Global polarization within the 3FD model

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Motivation

Do the global polarization, angular momentum and flow correlate?

Important: global polarization is measured in midrapidity region $|\eta| < 1$.

Thermodynamic approach to Λ polarization

Relativistic Thermal Vorticity

$$\varpi_{\mu\nu} = \frac{1}{2}(\partial_\nu \hat{\beta}_\mu - \partial_\mu \hat{\beta}_\nu),$$

where $\hat{\beta}_\mu = \hbar \beta_\mu$ and $\beta_\mu = u_\nu / T$ with $T =$ the local temperature.

ϖ is related to **mean spin vector, $\Pi^\mu(p)$, of a spin 1/2 particle** in a relativistic fluid [F. Becattini, et al., Annals Phys. **338**, 32 (2013)]

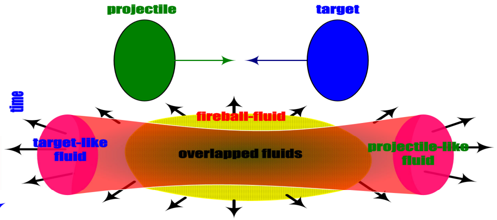
$$\Pi^\mu(p) = \frac{1}{8m} \frac{\int_\Sigma \mathrm{d}\Sigma_\lambda p^\lambda n_F (1 - n_F)\, p_\sigma \epsilon^{\mu\nu\rho\sigma} \partial_\nu \hat{\beta}_\rho}{\int_\Sigma \Sigma_\lambda p^\lambda \, n_F},$$

n_F = Fermi-Dirac distribution function,
integration over the freeze-out hypersurface Σ.

"'**an educated ansatz for the Wigner function** of the Dirac field"'

3FD Equations of Motion

Produced particles populate mid-rapidity $\Rightarrow$ fireball fluid



Target-like fluid: $\partial_\mu J^\mu_t = 0$ $\qquad$ $\partial_\mu T^{\mu\nu}_t = -F^\nu_{tp} + F^\nu_{ft}$

Leading particles carry bar. charge $\qquad$ exchange/emission

Projectile-like fluid: $\partial_\mu J^\mu_p = 0$, $\qquad$ $\partial_\mu T^{\mu\nu}_p = -F^\nu_{pt} + F^\nu_{fp}$

Fireball fluid: $J^\mu_f = 0$, $\qquad$ $\partial_\mu T^{\mu\nu}_f = F^\nu_{pt} + F^\nu_{tp} - F^\nu_{fp} - F^\nu_{ft}$

Baryon-free fluid $\qquad$ Source term $\qquad$ Exchange

The source term is delayed due to a formation time τ

Total energy-momentum conservation:

$$\partial_\mu (T^{\mu\nu}_p + T^{\mu\nu}_t + T^{\mu\nu}_f) = 0$$

Hydrodymanic densities

Baryon current:

$J^{\mu}_{\alpha} = n_{\alpha} u^{\mu}_{\alpha}$

n_{α} = baryon density of α-fluid

u^{μ}_{α} = 4-velocity of α-fluid

Energy-momentum tensor:

$T^{\mu\nu}_{\alpha} = (\varepsilon_{\alpha} + P_{\alpha}) u^{\mu}_{\alpha} u^{\nu}_{\alpha} - g_{\mu\nu} P_{\alpha}$

ε_{α} = energy density

P_{α} = pressure

+ Equation of state:

$$P = P(n, \varepsilon)$$

Physical Input

- **Equation of State**
  crossover EoS and 1st-order-phase-transition (1PT) EoS
  [Khvorostukhin, Skokov, Redlich, Toneev, (2006)]

- **Friction**
  calculated in hadronic phase (Satarov, SJNP 1990)
  fitted to reproduce the baryon stopping in QGP phase

- **Freeze-out**
  Freeze-out energy density $\varepsilon_{frz} = 0.4$ GeV/fm^3

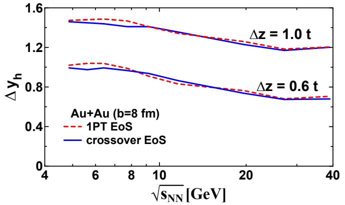
All parameters of the 3FD model are exactly the same as in calculations of other (bulk and flow) observables

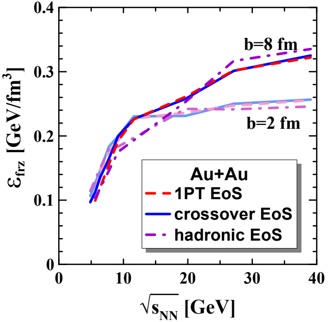
Estimation of Polarization

Polarization

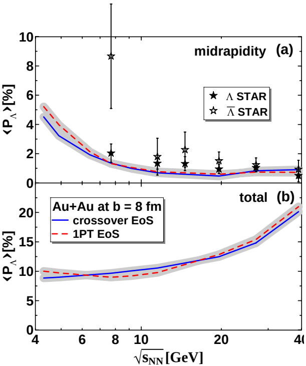
04.08.2020

- based on mean vorticity $\langle \varpi_{\mu\nu} \rangle$ and isochronous freeze-out.
- $\langle \varpi_{\mu\nu} \rangle$ averaged over "midrapidity region".
- Calculation over central region (= "midrapidity region") rather than over true midrapidity region
- Therefore, it is an estimation rather than calculation.
- Refined approach as comrared to PRC 100 (2019) 014908





“Midrapidity” Polarization



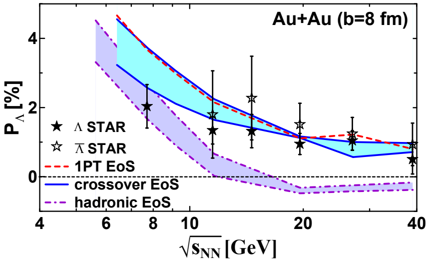
Estimation of uncertainty:

$\sim$ 20% (for midrapidity)

$\sim$ 30% (for total)

Ivanov, Toneev, Soldatov, PRC **100** (2019)

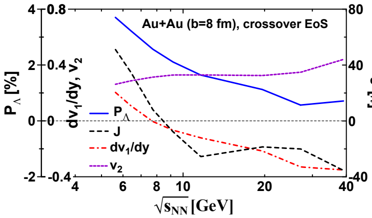
Refined estimation 2004.05166 [nucl-th]

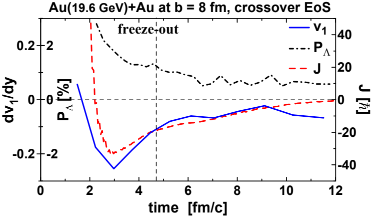


Correlations

Global polarization correlates with neither the angular momentum accumulated in the central region nor with directed and elliptic flow.

Correlation between the angular momentum and directed flow





Polarization due to axial vortical effect

Polarization

04.08.2020

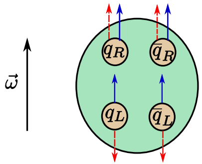
Relativistic Kinematic Vorticity = $\omega_{\mu\nu} = \frac{1}{2}(\partial_\nu u_\mu - \partial_\mu u_\nu)$

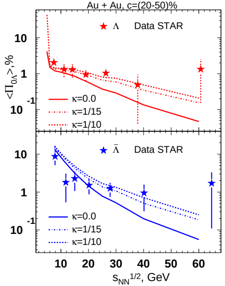
u_μ = collective local 4-velocity of the matter,

is relevant to the **axial vortical effect**

[A. Vilenkin, PRD 20, 1807 (1979); 21, 2260 (1980).]

$$\text{strange axial current} = J^\nu_{5s} = N_c \int d^3x \left(\frac{\mu_s^2}{2\pi^2} + \kappa\frac{T^2}{6}\right) \epsilon^{\nu\alpha\beta\gamma} u_\alpha \partial_\beta u_\gamma$$





$$\text{polarization} = \langle \Pi^\Lambda \rangle = \left\langle \frac{m_\Lambda}{N_\Lambda\, p_y} J^0_{5s} \right\rangle$$

μ_s = chemical potential of s-quark, T = temperature,

κ = a variable parameter,

p_y = Λ's momentum transverse to reaction plane

M. Baznat, K. Gudima, A. Sorin and O. Teryaev,

PRC 97, 041902 (2018)

Polarization due to AVE

Polarization

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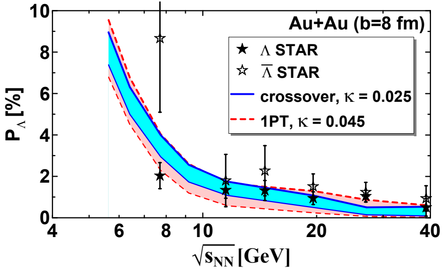
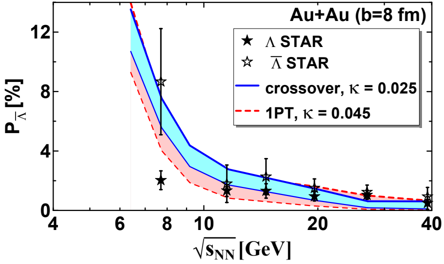
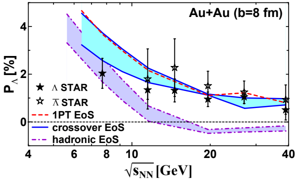
AVE explains difference between P_Λ and $P_{\bar{\Lambda}}$

AVE P exceeds thermodynamic P at low collision energies





Thermodynamic



Summary

- **Global Λ polarization correlates with neither the angular momentum accumulated in the central region nor with v_1 and v_2 flow**

- **Correlation between the angular momentum and directed flow**

- **AVE well describes STAR data on global polarization and explains difference between P_Λ and $P_{\bar{\Lambda}}$**
- AVE P essentially exceeds thermodynamic P at low collision energies