LANL/UVA Solid Polarized Targets

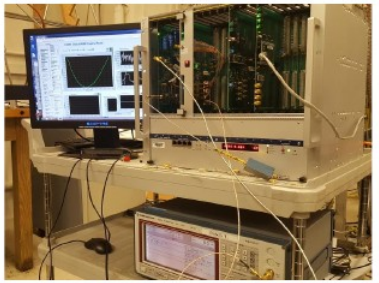
Dustin Keller
University of Virginia

Progress and developments with E1039 polarized target system

Outline

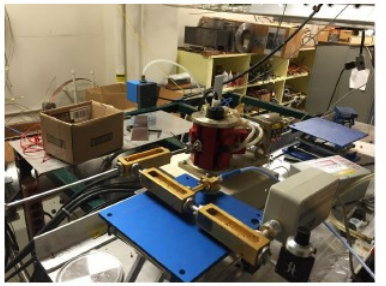
- Status on the Target
- Results of UVA Test Run
- SPT Expectations and Uncertainties
- Personnel Requirements
- Still to Come

E1039 Polarized Target



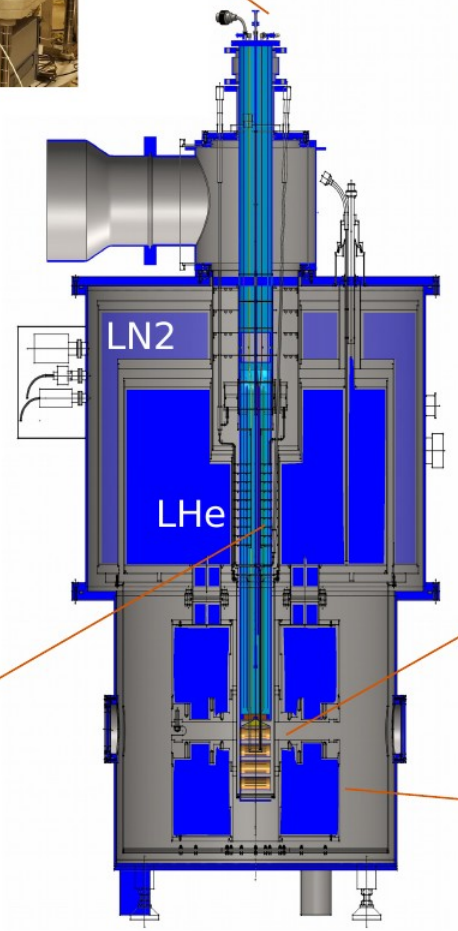
NMR

Insert



Microwave

Pumps



Target material

Fridge

Magnet

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

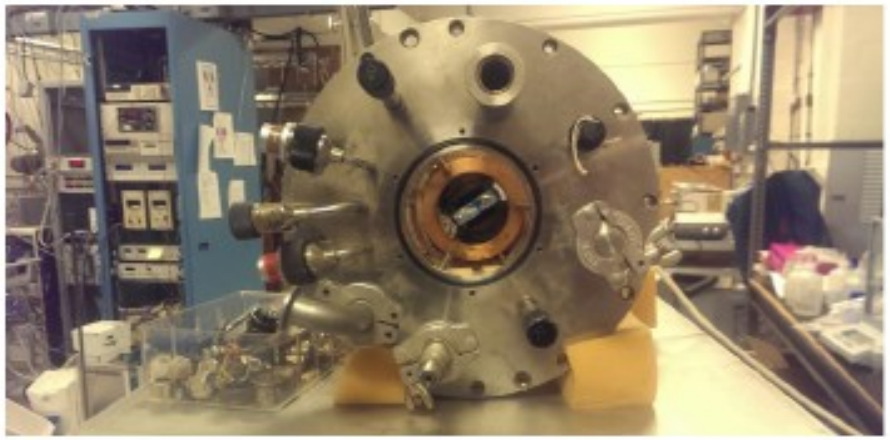
magnet is in a very good shape

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



POLARIZED TARGET SUBSYSTEMS

Magnet | **Fridge** | Insert | NMR | Microwave | Pumps | Target materi

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

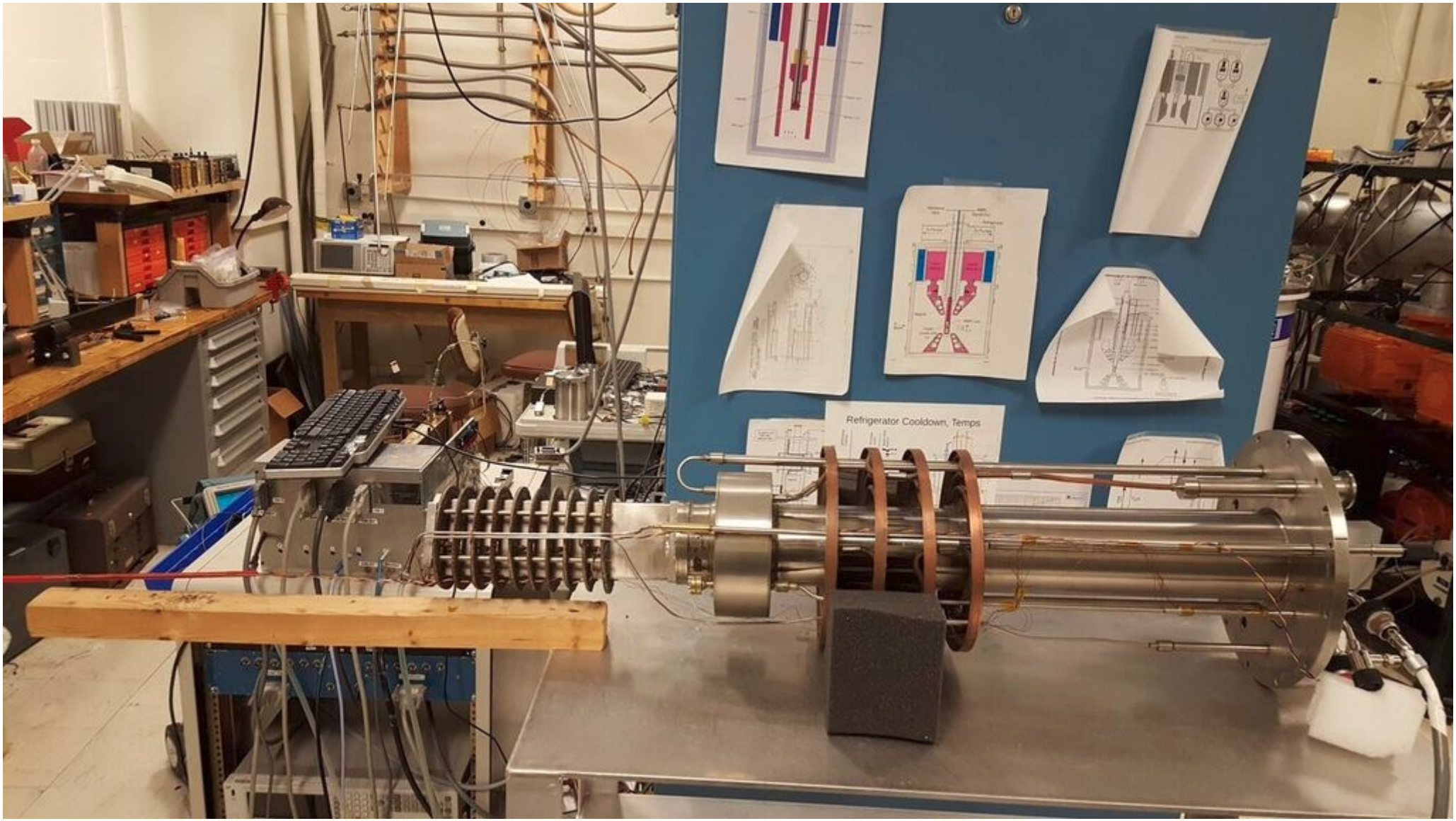
Fridge alignment

- made laser setup
- shell, fridge, turret and piston rotation
- target insert length

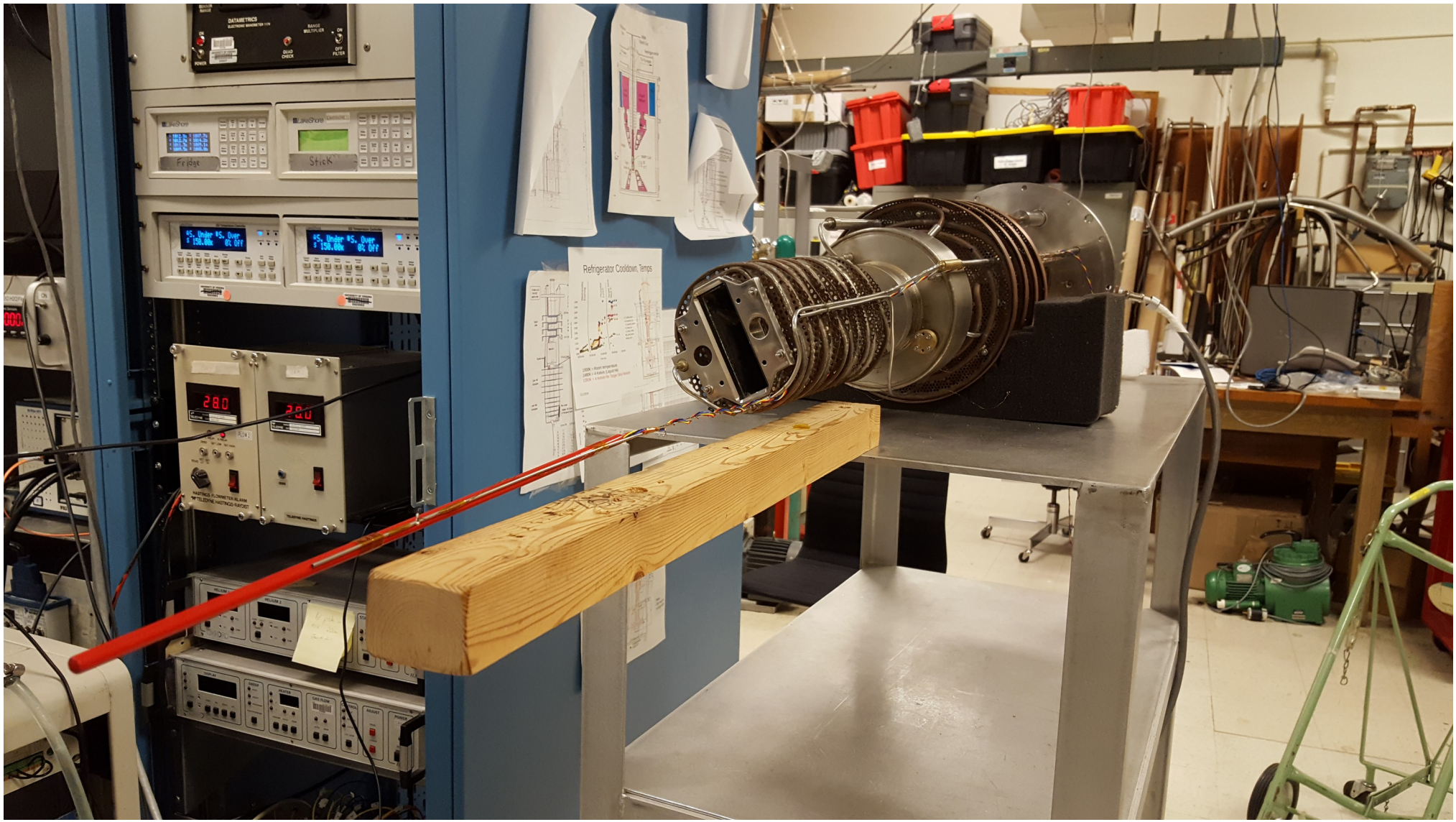
Fridge tests

- 4th and 5th cooldowns
- reached 1K 07/2015

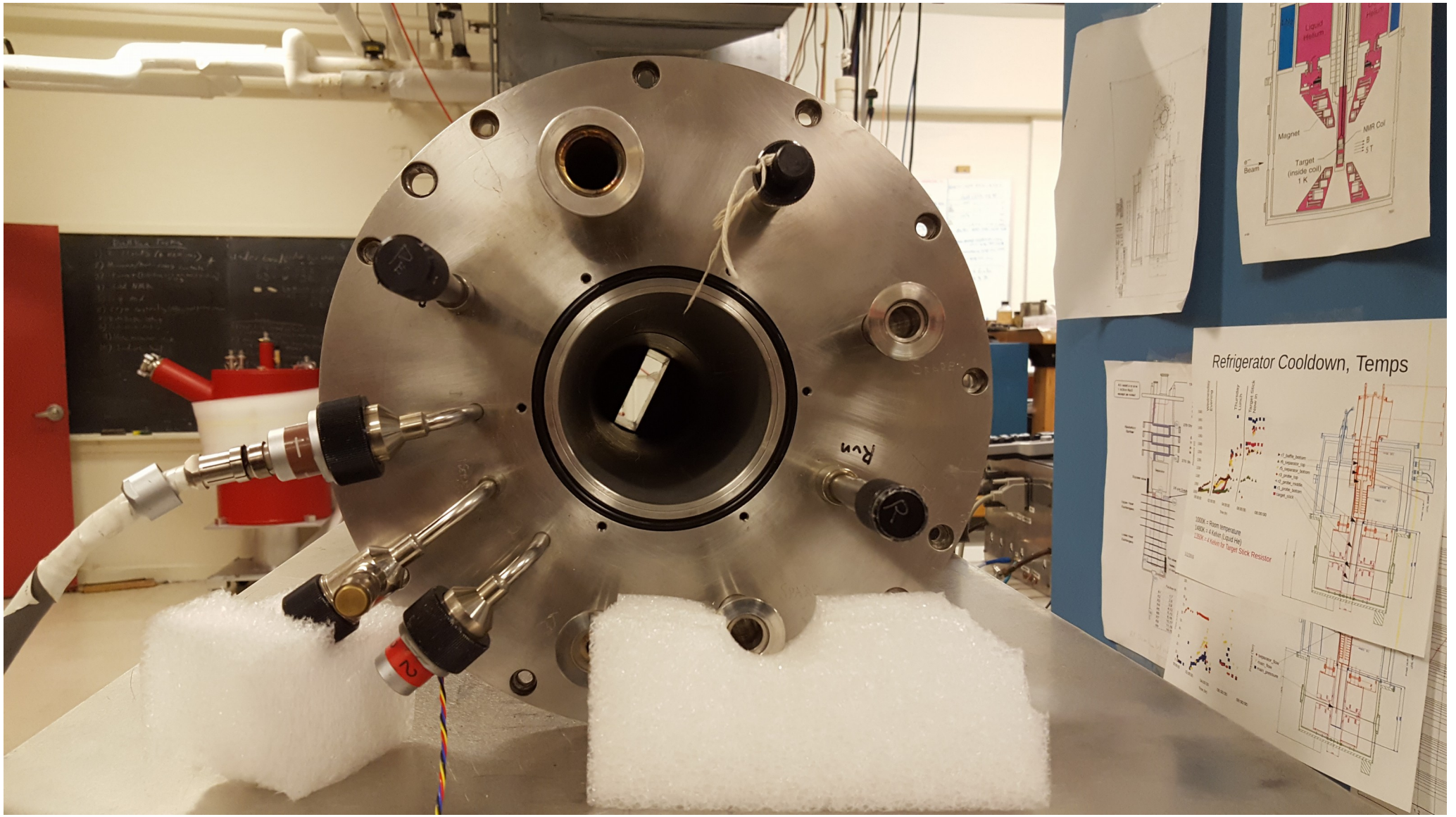
Recent Modifications



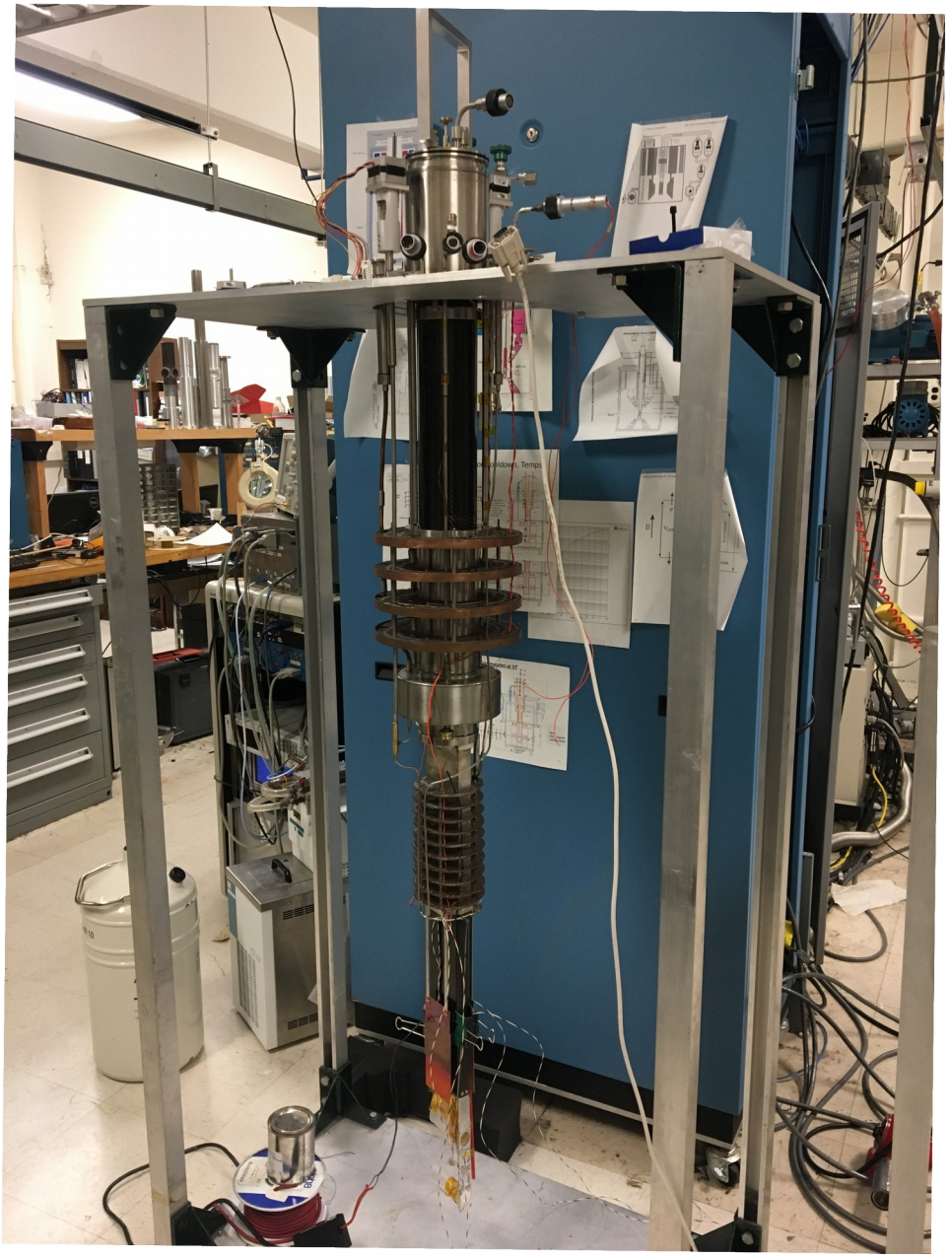
Bottom of Fridge



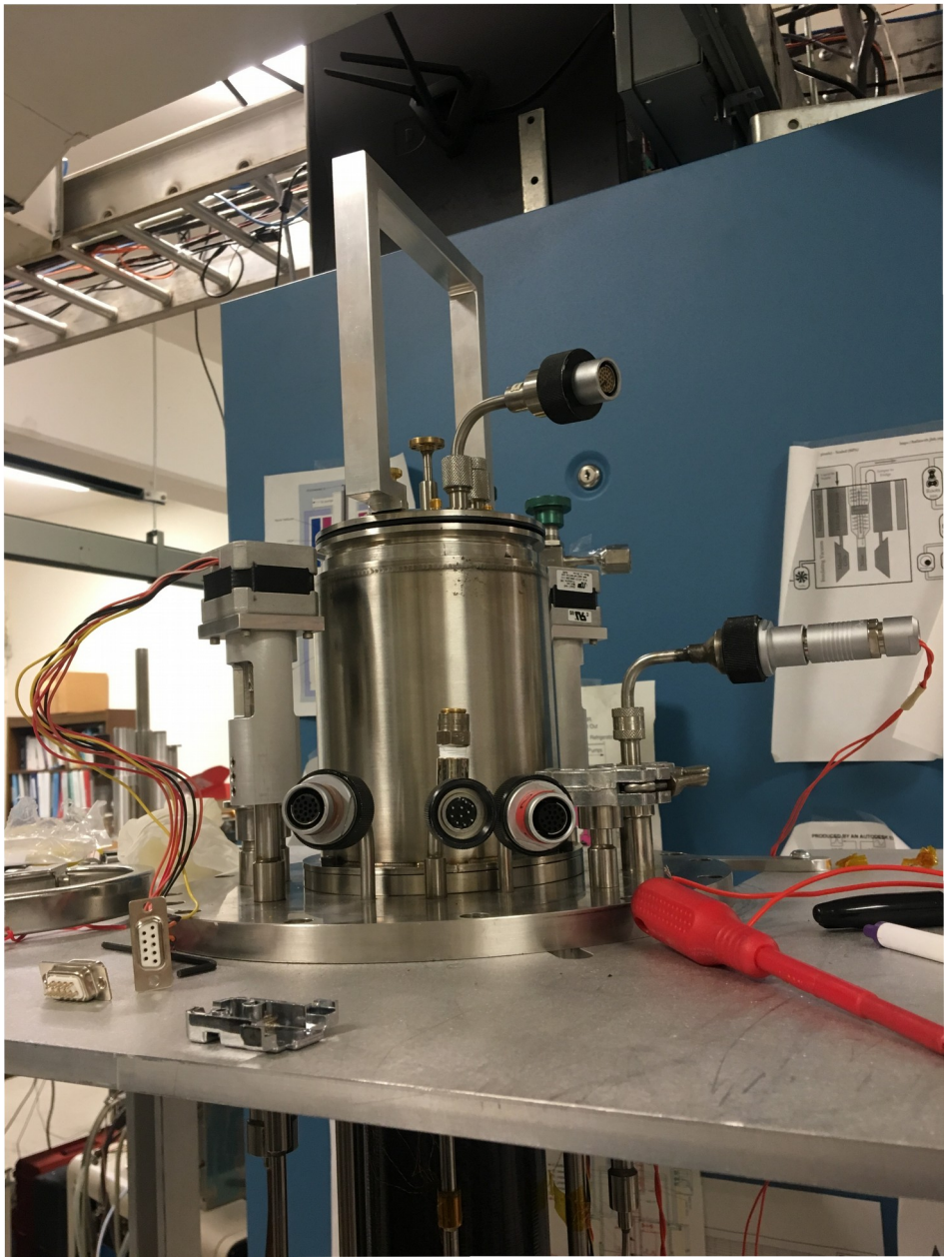
Top of Fridge



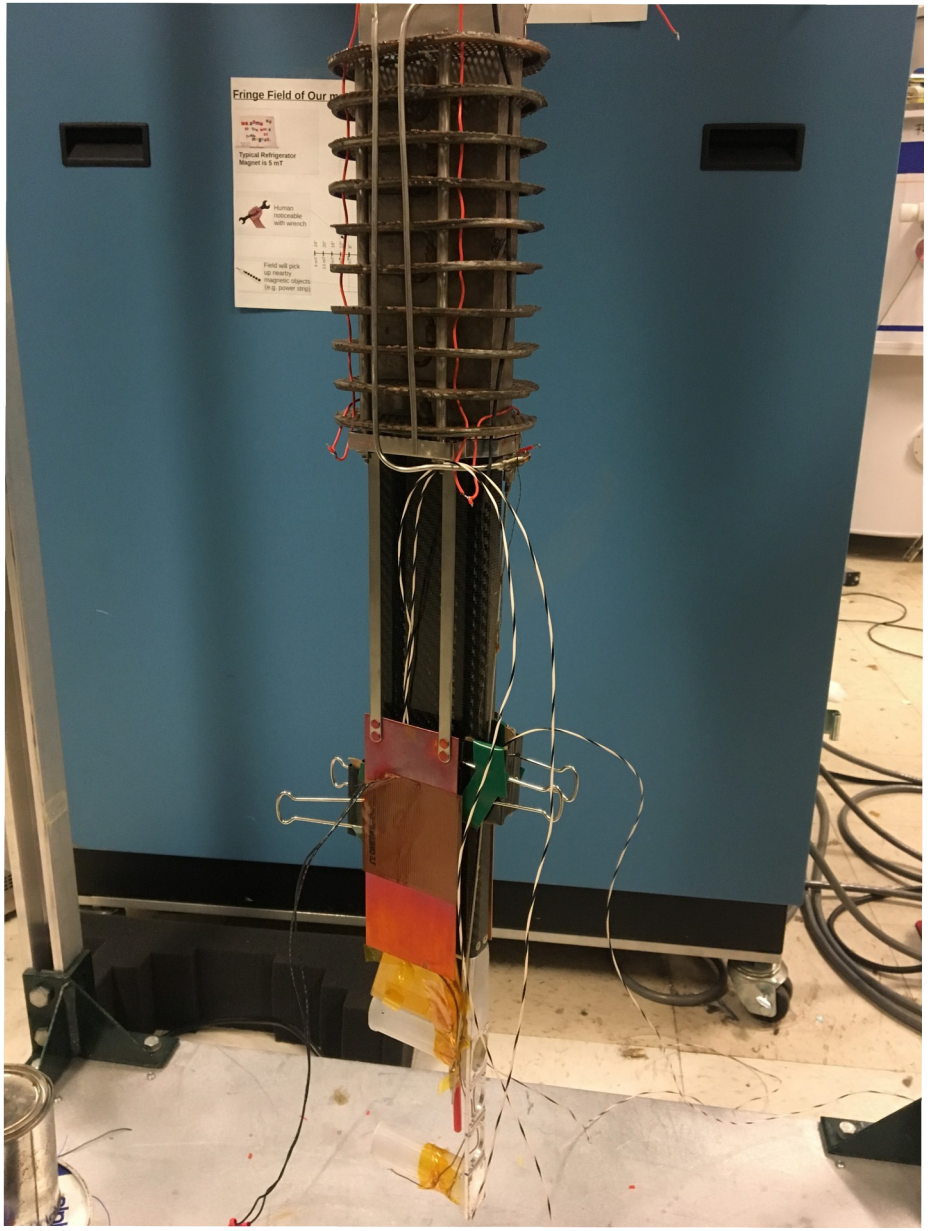
Upright Full View



Upright top



Upright Heater



POLARIZED TARGET SUBSYSTEMS

New insert

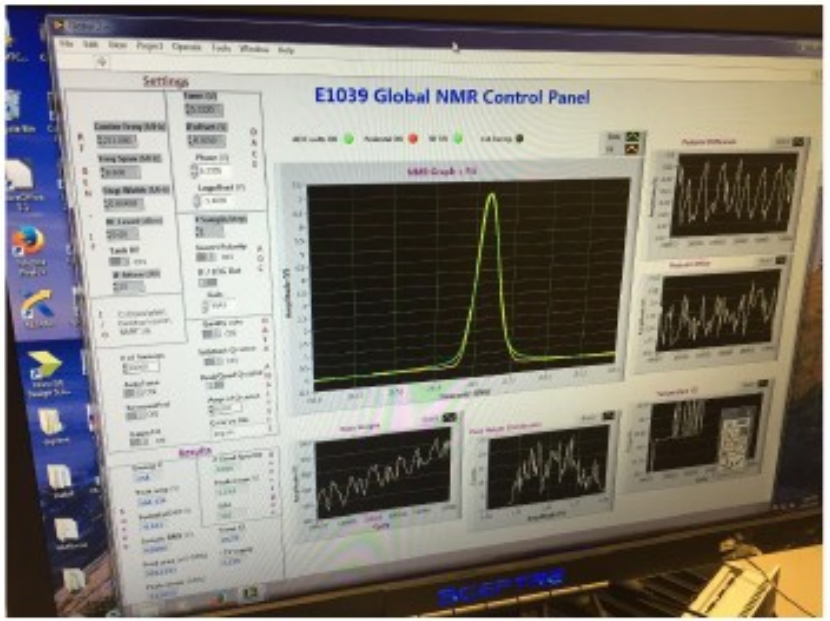
- four 2.7x2x80mm long target cups
- NH3, C disk, empty
- six NMR channels (3 per cup)
- microwave horn for full cup volume
- temperature sensors
- He3 bulb line
- copper thermal barrier
- carbon fiber enclosure

POLARIZED TARGET SUBSYSTEMS

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

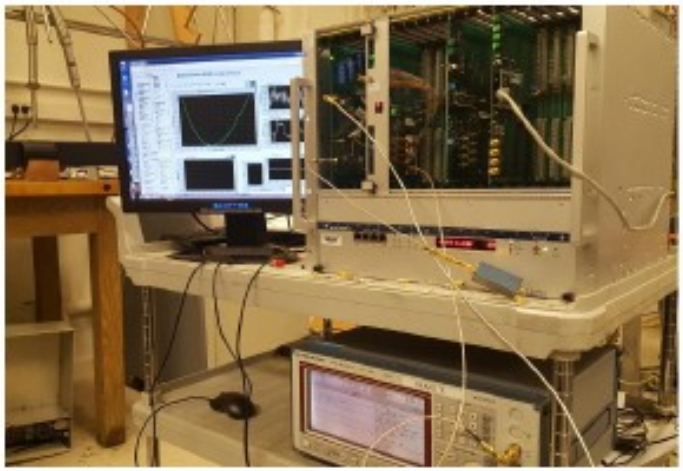
New NMR system developed by LANL

- 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



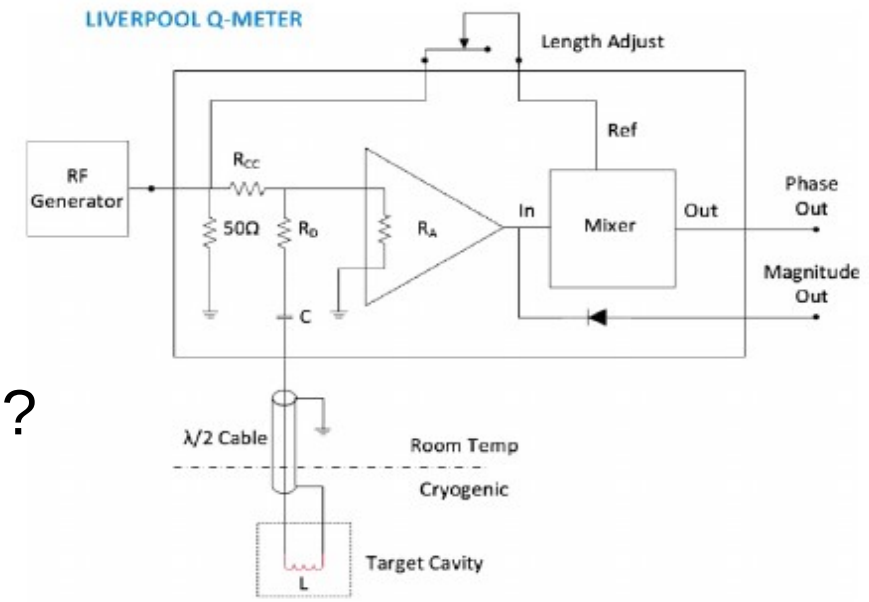
LANL NMR system tests at UVA

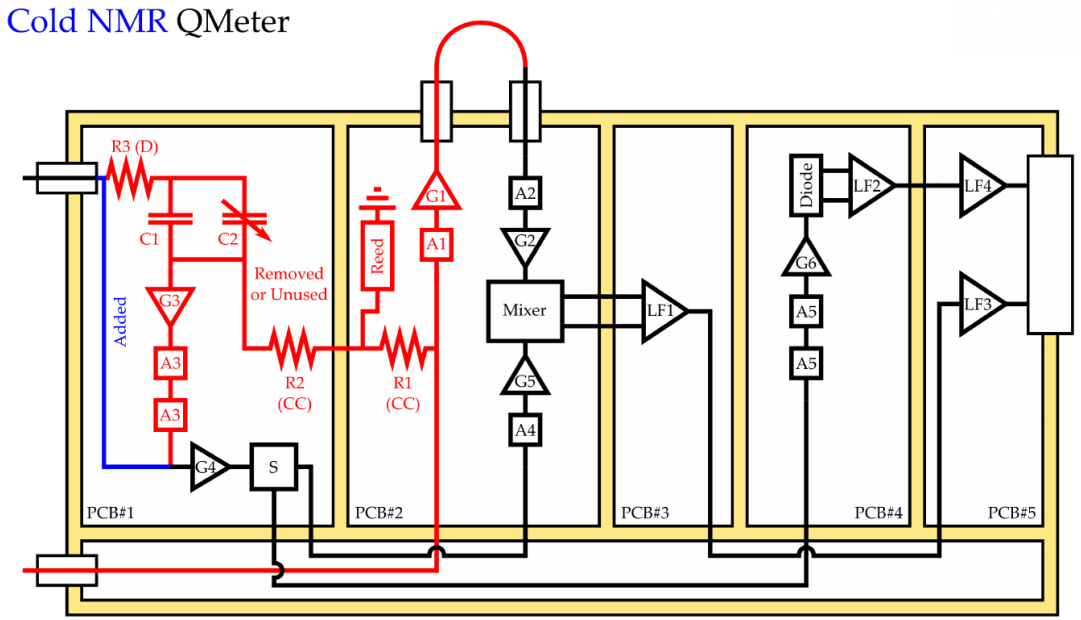
- 1st NMR cooldown 2014 (total 3 cold tests)
- 04/2016 full comparison to Liverpool Q-meter
- signal/noise ratio - waiting for results



NMR System

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

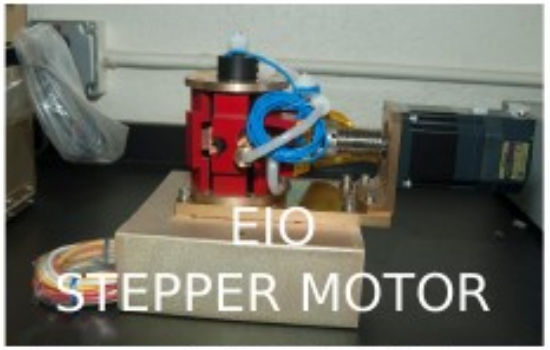




POLARIZED TARGET SUBSYSTEMS

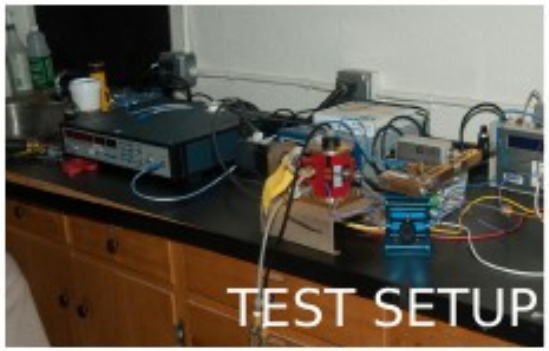
New microwave source

- purchased by LANL
- new EIO tube from CPI, 20W output
- controlled by stepper motor
- new PS with software control UI



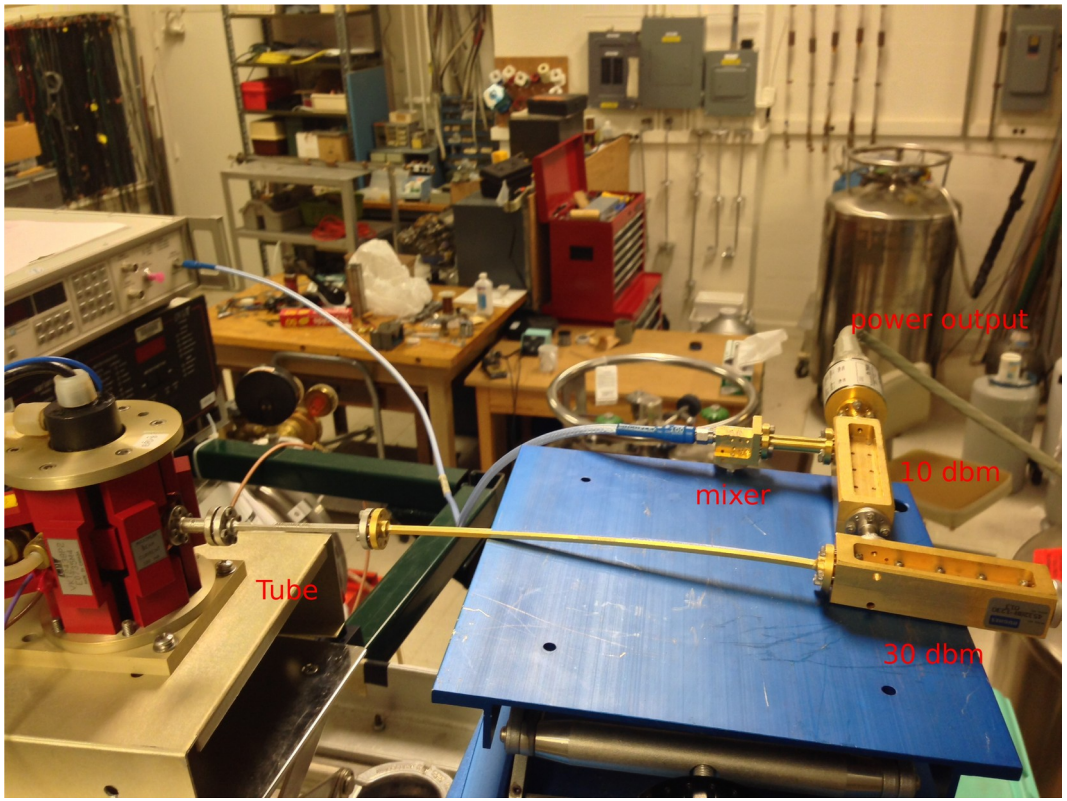
Microwave source test

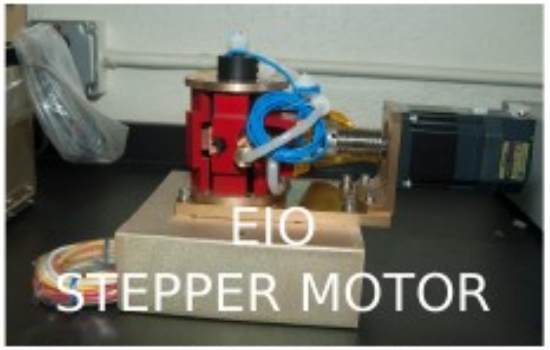
- built setup at UVA in 2015
- checked freq adjustments
- checked cathod HV adjustment



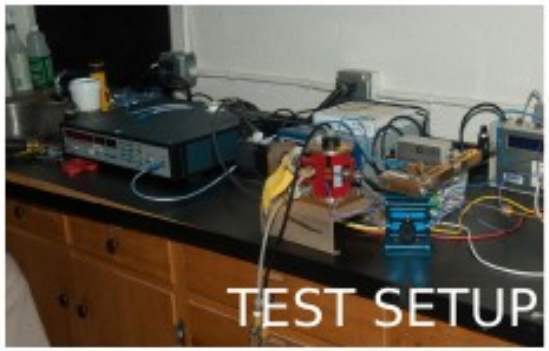
POLARIZED TARGET SUBSYSTEMS

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



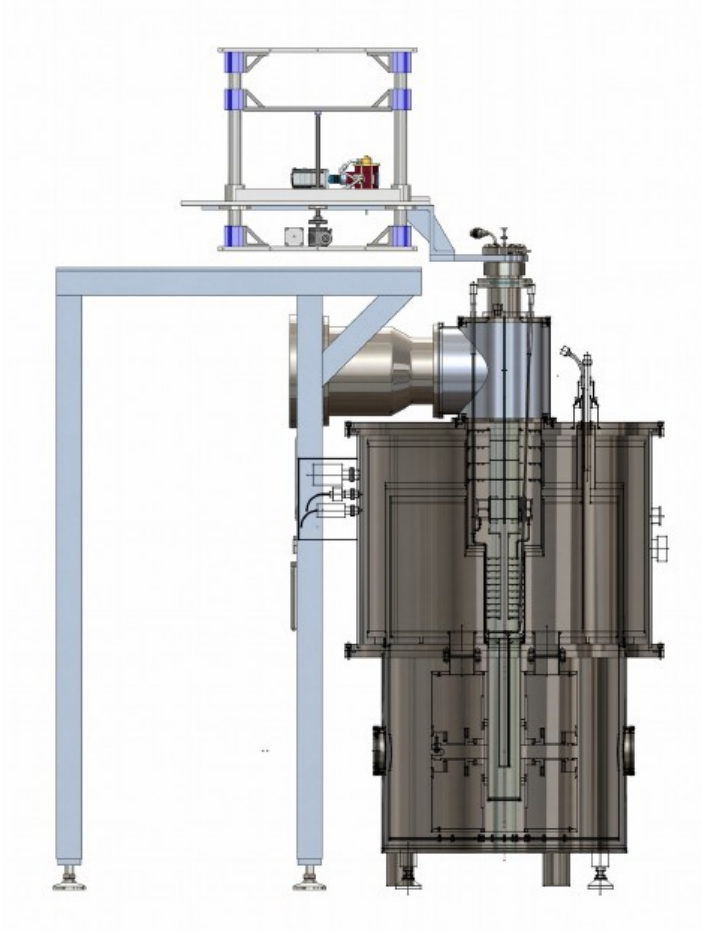


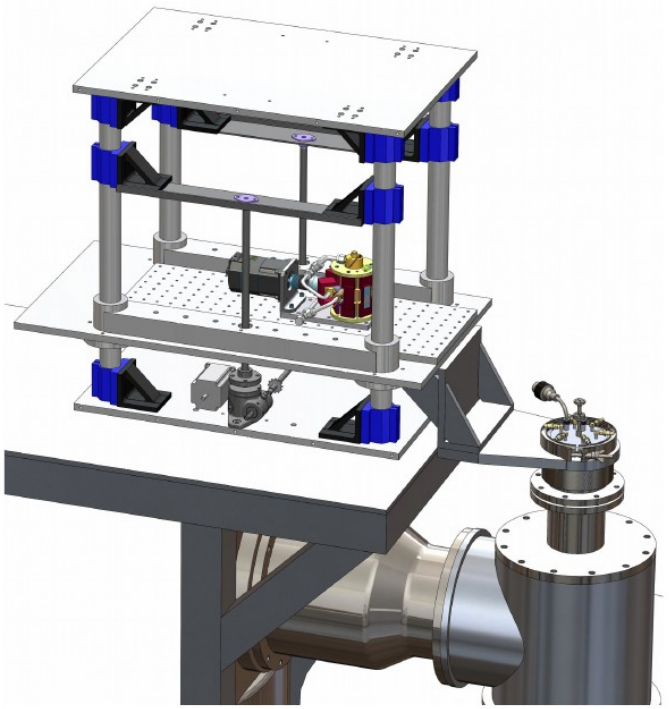
CPI

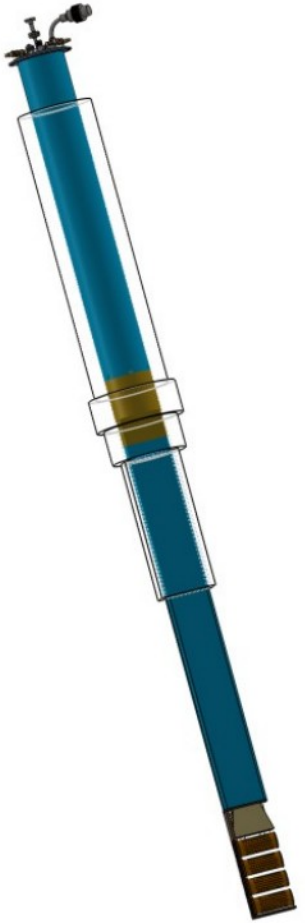


- Variation of the beam voltage allows up to 0.4% frequency tuning
- Cavity size adjustment allows an additional 1.5%
- D-band (~140 GHz)

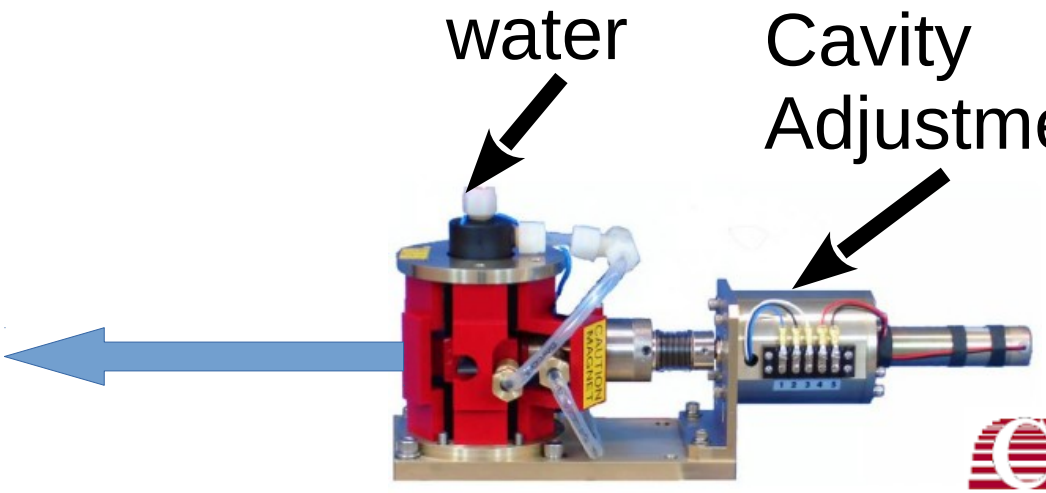
Microwave Setup





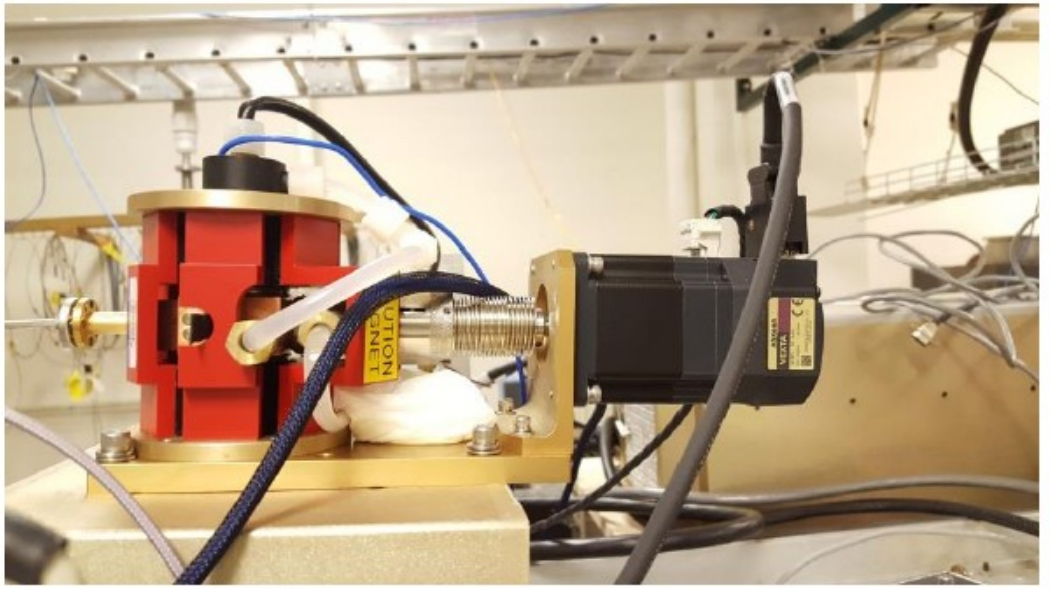


Target



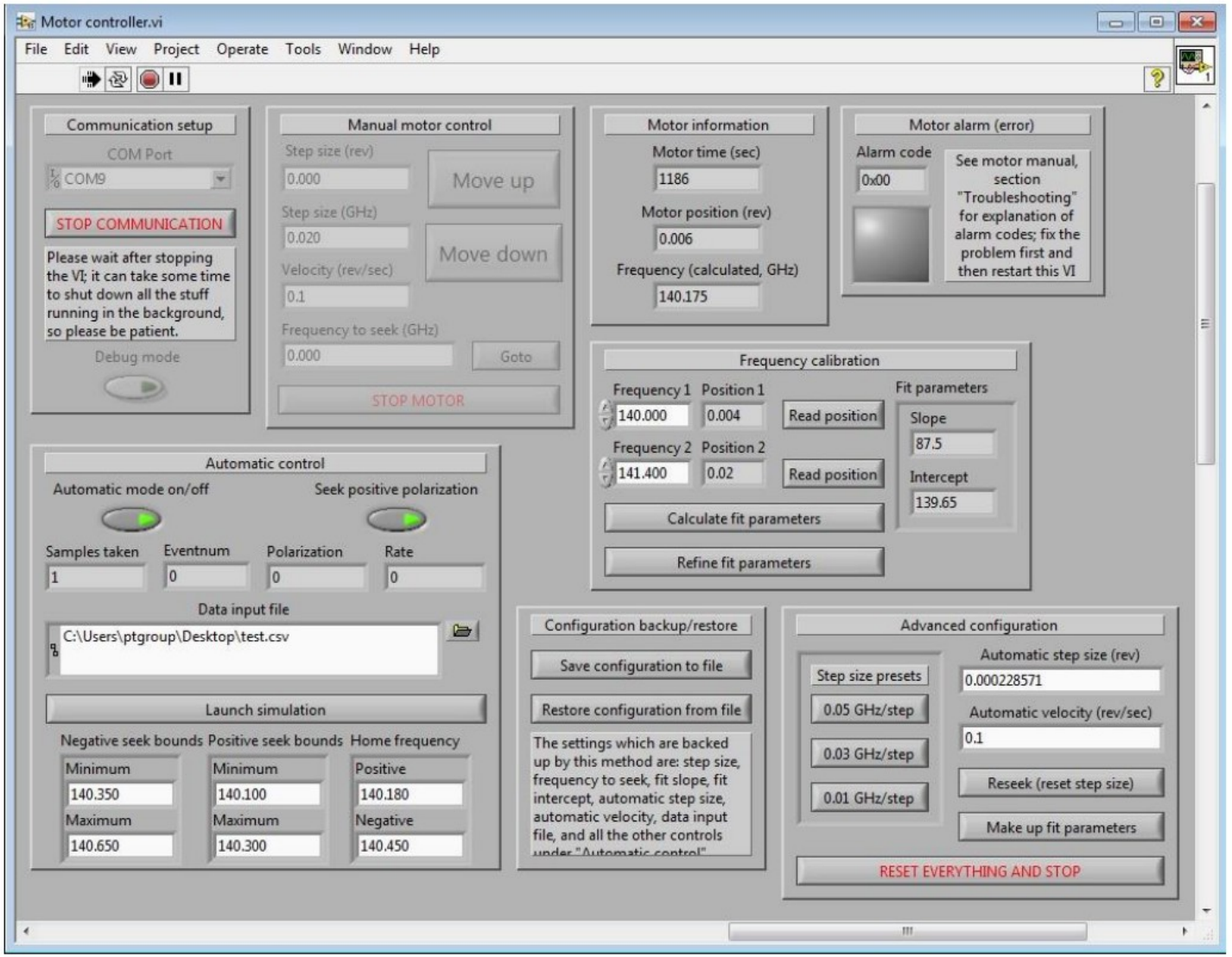
Microwave Controls

- Stepper motor



- New software controlled microwave power supply

Motor Control



This is the main microwave controller VI.

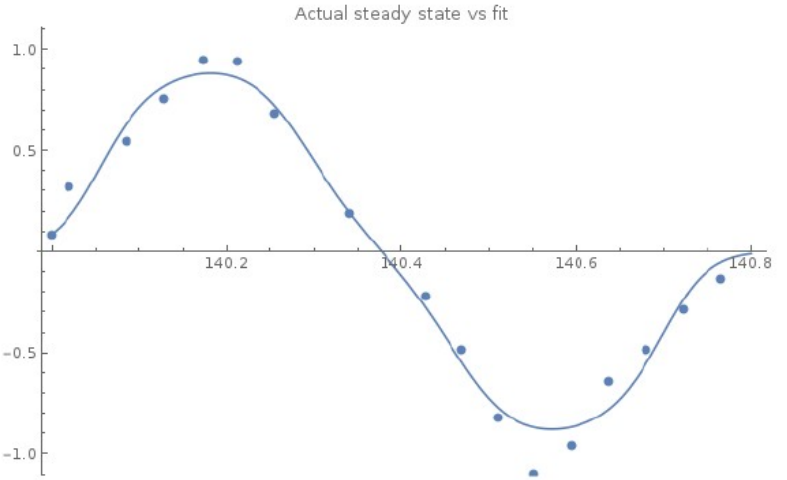
Can be run in automatic mode or manual mode.

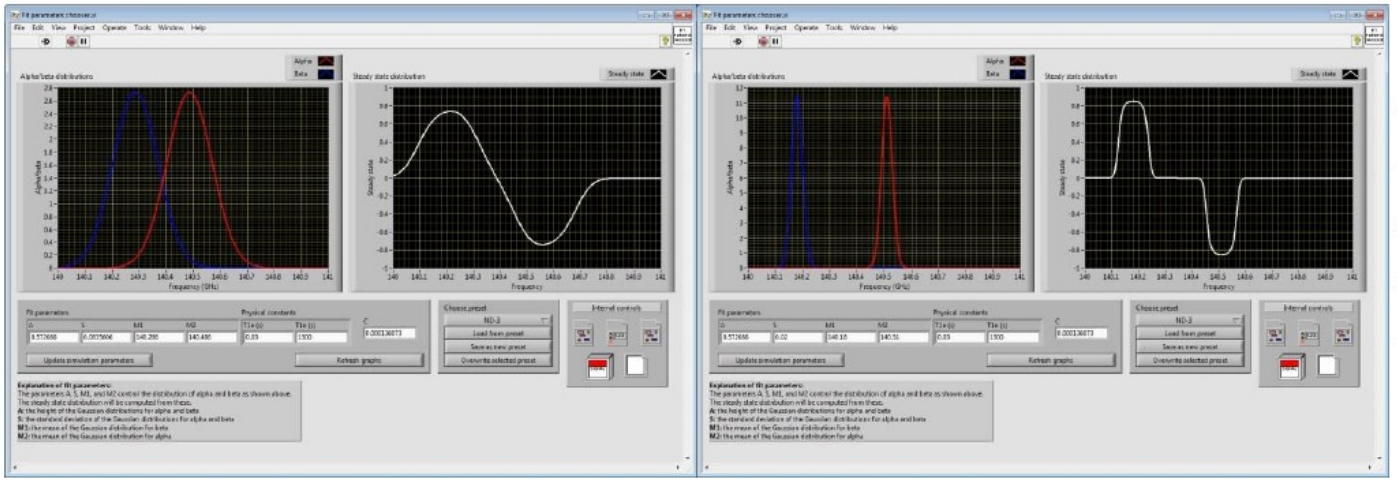
First we should do the frequency calibration by moving the motor manually.

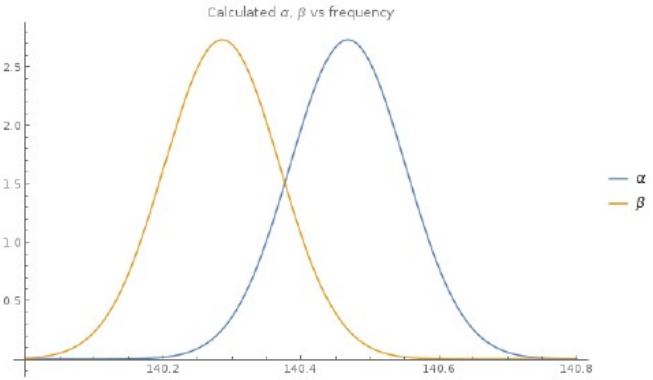
Can be run in real time experiment or in simulation mode.

Simulation

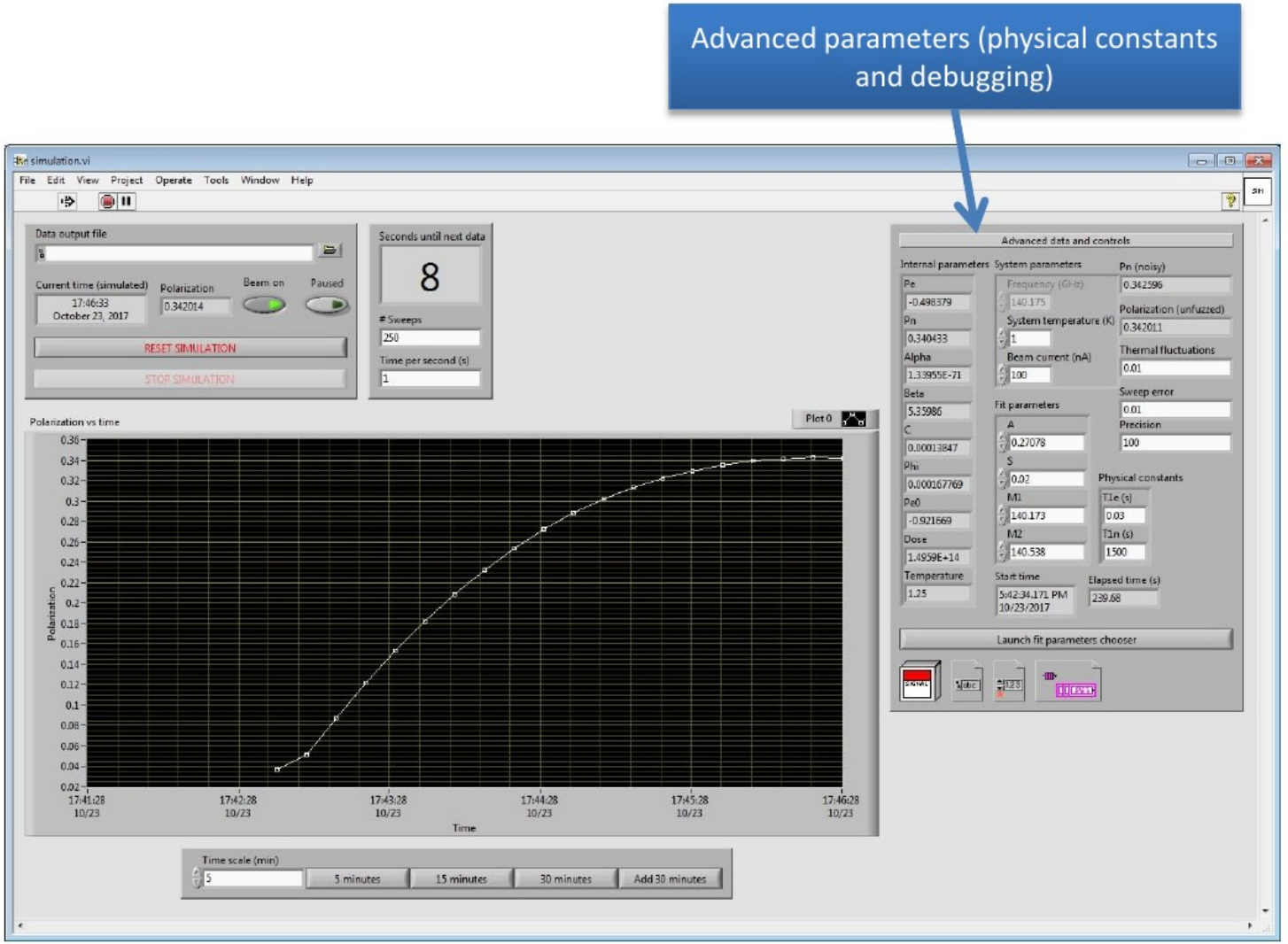
- Written in LabVIEW to work with stepper motor
  - Can also be run by itself to produce data
- Implements model
  - Parameters α and β calculated from frequency







Simulation



This is the main microwave simulation controller VI.

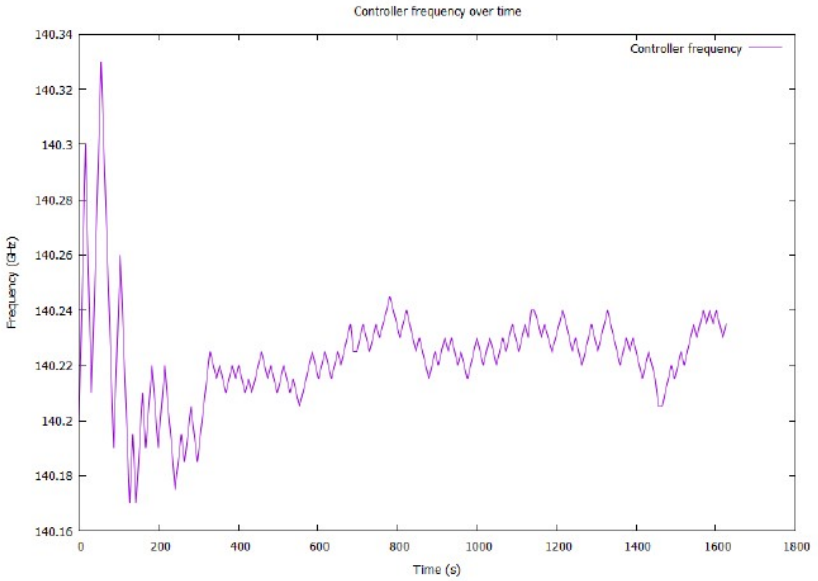
Can be started through main controller VI.

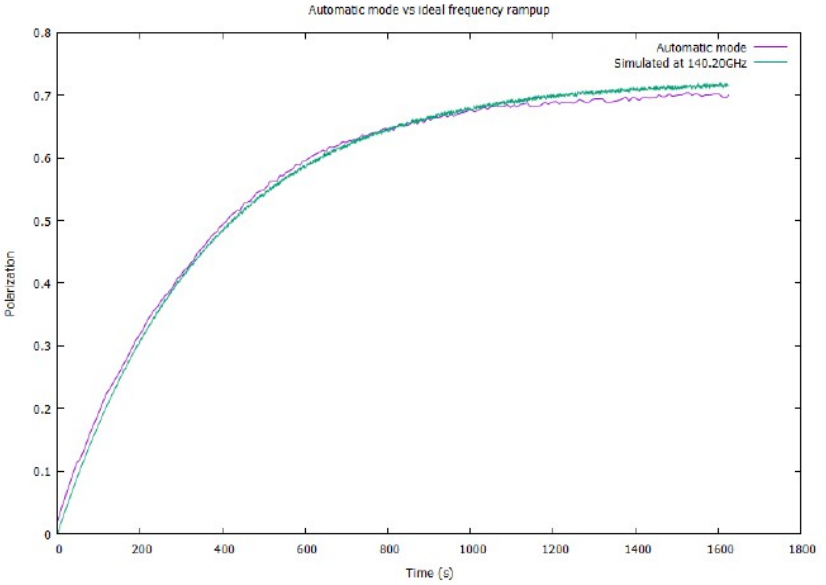
Can change many parameters and run for different material.

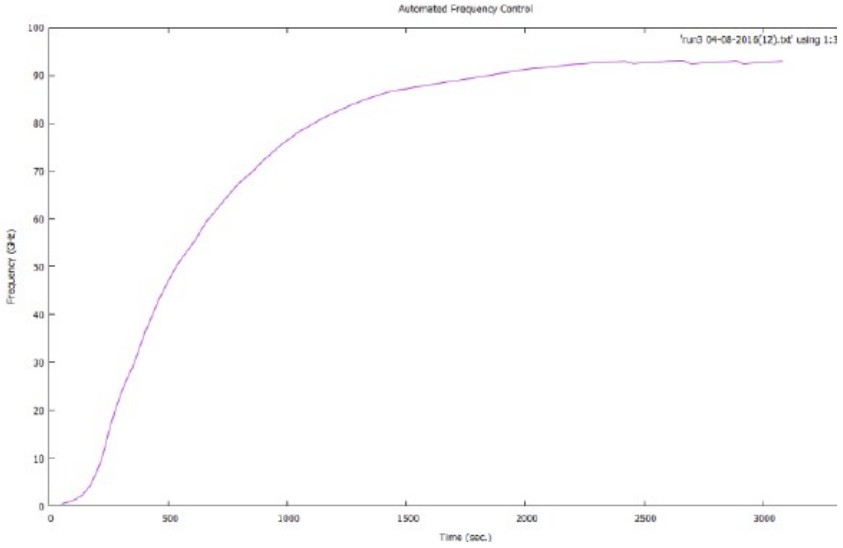
Mimic the real experimental NMR setup.

Can be used for training purposes and testing purposes

Testing Performance



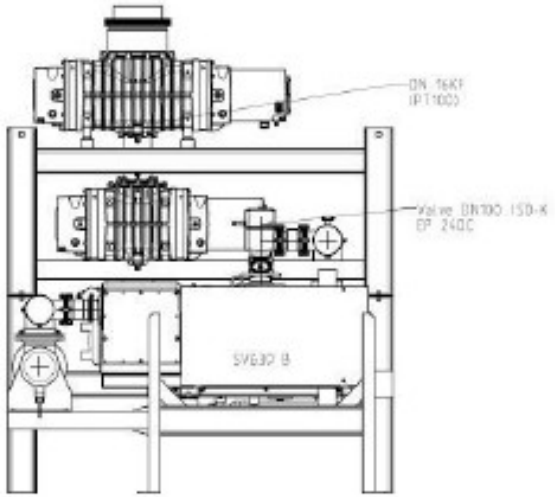


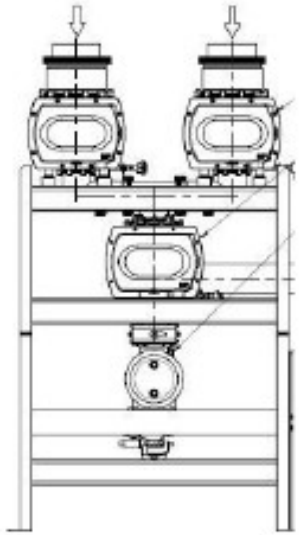


POLARIZED TARGET SUBSYSTEMS

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

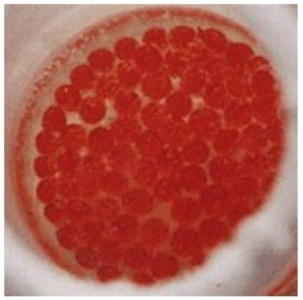
- dedicated setup to produce NH3 beads
- NH3 gas slowly frozen above LN2 bath
- ~1000 g is needed for 2 yr run
- ~450 g currently produced
- purchased three LN2 dewars for storage

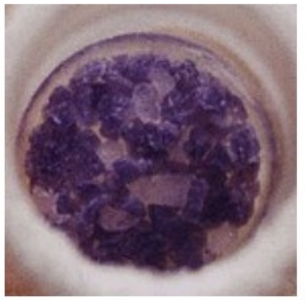
Pre-Irradiation

- 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

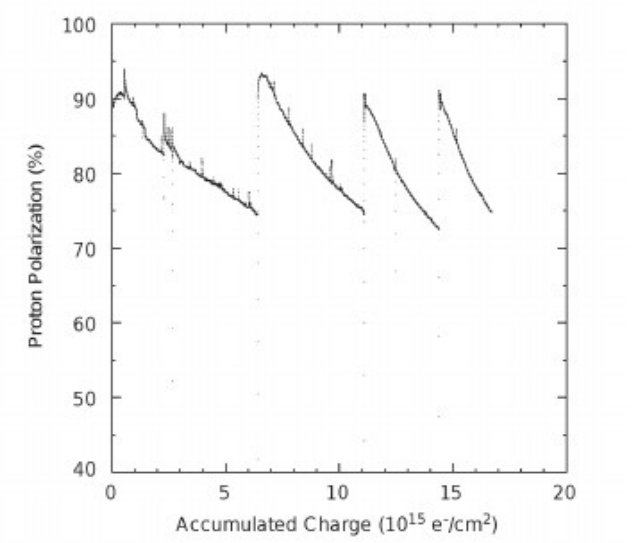
- Successful material for DNP characterized by three measures:
  1. Maximum polarization
  2. Dilution factor
  3. Resistance to ionizing radiation

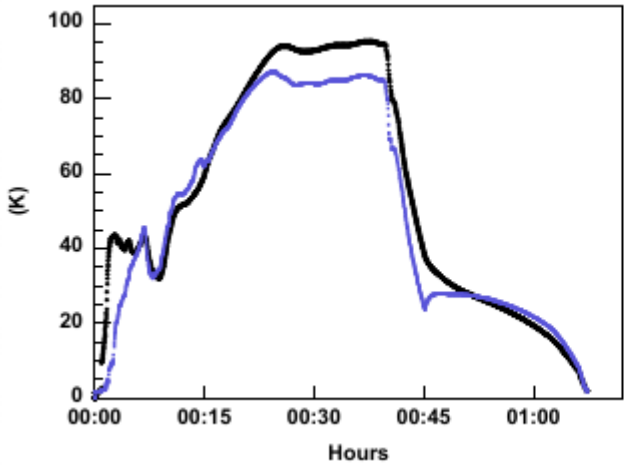


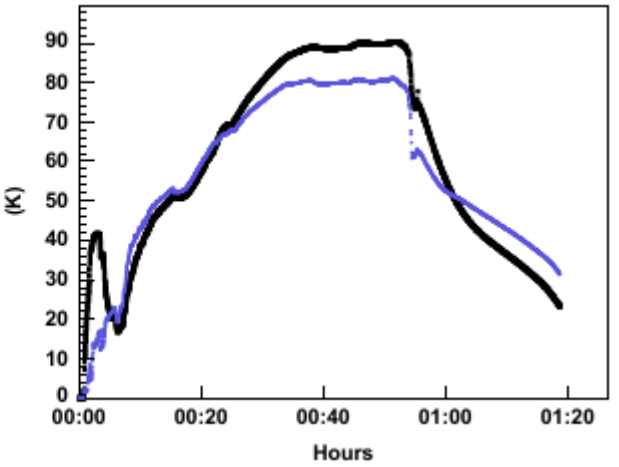


Material	Butanol	Ammonia, NH_3	Lithium Hydride, ^7LiH
Dopant	Chemical	Irradiation	Irradiation
Dil. Factor (%)	13.5	17.6	25.0
Polarization (%)	90-95	90-95	90
Material	D-Butanol	D-Ammonia, ND_3	Lithium Deuteride, ^6LiH
Dil. Factor (%)	23.8	30.0	50.0
Polarization (%)	40	50	55
Rad. Resistance	moderate	high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

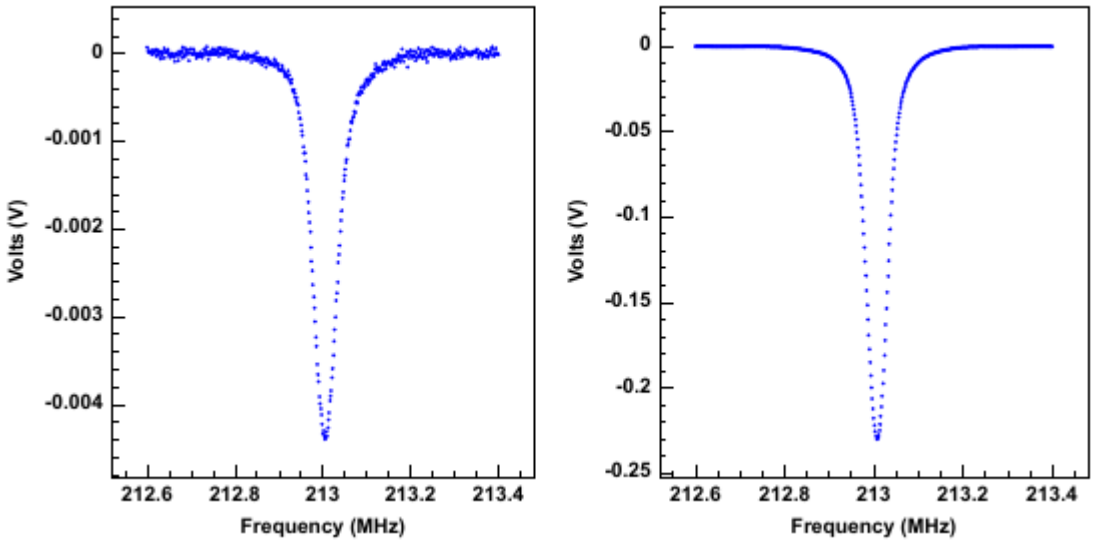
Sources of Uncertainty in Polarization

- 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

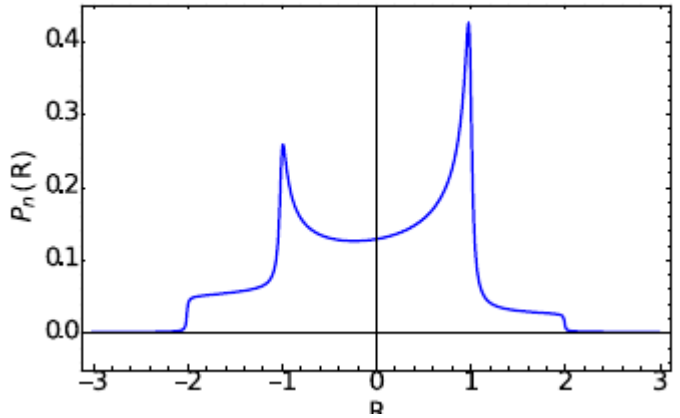
~0.3%

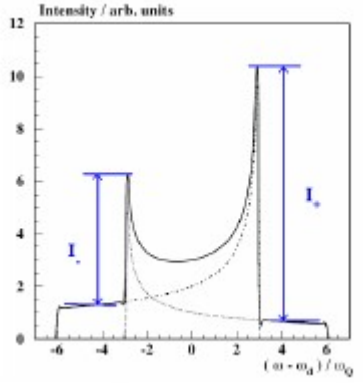


Proton

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

~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

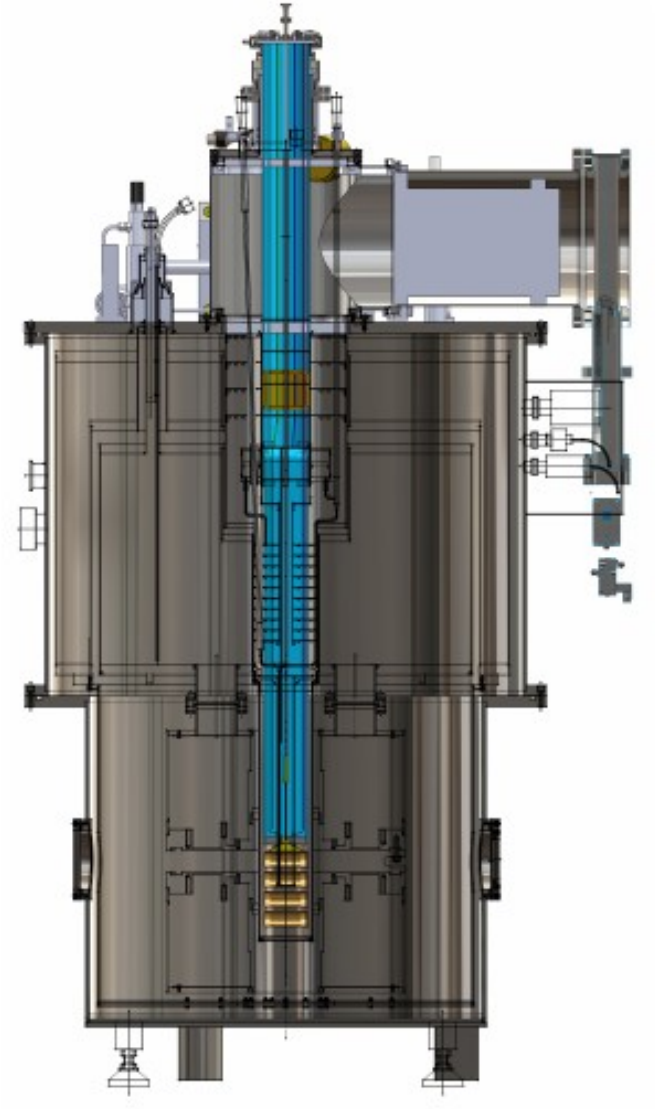
$$P_{TE} = \tanh\left(\frac{\mu B}{kT}\right) \qquad P_E = G\frac{\int S_E(\omega)\, d\omega}{\int S_{TE}(\omega)\, d\omega} P_{TE} = GC_{TE}A_E \qquad C_{TE} = \frac{P_{TE}}{A_{TE}}$$

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	

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

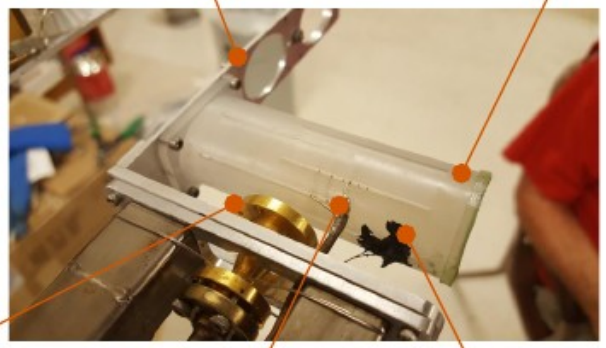
Full System



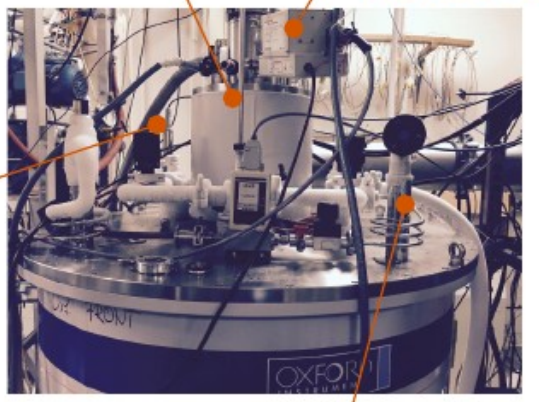
Test Full System

Final preparations and run

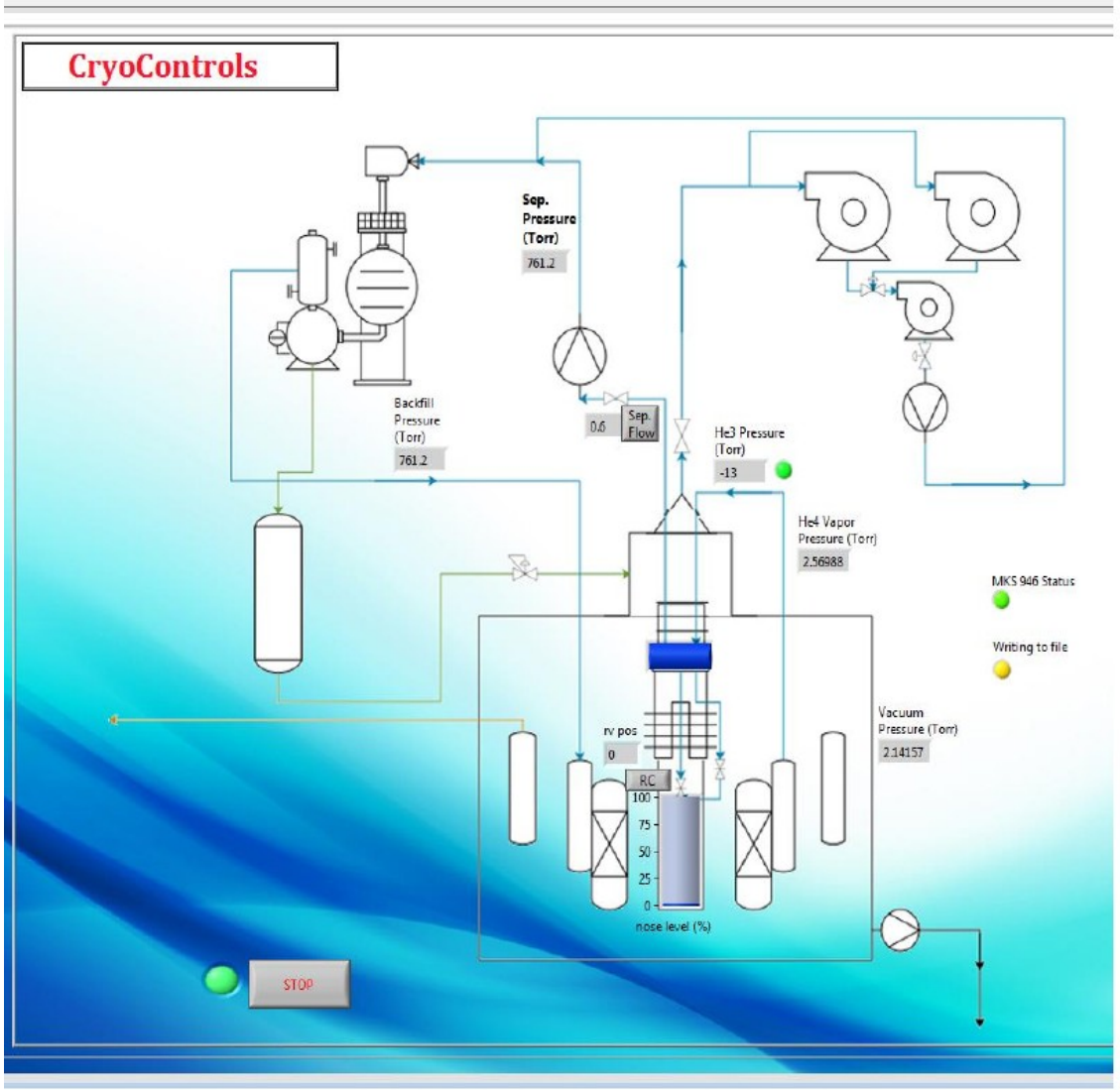
made test target insert, practiced installation



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

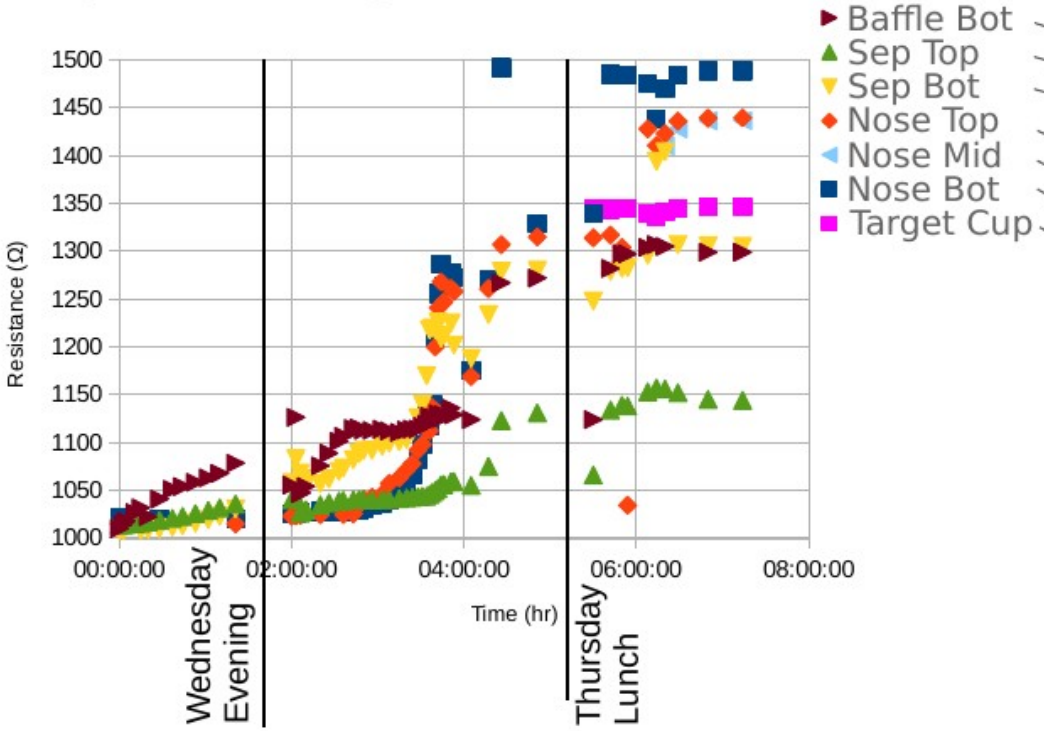
Test results

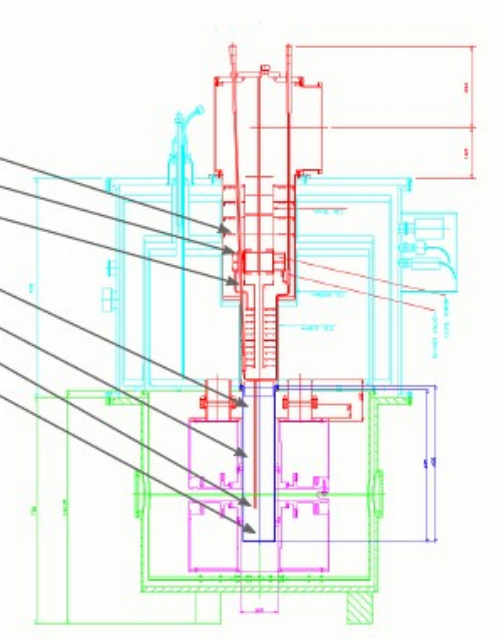
Fridge performance

separator and nose fill

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

very stable, very little attention required



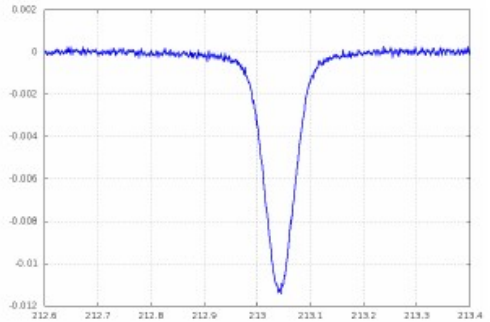


Results of All the Work

Test results

Polarization

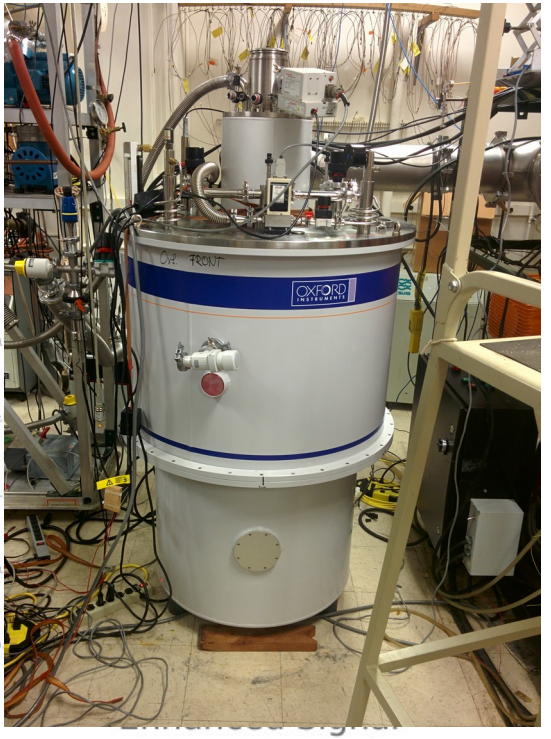
- polarized fresh NH3 both positively and negatively
- took extensive TE measurements
- alternated UVA and new LANL NMR systems

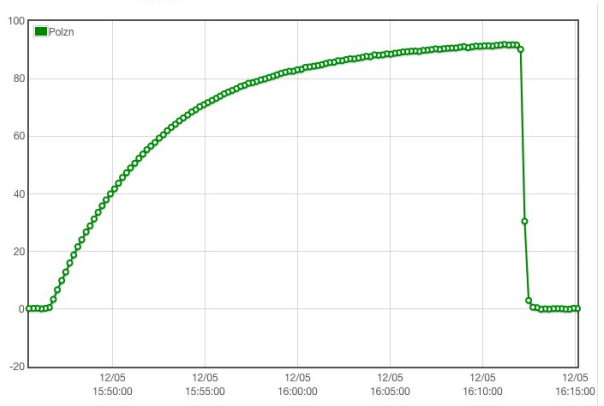


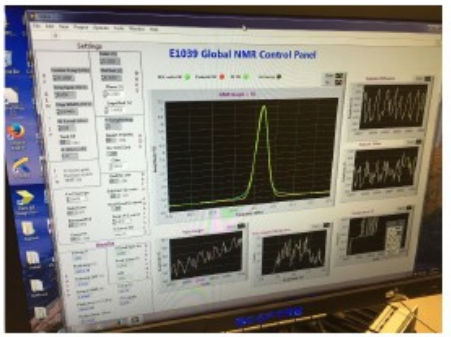
Frequency, MHz

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 (^{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

Thank You