From hyperons to hypertritons: a route to unravel proton spin polarization

Speaker: Dai-Neng Liu

Fudan University / Goethe University

In Collaborated with Marcus Bleicher, Jan Steinheimer, Yunpeng Zheng, Kaijia Sun, Jinhui Chen, Yugang Ma

The 1st Conference on Strong-Interaction Spin Physics, Qingdao, China, from July 27 to 30, 2026

Contents

1. Global polarization in heavy-ion collisions

STAR Col., Nature 548, 62 (2017)
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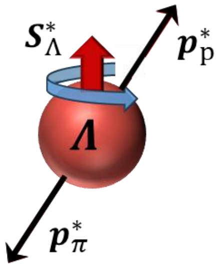

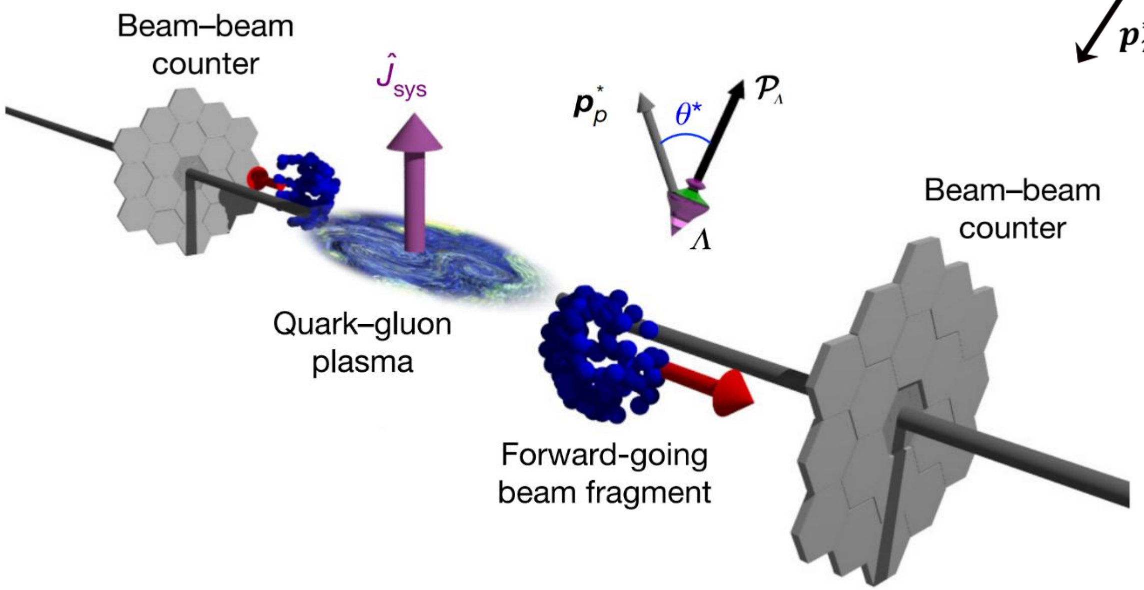

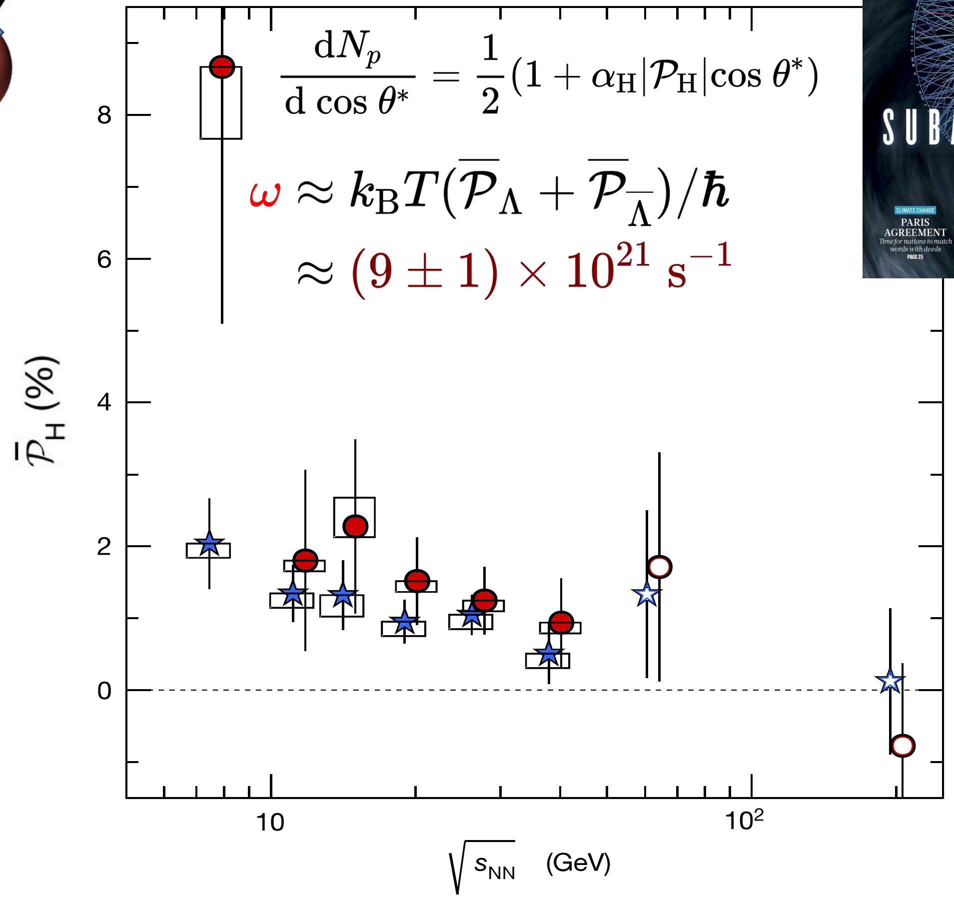

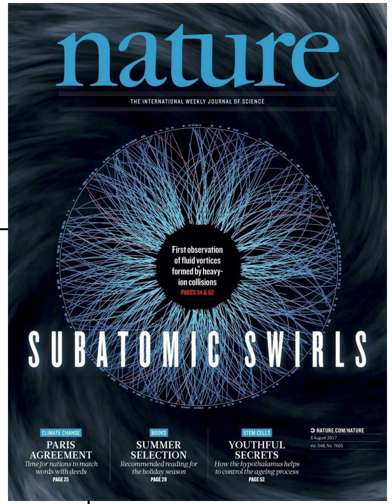

Liang, Wang, Phys. Rev. Lett. **94**, 102301 (2005)
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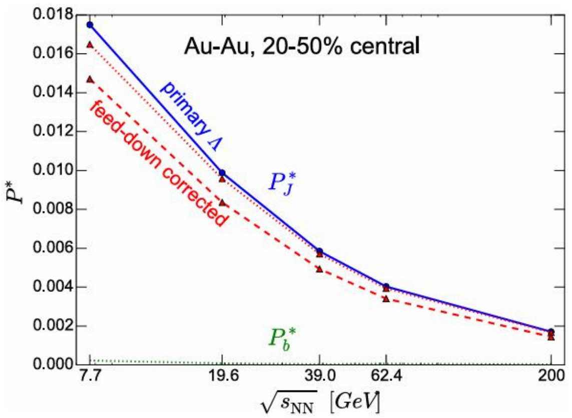
Becattini, Karpenko, Phys. Rev. Lett. **120**, 012302 (2018)

Most vortical fluid!

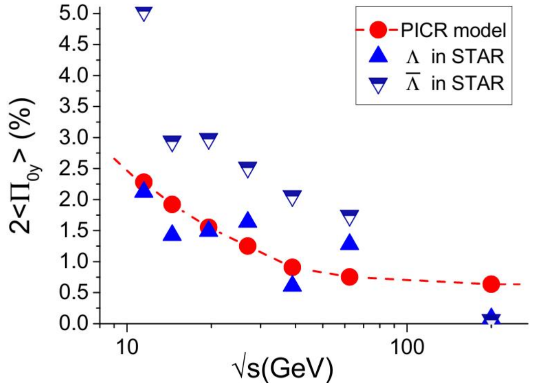
1. Theoretical simulations

Hydro



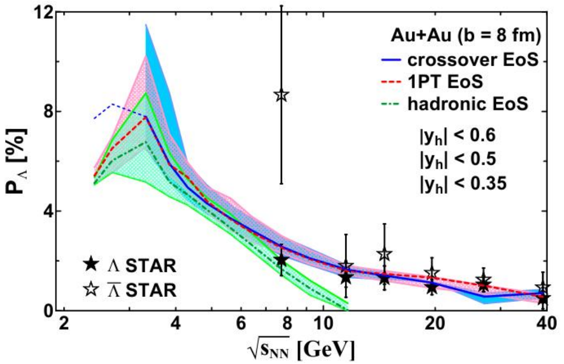
3+1D cascade+viscous hydro, UrQMD + vHLLE

Karpenko, Becattini, Eur. Phys. J. C 77, 213 (2017)



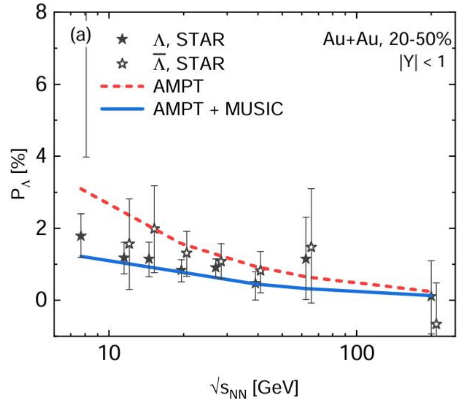
Yang-Mills flux-tube (initial) & 3+1D PICR hydro

Xie, Wang, Csernai, Phys. Rev. C 95, 031901(2017)



Thermodynamic approach and three-fluid dynamics

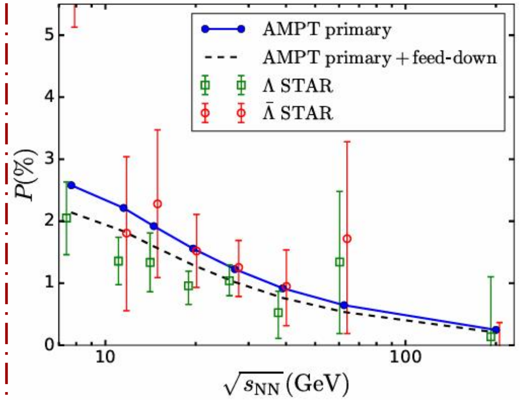
Ivanov, Phys. Rev. C 103, 031903 (2021)



AMPT+MUSIC

Fu, Xu, Huang, Song, Phys. Rev. C 103, 024903 (2021)

AMPT



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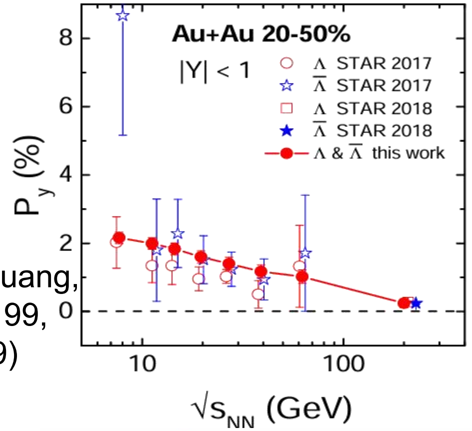

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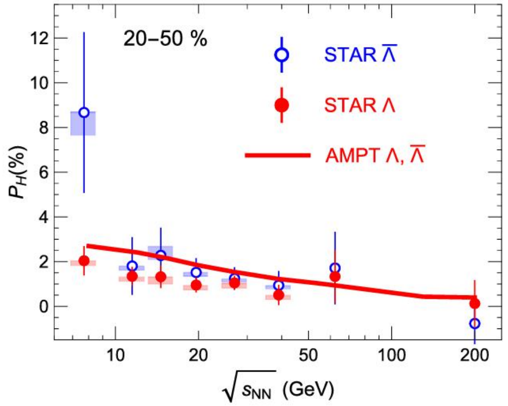
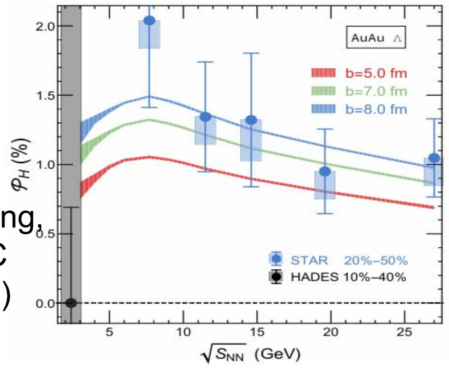
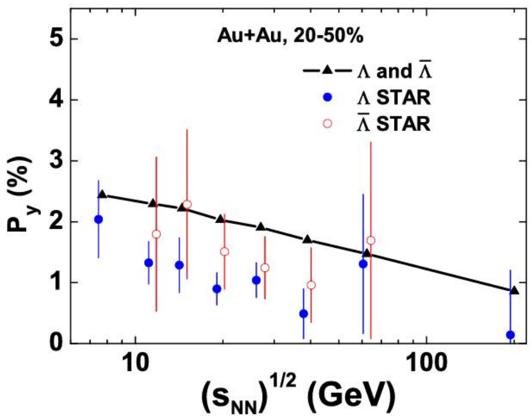


Shi, Li, Liao, Phys. Lett. B 788, 409 (2019)



Guo, Liao, Wang, Xing, Zhang, Phys. Rev. C 104, L041902 (2021)



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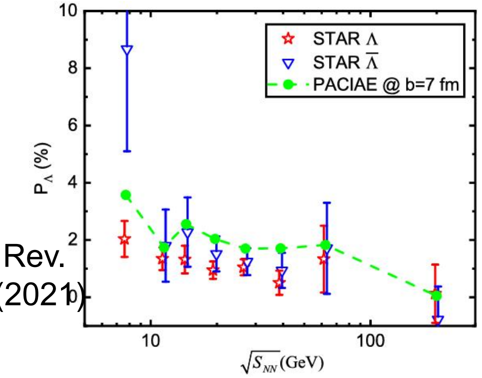
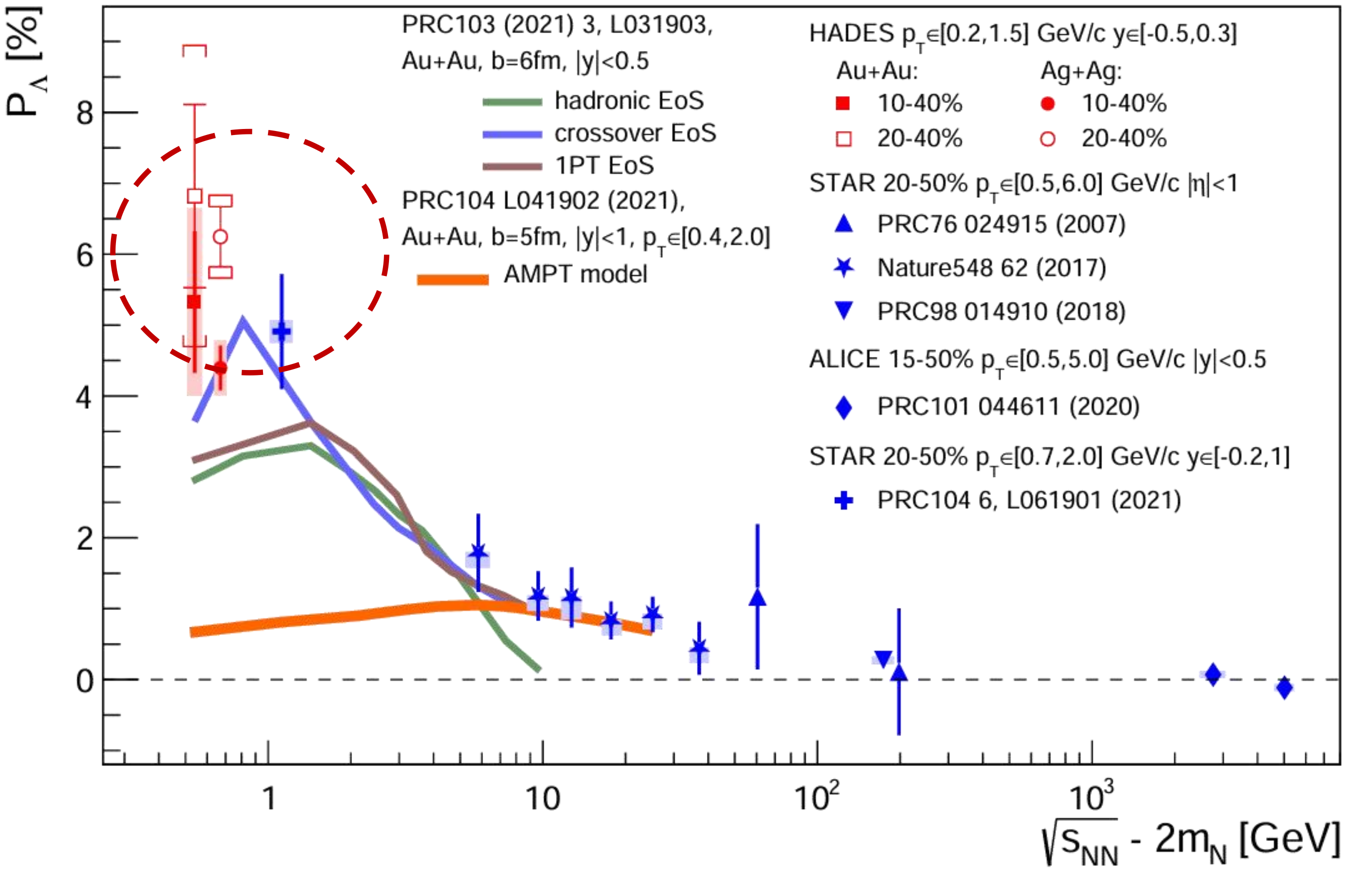
AMPT(initial) + chiral kinetic approach



Lei et. al, Phys. Rev. C 104, 054903 (2021)

Microscopic transport model PACIAE

1. Experimental polarization at low energies



HADES, Phys.Lett.B (2022) 137506

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Deng, Huang, Ma, Phys. Lett. B 835, 137560 (2022)
Bravina, Bugaev, Oleksandr, Zabrodin, Symmetry 13, 1852 (2021)
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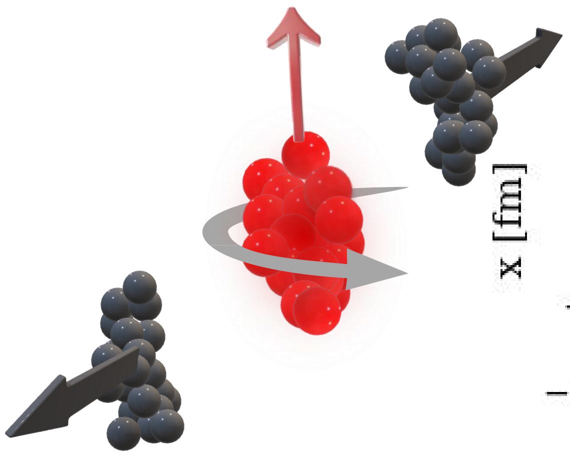
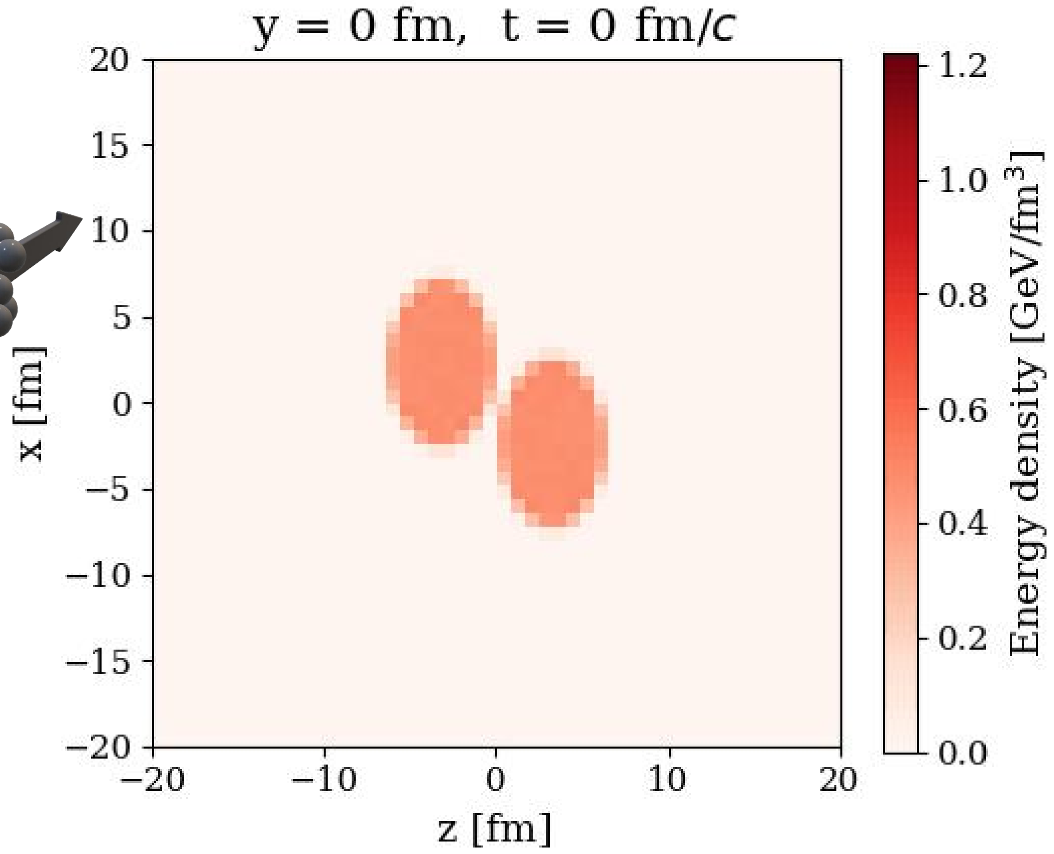
Voronynk, Tsegelnik, Kolomeitsev, Phys. Rev. C **111**, 034907 (2025)

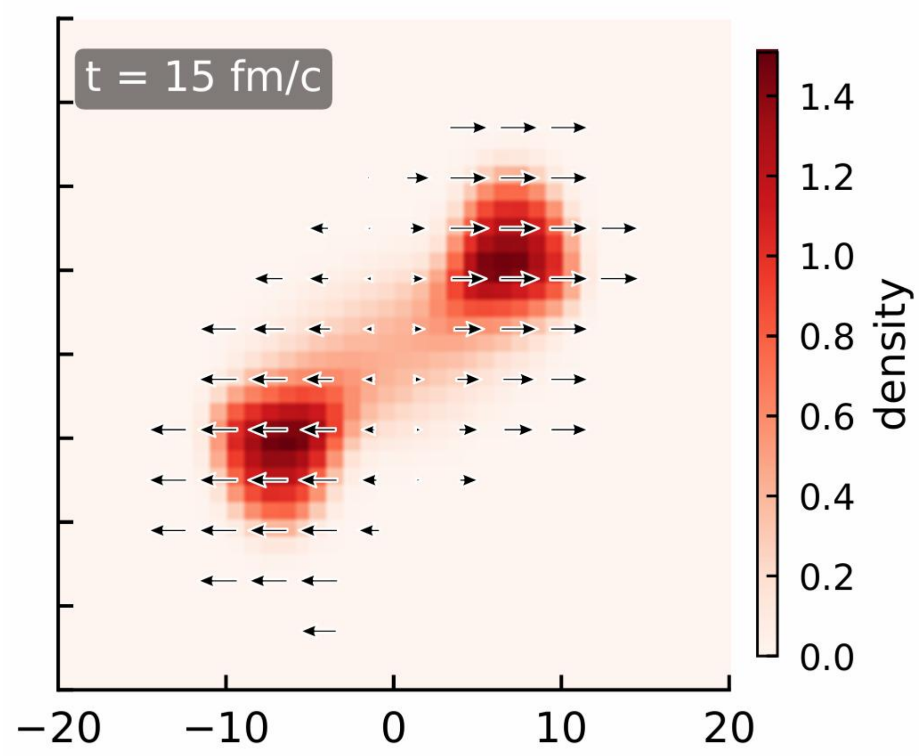
Niida, Voloshin, Int.J.Mod.Phys.E 33, 2430010 (2024)
Becattini, Buzzegoli, Niida, Pu, Tang, Wang, Int.J.Mod.Phys.E 33, 2430006 (2024).

Experiments not see peak till 2.X GeV
Futher study at FAIR/HIAF?
New spin polarization mechanism?
How is it related to EoS at high baryon density region?

2. Energy density evolution in UrQMD







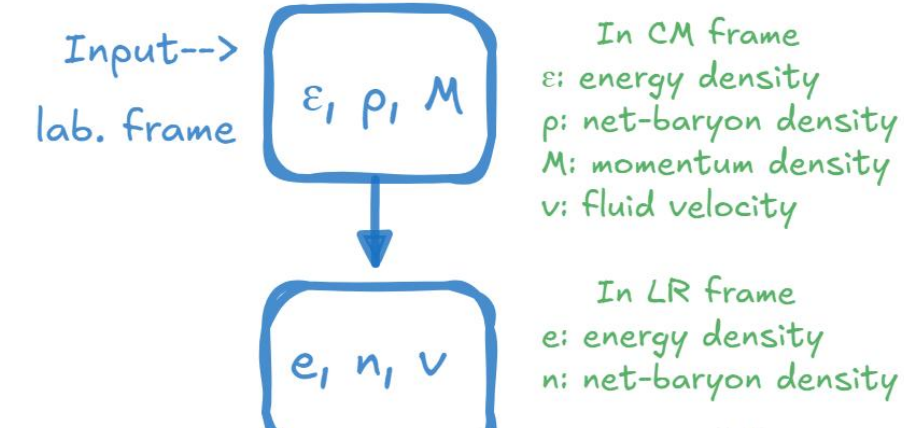
2. Temperature and vorticity

- Thermal vorticity

$$\varpi_{\mu\nu} = -\frac{1}{2}(\partial_\mu \beta_\nu - \partial_\nu \beta_\mu), \qquad \beta^\mu = u^\mu / T$$

- Spin polarization vector of single pariticle

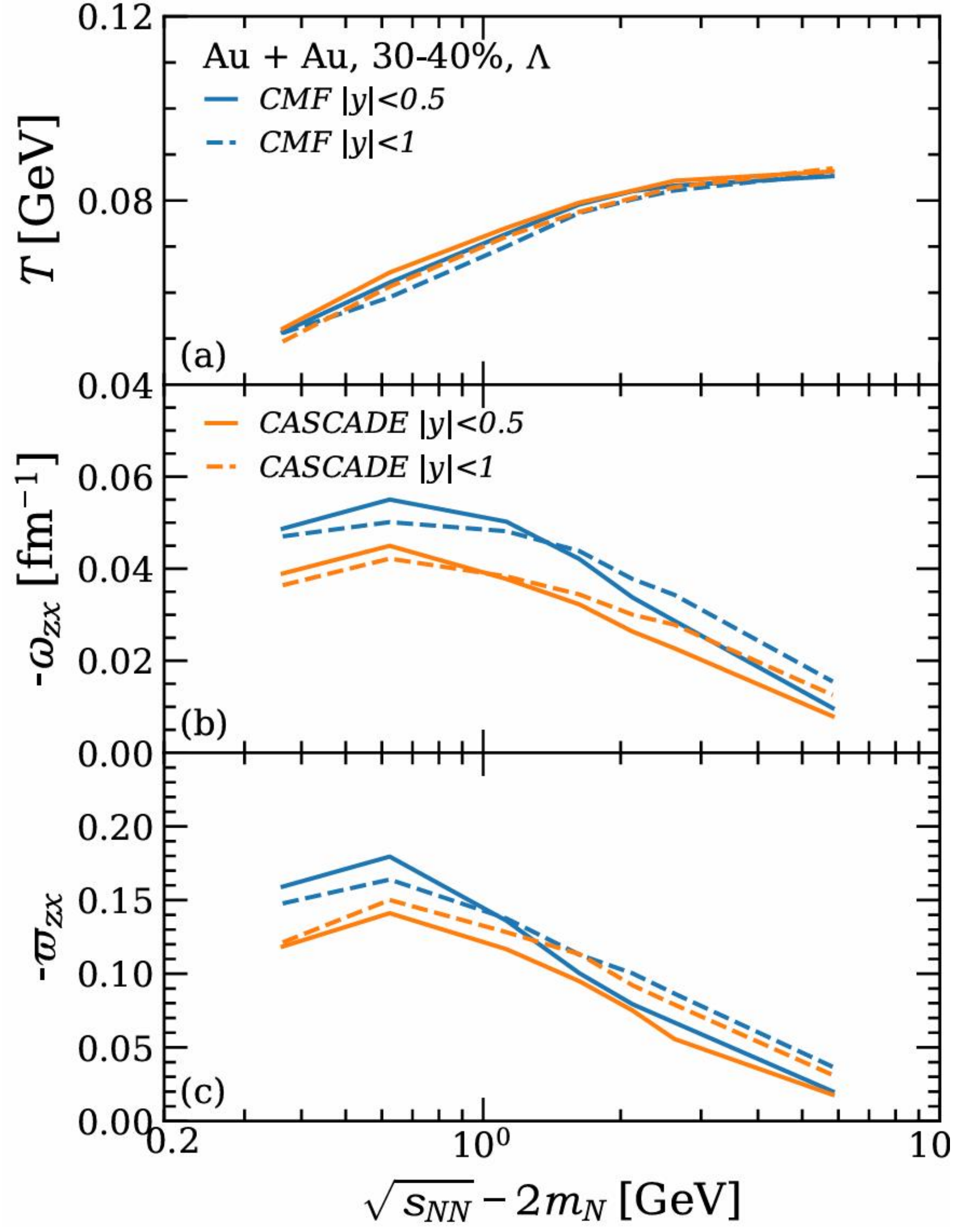
$$\mathcal{P}^\mu(x,p) = -\frac{s+1}{6m}(1-n_F)\epsilon^{\mu\nu\rho\sigma} p_\nu \varpi_{\rho\sigma}(x),$$



$$v = \frac{M}{\epsilon + p(e,n)}$$

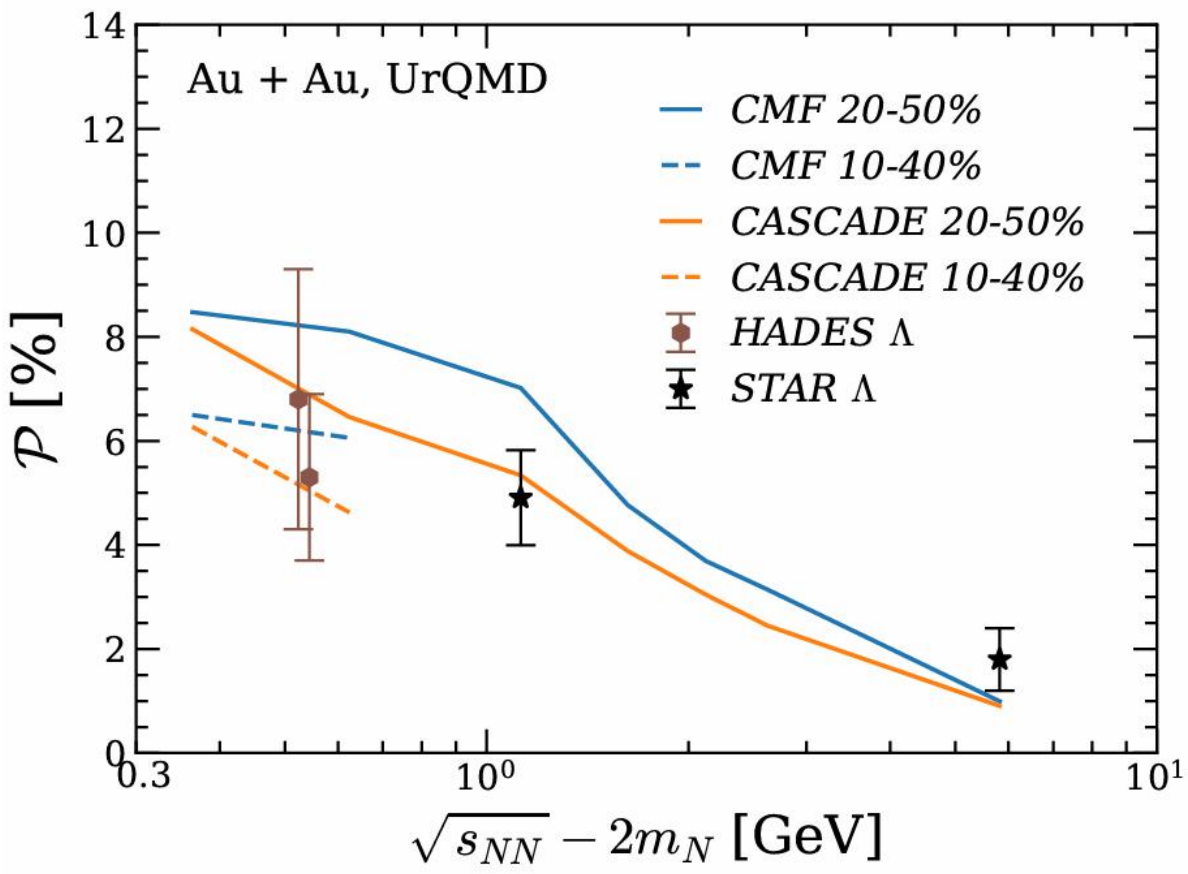
$$e = \epsilon - vM$$

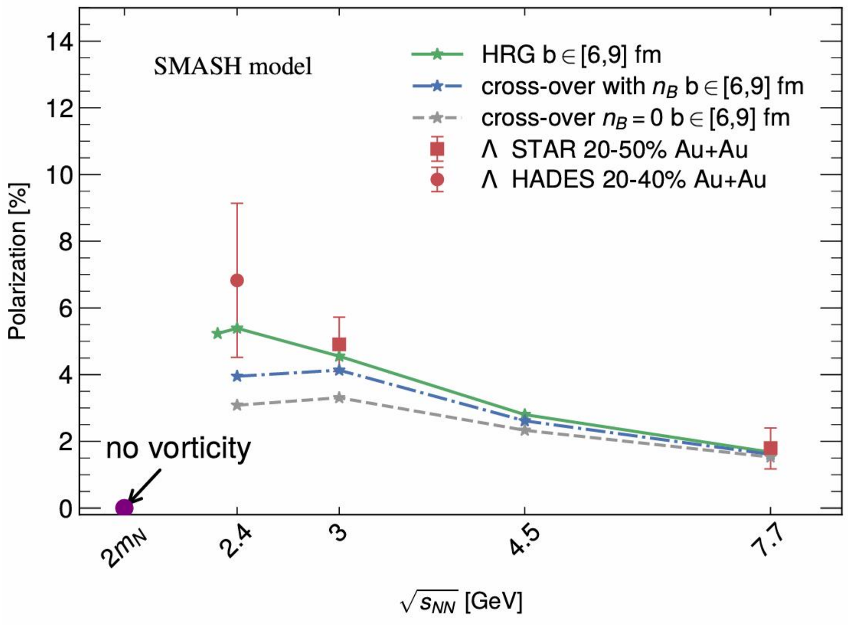
$$n = \rho \cdot \frac{1}{\gamma}$$



Steinheimer, et al, J. Phys. G 52, 035103 (2025)

2. Vorticity and global polarization





Yi, Pu, Pang, Qin, and Wang, 2603.27521

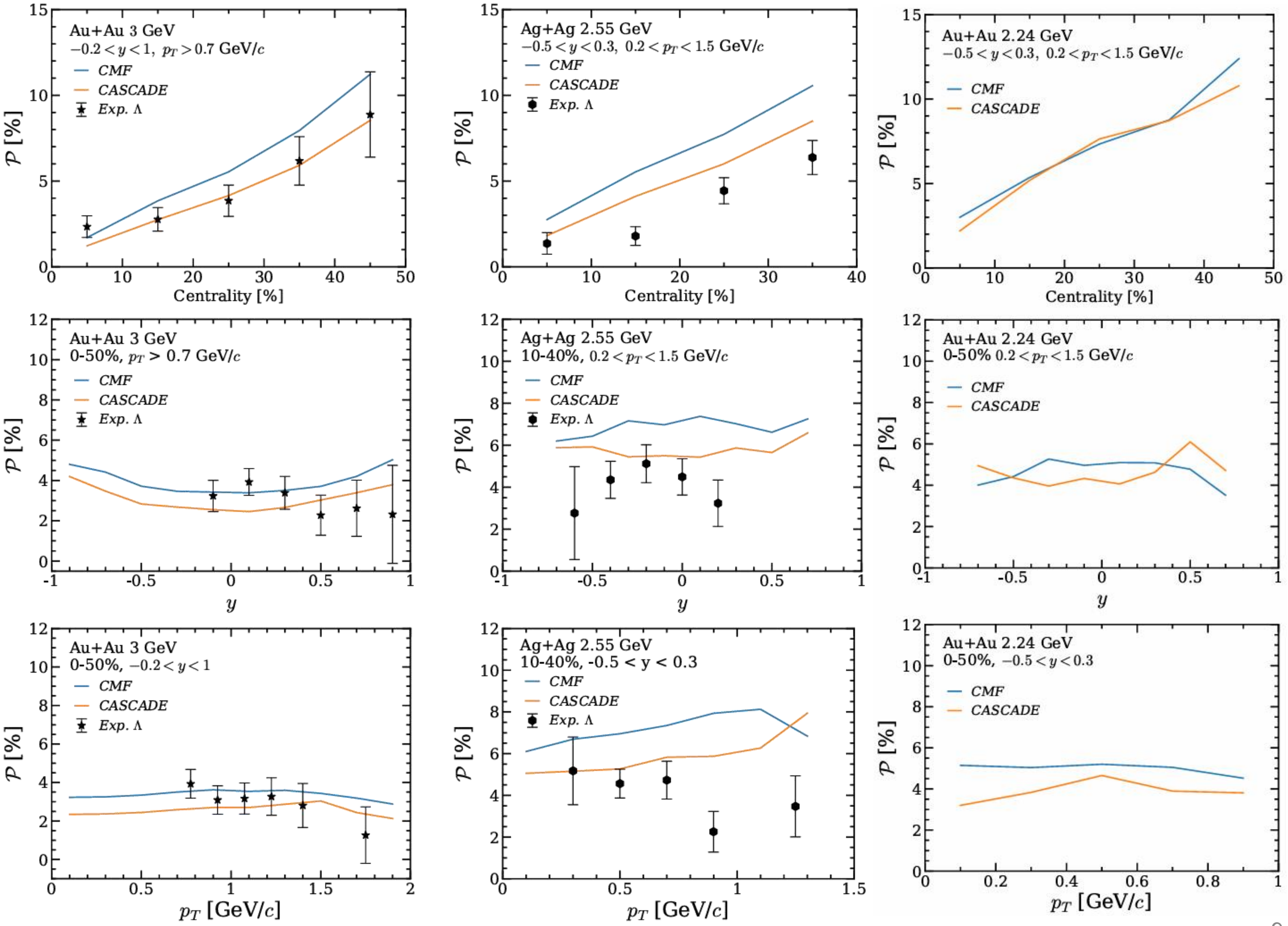
Peak?

$$\mathcal{P}^\mu(x,p) = -\frac{s+1}{6m}(1-n_F)\epsilon^{\mu\nu\rho\sigma}p_\nu\varpi_{\rho\sigma}(x), \qquad \mathbf{S}^*(x,p) = \mathbf{S} - \frac{\mathbf{p}\cdot\mathbf{S}}{E_p(m+E_p)}\mathbf{p}$$

Liu, et. al, arXiv: 2606.13333

2. Polarization

- ➢ **Centrality**
- ➢ **Rapidity**
- ➢ **Transverse momentum**



- ■ **Au + Au 3 GeV, 2.24 GeV**
- ■ **Ag + Ag 2.55 GeV**

Liu, et. al, arXiv: 2606.13333

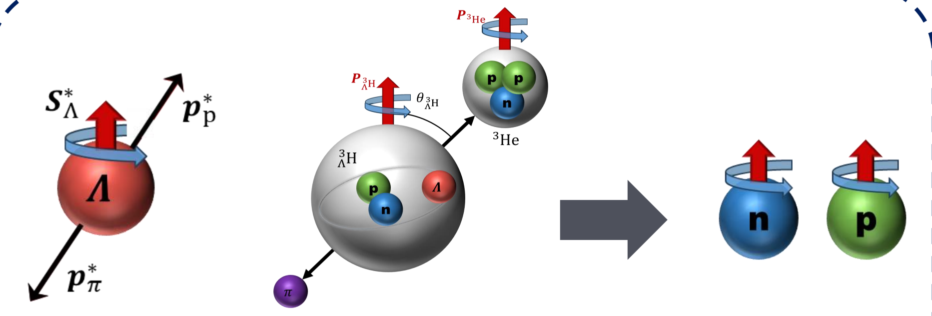
3. Polarization of nucleon?

Stable Nucleon		Unstable hadrons		Unstable (hyper)nuclei
$p(uud)$ $n(udd)$ $\bar{p}(\overline{uud})$ $\bar{n}(\overline{udd})$	$\Rightarrow$	$\Lambda(uds)$ $\Xi(uss)$ $\Omega(sss)$ $\phi(s\bar{s})$ $K^{*0}(d\bar{s})$ $J/\psi(c\bar{c})$ …	$\Leftrightarrow$	${}^{3}_{\Lambda}\mathrm{H}(np\Lambda)$ ${}^{4}\mathrm{Li}(nnpp)$ ${}^{3}_{\bar{\Lambda}}\overline{\mathrm{H}}(\bar{n}\bar{p}\bar{\Lambda})$ ${}^{4}\overline{\mathrm{Li}}(\bar{n}\bar{n}\bar{p}\bar{p})$ …

- The baisc constituents of visible matter and dominant baryonic degrees of freedom in nuclear collisions
- Light quark spin polarization
- Spin Hall effect

$$\mathcal{P}_\Lambda \approx \mathcal{P}_s \qquad \mathcal{P}_p = \frac{4\mathcal{P}_u - \mathcal{P}_d}{3}$$

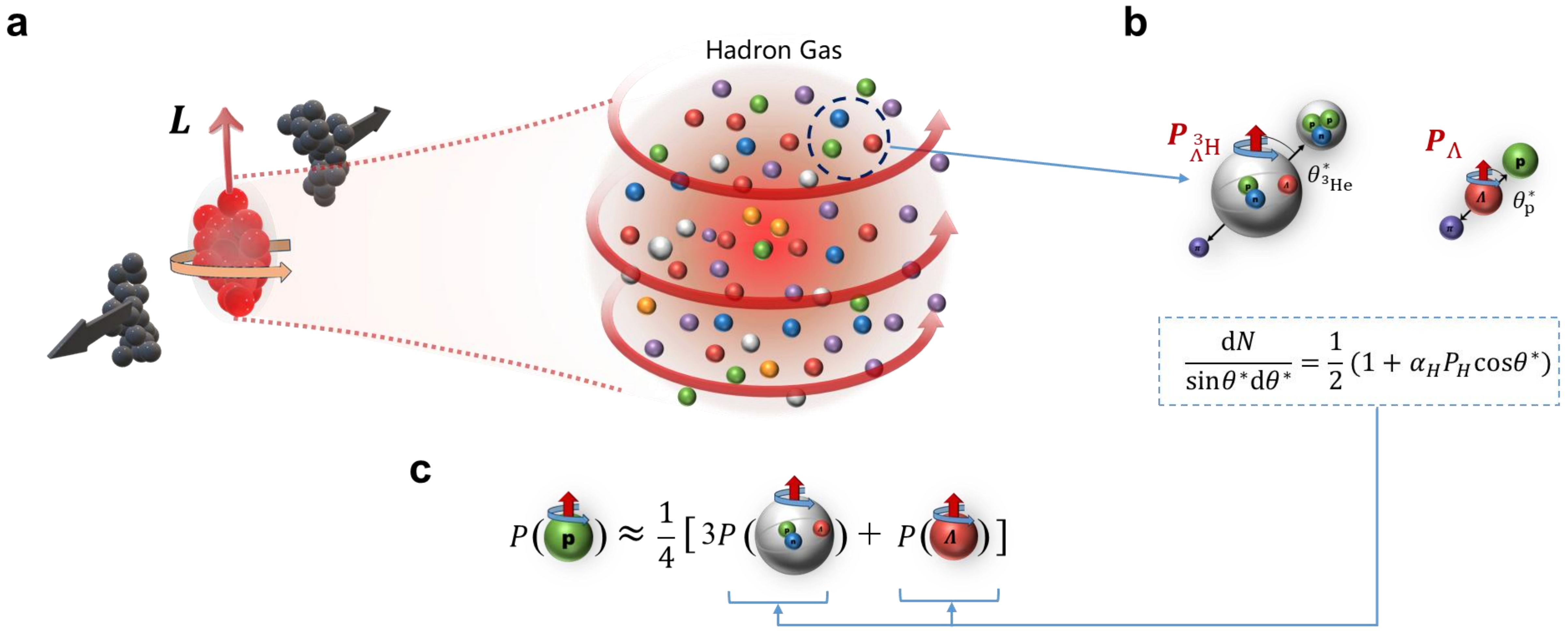
SU(6) quark model



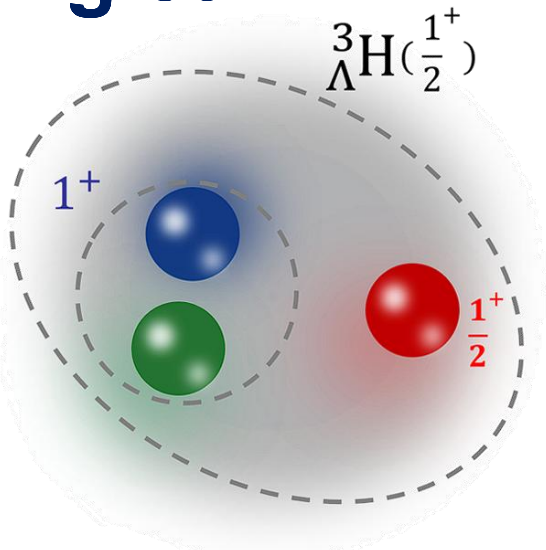
$\Lambda \to p + \pi^-$ ${}^{3}_{\Lambda}\mathrm{H} \to {}^{3}\mathrm{He} + \pi^-$

Liang and Wang, Phys. Rev. Lett. 94, 102301 (2005).
Liu and Yin, Phys. Rev. D **104**, 054043 (2021)
Liu and Xu, Phys. Rev. C 109, 014615 (2024)
Xu, Phys. Rev. C 111, 059902 (2025)

3. Reveal proton spin polarization



3. (Anti-)Hypertriton Polarization with Spin-1/2 Triglet



➢ Spin wavefunction

$$
\begin{aligned}
|\tfrac{1}{2},\uparrow\rangle_{{}^3_\Lambda\mathrm{H}} &= \frac{\sqrt{6}}{3}|\tfrac{1}{2},\tfrac{1}{2}\rangle_n|\tfrac{1}{2},\tfrac{1}{2}\rangle_p|\tfrac{1}{2},-\tfrac{1}{2}\rangle_\Lambda \\
&- \frac{\sqrt{6}}{6}\big(|\tfrac{1}{2},\tfrac{1}{2}\rangle_n|\tfrac{1}{2},-\tfrac{1}{2}\rangle_p|\tfrac{1}{2},\tfrac{1}{2}\rangle_\Lambda \\
&+ |\tfrac{1}{2},-\tfrac{1}{2}\rangle_n|\tfrac{1}{2},\tfrac{1}{2}\rangle_p|\tfrac{1}{2},\tfrac{1}{2}\rangle_\Lambda\big),
\end{aligned}
$$

$$
\begin{aligned}
|\tfrac{1}{2},\downarrow\rangle_{{}^3_\Lambda\mathrm{H}} &= -\frac{\sqrt{6}}{3}|\tfrac{1}{2},-\tfrac{1}{2}\rangle_n|\tfrac{1}{2},-\tfrac{1}{2}\rangle_p|\tfrac{1}{2},\tfrac{1}{2}\rangle_\Lambda \\
&+ \frac{\sqrt{6}}{6}\big(|\tfrac{1}{2},\tfrac{1}{2}\rangle_n|\tfrac{1}{2},-\tfrac{1}{2}\rangle_p|\tfrac{1}{2},-\tfrac{1}{2}\rangle_\Lambda \\
&+ |\tfrac{1}{2},-\tfrac{1}{2}\rangle_n|\tfrac{1}{2},\tfrac{1}{2}\rangle_p|\tfrac{1}{2},-\tfrac{1}{2}\rangle_\Lambda\big).
\end{aligned}
$$

➢ Coalescence model for hypertriton production (without baryon spin correlation)

$$\hat{\rho}_{np\Lambda} = \hat{\rho}_n \otimes \hat{\rho}_p \otimes \hat{\rho}_\Lambda$$

$$
\begin{aligned}
E\frac{d^3N_{{}^3_\Lambda\mathrm{H},\pm\frac{1}{2}}}{d\mathbf{P}^3} &= E\int \prod_{i=n,p,\Lambda} p_i^\mu d^3\sigma_\mu \frac{d^3p_i}{E_i}\bar{f}_i(\mathbf{x}_i,\mathbf{p}_i) \\
&\times \left(\frac{2}{3}w_{n,\pm\frac{1}{2}}w_{p,\pm\frac{1}{2}}w_{\Lambda,\mp\frac{1}{2}} + \frac{1}{6}w_{n,\pm\frac{1}{2}}w_{p,\mp\frac{1}{2}}w_{\Lambda,\pm\frac{1}{2}} \right. \\
&\left. + \frac{1}{6}w_{n,\mp\frac{1}{2}}w_{p,\pm\frac{1}{2}}w_{\Lambda,\pm\frac{1}{2}}\right) \\
&\times W_{{}^3_\Lambda\mathrm{H}}(\mathbf{x}_n,\mathbf{x}_p,\mathbf{x}_\Lambda;\mathbf{p}_n,\mathbf{p}_p,\mathbf{p}_\Lambda)\delta(\mathbf{P}-\sum_i \mathbf{p}_i)
\end{aligned}
$$

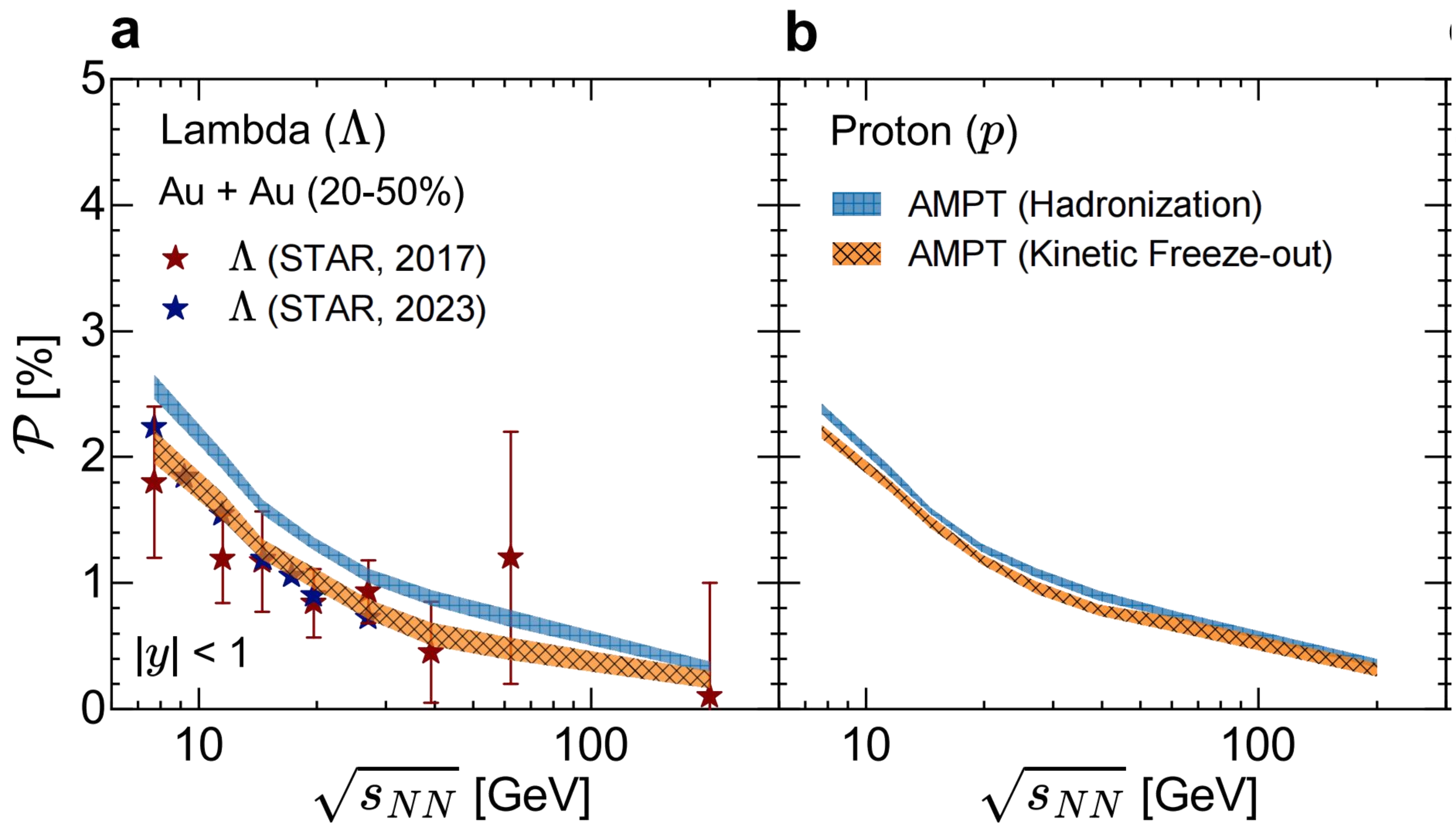
$$
\begin{aligned}
\mathcal{P}_{{}^3_\Lambda\mathrm{H}} &\approx \frac{\frac{2}{3}\mathcal{P}_n + \frac{2}{3}\mathcal{P}_p - \frac{1}{3}\mathcal{P}_\Lambda - \mathcal{P}_n\mathcal{P}_p\mathcal{P}_\Lambda}{1 - \frac{2}{3}(\mathcal{P}_n+\mathcal{P}_p)\mathcal{P}_\Lambda + \frac{1}{3}\mathcal{P}_n\mathcal{P}_p} \\
&\approx \frac{2}{3}\mathcal{P}_n + \frac{2}{3}\mathcal{P}_p - \frac{1}{3}\mathcal{P}_\Lambda
\end{aligned}
$$

Small spin polarizations and correlations

$$\mathcal{P}_p \approx \mathcal{P}_n$$

$$\mathcal{P}_p \approx \frac{1}{4}\left(3\mathcal{P}_{{}^3_\Lambda\mathrm{H}} + \mathcal{P}_\Lambda\right)$$

3. Λ, proton, and hypertriton global polarization

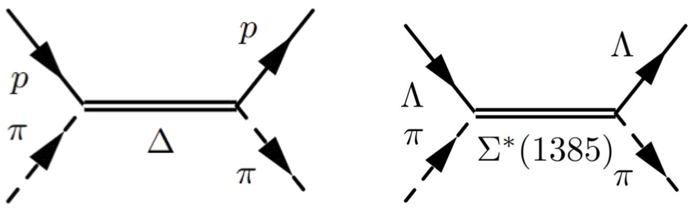


➢ **Feed-down effect**

$$\mathcal{P}_D = \frac{N_D^* + \sum_i \frac{s_{M_i}+1}{s_D+1}\mathcal{C}_{M_i\to D}\mathcal{B}_{M_i\to D}N_{M_i}}{N_D^* + \sum_i b_{M_i\to D}N_{M_i}}\mathcal{P}_D^*$$

$$\mathcal{P}_\Lambda^{\mathrm{fd}} = -\frac{1}{3}\mathcal{P}_{\Sigma^0}$$

➢ **Scattering effect**



$$\mathcal{C}_{D\to R} = \frac{5}{9}$$

Liu, et.al, Phys. Rev. Res. **8**, 033057 (2026)

3. Global hypertriton polarization

Spin-dependent Coalescence model

Production

$$N_{^3_\Lambda\mathrm{H},\pm\frac{1}{2}} = \sum_{np\Lambda} g_{^3_\Lambda\mathrm{H},\pm\frac{1}{2}} W_{^3_\Lambda\mathrm{H}}(\mathbf{x}_n, \mathbf{x}_p, \mathbf{x}_\Lambda; \mathbf{p}_n, \mathbf{p}_p, \mathbf{p}_\Lambda),$$

$$W_3(\rho, \lambda, p_\rho, p_\lambda) = 8^2 \exp\left[-\frac{\rho^2}{\sigma_\rho^2} - \frac{\lambda^2}{\sigma_\lambda^2} - p_\rho^2\sigma_\rho^2 - p_\lambda^2\sigma_\lambda^2\right]$$

$$\rho = \frac{1}{\sqrt{2}}(x_1' - x_2'), \quad p_\rho = \frac{\sqrt{2}(m_2 p_1' - m_1 p_2')}{m_1 + m_2},$$

$$\lambda = \sqrt{\frac{2}{3}}\left(\frac{m_1 x_1' + m_2 x_2' - x_3'}{m_1 + m_2}\right),$$

$$p_\lambda = \sqrt{\frac{3}{2}}\frac{m_3(p_1' + p_2') - (m_1 + m_2)p_3'}{m_1 + m_2 + m_3}.$$

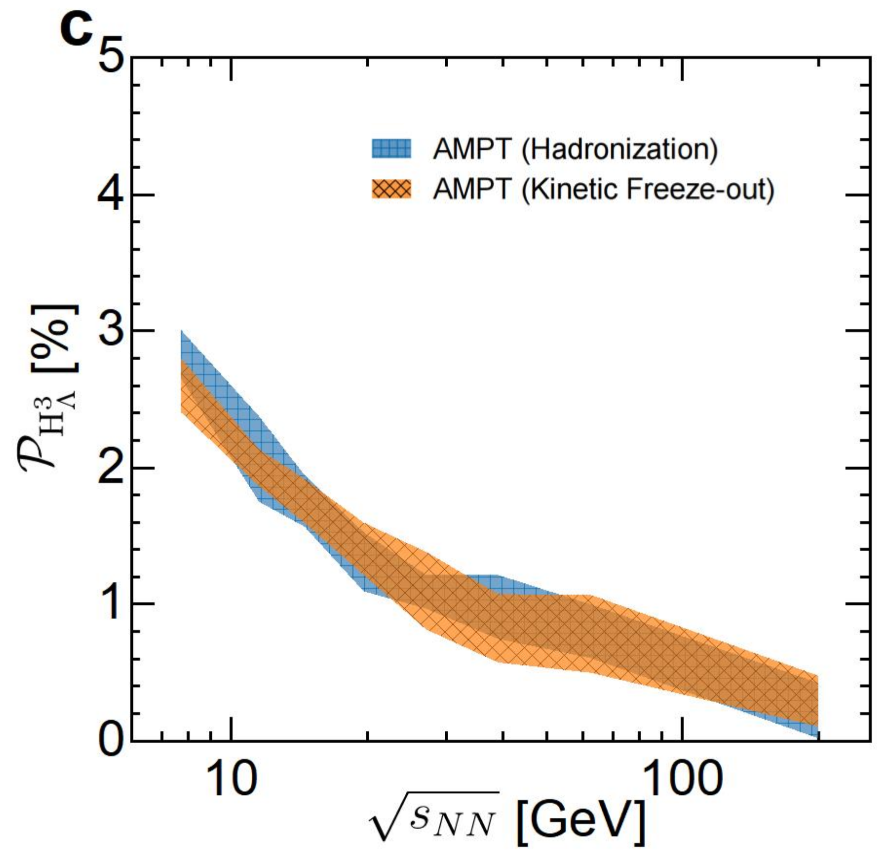
Spin statistical factor

$$\begin{aligned} g_{^3_\Lambda\mathrm{H},\pm\frac{1}{2}} &= \frac{2}{3} w_{n,\pm\frac{1}{2}} w_{p,\pm\frac{1}{2}} w_{\Lambda\mp\frac{1}{2}} \\ &+ \frac{1}{6} w_{n,\mp\frac{1}{2}} w_{p,\pm\frac{1}{2}} w_{\Lambda\pm\frac{1}{2}} \\ &+ \frac{1}{6} w_{n,\pm\frac{1}{2}} w_{p,\mp\frac{1}{2}} w_{\Lambda\pm\frac{1}{2}}, \end{aligned}$$

$$w_{i,\pm\frac{1}{2}} = \frac{1}{2}(1 \pm \mathcal{P}_i)$$

Polarization

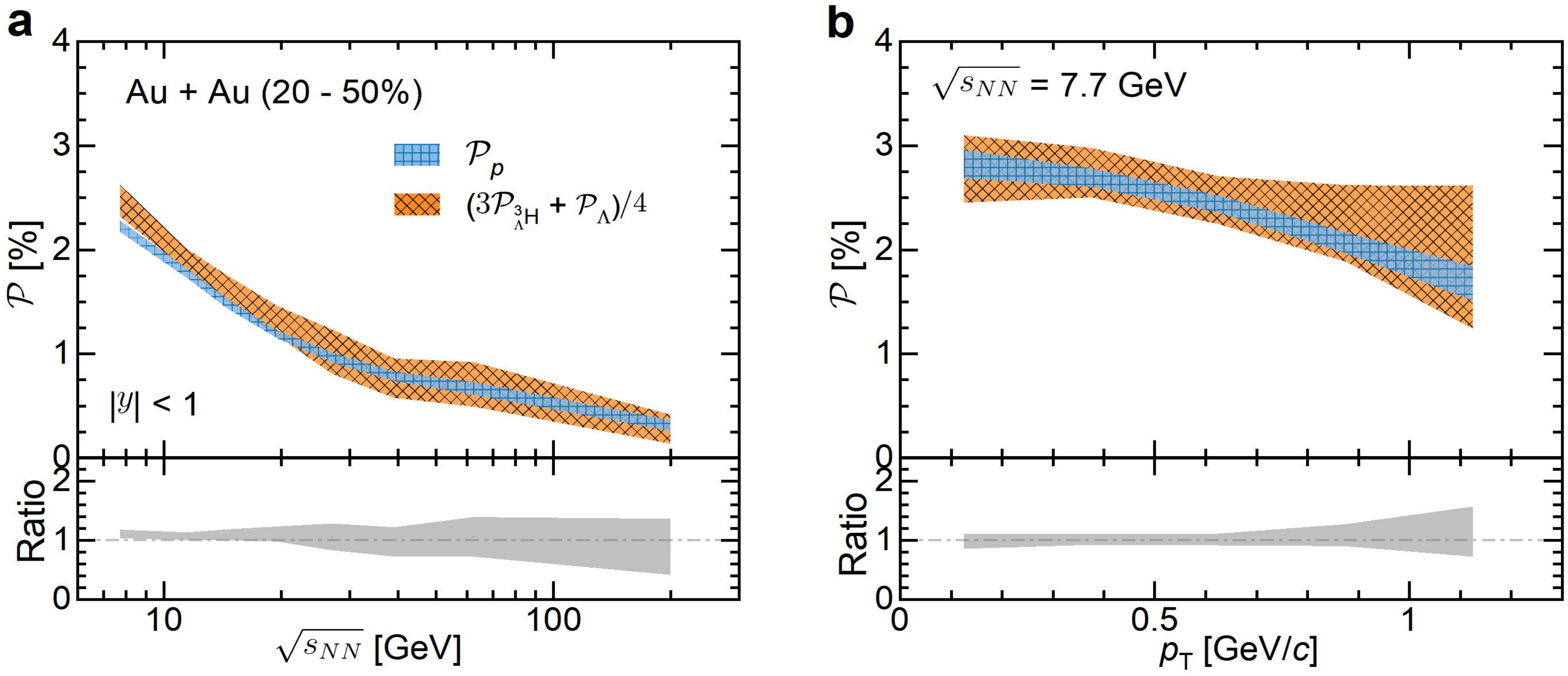
$$\mathcal{P}_{^3_\Lambda\mathrm{H}} = \frac{N_{^3_\Lambda\mathrm{H},+\frac{1}{2}} - N_{^3_\Lambda\mathrm{H},-\frac{1}{2}}}{N_{^3_\Lambda\mathrm{H},+\frac{1}{2}} + N_{^3_\Lambda\mathrm{H},-\frac{1}{2}}}$$



$$\mathcal{P}_{^3_\Lambda\mathrm{H}} \approx \frac{2}{3}\mathcal{P}_n + \frac{2}{3}\mathcal{P}_p - \frac{1}{3}\mathcal{P}_\Lambda \approx \frac{1}{3}(4\mathcal{P}_p - \mathcal{P}_\Lambda)$$

Liu, et.al, Phys. Rev. Res. **8**, 033057 (2026)

3. Global proton polarization via hypertriton and hyperon



$$\mathcal{P}_{^3_\Lambda\mathrm{H}} \approx \frac{2}{3}\mathcal{P}_n + \frac{2}{3}\mathcal{P}_p - \frac{1}{3}\mathcal{P}_\Lambda \approx \frac{1}{3}\left(4\mathcal{P}_p - \mathcal{P}_\Lambda\right)$$

$$\mathcal{P}_p \approx \frac{1}{4}\left(3\mathcal{P}_{^3_\Lambda\mathrm{H}} + \mathcal{P}_\Lambda\right)$$

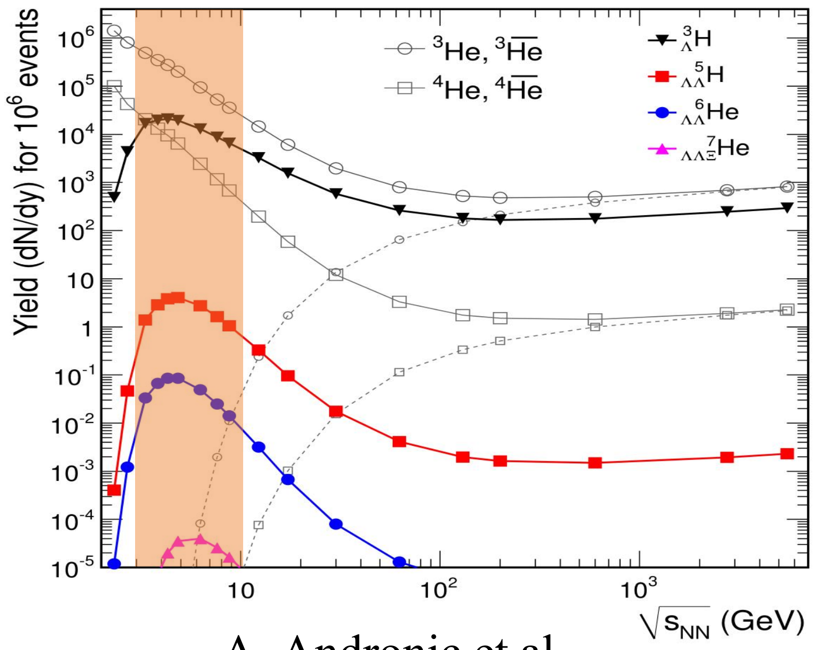
Liu, et.al, Phys. Rev. Res. **8**, 033057 (2026)

4. Summary and outlook

1. Λ global polarization from cascade modes describes better of experimental data
2. No peak of Λ global polarization appears at energy 2.24-7.7 GeV within UrQMD model
3. A linear relationship is used for extract the proton polarization

$$\mathcal{P}_p \approx \frac{1}{4}\left(3\mathcal{P}_{^3_\Lambda\mathrm{H}} + \mathcal{P}_\Lambda\right)$$

4. Hypertriton polarization in HIAF energies



A. Andronic et al.,
Phys.Lett.B 697 (2011) 203

Thank you for your attention!