Targets for a Neutral Kaon Beam

Chris Keith
JLab Target Group

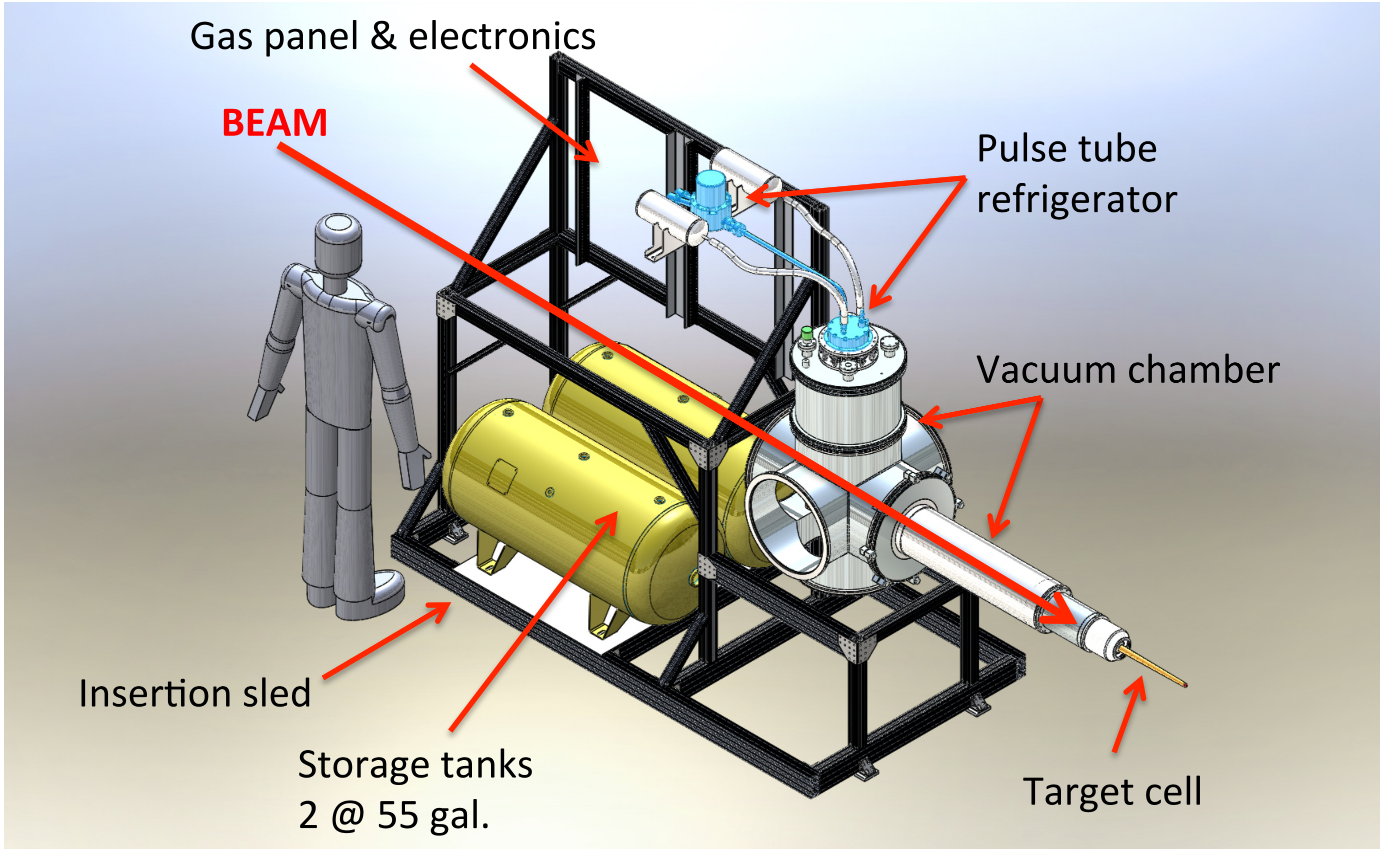
Jefferson Lab

Targets for a neutral kaon beam

- Restrict today's discussion to a potential kaon facility in Hall D only.
- Focus on possible cryotargets and dynamically polarized targets that could be built and operated with minimal R&D.

The existing Hall D cryotarget

- The GluEx experiment in Hall D is using a small LH2 cryotarget designed and constructed by the Target Group & Hall D.



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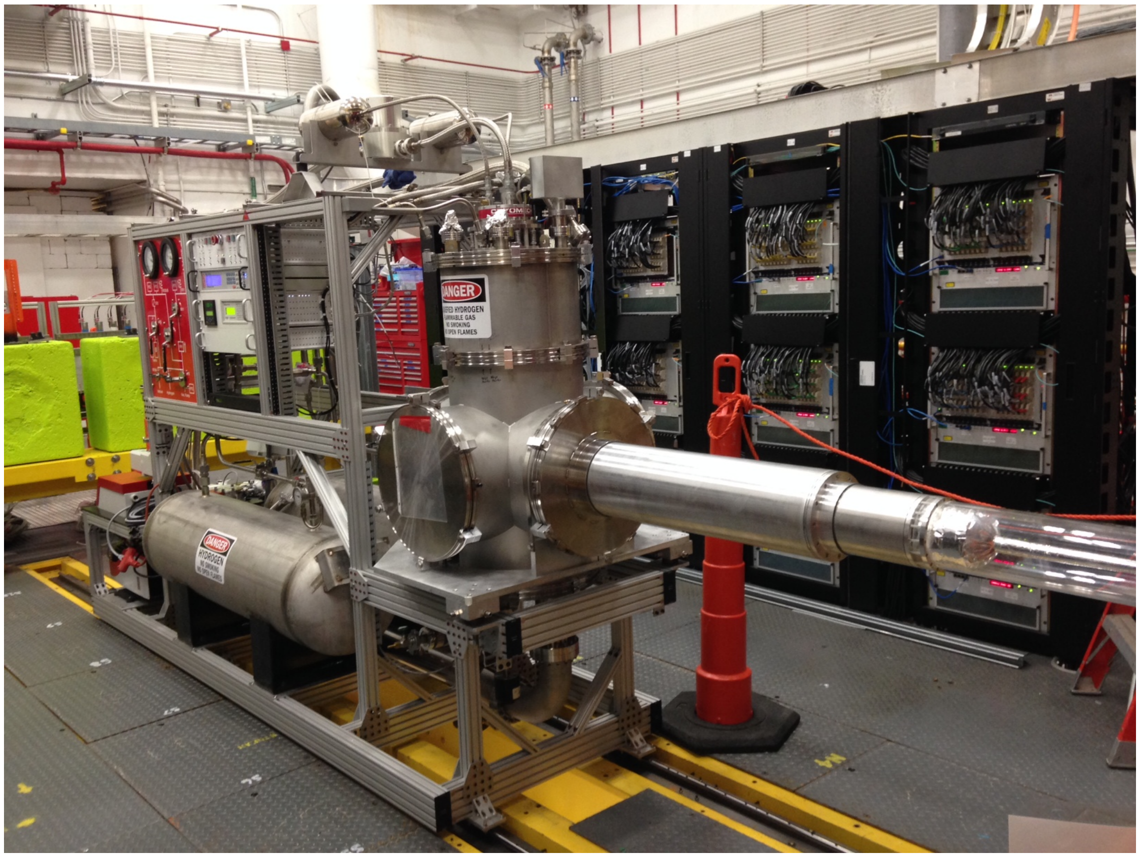
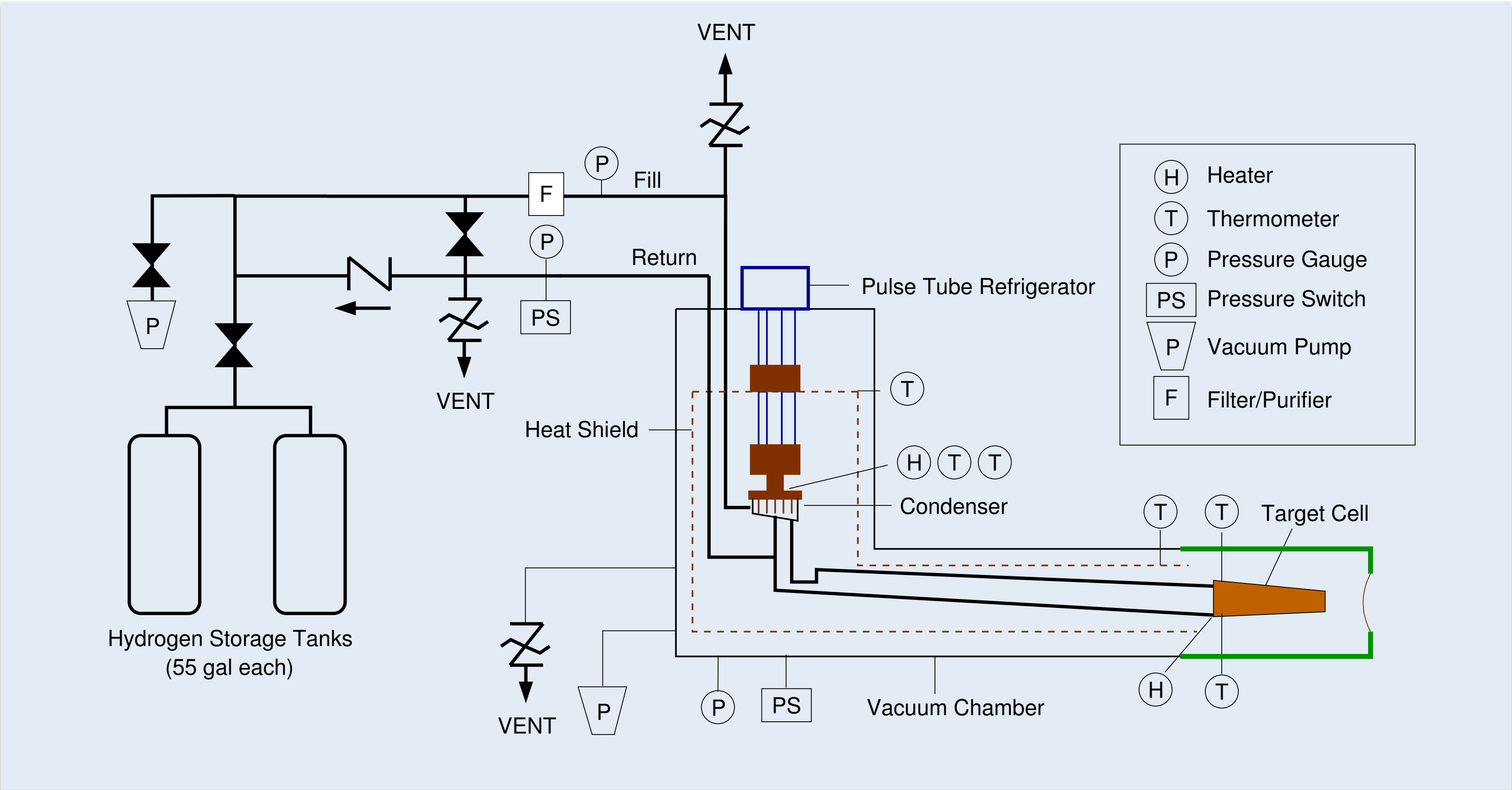


The existing Hall D cryotarget

- Hydrogen gas is condensed in a small vessel that is cooled to 20 K by a mechanical cryocooler (pulse tube refrigerator).
- LH2 drains from the condenser into the target cell, through a pair of 2 m long pipes (the fill and return lines).



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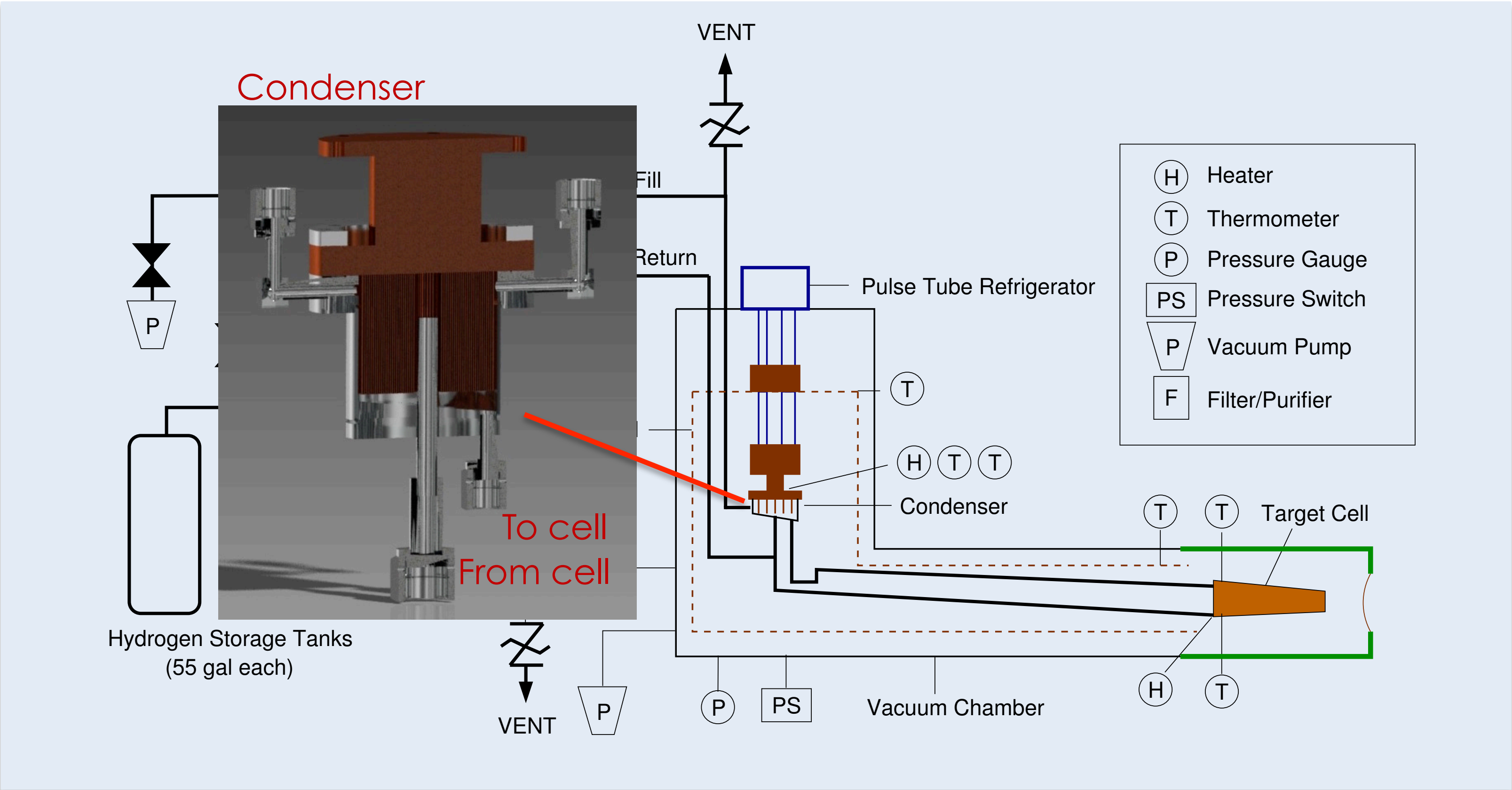
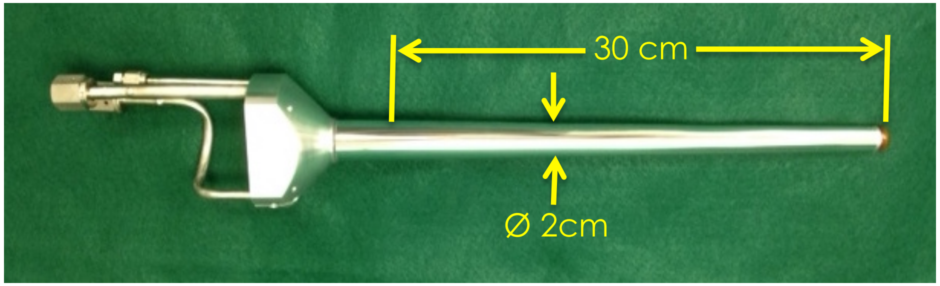


The existing Hall D cryotarget

- The target cell is modeled after designs used for many years in Hall B.



GluEx Target Cell

- Cylinder Is 130μm aluminized kapton.
- Entrance & exit windows are 75μm kapton.
- Base is aluminum, with stainless steel tubes.
- Burst pressure is ~180 psid at room temperature.
- Two internal thermometers (cernox 1050SD).
- 50 W external heater.

Modified Hall D cryotarget

Increasing the size of the *existing cryotarget* is subject to two limitations

- Diameter of the vacuum chamber & start counter
- Volume of LH2 in the system

- The vacuum chamber limits the target to a maximum diameter of ~ 6 cm.

- The target system is designed to safely relieve ~400 ml of LH2 in the event of a catastrophic vacuum failure.
  - 100 ml of LH2 is condensed in the target cell
  - 300 ml is condensed in the rest of the system to permit subcooling the liquid below the saturated vapor pressure and suppress boiling.
- If we ignore subcooling, the cell volume can increase ~4x without modification to the rest of the system.

Some examples

- Cell length = 30 cm → Max. dia. = 4 cm
- Cell diameter = 2 cm → Max. length = 120 cm
- Cell diameter = 6 cm → Max. length = 14 cm

Modified Hall D cryotarget

Larger targets are of course possible, but will require a reevaluation of (or significant modifications to) the existing Hall D cryotarget.

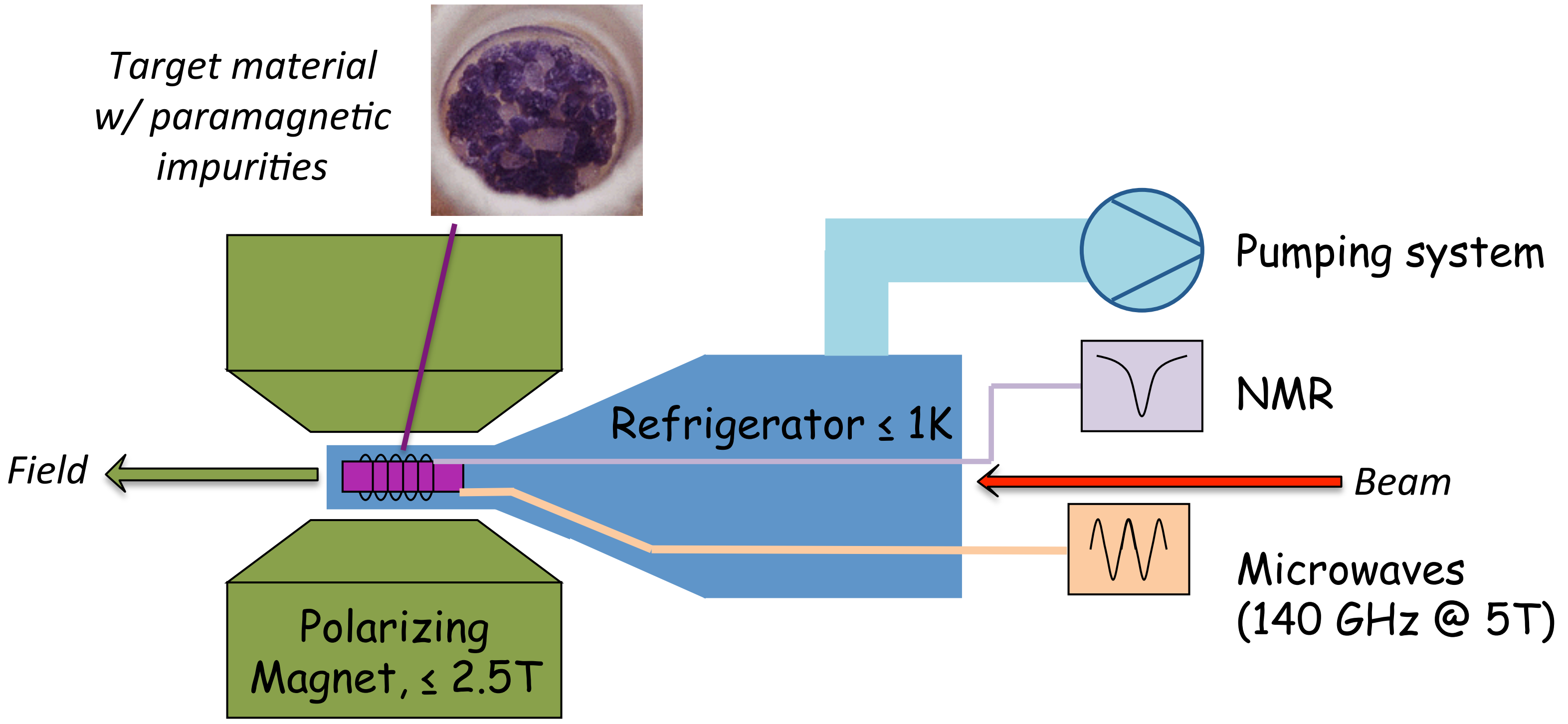
Or construction of a new target.

Points to consider:

- Storage volume (inside or outside Hall D)
- Cell material (kapton or aluminum)
- Condensation rate ~10 ml/min

A polarized proton target for Hall D

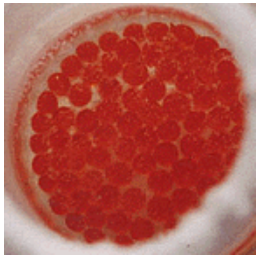
- Instrumentation for a dynamically polarized target

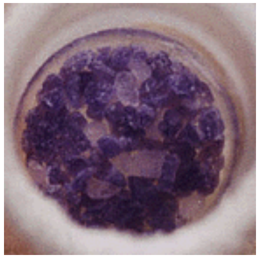


A polarized proton target for Hall D

DNP polarized target is characterized by four quantities

1. Maximum polarization
2. Dilution factor
3. Radiation resistance
4. Polarizable background nuclei

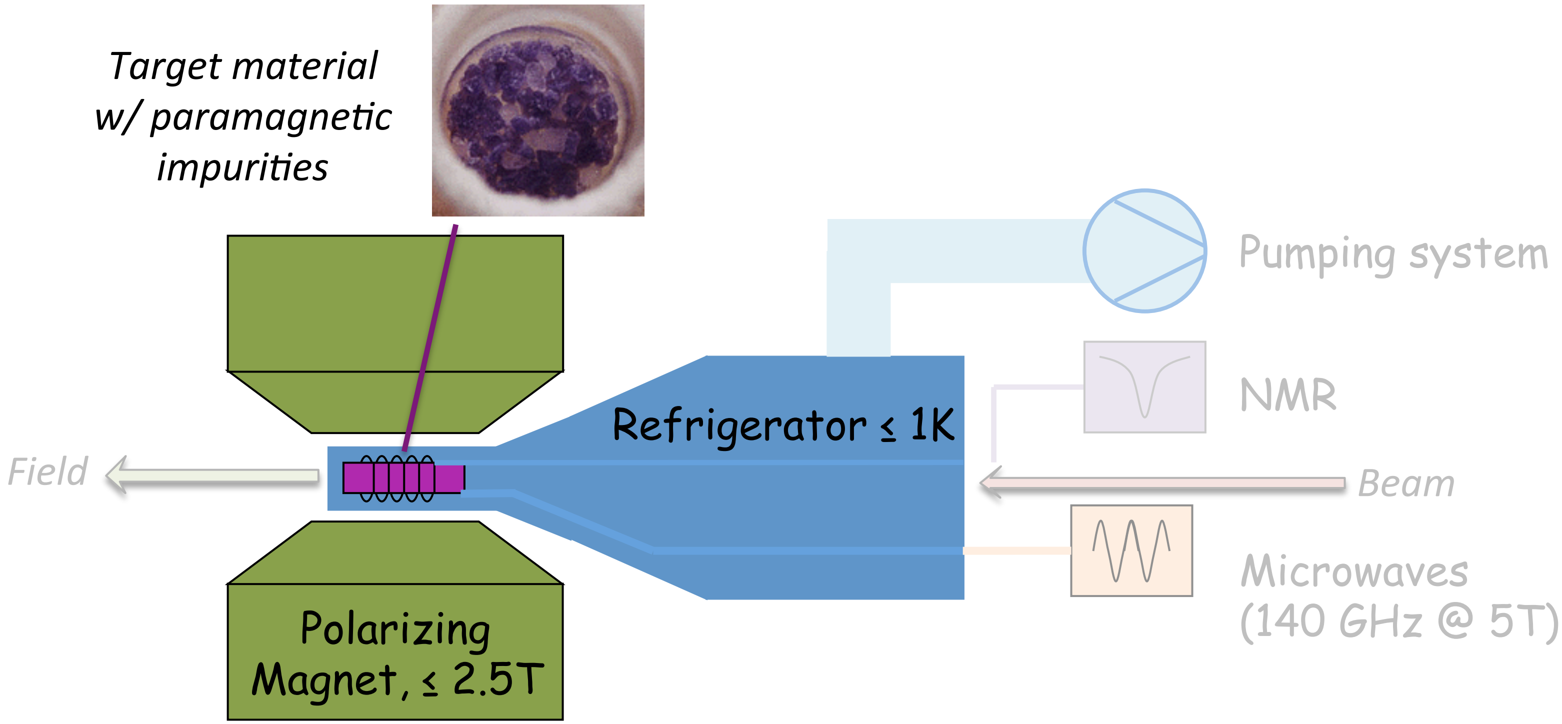




Material	Butanol, C_4H_9OH	Ammonia, NH_3	Lithium hydride, ^7LiH
Dil. Factor (%)	13.5	17.7	25.0
Polarization (%)	> 90%	> 90%	90%
Pol. background	none	^{14}N, ^{15}N	^7Li
Material	D-Butanol, C_4D_9OD	D-Ammonia, ND_3	Lithium deuteride, ^6LiD
Dil. Factor (%)	23.8	30.0	50.
Polarization (%)	> 80%	50%	55%
Pol. background	none	^{14}N, ^{15}N	^6Li
Rad. resistance	moderate	high	extremely high
Comments	*Easy to produce and handle*	*Works well at 5T and 1K*	*Slow polarization, long relaxation*

A polarized proton target for Hall D

- Instrumentation for a dynamically polarized target



A polarized proton target for Hall D

DNP targets fall under two classifications:

1. Continuously polarized (microwaves on 100% of the time)
   - Highest luminosity (up to 10^{35})
   - Highest beam efficiency (depends on luminosity)
   - However, continuous polarization requires a high field (few tesla), high uniformity (10^{-4}) magnet during data acquisition

2. Frozen Spin (microwaves on 5-10% of the time)
   - Only requires high field, high uniformity (10^{-4}) magnet during polarization Holding field requirements are less severe (10^{-3})
   - 90-95% efficiency is reasonable
   - Requires very low temperatures (≤ 50 mK)
   - Luminosity limited to $10^{32} – 10^{33}$

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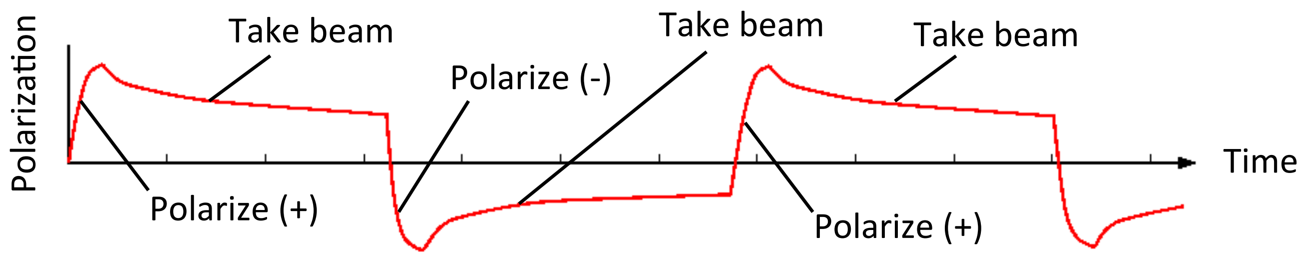


A polarized proton target for Hall D

Can the Hall D solenoid be used as a ***polarizing*** magnet?

E. Chudakov:

Central field = 1.6 T (too low)

dB/dz = 0.25 T/m (~ 500 ppm, too high)

→ probably need ~ 1 T trim coils

A polarized proton target for Hall D

Can the Hall D solenoid be used as a Frozen Spin ***holding*** magnet?

FROST: 4000 hrs @ 24 mK/0.5 T

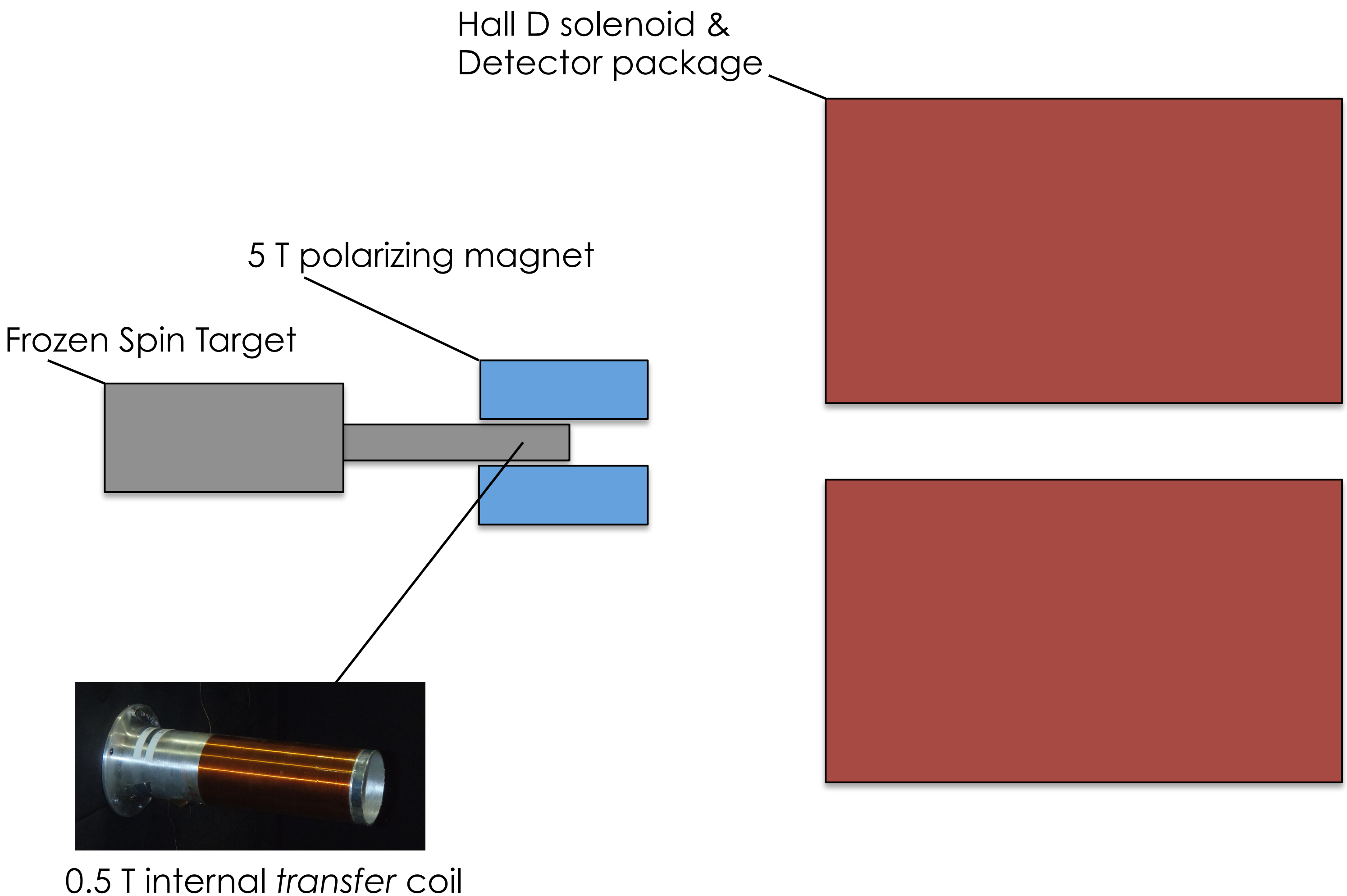
Data on the field dependence of the relaxation time is conflicting.

ammonia: T_1 α exp(B/T)
propandiol: T_1 α B
butanol: T_1 α B^3

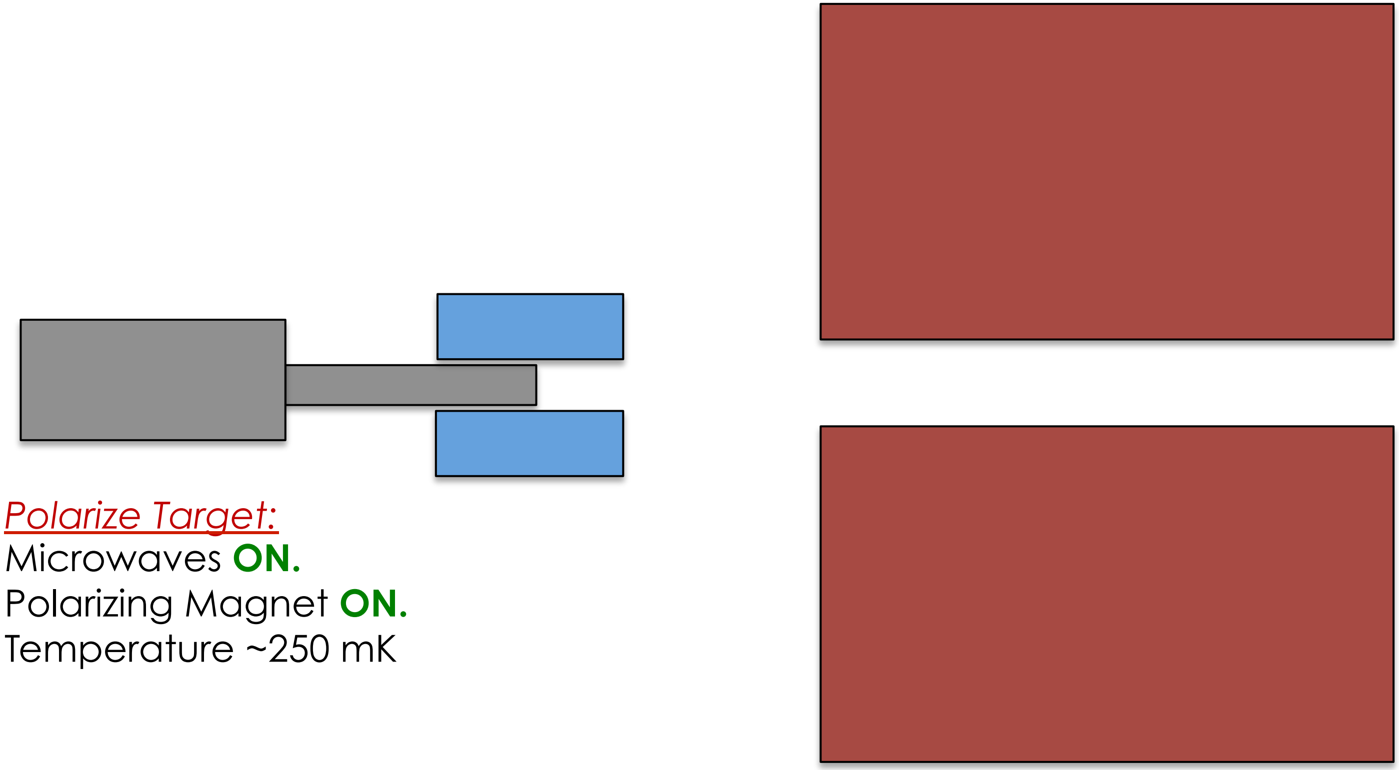
At a 1.6 T holding field, we can reasonably expect $T_1 \geq 10{,}000$ hrs

→ the solenoid will make a great holding magnet!

A polarized proton target for Hall D

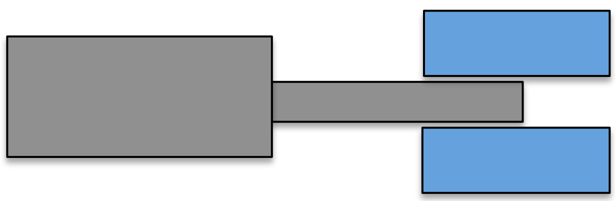


A polarized proton target for Hall D

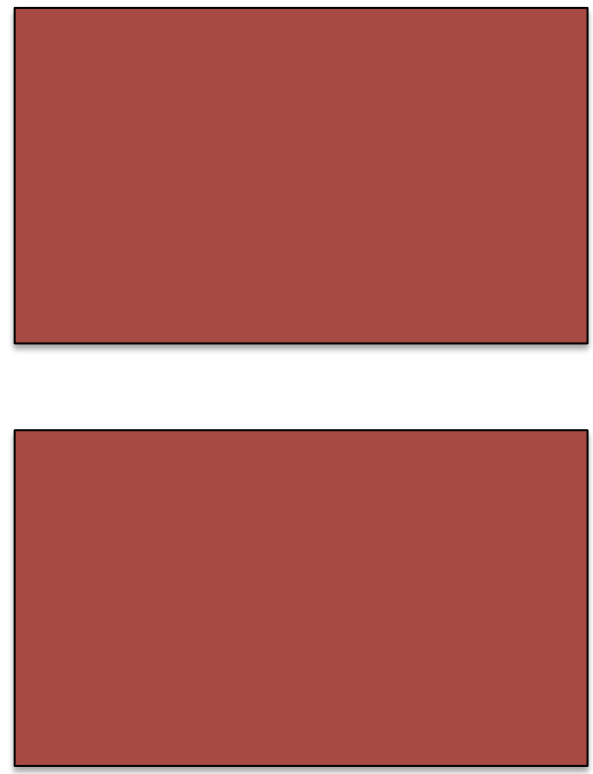


Polarize Target:
Microwaves **ON.**
Polarizing Magnet **ON.**
Temperature ~250 mK

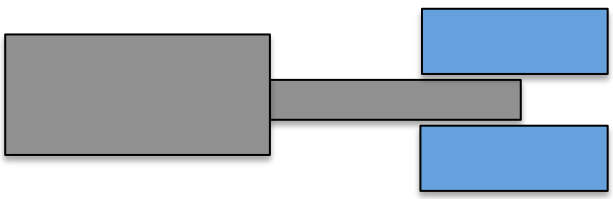
A polarized proton target for Hall D

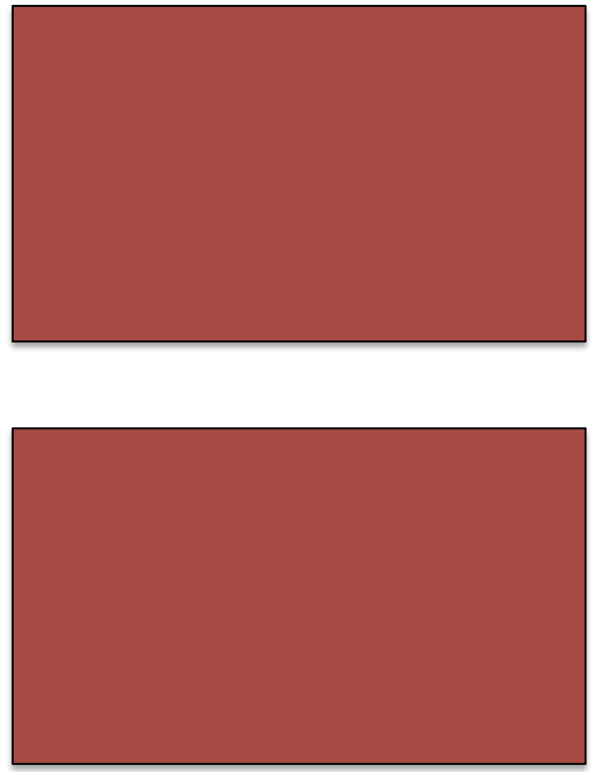


Target polarized:
Microwaves **OFF.**
Target cools to <50 mK at 5 T



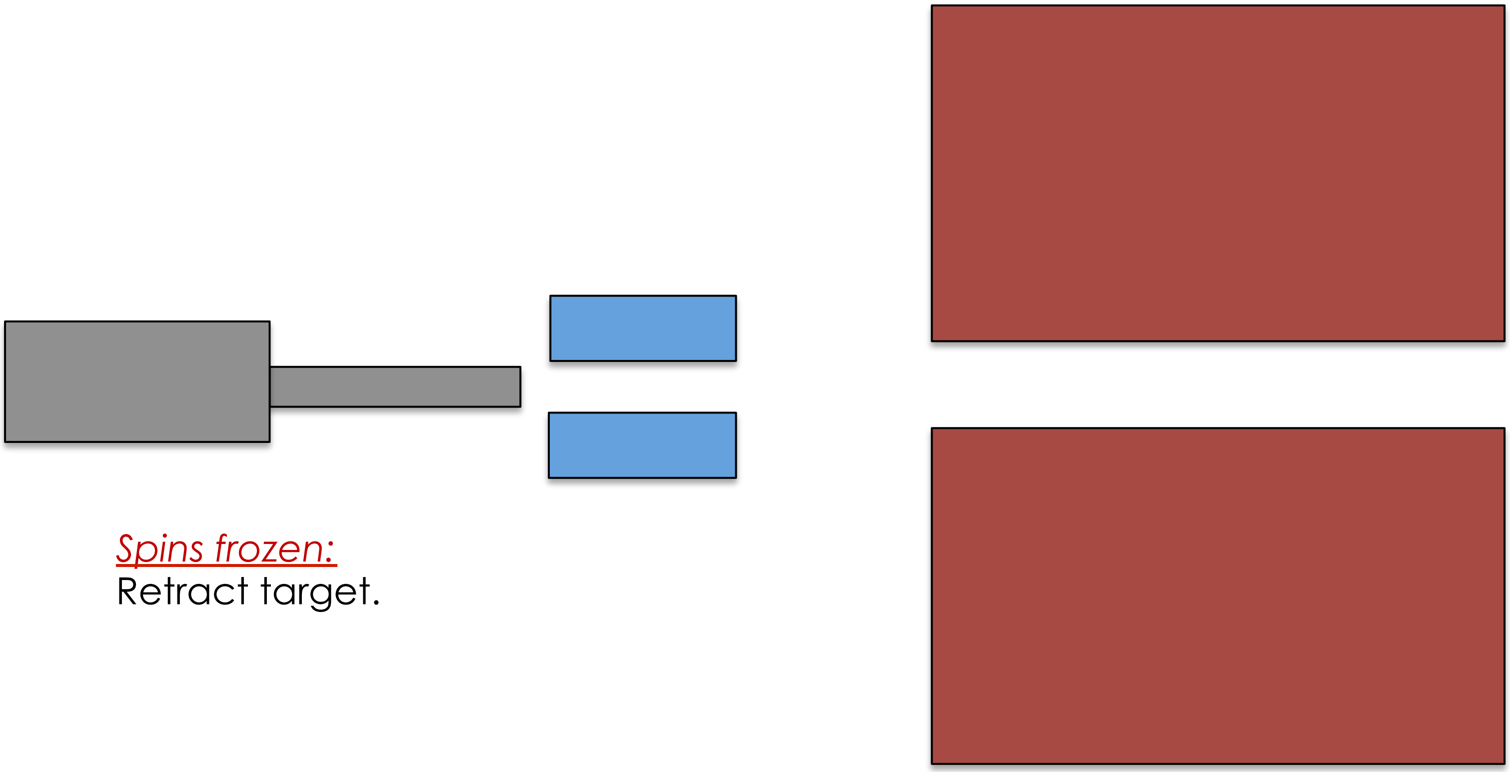
A polarized proton target for Hall D



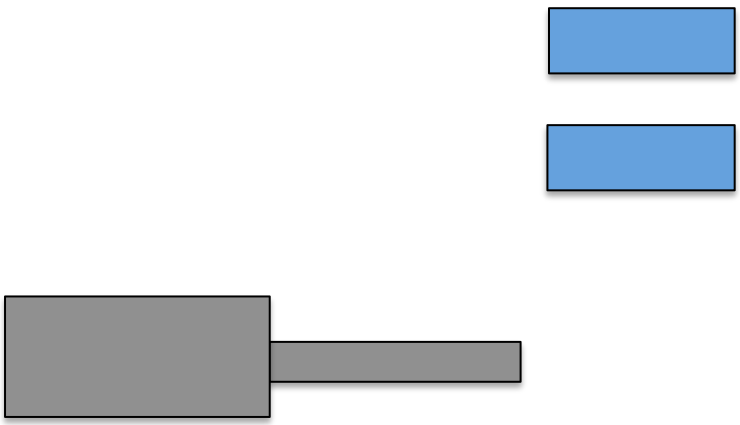


Spins frozen:
Polarizing magnet **OFF.**
Internal transfer coil **ON.**

A polarized proton target for Hall D

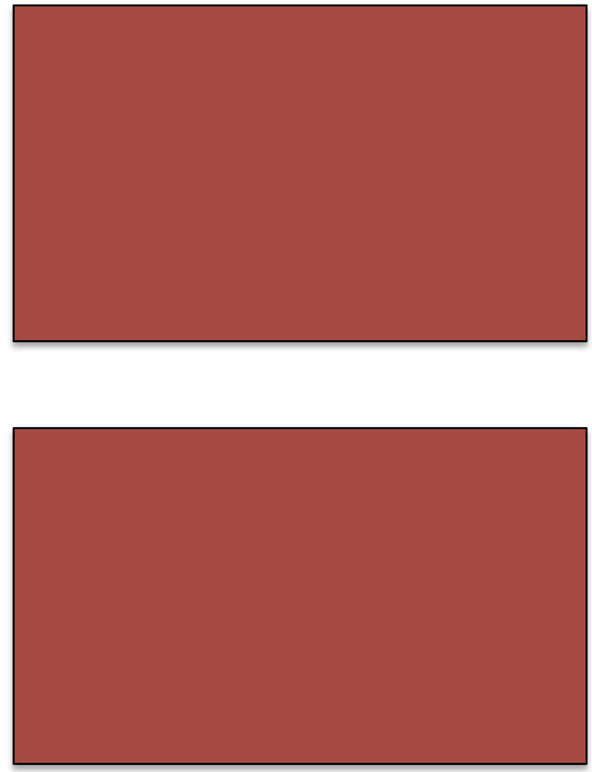


A polarized proton target for Hall D

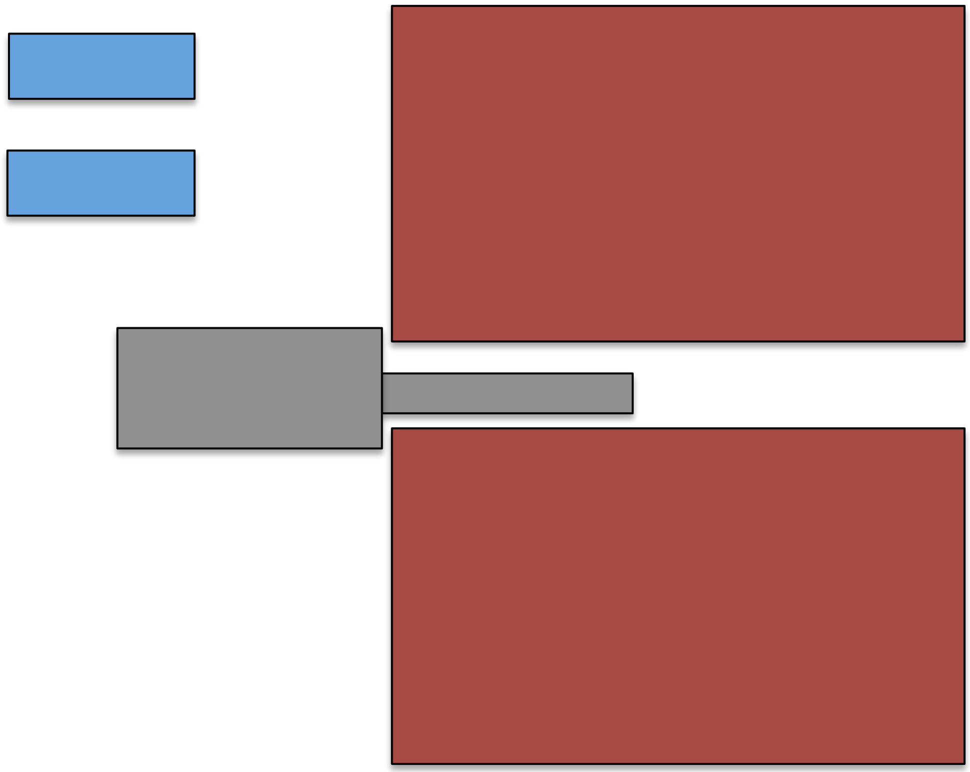


Spins frozen:

Move polarizing magnet out of the way.



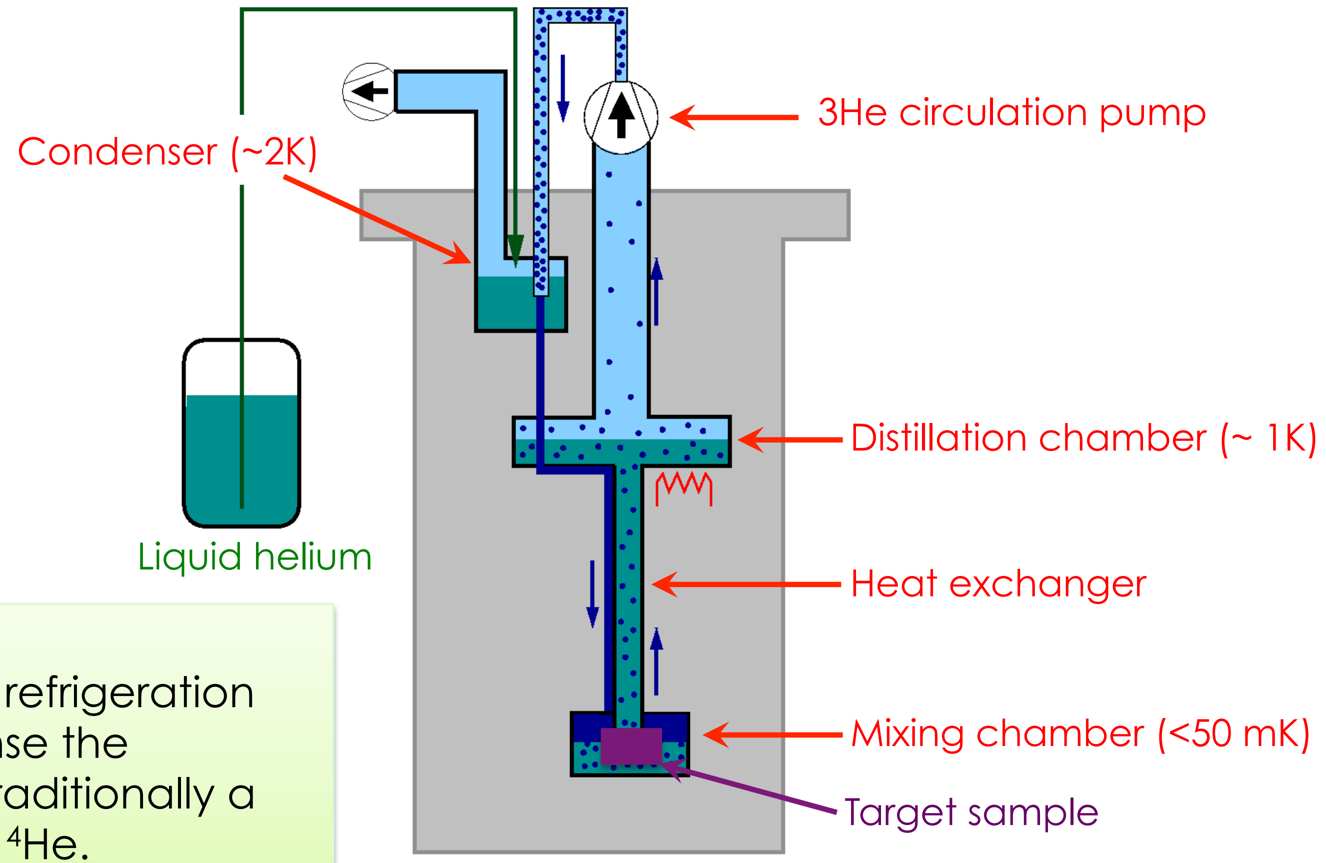
A polarized proton target for Hall D



Spins frozen:
Push target into place.
BEAM ON.
(Repeat as necessary.)

A polarized target for Hall D

A frozen spin target requires temperatures ≤ 50 mK for best performance ➔ a ^{3}He-^{4}He Dilution Refrigerator



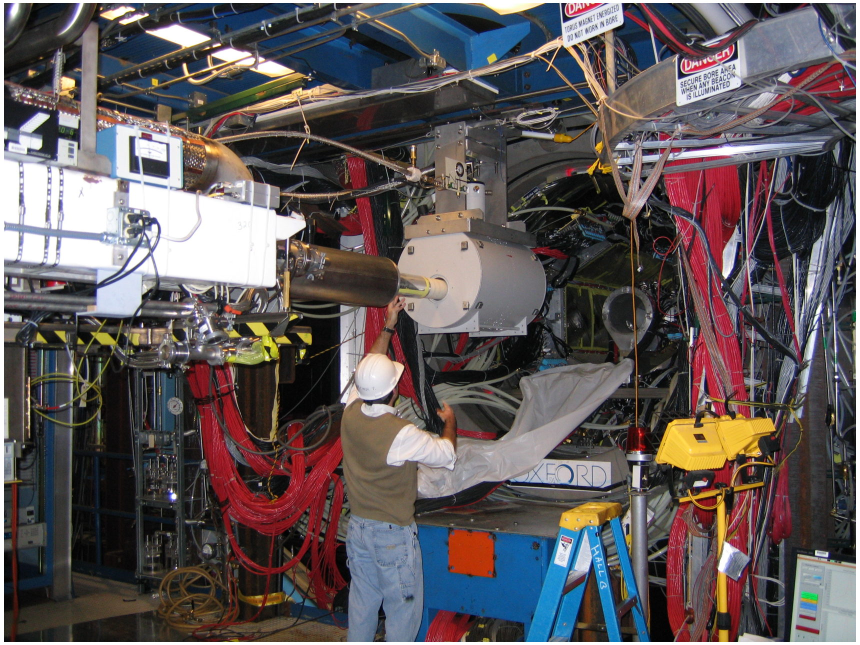
<u>Important:</u>
DRs require a 2nd refrigeration circuit to condense the circulating ^{3}He, traditionally a pumped bath of ^{4}He.

A polarized target for Hall D

FROST consumed ~10 l/hr of LHe during polarization (microwaves ON) and ~5 l/hr in the frozen spin state (microwaves OFF)

➔ LHe came from the *End Station Refrigerator (ESR)*

Hall D refrigerator may not be capable of supporting both the Hall D solenoid and a frozen spin target!

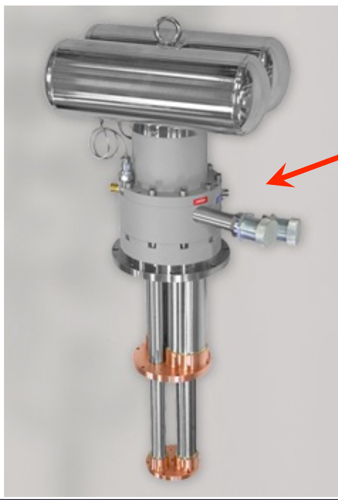


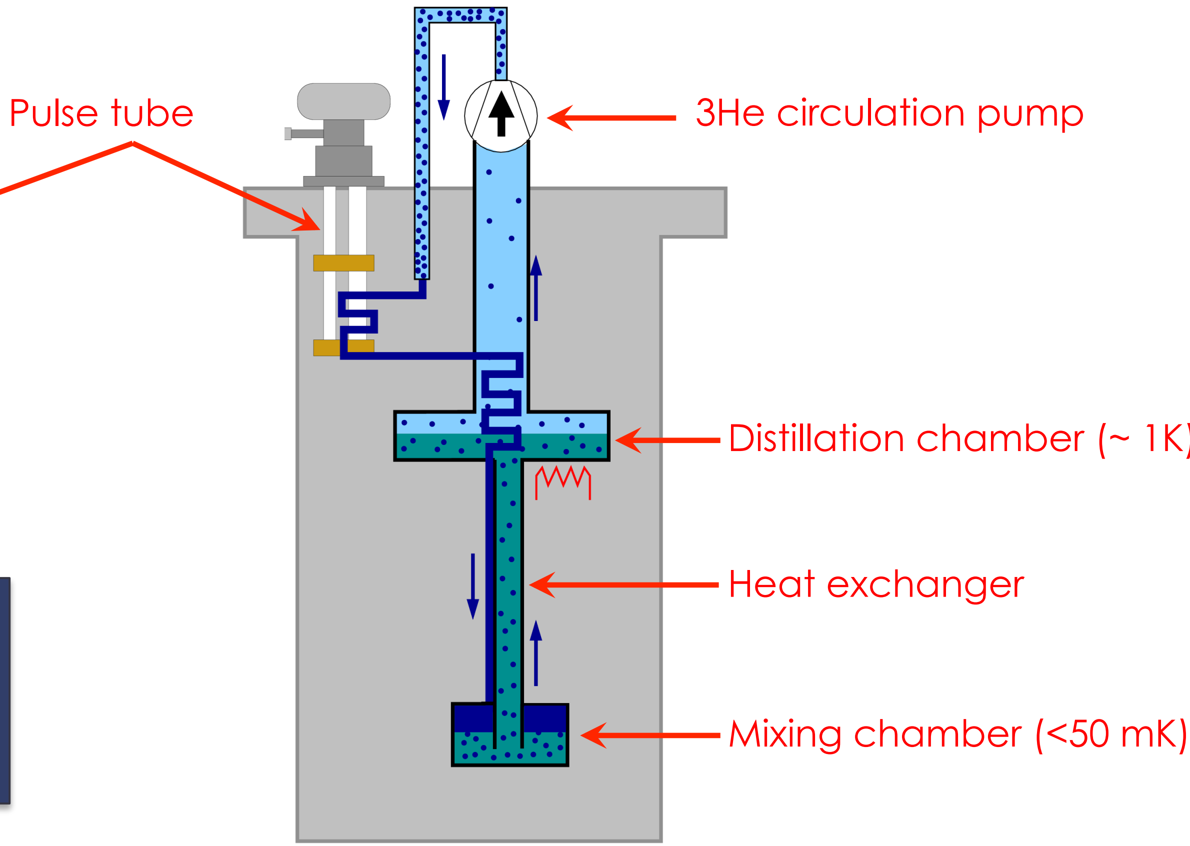
Weekly delivery of commercial dewars of LHe?

A polarized target for Hall D

Cryogen-free dilution refrigerators

Most modern day DRs use pulse tube refrigerators to condense ^{3}He





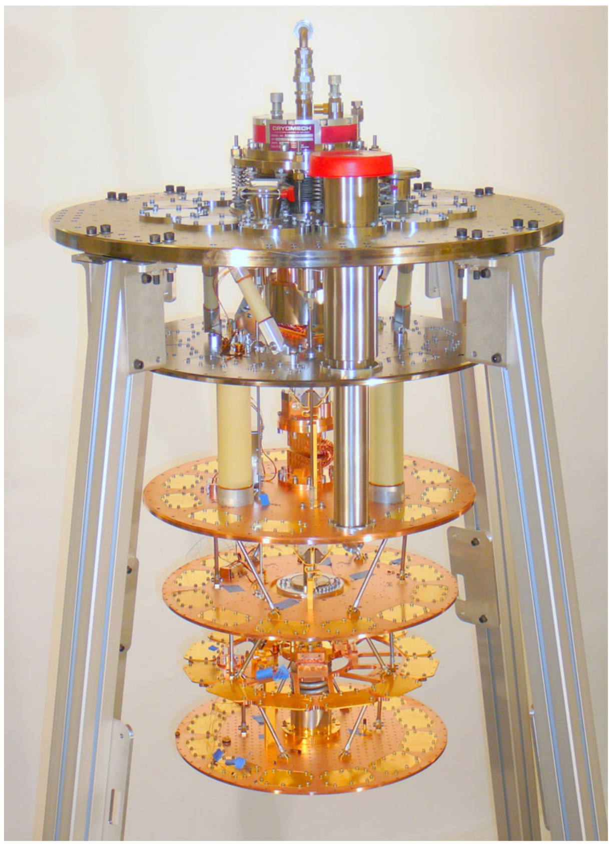
Cryomech PT415

- 2.8 K base temperature
- 1.5 W at 4.2 K
- 20,000 hour maintenance cycle

A polarized target for Hall D

Cryogen-free dilution refrigerators

Most modern day DRs use pulse tube refrigerators to condense ^3He
(one pulse tube can condense ~4 mmol/s)



To match the 30 mmol/s circulation capacity of the FROST DR , we would need 7 pulse tubes

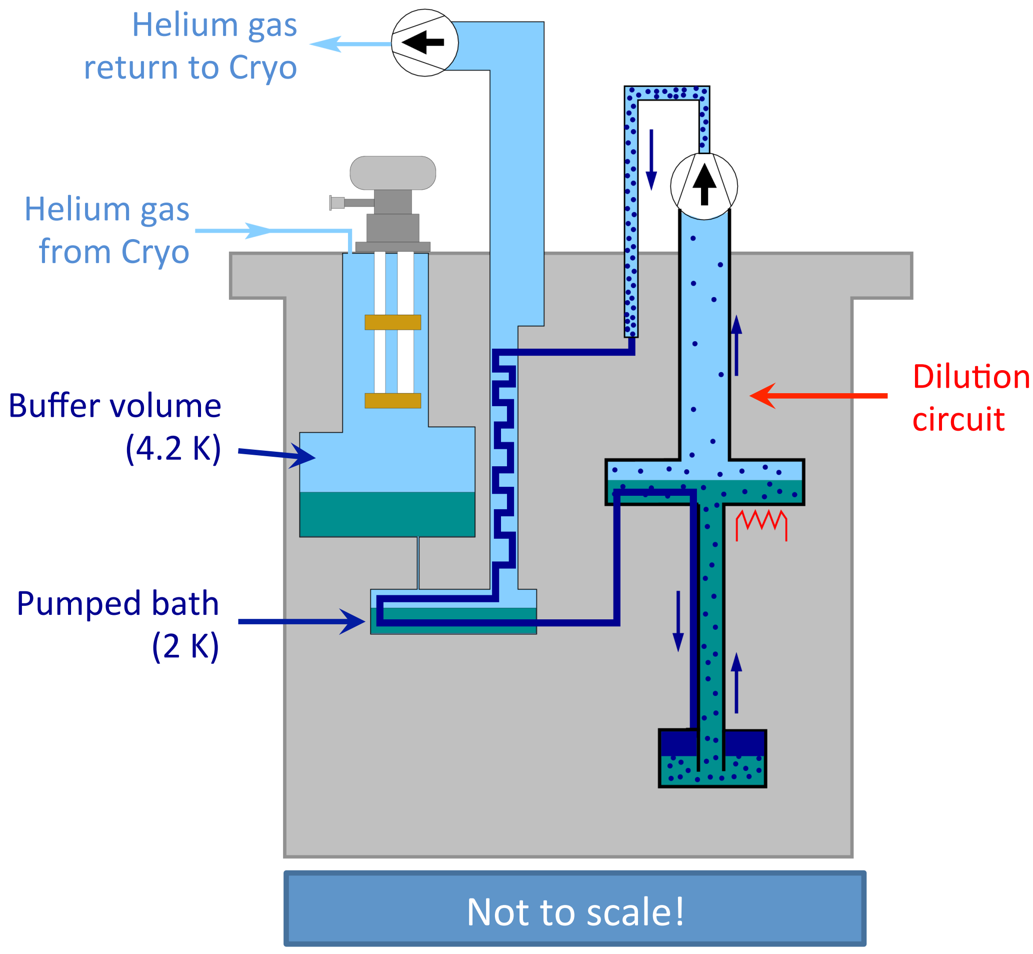
But we only need this capacity while polarizing, about 5 – 10 % of the time!

In Frozen spin mode, FROST circulated 1- 2 mmol/s

A polarized target for Hall D

Cryogen-free FROZEN SPIN TARGET
Use two pulse tube refrigerators to condense ^{4}He into a buffer volume inside the target cryostat.

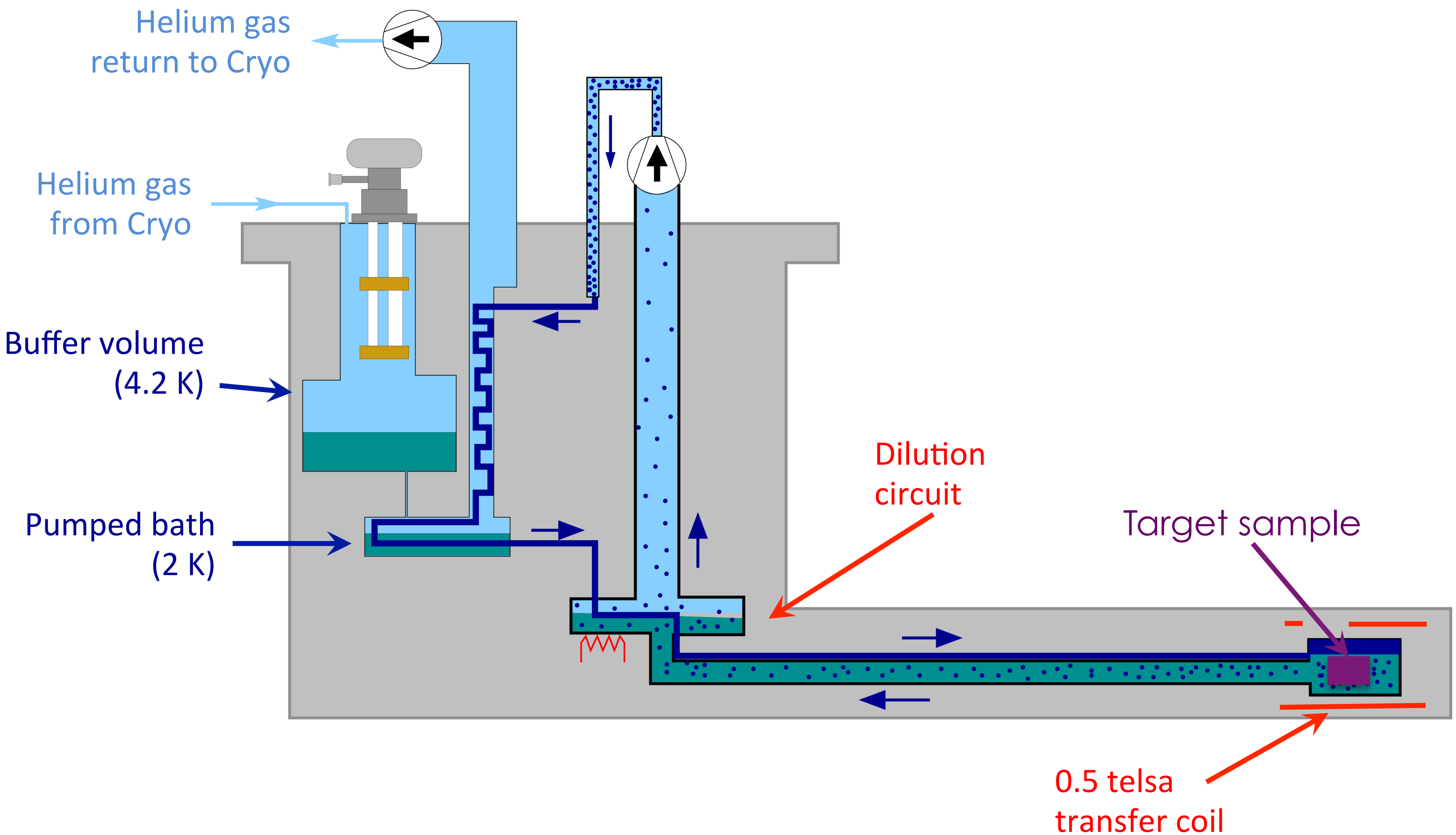
Excess liquid accumulates in the volume while the target is in the frozen spin state (low ^{3}He circulation), and it is consumed when the target is being polarized with microwaves (high circulation).



A polarized target for Hall D

<u>Cryogen-free FROZEN SPIN TARGET</u>

A more realistic design will mimic the geometry of the Hall D cryotarget.



A polarized target for Hall D

Target dimensions are critical!

- To match the areal density of a 30 cm LH2 target
  → 3.5 cm long butanol (gives same *TOTAL* luminosity)
  → 23 cm long butanol (gives same *PROTON* luminosity)

Polarizing field should be uniform to ~100 ppm over the entire *VOLUME*
→ cost increase of polarizing magnet

Required microwave power is proportional to the target MASS.
→ cost increase of refrigerator

Some examples

- Ø2.0 cm x 3.5 cm → 11 cm^3, 7 g (rel. Easy)
- Ø6.0 cm x 23 cm → 650 cm^3, 400 g (HARD!!)

Summary: targets for a kaon facility

- The existing hall D cryotarget can provide LH2 targets with a diameter of ~6cm and volume up to 400 ml.
- Larger cells are possible, but will require some modification or new construction.
- Dynamically polarized targets are also a clear possibility, with frozen spin being the most likely choice. Size matters.
- Cryogenic support for a polarized target will be a concern. A cryogen-free frozen spin target might be a viable option.