A1n Target Cell Production

and related activities

Target-production people power

- Huong Nguyen (Research Scientist)
- Vladimir Nelyubin (Senior Research Scientist)
- Sumudu Katugampola (Grad student - rising 7th year)
- Chris Jantzi (Grad student - rising 5th year)
- W. Al Tobias (Physics Dept. Staff)
- Todd Averett (W & M Professor)

G. Cates – UVa

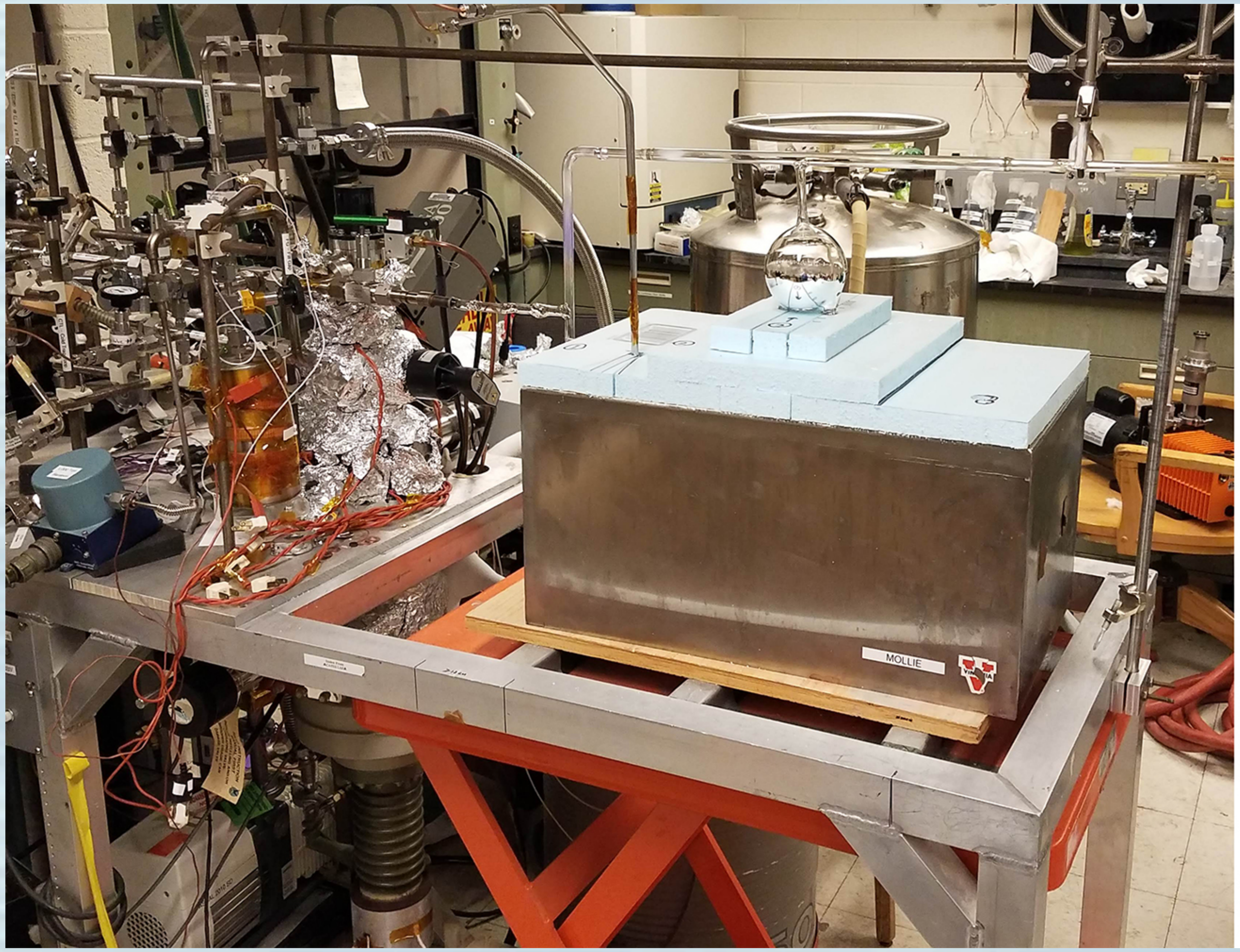
July 24, 2019

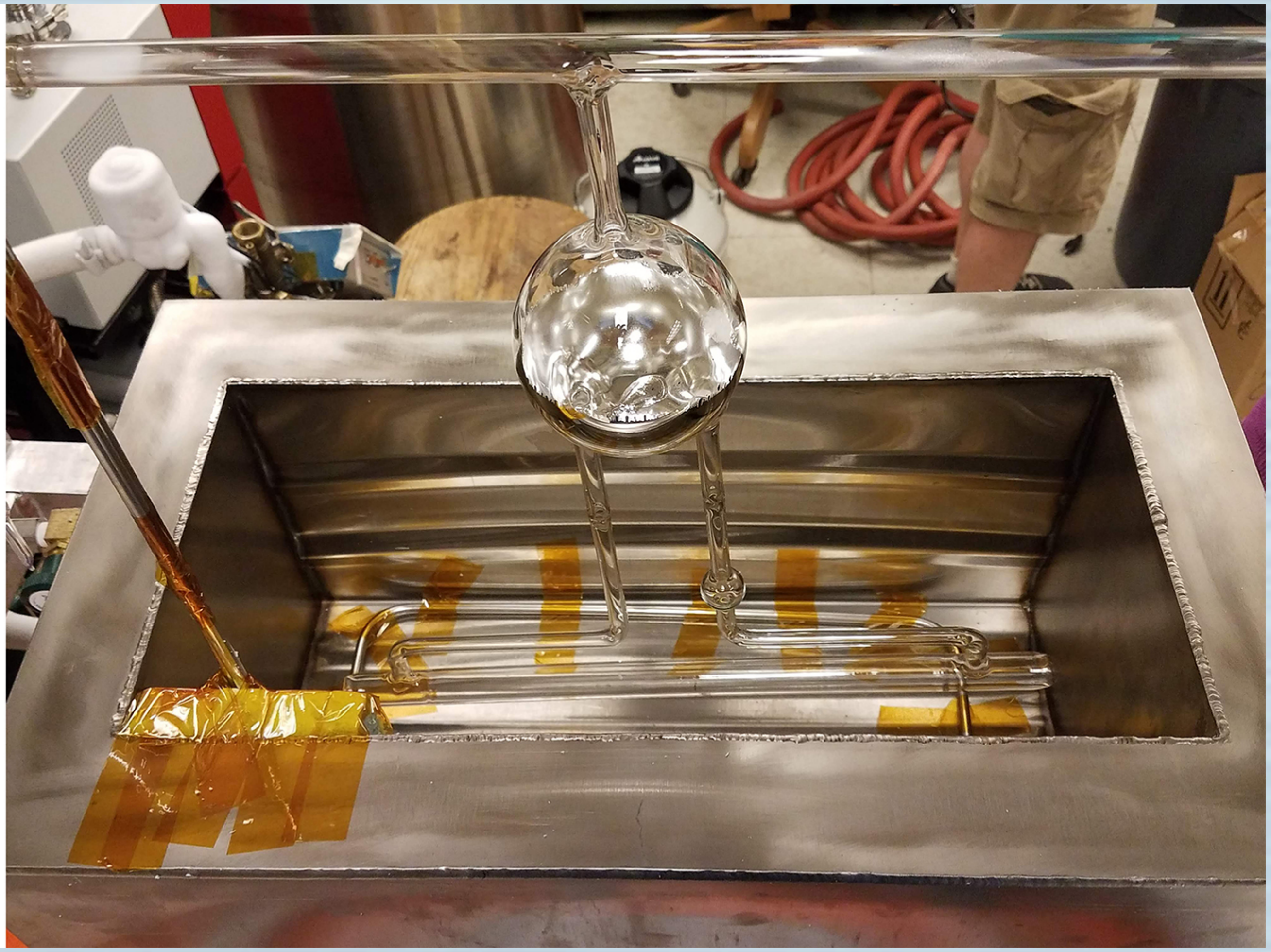
UNIVERSITY of VIRGINIA

Quick summary
(more details to follow)

- We have produced three cells with figures-of-merit within 64-83% of the desired goal.
- There is good reason to **expect** a high yield at the top of this range or better.
- Four other cells had poor performance for well understood (and avoidable) problems.
- Target-cell production is in full swing. If needed, we can probably produce as many as 14 more target cells by November 1st.

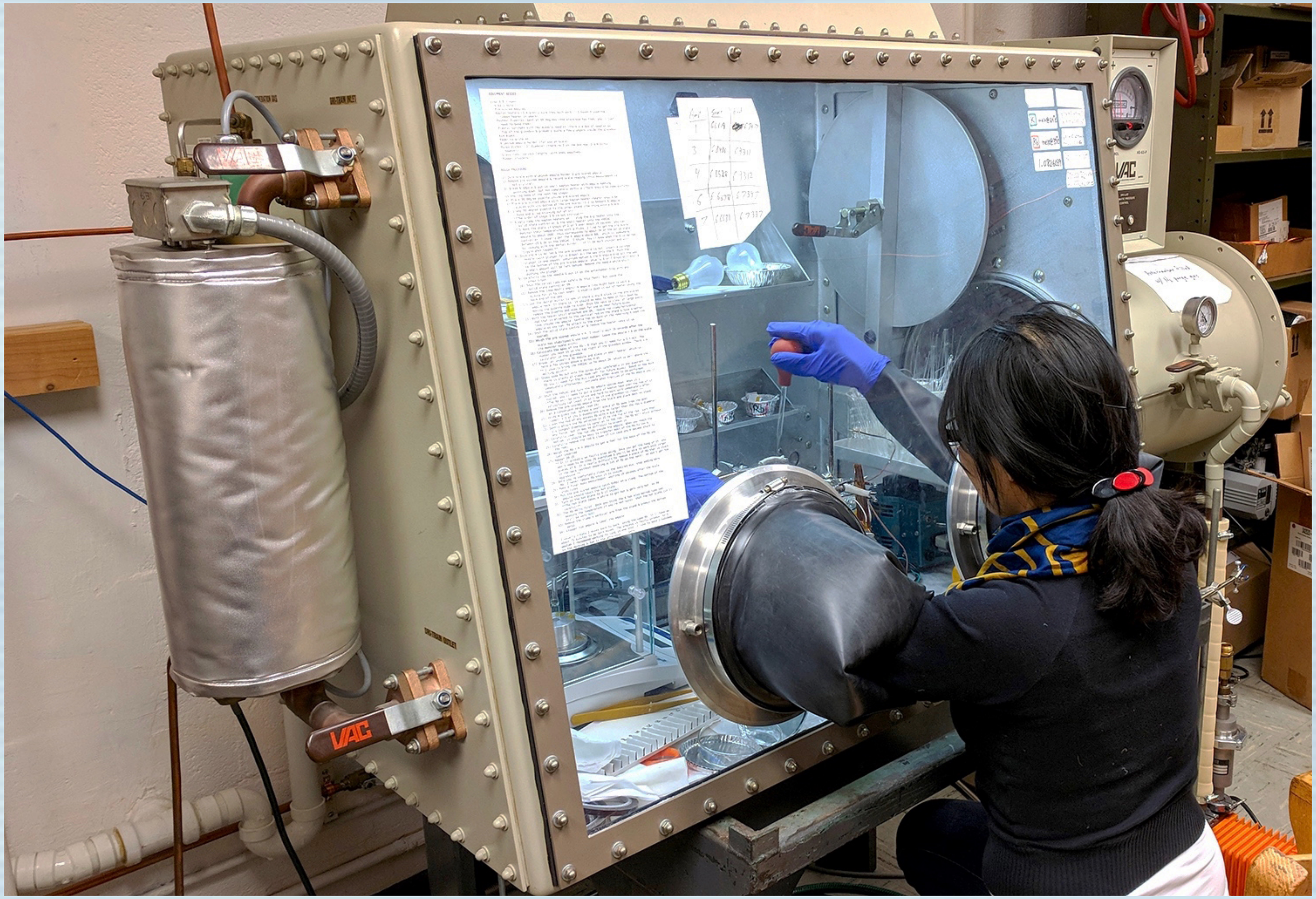
Cell filling apparatus





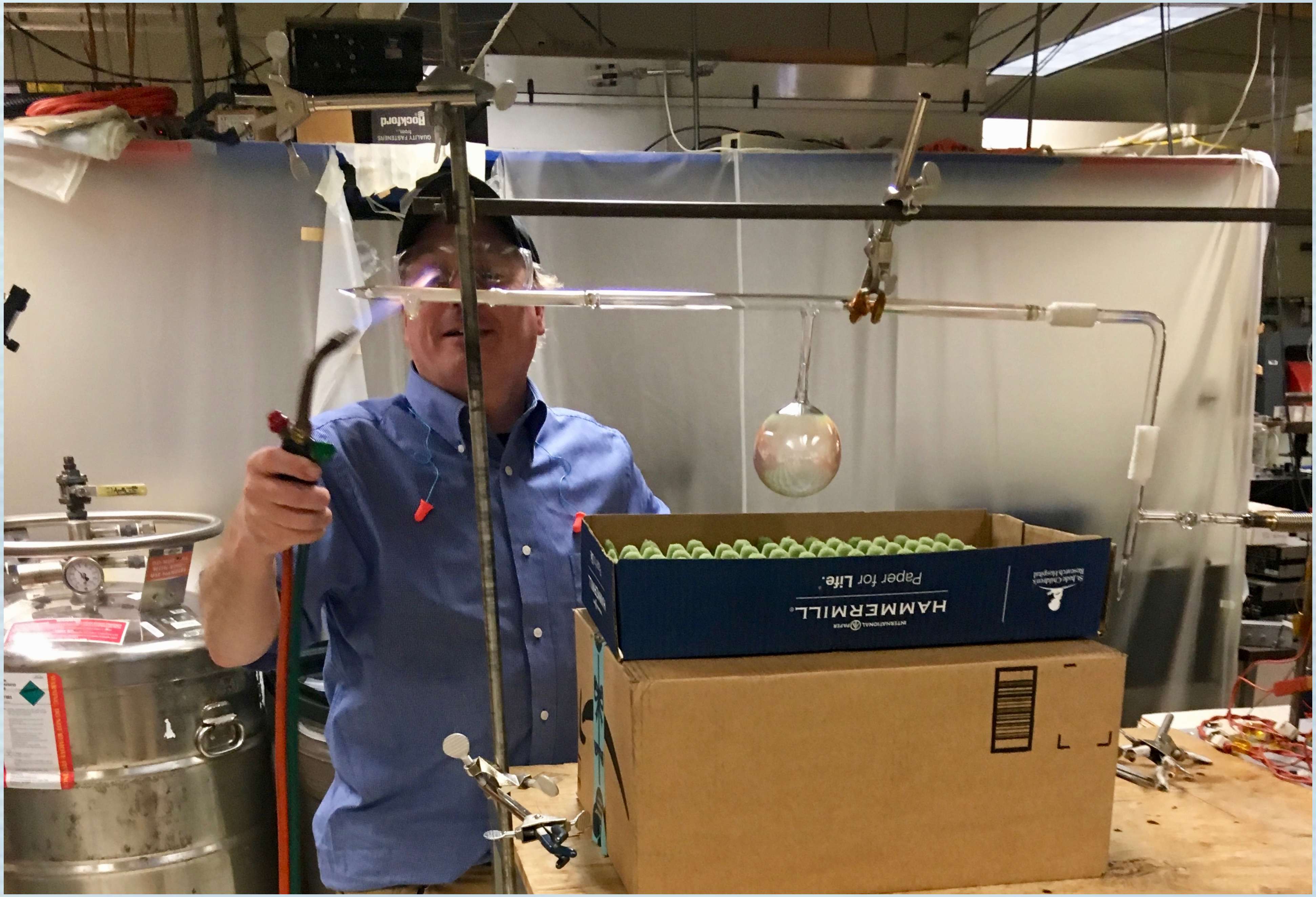
- Target cells are filled at cryogenic temperatures

Apparatus for preparing alkali-hybrid K/Rb mixture



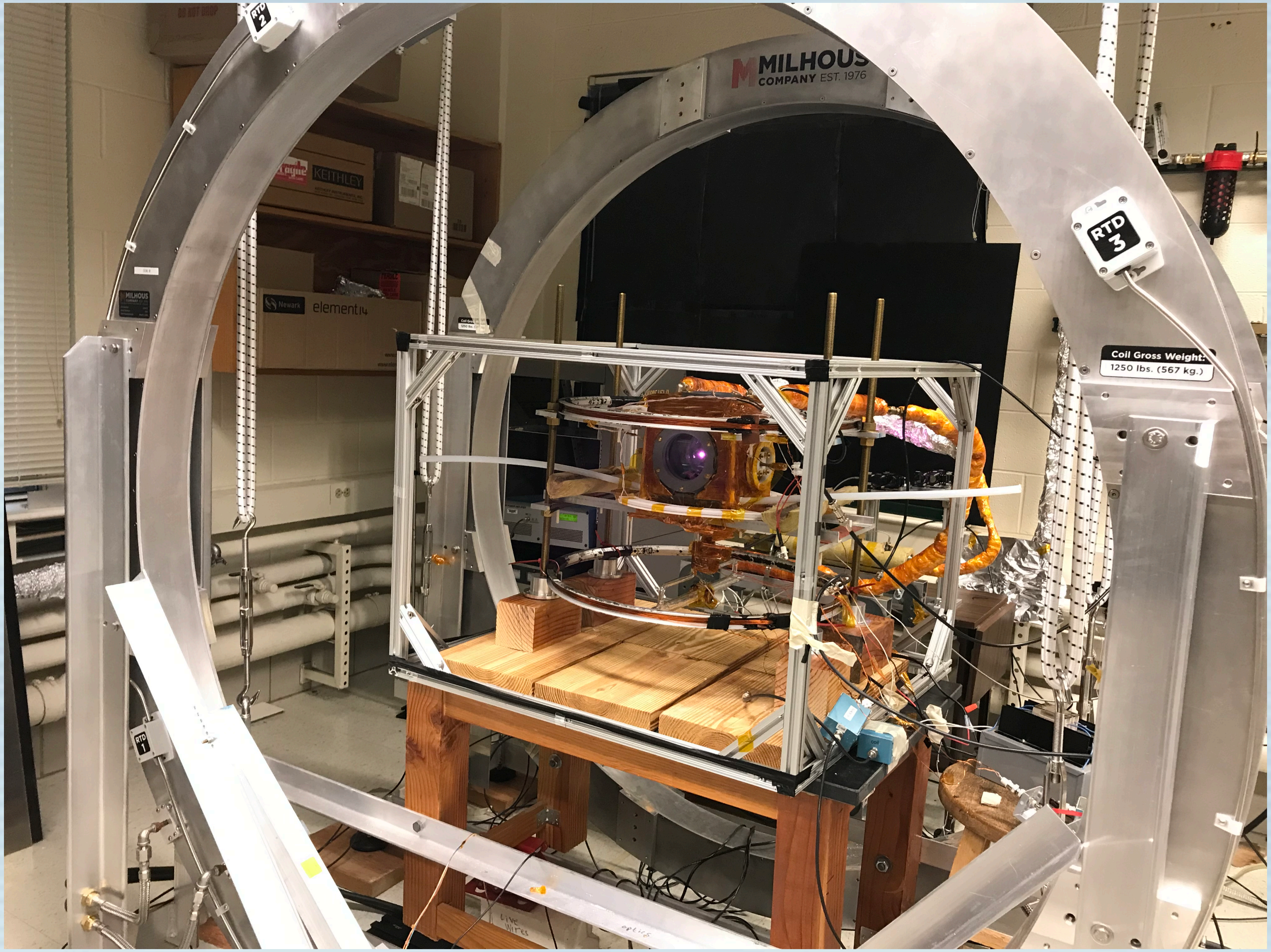
Huong preparing the new alkali-hybrid mixes
we are currently using.

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



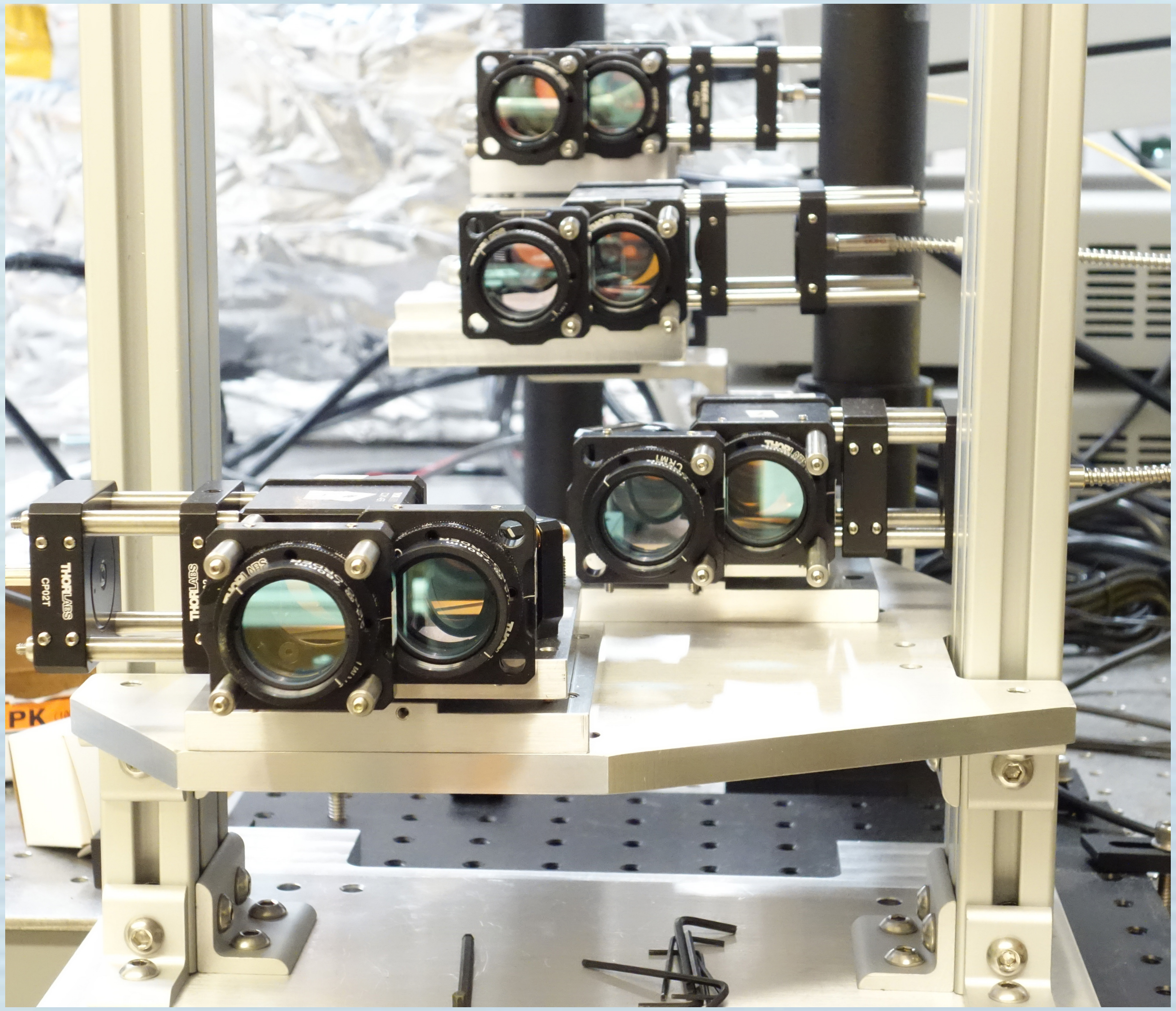
Standardized bench tests for the target cells

Our updated testing apparatus



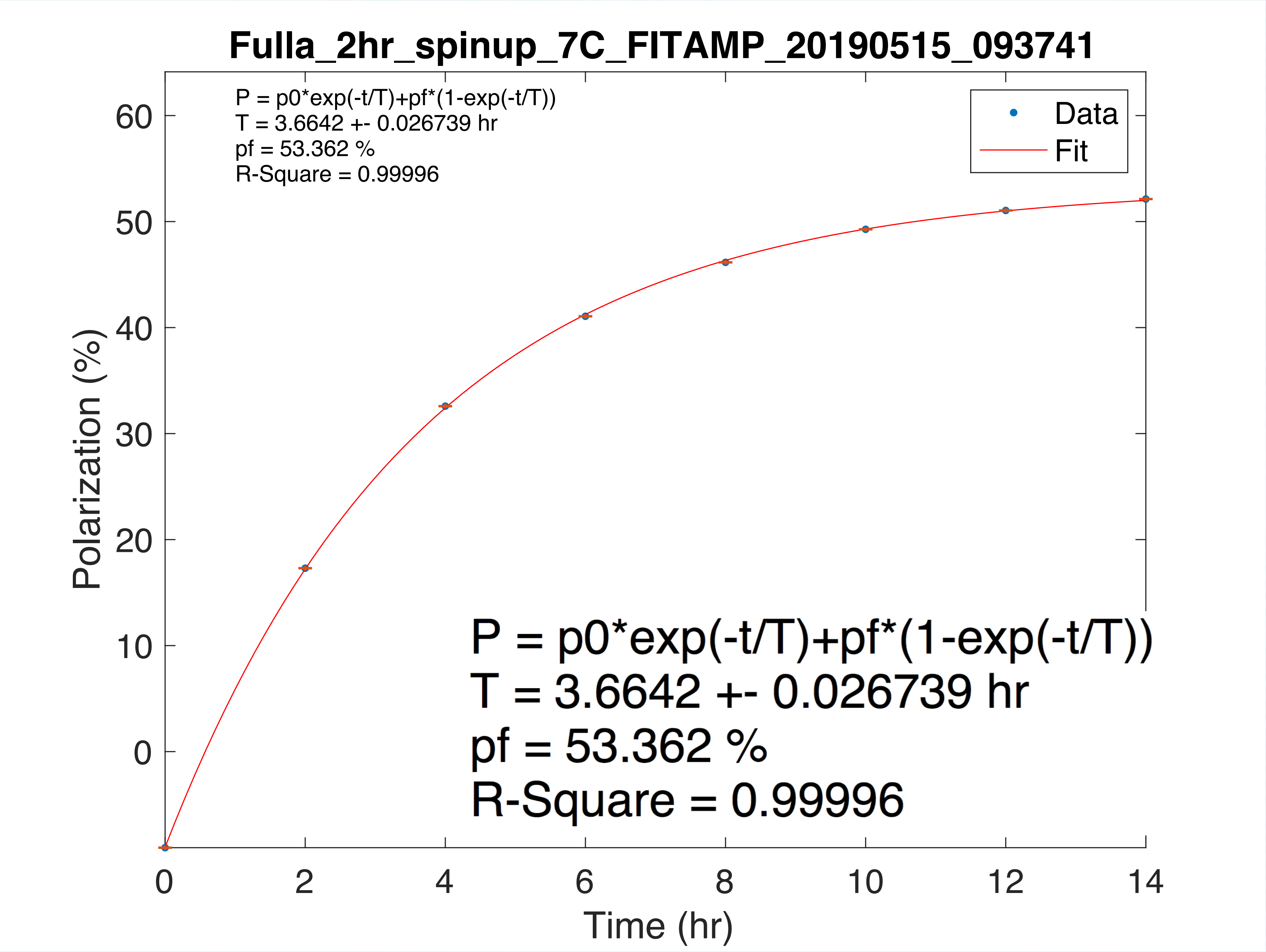
- RF coils are larger, although some losses still occur (typically 3-6% per scan).
- No efforts are being made to minimize AFP losses since they are essential to our simulated beam tests.

Laser system for optical pumping



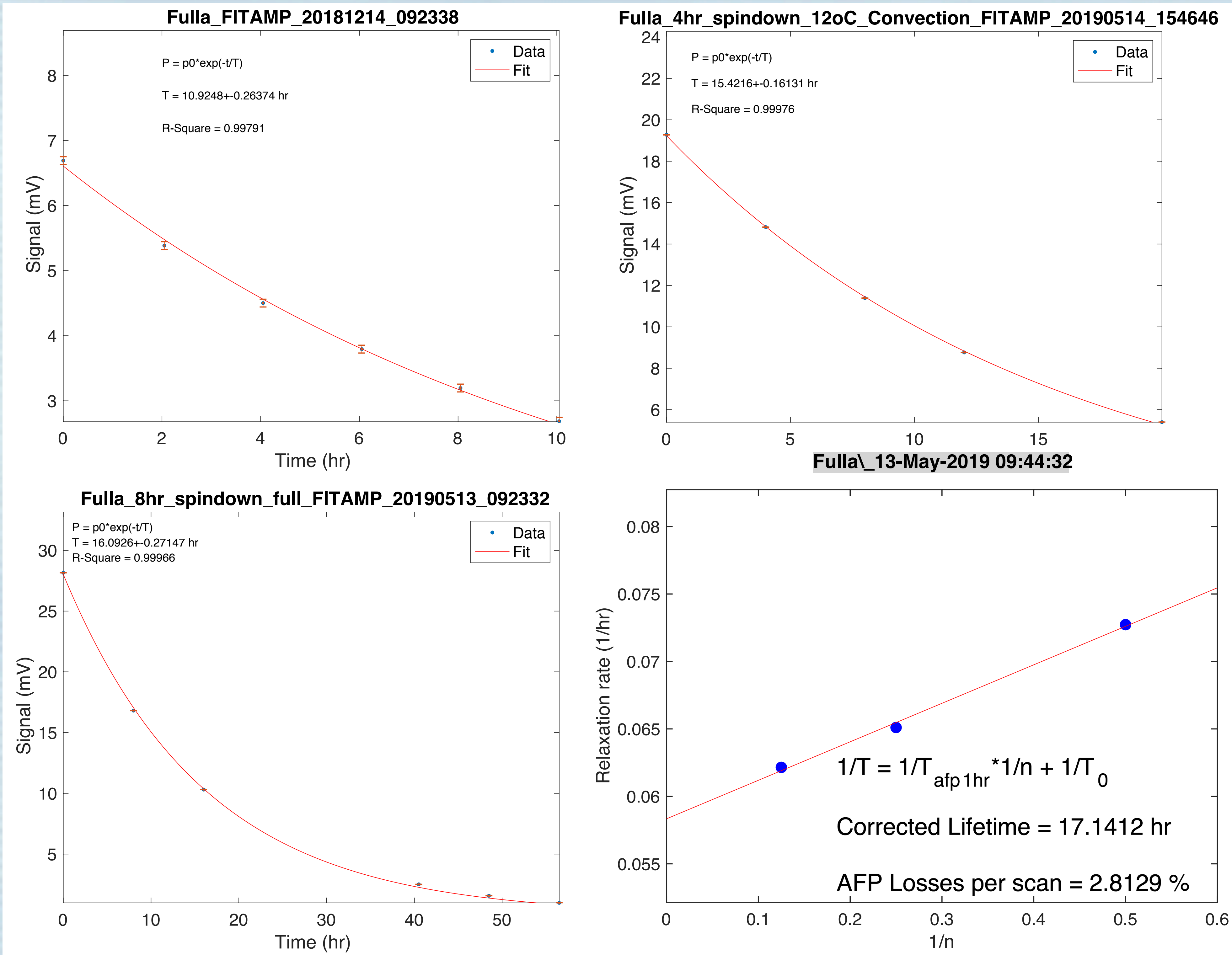
- We now have four 50W Raytum Photonics diode laser arrays, as well as some Comets.
- We typically pumped with 80-93 Watts from one direction, although we performed one test at 120 W.

Spin-ups and simulated beam tests



- *Test performed with AFP losses equivalent to 14μA electron beam.*
- *Extrapolating to 30μA indicates in-beam polarization of 50%.*

Determining the cold lifetime and AFP losses



- By performing spin-downs at multiple sampling rates, both the cold lifetime and the AFP losses per scan can be extracted.

Detailed summary

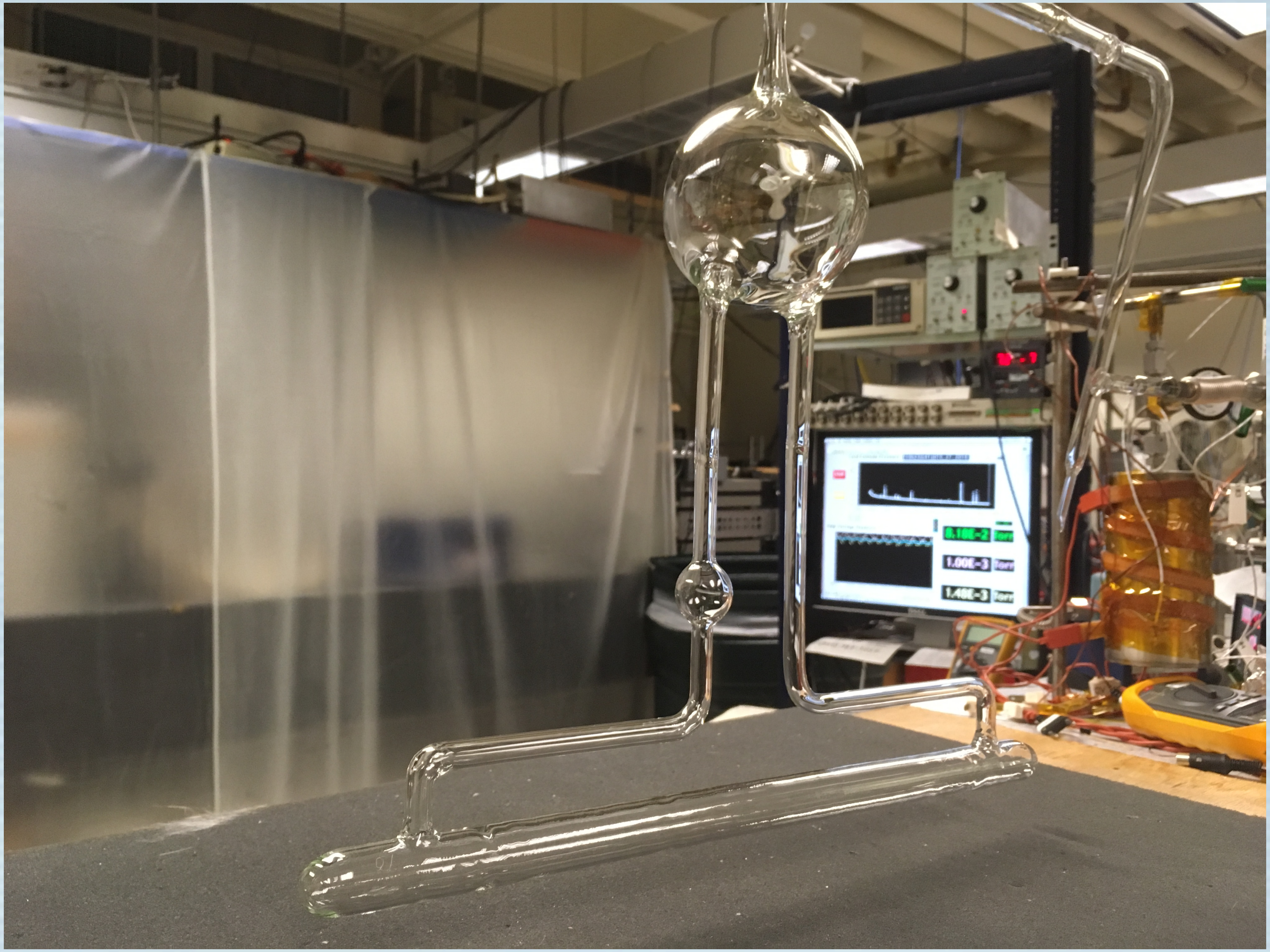
Table I: Target-cell production since the fall of 2018						
name	fill date	cold lifetime	max pol.	pol. at 30 μA	Known issues	Fractional figure-of-merit†
Fulla	9/07/2018	17.1 hrs	53%	50%	some overheating of pumping chamber	83%
Florence	9/28/2018	11 hrs	45%	44%	significant overheating of pumping chamber	64%
Noah	3/07/2019	short	-	-	leak in gas system	-
Briana	3/27/2019	22.9 hrs	53%	47.8%	-	76%
Elle	3/29/2019	short	-	-	leak in gas system	-
Sandy-II	5/28/2019	short	-	-	Alternative fabrication of transfer tubes	-
Phoenix	6/3/2019	short	-	-	Alternative fabrication of transfer tubes	-
† Figure-of-merit compared to 55% at 30 μA.						

- Fulla, Florence and Briana were reasonably consistent with each other when overheating of the pumping chamber is taken into account.
- Sandy-II and Phoenix represented failed attempts at an improved method of fabrication.

Can we expect to do better?

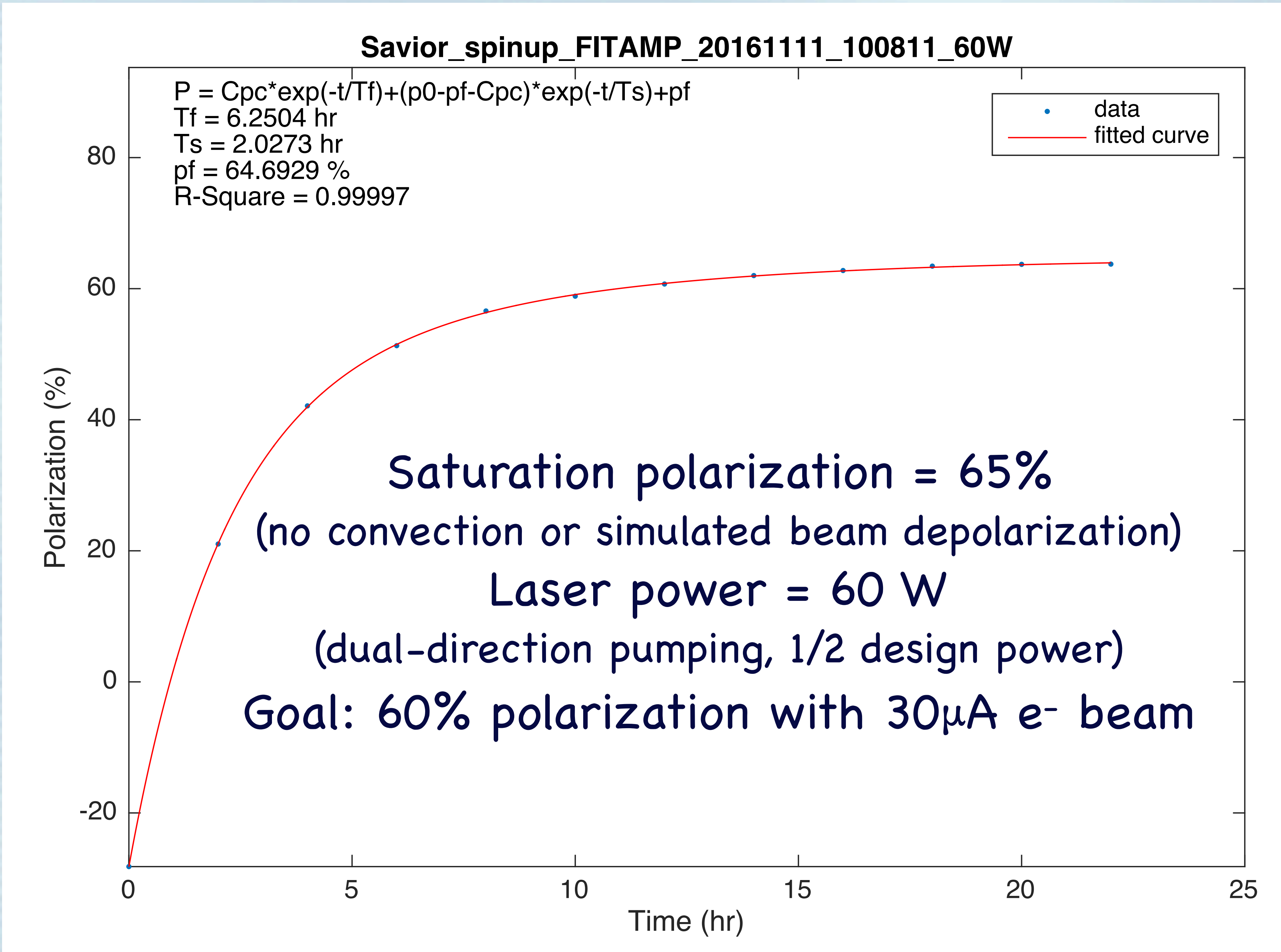
yes...

First production A_1^n target: Savior



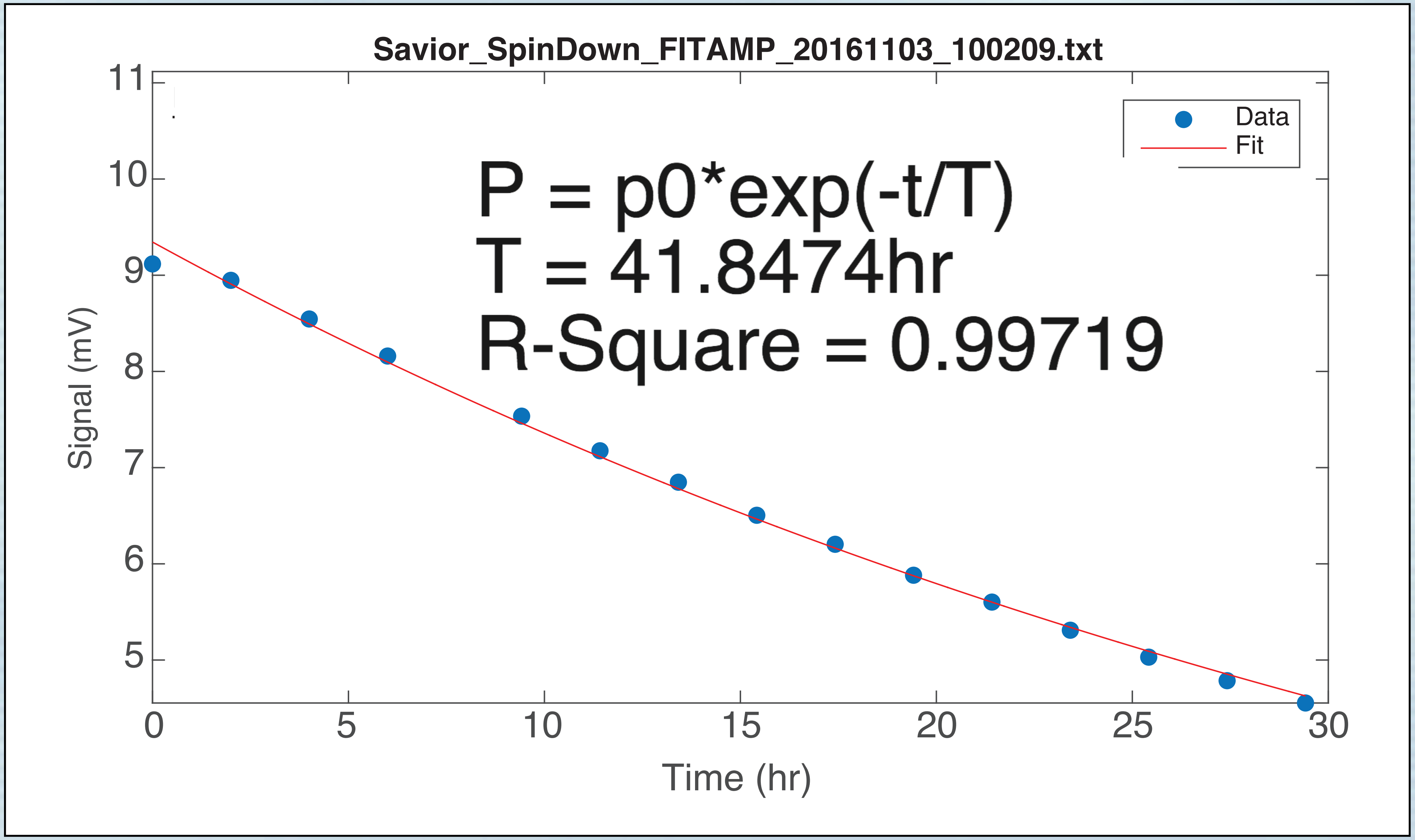
On the gas system prior to being filled.

Polarization test of Savior



While not a simulated beam test, these measurements were suggestive that the 60% at full beam was achievable.

Spin-down of Savior



- The longest spin-down observed in a new target cell is about 23 hours, well below the above 42 hours.
- There is no obvious reason that the 40-hour range cannot be reached, and such cells will probably have significantly better performance.

What issues are holding us back?

- Early on we identified overheating of the target chamber as having potential to reduce the cold lifetime.
  - The lifetimes of Florence, Fulla and Briana, 11, 17 and 23 hrs respectively, are consistent with improvements due to less heating.
- Could there be a better way to make the transfer tubes?
  - We tried a technique suggested by Gordon, intended to make the construction of the transfer tubes more similar to the construction of the target chambers. It made matters worse, not better. Note, Mike was skeptical!
- There are good reasons to believe that we can do a better job cleaning the gas during filling.
  - The cell Yeti will be filled with a liquid helium trap as the last thing the gas sees before entering the cell, patterned off of the trapping scheme followed during SLAC E142.

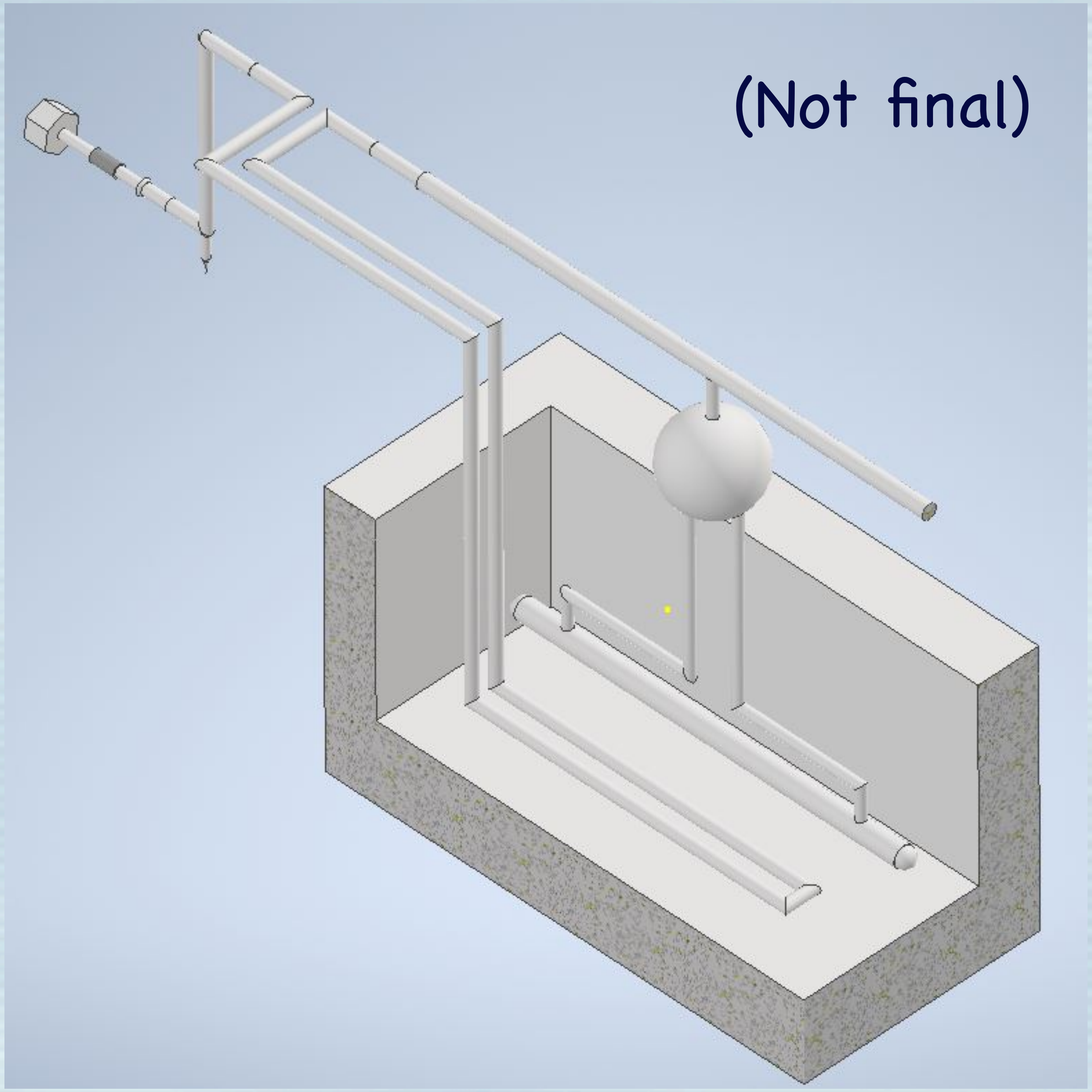
Summary from Todd of spherical-cell performance

(includes both recent and historic fills from both UVa and W&M, filled at both room temperature and using cryogens)

WM/UVa Spherical Cell Summary				yellow = same string					
Cell Name	Date Filled	Fill Location	Glassblower	Bake Temp (C)	Getter or Cold Trap?	Pre-mix Alkali Y/N	Cooldown	Density (amg)	Lifetime (hrs)
Apfel	2016	Mainz	Mainz	unknown	both	N	LN2	~3	(Uncorrected) 163
Murex	4/17/17	W&M	Mainz	390	getter	N	LN2	1.23	(Uncorrected) 95
Horley	4/10/17	W&M	Mainz	390	getter	N	LN2	2.5	(Uncorrected) 33
Pebbles	5/10/19	W&M	Souza	450	getter	Y, UVA (K: 200mg)	None	0.72	(Uncorrected) 105
Bam-Bam	5/6/19	W&M	Souza	450	getter	Y, UVA (K: 200mg)	LHe	6.73	(Uncorrected) 29
Kappa1	06/02/2016	UVA	Souza	Flame Bake	LHe Cold Trap	Y, UVA (K: 1000mg)	None	0.84	(Corrected) 170
Kappa2	01/28/2019	UVA	Souza	380	LN2 Cold Trap	Y, UVA (K: 200mg)	None	0.84	(Corrected) 23
Kappa3	02/08/2019	UVA	Souza	400	LHe Cold Trap	Y, UVa (K: 200mg)	None	0.86	(Corrected) 175
Kappa4	02/19/2019	UVA	Souza	400	LHe Cold Trap	Y, UVA (K: 200mg)	None	0.85	(Uncorrected) 88

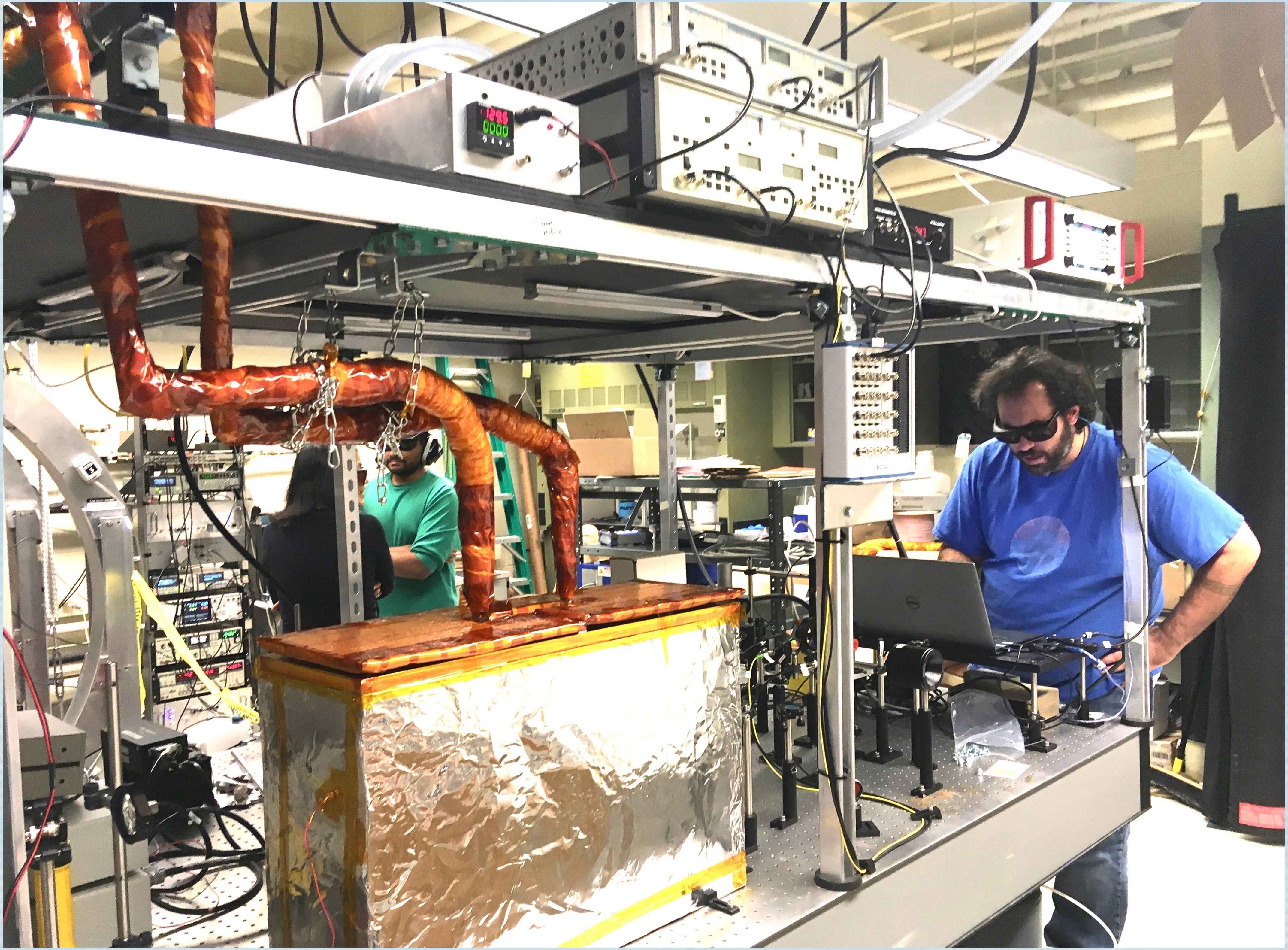
- UVa fills of spheres were all at room temperature, but the difference between LHe trapping and LN2 trapping was clearly evident.
- W&M fills included room temperature, LN2 and LHe fills (that is, high-density fills).
- W&M data suggest that higher densities have shorter lifetimes beyond what would be expected from He-He collisions.
- All of the trends described above are suggestive that cleaner gas would help, particularly at UVa where our system is older and presumably more contaminated.

New liquid-helium trap

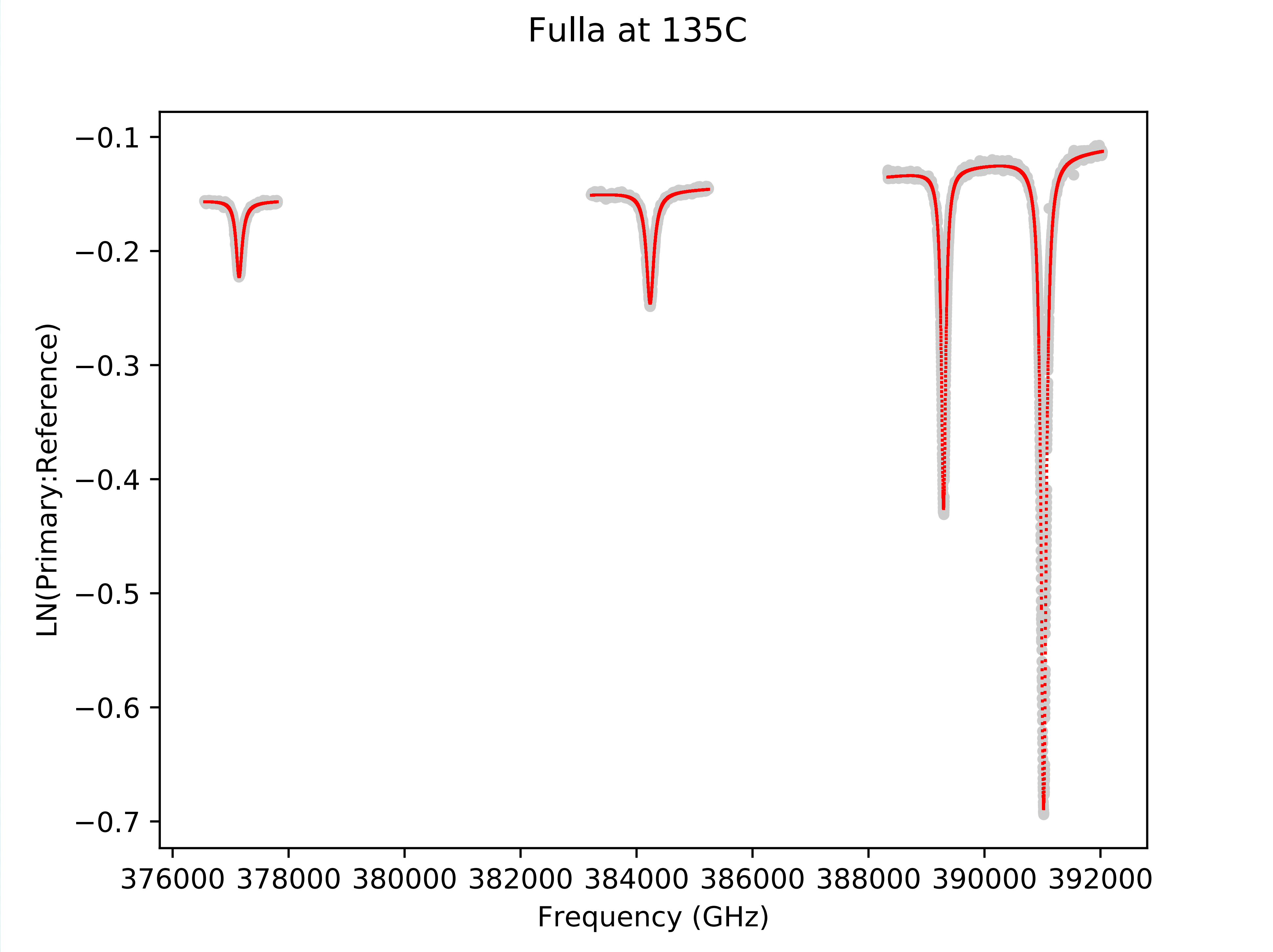


- The trap will be the LAST thing seen by the He-3 as it moves into the target cell.
- The trap will be baked along with the cell prior to filling.
- This approach is similar to what we used for SLAC E142, when we had lifetimes as high as 63 hrs.

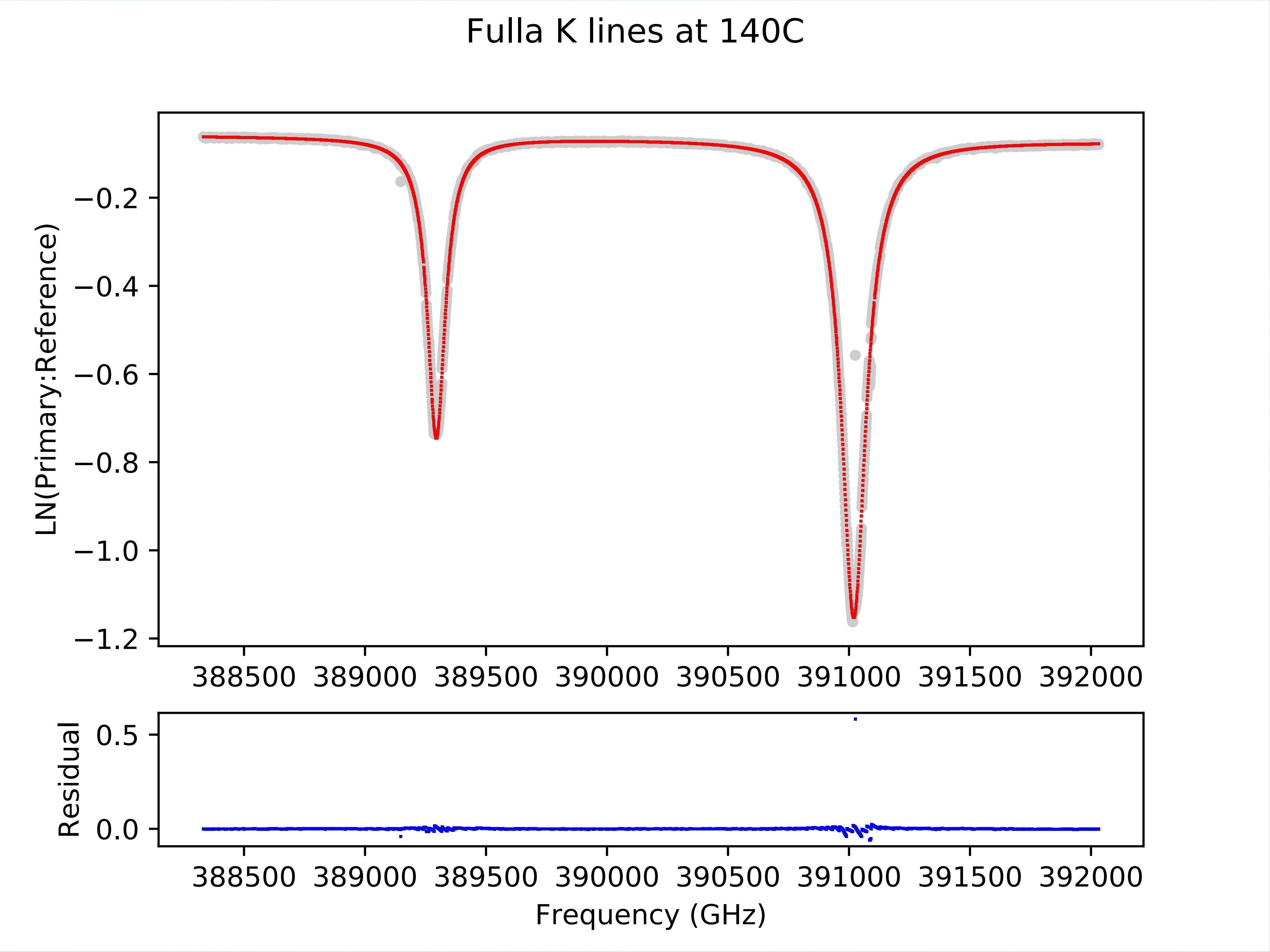
Cell Characterization system



Cell Characterization system



Cell Characterization system



Summary

- Target production is now moving well.
- Rate of production could be as high as one per week.
- It is reasonable to **expect** a high yield of targets capable of 50% polarization in 30μA of beam.
- It is **likely** a subset of these targets will be capable of 55% in 30μA of beam.
- It is quite possible that fine tuning will result in very high-performing targets capable of 60% in 30μA of beam.

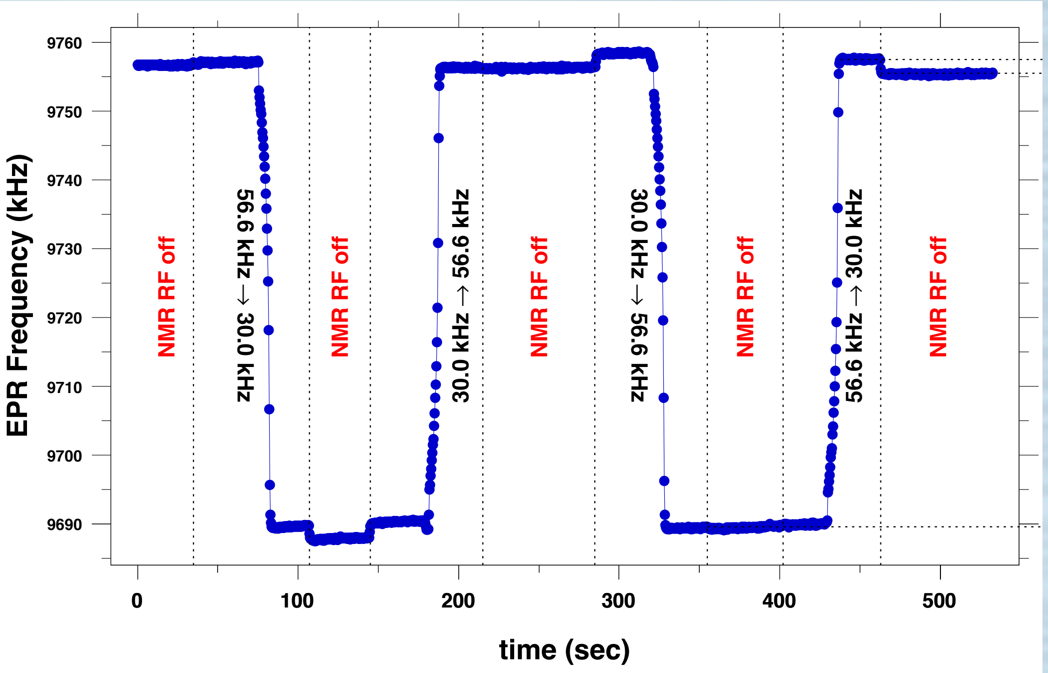
Backup slides

Polarimetry and measuring an updated value for κ_0

EPR polarimetry requires accurate knowledge of the atomic parameter κ_0

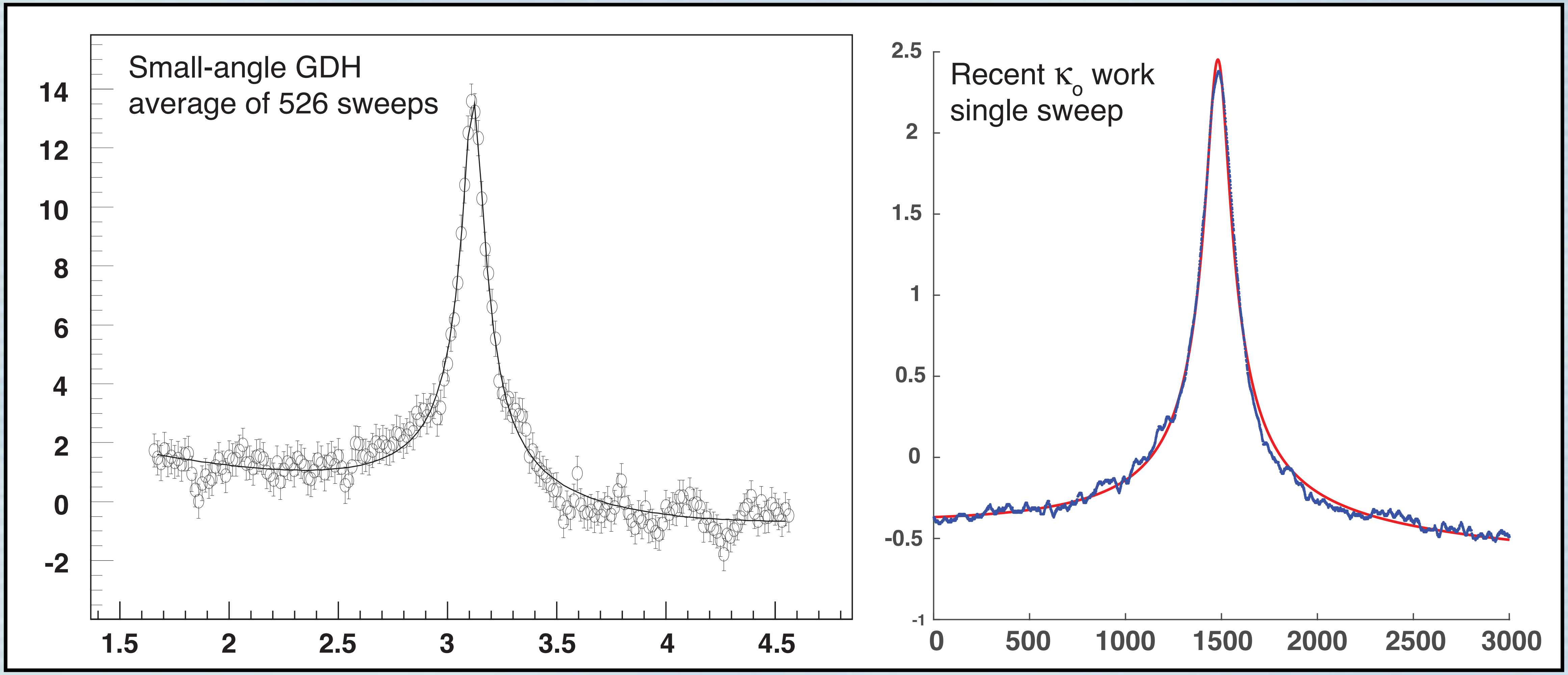
$$\Delta\nu = \frac{8\pi}{3}\frac{\mu_B g_e}{h(2I+1)}\left(1 \mp \frac{8I}{(2I+1)^2}\frac{\mu_B g_e B}{hA}\right)\kappa_0 \mu_K [\mathrm{He}] P$$

κ_0



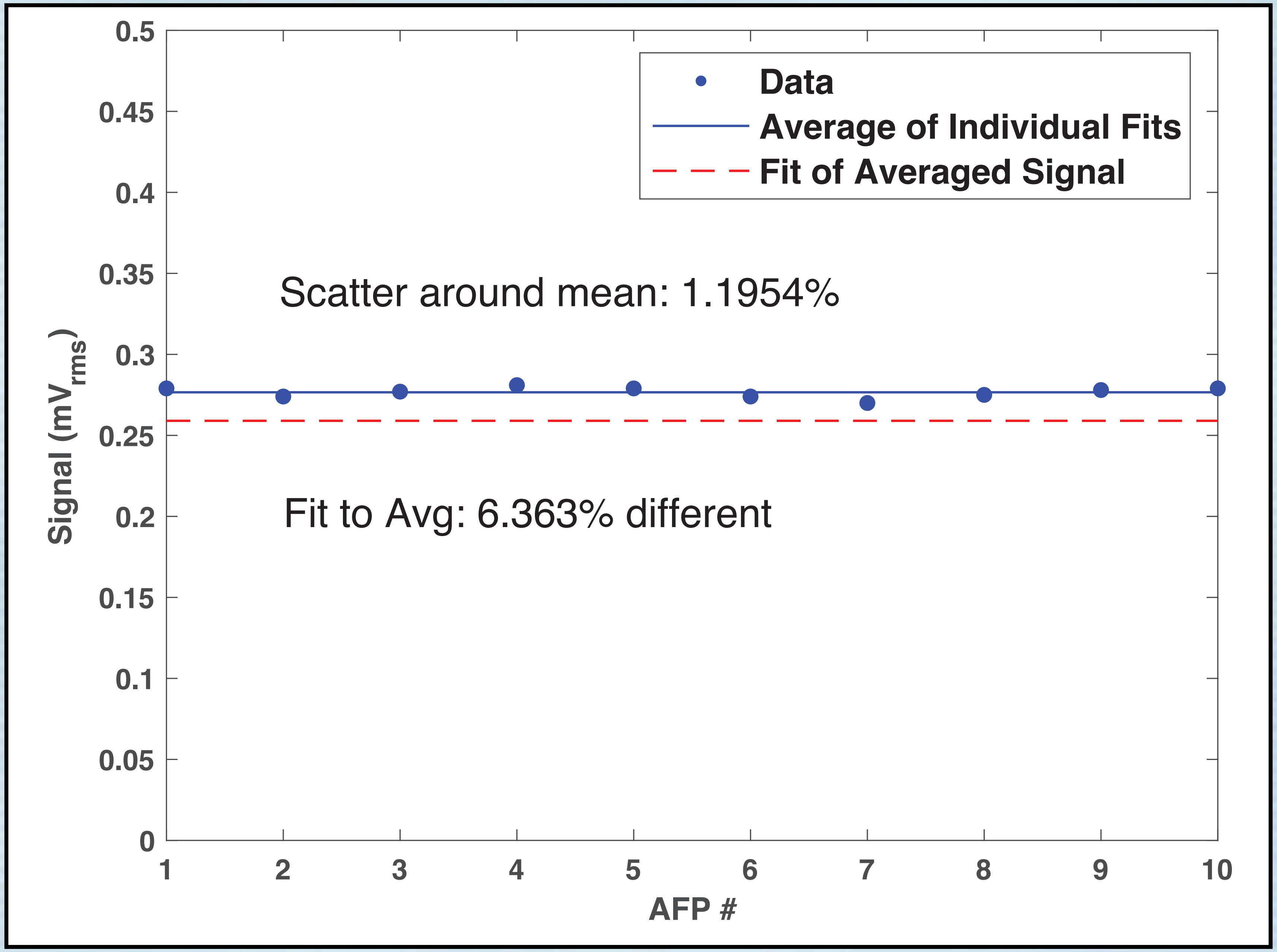
- RF generator is locked to a Zeeman transition in one of the two alkali species (K or Rb).
- The transition frequency is shifted due to the effective magnetic field of the polarized ^{3}He.
- By flipping the ^{3}He spins with respect to the holding field, the resulting frequency shift provides an absolute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

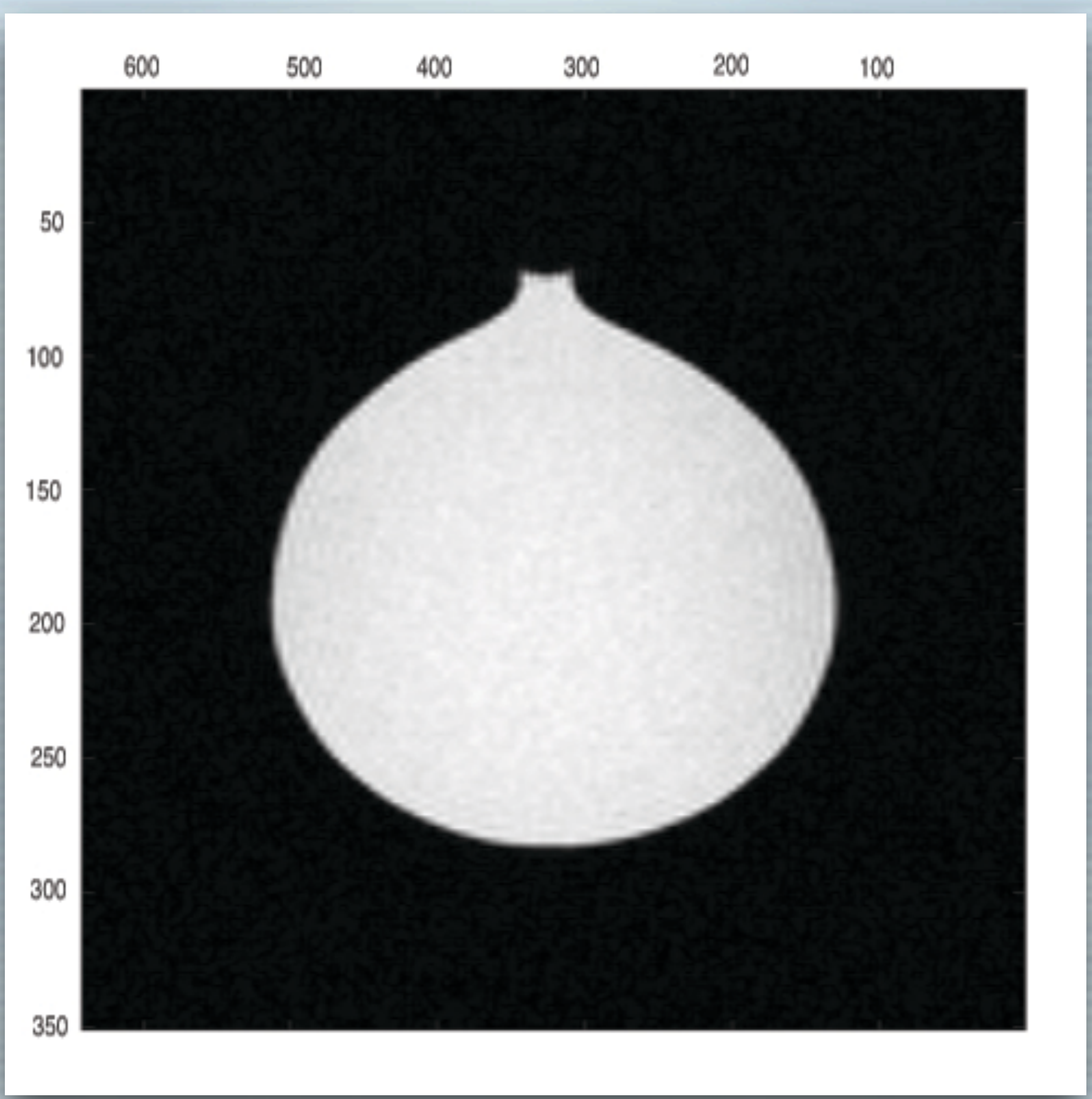
Water calibrations: the average of fits versus the fit of an average



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

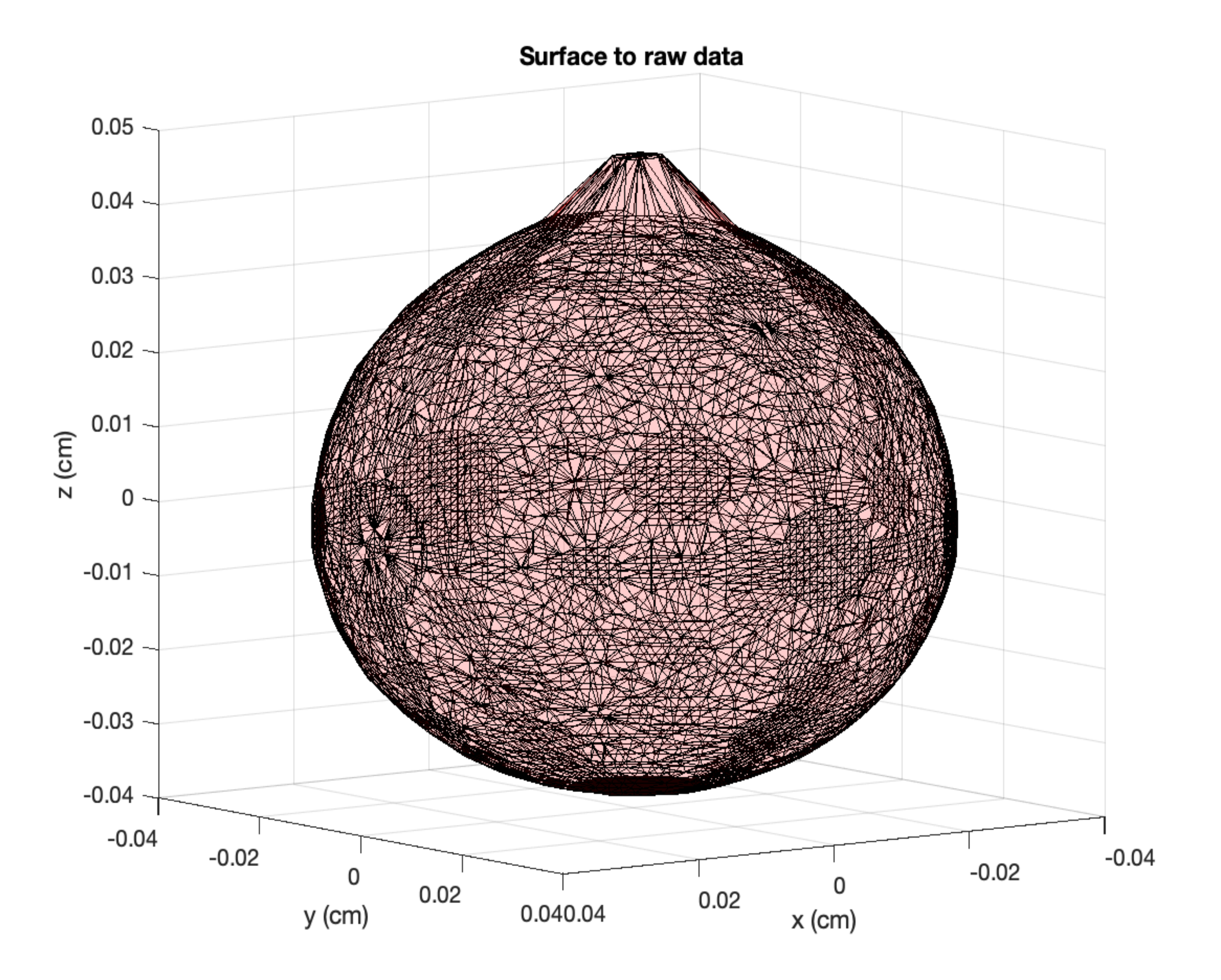
Characterizing our water cells

- 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.

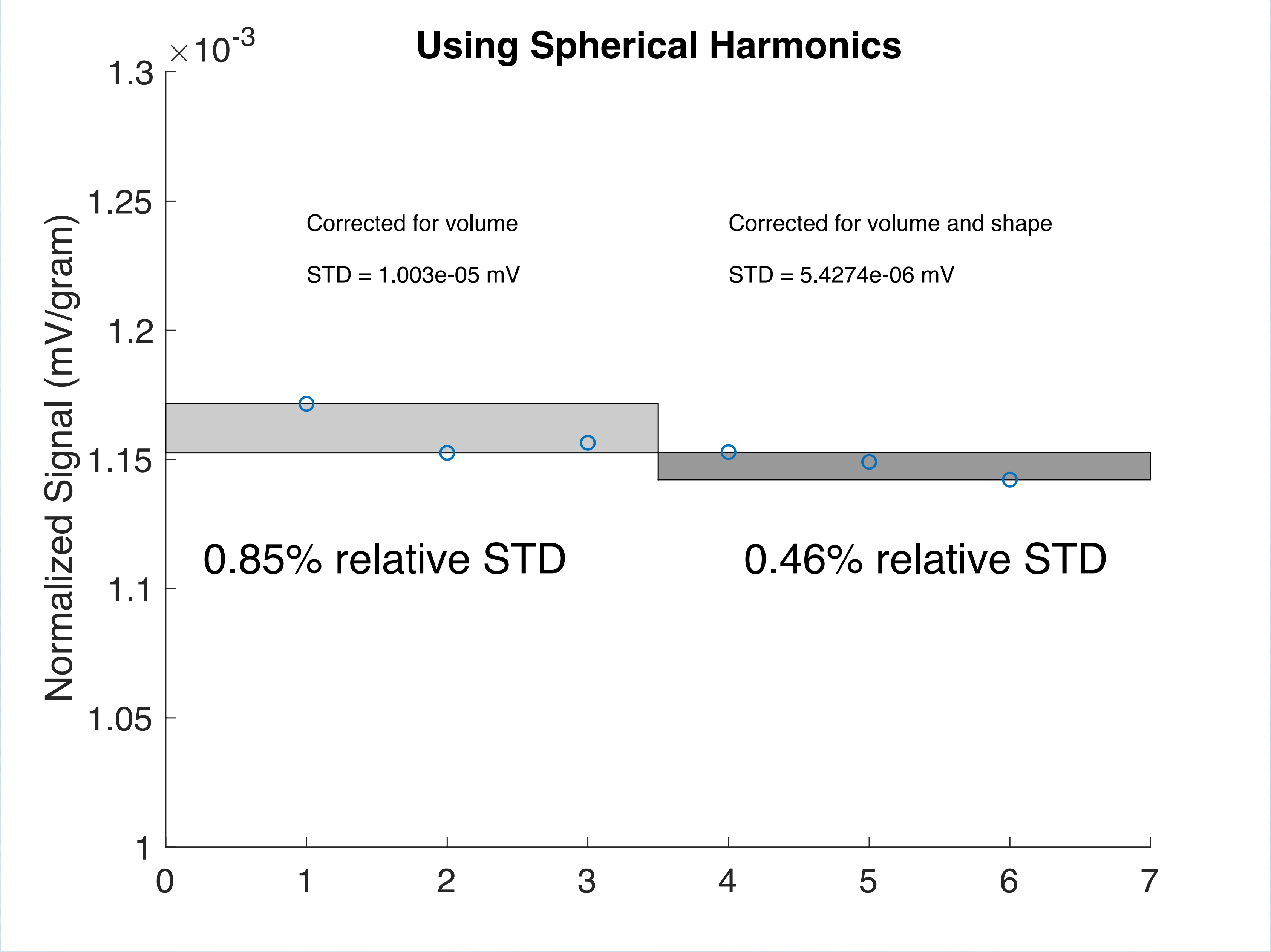


Characterizing our water cells

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

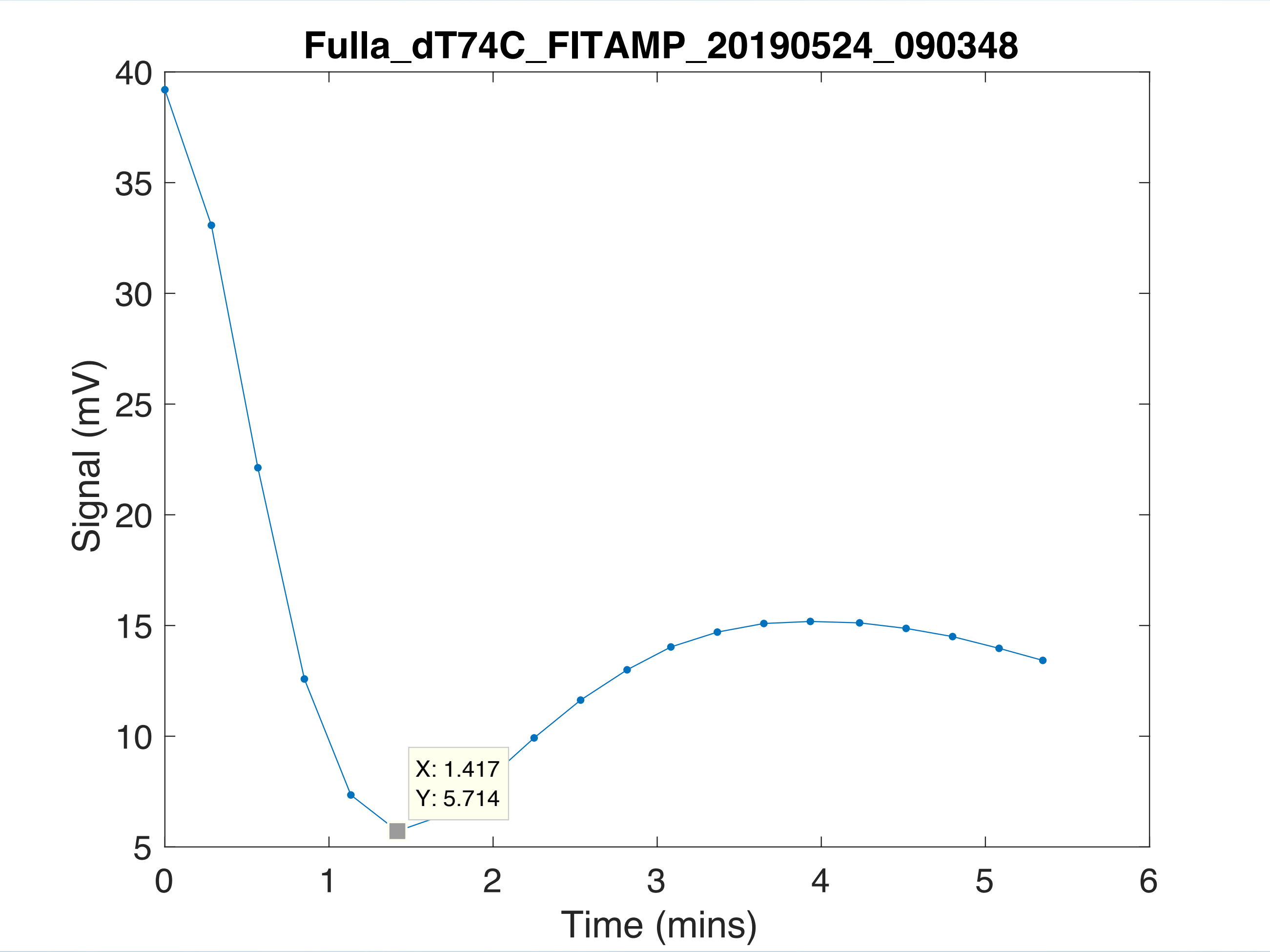


Characterizing our water cells:
fitting their shapes to spherical harmonics



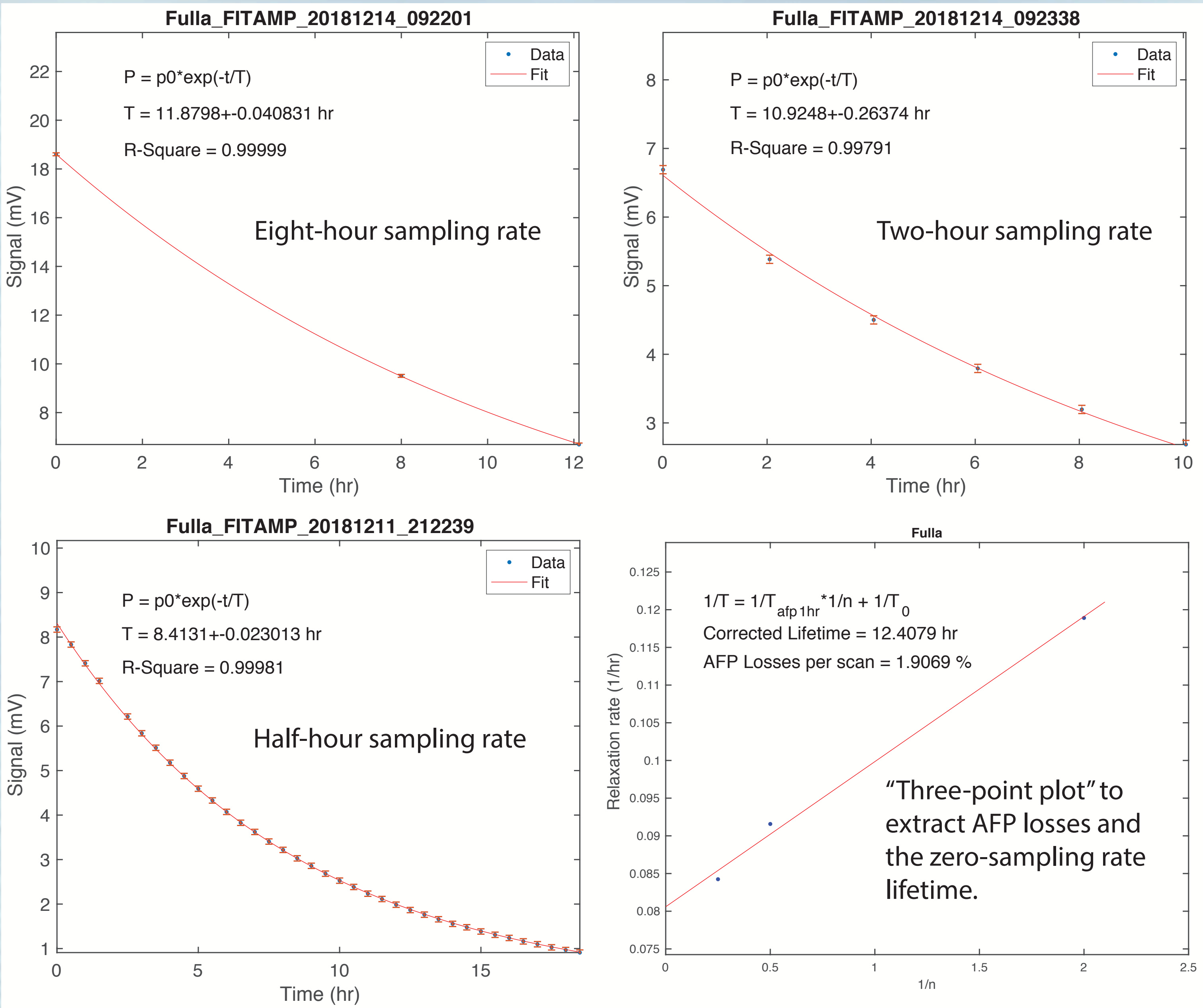
- Spherical geometry already suppresses sample dependence (0.85% is already very good).
- Preliminary shape analysis already is giving further suppression of a factor of ~2.

Convection-based mixing estimate



- Using the time between the depolarizing pulse and the passing reduction in signal, we estimated 5.3 cm/min at 74C difference between the two transfer tubes.
- Accordingly, 12-18 C difference corresponds to 0.9 - 1.3 cm/minute, or a 31 - 44 minute refresh rate.
- Transversity cells, mixed by diffusion, had a roughly 83 minute 1/e mix time.
- Better calibrated convection studies are planned for the near future.

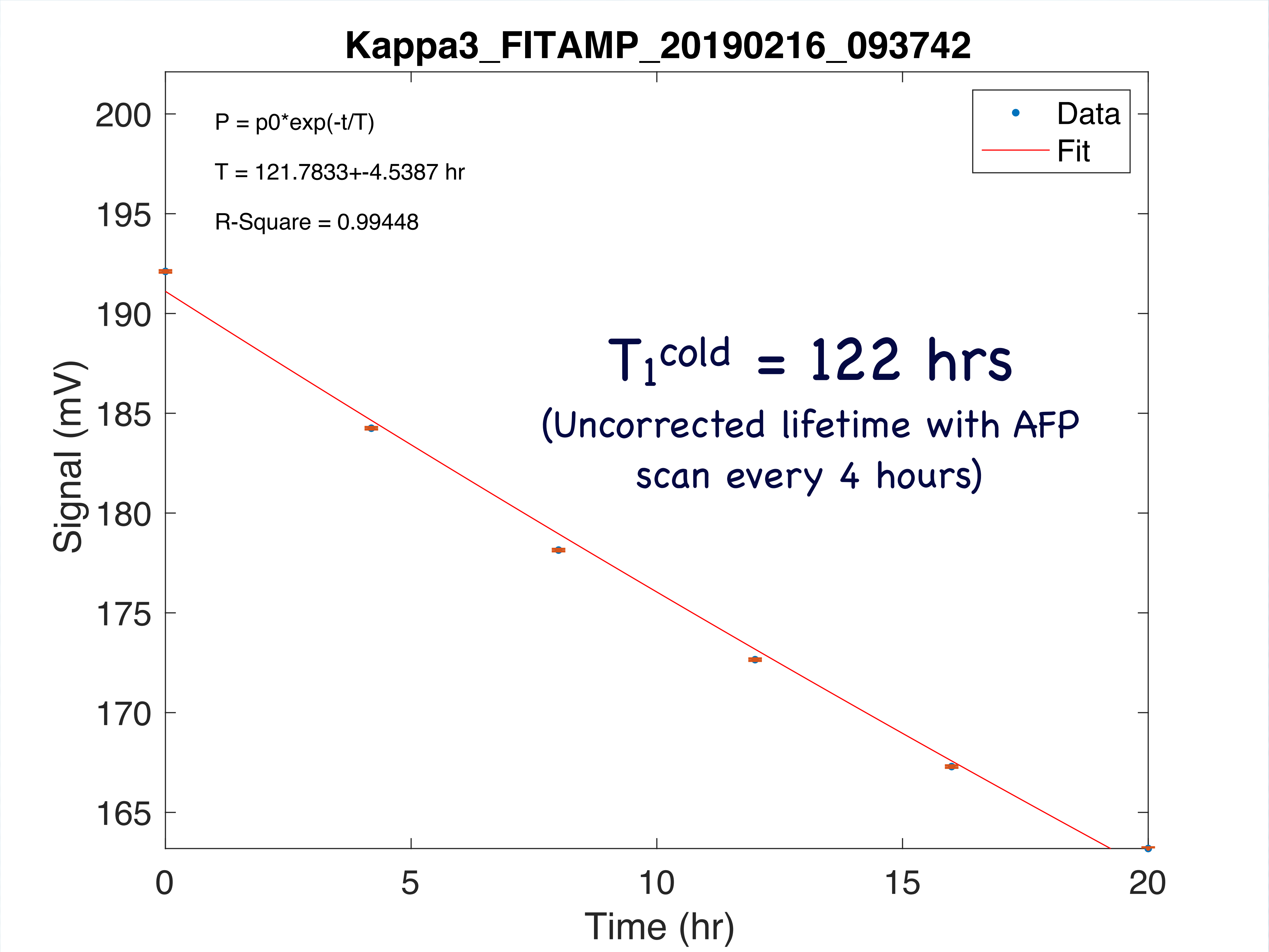
The perils of not driving convection



$$P_{\mathrm{pc}}(t) = C_{\mathrm{pc}} e^{-\Gamma_{\mathrm{f}} t} + \left(P^{0}_{\mathrm{pc}} - P^{\infty}_{\mathrm{pc}} - C_{\mathrm{pc}}\right) e^{-\Gamma_{\mathrm{s}} t} + P^{\infty}_{\mathrm{pc}}$$

- Early measurements of Fulla were made with no convection.
- Multiple spin-downs suggested a 12.4 hr cold lifetime, and 1.9% AFP losses.
- But in a two chambered cell, time constants characterizing spin relaxation are intertwined with mixing times.
- In reality, AFP losses were extremely high in the target chamber, and the measured lifetimes in the pumping chamber were totally dominated by slow mixing times.
- Because Γ_f was under 2hrs, the spin-downs appeared quite normal.

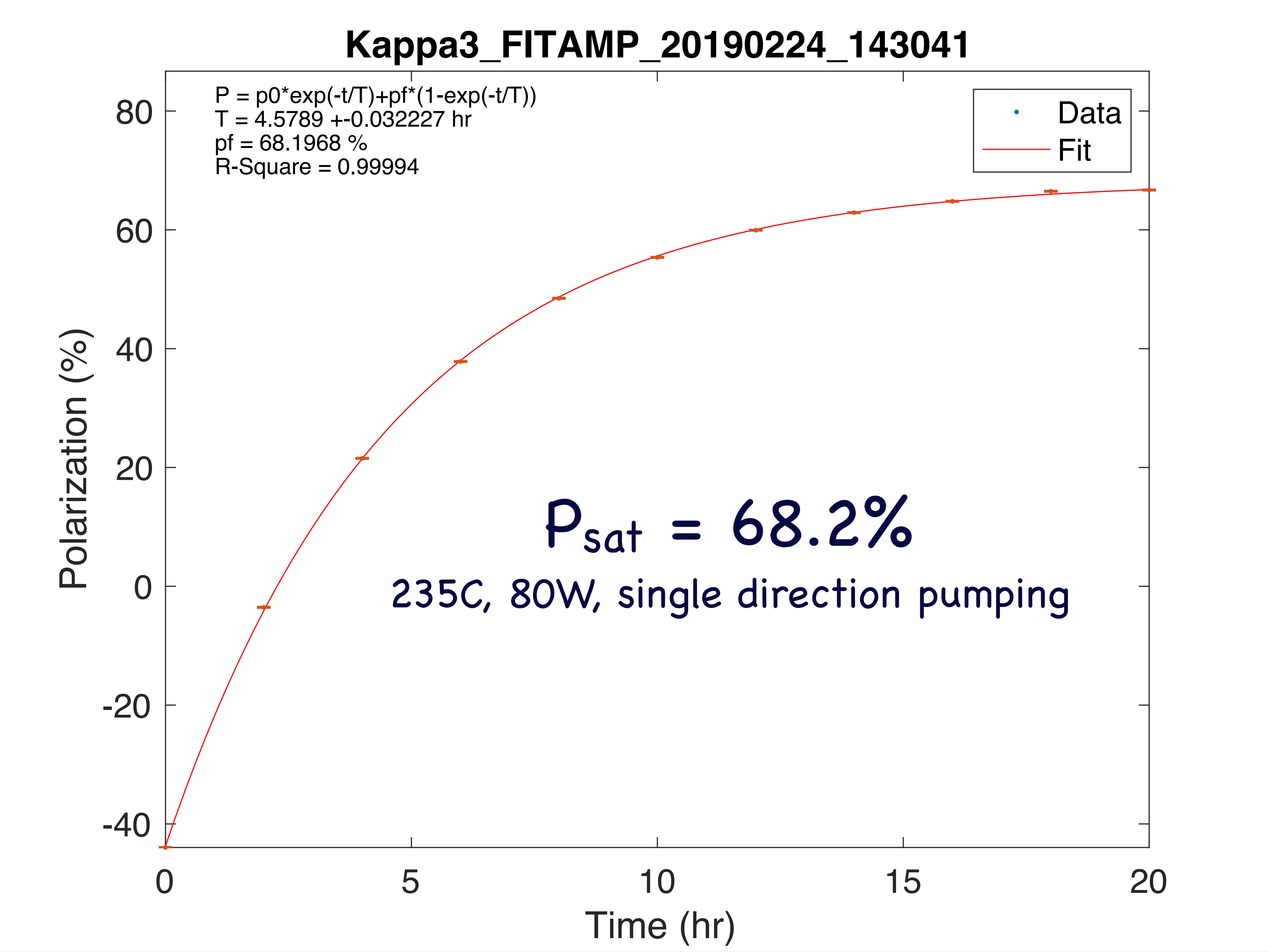
Test sphere Kappa3 results - cold lifetime study



T_1^{cold} = 122 hrs

(Uncorrected lifetime with AFP scan every 4 hours)

Kappa3 - polarization test



P_{sat} = 68.2%

235C, 80W, single direction pumping