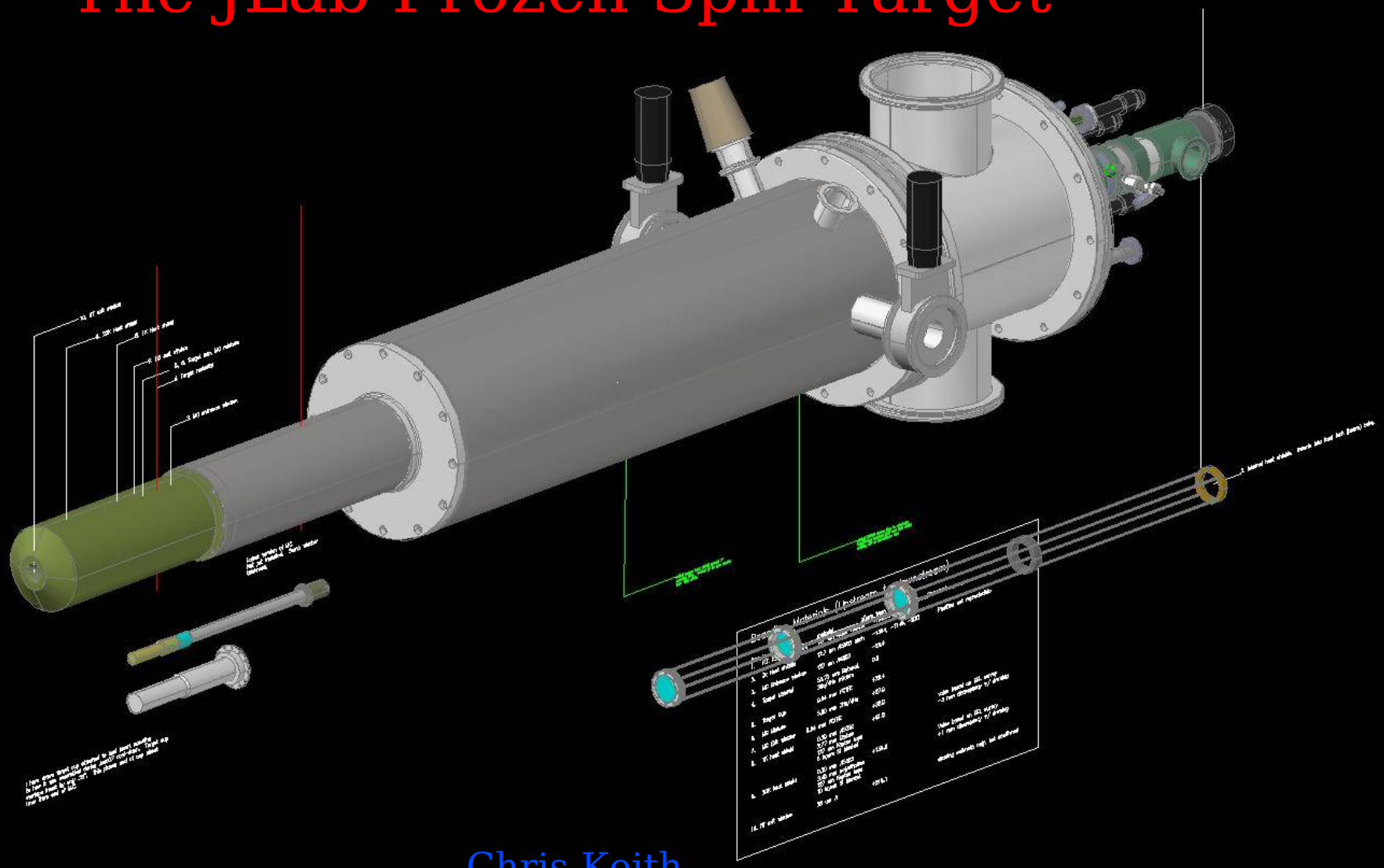
—— FroST ——

The JLab Frozen Spin Target



Chris Keith
JLab Target Group

The Frozen Spin in a Nutshell

FROST is a polarized proton target (15mm X 50mm) specifically designed for tagged photon experiments inside CLAS.

It is similar to the standard Hall B Polarized Target, but with two additional levels of complexity:

1) two superconducting magnets instead of one;
2) additional refrigeration for millikelvin temperatures.

FROST provides a much larger “aperture” for scattered particles, about 75% of 4π compared to 25% for the old target.

Limited to low intensity beams only!

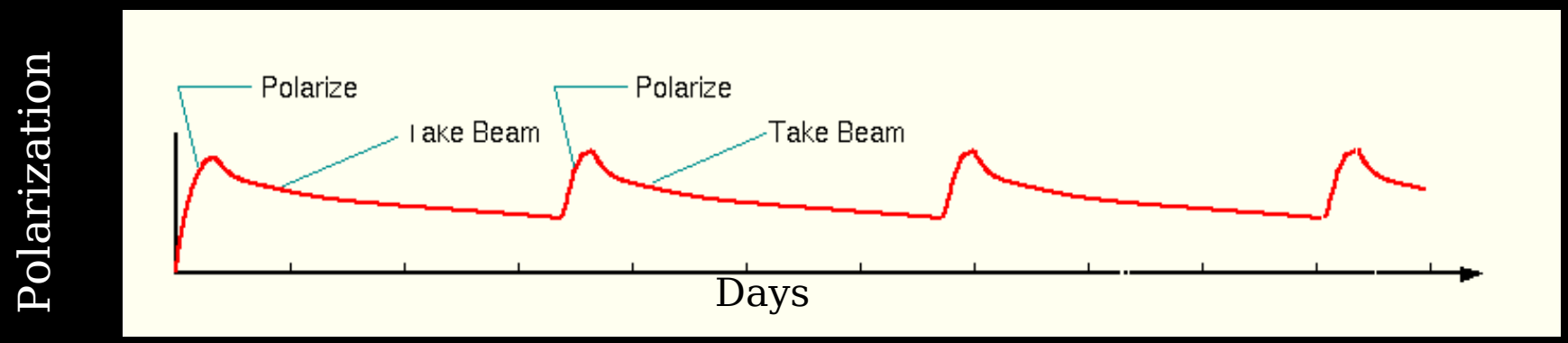
2 Steps to Freezing the Spin

1. Polarize target material (C_4H_9OH) at moderate temperature (~0.3K) inside high field (5.0 T), high homogeneity magnet using microwave-induced spin flips (*Dynamic Nuclear Polarization*)

2. Reduce target temperature to ~50 mK, and hold polarization with smaller, internal "holding" magnet (0.5 T) during data acquisition.

The target polarization then decays exponentially during the data acquisition phase of the experiment.

The target must be re-polarized (step 1) every few days.



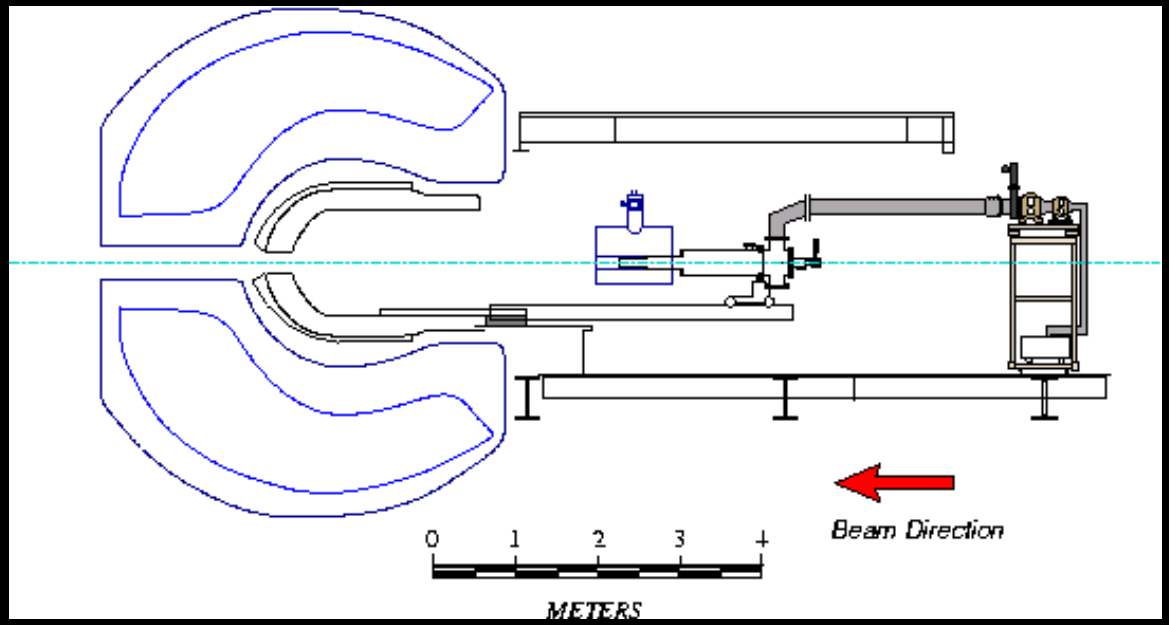
The Frozen Spin Waltz

Polarizing Mode

-Target is fully retracted, 5 T magnet moved to polarizing postion (5 min)

- Target is inserted into magnet, magnet energized (40 min)

- Microwaves ON, target polarizes, refrigerator warms to 250 – 300 mK. (2 hours)

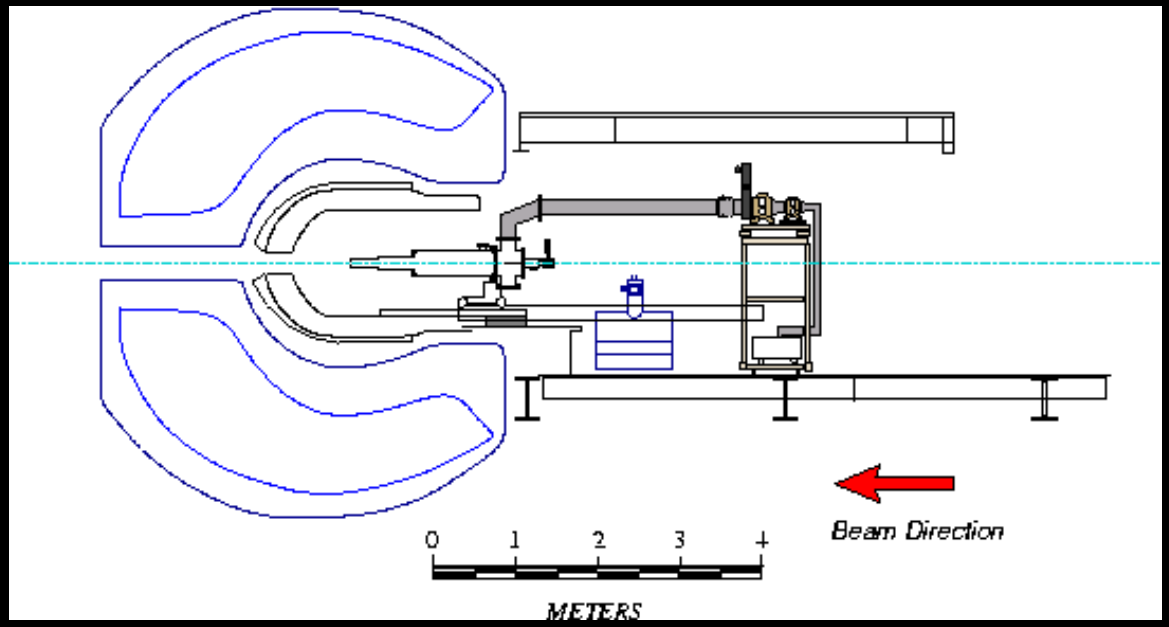


Frozen Spin Mode

- Microwaves OFF, target cools to 60 mK (30 - 40 min)

- 5T magnet off,
0.5T holding coil on (40 min)

- Target fully retracted, magnet moved away, target moved into CLAS (5 min)



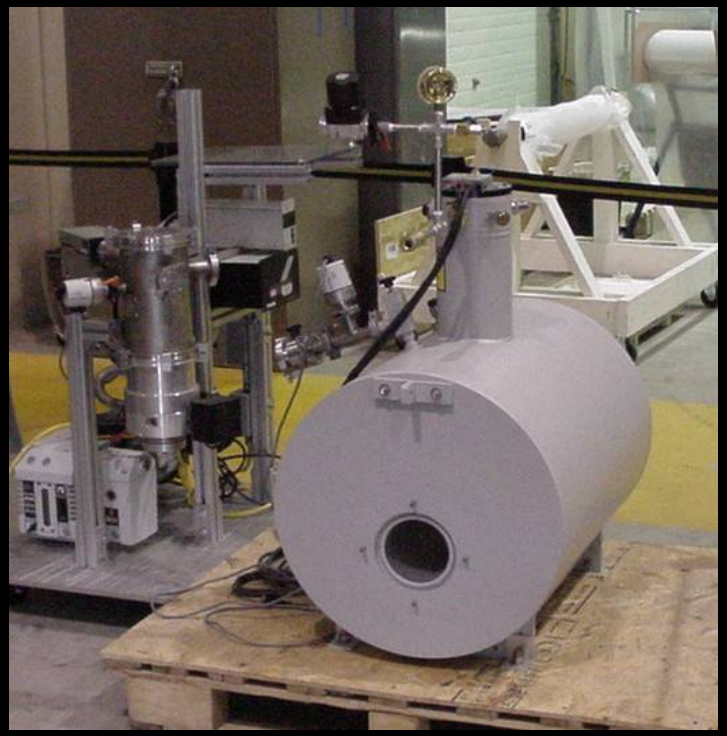
Equipment for the Hall B Frozen Spin Target

1 dilution refrigerator
80 liters 3He
300 liters 4He
2 superconducting magnets + power supplies
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 liquid level meters
3 chillers
1 microwave generator + waveguide components

And everything has to move!

Polarizing Magnet

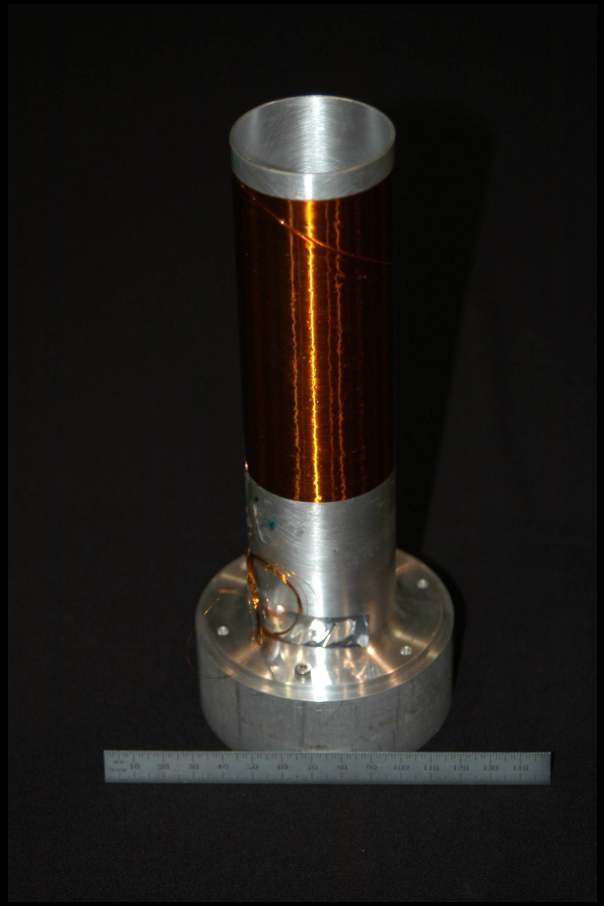
Max. Field: 5.1 T
$\Delta B/B$: $< 3\times10^{-5}$
Bore: Ø127 mm



Cryomagnetics, Inc
Oak Ridge, TN

Holding Magnet

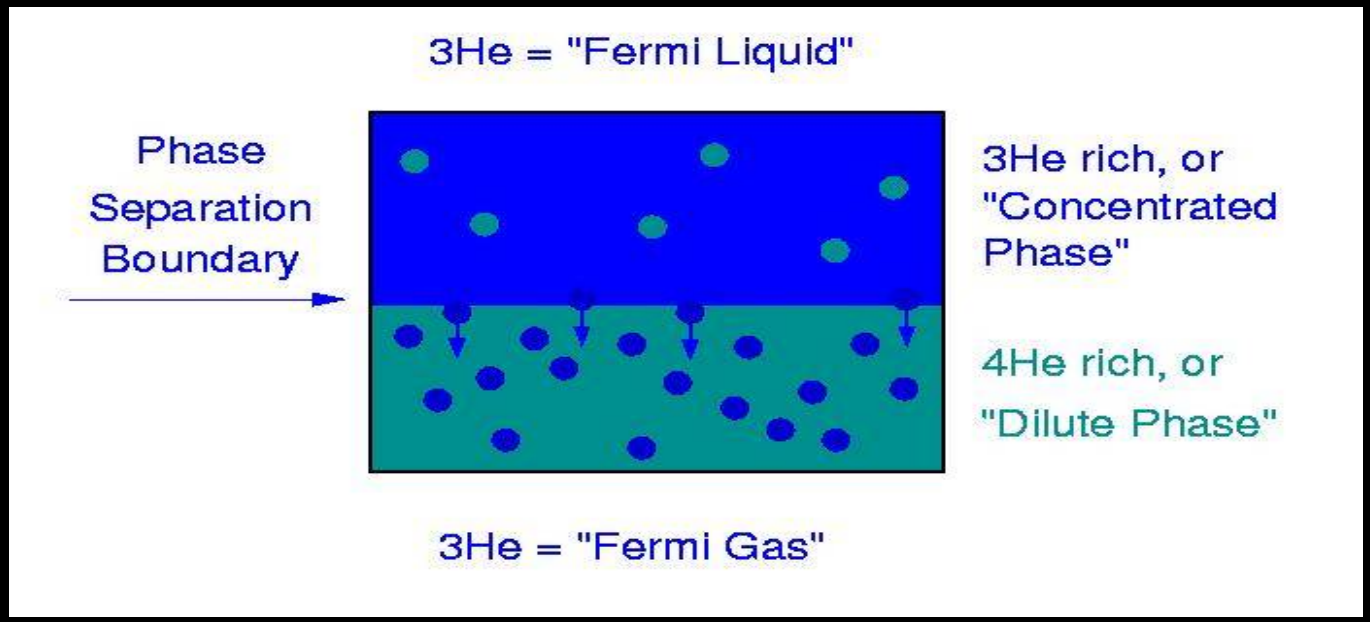
Max. Field: 0.56 Tesla
$\Delta B/B$: $< 3\ 10^{-3}$
Bore: Ø 50 mm
Wire: Ø.1 mm multifil NbTi, 3 layers



Mike Seely
JLab Target Group

$^3He/^4He$ Dilution Refrigeration

- below 0.8 K, a $^3He/^4He$ mixture will separate into two phases



The "Mixing Chamber"

^3He atoms are removed (distilled) from the dilute phase. ^3He from concentrated phase absorb heat from the surroundings and dissolve into the dilute phase in order to re-establish equilibrium.

^3He concentration in lower phase is *always* nonzero. Cooling power decreases as T^2

Practical Dilution Refrigeration

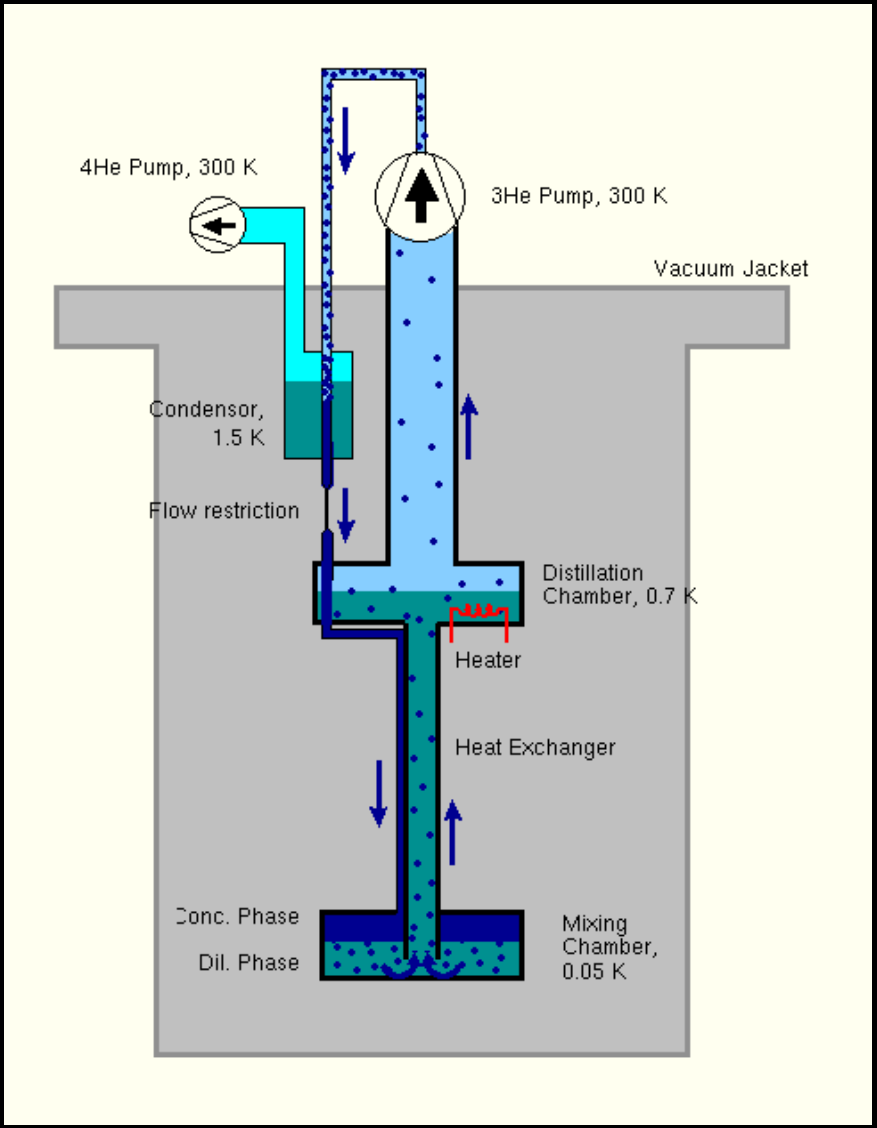
- ^{3}He is "distilled" from the lower, dilute phase of the mixing chamber

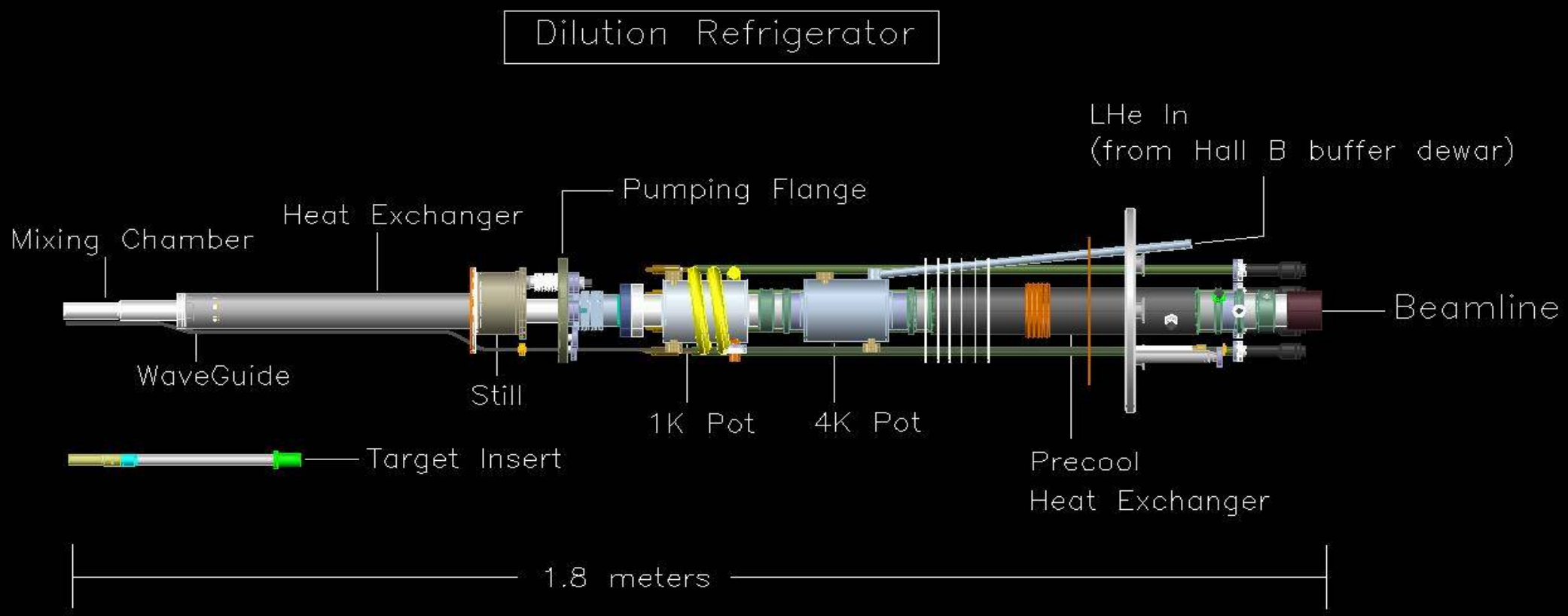
- after distillation, the ^{3}He is recondensed in a LHe bath at ~1.5K and returned to mixer at elevated temperature T_c

- the cooling power and min. temperature depend strongly on heat exchange between the conc. (warm) and dil. (cold) fluid streams

$$\dot{Q}(T_m) = \dot{n}\left[H_d(T_m^2) - H_c(T_c^2)\right]$$
$$= \dot{n}\left[94.5\,T_m^2 - 12.5\,T_c^2\right]$$

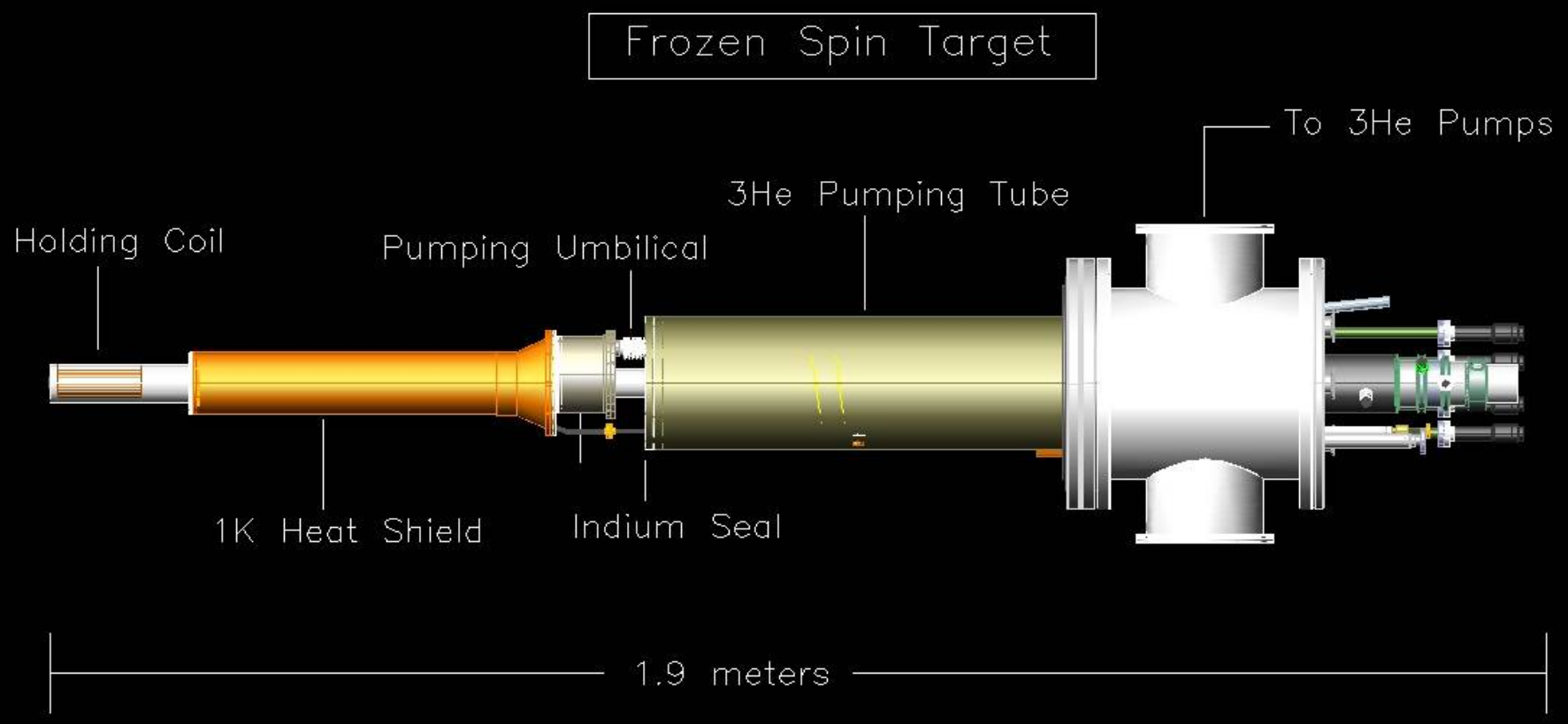
Performance of HX determines T_c



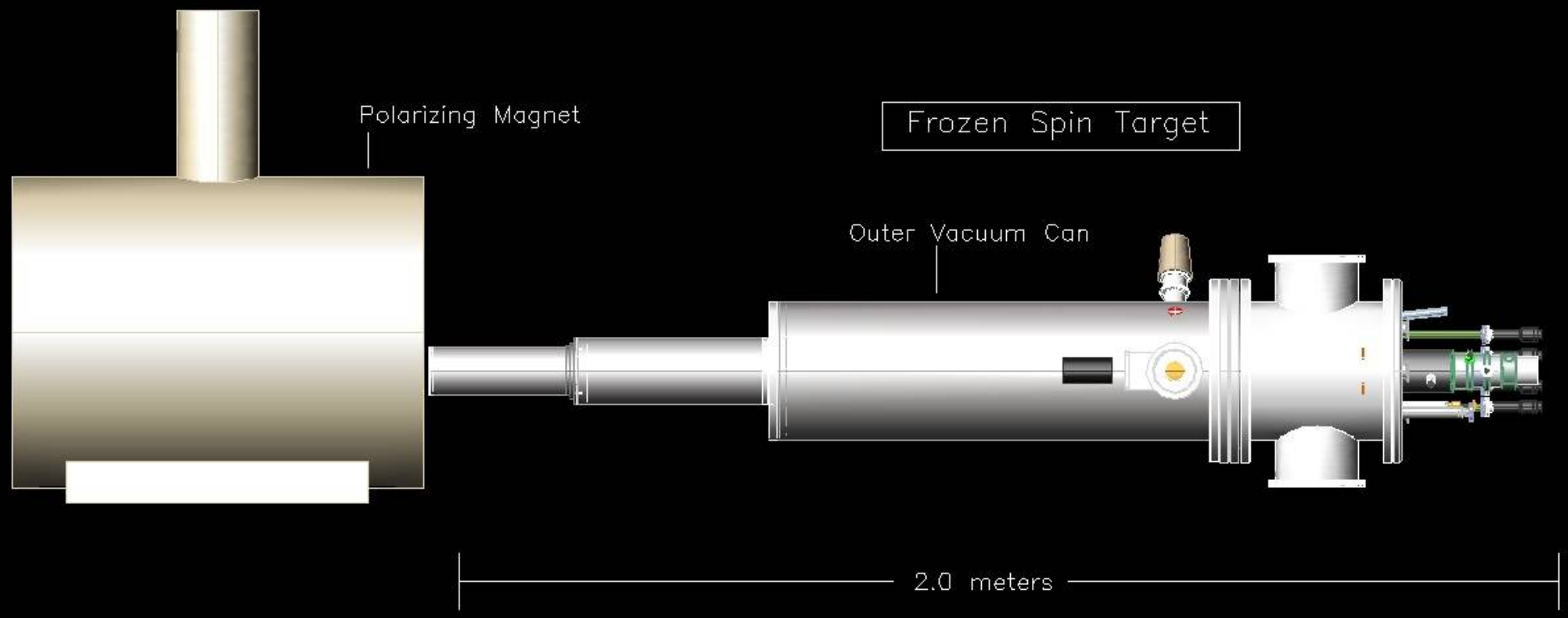


Waveguide for polarizing the target is located beneath the mixing chamber.

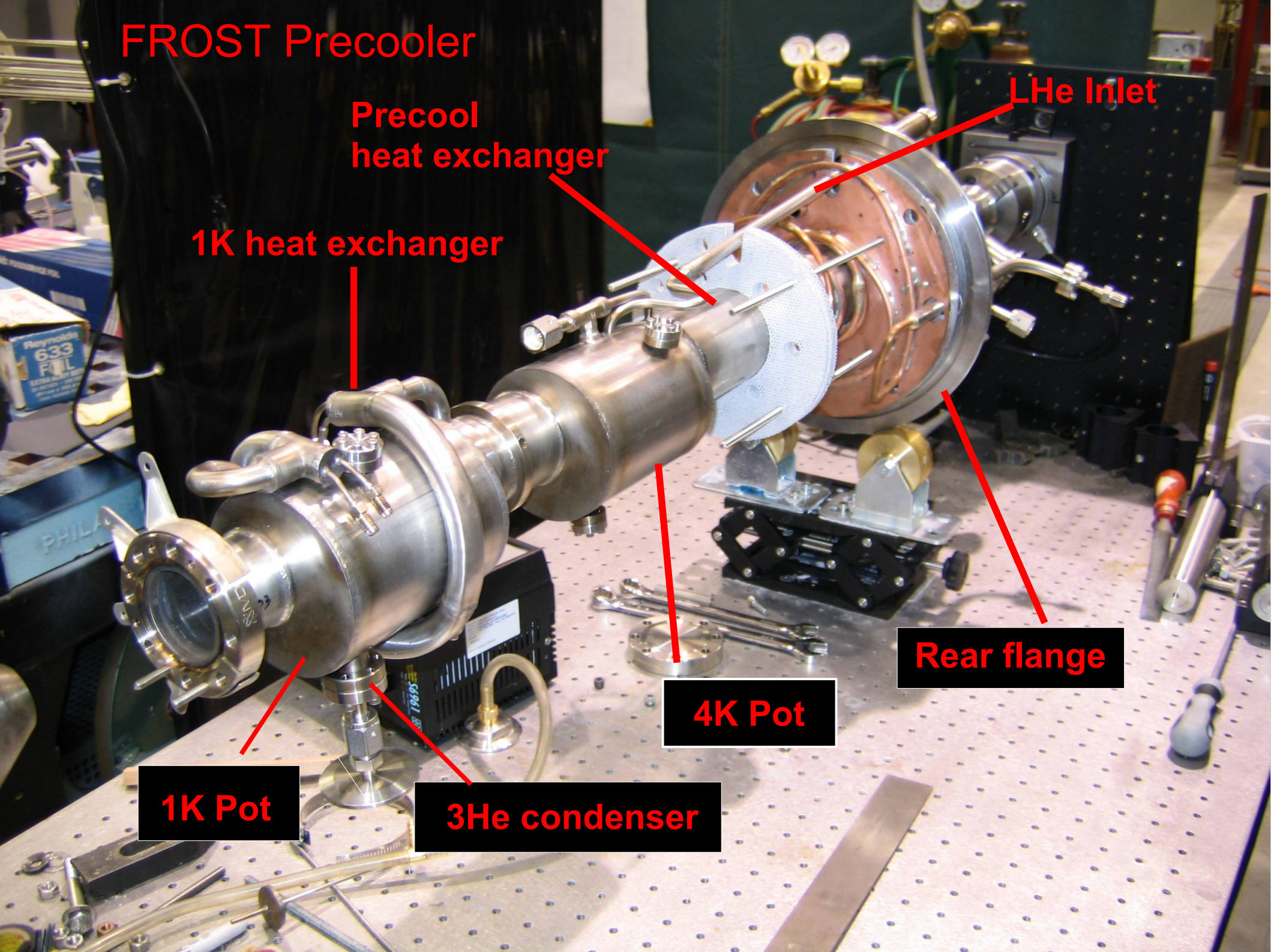
Two NMR coils, tuned for 24 and 212 MHz, are wrapped around the mixing chamber and used to measure polarization.



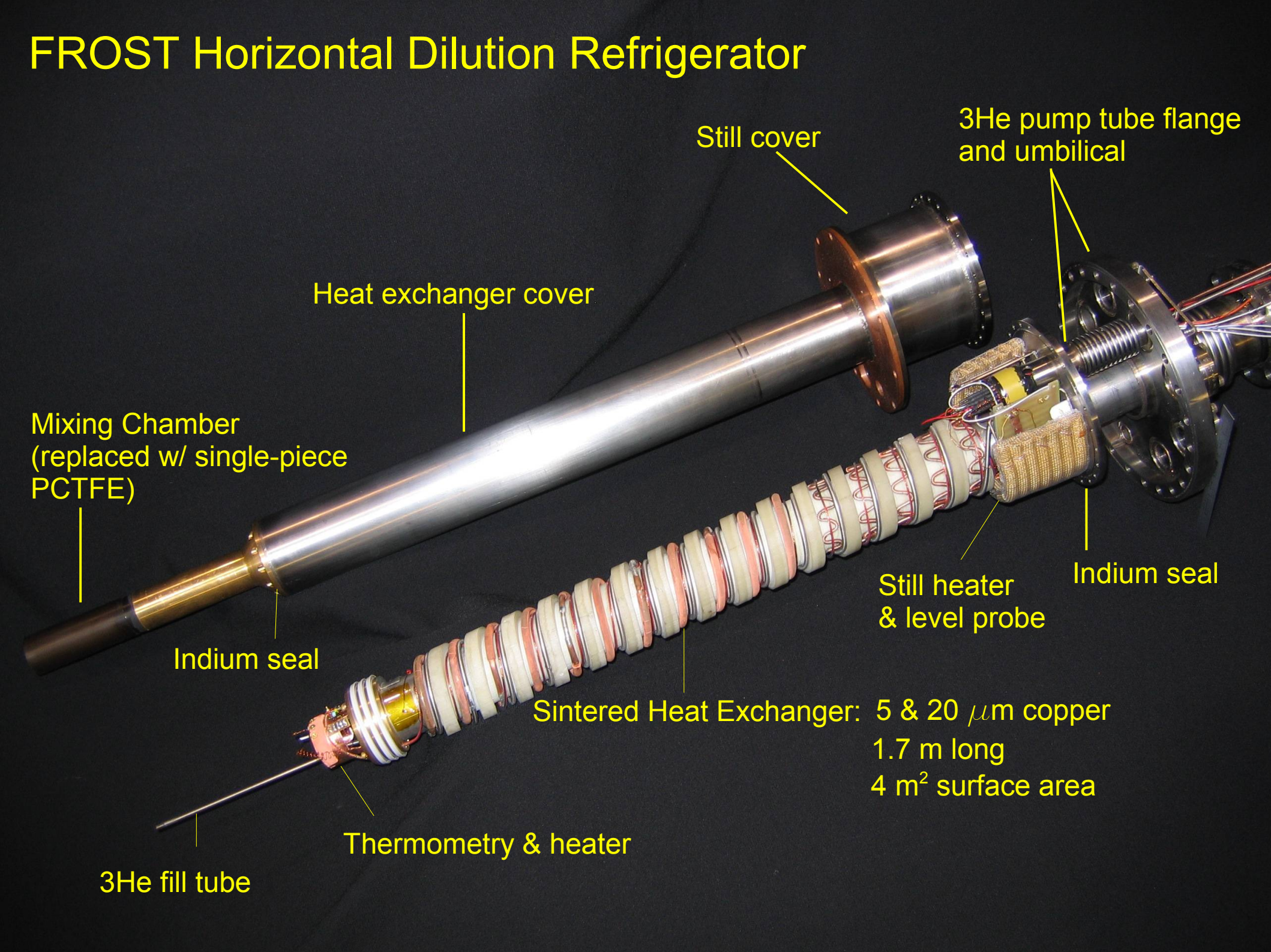
Refrigerator is inserted into pumping tube.
0.56 tesla holding coil attaches to 1K shield (cooled by still).



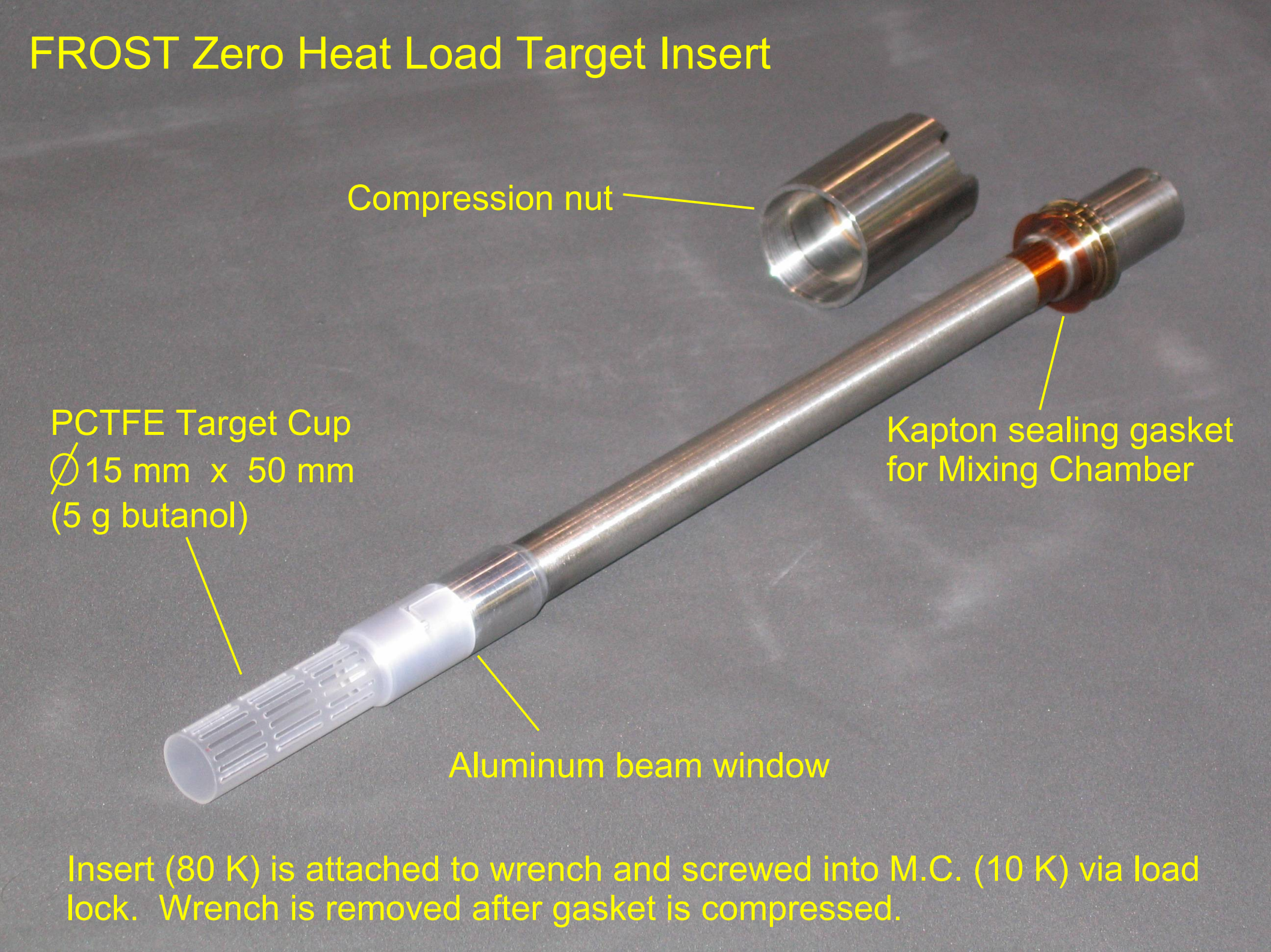
Frozen Spin Target with 5T polarizing magnet


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

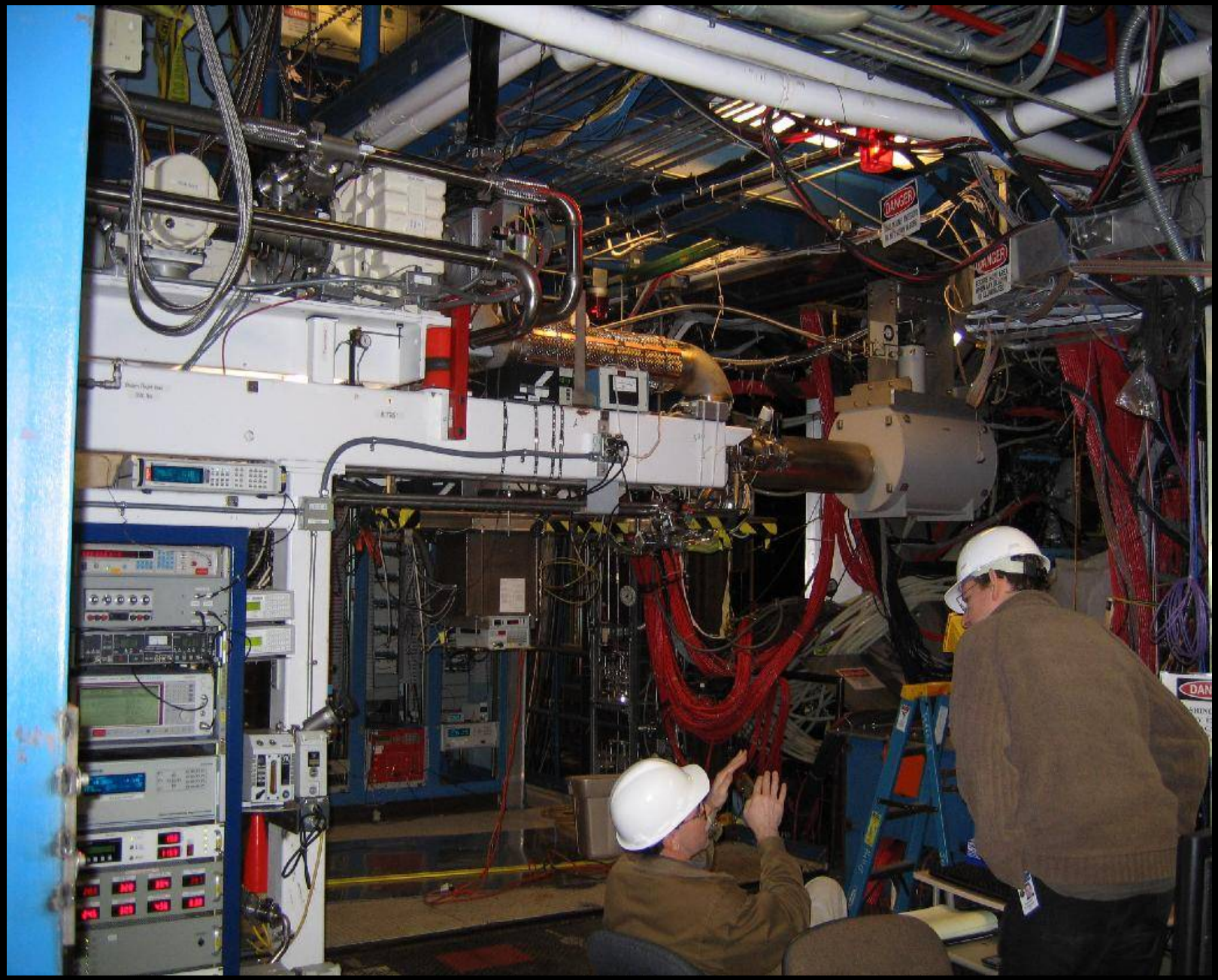
FROST Horizontal Dilution Refrigerator



FROST Zero Heat Load Target Insert



Insert (80 K) is attached to wrench and screwed into M.C. (10 K) via load lock. Wrench is removed after gasket is compressed.


DANGER
DANGER

Frozen Spin Target Results

	Design Goal	Result
Base temperature:	< 50 mK	28 mK (w/o beam) 30 mK (w/ beam)
Cooling Power:	10 μW (Frozen) 20 mW (Polarizing)	100 μW @ 50 mK 100 mW @ 300 mK
Polarization:	80%	+ 82% - 85%
1/e Relaxation Time:	500 hours	2800 hours (+ Pol.) 1600 hours (- Pol.)