

Hyperon polarization and spin spin correlation in heavy ion collisions from STAR

Xingrui Gou (苟兴瑞)

2026/05/13

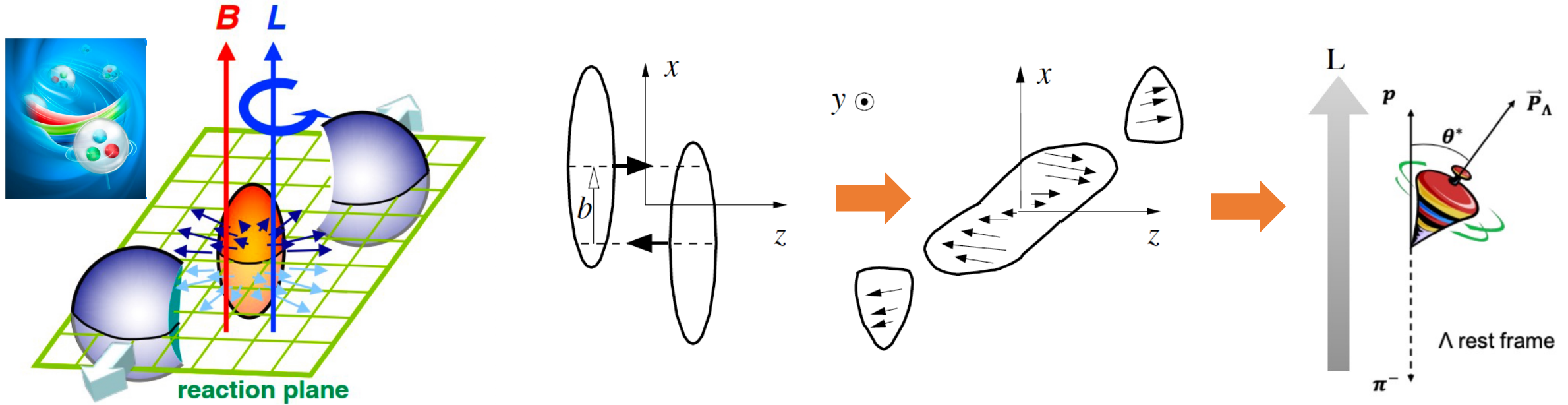
International Symposium on Spin Polarization in Relativistic
Heavy Ion Collisions 2026

- Introduction

- Differential measurements of global polarization
 - Energy, system size, centrality dependence.....

- Spin spin correlation

- Summary



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)

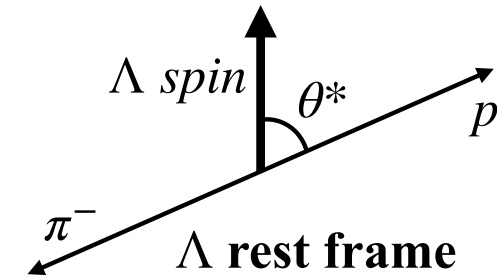
- “Self-analyzing”, parity-violating weak decay channel of hyperons
 - Daughter baryon is preferentially emitted in the direction of the hyperon spin

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

α_H : hyperon decay parameter

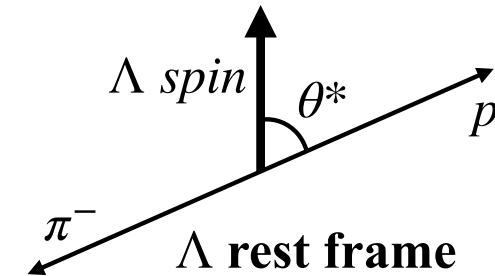
P_H : hyperon polarization

θ^* : polarization angle



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

- “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%, $c\tau \sim 7.9\text{cm}$)

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

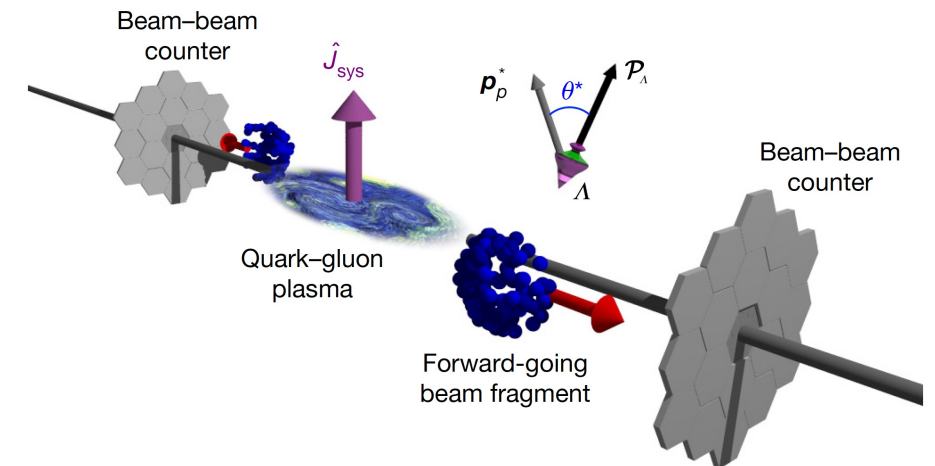
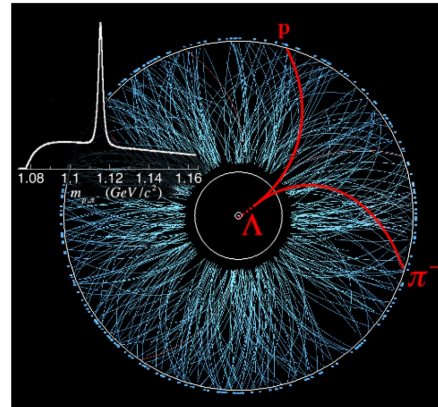
$$\alpha_\Lambda = -\alpha_{\bar{\Lambda}} = 0.732 \pm 0.014$$

A_0 : Acceptance correction factor

Ψ_1 : First-order event plane angle

$\text{Res}(\Psi_1)$: Event plane resolution

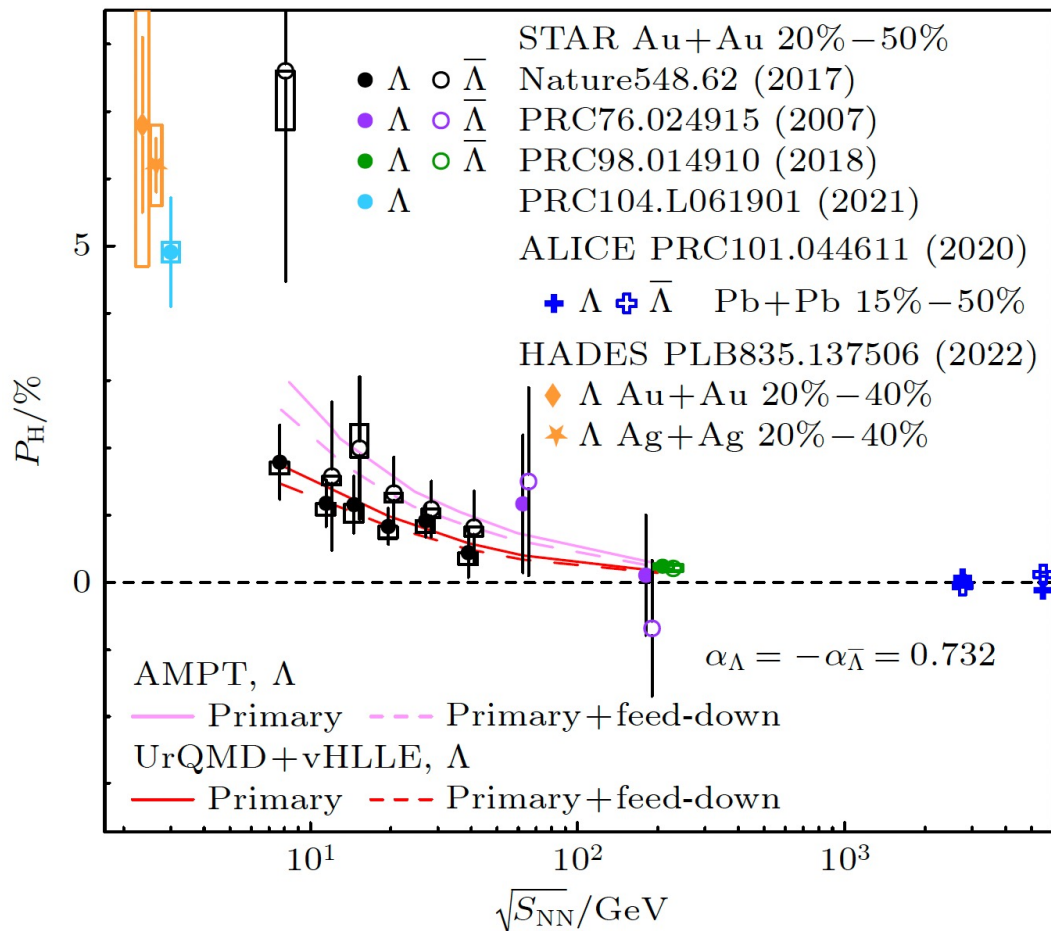
STAR, PRC76, 024915 (2007)



Observation of Λ global polarization

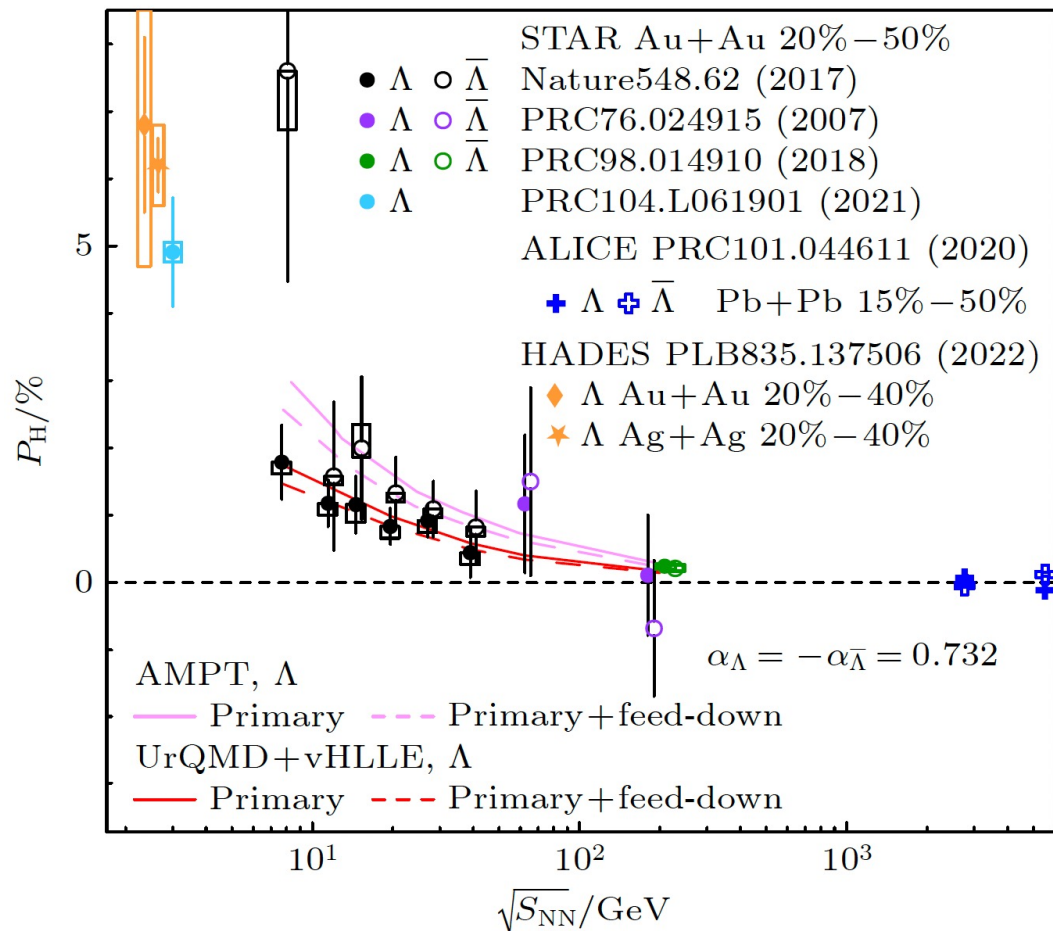


Acta Phys. Sin. Vol. 72, No. 7(2023) 072401



- 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 BES-II(7.7-27 GeV)
PRC108,014910(2023), preliminary results(2024)
- ALICE, high precision P_H in Pb+Pb 5.02 TeV
Preliminary results, SPIN2025

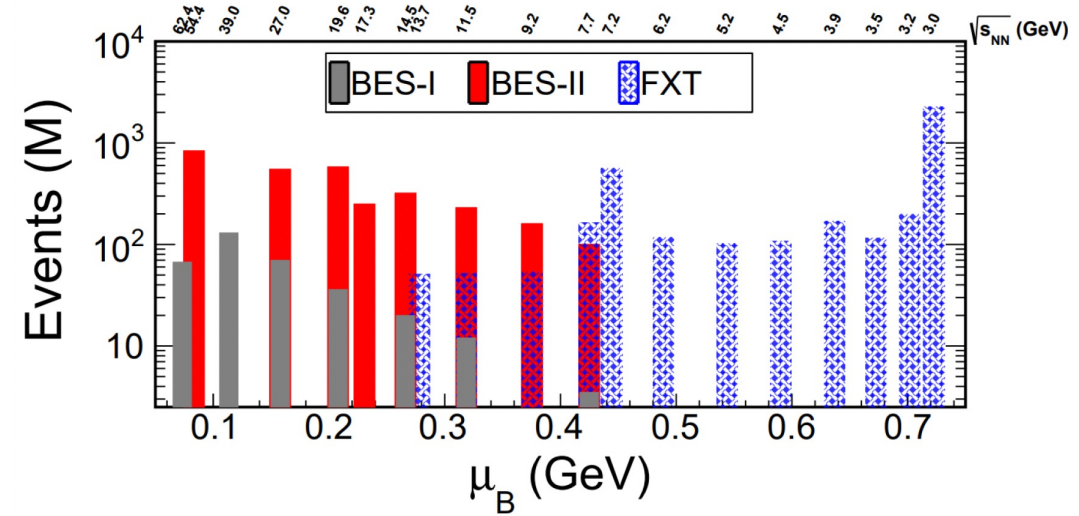
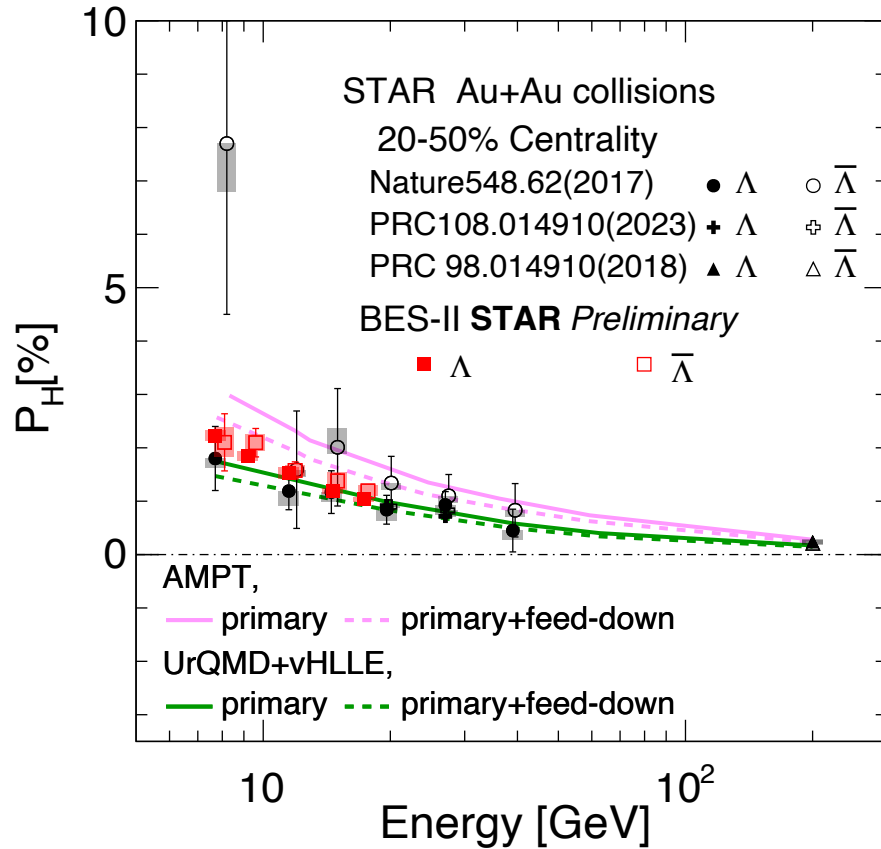
Acta Phys. Sin. Vol. 72, No. 7(2023) 072401



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
- Anum Arslan et al. PRC 111, 044911(2025)
- Fang, K. Fukushima, Pu, Wang, PRL.136(2026) 18, 182301
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Global polarization : energy dependence



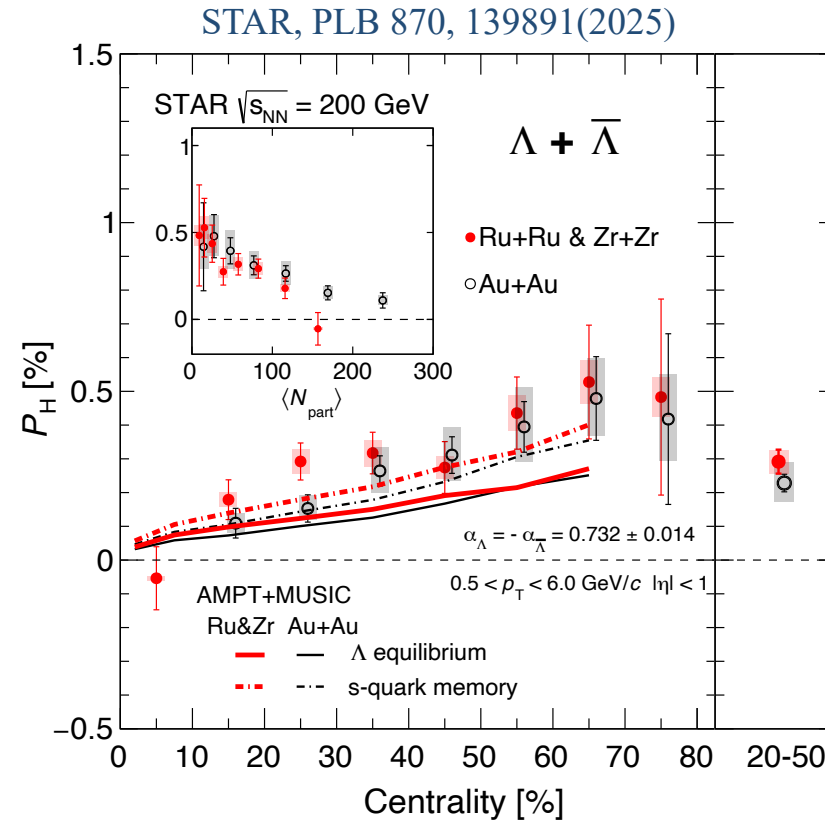
□ Greatly improved precision from Beam Energy Scan phase-II at 7.7, 9.2, 11.5, 14.6, 17.3 GeV

□ 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

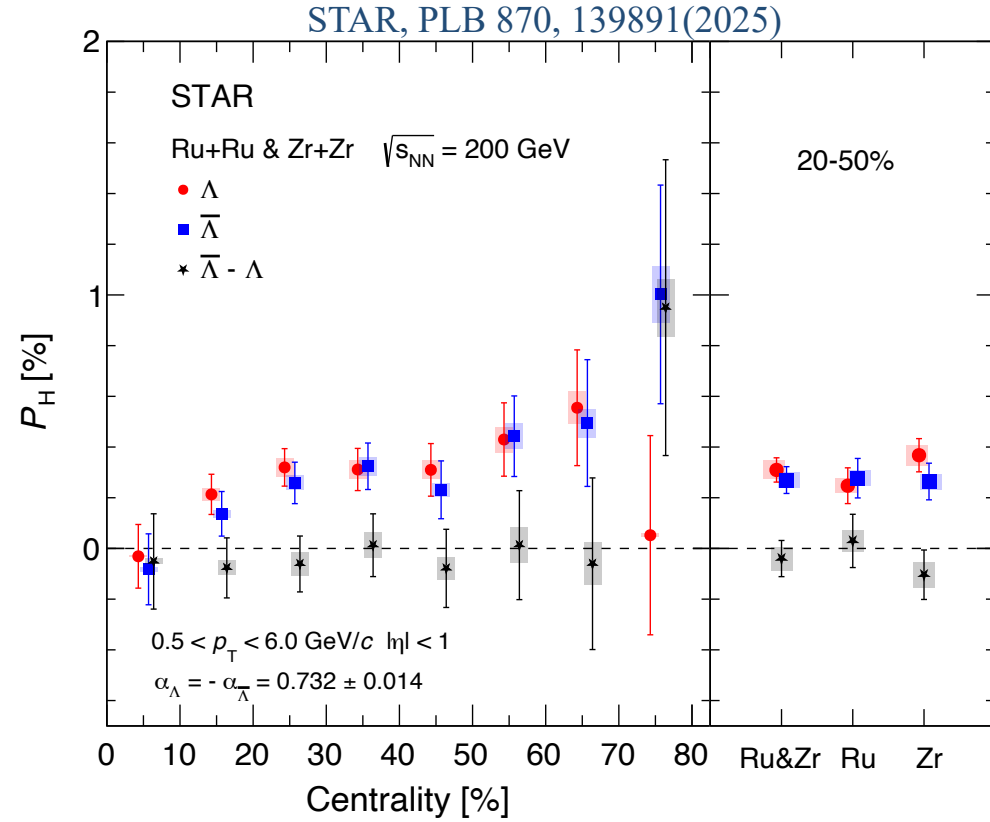
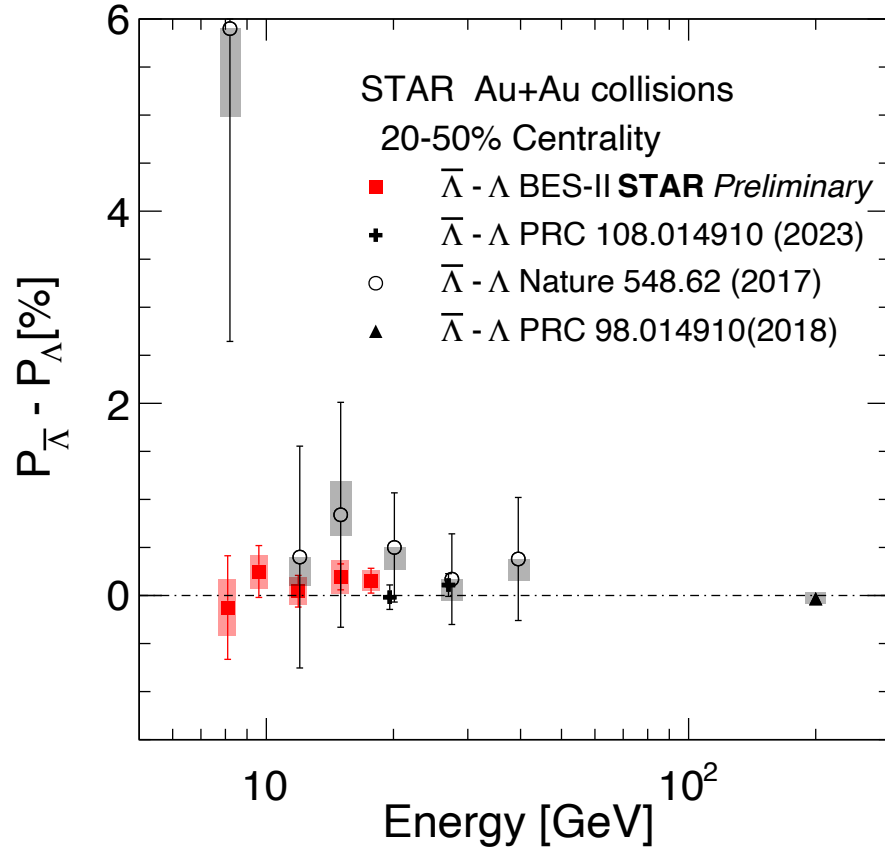
- $P_H = 1.17 \pm 0.40(stat) \pm 0.27(syst)$ [BES-I] \longrightarrow $1.19 \pm 0.04(stat) \pm 0.05(syst)$ [BES-II] at 14.6 GeV
 Nature 548.62(2017)

Global polarization : system size dependence



- Significant global polarization observed in isobar collisions, increase with centrality
- No significant difference between Ru+Ru, Zr+Zr and Au+Au collisions

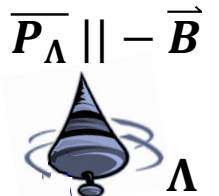
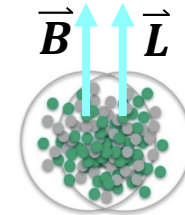
Global polarization : splitting of Λ and $\bar{\Lambda}$



□ 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)

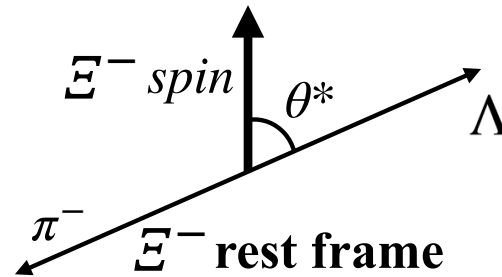
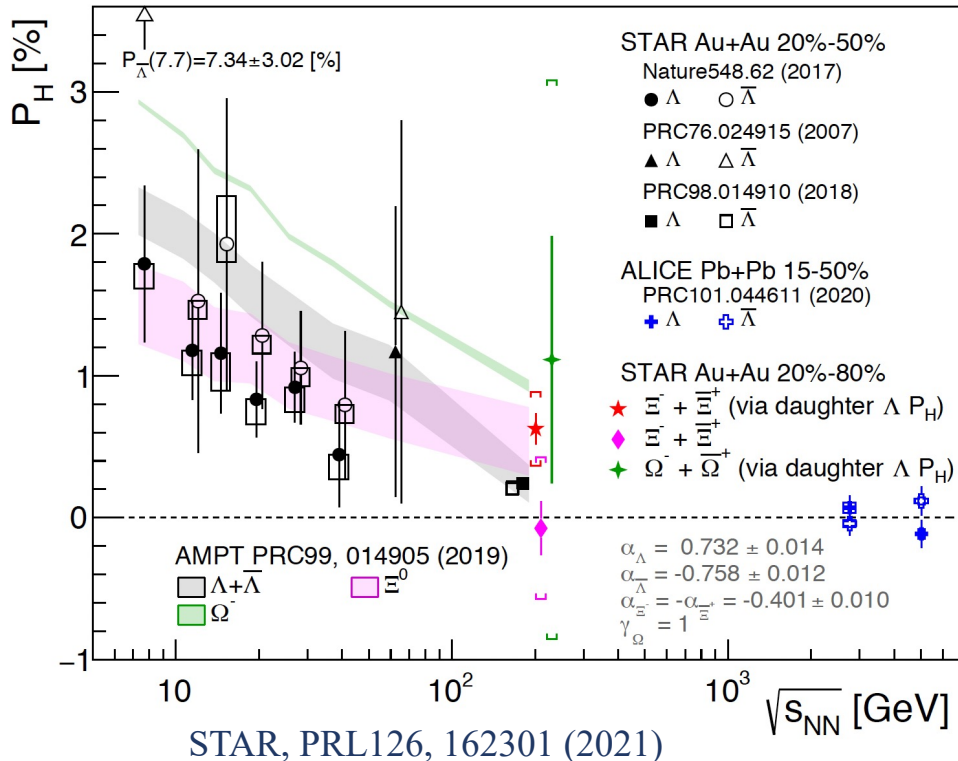


$\Xi^- + \bar{\Xi}^+$ global polarization measurement



□ 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)



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

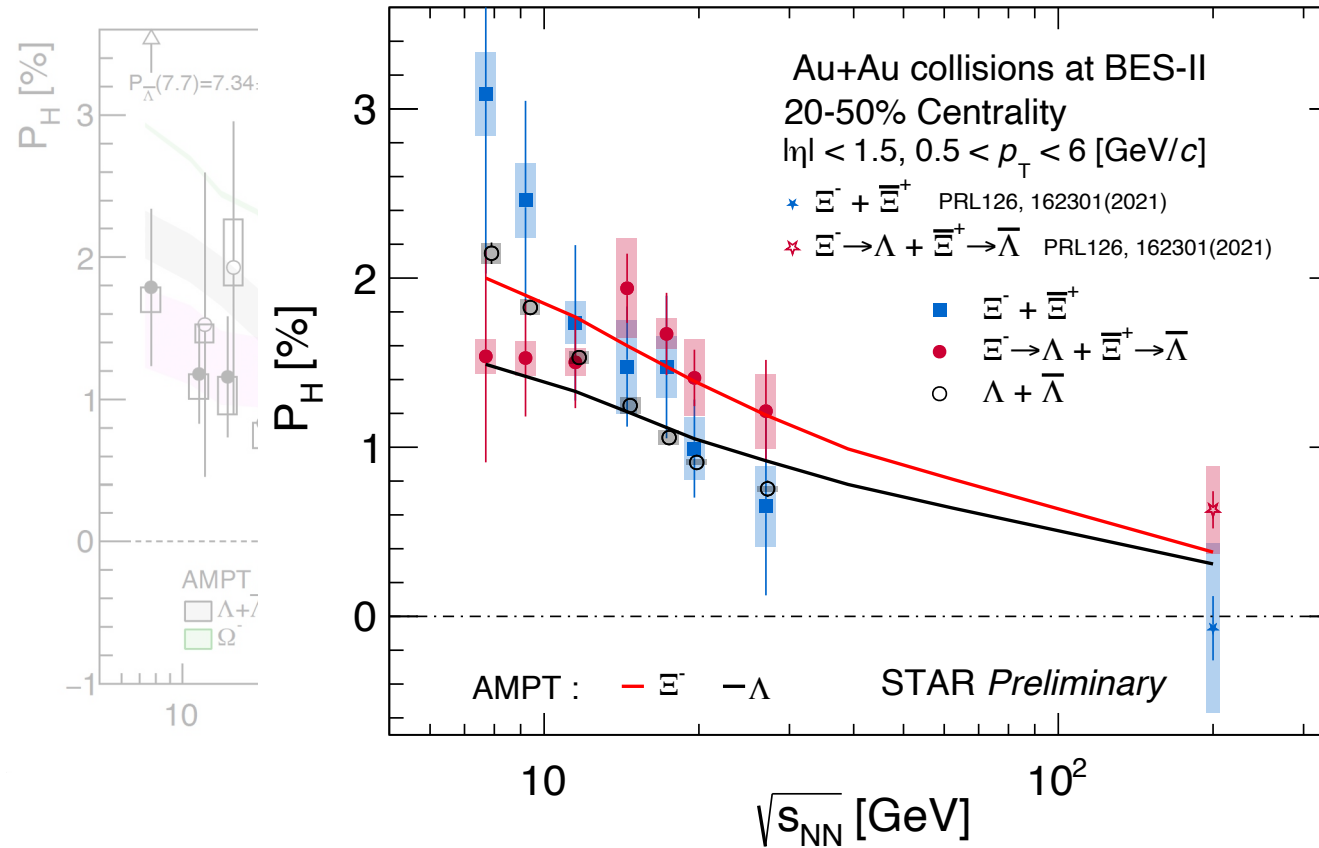
α_H : hyperon decay parameter
 P_H : hyperon polarization
 θ^* : polarization angle

□ Collision energy, centrality, p_T , η dependence?

□ Possible Λ, Ξ, Ω global polarization difference?

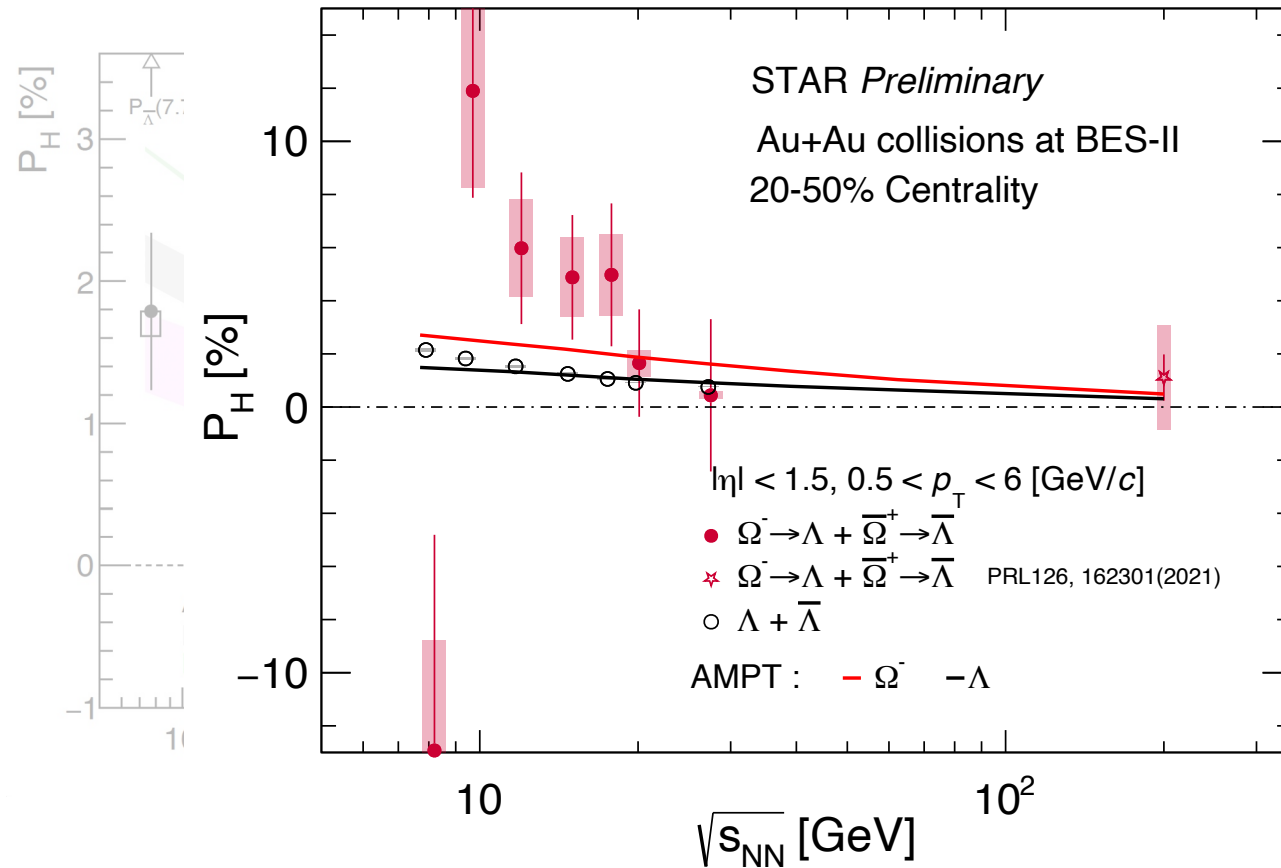
$$P_\Lambda \cong P_S, \text{ assuming that } P_{u,d} \sim P_S \longrightarrow P_\Xi \sim P_\Lambda, P_\Omega \sim \frac{5}{3} P_\Lambda$$

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



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

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

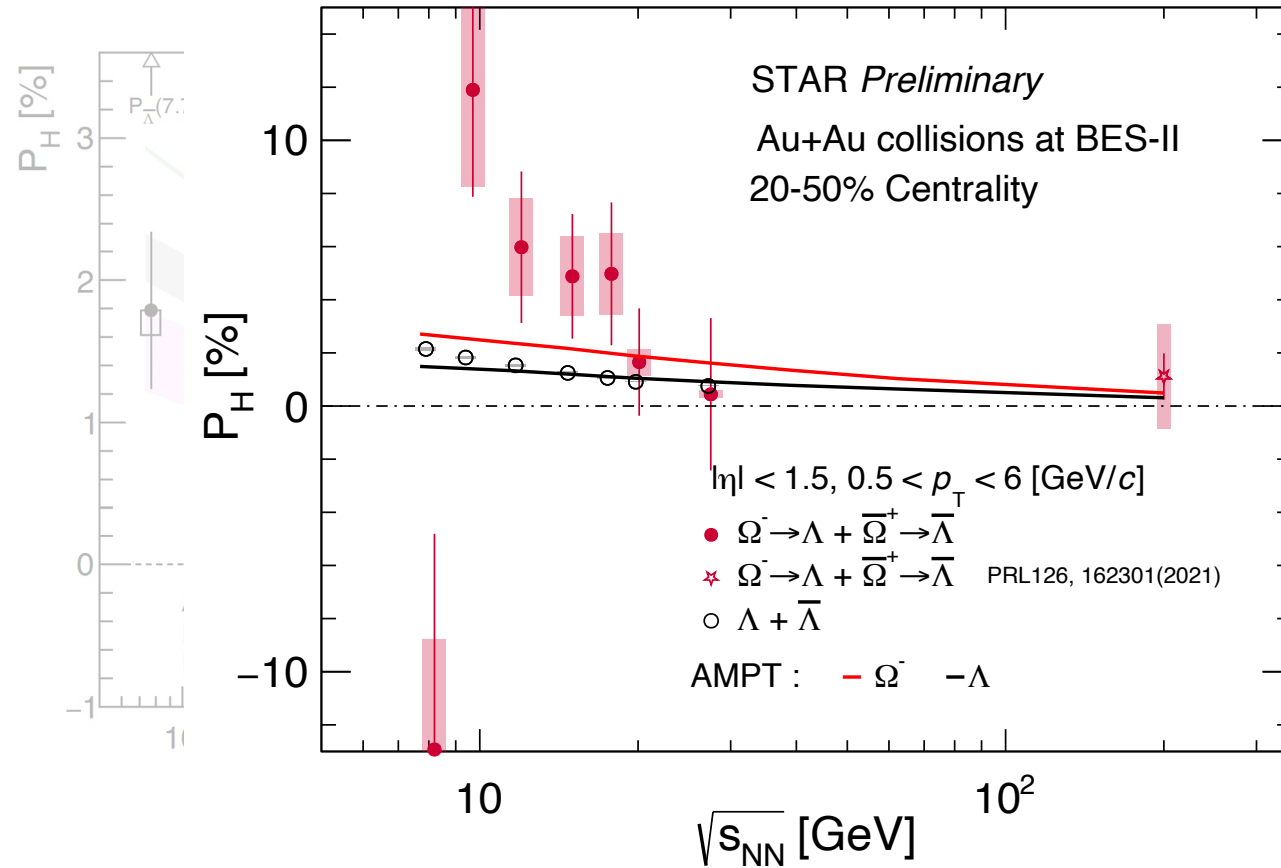


□ Global polarization of $\Omega^- + \bar{\Omega}^+$ seems to decrease with increase in collision energy

□ 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 Phys. Rev. D 109, 114003(2024)

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

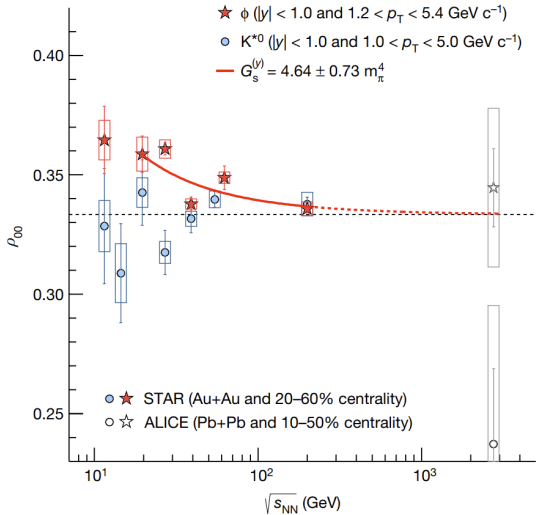
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Model calculation:

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

Spin alignment

STAR, Nature 614 (2023) 7947

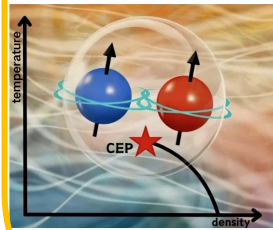
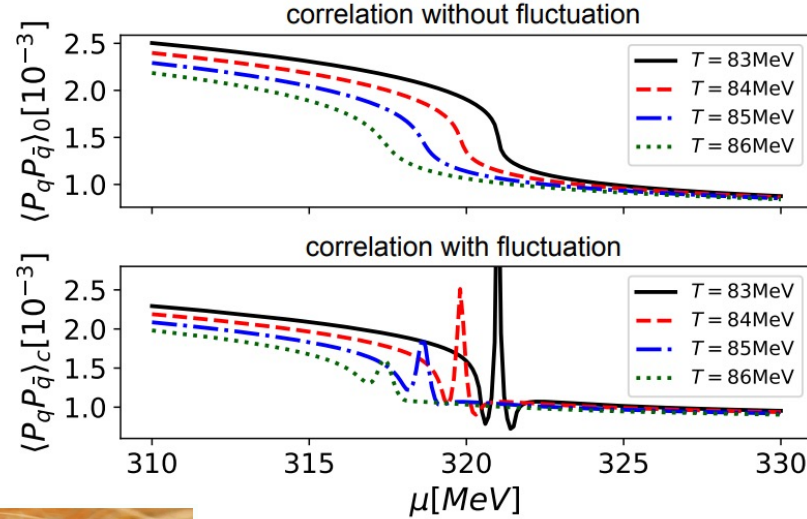


$$\rho_{00} - \frac{1}{3} \sim 10^{-2} \gg P_q^2 (10^{-4})$$



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

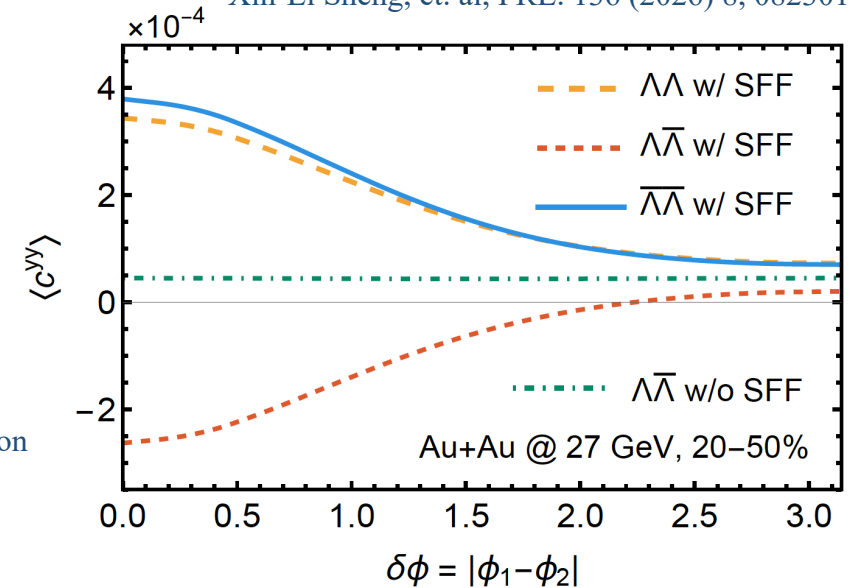
Hao-Lei Chen, et. al, PRL 135. 032302 (2025)



μ is quark chemical potential, $\mu = \mu_B/3$
 $\langle P_q P_{\bar{q}} \rangle_c$: spin correlation with critical fluctuation
 $\langle P_q P_{\bar{q}} \rangle_0$: spin correlation without critical fluctuation

SFF : local strong force field

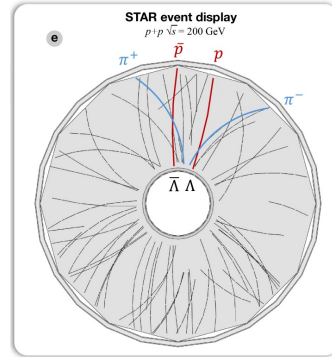
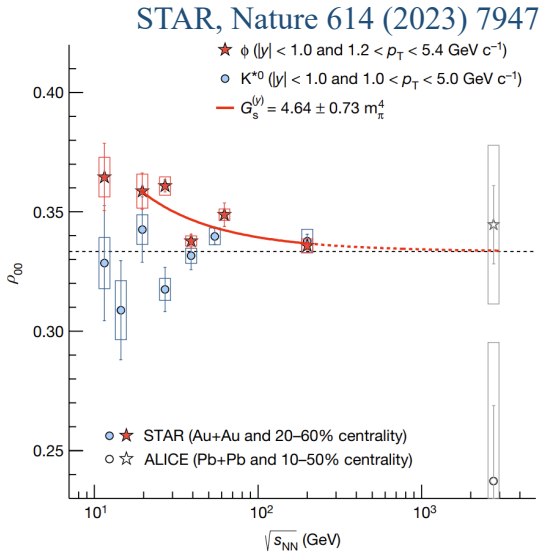
Xin-Li Sheng, et. al, PRL. 136 (2026) 8, 082301



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

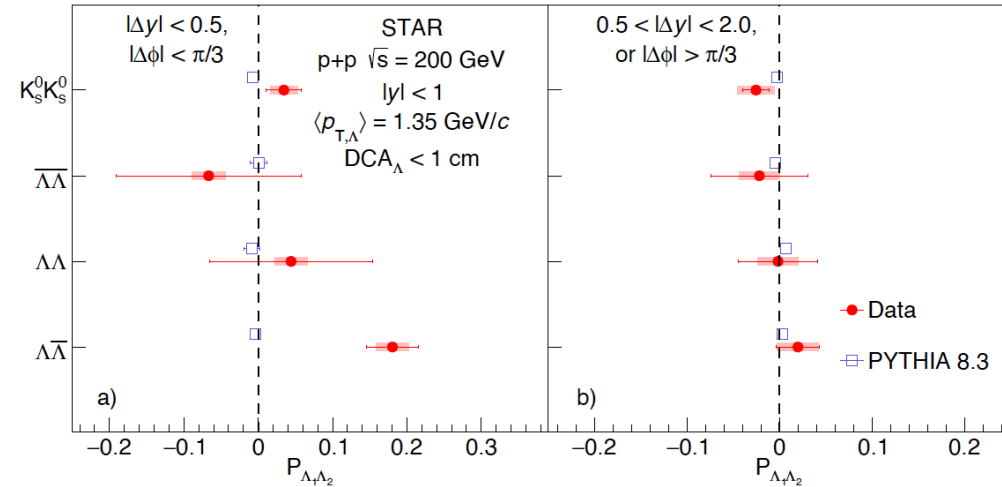
Different spin correlation behaviors of $\Lambda\Lambda$ and $\Lambda\bar{\Lambda}$ pairs are predicted by the theoretical model

Spin alignment



Spin correlations in pp measurement

STAR, Nature 650 (2026) 8100, 65-71



Spin correlation $P_{\Lambda_1 \Lambda_2}$ can be determined as follow,

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

$\theta_{1,2}^*$ 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

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



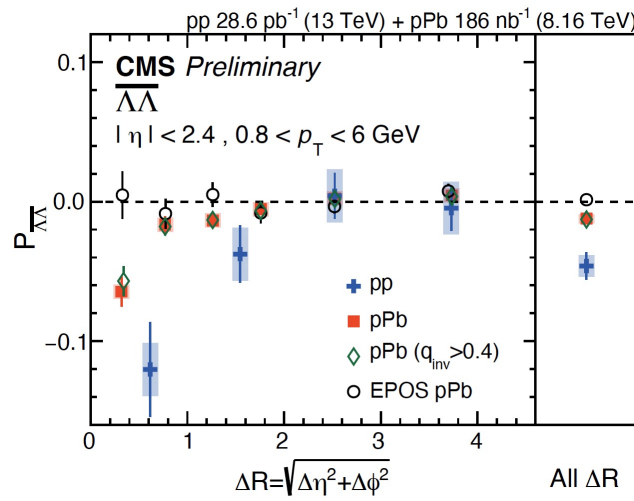
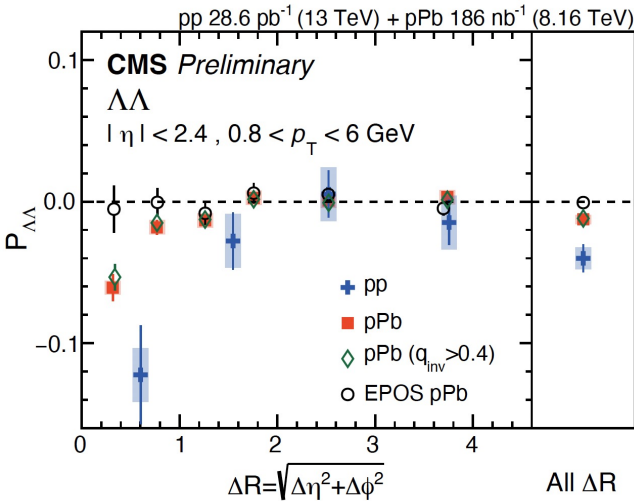
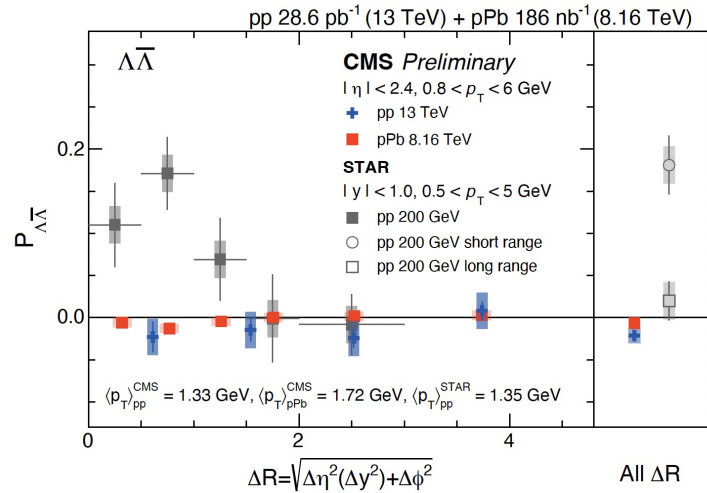
$$\langle P_q P_{\bar{q}} \rangle \neq \langle P_q \rangle \langle P_{\bar{q}} \rangle$$

Spin spin correlation



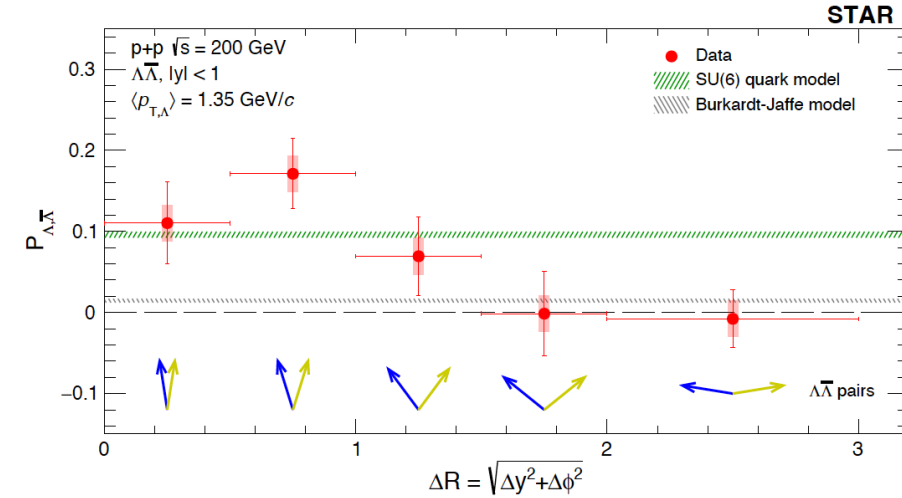
□ CMS results

<https://agenda.infn.it/event/47074/contributions/289117/>



□ STAR Spin correlations in pp measurement

STAR, Nature 650 (2026) 8100, 65-71



□ CMS experiment also observed spin spin correlation in pp and pPb collisions

□ STAR experiment :

- Au+Au collisions(7.7-200 GeV),
- Ru+Ru&Zr+Zr collisions(200 GeV),
- FXT energis(3.0-7.2 GeV)
-

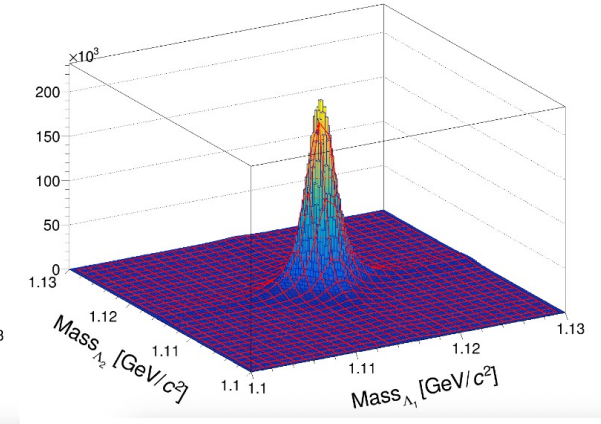
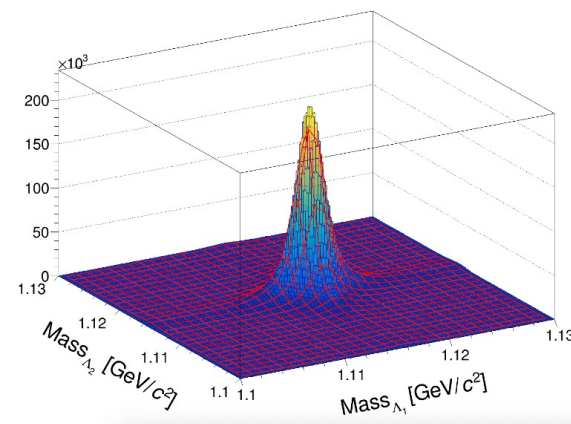
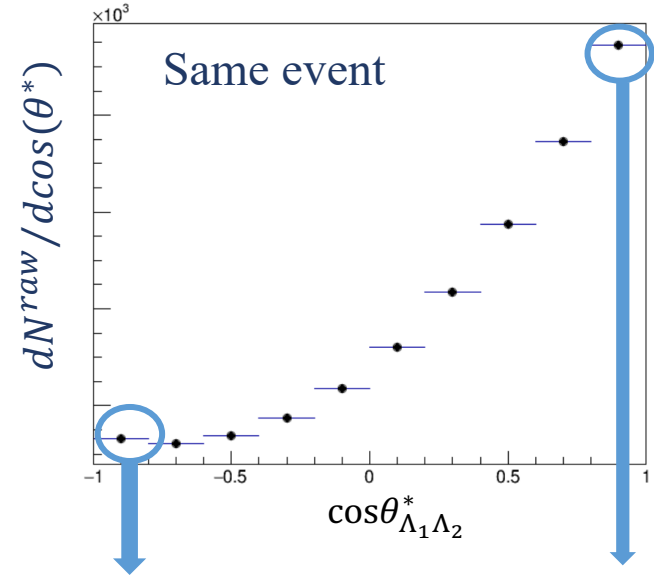
Spin spin correlation measurement



- Fit the $\Lambda_1\Lambda_2$ pair invariant mass distribution in $\cos\theta_{1,2}^*$ bin
 - Signal (2D Gaussian) + background (2nd order polynomial)
- Signal = Total counts – Fit background counts
- Measured $dN^{raw}/dcos(\theta^*)$ distributions

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

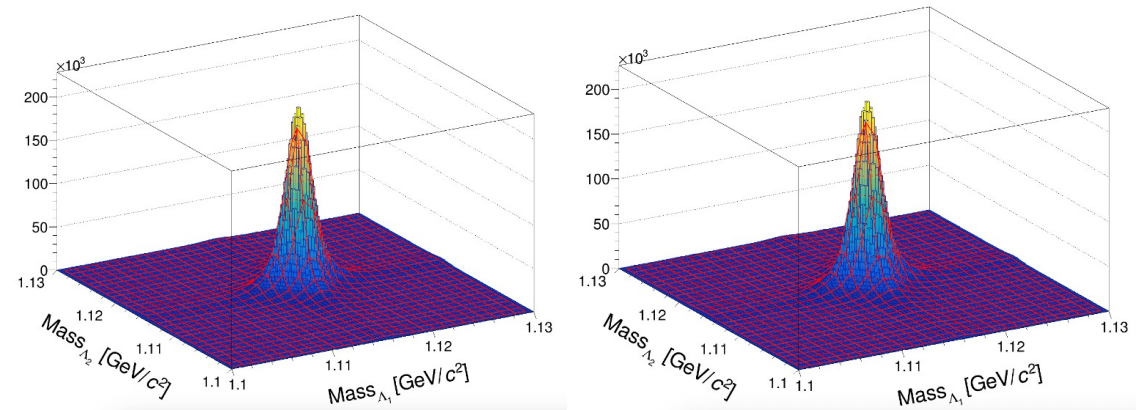
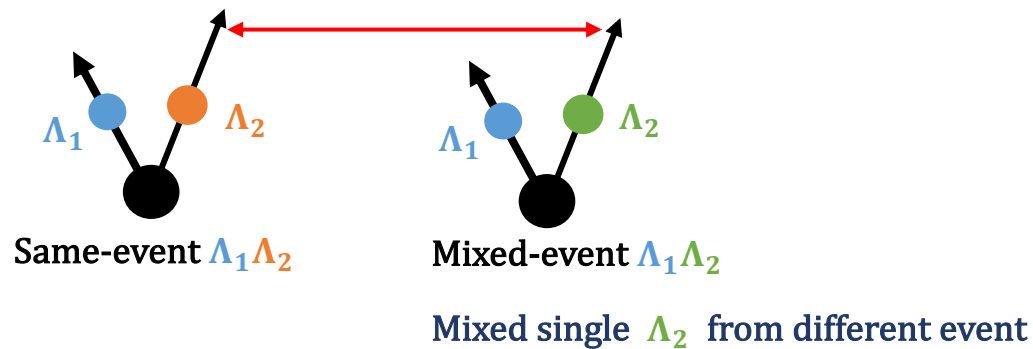
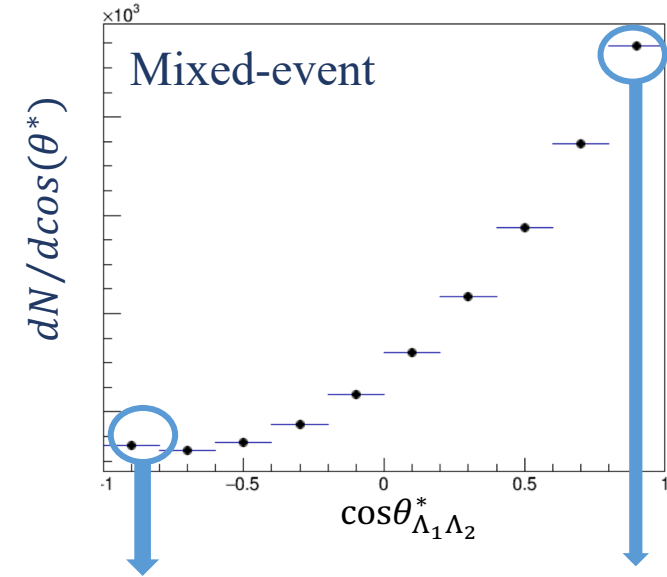
STAR, Nature 650 (2026) 8100, 65-71



Spin spin correlation measurement



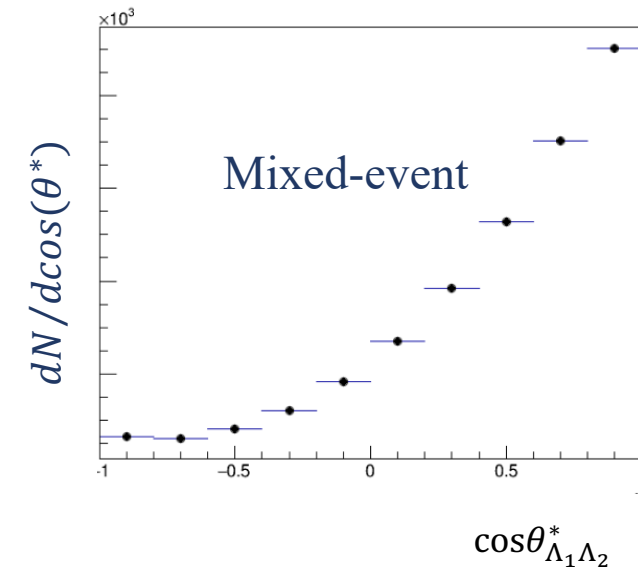
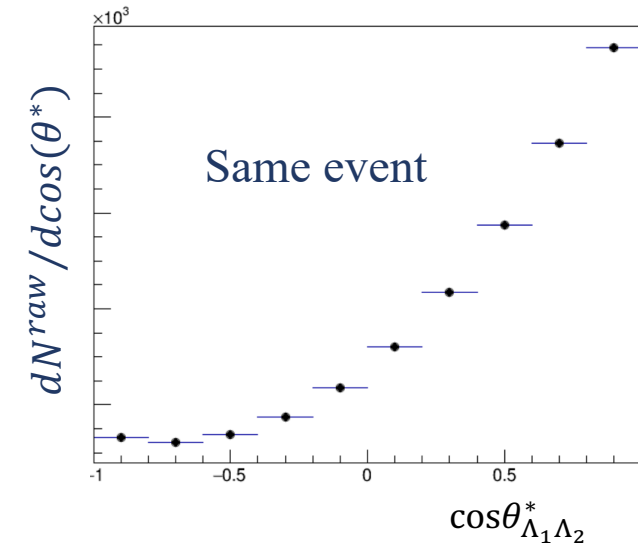
- ❑ Fit the $\Lambda_1\Lambda_2$ pair invariant mass distribution in $\cos\theta_{1,2}^*$ bin
 - Signal (2D Gaussian) + background (2nd order polynomial)
- ❑ Signal = Total counts – Fit background counts
- ❑ Measured $dN^{raw}/d\cos(\theta^*)$ distributions
- ❑ Mixed-event hyperon pairs use to correct the detector effects :
Same event / Mixed event



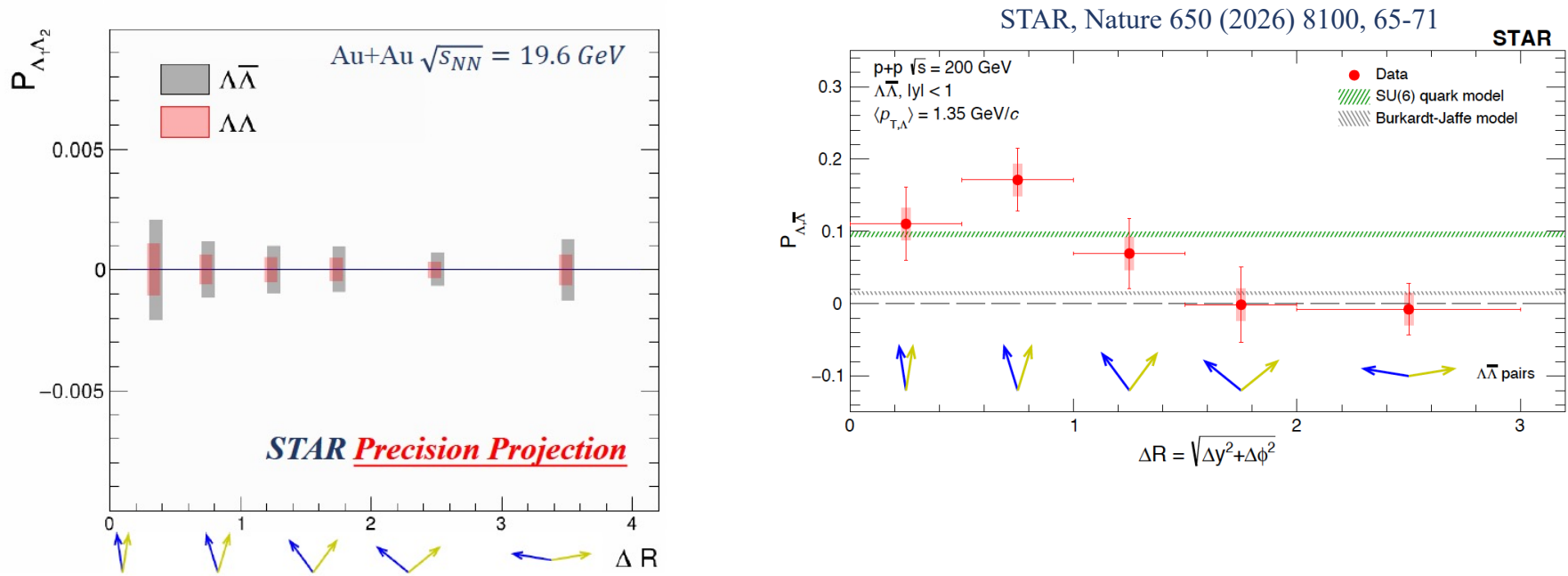
Spin spin correlation measurement



- ❑ Fit the $\Lambda_1\Lambda_2$ pair invariant mass distribution in $\cos\theta_{1,2}^*$ bin
 - Signal (2D Gaussian) + background (2nd order polynomial)
- ❑ Signal = Total counts – Fit background counts
- ❑ Measured $dN^{raw}/d\cos(\theta^*)$ distributions
- ❑ Mixed-event hyperon pairs use to correct the detector effects :
Same event / Mixed event
- ❑ Correlation signal is extracted by fitting $dN/d\cos(\theta^*)$ distribution after Mixed-event correction



$\Lambda\Lambda$ and $\Lambda\bar{\Lambda}$ spin correlation statistical projection



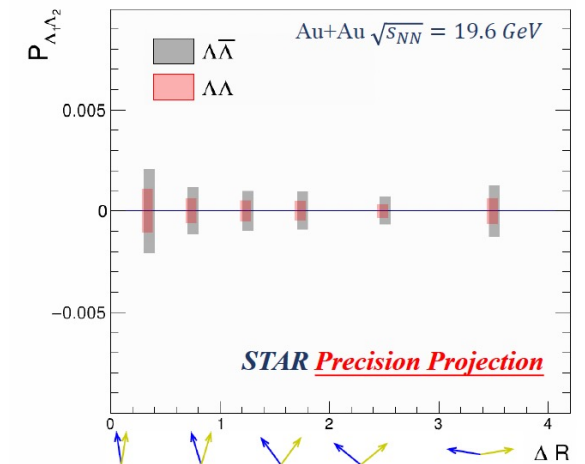
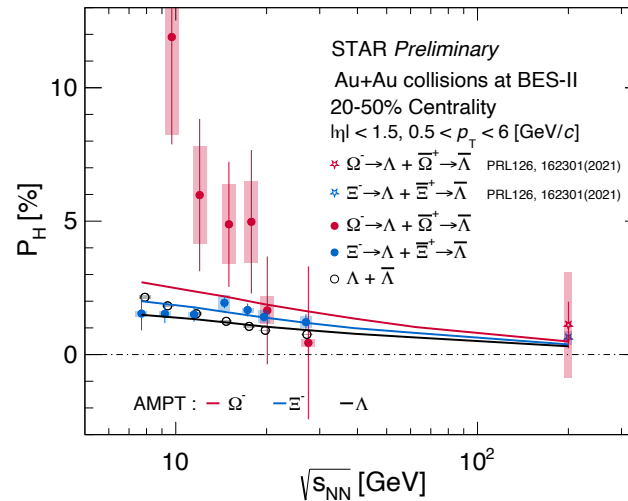
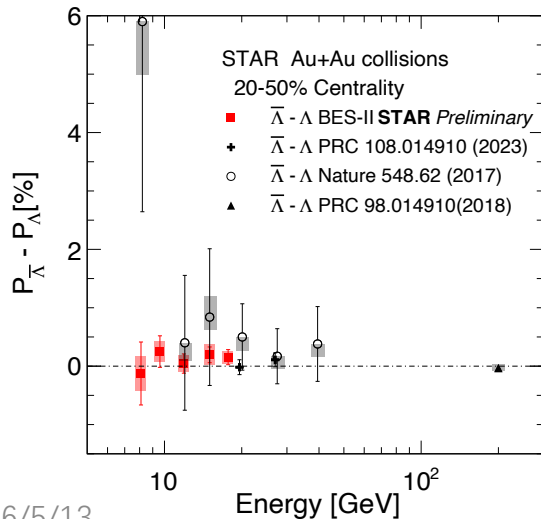
- ❑ Measurement precision in Au+Au collisions is better than in pp collisions
- ❑ Stay tuned for the results
 - Au+Au collisions at BES-II energies, isobar collisions at 200 GeV, and more

Global polarization

- ✓ 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

Spin spin correlation

- ✓ Detector acceptance corrected using mixed-event method. Further checks are on-going.



Back Up

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:

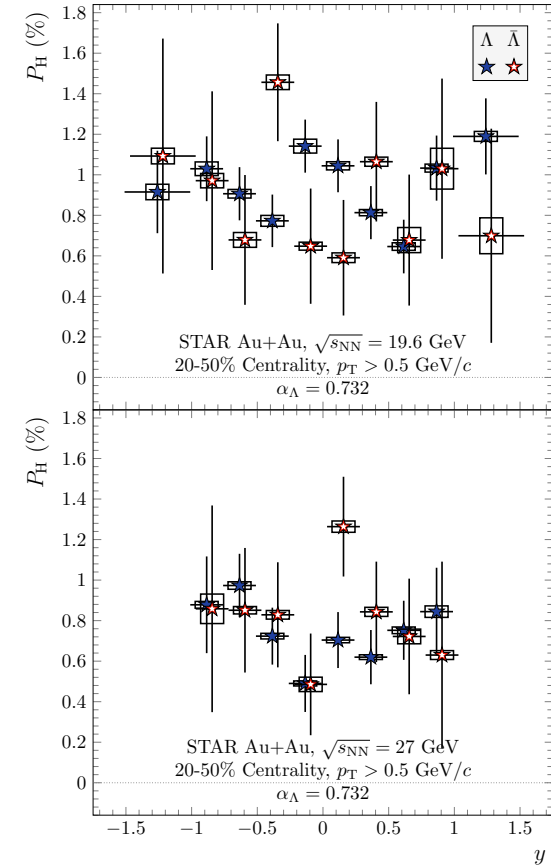
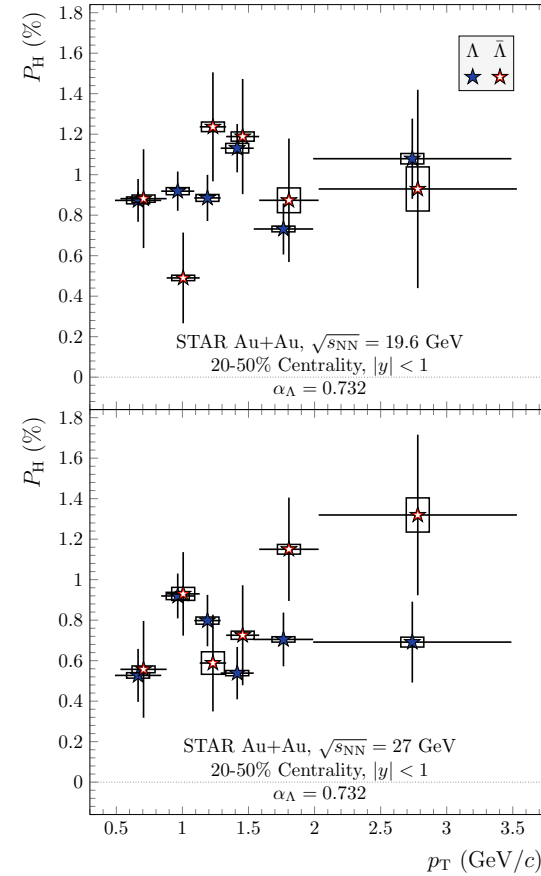
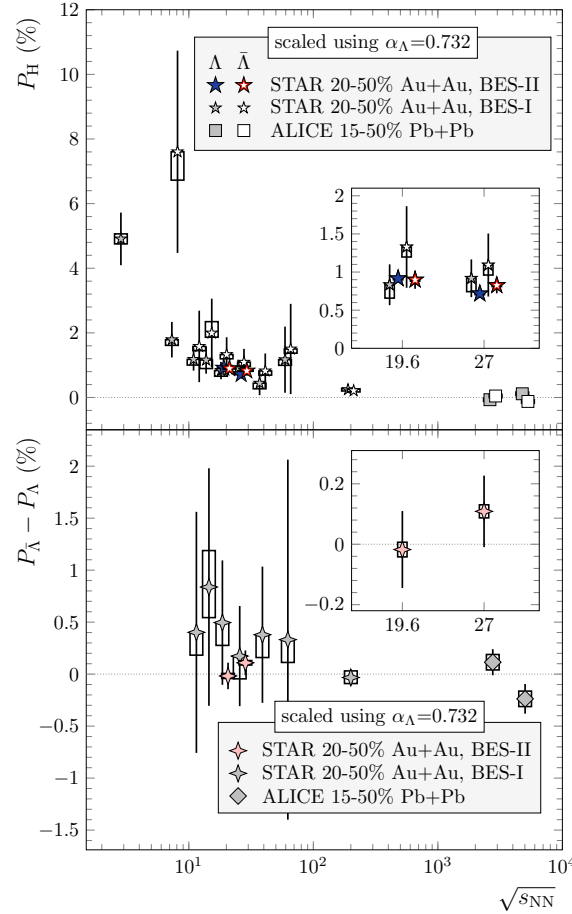
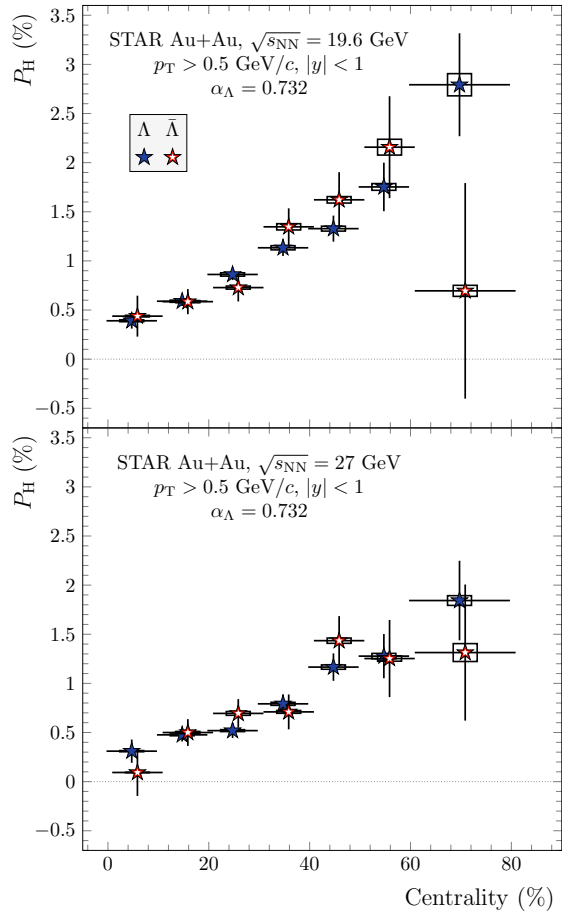
$$\frac{dn}{d\Omega_p} = \frac{1}{4\pi} (1 + \alpha_\Lambda \mathbf{P}_\Lambda \cdot \hat{\mathbf{p}}), \quad \frac{dN}{d\Omega_p} = \frac{1}{4\pi} \left[1 + \frac{\alpha_\Lambda}{2(J+1)} [1 + (2J+1)\gamma_\Omega] \mathbf{P}_\Omega \cdot \hat{\mathbf{p}} \right]. \quad \Rightarrow \quad \mathbf{P}_\Lambda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

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)

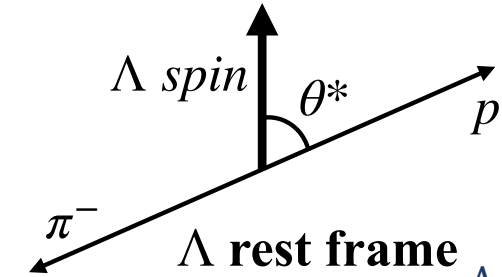
Global polarization collision energy dependence



- ❑ 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)

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



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

- The spin correlations $C_{\Lambda_1\Lambda_2}^S$ can be determined as follow,

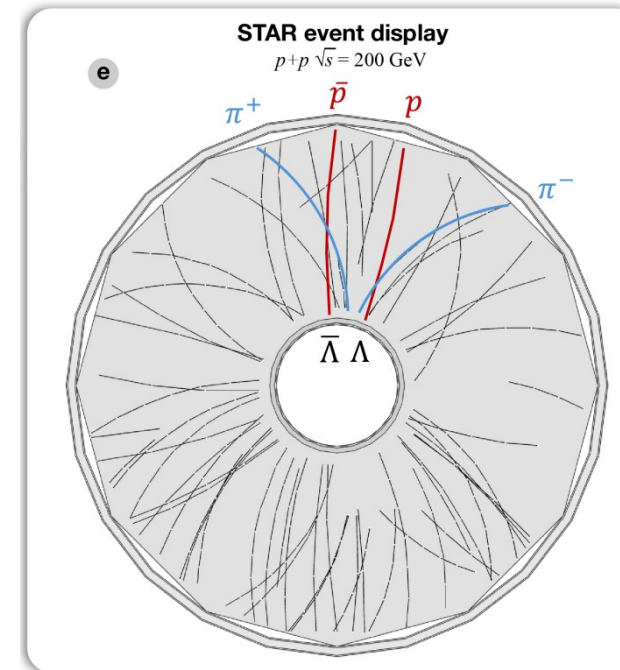
$$\frac{1}{N} \frac{dN}{d \cos \theta_{1,2}^*} = \frac{1}{2} [1 + \alpha_1 \alpha_2 C_{\Lambda_1\Lambda_2}^S \cos \theta_{1,2}^*]$$

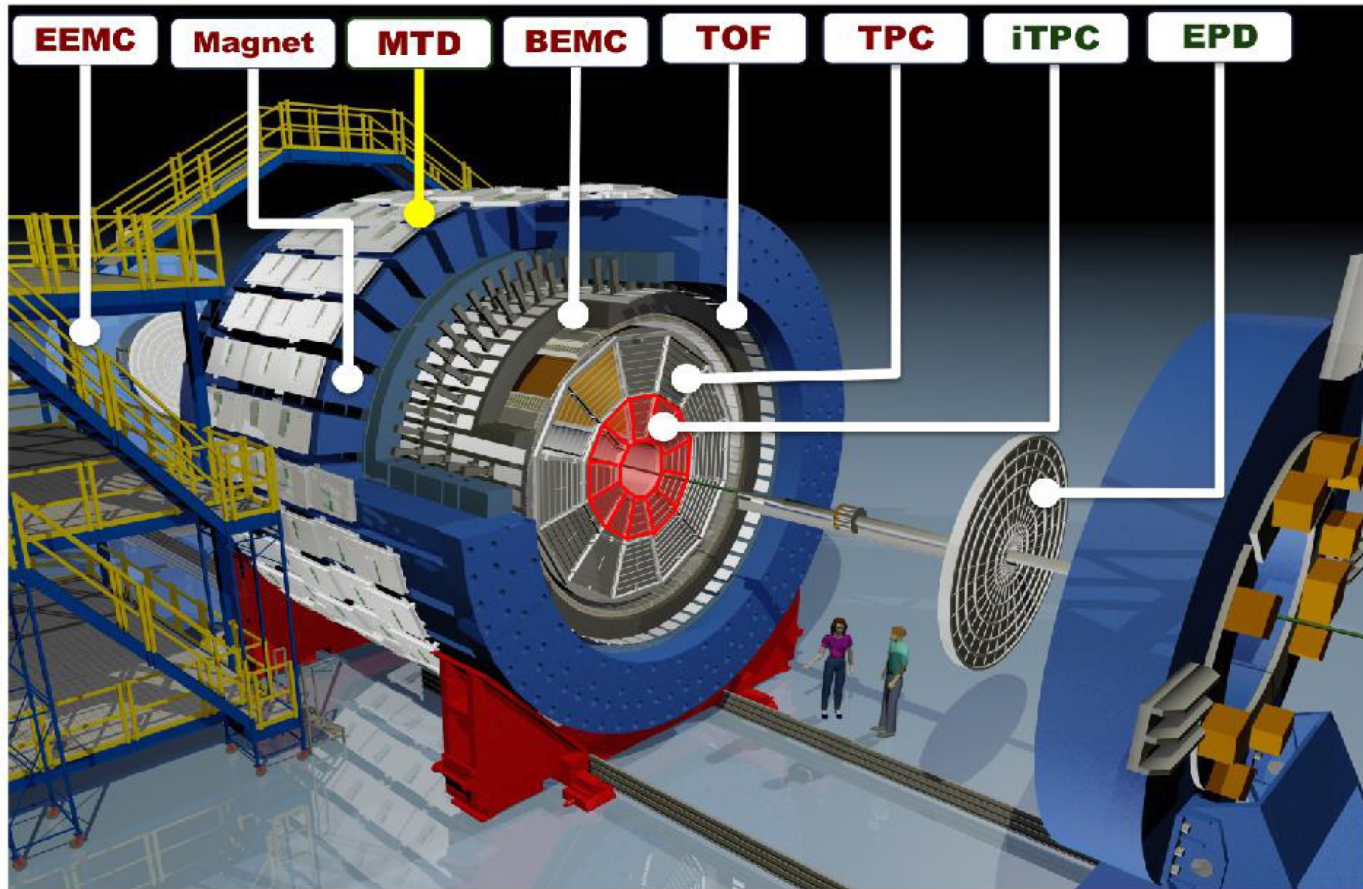
STAR, Nature 650 (2026) 8100, 65-71

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

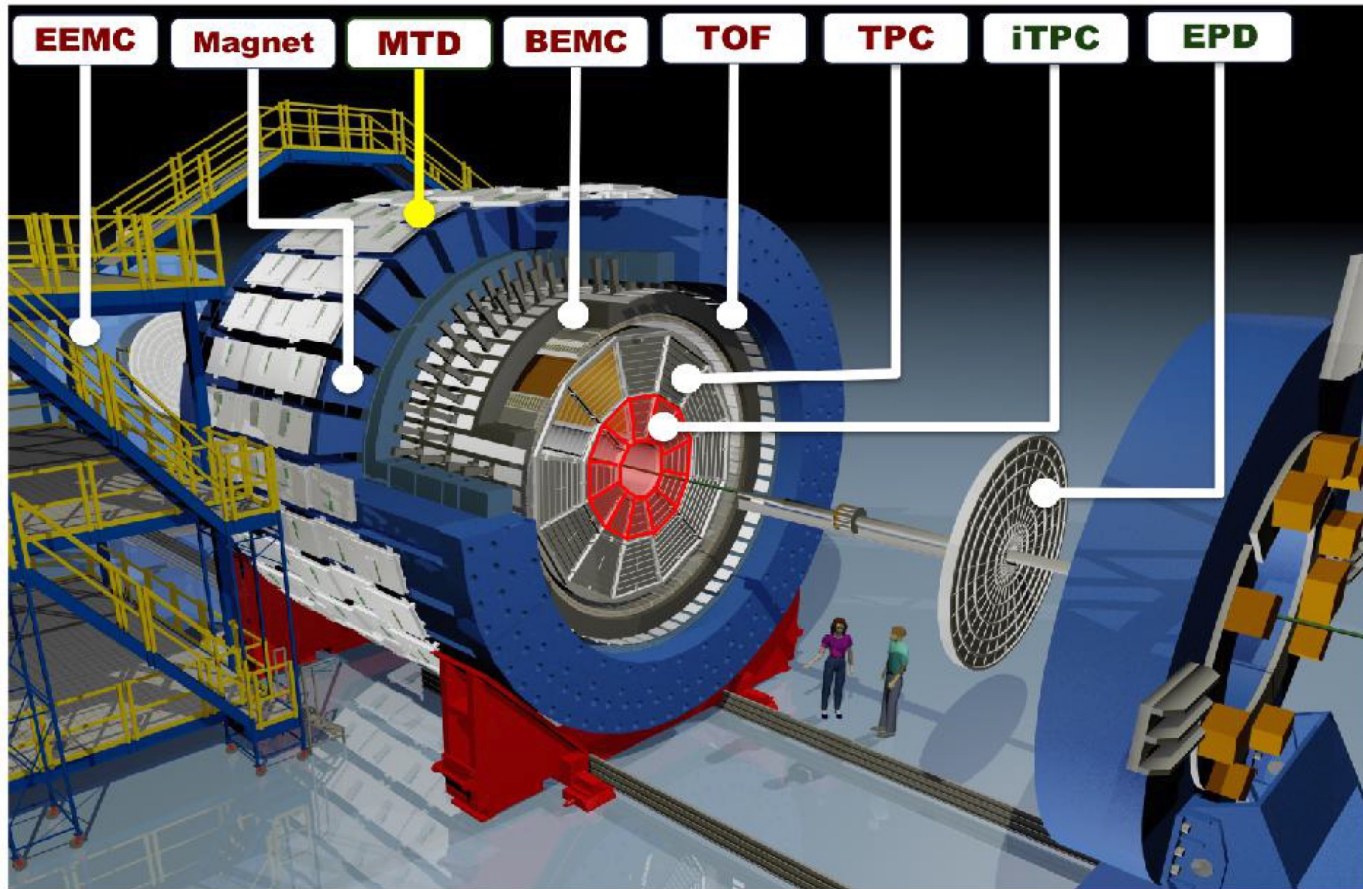
α_H : hyperon decay parameter

$C_{\Lambda_1\Lambda_2}^S$: spin correlation of $\Lambda_1\Lambda_2$ pair





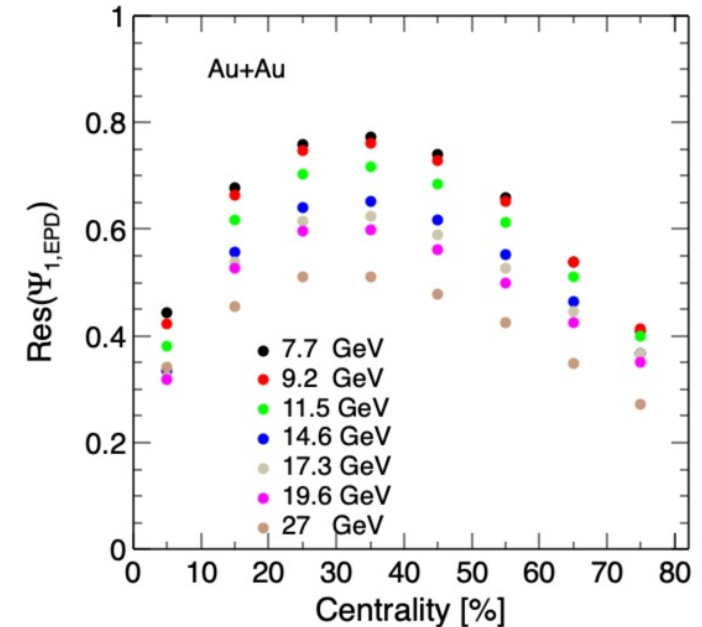
- ❑ **Event Plane Detector**
 - Event plane reconstruction
 - $2.1 < |\eta| < 5.1$
- ❑ **Zero Degree Calorimeters**
 - Event plane reconstruction
 - $6.3 < |\eta|$
- ❑ **Time Projection Chamber**
 - Upgrade with inner TPC
 - Better track quality
 - Larger acceptance
 - $|\eta| < 1.0 \rightarrow |\eta|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

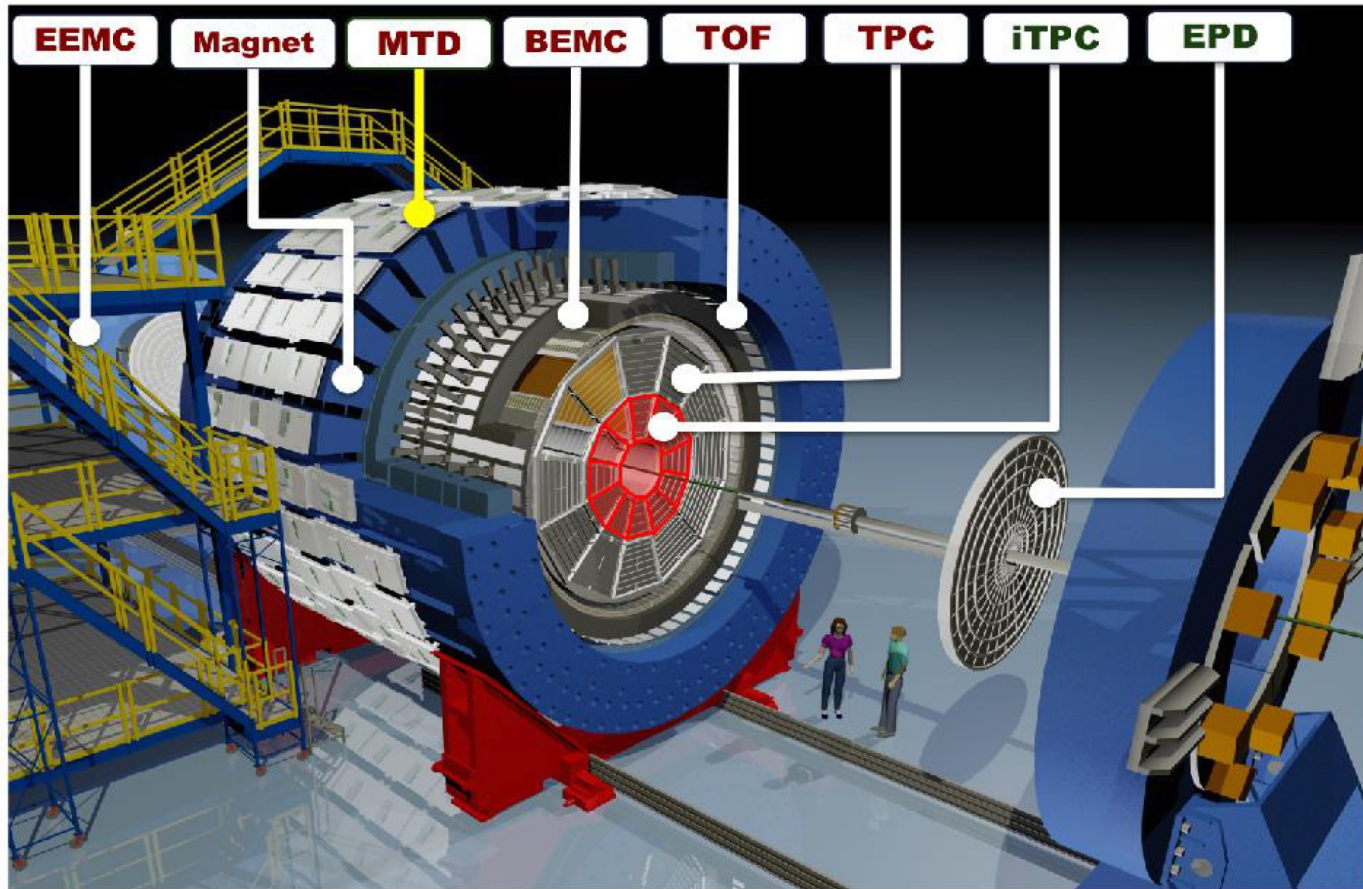


- First-order event plane reconstructed by EPD, ZDC

- **Event Plane Detector**
 - Event plane reconstruction
 - $2.1 < |\eta| < 5.1$
- **Zero Degree Calorimeters**
 - Event plane reconstruction
 - $6.3 < |\eta|$

Event plane resolution





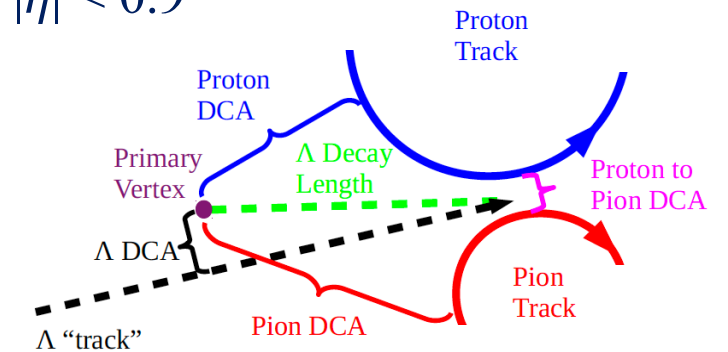
- Hyperons reconstructed using KF Particle package

Time Projection Chamber

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

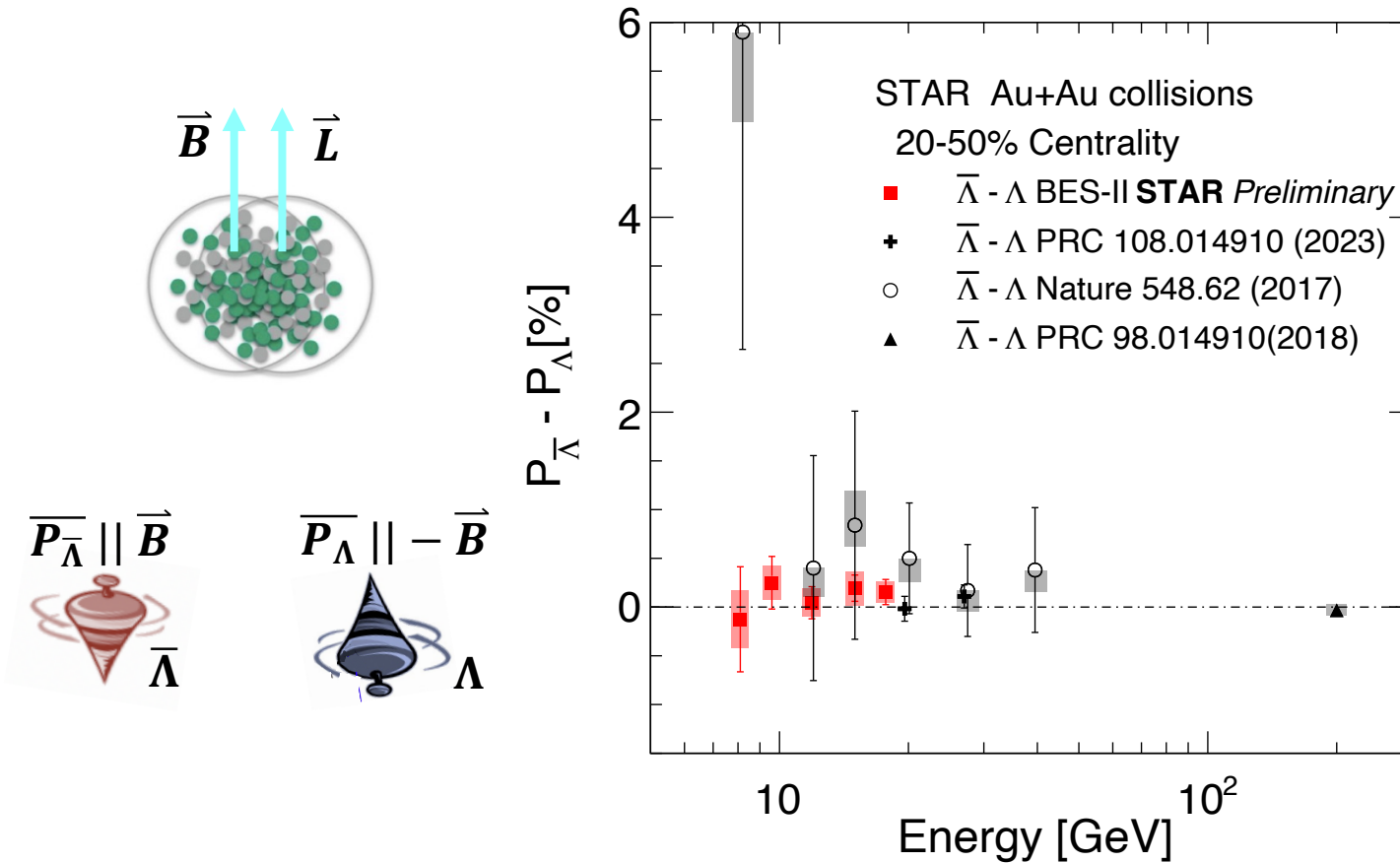
Time Of Flight

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



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

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



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

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

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

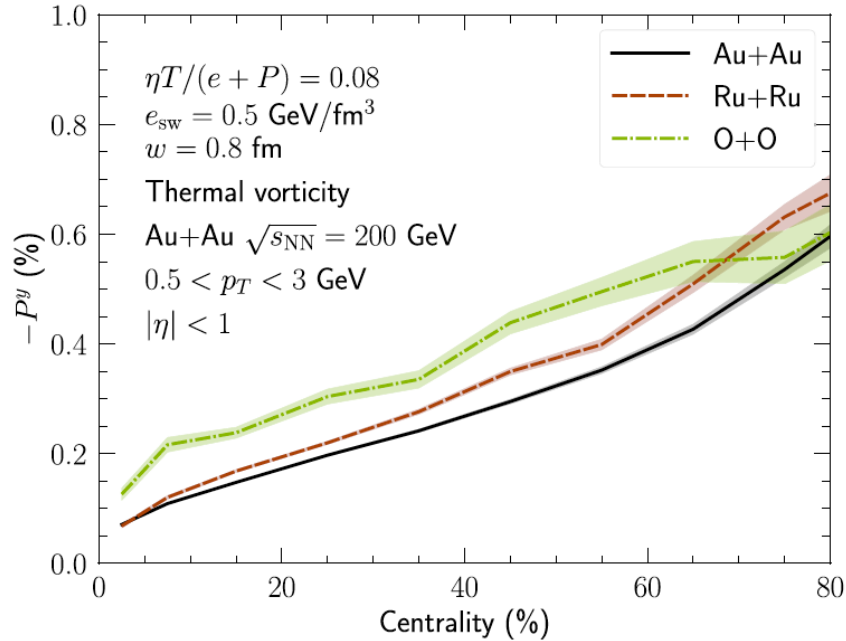
$$T = 150 \text{ MeV}, \mu_{\Lambda} = -1.93 \times 10^{-1} \text{ MeV}/T$$

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

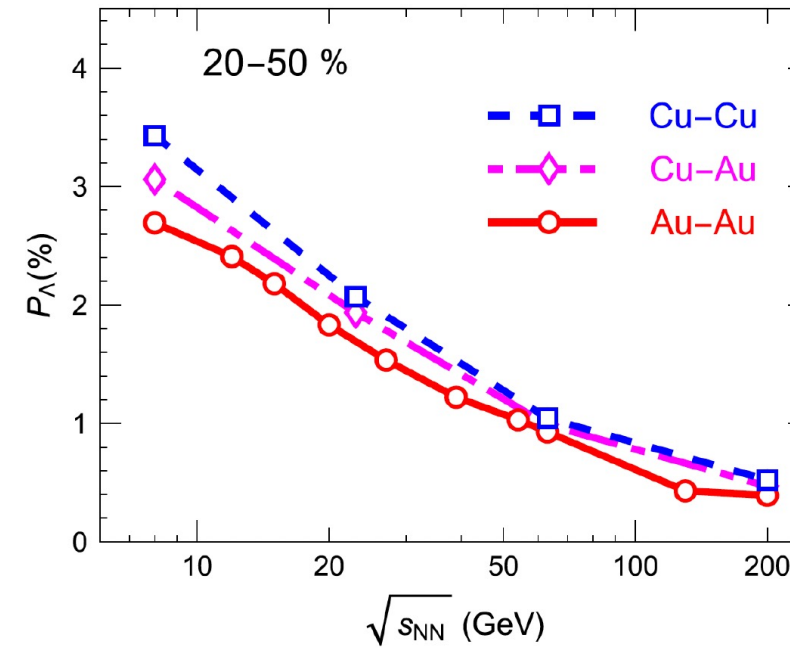
Global polarization : system size dependence



S. Alzhrani et al., PRC 106.014905



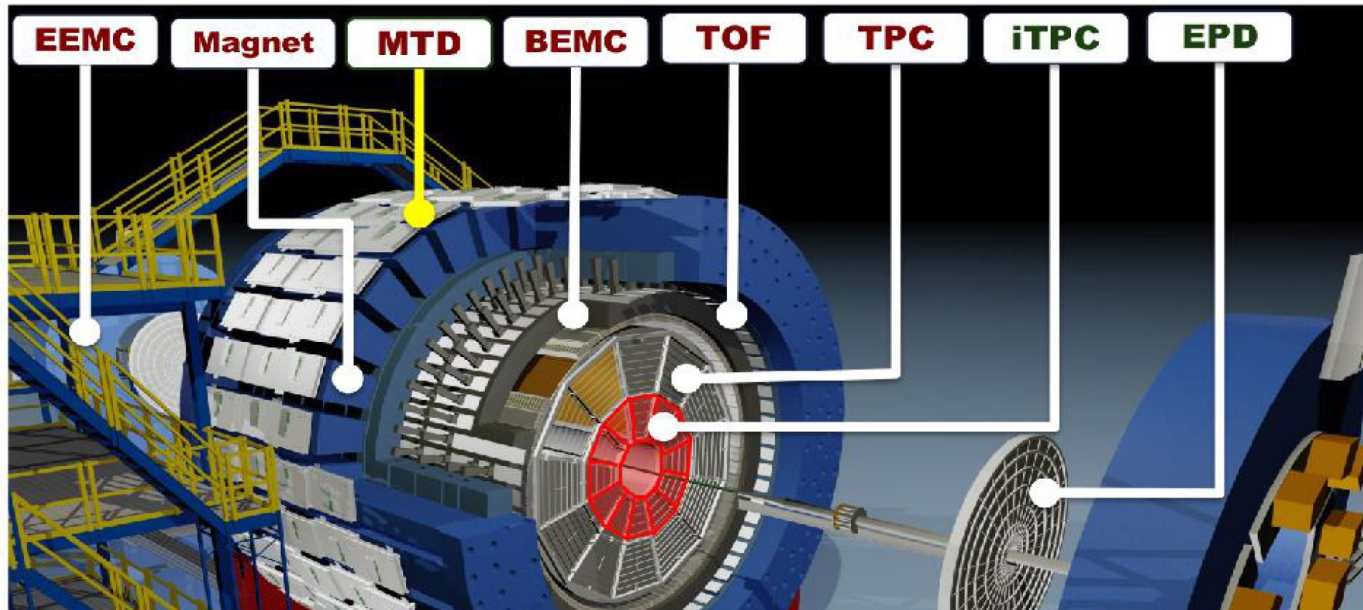
S.Z. Shi, K.L. Li, J.F. Liao, PLB 788 (2019) 409–413



□ Smaller polarization predicted for larger system due to longer lifetime

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

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

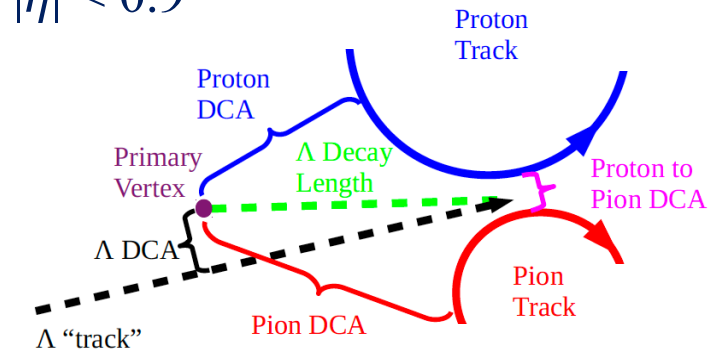
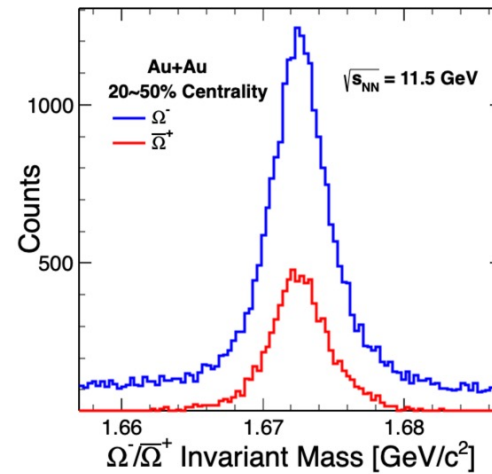
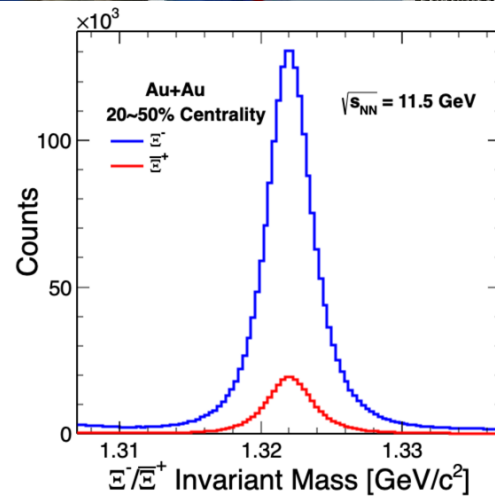
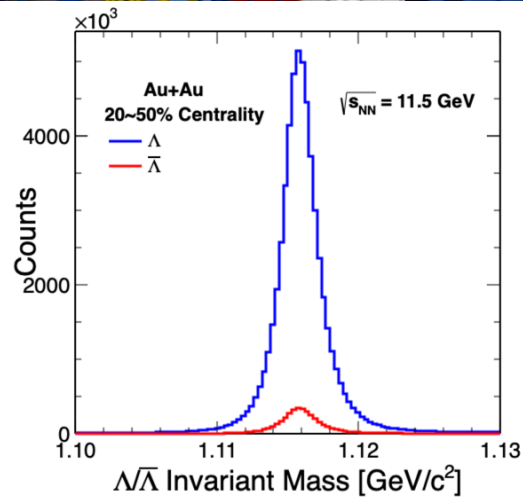


Time Projection Chamber

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

Time Of Flight

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



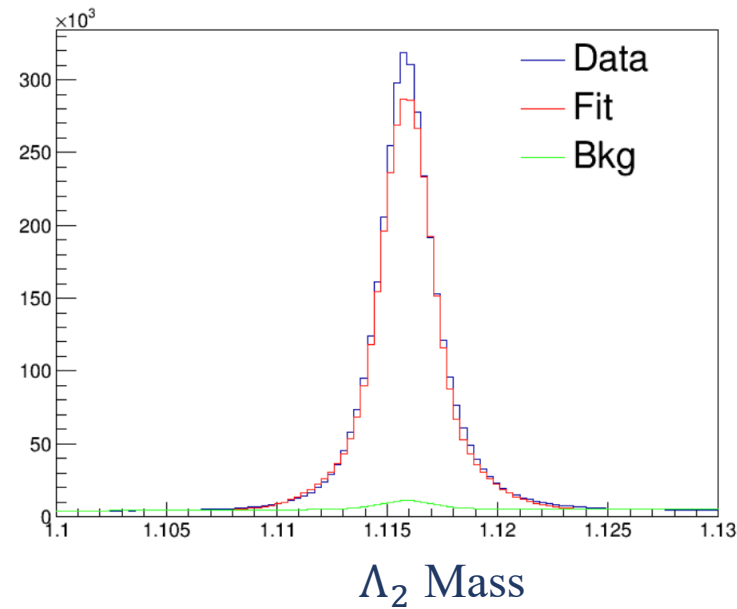
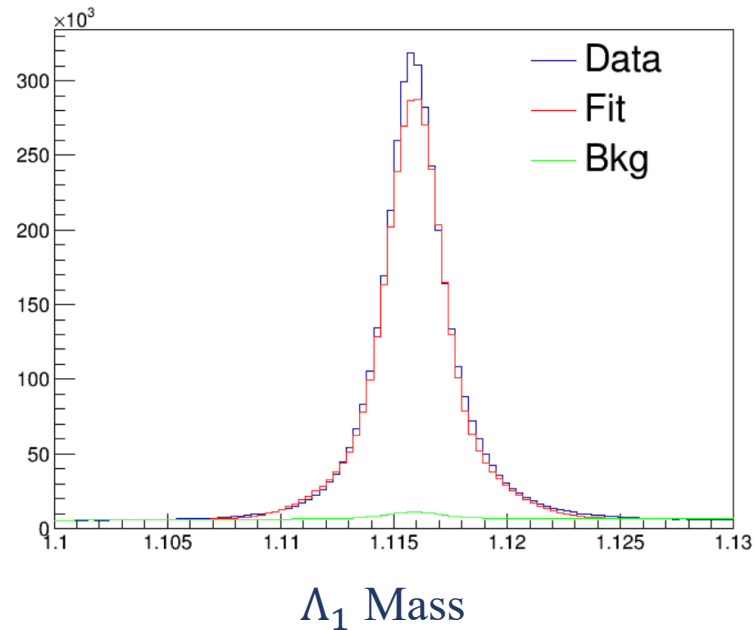
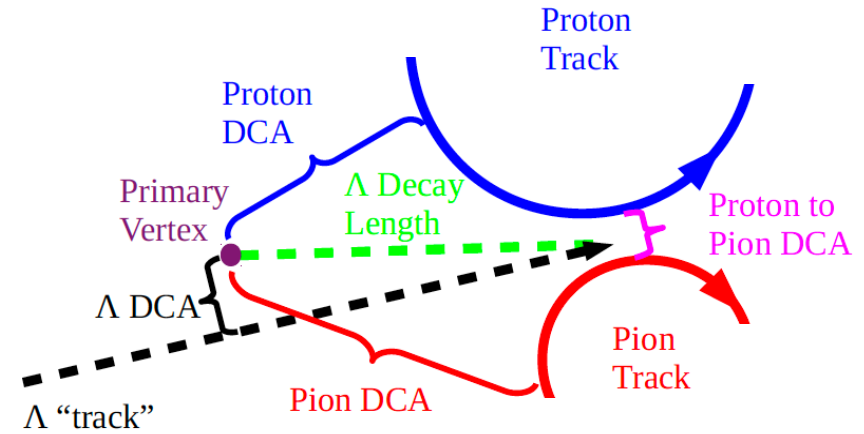
- $\Lambda \rightarrow p + \pi^-$
- $\Xi^- \rightarrow \Lambda + \pi^-$, $\Lambda \rightarrow p + \pi^-$
- $\Omega^- \rightarrow \Lambda + K^-$, $\Lambda \rightarrow p + \pi^-$

Λ Hyperon Reconstruction

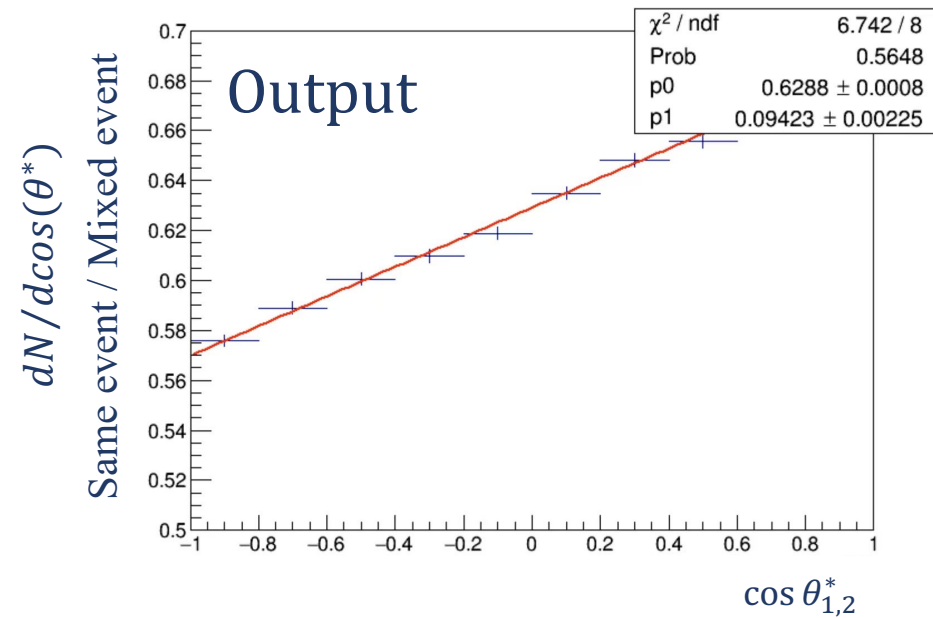
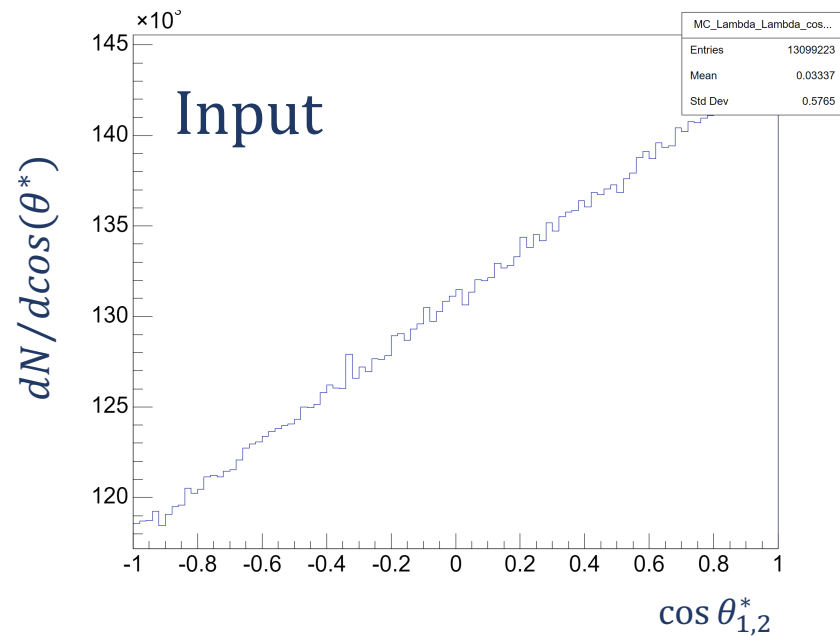


- Particle identification by TPC and TOF
- Hyperons reconstructed using KF Particle package

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



Mixed-event method -- Closure test with simulation



- ❑ Pure simulation with embedding data in Au+Au collisions at 14.6 GeV
- ❑ Input spin correlation = 0.1000
- ❑ Fit function: $dN/d\cos(\theta^*) = p_0[1 + p_1\cos(\theta^*)]$ p_0 is normalization, $p_1 = \alpha_1\alpha_2 C_{\Lambda_1\Lambda_2}^S$
- ❑ Spin correlation: $C_{\Lambda_1\Lambda_2}^S = \frac{p_1}{\alpha_1\alpha_2} = 0.0942 \pm 0.0023$
- ❑ Input and Output are consistent within $\sim 2.5 \sigma$

$K_S^0 K_S^0$ spin correlation



- The K_S^0 reconstructed by π^-, π^+ decay channel using TPC and TOF
- Spin correlation signal is extracted by fitting $dN/d\cos(\theta^*)$ distribution after Mixed-event correction
- Spin correlation of $K_S^0 K_S^0$ pair is consistent with zero within uncertainty.

