Polarized Target Update

E1039

Progress and recent developments with the polarized target system

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The Target Situation for E1039

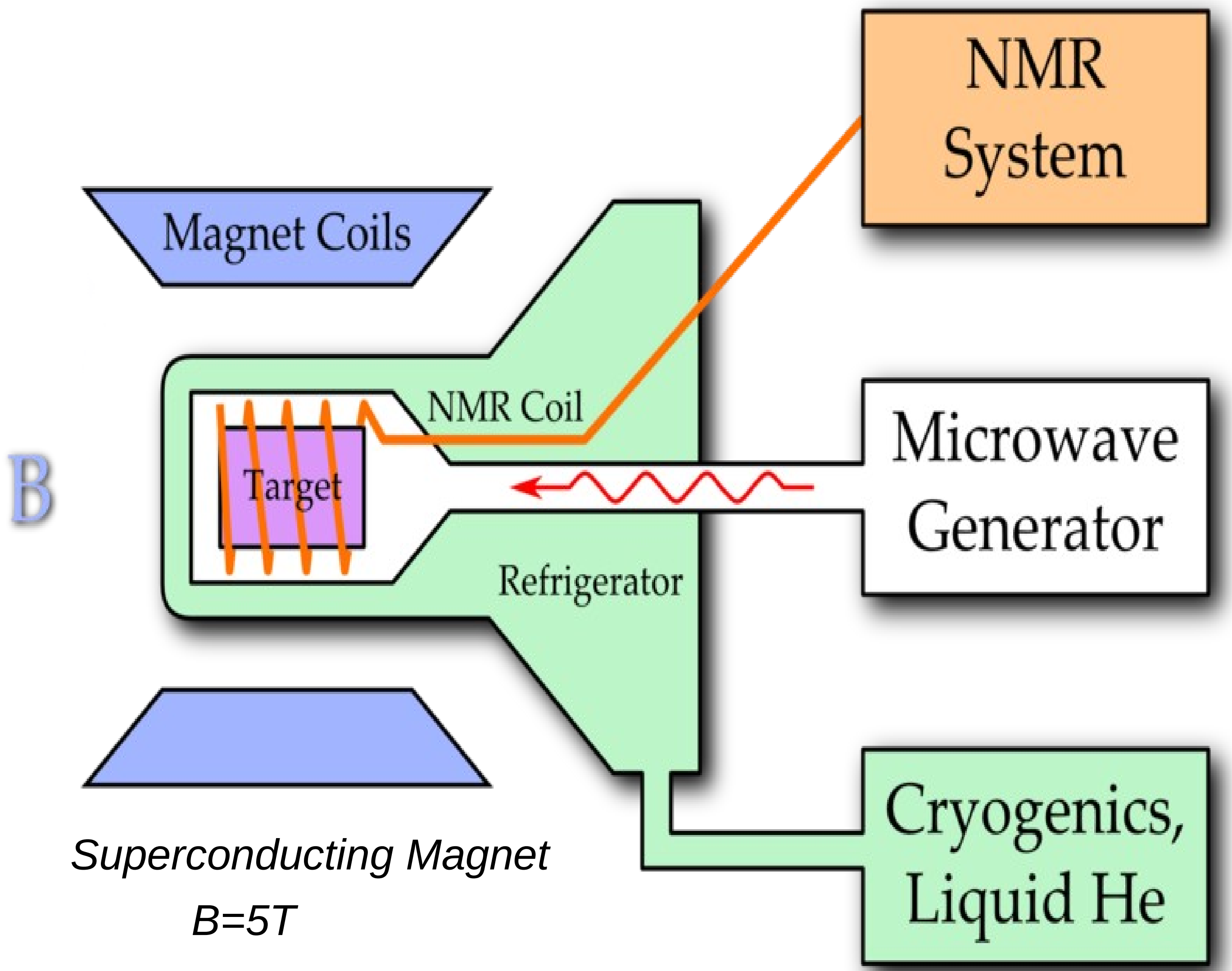
Recently Accomplished

- Fridge repairs/preps
- Piston for UVA testing
- Re-install fridge
- Cooldown with test stick
- Polarized to more than ~70%
- Test new NMR systems
- Vacuum can pop-valve repair
- 10 mils window test
- Material Fab and Irr

Still to Come

- First fully equipped insert
- Insert Warm/Cold Test
- Further NMR
- Frequency control auto-algorithm
- Cryosystem auto-control
- 10 mils window cold test
- Fully integrated cooldown
- More Material Fab and Irr
- ^{3}He pressure setup

General System



Superconducting Magnet

B=5T

Polarization Detection

Tuned To Larmor of spin species

Proton (42.6 MHz/T)

~213 MHz at 5T

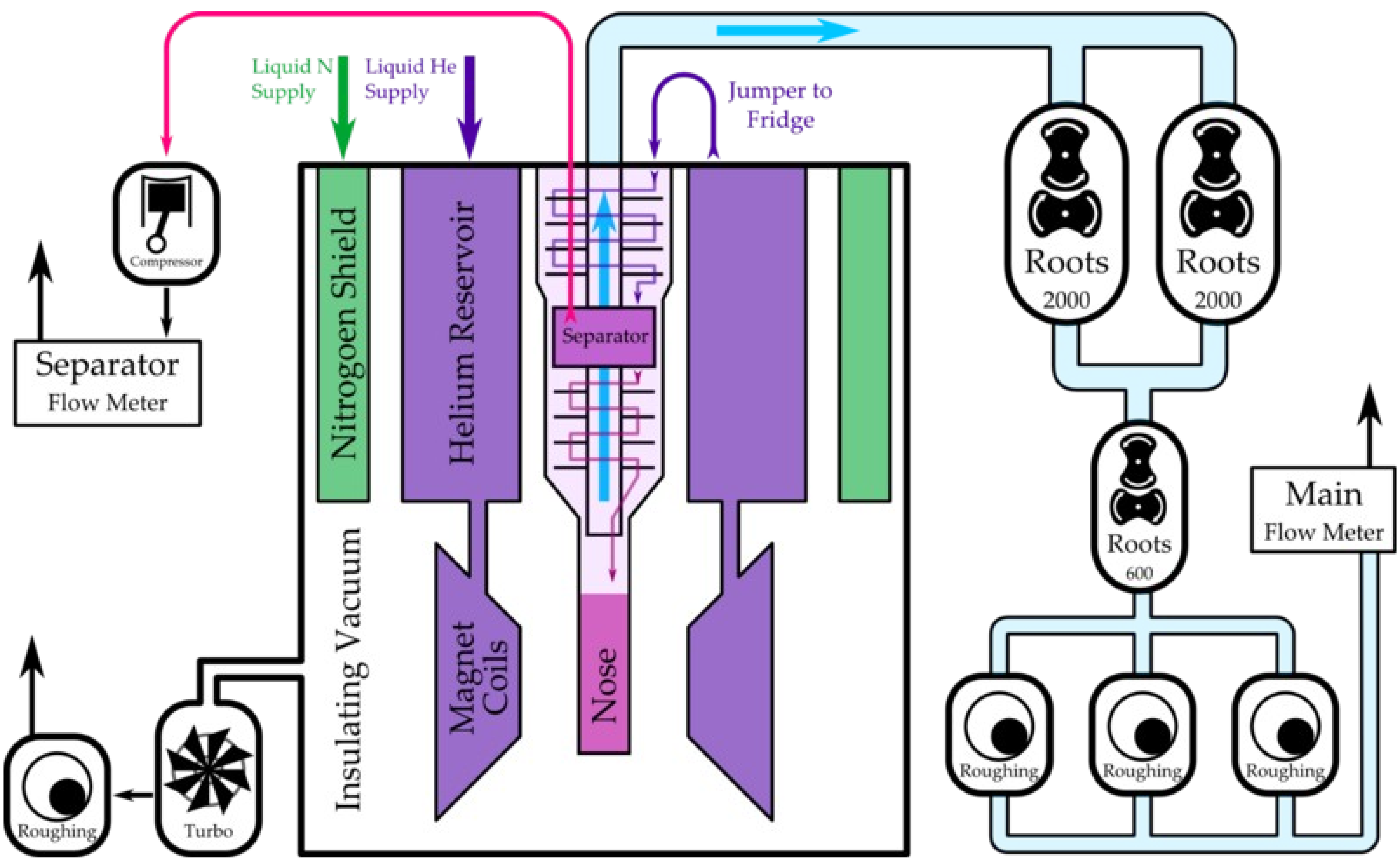
Larmor-ESR

50-185 GHz

~140 GHz at 5T

T=~1K(~1.5W)

Vacuum Pumping Subsystem



Cryogenic Instrumentation

UVA Polarized Target System

Microwave

Target Insert

Pumps

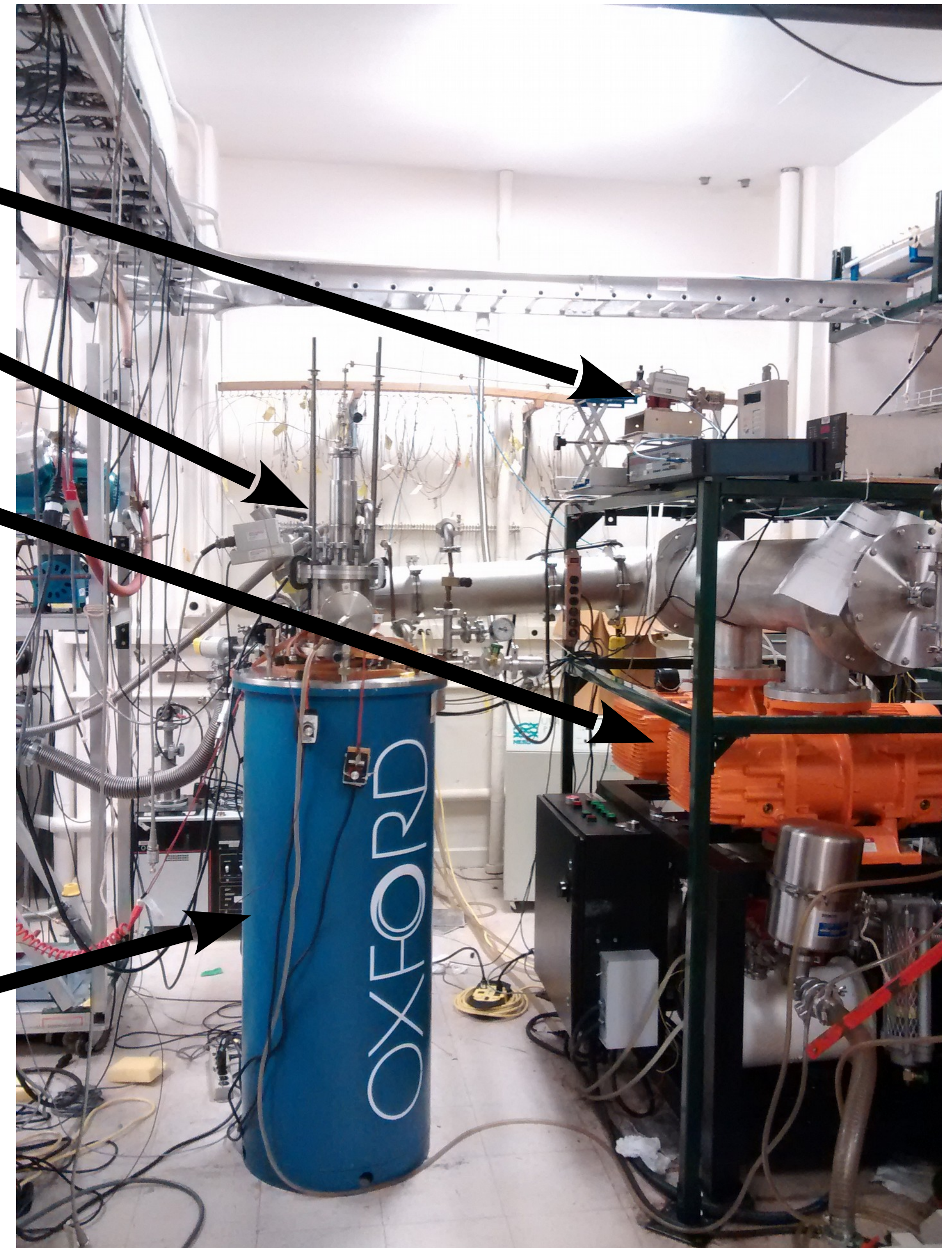
Two Parallel
2063H 63 m^3/Hour

ROOTS: 600 m^3/Hour

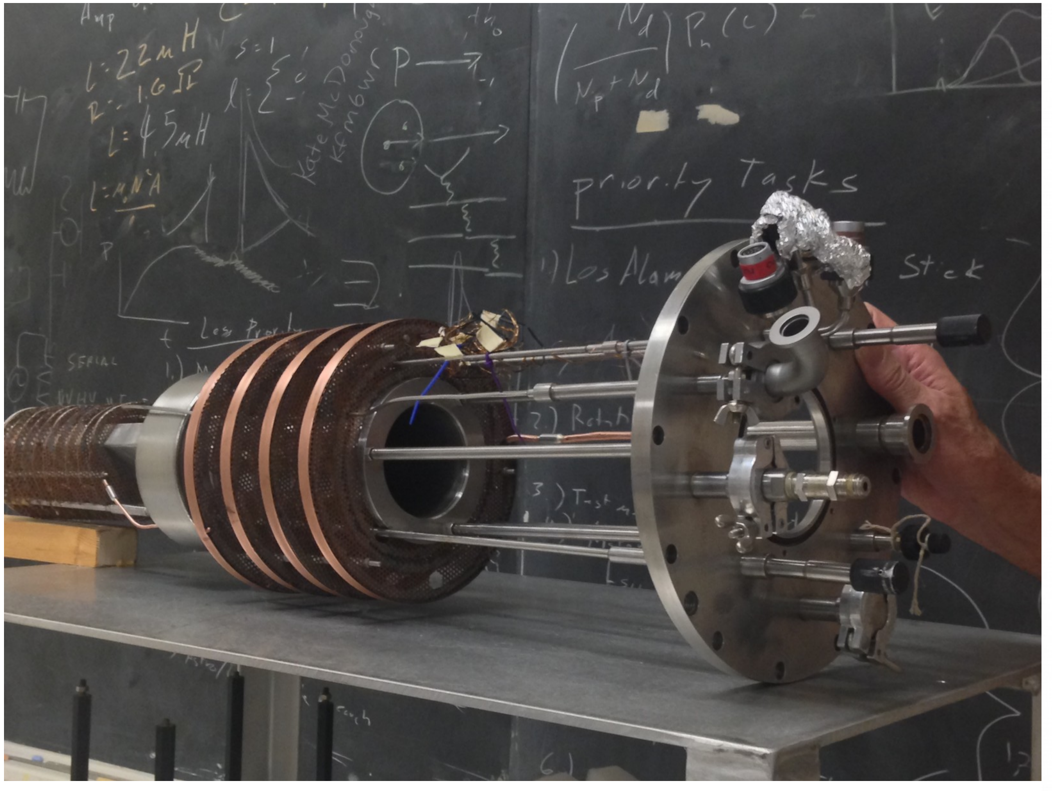
ROOTS: Two Parallel
2000 m^3/Hour

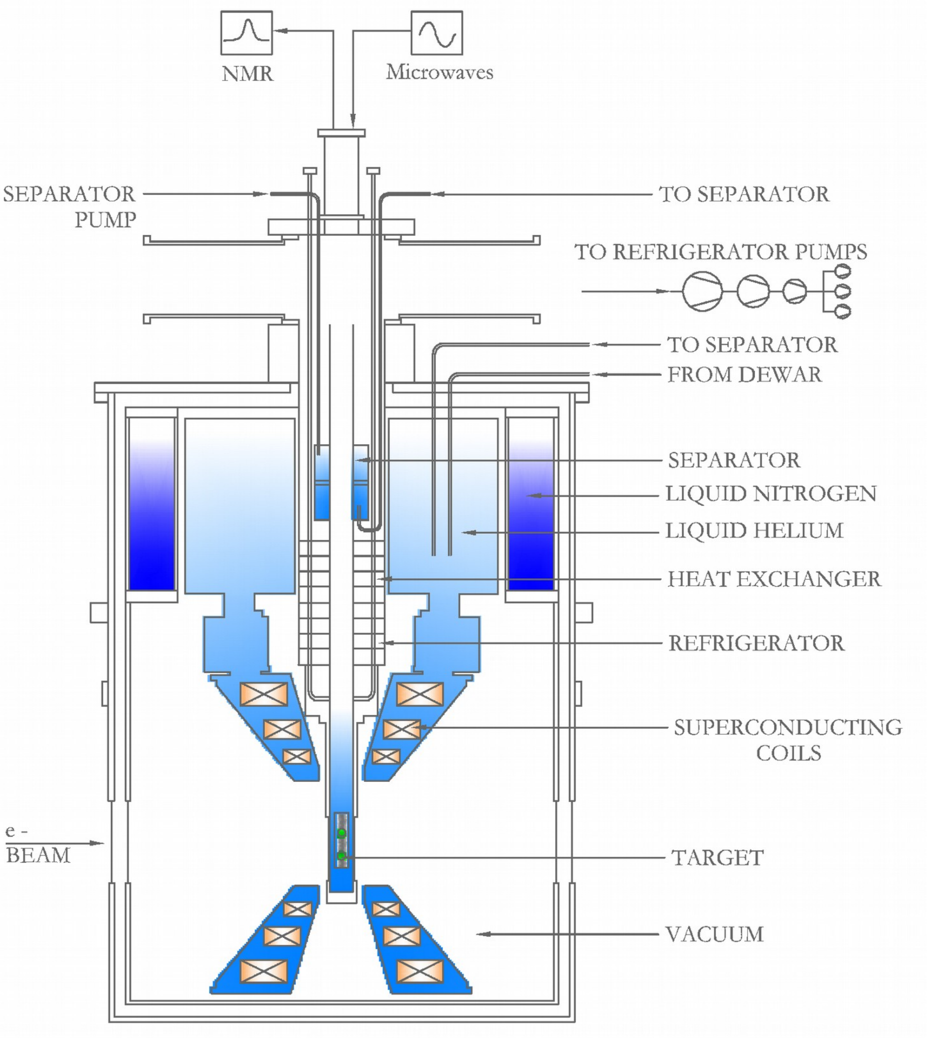
1W (~0.121 Torr)

Magnet



Evaporation Fridge

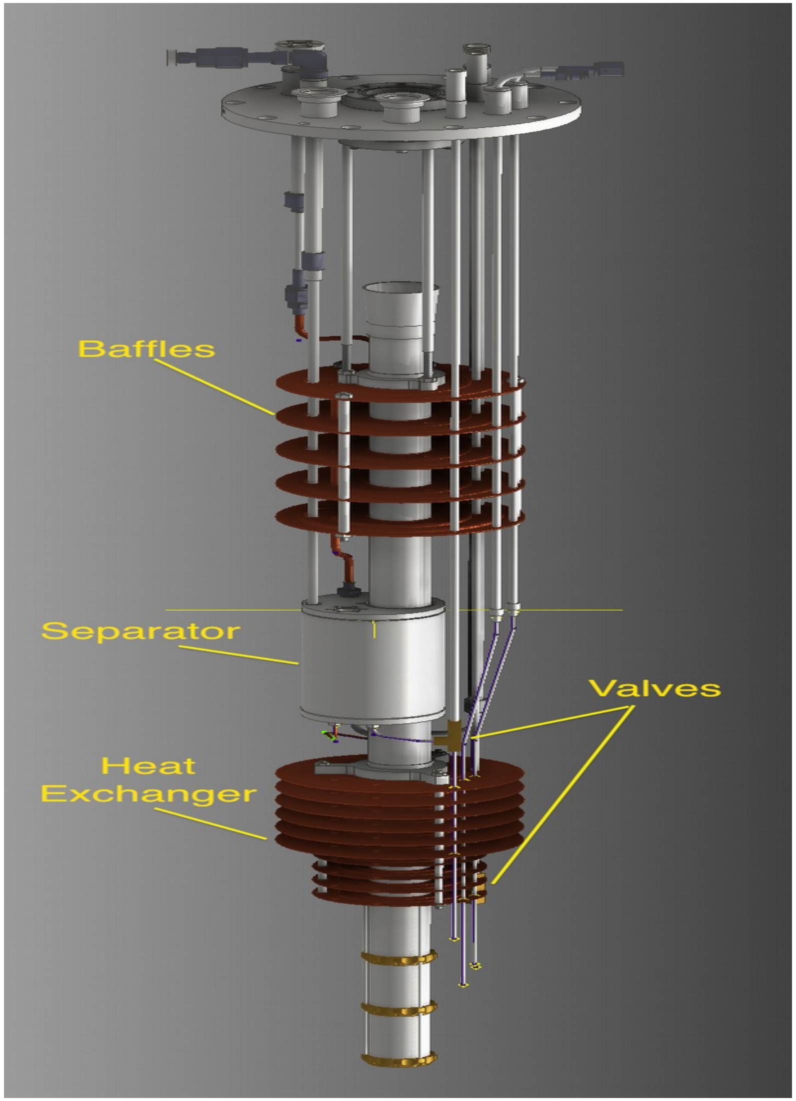




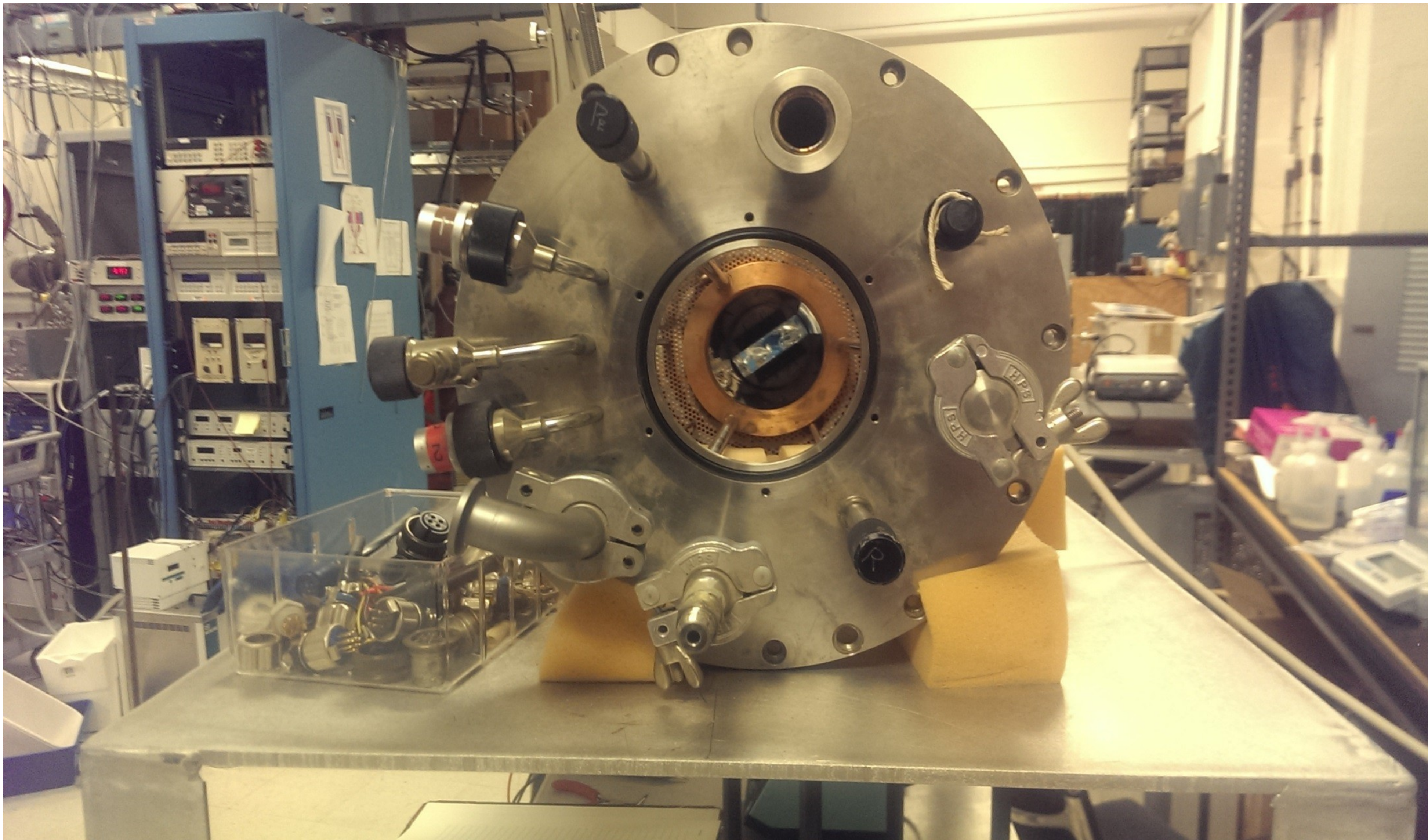
- ~100 nA (charge beam system)
- Dilution factor f<50%
- Luminosity: 10^{35} cm^{-2}s^{-1}
- 1 K (high cooling power)
- Polarization: p~98%, d~45%

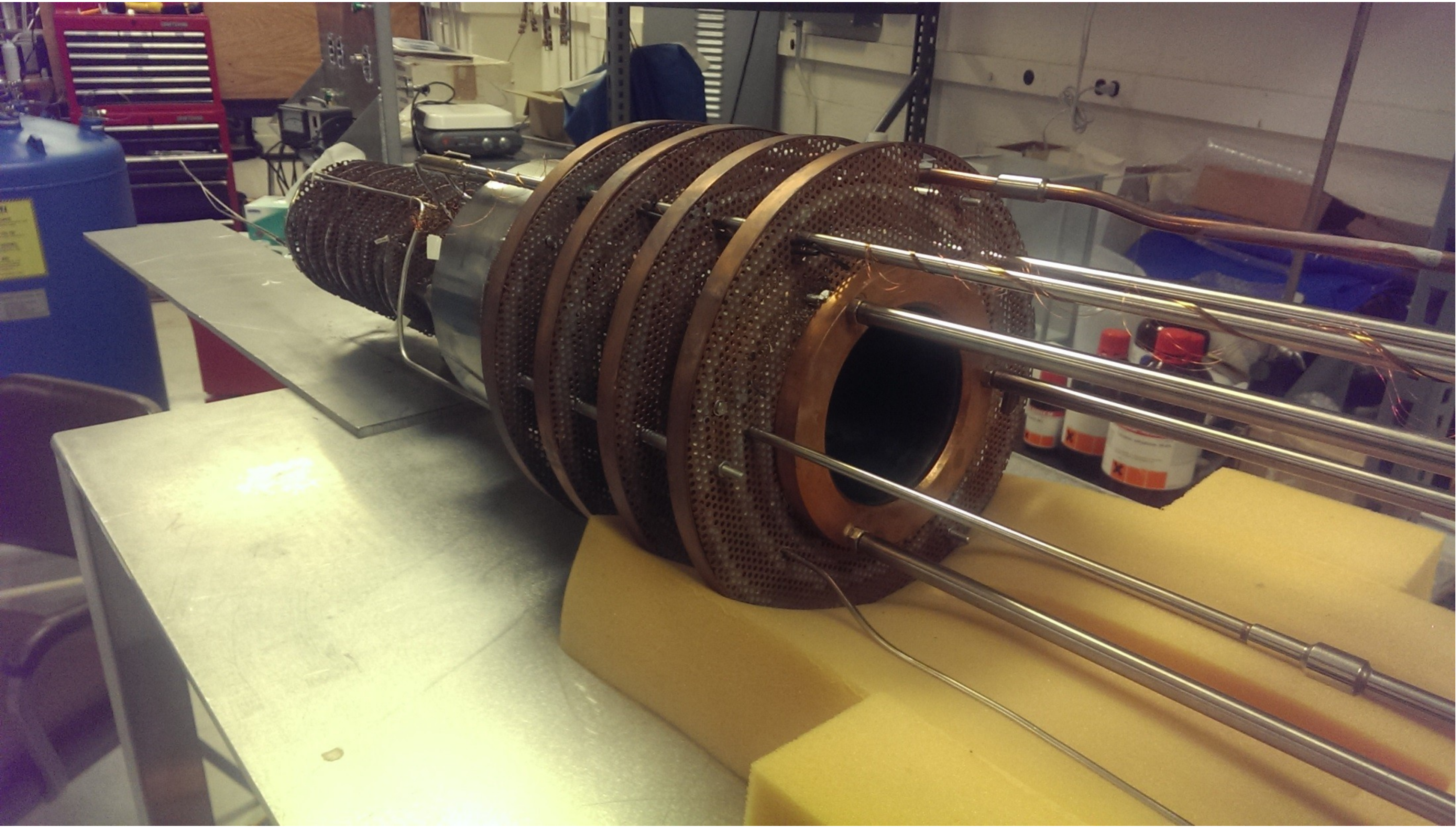
Fridge Updates

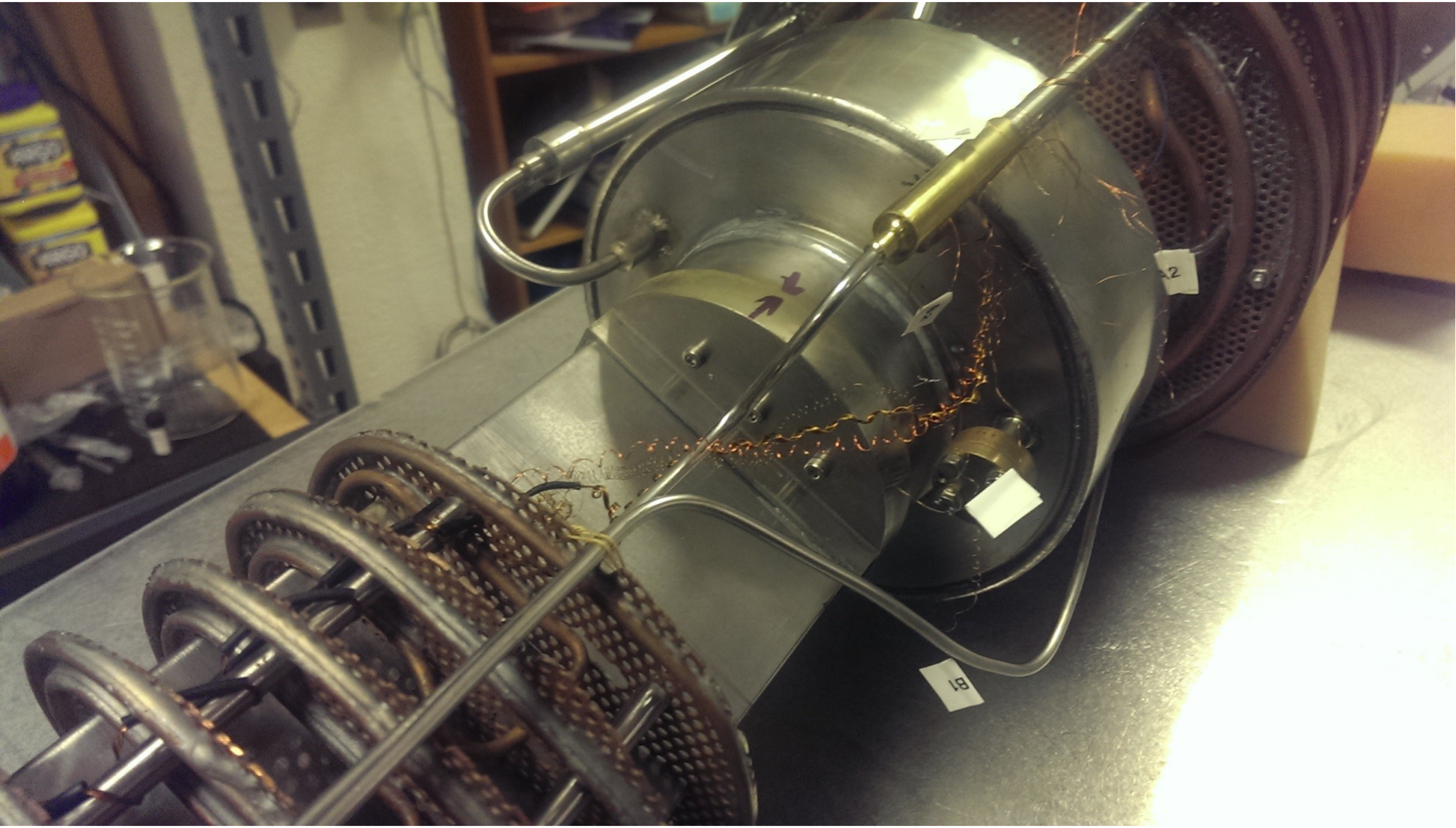
- Separator Can (New)
- Heat exchangers (Clean)
- Leak check
- Valves (re-fit)
- New Helium channel (nose)
- 8-sensors

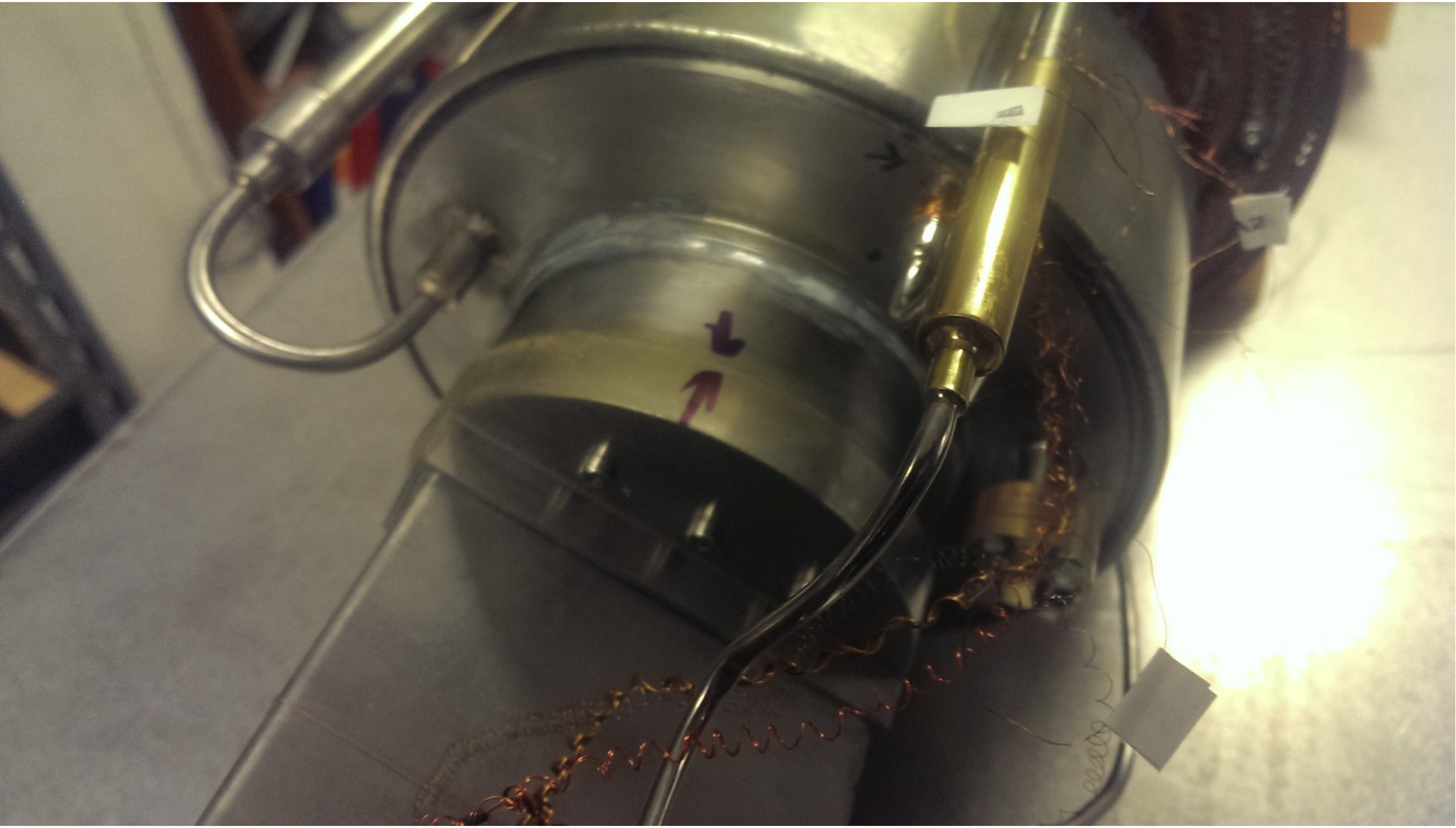



ARGO

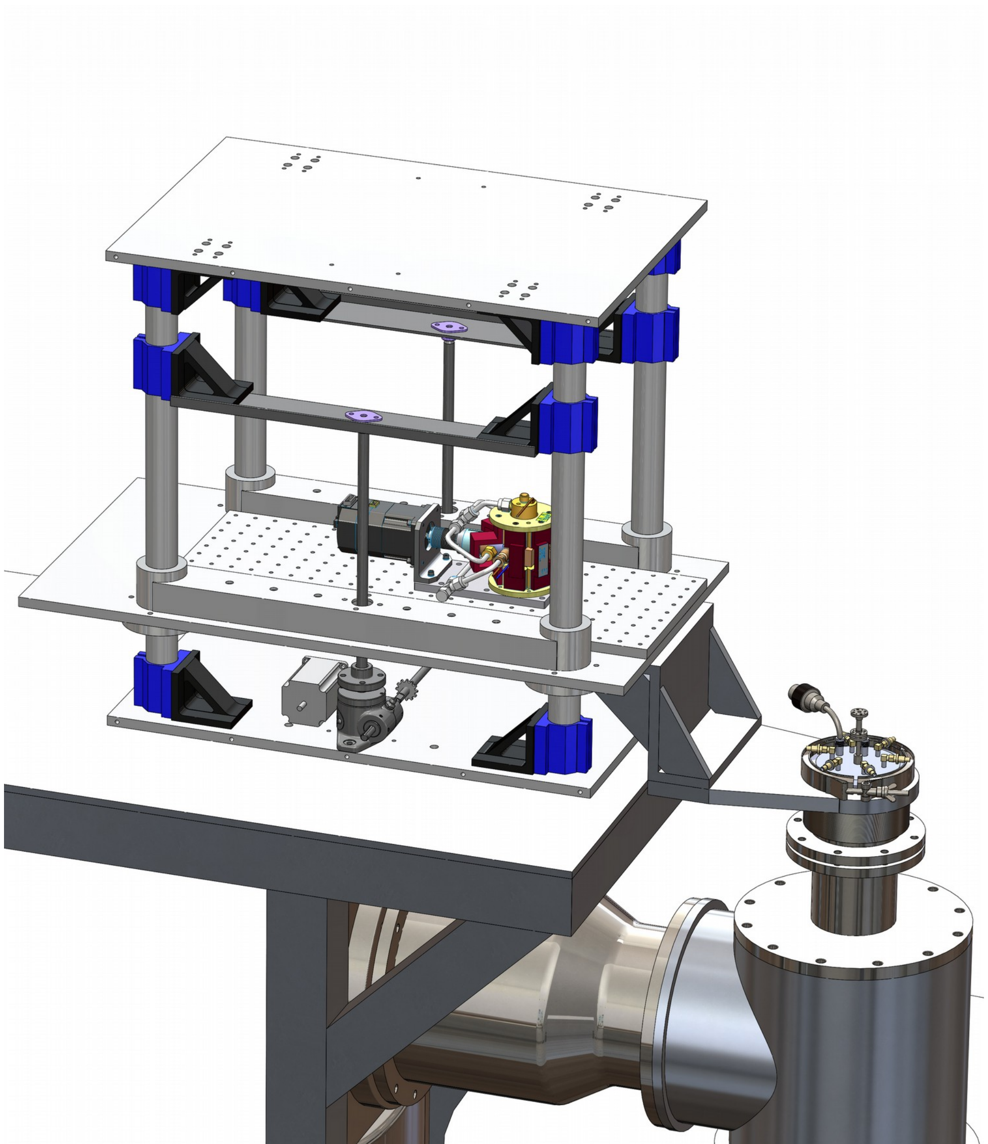


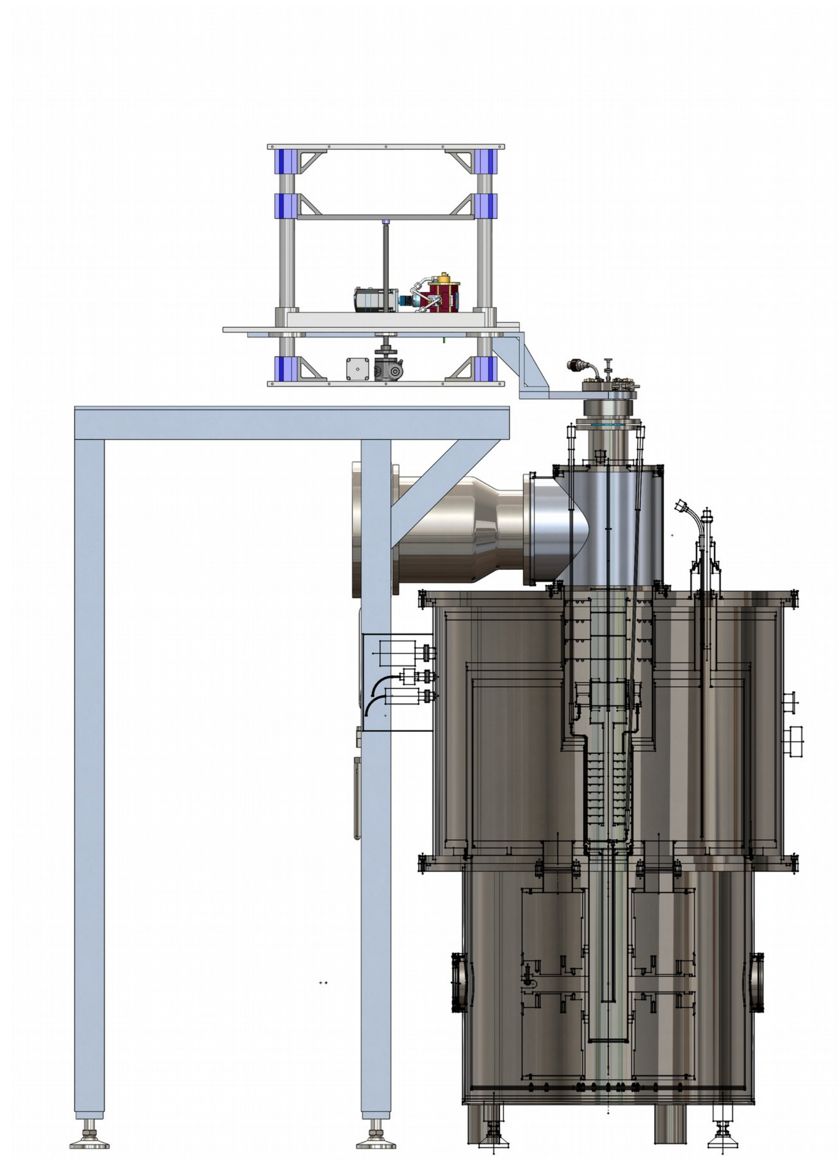



A2
B1

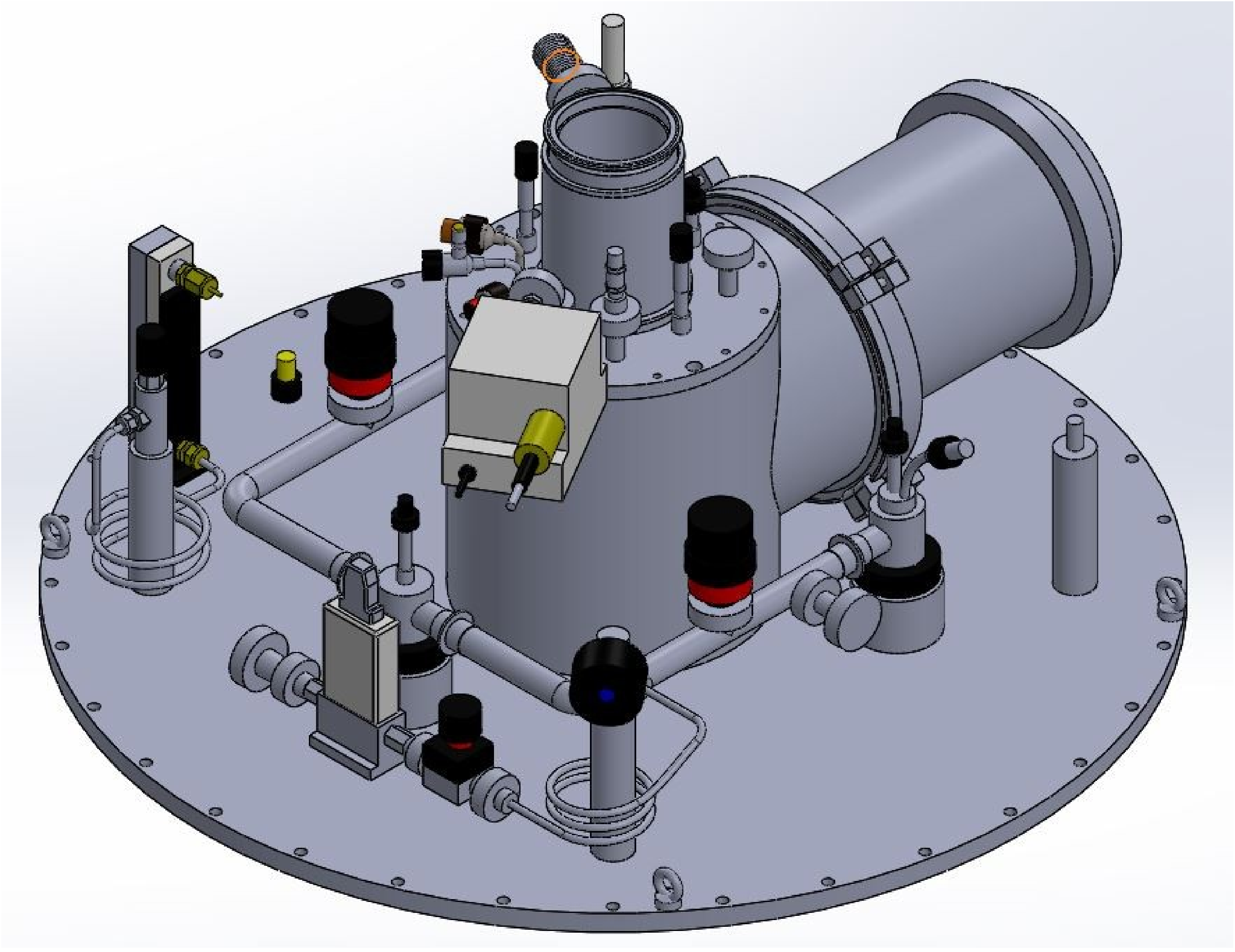


Actuator (at LANL)

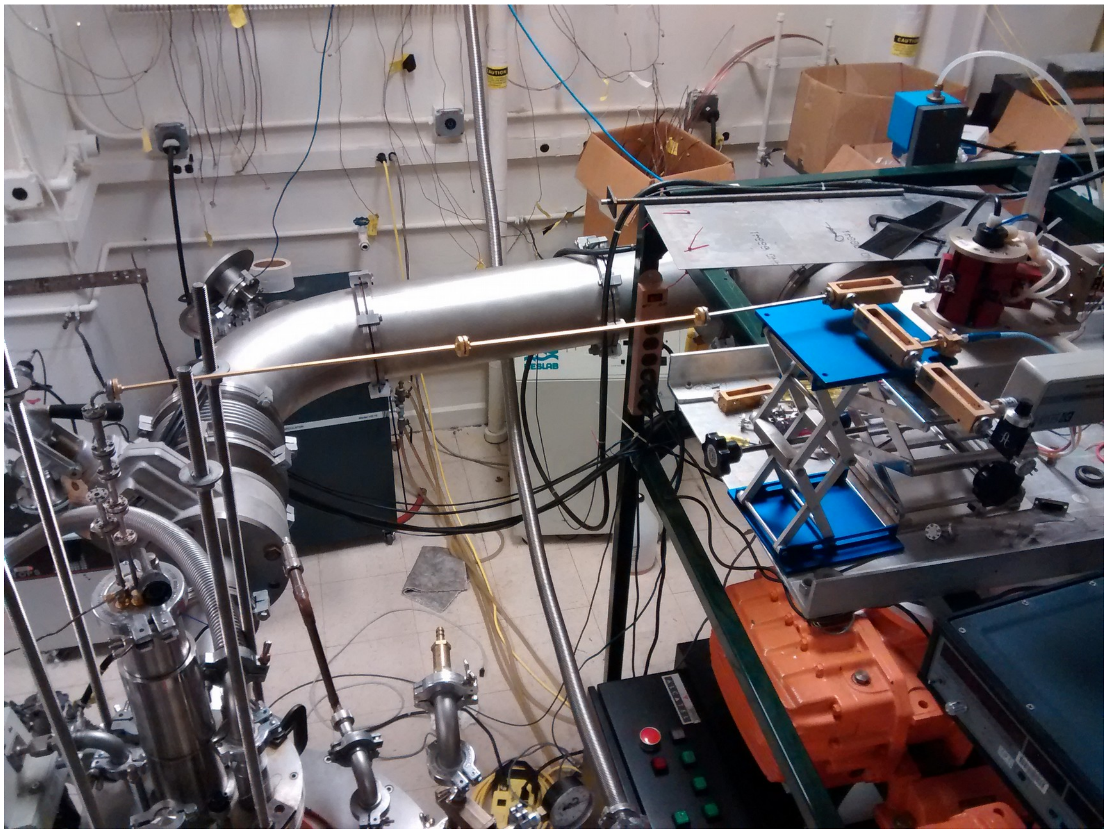




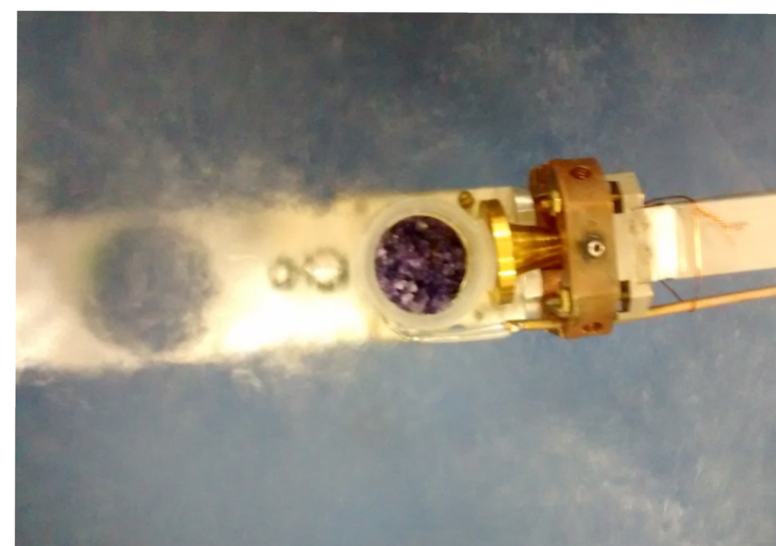
Piston for Insert (at UVA)



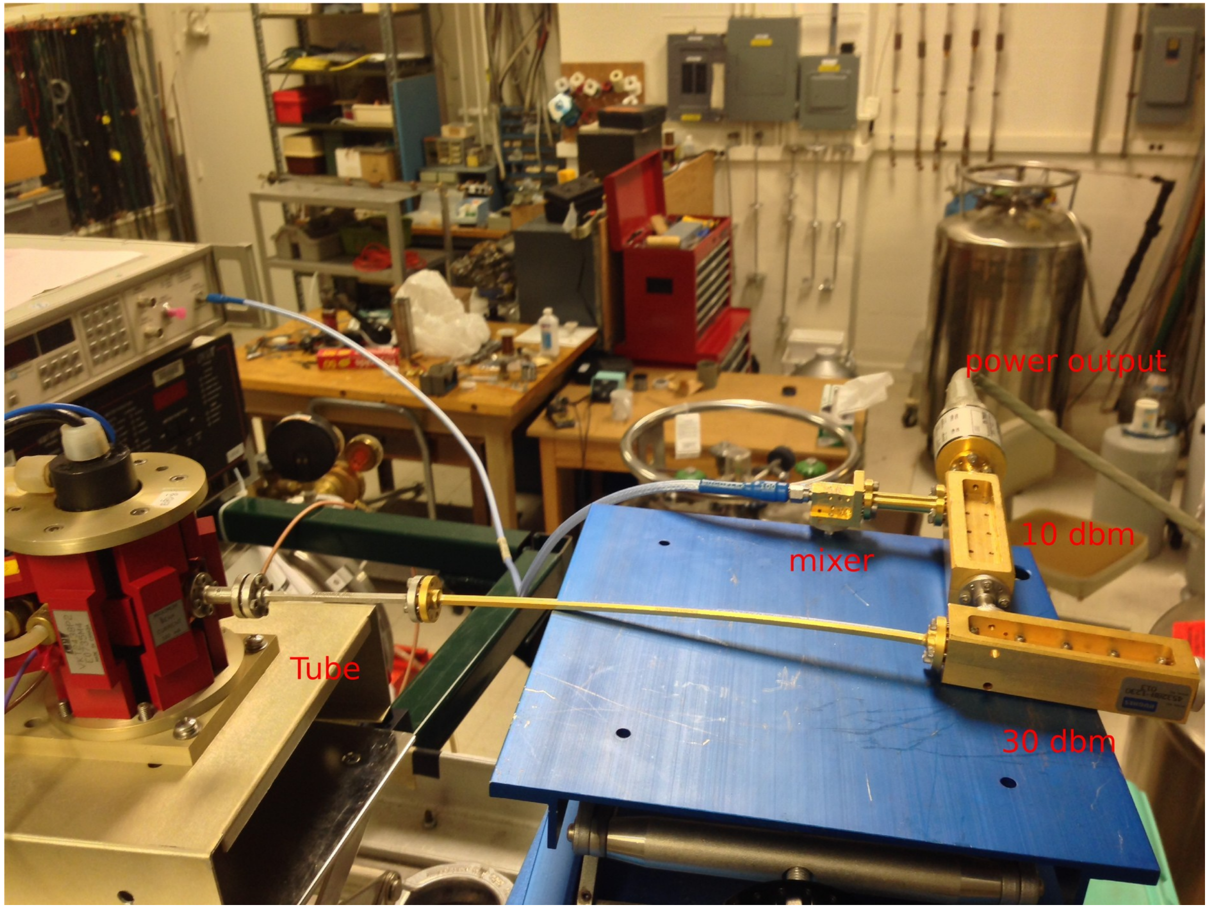
Microwave Generator



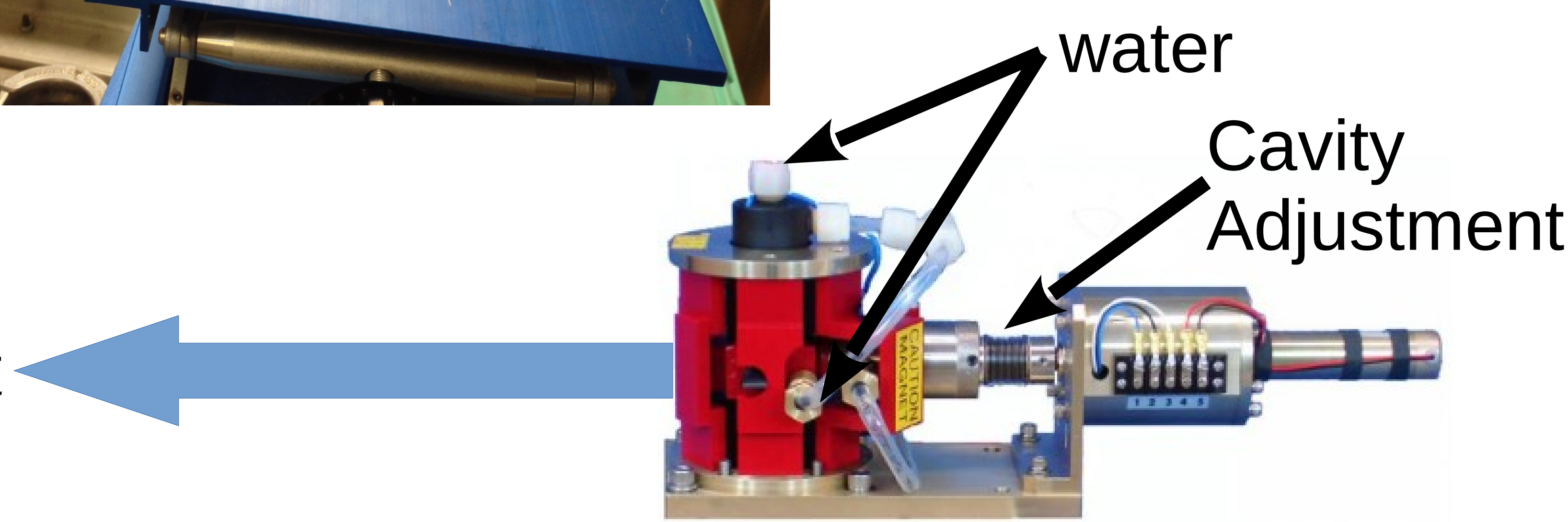
- Microwave Tube
- Power Supply
- 20 Watts at tube
- ~1 Watts on target



Extended Interaction Oscillator



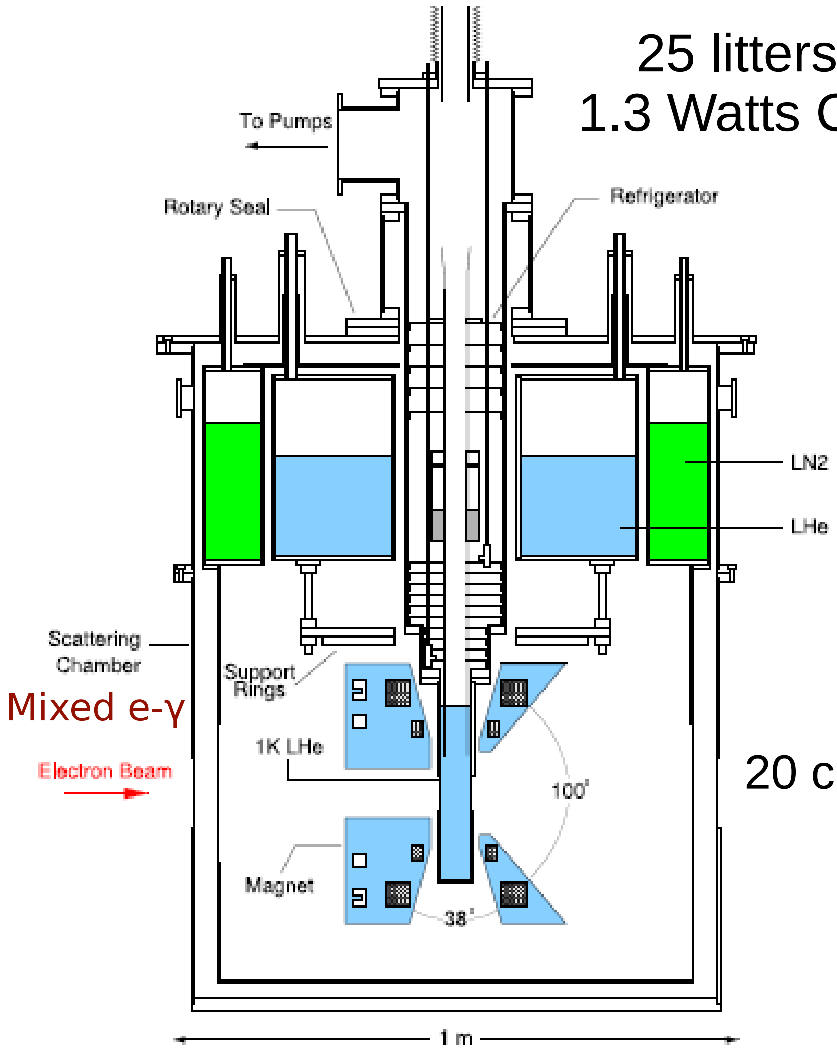
- Variation of the beam voltage allows up to 0.4% frequency tuning
- Cavity size adjustment allows an additional 1.5%
- D-band (~140 GHz)



UVA/Jlab Polarized Target

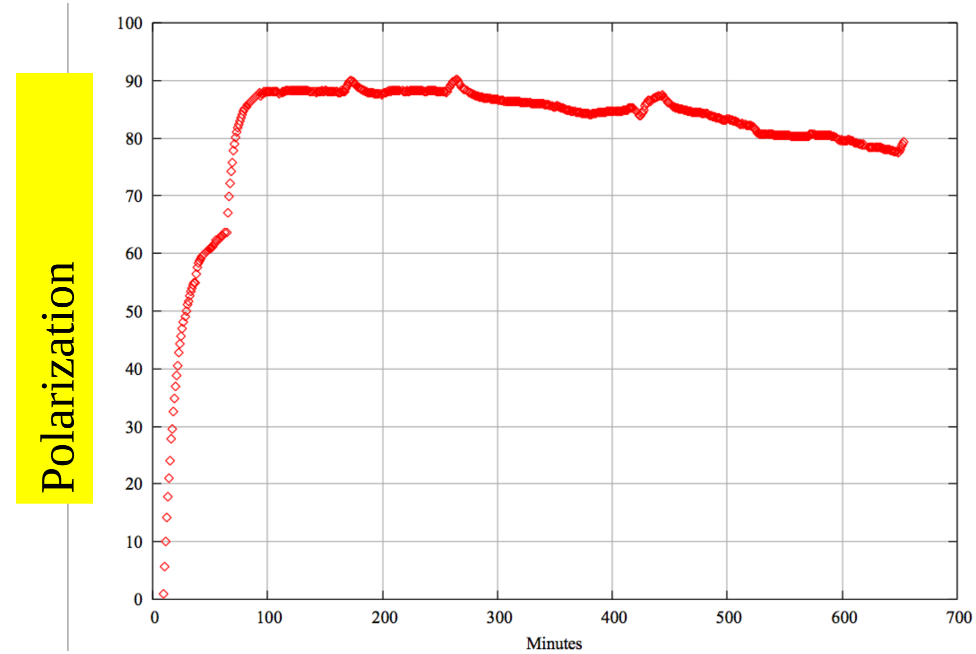
Solid polarized proton target, NH_3

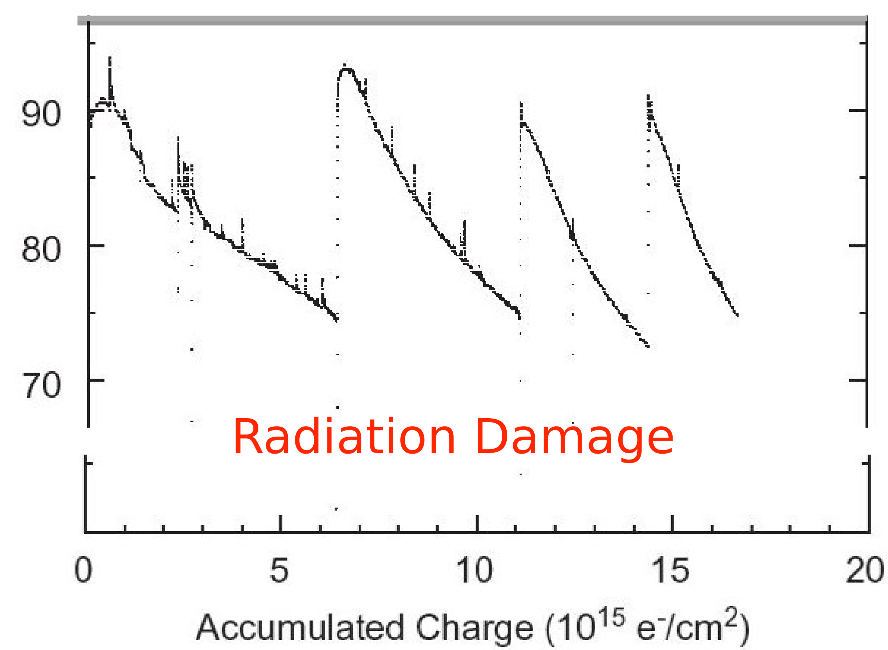
- 4He evaporation refrigerator
- 5 T polarizing field
- Dynamic Nuclear Polarization



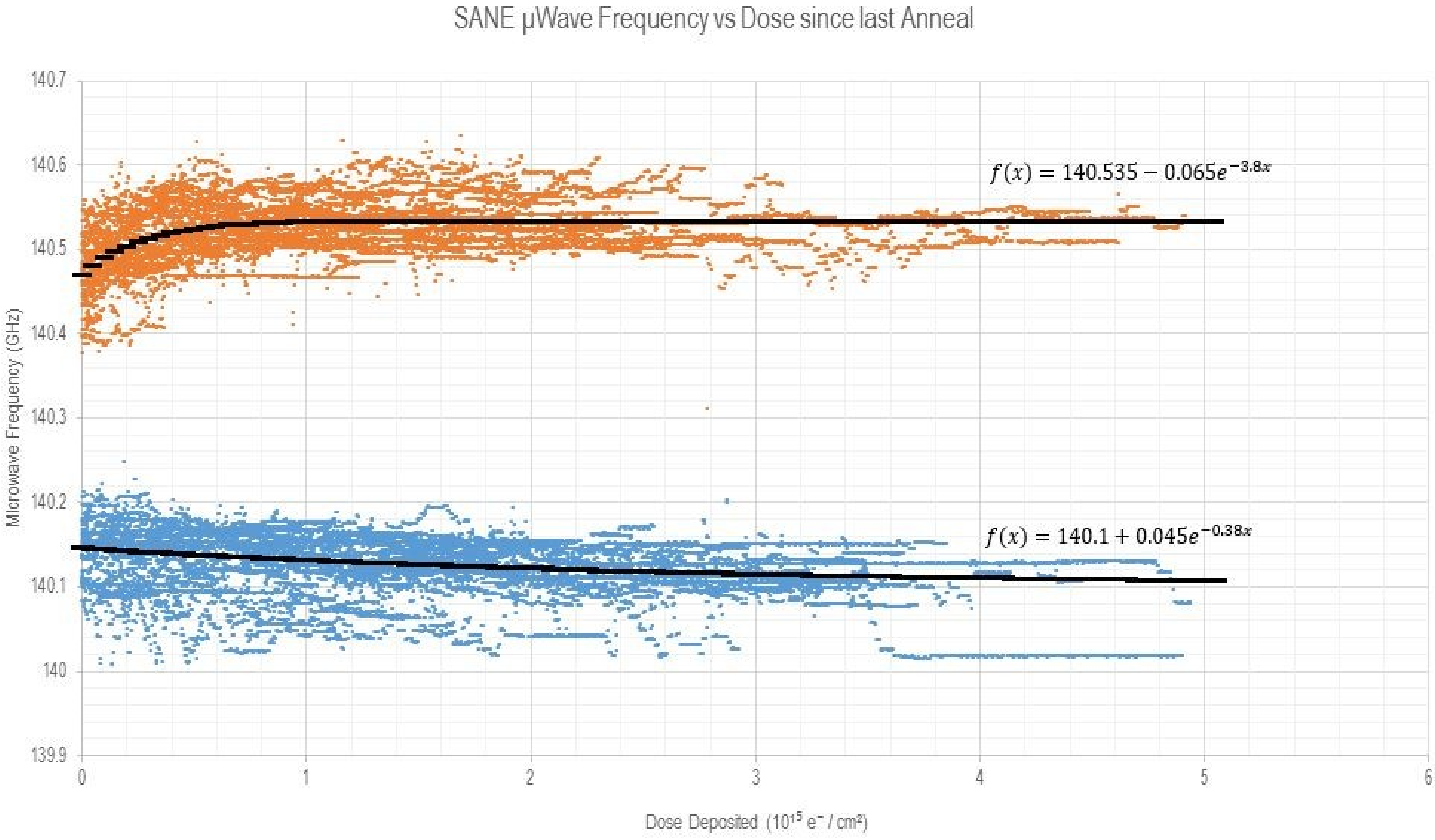
25 litters/min
1.3 Watts Cooling

20 cm bore





Manual Frequency Control



“Frequency Drift”

- Optimal frequency for positive and negative polarization is *not* constant

- Changes take place as more centers are created in the material as a result of irradiation.

- Steady state of polarization at a particular frequency also vulnerable to other variables such as temperature, radiation damage, number of anneals, etc.

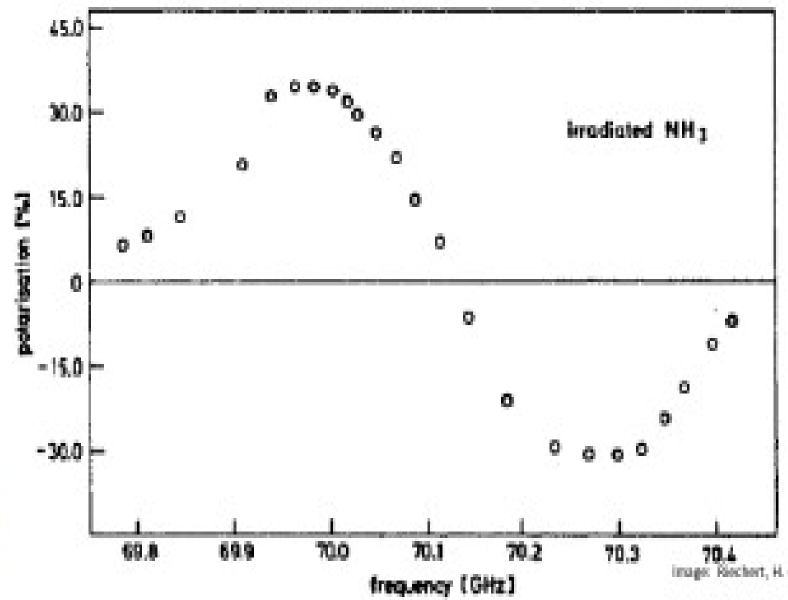


Image: Reichert, H. (1983)

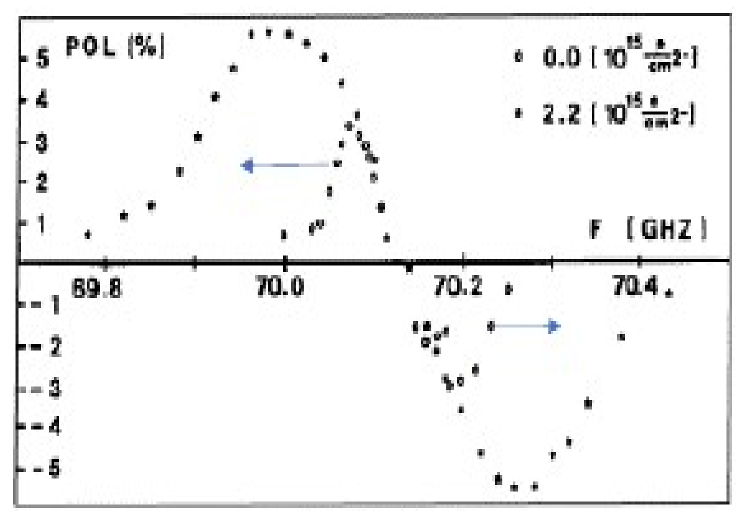
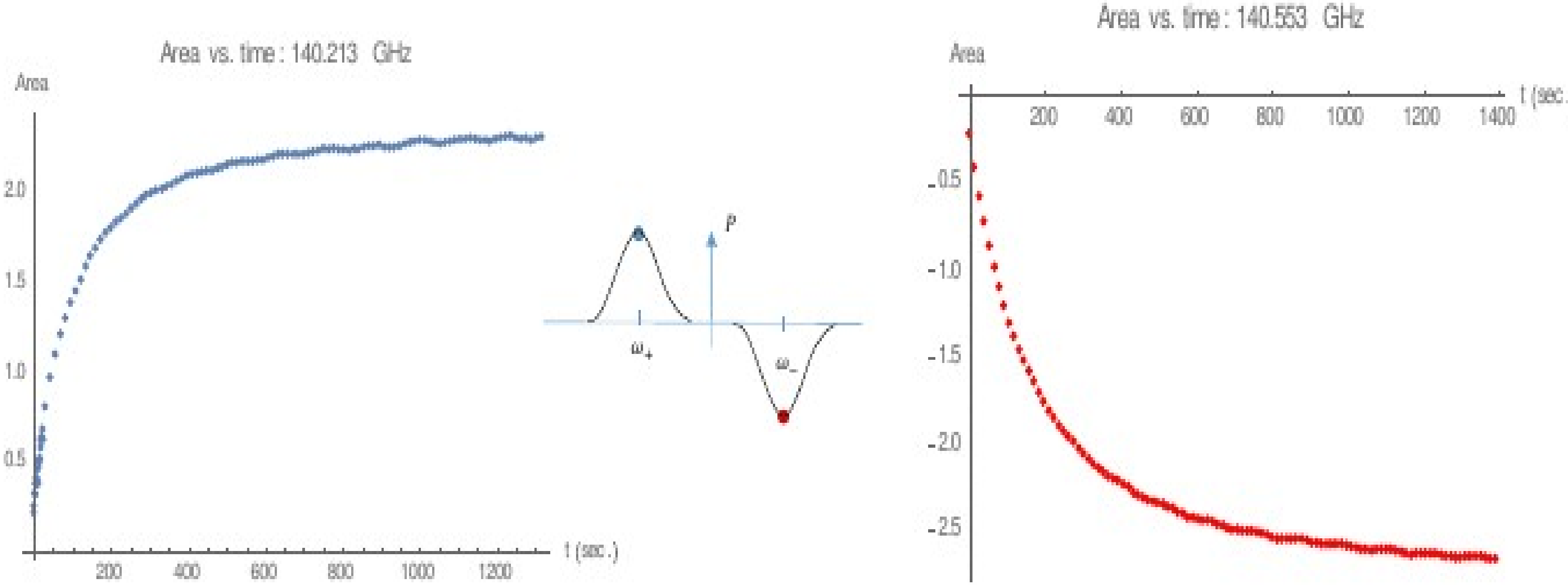


Image: Althoff, et al (1986)

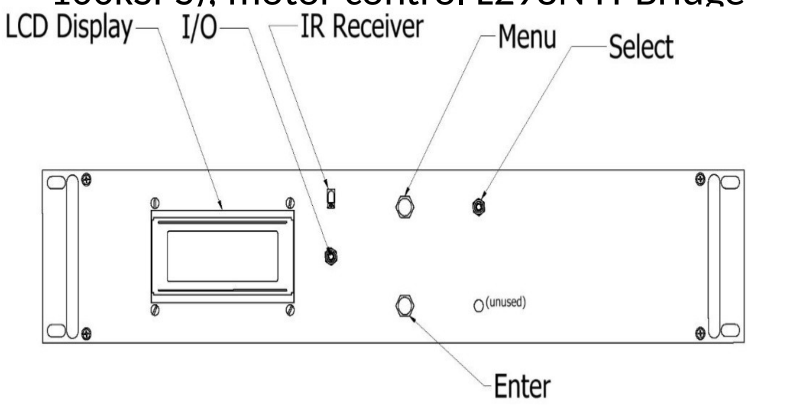
Maintaining Highest Polarization

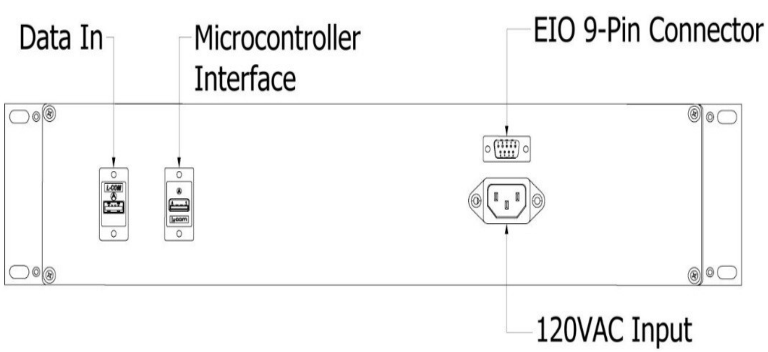
- Manually maintaining optimal polarization is tedious, error prone
- If characteristics of polarization growth/decay are understood, process can be automated
  - Input = EIO voltage divider value ∝ μ-wave frequency
  - Output = Polarization value from PDP software



Creating a Controller

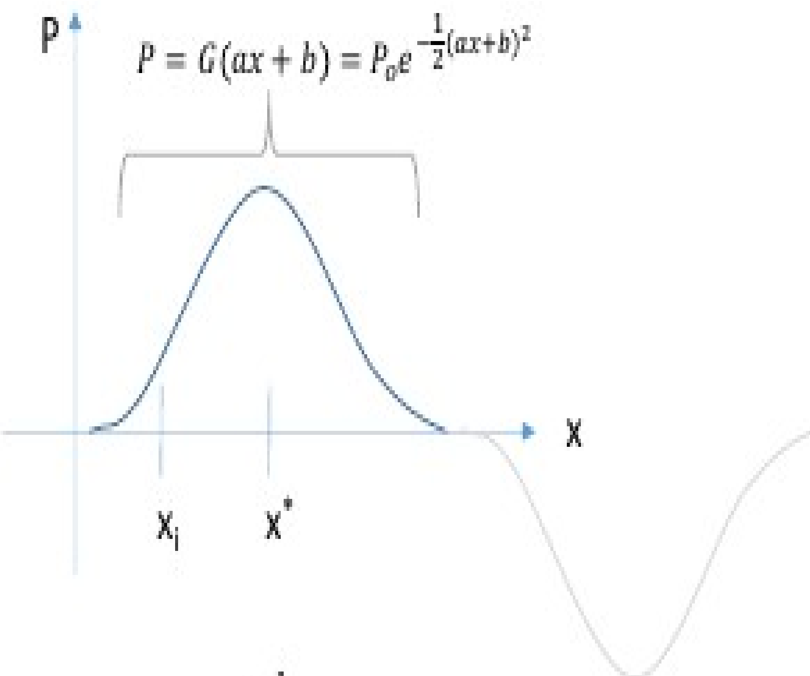
- Standard 2U Rack-mount hard wear
- Front-panel readout and user interface
- Remote control
- Uses Parallax Micro-controller P8X32A, 8 core overclocked 100 MHz, ADC: AD7680 (16-bit, 100kSPS), motor control L298N H-Bridge





Frequency Seeking Algorithm

- Original algorithm used recursive estimators of a, b in $P_o e^{-\frac{1}{2}(ax+b)^2}$ to determine which position to move to next.



$$x^* = \frac{-b}{a}$$

$$x_{i+1} = -\frac{b_{i+1}}{a_{i+1}} + \varepsilon_{i+1}$$

Probing signal

$$|\varepsilon_{i+1}| < \frac{a}{0.2}$$

$$a_{i+1} = a_i + C_i[P_i - G(a_i x_i + b_i)]$$

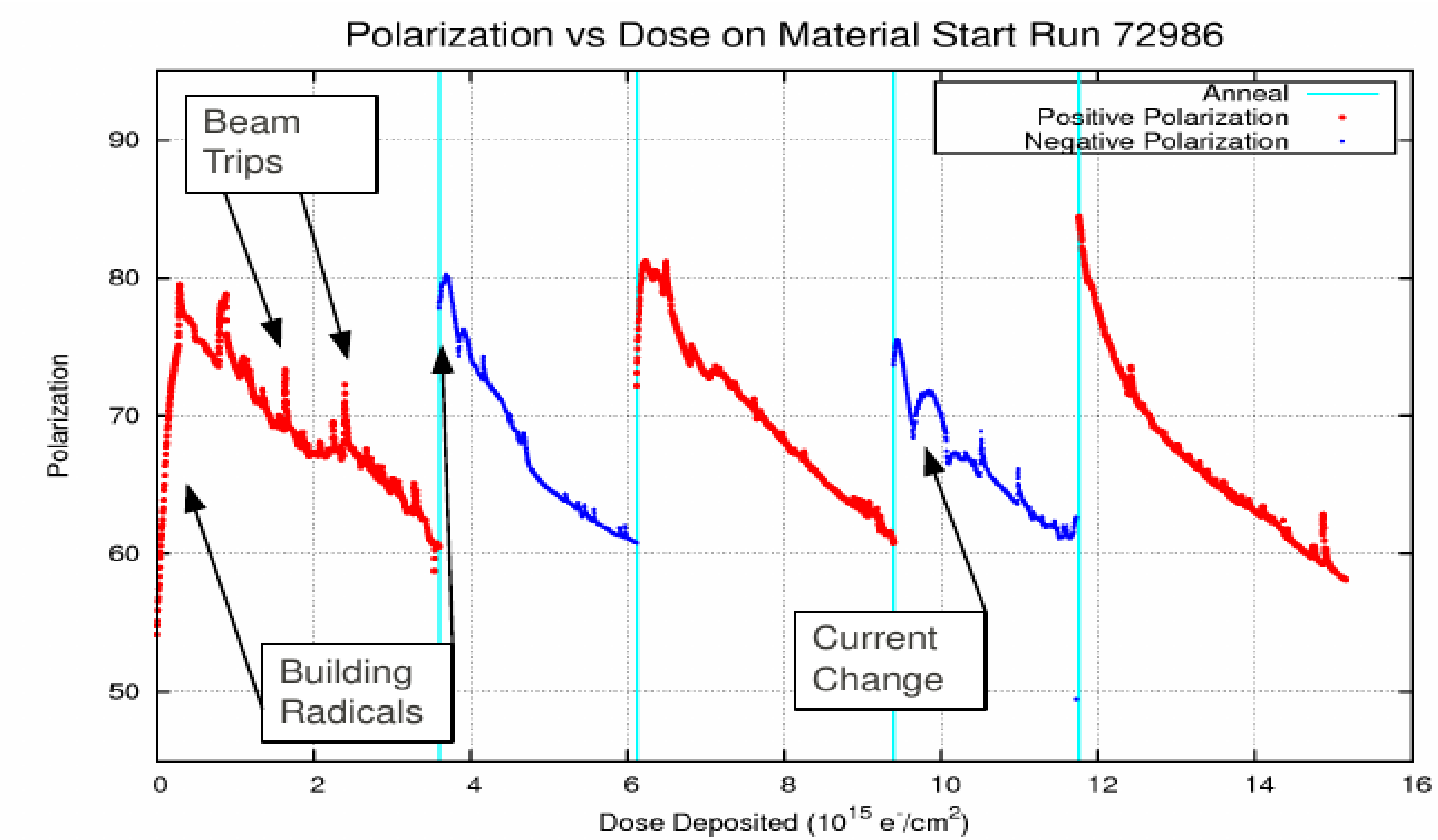
$$b_{i+1} = b_i + D_i[P_i - G(a_i x_i + b_i)]$$

$$C_i = \frac{\partial G_1}{\beta + (\partial G_1)^2 + (\partial G_2)^2} \qquad \partial G_1 = \left.\frac{\partial G(ax_i + b)}{\partial a}\right|_{ai,bi}$$

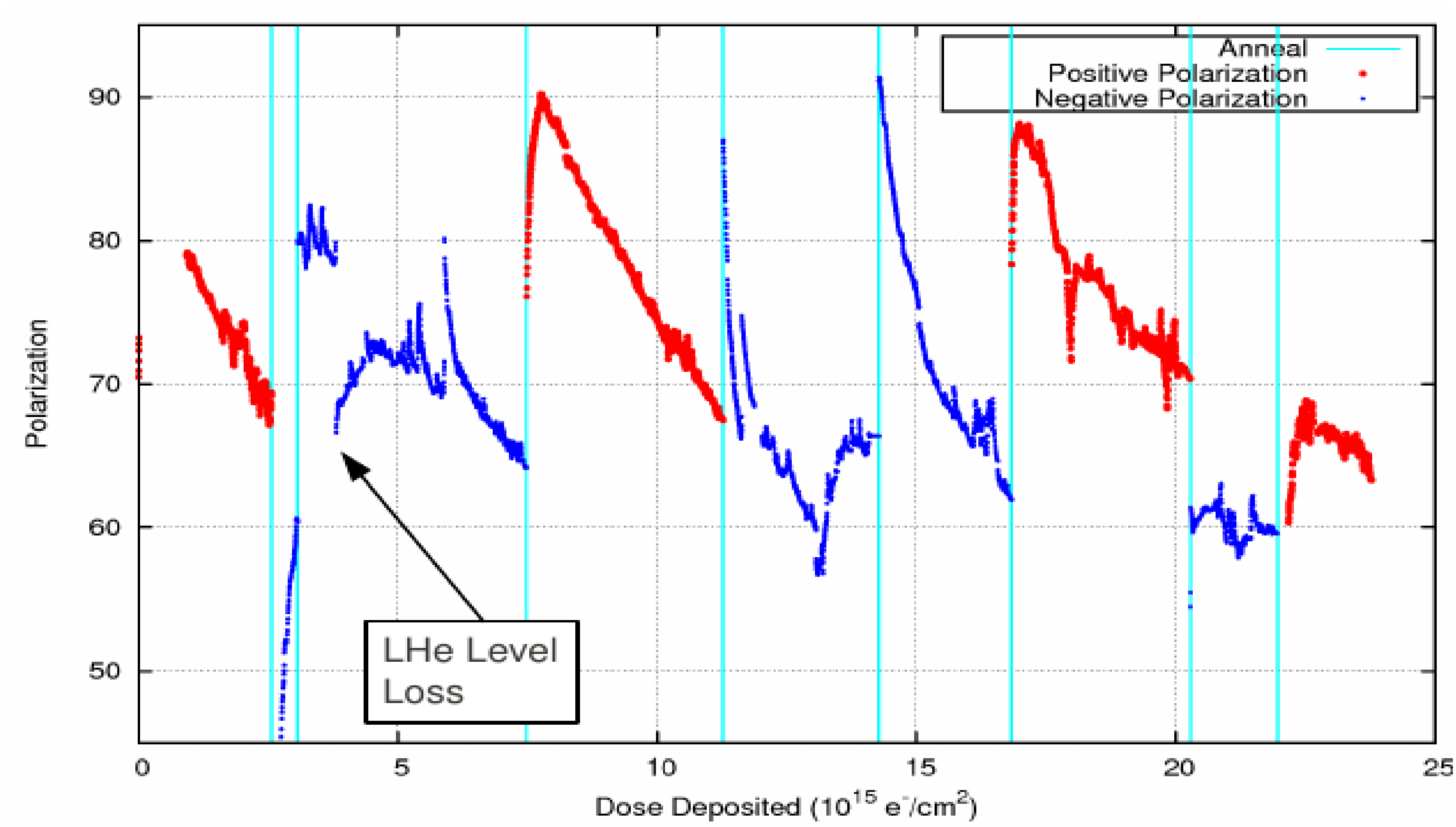
$$D_i = \frac{\partial G_2}{\beta + (\partial G_1)^2 + (\partial G_2)^2} \qquad \partial G_2 = \left.\frac{\partial G(ax_i + b)}{\partial b}\right|_{ai,bi}$$

$$\beta \rightarrow 0.1(P_o)$$

Characteristics of Polarization



Characteristics of Polarization



System Characterization, Simulation

"Ramp-ups" follow an exponential growth

Frequency response can be approximated as a second order system

$$P_n(t) = -[(\lambda_1 + a_{11})/a_{12}]C_1 e^{-\lambda_1 t} - [(\lambda_2 + a_{11})/a_{12}]C_2 e^{-\lambda_2 t} + P_n(\infty), \qquad (10)$$

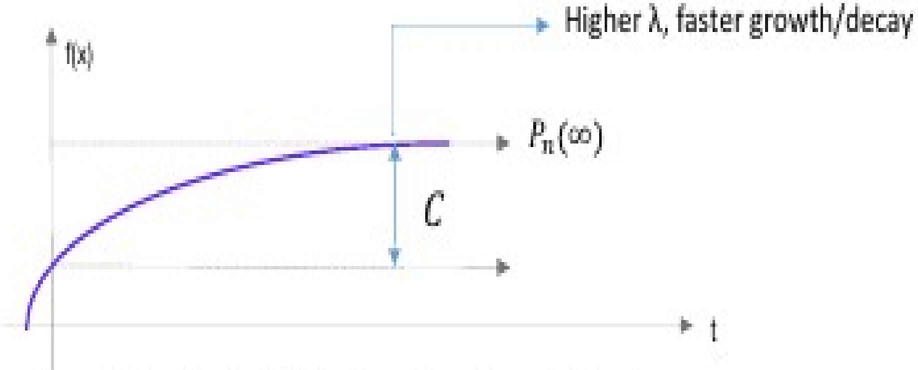
Credit: [illegible] (1996)

$$P_n(t) \approx P_n(\infty) + C_1 e^{-\lambda_1 t} + C_2 e^{-\lambda_2 t}$$

$$\lambda_1 = \frac{C\theta + 1}{2} \qquad \lambda_2 = \frac{C\theta + 1}{2} + \beta(C + 1) \qquad \theta \ll \beta \qquad C = \frac{n_e}{n_n}$$

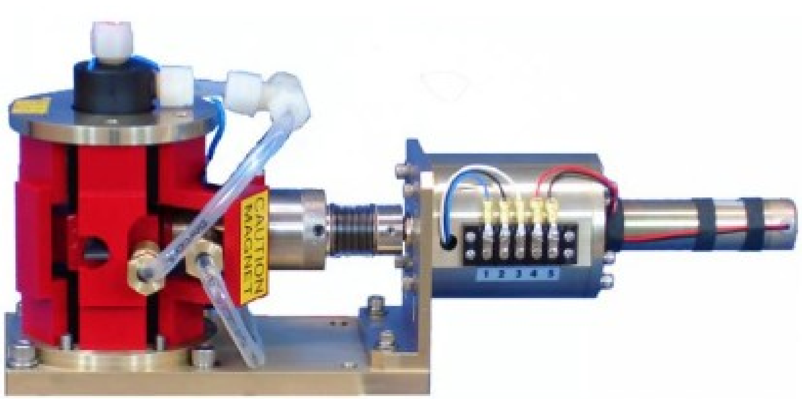
First exponential term extremely small (can essentially be neglected)

$$P_n(t) \approx P_n(\infty) + C_1 e^{-\lambda t}$$



$*P_n(\infty) = C\ , if\ starting\ from\ t = 0, P = 0$

CPI Fitted Stepper Motor



All modern CPI tubes use new stepper can also fit old tubes

- Skip Controller Box
- PC-Labview
- Control Algorithm ported in
- Optimize automation with stepper control

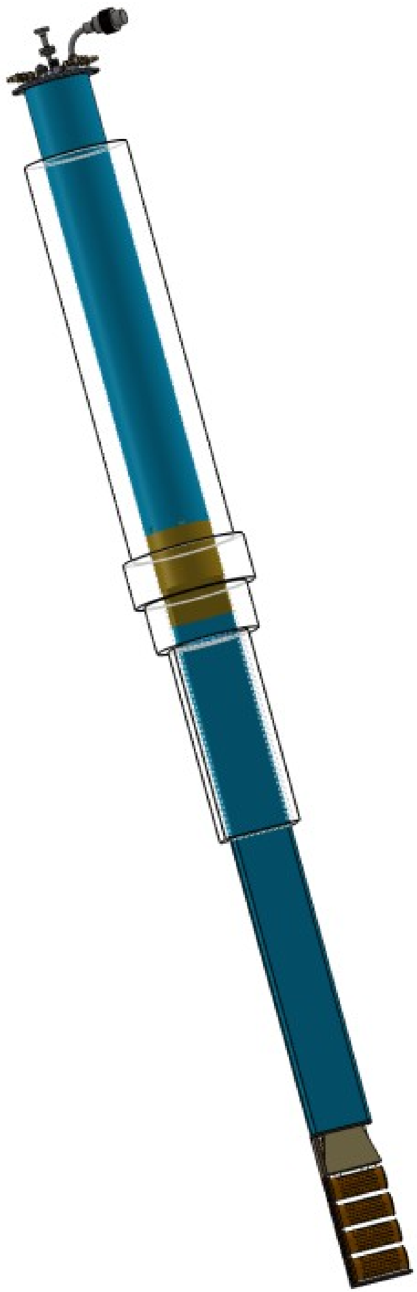
Target Material and Irradiation

- Fragments of $^{14}NH_3$ (ammonia)
- Irradiated in electron beam of ~12 MeV to ~10^{17} electrons cm^{-2} under liquid Argon (production of ^{39}Cl)
- Routinely done at NIST (Gaithersburg)
- Polarizations of 90% - 95% obtained
- Total produced ~250g out of 1000g
- Total Irradiated and ready for experiment ~100g

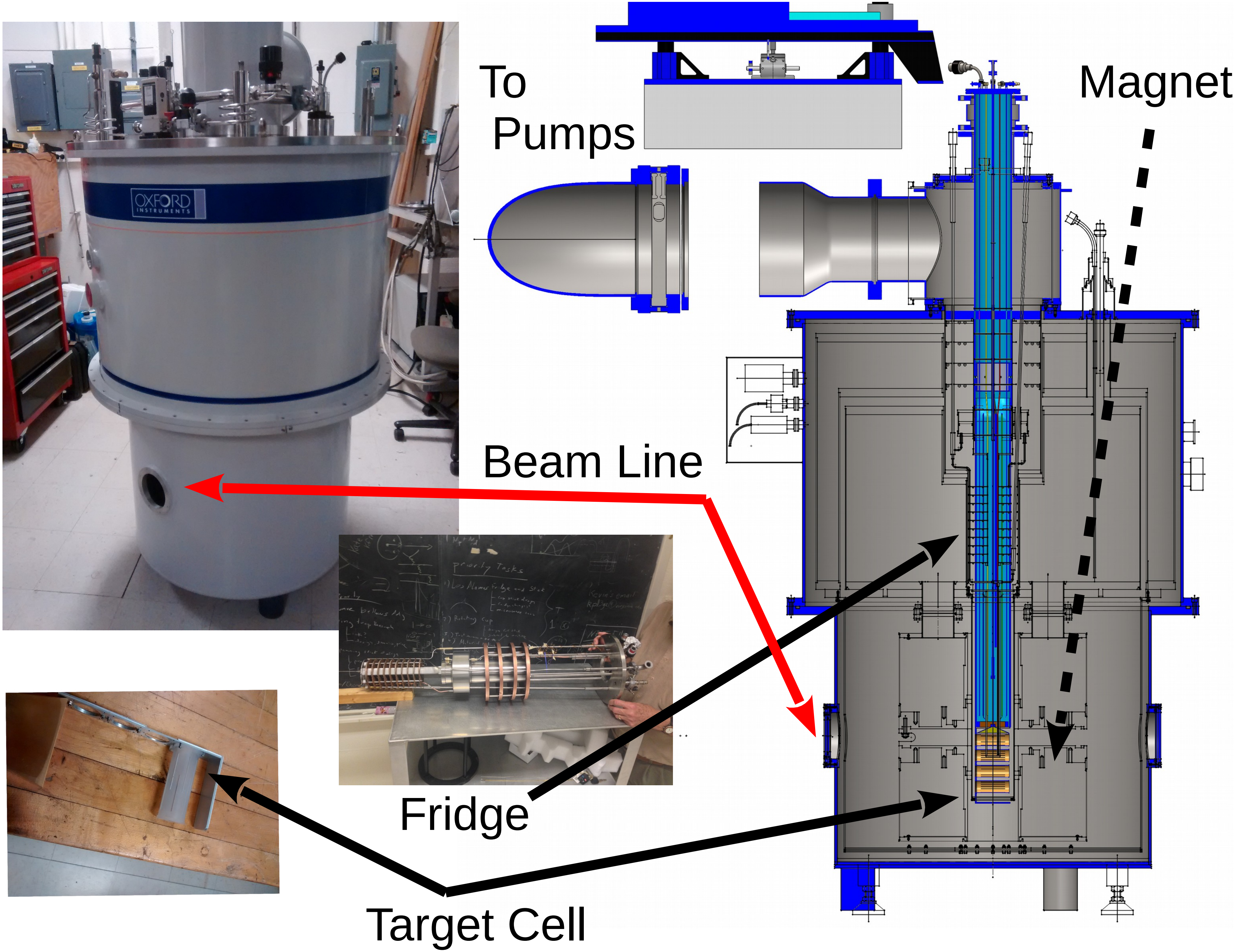
Material Inventory

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

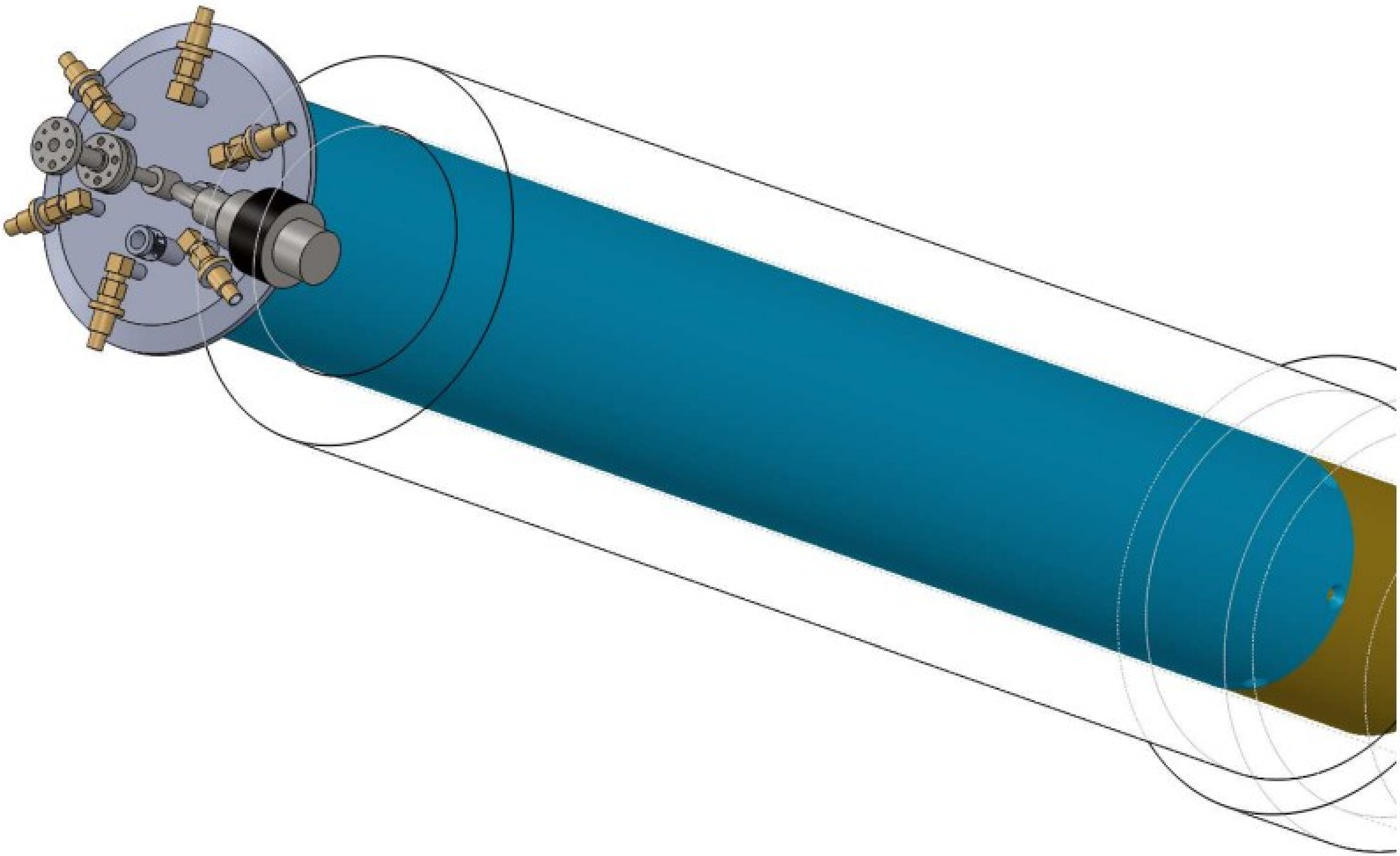
Target Insert



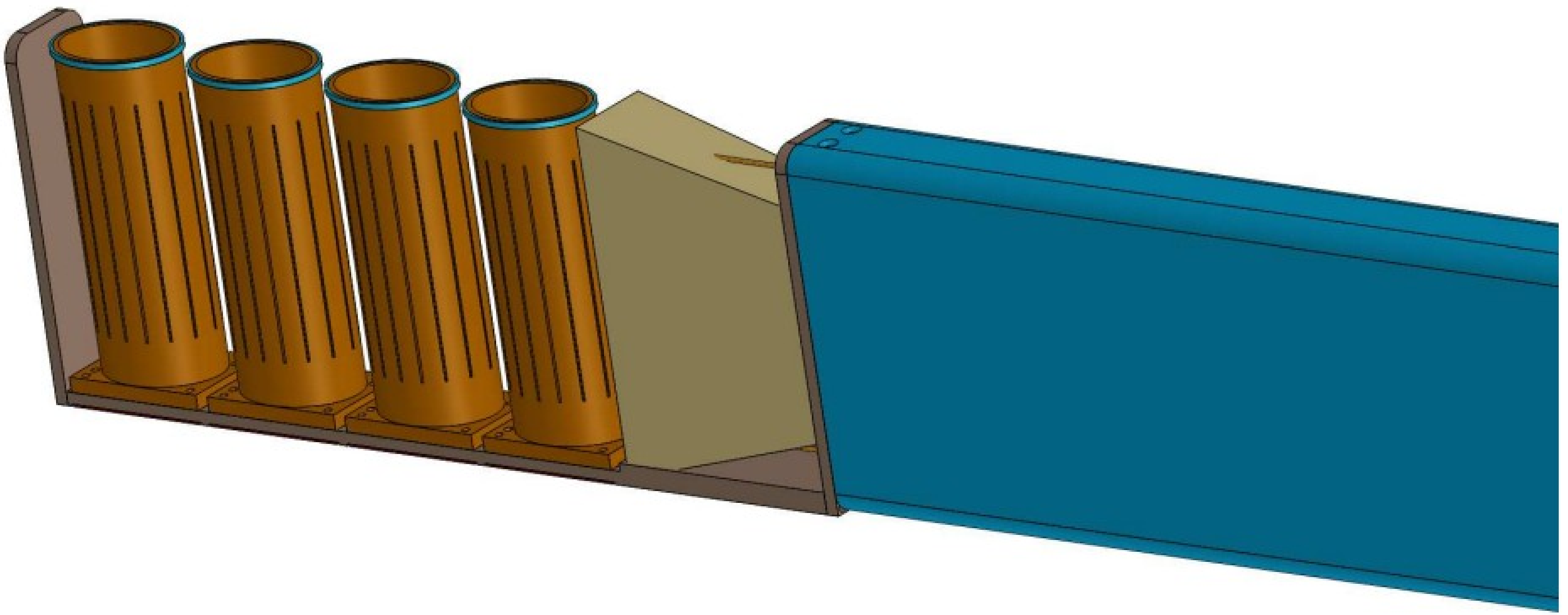
- Design and fit into fridge model
- Assembly
- Construct and Warm Test
- Cooldown Test
- Adjustments
- Load and Polarization Test


To
Pumps
Magnet
OXFORD INSTRUMENTS
Beam Line
Fridge
Target Cell

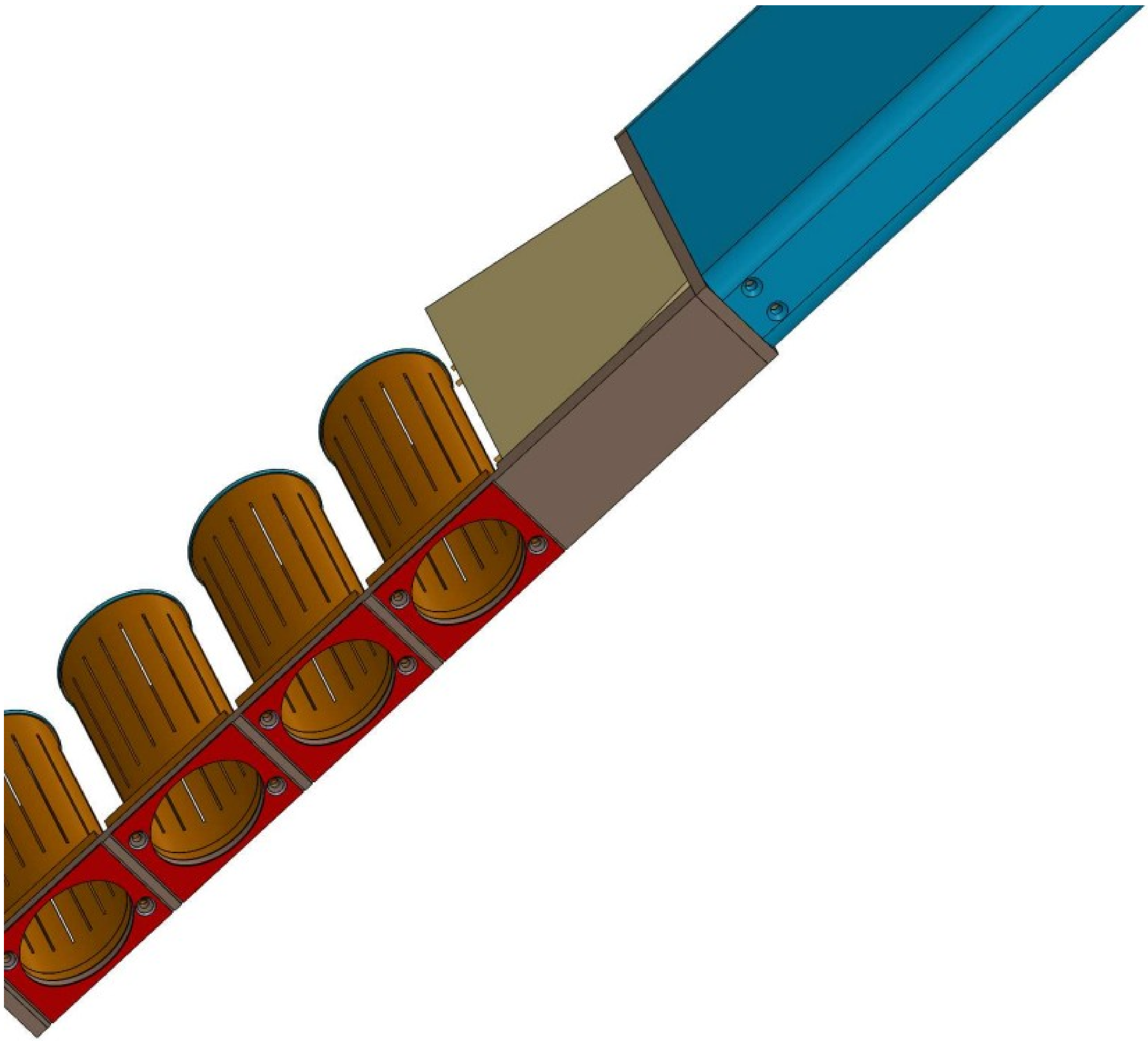
Top of Insert



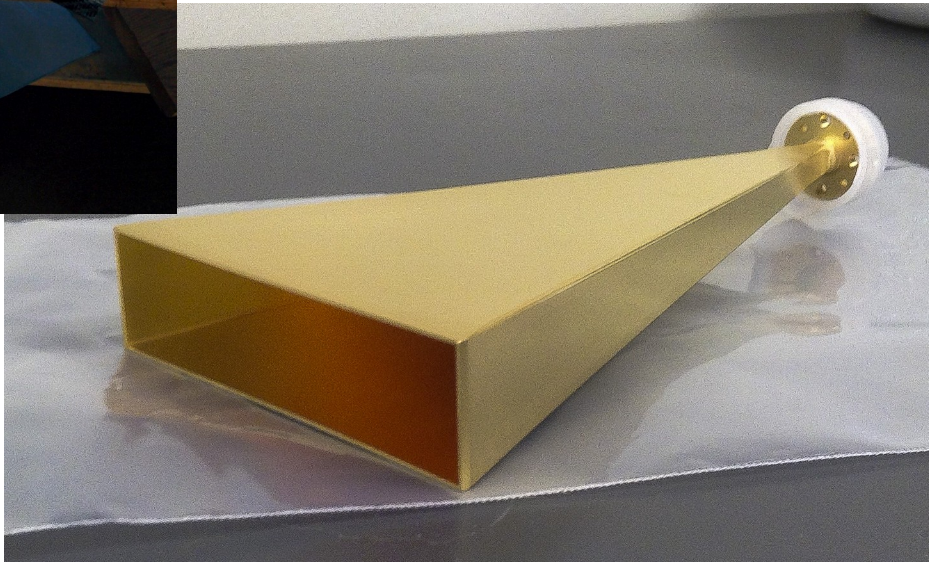
Ladder and Cups



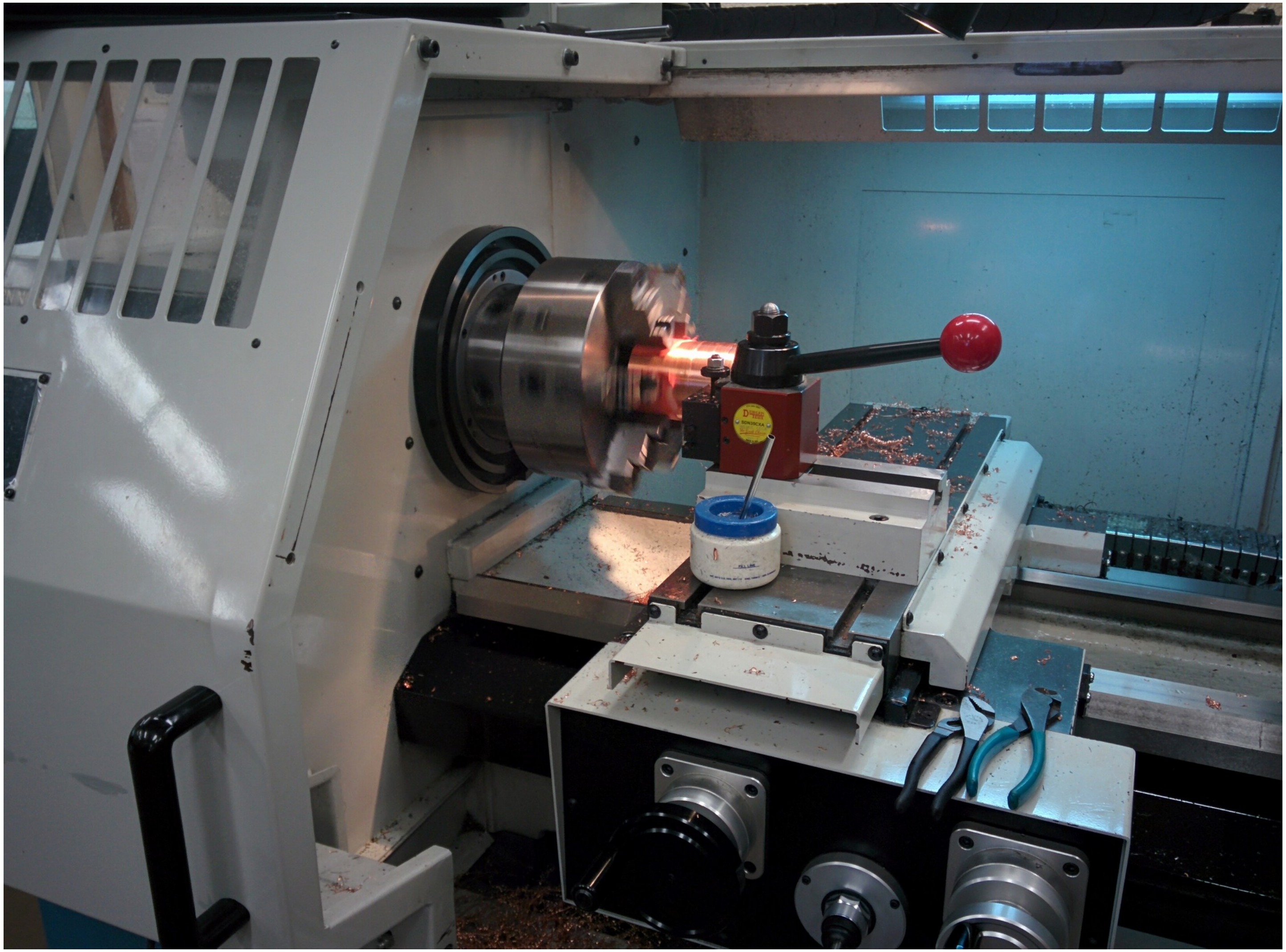
Load End



Carbon Fiber and Horn

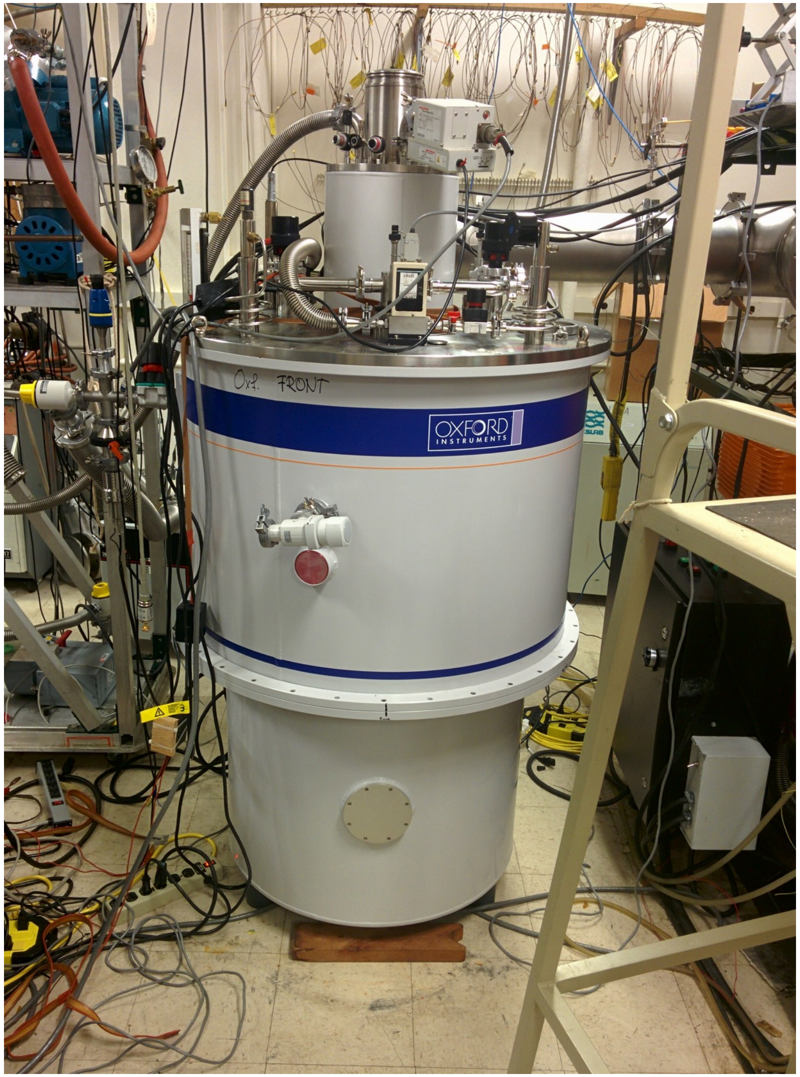


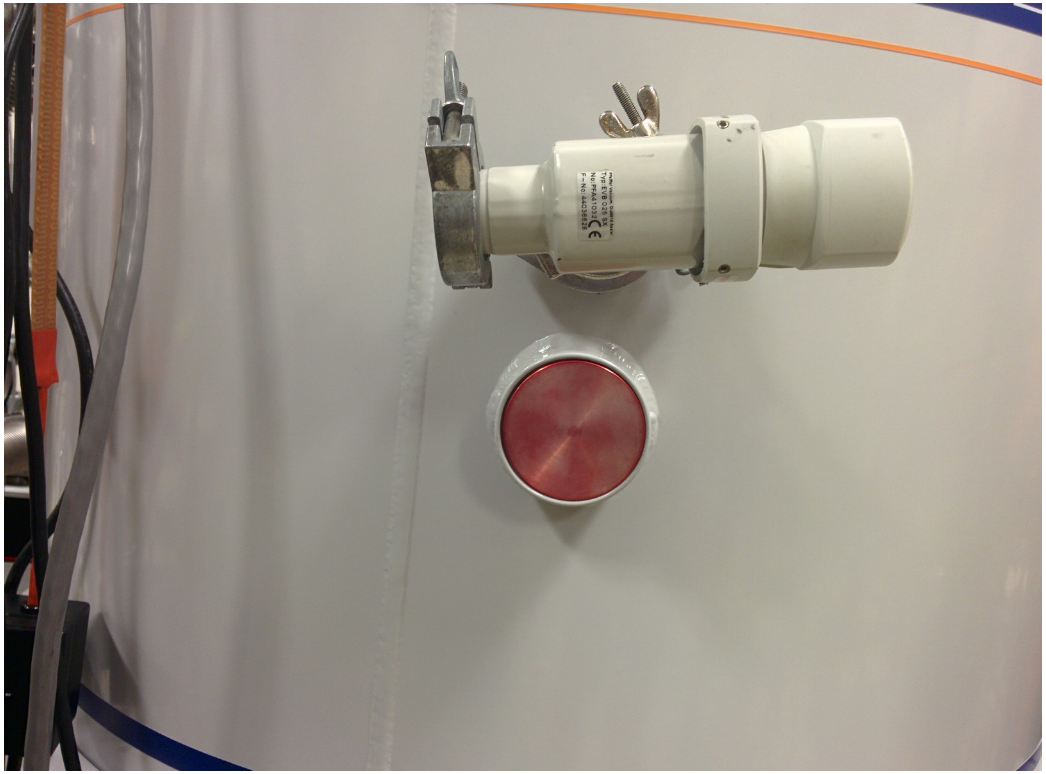
Machining Copper Thermal Barrier



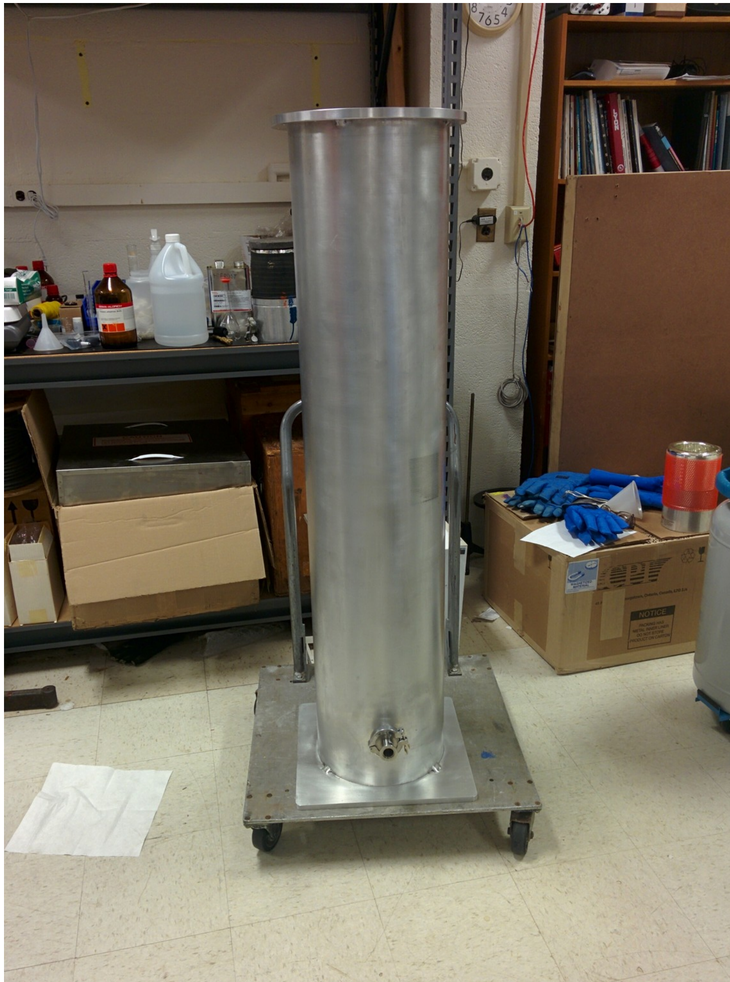
Cups and Ladder

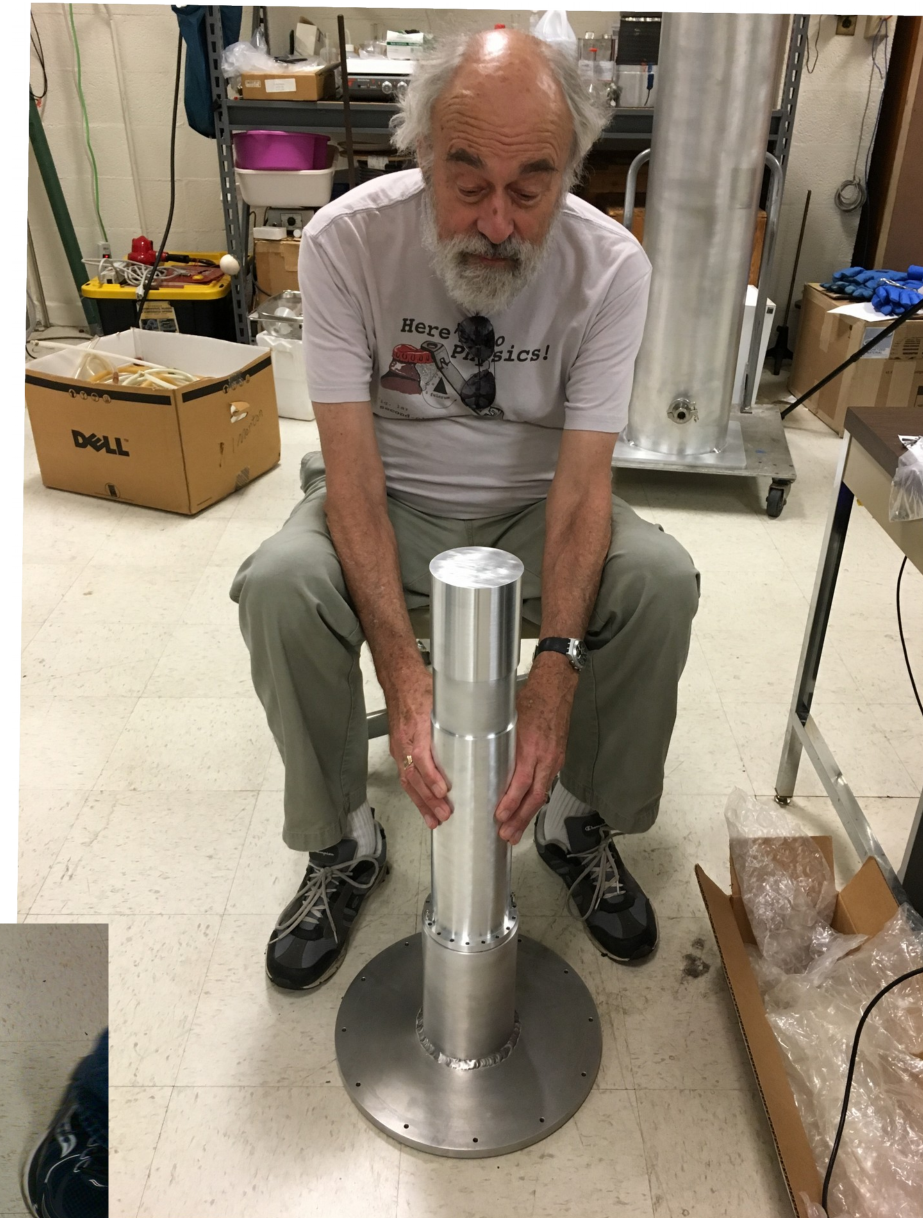
Vacuum Repair



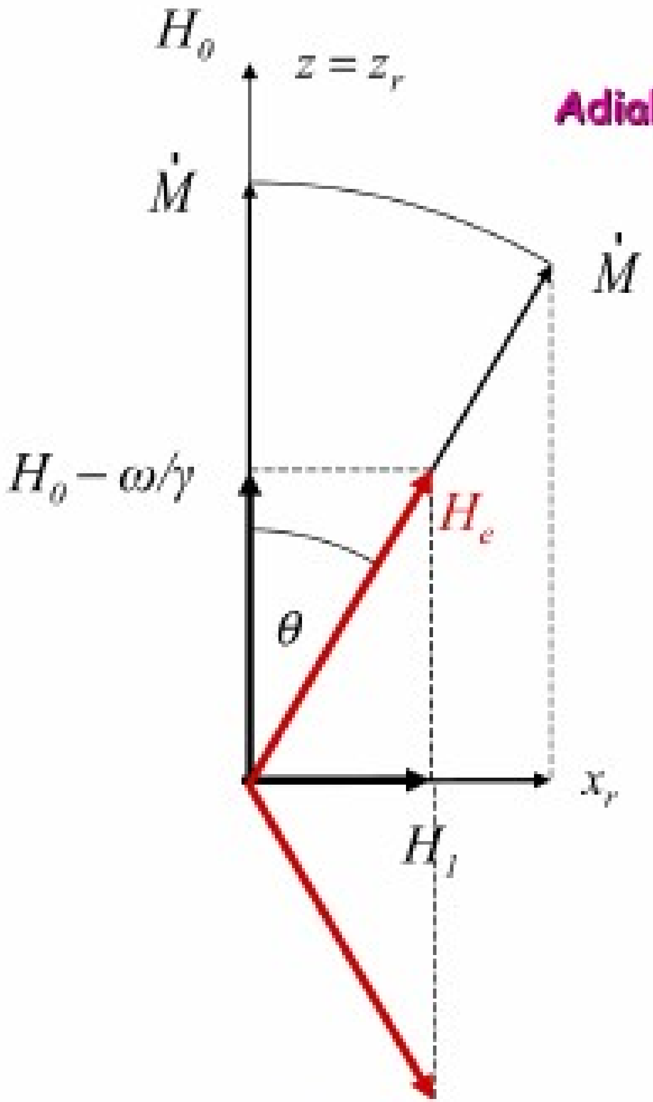


- With 2 Turbos got to 2×10^{-4}
- After repair got to 1×10^{-5}




DELL

Adiabatic Fast Passage at 1 K



Adiabatic: $\frac{dH}{dt} = \gamma H_1^2$ **Fast** (faster than relaxation): $\frac{1}{\tau} = |\gamma H_1|$

External field $\dot{H}$ contains **rf field**

static field: $H_z = H_0$ rf field: $H_x = 2H_1\cos(\omega t)$

$$\dot{H} = H_0\hat{z} + H_1\cos(\omega t)\hat{x} + H_1\sin(\omega t)\hat{y}$$

rotating frame ↓

$$\overset{r}{H_e} = (H_0 - \frac{\omega}{\gamma})\hat{z}_r + H_1\hat{x}_r \qquad \tan\theta = \frac{H_1}{H_0 - (\omega/\gamma)} = \frac{\omega_1}{\omega_0 - \omega}$$

Larmor frequency: $\omega_0 = \gamma H_0$

For any vector $\dot{\mu}$ satisfying a similar equation of motion the angle between $\dot{\mu}$ and $\dot{H}$ remains constant provided the change of direction of $\dot{H}$ in time is sufficiently slow

AFP Efficiency

AFP was performed on different target materials

Spin-flip efficiencies for different materials are shown below
(δp = pol. ratio before and after spin-flip)

UVA recently achieved over 50% AFP efficiency for NH_3

UVA-study

Nuc.lei	Dopant	Spins/g	δp
ND_3	Irr.	$2x10^{17}$	-0.88
NH_3	Irr.	$2X10^{17}$	-0.57
D-but.	Irr.	$1X10^{17}$	-0.77

Table 1
Results from AFP experiments with various nuclei in different target materials

Nuclei	Substance dopant	e^- conc. (spins/g)	δP^{max}
^1H	1-butanol EHBA-Cr(V)	2.0×10^{19}	-0.76
^7Li ^1H	^7LiH (irradiated)	low	-0.90 -0.90
^{19}F ^1H	8-fluoro-1-pentanol TEMPO	1×10^{20}	-0.37 -0.40
^2H	1-butanol-d_{10} EHBA-Cr(V)-d_{22}	2.36×10^{19} 6.35×10^{19}	-0.92 -0.90

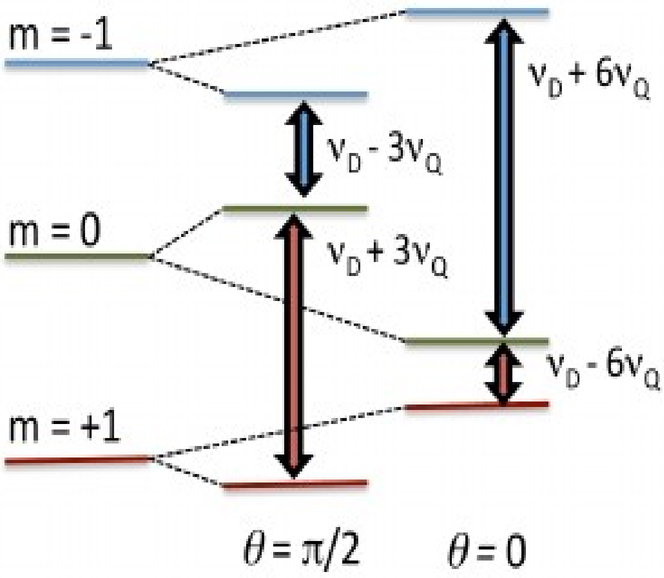
NIM A 356 (1995) 108

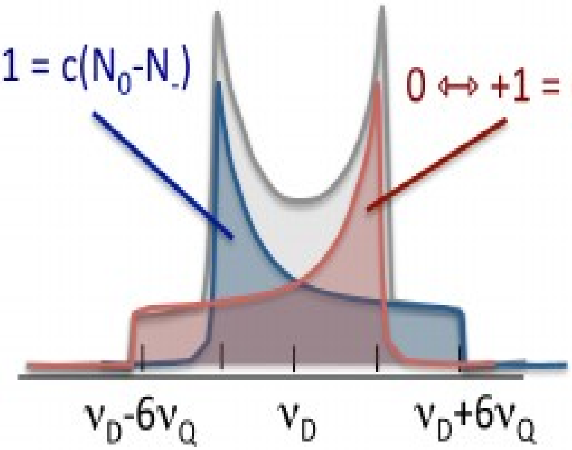
The Need For Tensor Polarized Target

- Deuteron also has an electric quadrupole moment, $eq_D = 2.86\ e{\cdot}fm^2$
- eq_D interacts with electric field gradients within the lattice producing two, overlapping NMR lines (Pake doublet)

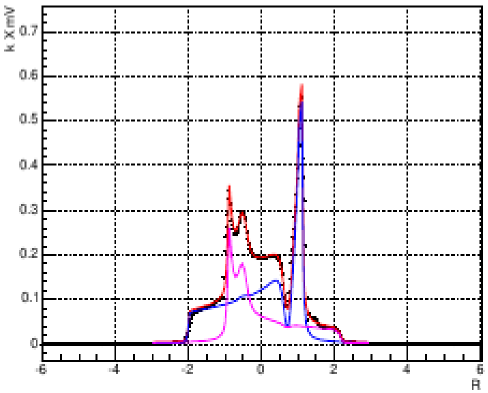
$$E_m = -h\nu_D m + h\nu_Q\left[3\cos^2\theta - 1\right]\left[3m^2 - I(I+1)\right]$$

ν_D = deut. Larmor freq.
ν_Q = ND_3 quadrupole freq.
eq = deuteron quadrupole moment
θ = angle between elec. & mag. fields





A~38% for d-butanol



Updates to UVA system

- NMR (Q-meters)
- Flow Meters/Sensors
- OVC Turbo (300l/s)
- All Roots pumps running

Still To Come

- First fully equipped insert
- Insert Warm/Cold Test
- Further NMR
- Frequency control auto-algorithm
- Cryosystem auto-control
- 10 mils window cold test
- Fully integrated cooldown
- More Material Fab and Irr
- ^{3}He pressure setup