

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. Kaneshue

Polarized Ion Sources and Beams at EIC

March 19, 2026

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.
- Closer to realization than deuteron source.



^3He Source at BNL

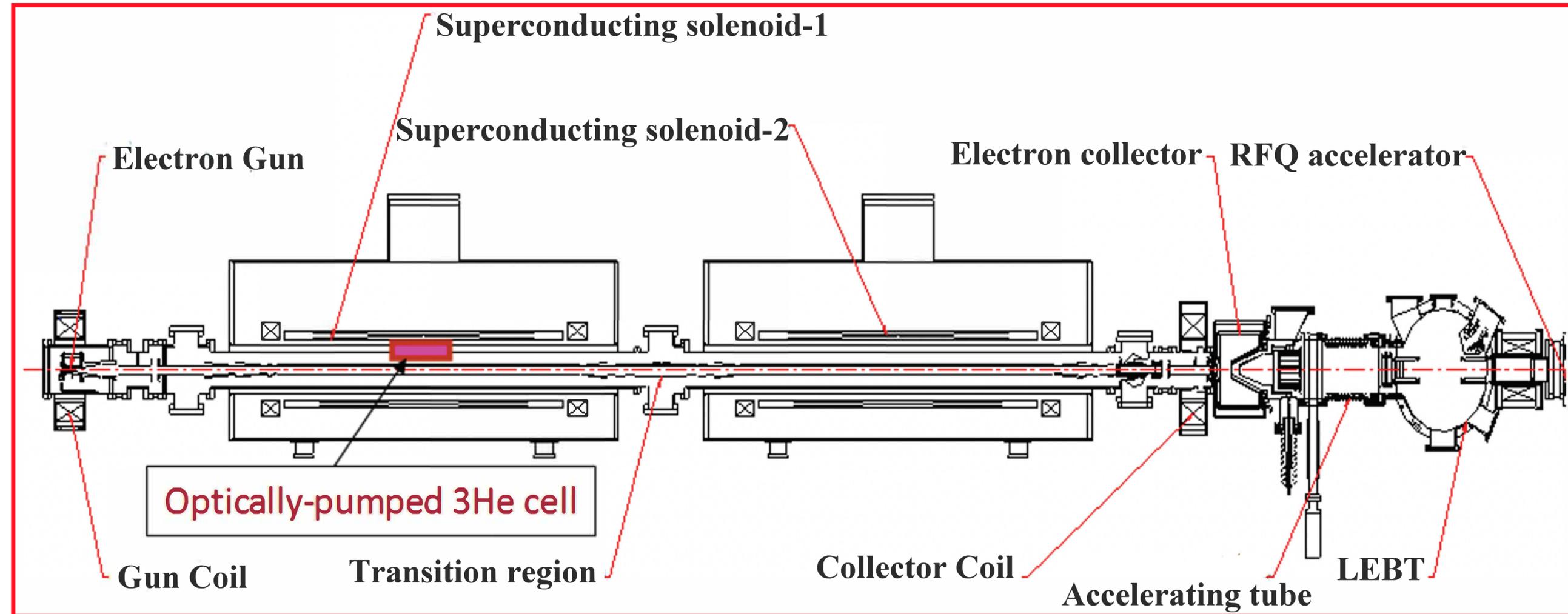
- Originally proposed by A. Zelenski and J. Alessi in ICFA Newsletter in 2003.
- Developed by collaboration between BNL and MIT.
- Identified as High Priority R&D for EIC by EICAC review in 2009, continued by Office of Nuclear Physics community review in 2017, again in 2018 by assessment of US National 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



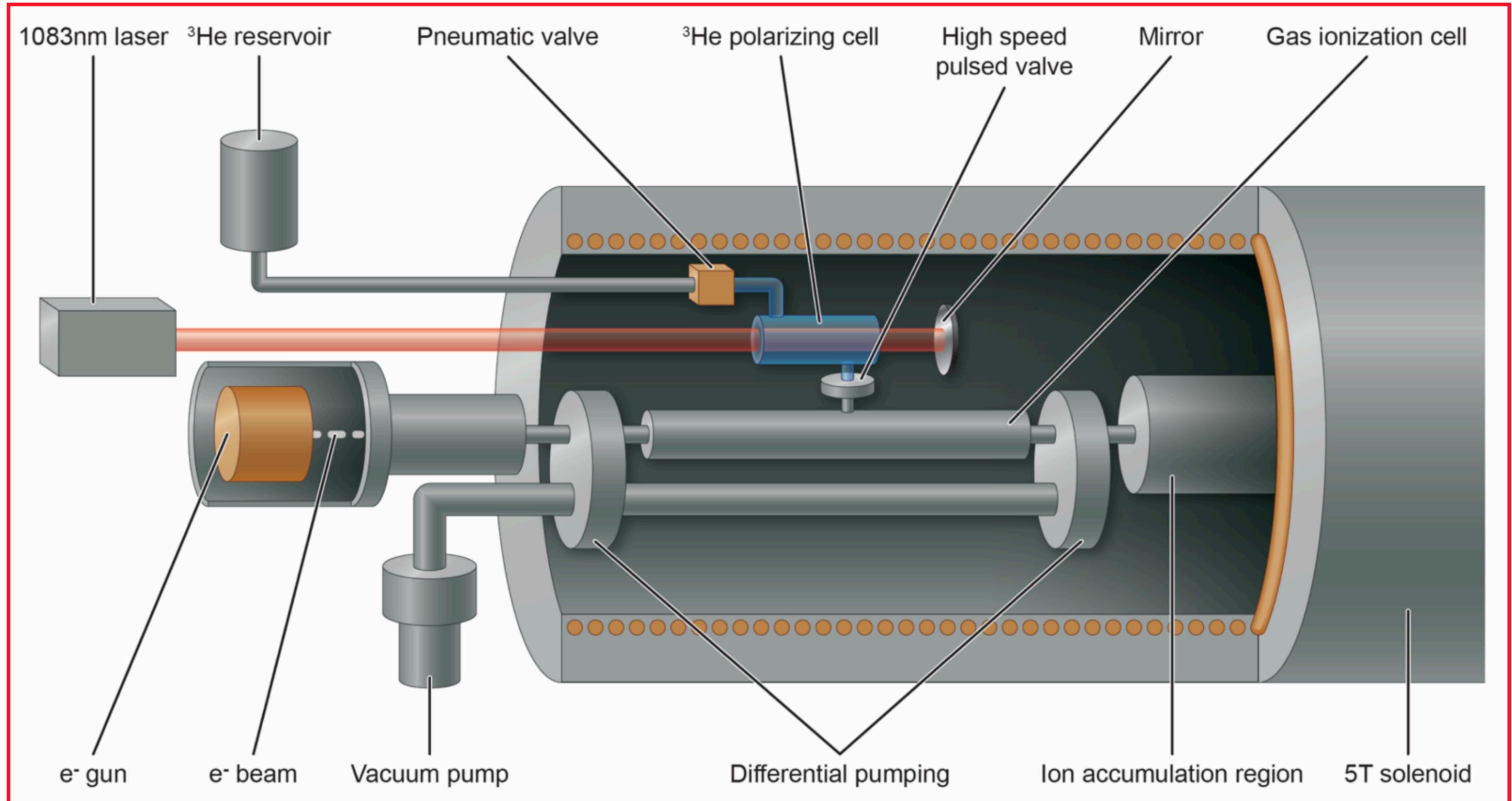
- Second 5T solenoid extends trap length for 40% increase in Au capacity.
- Tested from 2018 - 2022, now installed and currently operating.

3He inside of Extended EBIS



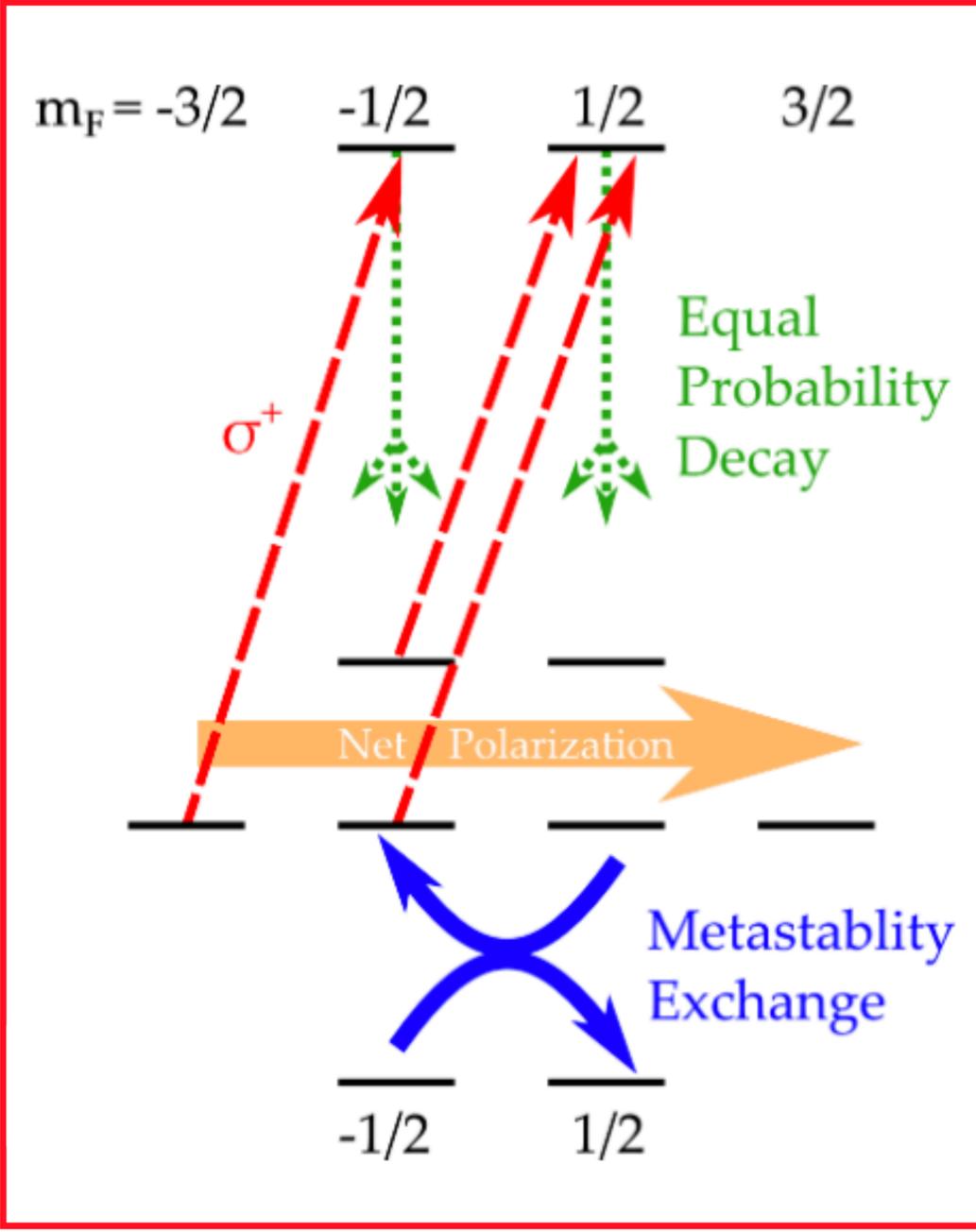
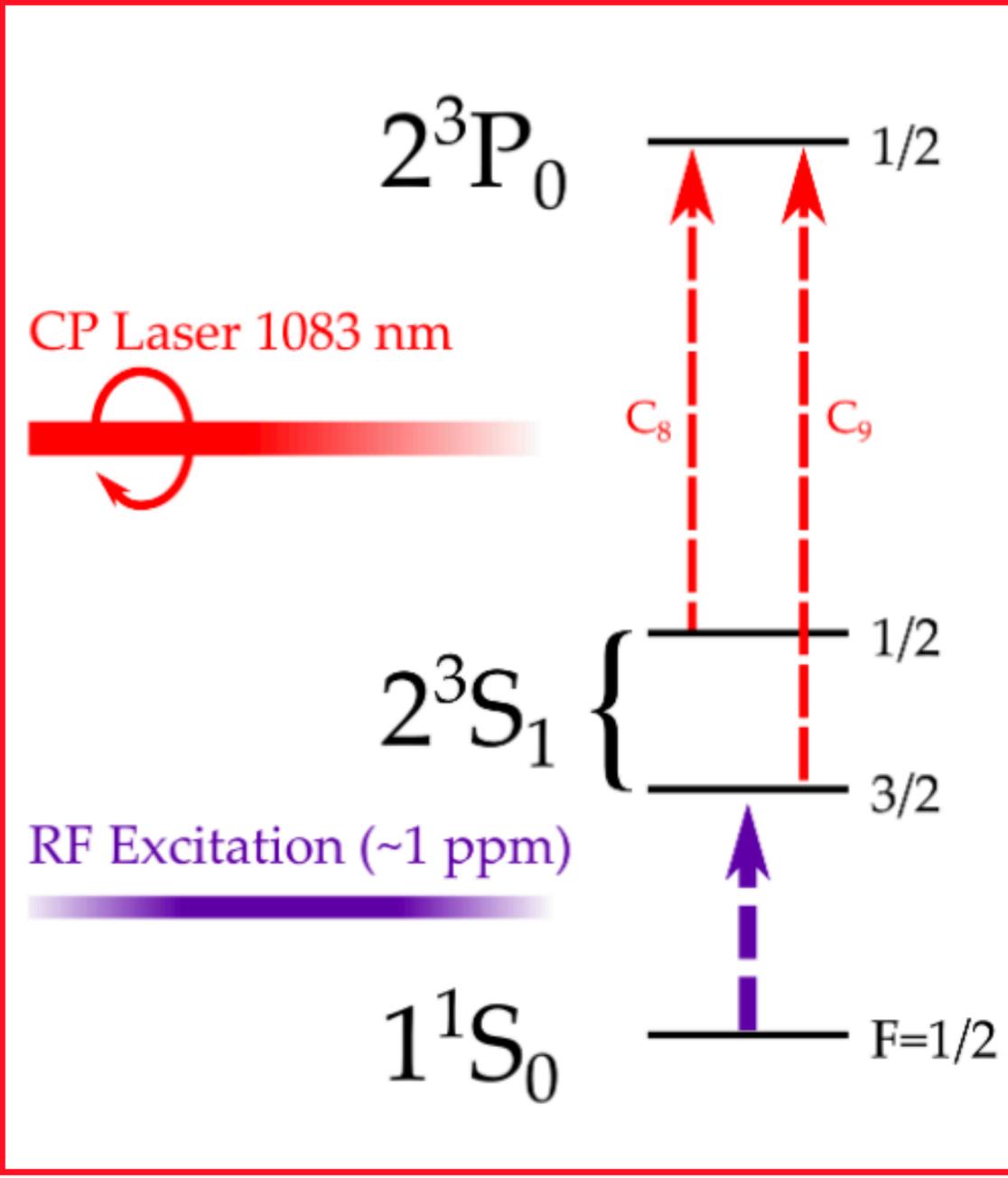
- 3He always part of the plan for tandem EBIS, space in first solenoid for polarization and injection into the drift tube.
- 3He ionized to 3He^+ in first trap, then 3He^{++} in second trap.

Conceptual layout of ^3He in EBIS



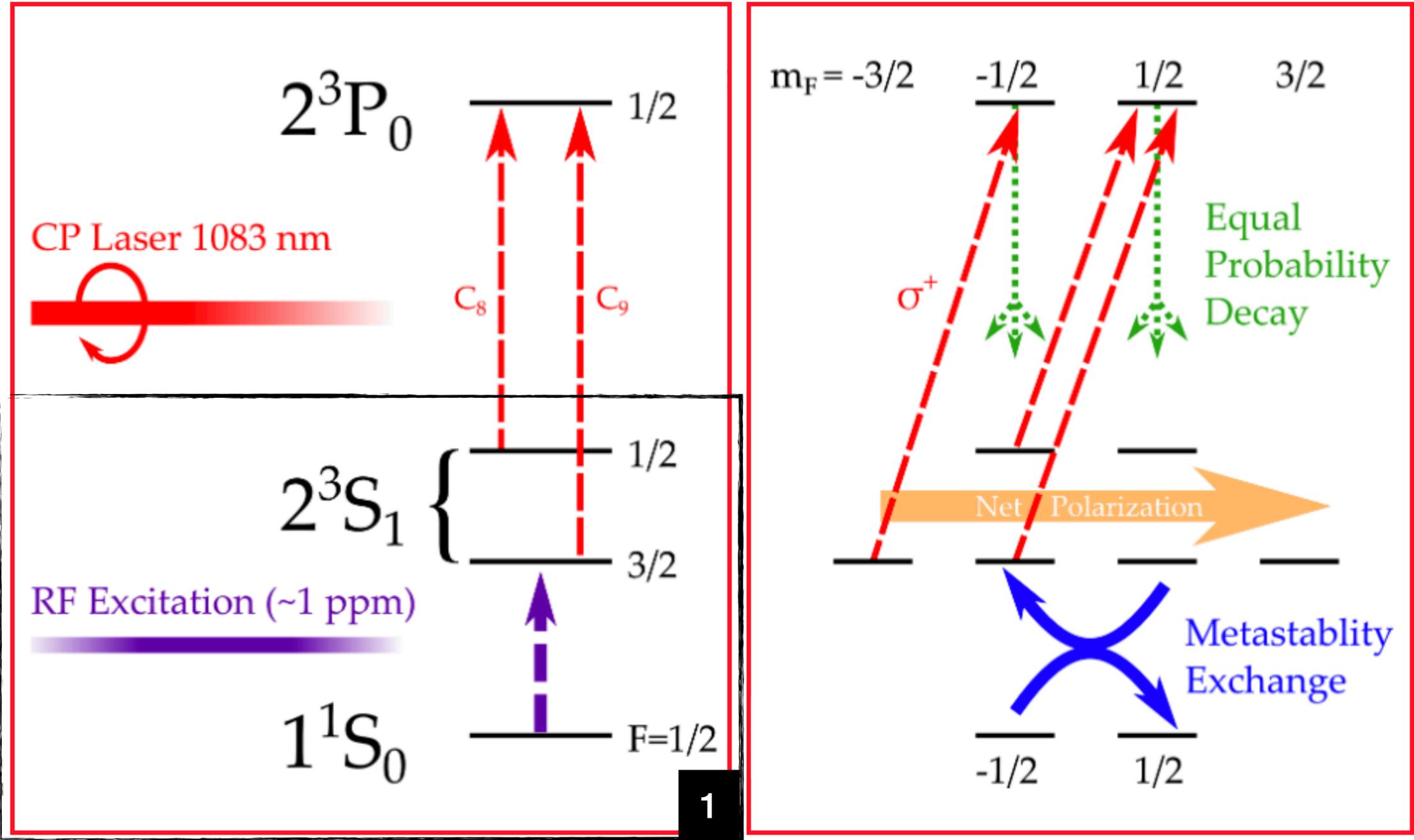
Metastability Exchange Optical Pumping 3He

- Simple low field model for Helium 3 system.
- RF excitation mixes G.S. into higher states, some settle into metastable state for OP.
- CP laser light drives angular momentum into system.
- OP generates a population “dissymmetry” in M.S.
- Net polarization communicated to ground state via M.E. collisions.



Metastability Exchange Optical Pumping 3He

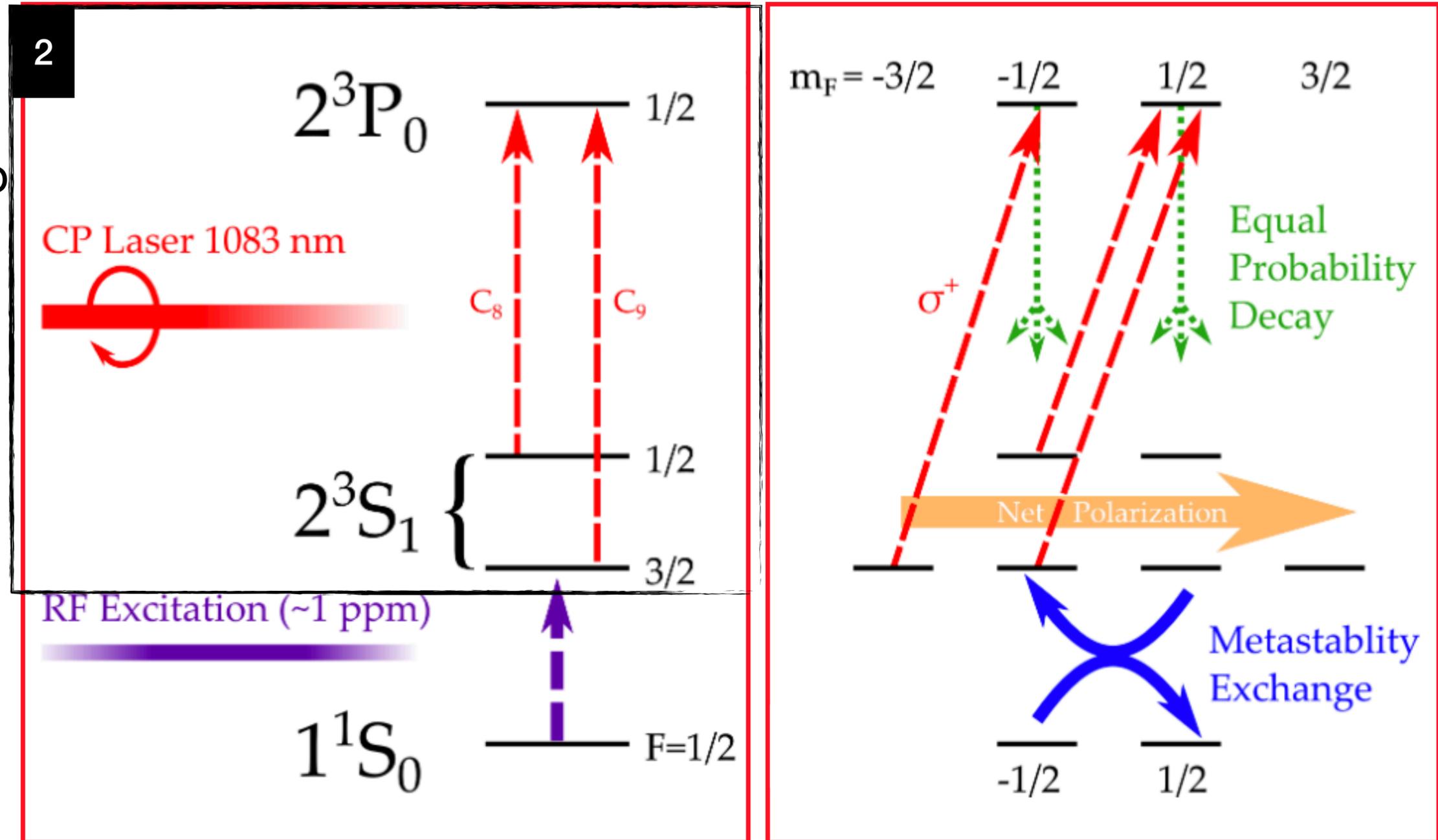
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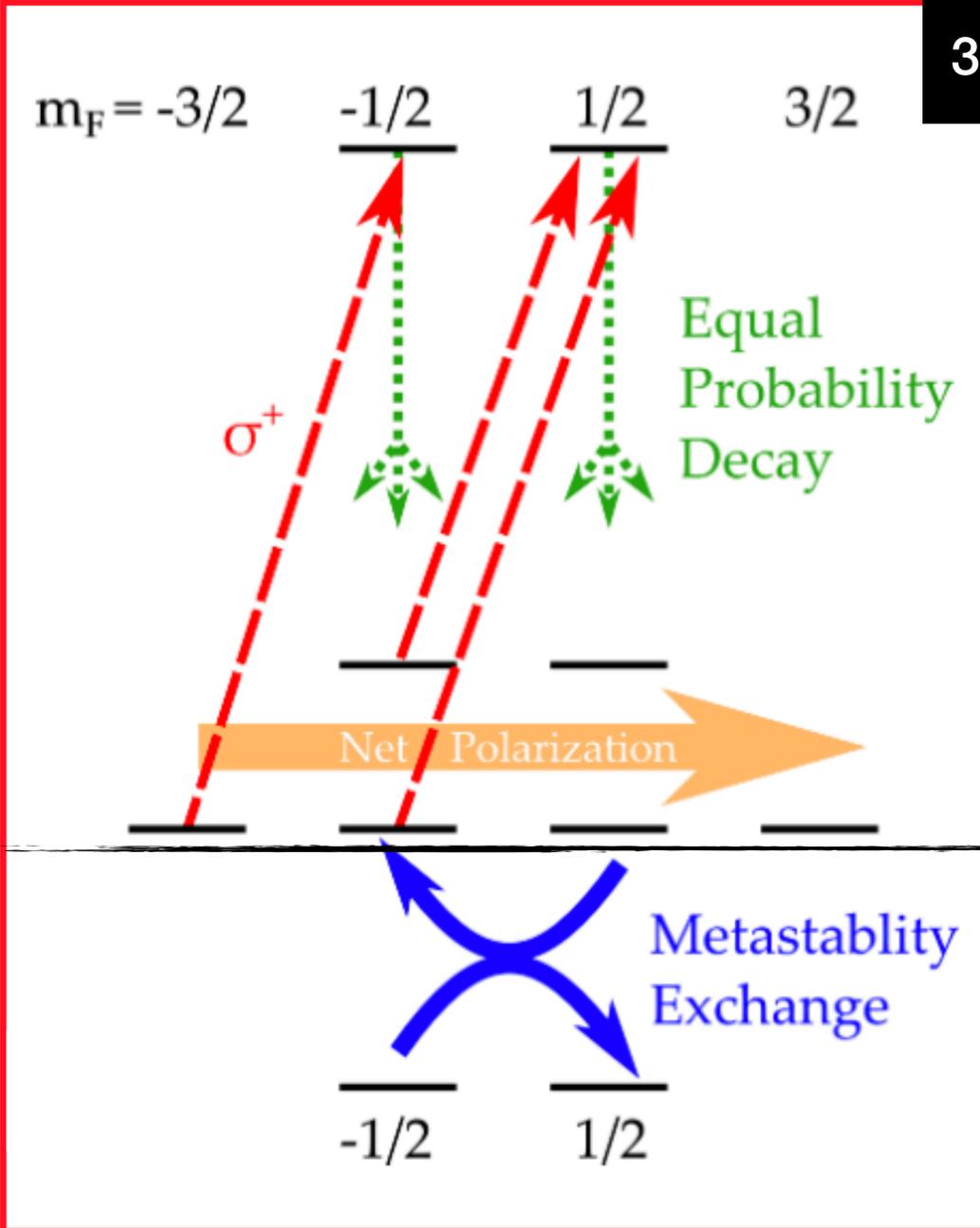
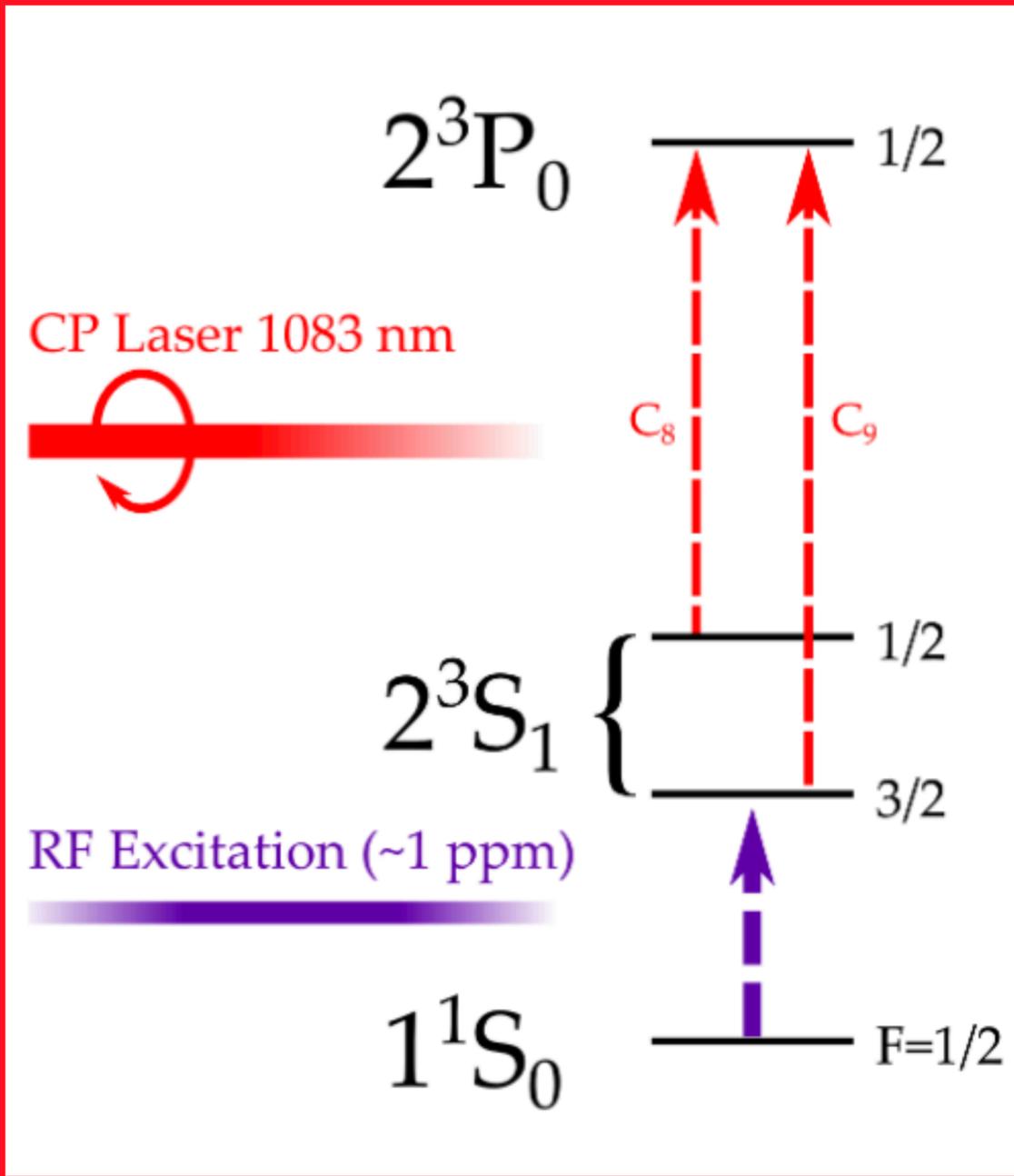
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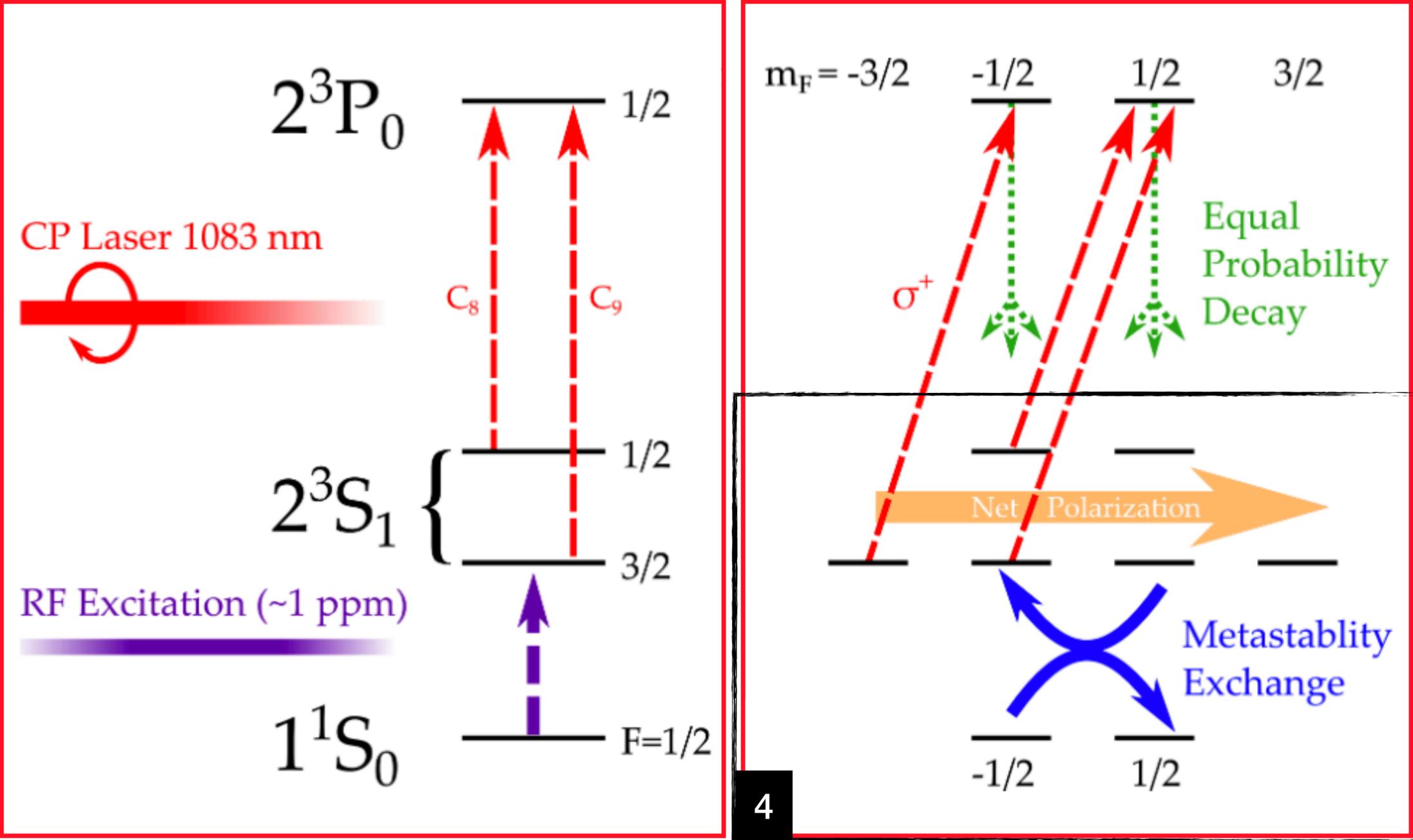
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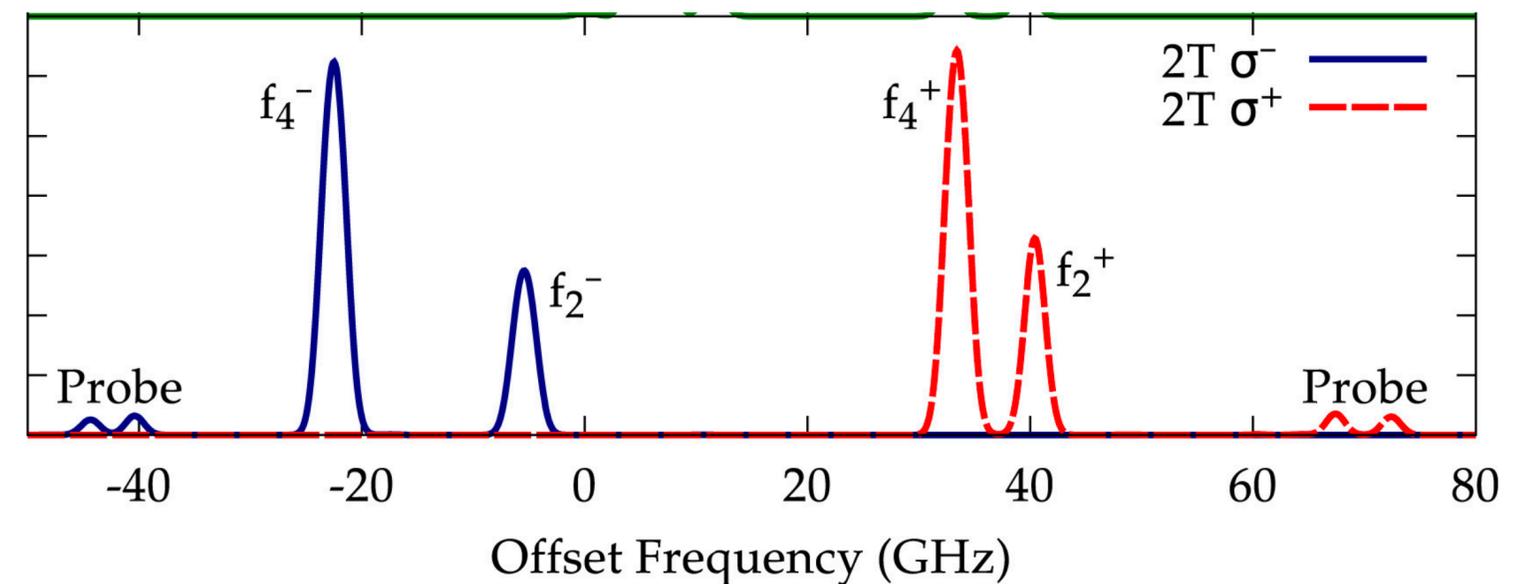
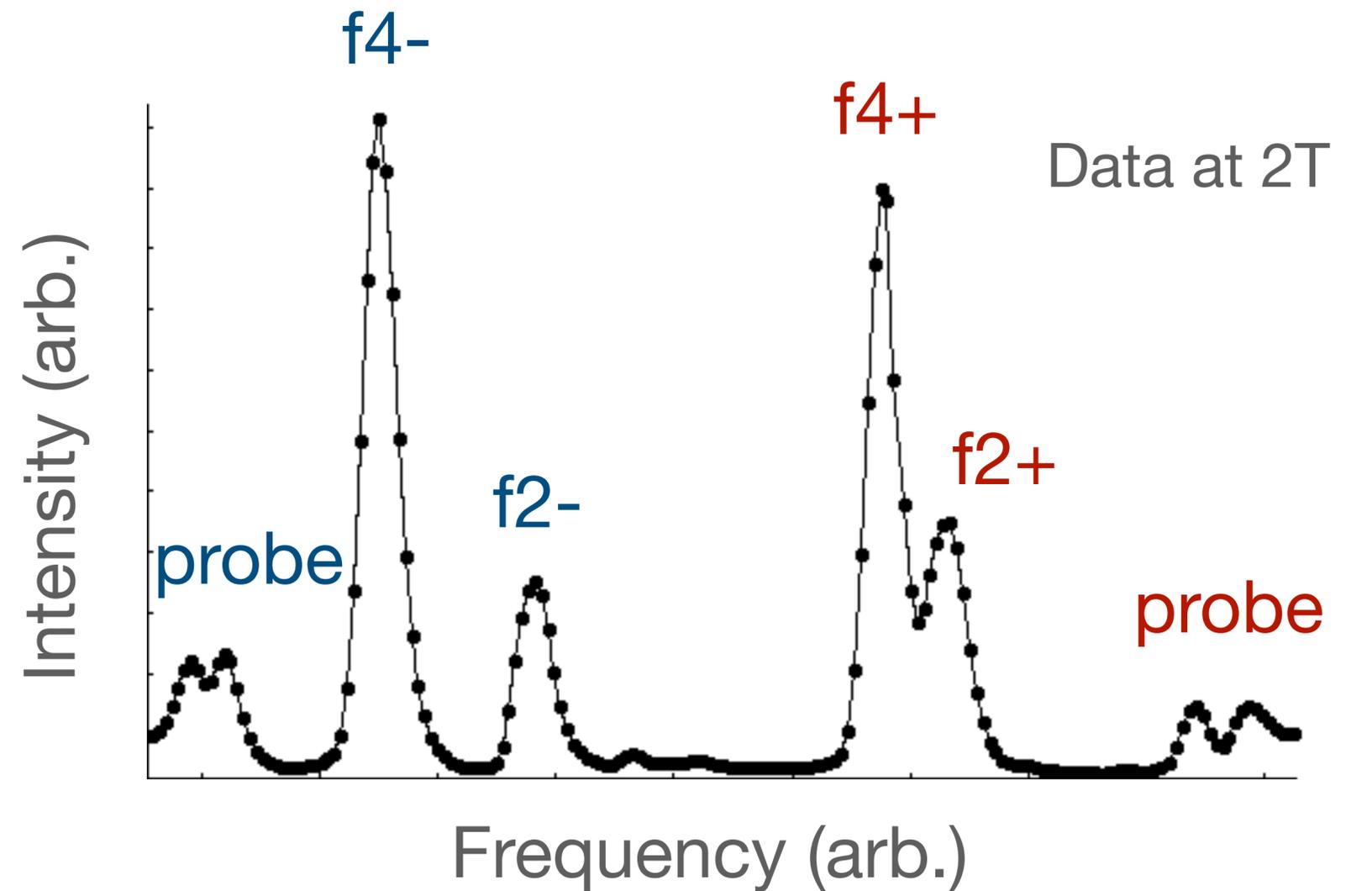
KEY FEATURES: Can be done at high field (5T) and requires no exchange gas!

Optical Polarimetry

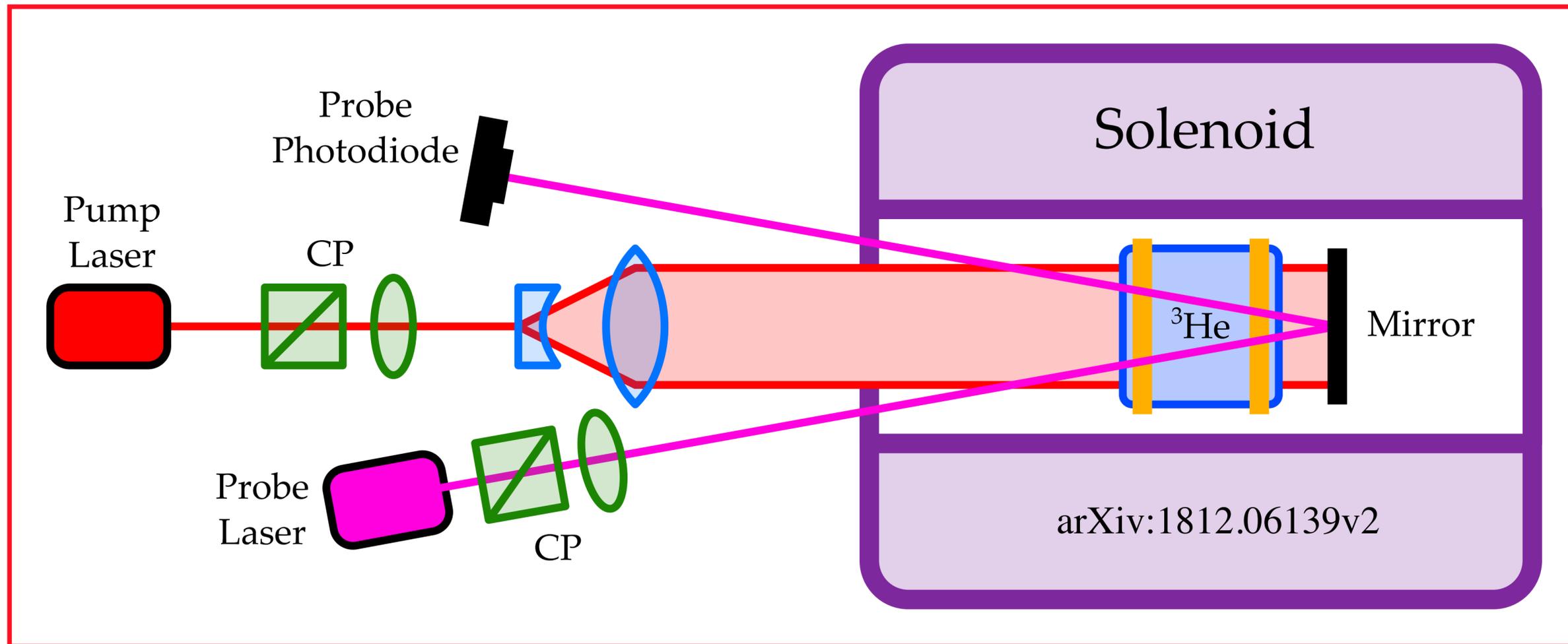
- Right and left handed CP light address 8 transitions each.
- Two probe lines can be used to monitor the population of two particular 2^3s sublevels which can be used to extract the polarization.

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

- 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.



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

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

A. Zelenski ^a, G. Atoian ^a, E. Beebe ^a, S. Ikeda ^a, T. Kaneshue ^a, S. Kondrashev ^a, J. Maxwell ^{b,c}, R. Milner ^b, M. Musgrave ^b,
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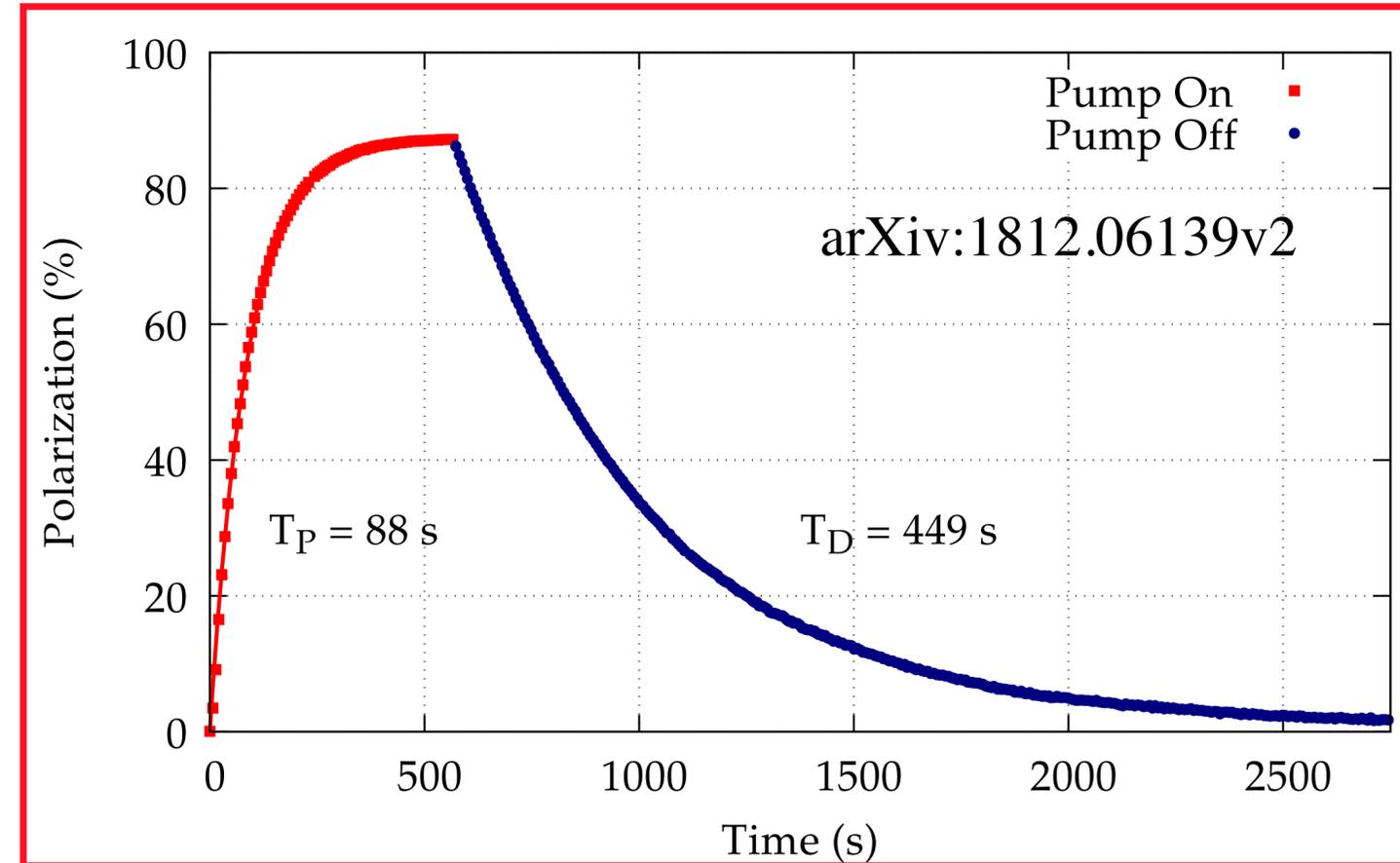
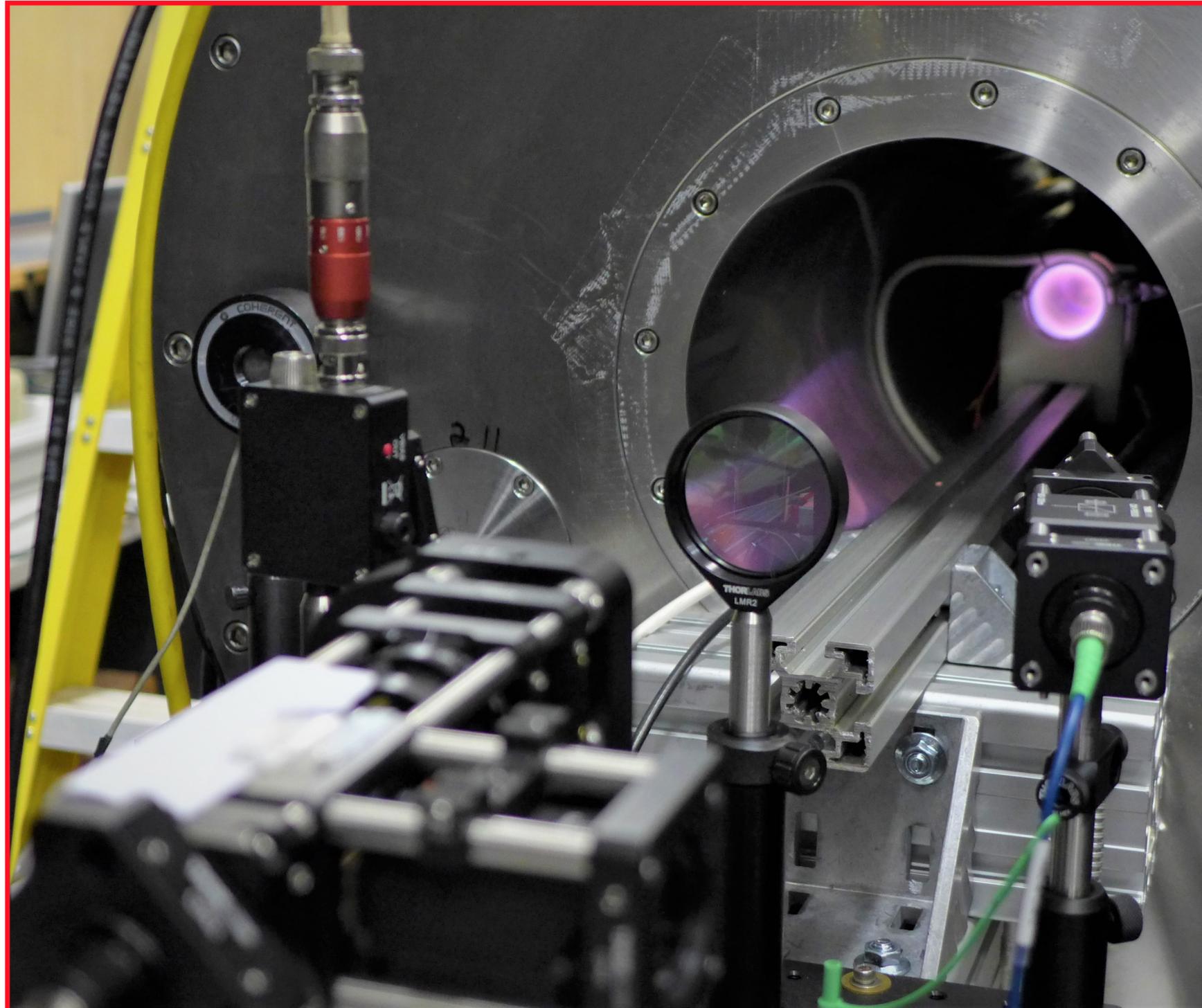
^a*Brookhaven National Laboratory, Upton, NY 11973, USA*

^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

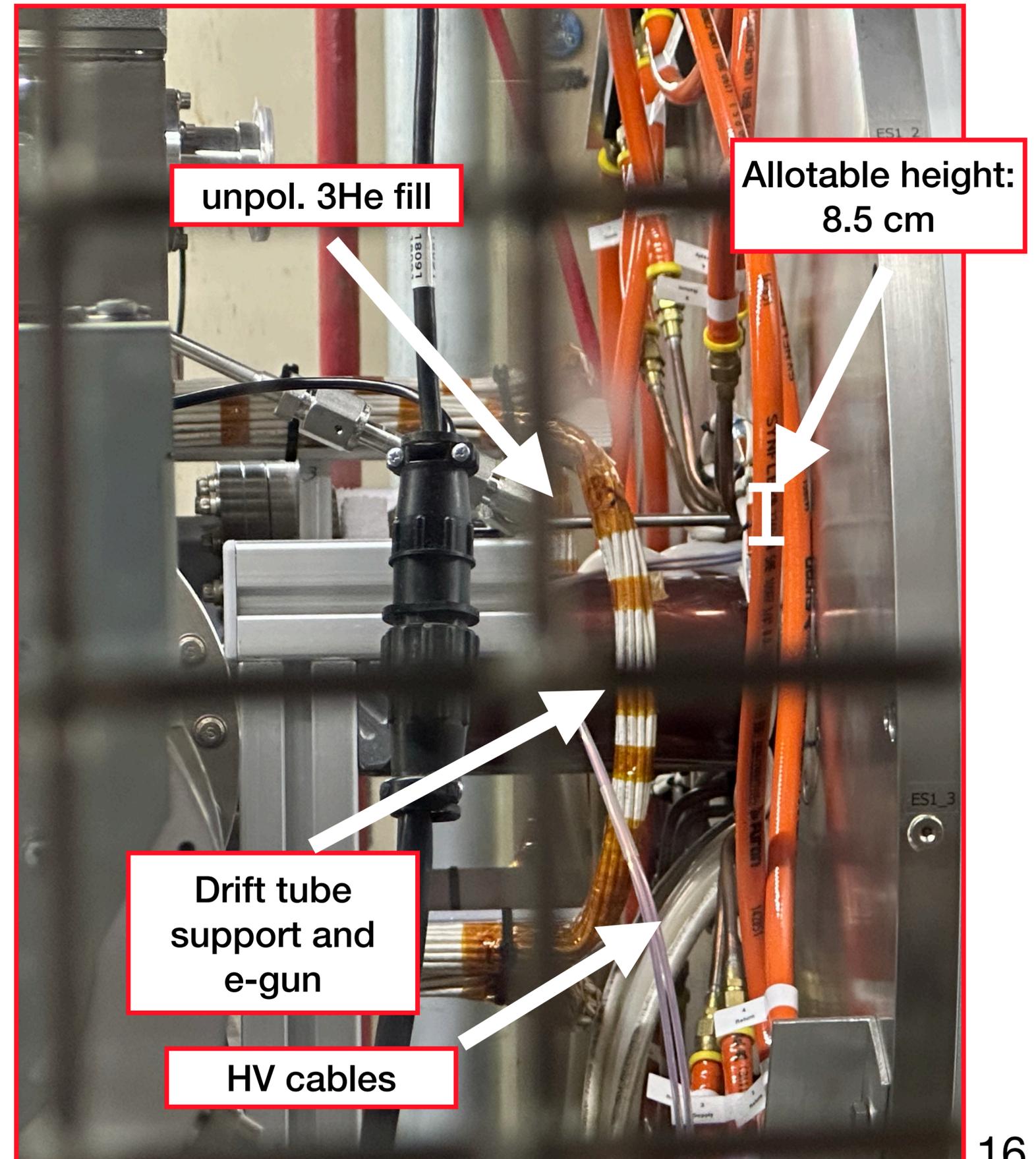
Previous BNL MEOP results



- 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.

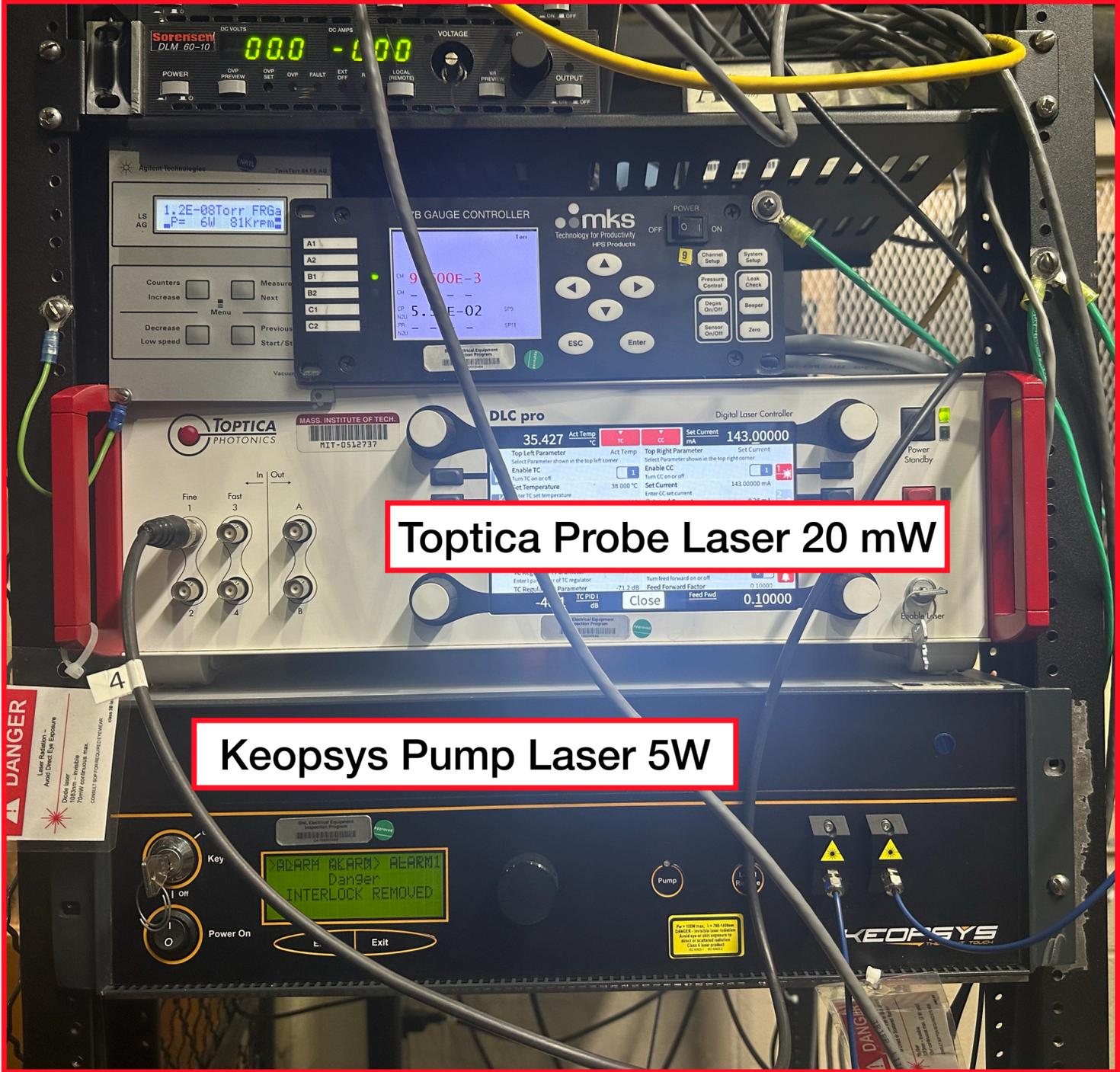
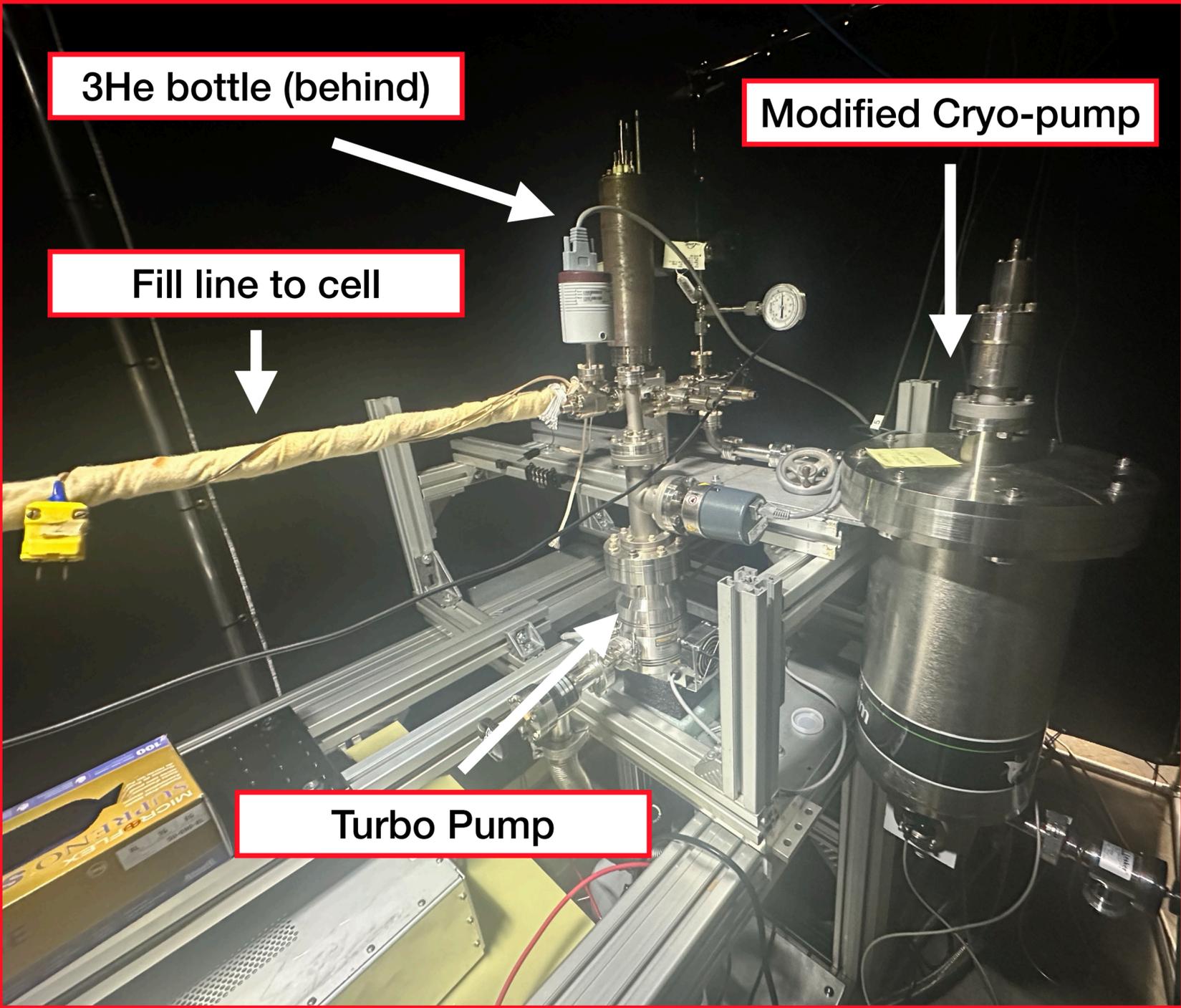


Resuming ^3He Studies at BNL

- 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 18

Gas purification

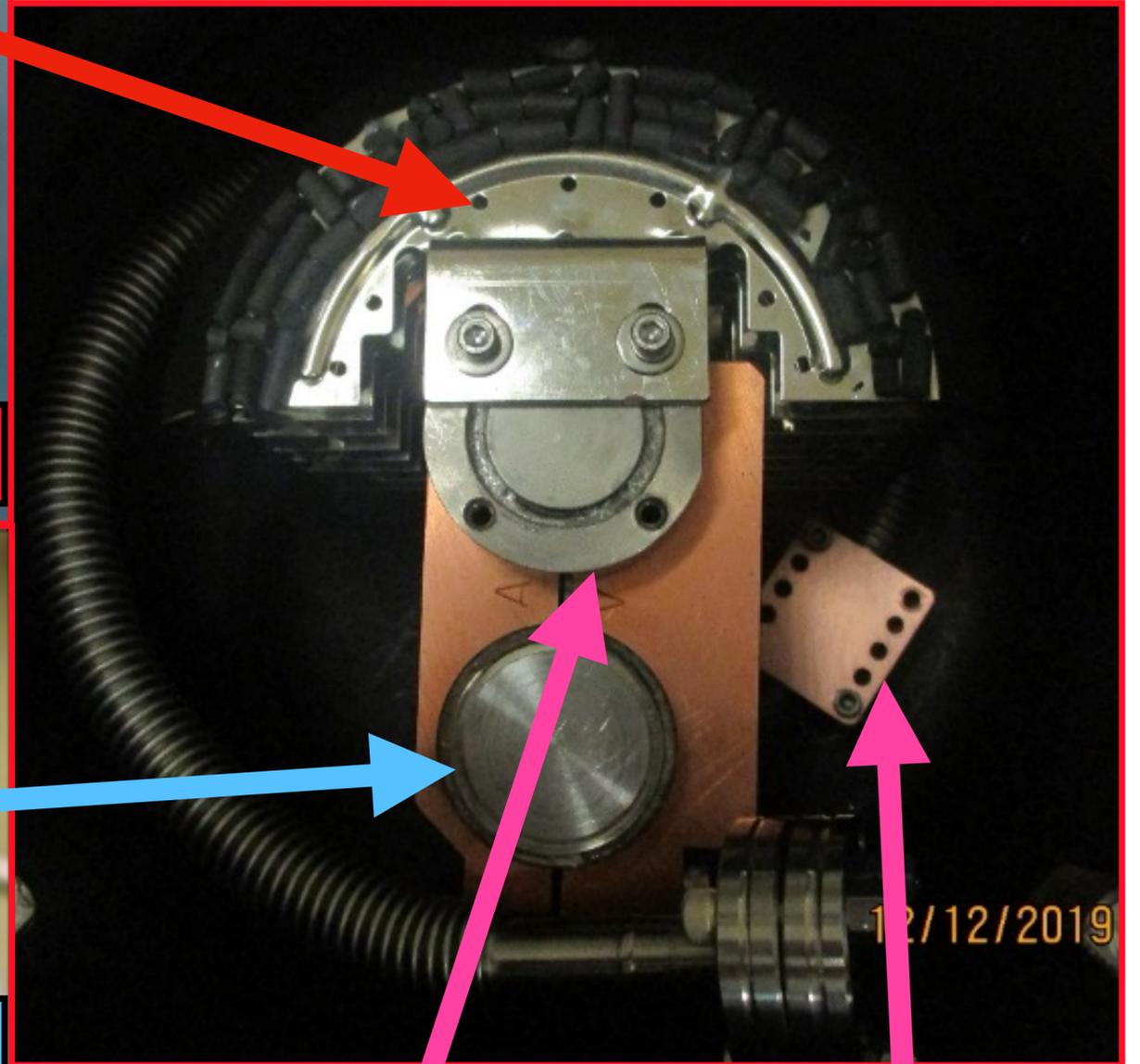
- Previous studies have found that purity of gas mixture impacts final maximum polarization and relaxation.
- Monitor purity of gas mixture by spectroscopic measurement of plasma.
- Modified cryo-pump, designed by Anatoli, pumps gasses other than ^3He to below 10^{-7} torr.
- ^3He pressure controlled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



Modified baffle w/ charcoal.



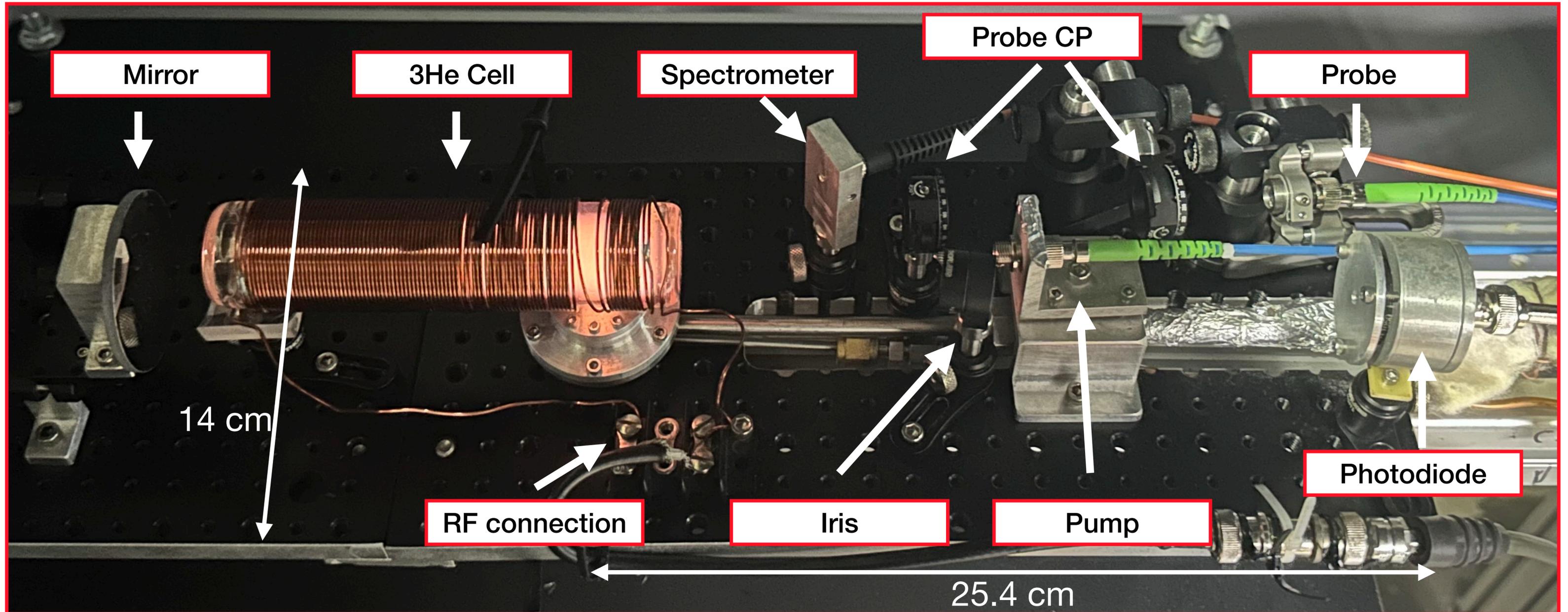
Cryo-vessel with charcoal.



Cryo-pump second stage
cold head 10k

Cryo-pump first stage
cold head 55k

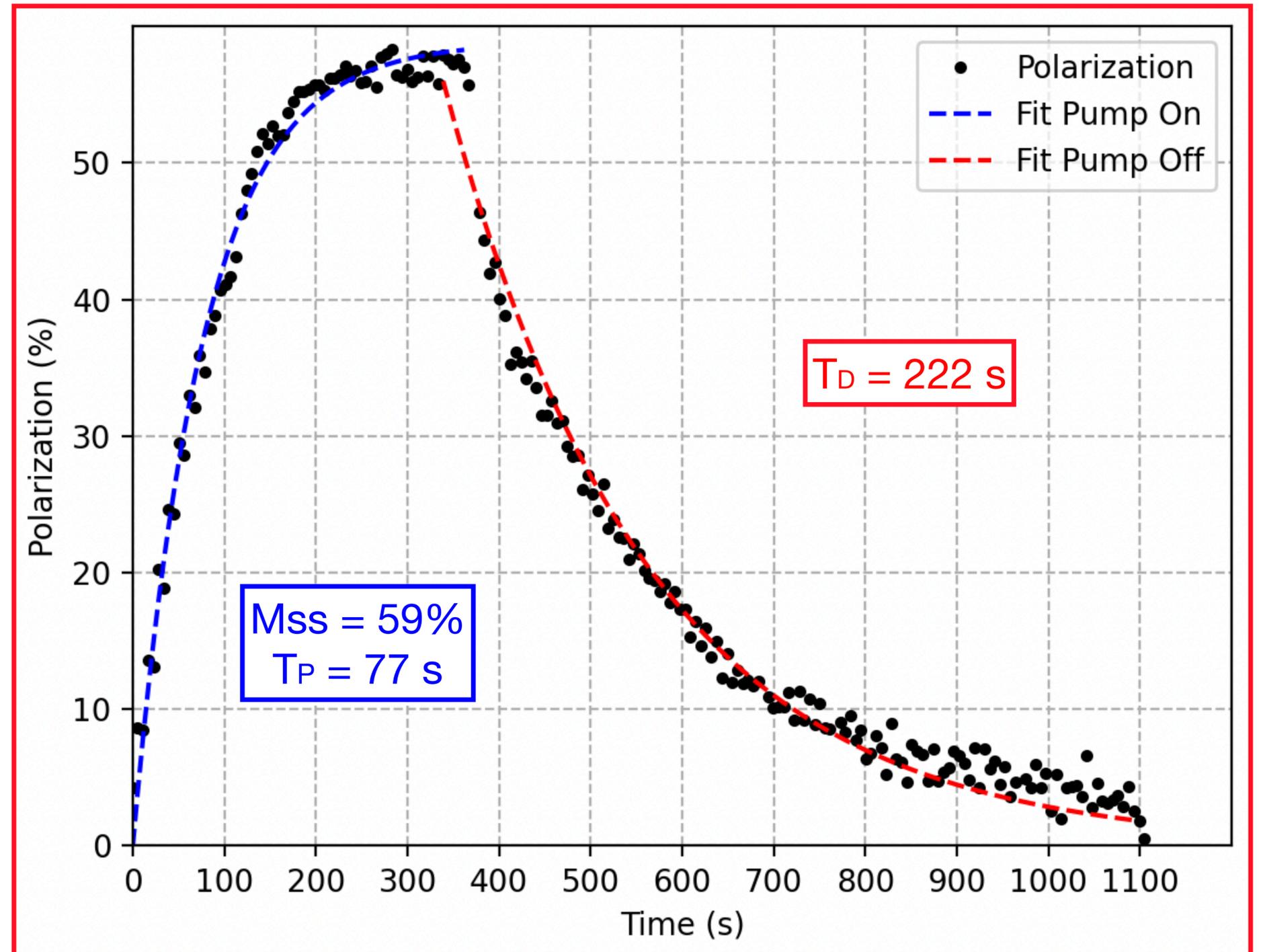
Reducing the Optics Footprint



First draft of a compact polarization setup.

First polarization with refillable cell in 2024

- 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.

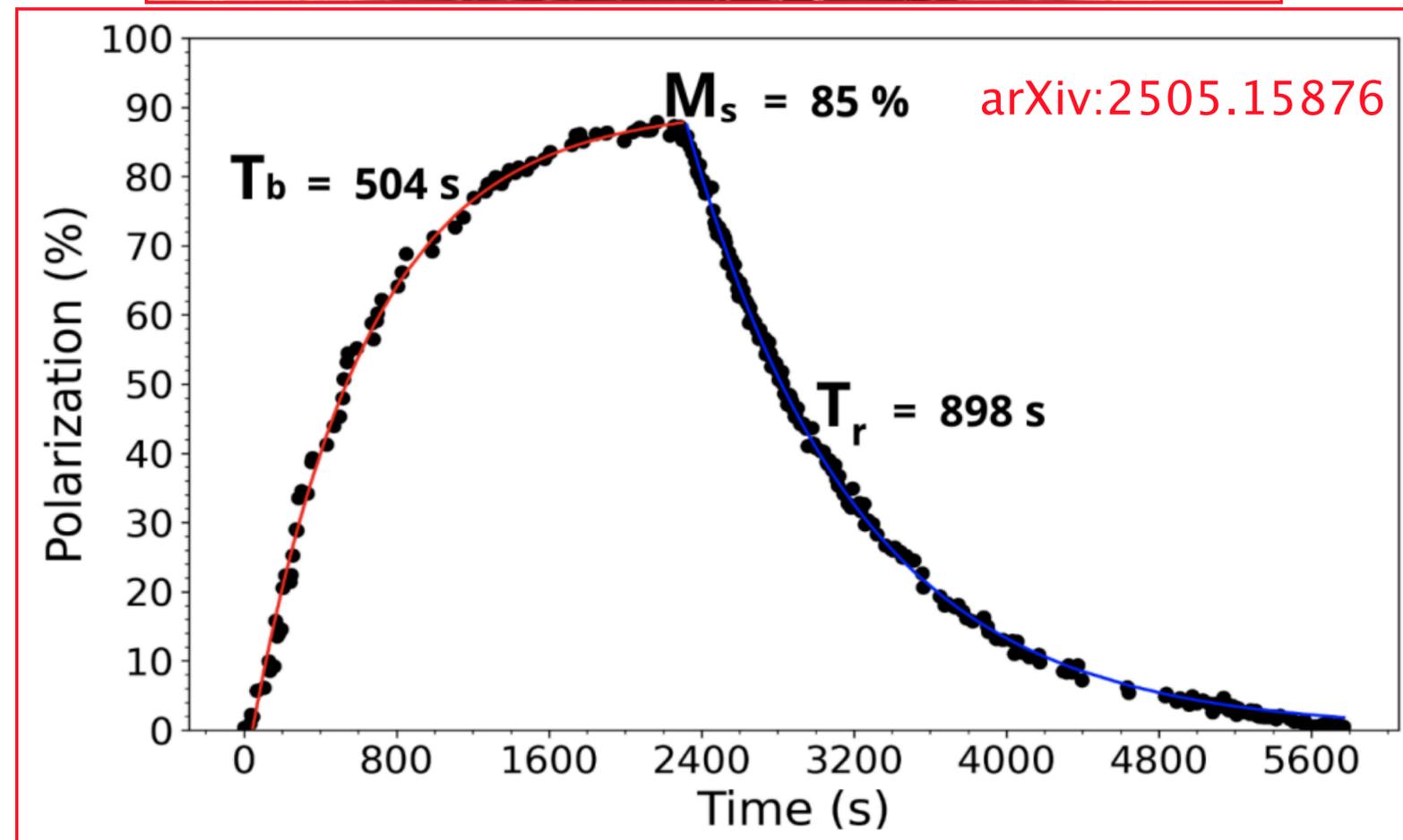


Challenges in 2025

- Lost our primary pumping laser on Jan 1, due to a failure of the “human interface” board (IHM) which controls parameter tuning.
- RMA was returned to us in April and survived until July when we saw another failure of the IHM while attempting first sealed cell testing.
- Reissued an RMA and Keopsys identified a short on the main control board responsible for frying the IHM both times, likely during power switch overs at BNL.
- Received the repaired laser at beginning of December 2025.
- Ordered a new, backup laser without IHM and with direct USB control of parameters through full digital interface. Will NOT happen again during data taking at Absolute polarimeter.
- Sourced two competitors (Toptica France, Precislasers) and spoke with two other companies at APS on Tuesday this week: NXT (Hamamatsu) and Vexum.
- Several weeks at the end of the year without magnet due to planned maintenance work that was never completed on the roof of 930B -> next week.

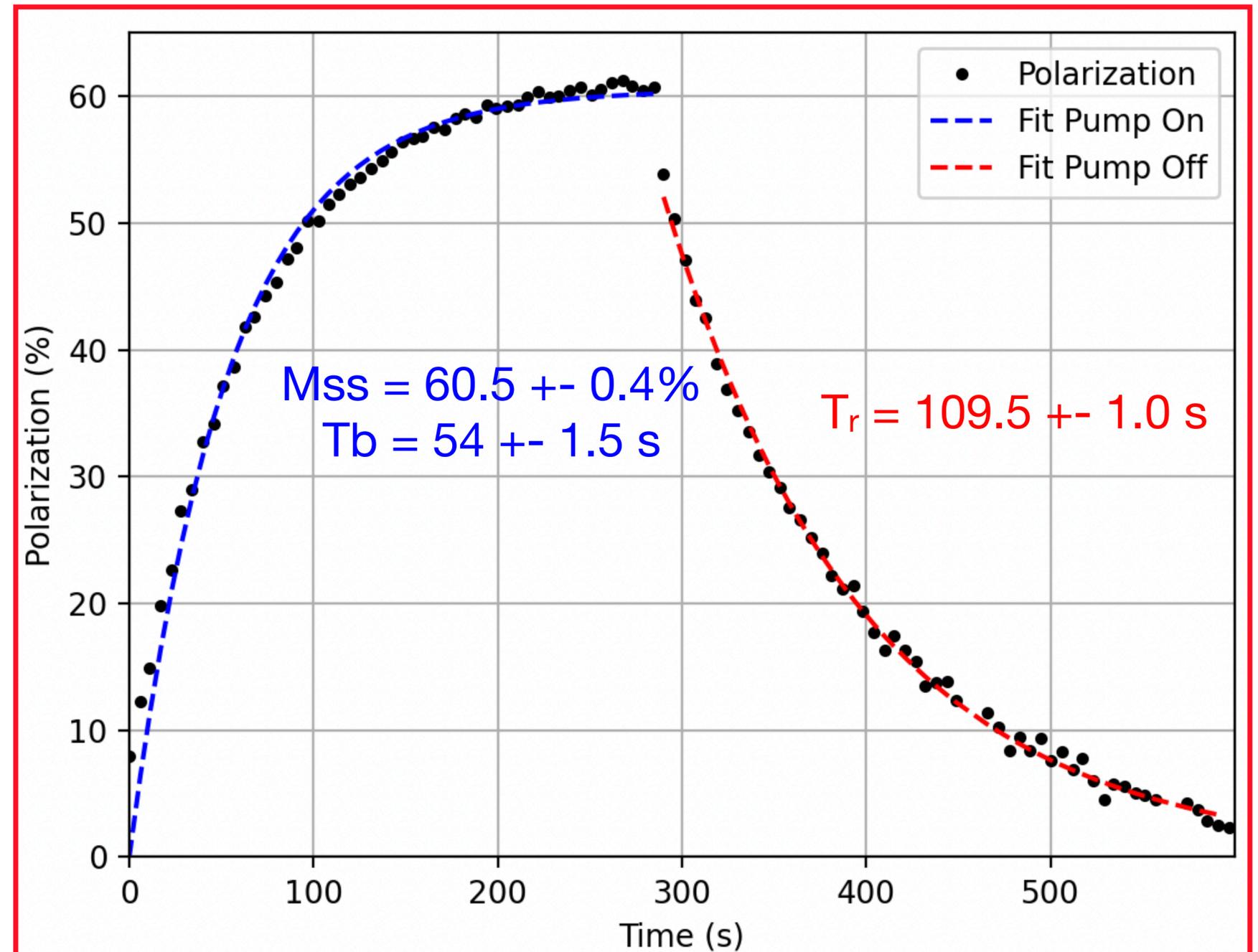
Cross Check with JLab Cell

- Sister group at JLab recently prepared a 1mbar cell and published ($>80\%$) polarizations (P. Pandey et al. 2025).
- Similar dimensions as final EBIS cell give us the opportunity to cross check against a sample of known purity.
- After laser repairs last year, used sealed cell to compare with refillable cell and refine technique.
- New results are encouraging for upcoming double-stem cell testing.



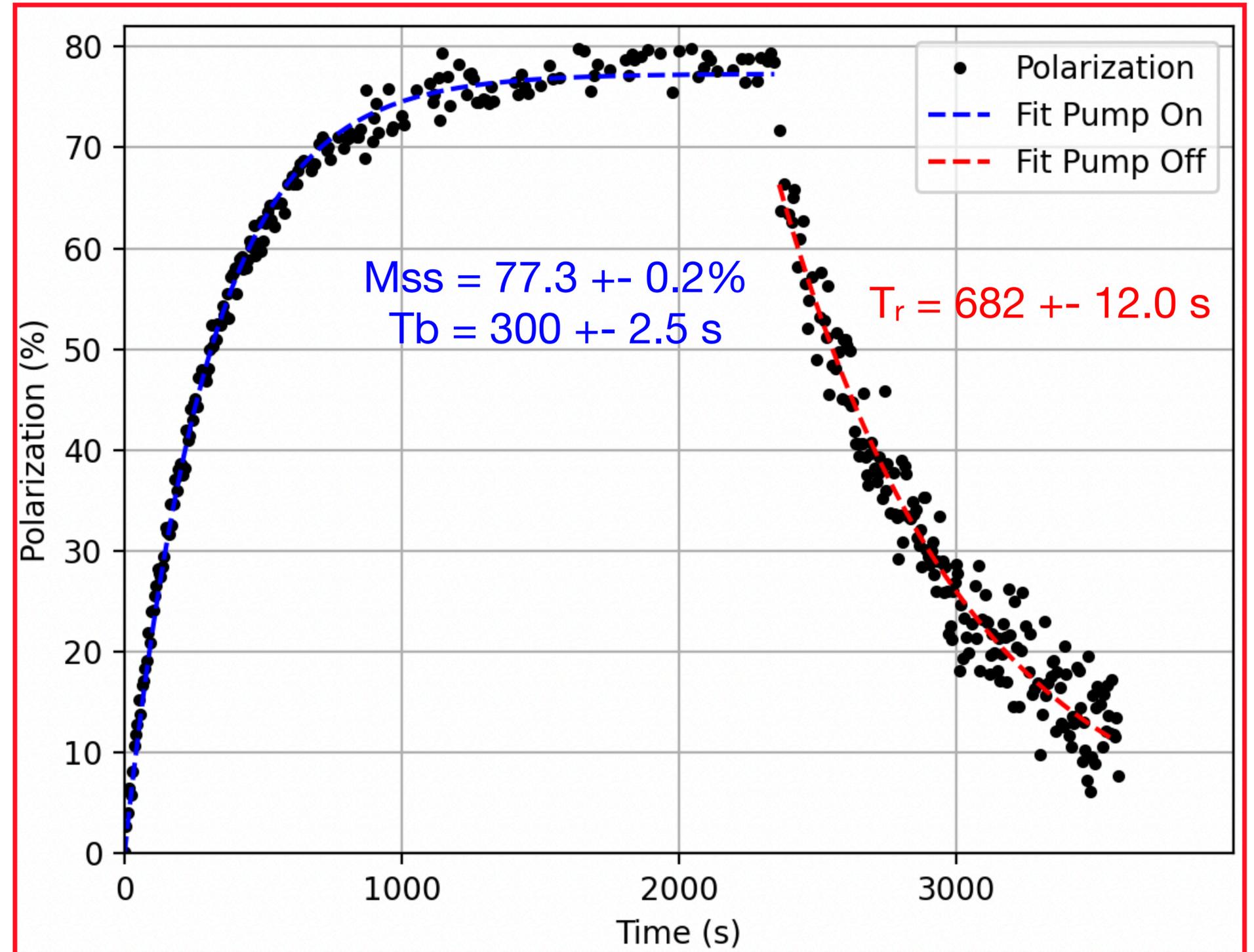
2024 Parameters on sealed cell

- Data with same operational parameters we used for the 2024 refillable cell, taken on the JLab sealed cell.
- Similar steady state polarizations, build times, and relaxation times.
- Pressure is a bit lower than refillable cell.
- Key difference is the RF plasma tune is different for this cell -> same power from signal generator may have coupled differently into plasma.
- Also, lower probe intensity at cell face.
- Brighter plasma at same power, faster relaxation and faster build due to the metastability exchange rate.



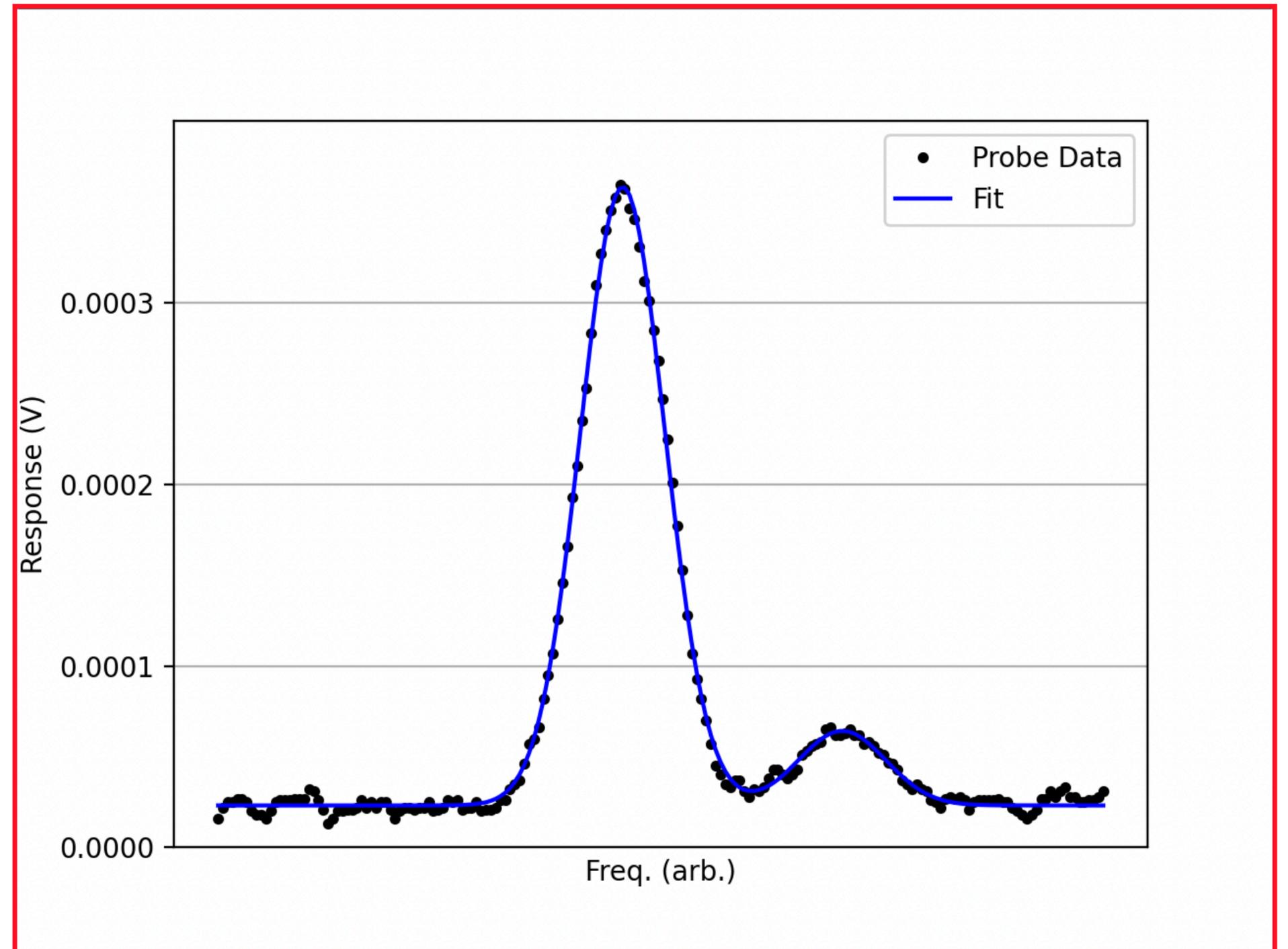
New tricks with sealed cell

- Data from last week with sealed cell from JLAB.
- Much closer to 80% polarization.
- New technique for RF tuning and reduced probe power improves polarization at cost of SNR.
- Improving fitting to reduce uncertainty, particularly at steady state.
- Gas optical spectra same as the refillable cell after 2024 bake.
- Same operational parameters give 60% on both cells -> optimistic we will see improvements in upcoming tests of refillable cell.

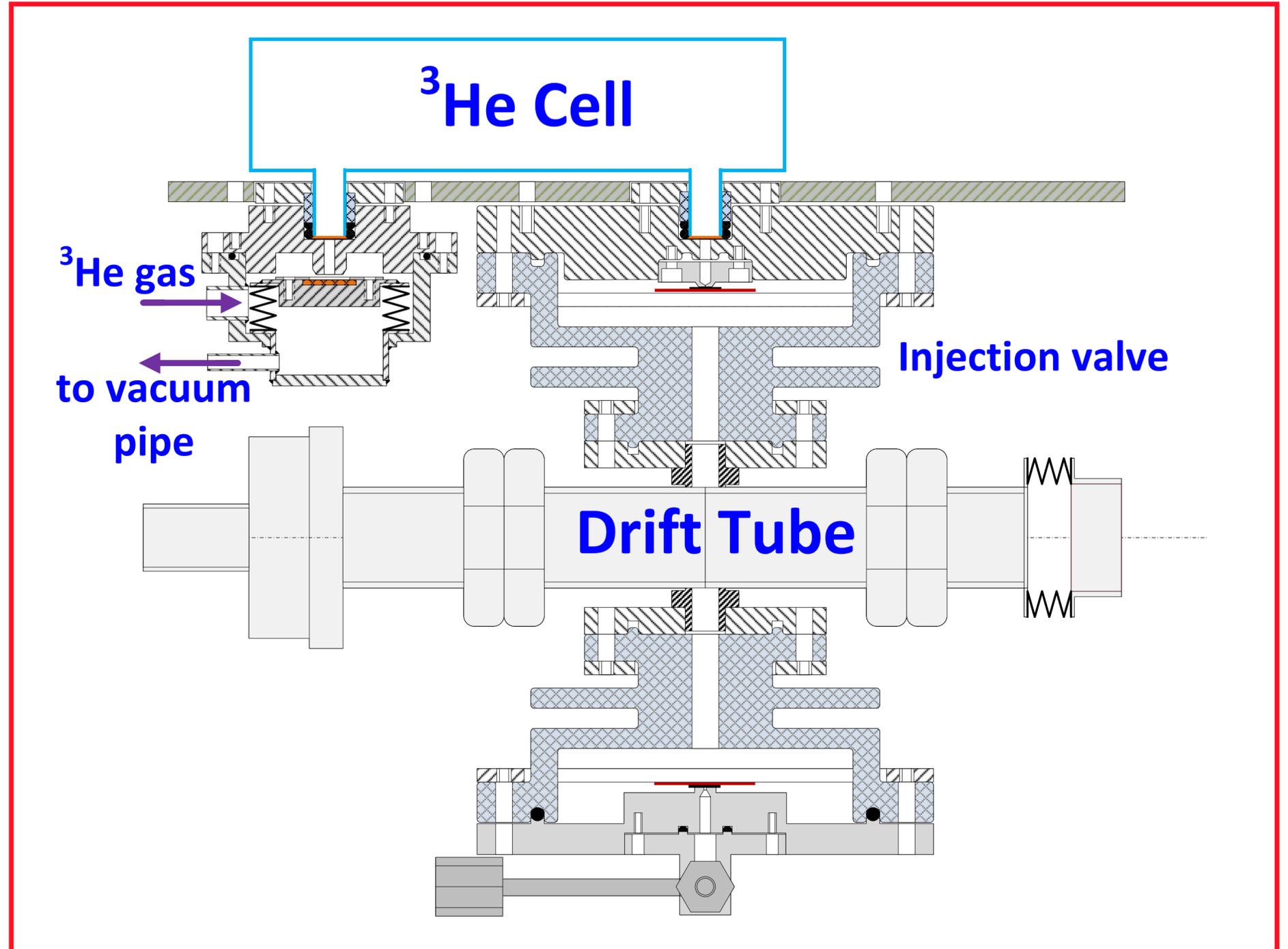
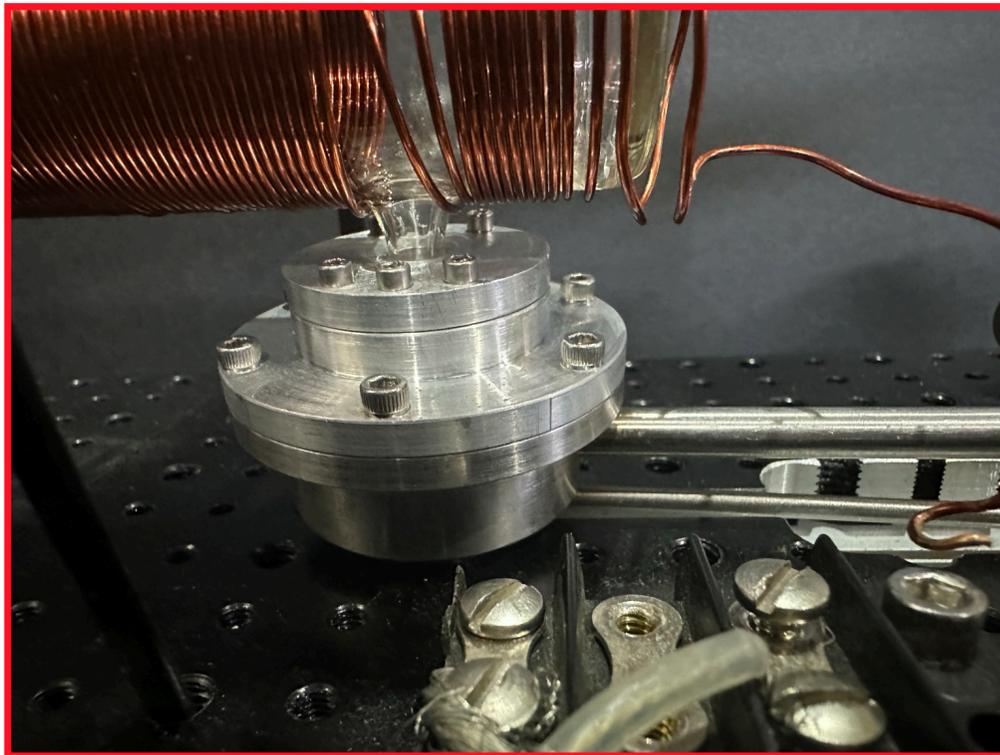


Fitting at high polarizations

- As we get above 70% polarizations, the second probe peak becomes quite small.
- Often we will mis-fit the ratio above 70% -> increases uncertainty in measurement.
- Working to improve SNR, but we're near the limit with the lock-in and spatial constraints in EBIS.
- Working with Andrei Sukhanov to improve fitting second peak based on location of first peak.



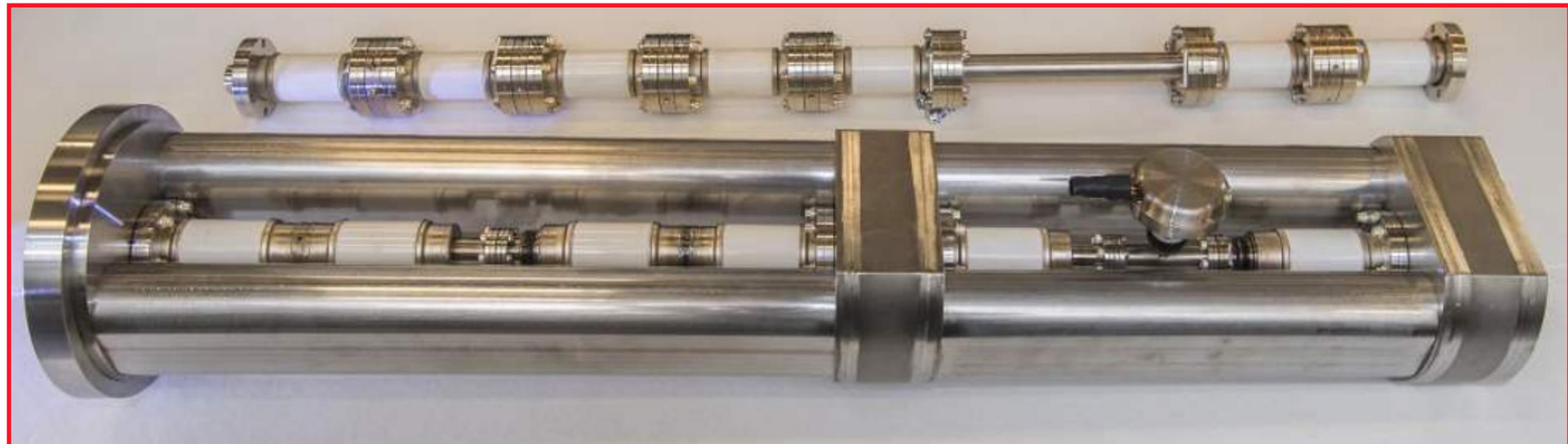
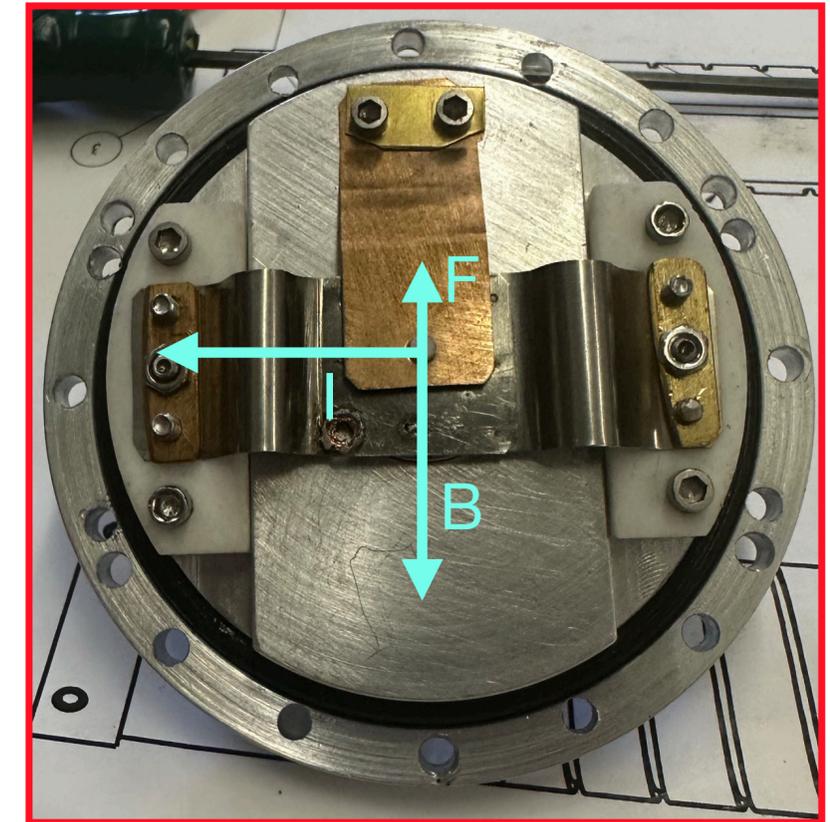
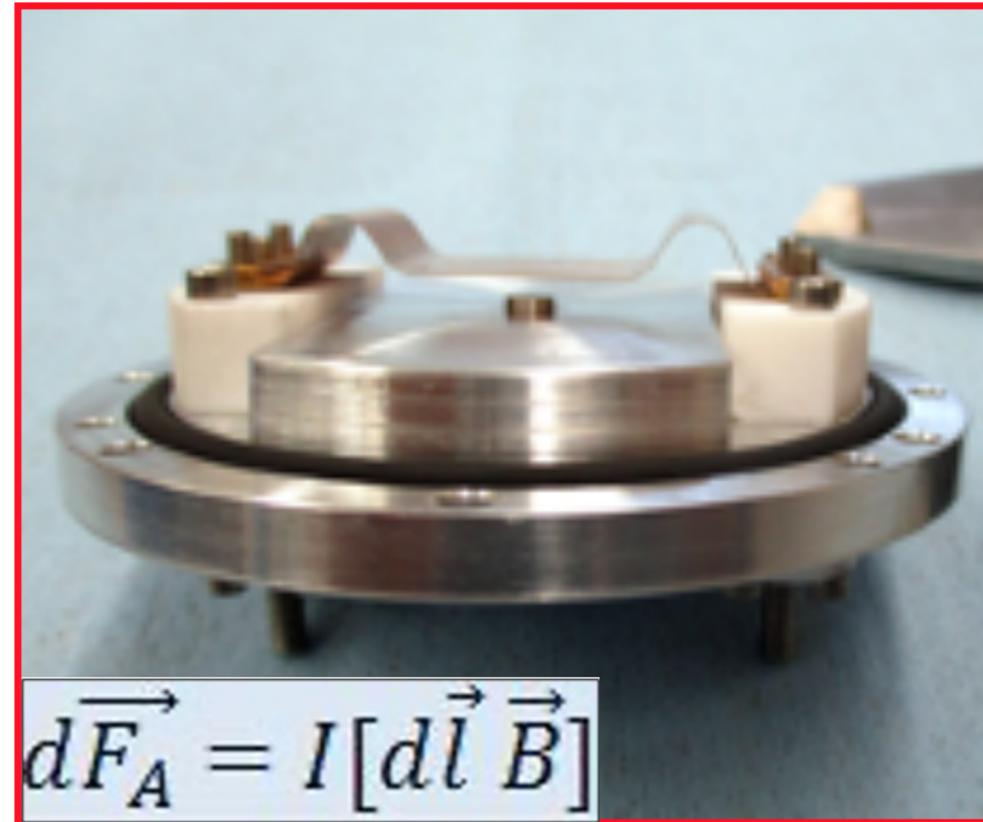
Filling and Injection in EBIS



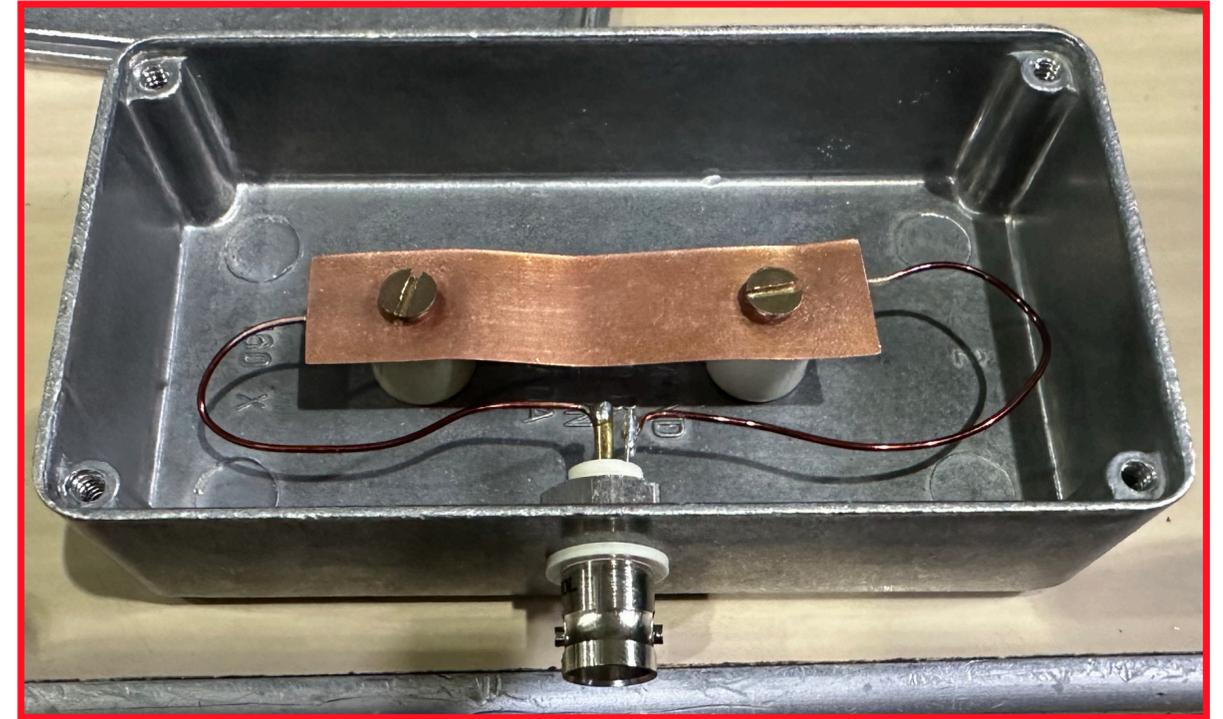
- Currently using the pneumatic valve to fill and seal the cell.
- A valve to inject into drift tubes has been designed and implemented for unpolarized ^3He .
- Injection valve manufactured last week.

Injection into EBIS Drift Tube

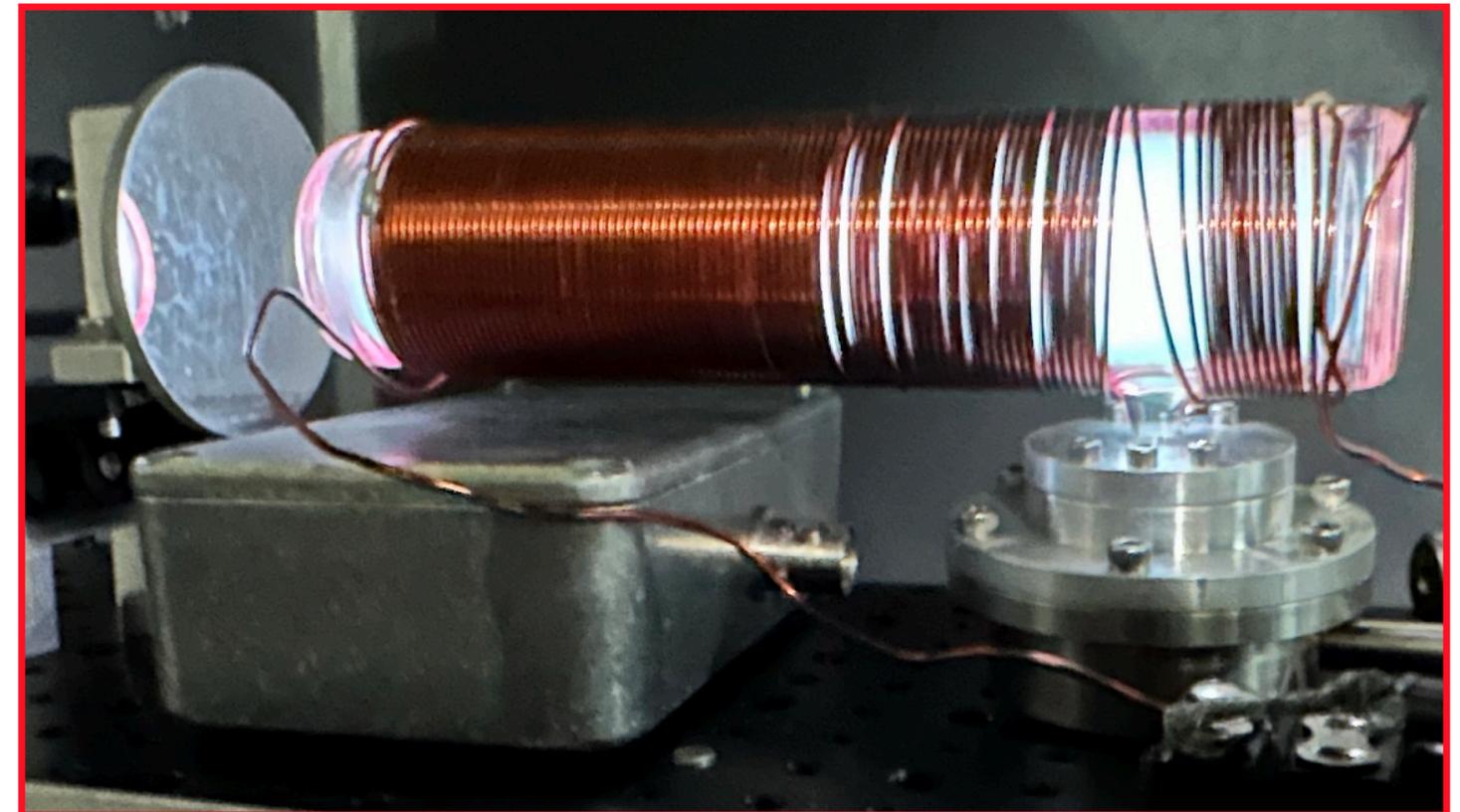
- Injection port is sealed by force from a spring.
- Lorentz force in magnetic field opens the valve when a large current is passed through the wire.
- Tested and currently used for unpolarized ^3He .



Mock Pulse Valve

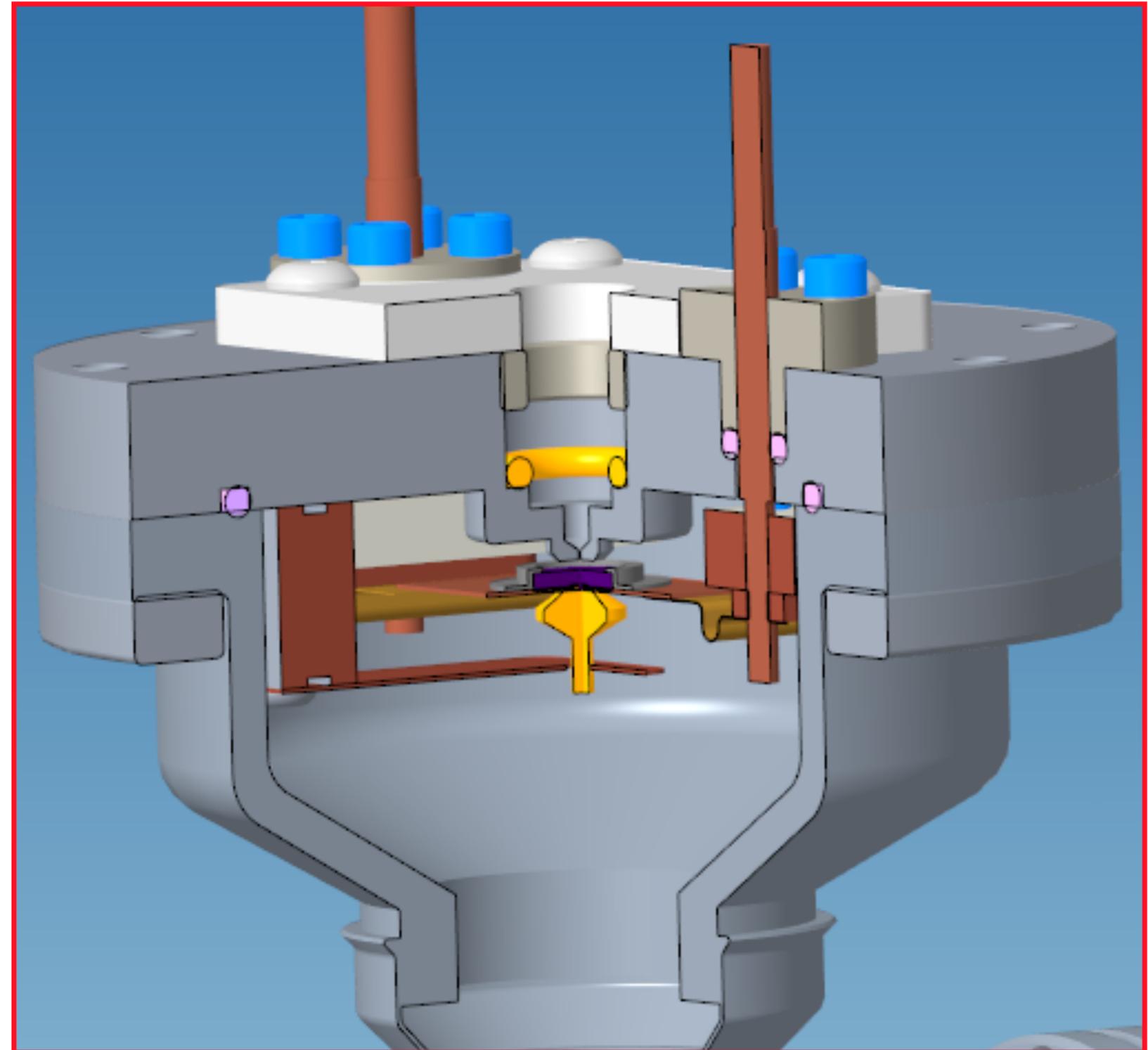


- Constructed a mock pulse valve to test effect of 10 A current on the cell polarization.
- Aluminum case with copper strip of roughly the same dimensions as pulse valve.
- Strip is about 1 in away from the cell.
- Saw no measurable effect in refillable cell at Hz up to 1kHz, but limited to 60% max pols at the time.

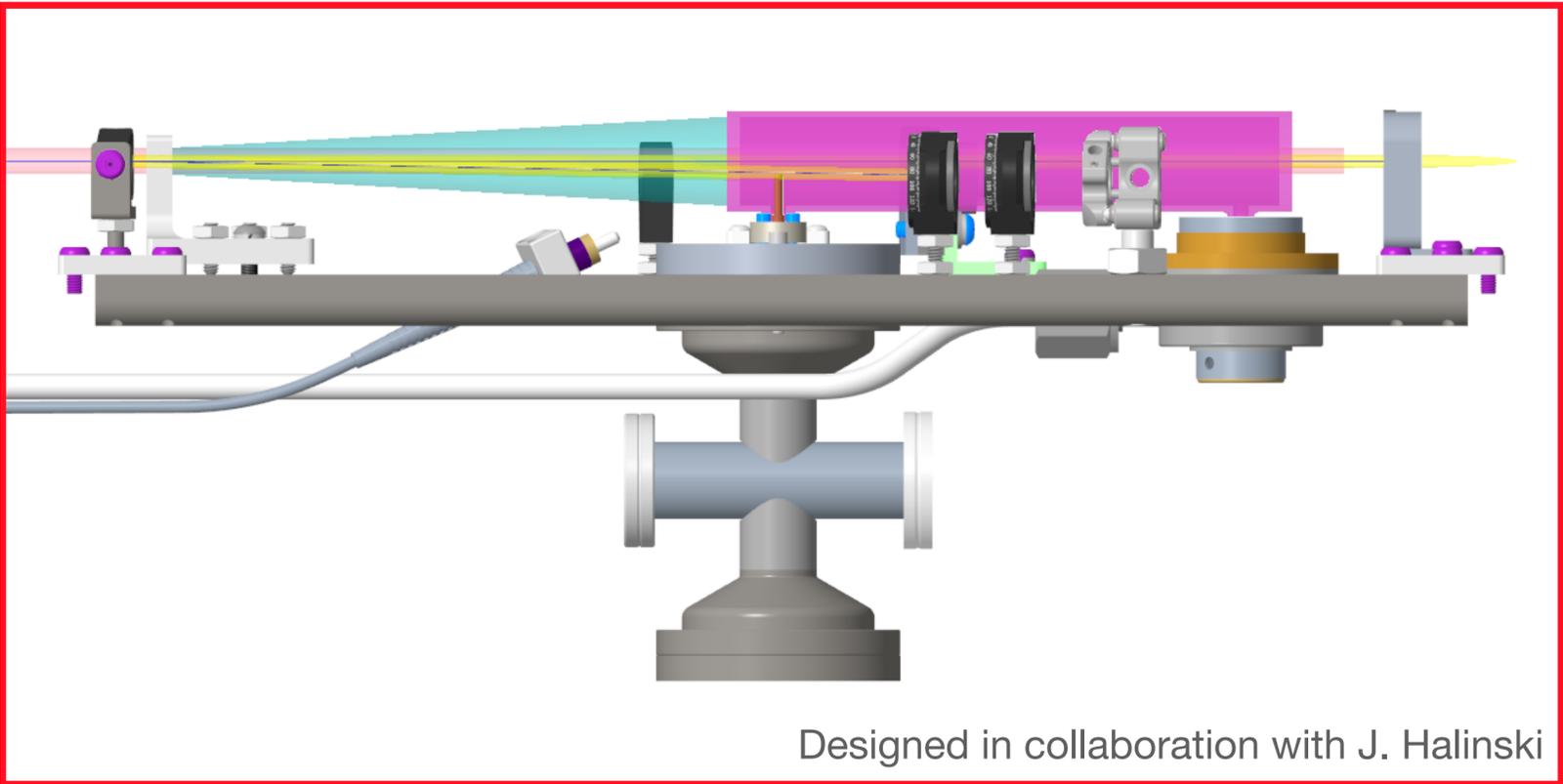
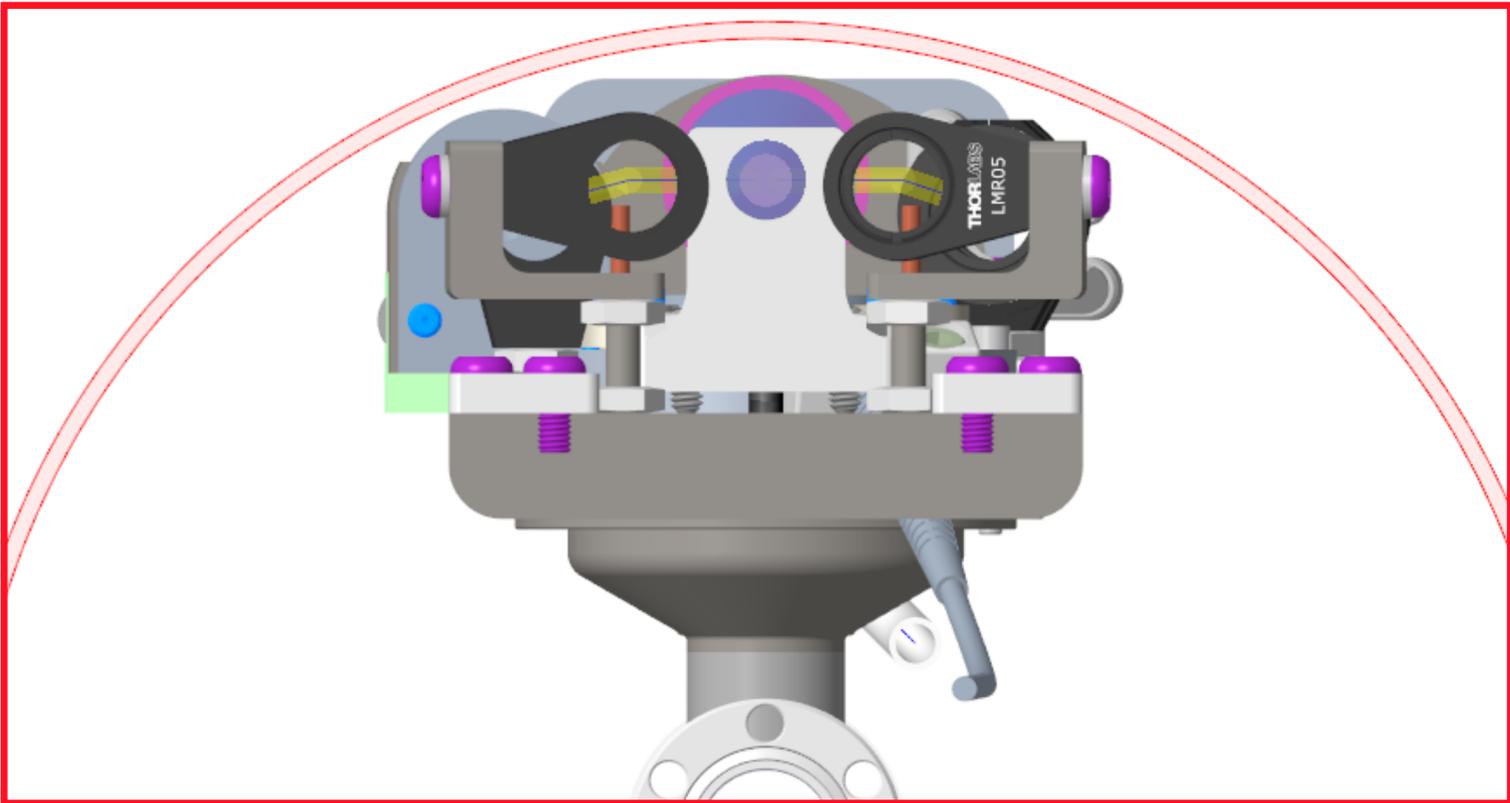


Test pulse valve

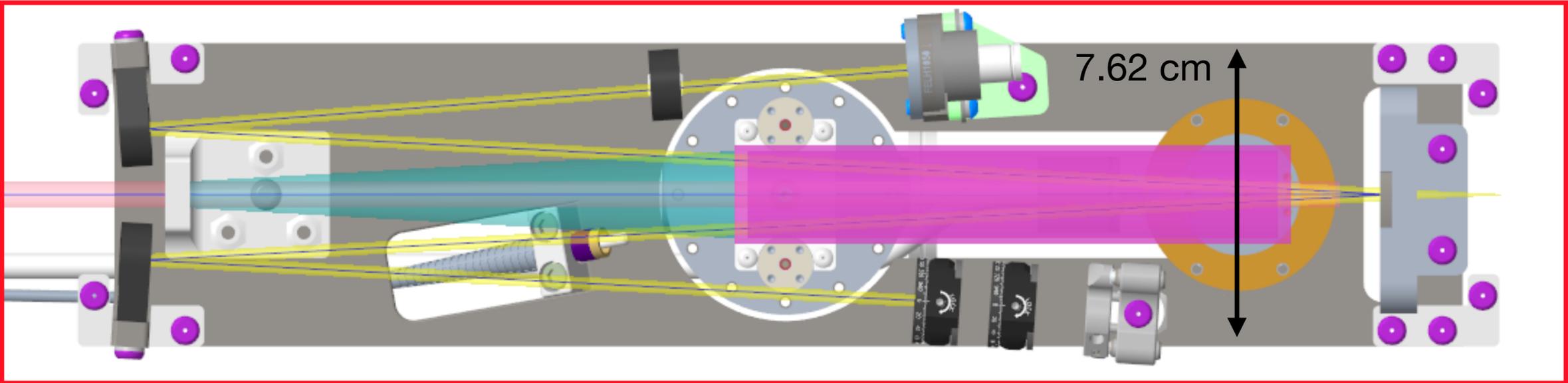
- Double injection valve: top will have cell connection and polarized ^3He , bottom will have unpolarized ^3He injection.
- Final version waiting on a brazed ceramic connection due to 40kV potential, will arrive by summer install.
- We will face hydrogen challenges with second stem, now we have two valves that we cannot bake.



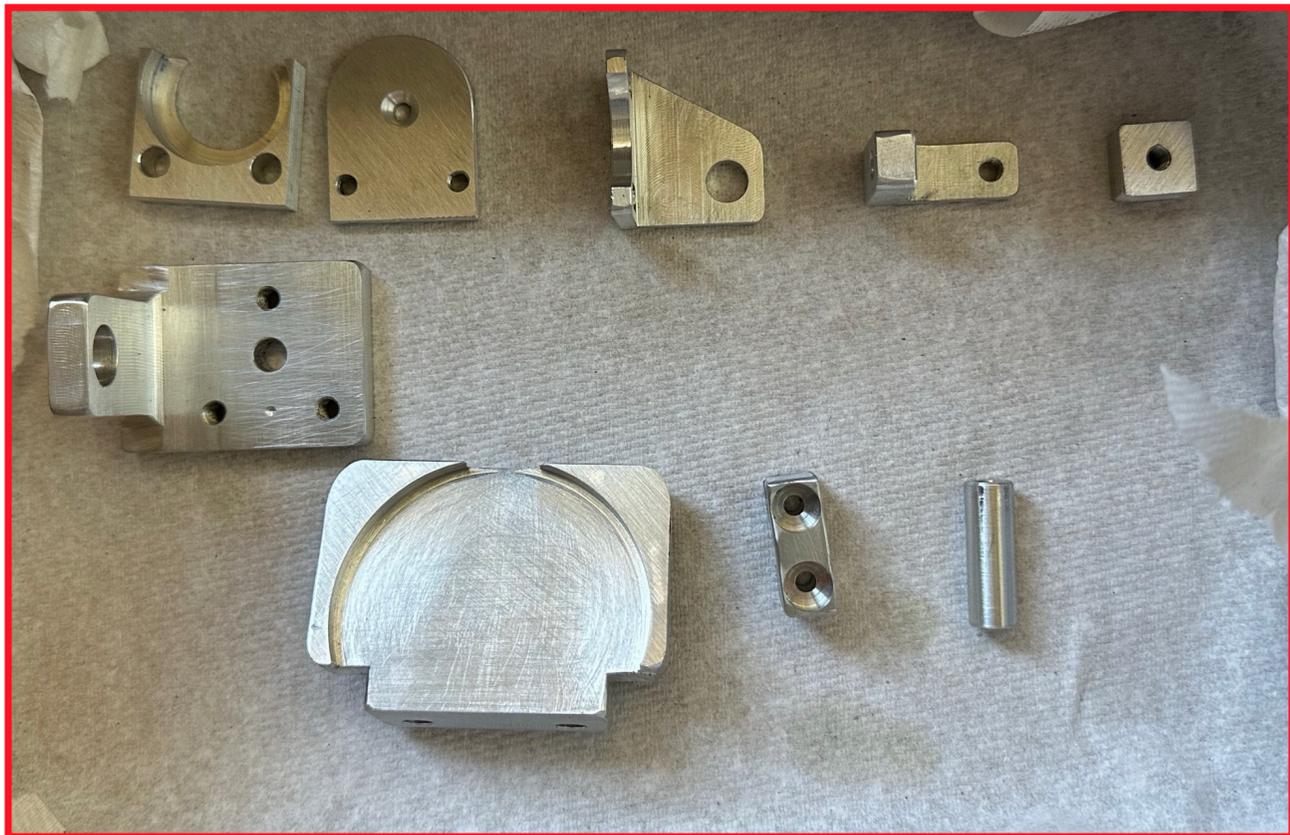
Updated EBIS layout

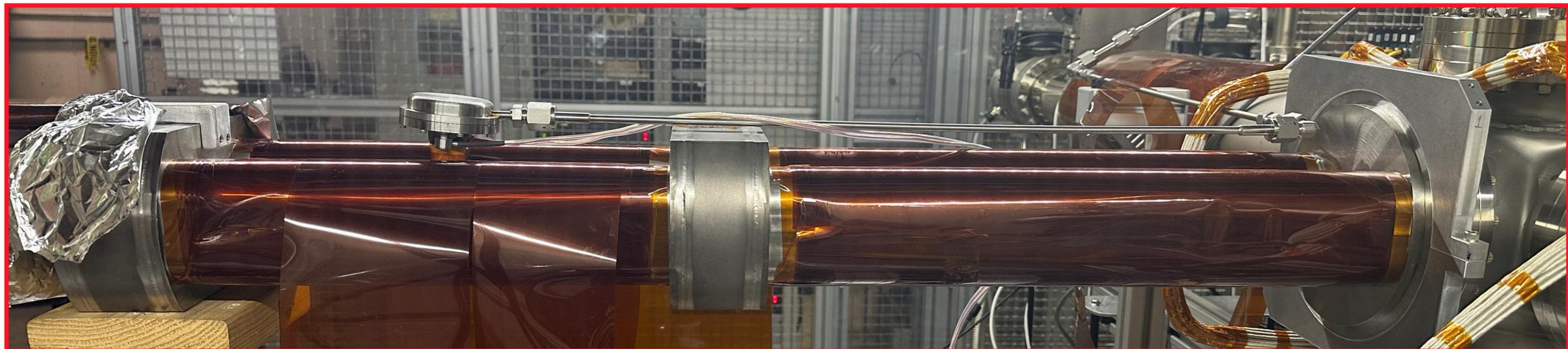
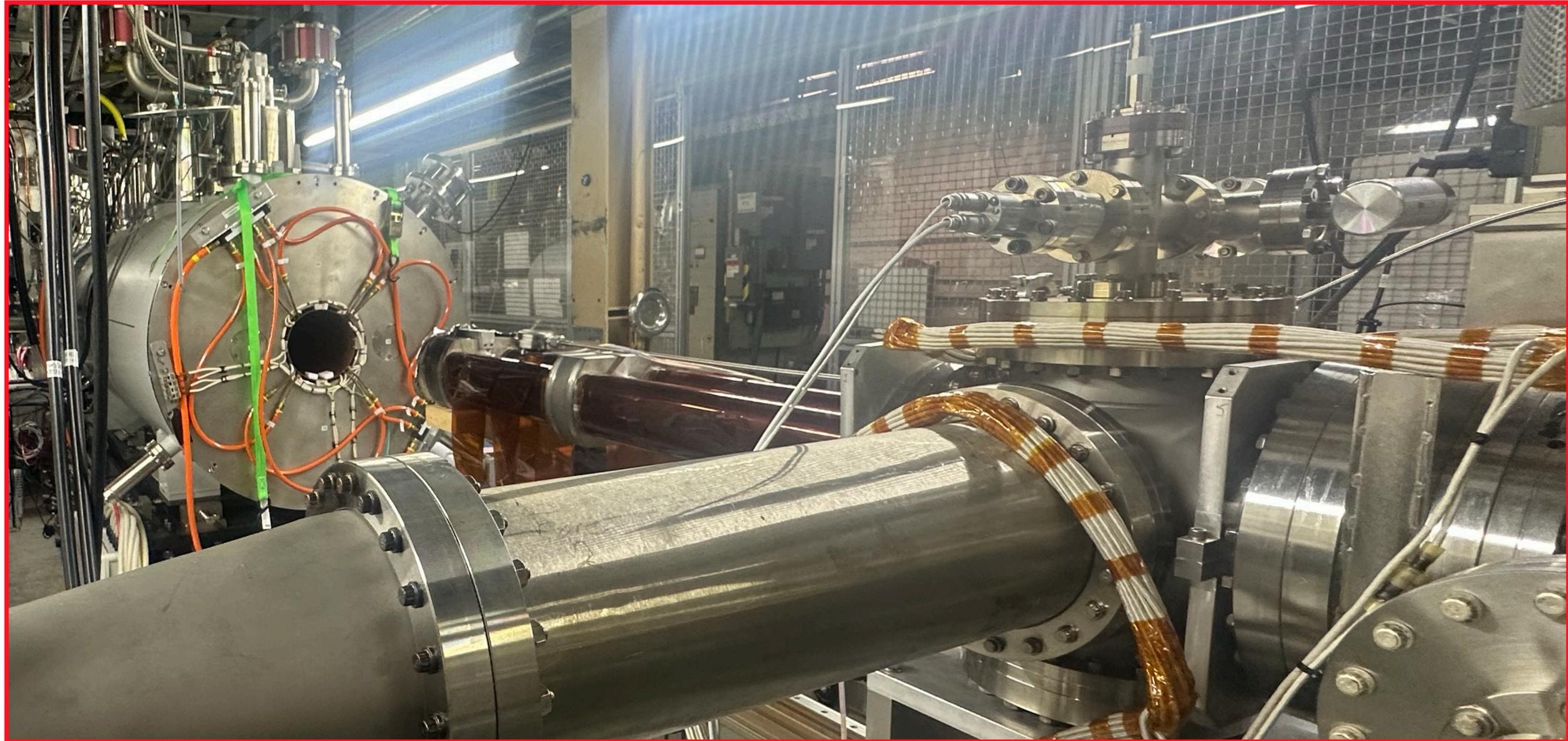


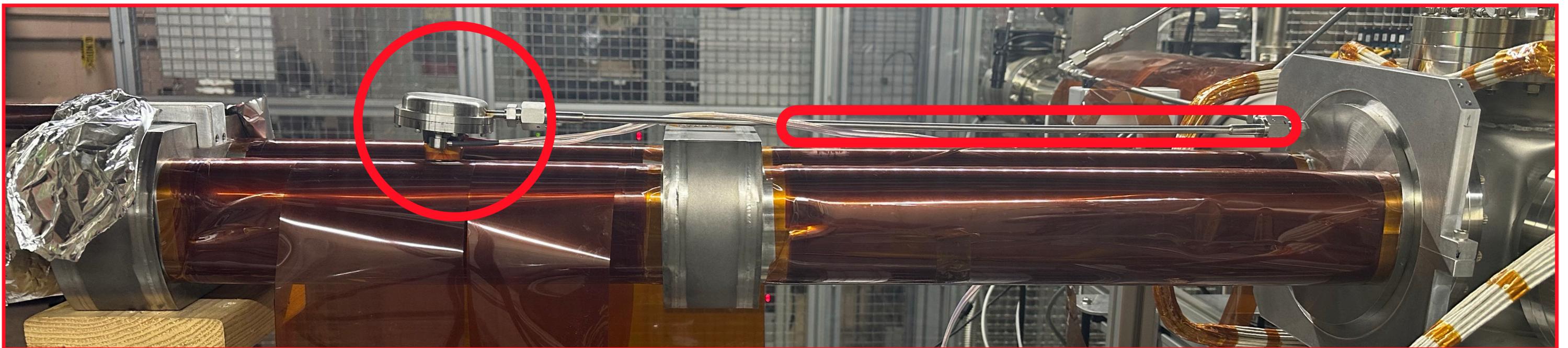
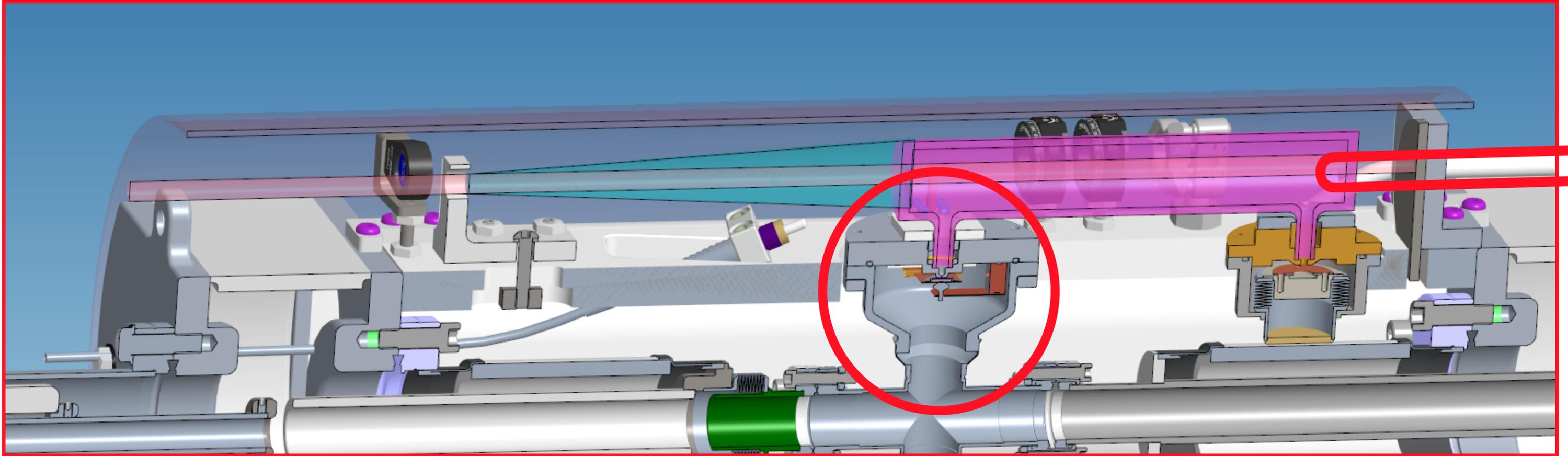
Designed in collaboration with J. Halinski



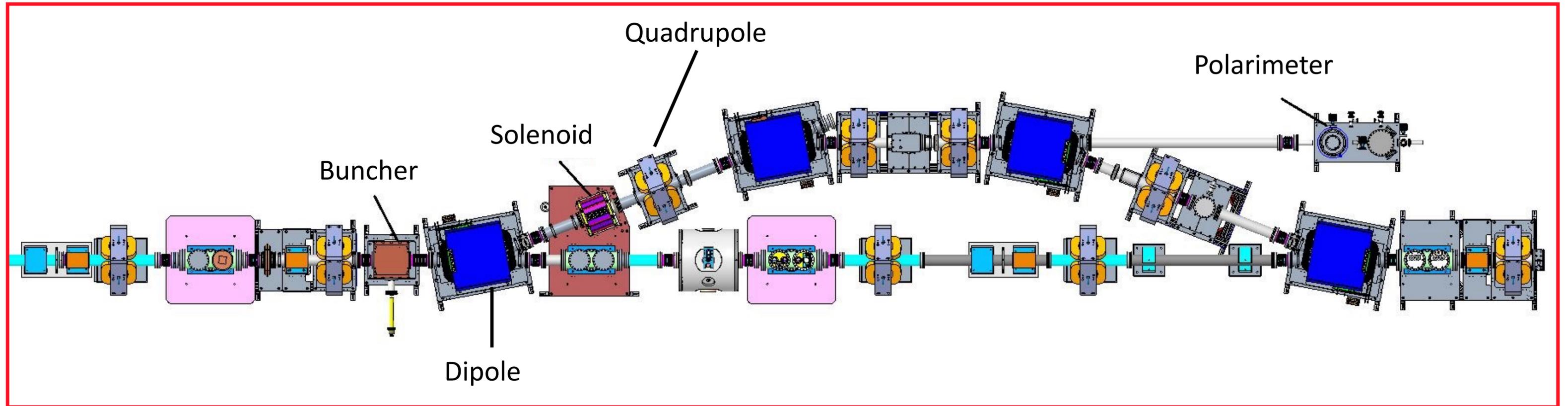
Machined parts for EBIS mount







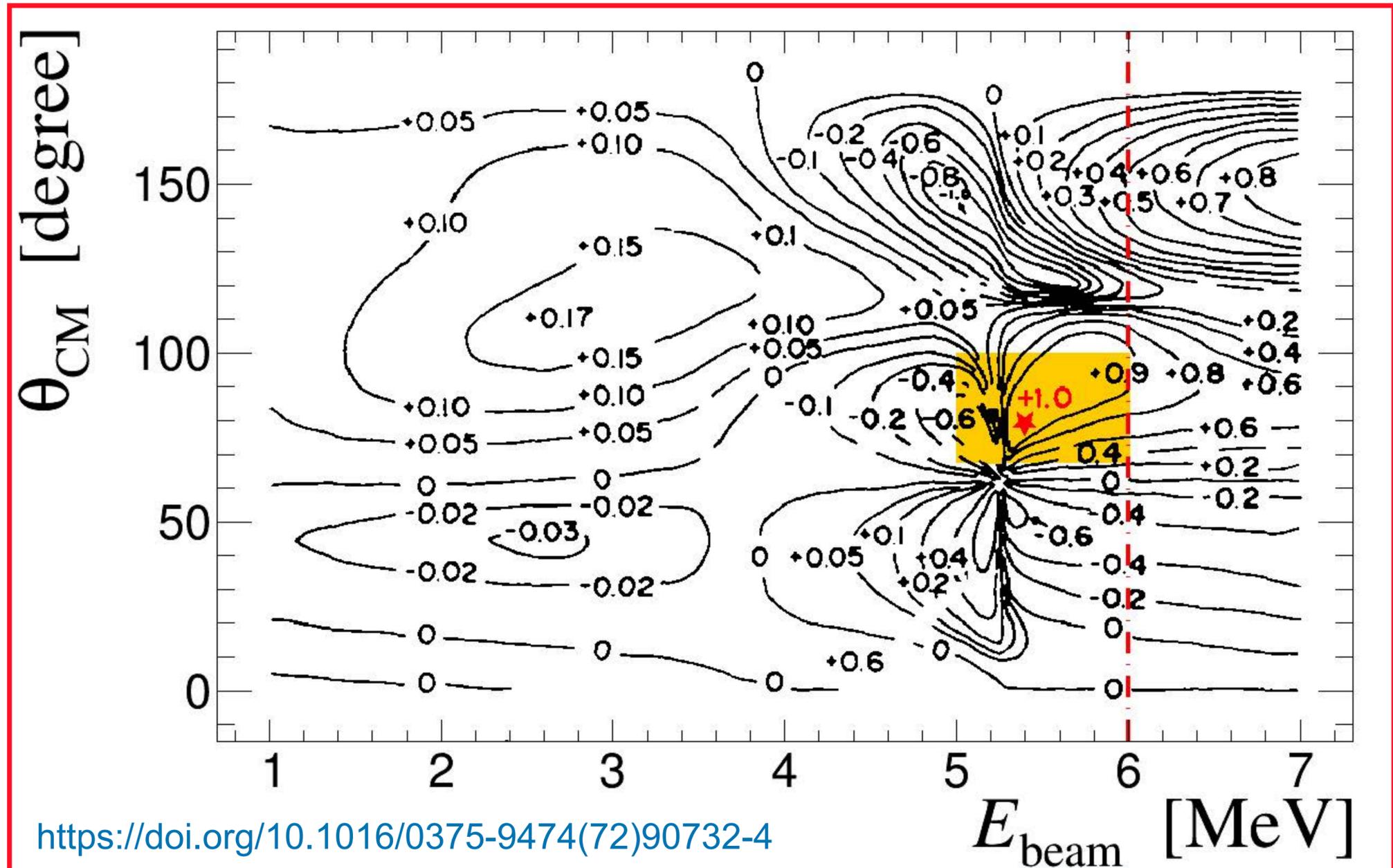
Chicane Spin Flip and Polarimetry



- 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.

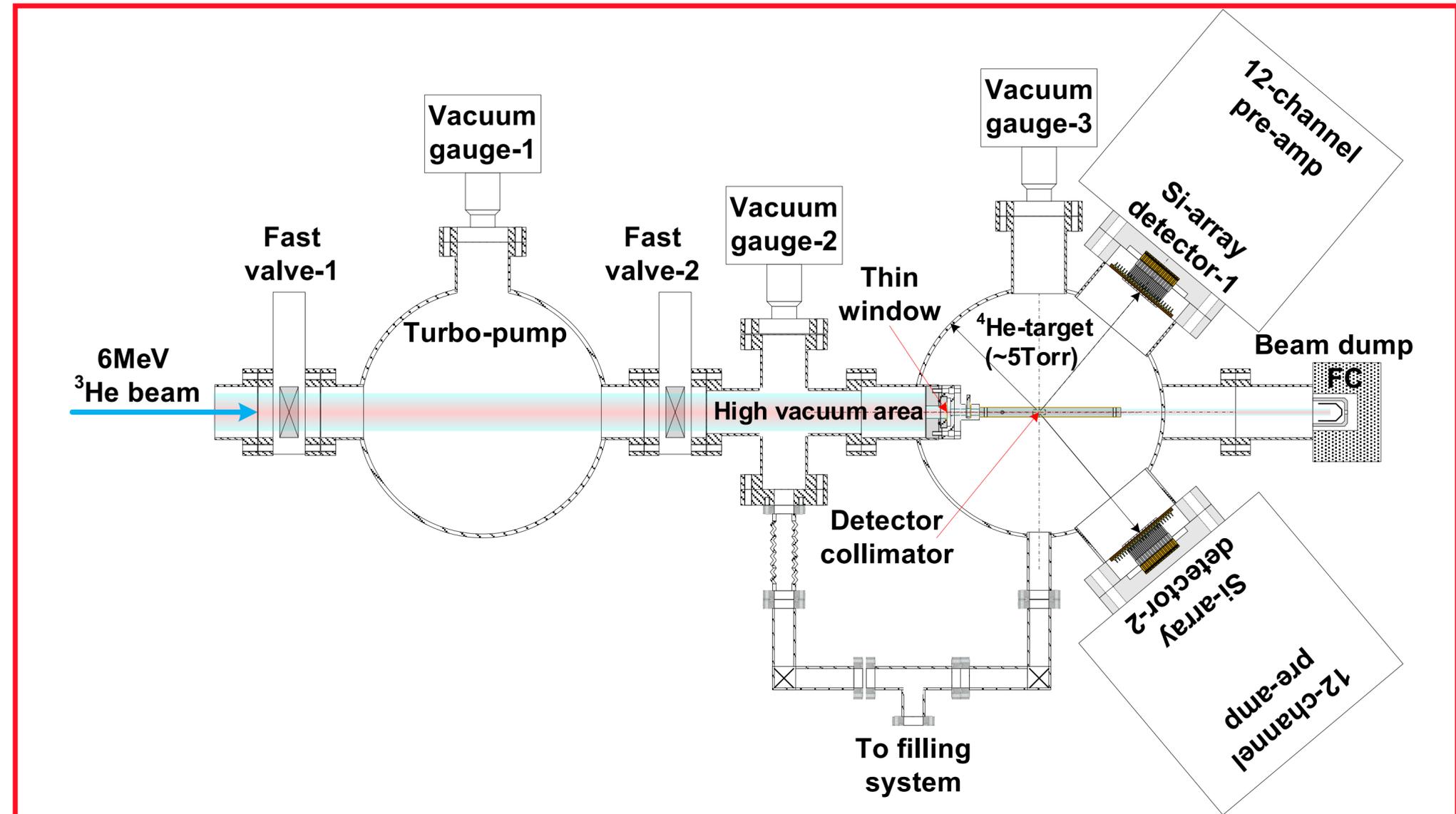
Absolute nuclear polarimeter

- 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.



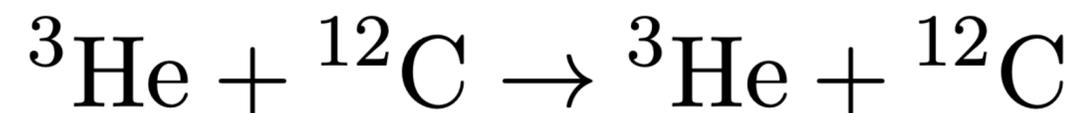
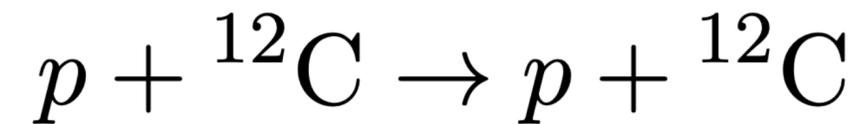
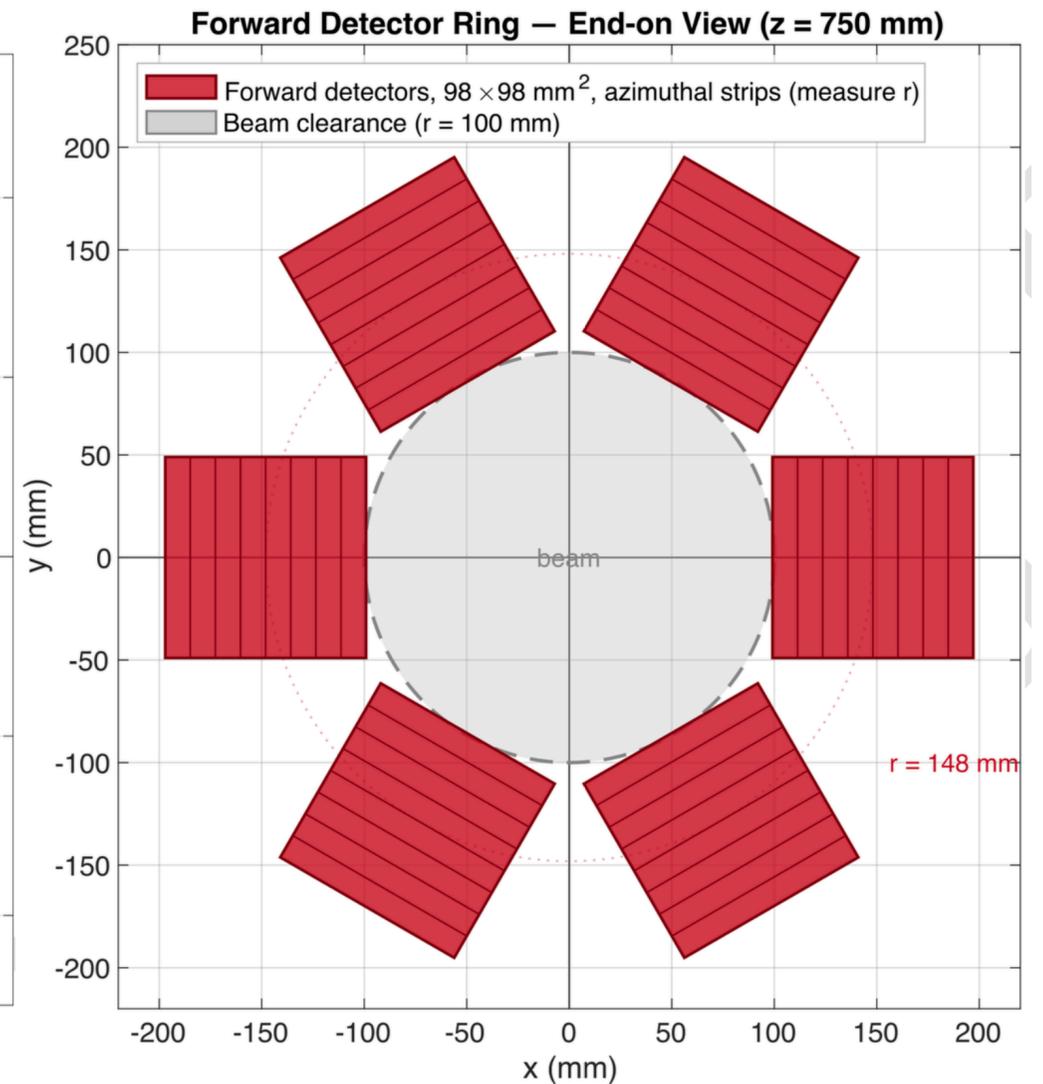
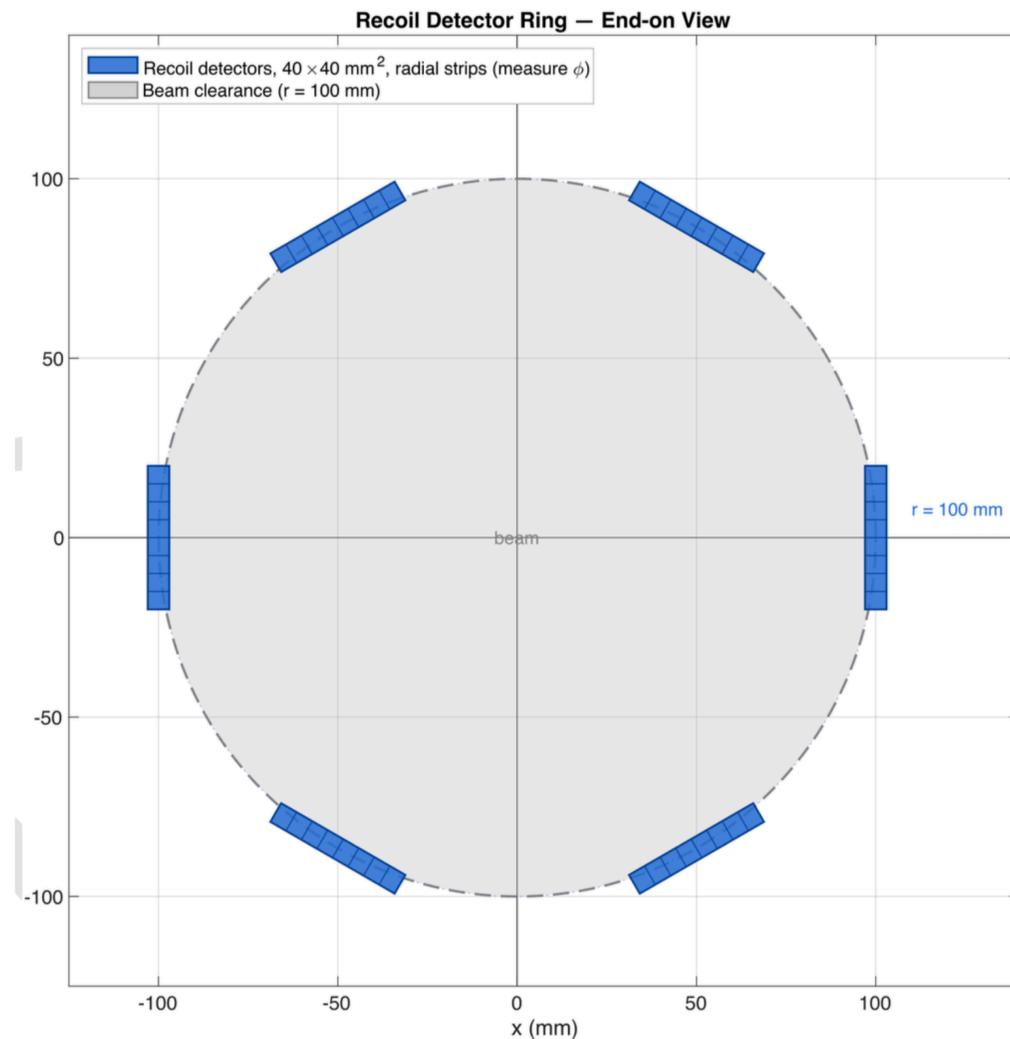
Absolute nuclear polarimeter

- Polarized ^3He around 6MeV elastically scatters from ^4He into two symmetric silicon detectors.
- Talk in this session by Prajwal about storage cells in AGS for polarimetry.
- Also, ongoing discussion around the long-term development of a ^3He jet polarimeter.



Booster Polarimeter

- There is now an effort to develop a carbon polarimeter for Booster for measurements in 2028.
- Double ring design to detect forward scattered ^3He along with recoil C.
- Will provide essential experimental input on analyzing powers for ^3He on C at Booster energy.
- Possibility to extend to d, Li6, and Li7 as well.
- Talk by Vera at 09:40 tomorrow.



Looking Forwards

- Up to 90% polarization has been achieved with MEOP at required pressure and field.
- After MAC in 2025, July, August, and September were approved for EBIS maintenance and development.
- NSRL requirements in September and October have reduced this to 5 weeks.
- Test injection valve manufacturing complete, double stem open cell tests beginning May.
- Install in testEBIS first to minimize work in EBIS area during the actual install.
- Start opportunistic data taking at absolute polarimeter in September and October.
- Realization of over 20 years of effort from BNL-CAD and MIT.