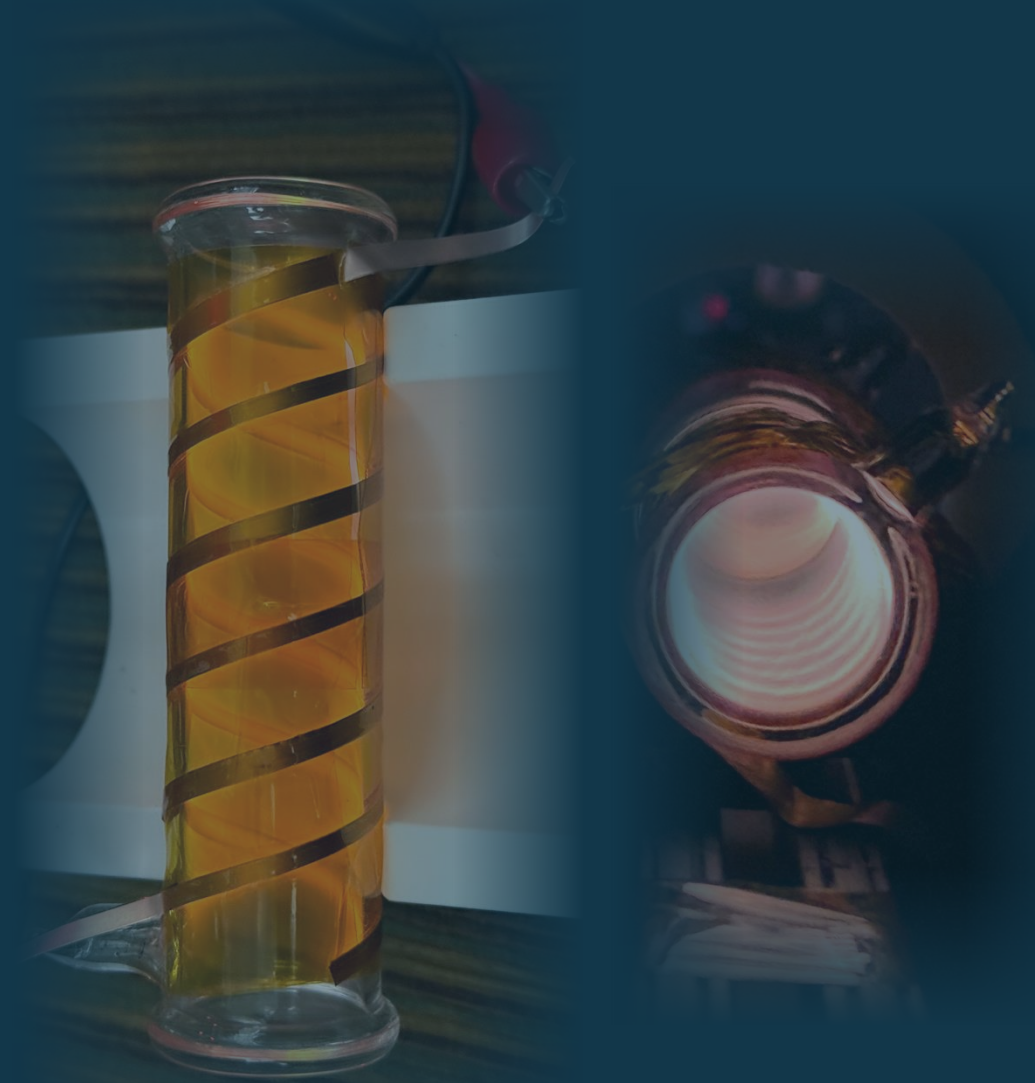
CLAS12 COLLABORATION MEETING

Progress towards a Polarized ^{3}He Target in CLAS12



Hao Lu

Jefferson Lab
November 19, 2026

A polarized neutron target for CLAS12

Effective neutron target

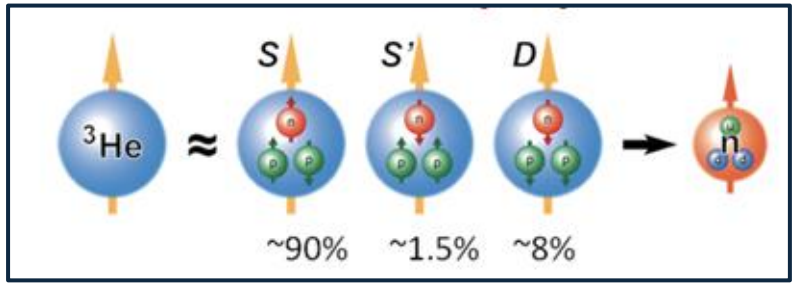
The neutron carries most of the ^{3}He nuclear spin. Nuclear corrections remain essential.

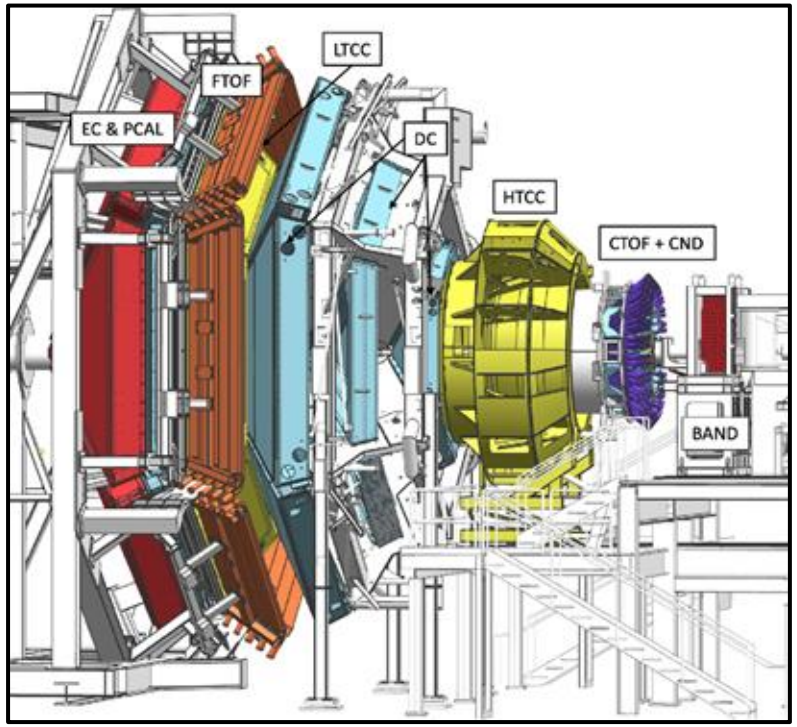
Neutron spin measurements

Complement the polarized proton and deuteron programs.

Target requirement

Provide polarized ^{3}He at useful luminosity inside the 5 T solenoid.





PR12-20-002 (2020), Abstract and Executive Summary

Luminosity requirement and target design

Luminosity goal

$L \approx 4.5 \times 10^{34}$ ^{3}He cm^{-2} s^{-1}
At 2.5 μA: $n\ell \approx 3 \times 10^{21}$ ^{3}He cm^{-2}

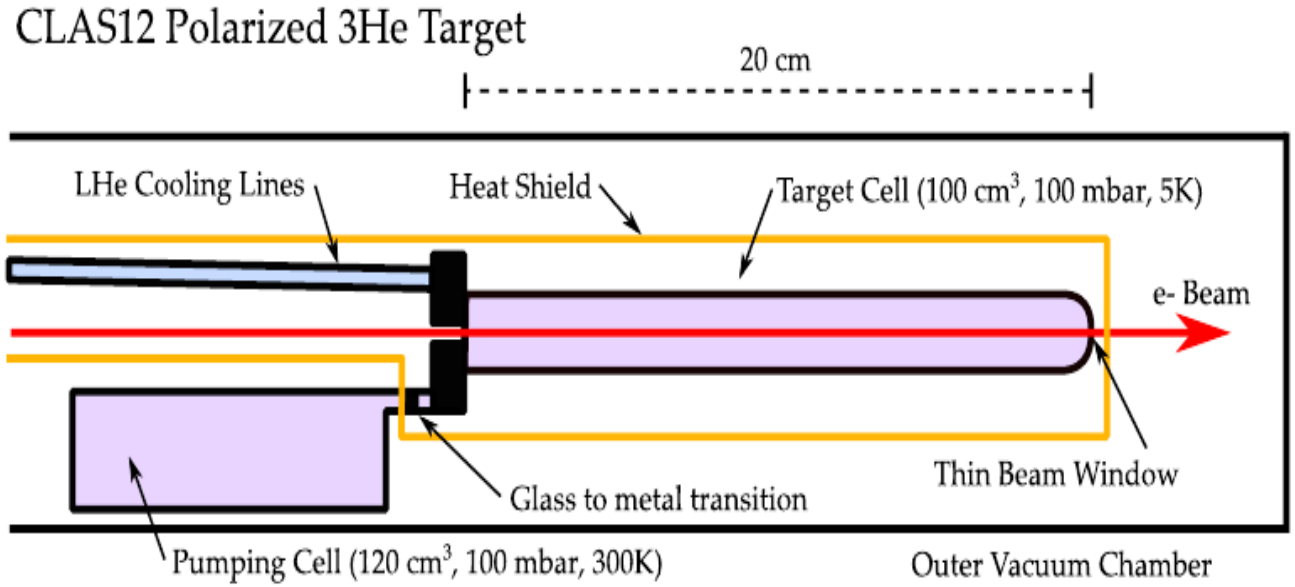
Density determines the cold cell

100 mbar, 20 cm long, at 5 K
Cooling raises the gas density at a practical pumping pressure.

Polarization in the 5 T solenoid

Warm MEOP cell supplies polarized gas to the cold target cell.

Two cells serve different needs



Warm cell: produce polarization
Cold cell: provide target density
Target polarization goal: 60%

Design: PR12-20-002 (2020); J. Maxwell & R. Milner, Nucl. Instrum. Methods A 1012 (2021) 165590.

MEOP and the high-field operating regime

Polarization mechanism

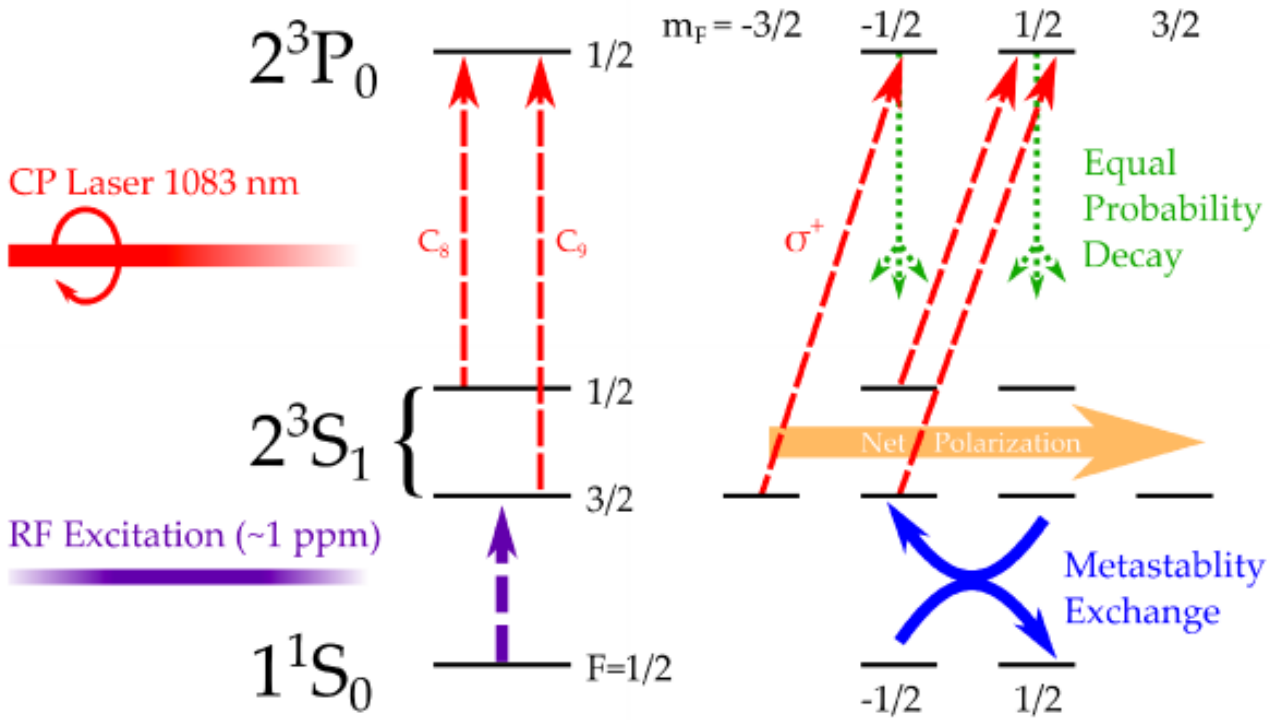
RF discharge creates metastable atoms. 1083 nm light pumps 2^3S–2^3P transitions.

Ground-state nuclei

Metastability exchange connects the optically pumped states to the bulk gas.

High-field tradeoff

Hyperfine decoupling slows transfer but can suppress relaxation channels and resolve useful transitions.



J. Maxwell & R. Milner, Nucl. Instrum. Methods A 1012 (2021) 165590; Courtade et al., Eur. Phys. J. D 21 (2002) 25.

French-led advances in high-pressure MEOP

LKB at ENS, Paris

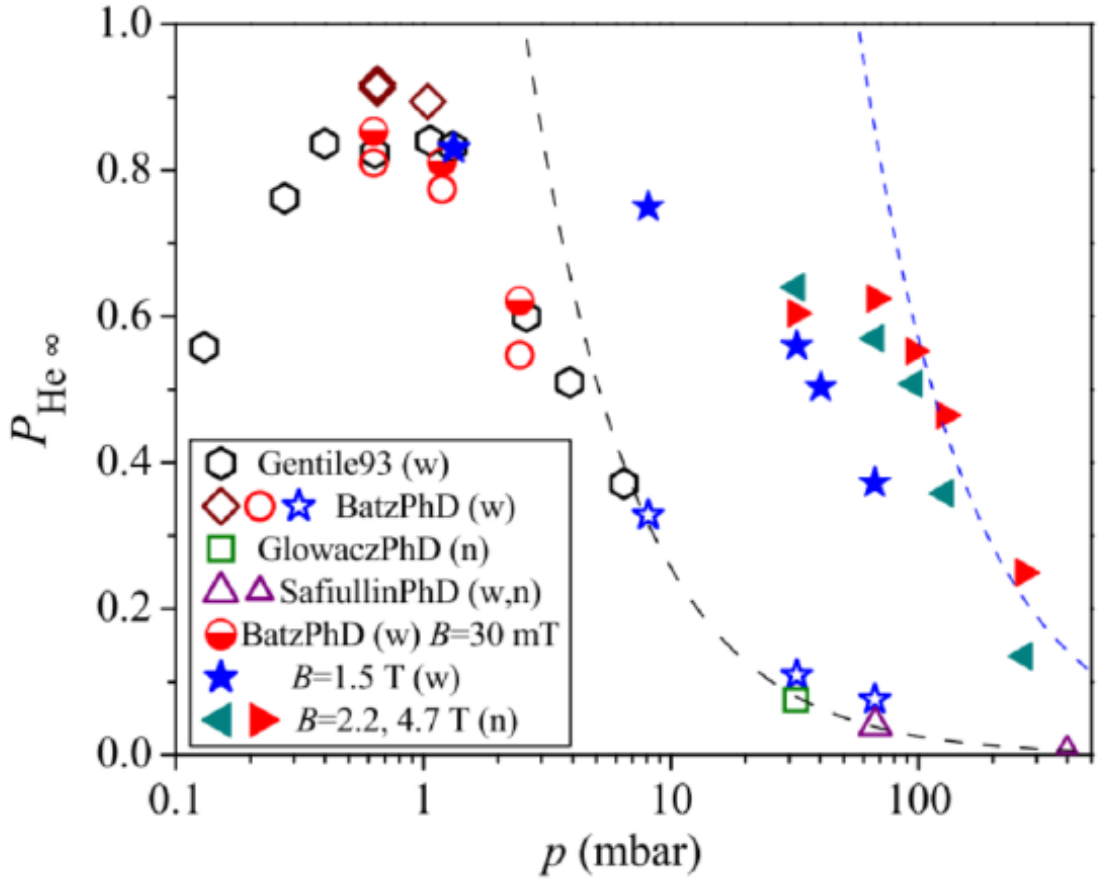
Nacher, Tastevin, Courtade and colleagues established high-field spectroscopy and polarimetry.

1.5 T development

Abboud et al. reported 80% at 1.33 mbar and 25% at 67 mbar.

French–Polish studies

Nikiel-Osuchowska et al. studied 1–267 mbar at 4.7 T, extending useful pressure performance.



Abboud et al., Europhys. Lett. 68 (2004) 480; Nikiel-Osuchowska et al., Eur. Phys. J. D 67 (2013) 200.

MIT-Bates: the cryogenic double-cell approach

Physics demonstration

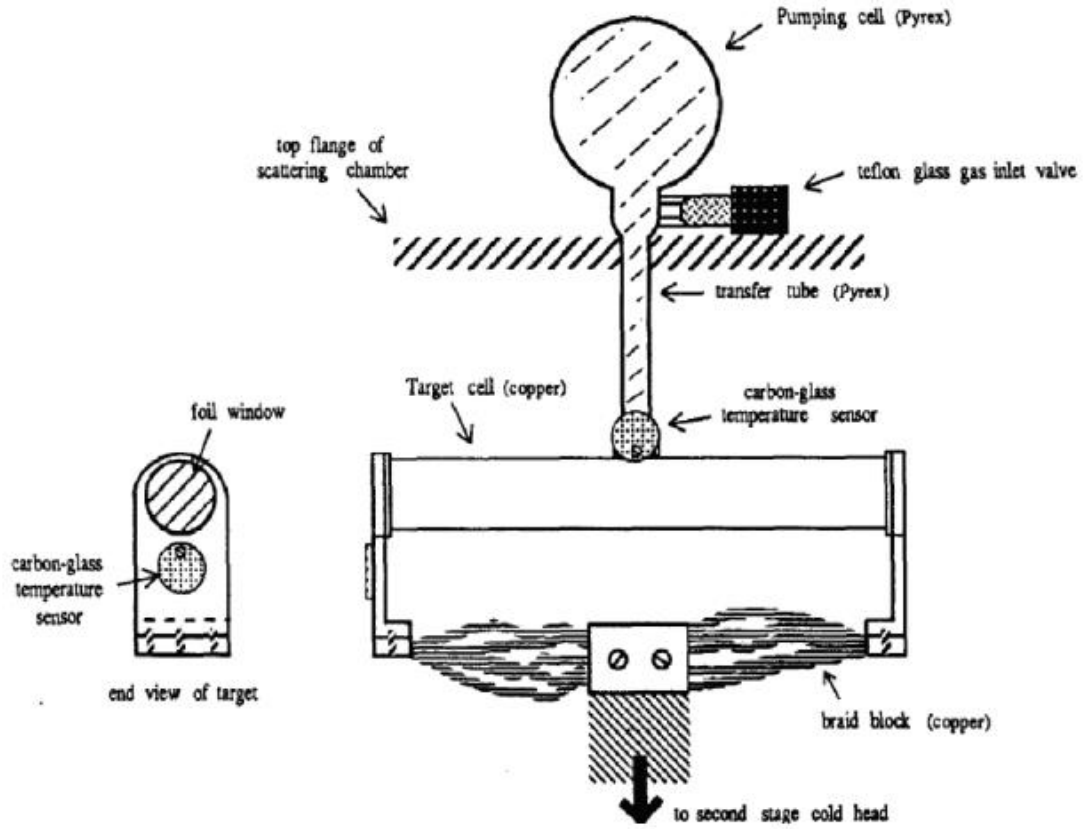
Inclusive quasielastic ^{3}He(e,e′) spin asymmetries probed neutron form-factor sensitivity.

Cryogenic double cell

Warm Pyrex pumping cell connected to a copper scattering cell with thin foil windows.

Density increase

Published comparison: 2.6 mbar, 17 K and about 40% polarization. Cold-cell operation raised density.



Milner, McKeown & Woodward, Nucl. Instrum. Methods A 274 (1989) 56; Maxwell & Milner, A 1012 (2021) 165590.

JLab high-field MEOP test stand

Magnetic field

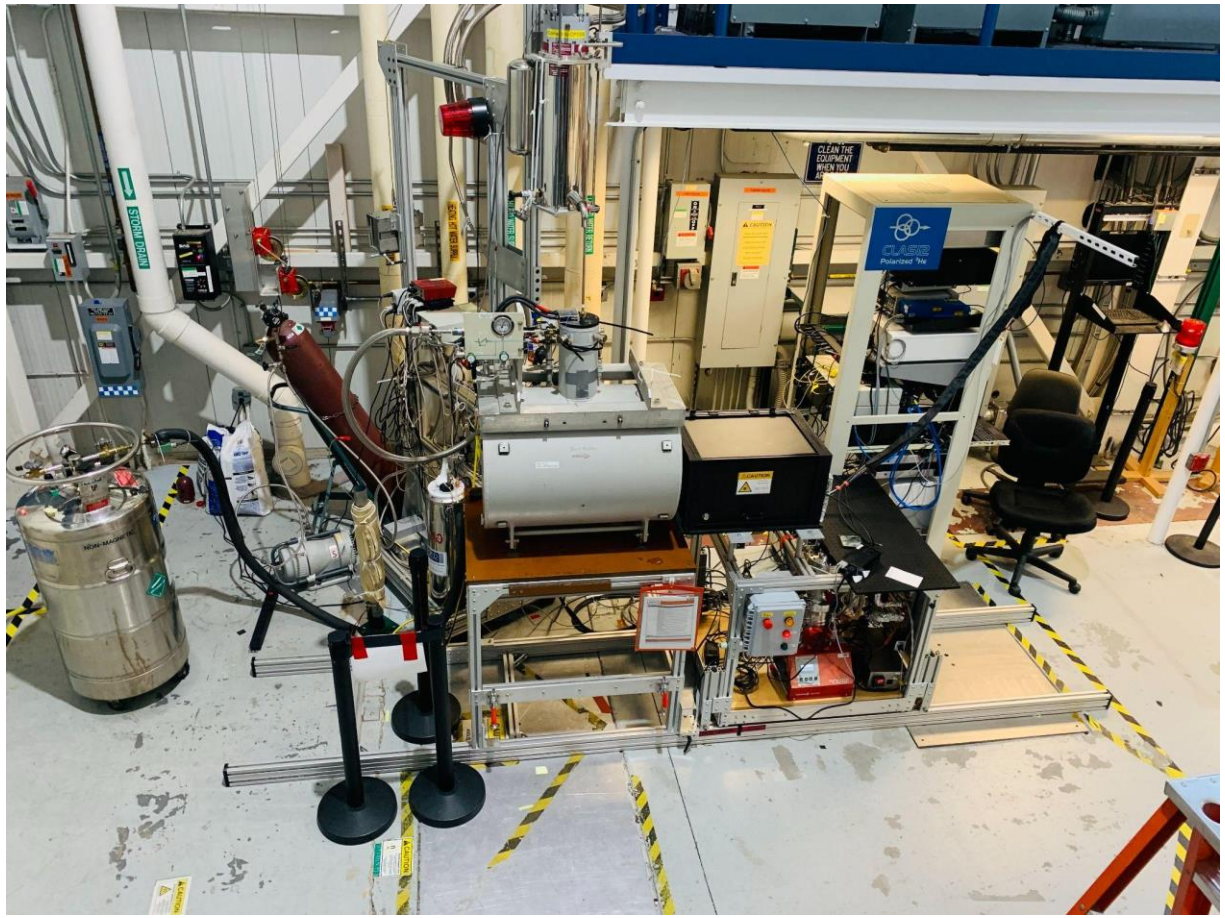
FROST superconducting magnet supports measurements up to 5 T.

Optical enclosure

Pump and probe optics control polarization production and readout.

Acquisition

RF drive, lock-in detection and laser control support systematic scans.



MEOP electronics and laser control



Pump and discharge

Pump laser, RF amplifier and signal generator

Probe readout

Probe laser, photodiode amplifier and lock-in detection

Wavelength monitoring supports laser tuning.



Pump laser system

Seed laser

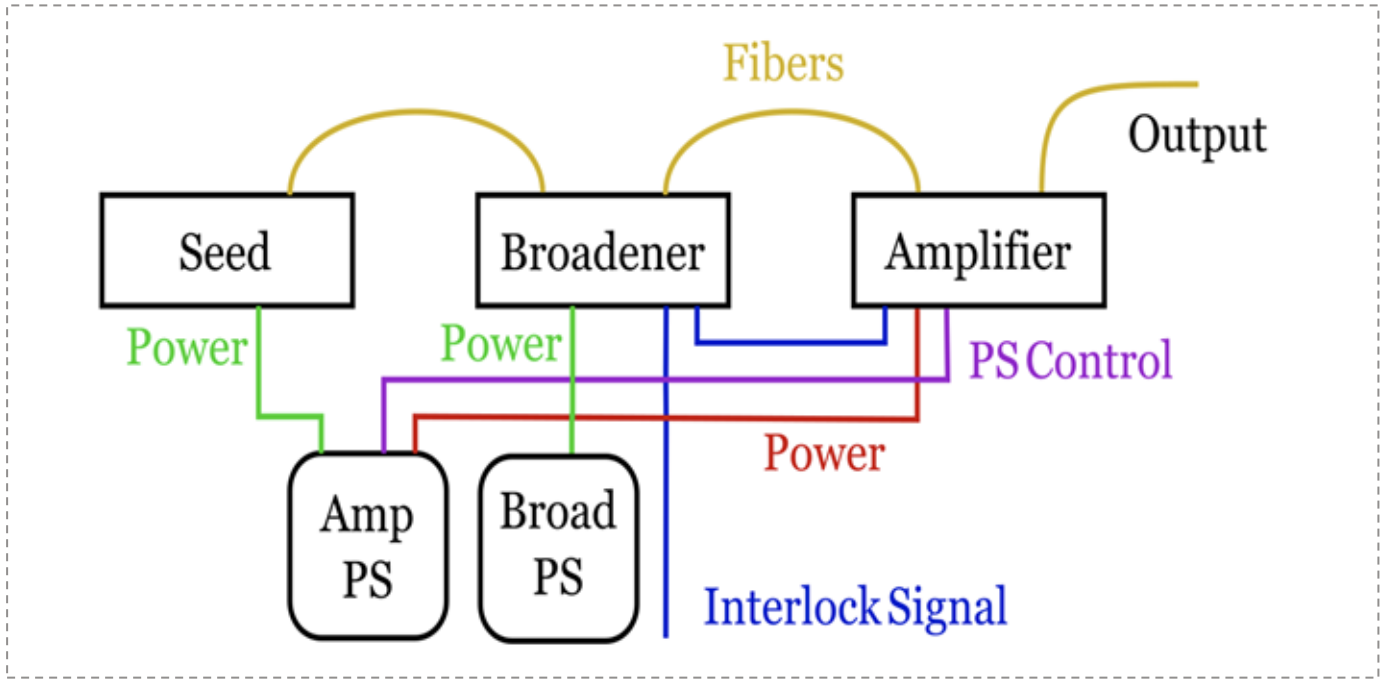
Provides the initial laser light

Broadener

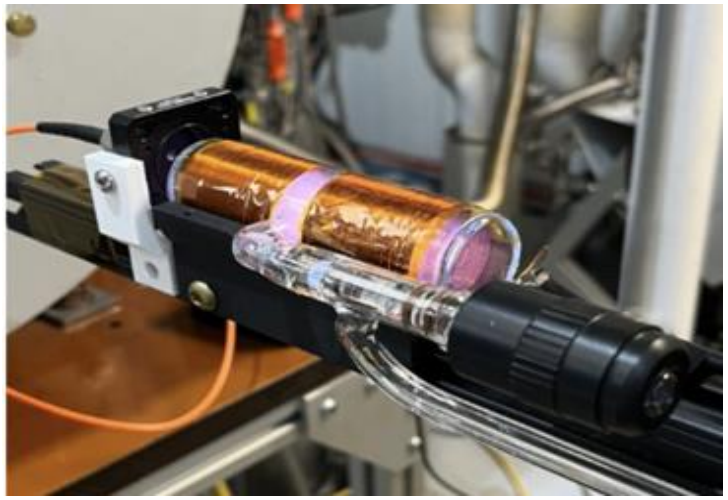
Broadens the spectrum to cover the pumping transition

Amplifier

Raises the pump power for optical pumping

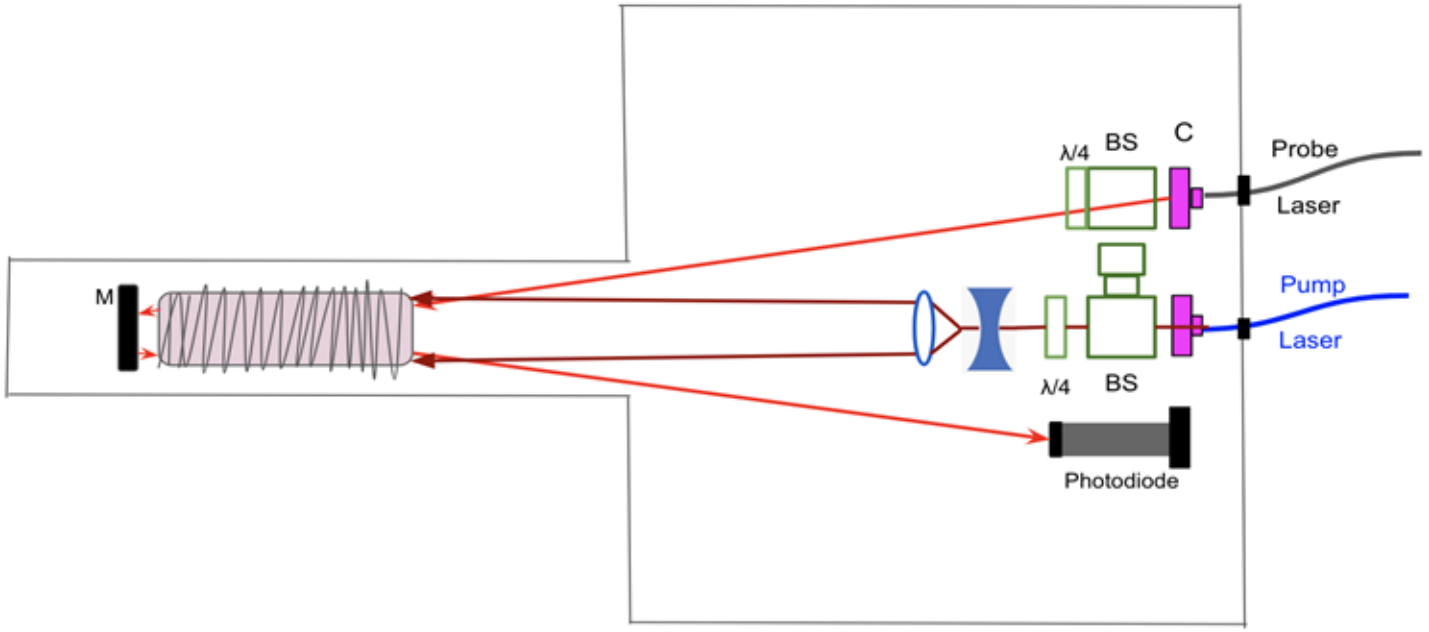


Fillable cell and pump–probe optics





Cell and optical enclosure



JLab baseline: Li et al. (2023)

Operating range

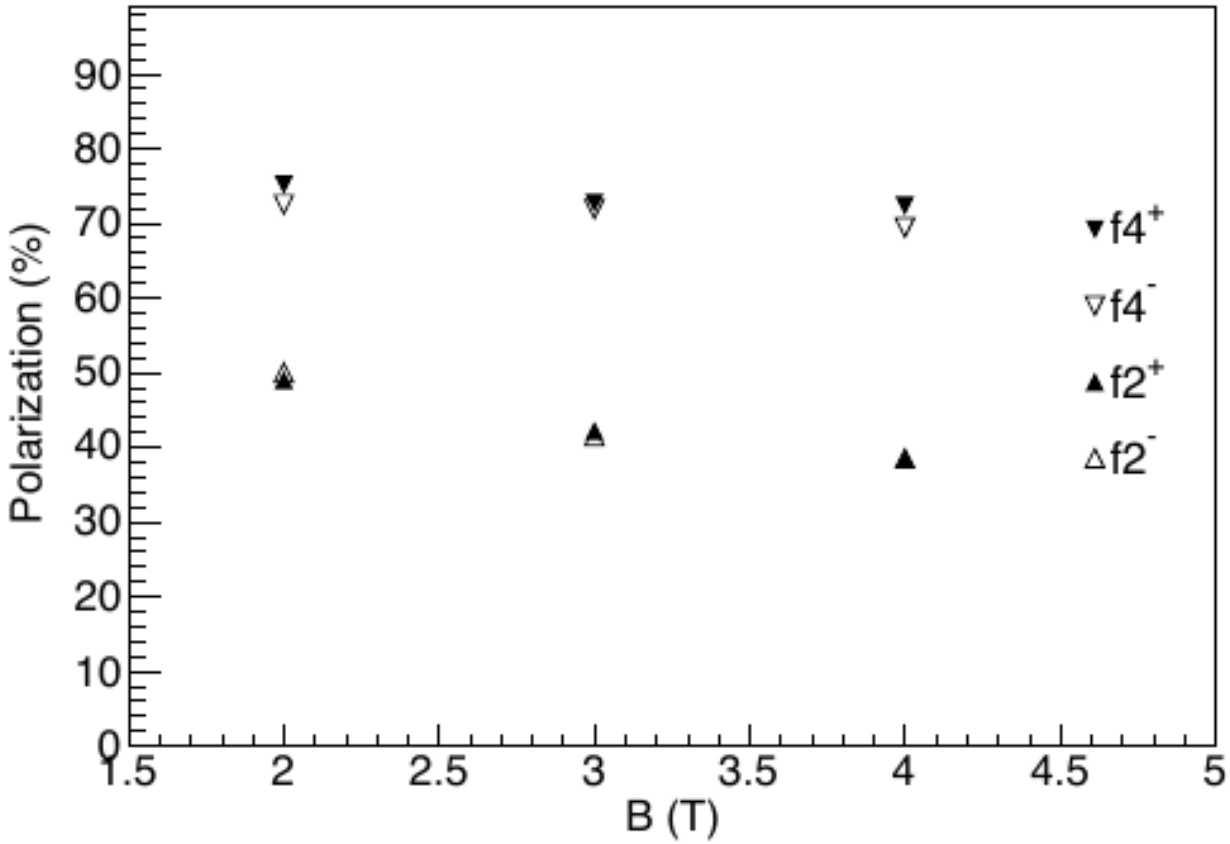
1 torr sealed cell, about 1.3 mbar, tested at 2, 3 and 4 T.

Published polarization

Maximum about 75%. At 4 T, f_4^+ reached 72% and f_4^- reached 69% in Table 1.

Transition dependence

The f_4 schemes outperformed f_2 under these low-pressure conditions.



X. Li et al., NIM A 1057 (2023) 168792, Fig. 8 / Table 1

Cleaned cell: published low-pressure results

Cell preparation

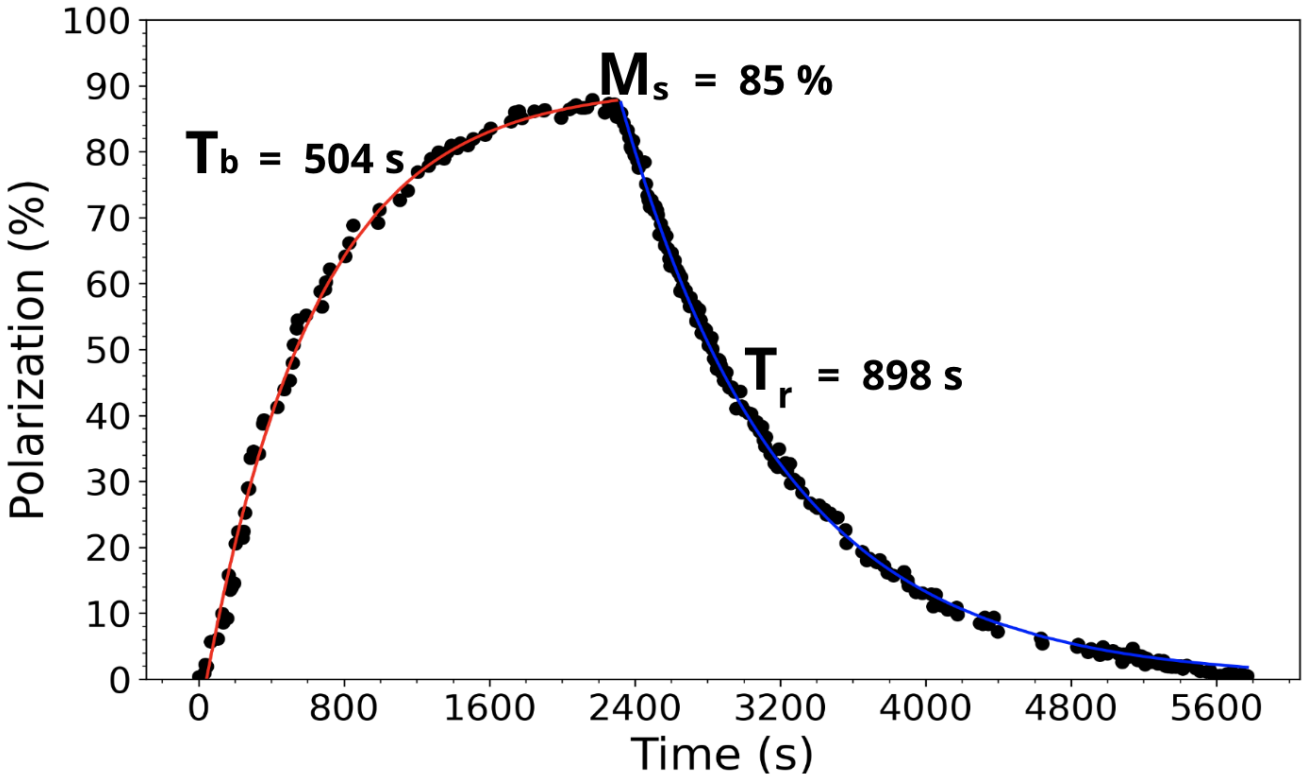
200 °C bakeout, helium pump-and-purge conditioning, RGA and emission-spectrum monitoring.

Published performance

1.2 mbar sealed cell, up to 86% over 2–5 T. The shown 5 T example reaches 85%.

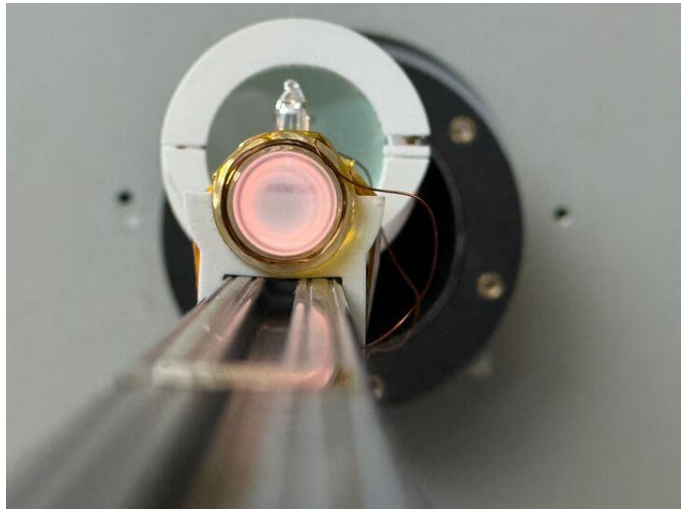
Shown cycle

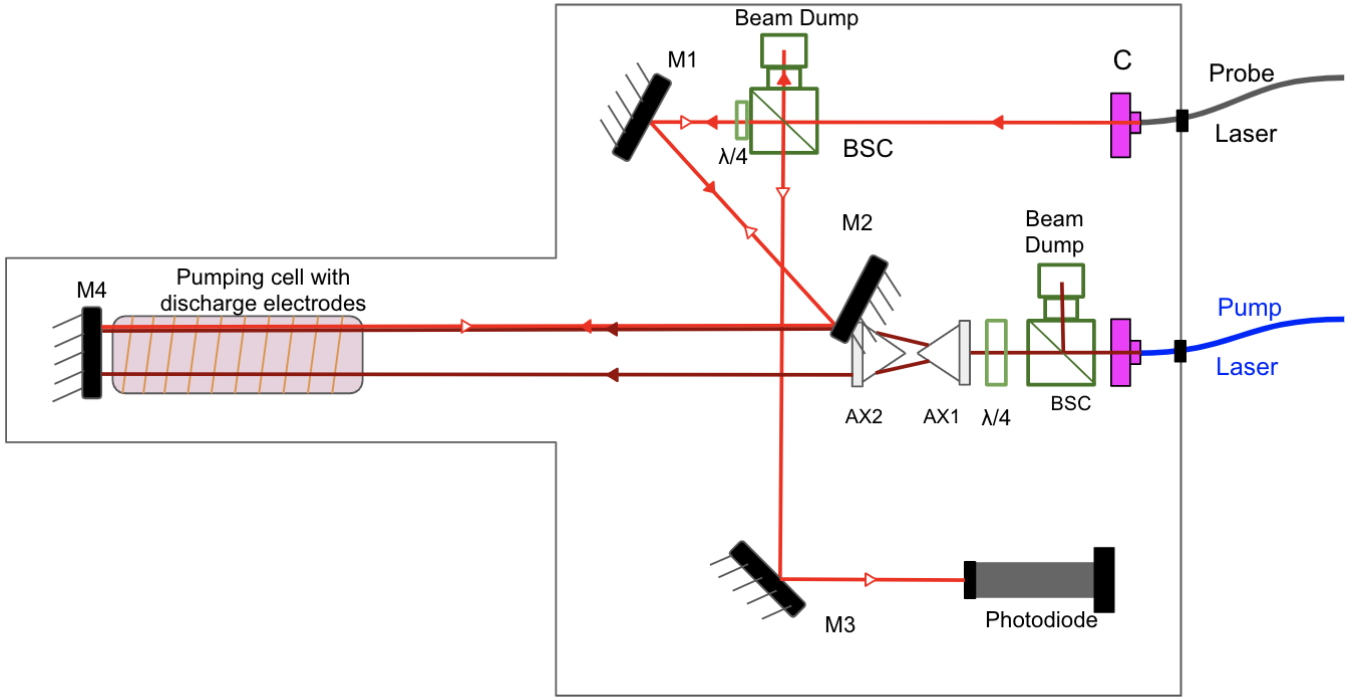
f_4^+ pumping at 5 T. Buildup time 504 s and discharge-on relaxation time 898 s.



Pandey, Lu et al., NIM A 1081 (2026) 170870, Fig. 4

Pump-profile matching with axicons





M1-M4: Mirrors
BS: Beam Splitter Cube
C : Collimator
AX: Axicons
Maroon red: Pump laser
Red solid arrow: incident probe laser
Red unfilled arrow: Reflected probe laser

Spatial overlap of the pump light and metastable population matters

Unpublished low-pressure result: ≈90%

Operating point

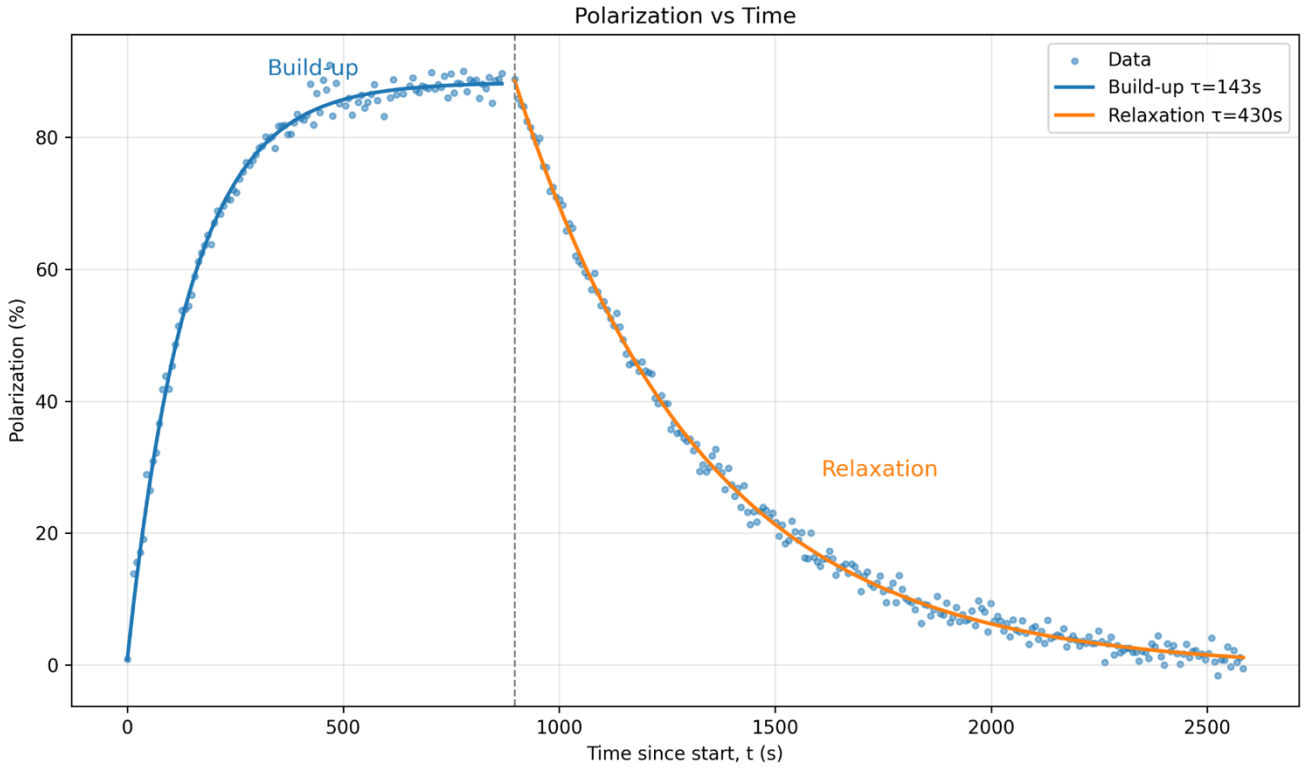
1.2 mbar, 2 T, f_4^- pumping, following laser-profile matching.

Measured cycle

Buildup time: 143 s
Relaxation time: 430 s

Status

Preliminary result shown at DNP in October 2025, after submission of the 86% paper.



Preliminary unpublished result

Earlier 50 mbar tests

Preparation attempts

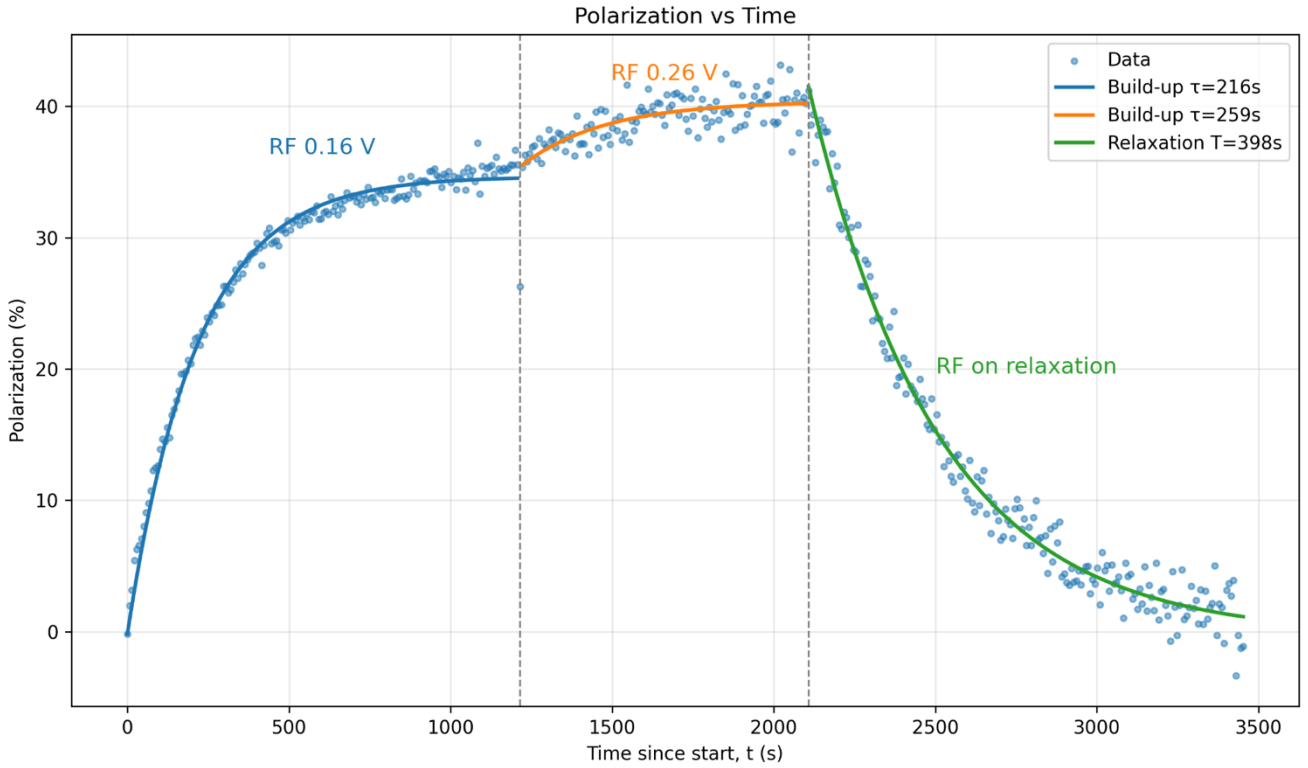
Cleaning and baking that worked at low pressure did not deliver similarly high polarization.

50 mbar at 2 T

Approximately 40% using f_2^+ after changing the discharge setting during buildup.

Early 100 mbar tests

Little polarization despite repeated cell preparation attempts.



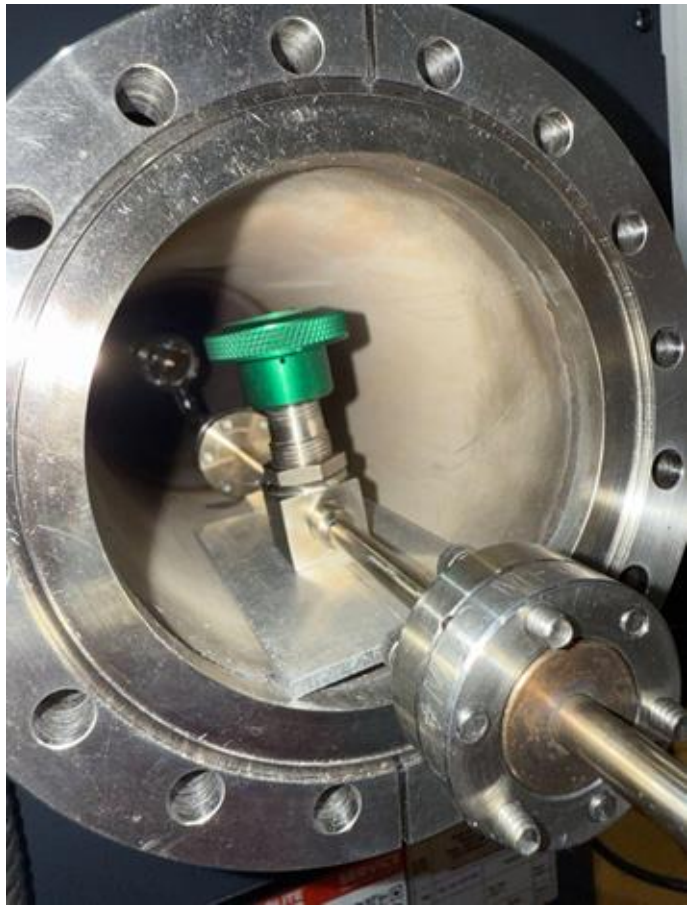
Preliminary 50 mbar result; RF setting changes during the cycle

Cell preparation for higher pressure

Cleaning and bakeout

Repeated preparation attempts did not reproduce the low-pressure performance at 50–100 mbar.



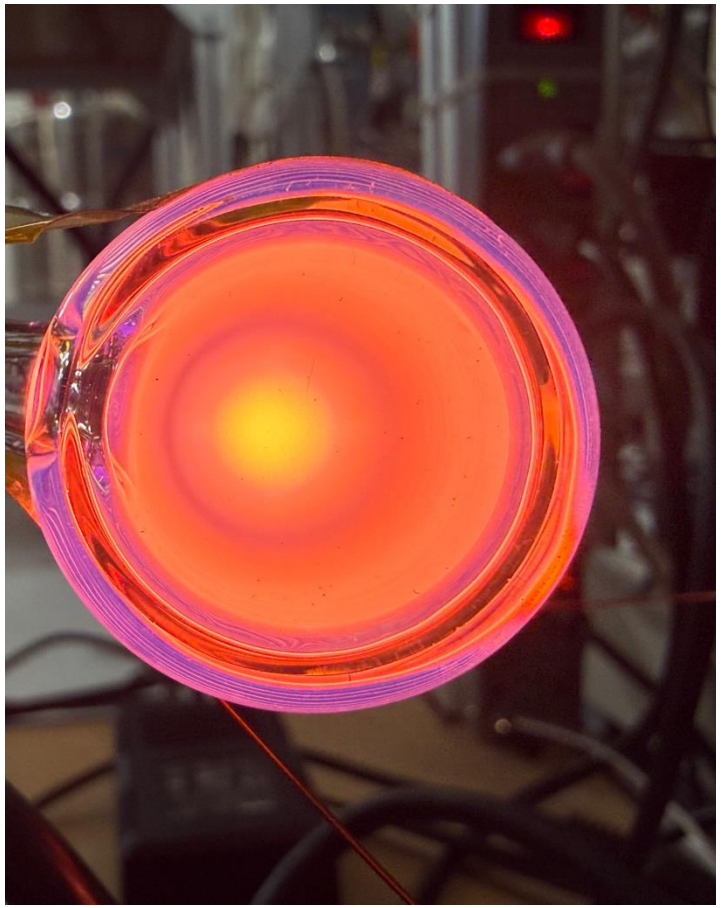


Furnace and vacuum connection used for cell preparation

Gas purity and discharge monitoring

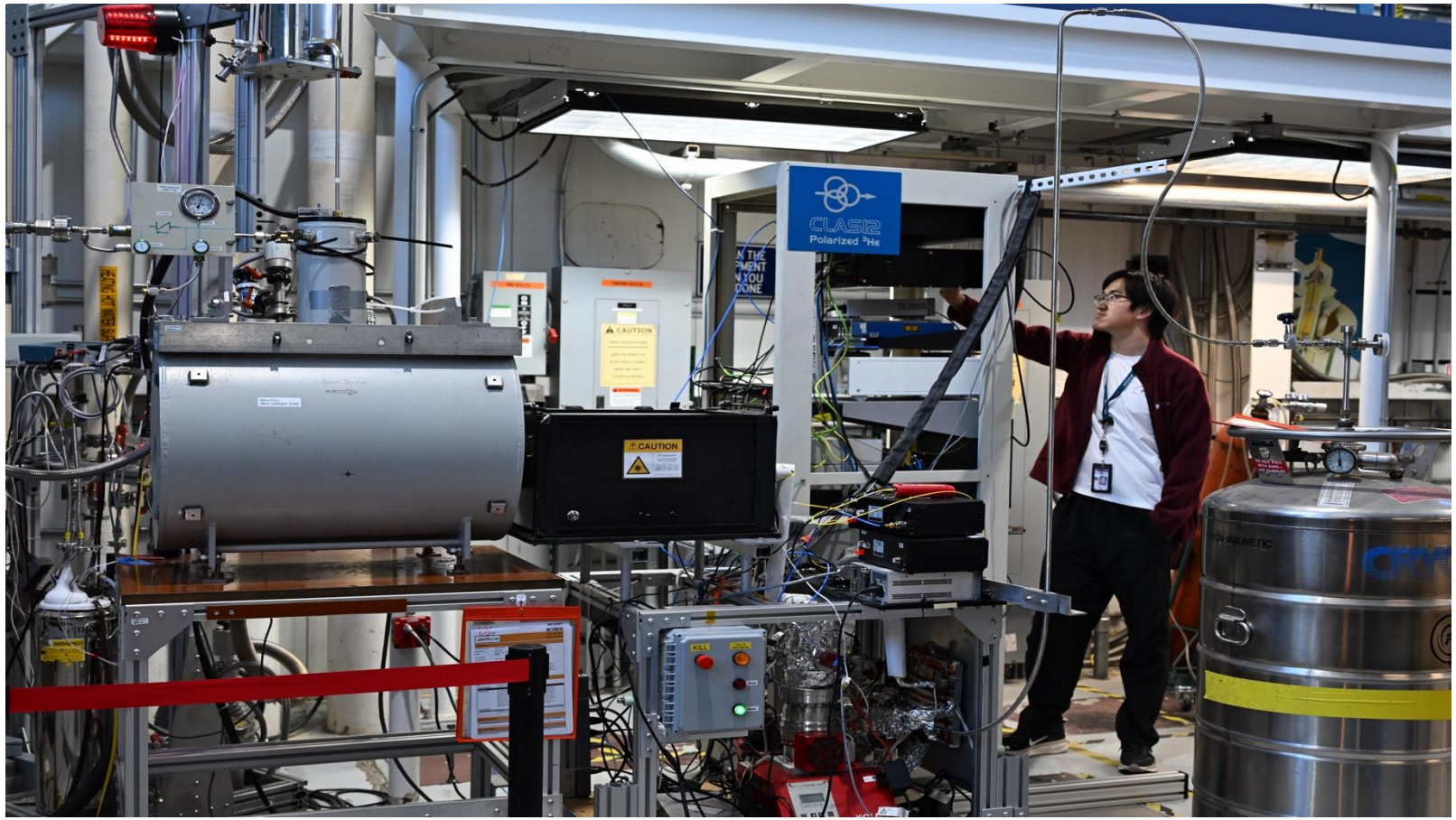


Cell preparation



Discharge appearance

Updated setup with the liquid-helium cold trap

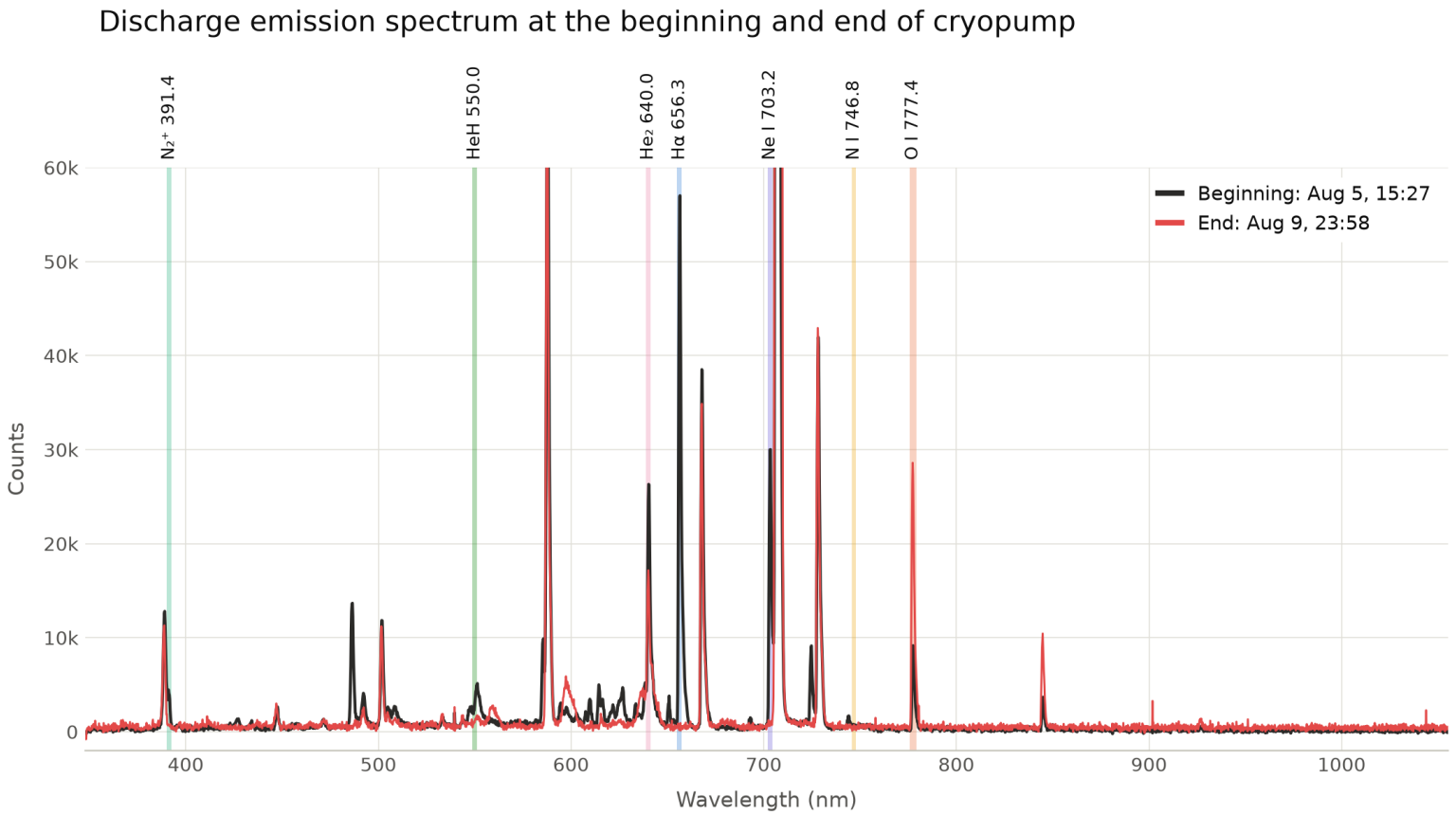


Gas conditioning

Liquid-helium cold trap added to the gas-handling system

Emission spectra track the changes during conditioning.

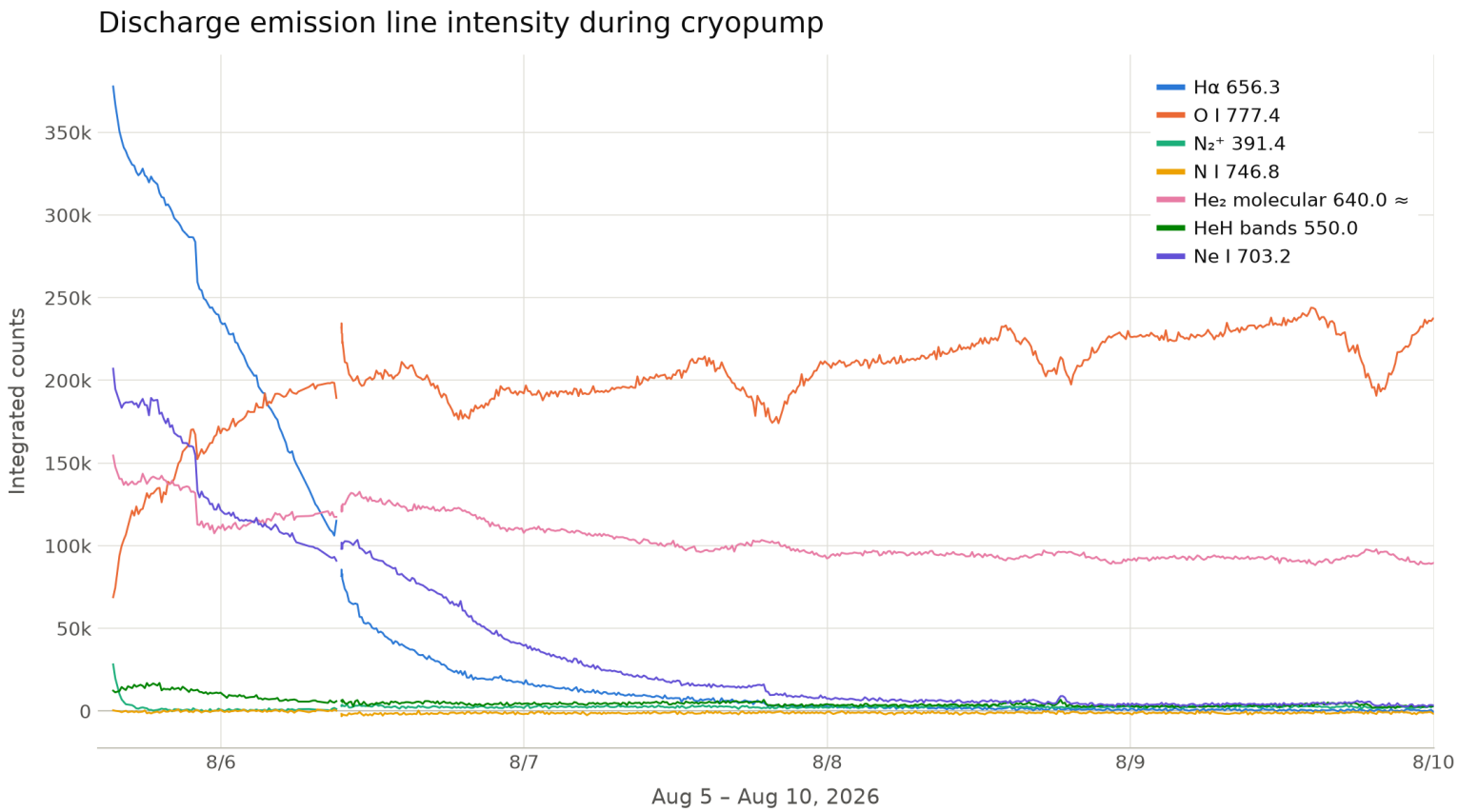
Liquid-helium cold trap: emission spectra



Cold-trap conditioning changes the discharge spectrum; several monitored features decrease.

Preliminary emission monitoring, August 5–9, 2026; line assignments provisional

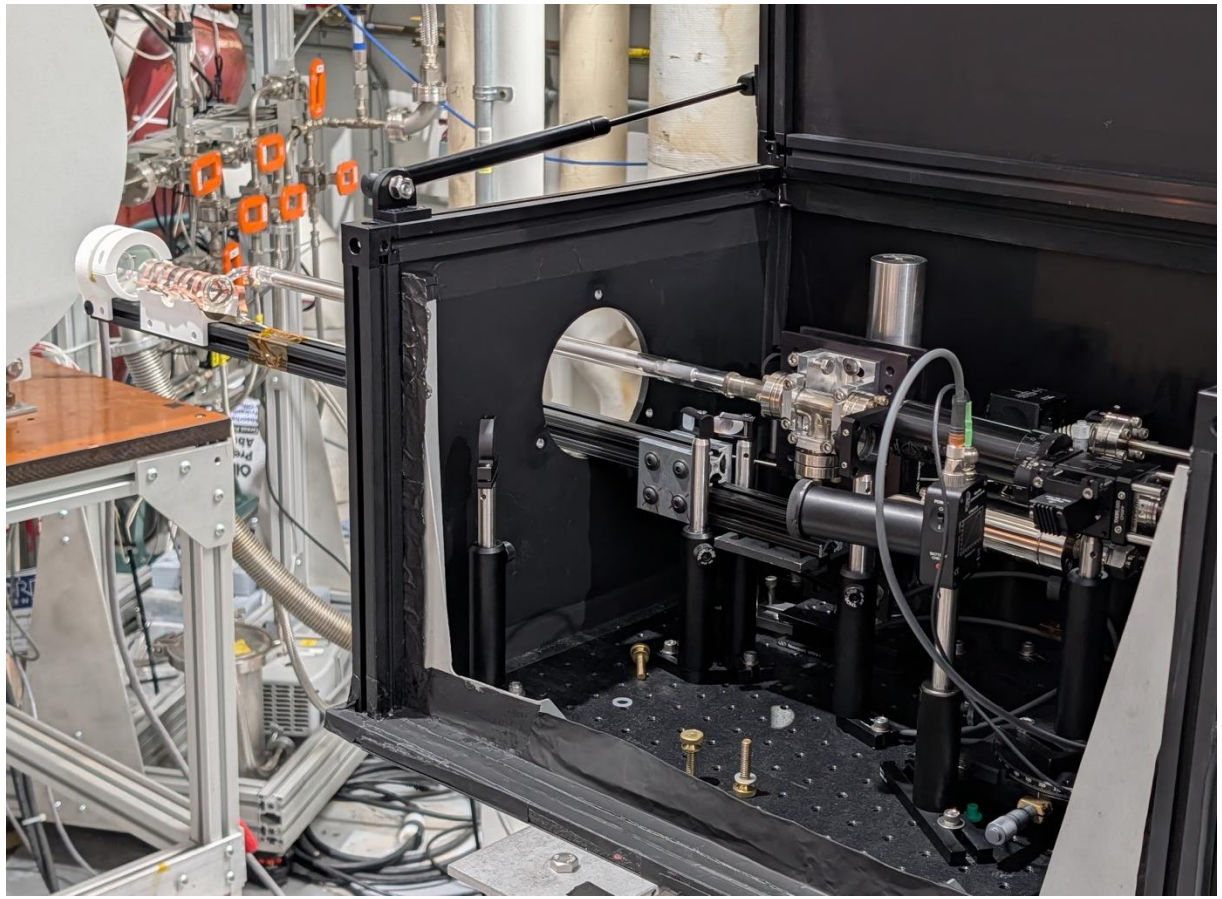
Emission monitoring during cryopumping

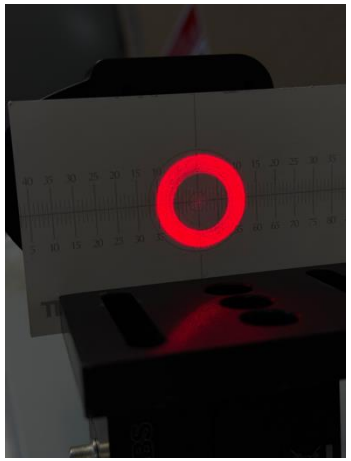


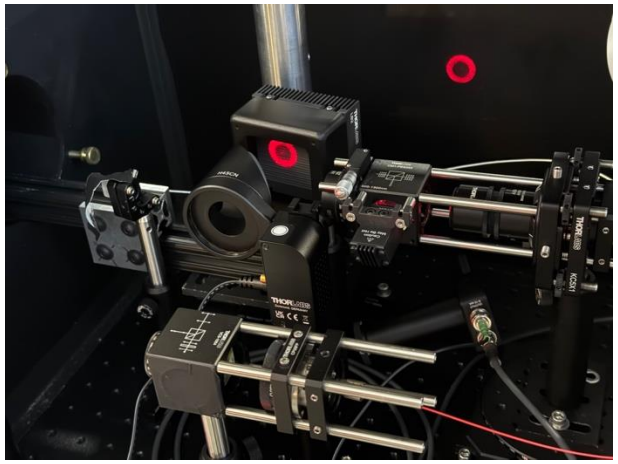
Tracked intensities evolve over several days. Emission counts also depend on plasma conditions.

Preliminary internal spectra, August 5–10, 2026; supplied assignments provisional

Updated cell and optical arrangement







Pump profile and light control

Pump shutter and beam dump control pumping intervals and stray light.

Revised RF electrodes support operation of the 100 mbar cell.

Preliminary 100 mbar polarization: ≈70%

November example

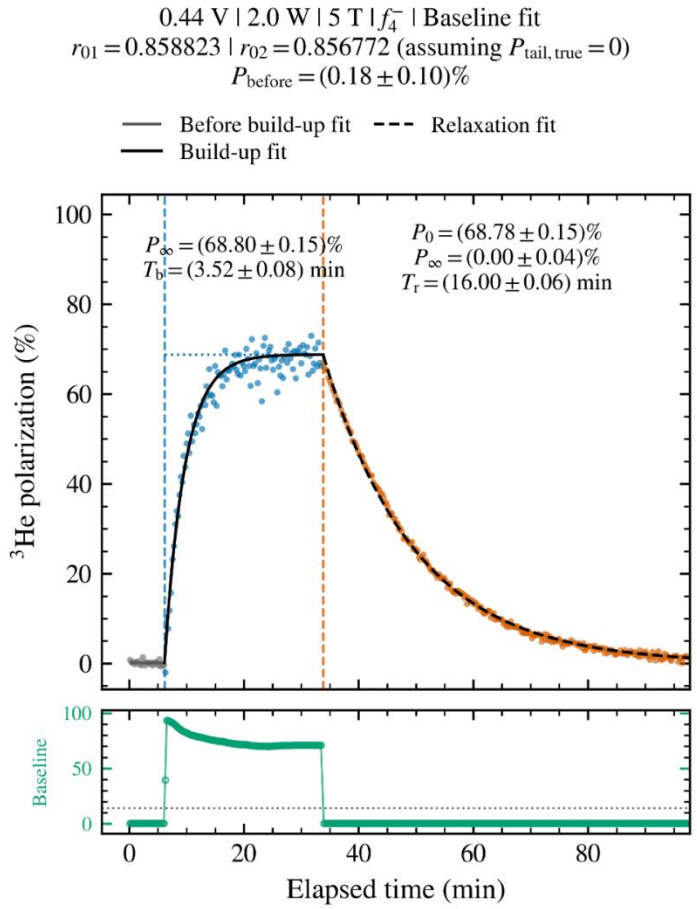
68.8% fitted steady-state polarization at 5 T using f_4^-.

Measured timescales

Buildup 3.52 min. Discharge-on relaxation 16.00 min in this run.

Conditions and uncertainty

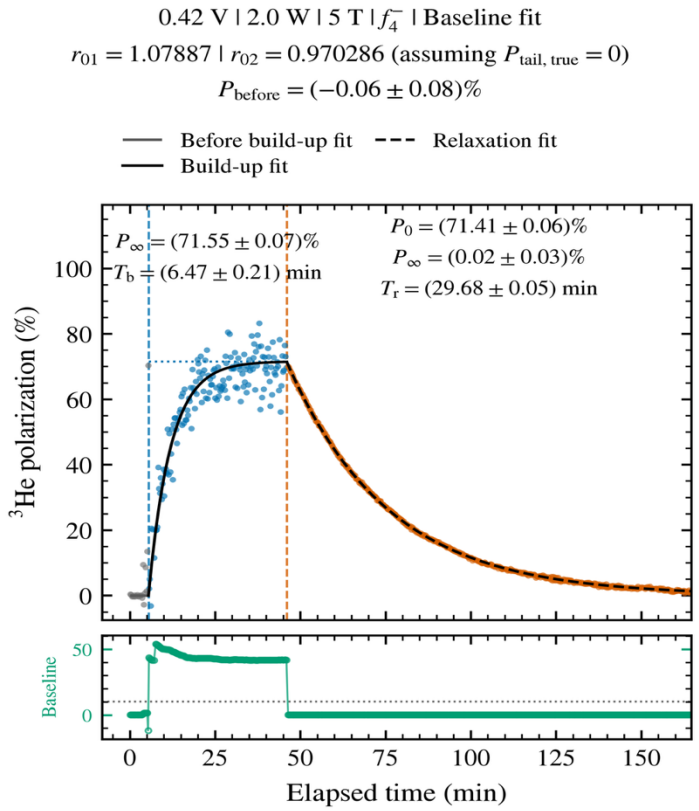
0.44 V RF setting, 2 W pump power. Printed errors are fit errors, with systematics still to assess.

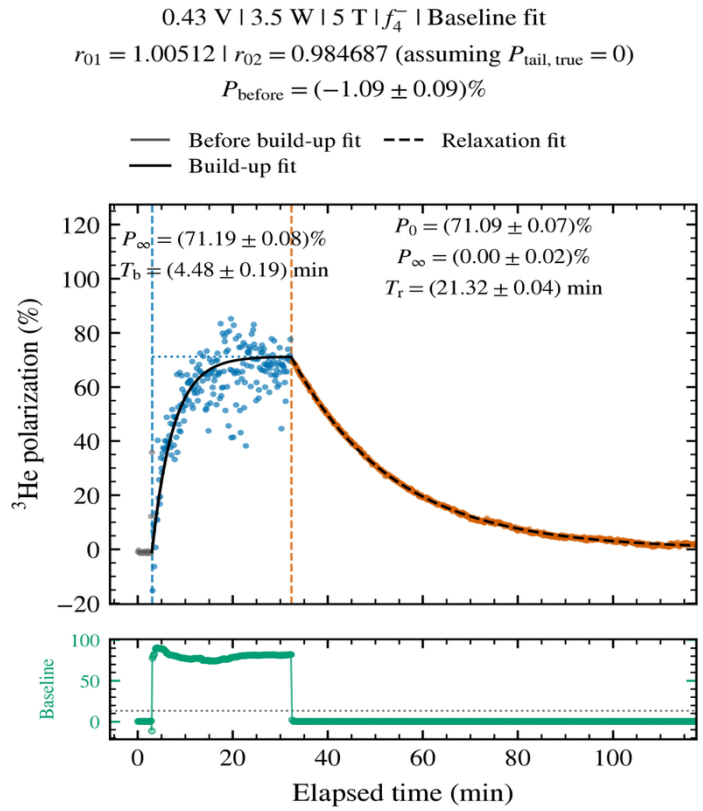


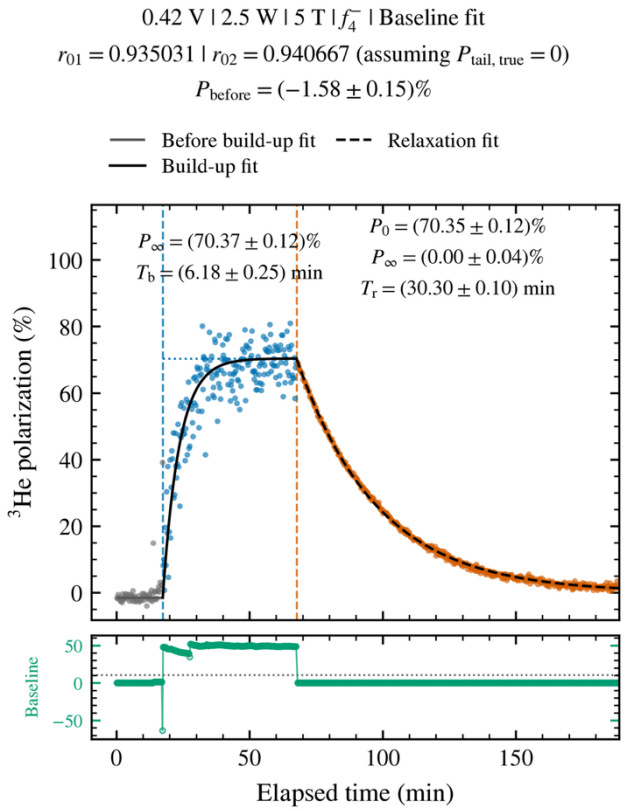
Preliminary 100 mbar measurement, November update; fit errors shown in plot

Earlier 100 mbar results above 70%

More concentrated laser ring profile; highest polarization obtained so far



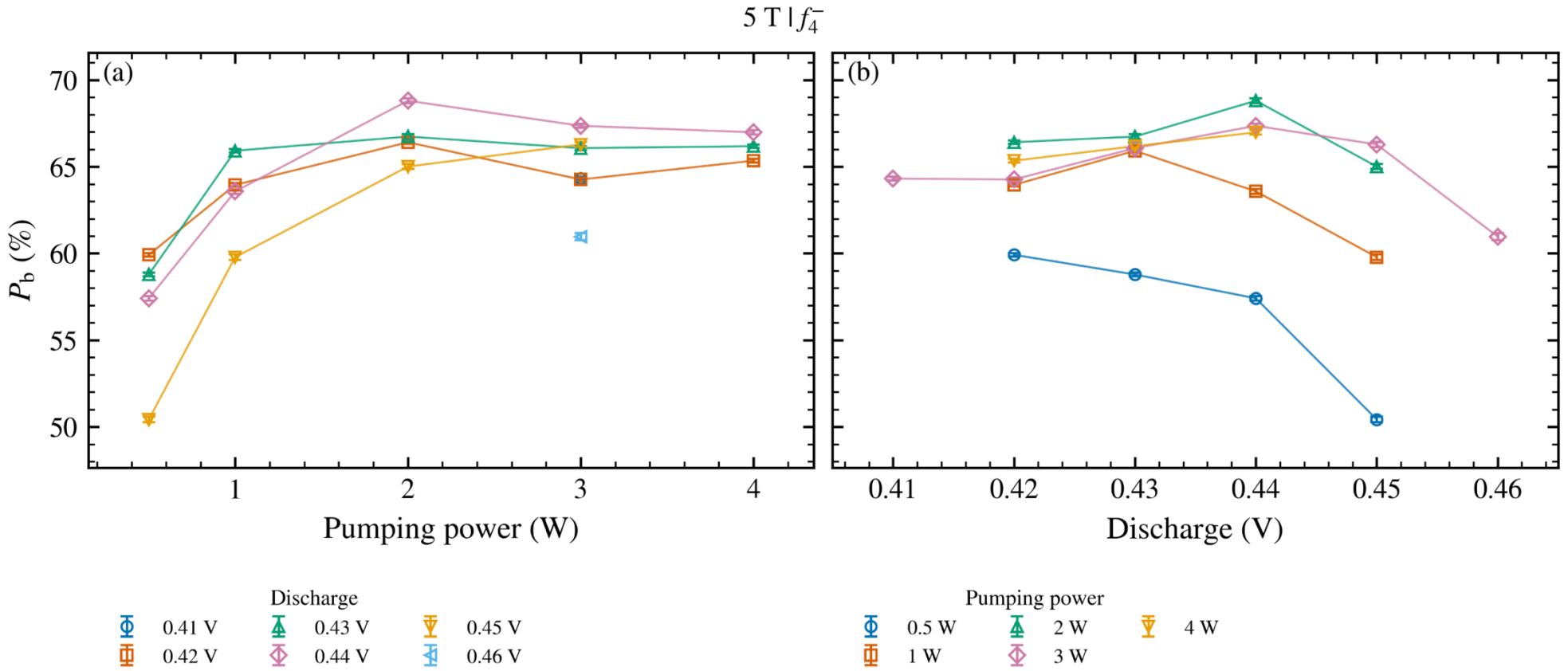




≈71.55% **≈71.19%** **≈70.37%**

Preliminary October results at 100 mbar, 5 T. Displayed uncertainties are fit errors; systematic optimization is ongoing.

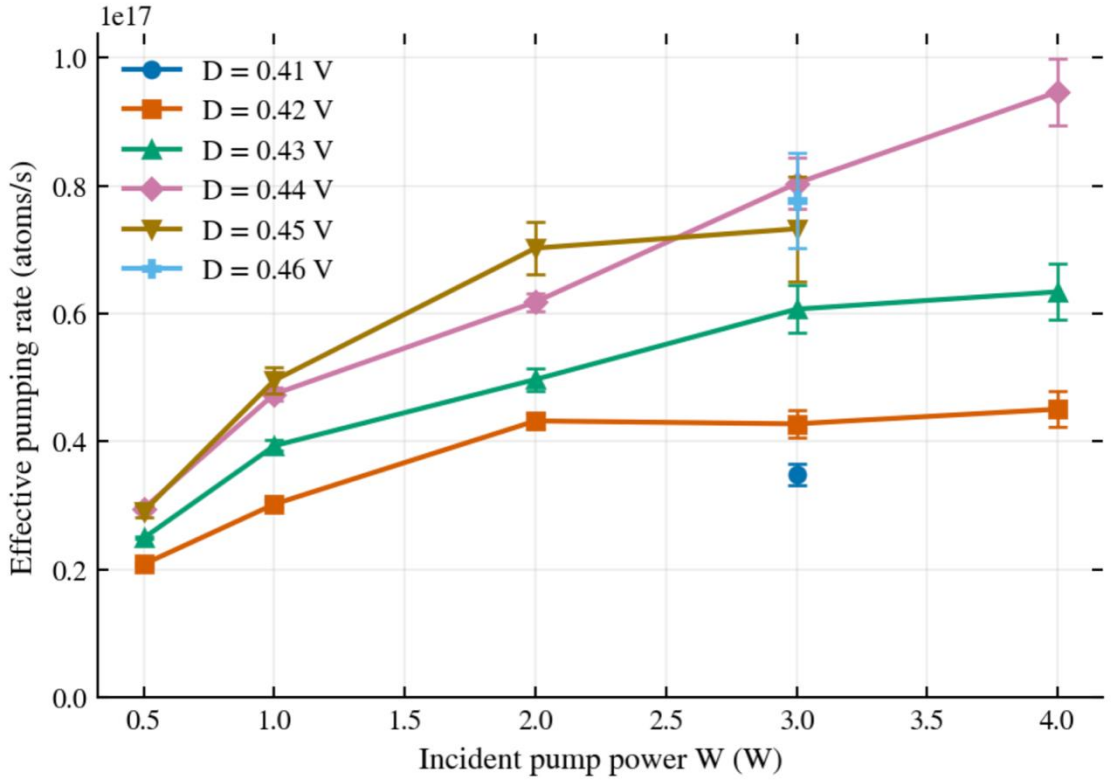
Pump power and discharge determine the optimum

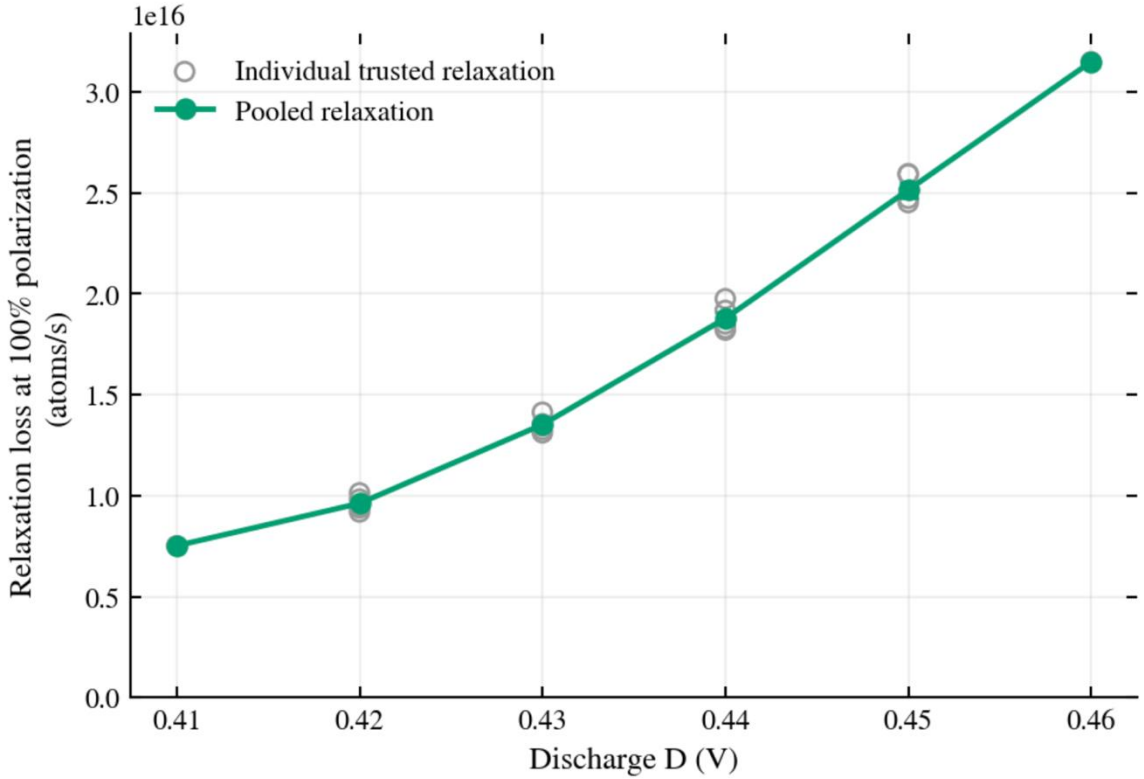


Increasing pump power does not increase polarization indefinitely. The optimum depends on discharge.

Preliminary 5 T, f_4^- parameter scan, November update

Buildup and relaxation compete





Stronger discharge increases both pumping and relaxation. The optimum follows their balance.

Preliminary kinetic-rate analysis, November update

Remaining challenges for the full target

Gas exchange and relaxation

Polarization transfer from ~300 K to ~5 K

Robust glass-to-metal joints

Maintain leak-tight seals through thermal cycling

Cooling and thermal design

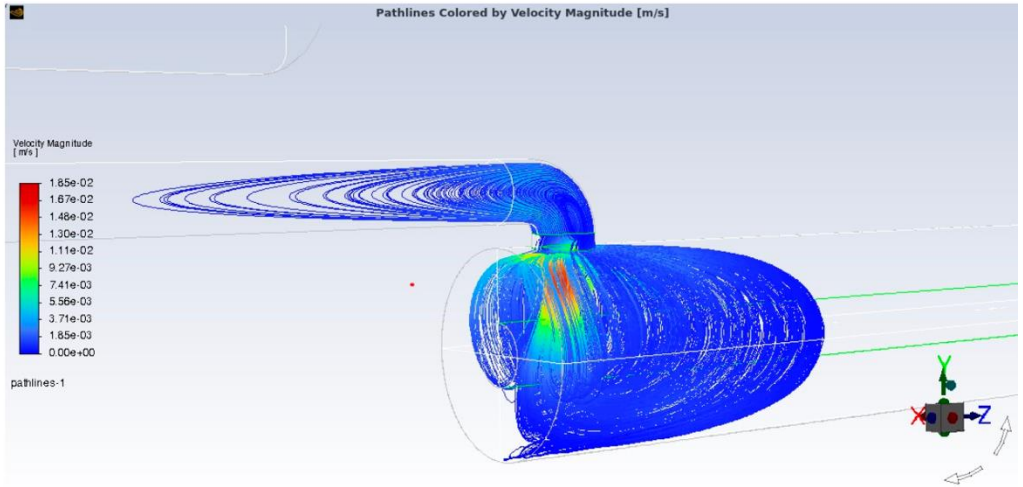
Cooling margin, heat exchanger and radiation shield

Cold-cell polarimetry

Determine polarization in the cold volume

Operation under beam

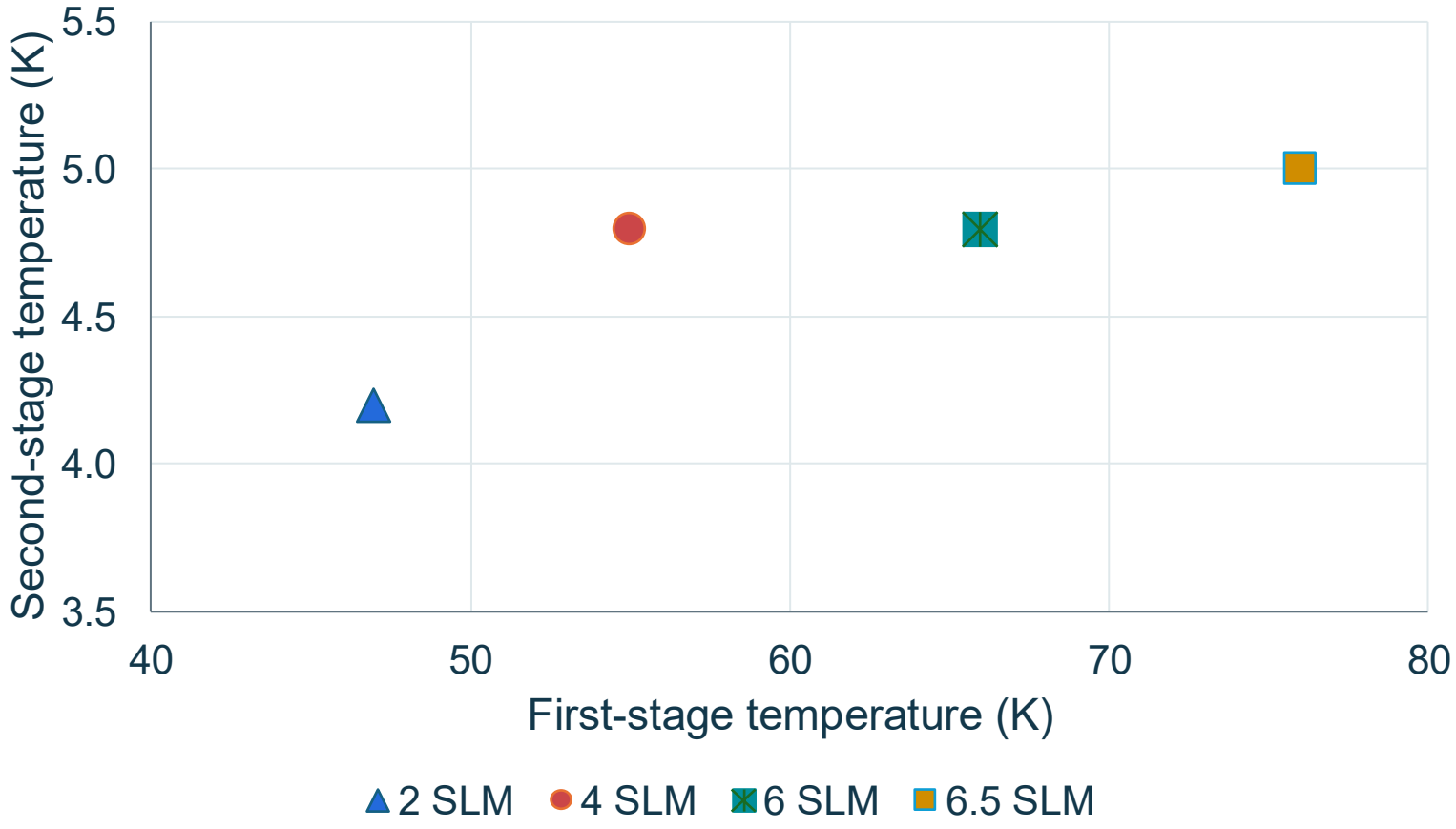
Heating, depolarization and CLAS12 integration





Maxwell & Milner, Nucl. Instrum. Methods A 1012 (2021) 165590

Cryostand cooling under gas flow



2–6.5 SLM

Displayed flow rates

Second stage

Approximately 4–5 K
over the tested flow range

First stage

Approximately 47–76 K

Preliminary.

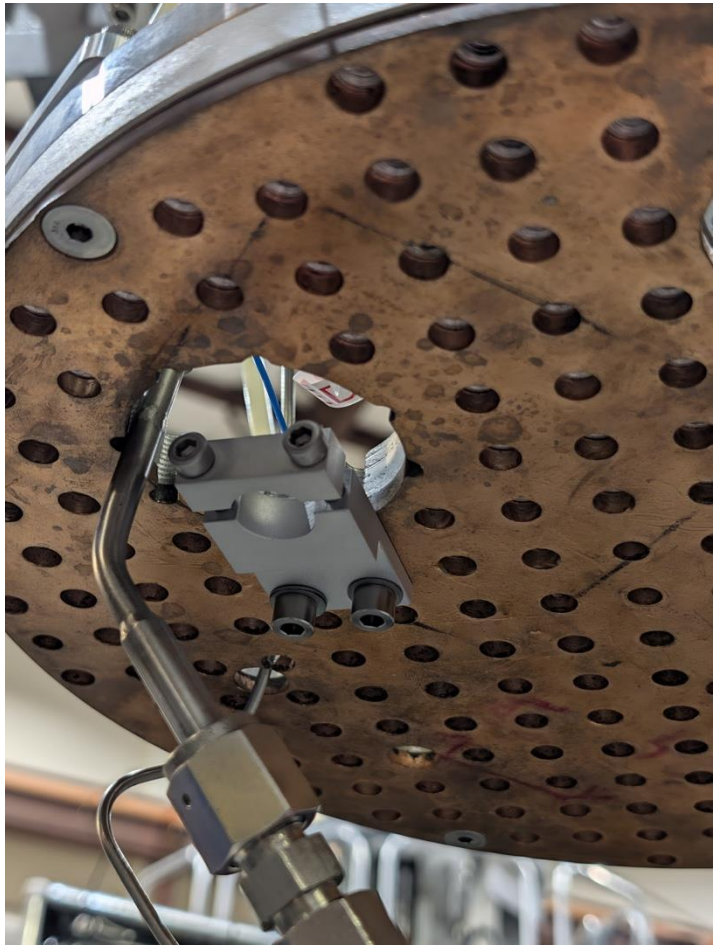
Glass-to-metal joints: cold-shock tests ongoing

Cryostand installation

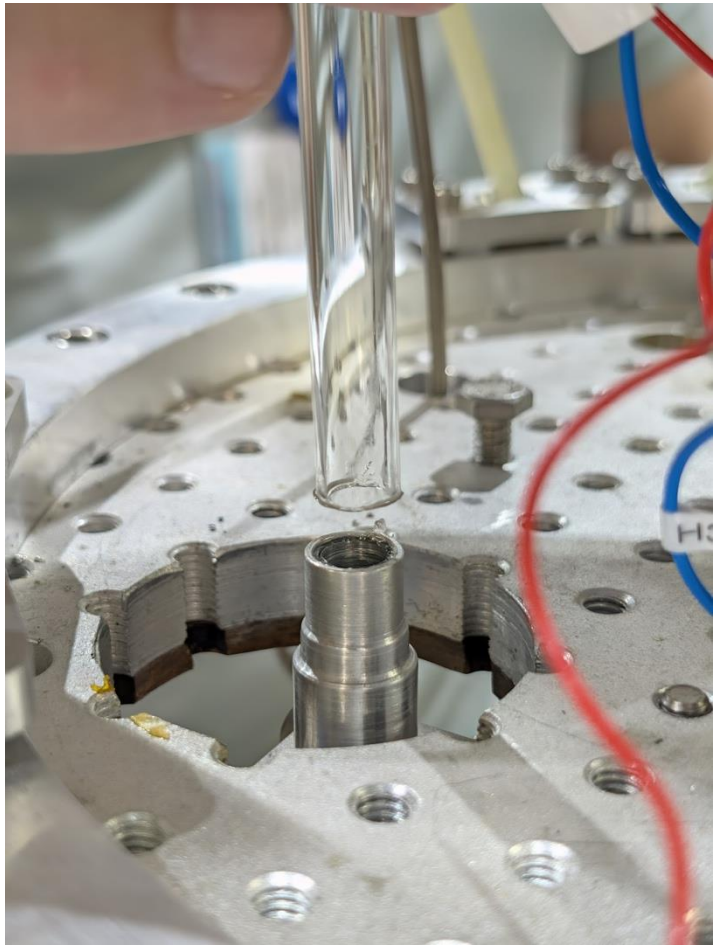
Test-tube mount and metal interface for the cold shock study

Joint qualification

Cold-shock tests are ongoing. Thermal cycling and leak checks will guide joint qualification.



Mount beneath the cryostand plate



Glass tube and metal interface

Next cold test with the cryostand

Planned double-cell assembly

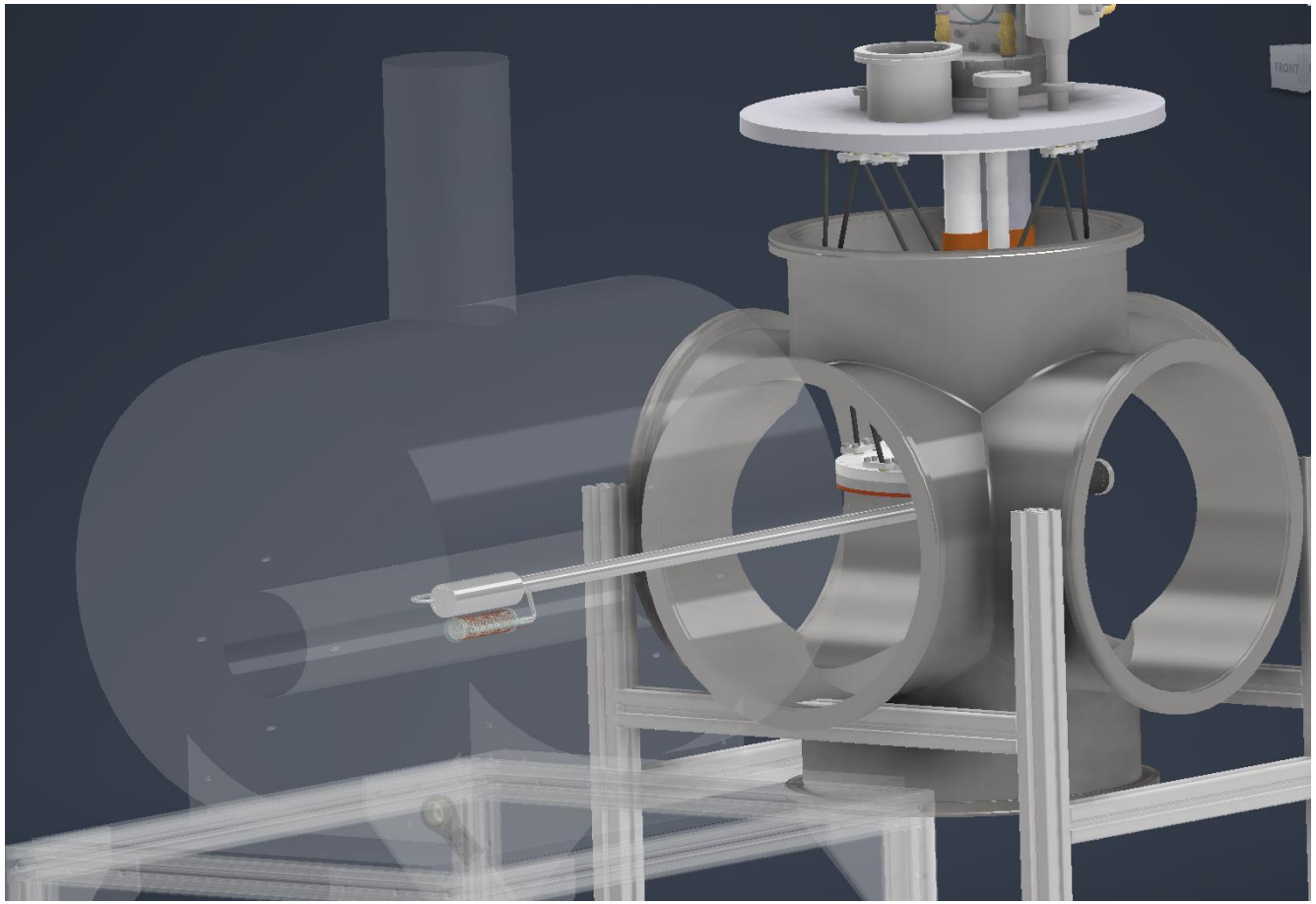
Connect the warm pumping cell to the cold test volume. Assembly is still ahead.

Measurements

Cooling response, gas transfer and polarization retention in the coupled system.

Key question

How much polarization can we retain in the cold volume?



Preliminary CAD of the next cold test; operating performance remains to measure

Milestones towards a CLAS12 target

2021–2025	Establish high-field MEOP and low-pressure performance
2026 · preliminary	Reach approximately 70% polarization at 100 mbar, 5 T
Ongoing	Complete cold-shock tests and qualify transition joints
Next	Build the cryogenic double-cell assembly
Following assembly	Measure polarization transfer and cold-cell polarization retention
After bench validation	Develop the MEOP module for Hall B integration
Longer term	Establish readiness for beam tests in CLAS12

Summary

High-pressure polarization

Preliminary ≈70% at 100 mbar and 5 T meets the warm-cell polarization milestone.

Cryogenic development

Cooling tests reach about 4–5 K on the second stage. Joint cold-shock tests are ongoing.

Next demonstration

Assemble the double-cell test and measure polarization retention in the cold volume.

Acknowledgement

Jefferson Lab

James Maxwell, Hao Lu, James Brock, Chris Keith, Harut Avagyen

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Pushpa Pandey, Yijie Wang, Richard Milner

UTK

Dien Nguyen, Jordan O'Kronley

Shandong U

Xiaqing Li