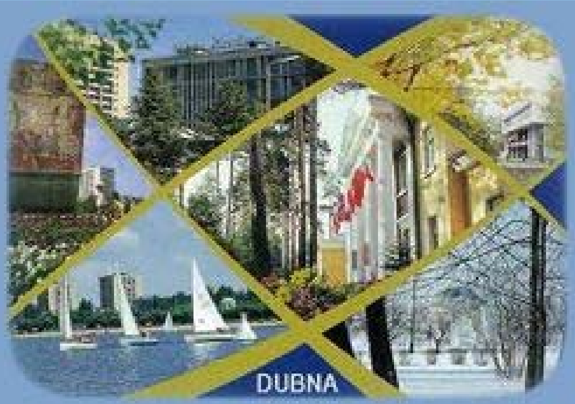
HDice, the Polarized Solid HD Target in the Frozen Spin Mode for Experiments with CLAS

Xiangdong Wei

Thomas Jefferson National Accelerator Laboratory



The 20th INTERNATIONAL SYMPOSIUM on
Spin Physics (SPIN2012)
JINR, Dubna, Russia
September 17 - 22, 2012

Jefferson Lab
Thomas Jefferson National Accelerator Facility

JSA

Collaborators

- *Jefferson Lab*

X. Wei, C. Bass, A. Deur, G. Dezern, T. Kageya, D. Kashy, M. Lowry, O. Pastor, A. M. Sandorfi, R. Teachey, and M. Zarecky

- *Universita di Roma "Tor Vergata" and INFN-Sezione di Roma2*

A. D'Angelo

- *University of Virginia*

C. Hanretty, P. Peng

- *Carnegie-Mellon University*

D. Ho

- *Norfolk State University*

M. Khandaker

- *Blaise Pascal University*

V. Laine

- *University of Connecticut*

T. O'Connell

- *Catholic University of America*

N. Walford

- *and the* ***CLAS Collaboration***

Topics

- *How the HDice target works*
- *Target Production*
- *Performance of HDice target*
- γ*+HDice results with CLAS*
- *e+HDice test results*
- *Conclusion*

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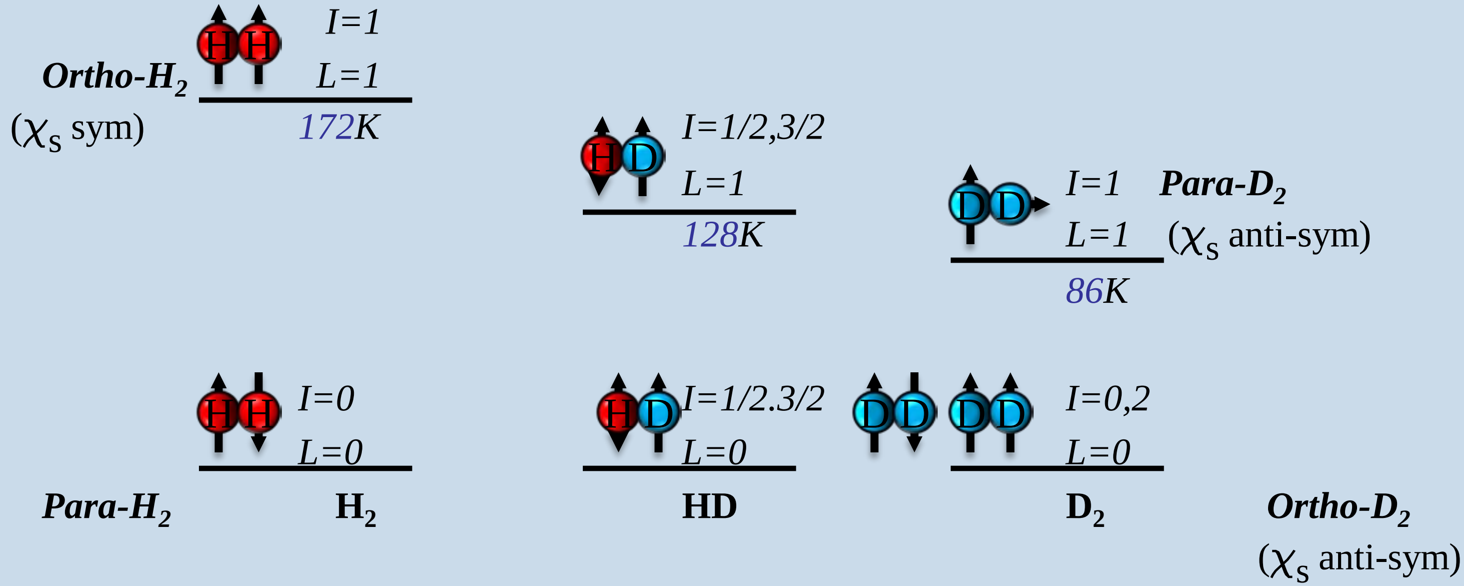
Polarizing HD: the rotational levels of the solid hydrogens

At liquid helium temperature and below, only J=1 and 0 states are occupied, for H_2 and D_2, and only J=0 is populated for HD



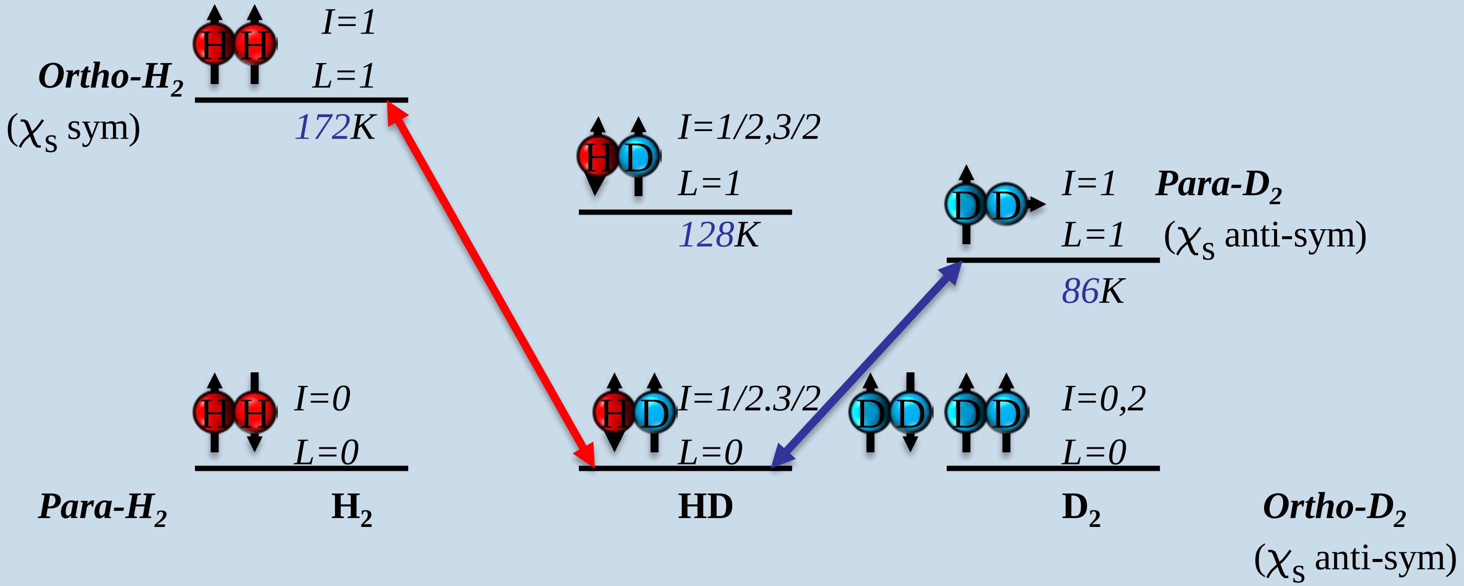
The relative energy spacing of the low-lying nuclear spin, I, and molecular orbital angular momentum, L, levels in H_2, HD and D_2 system. The symmetries of the nuclear spin wavefunction, χ_S, are indicated.

Polarizing HD: cross coupling between H and D, POLARIZING

At J=0 states, protons and deuterons are de-coupled from the lattice.

⇒long relaxation time or non-polarizable

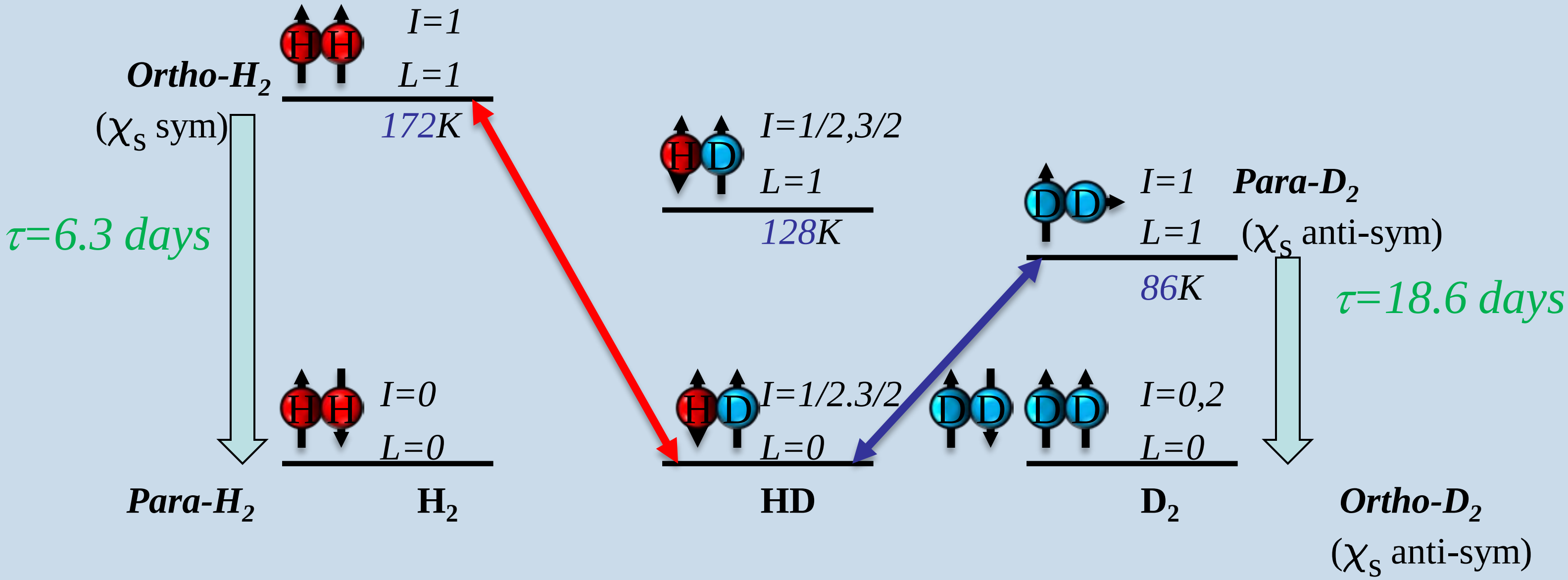
⇒help from J=1 H_2 and D_2 through spin-wave is needed for polarizing HD



The relative energy spacing of the low-lying nuclear spin, I, and molecular orbital angular momentum, L, levels in H_2, HD and D_2 system. The symmetries of the nuclear spin wavefunction, χ_S, are indicated.

Polarizing HD: L=1 molecus decay to L=0, AGING

The life time for J=1 H_2 is 6.3 days whiles for J=1 D_2 is 18.6 days.
⇒polarization mechanism disappears after "aging"
⇒Highly polarized frozen spin target



The relative energy spacing of the low-lying nuclear spin, I, and molecular orbital angular momentum, L, levels in H_2, HD and D_2 system. The symmetries of the nuclear spin wavefunction, χ_S, are indicated.

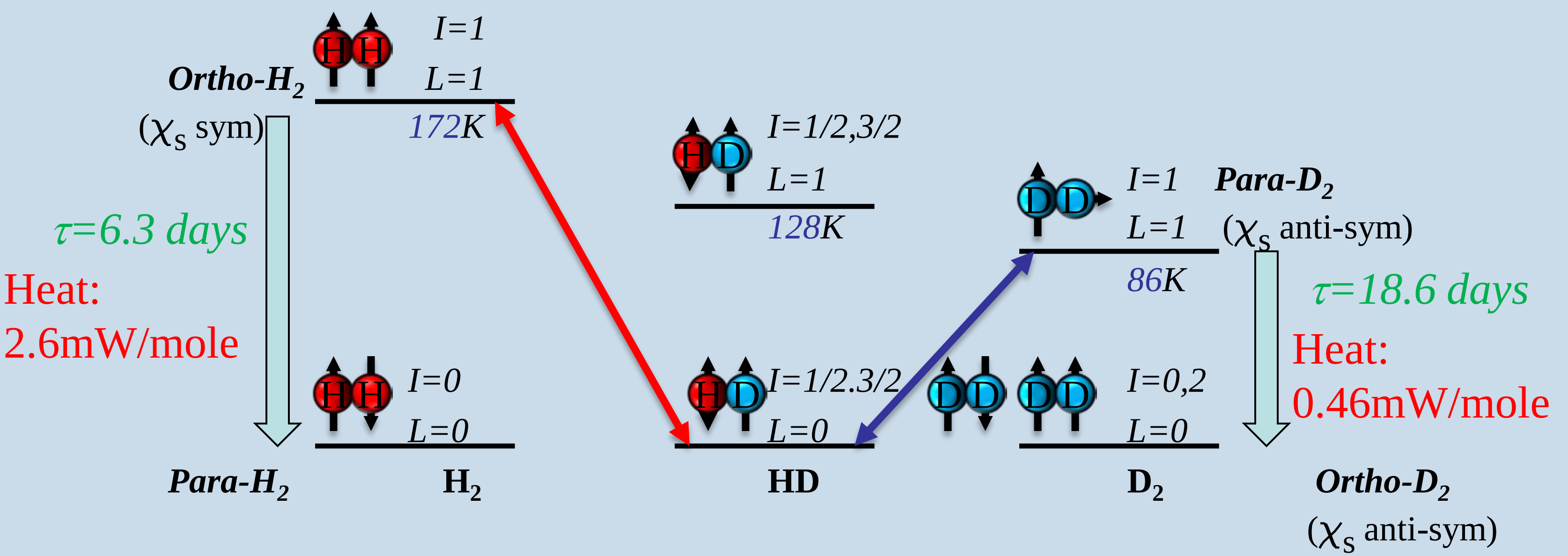
![HDice logo]

Heat generation due to L=1 to L=0 Conversion

Heat generation (J=1 to J=0): 2.6mW/mole for H_2 and 0.46mW/mole for D_2.

⇒For HDice at c_1~0.001, 0.94μW/target from H_2 and 0.17μW/target from D_2.

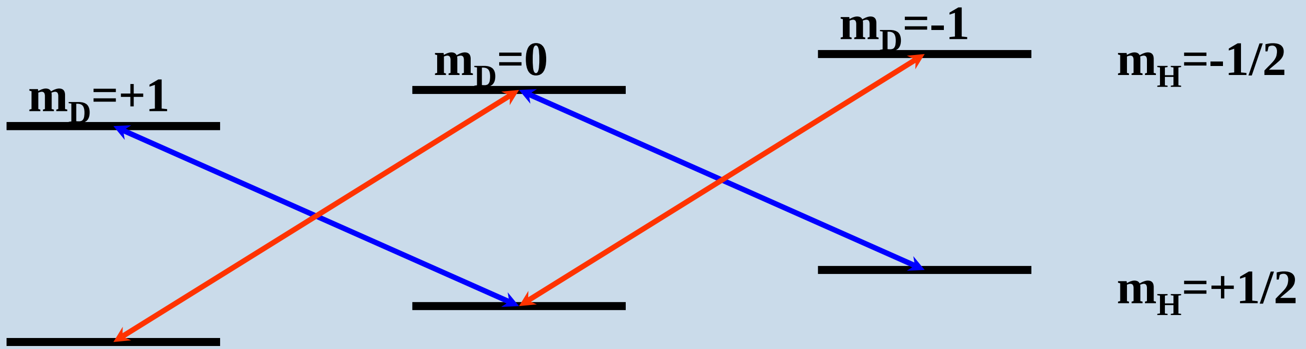
⇒Heat has to be removed from HD in order to polarize HD target



HDice dilution refrigerator cooling power at 10mK : 10μW ☺

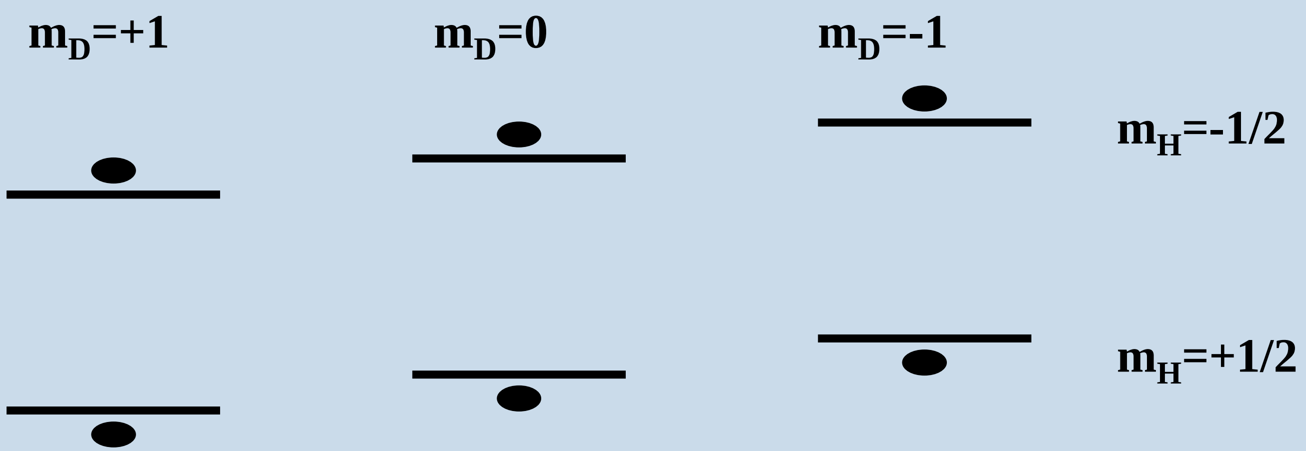
The relative energy spacing of the low-lying nuclear spin, I, and molecular orbital angular momentum, L, levels in H_2, HD and D_2 system. The symmetries of the nuclear spin wavefunction, χ_S, are indicated.

Polarizing D with RF Transition



Polarizing D with RF Transition

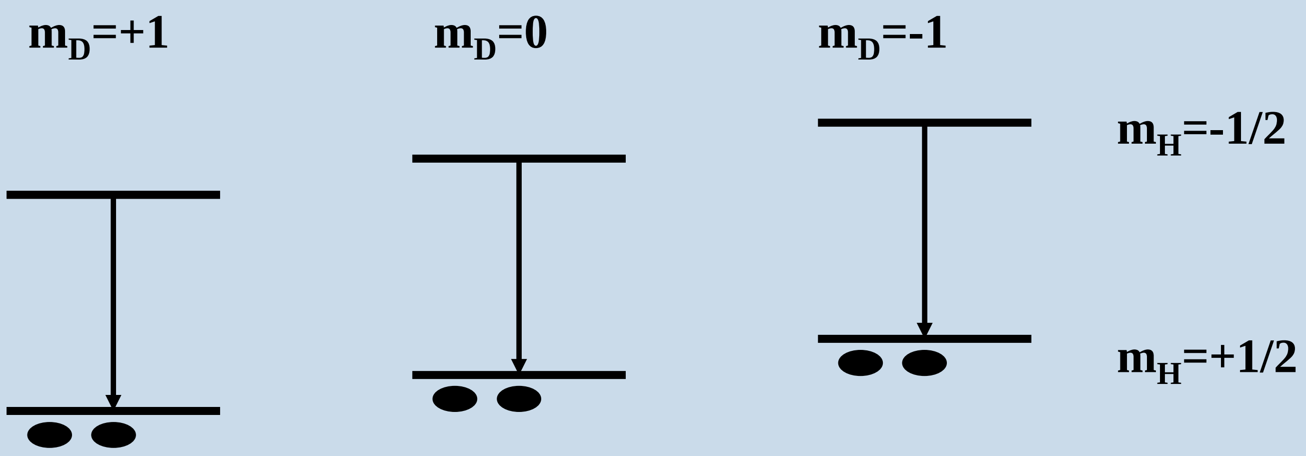
All 6 states are equally populated.



$P^H=0$, $P^D=0$

Polarizing D with RF Transition

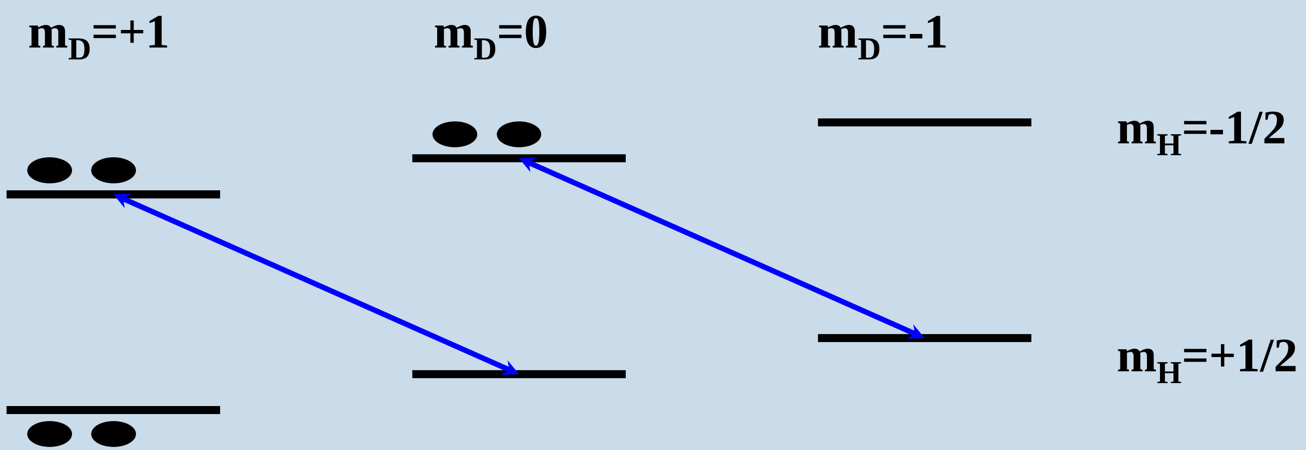
Polarizing H with brute force.



$P^H=1, \qquad P^D=0$

Polarizing D with RF Transition

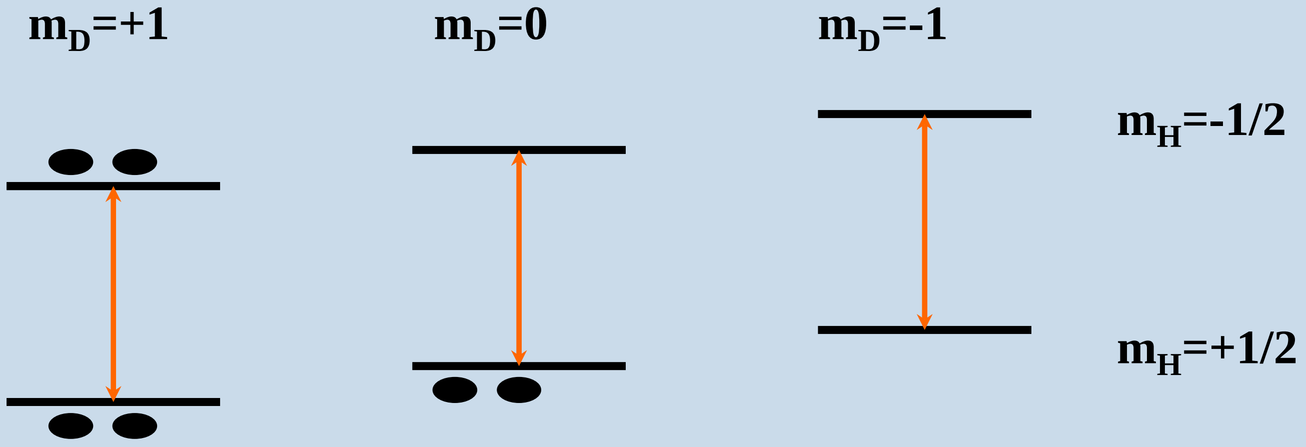
Inducing RF transition to polarize D.



P^H=-1/3, P^D=+2/3

Polarizing D with RF Transition

Inducing RF transition to reverse P^H.



P^H=+1/3, P^D=+2/3

Topics

- *How the HDice target works*
- ***Target Production***
- *Performance of HDice target*
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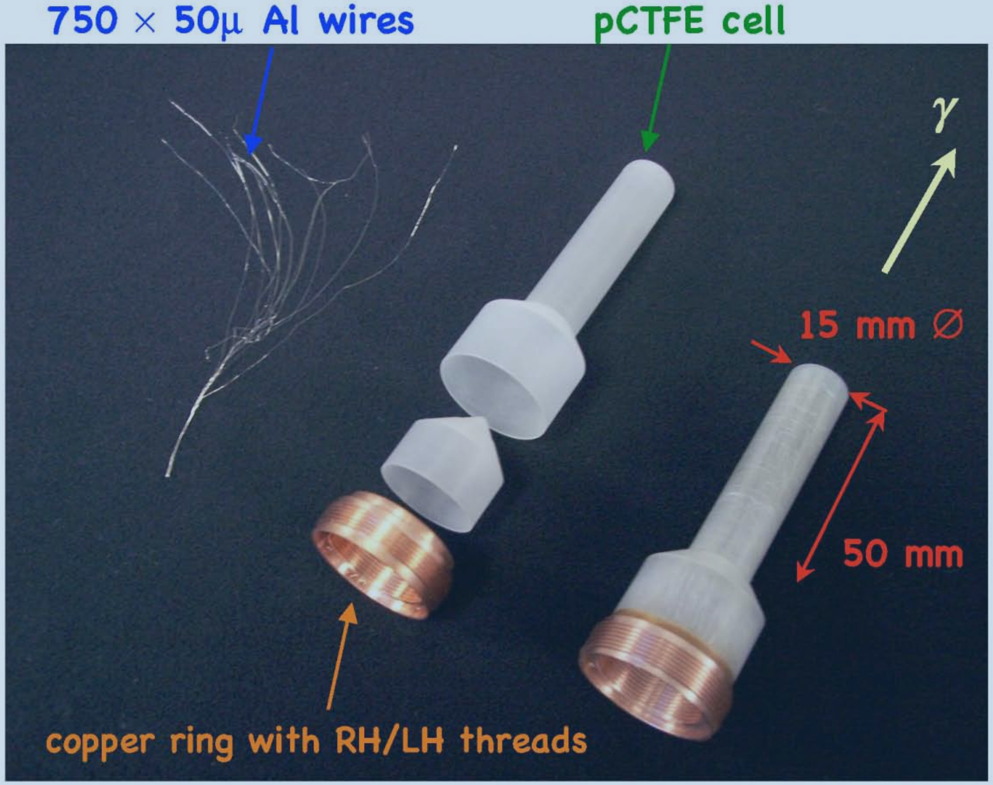
Instrumentation: Target Cell

- HDice target cells:



- material in the beam path:

  77% HD + 17 % Al + 6% pCTFE (remove with vertex cuts)

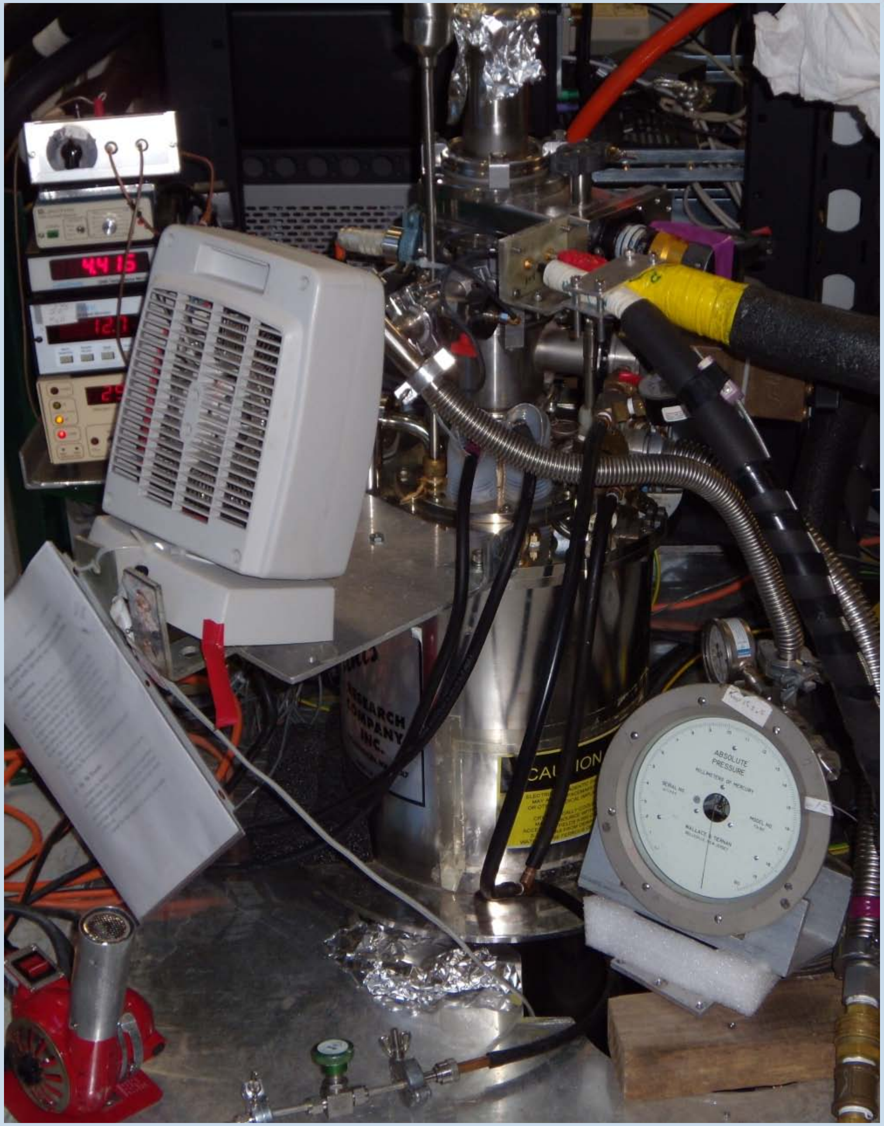
Instrumentation: Production Dewar

Production **D**ewar (**PD**)

- sample space temperature
  2K-300K variable

- magnetic field
  2 Tesla

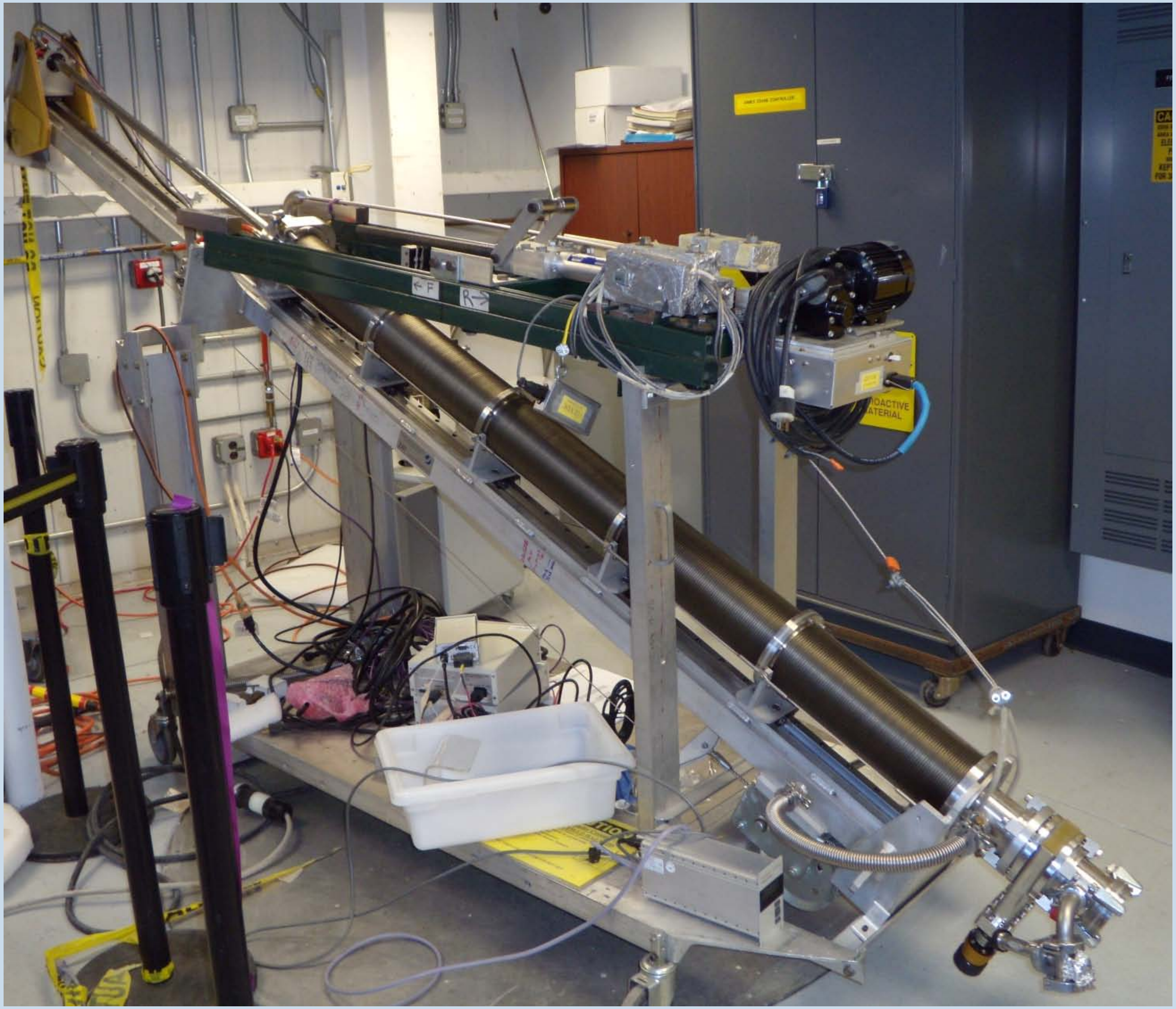
- target injection, transportation
  and NMR calibration



Instrumentation: Transfer Cryostat

Transfer **C**ryostat (**TC**)

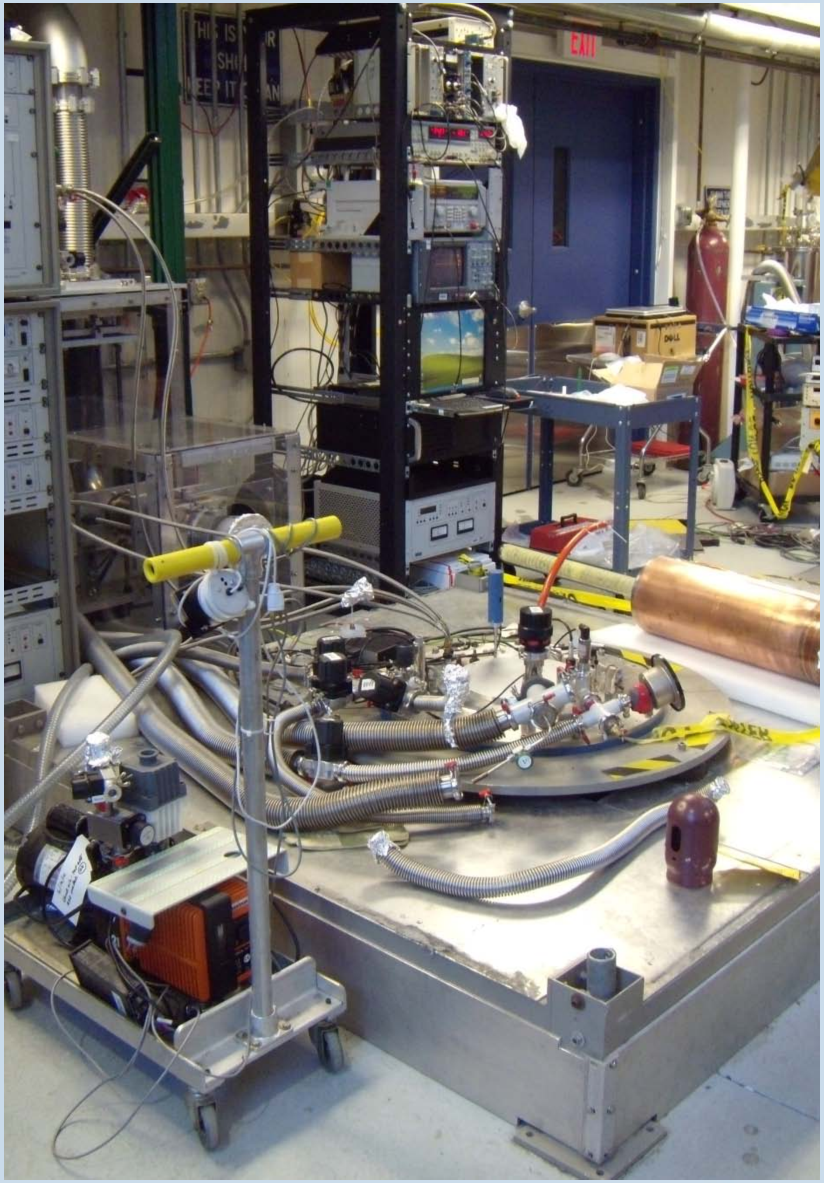
- temperature
  2K
- magnetic field
  0.1 Tesla
- target transfer
  between dewars



Instrumentation: Dilution Refrigerator

Dilution **F**ridge (**DF**)

- sample space temperature
  ⩾8mK
- magnetic field
  15 Tesla
- polarization



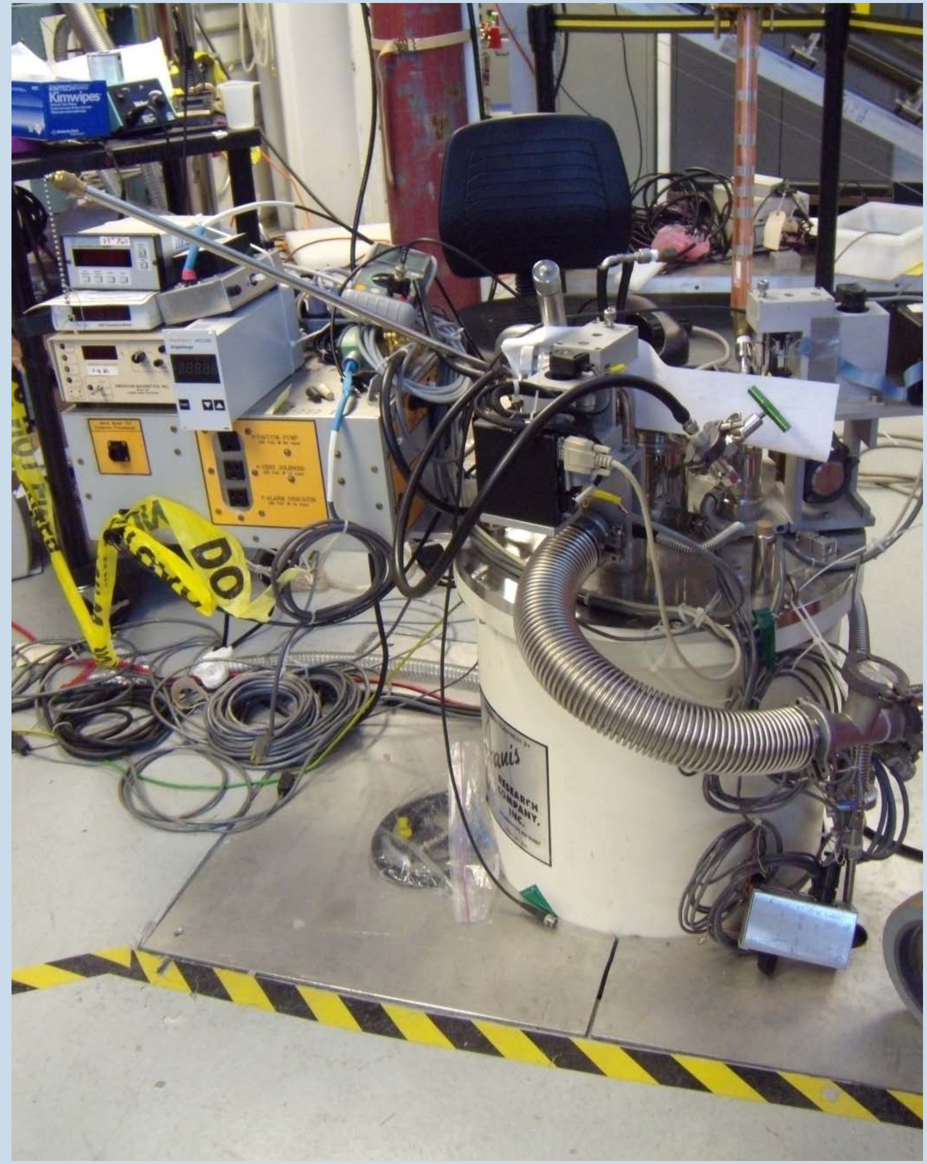
Instrumentation: Storage Dewar

Storage **D**ewar (**SD**)

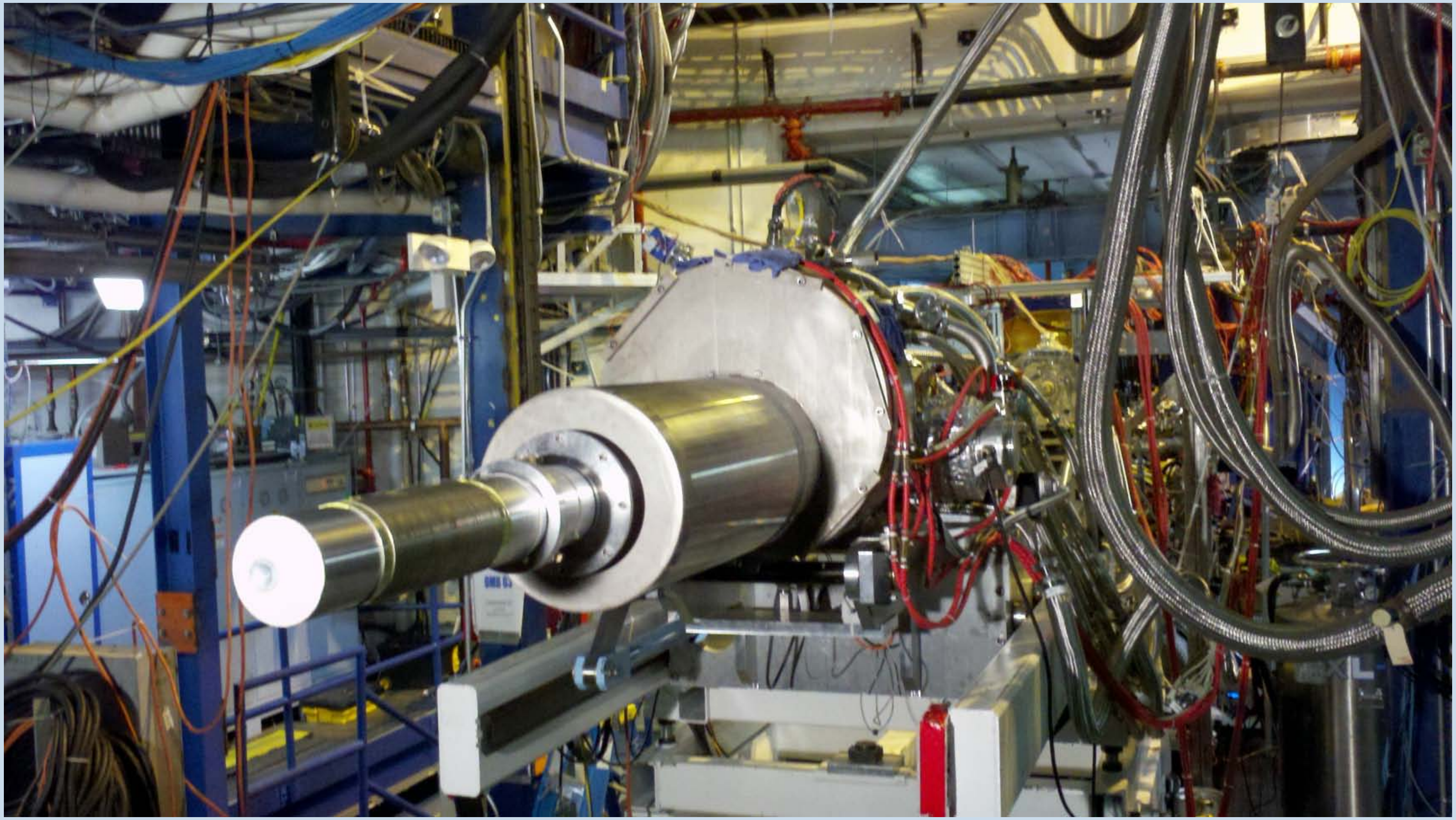
- sample space temperature
  1.6K-300K variable

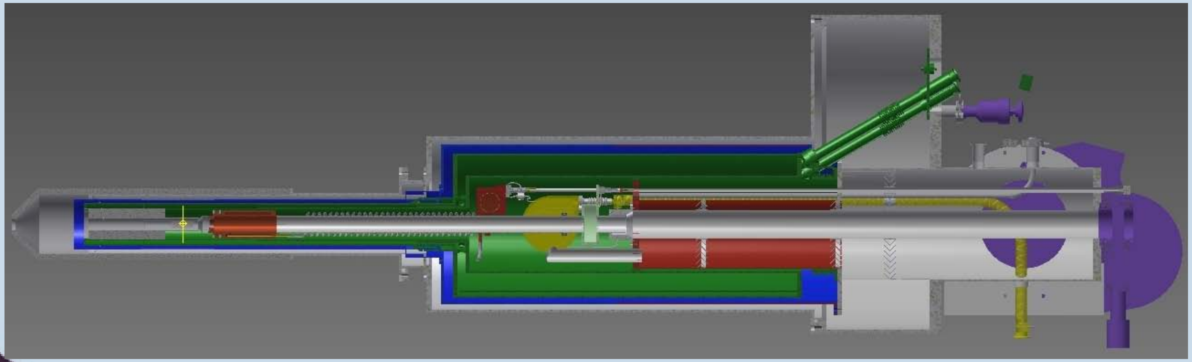
- magnetic field
  7 Tesla

- storage and/or transportation



Instrumentation: In-Beam Cryostat





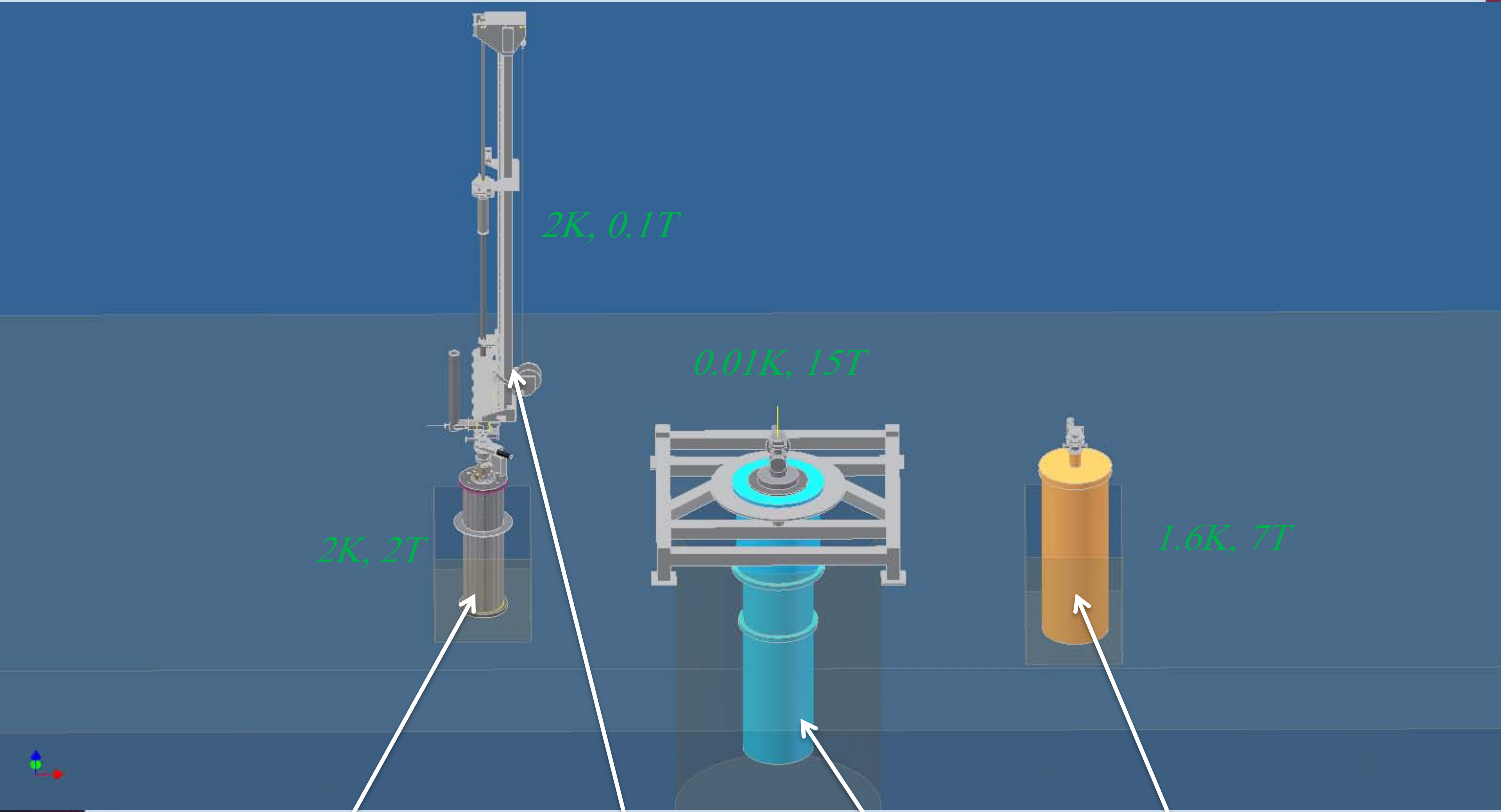
- T: 50mK
- $B_{//}$: 1.0T
- $B_{\perp}$: 0.075T
- $B_{auxiliary}$: >0.1T
- B_{backup}: 0.01T

In-**B**eam **C**ryostat (**IBC**)

Operation: Target transfer

PD DF SD TC

Operation: Target transfer



PD
(Injecting target, NMR-TE)

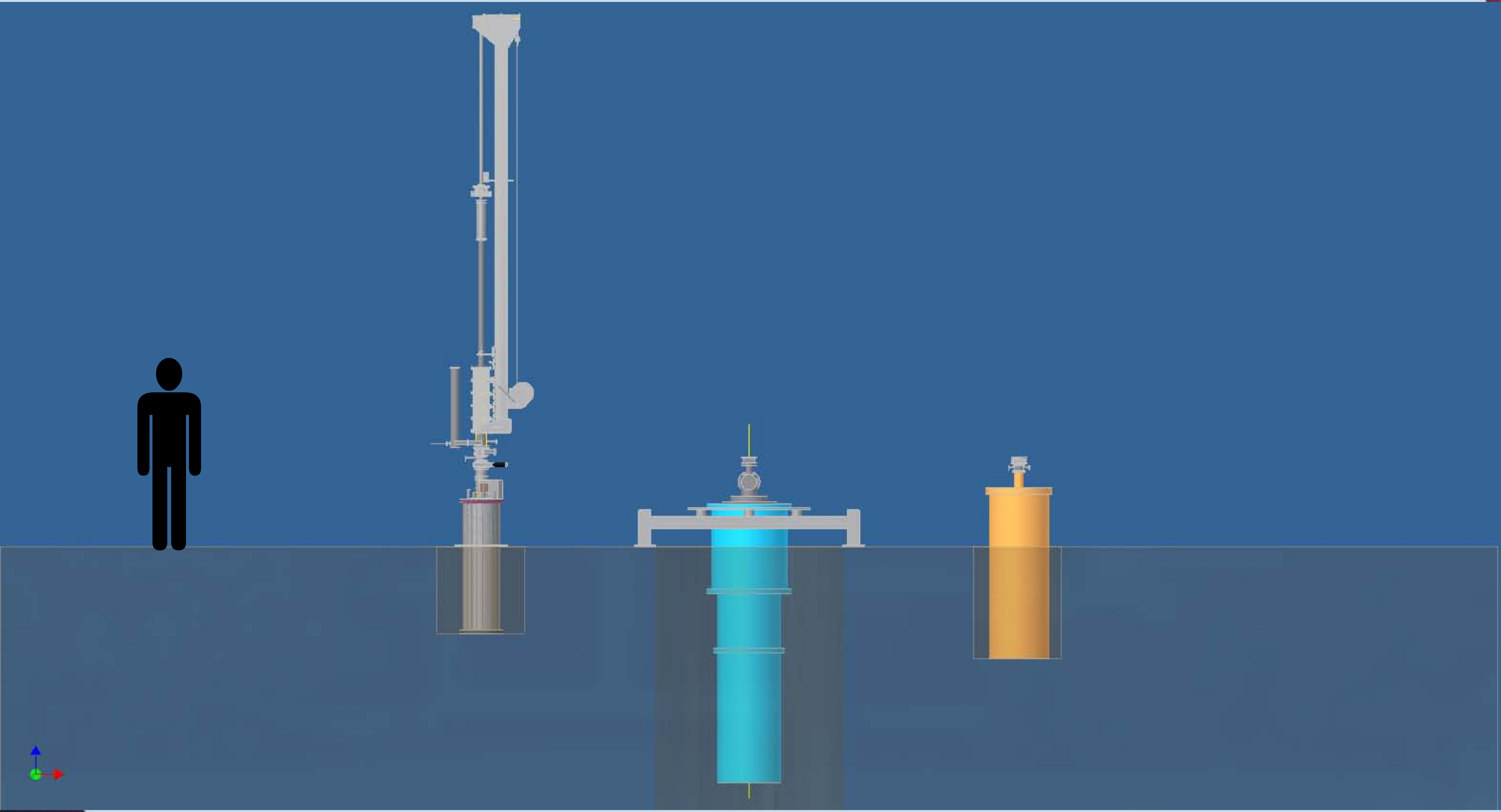
TC
(Moving target)

DF
(Polarizing target)

SD
(Storing/transporting target)

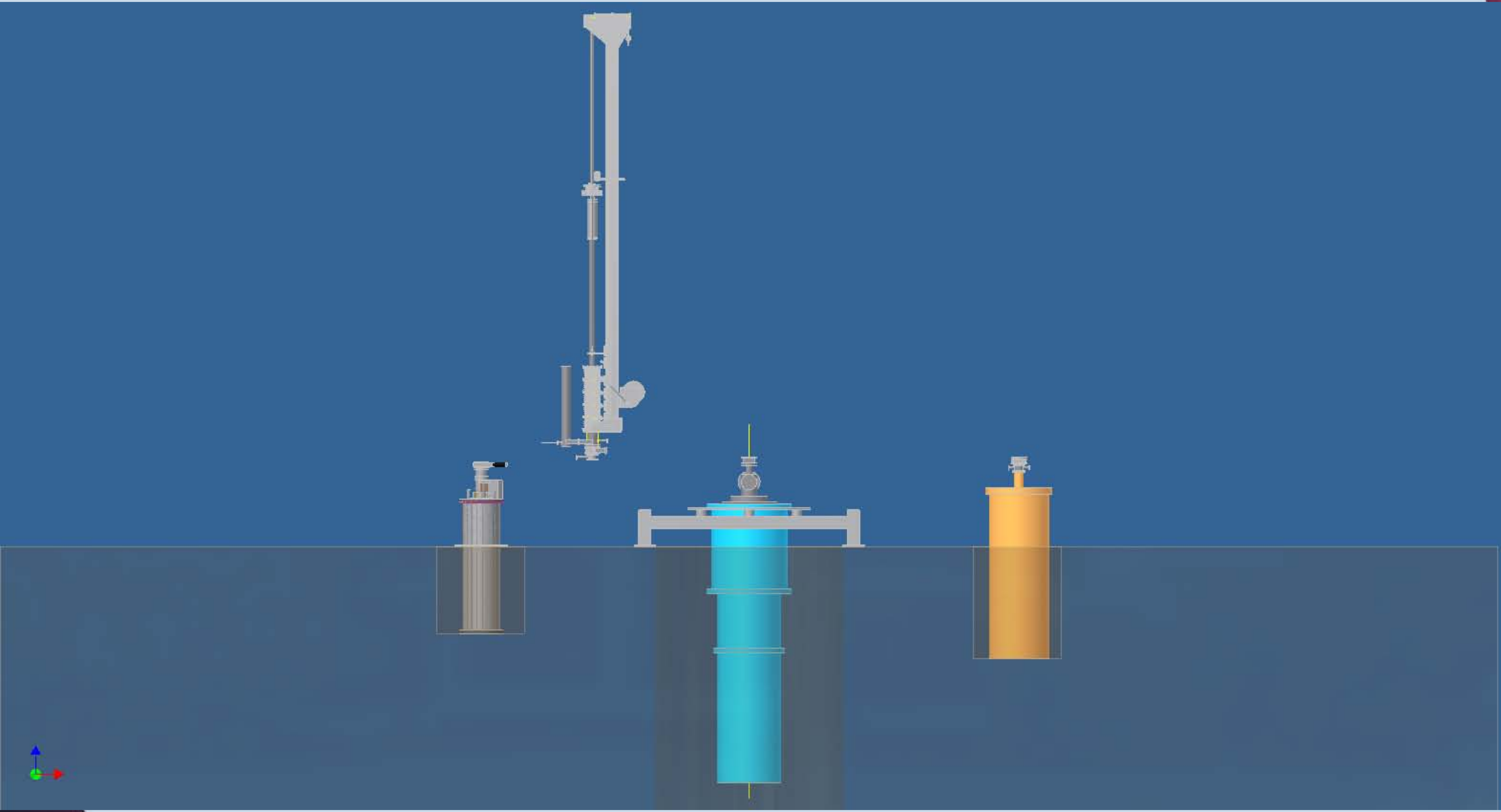
HDice

Operation: Target transfer



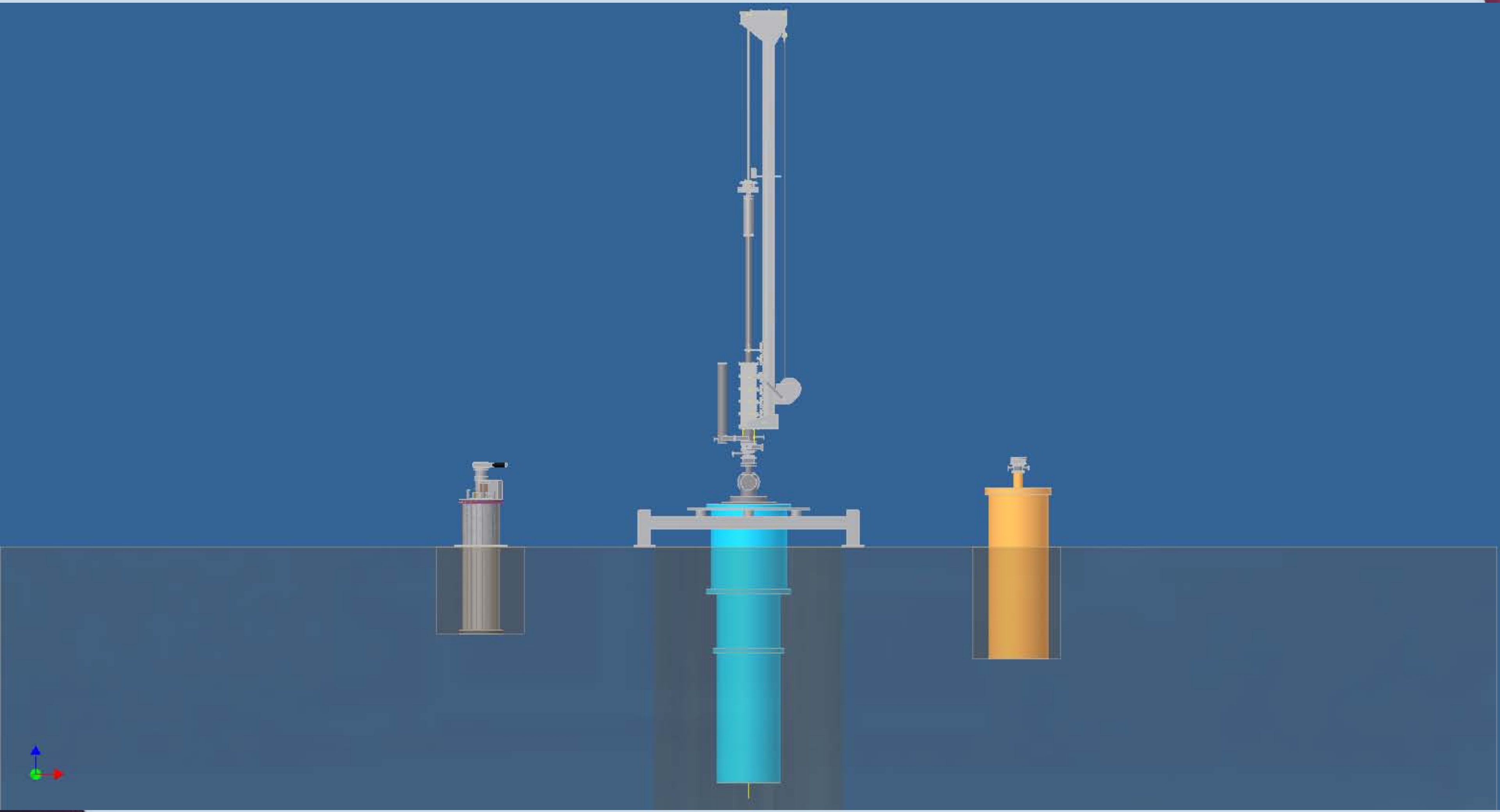
Target transfer between PD and DF

Operation: Target transfer



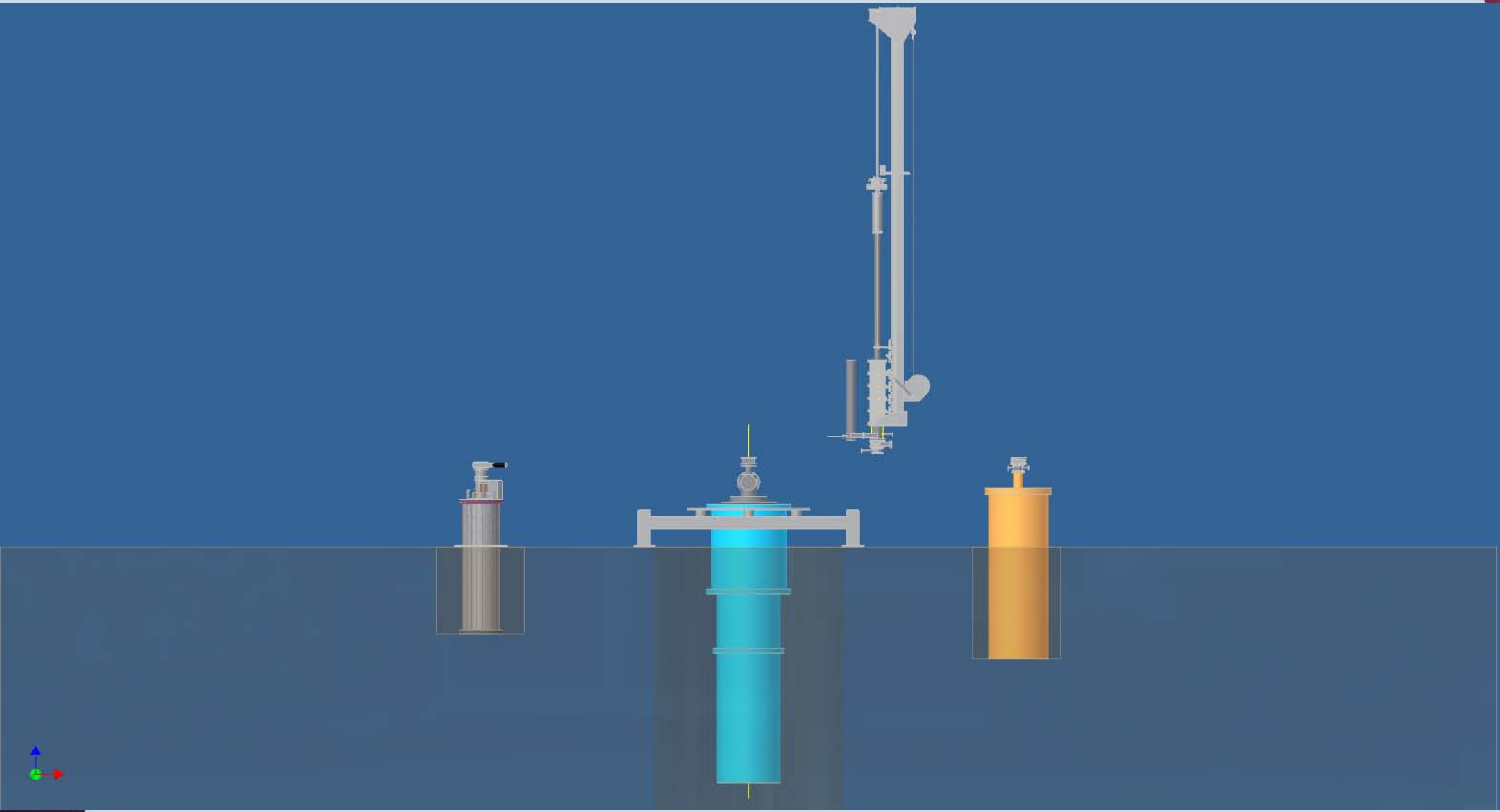
Target transfer between PD and DF

Operation: Target transfer



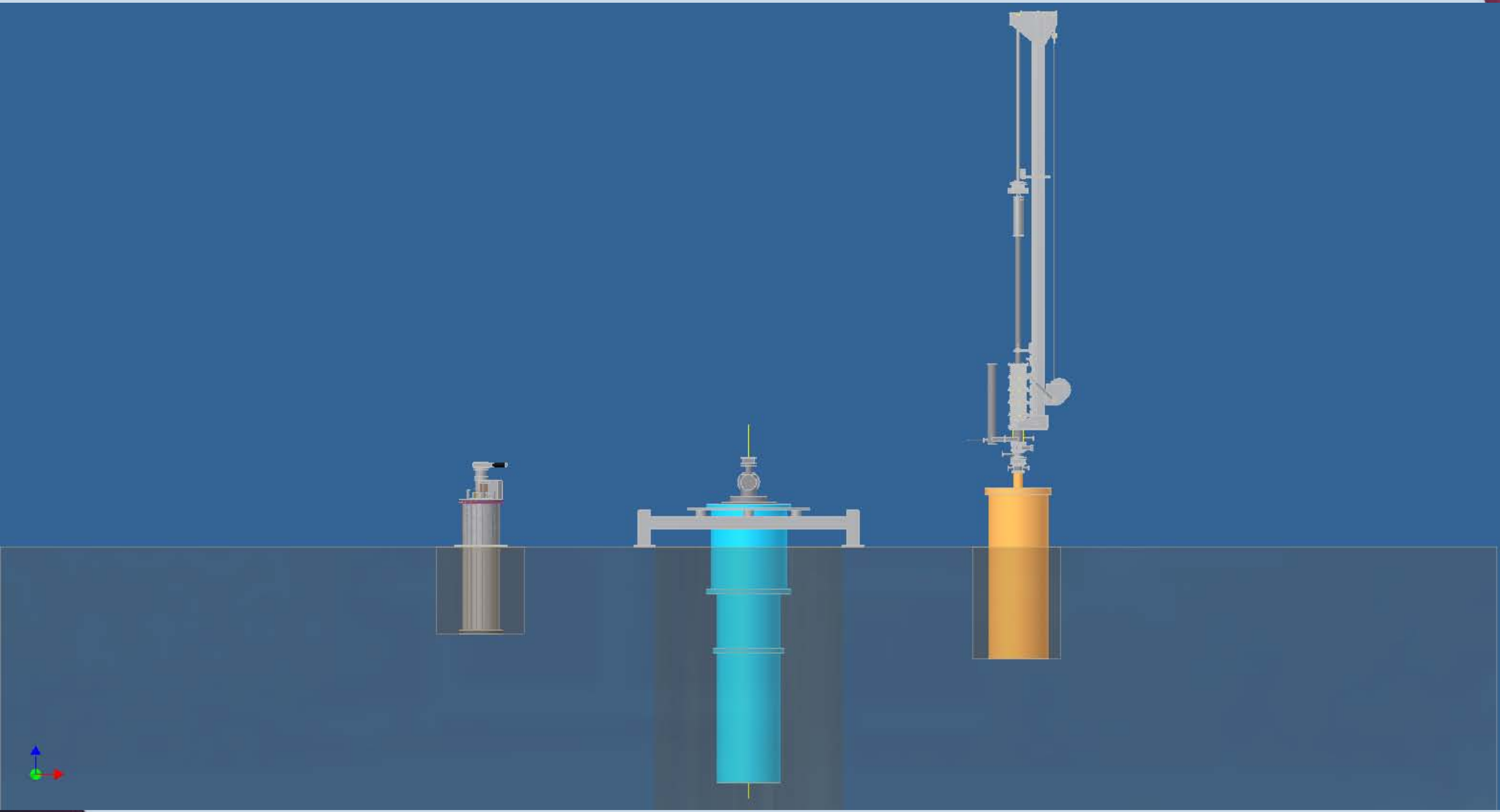
Target transfer between PD and DF

Operation: Target transfer



Target transfer between DF and SD

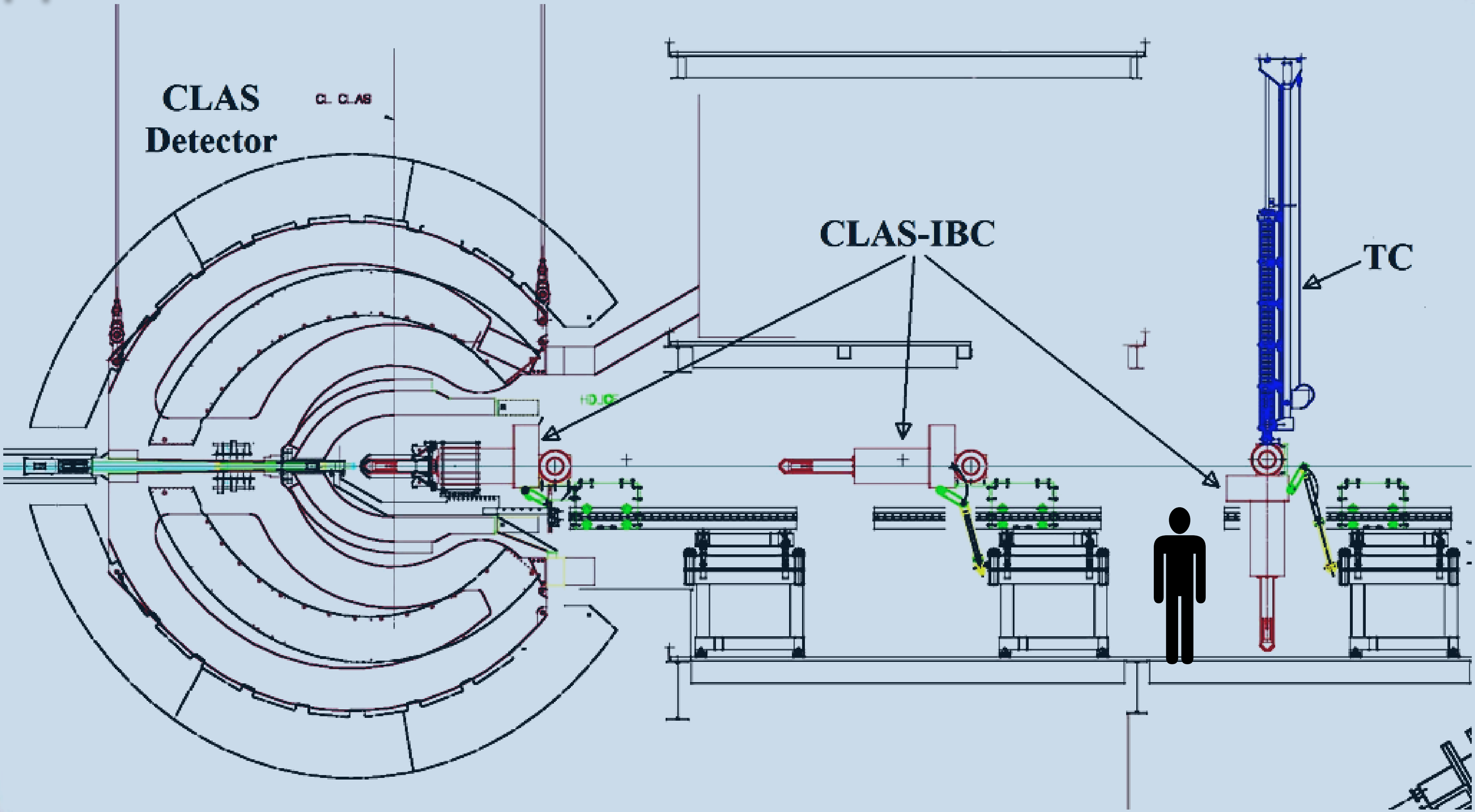
Operation: Target transfer



Target transfer between DF and SD

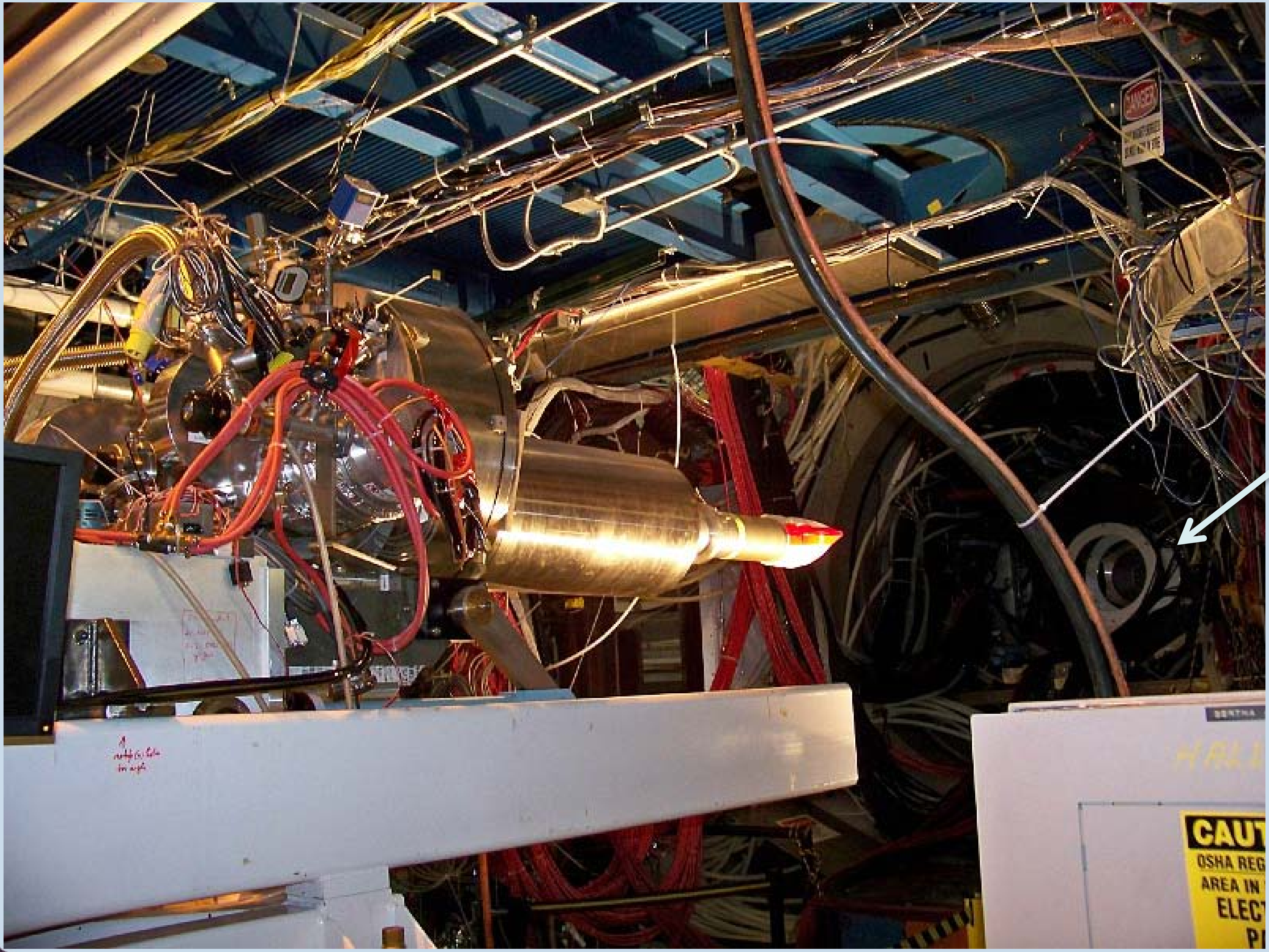
HDice

Operation: G-14 Run at Hall-B



Loading target into IBC and moving IBC inside CLAS

Operation: G-14 Run at Hall-B



Moving IBC into CLAS

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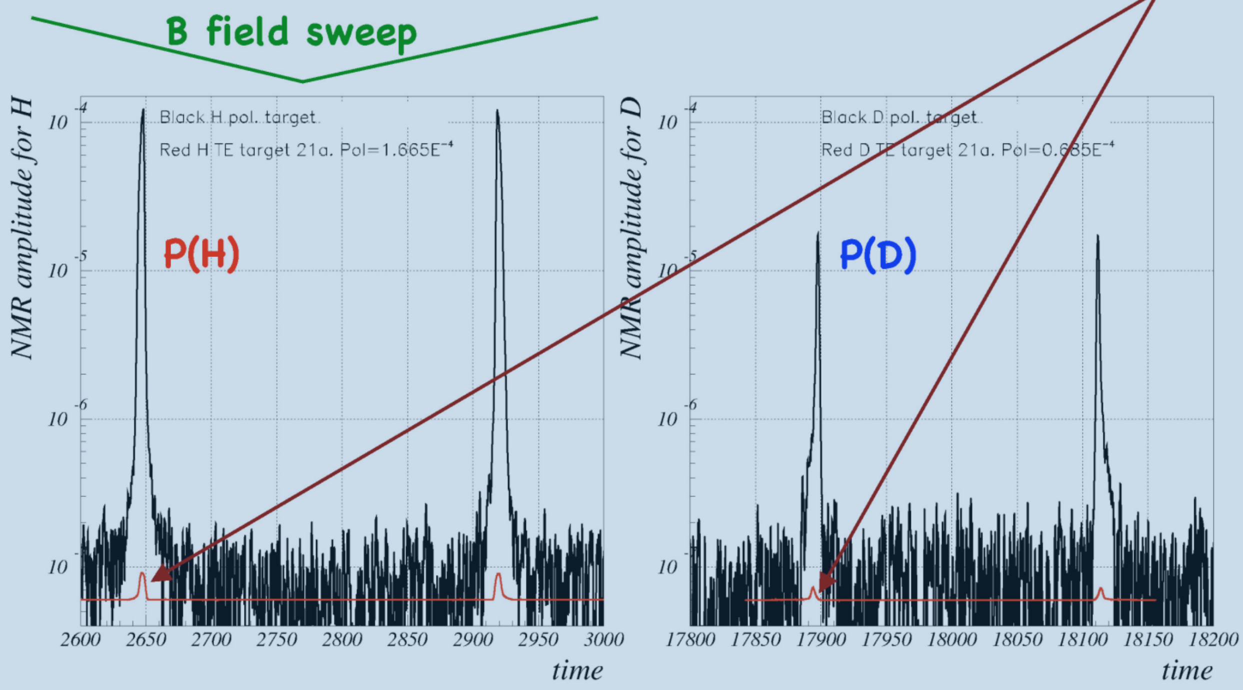
Target Polarization Calibration for G-14 Run

HD removed from DF after 3 months *Aging* at high field and low temp

- Frozen-spin NMR compared to thermal equilibrium (TE) calibration



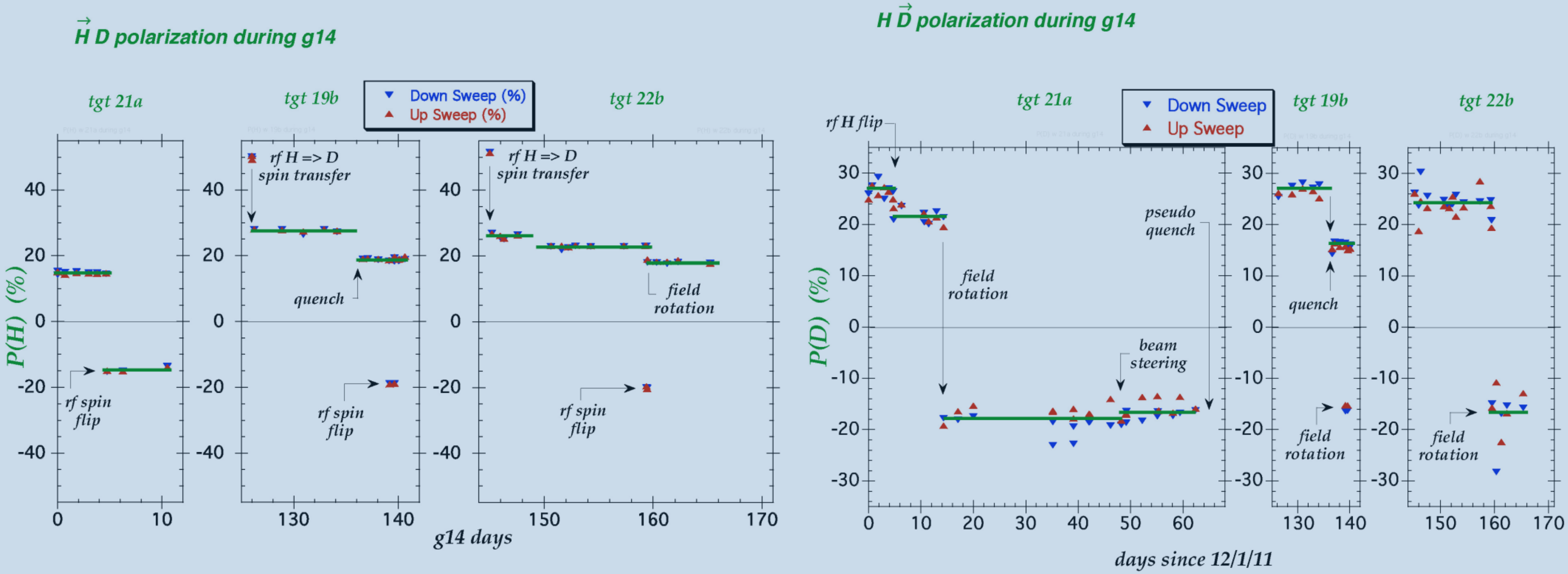
- HD target 20b:

$\Rightarrow$ P(H) = 61.3 ±1.8% $\Rightarrow$ P(D) = 15.5 ±0.6%

Tgt 20b NMR

Number of sweeps: 1 for polarized signals and ~250 for TE signals

Target Relaxation Times for H and D during G-14 Run



The HDice targets were in frozen spin mode during G-14 Run. Relaxation times was longer than one year at B=0.9T and T<100mK .

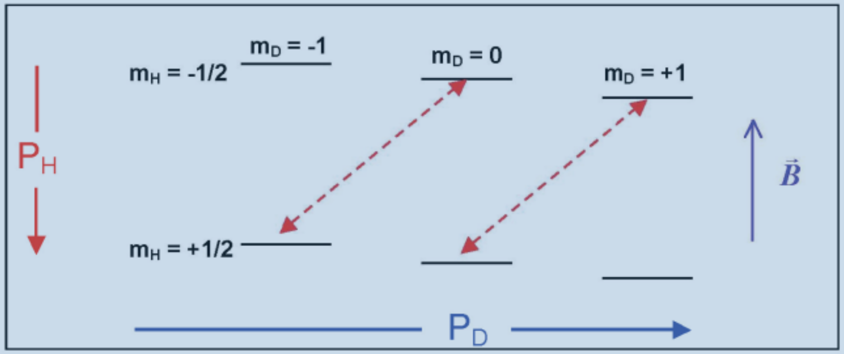
Polarization Manipulation during G-14 Run

Increasing D polarization by spin transfer:

- *Brute force* (high B/low T) $\Rightarrow$ $P_D \sim 15\%$ ($\mu_D / \mu_H \sim 1/3$)
- *1st forbidden adiabatic fast passage* (**FAFP**) to invert state populations

Zeeman levels of HD

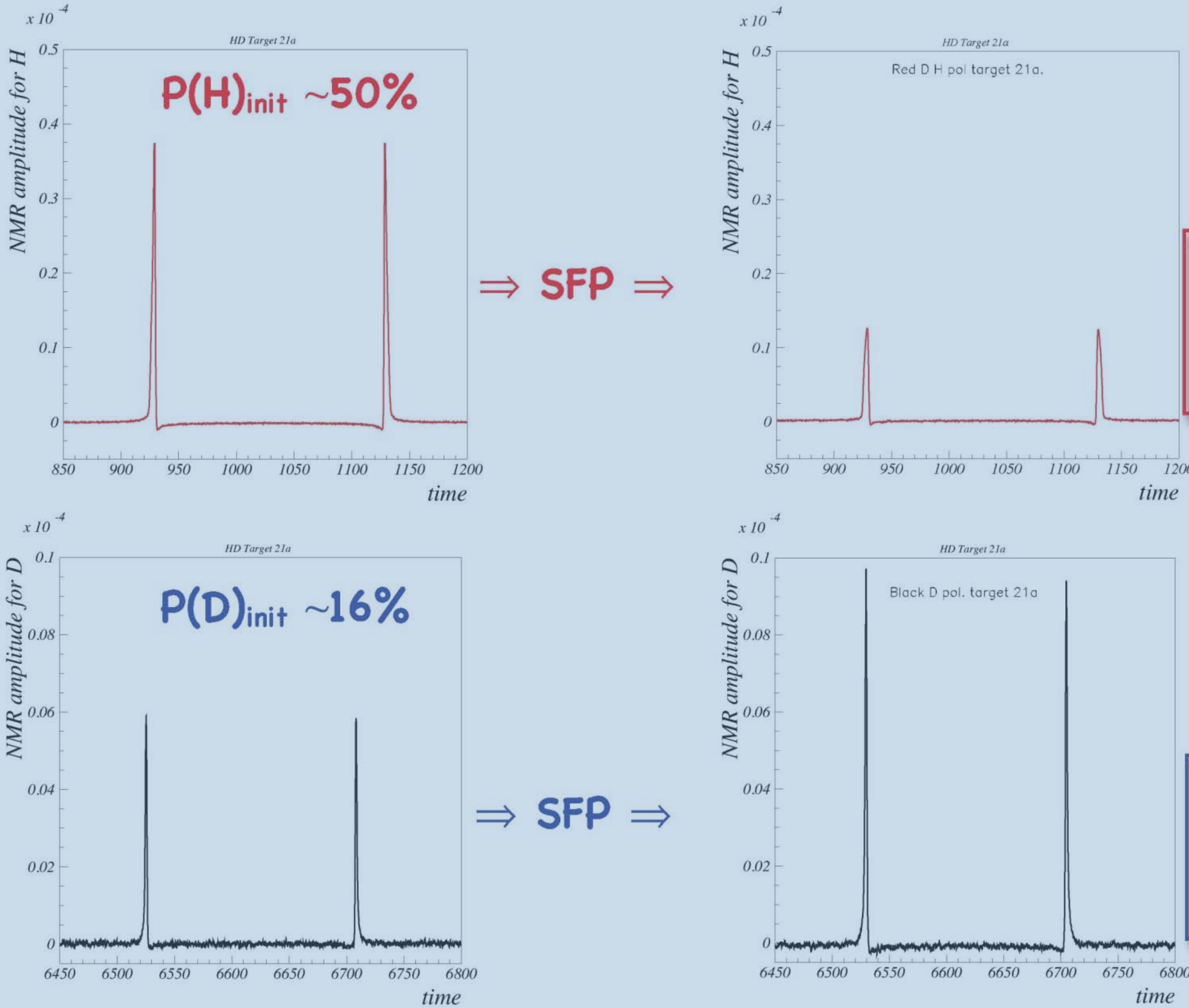
- **polarize H**
- **RF transfer**
P(H) → P(D)



- *requires high RF powers and very uniform fields*

- alternative: ***saturate the FAFP transition***
→ equalize { $m_H = +1/2$; $m_D = -1, 0$ } ⇔ { $m_H = -1/2$; $m_D = 0, +1$ }

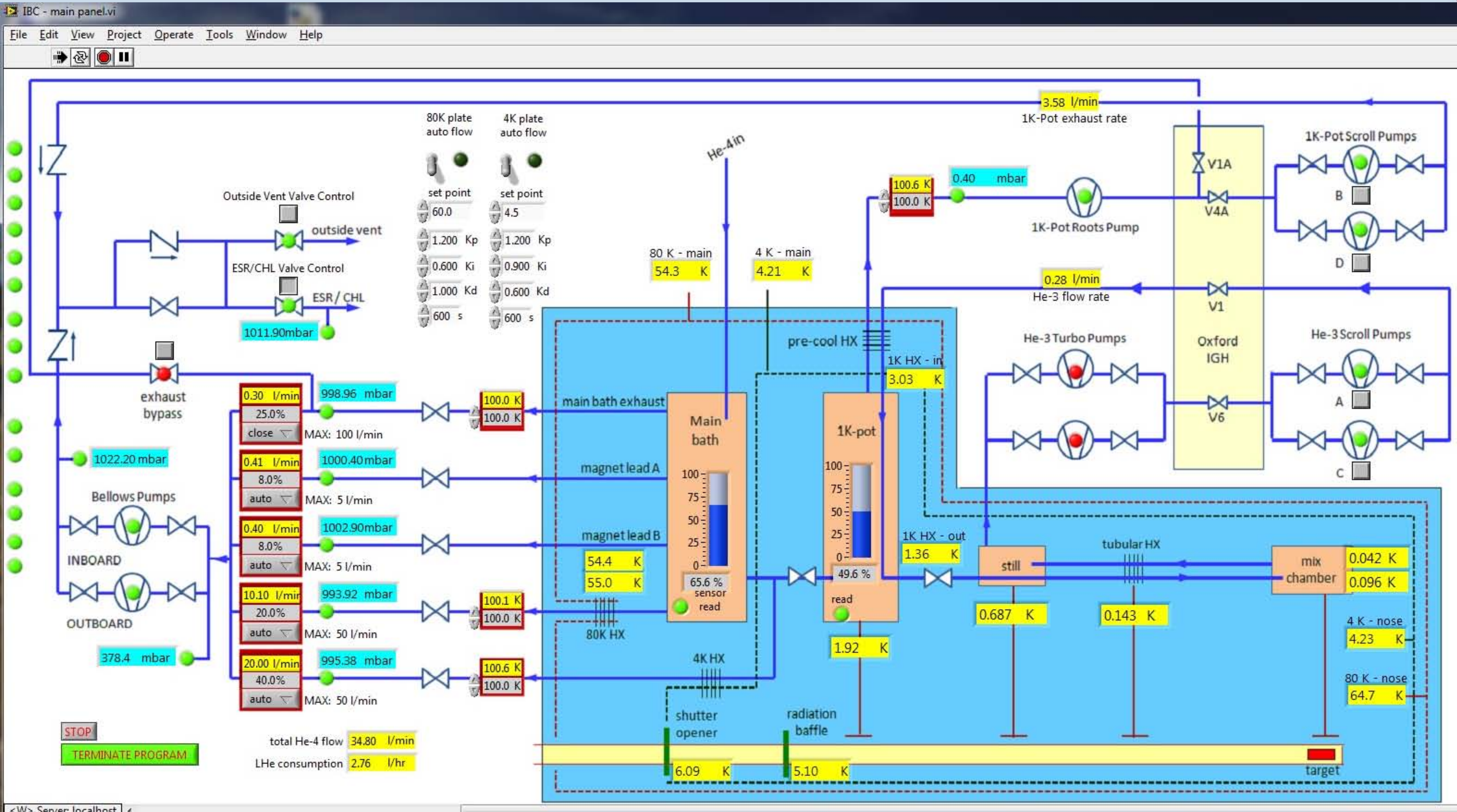
Polarization Manipulation with SFP during G-14 Run



P(H) final = 28 ±1%

P(D) final = 27 ±1%

In-Beam Cryostat Performance during G-14 Run



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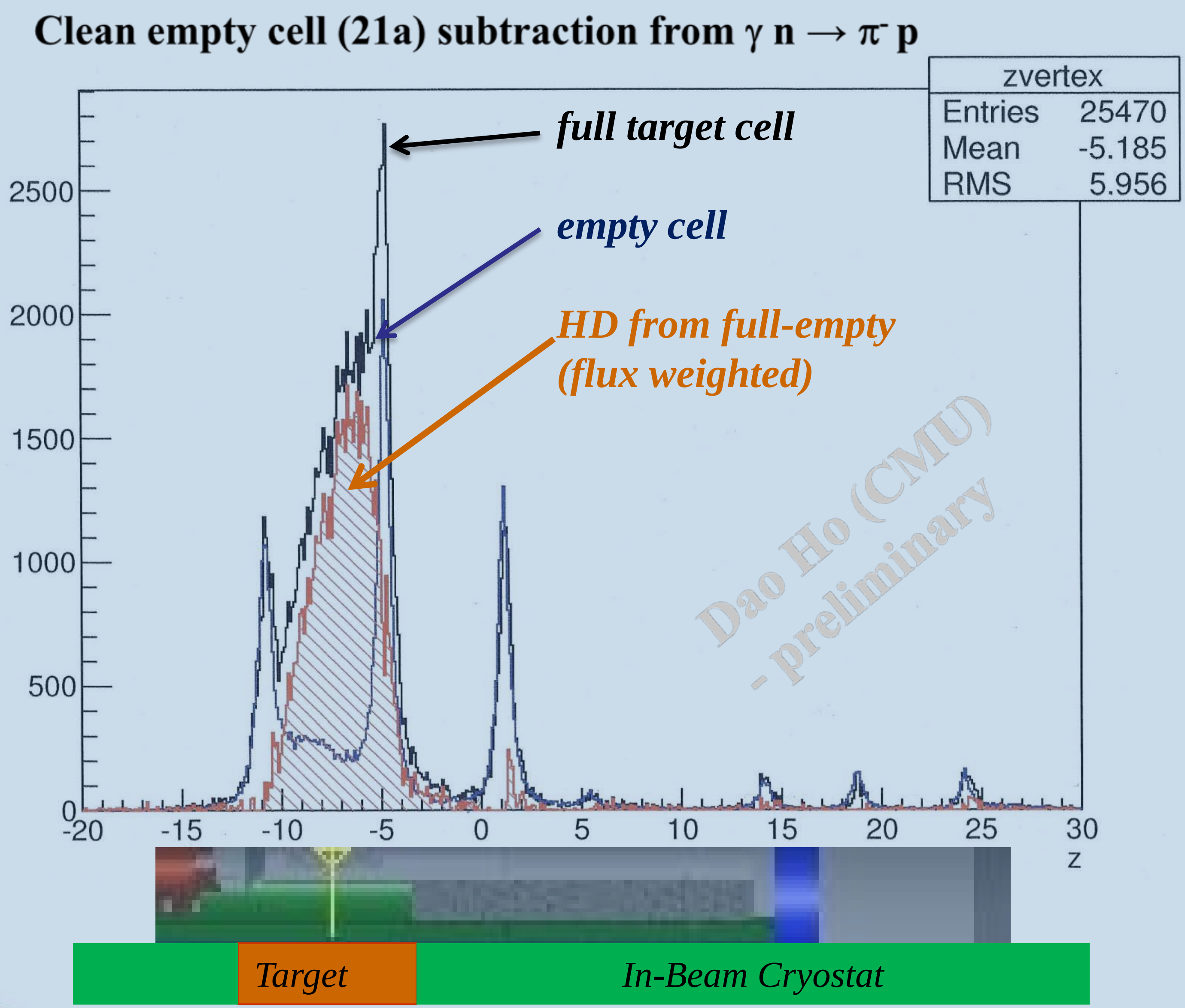
Reconstructed Vertex for HDice Target during G-14 Run



On-going Analysis for G-14 Run

identified analysis projects:

γ n (p) $\rightarrow$ $K^{\circ}\Lambda$ (p)

γ n (p) $\rightarrow$ $K^{-}\Sigma^{+}$ (p)

γ n (p) $\rightarrow$ π^{-}p (p)

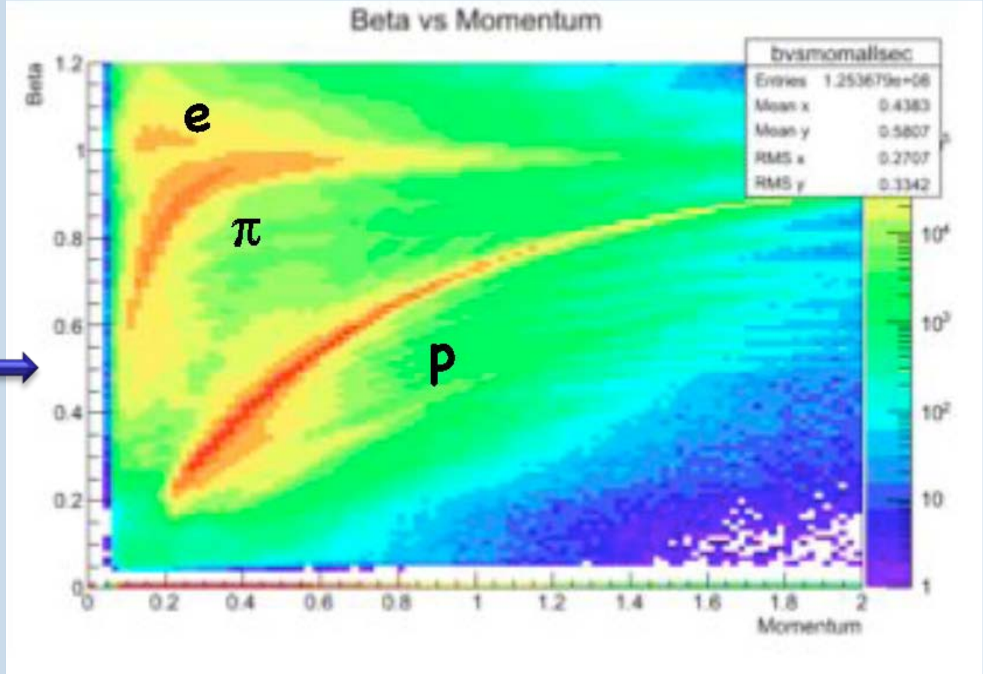
γ n (p) $\rightarrow$ $\pi^{+}\ \pi^{-}$ n (p) $\Leftrightarrow$ $\pi^{+}\ \Delta^{-}$ (p), $\pi^{-}\ \Delta^{+}$ (p), ρn (p)

γ n (p) $\rightarrow$ $\pi^{+}\ \pi^{-}\ \pi^{\circ}$ n (p) $\Leftrightarrow$ η n (p), ω n (p)

γ n (p) $\rightarrow$ $\pi^{\circ}\ \pi^{-}$p (p)

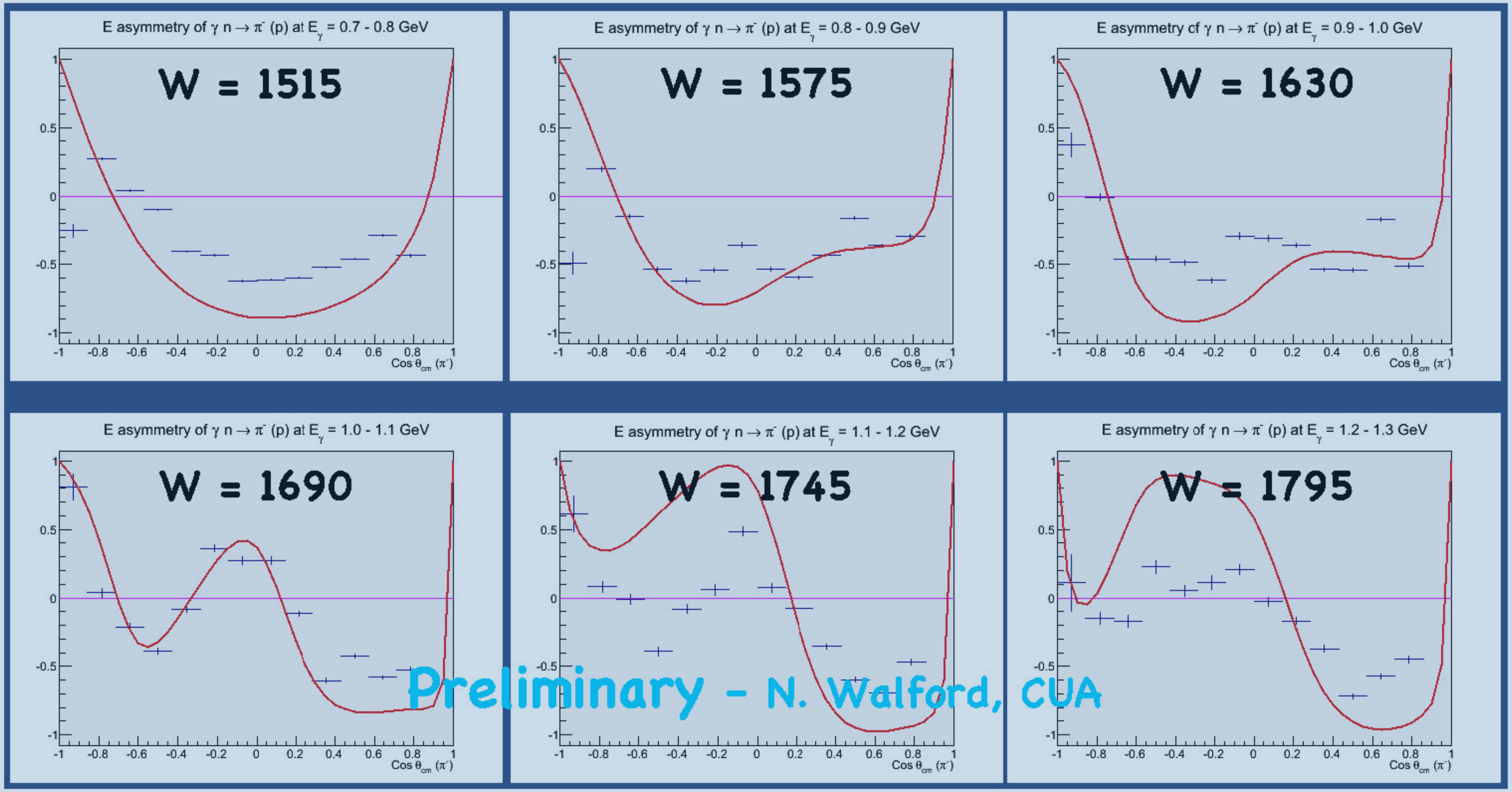
1st look at data

Beta vs. Momentum



1st look at neutron data from G-14/H$\vec{D}$ice (concluded on 05/18/2012)

- $\vec{\gamma}\,\vec{n}\,(p) \rightarrow \pi^- p\,(p)$
- E beam-target helicity asymmetry from a few % of the g14 data:



— SAID extrapolations from proton data

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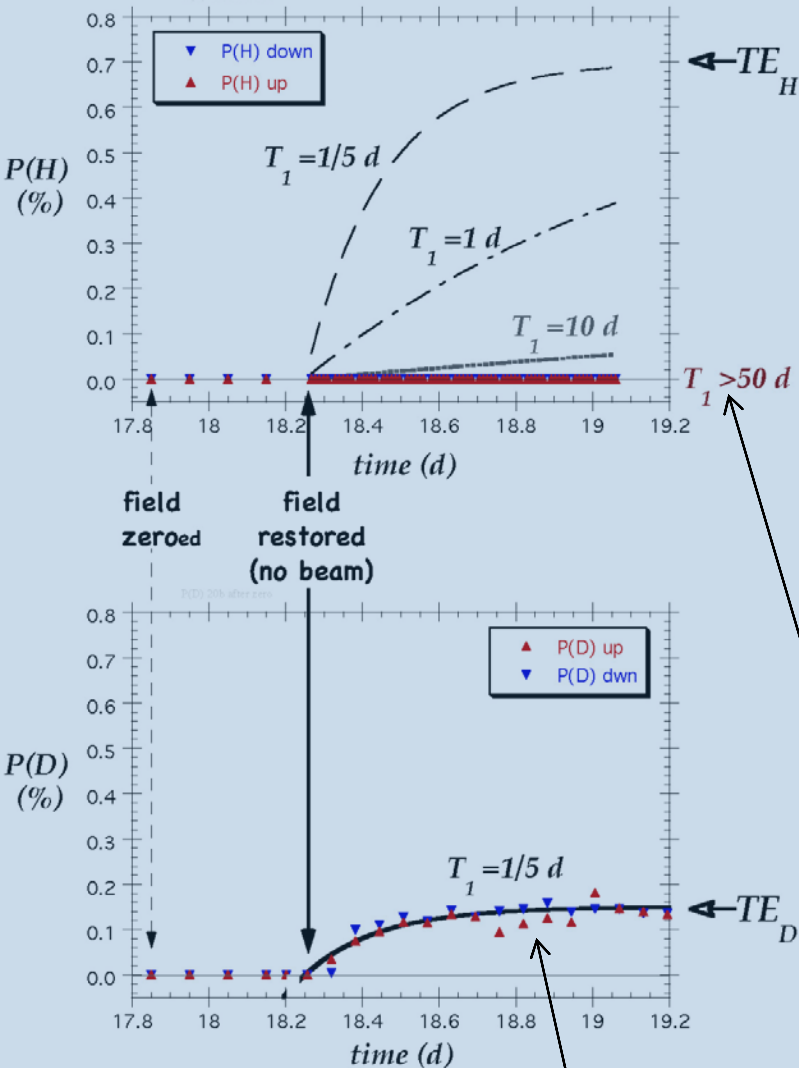
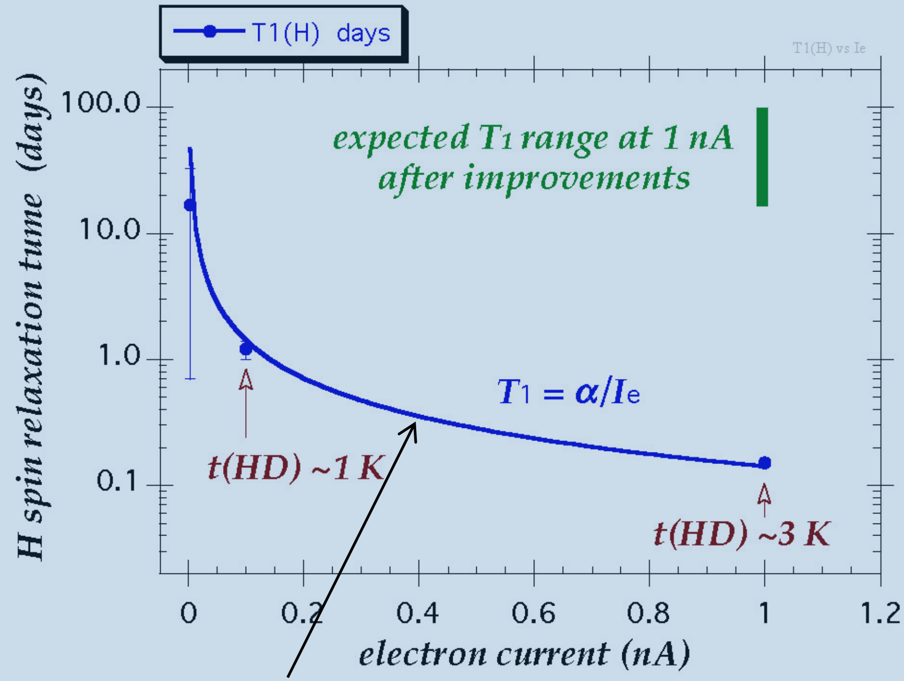
Electron Beam Tests, e + HD to check radiation damage





Beam Heating is the main concern for H.

⇒redesign target cell

build faster beam raster

H is not harmed, T_1(H) > 50 d.

D is damaged by radiation, T_1(D) = 0.2 d.

Conclusion

- ***HDice target has been successfully installed at CLAS.***
- ***Performance of HDice target demonstrated a huge potential for photon experiments.***
- ***Comparing with the conventional target, which polarizes 80% of the 20% usable material, the HDice has 20% polarization of 80% target material.***

  BUT, WE TOOK THE DATA AT 10 TIMES FASTER RATE BECAUSE OF LOW BACKGROUND.
- ***Electron beam on HDice test shown the road of improvement.***