LANL/UVA Solid Polarized Target

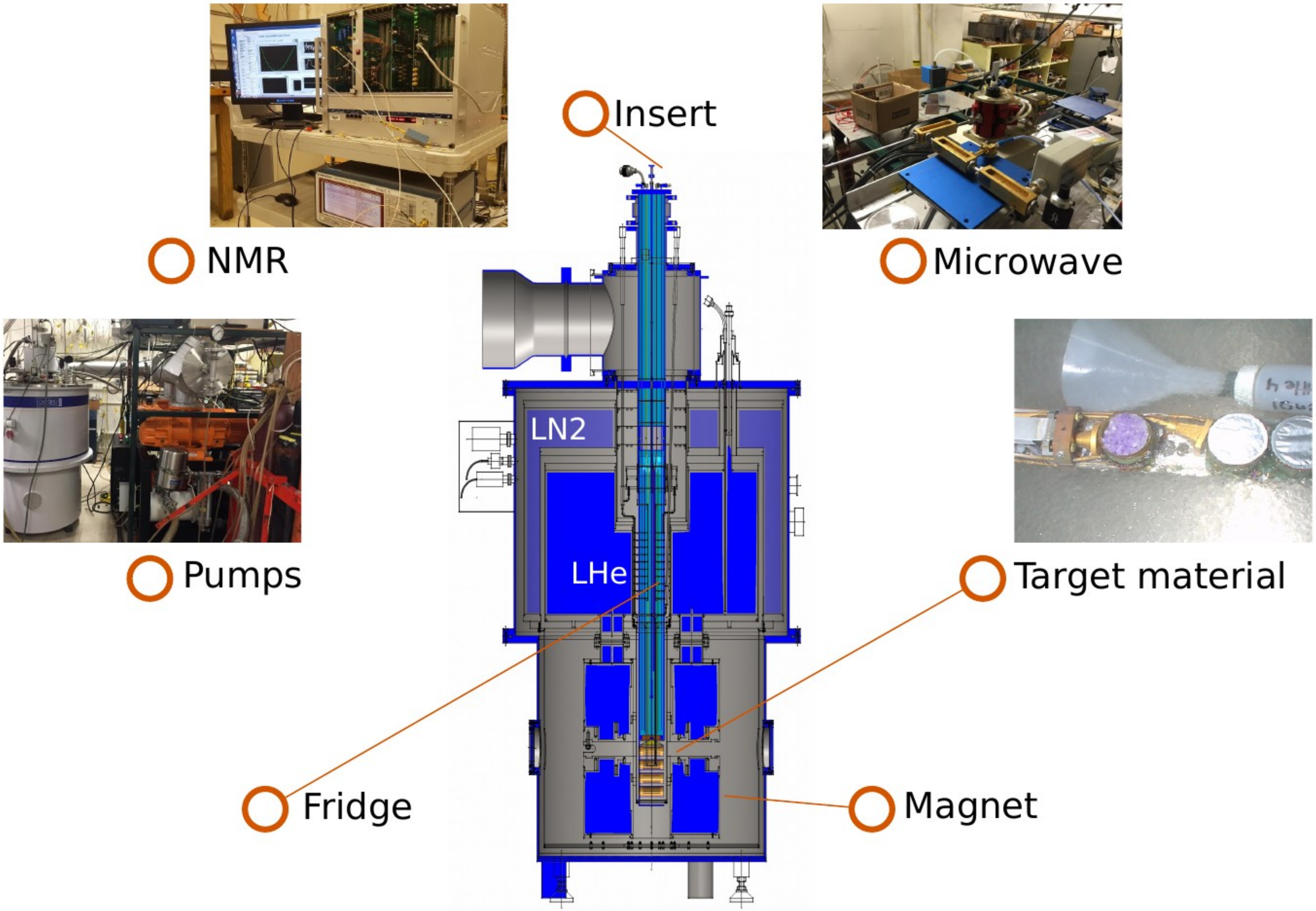
Dustin Keller
University of Virginia

Progress and developments with E1039 polarized target system

Outline

- Status on the Target
- Results of UVA Test Run
- SPT Expectations and Uncertainties
- Personnel Requirements
- Still to Come

E1039 Polarized Target



So Far Accomplished

- Rotation/Modification of Magnet
- Fridge Repairs/Modifications
- Design Build Target Insert (second one under construction)
- Redesign/Build NMR for VME (low noise cold system)
- Machine 2 nose pieces with beam window
- Production of some material (50% for proton 5% of deuteron)
- Automated Microwave Control system (ready for beta test, but PS?)
- Integrated Cryocontrols (ready for beta test, need all variable in DS)
- Fully integrated target run (several test runs)
- Target Annealing system test

POLARIZED TARGET SUBSYSTEMS

Original design by S.Penttila, Oxford Instr.

- kept at LANL storage since ~2000

Feasibility study

- shipped to UVA in 2013
- 1st cooldown 06/2013

Rotation of the coils

- shipped to Oxford Instruments
- new configuration, 2nd cooldown
- $dB/B < 10^{-4}$ on 3d grid, 5T over 8cm

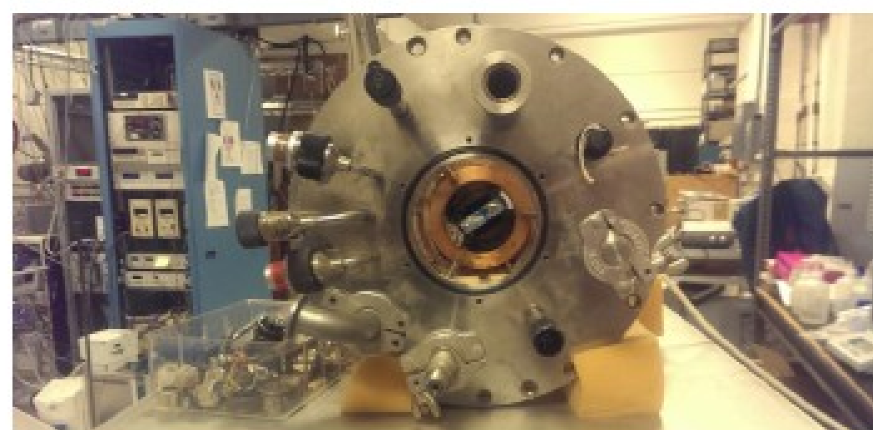
Back to UVA

- 3rd cooldown, rotated coils test
- magnet is in a very good shape

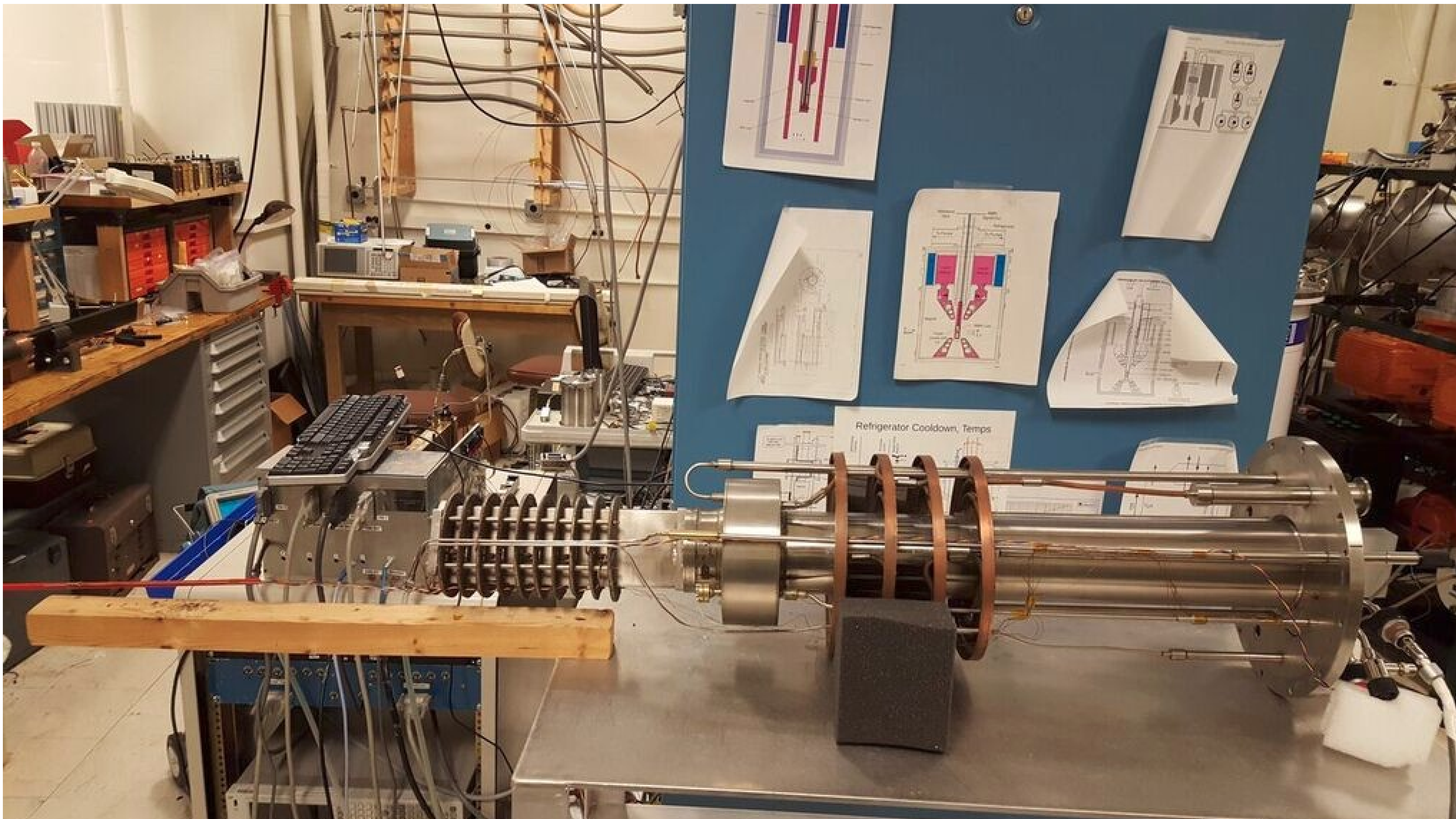
POLARIZED TARGET SUBSYSTEMS

Fridge modifications

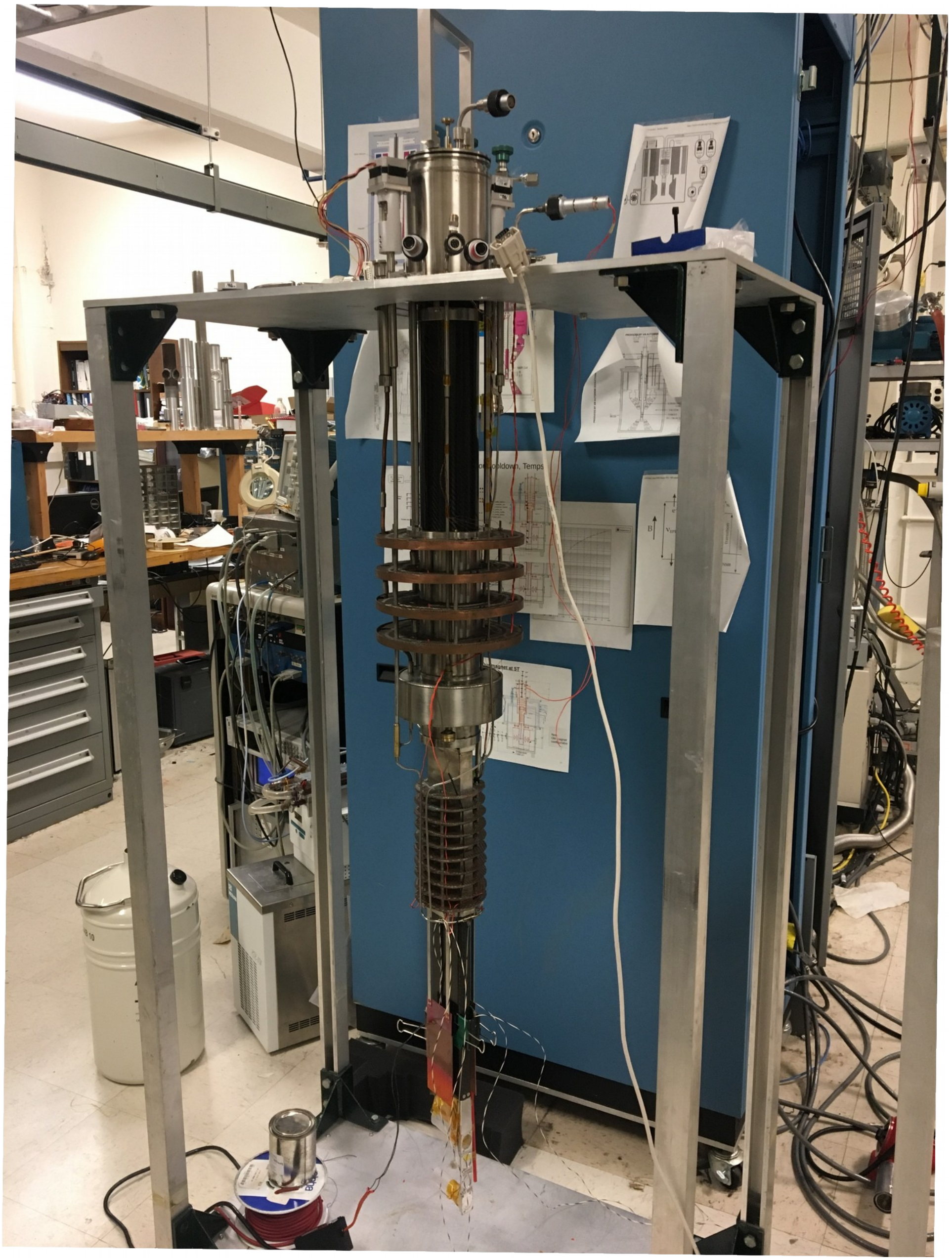
- replaced separator can
- cleaned heat exchangers oxide/corrosion
- leak checked
- refitted run and bypass valves
- installed new LHe channel
- installed 8 temperature sensors
- manufactured new nose, 10mil window



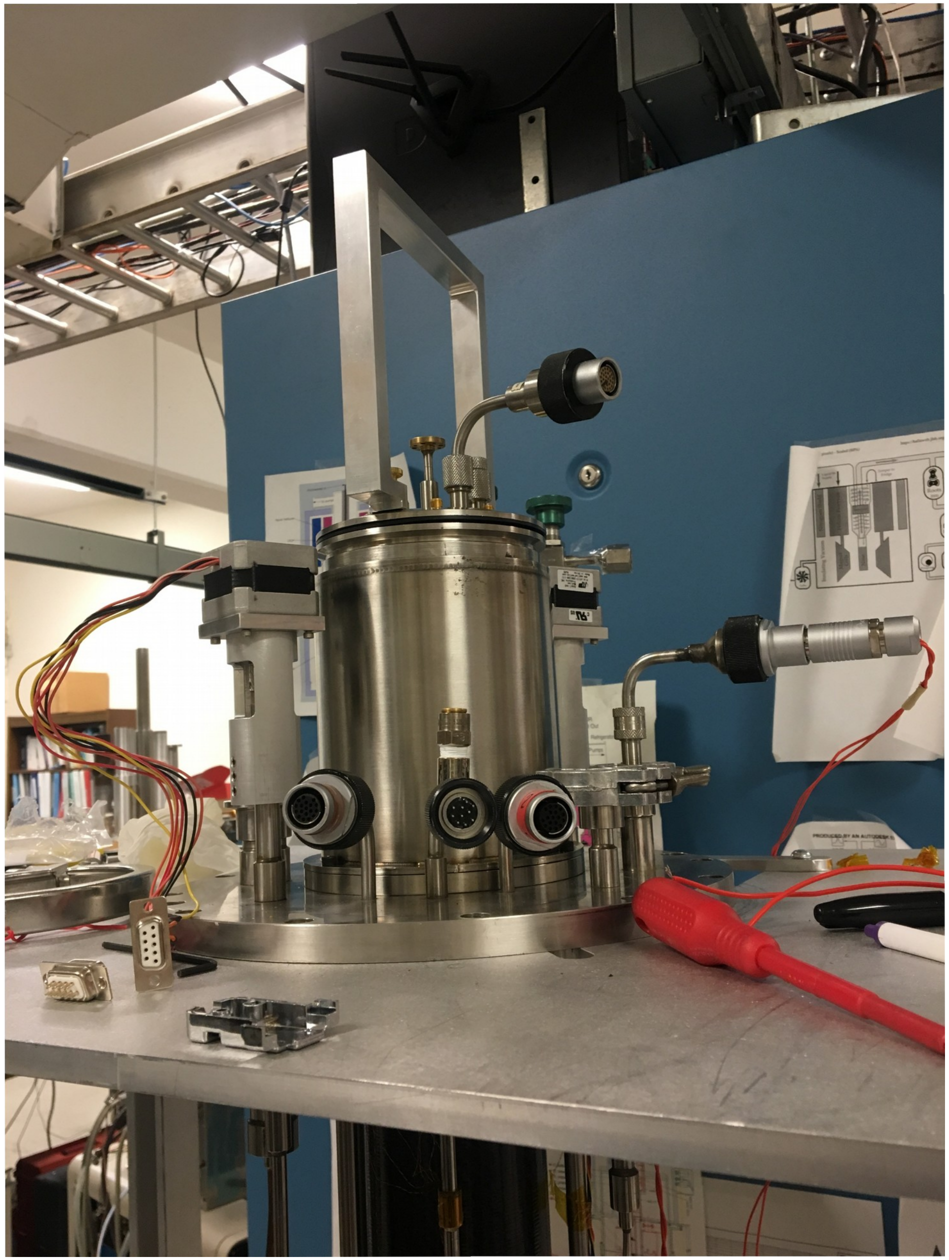
Recent Modifications



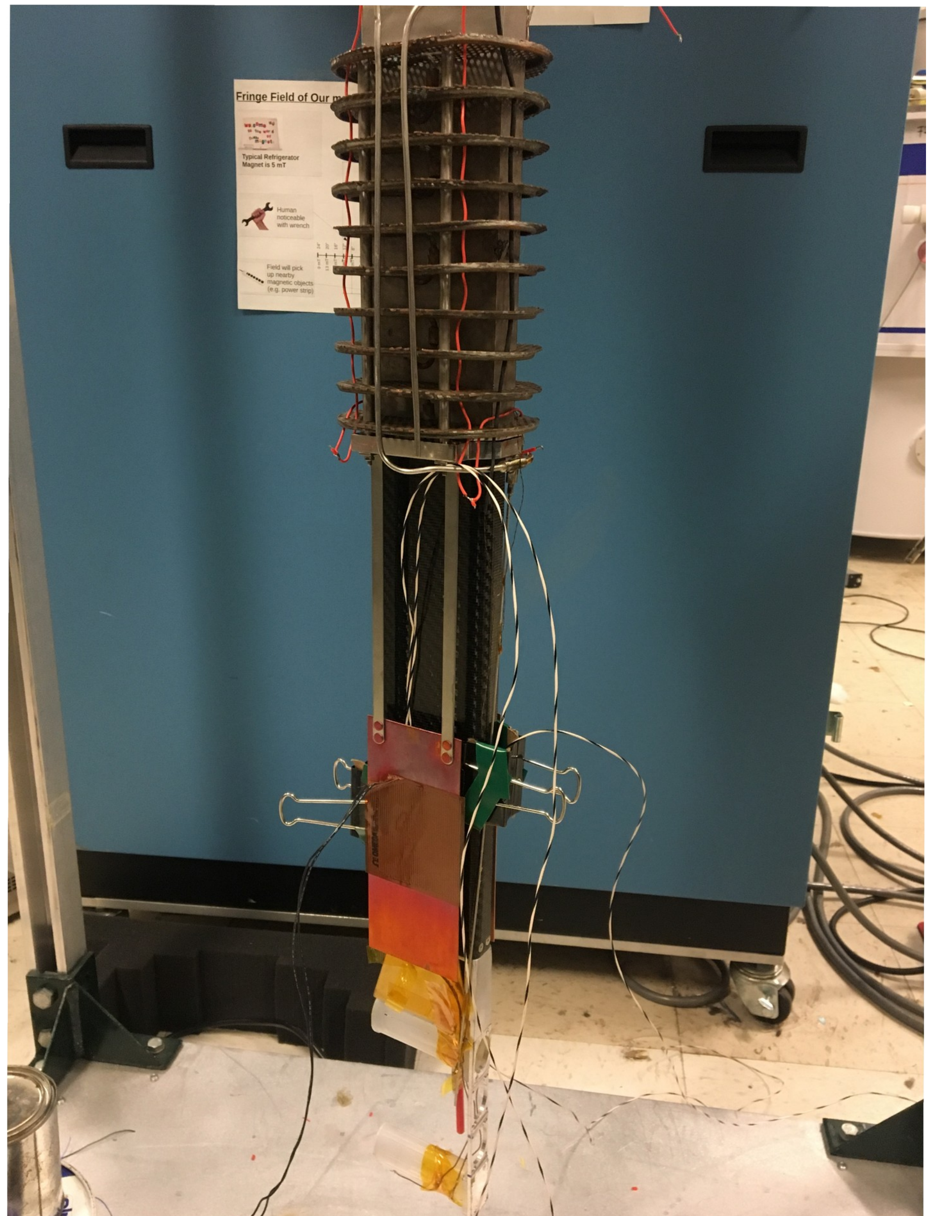
Upright Full View



Upright top



Upright Heater

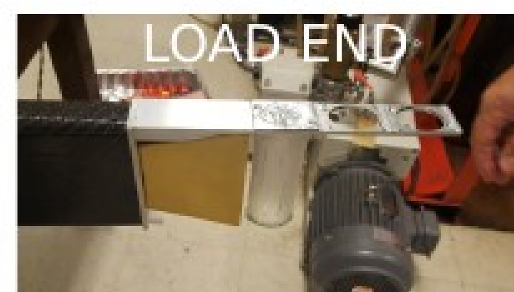


POLARIZED TARGET SUBSYSTEMS

Magnet — Fridge — **Insert** — NMR — Microwave — Pumps — Target material

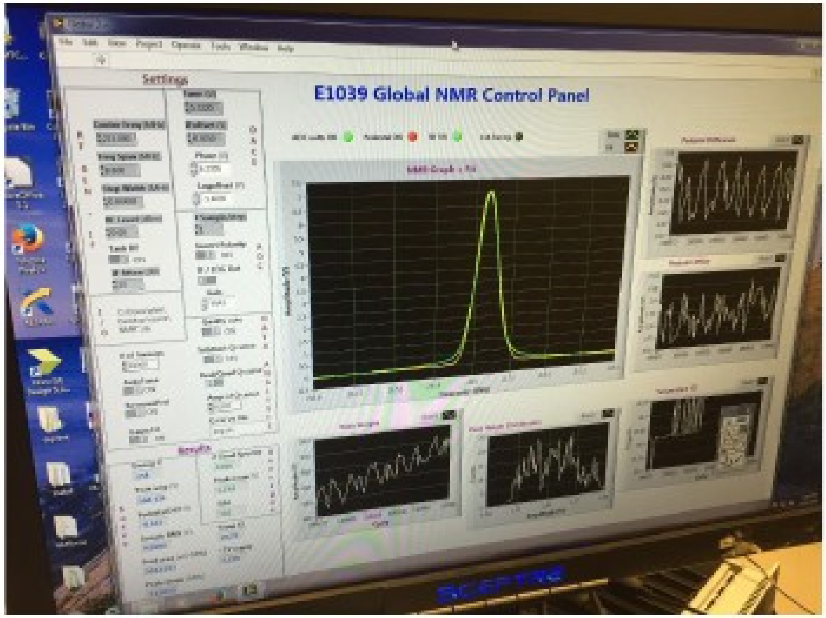
New insert

- four 2.7x2x80mm long target cups
- NH3, C disk, empty
- six NMR channels (3 per cup)
- microwave horn for full cup volume
- temperature sensors
- He3 bulb line
- copper thermal barrier
- carbon fiber enclosure



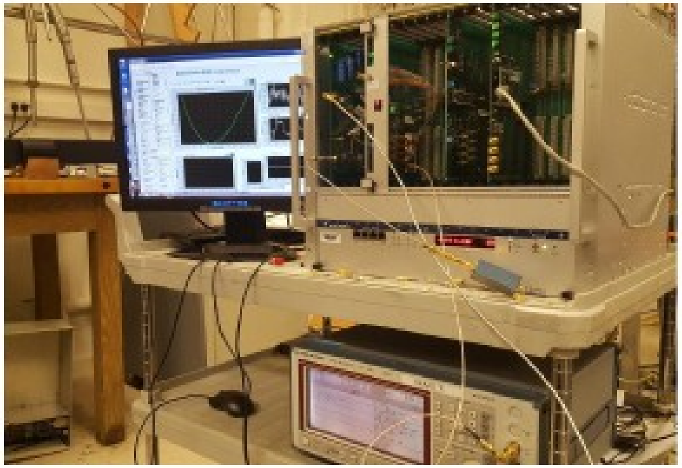
POLARIZED TARGET SUBSYSTEMS

Magnet — Fridge — Insert — **NMR** — Microwave — Pumps — Target material



New NMR system developed by LANL

- followed general Liverpool design
- Q-meter as double wide VME module
- 1 analog / 1 digital boards, crate controller
- 16 bit ADCs/DACs, modern RF electronics
- USB/Ethernet interface, LabView based DAQ

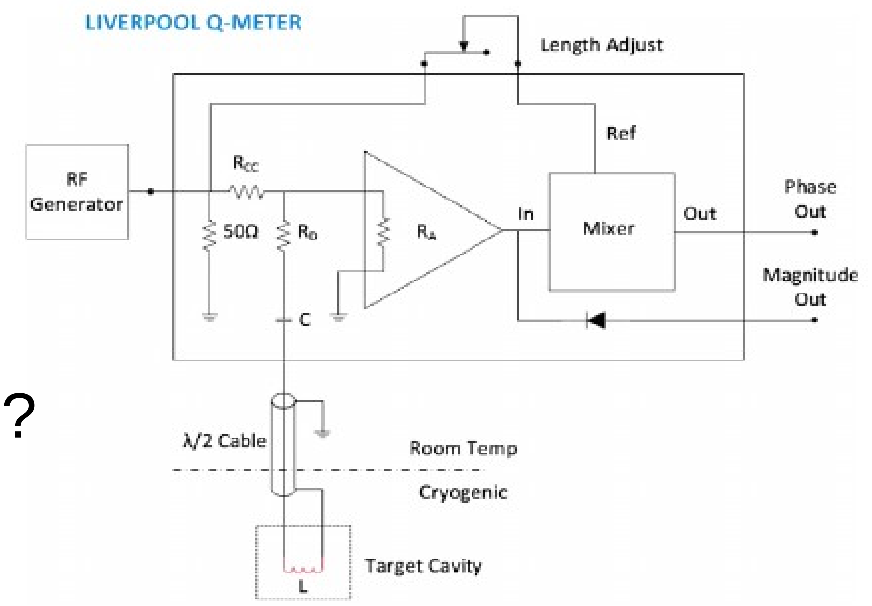


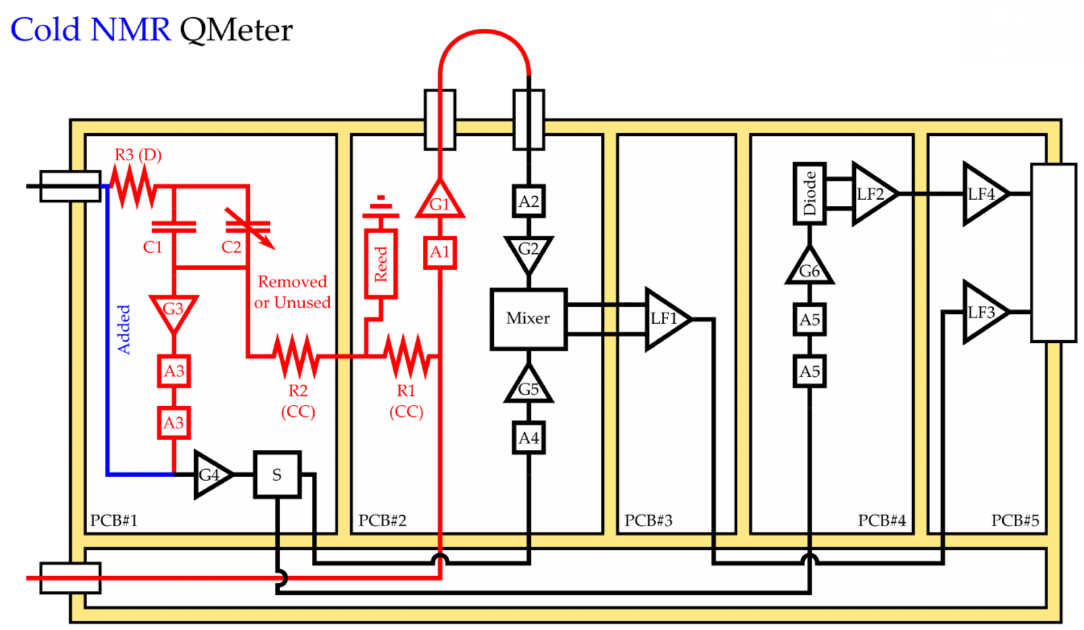
LANL NMR system tests at UVA

- 1st NMR cooldown 2014 (total 3 cold tests)
- 04/2016 full comparison to Liverpool Q-meter signal/noise ratio - waiting for results

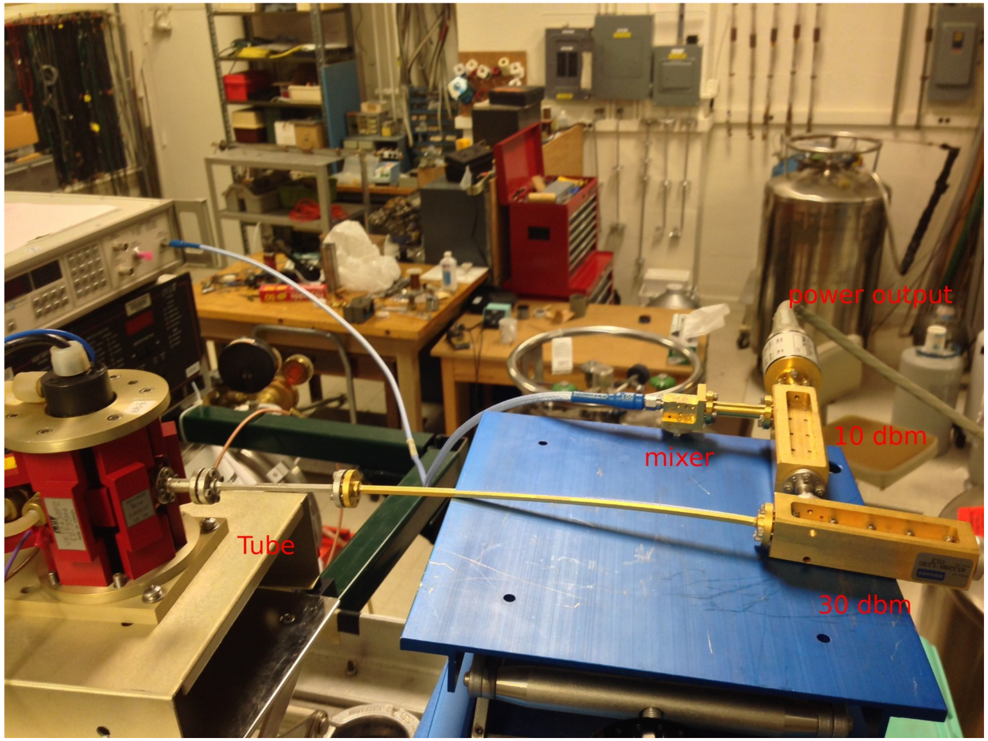
NMR System

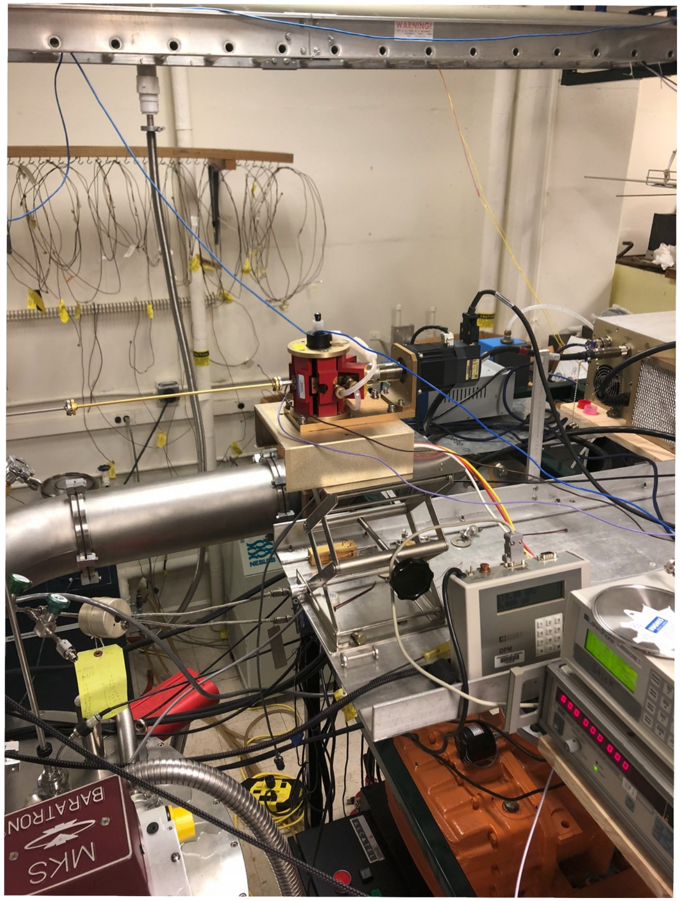
- New LANL-NMR checked
- Compares to UVA-Liverpool
- Cold LANL-NMR
- Compares to Cold UVA-Liverpool?



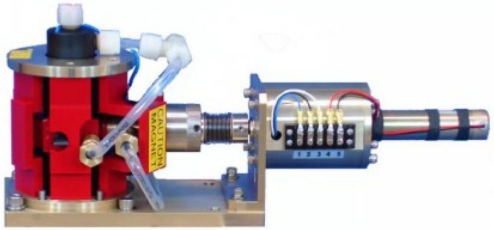


Microwave Generator Setup

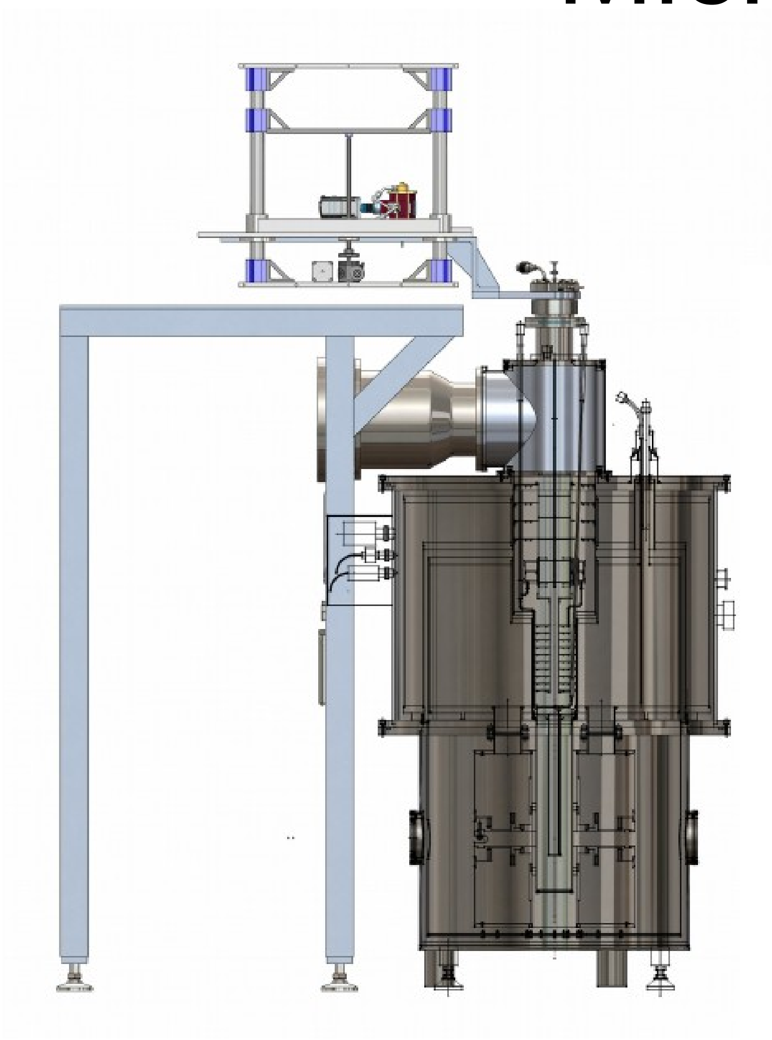


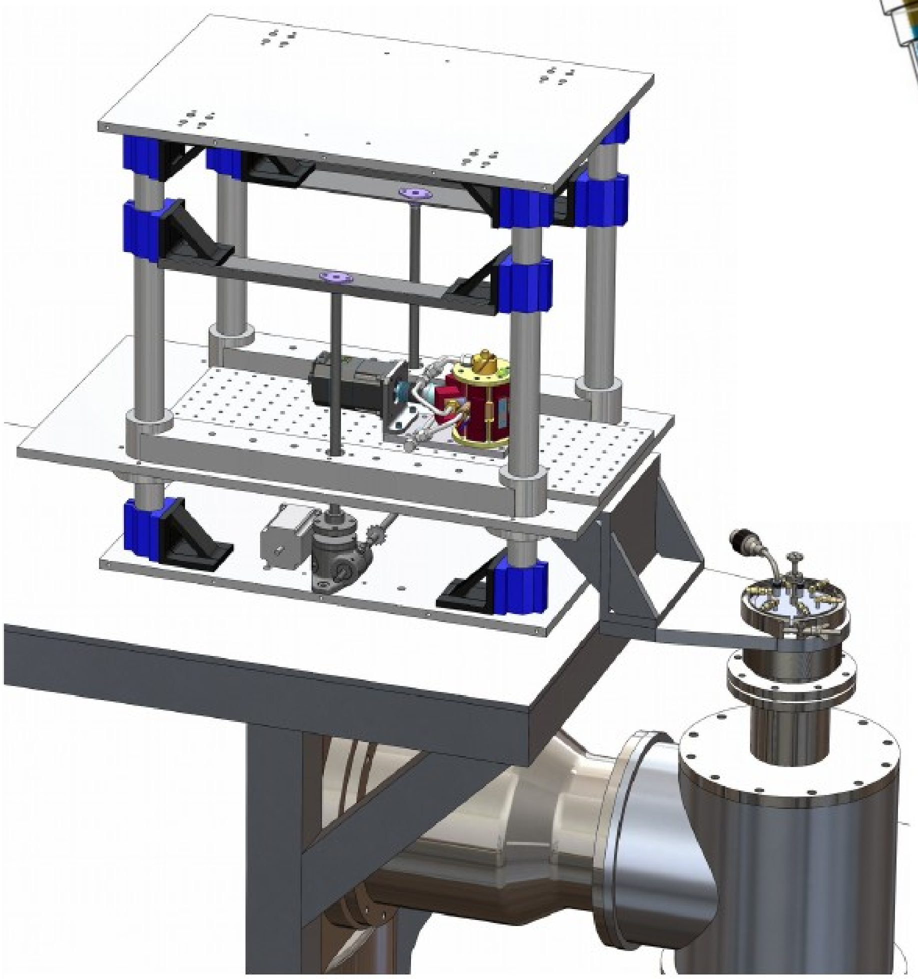


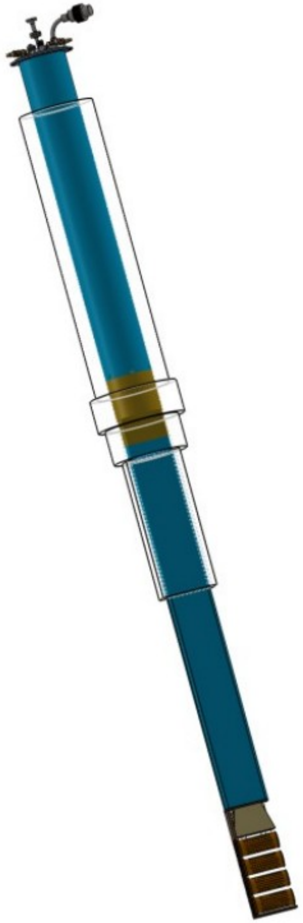
- 20W EIO attenuate down to mW scale: Mixer and Power meter
- Mixer has 10 mW damage threshold
- F→D (140 GHz), right angle bend
- Cavity size adjustment allows an additional 1.5%
- Measure power at EIO and measure at helium evaporation (10 l/s per Watt)



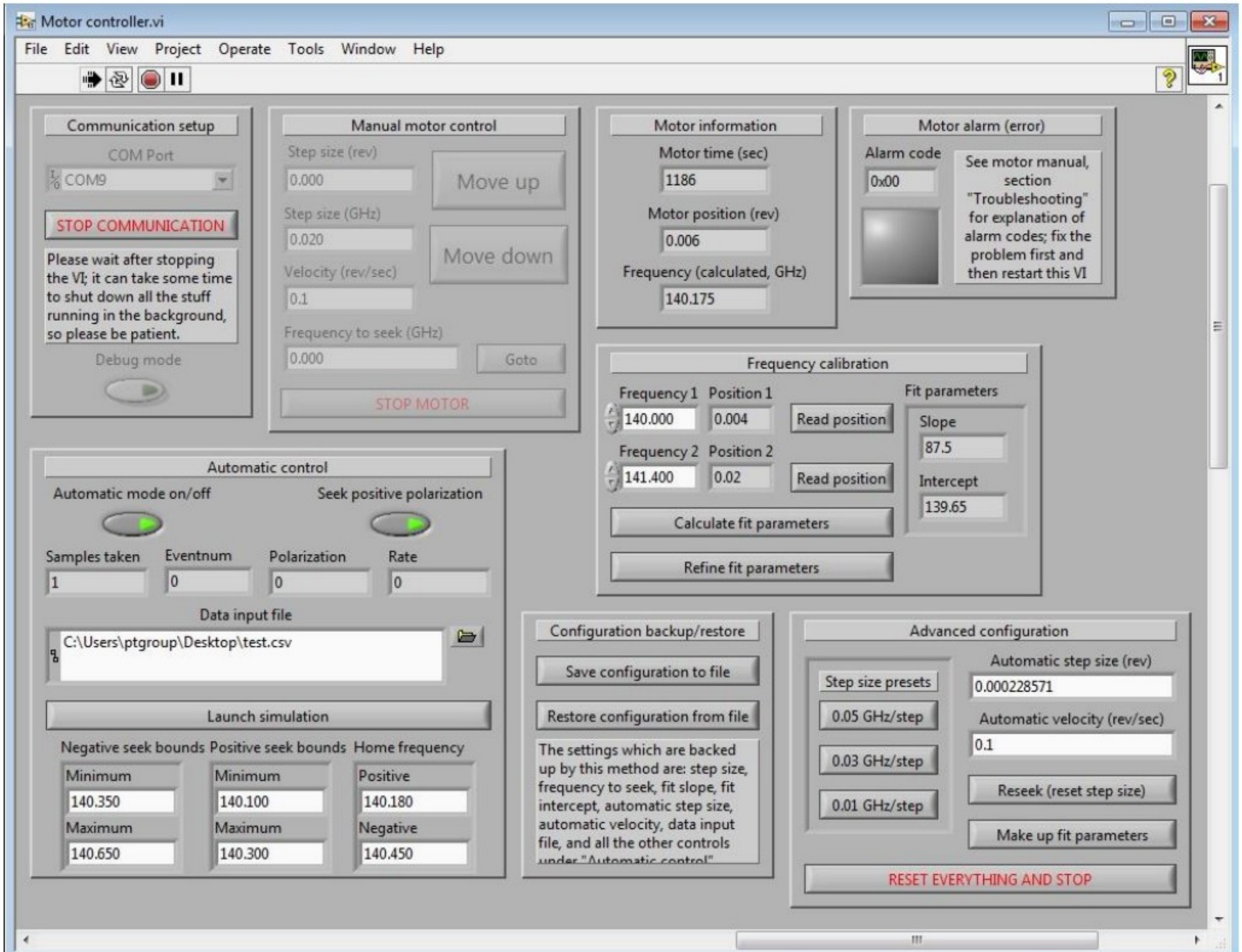
Microwave Setup







Motor Control



This is the main microwave controller VI.

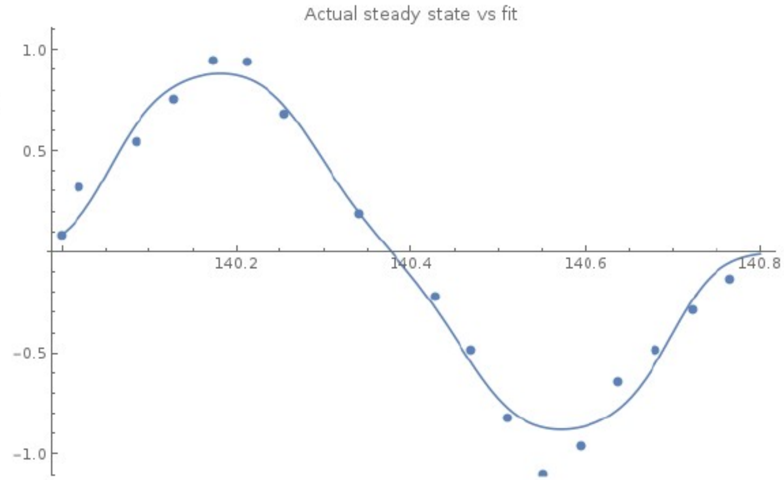
Can be run in automatic mode or manual mode.

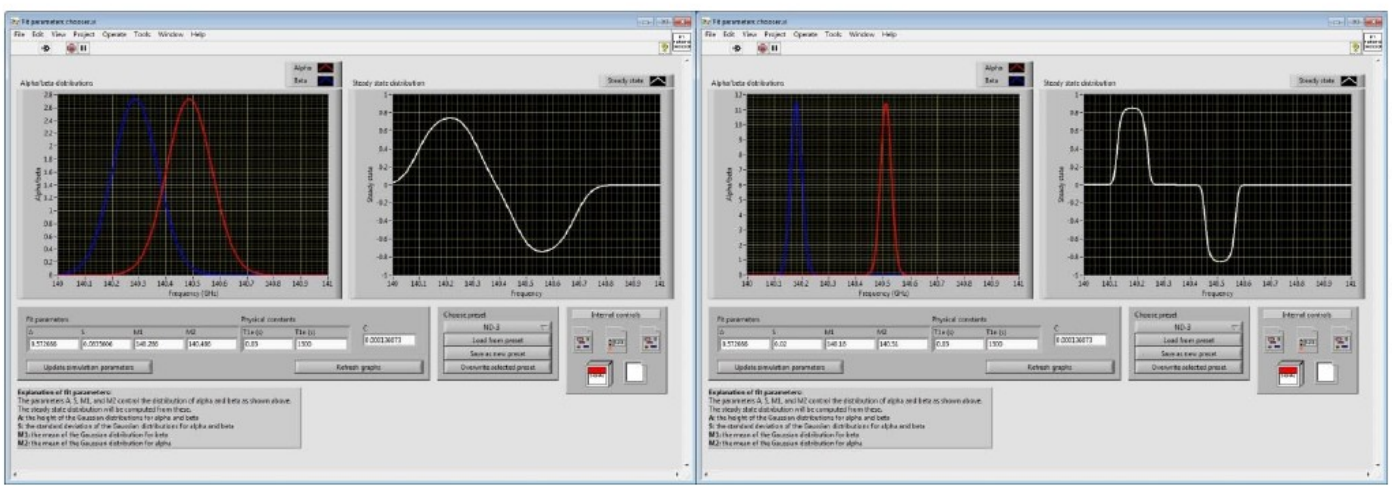
First we should do the frequency calibration by moving the motor manually.

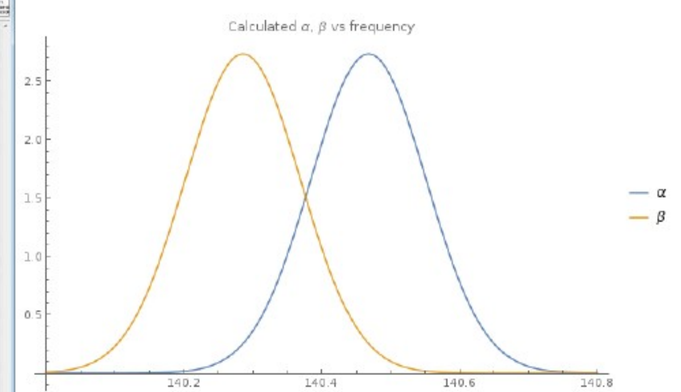
Can be run in real time experiment or in simulation mode.

Simulation

- Written in LabVIEW to work with stepper motor
  - Can also be run by itself to produce data
- Implements model
  - Parameters α and β calculated from frequency

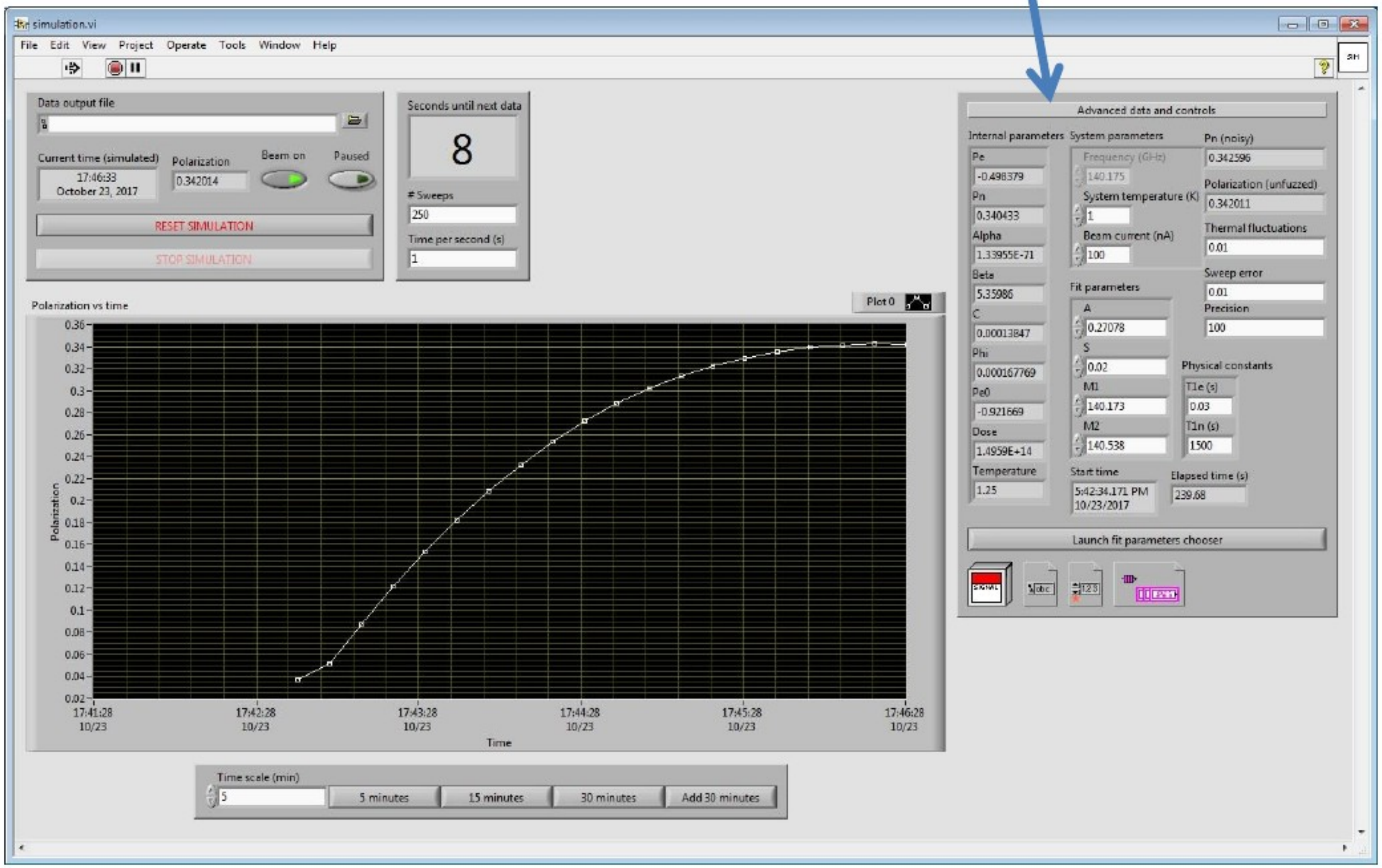






Simulation

Advanced parameters (physical constants and debugging)



This is the main microwave simulation controller VI.

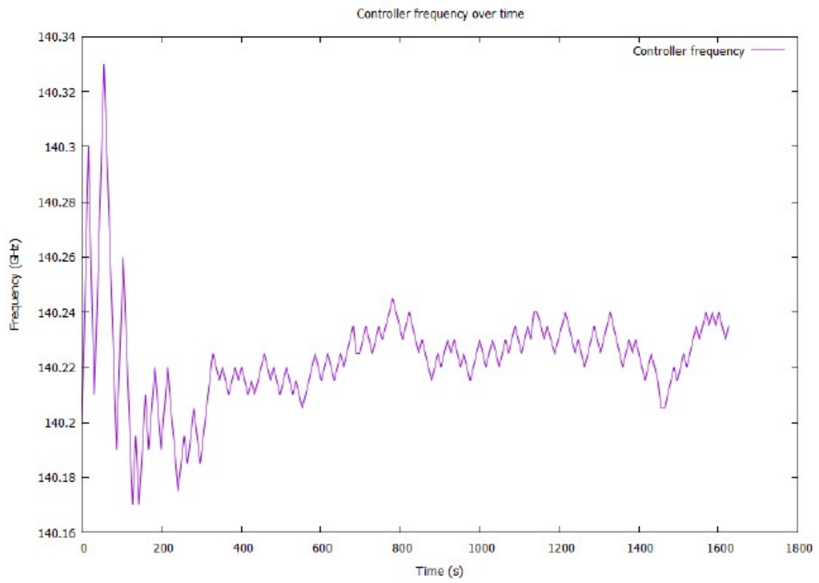
Can be started through main controller VI.

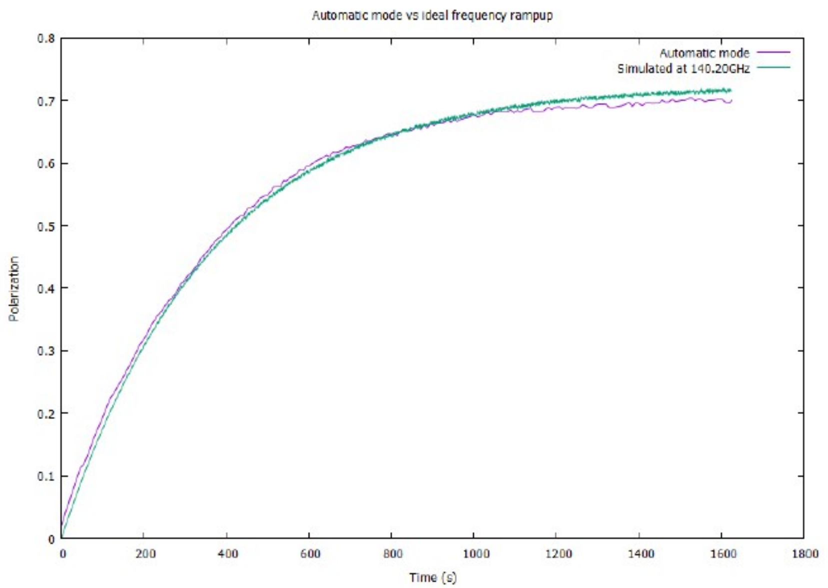
Can change many parameters and run for different material.

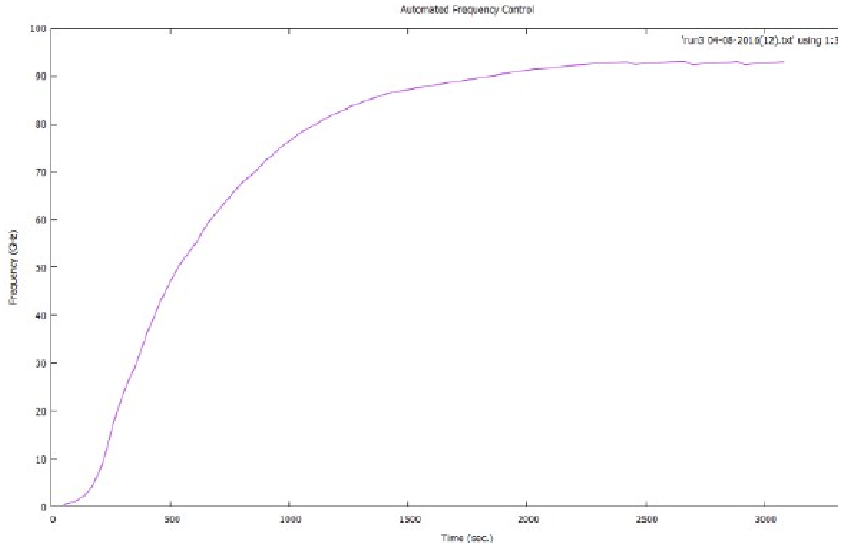
Mimic the real experimental NMR setup.

Can be used for training purposes and testing purposes

Testing Performance





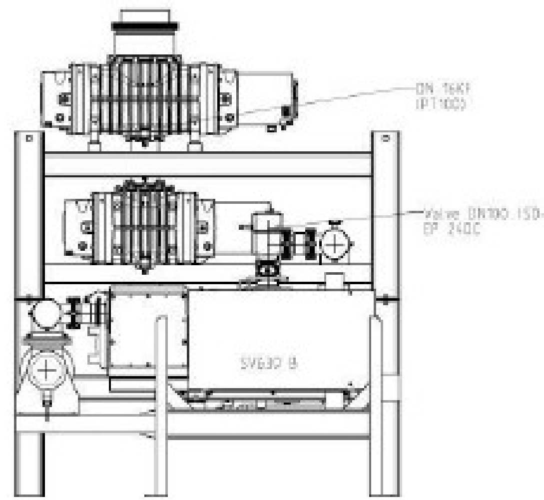


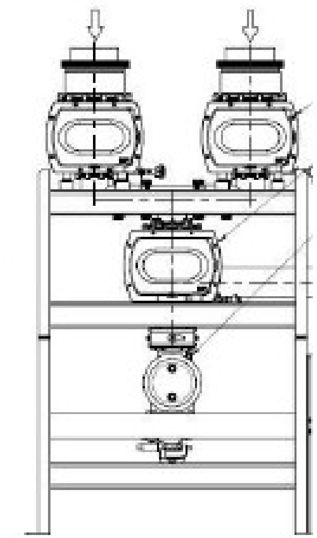
POLARIZED TARGET SUBSYSTEMS

Magnet — Fridge — Insert — NMR — Microwave — **Pumps** — Target material

Pumping system

- designed and built by Oerlikon
- target heat load ~1.4W
- μ-wave:~1W, beam:~0.37W
- 3 roots (7000), 1 rotary vane (840)
- requires 100L LHe per day
- 14000 m3/hr pumping capacity





Construction and tests

- first assembly at LANL spring 2015
- tested and shipped to FNAL
- assembled and tested 10/2015

POLARIZED TARGET SUBSYSTEMS

Production

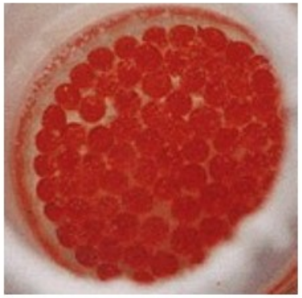
- dedicated setup to produce NH3 beads
- NH3 gas slowly frozen above LN2 bath
- ~1000 g is needed for 2 yr run
- ~450 g currently produced
- purchased three LN2 dewars for storage

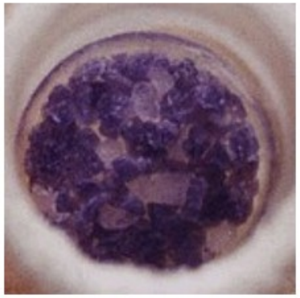
Pre-Irradiation

- creates paramagnetic centers for DNP
- 14 MeV electron beam under LAr bath
- routinely done at NIST (Gaithersburg)
- time consuming, trained manpower
- ~100 g irradiated and ready for experiment

Target Material

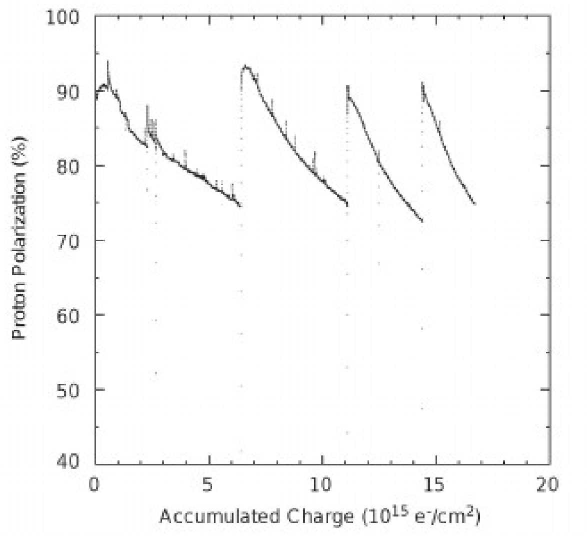
- Successful material for DNP characterized by three measures:
  1. Maximum polarization
  2. Dilution factor
  3. Resistance to ionizing radiation

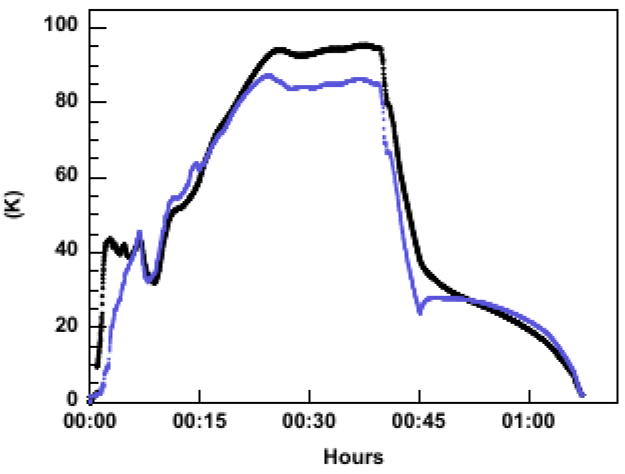


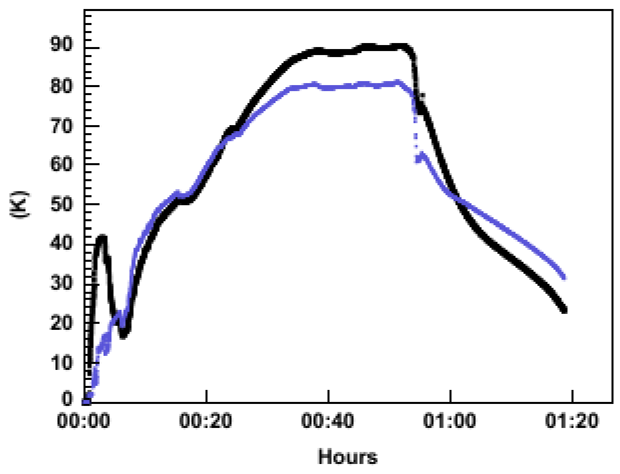


Material	Butanol	Ammonia, NH_3	Lithium Hydride, ^7LiH
Dopant	Chemical	Irradiation	Irradiation
Dil. Factor (%)	13.5	17.6	25.0
Polarization (%)	90-95	90-95	90
Material	D-Butanol	D-Ammonia, ND_3	Lithium Deuteride, ^6LiH
Dil. Factor (%)	23.8	30.0	50.0
Polarization (%)	40	50	55
Rad. Resistance	moderate	high	very high
Comments	*Easy to produce and handle*	*Works well at 5T/1K*	*Slow polarization, but long T_1*

Radiation Damage and Recovery







- Maximum Polarization decays as a function of dose
- Heat material (Anneal) to allow radicals to recombine
- Done by heat wire around target cell raising to 80-100K for 20-60 minutes
- Needed at 4Pprotons/cm^2 (about every shift)
- Once exhausted (40 Pprotons/cm^2) need target material replacement

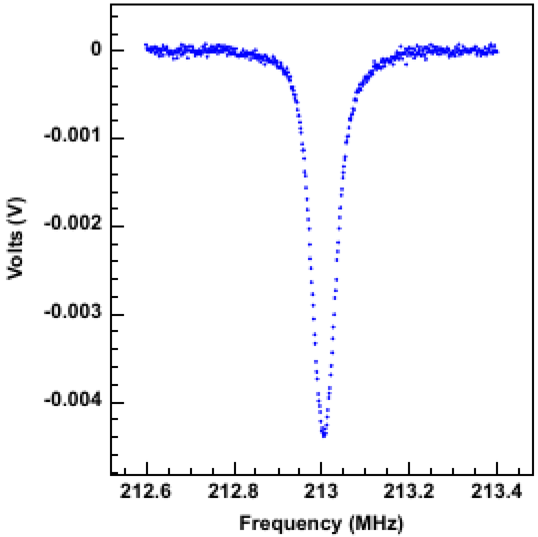
Sources of Uncertainty in Polarization

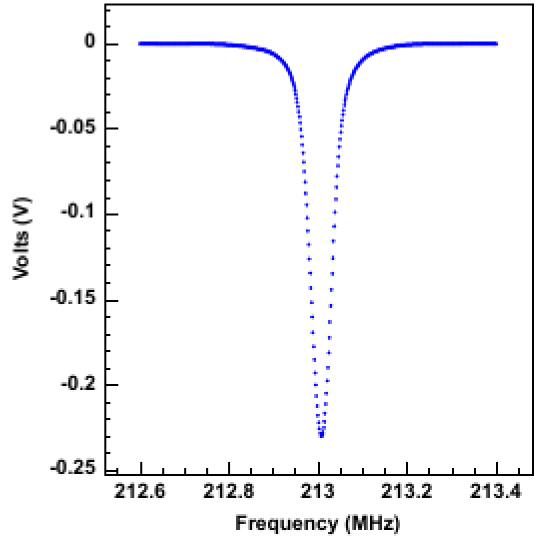
- Changes in DF/Packing Fraction
- Field Drifts (Magnet/Power supply)
- Enhanced Measurement errors
- TE Calibration errors

Nuclear Instruments and Methods in Physics Research A 728 (2013) 133–144

Polarization Calibration and Measurement

~0.3%

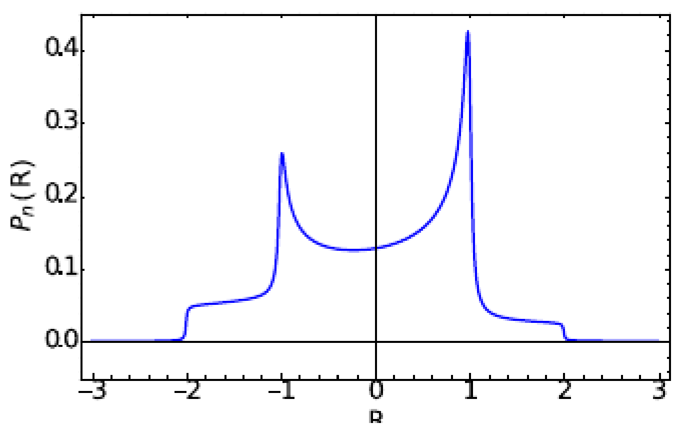


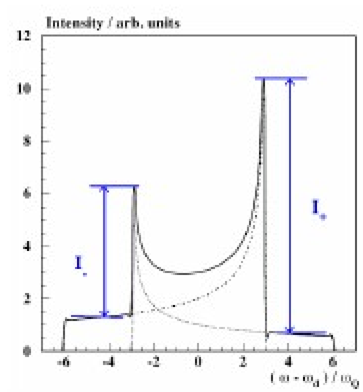


Proton

$$P_{TE} = \tanh\left(\frac{\mu B}{kT}\right)$$

~0.05%





Deuteron

$$P_{TE} = \frac{4 + \tanh\frac{\mu B}{2kT}}{3 + \tanh^2\frac{\mu B}{2kT}}$$

$$P_z = \frac{R^2 - 1}{R^2 + R + 1}$$

Neutron

$$P_n = (1 - 1.5\alpha_D)P_d \approx 0.91 P_d$$

Uncertainty in Polarization

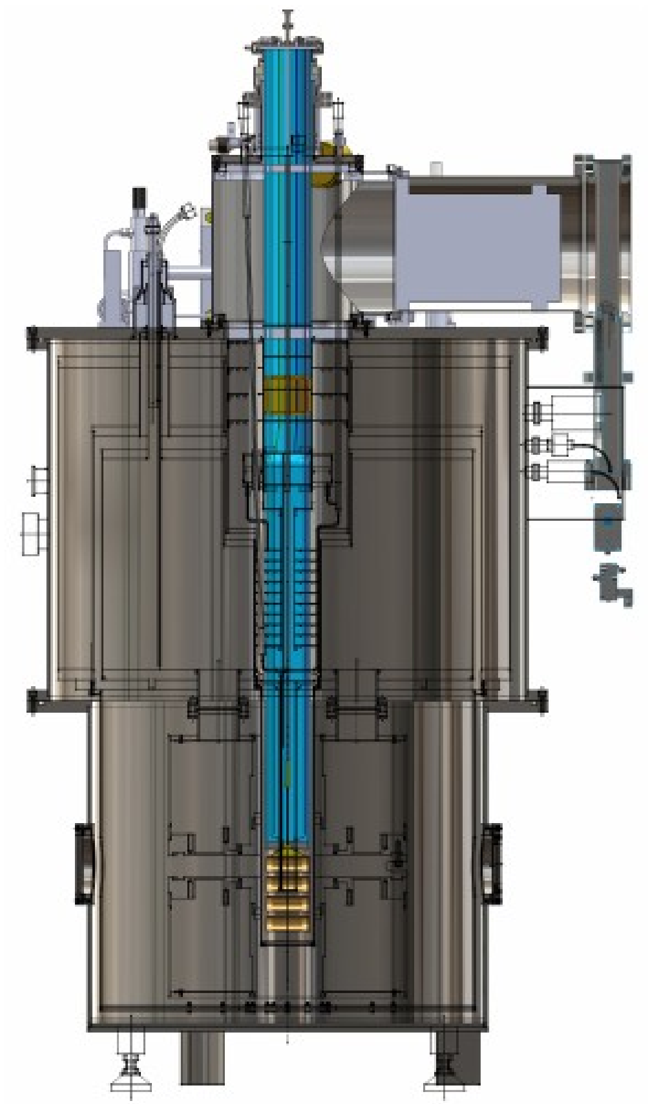
$$P_{TE} = \tanh\left(\frac{\mu B}{kT}\right) \qquad P_E = G\frac{\int S_E(\omega)\,d\omega}{\int S_{TE}(\omega)\,d\omega}P_{TE} = GC_{TE}A_E \qquad C_{TE} = \frac{P_{TE}}{A_{TE}}$$

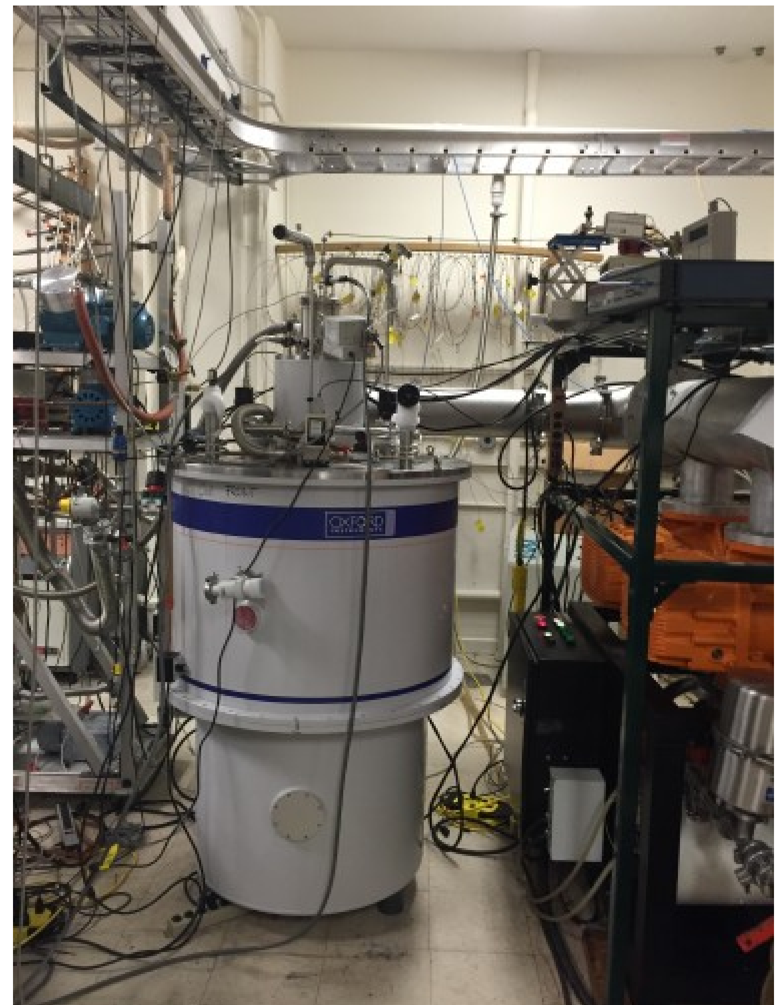
Procedural errors
can be to be pretty small:
Assuming the right procedure
(Target is thermalized to TE)

(#)	Type	Source	Error (%)	
(1)	S_{TE}	ΔT	1.45	(Temp/pressure measurements)
(2)	A_{TE}	ΔA_{TE}	1.61	(area measurements)
(3)	A_{TE}	ΔA_{fit}	0.75	(background subtraction)
(4)	S_E	R_B	0.50	(setability)
(5)	S_E	ΔV_Q	0.75	(NMR temp sensitivity)
(6)	S_E	NMR-tune	0.47	(NMR tune and tune drifts)
(7)	S_E	ΔB_{drift}	0.25	
(8)	G	ΔV_{Yale}	0.10	
(9)	–	$\Delta \overline{P}_{run}$	0.50	(Charge averaging)
		$\Delta P/P$	2.60	

$$\frac{\delta P_E}{P_E} = \left[\left(\frac{\delta G}{G}\right)^2 + \left(\frac{\delta P_{TE}}{P_{TE}}\right)^2 + \left(\frac{\delta A_{TE}}{A_{TE}}\right)^2 + \left(\frac{\delta A_E}{A_E}\right)^2 + \left(\frac{\delta S_{TE}}{S_{TE}}\right)^2 + \left(\frac{\delta S_E}{S_E}\right)^2\right]^{1/2}$$

Full System

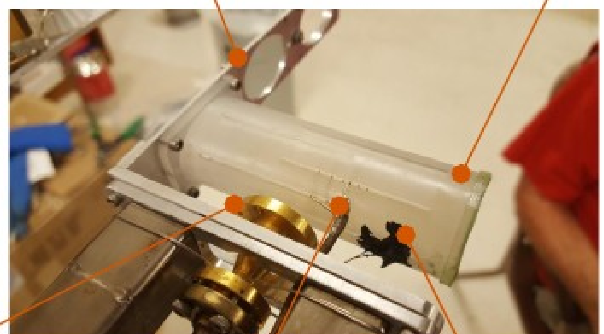


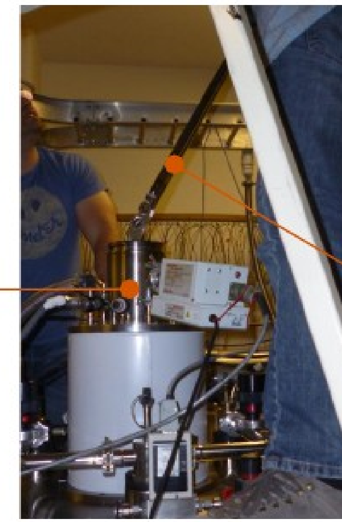


Test Full System

Final preparations and run

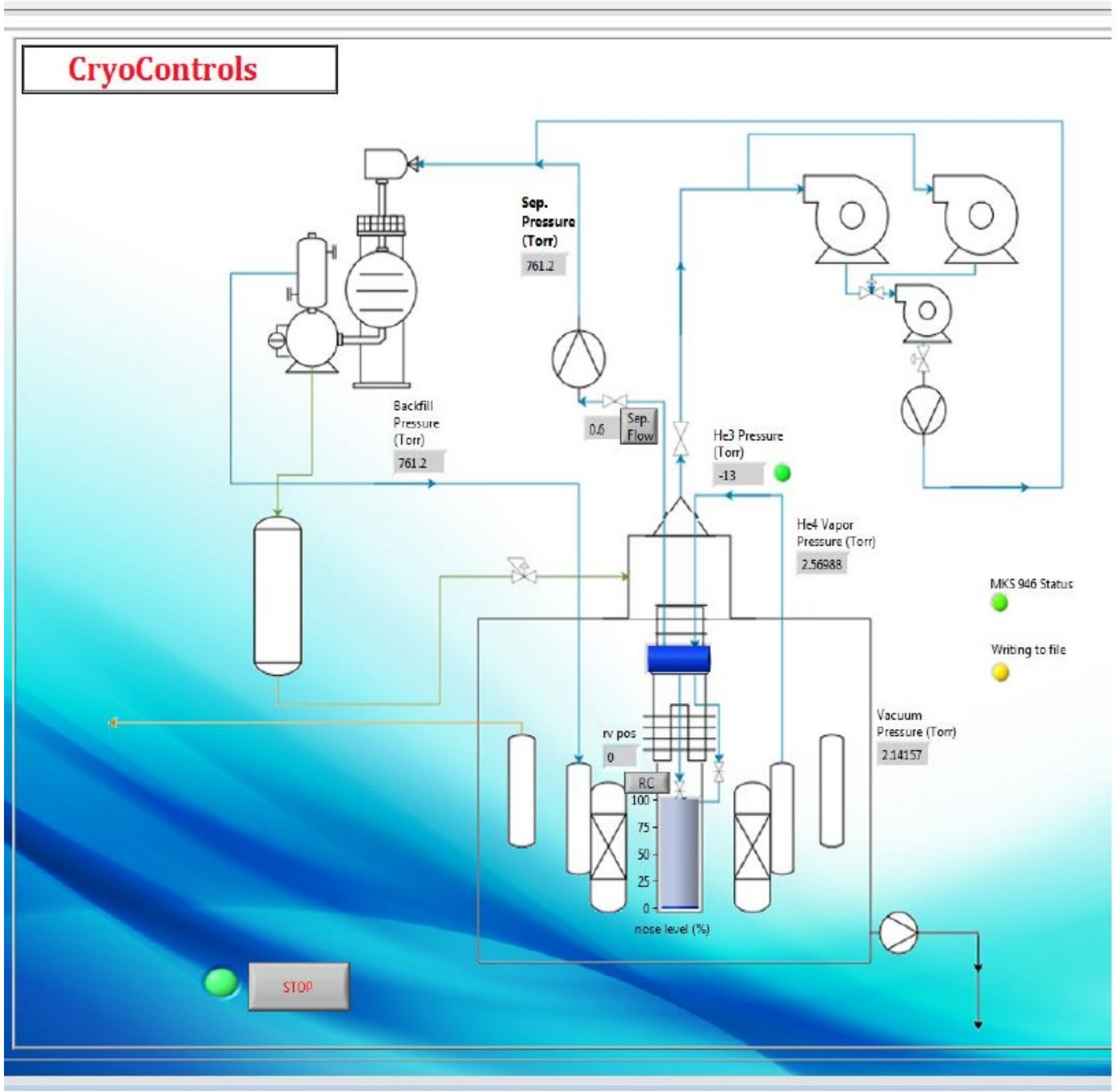
made test target insert, practiced installation





getting cold

The main cryocontrol VI



This contain all monitoring for the target including the pressures, flows, valve position and He level probe reading.

This also include buttons to access the flow, pressure and valve position controls next to their reading.

This main VI check whether the devices are connected to correct ports and function continuously.

Graphics shows where these readings are from.

Logs all the readings to a text file ~each second.

Cryogenic Performance

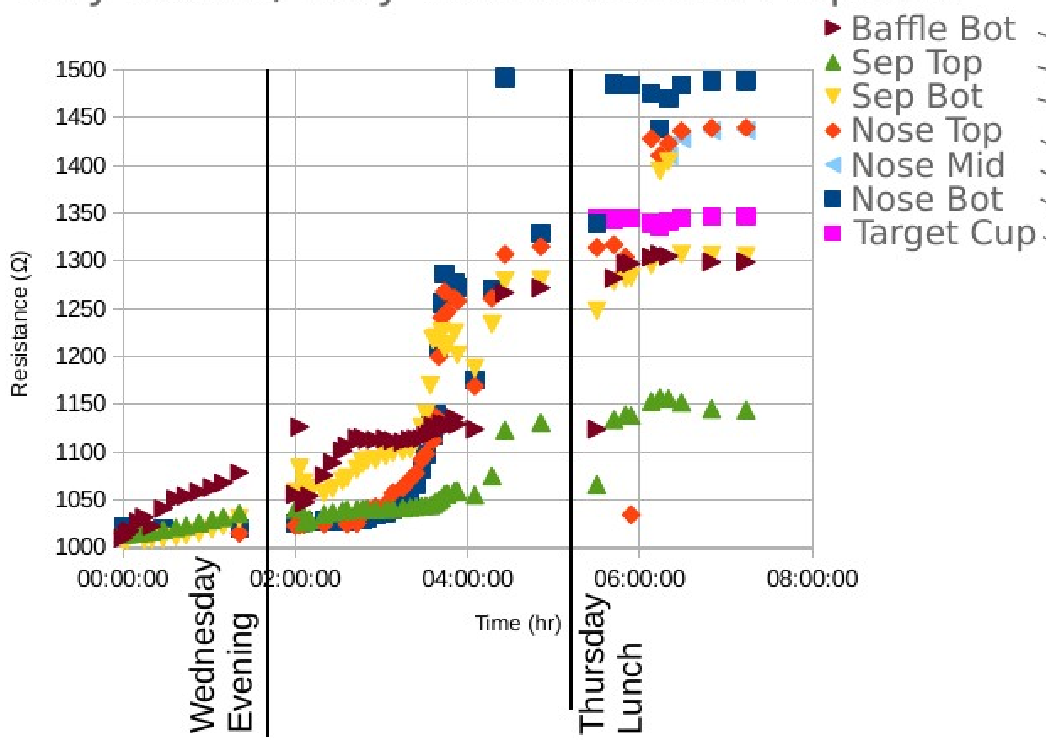
Test results

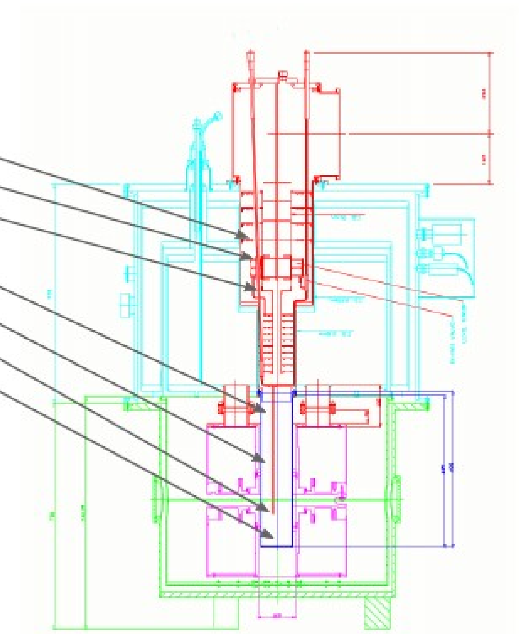
Fridge performance

separator and nose fill

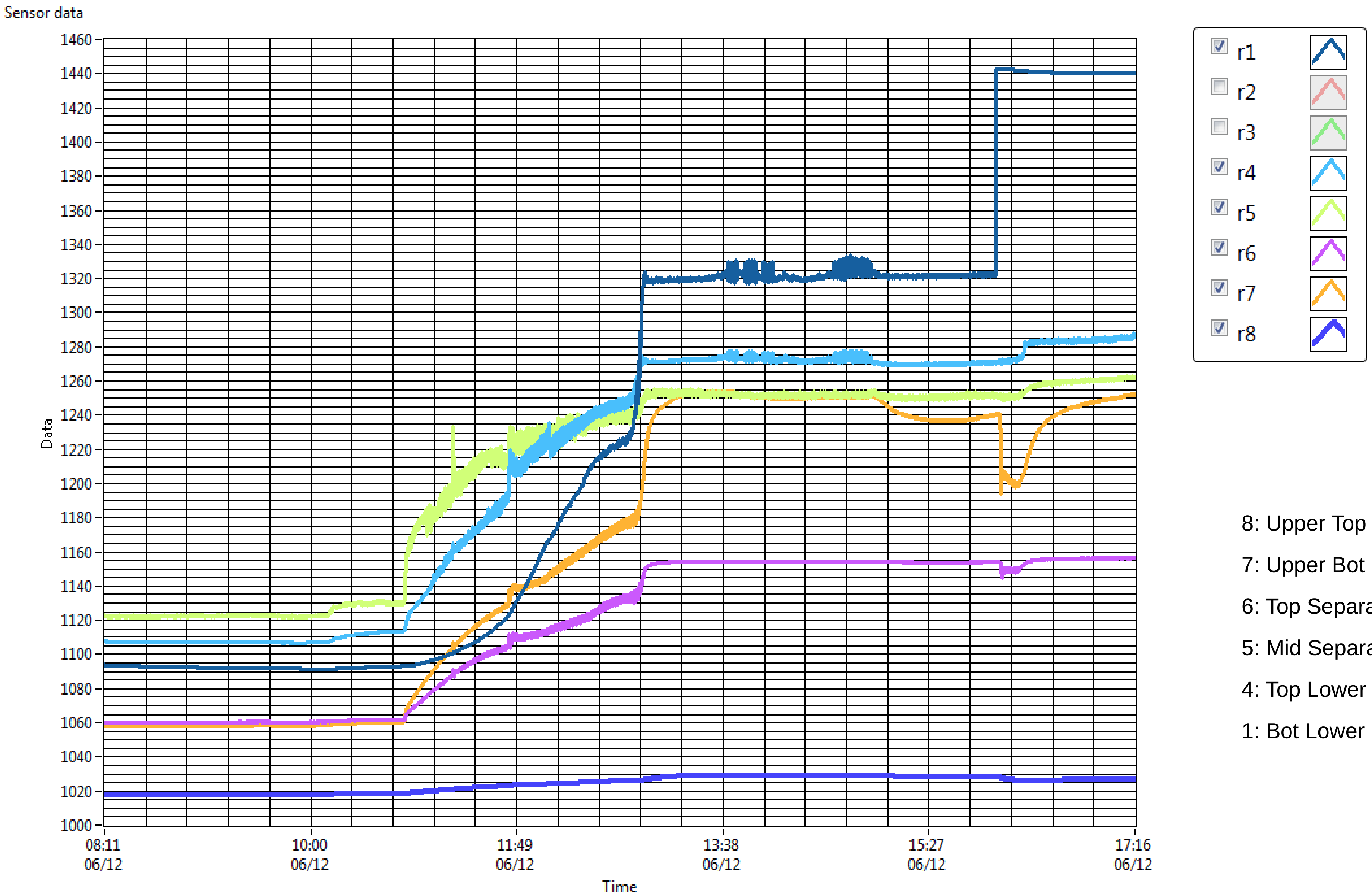
~1hr to fill the nose after a night on standby

very stable, very little attention required





Fridge Sensors



8: Upper Top HX

7: Upper Bot HX

6: Top Separator

5: Mid Separator

4: Top Lower HX

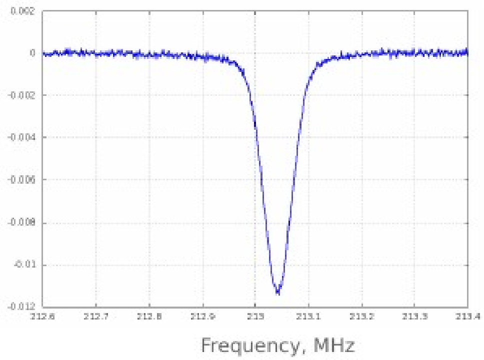
1: Bot Lower HX

Results of All the Work

Test results

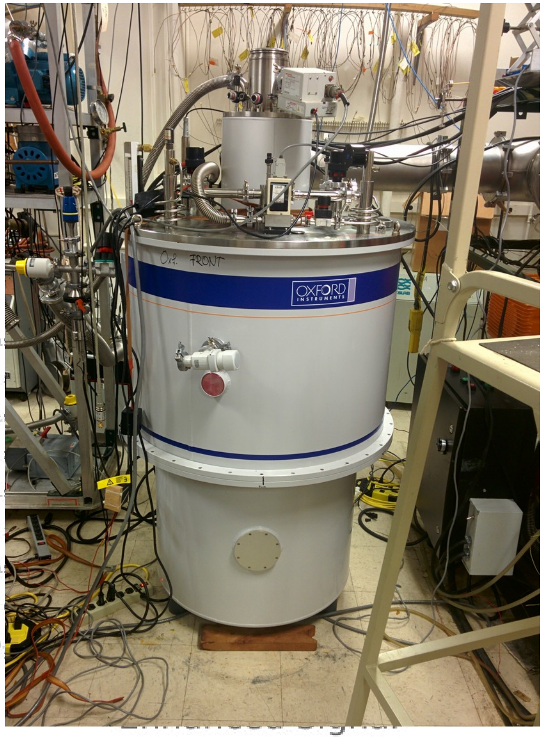
Polarization

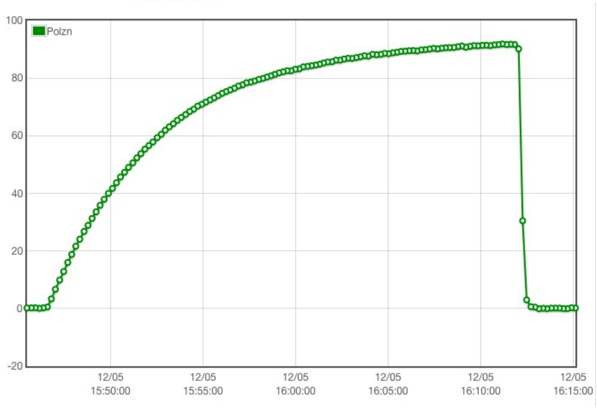
- polarized fresh NH3 both positively and negatively
- took extensive TE measurements
- alternated UVA and new LANL NMR systems

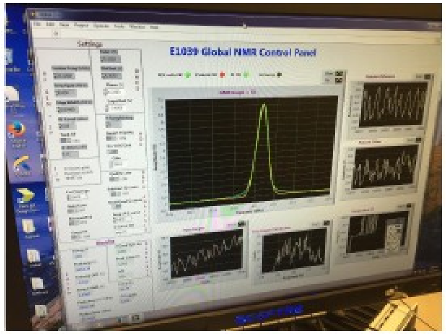


TE signal

UVA NMR Signal







LANL NMR Signal

Target Personnel

- Target Experts (On call for all target systems, should be within 20 mins of experiment): Need at least 5 to cycle on month long shifts

  --No Training Materials for this, see me--

- Target Operators (Maintain polarization and cryogenics, move target position, Monitor Target Alarms, Check sheet and Target Log, Contact Target Expert as needed): Need about 50 to cover 4 months of running

  --Training Materials will be available from UVA--

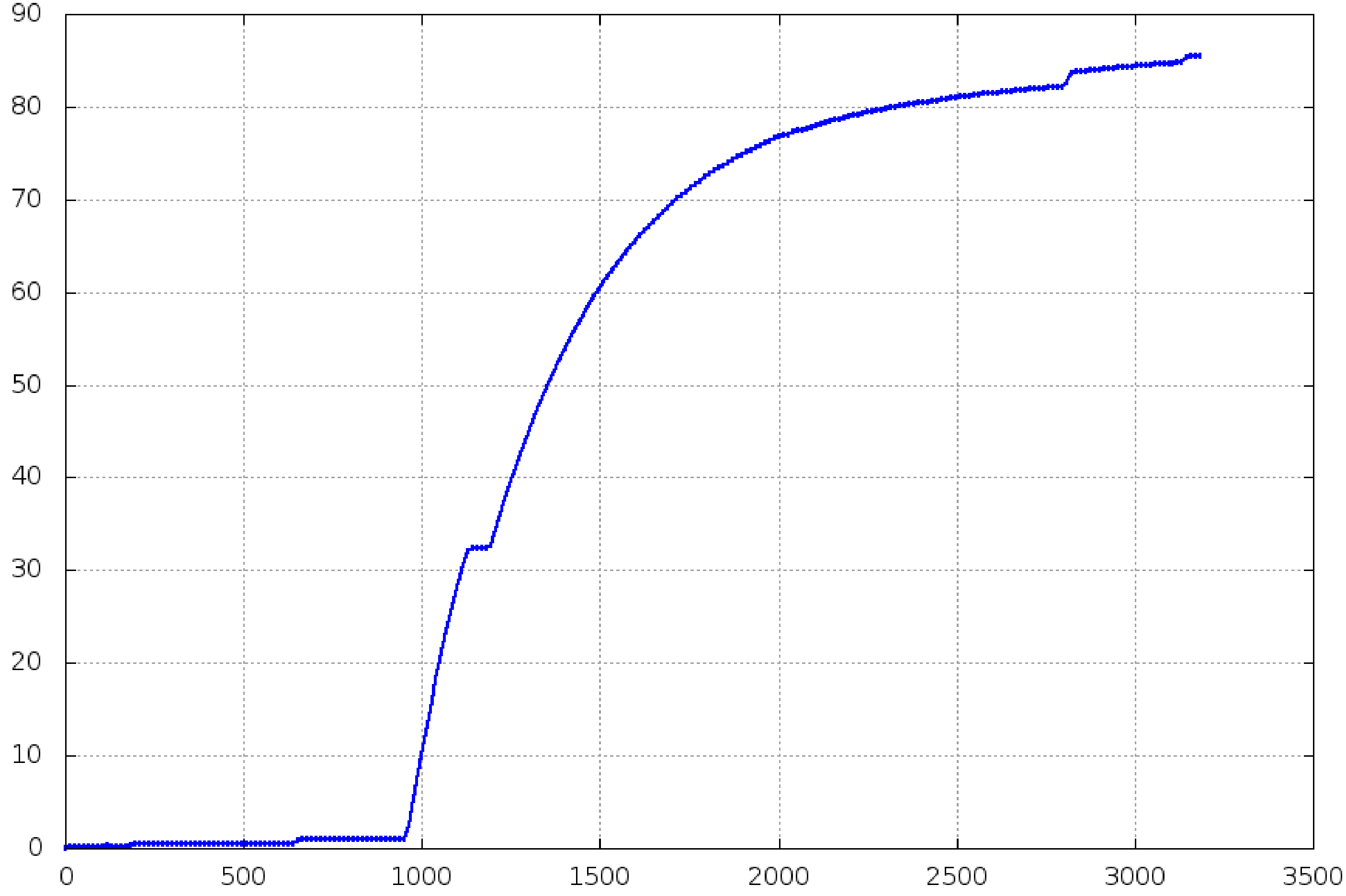
Still to Come

- Secondary pressure/temp sensor (^{3}He bulb-Just test)
- Additional Fridge Modifications for ease of target change-out (Just test)
- Cold NMR system optimal signal to noise for Deuteron/Neutron (Just test)
- Maximize number of target cells equipped with cold NMR (Probably 3)
- Remote Control for Microwave (Ready for Testing)
- Cryosystem auto-control (Close to finished)
- Annealing system (Still deciding which one)
- Material purchase and irradiation (ND_3 ~$40K)
- Making material and doing the irradiations (only 500g done out of 2.6kg)
- Couple more cooldowns coming up soon for testing what is mentioned

Results of Cooldown

- There is a power restriction (think we got it)
- All coils are doing about the same
- All cell location are doing about the same
- Warm NMR seem OK
- Polarization multiple cells/coils ~85%
- All functionality tests went well
- System runs smooth but uses lots of LHe (~17 SLM with vacuum 7X10^-7 tor)

Initial Run: Central Top Coil



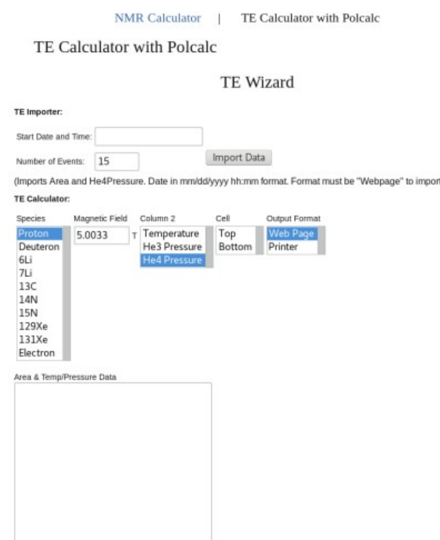
- 85.5%(2.7%)(5.5%)
- 5-10:1

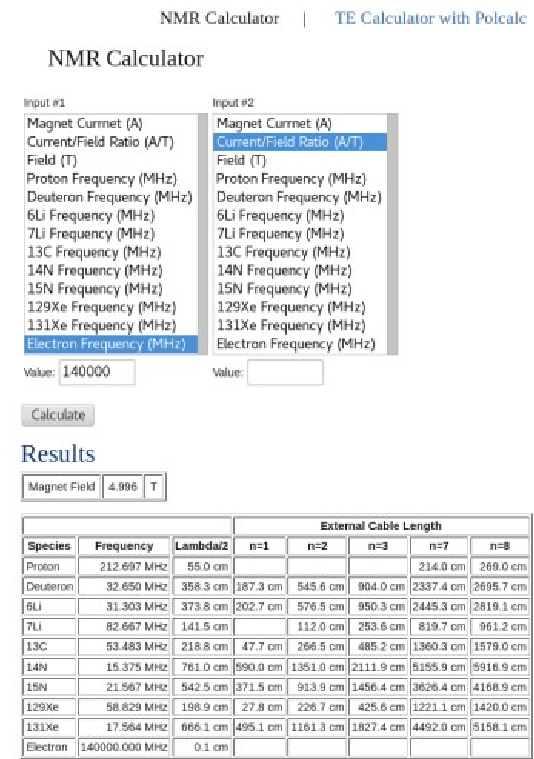
Still to Come

- Secondary pressure/temp sensor calibration (^{3}He bulb-Just test)
- Infrastructure for target changes
- Cold NMR system optimal signal to noise for Deuteron/Neutron
- Configure one stick with 3 active cells 2 cold-NMR one warm
- Remote Control for Microwave (further testing)
- Cryosystem auto-control (further testing)
- Annealing system (testing needed with temp sensors on insert)
- Material purchase and irradiation (ND_3 ~$40K)
- Making material and doing the irradiations (only 500g done out of 2.6kg)
- Lots of work on radiation protection for equipment (motors, etc…)
- Lots of work on setting up full cryocontrols and target variables data flow to run and test all at once
- Need more cooldowns coming up soon but where?

SOLID POLARIZED TARGET GROUP *at the* UNIVERSITY *of* VIRGINIA

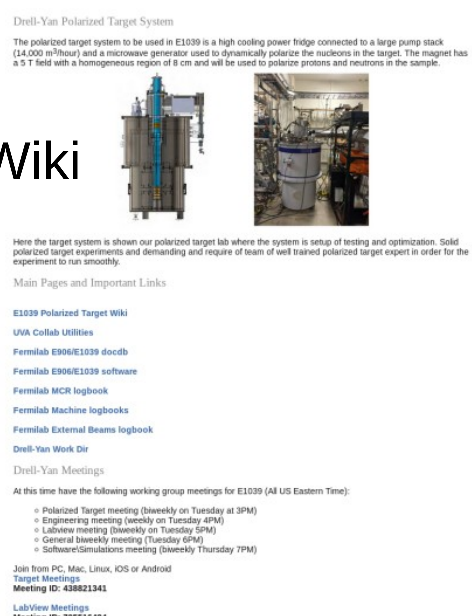
Target Tools





			External Cable Length				
Species	Frequency	Lambda/2	n=1	n=2	n=3	n=7	n=8
Proton	212.697 MHz	55.0 cm				214.0 cm	269.0 cm
Deuteron	32.650 MHz	358.3 cm	187.3 cm	545.6 cm	904.0 cm	2337.4 cm	2695.7 cm
6Li	31.303 MHz	373.8 cm	202.7 cm	576.5 cm	950.3 cm	2445.3 cm	2819.1 cm
7Li	82.667 MHz	141.5 cm		112.0 cm	253.6 cm	819.7 cm	961.2 cm
13C	53.483 MHz	218.8 cm	47.7 cm	266.5 cm	485.2 cm	1360.3 cm	1579.0 cm
14N	15.375 MHz	761.0 cm	590.0 cm	1351.0 cm	2111.9 cm	5155.9 cm	5916.9 cm
15N	21.567 MHz	542.5 cm	371.5 cm	913.9 cm	1456.4 cm	3626.4 cm	4168.9 cm
129Xe	58.829 MHz	198.9 cm	27.8 cm	226.7 cm	425.6 cm	1221.1 cm	1420.0 cm
131Xe	17.564 MHz	666.1 cm	495.1 cm	1161.3 cm	1827.4 cm	4492.0 cm	5158.1 cm
Electron	140000.000 MHz	0.1 cm					

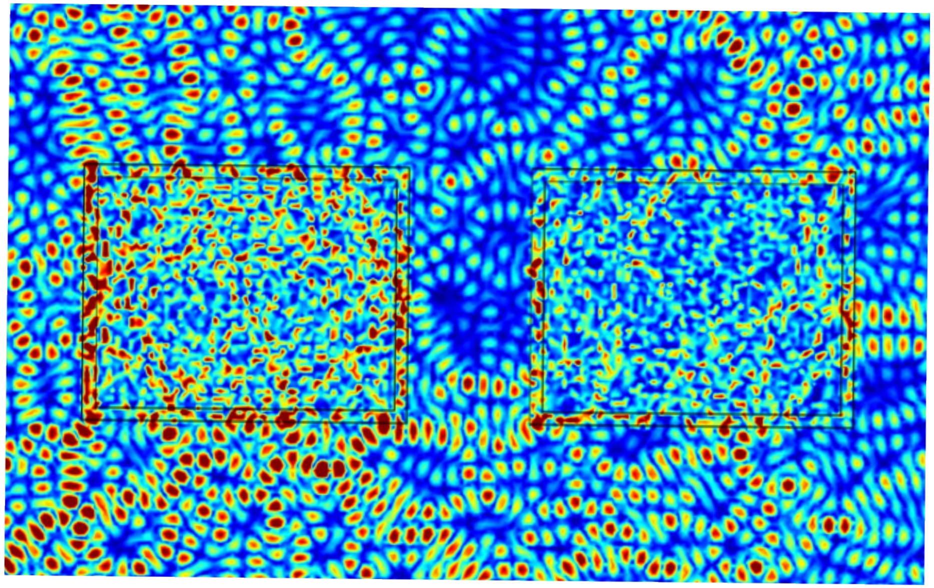
E1098 Target Wiki

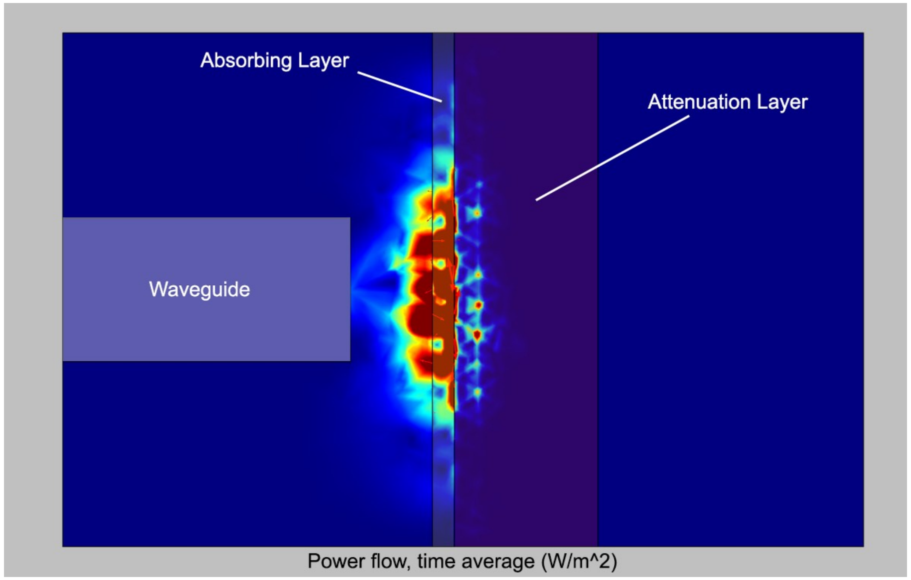


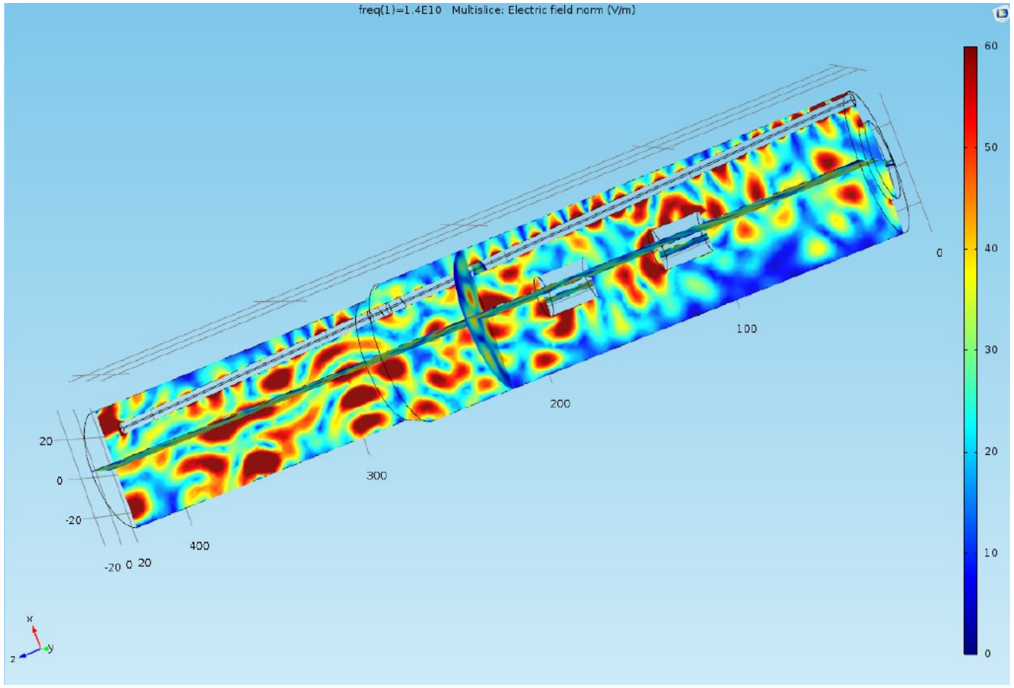
The Solid Polarized Target Group-UVa

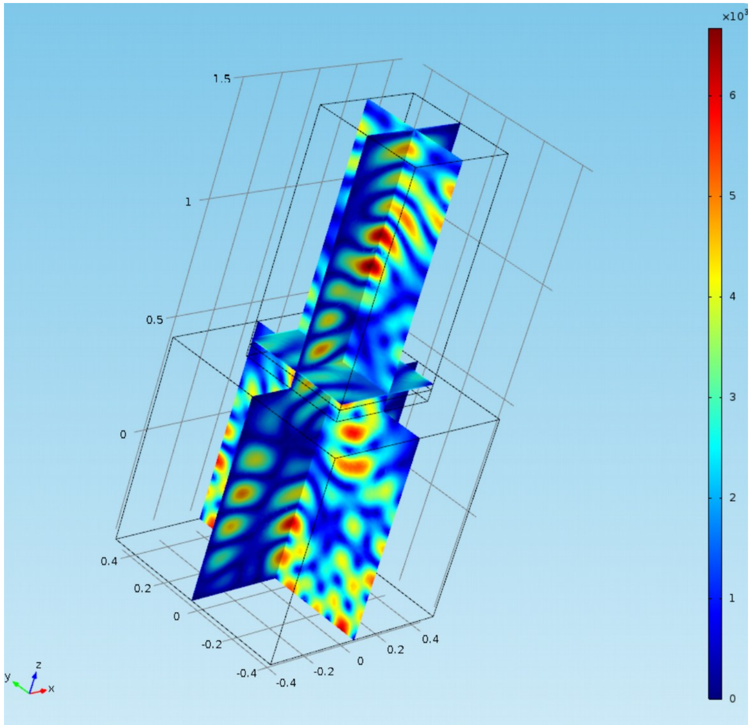
http://twist.phys.virginia.edu/

COMSOL Microwave Simulation

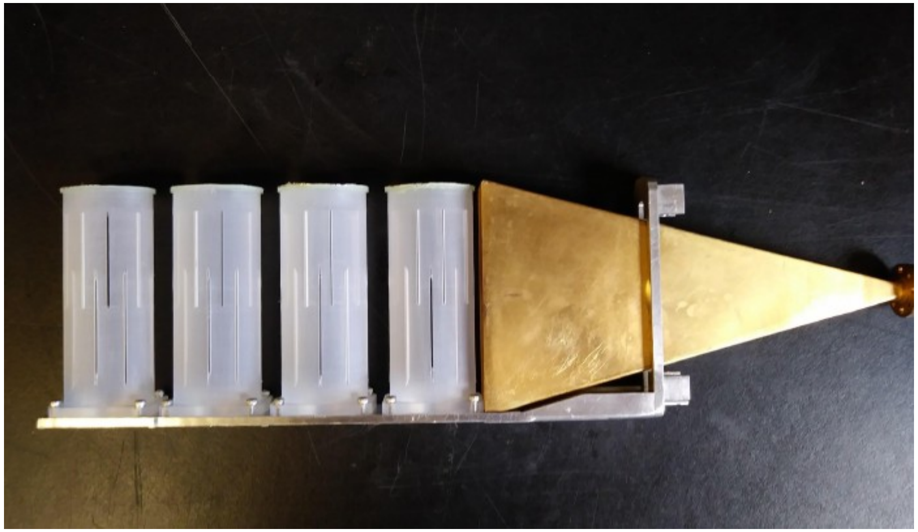


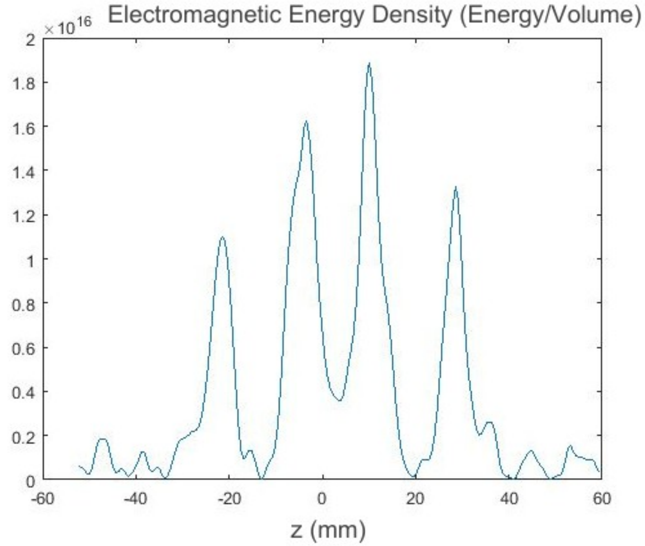


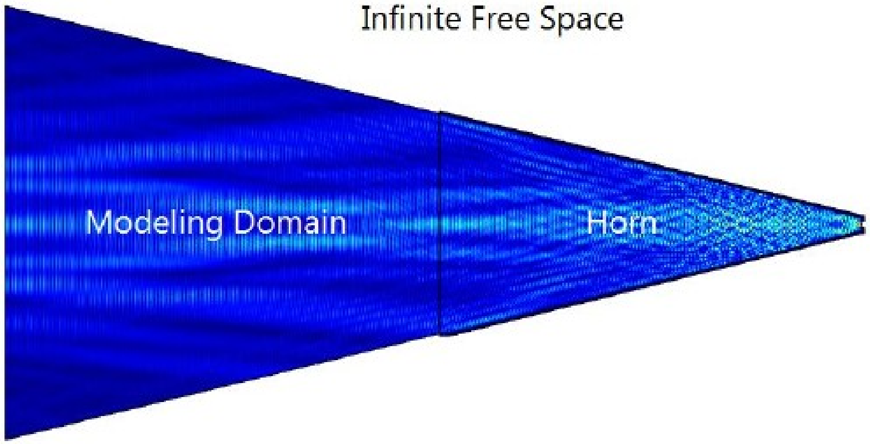


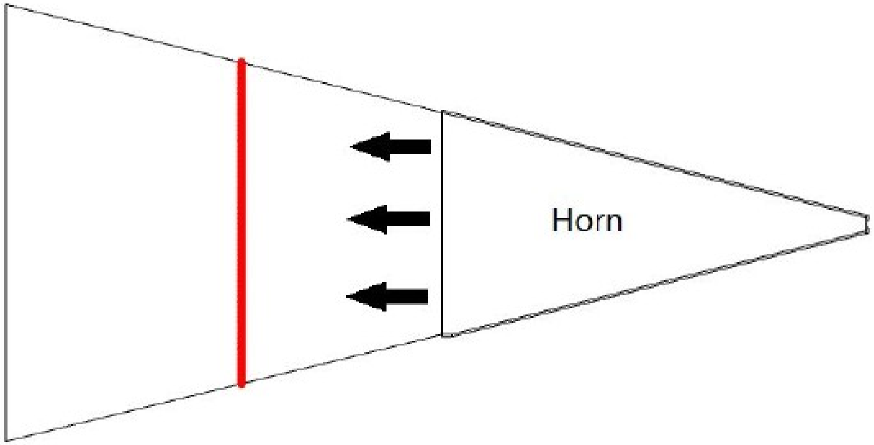


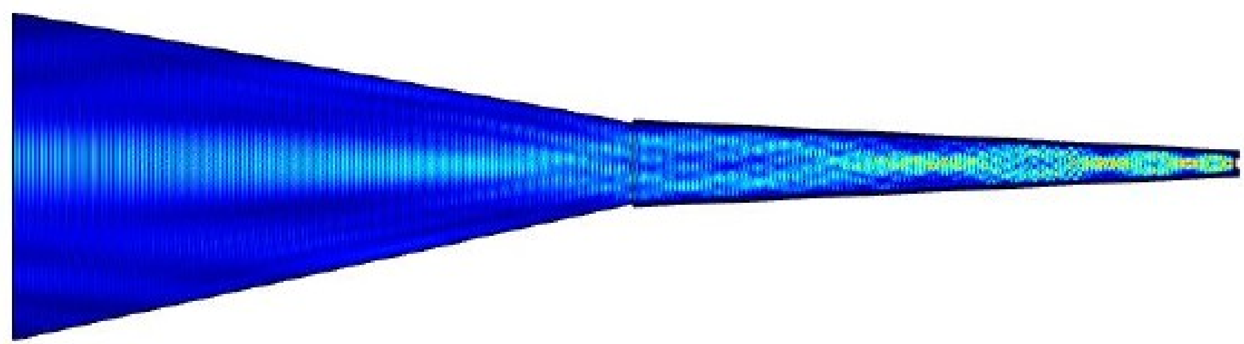
Microwave Profile

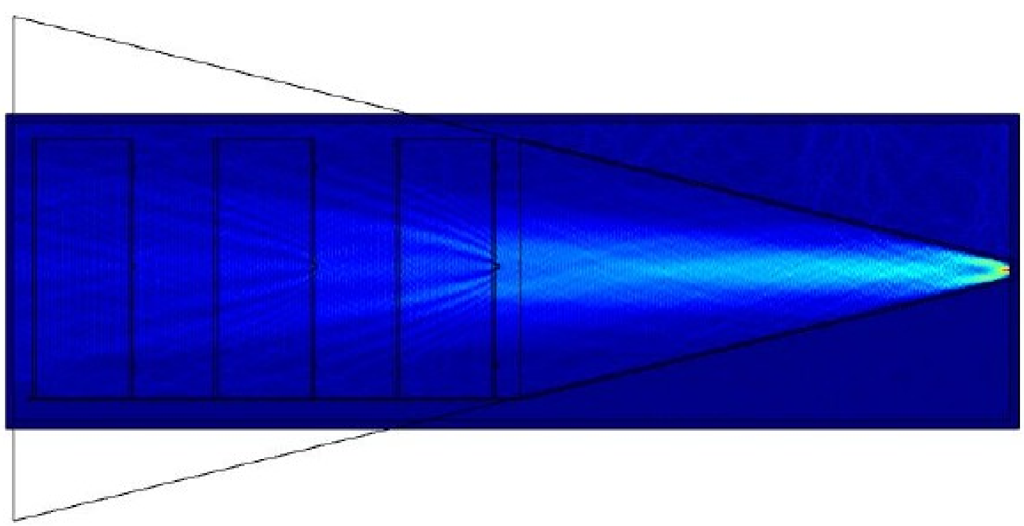


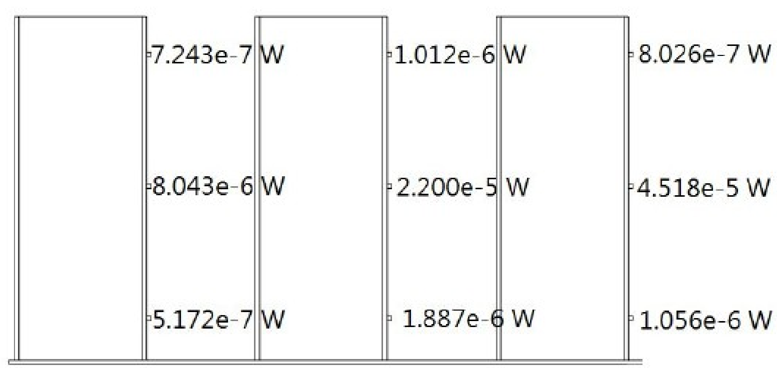




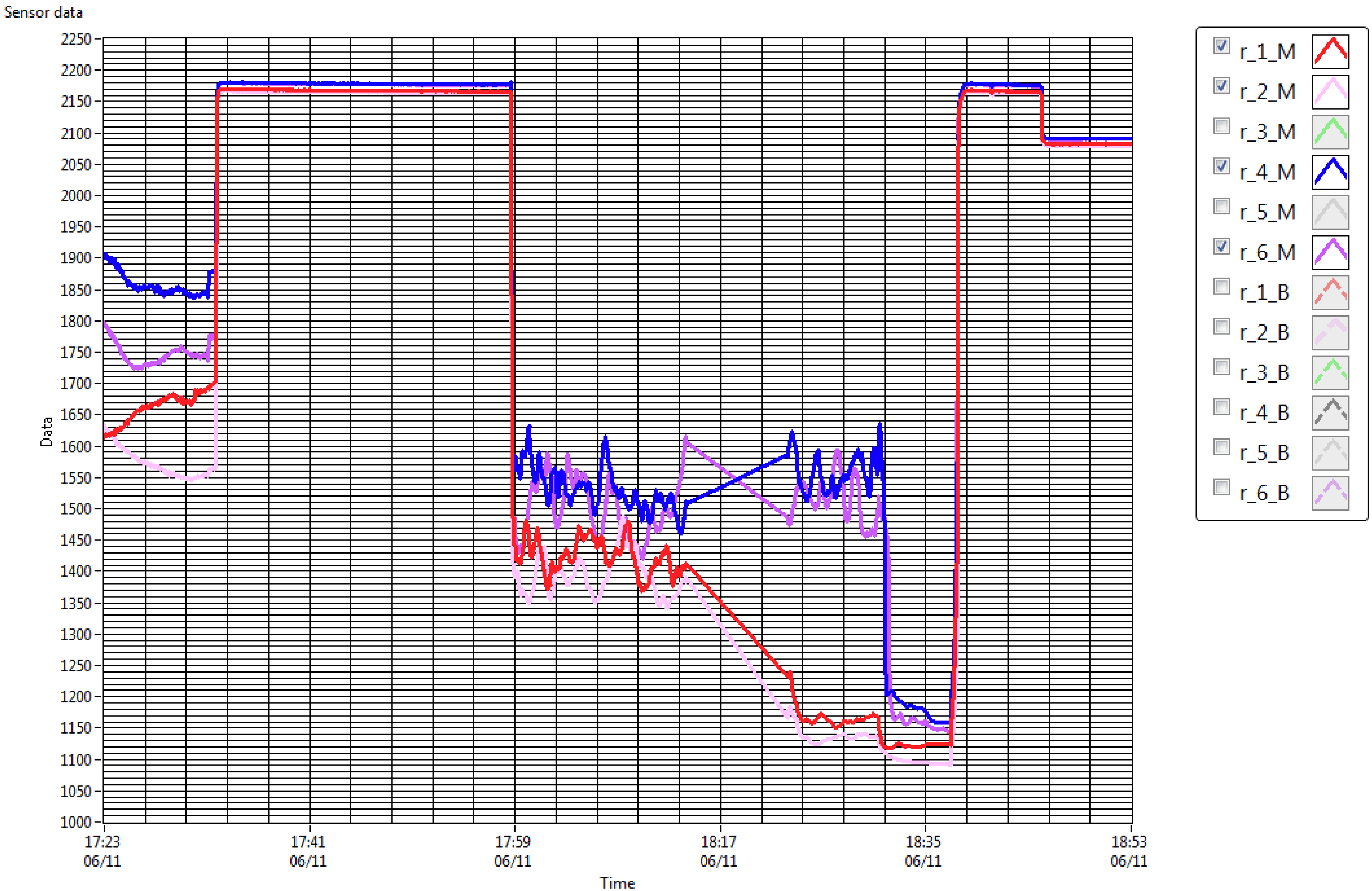




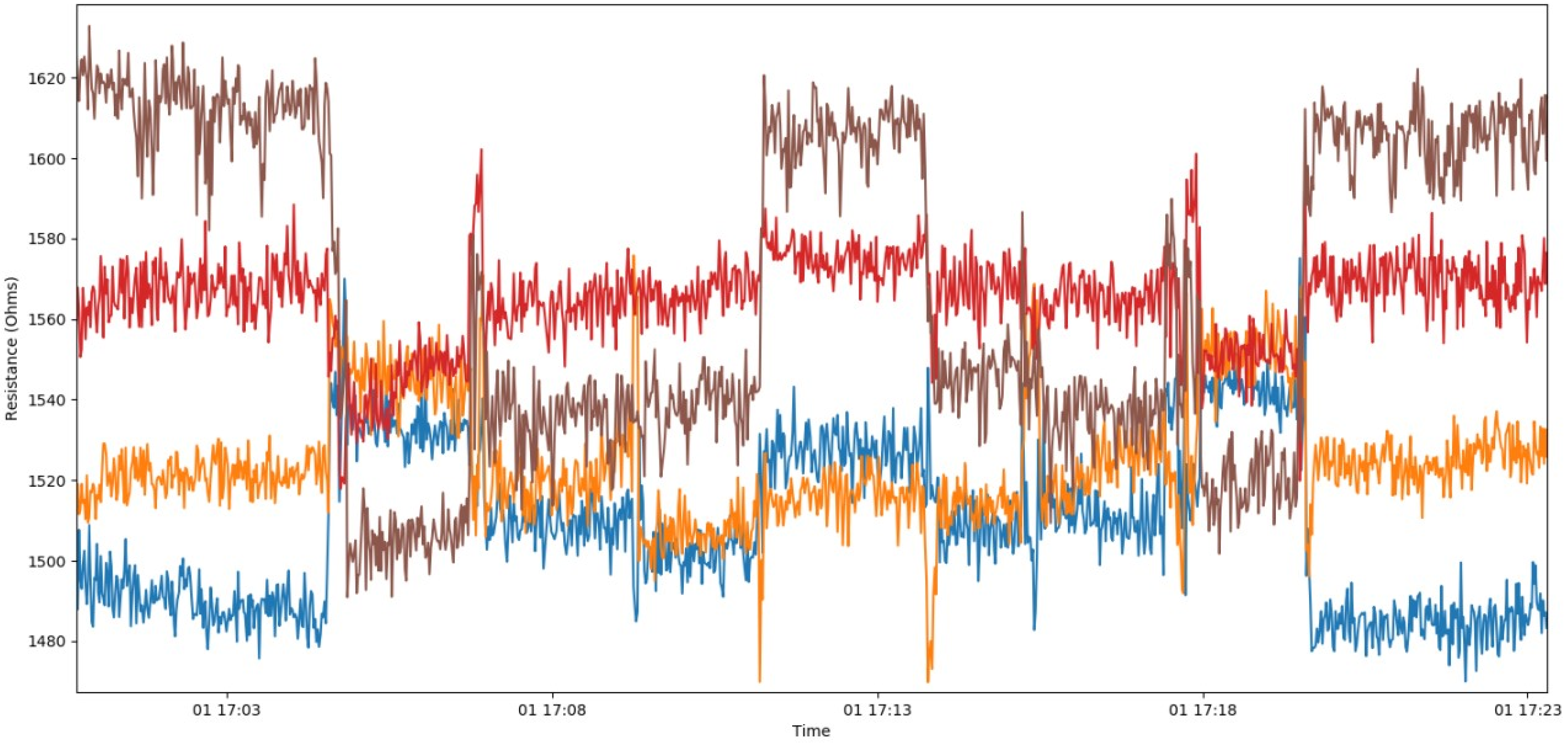


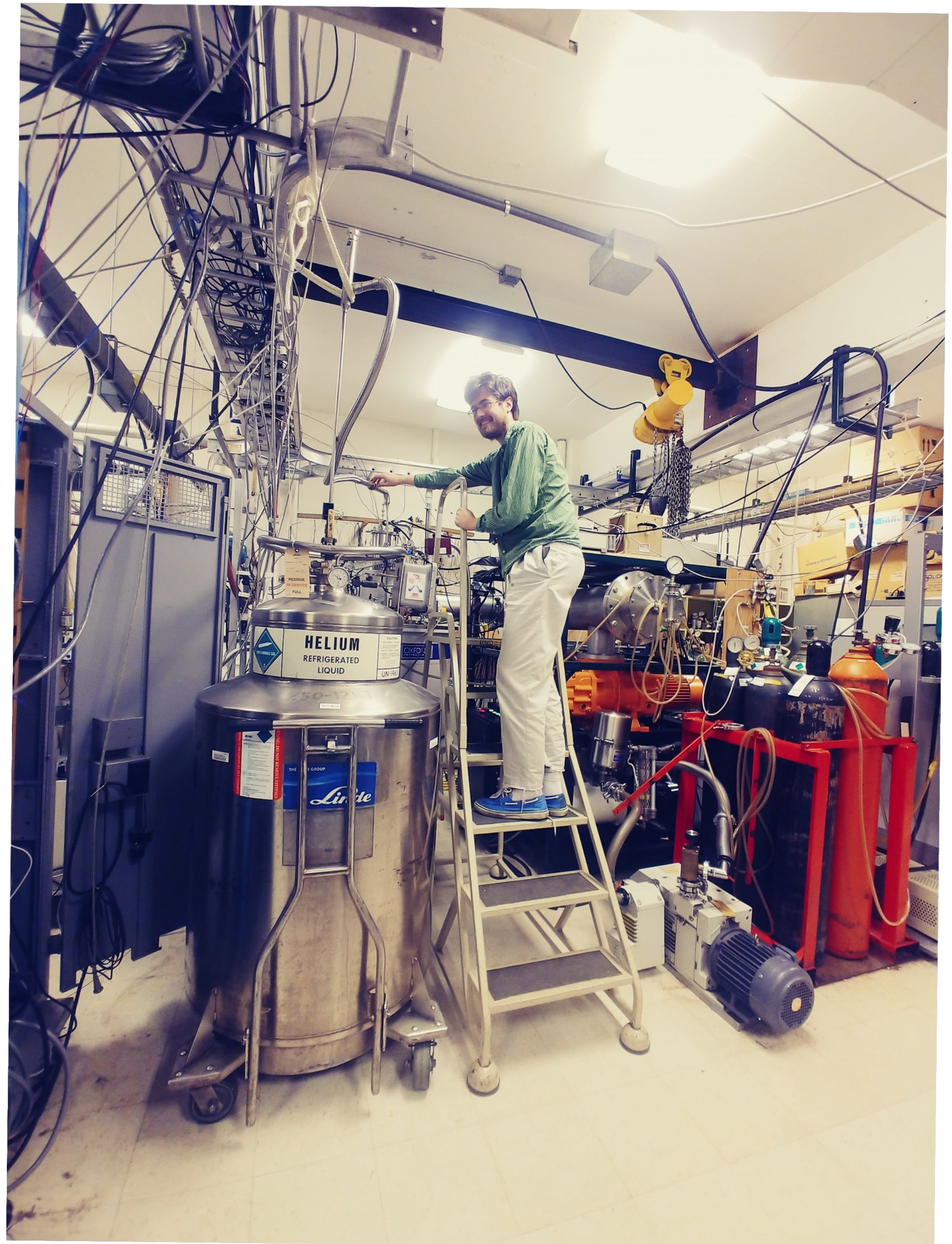

7.243e-7 W
1.012e-6 W
8.026e-7 W
8.043e-6 W
2.200e-5 W
4.518e-5 W
5.172e-7 W
1.887e-6 W
1.056e-6 W

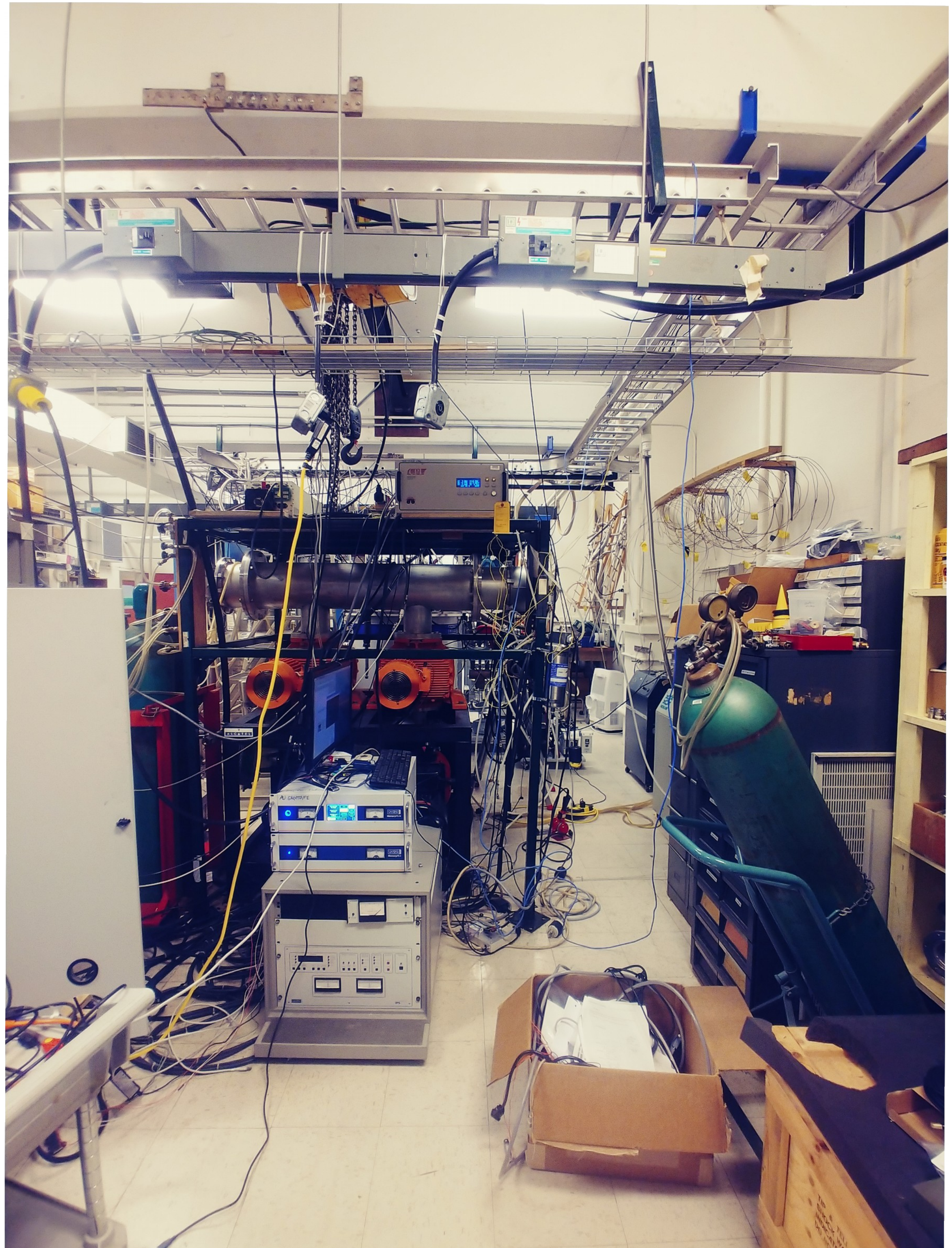
Absorption at Resonance

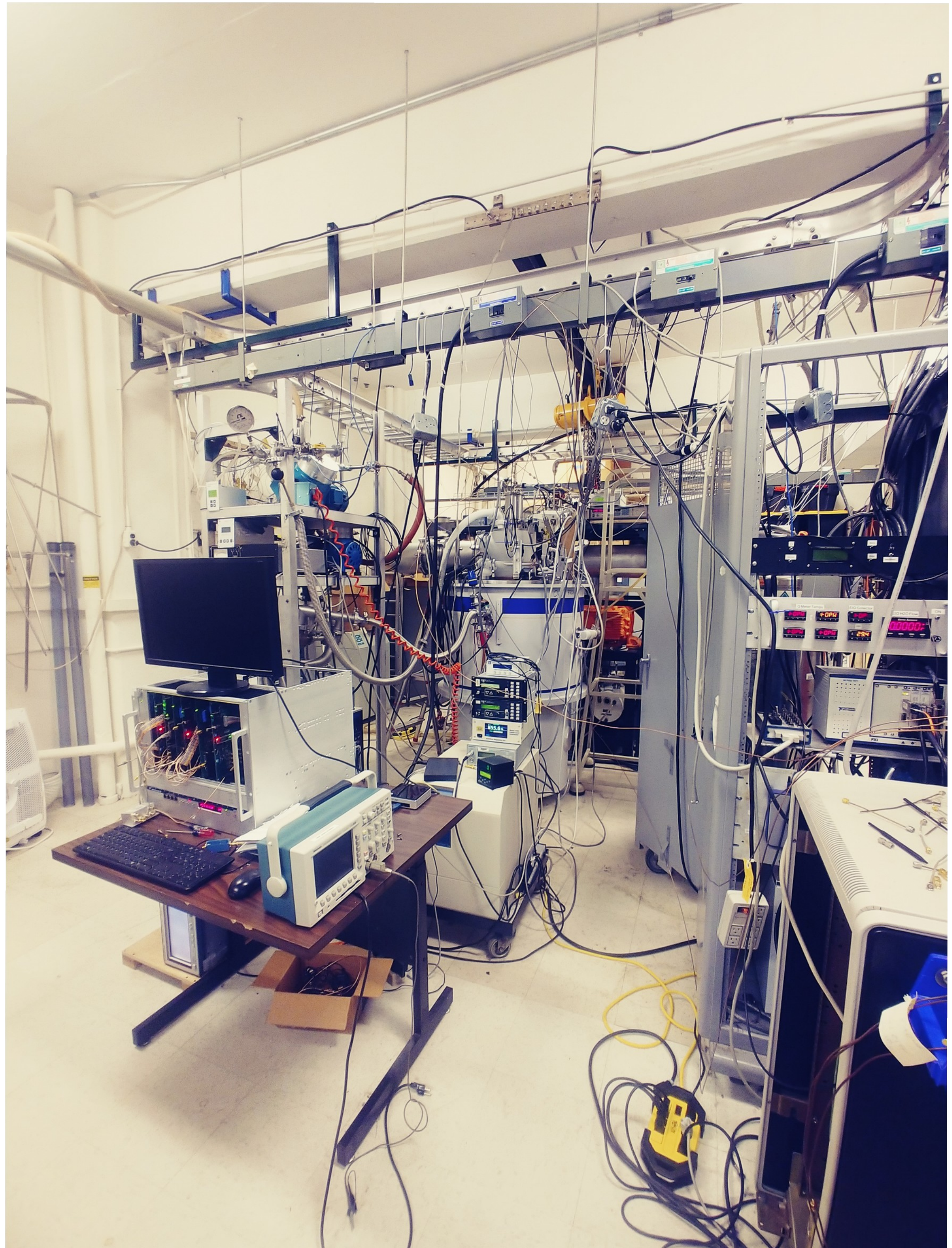


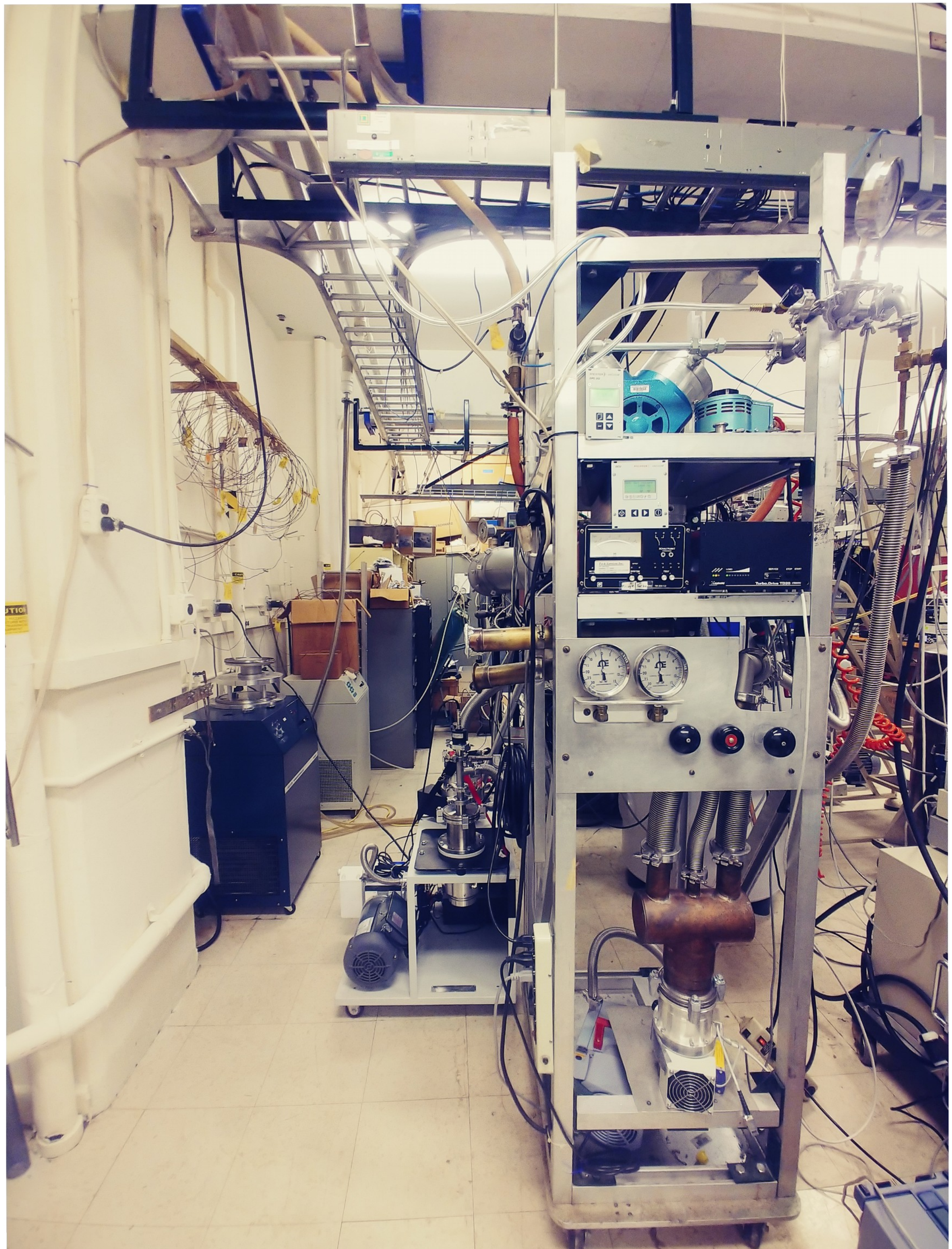
Microwave Studies




HELIUM
REFRIGERATED
LIQUID
Linde

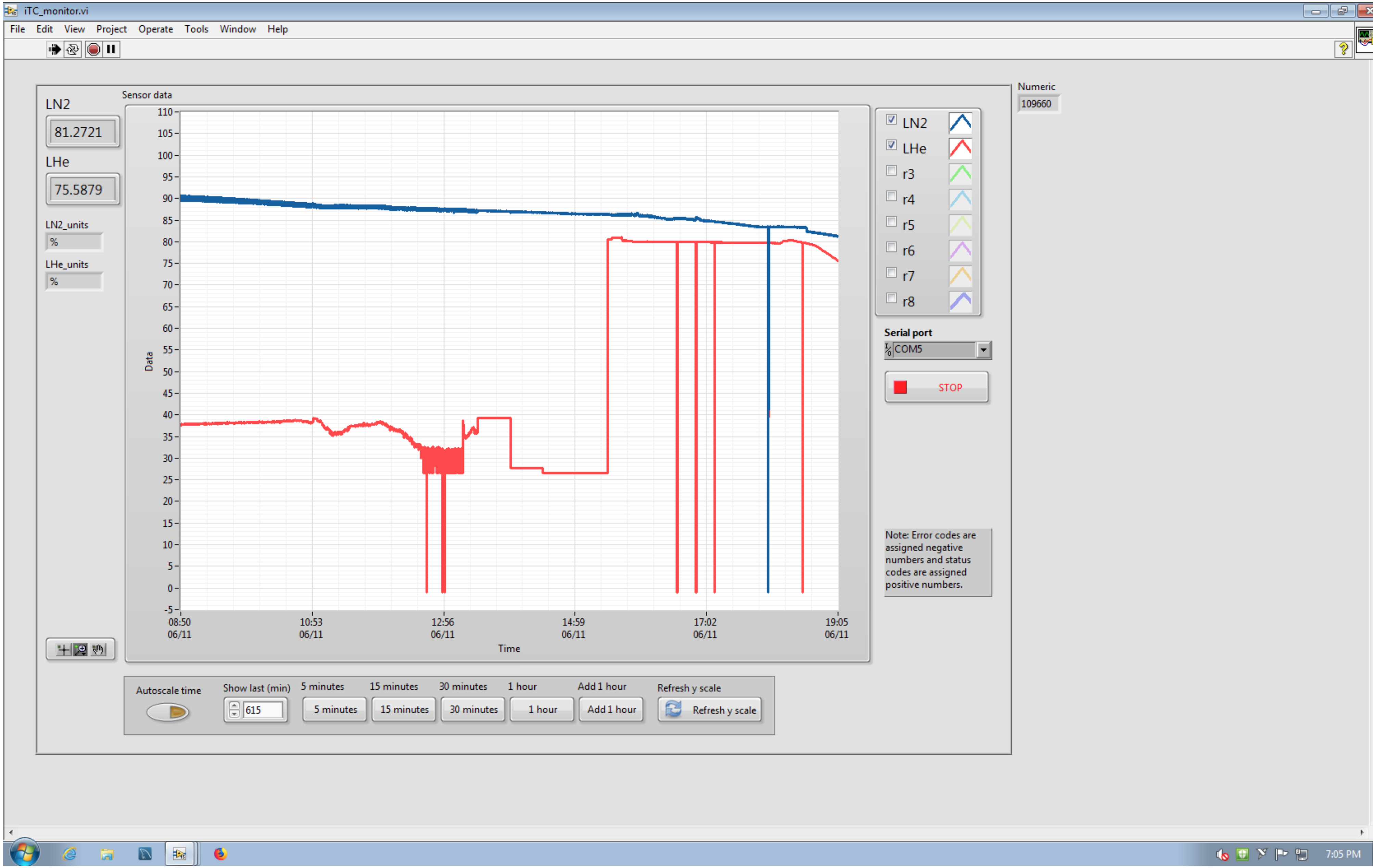




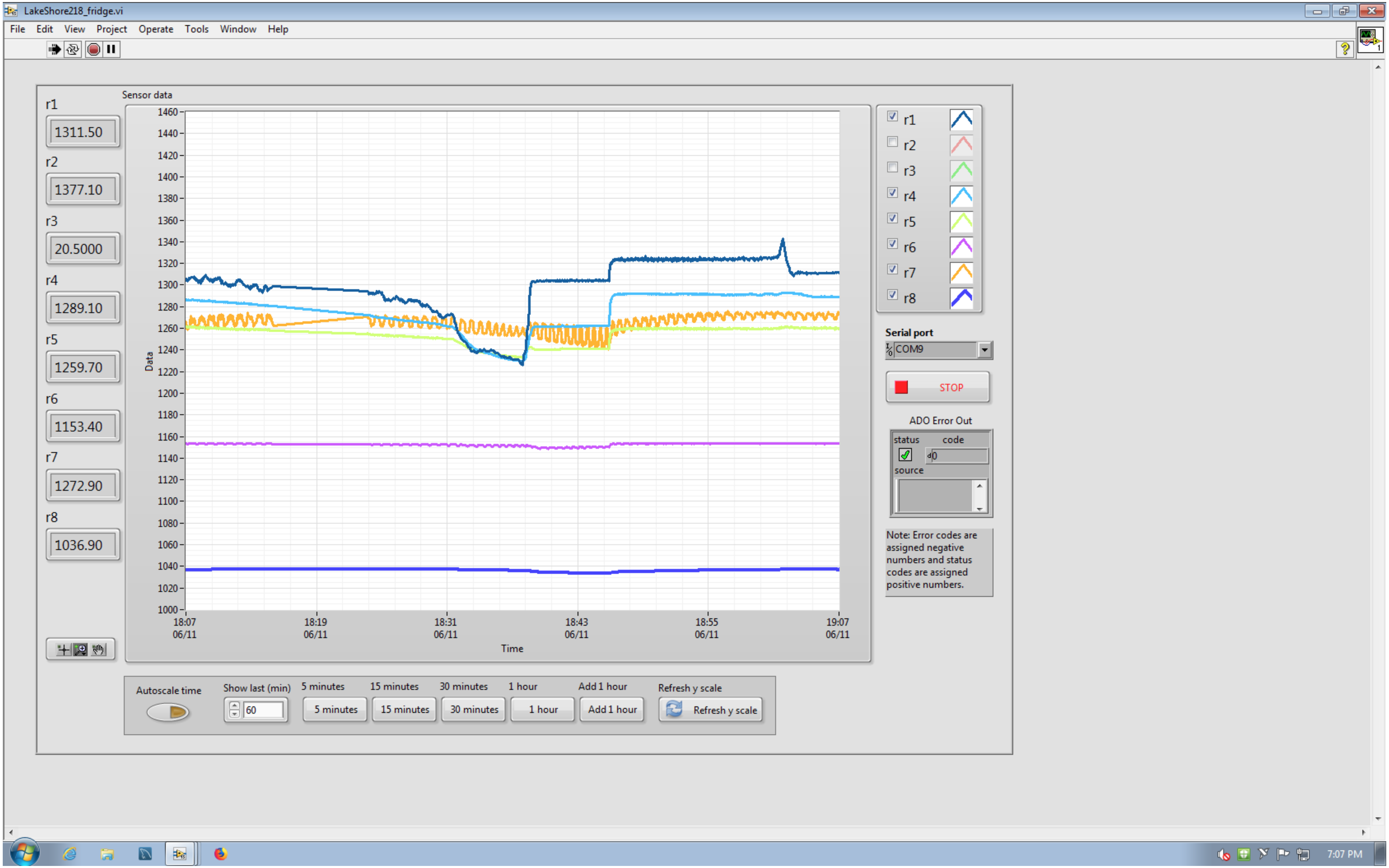


Target Insert Sensors

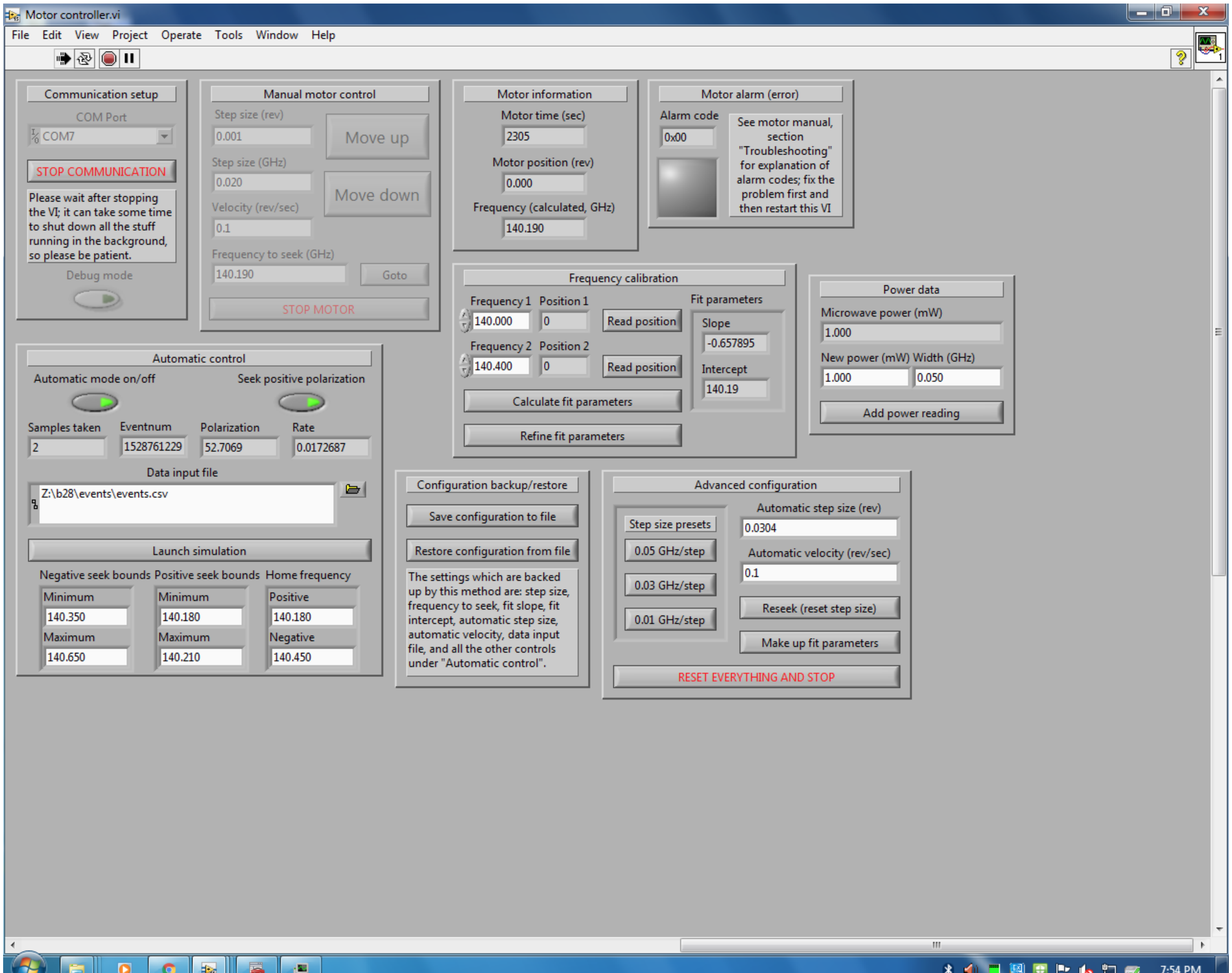
Liquid Helium and Nitrogen Level



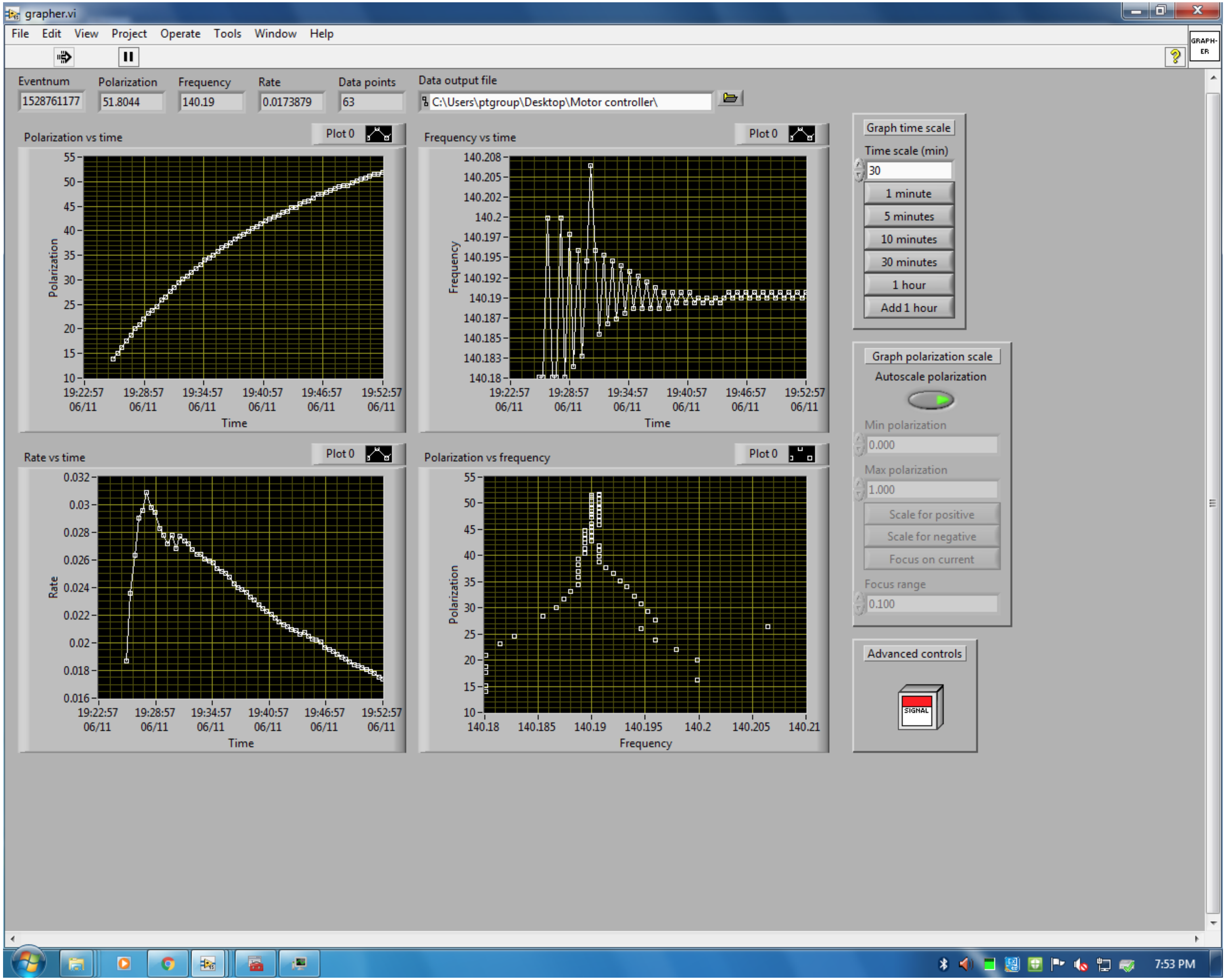
Refrigerator Sensors



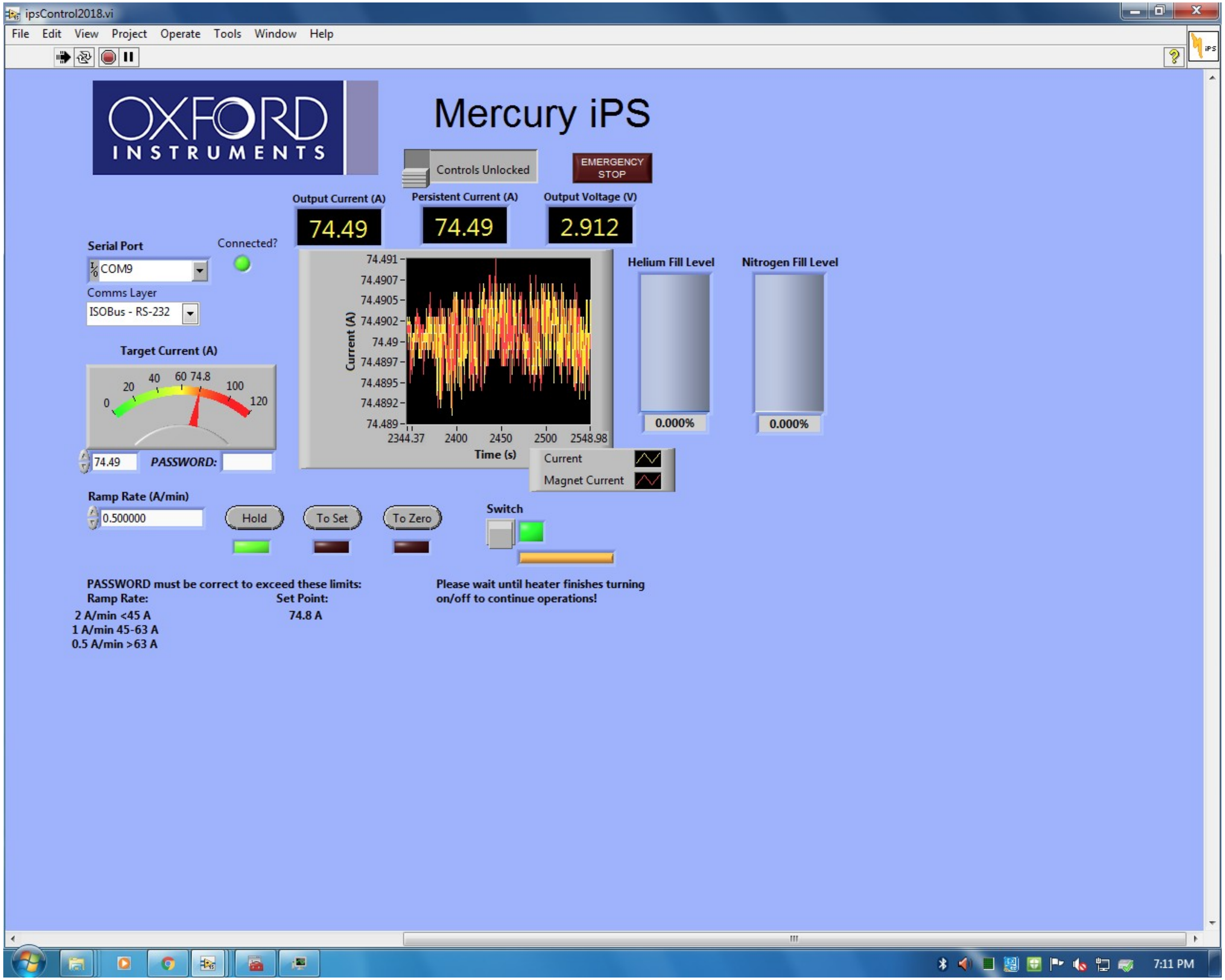
Microwave Control VI



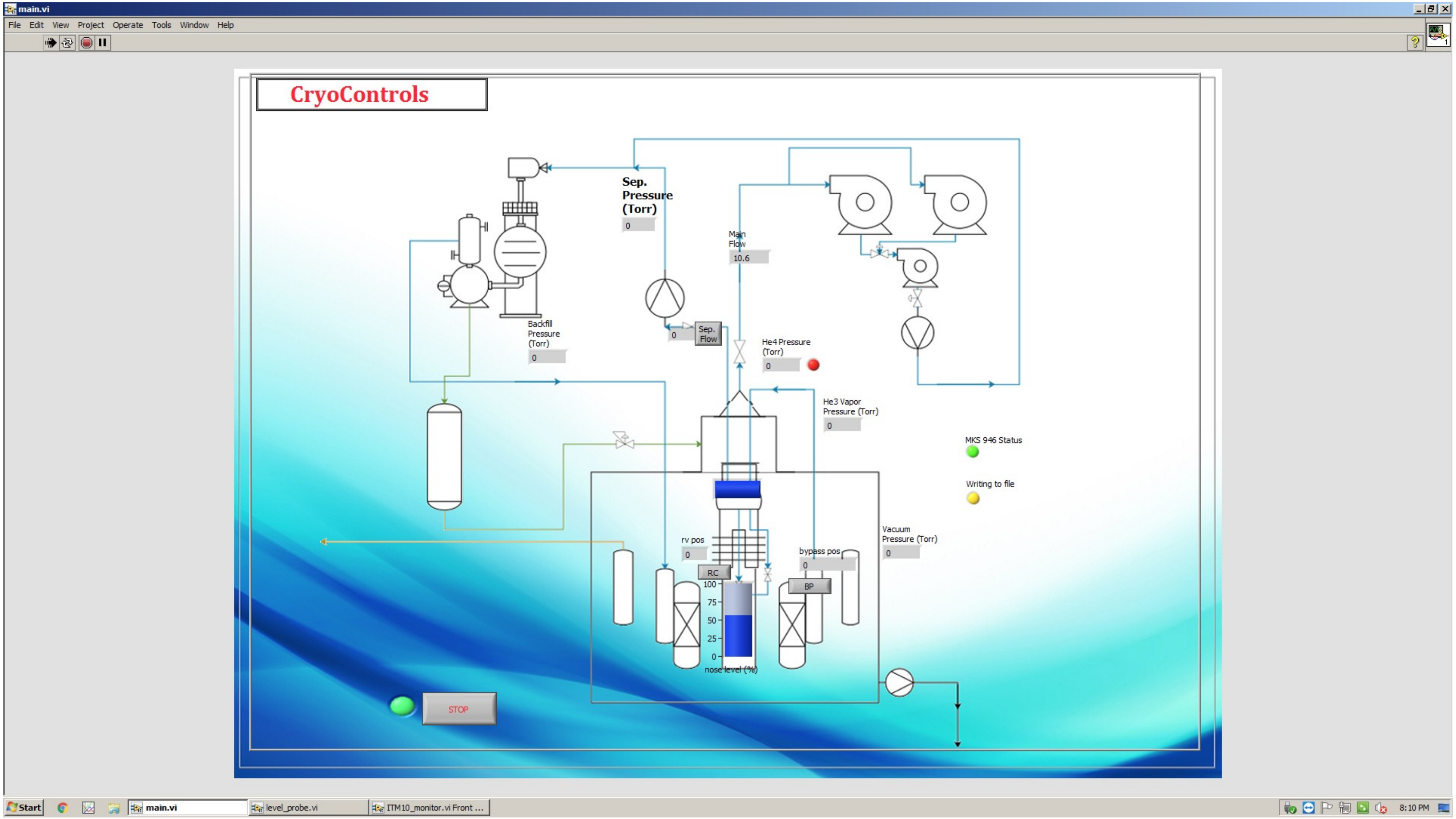
Automated Frequency Control



Magnet PS control



Cryocontrols



Pop-up Controls