SBS G_E^n Target Update

- Engineering, detailed design, fabrication, procurements
- Target cell production (presently for A_1^n)
- Progress in the SBS G_E^n target-cell development
- New technique for magnetic field direction measurement.
- Progress in our new κ_0 measurement (only if time permits)

G. Cates - UVa

February 25, 2019

UVa Polarized ^{3}He target team

People-power

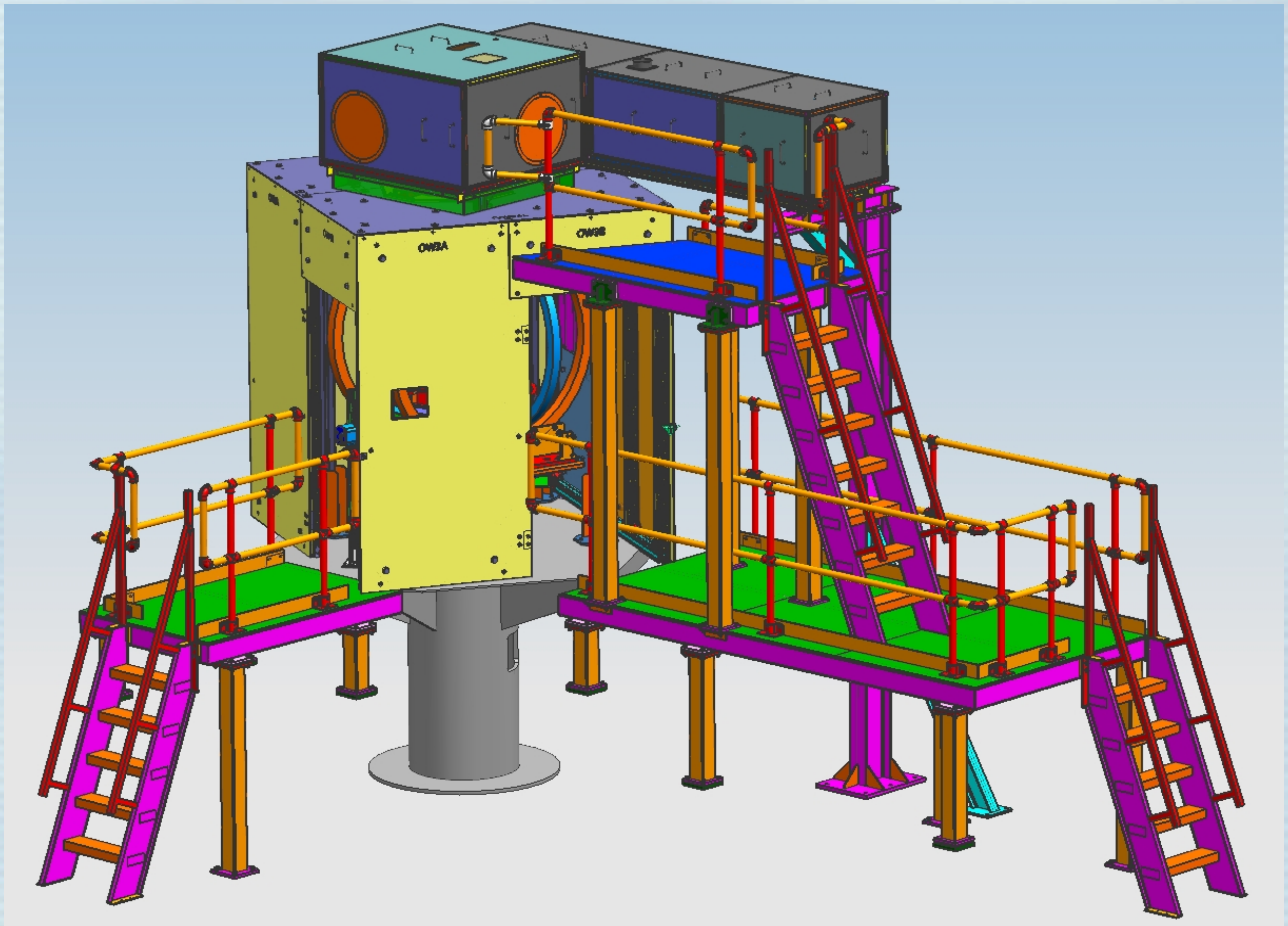
- Huong Nguyen (Research Scientist)
- Vladimir Nelyubin (Senior Research Scientist)
- Sumudu Katugampola (Grad student - 6th year)
- Chris Jantzi (Grad student - 4th year)
- W. Al Tobias (Physics Dept. Staff)

University of Virginia

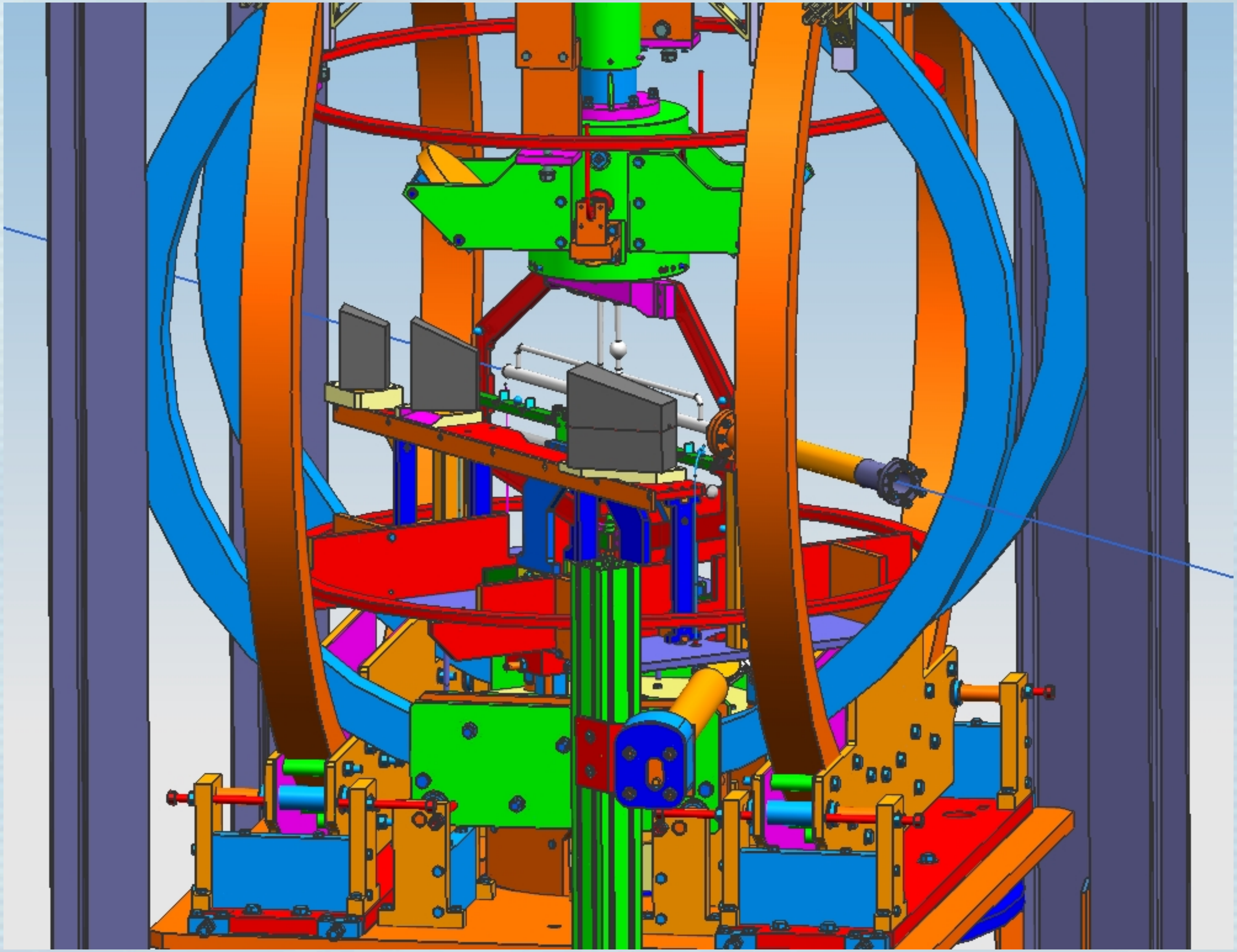
Engineering and design

- Engineering is essentially complete
- Detail design is still in progress
- Some procurements and construction has begun.

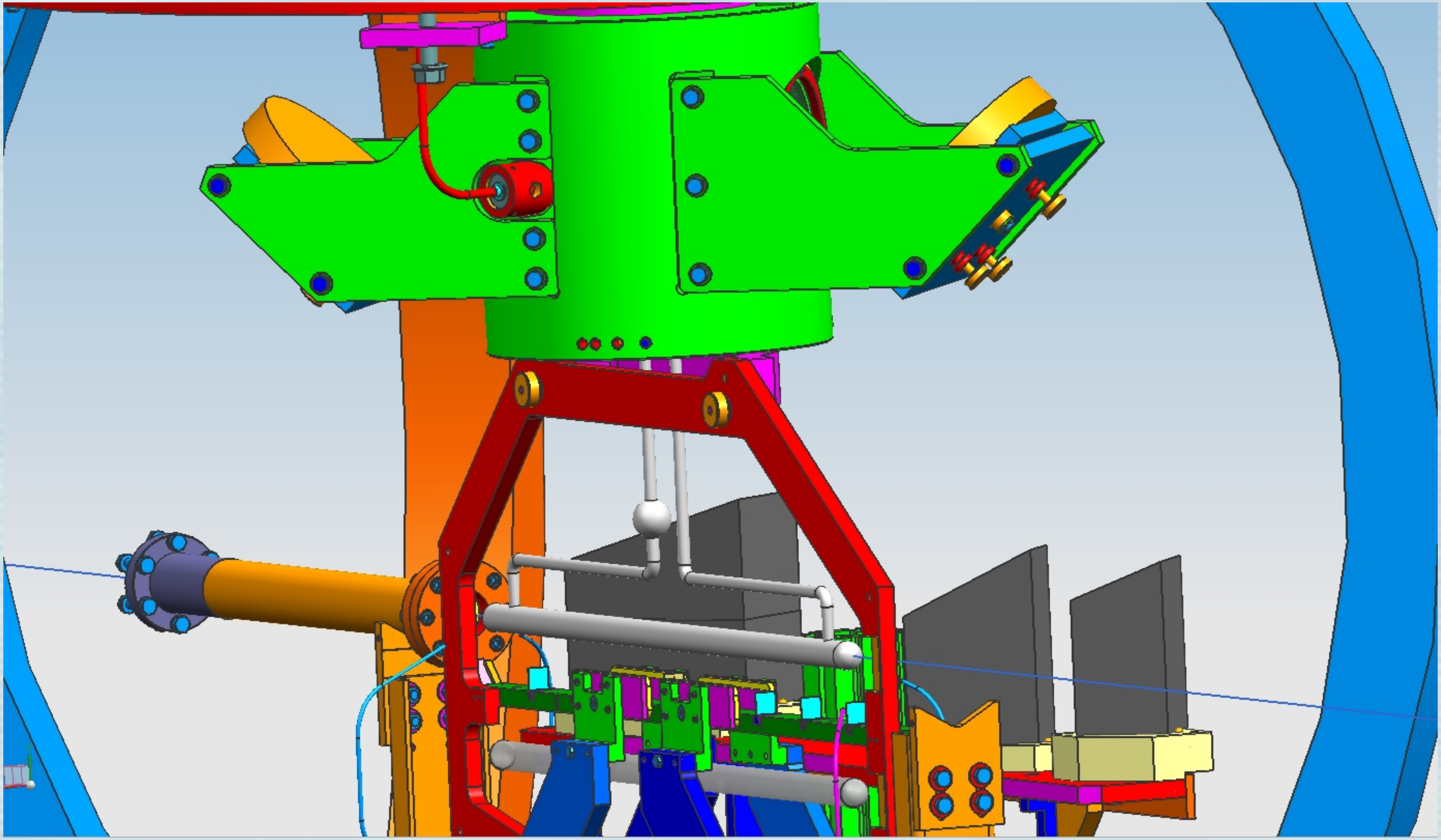
Overview of SBS GEn polarized ^{3}He system



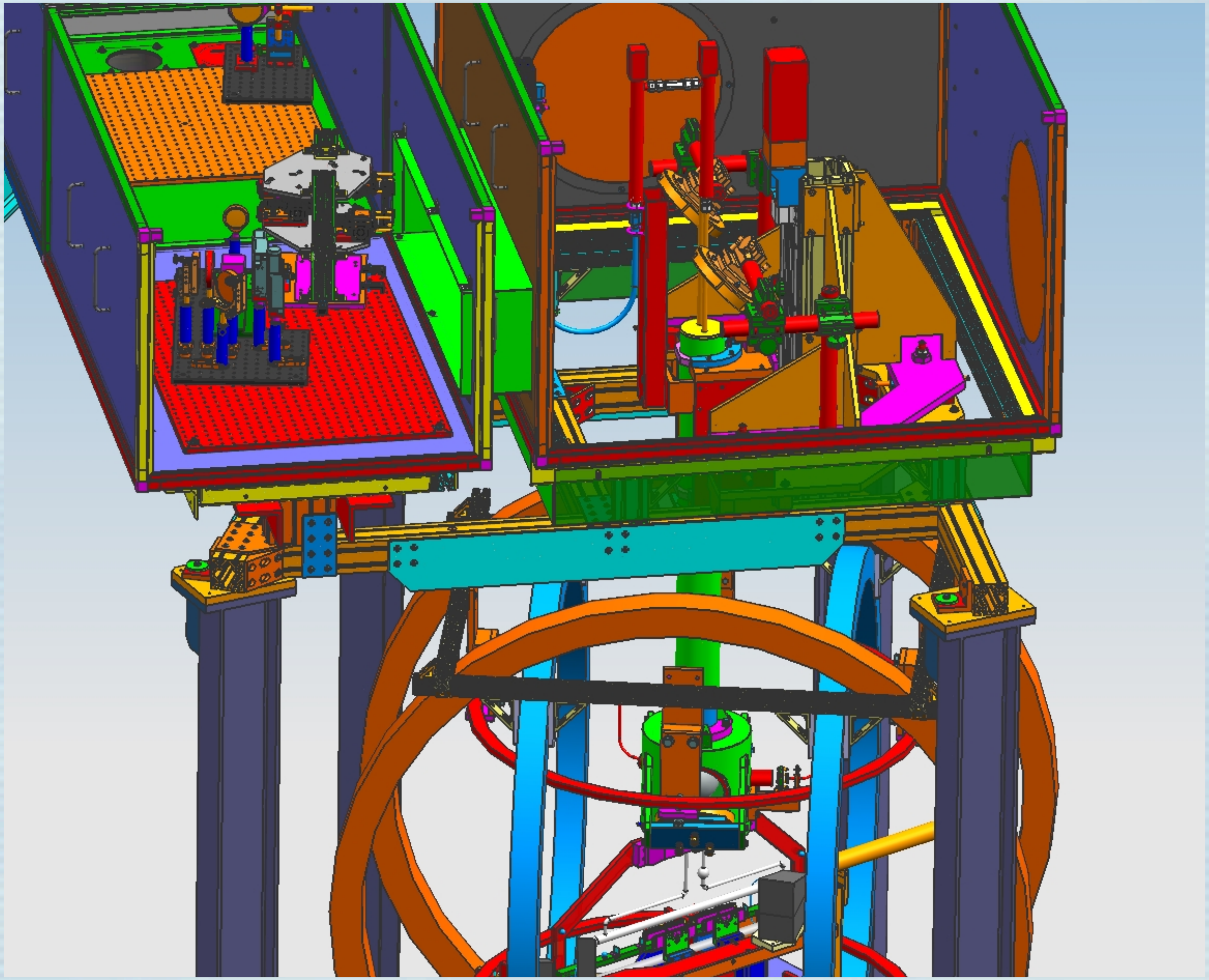
SBS G_E^n Polarized ^{3}He system - inside the magnetic shielding



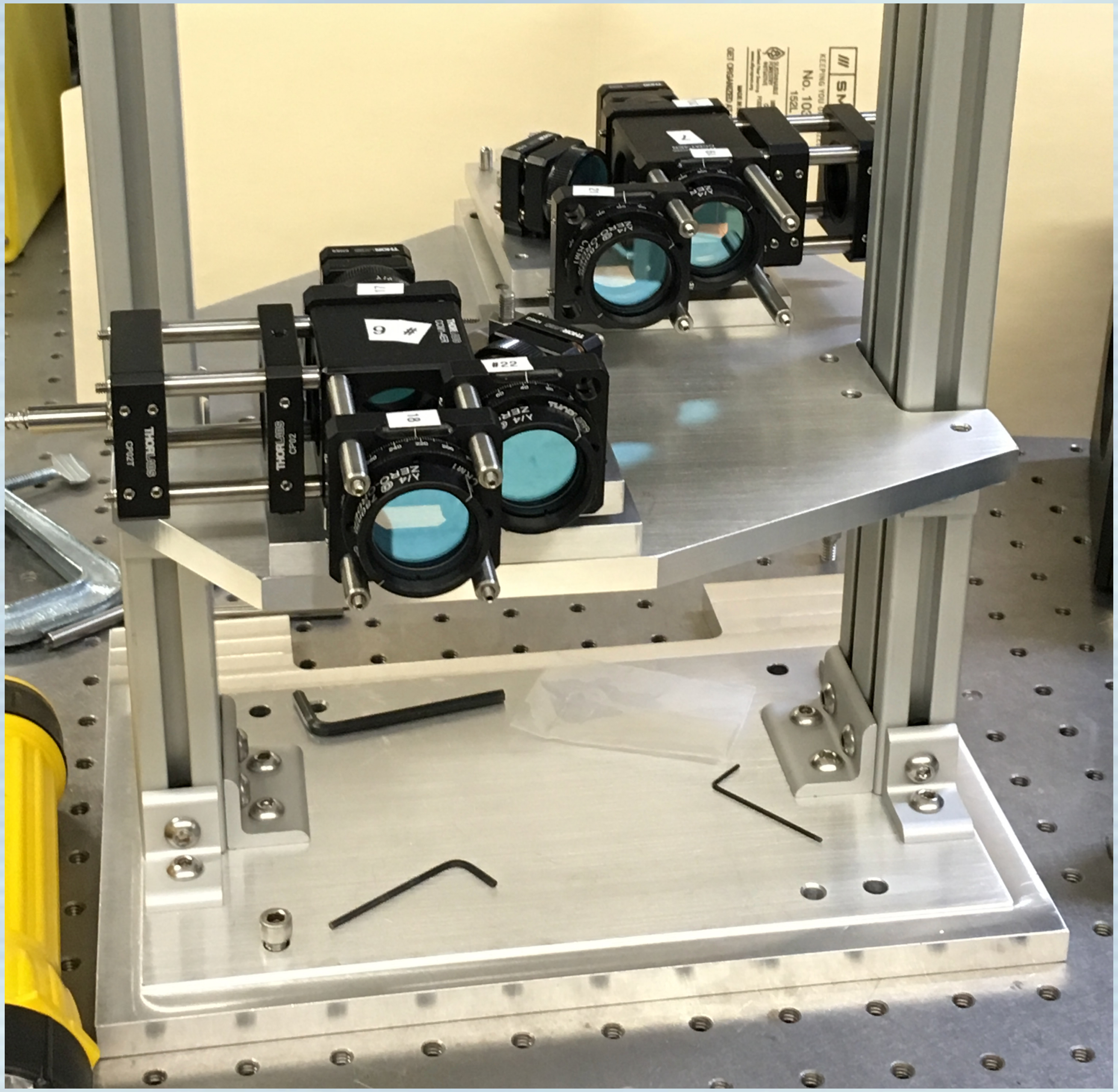
SBS G_E^n Polarized ^{3}He system - focusing on the target ladder



SBS G_E^n Polarized ^{3}He system - emphasizing the optics system



SBS compact optics - being built at UVa



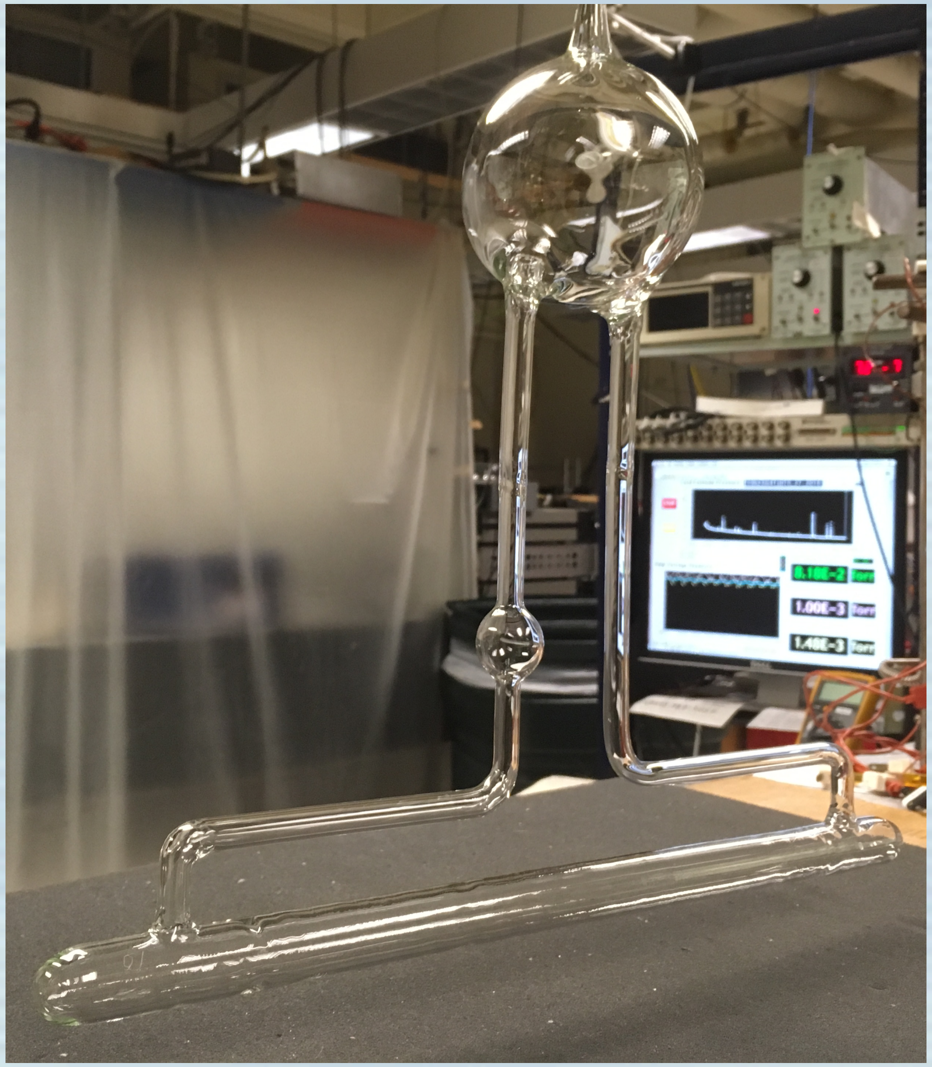
Two out of four of the optics modules for SBS. The next two modules will "hang" from a second platform stacked above the platform shown.

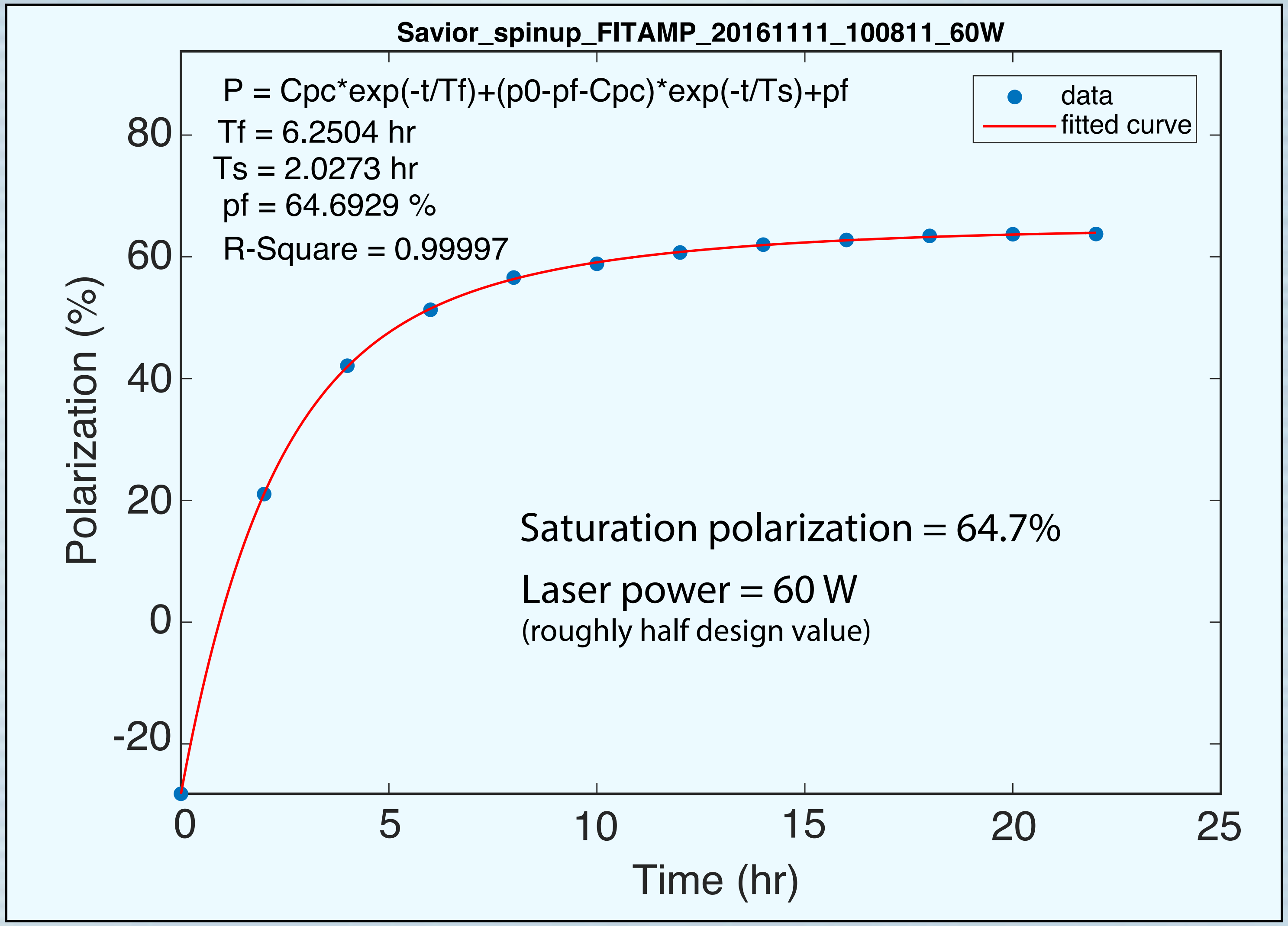
Target Cell Production

What is required for target cell production ?

- Glassblowing of the components (Mike Souza)
- Pressure testing end windows
- Preparing hybrid mixtures of K and Rb
- Cell filling
- Bench testing (including polarimetry).
- Cell characterization (pressure, K/Rb ratio, glass thickness, etc.).

Target cell savior





- ✦ Stage-I target cell (3 liter all glass) for A_1^n
- ✦ Excellent performance - important proof of principle
- ✦ Filled in October 2016, Delivered to JLab January 2018

Sanguine with our proof-of-principle, we shifted focus to other important issues

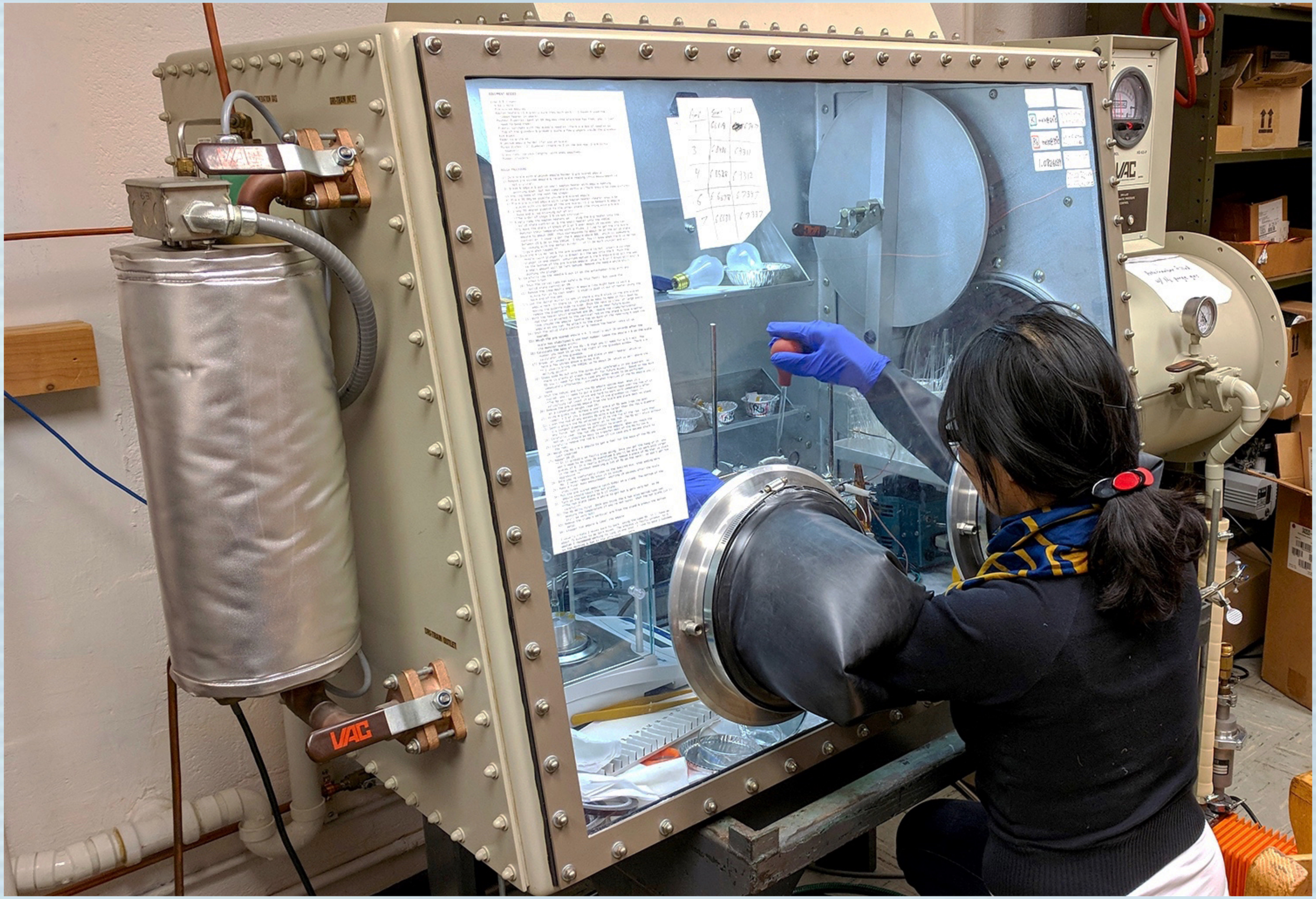
- Development of Stage-II target cells
- Magnetic field calculations for both SBS and the new Hall C polarized ^{3}He target.
- Developing compact high-power optics
- Building and commissioning new bench testing apparatus capable of testing Stage-II target cells.
- Advancing polarimetry issues and κ_0
- Developing magnetic-field measurement system for SBS
- **Building new cell characterization system**

Recent return to target cell production

Stage-I (A_1^n, 3-liter)

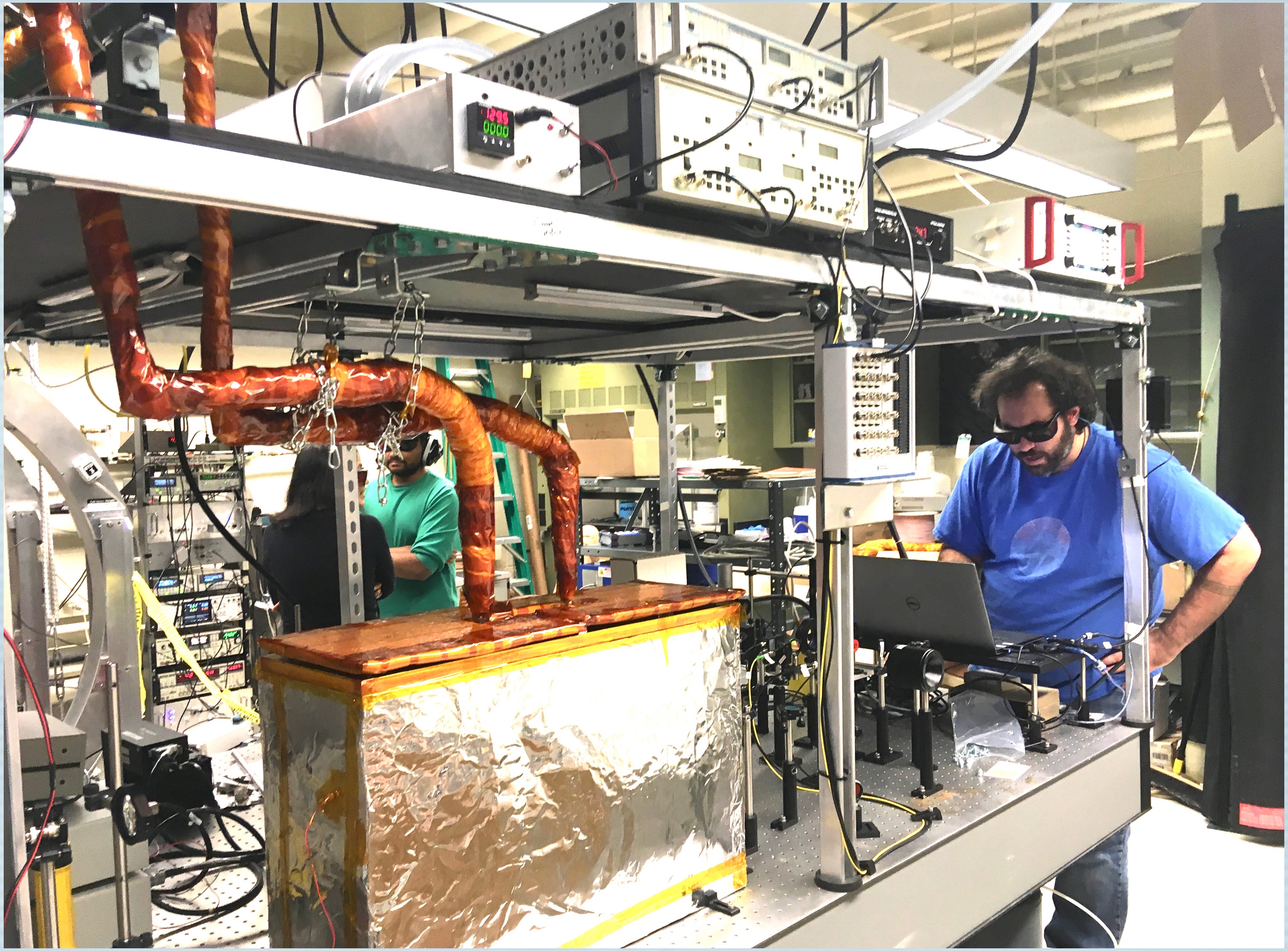
- First two target cells had unacceptably short lifetimes.
- Concluded that the short lifetimes were due to overheating the pumping chamber when “chasing” the alkali mixtures.
- Also concluded we would benefit from new alkali-hybrid mixtures.
- Constructed series of large 1-atm. spherical cells to establish quality control.
- Spheres are approximately size of Stage-I pumping chambers.

Apparatus for preparing alkali-hybrid K/Rb mixture



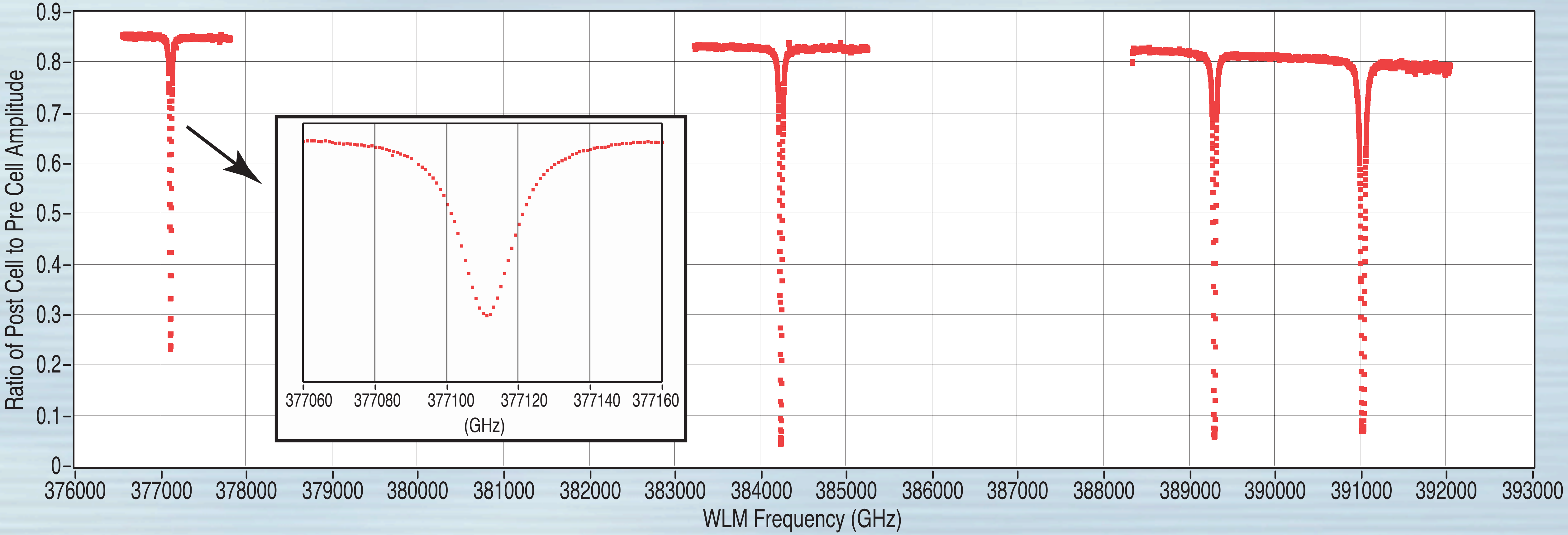
Huong preparing the new alkali-hybrid mixes
we are currently using.

New Cell Characterization system



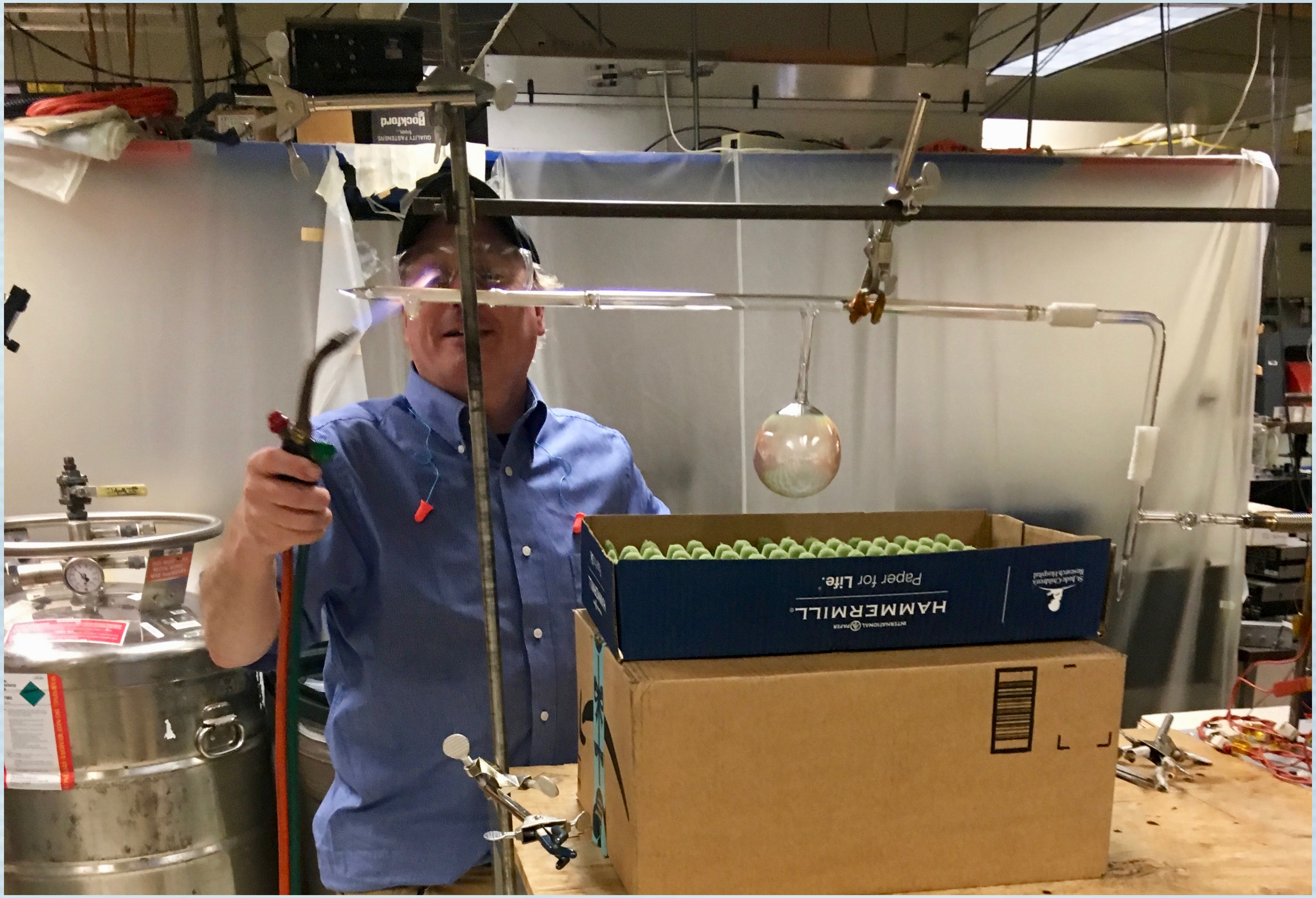
Became operational December 2018

Pressure broadening scan with new system



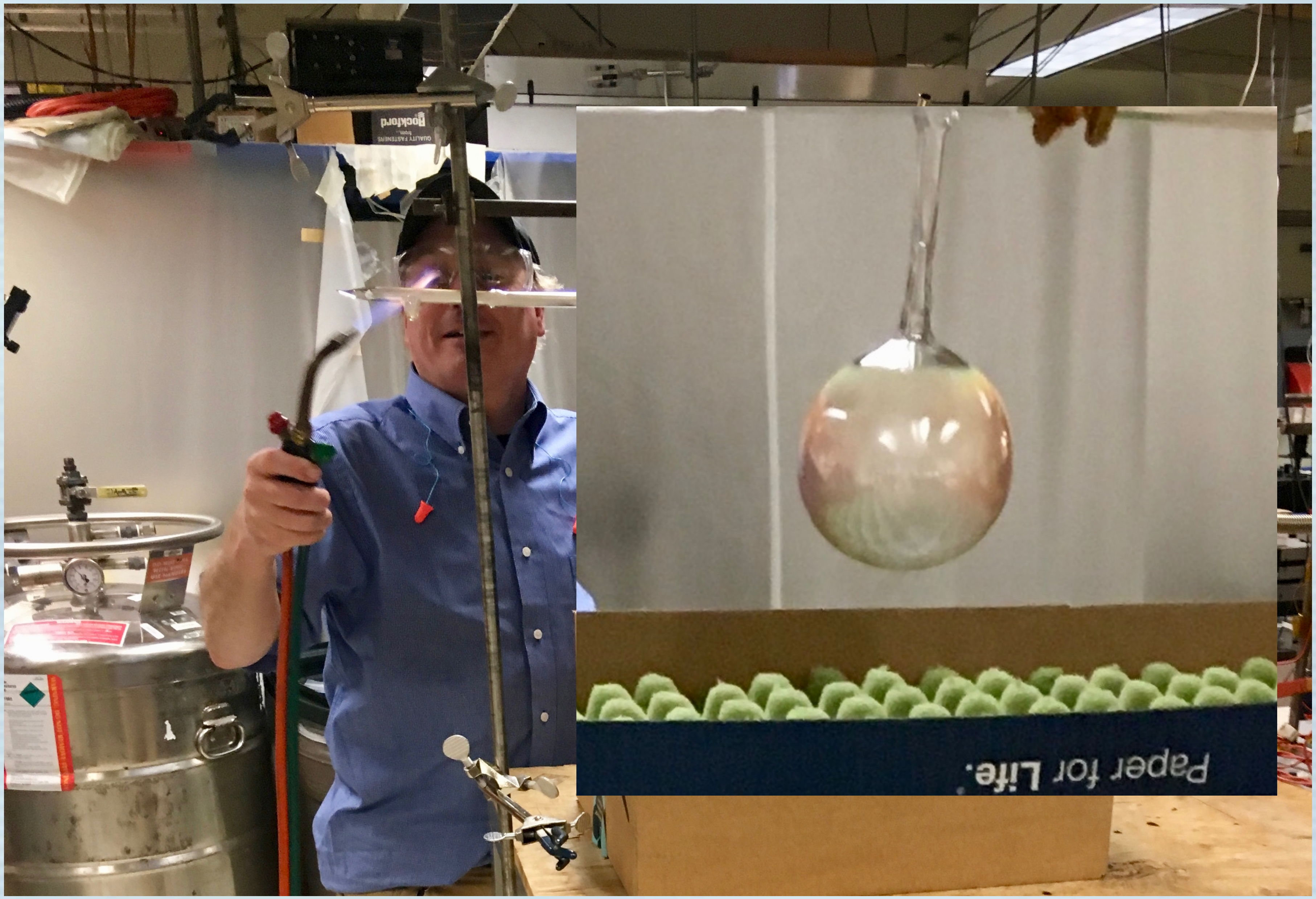
- Became operational December 2018
- Providing, for the first time, nearly real-time feedback on what we are putting in our cells.
- Key for fine-tuning our K:Rb ratios

William (Al) Tobias "chasing" alkali mixture into spherical test cell



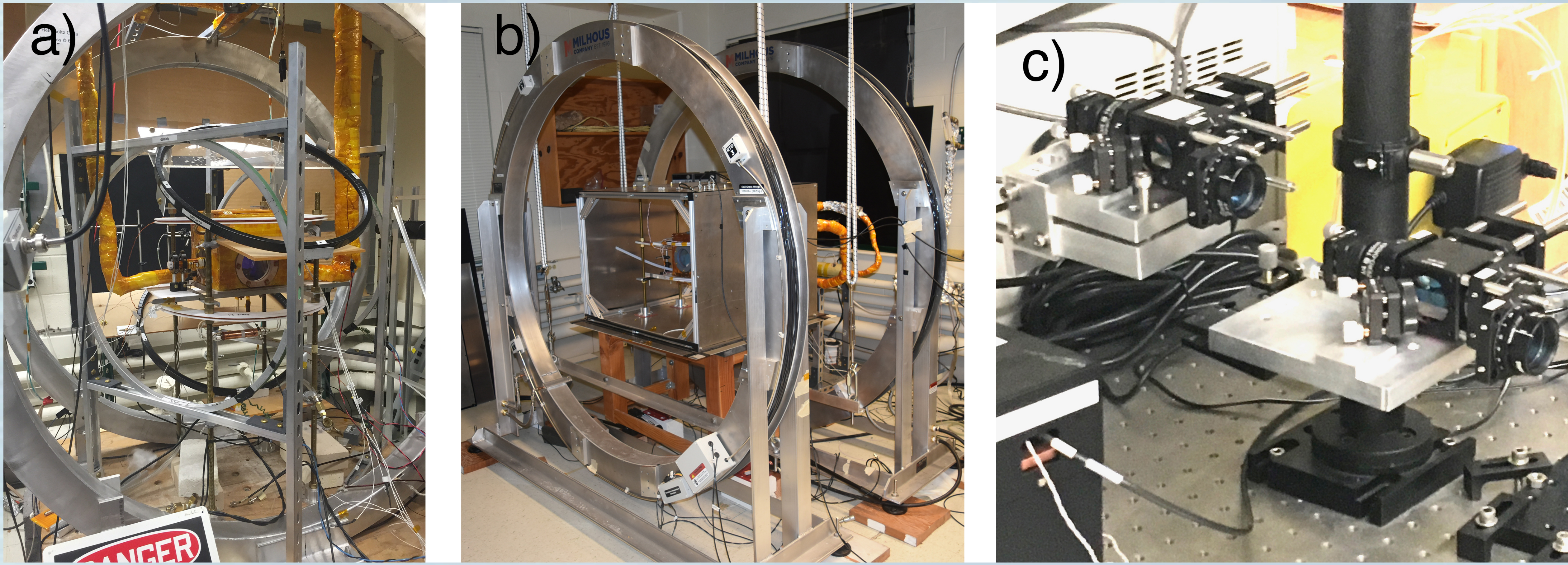
- Al Tobias has temporarily taken responsibility for alkali chasing.
- Al is also working closely training everyone else.

William (Al) Tobias “chasing” alkali mixture into spherical test cell



- Al Tobias has temporarily taken responsibility for alkali chasing.
- Al is also working closely training everyone else.

Apparatus for target polarization tests

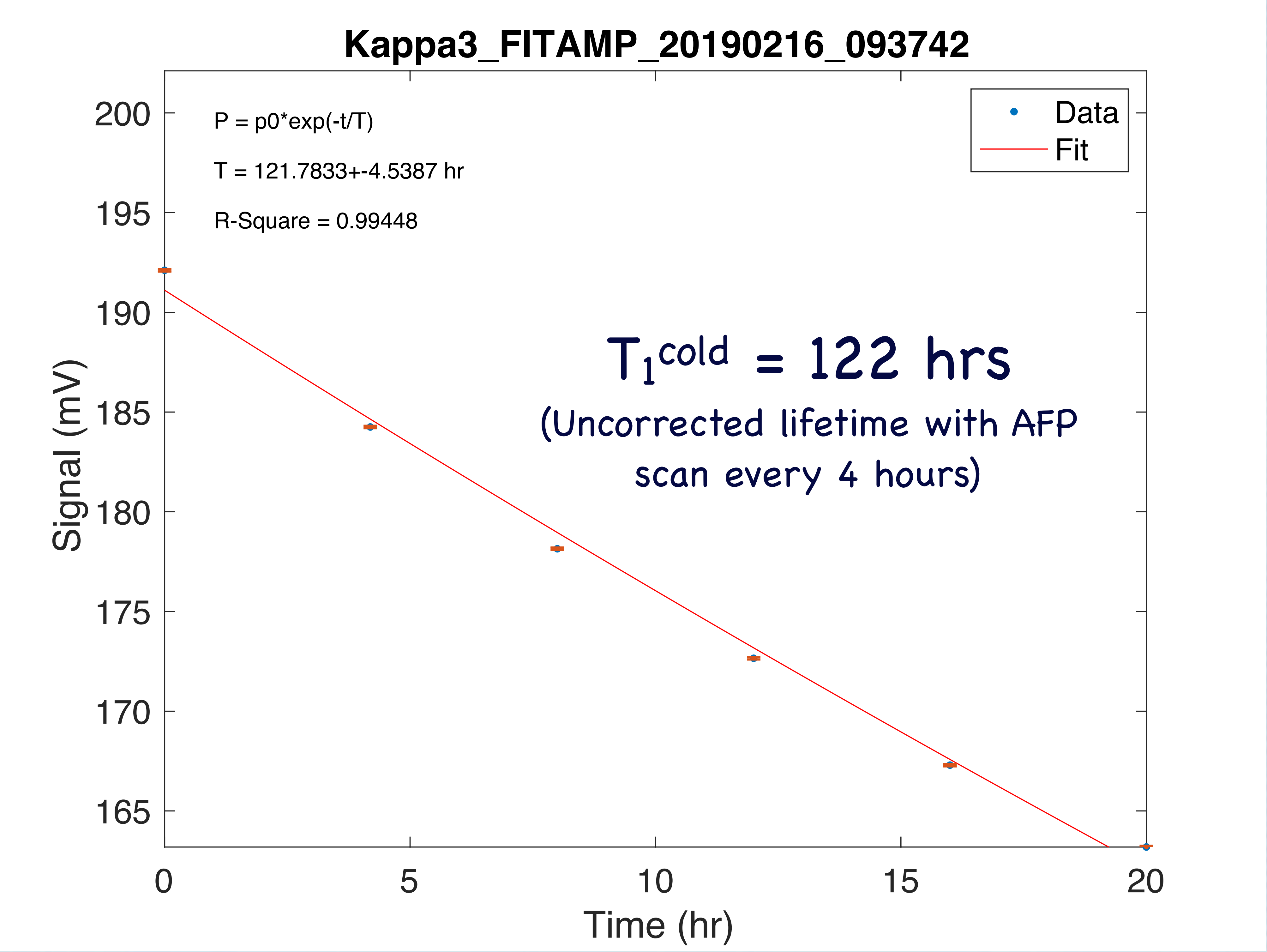


a) "Downstairs" setup

b) New "Upstairs" setup - capable testing the larger Stage-II target cells

c) Laser optics modules currently being used for single-direction pumping.

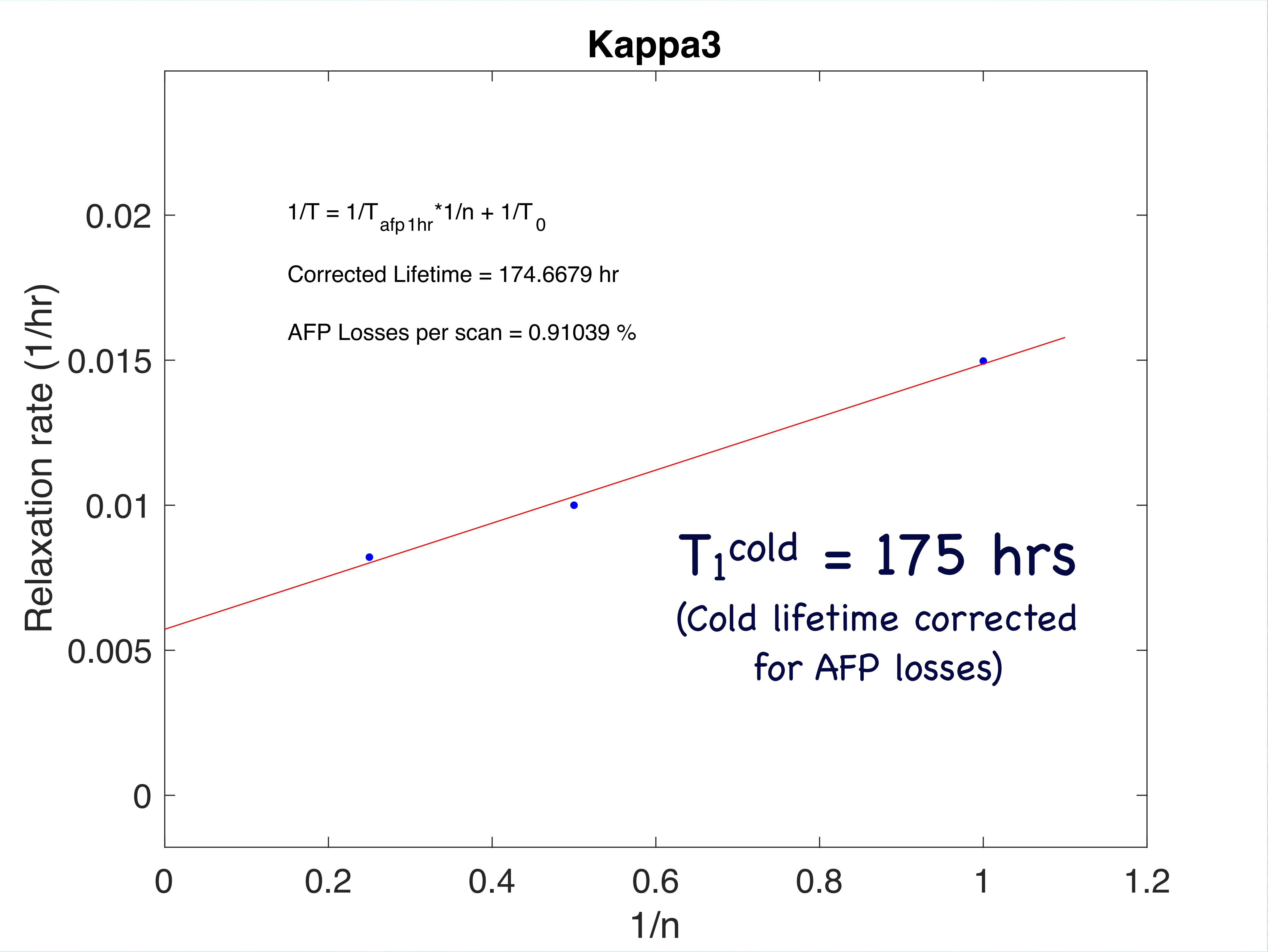
Test sphere Kappa3 results - cold lifetime study



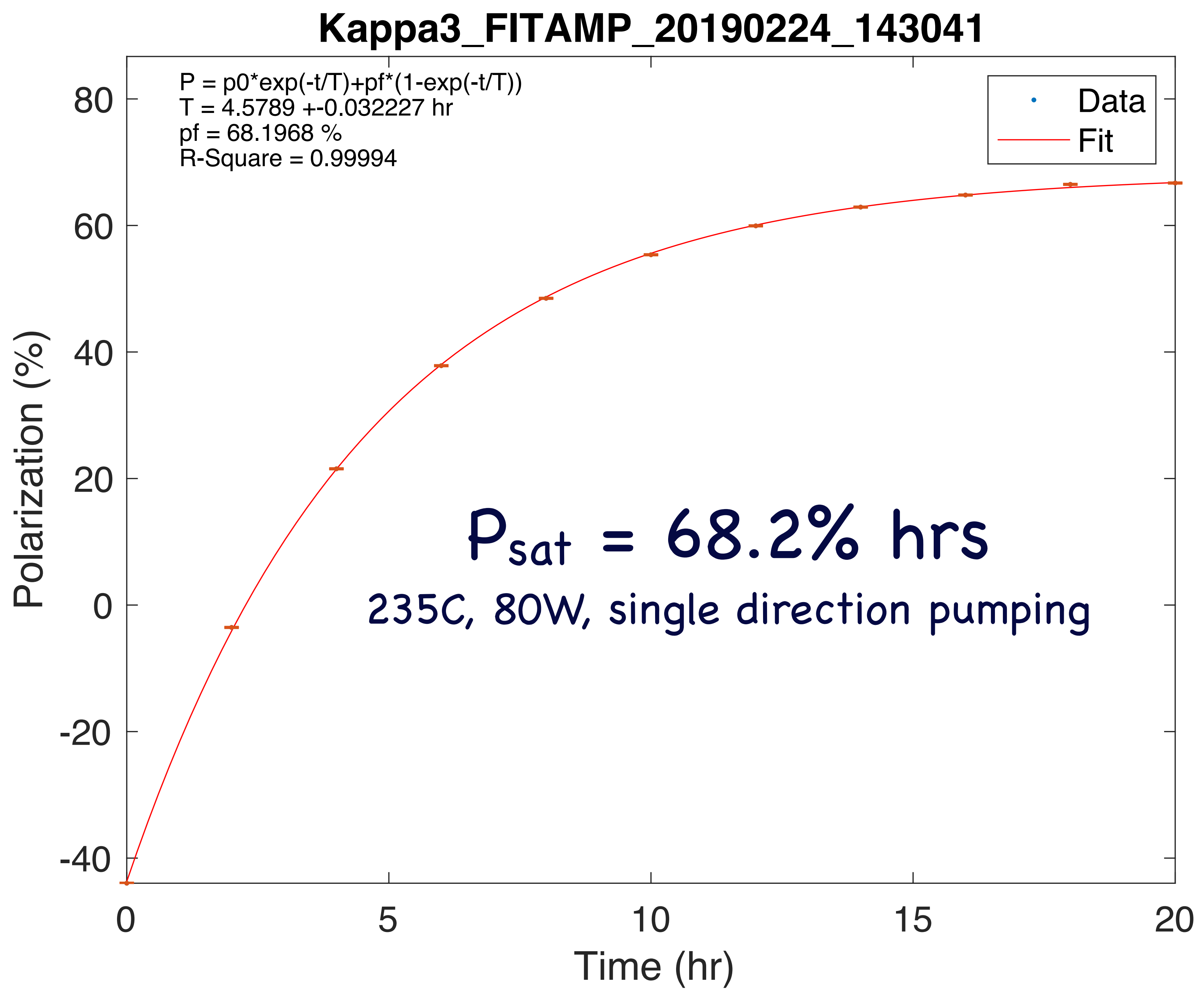
T_1^{cold} = 122 hrs

(Uncorrected lifetime with AFP scan every 4 hours)

Kappa3 - extrapolating cold lifetime to zero AFP losses



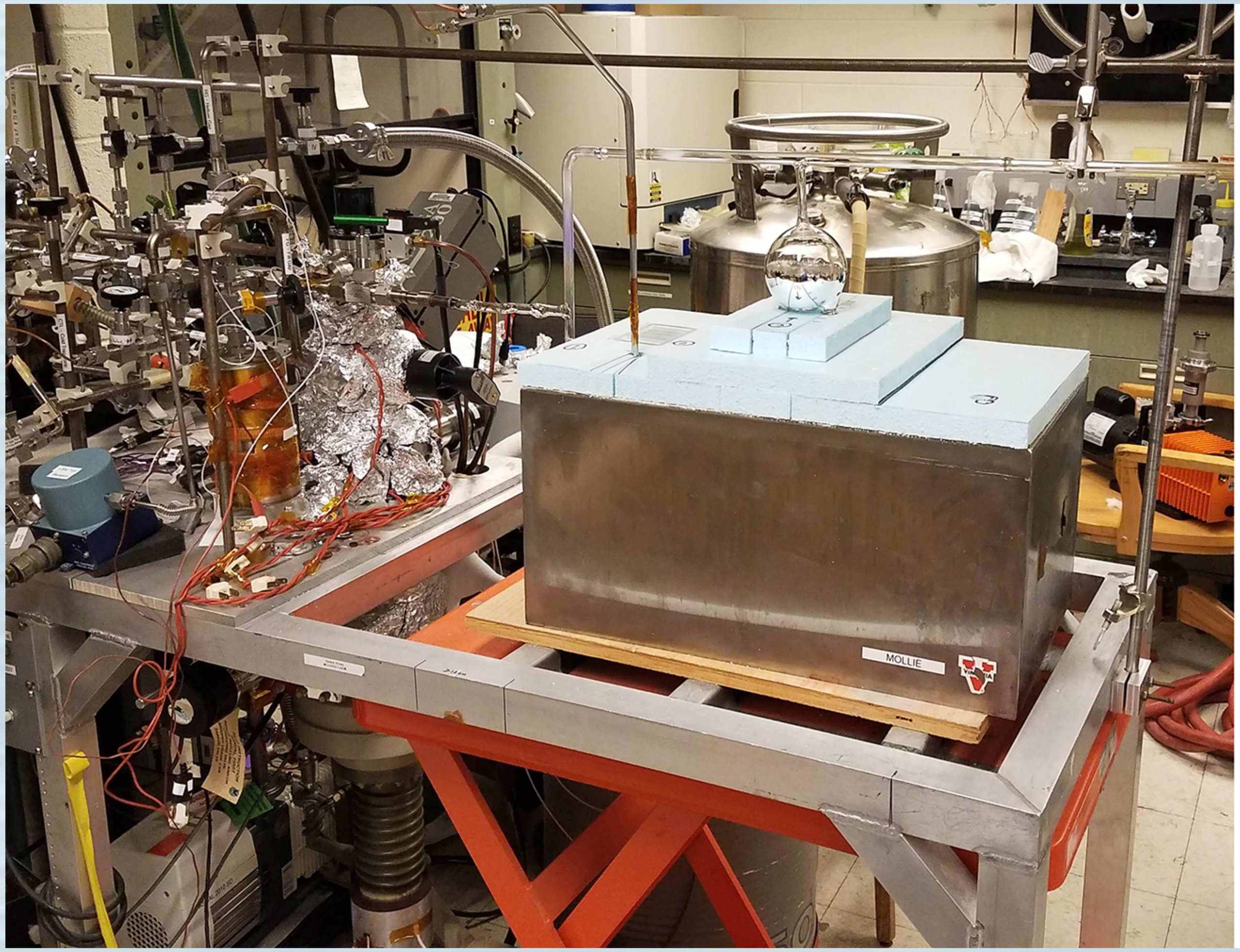
Kappa3 - polarization test

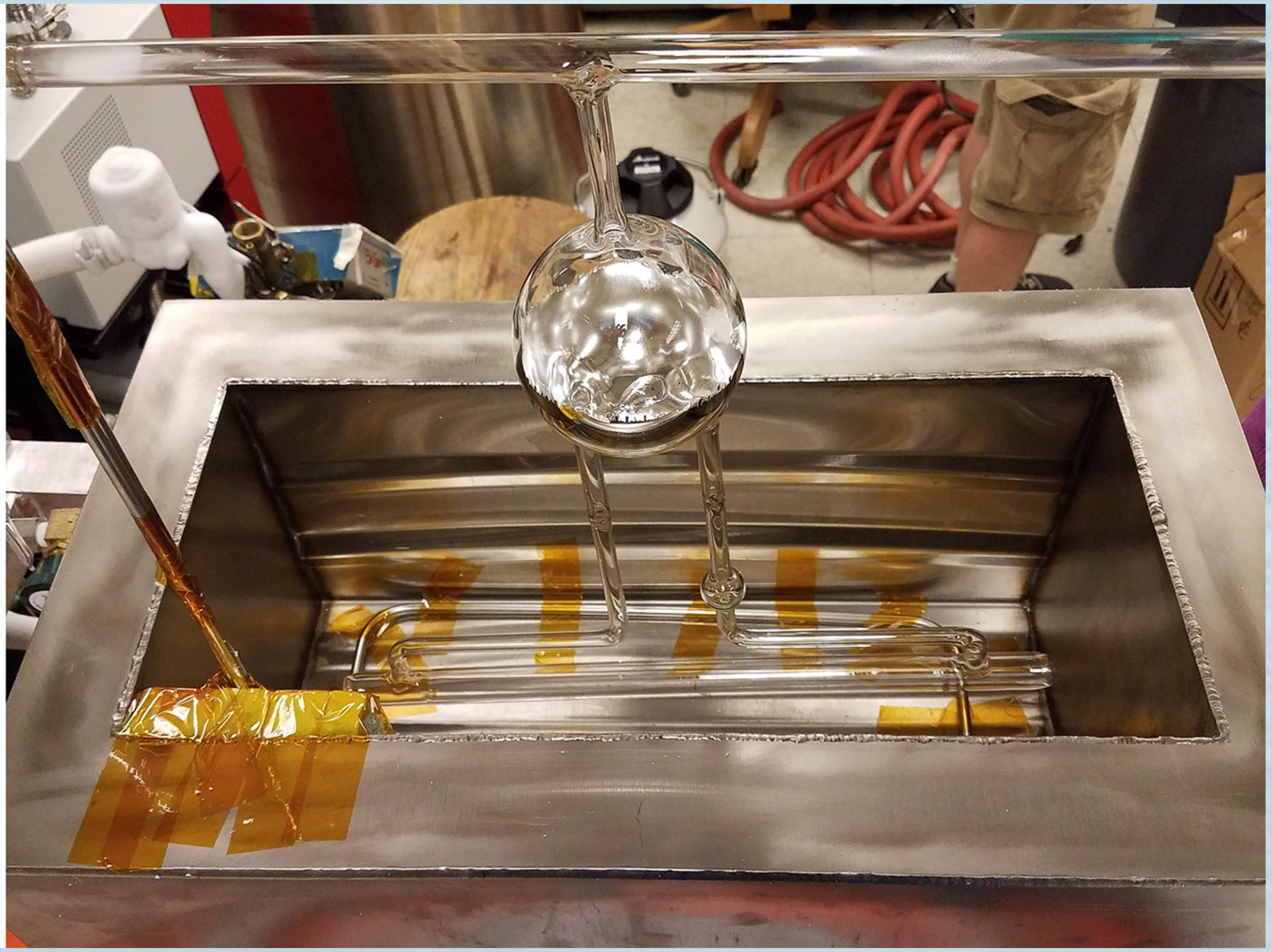


P_{sat} = 68.2% hrs

235C, 80W, single direction pumping

Cell filling apparatus

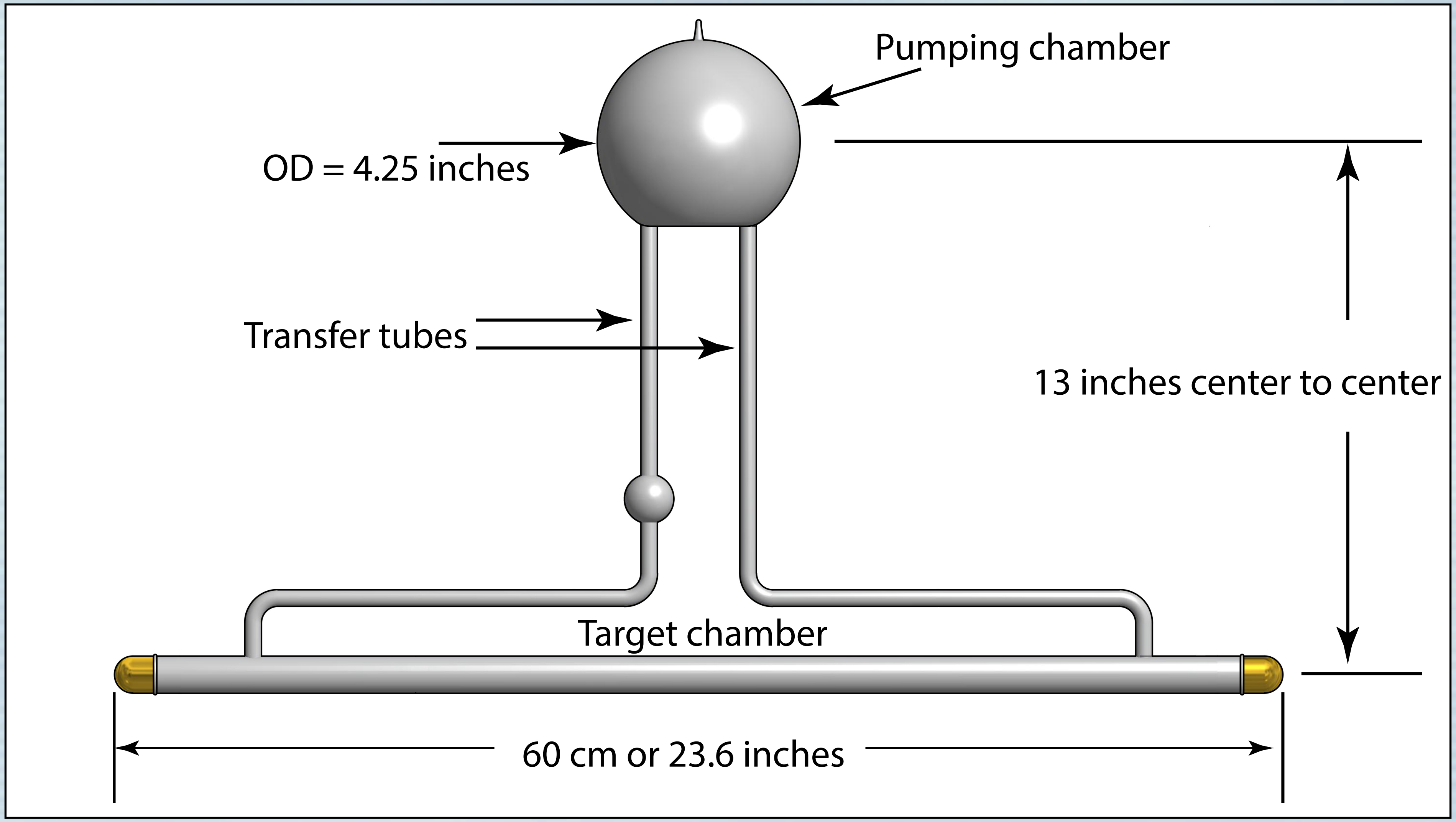




- Stage-I target cells are filled at cryogenic temperatures
- This will change for the Stage-II cells (which is a good thing!)
- Target cell "Noah" is currently mounted on our gas-handling system

SBS G_E^n (Stage-II) cell development

The SBS G_E^n (Stage-II) target cell design



Predominantly three differences with Stage-I target cells:

- Contains <u>**6**</u> STP liters of He^3 instead of 3 STP liters
- Metal end windows on the target chamber
- 60 cm target chamber instead of 40 cm

Incorporating metal into spin-exchange polarized ^{3}He target cells

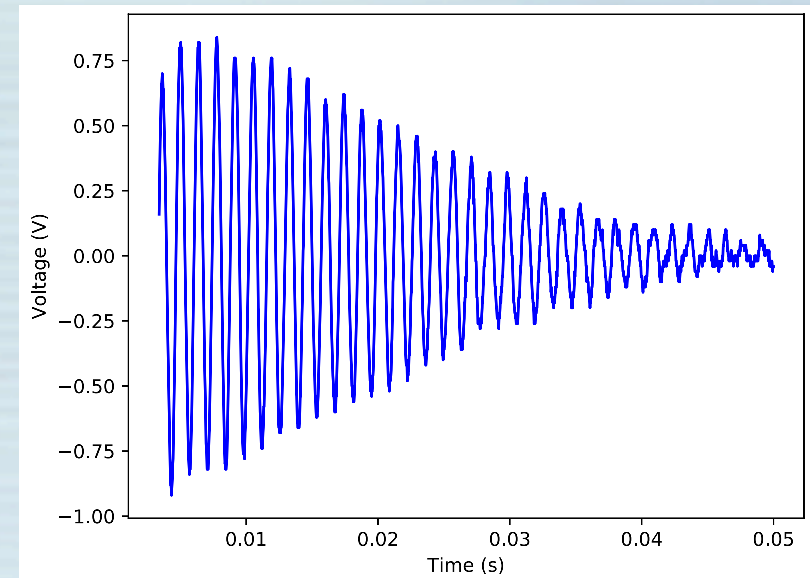
Nuclear spin relaxation of ^{3}He in glass and metal containers used for spin-exchange optical pumping — version 9.1*

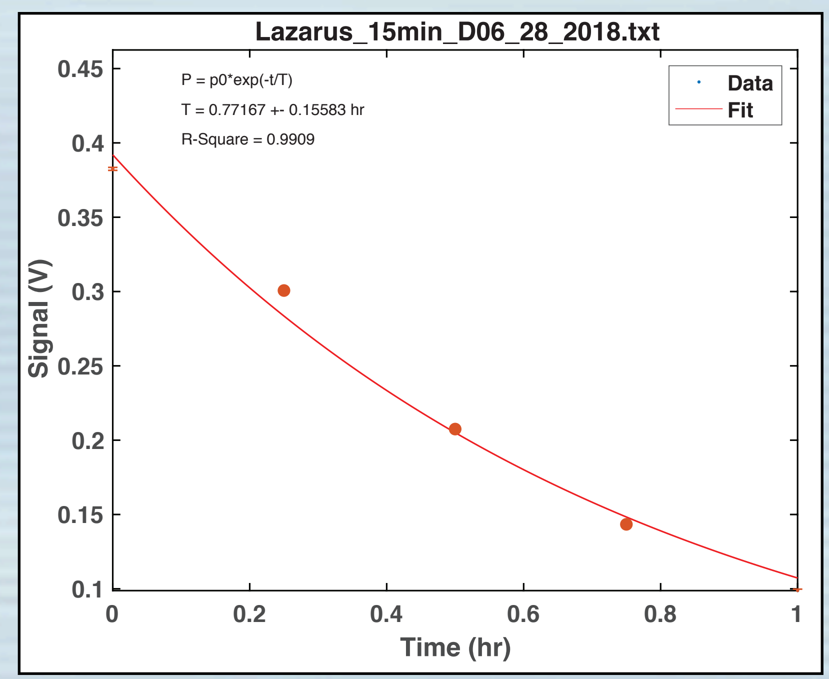
Daniel Matyas, Sumudu Katugampola, Yunxiao Wang, Maduka Kaluarachchi,
Peter A. M. Dolph, V. Nelyubin, W.A. Tobias, and G.D. Cates†
University of Virginia, Charlottesville, VA 22903
(Dated: August 22, 2018)

We present studies of nuclear spin relaxation of ^{3}He that has been polarized using spin-exchange optical pumping and that is contained in sealed cells made out of glass and metal. Our results show

- Just incorporating metal, let alone a thin end window, was a significant challenge.
- That long sustained effort that resulted in a successful approach.
- Should not contribute more than 1/200hrs spin relaxation rate
- Now focusing on how to use that technology to incorporate a thin metal end-window

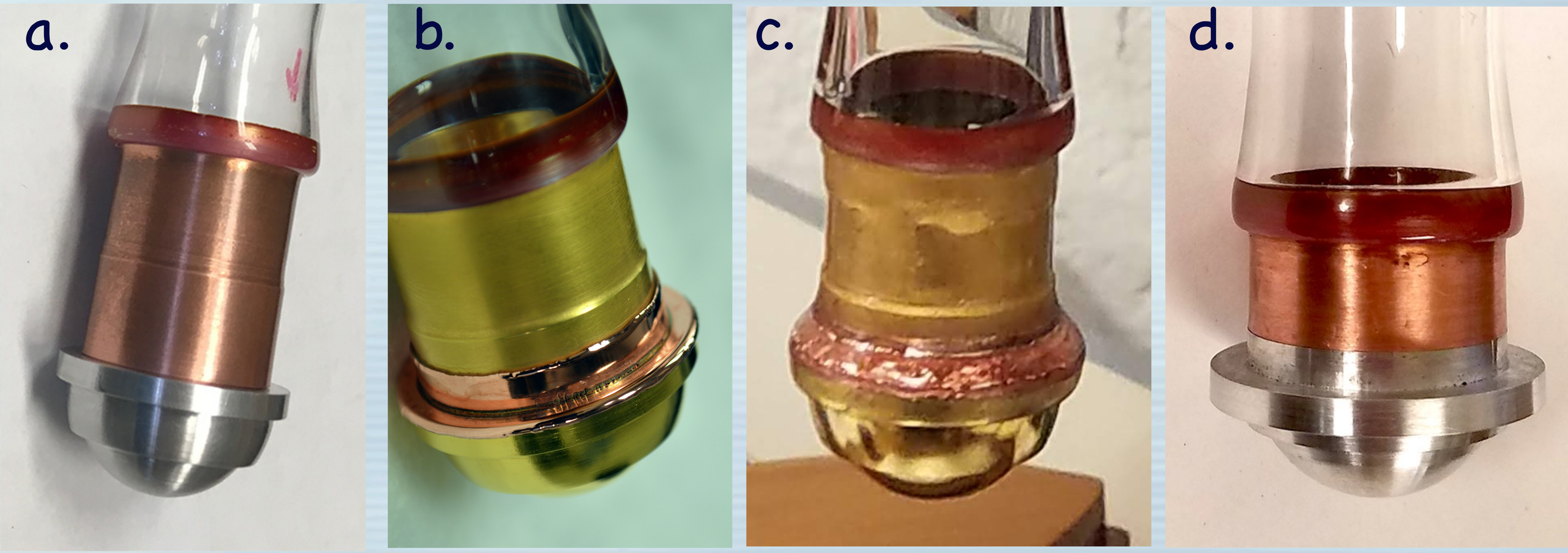
Test of Lazarus - first test cell containing thin (6 mil) aluminum window





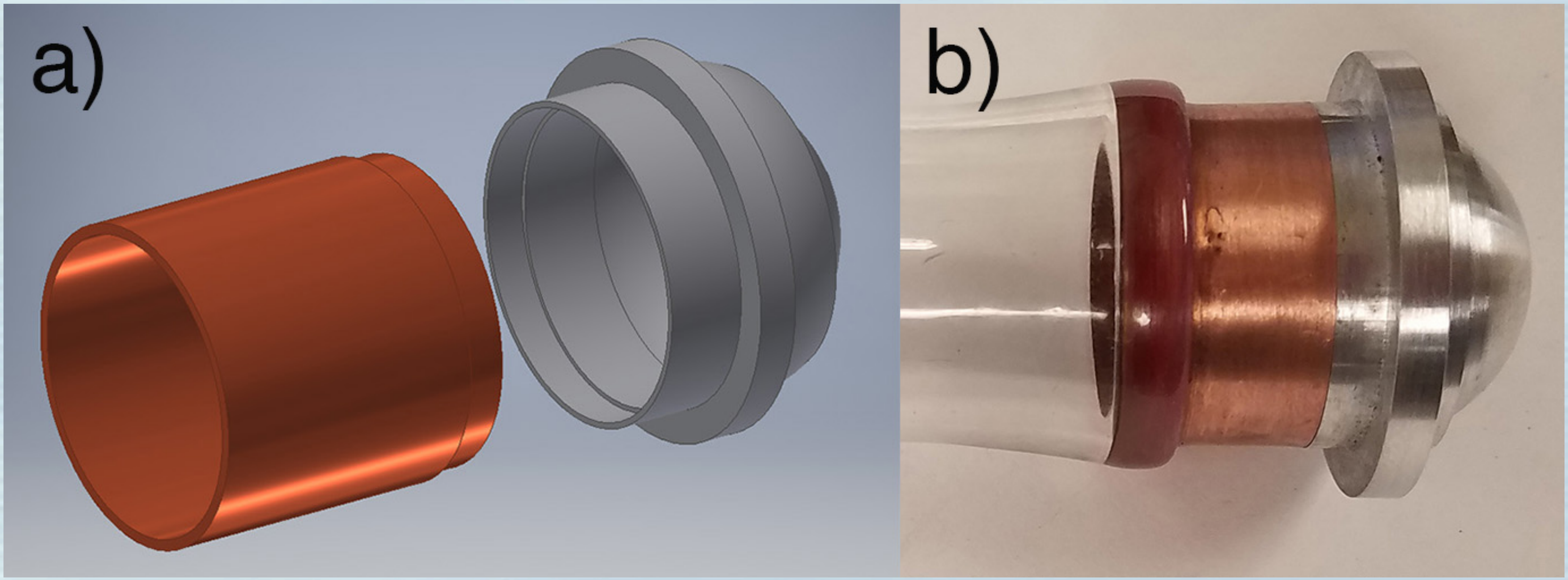
Lifetime was short, but there were multiple problems with the cell, so we considered this a partial success.

Comparing Mark-I and Mark-II window assemblies



a. Mark-I design prior to “electro-welding”.
b. Mark-I design after electro-welding.
c. Mark-I design after repairing leaks.
d. Mark-II design that eliminates the aluminum/copper junction occurring at an inside corner.

Mark-II window assembly design and pieces before processing

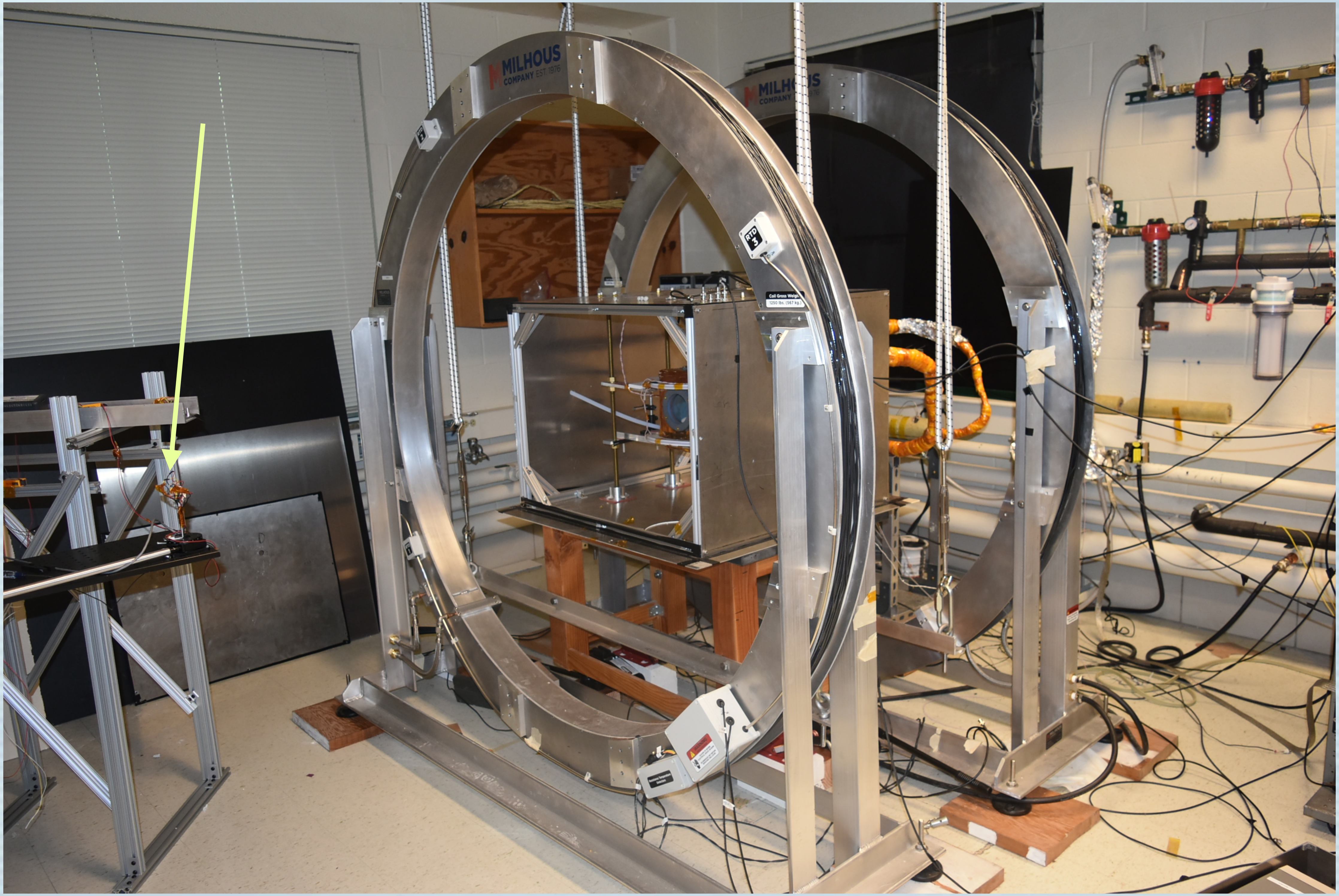


Mark-II window assembly ready to be incorporated into a test cell

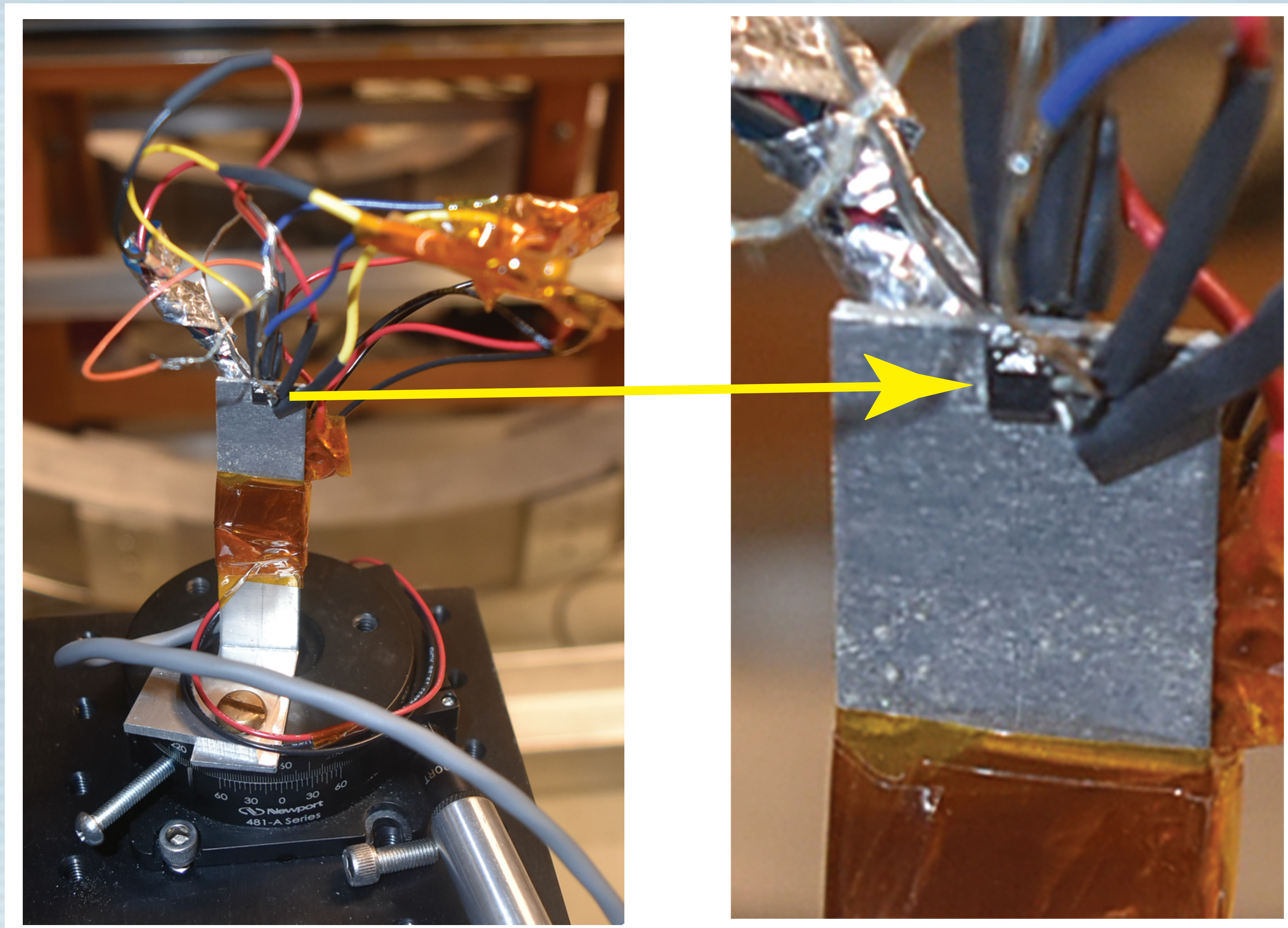
- Effort on hold until we produce two additional high-quality Stage-I target cells for A_1^n

For SBS G_E^n, we need to know the direction of the magnetic field at the level of roughly 1 milliradian

Setup to test new approach to measuring magnetic field direction

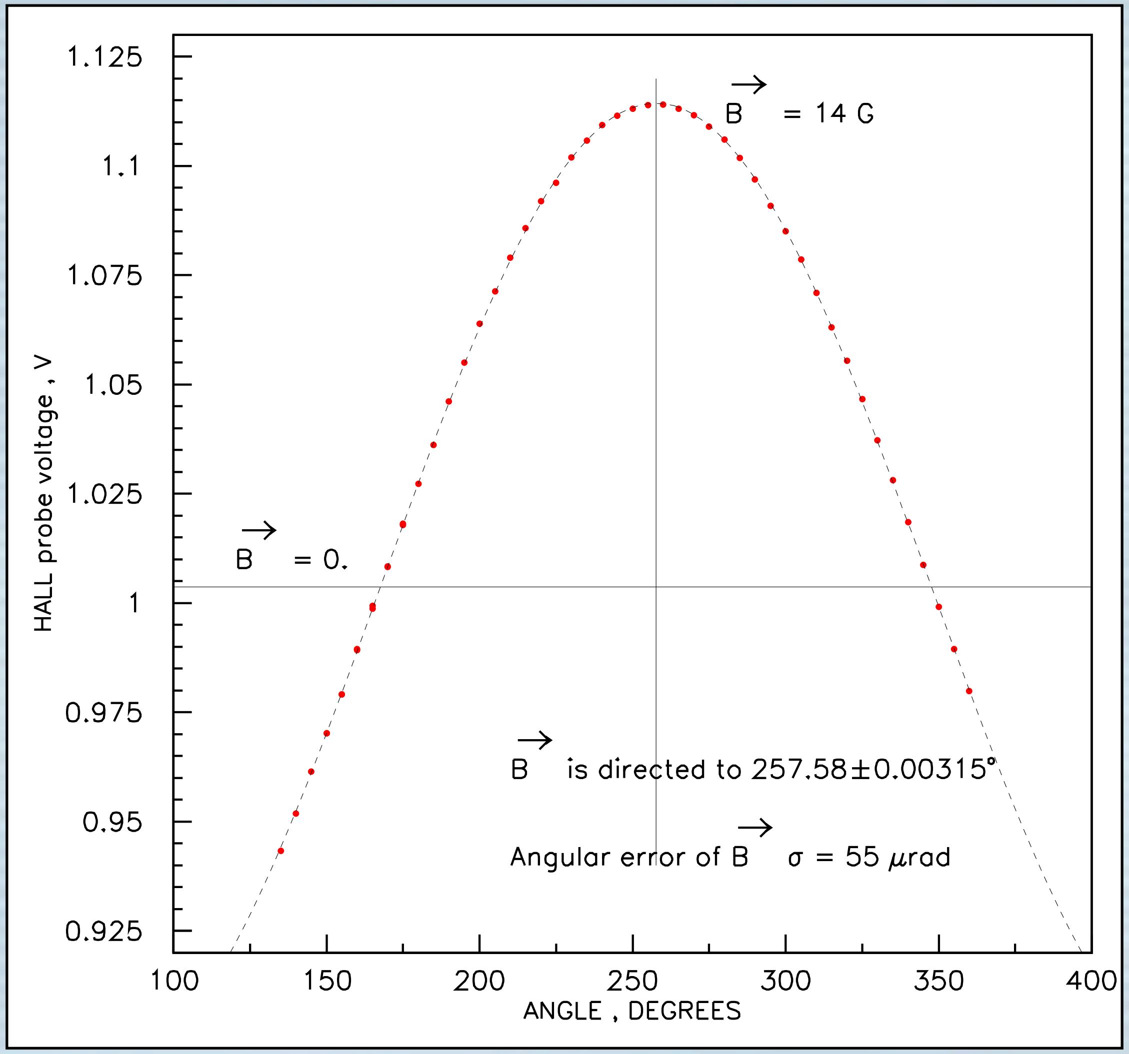


Hall Probe field-direction measurement



Shown is the Hall Probe mounted on a precision rotation stage for sensitivity study.

Field direction measurement



- Hall Probe is mounted on a precision optical rotation stage.
- Measure Hall Probe voltage many times at 10 Hz using 16 bit ADC for each angle.
- Build histogram of voltages (for each angle), and fit for central value and sigma.
- Plot voltages versus angle, and fit to voltage = $A_{offset} + A_{gain} \cos(\theta + A_{shift})$
- Sigma = 55 microradians !
- The technique looks solid, still needs absolute calibration with known magnetic field and implementation to incorporate into the target system.

Status and plans

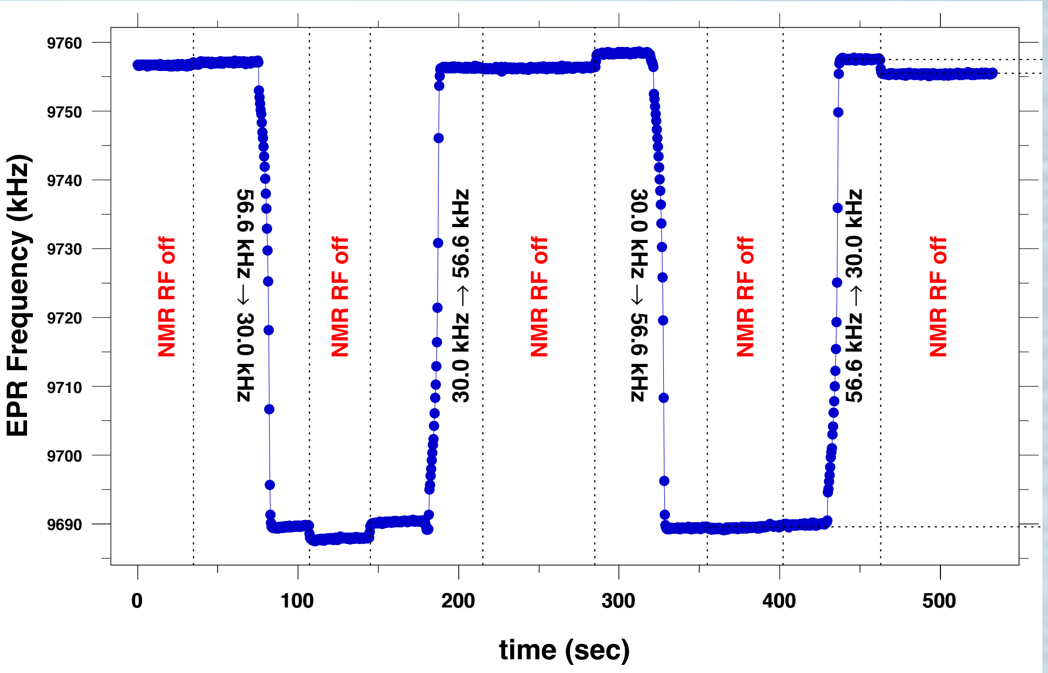
- Produce two high-performance Stage-I target cells before resuming Stage-II work.
- Test the Mark-II thin aluminum end window.
- Produce a 3-liter version of the GEn (Stage-II) target cell.
- Produce first full Stage-II target.
- Production of Stage-II targets
- Need to fully implement magnetic-field measurement technique (i.e. how will we do it during the experiment)

Polarimetry and measuring an updated value for κ_0

EPR polarimetry requires accurate knowledge of the atomic parameter κ_o

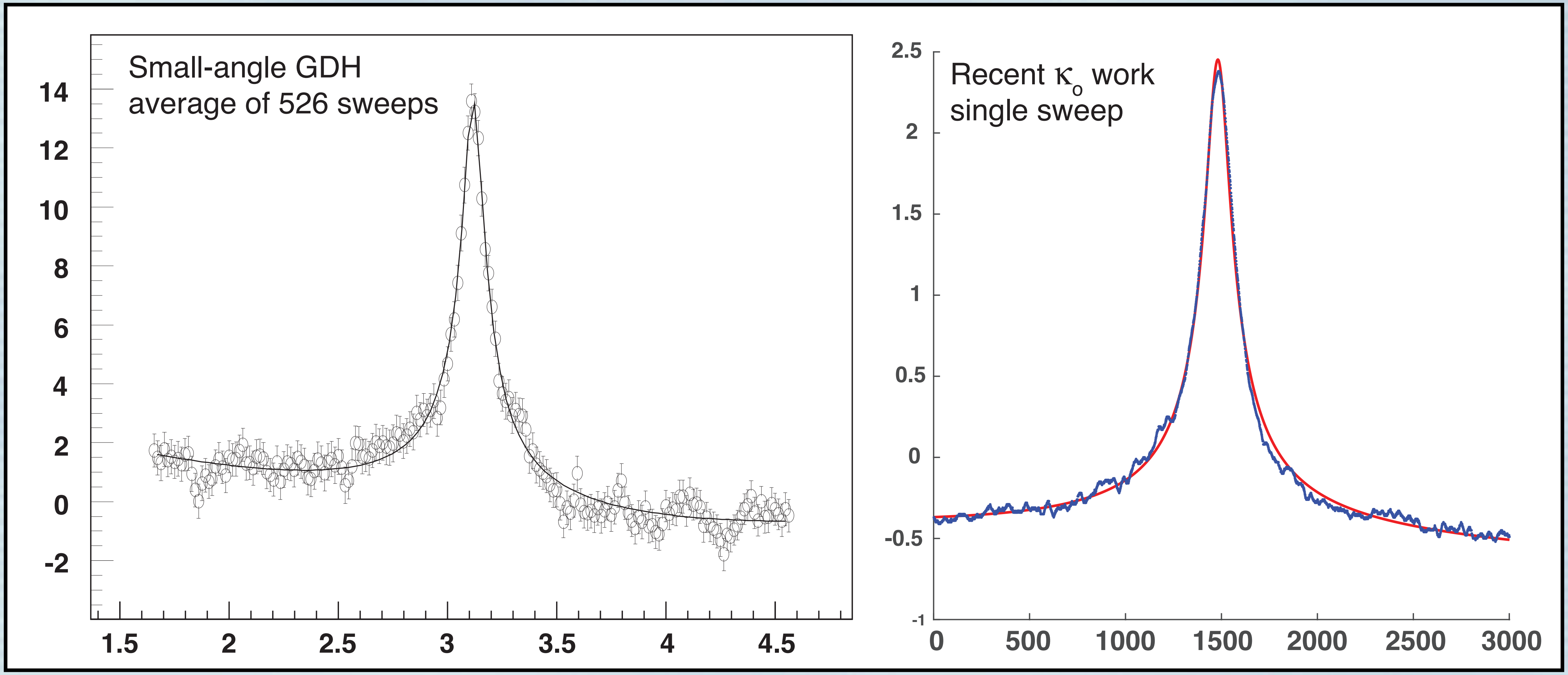
$$\Delta\nu = \frac{8\pi}{3}\frac{\mu_B g_e}{h(2I+1)}\left(1 \mp \frac{8I}{(2I+1)^2}\frac{\mu_B g_e B}{hA}\right)\kappa_0 \mu_K [\mathrm{He}] P$$

κ_0



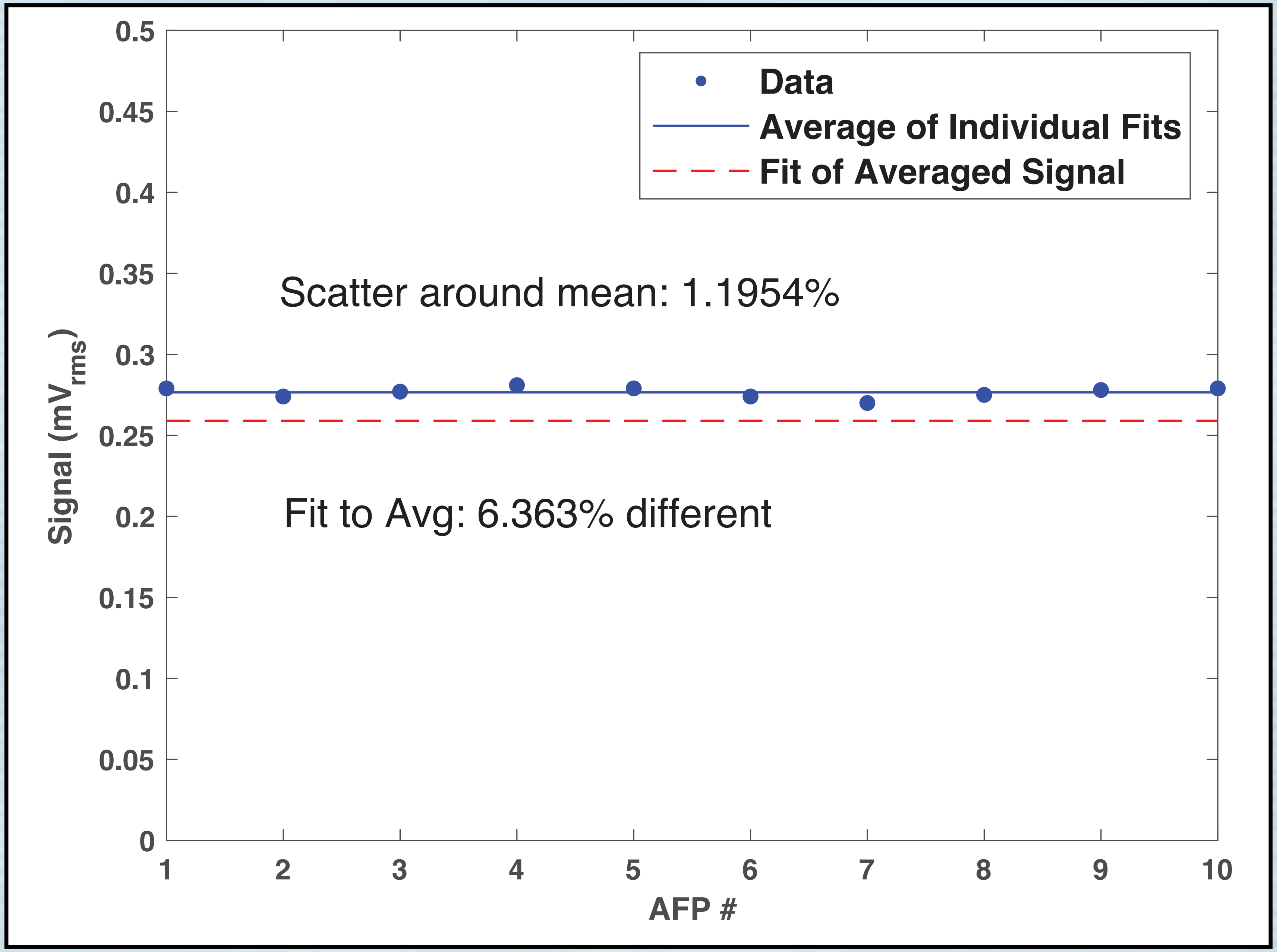
- RF generator is locked to a Zeeman transition in one of the two alkali species (K or Rb).
- The transition frequency is shifted due to the effective magnetic field of the polarized ^{3}He.
- By flipping the ^{3}He spins with respect to the holding field, the resulting frequency shift provides an absolute calibration of polarization.
- Interpreting the frequency shift requires knowing κ_o .

Our current approach for determining κ_o: calibrate NMR using water and simultaneously measure frequency shift



From recent work, shown above is a comparison of averaged water signal with a single-shot signal.

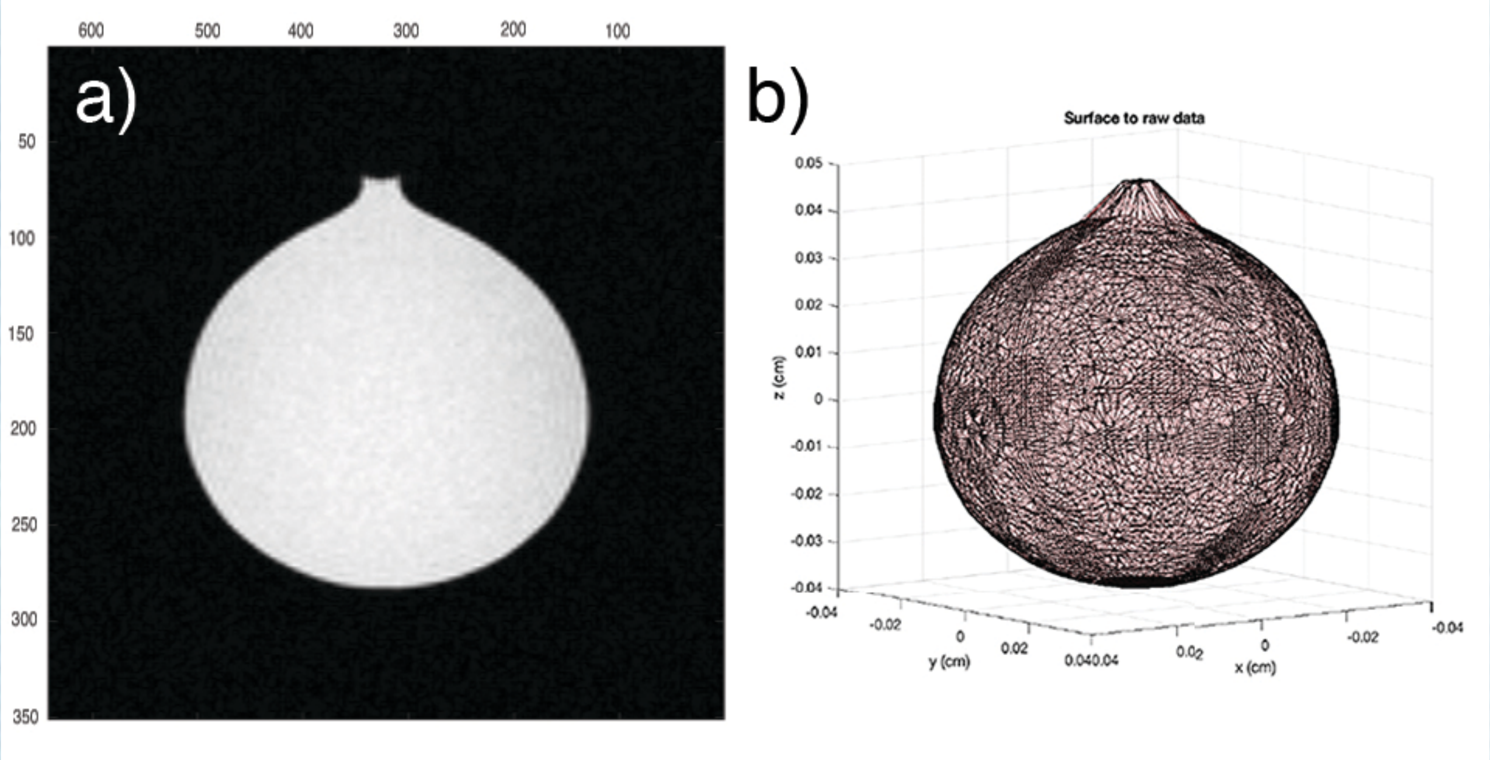
Water calibrations: the average of fits versus the fit of an average



We consistently see a difference up to several percent. I believe all previous water calibrations suffer from this systematic.

Characterizing our water cells

- It is easy to determine the exact amount of water by weighing the cell before and after filling it.
- Nominally, the cell is a sphere.
- The departure of the water cell from being perfectly spherical can affect the resulting signal at a level as large as a few percent.
- To determine the exact shape of the water cell, we acquired a high-resolution MRI scan, the data from which can be fit in various ways.



Characterizing our water cells:
fitting their shapes to spherical harmonics

Jack - Surface Simulation

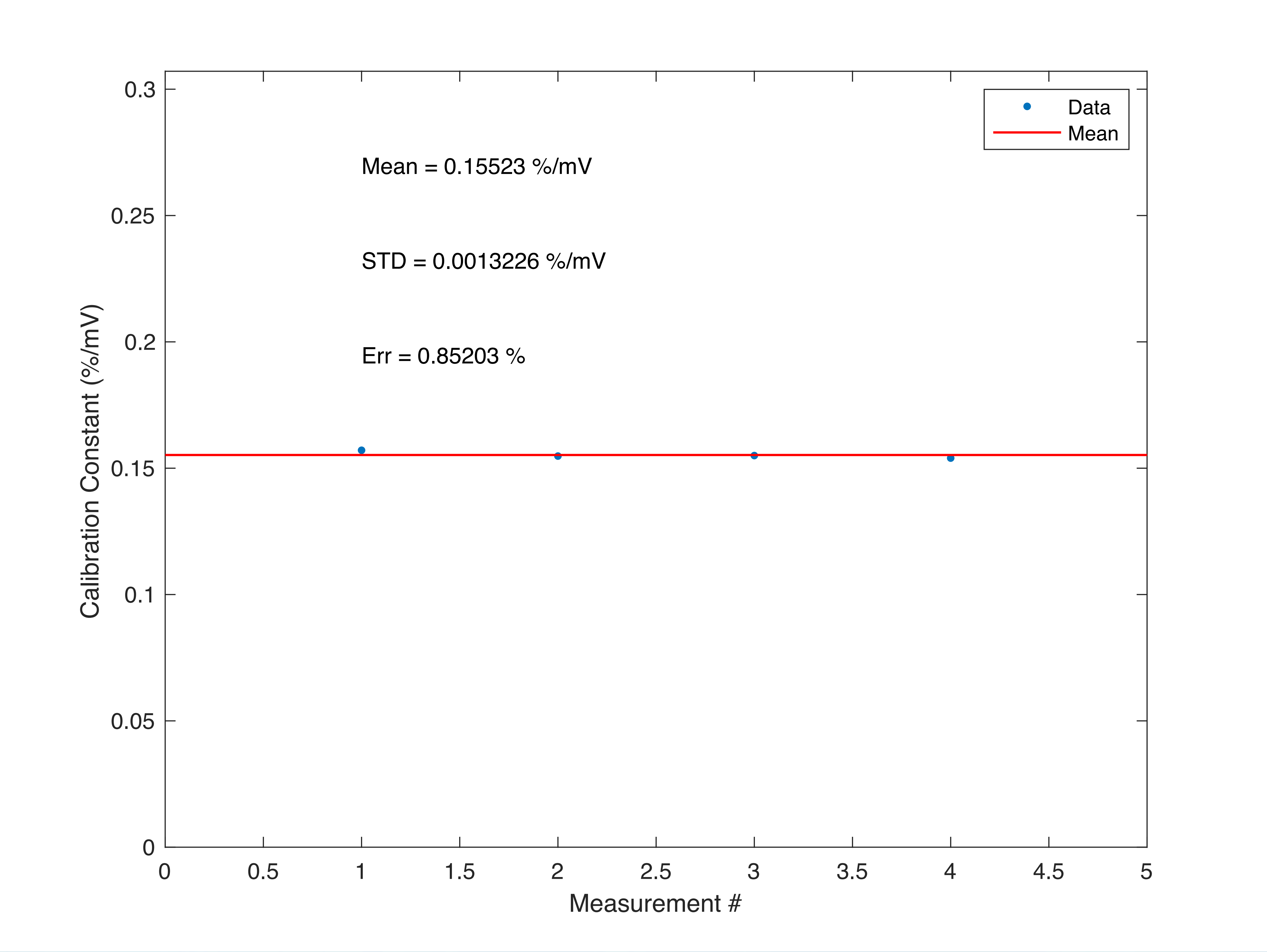
Spherical Harmonic Order fitted up to	Simulated signal from Spherical portion from raw data (V)	Simulated signal from spherical portion after fitting (V)	Deviation of fitted signal size from raw signal (%)	Deviation of fitted signal from that of L = 0 (%)	
L = 0	9.6824E-07	9.5259E-07	1.6163E+00	0.0000E+00	
L = 1	9.6824E-07	9.5389E-07	1.4821E+00	1.3647E-01	
L = 2	9.6824E-07	9.4704E-07	2.1895E+00	-5.8262E-01	
L = 3	9.6824E-07	9.4502E-07	2.3982E+00	-7.9468E-01	
L = 4	9.6824E-07	9.446E-07	2.4415E+00	-8.3877E-01	

Other Information

Signal from stem as a percentage of the signal from spherical portion	0.16%			

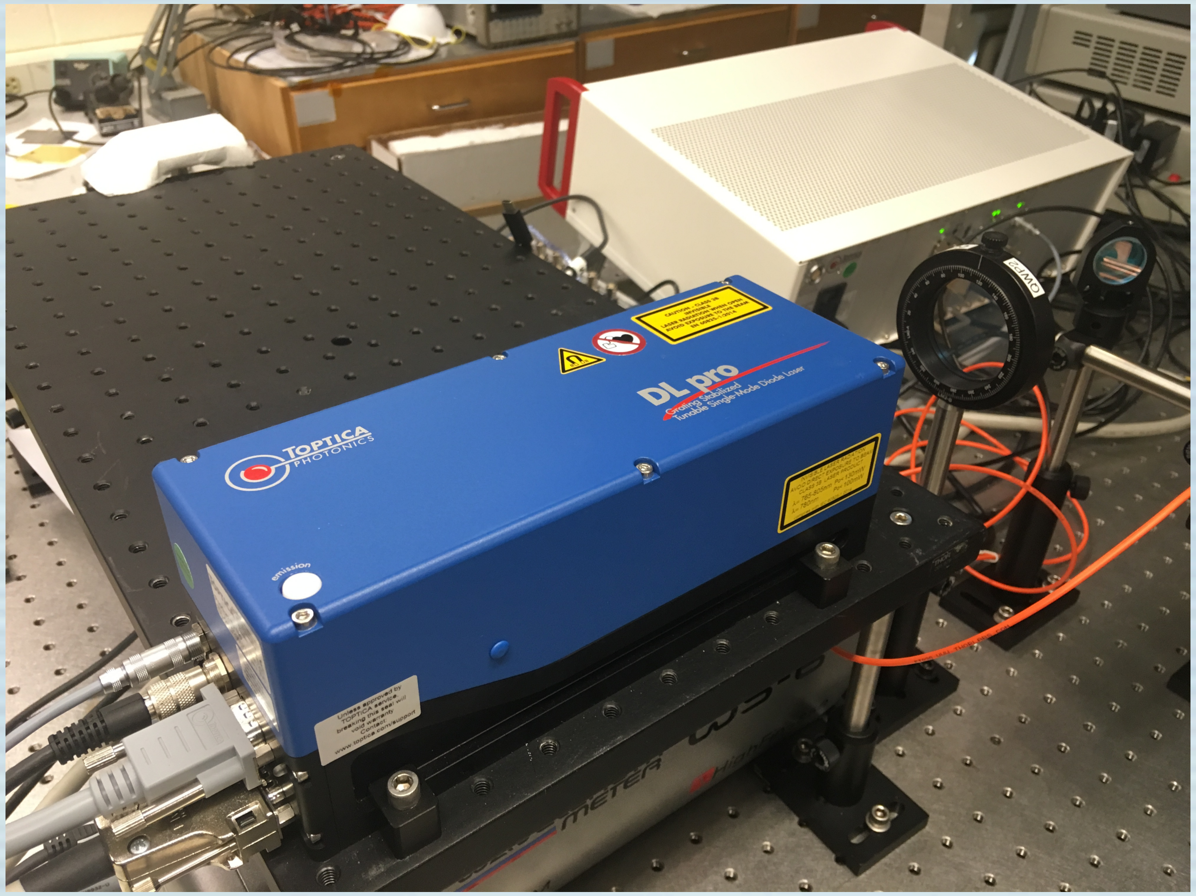
Additional slides

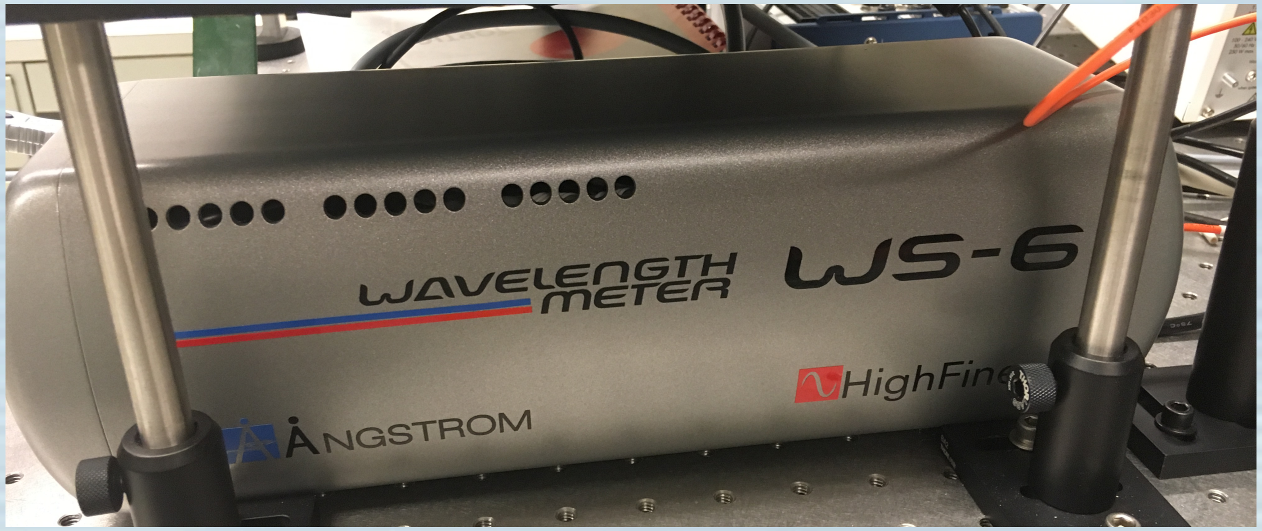
EPR calibration of NMR for Kappa3



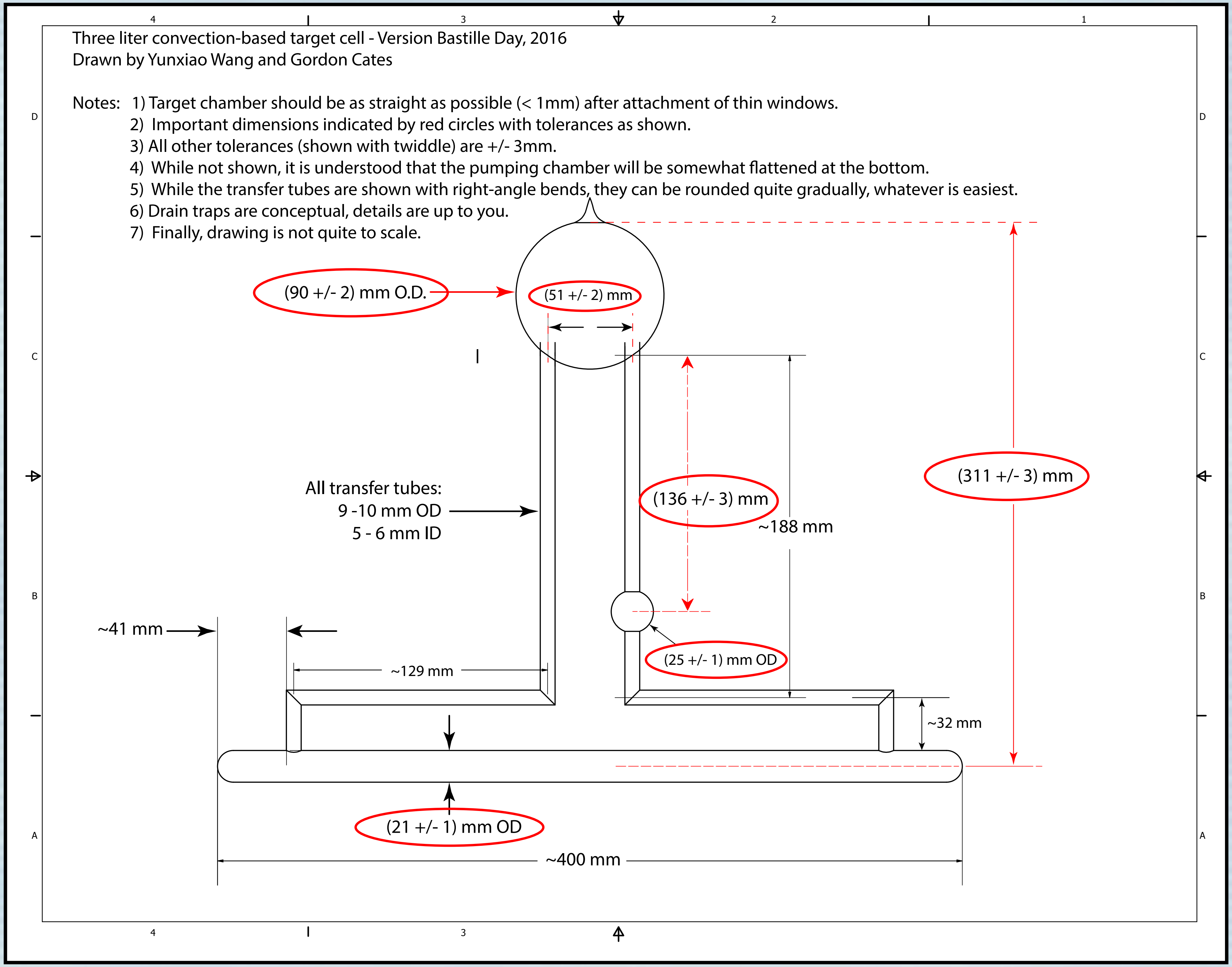
Cell Characterization laser

- Requires a scannable single frequency laser.
- Our Coherent 899-29 is just too old!
- We have obtained a new Toptica DL Pro, scannable from roughly 700 - 800 nm. Roughly 100 mW over our frequency range of interest.



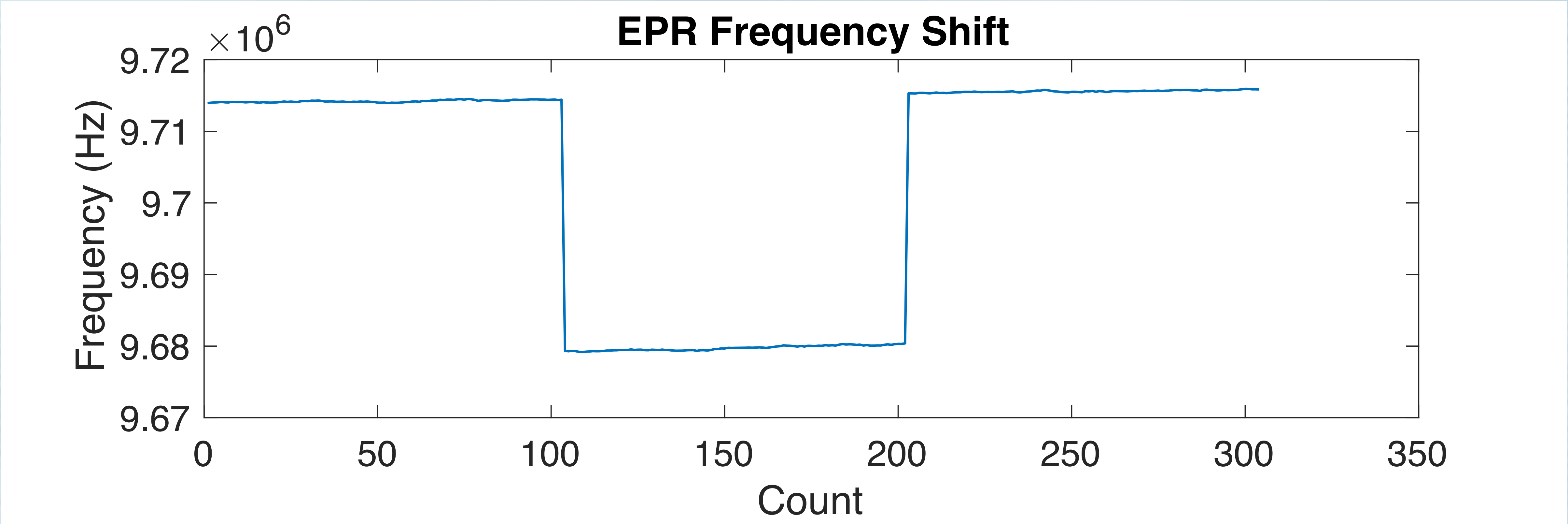


Design of the Hall C convection target



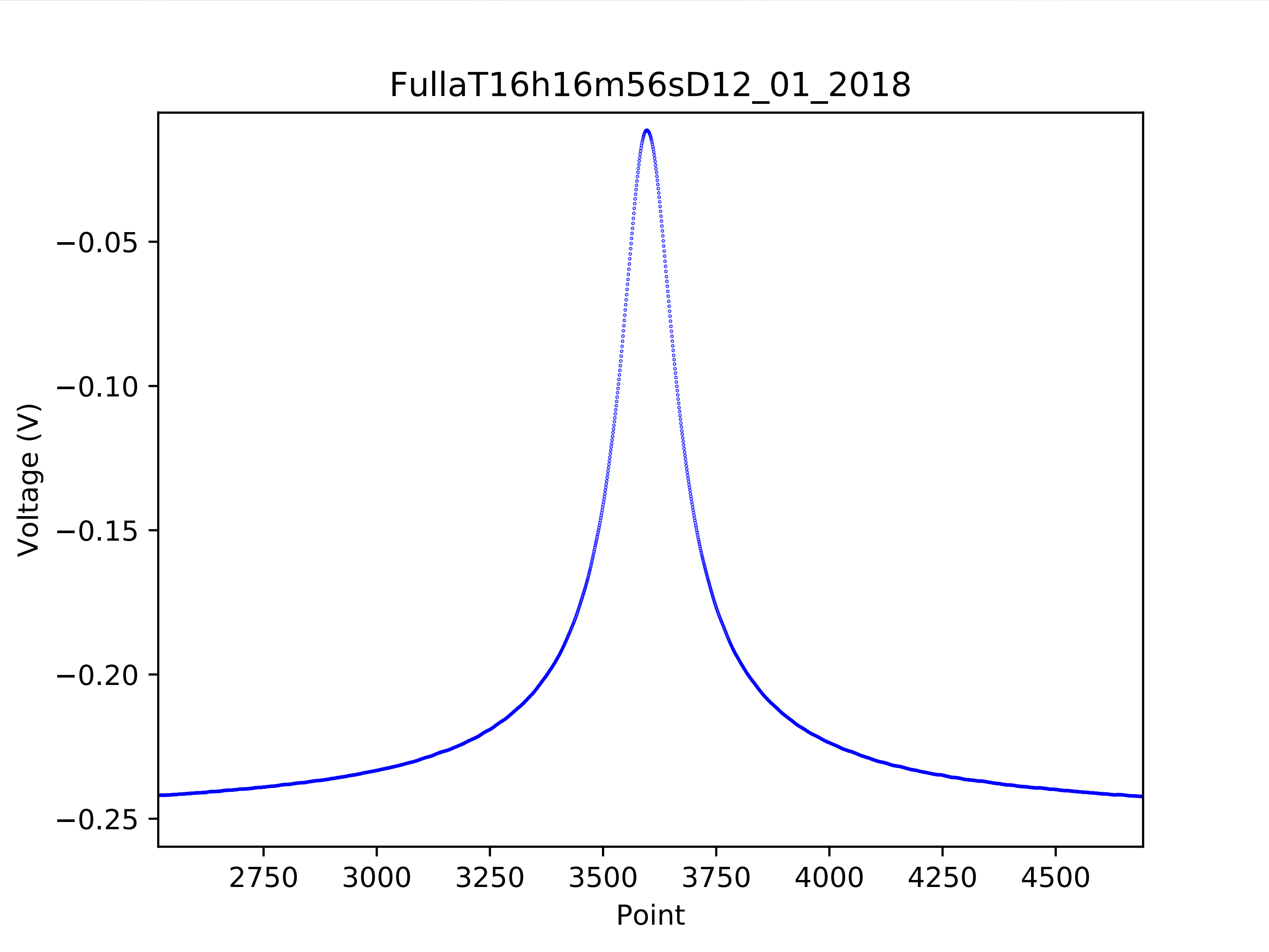
Note that the pumping chamber extends from roughly 22.1cm to 31.1 cm above the center of the target chamber.

Polarimetry in the new test apparatus



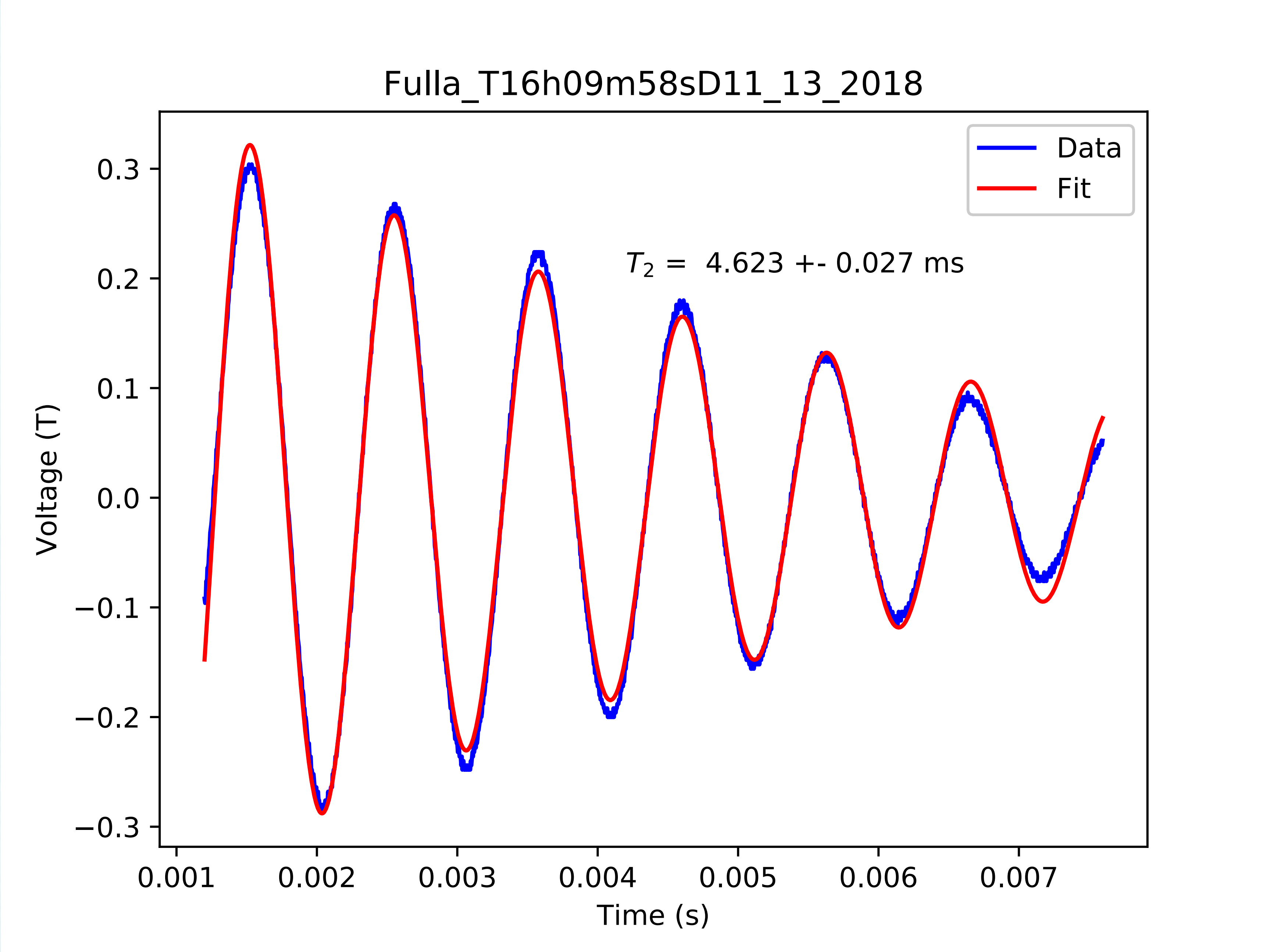
- EPR frequency shifts are, at present, being used for our absolute polarimetry calibration.

AFP measurement

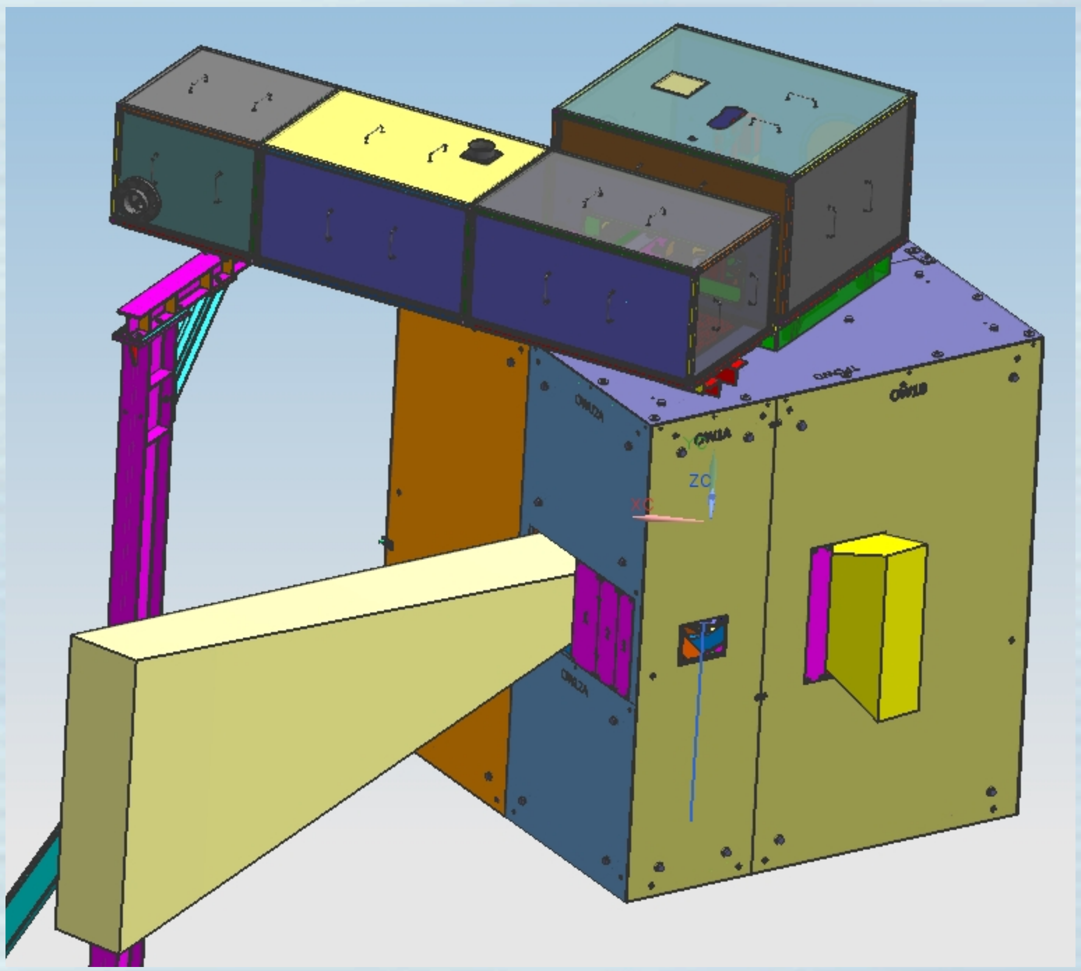


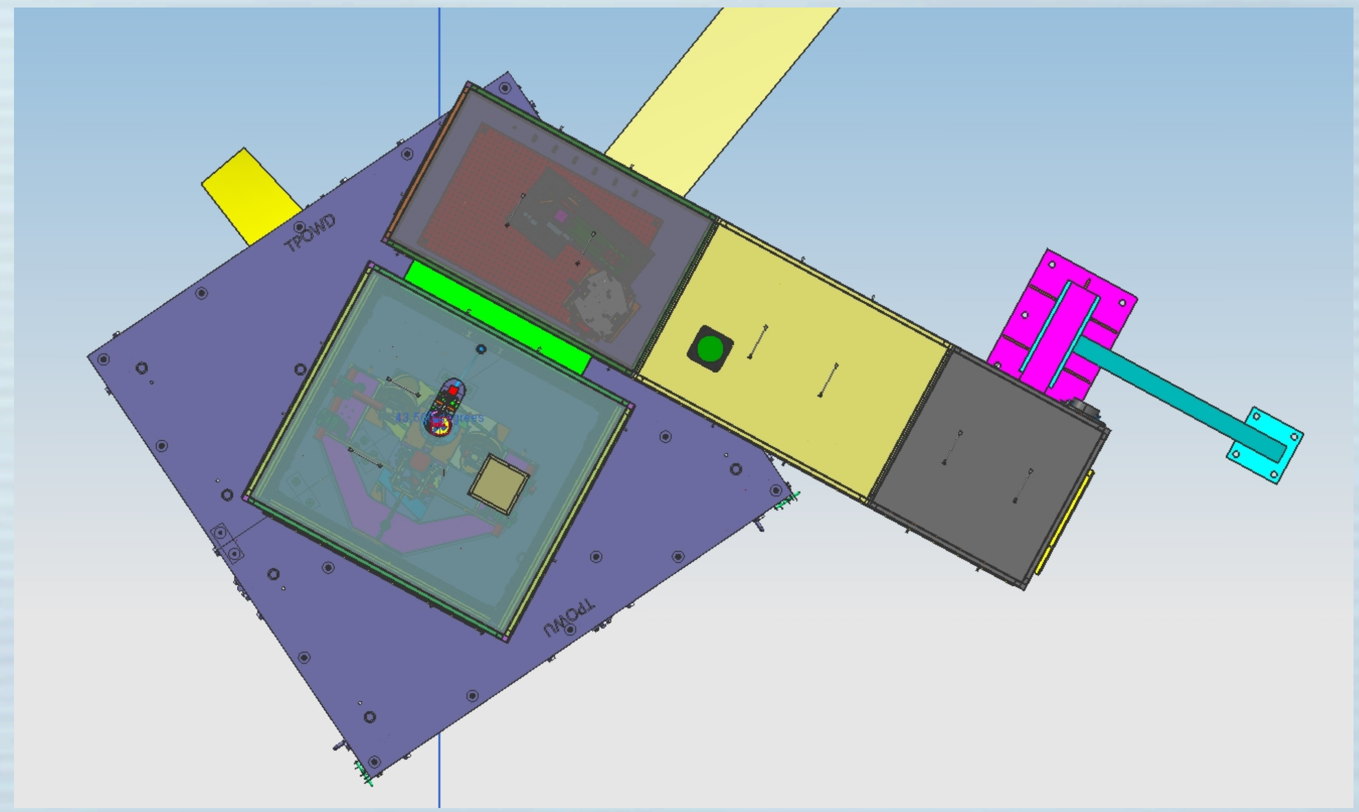
- AFP system is extremely low noise, but losses are large, around 4-7% per scan because of the size of the rf coils and the proximity of aluminum to the target chamber.
- Losses are actually useful when you are simulating be depolarization.
- For spin-downs, we sample at multiple rates to back-out the zero-loss lifetimes.

pNMR signal from



Engineering and design





Overview with magnetic shielding in place