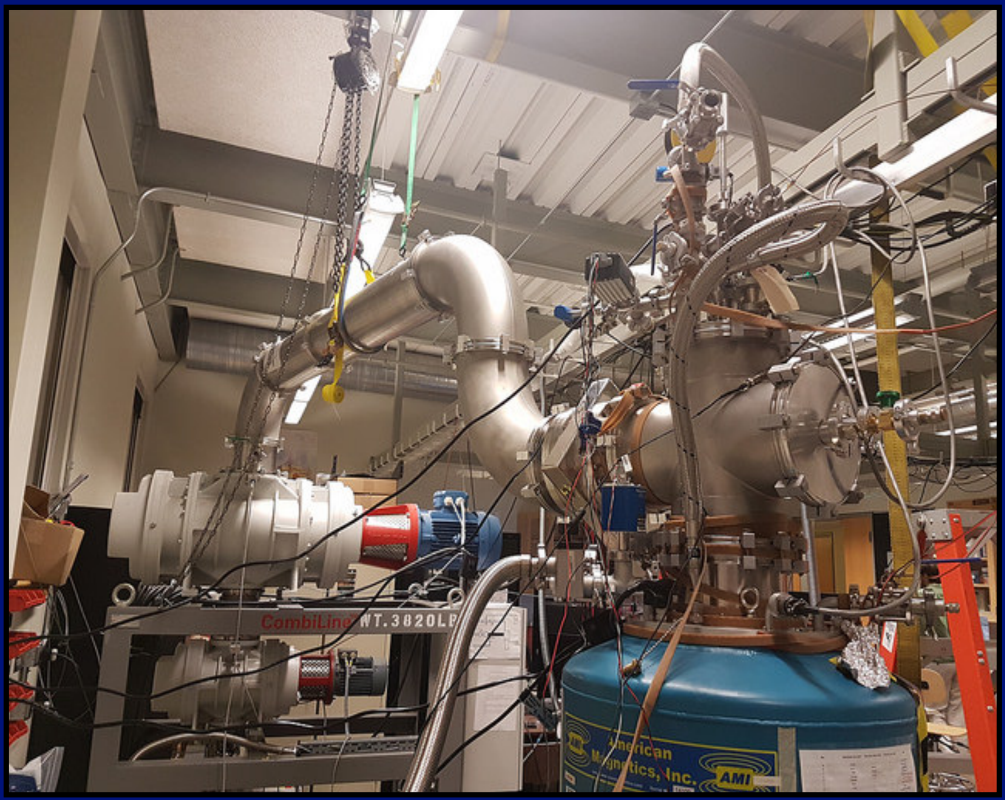
Polarized Target Update



Jefferson Lab
Hall A/C Collaboration Meeting

2020-07-17

Karl Slifer
University of New Hampshire

This Talk

Latest Hardware Developments

Material Preparation
- Proton
- Deuteron

NMR Analysis

Tensor Program

E12-13-011: *"The b_1 experiment"*

30 Days in Jlab Hall C
A⁻ Physics Rating
Conditional Approval (Target Performance)

Contact : K. Slifer
Solvignon, Long, Chen,
Rondon, Kalantarians

E12-15-005: *"A_{zz} for $x>1$"*

44 Days in Jlab Hall C
A⁻ Physics Rating
Conditional Approval (Target Performance)

Contact : E. Long
Slifer, Solvignon,
Day, Higinbothan, Keller

UNH Polarized Target Group

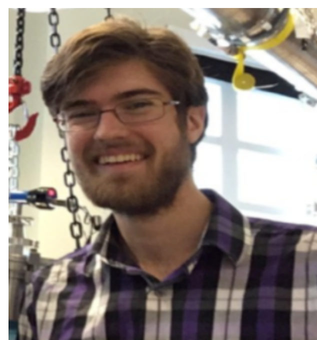
Karl S

Marie Boer

Elena Long

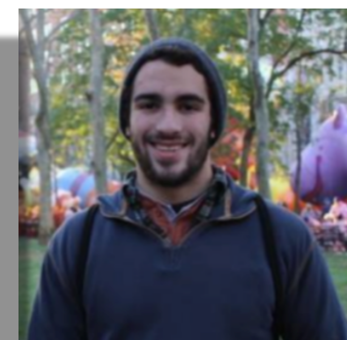
Nathaly S.

Michael M.



David R.

Emad M.

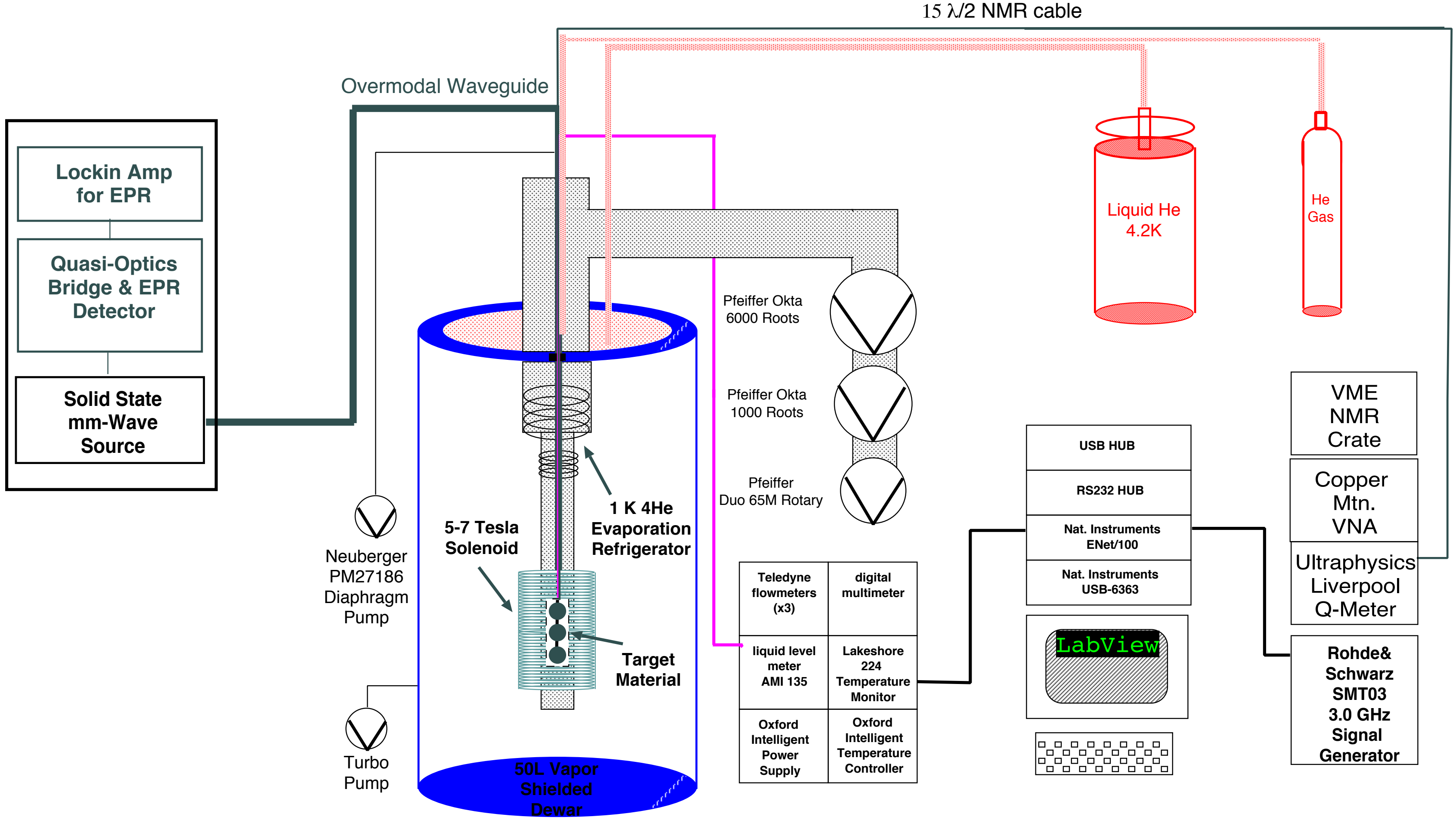


Tristan A.

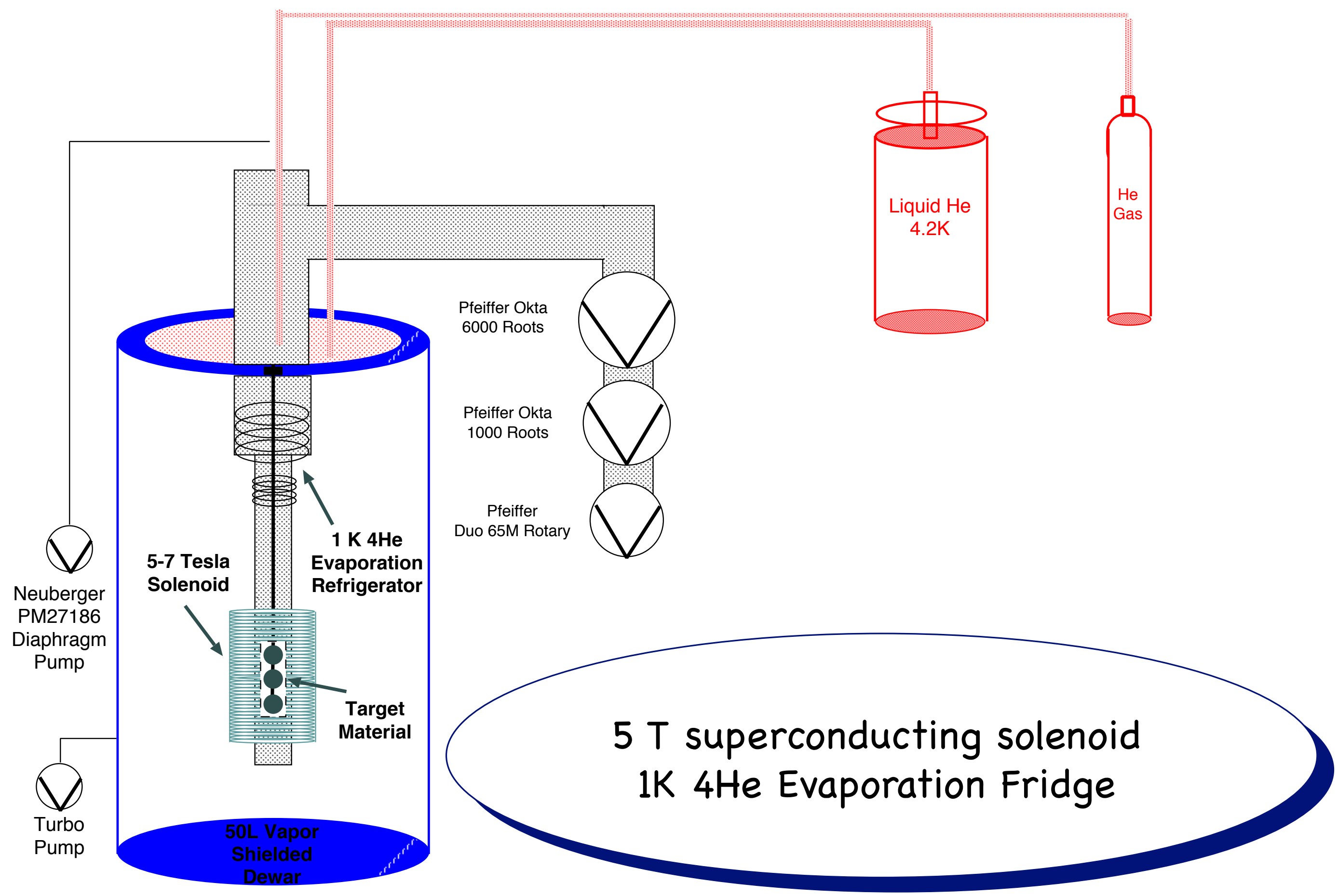
+ many more undergrads

close collaboration with
W. Brook's group at USFSM

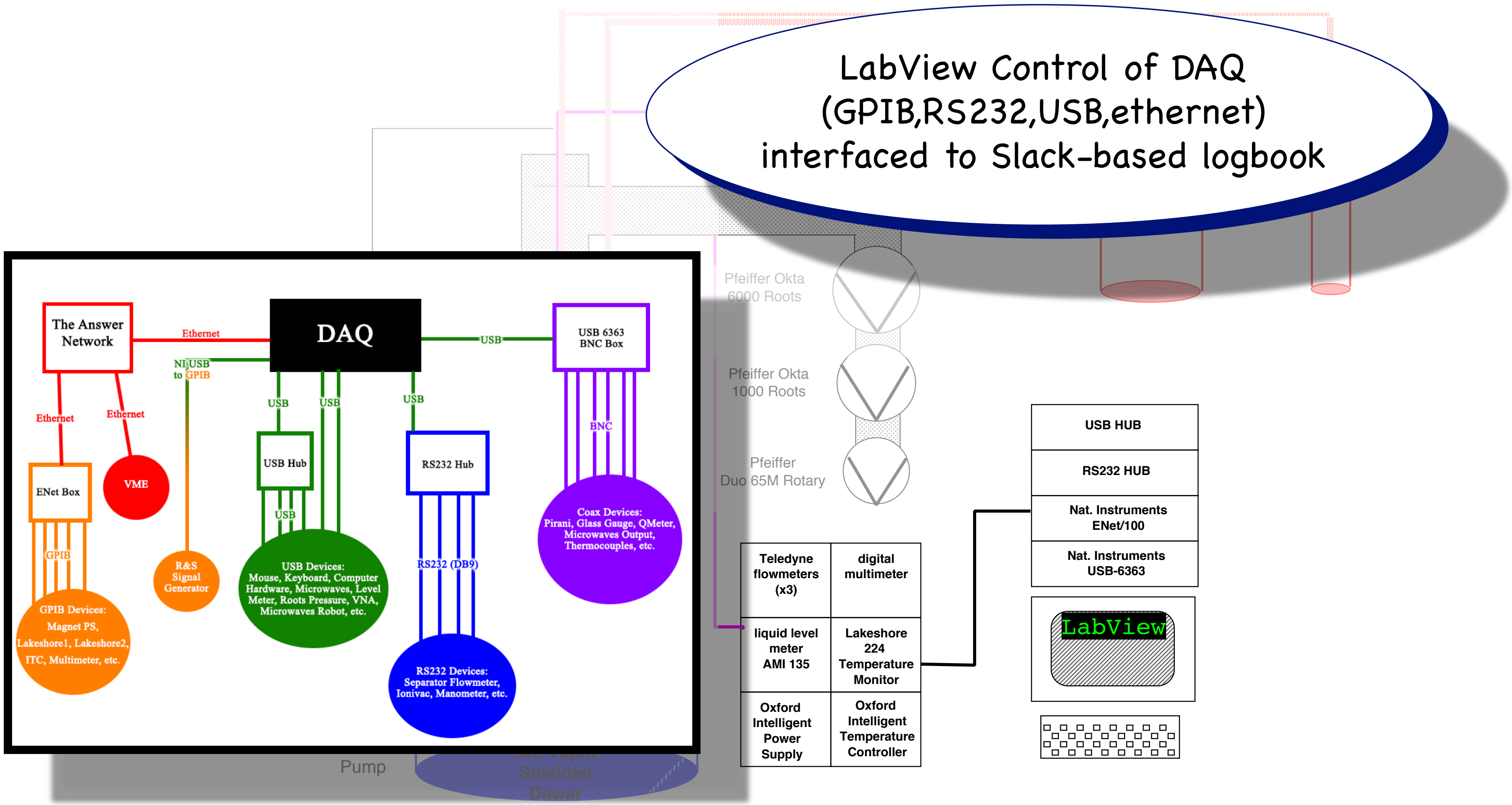
UNH Polarized Target Lab



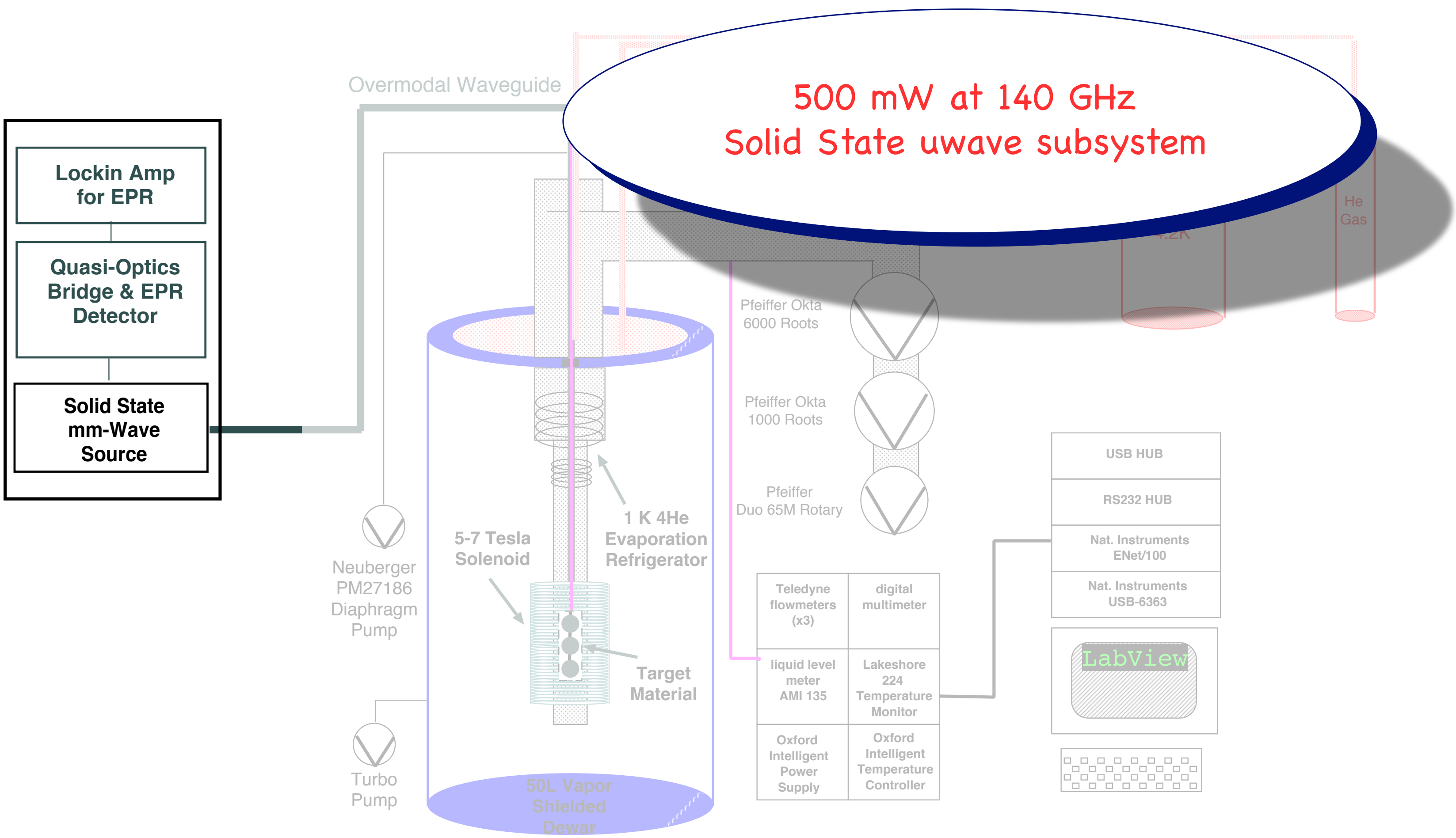
UNH Polarized Target Lab



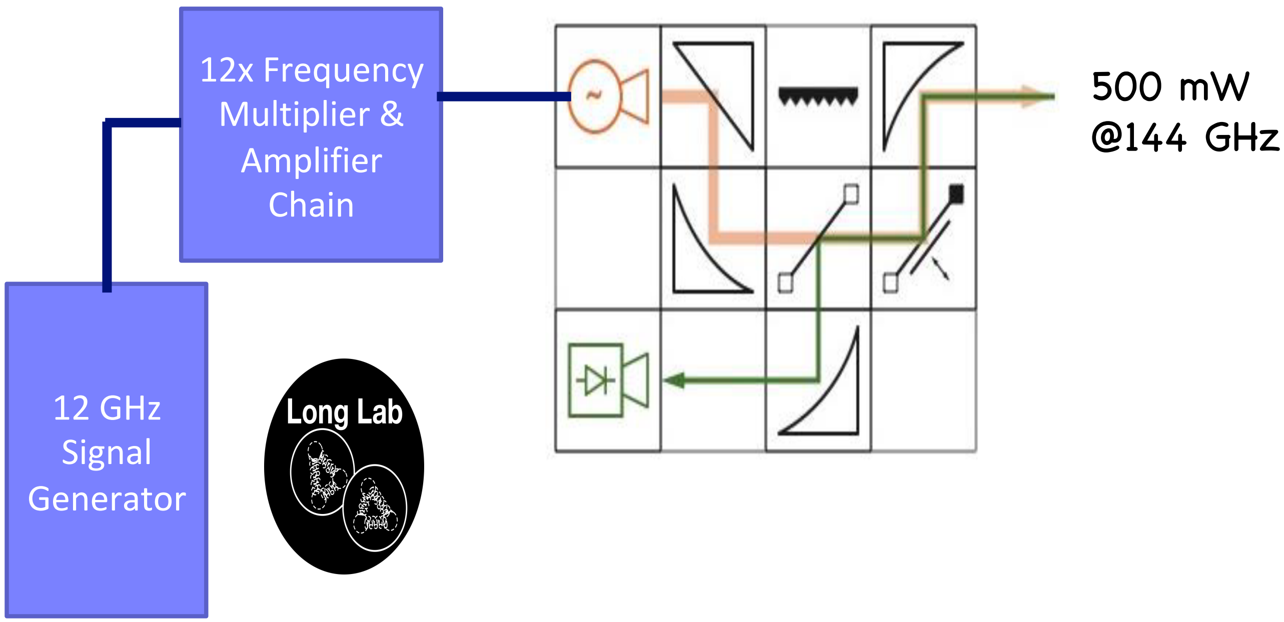
UNH Polarized Target Lab



UNH Polarized Target Lab

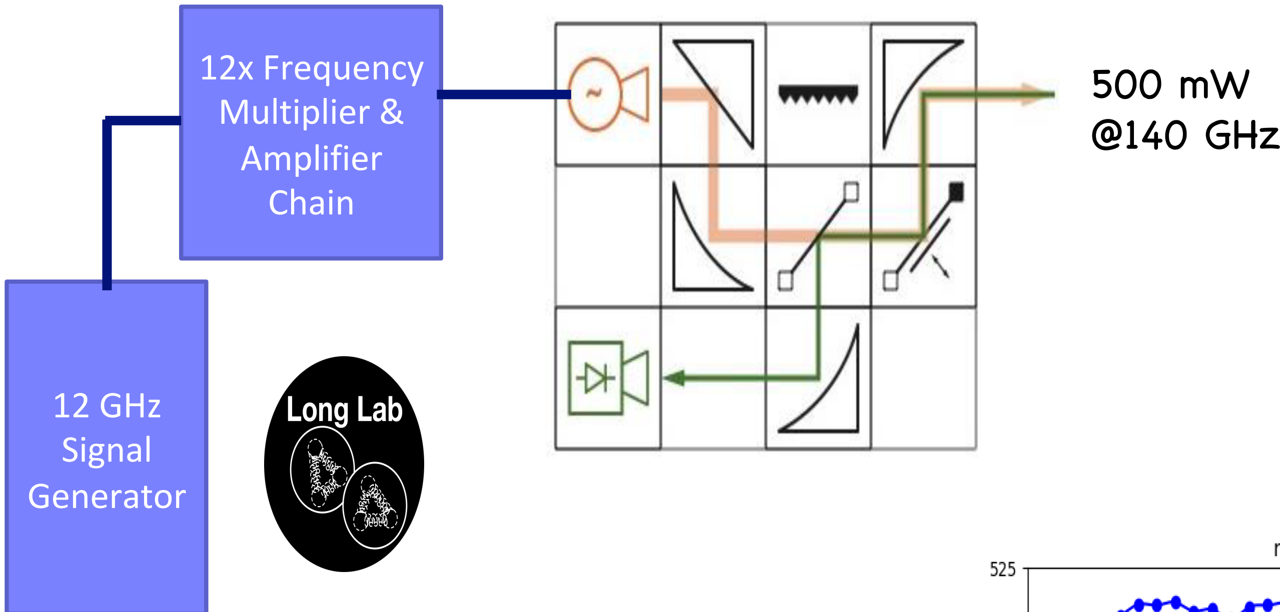


Solid State mm-Wave System

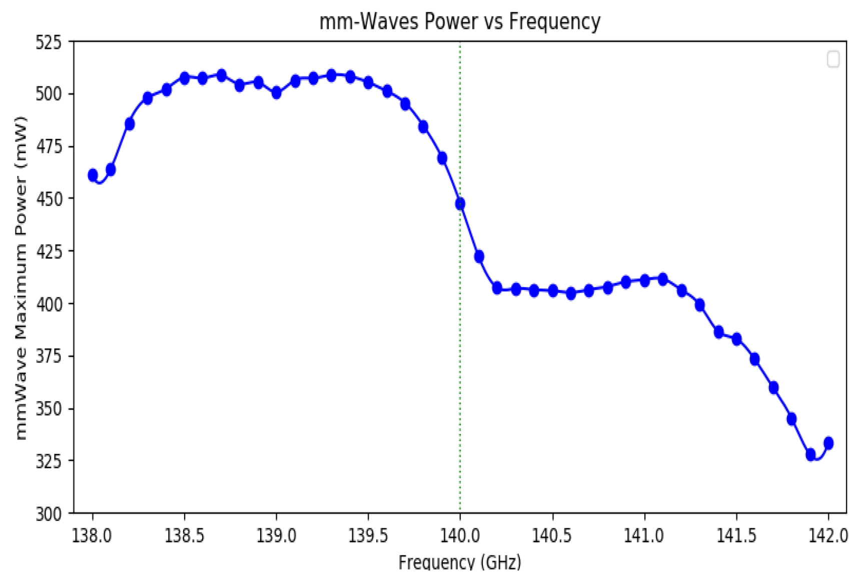


Cheaper than EIO
No cooling
Sits directly above target
Passes thru air gap

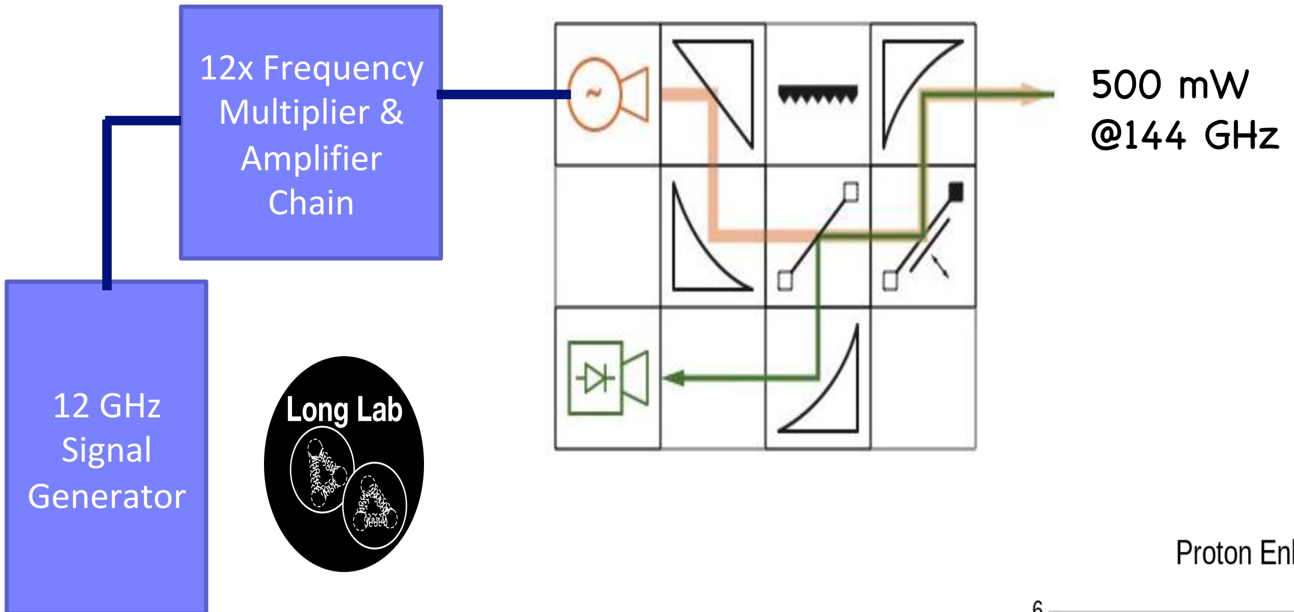
Solid State mm-Wave System



Cheaper than EIO
No cooling
Sits directly above target
Passes thru air gap
Low Loss Overmodal waveguide
Wide Frequency Range



Solid State mm-Wave System



Cheaper than EIO
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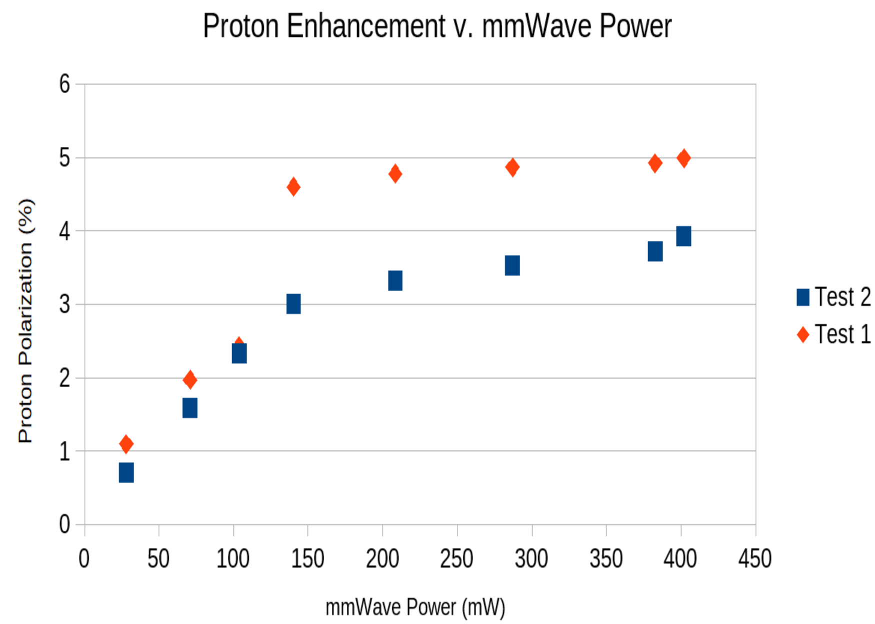
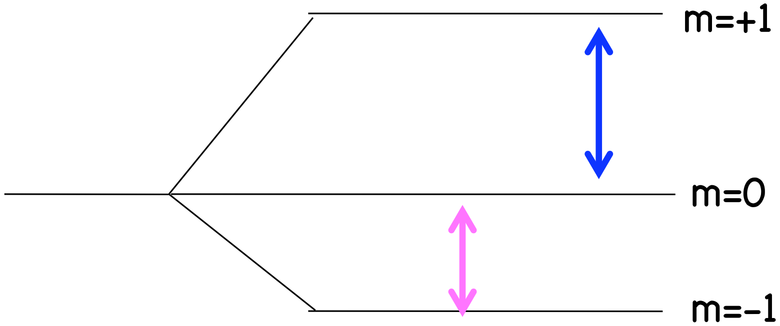


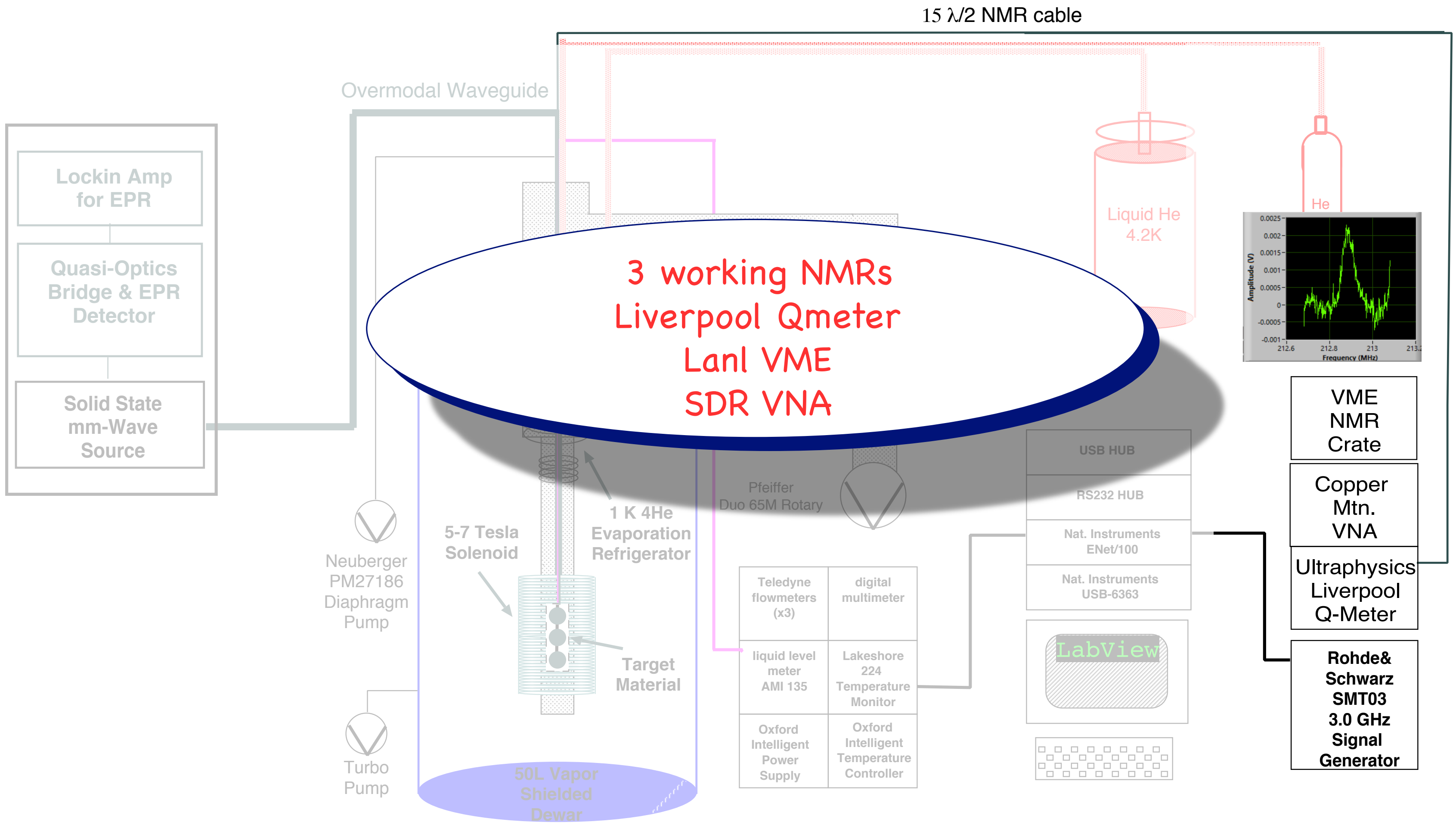
Our tests indicate polarization saturation

Solid State mm-Wave System

Cheaper than EIO
No cooling
Sits directly above target
Passes thru air gap
Low Loss Overmodal waveguide
Wide Frequency Range
Frequency Hopping as fast as 1 khz
(mimics multiple sources for populating m=0)



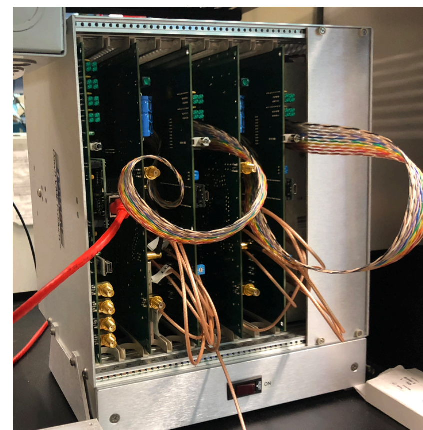
UNH Polarized Target Lab



3 NMR Systems used at UNH

1) Liverpool Q-Meter
gold standard, but blackbox and difficult to tune

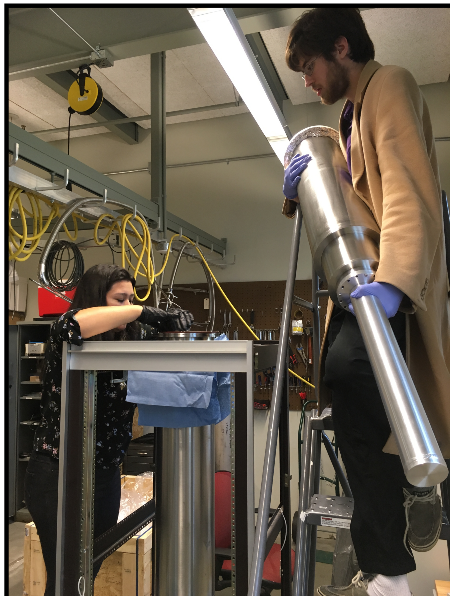
2) VME based replacement
our most reliable system at 5T



3) SDR-based Vector Network Analyzers VNA
easy to tune at any frequency
TEs at 1T, 2T, 5T
Real and Imaginary Z
We haven't yet tested linearity

UNH He Evaporation Refrigerator

Complete Fridge



Vacuum shells

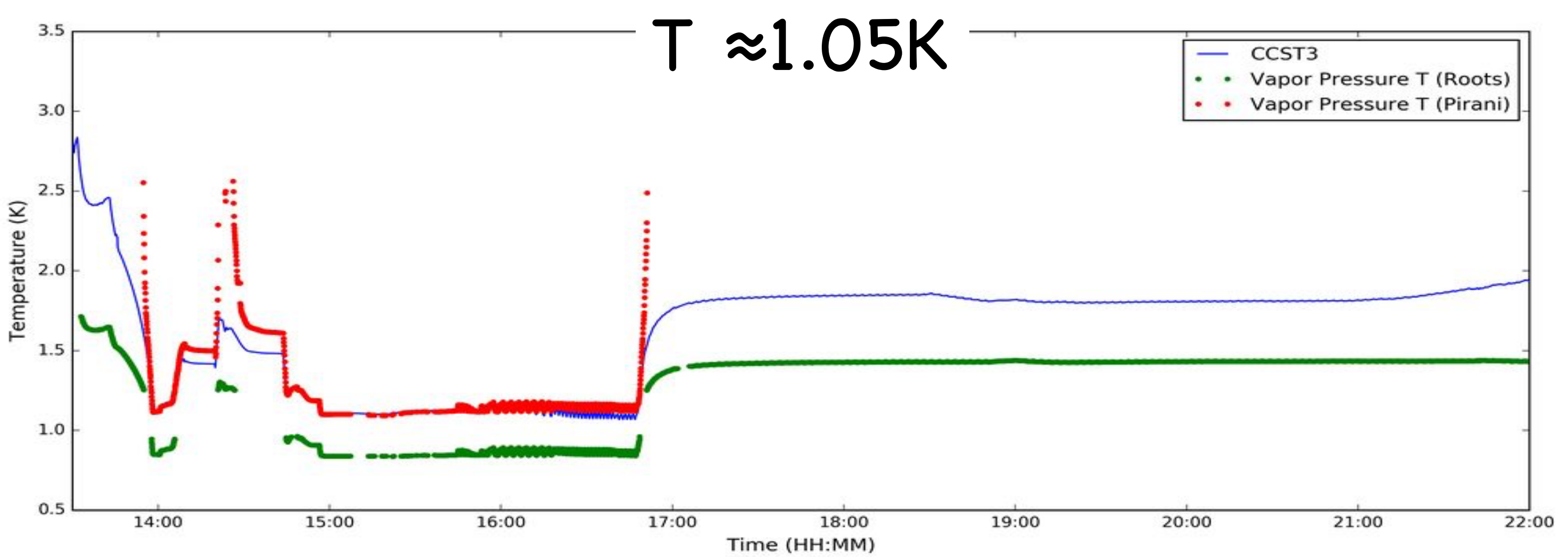
All Machining Completed at UNH

- ✓ Heat Exchanger
- ✓ Separator Pot
- ✓ Radiation Baffles
- ✓ Needle valves
- ✓ Vacuum Shells

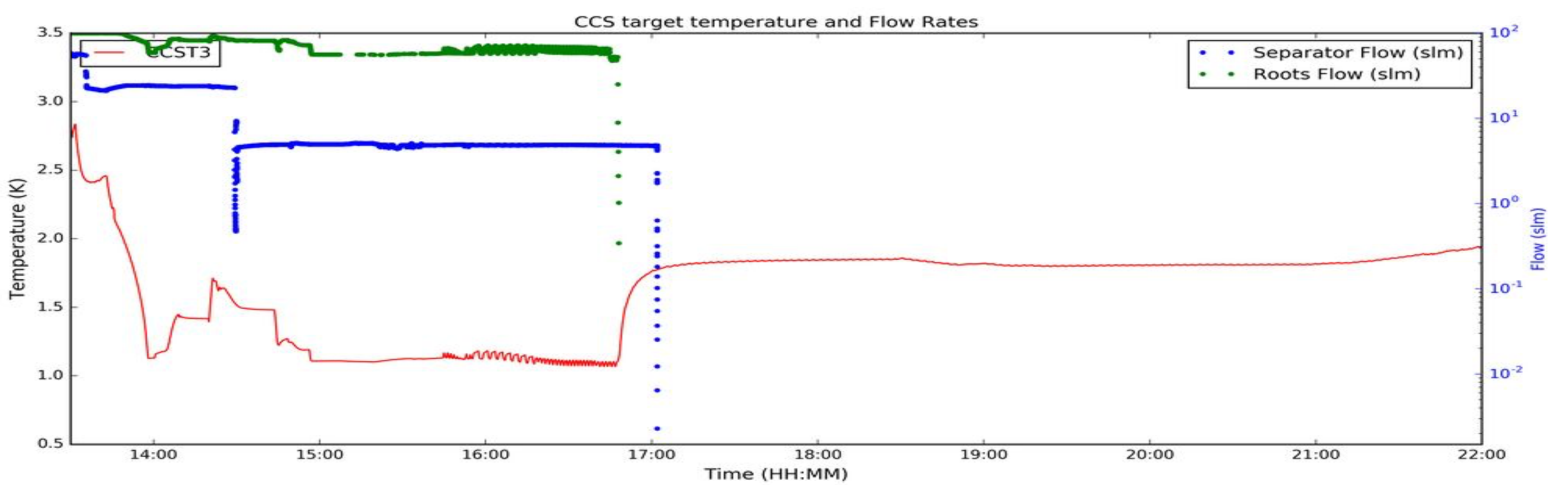
Final brazing/welding of needlevalves fittings @ Jlab

UNH He Evaporation Refrigerator

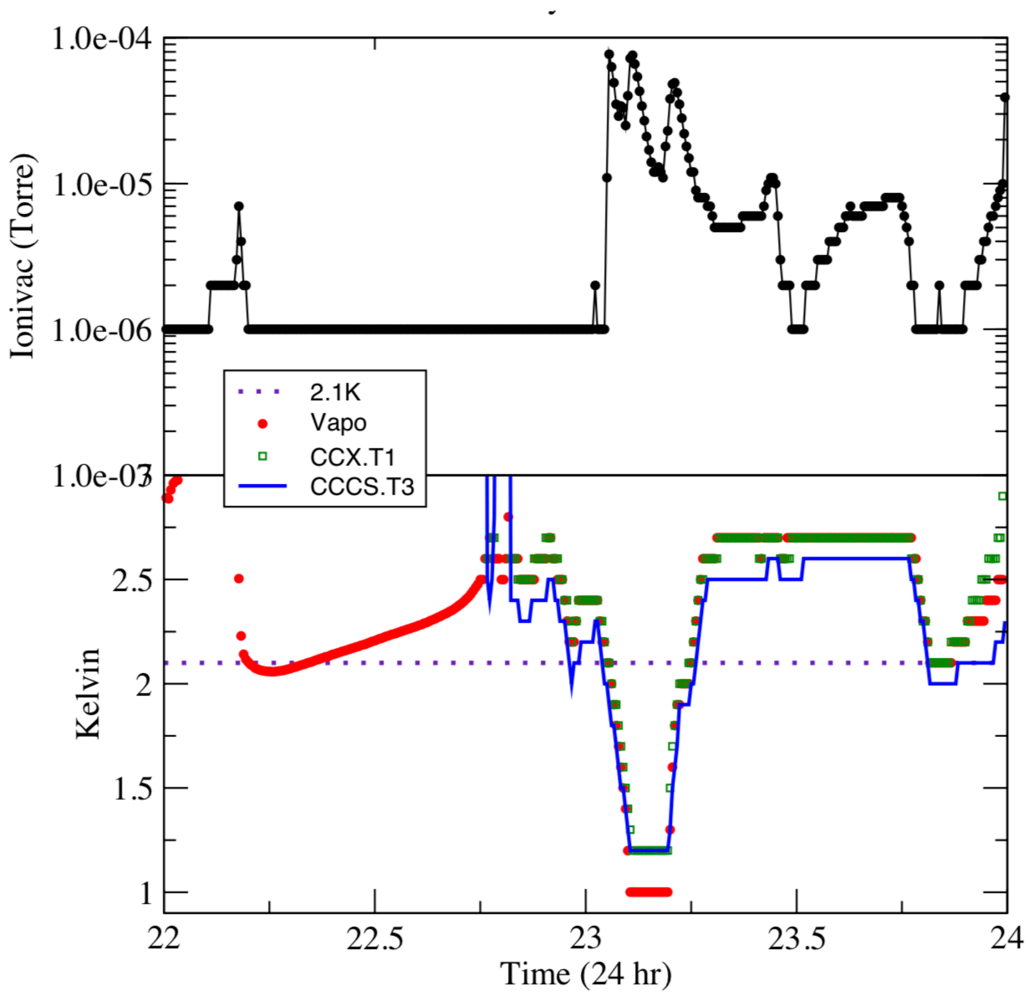
Vapor Pressure



Calibrated thermistor



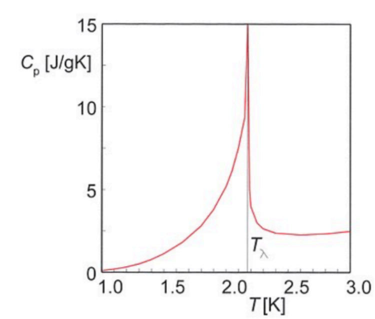
UNH He Evaporation Refrigerator



1 Kelvin Running
during 3 cooldowns

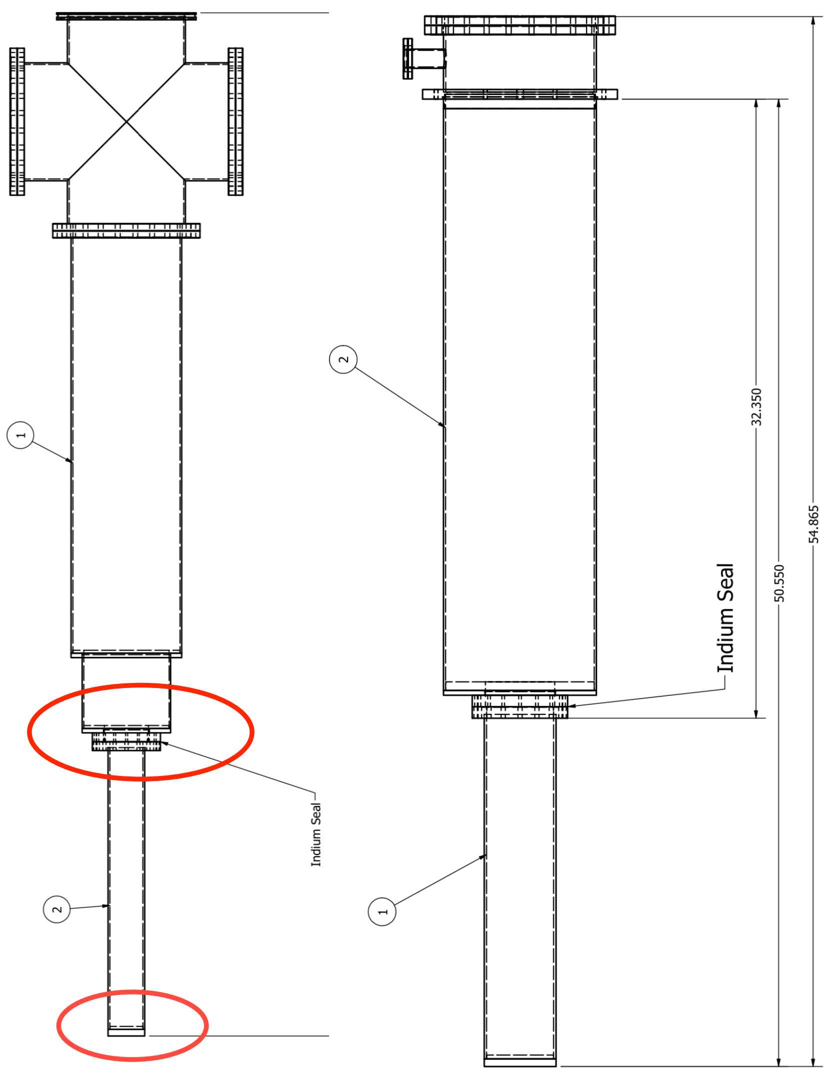
Operationally measured
>45W cooling power!!!!!
at 2K

Wrestling with a superfluid leak that
compromises vacuum



Complete Fridge

Addressing Superfluid Helium Leak



1) new CF shells from Lesker

2) patched suspect weld joints in the nose

3) new needle valves to better control the LL

Addressing Superfluid Helium Leak

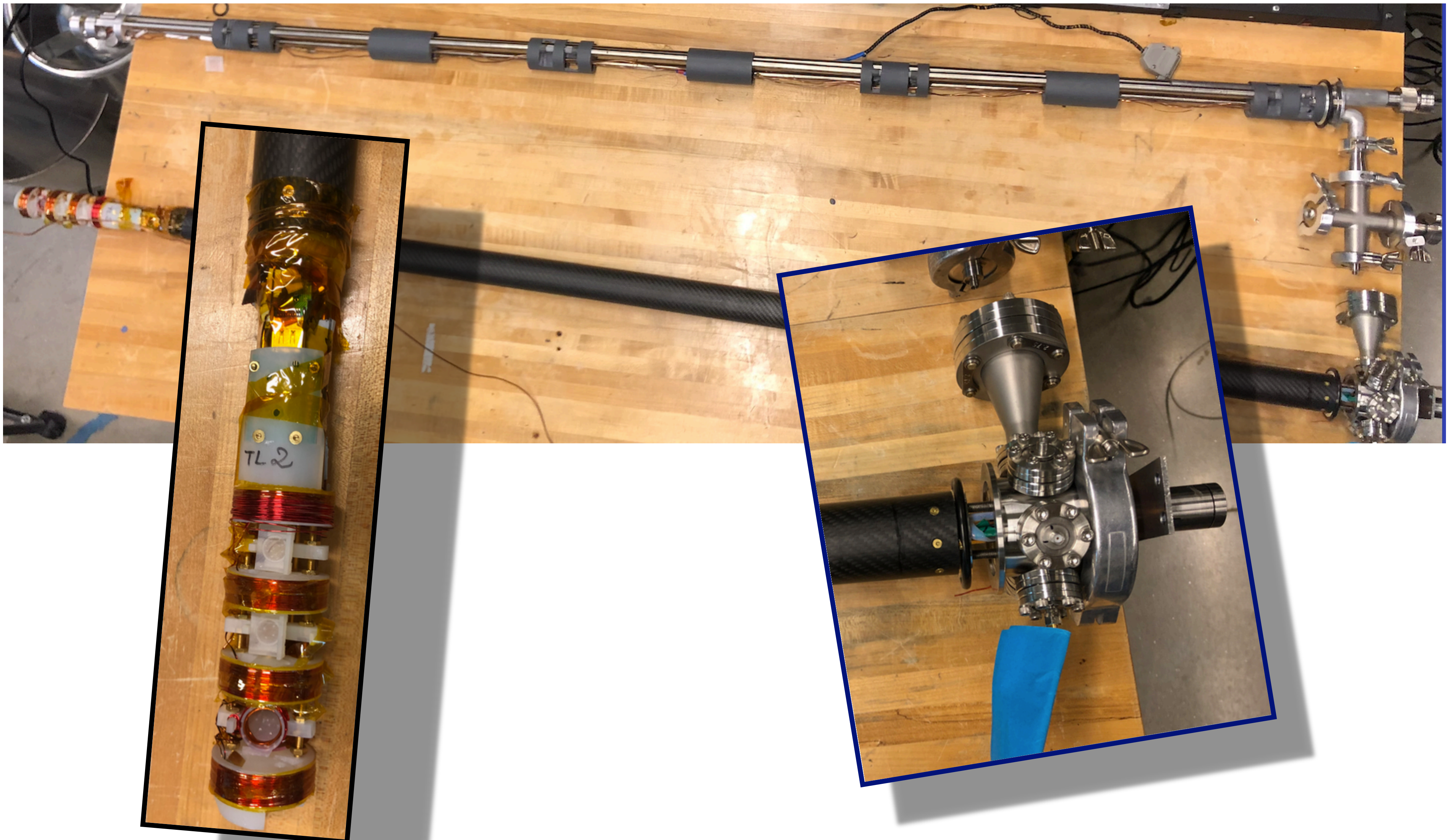
Nose made from 6061 Aluminum

suspect that the weld joints leak

So Patched with DP190 epoxy
and 7075 Aluminum collars

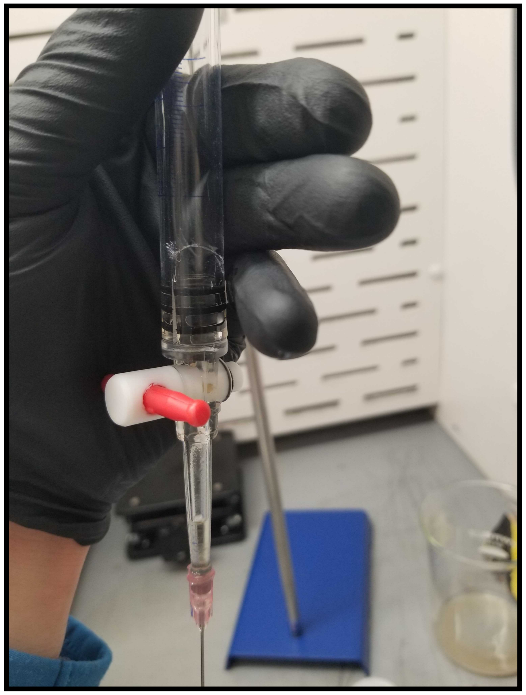
New custom Needle Valves for bypass & Heat Exchanger
Thanks to James Brock for design!!

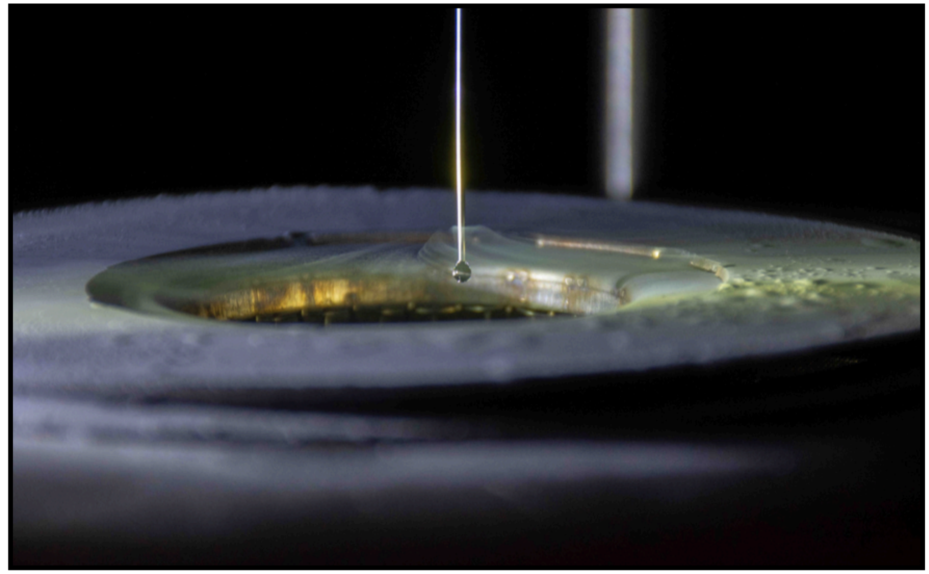
Target Stick



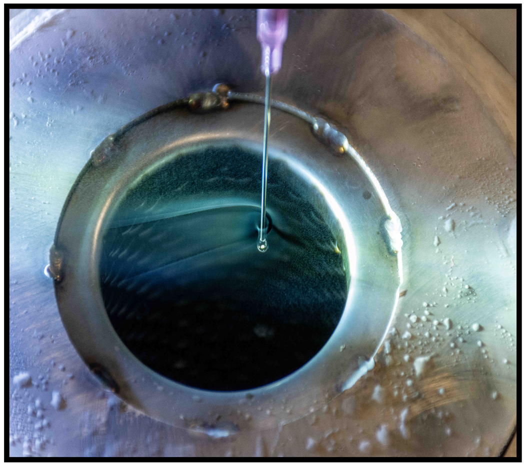
TEMP STABILIZED NMR CABLES

Target Material Production at UNH





Target Material Production at UNH

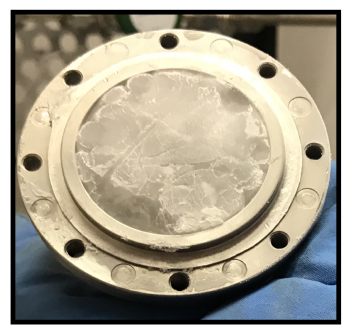


Butanol and other alcohols solidification

grade 5.5 NH_3

Chemical Doping

Rapid vs SlowCooling of NH_3



Target Material Production at UNH

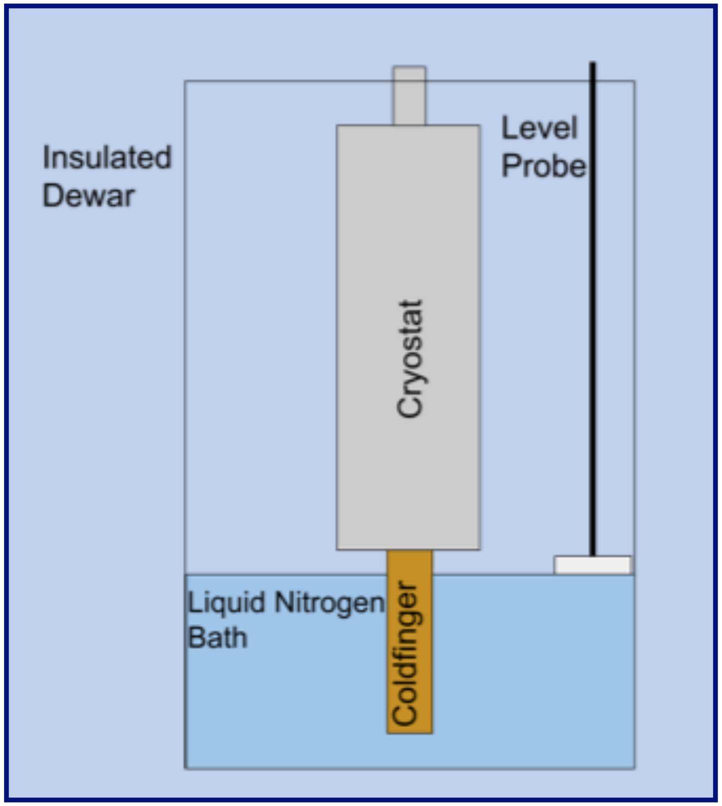
-Dedicated **fume hood** for Handling Ammonia and other caustic/toxic materials

-New **Vacuum GloveBox** allows for over/underpressuring

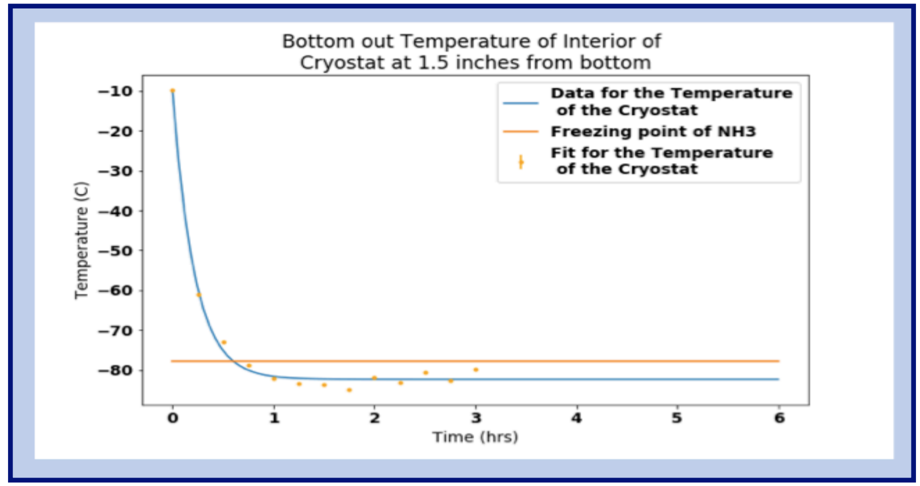
-Primarily chemical doping of ammonia and alcohols for now.
But potential to do much more.

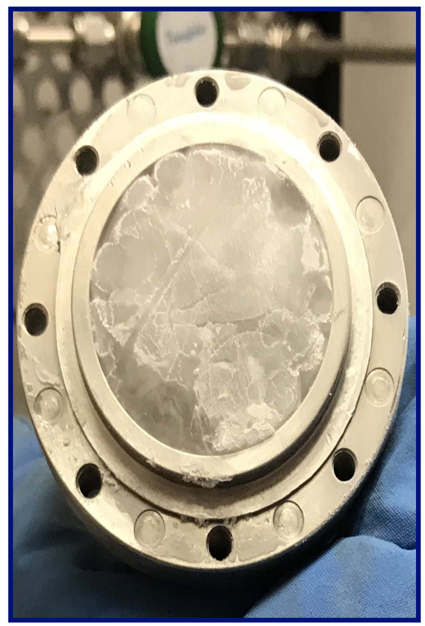
-We produced about 200 grams of NH_3

Slow Frozen Ammonia



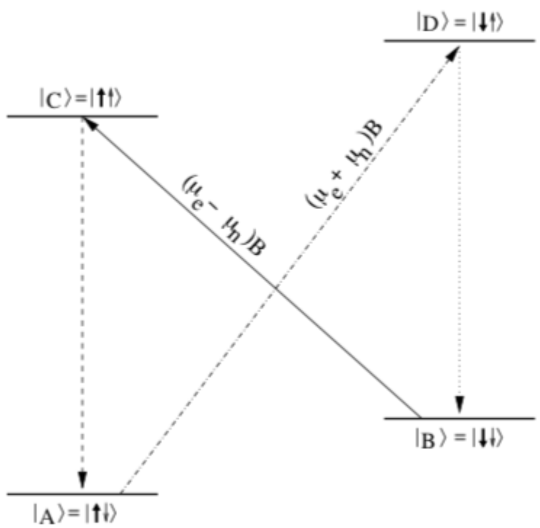
Technique to solidify NH3 just below its freezing point creates a more crystalline solid





Doping Materials

DNP needs paramagnetic centers at the level of aobut 10^{19}/cc



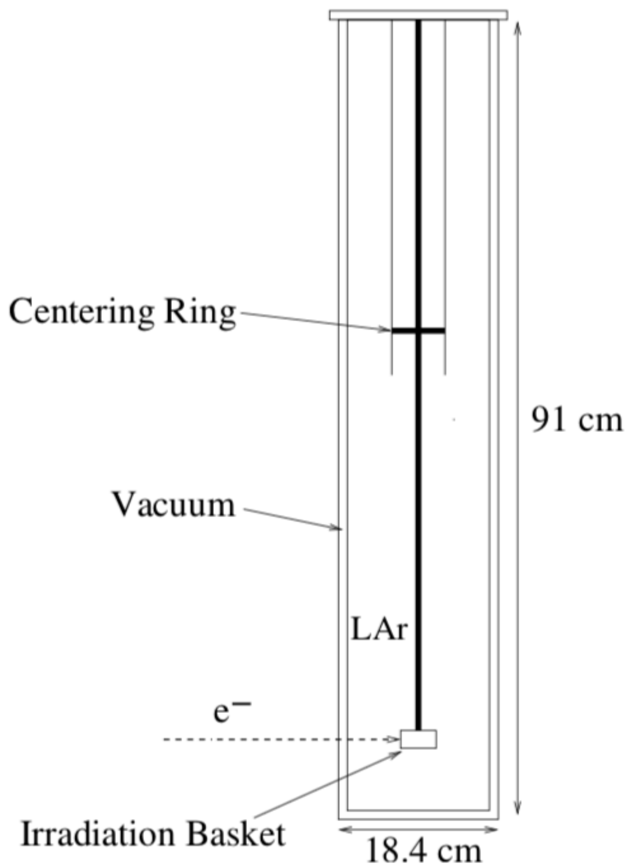
chemical doping : typically stable nitroxyl or trityl radicals

Irradiation : typically EB, but also UV, insitu and other radiation

few 10^{15}/cm^2

Material Irradiations

Electron beam irradiations have been traditionally done under liquid argon (to avoid creating Nitrates) but the penetration depth of the e- beam depends very strongly on the type of coolant used



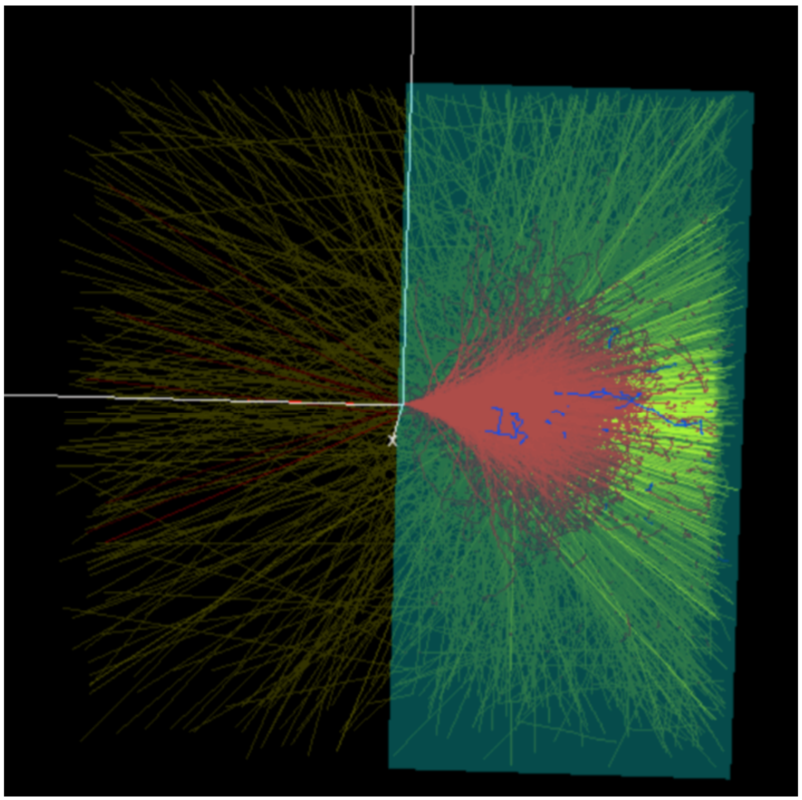
Classic Irradiation Dewar used by UVA
From J. Mellor

Can lead to under-irradiated material because the beam passes thru a lot of material (walls and coolant) before it encounters the target.

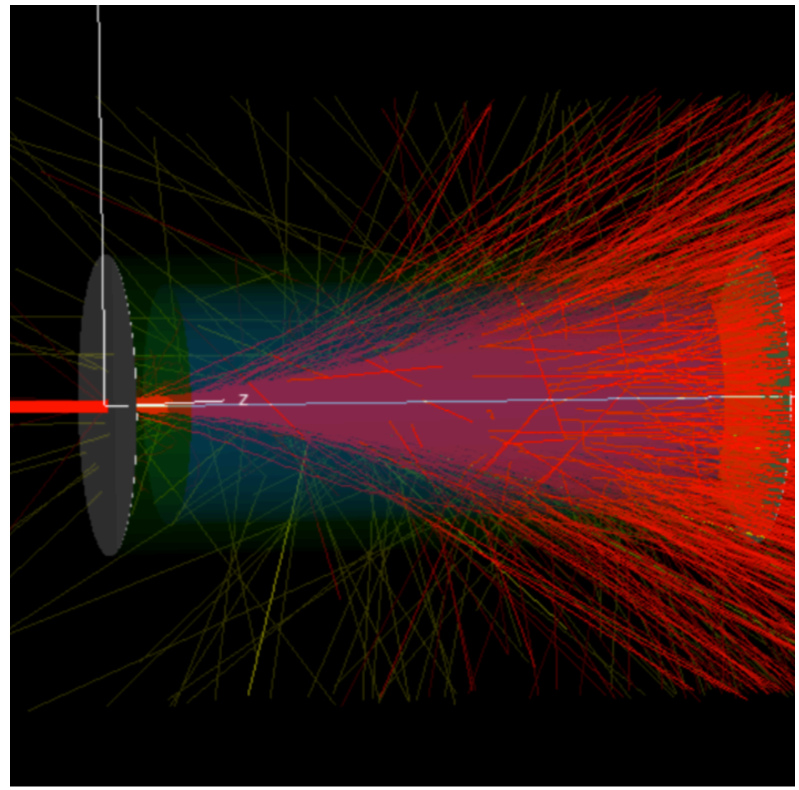
EGSNRC Simulation

egs work by Emad Mustafa

19 MeV electrons incident on target material



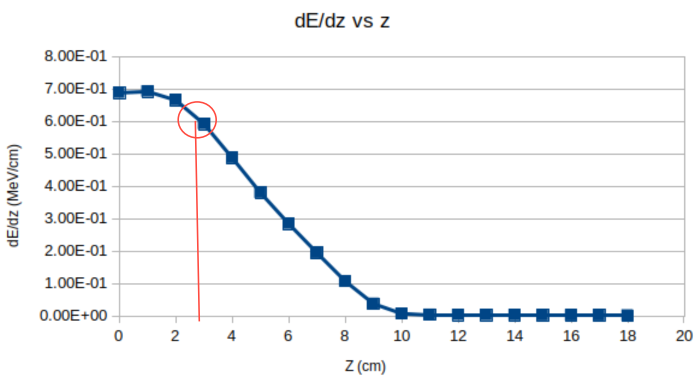
Butanol in liquid Argon.



Butanol in liquid Helium.

(Red=electrons, yellow=photons, blue=positrons)

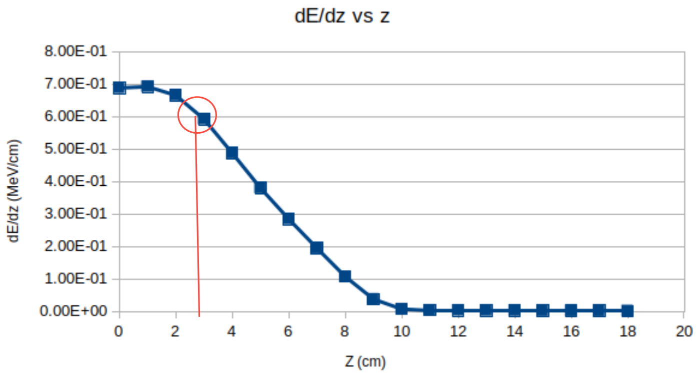
Energy Deposition from E-Beam



NH_3 Target in liquid Argon

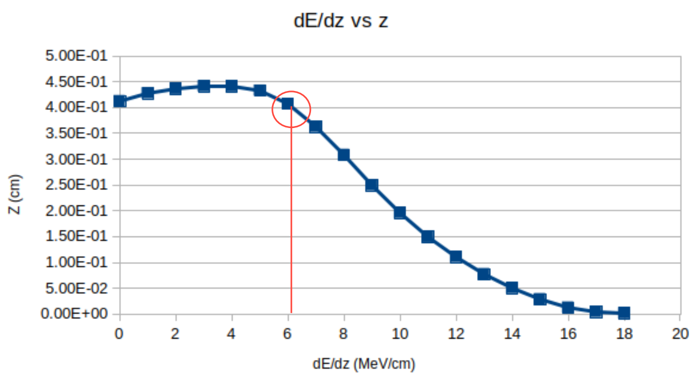
dE/dz falls to 90% at 3cm

Energy Deposition from E-Beam



NH_3 Target in liquid Argon

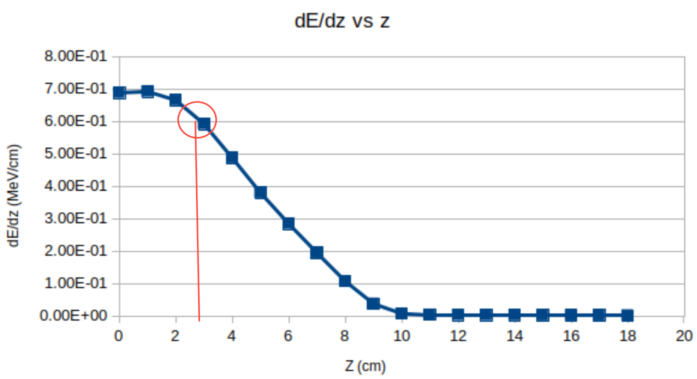
dE/dz falls to 90% at 3cm



NH_3 Target in liquid Helium

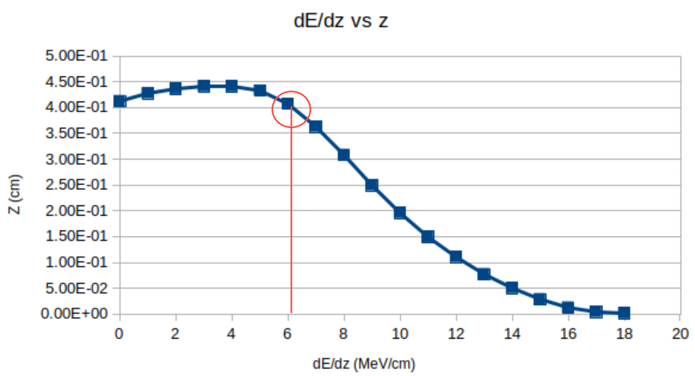
dE/dz falls to 90% at 6 cm

Energy Deposition from E-Beam



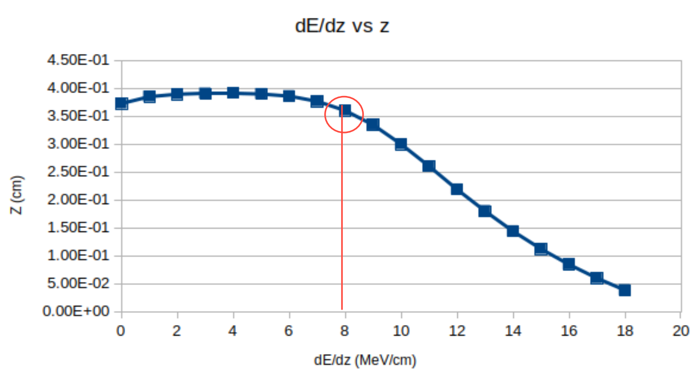
NH_3 Target in liquid Argon

dE/dz falls to 90% at 3cm



NH_3 Target in liquid Helium

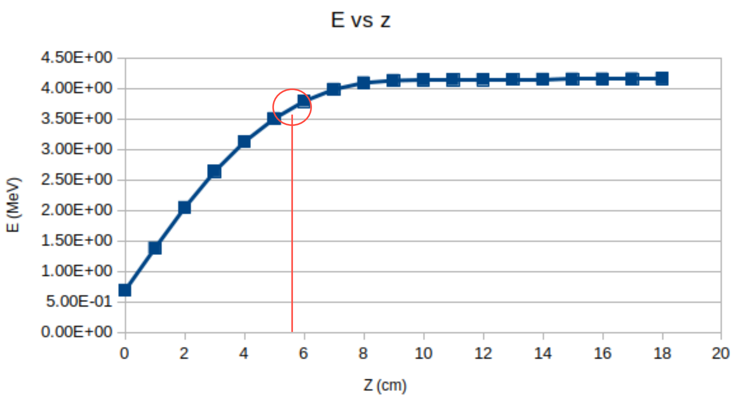
dE/dz falls to 90% at 6 cm



NH_3 Target in gaseous Helium (20K)

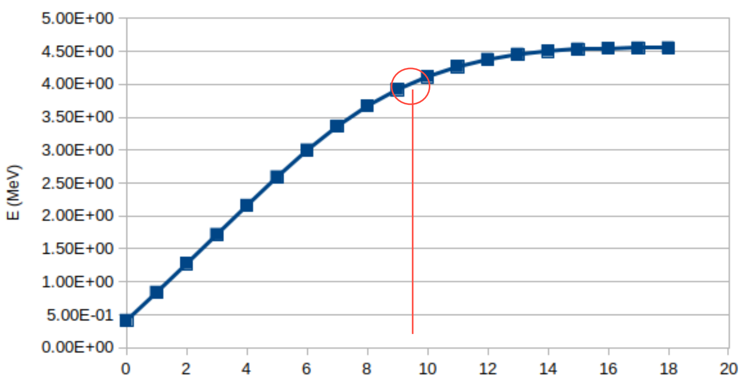
dE/dz falls to 90% at 8 cm

Energy Deposition from E-Beam



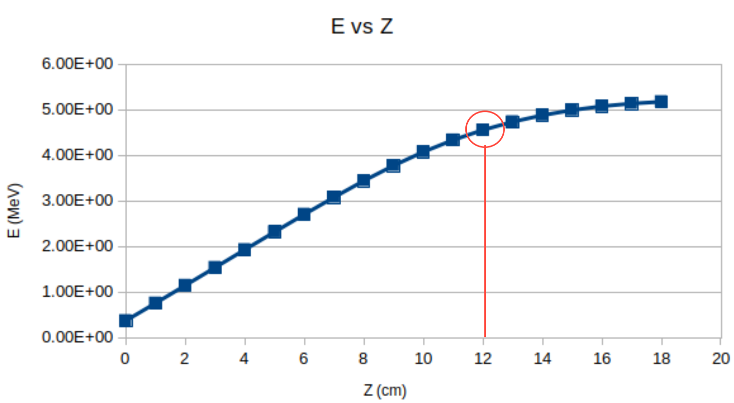
NH_3 Target in liquid Argon

90% saturated at 5.5 cm



NH_3 Target in liquid Helium

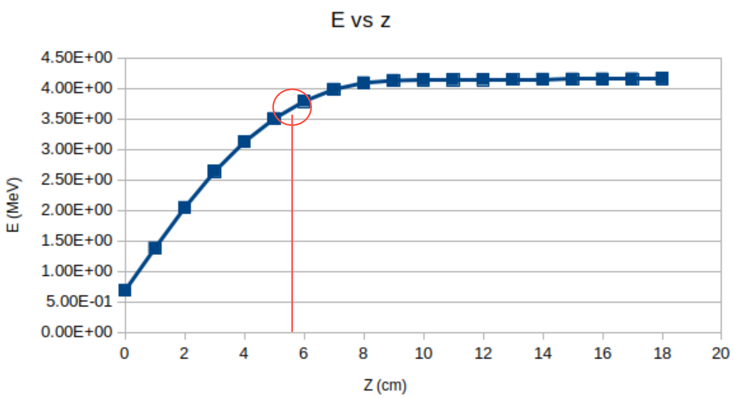
90% saturated at 9 cm



NH_3 Target in gaseous Helium (20K)

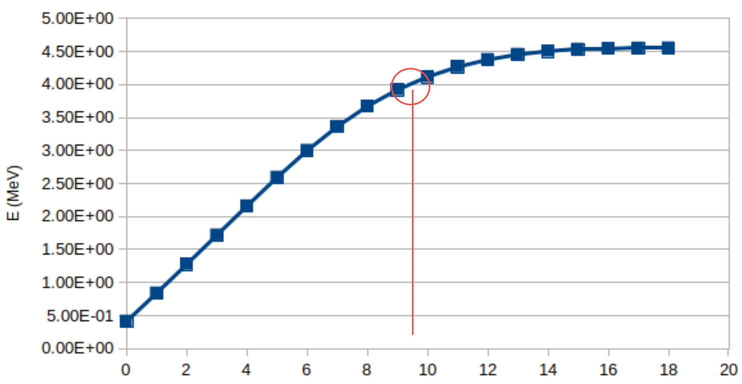
90% saturated at 12 cm

Energy Deposition from E-Beam



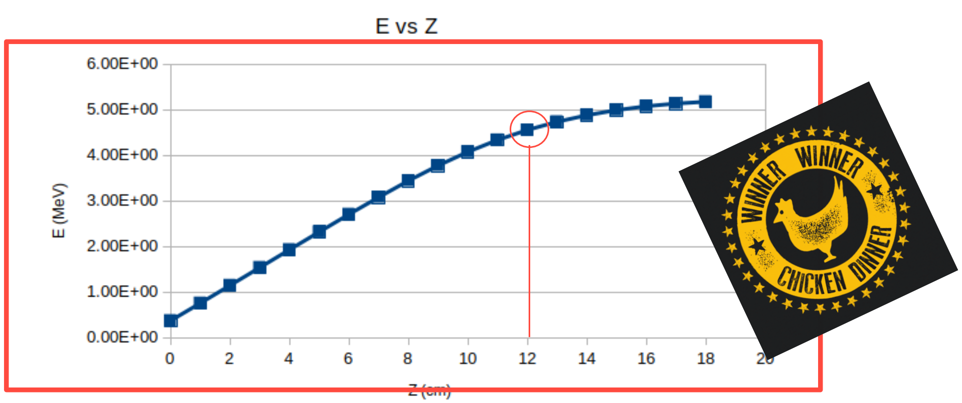
NH_3 Target in liquid Argon

90% saturated at 5.5 cm



NH_3 Target in liquid Helium

90% saturated at 9 cm

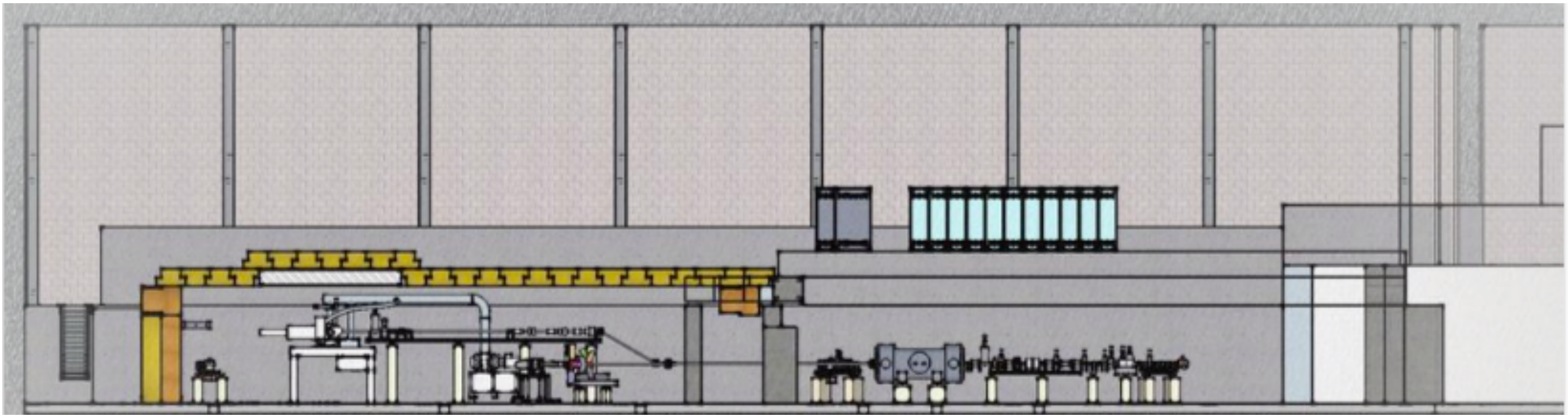


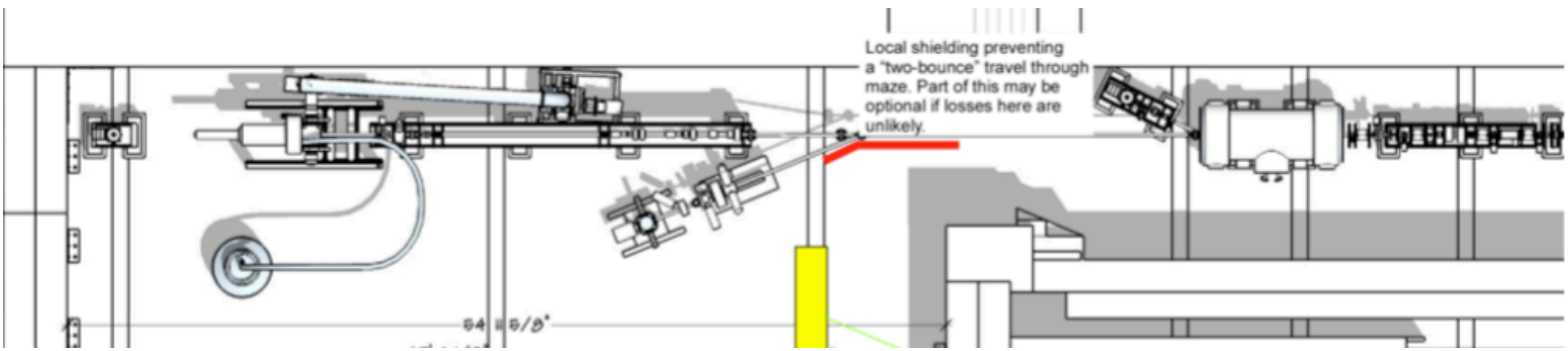
NH_3 Target in gaseous Helium (20K)

90% saturated at 12 cm

Upgrade Injector Test Facility

10 MeV, 10 uA rastered electron beam

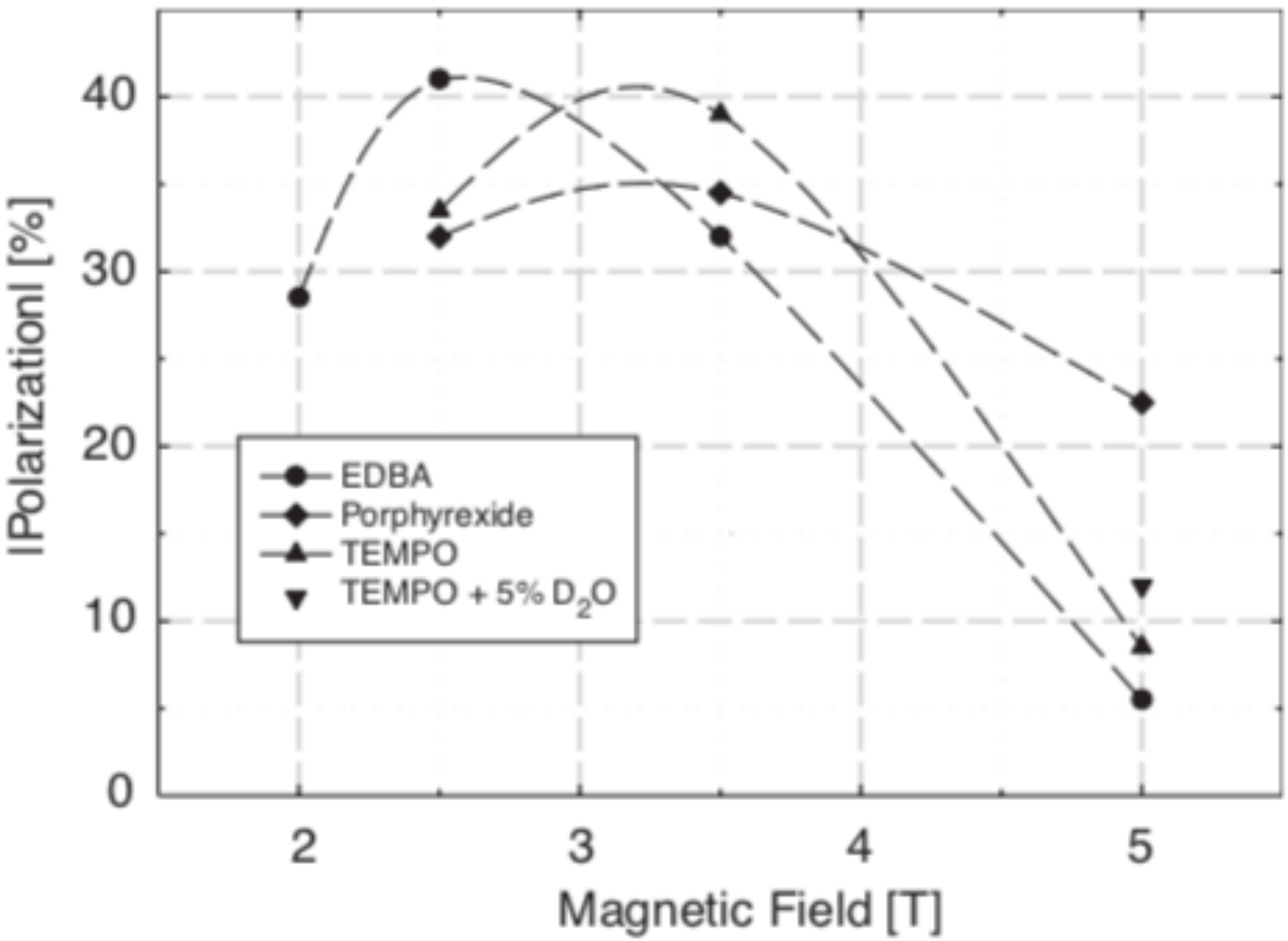




Deuterated Material

Deuterated Material

Nitroxyl doping of D-Butanol displays strong field dependence



St. Goertz NIMA 526(2004) 43

Deuterated Material

Spin temperature theory

$$P_{max} = \frac{I+1}{3}\frac{\omega_e}{\kappa T}\frac{\omega_I}{2D}$$

Paramagnetic Center
ESR linewidth

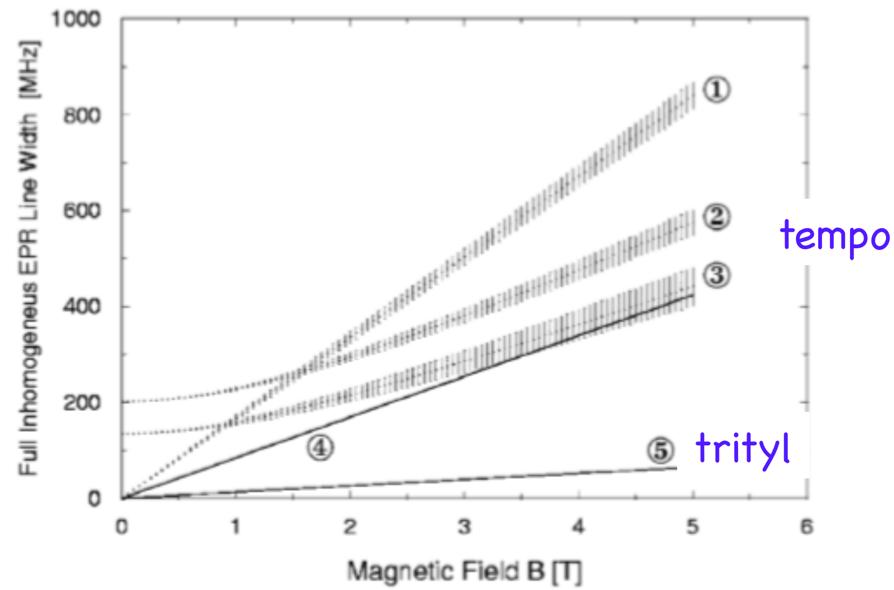
St. Goertz NIMA 526(2004) 43

Deuterated Material

Spin temperature theory

$$P_{max} = \frac{I+1}{3}\frac{\omega_e}{\kappa T}\frac{\omega_I}{2D}$$

Paramagnetic Center
ESR linewidth



trityl esr line is about an order
of magnitude smaller

Leading to world record deut pol: 80%

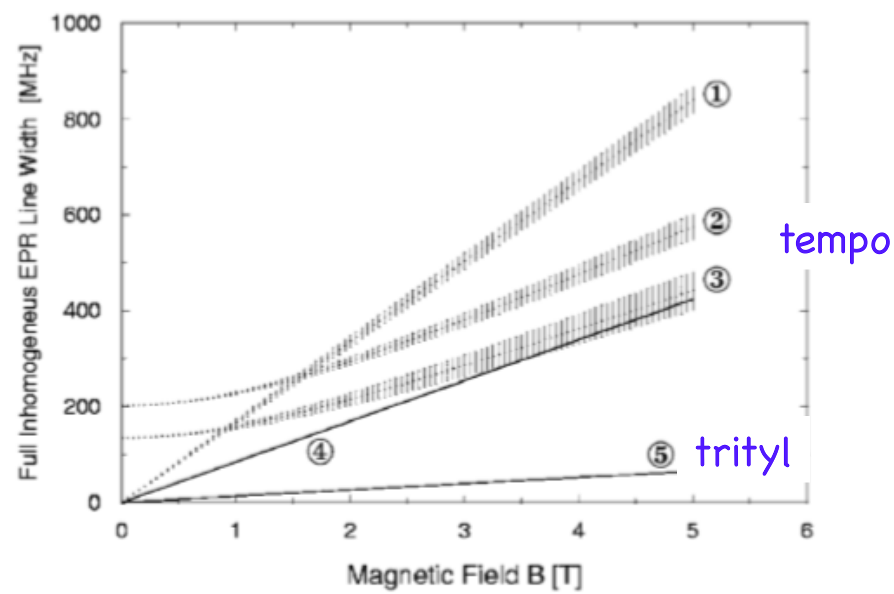
St. Goertz NIMA 526(2004) 43

Deuterated Material

Spin temperature theory

$$P_{max} = \frac{I+1}{3}\frac{\omega_e}{\kappa T}\frac{\omega_I}{2D}$$

Paramagnetic Center
ESR linewidth



52-Radical Finland : readily dissolved in diols

OX063: works better in longer chained alcohols

optimum spin density 1.5×10^{19} /g

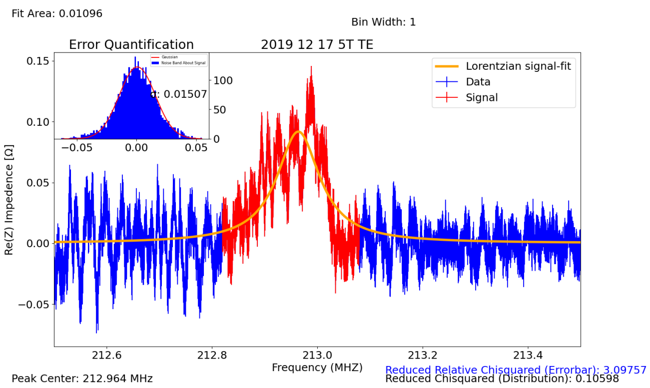
trityl esr line is about an order of magnitude smaller

Leading to world record deut pol: 80%

St. Goertz NIMA 526(2004) 43

NMR Analysis

Thermal Equilibrium

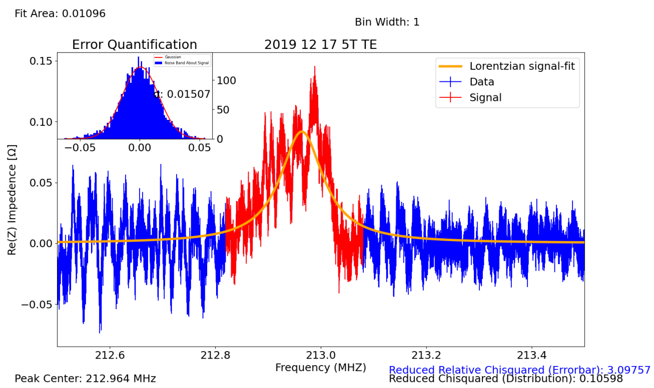


5T, 2.2 K

2019-12-17
Tempo Doped Polymer

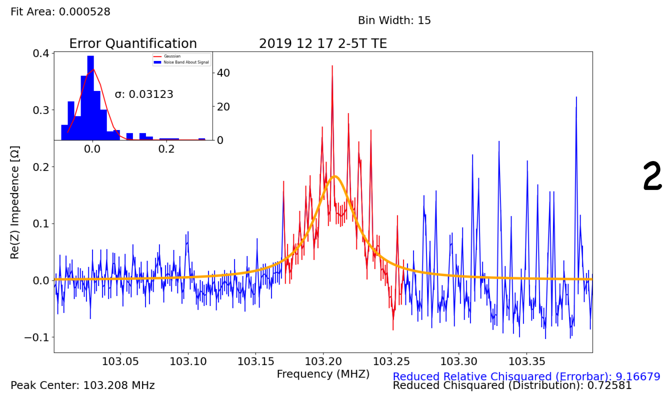
Analysis from Tristan Anderson

Thermal Equilibrium



5T, 2.2 K

2019-12-17
Tempo Doped Polymer

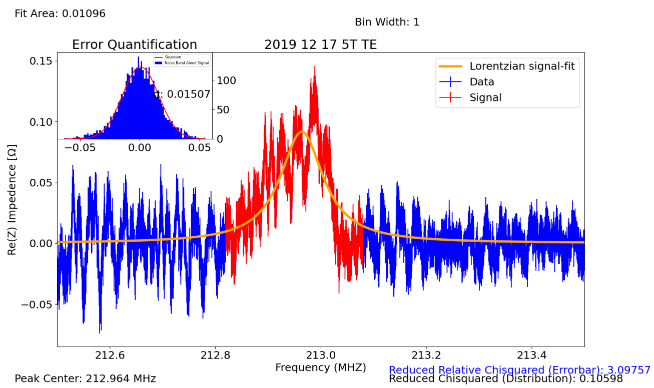


2.5T, 2.1K

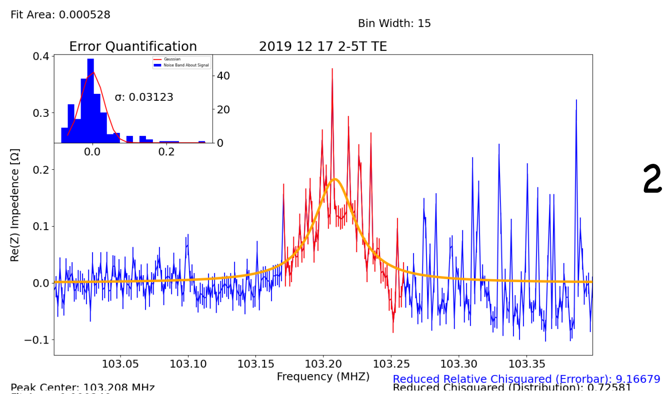
Analysis from Tristan Anderson

Thermal Equilibrium

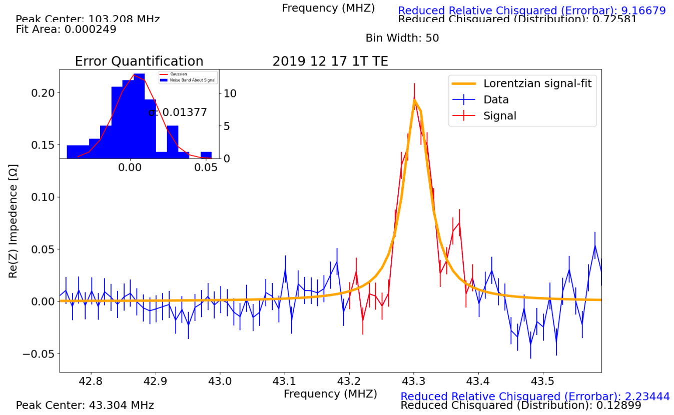
2019-12-17
Tempo Doped Polymer



5T, 2.2 K



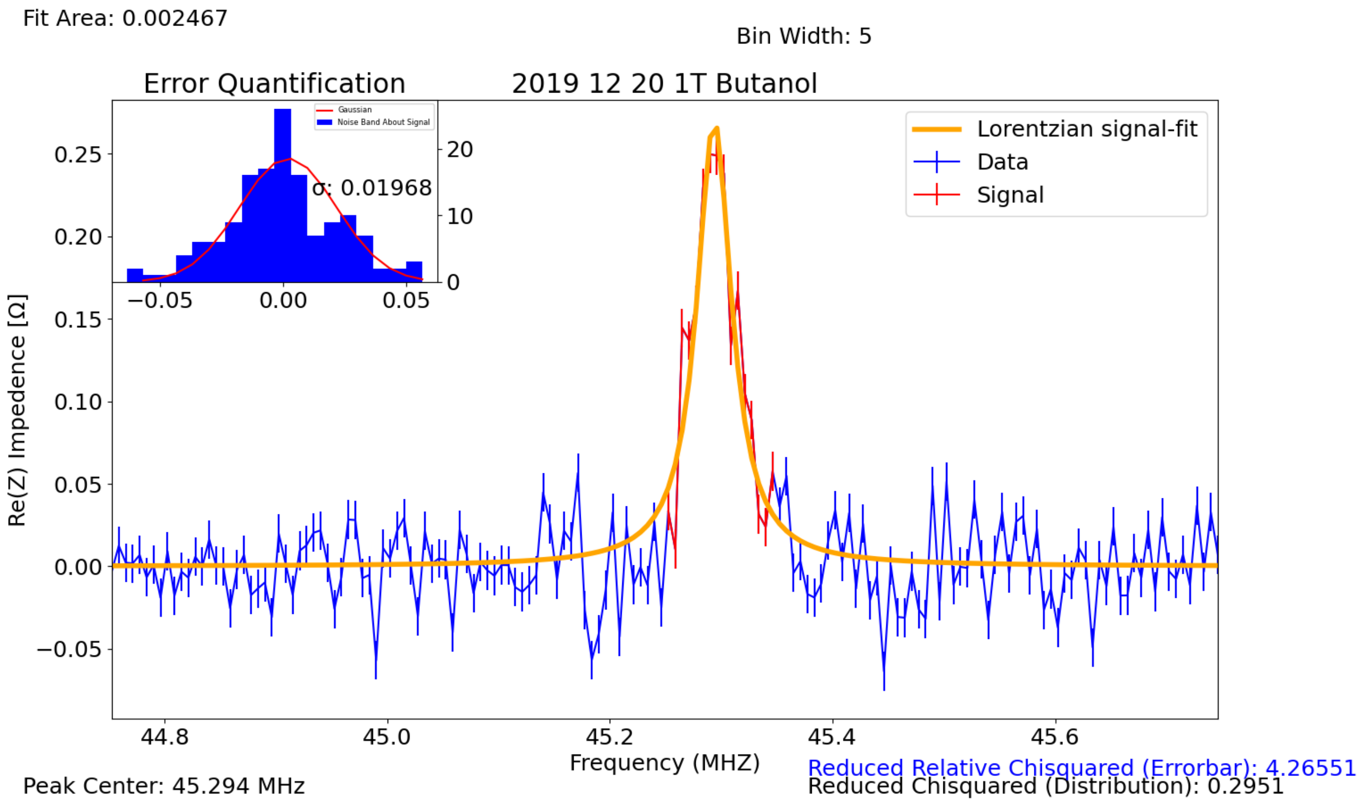
2.5T, 2.1K



1T, 2.1K

Analysis from Tristan Anderson

Thermal Equilibrium

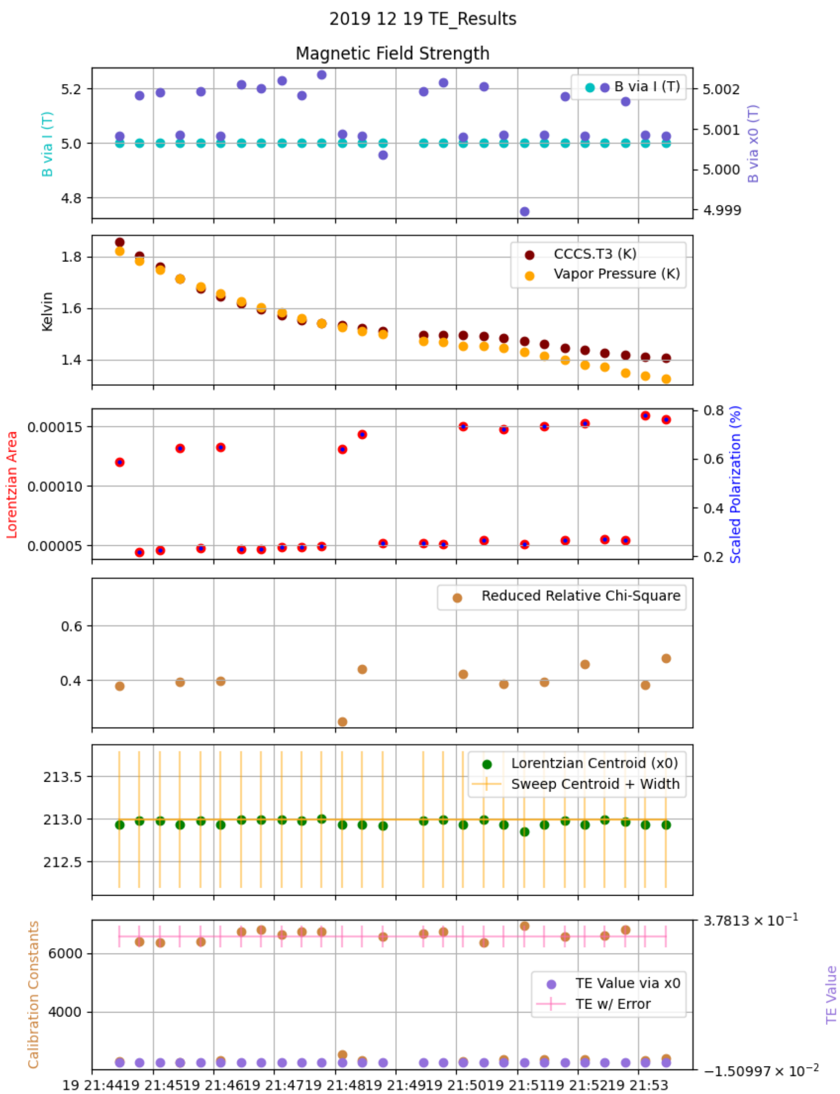


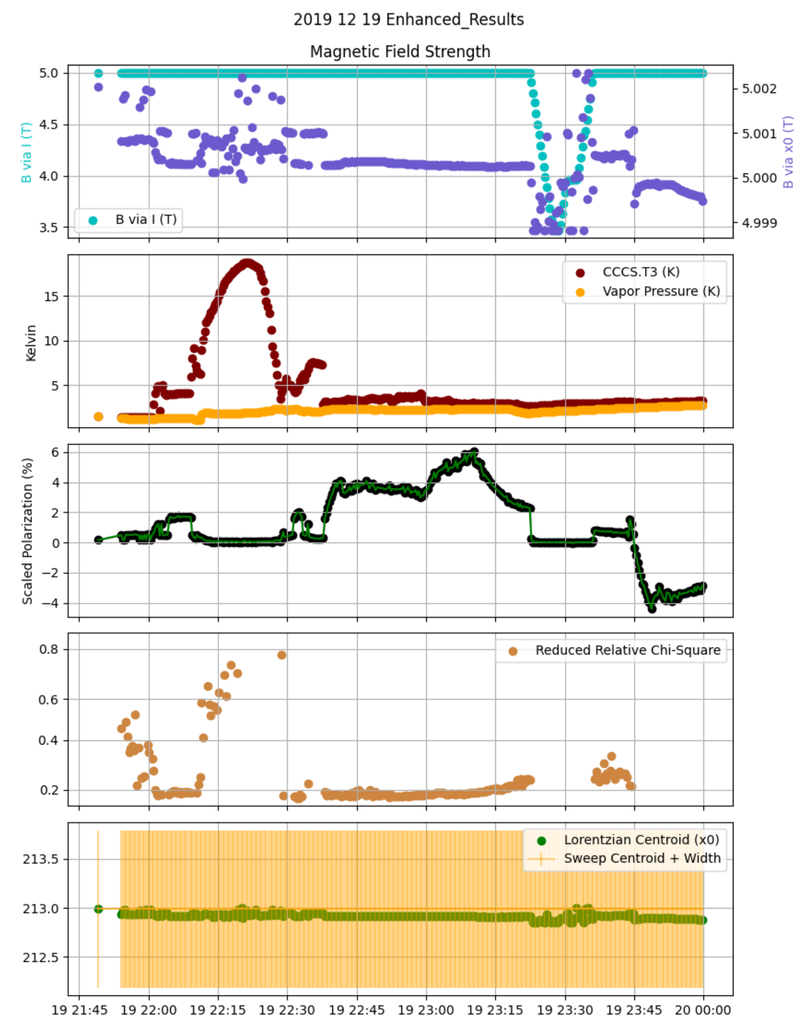
2019-12-20
Tempo Doped Butanol

1Tesla, 2.5K

Analysis from Tristan Anderson

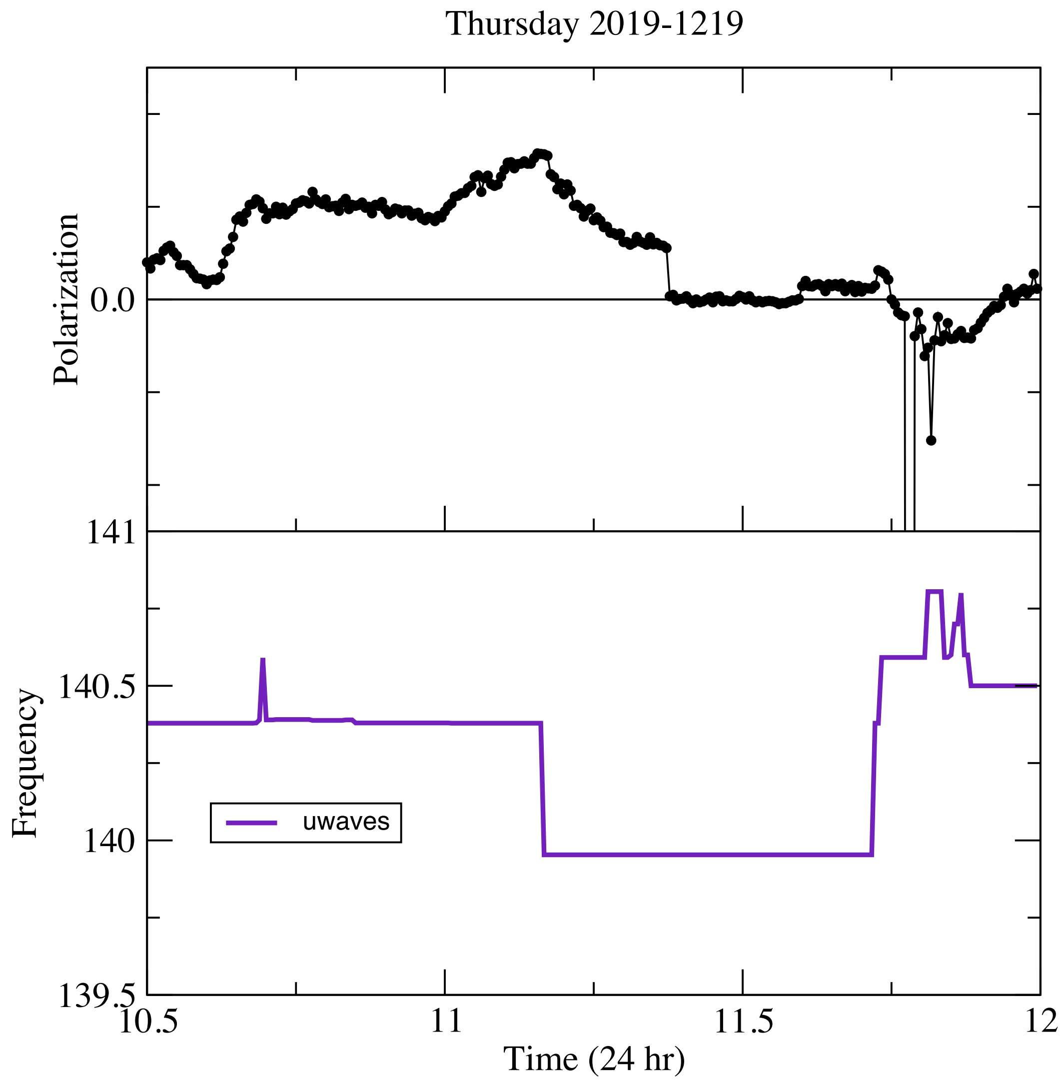
12/19 AralDite



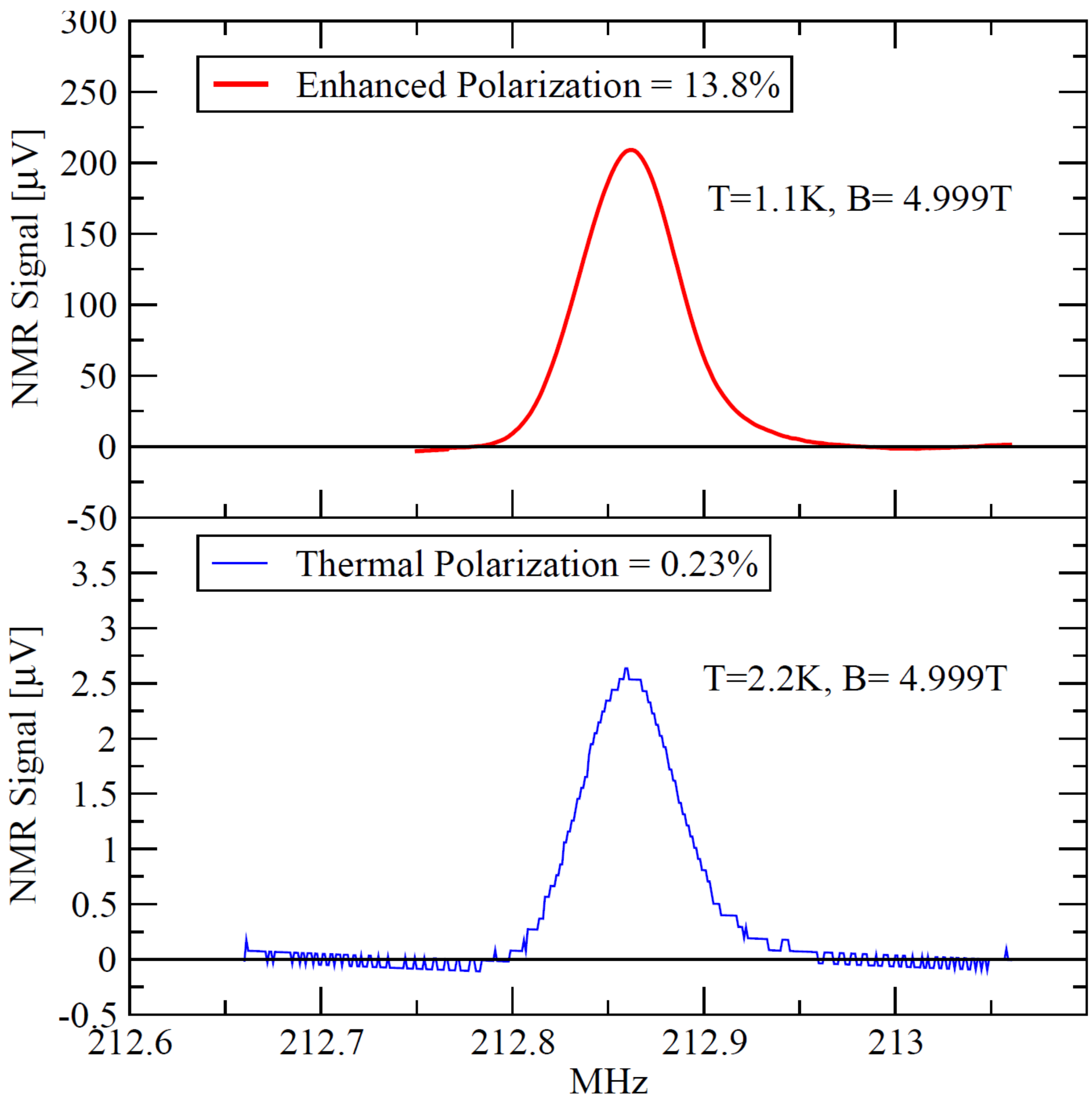


Analysis from Tristan Anderson

DNP Spin Flip



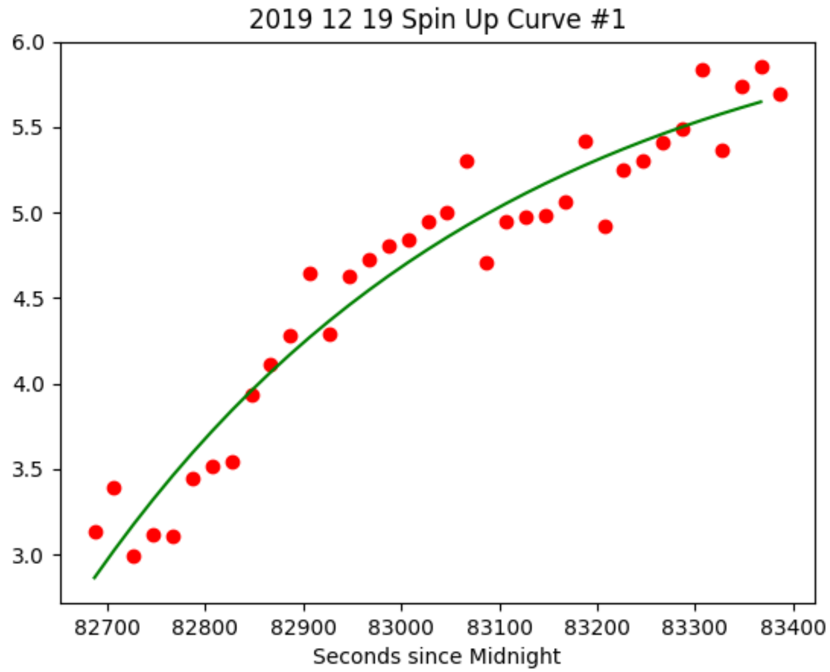
Tempo Doped Polymer



Dynamically Enhanced Polarization

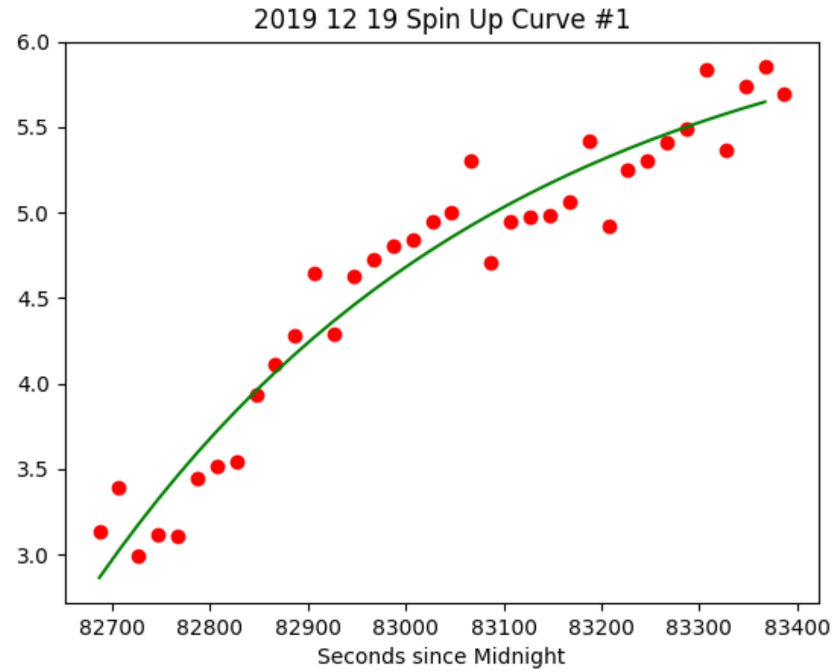
Thermal Signal

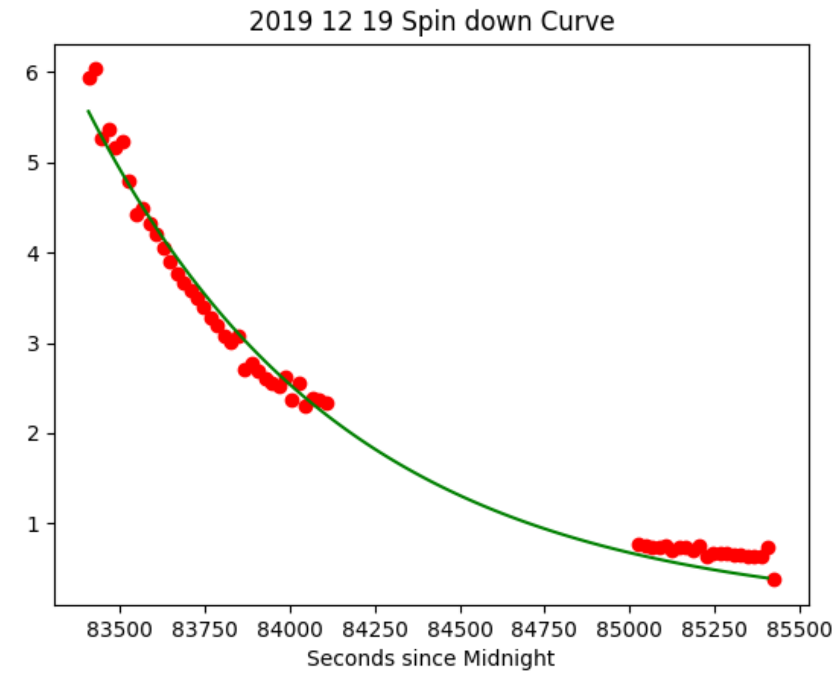
12/19 AralDite



	12/19 tempo-araldite
Buildup (s)	425
Relax	
P max	6.3%

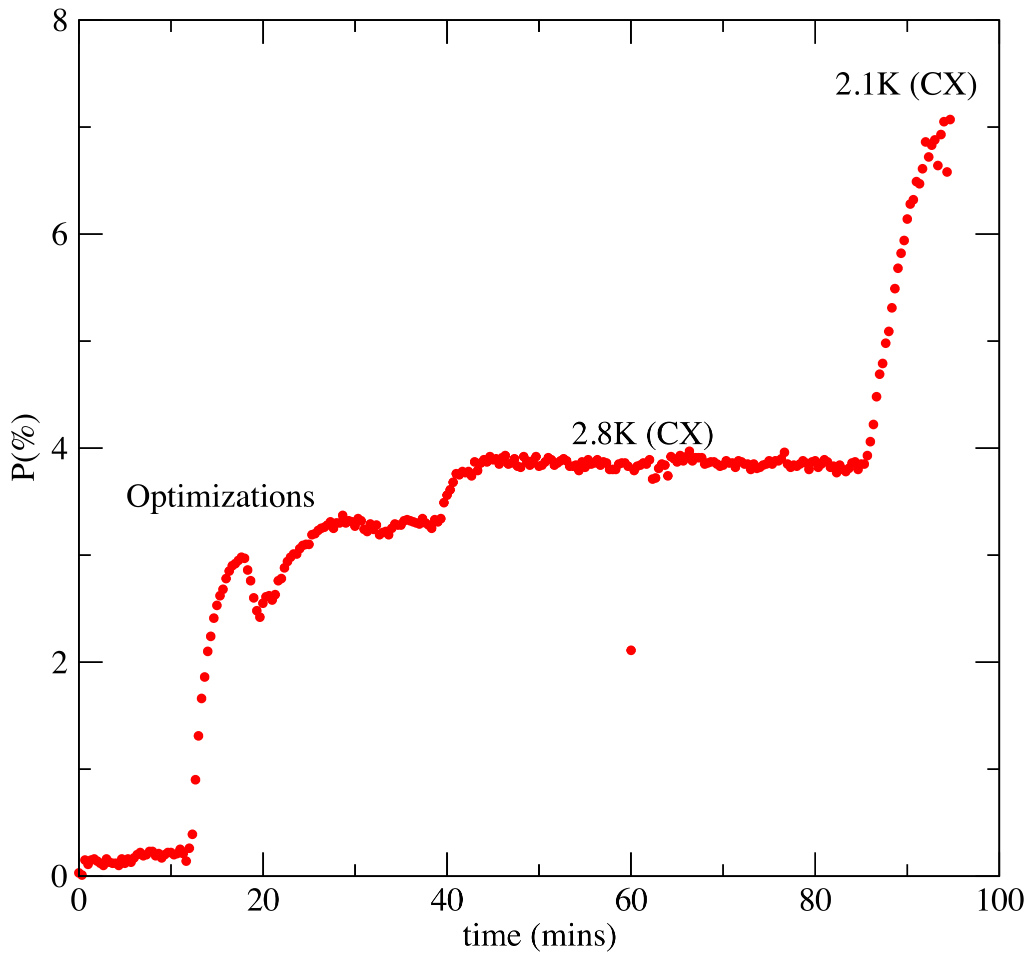
12/19 AralDite





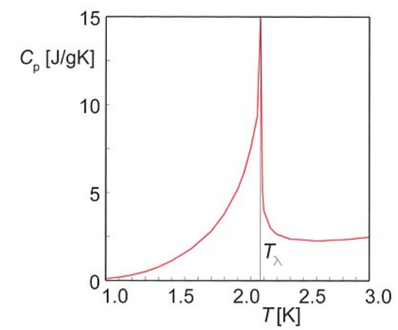
	12/19 tempo-araldite
Buildup (s)	425
Relax	756
P max	6.3%

Tempo Doped Butanol Spinup

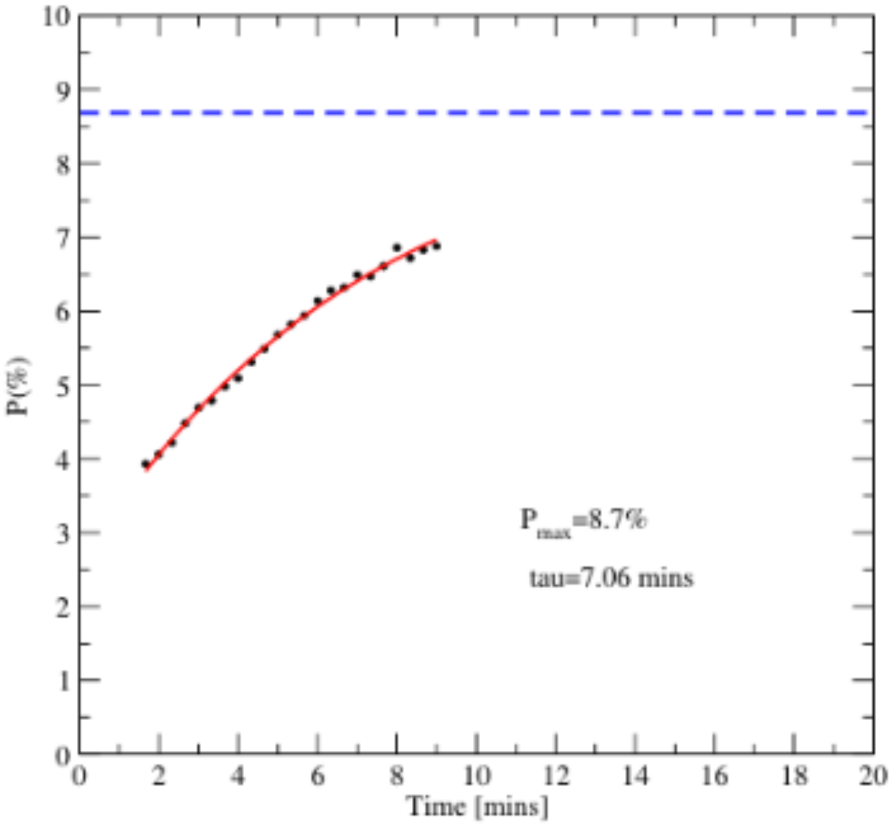


2020-12-21

Healthy spin up at 2.1K
But below 2.1K we have
a superfluid leak thru
an indium seal which
destroys our fridge vacuum



Tempo Doped Butanol Spinup

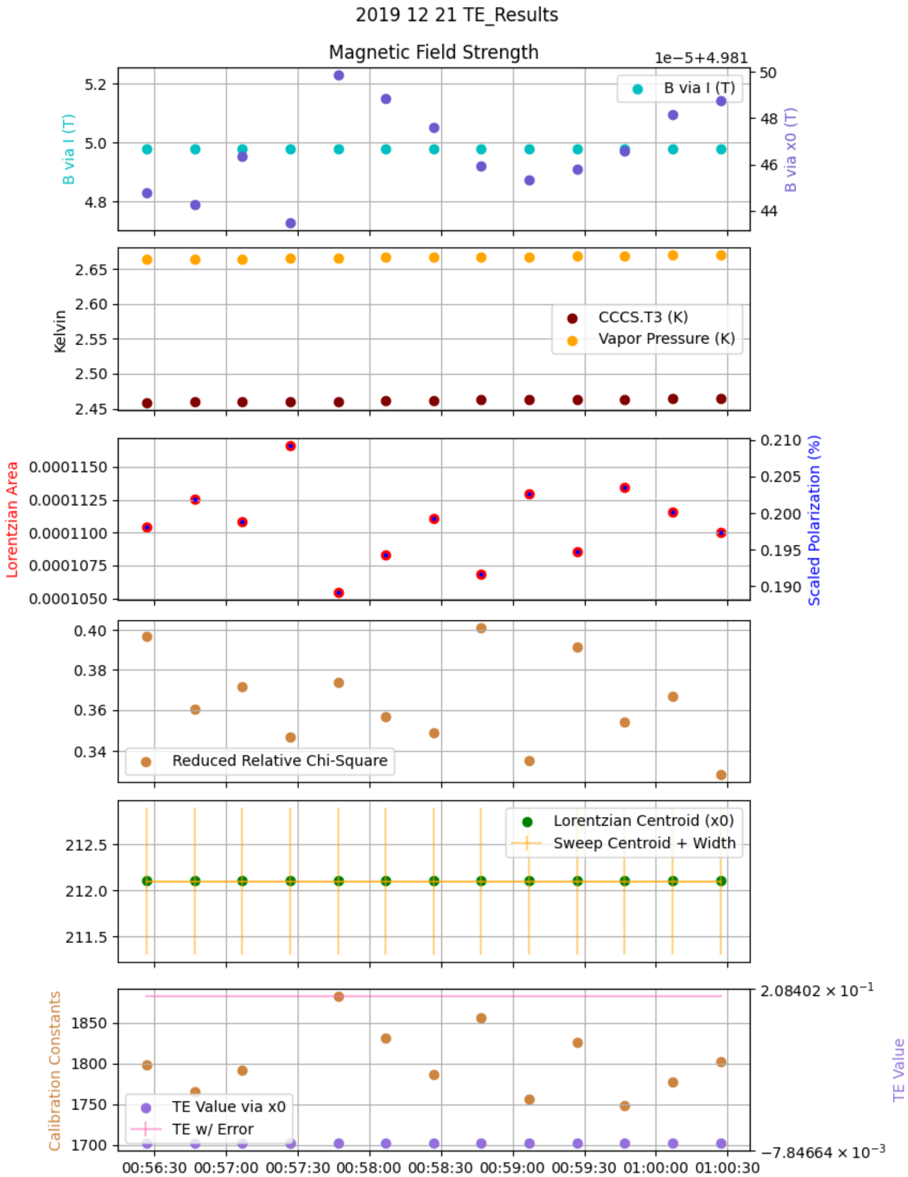


2020-12-21

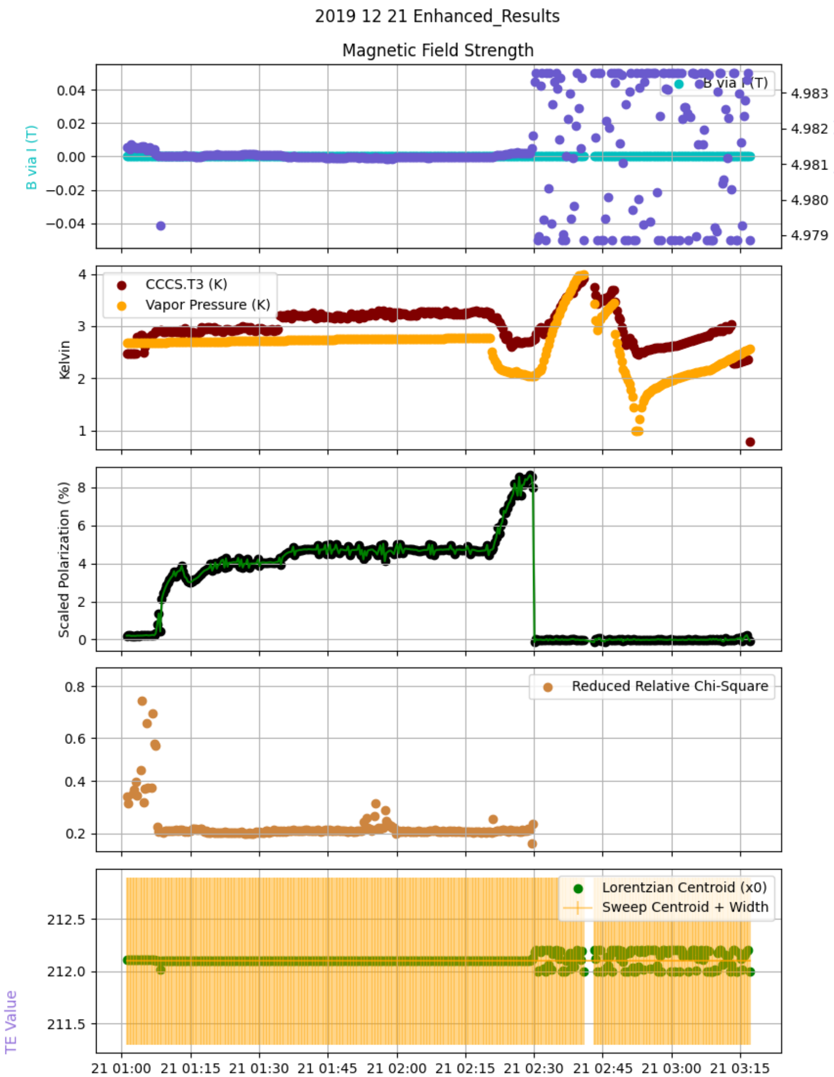
Max polarization of 8.7% at 2.1K

	12/19 tempo-araldite	12/21 Tempo-Butanol
Buildup (s)	425	420
Relax	756	--
P max	6.3%	8.7%

21 BUTANOL

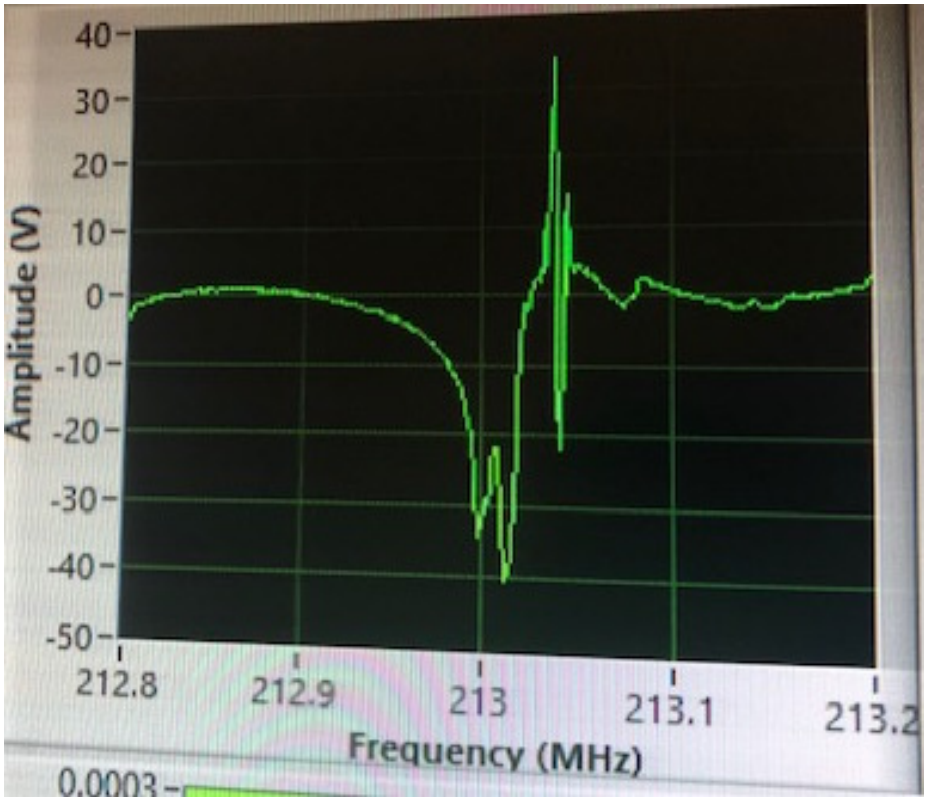


2019 12 21 TE_Results
Magnetic Field Strength
B via I (T)
B via x0 (T)
CCCS.T3 (K)
Vapor Pressure (K)
Kelvin
Lorentzian Area
Scaled Polarization (%)
Reduced Relative Chi-Square
Lorentzian Centroid (x0)
Sweep Centroid + Width
Calibration Constants
TE Value via x0
TE w/ Error
TE Value



2019 12 21 Enhanced_Results
Magnetic Field Strength
B via I (T)
B via x0 (T)
CCCS.T3 (K)
Vapor Pressure (K)
Kelvin
Scaled Polarization (%)
Reduced Relative Chi-Square
Lorentzian Centroid (x0)
Sweep Centroid + Width

RF Hole Burning



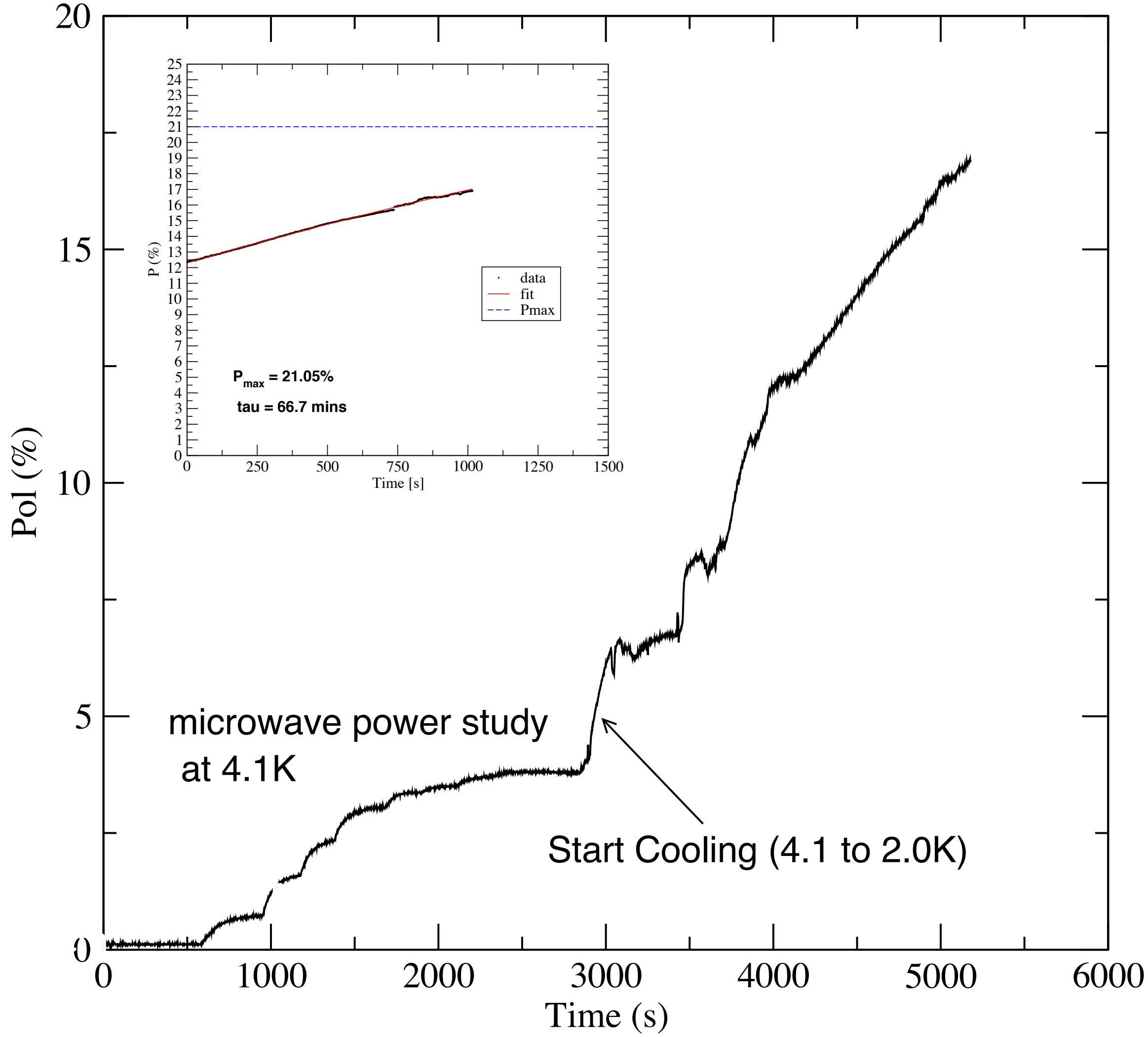
Proven method to enhance
Tensor polarization

We have a working RF system
-READY TO TEST WITH D-material

This technique has been used
By D. Keller at Uva to achieve
P_{zz} =38%

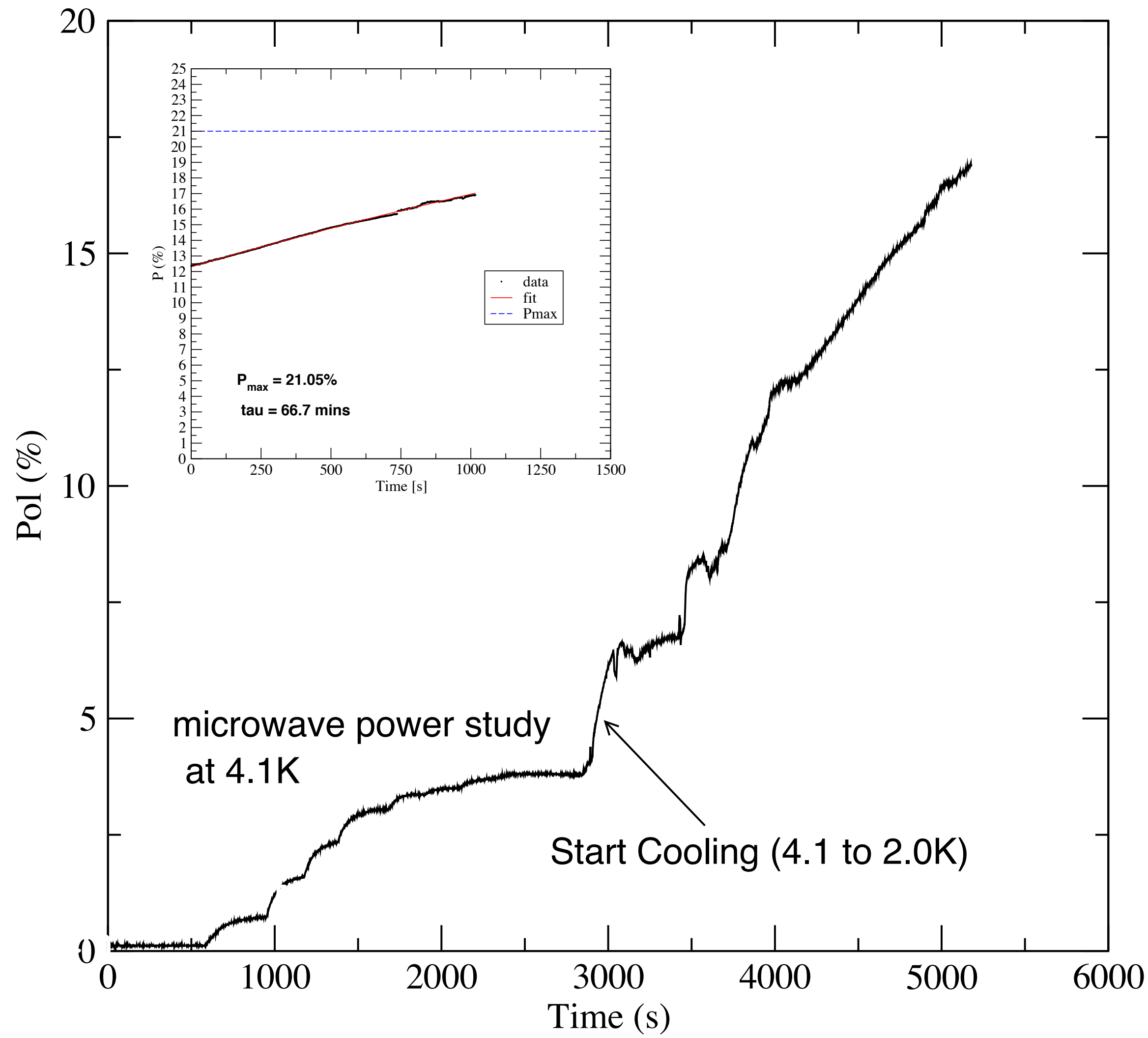
Tempo Doped Araldite Spin Up

2019-03-15



Tempo Doped Araldite Spin Up

2019-03-15



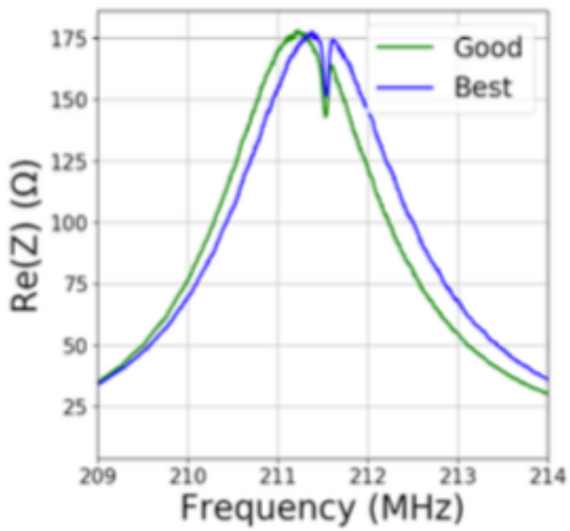
5Tesla, 2K

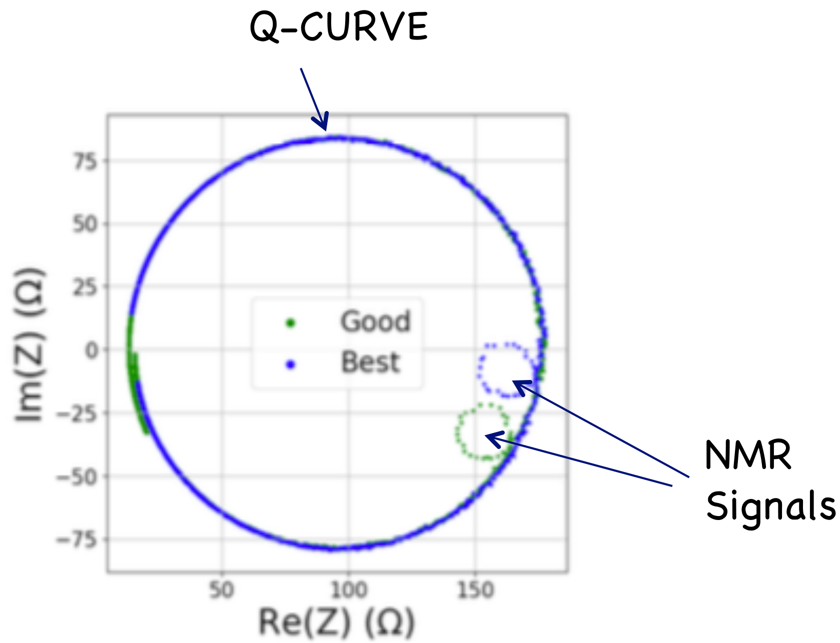
P_{max} = 21.1%,

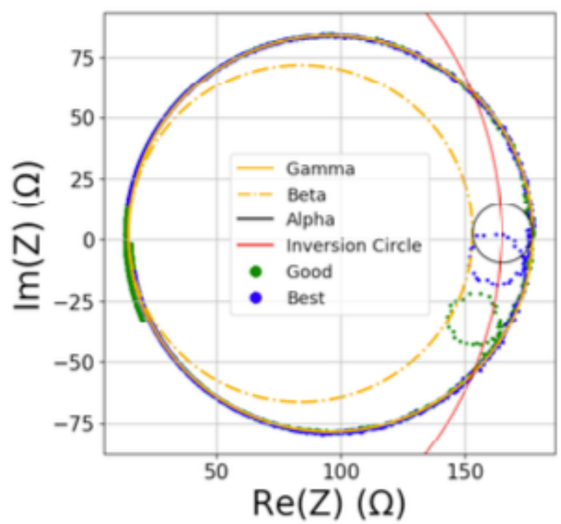
τ=66.7 mins

compare to 33% at 3.35T, 1.2 K in Noda et al, NIMA 776 (2015) 8-14

NMR Signal Modeling

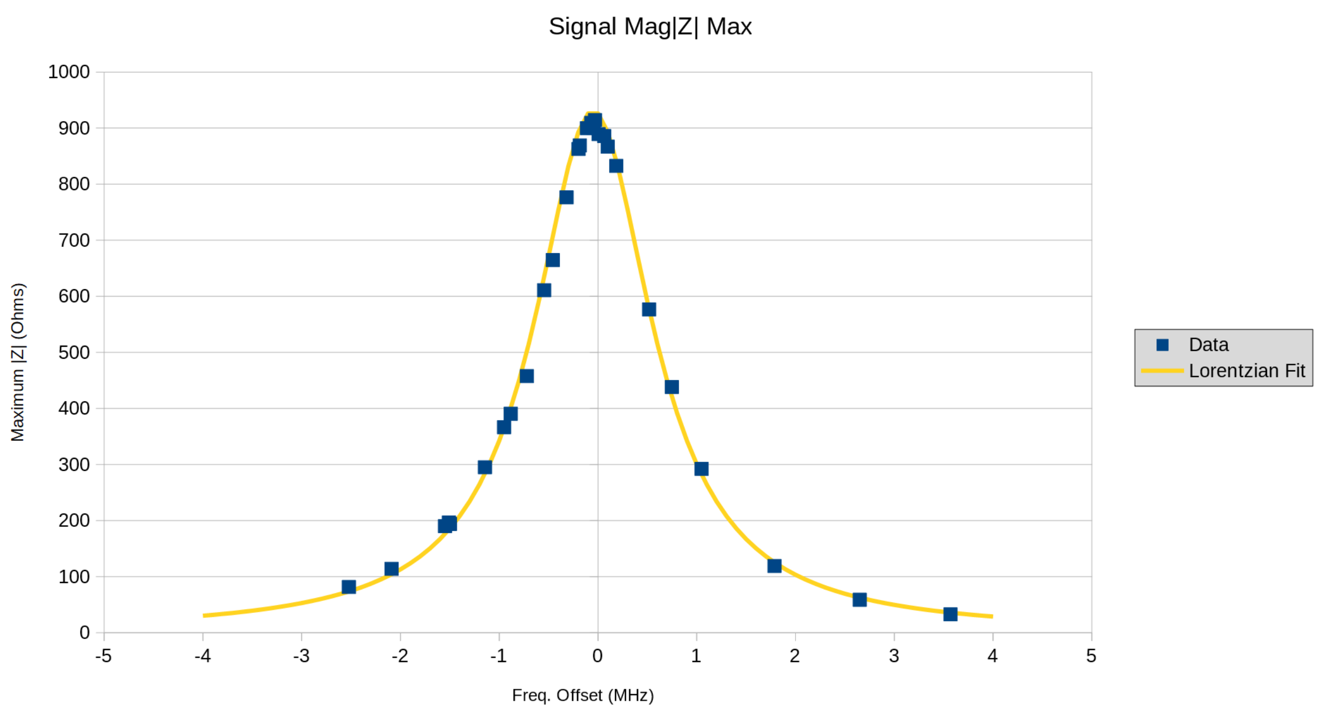






thanks to Ryan Williams

NMR TUNE



Amplification of NMR signal as a function of offset from Q-curve center

thanks to Elena Long

Summary

UNH target lab is fully functional.

- Fridge has healthy cooling power
- SS microwave source works well
- target material preparation going well
- 3 working NMR systems
  - TEs at 1Tesla !
- Big hardware mods to address a superfluid leak

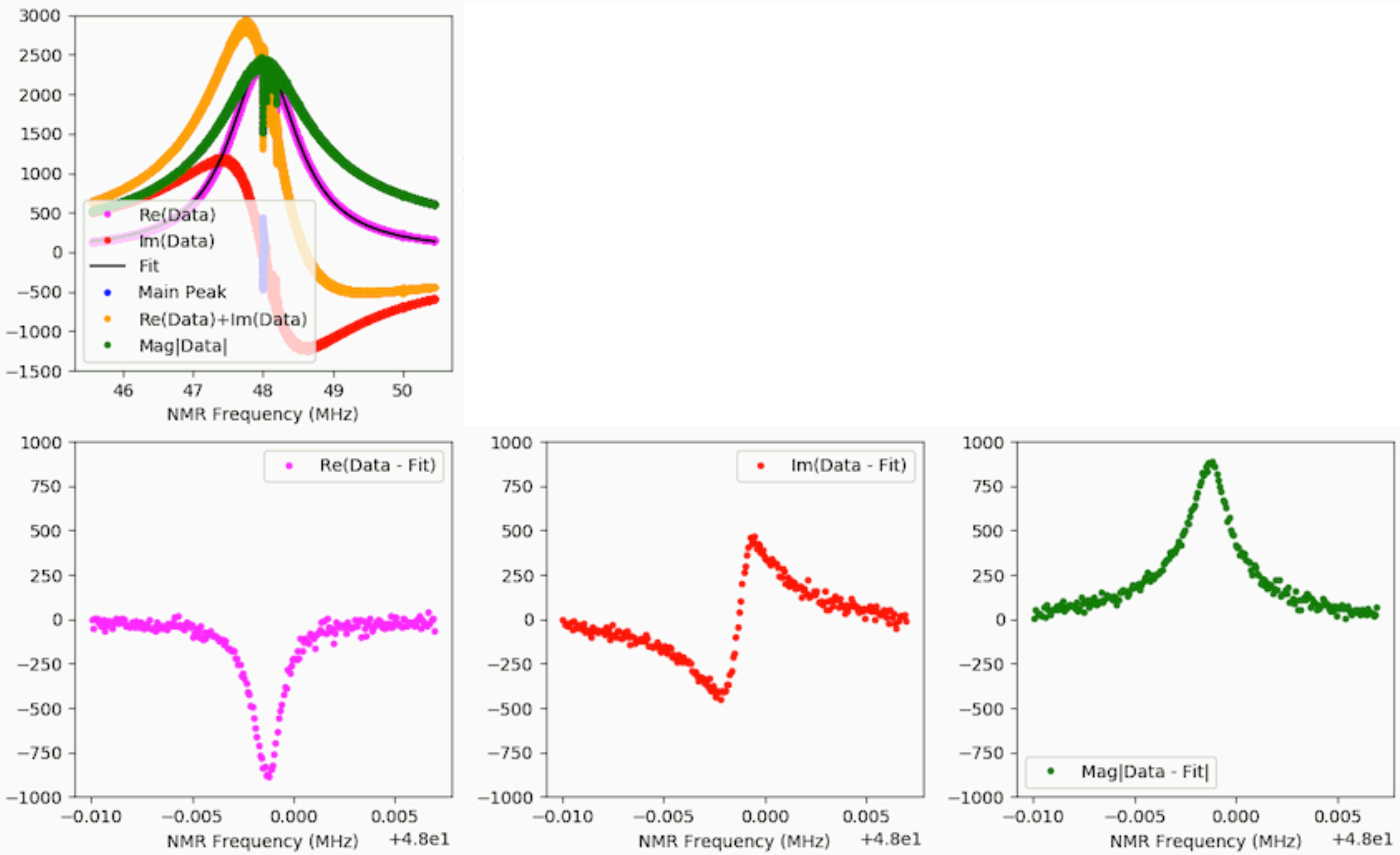
Max polarization

- Polymers (tempo) 21% compares reasonably well to published max
- Butanol (tempo) 9% lower than expected

But neither were measured at 1K

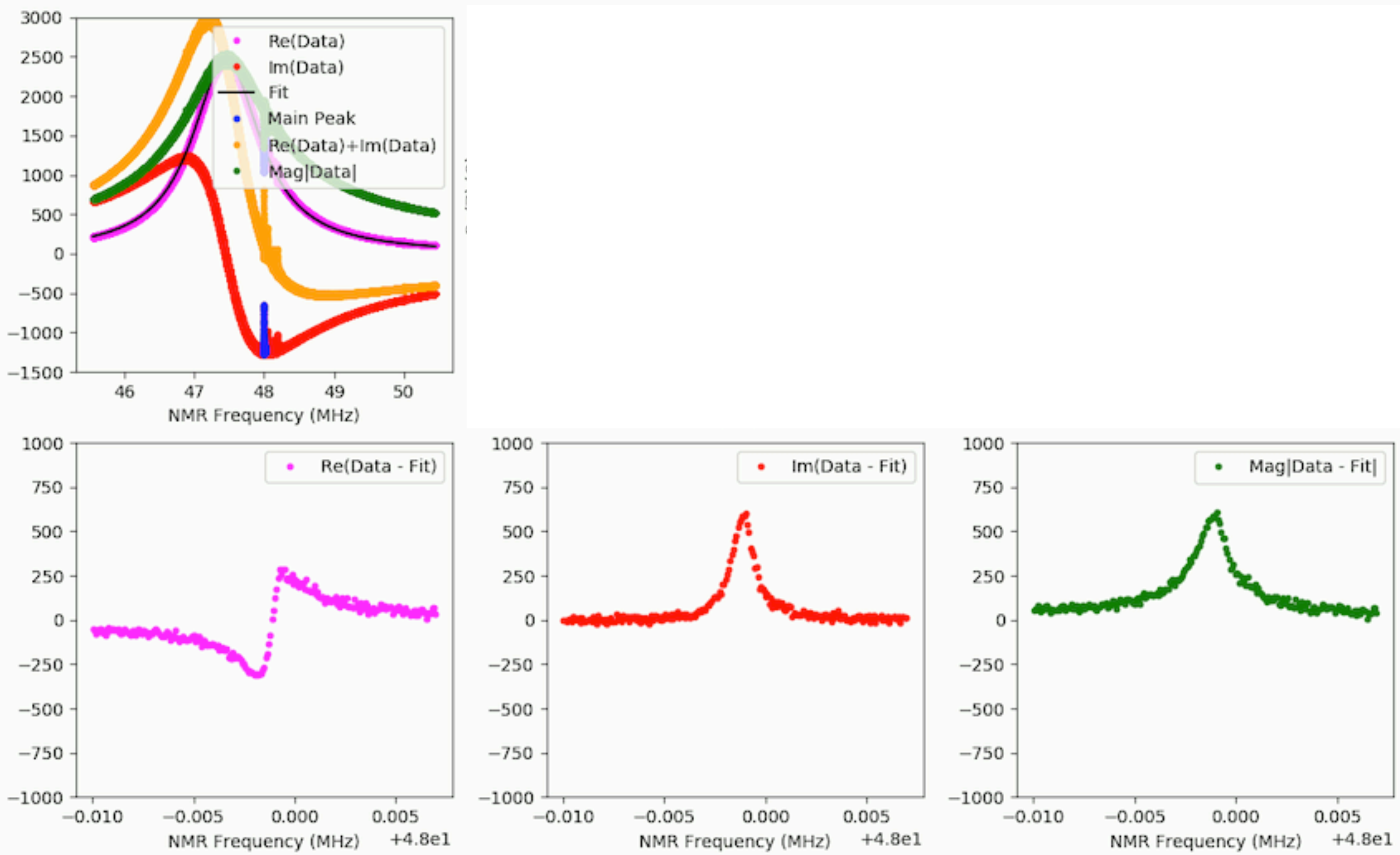
Next step is moving to deuterated materials for Tensor Polarization

Well Tuned Circuit



thanks to Elena Long

OFF TUNE CIRCUIT



thanks to Elena Long