Feasibility studies of Λ transverse polarization in p+p interactions within NA61/SHINE at the CERN SPS

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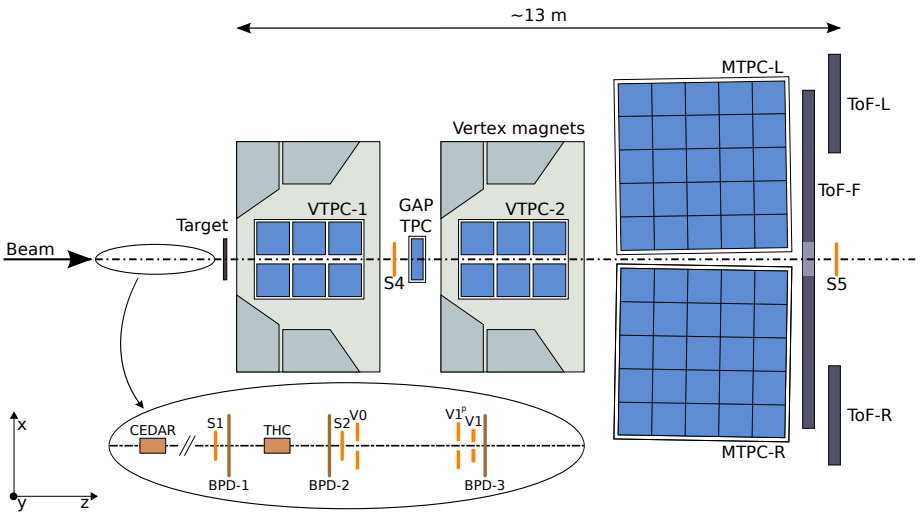
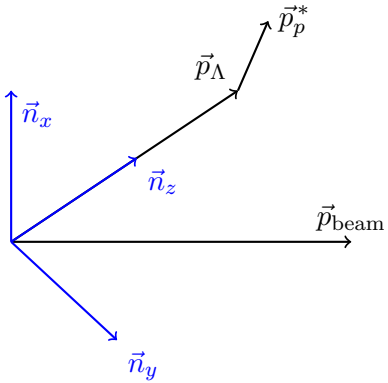


Introduction



Transverse polarization definition:

1. Rotate from Lab frame to production plane coordinate system:

$$\hat{n}_x = \frac{\vec{p}_{\text{beam}} \times \vec{p}_\Lambda}{|\vec{p}_{\text{beam}} \times \vec{p}_\Lambda|}, \quad \hat{n}_z = \frac{\vec{p}_\Lambda}{|\vec{p}_\Lambda|}, \hat{n}_y = \hat{n}_z \times \hat{n}_x$$

2. Boost along $\hat{n}_z$ to Λ rest frame.
3. Calculate cosine of angles between proton momentum $\vec{p}_p$ and axes: $\cos\theta_i = p_{p\,i}/|\vec{p}_p|$, $i = x, y, z$

Motivation

None of the theoretical models[1−3] describes well all experimental data on transverse Λ polarization, its dependence on the transverse momentum of the hyperon and on the Feynman variable x_F.

4. Fit distribution of the $\cos\theta_i$ to the theoretical prediction and extract P_i – projection of polarization.

$$f(\cos\theta_i) = \frac{1 + \alpha P_i \cos\theta_i}{2},$$

where $\alpha = 0.732 \pm 0.014$.

According to parity conservation in the strong interaction, $P_y \equiv P_z \equiv 0$ if the incident proton beam is unpolarized. Thus the measurements of P_y and P_z are usually used for checking the systematic uncertanties.

Bias due to Λ selection cuts and limited detector acceptance

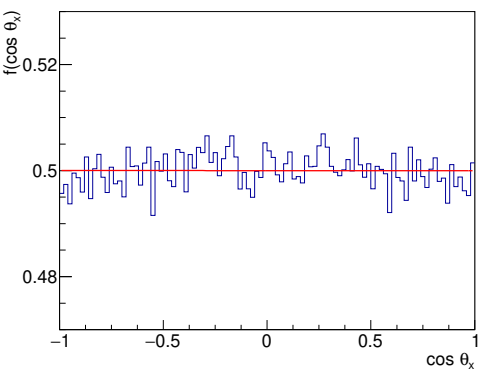
- 10^8 events of inelastic p+p simulated within EPOS[4] & Geant3[5] at 158 GeV/c beam momentum
- In EPOS, $P_x \equiv 0$: no Λ polarization.
- 10^7 Λ's with $p\pi^-$ channel

Selection cuts[6] were applied:

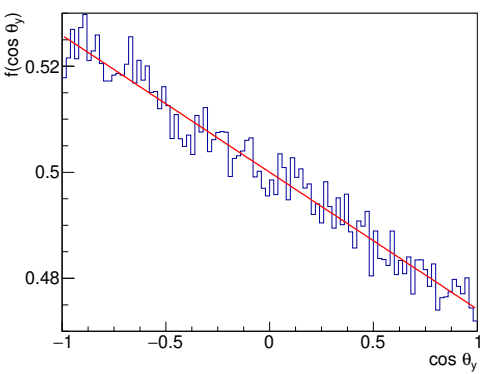
- Z difference between Λ vertex and primary vertex $\Delta z = z_\Lambda - z_{PV}$ based on rapidity y:
- Number of points in VTPC's >10 for both p and π^- tracks

$$\begin{cases} \Delta z > 10 \text{ cm}, \ y < 0.25 \\ \Delta z > 15 \text{ cm}, \ 0.25 < y < 0.75 \\ \Delta z > 40 \text{ cm}, \ 0.75 < y < 1.25 \\ \Delta z > 60 \text{ cm}, \ y > 1.25 \end{cases}$$

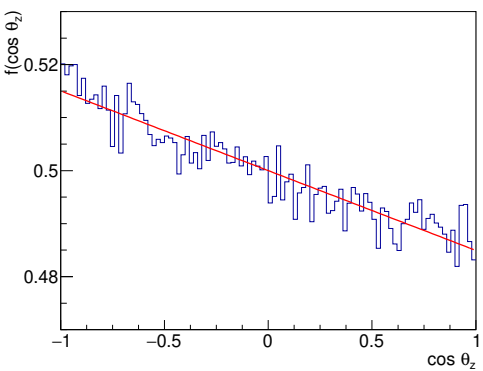
Distributions of $\cos\theta_i$:



$P_x = (-0.08 \pm 1.5) \cdot 10^{-3}$



$P_y = (-7.1 \pm 0.2) \cdot 10^{-2}$



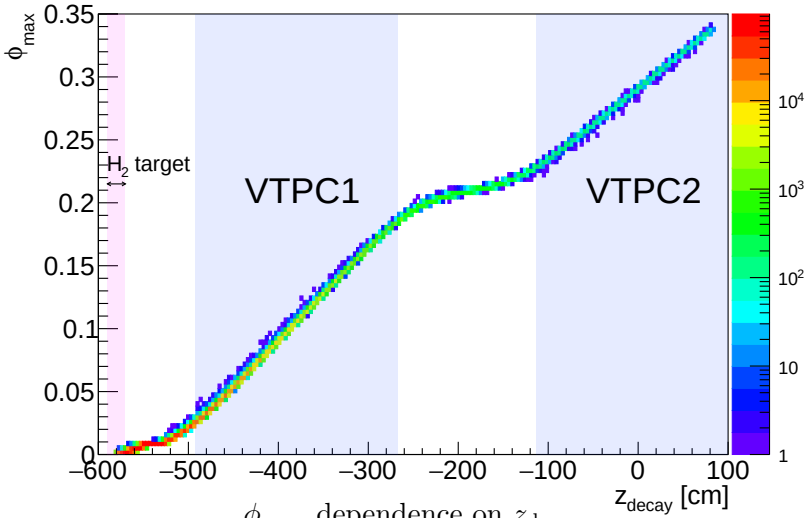
$P_z = (-4.1 \pm 0.2) \cdot 10^{-2}$

Λ precession in magnetic field

The equation of motion of the spin vector $\vec{S}$ in Λ rest frame is

$$\frac{d\vec{S}}{d\tau} = \frac{\mu_\Lambda \mu_N}{\hbar}\left[\vec{S} \times \vec{B}\right]$$

Considering $dz = \frac{p_z}{mc} c d\tau$, **integrate eq.** using NA61/SHINE magnetic field $\vec{B}$ [7]. Initial condition: generate random spin vectors $\vec{S}$ uniformly distributed on unit sphere. Among these vectors, choose one with maximum angle change, $\phi_{\text{max}} = \max(\angle(\vec{S}_{\text{init}}, \vec{S}_{\text{final}}))$.



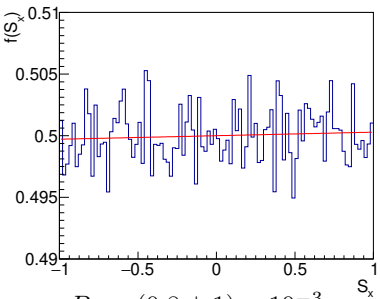
ϕ_{max} dependence on z_{decay}

To estimate magnetic field impact on Λ polarization bias, for every Λ,

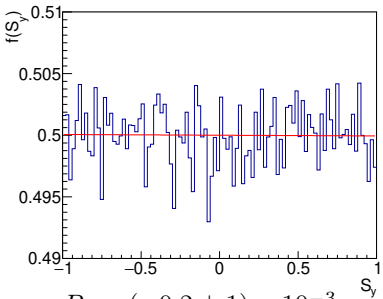
- Assign polarization vector $\vec{S}$ uniformly distributed value,
- Propagate it in magnetic field until decay,
- Project $\vec{S}$ on $\hat{n}_x$, $\hat{n}_y$, $\hat{n}_z$ and fit their distributions.

Bias due to magnetic field: Magnetic field impact on Λ polarization estimation

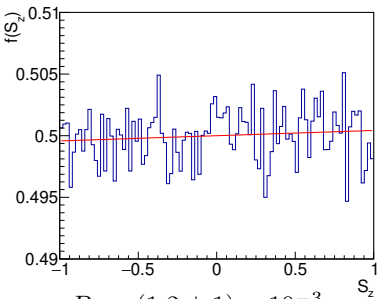
Distribution of $\vec{S}_{\text{init}}$ (before precession):



$P_x = (0.8 \pm 1) \times 10^{-3}$

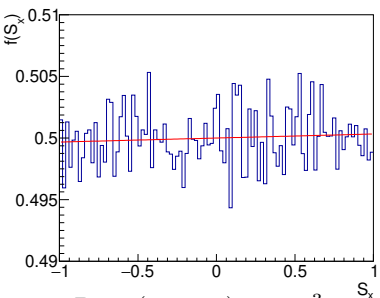


$P_y = (-0.2 \pm 1) \times 10^{-3}$

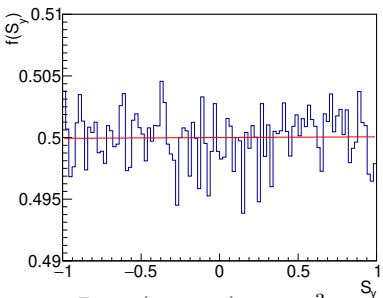


$P_z = (1.2 \pm 1) \times 10^{-3}$

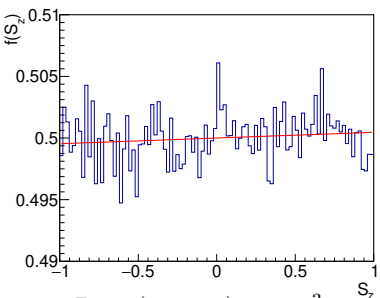
Distribution of $\vec{S}_{\text{final}}$ (after precession):



$P_x = (0.9 \pm 1) \times 10^{-3}$



$P_y = (0.2 \pm 1) \times 10^{-3}$



$P_z = (1.3 \pm 1) \times 10^{-3}$

Despite $\phi_{\max}$ is significant, polarization bias is $\sim 10^{-4}$ due to averaging over all Λs.

Summary

- NA61/SHINE has a large potential to study Λ transverse polarization in p–p and p–A collisions.
- Geometrical acceptance significantly biases the result and it should be taken into account via MC corrections.
- **Magnetic field impact** on Λ polarization due to precession is **smaller** than detector acceptance-based polarization bias.
- To limit possible precession-based bias, $\Delta z < 1$ m ($\phi_{\max} < 0.05$) cut can be used.

Bibliography

(1) *Physics Letters B* **85** no. 4, 417–420 (1979)

(2) *Physics Letters B* **105** no. 5, 403–405 (1981)

(3) *Phys. Rev. D* **24**, 2419 (1981)

(4) *Phys. Rev. C* **74**, 044902 (2006)

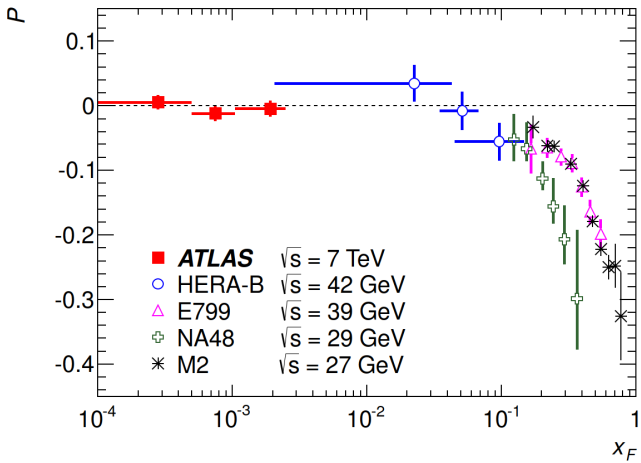
(5) *CERN Program Library Long Writeup* W5013 (1993)

(6) *Eur. Phys. J. C* 76: 198 (2016)

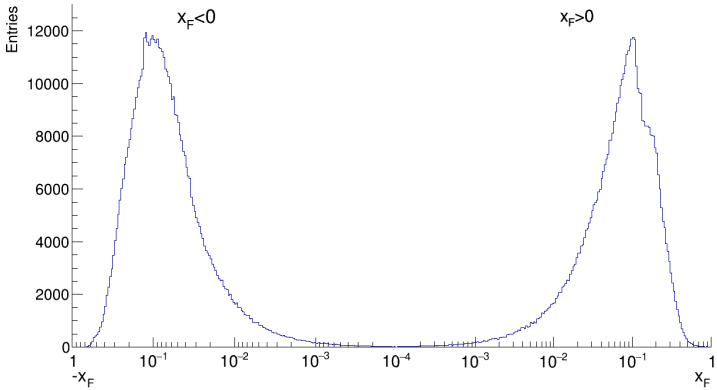
(7) *JINST* **9** P06005 (2014)

Backup Slides

x_F distribution



The Λ transverse polarization measured by ATLAS compared to measurements from lower center-of-mass energy experiments. In NA61/SHINE experiment, $p_{\text{lab}} = 158$ GeV/c corresponds to $\sqrt{s} = 17$ GeV and Λ peaked at $x_F \approx 0.1$. [ATLAS Collaboration, *Phys. Rev. D* **91** 032004 (2015)].



Distribution of simulated Λ over x_F defined as $x_F = (p_z)^{\text{CMS}}/(p_z)^{\text{CMS}}_{\text{max}}$. Left part - distribution of Λ with negative x_F, right part - with positive x_F.