LANL/UVA Solid Polarized Target

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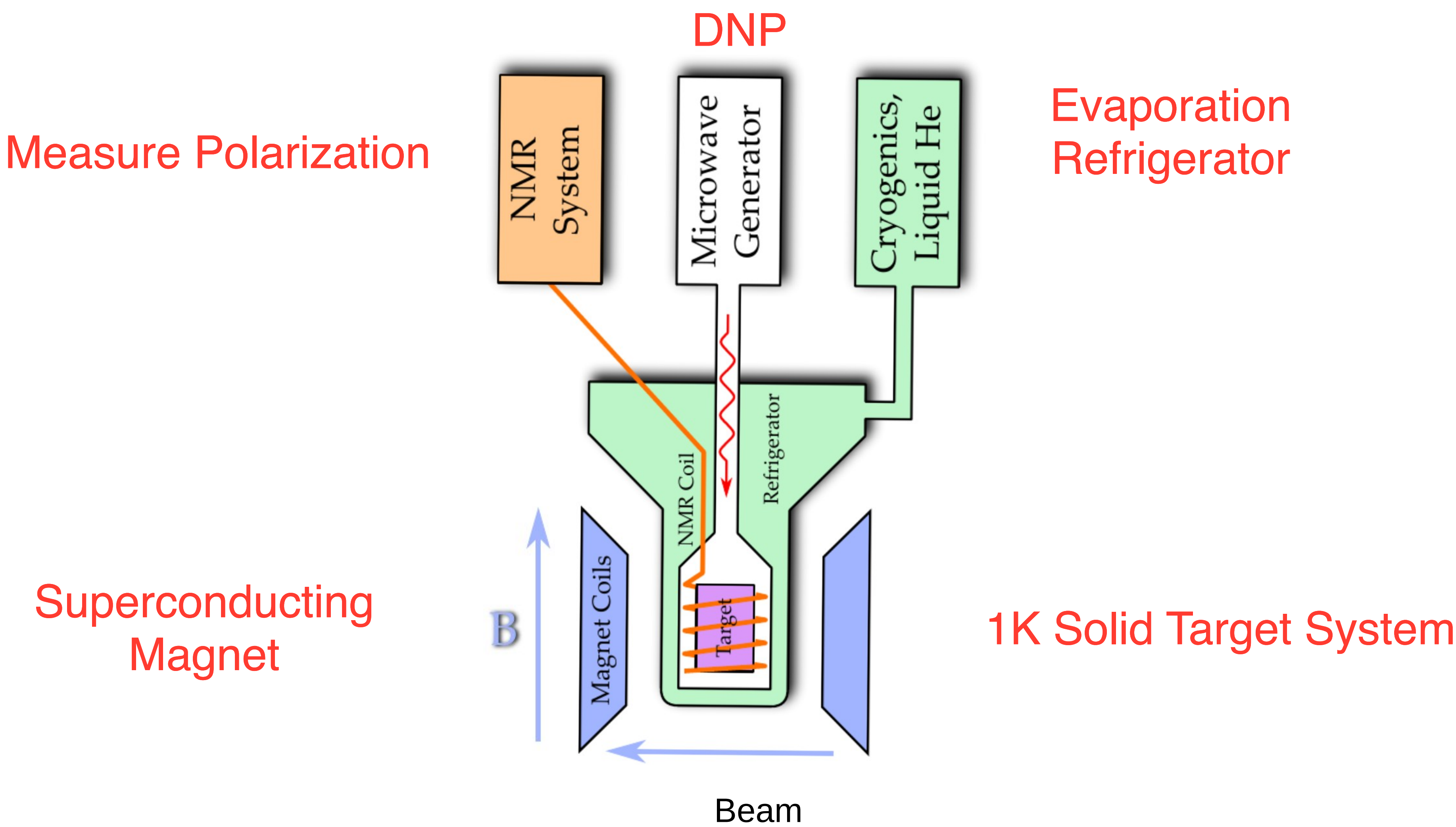
Progress and developments with E1039 polarized target system

Outline

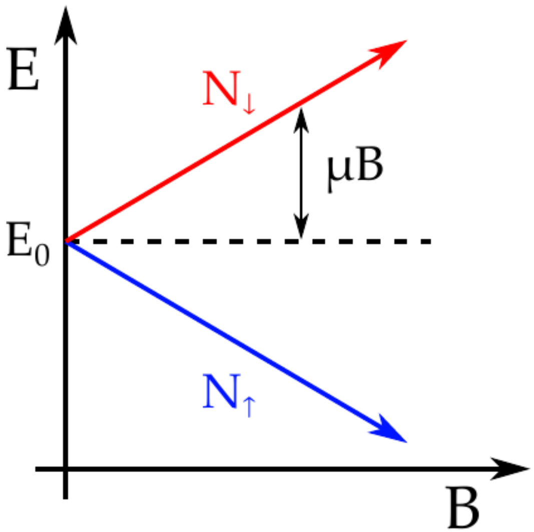
- Polarized Target Setup
- System Status
- Expectations and Uncertainties
- Personnel Requirements
- Still to Come

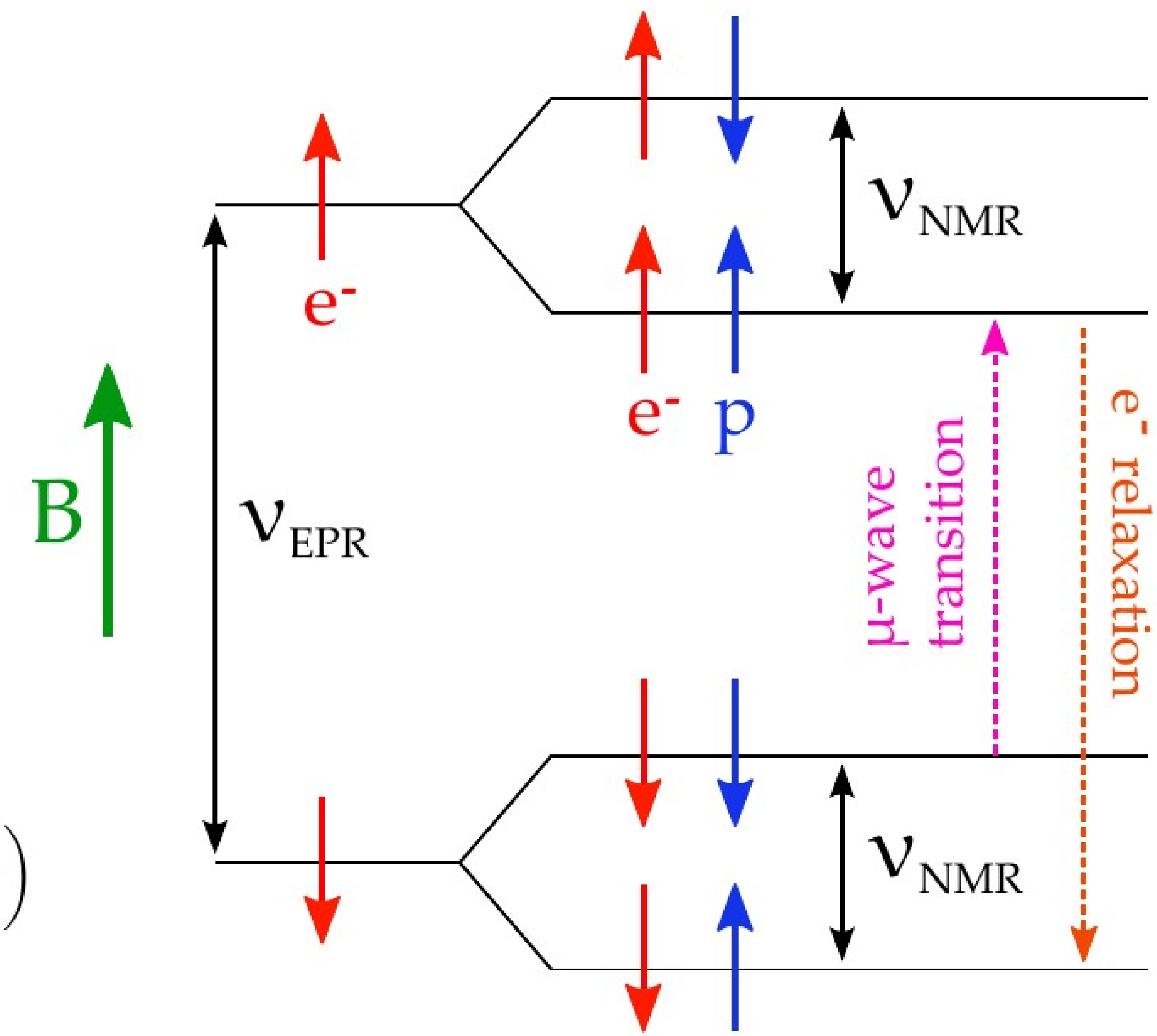
Polarized Target System



Vertically Pointing 5T Split Pair

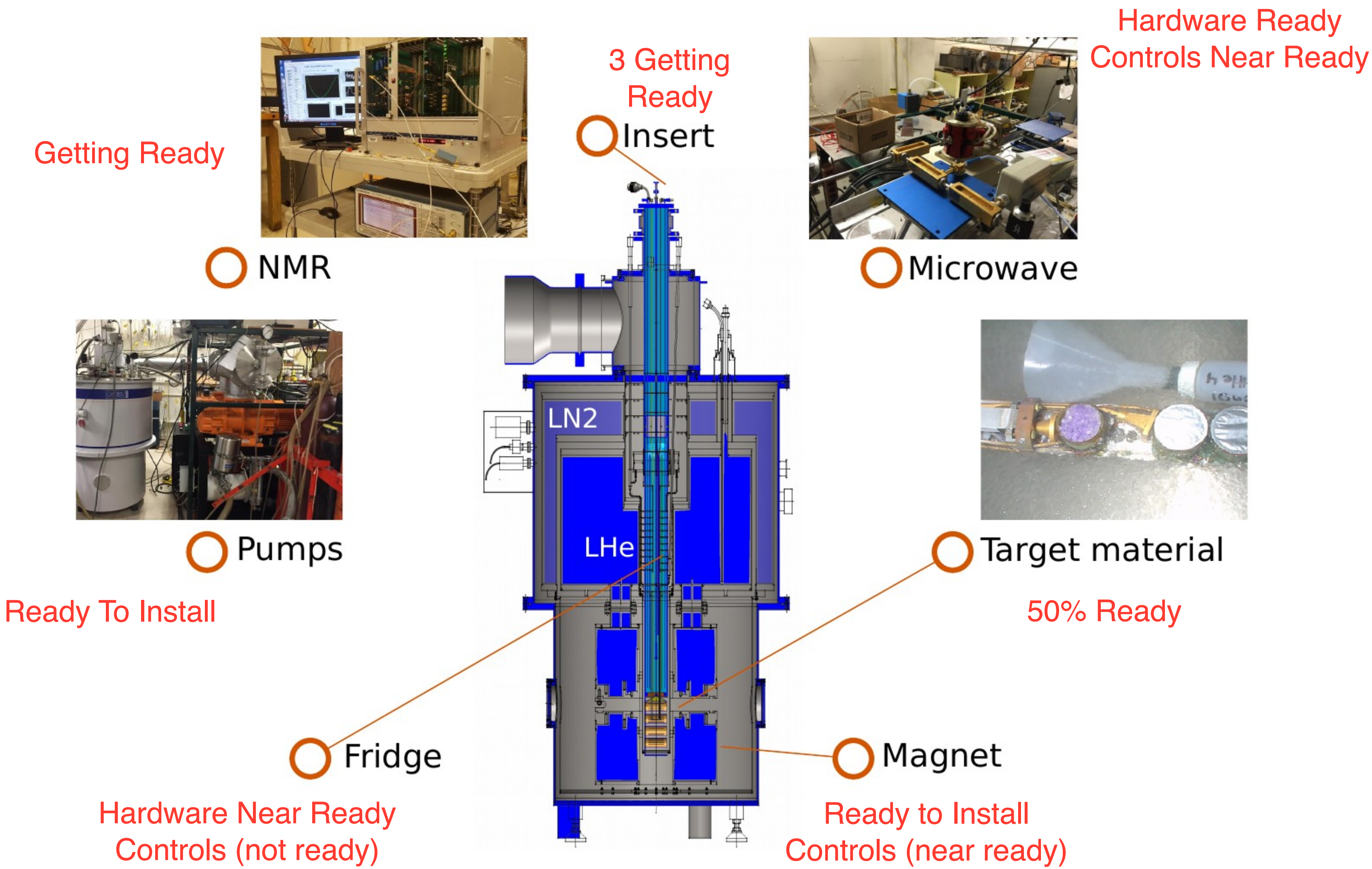
DNP Proton Polarization





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

E1039 Polarized Target



So Far Accomplished

- Rotation/Modification of Magnet
- Fridge Repairs/Modifications
- Design Build Target Insert (3-built, one metal)
- 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
- Integrated Cryocontrols (test version showing up on website)
- Target Annealing system test
- Three Fully integrated System Tests

Last 3 Cooldowns :
1.) New NMR, Magnet, Fridge, Pol
2.) NMR, Max Pol
3.) Microwave opt, Autocontrols

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

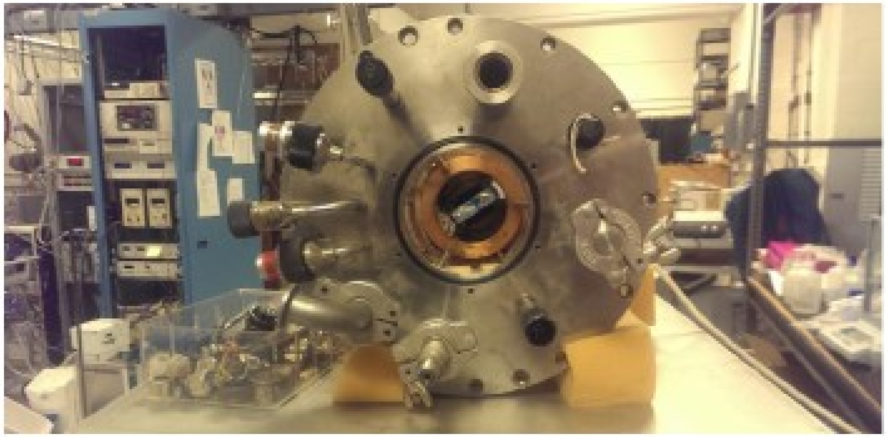
- 3rd cooldown, rotated coils test
- magnet is in a very good shape

Previous cooldown saw some drift

POLARIZED TARGET SUBSYSTEMS

Fridge modifications

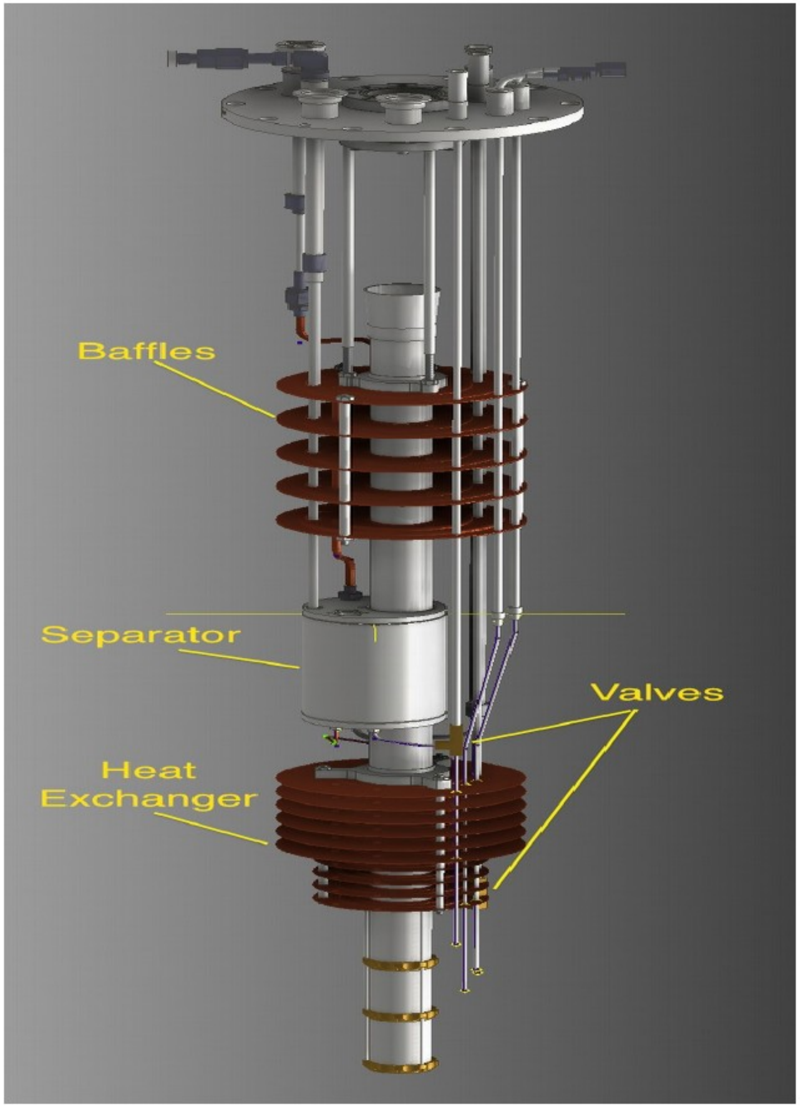
- replaced separator can
- cleaned heat exchangers oxide/corrosion
- leak checked
- refitted run and bypass valves
- installed new LHe channel
- installed 8 temperature sensors
- manufactured new nose, 10mil window



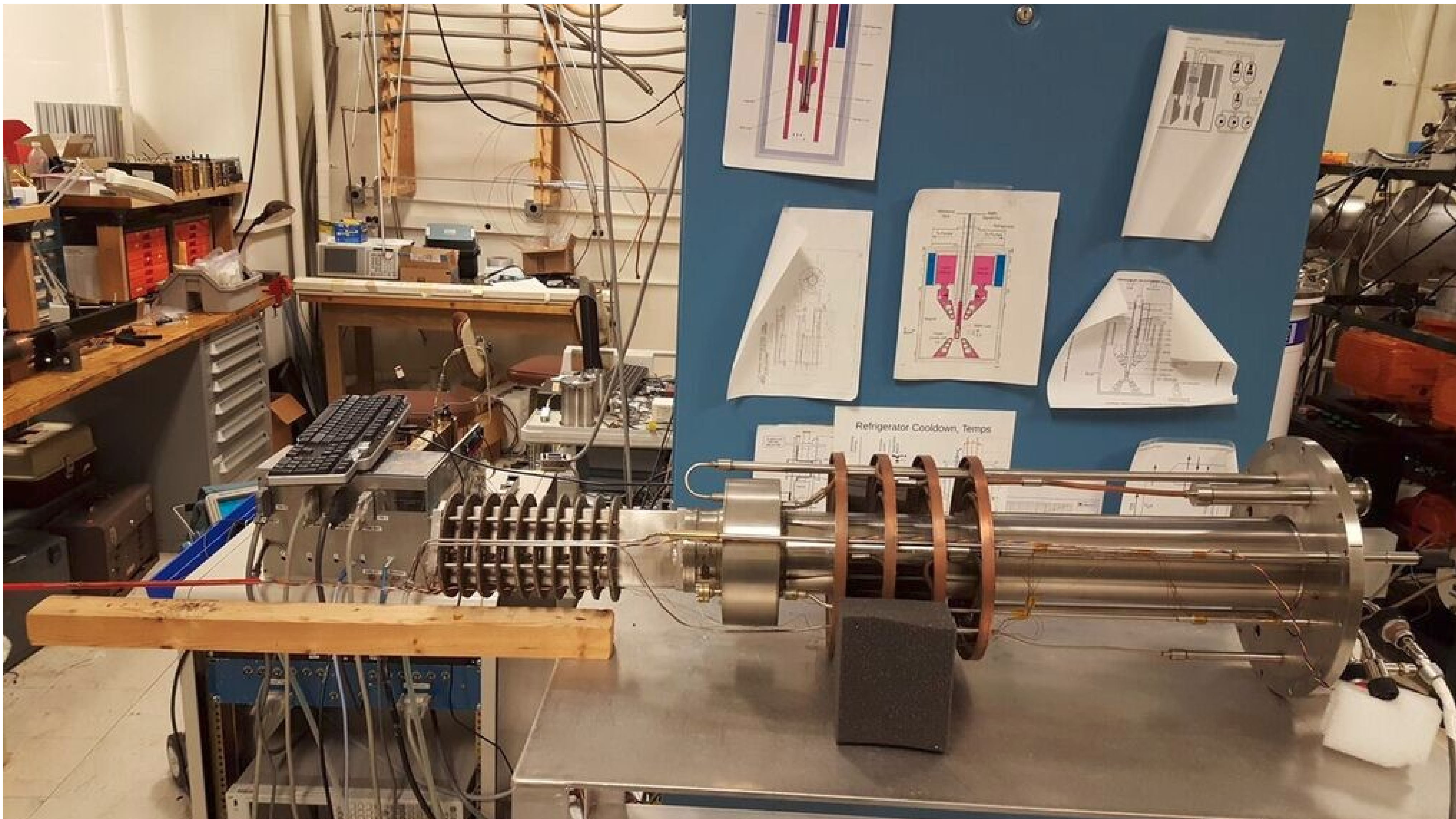
Fridge Modifications

- Separator Can (New)
- Heat exchangers (Clean)
- Leak check
- Valves (re-fit)
- New Helium channel (nose)
- 8-sensors

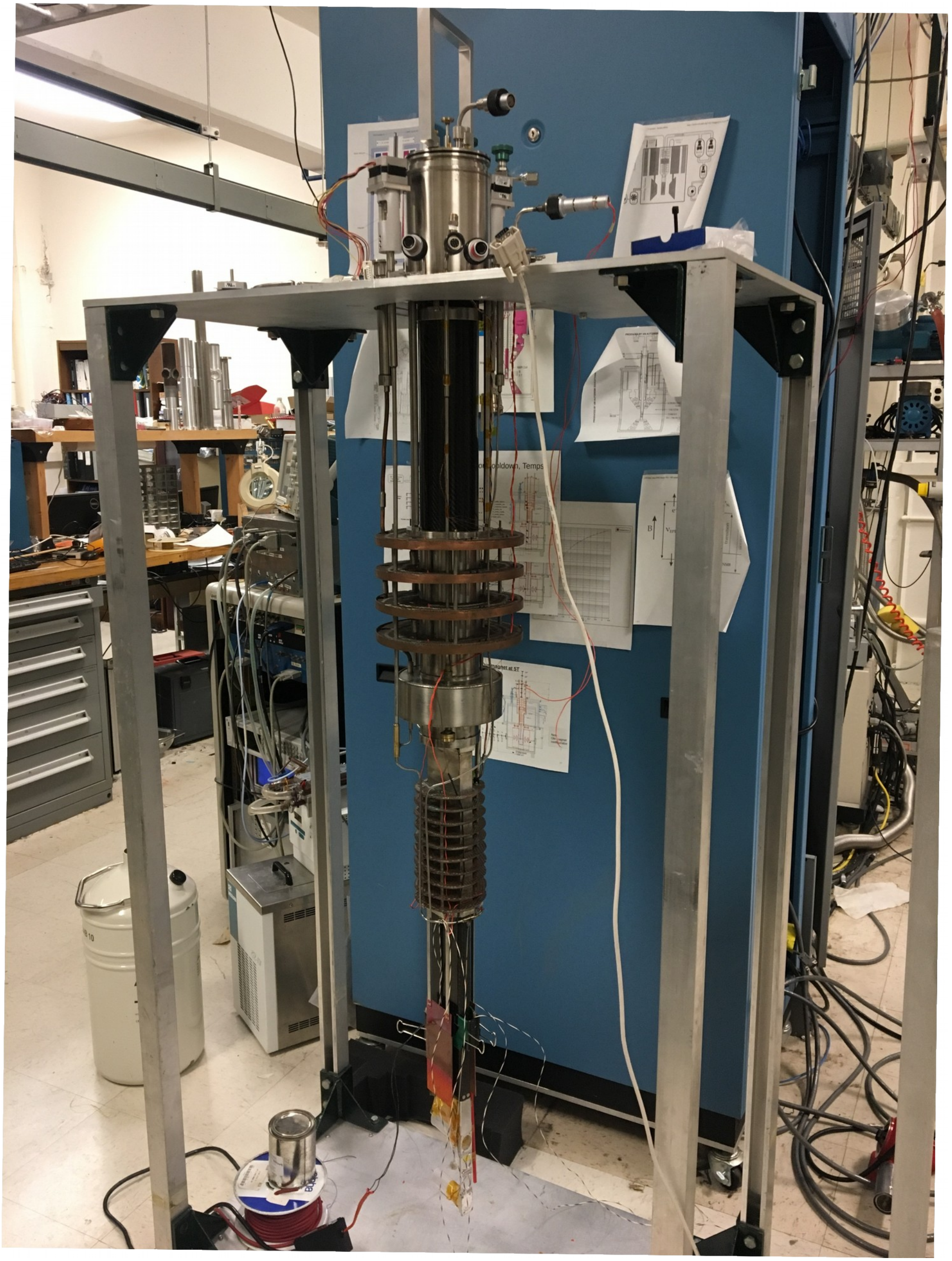
This cooldown:
Seem to have a leaky valve



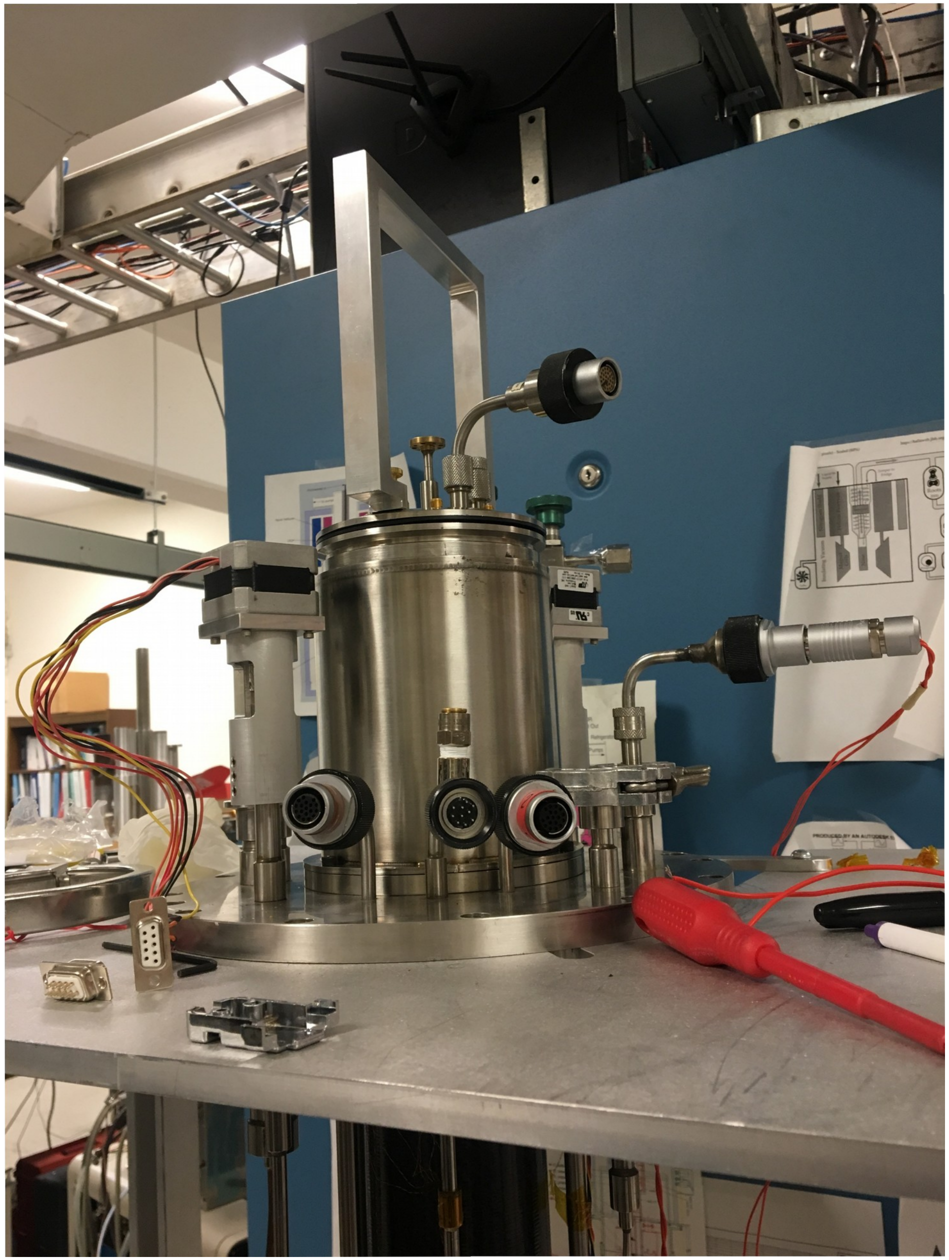
Recent Modifications



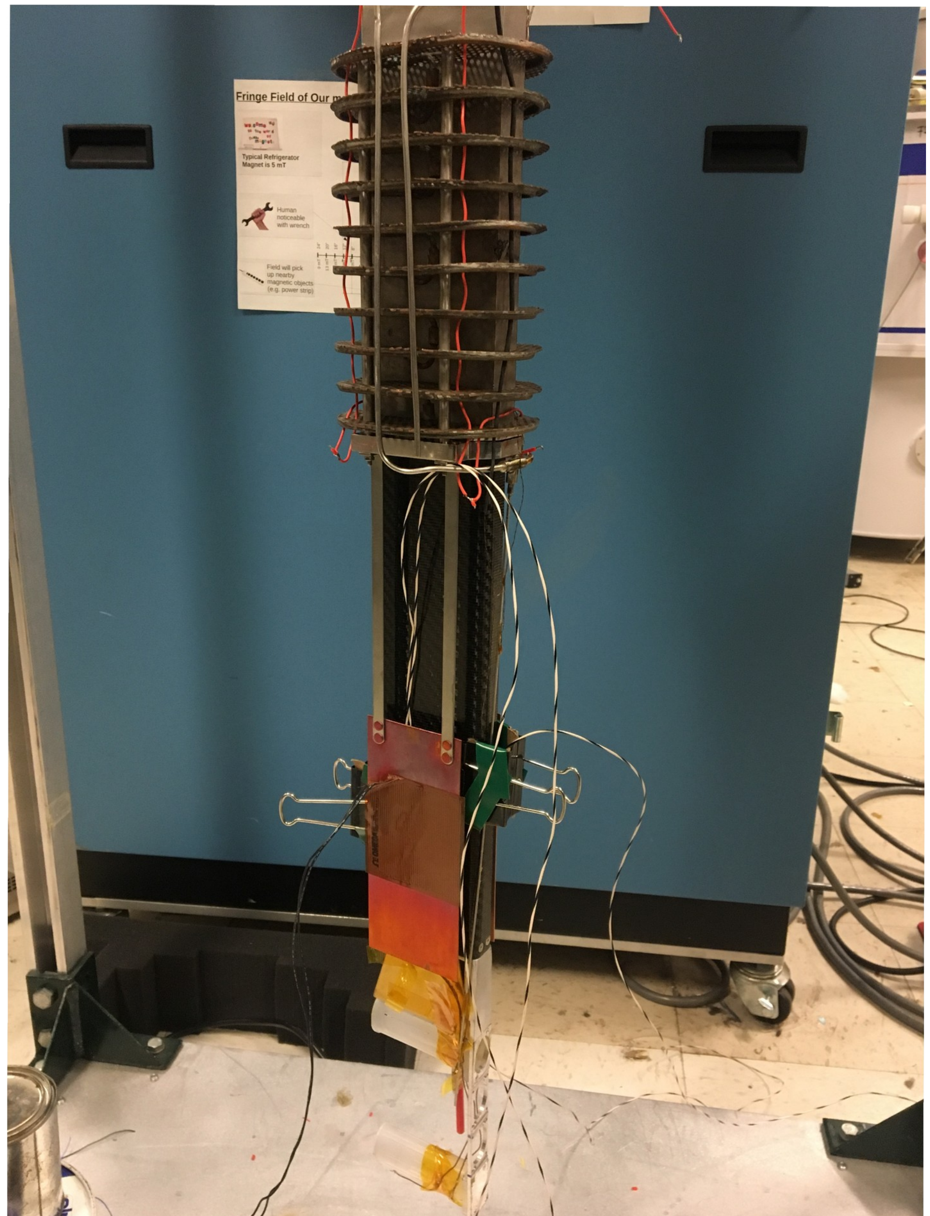
Upright Full View



Upright top



Upright Heater



POLARIZED TARGET SUBSYSTEMS

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

New insert

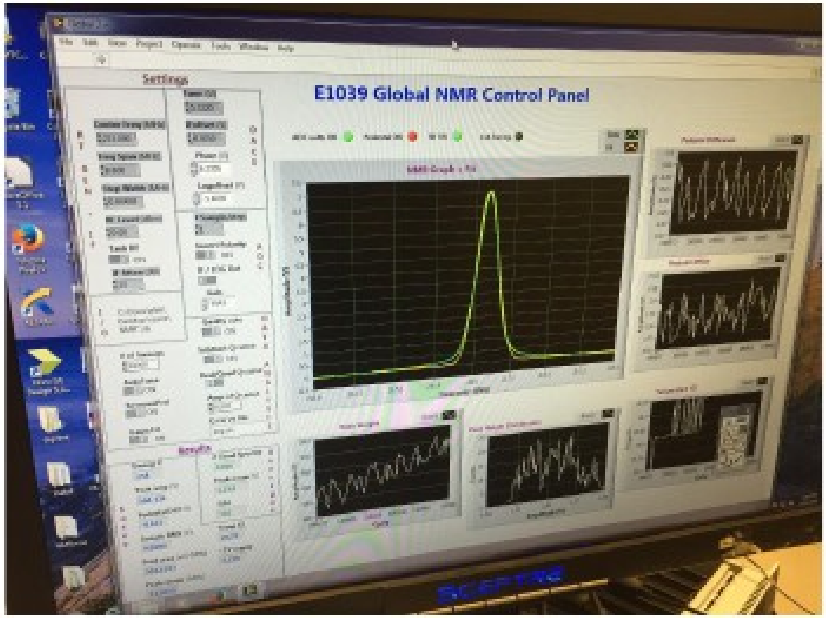
- four 2.7x2x80mm long target cups
- NH3, C disk, empty
- six NMR channels (3 per cup)
- microwave horn for full cup volume
- temperature sensors
- He3 bulb line
- copper thermal barrier
- carbon fiber enclosure

POLARIZED TARGET SUBSYSTEMS

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

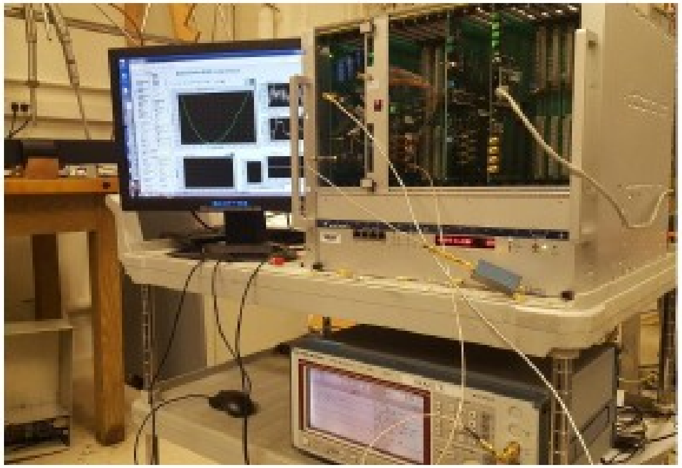
New NMR system developed by LANL

- 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



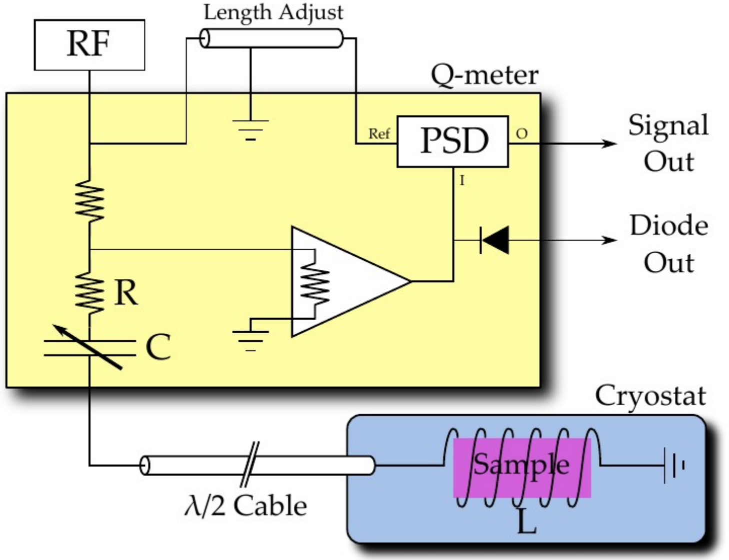
LANL NMR system tests at UVA

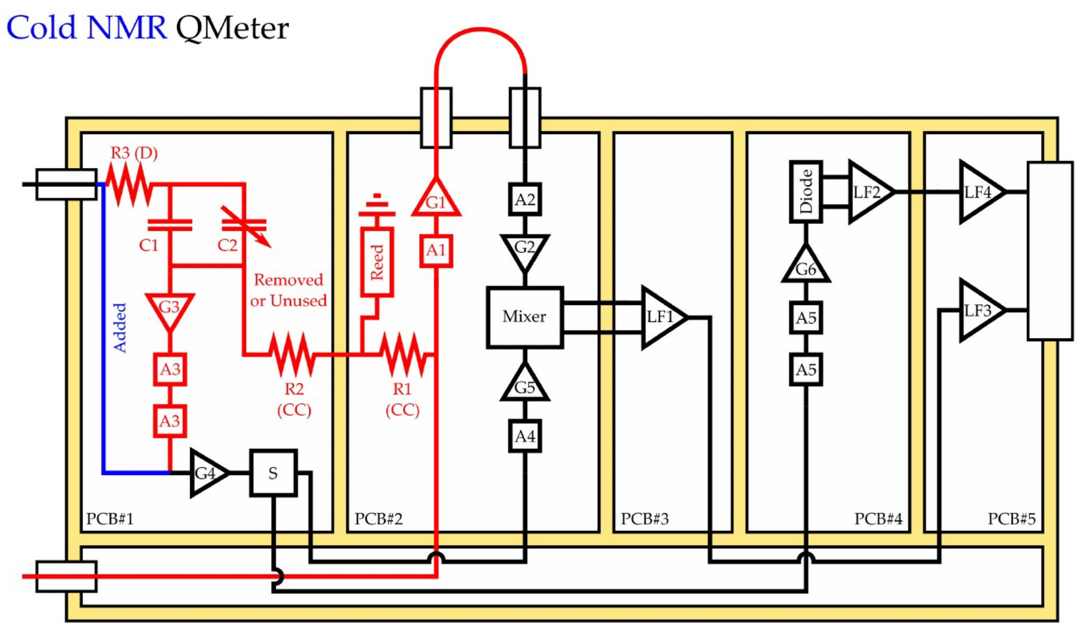
- 1st NMR cooldown 2014 (total 3 cold tests)
- 04/2016 full comparison to Liverpool Q-meter
- signal/noise ratio - waiting for results



NMR System

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

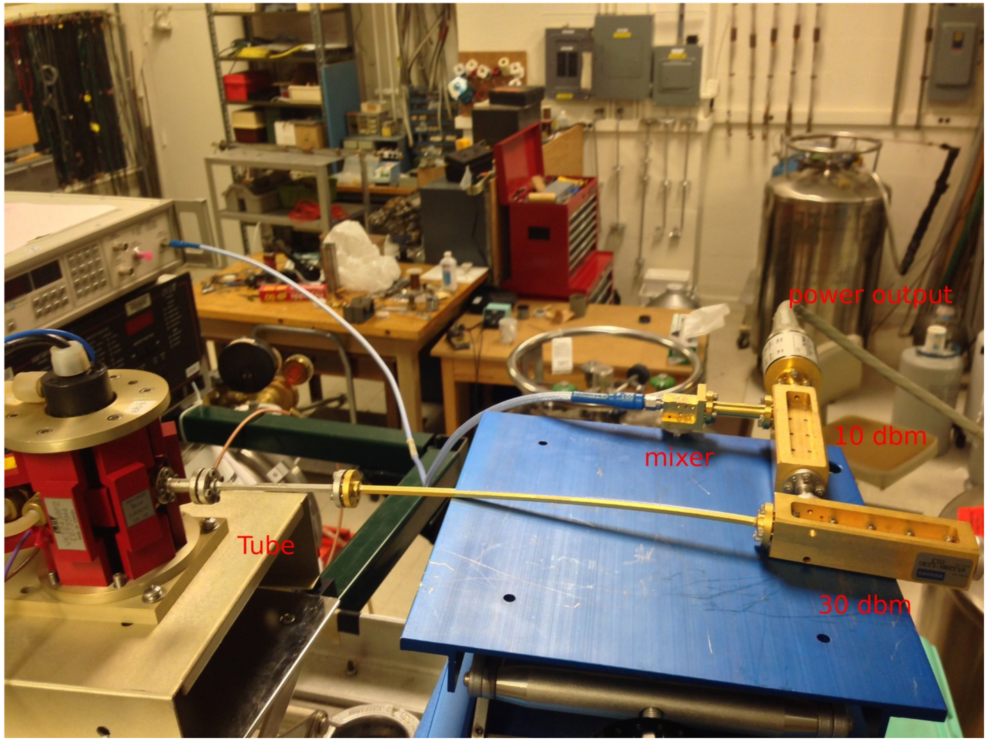


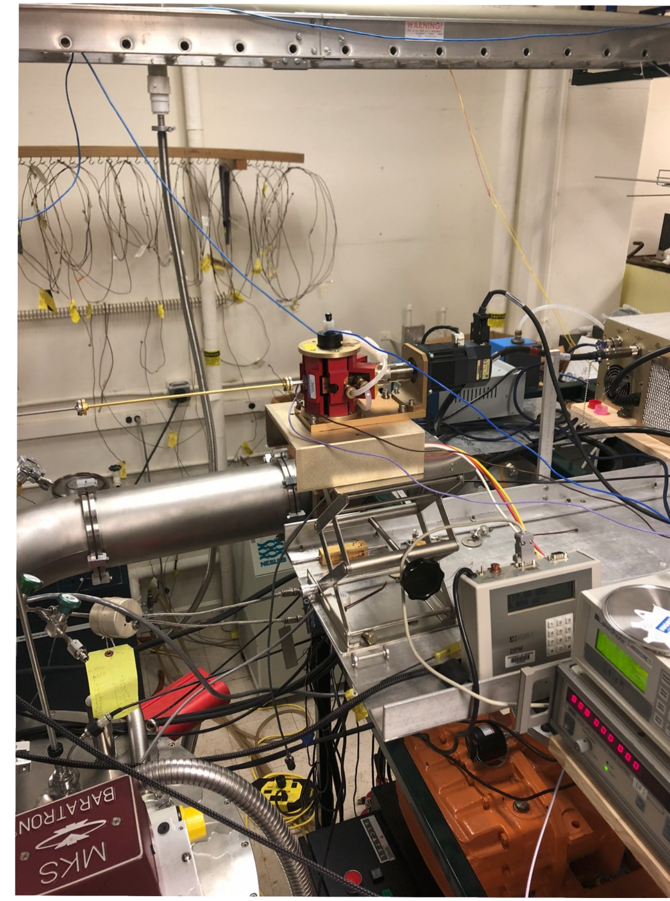


NMR Comparison tests

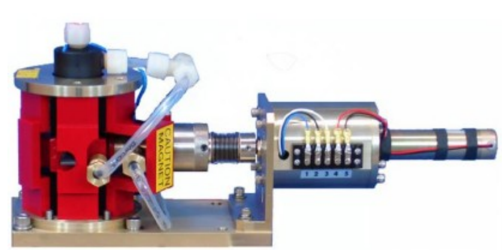
- Signal to Noise (Liverpool to New)
- Temperature variation (temp control + record)
- Linearity (Liverpool to New: Ratio ~1%)
- Full scale polarization comparison (pol ~3%)

Microwave Generator Setup

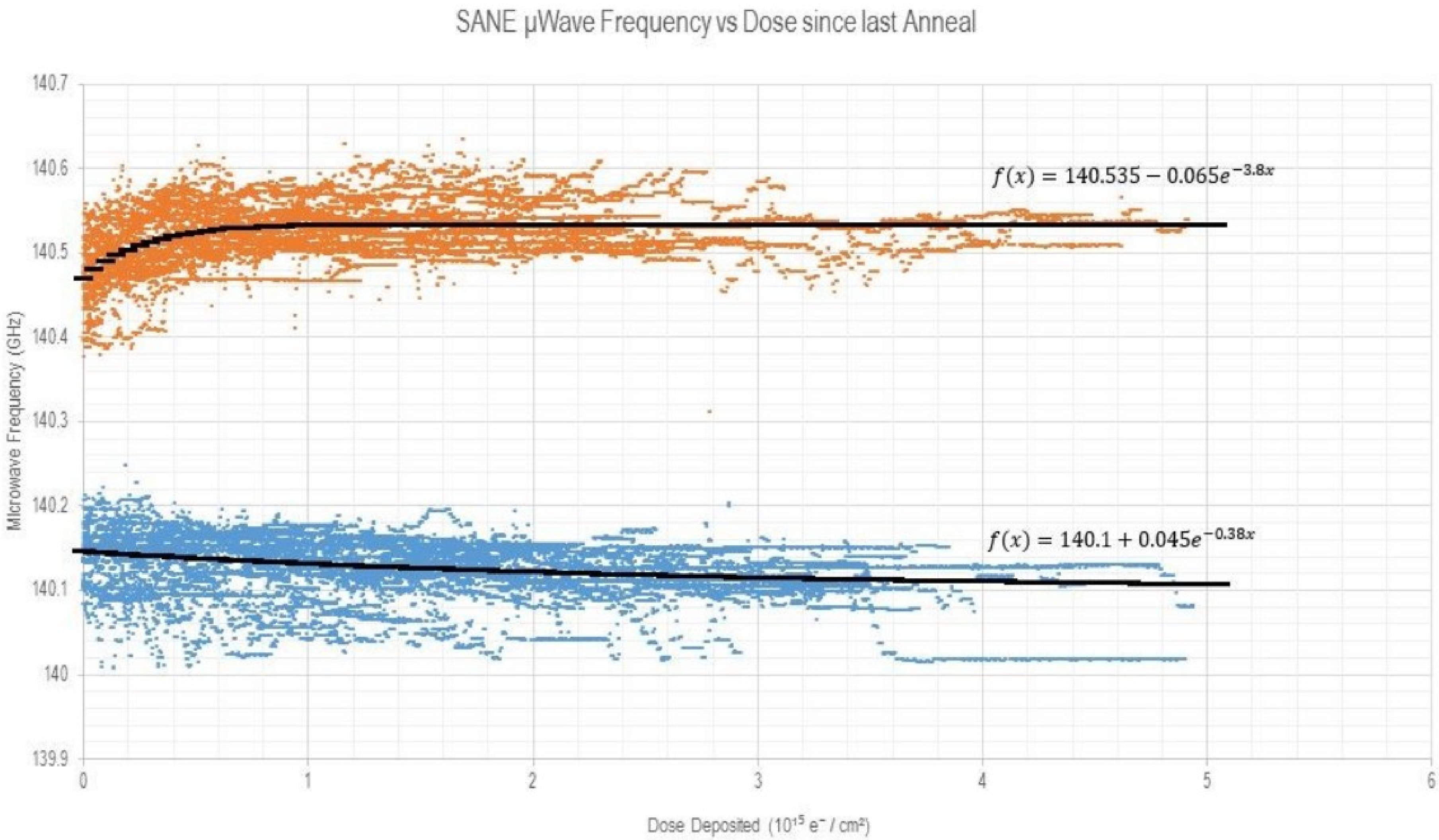




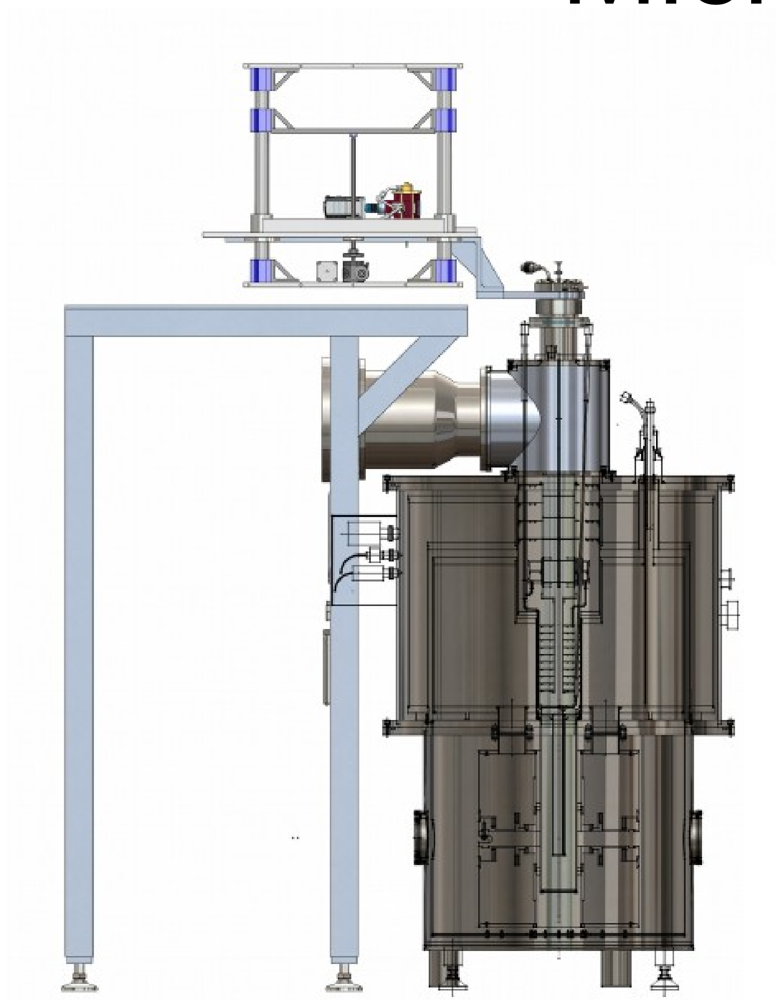
- 20W EIO attenuate down to mW scale: Mixer and Power meter
- Mixer has 10 mW damage threshold
- F→D (140 GHz), right angle bend
- Cavity size adjustment allows an additional 1.5%
- Variation of beam voltage allows to an additional 0.5% frequency adjustment
- Measure power at EIO and measure at helium evaporation (10 l/s per Watt)

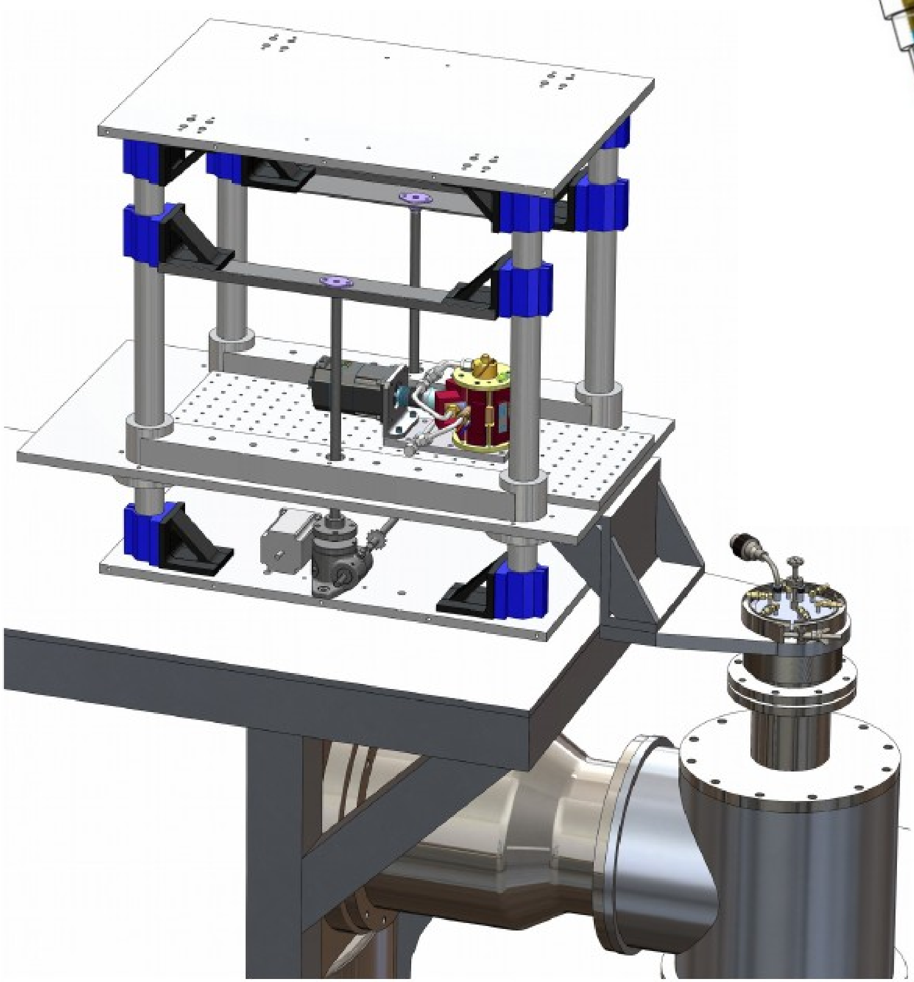


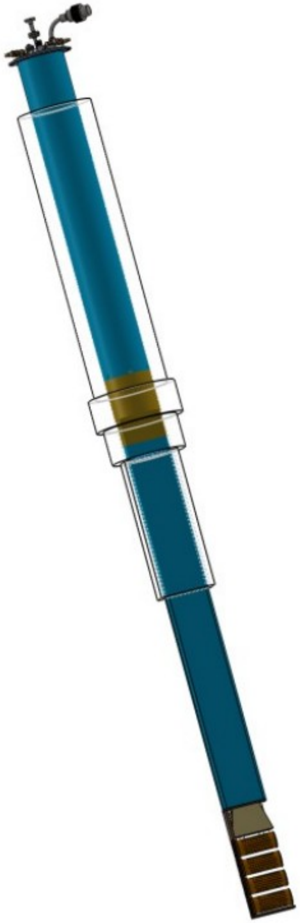
Polarization Frequency



Microwave Setup







Microwave Test

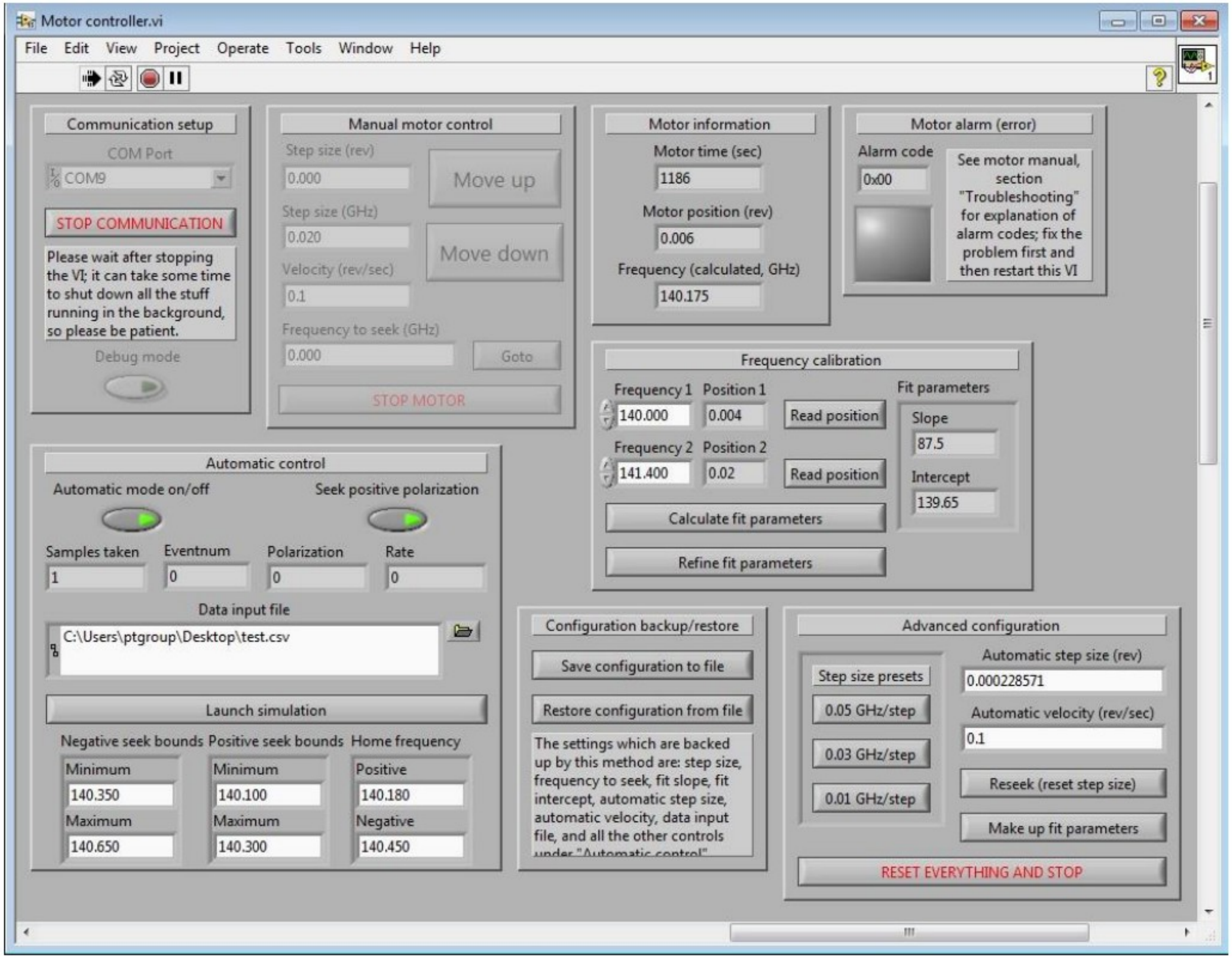
- Testing Slow Controls for Microwave
- Testing for homogeneous irradiation
- Testing for optimal cell configuration

Microwave each cell equally

Microwave each coil equally

Need for reflectors

Motor Control



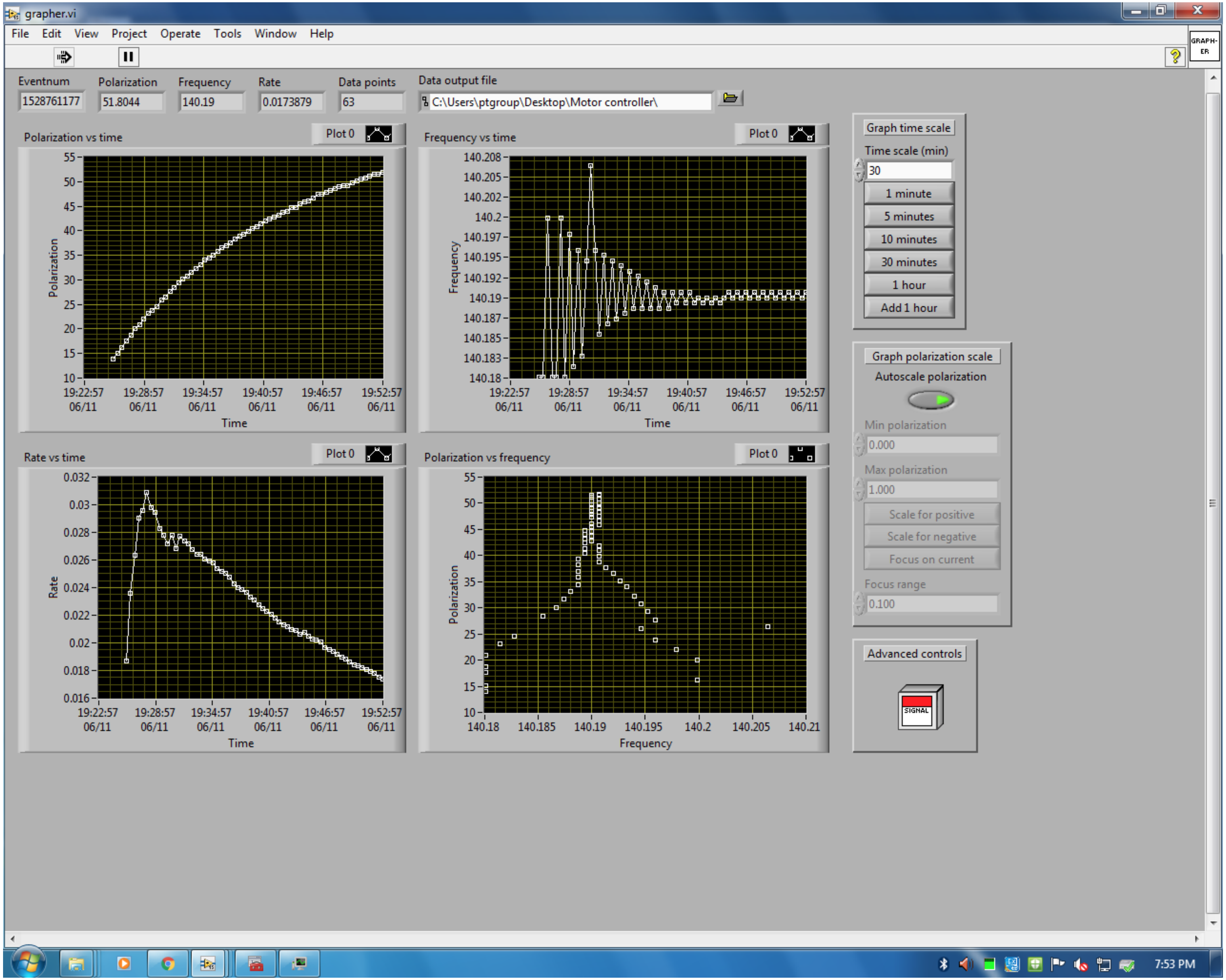
This is the main microwave controller VI.

Can be run in automatic mode or manual mode.

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

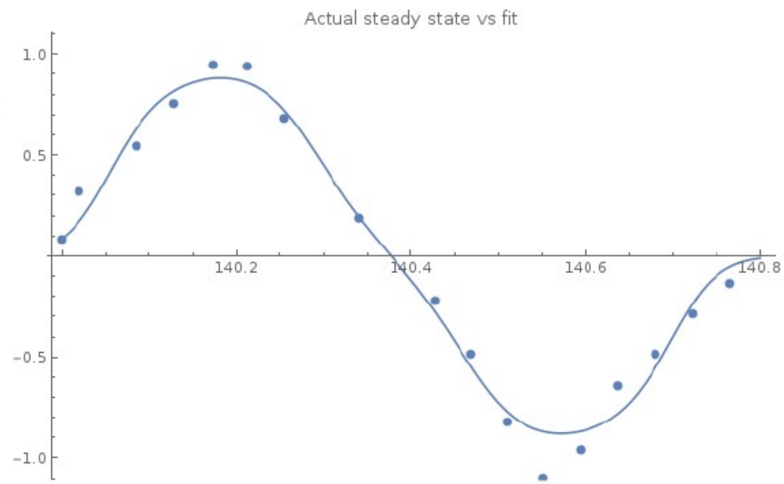
Can be run in real time experiment or in simulation mode.

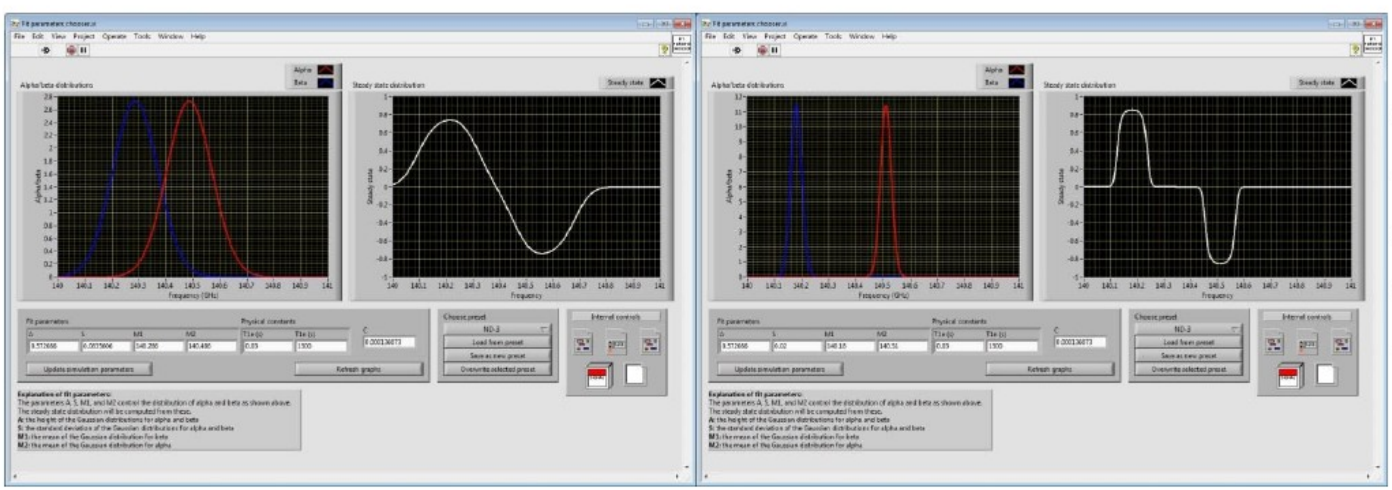
Automated Frequency Control

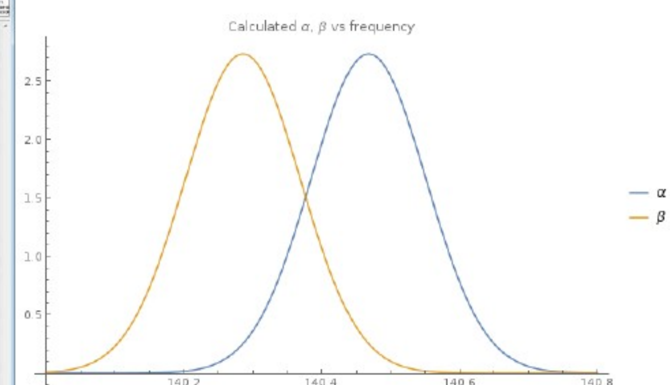


Simulation

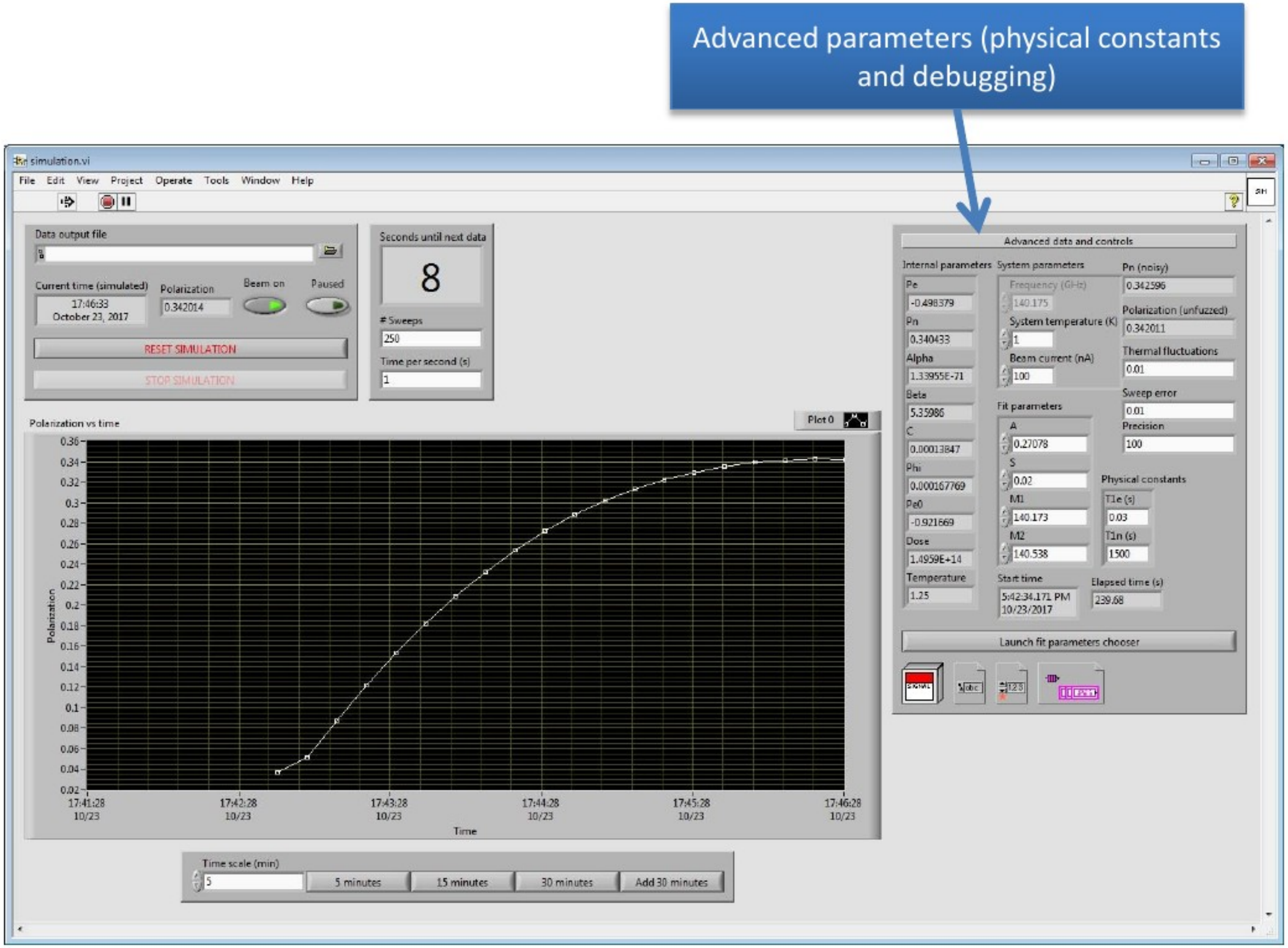
- Written in LabVIEW to work with stepper motor
  - Can also be run by itself to produce data
- Implements model
  - Parameters α and β calculated from frequency







Simulation



This is the main microwave simulation controller VI.

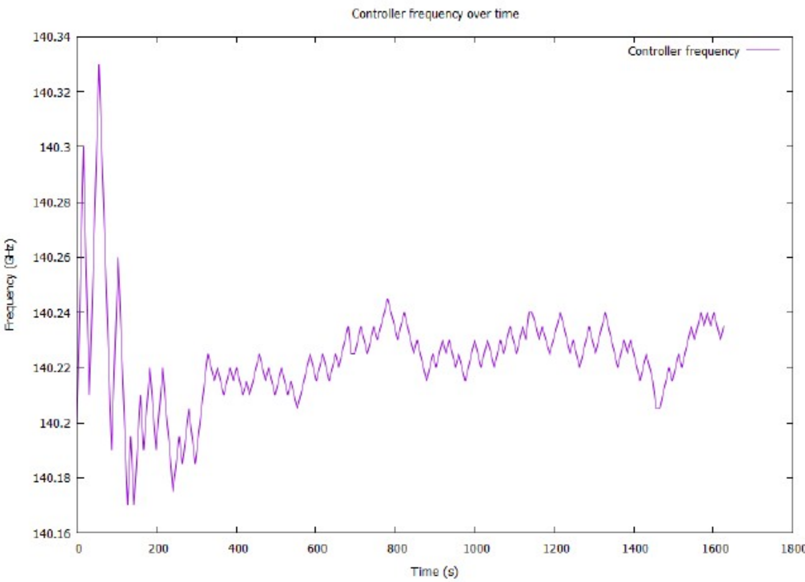
Can be started through main controller VI.

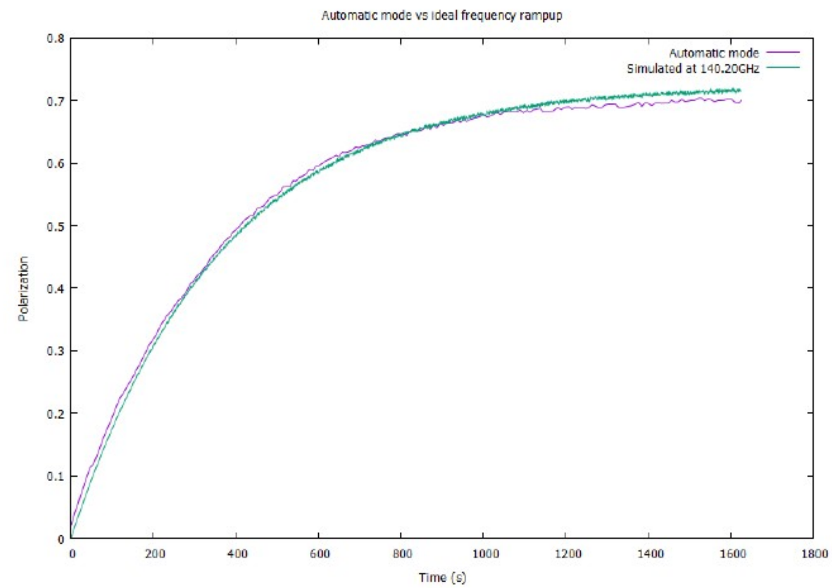
Can change many parameters and run for different material.

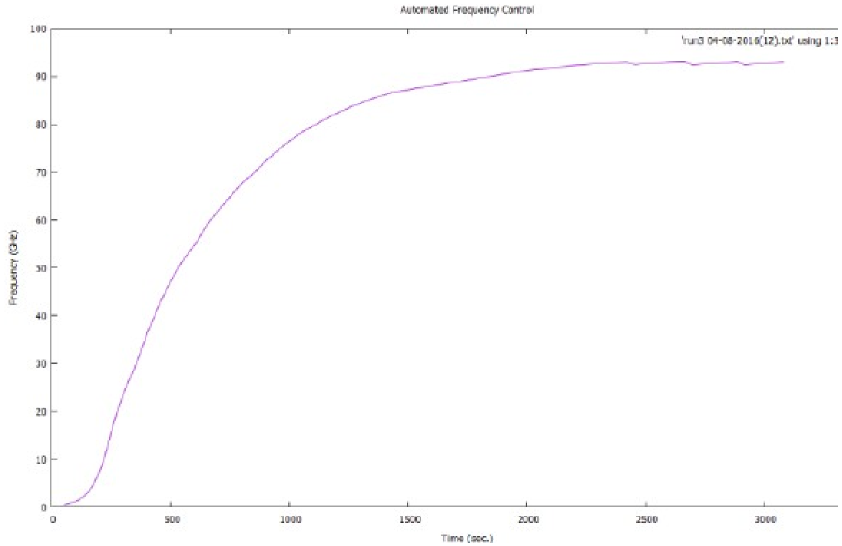
Mimic the real experimental NMR setup.

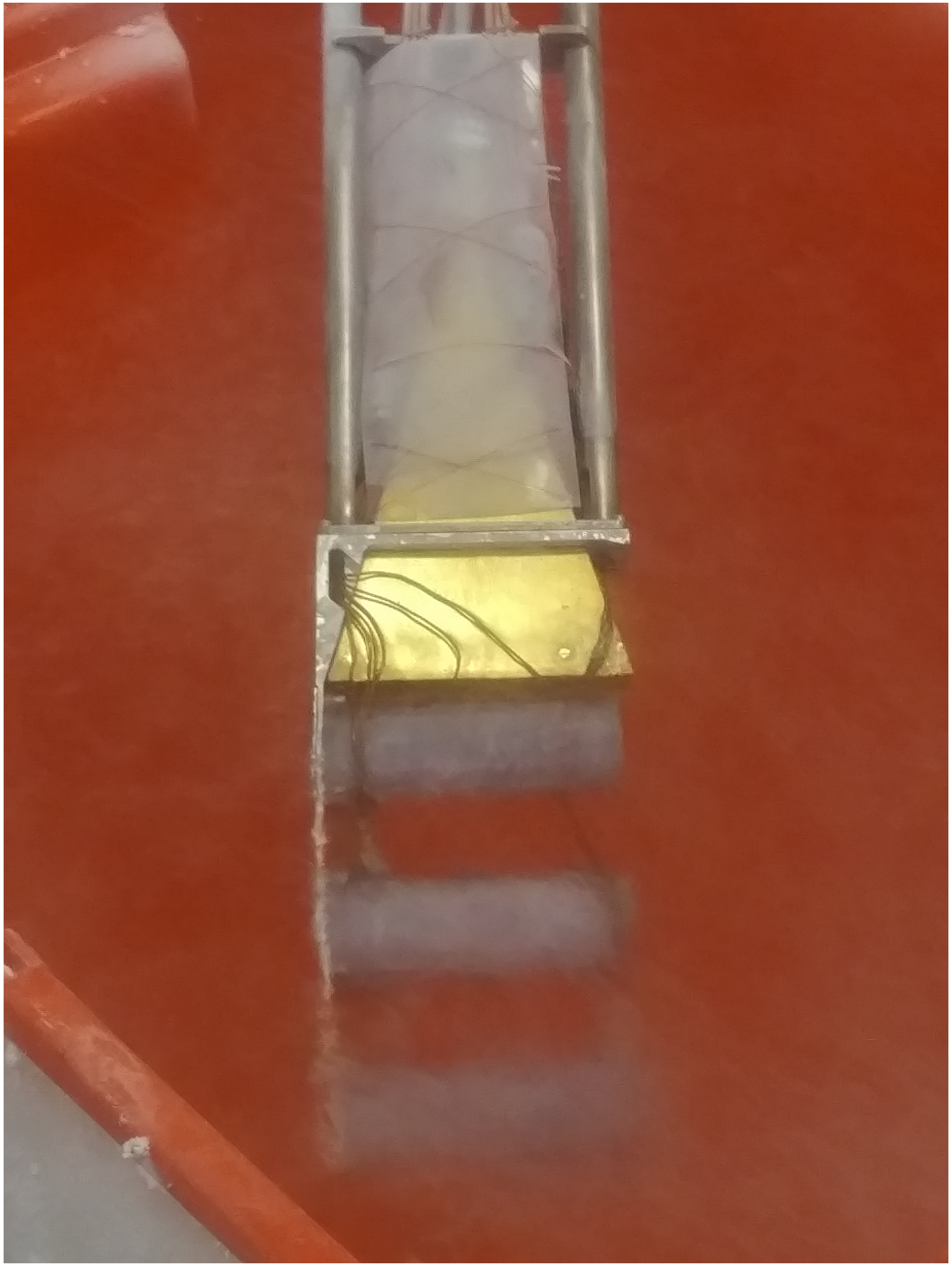
Can be used for training purposes and testing purposes

Testing Performance

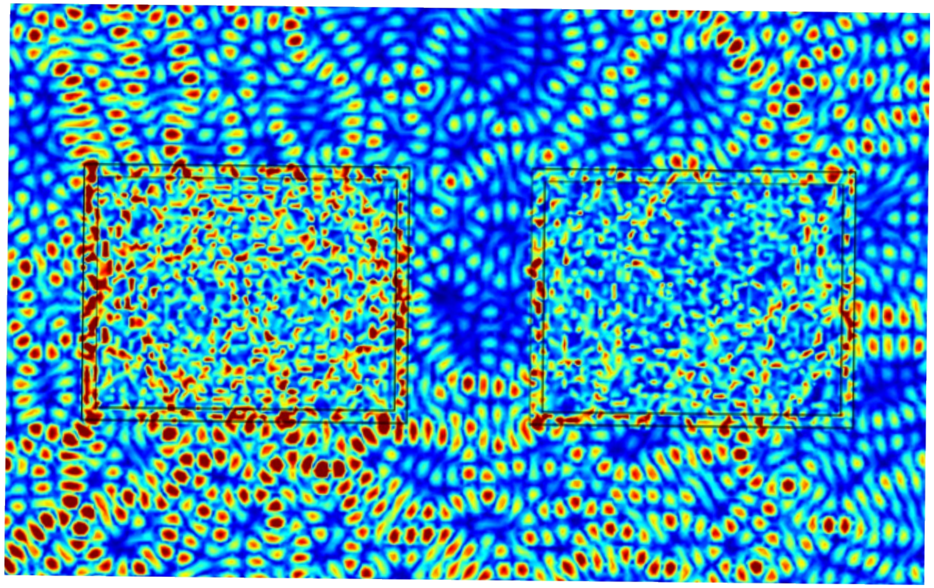


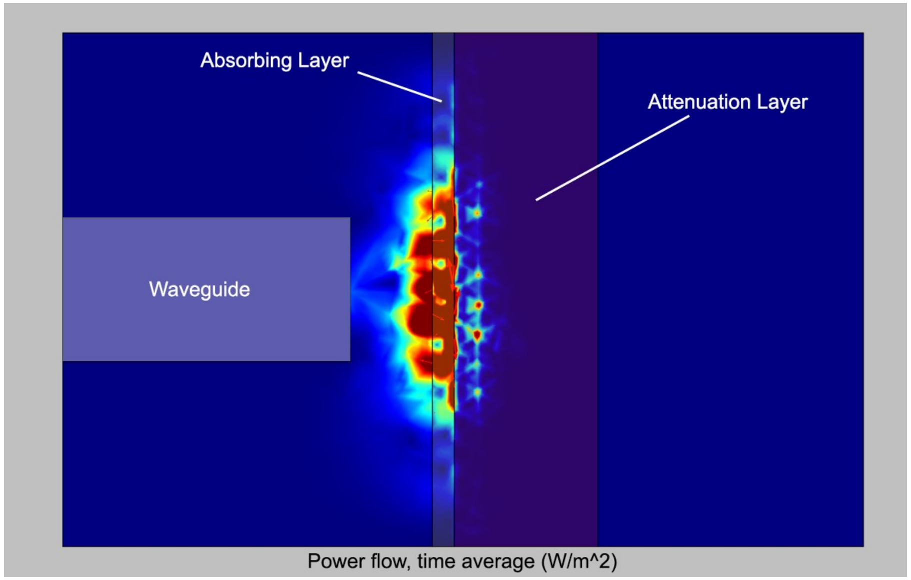


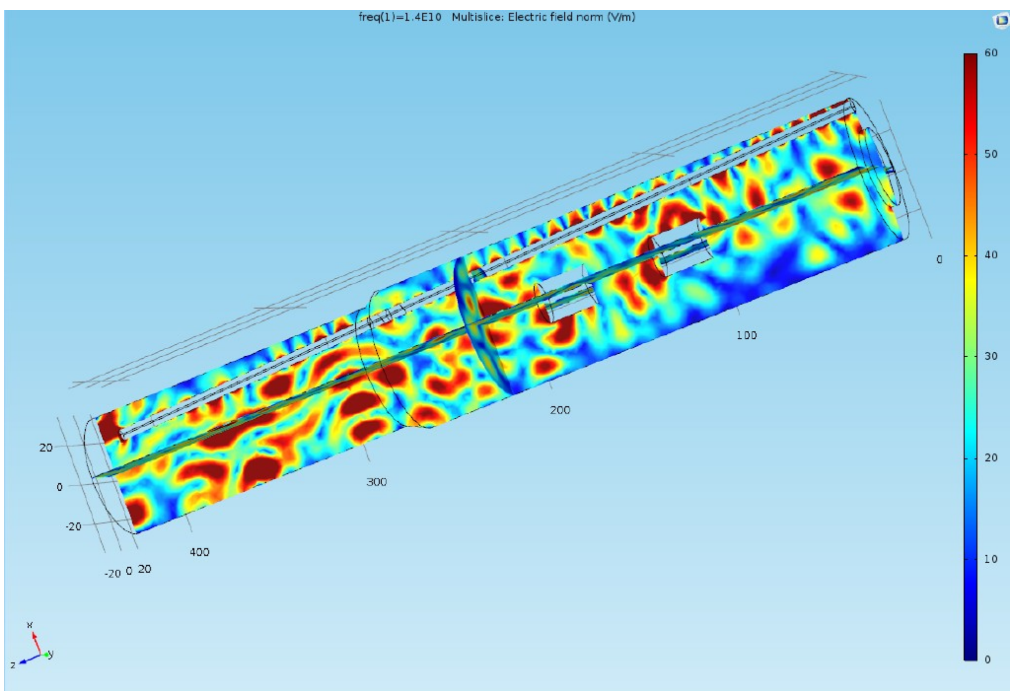


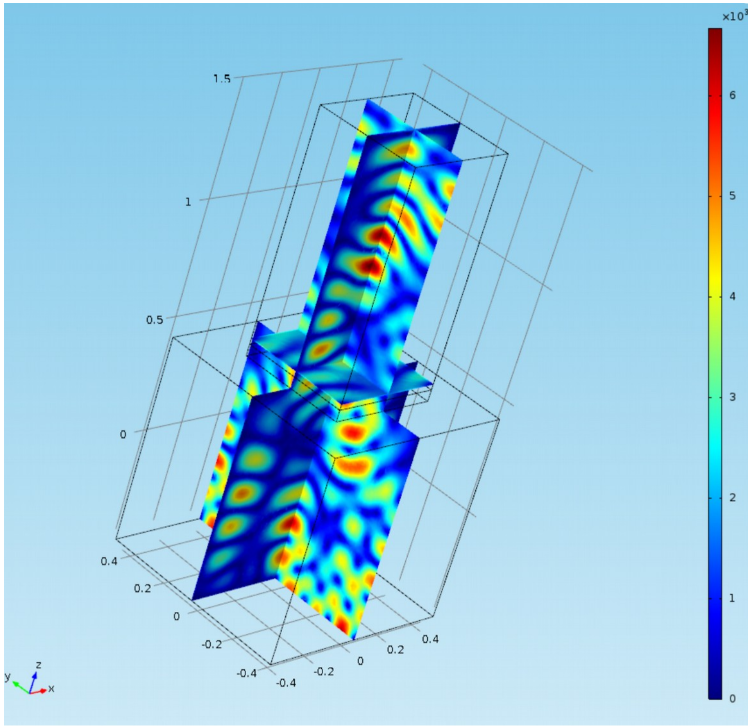


COMSOL Microwave Simulation

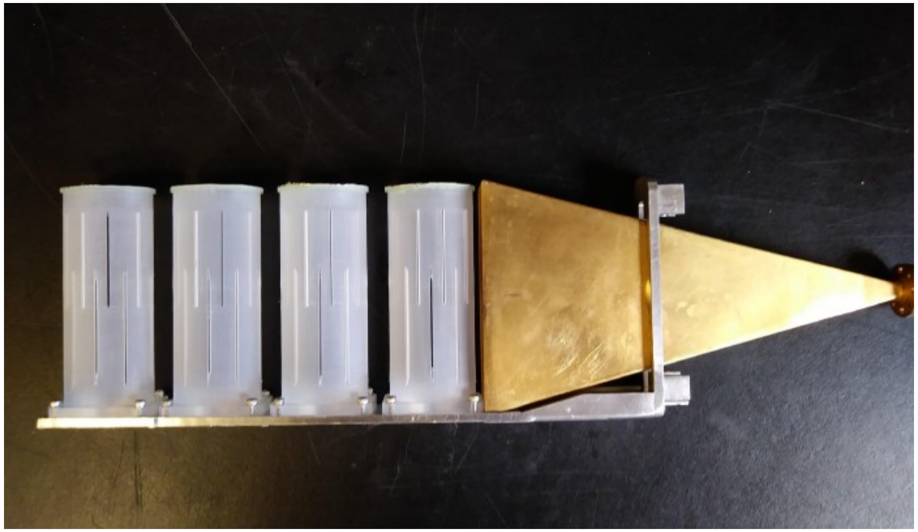


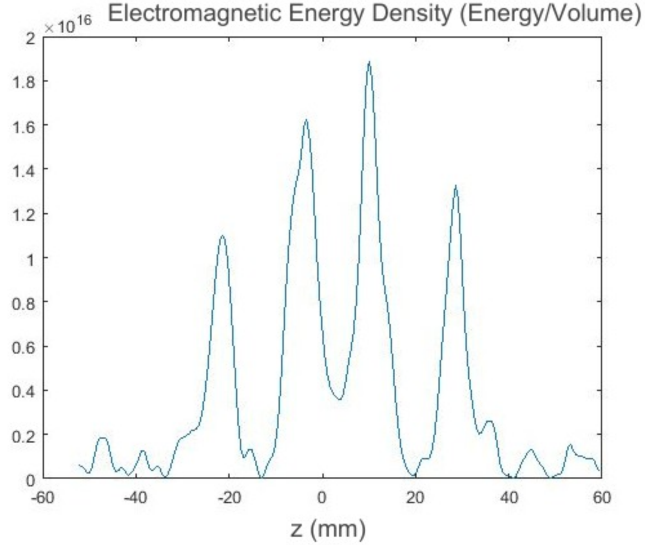


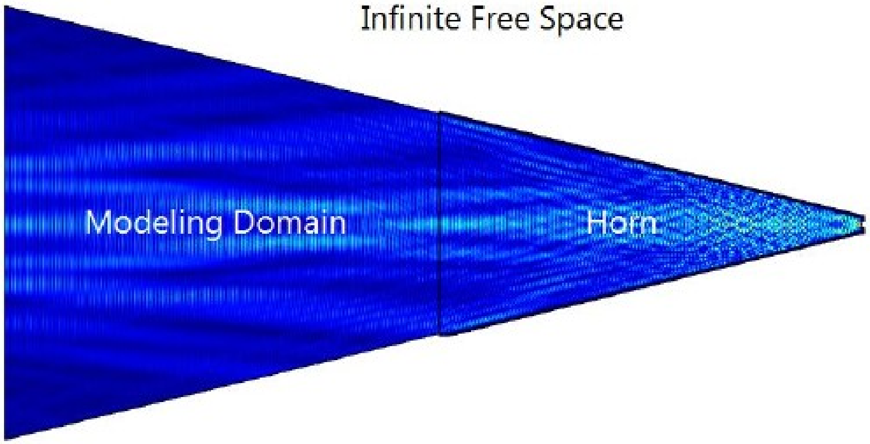


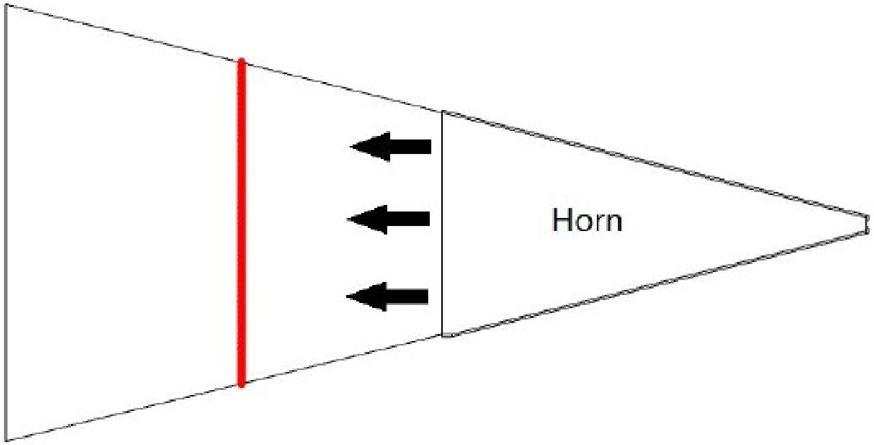


Microwave Profile









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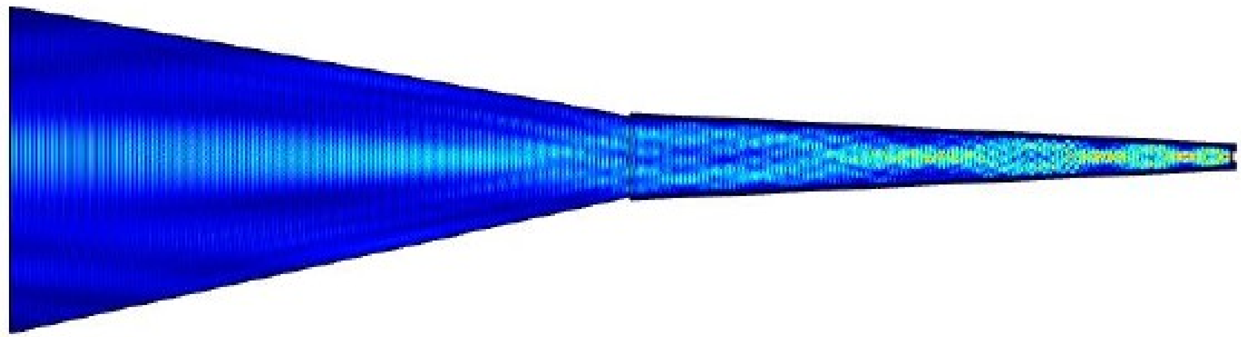
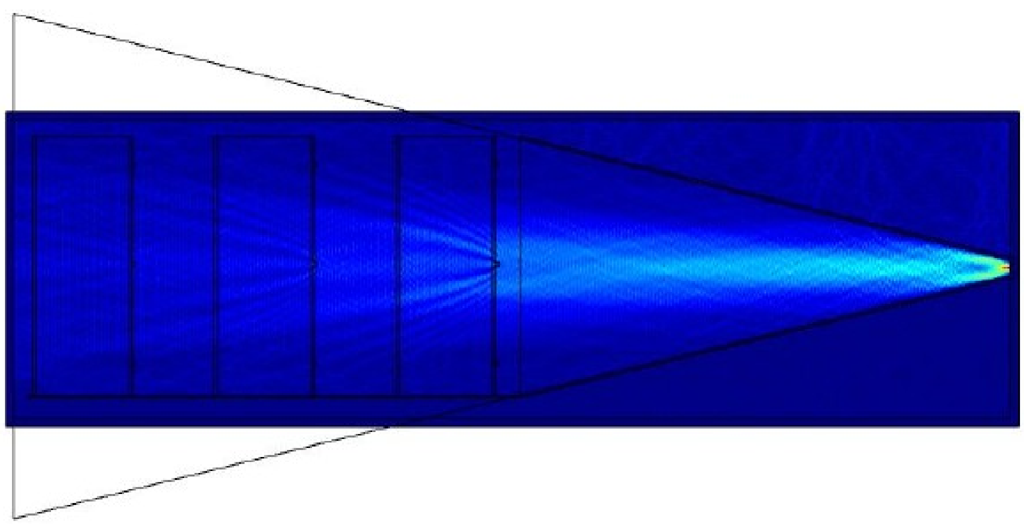
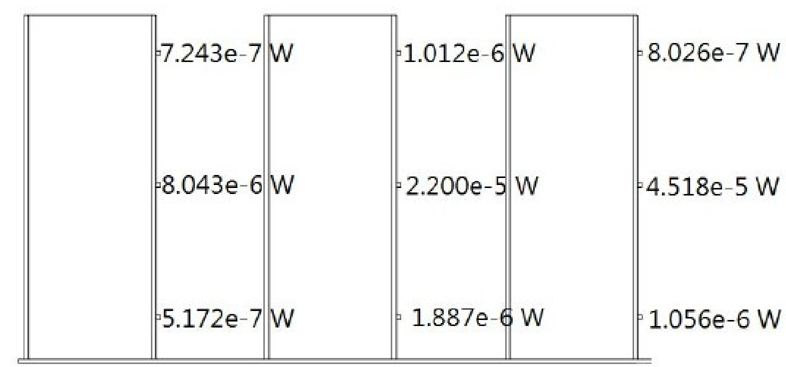
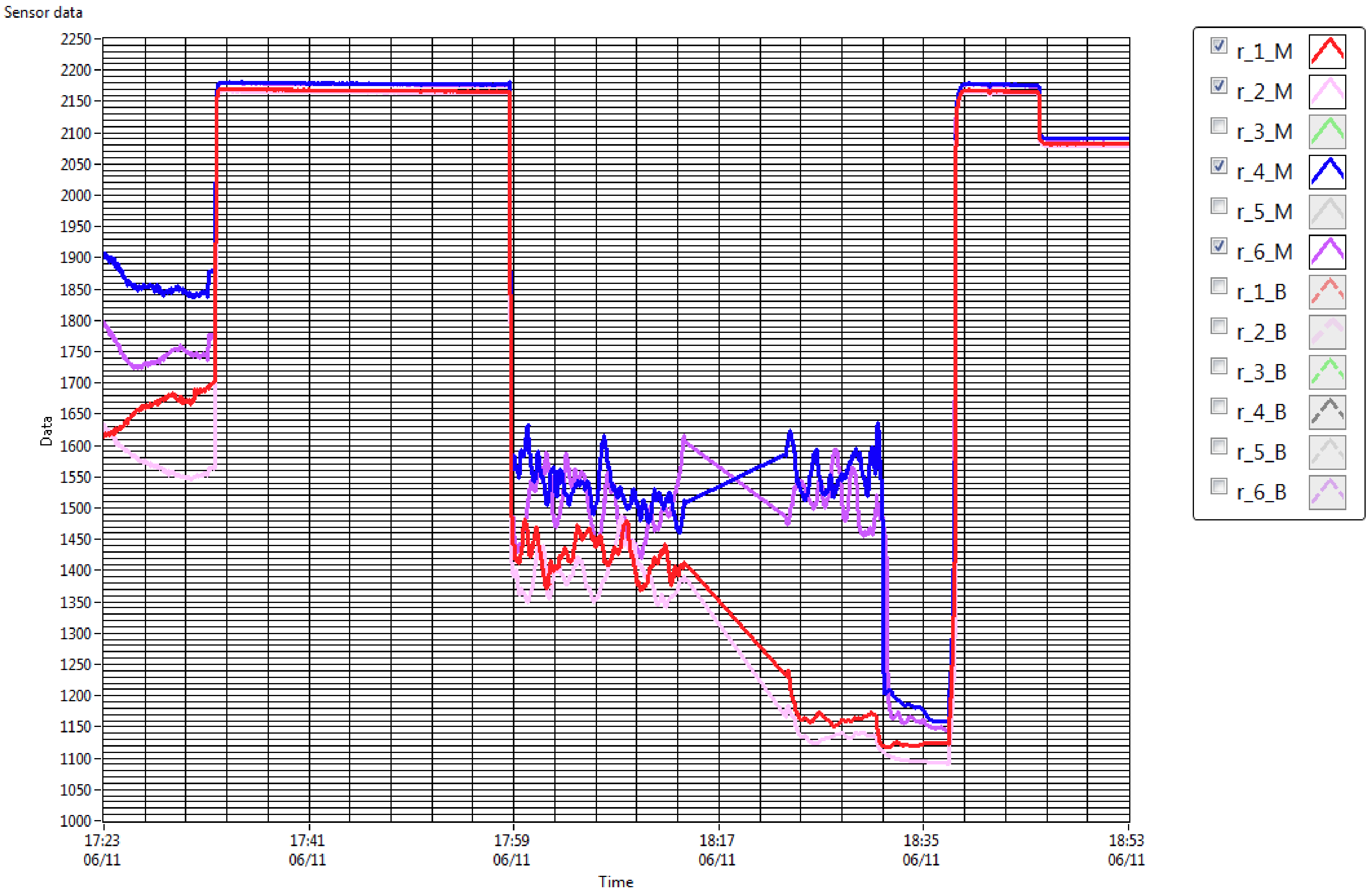


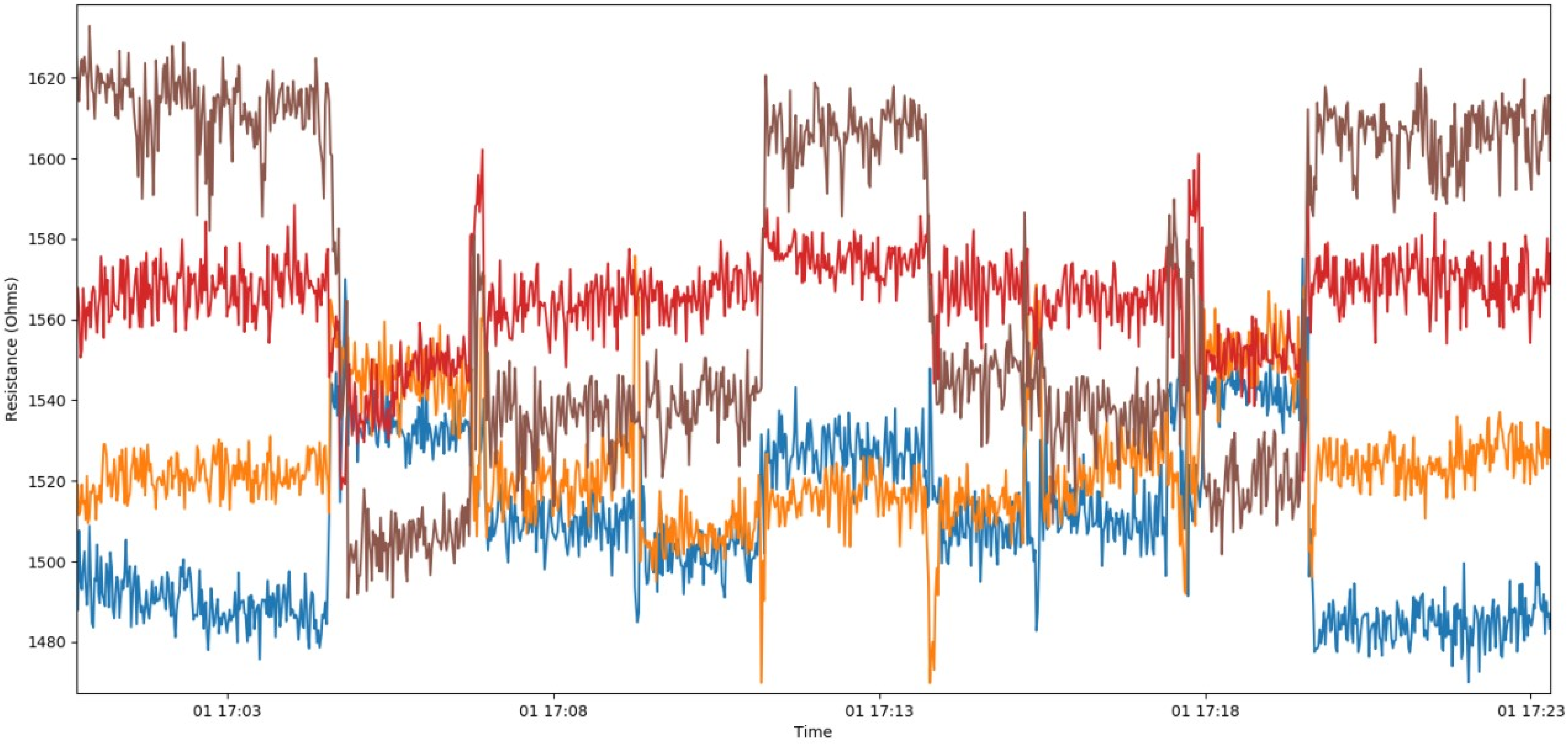




Absorption at Resonance



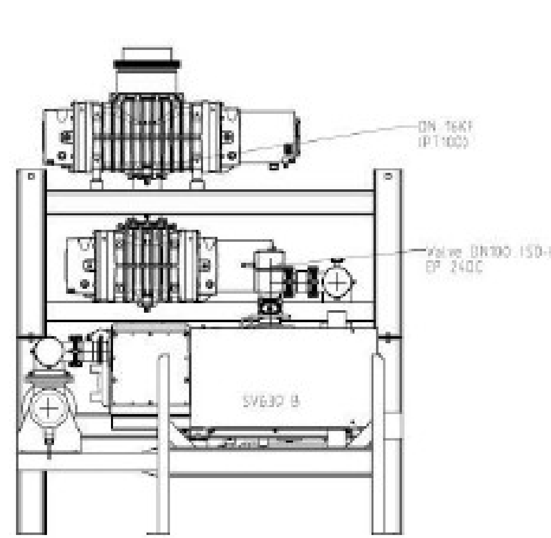
Microwave Studies

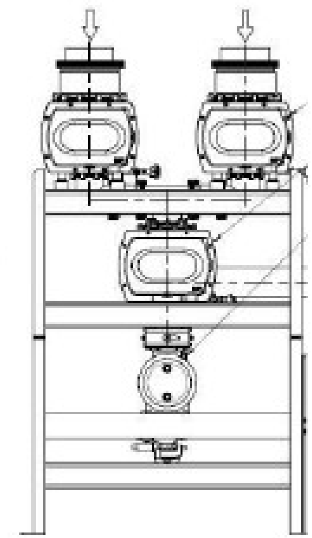


POLARIZED TARGET SUBSYSTEMS

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

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

Production

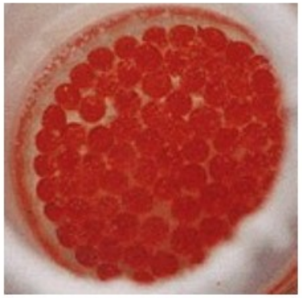
- dedicated setup to produce NH3 beads
- NH3 gas slowly frozen above LN2 bath
- ~1000 g is needed for 2 yr run
- ~450 g currently produced
- purchased three LN2 dewars for storage

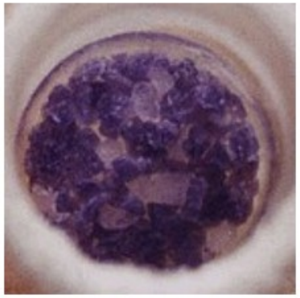
Pre-Irradiation

- 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

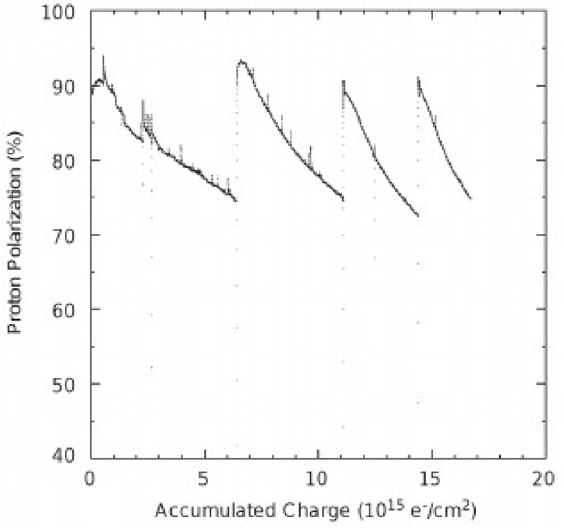
- Successful material for DNP characterized by three measures:
    1. Maximum polarization
    2. Dilution factor
    3. Resistance to ionizing radiation

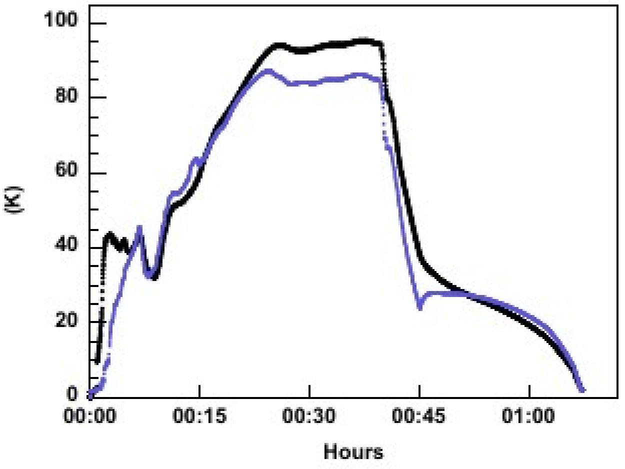


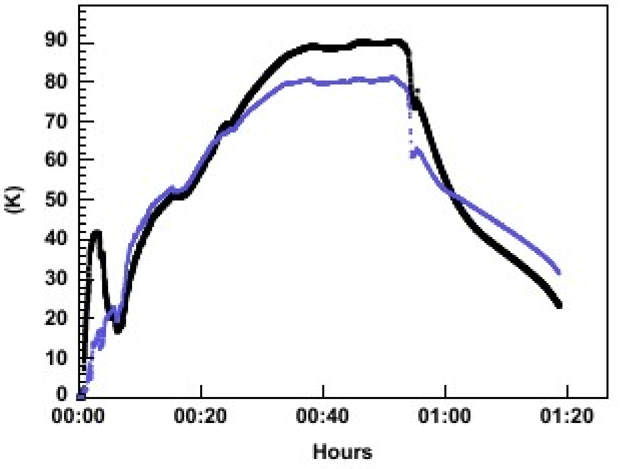


Material	Butanol	Ammonia, NH_3	Lithium Hydride, ^7LiH
Dopant	Chemical	Irradiation	Irradiation
Dil. Factor (%)	13.5	17.6	25.0
Polarization (%)	90-95	90-95	90
Material	D-Butanol	D-Ammonia, ND_3	Lithium Deuteride, ^6LiH
Dil. Factor (%)	23.8	30.0	50.0
Polarization (%)	40	50	55
Rad. Resistance	moderate	high	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

A Word on Systematics

Target Temperature Change over beam spill

Microwave Profile

Dose Accumulation

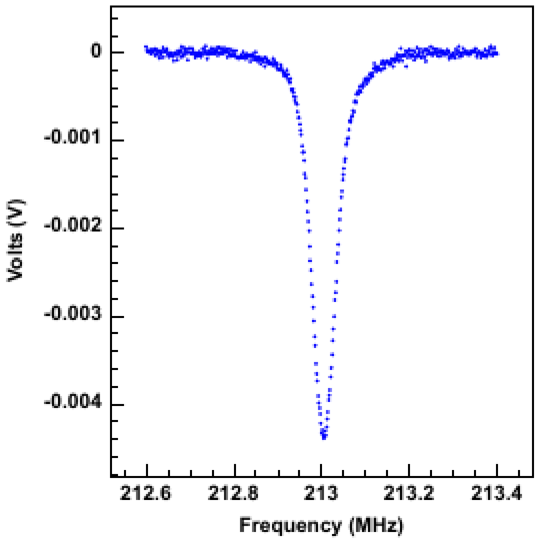
TE Calibrations Take Time

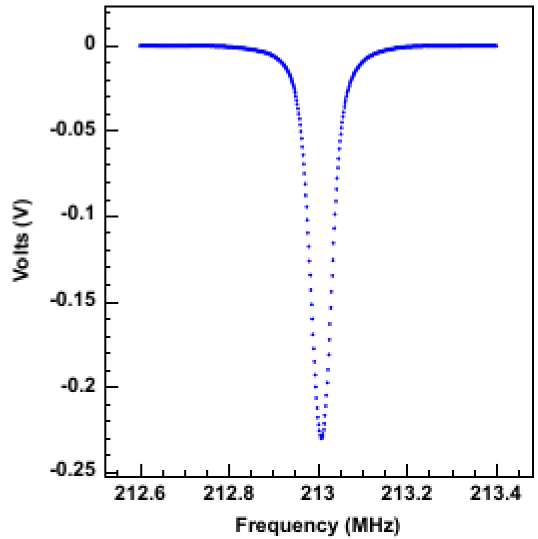
Dilution Factor and Packing Fraction

NIM A 728 (2013) 133-144

Polarization Calibration and Measurement

~0.3%

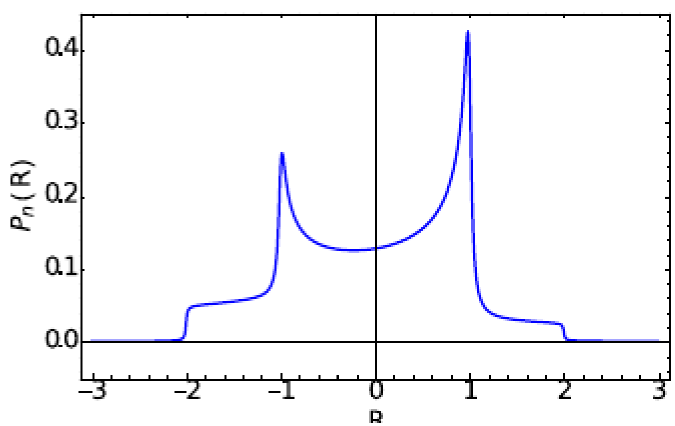


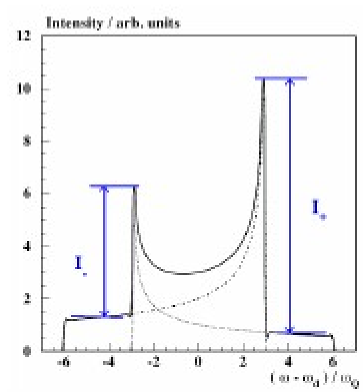


Proton

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

~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

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

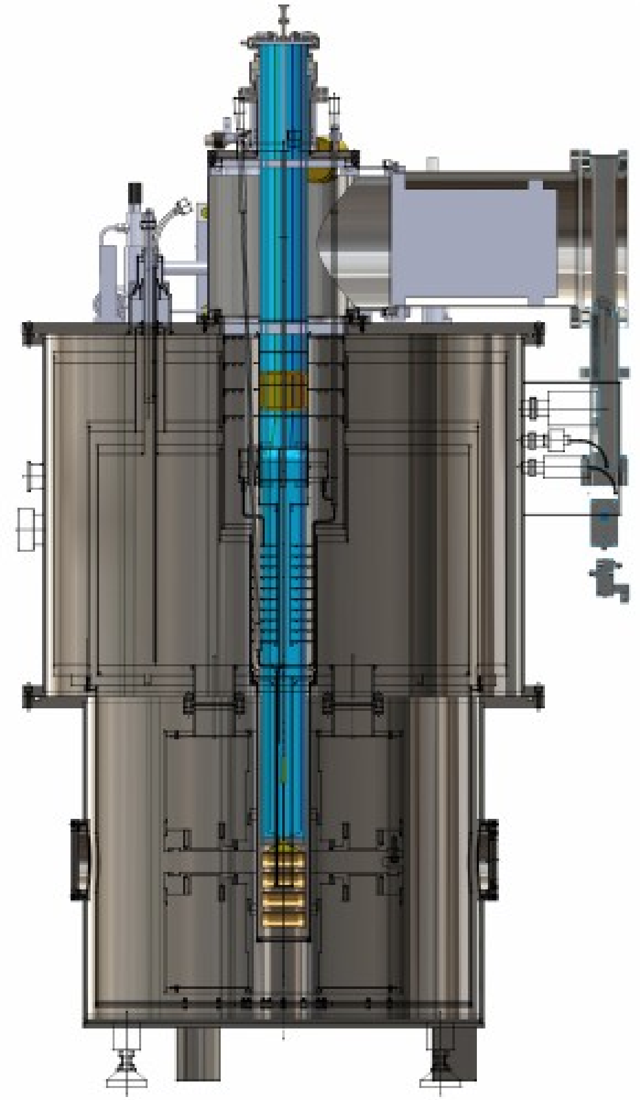
Procedural errors
can be to be pretty small:
Assuming the right procedure
(Target is thermalized to TE)

(#)	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

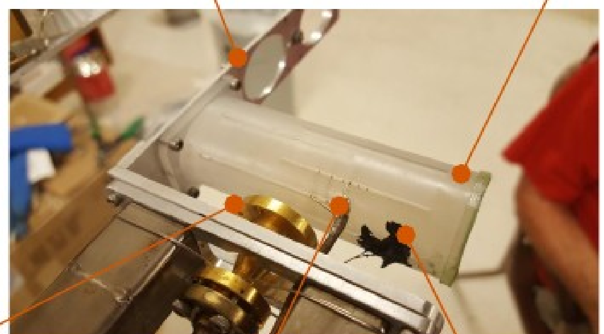
UVA Cooldowns

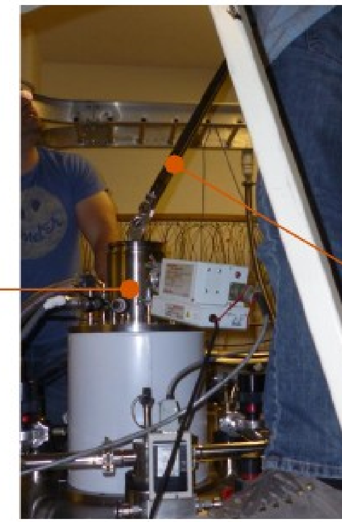


3 Test Full System

Final preparations and run

made test target insert, practiced installation





getting cold

Last Cooldown Highlights

Got Insulating Vacuum down to 3.7X10^-6, average boil off 17 SLM

First Polarization of ND3: 20%

Coil Position Tests:
Position 1: coil 1=80%, coil 2=85%, coil 3=80%
Position 2: NM
Position 3: Coil 1=78%, Coil 2=85%, Coil 2=NM
Position 4: Coil 1=NM, 80%, coil 3=85%

Magnetic Field Drifts: 0.02A/4days

Generate Field Map

Cryogenic Performance

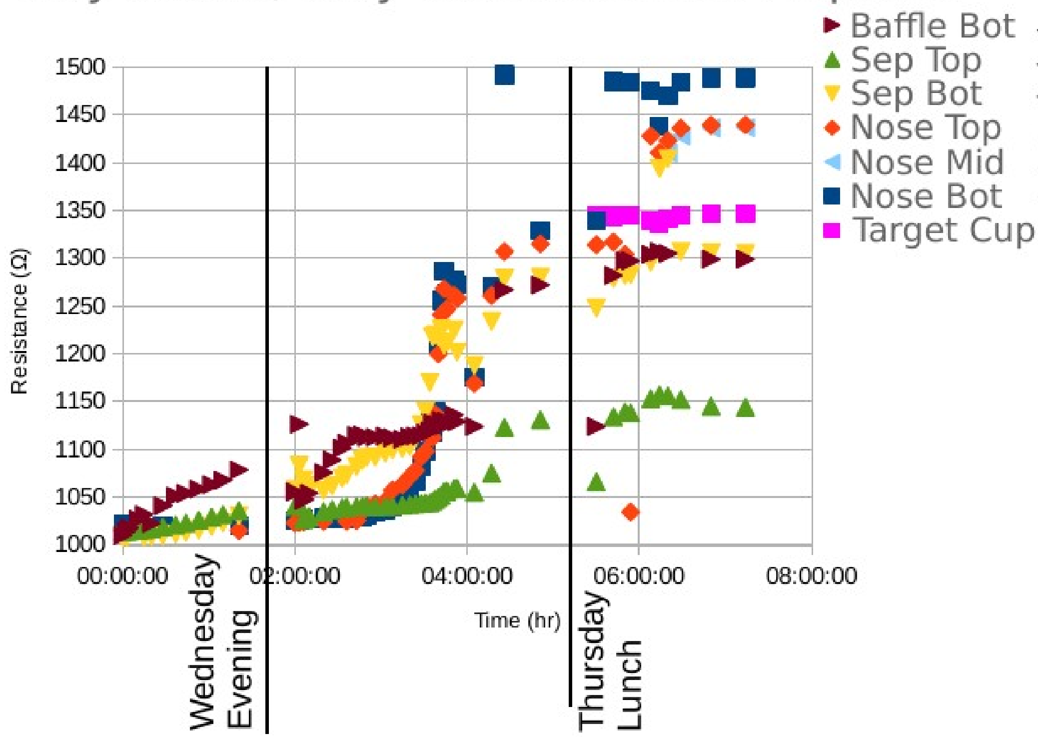
Test results

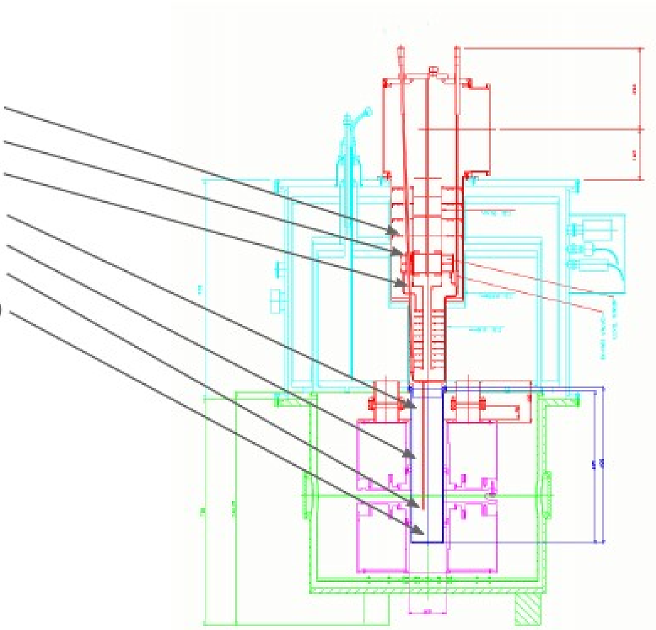
Fridge performance

separator and nose fill

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

very stable, very little attention required





Results of All the Work

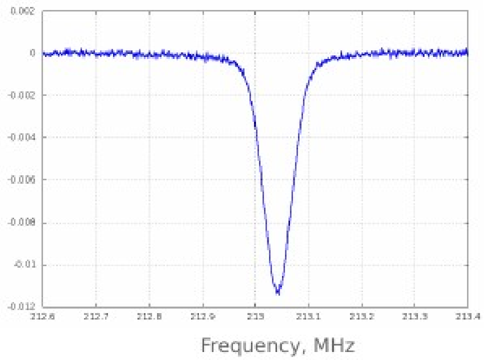
Test results

Polarization

polarized fresh NH3 both positively and negatively

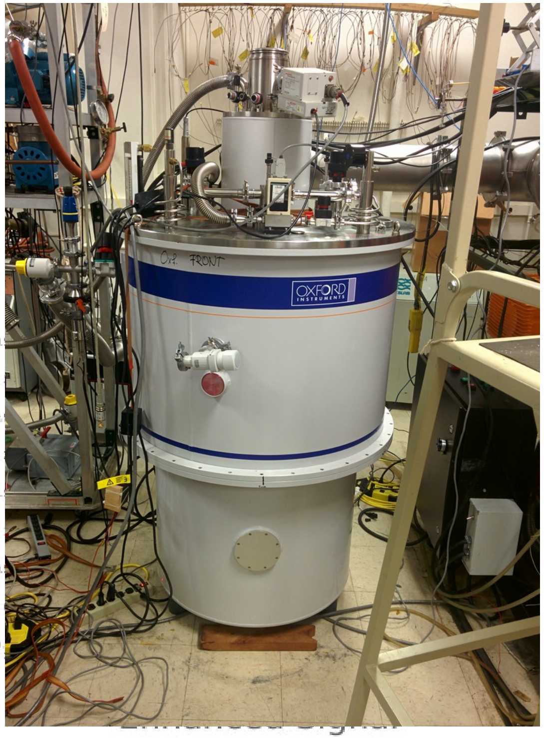
took extensive TE measurements

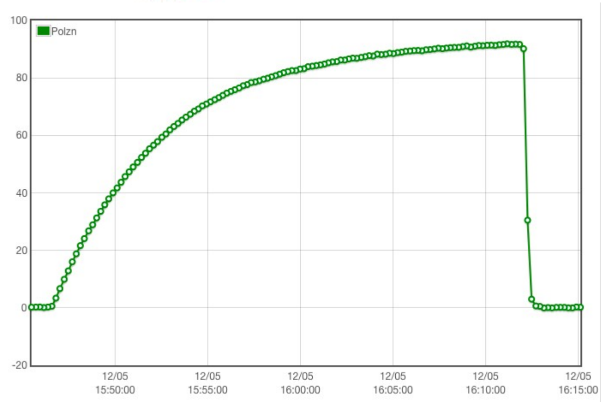
alternated UVA and new LANL NMR systems

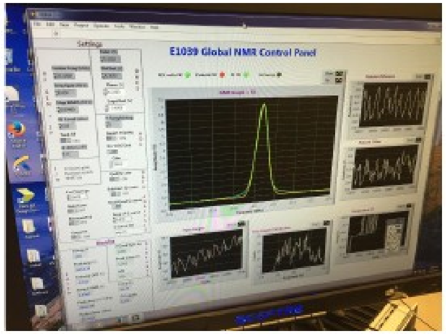


TE signal

UVA NMR Signal

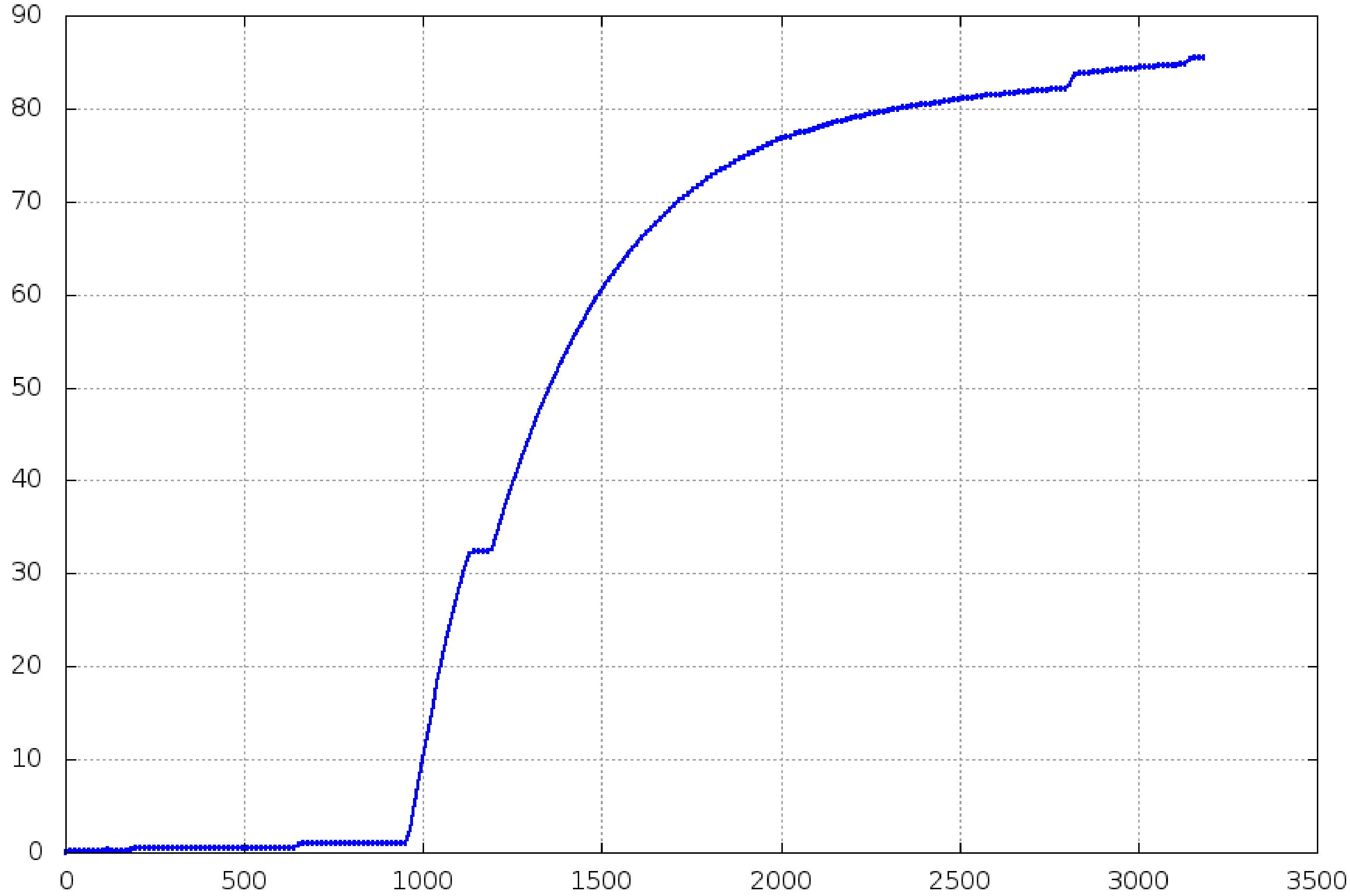






LANL NMR Signal

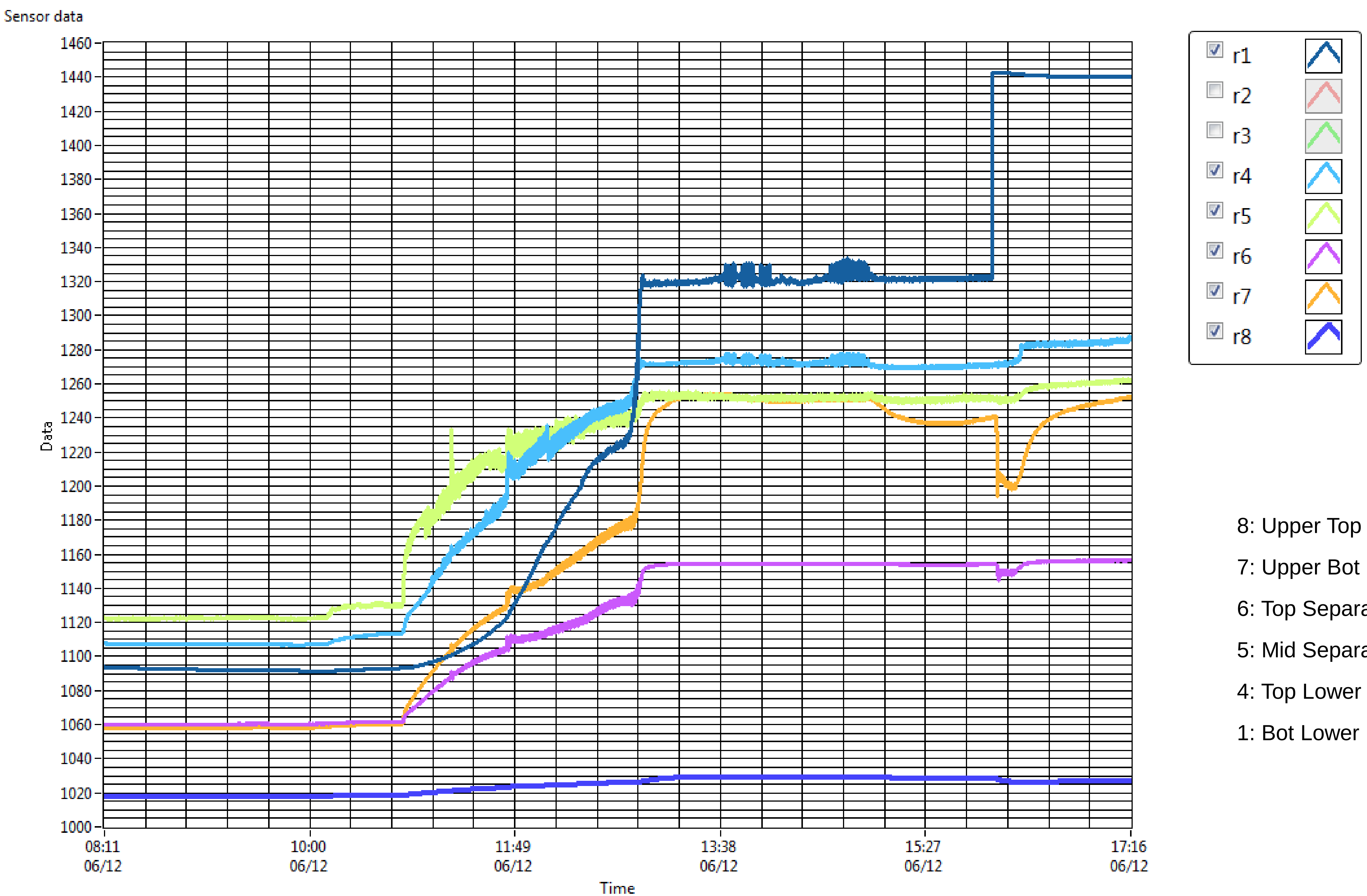
Initial Run: Central Top Coil



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

Results of This Cooldown

Fridge Sensors



8: Upper Top HX

7: Upper Bot HX

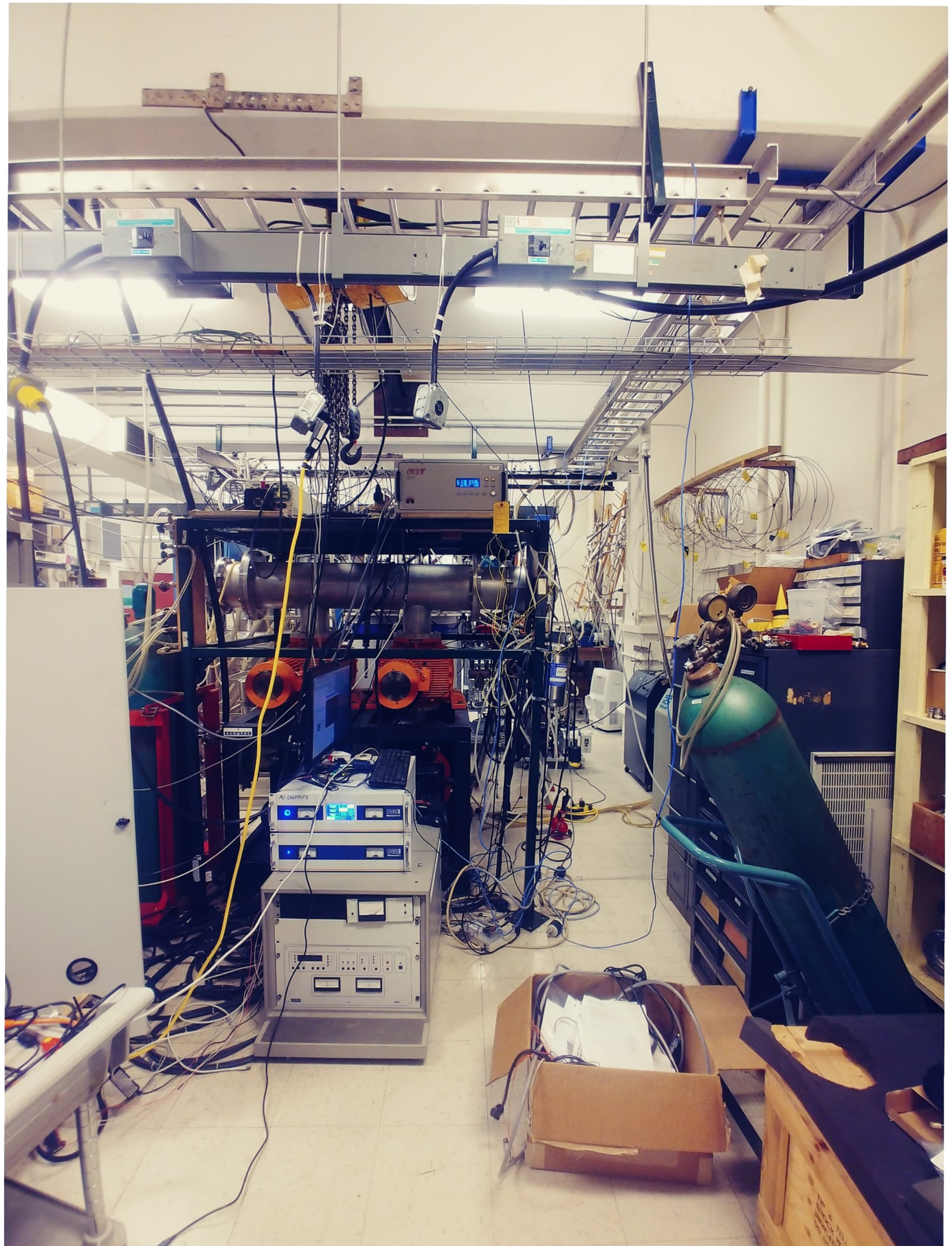
6: Top Separator

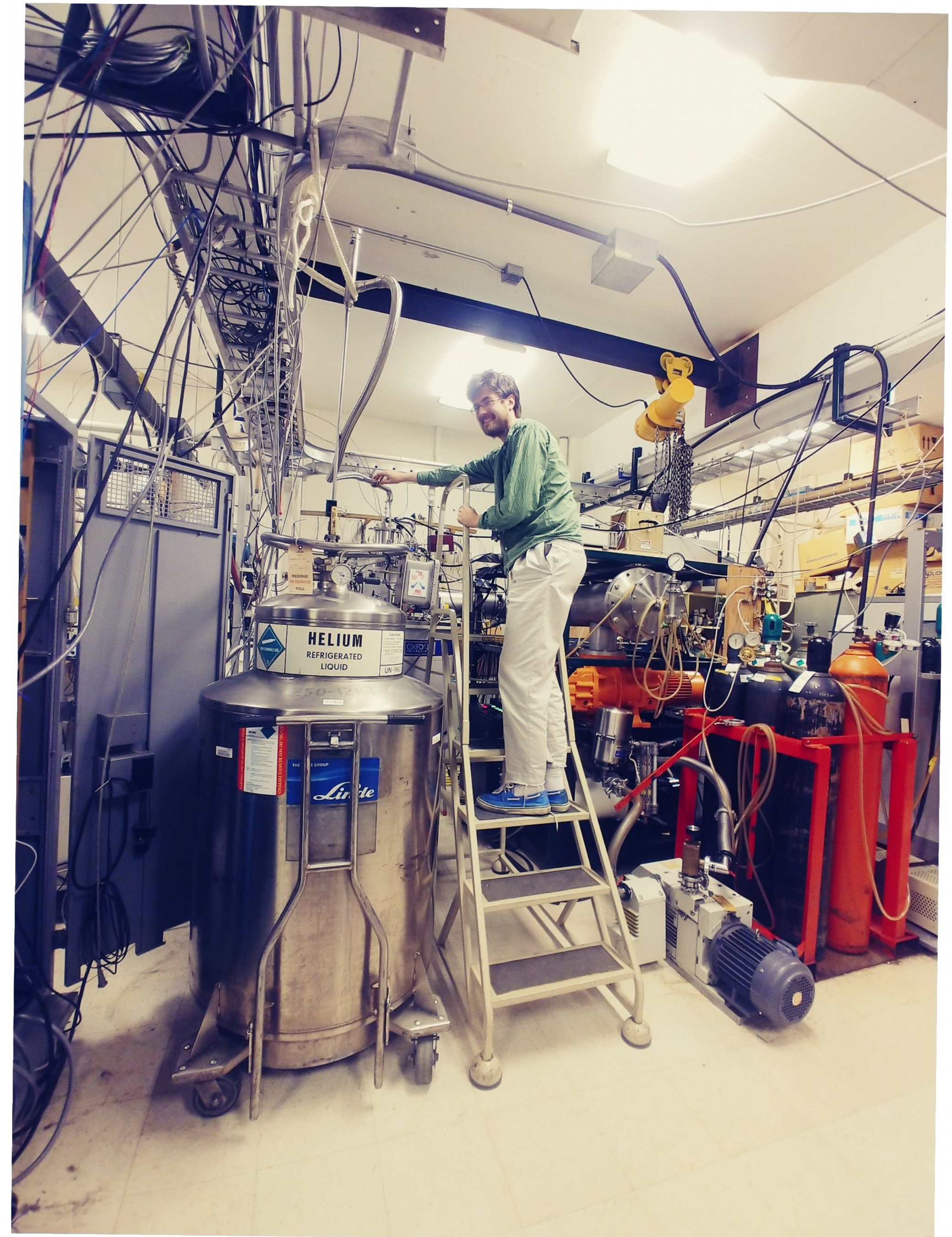
5: Mid Separator

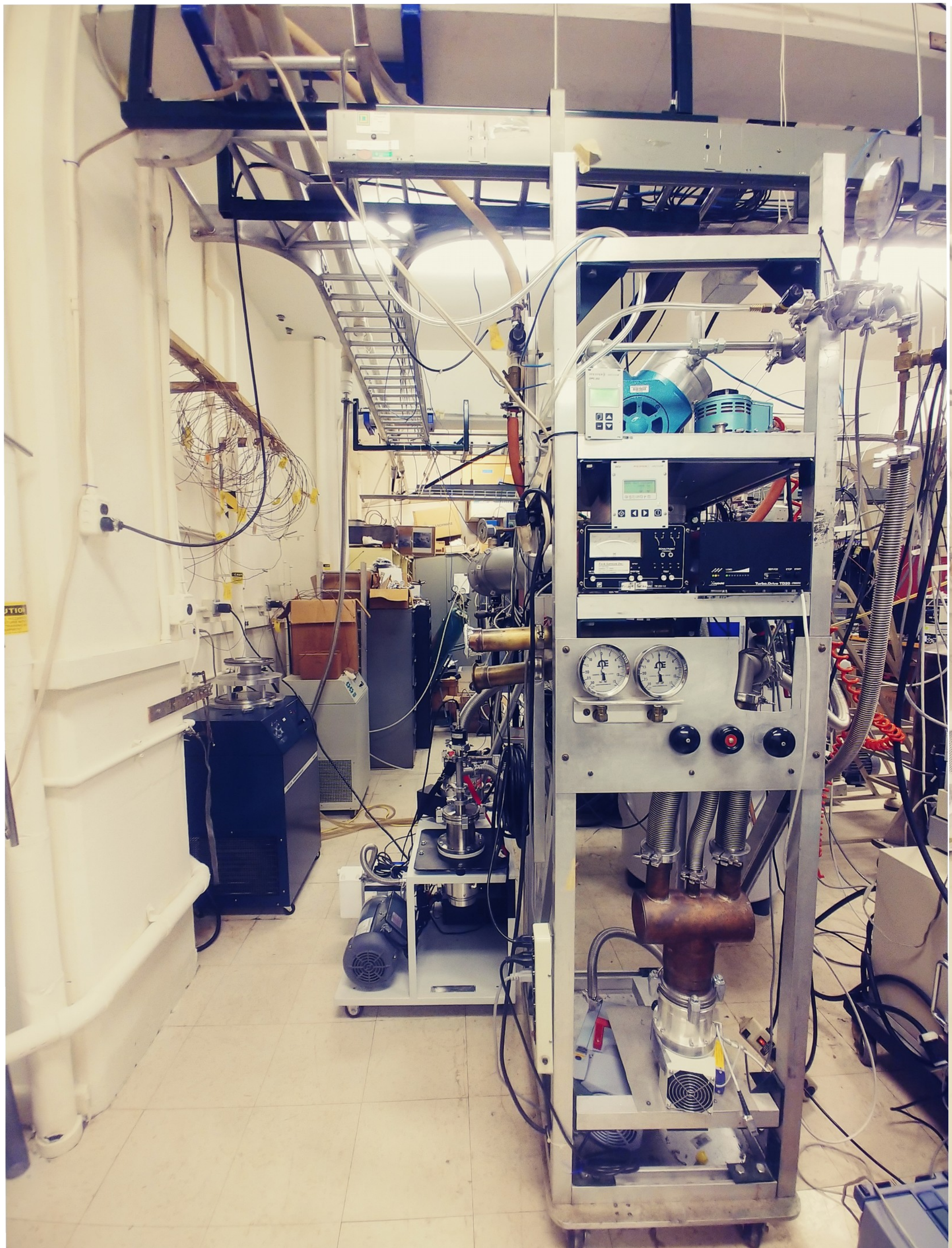
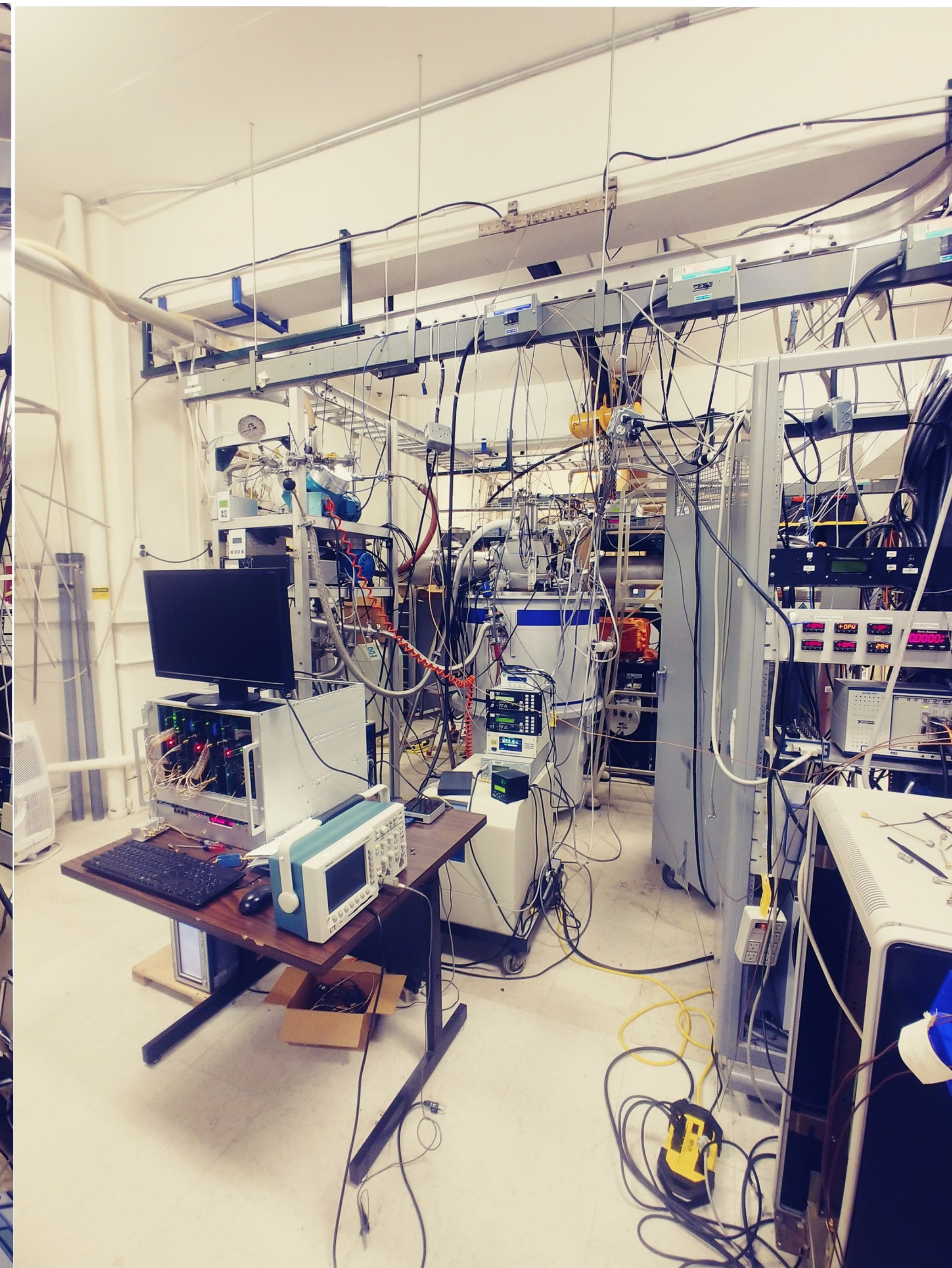
4: Top Lower HX

1: Bot Lower HX


OXFORD
INSTRUMENTS




HELIUM
REFRIGERATED
LIQUID


250-1485
HELIUM
REFRIGERATED
LIQUID
CAUTION
UN-1963
NON-MAGNETIC
OXFORD
INSTRUMENTS
DANGER
HIGH VOLTAGE

Focus on Slow Controls and Automation and Hardware

MKS - Main Flow

MKS - Separator Flow Control

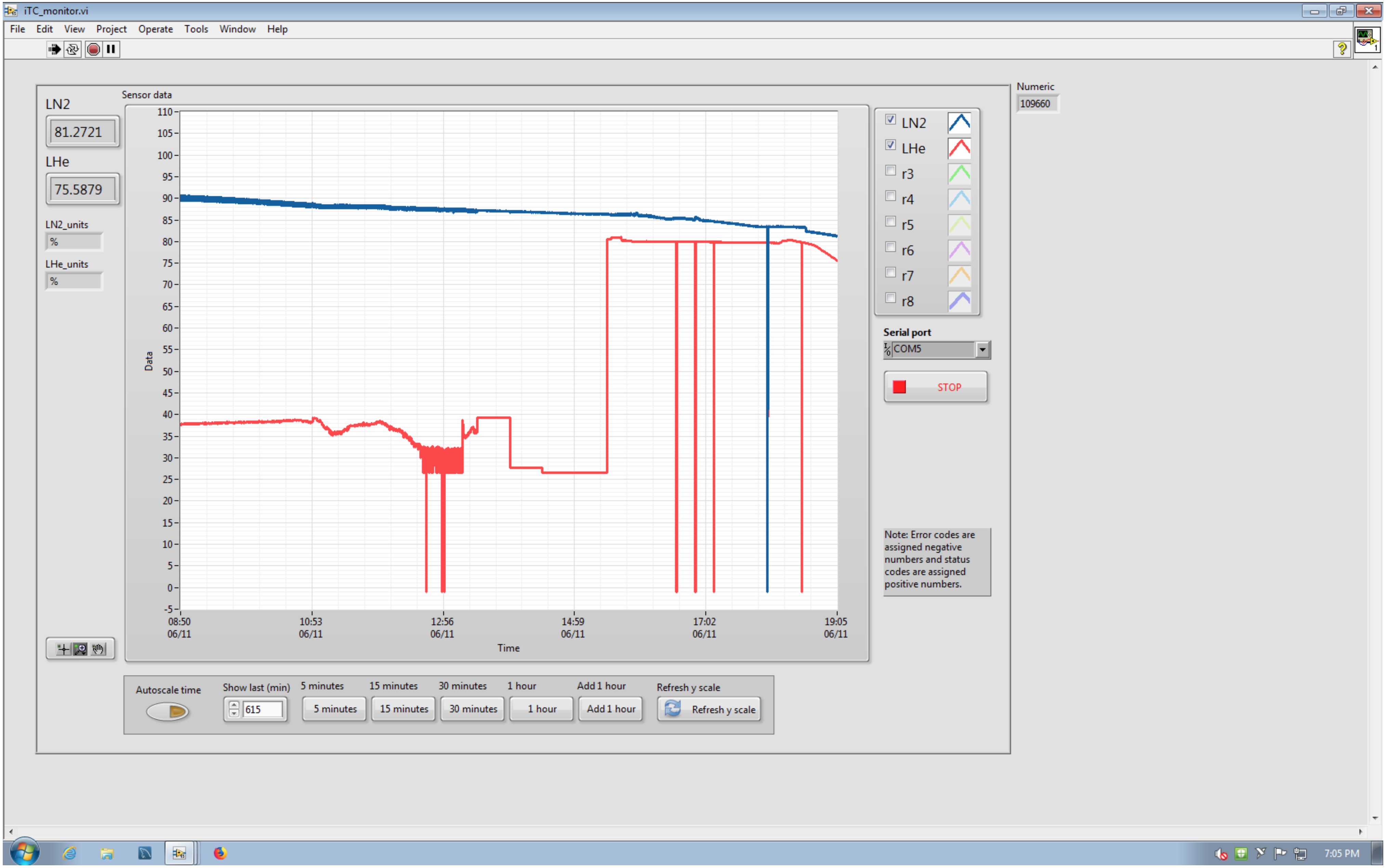
Run Valve Repair

He3-pressure

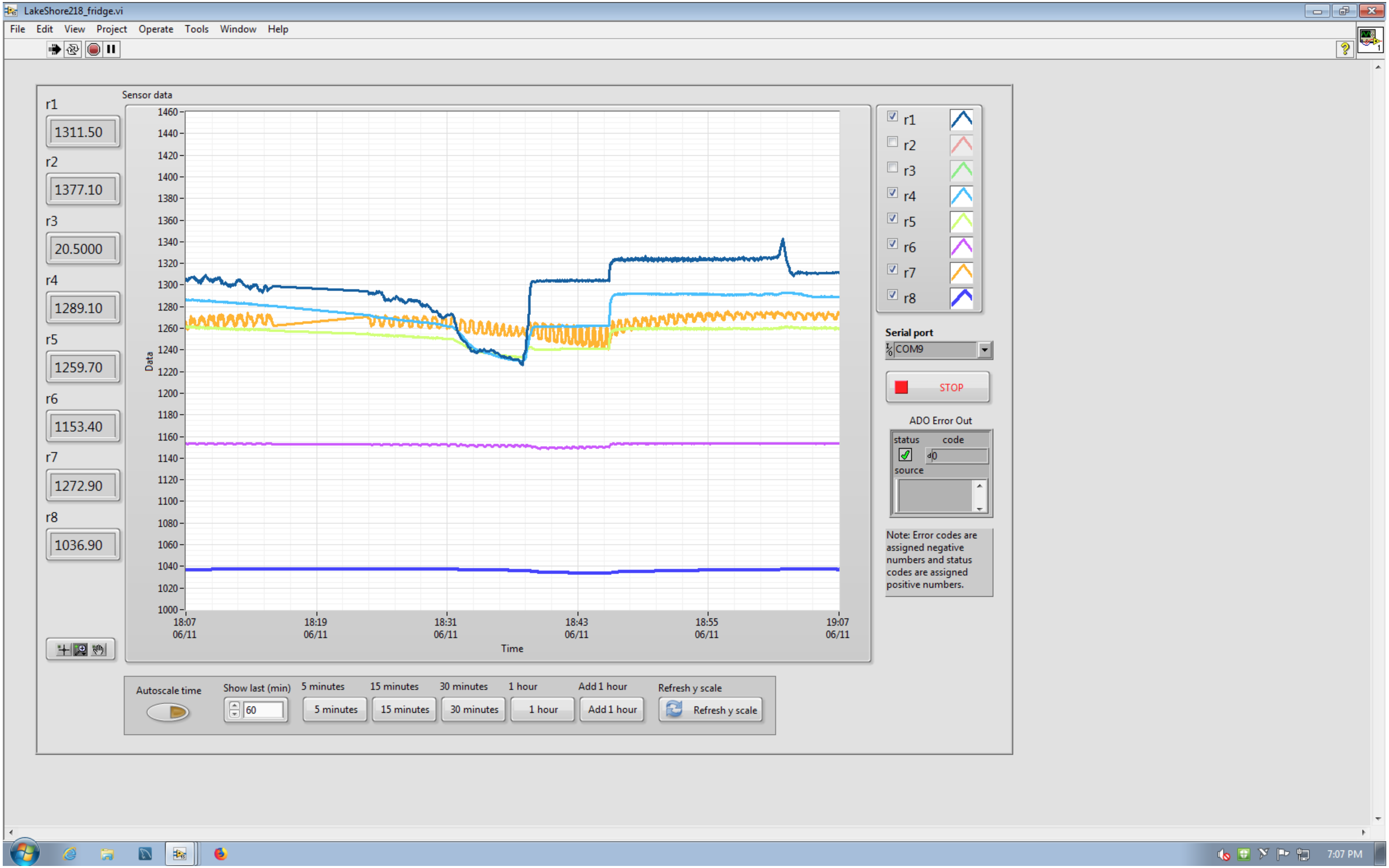
Software - first time all at once

Target Insert Sensors

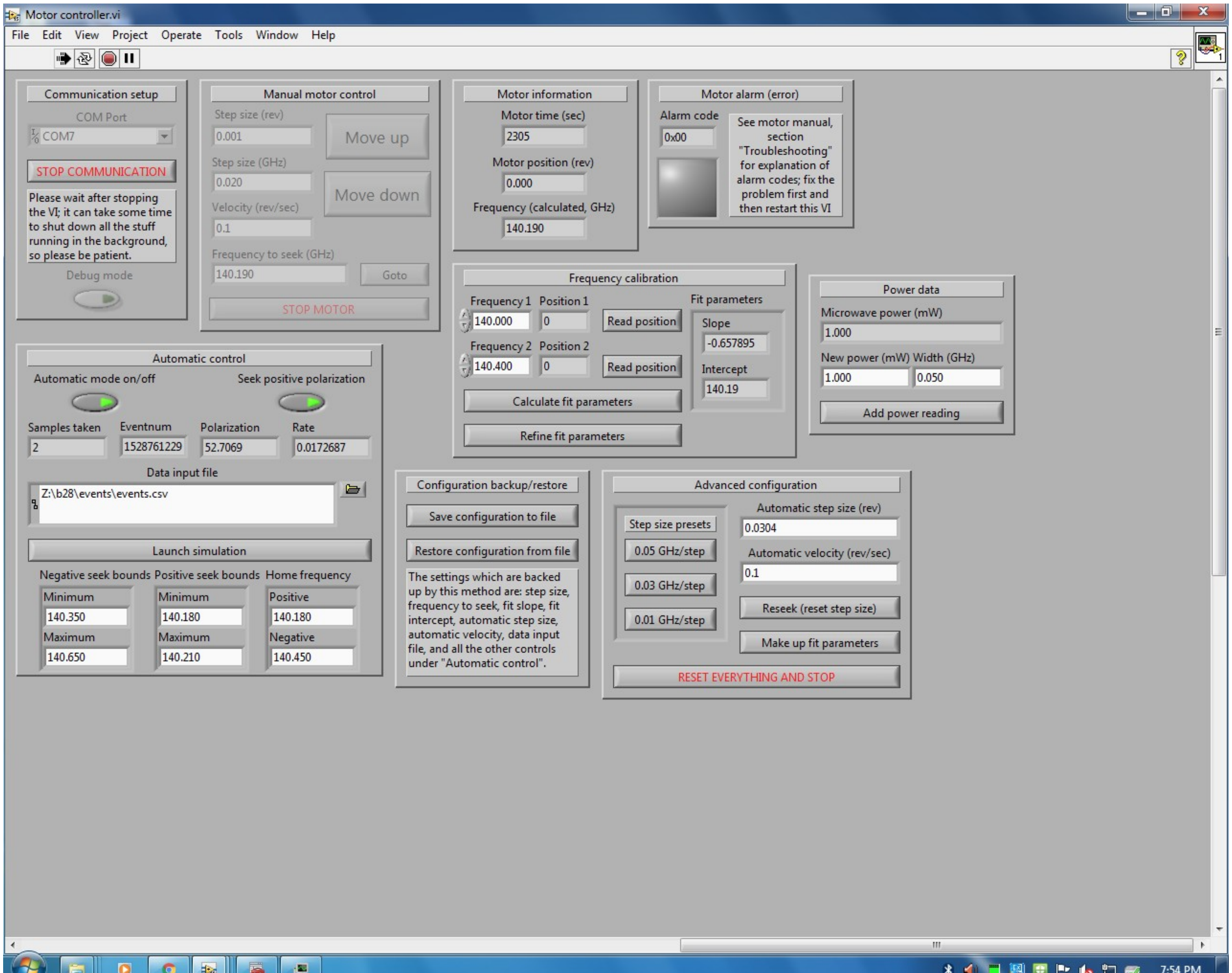
Liquid Helium and Nitrogen Level



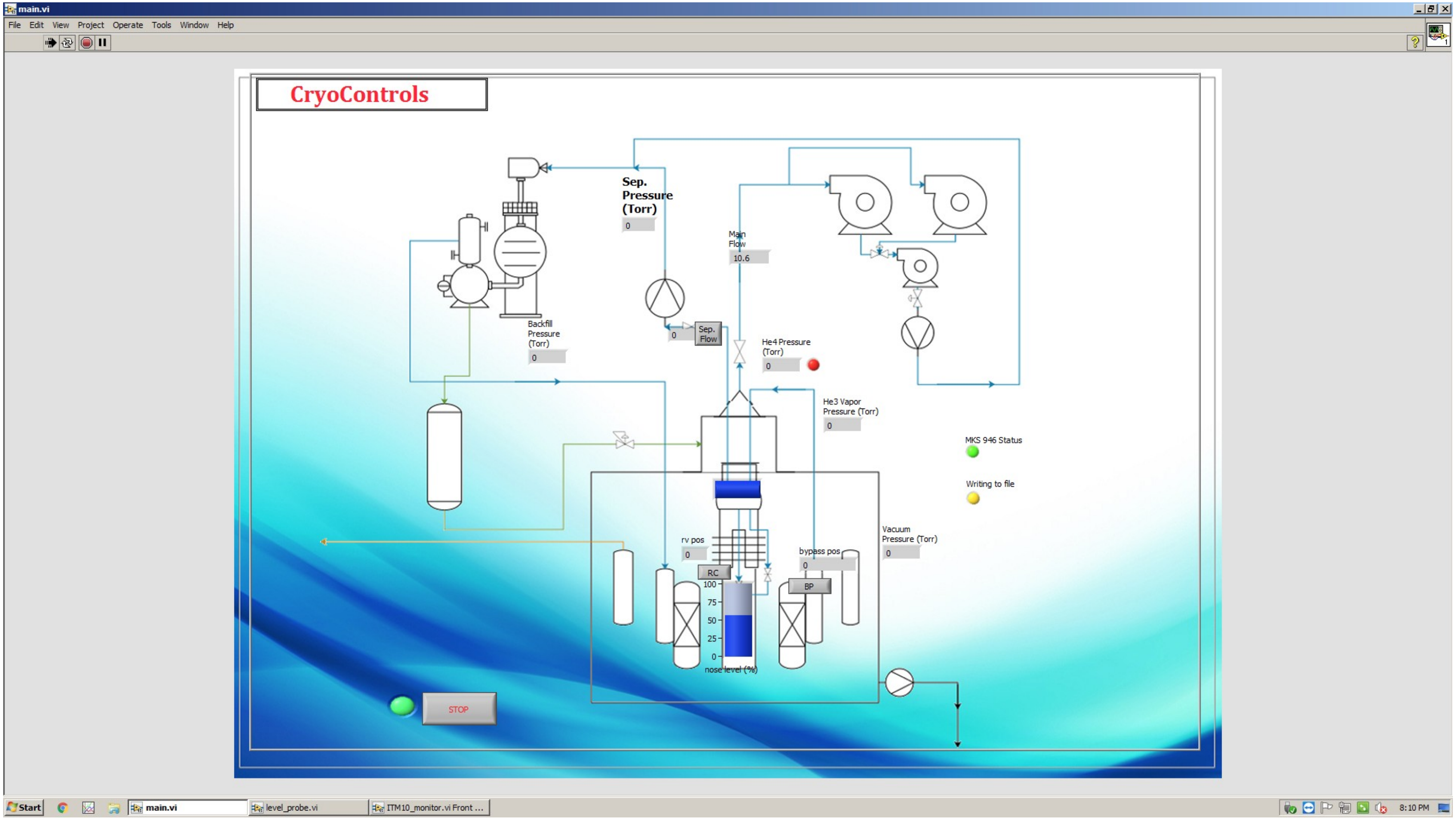
Fridge Sensors



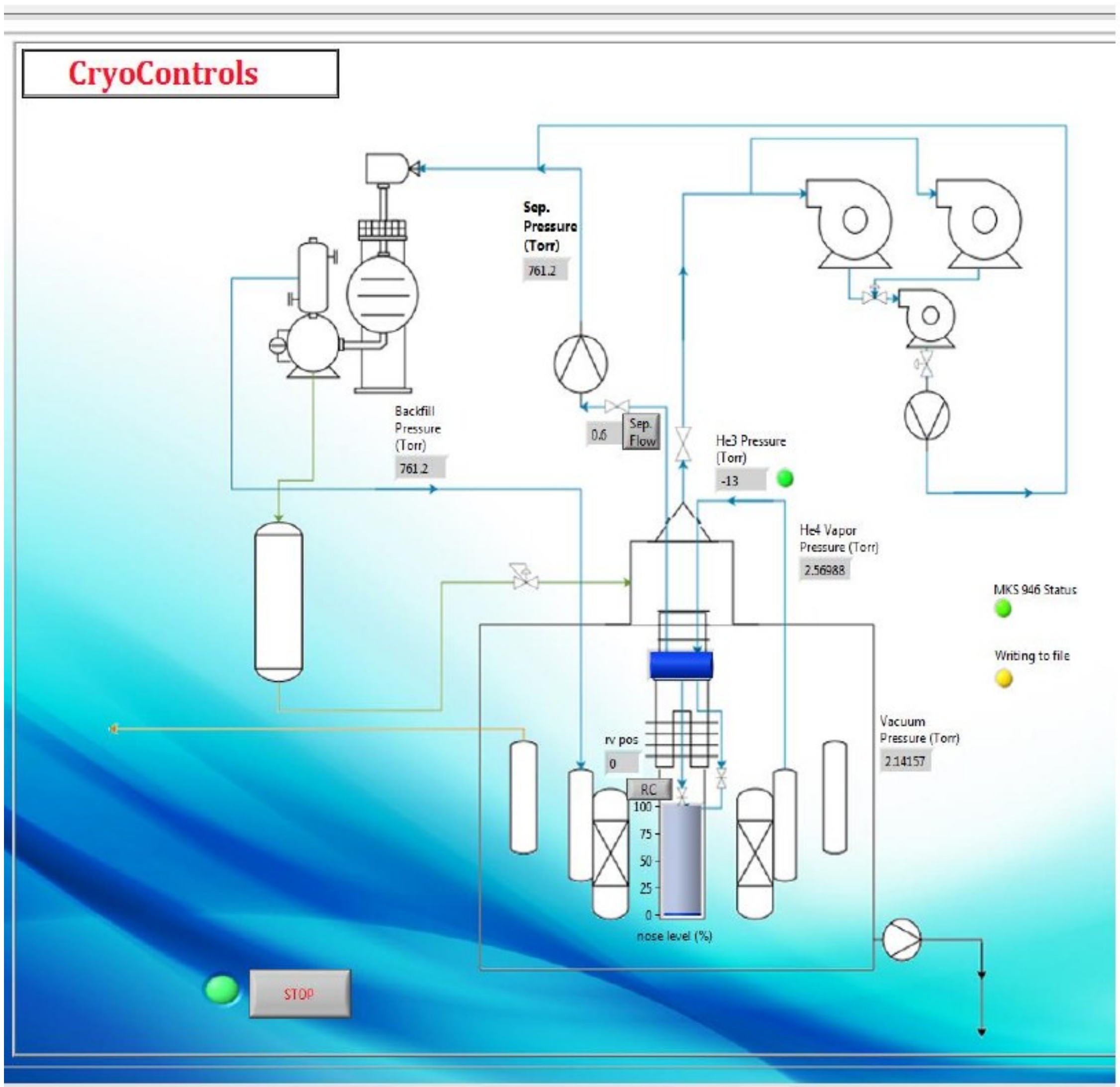
Microwave Control VI



Cryocontrols



The main cryocontrol VI



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

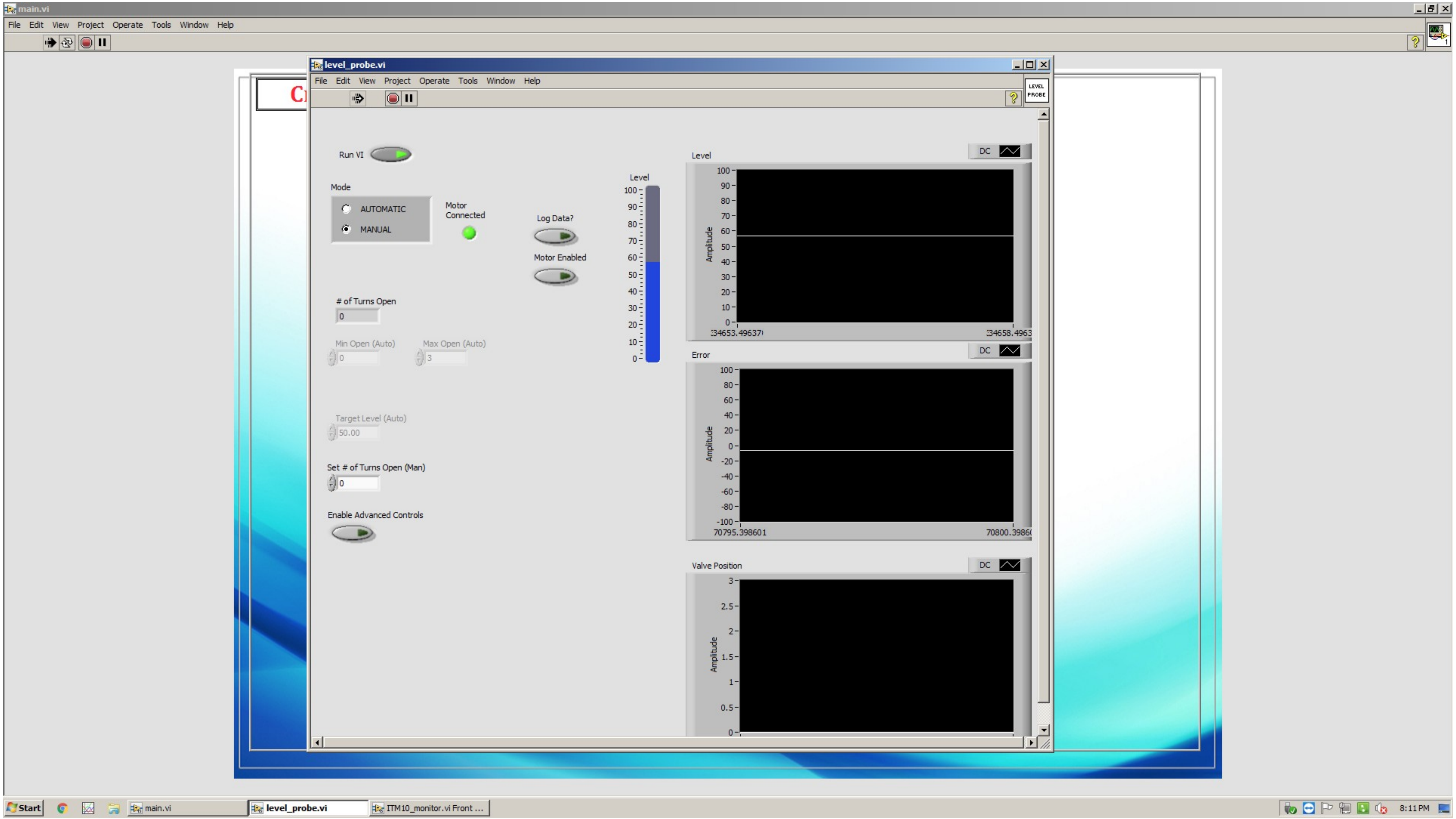
This also include buttons to access the flow, pressure and valve position controls next to their reading.

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

Graphics shows where these readings are from.

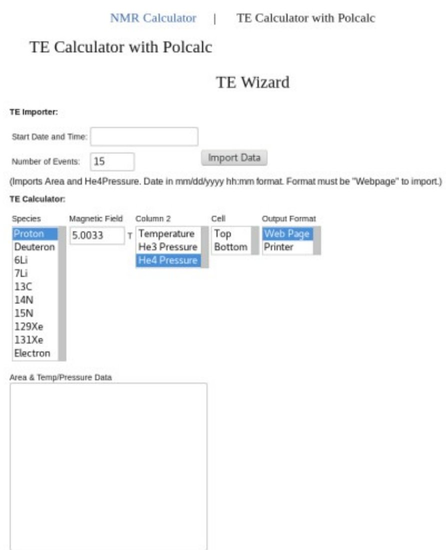
Logs all the readings to a text file ~each second.

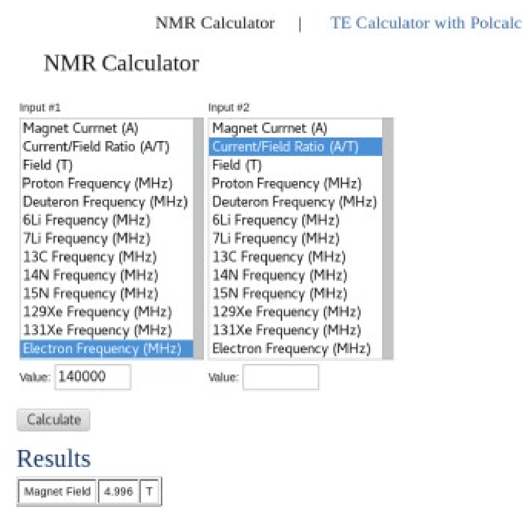
Pop-up Controls



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

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 m^3/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 8 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 and 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 E906/E1039 docdb

Fermilab E906/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):

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

Join from PC, Mac, Linux, iOS or Android
Target Meetings
Meeting ID: 438821341

LabView Meetings
Meeting ID: 705516494

The Solid Polarized Target Group-UVa

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

Minimum Target Personnel

- Team Leader + Senior Advisers
- Min. 3 Target Experts (on call near exp)
- Min. 1 Slow Controls Software Expert
- Min. 1 Target Technicians
- Dedicated grad and undergrads students
- Target Operators: all collaboration members, training materials will be provided by UVA

Still to Come

- Secondary pressure/temp sensor calibration (^{3}He bulb-Just test) +MKS Units
- Infrastructure for target changes Moving to FNAL
- Cold NMR system optimal signal to noise for Deuteron/Neutron Still UVA
- Configure one stick with 3 active cells 2 cold-NMR one warm 3 inserts now
- Remote Control for Microwave (further testing) add modulation
- Cryosystem auto-control (further testing)
- Annealing system (testing needed with temp sensors on insert) testing still needed
- 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?

Fridge cooldown:
UVA

Magnet cooldown:
FNAL