

Spin polarization from heavy-ions to O-O collisions

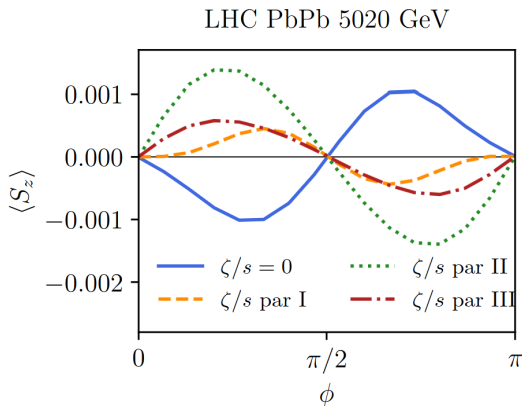
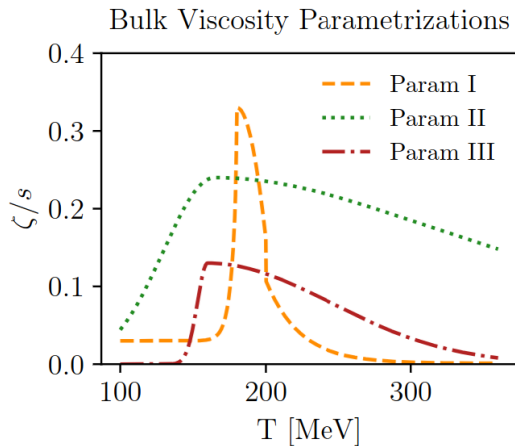
Based on ongoing work with E. Grossi, A. Vignoli (UniFi & INFN), A. Palermo (IDP Tours), D. Roselli (CUHK)

Francesco Palli (UniFi & INFN)

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Motivation

Longitudinal polarization is strongly sensitive to **bulk viscosity** parameterization at LHC energies and can therefore be used to constrain the transport coefficients

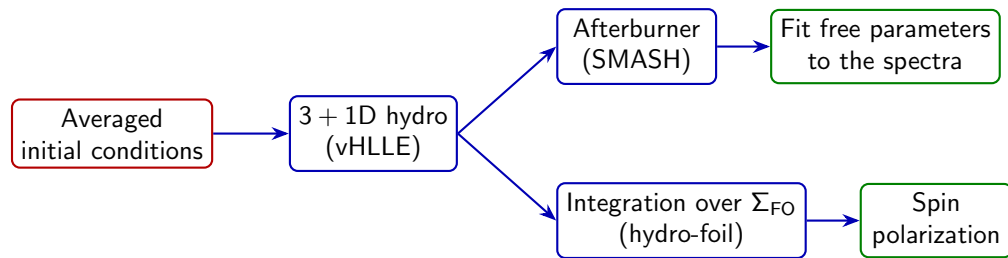


- **Framework** (initial conditions and workflow description) [\[2404.14295\]](#)
- **New results for heavy-ions** (PbPb @ 5.36 TeV)
- **Preliminary results for OO** (5.36 TeV)
- **Fluctuations**

Question

Vorticity and shear induced polarization with average event hydro provide a good description of spin polarization for Λ hyperons in heavy-ion collisions. Does this extend to light-ion collisions?

Model overview



Limitations (more severe for light-ions!)

- Averaging removes event-by-event fluctuations
- No pre-equilibrium dynamics is included

Initial conditions (IC)

We consider an IC model developed in [C.Shen et al. 2106.08125]. The positions of the participants in the transverse plane are sampled from a Woods-Saxon (PbPb) or from NLEFT tables (OO). The stress tensor on the $\tau = \tau_0$ slice is assumed to be

$$T^{\tau\tau} = e(x, y, \eta) \cosh(fy_{CM}) \quad T^{\tau\eta} = \frac{1}{\tau_0} e(x, y, \eta) \sinh(fy_{CM})$$

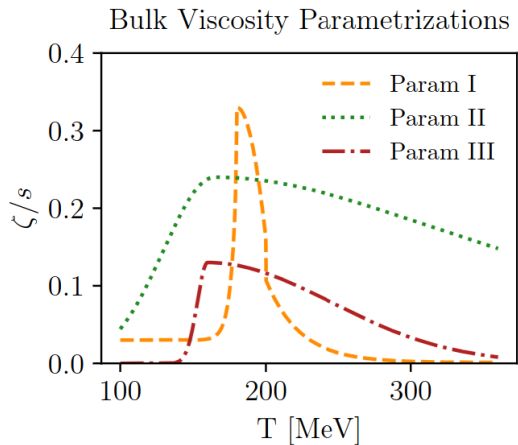
Three free parameters ($f = 0.15$ fixed) are fitted to reproduce the spectra using **SMASH**

Parameter	Description
w [fm]	Size of the initial hot spot
η_0	Size of the mid-rapidity plateau
σ_η	Space-time rapidity fall off width
f	Initial longitudinal flow fraction

Average event hydro

Average profile of 20k events for each centrality class. The (3 + 1)D viscous hydro is performed using **vHLL** [Karpenko et al.]

Parameter	Value
τ_0 [fm/c]	1
e_{crit} [GeV/fm ³]	0.4
η/s	0.08
ζ/s	Param. III



Spin polarization at freezeout

Spin polarization is obtained through an integration over the freezeout hypersurface Σ using **hydro-foil** [A. Palermo]

$$S^\mu(p) = -\epsilon^{\mu\rho\sigma\tau} p_\tau \frac{\int_\Sigma d\Sigma \cdot p n_F(1 - n_F) \left[\omega_{\rho\sigma} + 2 \hat{t}_\rho \frac{p^\lambda}{\epsilon} \Xi_{\lambda\sigma} \right]}{8mT_H \int_\Sigma d\Sigma \cdot p n_F}$$

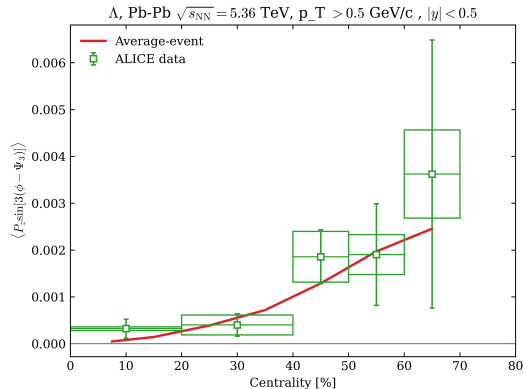
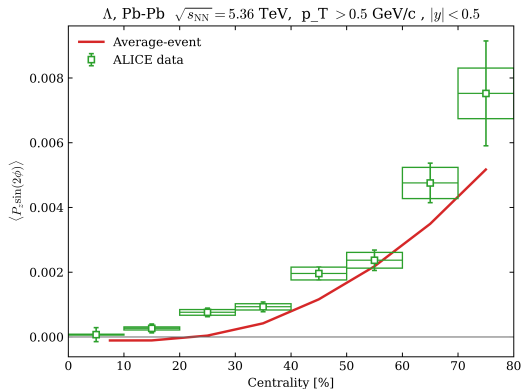
with kinematical **vorticity** and **shear** defined as

$$\omega_{\mu\nu} = \frac{1}{2} (\partial_\nu u_\mu - \partial_\mu u_\nu) \quad \Xi_{\mu\nu} = \frac{1}{2} (\partial_\nu u_\mu + \partial_\mu u_\nu)$$

A key hypothesis is the **isothermal approximation**, that is the hadronization hypersurface is at $T = T_H$ ($\sim$ true at high energies)

New formula for spin polarization that does not rely on this hypothesis (numerical tests ongoing) [Sheng, Roselli, Becattini 2509.14301]

Pb-Pb at $\sqrt{s_{NN}} = 5.36$ TeV

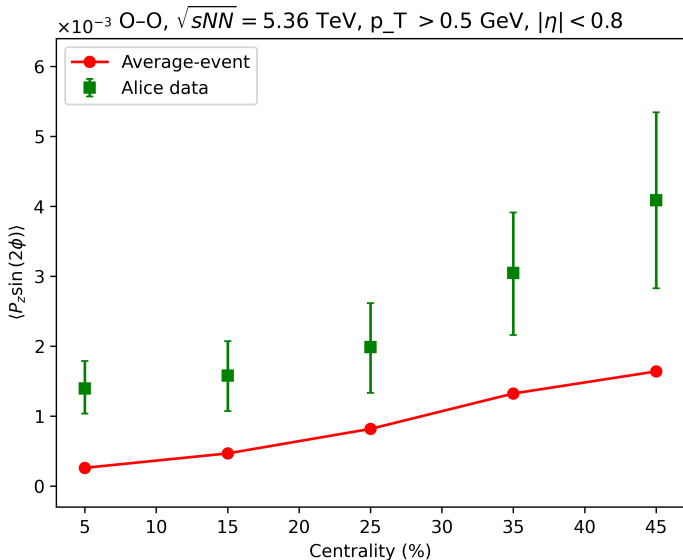


ALICE data from [\[2606.18070\]](#)

O-O at $\sqrt{s_{NN}} = 5.36$ TeV

Preliminary ALICE data suggest that polarization is non-zero for more central OO collisions, unlike in Pb-Pb
[\[ALI-PREL-620896\]](#)

The model captures the centrality trend but **underestimates** the magnitude of the Λ polarization



Fluctuations

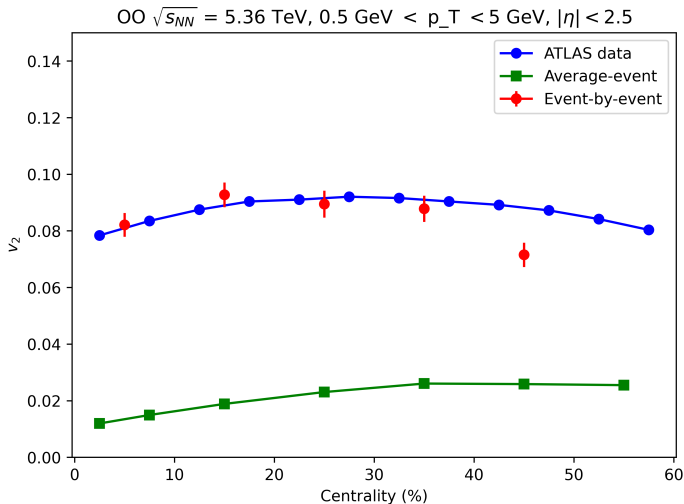
Including event-by-event fluctuations substantially improves the description of O-O elliptic flow

Event-by-event sample

- 200 hydro events per centrality class
- 100 SMASH oversamples per hydro event

Polarization **ongoing**

ATLAS data from [\[2509.05171\]](#)



Spin polarization is a powerful probe of QGP properties

- Average event hydro with no pre-equilibrium evolution provides a good description of global and local polarization in heavy-ion collisions
- The same model applied to OO collisions reproduces the centrality dependence but systematically **underestimates** polarization
- Event-by-event fluctuations substantially improve the description of OO elliptic flow, while their effect on longitudinal polarization is currently being quantified

Outlook

- Inclusion of pre-equilibrium dynamics
- Different IC models

Backup

Initial conditions

The thickness function is given by

$$T_{A(B)} = \sum_{i \in A(B)} \frac{1}{2\pi w^2} \exp \left[-\frac{(x - x_i)^2 + (y - y_i)^2}{2w^2} \right]$$

Local four-momentum per unit transverse area is

$$\frac{dE}{d^2\mathbf{x}_T} = [T_A + T_B] m_N \cosh y_{\text{beam}} = M \cosh y_{\text{CM}}$$

$$\frac{dP_z}{d^2\mathbf{x}_T} = [T_A - T_B] m_N \sinh y_{\text{beam}} = M \sinh y_{\text{CM}}$$

where $y_{\text{beam}} = \text{arccosh} \frac{\sqrt{s_{NN}}}{2m_N}$ and $y_{\text{CM}} = \text{arctanh} \left(\frac{T_A - T_B}{T_A + T_B} \tanh y_{\text{beam}} \right)$

M is the **invariant mass**

$$M(x, y) = m_N \sqrt{T_A^2 + T_B^2 + 2 T_A T_B \cosh 2y_{\text{beam}}}$$

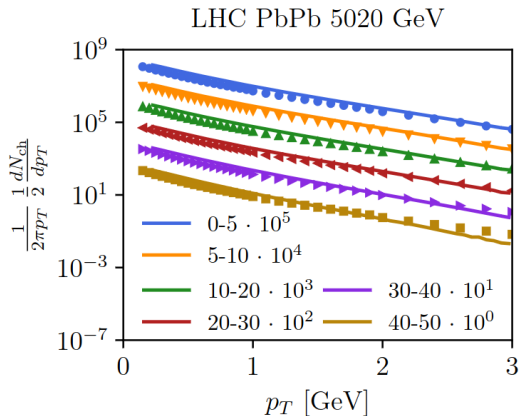
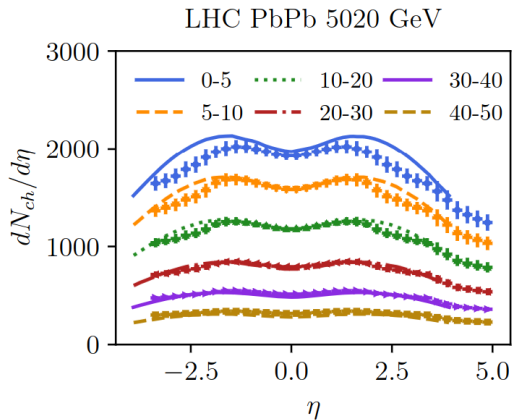
Requiring energy and momentum conservation when mapping to hydrodynamics, we get a set of constraints on the stress tensor and therefore on $e(x, y, \eta)$

$$e(x, y, \eta) = \mathcal{N}_e(x, y, w) \exp \left[-\frac{(|\eta - (y_{CM} - y_L)| - \eta_0)^2}{2\sigma_\eta^2} \times \theta(|\eta - (y_{CM} - y_L)| - \eta_0) \right]$$

A similar construction is performed for $J^\mu(x, y, \eta)$

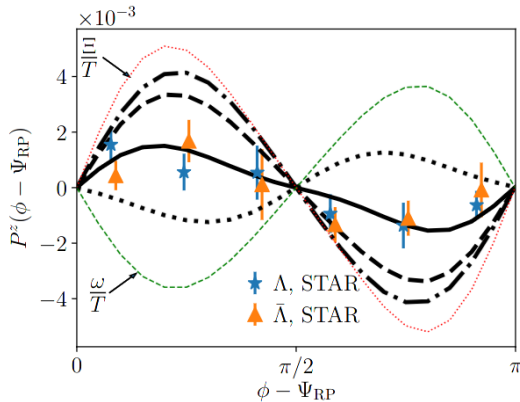
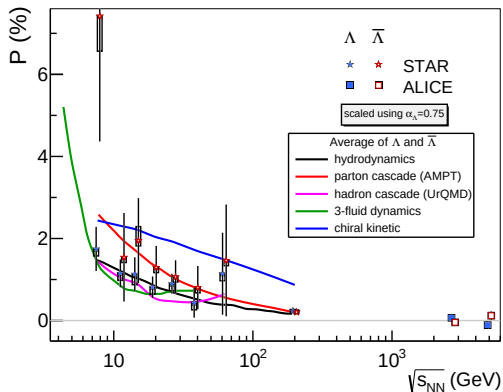
Fitting to the spectra

IC free parameters are fitted to reproduce the spectra using **SMASH**

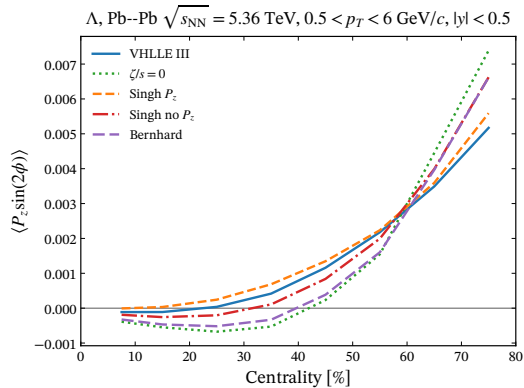
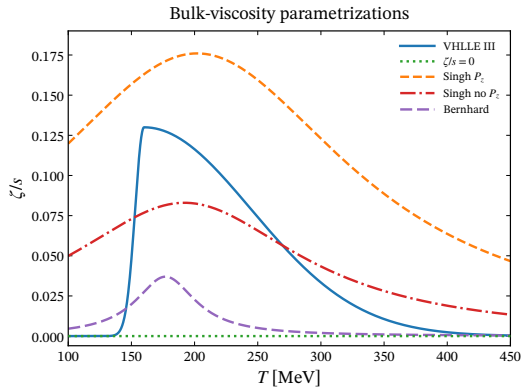


Vorticity vs shear

The vorticity contribution is enough for **global** polarization but the shear one is needed for **local** polarization [Becattini et al '21]



Second harmonic and bulk viscosity



Pz and bulk viscosity

