A1n Target Cell Production

and related activities

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)

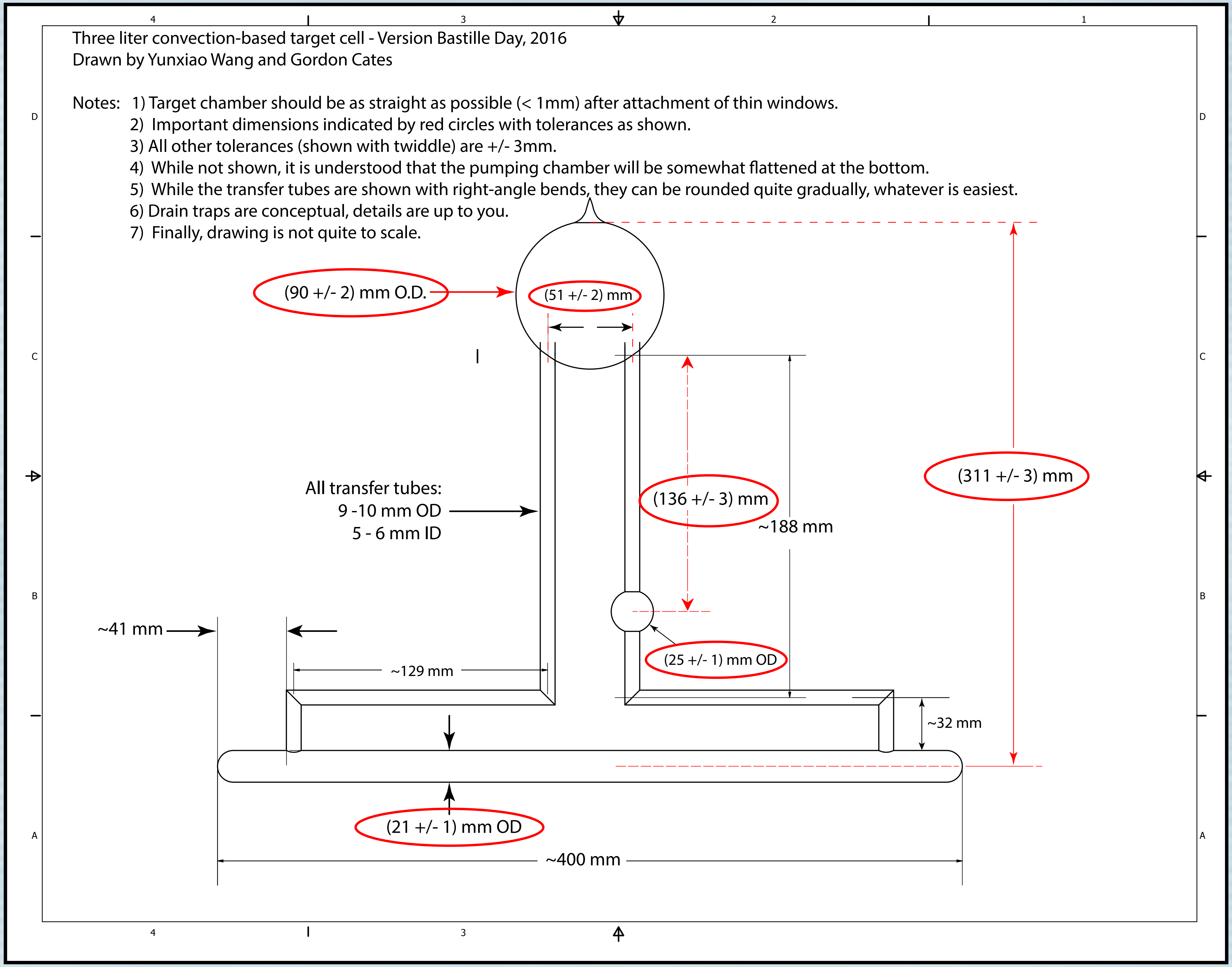
G. Cates – UVa

December 10, 2018

What is required for target cell production ?

- Fabrication of the aluminosilicate glass cells themselves.
  - fabricating thin glass end windows.
  - pressure testing the end windows (have tested a new batch recently).
  - fabricating the full cell.
- Filling and sealing the glass cells.
  - assembling the cell manifold on the vacuum system and and baking.
  - filling with hybrid alkali mixture.
  - cryogenic filling and pull-off.
- Bench testing the finished target cells.
  - Cold spin-down tests.
  - Full polarization tests.
  - Simulated beam tests.
  - Faraday-rotation tests, alkali-vapor polarization, K/Rb densities and ratio, X-factor, etc.
- Characterizing the finished target cell using a single-frequency laser.
  - Pressure broadening measurements to determine the pressure and the ratio of K to Rb.
  - Interference measurements of glass thicknesses.

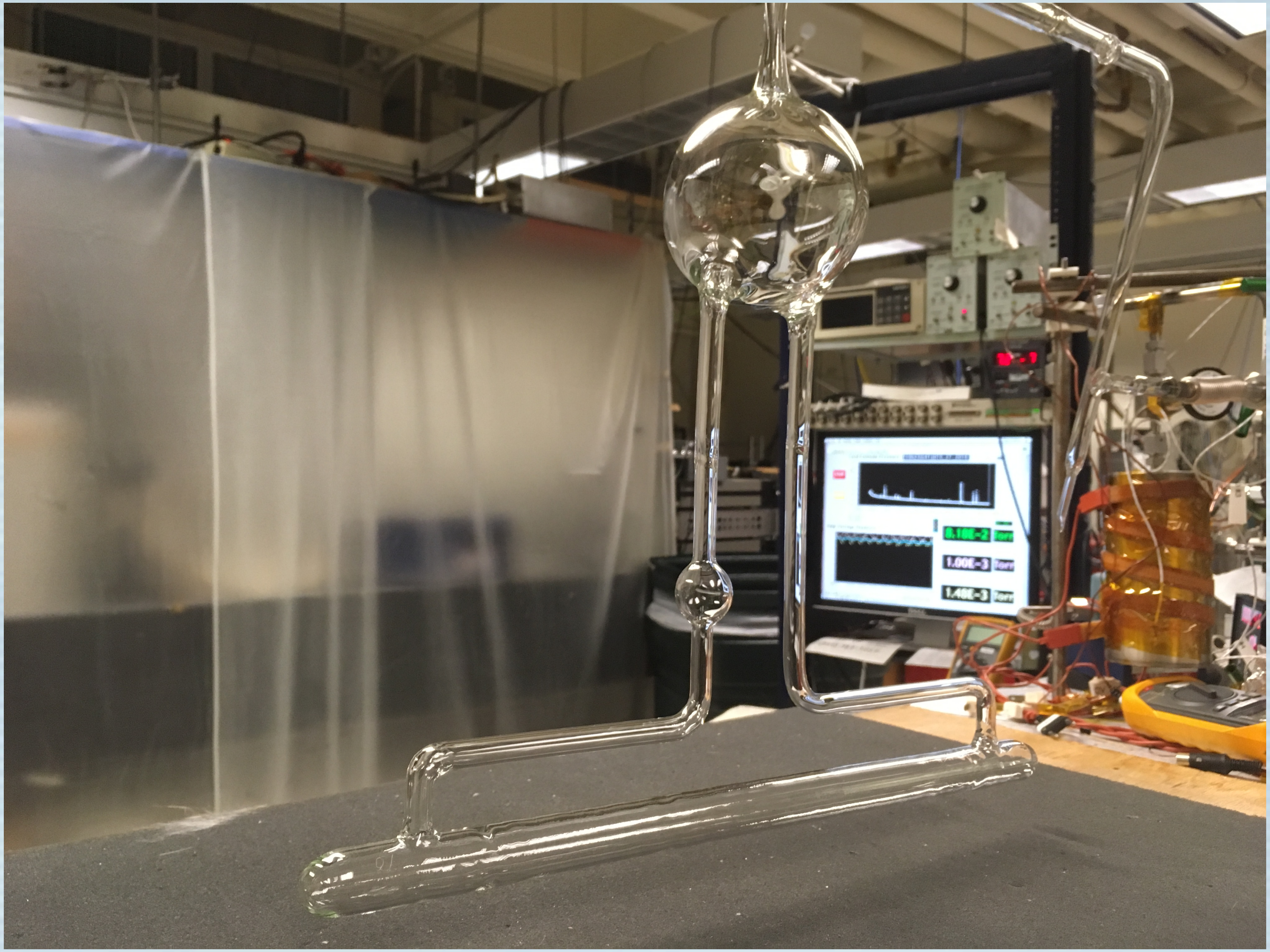
Design of the Hall C convection target



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

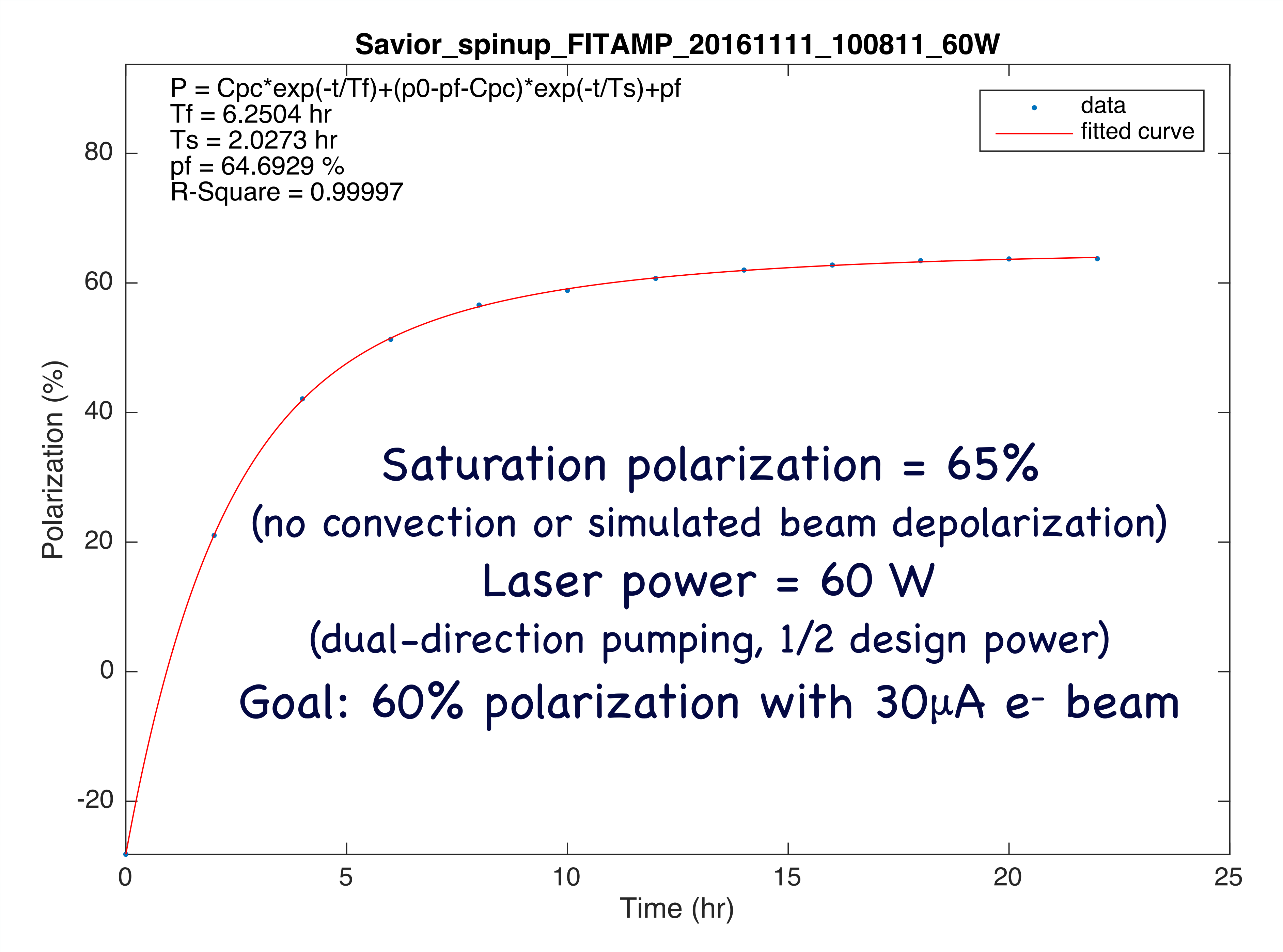
Cell filling activity

First production A_1^n target: Savior



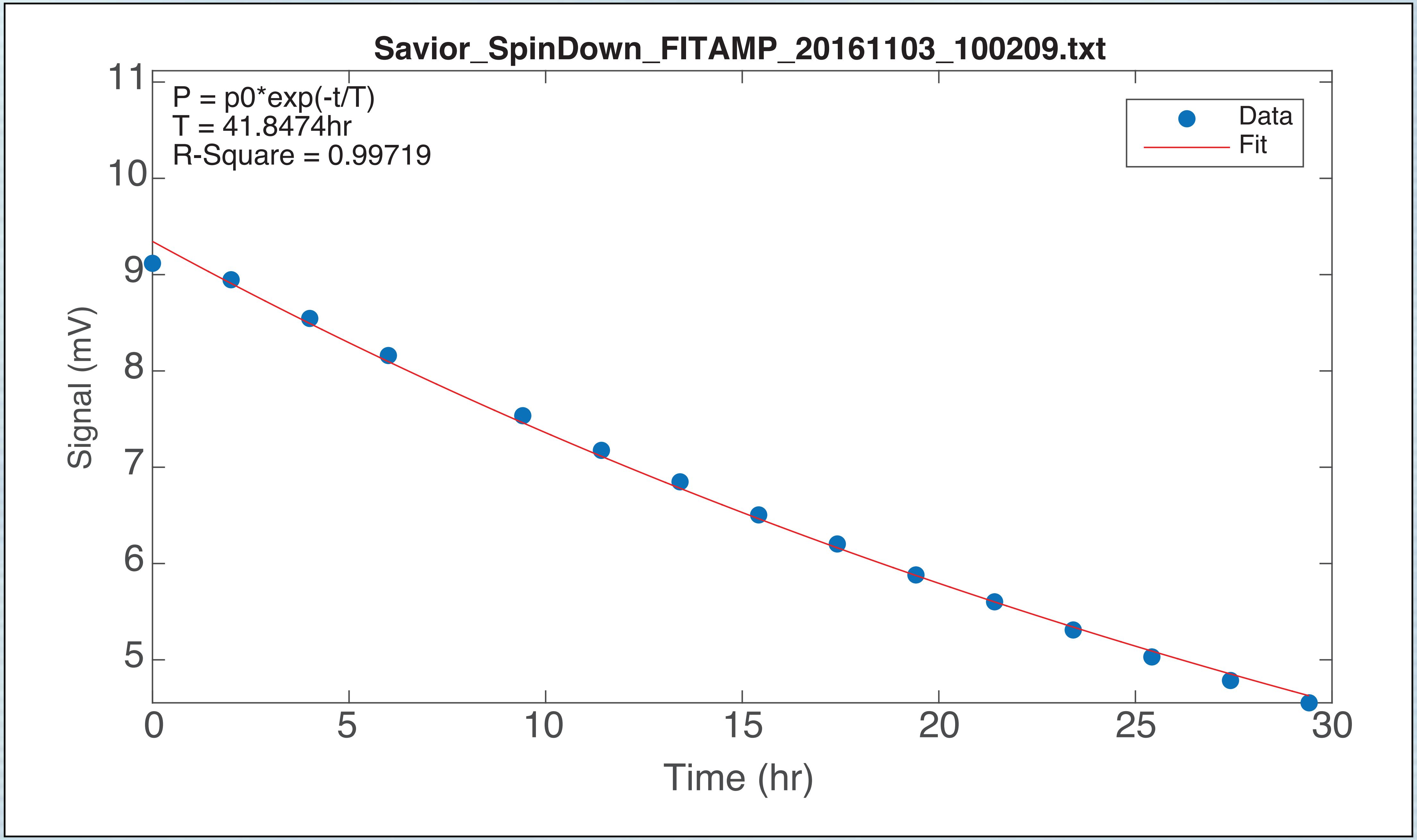
On the gas system prior to being filled.

Polarization test of Savior

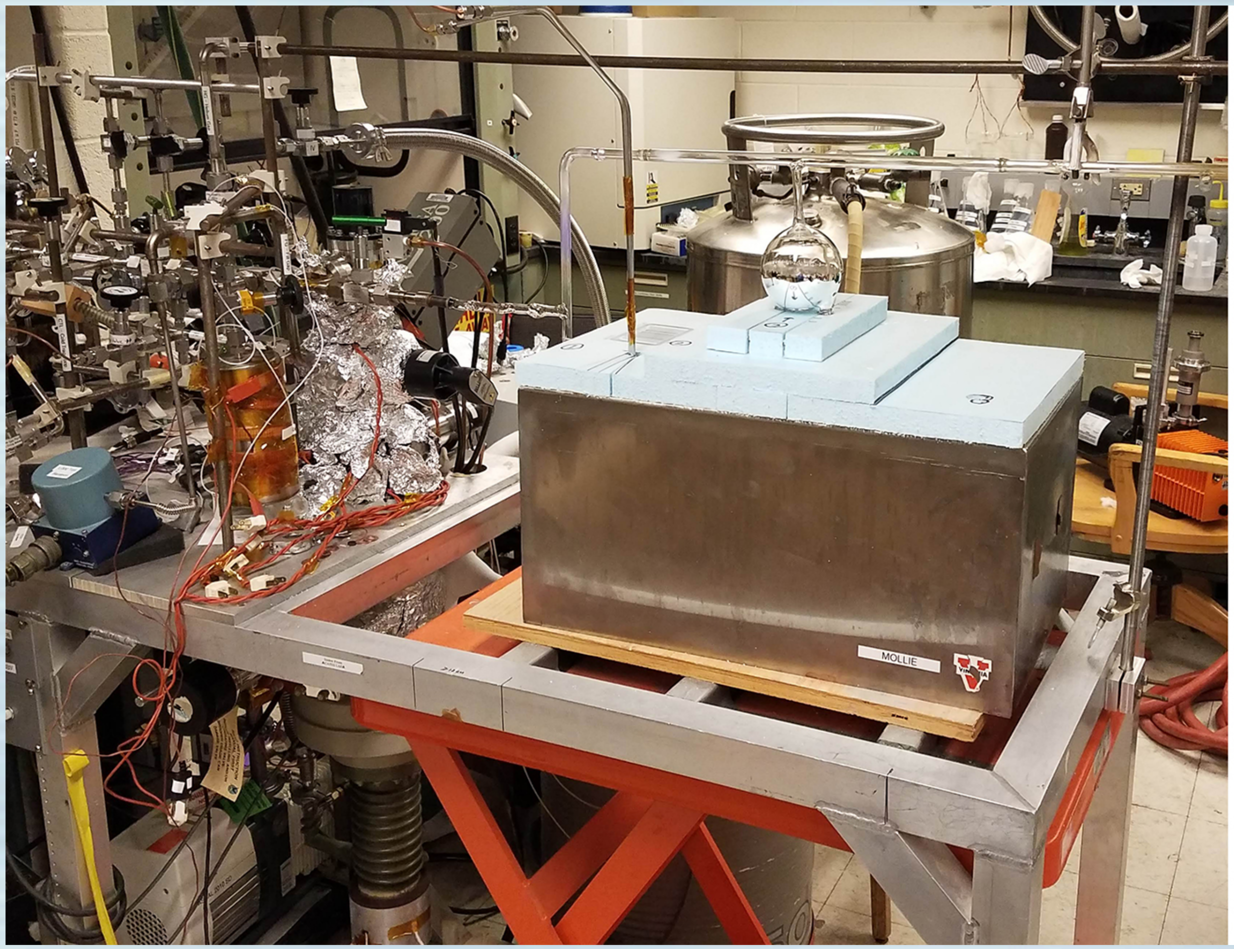


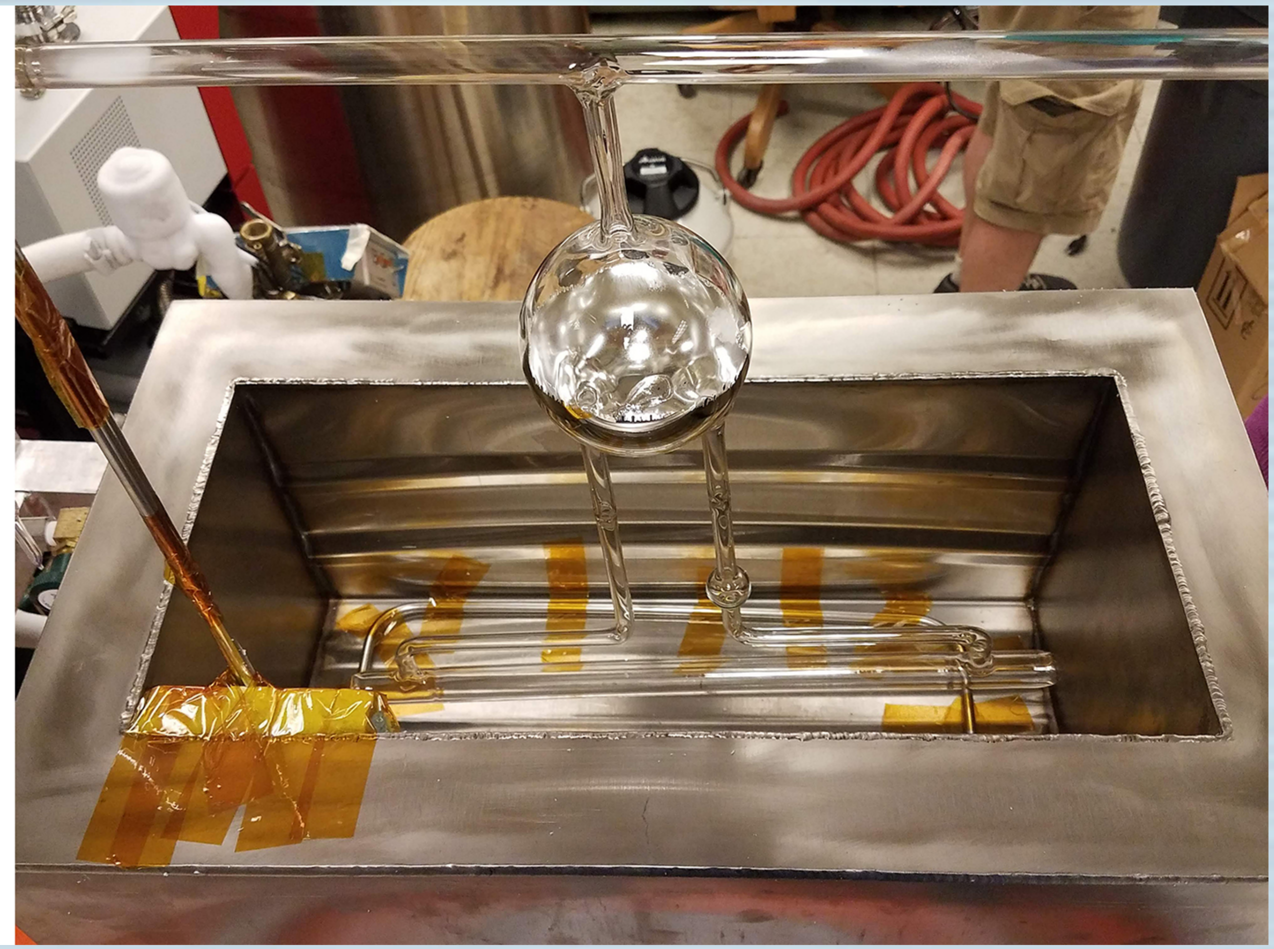
While not a full simulated beam test, this was nonetheless extremely encouraging.

Spin-down of Savior



Cell filling activity this year (2018)





- Cell-filling team includes Huong Nguyen, Chris Jantzi, Sumudu Katagampola and Al Tobias.
- Mike Souza visited our lab in late August to touch bases, coordinate, and give us glass-blowing lessons.
- Three cells filled so far in 2018.

A_1^n Cells filled to date

First batch

- Unnamed - was compromised after a crack caused catastrophic backfill.
- Levon - filled Aug. 23, 2016
  - produced signal, but exploded during first spin-up.
  - taught us that we weren't controlling pumping chamber thickness (ever!). Now we are!
- Savior - filled Oct. 27, 2016
  - Excellent performance, will be discussed more later.

Second batch

- V-Nunn (was unnamed above) - July 25, 2018
  - exploded during warm-up, probably due to stresses from earlier back-fill
- Fulla - filled September 7, 2018
  - Lifetime measured to be in the 15-17 hour range, but ….
  - Many questions remain as we break in our new testing apparatus.
  - Studies still underway.
- Florence - filled Sept. 28, 2018
  - Appeared to have short lifetime that was degrading with time.

Status and lessons learned

Status:

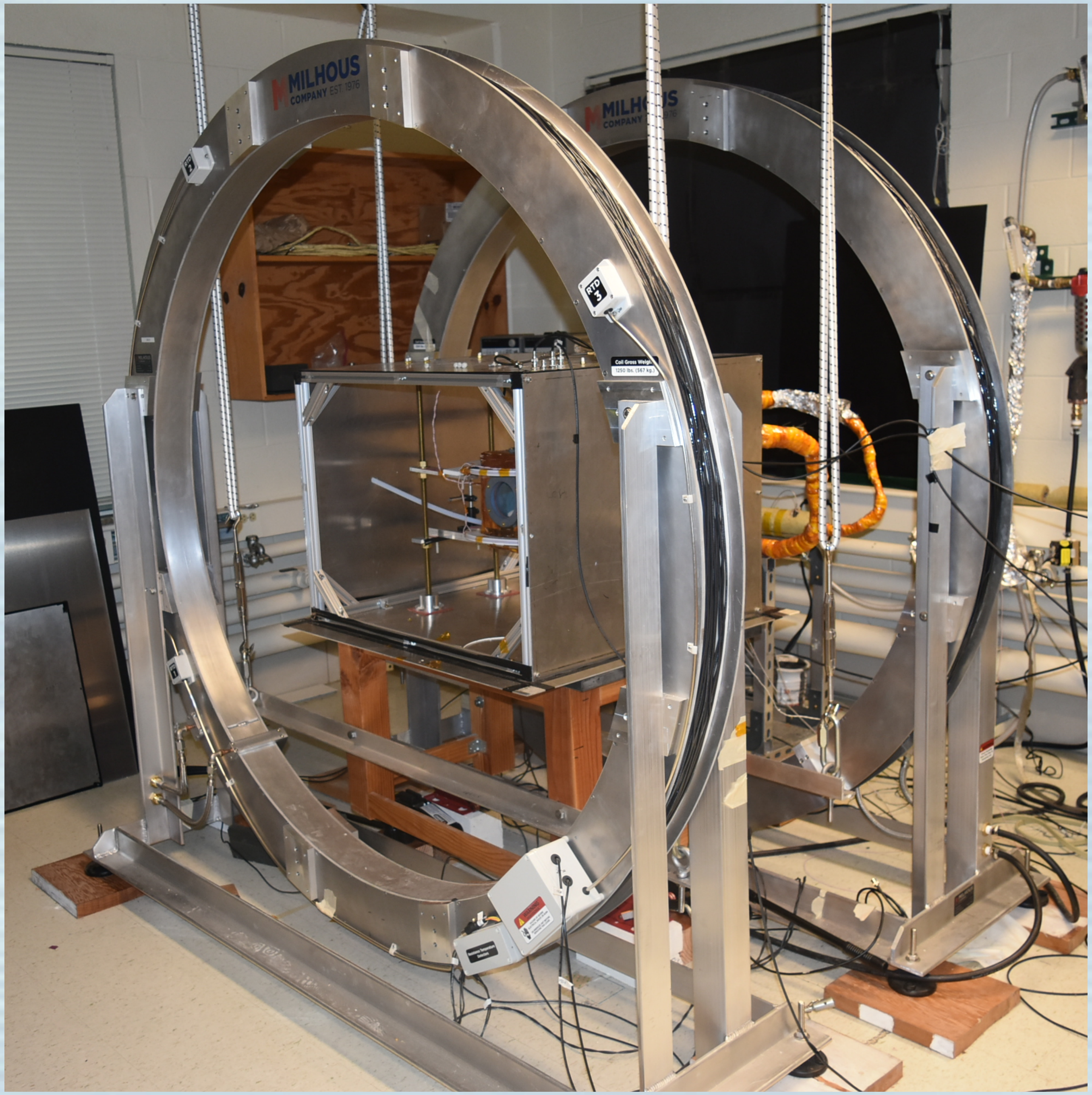
- Our lab re-established production capability in late 2016.
- The A1n cell-production team now has three cell-fills behind it.
- We are in a strong position to ramp up production.

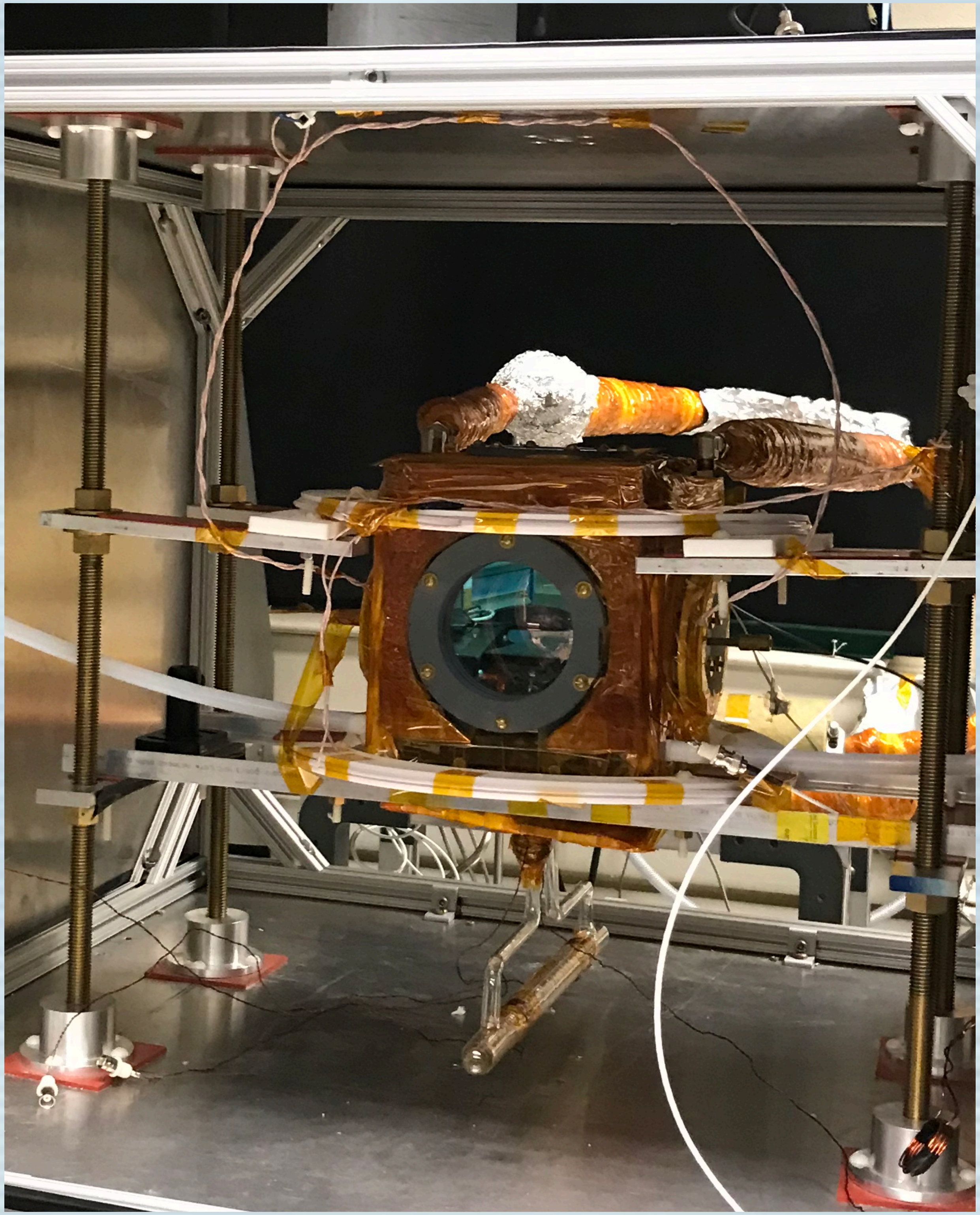
Lessons learned:

- In late 2016, we learned that we had not been adequately controlling the pumping chamber wall thickness (this goes all the way back to the earliest JLab He-3 experiments). Since most target ruptures are at the pumping chamber, this was a very important thing to establish.
- We have identified the quantity of alkali-metal mixture as an area to improve on subsequent cells. Note that the top-performing cells our group has produced over the years put emphasis on using much less alkali metal.
- We have also identified baking temperature as an area where further improvement is possible.

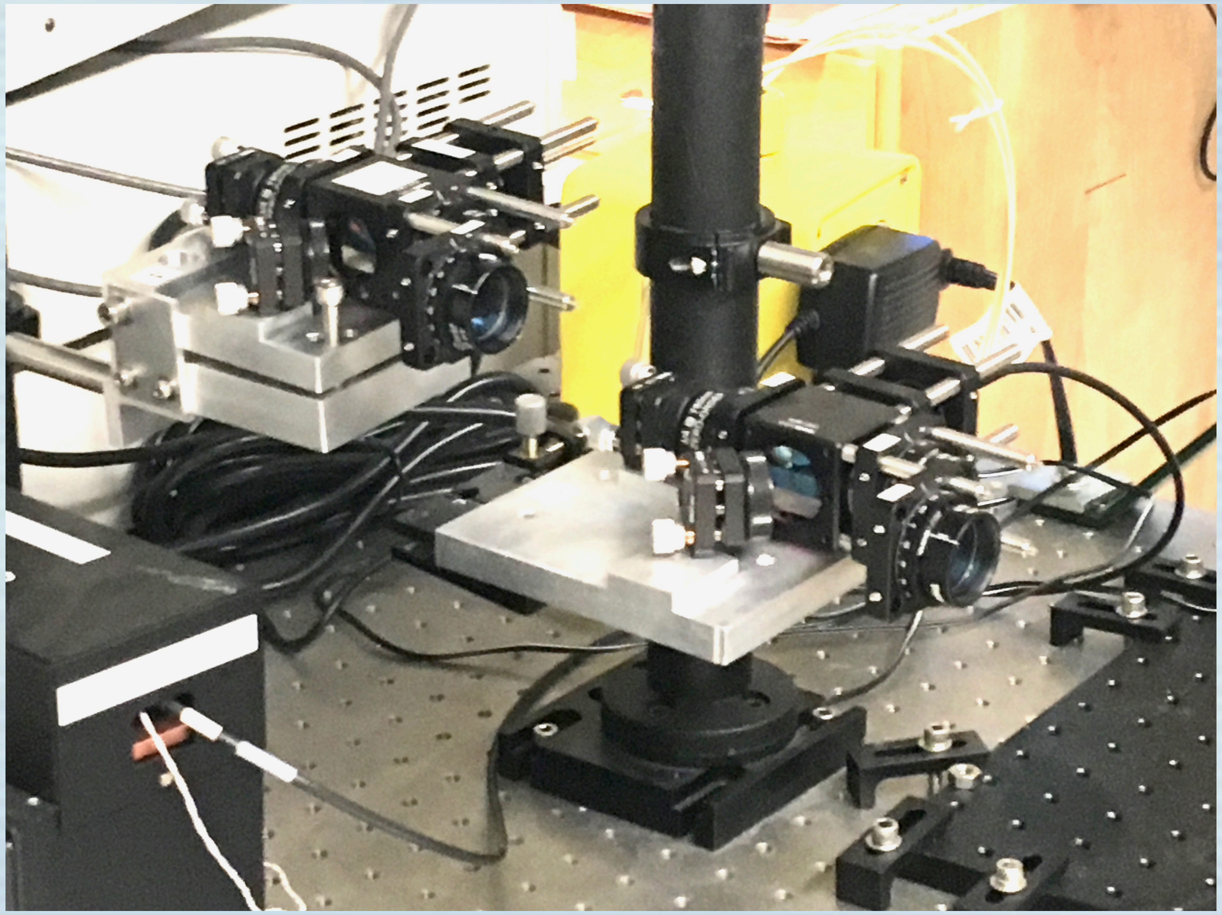
Bench testing target cells

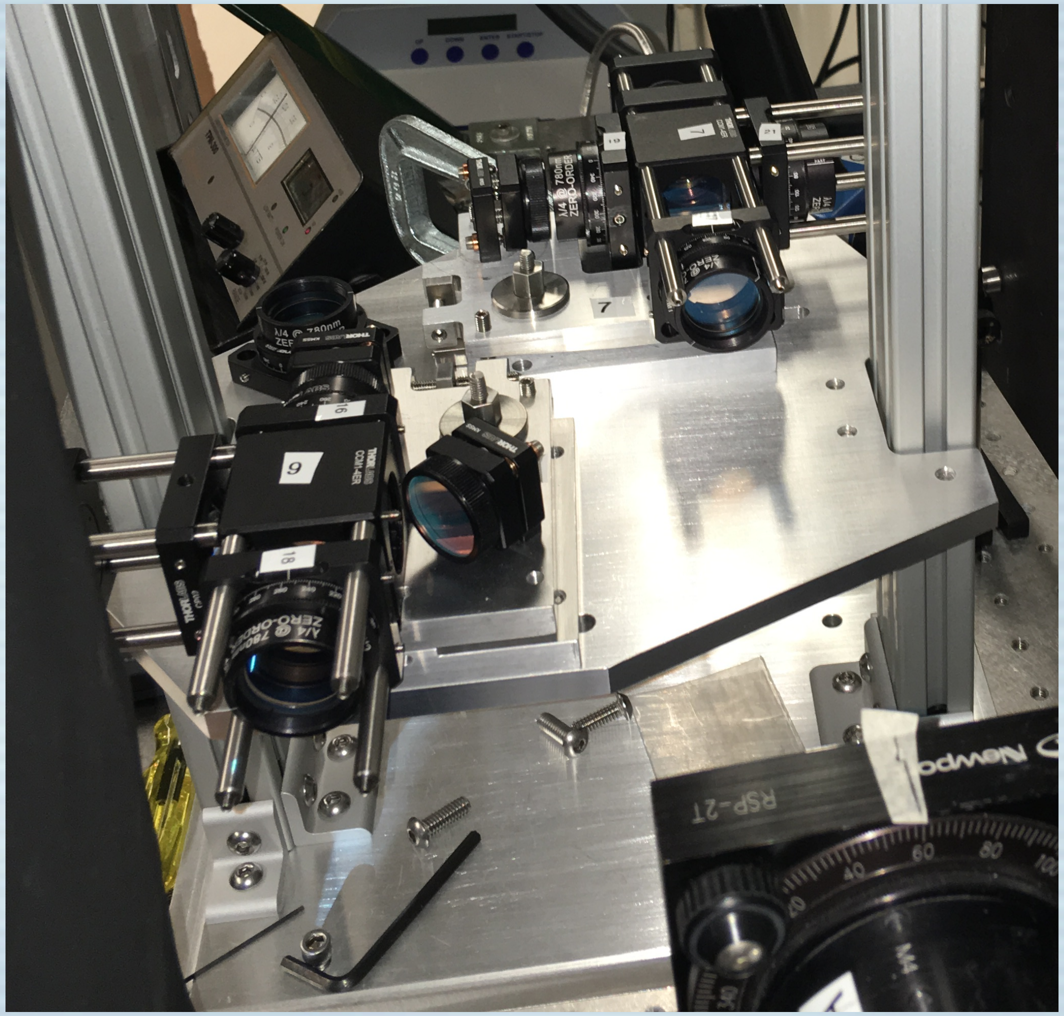
New apparatus for bench-testing target cells





Laser system and the "Death Star"



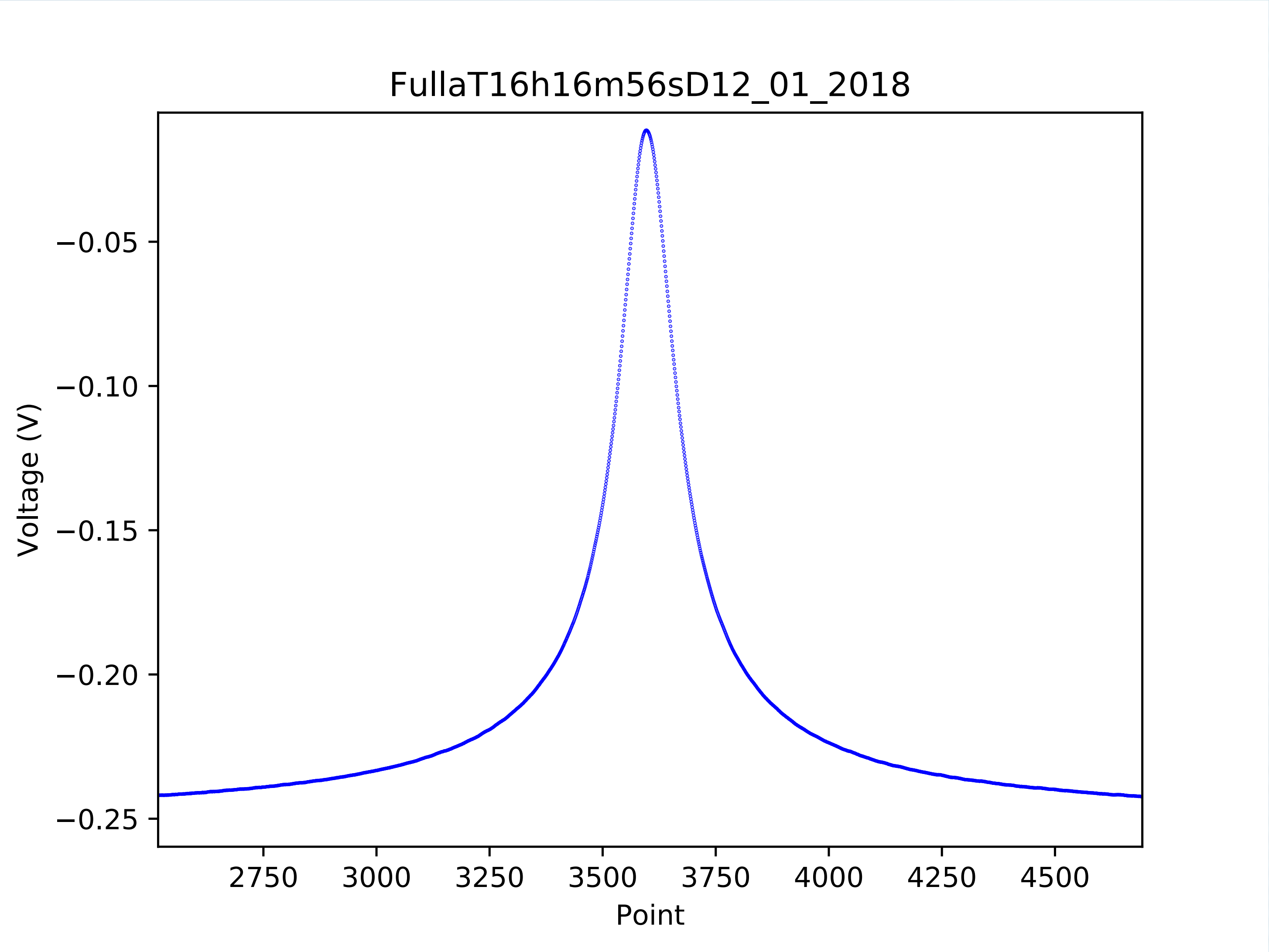


Shown are the optics for the two lasers currently being used to deliver roughly 70 Watts.

Additional optics modules in preparation to be added to the system.

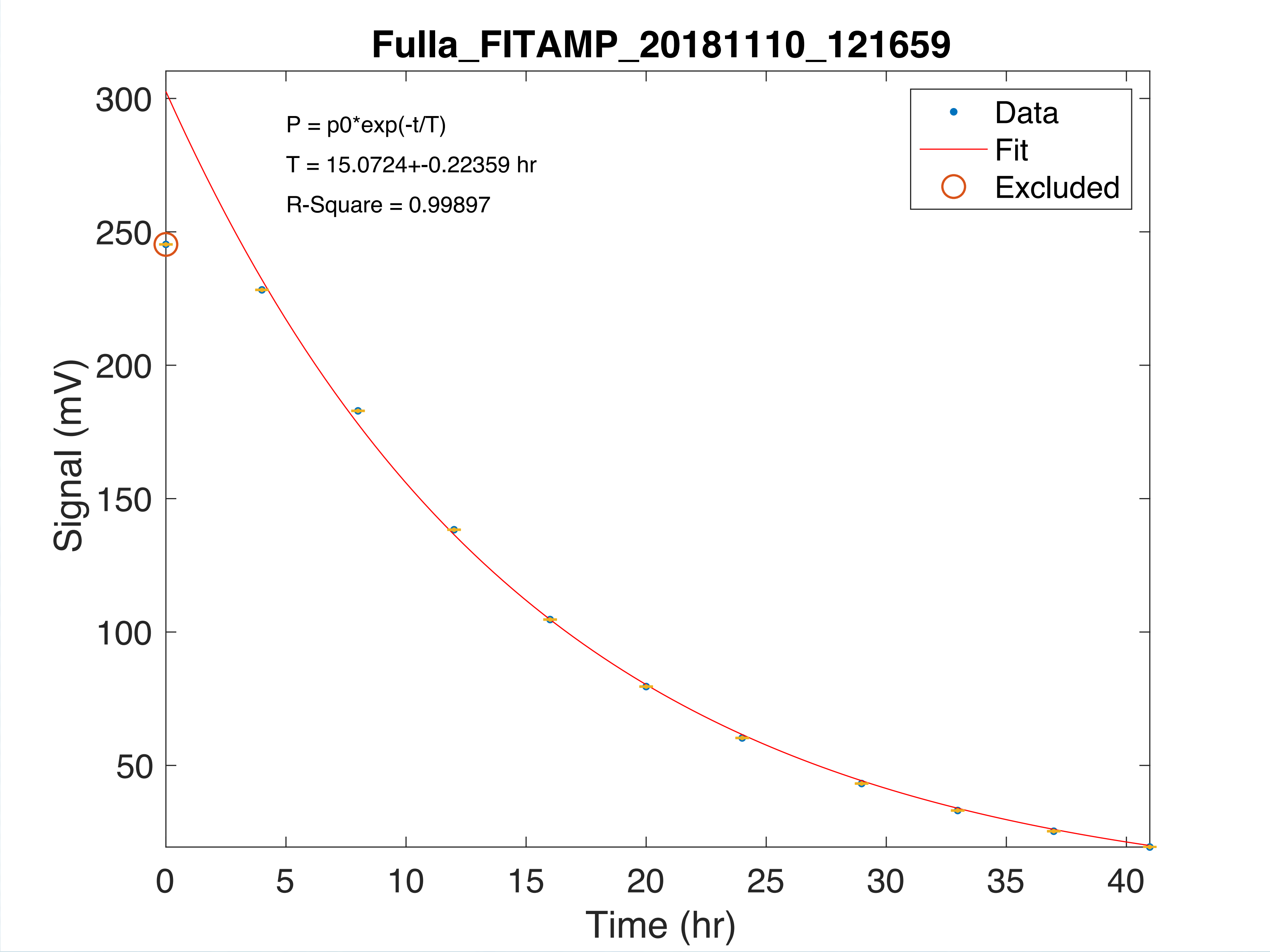
The center of our system is the "Death Star", a portable system with four 50-Watt lasers, which can be added to other extent lasers for up to nearly 250 Watts, although the full power will only be used for the SBS GEn targets.

AFP measurement

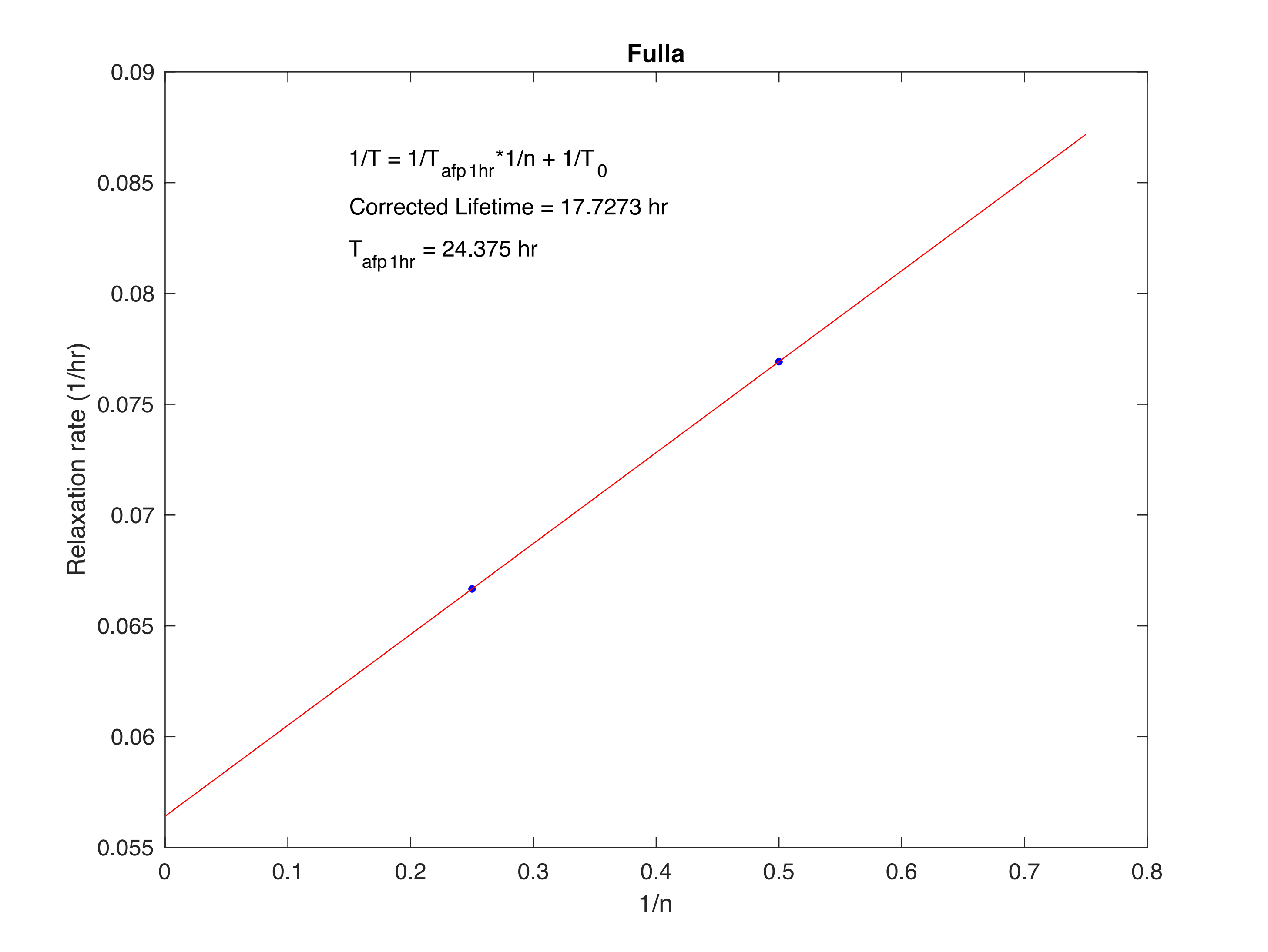


- AFP system is extremely low noise, but losses are large, around 4-7% per scan because of the size of the rf coils and the proximity of aluminum to the target chamber.
- Losses are actually useful when you are simulating be depolarization.
- For spin-downs, we sample at multiple rates to back-out the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

Spin-down of Fulla

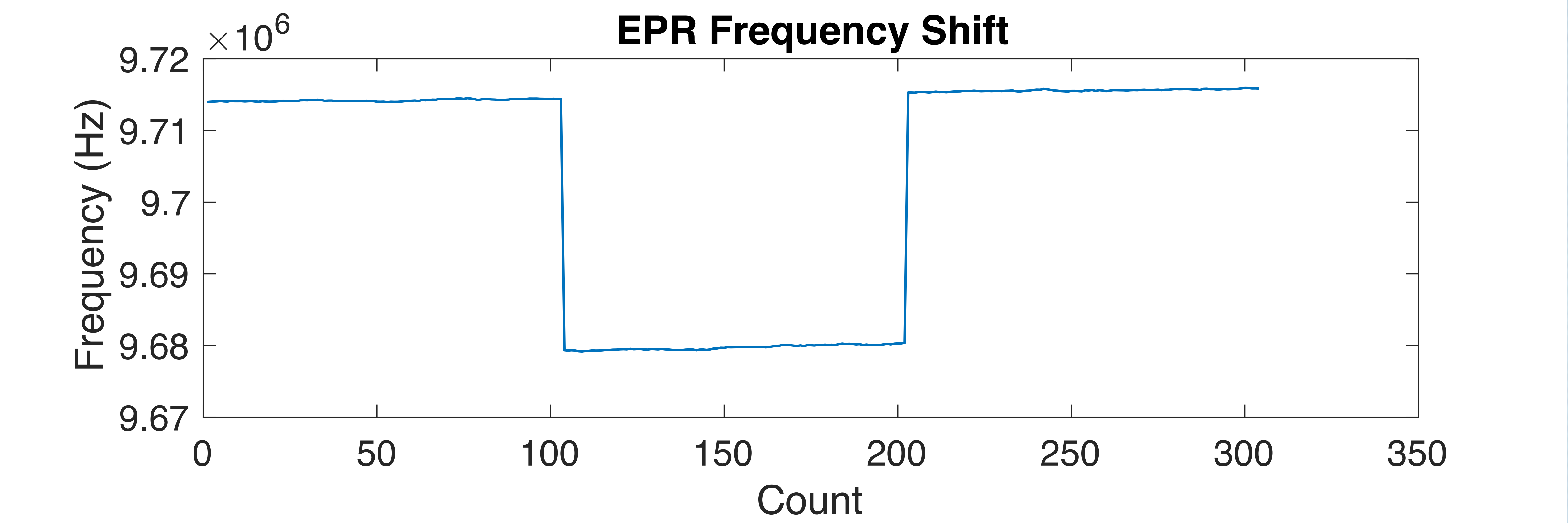


Determining zero-loss lifetime



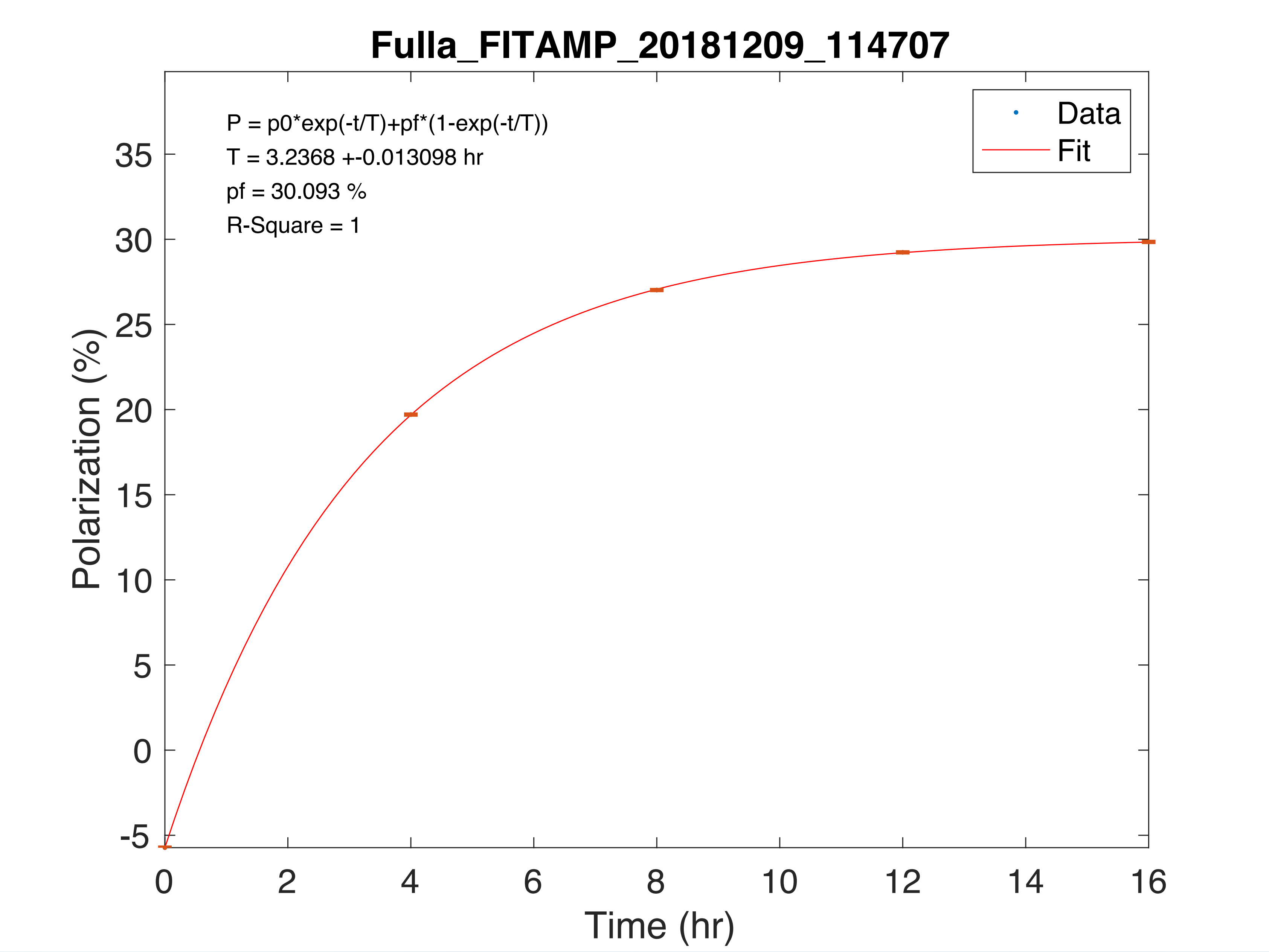
- Shown are fitted lifetimes as a function of the sampling rate to extract the zero-loss lifetime.
- Zero-loss lifetime of Fulla is (at present) in the range of 15-17 hours.
- It is possible that we still have elements in our system that are causing relaxation, but nevertheless, we have nominally concluded that Fulla is only a marginal cell.

Polarimetry in the new test apparatus



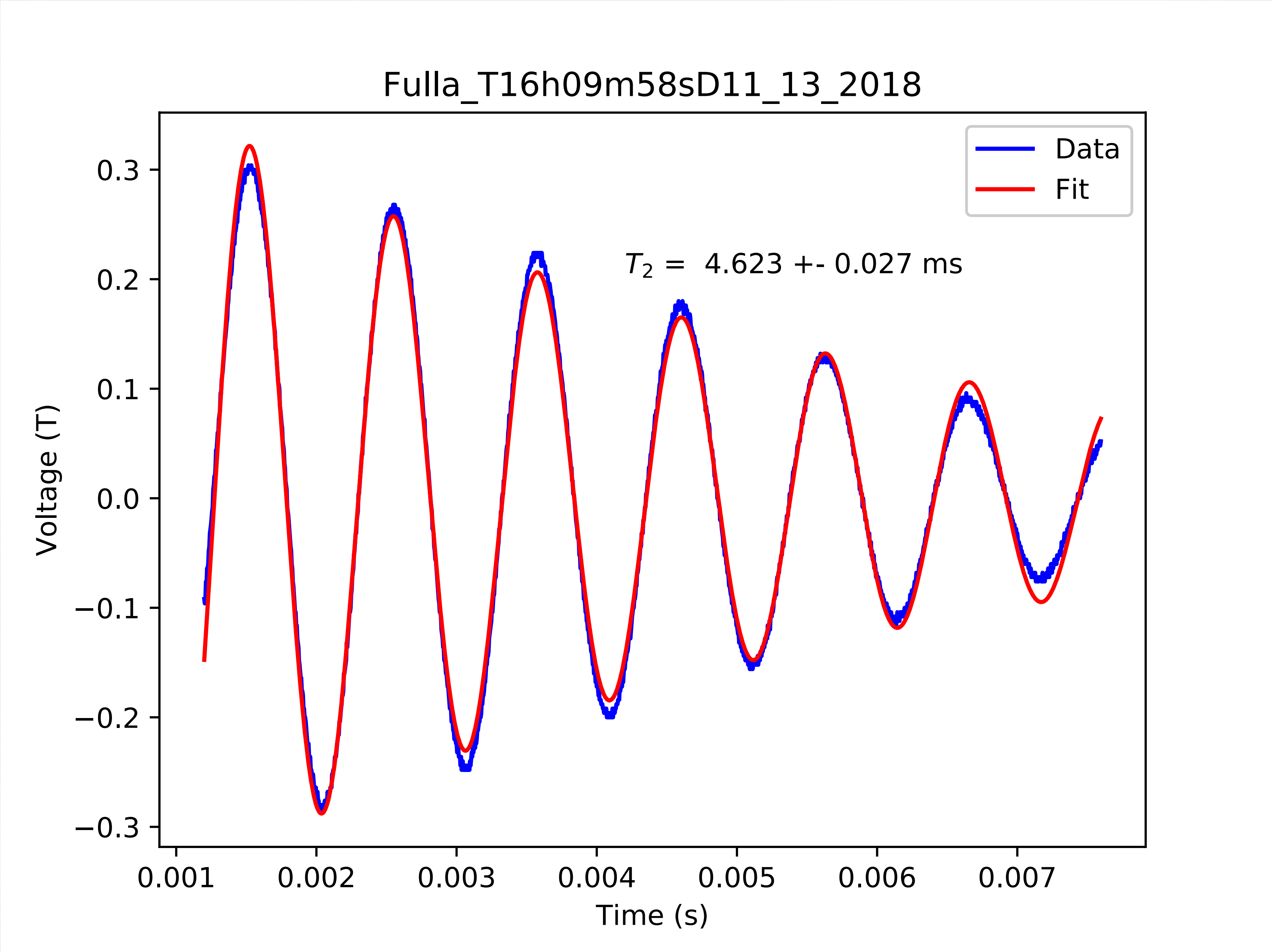
- EPR frequency shifts are, at present, being used for our absolute polarimetry calibration.

Non-optimized spin-up of Fulla



- Focus was on understanding our system, not optimizing polarization.
- Losses per AFP scan above were 6 - 7%.
- No temperature scan performed, set T=235C, laser P = 70 Watts.
- For spin-downs, we sample at multiple rates to back-out the zero-loss lifetimes.

pNMR signal from



Summary of target-cell tests

- Our “upstairs” system is still in early testing, but looks good.
- Whether “upstairs" or “downstairs”, we can do full-laser power tests of all target cells before delivering to JLab.
- Once we are confident of our system, we will initiate simulated beam tests.
- At present, only “Savior” should be considered a good cell, but we anticipate producing cells at roughly one/month, and anticipate having 6 - 8 cells by June 2019.

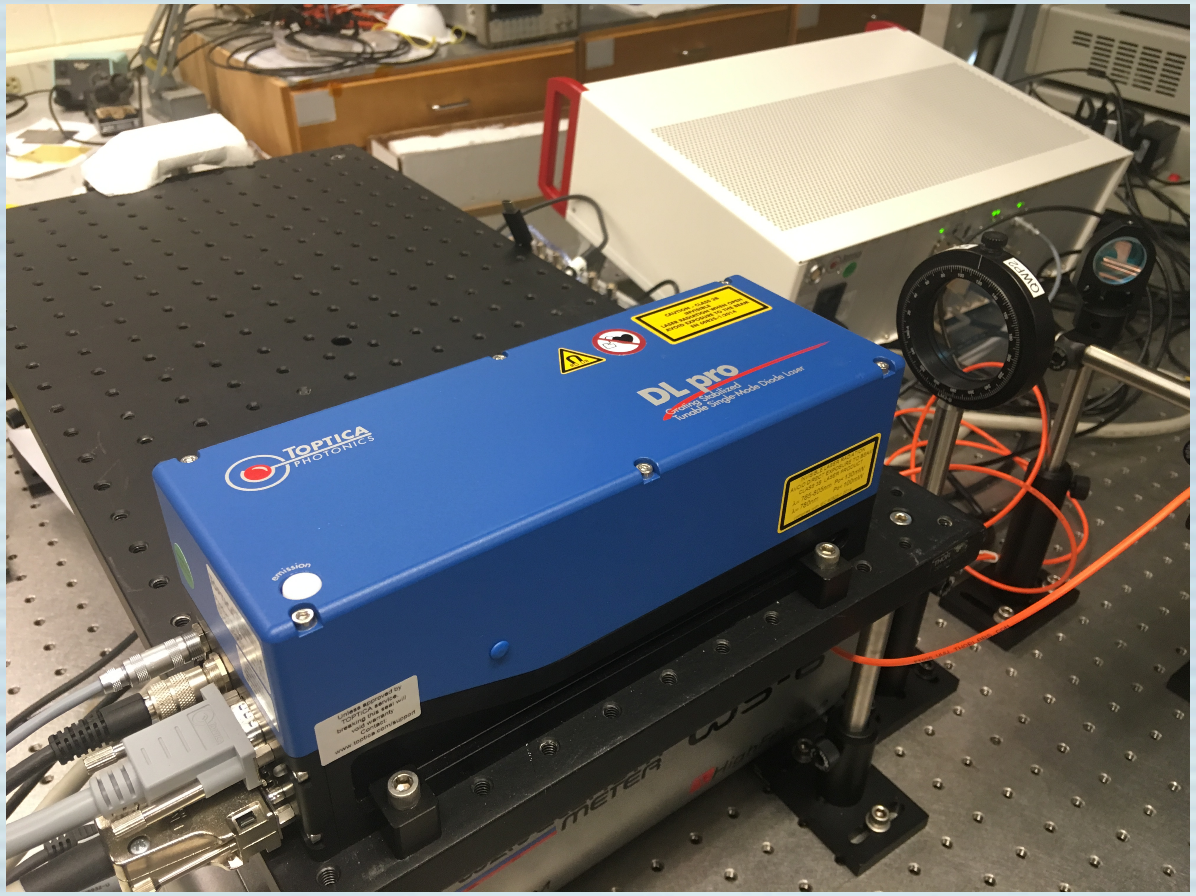
Un-polarized cell characterization using a single-frequency laser

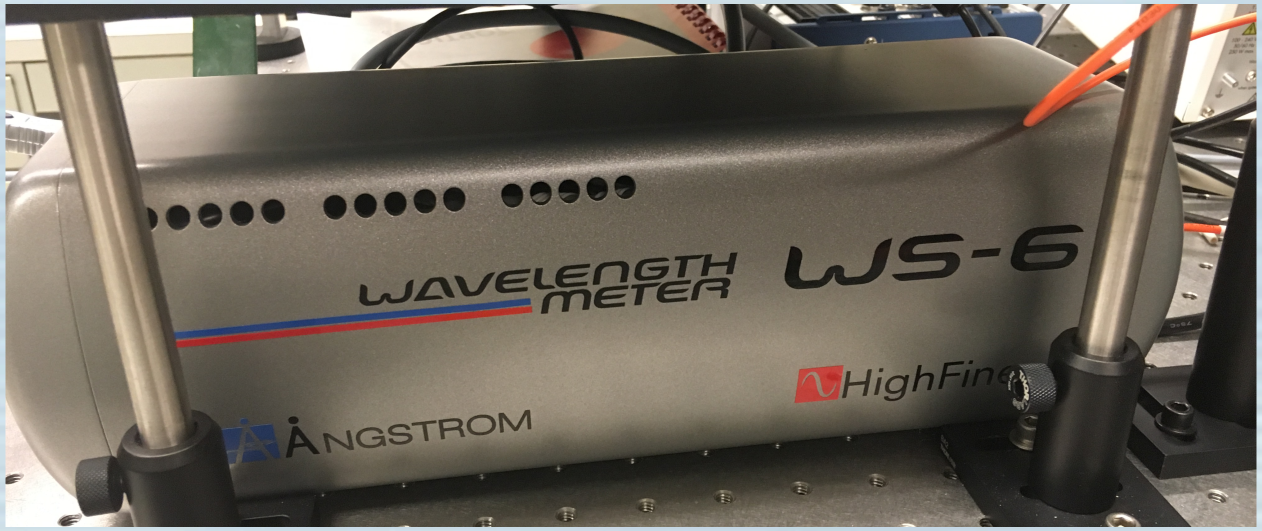
Single-frequency laser cell characterization

- Provides ~1% determination of pressure in cells even after they have been sealed.
- Provides measure of the ratio of K to Rb for that particular cell under operating conditions. It is critical to keep this within a certain range when constructing targets.
- Provides measurements of glass thicknesses at various points in the cell - critical for radiative corrections and other issues.

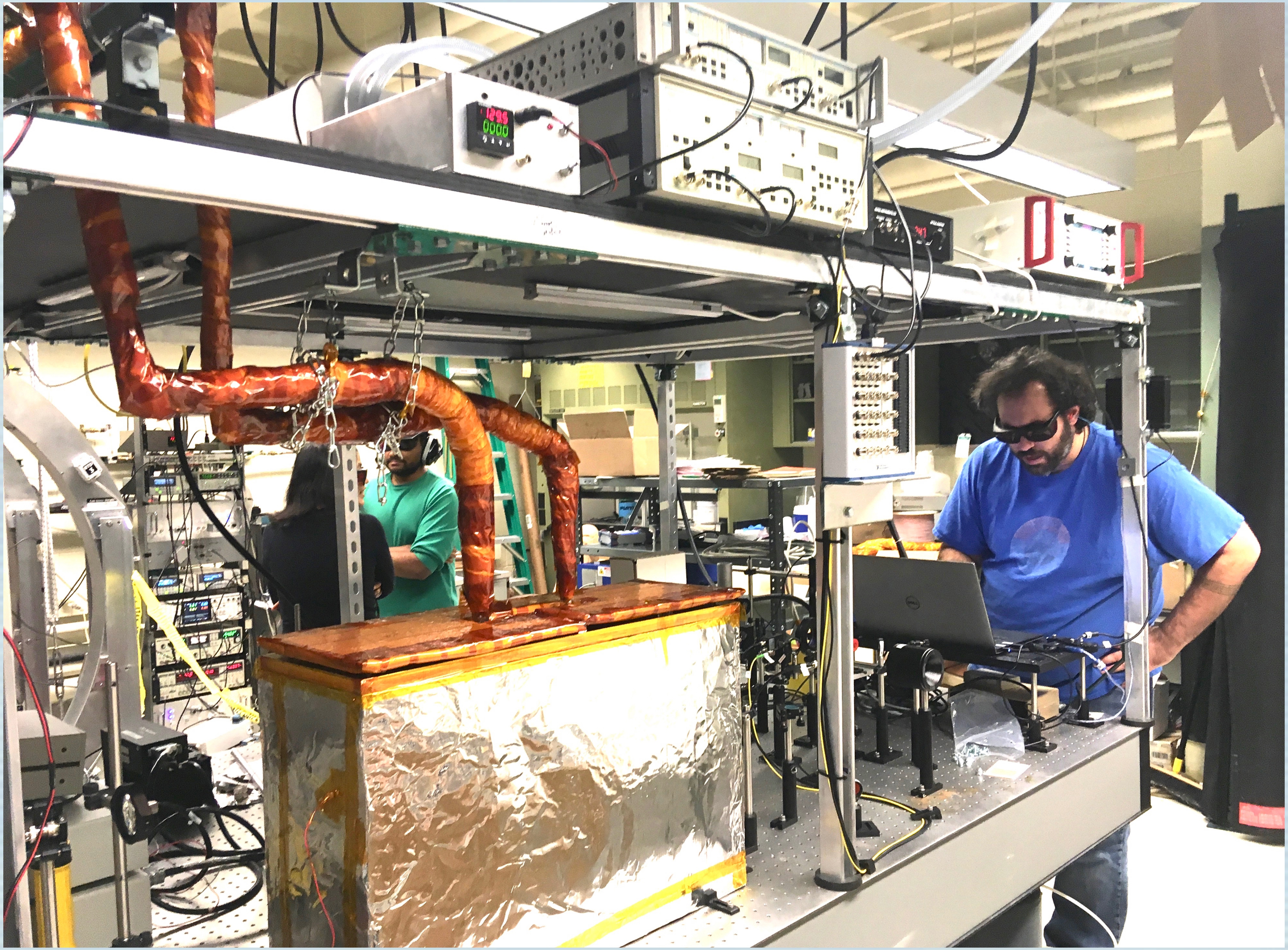
Cell Characterization laser

- 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.

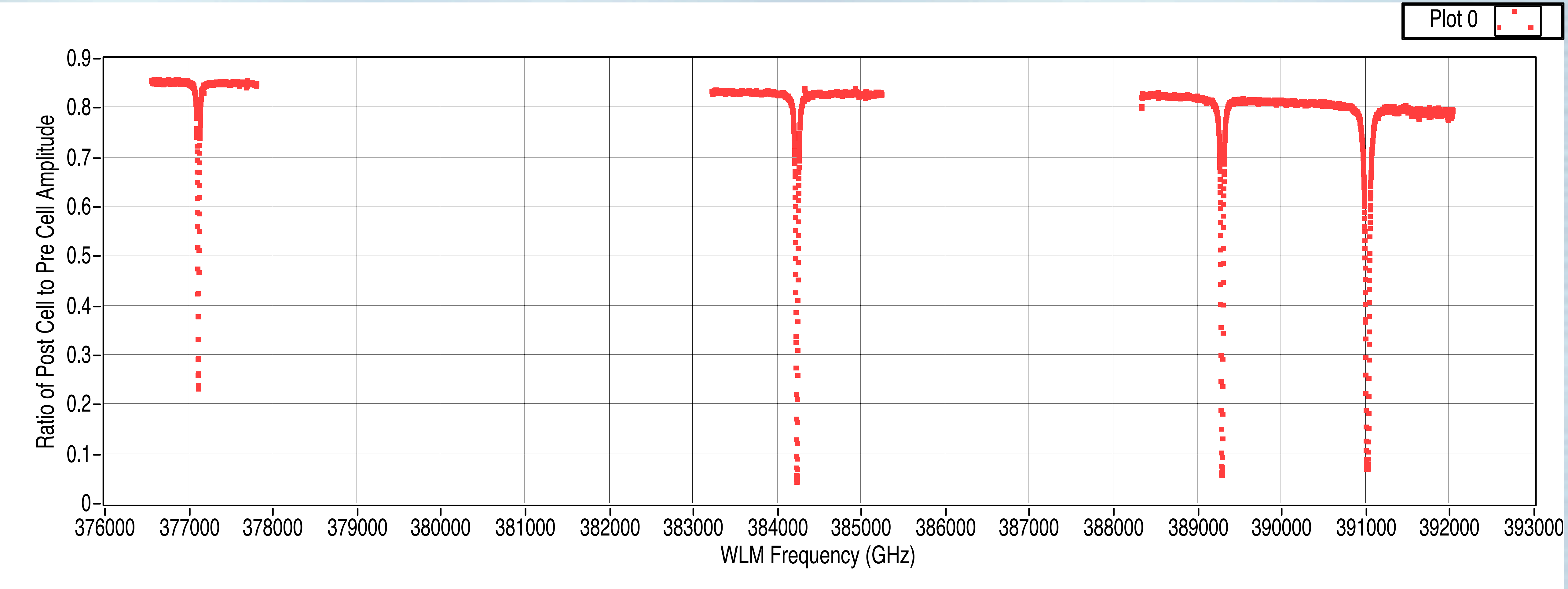




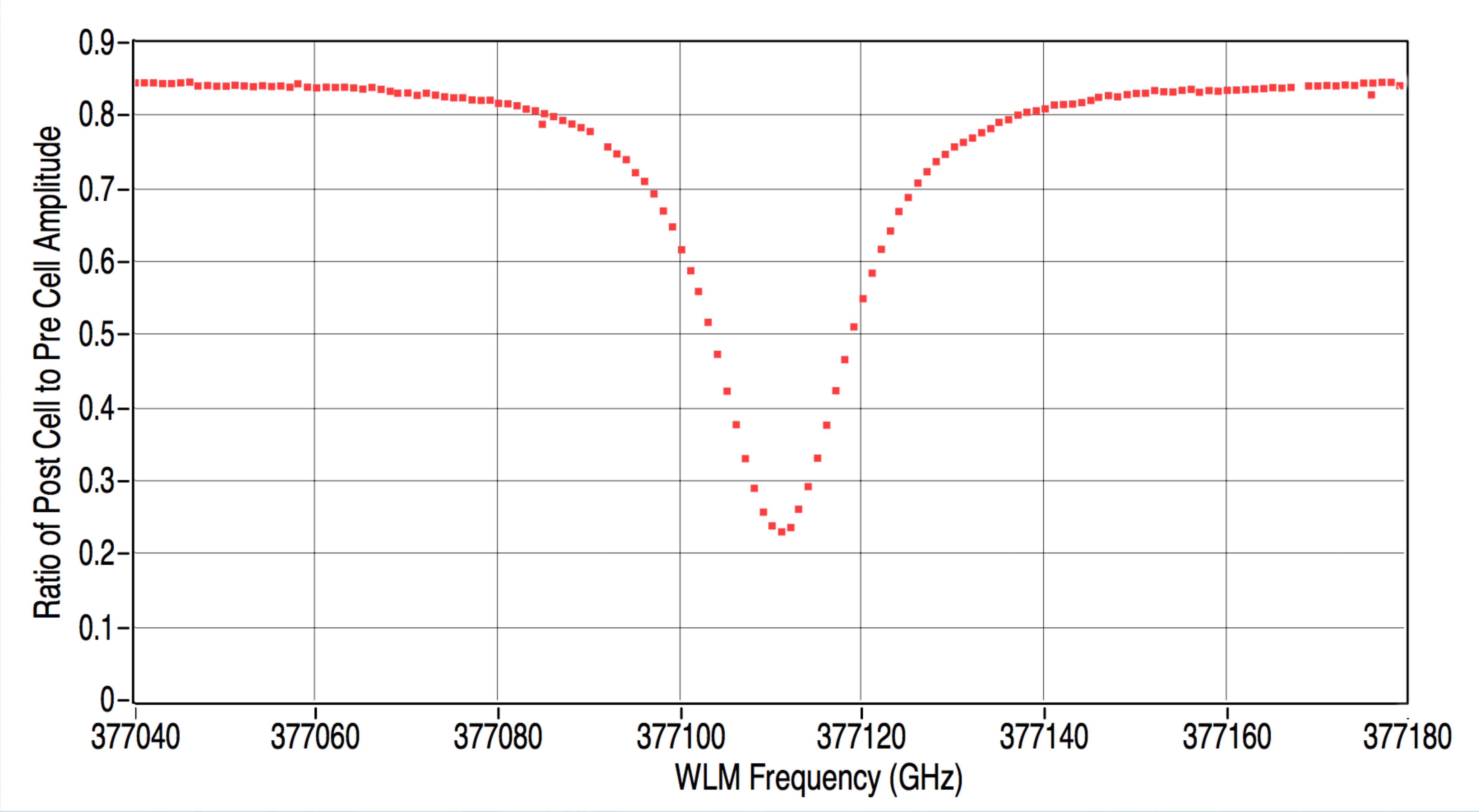
Cell Characterization system



Cell Characterization system



Cell Characterization system

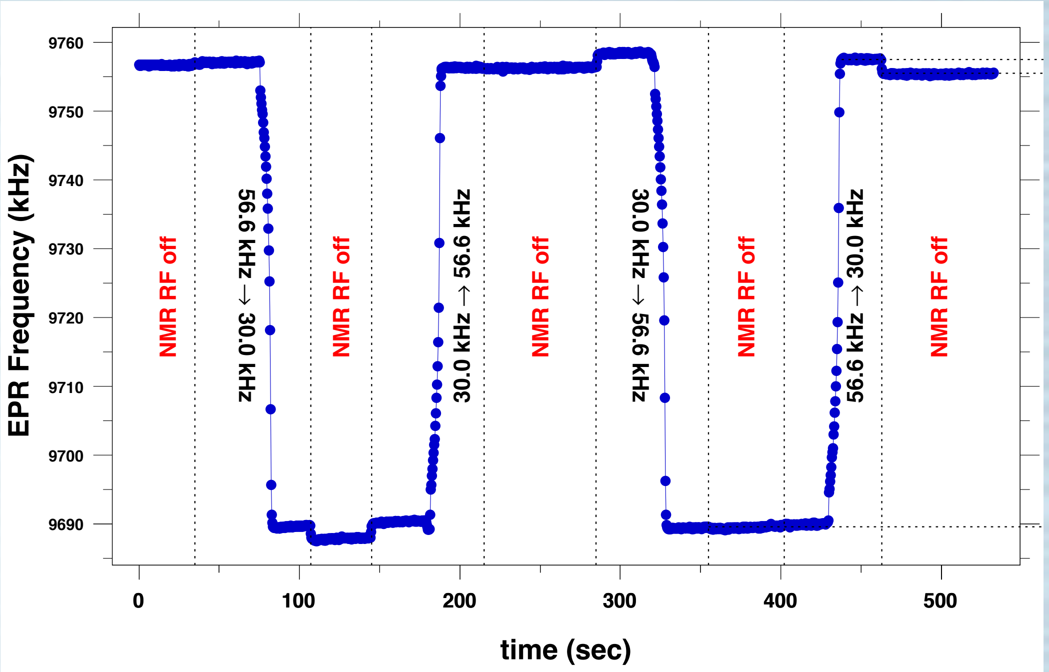


Polarimetry and measuring an updated value for κ_0

EPR polarimetry requires accurate knowledge of the atomic parameter κ_0

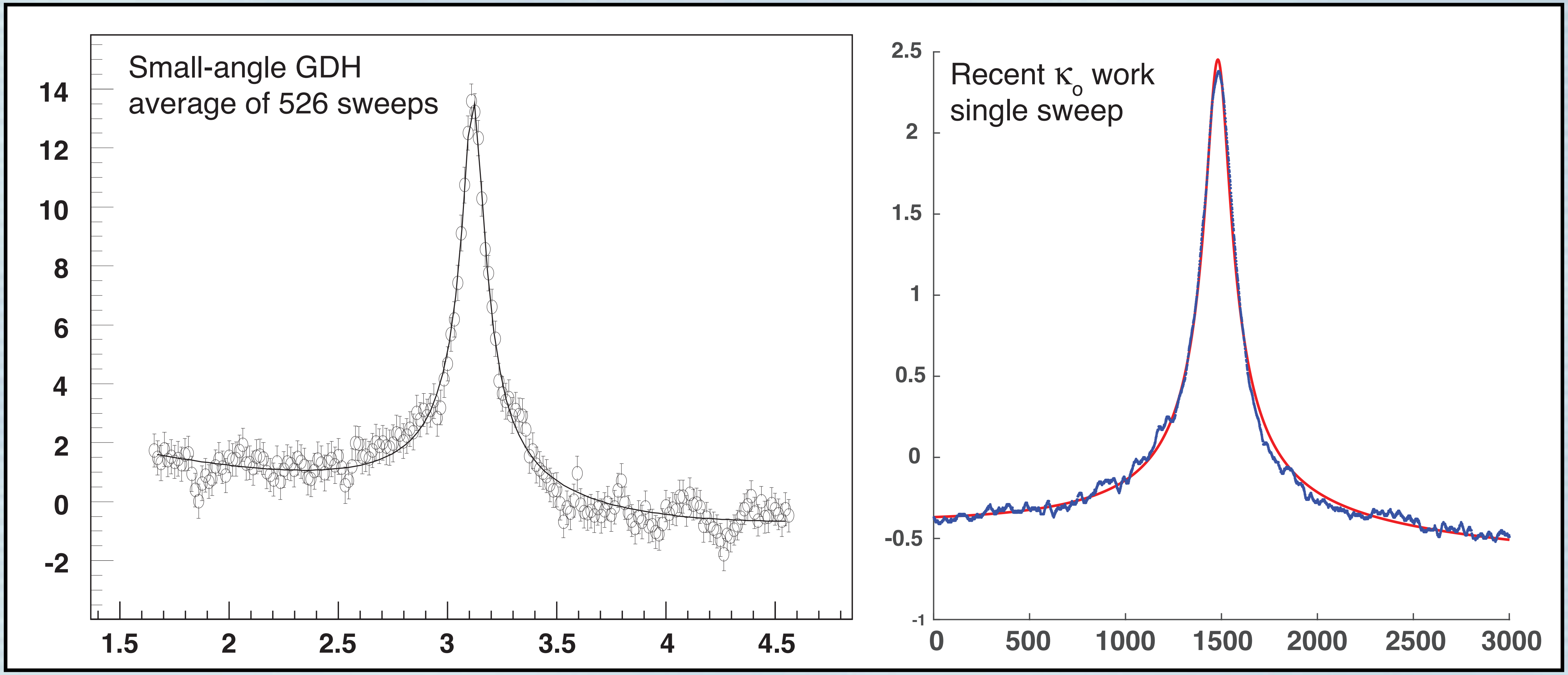
$$\Delta\nu = \frac{8\pi}{3}\frac{\mu_B g_e}{h(2I+1)}\left(1 \mp \frac{8I}{(2I+1)^2}\frac{\mu_B g_e B}{hA}\right)\kappa_0 \mu_K [\mathrm{He}] P$$

κ_0



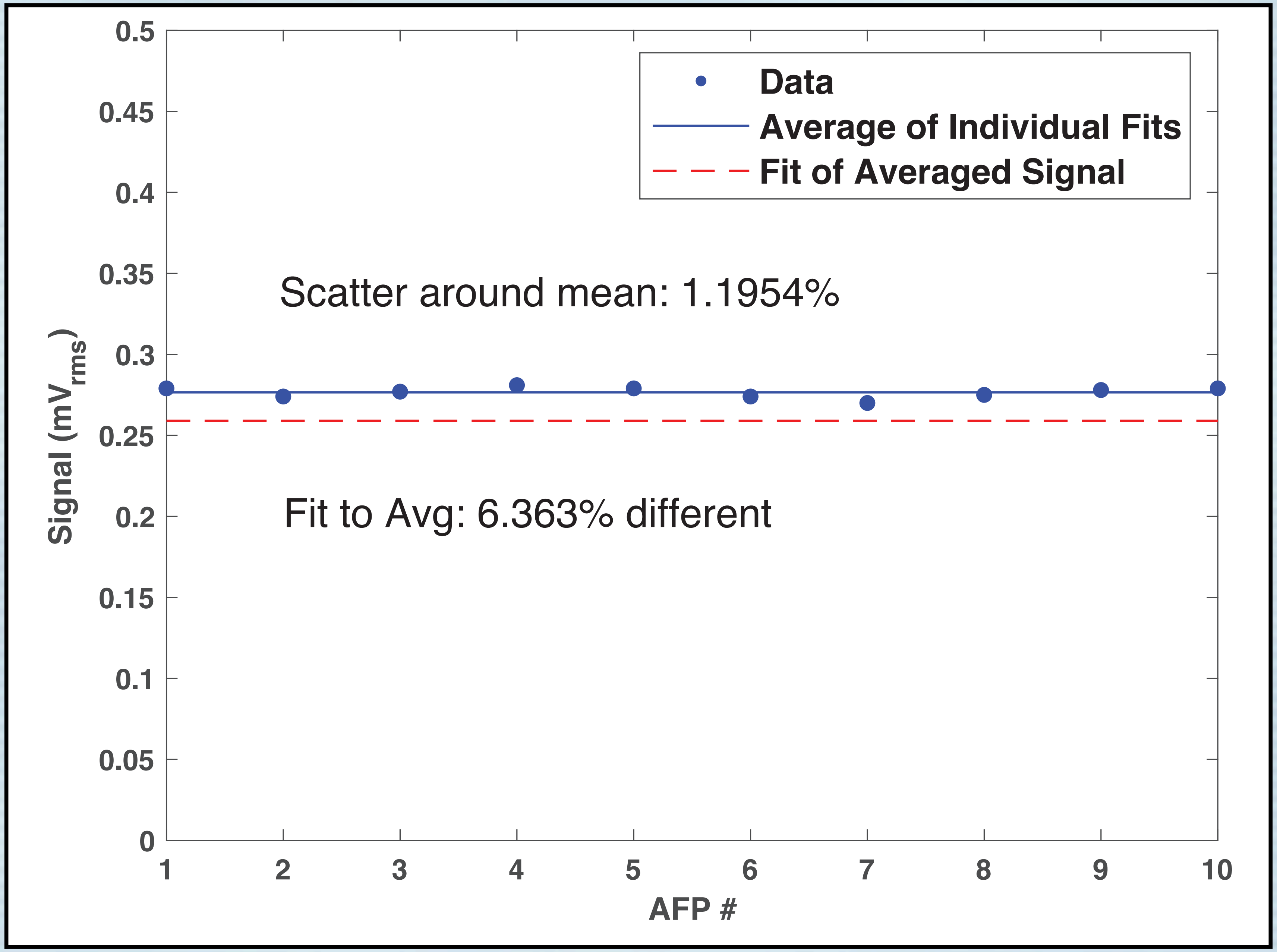
- RF generator is locked to a Zeeman transition in one of the two alkali species (K or Rb).
- The transition frequency is shifted due to the effective magnetic field of the polarized ^{3}He.
- By flipping the ^{3}He spins with respect to the holding field, the resulting frequency shift provides an absolute calibration of polarization.
- Interpreting the frequency shift requires knowing κ_0 .

Our current approach for determining κ_0: 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.

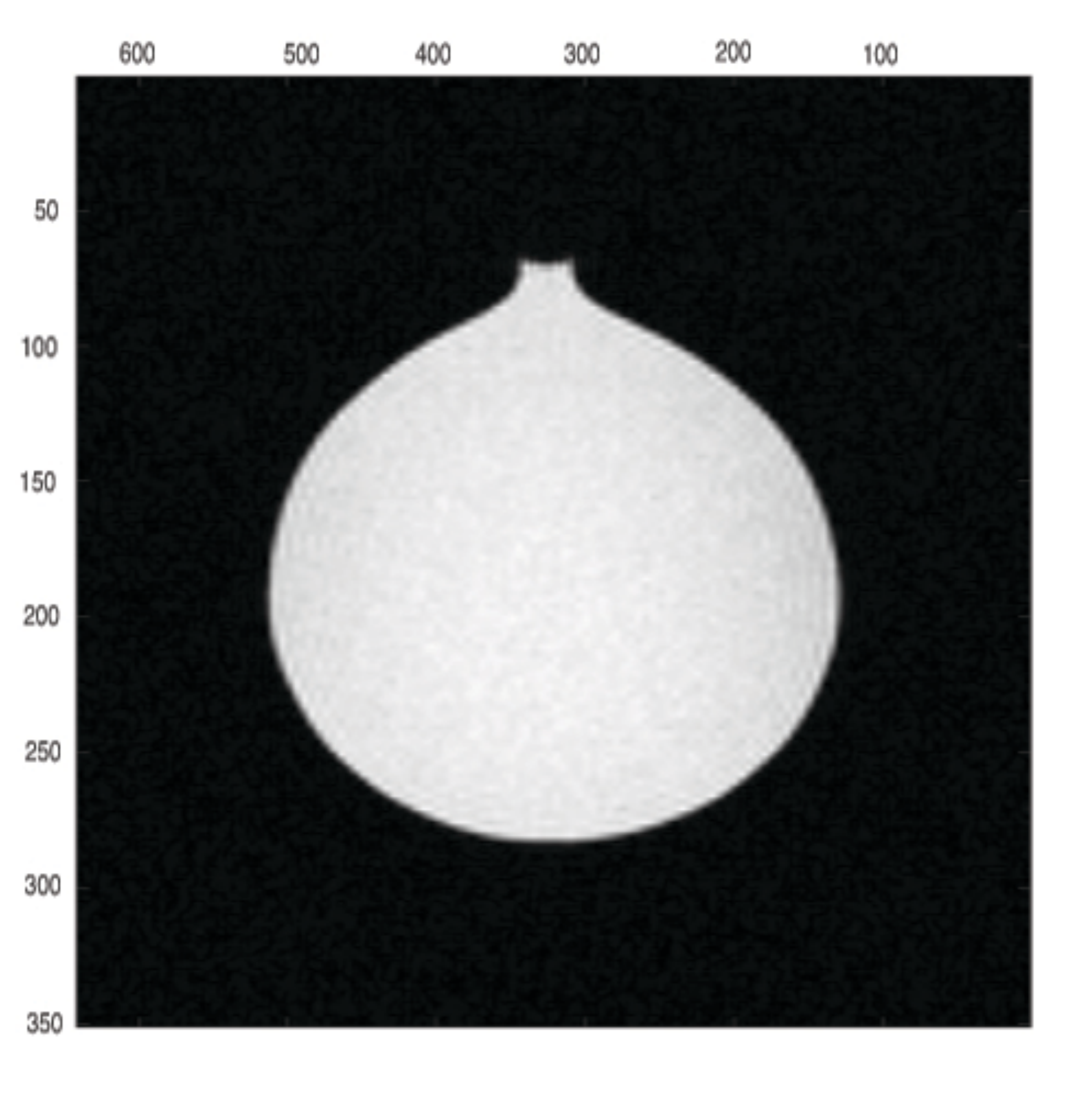
Water calibrations: the average of fits versus the fit of an average



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

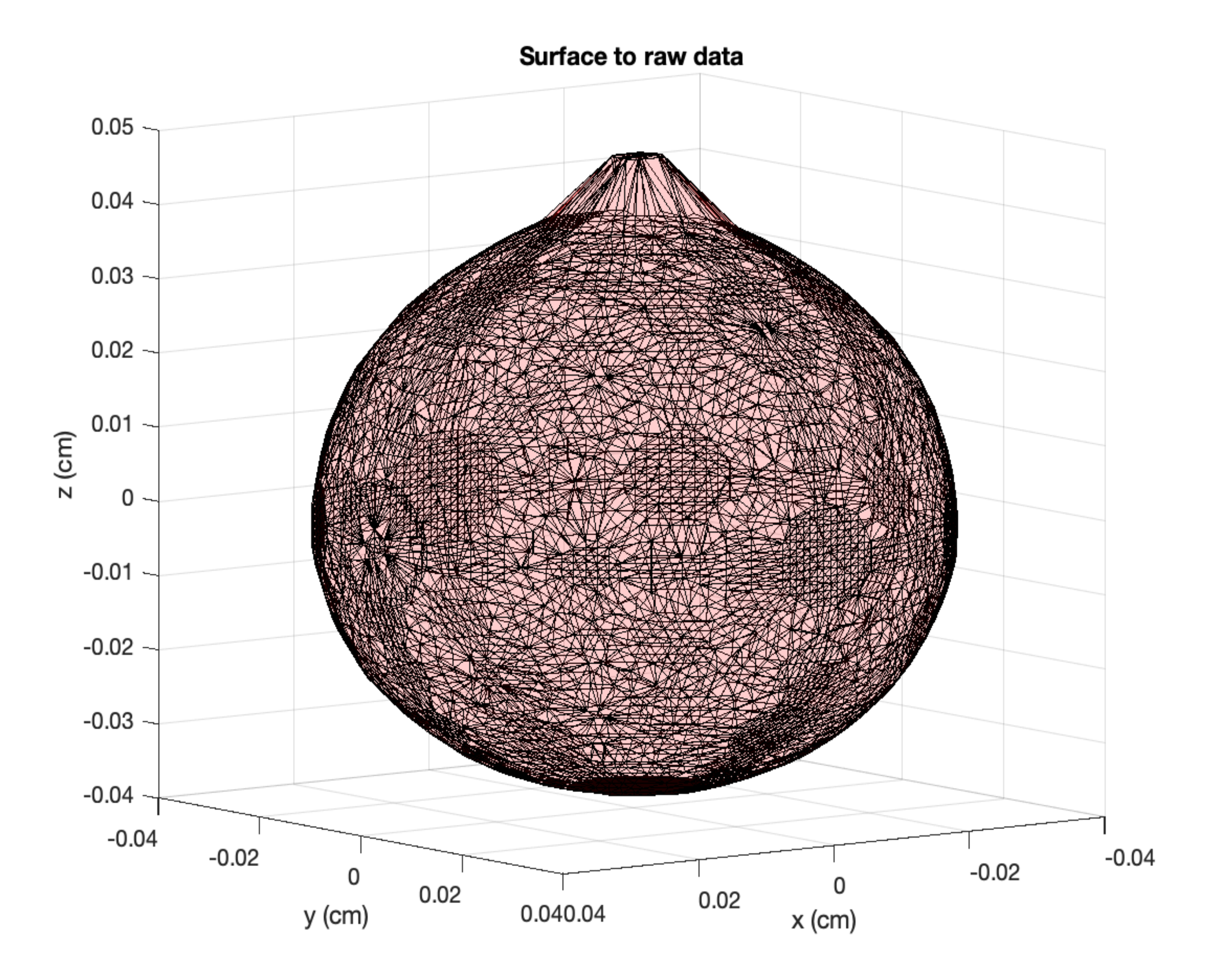
Characterizing our water cells

- 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

Shown below is a surface constructed along the perimeter of the non-zero voxels from the MRI scan shown on the previous slide.



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%			

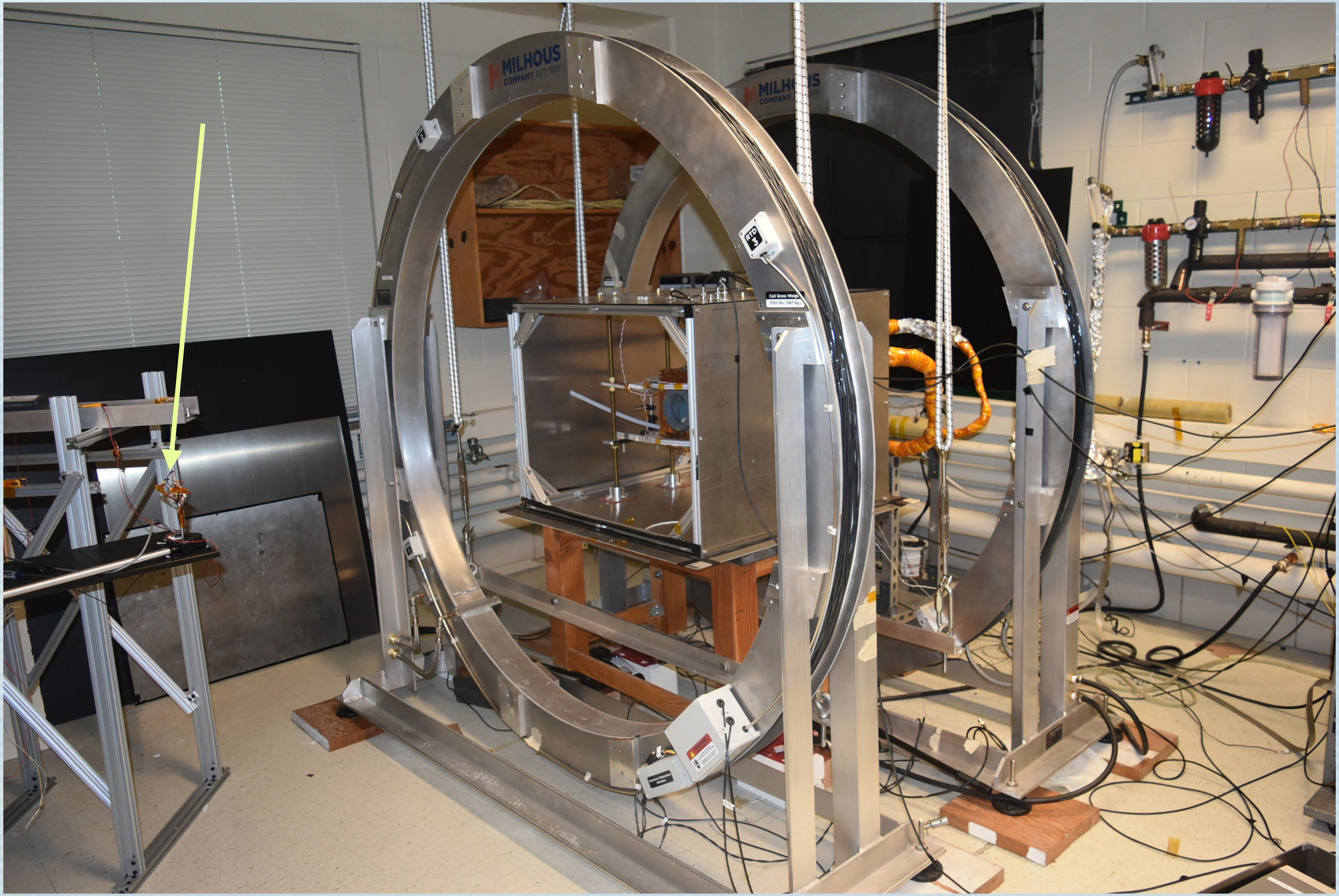
Summary

- Everything is in place to ramp up production, including cell characterization.
- Savior demonstrates we can produce acceptable cells.
- We believe the yield will be good once we freeze our protocols.
- Full testing will be possible at UVa.
- We anticipate 6 - 8 cells by June.

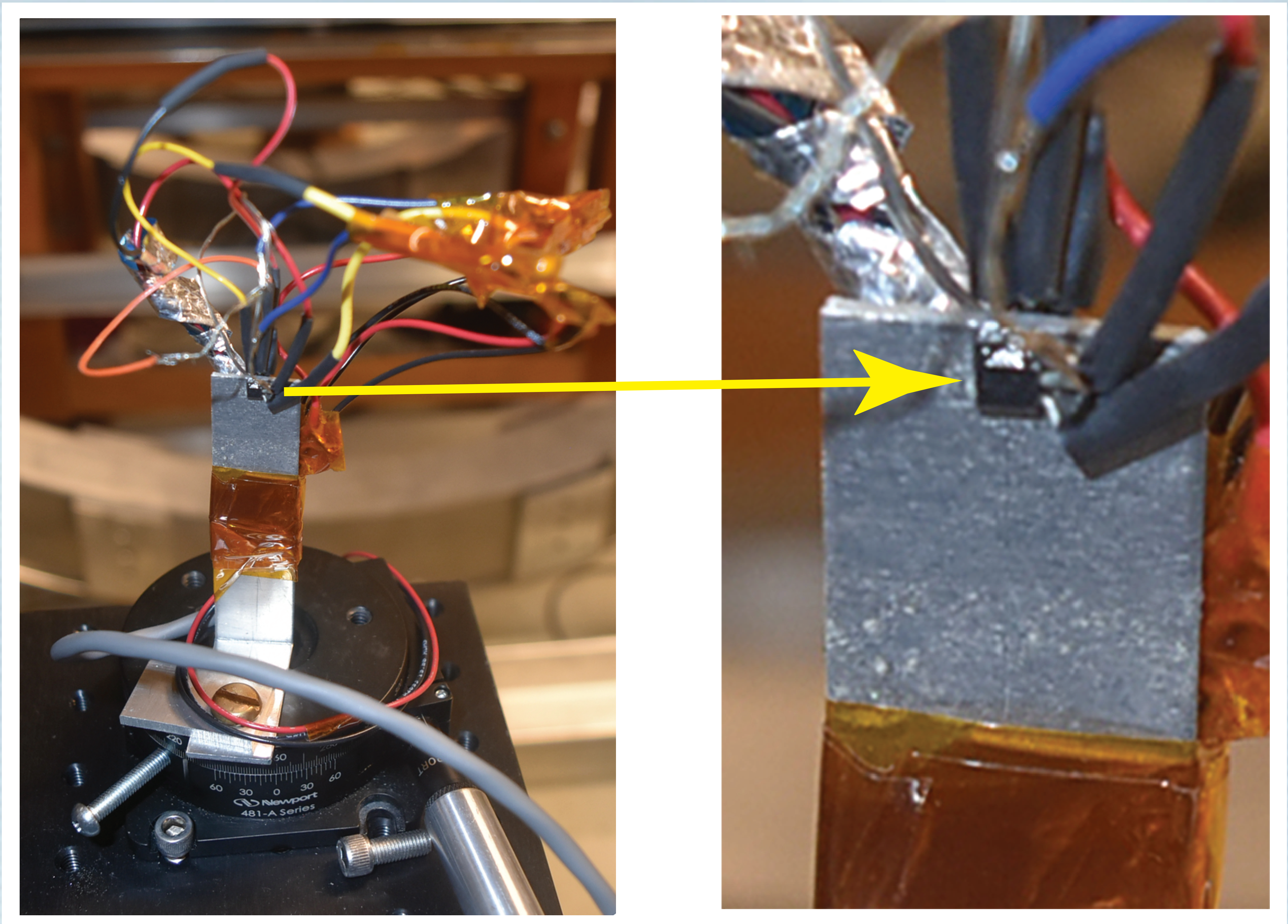
Backup slides

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

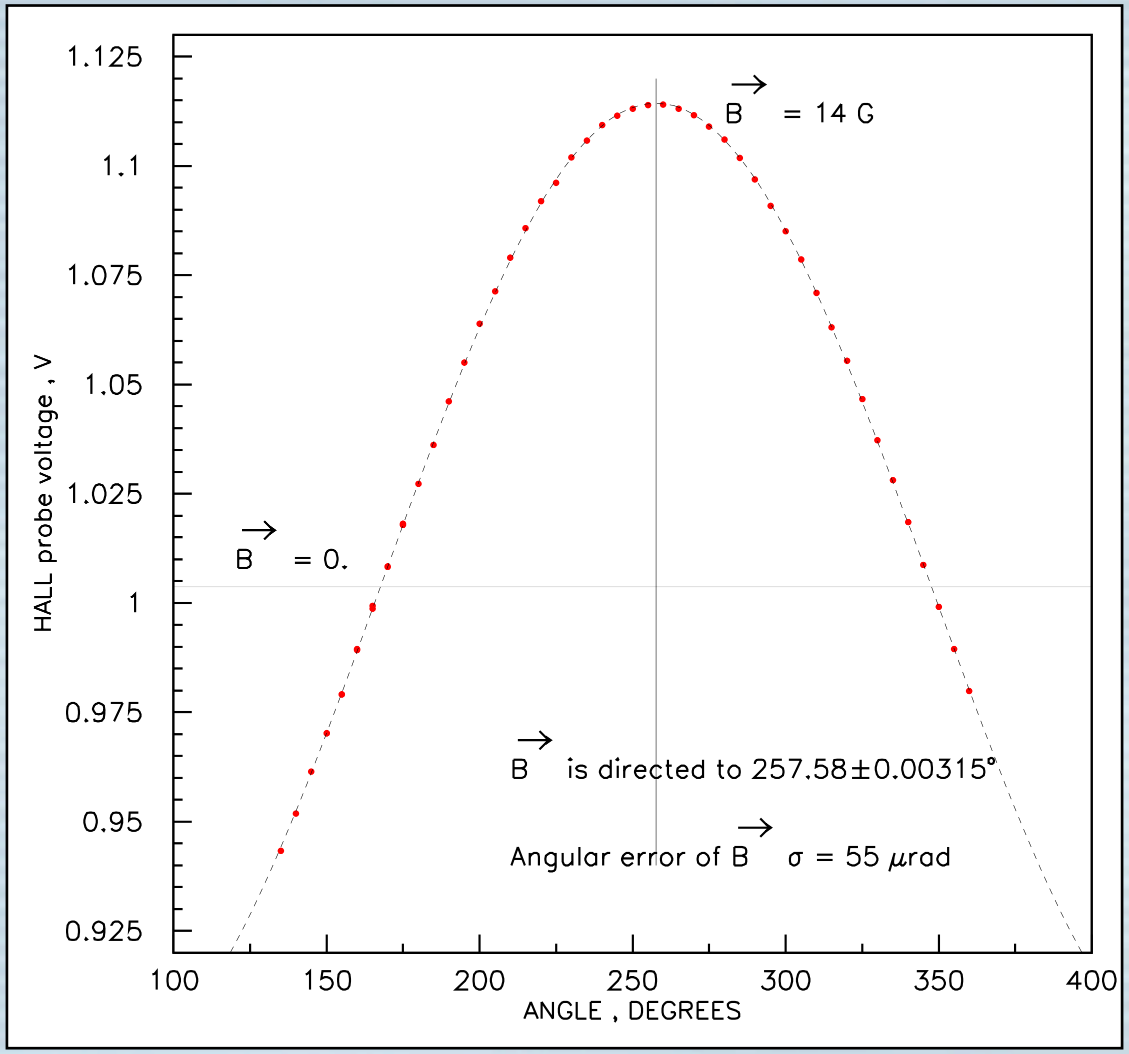


Hall Probe field-direction measurement



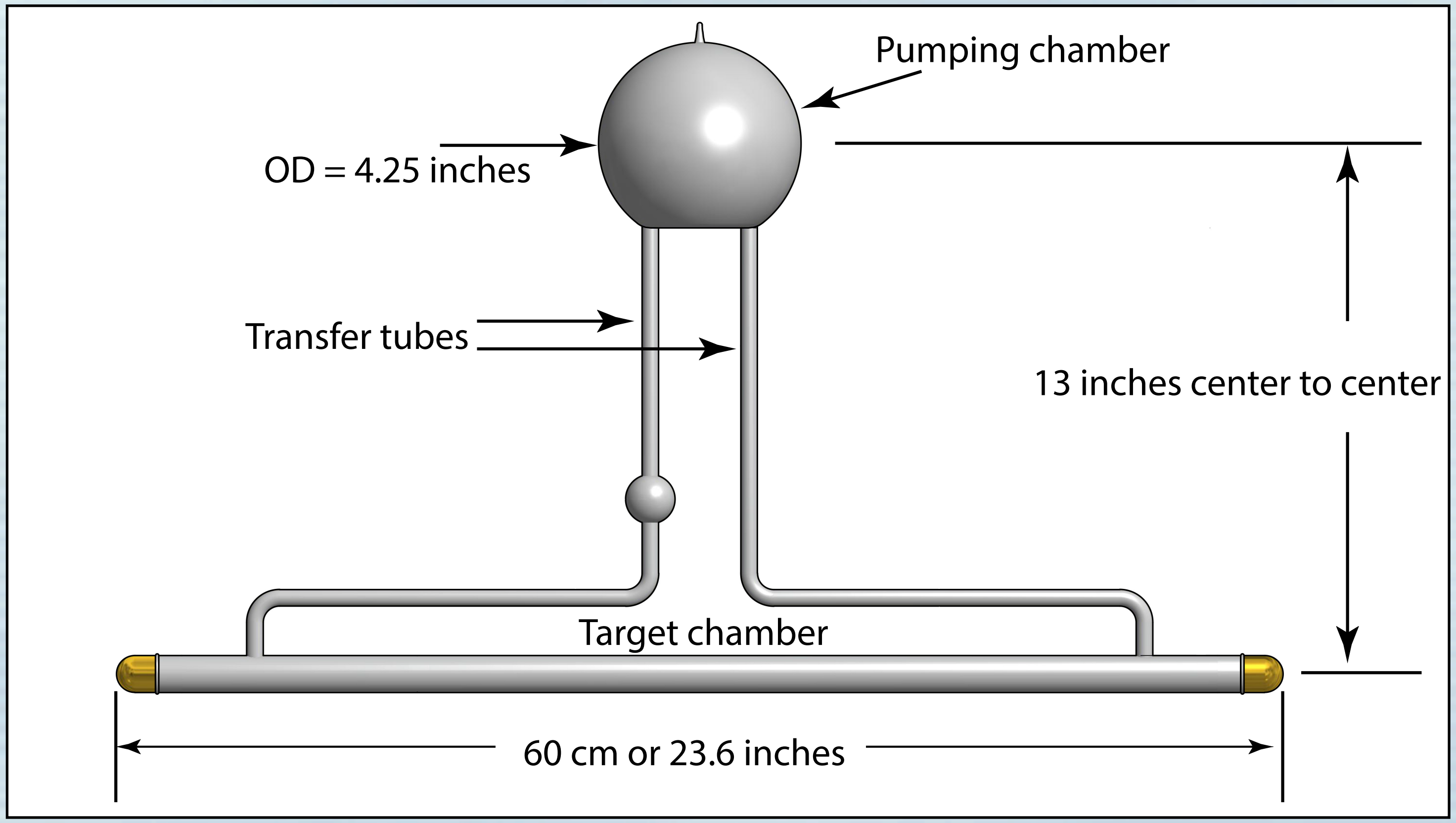
Shown is the Hall Probe mounted on a precision rotation stage for sensitivity study.

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.

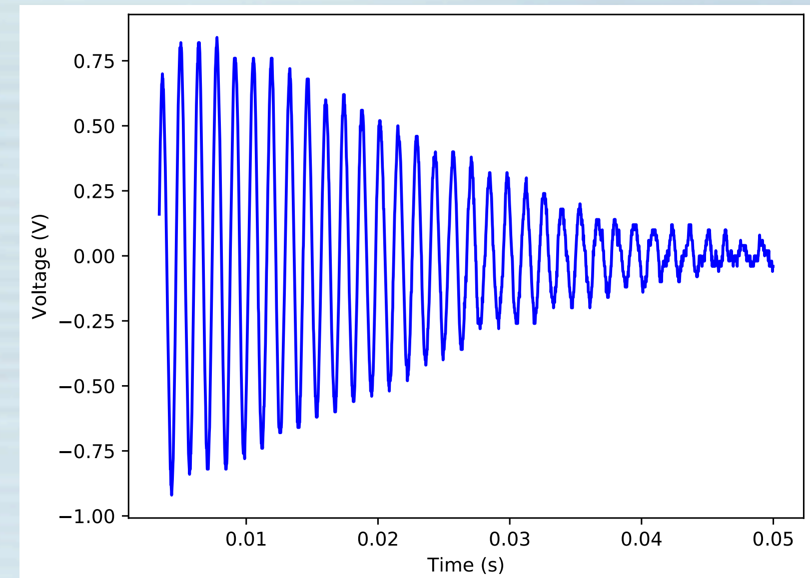
Glass-and-metal target cell development

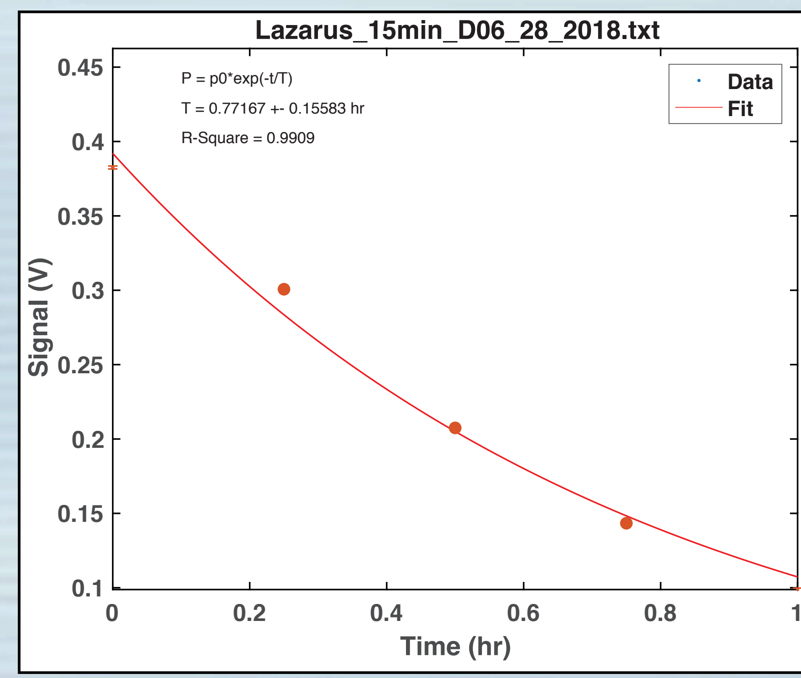


G_E^n-style Stage-II target cell design

Nearly ready to begin testing the Mark-II end-window assembly

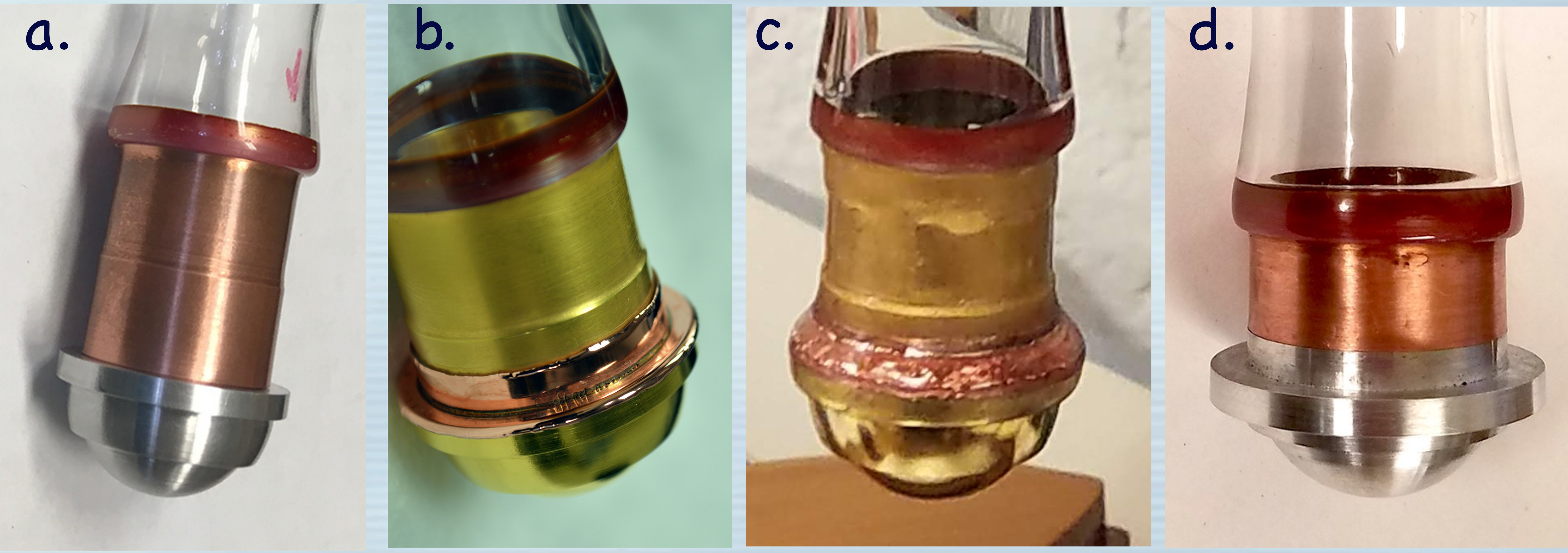
Test of Lazarus - first test cell containing thin (6 mil) aluminum window





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.