

The Polarized Target Program for CLAS12

Chris Keith

JLab Target Group

U.S. DEPARTMENT OF ENERGY | Office of Science

Jefferson Lab

Timeline of polarized targets at JLab

1994: First beam on (unpolarized) solid target (Hall C)

1998: First polarized solid target at JLab (Gen, Hall C)

1998: The first polarized ^{3}He target at JLab (GDH,

1999: The first polarized target in CLAS (EG1, Hall

2007: The first frozen-spin polarized target at JLab

2009: The first solid polarized target in Hall A (g2p

2009: Simultaneous use of three polarized targets

2020: The first polarized ^{3}He target at 12 GeV (A1n /d2n, Hall C)

2022: The first polarized solid target at 12 GeV (Run Group C, Hall B)

20 polarized target installations, from the first in 1998 to the most recent in 2022...

Every 14 months!

Eight more could run in the next decade!

Future polarized targets at JLab

Hall B	Run Group C	NH_3, ND_3	**E12-06-109**: *Longitudinal spin structure of the nucleon* **E12-06-109a**: *DVCS on the neutron with a polarized deuterium target* **E12-06-119b**: *DVCS on a longitudinally polarized proton target* **E12-07-107**: *Spin-orbit correlations with a longitudinally polarized target* **E12-09-009**: *Spin-orbit correlations in kaon electroproduction* **E12-09-007b**: *Study of partonic distributions using SIDIS kaon production*
Hall B	Run Group G	NH_3,^{7}LiD	**E12-14-001**: *The EMC effect in spin structure functions*
Hall B	Run Group H	NH_3	**E12-11-111**: *Transverse Spin Effects in SIDIS at 11 GeV with a Transversely Polarized Target using CLAS12* **E12-12-009:** *Measurement of Transversity with Dihadron Production in SIDIS with Transversely Polarized Target* **E12-12-010:** *Deeply Virtual Compton Scattering with Transversely Polarized Target using the CLAS12 Detector*
Hall B	Run Group N	^{3}He	**C12-20-002:** *Spin Dependent Electron Scattering with Polarized 3He target*
Hall C	Tensor	ND_3	**E12-13-011**: *The Deuteron Tensor Structure Function b1* **E12-15-005:** *Measurement of Quasi-Elastic and Elastic Deuteron Tensor Asymmetries* **E12-24-002:** *Revealing the Transition Region of QCD with the Proton's g2 Structure Function*
Hall A	SoLID	NH_3	**E12-11-108**: *Target Single Spin Asymmetries in SIDIS (e,e′$\pi^{\pm}$) Reaction on a Transversely Polarized Proton Target* **E12-11-108A**: *Target Single Spin Asymmetries in the N(e, e') Reaction on Transversely Polarized Protons* **E12-12-010:** *$K^{\pm}$ Production in SIDIS using Transversely Polarized Targets and the SoLID Spectrometer*
		^{3}He	**E12-10-006:** *Target Single Spin Asymmetry in SIDIS Electro-Pion Production on a Transversely Polarized 3He Target* **E12-11-007:** *Asymmetries in SIDIS Charged Pion on a Longitudinally Polarized He-3 Target*
Hall A	SBS	^{3}He	**E12-0-018:** *Semi-Inclusive pion and kaon electro-production from transversely polarized 3He target with SBS & BB*
Hall D	FROST-D	multiple	**E12-20-011:** *Measurement of the High-Energy Contribution to the Gerasimov-Drell-Hearn Sum Rule* **E12-25-012:** *High Precision Measurement of Phi-Nucleon Cross Section Using a Tensor Polarized Deuteron Target*

Polarized targets in Hall B

The original CLAS detector was **built with polarized targets in mind**, and three distinct systems were used during its history.



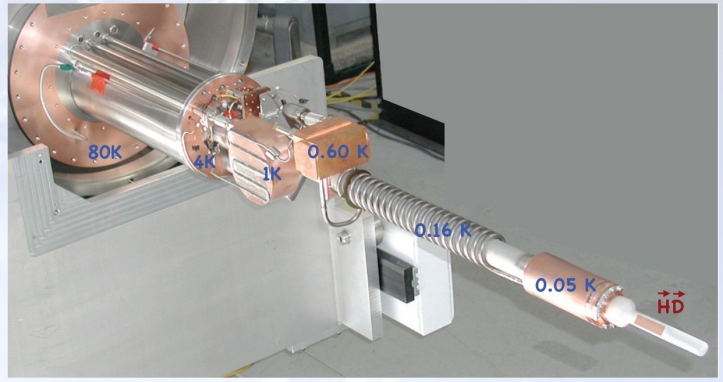
The eg1 target, longitudinal pol.

- eg1 (1999)
- eg1b (2000)
- eg4 (2004)
- eg1-DVCS (2008)



FROST

- g9a – longitudinal pol. (2008)
- g9b – transverse pol. (2009)



HDice

- g14 – longitudinal pol. (2012)

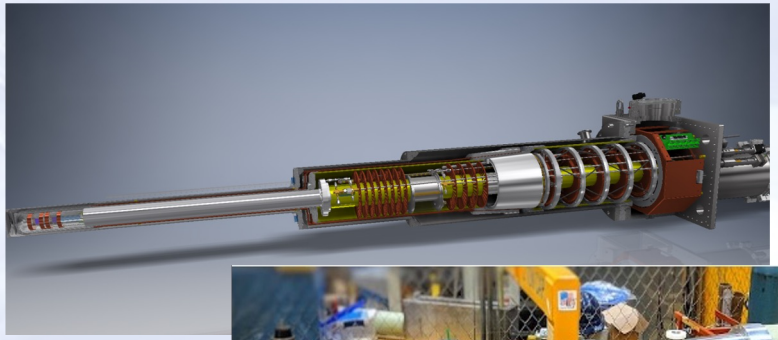
The Target Group's role

The Target Group is currently involved in nine polarized target projects at various stages of development

1. Longitudinally polarized target for CLAS12 (operational)
2. Polarized lithium deuteride target development for CLAS12 (R&D)
3. Transversely polarized target for CLAS12 (conceptual)
4. Polarized ^{3}He target for CLAS12 (R&D)
5. R&D lab for polarized target (assembly)
6. Irradiation cryostat for UITF (assembly)
7. Tensor polarized target for Hall C (R&D)
8. Frozen spin polarized target for Hall D (conceptual)
9. Genesis Award: *A.I. Era Spin Physics of Quantum Systems: Real-Time Feedback and Neural Network Optimization of Polarized Targets*

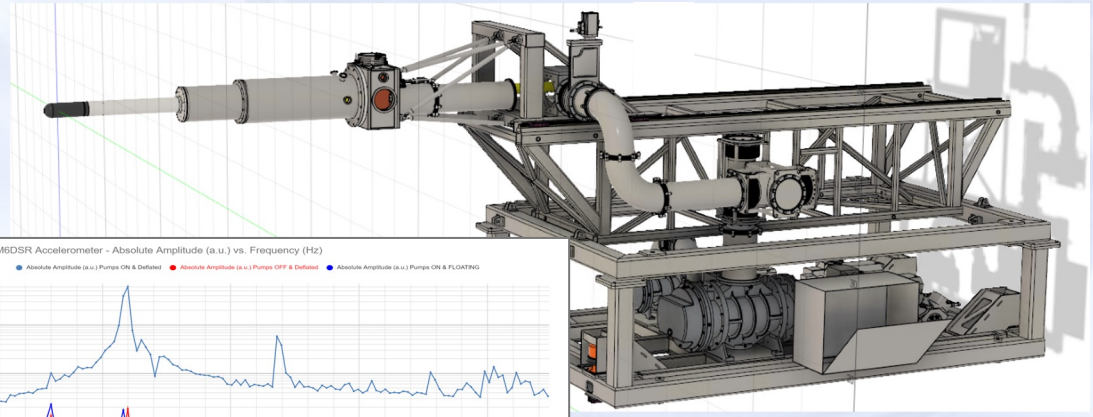
backup slides

CLAS12 longitudinally polarized target





Horizontal, high cooling power
1 K evaporation refrigerator



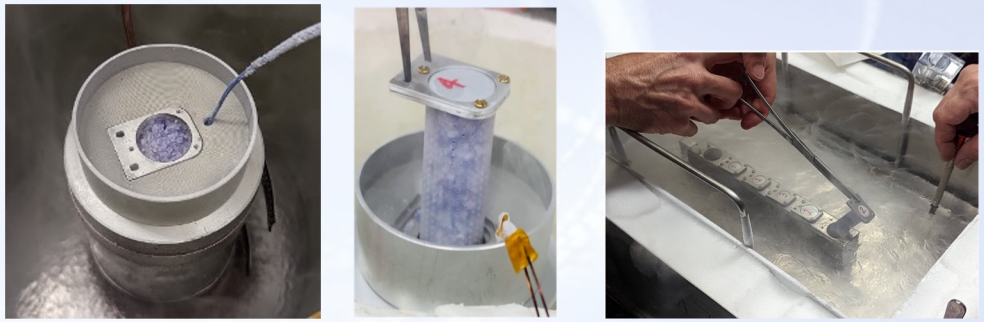
Vibration isolation of cryostat from roots pumps: 300x improvement

Designed and constructed for Run Group C

- NH_3, ND_3, Carbon, CH_2, CD_2
- Part 1: June 2022 – March 2023
- Part 2: 2028

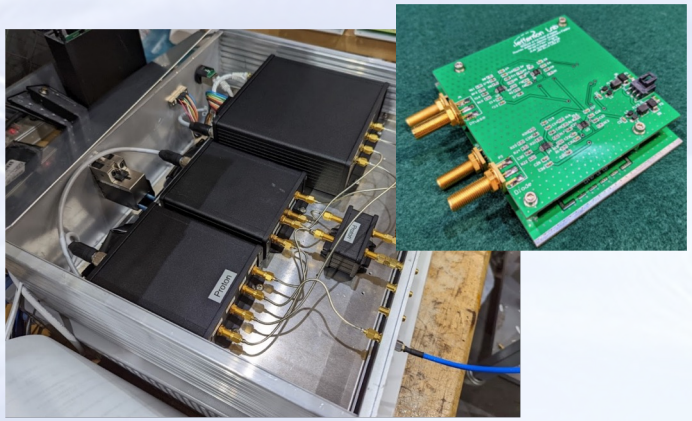
- New construction techniques and materials for 1 K refrigerator
- Improved vibration isolation of vacuum pumps
- New sample handling and storage methods

- Protons/deuterons polarized 69 times
- 75 target exchanges
- Four days lost to overhead and maintenance

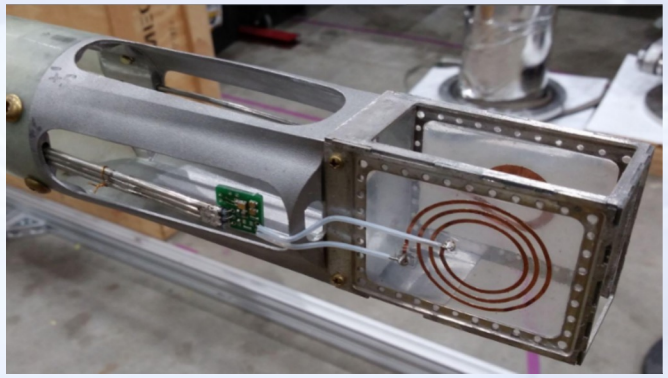


Loading and storage of frozen ammonia in PCTFE target cells

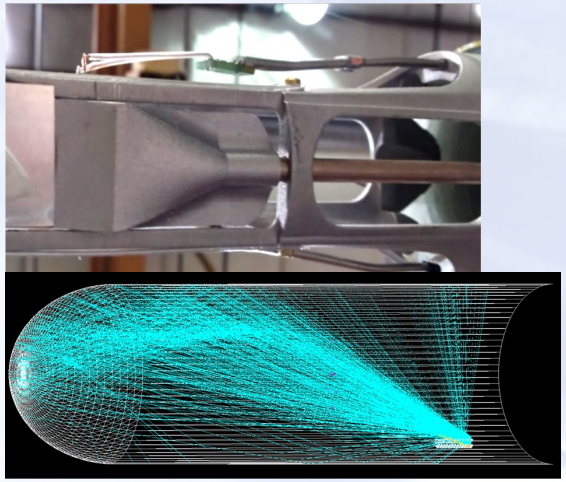
CLAS12 longitudinally polarized target



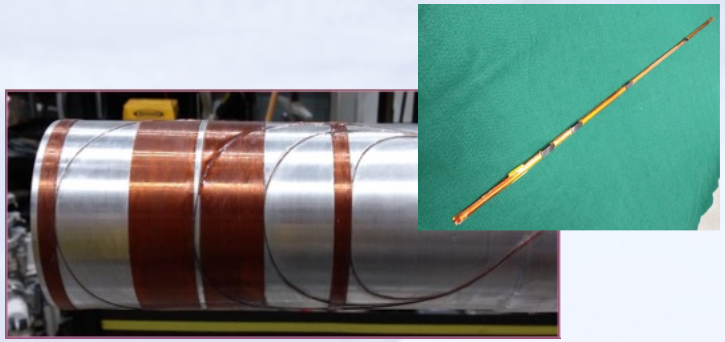
JLab-designed and constructed NMR electronics



Deuteron NMR coil with cold, electronic tuning



3D printed microwave horn and simulation

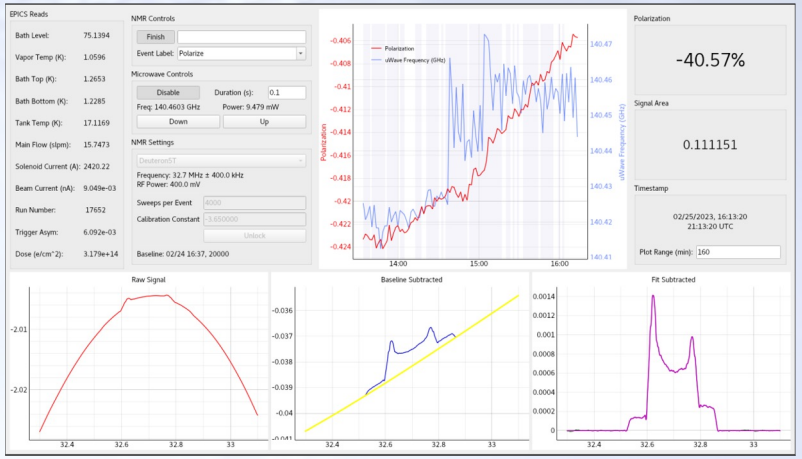


Superconducting shim coils & HTSC leads

Designed and constructed for Run Group C

- NH_3, ND_3, Carbon, CH_2, CD_2
- Part 1: June 2022 – March 2023
- Part 2: 2028

- New NMR hardware and software
- 3D printed microwave components
- Superconducting shim coils for field optimization
- Much more



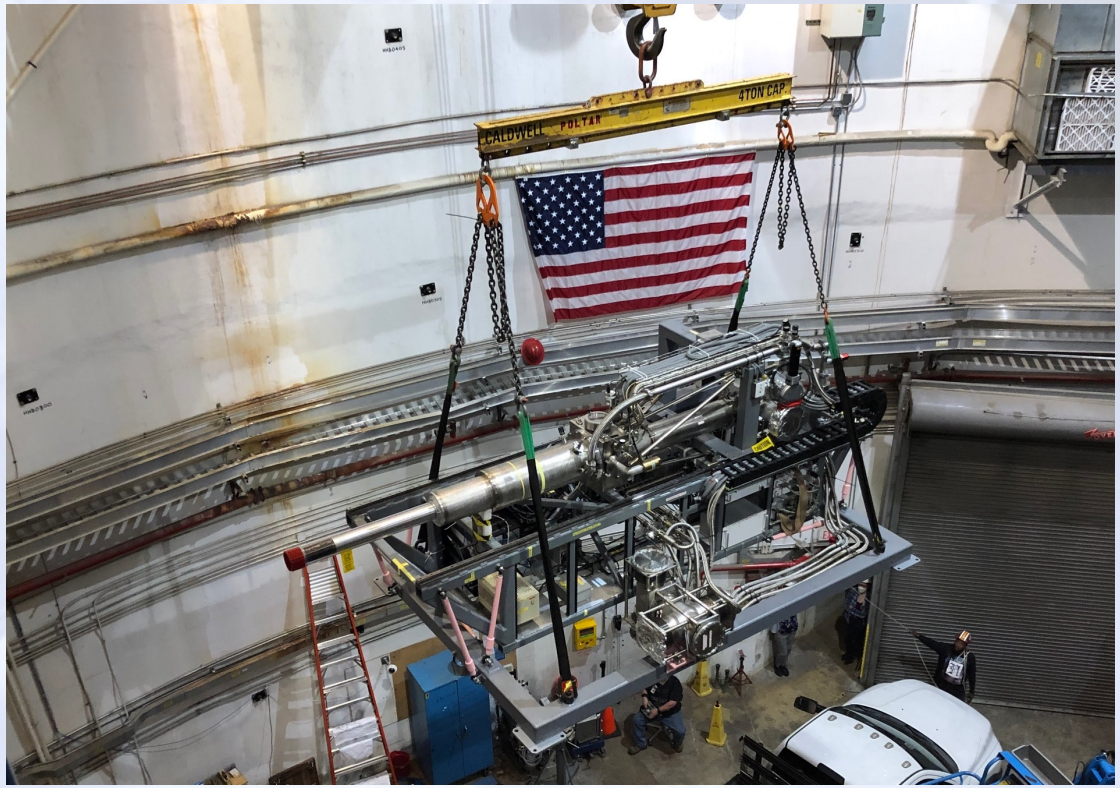
NMR data acquisition and control software

CLAS12 longitudinally polarized target

The **Run Group C** experiments in CLAS12 are expected to continue in 2028

- Spin structure functions of longitudinally-polarized protons and neutrons
  - NH_3 and $\mathbf{ND_3}$

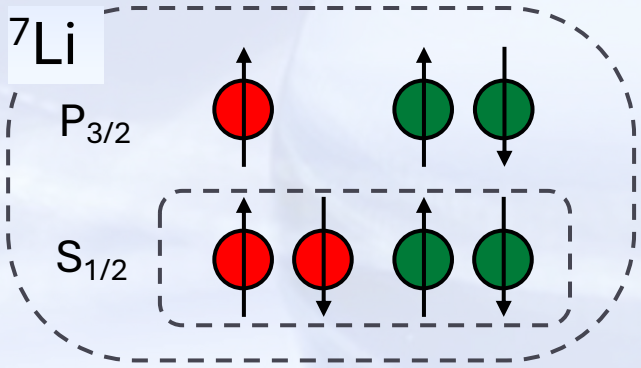


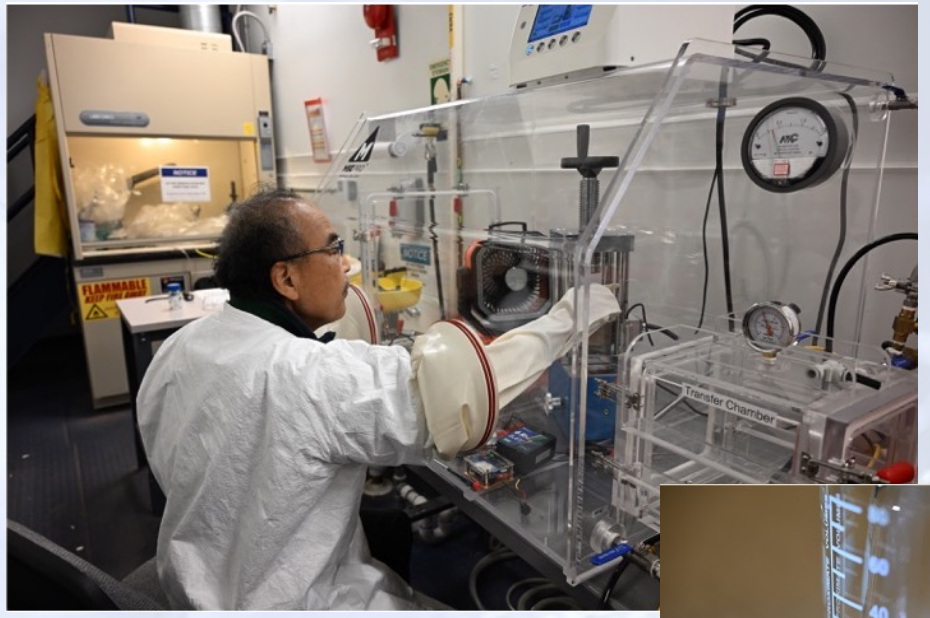


Run Group G polarized target

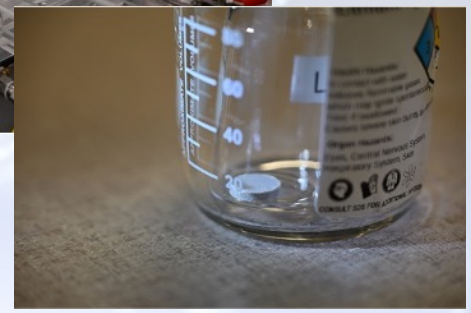
Run Group G will follow Run Group C

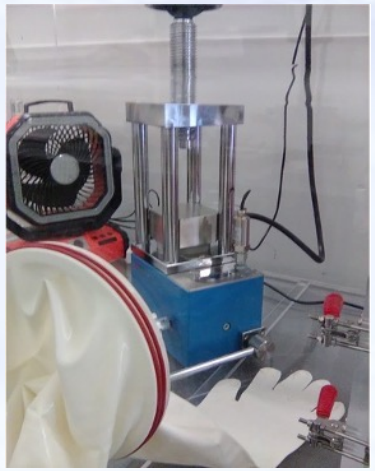
- Compare spin structure functions of longitudinally-polarized protons and ^{7}Li (polarized EMC effect)
  - NH_3 and ^{7}LiD

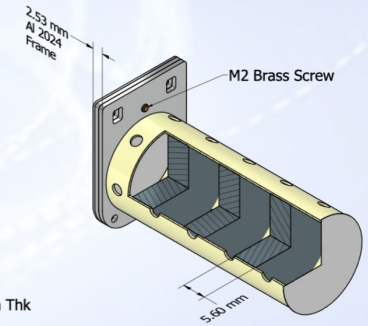




Tsuneo Kageya







Cell 0.2 mm Thk

Compared to ammonia, lithium hydride is more difficult to irradiate for DNP & will require extensive testing.

Need both the irradiation cryostat and DNP test stand!

High-field polarized ^{3}He

There are two **O**ptical **P**umping techniques for polarizing ^{3}He

SEOP

Spin-Exchange Optical Pumping

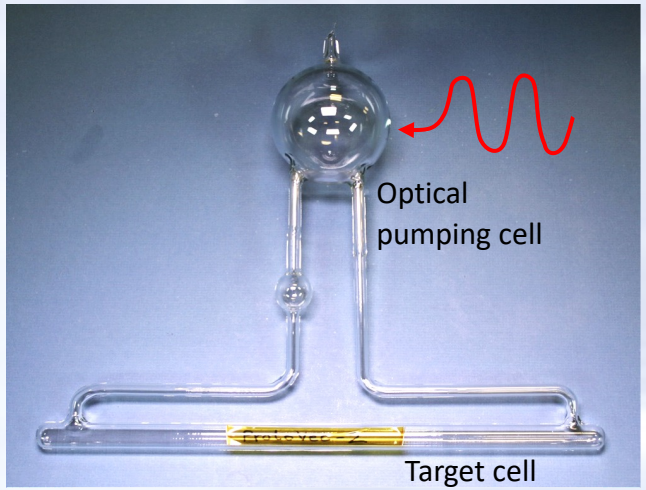
Polarize ^{3}He indirectly via OP of **alkali atoms**

Magnetic field: tens of gauss

Gas pressures: several **atmospheres**

Polarization: 50%

Time scale: hours



MEOP

Metastability-Exchange Optical Pumping

Polarize ^{3}He indirectly via OP of **excited ^{3}He atoms**

Magnetic field: tens of gauss

Gas pressures: tens of **millibar**

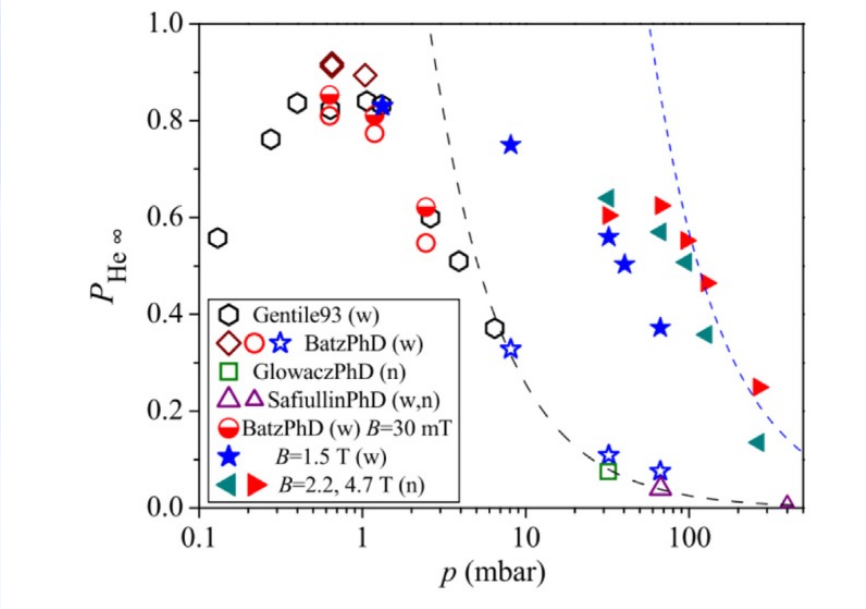
Polarization: 90%

Time scale: seconds



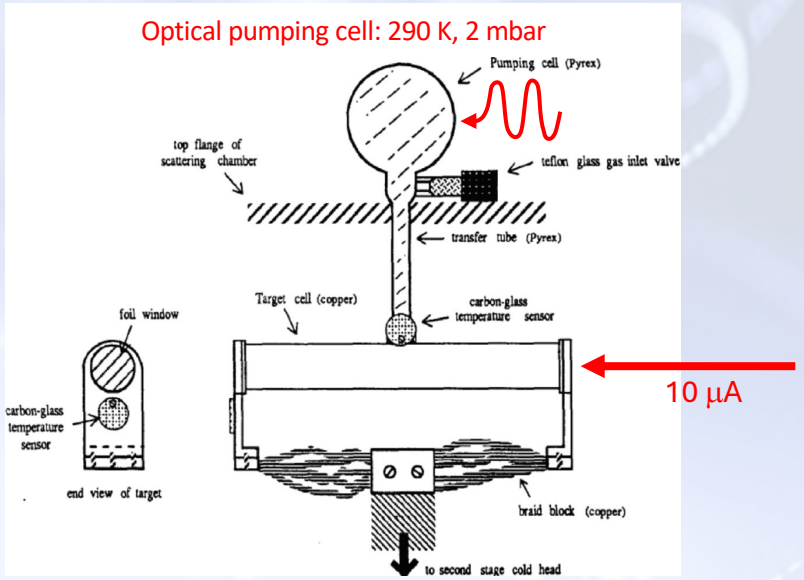
High-field polarized ^{3}He

Laboratoire Kastler Brossel (Paris)
MEOP works in **fields up to 5 T** and **pressures up to 100 mbar.**



T.R. Gentile, P.J. Nacher, B. Saam, T.G. Walker, *Optically polarized ^{3}He,* Rev. Modern Phys. 89 (2017) 045004

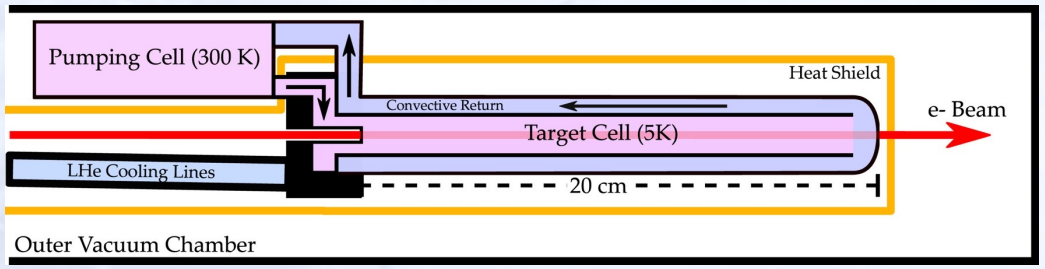
MEOP was used to polarize ^{3}He (40%) for MIT-Bates E-88-02.
The target cell was **cryogenically cooled** to 13 K to **increase the gas density x22**.



R. Milner, R. McKeown, C. Woodward, *A polarized ^{3}He target for nuclear physics,* NIM A 274 (1989) 56

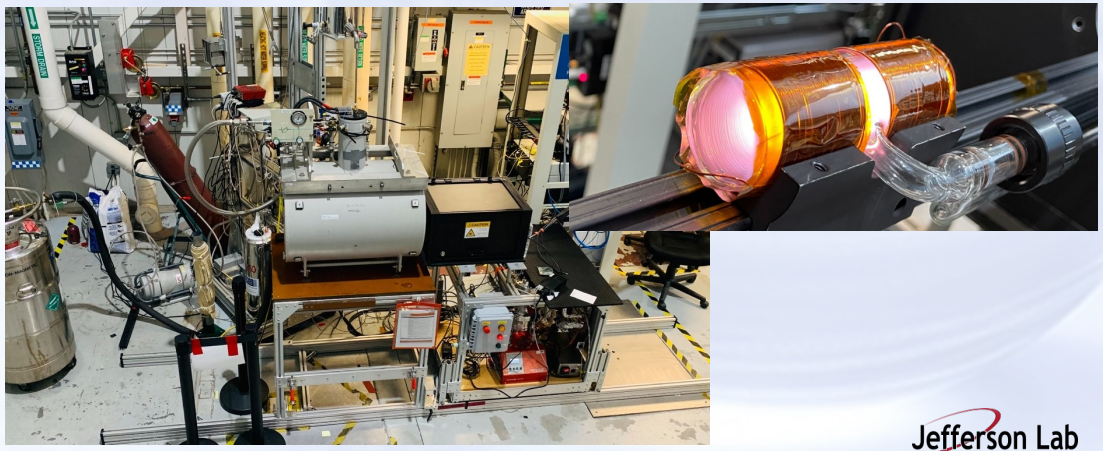
High-field polarized ^{3}He

Maxwell and Milner (2021)
A MEOP target for high field spectrometers like CLAS12



J.D. Maxwell and R.G. Milner, *A concept for polarized 3He targets for high luminosity scattering experiments in high magnetic field environments,* NIM A 1012 (2021) 165590.

PR12-20-002: *A program of spin-dependent scattering from a polarized 3He target in CLAS12*
Scientific rating: A-
Recommendation: C1
Comments: **"The PAC recommends to continue the ongoing polarized target R&D vigorously."**



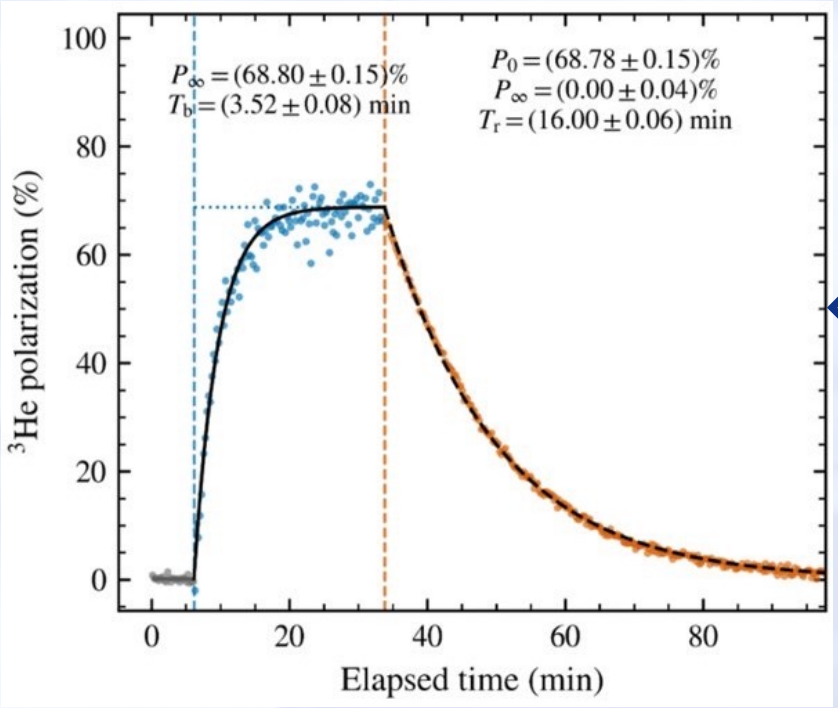
MEOP test stand in the Target Development

A multi-stage R&D program

1. Low field + Low pressure (complete)
2. High field + Low pressure (complete)
3. High field + High pressure (in progress)
4. High field + High pressure + Low temperature

Jefferson Lab Target Group · Massachusetts Institute of Technology · Shandong University · The University of Tennessee Knoxville

High-field polarized ^{3}He



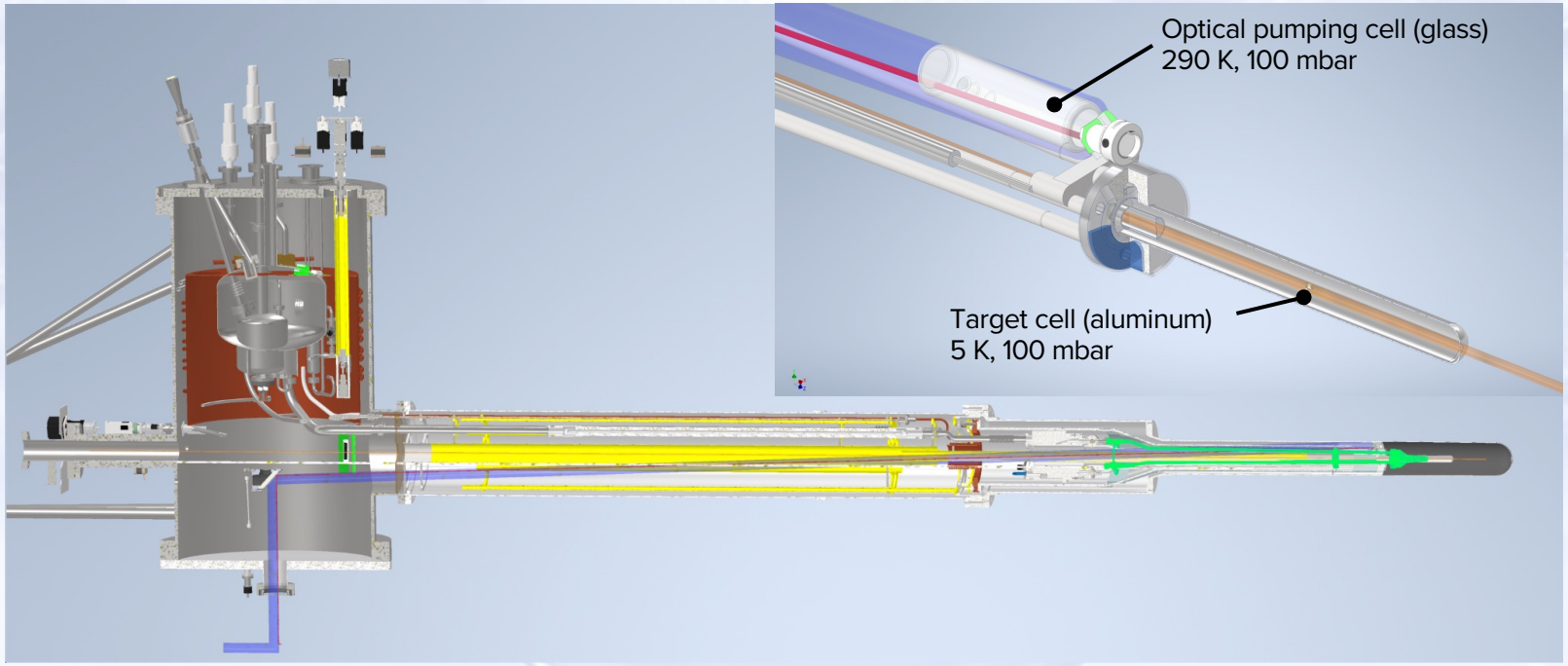
Latest Results
69% at 100 mbar!!

See Hao Lu's talk!
CLAS Collab. Nov. 19

Jefferson Lab Target Group
Massachusetts Institute of Technology
SHANDONG UNIVERSITY
THE UNIVERSITY OF TENNESSEE KNOXVILLE

High-field polarized ^{3}He

Ultimate goal: design & construction of a double-cell polarized ^{3}He target incorporated into the existing Hall B cryotarget



Design parameters

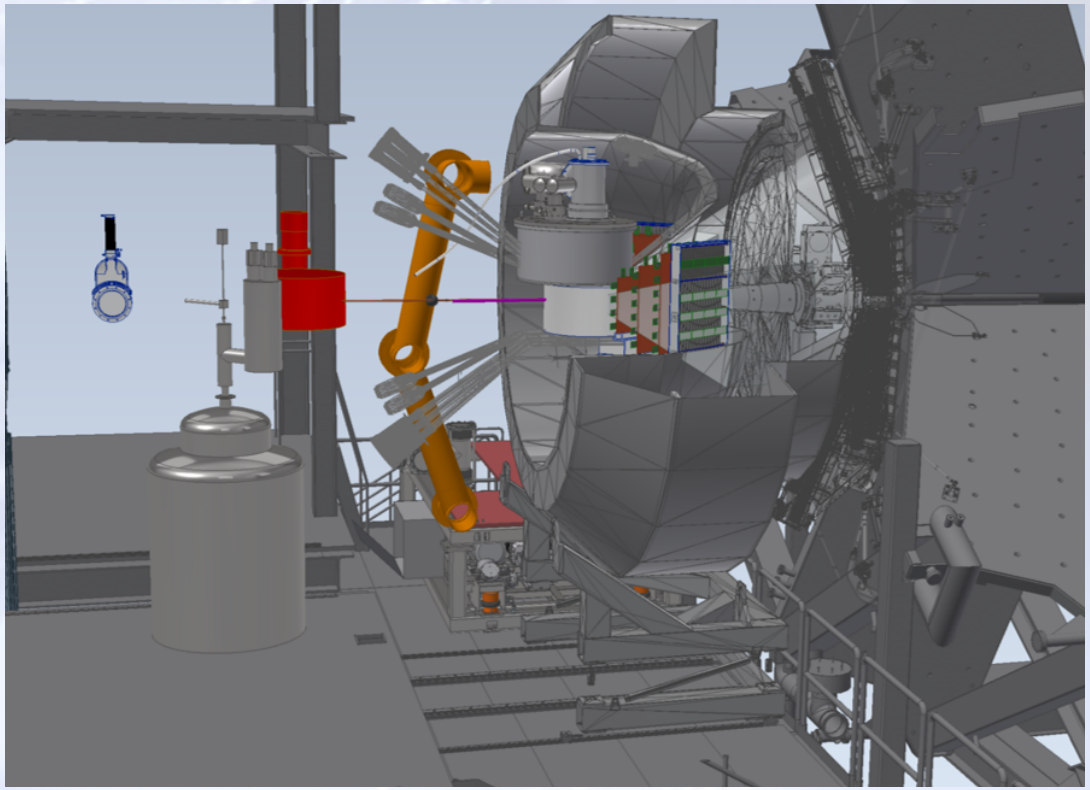
Pressure: 100 mbar
Target cell length: 20 cm
Target cell temperature: 5 K
Equivalent RT density: 5.8 atm
Polarization: 60%
Beam current: 0.5 μA
Luminosity: 10^{34}

Jefferson Lab Target Group
Massachusetts Institute of Technology
SHANDONG UNIVERSITY
THE UNIVERSITY OF TENNESSEE KNOXVILLE

Transversely polarized target

Run-Group-H is three A-rated experiments to study semi-inclusive and DVCS reactions from **transversely-polarized** protons (NH_3) in Hall B.

These experiments will utilize a new dynamically polarized target currently in the conceptual design stage by the JLab Target Group.

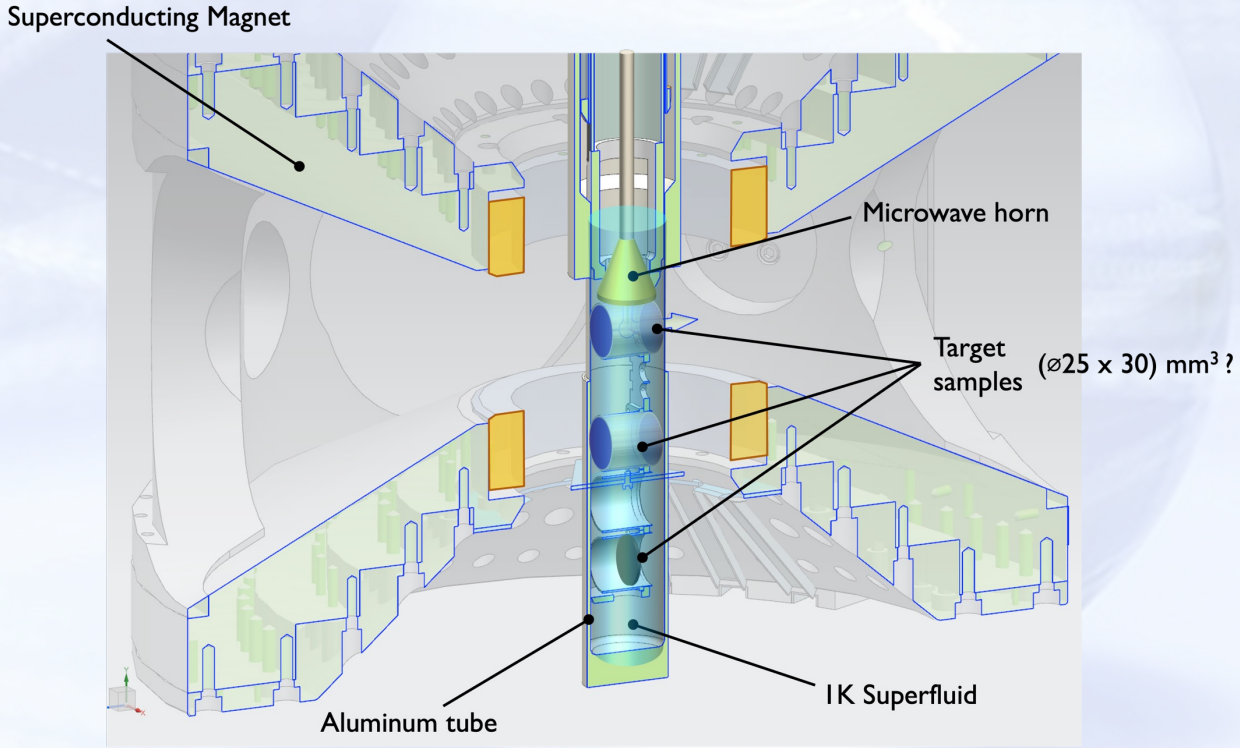


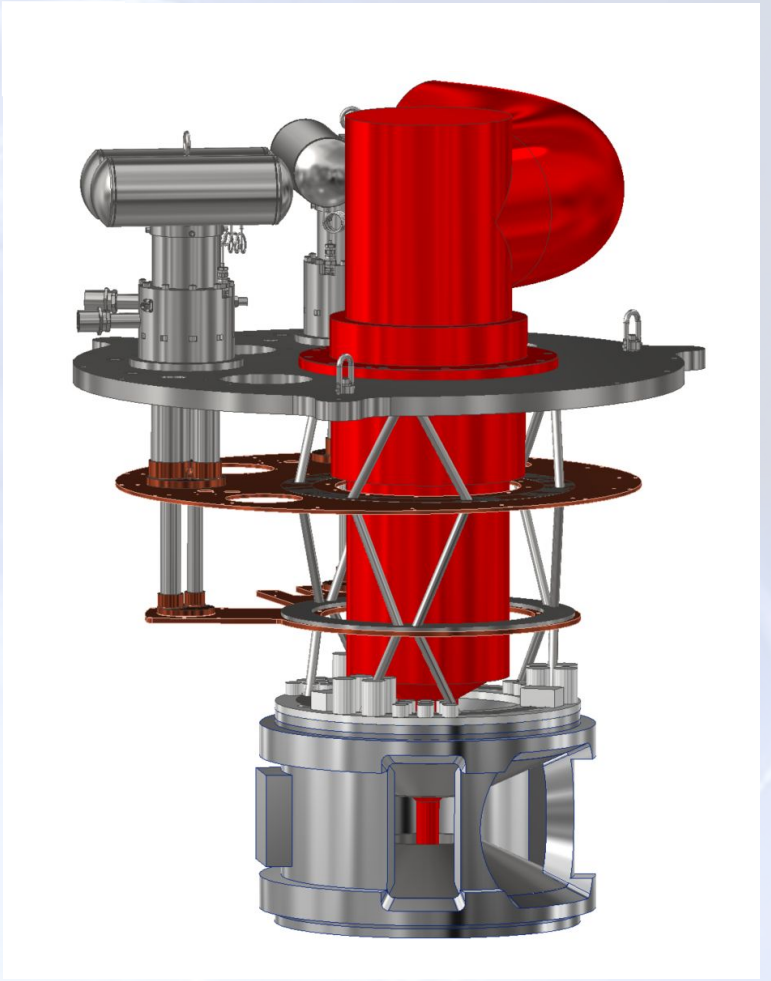
E12-11-111: *Transverse Spin Effects in SIDIS at 11 GeV with a Transversely Polarized Target using CLAS12*
E12-12-009: *Measurement of Transversity with DiHadron Production in SIDIS with Transversely Polarized Target*
E12-12-010: *Deeply Virtual Compton Scattering with Transversely Polarized Target using the CLAS12 Detector*

Transversely polarized target

The design mimics the 6 GeV targets, with a vertical target ladder inside a 1 K bath and 5 T field.

- More compact to field inside the HTCC





Transversely polarized target

We plan to save time and money by re-purposing as many components as possible from the Run Group C polarized target

- Vacuum pumps
- Gas piping
- Electronics
- Microwaves

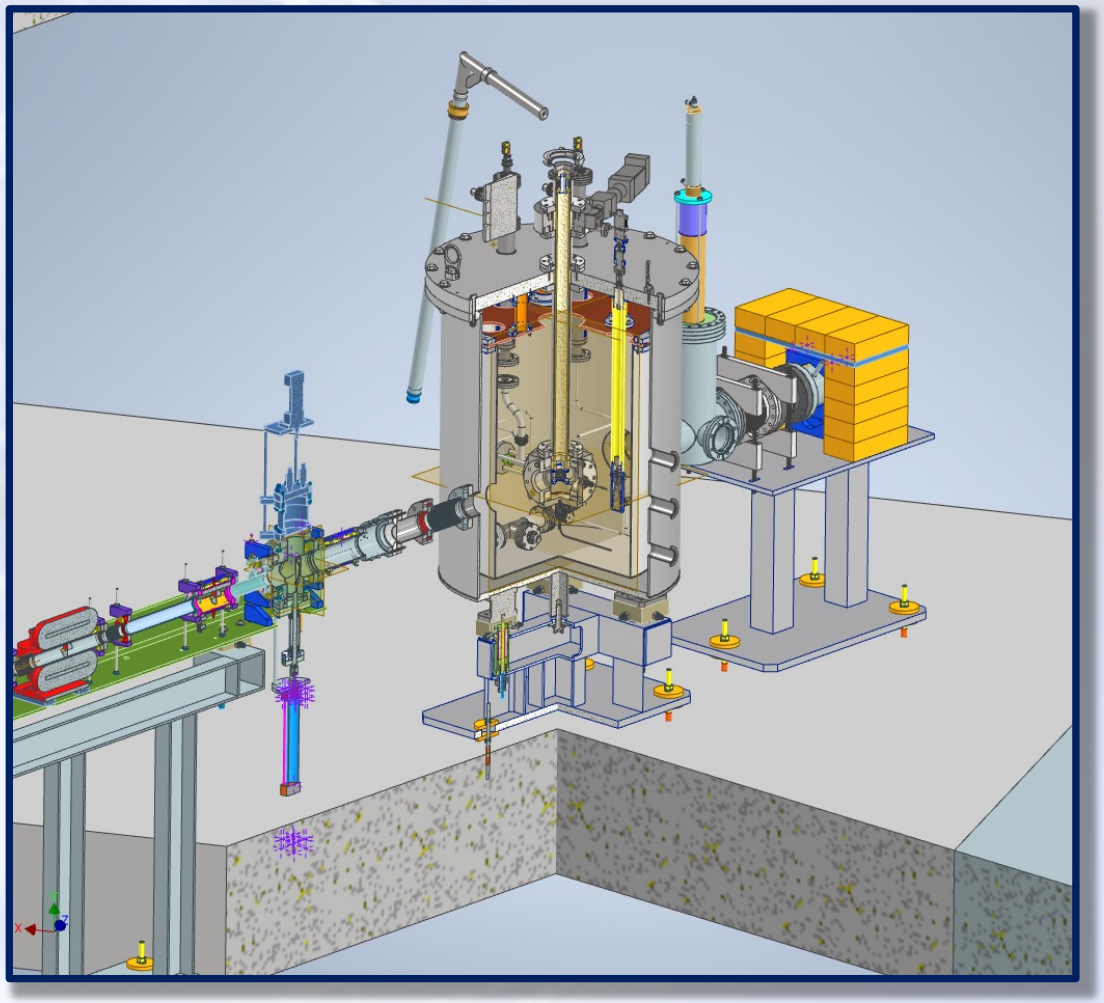
That means we “only” need new construction of a few items

- Superconducting magnet → Procurement in FY27
- 1 K refrigerator
- Target ladder
- Vacuum chamber with exit window
- Support/Alignment platform

An irradiation facility at JLab

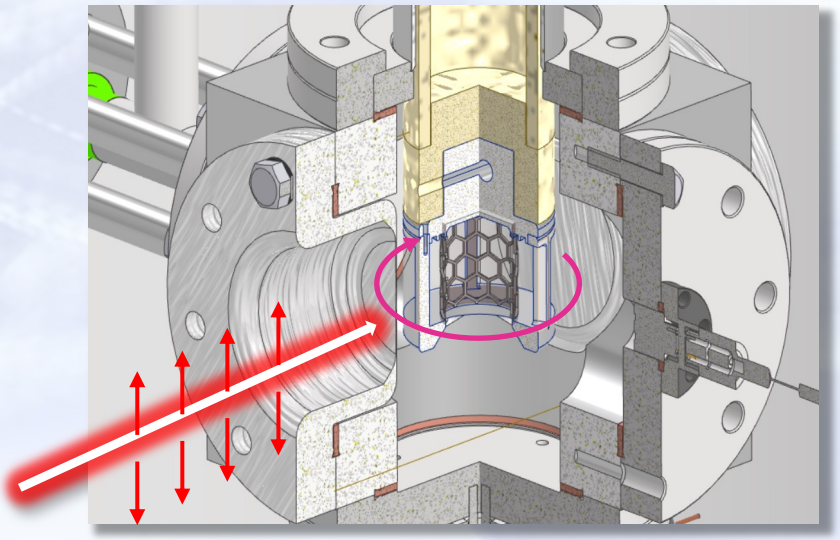
A variable-temperature cryostat for irradiating polarized target materials at the CEBAF injector and/or the Upgrade Injector Test Facility (UITF)

- 8 MeV, 1 – 10 uA
- 3 - 300 K
- NH_3, ND_3, ^7LiD, ?
- Typical dose: 10^{17} e-/cm^2
  - (5 hours at 10 mA and 90 K)

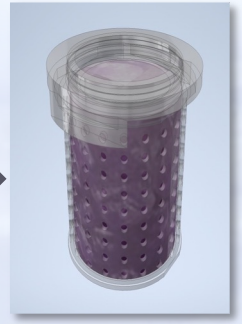


An irradiation facility at JLab

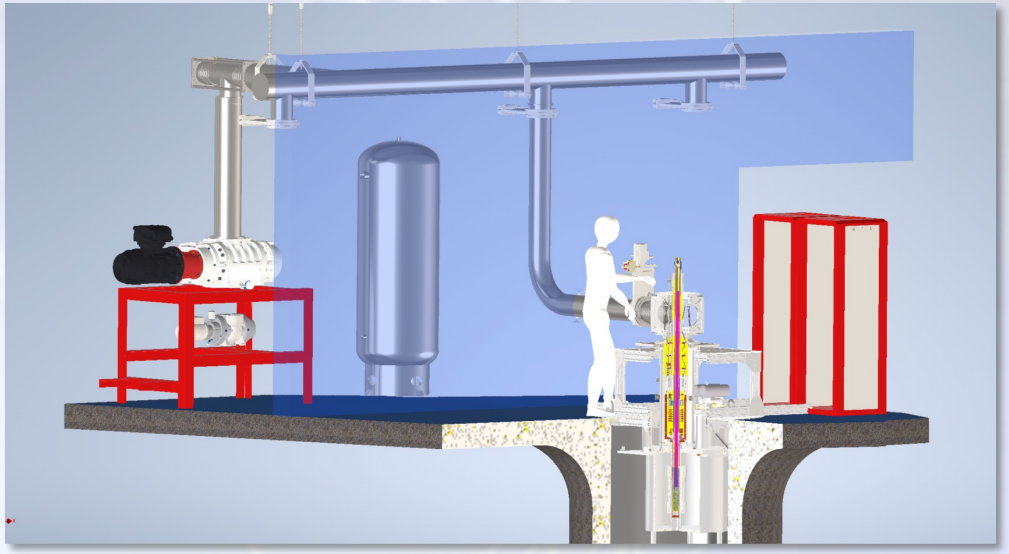
Irradiate target materials at the **UITF**



Carry them **100 steps**



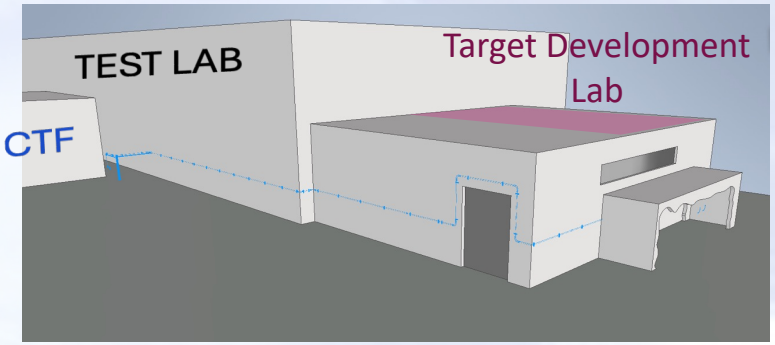
Test them in the **Target Development Lab**



An R&D lab for dynamic polarization

Goals and Activities

- Test existing and new materials (H, D, ^{6}Li, ^{7}Li, ^{13}C, ^{19}F …)
- Use magnetic resonance and IR spectroscopy to study radiation damage and repair
- Develop and test new microwave, NMR, and cryogenic instrumentation
- Pursue AI/ML efforts for optimizing and measuring polarization
- **Train new scientists!**

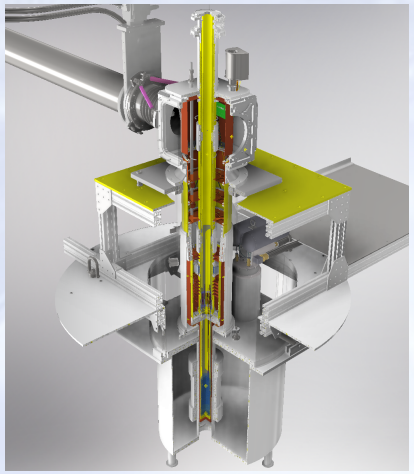




1 K refrigerator



Cryogen-free 5 T magnet



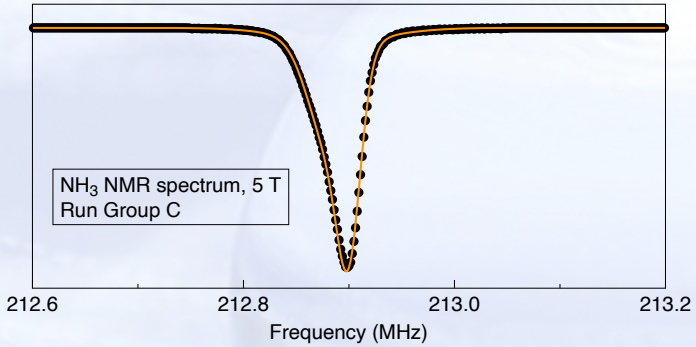
Magnet and fridge assembly

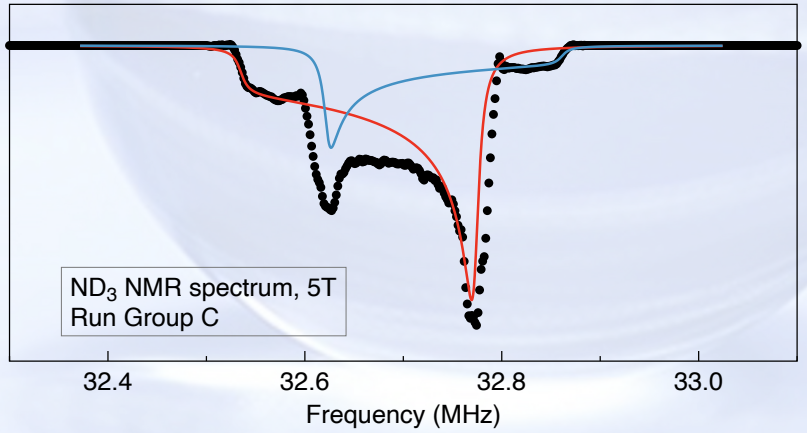


Test stand for Dynamic Nuclear Polarization

An irradiation facility at JLab

Quantify the results using DNP/NMR

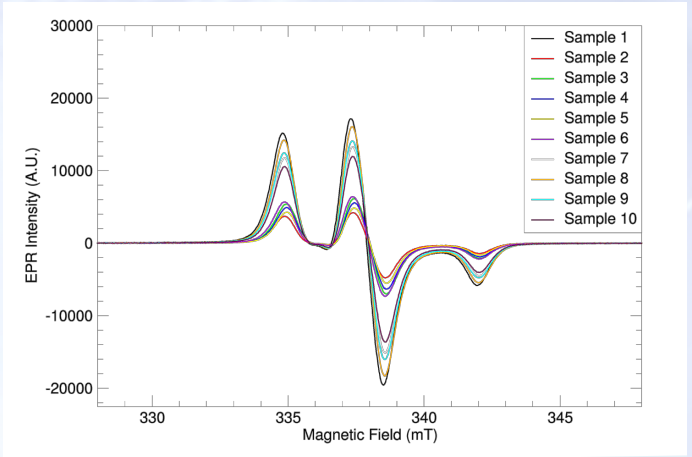




… and Electron Spin Resonance (ESR)



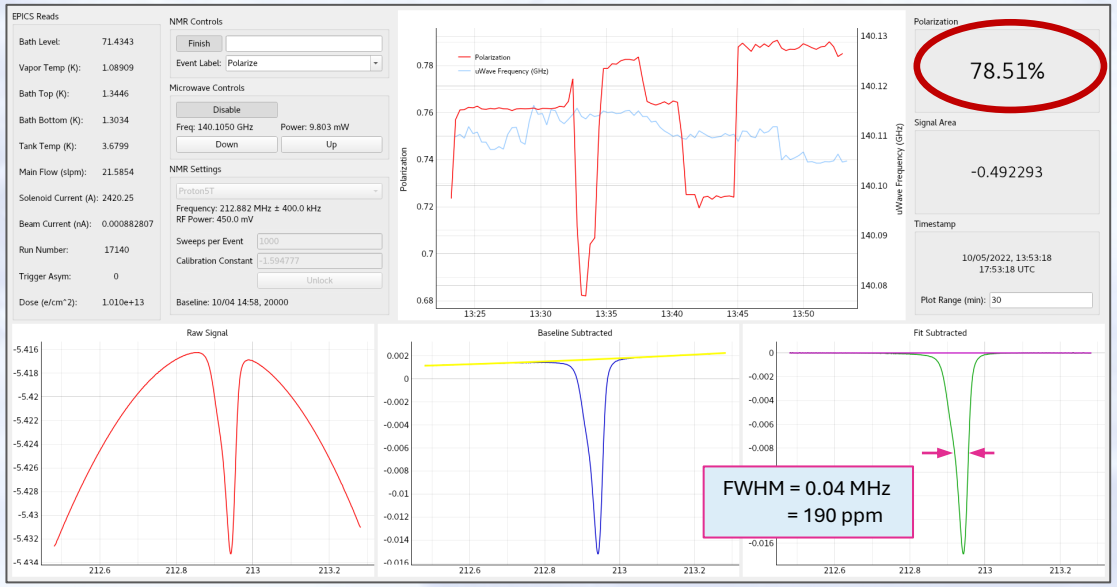
Bruker Magnettech ESR5000
benchtop spectrometer
(on order, delivery expected next week)



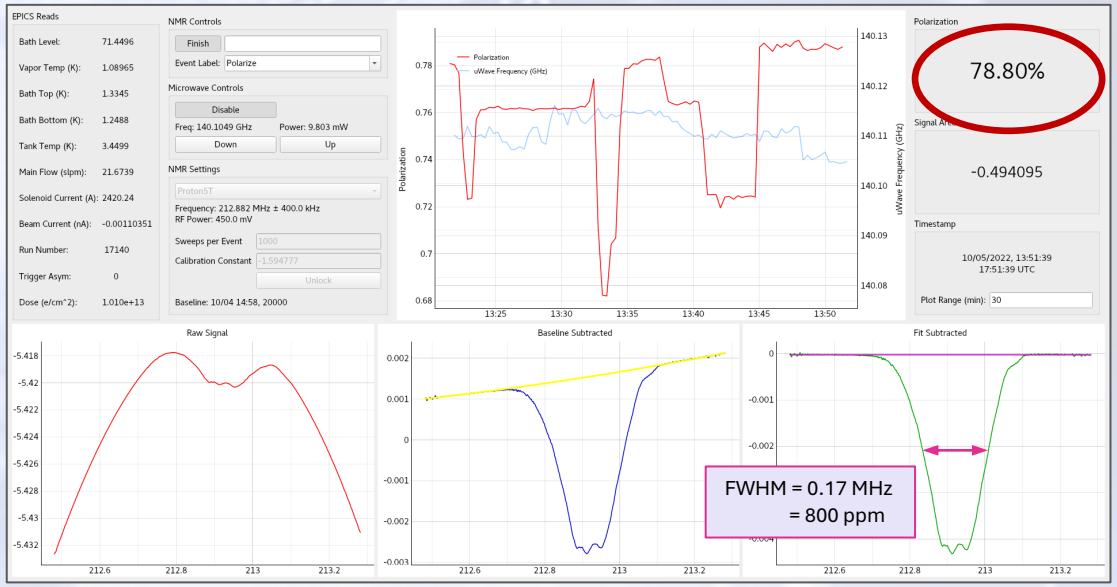
An R&D lab for dynamic polarization

One example: What are the actual requirements for magnetic field uniformity?

A typical proton NMR signal in Run Group C



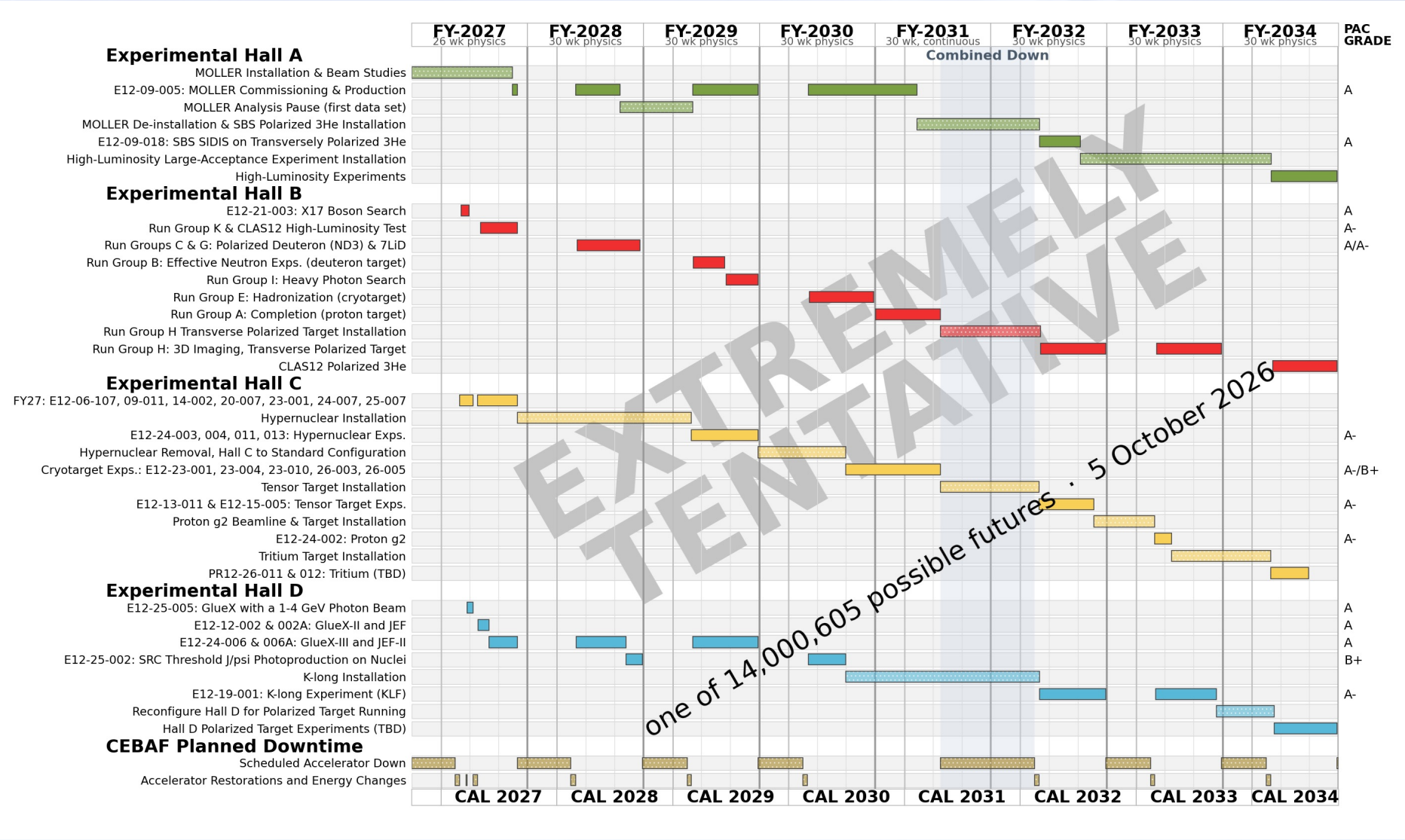
Badly distorted field → same polarization??



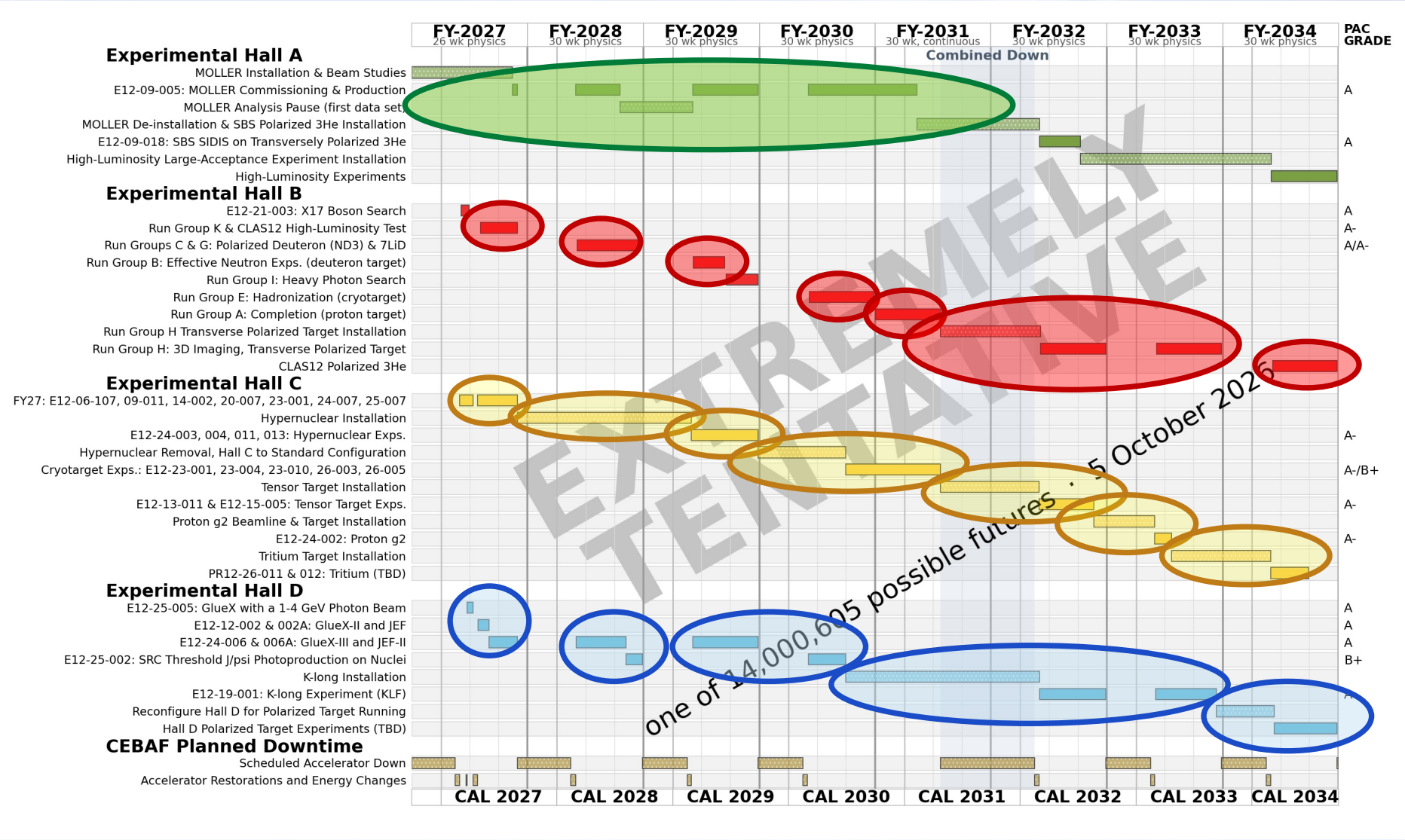
Other questions to answer

- How can we improve the deuteron polarization in ND_3?
- Is ^7LiH a viable alternative to NH_3?
- How can we implement AI/ML techniques to improve target performance?

The JLab Target Group



The JLab Target Group



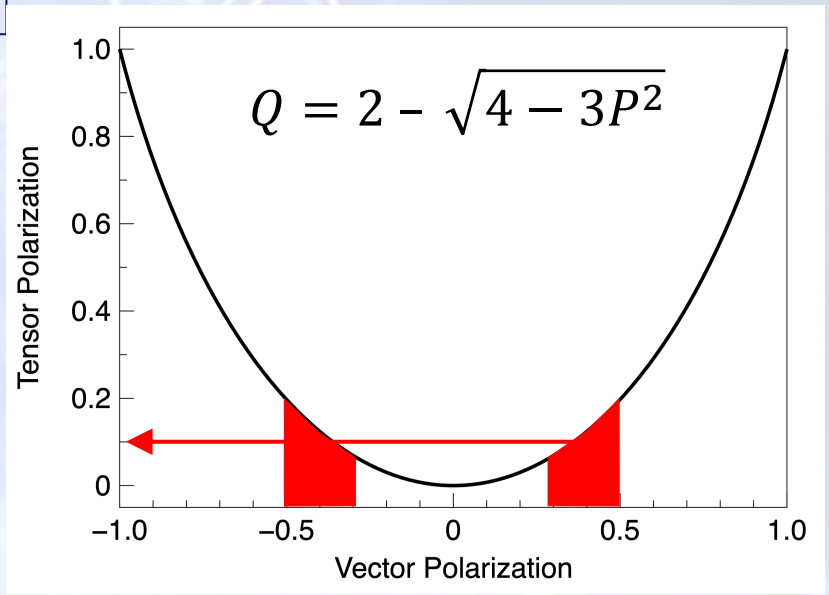
THANK YOU!

QUESTIONS?

BACKUP SLIDES

Tensor polarized target

- Isolate Short-Range effects in nucleon-nucleon interactions
- Probe quark see tensor polarization
- Final-state interactions and color transparency

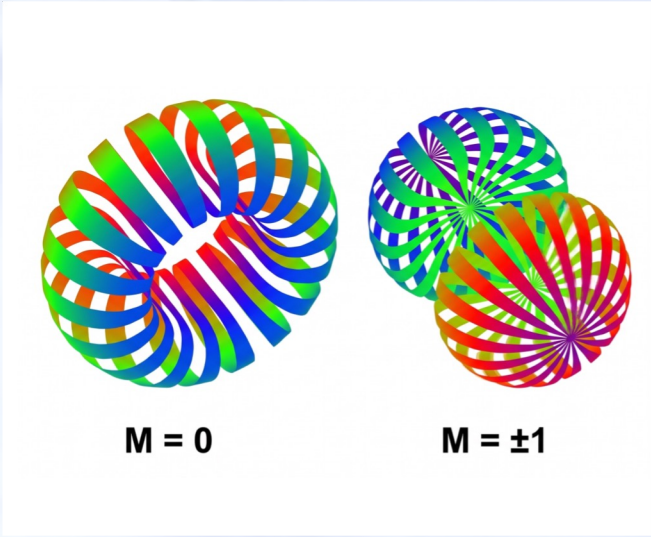


Vector Polarization

$$P = N_+ - N_-$$

Tensor Polarization

$$Q = 1 - 3N_0$$



Using dynamic polarization alone, the **tensor polarization** will only be about **10-15%**

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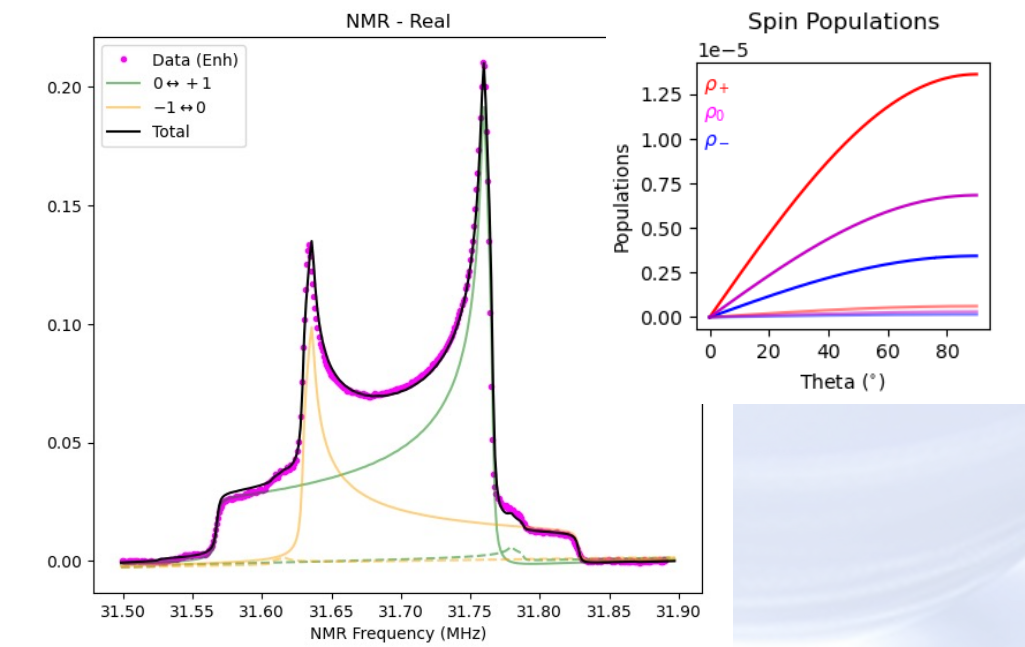
Tensor polarized target

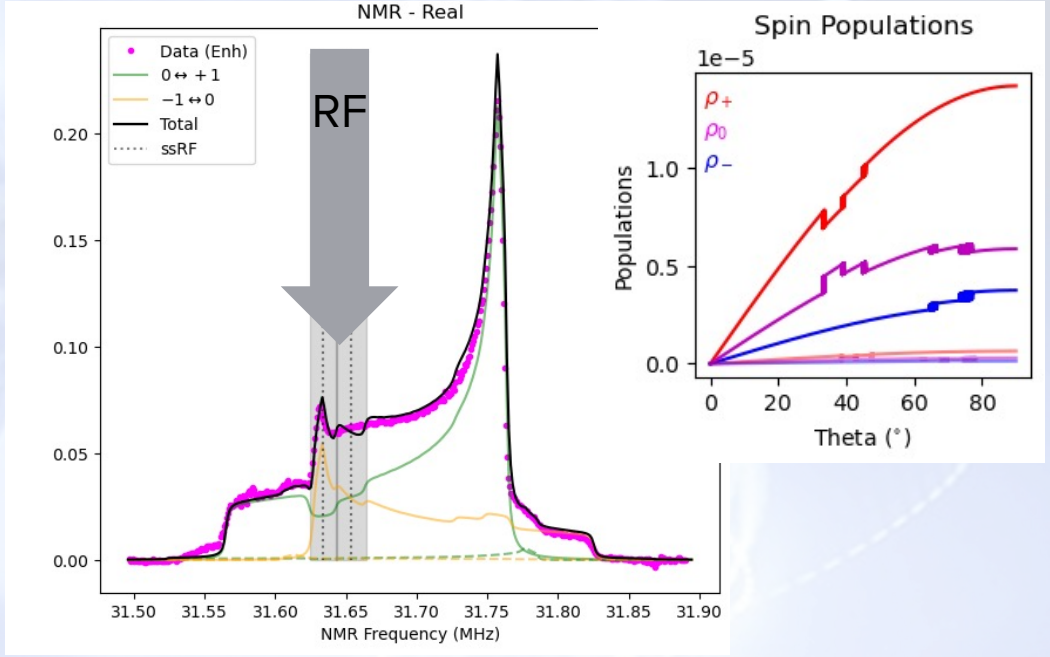
Images courtesy of Elena Long

Selective Semi-saturating RF (ssRF or "hole burning")

RF can be used to partially saturate portions of the deuteron NMR line to **reduce the m = 0 population** and **increase the tensor polarization.** The goal is Q = 20%.

P.P.J. Delheij, D.C. Healey and G.D. Wait, NIM A251 (1986) 498
D. Keller, Eur. Phys. J. A. (2017) **53**: 155





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Tensor polarized target in Hall C



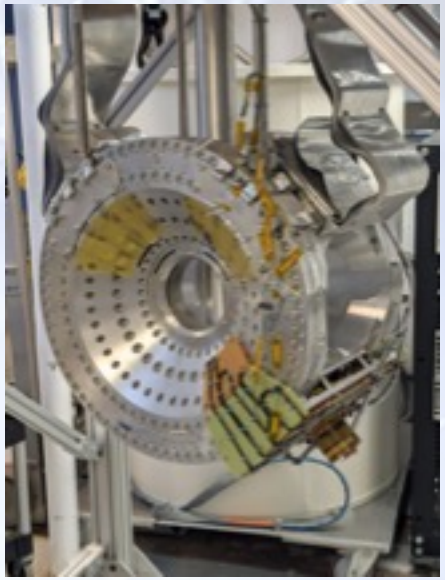
E12-13-011: *The Deuteron Tensor Structure Function b1*
E12-15-005: *Measurement of Quasi-Elastic and Elastic Deuteron Tensor Asymmetries*
E12-24-002: *Revealing the Transition Region of QCD with the Proton's g2 Structure Function*

The target system was last used in 2012 (Hall A).

Extensive refurbishment with new equipment will commence in 2027, led by UNH.







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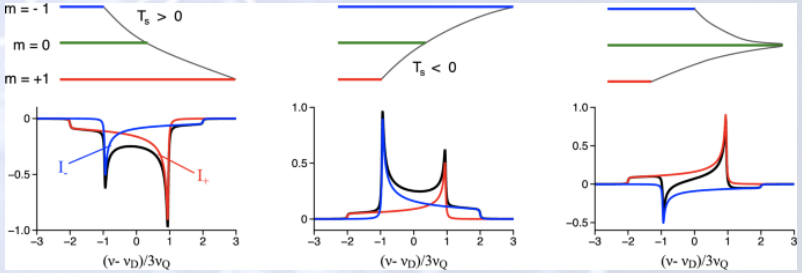
Tensor polarized target in Hall D

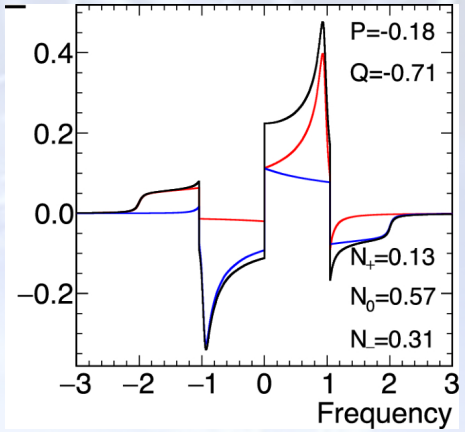
E12-25-012: *High precision measurement of phi-nucleon cross section using a tensor polarized deuteron target*





Test stand under assembly at UTK





M.M Dalton, A. Deur, A. & C.D.Keith, Potential for tensor polarized deuterons in Hall D at Jefferson Lab. *Eur. Phys. J. A* **61**, 111 (2025). https://doi.org/10.1140/epja/s10050-025-01580-y

FROST-D Polarized Target

Dynamic nuclear polarization inside the Hall D solenoid at 2.5 T and 0.3 K.

Frozen spin operation at >50 mK / 2.5 T is also possible.

THE UNIVERSITY OF TENNESSEE KNOXVILLE · OAK RIDGE National Laboratory · Jefferson Lab Target Group

Genesis Mission Award

A.I. Era Spin Physics of Quantum Systems: Real-Time Feedback and Neural Network Optimization of Polarized Targets

Bring AI/ML methods to tensor polarized in three sub-areas:

- Optimization of hole-burning profiles using real-time analysis of deuteron NMR signals
- Near-real-time estimation of target material packing fractions and dilution factors from scattering data
- Optimization anneal temperatures, durations, and scheduling trained from historic data and ESR studies

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