Λ global polarization in relativistic heavy-ion collisions: News from the Core–Corona model

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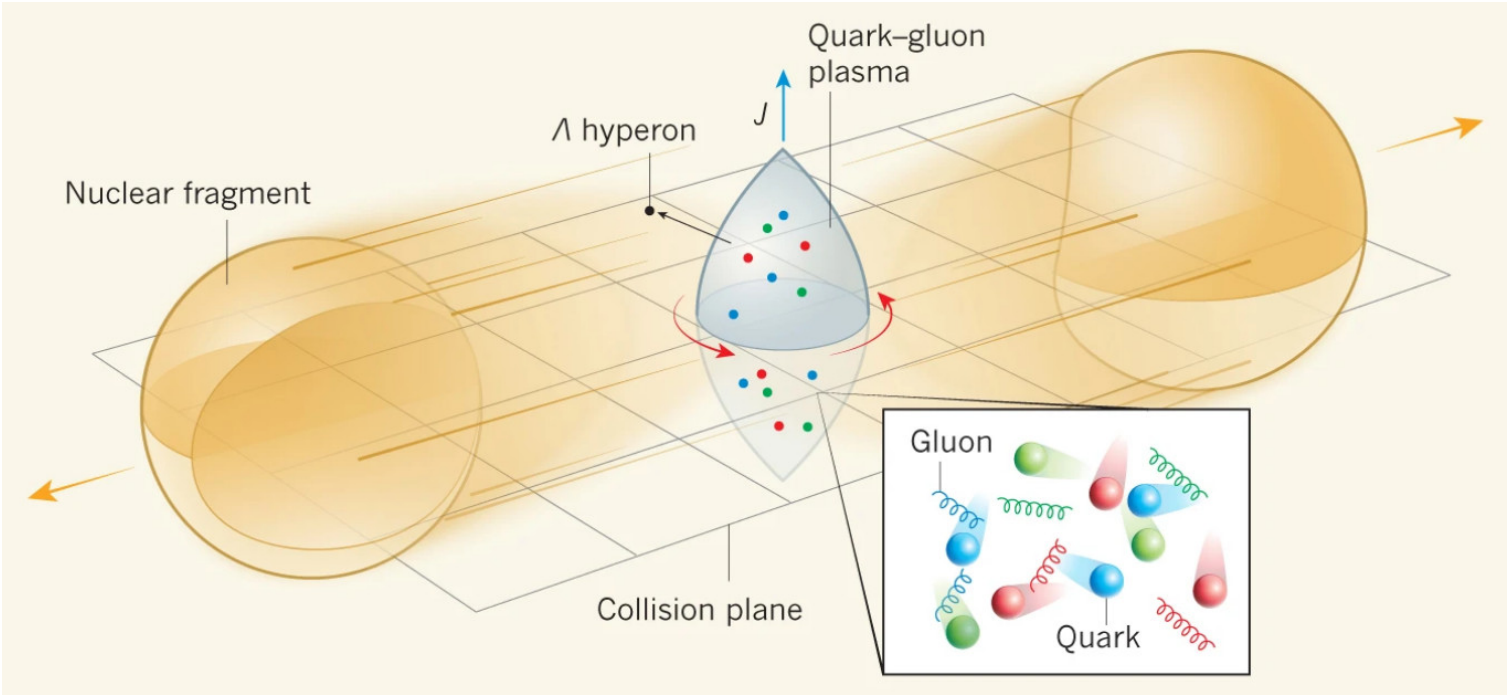
Overview

1. Introduction: Λ and $\overline{\Lambda}$ polarization in heavy-ion collisions
2. Summary of recent results
3. Core-Corona description of Λ polarization
4. Field-theoretical description of intrinsic polarizations
5. Glauber model for Λ production
6. Results for the global Λ polarization
7. Conclusions

Hot, dense, swirling QCD matter in HICs

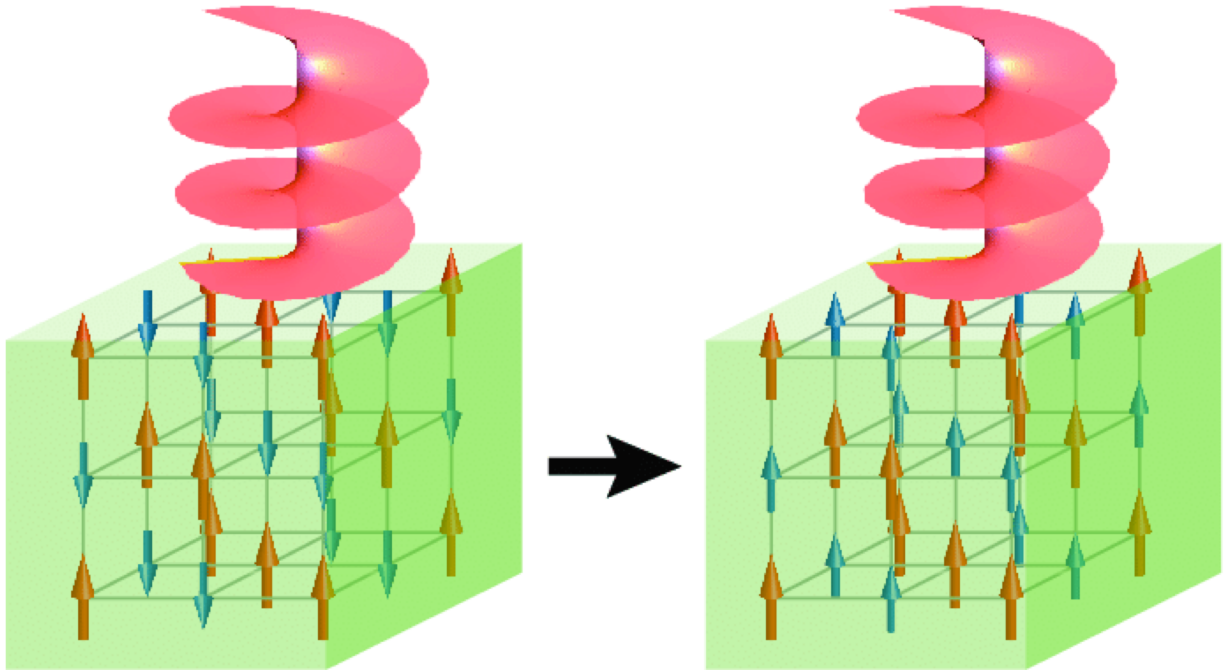


Non-central collisions have large angular momentum $L \sim 10^5 \hbar$.
Shear forces in initial condition introduce vorticity to the QGP.

Spin-orbit coupling: spin alignment, or polarization, along the direction of the vorticity - on average - parallel to J.

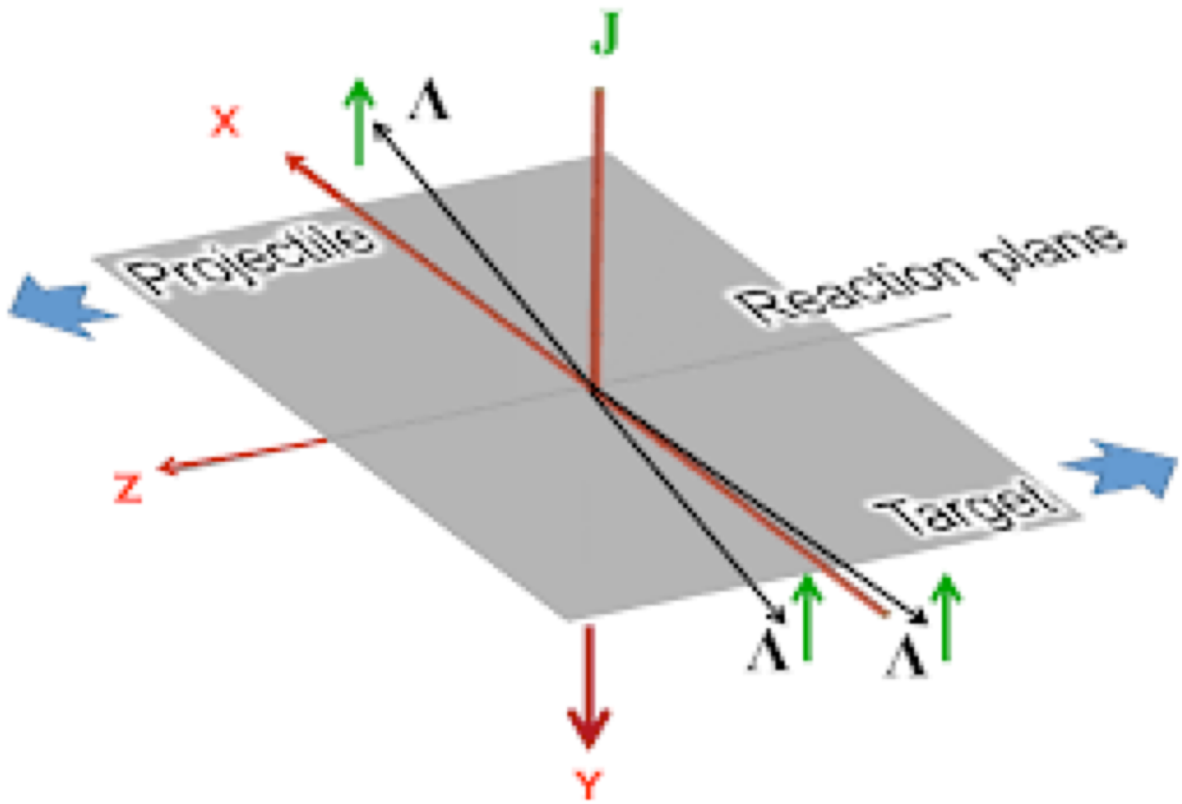
Barnett effect

- A spinning ferromagnet experiences a change in its magnetization



Global Λ polarization

- Λ's are produced globally polarized in a heavy-ion reaction



Summary of recent results

1. STAR isobar result
2. Consolidated BES-II picture for Λ and $\overline{\Lambda}$ excitation function

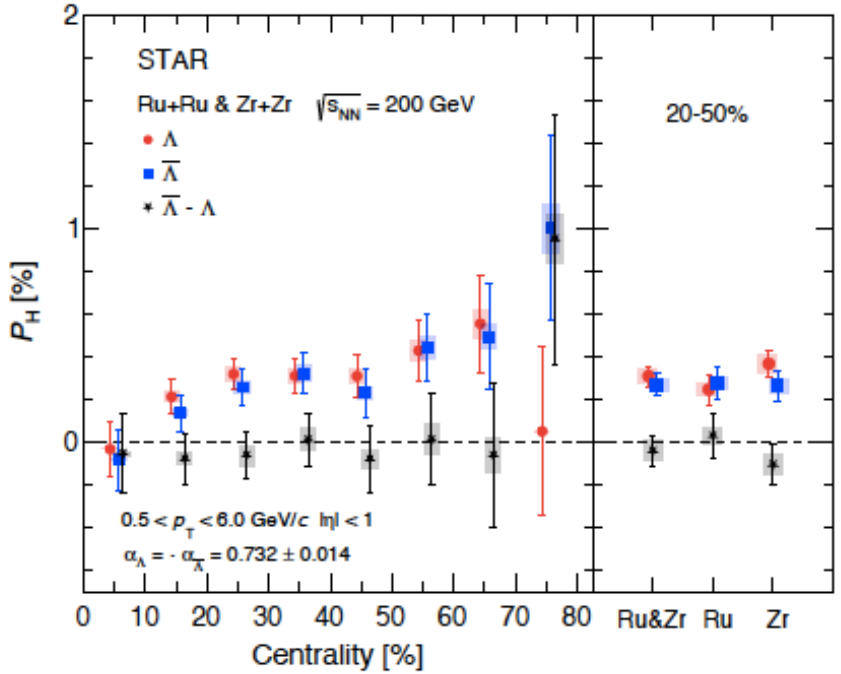
These results strengthen the established global trends:

- Polarization grows toward peripheral collisions and lower beam energy
- Λ and $\overline{\Lambda}$ excitation functions remain consistent within errors
- A simple magnetic-field interpretation of their splitting receives no positive support.

3. STAR finds larger out-of-plane polarization for hyperons emitted in plane, encoded in a positive second-harmonic coefficient at 2.4 sigma
4. At low energy, theory has become less consensual: Recent calculations **locate the turnover of the Λ excitation function** around 2.4 to 3 GeV, or **either find no turnover** within the current acceptance.
5. A new proposed background/production mechanism could account for roughly one quarter of STAR's 3-GeV signal without invoking medium vorticity

STAR combined Ru+Ru and Zr+Zr 20-50% centrality

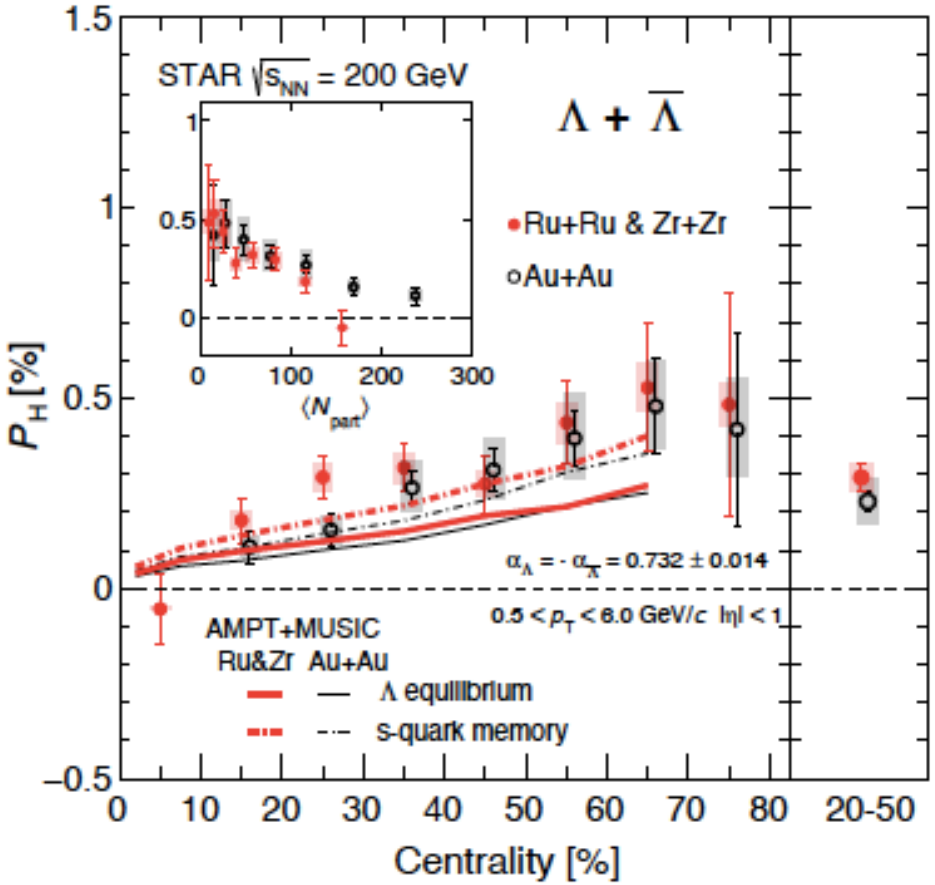
Phys. Lett. B 870 (2025) 13989



- STAR obtains $P_\Lambda = 0.310 \pm 0.048(\text{stat}) \pm 0.036(\text{syst})\%$
- $P_{\overline{\Lambda}} = 0.270 \pm 0.053(\text{stat}) \pm 0.030(\text{syst})\%$.
- The two species and the two isobar systems are mutually consistent.
- The difference between the Λ and $\overline{\Lambda}$ splittings is consistent with zero
- **No evidence, at present precision, for a magnetic contribution in Ru more than in Zr**

Centrality dependence

Phys. Lett. B 870 (2025) 13989



- The polarization rises from central to peripheral collisions
- Compared with 200 GeV Au+Au at the same centrality (20-50%), the isobars global Λ polarization show no clear system-size dependence

p_T and η dependence

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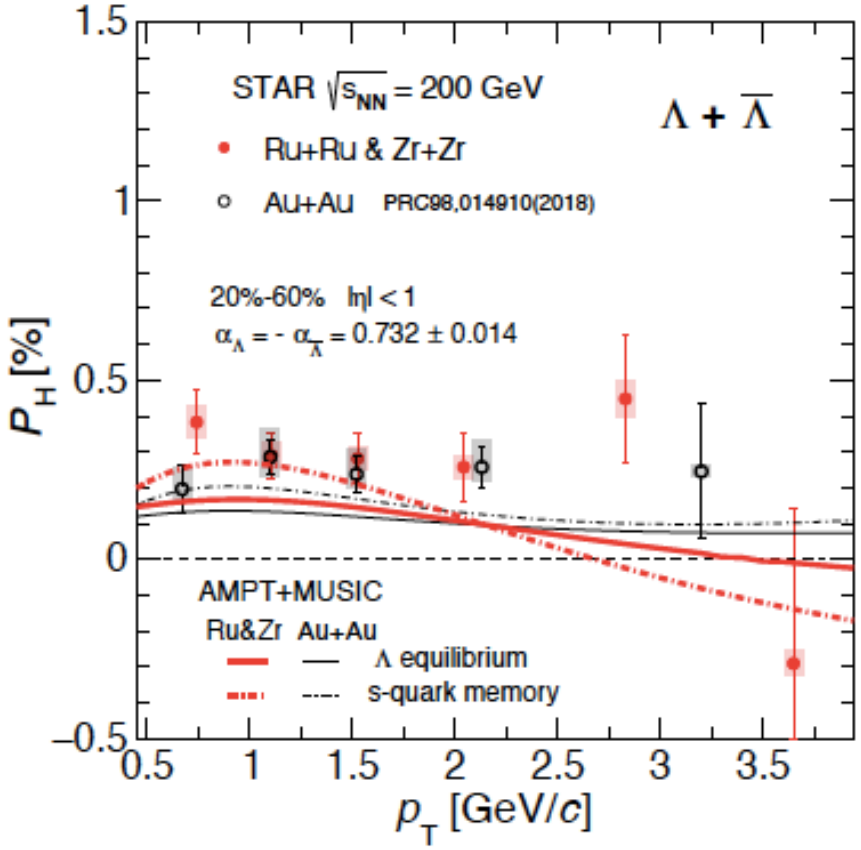

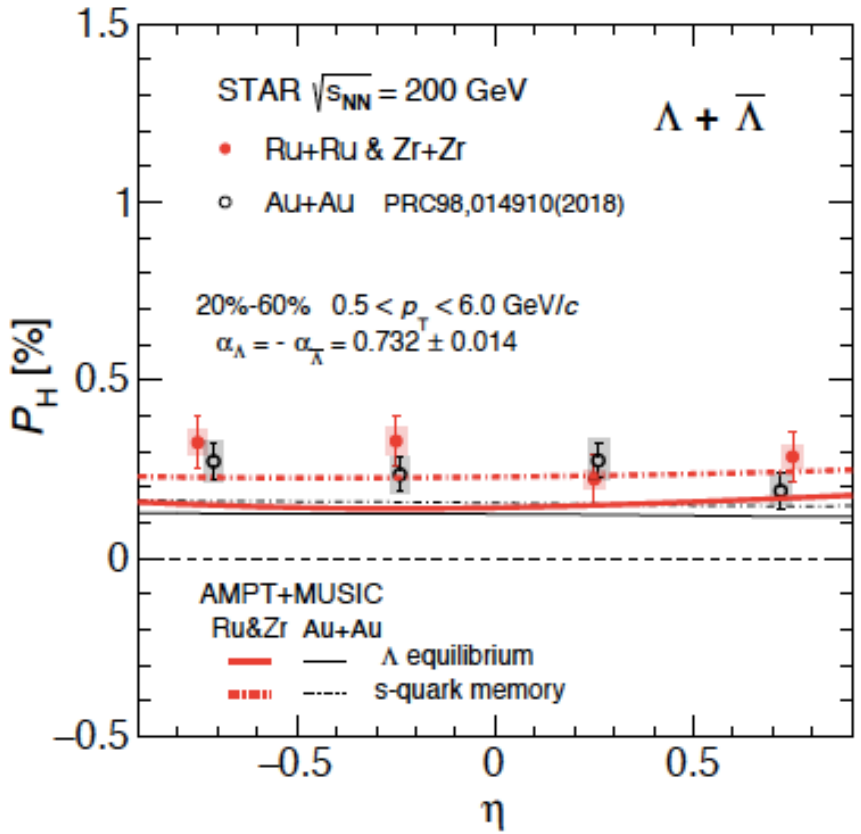

- No significant p_T or pseudorapidity dependence in the measured range

Polarization second harmonic

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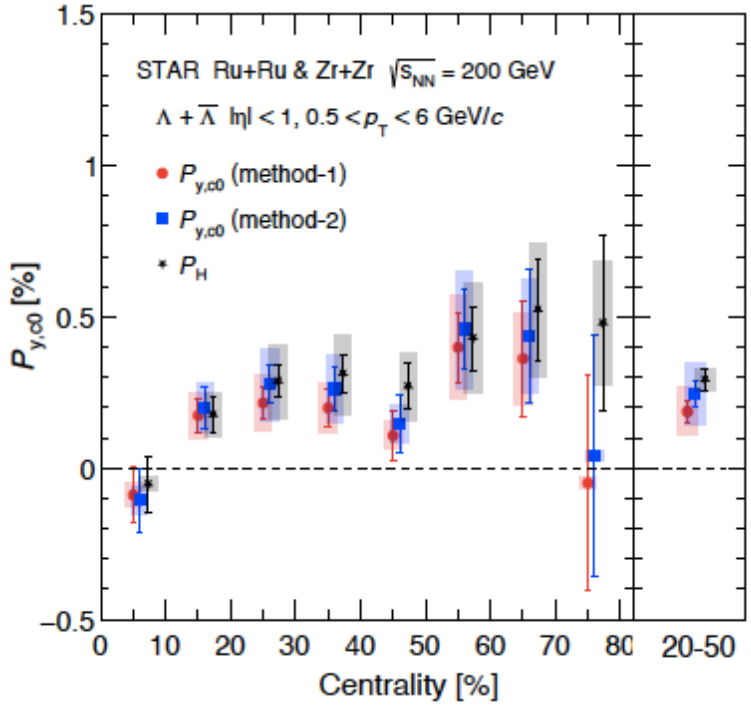
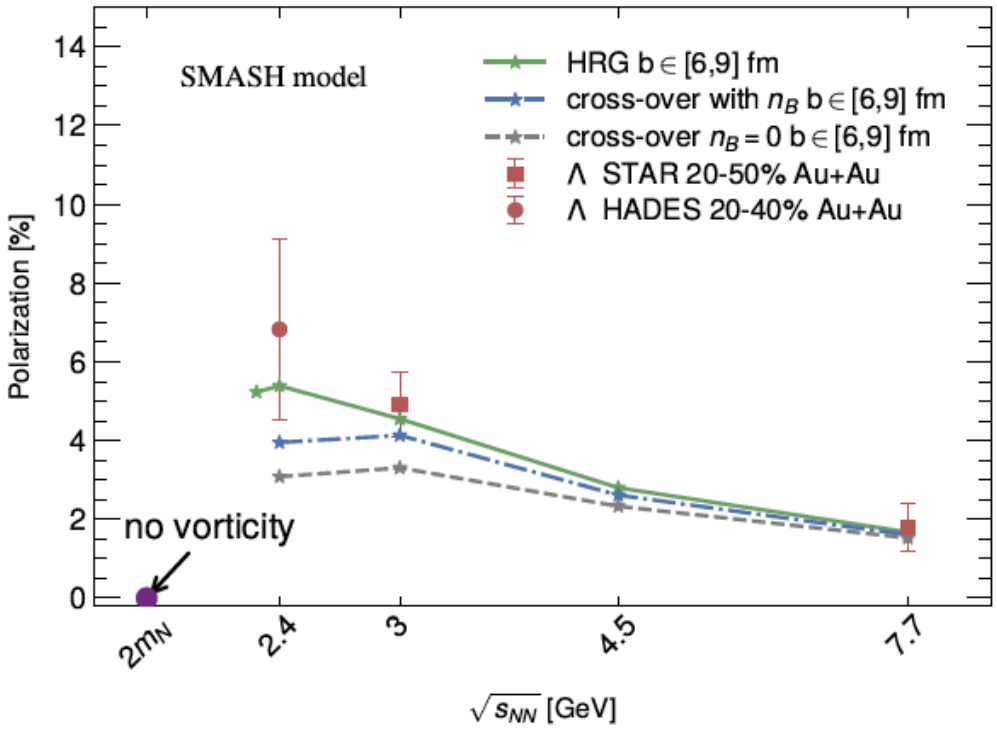


- The novel observable is the second harmonic coefficient
- P_{y,c_2} is positive at 2.4 sigma
- This means stronger polarization for hyperons emitted in plane.
- Thermal-vorticity-only calculations often predict the opposite sign; shear terms can flip it.

Theoretical results: Influence of EoS

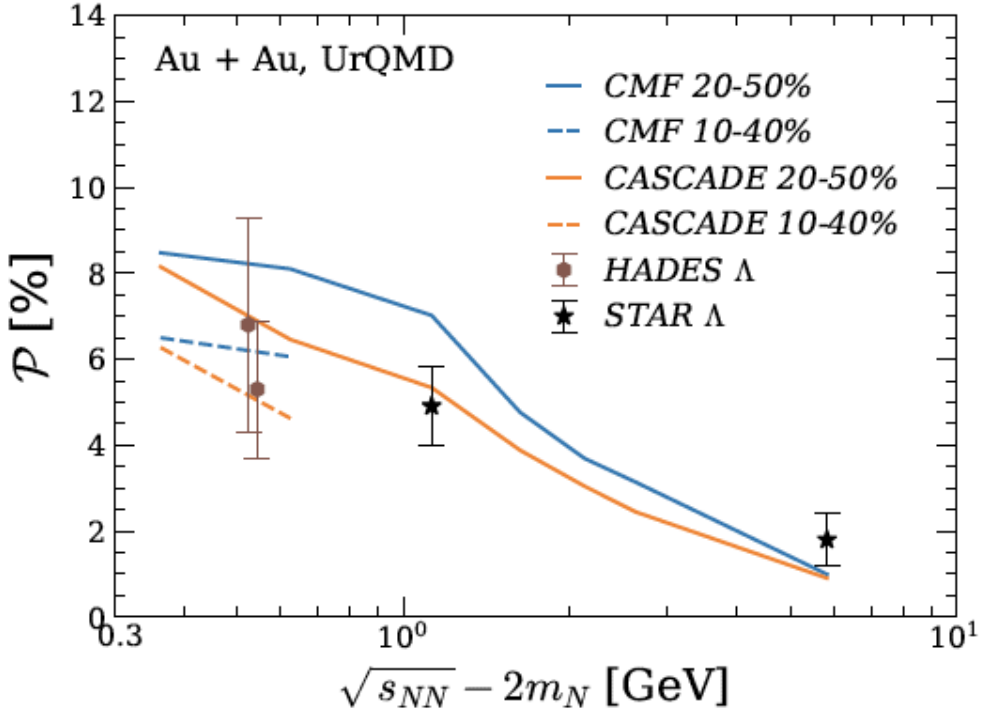
arXiv:2603.27521



- SMASH plus thermal-vorticity Cooper-Frye prescription
- Comparison between HotQCD, NEOS-BQS and HRG EoS
- The HRG temperature mapping better describes the low-energy data
- **The inferred maximum moves with the EoS between 3 GeV for HotQCD/NEOS-BQS and 2.4 GeV for HRG**

UrQMD with two EoS: No low-energy falloff

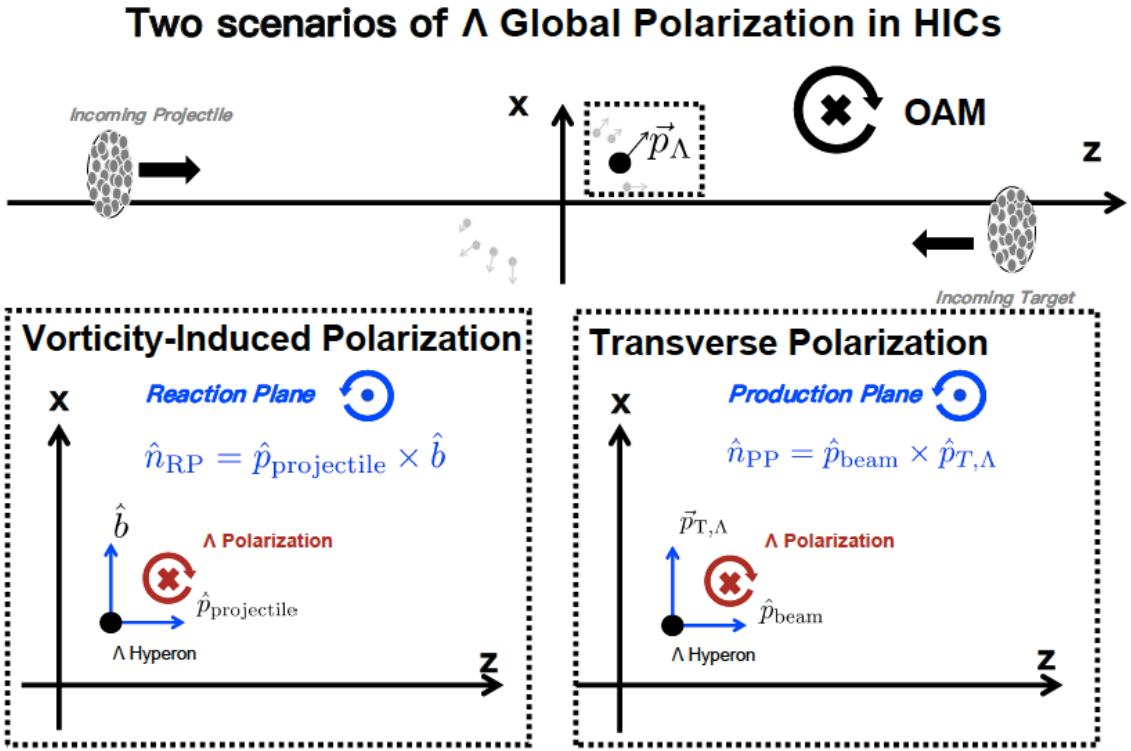
arXiv:2606.13333



- UrQMD study covers Ag+Ag and Au+Au at $\sqrt{s_{NN}}$ =2.24 - 7.7 GeV
- Compares an HRG-like with a chiral mean-field EoS
- Substantial EoS sensitivity, however, Λ polarization does not decrease at low energy
- The source of the large vorticity is attributed to baryon stopping

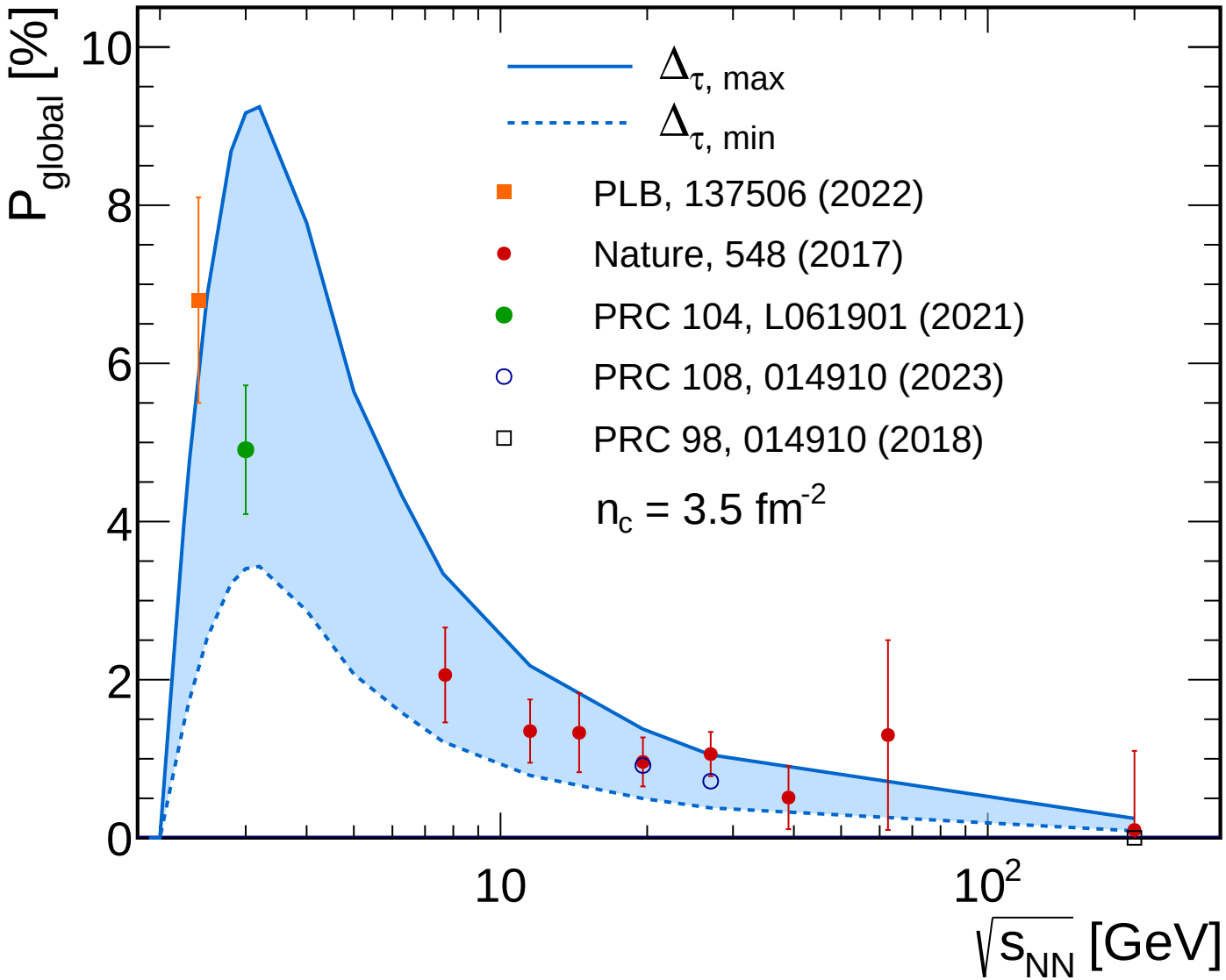
Scenario without vorticity

arXiv:2603.19581

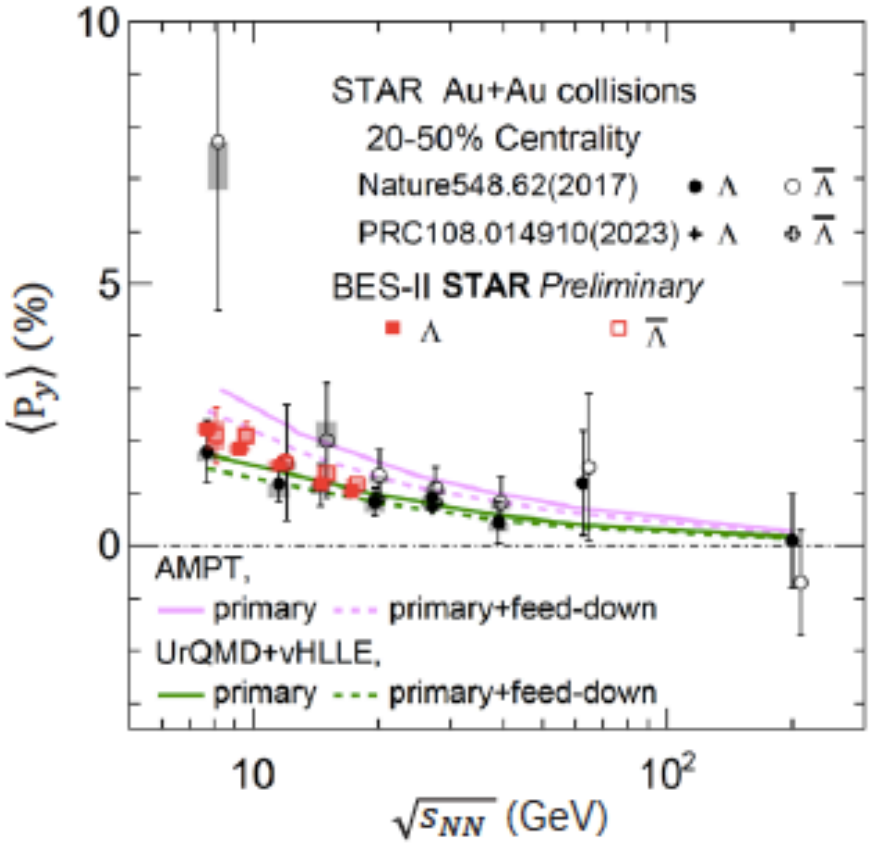


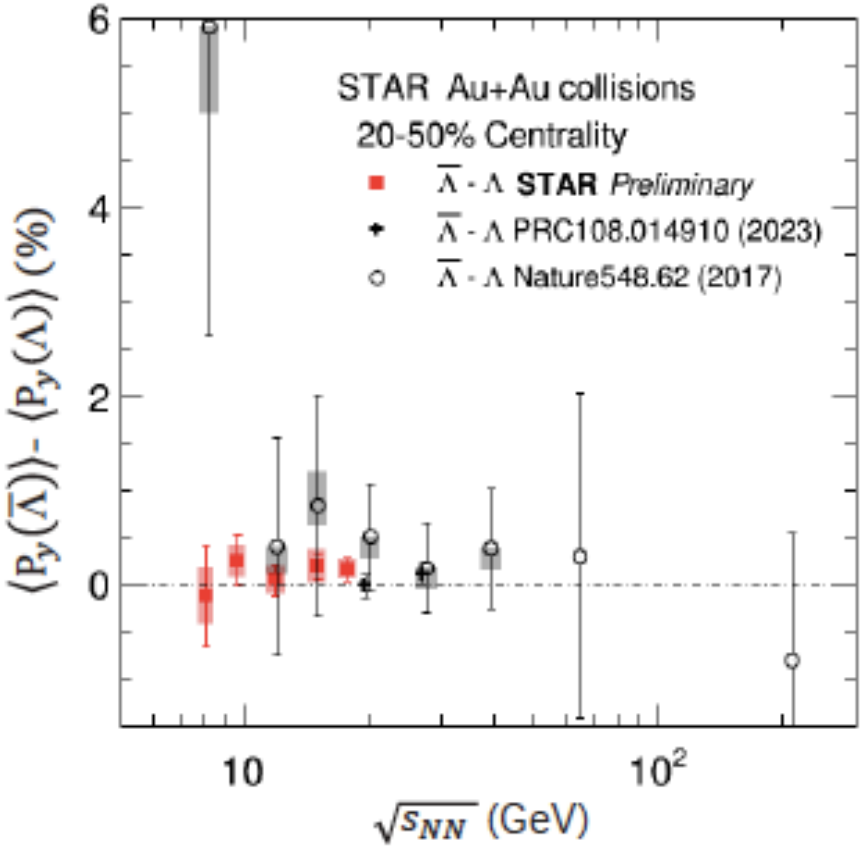
- Connection between transverse Λ polarization in unpolarized hadron production with heavy-ion global Λ polarization
- Directed flow correlates Λ production plane with reaction plane, allowing production-plane polarization to project onto the global polarization axis
- Au+Au simulation at $\sqrt{s_{NN}} = 3$ GeV yields approximately 23% of STAR's measured global polarization

Core-Corona model Λ global polarization excitation function



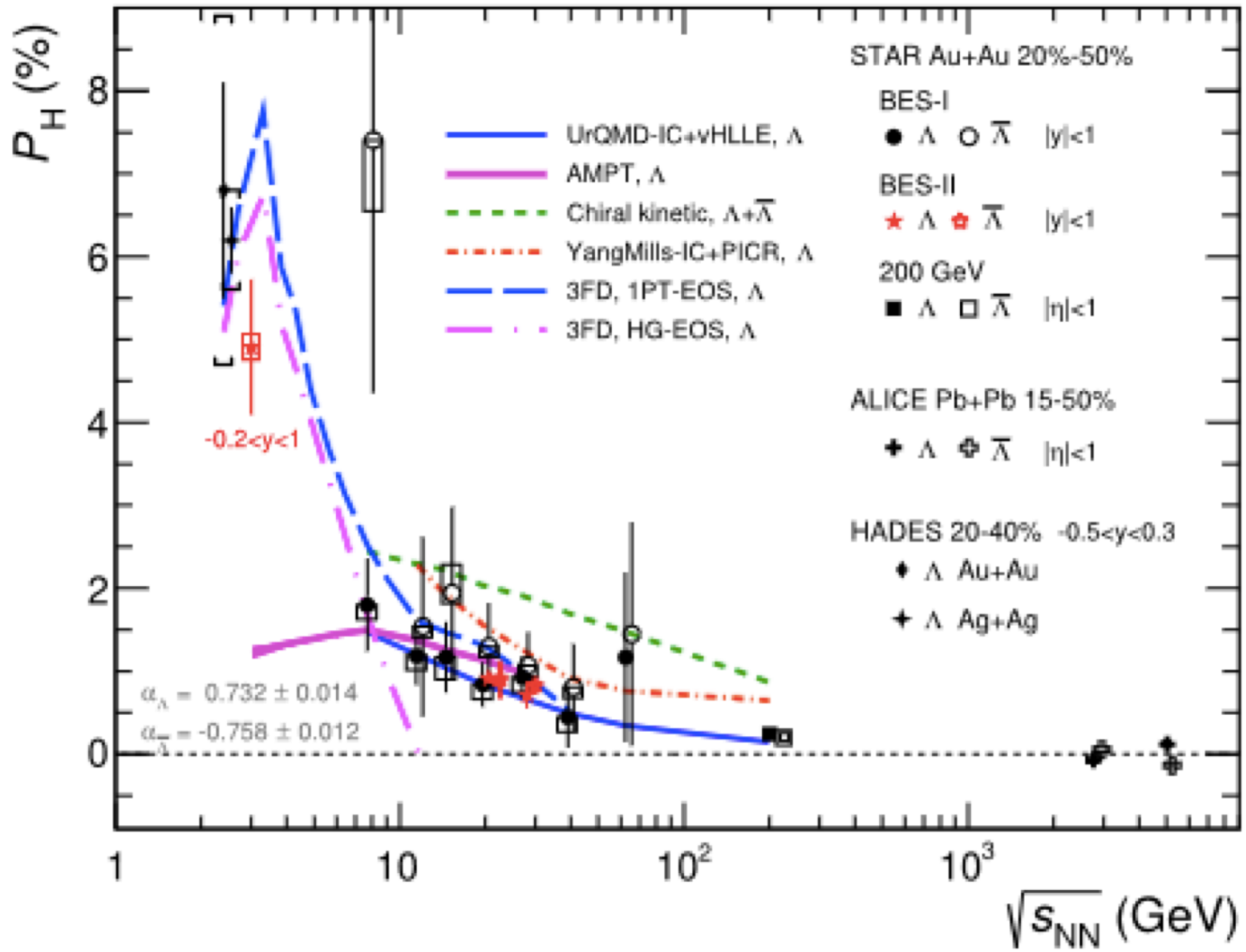
Features of Λ and $\overline{\Lambda}$ polarization excitation functions





EPJ Web of Conferences 316, 06013 (2025) SQM 2024

Features of Λ and $\overline{\Lambda}$ polarization excitation functions



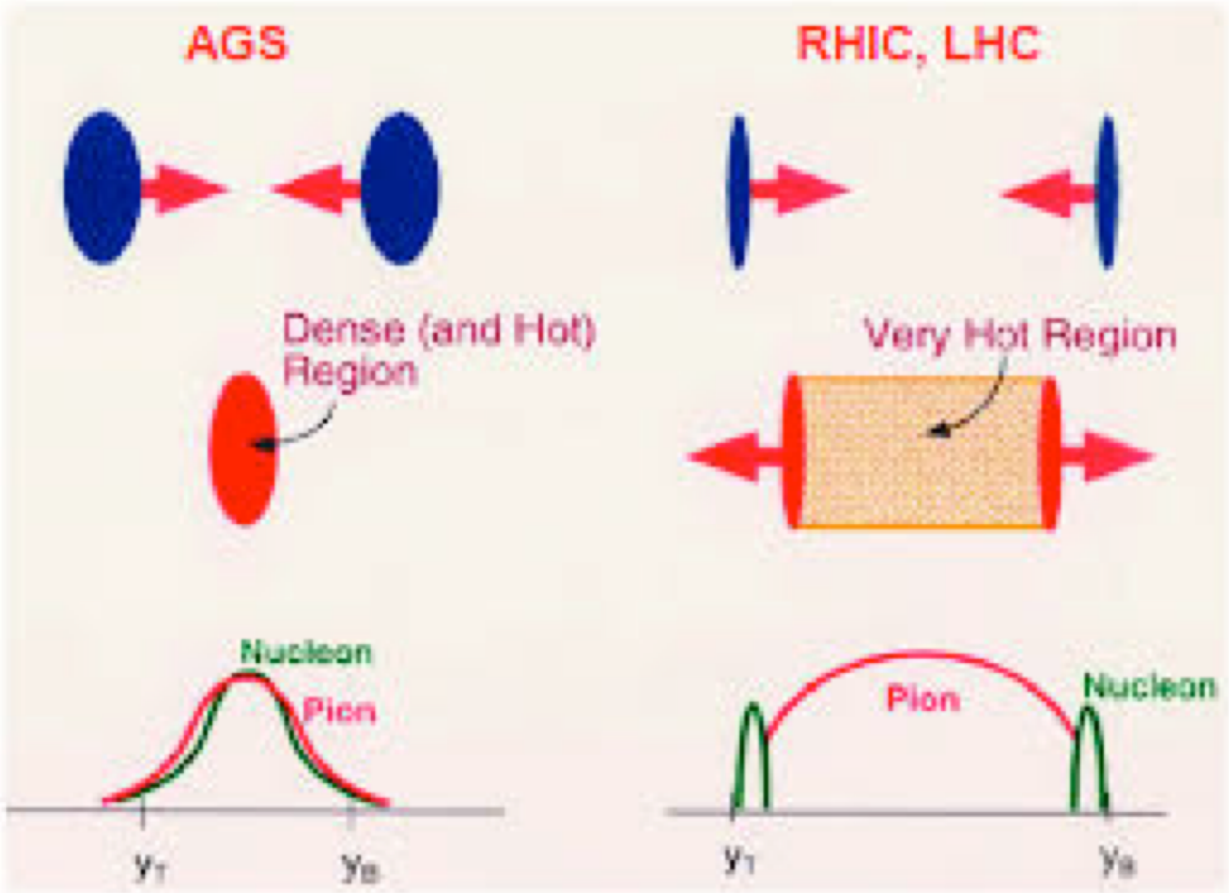
Int. J. Mod. Phys, E 33, 2430010 (2024)

Features of Λ and $\overline{\Lambda}$ polarization excitation functions

The large $\overline{\Lambda}$ polarization in the STAR 2017 Nature paper is now understood to be inflated by an outdated value of the weak decay parameter $\alpha_{\overline{\Lambda}}$, and when modern decay-parameter measurements (BES-III, 2019–2022) are used, the apparent excess of $\overline{\Lambda}$ polarization largely disappears.

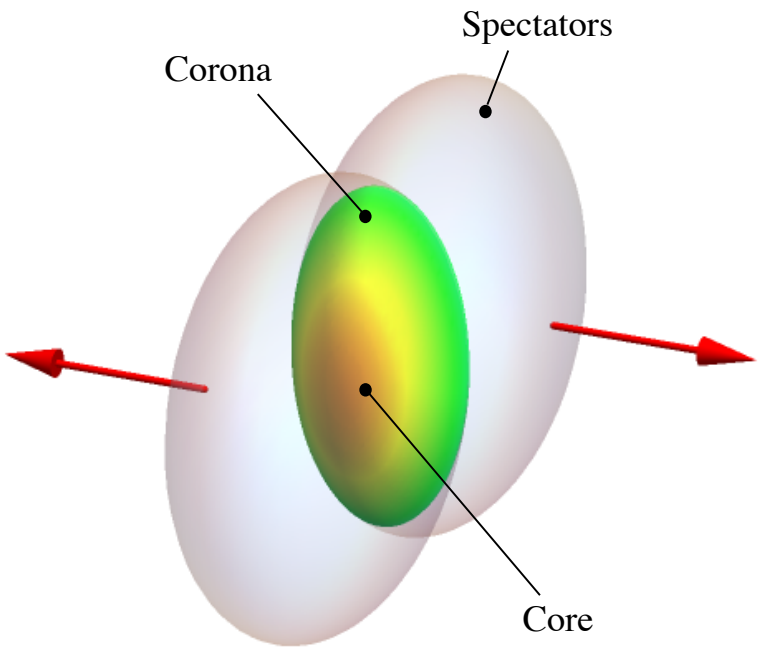
Hot vs Hot and Dense

- In a heavy-ion reaction, the interaction region has different properties depending on the energy of the colliding nuclei



Core Corona: two-component source

Non-central heavy-ion collision of a symmetric system:
Λs from core via QGP processes
Λs from corona via n + n reactions



A+A

$$N_\Lambda = \overbrace{N_{\Lambda\,\mathrm{QGP}}}^{core} + \overbrace{N_{\Lambda\,\mathrm{REC}}}^{corona}$$

Polarization asymmetry -spin alignment asymmetry- of any baryon species produced in high-energy reactions

$$\mathcal{P} = \frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}$$

$N^{\uparrow}$ and $N^{\downarrow}$ baryons with spin aligned and opposite to a given direction.

A.A., I. Dominguez, I. Maldonado, M. E. Tejeda- Yeomans,
Particles 6, 405 (2023); , Rev. Mex. Fis. Suppl. 3, 040914 (2022); PRC 105, 034907 (2022); PLB 810, 135818 (2020)

Λ polarization

$$\mathcal{P}^{\Lambda} = \frac{(N^{\uparrow}_{\Lambda\ QGP} - N^{\downarrow}_{\Lambda\ QGP}) + (N^{\uparrow}_{\Lambda\ REC} - N^{\downarrow}_{\Lambda\ REC})}{(N^{\uparrow}_{\Lambda\ QGP} + N^{\uparrow}_{\Lambda\ REC}) + (N^{\downarrow}_{\Lambda\ QGP} + N^{\downarrow}_{\Lambda\ REC})}$$

- Define the intrinsic polarization

$$z_{QGP} = \frac{N^{\uparrow}_{\Lambda\ QGP} - N^{\downarrow}_{\Lambda\ QGP}}{N_{\Lambda\ QGP}}, \qquad z_{REC} = \frac{N^{\uparrow}_{\Lambda\ REC} - N^{\downarrow}_{\Lambda\ REC}}{N_{\Lambda\ REC}}$$

- Therefore,

$$\mathcal{P}^{\Lambda} = \frac{N_{\Lambda\ QGP}}{N_{\Lambda\ QGP} + N_{\Lambda\ REC}} z_{QGP} + \frac{N_{\Lambda\ REC}}{N_{\Lambda\ QGP} + N_{\Lambda\ REC}} z_{REC}$$

$$= \frac{\frac{N_{\Lambda\ QGP}}{N_{\Lambda\ REC}}}{1 + \frac{N_{\Lambda\ QGP}}{N_{\Lambda\ REC}}} z_{QGP} + \frac{1}{1 + \frac{N_{\Lambda\ QGP}}{N_{\Lambda\ REC}}} z_{REC}.$$

Ingredients to compute the intrinsic polarizations

$$z = 1 - e^{-\Delta\tau/\tau} \quad \textbf{intrinsic polarixation}$$

$$\tau = \frac{1}{\Gamma} \quad \textbf{relaxation time}$$

$$\Gamma = V \int \frac{d^3p}{(2\pi)^3} \left[\Gamma^+(p_0) - \Gamma^-(p_0)\right] \quad \textbf{interaction rate}$$

for spin alignment

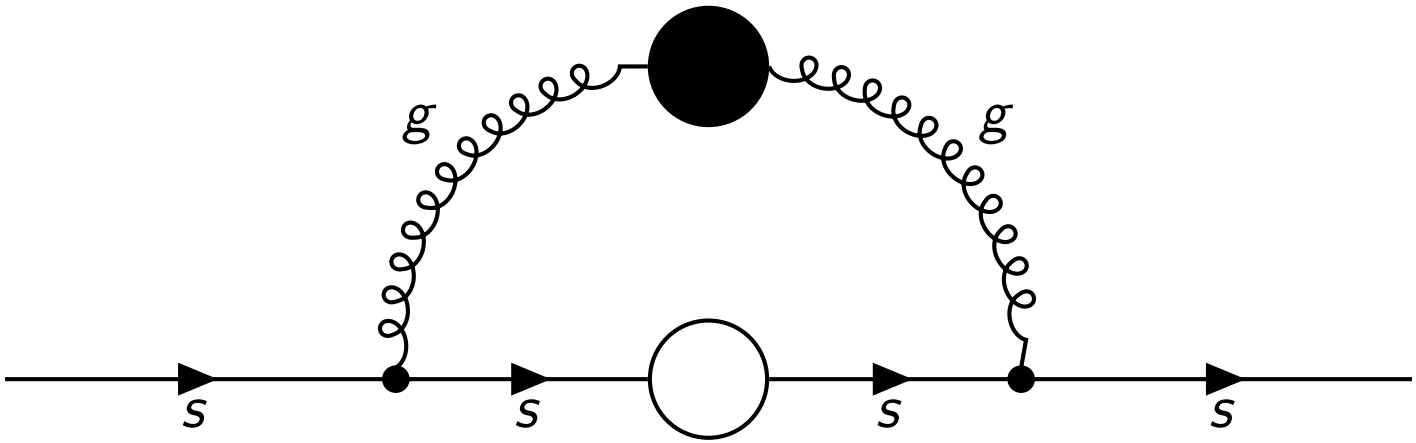
$$\Gamma^{\pm}(p_0) = \tilde{f}(p_0 - \mu_B \mp \Omega/2)\mathrm{Tr}\left[\mathrm{Im}\Sigma^{\pm}\right]$$

$$O^{\pm} = \frac{1}{2}\left[1 \pm i\gamma_1\gamma_2\right] \quad \textbf{spin projection operators}$$

Intrinsic polarization in the QGP

Ingredients

- Imaginary part of rotating quark self-energy Σ immersed in a thermal QCD medium
- Thermal gluon propagator in HTL approximation

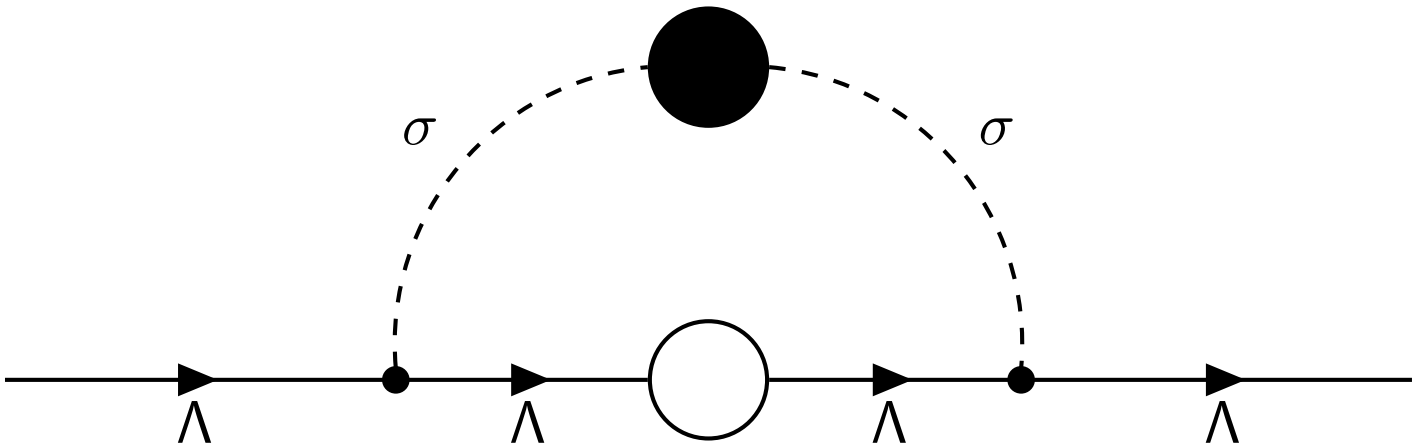


- **Propagator of a quark in a rotating environment**

In the Corona, interactions modeled by σ exchange

Ingredients

- Imaginary part of the rotating Λ self-energy Σ immersed in a thermal nuclear environment
- Thermal σ propagator accounting for the fact that the nucleon mass $M_N \gg T$



- **Propagator of a Λ in a rotating environment**

T- and μ_B-dependent σ propagator

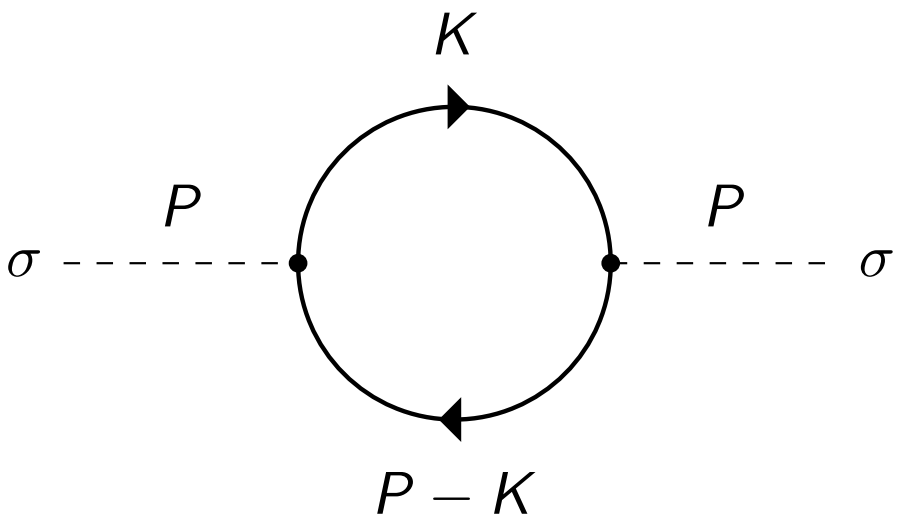
- In the **linear Relativistic Mean Field model**, the Lagrangian density that describes the coupling of nucleons and σ is

$$\mathcal{L} = \bar{\psi}\left[i\gamma^\mu\partial_\mu - M_N - g_\sigma\sigma\right]\psi + \frac{1}{2}\partial_\mu\sigma\partial^\mu\sigma - \frac{1}{2}m_\sigma^2\sigma^2$$

- corona as a medium where nucleons and σs interact at finite temperature T and baryon chemical potential μ, the one-loop **effective σ propagator** Δ^* can be written, in the imaginary time formalism of finite temperature field theory, as

$$\Delta^*(i\omega, p) = \frac{1}{\omega^2 + p^2 + m_\sigma^2 + \Pi}$$

T- and μ_B-dependent σ propagator



$$\Pi = -g_\sigma^2 \sum_n \int \frac{d^3k}{(2\pi)^3} \, \mathrm{Tr}\left[(M_N - \not{K})(M_N - (\not{K} - \not{P}))\right] \tilde{\Delta}(K)\tilde{\Delta}(K-P)$$

$\tilde{\Delta}(K)$ is the Matsubara fermion propagator and we have defined

$$P = (i\omega, \vec{p}), \quad K = (i\tilde{\omega}_n + \mu, \vec{k})$$

A.A., I. Dominguez, I. Maldonado, J.J. Medina-Serna, M. E. Tejeda- Yeomans, Phys. Lett. B **869**, 139873 (2025)

Propagator of a spin 1/2 fermion in a rotating environment

The physics within a relativistic rotating frame is most easily described in terms of a metric tensor resembling that of a curved space-time.

- Rigid cylindrical rotation with angular velocity Ω

$$g_{\mu\nu} = \begin{pmatrix} 1-(x^2+y^2)\Omega^2 & y\Omega & -x\Omega & 0 \\ y\Omega & -1 & 0 & 0 \\ -x\Omega & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}$$

- Dirac equation

$$\left[i\gamma^\mu\left(\partial_\mu+\Gamma_\mu\right)-m\right]\Psi=0$$

- Γ_μ is the affine connection that can be computed from the metric tensor

Fermion propagator in a rotating environment

Remarks:

- Causality requires that $\Omega R < 1$. For a given R this sets an upper limit to Ω, otherwise more sophisticated boundary conditions needed
- The propagator is in general **not translational invariant**. However, a suitable approximation is that the fermion is **totally dragged** $\Rightarrow$ the angular position $\varphi + \Omega t = 0$. This is reasonable when ignoring radial expansion
- In this sense Ω needs to also be the largest of the intrinsic energy scales

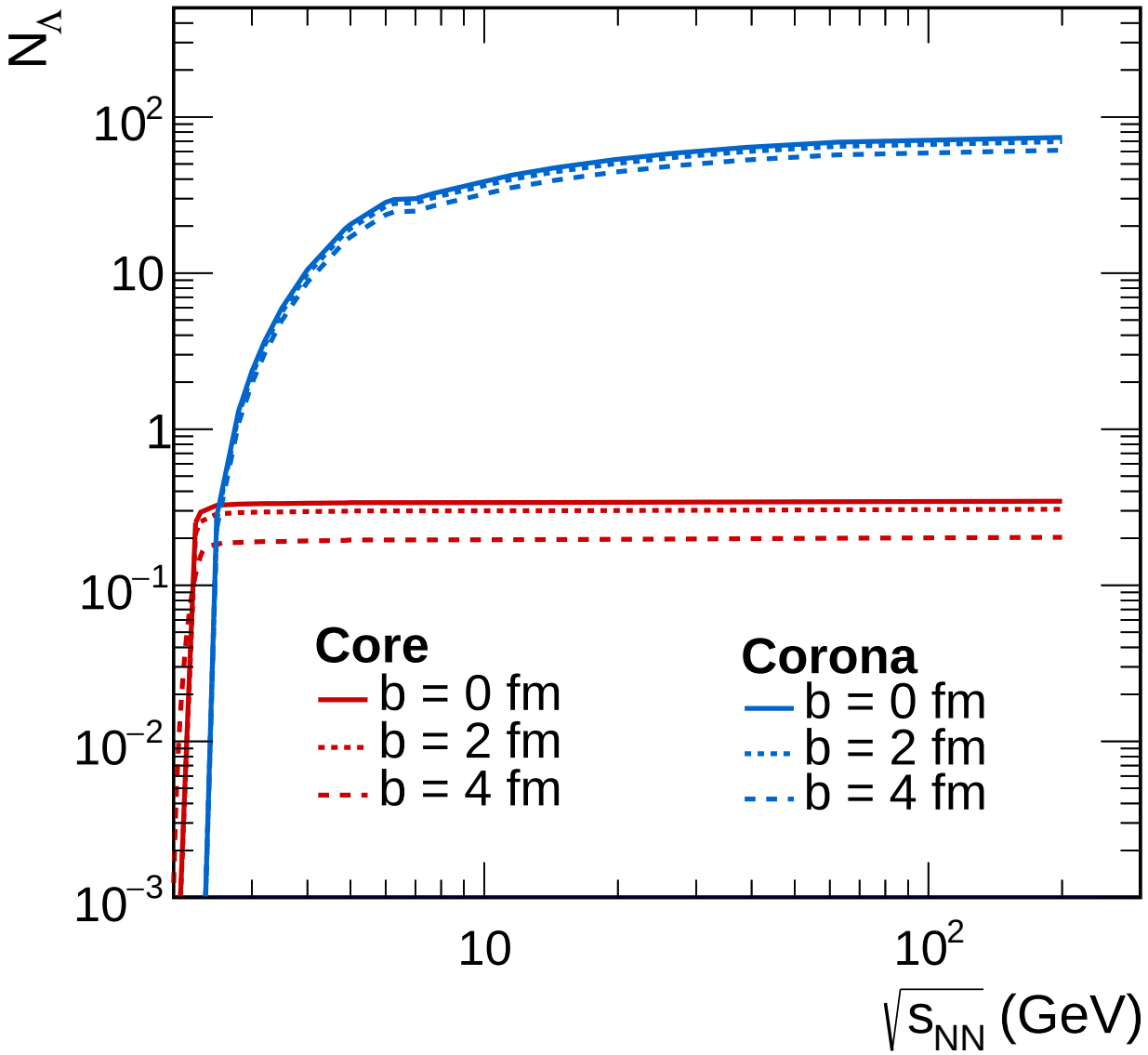
Fermion propagator in a rotating environment

Under these considerations, the propagator becomes translationally invariant. We can carry out the integration and the summation and take the Fourier transform to momentum space, we obtain

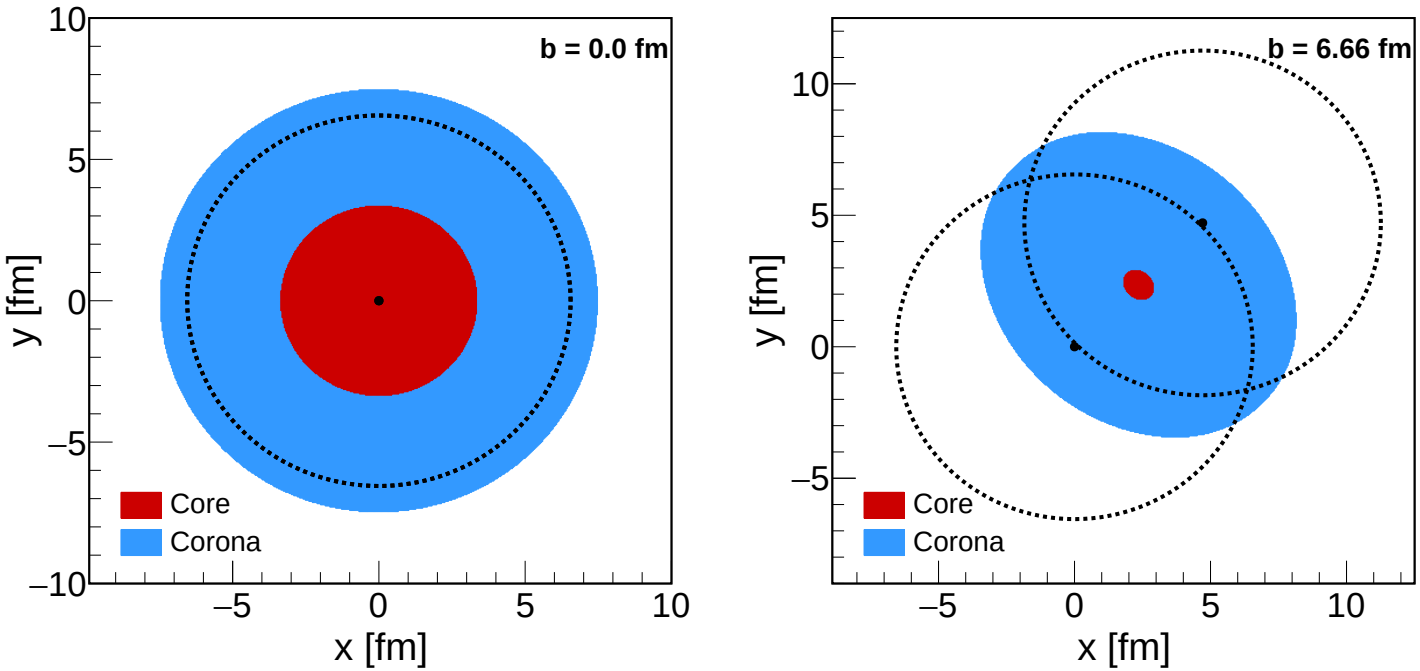
$$S(p) = \frac{\gamma^0(p_0+\Omega/2) - \gamma^3 p_3 - \gamma_\perp \cdot p_\perp + m}{(p_0+\Omega/2)^2 - p_3^2 - p_\perp^2 - m^2 + i\epsilon}\mathcal{O}^+ + \frac{\gamma^0(p_0-\Omega/2) - \gamma^3 p_3 - \gamma_\perp \cdot p_\perp + m}{(p_0-\Omega/2)^2 - p_3^2 - p_\perp^2 - m^2 + i\epsilon}\mathcal{O}^-.$$

A.A., L. A. Hernández, K. Raya, and R. Zamora, PRD 103, 076021 (2021)
A.A. I.Domínguez, J.J. Medina-Serna, M.E. Tejeda-Yeomans, PRD 114, 016034 (2026)

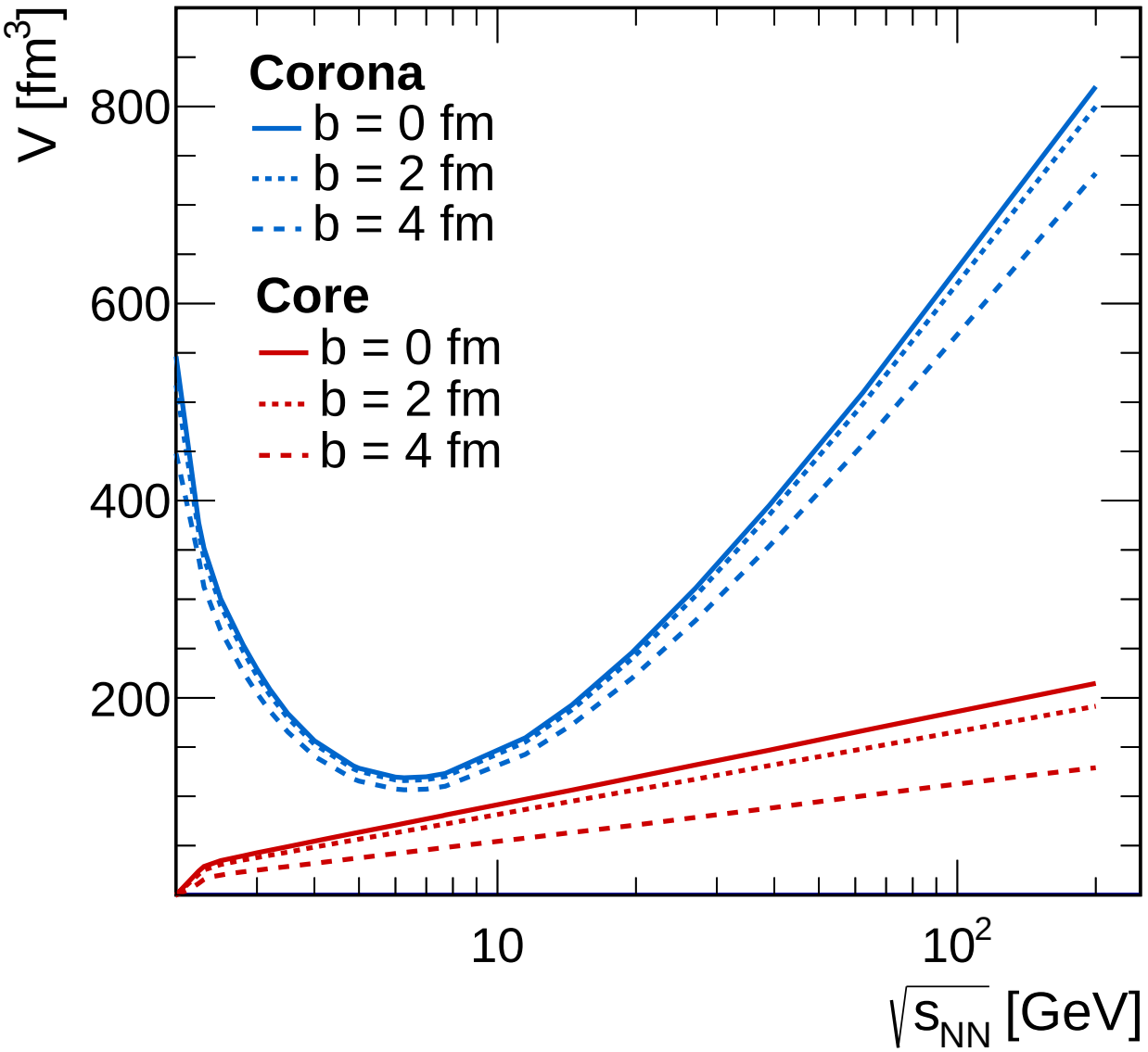
Glauber model to compute the number of Λs



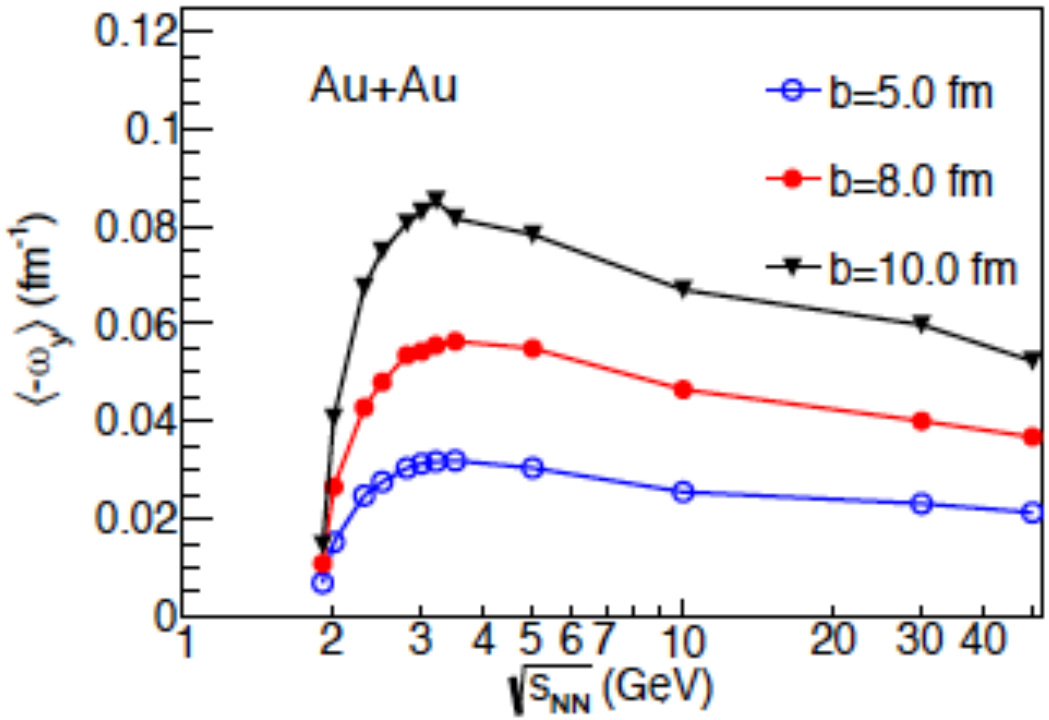
Glauber model to compute the number of Λs



Reaction volume

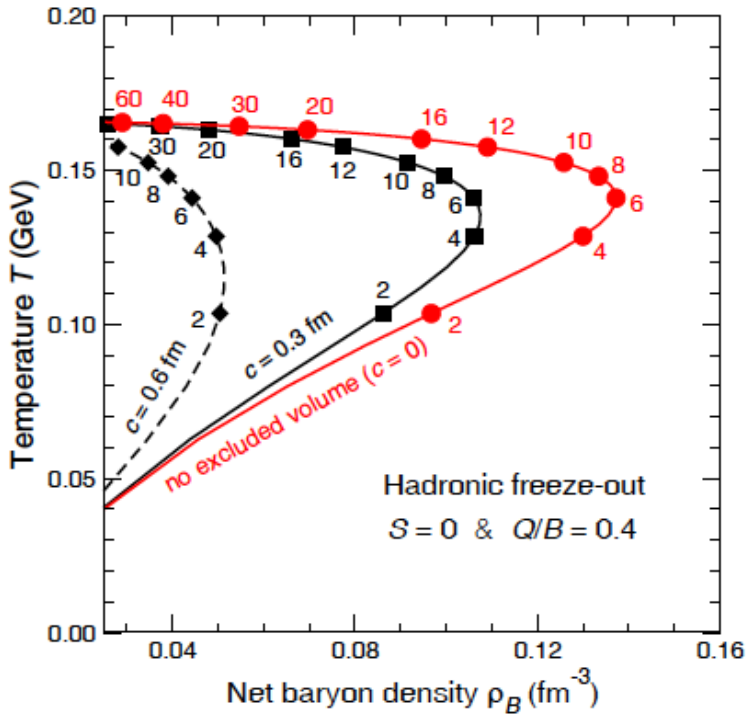


Initial angular velocity from UrQMD



X.-G. Deng *et al.*, PRC 101 (2020) 6, 064908

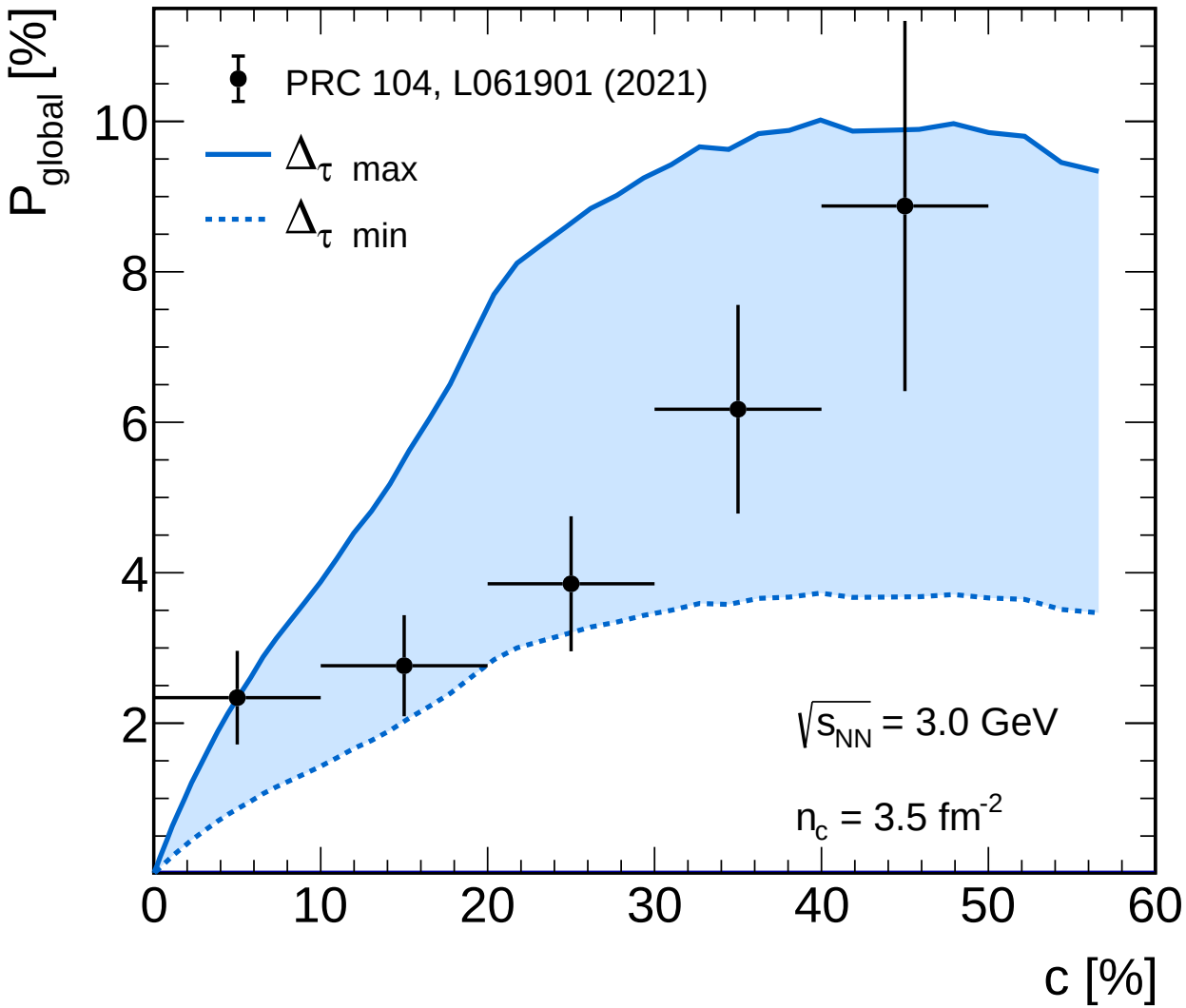
Freeze-out curve, $T_0 = 155$ MeV



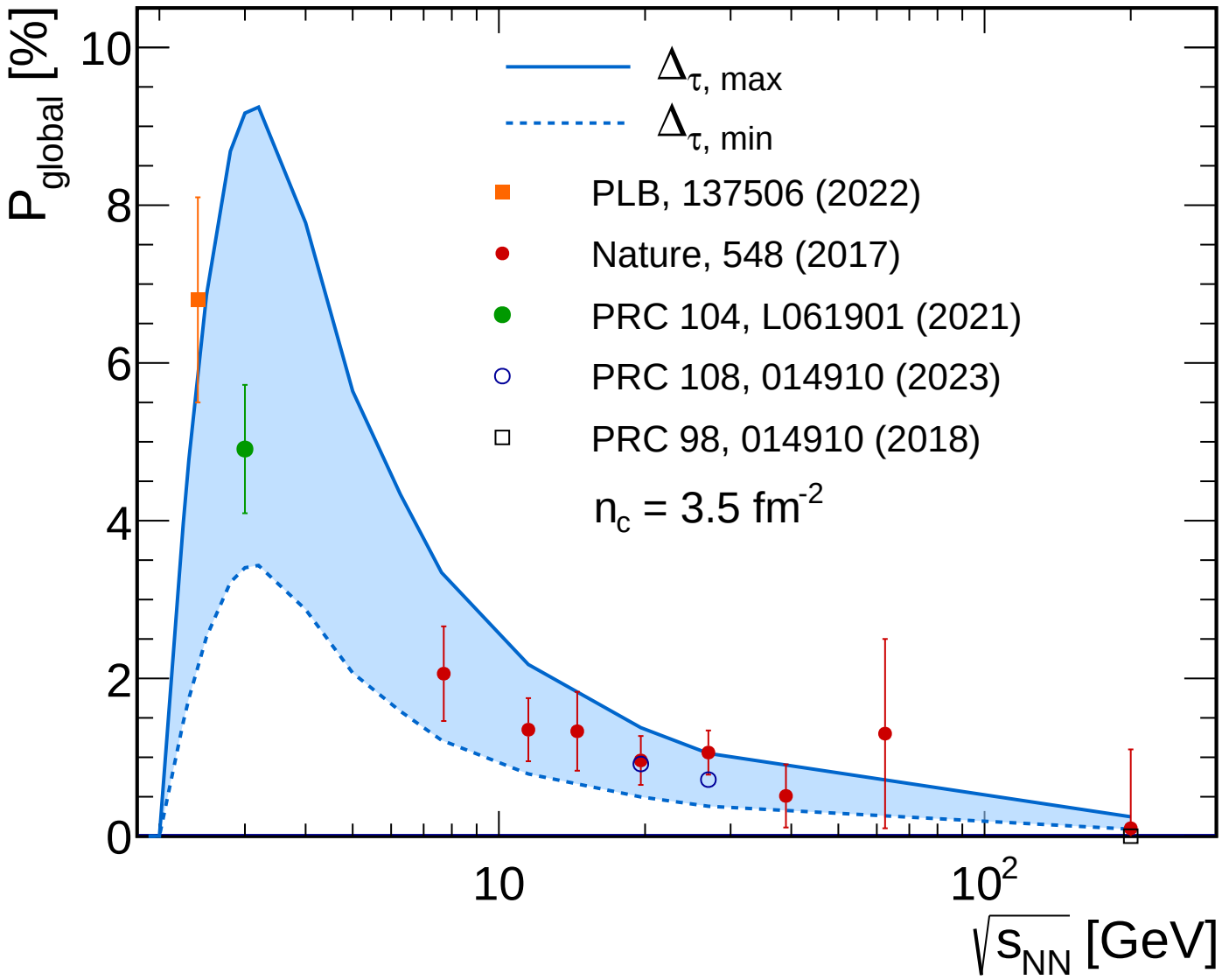
$$\frac{T(\mu_B)}{T_0} = 1 - 0.0120\left(\frac{\mu_B}{T_0}\right)^2 - 0.0025\left(\frac{\mu_B}{T_0}\right)^4,$$

$$\mu_B(\sqrt{s_{NN}}) = \frac{1.3075\ \text{GeV}}{1 + 0.288\text{GeV}^{-1}\sqrt{s_{NN}}}$$

Results


PRC 104, L061901 (2021)
Δ_τ max
Δ_τ min
$\sqrt{s_{NN}}$ = 3.0 GeV
n_c = 3.5 fm^{-2}
P_{global} [%]
c [%]
0
10
20
30
40
50
60
2
4
6
8
10

Excitation function for global Λ polarization



Conclusions

- Global Λ polarization remains a robust signal of angular-momentum transfer, but at a few GeV it is becoming a multi-mechanism observable rather than a direct one-to-one vorticity meter.
- STAR isobars: precise $\mathcal{P}_{\Lambda}$ approximately equal to $\mathcal{P}_{\overline{\Lambda}}$, no clear Ru/Zr or system-size effect, but a new azimuthal modulation sensitive to shear
- Low-energy theory: EoS and stopping matter; predicted turnover lies near $\sqrt{s_{NN}} = 2.4$ - 3 GeV or may be absent within current acceptance.

Conclusions

- Excitation function for the global Λ polarization using the Core-Corona model, accounting for the contributions to Λ production from a high-density region (the core) and a less dense region (the corona) in the nuclear collision **predicts a maximum at $\sqrt{s_{NN}} \simeq 3$ GeV.**
- Field theoretical description based on two ingredients: a fermion propagator that carries the information of the medium vortical motion with a constant angular velocity, and suitable mediator propagators at finite density and temperature.
- For the centralities where the polarization is experimentally reported, we find that the polarization originates mainly in the corona.
- Under a set of simple but physically motivated assumptions, the model provides a good description of the Λ polarization excitation function when accounting for subthreshold production in a nuclear environment.

THANK YOU!

BACKUP

Gluon propagator at finite T and μ_B

- In a covariant gauge, the Hard Thermal Loop (HTL) approximation to the effective gluon propagator is given by

$$^*G_{\mu\nu}(K) = {}^*\Delta_L(K) P_{L\,\mu\nu} + {}^*\Delta_T(K) P_{T\,\mu\nu}$$

- The gluon propagator functions for longitudinal and transverse modes, ${}^*\Delta_{L,T}(K)$, are

$$^*\Delta_L(K)^{-1} = K^2 + 2m^2 \frac{K^2}{k^2}\left[1 - \left(\frac{i\omega_n}{k}\right) Q_0\left(\frac{i\omega_n}{k}\right)\right],$$

$$^*\Delta_T(K)^{-1} = -K^2 - m^2\left(\frac{i\omega_n}{k}\right)\left\{\left[1 - \left(\frac{i\omega_n}{k}\right)^2\right] Q_0\left(\frac{i\omega_n}{k}\right) + \left(\frac{i\omega_n}{k}\right)\right\}$$

$$\begin{aligned} m^2 &= \frac{1}{6} g^2 C_A T^2 + \frac{1}{12} g^2 C_F \left(T^2 + \frac{3}{\pi^2}\mu^2\right), \; C_A = 3, \; C_F = 4/3, \\ \alpha_s &= g^2/4\pi = 1/3 \end{aligned}$$

Approximation for $M_N \gg T$

- Since $M_N \gg T$

$$\Pi = M_T^2 + (i\omega)\Bigg\{\Bigg[3x^2\left(2x^2+1\right)\lambda_1 - x\lambda_2 + x\left(5x^2+1\right)\gamma_T\Bigg]\ln\left(\frac{x+1}{x-1}\right) - \Bigg[\frac{2x^2\left(5x^2+1\right)}{\sqrt{3x^2+1}}\gamma_T + \frac{x^3\left(10x^2+7\right)}{\sqrt{3x^2+1}}\lambda_1\Bigg]\ln\left(\frac{x^2+\sqrt{3x^2+1}+1}{x^2-\sqrt{3x^2+1}+1}\right) + \left[4x\left(2x^2+1\right)\lambda_1 + 2\lambda_2 + \frac{2}{3}\left(15x^2-2\right)\gamma_T\right]\Bigg\}$$

- $x \equiv i\omega/p$

Approximation $M_N \gg T$

where we have introduced the definitions

$$
\begin{aligned}
M_T^2 &\equiv \frac{2g_\sigma^2 M_N T}{\pi^2} K_1\left(\frac{M_N}{T}\right)\cosh\left(\frac{\mu}{T}\right), \\
\gamma_T &\equiv \frac{2g_\sigma^2 M_N}{\pi^2} K_1\left(\frac{M_N}{T}\right)\sinh\left(\frac{\mu}{T}\right), \\
\lambda_1 &\equiv \frac{2g_\sigma^2 T}{\pi^2} e^{-\frac{M_N}{T}}\cosh\left(\frac{\mu}{T}\right), \\
\lambda_2 &\equiv \frac{2g_\sigma^2 T}{\pi^2} e^{-\frac{M_N}{T}}\sinh\left(\frac{\mu}{T}\right)
\end{aligned}
$$

- M_T is the **thermal mass**, γ_T λ_1, and λ_2 are related to **Landau damping.**

Analytical properties

- Analytic continuation back to Minkowski $x \to p_0/p$ with p_0 real.
- For $-1 < x < 1$

$$\frac{x+1}{x-1} < 0, \qquad \frac{x^2+\sqrt{3x^2+1}+1}{x^2-\sqrt{3x^2+1}+1} < 0$$

- The logarithmic terms develop an imaginary part, explicitly

$$\ln\left(\frac{x+1}{x-1}\right) = \ln\left|\frac{x+1}{x-1}\right| + i\pi\theta\left(1-x^2\right)$$

$$\ln\left(\frac{x^2+\sqrt{3x^2+1}+1}{x^2-\sqrt{3x^2+1}+1}\right) = \ln\left|\frac{x^2+\sqrt{3x^2+1}+1}{x^2-\sqrt{3x^2+1}+1}\right| + i\pi\theta\left(1-x^2\right)$$

Dispersion relation

- Large p

$$\omega(p) = p\left(1+\kappa\ \exp\left[-\frac{\alpha_1\gamma_T+\alpha_2\lambda_1+\alpha_3\lambda_2}{3(\lambda_1+2\lambda_2)}p\right]\right)$$

$$\kappa \equiv \exp\left[\frac{-2M\sigma^2}{p(\lambda_1+2\lambda_2)}+\frac{\alpha_1\gamma_T+\alpha_2\lambda_1+\alpha_3\lambda_2}{\lambda_1+2\lambda_2}\right]$$

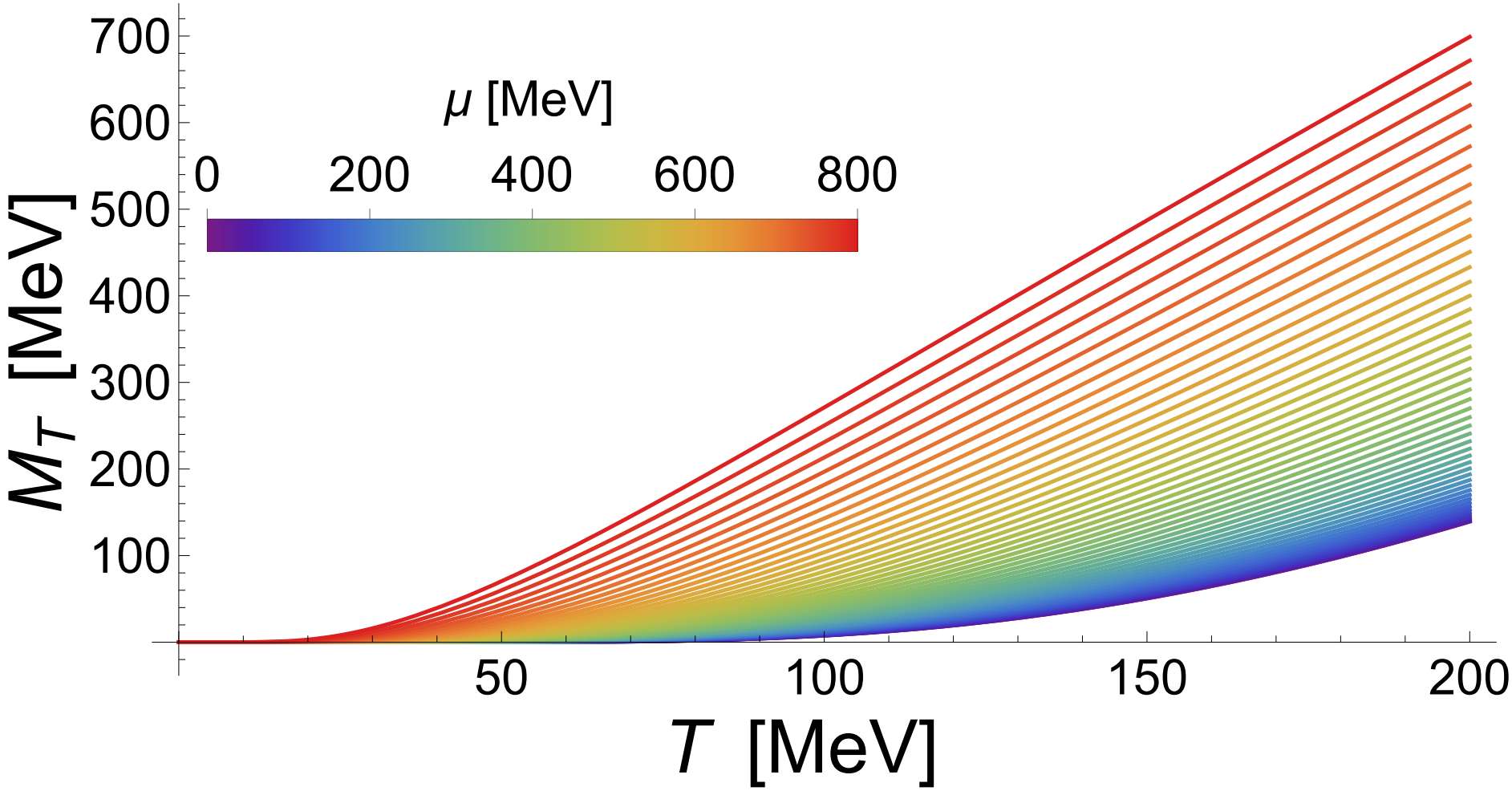
$$\alpha_1 \equiv \frac{2}{3}(13-18\ln(2)) \approx 0.3489$$

$$\alpha_2 \equiv \frac{3}{2}(2-11\ln(2)) \approx 0.5631$$

$$\alpha_3 \equiv \ln(2) \approx 0.6931$$

Thermal mass

$g_\sigma = 10.5$ and $m_\sigma = 510$



The effective propagator

$$\Delta^*(p_0,p) = \frac{-1}{P^2 - M_\sigma^2 - \gamma_T p_0 F(x) - i\pi A(x)\theta(p^2 - p_0^2)}$$

$$P^2 = p_0^2 - p^2, \qquad M_\sigma^2 = m_\sigma^2 + M_T^2$$

$$\begin{aligned} A(x) &= \gamma_T \left(5x^2+1\right)\left(x - \frac{2x^2}{\sqrt{3x^2+1}}\right) \\ &+ \lambda_1\, x^2 \left(3(2x^2+1) - \frac{x(10x^2+7)}{\sqrt{3x^2+1}}\right) - \lambda_2 \end{aligned}$$

- $x \equiv p_0/p$

The effective propagator

$$
\begin{aligned}
F(x) = & \left[3\left(2x^2+1\right) x\lambda_1 - \lambda_2 \right. \\
& \left. + \left(5x^2+1\right)\gamma_T \right] x \ln\left(\frac{x+1}{x-1}\right) \\
& - \left[2\frac{\left(5x^2+1\right)}{\sqrt{3x^2+1}}\gamma_T + \frac{x\left(10x^2+7\right)}{\sqrt{3x^2+1}}\lambda_1 \right] \\
& \times x^2 \ln\left(\frac{x^2+\sqrt{3x^2+1}+1}{x^2-\sqrt{3x^2+1}+1}\right) \\
& + \left[4x\left(2x^2+1\right)\lambda_1 + 2\lambda_2 + \frac{2}{3}\left(15x^2-2\right)\gamma_T \right]
\end{aligned}
$$

Dispersion relation and damping rate

$$\begin{aligned}
\omega^2(p) &= p^2 + m_\sigma^2 + \mathrm{Re}\left[\Pi\Big|_{p_0=\omega(p)}\right] \\
&= p^2 + m_\sigma^2 + M_T^2 + \gamma_T \omega(p) F\left(\omega(p)/p\right) \\
\gamma(p) &= -\frac{1}{2\omega(p)} \mathrm{Im}\left[\Pi\Big|_{p_0=\omega(p)}\right] \\
&= \frac{\gamma_T}{2}\pi A\left(\omega(p)/p\right)\theta(p^2-\omega(p)^2)
\end{aligned}$$

At leading order

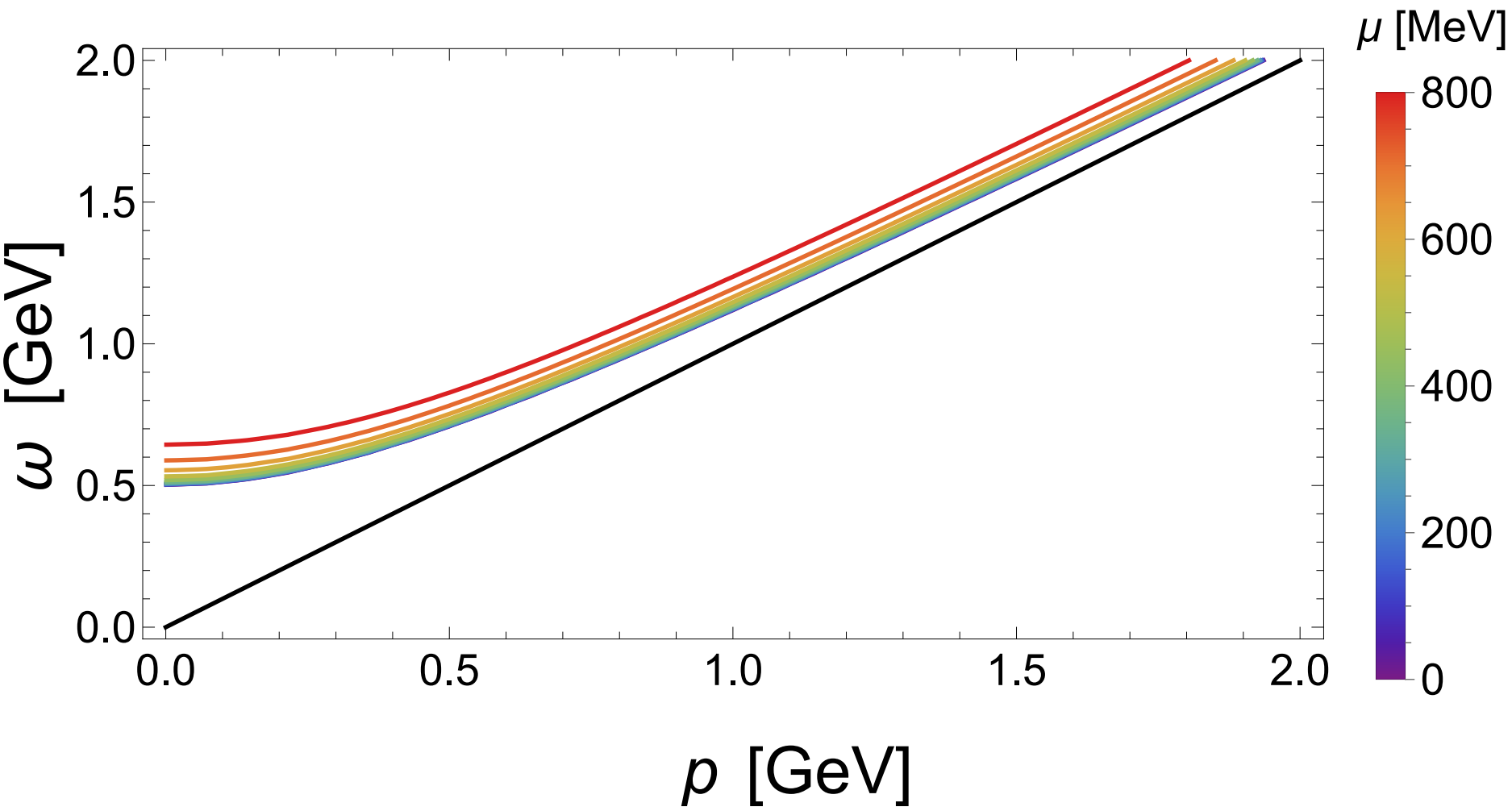
$$\omega(p) = p^2 + M_\sigma^2$$

In the limit $p \to 0$, $F(p_0/p) \to 0$, therefore,

$$\omega^2(p=0) = M_\sigma^2 = m_\sigma^2 + M_T^2$$

Dispersion relation

T =150 MeV, $g_\sigma = 10.5$, $m_\sigma = 510$ MeV



Spectral density

$$\begin{aligned}\rho(p_0,p) &= 2\mathrm{Im}\Delta^*(q_0+i\eta,q)\\ &= 2\pi Z(\omega(p))\left[\delta(p_0-\omega(p))-\delta(p_0+\omega(p))\right]+\beta(p_0,p)\end{aligned}$$

- Small p

$$Z(p)\approx\frac{1}{2\sqrt{p^2+M_\sigma^2}}$$

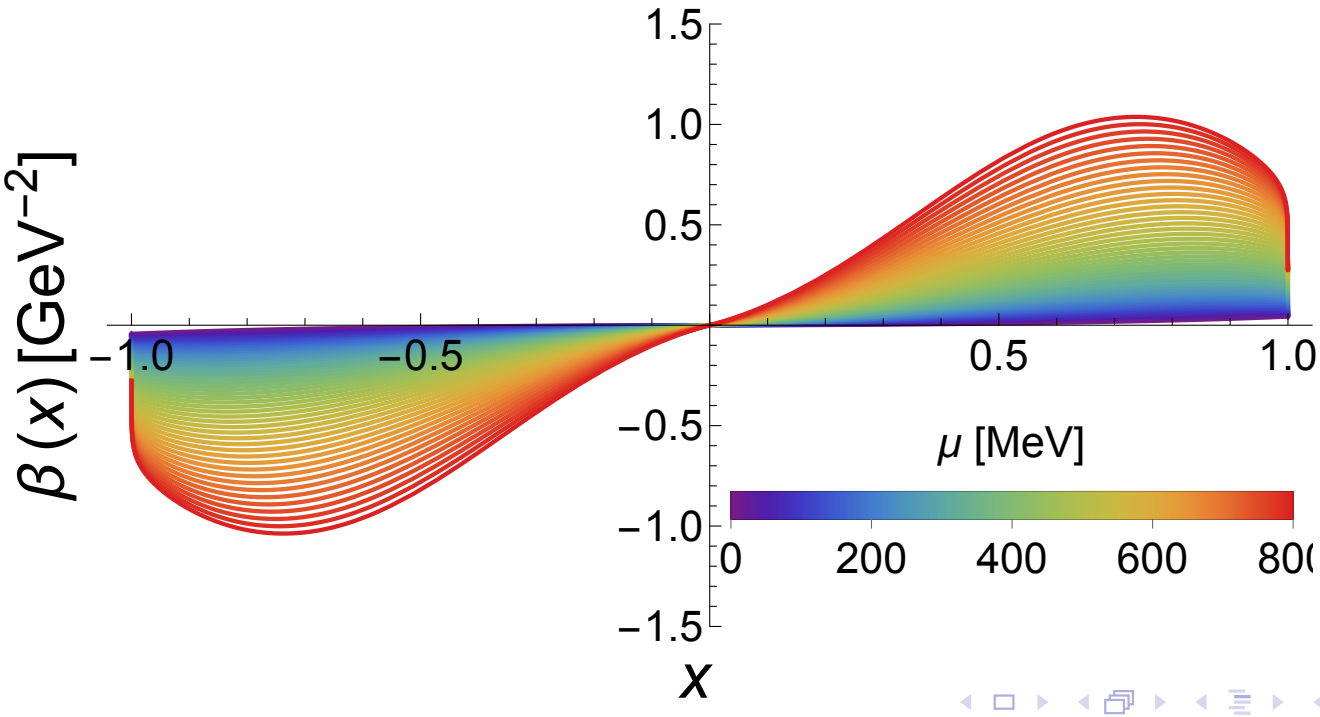
- Large p

$$Z(p)\approx\frac{12\kappa}{\lambda_1+2\lambda_2}\exp\left[-\frac{2p}{(\lambda_1+2\lambda_2)}\right]$$

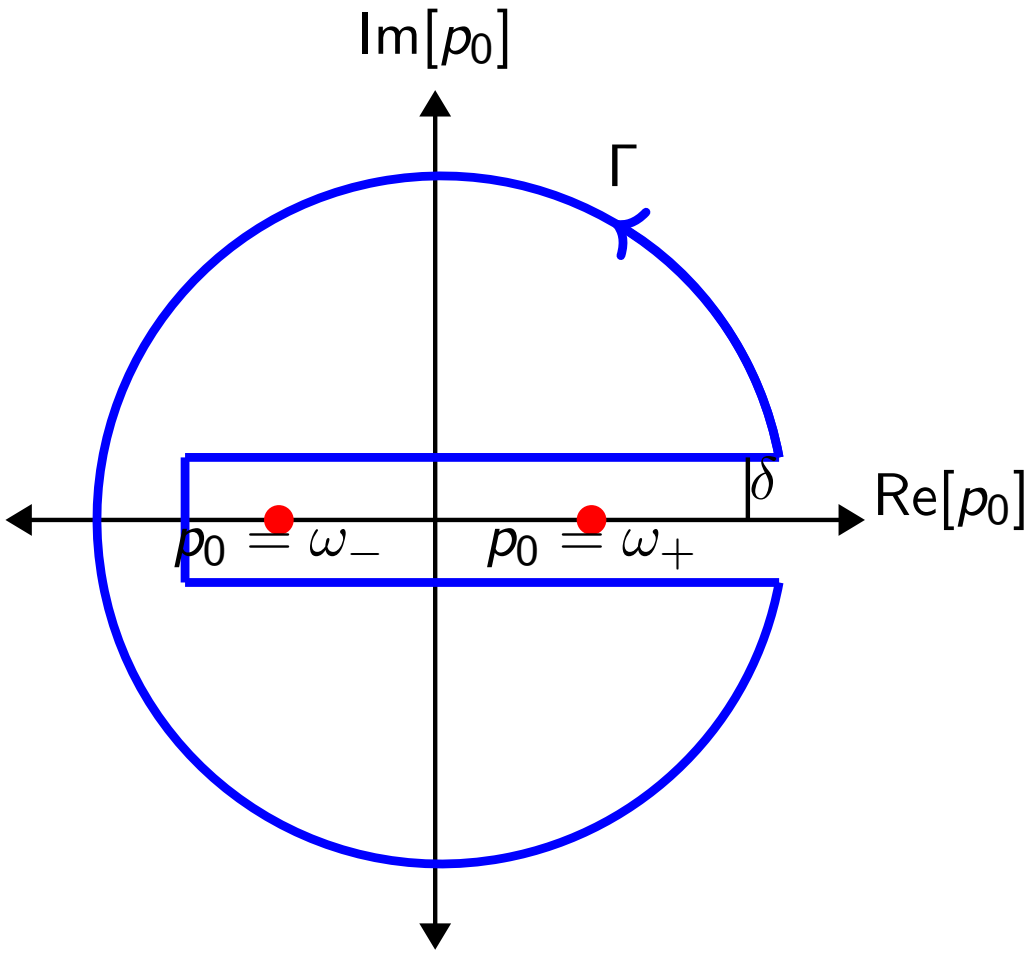
Spectral Density

$$\beta(p_0,p) = 2\pi\gamma_T p_0 A(x)\theta\left(1-x^2\right) \times \left[\left(P^2-M_\sigma^2-\gamma_T p_0 F(x)\right)^2-\left(\gamma_T p_0 A(x)\,\pi\right)^2\right]^{-1}$$

T =150 MeV, $g_\sigma = 10.5$, $m_\sigma = 510$



Sum rules



Sum rules

- Use Cauchy's theorem to write

$$
\begin{aligned}
\Delta^*(p_0,p) &= \oint_\Gamma \frac{dz}{2i\pi}\frac{\Delta^*(z,p)}{z-p_0} \\
&= \int_{-\infty}^{\infty}\frac{dp_0'}{2i\pi}\frac{\Delta^*(p_0+i\delta,p)-\Delta^*(p_0'-i\delta,p)}{p_0'-p_0} \\
&+ \oint_{\Gamma'}\frac{dz}{2i\pi}\frac{\Delta^*(z,p)}{z-p_0} \\
&= \int_{-\infty}^{\infty}\frac{dp_0'}{2\pi}\frac{\rho(p_0',p)}{p_0'-p_0} + \oint_{\Gamma'}\frac{dz}{2i\pi}\frac{\Delta^*(z,p)}{z-p_0}
\end{aligned}
$$

Sum rules

Since $\Delta^*(z,p) \sim 1/z^2$ for $z \to \infty$, there is no contribution from Γ'. On the other hand

$$\lim_{p_0 \to 0} \Delta^*(p_0,p) = \frac{1}{p^2 + m_\sigma^2 + M_T^2}$$

As a consequence, thre fist sum rule is

$$\int_{-\infty}^{\infty} \frac{dp_0'}{2\pi} \frac{\rho(p_0',p)}{p_0'} = \frac{1}{p^2 + m_\sigma^2 + M_T^2}$$

Sum rules

Other sum rules can be obtained considering the asymptotic expansion

$$\frac{1}{p_0' - p_0} = -\frac{1}{p_0} \sum_{n=0}^{\infty} \left(\frac{p_0'}{p_0} \right)^{2n+1}$$

which implies

$$\begin{aligned} \Delta^*(p_0, p) &= \int_{-\infty}^{\infty} \frac{dp_0'}{2\pi} \frac{\rho(p_0', p)}{p_0' - p_0} \\ &= -\frac{1}{p_0} \sum_{n=0}^{\infty} \int_{-\infty}^{\infty} \frac{dp_0'}{2\pi} \left(\frac{p_0'}{p_0} \right)^{2n+1} \rho(p_0', p) \end{aligned}$$

Sum rules

For $n = 0$

$$\int_{-\infty}^{\infty} \frac{dp_0'}{2\pi} p_0' \ \rho(p_0', p) = 1$$

For $n = 1$

$$\int_{-\infty}^{\infty} \frac{dp_0'}{2\pi} p_0'^3 \ \rho(p_0', p) = p^2 + M_\sigma^2$$

For $n = 2$

$$\int_{-\infty}^{\infty} \frac{dp_0'}{2\pi} p_0'^5 \ \rho(p_0', p) \ = \ (p^2 + M_\sigma^2)^2$$

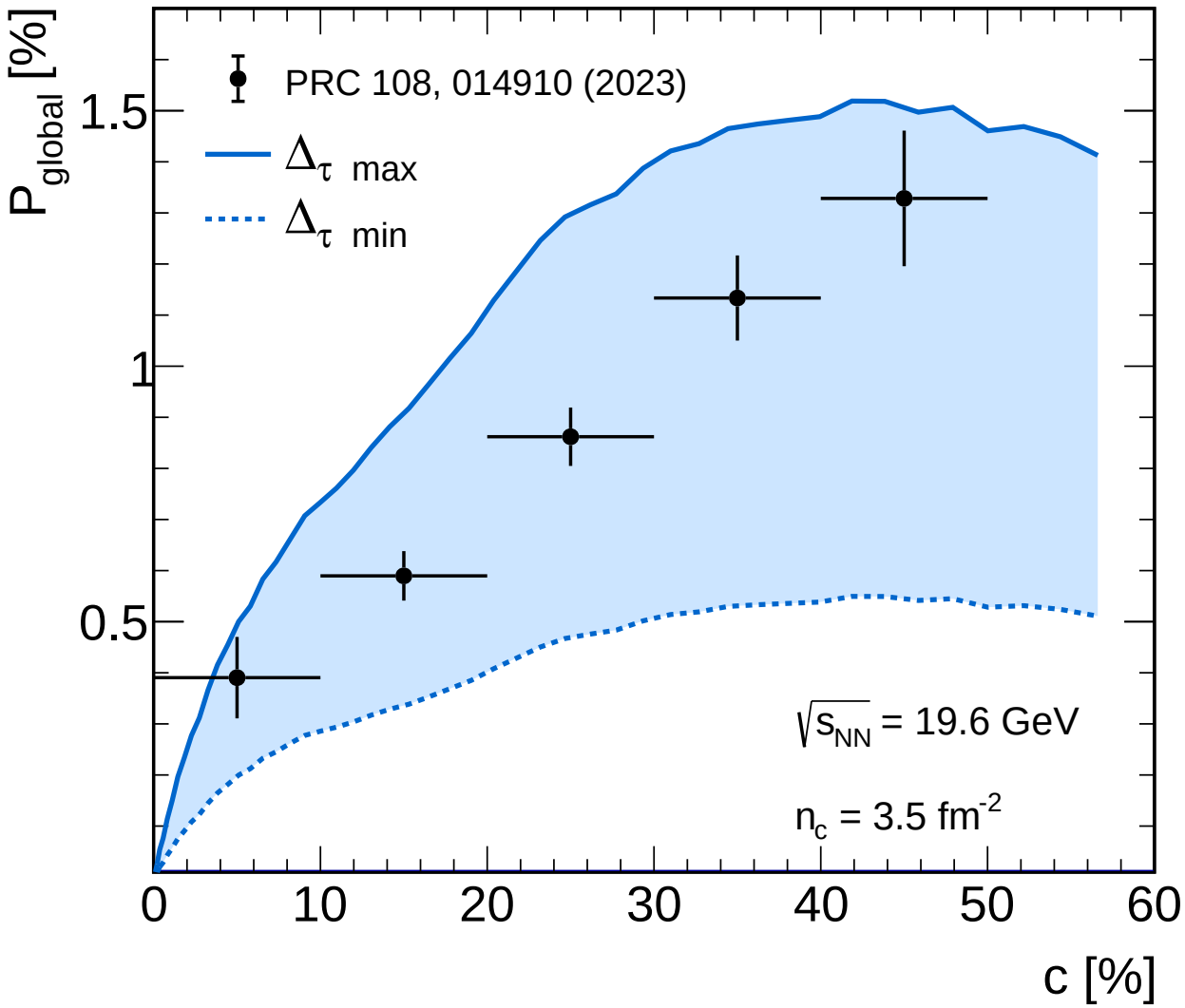
Glauber model to compute the number of Λs

$$
\begin{aligned}
n_p(\vec{s},\vec{b}) &= T_A(\vec{s})\left[1-e^{-\sigma_{NN}(\sqrt{s_{NN}})\,T_B(\vec{s}-\vec{b})}\right] \\
&+ T_B(\vec{s}-\vec{b})\left[1-e^{-\sigma_{NN}(\sqrt{s_{NN}})\,T_A(\vec{s})}\right] \qquad \textbf{number of participants} \\
T_A(\vec{s}) &= \int_{-\infty}^{\infty} dz\,\rho_A(z,\vec{s}) = \int_{-\infty}^{\infty} dz\,\frac{\rho_0}{1+e^{\frac{r-R_A}{a}}}, \qquad \textbf{thickness function} \\
N_{p\ QGP} &= \int d^2s\ n_p(\vec{s},\vec{b})\ \theta\left[n_p(\vec{s},\vec{b})-n_c\right] \\
\langle s\rangle &= N_{\Lambda\ QGP} = 0.0025\ N_{p\ QGP} \\
N_{\Lambda\ REC} &= \sigma^{\Lambda}_{NN}\int d^2s\ T_B(\vec{s}-\vec{b})\,T_A(\vec{s})\ \theta\left[n_c-n_p(\vec{s},\vec{b})\right]
\end{aligned}
$$

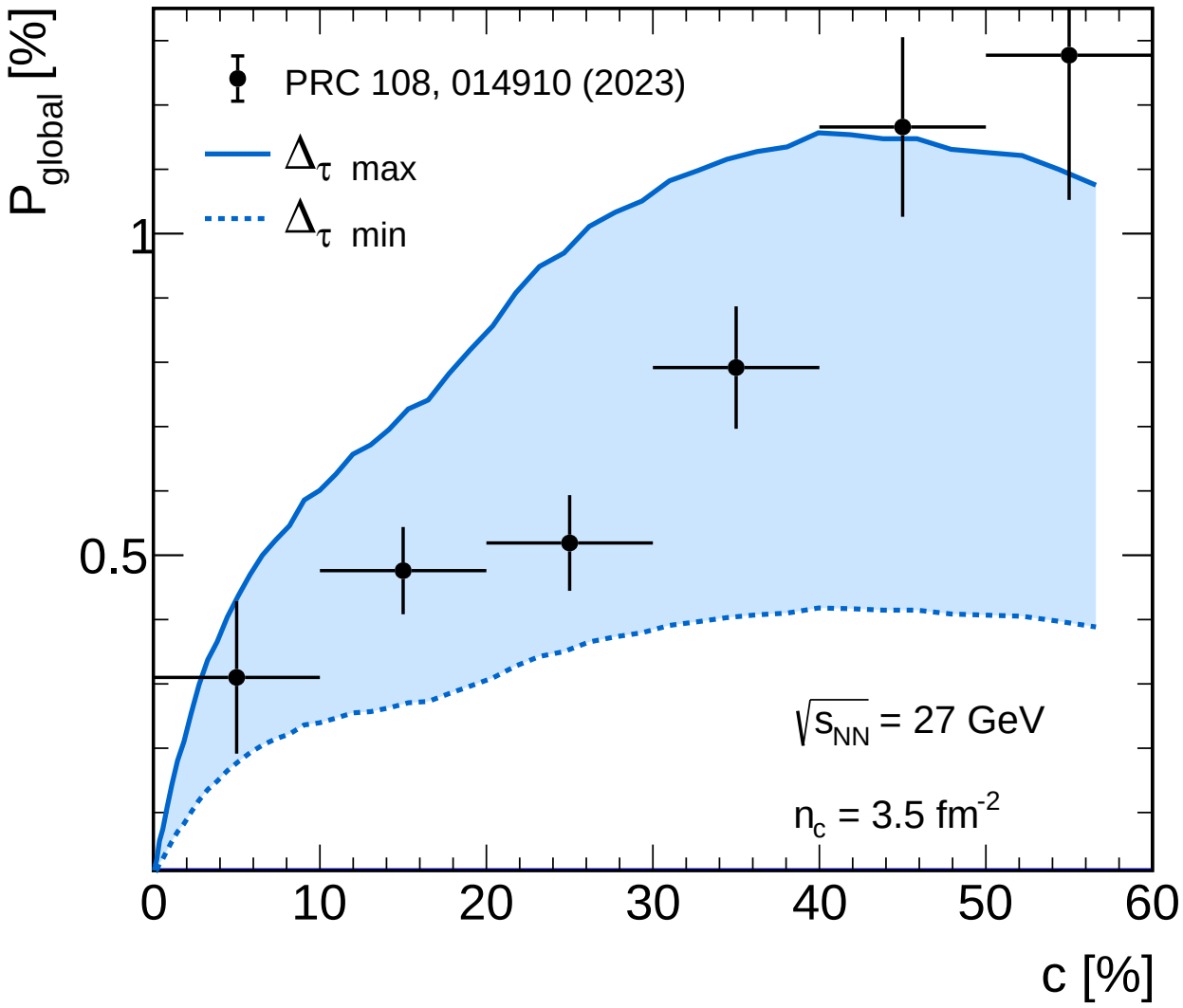
Reaction lifetimes, volumes and angular velocity

$$
\begin{aligned}
\Delta\tau^{\max}_{REC} &= \left(2.05\ln(\sqrt{s_{NN}}/1\ \text{GeV}) + \frac{12.81}{\sqrt{s_{NN}}} - 4.5\right)\ \text{fm} \\
\Delta\tau^{\min}_{REC} &= \left(1.23\ln(\sqrt{s_{NN}}/1\ \text{GeV}) + \frac{7.68}{\sqrt{s_{NN}}} - 2.7\right)\ \text{fm}, \\
V_{REC} &= A_{REC}\Delta\tau_{REC}, \\
V_{QGP} &= A_{QGP}\Delta\tau_{QGP} \\
\Omega(\sqrt{s_{NN}}, b) &= \frac{b^2}{2V_N}\left[1 + 2\left(\frac{M_P}{\sqrt{s_{NN}}}\right)^{\frac{1}{2}}\right]
\end{aligned}
$$

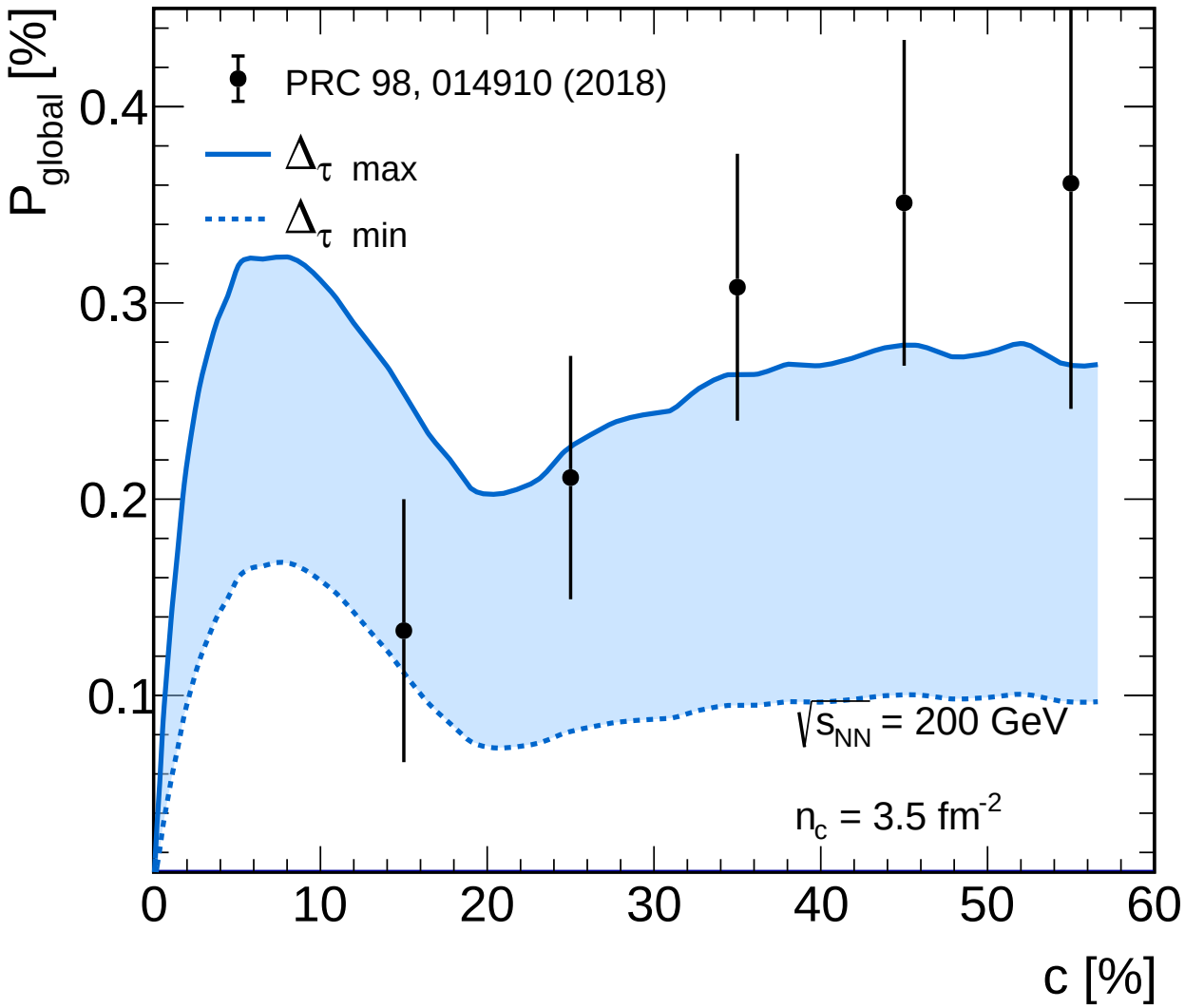
Results


PRC 108, 014910 (2023)
Δ_τ max
Δ_τ min
P_{global} [%]
1.5
1
0.5
0
10
20
30
40
50
60
c [%]
$\sqrt{s_{NN}}$ = 19.6 GeV
n_c = 3.5 fm^{-2}

Results


PRC 108, 014910 (2023)
Δ_τ max
Δ_τ min
P_{global} [%]
1
0.5
$\sqrt{s_{NN}}$ = 27 GeV
n_c = 3.5 fm^{-2}
0
10
20
30
40
50
60
c [%]

Results


PRC 98, 014910 (2018)
Δ_τ max
Δ_τ min
P_{global} [%]
0.4
0.3
0.2
0.1
$\sqrt{s_{NN}}$ = 200 GeV
n_c = 3.5 fm^{-2}
0
10
20
30
40
50
60
c [%]