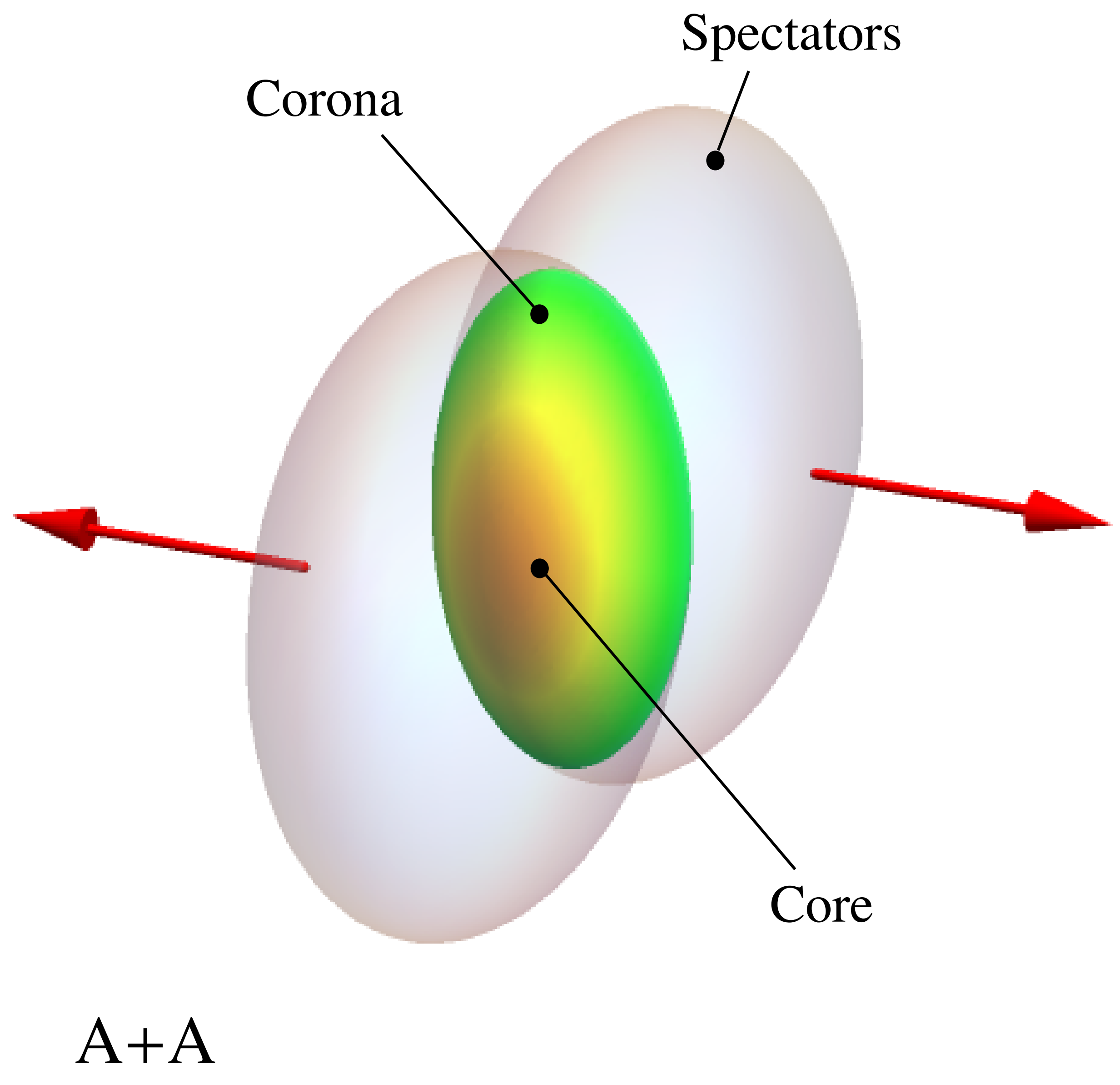
Time to relax and talk about Λ polarization

A. Ayala, D. de la Cruz, S. Hernández-Ortíz, L. A. Hernández, and JS, PLB **801** (2020) 135169

A. Ayala, D. de la Cruz, L. A. Hernández, and JS, PRD **102** (2020) 056019

A. Ayala, M. A. Ayala Torres, E. Cuautle, I. Dominguez, M. A. Fontaine Sanchez, I. Maldonado, E. Moreno-Barbosa, P. A. Nieto-Marin, M. Rodriguez-Cahuantzi, JS, M. E. Tejeda-Yeomans, and L- Valenzuela-Cazares, PLB **810** (2020) 135818



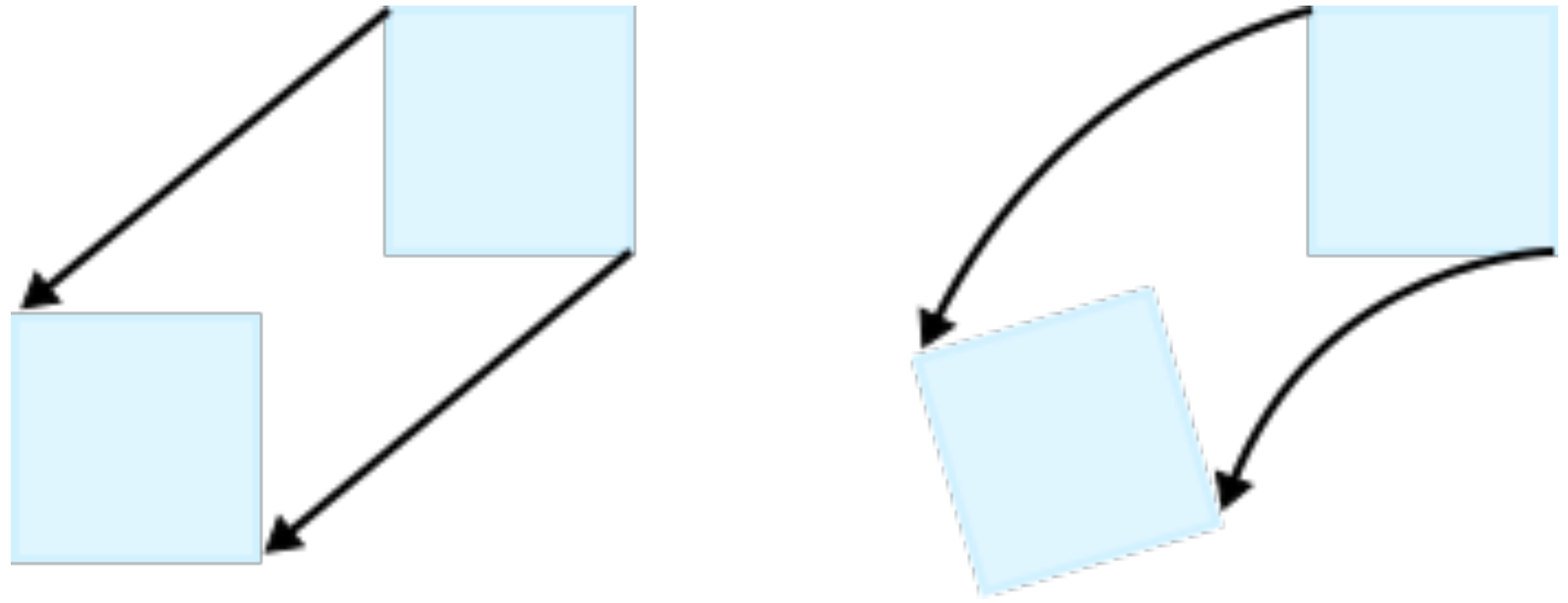
MexNICA Collaboration Winter Meeting, Dec. 17 2020

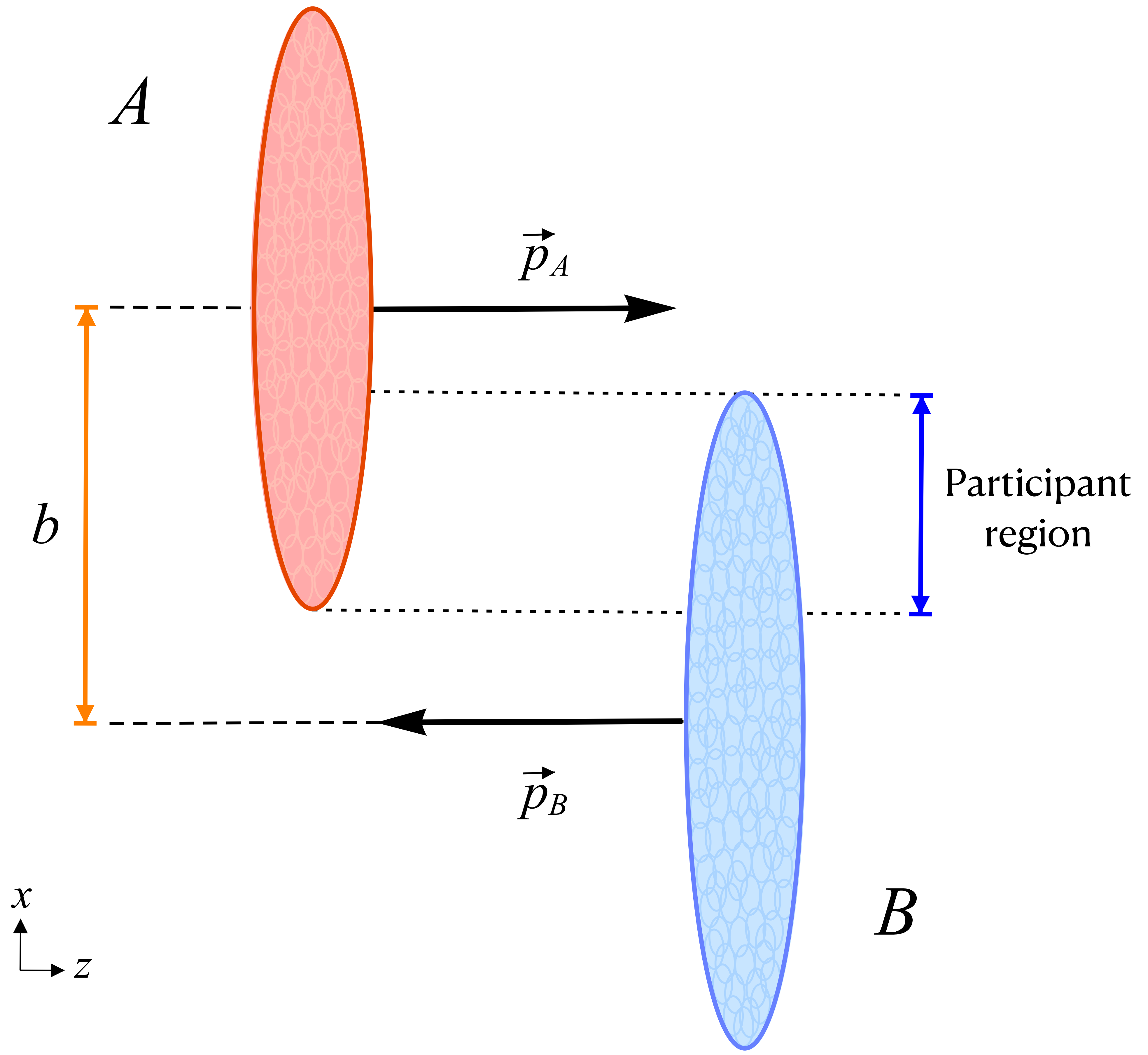
Heavy-ion collisions

and some of its properties

- "High" energy $\sim 10 - 200\,\mathrm{GeV}$
- High temperatures $\sim 150\,\mathrm{MeV}$
- High magnetic fields $\sim m_\pi^2$
- High global angular momentum $\sim 10^6\hbar$

➔ Spinning QGP





Vorticity

Classically

$$\omega = \nabla \times v$$

Relativistic

$$\omega^{\mu} = \epsilon^{\mu\nu\rho\sigma} u_{\nu} \partial_{\rho} u_{\sigma}$$

Relativistic-thermal

$$\varpi_{\mu\nu} = \frac{1}{2}\left[\partial_{\nu}\beta_{\mu} - \partial_{\mu}\beta_{\nu}\right] \quad \beta_{\mu} \equiv \frac{u_{\mu}}{T}$$

Vorticity

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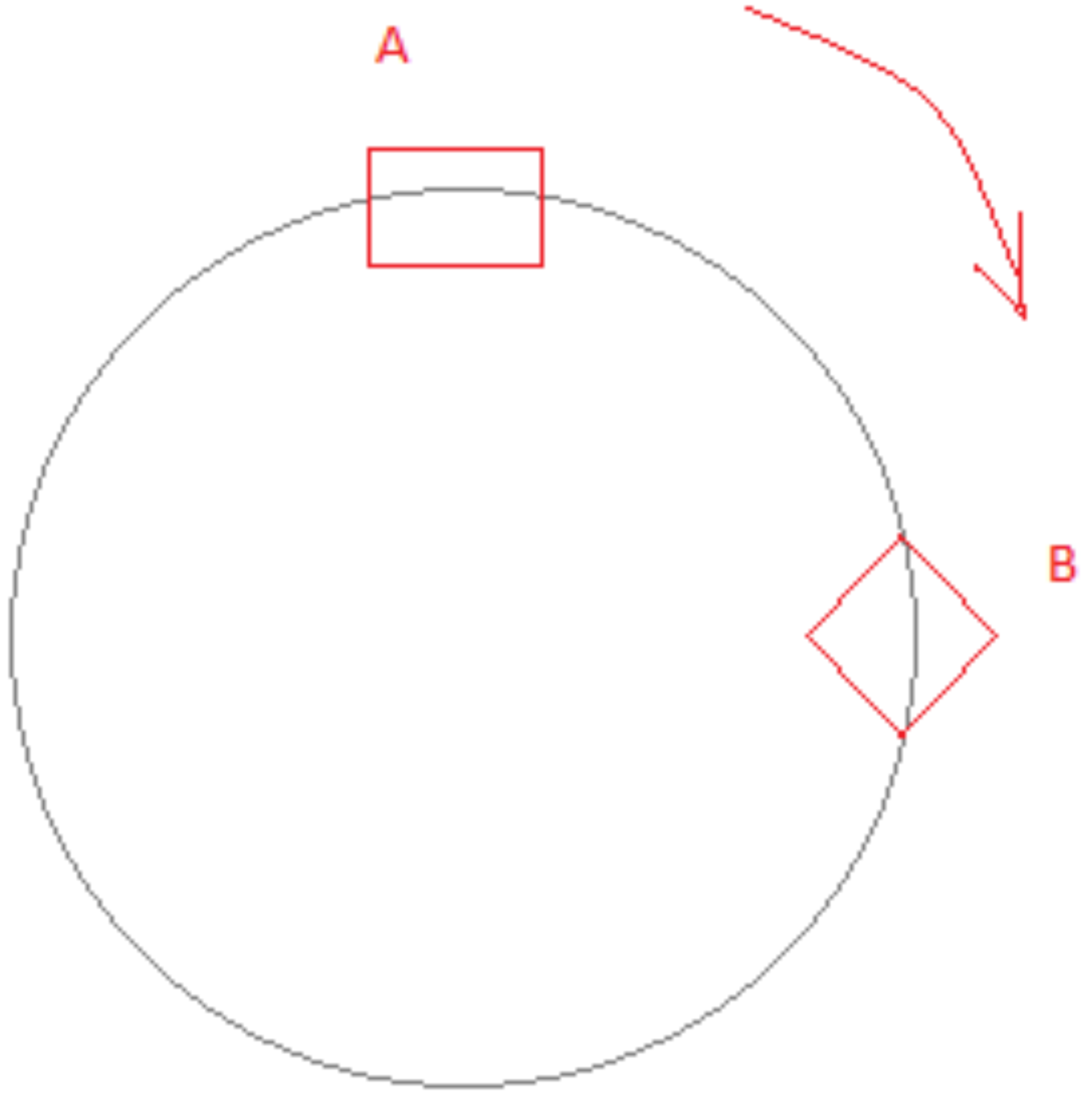
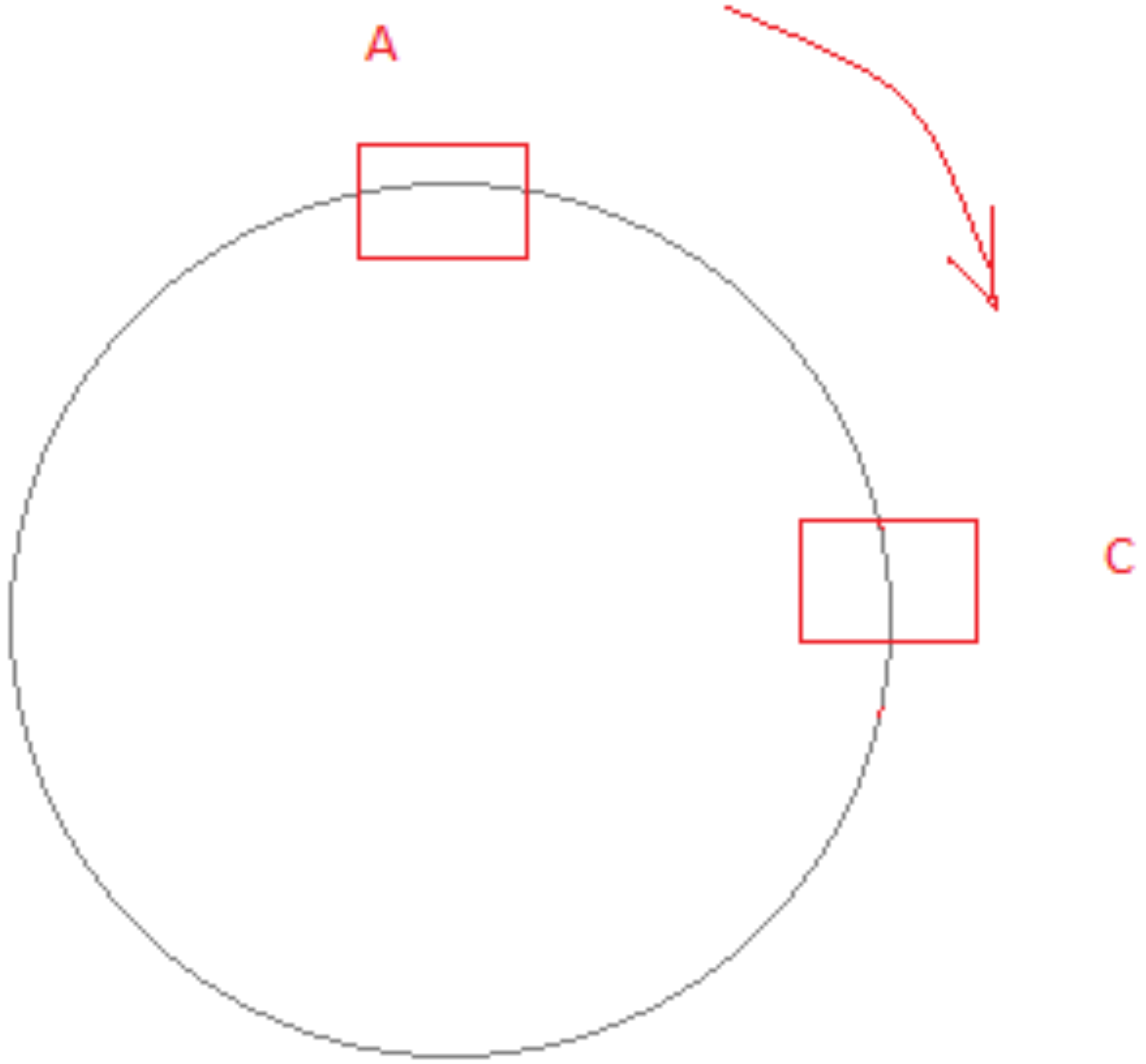
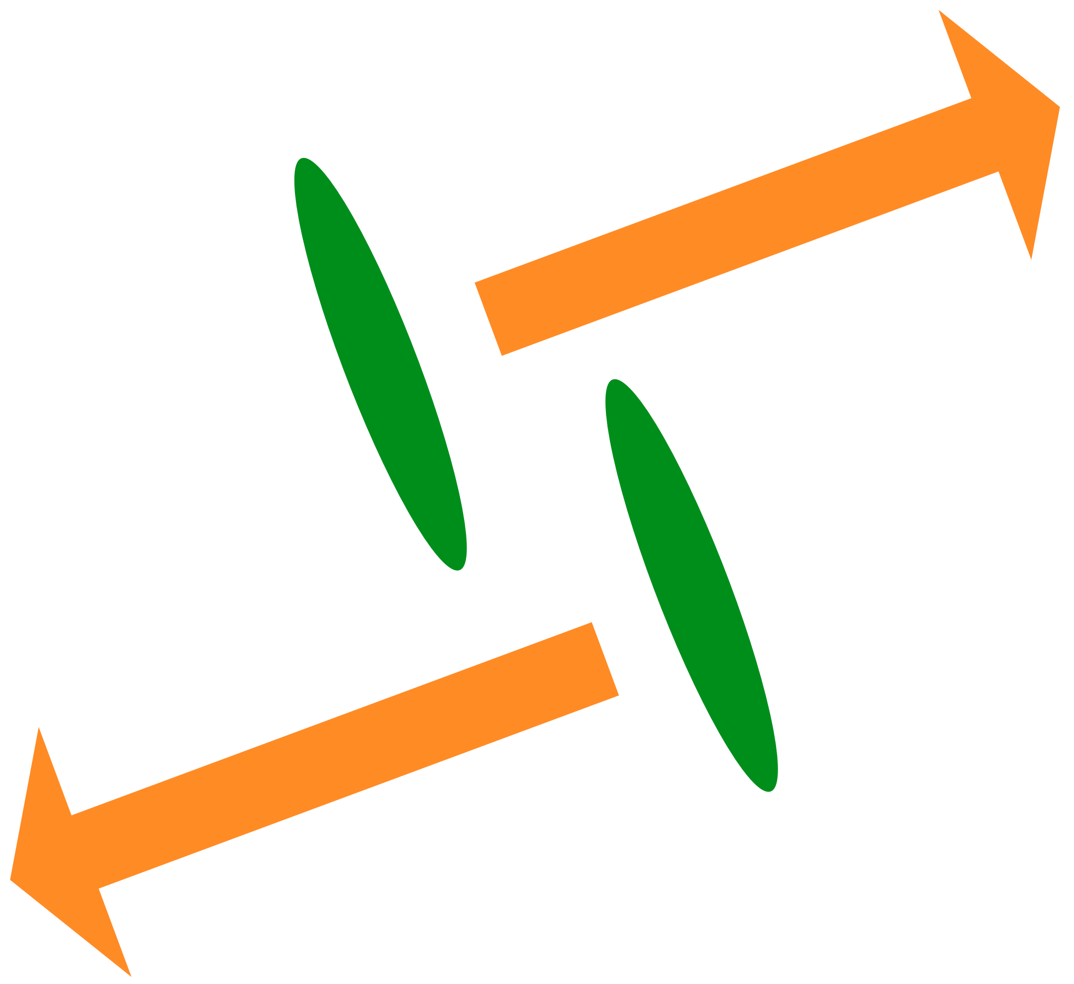




Spinning QGP



Large global angular momentum

$$J = \vec{r} \times \vec{p} \sim \frac{Ab\sqrt{s_{NN}}}{2} \sim 10^6 \hbar$$

how does this translate into vorticity?

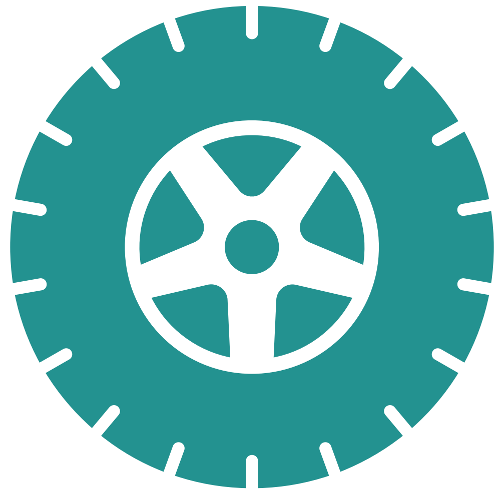
Spinning QGP

$$\omega = \frac{(\mathscr{P}_\Lambda + \mathscr{P}_{\overline{\Lambda}})}{\hbar} k_B T$$

$$\omega \simeq 9 \times 10^{21}\,\mathrm{s}^{-1} \simeq 6\,\mathrm{MeV} \simeq 0.03\,\mathrm{fm}^{-1}$$

"The most vortical fluid"

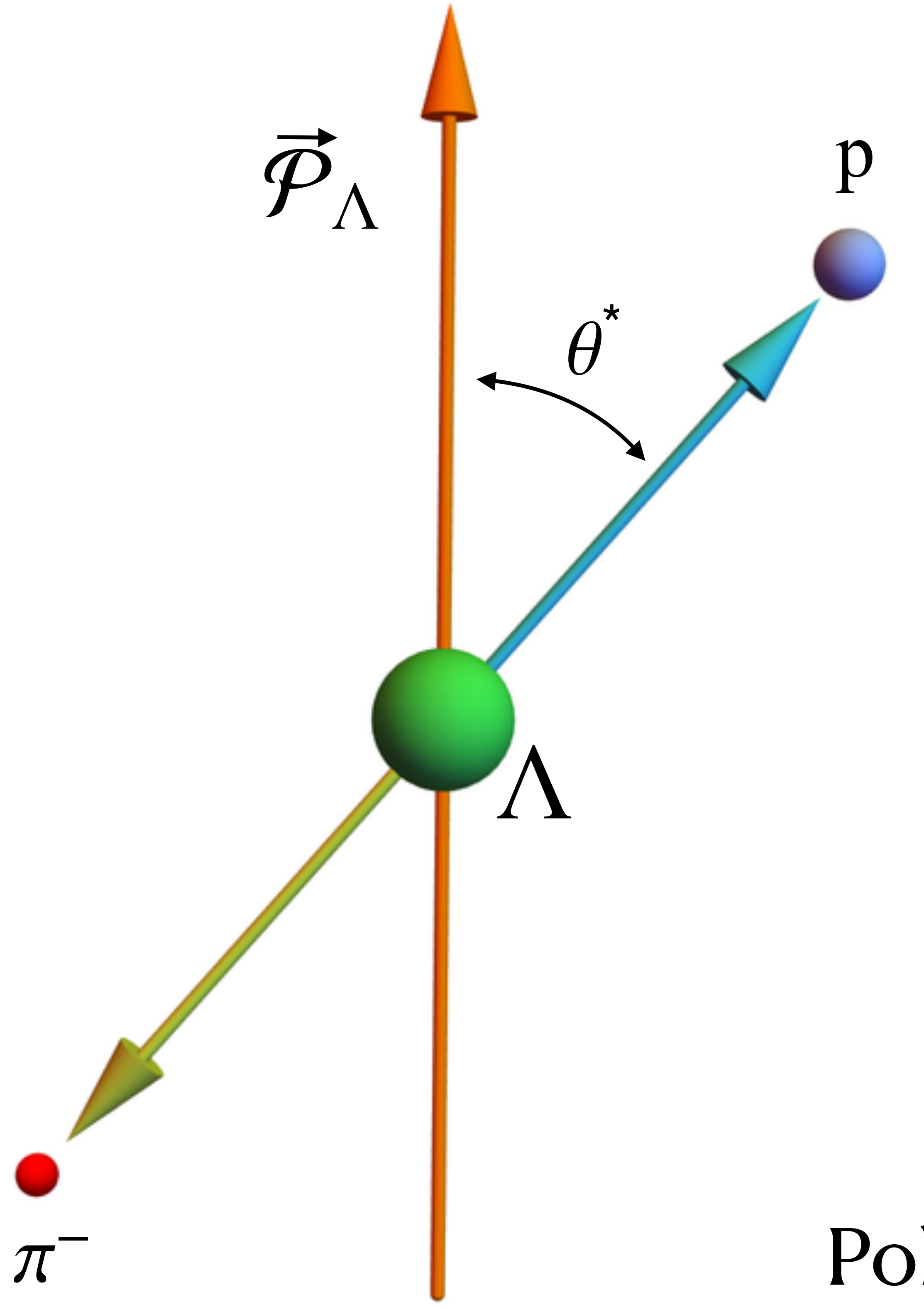
$\omega_{\mathrm{u}} \sim 10^{-17}\,\mathrm{s}^{-1}$



$\omega_{\mathrm{a}} \sim 10^{2}\,\mathrm{s}^{-1}$

$\omega_{\mathrm{QGP}} \sim 10^{22}\,\mathrm{s}^{-1}$

Λ hyperon polarization: probing the swirl



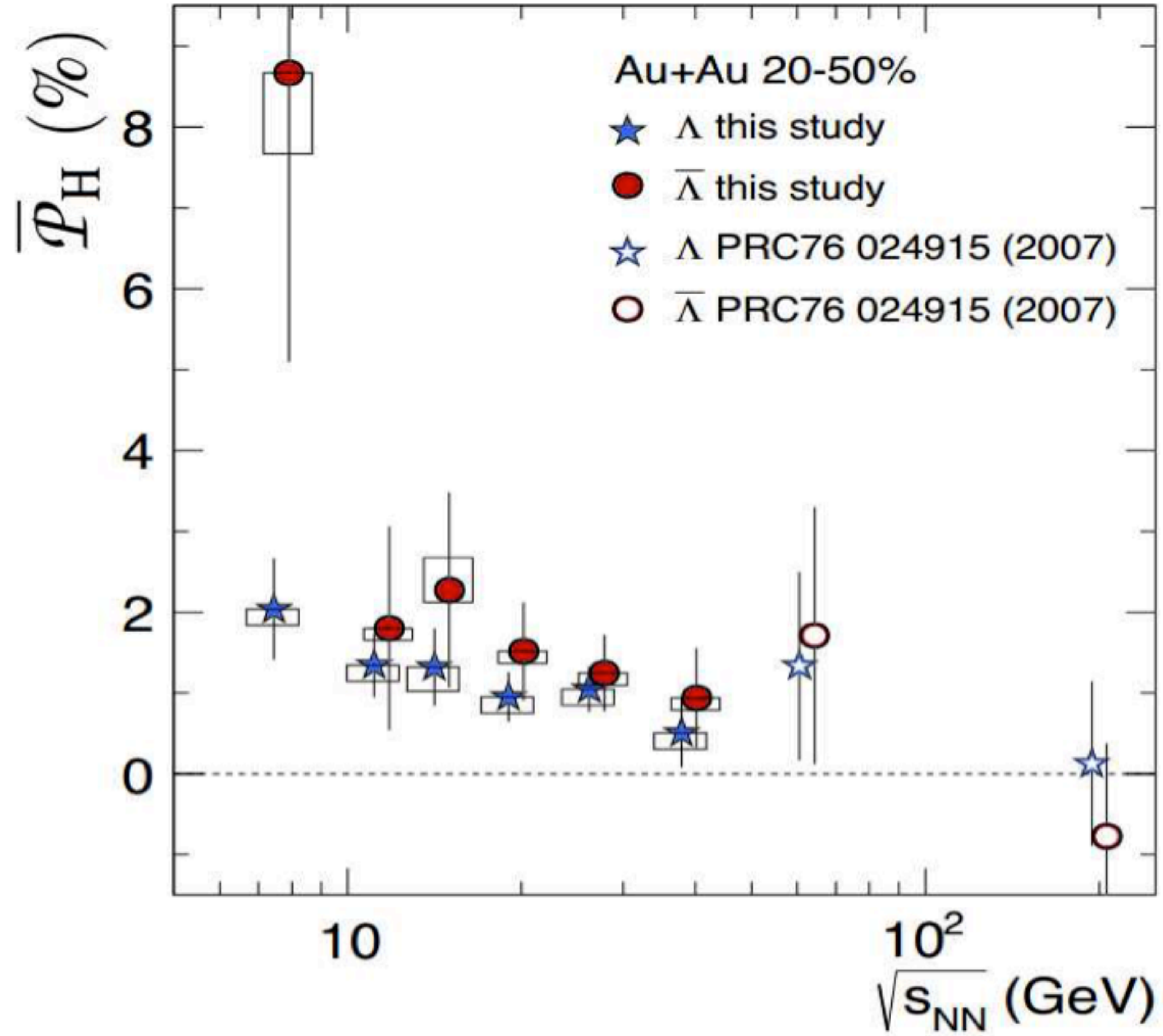
$$\frac{dN}{d\cos\theta^*} \propto 1 + \alpha_\Lambda \mathcal{P}_\Lambda \cos\theta^*$$

$$S^\mu = -\frac{1}{8m}e^{\mu\rho\sigma\tau}p_\tau \frac{\int d\Sigma_\lambda p^\lambda n_F(1-n_F)\overline{\omega}_{\rho\sigma}}{\int d\Sigma_\lambda p^\lambda n_F}$$

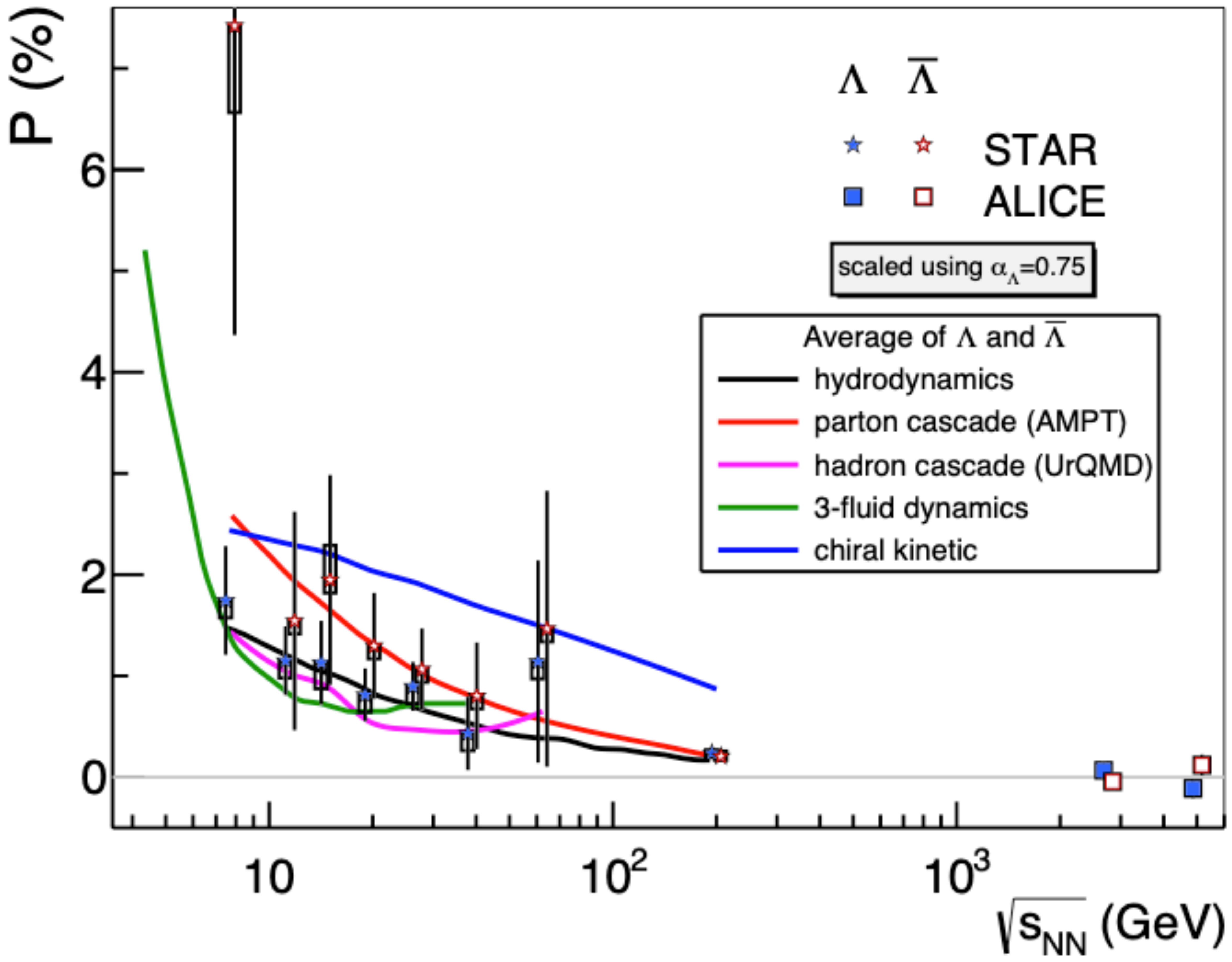
Becattini et al. 2013

Polarization in direction $\vec{n}$: $$\mathcal{P}_n \sim \vec{S} \cdot \vec{n}$$

Polarization measurements



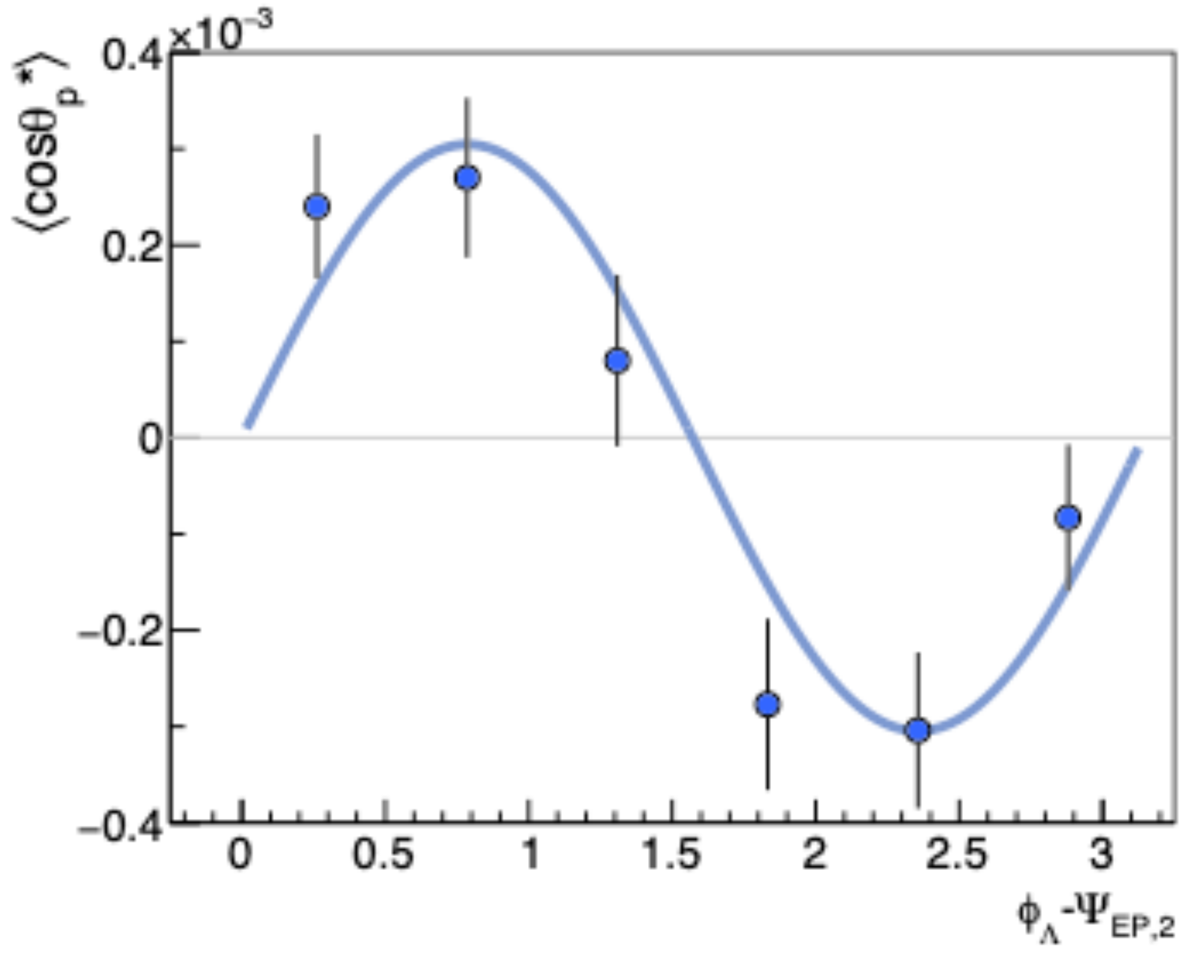
Experiment

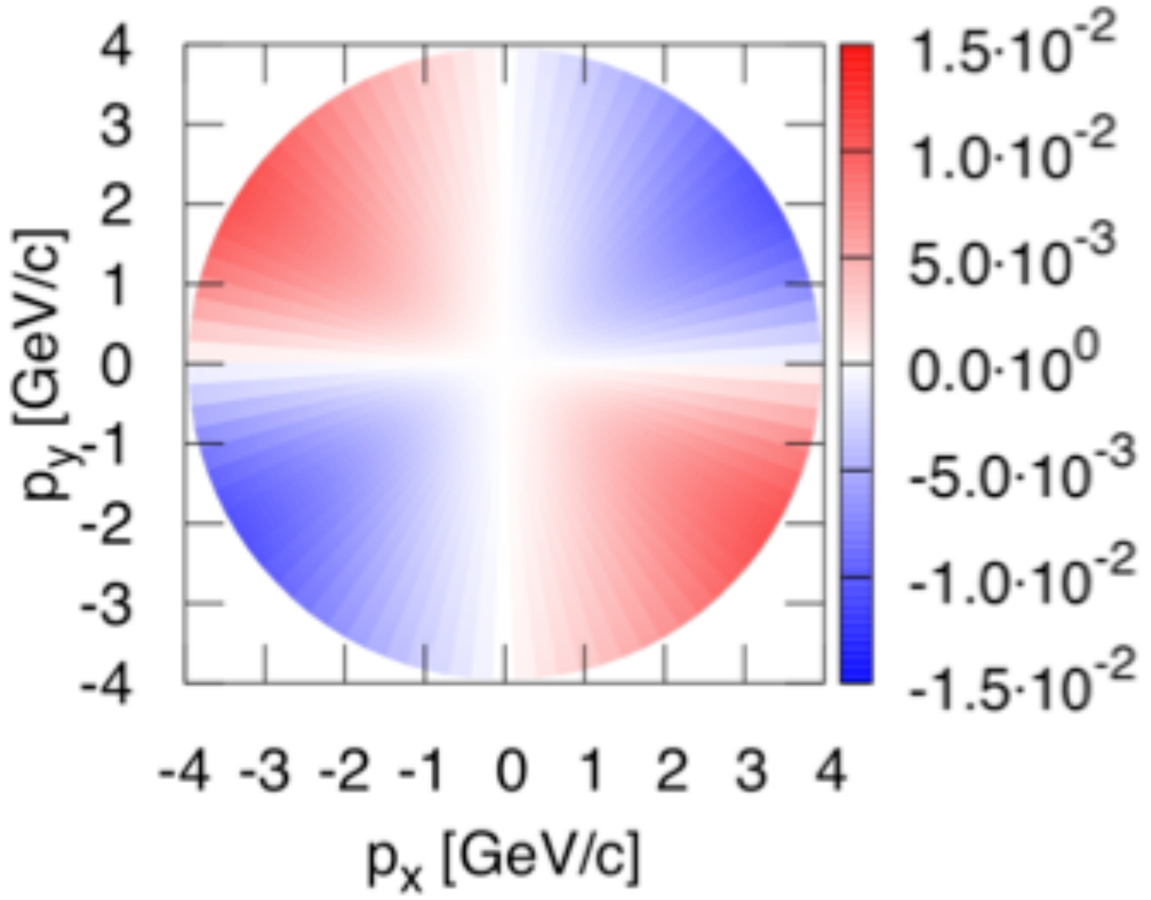


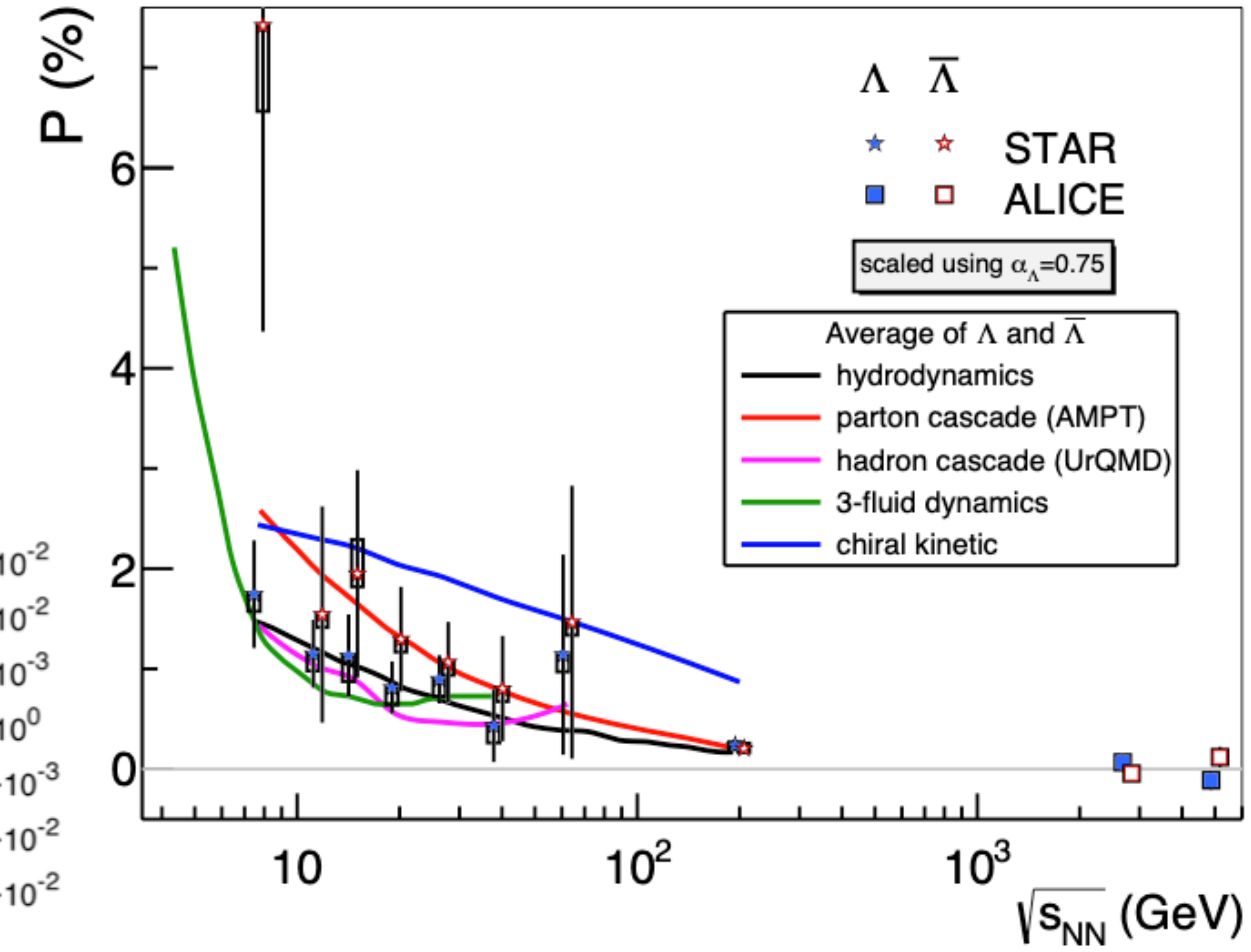
Theory

Polarization measurements

- Good agreement with exp.
- Disagreement for local polarization



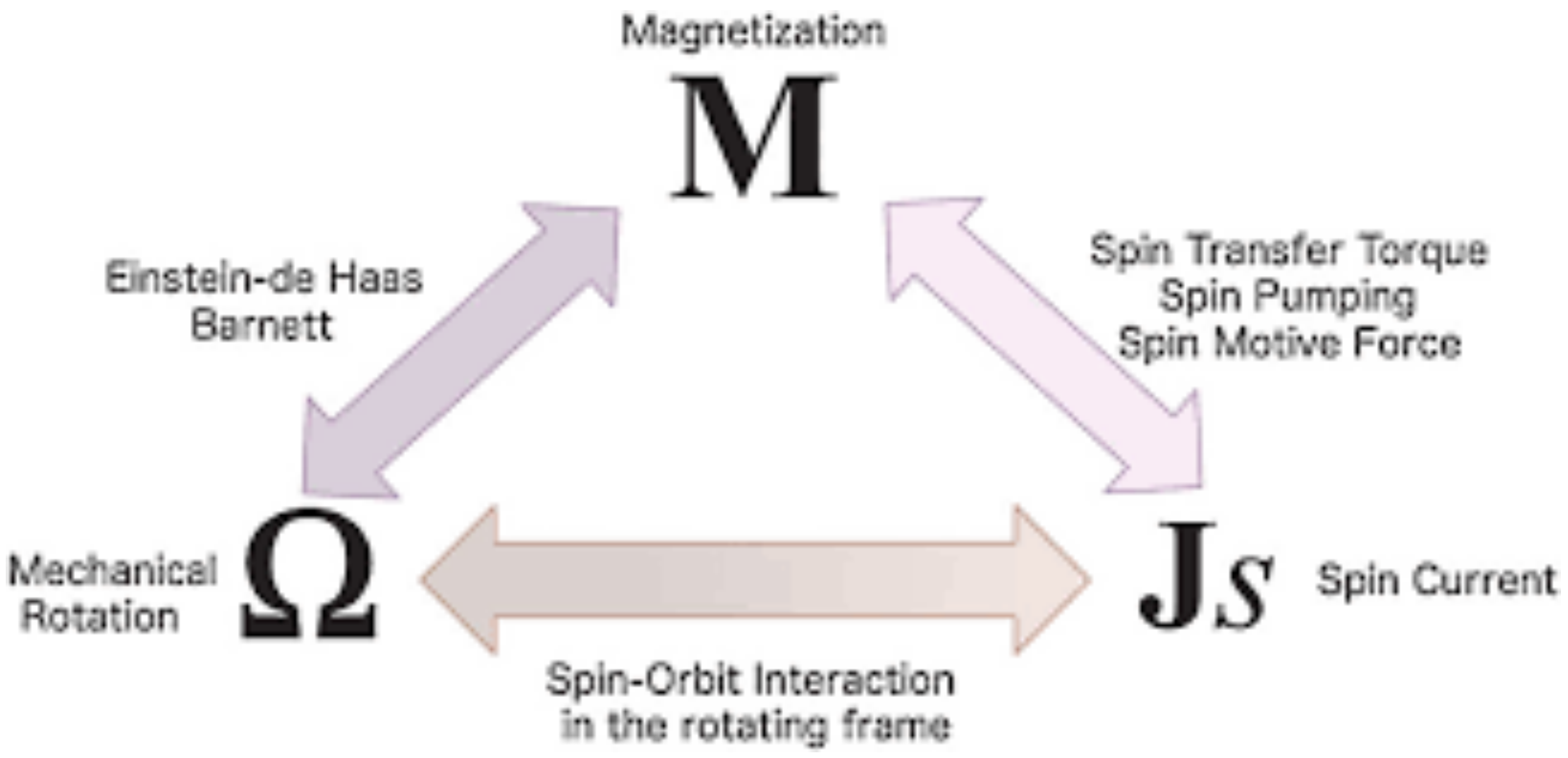


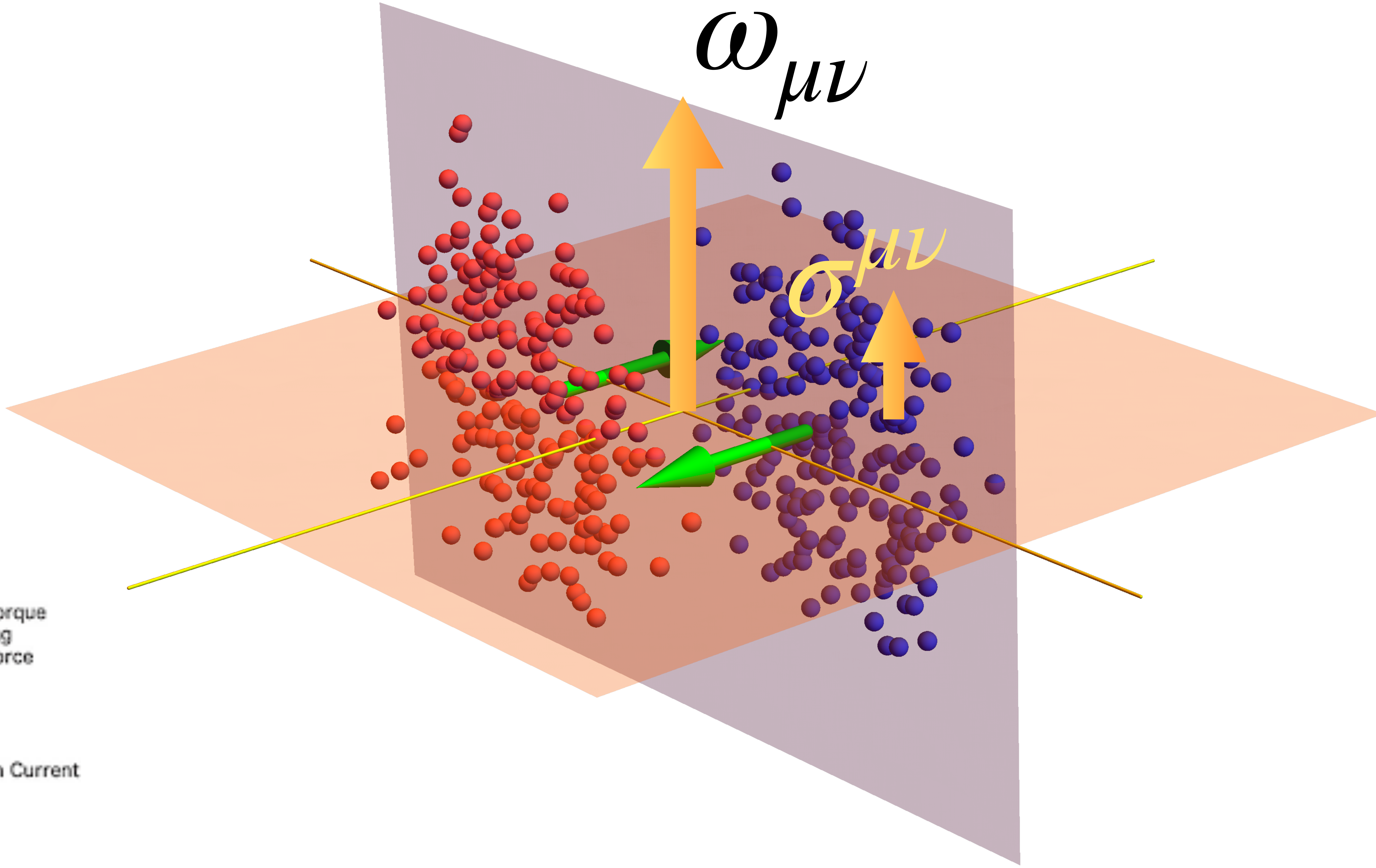


Theory

What if there is a spin-vorticity interaction?

- Interaction can induce spin alignment
- Alignment ceases at the relaxation time



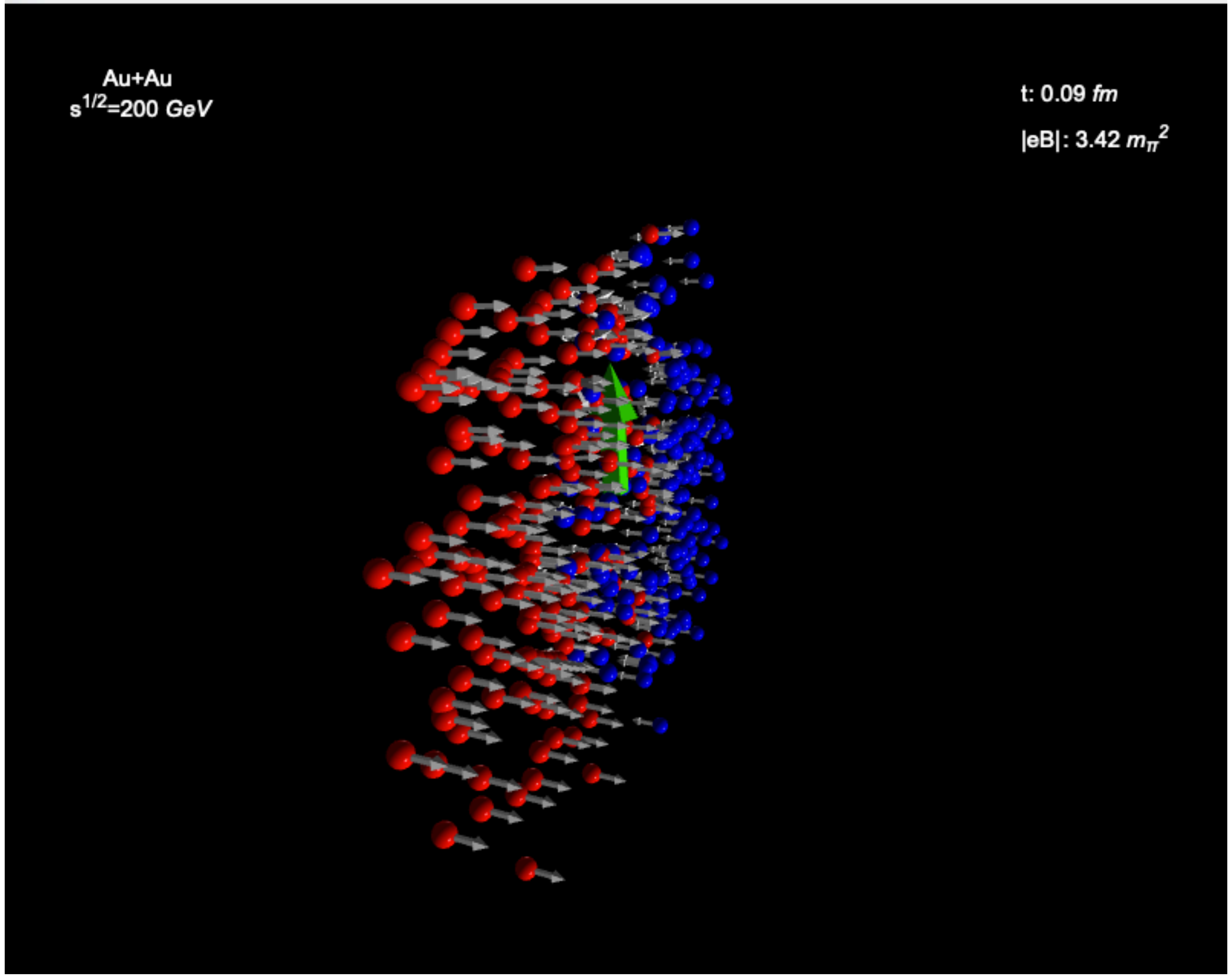


Why is this relevant?

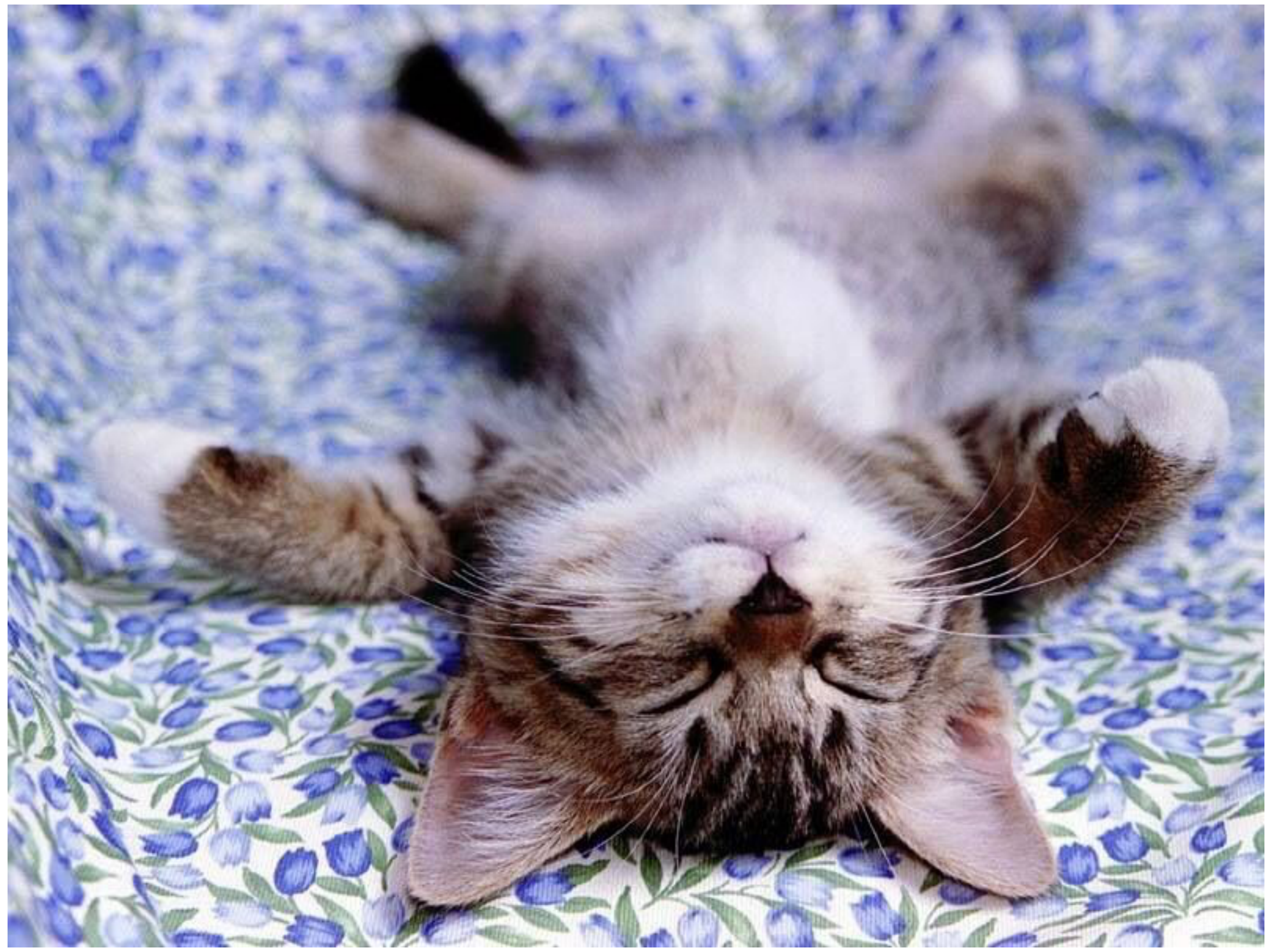
Vorticity from simulations

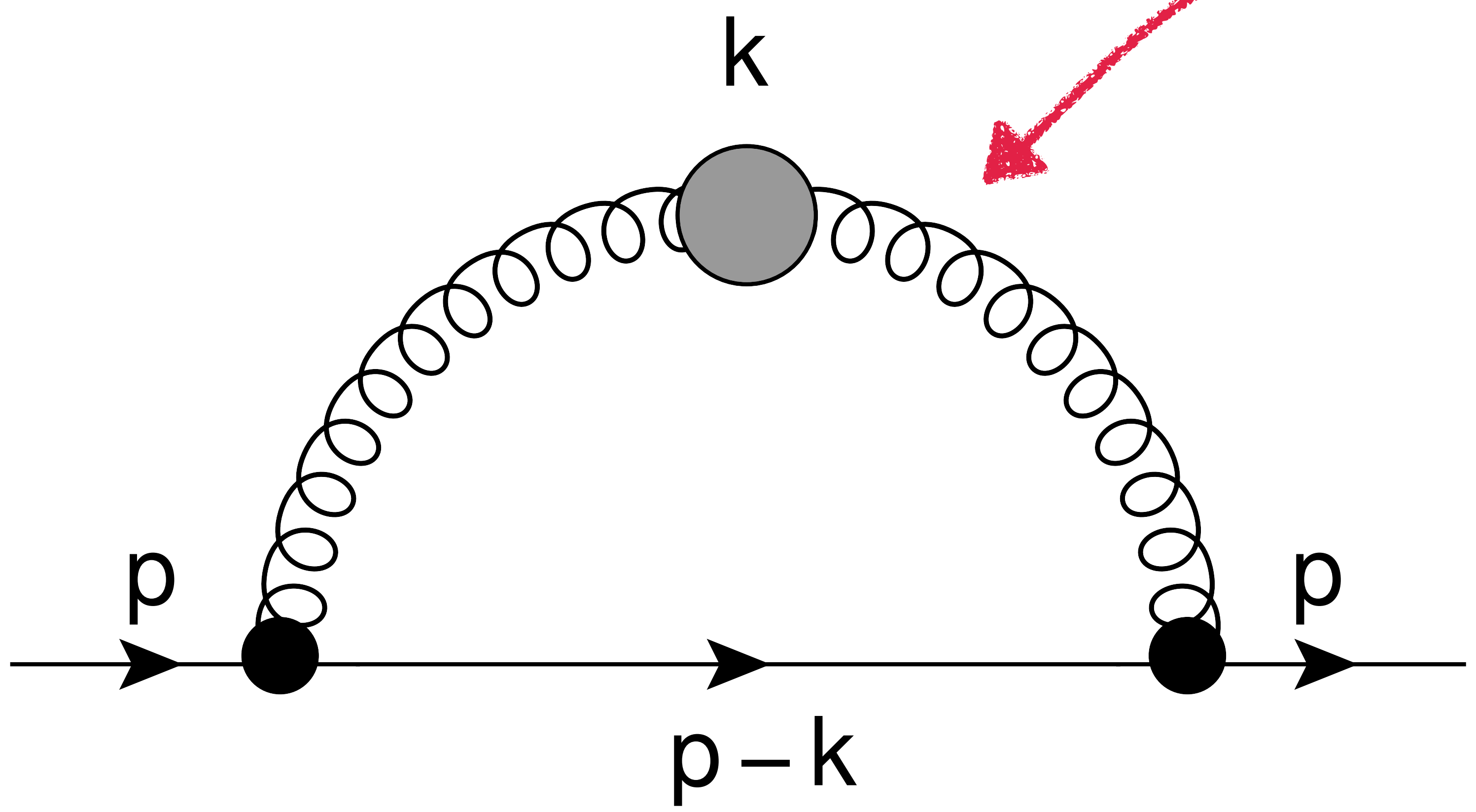
- UrQMD to track particle's momentum & energy
- Obtain velocity
- Take curl

$$\omega = \nabla \times \overrightarrow{v}$$



Calculation of the relaxation time





self-energy

$$\Gamma = \tilde{f}(p_0)\mathrm{Tr}\left[\gamma^0 \mathrm{Im}\Sigma\right]$$

$$\tau = \frac{1}{\Gamma}$$

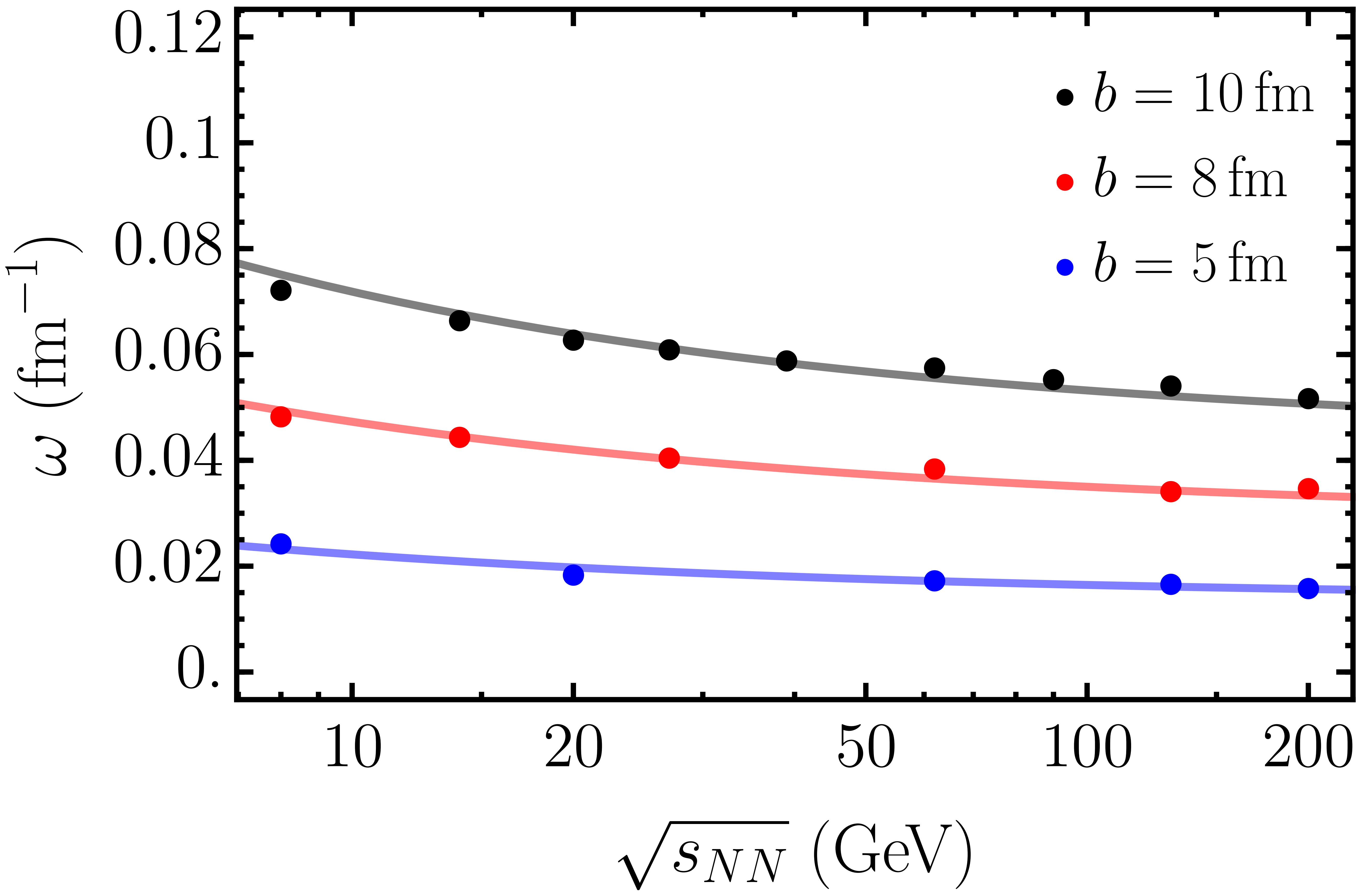
Calculation of the relaxation time

$$\Gamma \propto \left(\frac{\omega}{T}\right)^2$$

How to obtain ω?

→ UrQMD/AMPT/etc.

$$\omega = \frac{\omega_0}{2}\frac{b^2}{V}\left[1 + 2\left(\frac{m_N}{\sqrt{s_{NN}}}\right)^{1/2}\right]$$

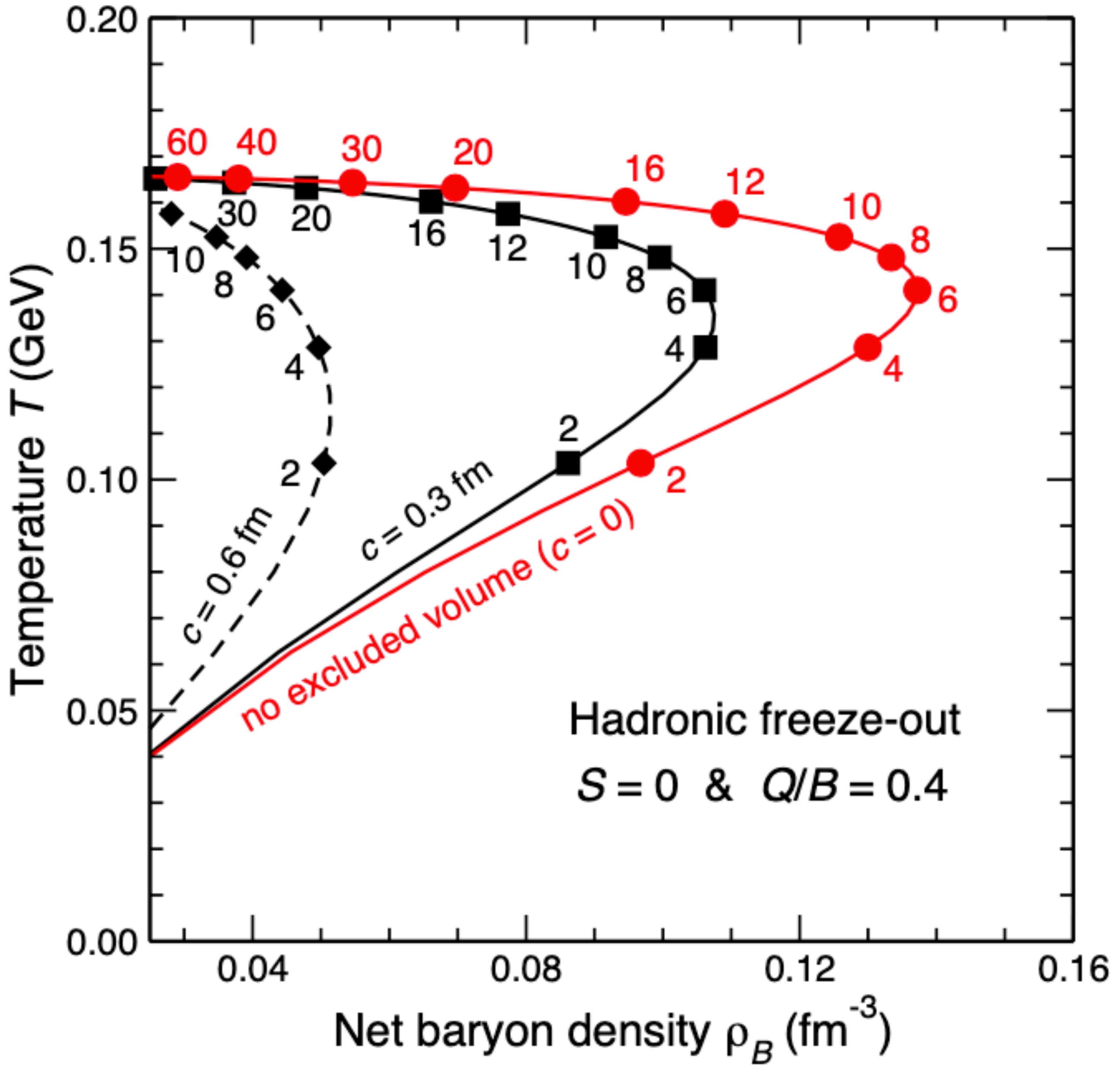


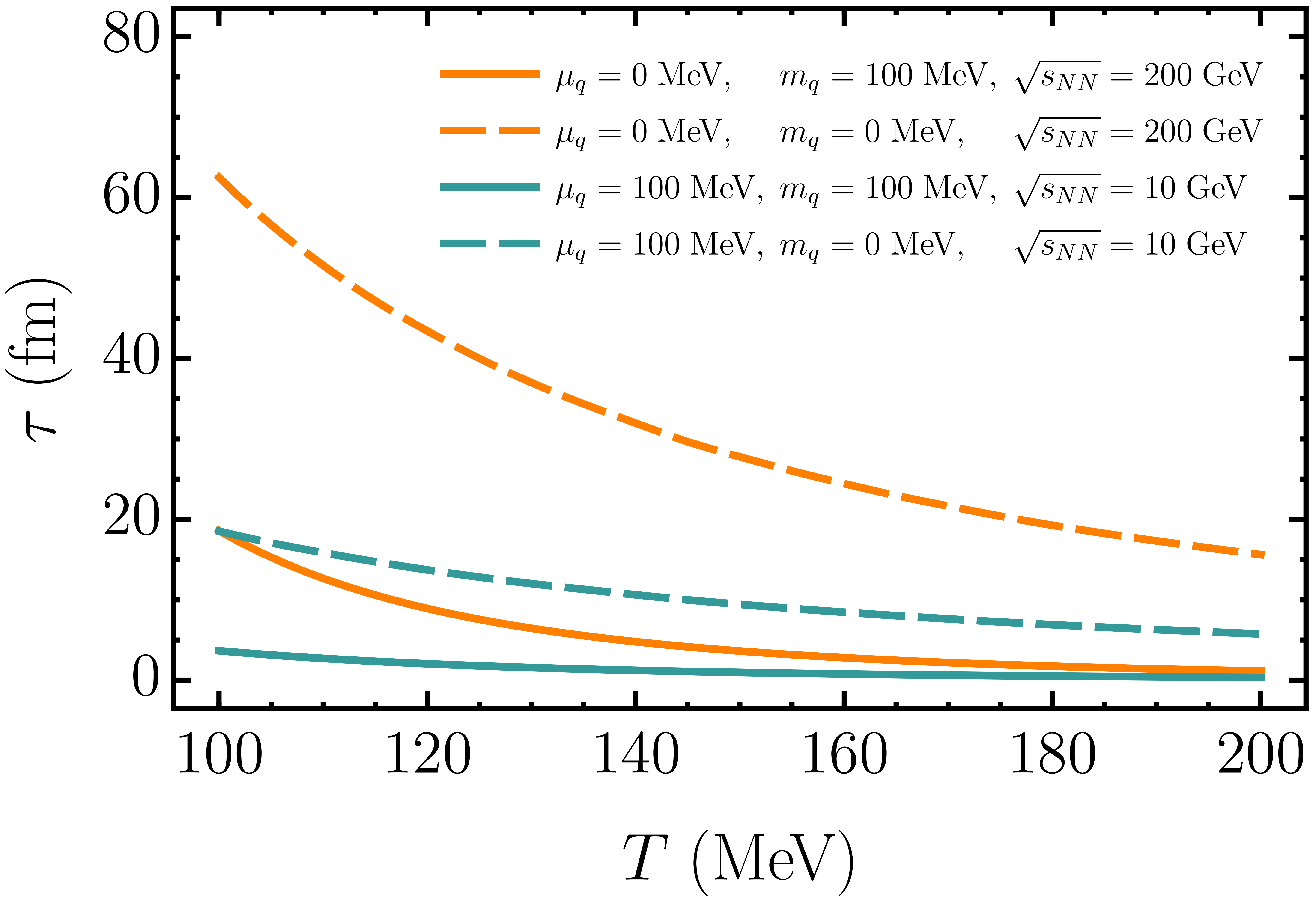
Calculation of the relaxation time

$\mu_{\text{LHC}} \sim 2\,\text{MeV}$

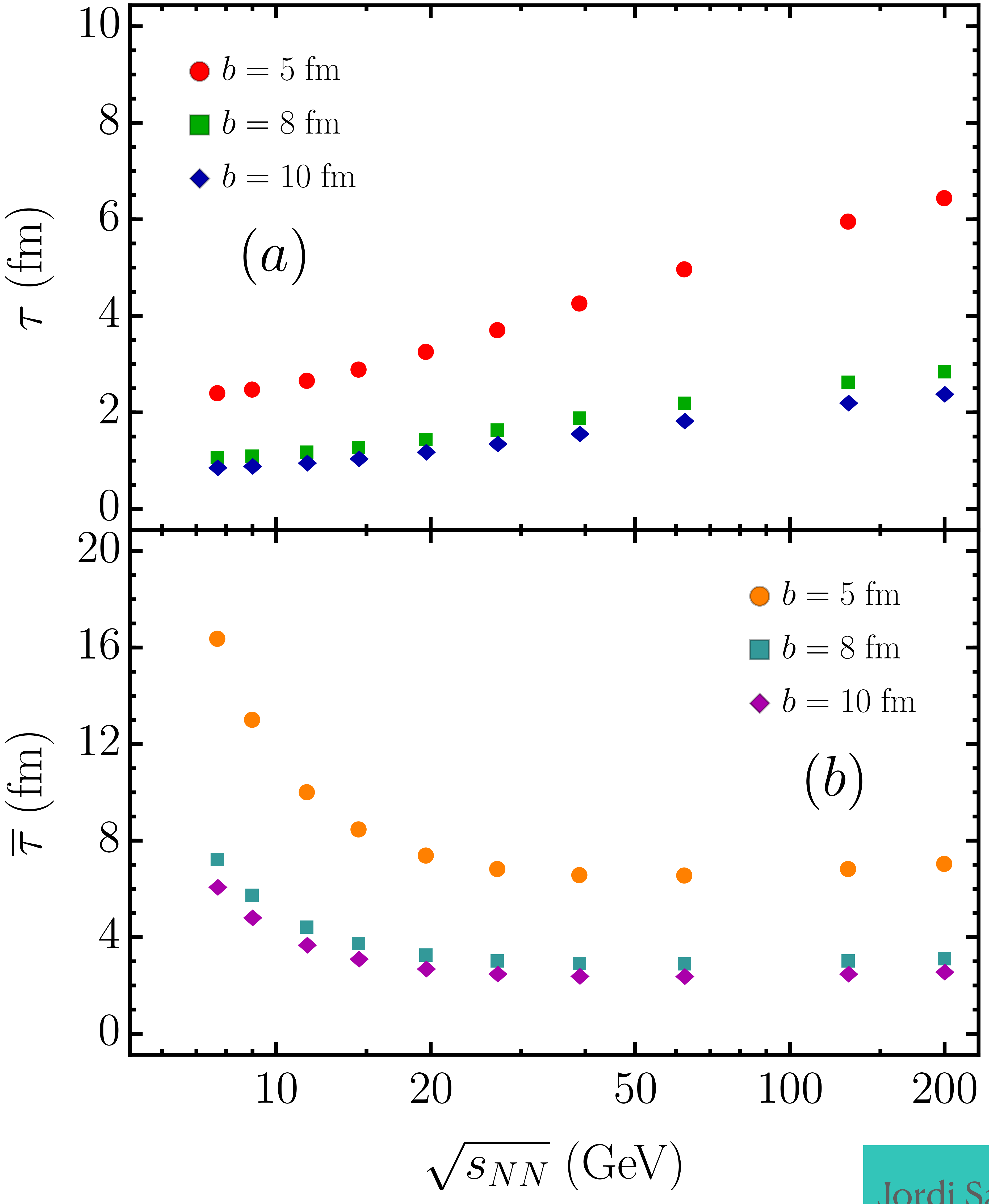
$\mu_{\text{RHIC}} \sim 20\,\text{MeV}$

$\mu_{\text{NICA}} \sim 200\,\text{MeV}$





Relaxation time for realistic HICs



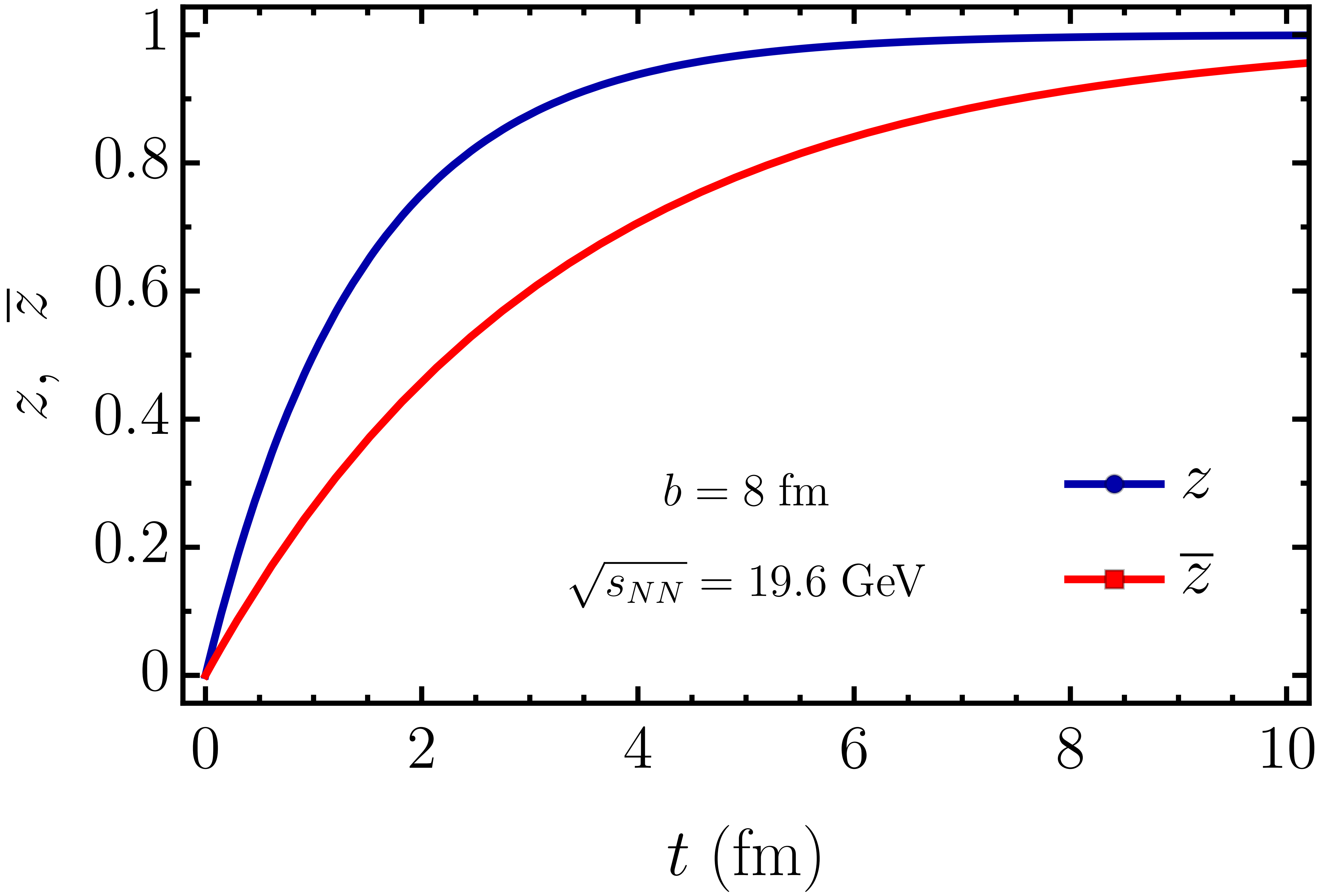
$$\tau \propto \frac{1}{\omega^2} \propto \frac{1}{b^4}$$

- Strong dependence on b
- Larger relaxation times for $\bar{s}$
- Different behavior for s and $\bar{s}$

Intrinsic global polarization

$$z = 1 - e^{-t/\tau}$$

$$\bar{z} = 1 - e^{-t/\bar{\tau}}$$



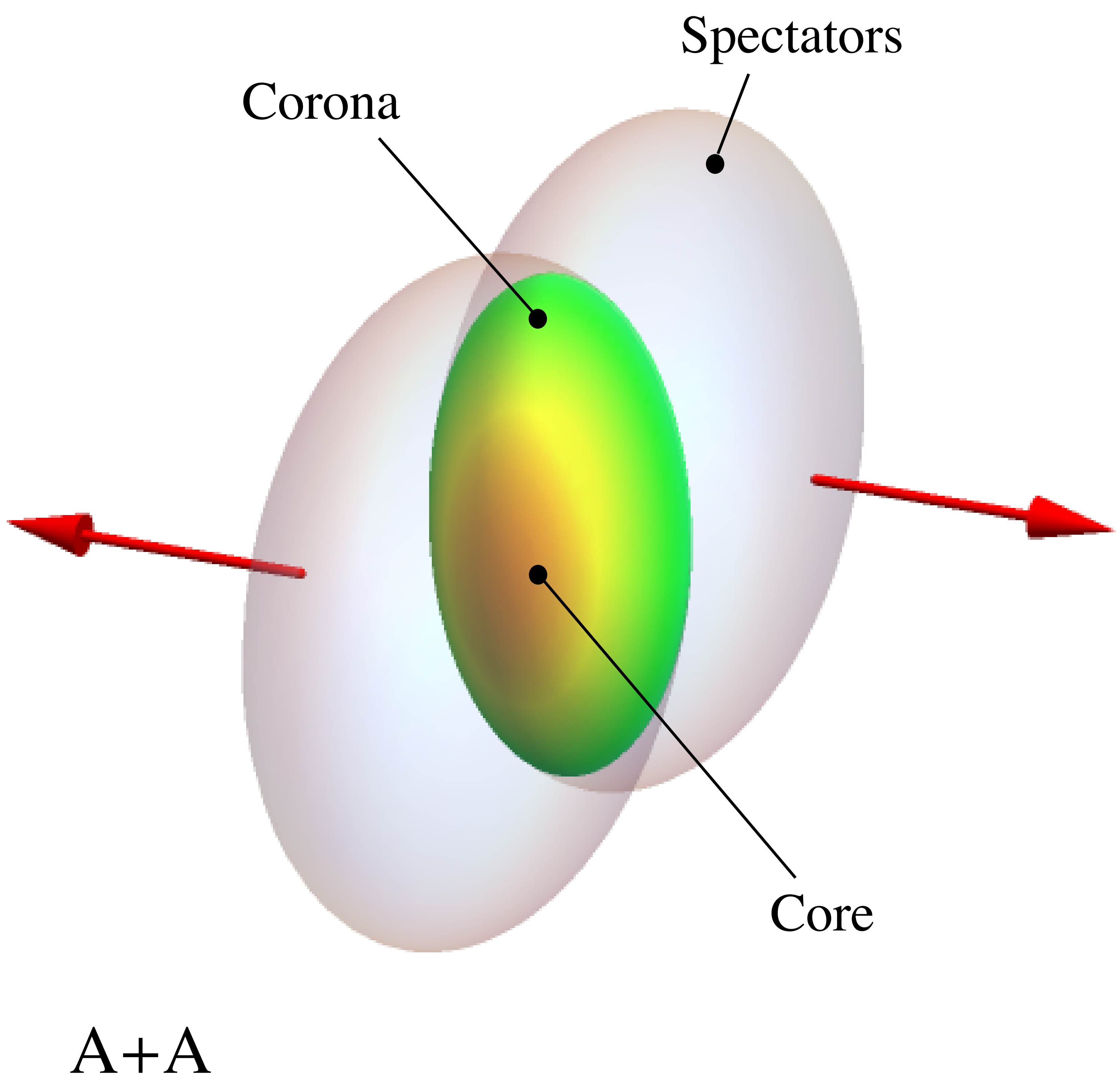
Λs should polarize more than $\bar{\Lambda}$!

Λ polarization from a two-component source

$$N_\Lambda = \underbrace{N_{\Lambda\,\mathrm{QGP}}}_{\text{Core}} + \underbrace{N_{\Lambda\,\mathrm{REC}}}_{\text{Corona}}$$

It is reasonable to think that Λs will be generated in different amounts in each region!

$$\mathscr{P}^\Lambda = \frac{\left(N^\uparrow_{\Lambda\,\mathrm{QGP}} + N^\uparrow_{\Lambda\,\mathrm{REC}}\right) - \left(N^\downarrow_{\Lambda\,\mathrm{QGP}} + N^\downarrow_{\Lambda\,\mathrm{REC}}\right)}{\left(N^\uparrow_{\Lambda\,\mathrm{QGP}} + N^\downarrow_{\Lambda\,\mathrm{REC}}\right) + \left(N^\uparrow_{\Lambda\,\mathrm{QGP}} + N^\downarrow_{\Lambda\,\mathrm{REC}}\right)}$$



Λ polarization from a two-component source

This can be rewritten as

$$\mathscr{P}^{\Lambda} = \frac{z\dfrac{N_{\Lambda}\text{QGP}}{N_{\Lambda}\text{REC}}}{\left(1 + \dfrac{N_{\Lambda}\text{QGP}}{N_{\Lambda}\text{REC}}\right)} \qquad \mathscr{P}^{\bar{\Lambda}} = \frac{\bar{z}\dfrac{N_{\Lambda}\text{QGP}}{N_{\bar{\Lambda}}\text{REC}}}{\left(1 + \dfrac{N_{\Lambda}\text{QGP}}{N_{\bar{\Lambda}}\text{REC}}\right)}$$

Some simplifications...

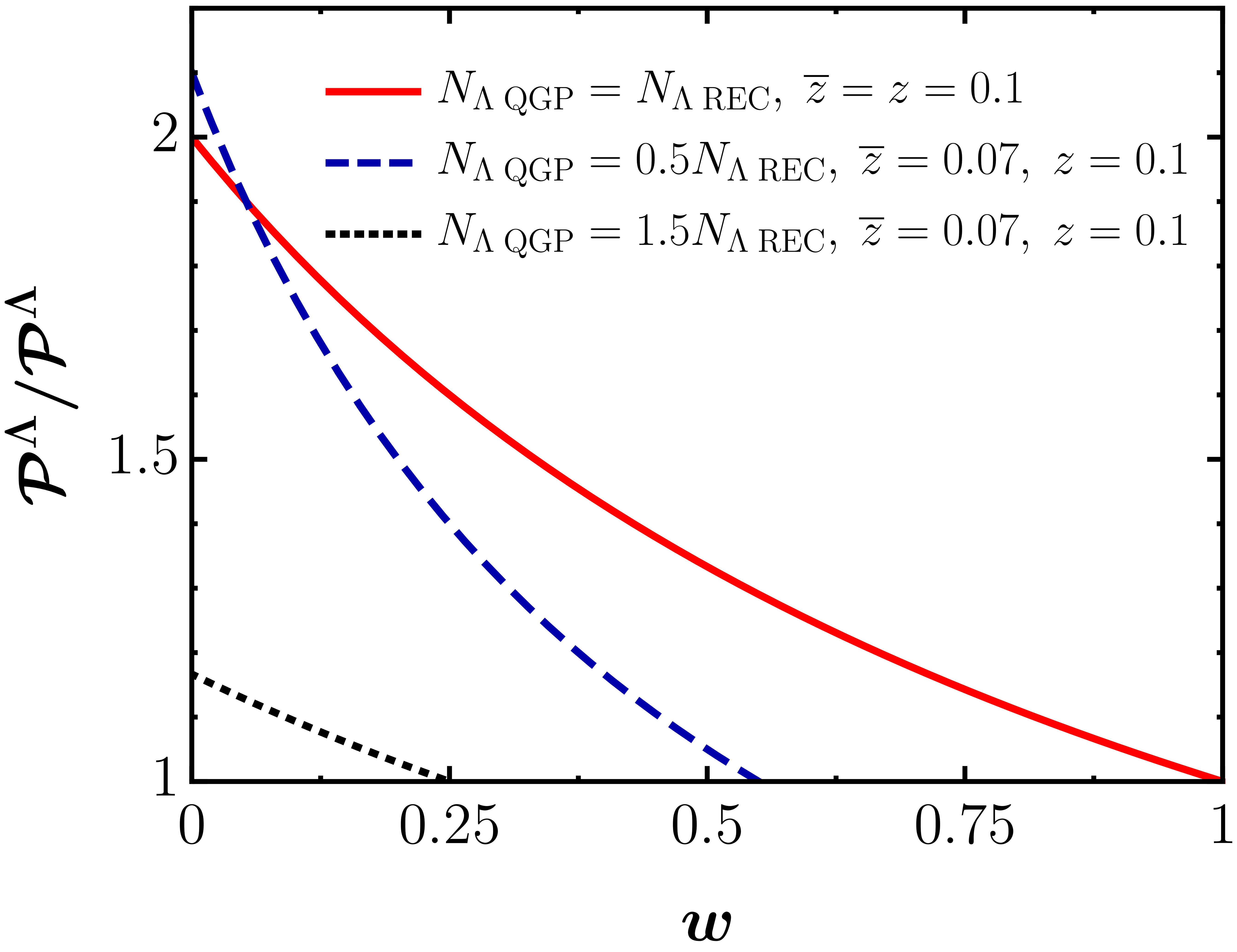
$$N_{\bar{\Lambda}}\text{QGP} \simeq N_{\Lambda}\text{QGP} \qquad N_{\bar{\Lambda}}\text{REC} = w\, N_{\Lambda}\text{REC}$$

suppression factor

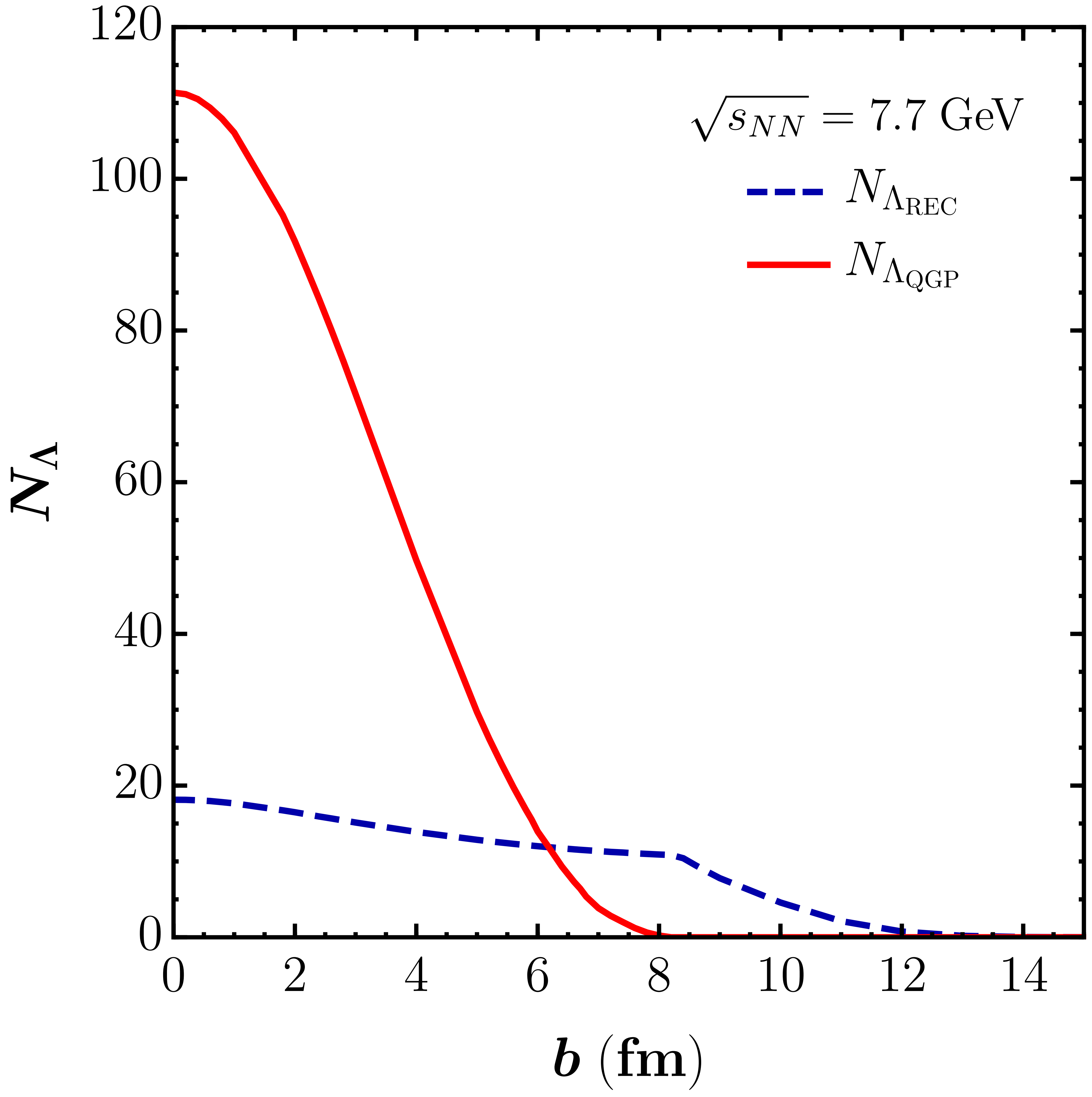
Λ polarization from a two-component source

$$\mathscr{P}^{\Lambda} = \frac{z\frac{N_{\Lambda}\text{QGP}}{N_{\Lambda}\text{REC}}}{\left(1+\frac{N_{\Lambda}\text{QGP}}{N_{\Lambda}\text{REC}}\right)}$$

$$\mathscr{P}^{\overline{\Lambda}} = \frac{\frac{z}{w}\frac{N_{\Lambda}\text{QGP}}{N_{\Lambda}\text{REC}}}{\left(1+\frac{1}{w}\frac{N_{\Lambda}\text{QGP}}{N_{\Lambda}\text{REC}}\right)}$$



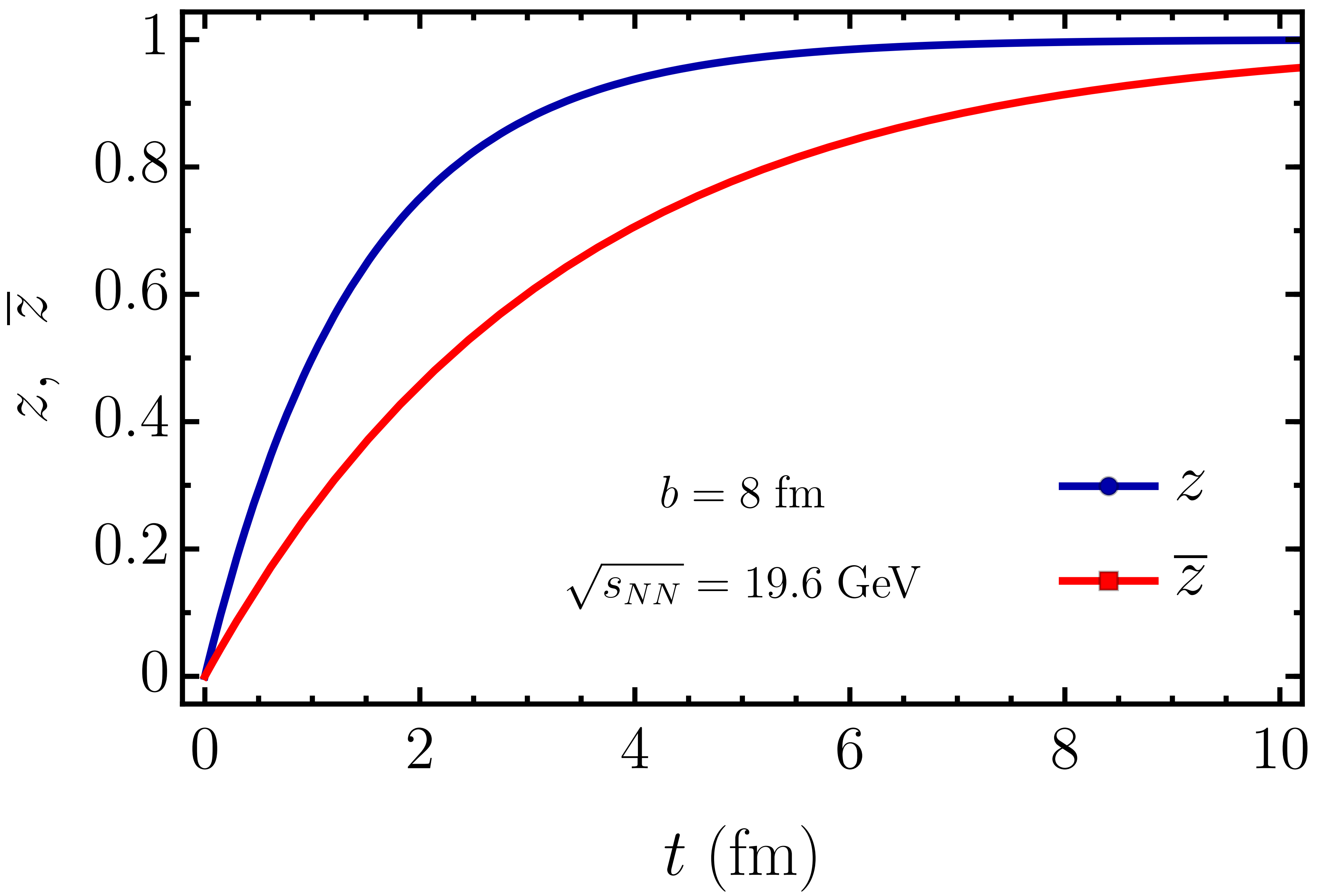
Λ polarization from a two-component source

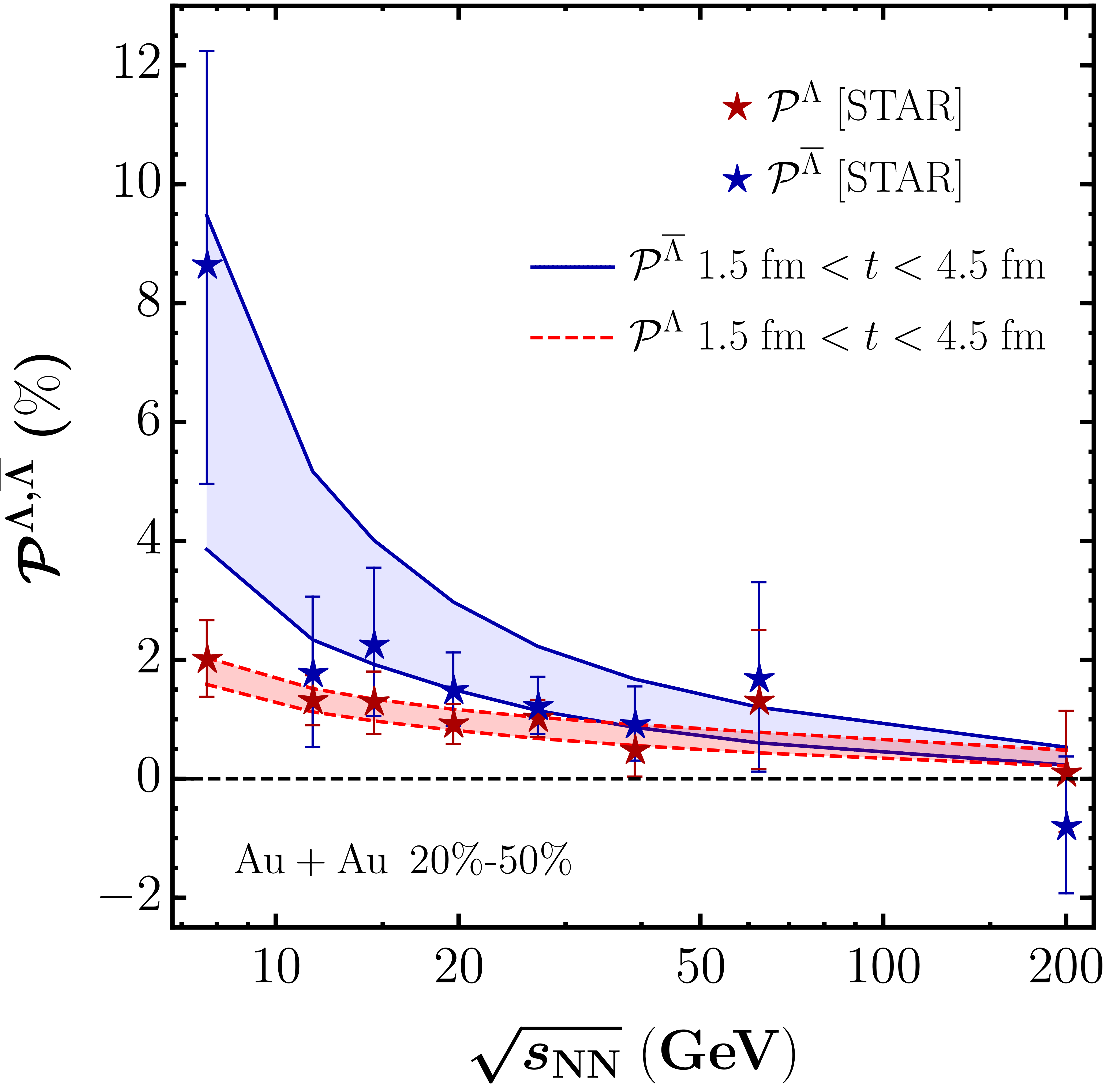


- Swapping of dominant region
- Semi-central collisions

Λ polarization from a two-component source

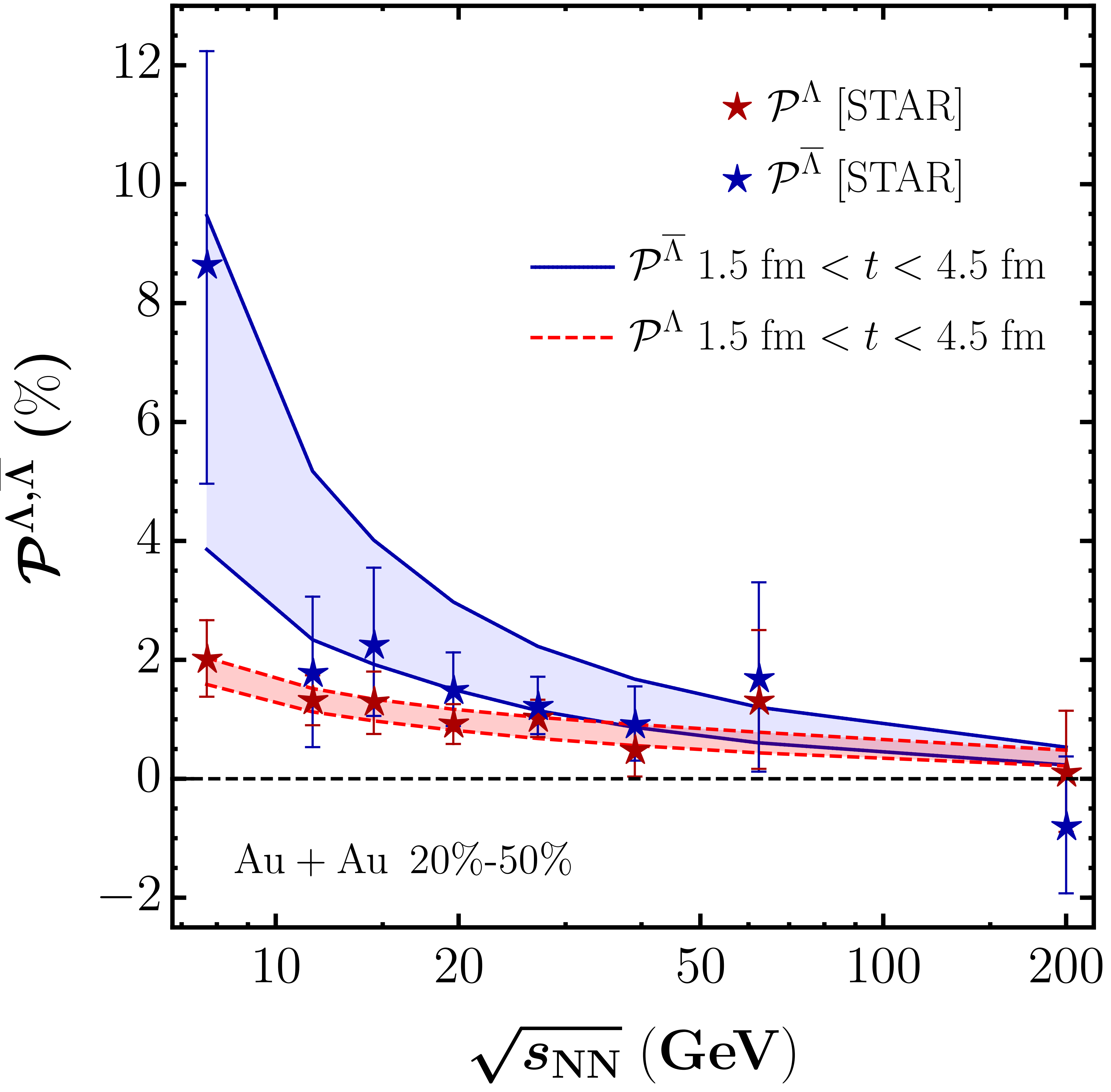
- More polarization of $\overline{\Lambda}$s than Λs!
- Data well described for QGP formation times between 1.5 and 4.5 fm





Summary

- Vorticity generated in HIC's
- Polarization measurements to probe vorticity
- Spin alignment is quite important!
- Good agreement



Questions?