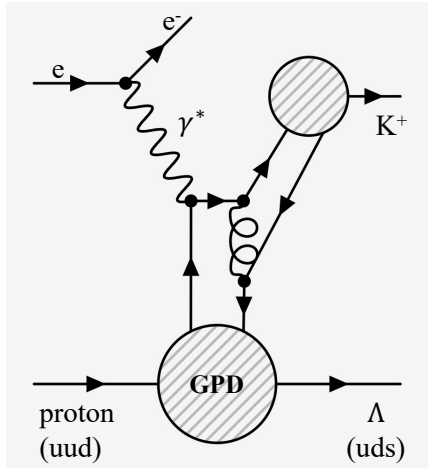




Deep Exclusive
Meson Production



Resolving the Λ hyperon polarization puzzle thru DEMP

Kong Tu

Jan 8, 2025



@BrookhavenLab

Based on paper: *Phys. Rev. C* 109 (2024) 5, 055205

FY2026 NPP LDRD Type B Pre-Proposal

Proposal title: **Resolving the Λ hyperon polarization puzzle thru DEMP**

Primary Investigator: **Zhoudunming (Kong) Tu**

Other Investigators: **Francesco Bossu (IRFU, Saclay), Shohini Bhattacharya (Uconn), Kyungseon Joo (UConn), Wenliang Li (Mississippi State), 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, 2025**

To: **Sep 30, 2027**

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 FY26 and FY27: **\$250k/year**

Original puzzle: Large transverse Λ polarization from unpolarized target

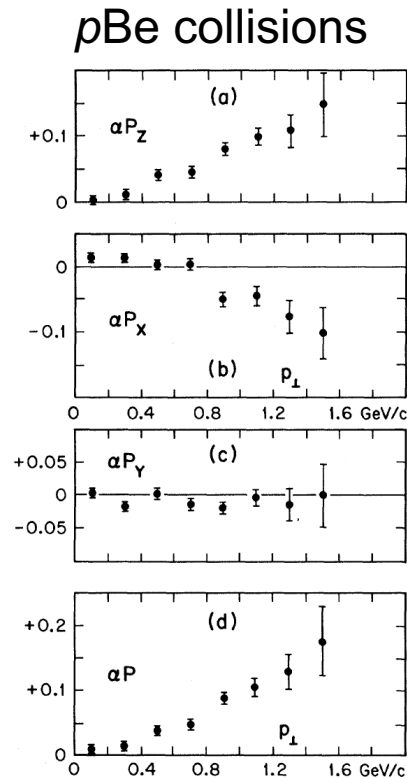
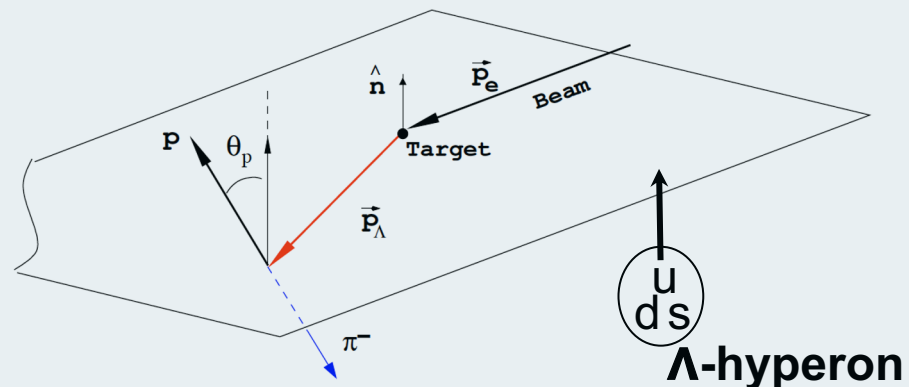


FIG. 3. Three components and magnitude of the $\Lambda^0 \rightarrow p + \pi^-$ asymmetry as a function of Λ^0 transverse momentum.

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

Production plane

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



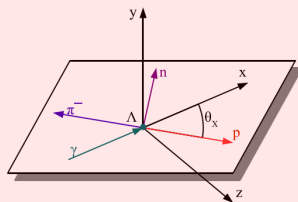
Λ^0 -polarization has been observed in p+p, NC/CC DIS, e+e, p+A, and AA* collisions.

* 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.

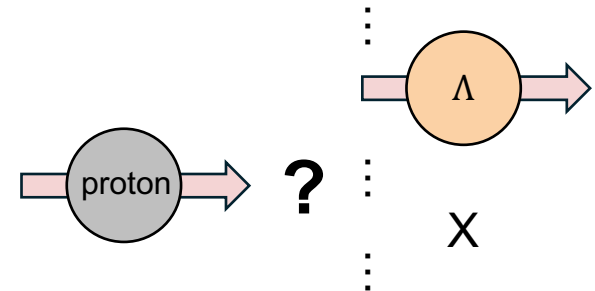
In Λ rest frame:

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

$\alpha = +(-)0.642 \pm 0.013 - \Lambda (\bar{\Lambda})$ 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.

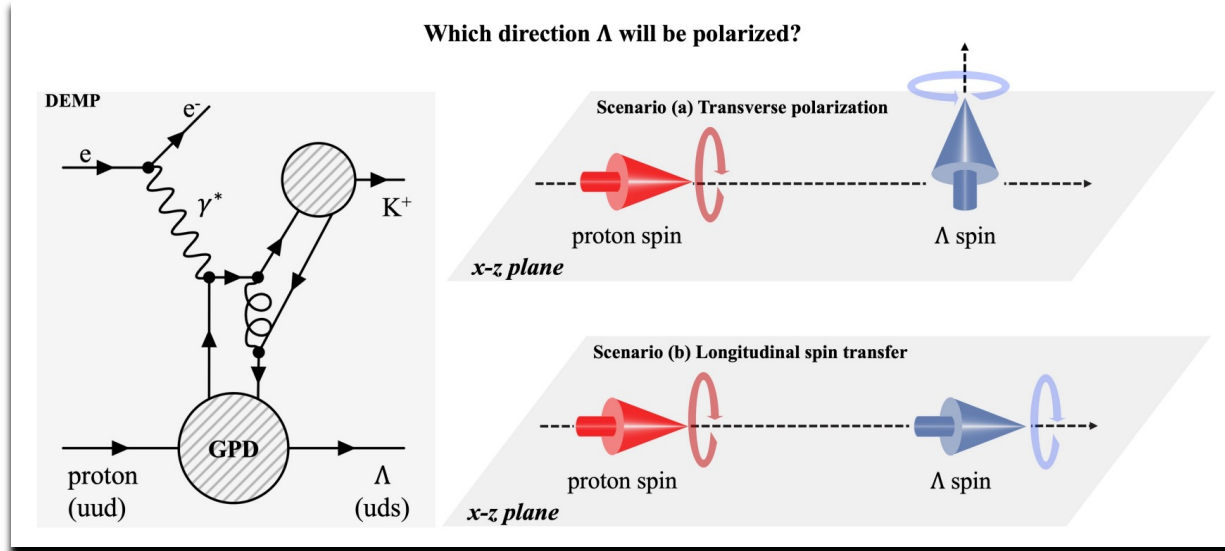


So-called **longitudinal spin transfer** has always been measured zero using Λ hyperon.

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 and Joo have 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 its connections to GPDs. **(co-PI Li is expert in EIC physics and detector simulation and co-PI Bhattacharya is GPD expert.)**

FY25 review: VERY POSITIVE

A total of 4 reviewers, all positive comments/reviews and one recommendation.

"The PI is highly visible in the EIC community despite his relatively early stage of career. Very likely to receive ECA."

*"This is an outstanding proposal. The PI is a creative thinker and doer, and the well-chosen co-PIs bring complementary strengths to the table. The proposal brings new scientific tools to solve a 50 year old puzzle. The solution of this puzzle has ramifications not only for EIC science but for quantum information science and the physics of the quark-gluon plasma. **It creates a novel synergy between BNL and Jlab and key international partners in Saclay+IJLabs in France. This is a must fund proposal.** I am genuinely excited to see the results of the science deliverables."*

"First BNL-funded project involving JLab 12GeV experiments, should be encouraged. There can be many such collaborations. The measurement may also be pursued at a second EIC detector."

"This proposal includes great intellectual merit because the PI and Co-PI have experience with observation data and good planning for data collection and simulations. The PI has experience and primary data taken from CLAS12 and plans for more research to resolve problems."

"Non-monetary ROI (synergy between BNL & JLAB, impact on EIC) is probably the most important long-term aspect."

"Mostly Early Career Award (ECA) funds, as well as DOE NP funds aimed at promoting collaboration between BNL and JLAB."

"The PI is highly visible in the EIC community despite his relatively early stage of career. Very likely to receive ECA."

...and many more positive comments

FY25 review: VERY POSITIVE

A total of 4 reviewers, all positive comments/reviews and **one recommendation.**

“Overall very positive, but I feel the connection to Lambda polarization puzzle is a bit oversold. Solid theory work is needed to establish such a connection.”

“It is not entirely clear to me how the present measurement can shed new light on the Lambda polarization puzzle. The exclusive reaction $\gamma + p \rightarrow K + \Lambda$ has been studied in the literature (see e.g., 1901.11380) in the GPD framework. The PI also adopts the GPD picture as shown in Fig.1. In this framework, by measuring the initial proton and final Lambda spins, one can constrain proton-Lambda transition GPDs. This may be in itself a new and interesting measurement for GPD studies, but I don't see immediately how this might be related to the Lambda polarization puzzle in inclusive processes (as opposed to the exclusive GPD process considered here).”

Response: indeed, exclusive and inclusive production of Lambda are different. However, the connection is that many models that could explain the inclusive transverse lambda polarization simply fail to apply in this case, and if the same phenomenon is observed, it automatically invalidates those models.

That said, we also got inspiration from this comment that the GPD prospective should be explored given its own interest. Therefore, we invite a well-known **GPD theorist, Prof. Shohini-Bhattacharya**, to be on board with this proposal.

What we ask for: same as last year

Title: DEMP as a probe to the A hyperon polarization puzzle
LDRD Type B
PI: Zhoudunming Tu

Resource Category	DESCRIPTION	FY25	FY26
050 Salary - Scientific		10,126	10,481
051 Salary - Research Assoc		105,562	109,257
050 Salary - Professional		0	0
Total FTEs		1.05	1.05
TOTAL SALARY/WAGE & FRINGE		115,689	119,738
187 Joint Appointments		0	0
TOTAL OTHER LABOR		0	0
180/185 Graduate student visitor		8,560	8,757
186 OEP Collaborators		0	0
190/191 Contract Labor		0	0
201 Scientific Distributed Labor		0	0
TOTAL PURCHASED LABOR		8,560	8,757
various subcontract			0
280 Foreign Travel		25,000	30,000
290 Domestic Travel		0	0
various Computer for post doc/misc purchases		4,898	2,271
TOTAL MSTC		29,898	32,271
170 Relocation Expense		8,000	
240 Registration Fees		0	0
271 Communications		0	0
TOTAL COM/MISC		8,000	0
TOTAL DIRECT COSTS		162,146	160,766
251 Electric Distributed (Electric Power Burden)		926	958
700/701/481 Organizational Burden		12,841	13,291
TOTAL ORGANIZATIONAL BURDEN		13,767	14,249
745 Procurement (Material Handling)		2,093	2,259
735 G&A Burden		0	0
730 Common Institutional Support		71,994	72,727
722 Safeguards & Security Assess		0	0
TOTAL LABORATORY BURDEN		74,087	74,986
705 LDRD Burden		0	0
TOTAL PROGRAM COSTS		250,000	250,000
740 Full Cost Recovery		0	0
TOTAL PROGRAM COSTS		250,000	250,000

Labor Band	Name	FY25		FY26	
		FTE	Amount	FTE	Amount
RA1	post doc	1.00	105,562	1.00	109,257
SCI1	Zhoudunming Tu	0.05	10,126	0.05	10,481
Total		1.05	115,689	1.05	119,738

This budget supports a 100% FTE BNL postdoc (with laptop), 5% FTE of Tu, graduate student visits from Uconn, Scalay, to BNL, and travels.

*This budget **does not** include contributions from CFNS, e.g., a new perspective postdoc could be contributing as well.*

Summary

- 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.
 - Connections between **Λ polarization and transition GPDs.**
 - 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.