

LANL/UVA Solid Polarized Target

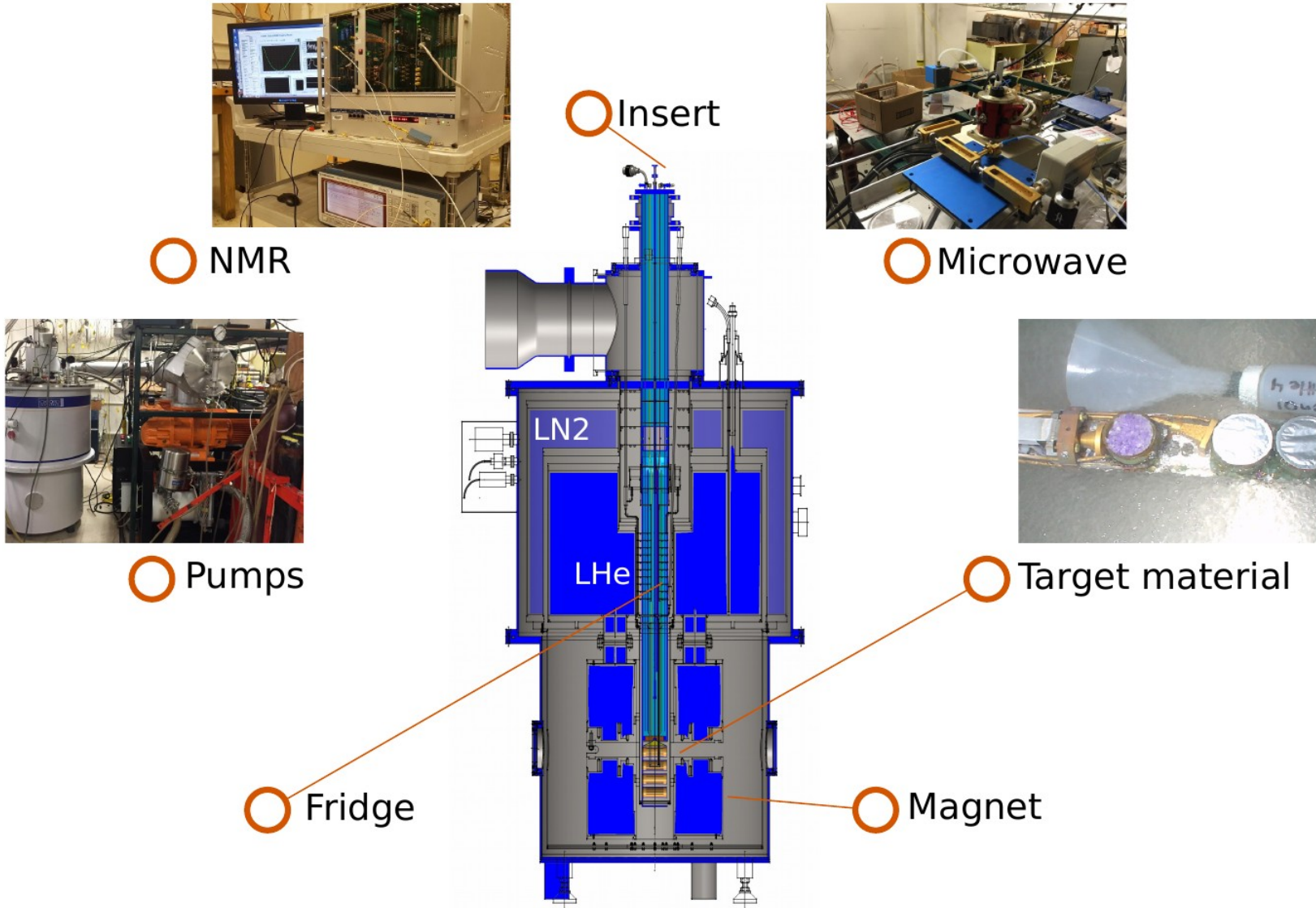
Dustin Keller
University of Virginia

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

Magnet

Fridge

Insert

NMR

Microwave

Pumps

Target material

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

Magnet

Fridge

Insert

NMR

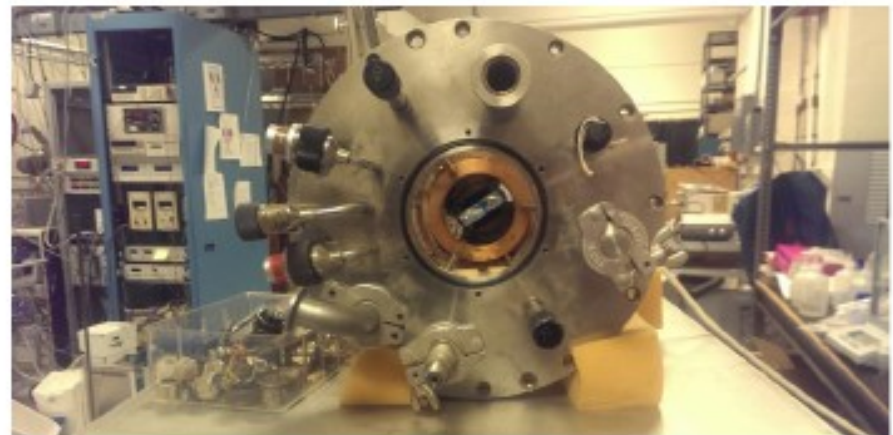
Microwave

Pumps

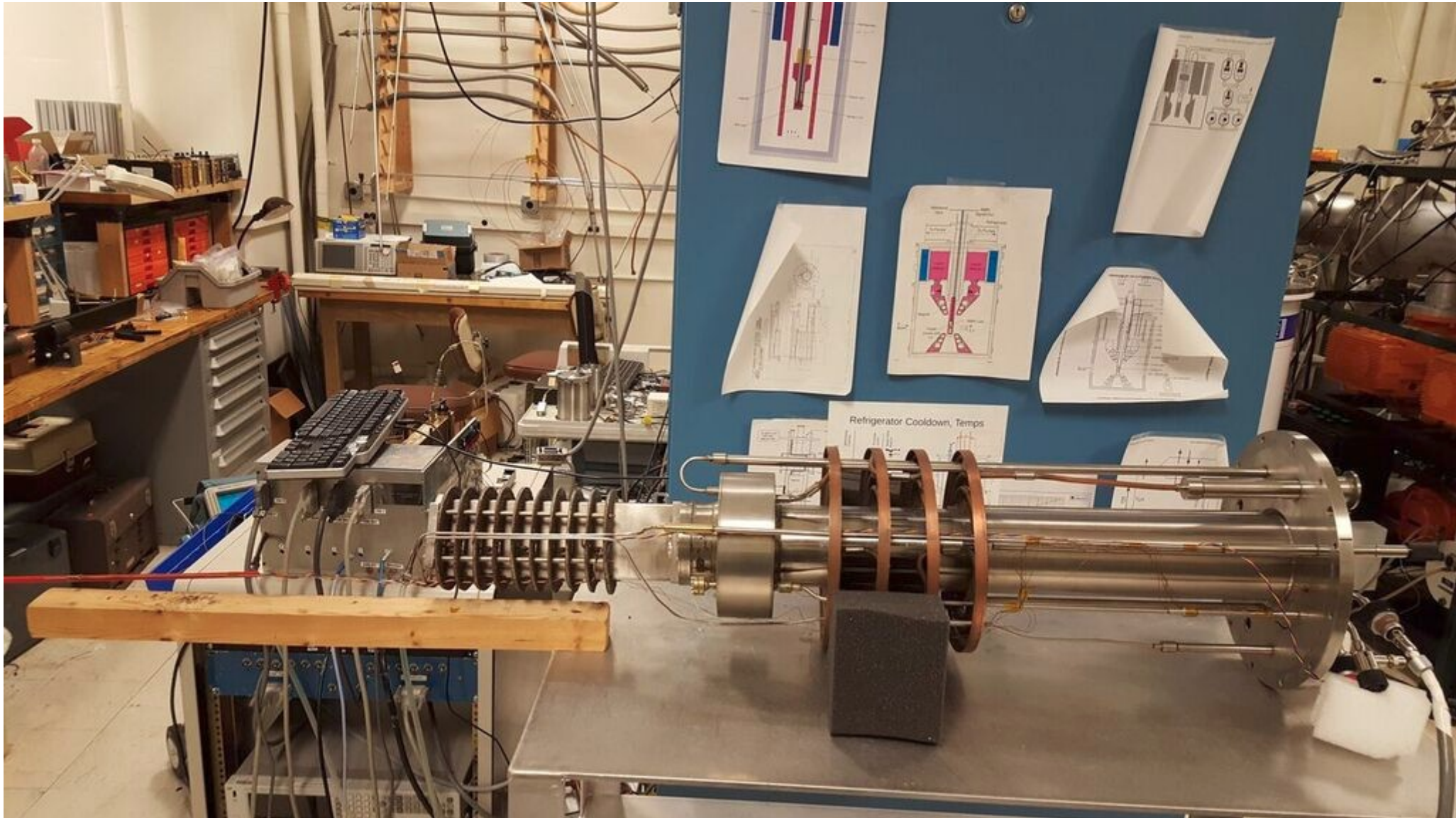
Target material

Fridge modifications

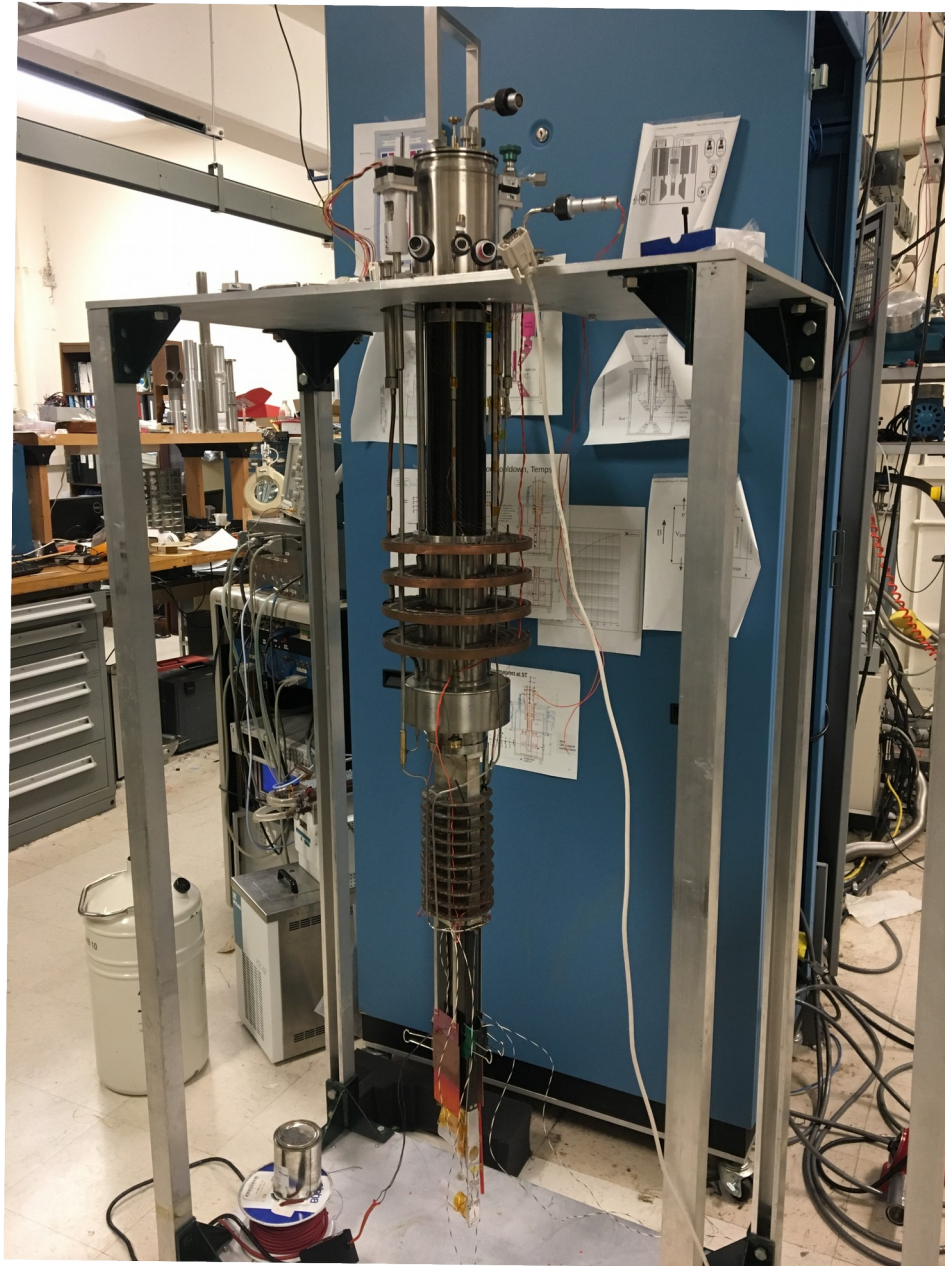
- replaced separator can
- cleaned heat exchangers oxide/corrosion
- leak checked
- refitted run and bypass valves
- installed new LHe channel
- installed 8 temperature sensors
- manufactured new nose, 10mil window



Recent Modifications



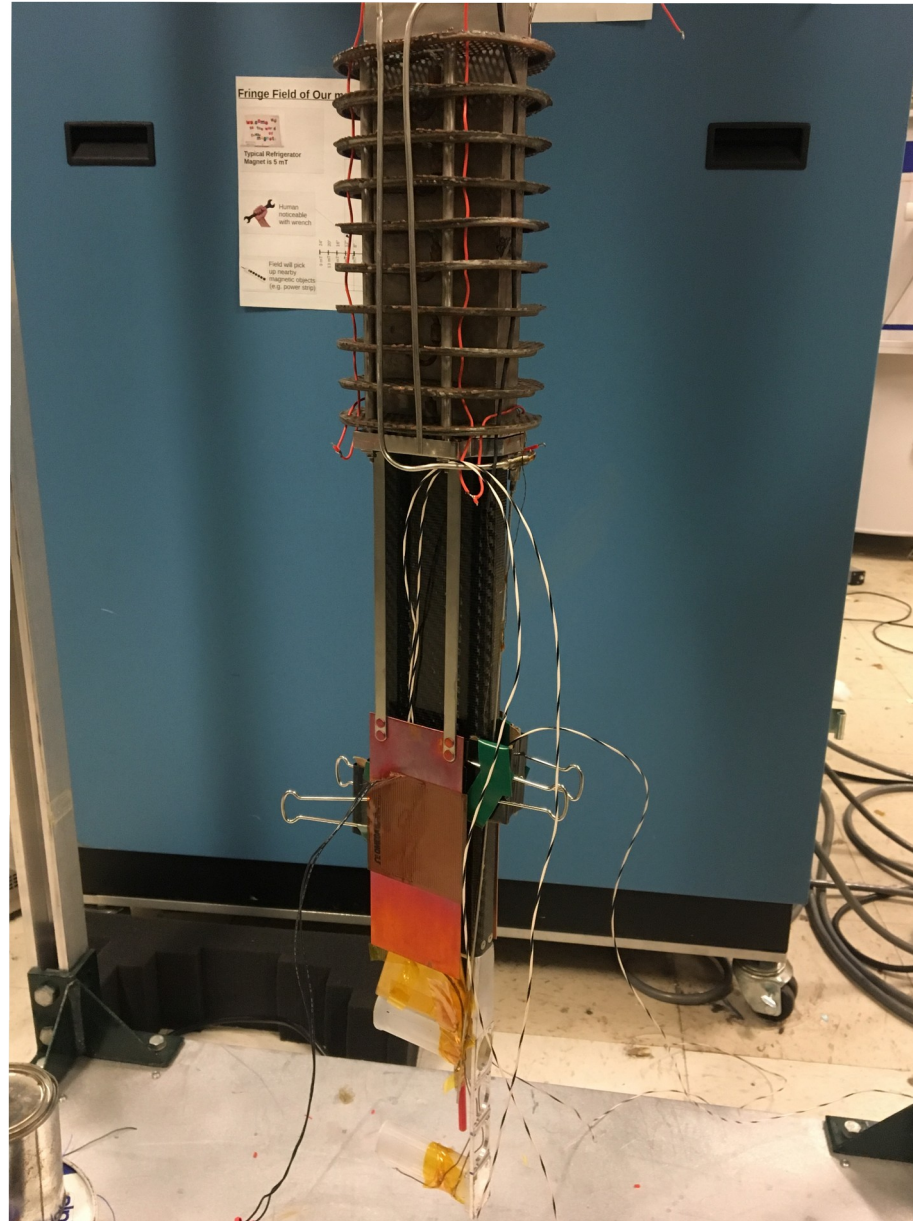
Upright Full View



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

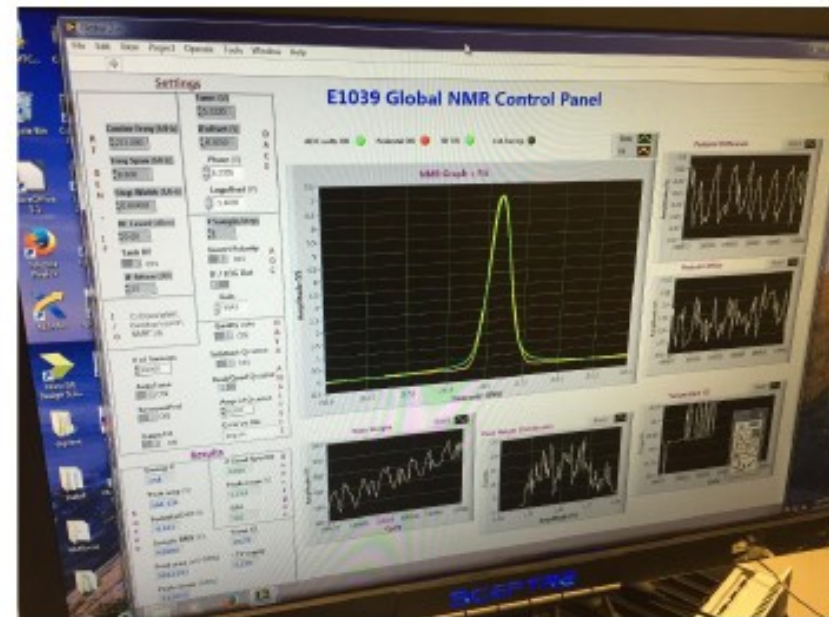
followed general Liverpool design

Q-meter as double wide VME module

1 analog / 1 digital boards, crate controller

16 bit ADCs/DACs, modern RF electronics

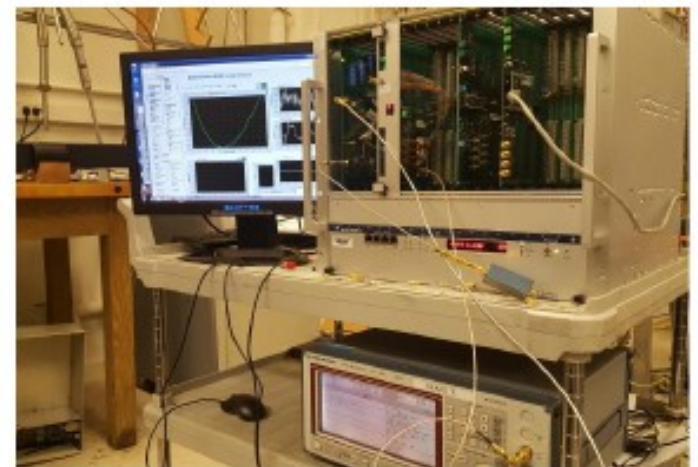
USB/Ethernet interface, LabView based DAQ



LANL NMR system tests at UVA

1st NMR cooldown 2014 (total 3 cold tests)

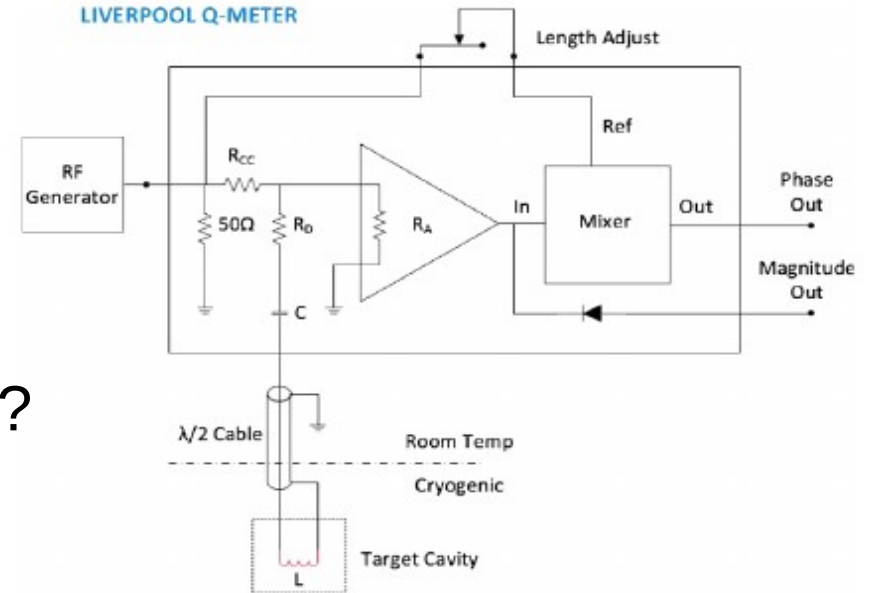
04/2016 full comparison to Liverpool Q-meter
signal/noise ratio - waiting for results



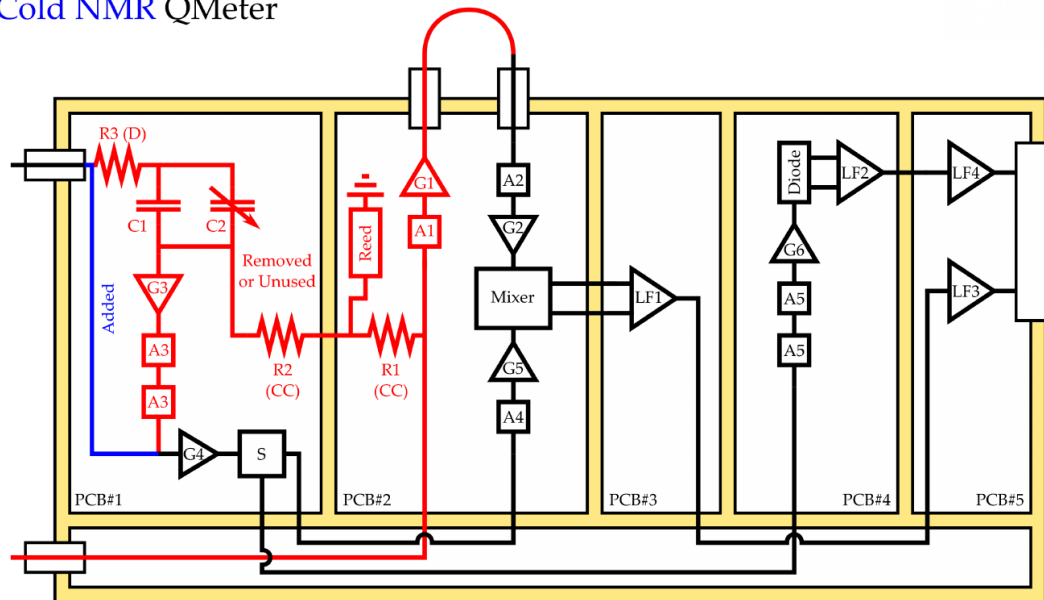
NMR System

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

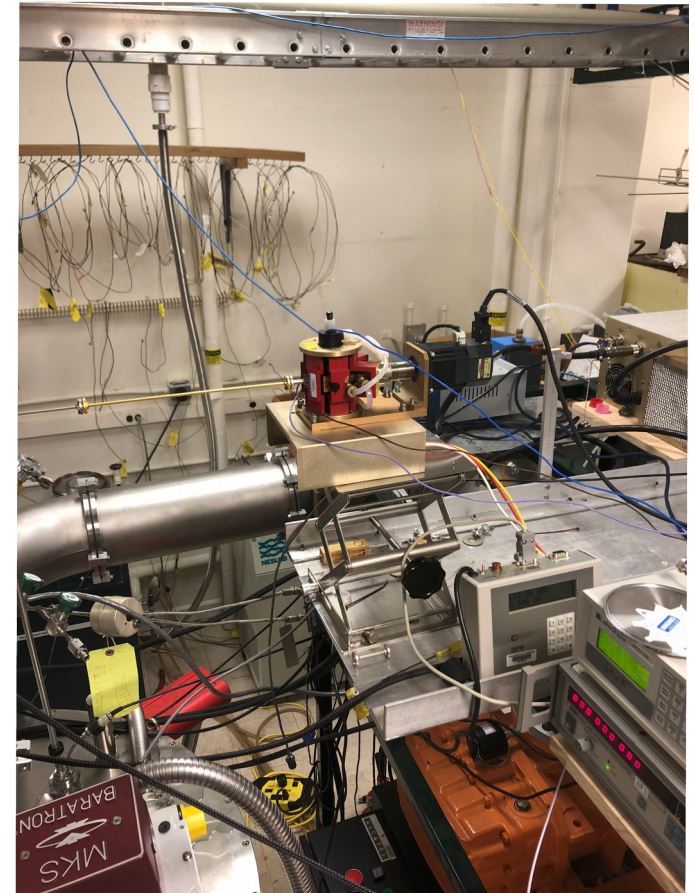
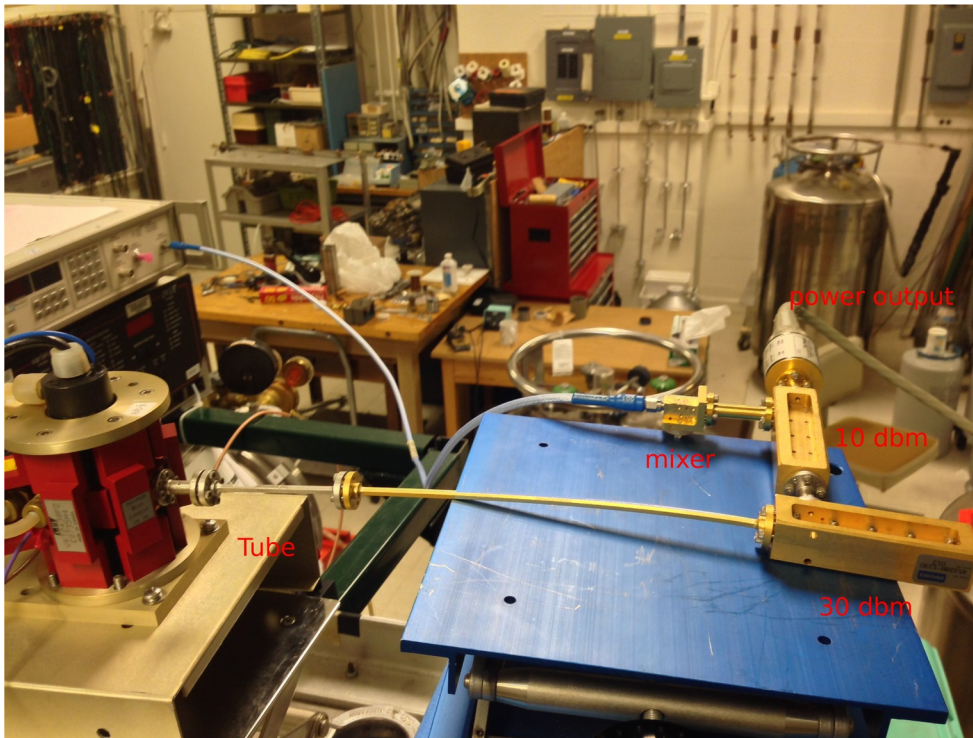
LIVERPOOL Q-METER



Cold NMR QMeter



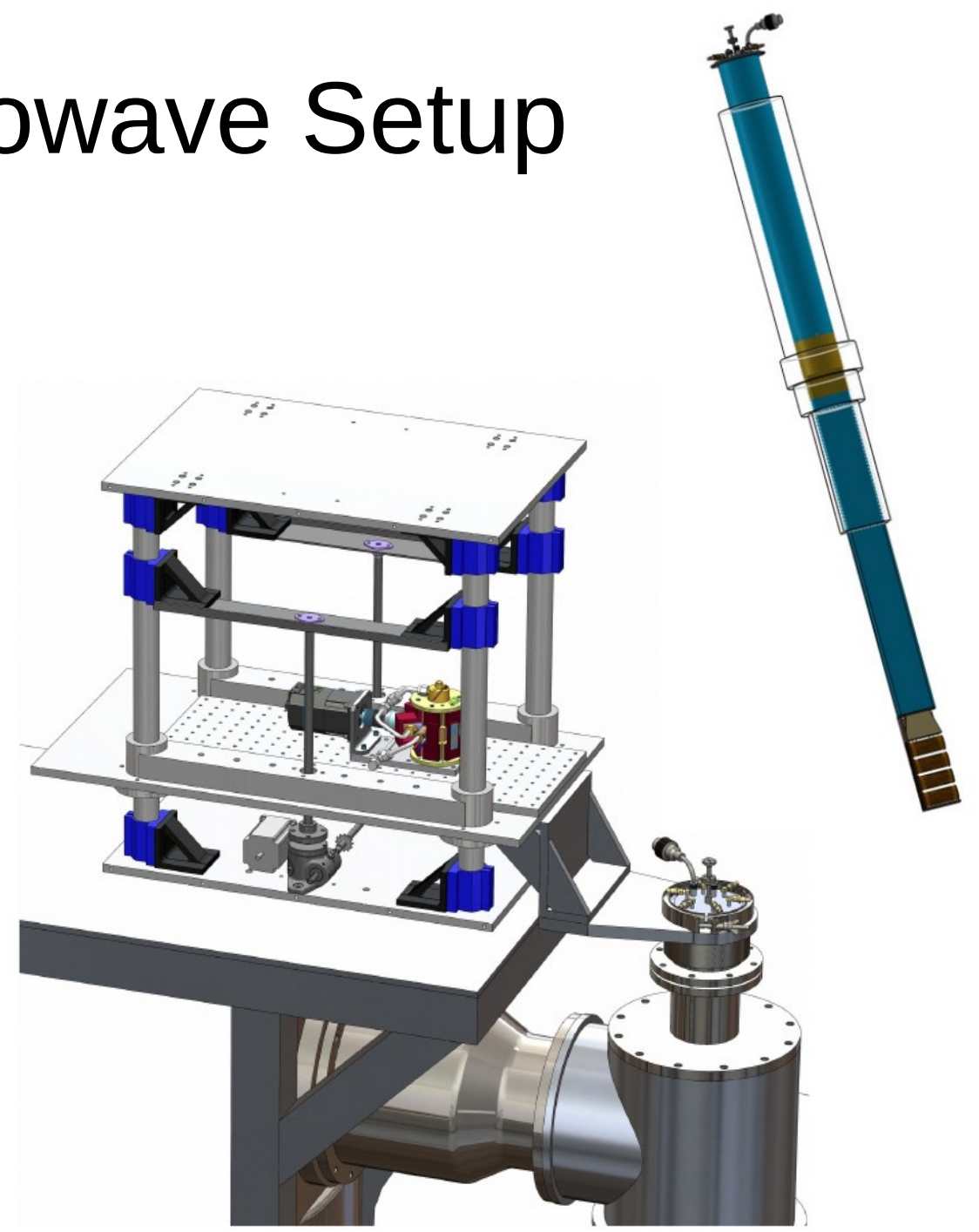
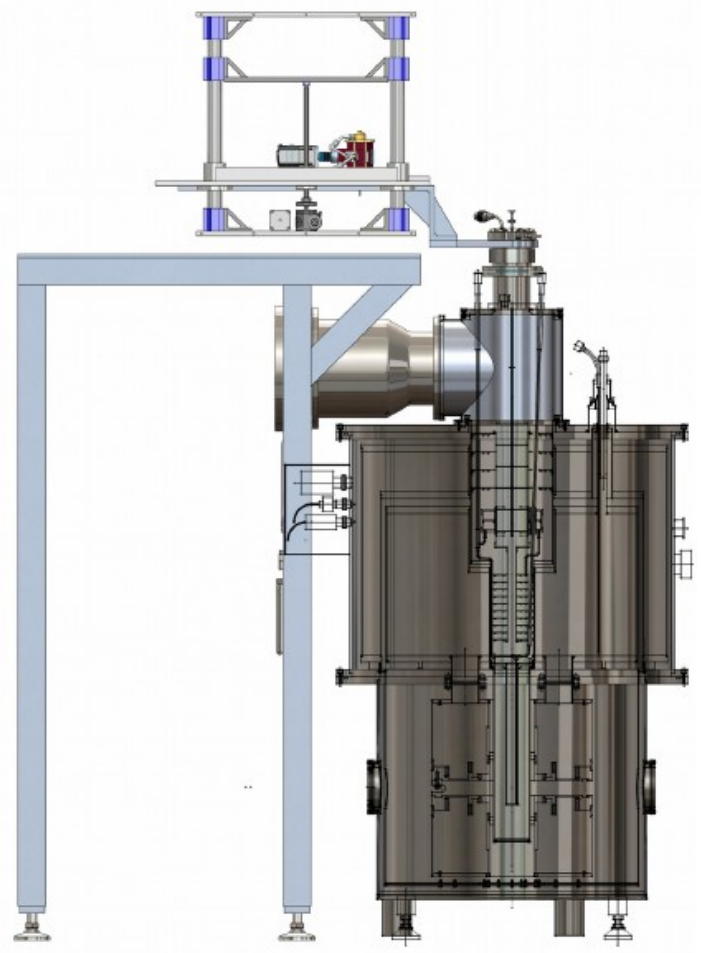
Microwave Generator Setup



- 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



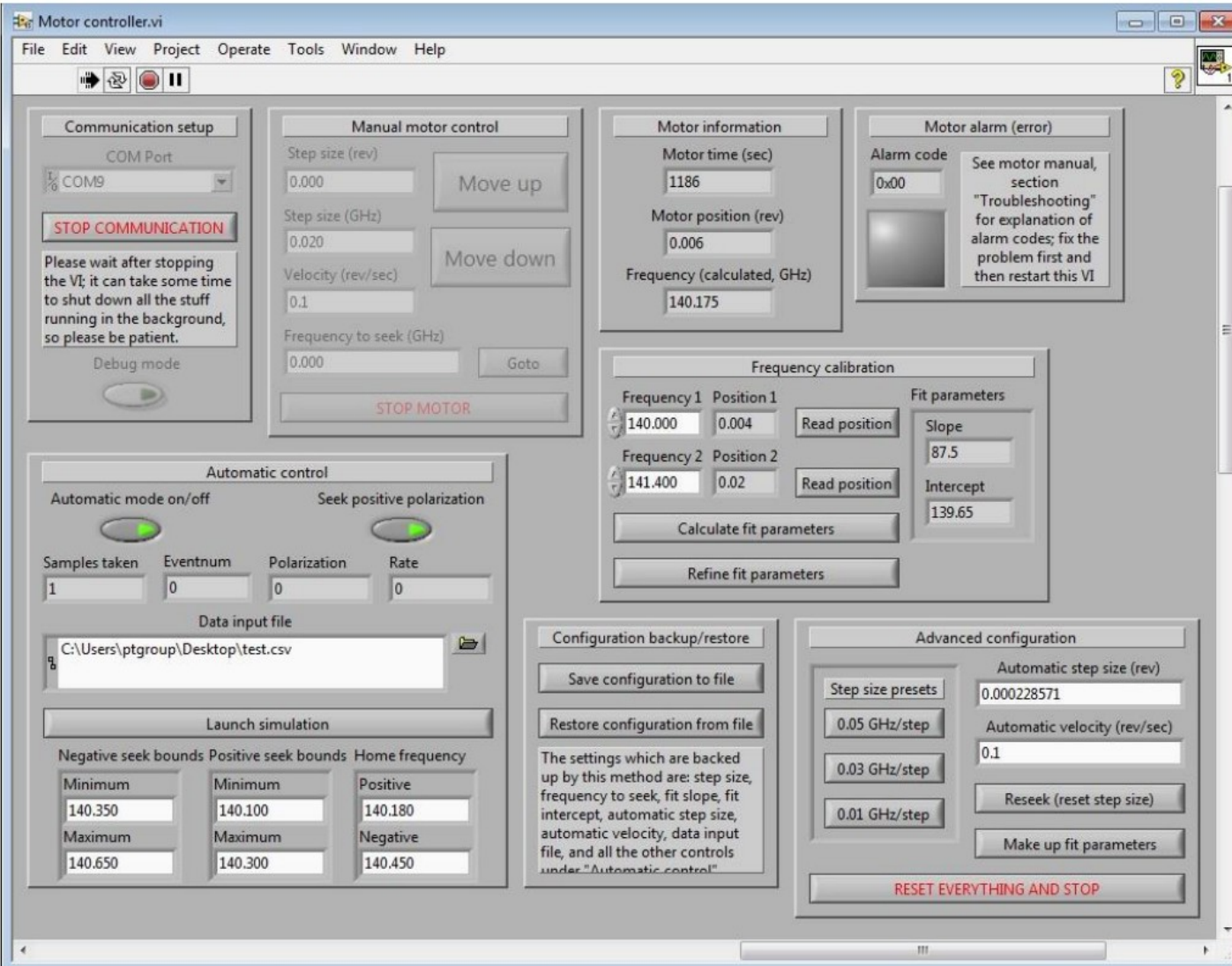
Motor Control

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.

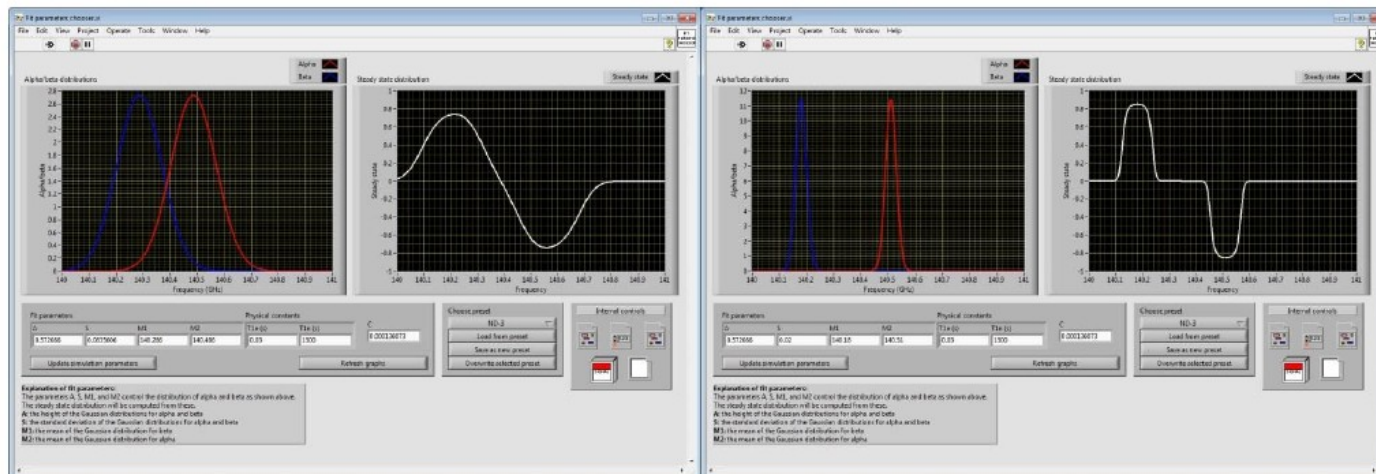
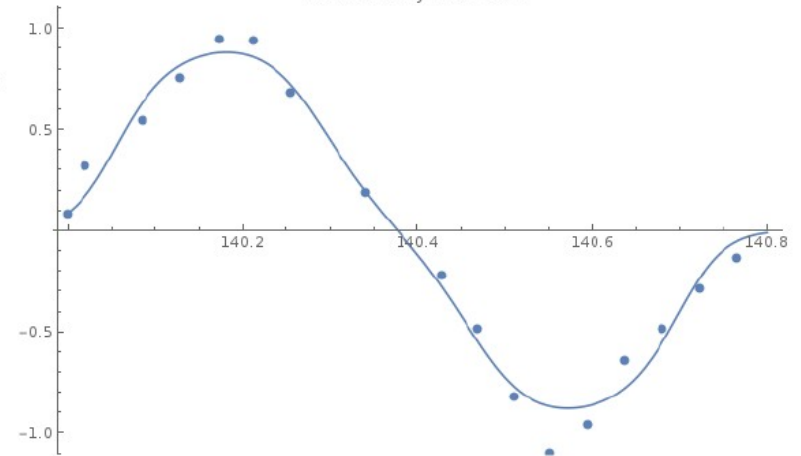
Can be run in real time experiment or in simulation mode.



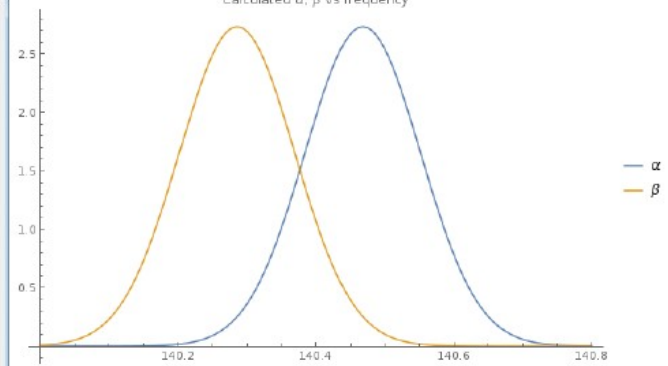
Simulation

- 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

Actual steady state vs fit



Calculated α , β vs frequency



Simulation

Advanced parameters (physical constants and debugging)

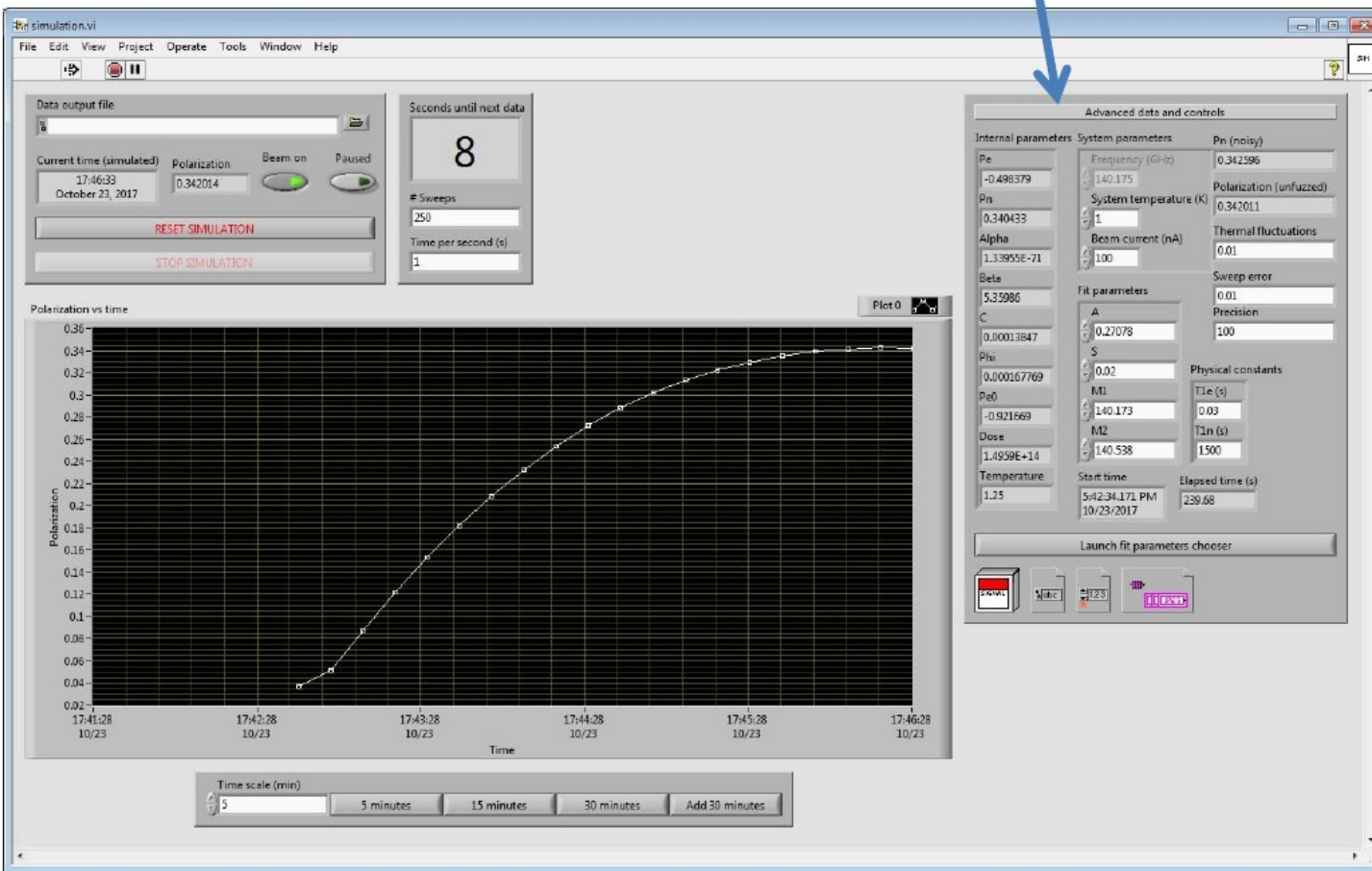
This is the main microwave simulation controller VI.

Can be started through main controller VI.

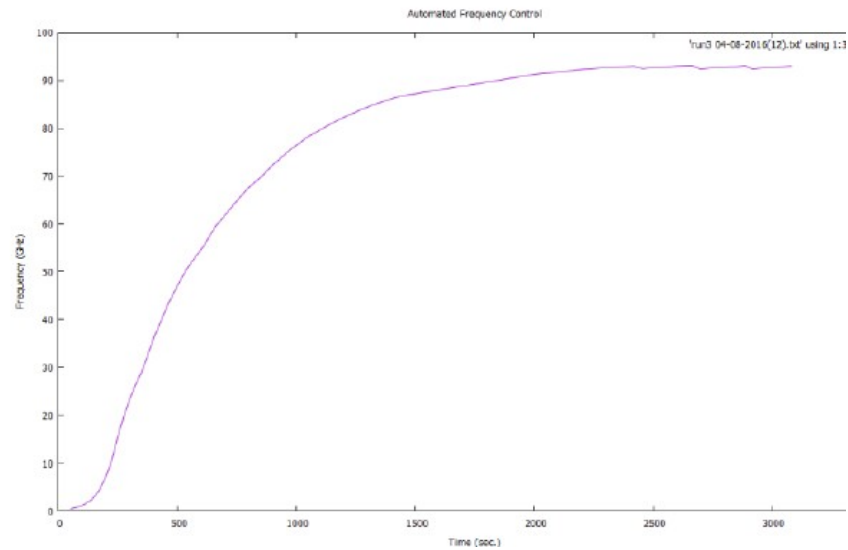
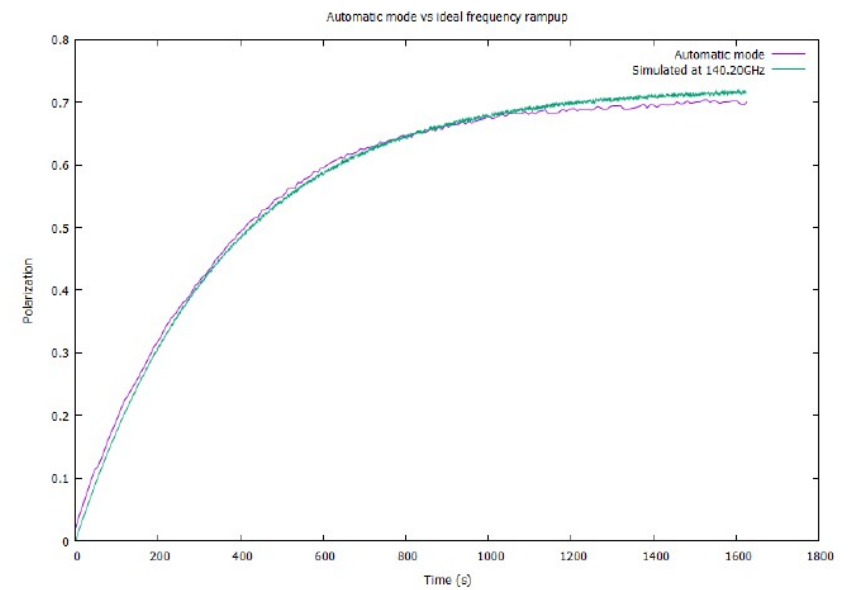
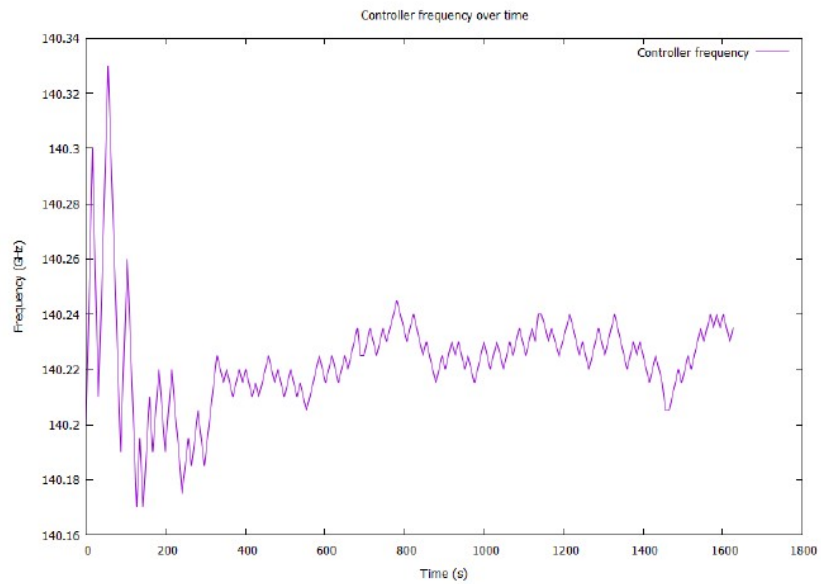
Can change many parameters and run for different material.

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

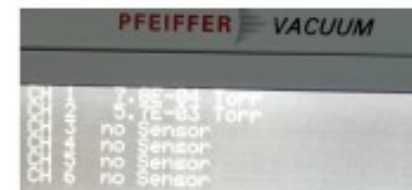
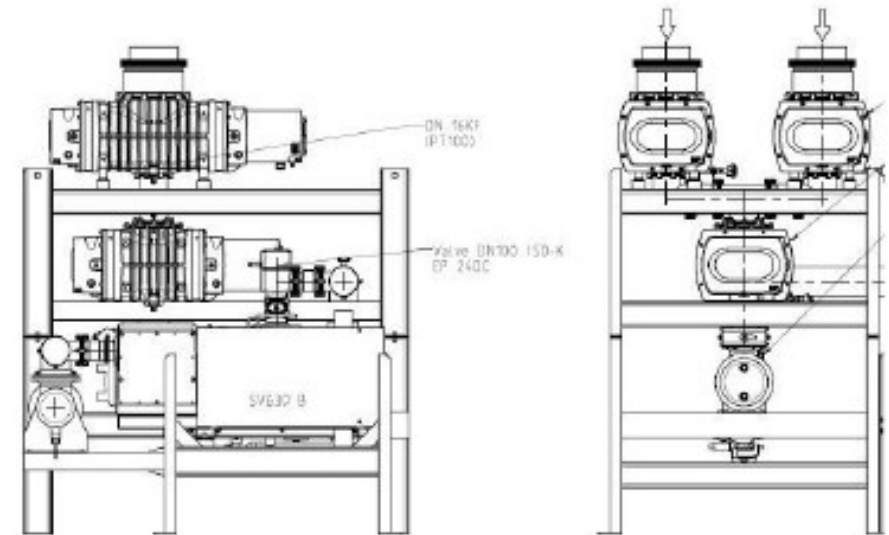
target heat load $\sim 1.4\text{W}$

μ -wave: $\sim 1\text{W}$, beam: $\sim 0.37\text{W}$

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

Magnet

Fridge

Insert

NMR

Microwave

Pumps

Target material

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)

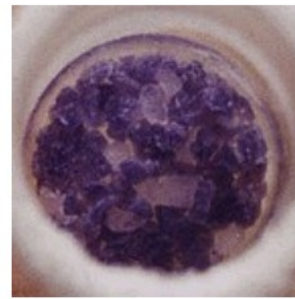
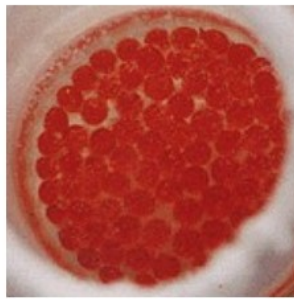
time consuming, trained manpower

~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, ${}^7\text{LiH}$
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, ${}^6\text{LiH}$
Dil. Factor (%)	23.8	30.0	50.0
Polarization (%)	40	50	55

Rad. Resistance

moderate

high

very high

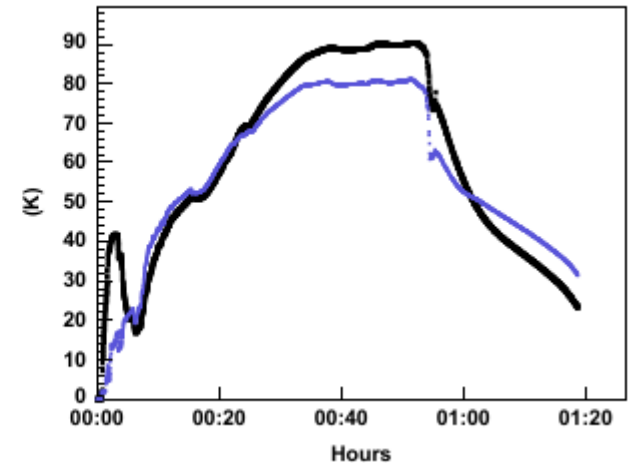
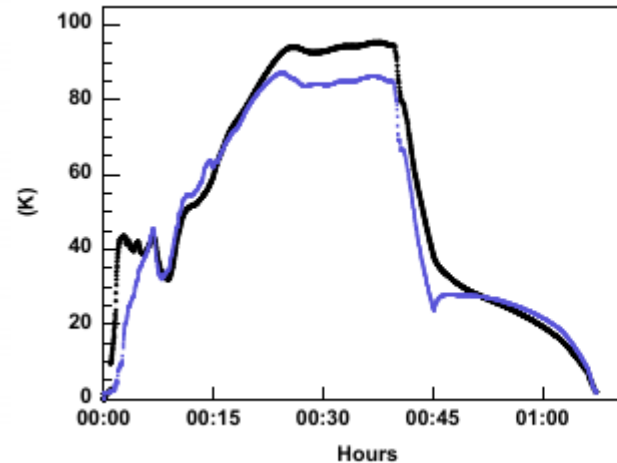
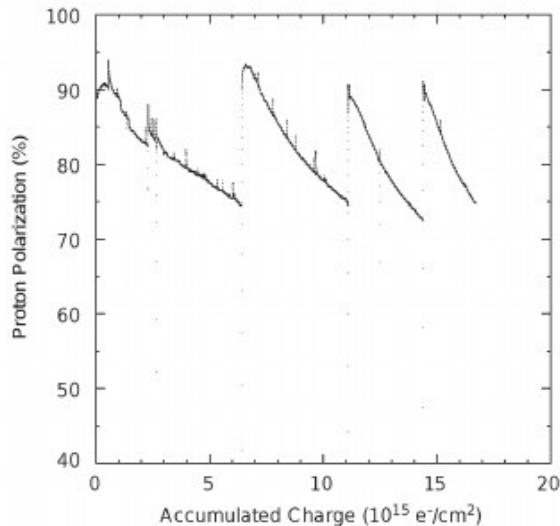
Comments

Easy to produce and handle

Works well at 5T/1K

Slow polarization, but long T_1

Radiation Damage and Recovery



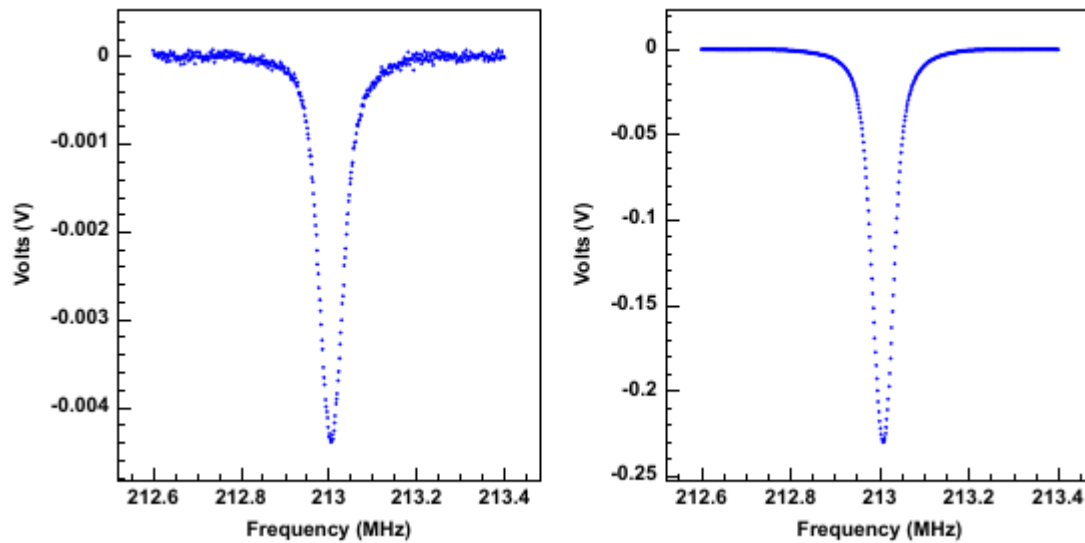
- Maximum Polarization decays as a function of dose
- Heat material (Anneal) to allow radicals to recombine
- Done by heat wire around target cell raising to 80-100K for 20-60 minutes
- Needed at 4Pprotons/cm² (about every shift)
- Once exhausted (40 Pprotons/cm²) need target material replacement

Sources of Uncertainty in Polarization

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

Polarization Calibration and Measurement

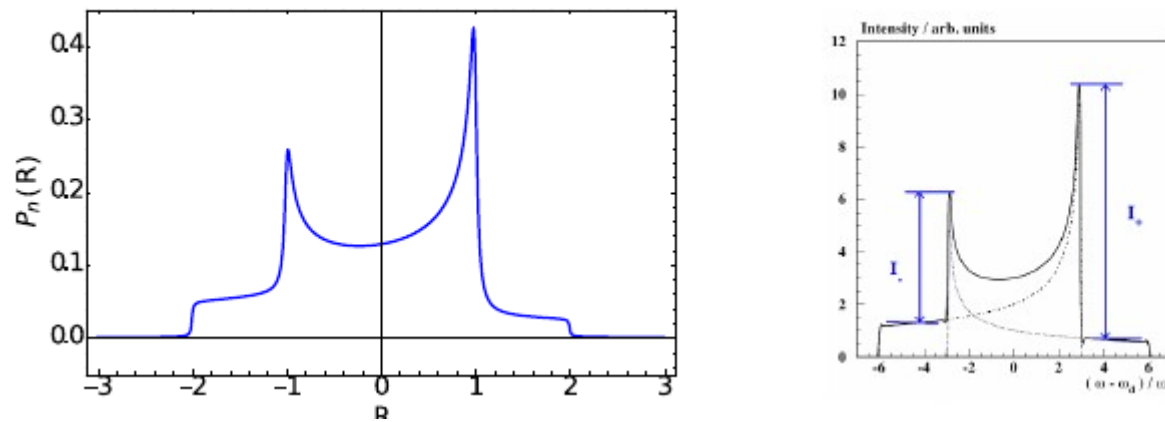
~0.3%



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

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

Uncertainty in Polarization

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

$$P_E = G \frac{\int S_E(\omega) d\omega}{\int S_{TE}(\omega) d\omega} P_{TE} = GC_{TE}A_E$$

$$C_{TE} = \frac{P_{TE}}{A_{TE}}$$

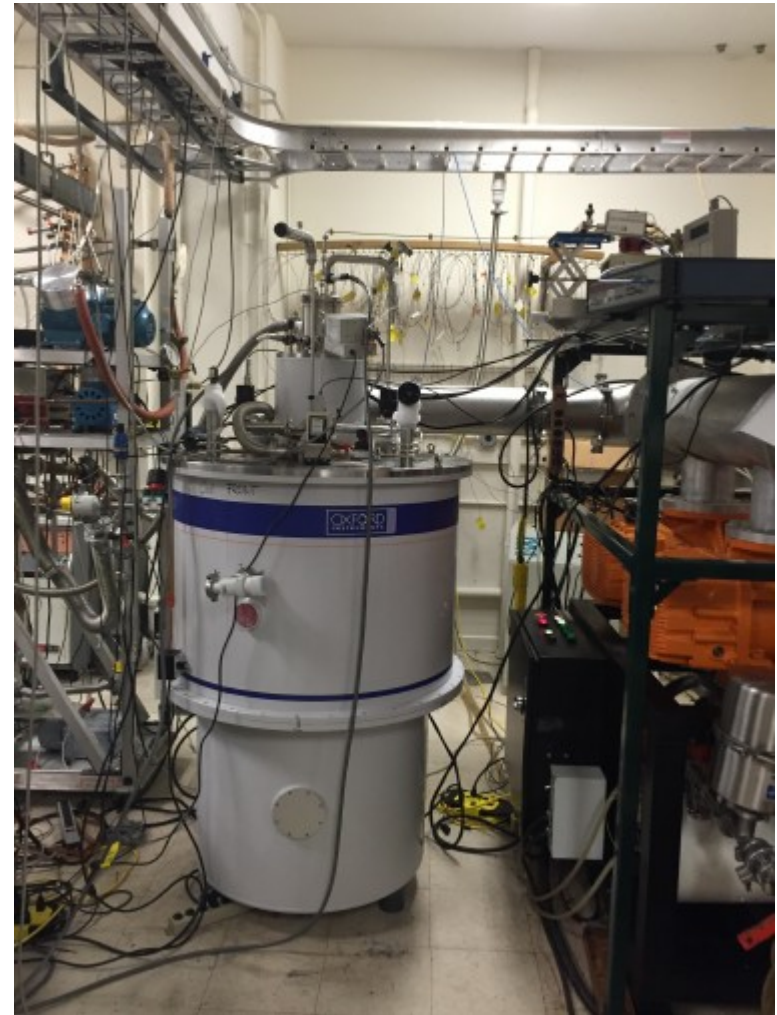
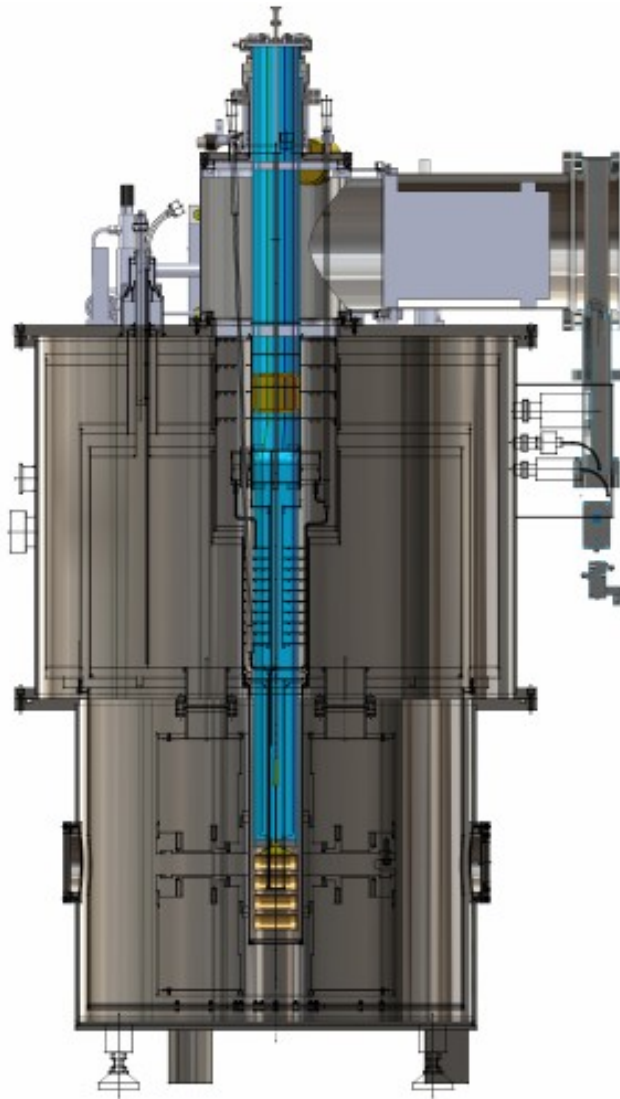
Procedural errors
can be to be pretty small:
Assuming the right procedure
(Target is thermalized to TE)

(#)	Type	Source	Error (%)
(1)	S_{TE}	ΔT	1.45
(2)	A_{TE}	ΔA_{TE}	1.61
(3)	A_{TE}	ΔA_{fit}	0.75
(4)	S_E	R_B	0.50
(5)	S_E	ΔV_Q	0.75
(6)	S_E	NMR-tune	0.47
(7)	S_E	ΔB_{drift}	0.25
(8)	G	ΔV_{Yale}	0.10
(9)	-	ΔP_{run}	0.50
		$\Delta P/P$	2.60

(Temp/pressure measurements)
(area measurements)
(background subtraction)
(setability)
(NMR temp sensitivity)
(NMR tune and tune drifts)
(Charge averaging)

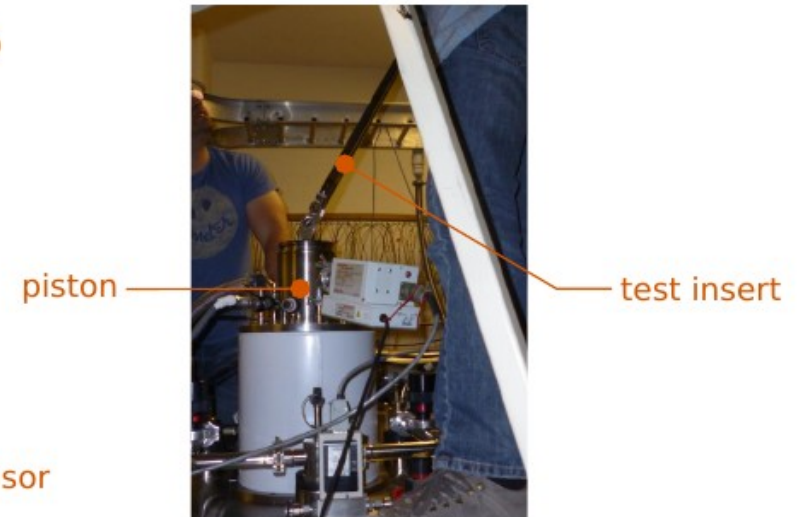
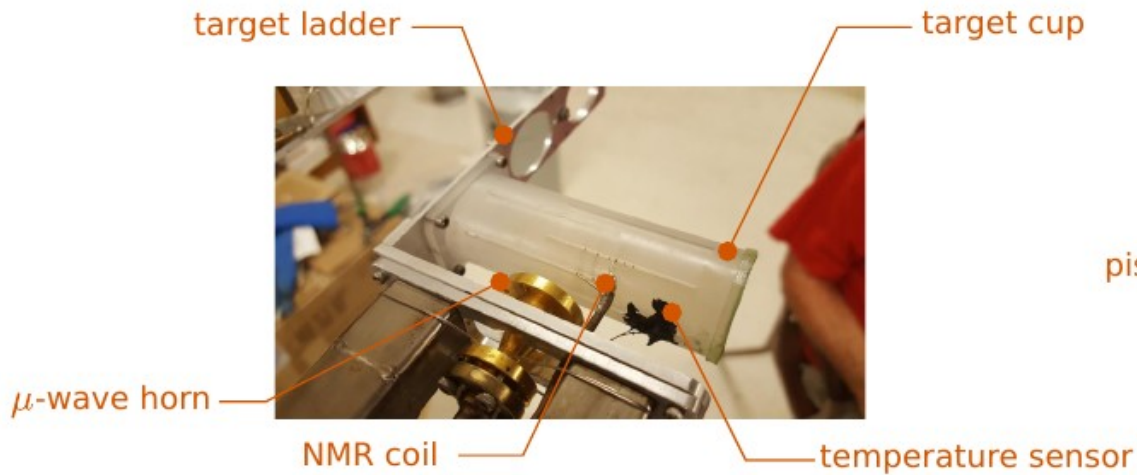
$$\frac{\delta P_E}{P_E} = \left[\left(\frac{\delta G}{G}\right)^2 + \left(\frac{\delta P_{TE}}{P_{TE}}\right)^2 + \left(\frac{\delta A_{TE}}{A_{TE}}\right)^2 + \left(\frac{\delta A_E}{A_E}\right)^2 + \left(\frac{\delta S_{TE}}{S_{TE}}\right)^2 + \left(\frac{\delta S_E}{S_E}\right)^2 \right]^{1/2}$$

Full System

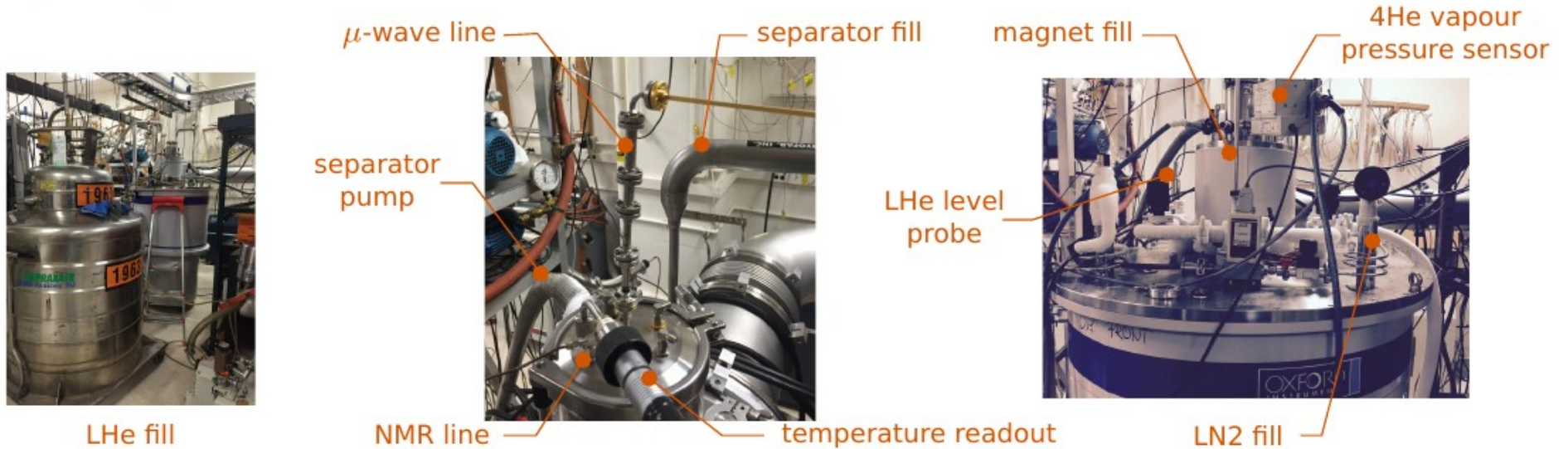


Test Full System

Final preparations and run
made test target insert, practiced installation

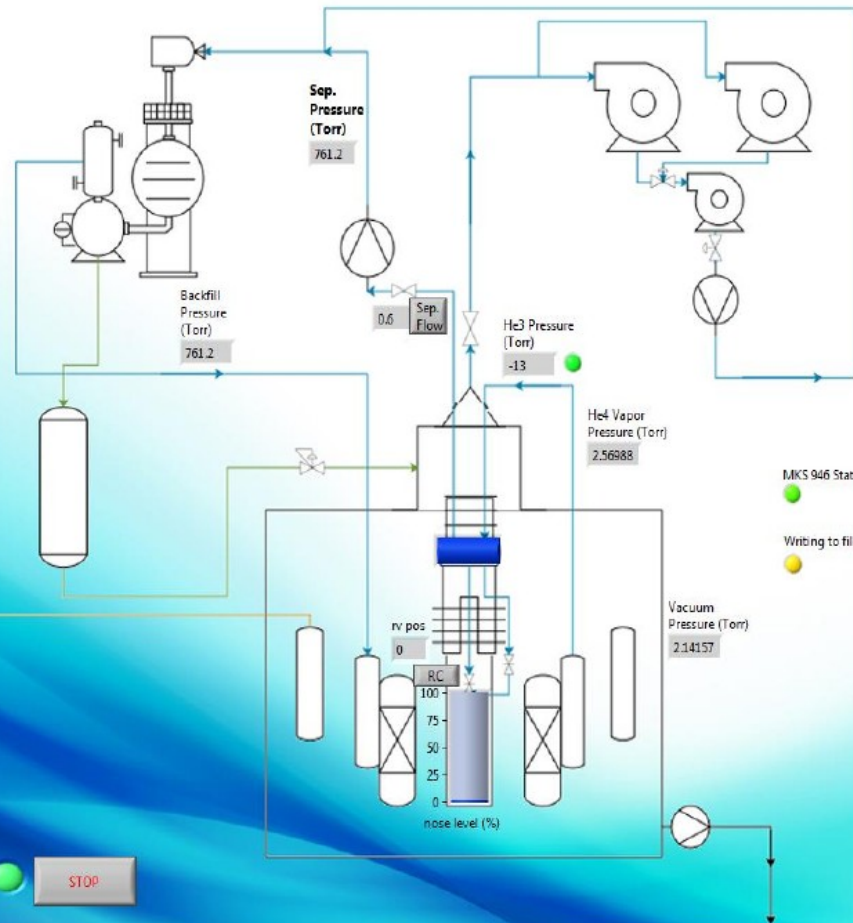


getting cold



The main cryocontrol VI

CryoControls



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

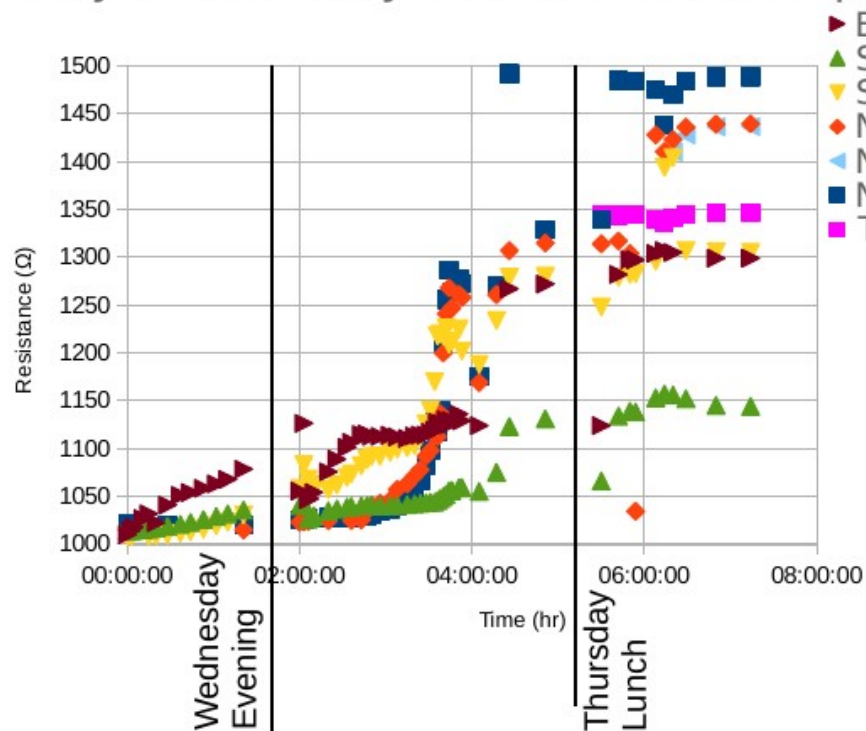
Test results

Fridge performance

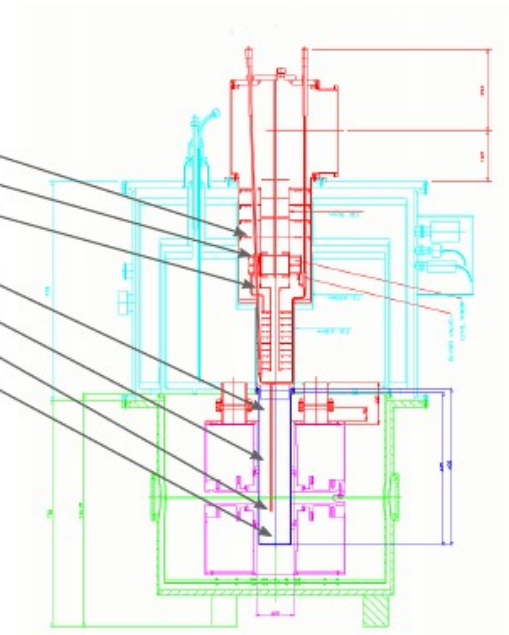
separator and nose fill

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

very stable, very little attention required

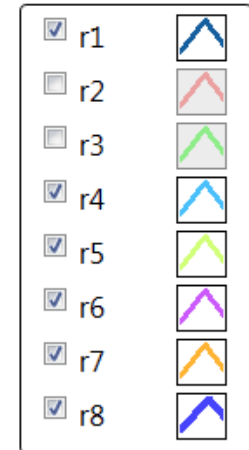
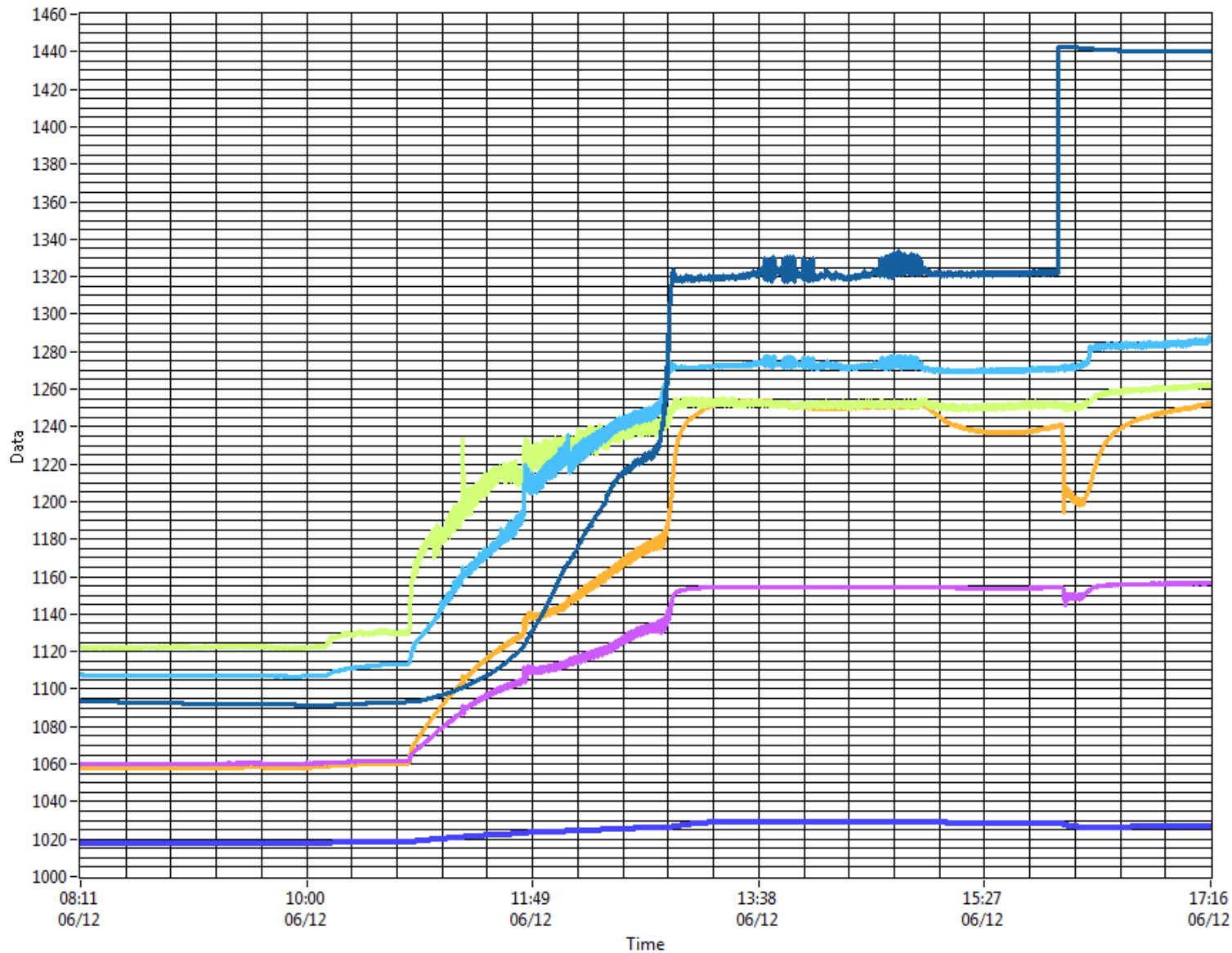


- ▶ Baffle Bot
- ▲ Sep Top
- ▼ Sep Bot
- ◆ Nose Top
- ◀ Nose Mid
- Nose Bot
- Target Cup



Fridge Sensors

Sensor data



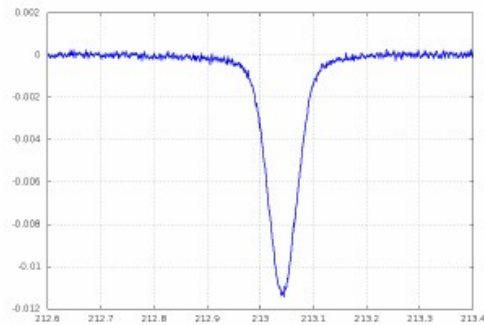
- 8: Upper Top HX
- 7: Upper Bot HX
- 6: Top Separator
- 5: Mid Separator
- 4: Top Lower HX
- 1: Bot Lower HX

Results of All the Work

Test results

Polarization

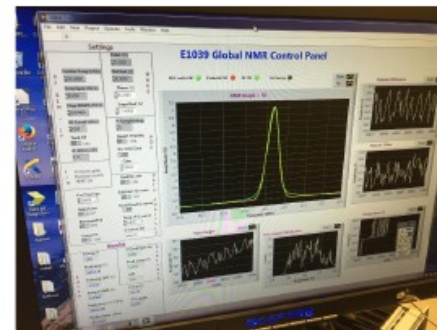
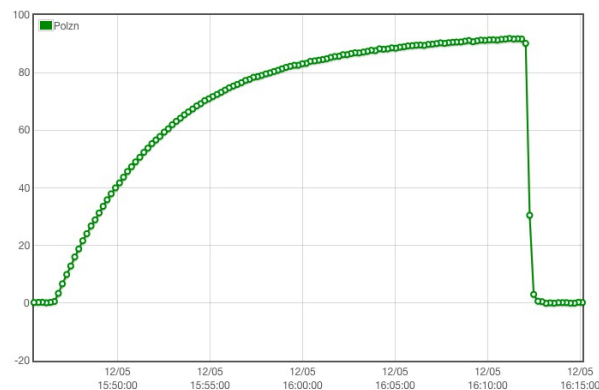
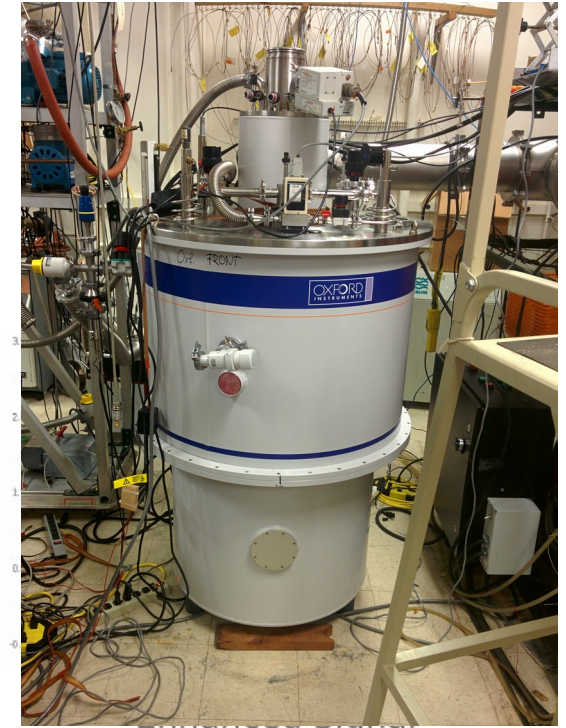
polarized fresh NH₃ both positively and negatively
took extensive TE measurements
alternated UVA and new LANL NMR systems



Frequency, MHz
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--

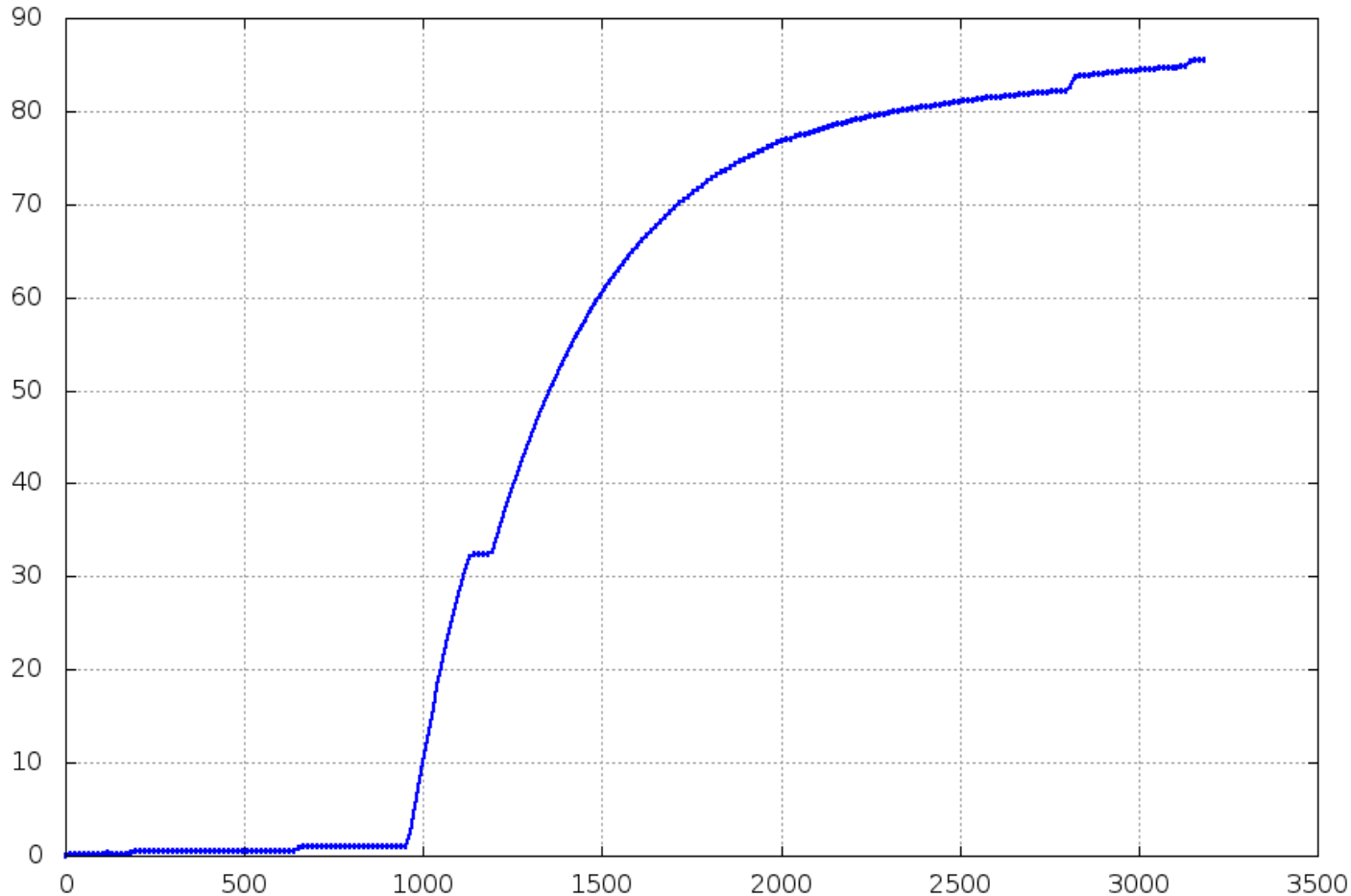
Still to Come

- Secondary pressure/temp sensor (^3He 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 7×10^{-7} tor)

Initial Run: Central Top Coil



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

Still to Come

- Secondary pressure/temp sensor calibration (^3He 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

SOLID POLARIZED TARGET GROUP *at the* UNIVERSITY OF VIRGINIA

- RESEARCH
- EXPERIMENTS
- PEOPLE
- GROUP THESES AND TECHNICAL NOTES
- TOOLS
- GROUP HOSTED WORKSHOPS
- POLARIZED TARGET GROUPS
- WORK LINKS
- UNDERGRADUATE JOB OPPORTUNITIES
- VIDEOS
- STORAGE DEWARs



Our research program is at the forefront of the studies of the fundamental properties of the nucleons, i.e. the proton and neutron, which are the two building blocks of the atomic nucleus. The interactions of quarks and gluons, the underlying constituents of strongly interacting matter, are well described by the basic theory, Quantum Chromodynamics (QCD). However, the way in which quarks and gluons are confined within the nucleons and the mesons (responsible for nuclear forces), is poorly understood in QCD.

We concentrate on experiments that use spin degrees of freedom (i.e. using polarized targets and beams) in electron-nucleon/nucleus interactions to extract new information about the properties of these fundamental building blocks of nature and lend new insights into these basic and longstanding problems. We are unique among university based research groups as we have the capabilities of developing, building and maintaining the cryogenic polarized targets critical for this research which is carried out at the Jefferson Lab whose unique capabilities make this research possible.

Drell-Yan Polarized Target System

The polarized target system to be used in E1039 is a high cooling power fridge connected to a large pump stack (14,000 m³/hour) and a microwave generator used to dynamically polarize the nucleons in the target. The magnet has a 5 T field with a homogeneous region of 6 cm and will be used to polarize protons and neutrons in the sample.



Here the target system is shown our polarized target lab where the system is setup of testing and optimization. Solid polarized target experiments are demanding and require of team of well trained polarized target expert in order for the experiment to run smoothly.

Main Pages and Important Links

- E1039 Polarized Target Wiki
- UVA Collab Utilities
- Fermilab E996/E1039 docdb
- Fermilab E996/E1039 software
- Fermilab MCR logbook
- Fermilab Machine logbooks
- Fermilab External Beams logbook

Drell-Yan Work Dir

Drell-Yan Meetings

At this time have the following working group meetings for E1039 (All US Eastern Time):

- o Polarized Target meeting (biweekly on Tuesday at 3PM)
- o Engineering meeting (weekly on Tuesday 4PM)
- o Labview meeting (biweekly on Tuesday 5PM)
- o General biweekly meeting (Tuesday 6PM)
- o Software/Simulations meeting (biweekly Thursday 7PM)

Join from PC, Mac, Linux, IOS or Android

Target Meetings
Meeting ID: 438821341

LabView Meetings
Meeting ID: 705516494

E1098 Target Wiki

Target Tools

NMR Calculator | TE Calculator with Polcalc

NMR Calculator

NMR Calculator | TE Calculator with Polcalc

TE Calculator with Polcalc

TE Wizard

TE Importer:

Start Date and Time:

Number of Events:

(Imports Area and He4Pressure. Date in mm/dd/yyyy hh:mm format. Format must be "Webpage" to import.)

TE Calculator:

Species	Magnetic Field	Column 2	Cell	Output Format
Proton	5.0033	Temperature	Top	Web Page
Deuteron		He3 Pressure	Bottom	Printer
6Li		He4 Pressure		
7Li				
13C				
14N				
15N				
129Xe				
131Xe				
Electron				

Area & Temp/Pressure Data

Input #1	Input #2
Magnet Current (A)	Magnet Current (A)
Current/Field Ratio (A/T)	Current/Field Ratio (A/T)
Field (T)	Field (T)
Proton Frequency (MHz)	Proton Frequency (MHz)
Deuteron Frequency (MHz)	Deuteron Frequency (MHz)
6Li Frequency (MHz)	6Li Frequency (MHz)
7Li Frequency (MHz)	7Li Frequency (MHz)
13C Frequency (MHz)	13C Frequency (MHz)
14N Frequency (MHz)	14N Frequency (MHz)
15N Frequency (MHz)	15N Frequency (MHz)
129Xe Frequency (MHz)	129Xe Frequency (MHz)
131Xe Frequency (MHz)	131Xe Frequency (MHz)
Electron Frequency (MHz)	Electron Frequency (MHz)

Value: Value:

Results

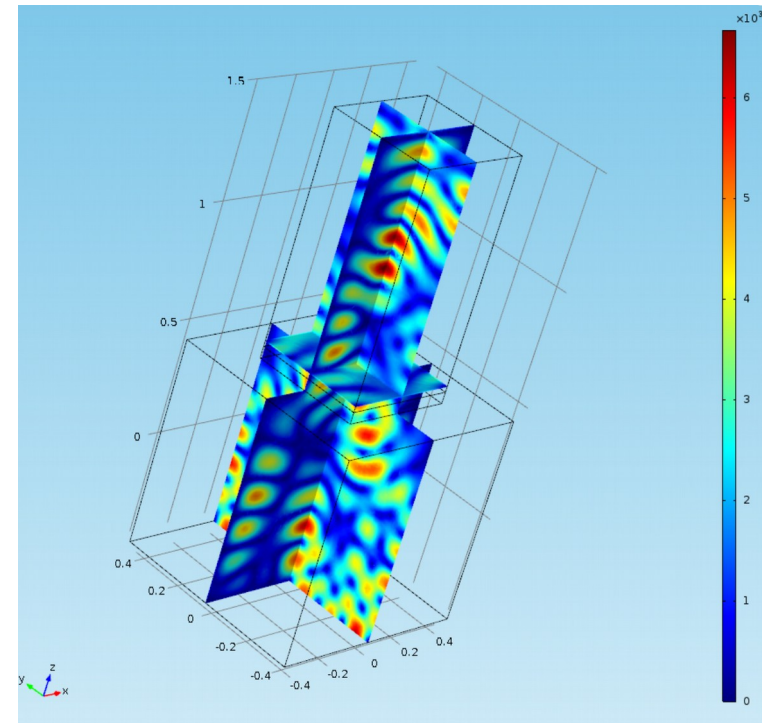
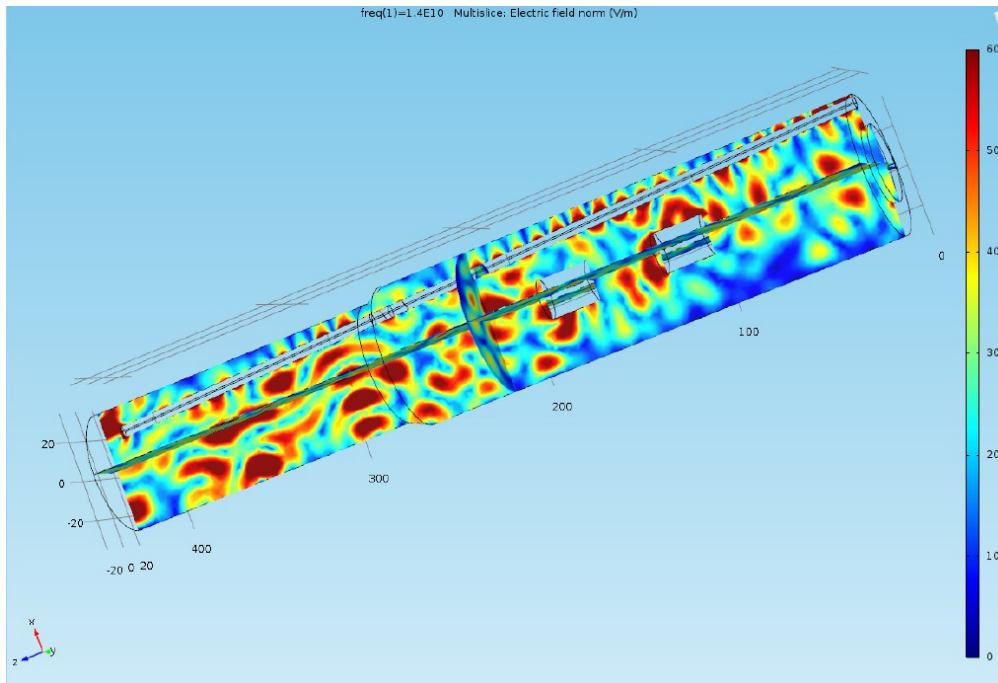
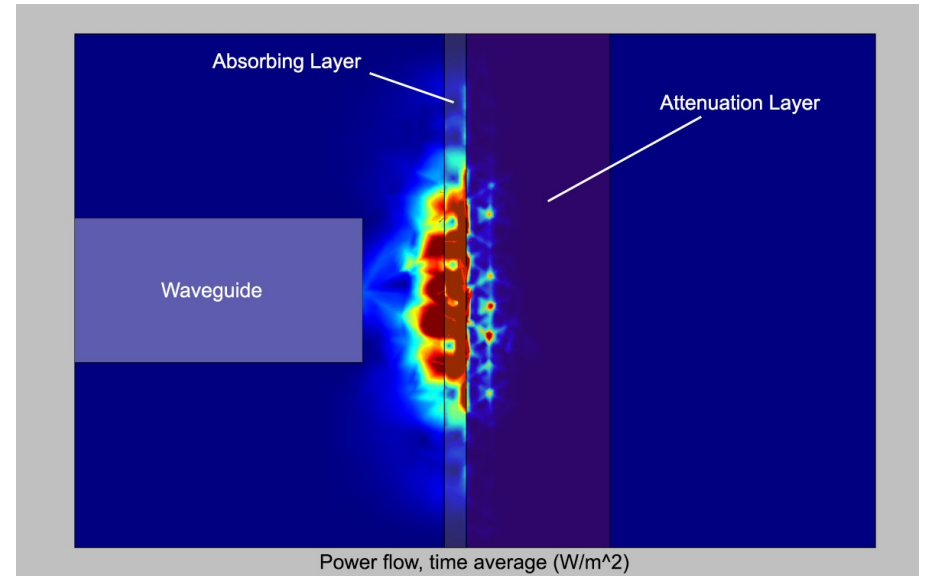
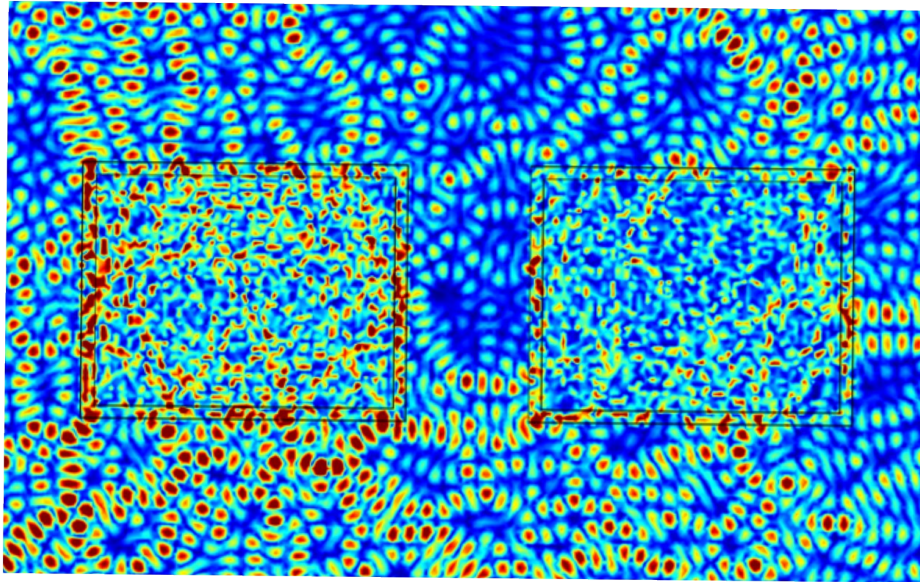
Magnet Field T

Species	Frequency	Lambda/2	External Cable Length				
			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	5918.9 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					

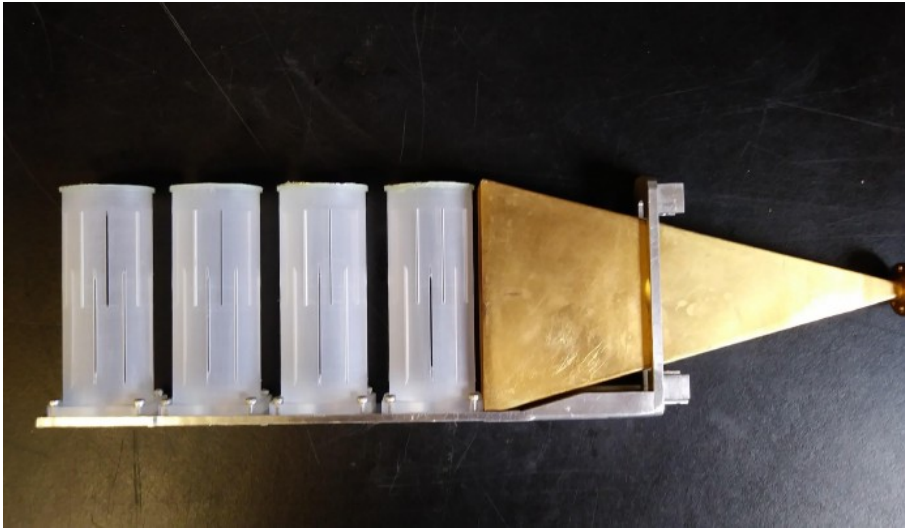
The Solid Polarized Target Group-UVA

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

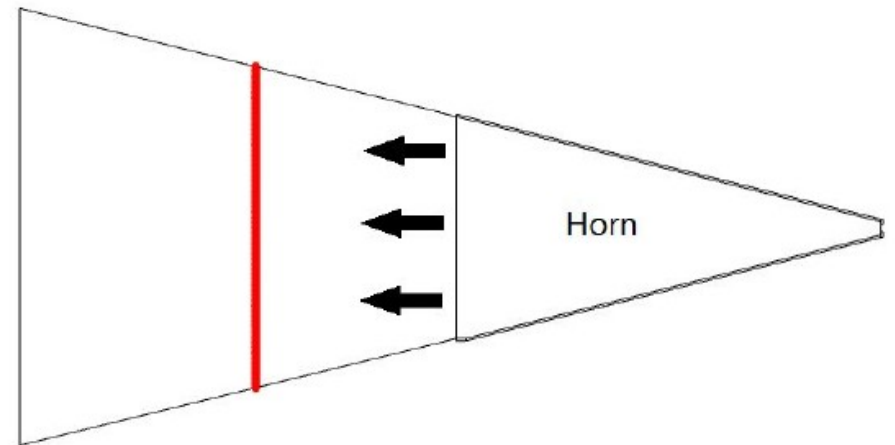
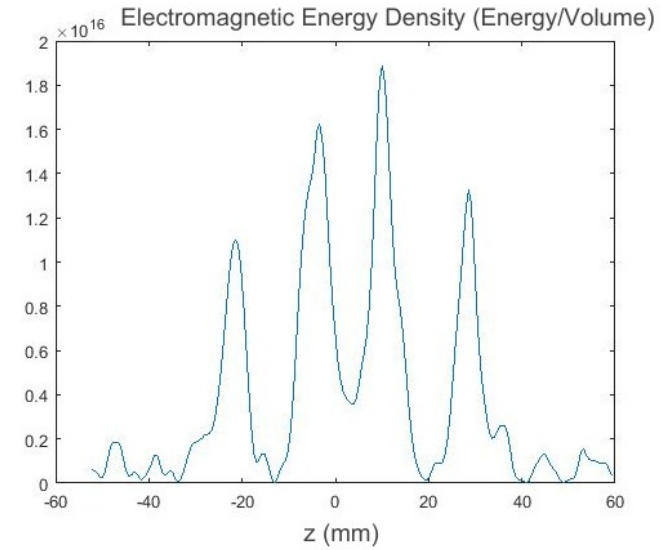
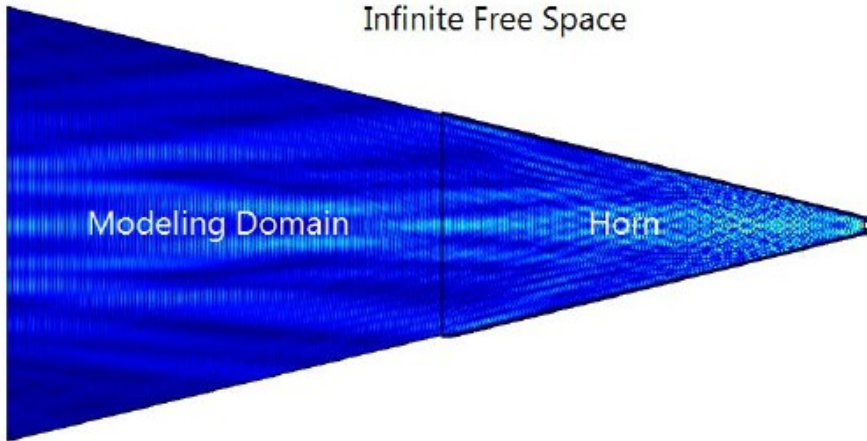
COMSOL Microwave Simulation

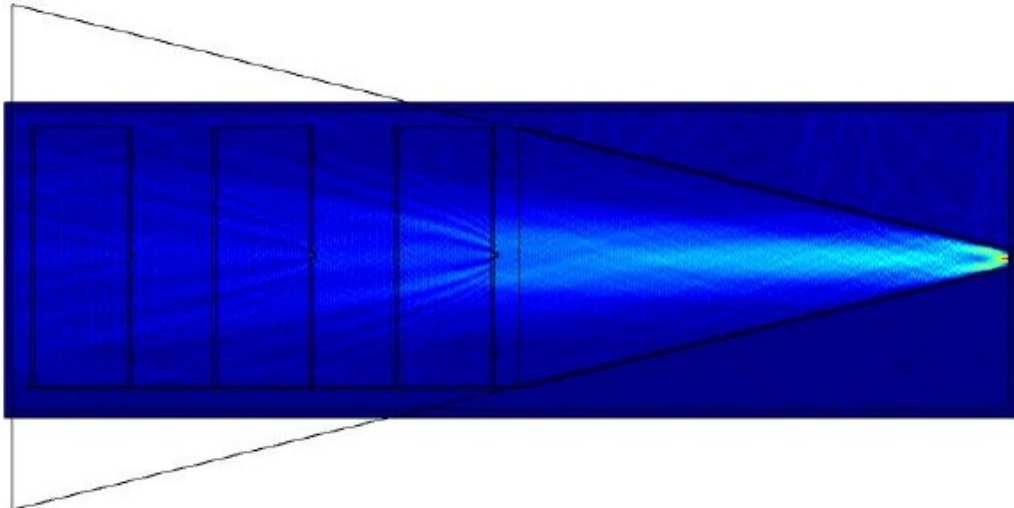
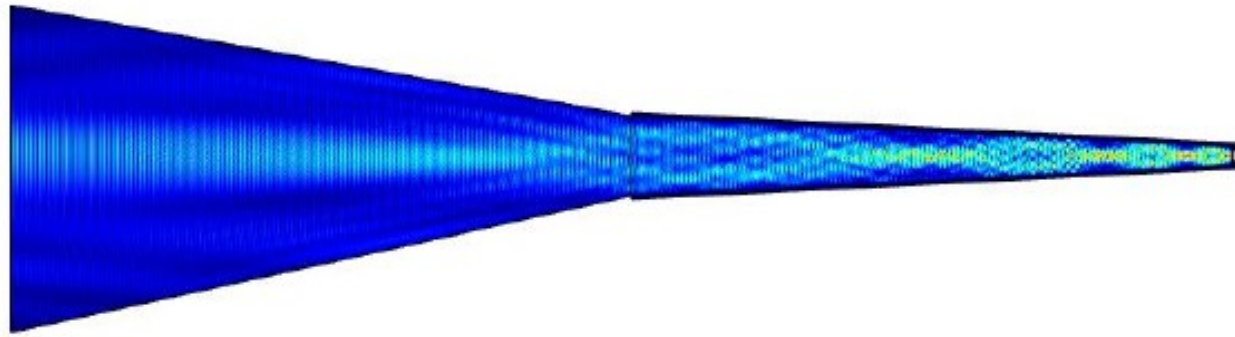


Microwave Profile



Infinite Free Space

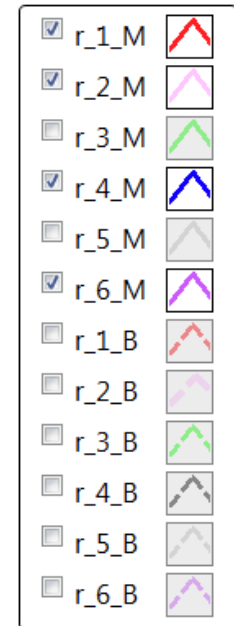
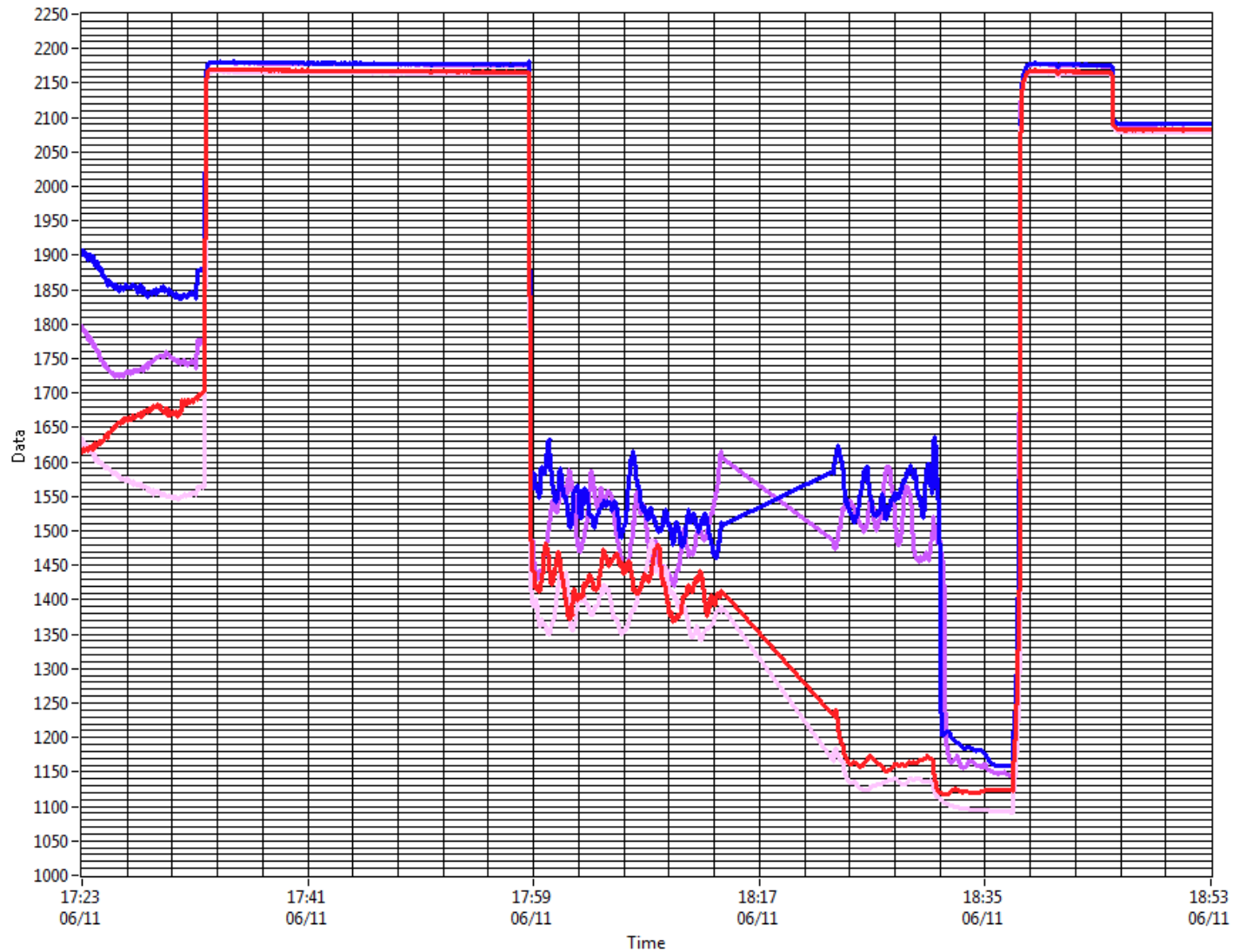




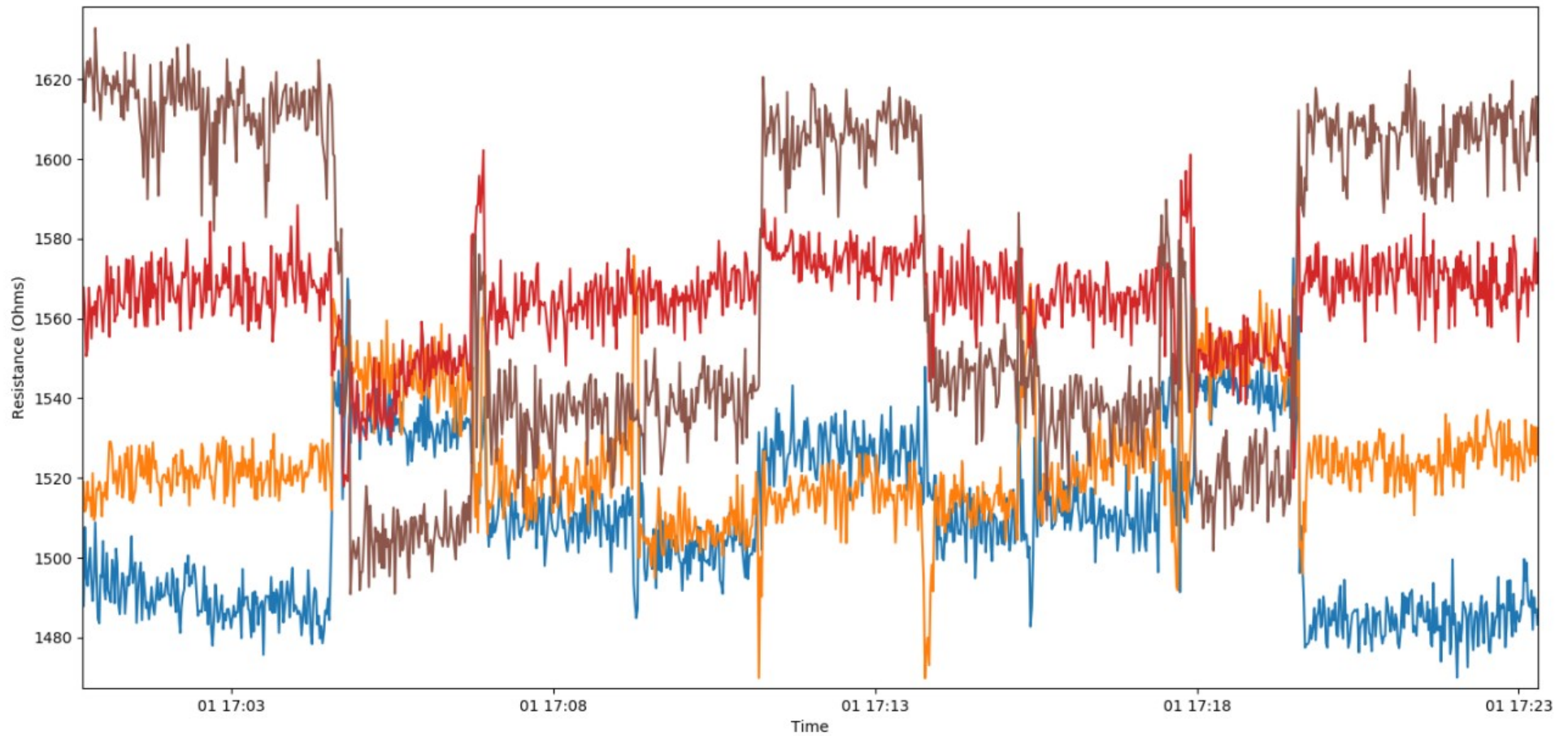
$7.243 \times 10^{-7} \text{ W}$	$1.012 \times 10^{-6} \text{ W}$	$8.026 \times 10^{-7} \text{ W}$
$8.043 \times 10^{-6} \text{ W}$	$2.200 \times 10^{-5} \text{ W}$	$4.518 \times 10^{-5} \text{ W}$
$5.172 \times 10^{-7} \text{ W}$	$1.887 \times 10^{-6} \text{ W}$	$1.056 \times 10^{-6} \text{ W}$

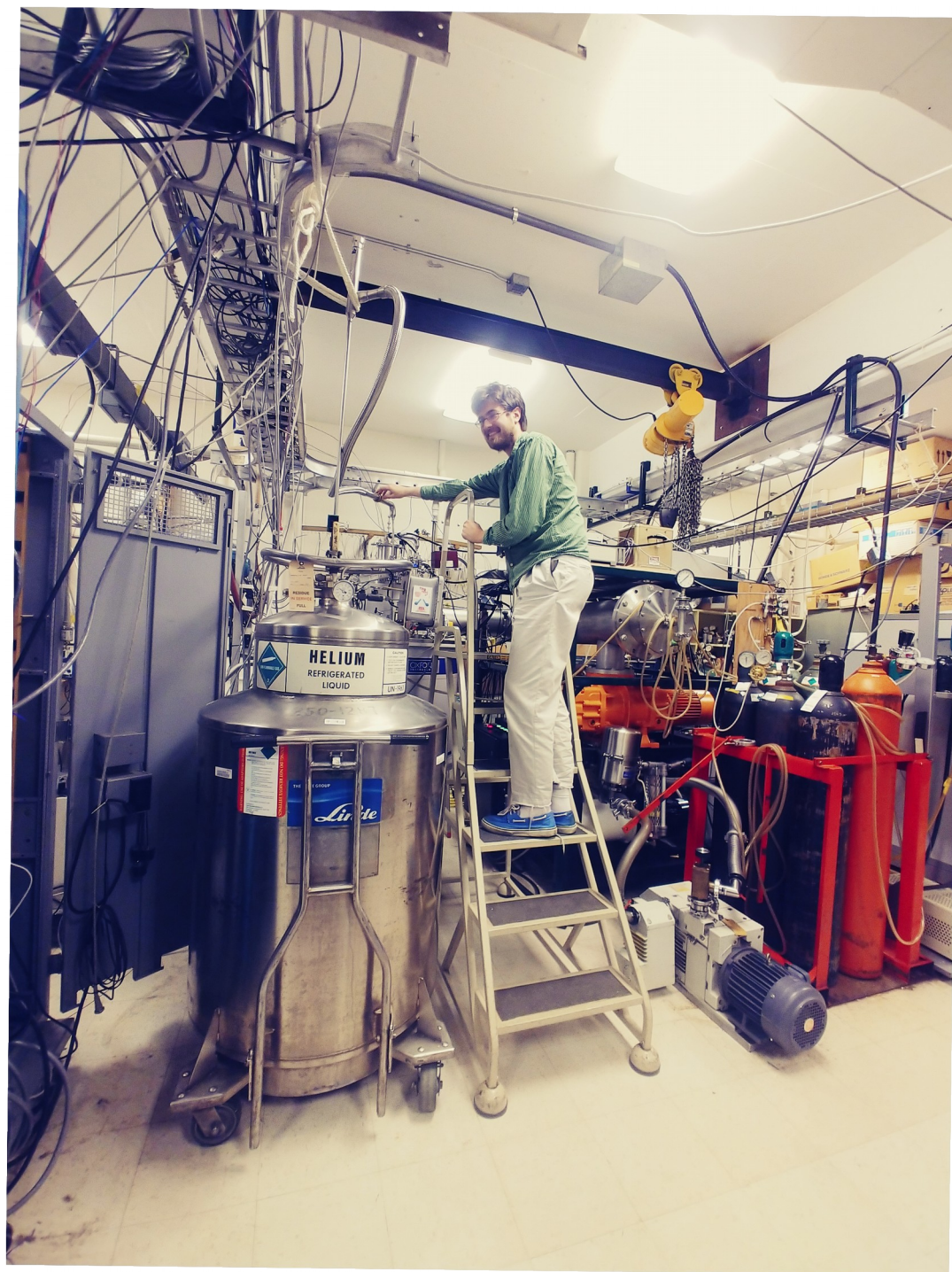
Absorption at Resonance

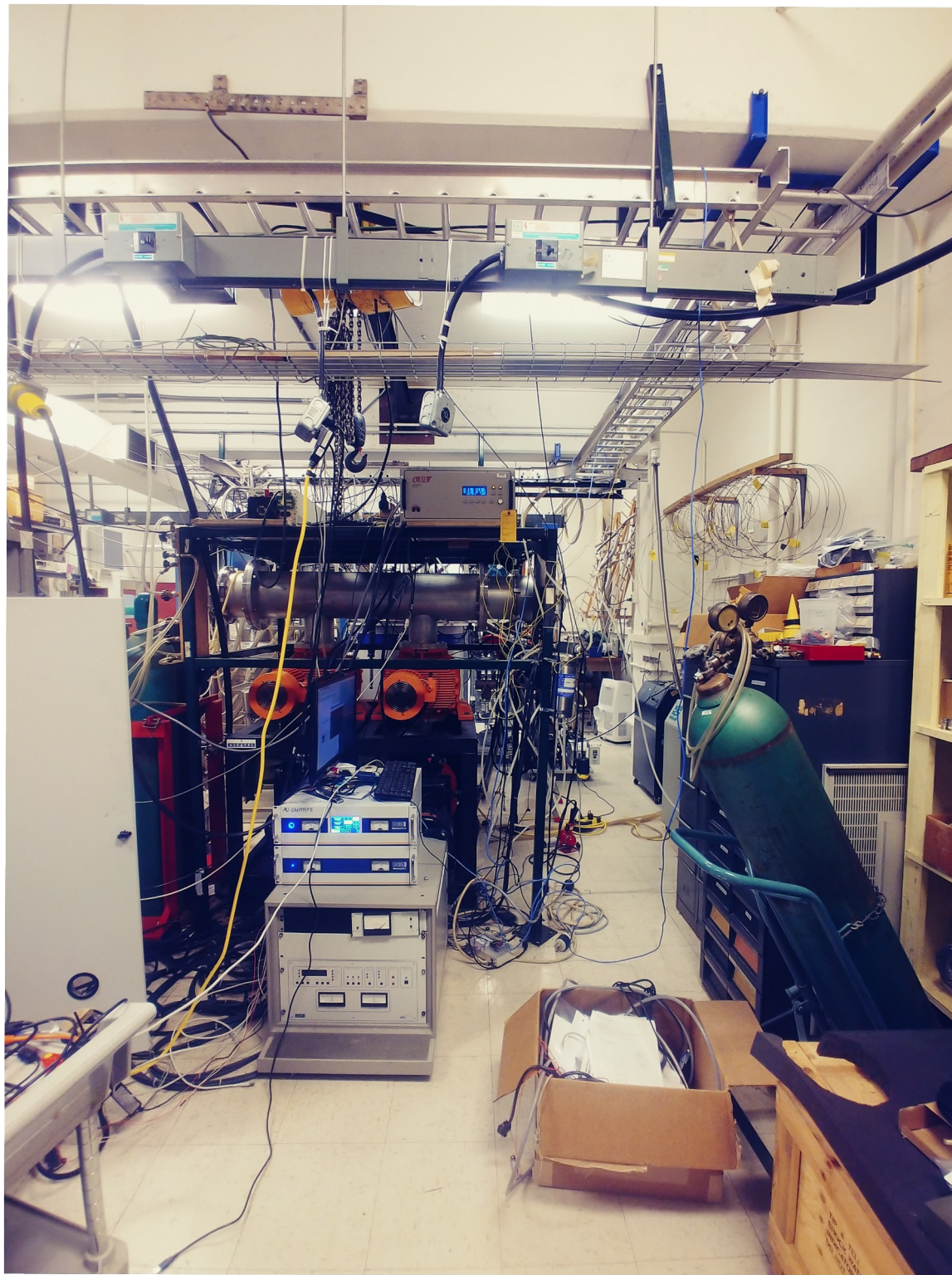
Sensor data

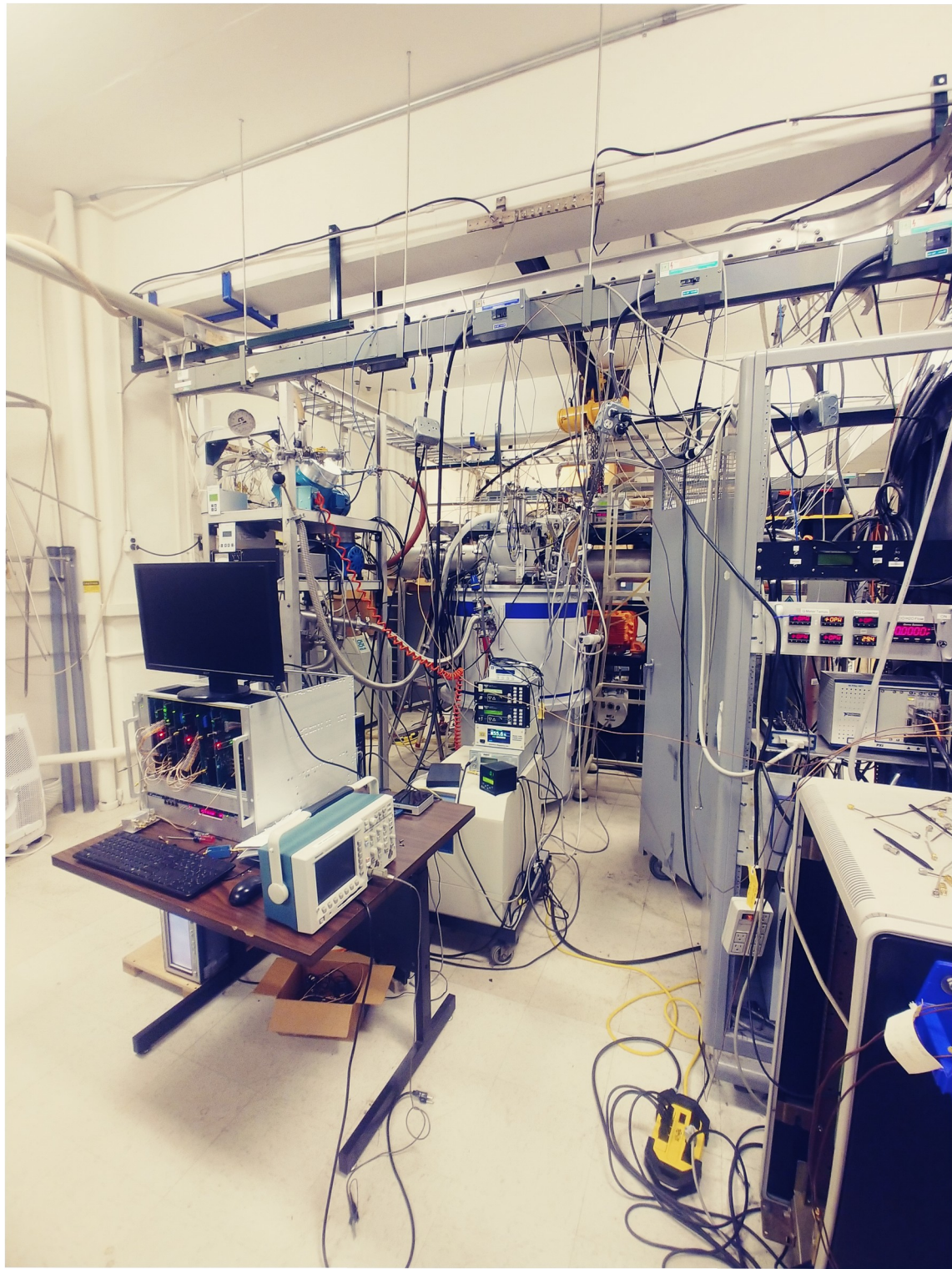


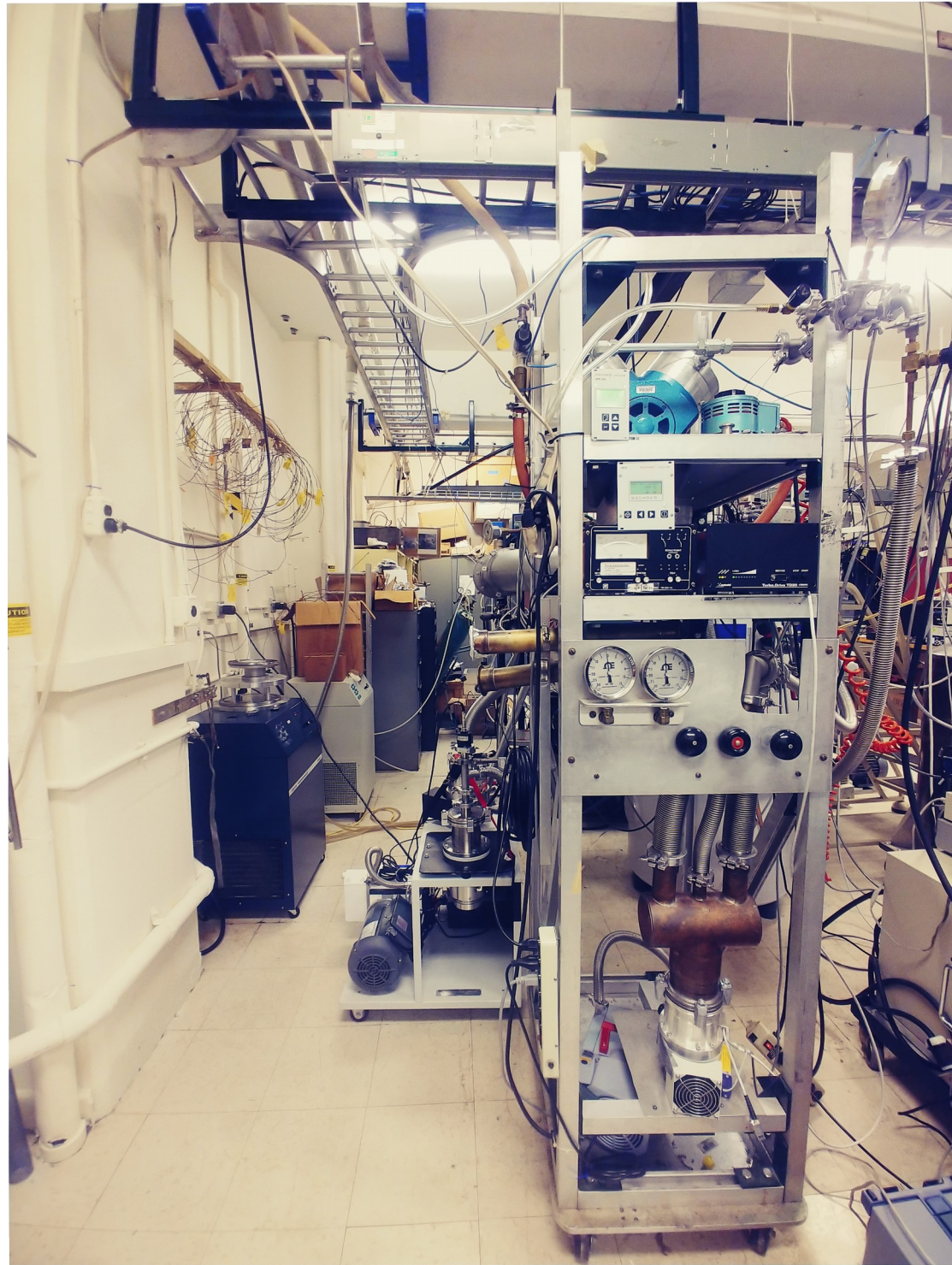
Microwave Studies







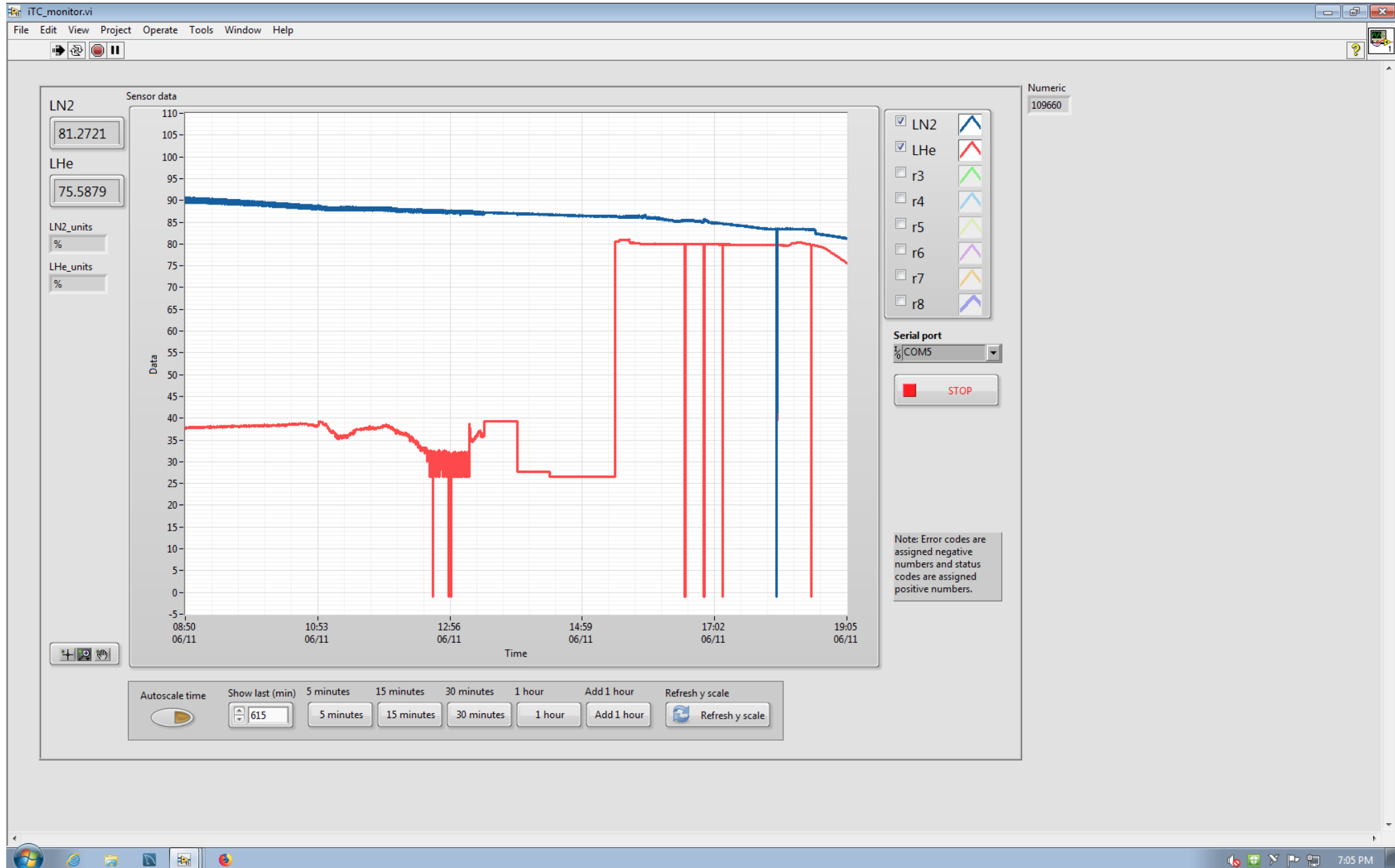




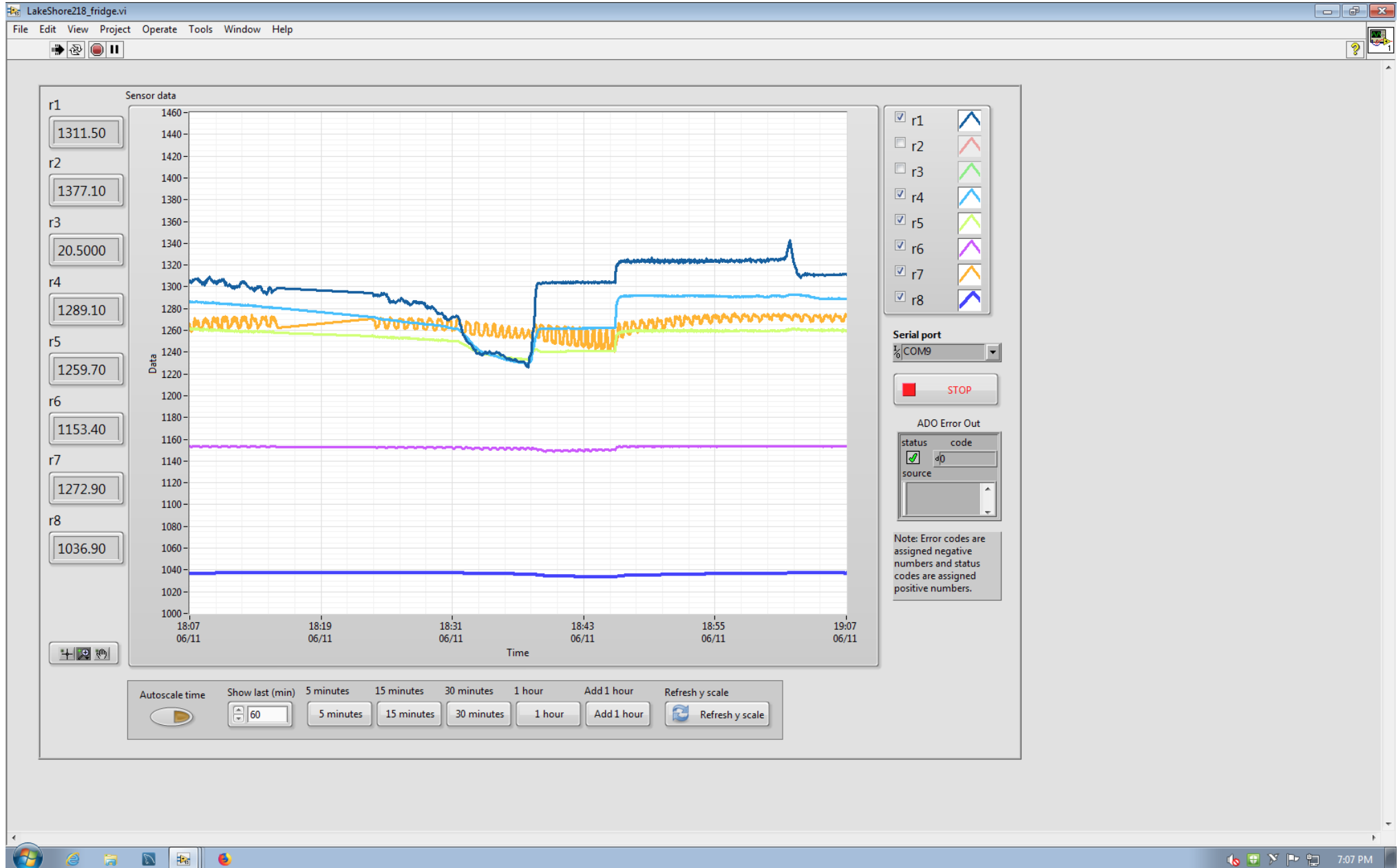
Target Insert Sensors



Liquid Helium and Nitrogen Level



Refrigerator Sensors



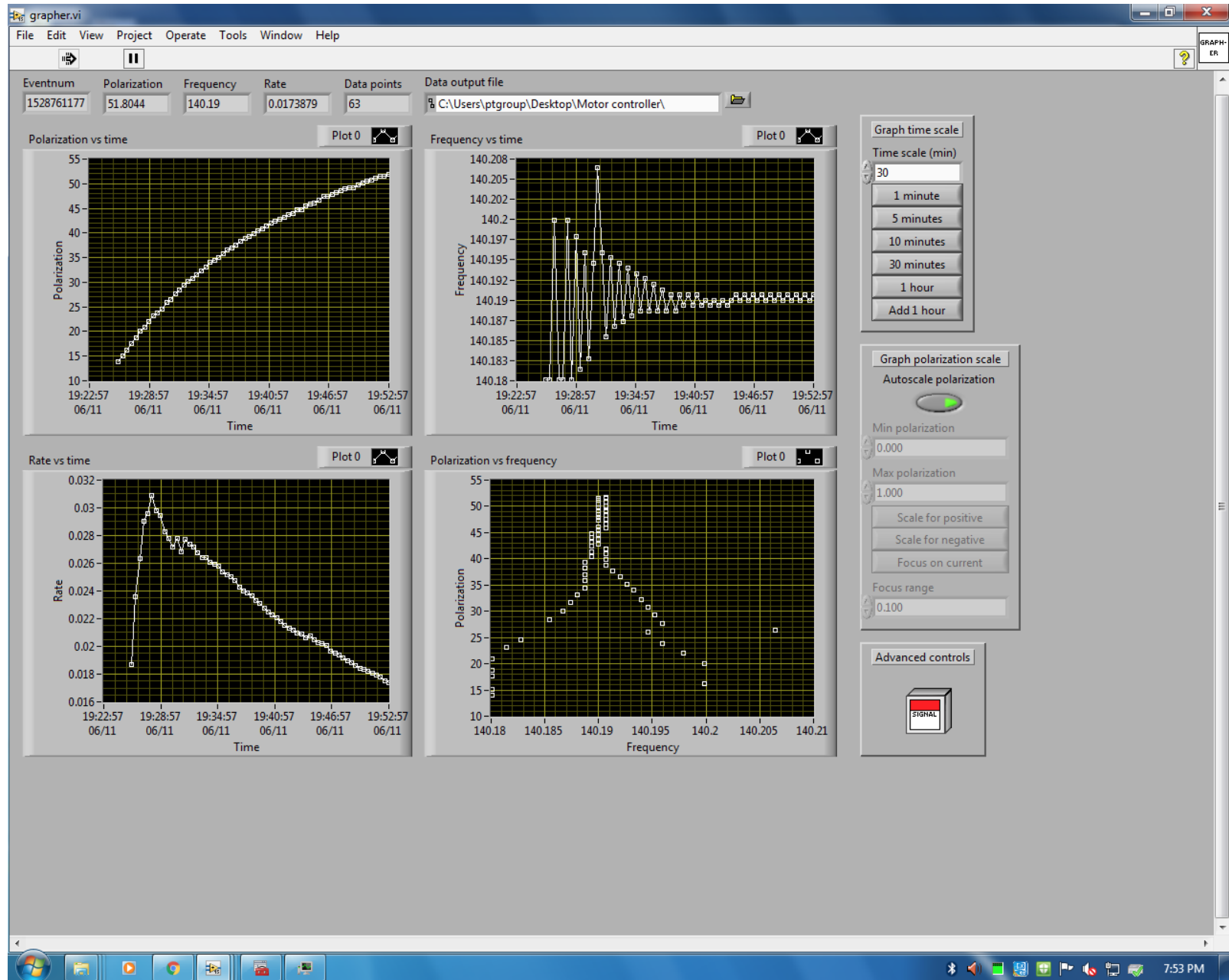
Microwave Control VI

The screenshot displays the 'Motor controller.vi' software interface, which is organized into several functional panels:

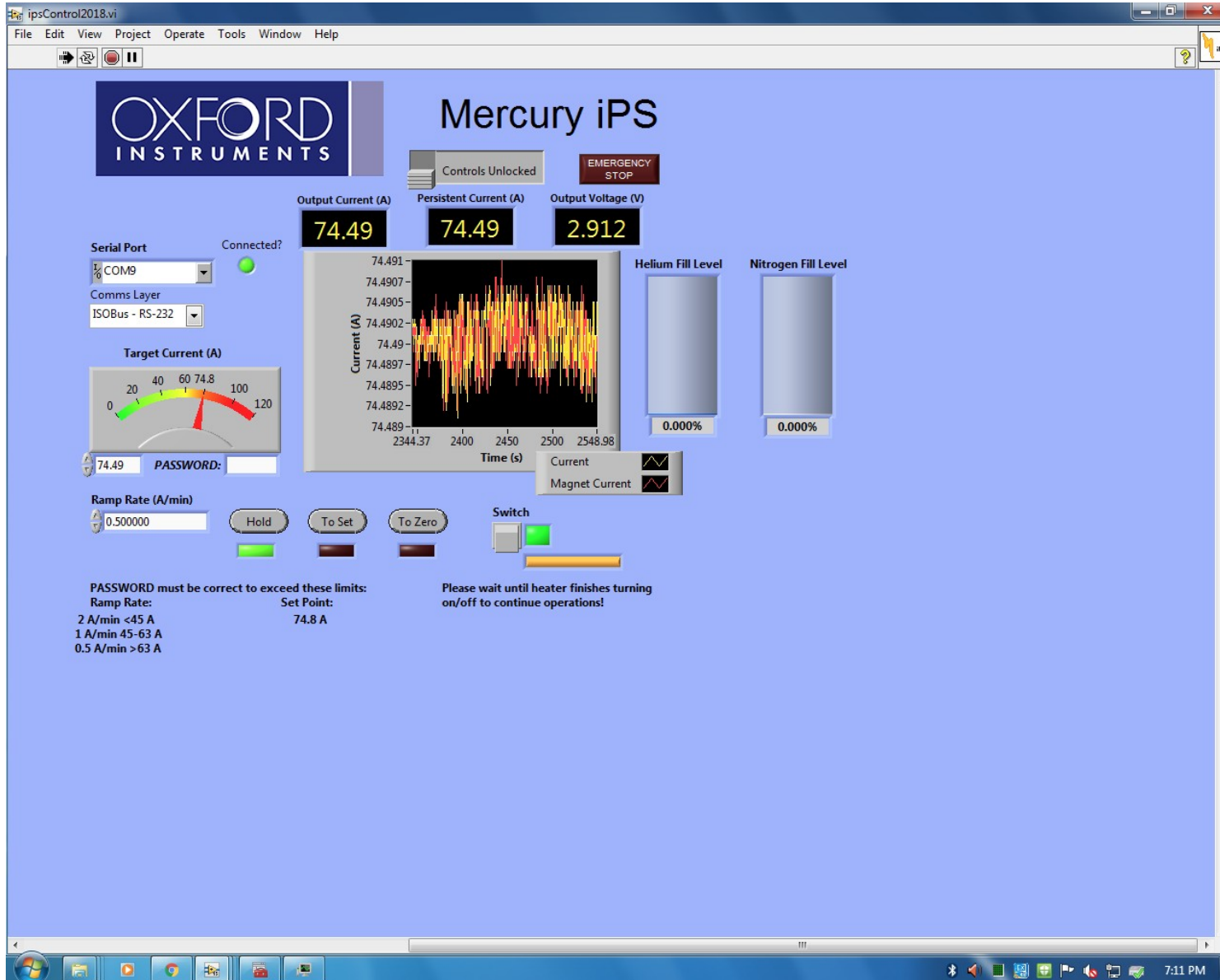
- Communication setup:** Includes a COM Port dropdown set to 'COM7', a 'STOP COMMUNICATION' button, a warning message: 'Please wait after stopping the VI; it can take some time to shut down all the stuff running in the background, so please be patient.', and a 'Debug mode' toggle.
- Manual motor control:** Features input fields for 'Step size (rev)' (0.001), 'Step size (GHz)' (0.020), 'Velocity (rev/sec)' (0.1), and 'Frequency to seek (GHz)' (140.190). It includes 'Move up', 'Move down', and 'Goto' buttons, along with a 'STOP MOTOR' button.
- Motor information:** Displays 'Motor time (sec)' (2305), 'Motor position (rev)' (0.000), and 'Frequency (calculated, GHz)' (140.190).
- Motor alarm (error):** Shows an 'Alarm code' of '0x00' and a text box with instructions: 'See motor manual, section "Troubleshooting" for explanation of alarm codes; fix the problem first and then restart this VI'.
- Frequency calibration:** Contains two frequency/position pairs (140.000/0 and 140.400/0) with 'Read position' buttons. It also includes 'Fit parameters' (Slope: -0.657895, Intercept: 140.19) and buttons for 'Calculate fit parameters' and 'Refine fit parameters'.
- Power data:** Shows 'Microwave power (mW)' (1.000) and 'New power (mW) Width (GHz)' (1.000, 0.050) with an 'Add power reading' button.
- Automatic control:** Includes 'Automatic mode on/off' and 'Seek positive polarization' toggles. A table displays 'Samples taken' (2), 'Eventnum' (1528761229), 'Polarization' (52.7069), and 'Rate' (0.0172687). It also has a 'Data input file' field and a 'Launch simulation' button.
- Configuration backup/restore:** Provides 'Save configuration to file' and 'Restore configuration from file' buttons, with a note: 'The settings which are backed up by this method are: step size, frequency to seek, fit slope, fit intercept, automatic step size, automatic velocity, data input file, and all the other controls under "Automatic control".'
- Advanced configuration:** Features 'Automatic step size (rev)' (0.0304) and 'Automatic velocity (rev/sec)' (0.1) fields. It includes 'Step size presets' (0.05, 0.03, 0.01 GHz/step), 'Reseek (reset step size)', 'Make up fit parameters', and a 'RESET EVERYTHING AND STOP' button.

The interface also shows a standard Windows menu bar (File, Edit, View, Project, Operate, Tools, Window, Help) and a taskbar at the bottom with the system clock at 7:54 PM.

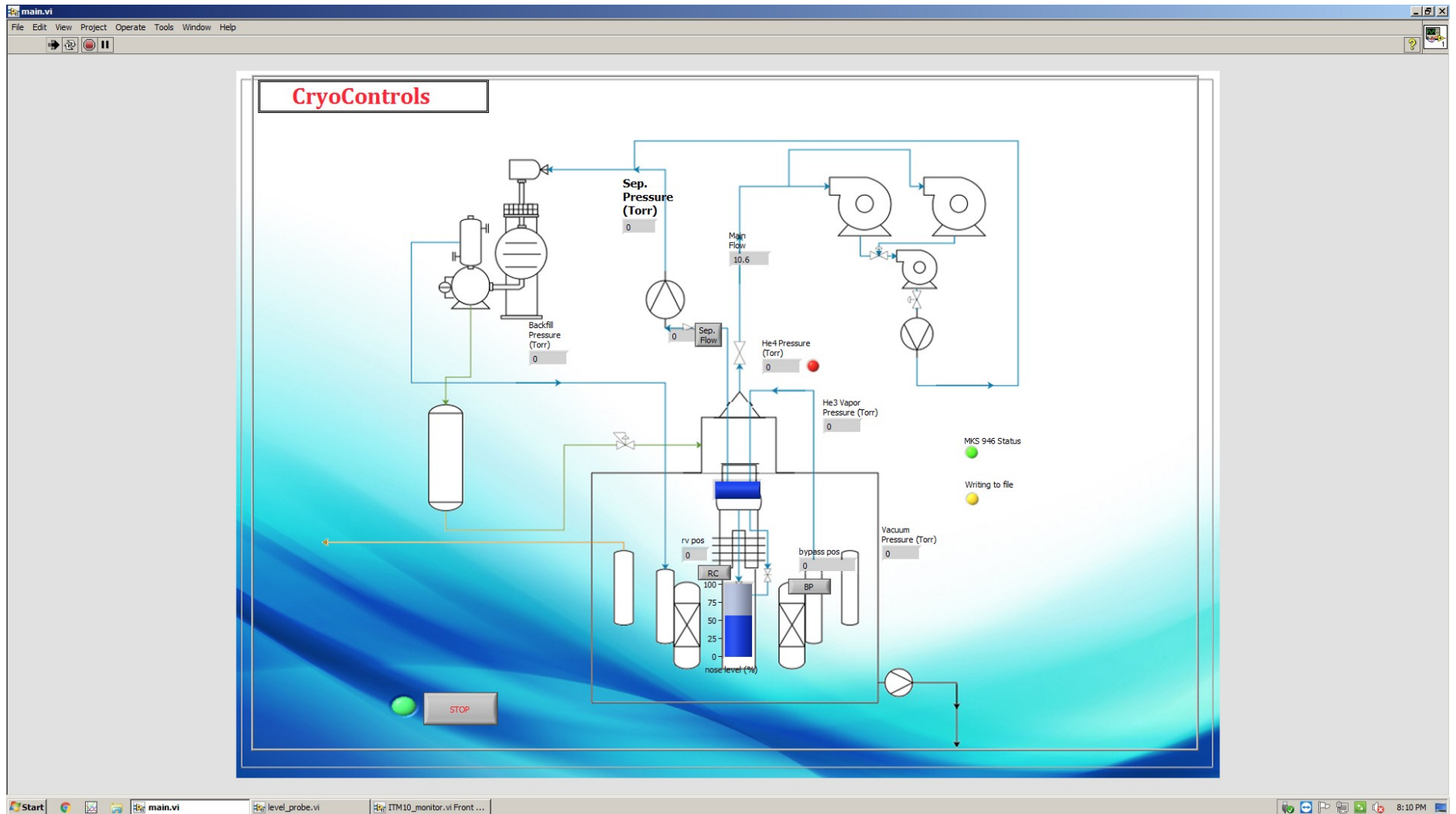
Automated Frequency Control



Magnet PS control



Cryocontrols



Pop-up Controls

