

Deep Exclusive
Meson Production



DEMP as a probe to the Λ hyperon polarization puzzle

Zhoudunming Tu

Dec 5, 2023



@BrookhavenLab

(based on a recent paper - [arXiv:2308.09127](https://arxiv.org/abs/2308.09127))
Also in recent talks, [SPIN 2023](#) and [EIC 2nd detector workshop](#)

FY2025 NPP LDRD Type B Pre-Proposal

Proposal title: **DEMP as a probe to the Λ hyperon polarization puzzle**

Primary Investigator: **Zhoudunming Tu**

Other Investigators: **Francesco Bossu (IRFU, Saclay), Abhay Deshpande (SBU/BNL), Wenliang Li (CFNS/SBU), Silvia Niccolai (IJCLab, France)**

Indicate if this is a cross-directorate proposal: **No**

If yes, identify other directorates/organizations:

Proposal Term: **2 years**

From: **Oct 1, 2024**

To: **Sep 30, 2026**

Abstract:

In the 1970s, an unexpected transverse Λ polarization in unpolarized proton-Beryllium collisions was discovered, which initiated extensive studies on spin phenomena in high-energy physics over the past five decades. Despite the emergence of numerous promising theoretical models, the foundational mechanism driving this polarization phenomenon remains elusive to this day. Notably, in both longitudinally and transversely target-polarized lepton-hadron and hadron-hadron collisions, the Λ hyperon exhibits no discernible polarization relative to the initial parton spin direction. Unraveling the mystery of how the Λ hyperon obtains its spin has evolved into one of the most important questions in addressing this puzzle. A recent experimental proposal aims to answer this question with a distinct and unequivocal approach, employing an exclusive channel known as Deep Exclusive Meson Production (DEMP).

In this LDRD proposal, we plan to make the first Λ polarization measurement in DEMP based on the newly-recorded data with longitudinally polarized target from Run Group C at CLAS12 Collaboration. We will also perform a quantitative feasibility study based on the EIC second detector and its far-forward detector subsystem, where the energy range is 100 times higher. The anticipated result at CLAS12 will provide instrumental constraint, if not a definitive answer, to the puzzle of Λ hyperon polarization. This will open a new set of physics measurements at the EIC to further understand the nonperturbative QCD.

Program: **NP**

Return on Investment: **DOE ECA for NP in medium energy**

Broader impact on the activities at the laboratory:

- I. Understanding nonperturbative QCD manifested in hadronization and hyperon spin structure – a **50-year puzzle**.
- II. **Stimulate collaboration** between Jlab physics community and the EIC/RHIC physics community with **synergy** in common physics problem.
- III. New experimental opportunities at the EIC beyond physics in the EIC White Paper – **potential for EIC 2nd detector** development.

Total planned funding per year in FY25 and FY26: **\$250k/year**

Original puzzle: Large transverse Λ polarization from unpolarized target

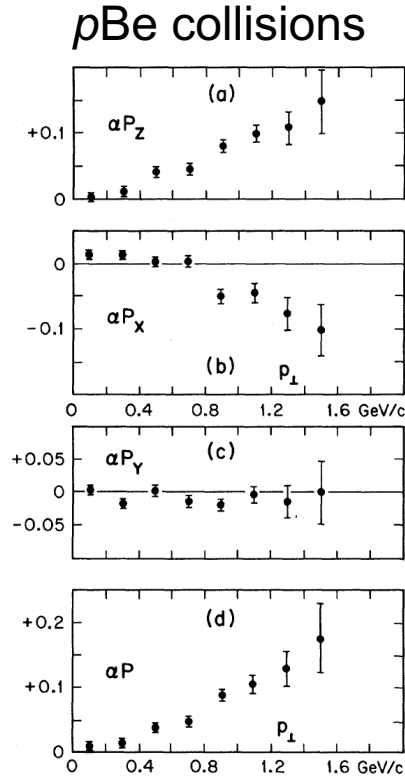
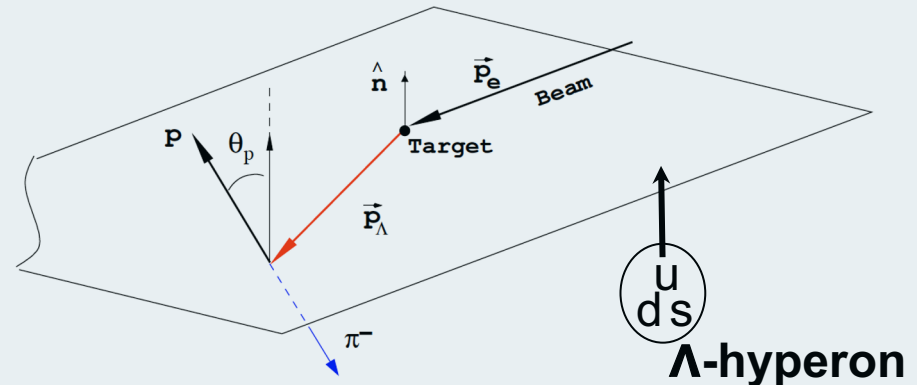


FIG. 3. Three components and magnitude of the $\Lambda^0 \rightarrow p + \pi^-$ asymmetry as a function of Λ^0 transverse momentum.

Phys. Rev. Lett. 36, 1113 (1976)

Production plane

Example: HERMES experiment of ep deep inelastic scattering (DIS).



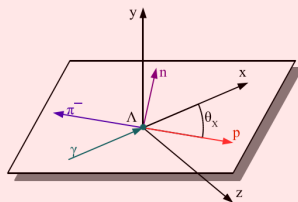
Λ^0 -polarization has been observed in p+p, NC/CC DIS, e+e, p+A, and AA* collisions.

* only in heavy-ion AA collisions, people think it's of different origin.

Another (aspect) puzzle: Λ is not polarized w.r.t nucleon spin

Parton spin direction

Example: COMPASS experiment of μ^+p deep inelastic scattering (DIS)



\vec{k} – unit vector along the proton momentum, x-axis align with the virtual photon direction.

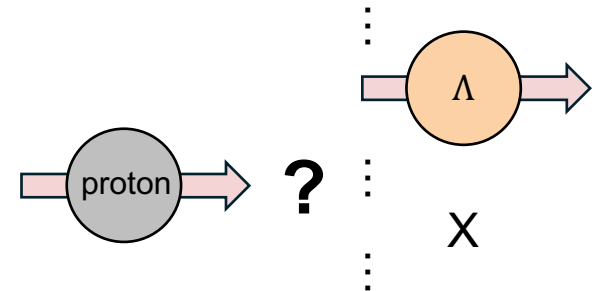
In Λ rest frame:

$$\frac{dN}{d\Omega} = \frac{N_{tot}}{4\pi} (1 + \alpha \vec{P} \vec{k})$$

$\alpha = +(-)0.642 \pm 0.013 - \Lambda (\bar{\Lambda})$ decay parameter, \vec{P} – polarization vector,

Λ^0 polarization is to measure the longitudinal spin transfer from lepton/photon or nucleon to quark.

No signal has been observed.

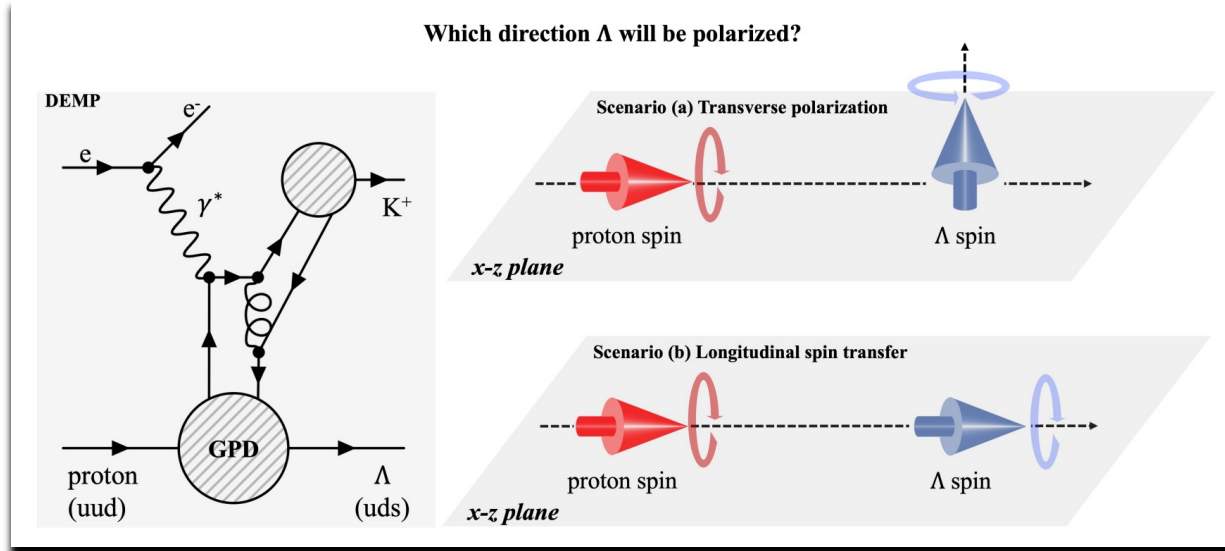


So-called **longitudinal spin transfer** has always been measured zero using Λ hyperon.

Question:

How does Λ obtains its spin?

Proposal - Λ polarization measurement in DEMP at CLAS12 and the EIC



Two expectations are both at their maximal strength, but only one can be true

Approach:

- Analyze the **fresh** new data (longitudinally polarized target) from [Run Group C](#) (RGC) at CLAS 12 – first measurement of Λ polarization in DEMP; **(co-PI Niccolai is the spokesperson of RGC and Bossu has significant expertise in meson production in CLAS.)**
- Exploratory study with simulation of the same measurement at the EIC 2nd detector at higher energy ranges and model study. **(co-PI Li, Deshpande are experts in EIC physics and detector simulation.)**

What we ask for 2 years:

- 100% stipend of a graduate student at IRFU, Saclay, co-supervised by co-PI Bossu and PI Tu, working on the CLAS12 analysis;
- A new BNL postdoc: ~70% of a postdoc FTE, working with co-PI Li on EIC simulations, where co-PI Deshpande will contribute the other ~30% (up to \$30k) of the postdoc FTE from CFNS and a fraction of FTE of co-PI Li.
- 3% FTE for PI Tu.
- Conference travels.

Summary – how Λ obtains its spin?

- One measurement, two facilities (Jlab 12 & EIC) - **Λ polarization measurement in DEMP** to pin down this 50-year puzzle.
- New physics opportunities at the EIC that are beyond the EIC White Paper physics.
- Deliverables:
 - High-impact data analysis in journal publication from CLAS12. **First measurement of Λ polarization in DEMP.**
 - High-impact feasibility study and journal publication from EIC simulations – Λ polarization in DEMP at the energy frontier.
 - New set of experimental observable for studying nonperturbative QCD in hadronization and hyperon spin.
 - Extra/new requirements and designs for the detector subsystem at the EIC second detector Far-Forward region.

Backup

Deep Exclusive Meson Production (DEMP) can be used to probe Λ polarization

Exclusive meson electro-production can give access:

- GPDs of the nucleon: Three-dimensional structures and orbital angular momentum
- Meson form factors through the Sullivan process
 - Sensitive to QCD confinement

See [[T. Horn 2017](#)] and [[G. Huber's talk](#)]

This proposal, we focus on:

$$e+p \rightarrow e' + K^+ + \Lambda^0$$

with polarization observables.

