The HDice Target at JLab

Collaborators

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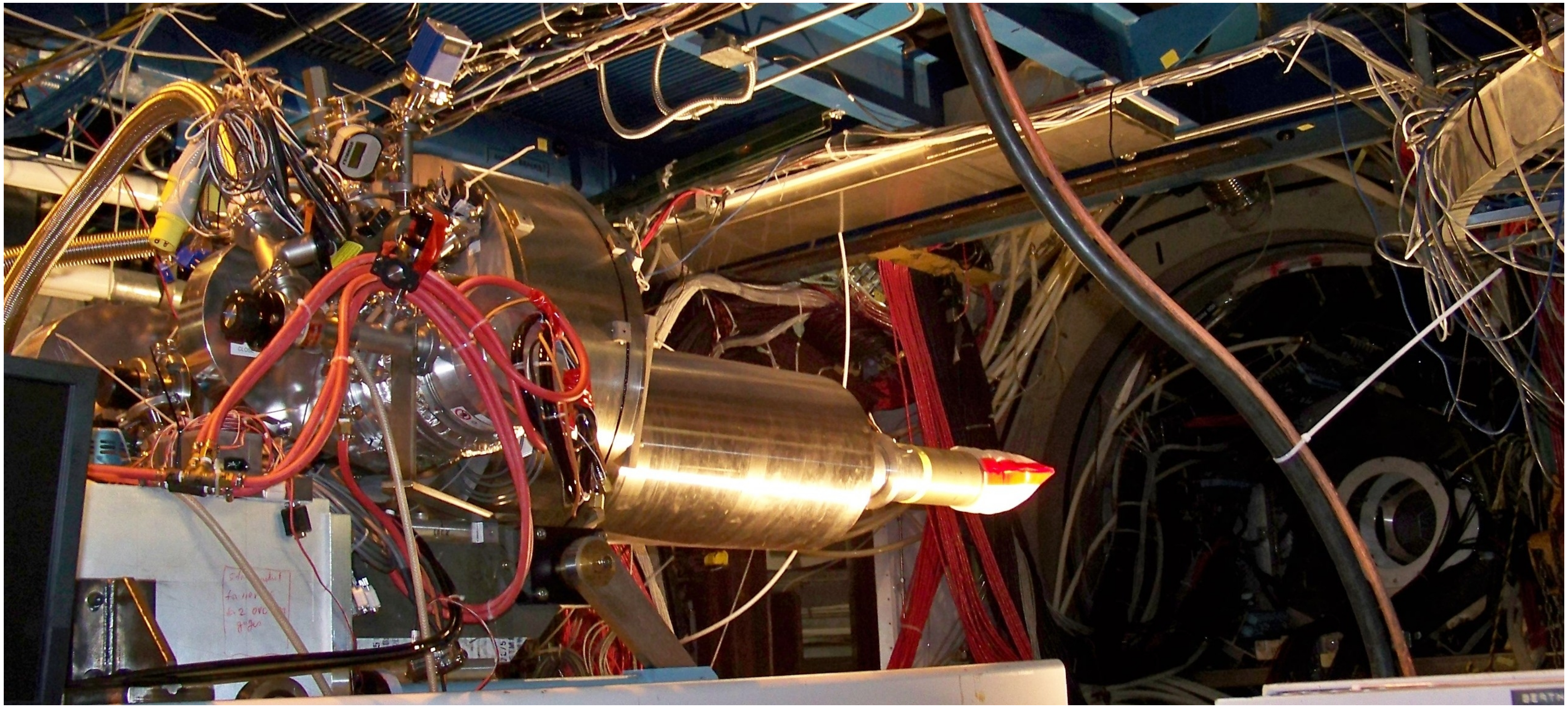
Overview

- Uses of HDice target
- Production of a target cell for experiment
- Polarization process/mechanisms
- Lessons learned: eHD during g14
- eHD test in the Upgraded Injector Test Facility

HDice

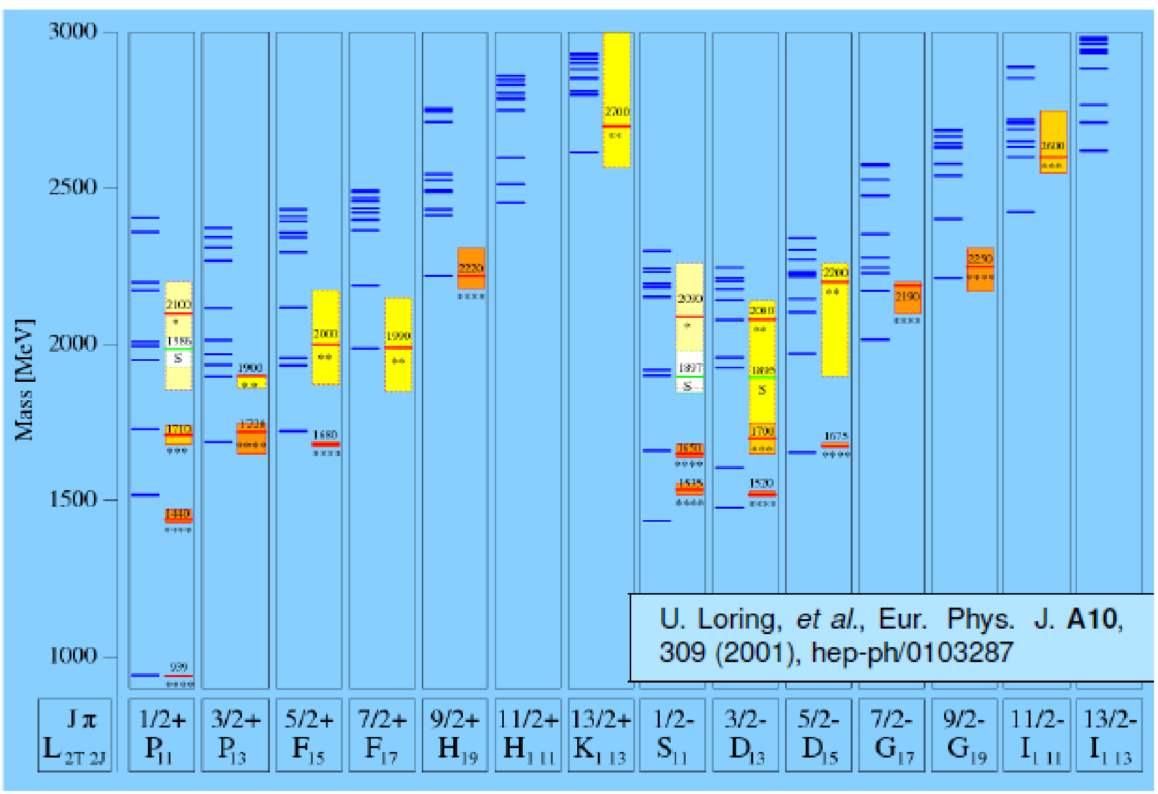
- A new type frozen spin target.
- Target material consists solely of polarizable protons and neutrons ⇒ no dilution factor coming from target material.
- Target material possesses a T1 on the order of years (no repolarization needed).
- Is a very complicated system requiring many steps in the production of a polarized target.

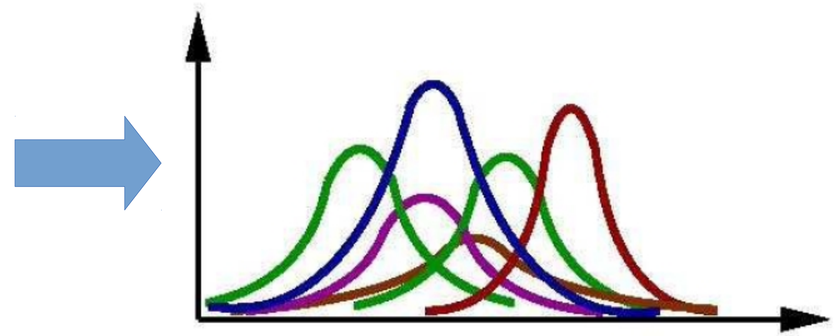


HDice

What is it good for?

- Has been used (with photons) in Hall B as part of the N* program
  ⇨ g14 (Nov 2011-May 2012)
- N* program seeks/sought to explore the excited states of the nucleon to better understand the internal dynamics of protons and neutrons





$$I = I_0 \{ (1 + \vec{\Lambda}_i \cdot \vec{\mathbf{P}}) + \delta_\odot (\mathbf{I}^\odot + \vec{\Lambda}_i \cdot \vec{\mathbf{P}}^\odot) + \delta_l [\sin(2\beta) (\mathbf{I}^s + \vec{\Lambda}_i \cdot \vec{\mathbf{P}}^s) + \cos(2\beta) (\mathbf{I}^c + \vec{\Lambda}_i \cdot \vec{\mathbf{P}}^c)] \}$$

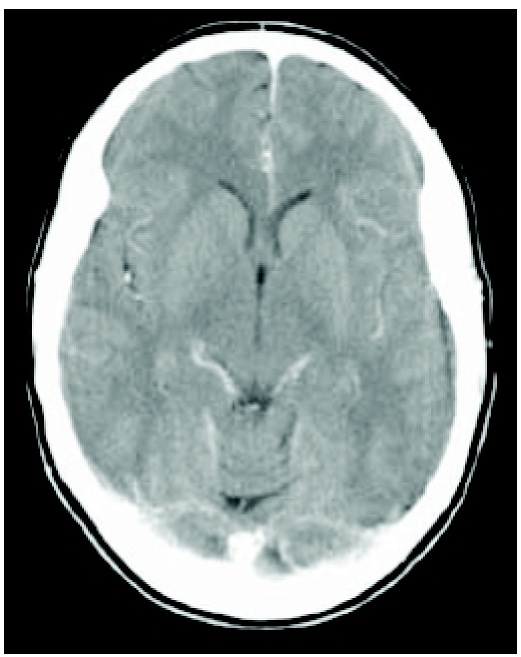
What is it good for?

- Next up: Transversely polarized frozen spin target for use with electrons.
- Three (A-rated) proposals from PAC 41 rated as having a high impact for Hall B:
  - SIDIS, C12-11-111, Marco Contalbrigo,... ⇨ [A;C1]
  - Dihadron production, PR-12-009, Harut Avakian,... ⇨ [A;C1]
  - DVCS, PR12-12-101, Latifa Elouadrhiri,... ⇨ [A;C1]
- C1 ⇨ requires successful demonstration to Lab management of viable performance in a subsequent eHD test run

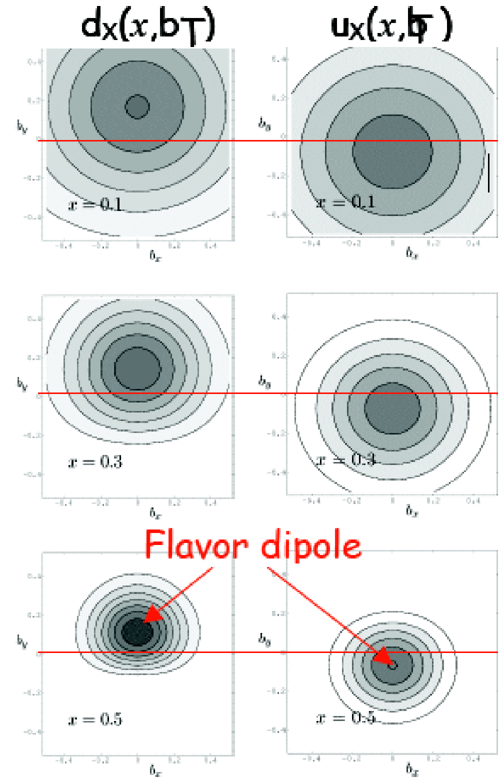
Why eHD?

- Provides a way to study proton tomography through the measurement of Generalized Parton Distributions (GPDs)

2(xy) + 1(z) Dim Cat scan of the human brain



2(xy) + 1(p) Dim scan of the nucleon

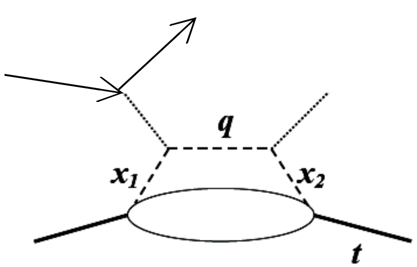


Why eHD?

- Provides a way to study proton tomography through the measurement of Generalized Parton Distributions (GPDs):

$$E(x,\xi,t),\ \tilde{E}(x,\xi,t),\ H(x,\xi,t),\ \tilde{H}(x,\xi,t)$$

- GPDs themselves provide access to the underlying framework; observables are calculated via integration of GPDs
- Tomographic distributions:



$$q(x,b_{perp})=\frac{1}{4\pi^2}\int e^{i\sqrt{ib_{perp}}}\,\mathbf{E(x,t)}\,d^2t$$

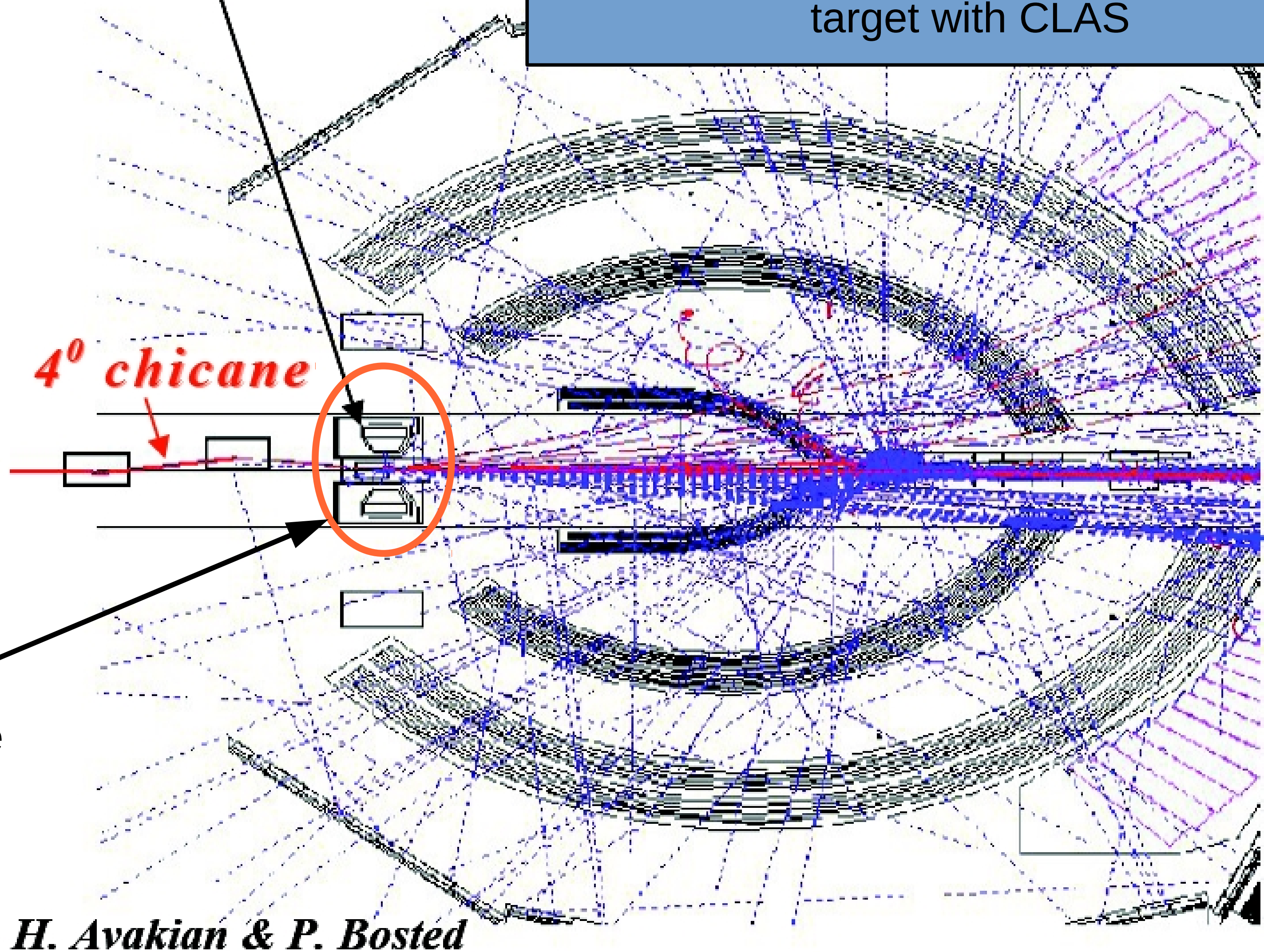
Transverse target polarization asymmetries are **required** for access to **E**

Why eHD?

(Why not a conventional target?)

Magnet (for transverse field)

UVA (Oxford) Transverse NH_3/ND_3 target with CLAS

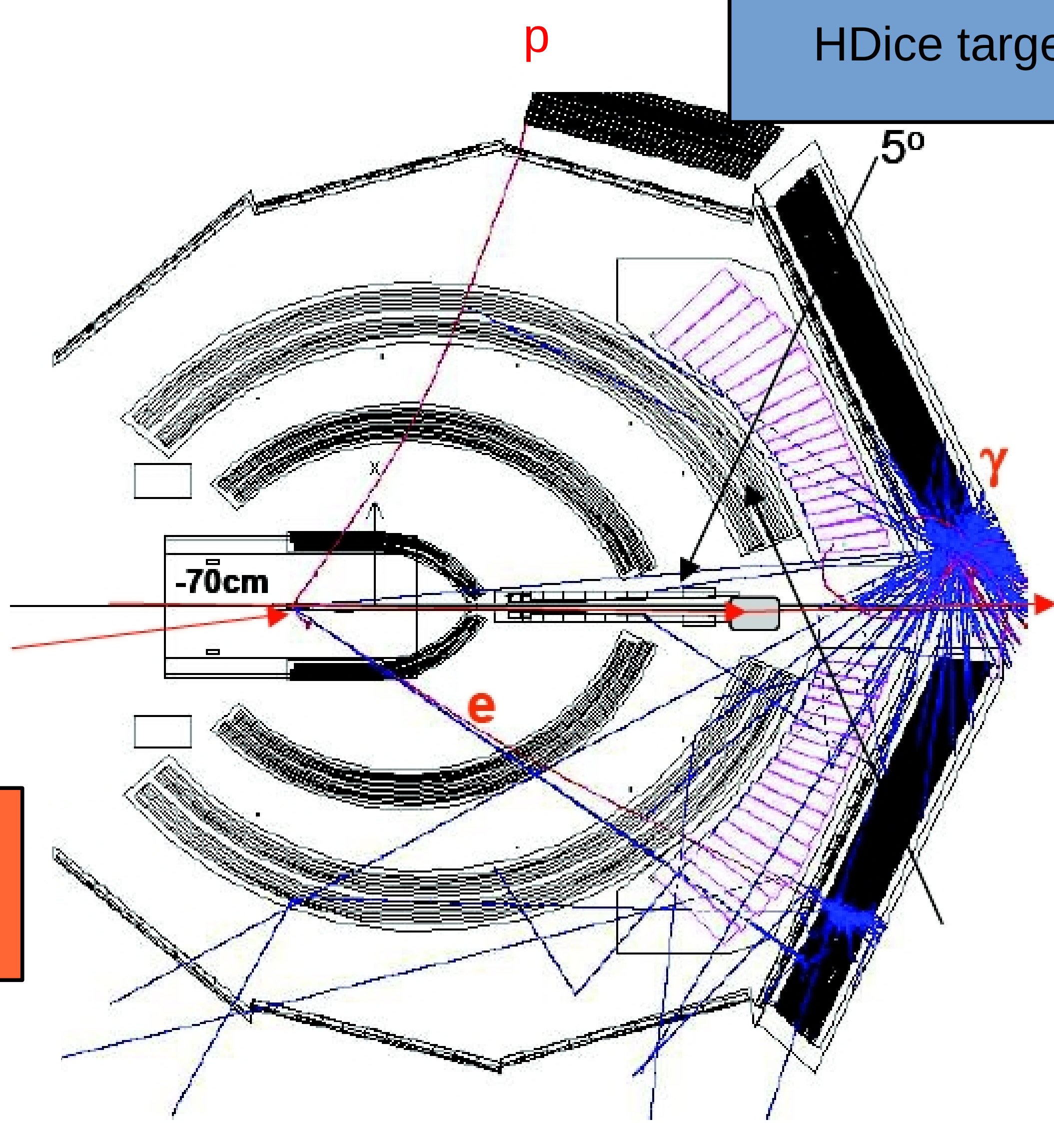


Limits acceptance

Why eHD?

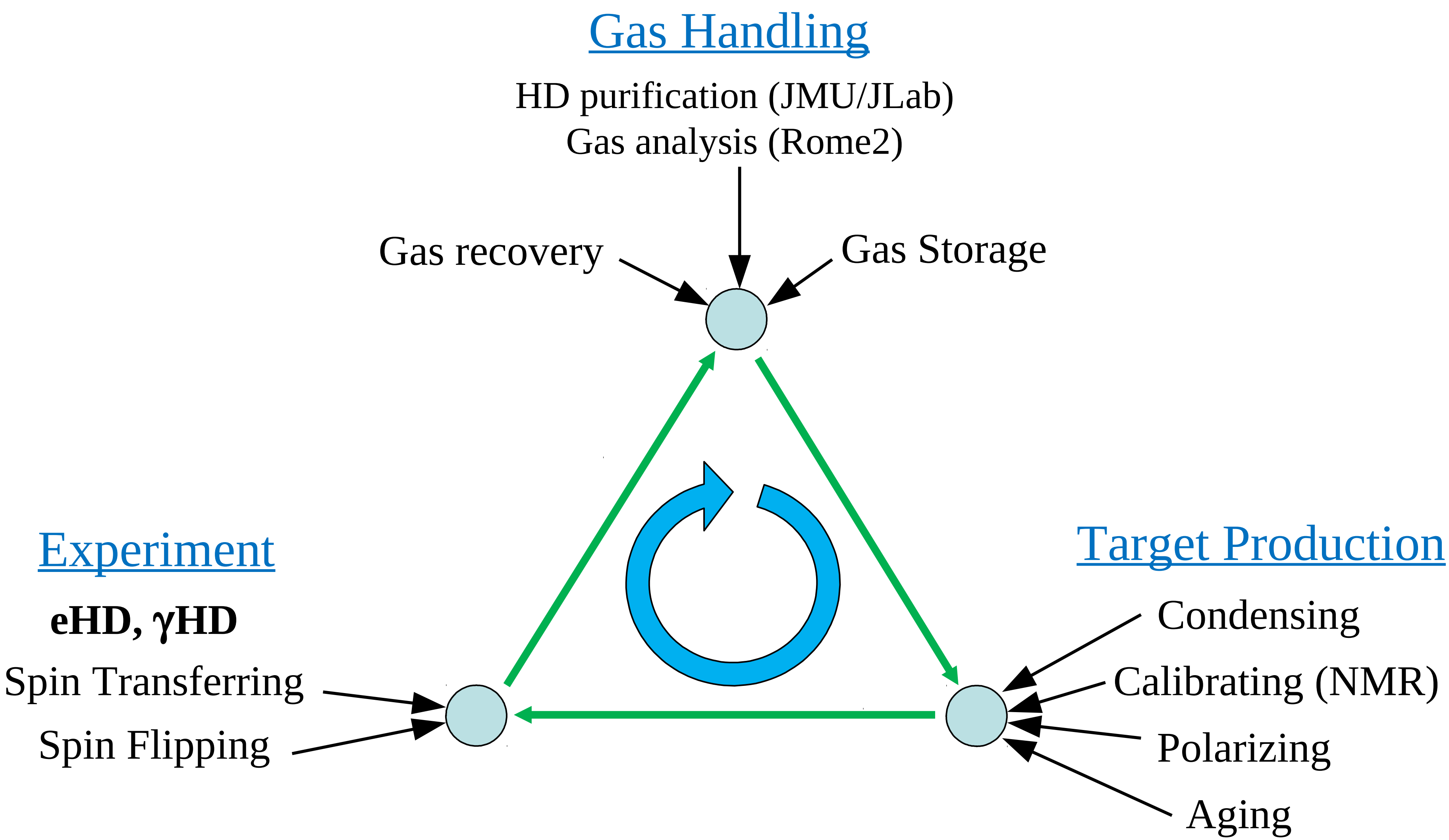
(Why not a conventional target?)

HDice target with CLAS



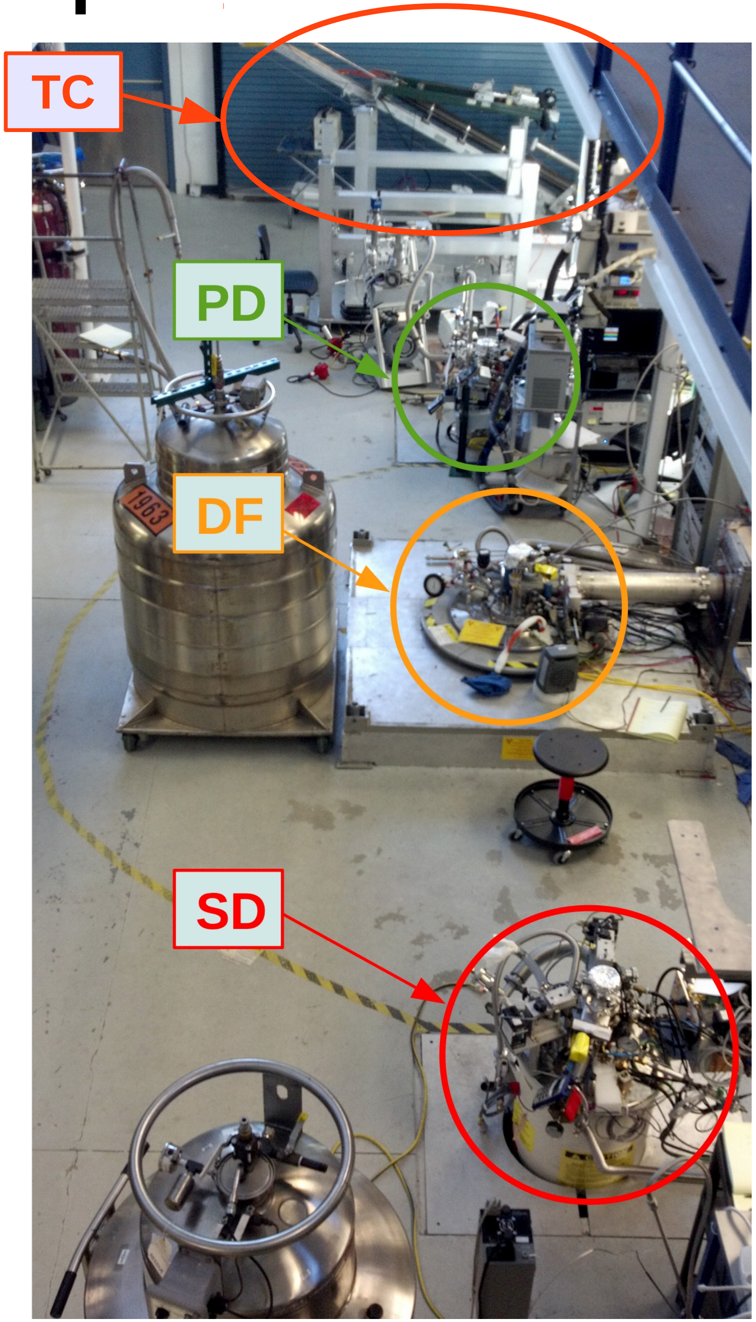
No large magnets to limit acceptance!

Life Cycle of HDice Target

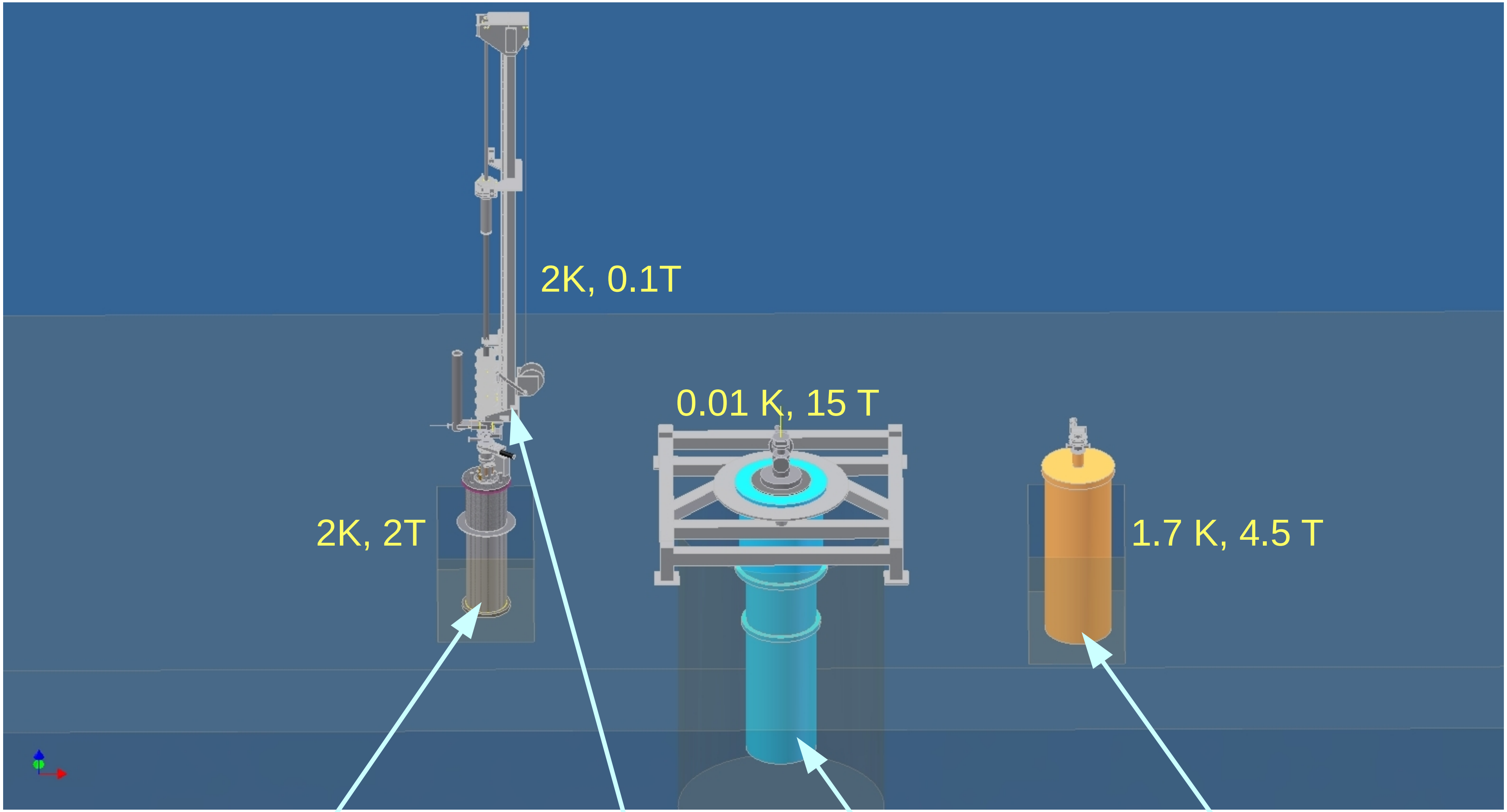


HDice polarized target production

- Made in the Production Dewar (PD)
  - gas to solid
  - initial NMR (TE calib)
- Transferred to Oxford Dilution Fridge (DF)
  - Polarized in a 15 T B field at 10 mK for at least 3 months
- Transferred to PD for NMR measurements
- Transferred to Storage Dewar (SD) for storage (or back to the DF)
- Transferred to the In-Beam Cryostat (IBC) for data taking
- All transfers facilitated by Transfer Cryostat (TC)



Target Transfers



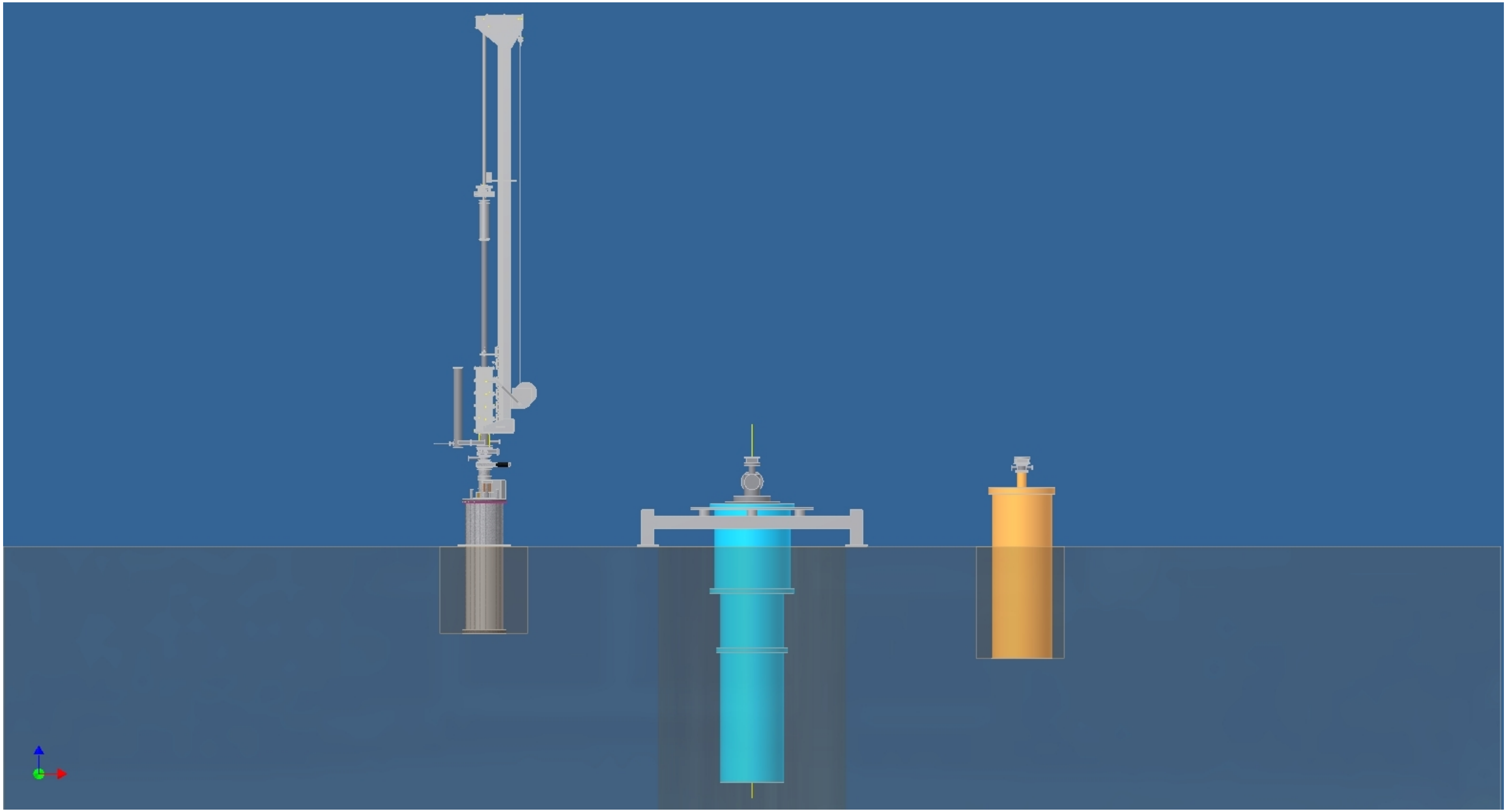
PD (Injecting target, NMR-TE)

TC (Moving target)

DF (Polarizing target)

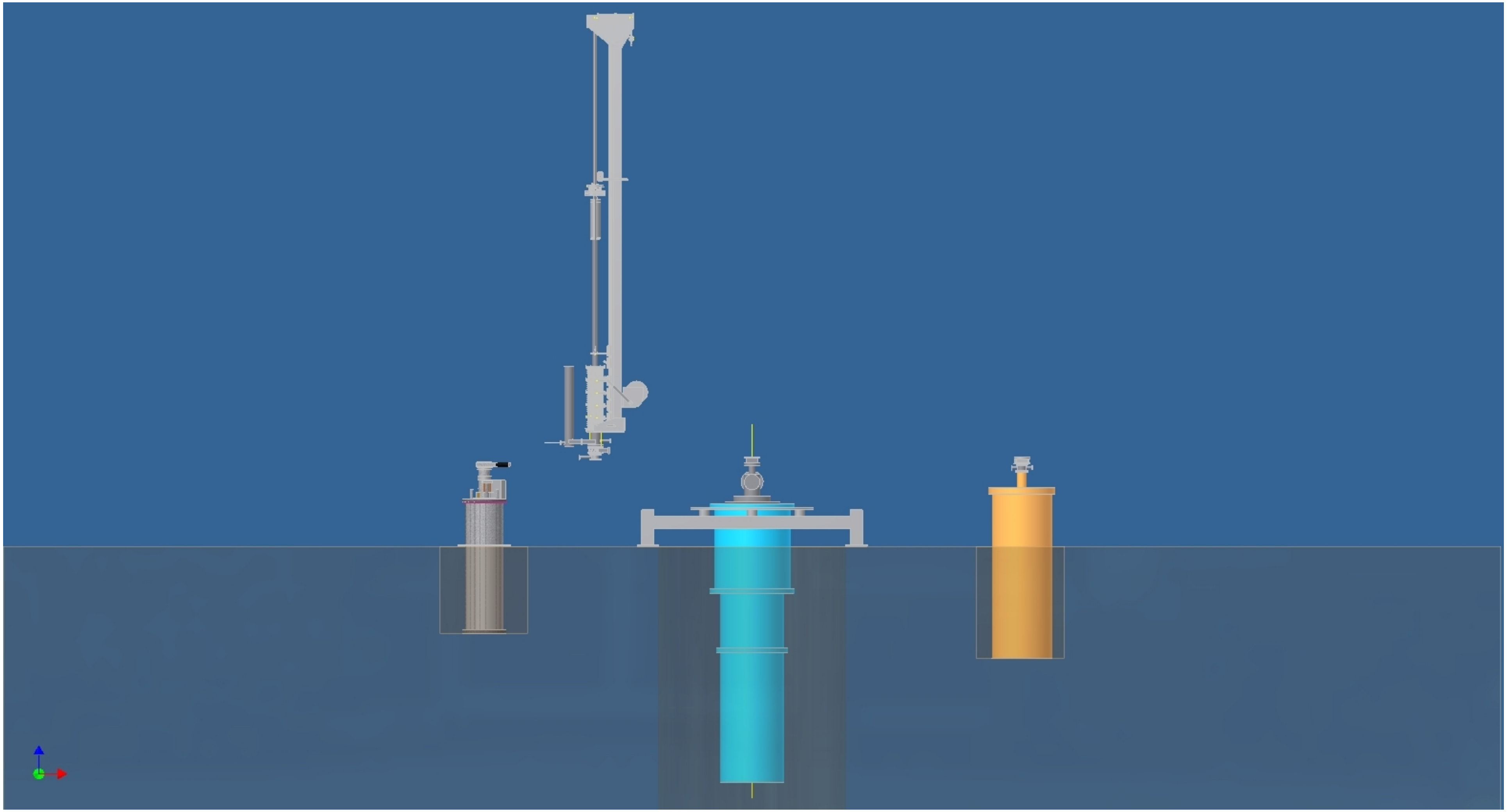
SD (Storing/transporting target)

Target Transfer: PD to DF



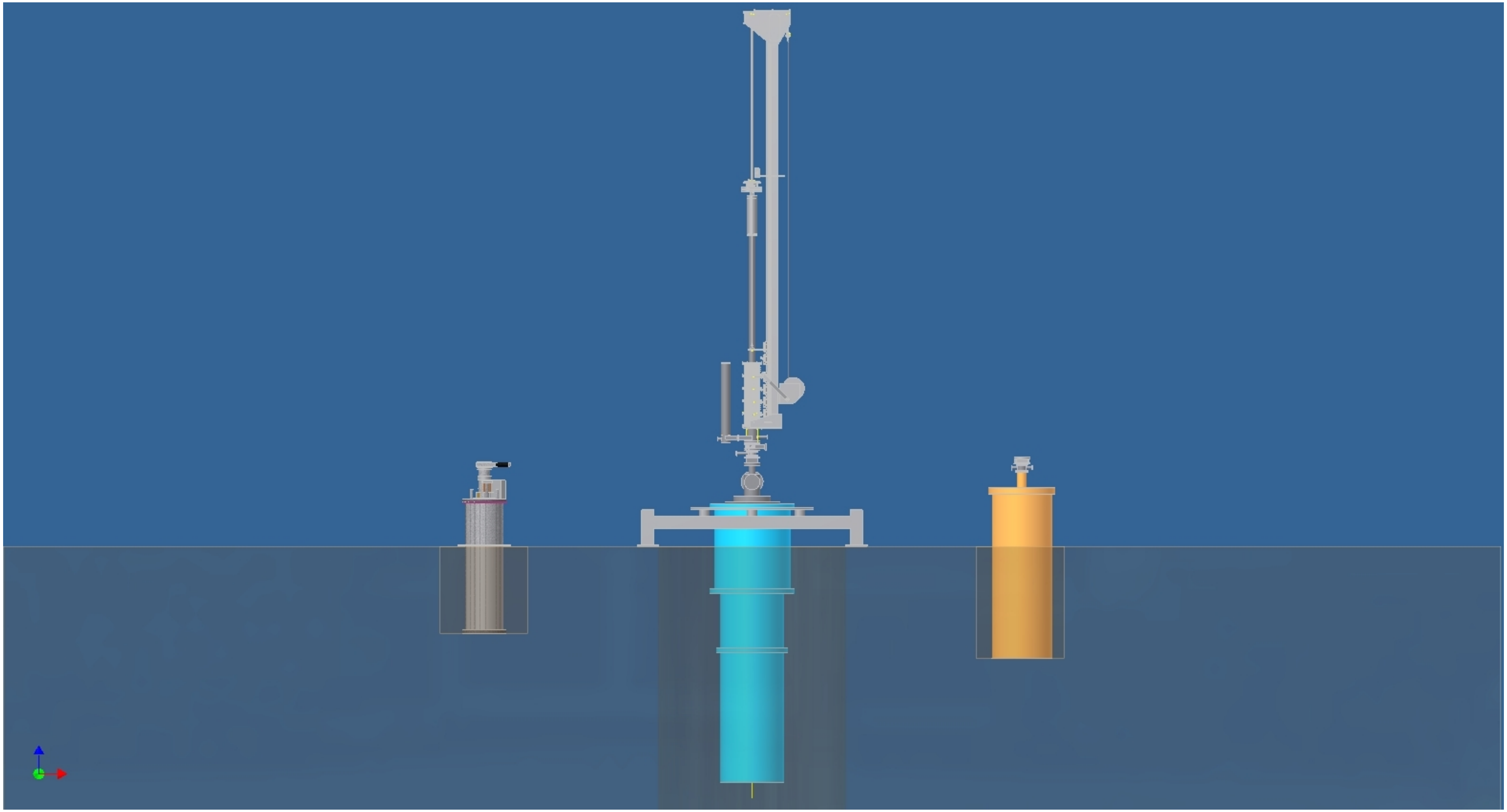
Target transfer between PD and DF for polarization

Target Transfer: PD to DF



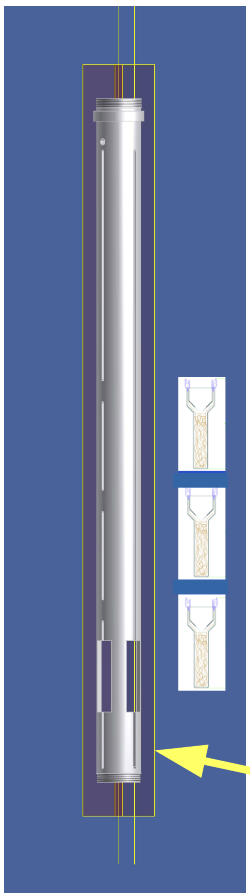
Target transfer between PD and DF for polarization

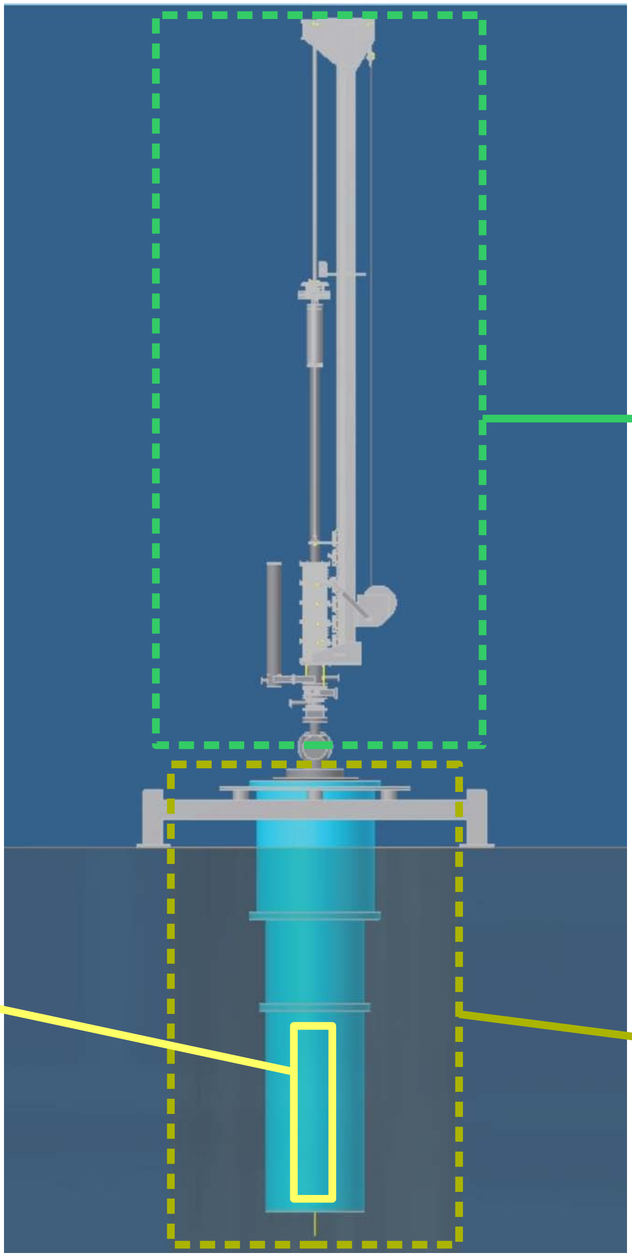
Target Transfer: PD to DF

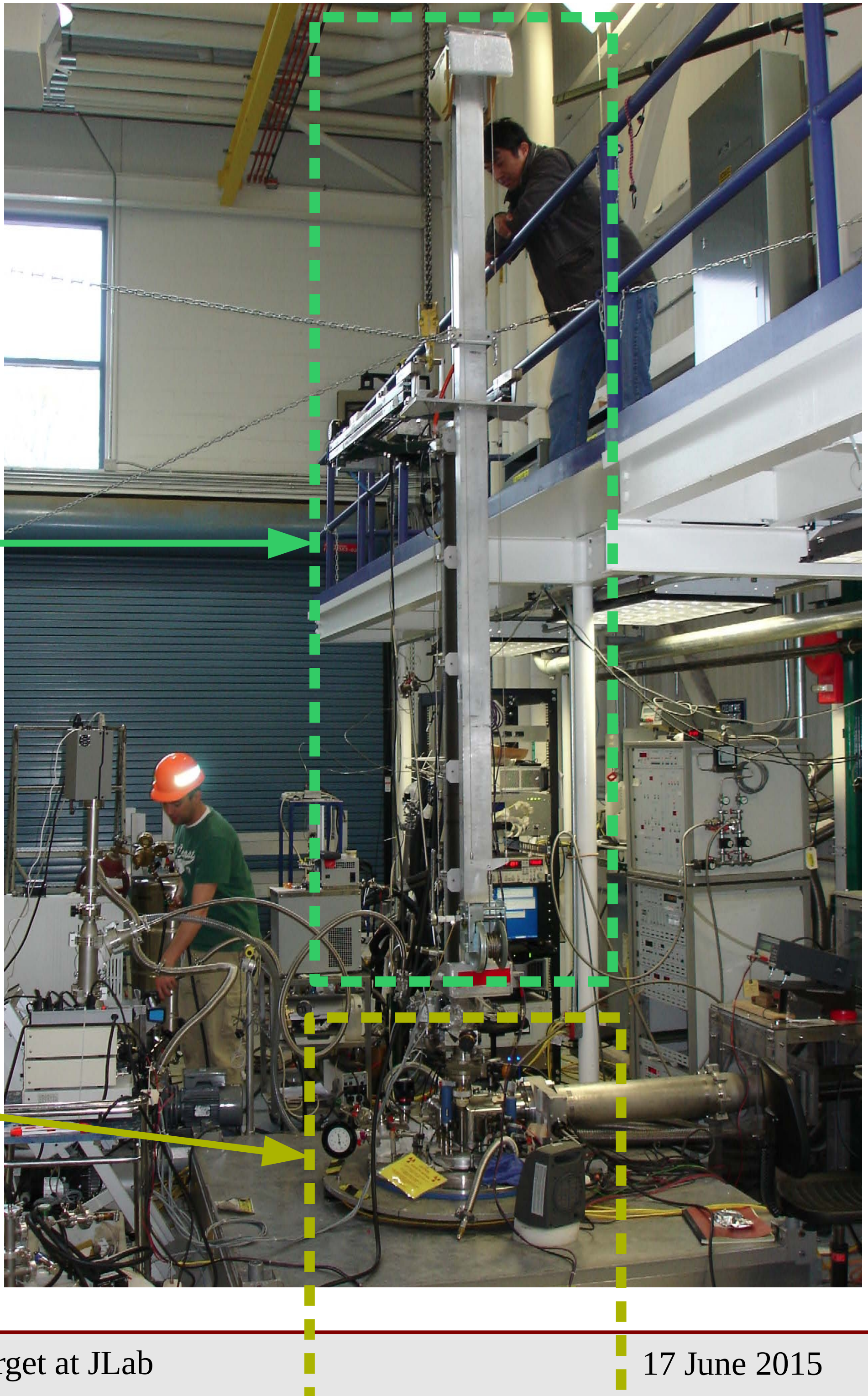


Target transfer between PD and DF for polarization

TC mounted on top of the DF

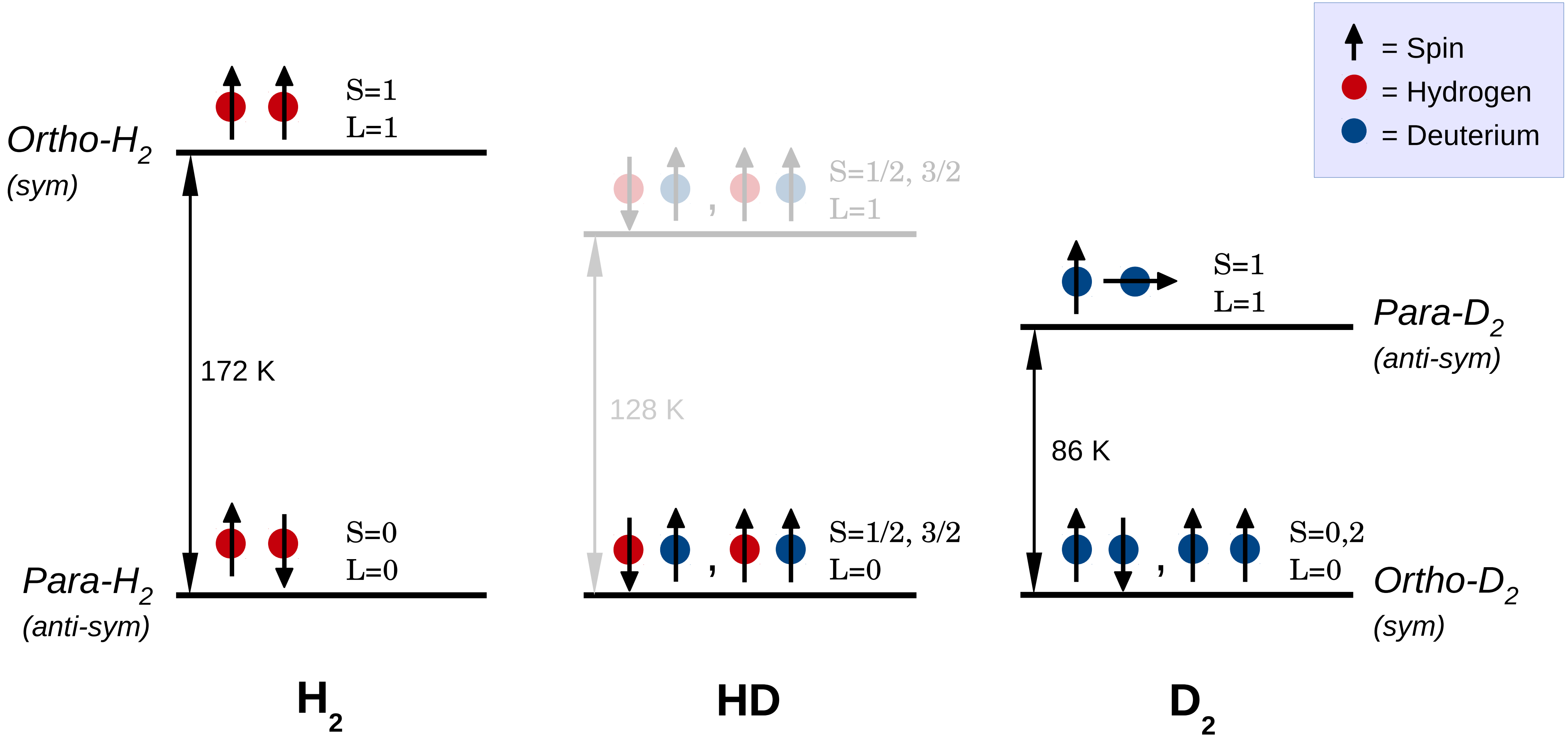






Polarization process

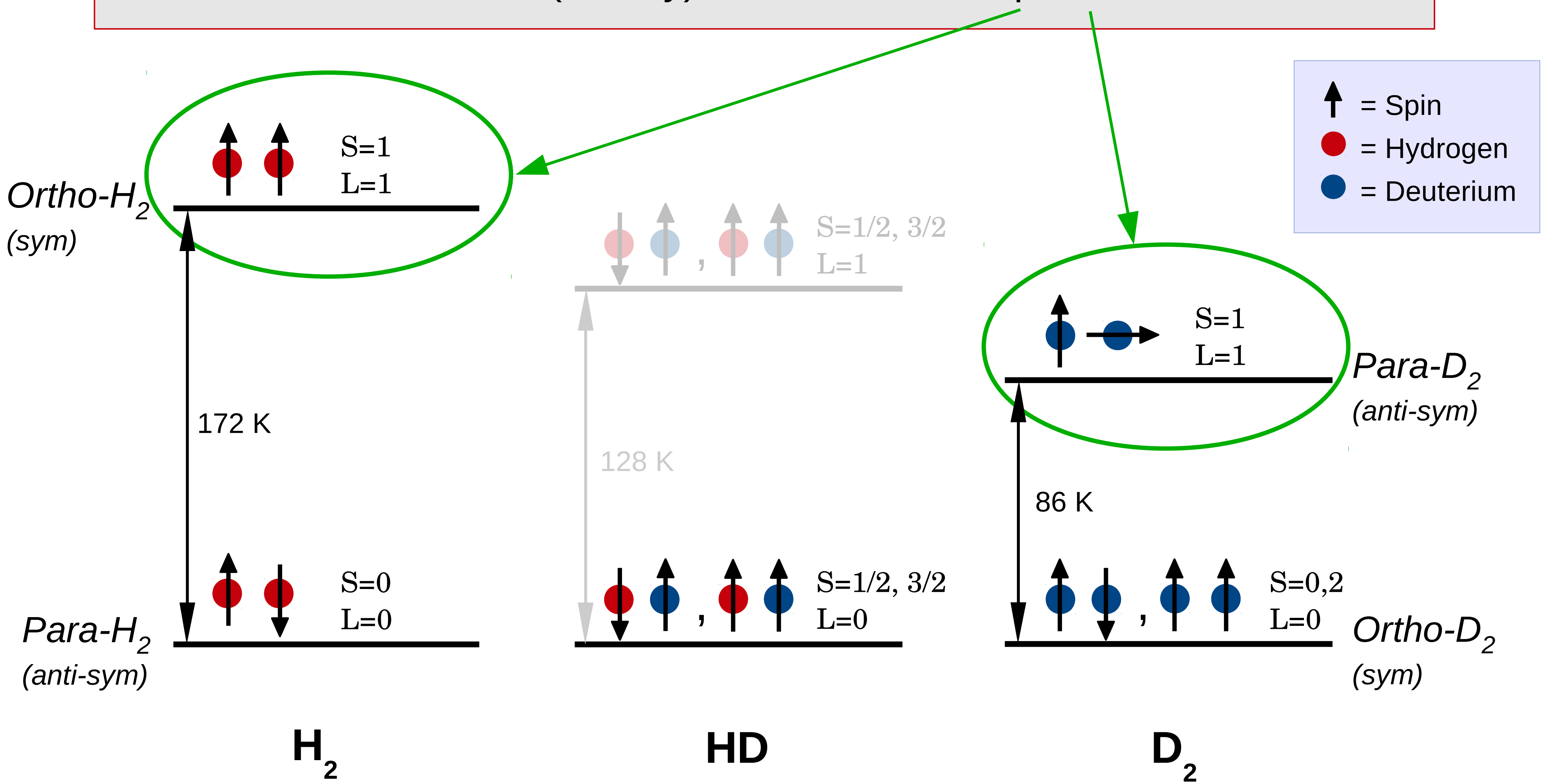
How does one make polarized, frozen-spin HD?



Polarization process

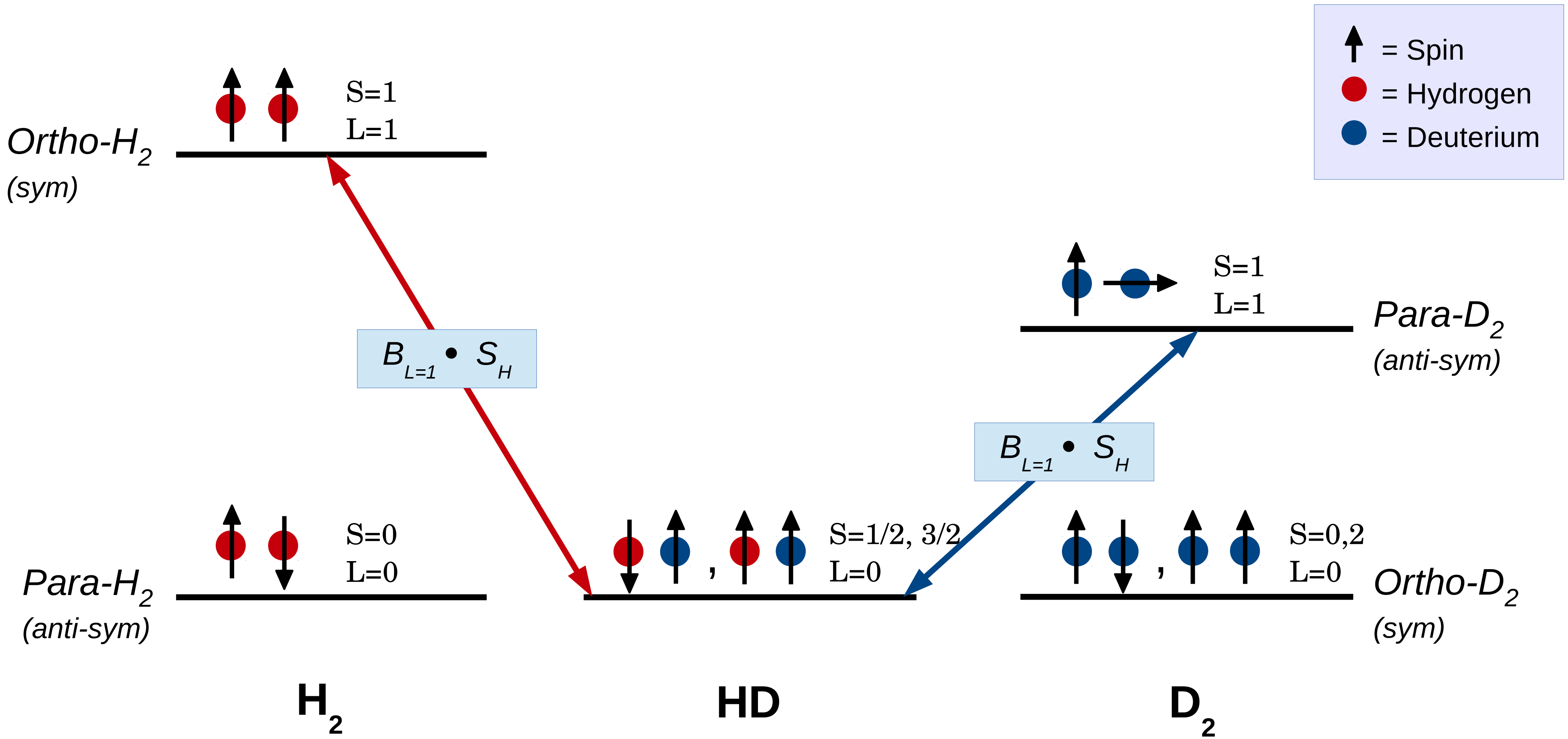
What polarization mechanisms can we use?

- For all molecules, we have 2 electrons paired in 1s orbital ⇒ no DNP
- For all molecules, we (initially) have $S \neq 0$ ⇒ couples to B field



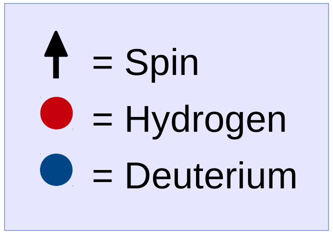
Polarization process

External magnetic field rapidly aligns the *Ortho-*H_2 and *Para-*D_2 which spin-exchange with the H and D (respectively) in the HD crystal.

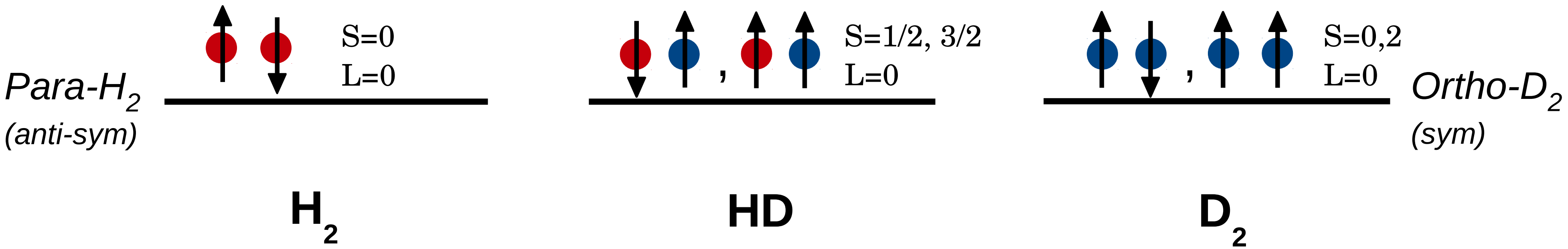


Polarization process

This process continues until there are only inactive, L=0 states remaining.



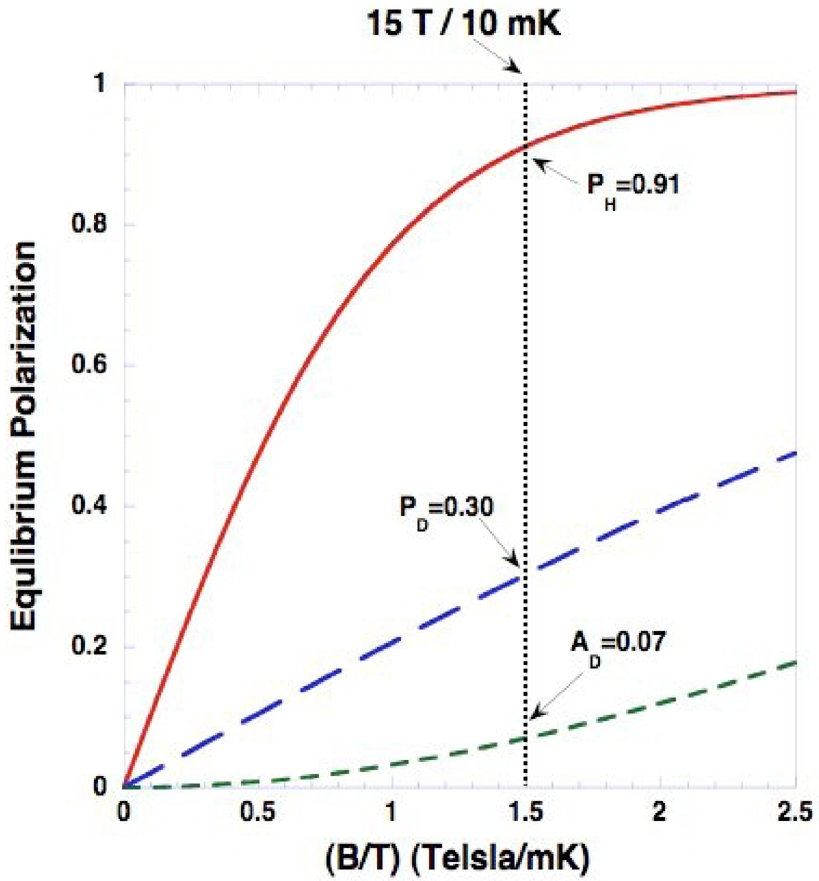
The nucleons are now in a frozen-spin state: a state in which the polarized nucleons are so cold, there are (essentially) no available depolarization mechanisms.



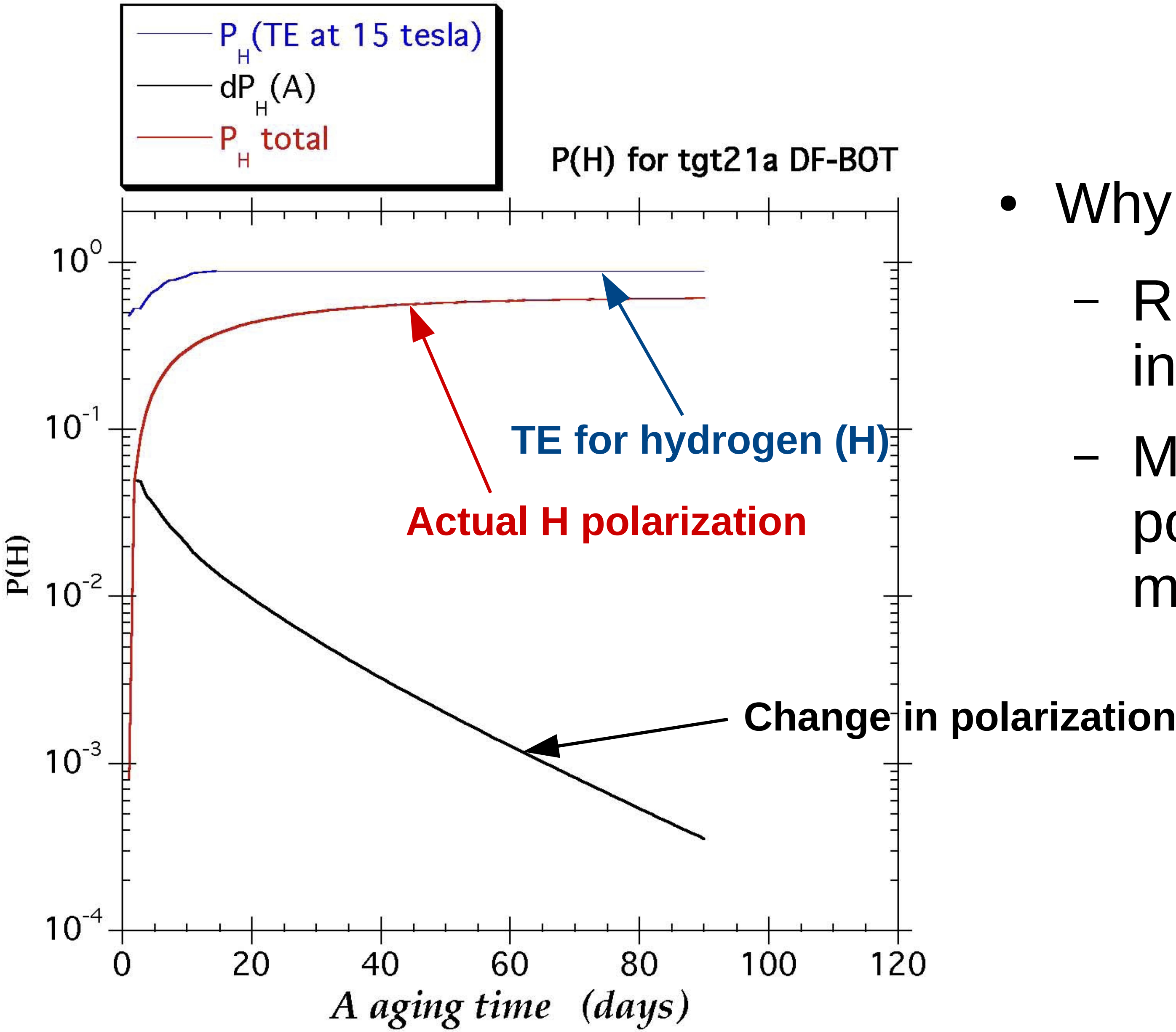
Polarization process

(in words)

- Solid HD target is loaded into Dilution Fridge.
- Spins are aligned using a 15 T magnet at temperatures of ~10 mK.
- The (L=1) H_2 and D_2 molecules are polarized (are considered impurities).
- Polarized (L=1) H_2 and D_2 nuclei spin exchange with HD, polarizing it.
- After ~3 months, the L=1 H_2 and D_2 molecules decay down to L=0 and are no longer polarizable.
- TE for these conditions lead to P(H) = 90% and P(D) = 30%



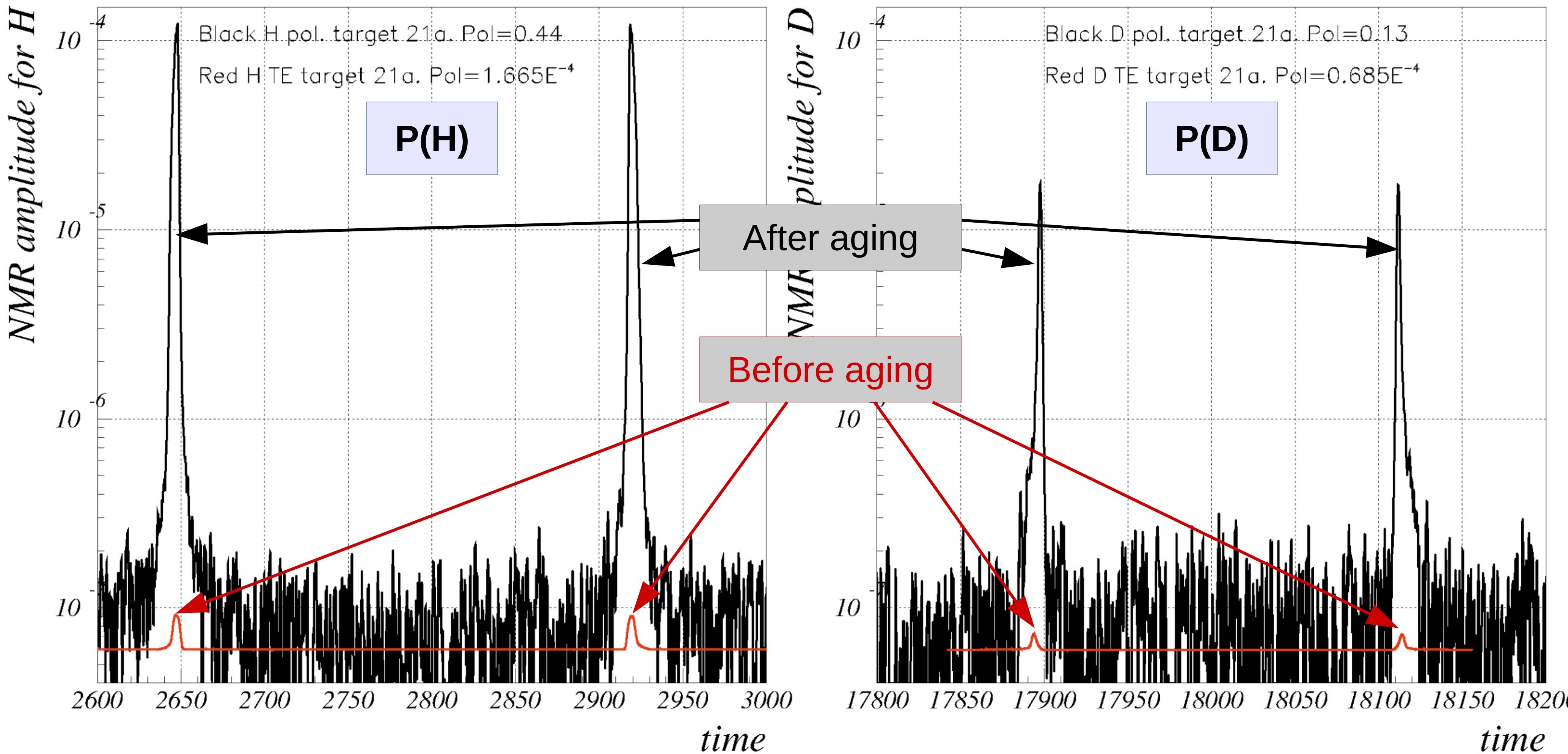
Polarizing the Target



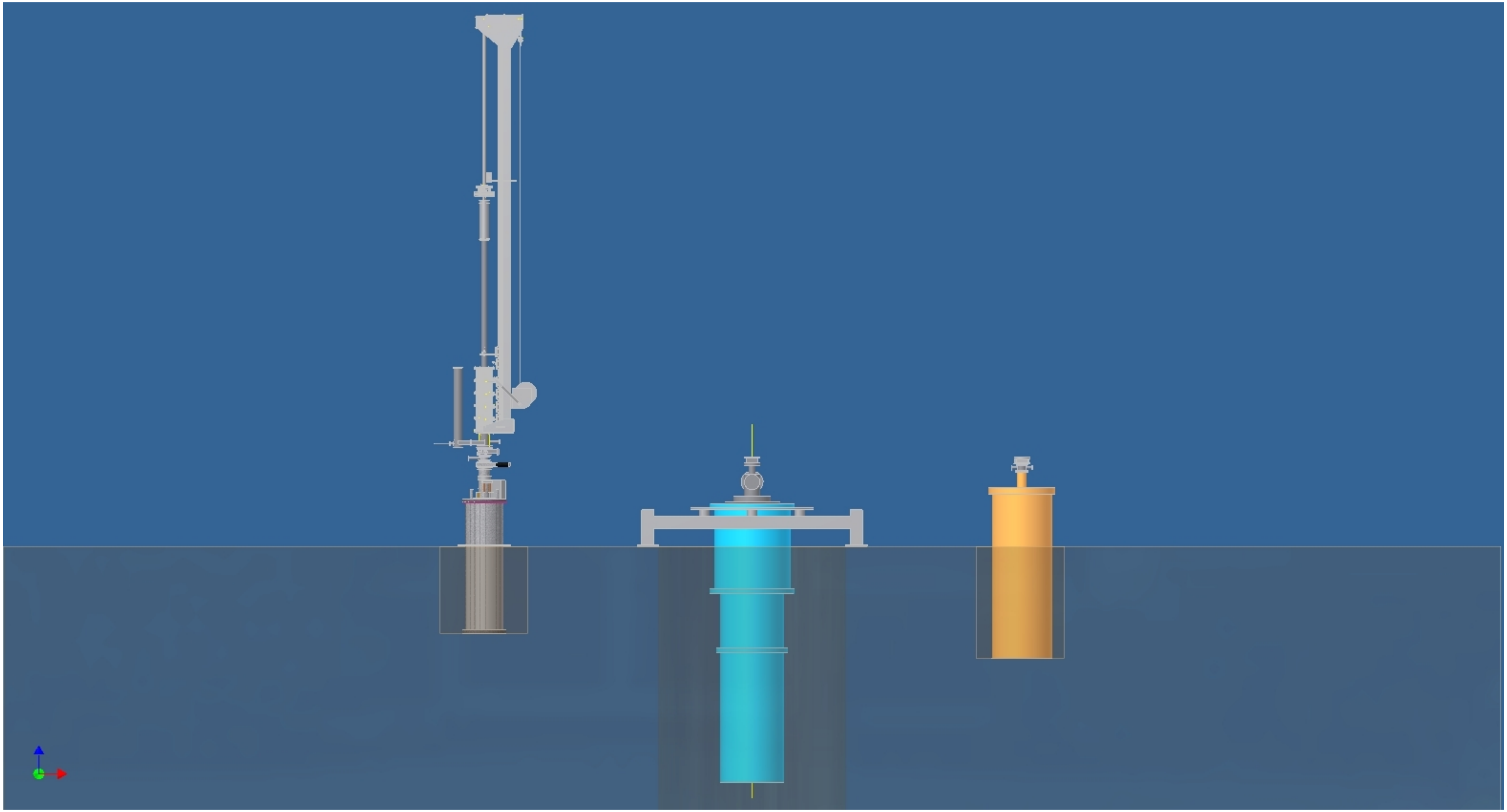
- Why so long?
  - Reaches 50% of TE in ~7 days
  - Maximum polarization a few months

Polarizing the Target

- After 3 months, target transferred from DF to PD for NMR
- Polarization can be determined and compared to before HD was aged in DF

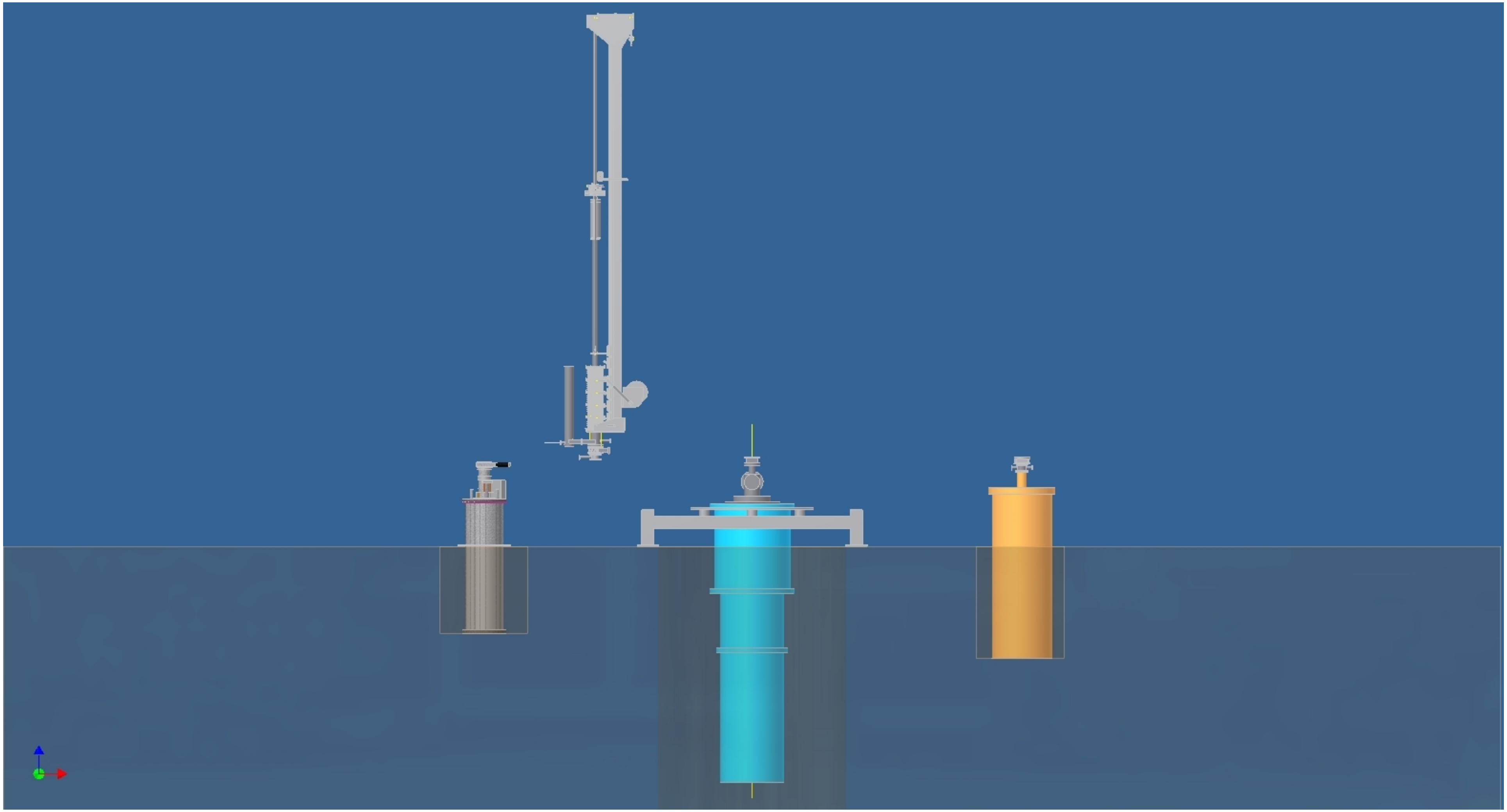


Target Transfer: PD to SD



Target transfer to SD for storage/transport

Target Transfer: PD to SD



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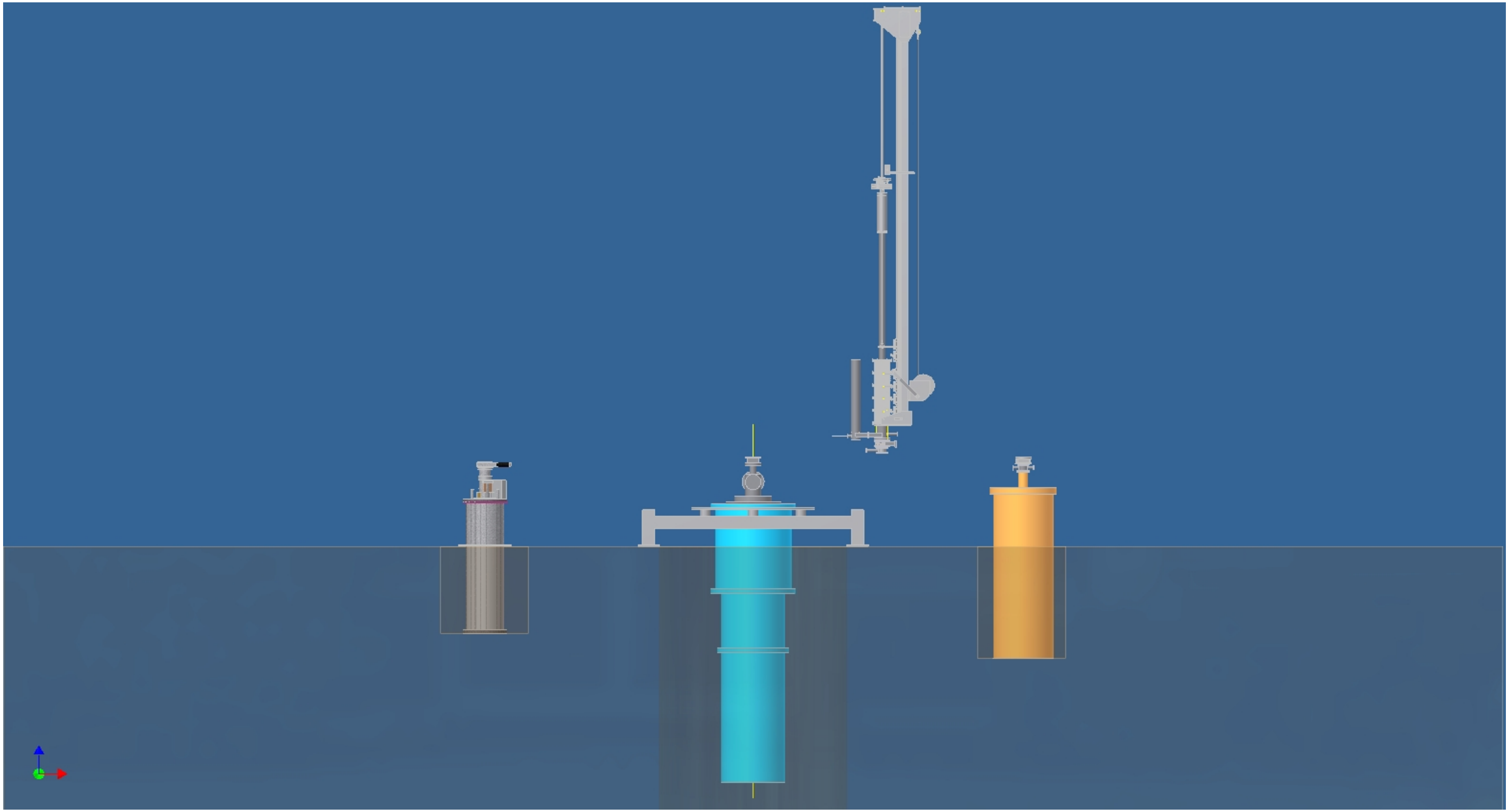
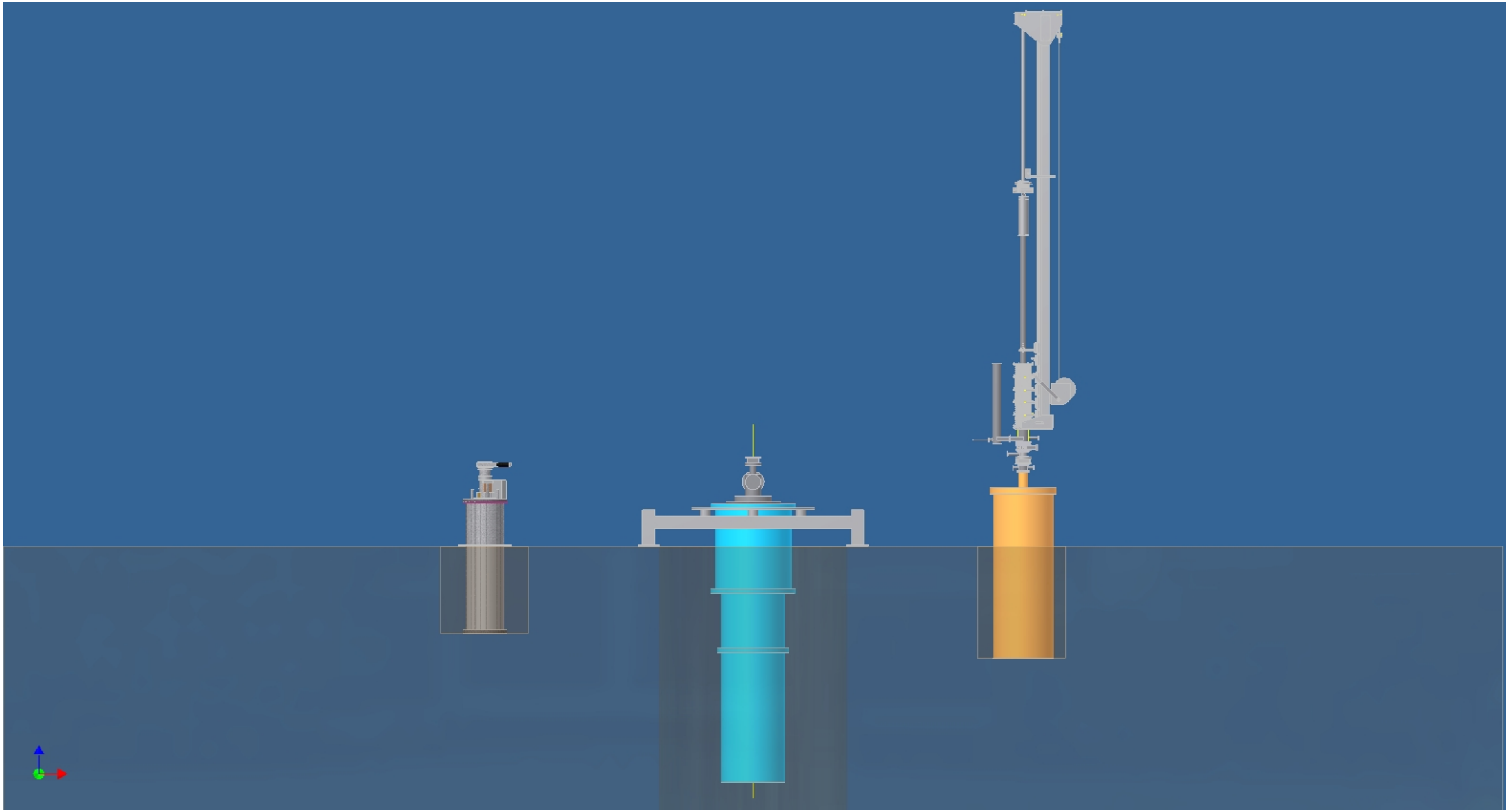


Target transfer to SD for storage/transport

Target Transfer: PD to SD

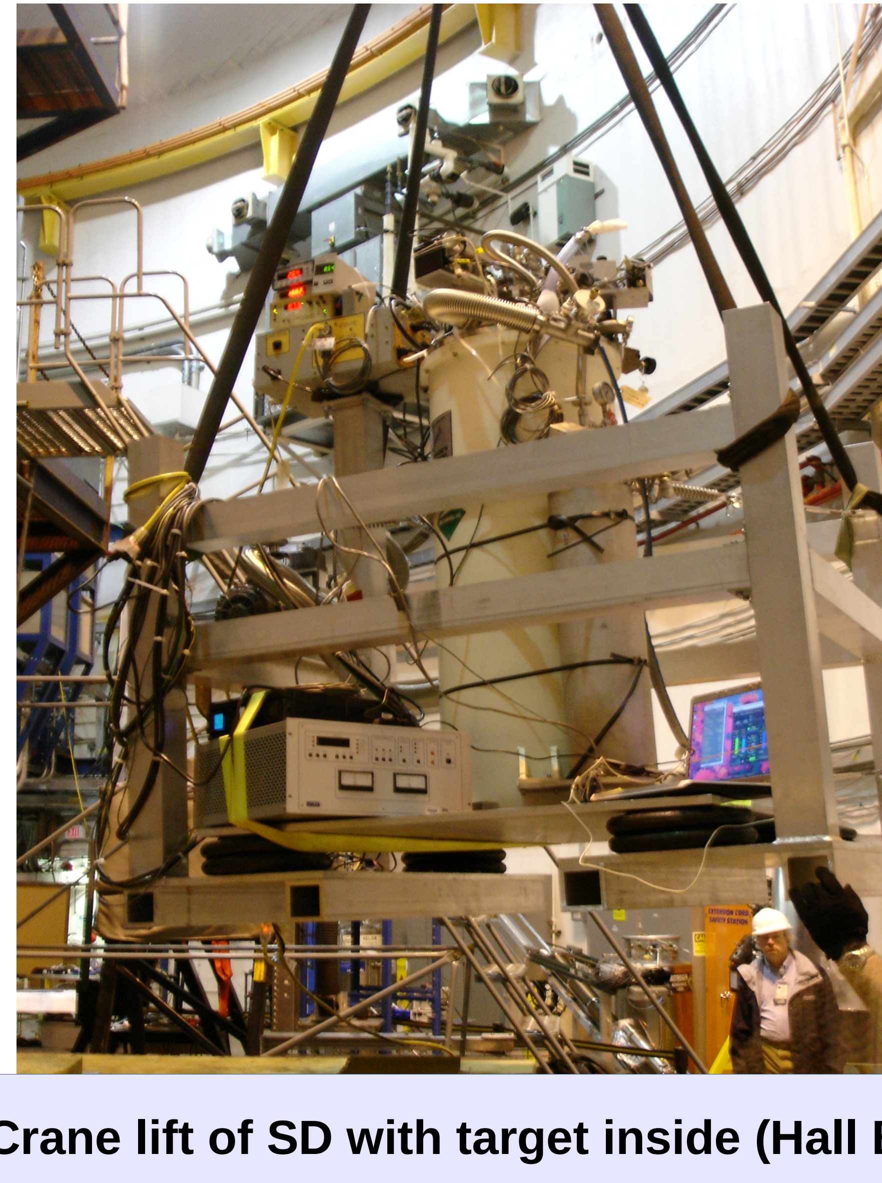


Target transfer to SD for storage/transport

Target Transport

- SD (with target) may be transported while magnet is on (persistent mode) and LHe space pumped to 1.7 K

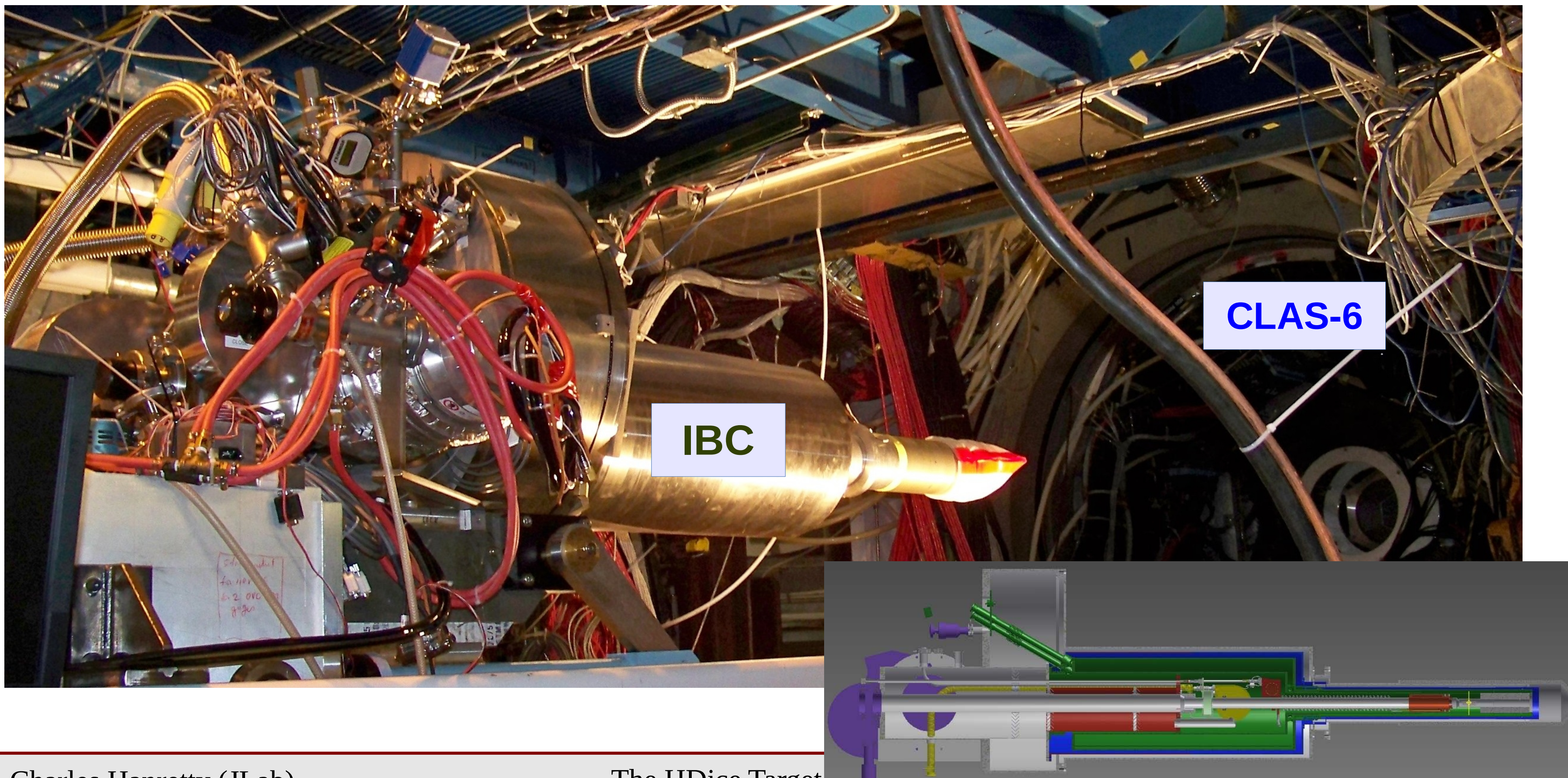
Transporting SD to Hall B (g14)



Crane lift of SD with target inside (Hall B)

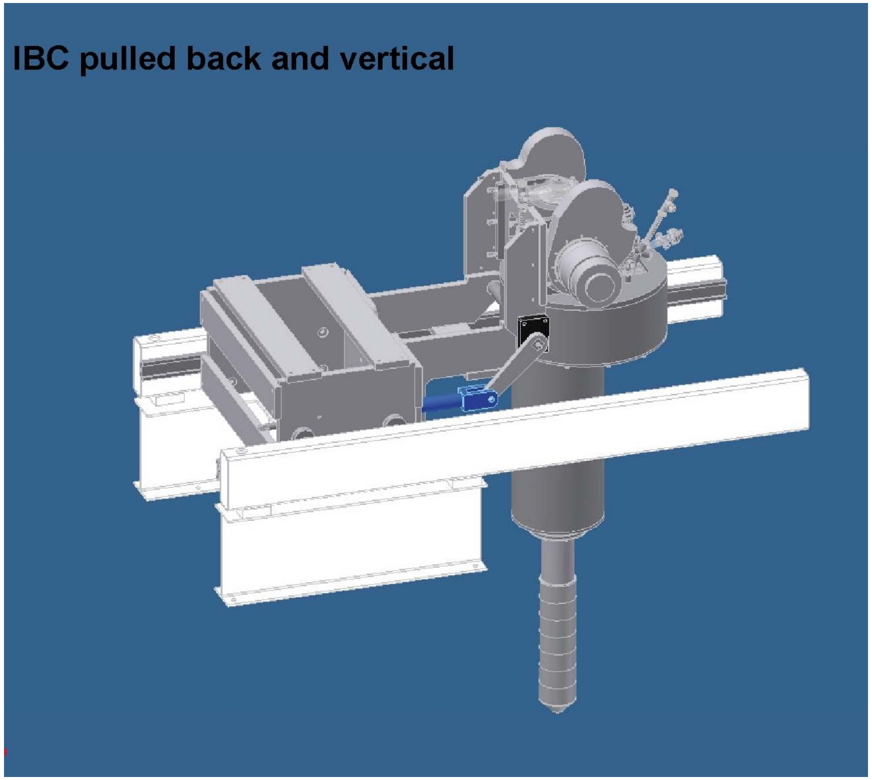
In-Beam Cryostat (IBC)

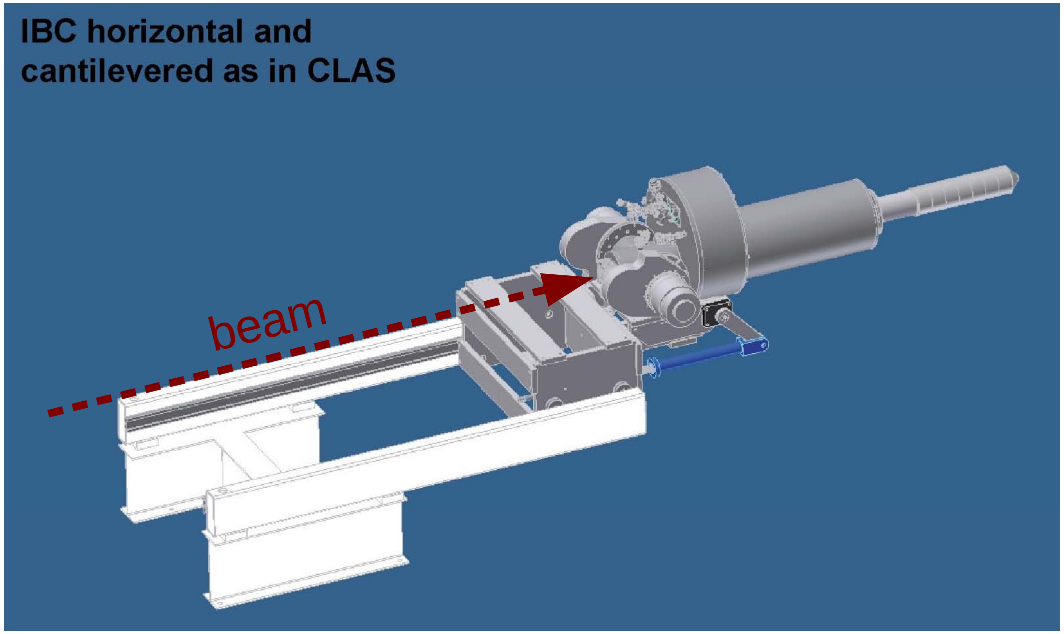
- For in-beam operations (data-taking), the In-Beam Cryostat (IBC) is used.



In-Beam Cryostat (IBC)

- IBC is a Dilution Refrigerator capable of operating both vertically (for docking with TC) and horizontally (for data-taking).
- T = 50 mK
- B = 1 T (solenoid); 0.075 T (saddle)





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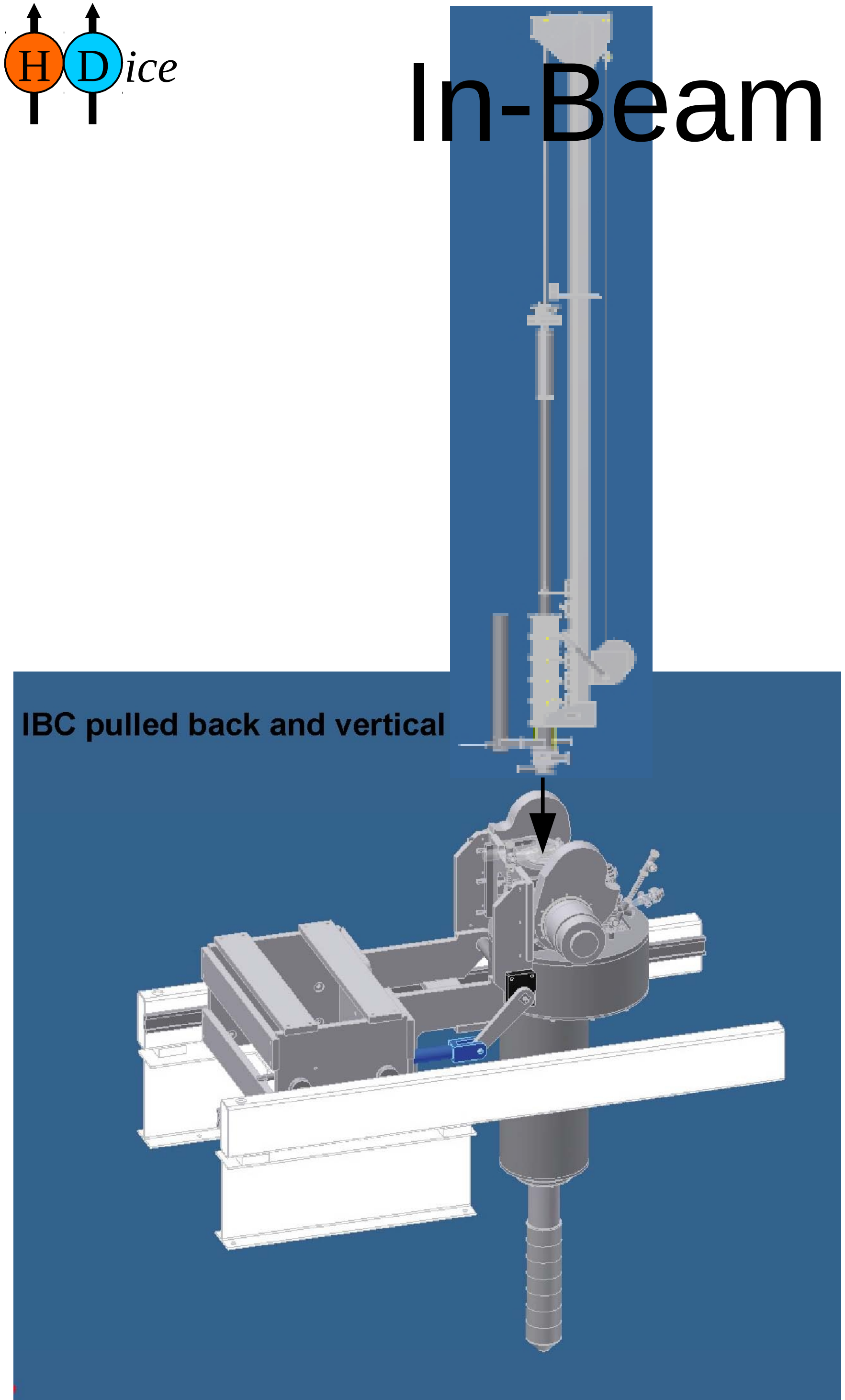

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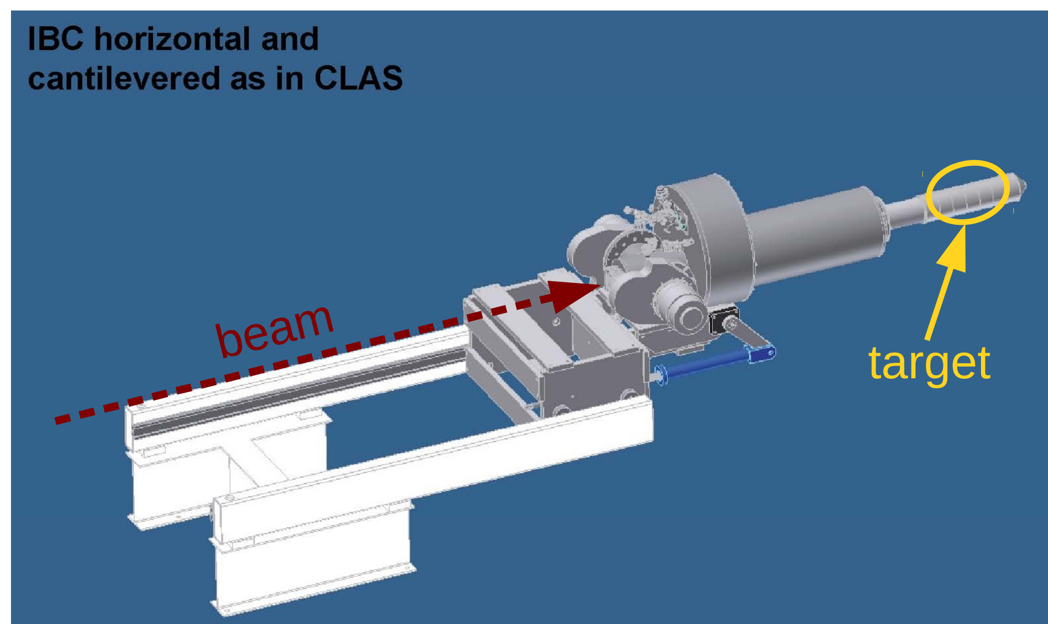


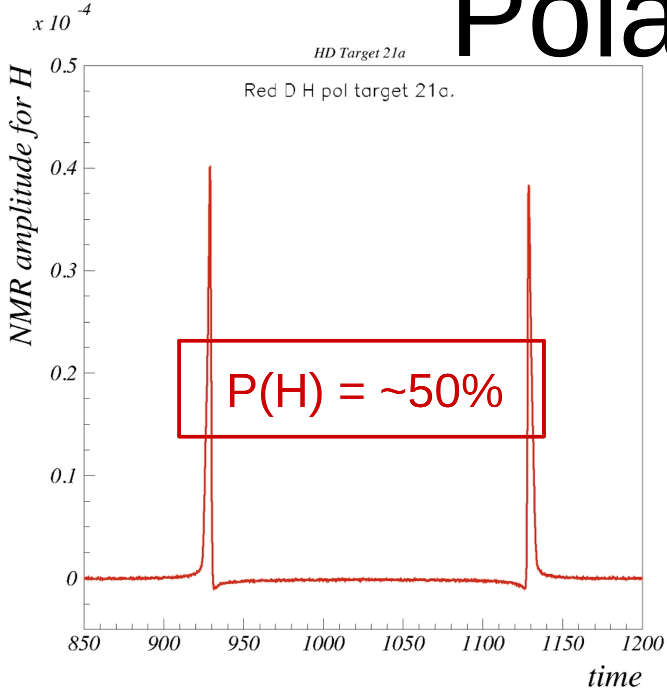
Ready for running but...

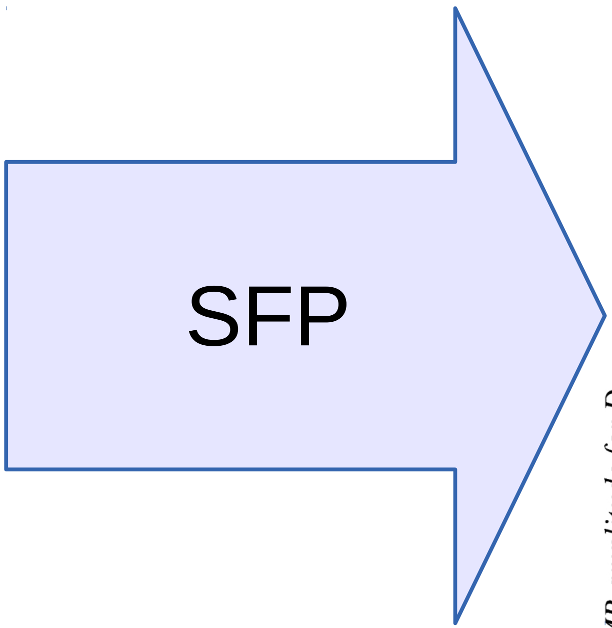
- ...Is there anything we can do to improve the target polarization?
- P(H) = 90% and P(D) = 30% are <u>ideal</u> values.
- In reality, P(H) = 60$\pm$5% and P(D) = 15$\pm$7% is essentially the best we can hope for using aging alone.
- Can we give some of the H polarization to D?

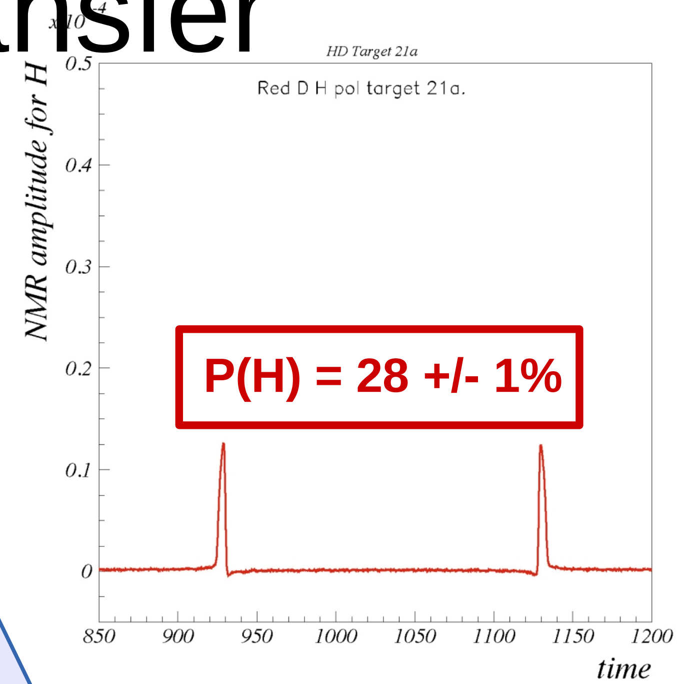
Polarization Transfer

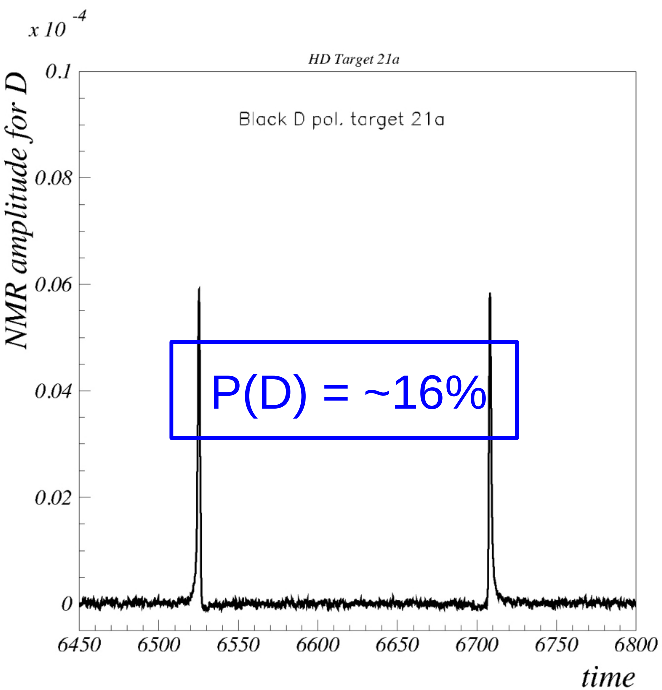
- Forbidden Adiabatic Fast Passage (FAFP):
  - Uses one large RF field sweep to transfer P(H) to P(D)
  - Pros: potential 100% efficiency
  - Cons: only one chance (one large RF field sweep), everything must work perfectly, high RF power heats fridge, (RF) field jitter decreases efficiency
- Saturated Fast Passage-Multi FAFP:
  - Uses many small RF sweeps to transfer P(H) to P(D)
  - Pros: guaranteed efficiency is 50%, lower RF power → less heating, (RF) field jitter helps
  - Cons: max efficiency is 50%

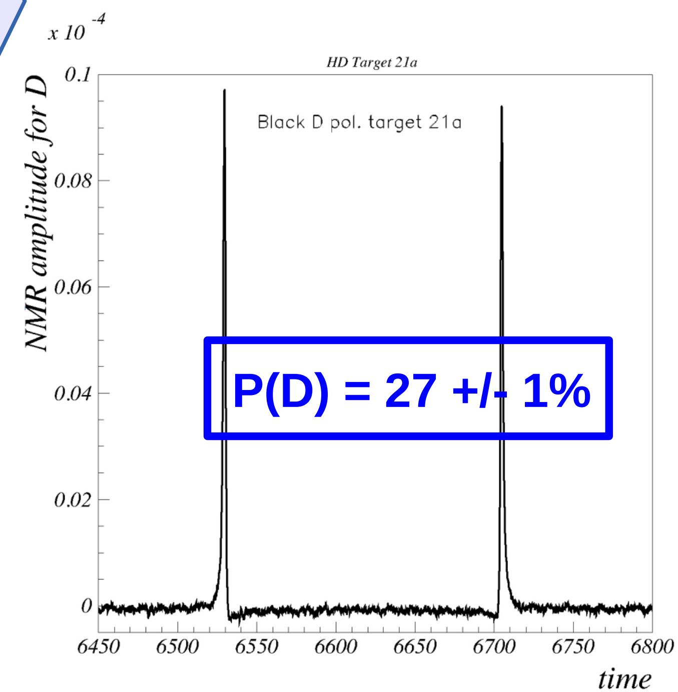
Polarization Transfer











Analyses using g14 data

Dao Ho (CMU):
$\gamma_c D \to p\,\pi^-\,(p)$
$\gamma_c D \to K^0\,\Lambda\,(p)$
$\gamma_c D \to D\,\pi^+\,\pi^-$
$\gamma_c D \to K^0\,\Sigma^0$

Peng Peng (UVA):
$\gamma_c p(n) \to p\,\pi^+\,\pi^-\,(n)$
$\gamma_c n(p) \to n\,\pi^+\,\pi^-\,(p)$
$\gamma_c n(p) \to p\,\pi^-\,(p)$

Irene Zonta (Roma-II):
$\gamma_c n(p) \to \rho n(p) \to n\,\pi^+\,\pi^-\,(p)$

Tsuneo Kageya (JLab):
$\gamma_c n(p) \to p\,\pi^-\,(p)$

Haiyun Lu (CMU, U. Iowa):
$\gamma_L n(p) \to p\,\pi^-\,(p)$

Jamie Fleming (U. Edinburgh):
$\gamma_L p \to p\,\pi^+\,\pi^-$
$\gamma_L n(p) \to n\,\pi^+\,\pi^-\,(p)$
$\gamma_c n(p) \to K^+\,\Sigma^-\,(p)$

Analyses using g14 data

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$\gamma_c D \rightarrow p\, \pi^- \,(p)$

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Peng Peng (UVA):

$\gamma_c p(n) \rightarrow p\, \pi^+\, \pi^- \,(n)$

$\gamma_c n(p) \rightarrow n\, \pi^+\, \pi^- \,(p)$

$\gamma_c n(p) \rightarrow p\, \pi^- \,(p)$

Tsuneo Kageya (JLab):

To be discussed at the Hadron Spectroscopy Working Group Meeting tomorrow

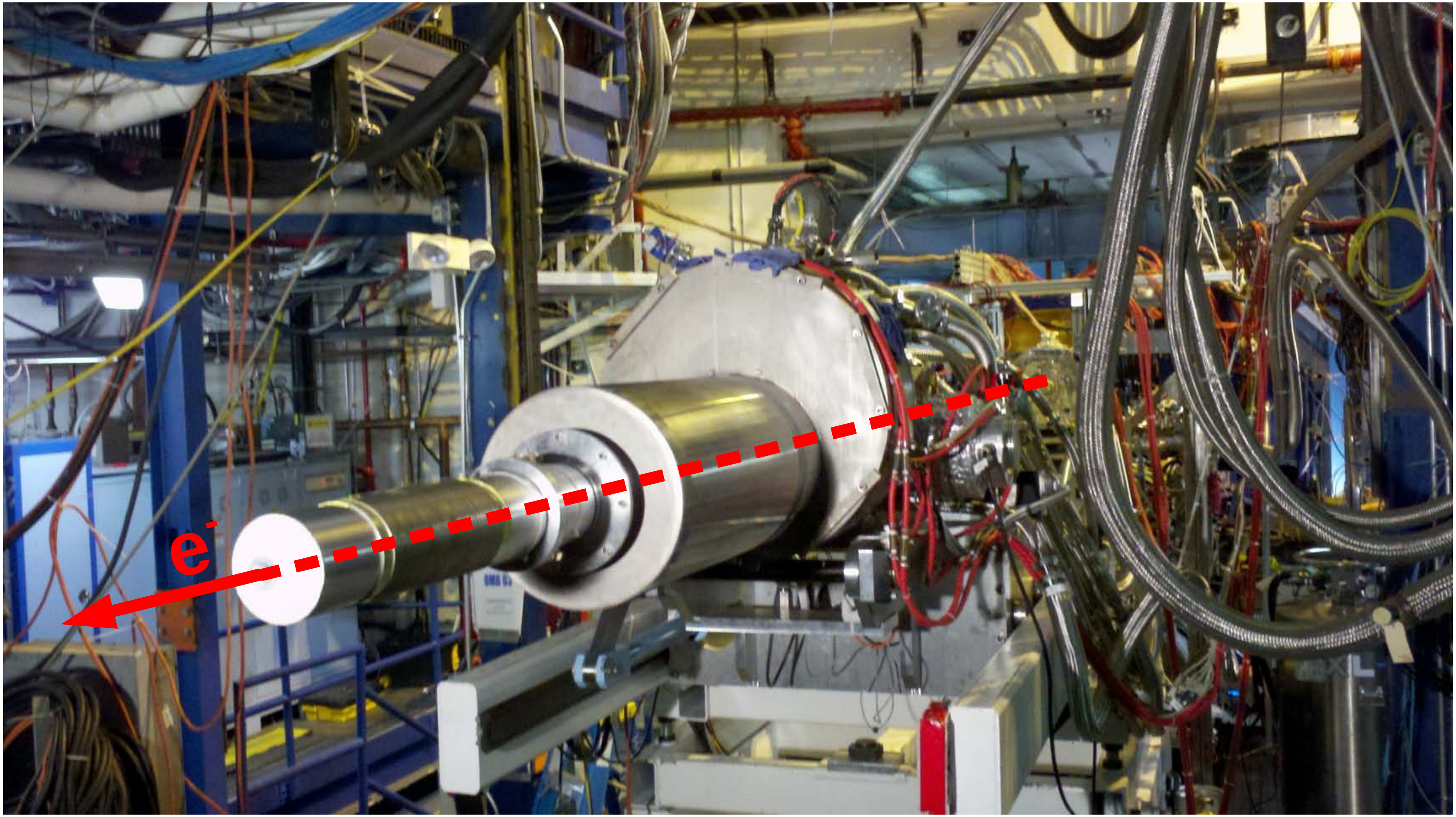
$\gamma_L n(p) \rightarrow p\, \pi^- \,(p)$

$\gamma_L n(p) \rightarrow n\, \pi^+\, \pi^- \,(p)$

$\gamma_c n(p) \rightarrow K^+\, \Sigma^- \,(p)$

eHD

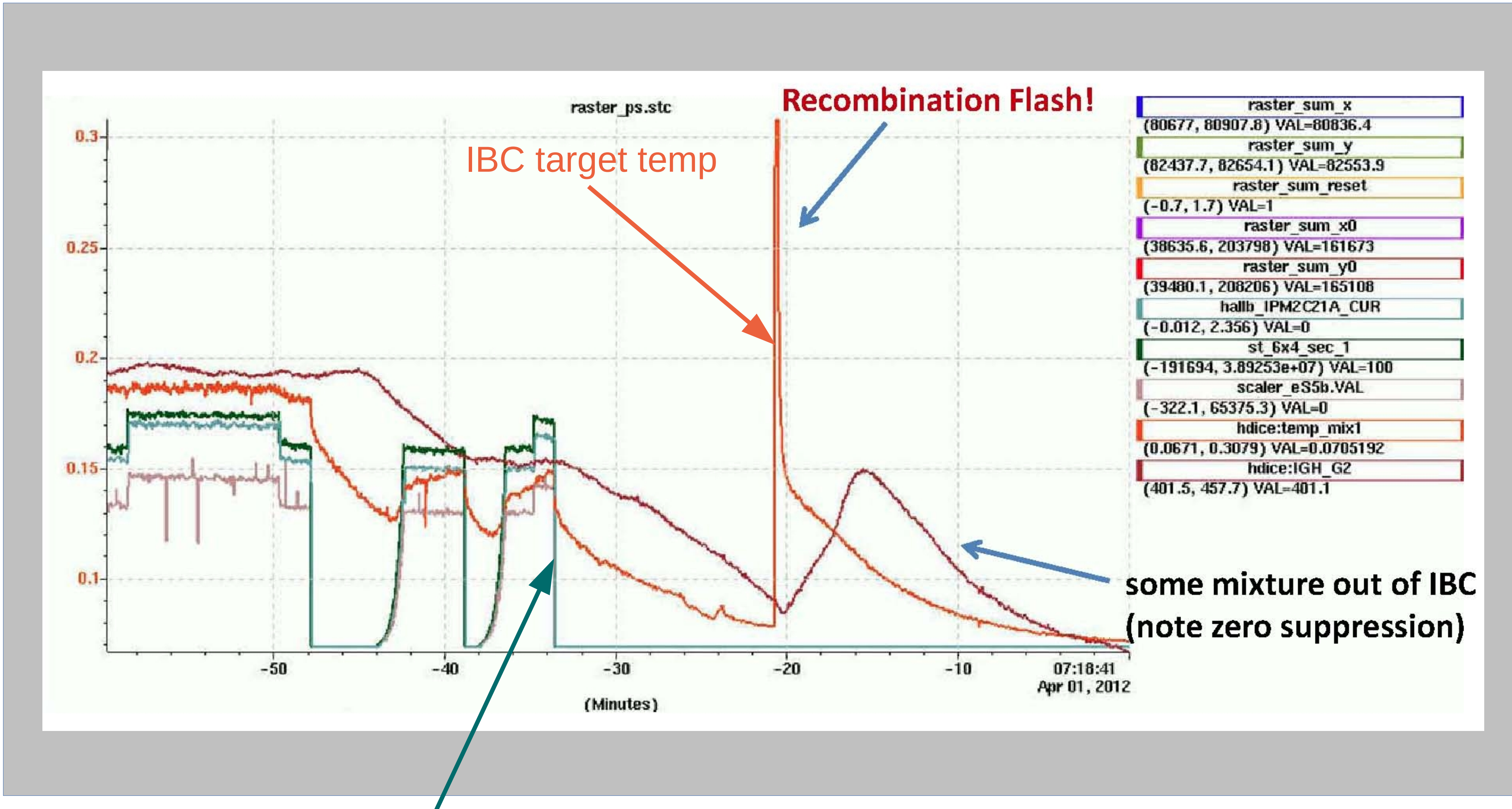
- During g14, eHD tests were conducted to study how the target (and IBC) fared with electrons.



eHD during g14

- Three depolarization mechanisms were found.
- Local beam heating:
  - The T1 of the target material is a function of B/T.
  - Temperature spikes reduce the T1 → no more frozen spin
- Unpairing of 1s electrons:
  - Beam heating unpairs the electrons in 1s shell
  - Residual electron is unpolarized (function of temp) → flips with a frequency that has Fourier components at D and H Larmor frequencies
  - Depolarizes nearby HD; depolarization spreads
- Ionization of HD:
  - HD molecule loses an electron (becomes ionized), is highly reactive
  - Chain of chemical reactions begin which culminate in a “recombination flash” → produces significant heat in target → loss of polarization

eHD during g14



Beam current

eHD during g14

- Three depolarization mechanisms were found.
- Local beam heating:
  - The T
  - Temp
- Unpairin
  - Beam
  - Resid a freque quencies
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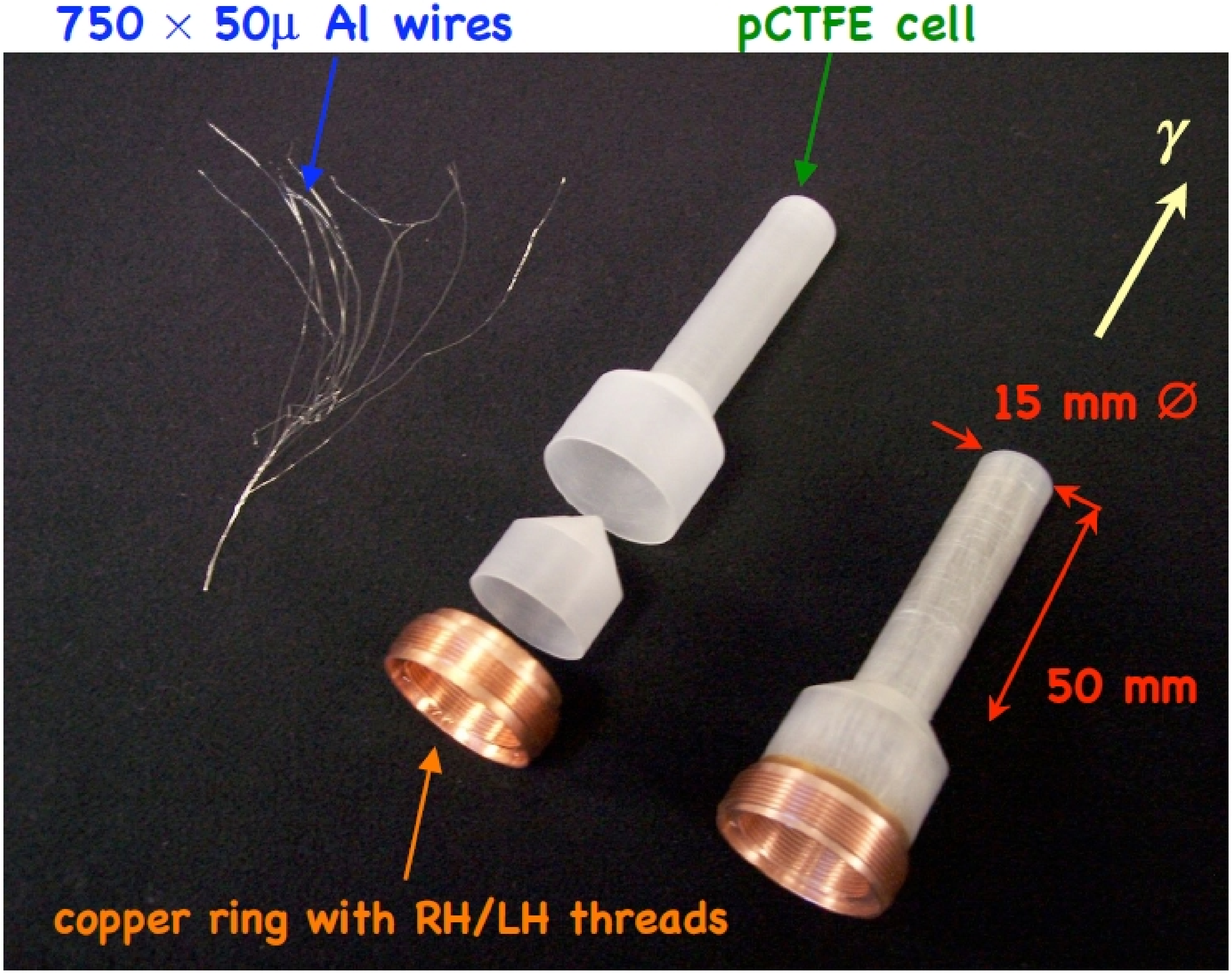
- Ionization of HD:
  - HD molecule loses an electron (becomes ionized), is highly reactive
  - Chain of chemical reactions begin which culminate in a “recombination flash” → produces significant heat in target → loss of polarization

<u>Solutions:</u>

- Make target cell shorter and fatter
- Make Aluminum wires shorter and fatter to remove heat faster
- Faster Raster

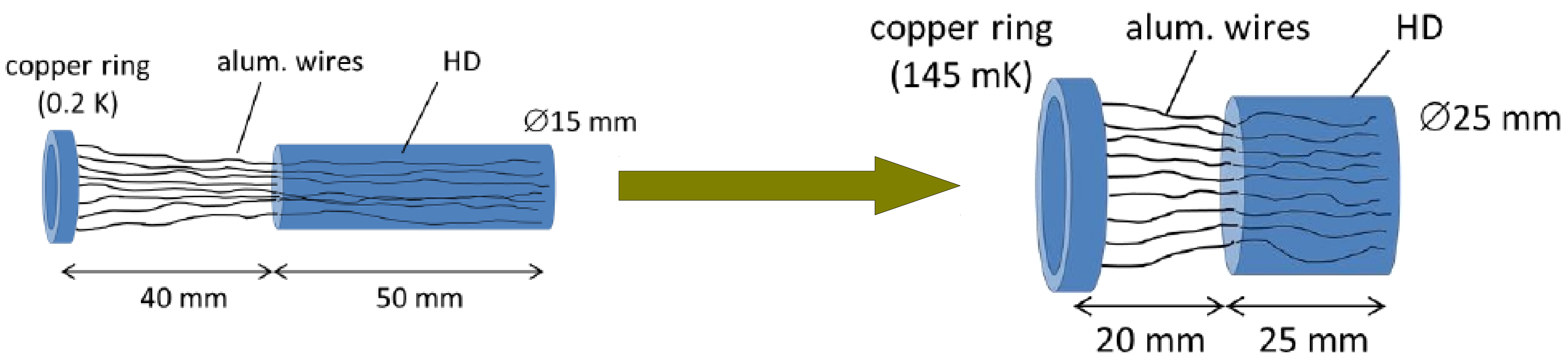
eHD: Target cell redesign

g14 Cell:



eHD: Target cell redesign

- eHD target cell will be half the length and almost twice the diameter of the g14 cell
- Aluminum wires will be shorter and thicker
- Effect: Lower equilibrium temperature of HD



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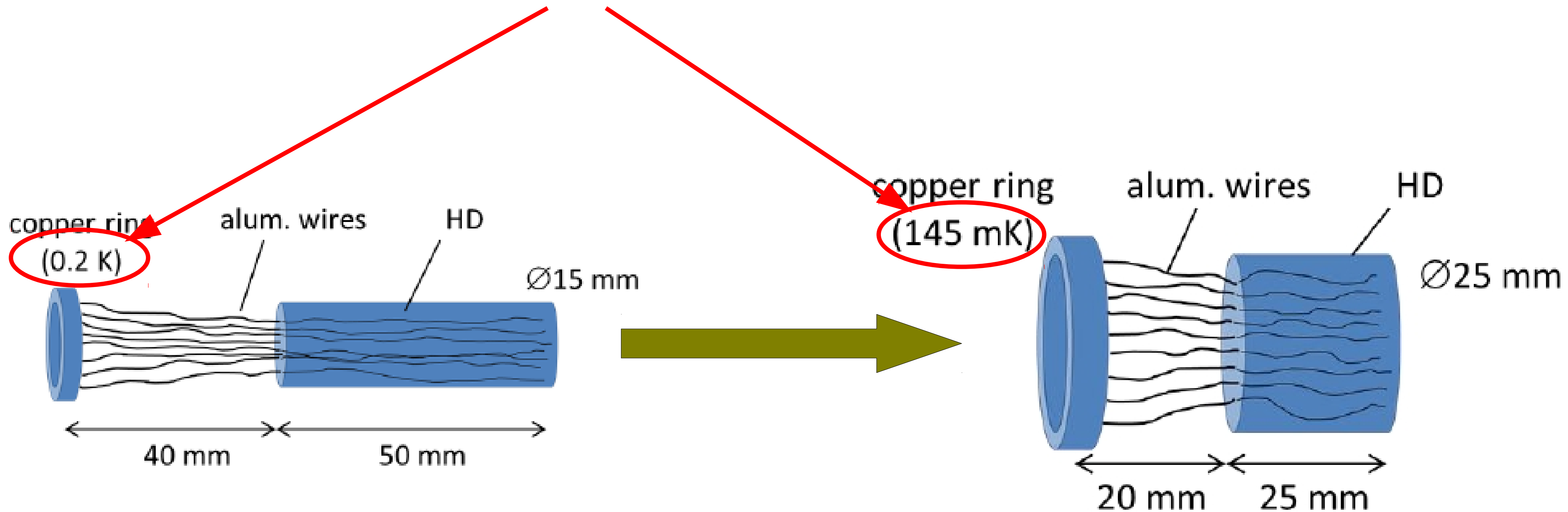
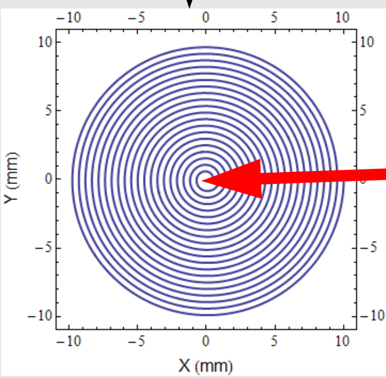


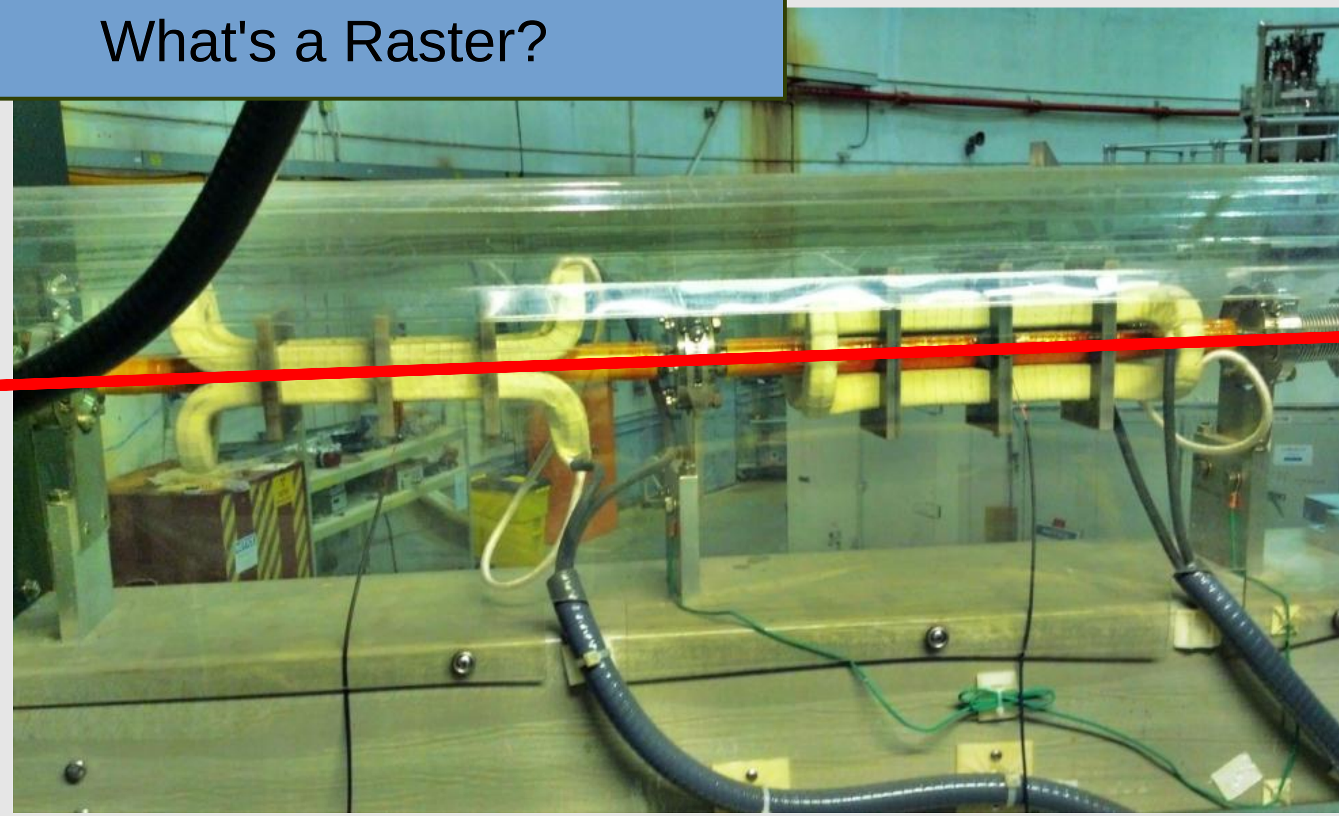
eHD: Faster Raster

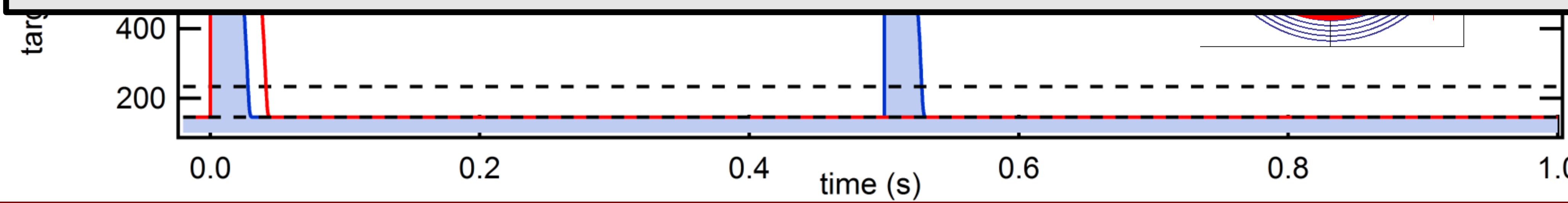
What's a Raster?

Upstream face of target



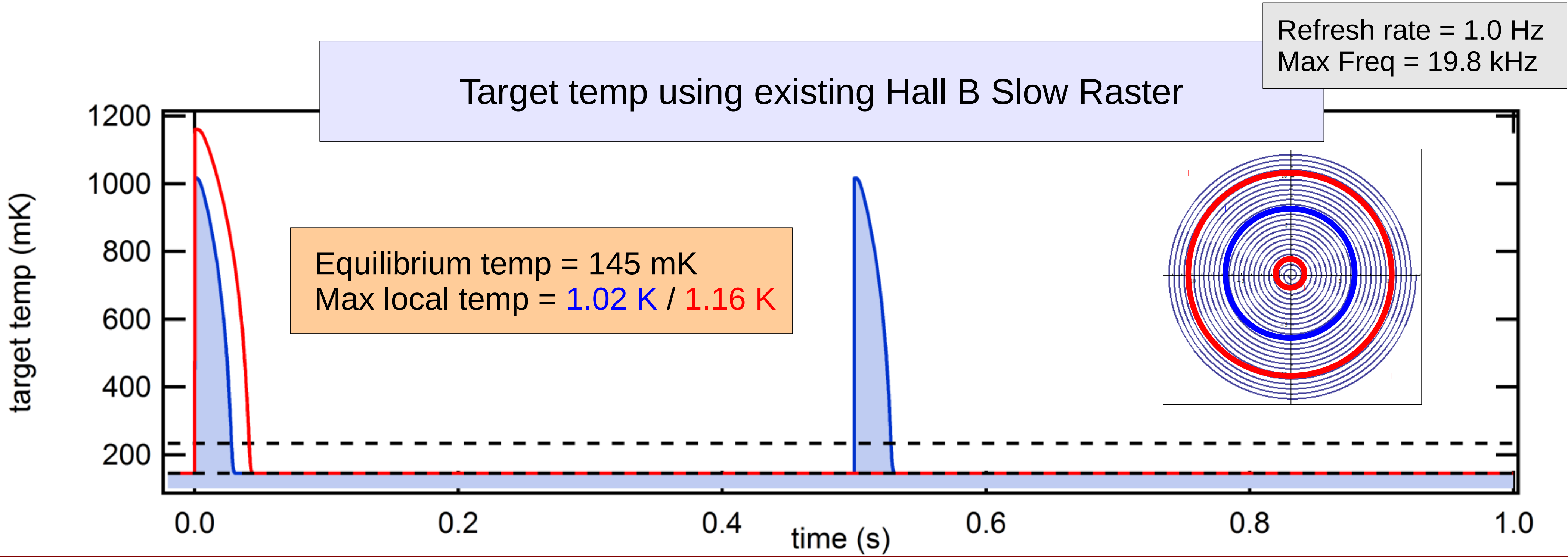
Beam





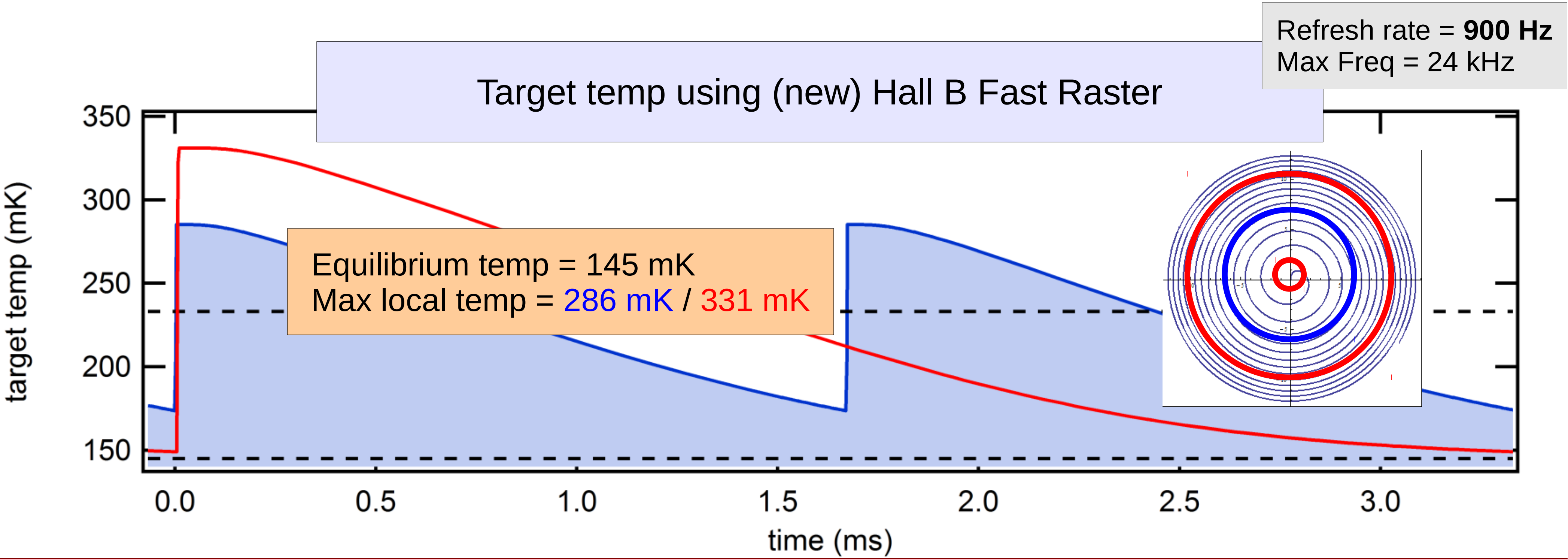
eHD: Faster Raster

- New target cell design leads to equilibrium temp of 145 mK but local temps can still reach over 1000 mK

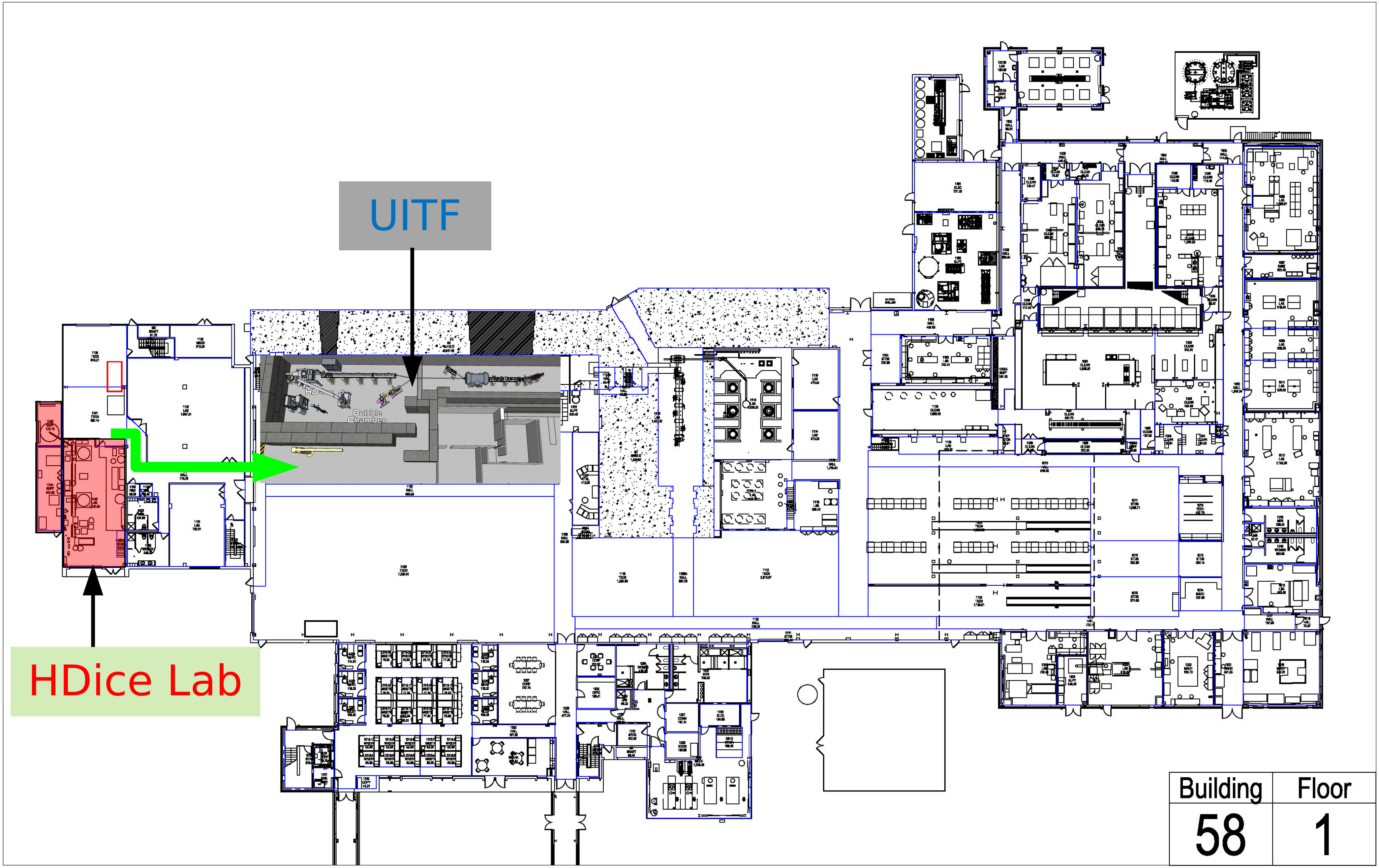


eHD: Faster Raster

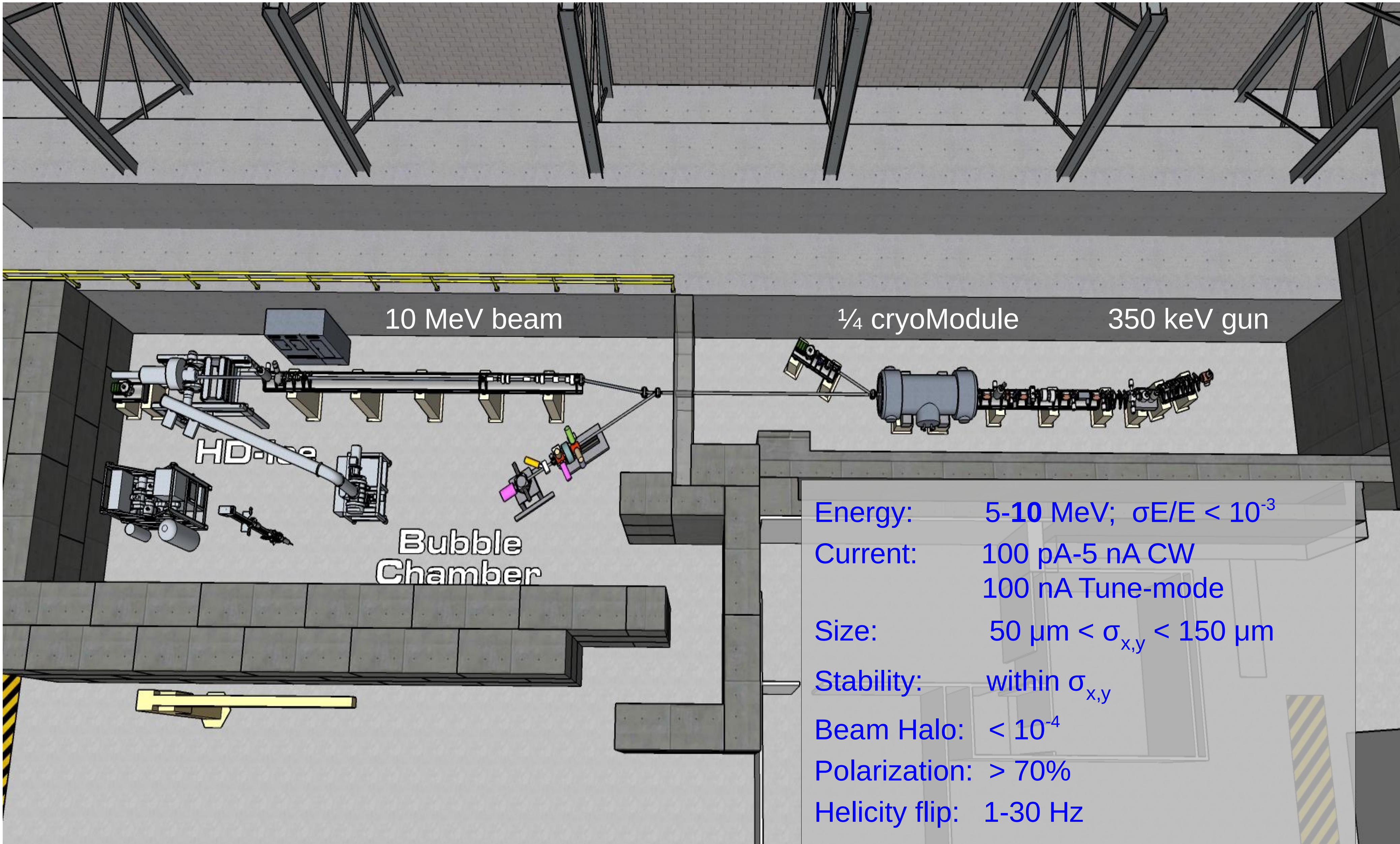
- New target cell design leads to equilibrium temp of 145 mK but local temps can still reach over 1000 mK
- By increasing the speed of the Raster (and altering the pattern), the temperature of the target material is greatly reduced



eHD Tests in UITF



eHD Tests in UITF



Energy: 5-**10** MeV; $\sigma E/E < 10^{-3}$

Current: 100 pA-5 nA CW
100 nA Tune-mode

Size: $50\ \mu m < \sigma_{x,y} < 150\ \mu m$

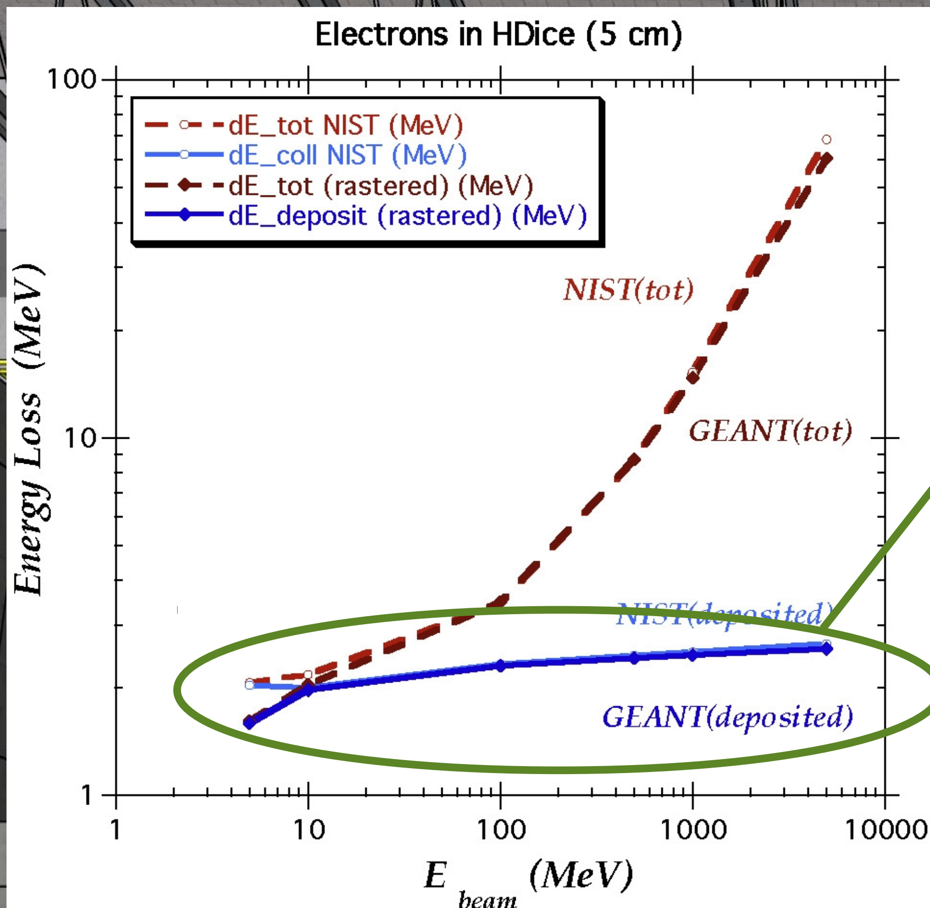
Stability: within $\sigma_{x,y}$

Beam Halo: $< 10^{-4}$

Polarization: > 70%

Helicity flip: 1-30 Hz

eHD Tests in UITF



Ionization and energy deposition are approx independent of E_{beam}

UITF at 10 MeV ≃ Hall B at 10 GeV

Energy: 5-**10** MeV; $\sigma E/E < 10^{-3}$

Current: 100 pA-5 nA CW
100 nA Tune-mode

Size: 50 μm < $\sigma_{x,y}$ < 150 μm

Stability: within $\sigma_{x,y}$

Beam Halo: < 10^{-4}

Polarization: > 70%

Helicity flip: 1-30 Hz

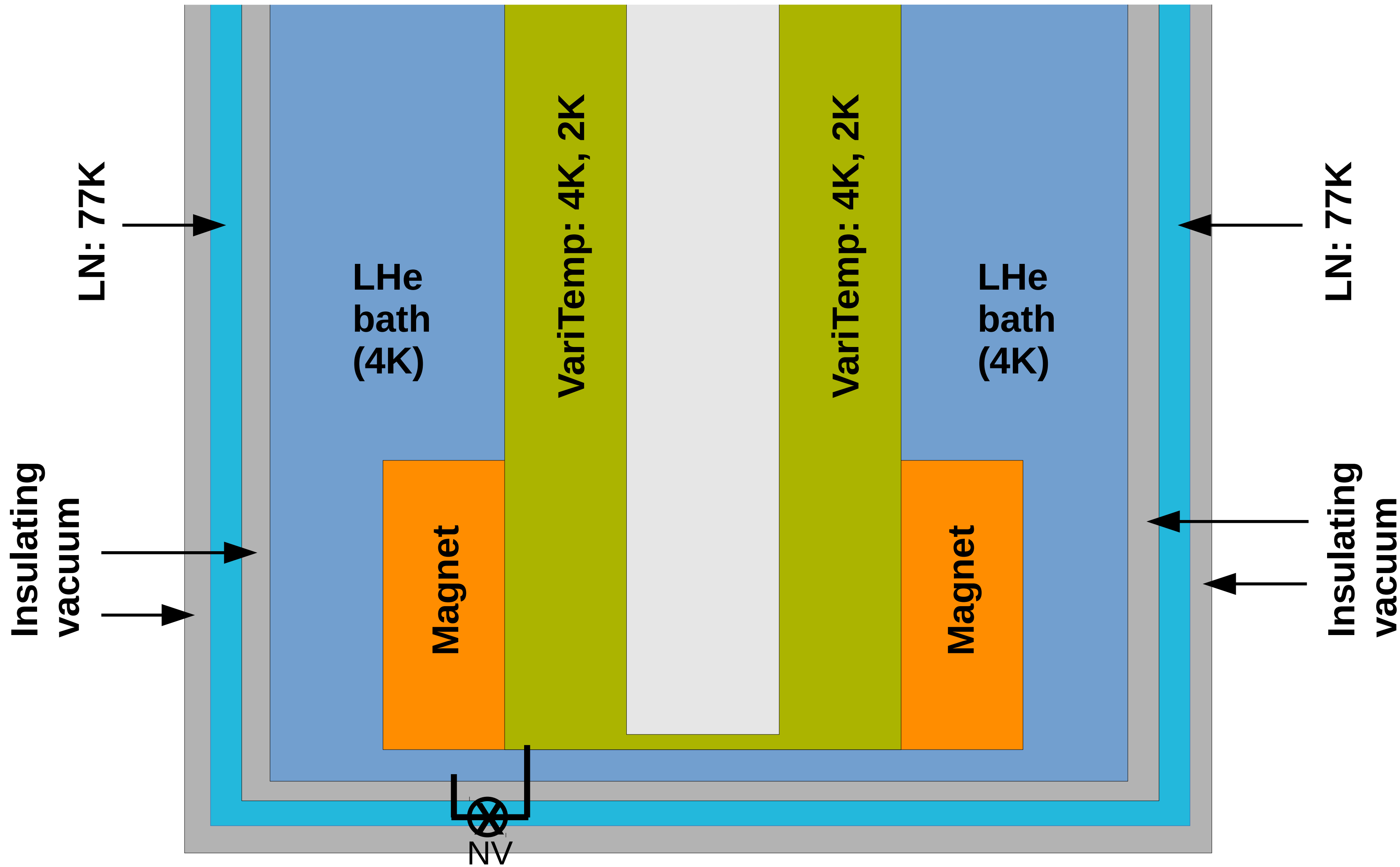
Summary

- HDice is a new type frozen spin target designed for fixed target experiments at JLab.
- Is a complicated target system utilizing many steps and pieces of equipment in the production of a single target cell.
- Has been used with photons as part of the N* program in Hall B (g14).
- Has potential as a transversely polarized frozen spin target for use with electrons ➡ no large magnets.
- eHD tests to be carried out in the UITF in Fall 2016

END

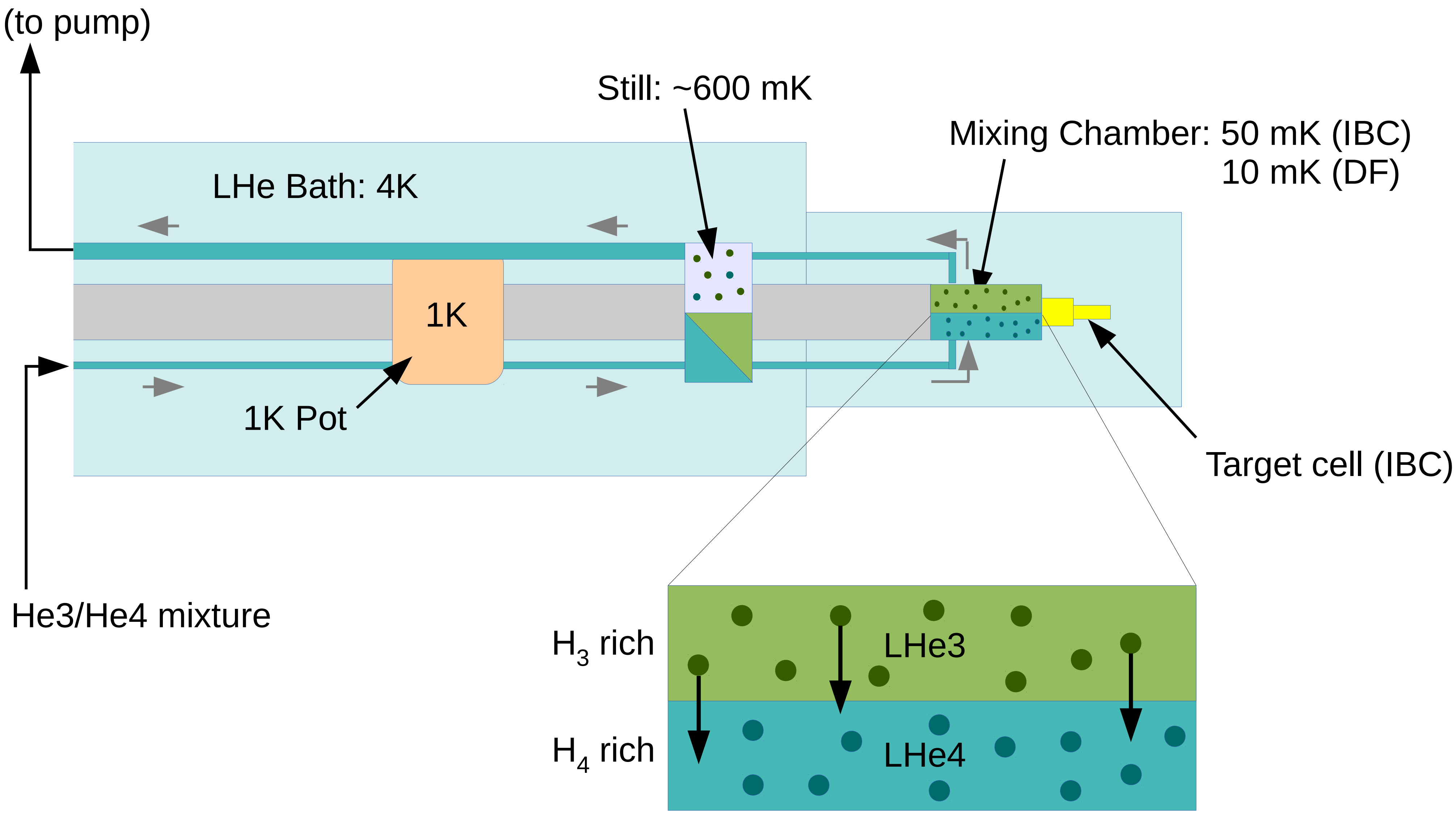
Cryostats

Helium Evaporation Fridge



Cryostats

(Horizontal) Dilution Fridge



Great, so that means that P(H)=90% and P(D)=30%, right?

If it were only that simple

P(H)=90% and P(D)=30% are **TE** values at 15 T and 10 mK

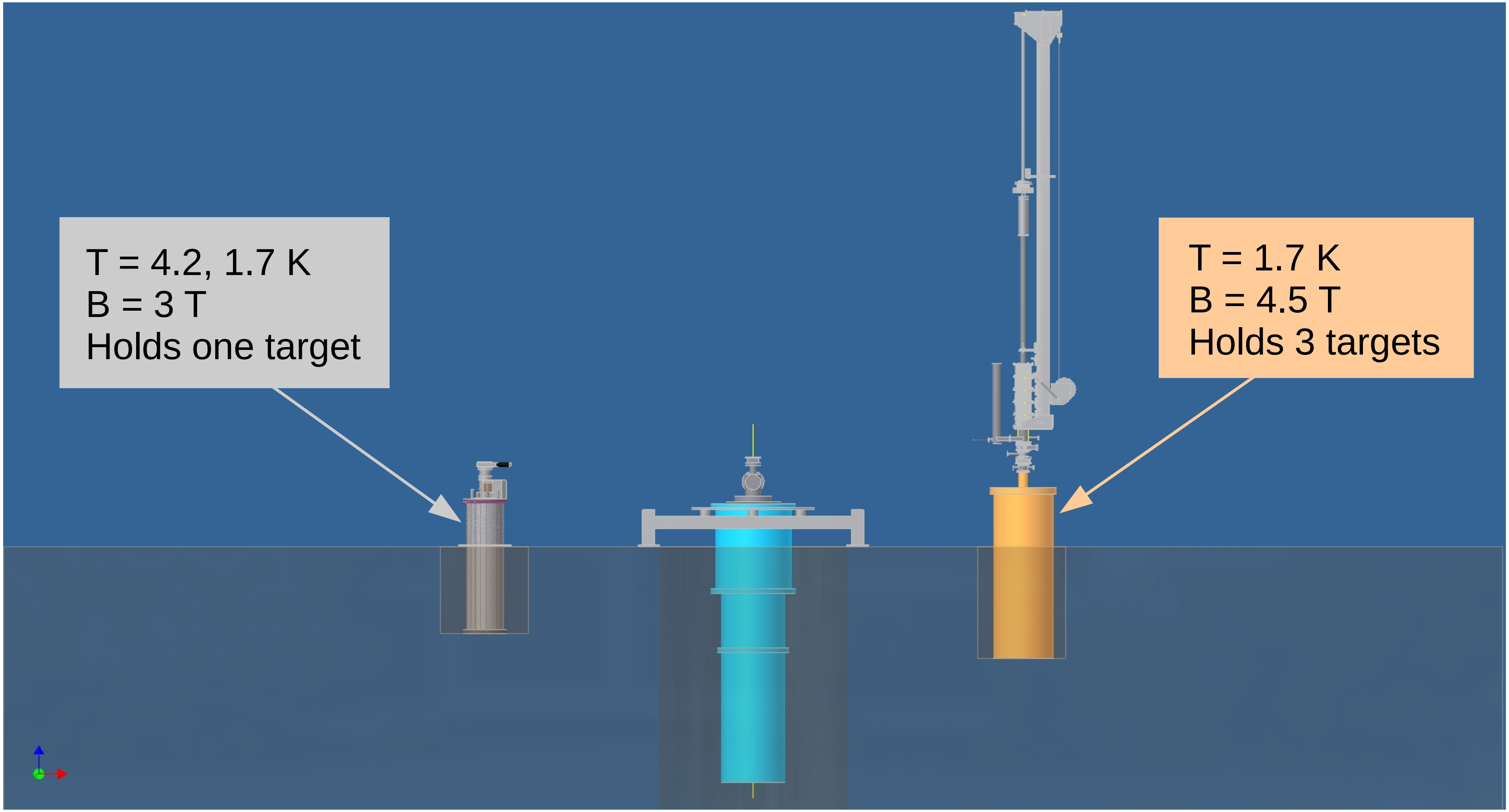
There are two effects that must strike a balance in this process:

As the (L=1) H2 and D2 states decay, the T1 of the target material grows
⇒ takes longer to reach the TE values
(deg of pol increases slower and slower)

L=1→0 decays release heat which must be removed from the HD in order to reach the TE values
⇒ HD can't immediately reach low temperatures (10 mK)
(max pol is decreased)

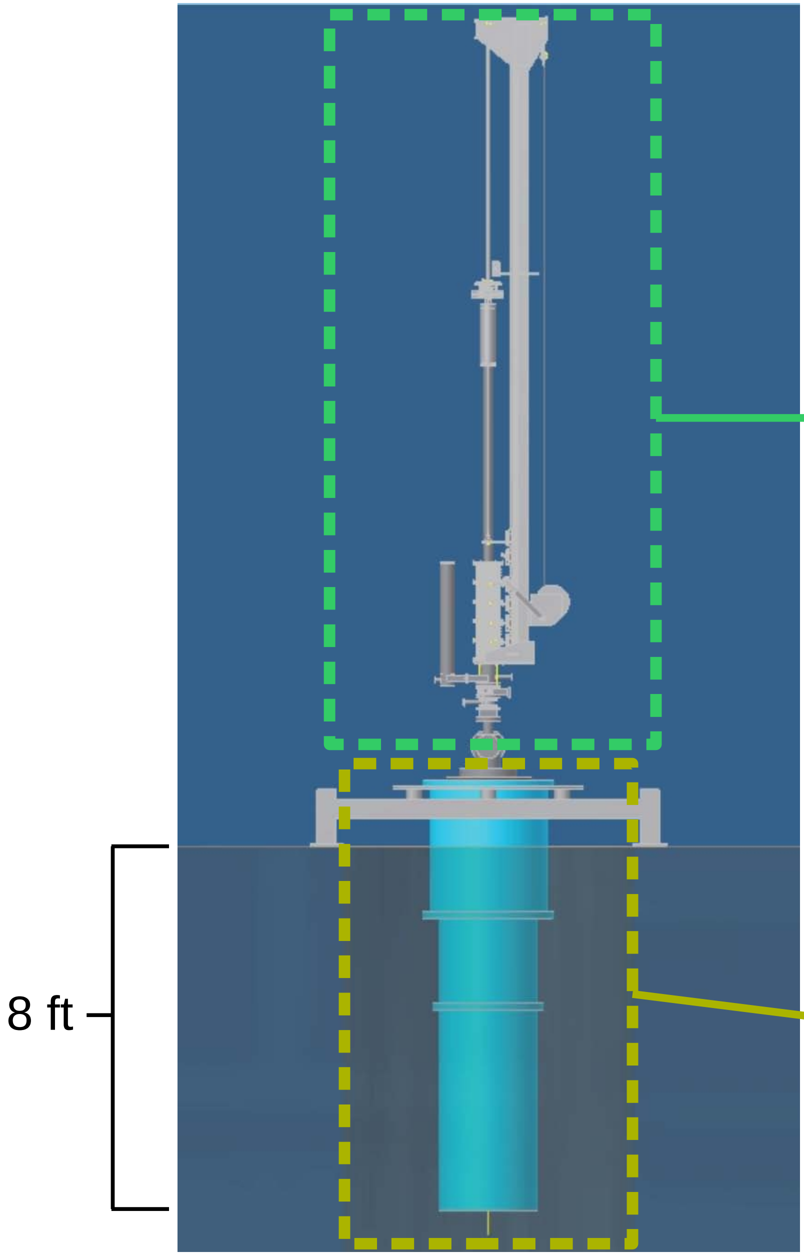
The result is that P(H)=60±5% and P(D)=15±7%

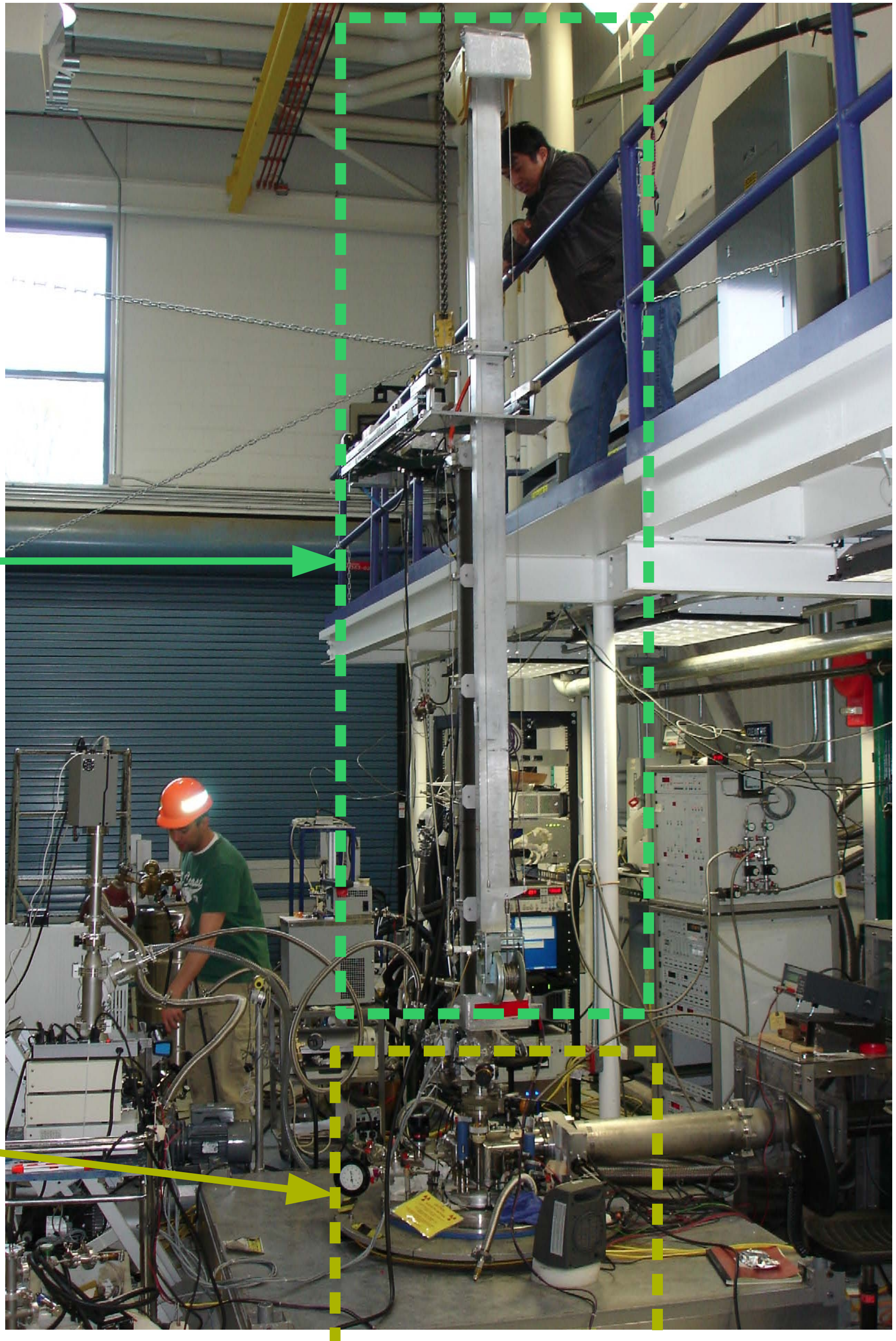
Target transfer & transport



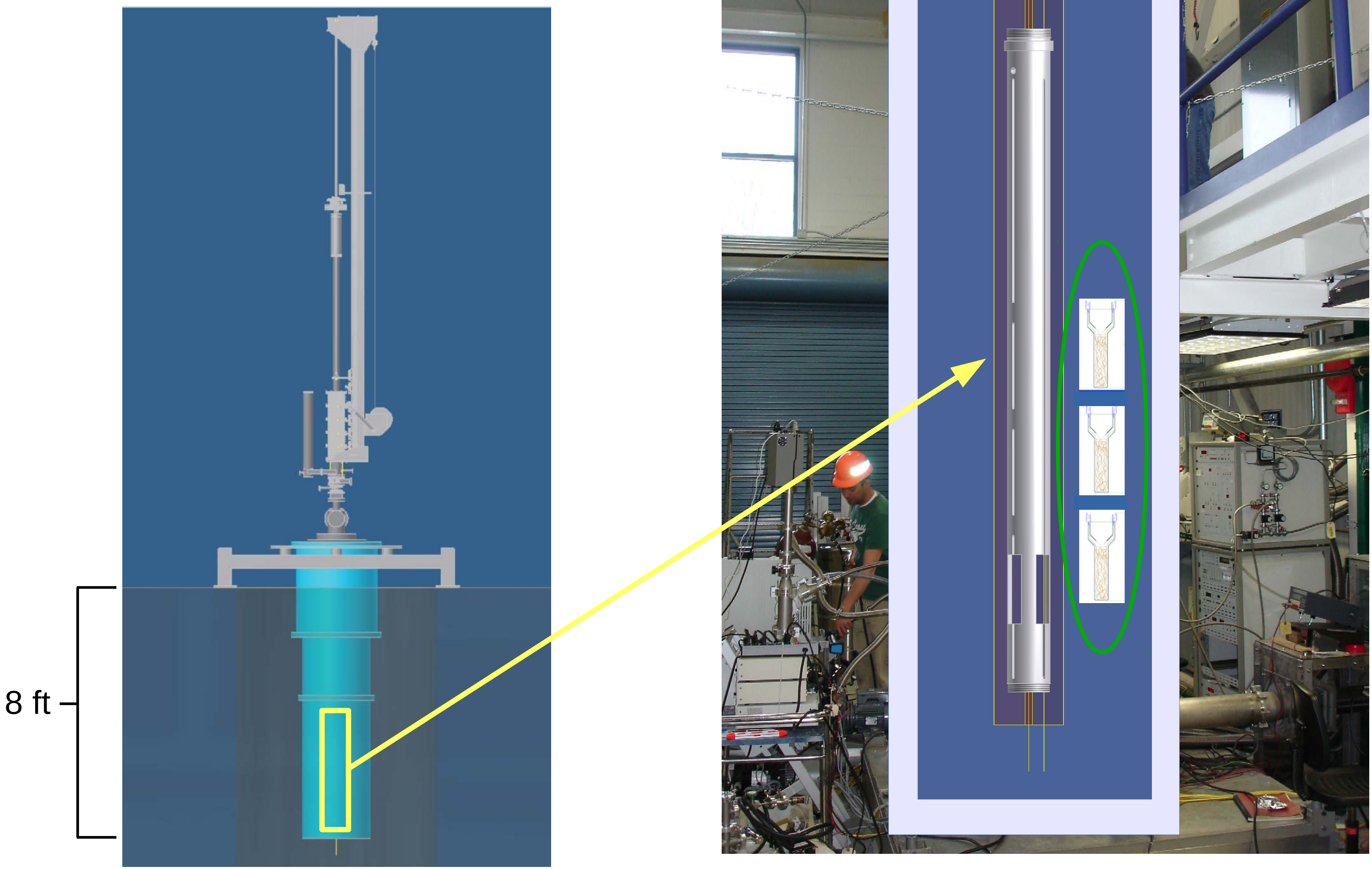
Target transfer to SD for storage/transport

TC mounted on top of the DF



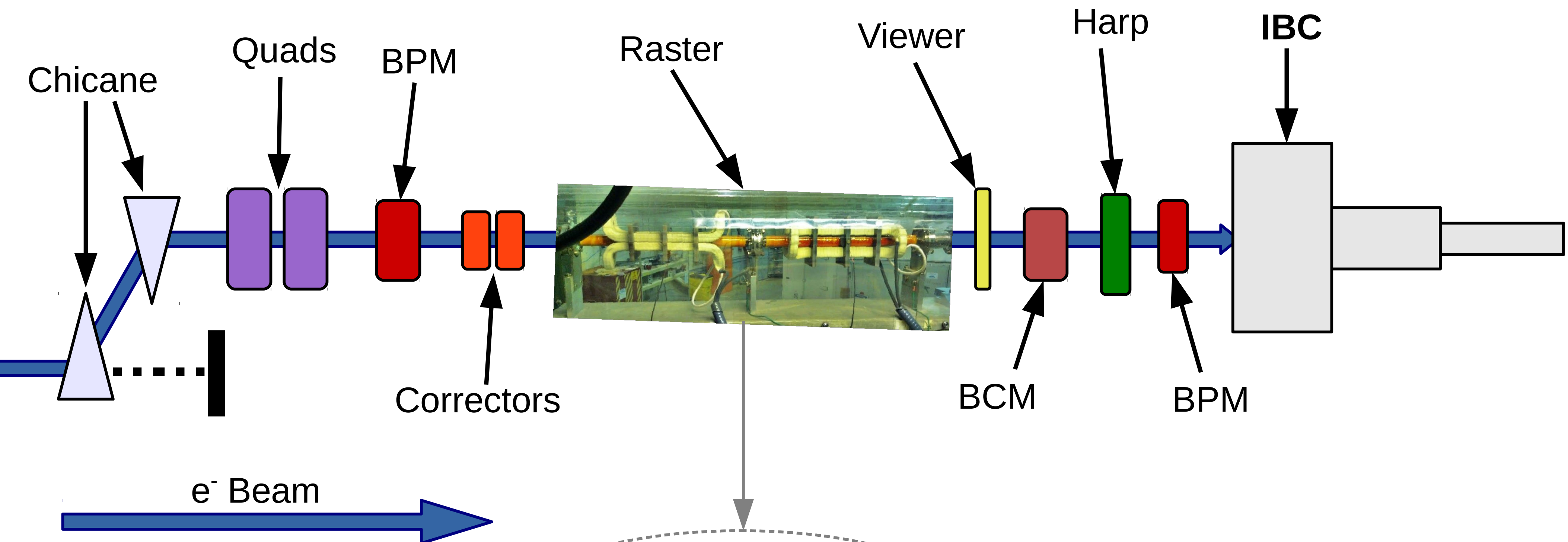


Target stacking in DF



UITF Beamline

(A compressed view)

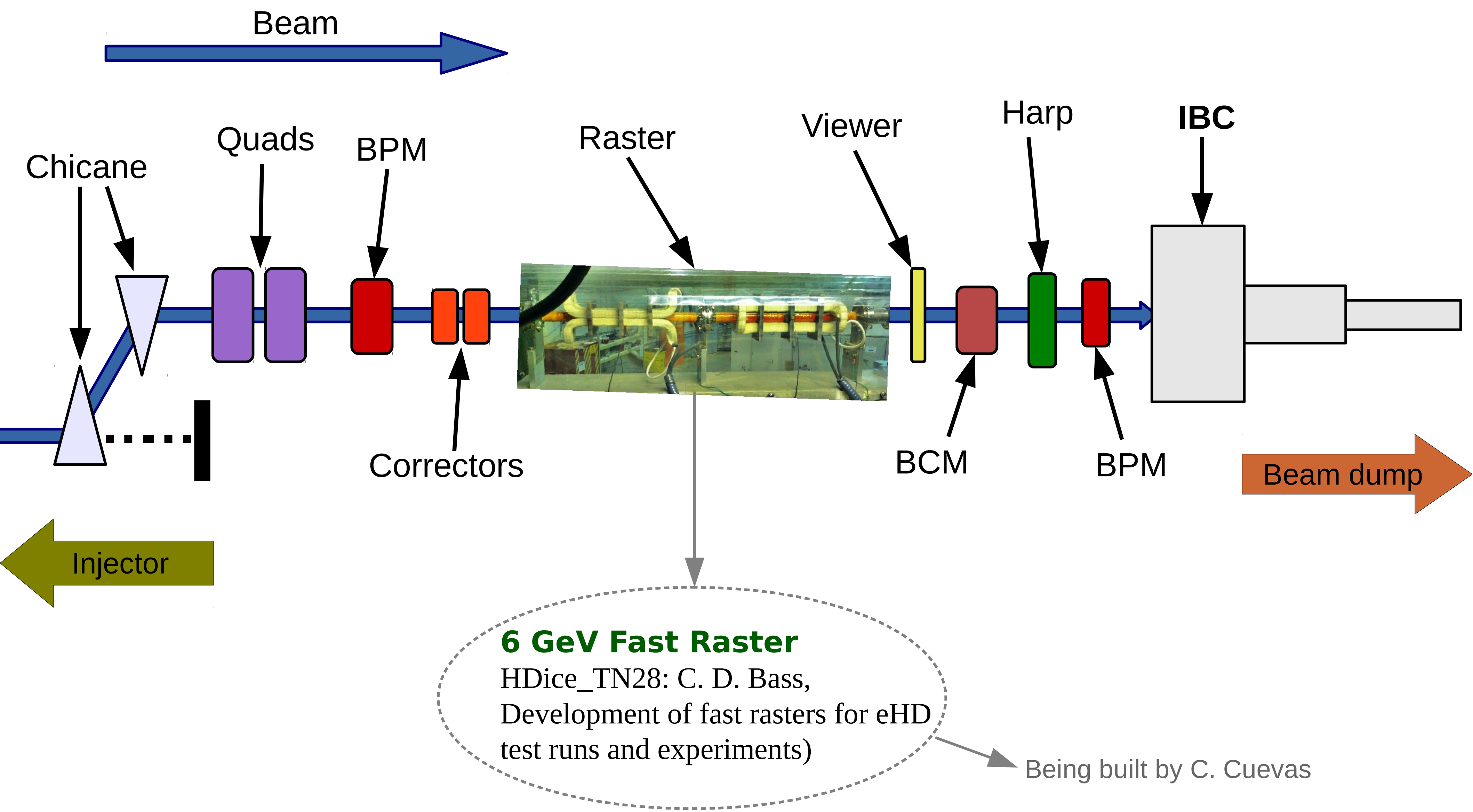


6 GeV Fast Raster
HDice_TN28: C. D. Bass,
Development of fast rasters for eHD
test runs and experiments)

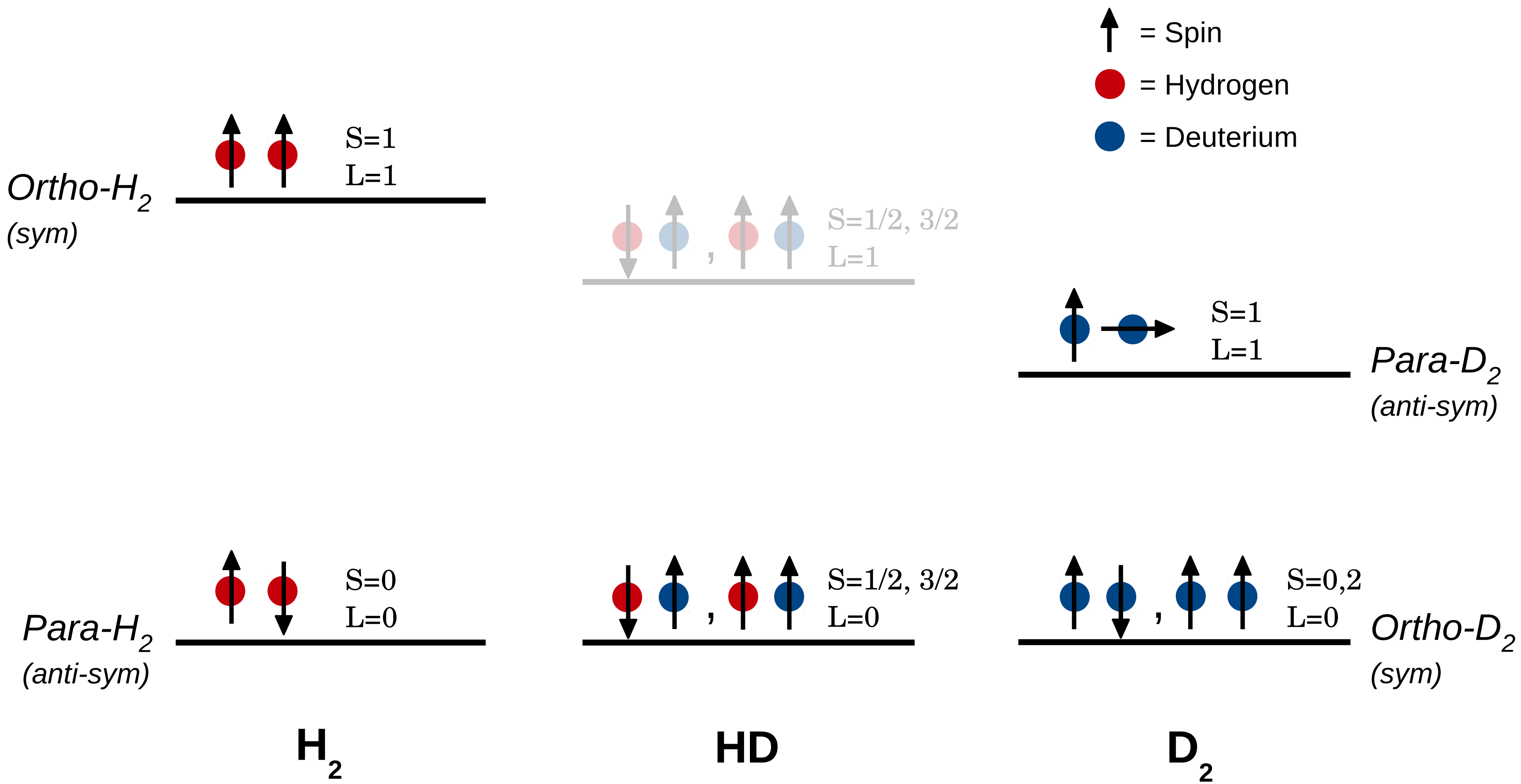
Being built by C. Cuevas

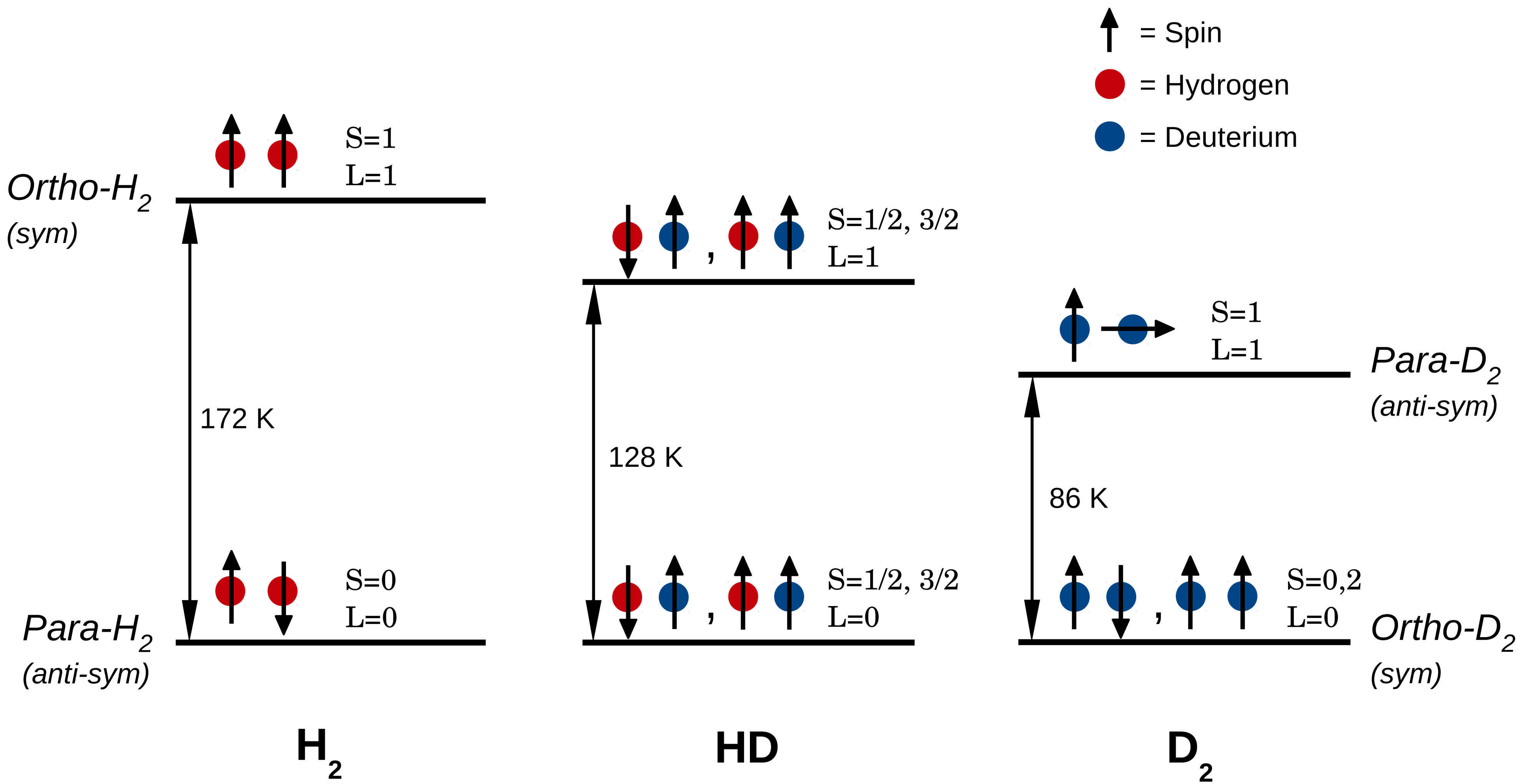
UITF Beamline

(A compressed view)

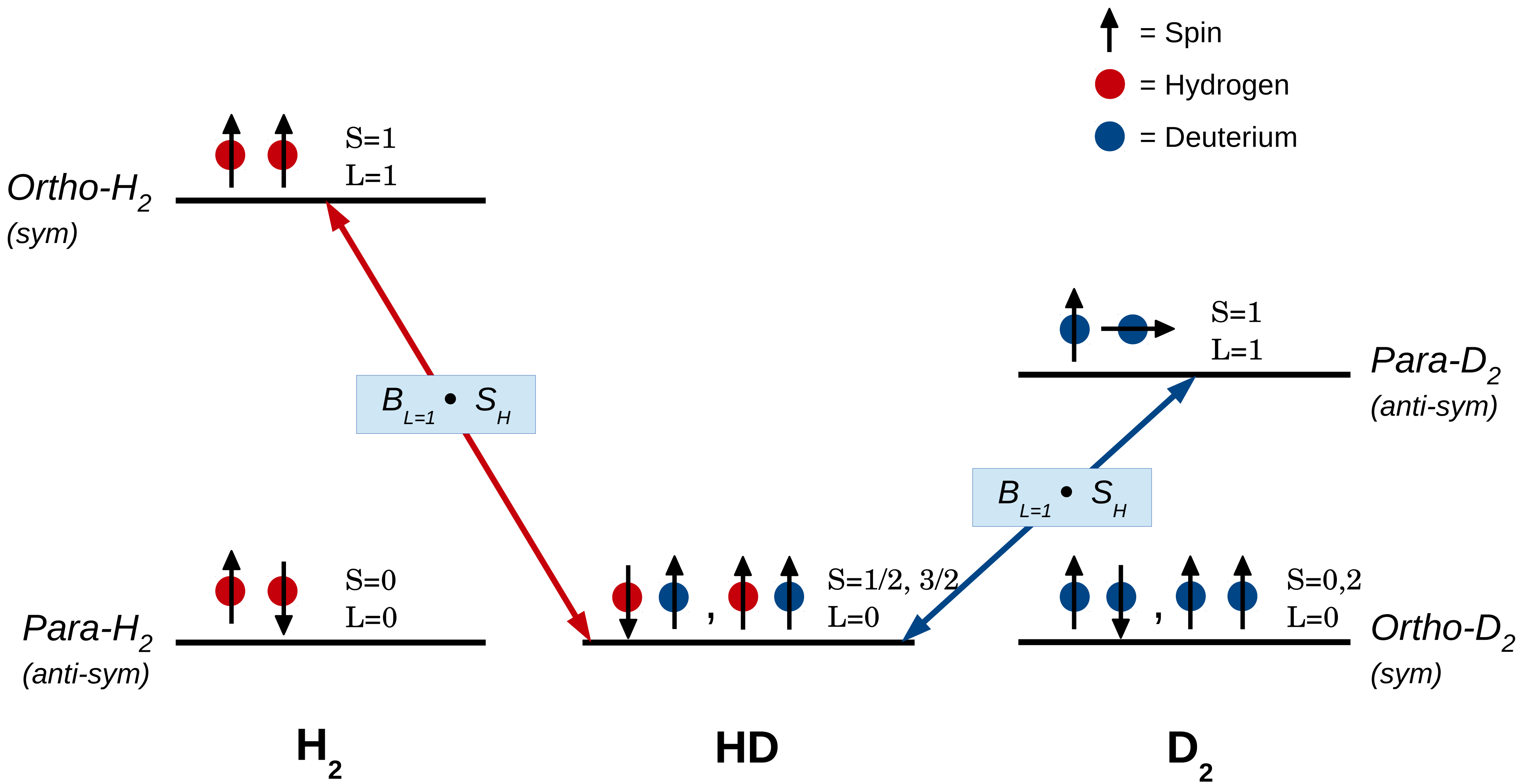


The following slides are pictures/cartoons made by [CMH]


= Spin
= Hydrogen
= Deuterium
Ortho-H2
(sym)
S=1
L=1
S=1/2, 3/2
L=1
S=1
L=1
Para-D2
(anti-sym)
Para-H2
(anti-sym)
S=0
L=0
S=1/2, 3/2
L=0
S=0,2
L=0
Ortho-D2
(sym)
H2
HD
D2

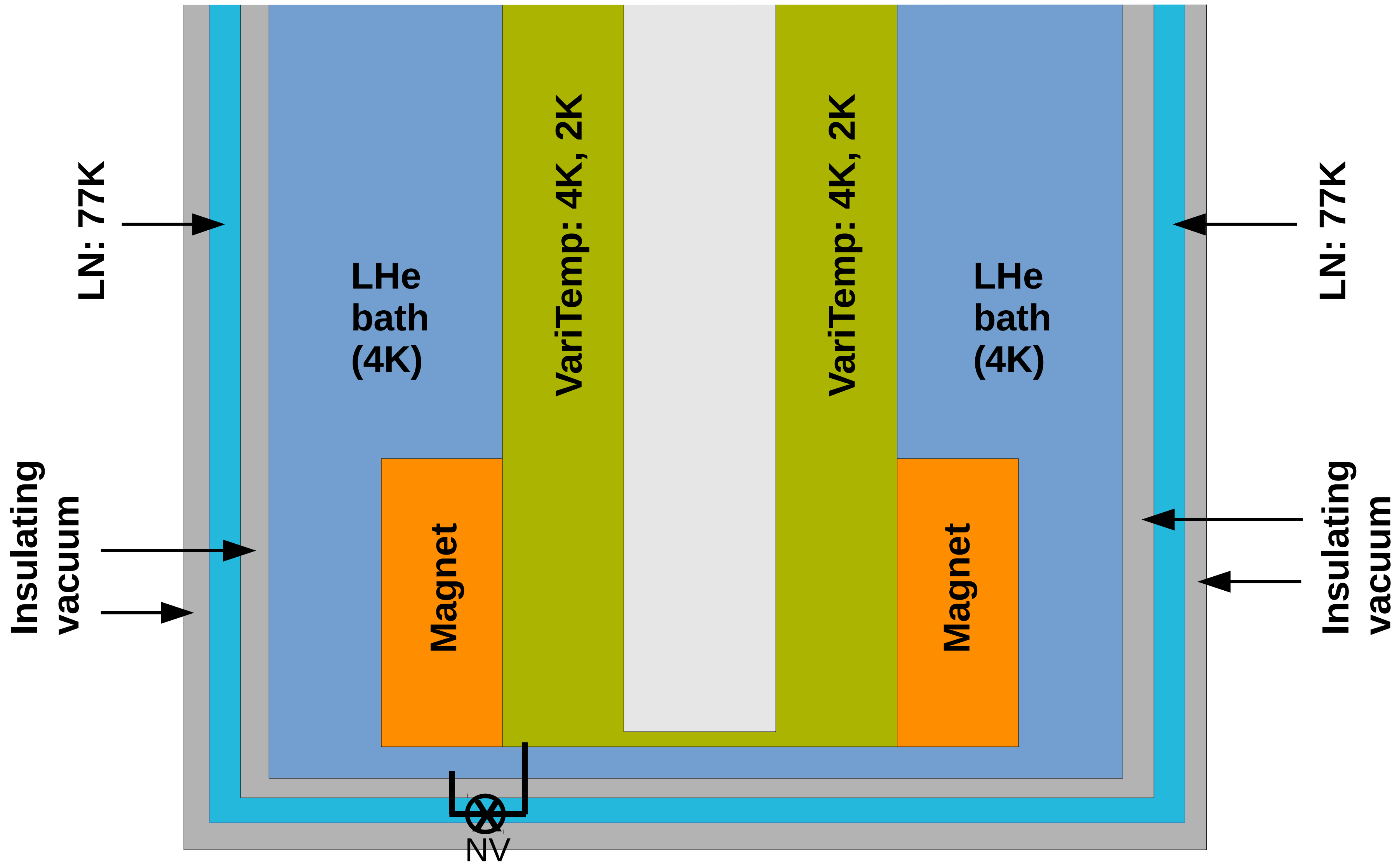


= Spin
= Hydrogen
= Deuterium
Ortho-H2
(sym)
S=1
L=1
172 K
Para-H2
(anti-sym)
S=0
L=0
S=1/2, 3/2
L=1
128 K
S=1/2, 3/2
L=0
S=1
L=1
Para-D2
(anti-sym)
86 K
S=0,2
L=0
Ortho-D2
(sym)
H2
HD
D2


= Spin
= Hydrogen
= Deuterium
Ortho-H2
(sym)
S=1
L=1
Para-H2
(anti-sym)
S=0
L=0
B L=1 • S H
S=1/2, 3/2
L=0
B L=1 • S H
S=1
L=1
Para-D2
(anti-sym)
S=0,2
L=0
Ortho-D2
(sym)
H2
HD
D2

Cryostats

Helium Evaporation Fridge



Cryostats

(Horizontal) Dilution Fridge