Global polarization of Λ and $\bar{\Lambda}$ hyperons in Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV

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On behalf of the ALICE collaboration

Motivation

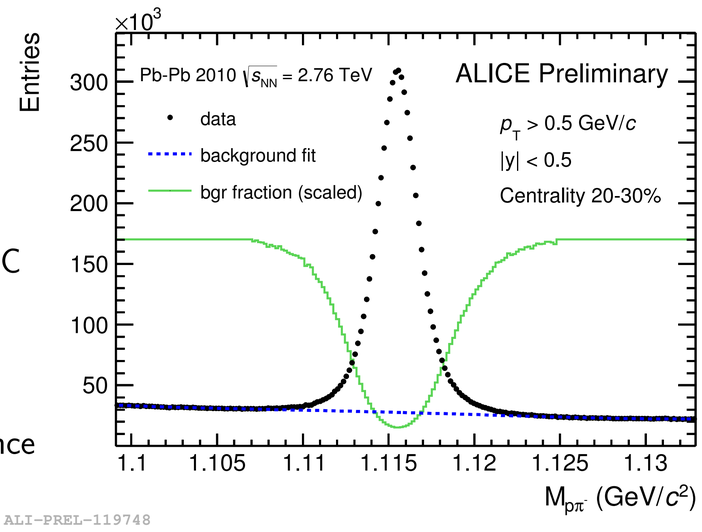
- The system created in **non-central** nucleus–nucleus collisions possesses large orbital angular momentum.
- Produced particles can become globally polarized along the direction of the system's angular momentum.
- The global polarization measurement for Λ and $\bar{\Lambda}$ hyperons further improves our understanding of the dynamics of the colliding system (see Ref. [1] for a recent overview):
  - Chiral Magnetic Effect (CME) – the global polarization is proportional to induced magnetic field.
  - Chiral Vortical Effect (CVE) – the global polarization is proportional to vorticity of created state of matter.
  - The difference in P_Λ and $P_{\bar{\Lambda}}$ disentangles CME and CVE.
- The vorticity is important for anisotropic (e.g. directed) flow.

Experimental method

Polarization is measured using anisotropic flow techniques:

$$P_{\Lambda,\bar{\Lambda}} = \mp\frac{8}{\pi\alpha_{\Lambda,\bar{\Lambda}}} \times \frac{\langle \sin(\phi_p^* - \psi^{\rm ZDCA,C})\rangle}{\sqrt{-\langle\cos(\psi^{\rm ZDCA} - \psi^{\rm ZDCC})\rangle}}$$

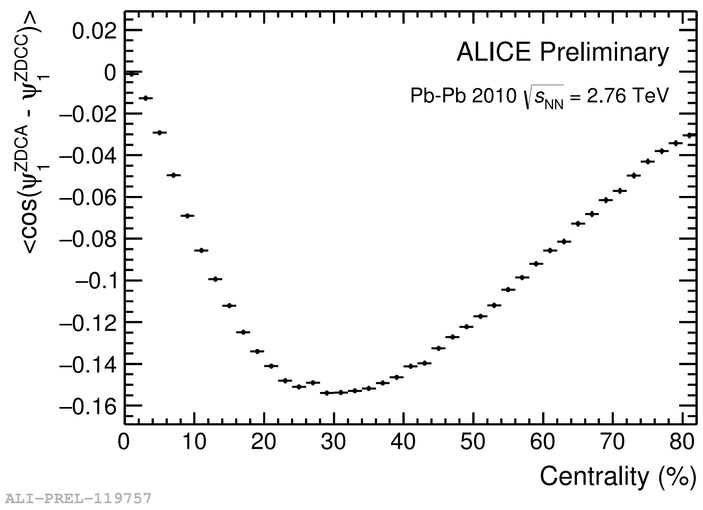
- ALICE Pb–Pb data of 2010 and 2011 (50M events)
- hyperon reconstruction: $\Lambda \to {\rm p} + \pi^-$ and $\bar{\Lambda} \to \bar{\rm p} + \pi^+$
- (anti-)proton and pion tracks reconstructed in ITS+TPC
- event plane reconstruction with neutron ZDC detectors
- ϕ_p^* – azimuthal angle of p or $\bar{\rm p}$ in hyperon rest frame
- $\alpha_{\Lambda,\bar{\Lambda}} = \pm(0.642 \pm 0.013)$ – hyperon decay parameter
- not discussed: a small A/C side ZDC resolution difference
- Ref. [2]: an earlier measurement + intro + formulas



Event plane reconstruction with nZDC detectors

The two neutron Zero Degree Calorimeters have 2 × 2-tower (7 × 7 cm^2) structure and measure energy deposited by spectator neutrons. They are located on the beam axis 114 m away on both A and C sides from the IP. Raw (uncorrected) flow vectors are evaluated in each event separately for A and C sides:

$$(X, Y) = \sum_{i=1}^{4} F_i\,(\cos\phi_i,\ \sin\phi_i)$$



ϕ_i – azimuthal angles of the towers, F_i – fractions of deposited energies. The raw flow vectors are then recentered and scaled to approach the ideal equalities

$$\langle X\rangle = \langle Y\rangle = 0, \quad \langle X^2\rangle = \langle Y^2\rangle$$

The event plane angles $\psi^{\rm ZDCA,C}$ are evaluated as

$$\psi = {\rm atan2}\,(Y,\ X)$$

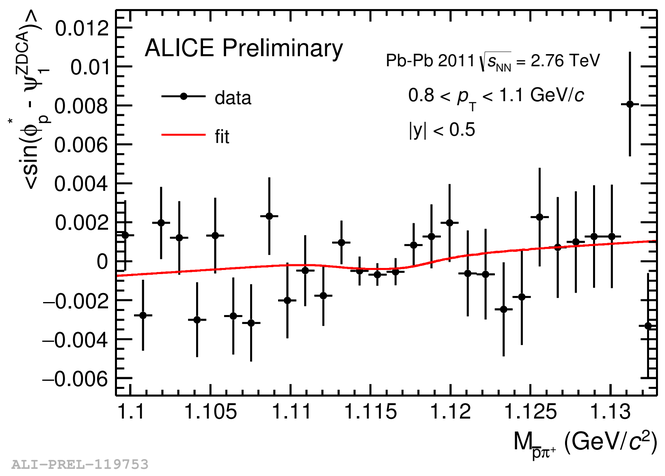
Extraction of $\langle\sin(\psi_p^* - \psi^{\rm ZDCA,C})\rangle$

The signal + background averages are evaluated as functions of reconstructed invariant mass and fitted with

$$(1 - f(m)) \times P_H + f(m) \times [\text{linear function}]$$

$f(m)$ – background fraction. The P_H corresponds to the polarization signal.

The averages are evaluated in slices of event centrality, particle's transverse momentum or particle's rapidity.



Feed-down correction

A majority of Λ are feed-down daughters of heavier particles (the very same for $\bar{\Lambda}$):

$X \to \Lambda + \ldots$ channel	Br($\Lambda + \ldots$), %	fraction f_X	$4/3 \times s(s+1)$	spin transfer t_X
$\Sigma^0 \to \Lambda + \gamma$	100	0.3 ± 0.2	1	$-1/3$
$\Sigma(1385)^{\pm,0} \to \Lambda + \pi^{\pm,0}$	87	0.3 ± 0.2	5	$1/3$
$\Omega^- \to \Lambda + K^-$	67.8	< 0.17	5	$1/3$
$\Xi^{\pm,0} \to \Lambda + \pi^{\pm,0}$	≈ 100	< 0.23	1	0.900 or 0.927

$$P_{\Lambda,\bar{\Lambda}}^{\rm meas} = (1 - \sum_X f_X) P_{\Lambda,\bar{\Lambda}}^{\rm true} + \sum_X f_X \times t_X \times P_X^{\rm true}$$

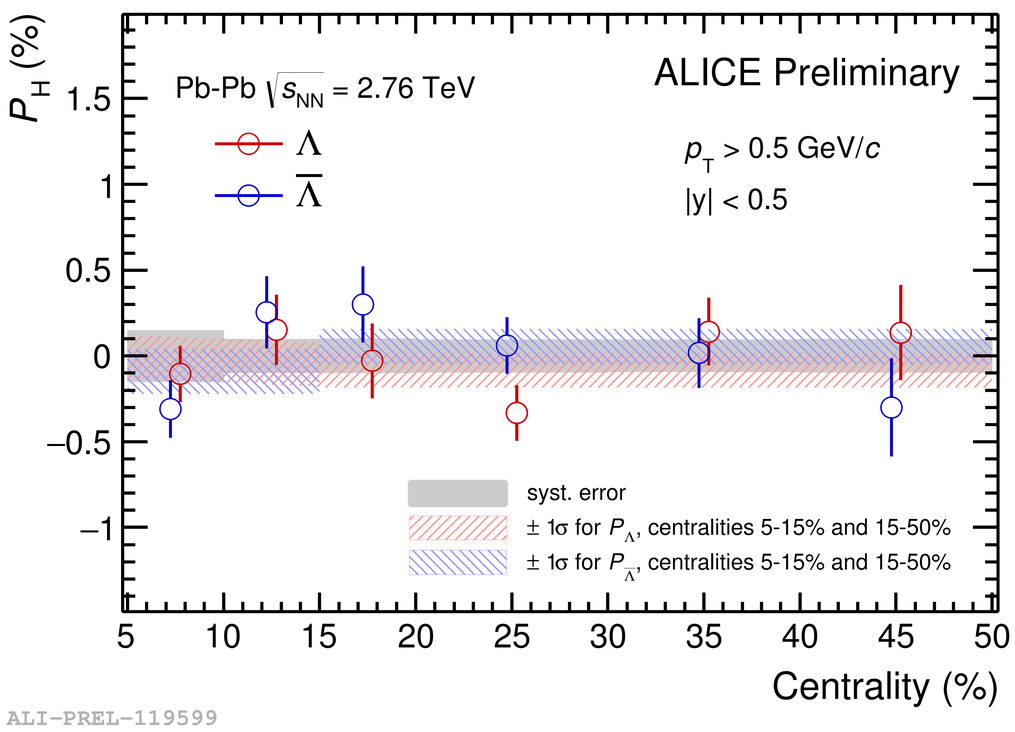
Assuming the thermal vorticity model ($P_X^{\rm true}$ are proportional to $s(s+1)$, where s is particle's spin, see Ref. [3] for a recent review):

$$P_{\Lambda,\bar{\Lambda}}^{\rm true} = P_{\Lambda,\bar{\Lambda}}^{\rm meas} \times \left(1 - \frac{4}{3} f_{\Sigma^0} + 0.87 \times \frac{2}{3} f_{\Sigma(1385)} + 0.68 \times \frac{2}{3} f_{\Omega^-} - 0.1\, f_{\Xi}\right)^{-1}$$

Ω^- and Ξ contributions are negligible, the contribution of $\Sigma(1385)$ is large only due to the model-dependent coefficient 5. A conservative estimate:

$$[\Lambda \text{ and } \bar{\Lambda} \text{ polarization scale feed-down}] = (1 - 4/3 \times f_{\Sigma^0})^{-1} = 1.7 \pm 0.5.$$

Results

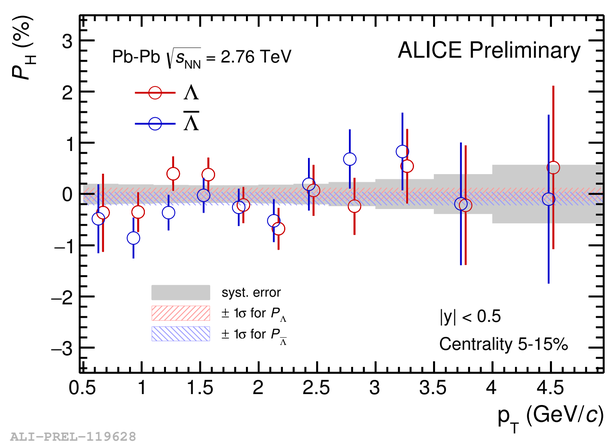


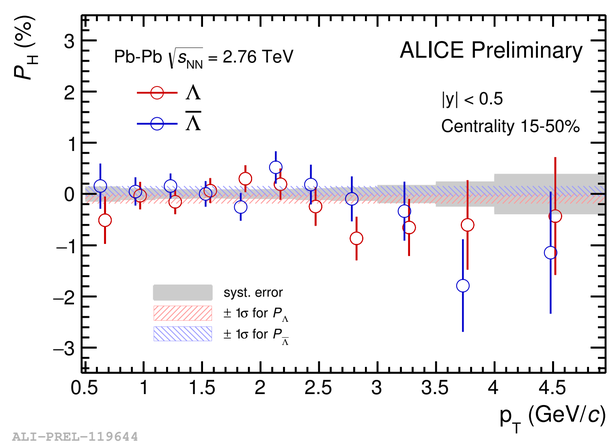
- Average polarization in wide centrality regions (feed-down not applied):

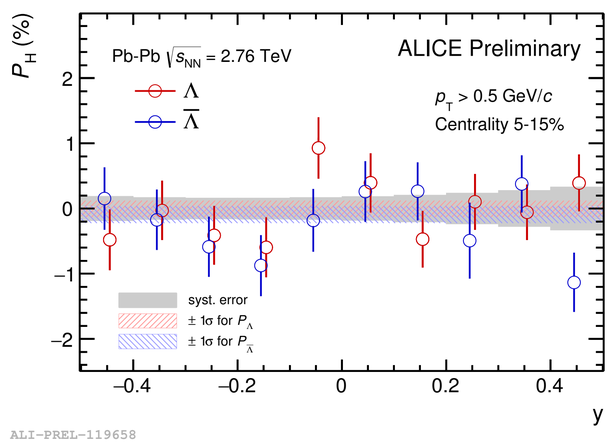
$$\text{5-15\% centrality} = \begin{cases} P_\Lambda = -0.0001 \pm 0.0013({\rm stat}) \pm 0.0004({\rm syst}) \\ P_{\bar{\Lambda}} = -0.0009 \pm 0.0013({\rm stat}) \pm 0.0008({\rm syst}) \end{cases}$$

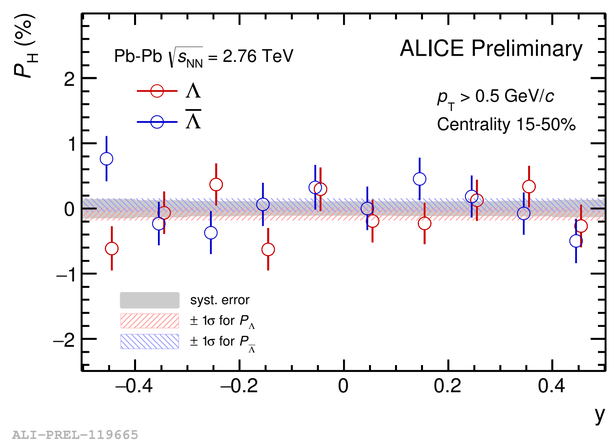
$$\text{15-50\% centrality} = \begin{cases} P_\Lambda = -0.0008 \pm 0.0010({\rm stat}) \pm 0.0004({\rm syst}) \\ P_{\bar{\Lambda}} = 0.0005 \pm 0.0010({\rm stat}) \pm 0.0003({\rm syst}) \end{cases}$$

- Main sources of systematic uncertainties: V0 selection cuts, fitting procedure and a non-uniform acceptance of pion and (anti-)proton reconstruction.









Conclusions

- The measured polarization values of Λ and $\bar{\Lambda}$ hyperons are below 0.2% and are consistent with zero within the precision of the measurement.
- Results are consistent with the trend of polarization decreasing with $\sqrt{s_{\rm NN}}$ as observed by the STAR collaboration.

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Literature

[1]. M. Lisa, for the STAR collaboration, plenary talk on "Strangeness in Quark Matter 2016".
[2]. B. I. Abelev *et al.* [STAR Collaboration], Phys. Rev. C **76**, 024915 (2007) [arXiv:0705.1691 [nucl-ex]].
[3]. F. Becattini, I. Karpenko, M. Lisa, I. Upsal and S. Voloshin, arXiv:1610.02506 [nucl-th].