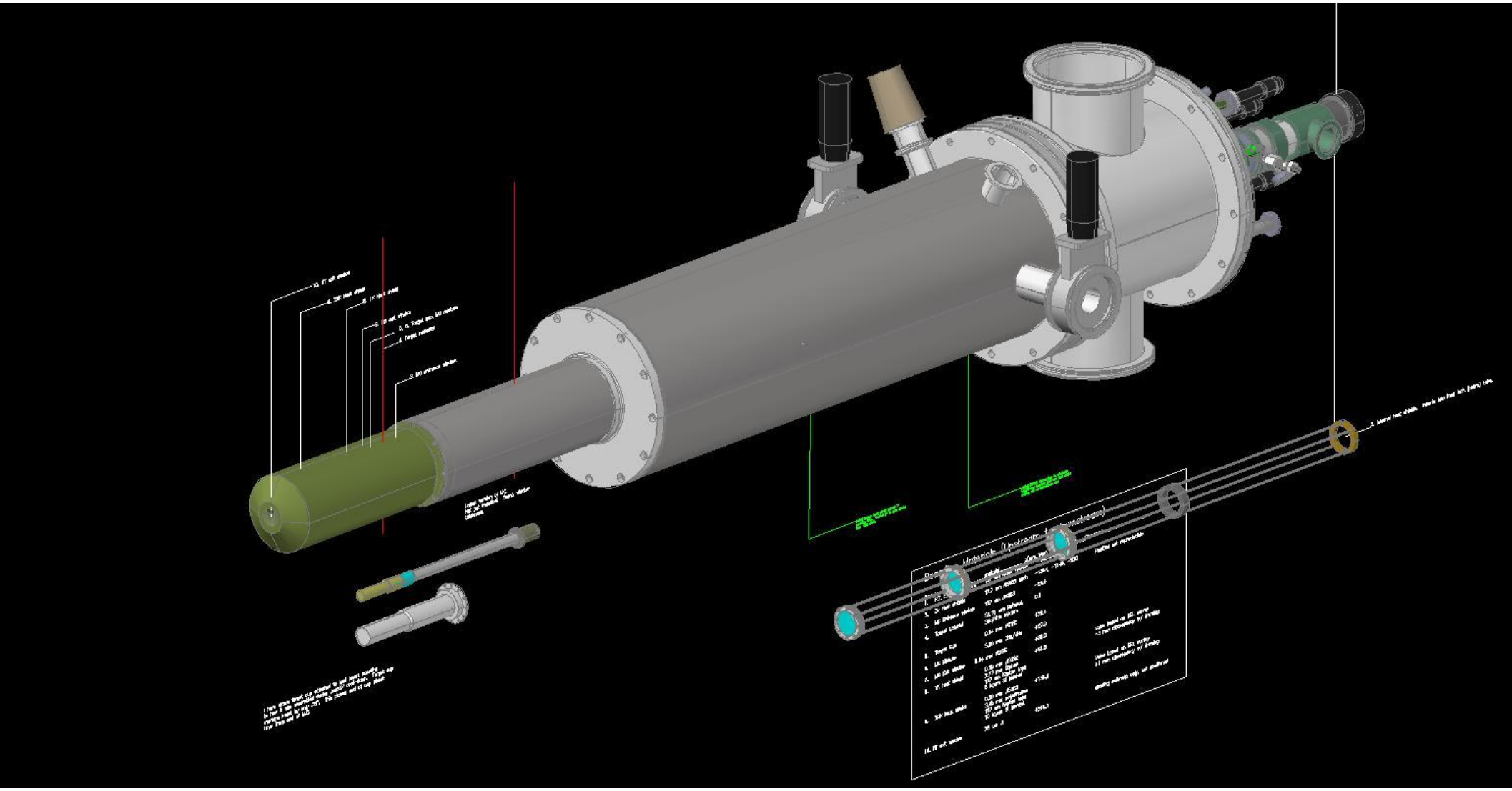
The JLab Frozen Spin Target



Jefferson Lab

Christopher D. Keith
JLab Target Group

SPIN08
October 10, 2008

The g9 Tagged Photon Experiments in CLAS

E02 – 112:	Search for Missing Nucleon Resonances in Hyperon Photoproduction
E03 – 105:	Pion Photoproduction from a Polarized Target
E04 – 104:	Helicity Structure of Pion Photoproduction
E05 – 012:	Measurement of Polarization Observables in Eta-Photoproduction with CLAS
E06 – 013:	Measurement of π^+ π^- Photoproduction in Double-Polarization

Experiments using CLAS

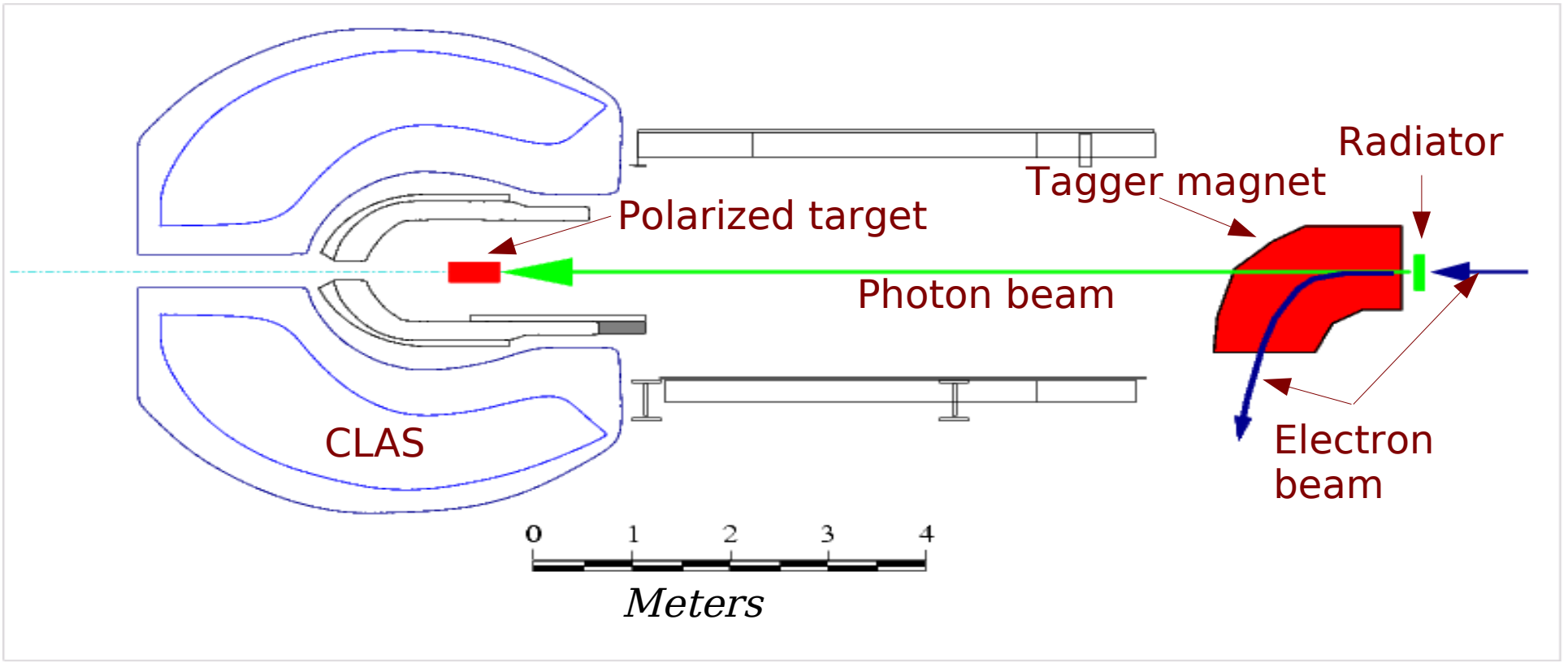
Common physics goals: Spectroscopy of baryon resonances.

Experimental technique: Measure **multiple** single- and double-spin observables using **all combinations** of linearly *and* circularly polarized photons, incident on longitudinally *and* transversely polarized protons.

First round of experiments used *longitudinally* polarized target
- completed Feb. 2008

Second round requires *transverse* target polarization.
- scheduled for 2010

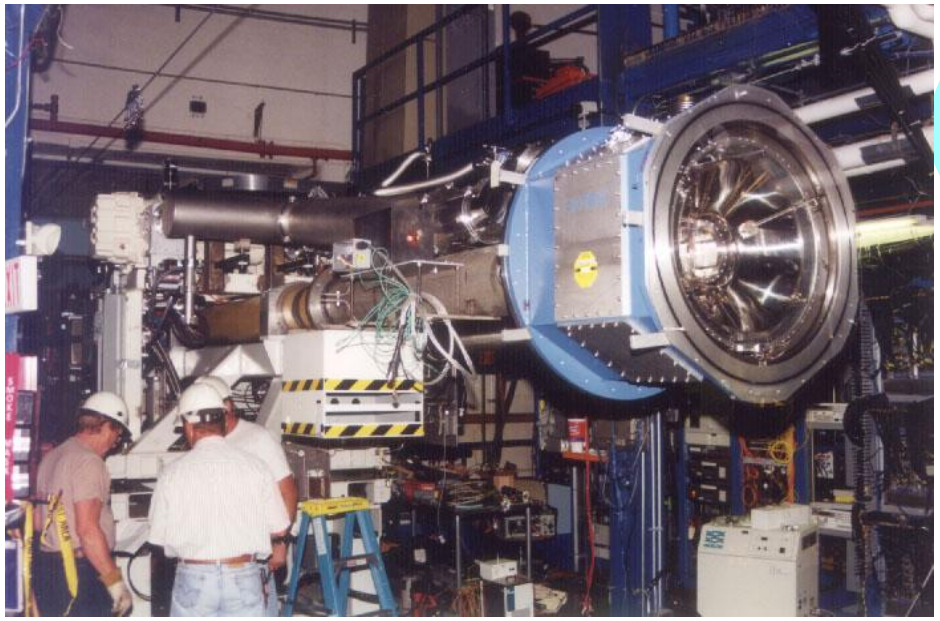
g9 Experimental Layout

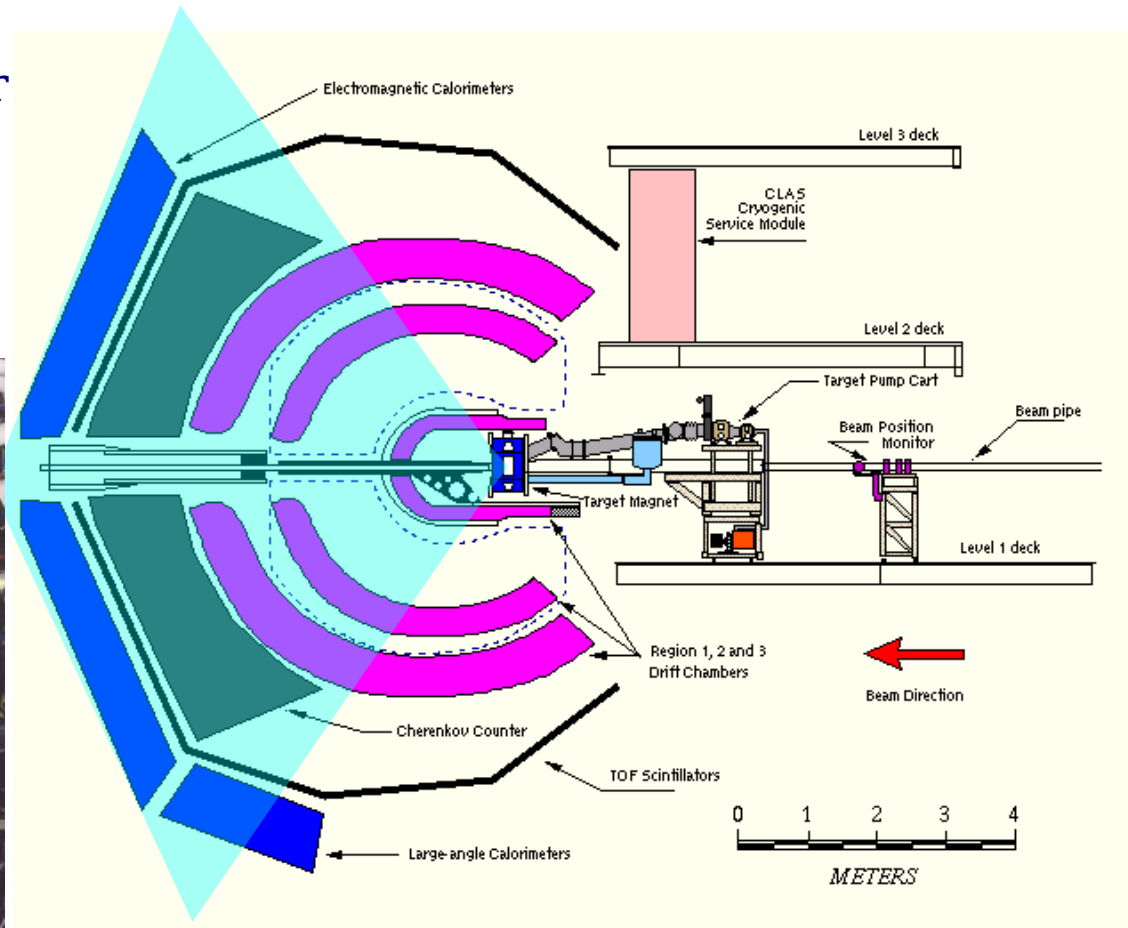


The Existing Hall B Polarized Target

Dynamically polarized NH_3/ND_3 target
Temperature: 1K
Polarizing Magnet: 5T Helmholtz pair

- **longitudinal only**
- **limits acceptance $\vartheta \leq 55°$**



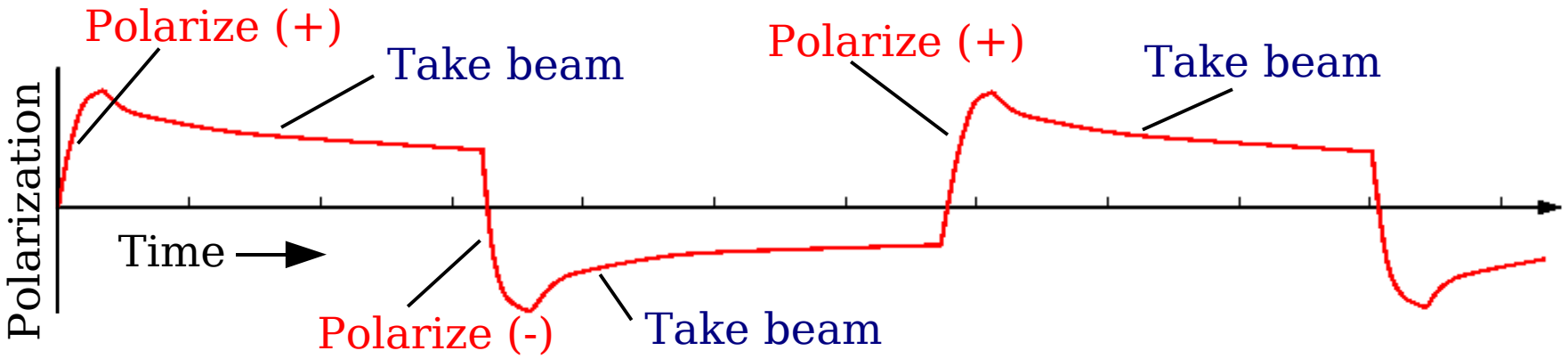


Construct (at JLab) a **Frozen Spin Target** with acceptance up to 135°, and both longitudinal *and* transverse capabilities

The Frozen Spin Technique

Operation is more complicated:

1) Polarize target (DNP) at high field (5 T) and low temperature (~ 0.5 K)
2) “Freeze” the spins at very low temperature (~ 0.05 K)
3) Maintain polarization polarization using a smaller magnet (0.5 T) with beam on target
4) Repeat steps 1 – 3 as needed



Polarization decay time T_1 depends on material, field, and temperature.

Goal: T_1 = 500 hrs

$\Delta P/P$ = -5% per day

FROST: Design Specifications

Material: 5 g frozen butanol (C_4H_9OH) + TEMPO (0.5% wt)

Polarizing Conditions: 5 Tesla at 0.3 K

Cooling requirements: ~ 20 mW

Polarization: ± 85%

Frozen Spin Conditions: 0.5 Tesla at 50 mK

Cooling requirements: ~ 10 μW

Proton Relaxation Time: $T_1 \geq 500$ hours

$\Delta P/P$ = -5% per day

FROST: Equipment List

1 $^{3}He/^{4}He$ dilution refrigerator
1 superconducting polarizing magnet + power supply
1 superconducting holding magnet + power supply
1 microwave generator + waveguide components
2 NMR coils + Q-meter circuits
2 control computers (EPICS + LabView)
2 gas panels + 22 valves
18 vacuum pumps
7 vacuum gate valves
30 thermometers
18 vacuum/pressure gauges
1 residual gas analyzer
4 LHe level meters
3 chillers

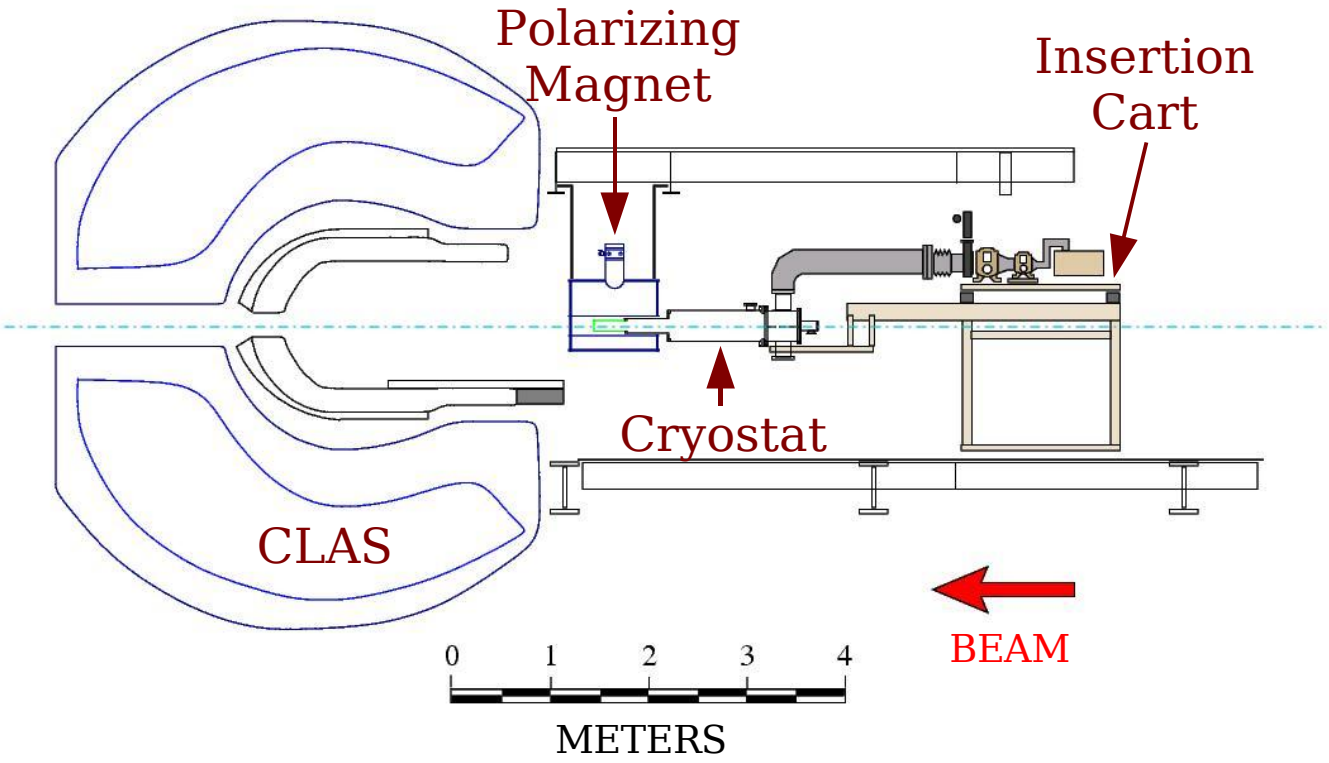
One Small Problem…

Target must be polarized outside of CLAS and **roll forward** (while cold!) for data acquisition phase.

The “Frozen Spin Waltz”

Polarizing Mode

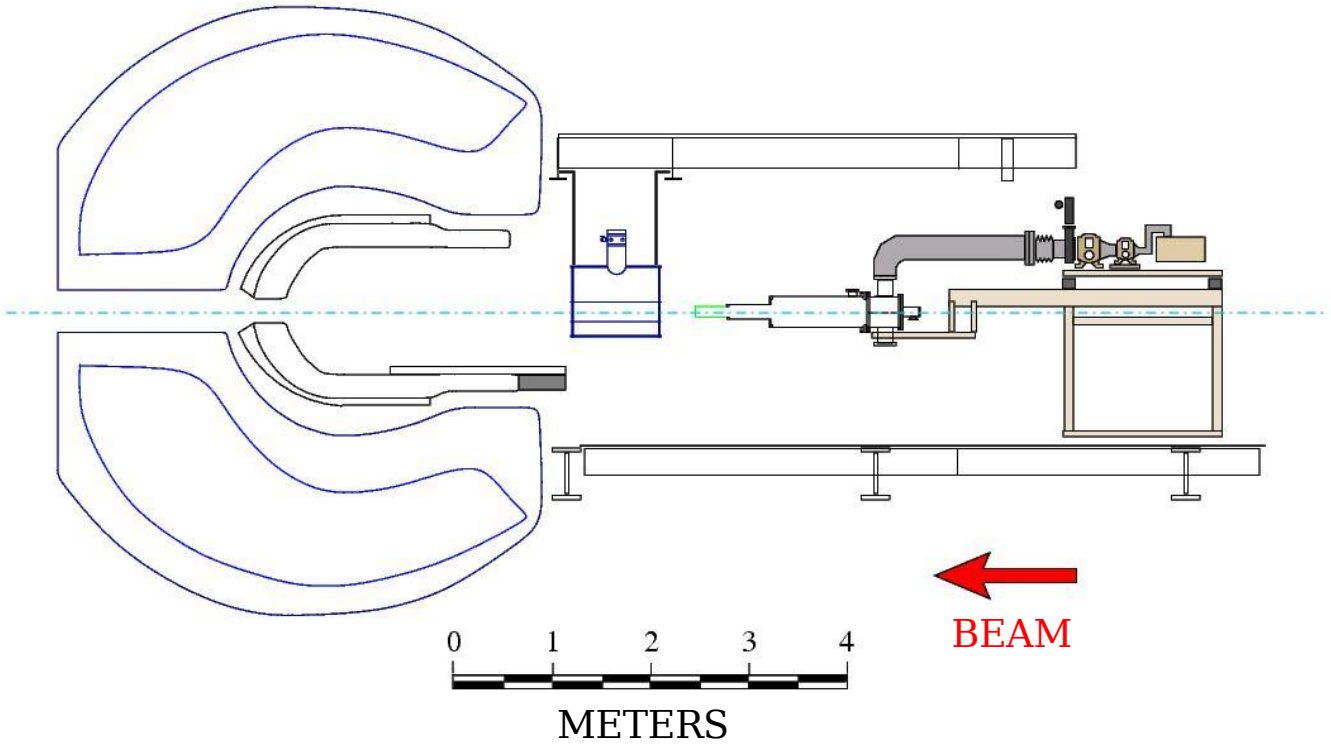
- Microwaves ON
- Polarizing magnet ON
- Holding magnet OFF
- Temperature ~1/2 K
- Photon beam OFF



The “Frozen Spin Waltz”

Transition Mode

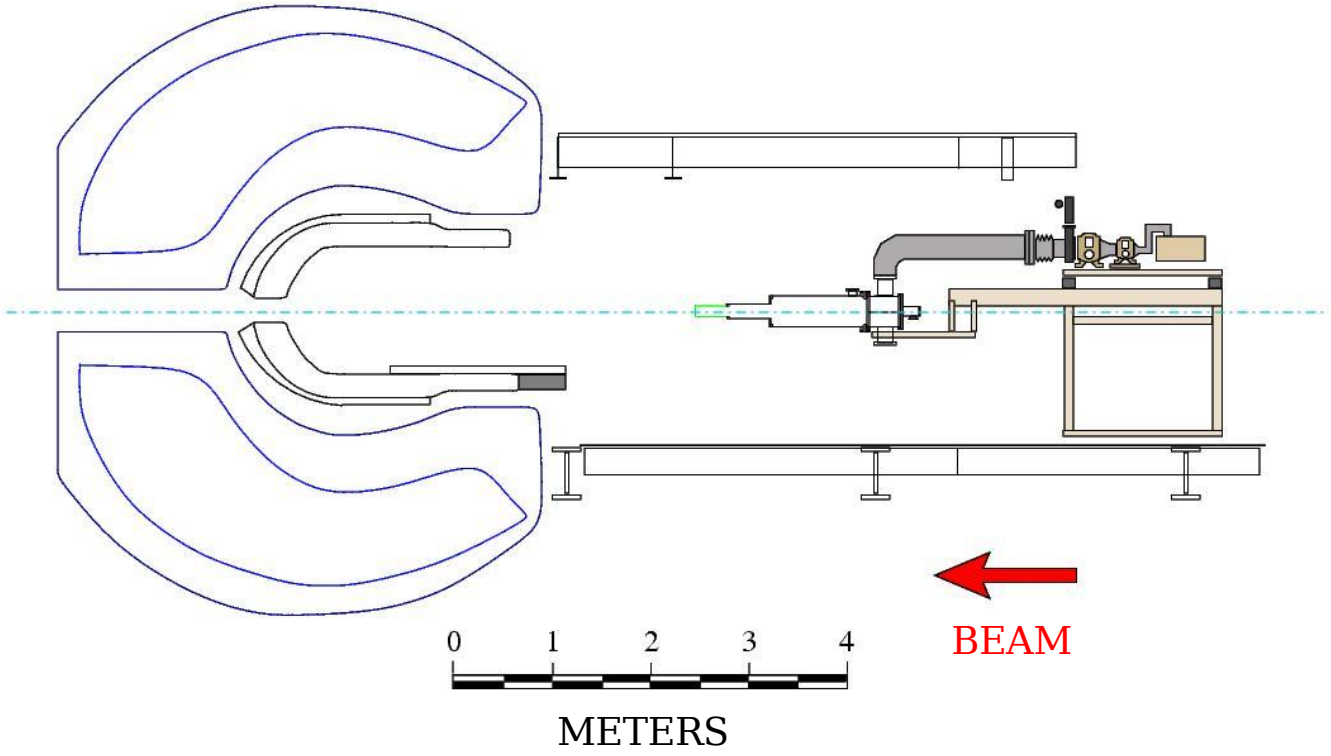
- Microwaves OFF
- Polarizing magnet OFF
- Holding magnet ON
- Temperature ≤0.07 K
- Photon beam OFF



The “Frozen Spin Waltz”

Transition Mode

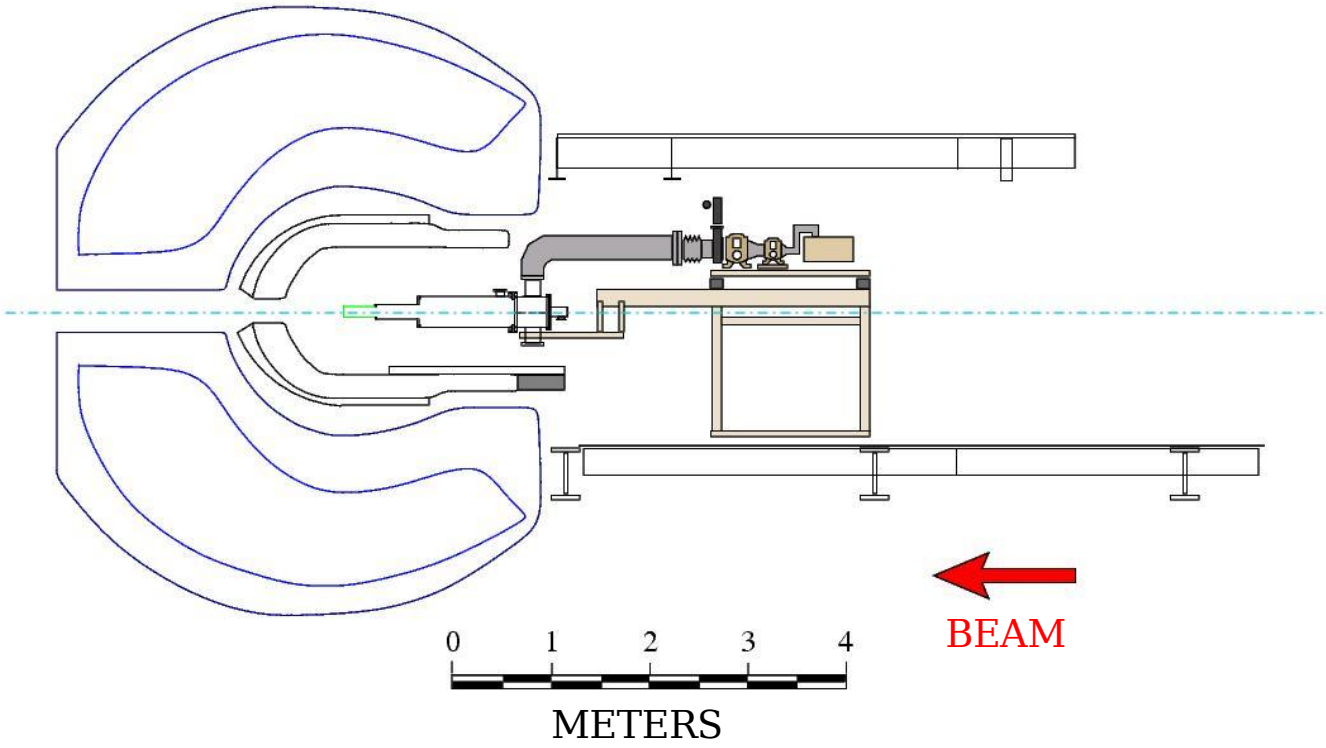
- Microwaves OFF
- Polarizing magnet OFF
- Holding magnet ON
- Temperature ≤0.07 K
- Photon beam OFF

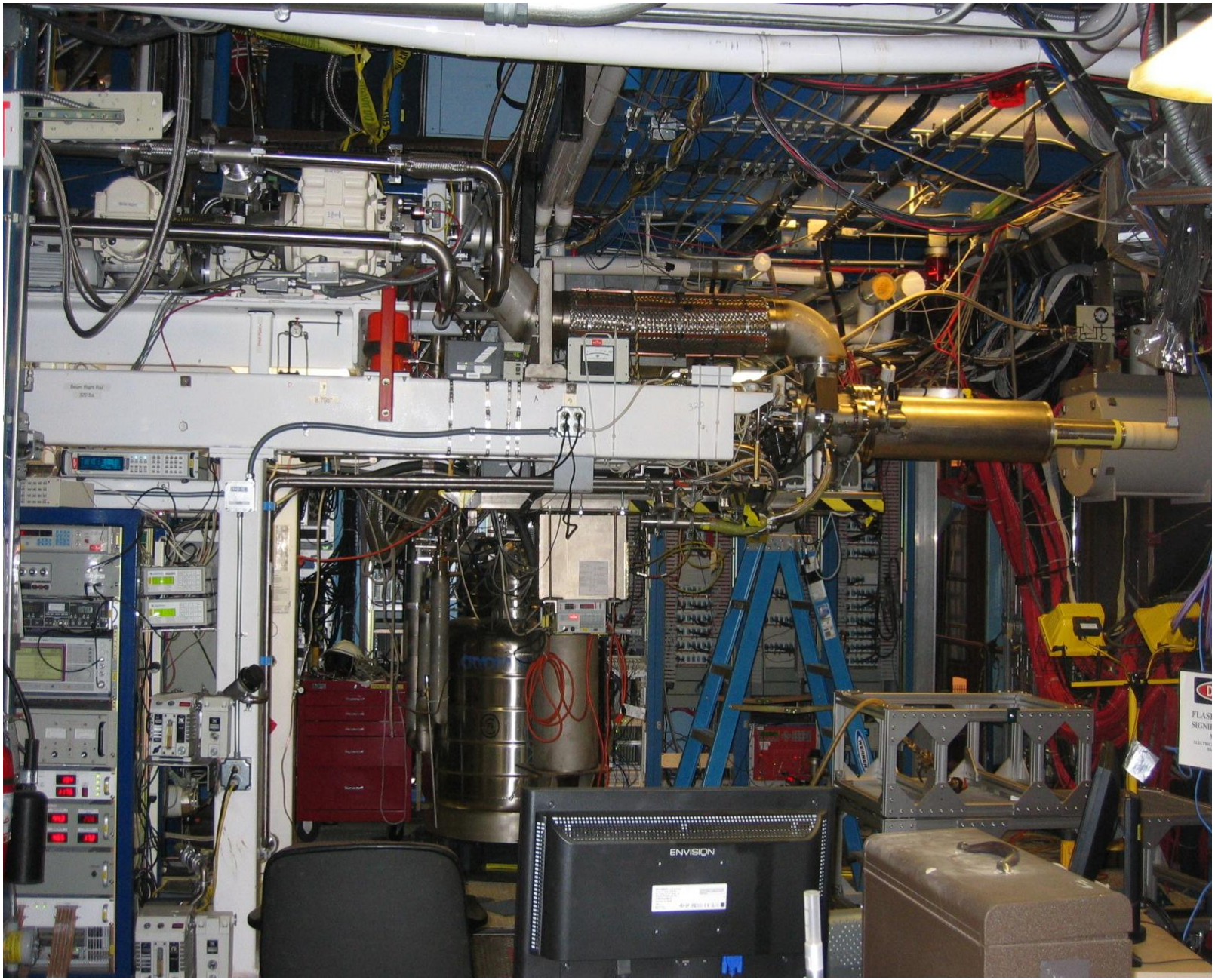


The “Frozen Spin Waltz”

Frozen Spin Mode

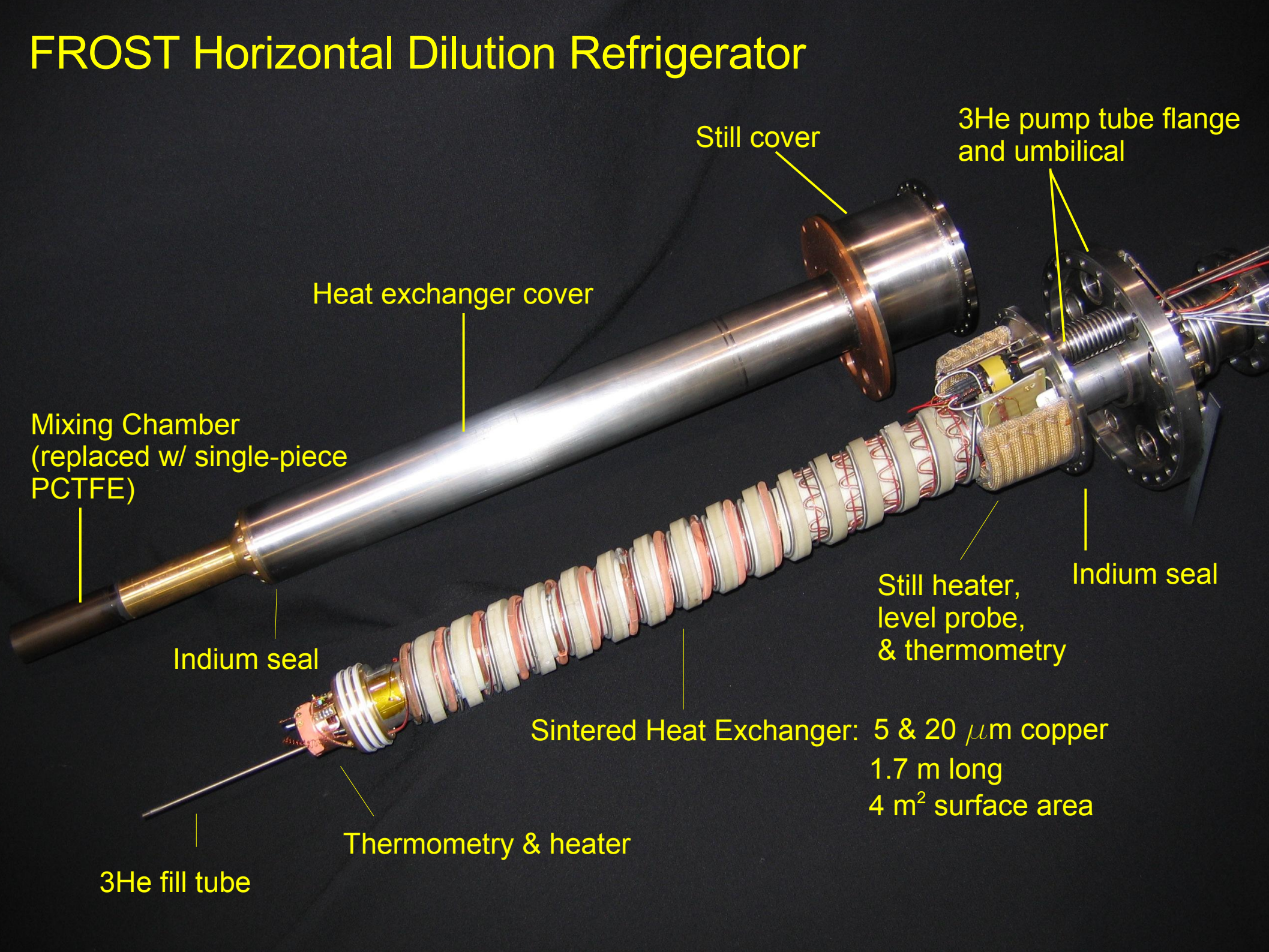
- Microwaves OFF
- Polarizing magnet OFF
- Holding magnet ON
- Temperature ≤0.05 K
- Photon beam ON





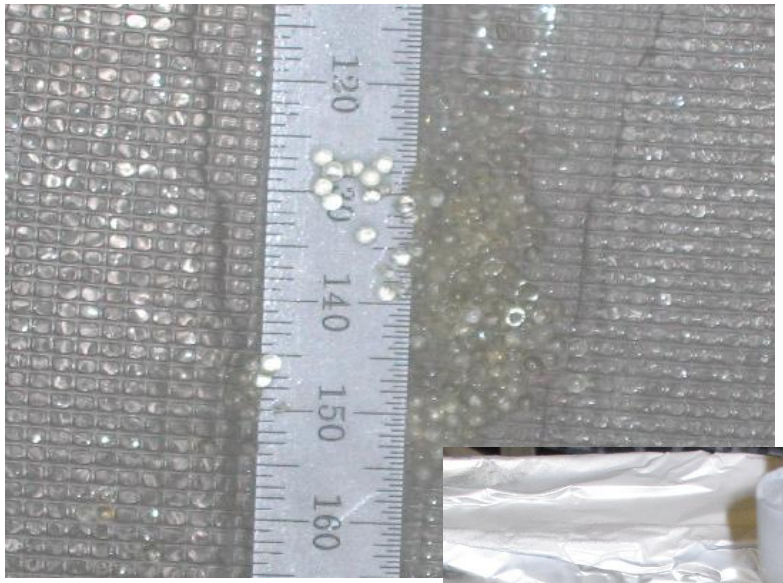
FROST in Hall B, February 2008

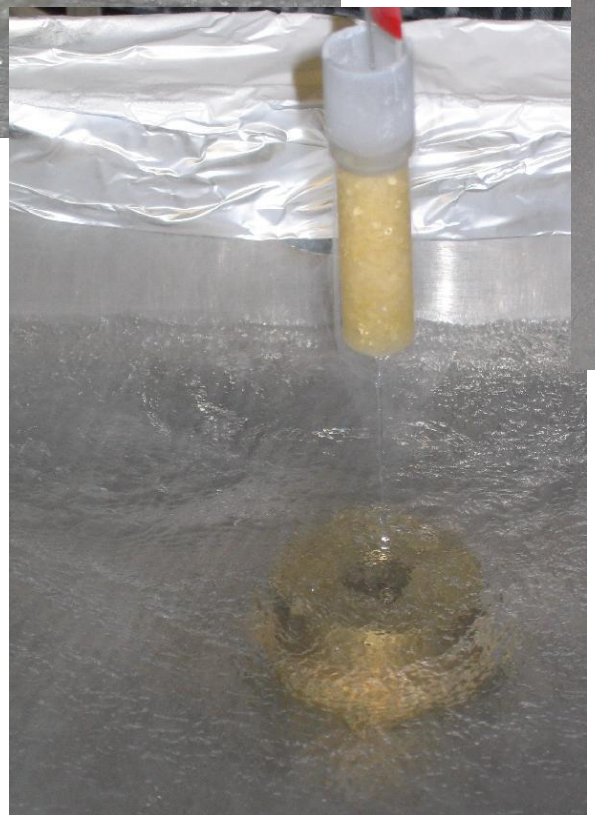
FROST Horizontal Dilution Refrigerator

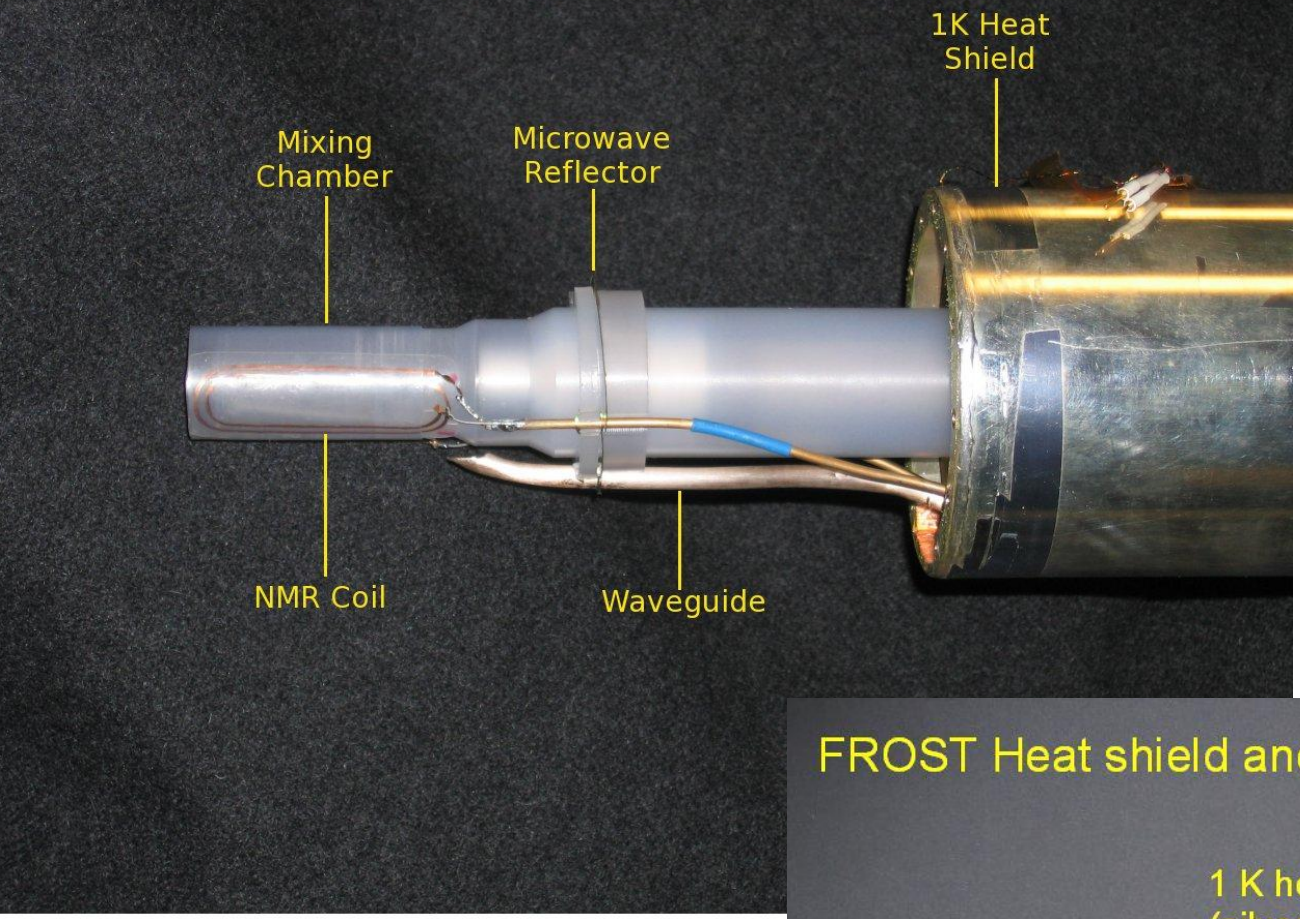


Frozen Spin Target: Material

5 g frozen butanol, 1 − 2 mm beads

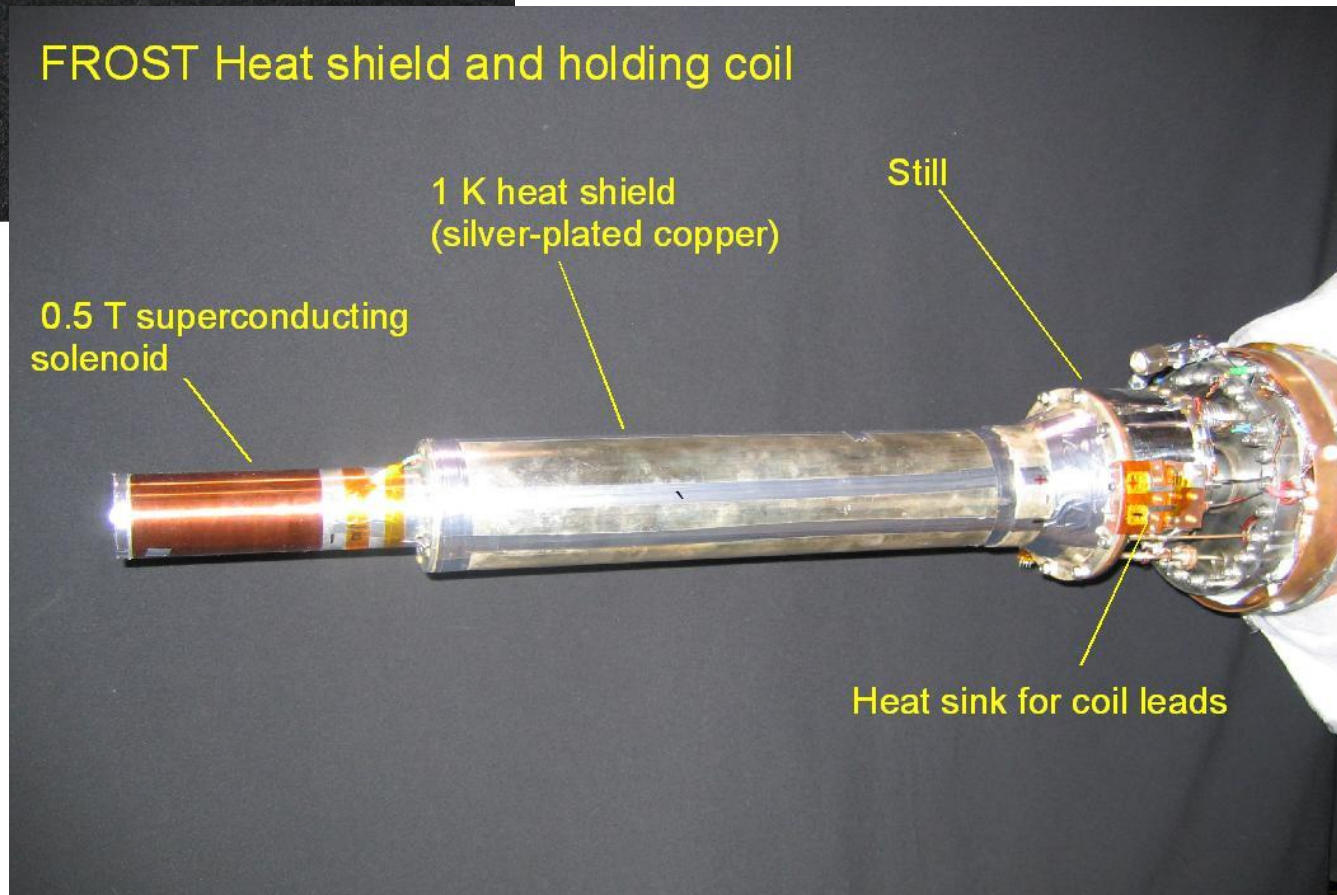






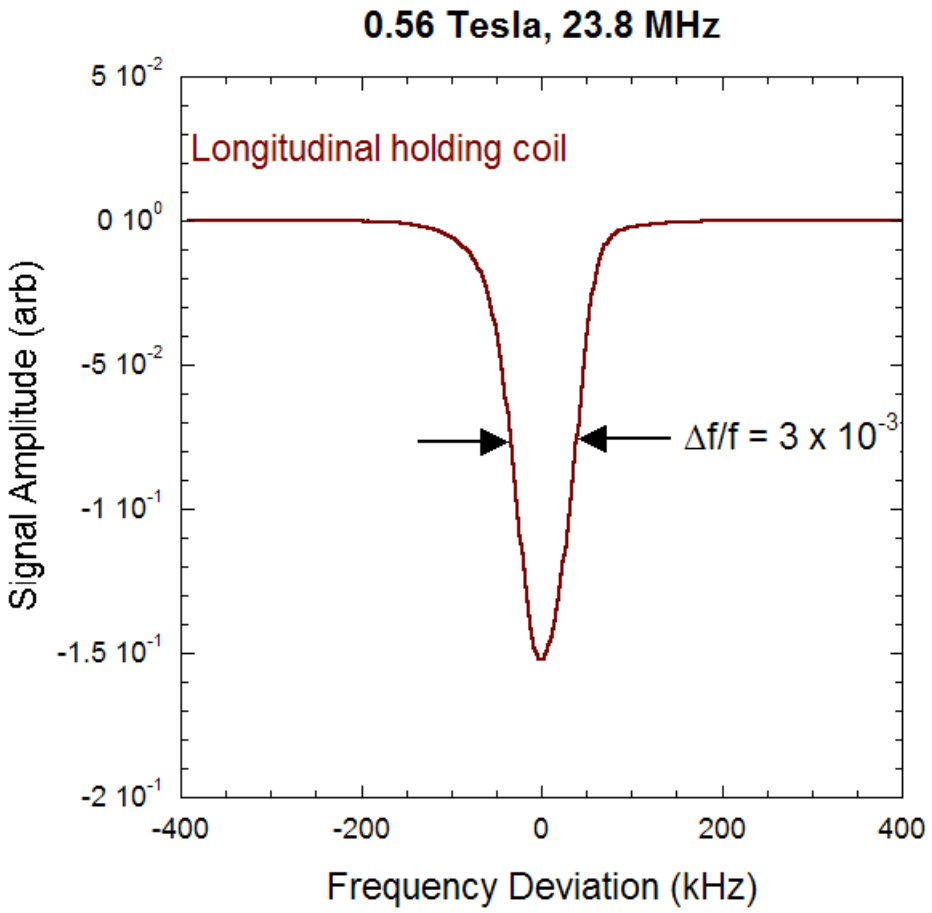
Target material is inserted into mixing chamber.

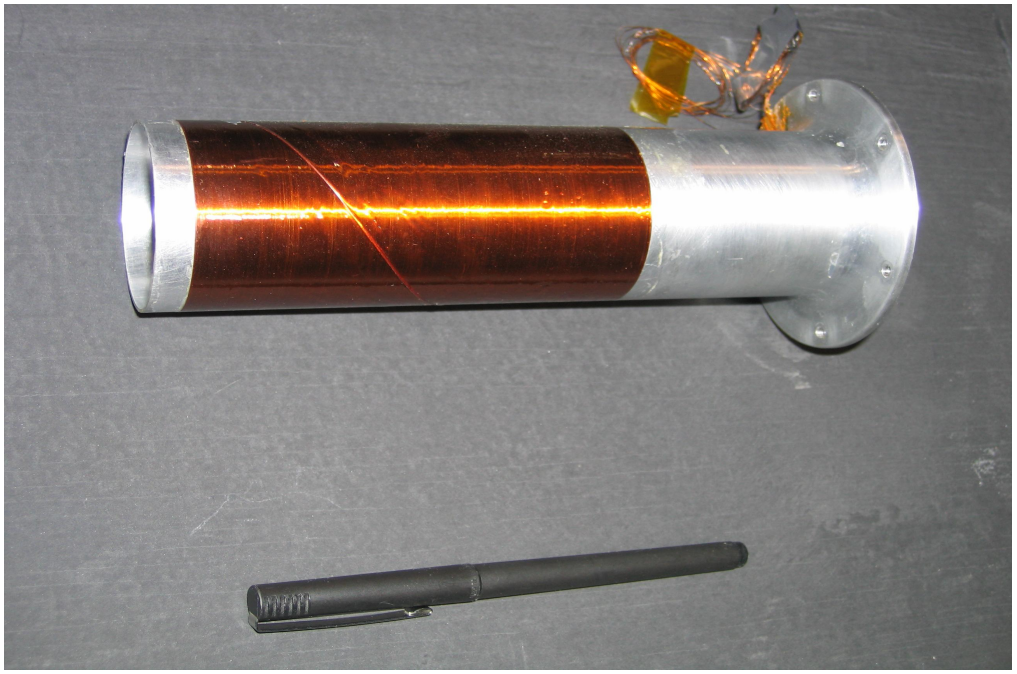
NMR coils (2) and microwave waveguide are fixed outside the mixing chamber.



Holding coil, longitudinal or transverse, attaches to 1 K heat shield.

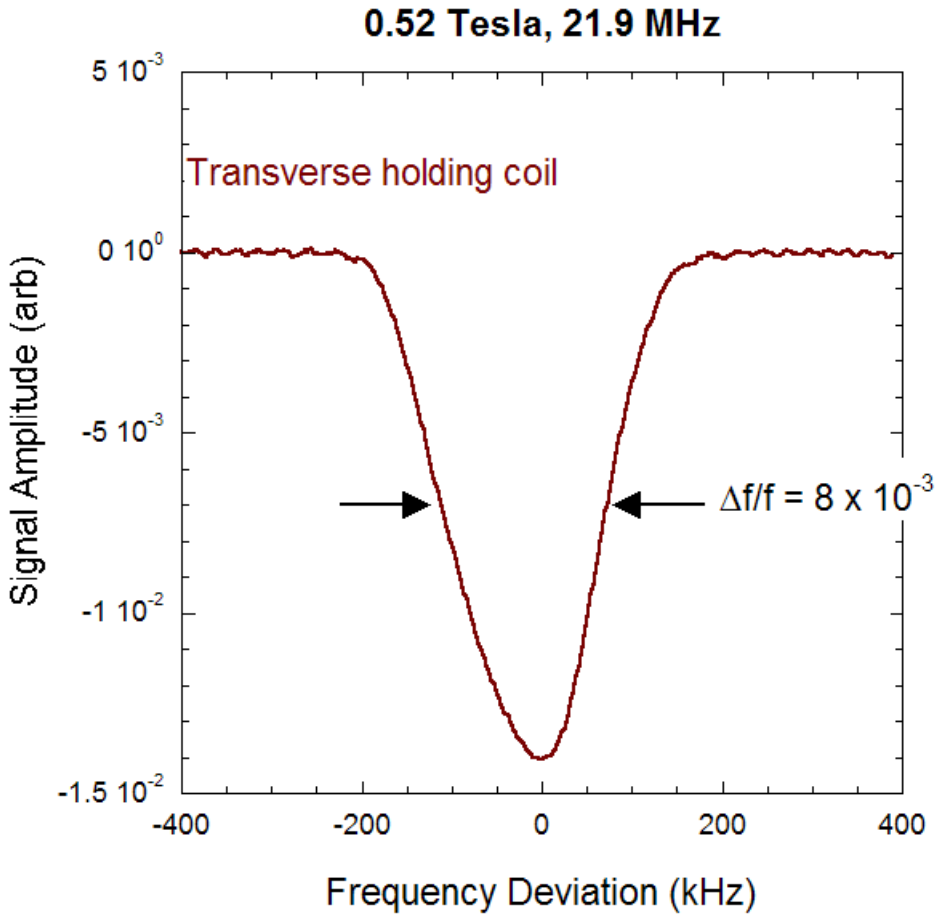
Also serves as a microwave cavity.





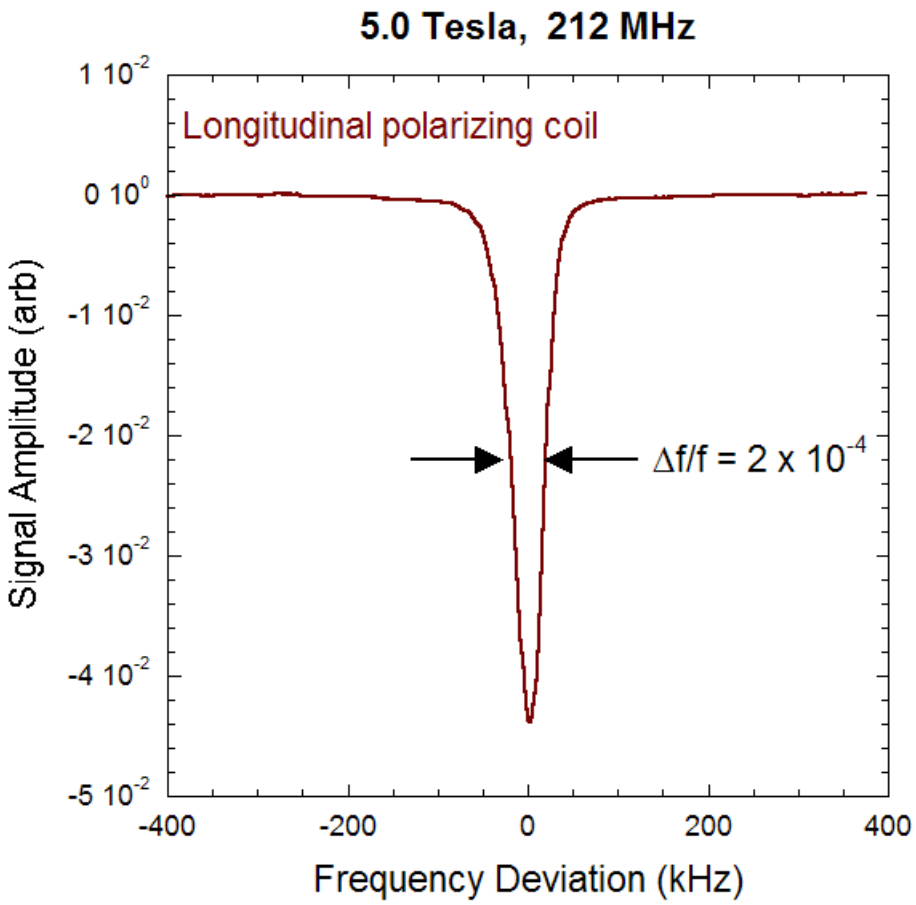
Field: 0.56 Tesla @ 22.3 A
$\Delta B/B$: < $3\ 10^{-3}$
Bore: Ø 50 mm
Thickness: 0.1 mm NbTi wire
(3 layers)

Longitudinal Holding Coil
and NMR Spectra

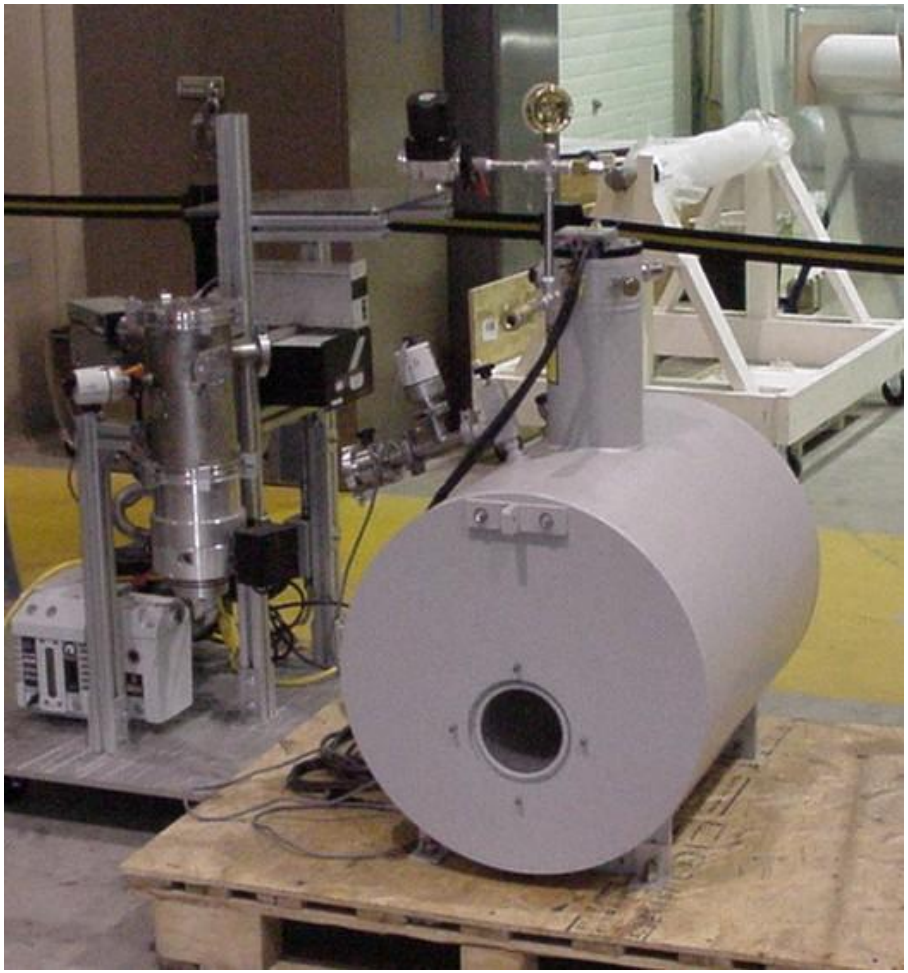


Transverse Holding Coil
and NMR Spectra

Field: 0.54 Tesla @ 38.5 A
$\Delta B/B$: < $8\ 10^{-3}$
Bore: Ø 50 mm
Thickness: 0.1 mm NbTi wire
(4 layers)



5 Tesla Polarizing Magnet
and NMR spectra

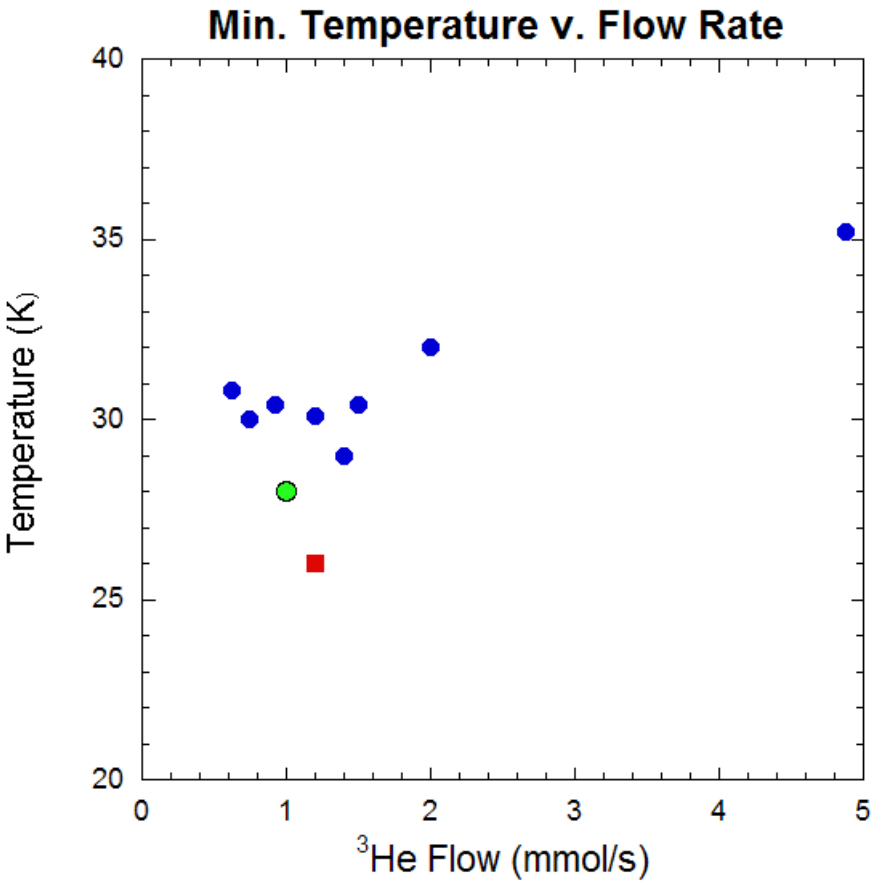


Max. Field: 5.1 T @ 82.5 A
ΔB/B: < 3×10^{-5}
Bore: Ø127 mm

Cryomagnetics, Inc.
Oak Ridge, TN

Frozen Spin Target: Base Temperature

- 26 mK (EEL Bldg)
- 28/30 mK (Hall B, no beam)
- 32 mK (Hall B, ~10^7 $\gamma\,s^{-1}$)



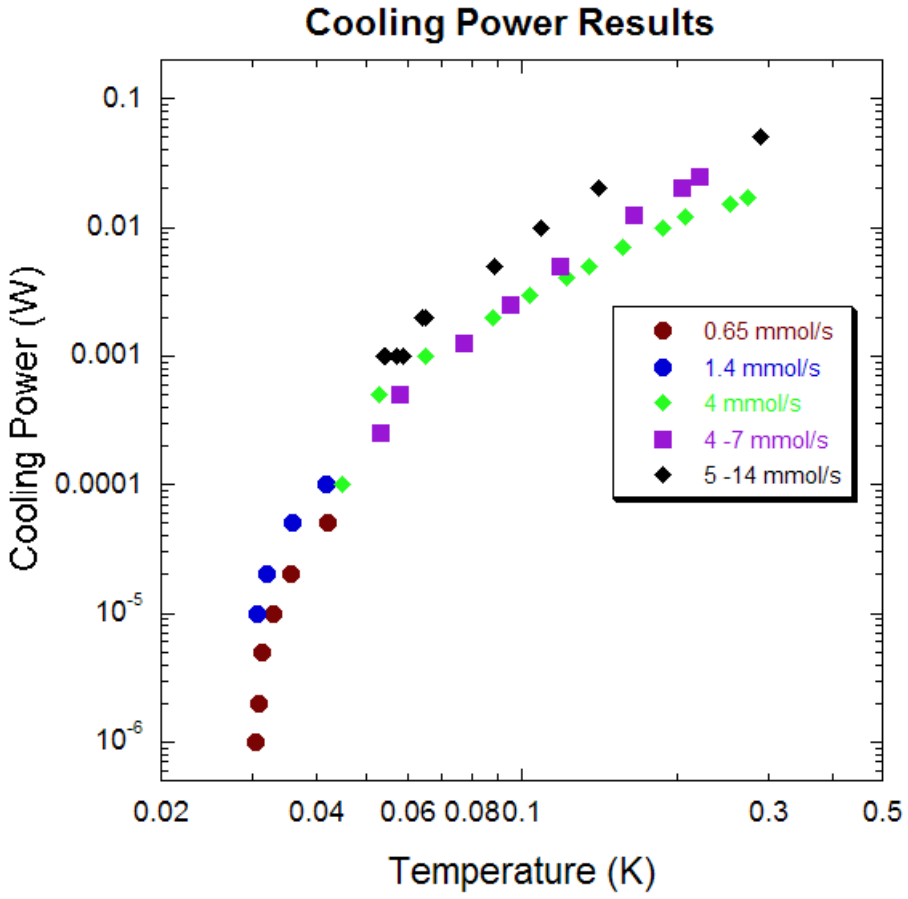
Frozen Spin Target: Cooling Power

300 mK: 60 mW

100 mK: 10 mW

50 mK: 800 μW

Refrigerator ran continuously
Oct. 29 '07 thru Feb. 12 '08
(~1100 hours of beam time)

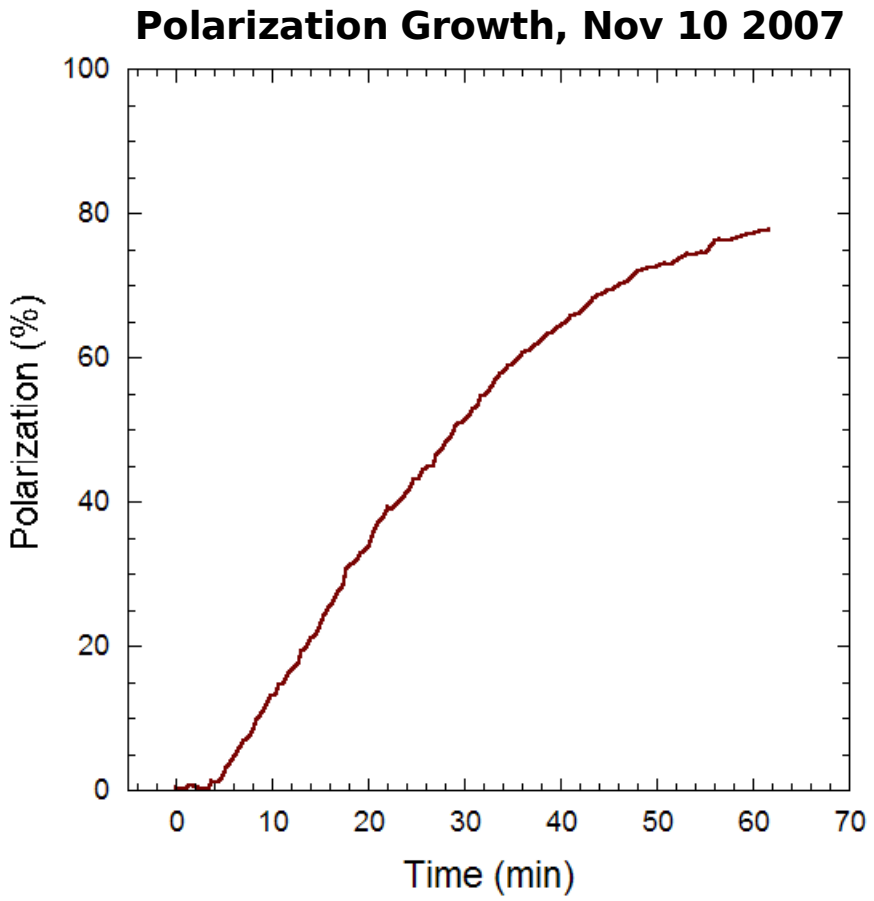


Frozen Spin Target: Polarization

Positive Polarization
7 times (1 unscheduled)
~ 80%

Negative Polarization
10 times (3 unscheduled)
~ -85%

All unscheduled polarizations due to failure of holding coil power supply.



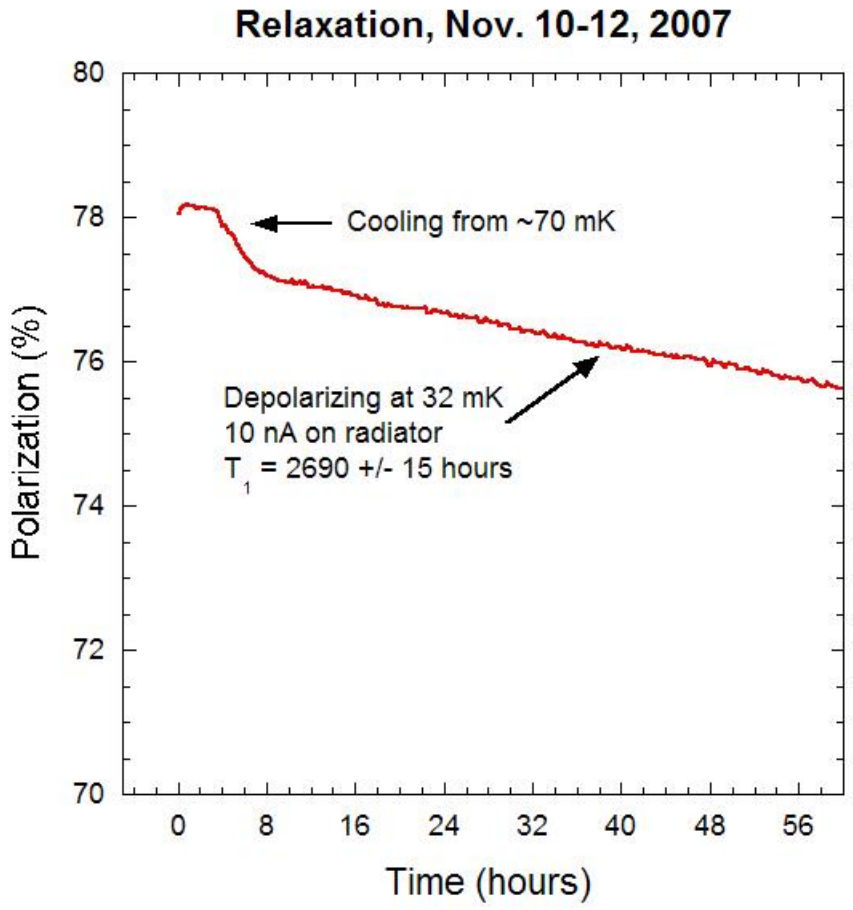
Frozen Spin Target: Relaxation Time

Positive Polarization
~ 3500 hours, w/o beam
~ 2700, w/ beam

Negative Polarization
~ 1800 hours, w/o beam
~ 1400, w/ beam

Polarization loss ~1 - 1.5% per day.

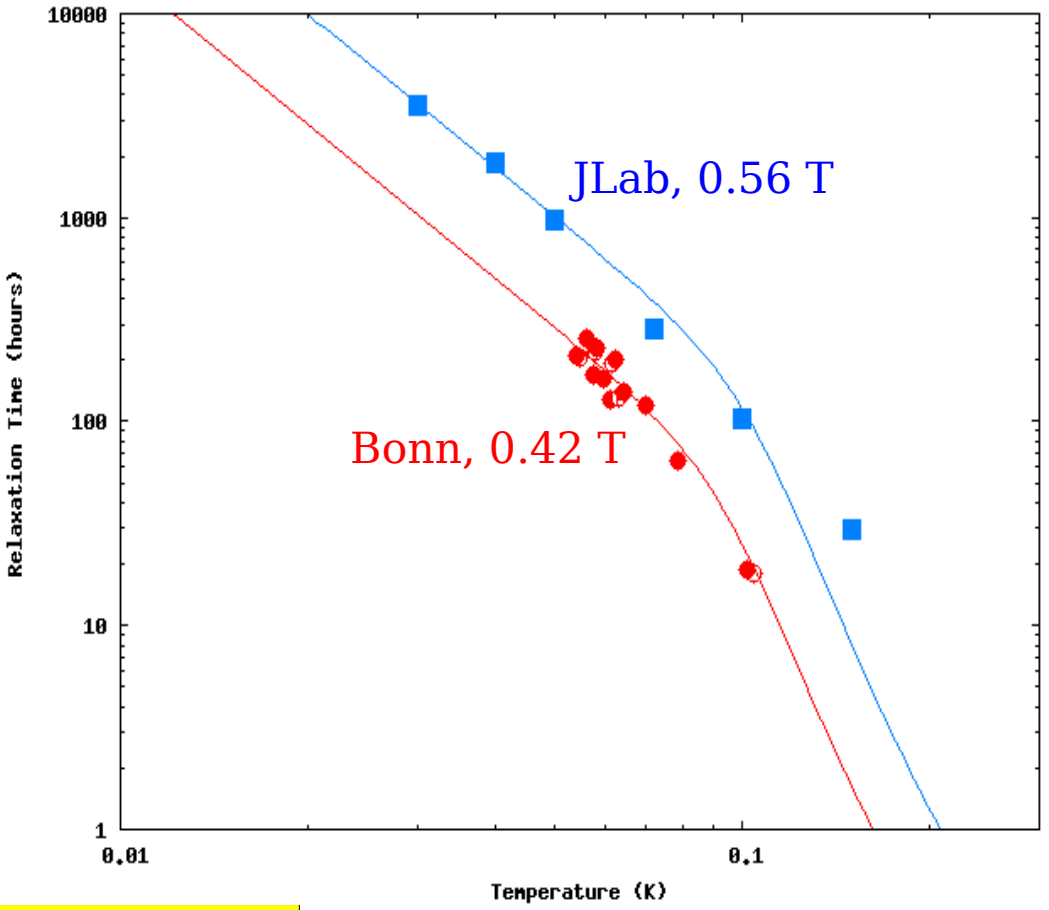
Re-polarize every 5 – 7 days.



Frozen Spin Target: Relaxation Time of Butanol

JLab
0.56 Tesla
28 – 150 mK

Bonn
0.42 Tesla
56 – 100 mK



"Semi-empirical" T_1 equation

W. de Boer, CERN Report 74-11 (1974)

$$T_{1p}^{-1} = [A T_{1e} H^2 \cosh^2(\frac{h\nu_e}{2kT})]^{-1} + [a \frac{H^b}{T^c}]^{-1}$$

$$A T_{1e} = 225[H^5 \coth(\frac{h\nu_e}{2kT}) + 6.75 \times 10^5 e^{-0.5/T}]^{-1}$$

Fit with 3 adj. parameters
a = 3.1×10^{-4}
b = 4.3
c = 2.5

Frozen Spin Target: Summary

- A Frozen Spin Target of polarized protons has been built for tagged photon experiments inside CLAS.

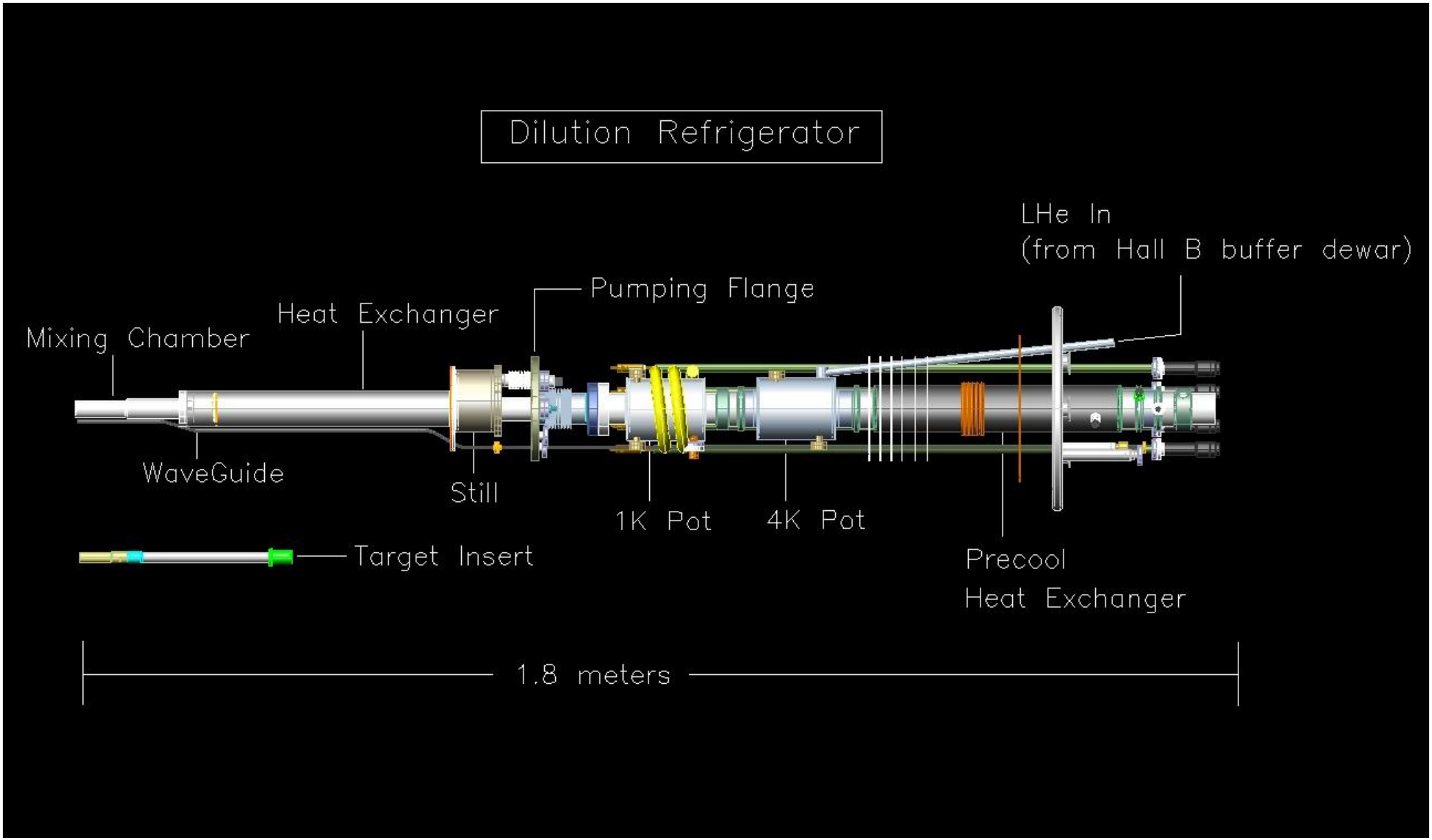
- In its first use (2007), FROST met or exceeded all design goals.

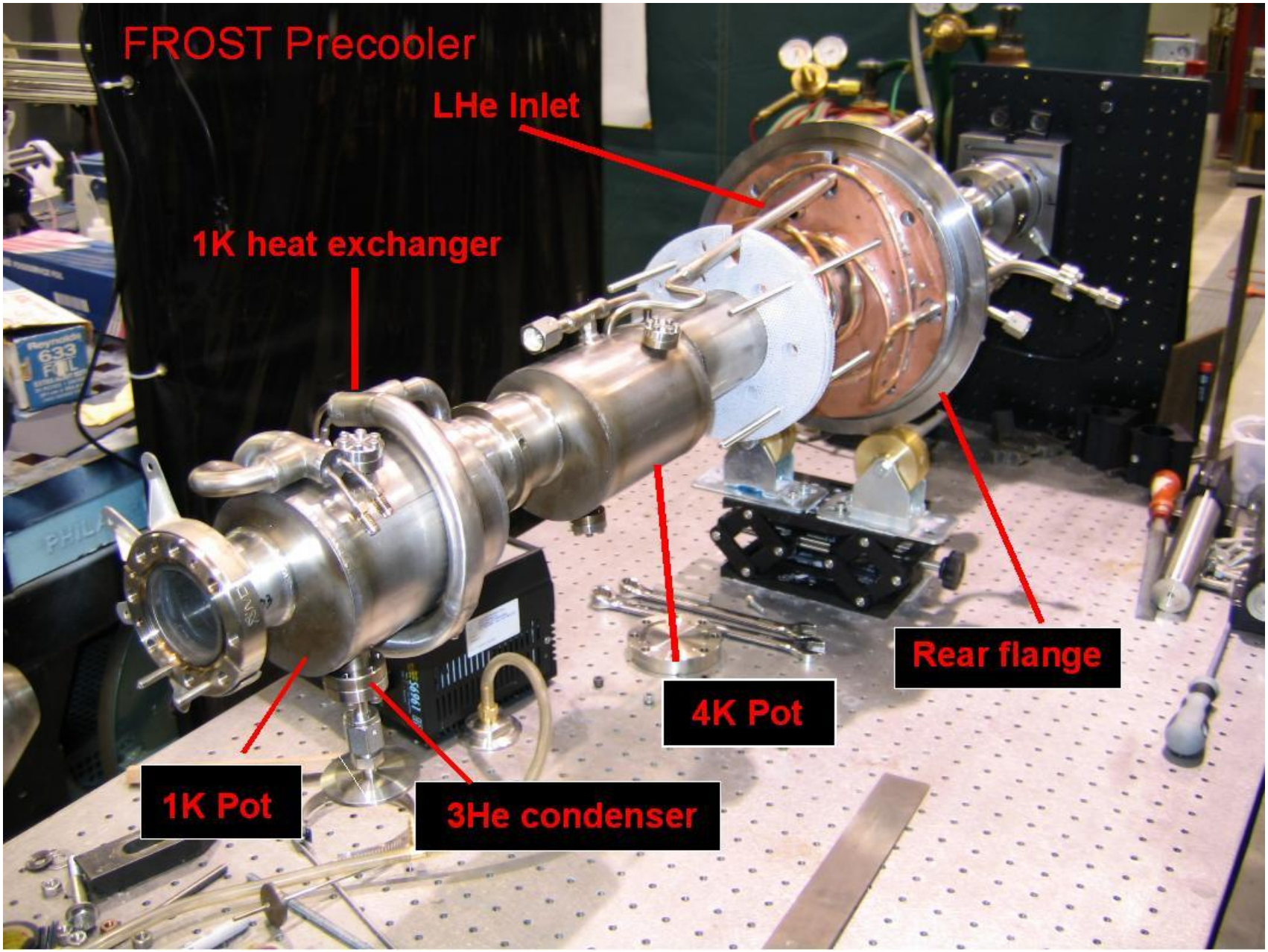
- FROST utilizes an internal, superconducting holding coil (H > 0.5 T) while in Frozen Spin mode.

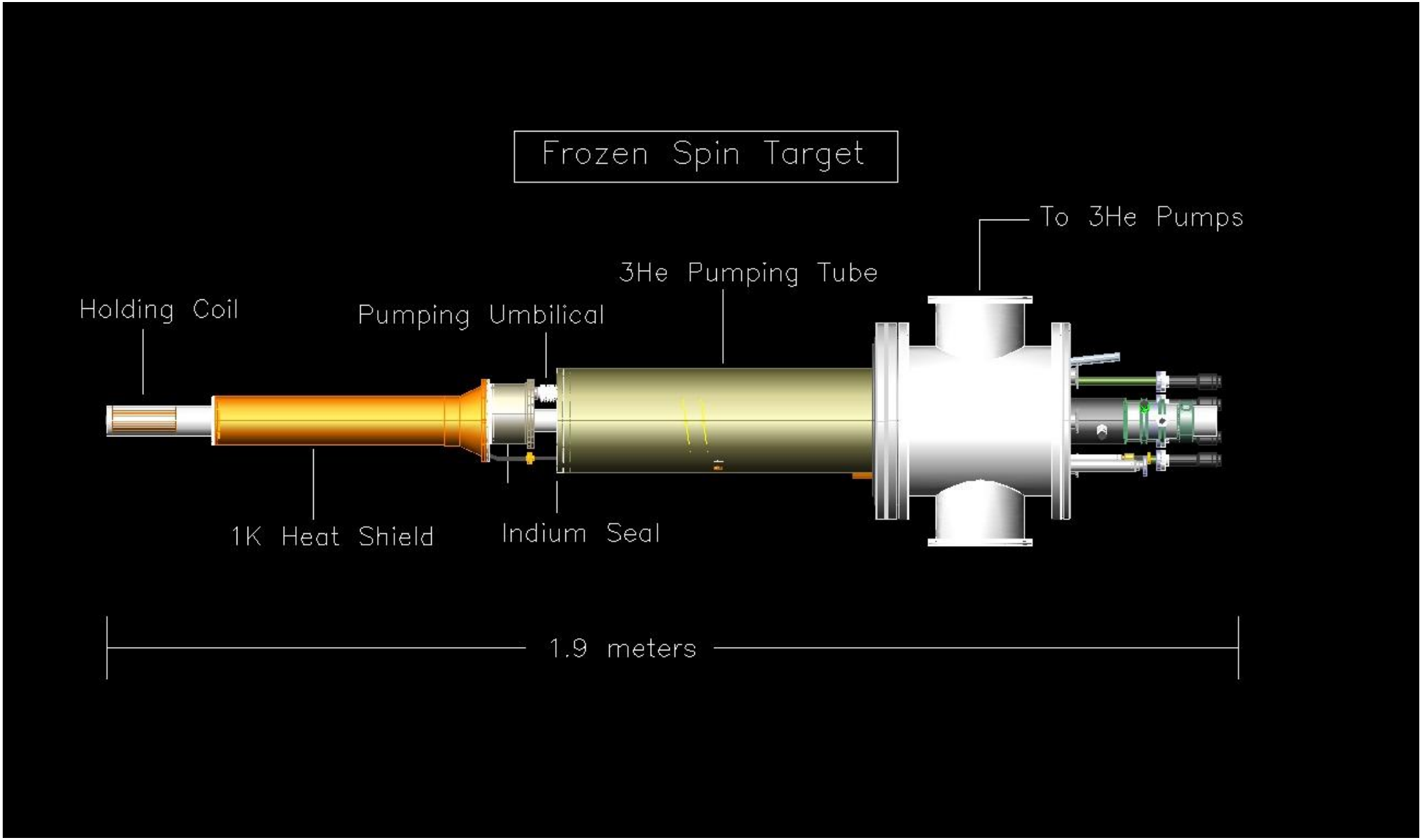
- Coils have been fabricated to provide either longitudinal or transverse holding fields.

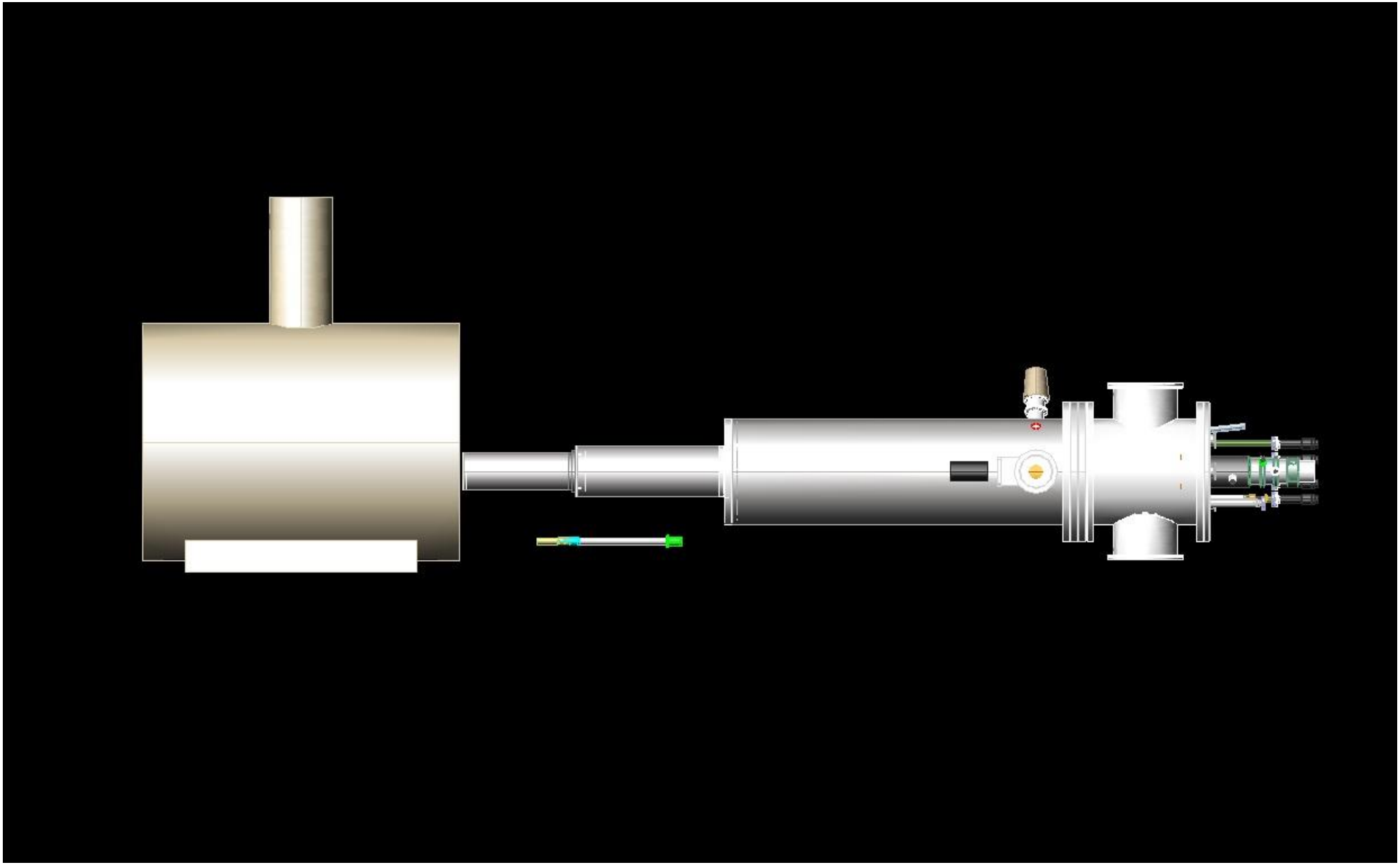
- With a base temperature < 30 mK, extraordinarily long (> 3000 hours) relaxation times were measured for the butanol target.

Additional Slides


Dilution Refrigerator
LHe In
(from Hall B buffer dewar)
Pumping Flange
Heat Exchanger
Mixing Chamber
WaveGuide
Still
1K Pot
4K Pot
Target Insert
Precool
Heat Exchanger
1.8 meters


FROST Precooler
LHe Inlet
1K heat exchanger
Rear flange
4K Pot
1K Pot
3He condenser


Frozen Spin Target
To 3He Pumps
3He Pumping Tube
Holding Coil
Pumping Umbilical
1K Heat Shield
Indium Seal
1.9 meters



Frozen Spin Target: Collaboration

JLab Target Group (*past member, +unofficial member)

Dr. Chris Keith (project leader, DR design, day-to-day operation)
Dr. Mike Seely (holding magnets)
Dr. David Meekins (target material preparation)
James Brock, Mark Hoegerl (fabrication & assembly)
David Griffiths (electrical)
Chris Carlin, +Sue Witherspoon (software)
Paul Hood, *Rusty Salmons, *Steve Knight (vacuum & plumbing)
+Amy Comer (heat exchanger R&D)
+Jim Rohrbach (machinist extraordinaire)

Hall B

Dr. Volker Burkert (signed the checks)
David Kashy & Pete Hemler (target cart design)
Mike Zarecky (draftsman)
Doug, Tom, Jill, Dennie, Calvin & rest of technical staff

Dr. Eugene Pasyuk (Arizona State U.) - liaison w/ g9 collaboration