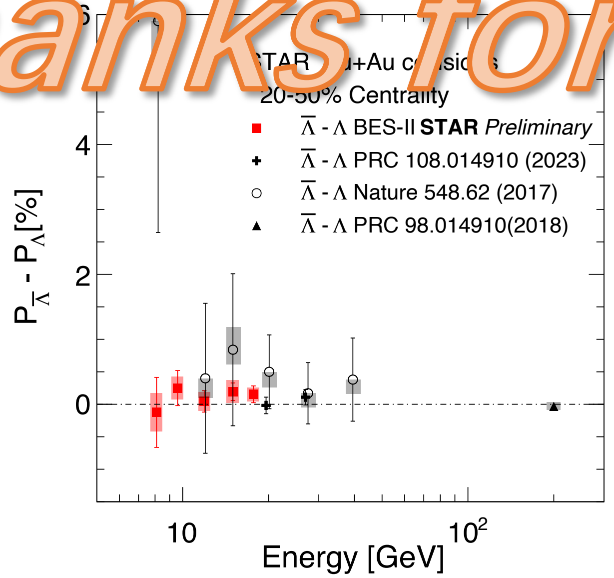


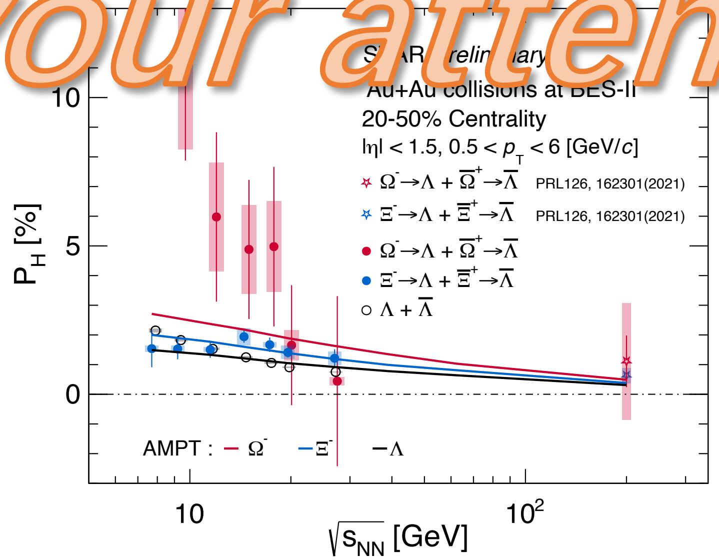


Summary

- No splitting observed between Λ and $\bar{\Lambda}$ global polarization in Au+Au collisions at 7.7 - 27 GeV and ${}^{96}_{44}$Ru + ${}^{96}_{44}$Ru, ${}^{96}_{40}$Zr + ${}^{96}_{40}$Zr collisions at 200 GeV
- The first measurement of $\Xi^- + \bar{\Xi}^+$ and $\Omega^- + \bar{\Omega}^+$ global polarization vs collision energy at $\sqrt{s_{NN}}$ = 7.7, 9.2, 11.5, 14.6, 17.3, 19.6 and 27 GeV
- Global polarization of $\Xi^- + \bar{\Xi}^+$ and $\Omega^- + \bar{\Omega}^+$ seems to decrease with collision energy, with a hint of larger $\Omega^- + \bar{\Omega}^+$ polarization

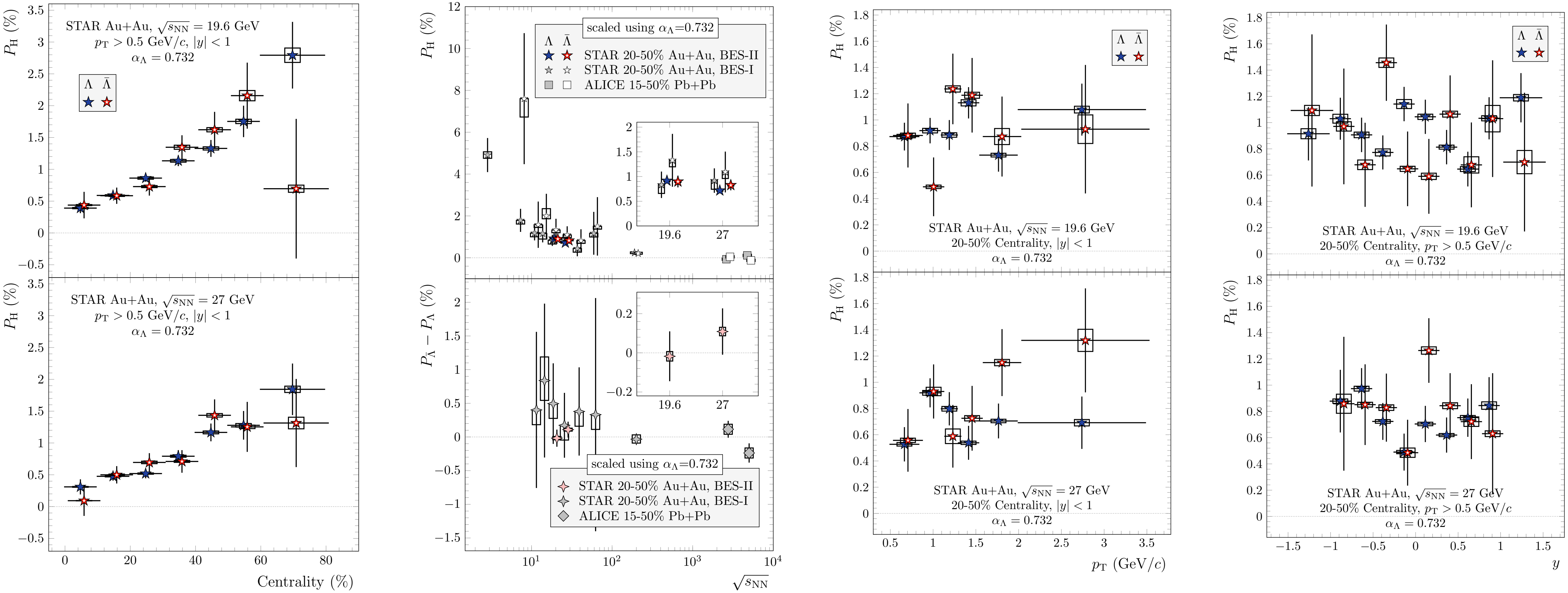
Thanks for your attention





Back Up

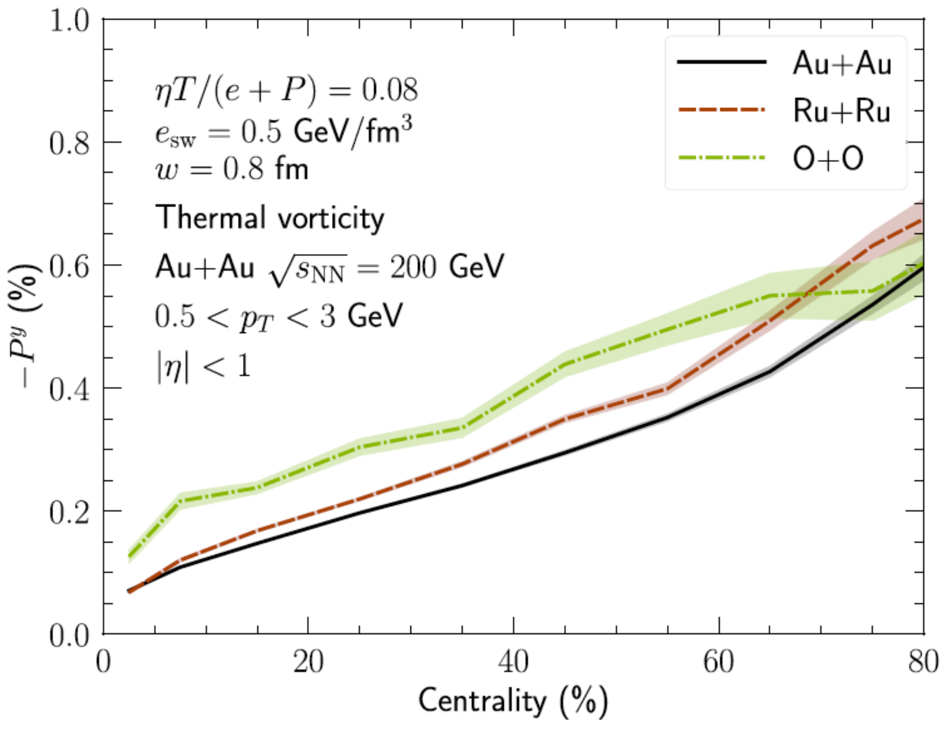
Global polarization collision energy dependence



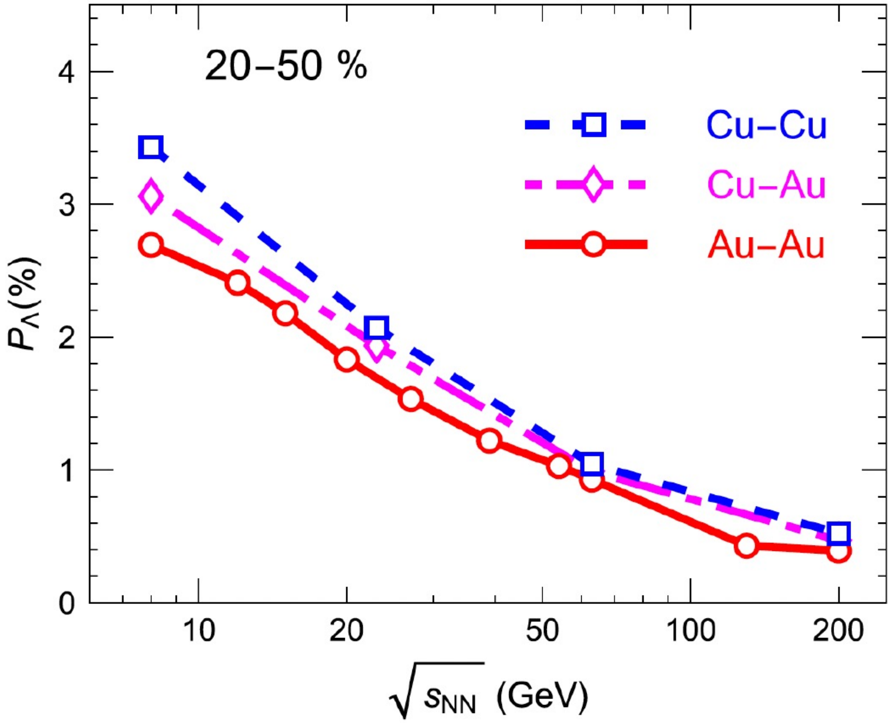
- ☐ Significant global polarization centrality dependence observed
- ☐ Lambda and AntiLambda global polarization are consistent
- ☐ No observed dependence of global polarization on p_T

System size dependence of Λ global polarization

S. Alzhrani et al., PRC 106.014905



S.Z, Shi, K.L. Li, J.F. Liao, PLB 788 (2019) 409–413



- Longer system lifetime dilutes the vorticity/polarization
- Collision system size dependence of global polarization?

$^{197}_{79}Au > ^{96}_{44}Ru, ^{96}_{40}Zr > ^{63}_{29}Cu > ^{16}_{8}O$

?

$P_\Lambda^{Au} < P_\Lambda^{Ru} \approx P_\Lambda^{Zr} < P_\Lambda^{Cu} < P_\Lambda^{O}$