Prospects of spontaneous Λ and $\bar{\Lambda}$ transverse polarization measurements at LHCb

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Motivation

Transverse Λ polarization was confirmed in 1976 in pBe collisions using a 300 GeV beam and followed by various pA and pp experiments with polarization values up to 30% [1] contradicting early pQCD calculations [2].

Common features observed include [3]:

- Transverse polarization of prompt Λ is negative
- Approximately independent of the beam energy
- Increases with increasing $|x_F|$ and increasing p_T up to a few GeV range

Polarization has been observed for beams other than protons including: e^+e^-, $e^\pm$ on various target nuclei, $\pi^\pm$, $K^\pm, \Sigma^-, \nu N, n$ [4, 5]

Polarization of other hyperons

Non-zero transverse polarization for other hyperons has been observed in hadronic collisions [6]

- Positive for $\Sigma^+(uus), \Sigma^-(dds), \bar{\Sigma}^+(\overline{uus}), \Sigma^0(uds)$
- Negative for $\Xi^0(uss), \Xi^-(dss), \bar{\Xi}^-(\overline{dss}), \Lambda\,(uds)$
- Zero for $\Omega^-(sss)$ and $\bar{\Lambda}(\overline{uds})$

Frameworks to explain Λ polarization

The phenomenological approach to characterize the Λ polarization has focused on:

- polarizing transverse-momentum dependent (TMD) fragmentation functions (FF) [7]
- higher twist multiparton correlators [8].

Λ polarization measurement

$m_\Lambda = 1115.683 \pm 0.006$ MeV/$c^2$and $c\tau = 7.89$ cm

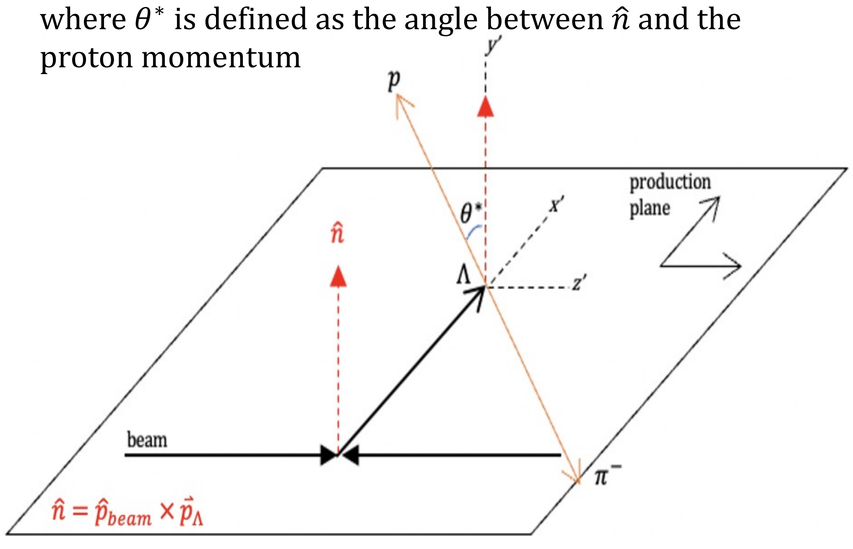
Λ polarization is measurable through the $\Lambda \to p\pi^-$ **self-analyzing decay**. The transverse polarization is defined in the $\vec{n} = \vec{p}_{beam} \times \vec{p}_\Lambda$ direction.

The angular distribution for polarized Λ:

$$\frac{dN}{d\cos\theta^*} = \frac{N}{2}(1 + \alpha_\Lambda P \cos\theta^*)\varepsilon_{tot}(\cos\theta^*)$$

$$\alpha_\Lambda = 0.732 \pm 0.014 \text{ [9]}$$

where θ^* is defined as the angle between $\hat{n}$ and the proton momentum



Polarization can then be extracted by fitting the $\cos\theta^*$ distribution in x_F and p_T bins, where x_F is defined as:

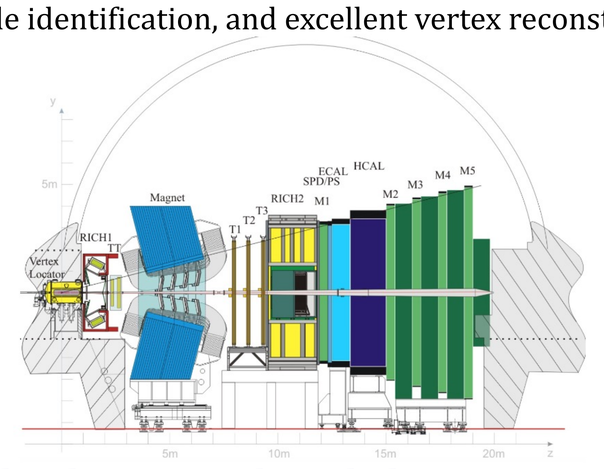
$$x_F = \frac{p_z^*}{|max(p_z^*)|} = \frac{2p_z^*}{\sqrt{s_{NN}}}$$

the longitudinal momentum in the center-of-mass frame being

$$p_z^* = \sqrt{m^2 + p_T^2}\sinh(y^*)$$

LHCb detector

The Large Hadron Collider beauty (LHCb) detector is a forward spectrometer ($2 < \eta < 5$) with precision tracking, particle identification, and excellent vertex reconstruction.



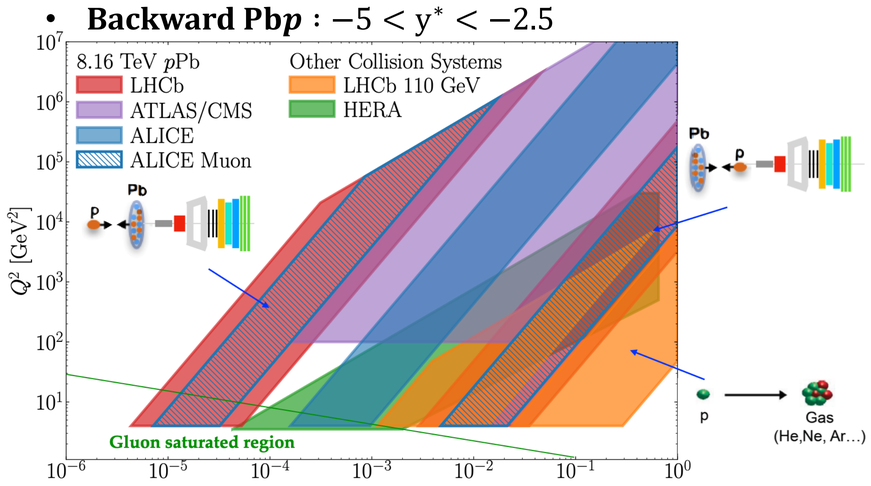
Collider data: pp, pPb, and Pbp

Data sets already available to be analyzed at LHCb in different collisions and energies

- ***pp***: $\sqrt{s_{NN}} = 5.02, 8.16, 13$ TeV
- ***p*Pb**: $\sqrt{s_{NN}} = 5.02, 8.16$ TeV
- **Pb*p***: $\sqrt{s_{NN}} = 5$ TeV

pPb data is taken in two different configurations:

- **Forward *p*Pb** : $1.5 < y^* < 4$
- **Backward Pb*p*** : $-5 < y^* < -2.5$

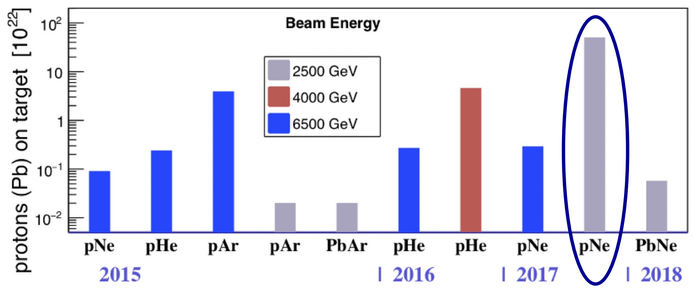


Fixed target data: SMOG

The System for Measuring the Overlap with Gas (SMOG) allows for collection of fixed-target data [10]

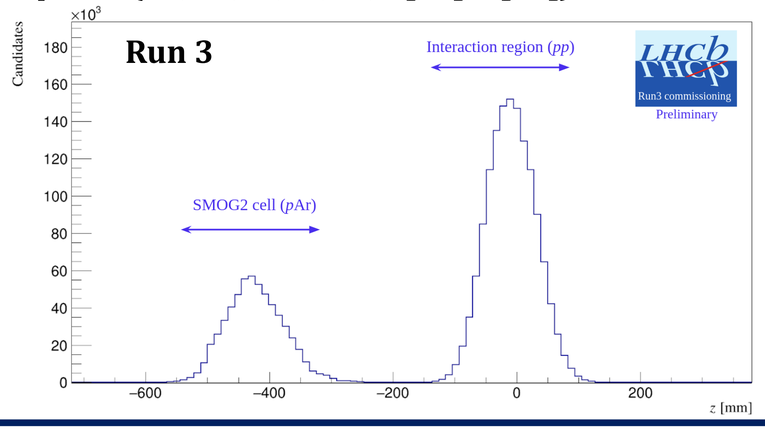
Injection of noble gas into the VELO while one of the circulating beams produces beam-gas collisions.

Access to central and backward rapidity, allowing for the observation of particles with larger, negative x_F



SMOG2 upgrade

Addition of target storage cell installed for Run 3, which allows for an increased injectable pressure and gas species (He, Ne, Ar, Kr, Xe, H_2, D_2, N_2, O_2)



Spin Physics at LHCb

Transverse hyperon polarization

Prospects for other transverse hyperon polarization measurements at LHCb have also been discussed; particularly of interest is **analyzing the transverse polarization of $\Xi^- \to \Lambda\pi^-$ and $\Omega^- \to \Lambda K^-$.**

LHCSpin

The LHCSpin project will open up the capabilities of future spin and polarized physics measurement capabilities at LHCb [12].

So far, R&D is officially supported to **add a transversely polarized target in the target storage cell** by 2029.

This will give insight on quark and gluon distributions at high x and intermediate Q^2, with complementary measurements to existing and future SIDIS experiments.

Summary

- Transverse Λ polarization was first observed over 40 years ago with **values up to 30% and has been linked to the process of hadronization**
- The **high energy from the LHC** and coverage from **LHCb's forward geometry** will be interesting to study transverse hyperon polarization at **different energies** (LHC energies) **and collision configurations** (heavy-ion, fixed-target, and pp)
- Ability to perform comprehensive measurements of the **polarization of Λ and $\bar{\Lambda}$ as a function of p_T and x_F** (both positive and negative x_F) using the LHCb detector in a kinematic area that has been poorly explored
- LHCb measurements, along with e^+e^- and SIDIS measurements, can put us in a better position to understand transverse hyperon polarization

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