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

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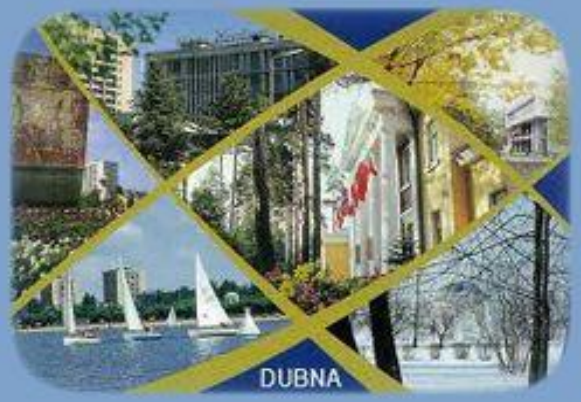

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Collaborators

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- *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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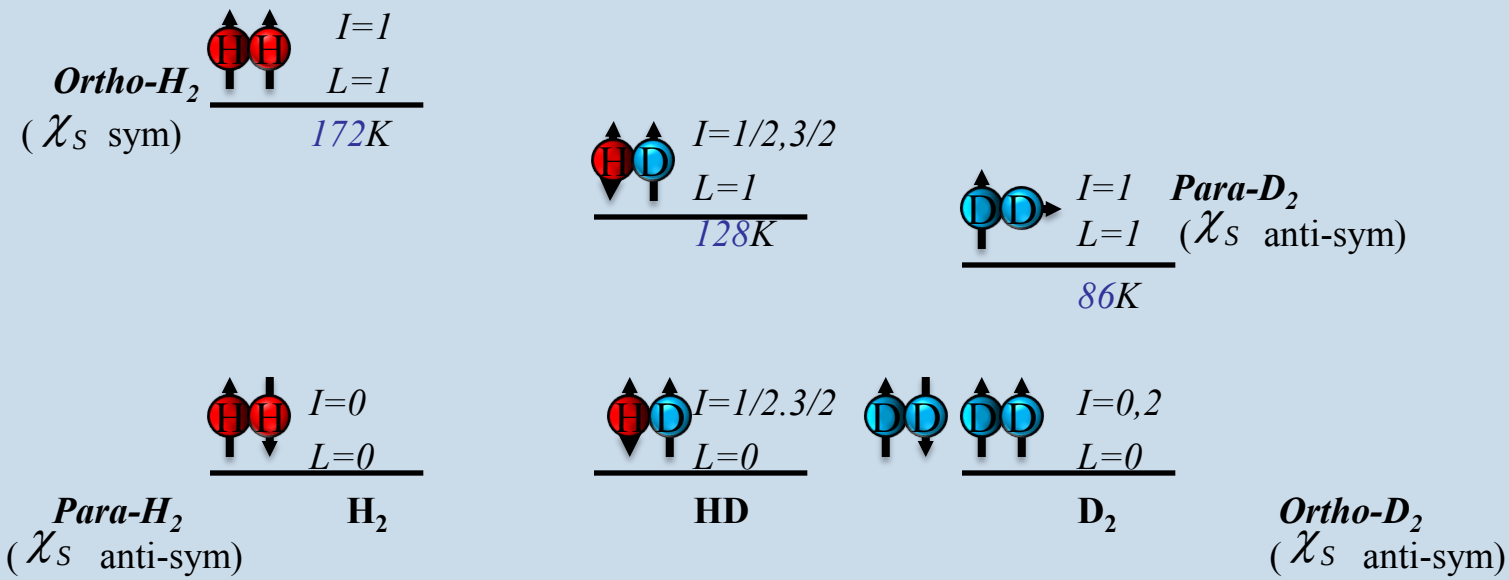
Polarizing HD: the rotational levels of the solid hydrogens

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



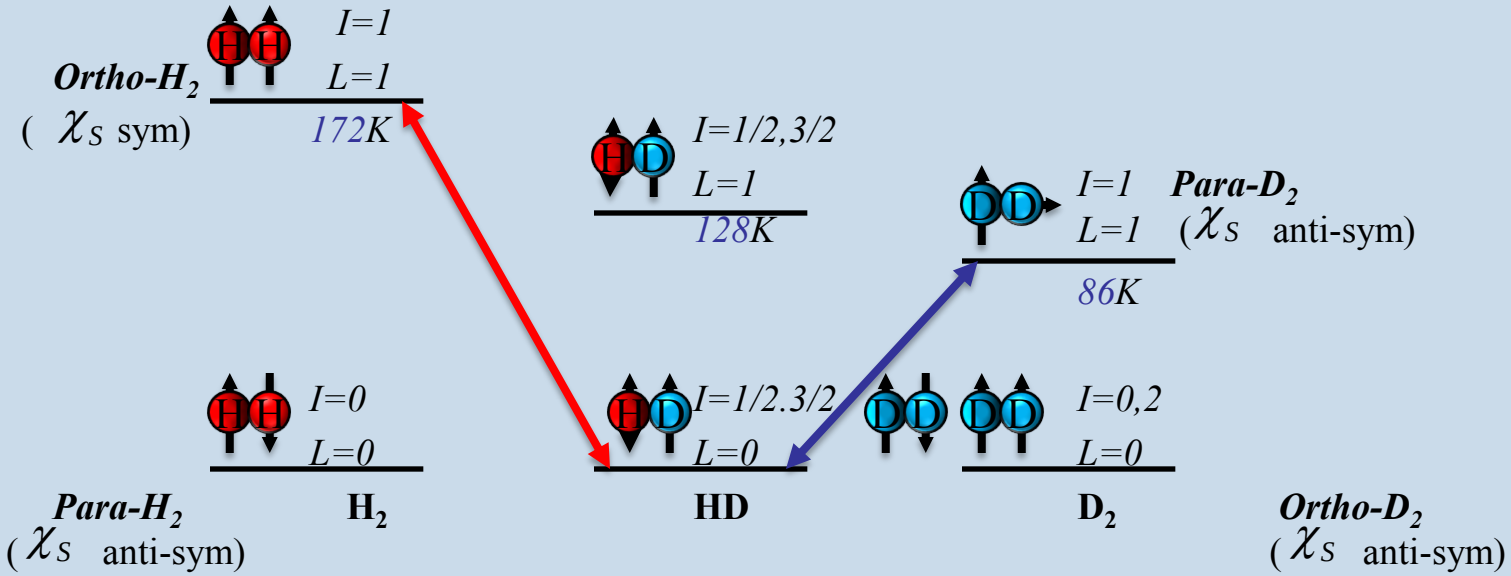
The relative energy spacing of the low-lying nuclear spin, I, and molecular orbital angular momentum, L, levels in H_2, HD and D_2 system. The symmetries of the nuclear spin wavefunction, c_S, are indicated.

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

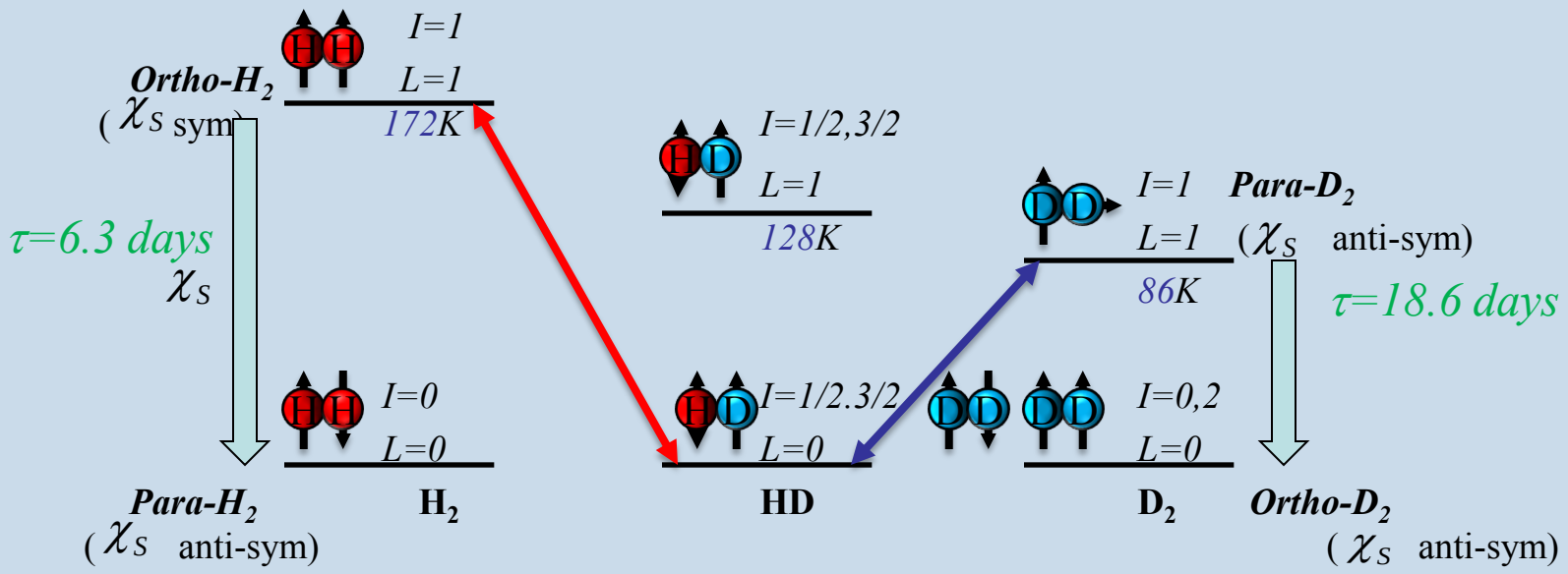
⇒help from J=1 H_2 and D_2 through spin-wave is needed for polarizing HD



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, c_S, are indicated.

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

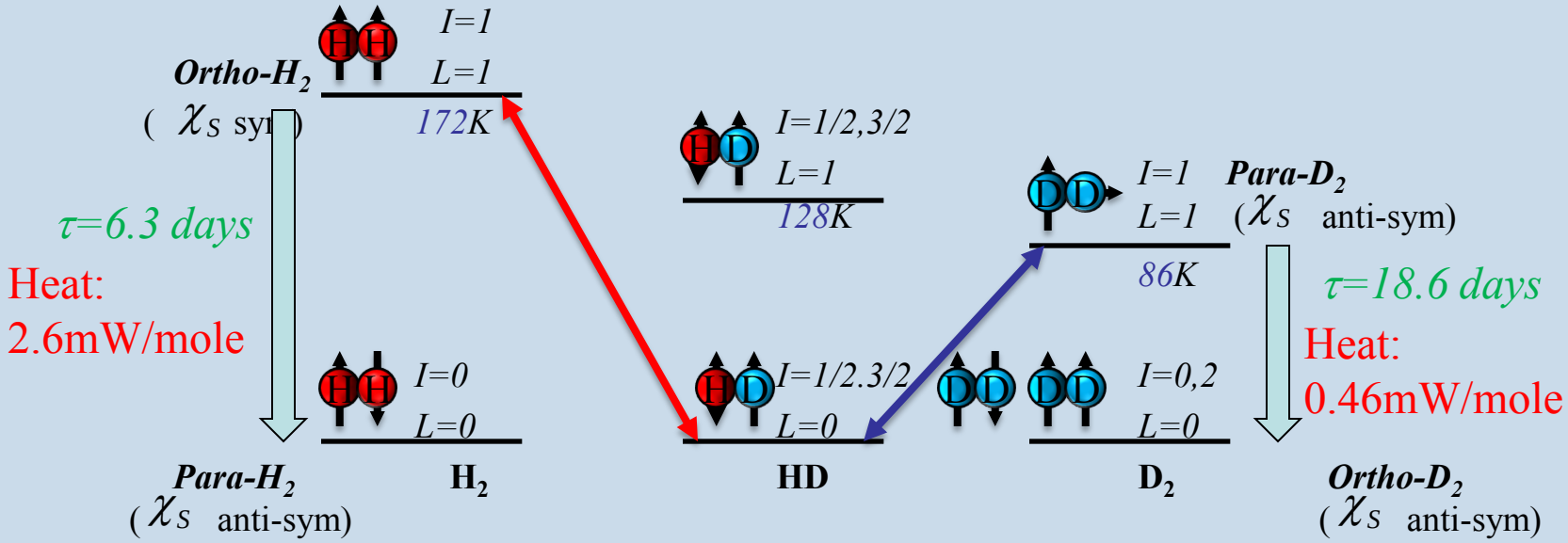
The life time for J=1 H_2 is 6.3 days whiles for J=1 D_2 is 18.6 days.
⇒polarization mechanism disappears after "aging"
⇒Highly polarized frozen spin target



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, c_S, are indicated.

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, c_S, are indicated.

Topics

- *How the HDice target works*
- ***Target Production***
- *Performance of HDice target*
- *γ+HDice results with CLAS*
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Instrumentation: Target Cell

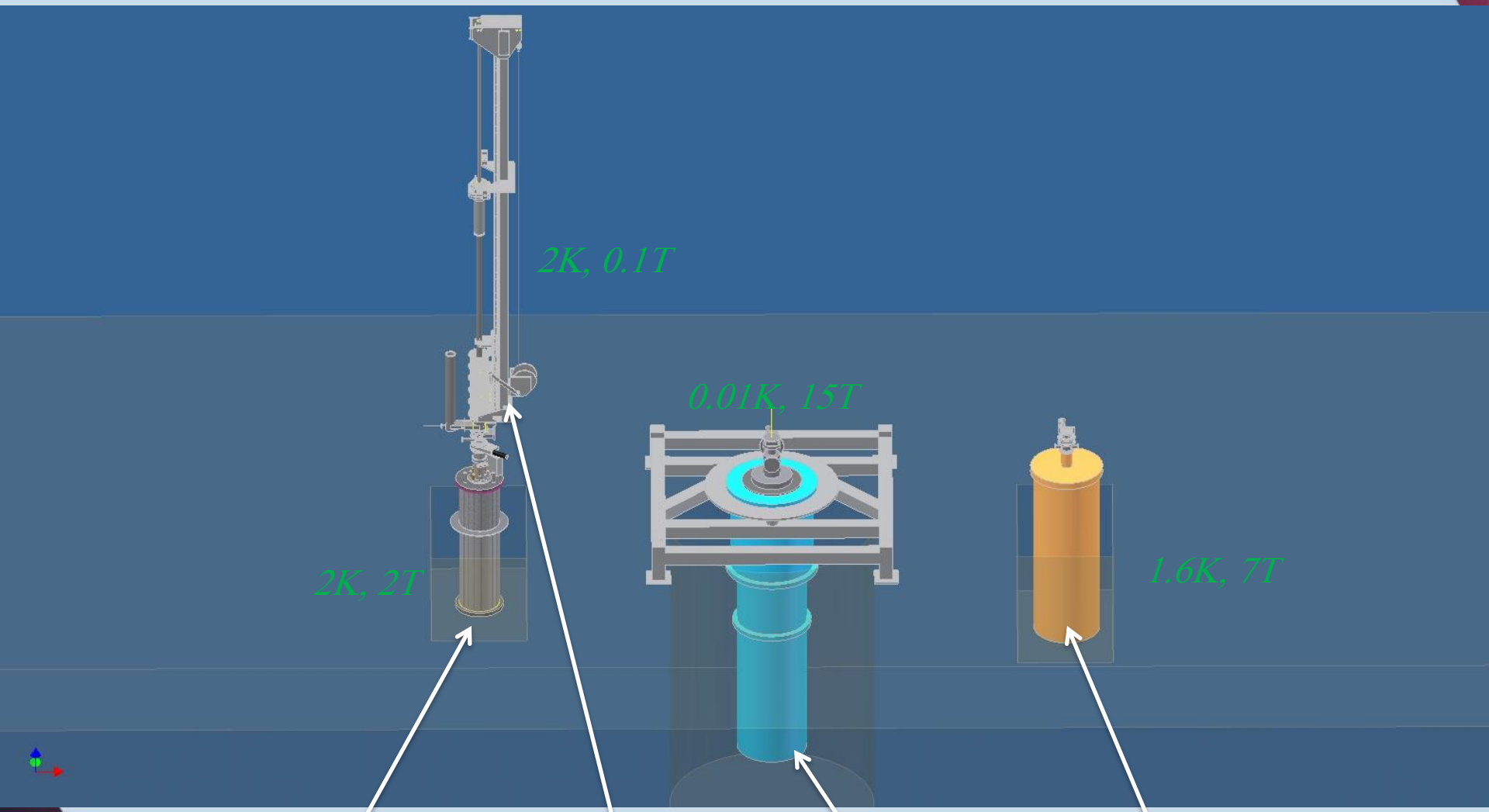
- HDice target cells:

- material in the beam path:

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

Operation: Target transfer

Operation: Target transfer



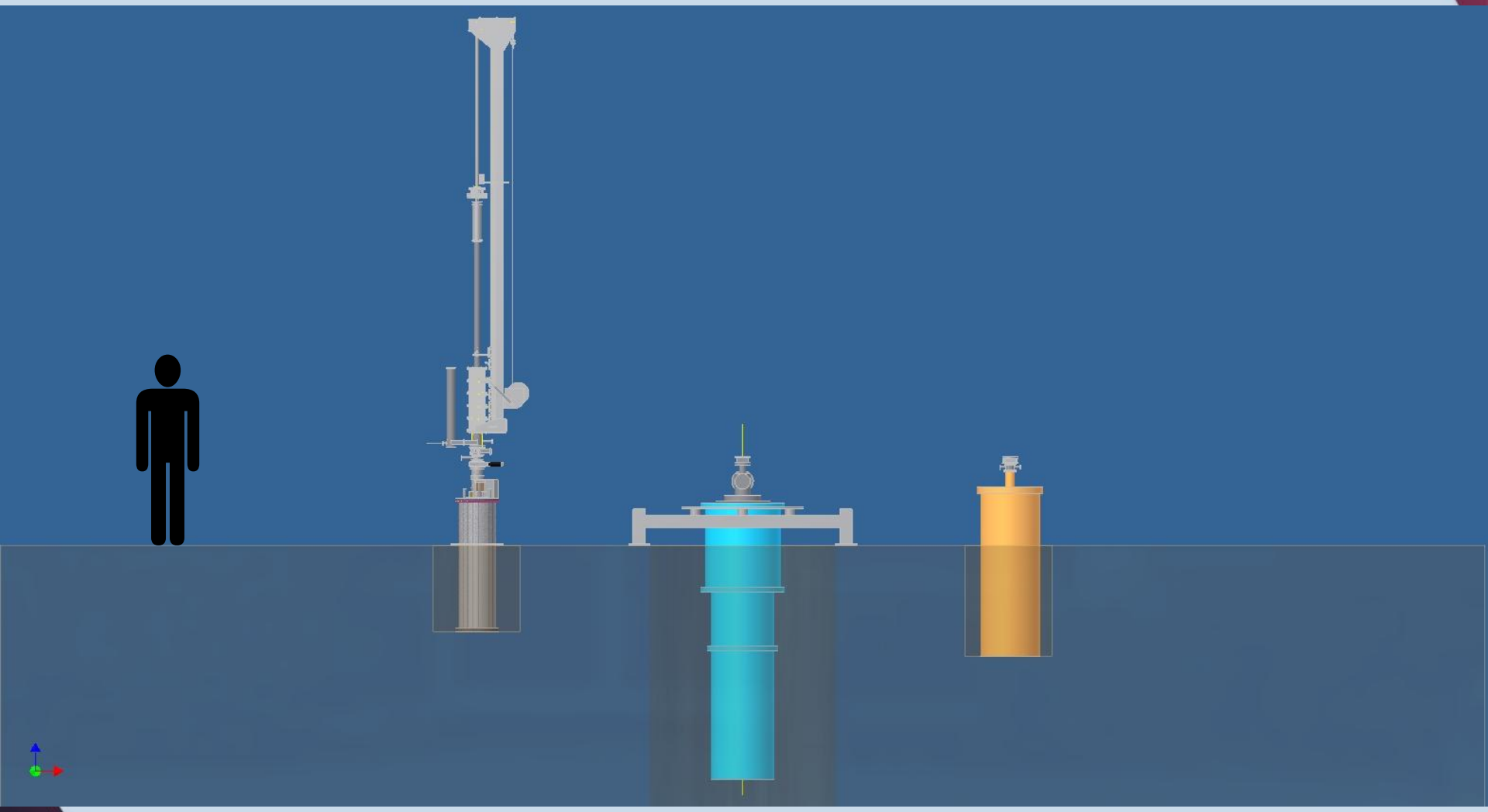
PD
(Injecting target, NMR-TE)

TC
(Moving target)

DF
(Polarizing target)

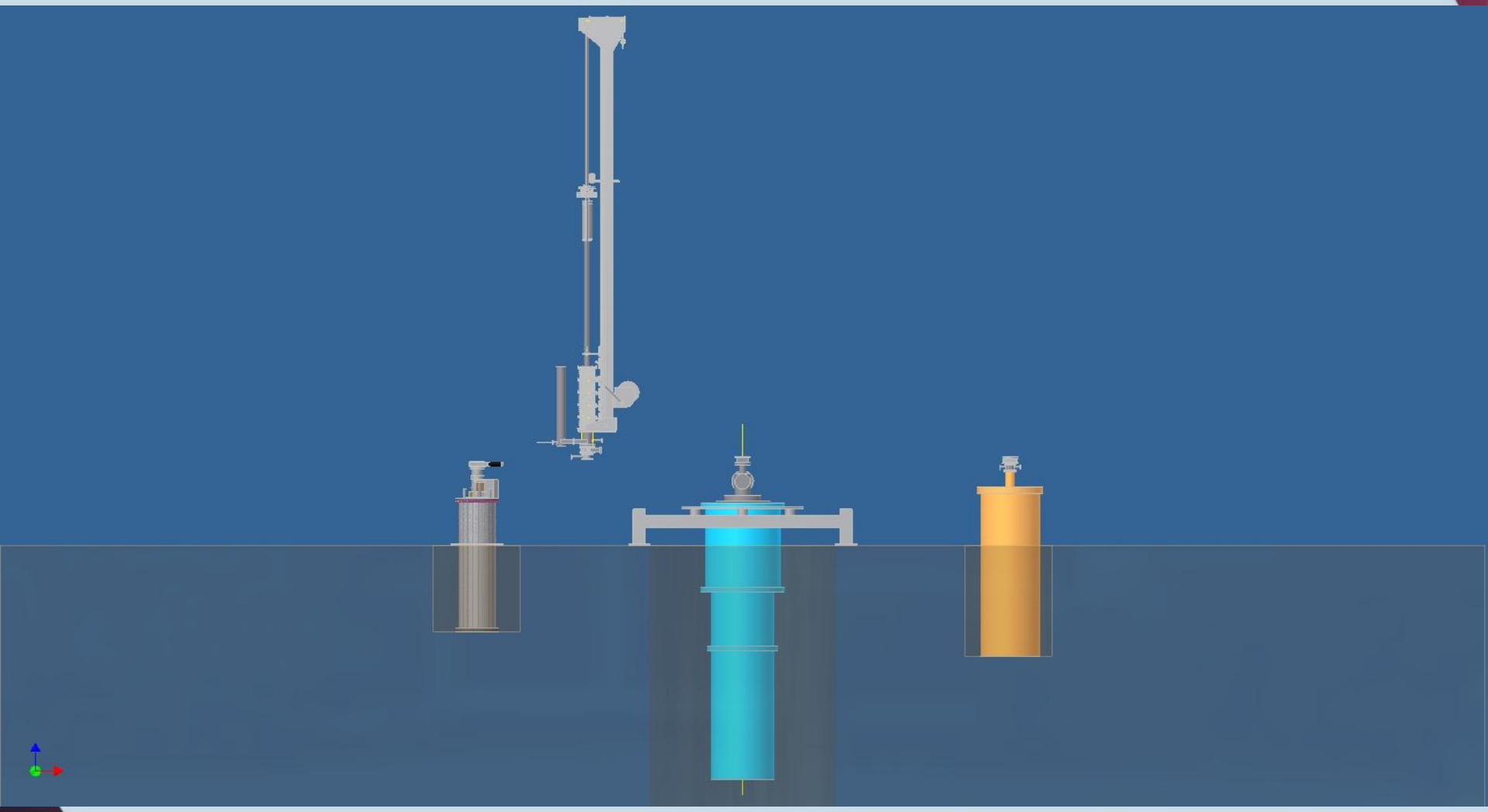
SD
(Storing/transporting target)

Operation: Target transfer



Target transfer between PD and DF

Operation: Target transfer



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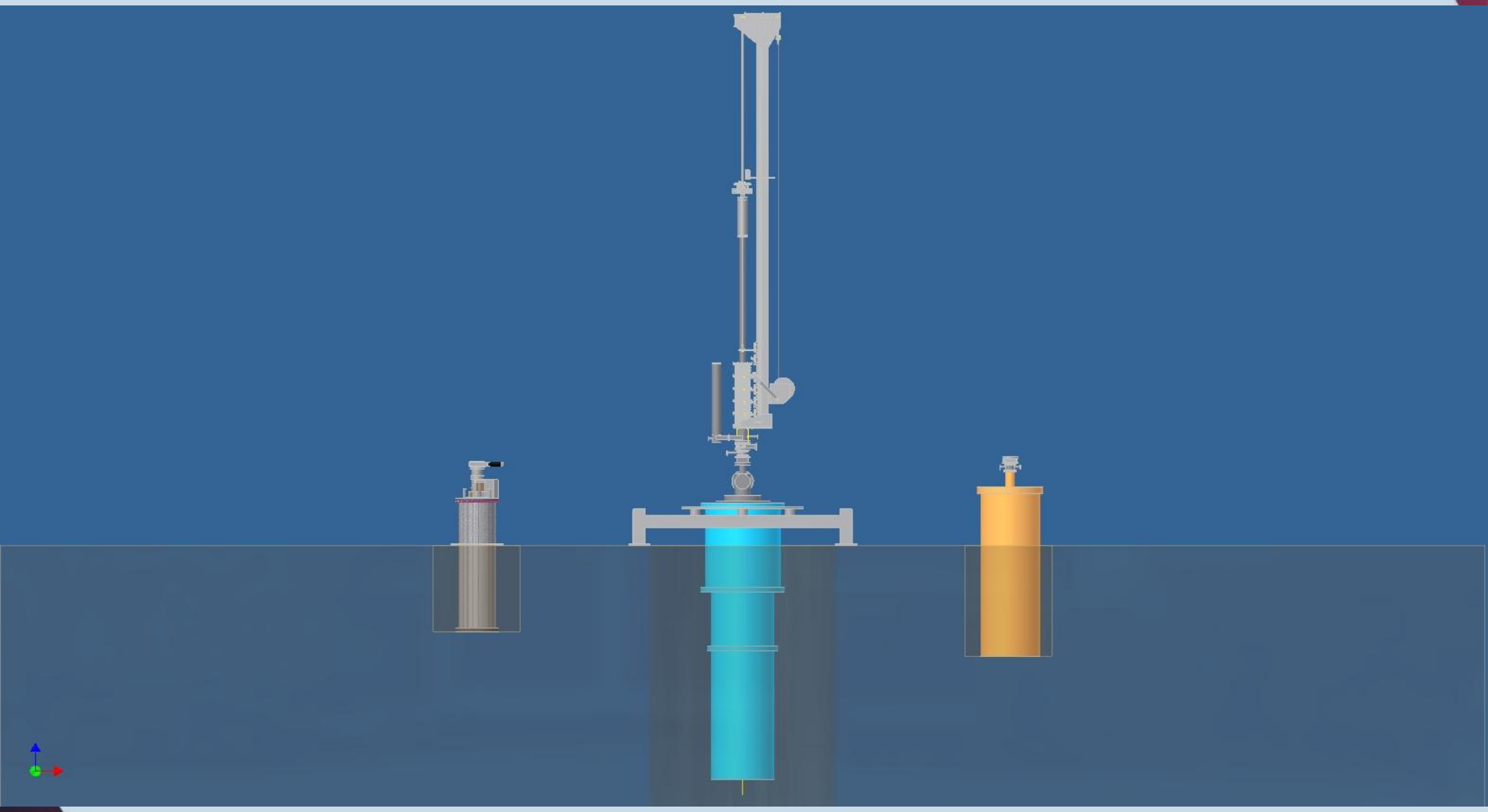

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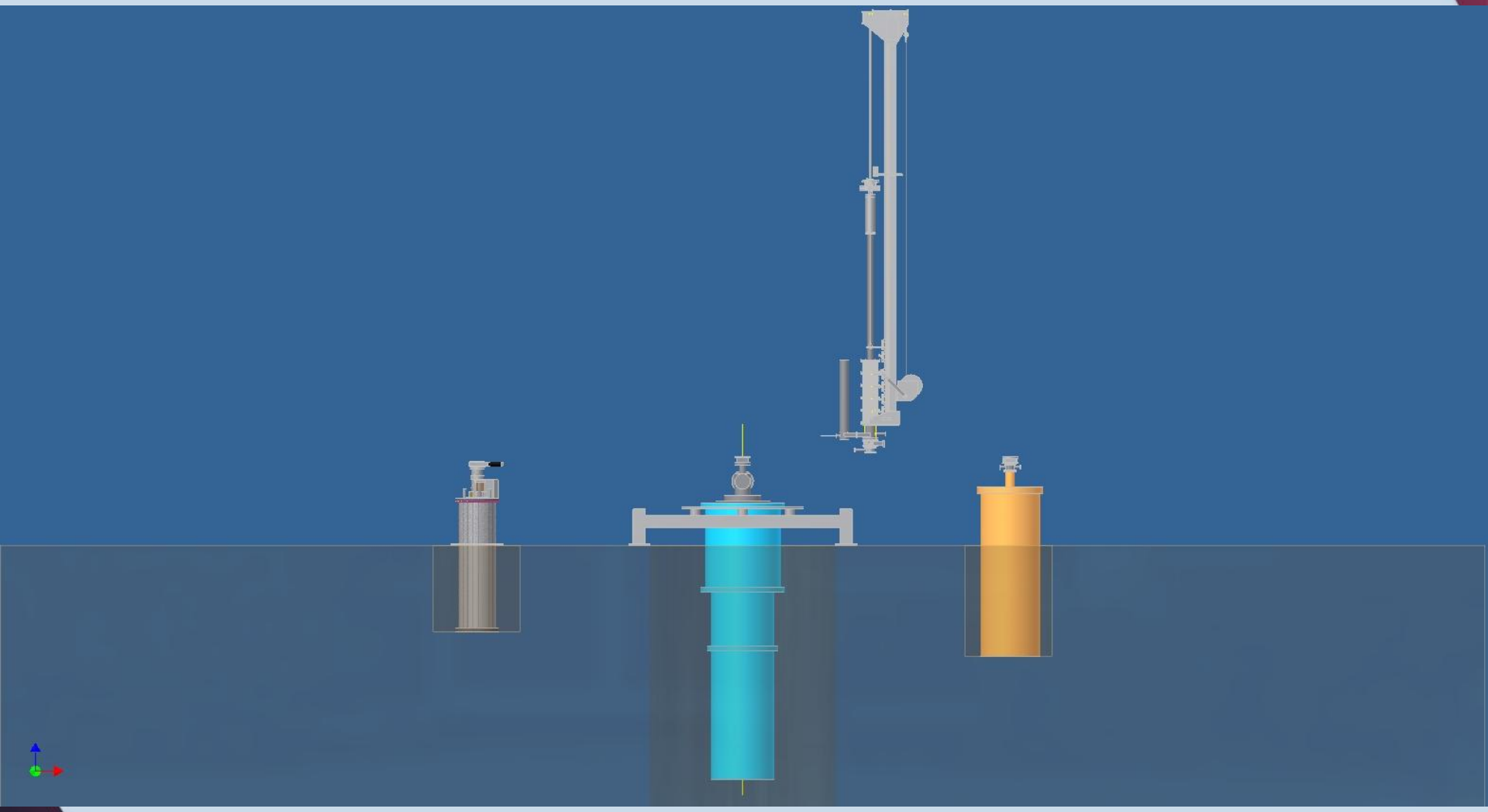
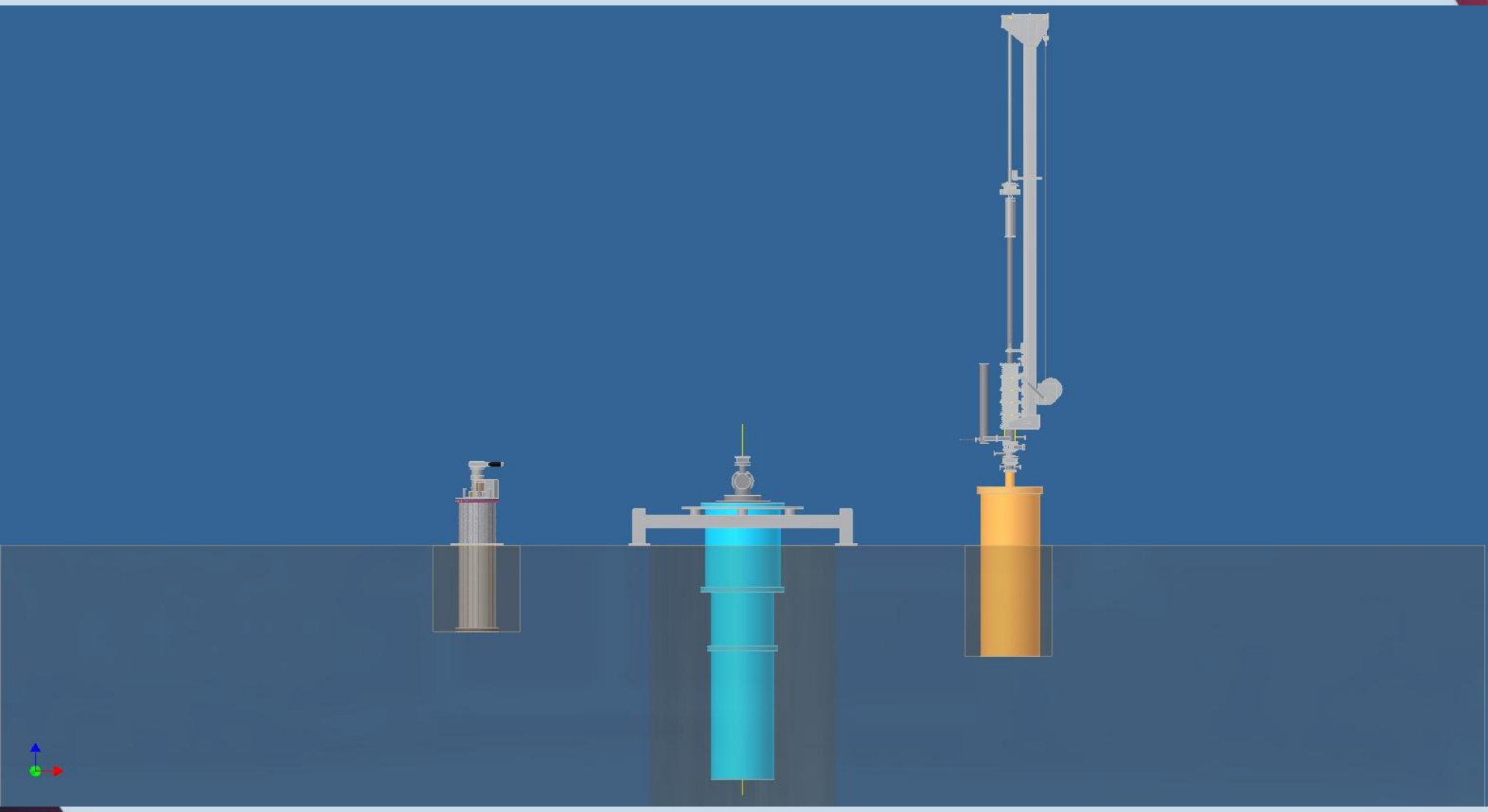


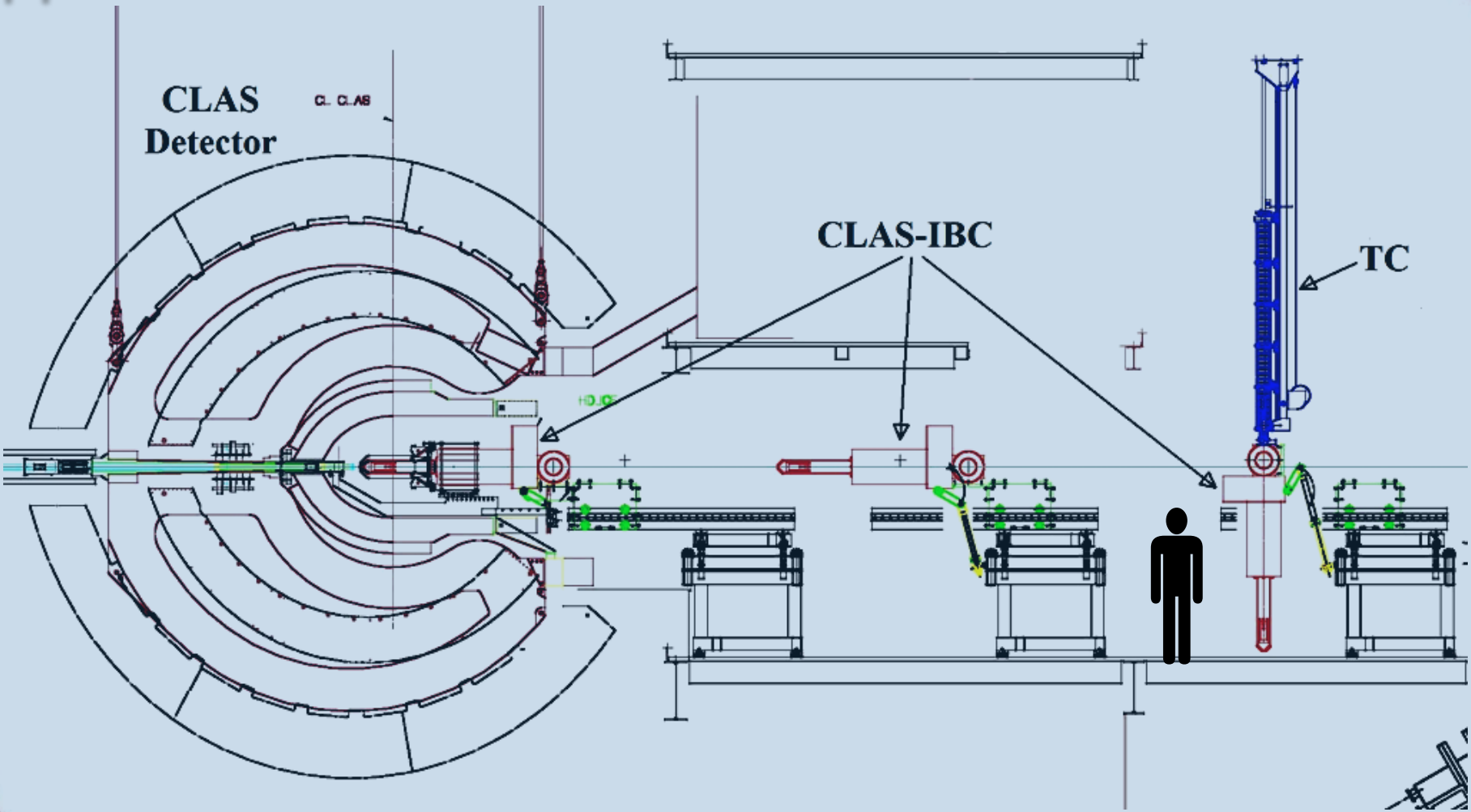
Target transfer between DF and SD

Operation: Target transfer



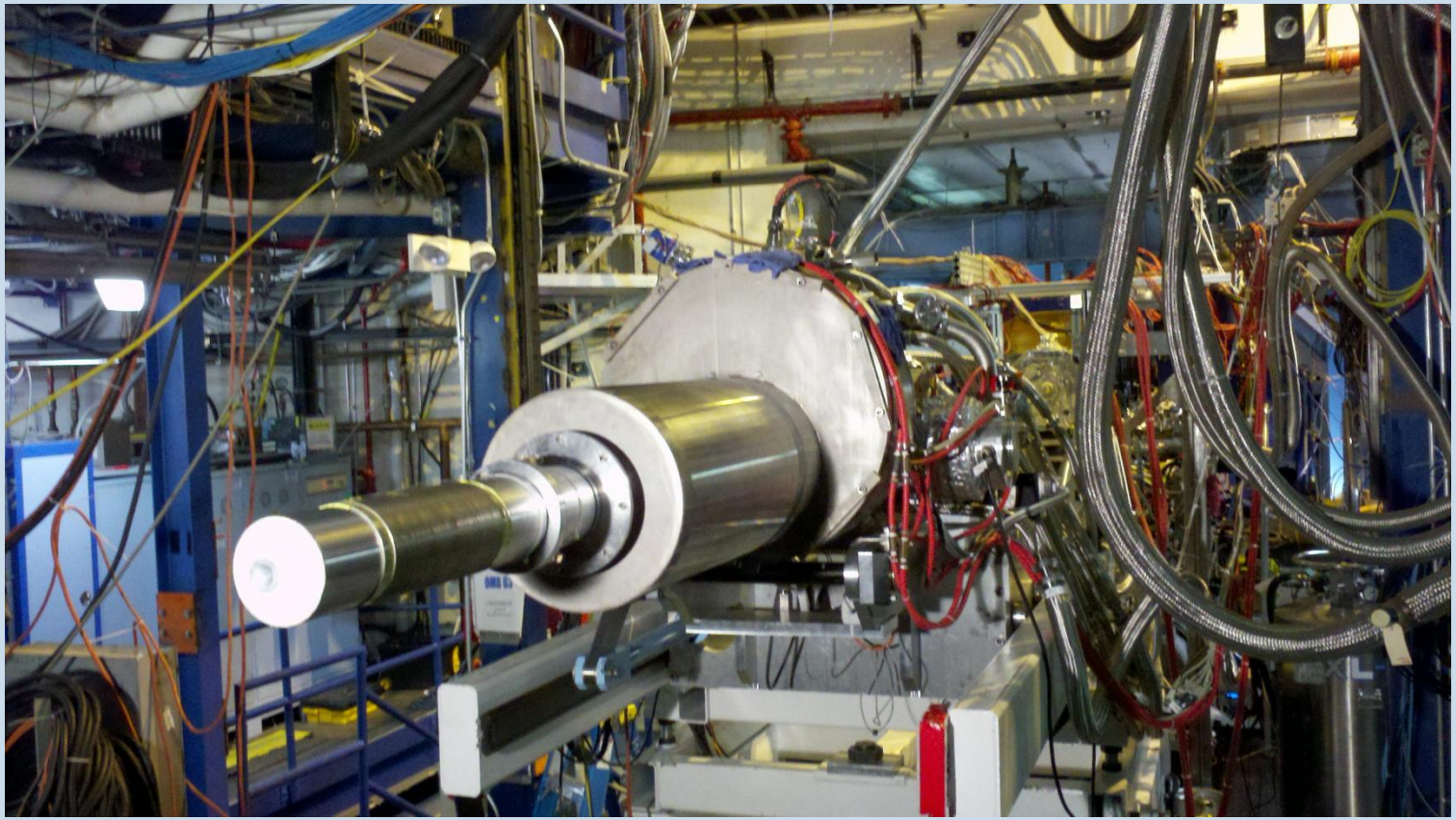
Target transfer between DF and SD

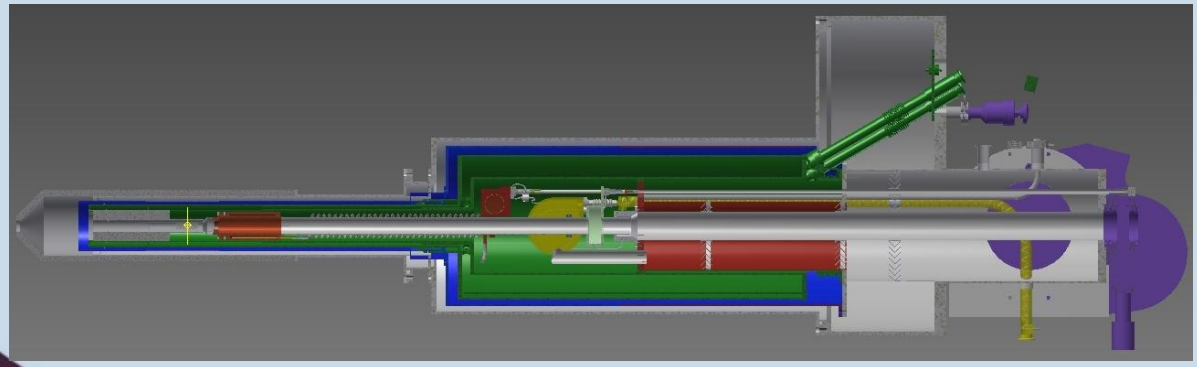
Operation: G-14 Run at Hall-B



Loading target into IBC and moving IBC inside CLAS

Instrumentation: In-Beam Cryostat





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

In-Beam Cryostat (IBC)

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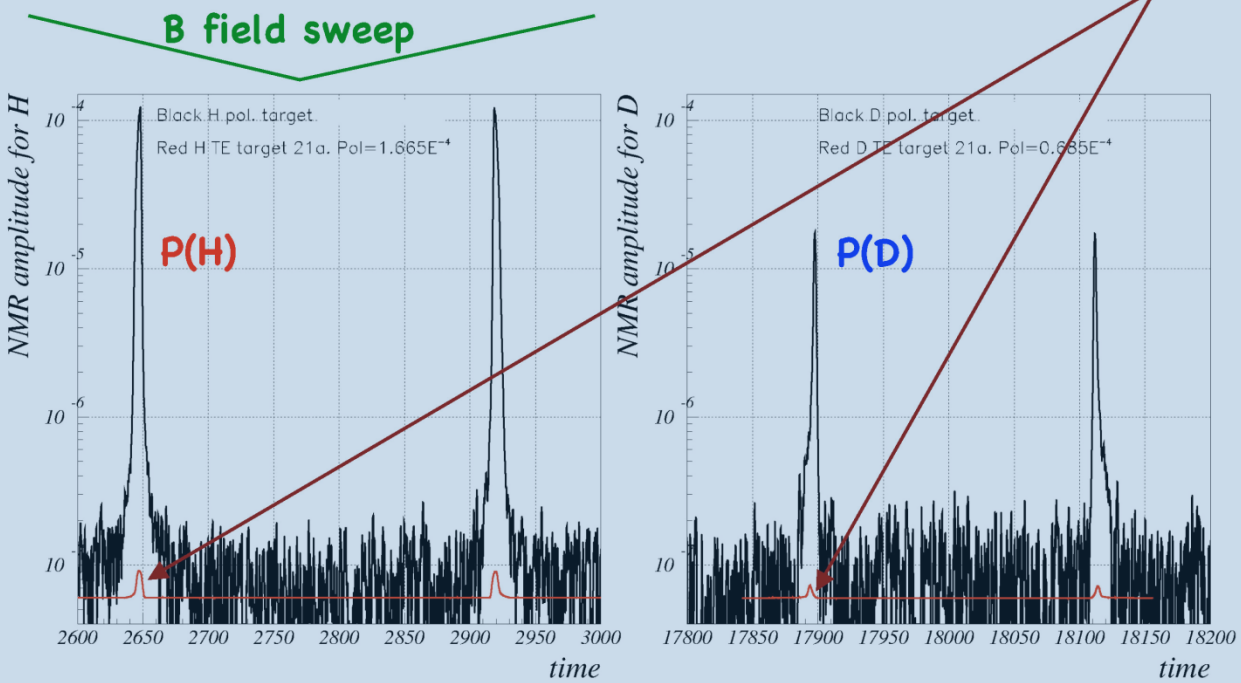
Target Polarization Calibration for G-14 Run

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:

⇒ P(H) = 61.3 ±1.8% ⇒ P(D) = 15.5 ±0.6%

Tgt 20b NMR

Number of sweeps: 1 for polarized signals and
(*typical*) ~250 for TE signals

Polarization Manipulation during G-14 Run

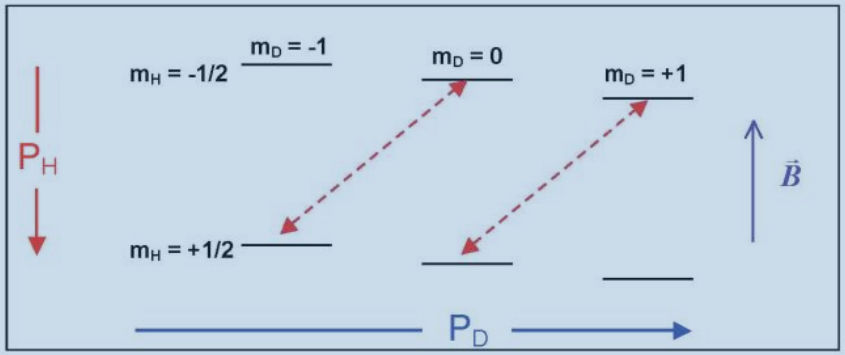
Increasing D polarization by spin transfer:

- *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

- **polarize H**

- **RF transfer**
  P(H) $\rightarrow$ P(D)

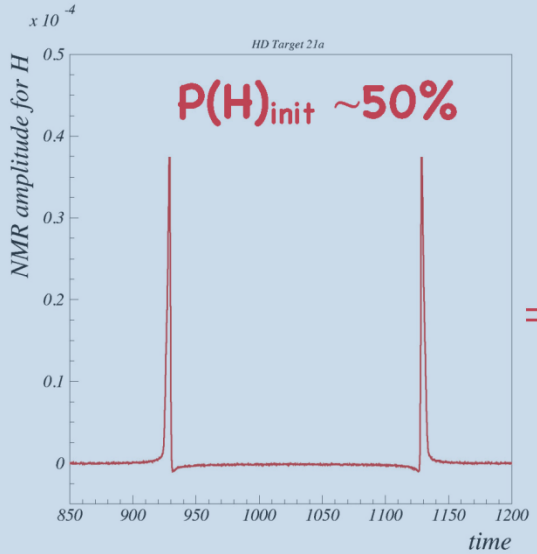
Zeeman levels of HD



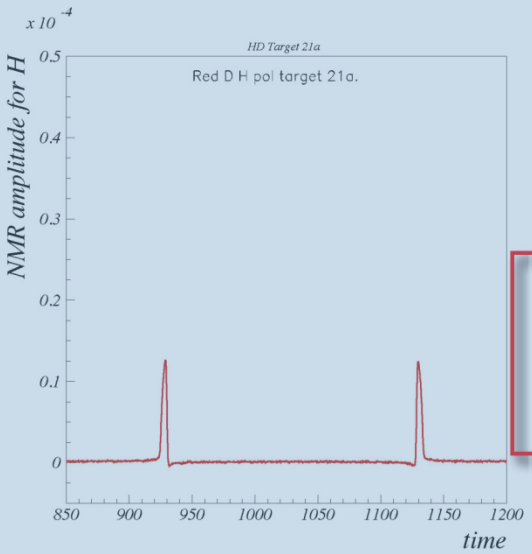
- *requires high RF powers and very uniform fields*

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

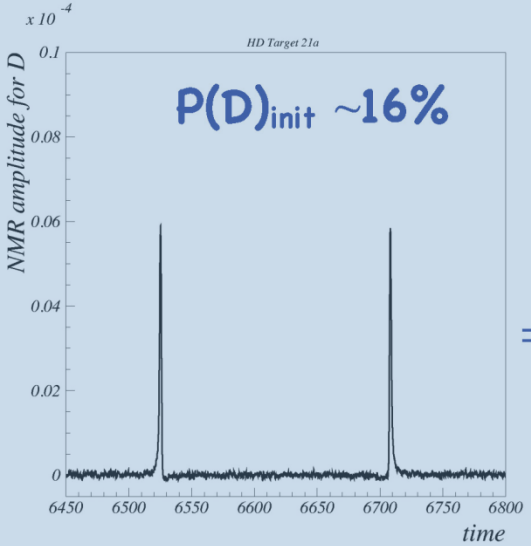
Polarization Manipulation with SFP during G-14 Run



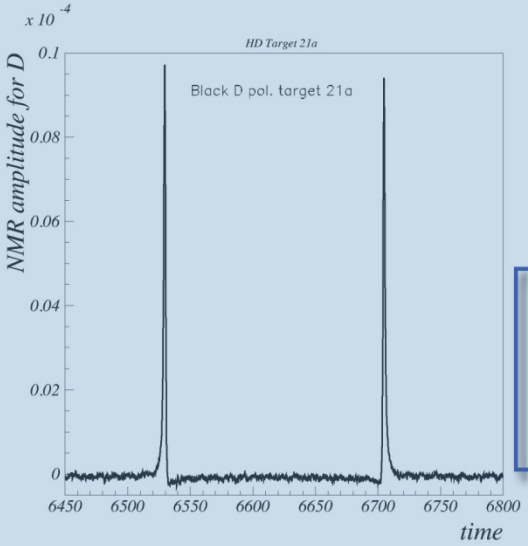
⇒ SFP ⇒



P(H) final = 28 ±1%



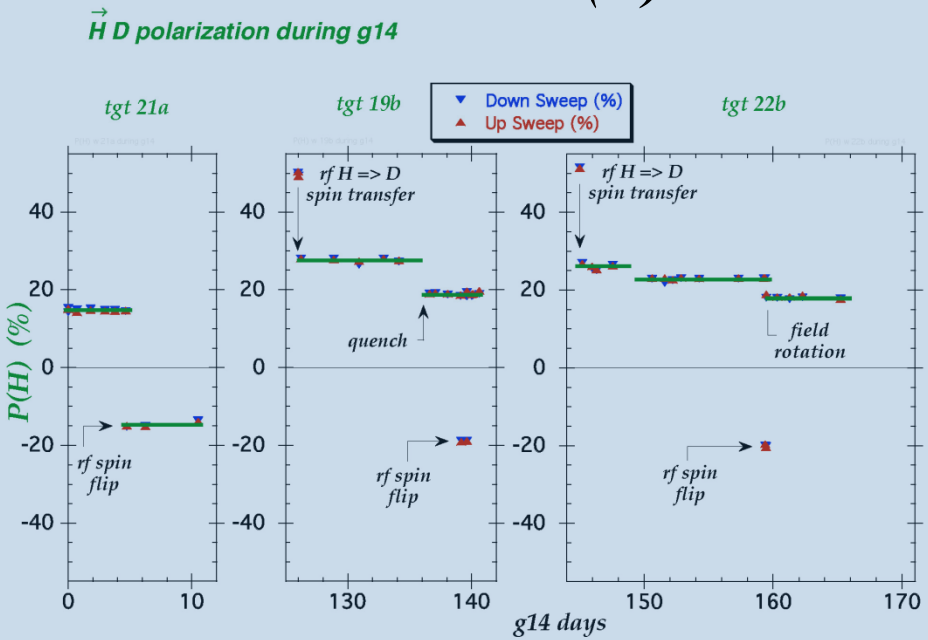
⇒ SFP ⇒



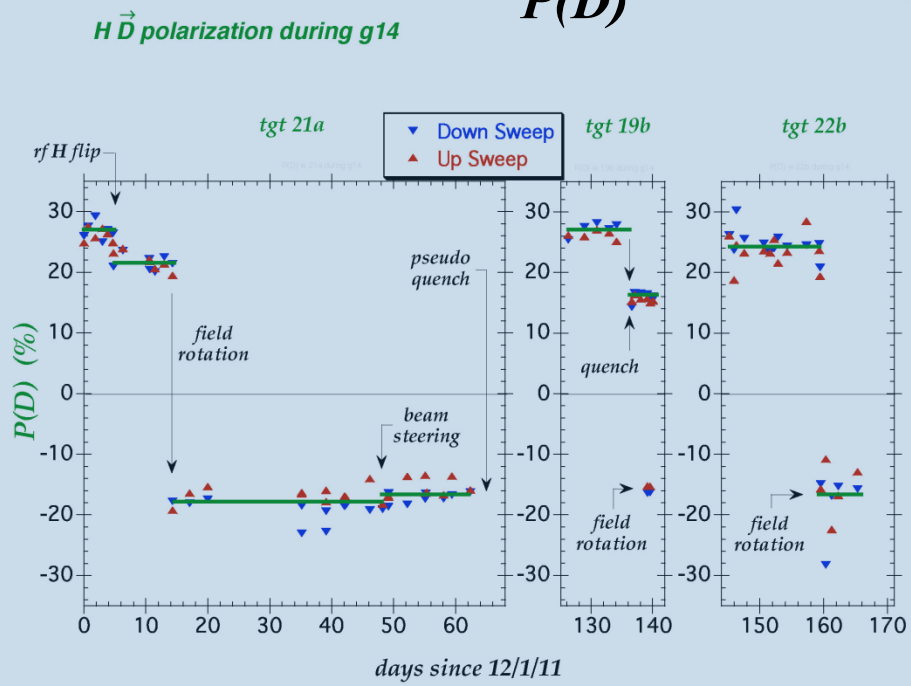
P(D) final = 27 ±1%

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

P(H)



P(D)



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 .

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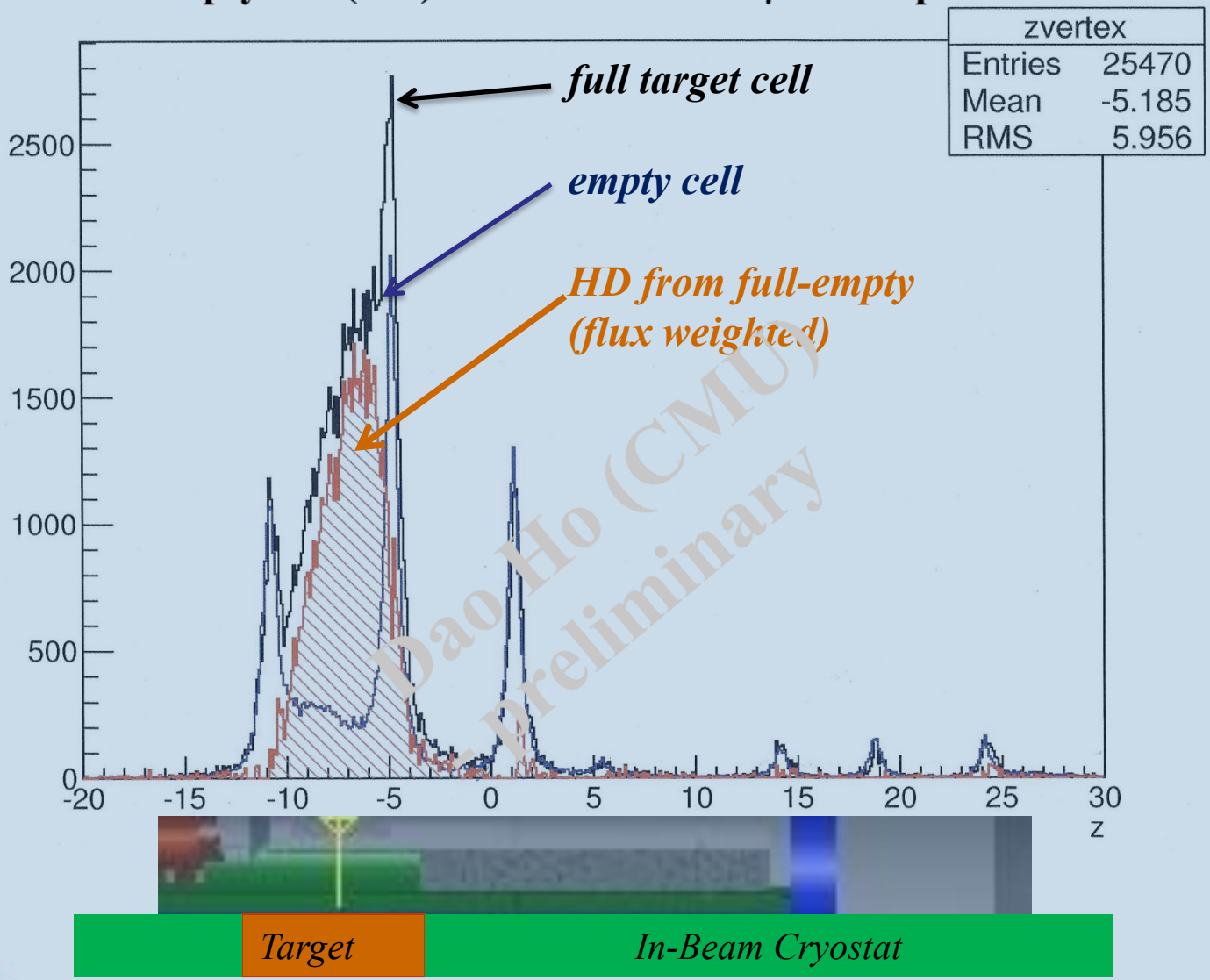
Reconstructed Vertex for HDice Target during G-14 Run

Clean empty cell (21a) subtraction from $\gamma\, n \rightarrow \pi^- p$



On-going Analysis for G-14 Run

identified analysis projects:

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

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

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

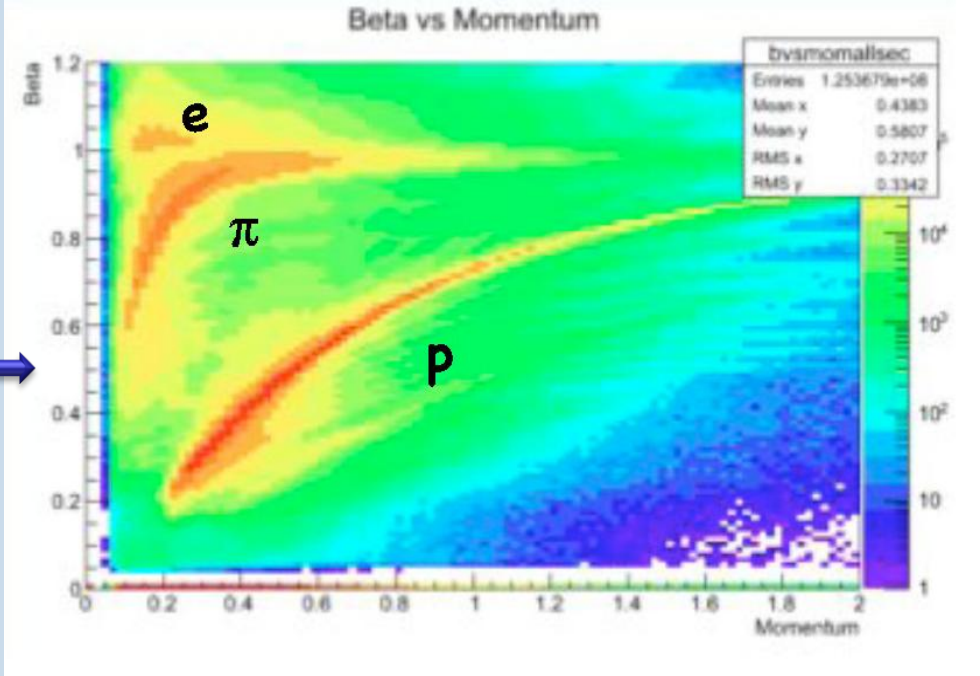
$\gamma\ n\ (p) \rightarrow \pi^{+}\ \pi^{-}\ n\ (p) \Leftrightarrow \pi^{+}\ \Delta^{-}\ (p),\quad \pi^{-}\ \Delta^{+}\ (p),\quad \rho n\ (p)$

$\gamma\ n\ (p) \rightarrow \pi^{+}\ \pi^{-}\ \pi^{\circ}\ n\ (p) \Leftrightarrow \eta\ n\ (p),\quad \omega\ n\ (p)$

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

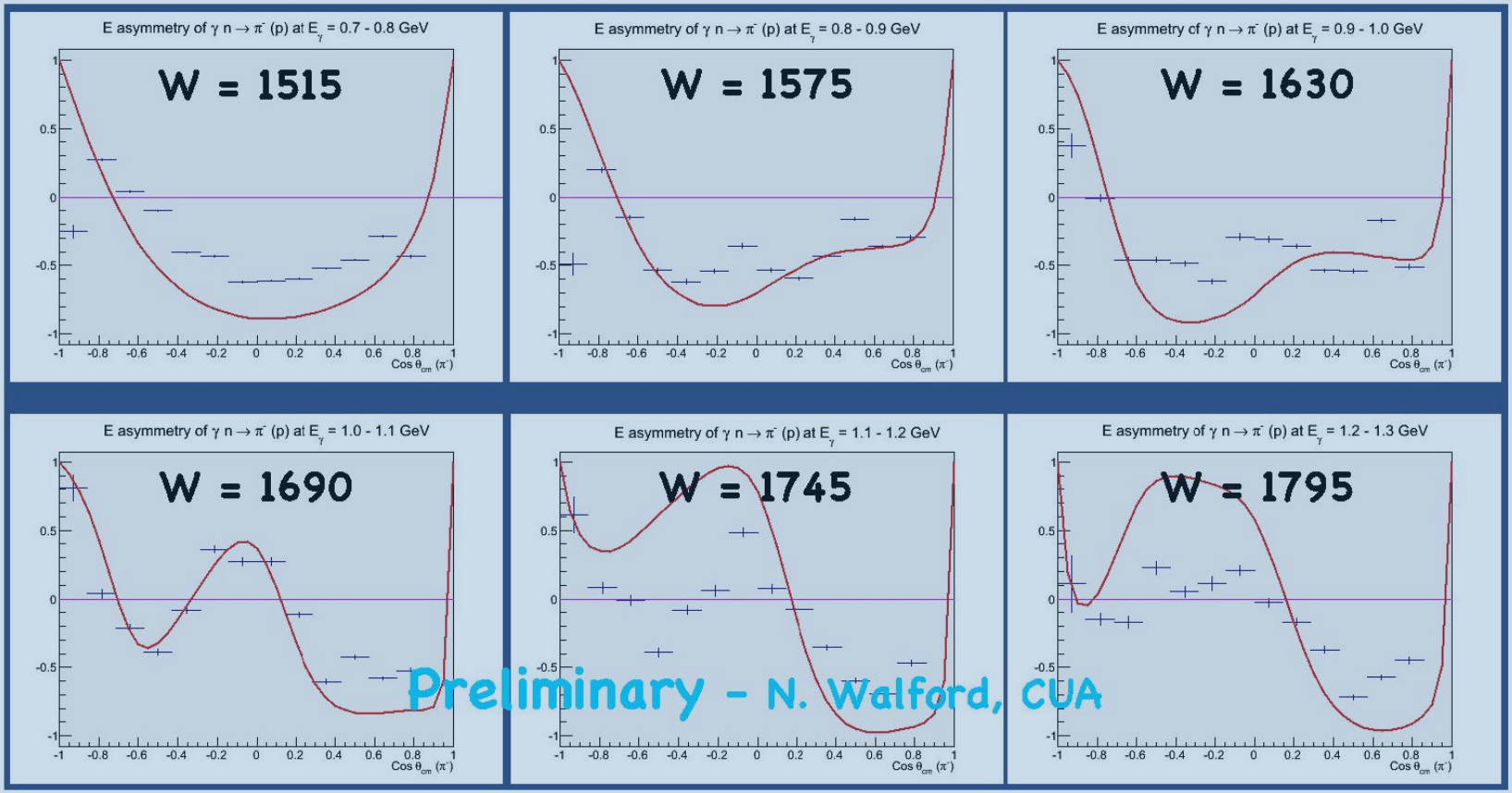
1st look at data

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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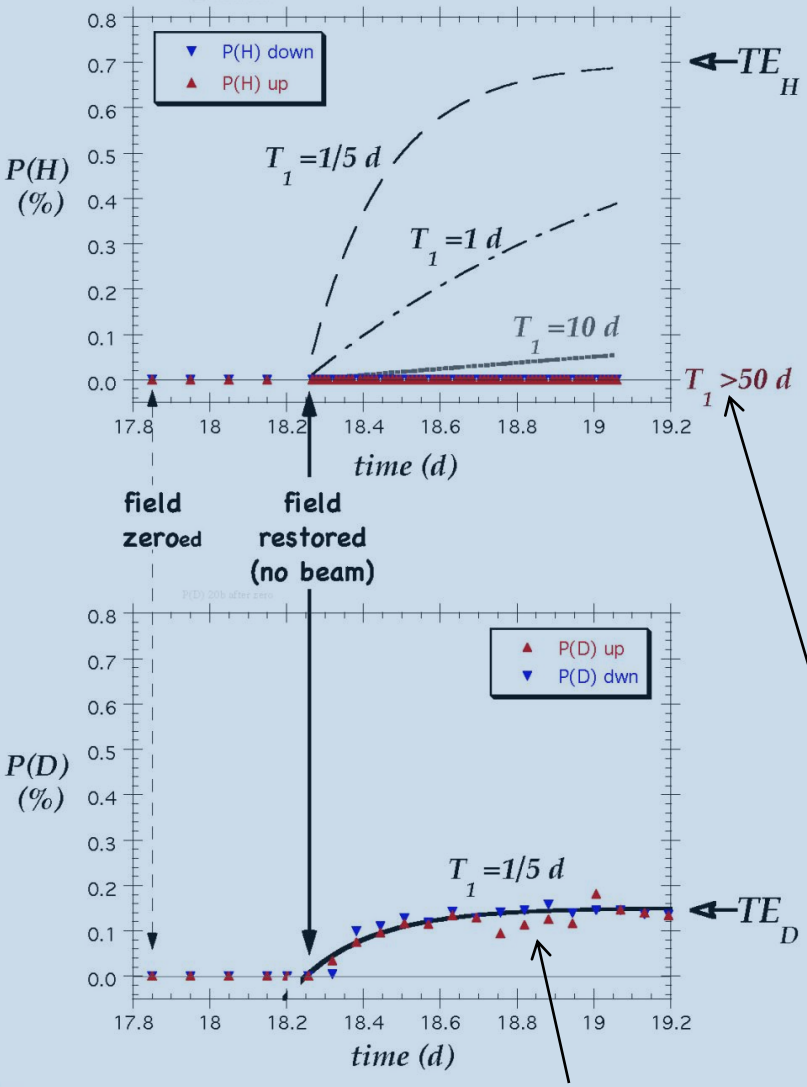
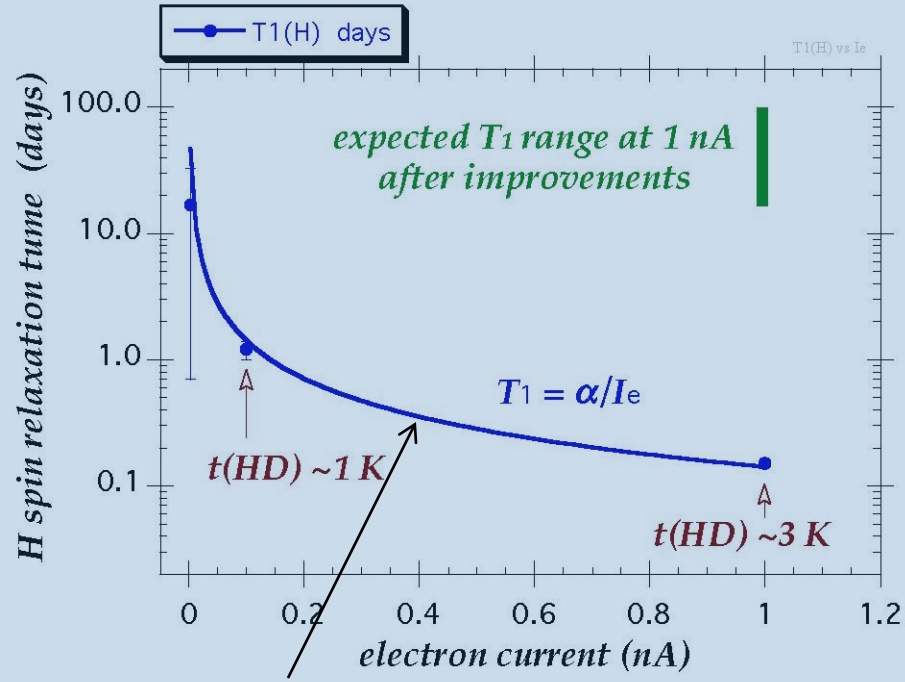
Electron Beam Tests for $\vec{e} + \vec{H}_{\perp} D$ runs with CLAS12





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, G-14 TOOK THE DATA AT 10 TIMES FASTER RATE BECAUSE OF LOW BACKGROUND FROM LOW Z.
- ***Electron beam on HD test shown the road of applying transversely polarized HDice target at CLAS12 Era.***