

Measurements of Hyperon Spin Polarization in Heavy Ion Collisions from STAR

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第二届旋转与磁场下的QCD
物质研讨会

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安徽淮南
安徽理工大学—力学与光电物理学院—基础物理研究中心承办



□ Introduction

□ Λ Global polarization

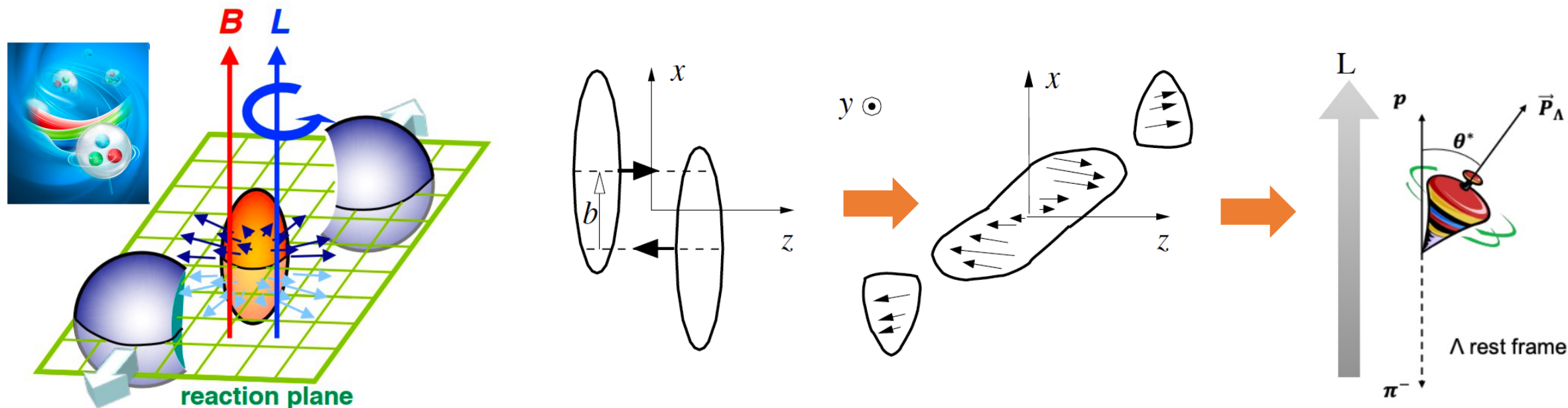
- Energy dependence
- Centrality, rapidity and transverse momentum dependence

□ E and Ω Global polarization

□ Summary and Outlook

- Future spin polarization measurements in STAR experiment

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)

□ Global orbital angular momentum leads to global polarization along L though spin-orbit coupling

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

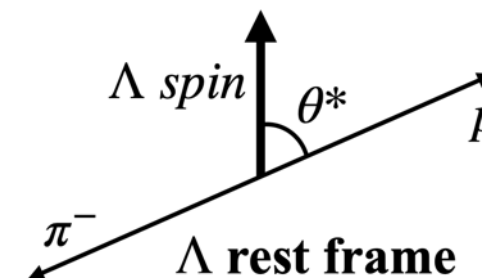
- “Self-analyzing”, parity-violating weak decay channel of hyperons
- Daughter baryon is preferentially emitted in the direction of the hyperon spin

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

α_H : hyperon decay parameter

P_H : hyperon polarization

θ^* : polarization angle



$\Lambda \rightarrow p + \pi^-$
(BR:63.9%, $c\tau \sim 7.9\text{cm}$)

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

PDG2021

- “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.

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

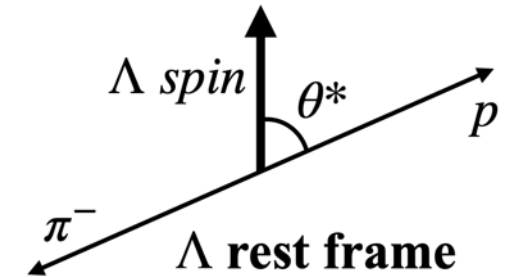
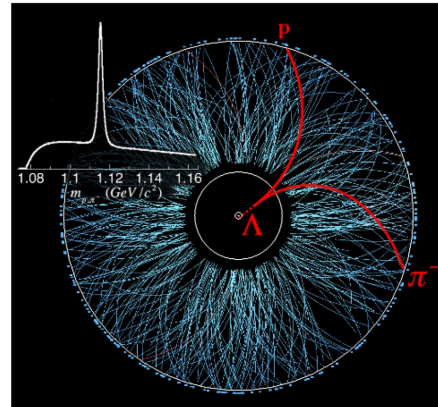
$$\alpha_{\Lambda} = -\alpha_{\bar{\Lambda}} = 0.732 \pm 0.014$$

A_0 : Acceptance correction factor

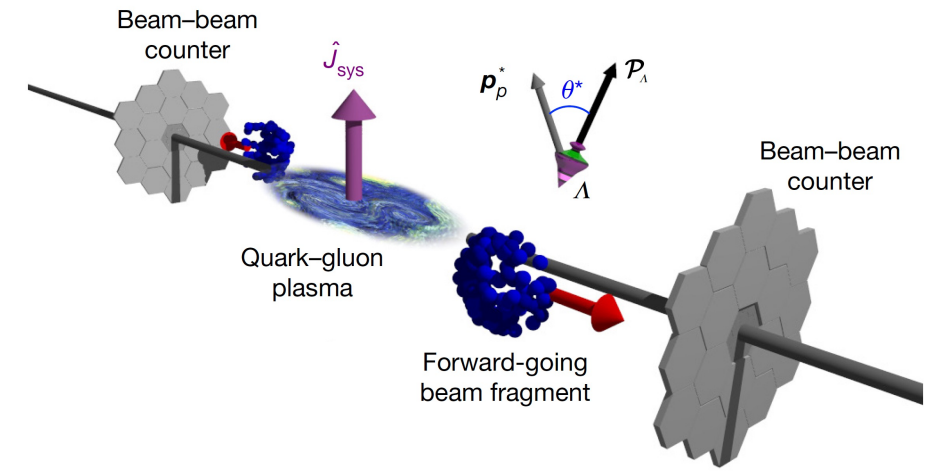
Ψ_1 : First-order event plane angle

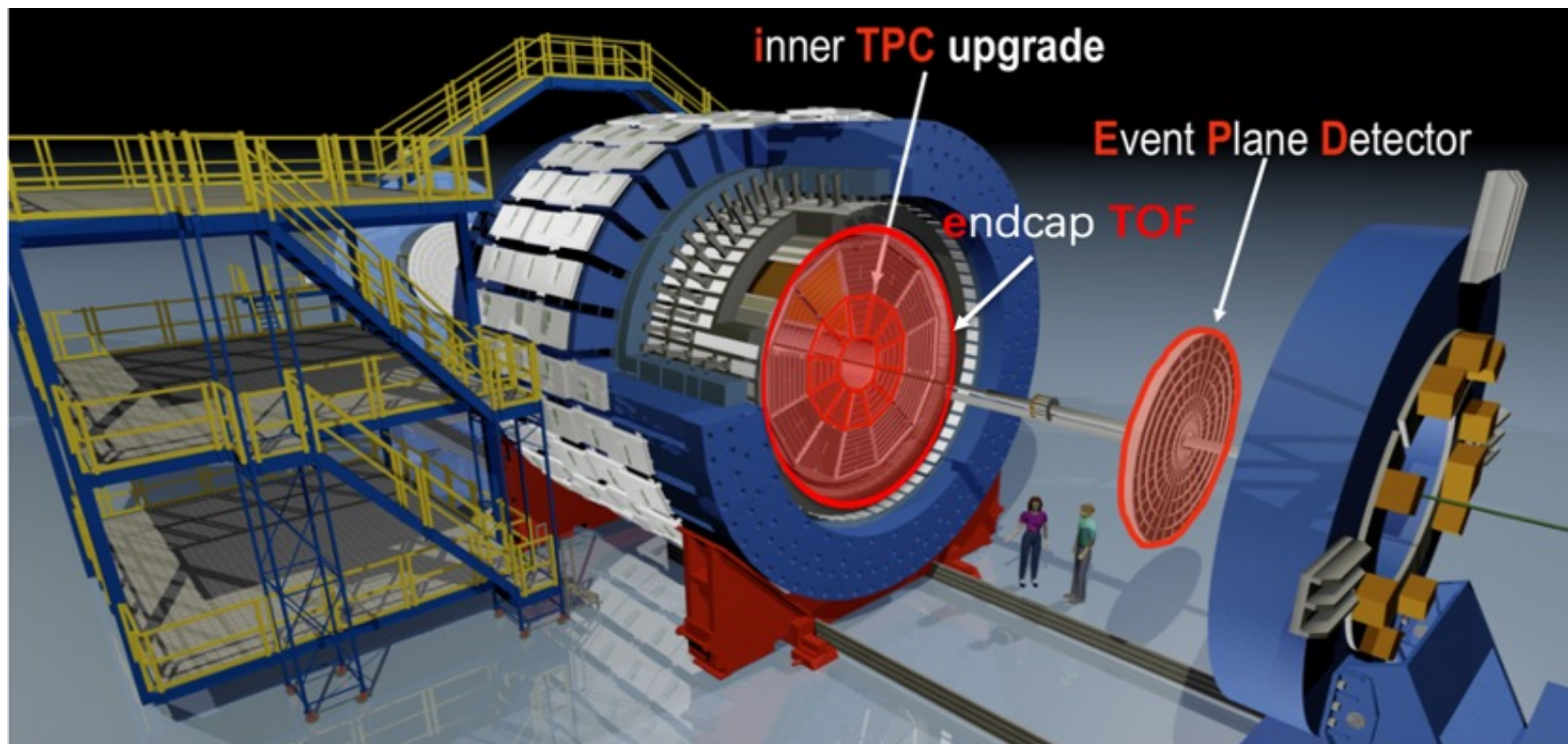
$Res(\Psi_1)$: Event plane resolution

STAR, PRC76, 024915 (2007)



$\Lambda \rightarrow p + \pi^-$
(BR:63.9%, $c\tau \sim 7.9\text{cm}$)



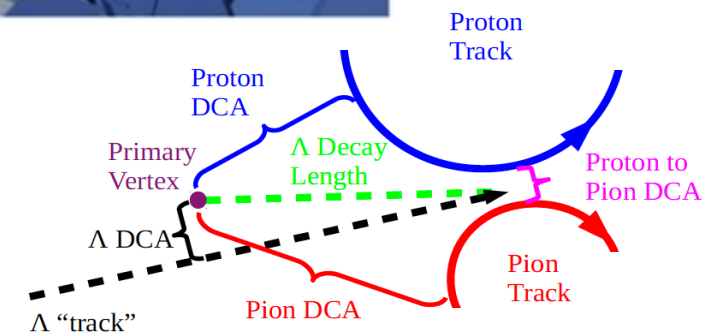


□ Event plane reconstruction:

Time Projection Chamber
Event Plane Detector
Zero Degree Calorimeters

□ $\Lambda/\bar{\Lambda}$ reconstruction:

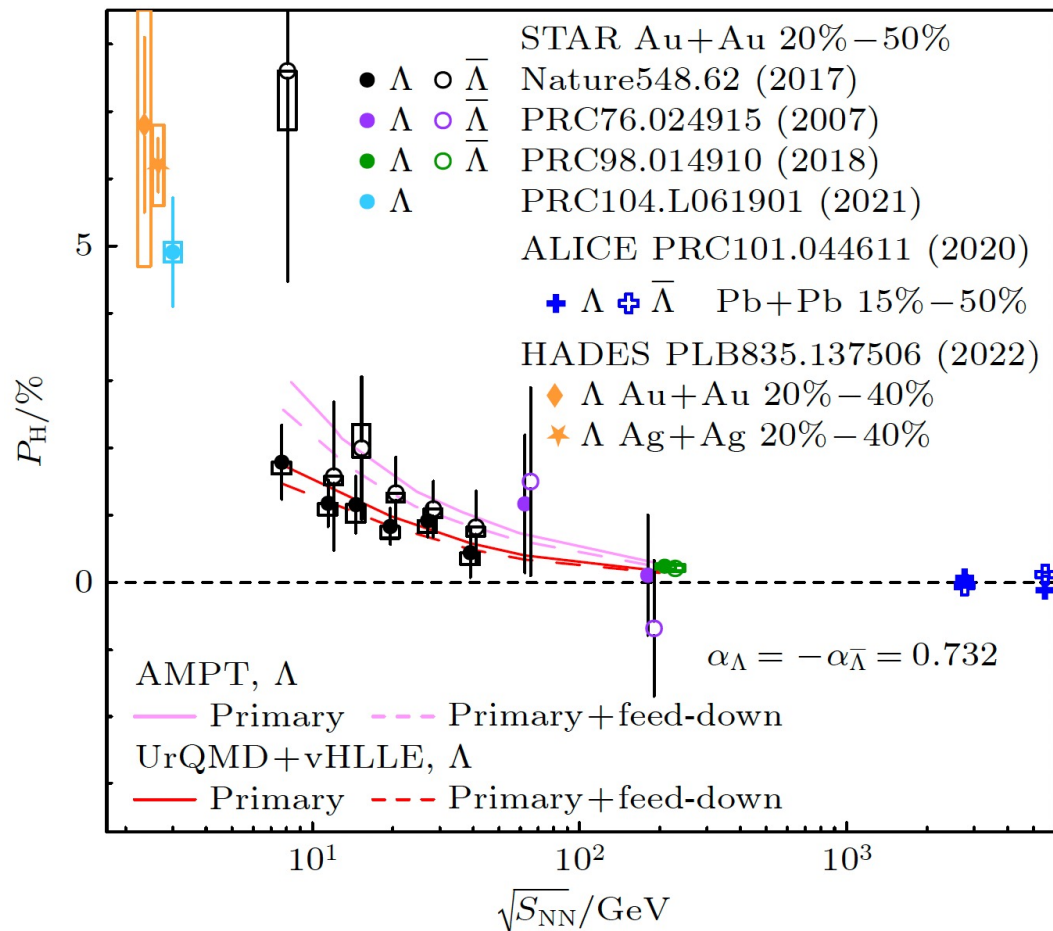
Time Projection Chamber
Time Of Flight



Observation of Λ global polarization

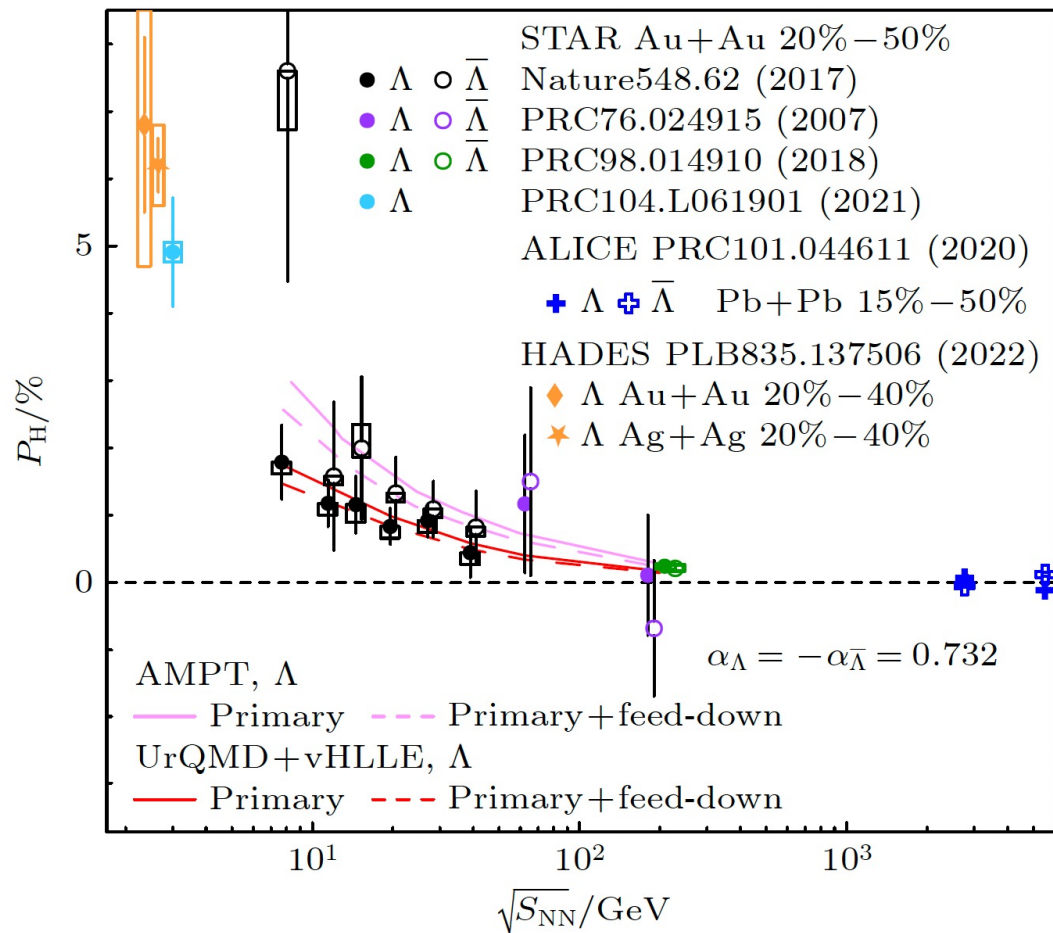


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- STAR, first measurement in AuAu 200 GeV
PRC 76, 024915 (2007)
- STAR, first observation in BES-I
Nature 548, 62 (2017)
- STAR, high precision P_H at 200 GeV
PRC 90, 014910 (2018)
- ALICE, LHC energy region
PRC 101, 044611 (2020)
- STAR, P_H at 3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

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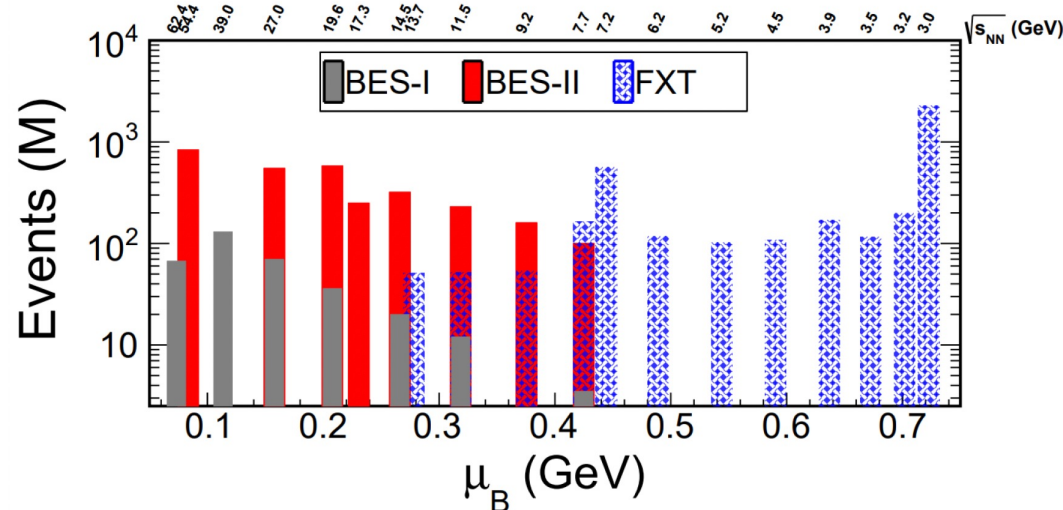
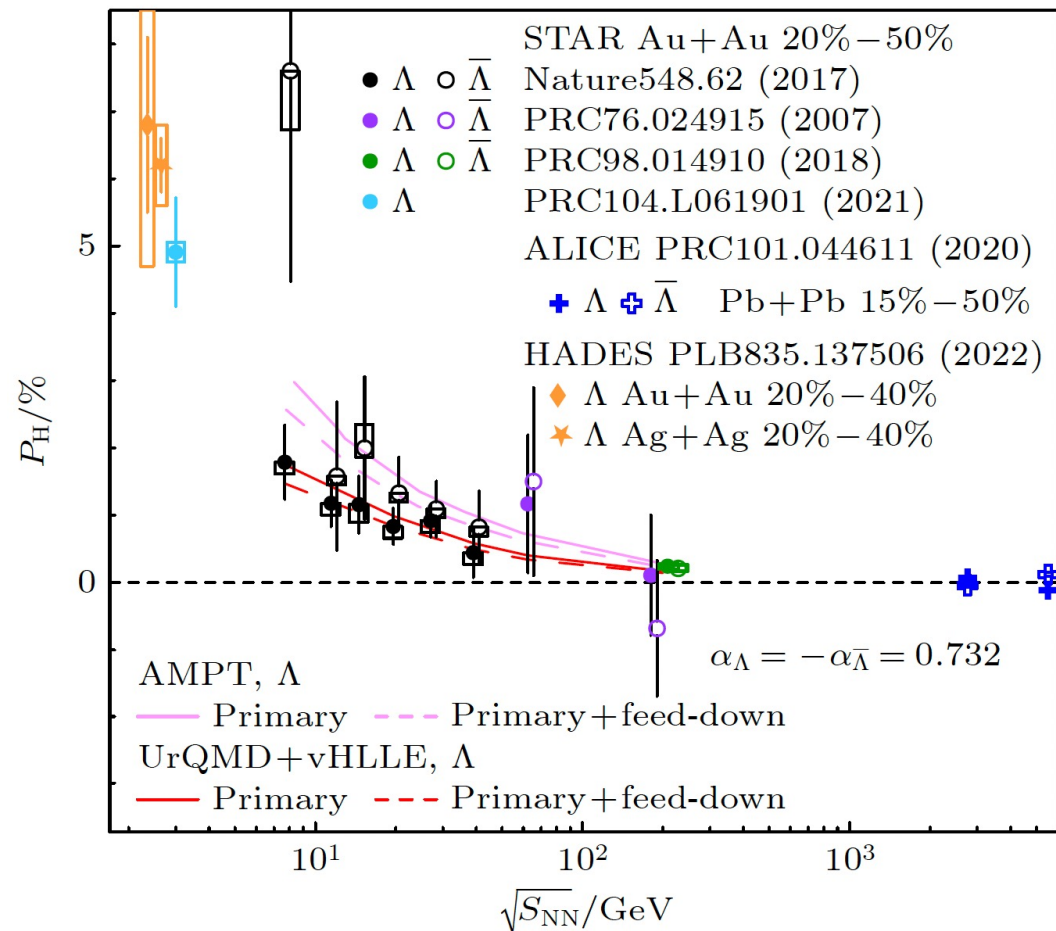
Significant collision energy dependence, described well by various theoretical models

- 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
- 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
- Yi, Wu, Zhu, Pu, Qin, PRC 111 4, 044901 (2025)
- Sun, et al., PRL 134 (2025) 2, 022301
- Anum Arslan et al. PRC 111, 044911(2025)
- L. Oliva, et al., PRC 114, 014914 (2026), B. Fu, et al., PRC 113, L041901 (2026), F. Liu, et al., PRD 113, 114051 (2026)
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Observation of Λ global polarization



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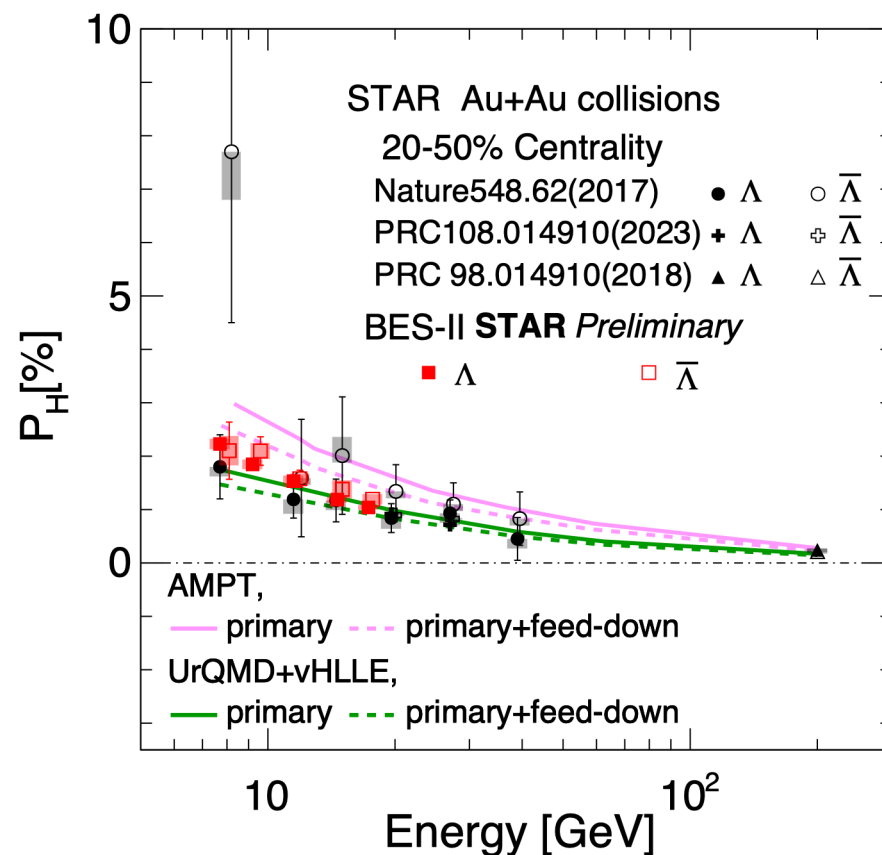
➤ Possible difference between Λ and $\bar{\Lambda}$ due to magnetic field effect?

▣ 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 recent highlights

- Λ , Ξ , Ω global polarization from BES-II

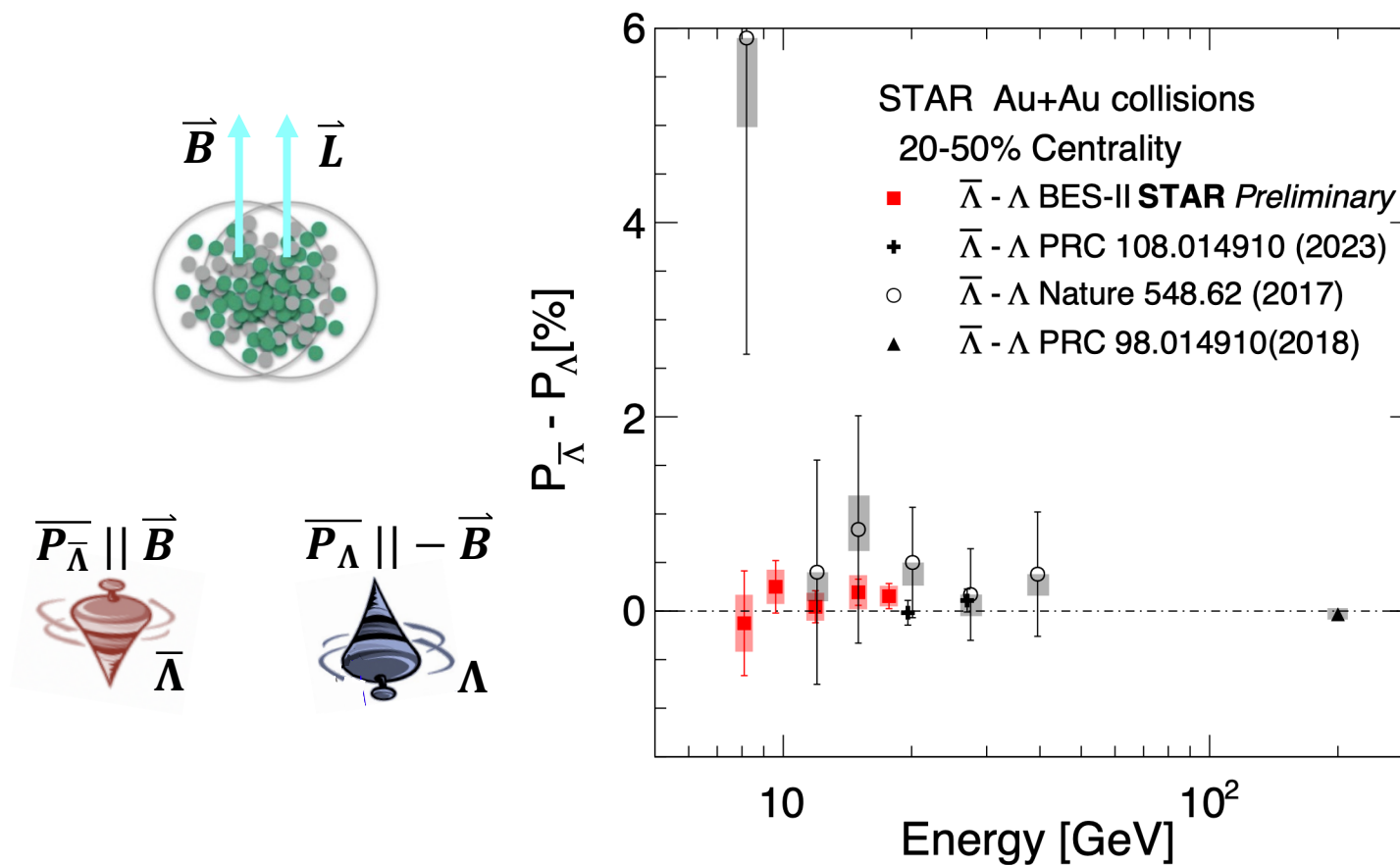


▣ New STAR preliminary results at $\sqrt{s_{NN}} = 7.7-17.3$ GeV from BES-II

▣ Significant improvement in precision was achieved, collision energy dependence consistent with BES-I

- $P_H = 1.17 \pm 0.40(stat) \pm 0.27(syst)$ [BES-I] $\longrightarrow$ $1.19 \pm 0.04(stat) \pm 0.05(syst)$ [BES-II] at 14.6 GeV
 Nature 548.62(2017)

Global polarization : splitting of Λ and $\bar{\Lambda}$ from BES-II



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

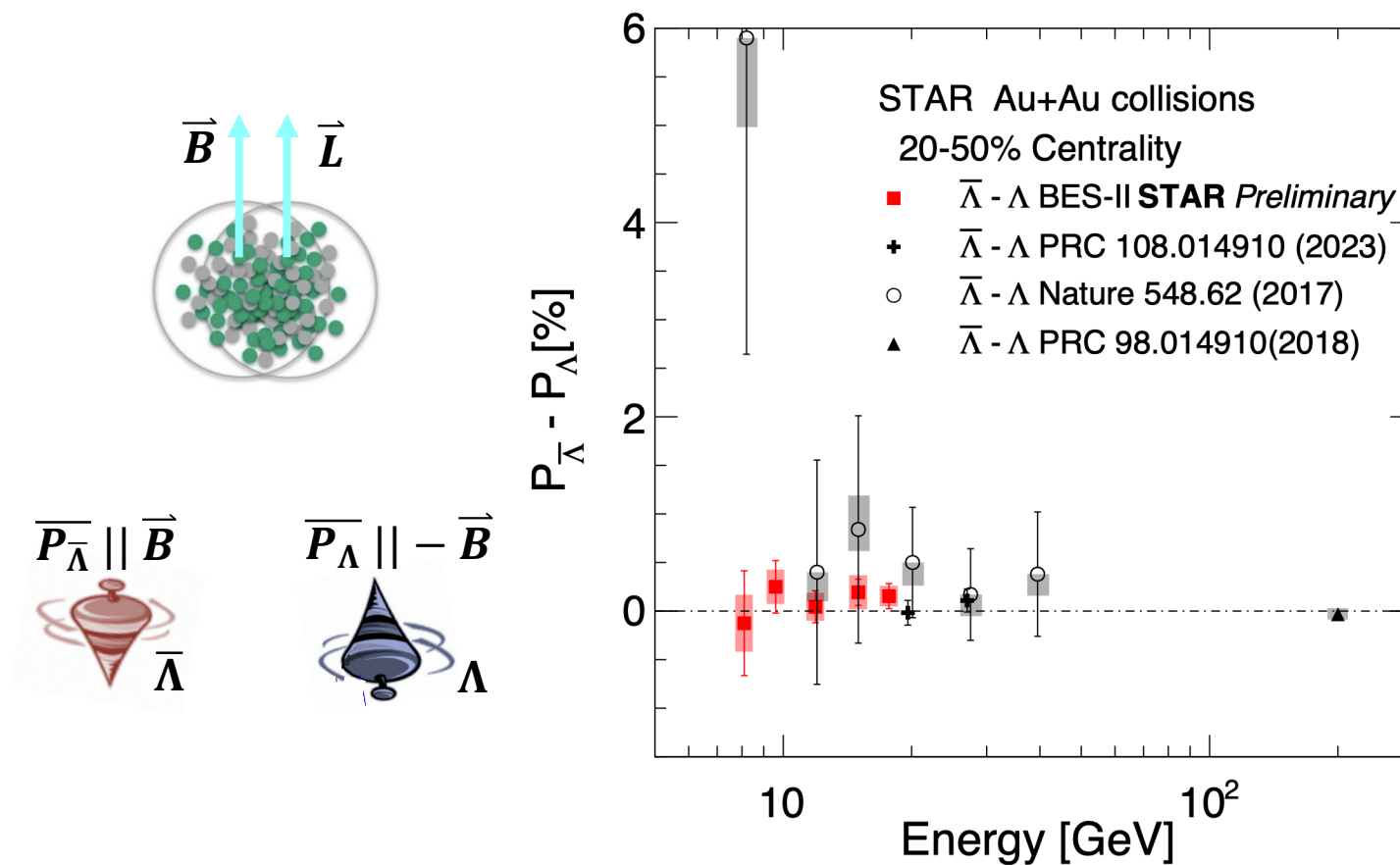
$$P_{\bar{\Lambda}} \approx \frac{1}{2} \frac{\omega}{T} - \frac{\mu_{\Lambda} B}{T}$$

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

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

- ❑ No obvious splitting between Λ and $\bar{\Lambda}$ global polarization with high precision
- ❑ Upper limit on late-stage magnetic field
 - $B \lesssim 10^{13} \text{ T}$ (95% confidence level) STAR, PRC 108,014910(2023)

Global polarization : splitting of Λ and $\bar{\Lambda}$ from BES-II



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

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

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

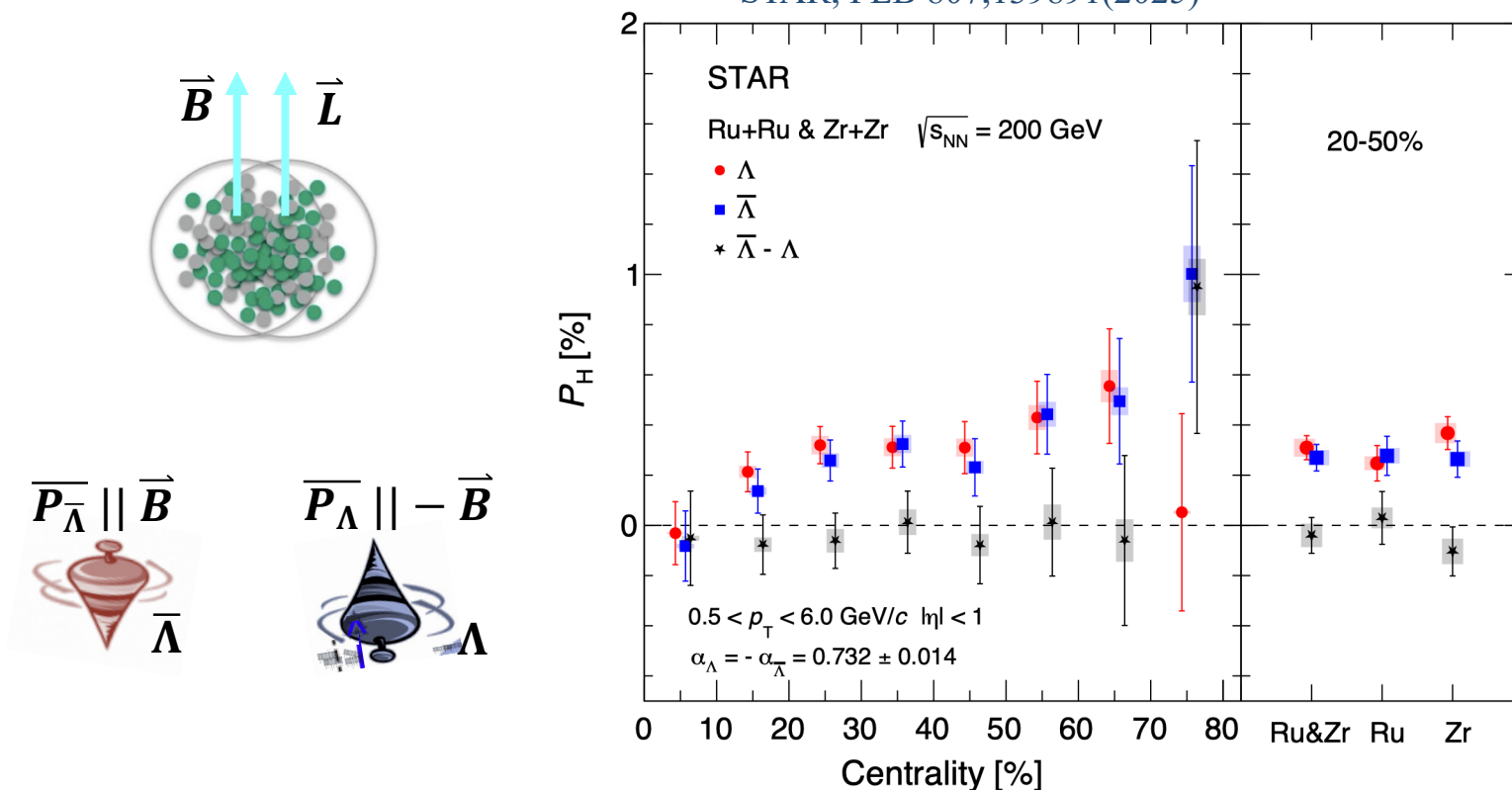
- ❑ No obvious splitting between Λ and $\bar{\Lambda}$ global polarization with high precision
- ❑ Small later-stage magnetic field at freeze out

A.P. Huang, Z.I. Yuan, M. Huang, PRD 110, 096025 (2024)

Global polarization : splitting of Λ and $\bar{\Lambda}$ from isobar collisions



STAR, PLB 807,139891(2025)



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

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

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

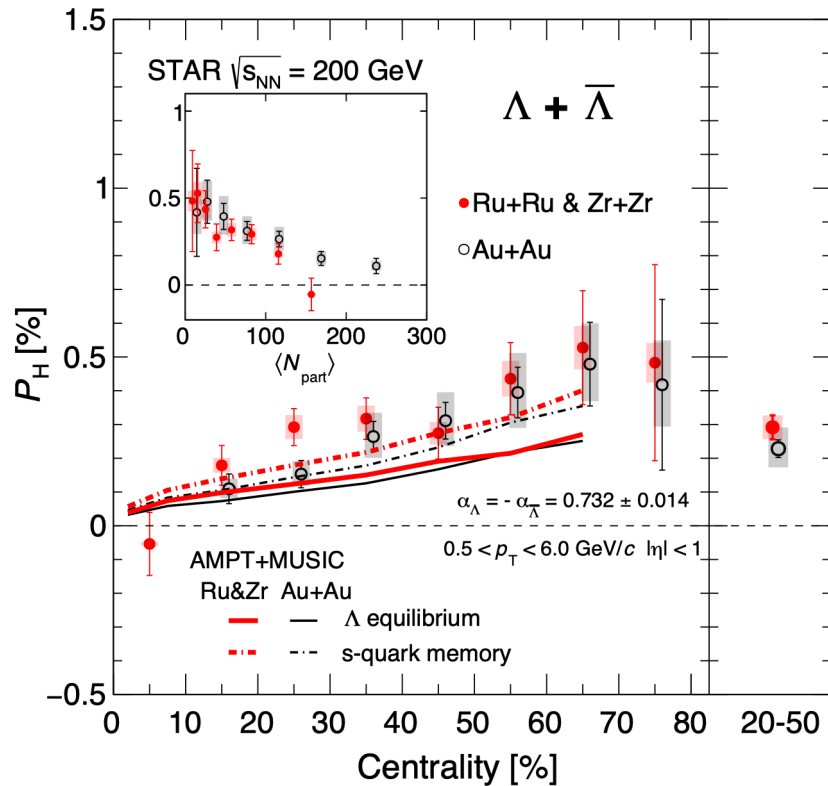
$$T = 150 \text{ MeV}, \mu_\Lambda = -1.93 \times 10^{-1} \text{ MeV}/T$$

- Significant global polarization observed in isobar collisions, increase with centrality
- No obvious splitting between P_Λ and $P_{\bar{\Lambda}}$
- No significant difference of P_Λ between ${}^{96}_{44}\text{Ru} + {}^{96}_{44}\text{Ru}$ and ${}^{96}_{40}\text{Zr} + {}^{96}_{40}\text{Zr}$ collisions

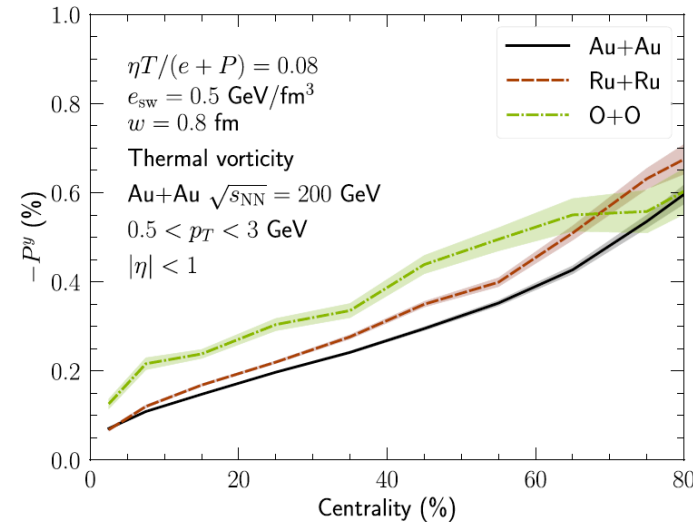
Global polarization : system size dependence



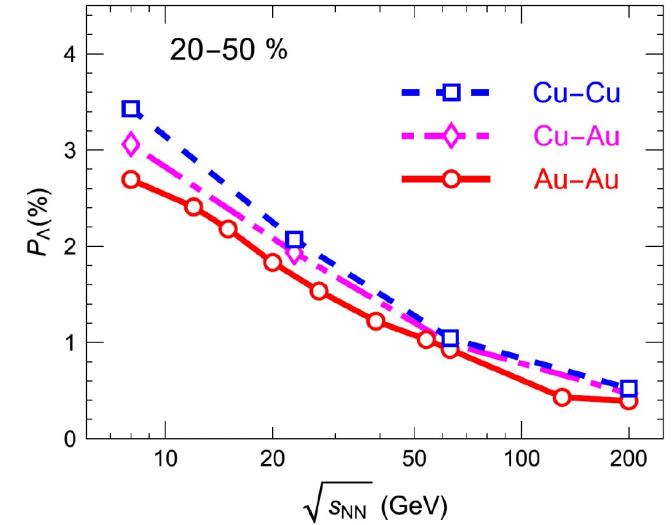
STAR, PLB 807,139891(2025)



S. Alzhirani et al., PRC 106.014905



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

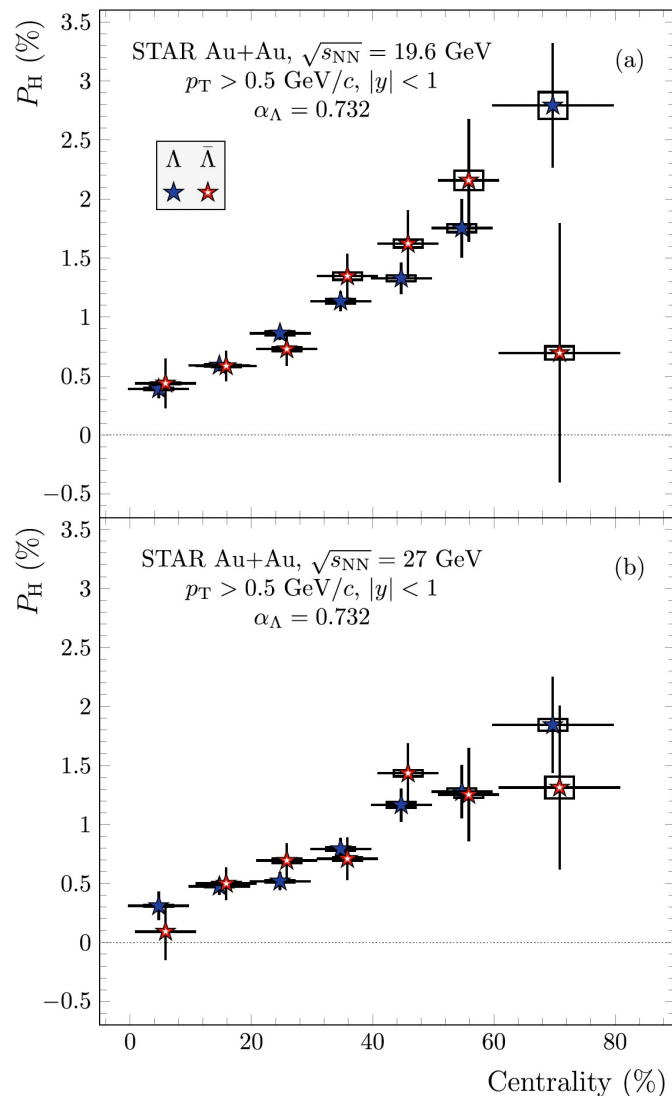


$$^{197}_{79}\text{Au} > ^{96}_{44}\text{Ru}, ^{96}_{40}\text{Zr} > ^{63}_{29}\text{Cu} > ^{16}_8\text{O}$$

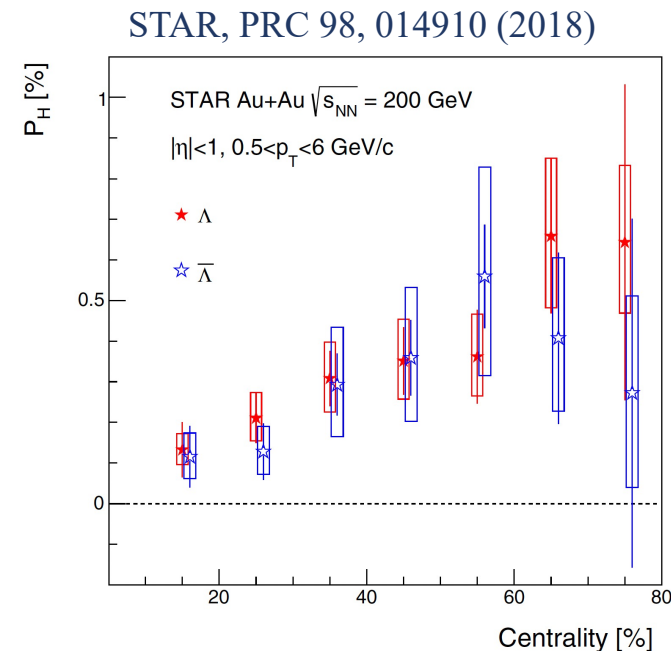
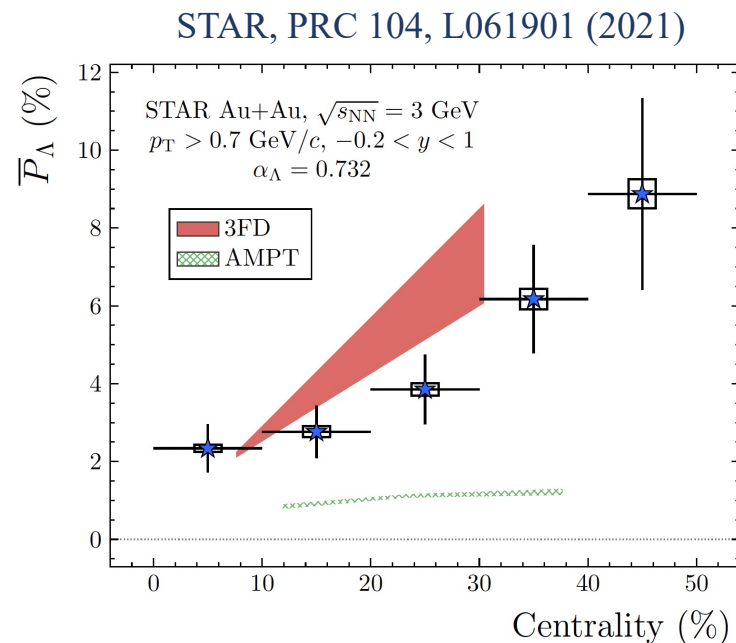
$$P_{\Lambda}^{\text{Au}} < P_{\Lambda}^{\text{Ru}} \approx P_{\Lambda}^{\text{Zr}} < P_{\Lambda}^{\text{Cu}} < P_{\Lambda}^{\text{O}}$$

- Smaller polarization predicted for larger system due to longer lifetime
- Significant global polarization observed in isobar collisions, increase with centrality
- No significant difference between Ru+Ru, Zr+Zr and Au+Au collisions

Global polarization : centrality dependence

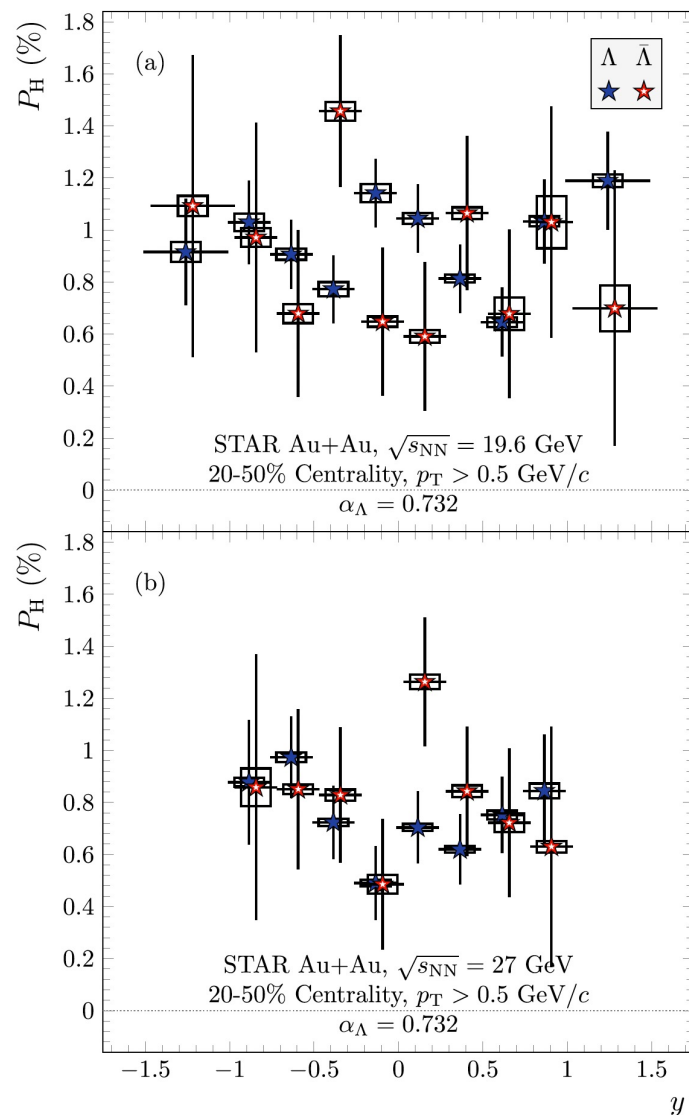


STAR, PRC 108, 014910 (2023)

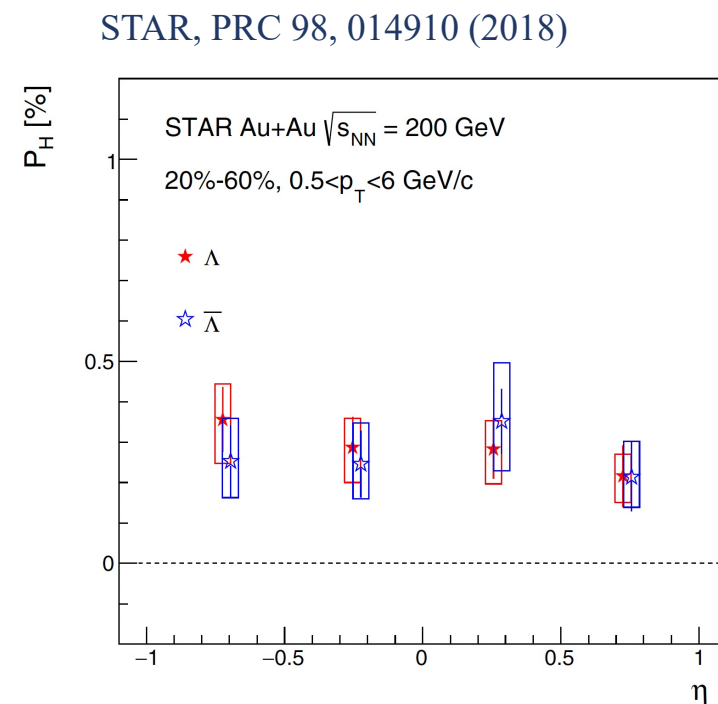
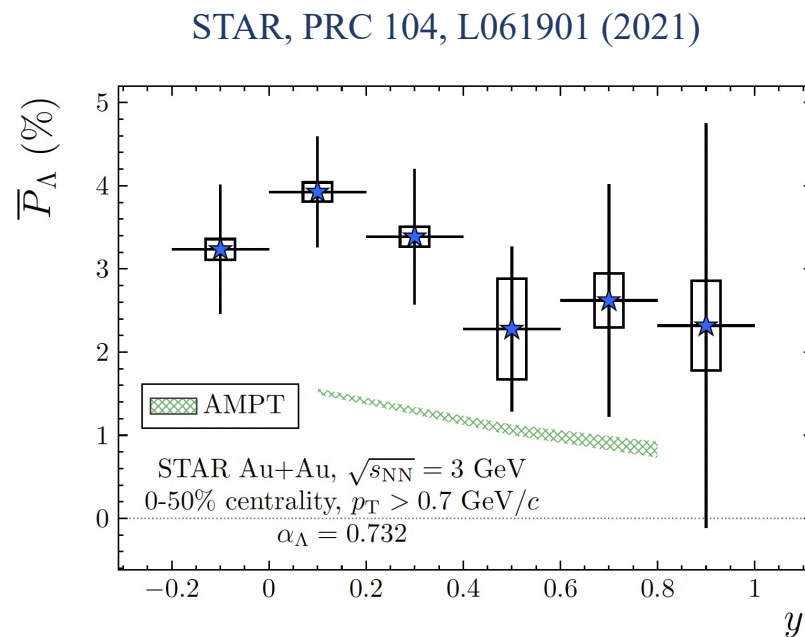


■ Significant centrality dependence observed from 3 to 200 GeV

Global polarization : rapidity dependence

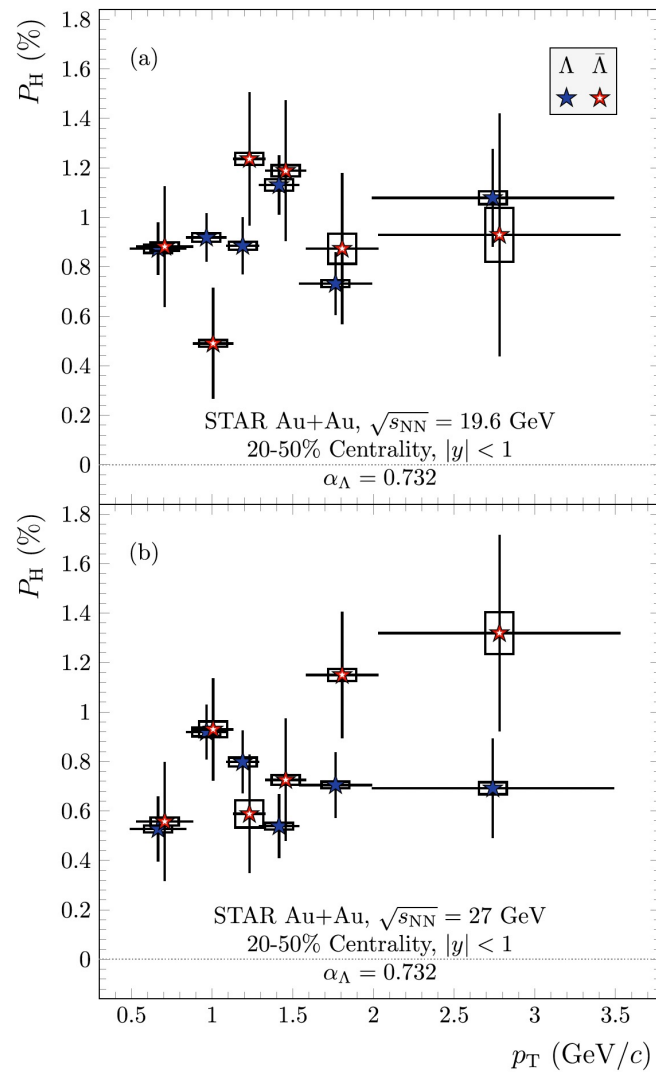


STAR, PRC 108, 014910 (2023)

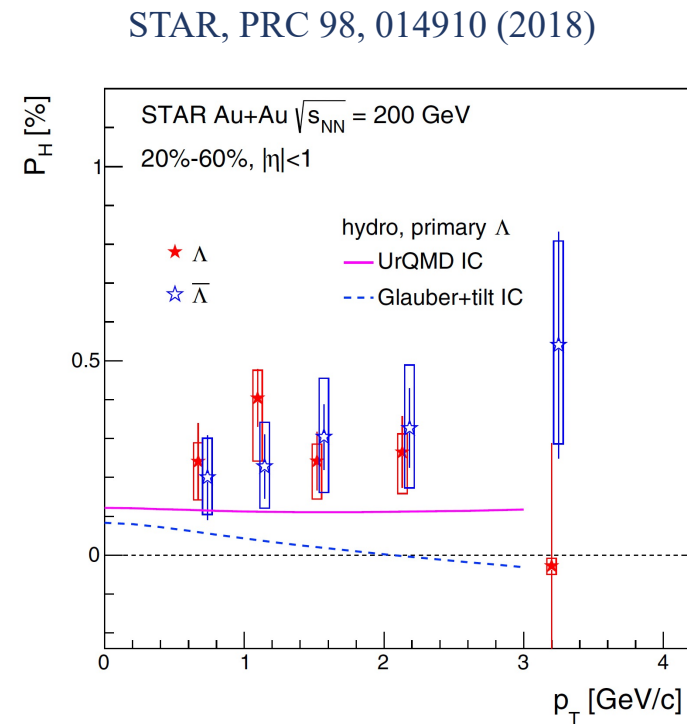
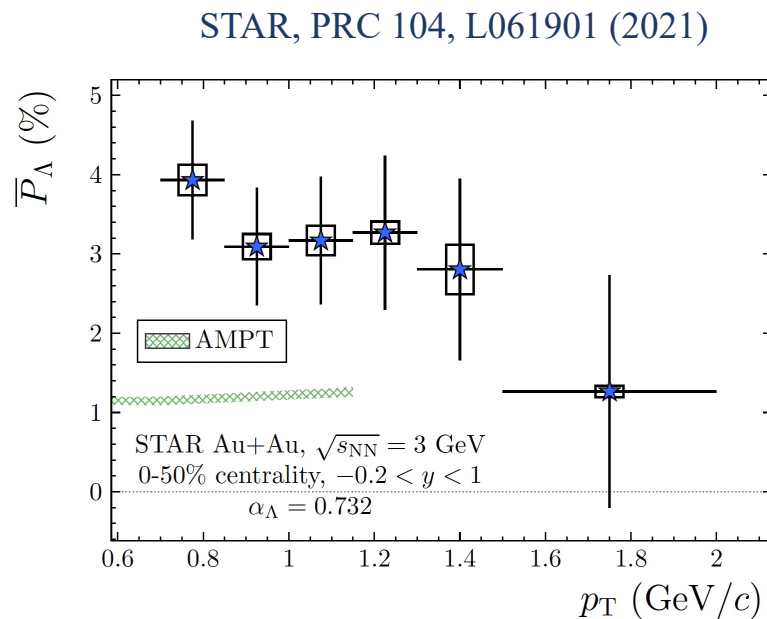


❑ No significant rapidity dependence observed in current measurements

Global polarization : transverse momentum dependence

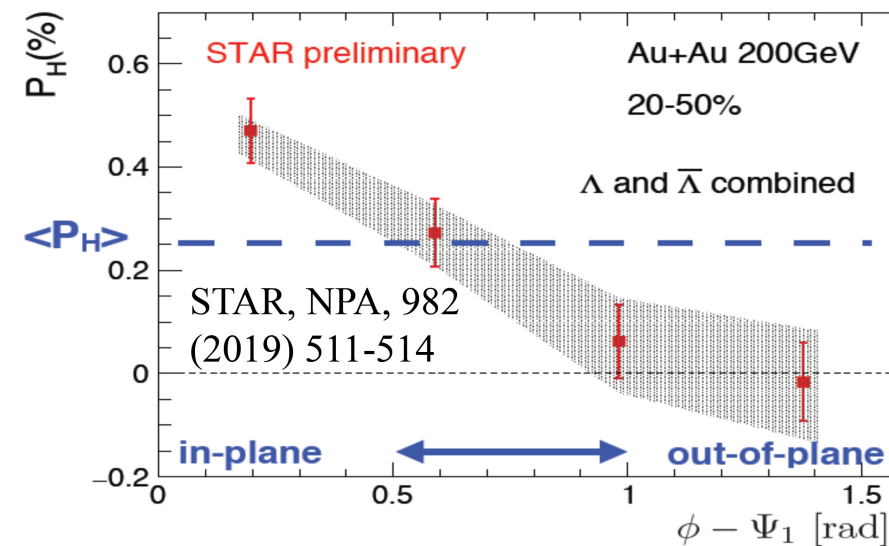
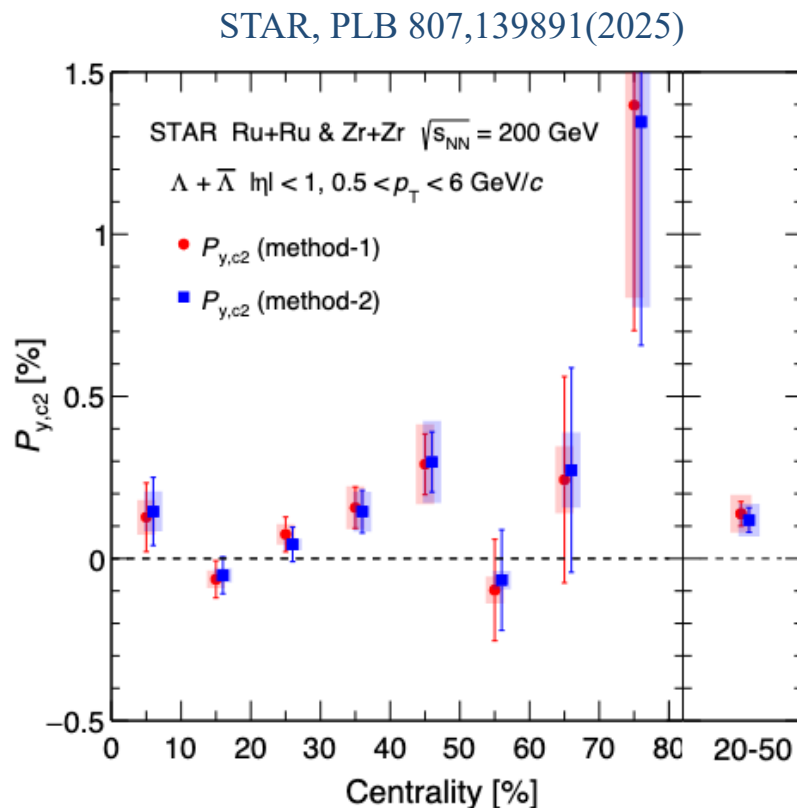


STAR, PRC 108, 014910 (2023)



❑ No significant transverse momentum dependence observed in current measurements

Global polarization : hyperon azimuthal angle dependence



$$P_H(\Delta\phi) = P_{y,c0} + 2P_{y,c2} \cos(2\Delta\phi)$$

$$\Delta\phi = \phi_\Lambda - \Psi_2$$

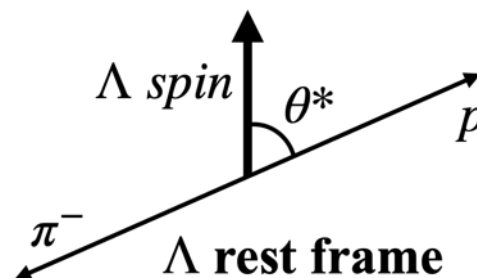
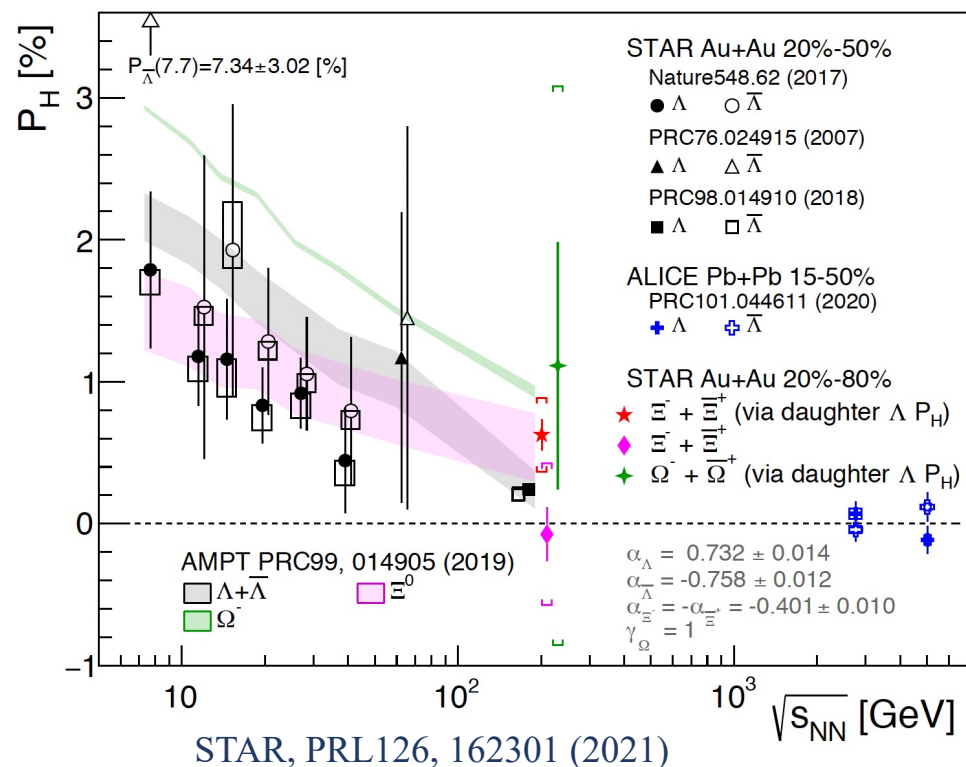
- Λ spin polarization as a function of azimuthal angle ϕ along the out-of-plane direction(y)
- Different theoretical models predict different azimuthal modulations of P_H , as $P_{y,c2}$
- Measurements of $P_{y,c2}$ in isobar collisions at 200 GeV $\sim 2.4 \sigma$

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



□ Possible larger Ξ global polarization than Λ due to earlier production, vorticity evolution or spin quantum number

- Measured via daughter Λ angle distribution in Ξ rest frame
- Or via daughter Λ polarization with spin transfer factor ($C_{\Xi^- \rightarrow \Lambda} = 0.944$, $C_{\Omega^- \rightarrow \Lambda} = 1.0$ is assumed)



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

α_H : hyperon decay parameter

P_H : hyperon polarization

θ^* : polarization angle

Hyperon	Decay mode	α_H	Spin
$\Lambda(uds)$	$\Lambda \rightarrow p + \pi^-$	0.732	1/2
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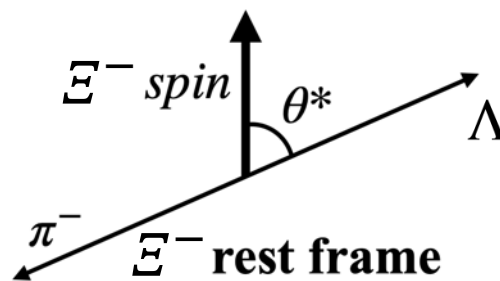
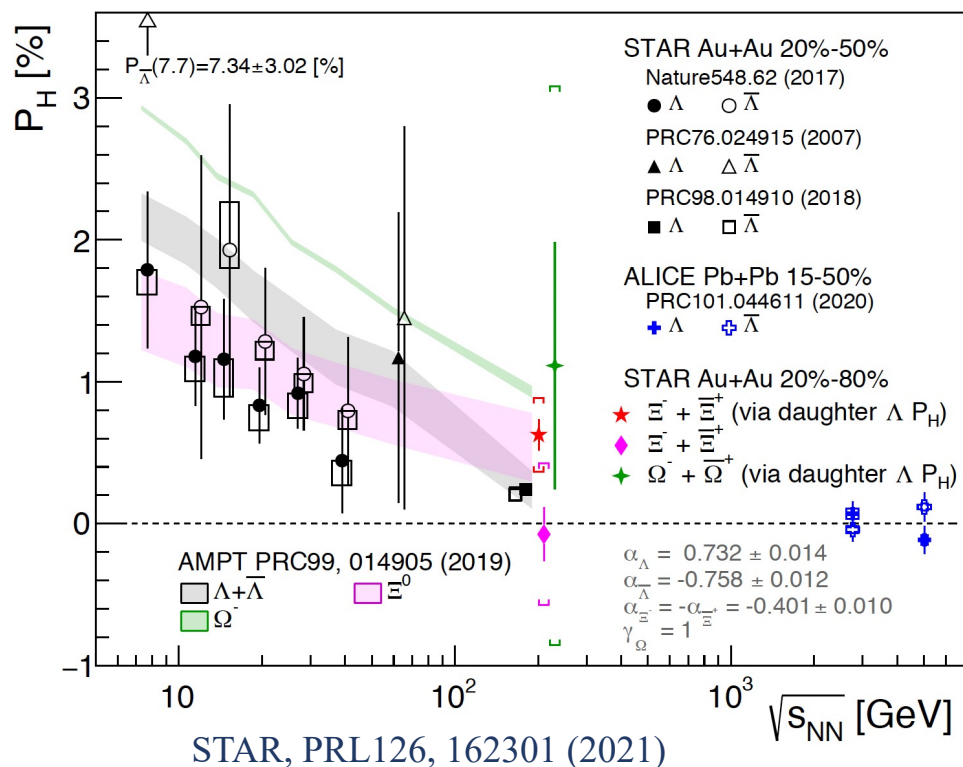
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$\Xi^- + \bar{\Xi}^+$ global polarization measurement



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

α_H : hyperon decay parameter

P_H : hyperon polarization

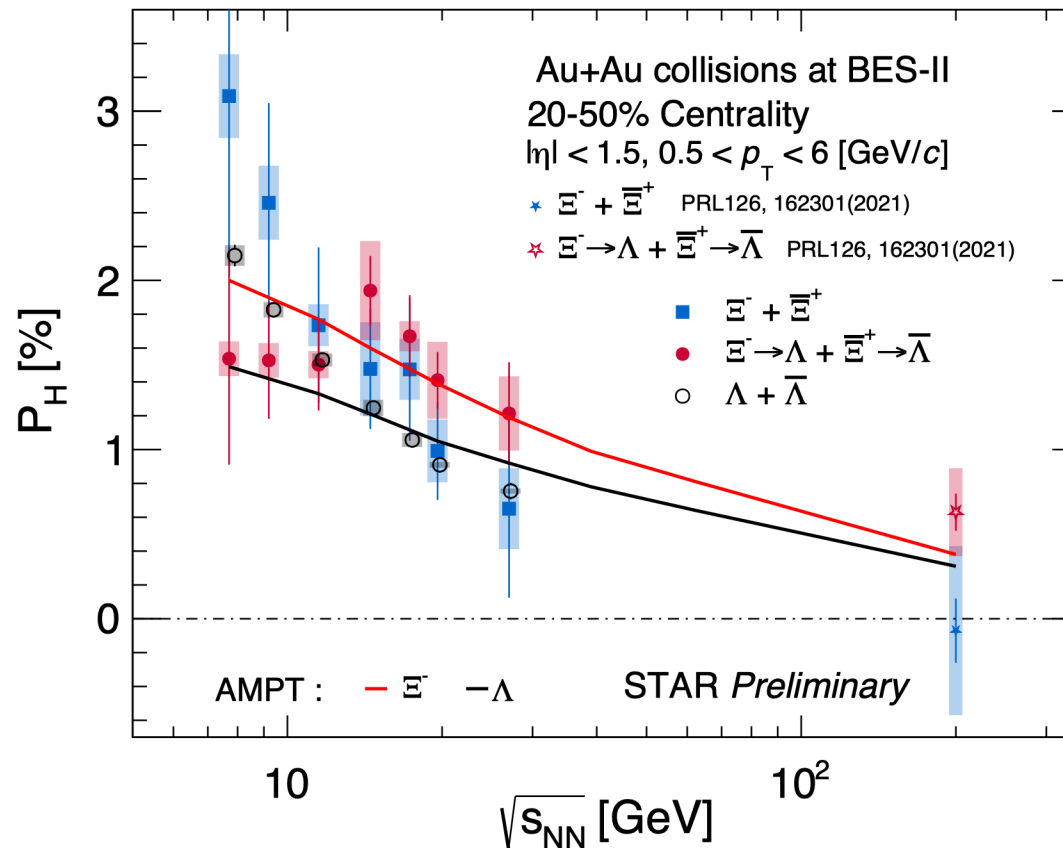
θ^* : polarization angle

□ Collision energy, centrality, p_T , η dependence?

□ Possible Λ, Ξ, Ω global polarization difference?

$$P_{\Lambda} \cong P_S, \text{ assuming that } P_{u,d} \sim P_S \longrightarrow P_{\Xi} \sim P_{\Lambda}, P_{\Omega} \sim \frac{5}{3} P_{\Lambda}$$

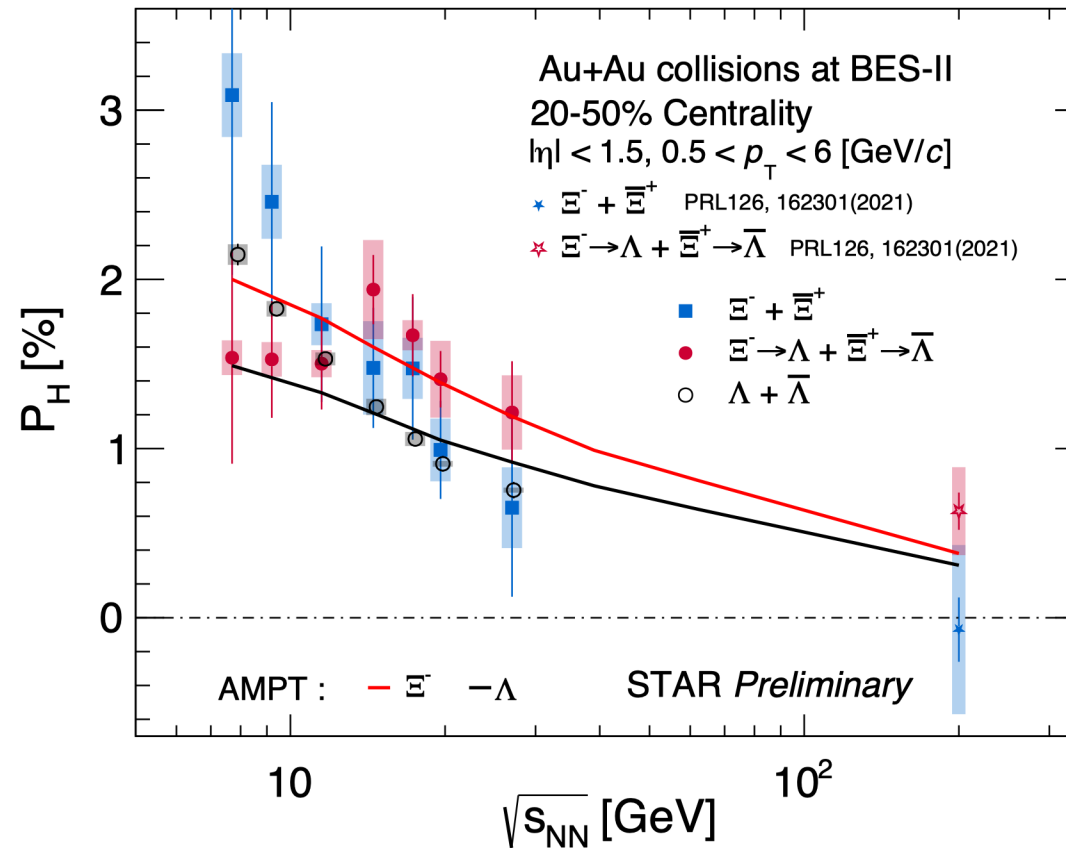
Z.-T. Liang and X.-N. Wang, PRL 94, 102301 (2005)
Hui Li et al., PLB 827, 136971(2022)



■ Significant $\Xi^- + \bar{\Xi}^+$ global polarization observed ($\sim 5 \sigma$)

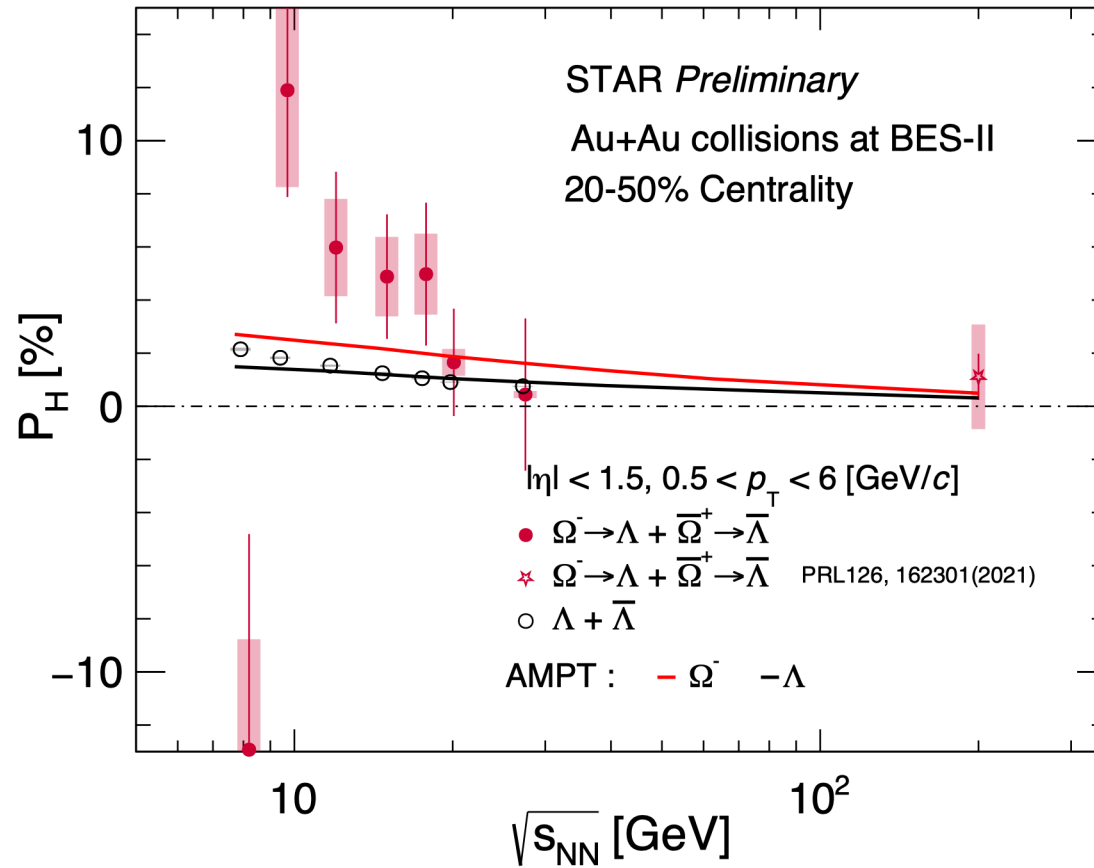
- $P_H = 1.940 \pm 0.205(\text{stat.}) \pm 0.293(\text{syst.})$ at 14.6 GeV

■ Global polarization of $\Xi^- + \bar{\Xi}^+$ seems to decrease with increase in collision energy



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

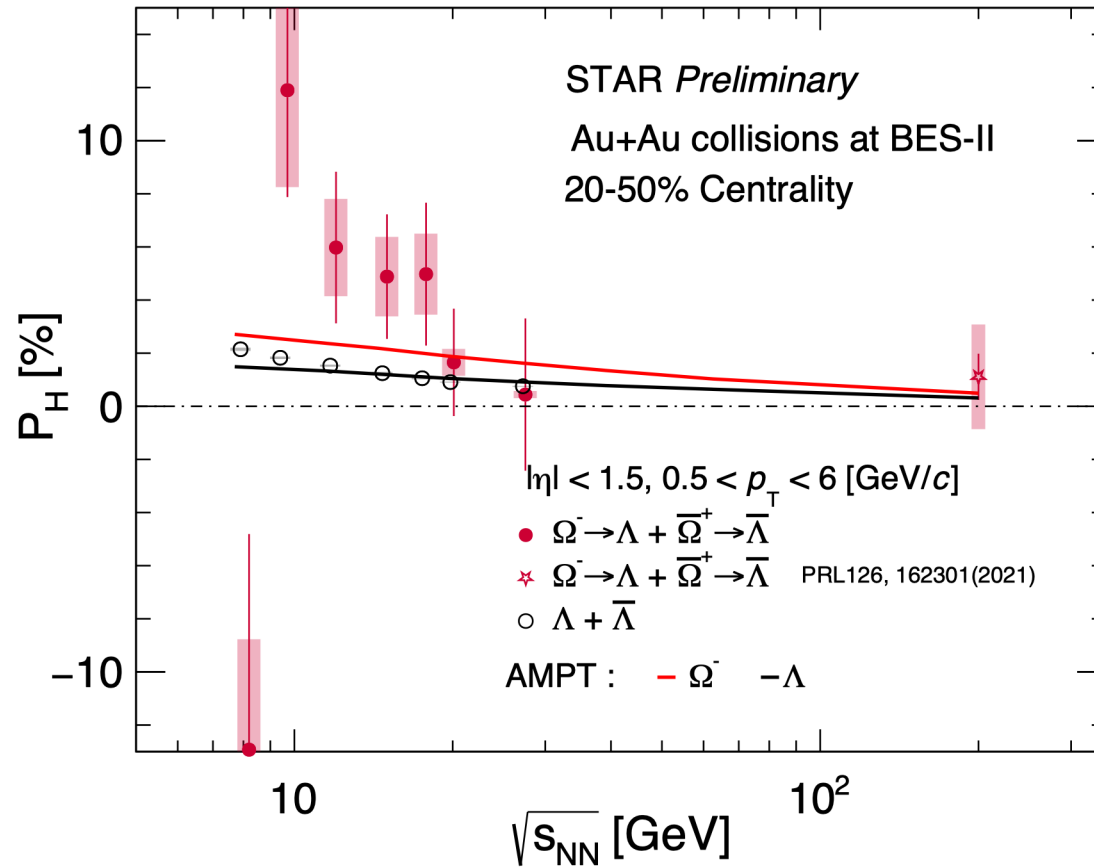
Model calculation:
H. Li, X. Xia et al Phys. Lett. B 827, 136971 (2022)



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

Model calculation:

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



- No quark spin correlation

$$P_{\Omega} = \frac{5}{3} P_{\Lambda}$$

- Include quark spin correlation

$$P_{\Omega} \approx \frac{5}{3} P_{\Lambda} + \frac{\delta_{\Omega}}{C_{\Omega}}$$

$\frac{\delta_{\Omega}}{C_{\Omega}}$: ss quark spin correlation

J. P. Lv, et al PRD 109, 114003(2024)

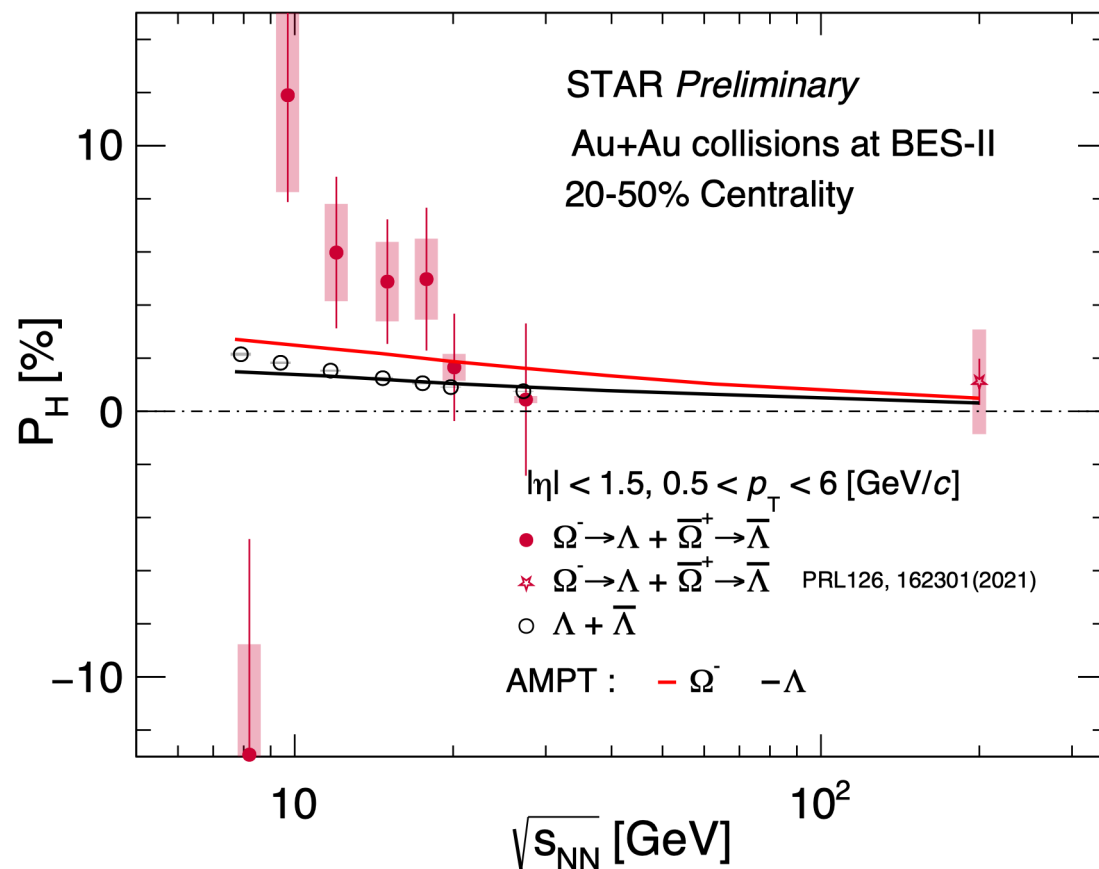
L.Oliva, et al PRC 114,014914(2026)

□ Global polarization of $\Omega^- + \bar{\Omega}^+$ seems to decrease with increase in collision energy

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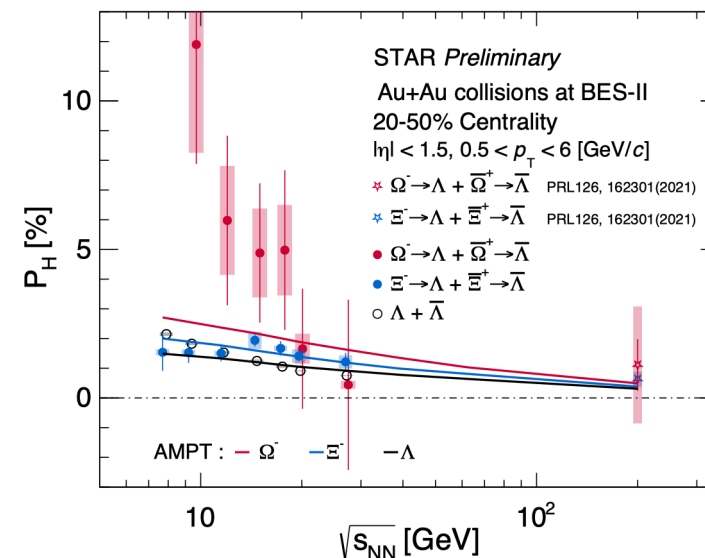
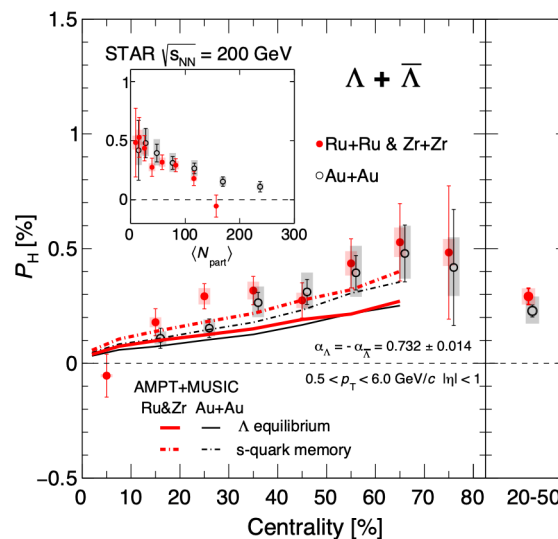
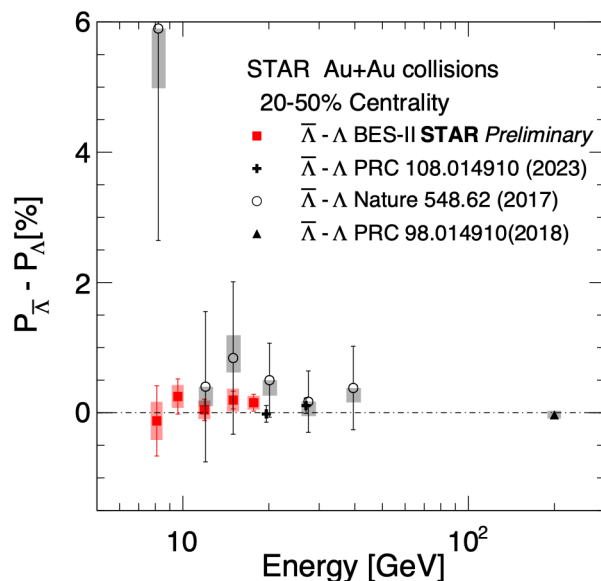
- Indirect measured Ω polarization via spin transfer factor $C_{\Omega \rightarrow \Lambda} \sim +1$ or -0.6 , based on the $\gamma_{\Omega} \sim \pm 1$
- Averaged BES-II energies,
 $P_{\Omega^- + \bar{\Omega}^+} = 3.730 \pm 1.062(stat.) \pm 1.290(syst.)$
 $P_{\Lambda + \bar{\Lambda}} = 1.436 \pm 0.019(stat.) \pm 0.050(syst.)$
- Difference with $5/3 P_{\Lambda + \bar{\Lambda}}$

Decay parameter	χ^2/NDF
$\gamma_{\Omega} \approx +1$	9.35/7
$\gamma_{\Omega} \approx -1$	22.76/7

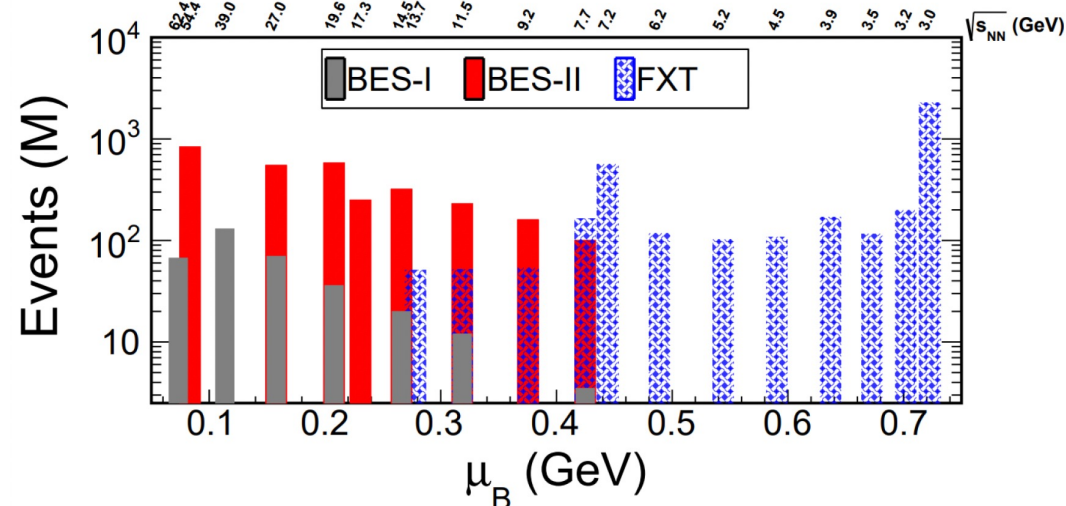
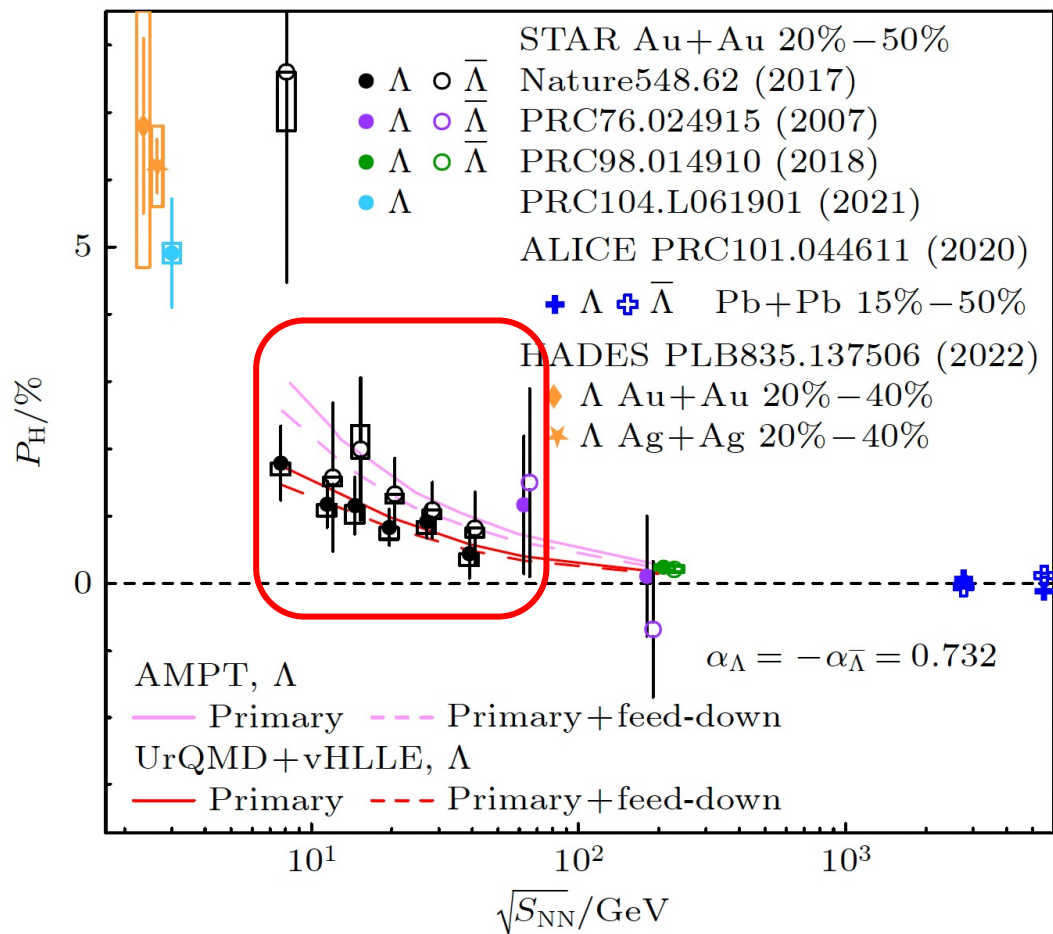
□ Global polarization of $\Omega^- + \bar{\Omega}^+$ help to determine the unknown decay parameter γ_{Ω} , which preferred value of $\sim +1$

Global polarization

- ✓ More measurements with high precision BES II data, no splitting between P_Λ and $P_{\bar{\Lambda}}$
- ✓ Significant global polarization observed in isobar collisions, no system size dependence
- ✓ Significant $\Xi^- + \bar{\Xi}^+$ global polarization observed ($\sim 5\sigma$), seems to decrease with collision energy, with a hint of larger $\Omega^- + \bar{\Omega}^+$ polarization

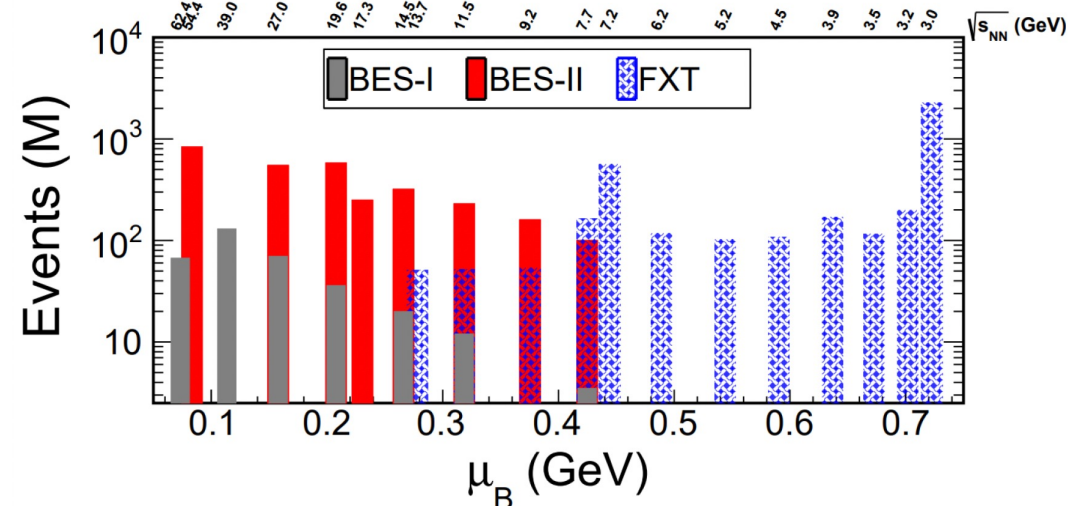
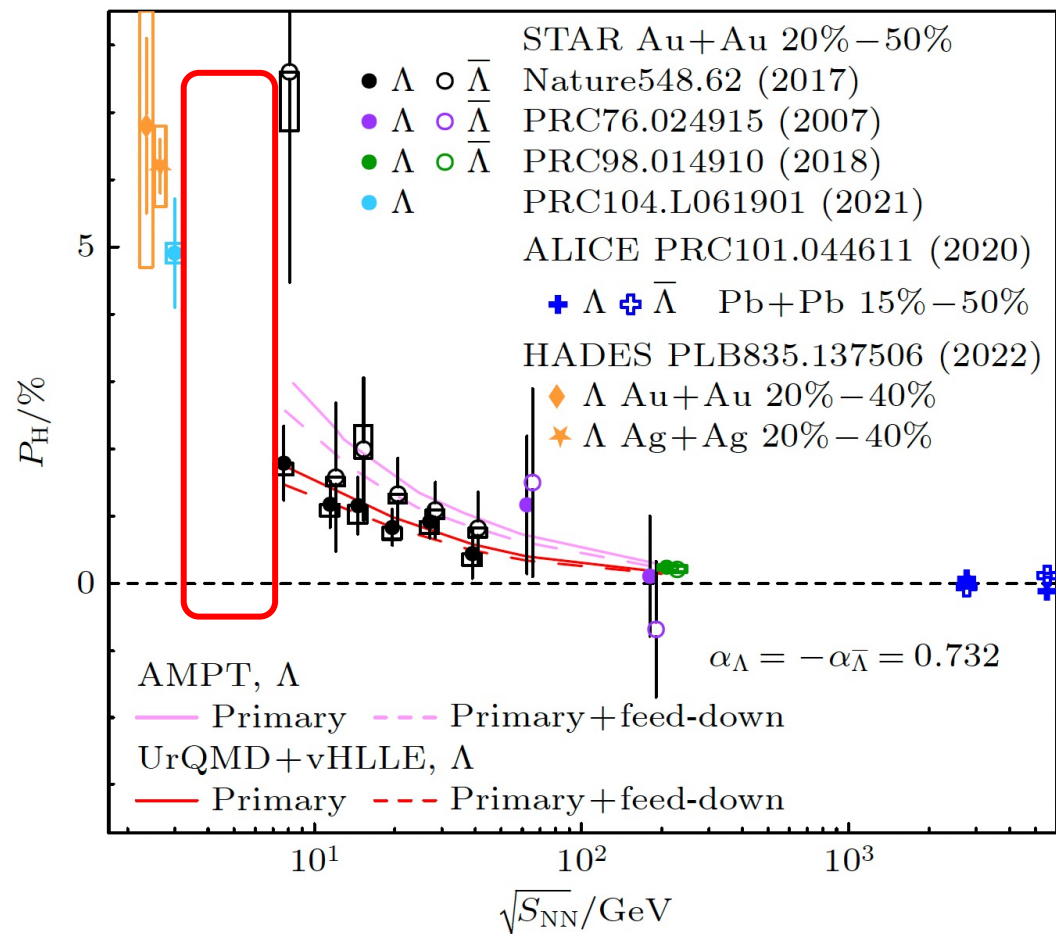


Outlook – Differential measurements in BES-II energies



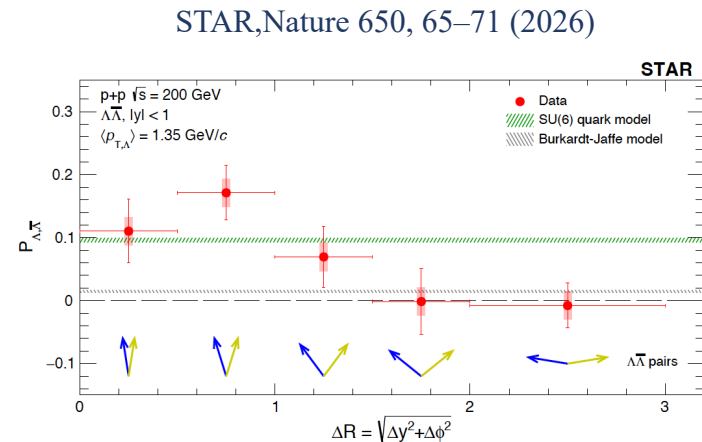
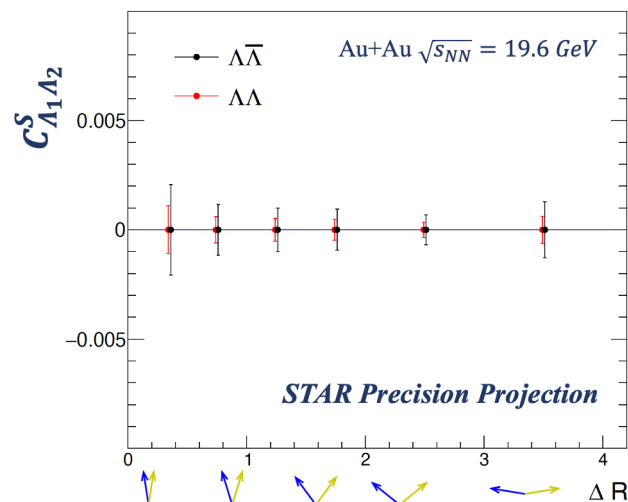
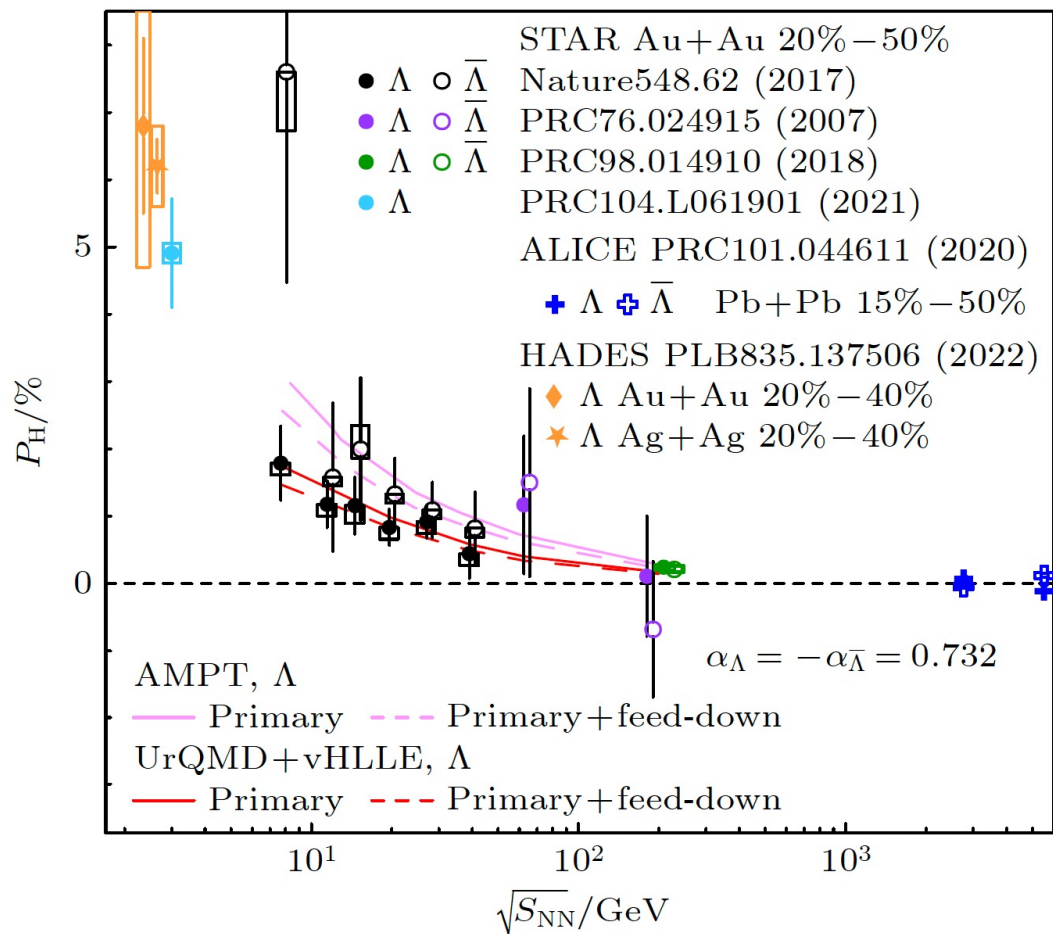
- Global polarization of Λ in BES-II 7.7~27 GeV
- Energy dependence have been presented
- Differential measurements, such as centrality, rapidity, transverse momentum dependence will submit to arXiv soon

Outlook – Global polarization in FXT energies



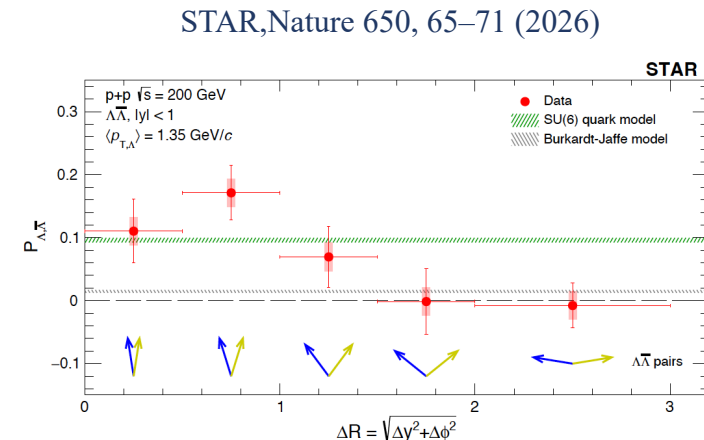
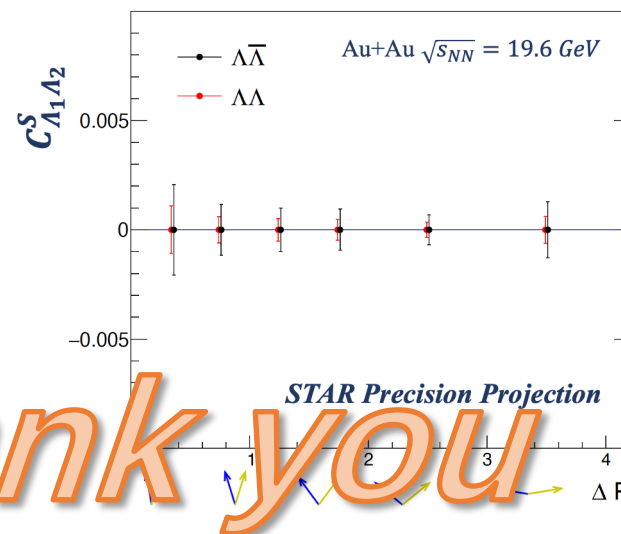
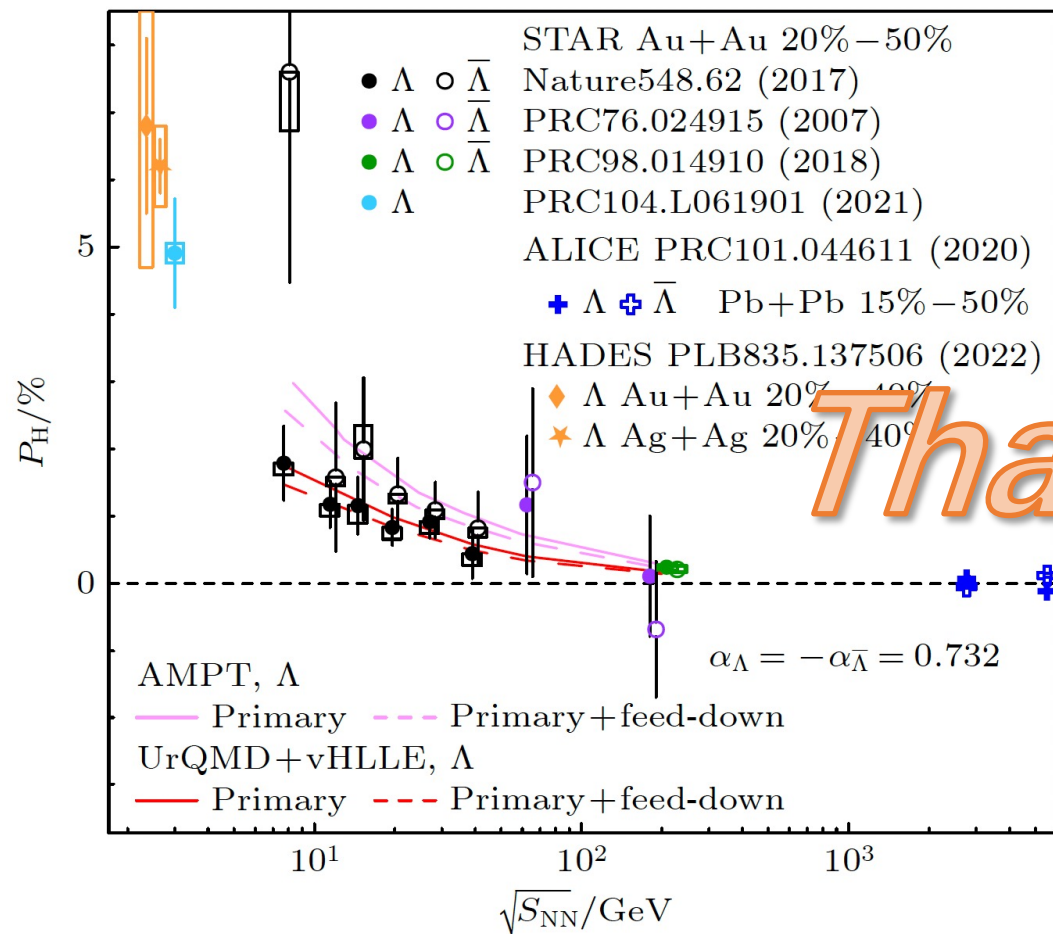
- Global polarization of Λ in FXT 3.0, 3.2, 3.5, 3.9, 4.5, 5.2, 6.2, and 7.2 GeV
- 2018 3GeV data~253M, 2021 3GeV data~2000M
- Measurements in FXT energies on-going

Outlook – Spin correlation in heavy ion collisions



- Measurement precision in Au+Au collisions is better than in pp collisions
- Stay tuned for the results
 - Au+Au collisions at BES-II and FXT energies, isobar collisions at 200 GeV, and more

Outlook – Spin correlation in heavy ion collisions

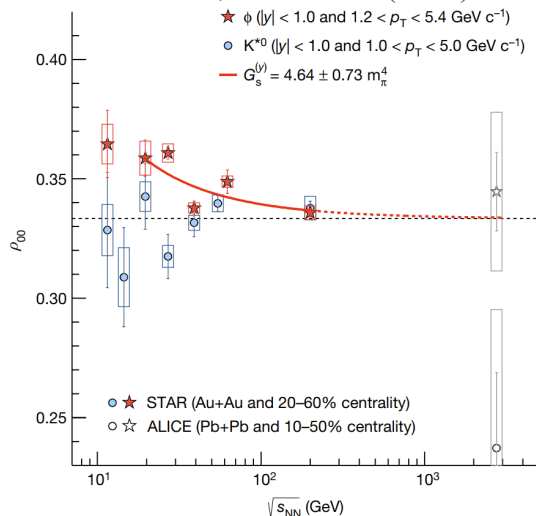


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Back Up

Spin alignment

STAR, Nature 614 (2023) 7947

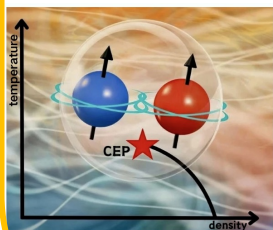
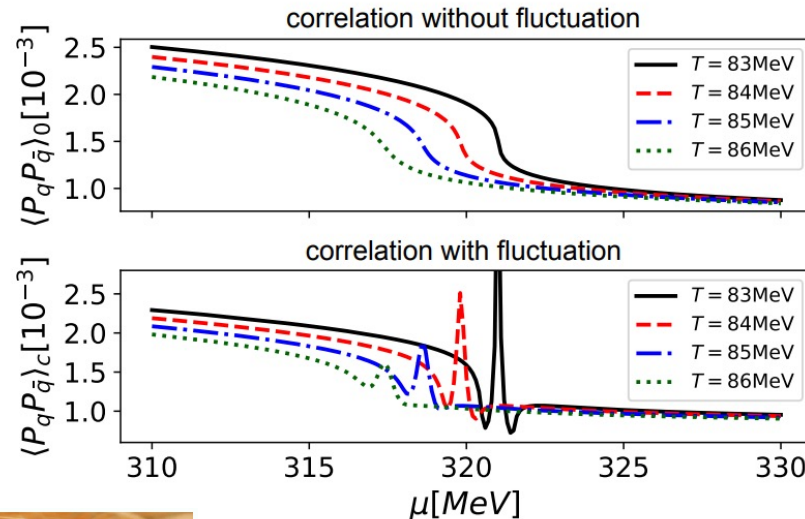


$$\rho_{00} - \frac{1}{3} \sim 10^{-2} \gg P_q^2 (10^{-4})$$



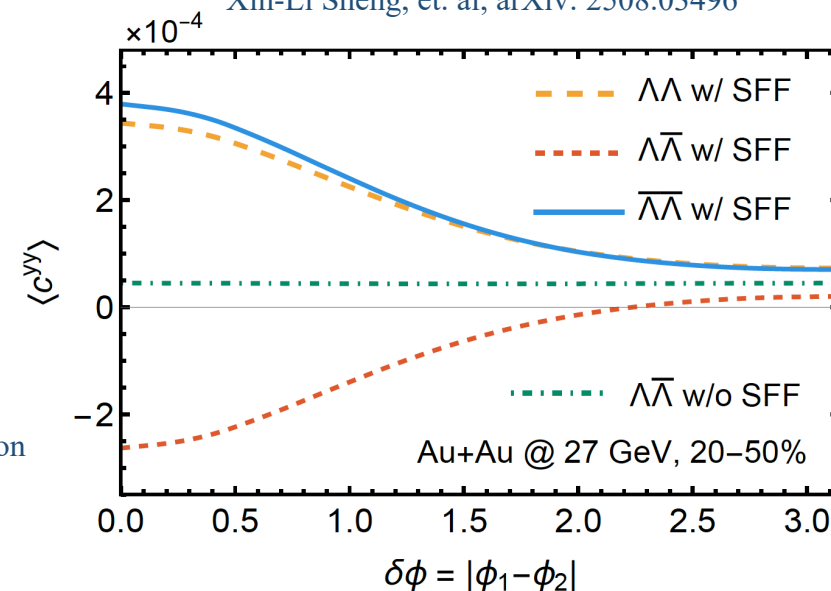
$$\langle P_q P_{\bar{q}} \rangle \neq \langle P_q \rangle \langle P_{\bar{q}} \rangle$$

Hao-Lei Chen, et. al, PRL 135. 032302 (2025)



SFF : local strong force field

Xin-Li Sheng, et. al, arXiv: 2508.03496

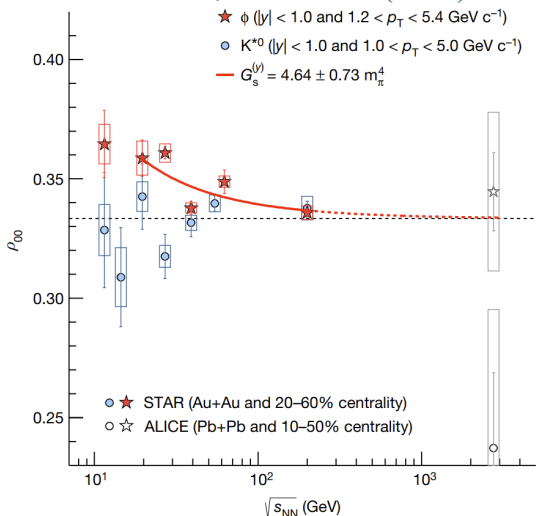


□ The hyperon spin correlation is sensitive to the CEP in the QCD phase diagram

□ Different spin correlation behaviors of $\Lambda\Lambda$ and $\Lambda\bar{\Lambda}$ pairs are predicted by the theoretical model

Spin alignment

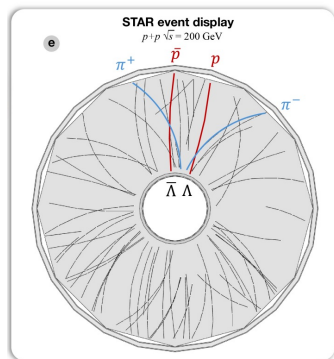
STAR, Nature 614 (2023) 7947



$$\rho_{00} - \frac{1}{3} \sim 10^{-2} \gg P_q^2 (10^{-4})$$

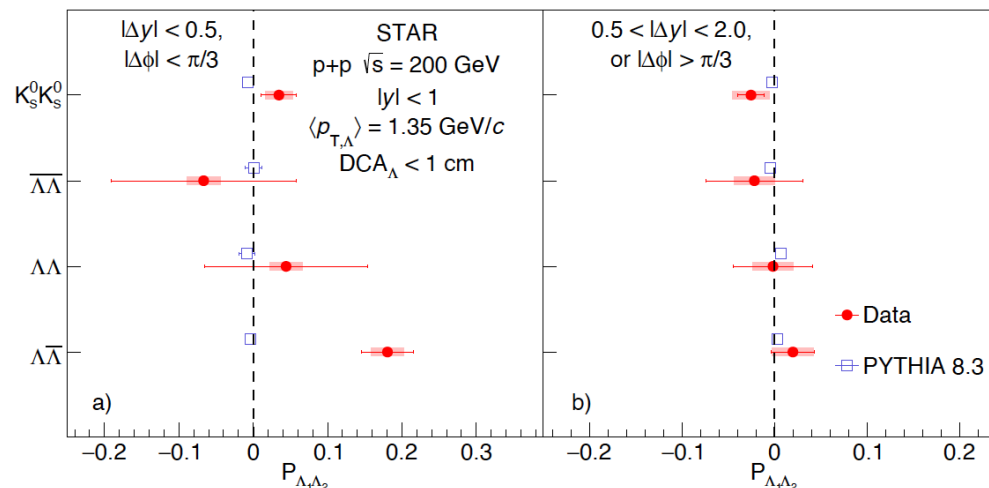


$$\langle P_q P_{\bar{q}} \rangle \neq \langle P_q \rangle \langle P_{\bar{q}} \rangle$$



Spin correlations in pp measurement

STAR, arXiv: 2506.05499



Spin correlation $C_{\Lambda_1 \Lambda_2}^S(P_{\Lambda_1 \Lambda_2})$ can be determined as follow,

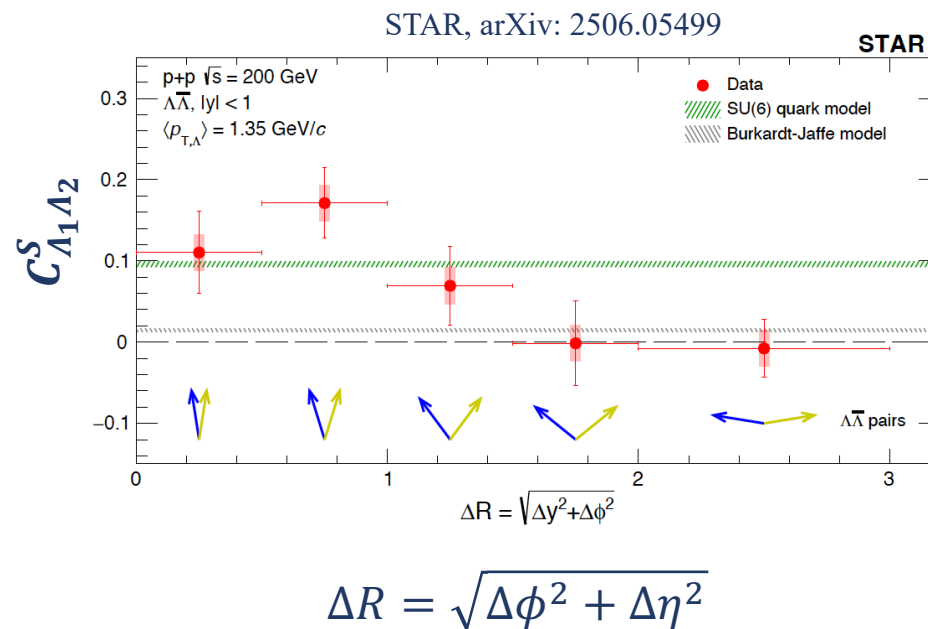
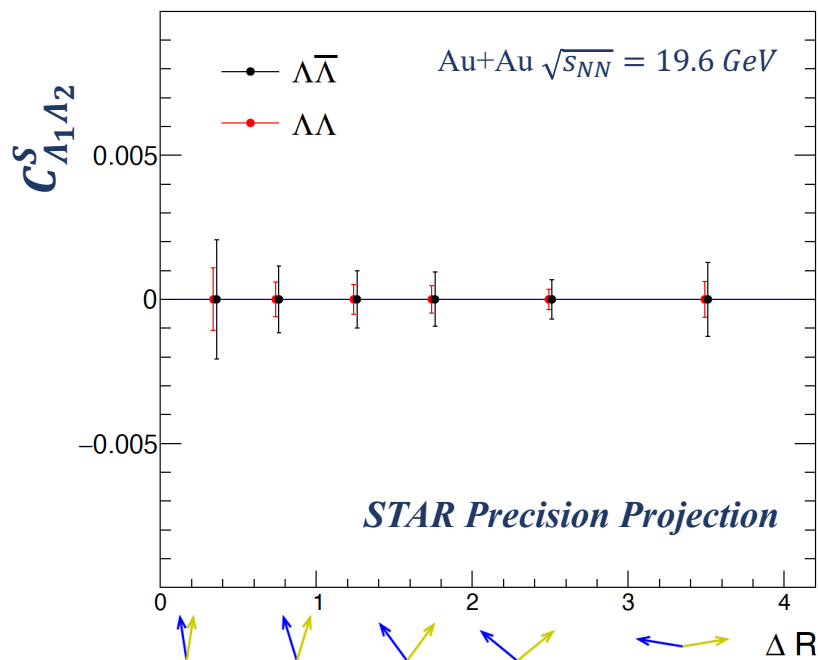
$$\frac{1}{N} \frac{dN}{d \cos \theta_{1,2}^*} = \frac{1}{2} [1 + \alpha_1 \alpha_2 C_{\Lambda_1 \Lambda_2}^S \cos \theta_{1,2}^*]$$

$\theta_{1,2}^*$ is the angle between the momentum of the protons, each boosted to the rest frame of their parent particle

A nonzero spin correlation is observed in $\Lambda \bar{\Lambda}$ pairs

How about heavy ion collisions?

$\Lambda\Lambda$ and $\Lambda\bar{\Lambda}$ Spin Correlation Statistical Projection

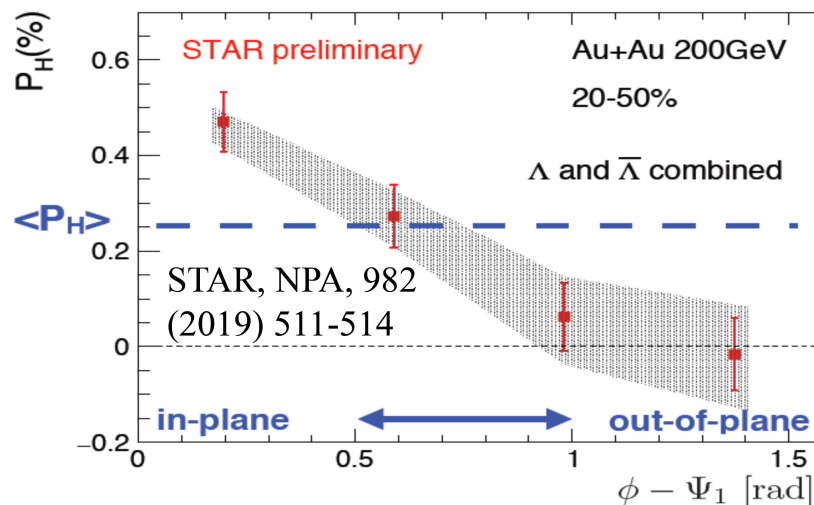


- Spin correlation as a function of distance between Λ_1 and Λ_2
- Measurement precision in Au+Au collisions is better than in pp collisions
- Stay tuned for the results
 - Au+Au collisions at BES-II energies, isobar collisions at 200 GeV, and more

Global polarization : azimuthal angle dependence

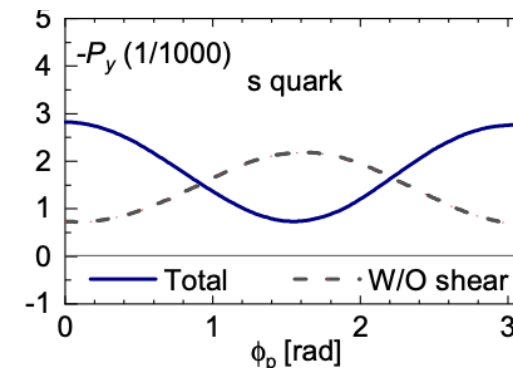
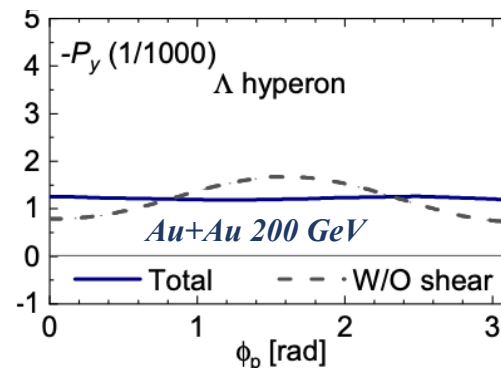


Baochi Fu et al. PRL 127 (2021) 14, 142301

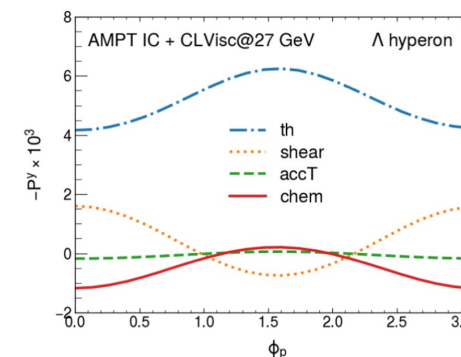
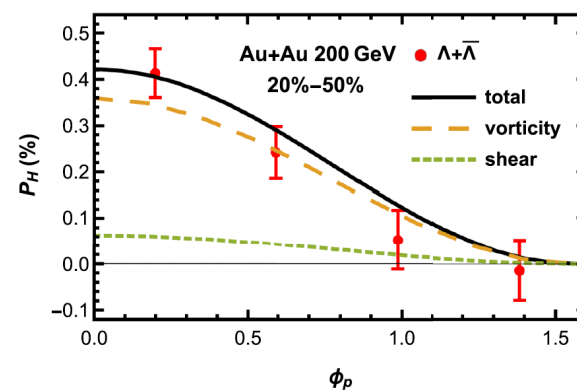


$$P_H(\Delta\phi) = P_{y,c0} + 2P_{y,c2} \cos(2\Delta\phi)$$

$$\Delta\phi = \phi_\Lambda - \Psi_2$$



Anum Arslan et al. PRC 111, 044911(2025) Xiangyu Wu et al. PRC 105, 064909(2022)



- Λ spin polarization as a function of azimuthal angle ϕ along the out-of-plane direction(y)
- Different theoretical models predict different azimuthal modulations of P_H , as $P_{y,c2}$

The weak decay $\Omega^- \rightarrow \Lambda + K^-$ 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:

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

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

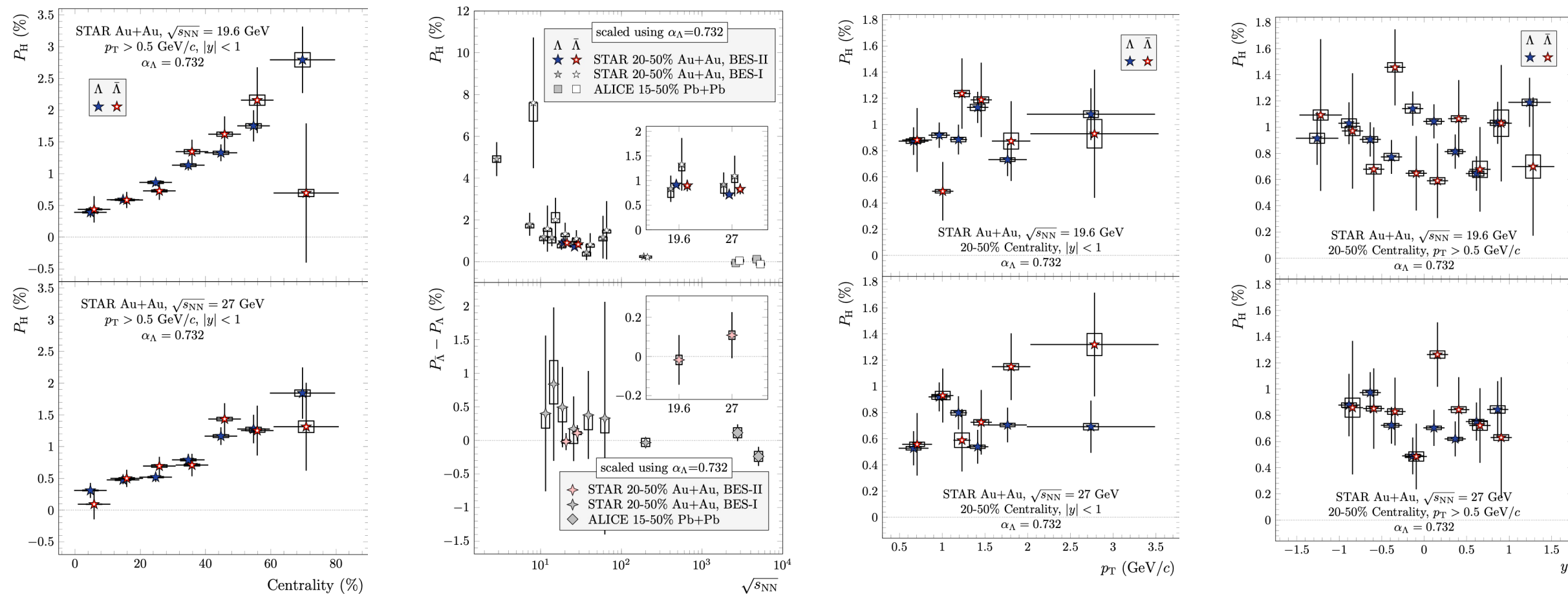
$$\frac{dn}{d\Omega_p} = \frac{1}{4\pi} (1 + \alpha_\Lambda \mathbf{P}_\Lambda \cdot \hat{\mathbf{p}}), \quad \frac{dN}{d\Omega_p} = \frac{1}{4\pi} \left[1 + \frac{\alpha_\Lambda}{2(J+1)} [1 + (2J+1)\gamma_\Omega] \mathbf{P}_\Omega \cdot \hat{\mathbf{p}} \right]. \quad \Rightarrow \quad \mathbf{P}_\Lambda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

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

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

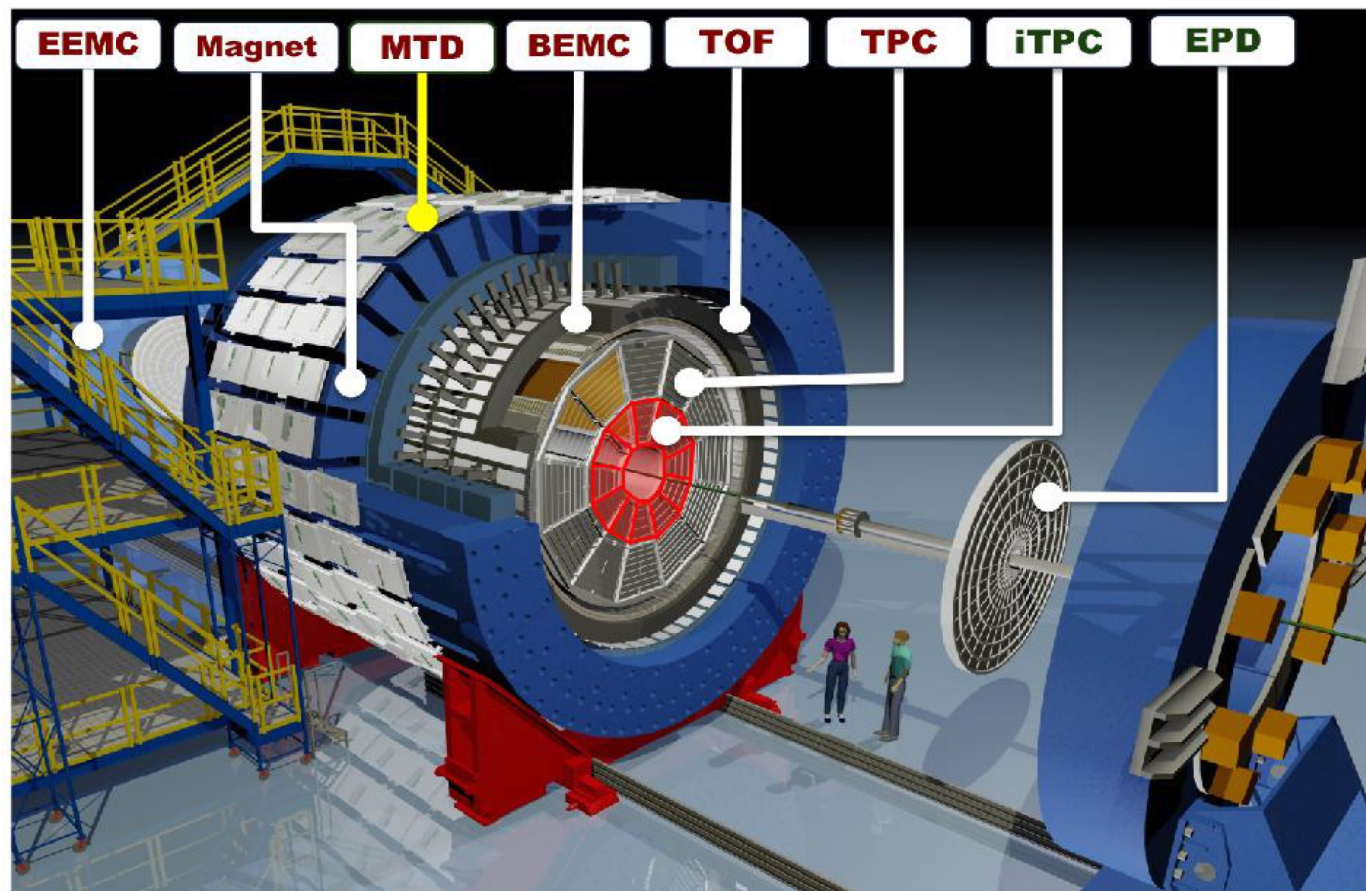
T.D. Lee and C.N. Yang, Phys. Rev. 108.1645 (1957)

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

PRC108,014910(2023)



- First-order event plane reconstructed by EPD, ZDC

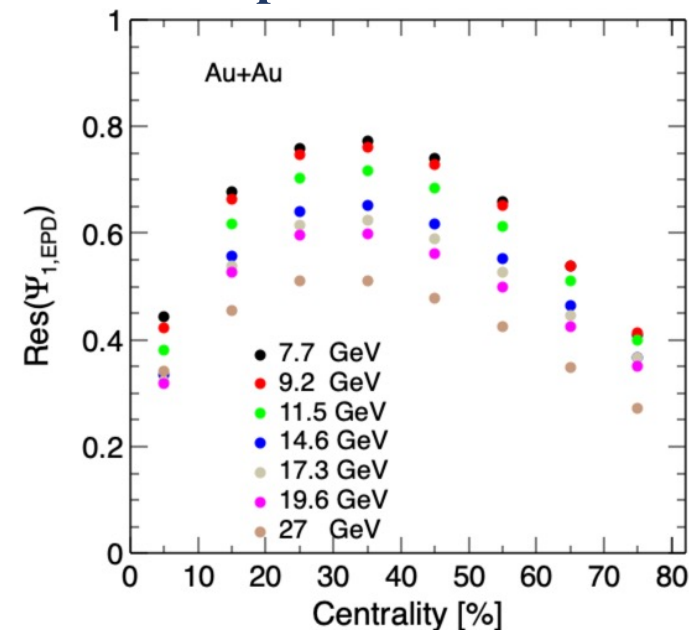
□ Event Plane Detector

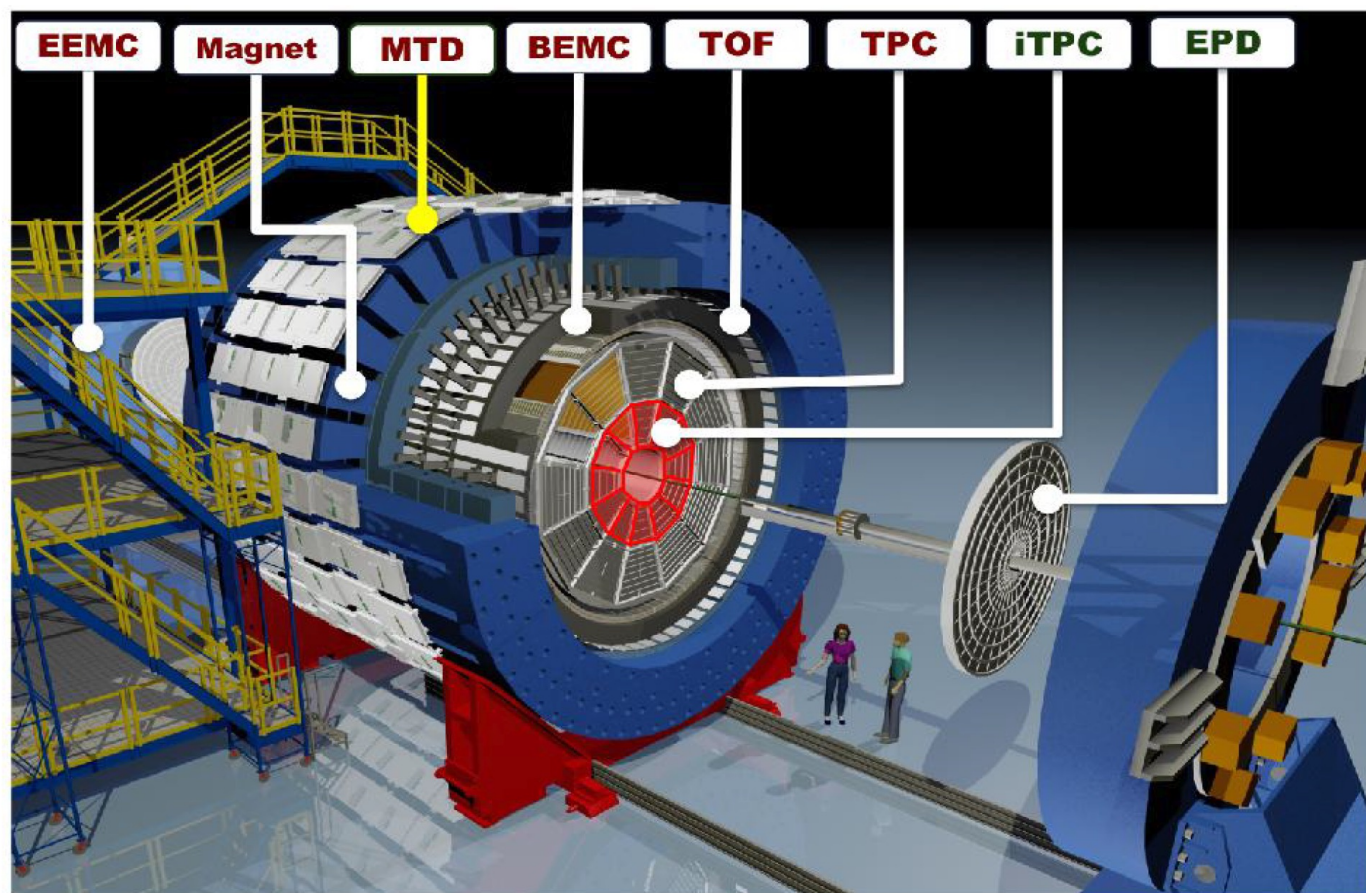
- Event plane reconstruction
- $2.1 < |\eta| < 5.1$

□ Zero Degree Calorimeters

- Event plane reconstruction
- $6.3 < |\eta|$

Event plane resolution





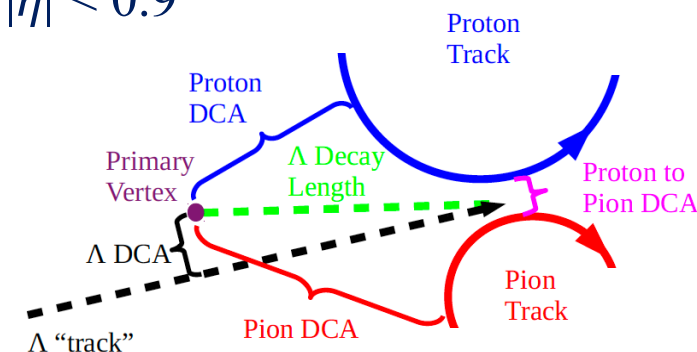
- Hyperons reconstructed using KF Particle package

Time Projection Chamber

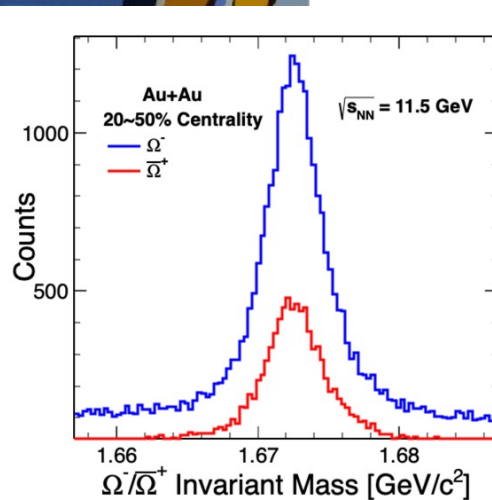
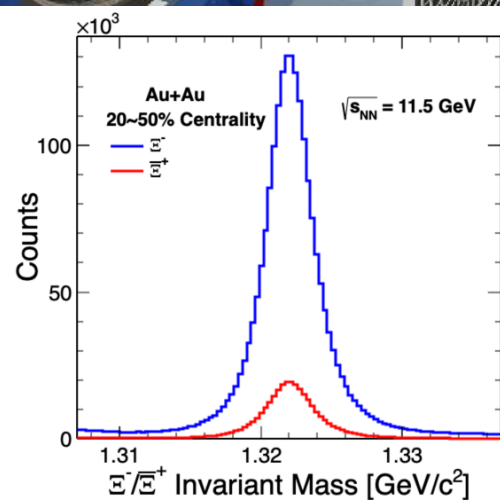
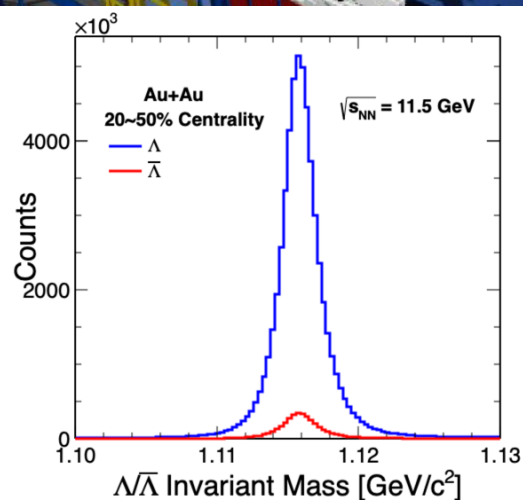
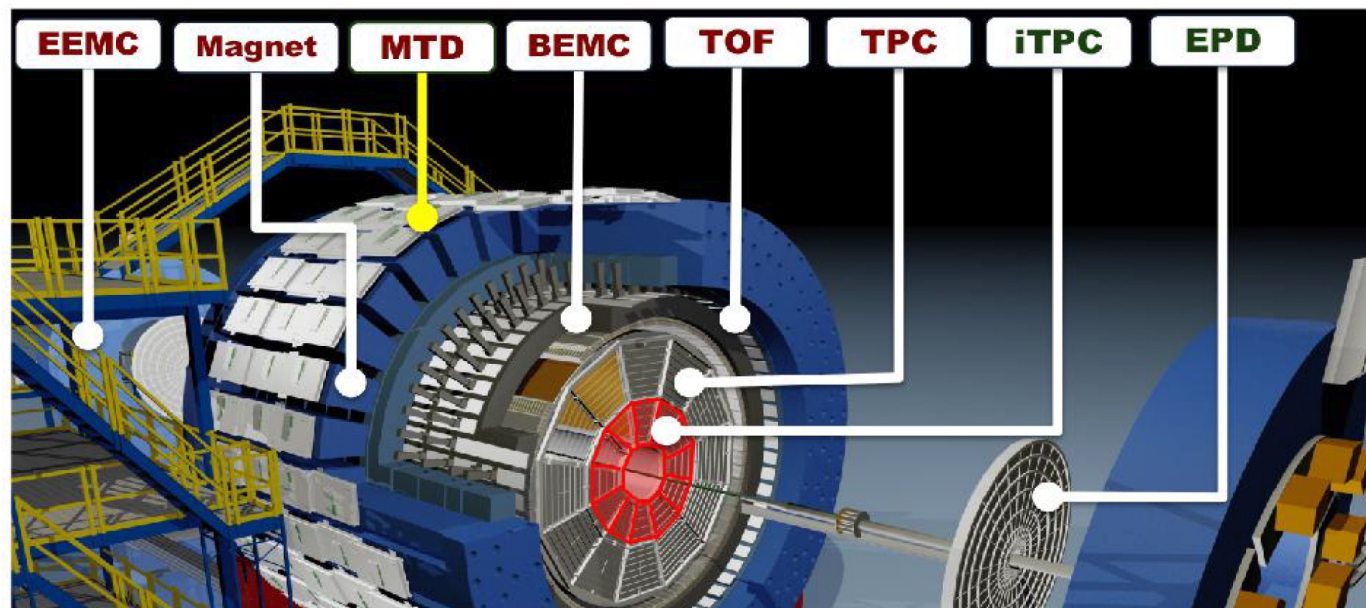
- Upgrade with inner TPC
- Better track quality
- Larger acceptance
- $|\eta| < 1.0 \rightarrow |\eta| < 1.5$

Time Of Flight

- PID via particle velocity
- $|\eta| < 0.9$



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

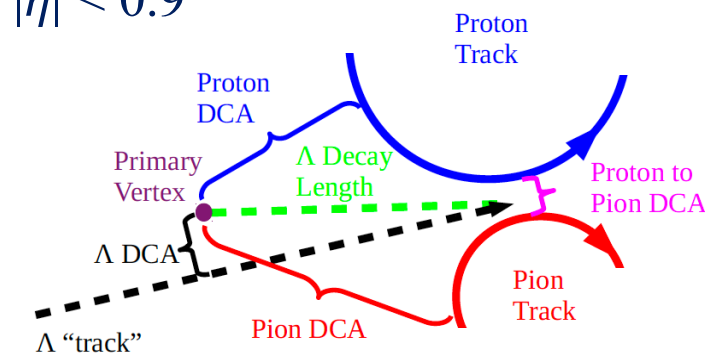


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