Preparations for RG-H:
Electrons on Transversely Polarized Hydrogen-Deuteride (HD)

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CLAS Collaboration

Collaborators

- Jefferson Lab (HDice – Physics Division)
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- Jefferson Lab (UITF – Accelerator Division)
  - J. Grames, M. Poelker
- University of Connecticut
  - K. Joo , T. O’Connell, K. Wei
- Universita di Roma Tor Vergata and INFN-Sezione di Roma 2 (Gas analysis)
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- INFN-Senzione di Ferrara, 44122 Ferrara, Italy
  - L.Barion, M. Contalbrigo, M. Statera

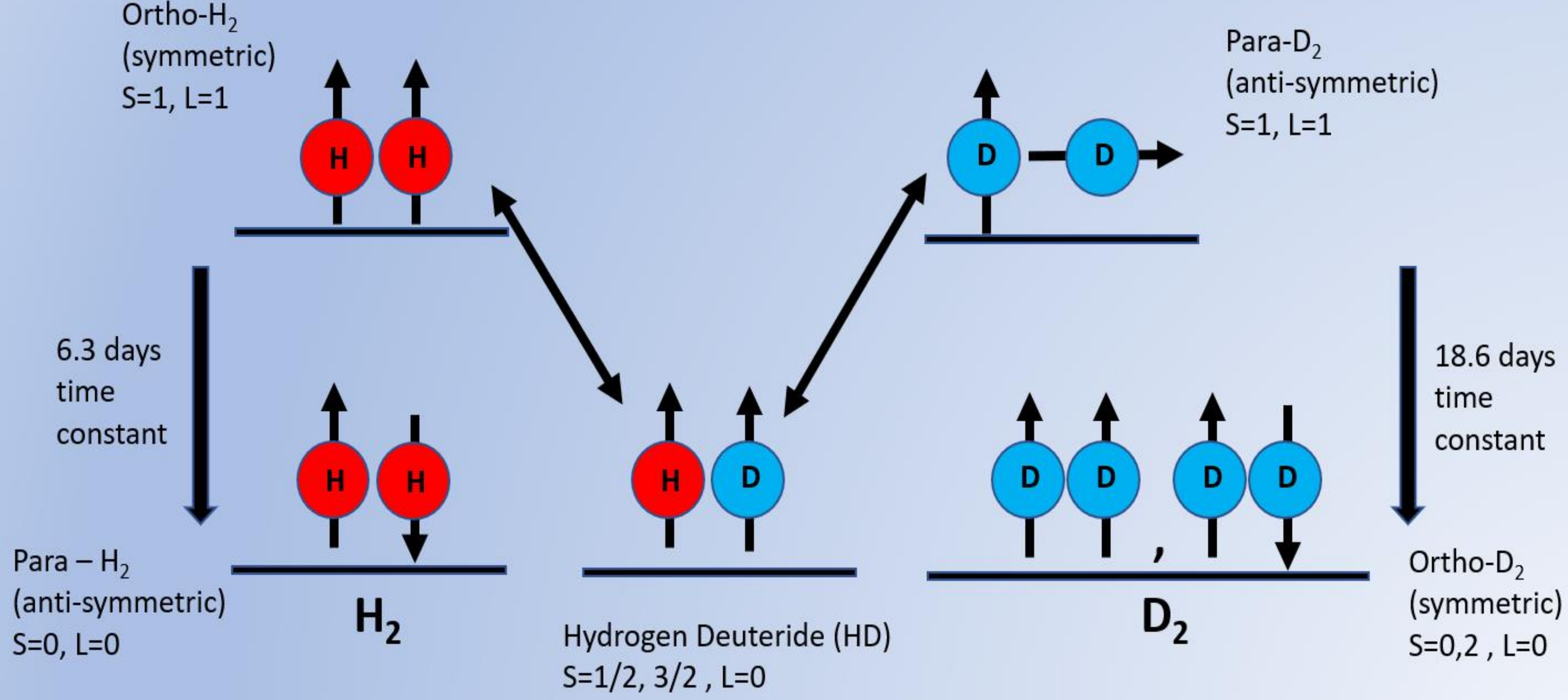
Motivation

- High-rated experiments approved for Hall B with CLAS12. Each has the main goal of studying the spin and flavor dependence of transverse space and momentum distributions of quarks inside the nucleon.
  - Transverse spin effects in SIDIS at 11 GeV with a transversely polarized target using the CLAS12 Detector
    - Contact: Marco Contalbrigo (mcontalb@fe.infn.it)
    - https://www.jlab.org/exp_prog/proposals/12/PR12-12-010.pdf
  - Measurement of transversity with dihadron production in SIDIS with transversely polarized target
    - Contact: Harut Avakian (Avakian@jlab.org)
    - https://www.jlab.org/exp_prog/proposals/12/PR12-12-009.pdf
  - Deeply Virtual Compton Scattering at 11 GeV with transversely polarized target using the CLAS12 Detector
    - Contact: Latifa Elouadrhiri (Latifa@jlab.org)
    - https://www.jlab.org/exp_prog/proposals/12/PR12-12-010.pdf

HDice Target

- Transverse polarization requires transverse magnetic fields to hold the target spin.
  - **Problem**: this can bend the beam into the detectors.
  - **Solution**: mitigate the problem by limiting the beam bending into the detectors (smaller B•dl)
    - ➢Can we use a transversely polarized HD target?
- An HDice target is a frozen spin target of hydrogen-deuteride (HD)
  - HDice target can be sustained by a low, transverse holding field (NIM A**737** (2014) 107)

HDice Target – Polarization Process

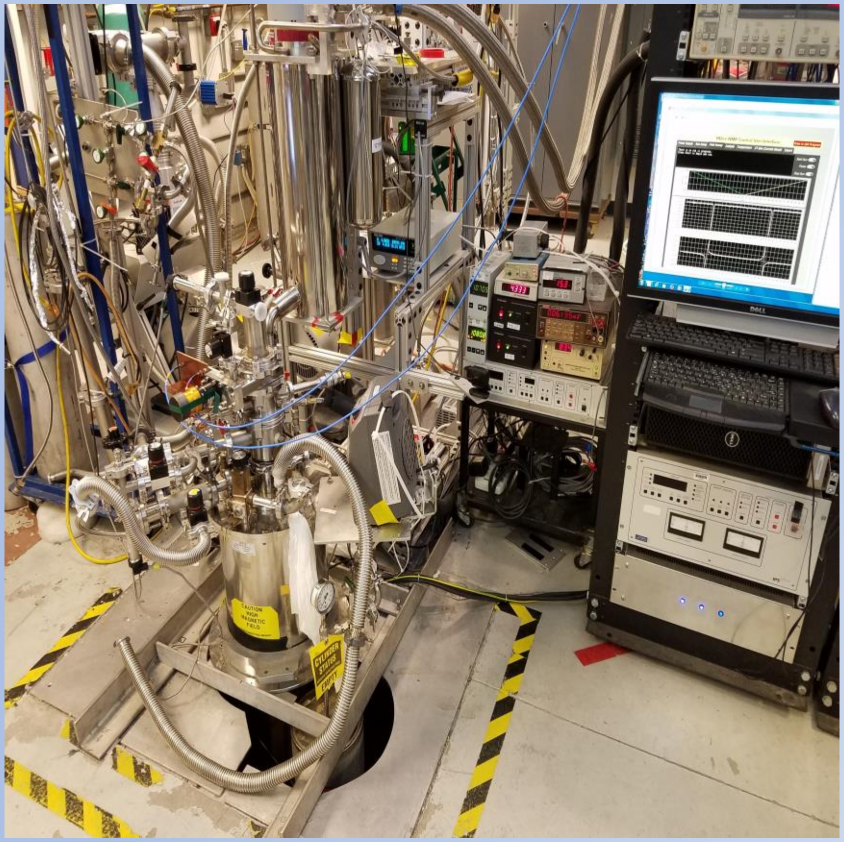


H_2
(~0.0005)

HD
(~0.9990)

D_2
(~0.0005)

HDice Target- Production



Production Dewar (PD) – a cryostat used for HD crystal formation and polarimetry with a temperature of 4.2 K (capable of as low as ~2 K) and a magnetic field up to 2 T.

Dilution Refrigerator (DF) – a cryostat used to polarize targets with a temperature of 10 mK and a magnetic field of 15 T.

HDice Target - Production

Transfer Cryostat (TC) – a cryostat used to transfer targets between cryostats with a temperature of 2K and a magnetic field of 0.1 T.

In-Beam Cryostat (IBC) – a cryostat used to operate the target under a particle beam with a temperature range of 50 mK to 300 mK, a longitudinal magnetic field up to 0.9 T, and a transverse magnetic field up to 0.07 T

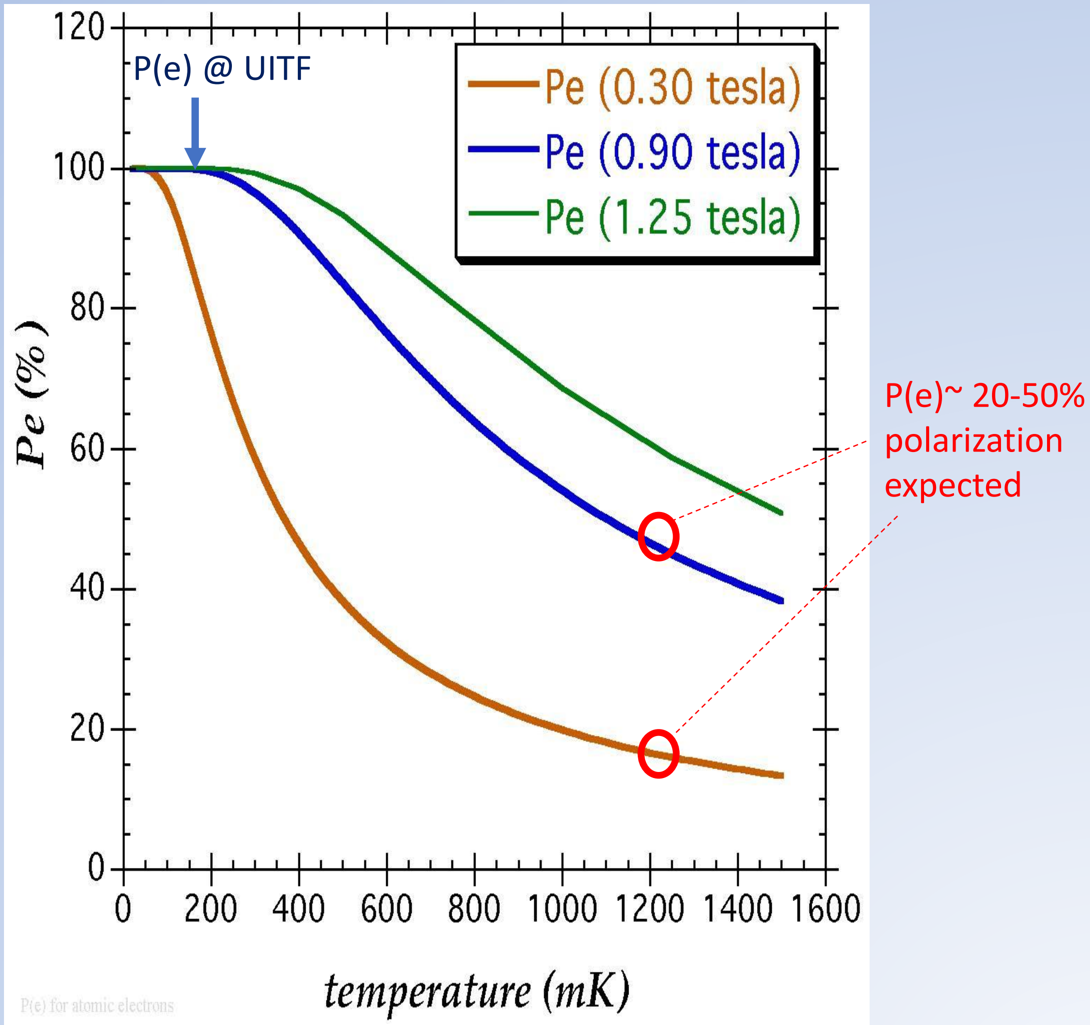
2012 e+HD Tests (during the *g14* experiment)

- Successful photon experiments during the *g14* (2012) run. (PRL 118 (2017) 242002)
- Runs were conducted to study the effect of an electron beam on the HDice target
- Results shows a significant loss of polarization due to the electron beam (after 1 nA-day)
- Identified three potential mechanisms of depolarization needing further testing:

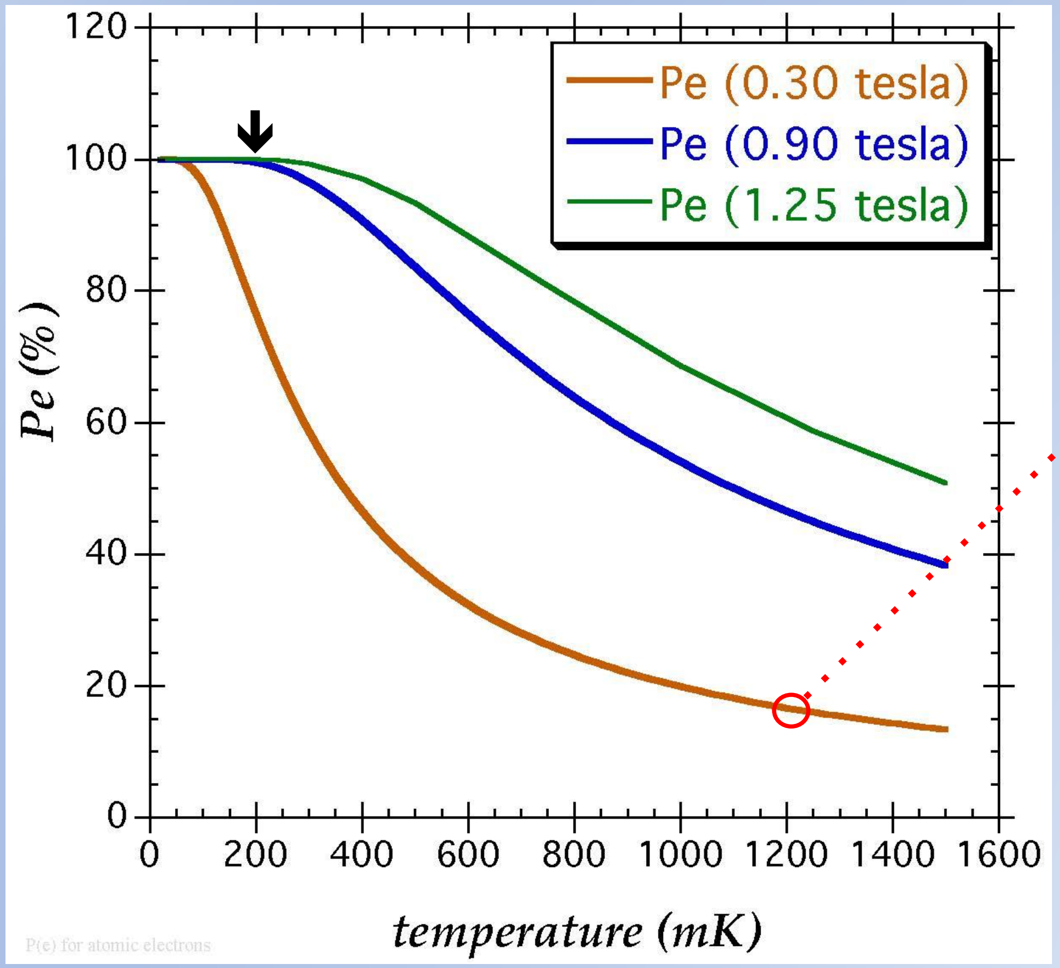
1. Beam heating: available raster too slow ⇔ target temp high ⇔ molecular electrons unpaired by Moller scattering were not fully polarized ⇔ spin flip of unpaired electrons generate fields that depolarize HD
2. 2012 tests were run with H spin parallel to the holding field; magnetic moment of unpaired electrons were opposite to H
   - ➢ spins can be diluted by hyperfine mixing
3. Set of chemical reactions that can lead to the build up of ortho (L=1)-H_2 , which can cause a loss of the frozen-spin state

Depolarization Mechanisms 1

- Electron beam unpairs electrons of HD
  - If unpaired electrons are only partially polarized, they flip generating varying field possessing a component at the nuclear Larmor frequencies of H and D, which depolarizes the target material
  - Depends on temperature, which peaked at 1.2K during electron beam runs in 2012



Flipping, unpaired electron during 2012 eHD test



- T(HD) ~ 1.2K in 2012 test runs
  - slow raster
  - Aluminum cooling wires too long

at $P_e = 0.2$

⬄ e^- population $N_+ = 0.6$, $N_- = 0.4$

and $T_1 \sim 4$ hr

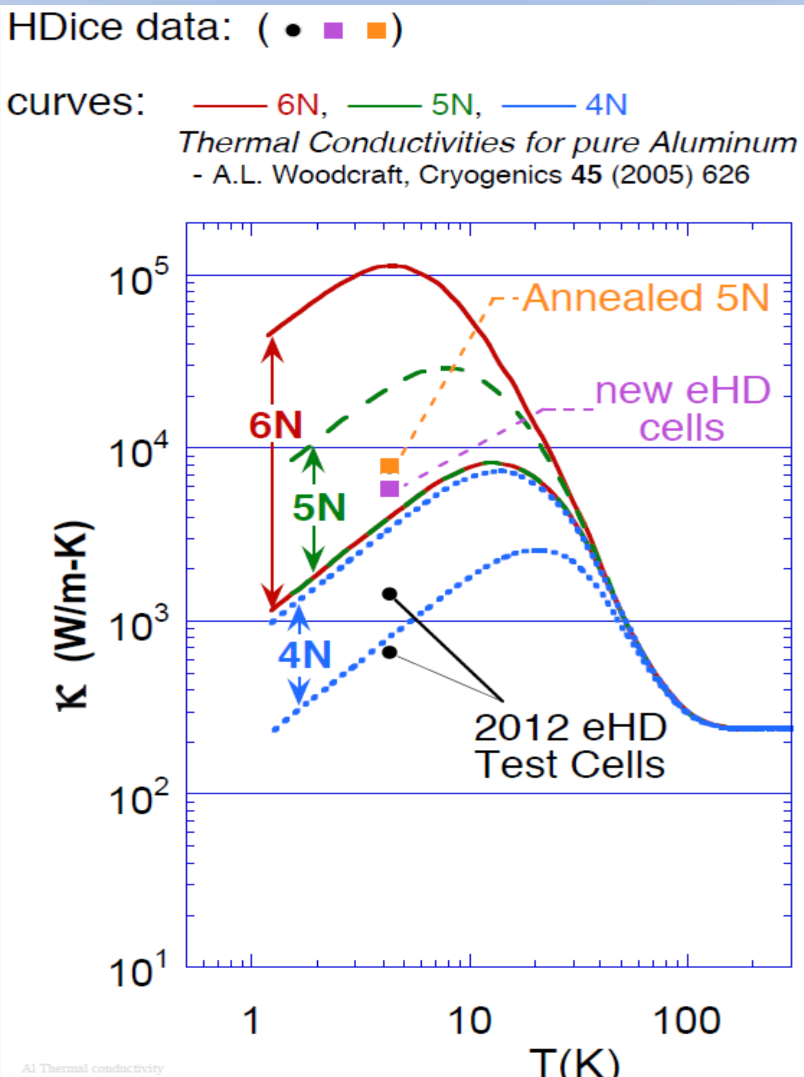
➔ at Pe = 0.999

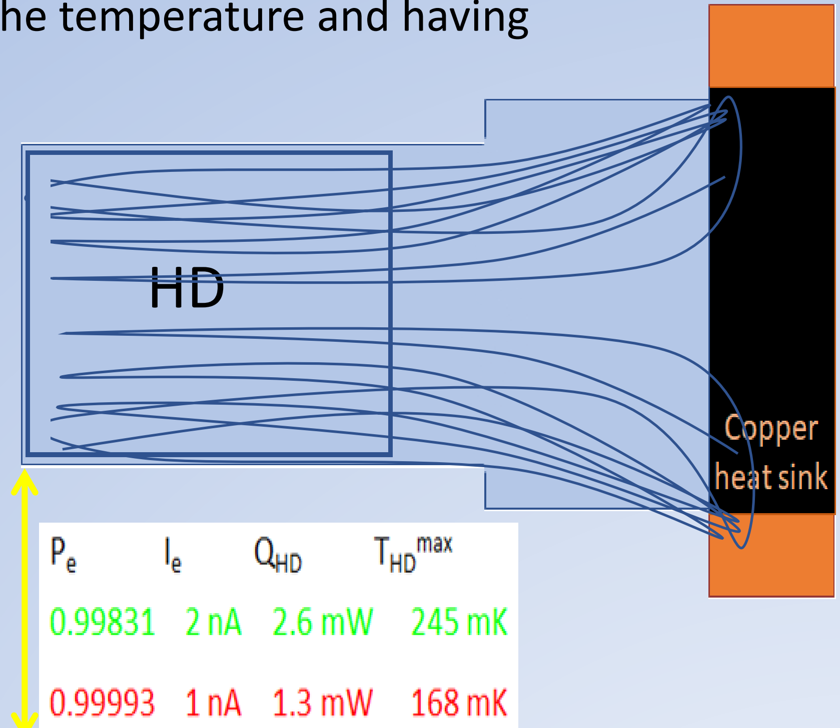
⬄ e- population $N_- = 0.001$

and T_1 should be ~1000 hr

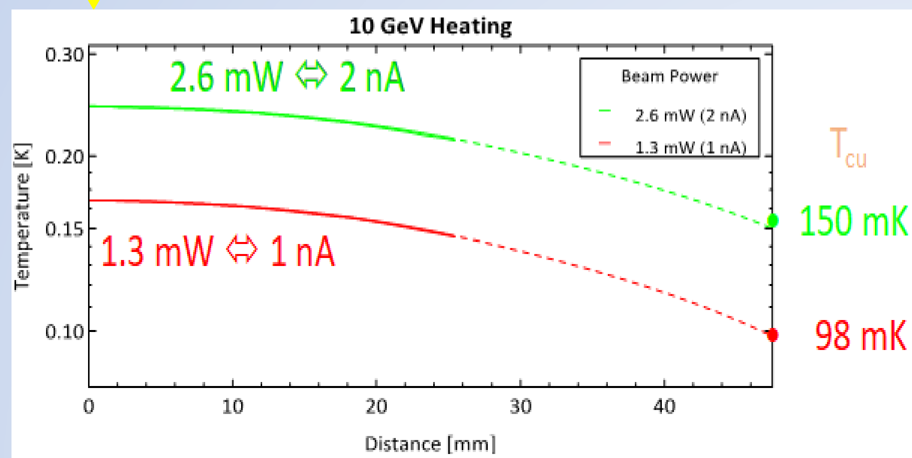
Depolarization Mechanism 1 - Solution

- **Solution**: Limit this effect by better controlling the temperature and having higher electron polarization



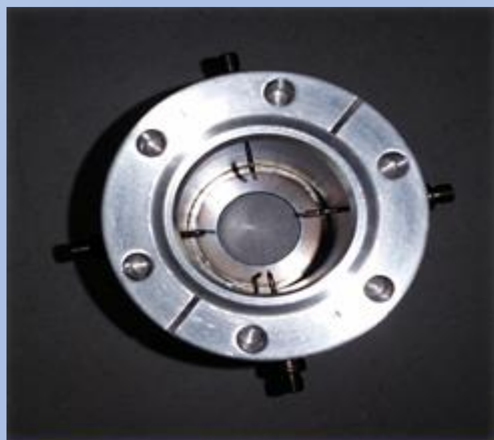


P_e	I_e	Q_{HD}	T_{HD}^{max}
0.99831	2 nA	2.6 mW	245 mK
0.99993	1 nA	1.3 mW	168 mK

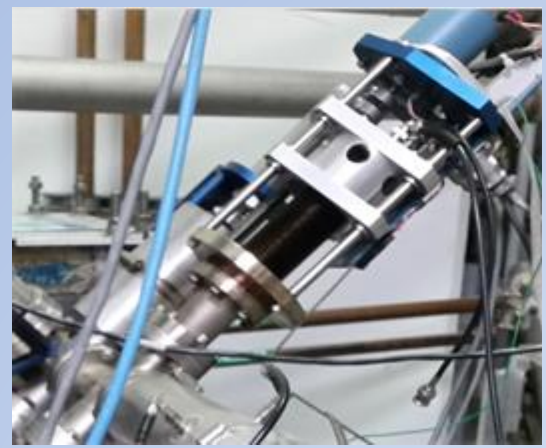


New 20 KHz spiral raster (1 KHz refresh rate)
Tests at 6 MeV in CEBAF injector

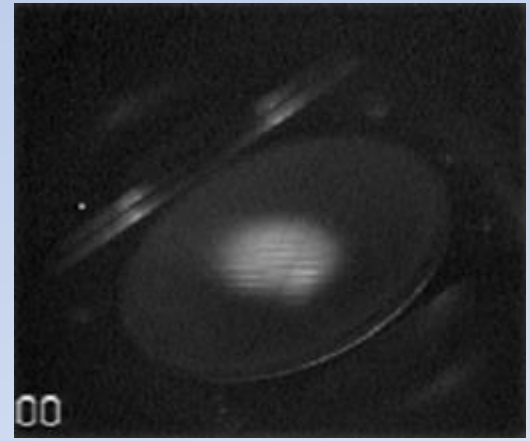
BPM

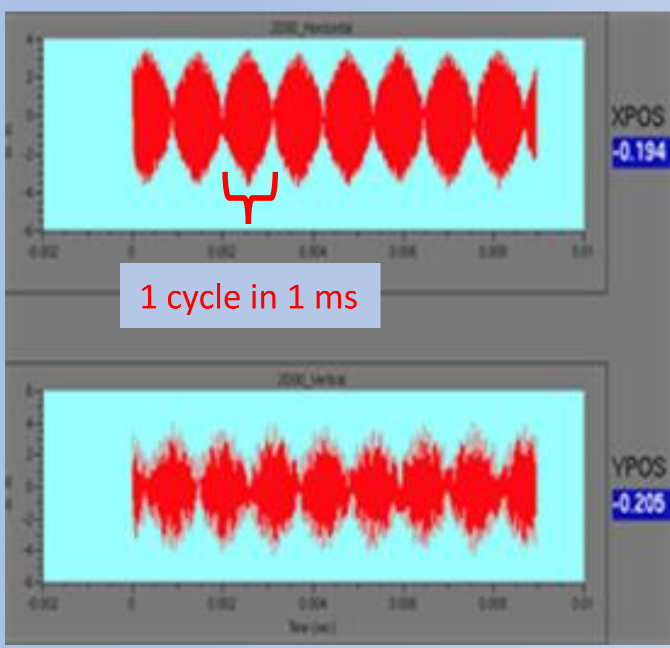


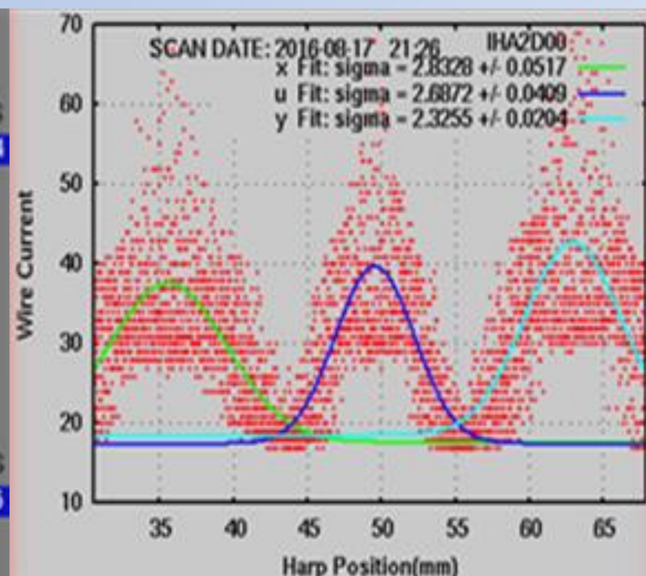
HARP

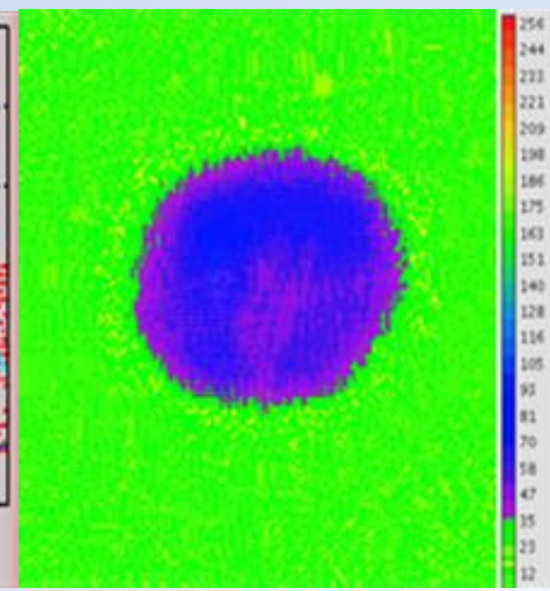


Viewer



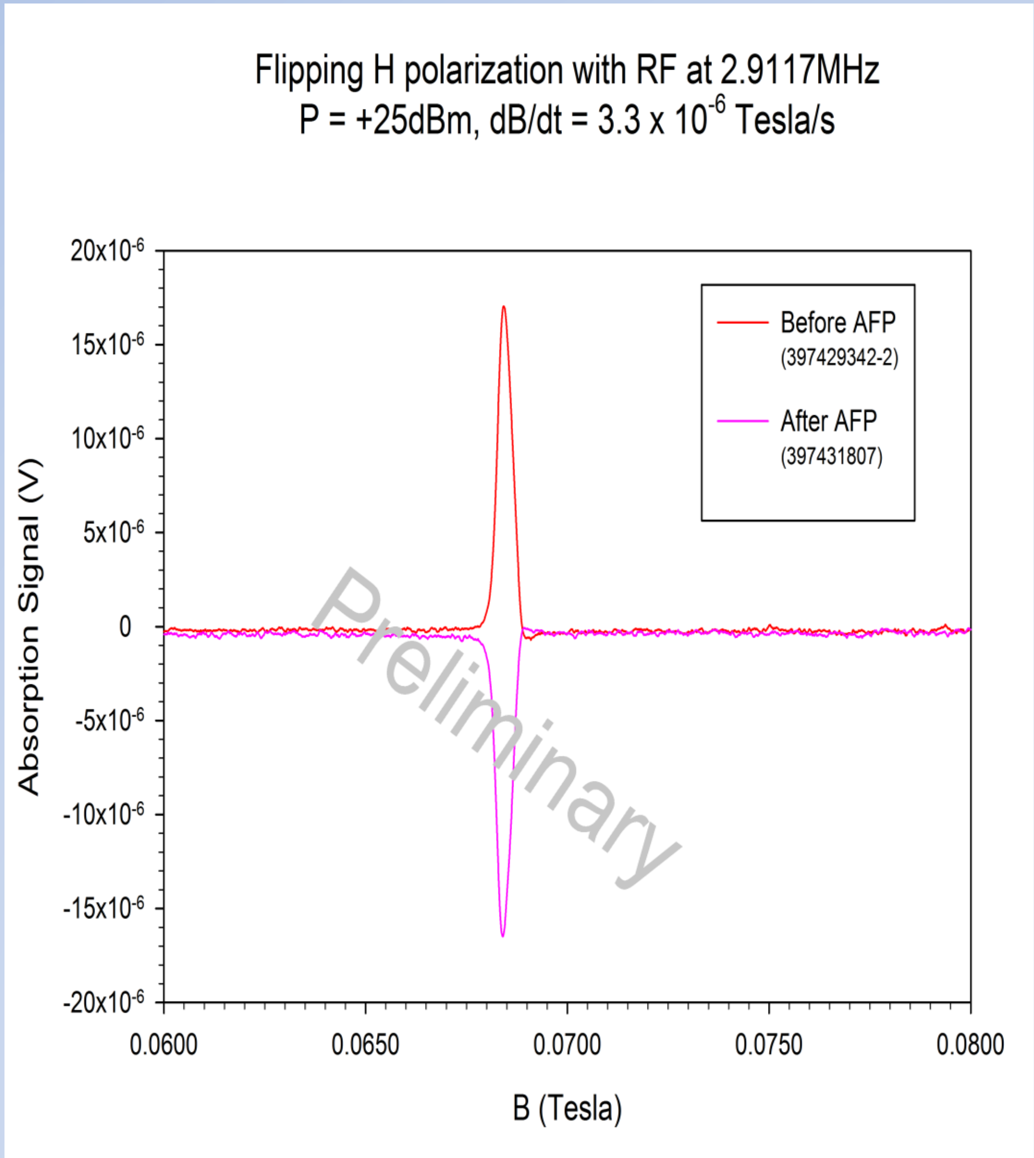






Depolarization Mechanism 2

- Hyperfine mixing of unpaired electrons with H (or D)
  - 2012 tests were run with spin of H parallel to holding field.
  - Electrons polarized by holding field possess magnetic moments opposite to H
  - Hyperfine mixing dilutes H polarization
- **Solution:** Use RF via AFP to align H opposite to holding field
  - Magnetic moments of electrons will be parallel to H
  - Unique state with NO hyperfine mixing



Depolarization Mechanism 3

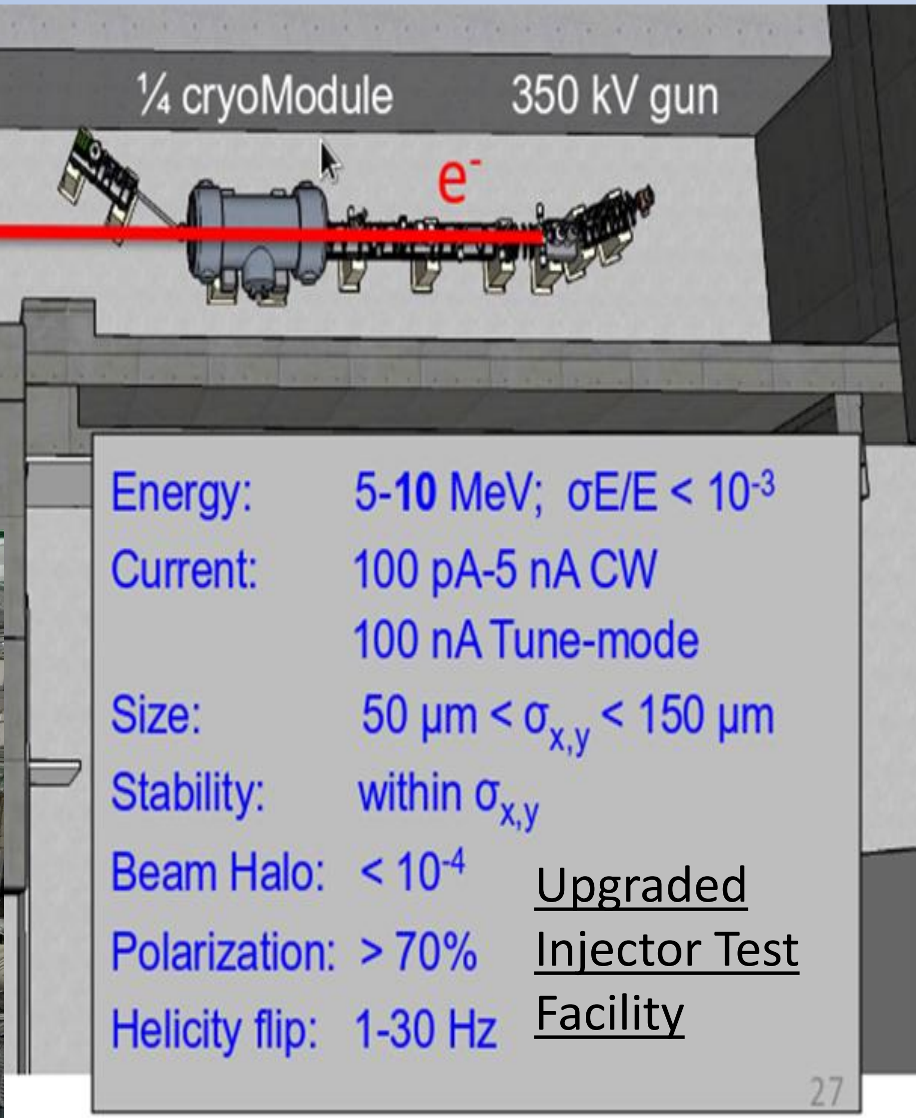
- Beam-induced chemical composition changes
  - HD molecule become ionized and highly reactive (as HD^+)
  - Potential reactions:

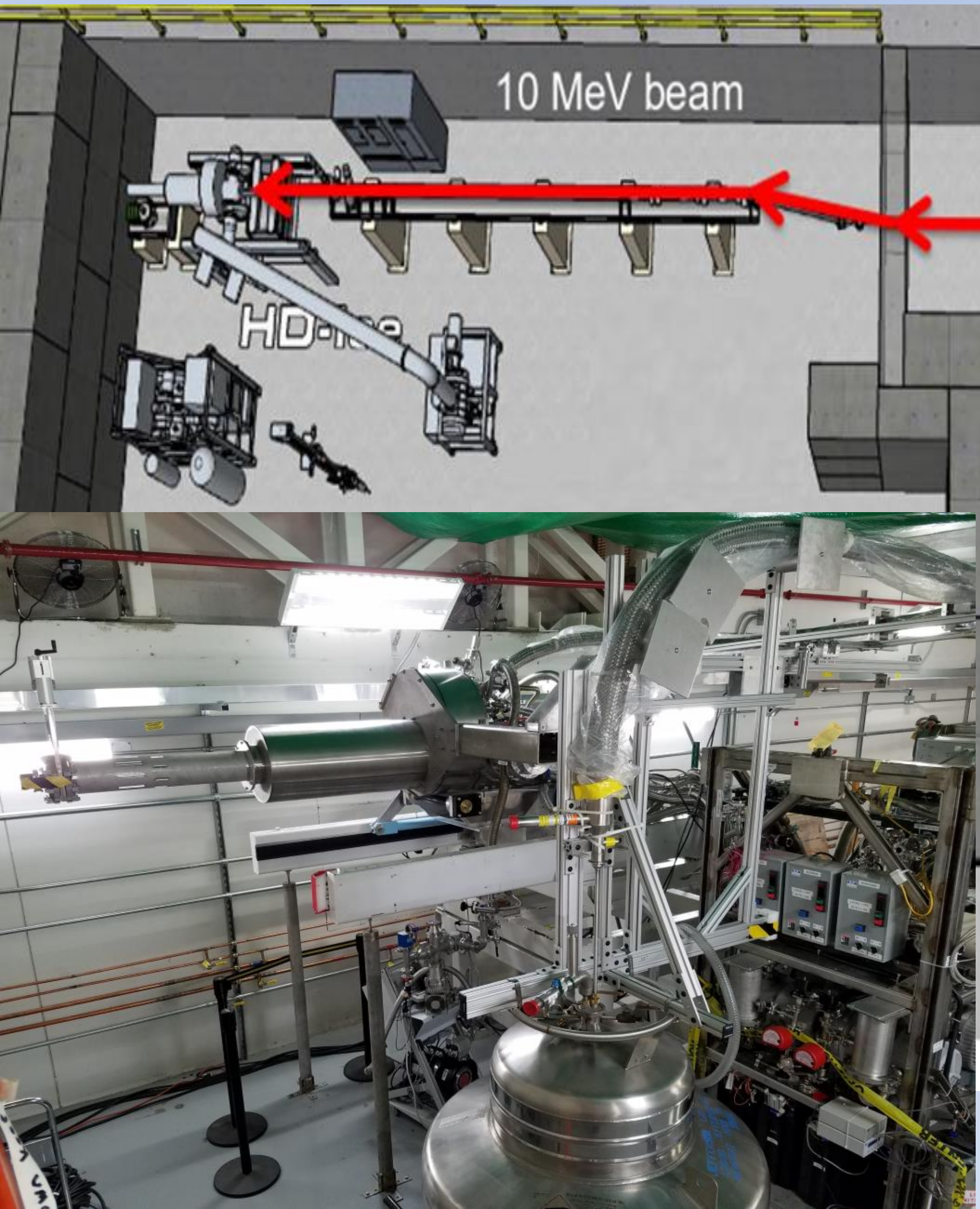
$$HD^+ + HD \rightarrow H_2D^+ + D\ (mobile)$$

$$H_2D^+ + e^- \rightarrow H_2 + D\ (can\ form\ H_2\ in\ 1st\ rotational\ state)$$

  - Buildup of ortho-H_2 can shorten the polarization relaxation time (T1) of the target material
- HD gas was analyzed with Raman scattering (in Rome) after 2012 eHD tests.
- Found no significant increases in H_2 , or D_2, but measurement limitations need to be studied with further beam tests

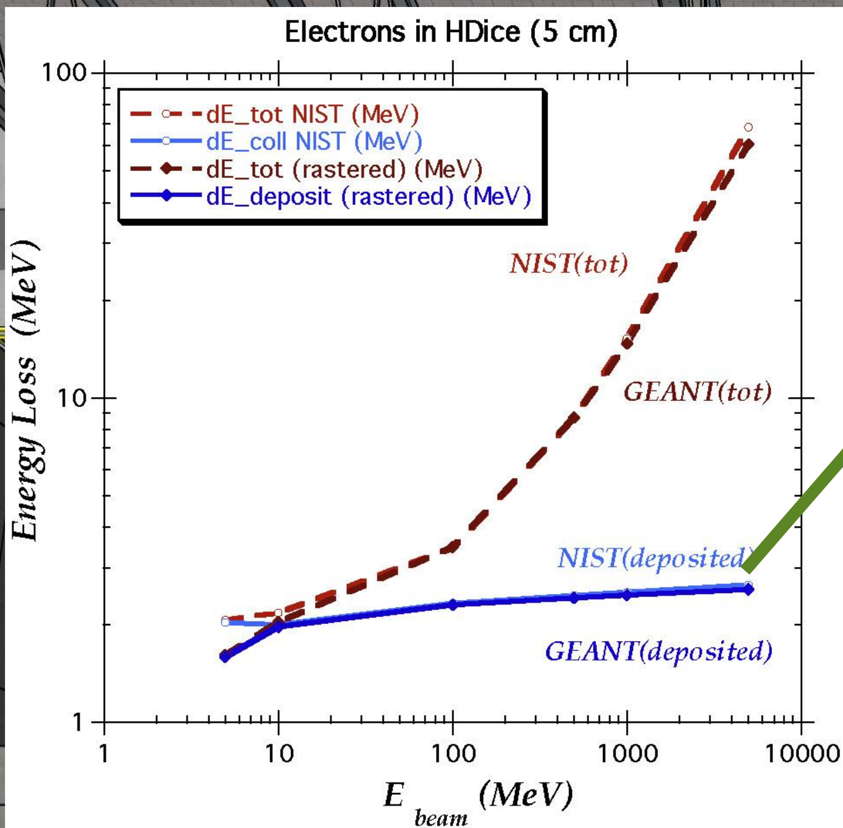
eHD Tests in UITF – 1st beams in 2019





<u>Upgraded Injector Test Facility</u>

eHD Tests in UITF



Ionization and energy deposition are approximately 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

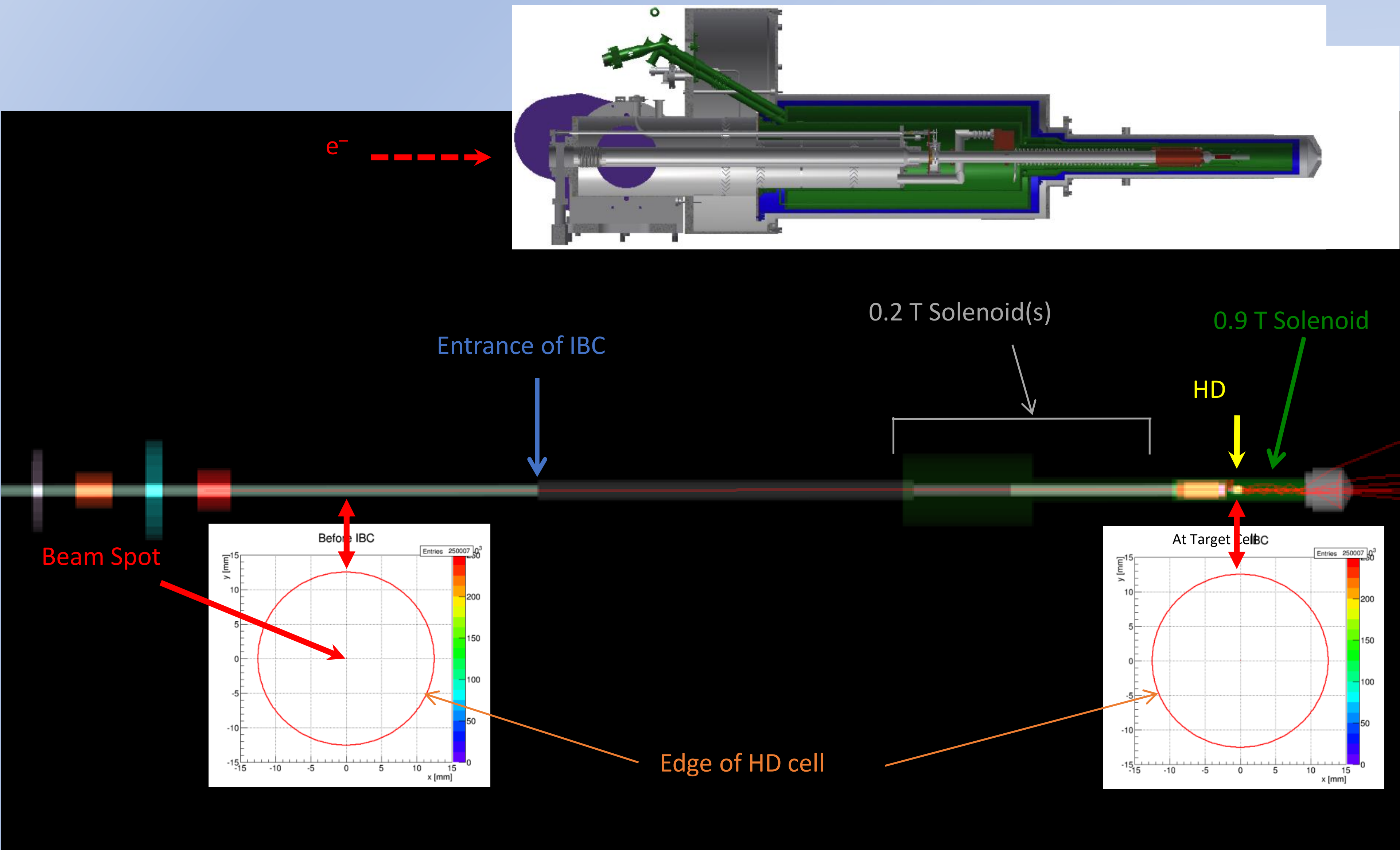
Stability: within $\sigma_{x,y}$

Beam Halo: < 10^{-4}

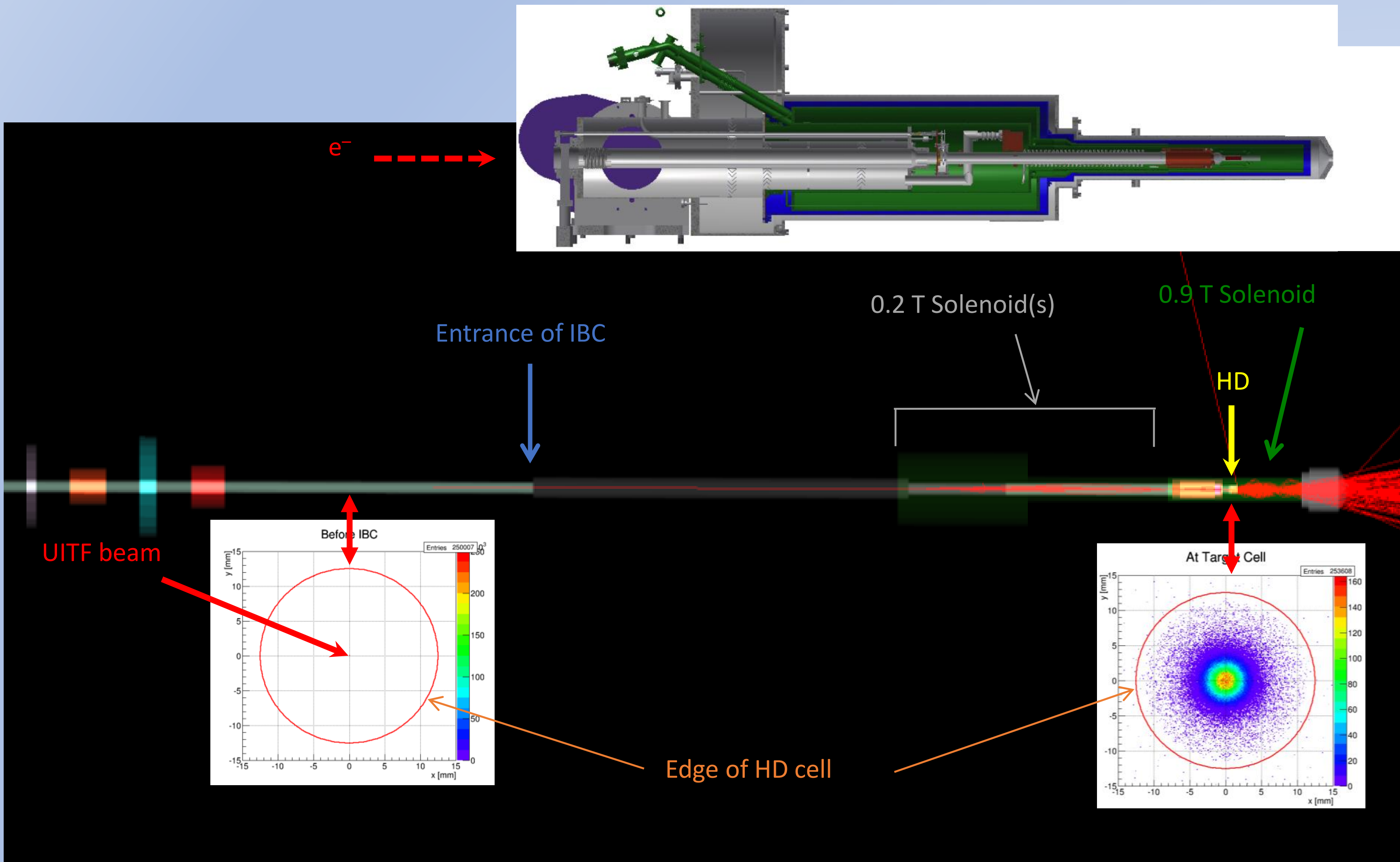
Polarization: > 70%

Helicity flip: 1-30 Hz

Pencil beam into IBC with normal orientation at 10 GeV

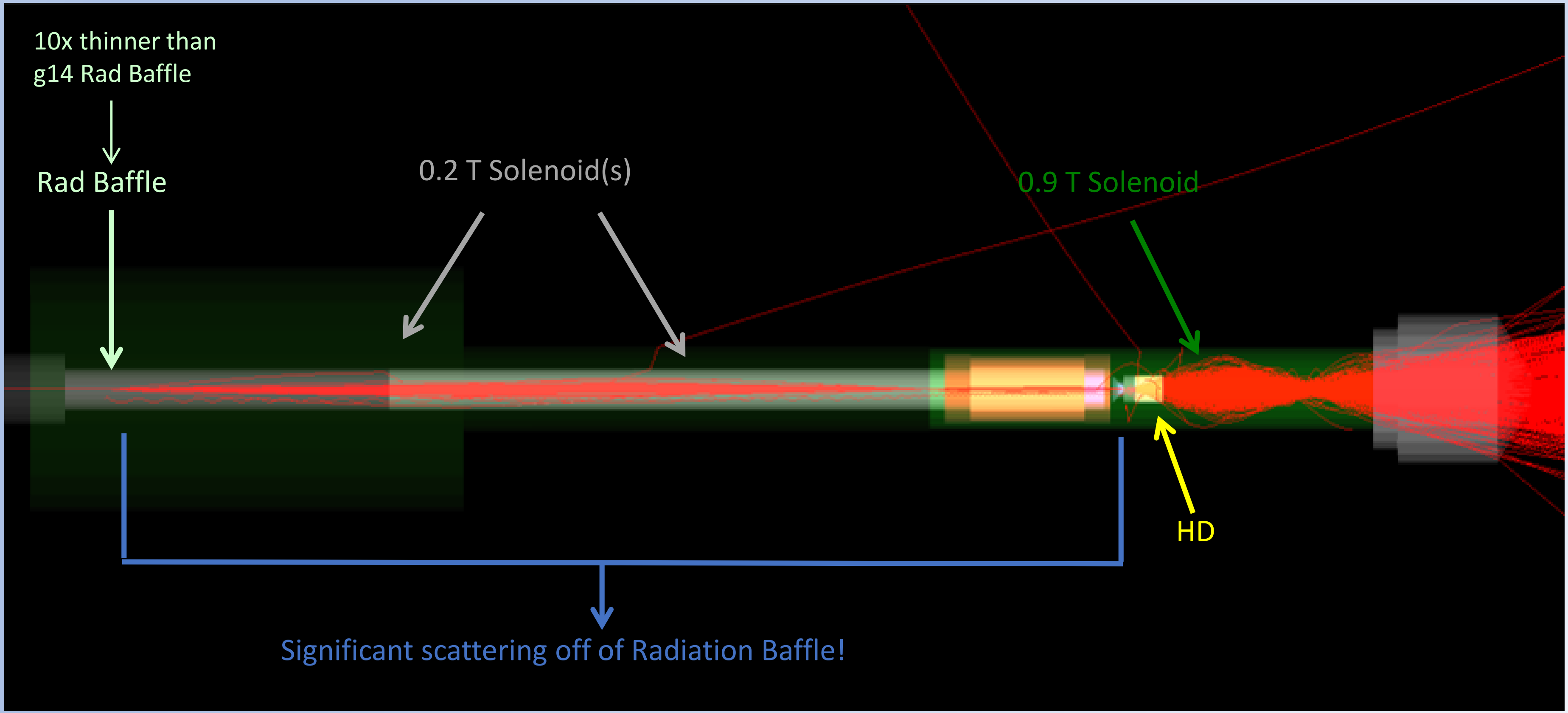


Pencil beam into IBC with normal orientation at <10 MeV



Pencil beam into IBC with normal orientation at <10 MeV

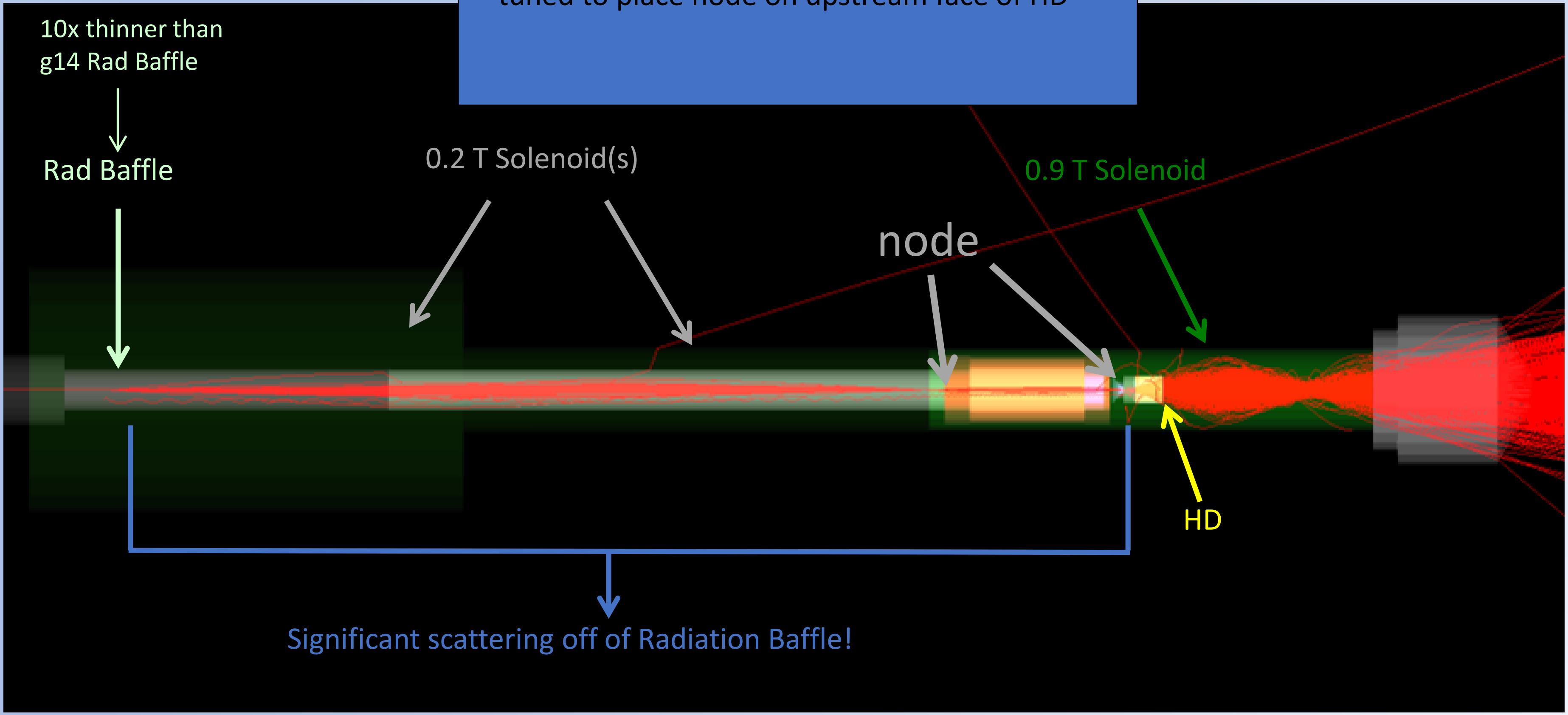
…… a closer view



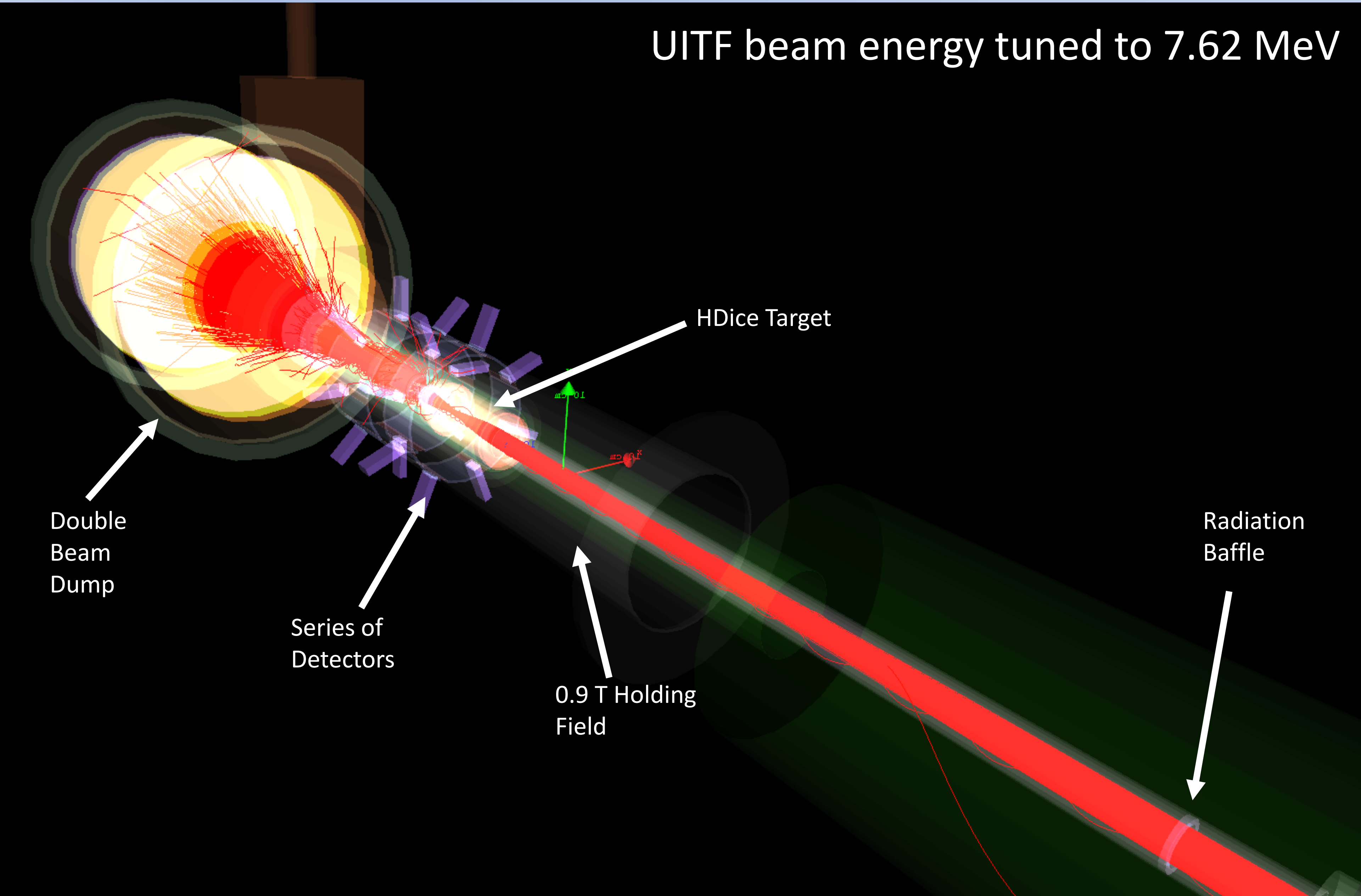
Pencil beam into IBC with normal orientation at <10 MeV

…… a closer view

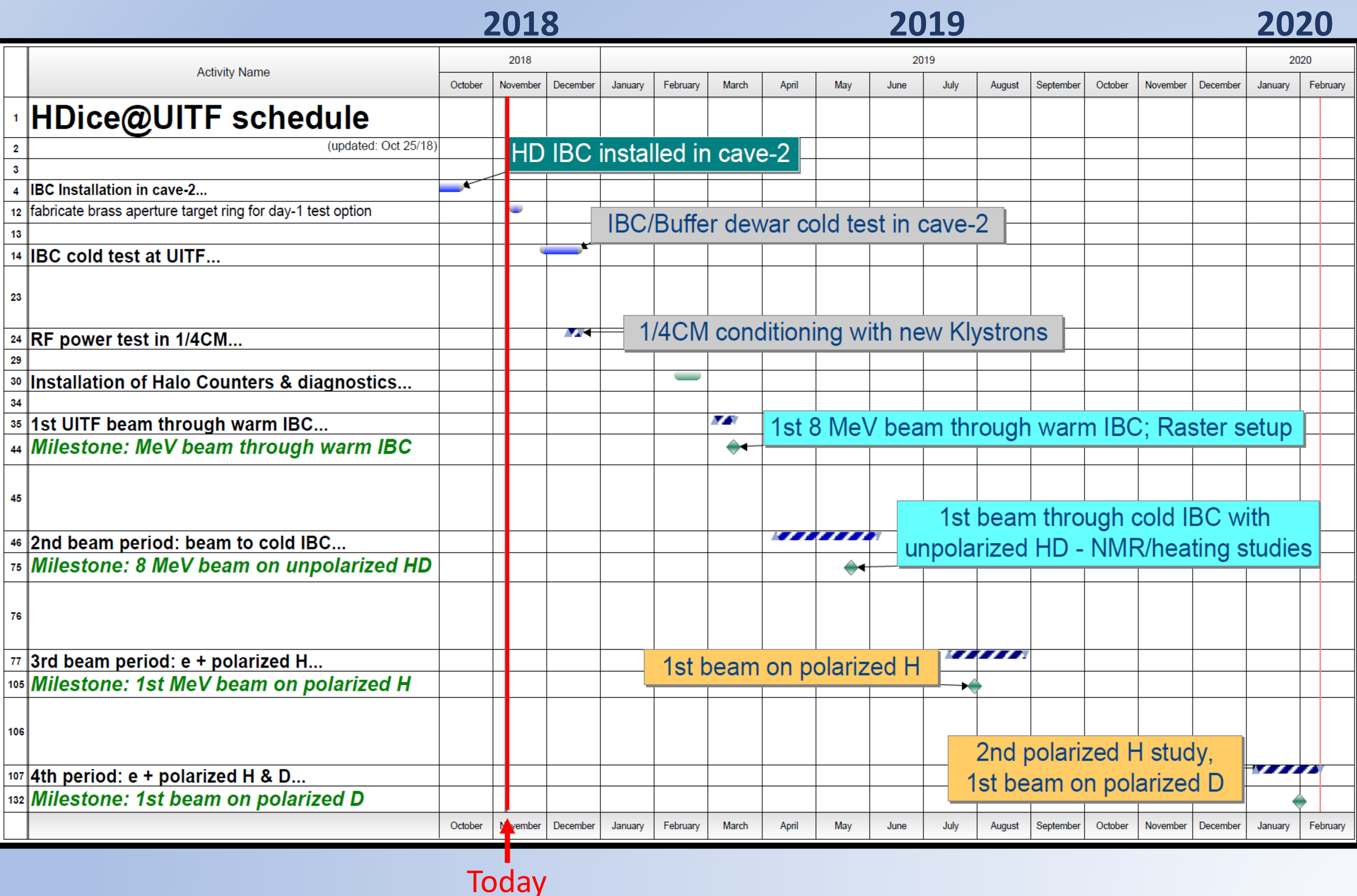
B fields are fixed ⟶ Beam energy needs to be tuned to place node on upstream face of HD



Simulated Beam through IBC in UITF



eHD Testing Schedule

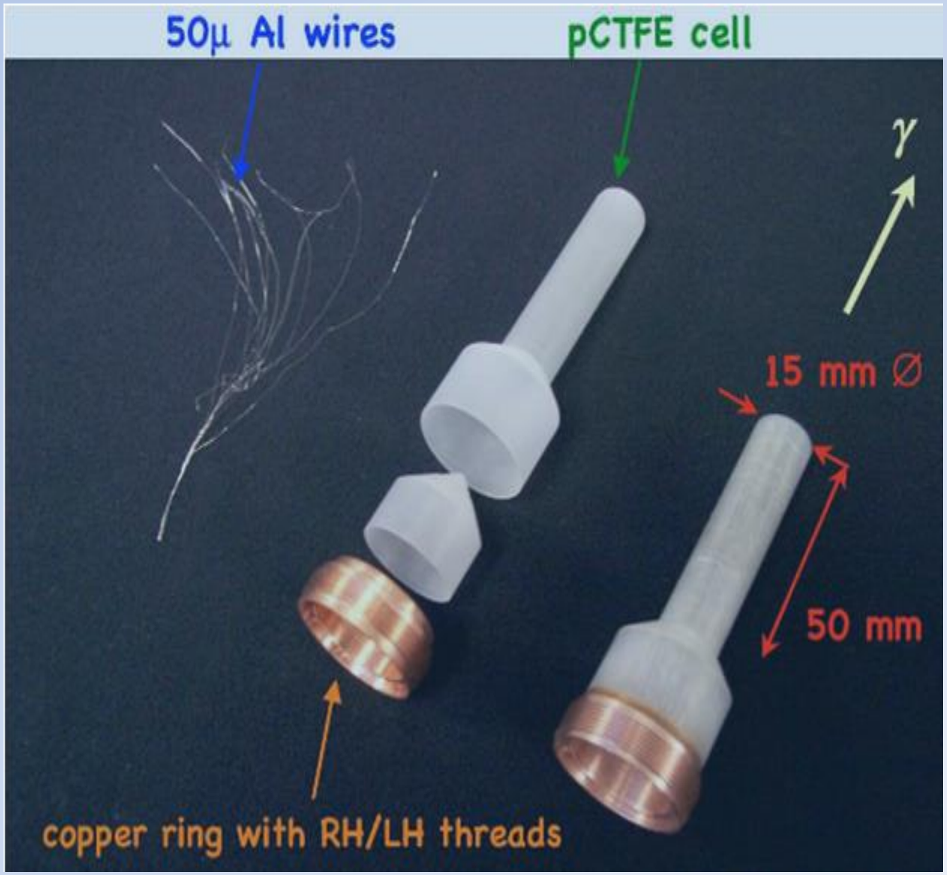


END

Questions?

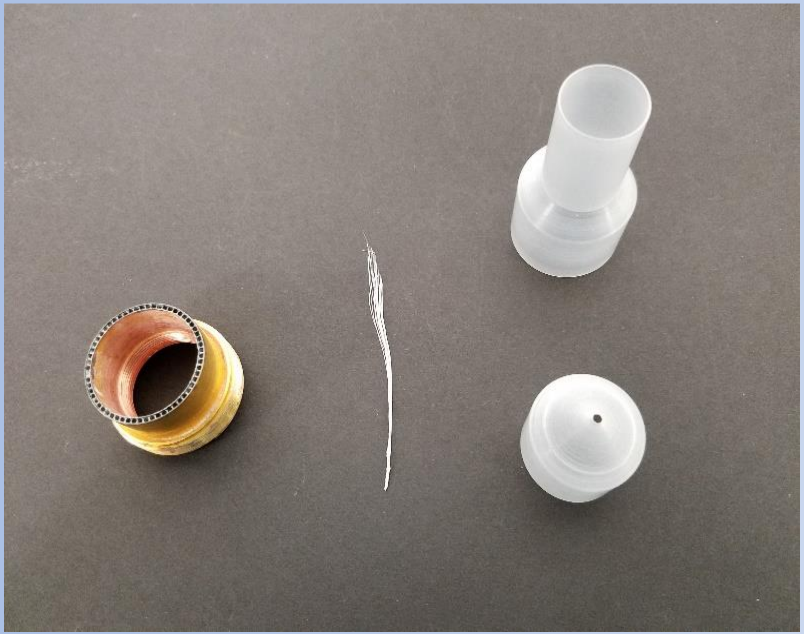
HDice Target Design – during g14 experiment

- An image of the HDice target cell used during the g14 test runs is shown to the right.
  - On the left is a bundle of 50 µm aluminum wires
  - 750 aluminum wires are separated into bundles and soldered into the copper ring base.
  - In the middle is a copper ring next to the lower and upper pCTFE (Kel-F) shells.
  - On the right is an assembled target cell used for the g14 experimental runs at Jlab.

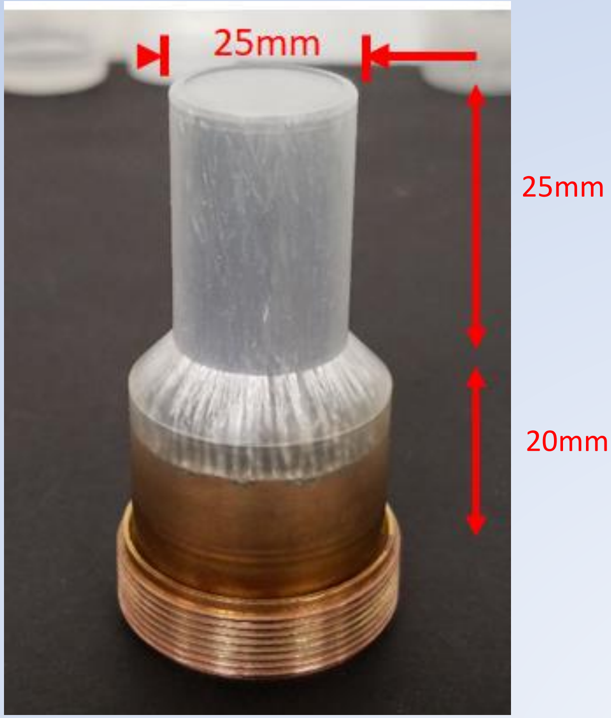


Depolarization Mechanism 1 - Solution

- **Solution**: Limit this effect by better controlling the temperature and having higher electron polarization
  - Faster Raster to limit temperature rises, redesign target – shorter Al wires, higher purity Al, smaller HD cell

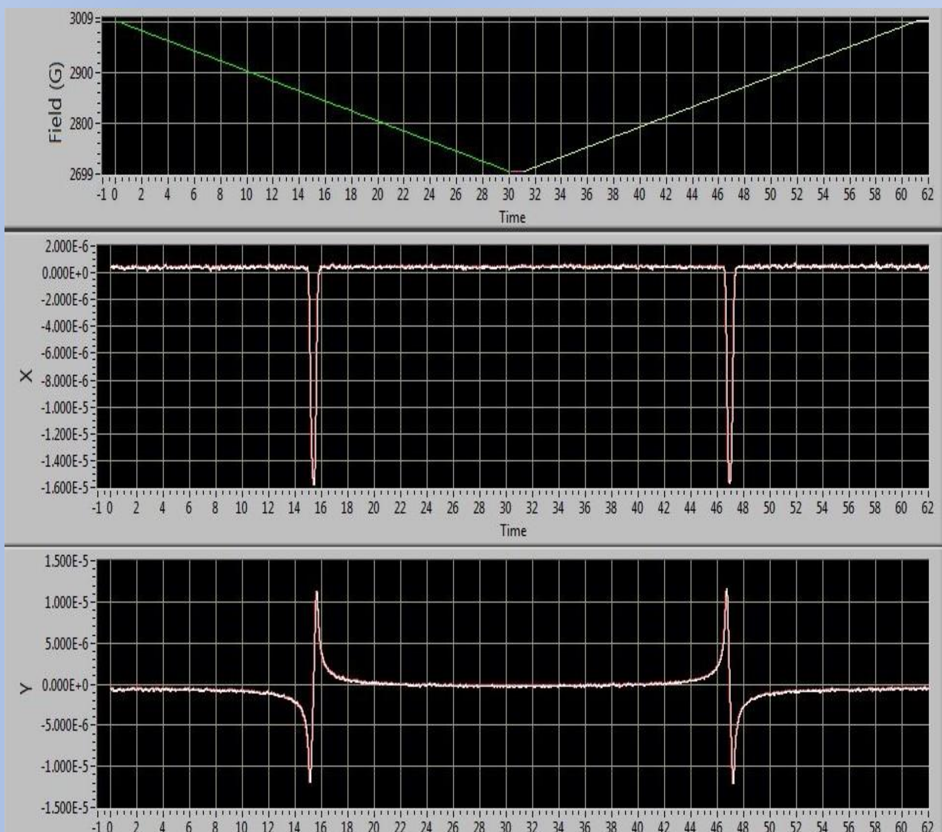


In the image on the left is the copper ring with 60 holes that is used as the copper base. In the middle is a single wire bundle of 24 wires. On the right is the outer kel-f shell (top) and the inner kel-f shell (bottom)



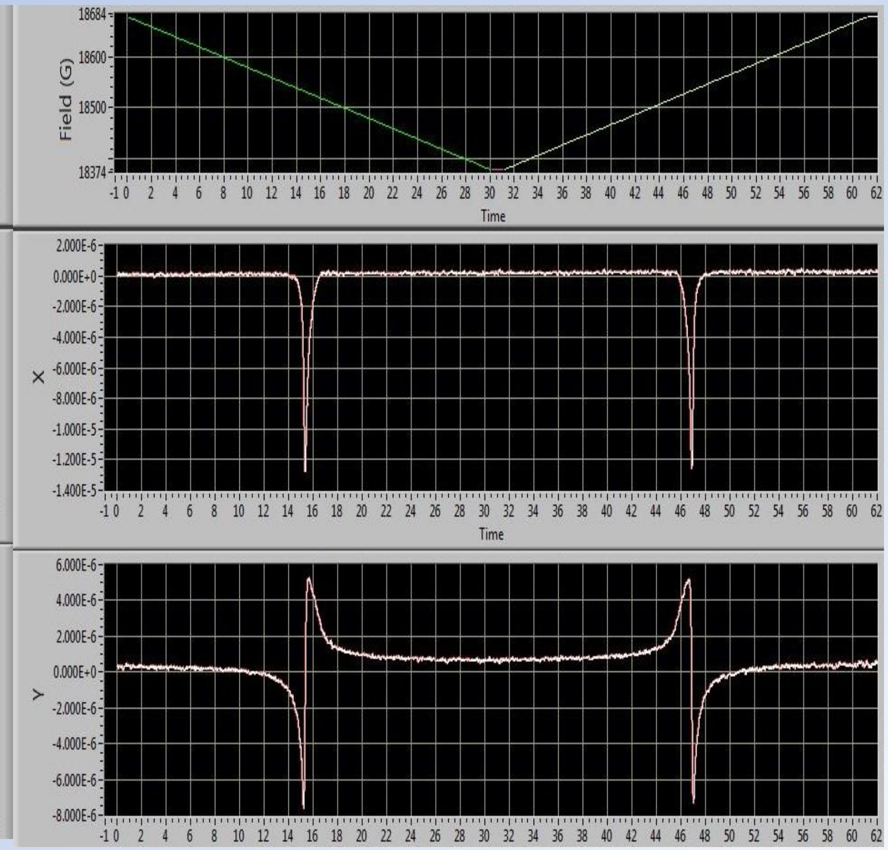
The image above shows a completed target cell ready for HD target production.

Polarization Measurement via NMR



Hydrogen NMR signal

Deterium NMR signal



Simulated Beam through IBC in UITF