Hyperon global polarization in Au+Au collisions over $\sqrt{s_{NN}} = 2.4 - 200$ GeV using equilibrium approaches

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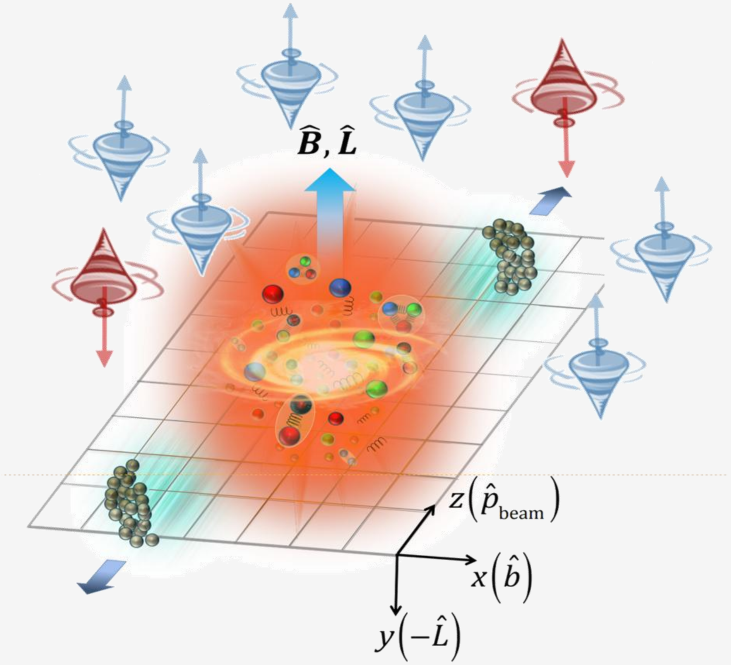
Based on: **CY**, S. Pu, L.-G. Pang, G.-Y. Qin, X.-N. Wang, arXiv:2603.27521
G.-H. Li, **CY**, X.-Y. Wu, S. Pu, G.-Y. Qin, arXiv: 2606.10341

Outline

- **Introduction**
- **Global polarization of Λ hyperons at a few GeV**
- **Global polarization of multi-strange hyperons across RHIC BES-II energies**
- **Summary and outlook**

Global Spin Polarization

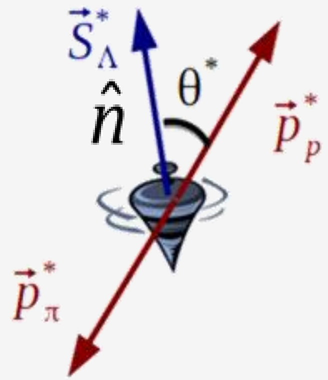
➢Spin-Orbital Coupling



Most vortical fluid !

Liang, Wang, PRL. 94, 102301 (2005)
Becattini and Karpenko, PRL 120, 012302
STAR, Nature 548, 62 (2017).

➢Parity-violating weak decay



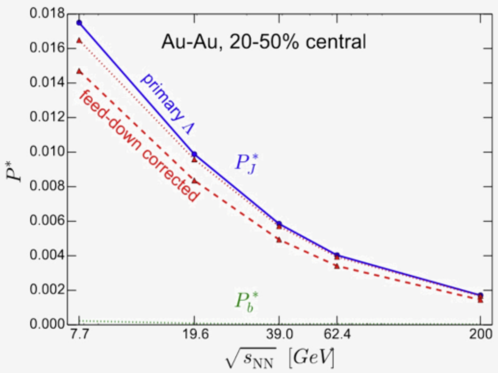
$$\Lambda(uds) \to p\,\pi^-$$
$$\Xi^-(dss) \to \Lambda\,\pi^-$$
$$\Omega^-(sss) \to \Lambda\,K^-$$

Angular distribution of decay products

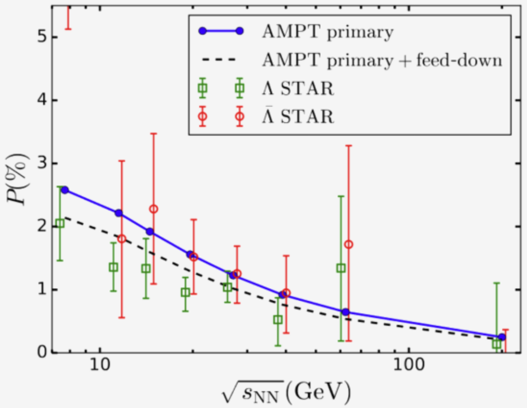
$$\frac{dN}{d\Omega^*} = \frac{1}{4\pi}\left(1 + \alpha_H P_H \cos\theta^*\right) \qquad P_D = C P_H$$

STAR, Phys.Rev.Lett. 126 (2021) 16, 162301
STAR, EPJ Web Conf. 364, 03001 (2026)

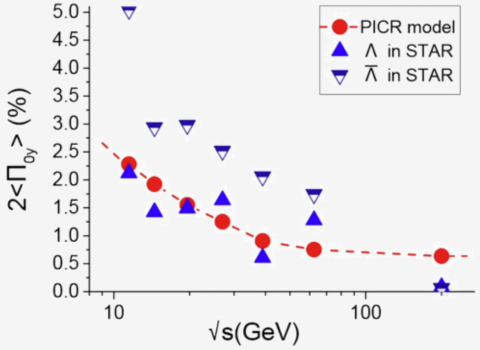
Phenomenological models for global polarization



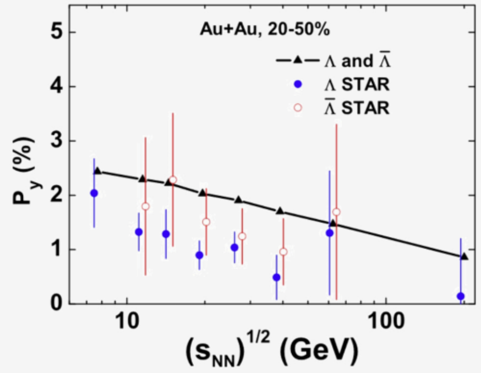
Karpenko, Becattini, EPJC(2017)



Li,Pang,Wang,Xia PRC(2017)

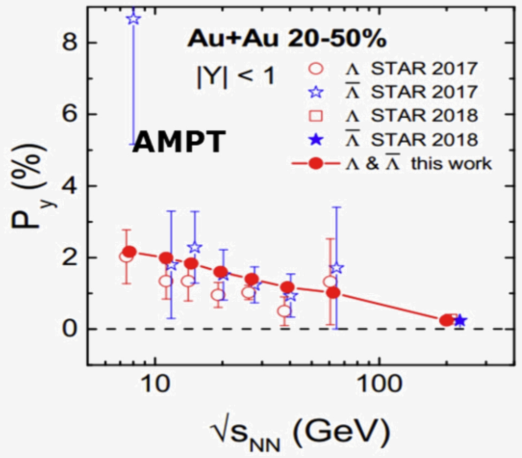


Xie, Wang, Csernai, PRC(2017)

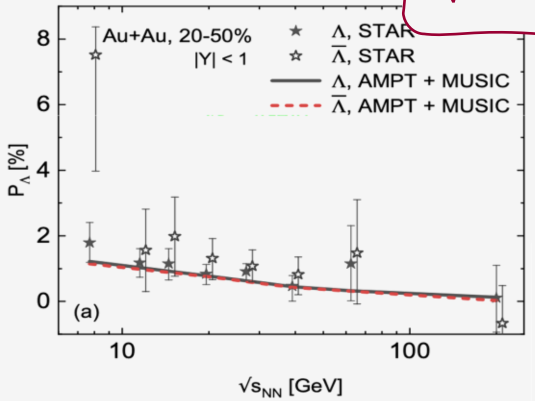


Sun, Ko, PRC(2017)

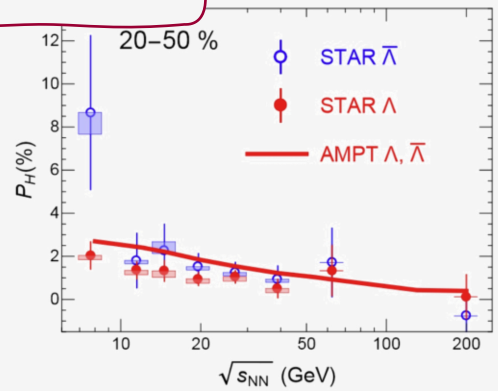
$\sqrt{S_{NN}} > 7.7$ GeV



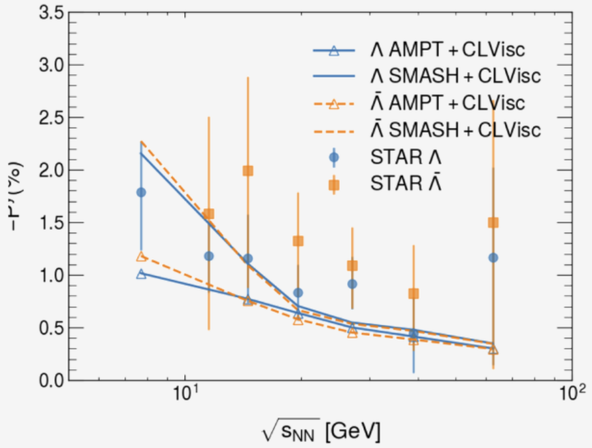
Wei, Deng, Huang, PRC(2019



Fu, Xu, Huang, Song, PRC (2021)



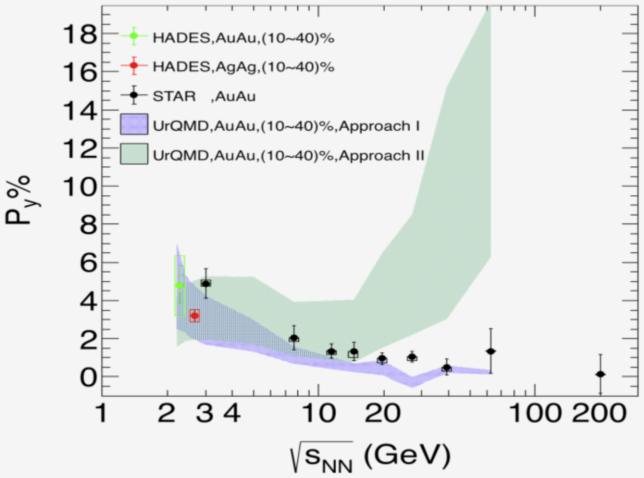
Shi, Li, Liao, PLB(2018)



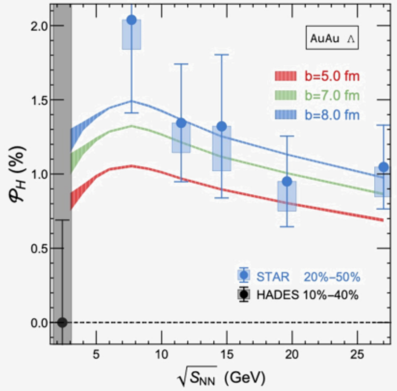
Wu, CY, Qin, Pu, PRC(2022)

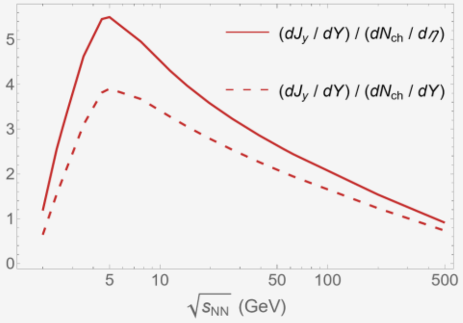
Global Polarization at a few GeV

➢ Theoretical prediction



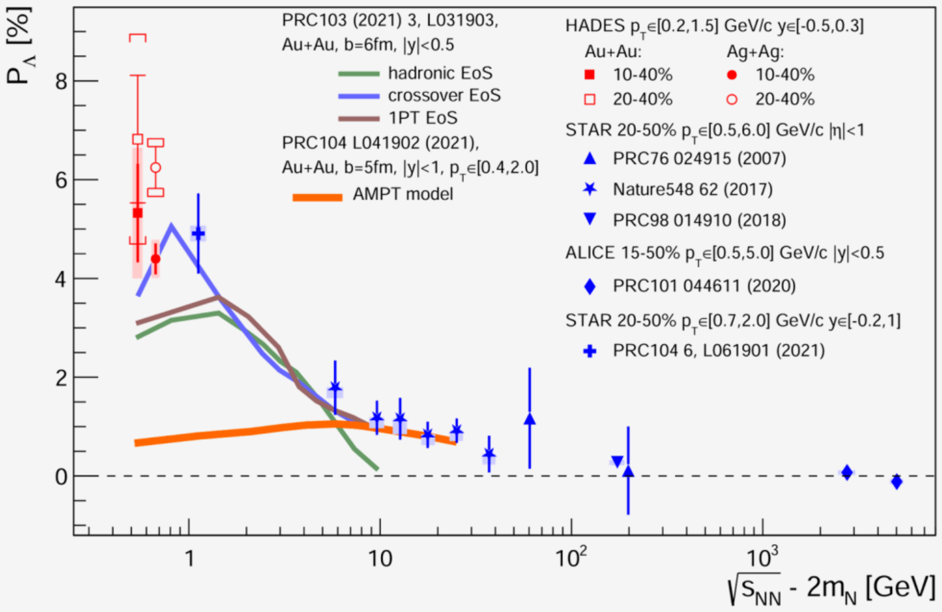
Deng, Huang PRC 2016, PRC 2020, PLB 2022





Guo, Liao, et. al, PRC 2021; Akridge et. al, PRC 2025
Also see : Liu, et. al, arXiv: 2606.13333

➢ Experimental results

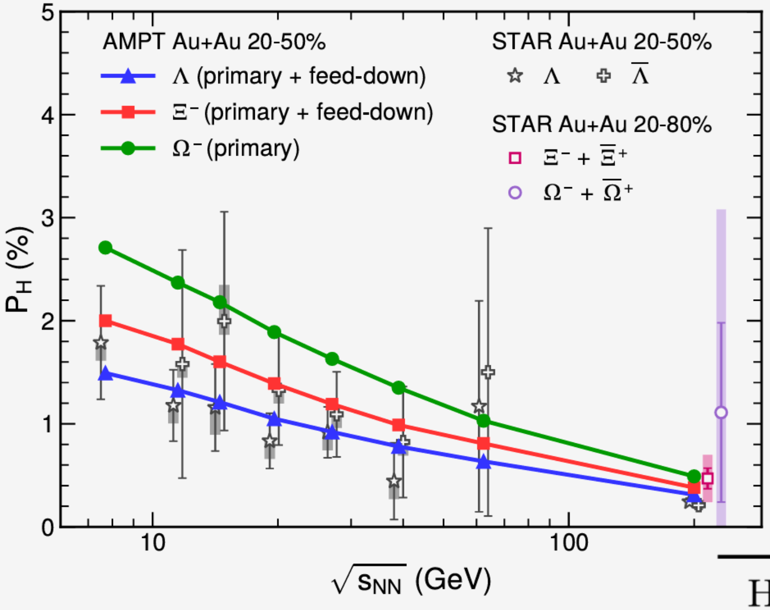


HADES, PLB (2022) 137506.
Ivanov, PRC 103, L031903 .

- ➢ **Will the polarization of Λ keep rising with decreasing energy?**
- ➢ **Is the vorticity picture still valid at a few GeV?**

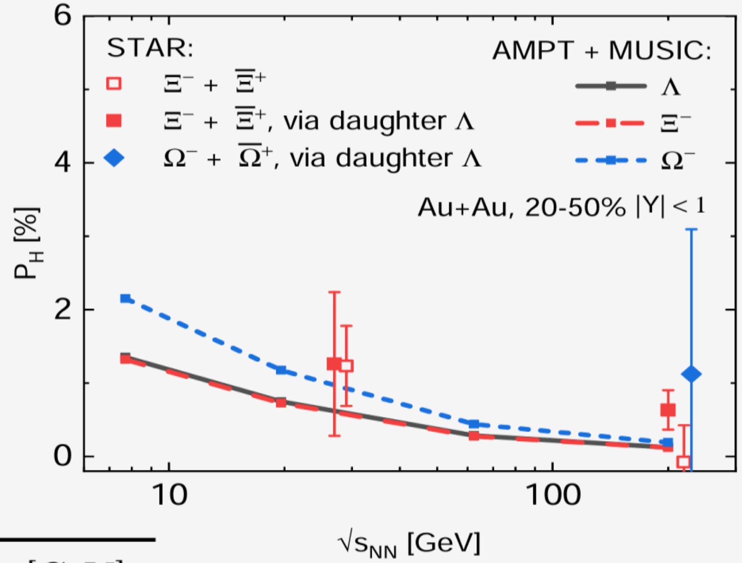
Global polarization of multi-strange hyperons

➢ Kinetic model +feed down



Becattini, Cao, Speranza, EPJC 79, 741 (2019).
Li, Xia, Huang, Huang, PLB 827, 136971 (2022);

➢ Hydrodynamic framework



Xia, Li, Huang, Huang, PRC 100, 014913 (2019)
Fu, Xu, Huang, Song, PRC 103, 024903 (2021).

Hyperon	Spin	Mass [GeV]
Λ	$1/2$	1.116
Ξ^-	$1/2$	1.322
Ω^-	$3/2$	1.672

The RHIC BES-II measurements will provide stronger constraints on theoretical models.
Can the vorticity-driven picture be extended to multi-strange hyperons?

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Polarization induced by different sources

➢Spin polarization at local equilibrium

$$\mathcal{S}^{\mu}(\mathbf{p}) = \mathcal{S}^{\mu}_{\rm thermal} + \mathcal{S}^{\mu}_{\rm shear} + \mathcal{S}^{\mu}_{\rm accT} + \mathcal{S}^{\mu}_{\rm chemical} + \mathcal{S}^{\mu}_{\rm EB}$$

$$\mathcal{S}^{\mu}_{\rm thermal}(\mathbf{p}) = \frac{\hbar}{8m_{\Lambda}N}\int d\Sigma^{\sigma}p_{\sigma}f_V^{(0)}(1-f_V^{(0)})\boxed{\epsilon^{\mu\nu\alpha\beta}p_{\nu}\partial_{\alpha}\frac{u_{\beta}}{T}},$$

Thermal vorticity

$$\mathcal{S}^{\mu}_{\rm shear}(\mathbf{p}) = -\frac{\hbar}{4m_{\Lambda}N}\int d\Sigma\cdot p f_V^{(0)}(1-f_V^{(0)})\frac{\epsilon^{\mu\nu\alpha\beta}p_{\alpha}u_{\beta}}{(u\cdot p)T}\frac{1}{2}p^{\sigma}\boxed{[(\partial_{\sigma}u_{\nu}+\partial_{\nu}u_{\sigma})-u_{\sigma}Du_{\nu}]}$$

Shear Induced Polarization (SIP)

$$\mathcal{S}^{\mu}_{\rm accT}(\mathbf{p}) = -\frac{\hbar}{8m_{\Lambda}N}\int d\Sigma\cdot p f_V^{(0)}(1-f_V^{(0)})\frac{1}{T}\epsilon^{\mu\nu\alpha\beta}p_{\nu}u_{\alpha}\boxed{(Du_{\beta}-\frac{1}{T}\partial_{\beta}T)},$$

Fluid Acceleration

$$\mathcal{S}^{\mu}_{\rm chemical}(\mathbf{p}) = \frac{\hbar}{4m_{\Lambda}N}\int d\Sigma\cdot p f_V^{(0)}(1-f_V^{(0)})\frac{1}{(u\cdot p)}\boxed{\epsilon^{\mu\nu\alpha\beta}p_{\alpha}u_{\beta}\partial_{\nu}\frac{\mu}{T}},$$

Spin Hall Effect (SHE)

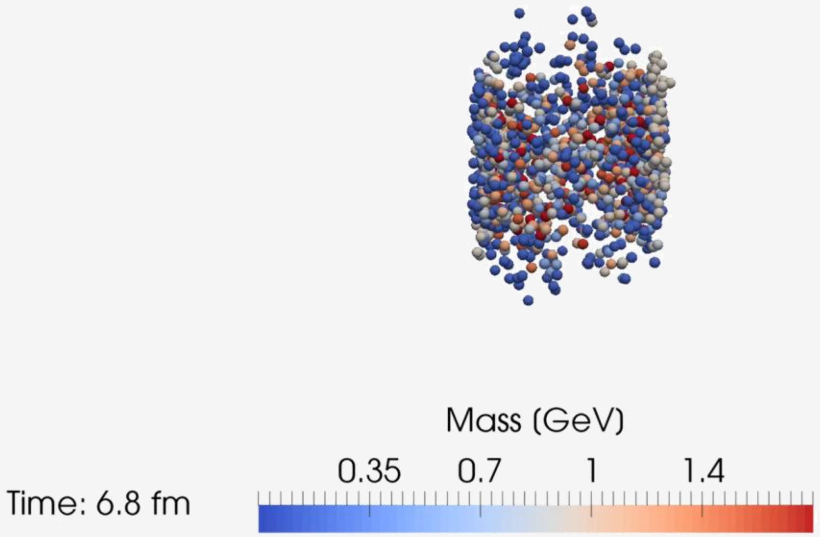
$$\mathcal{S}^{\mu}_{\rm EB}(\mathbf{p}) = \frac{\hbar}{4m_{\Lambda}N}\int d\Sigma\cdot p f_V^{(0)}(1-f_V^{(0)})\left(\frac{1}{(u\cdot p)T}\epsilon^{\mu\nu\alpha\beta}\boxed{p_{\alpha}u_{\beta}E_{\nu}+\frac{B^{\mu}}{T}}\right),$$

EM Field

Liu, Yin, PRD 104, 054043 (2021) ;
Becattini, Buzzegoli, Palermo, PLB 820, 136519 (2021) ;
Liu, Yin, JHEP 07,188 (2021);

Hidaka, Pu, Yang, PRD 97, 016004 (2018) ;
CY, Pu, Yang, PRC 04, 064901(2021)

SMASH Model



SMASH, Phys. Rev. C 94 (2016) 5, 054905

➢ SMASH

➢ It solves the relativistic Boltzmann equation effectively.

$$p^{\mu}\partial_{\mu} f + mF^{\mu}\partial_{p_{\mu}}(f) = C[f]$$

The collision kernel includes elastic collisions, string fragmentation, resonance formation and decays for all mesons and baryons up to mass 2.35 GeV.

Thermal Vorticity

At such low collision energies, hydrodynamic models may no longer be applicable.

Flow velocity

$$T^{\mu\nu}(\tau, x, y, \eta_s) = \frac{1}{\Delta V}\left\langle \sum_i \frac{p_i^\mu p_i^\nu}{p_i^0} \right\rangle,$$

$$T^{\mu}{}_{\nu} u^{\nu} = \varepsilon u^{\mu}$$

Thermal Vorticity

$$\boldsymbol{\varpi}_{\mathrm{T}} = (\varpi_{tx}, \varpi_{ty}, \varpi_{tz}) = \frac{1}{2}(\nabla \beta_t + \partial_t \boldsymbol{\beta}),$$

$$\boldsymbol{\varpi}_{\mathrm{S}} = (\varpi_{yz}, \varpi_{zx}, \varpi_{xy}) = \frac{1}{2}\nabla \times \boldsymbol{\beta}.$$

Baryon density

$$J_B^\mu = \frac{1}{N_e \Delta V} \sum_i Q_i \frac{p_i^\mu}{E_i}$$

$$N_B = J_B^\mu u_\mu$$

Global Polarization

$$\mathbf{P}_{\mathrm{H}} = \frac{S+1}{3}\left[\frac{E}{m}\boldsymbol{\varpi}_{\mathrm{S}}(x) + \frac{\mathbf{p}}{m} \times \boldsymbol{\varpi}_{\mathrm{T}}(x) - \frac{\mathbf{p} \cdot \boldsymbol{\varpi}_{\mathrm{S}}(x)}{m(E+m)}\mathbf{p}\right].$$

Equation of State

➢ Hadron Resonance Gas

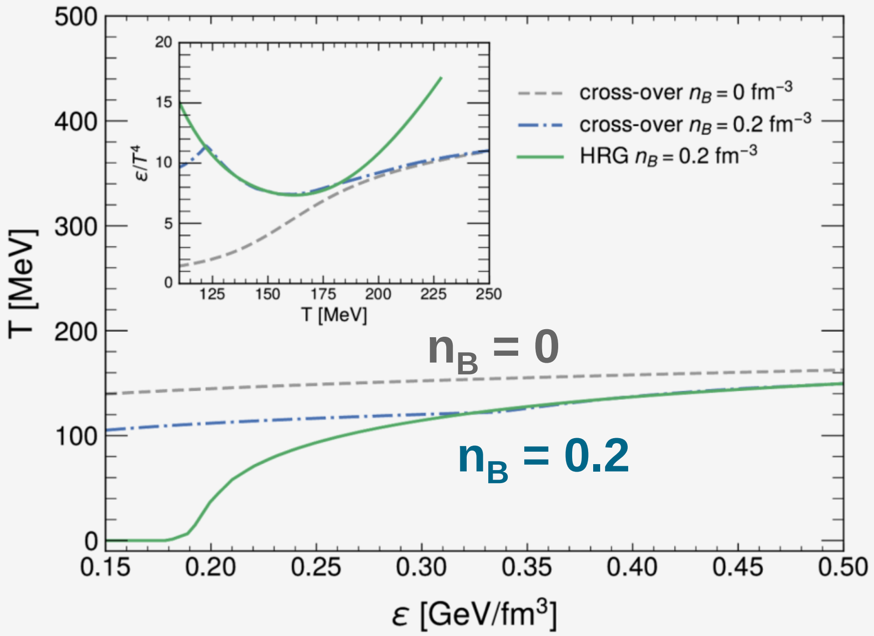
Grand canonical partition function

$$\ln Z_i^{id.gas} = \frac{V g_i}{2\pi^2}\int_0^\infty \pm p^2 \mathrm{d}p \ln\left[1 \pm \exp\left(-\left(E_i-\mu_i\right)/T\right)\right]$$

$$\begin{aligned} n_i &= \frac{g_i}{2\pi^2}\int_0^\infty \frac{p^2\ \mathrm{d}p}{\exp\left[\left(E_i-\mu_i\right)/T\right]\pm 1} \\ \varepsilon_i &= \frac{g_i}{2\pi^2}\int_0^\infty \frac{p^2\ \mathrm{d}p}{\exp\left[\left(E_i-\mu_i\right)/T\right]\pm 1}E_i \\ \mu_i &= b_i\mu_B + s_i\mu_S + q_i\mu_Q \end{aligned}$$

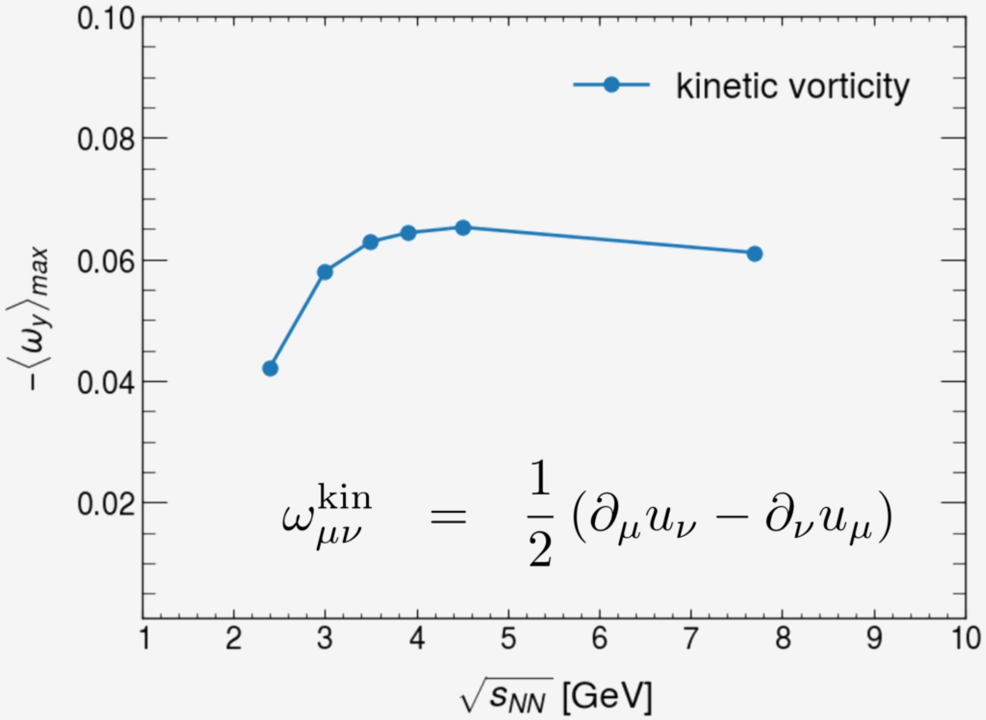
As the net baryon density increases, the extracted temperature at a given energy density will decrease.

$$\begin{aligned} n_B &= \sum_i n_i b_i \\ n_Q &= \sum_i n_i q_i \\ n_S &= \sum_i n_i s_i \\ n_Q &= 0.4 n_B, \quad n_S = 0 \end{aligned}$$

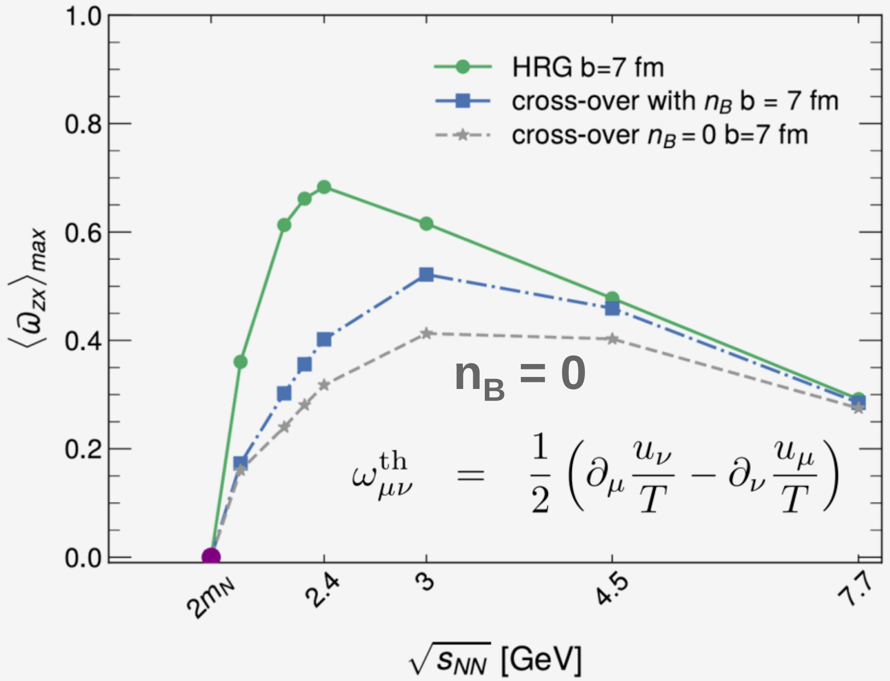


Vorticity Vs collision energy

➢ Kinetic vorticity



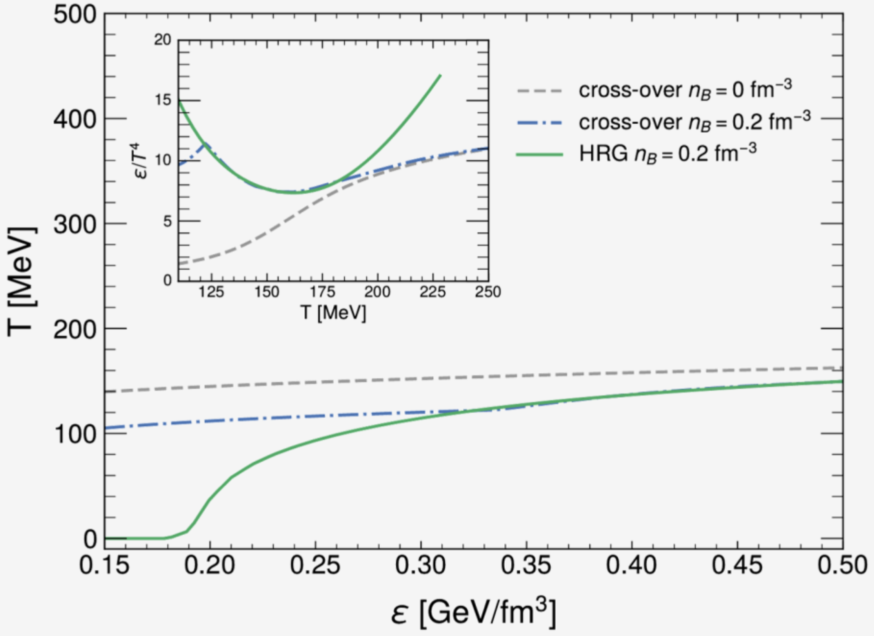
➢ Thermal vorticity



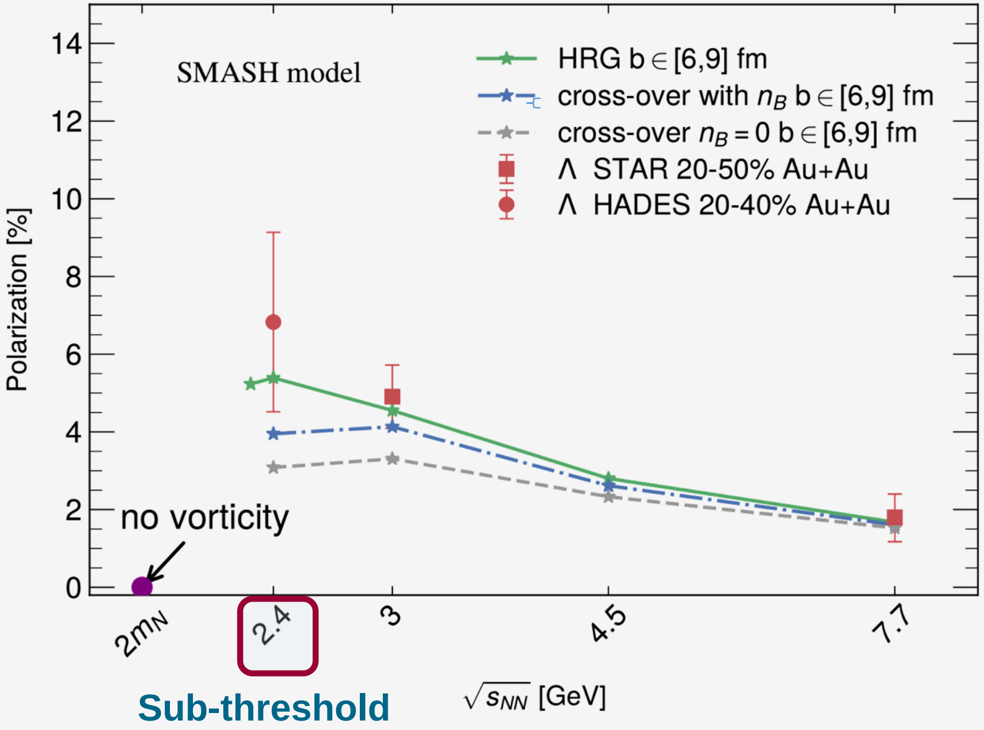
- ➢ **The kinetic vorticity peaks and then decreases at low collision energies.**
- ➢ **Including net baryon density, the thermal vorticity is enhanced and shows no decrease as the collision energy is reduced down to 2.4 GeV.**

Global Polarization at a few GeV

➢Equation of State



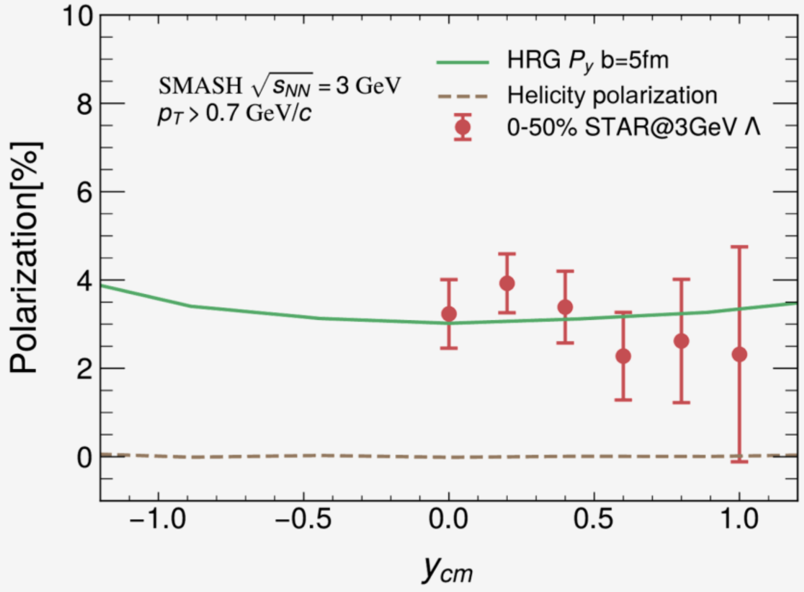
➢-Py Vs collision energy



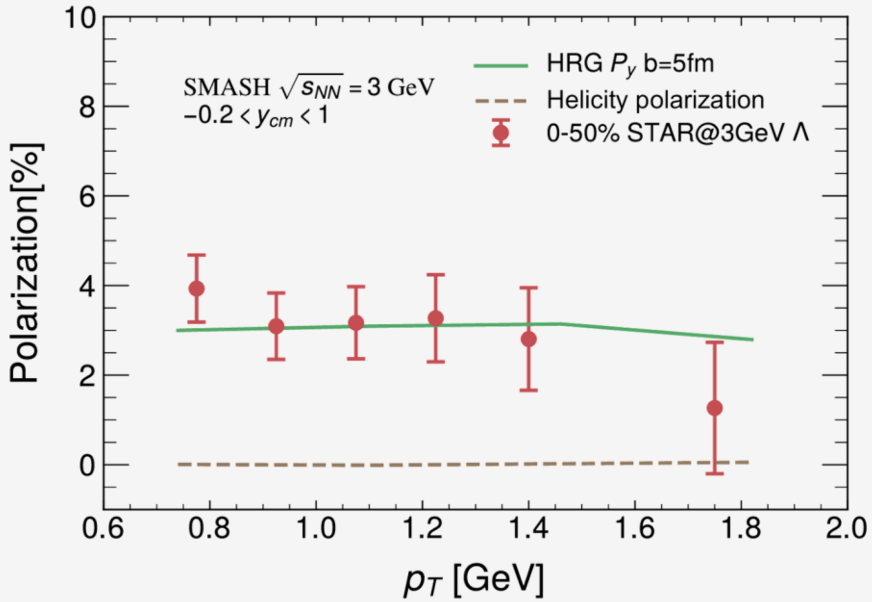
➢ **Assuming local equilibrium, the vorticity mechanism can still describe the low-energy Λ polarization data.**

Rapidity and pT dependence at 3 GeV

➢Rapidity dependence



➢pT dependence



- ➢ **Our results also have a good description of Global spin polarization at 3 GeV**

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- Introduction
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Setup of simulation

➢ (3+1) dimensional viscous hydrodynamic framework CLVisc

Solve the Energy-momentum conservation and net baryon current:

$$\nabla_\mu T^{\mu\nu} = 0, \qquad T^{\mu\nu} = e\, U^\mu U^\nu - P\,\Delta^{\mu\nu} + \pi^{\mu\nu},$$
$$\nabla_\mu J^\mu = 0, \qquad J^\mu = n\, U^\mu + V^\mu.$$

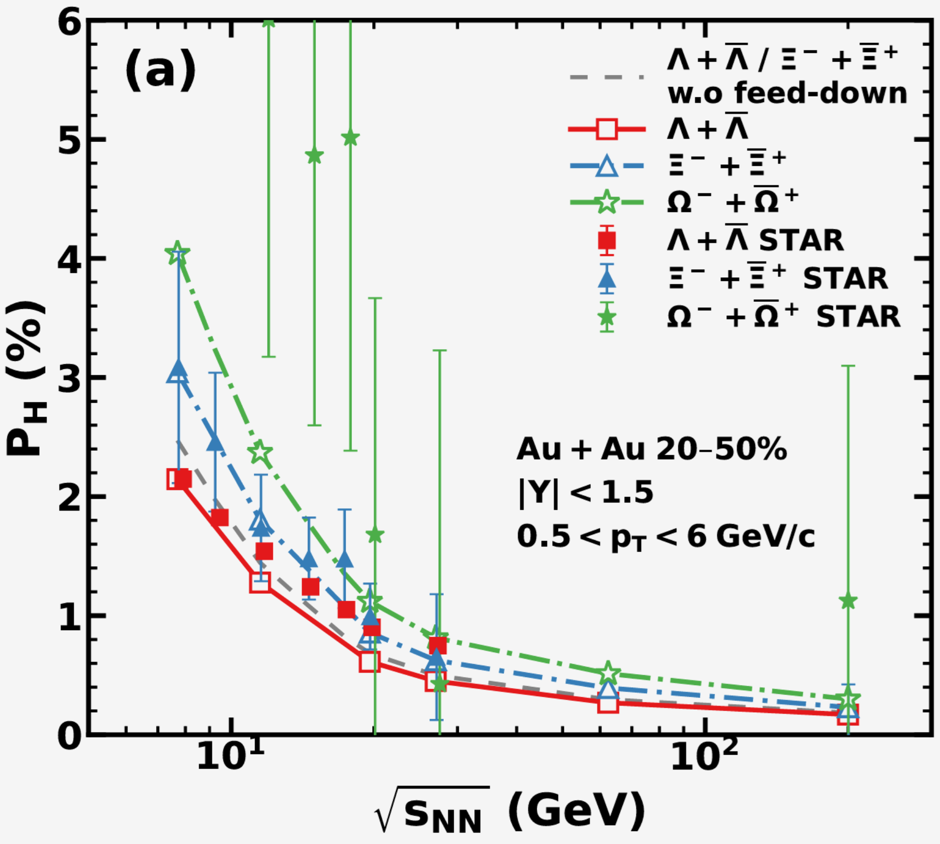
Pang, Wang, and Wang, PRC 86, 024911 .
Wu, Qin, Pang, and Wang, PRC 105, 034909.

➢ Normalized spin Polarization Vector for Spin-s Hyperons

$$\mathcal{P}^\mu(\mathbf{p}) = \frac{(s+1)\int d\Sigma \cdot p\, \mathcal{J}_5^\mu(p,x)}{3m_f \int d\Sigma \cdot p\, f_{\mathrm{eq}}},$$

Hyperon	Spin
Λ	$1/2$
Ξ^-	$1/2$
Ω^-	$3/2$

Collision energy dependence

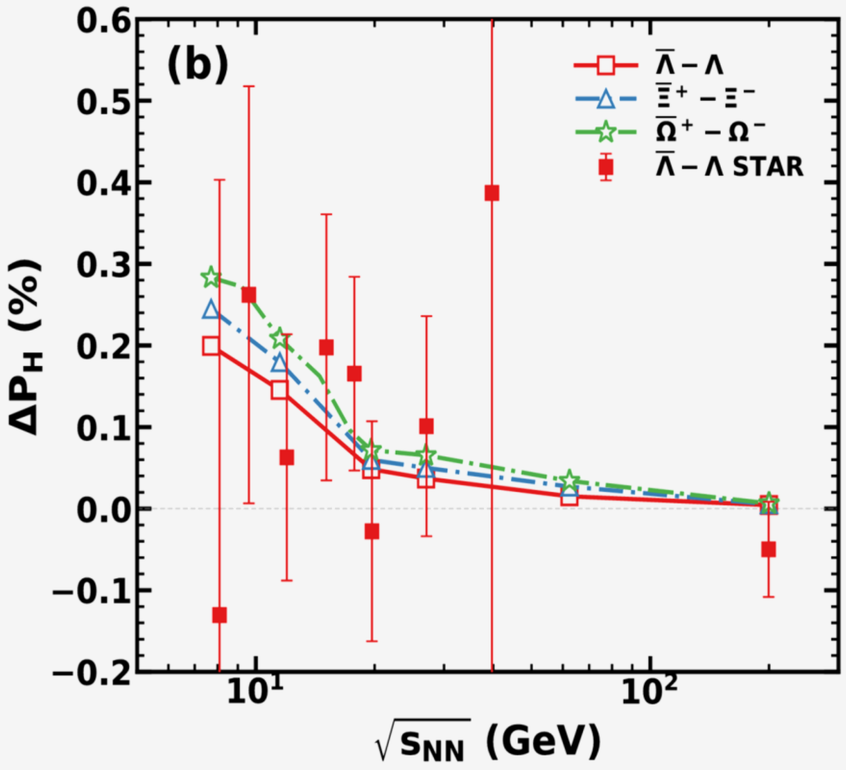


Hyperon	Spin	Mass [GeV]
Λ	1/2	1.116
Ξ^-	1/2	1.322
Ω^-	3/2	1.672

$$\mathcal{P}^{\mu}(\mathbf{p}) = \frac{(s+1)\int d\Sigma\cdot p\,\mathcal{J}_5^{\mu}(p,x)}{3m_f\int d\Sigma\cdot p\,f_{\text{eq}}},$$

- **Λ and Ξ have similar primary polarization.**
- **Feed-down suppresses P_Λ but enhances P_Ξ.**
- **The larger spin S=3/2 of Ω leads to a much larger polarization, but it is still below the experimental value.**

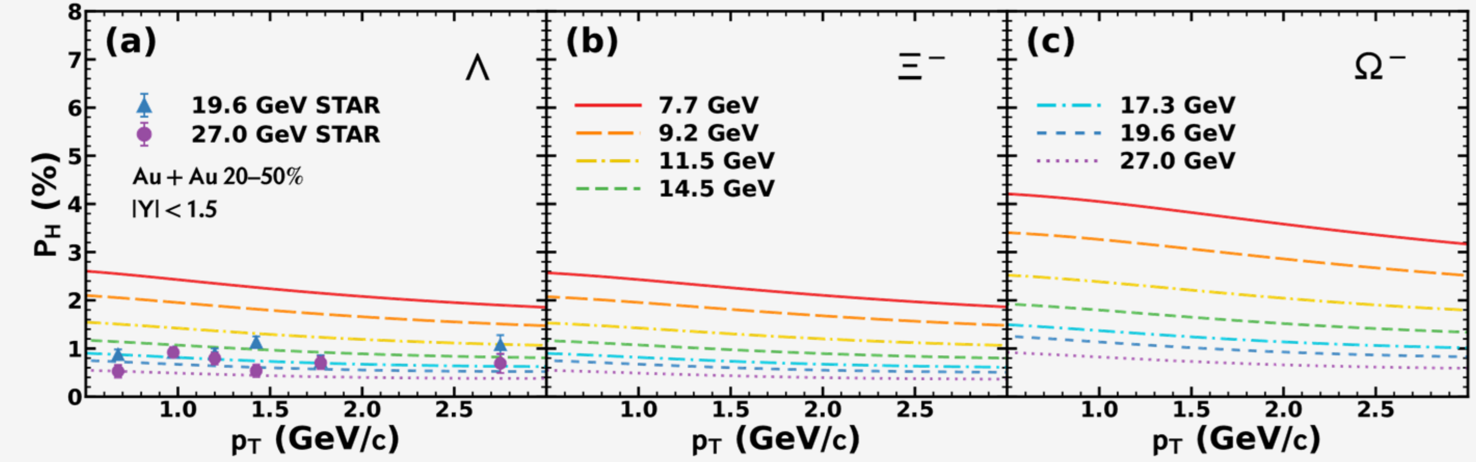
Hyperon–antihyperon splitting

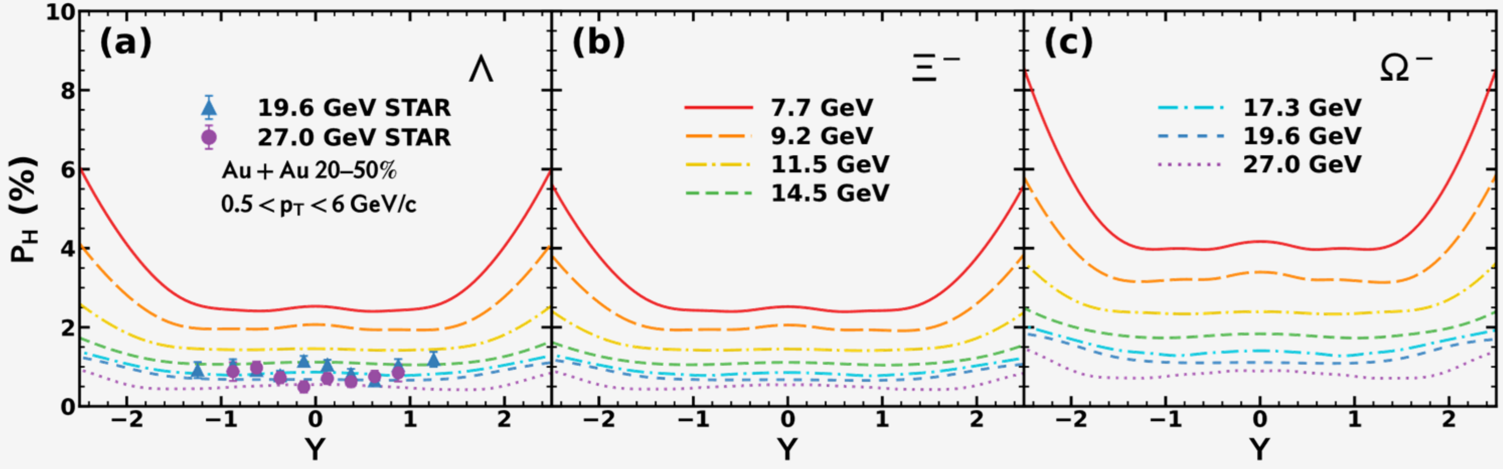


$$\mathcal{S}^{\mu}_{\text{chemical}}(\mathbf{p}) = \frac{\hbar}{4m_{\Lambda}N}\int d\Sigma\cdot p f_V^{(0)}(1-f_V^{(0)})\frac{1}{(u\cdot p)}\epsilon^{\mu\nu\alpha\beta}p_{\alpha}u_{\beta}\partial_{\nu}\frac{\mu}{T},$$

- **Anti-hyperons are predicted to be more polarized than hyperons.**
- **The splitting becomes larger toward lower collision energies.**
- **It is dominated by the chemical-potential-gradient contribution.**

p_T and rapidity dependence





- P_H decreases with increasing p_T.
- PH is nearly flat around midrapidity and increases at large |Y|.
- $P_\Omega > P_\Xi \gtrsim P_\Lambda$ over the explored kinematic range.

Summary

We have studied global hyperon polarization from $\sqrt{s_{NN}} = 2.4$ to 200 GeV at local-equilibrium assumption.

➢ **Λ polarization at a few GeV**

- ➢ Finite baryon density and the EoS strongly affect the extracted temperature and thermal vorticity.
- ➢ The HRG EoS describes the low-energy Λ data and suggests a possible peak near $\sqrt{s_{NN}} = 2.4$ GeV.

➢ **Multi-strange hyperons polarization across RHIC BES-II energies**

- ➢ P_H increases toward lower energies and follows $P_\Omega > P_\Xi \gtrsim P_\Lambda$.
- ➢ Hyperon–antihyperon splitting can be induced by chemical-potential gradients.
- ➢ The Ω result may point to additional strange-quark spin correlations

Thanks for your attention!

Back Up

Properties of multi-strange hyperons

Hyperon	m [GeV]	J	Weak decay	α_H	C
Λ	1.116	$\frac{1}{2}$	$\Lambda \to p\pi^-$	0.732	–
Ξ^-	1.322	$\frac{1}{2}$	$\Xi^- \to \Lambda\pi^-$	-0.401	0.944
Ω^-	1.672	$\frac{3}{2}$	$\Omega^- \to \Lambda K^-$	–	~ 1

α_H: weak-decay asymmetry parameter $\quad$ C: polarization-transfer coefficient

$C_{\Omega\to\Lambda K} \sim 1$ is assumed.

Mean-field

➢Hamilton's equations of motion

$$\frac{d\vec{r}_i}{dt} = \frac{\partial H_i}{\partial \vec{p}_i} = \frac{\vec{p}_i}{\sqrt{\vec{p}_i^2 + m_{eff}^2}}$$

$$\frac{d\vec{p}_i}{dt} = -\frac{\partial H_i}{\partial \vec{r}_i} = -\frac{\partial U}{\partial \vec{r}_i}$$

$$H_i = \sqrt{\vec{p}_i^2 + m_{eff}^2} + U(\vec{r}_i)$$

➢Skyrme potential

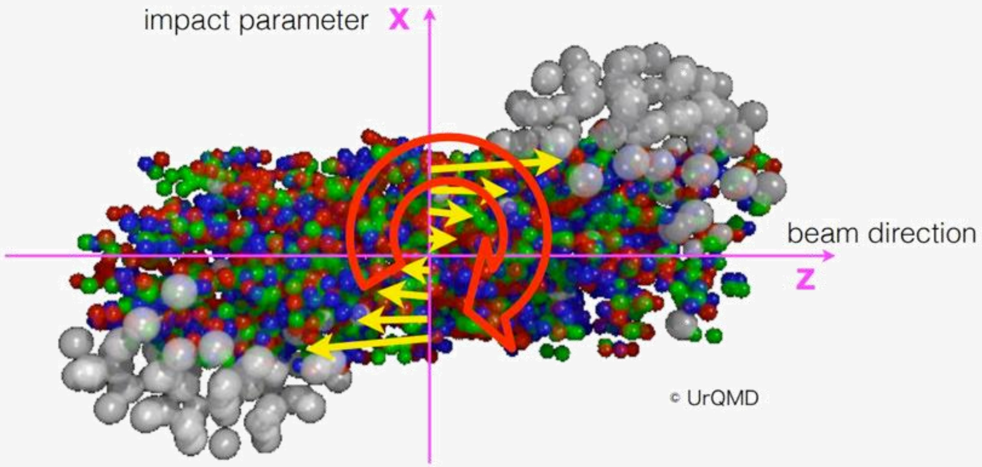
$$U(\vec{r}_i) = a\frac{\rho(\vec{r}_i)}{\rho_0} + b\left[\frac{\rho(\vec{r}_i)}{\rho_0}\right]^{\tau} \pm 2S_{pot}\frac{I_3}{I}\frac{\rho_{I_3}(\vec{r}_i)}{\rho_0}$$

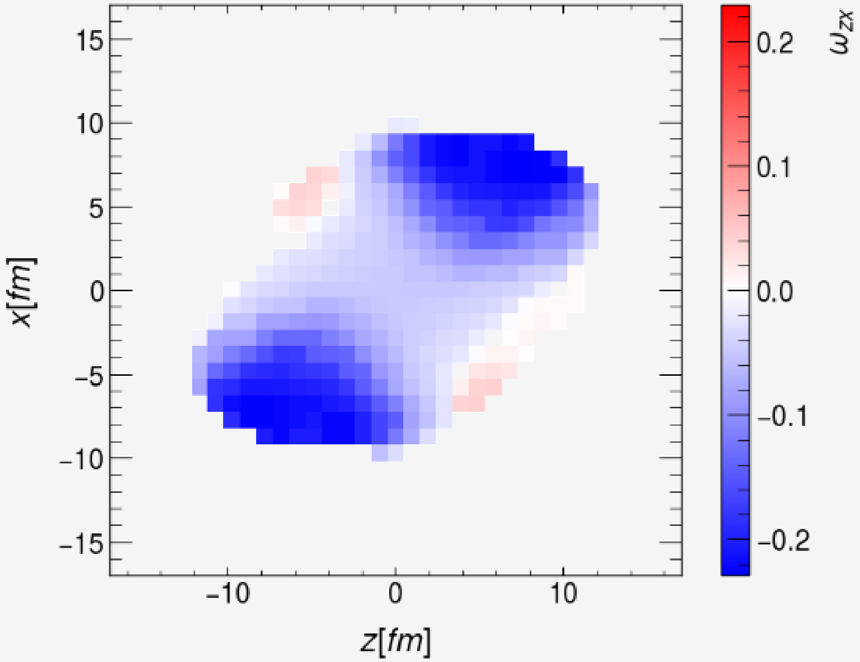
$$\rho_0 = 0.168\mathrm{fm}^{-3}$$

$$S_{\mathrm{pot}} = 18\mathrm{MeV}$$

$$a = -209.2\mathrm{MeV}, b = 156.4\mathrm{MeV}, \tau = 1.35$$

Vorticity


impact parameter
x
beam direction
z
© UrQMD


15
10
5
0
−5
−10
−15
x[fm]
−10
0
10
z[fm]
0.2
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−0.1
−0.2
ω_{zx}