# Polarized He-3 Ion Source at BNL

**Noah Wuerfel and Chris Ianzano**

in collaboration with

A. Zelenski, A. Poblaguev, A. Sukhanov, D. Raparia, E. Beebe, G. Atoian, J. Maxwell, J.Ritter, M. Okamura, M. Musgrave, R. Milner, S. Kondrashev, S. Ikeda, S. Trabocchi, T. Kanesue

Polarized Ion Sources and Beams at EIC

March 10, 2025

CFNS at Stony Brook

Brookhaven National Laboratory

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.

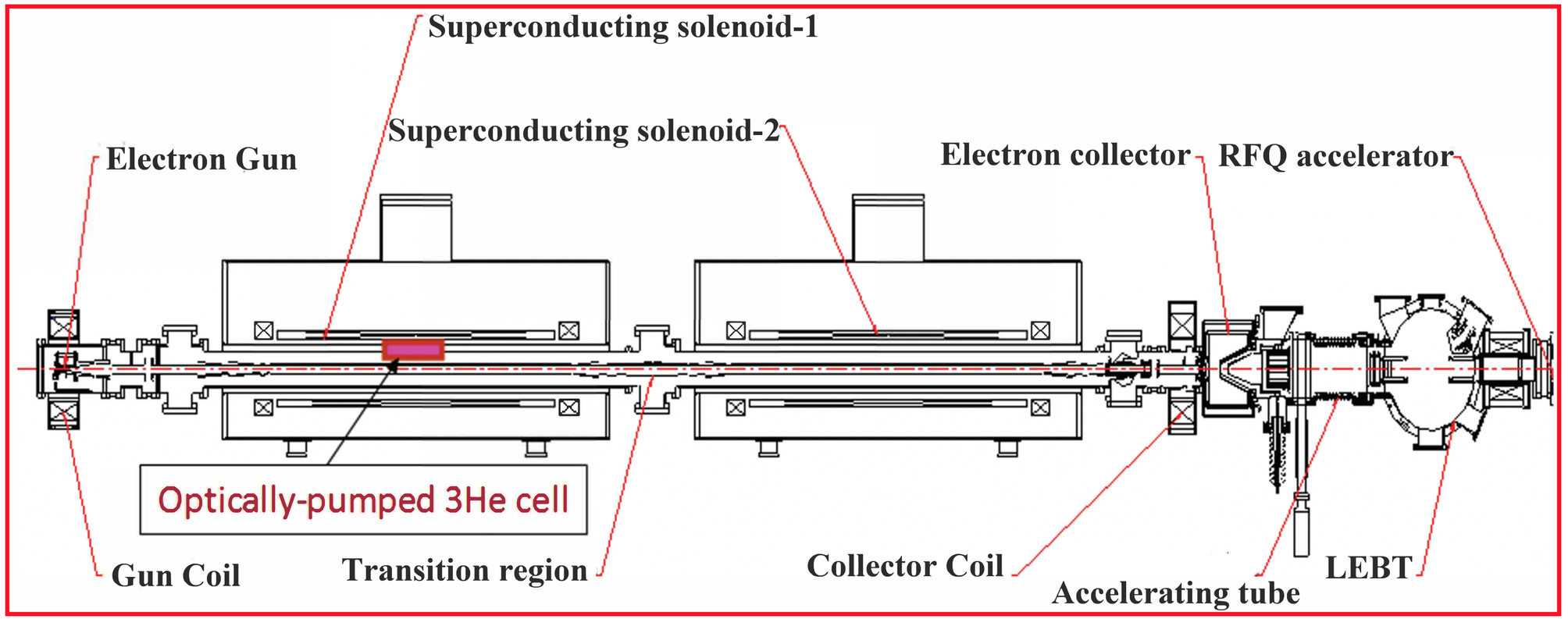
# 3He Source at BNL

- 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 x $10^{11}$ 3He++ ions in a 20 μs pulse ( 4 mA peak current)
  - Spin-flip and polarization measurement in beam transport line before injection to AGS and RHIC.

# Extended EBIS

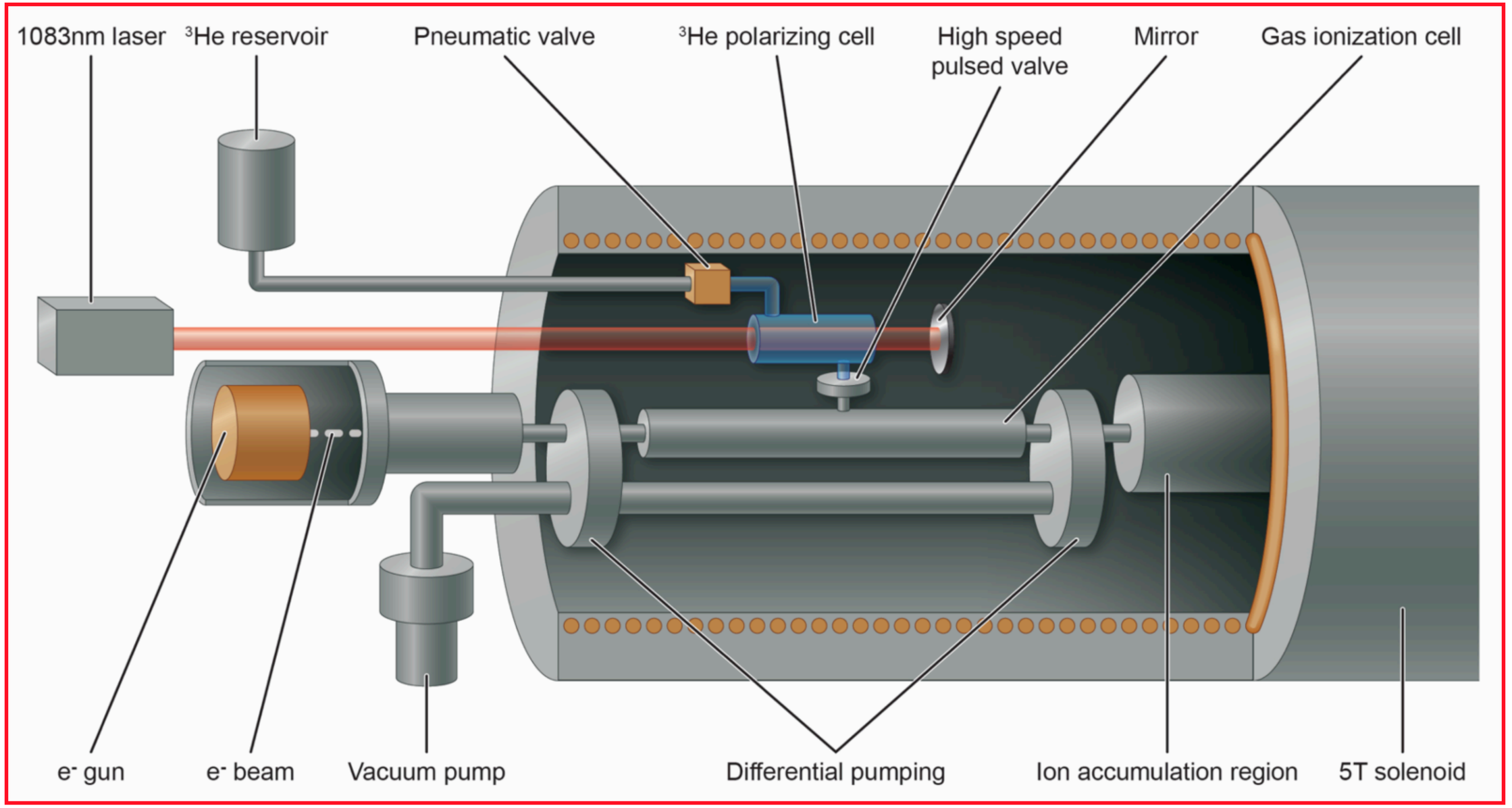

- Second 5T solenoid extends trap length for 40% increase in Au capacity.
- Tested from 2018 - 2022, now installed and currently operating.

# 3He inside of Extended EBIS



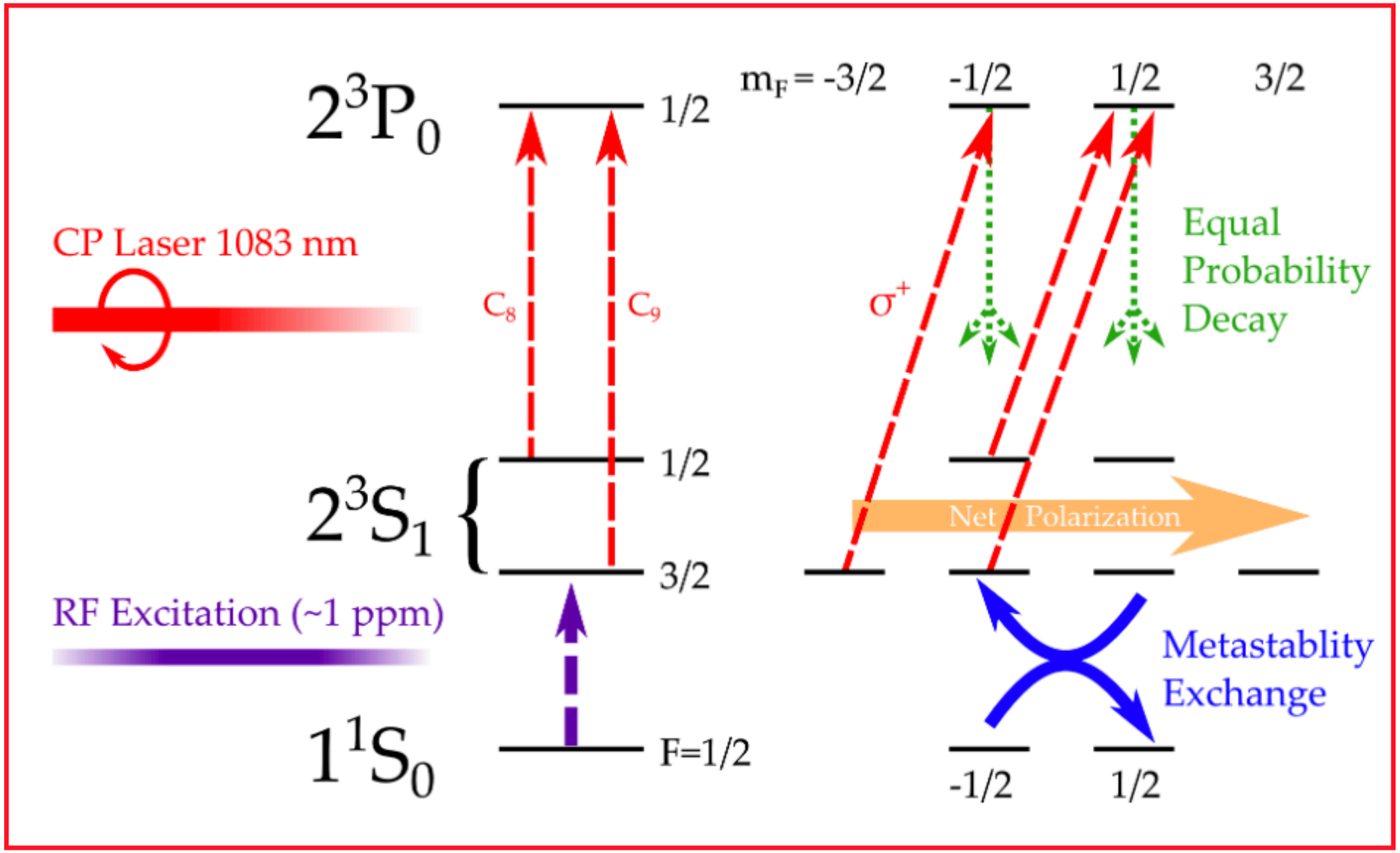

- Extended EBIS also provides opportunity to polarize 3He in situ for injection and ionization.
- 3He ionized to 3He+ in first trap, then 3He++ in second trap.

# 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.

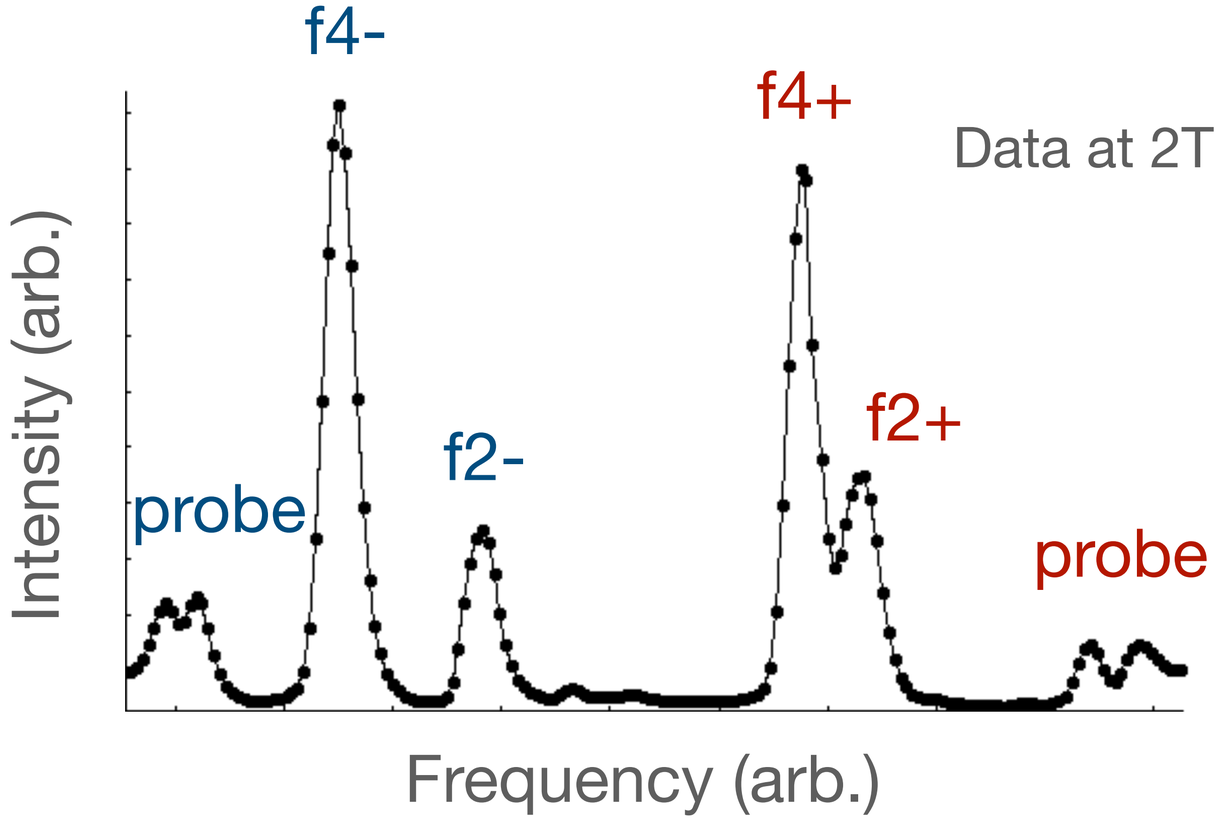


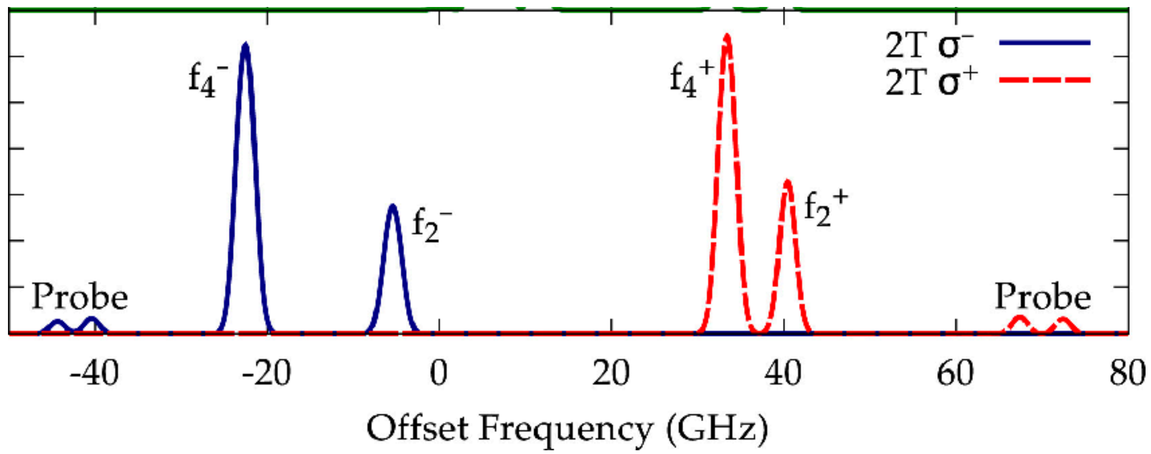
# Optical Polarimetry

- 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 $^3$He through Metastability Exchange Optical Pumping at High Field

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

*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*

2019

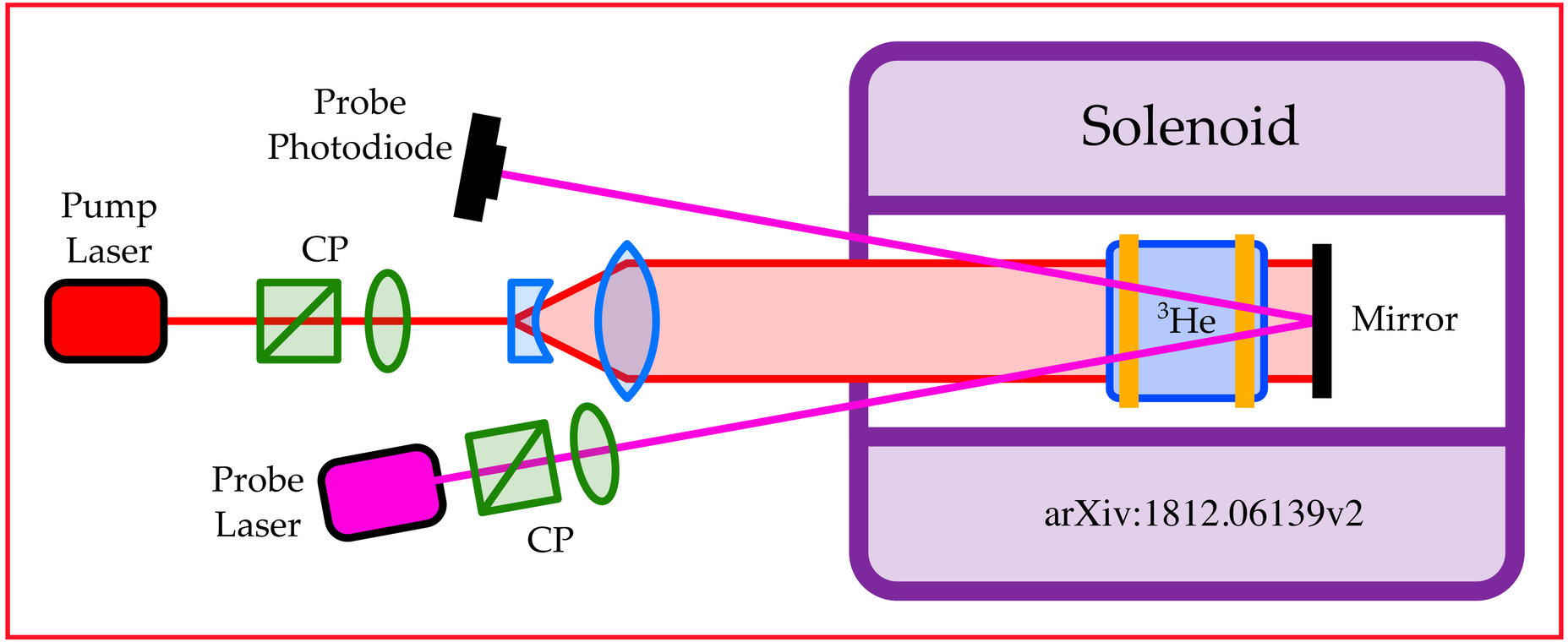
## Optically Pumped Polarized $^3$He$^{++}$ Ion Source Development for RHIC/EIC

A. Zelenski [a], G. Atoian [a], E. Beebe [a], S. Ikeda [a], T. Kanesue [a], S. Kondrashev [a], J. Maxwell [b,c], R. Milner [b], M. Musgrave [b], M. Okamura [a], A. A. Poblaguev [a,*], D. Raparia [a], J. Ritter [a], A. Sukhanov [a], S. Trabocchi [a]

[a] *Brookhaven National Laboratory, Upton, NY 11973, USA*
[b] *Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, MA 02139, USA*
[c] *Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA*

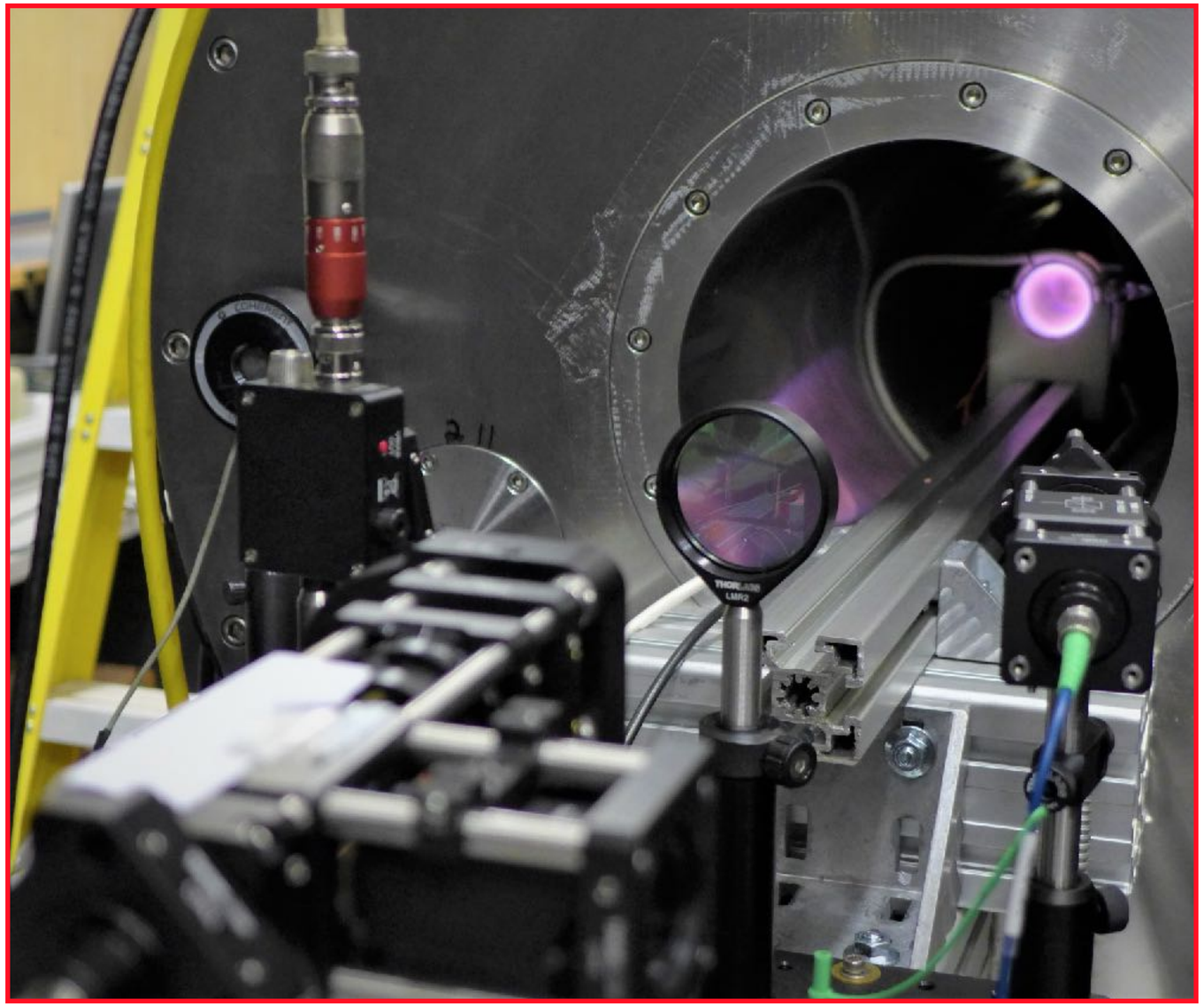
2023

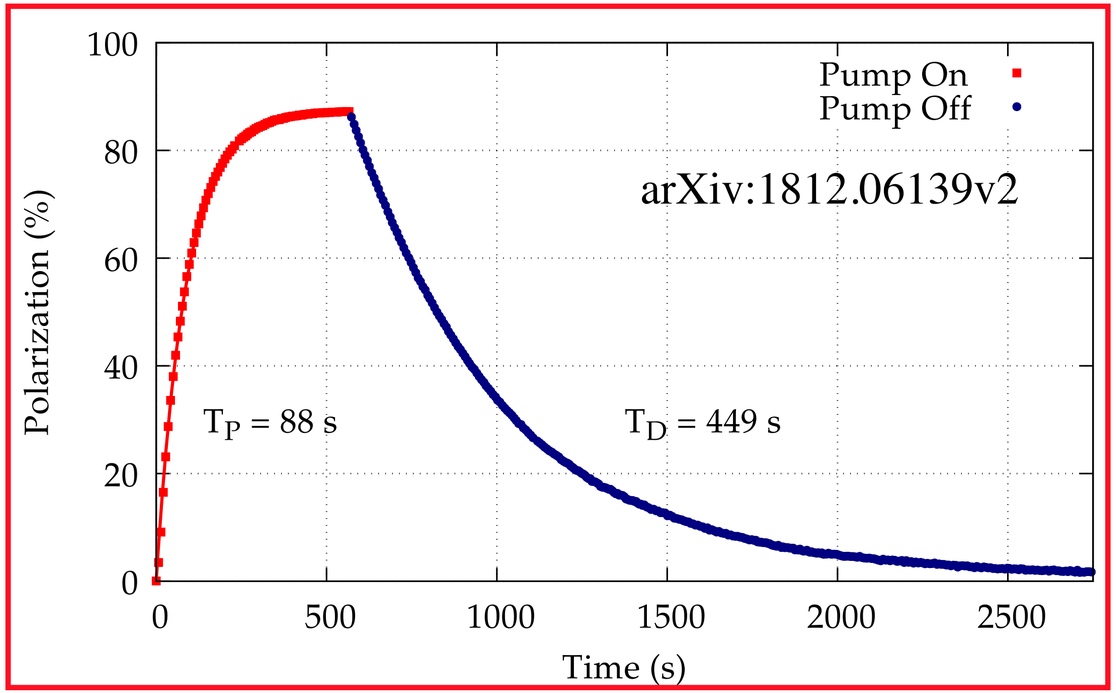
# Polarimetry Measurement




- 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

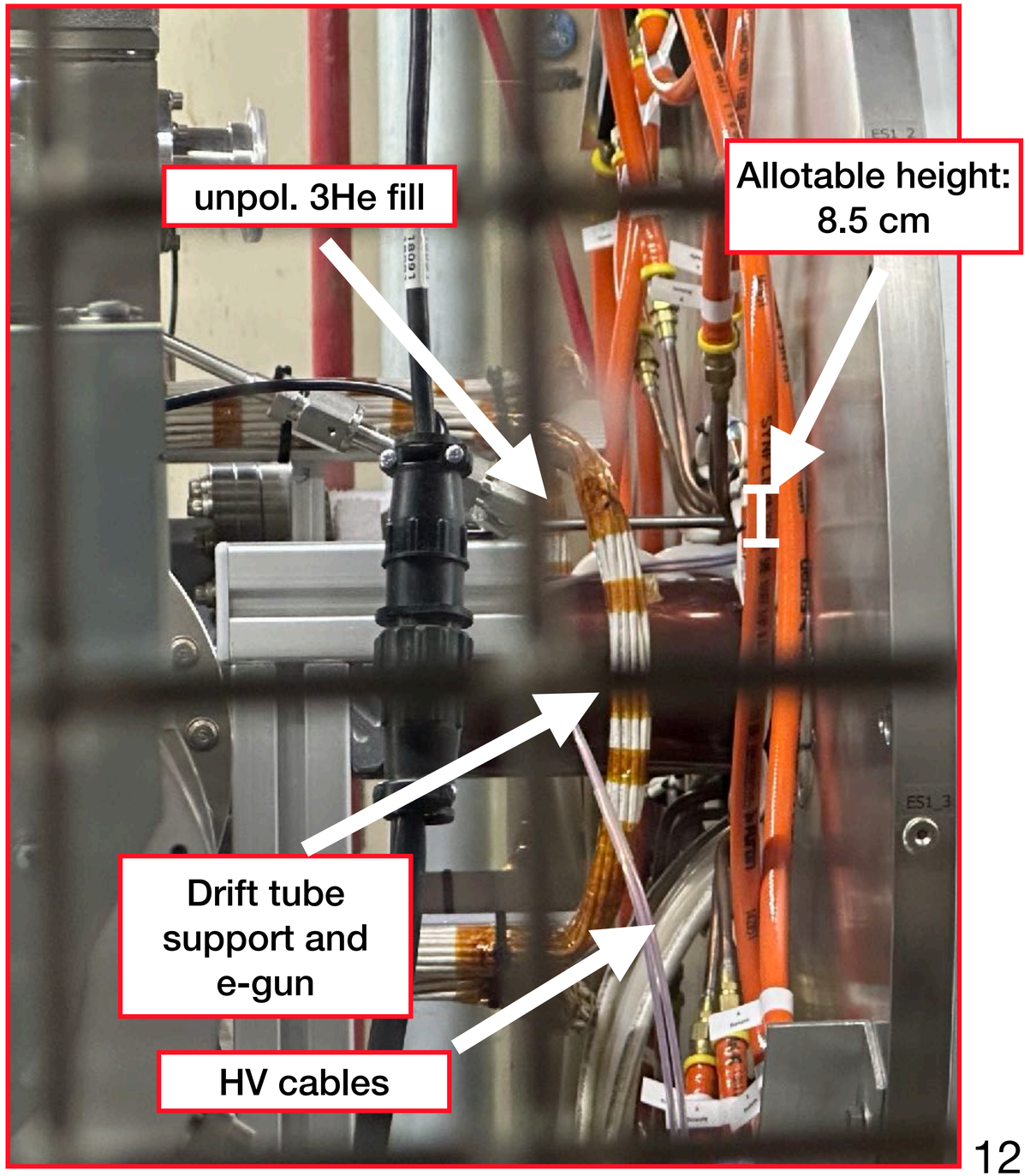


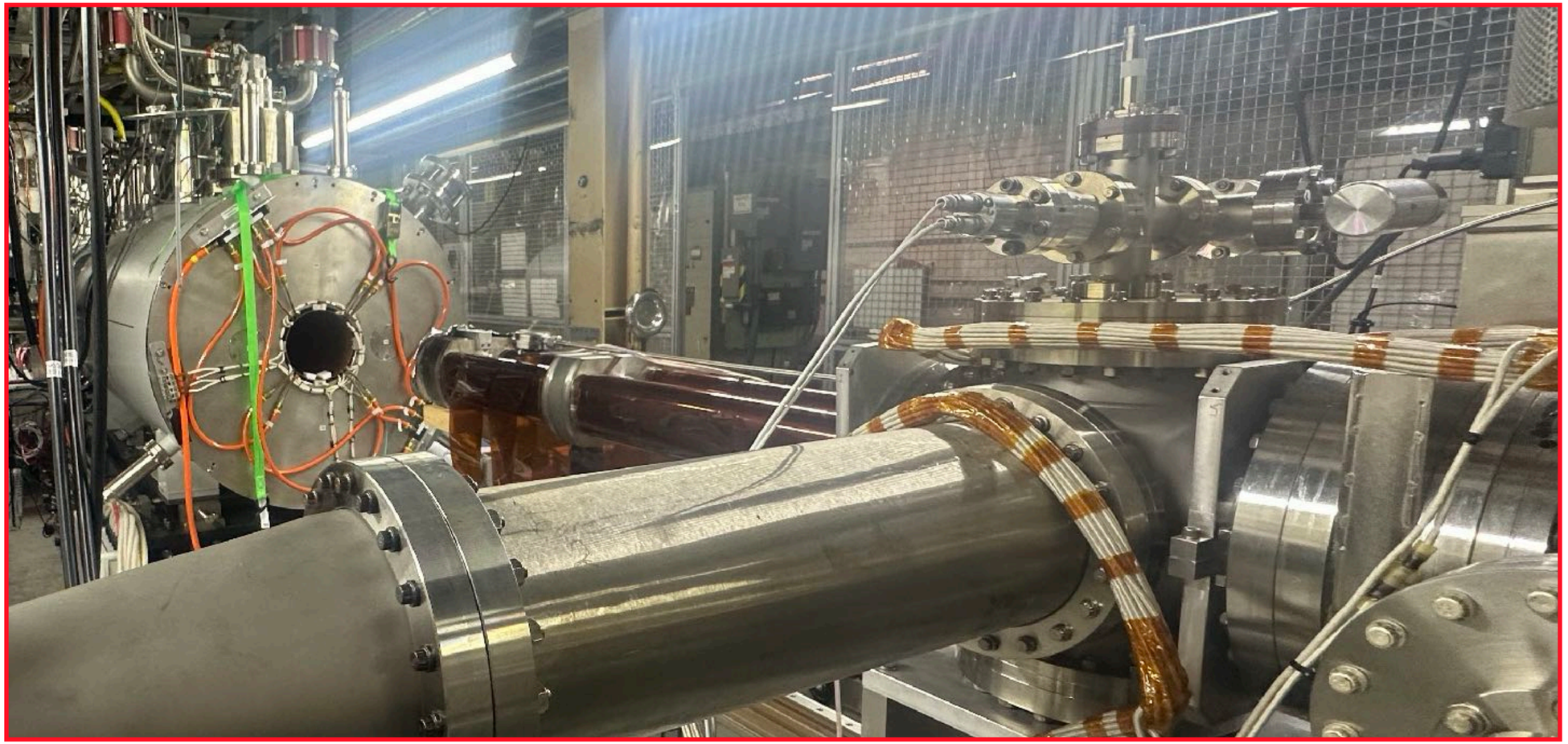


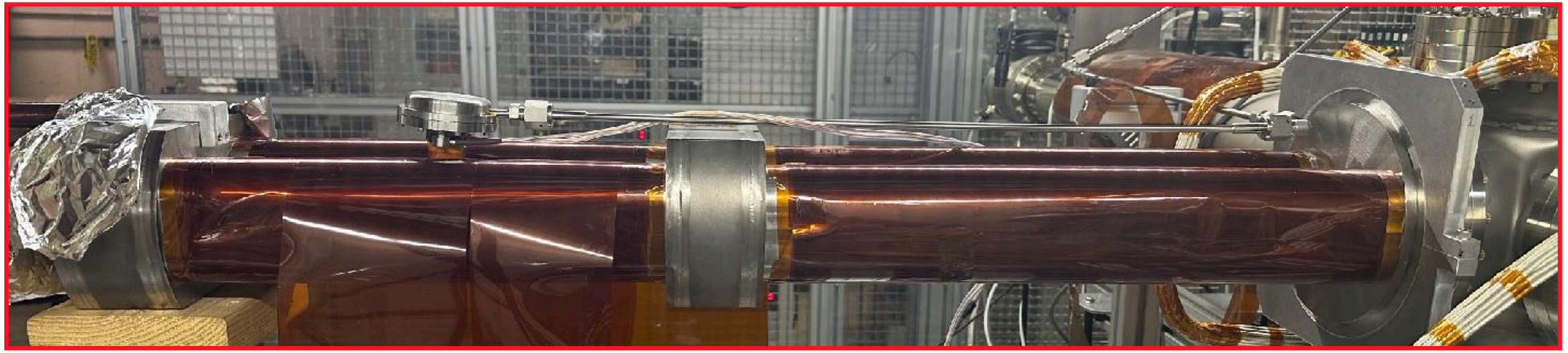

- Nearly 90% polarization!
- Good separation of pump and probe, and saturation of plasma by pump.
- But, this layout takes up too much space to go into EBIS.

# 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.

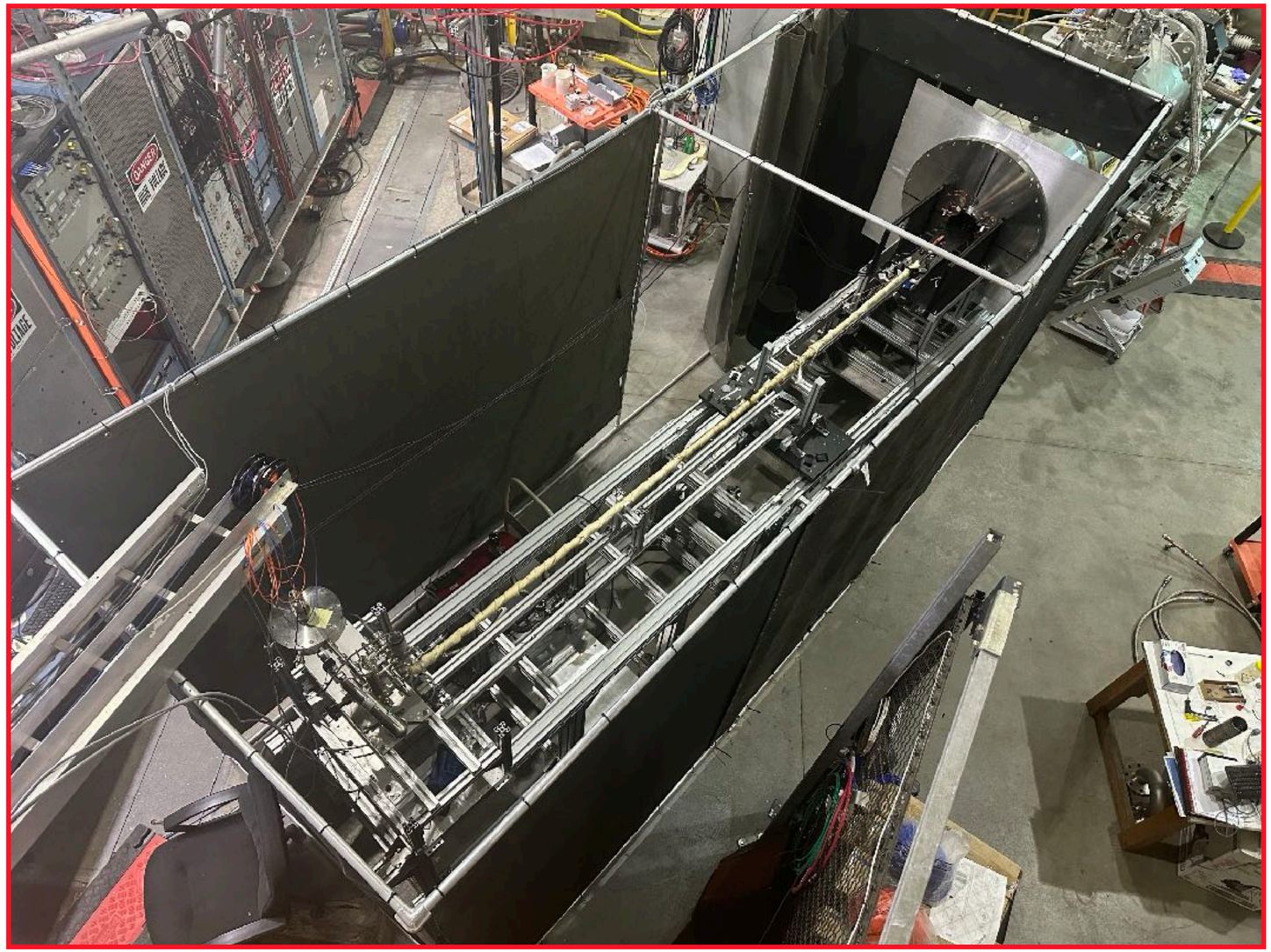




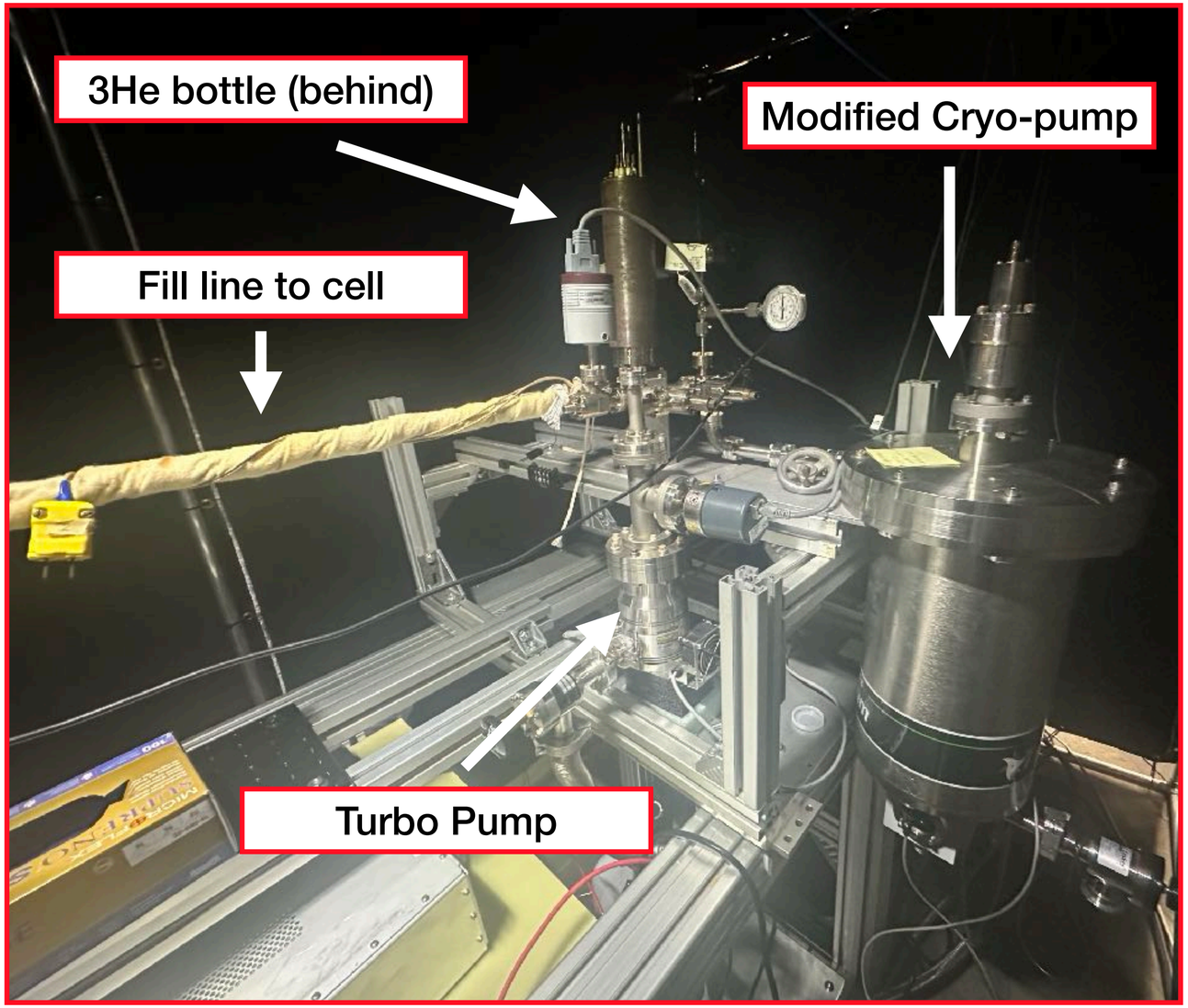


# Resuming 3He Studies at BNL

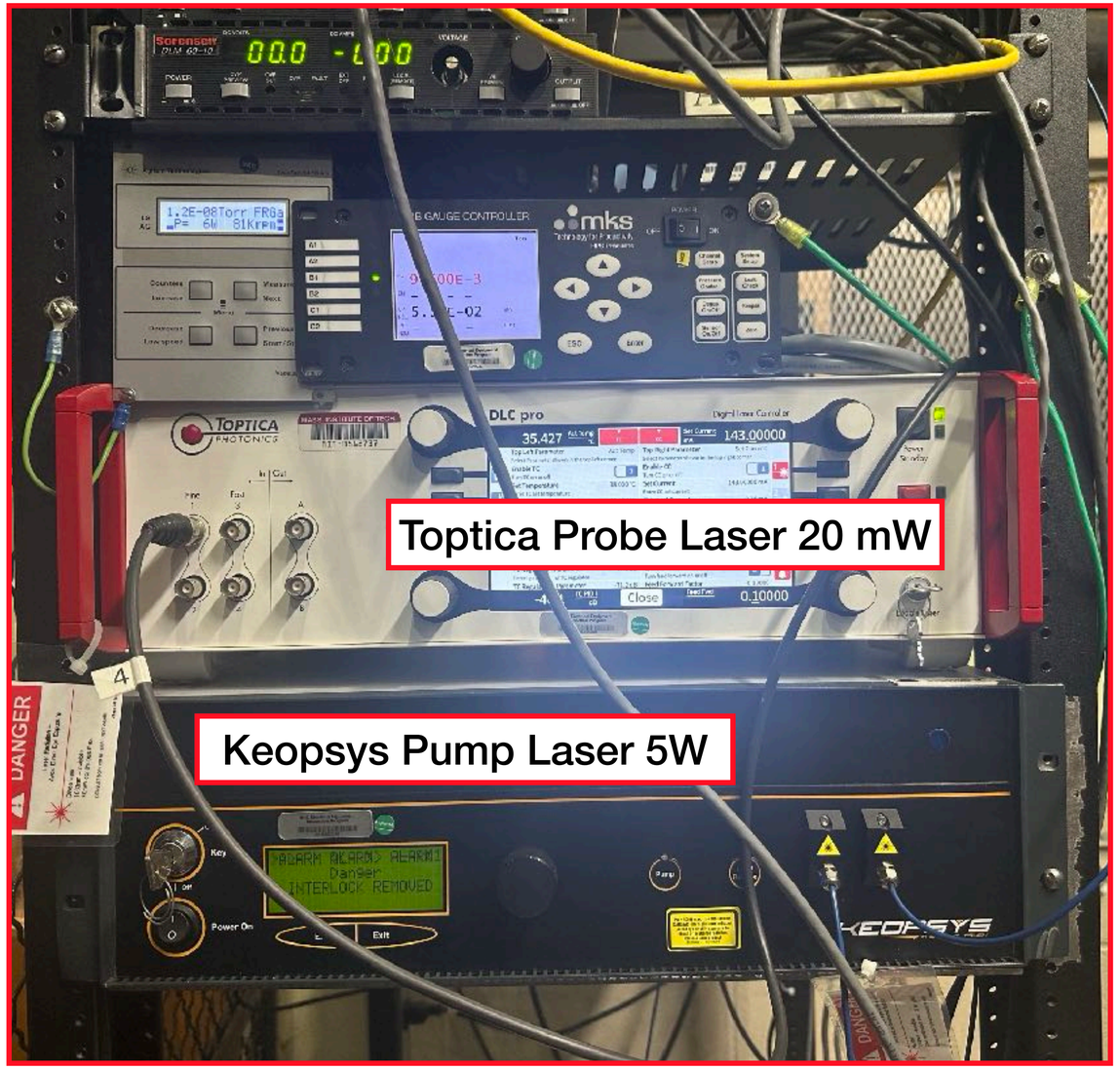
- Moved gas purification system into test lab with the original EBIS magnet.
- New laser enclosure, interlock, and safety approvals.
- Worked with CAD to reconnect DAQ with RHIC control systems.
- More compact optical polarization layout.



# Resuming 3He Studies at BNL



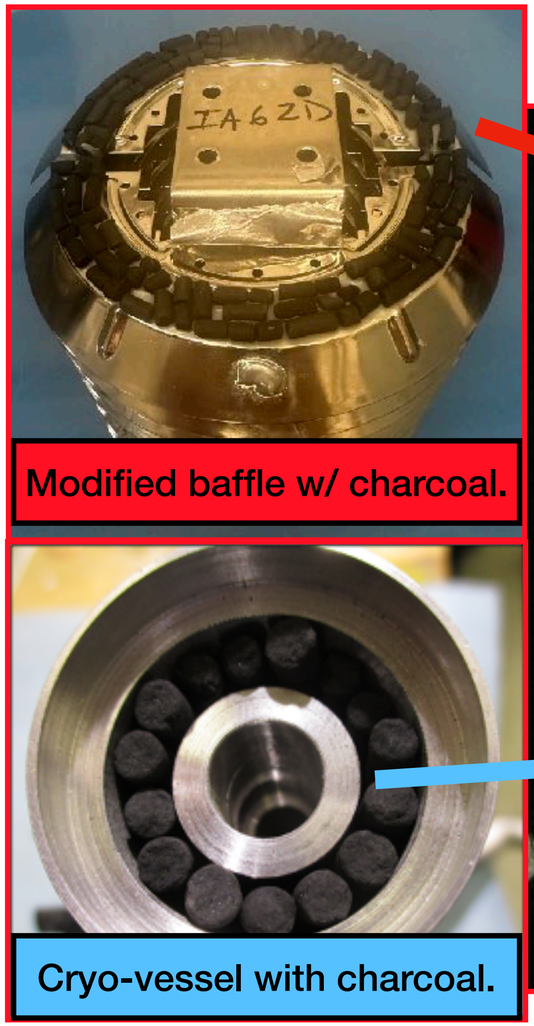

Cryogenic gas purification system

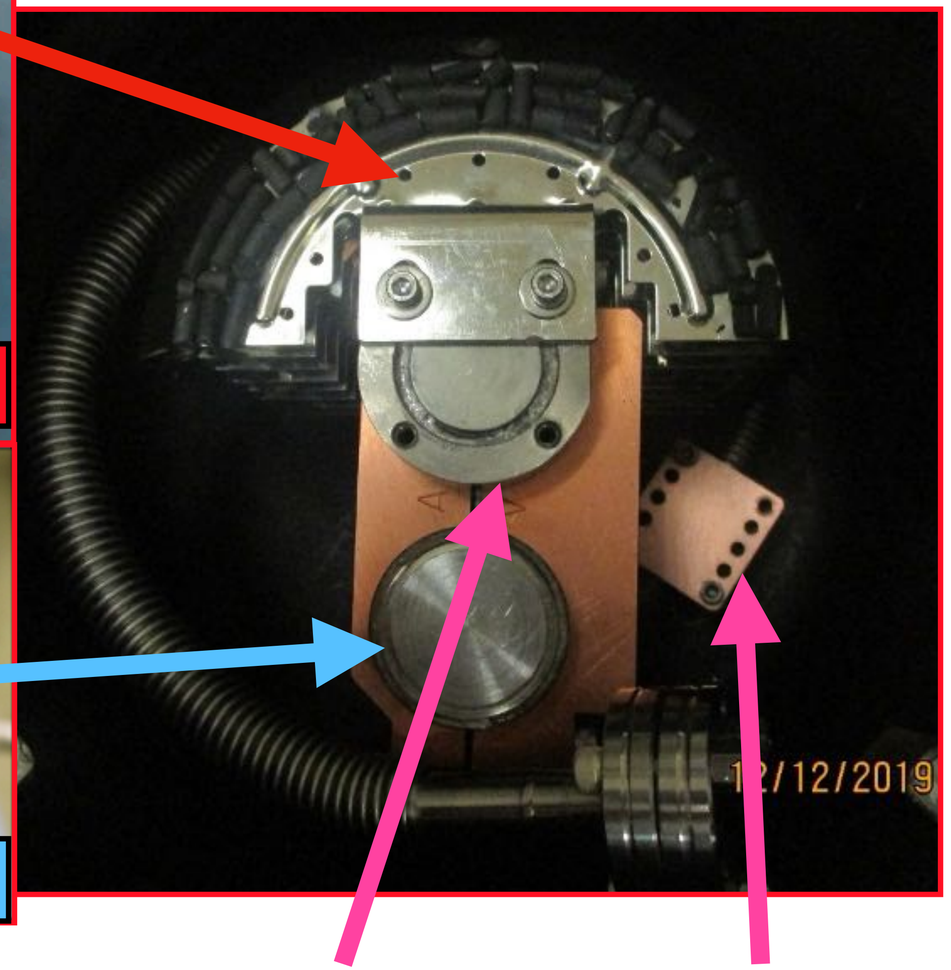



Controls rack with pump and probe

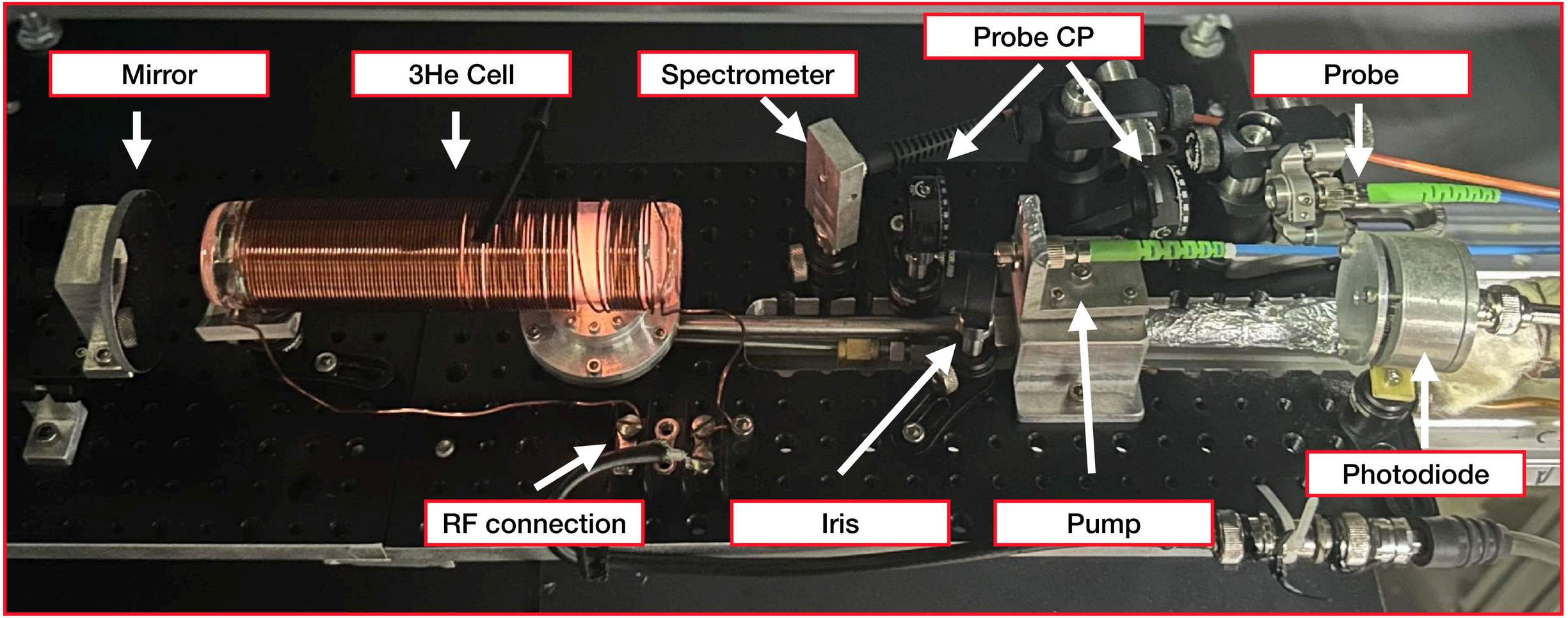
# Gas purification

- 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.



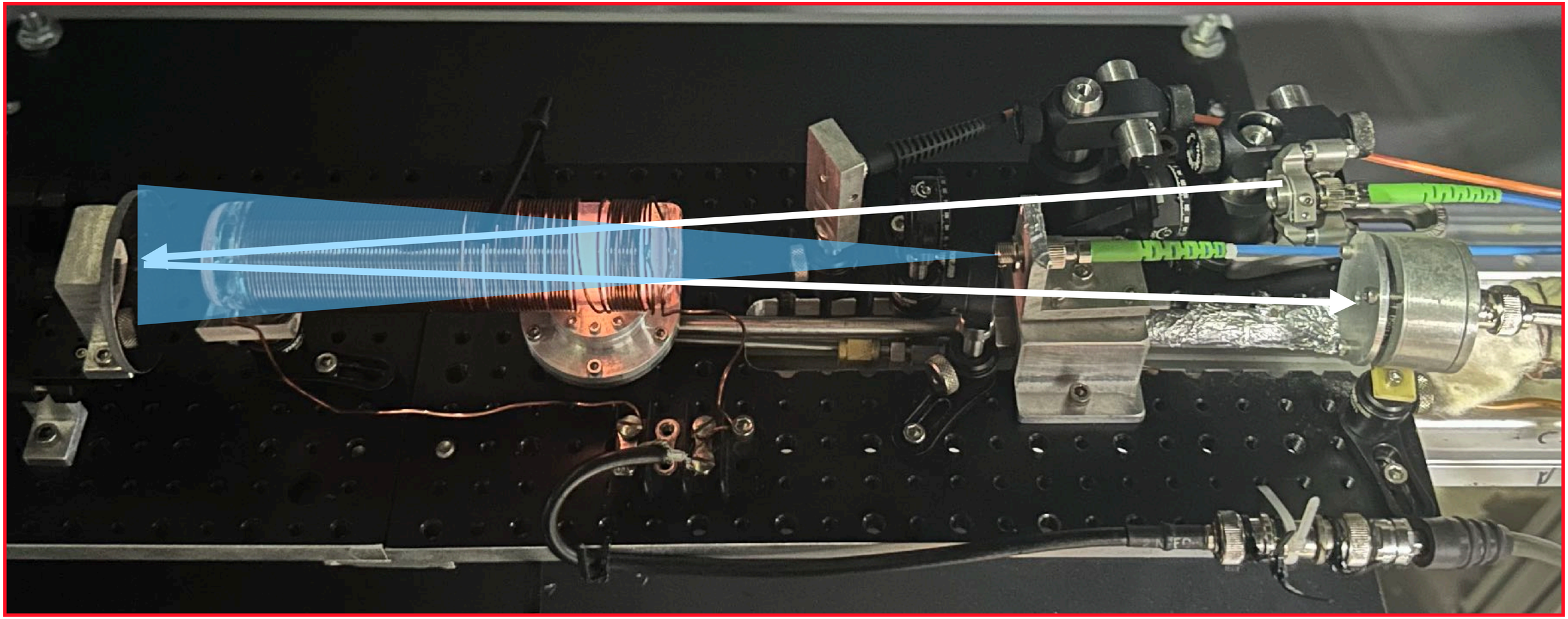



# Reducing the Optics Footprint




First draft of a compact polarization setup.

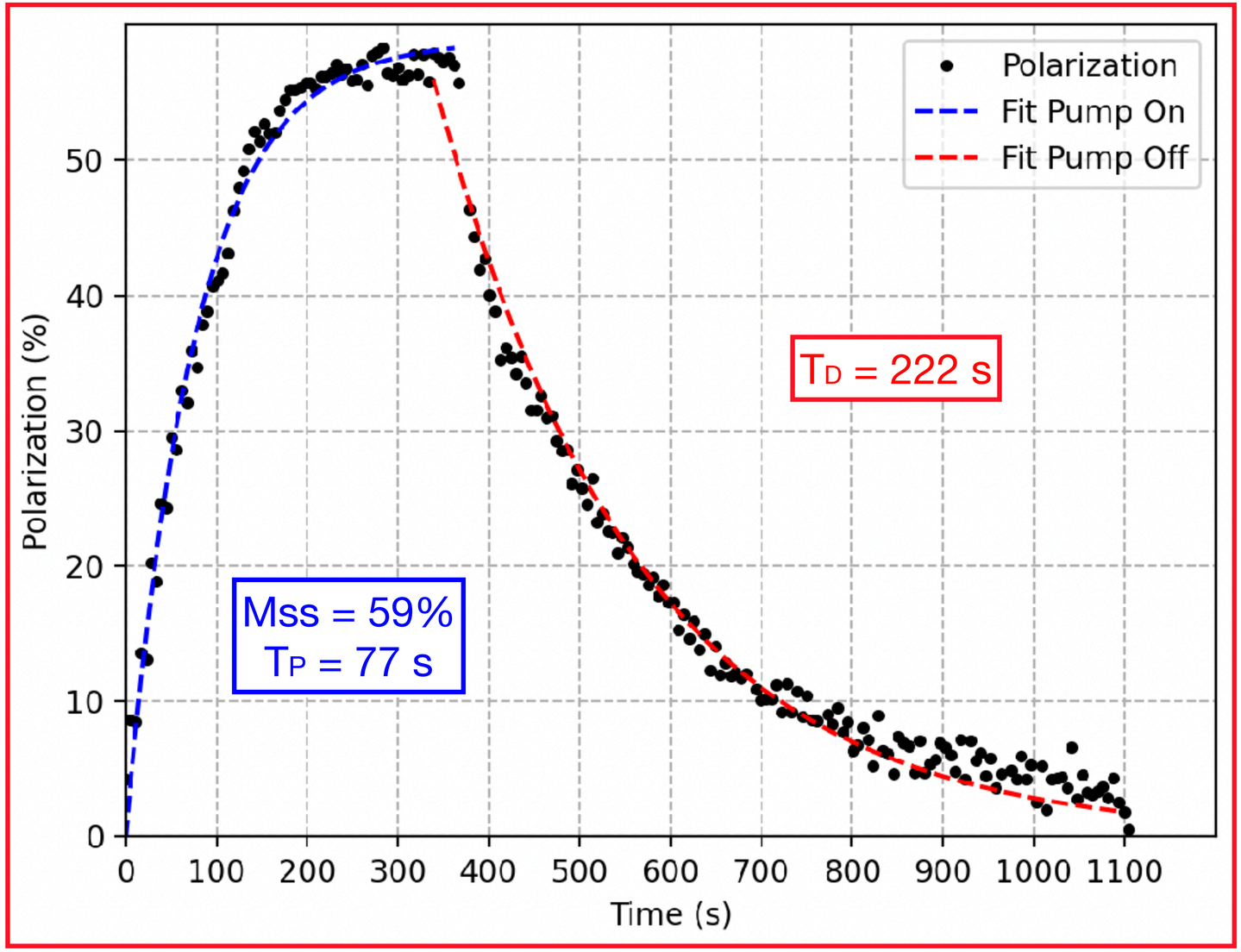
# Reducing the Optics Footprint



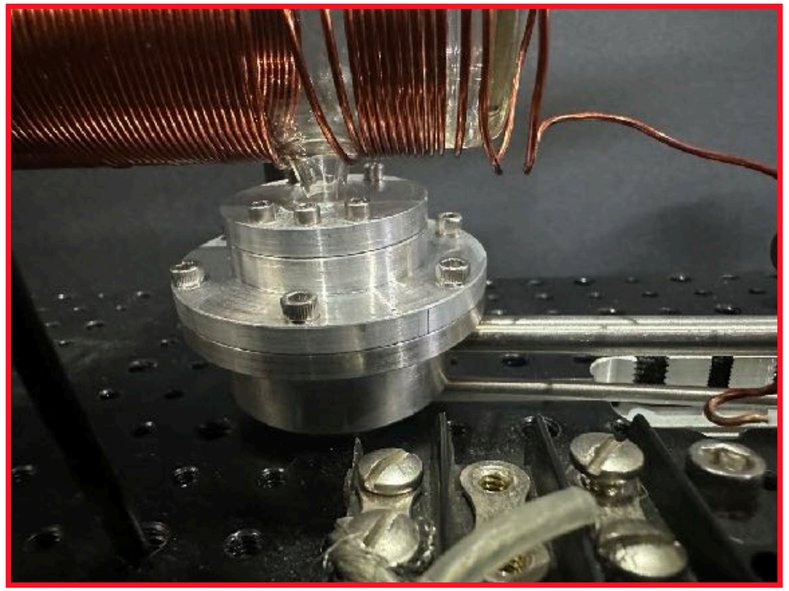
First draft of a compact polarization setup.

# Polarization with New Setup

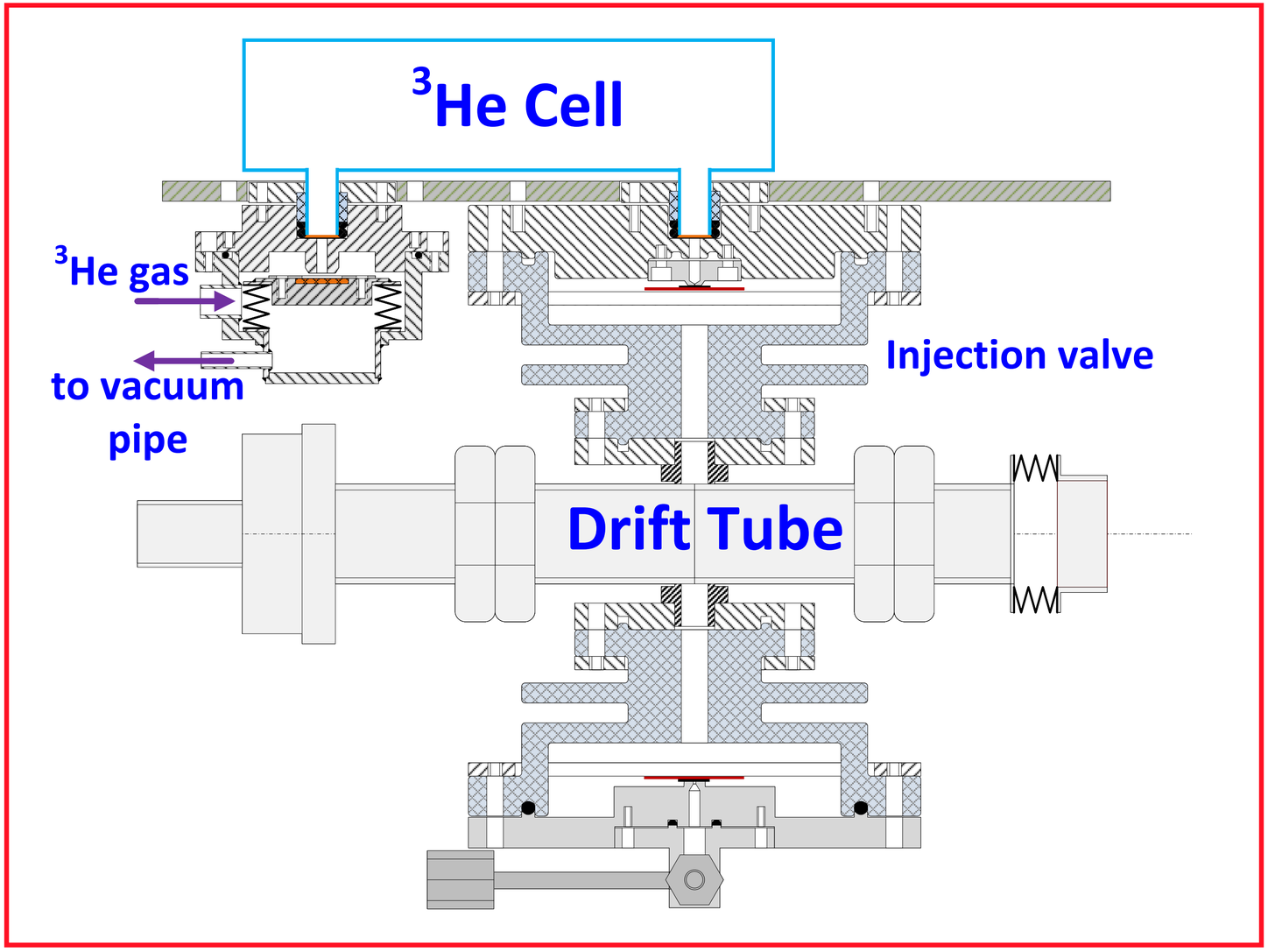
- Steady state polarizations near 60% at 3T and 2.5 Torr.
- Pumping on f4+ at 276.740 Thz.
- Probe signal depends on brightness of plasma, but highest polarizations require dim plasma.
- At high field, plasma distributes near the edges of the cell, but probe is traveling through center.
- Probe and pump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



# Filling and Injection in EBIS

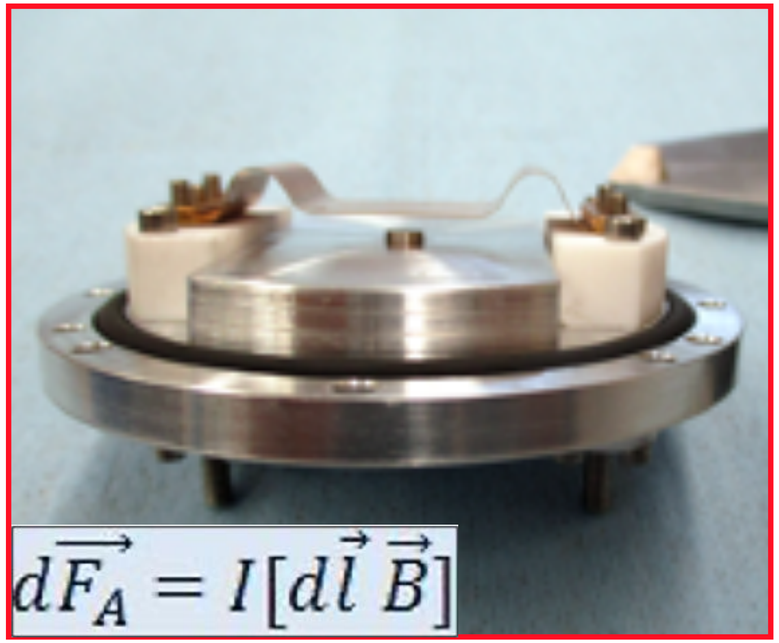


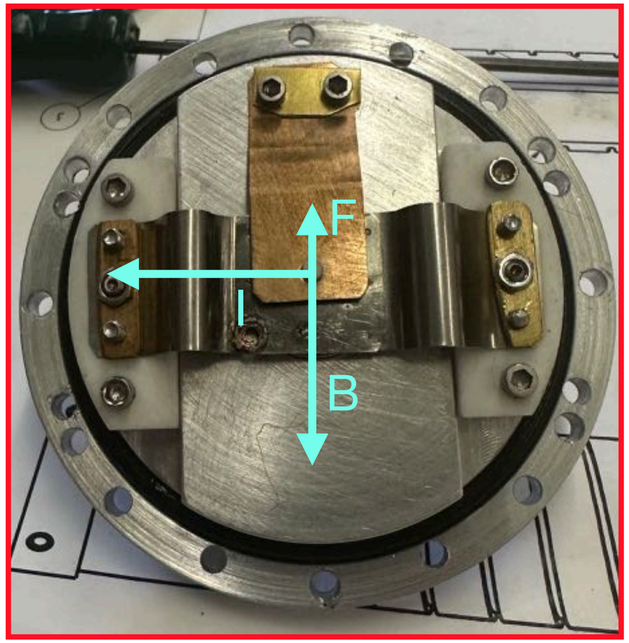
- Currently using the pneumatic valve to fill and seal the cell.
- A valve to inject into drift tubes has been designed and implemented for unpolarized 3He.

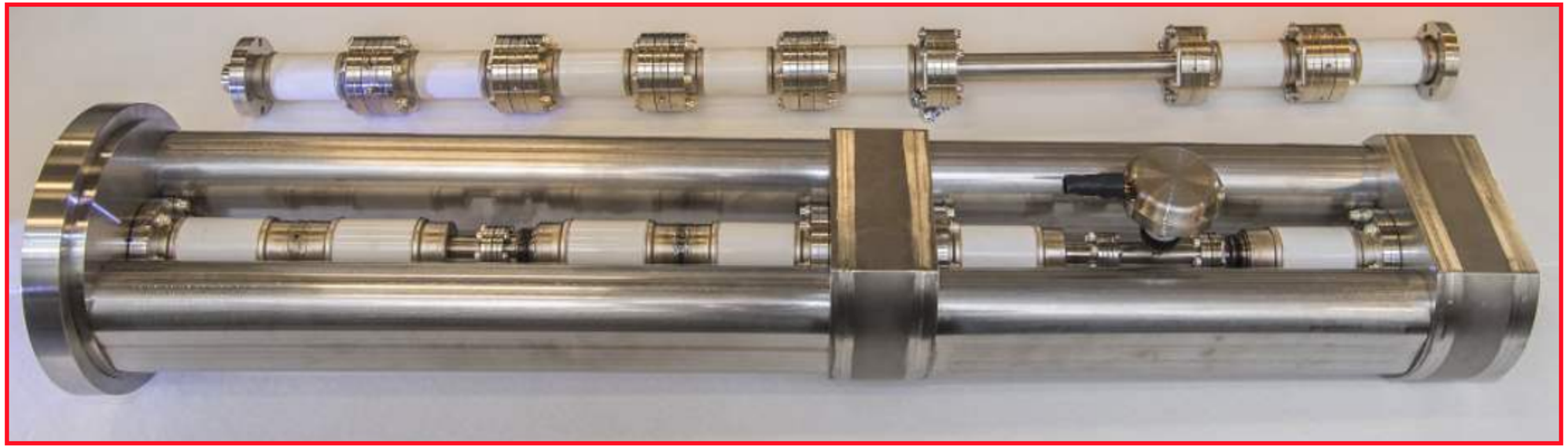


# Injection into EBIS Drift Tube

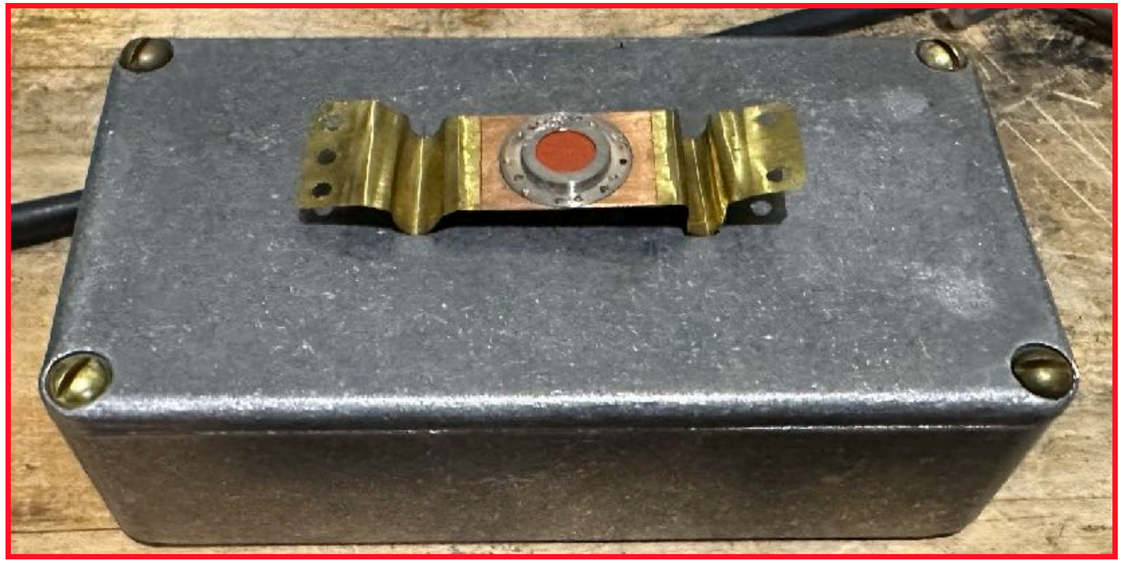
- Injection port is sealed by force from a spring.
- Lorentz force in magnetic field opens the valve when a large current is passed through the wire.
- Tested and currently used for unpolarized 3He.

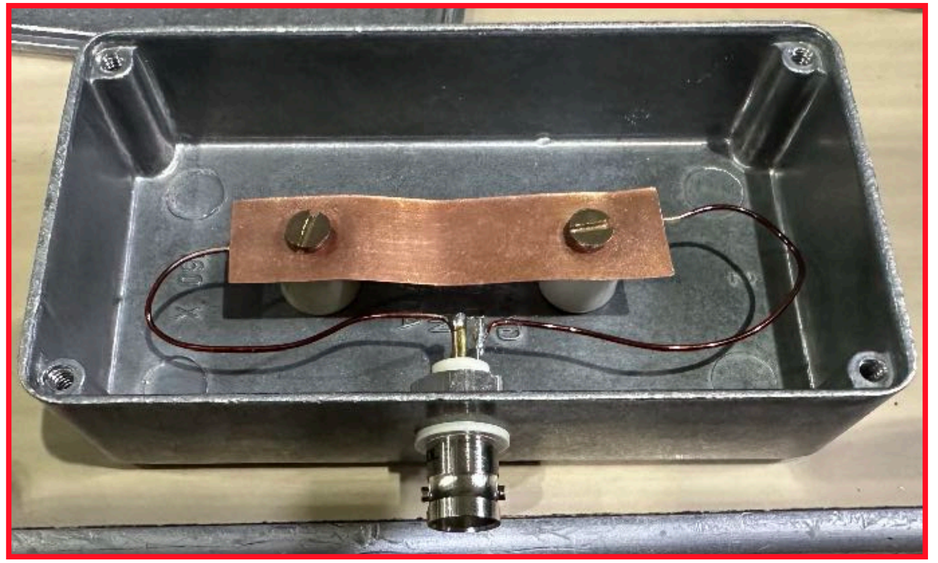


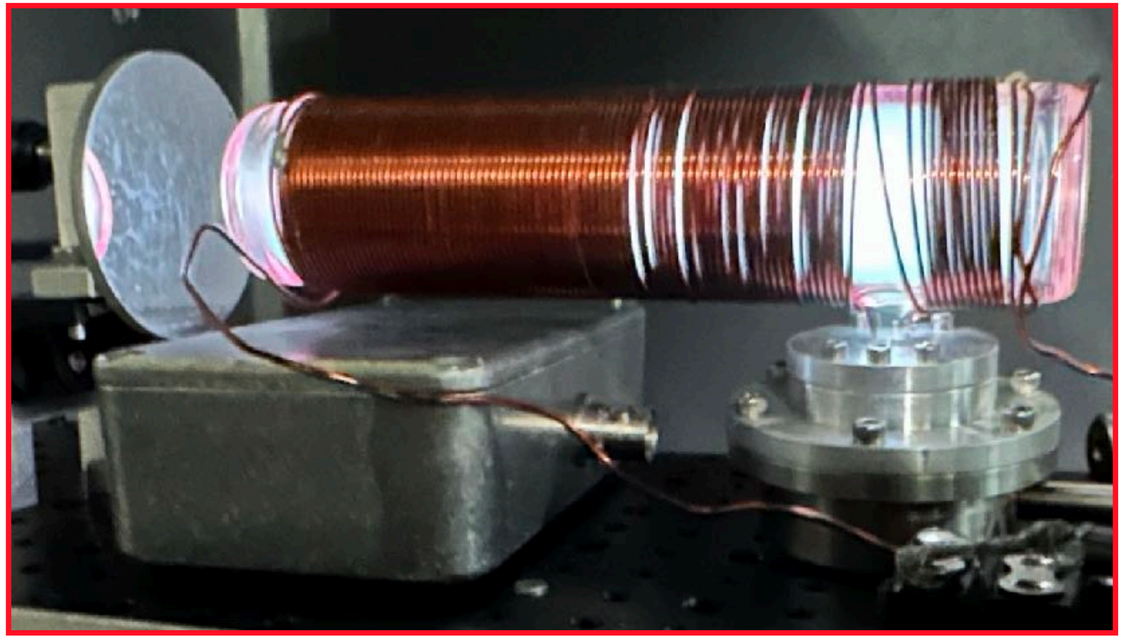



# Mock Pulse Valve

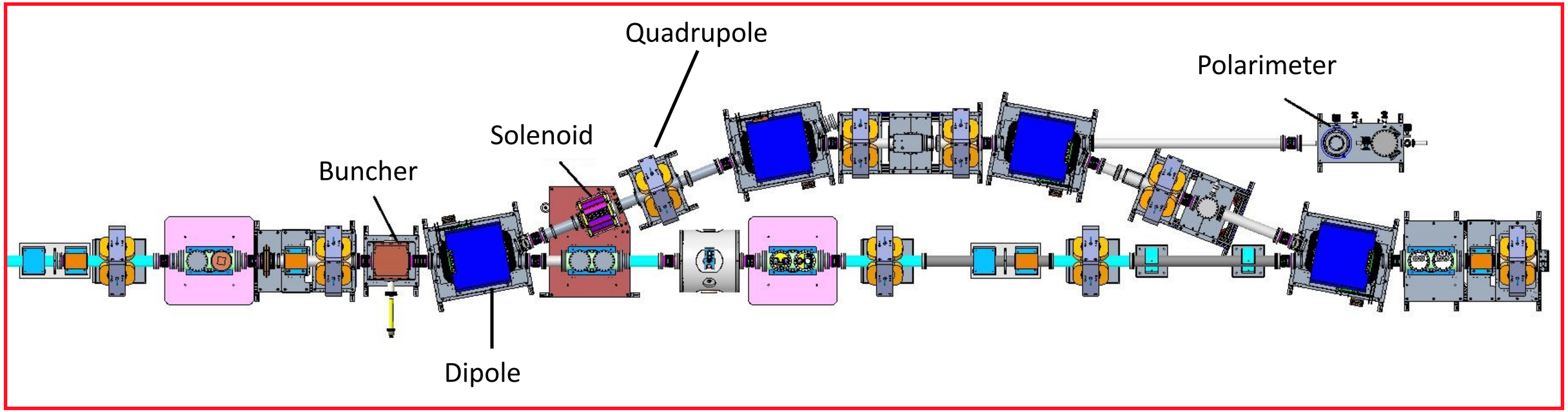




- Constructed a mock pulse valve to test effect of 10 A current on the cell polarization.
- Aluminum case with copper strip of roughly the same dimensions as pulse valve.
- Strip is about 1 in away from the cell.



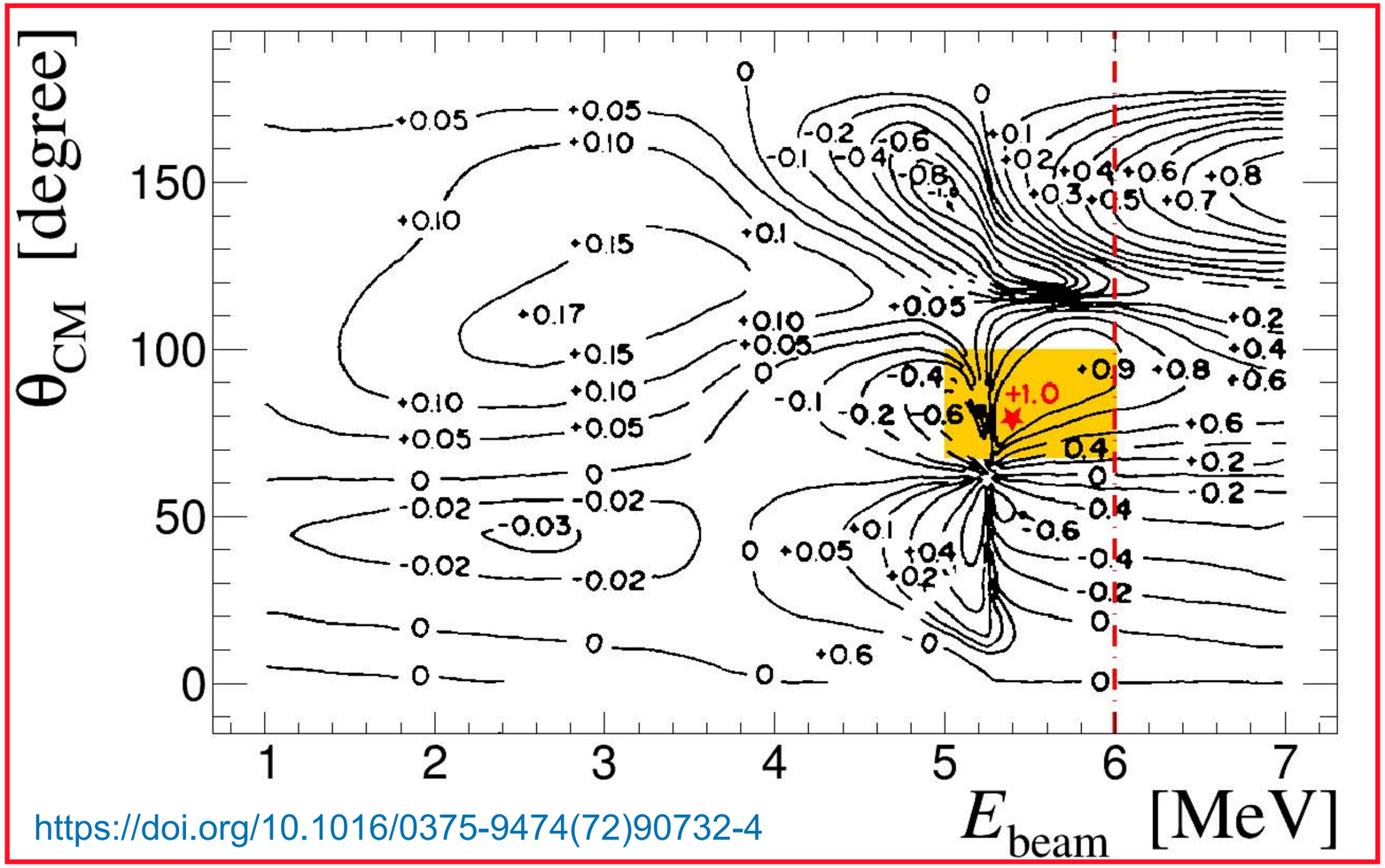
# Chicane Spin Flip and Polarimetry




- 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

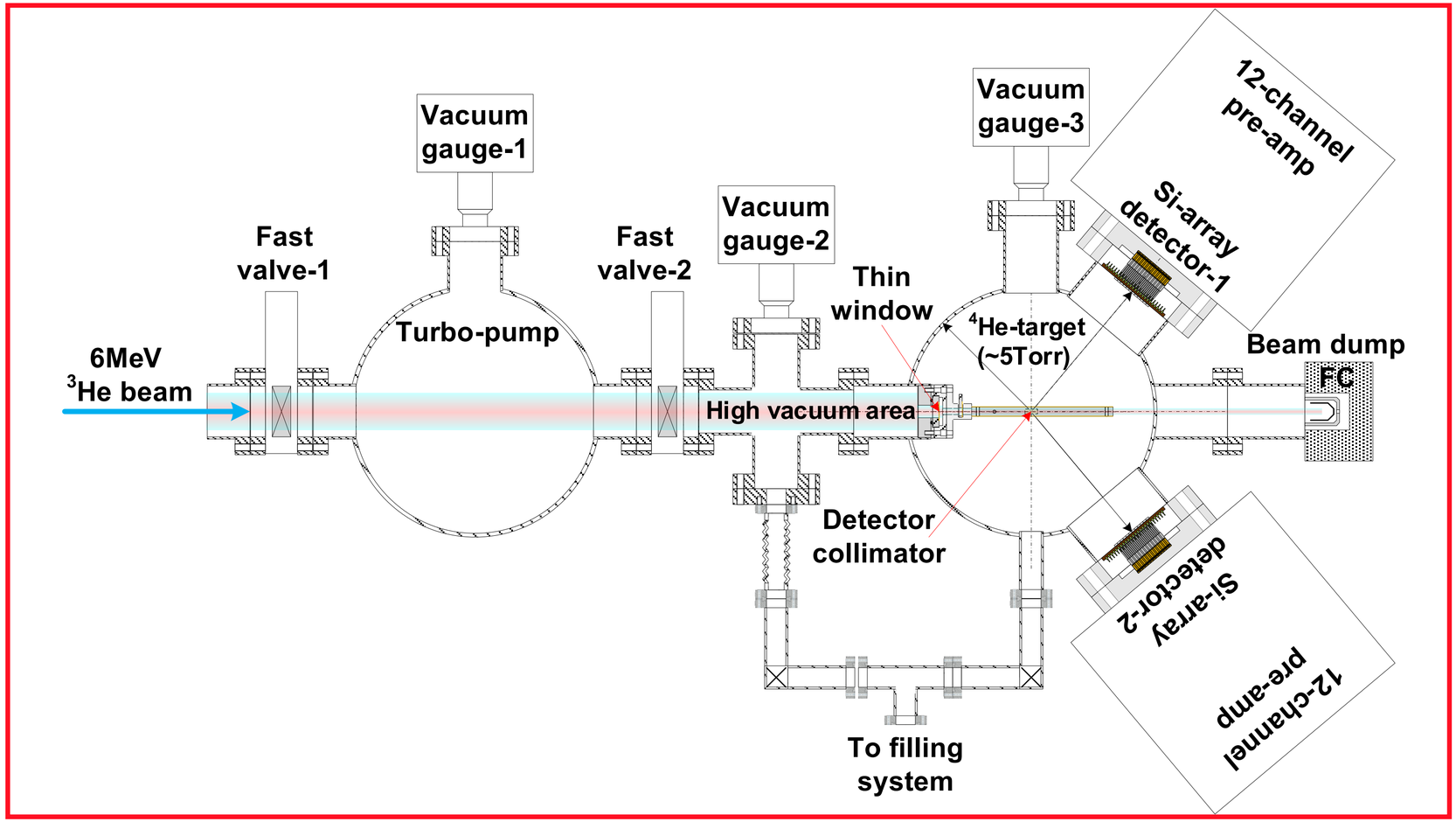
- Experimental data from Boykin, Baker, and Hardy studied elastic scattering of 3He and 4He (1972).
- Analyzing power nearly 100% at ~5.4 MeV and 79 deg.
- Suggests an absolute polarimeter with a 4He target and symmetric particle detection.




https://doi.org/10.1016/0375-9474(72)90732-4

# 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.
- Talk tomorrow on He3 Jet Polarimeter by Prajwal -> 3 total measurements of the 3He polarization.



# 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.