

Progress on a Polarized ${}^3\text{He}^{++}$ Ion Source at BNL

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in collaboration with

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Brookhaven
National Laboratory

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Jefferson Lab



**Massachusetts
Institute of
Technology**

Motivations

- RHIC is the first high energy accelerator-collider to successfully implement Siberian Snake for polarization maintenance in ring.
- Future location of Electron Ion Collider.
- Wide interest in polarized neutron structure.
- In polarized ^3He , nuclear polarization mostly carried by the neutron.
- ^3He magnetic moment is greater than deuteron and compatible with the spin manipulation at RHIC.
- BNL-CAD study in 2012 by Bai, Courant, Fischer, Ptitsyn, and Roser.



^3He Source at BNL

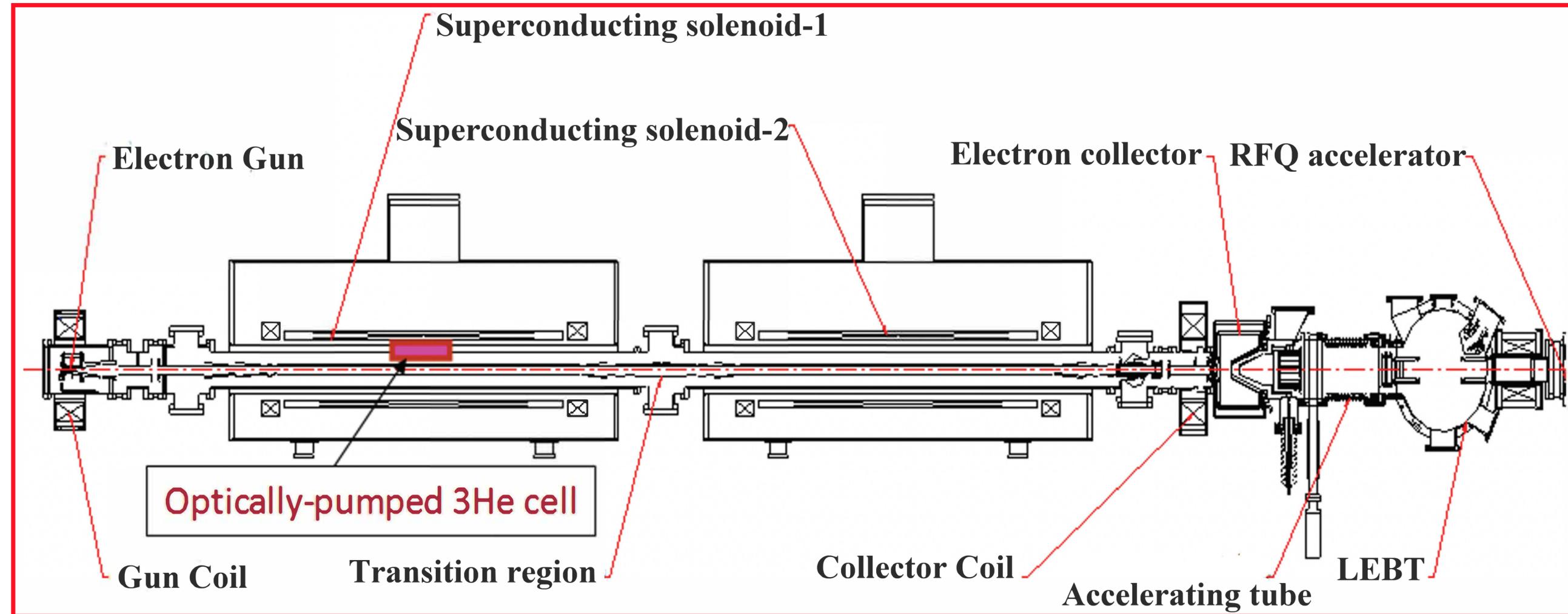
- Originally proposed by A. Zelenski and J. Alessi in ICFA Newsletter in 2003.
- Developed by collaboration between BNL and MIT.
- Identified as High Priority R&D for EIC by EICAC review in 2009, continued by Office of Nuclear Physics community review in 2017, again in 2018 by assessment of US National Academy of Sciences, and highlighted in the 2023 Long Range Plan for Nuclear Science.
- Anatoli left end of 2022, Chris and I took over the project in mid 2023 and beginning of 2024.
- Design goals:
 - Polarize ^3He by optical pumping in situ and inject into RHIC EBIS at 5T
 - Maximum polarizations $> 70\%$
 - Intensity of 2.5×10^{11} $^3\text{He}^{++}$ ions in a $20 \mu\text{s}$ pulse (4 mA peak current)
 - Spin-flip and polarization measurement in beam transport line before injection to AGS and RHIC.

Extended EBIS



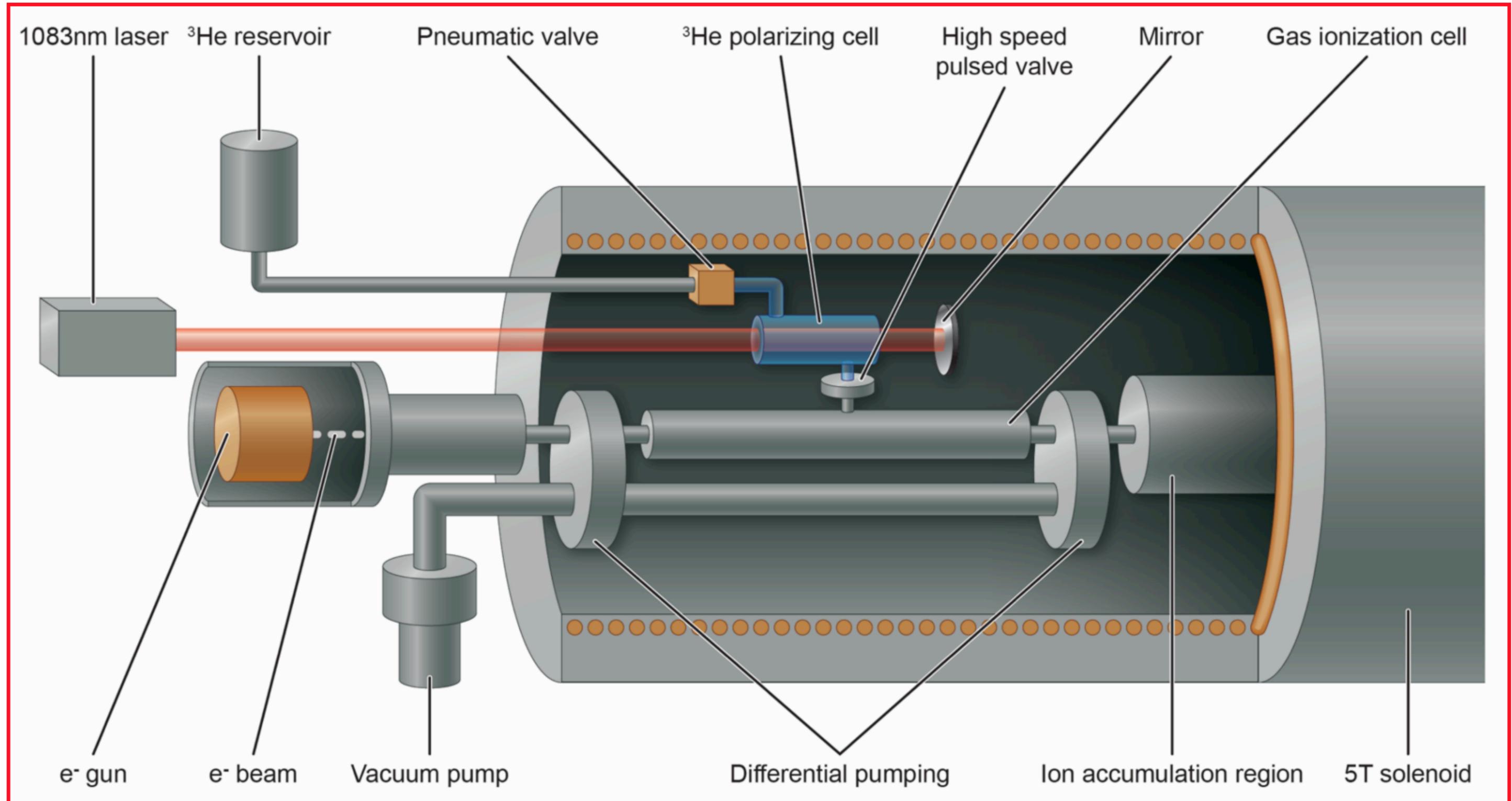
- Second 5T solenoid extends trap length for 40% increase in Au capacity.
- Tested from 2018 - 2022, now installed and currently operating.

3He inside of Extended EBIS



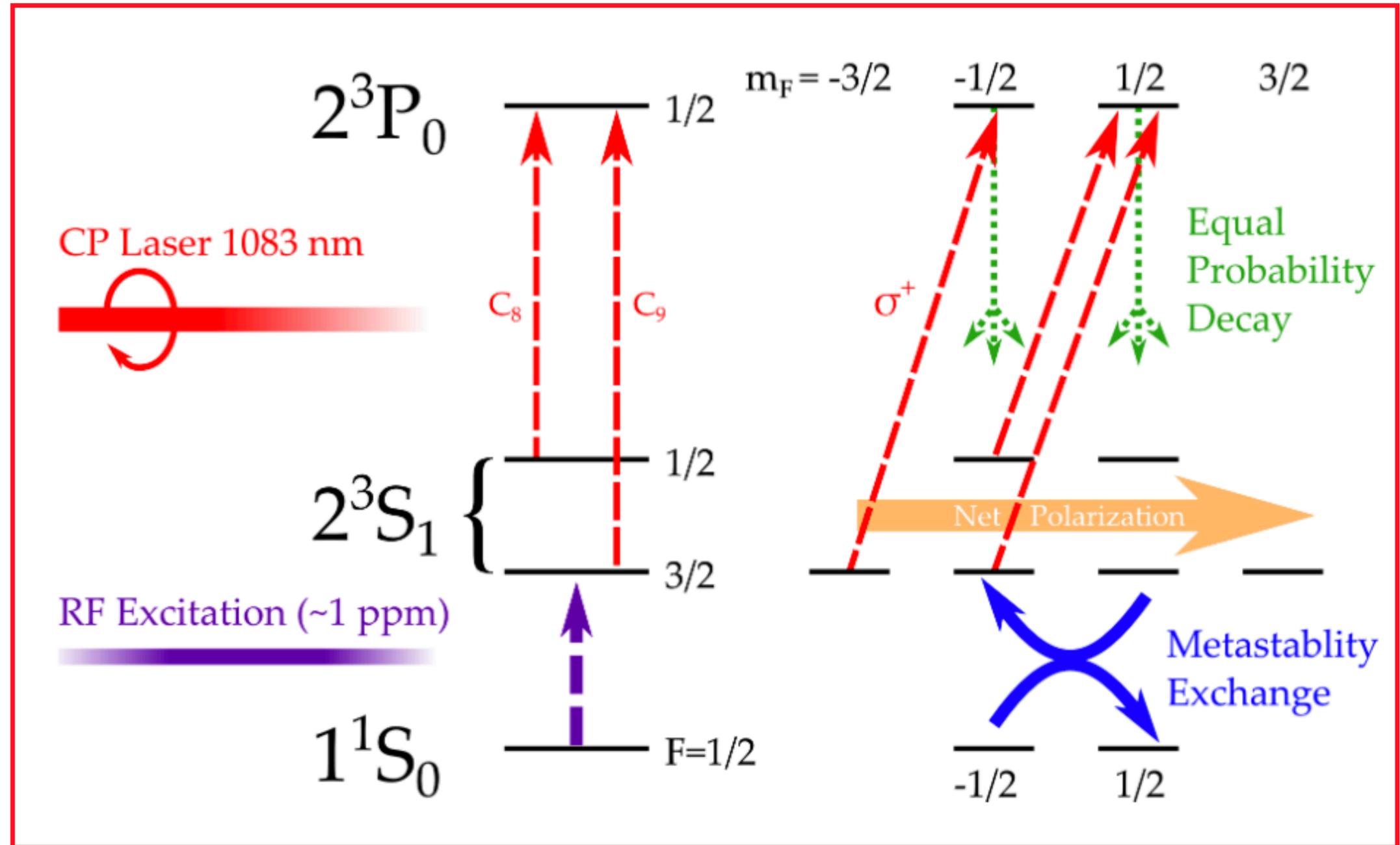
- Extended EBIS also provides opportunity to polarize ^3He in situ for injection and ionization.
- ^3He ionized to $^3\text{He}^+$ in first trap, then $^3\text{He}^{++}$ in second trap.

Conceptual layout of ^3He in EBIS



Metastability Exchange Optical Pumping 3He

- First developed by Colegrove, Schearer, and Walters in 1963 at low magnetic fields.
- In 2004 a group at Kastler Brossel Laboratory (LKB) in Paris achieved 80% pol. at 1 Torr in 1.5 T field.
- High field MEOP is attractive because it doesn't require any exchange gas.

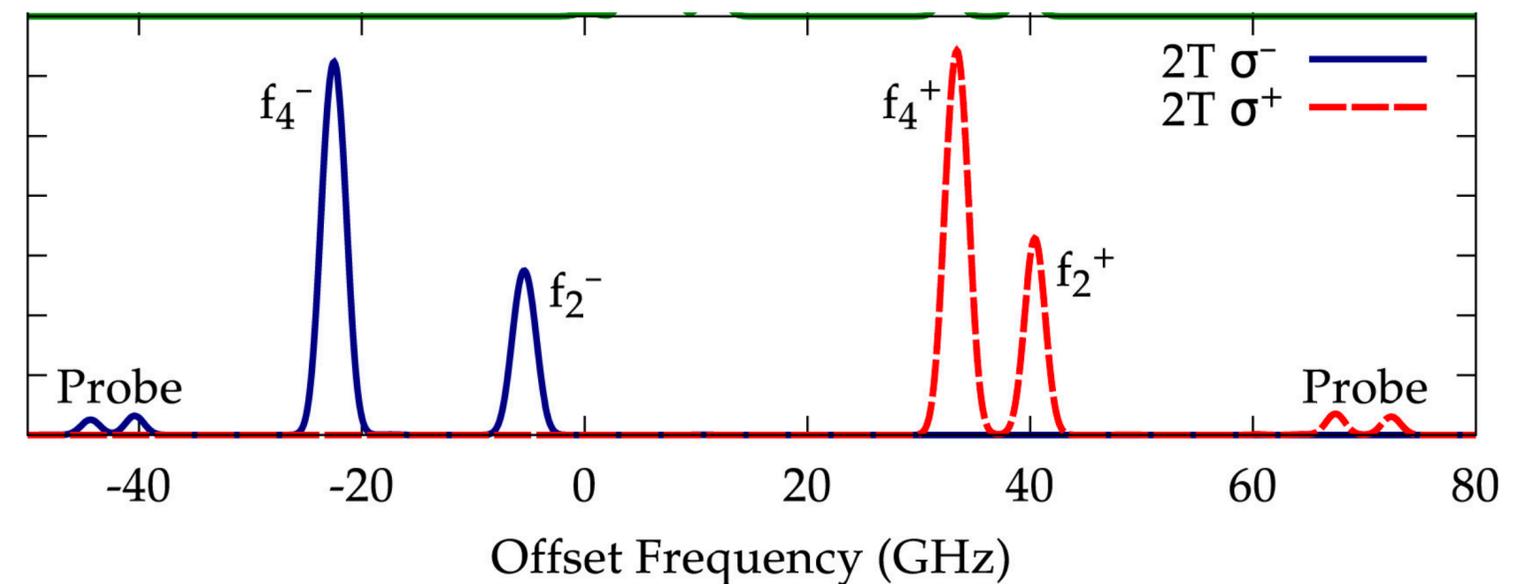
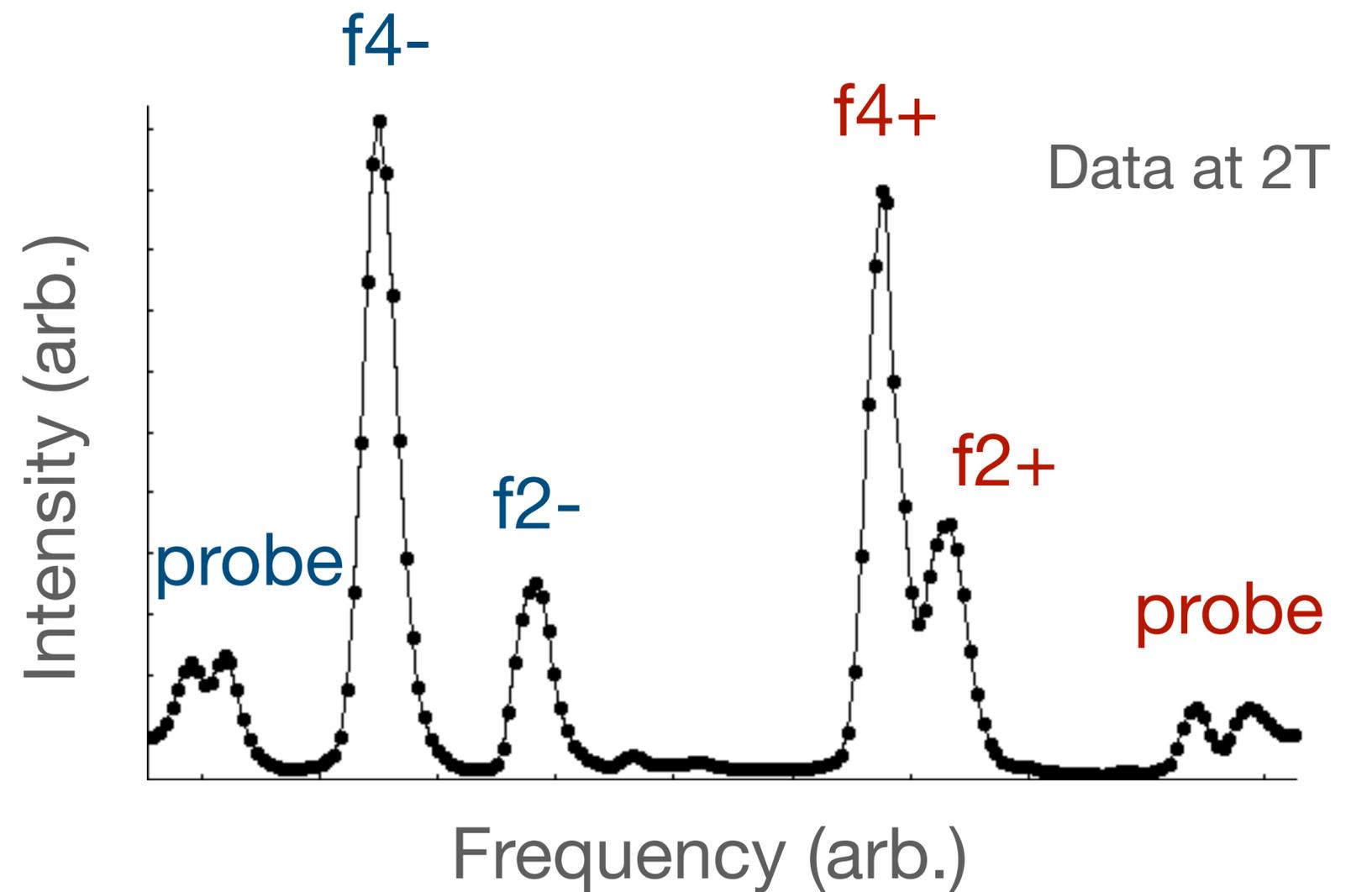


Optical Polarimetry

- Right and left handed CP light address 8 transitions each.
- Two probe lines can be used to monitor the population of two particular 2^3s sublevels which can be used to extract the polarization.

$$M = \frac{r/r_0 - 1}{r/r_0 + 1}$$

- r is ratio of probe peaks, r_0 is calibration at 0% polarization.
- Our data at 2T compared with P.J. Nacher's simulations at 2T.



Previous BNL MEOP results

Enhanced Polarization of Low Pressure ^3He through Metastability Exchange Optical Pumping at High Field

J.D. Maxwell*, C.S. Epstein, R.G. Milner, M. Musgrave

2019

Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, MA USA

J. Alessi, G. Atoian, E. Beebe, A. Pikin, J. Ritter, A. Zelenski

Collider-Accelerator Department, Brookhaven National Laboratory, Upton, NY USA

Optically Pumped Polarized $^3\text{He}^{++}$ Ion Source Development for RHIC/EIC

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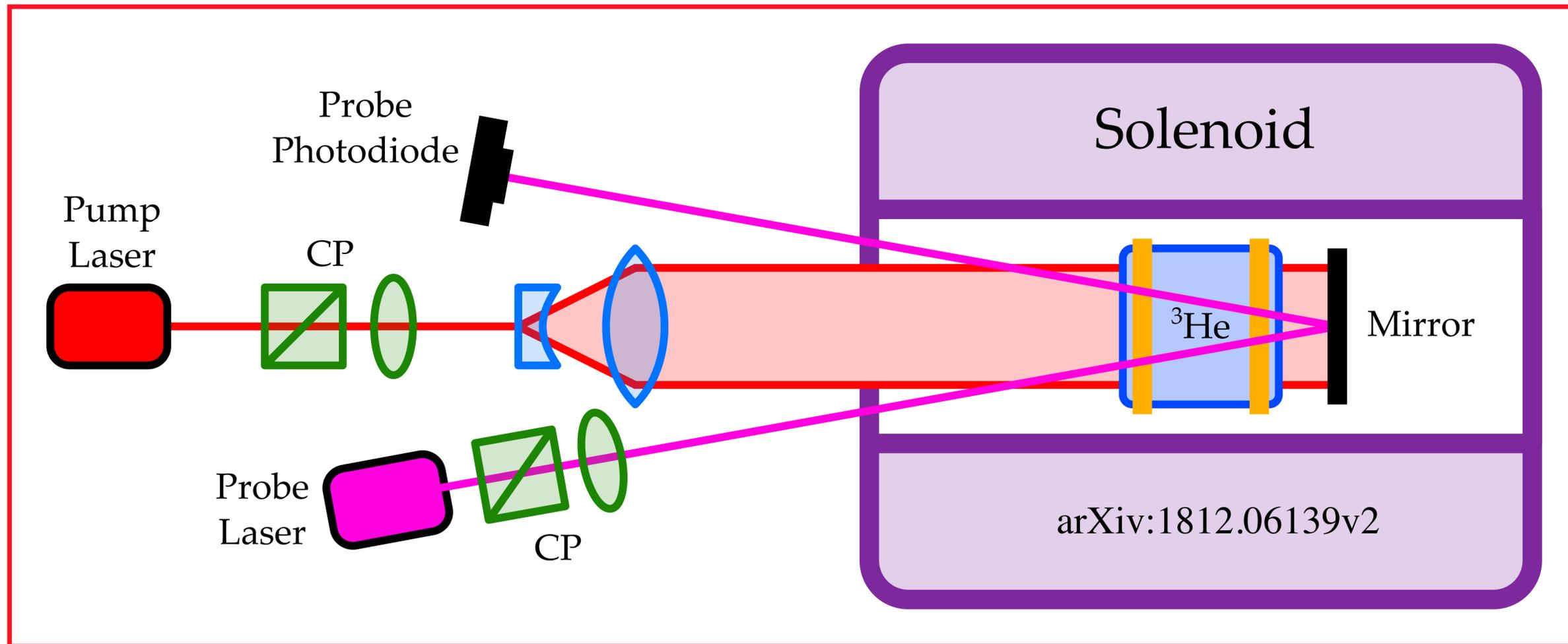
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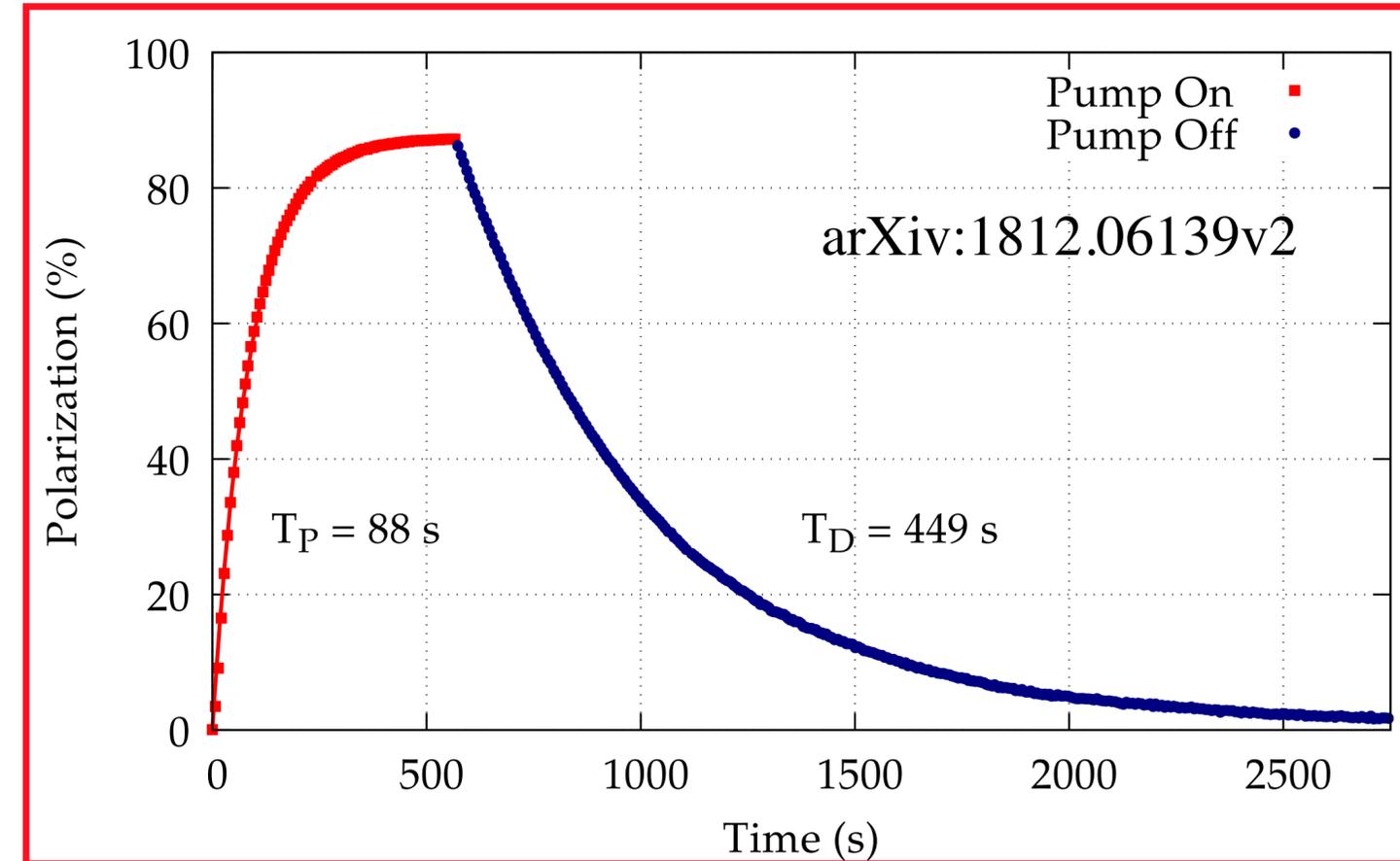
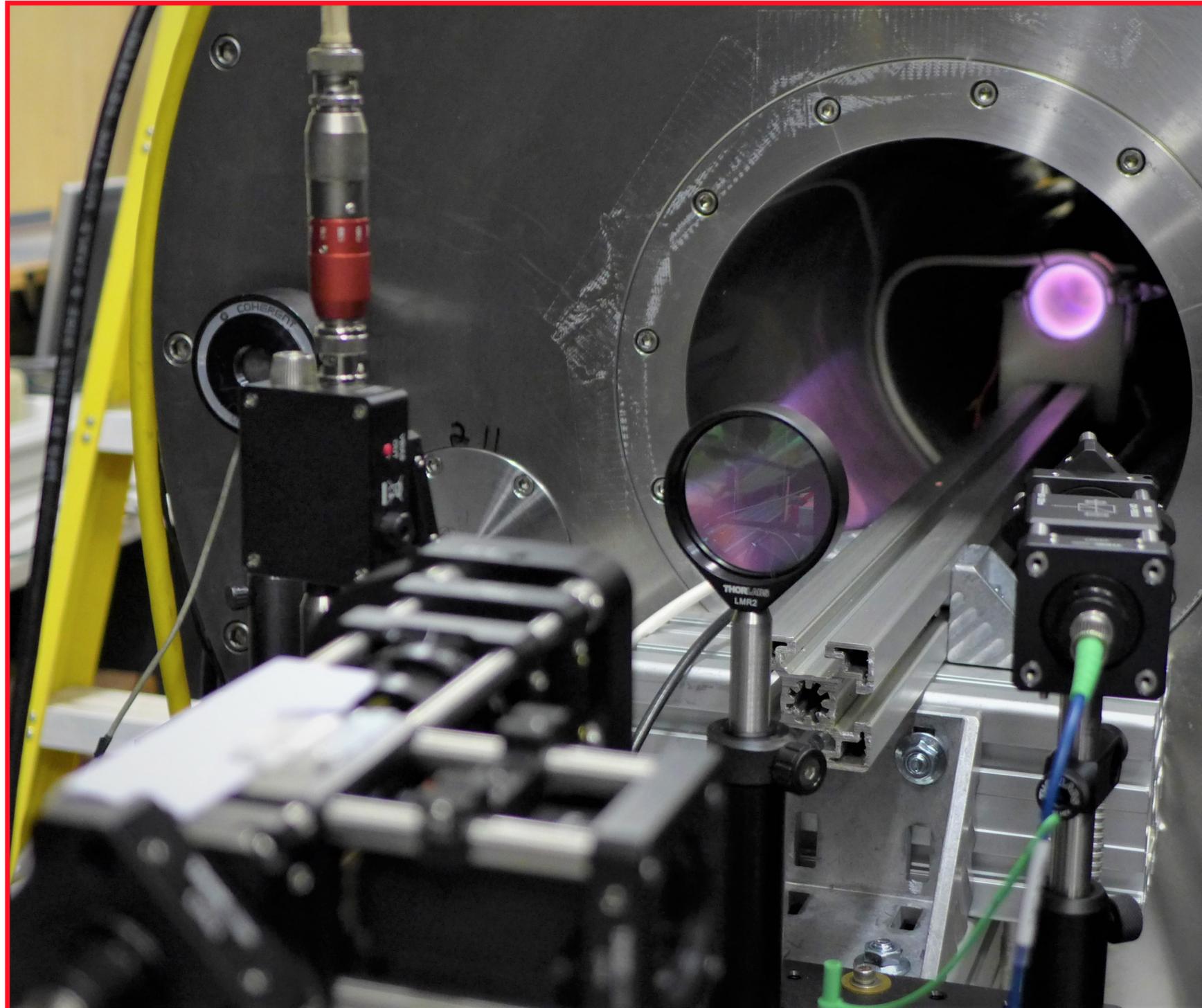
2023

Polarimetry Measurement



- Collimation of pump prevents reflection into photodiode, leaving a clean probe signal.
- Still, the probe signal is small, so the plasma is modulated at 282hz and the photodiode signal is downmixed by a lock-in amplifier.

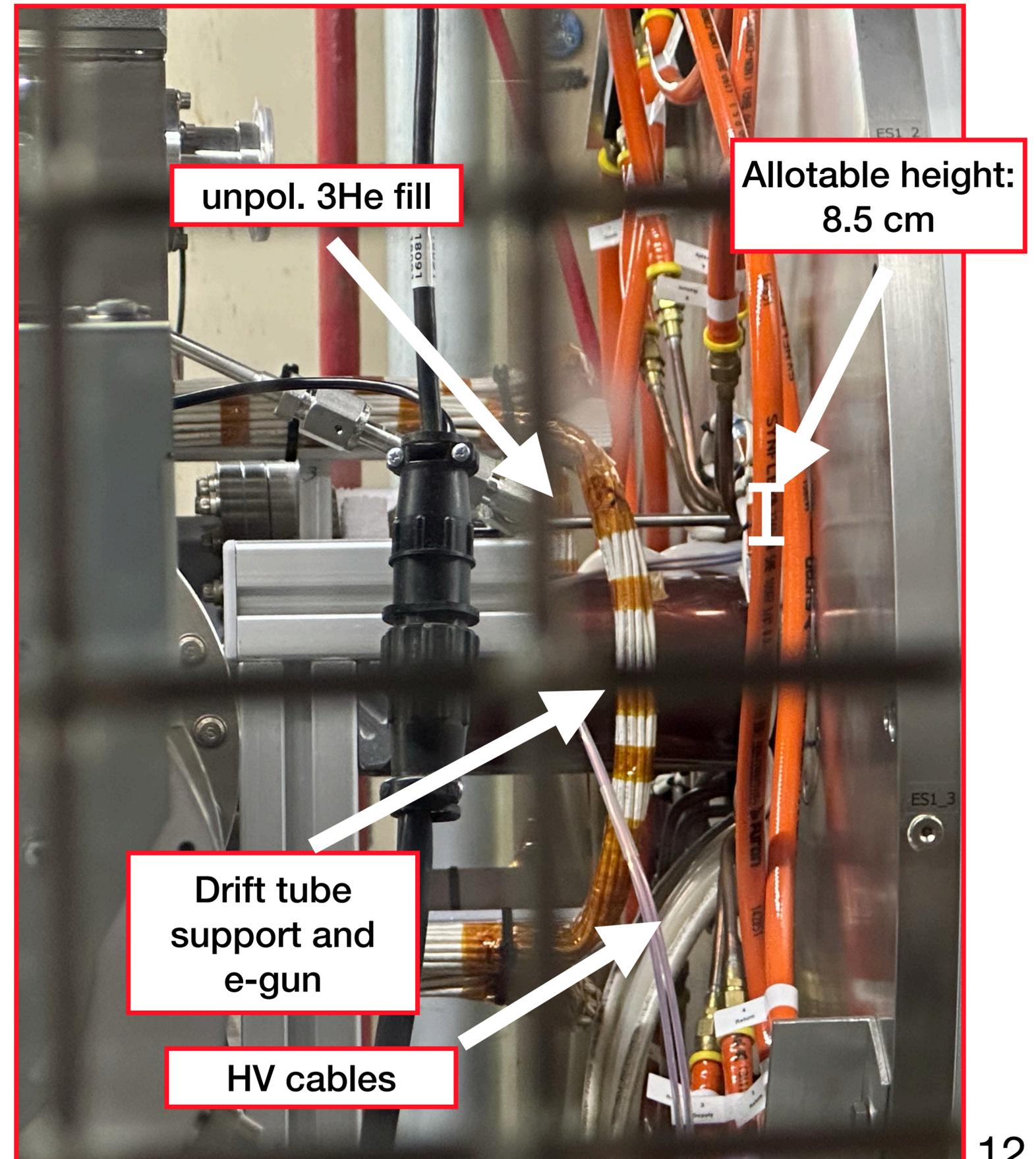
Previous BNL MEOP results



- Nearly 90% polarization!
- Good separation of pump and probe, and saturation of plasma by pump.
- But, this layout takes up too much space to go into EBIS.

Challenges in EBIS

- In actual EBIS, much of the bore space is already filled.
- Allowable cross section for in situ polarization cell and optics is just 8.5 cm height x 18.5 cm width.
- Possibility of sensitive fiber optics being caught on other objects, pump misalignment could burn cabling.
- Inhomogeneity in magnetic field depolarizes ^3He cell and causes challenges for steering the e-beam, requiring non-magnetic materials.

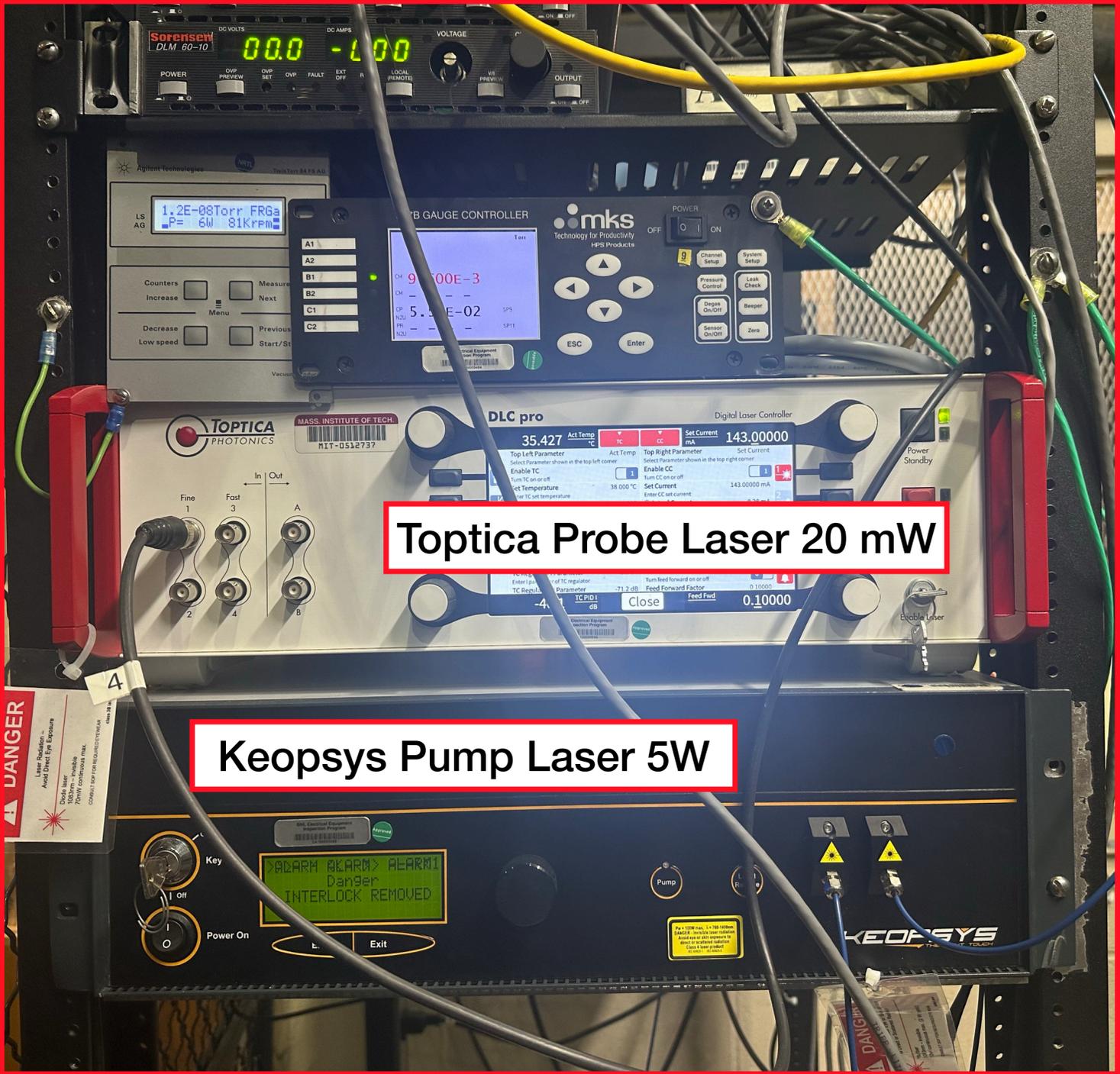
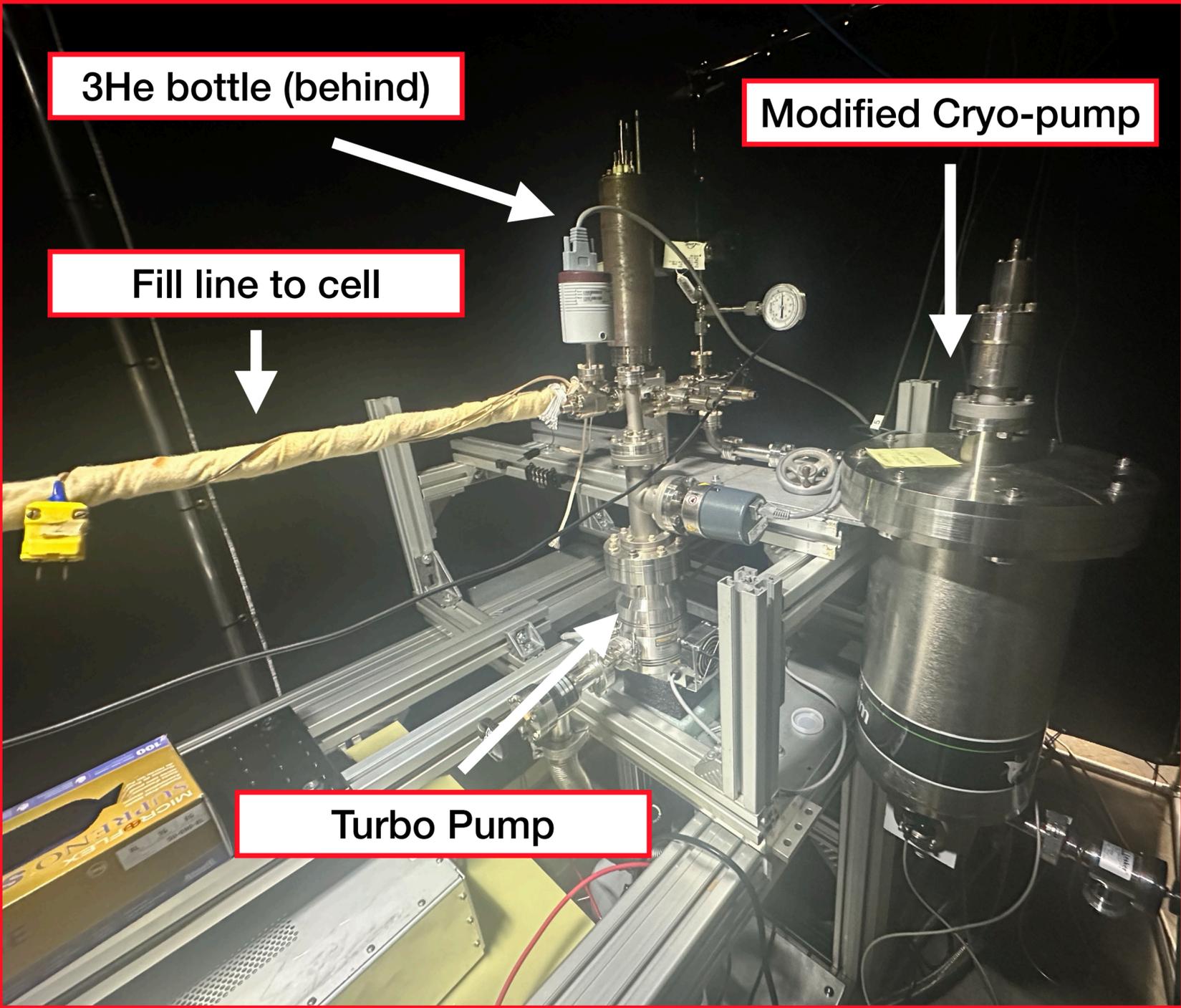


Resuming ^3He Studies at BNL

- Moved gas purification system into test lab with the original EBIS magnet.
- New laser enclosure, interlock, and safety approvals.
- Worked with CAD to reconnect DAQ with RHIC control systems.
- More compact optical polarization layout.



Resuming ^3He Studies at BNL



Cryogenic gas purification system

Controls rack with pump and probe 14

Gas purification

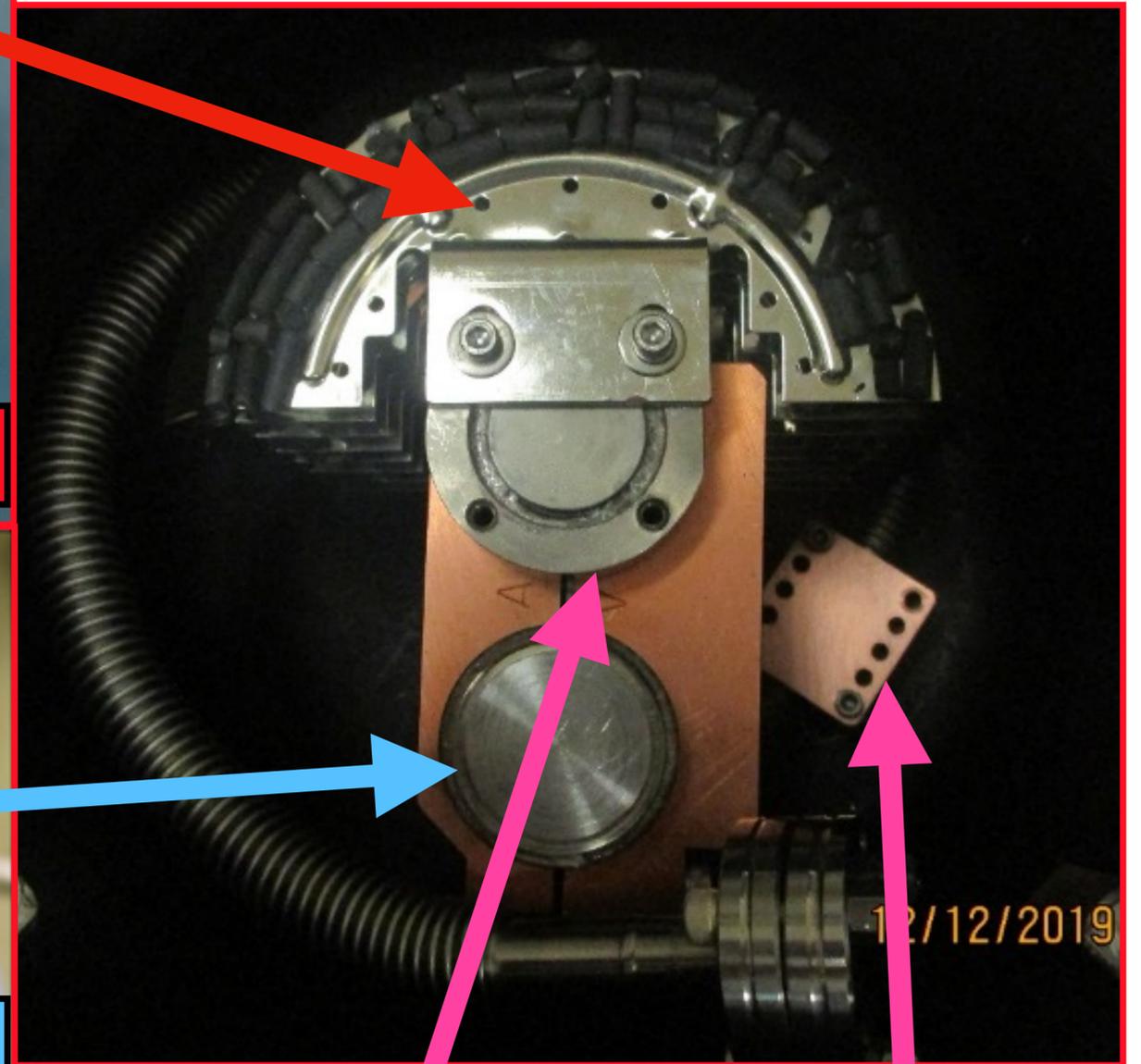
- Previous studies have found that purity of gas mixture impacts final maximum polarization and relaxation.
- Monitor purity of gas mixture by spectroscopic measurement of plasma.
- Modified cryo-pump, designed by Anatoli, pumps gasses other than ^3He to below 10^{-7} torr.
- ^3He pressure controlled by internal cartridge heater.



Modified baffle w/ charcoal.



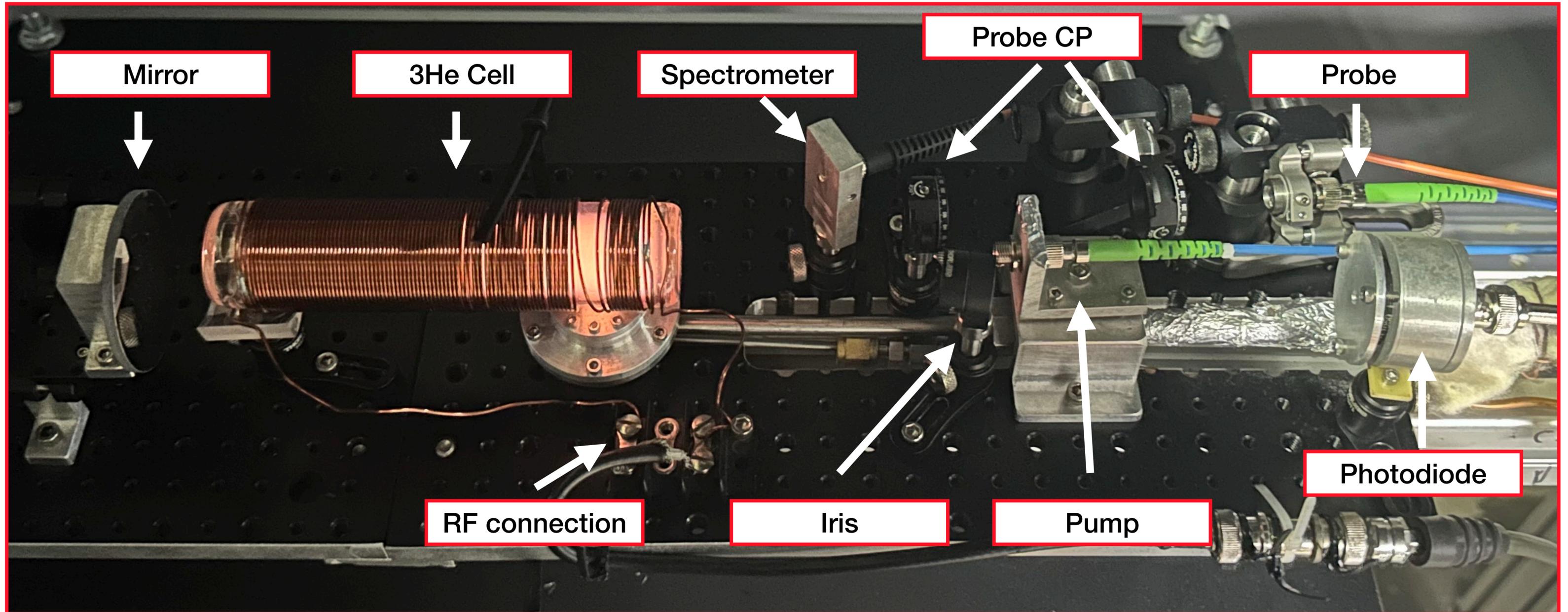
Cryo-vessel with charcoal.



Cryo-pump second stage cold head 10k

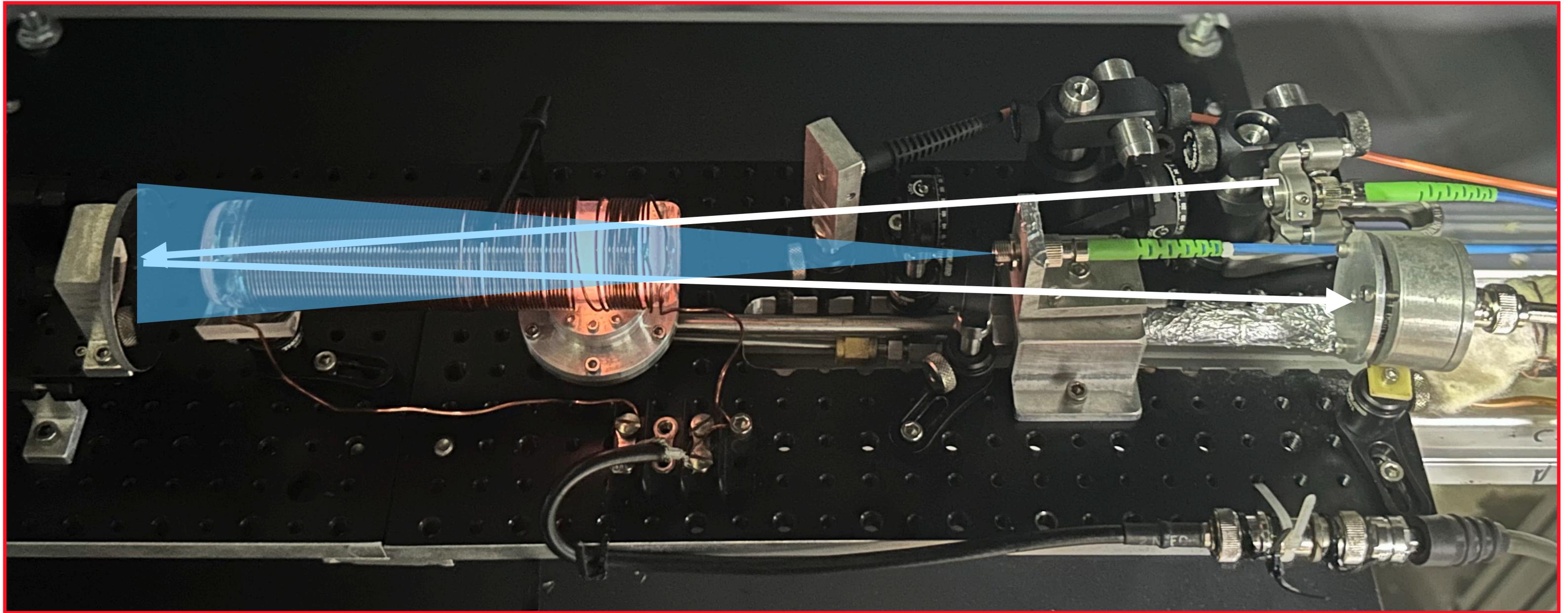
Cryo-pump first stage cold head 55k

Reducing the Optics Footprint



First draft of a compact polarization setup.

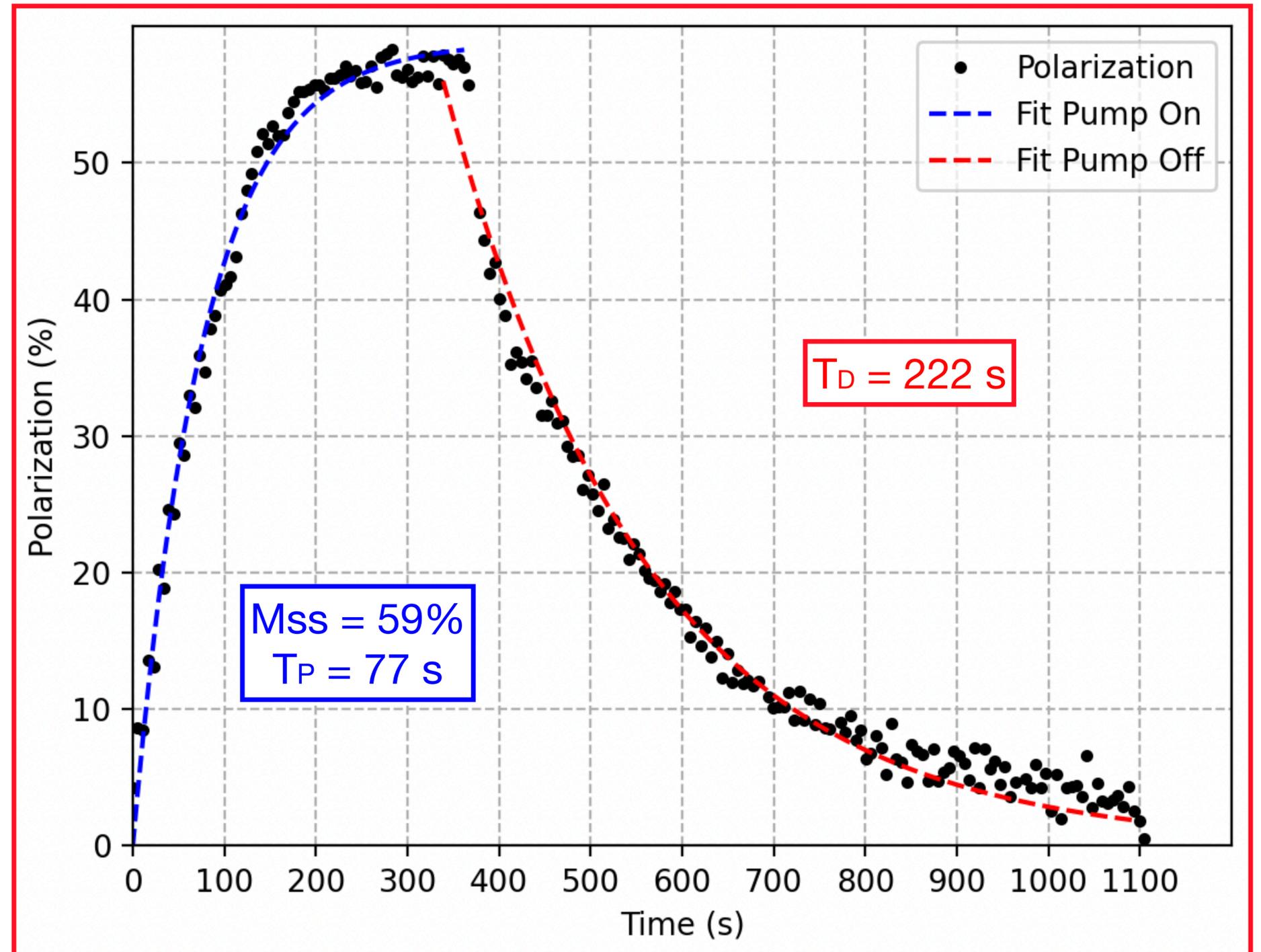
Reducing the Optics Footprint



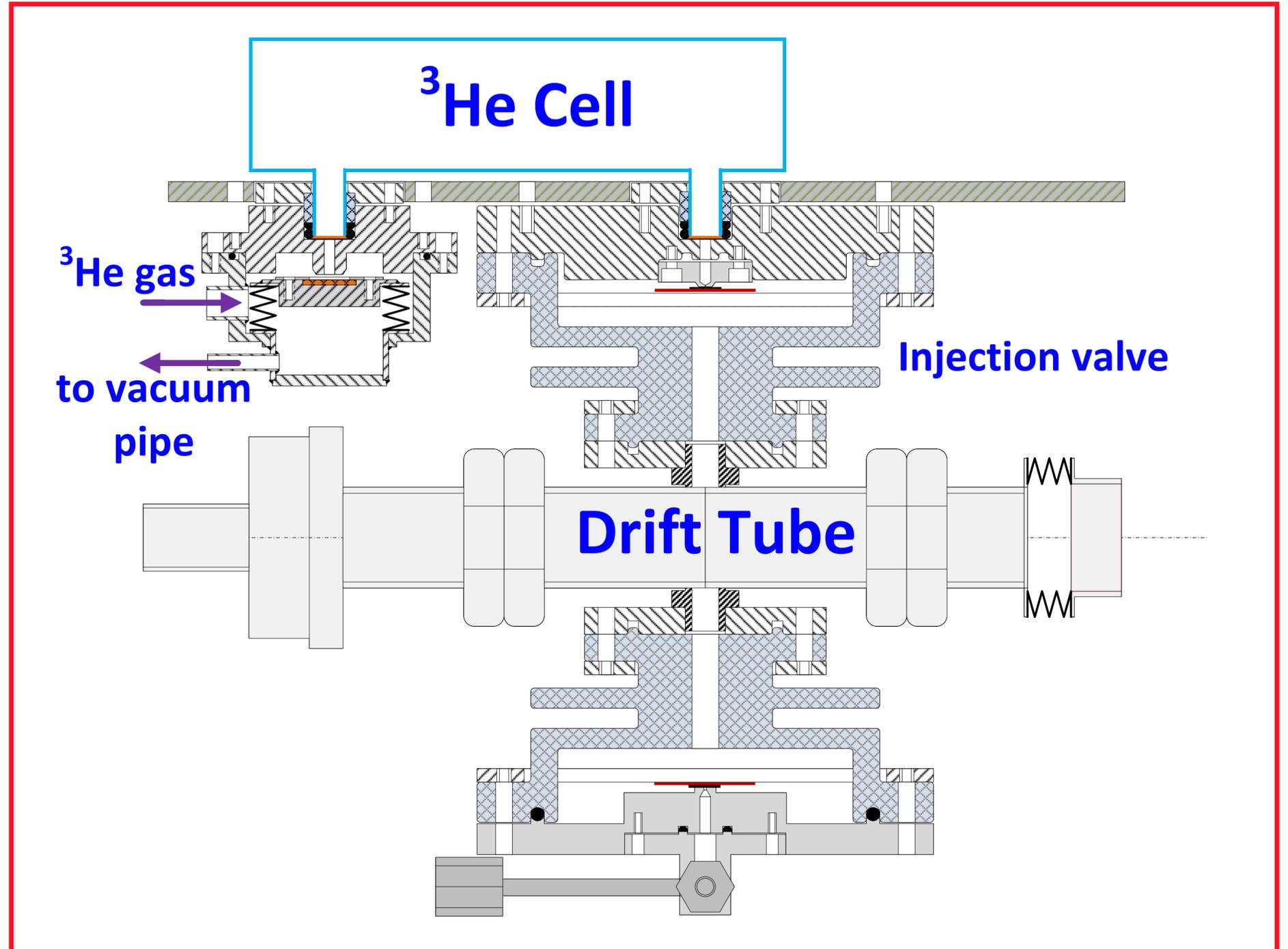
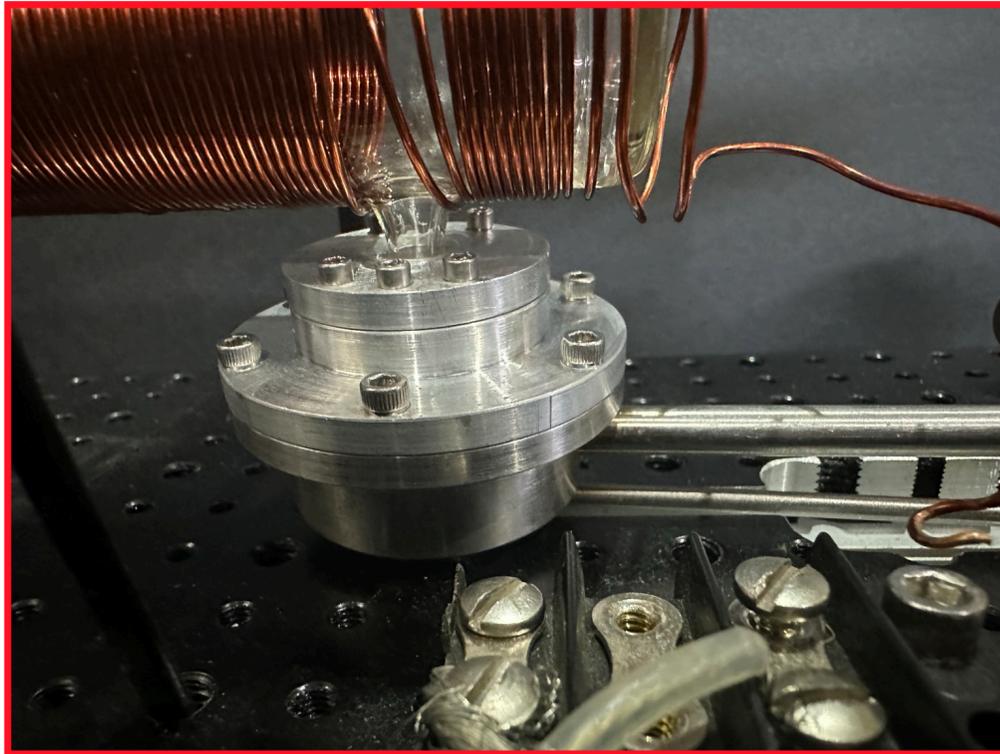
First draft of a compact polarization setup.

Polarization with New Setup

- Steady state polarizations near 60% at 3T and 2.5 Torr.
- Pumping on f4+ at 276.740 THz.
- Probe signal depends on brightness of plasma, but highest polarizations require dim plasma.
- At high field, plasma distributes near the edges of the cell, but probe is traveling through center.
- Probe and pump are poorly separated in the bore, further reducing signal.



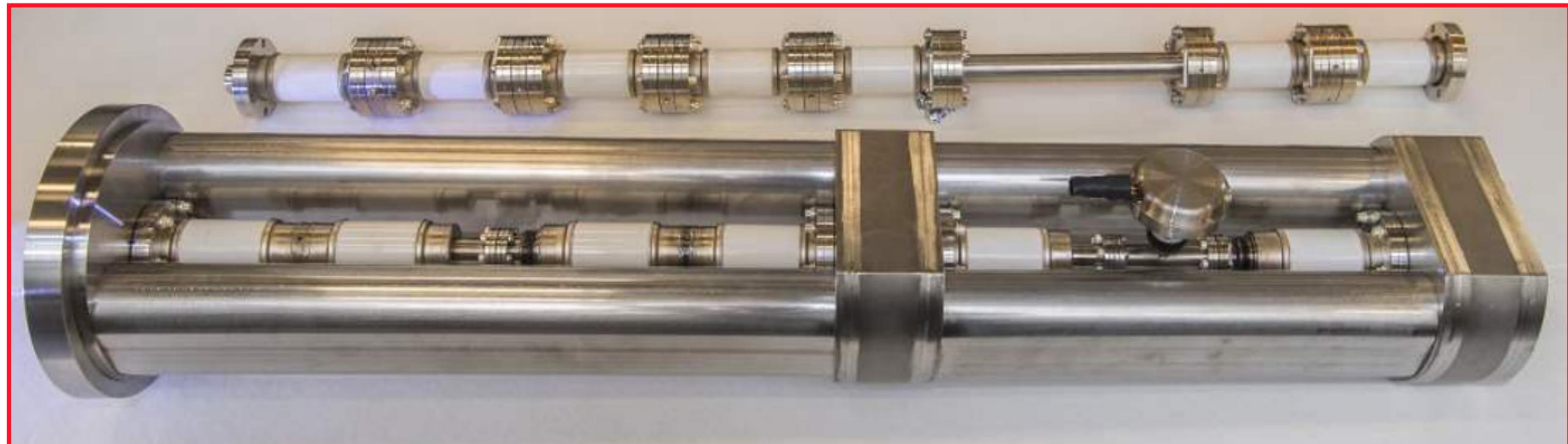
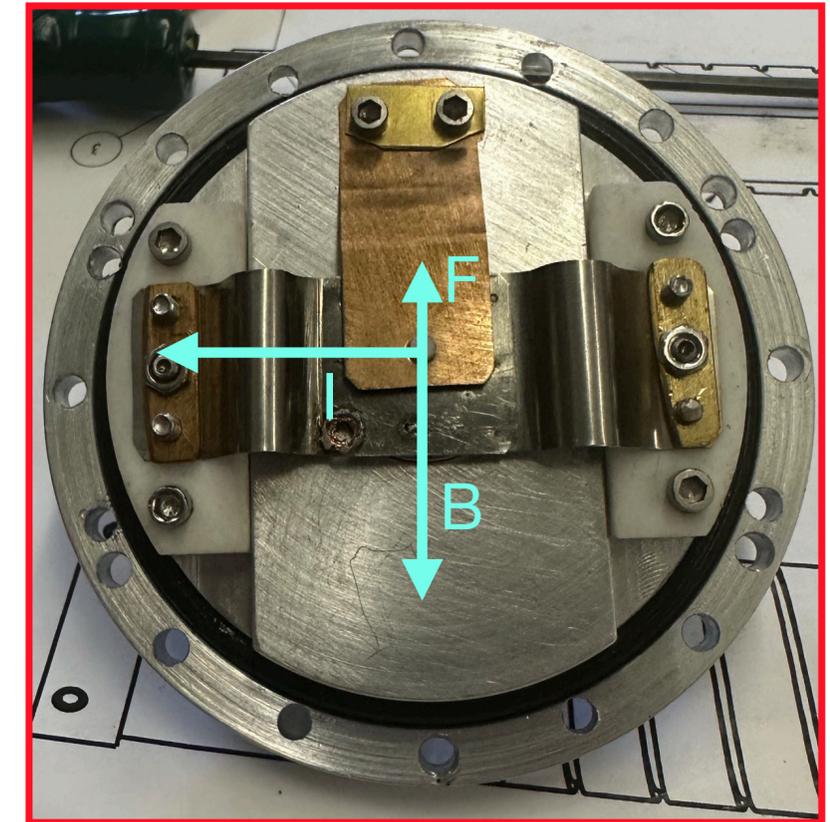
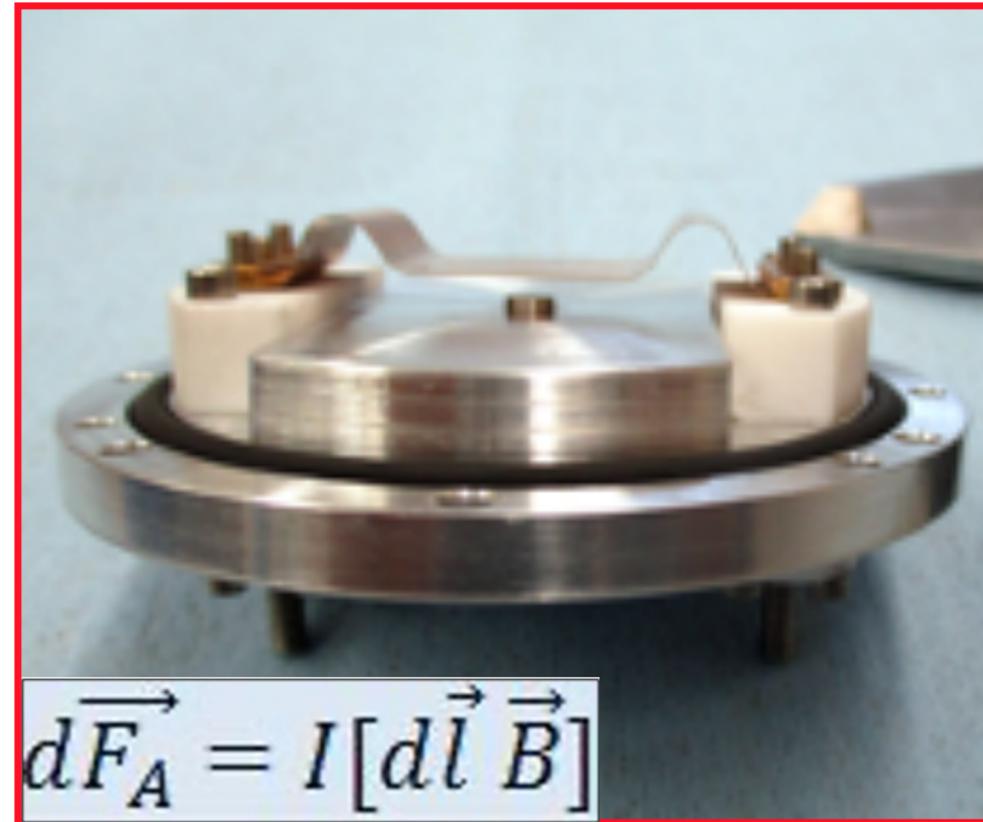
Filling and Injection in EBIS



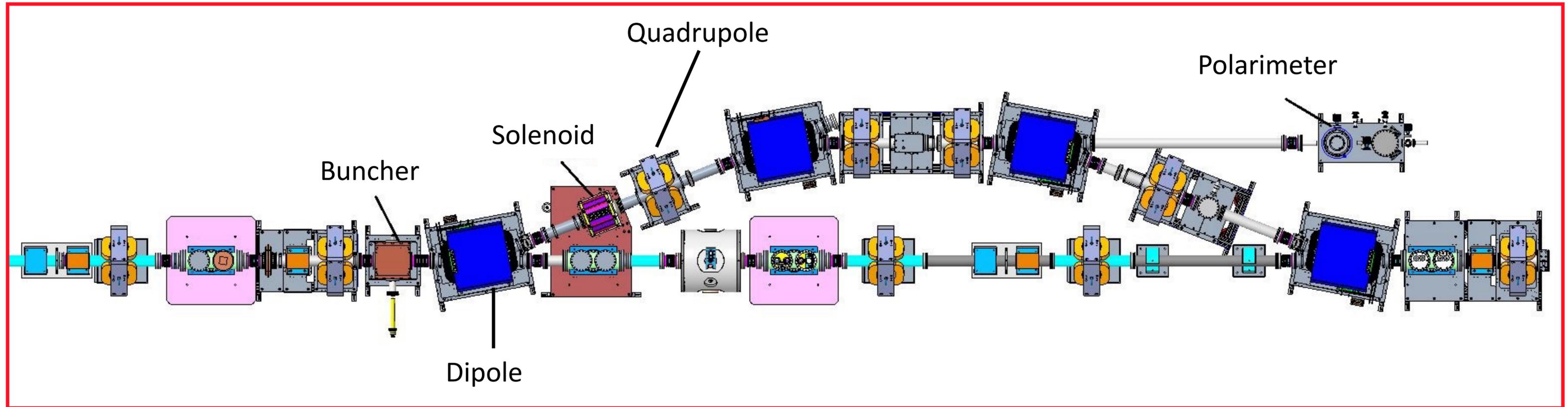
- Currently using the pneumatic valve to fill and seal the cell.
- A valve to inject into drift tubes has been designed and implemented for unpolarized ^3He .

Injection into EBIS Drift Tube

- Injection port is sealed by force from a spring.
- Lorentz force in magnetic field opens the valve when a large current is passed through the wire.
- Tested and currently used for unpolarized ^3He .



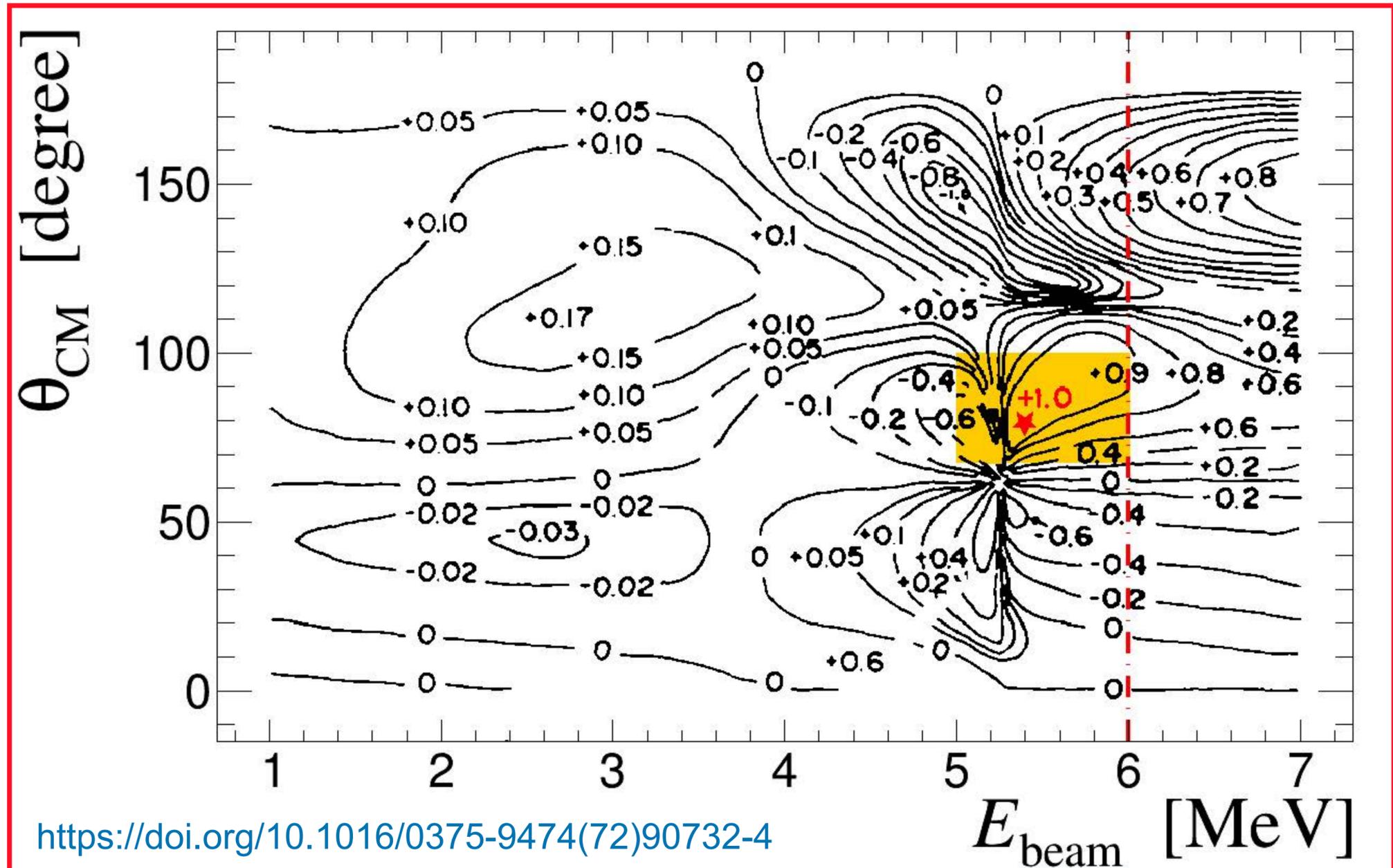
Chicane Spin Flip and Polarimetry



- Chicane has been constructed off the main injection path to rotate ^3He spin and provide in-line measurements of polarization after extraction from EBIS.
- Dipole and solenoid rotate spin from parallel to the beam path to vertical.

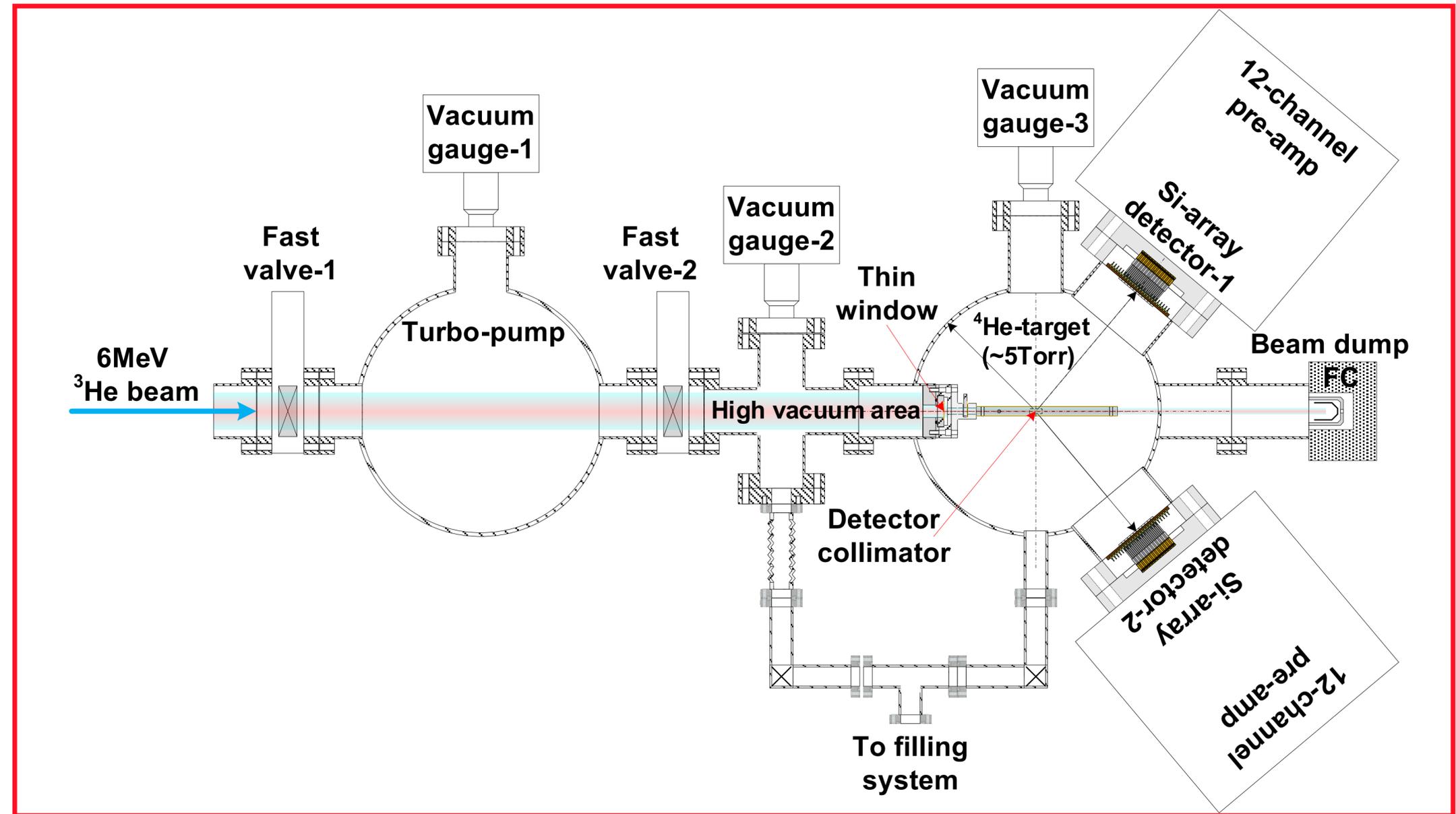
Absolute nuclear polarimeter

- Experimental data from Boykin, Baker, and Hardy studied elastic scattering of ^3He and ^4He (1972).
- Analyzing power nearly 100% at ~ 5.4 MeV and 79 deg.
- Suggests an absolute polarimeter with a ^4He target and symmetric particle detection.



Absolute nuclear polarimeter

- Polarized ^3He around 6MeV elastically scatters from ^4He into two symmetric silicon detectors.
- Chicane is complete, waiting for down period for installation of the nuclear polarimeter.



Metastable exchange optical pumping to polarize ^3He at high magnetic fields



📅 Sep 26, 2024, 11:40 AM

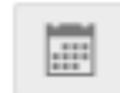
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📍 Cebaf Center Auditorium (Jefferson Lab)

Pushpa Pandey
(MIT)

Polarized Gas Targets I

Polarized ^3He Double-Cell Target Utilizing Metastability Exchange Optical Pumping at High Pressure and Magnetic Fields



📅 Sep 26, 2024, 12:00 PM

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📍 Cebaf Center Auditorium (Jefferson Lab)

Hao Lu
(University of Tennessee)

Polarized Gas Targets I

Similar efforts underway to bring high pressure MEOP target to JLAB

Summary

- Long series of feasibility studies for polarized ^3He in extended EBIS.
- Up to 90% polarization has been achieved with same methods at required pressure and field.
- Spin rotation and absolute polarimeter installation nearly complete.
- After Covid delay, the project is back up and running full time in an exact copy of the EBIS magnet.
- Ongoing optimization of polarization in compact setup, construction of a new injection valve, and further integration of polarization controls into RHIC control system.
- Goal to install in November 2025 downtime.

