Resolving the Λ Hyperon Polarization Puzzle through DEMP

Principal Investigator(s): Zhoudunming Tu (BNL), Francesco Bossù (IRFU, Saclay), Shohini Bhattacharya (UConn), Kyungseon Joo (UConn), Wenliang Li (CFNS/SBU), Silvia Niccolai (IJCLab, France)

List of the proposal participants: retaining postdoc or a new hire at BNL + graduate students from IRFU, Sacaly and UConn.

ECA eligibility: Zhoudunming Tu

Proposal term from: Oct 2025 to: Sep 2027

Annual funding: FY26 $250k FY27 $250k

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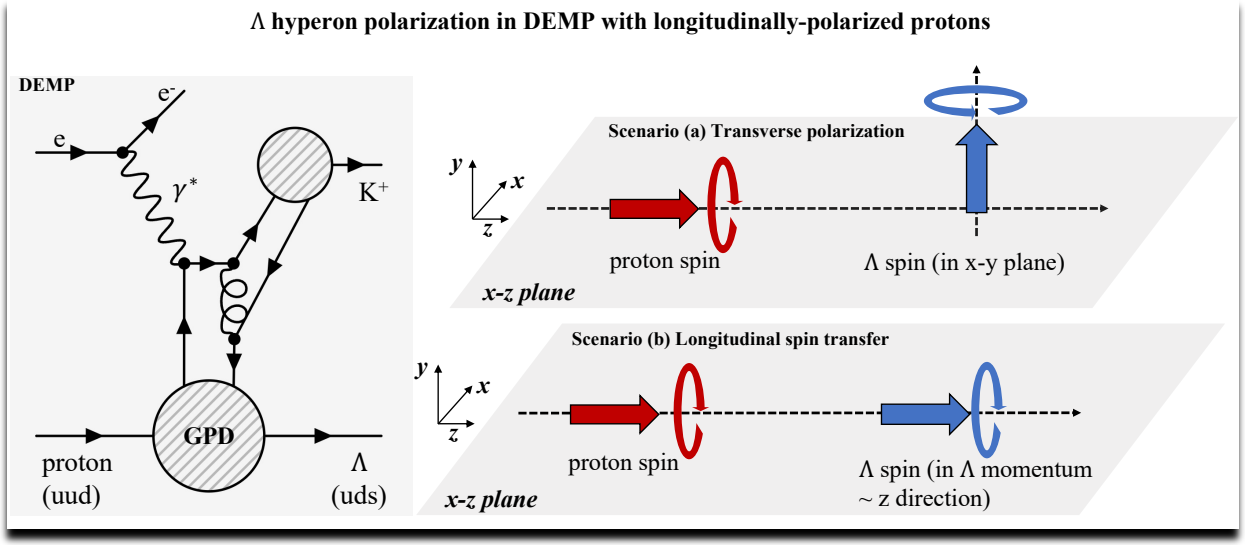
Based on paper: *Phys. Rev. C* 109 (2024) 5, 055205

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:

i) Analyze the **fresh** new data (longitudinally polarized target) from Run Group C (RGC) at CLAS12 – first measurement of Λ polarization in DEMP; **(co-PI Niccolai is the spokesperson of RGC, and Bossù and Joo have significant expertise in meson production in CLAS.)**

ii) Exploratory study with simulation of the same measurement at the EIC at higher energy ranges and model/theory study. **(co-PI Li and Bhattacharya** (theory) **are experts in EIC detector simulation and GPD physics.)**

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DEMP = Deep Exclusive Meson Production

Project objectives

The objective of this project is to make the first measurement of Λ polarization in DEMP in CLAS12 experiment and a feasibility study at the EIC 2nd detector. This will provide **i)** significant advancement in **understanding *how Λ obtains its spin*** in order to resolve the 50-year puzzle of Λ polarization; **ii)** a new set of experimental observables to study the **nonperturbative QCD in hyperon spin and hadronization** at the EIC**; iii) synergies** between the Jefferson Lab medium energy program and the BNL high energy program to broaden the EIC science program; **iv)** a training ground for the **next generation scientists** with existing experimental data for the future EIC experiments.

Research Plans:

1. Perform data analysis on the newly recorded RGC data from CLAS12 with longitudinally polarized proton target. Led by a postdoc at BNL and students from IRFU, Scalay and UConn.
2. Explore possibilities of different EIC detector configurations to measure the **Λ** polarization in DEMP; led by a BNL postdoc, working closely the local EIC group.
3. Based on the result of the experimental measurement from CLAS 12, perform a phenomenology study on modeling how Λ obtains its spin, and eliminate different models that are not consistent with the data. Make a quantitative prediction for the measurement at the EIC, based on the predictive power from our phenomenological model.
4. Identify and understand new experimental observables for both Jefferson Lab base and BNL base experiments, especially the aspect towards the transition GPDs where co-PI Bhattacharya has the expertise*.

*The team had received a strong and helpful recommendation from last year's application (FY25 LDRD Type B) that theory aspect needs to be strengthened and connection between the proposed measurement and transition GPDs should be improved. Therefore, we invited Prof. Bhattacharya as co-PI on our team to boost this theory effort.

None of these efforts is supported by programmatic funds

Project milestones and deliverables

First year:

- Hire/retain a postdoc at BNL* and co-PIs will identify graduate students at UConn and IRFU, Saclay. They will get familiar with the physics topics and experimental analysis framework at CLAS12 and the software of the EIC.
- Start data analysis in CLAS12 and EIC 1st and 2nd detector simulation on DEMP.
- Present preliminary results at domestic and international conferences that have a broad program for both Jefferson lab physics and the EIC physics.

Second year:

- Perform model study on the mechanism of Λ polarization based on the CLAS12 preliminary data, together with existing world data. A global analysis on Λ polarization. Explore theory connection with the transition GPDs with co-PI Bhattacharya's group.
- Finish and present the final CLAS12 analysis and EIC simulations, submit for publication if ready.
- Identify the new set of observables and physics topics at the EIC, especially for the science program of the EIC 2nd detector, and future funding opportunities to utilize the investment of this LDRD.

We do have one postdoc, **Jan Vanek, from the EIC group who is eligible and qualified for this position. Since he is an expert on Λ polarization, he would be a good fit to this project. However, we would also look for new postdoc hire if Vanek decides to find jobs elsewhere. In addition, we do have **identified a candidate from Uconn** who has significant experience of CLAS12, who will graduate in May 2025. Perfect timing for this position, if funded.*

Alignment with the Laboratory Mission and Vision

BNL's mission and vision are to deliver discovery sciences and transformative technology to power and secure the nation's future.

This proposal tackles a fundamental QCD problem that puzzled us for almost 50 years, which is deeply connected to the nonperturbative QCD - confinement.

In addition, this is a problem that interests both BNL and Jefferson lab scientists and **this project will be the first project that supports BNL scientists to involve Jlab physics program – a historical milestone if funded.** This could open new opportunities and collaborations (~ at least 10 years) between RHIC's shutdown and EIC data taking.

Potential Future Funding

- ECA funding opportunity is possible for PI-Tu. (See next slide).
- In addition, this LDRD helps to support students from UConn's group (co-PI Joo's group) as a **seed fund to start involving in the EIC research**. This has the potential to bring in more future funding for the EIC research.
- Part of this proposal is to study the feasibility of measuring Λ polarization measurement in DEMP at the EIC 2nd detector. The return of investment may attract interests from non-DOE funding sources to support the EIC 2nd detector (e.g., international contributions or groups that are not affiliated with EIC)

* Tu was awarded a grant from IANN-QCD for study of entanglement, which is a result of previous LDRD (FY19)

If ECA Eligible – How this LDRD Benefits Your Application

PI-Tu is eligible for ECA (until 2028), where he still has 2 attempts. Currently, he is preparing one for FY26 in the NP Heavy-Ion physics, which is not related to this LDRD. This is based on PI's previous experience and establishment.

However, this LDRD could expand the possible area for Tu's ECA proposal in future attempts (>= 2 years), namely to explore a new direction of research at BNL on a problem that has **common interests for both heavy-ion community and medium energy community.**

Will be under Medium Energy program. Given PI's eligibility, this project needs to be funded now in order to be useful for ECA proposal in 2 years.

This type of research project fits seamlessly to the intentions behind the LDRD Type B proposal call at BNL.

Names of Suggested BNL Reviewers

Raju Venugopalan (Nuclear Theory)

Bjoern Schenke (Nuclear Theory)

Lijuan Ruan (Nuclear experiment)

Aihong Tang (Nuclear experiment)

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LDRD Funding Table from BOM

Title: Resolving the ^ Hyperon Polarization Puzzle through DEMP
PI: Zhoudunming Tu

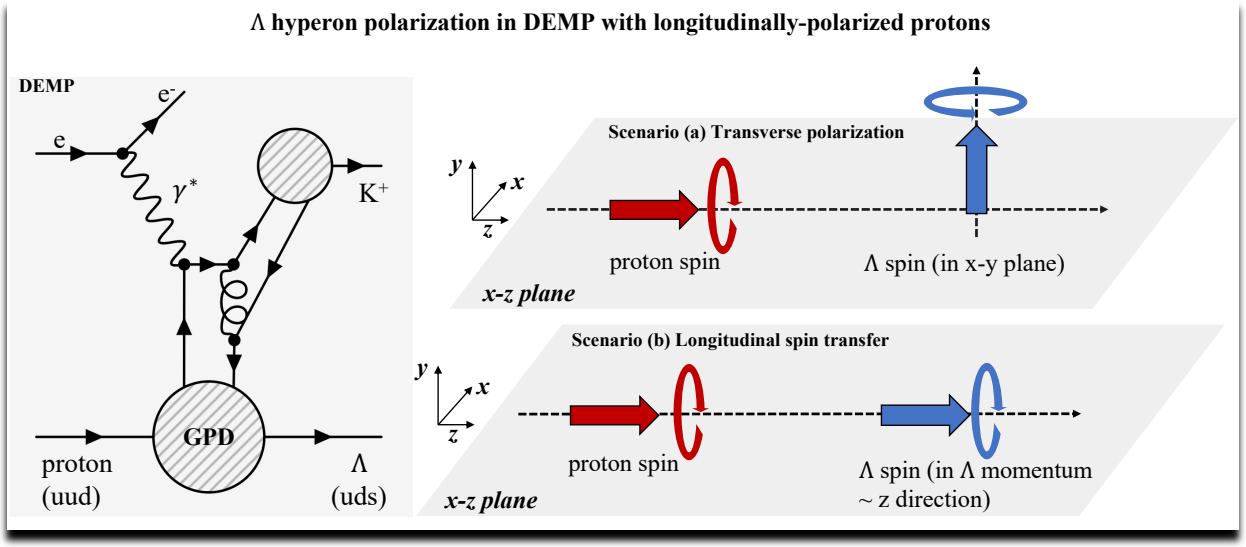
Resource Category	DESCRIPTION		FY26		FY27
050	Salary - Scientific		13,839		18,679
051	Salary - Research Assoc		107,035		110,781
050	Salary - Professional		0		0
050	Salary -Technical		0		0
050	Salary - Management & Admin.		0		0
	Total FTEs		**1.07**		**1.09**
TOTAL SALARY/WAGE & FRINGE			**120,874**		**129,460**
187	Joint Appointments		0		0
TOTAL OTHER LABOR			**0**		**0**
180/185	Consultants/Research Collab		10,000		10,230
186	OEP Collaborators		0		0
190/191	Contract Labor		0		0
201	Scientific Distributed Labor		0		0
TOTAL PURCHASED LABOR			**10,000**		**10,230**
various	Contracts - Low Value		0		0
280	Foreign Travel		9,000		9,225
290	Domestic Travel		7,500		7,688
various	Purchases		3,500		500
TOTAL MSTC			**20,000**		**17,413**
170	Relocation Expense		8,000		
240	Registration Fees		0		0
271	Communications		0		0
TOTAL COM/MISC			**8,000**		**0**
TOTAL DIRECT COSTS			**158,874**		**157,102**
251	Electric Distributed (Electric Power Burden)		1,209		1,295
700/701/481	Organizational Burden		14,384		15,406
TOTAL ORGANIZATIONAL BURDEN			**15,593**		**16,700**
745	Procurement (Material Handling)		1,400		1,219
735	G&A Burden		0		0
730	Common Institutional Support		74,133		74,979
722	Safeguards & Security Assess		0		0
TOTAL LABORATORY BURDEN			**75,533**		**76,197**
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	FY26 FTE	FY26 Amount	FY27 FTE	FY27 Amount
RA1	TBD	1.00	107,035	1.00	110,781
SCI1	Z. Tu	0.07	13,839	0.09	18,679
	Total	1.07	120,874	1.09	129,460

This budget supports a 100% FTE BNL postdoc (with laptop), 7% FTE of Tu, graduate student visits from UConn to BNL, and travels.

Thanks to Kelly Carroll for the budget

Summary: one measurement, two facilities



- This proposal plans to make the **first measurement of Λ polarization in DEMP** in CLAS12 and its feasibility at the EIC.
- This proposal is expected to bring future funding opportunities for PI and co-PIs, by **broadening the program at BNL** and bridging together the NP high-energy and medium-energy community.
- A perfect training ground for the **next-generation scientists with real-world experience on data analyses** and their applications to future experiments.

Back up

Original puzzle: Large transverse Λ polarization from unpolarized target

*p*Be collisions

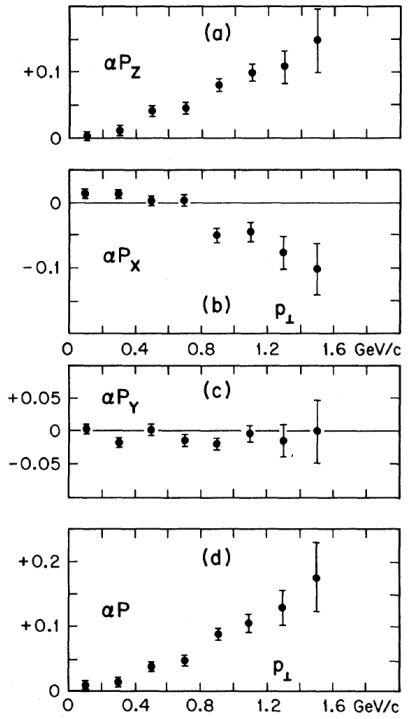
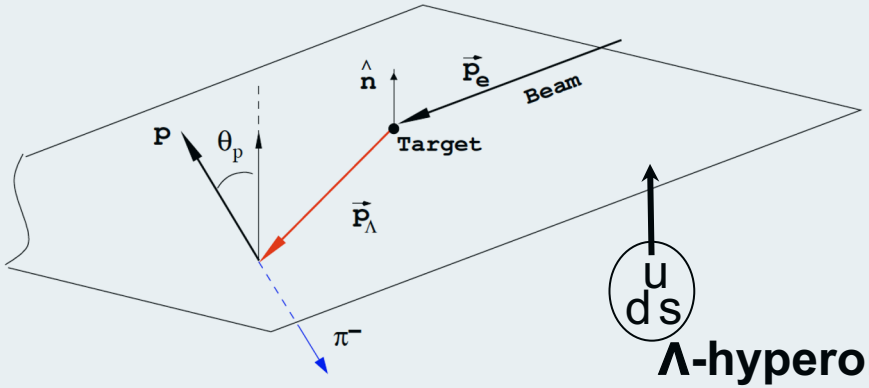


FIG. 3. Three components and magnitude of the $\Lambda^0 \to p + \pi^-$ asymmetry as a function of Λ^0 transverse momentum.

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

Production plane

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



Λ-hyperon

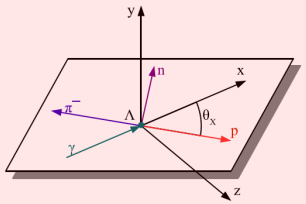
Λ^0-polarization has been observed in p+p, NC/CC DIS, e+e, p+A, and AA* collisions.

* 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 mu+p deep inelastic scattering (DIS)



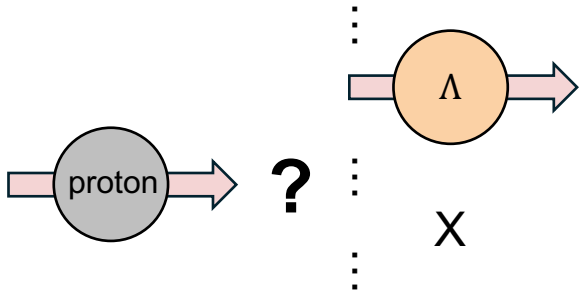
In Λ rest frame:

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

$\alpha = +(-)0.642 \pm 0.013 - \Lambda\ (\bar{\Lambda})$ decay parameter, $\vec{P}$ – polarization vector, $\vec{k}$ – unit vector along the proton momentum, x-axis align with the virtual photon direction.

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?