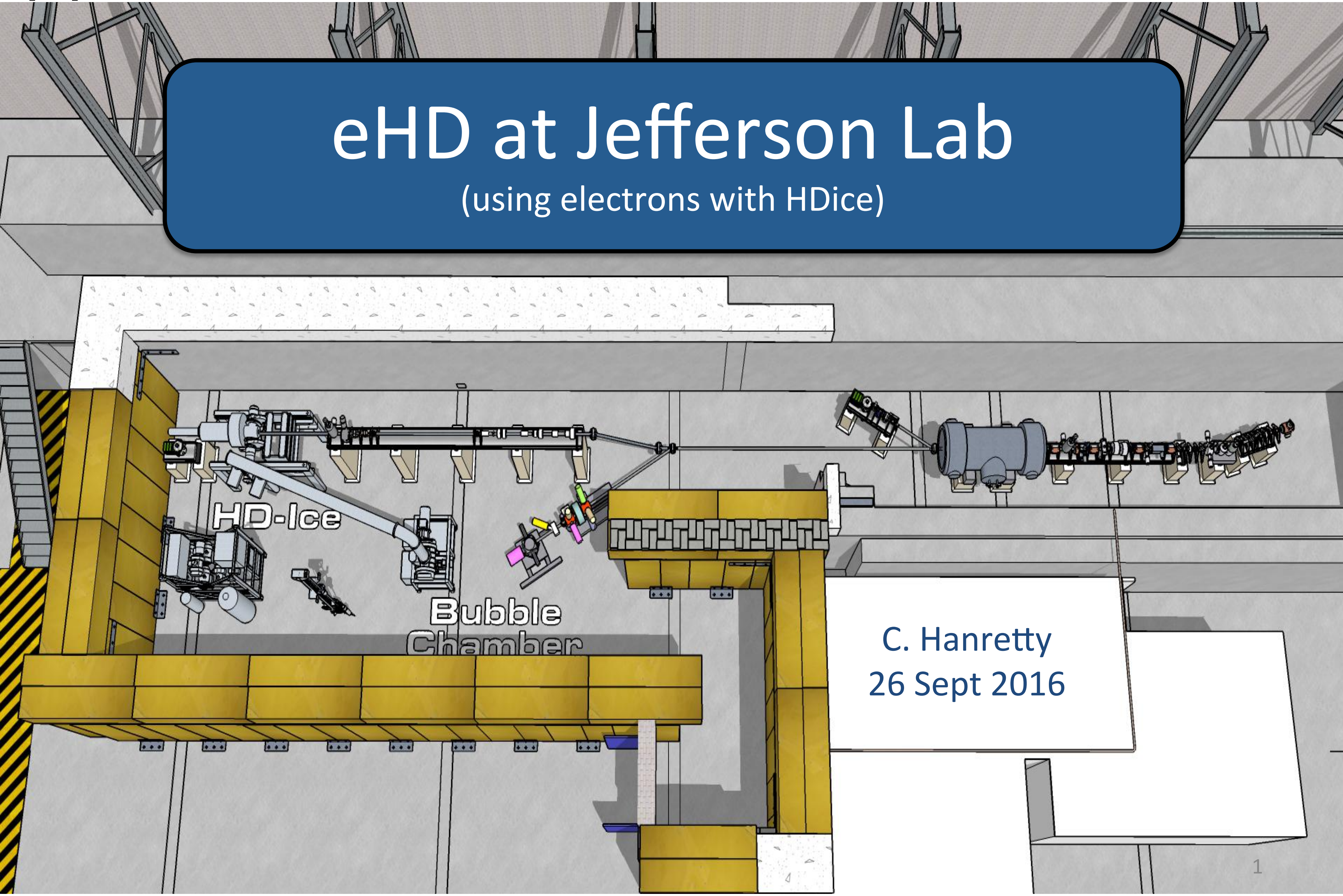
eHD at Jefferson Lab

(using electrons with HDice)



C. Hanretty

26 Sept 2016

Collaborators

Jefferson Lab (HDice – Physics Div)
G. Dezern, C. Hanretty, T. Kageya, M. Lowry, A. M. Sandorfi, X. Wei

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H. Areti, J. Grames, J. Gubeli, M. Poelker, W. Akers

Universita di Roma Tor Vergata and INFN-Sezione di Roma2 (Gas analysis)
A. D'Angelo

James Madison University (Gas distillation)
C.S. Whisnant

Universita di Ferrara and INFN di Ferrara (MgB_2 magnet)
M. Contalbrigo, P. Lenisa, M. Statera, G. Ciullo, L. Barion

Overview

- Motivation for transversely polarized target experiments with CLAS-12.
- What is HDice and how does it work?
- Lessons learned from 2012 eHD tests in Hall B.
- eHD at the Upgraded Injector Test Facility (UITF)
- Relating running eHD at UITF to running in CLAS-12.

CLAS12

Forward Detector (FD)

- TORUS magnet (6 coils)
- HT Cherenkov Counter
- Drift Chamber System
- LT Cherenkov Counter
- Forward ToF System
- Pre-Shower Calorimeter
- E.M. Calorimeter

Central Detector (CD)

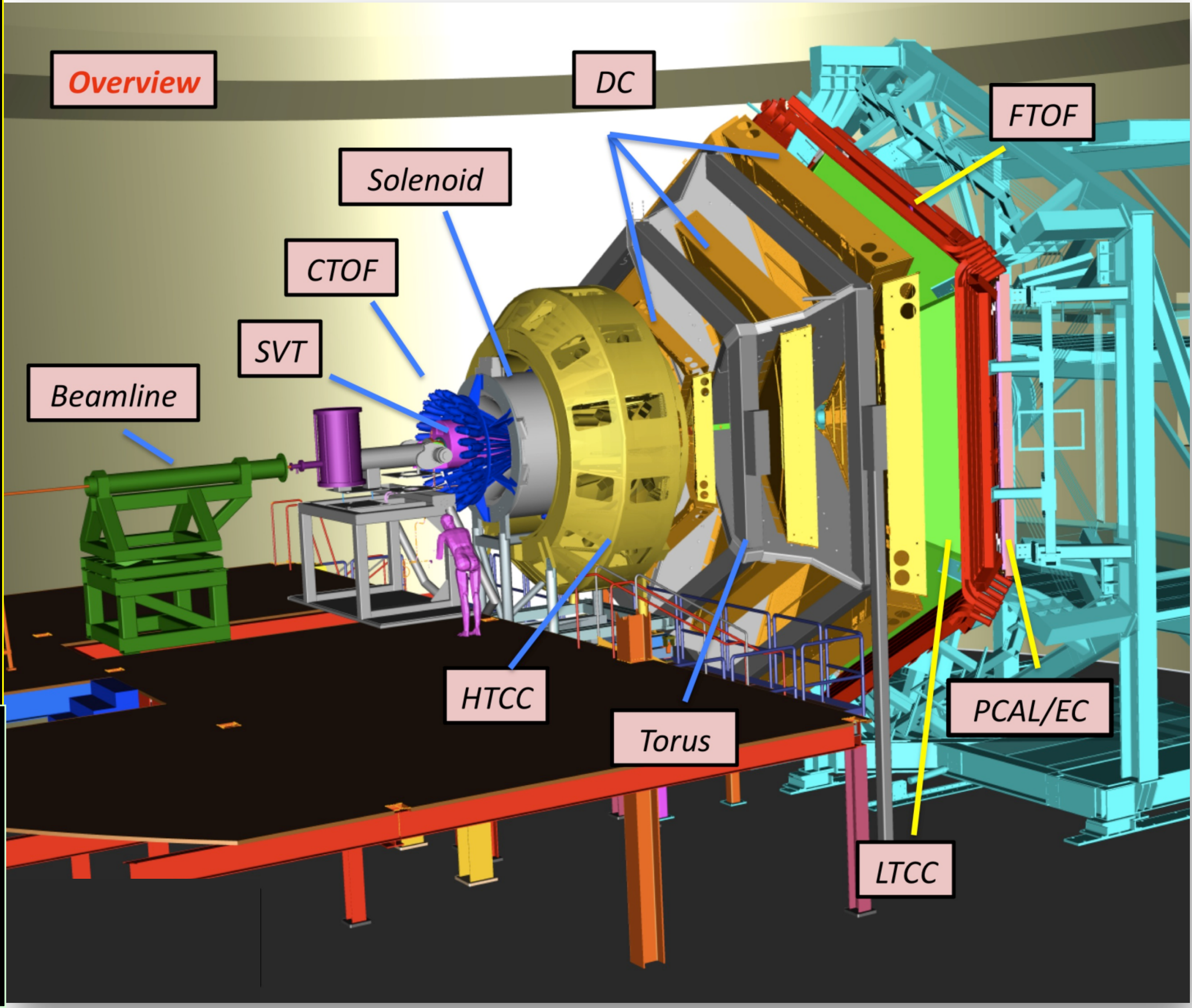
- SOLENOID Magnet
- Barrel Silicon Tracker
- Central Time-of-Flight

Beamline

- Targets
- Moller Polarimeter
- Photon Energy Tagger

Upgrades to the baseline

- MicroMegas
- Central Neutron Detector
- Forward Tagger
- RICH Detector (2 sectors)
- Polarized Target (long.)



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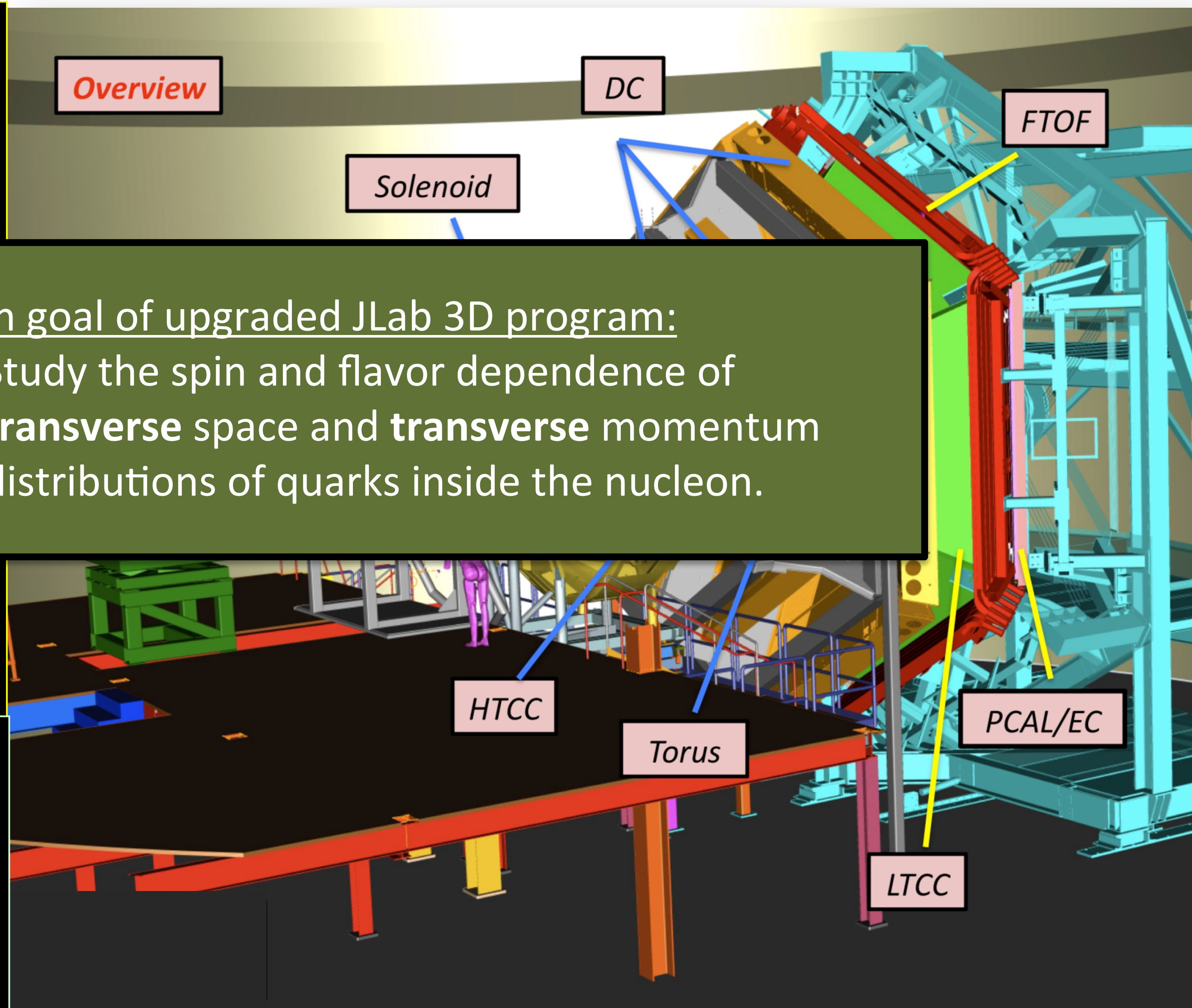


Main goal of upgraded JLab 3D program:

➔ Study the spin and flavor dependence of **transverse** space and **transverse** momentum distributions of quarks inside the nucleon.

1^{st} Order Issues with Transversely Polarized Target

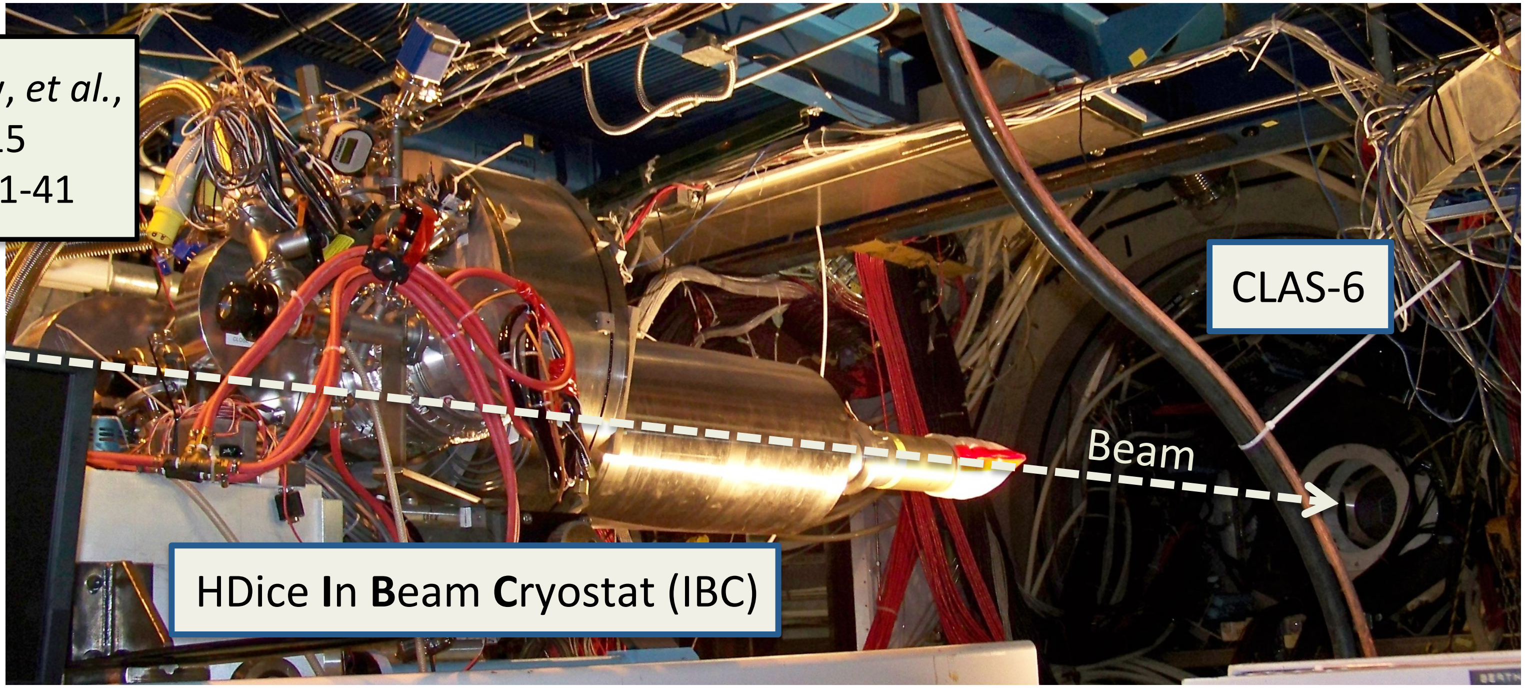
- A conventional target with transverse polarization requires use of "large" magnet around target (DNP)
  - A magnetic field transverse to beam axis bends beam into detectors (sheet of flame).
  - Frozen spin target does not require large magnetic field around target (smaller B • dl) ➡ HDice

- How to maintain a transverse field inside of CLAS-12 Solenoid: MgB_2 (next talk)

What is HDice?

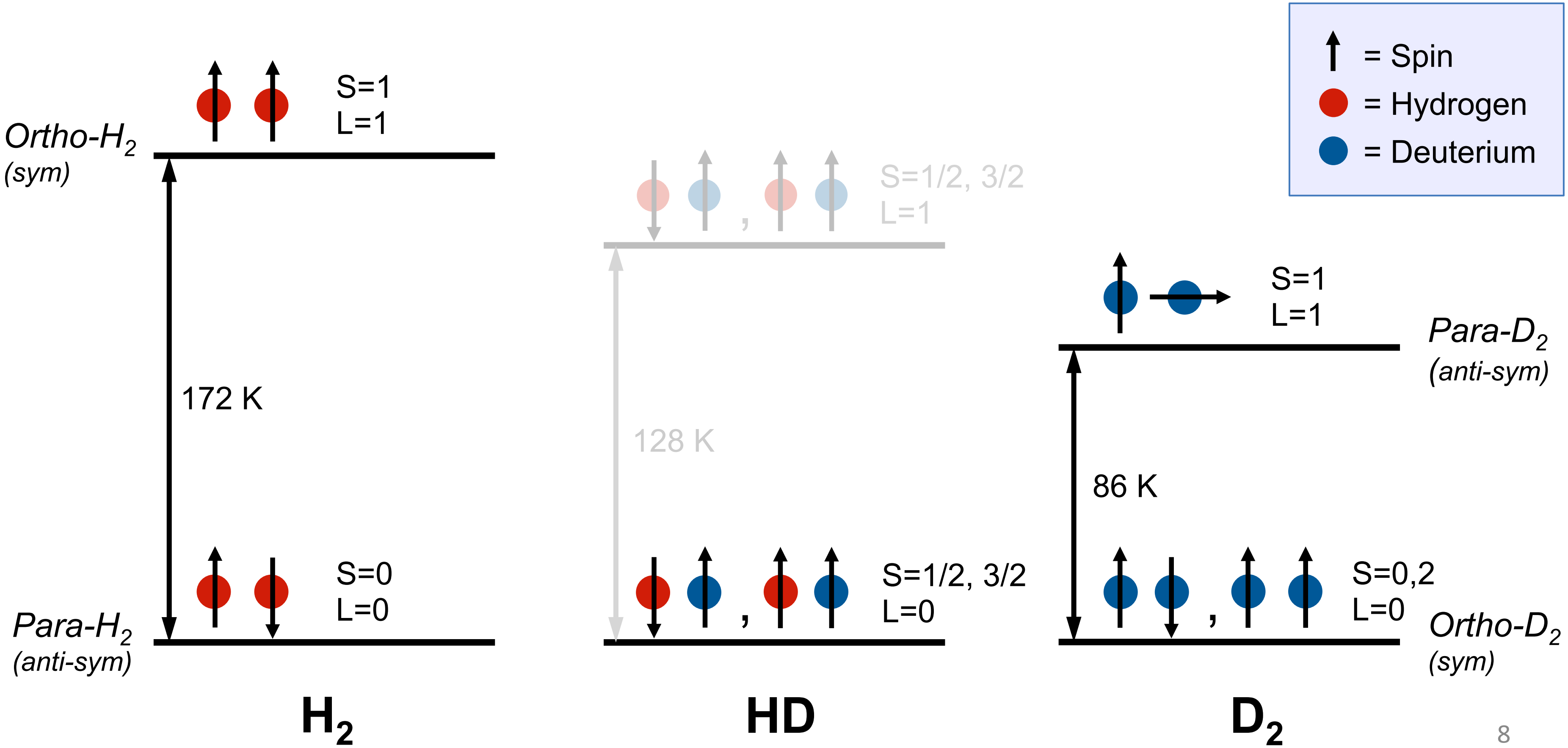
- A frozen spin target ⟶ no need for large magnet.
- Target material consists solely of polarizable protons and deuterons ⟶ no dilution factor coming from the target material.
- Target material possesses a T1 (relaxation time) on the order of years.
- A very complicated target system requiring many steps in the production of a single polarized target cell.

M. Lowry, *et al.*, NIM A 815 (2016), 31-41



Polarization Process

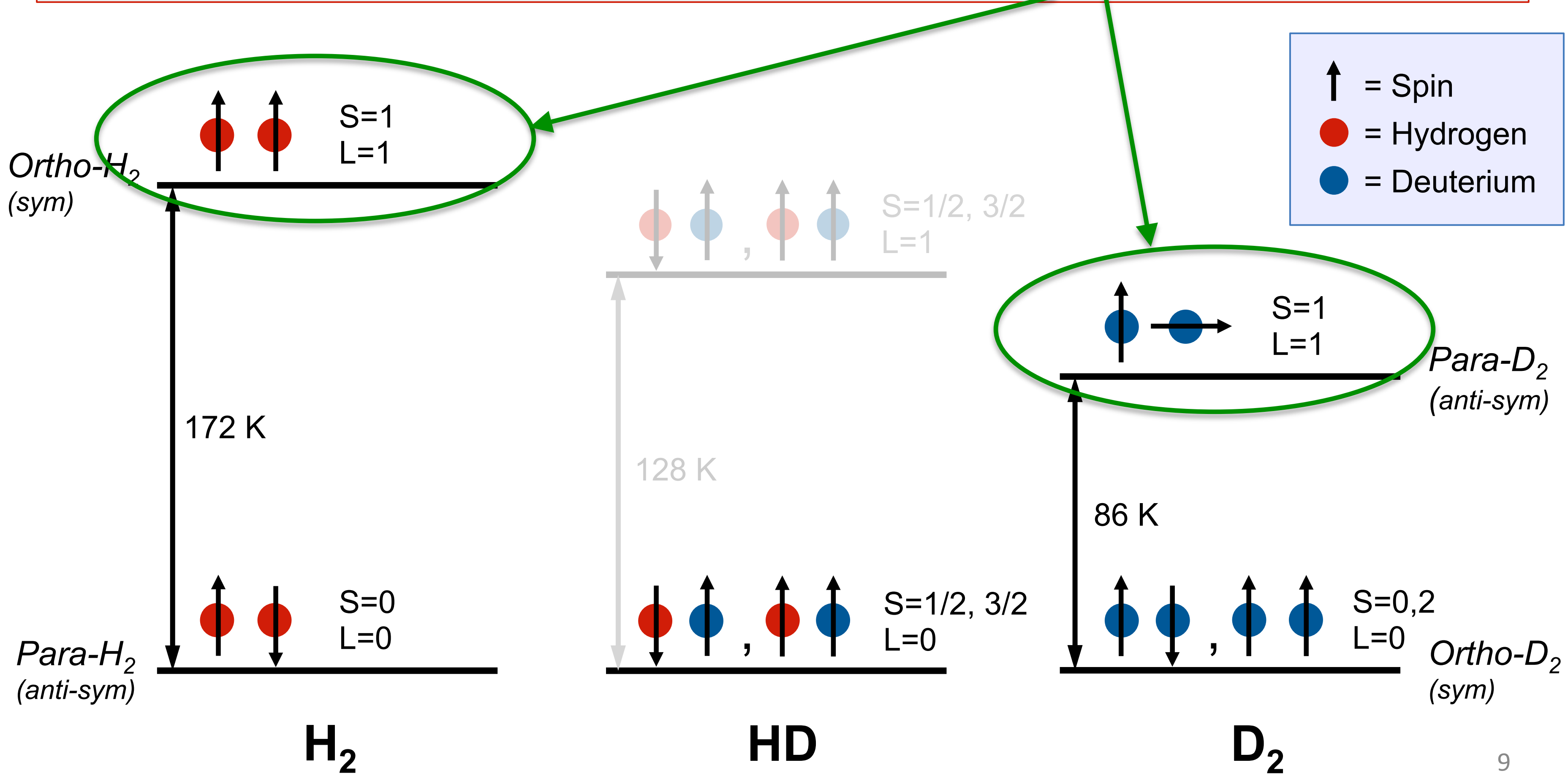
How does one make polarized, frozen spin HD?



Polarization Process

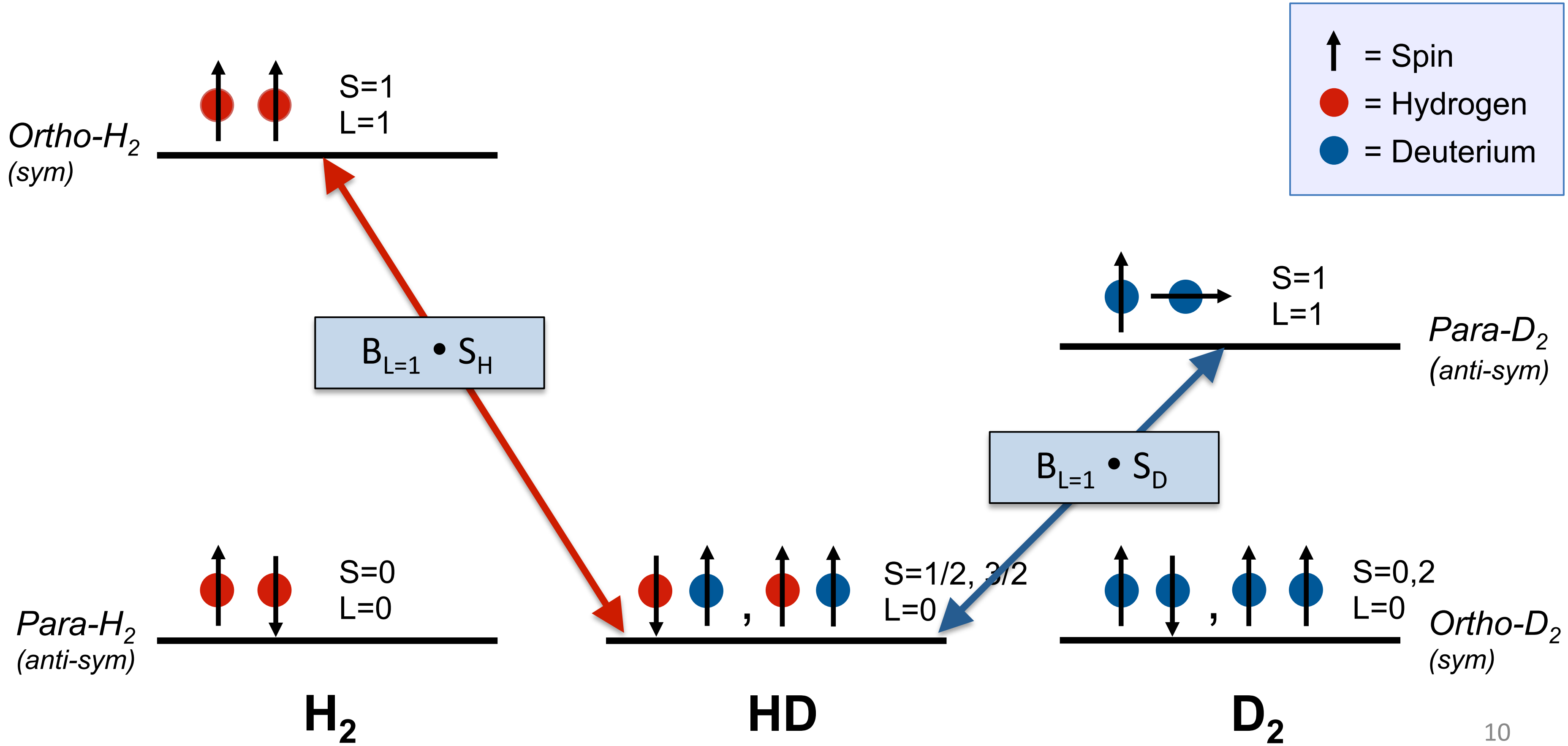
What polarizations mechanisms can we use?

- For all molecules, we have 2 electrons paired in 1s orbital ⟶ no DNP
- 1st excited states are metastable with L, S ≠ 0 ⟶ these couple to B field



Polarization Process

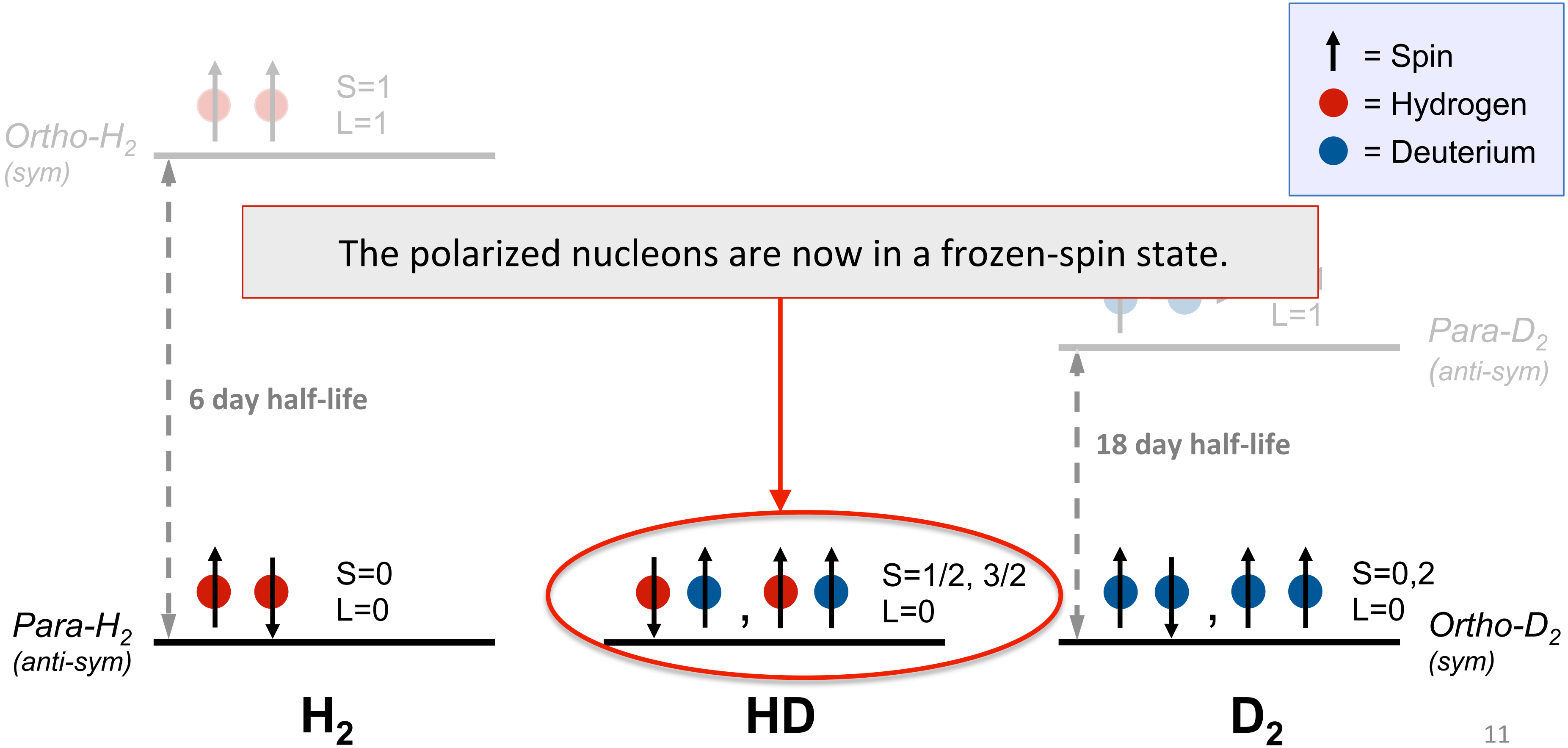
External magnetic field rapidly aligns *Ortho-H_2* and *Para-D_2* which spin-exchange with H and D (respectively) in the HD crystal before being repolarized by the magnetic field. Within ~ days ortho-H_2, HD and para-D_2 have reached their equilibrium polarizations.



Polarization Process

Once the population in the metastable excited states has decayed away (~ few months), only the inactive, L=0 level is populated.

The polarized nucleons are now in a frozen-spin state.



What experiments can benefit?

- Has been used with photons in Hall B as part of the N* program ⟶ g14 (Nov 2011 – May 2012).
- Next up: Transversely polarized frozen spin target for use with electrons.
- Three (A-rated) proposals approved by PAC 39, rated as high impact for Hall B by PAC41:
  - 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]

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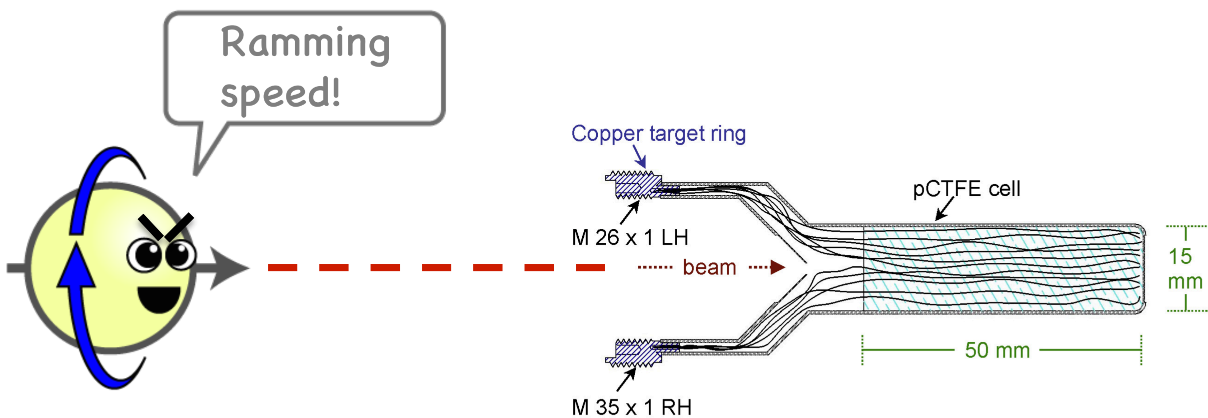
C1 → scheduling requires successful demonstration of viable performance in a subsequent eHD test runs

2012 eHD Test in Hall B

- During g14, several eHD runs were conducted opportunistically to study the effect of an electron beam on the HDice target.
- eHD test utilized existing Hall B Slow-Raster and target cell designed for photons (a setup not optimized for an electron beam).
- Results showed a significant loss of polarization due to the electron beam (after 1 nA-day) ➡ Focus of current R&D effort



2012 eHD Test in Hall B

- Depolarization attributed to three possible mechanisms:

1) Beam-induced chemical changes:
   - HD molecule ionizes and becomes highly reactive (HD^+)
   - A chain of reactions begins, producing atomic hydrogen:
     ➔ Temperature spikes occur from "recombination flashes"
     - Also seen in g14 photon runs (from $e^+ e^-$ pairs) with low frequently but with no apparent effect.

     ➔ Recombination leads to buildup of ortho-H_2 which can shorten T1 of material
     - Analysis of gas after 1nA-week in beam showed no large increase of ortho-H_2 (measurements had limited sensitivity)

2012 eHD Test in Hall B

- Depolarization attributed to three possible mechanisms:

2) Hyperfine mixing of unpaired electrons with (atomic) H (or D) spins:
   - Electrons polarized by holding field possess spins opposite to H
   - Hyperfine mixing dilutes H polarization
   - Depolarization first occurs locally, depolarization spreads
   - Temperature independent (function of B^{-2})

Solution:

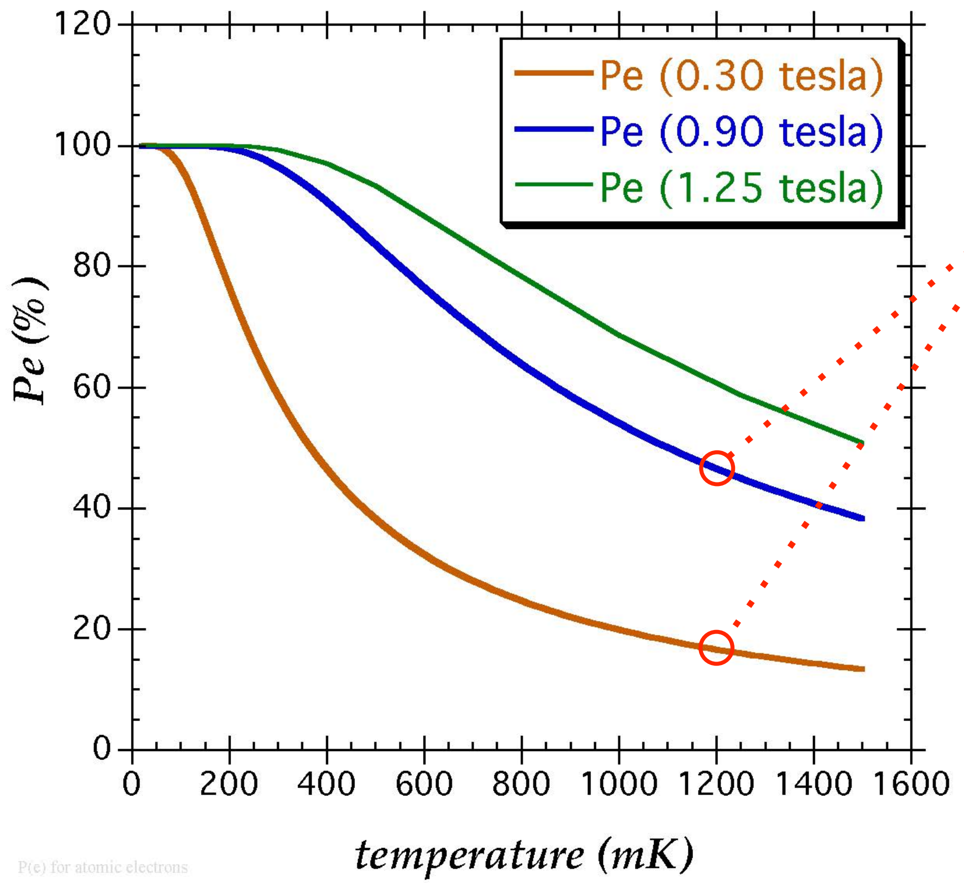
Use RF to align H (or D) spins with electron spins to prevent this mixing.

2012 eHD Test in Hall B

- Depolarization attributed to three possible mechanisms:

3) Beam unpairs 1s molecular electrons in target material:
   - Electron(s) may be unpolarized (depends on temperature)
   - If unpolarized (or has low polarization): flips, generating varying field possessing a component at the nuclear Larmor frequencies of H and D
   - Depolarization of local HD begins, spreads to rest of HD crystal

Flipping, unpaired electron during 2012 eHD test



P(e) for atomic electrons

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

➔ P_e ≈ 20-50%

at $P_e = 0.2$

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

and T_1 ~ 4 hr

2012 eHD Test in Hall B

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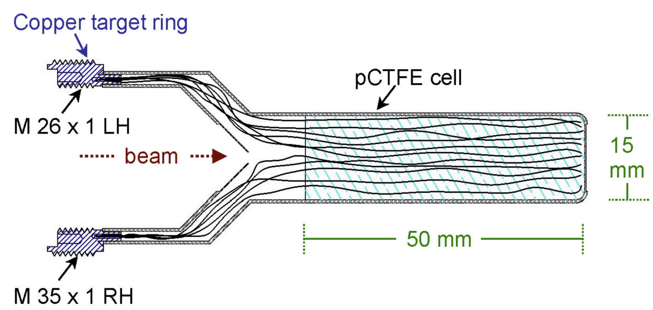
   - Depolarization of local HD begins, spreads to rest of HD crystal

Solution:

Suppress this effect through higher electron polarization (mitigation of beam heating).

➔ Faster Raster, shorter Al wires, higher purity Al, shorter HD cell

C.D. Bass, *et al.*, NIM A 737 (2014) 107-116



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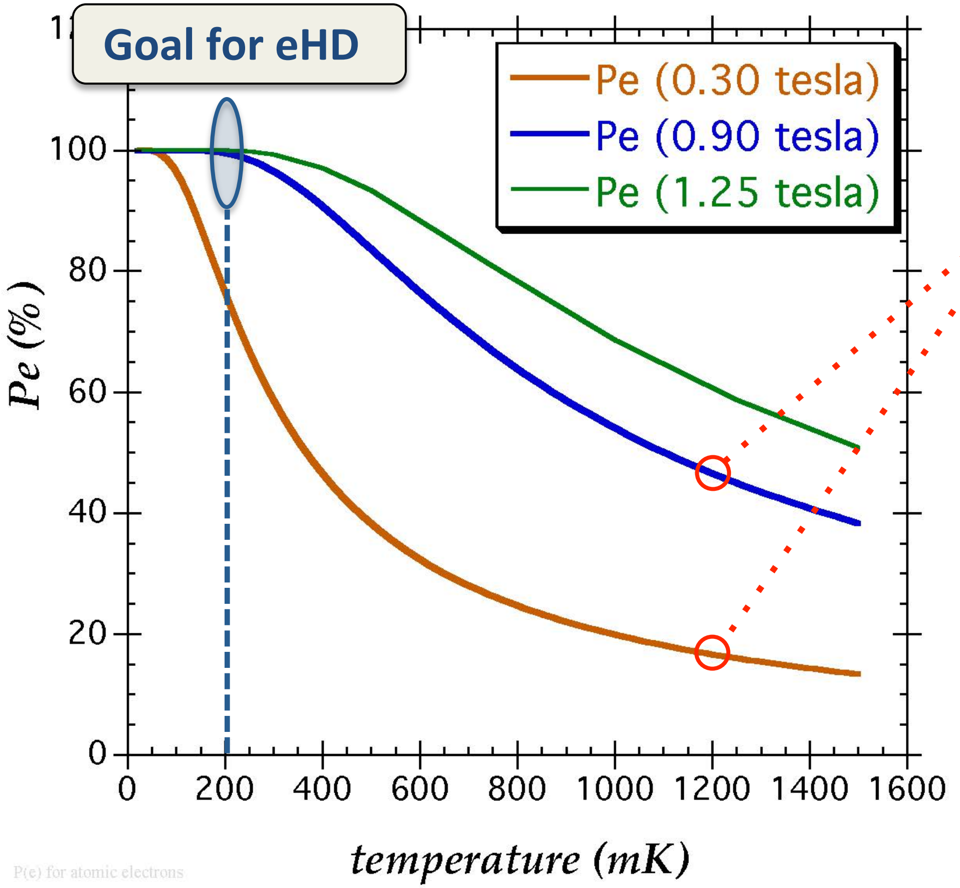

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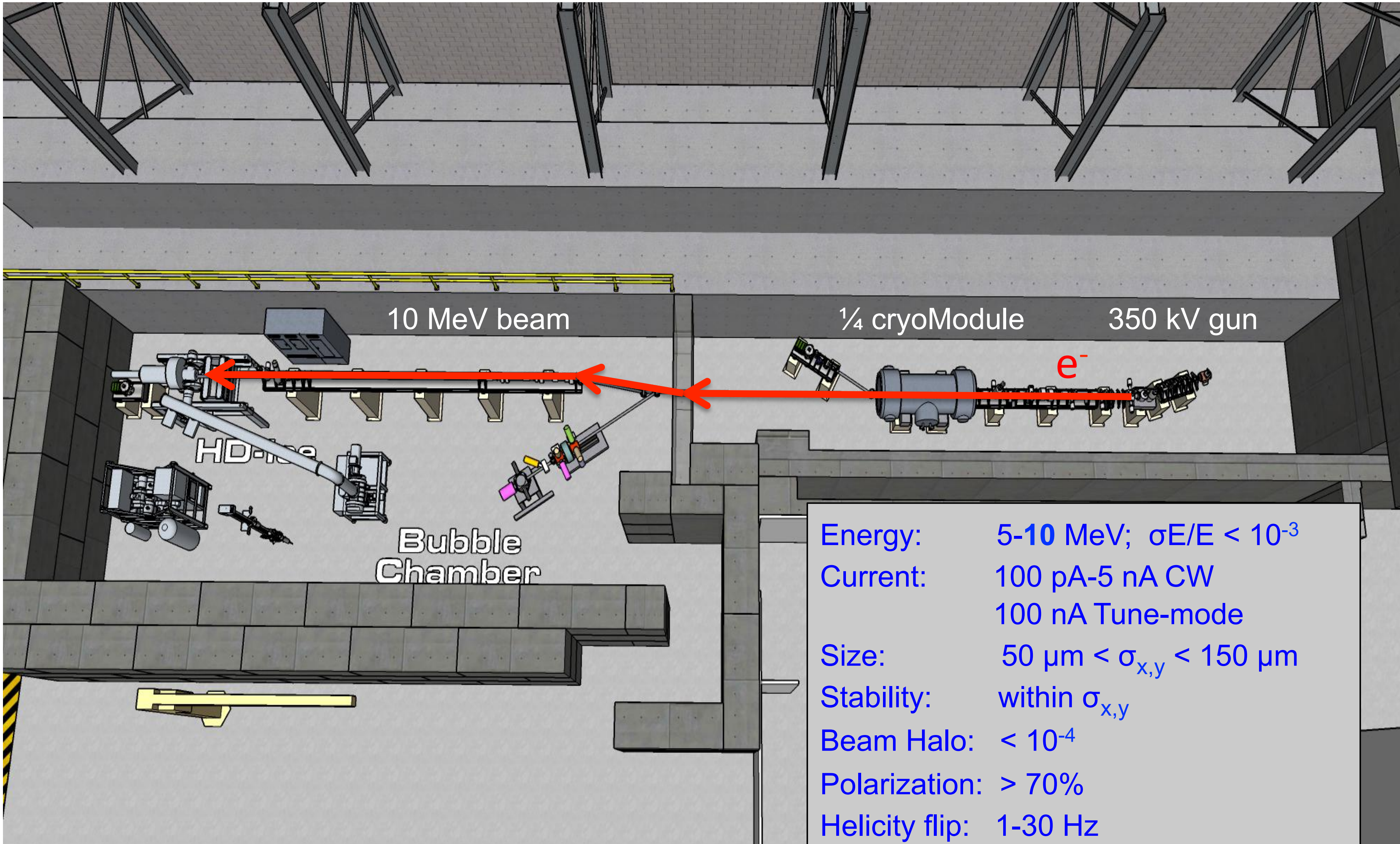
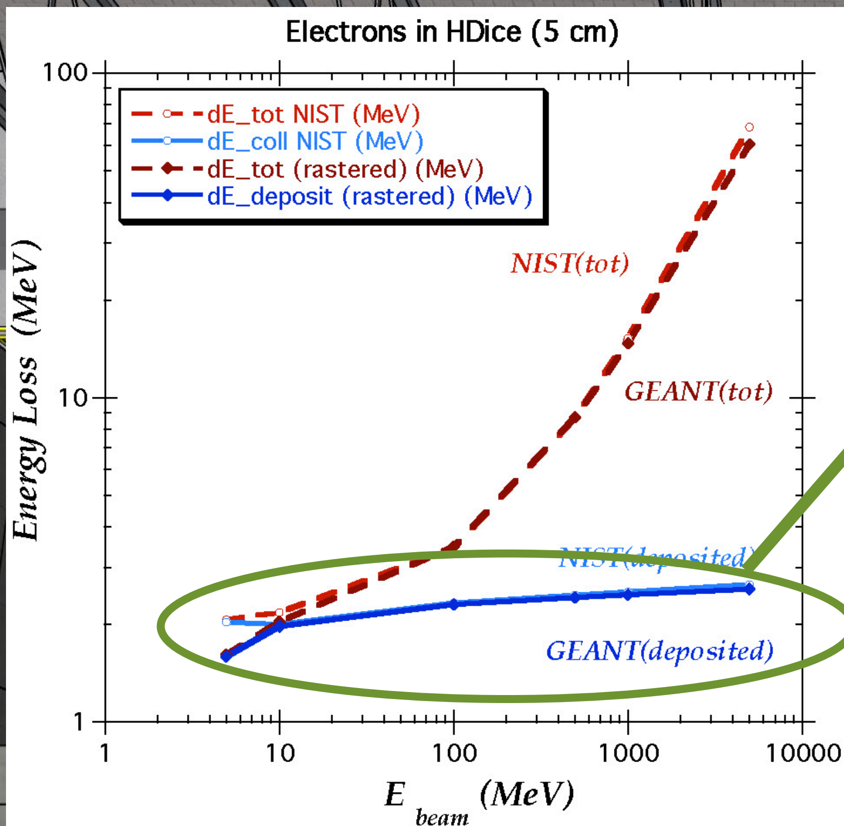
eHD Tests in UITF



Energy:	5-**10** MeV; $\sigma E/E < 10^{-3}$
Current:	100 pA-5 nA CW 100 nA Tune-mode
Size:	50 μm < $\sigma_{x,y}$ < 150 μm
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; σE/E < 10^{-3}
Current:	100 pA-5 nA CW
	100 nA Tune-mode
Size:	50 μm < $\sigma_{x,y}$ < 150 μm
Stability:	within $\sigma_{x,y}$
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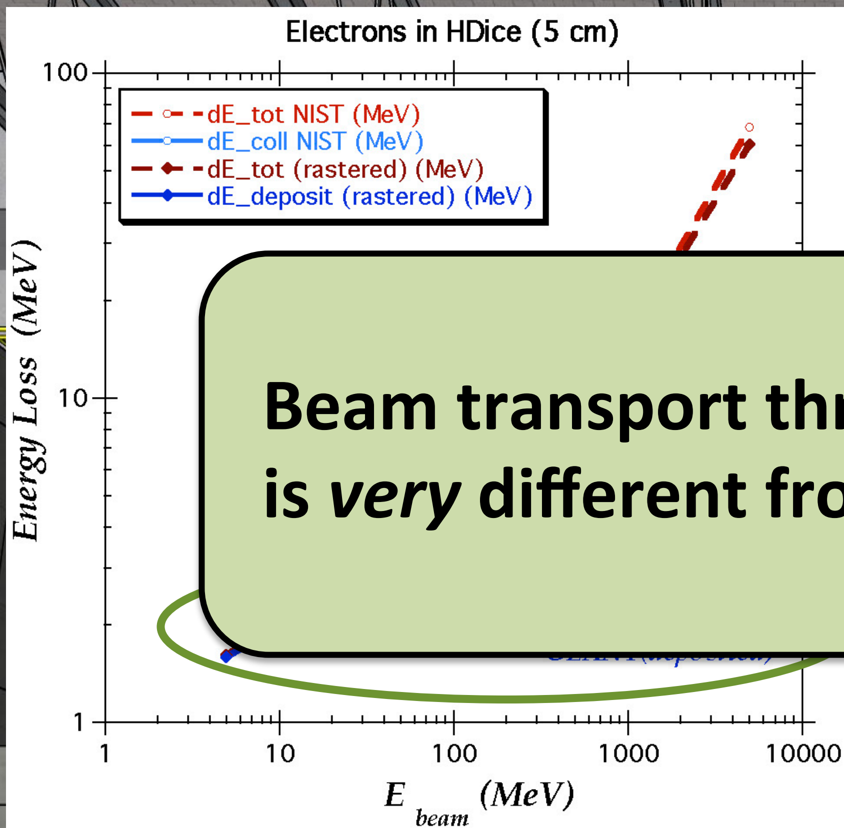
eHD Tests in UITF

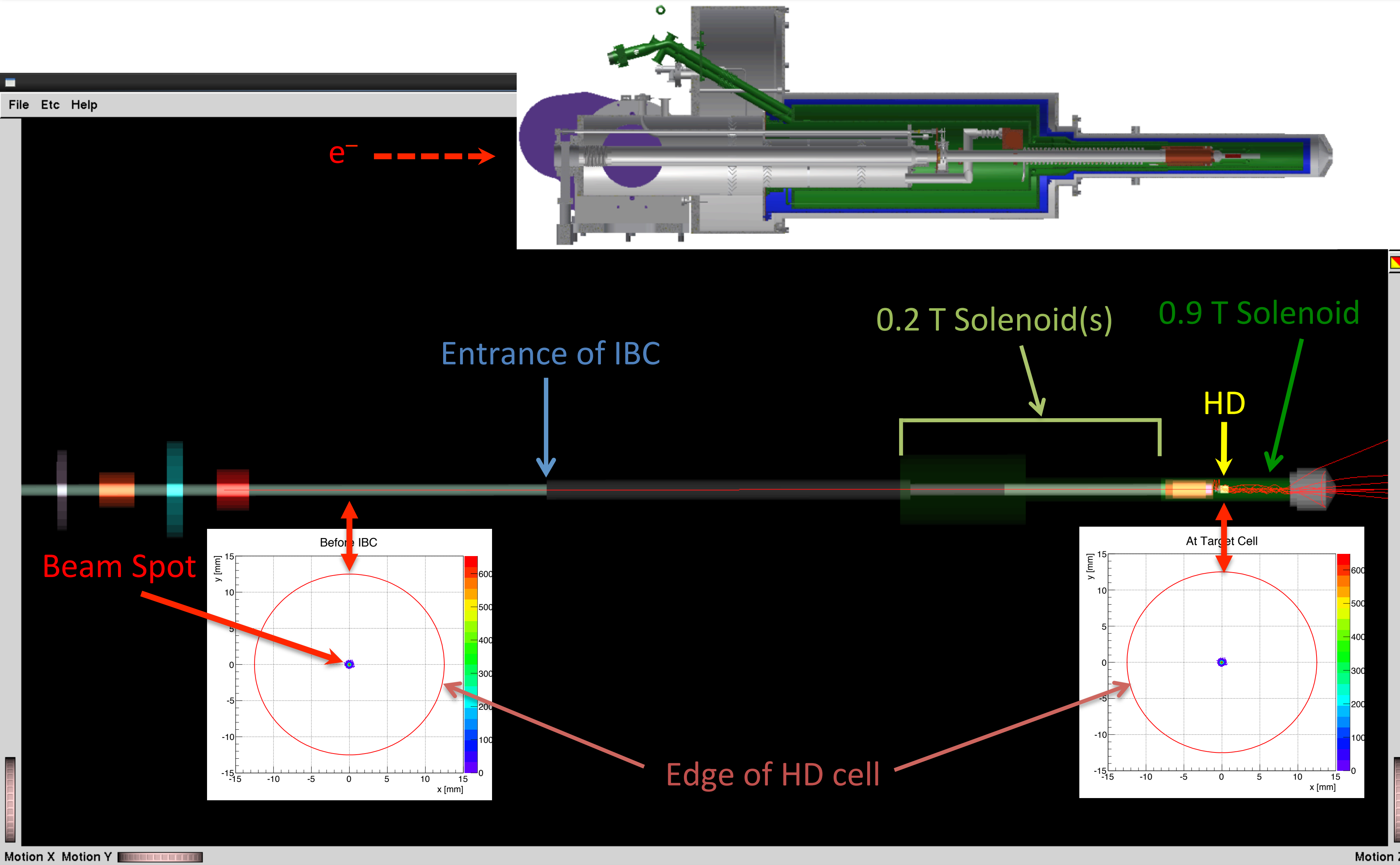


Ionization and energy deposition are approx independent of E_{beam} at 10 GeV

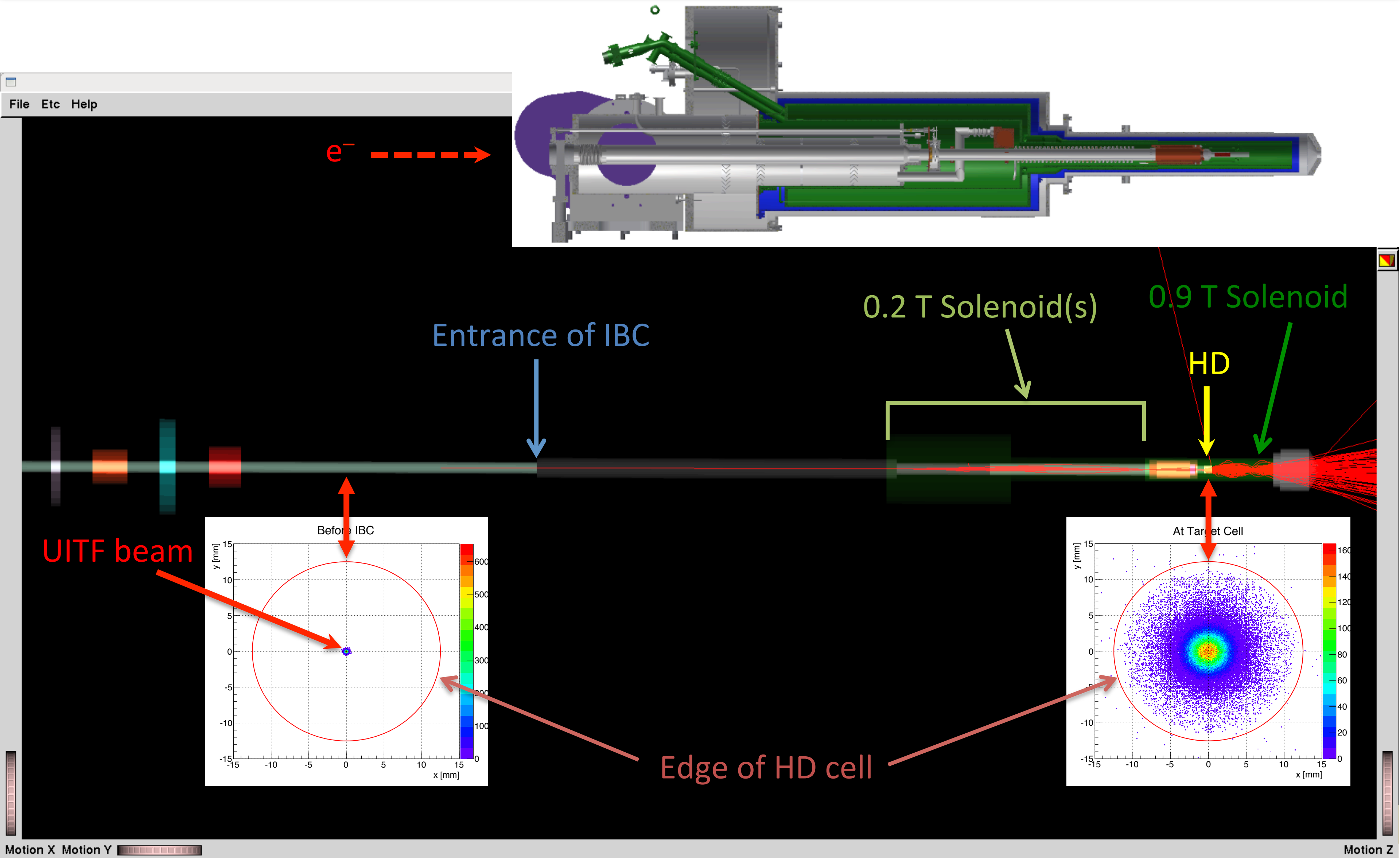
Beam transport through IBC at 10 MeV is *very* different from 10 GeV!!!

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

Pencil beam into IBC at **10 GeV**

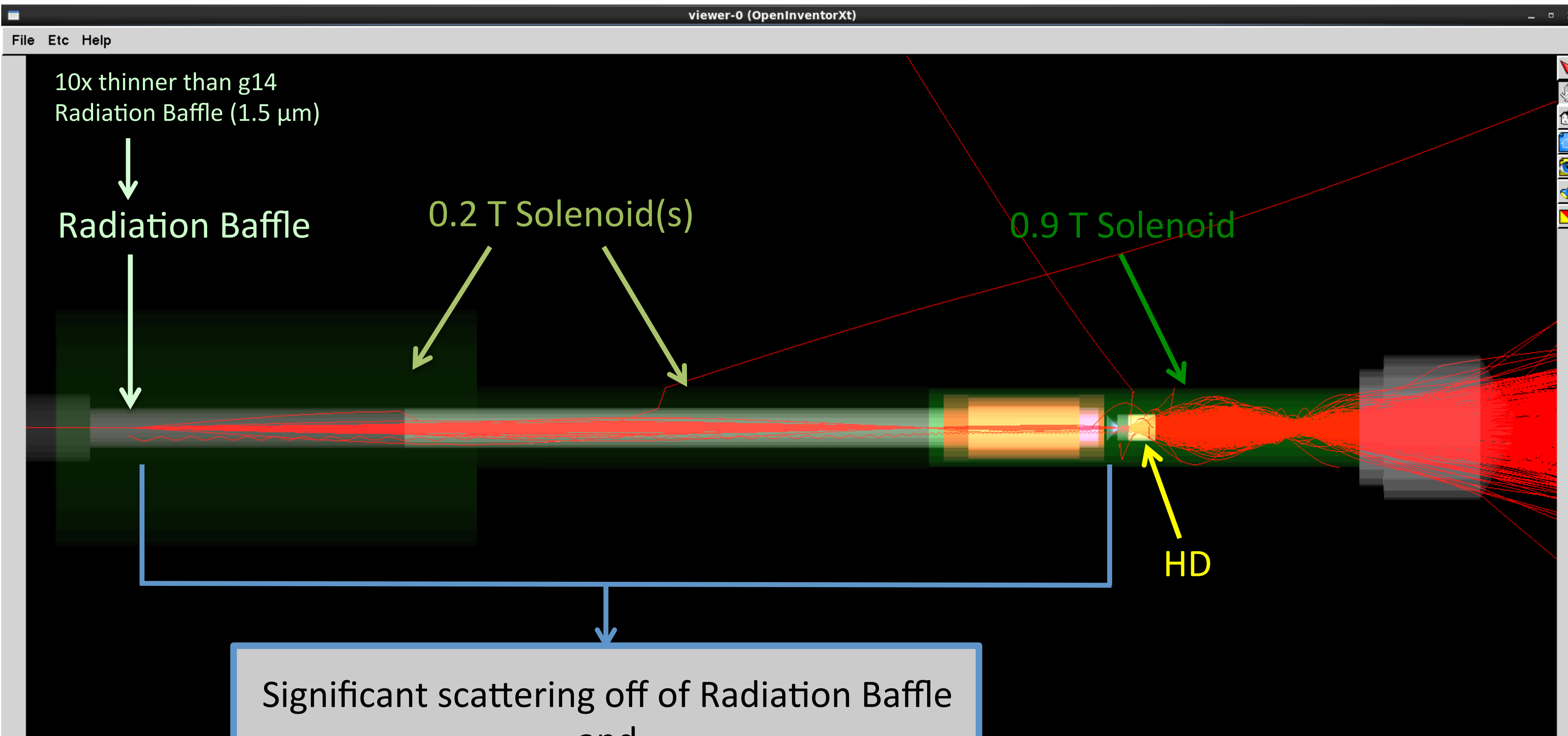


Pencil beam into IBC at **<10 MeV**



Pencil beam into IBC with normal orientation at <10 MeV

…… a closer view

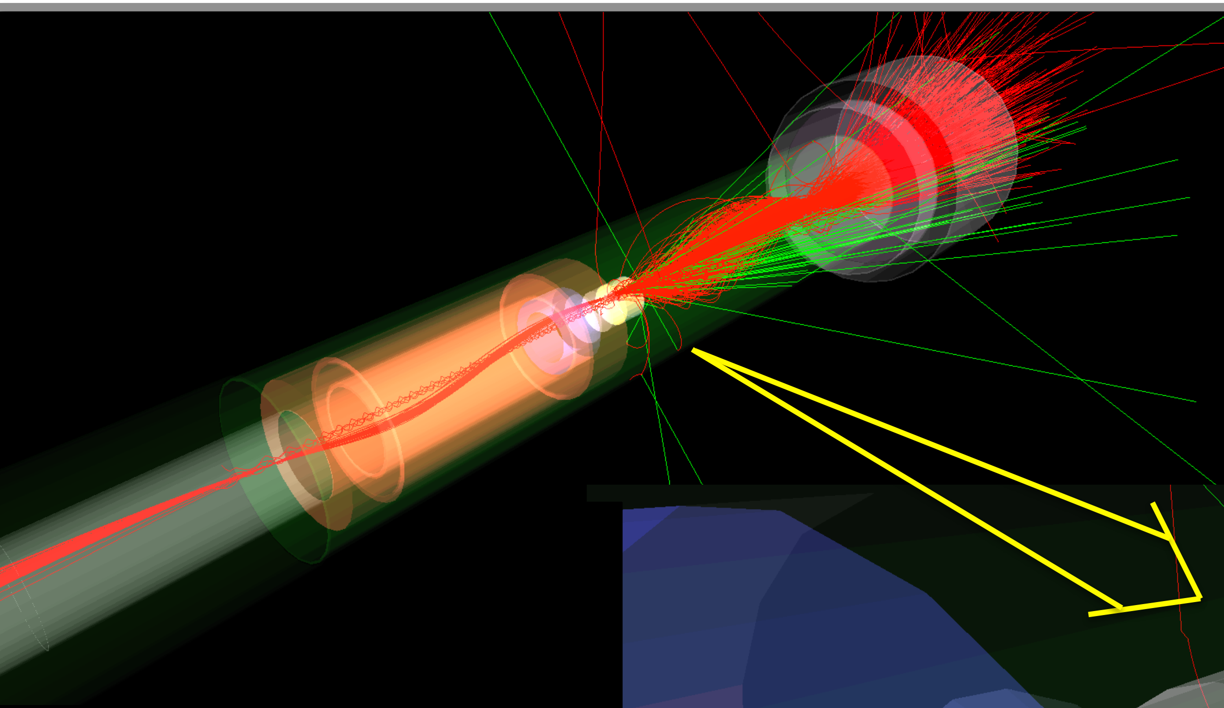


Significant scattering off of Radiation Baffle
-and-
Focusing effects from solenoids

HDice

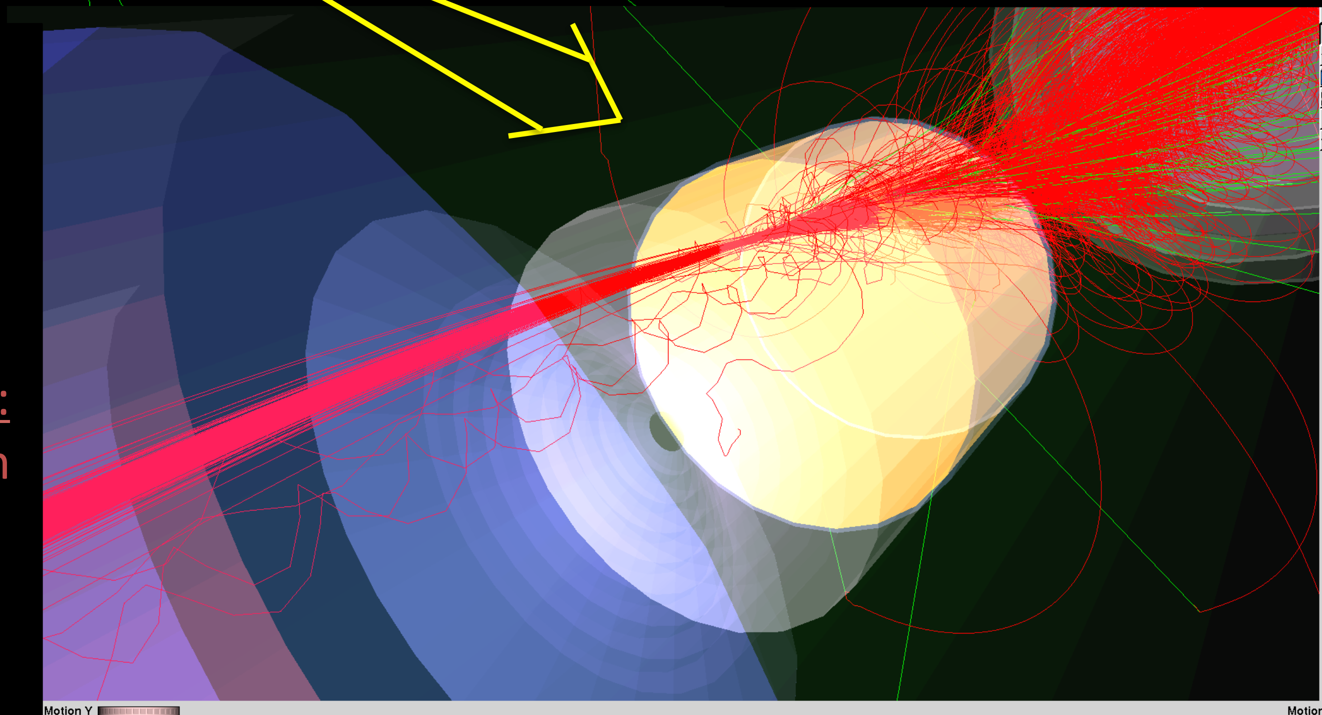
Jefferson Lab

Based on results from simulation of UITF beam:



Focusing by Solenoids:

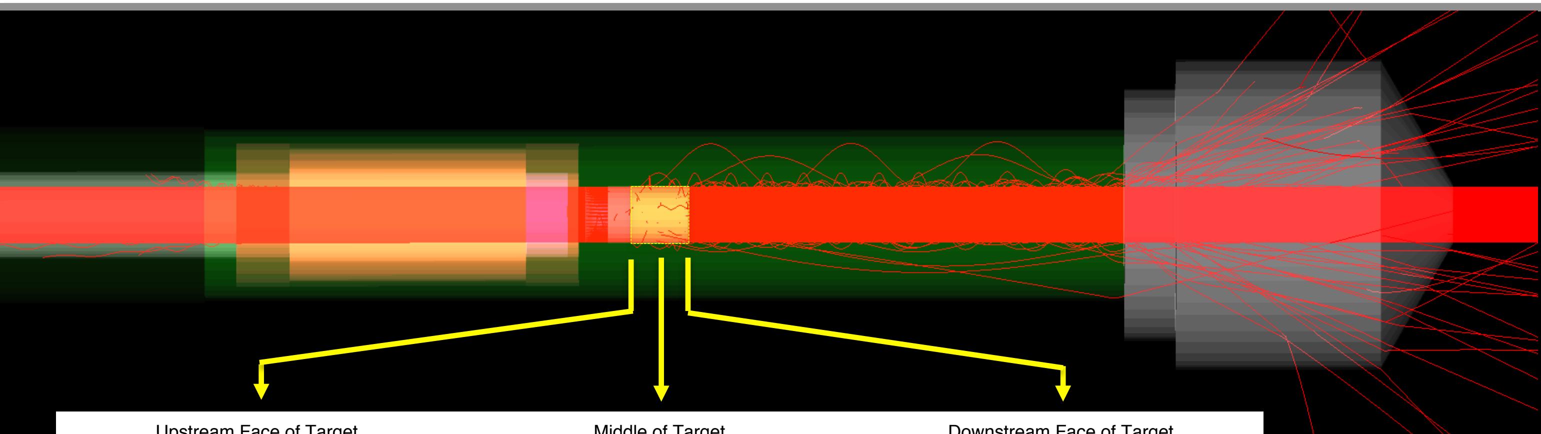
- Affects beam size and position
- → Tune beam energy to 7.86 MeV
- → HD radius = 9.5 mm

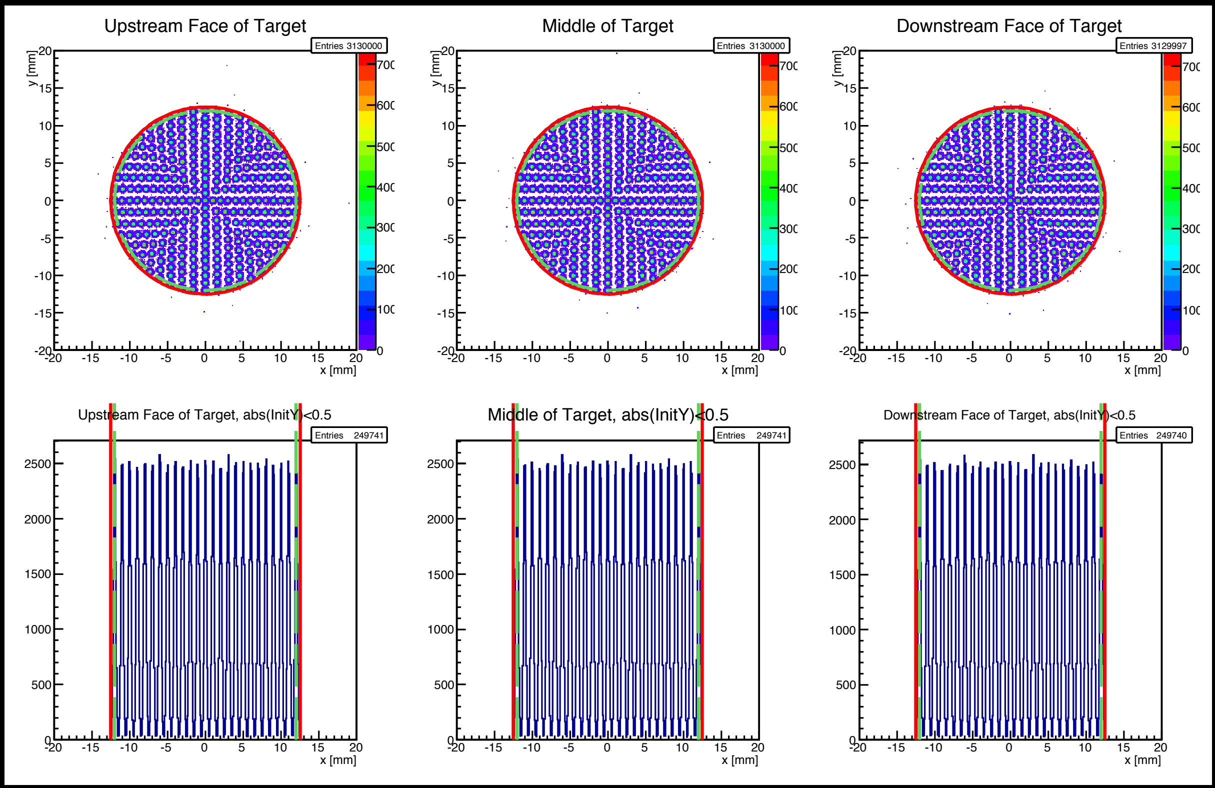


Multiple scattering in HD:

→ HD Length = 12.5 mm

Rastered **10 GeV** beam profiles **CLAS-12** target

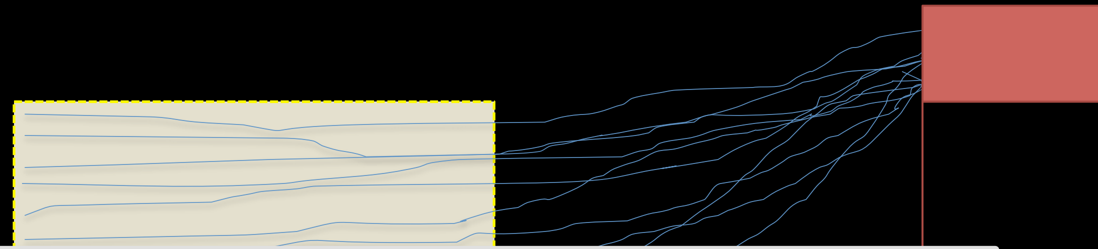




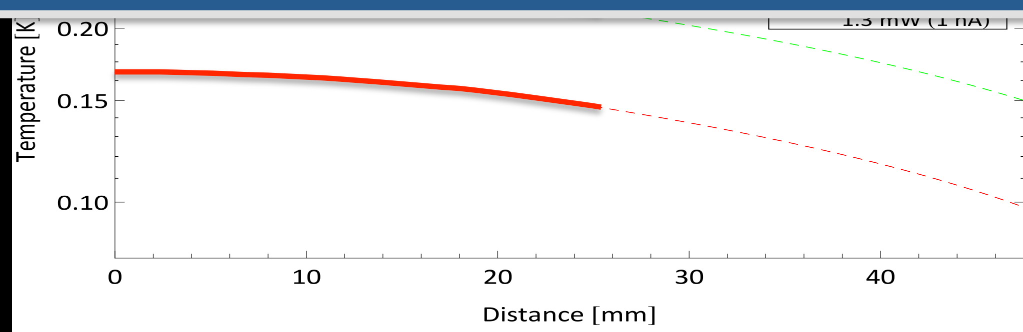
Target radius = 12.5 mm
Target length = 25 mm

- solenoid focusing and multiple scattering are both irrelevant
- beam uniformly illuminates the full target cell

Expected heat load from **10 GeV** on a **CLAS-12** target



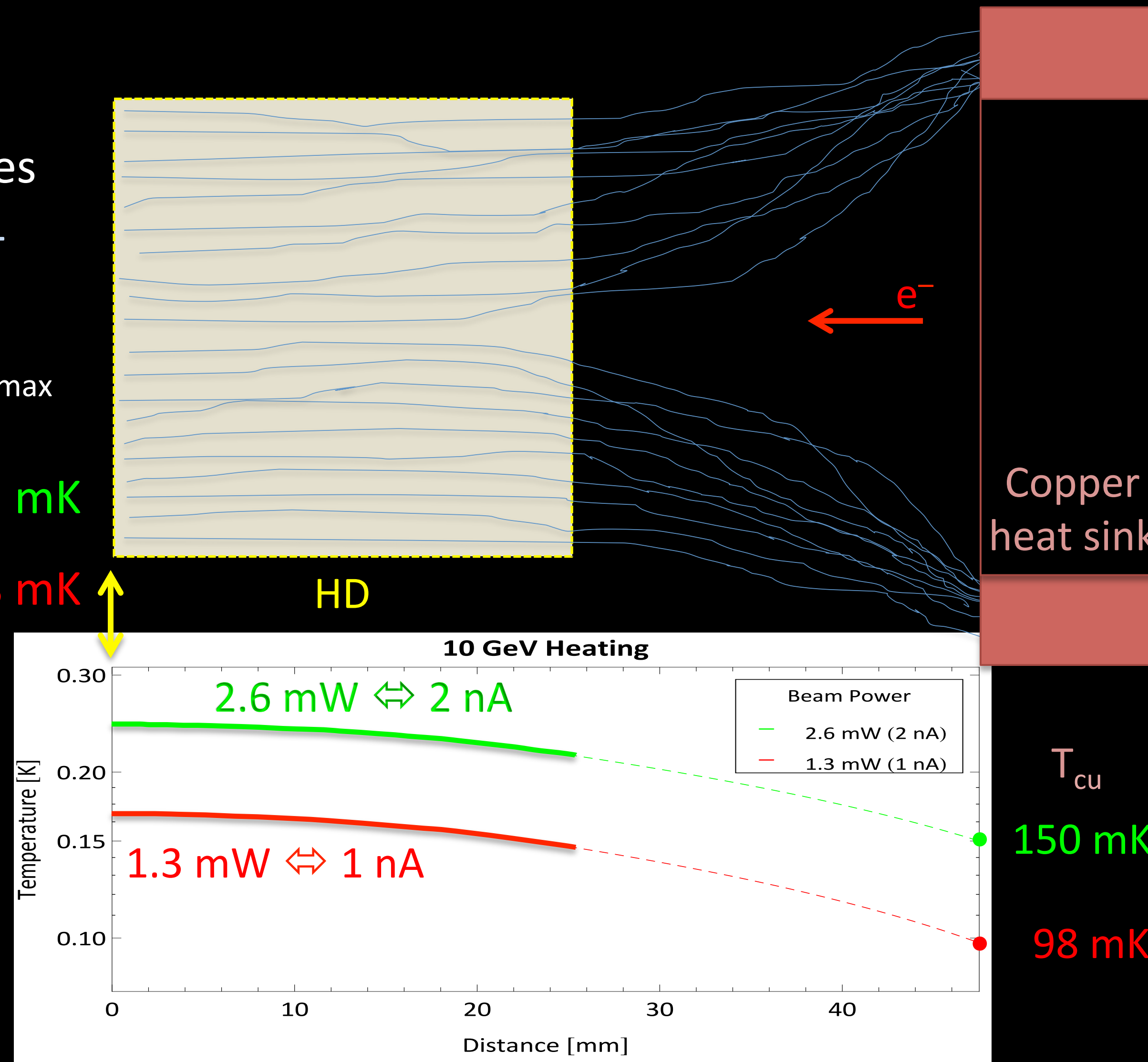
- Depolarization mechanism: beam ionizes HD, breaking paired *1s* electrons
- Unpaired electrons will be inert if they polarize in the 0.9 T IBC field ⇔ **polarization depends on temperature**
- HD temp depends on deposited beam power and temp of Cu heat sink (cooling power of IBC refrigerator)



Expected heat load from **10 GeV** on a **CLAS-12** target

- HD cell for CLAS-12:
  25 mm Ø x 25 mm L
  1800 x 3 mil Ø Al (5N) wires
- NEW holding field = 1.25 T

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

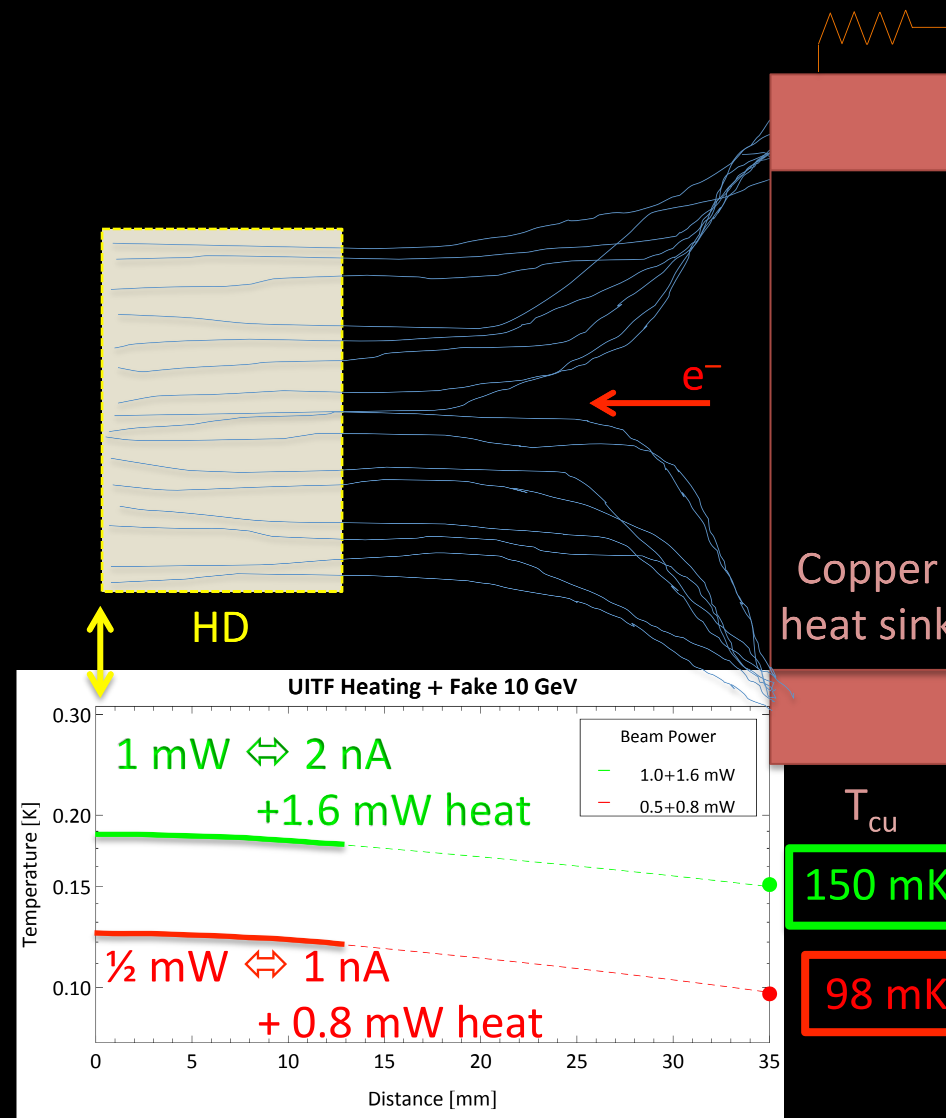


Simulating **10 GeV** heat load & polarizations at **UITF**

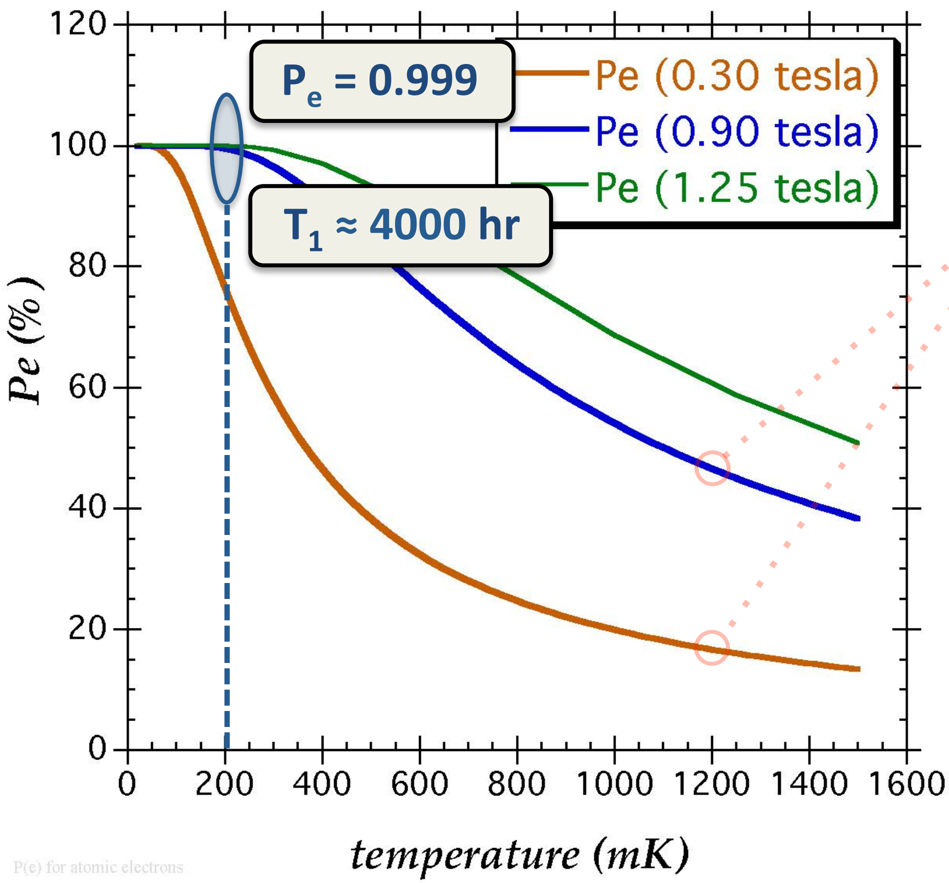
- **UITF** HD cell
- g14 IBC with 0.9 T holding field
- add heat to refrigerator to bring Cu heat sink up to 10 GeV conditions

P_e	I_e	Q_{HD}	T_{HD}^{max}
0.99757	2 nA	1+1.6 mW	186 mK
0.99991	1 nA	½+0.8 mW	125 mK

↑ ~ same P_e as 10 GeV and 1.25 T



For Reference: Flipping, unpaired electron during 2012 eHD test



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

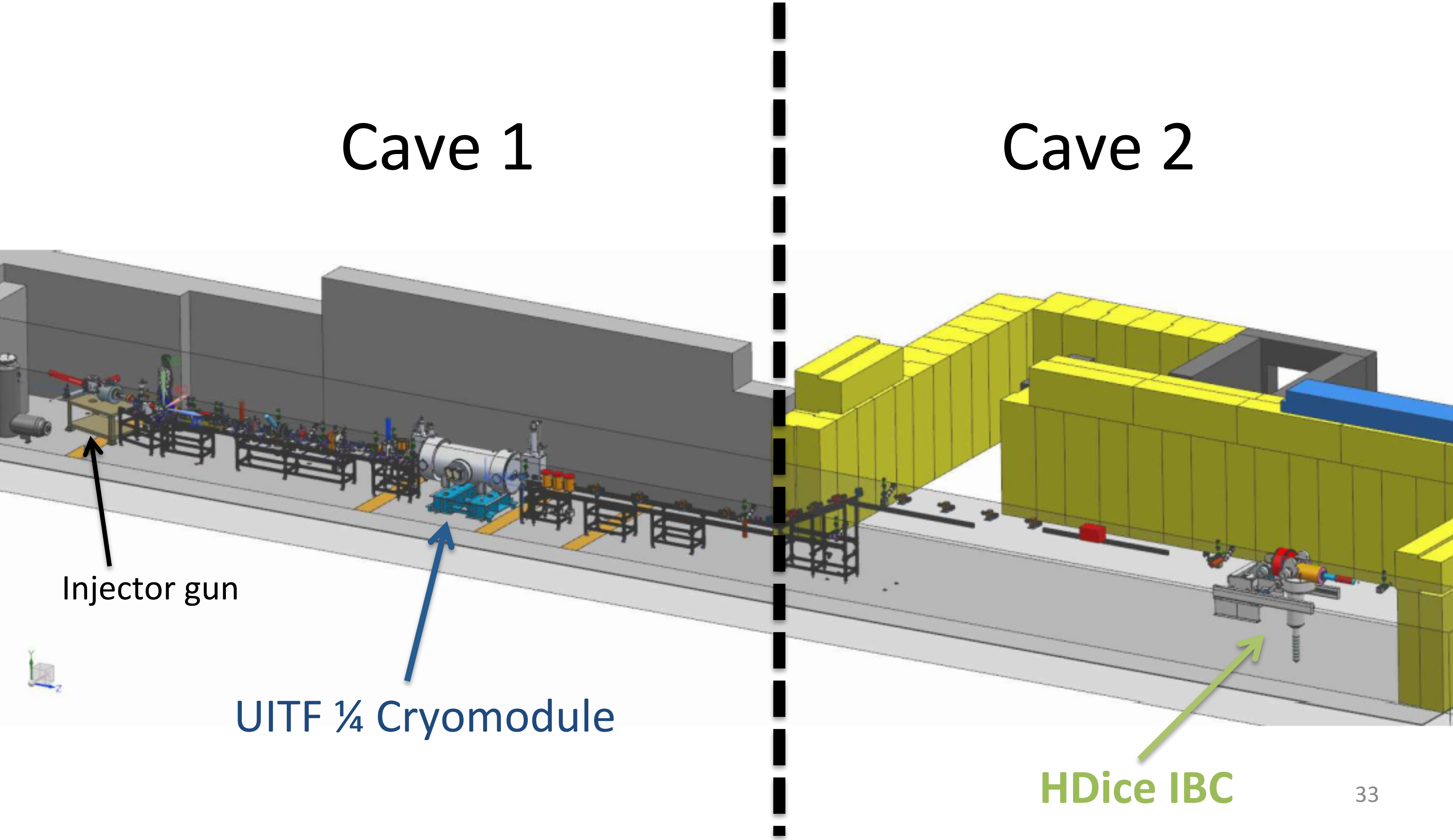
➔ $P_e \approx$ 20-50%

at $P_e = 0.2$

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

and $T_1 \sim 4$ hr

Preparing for eHD

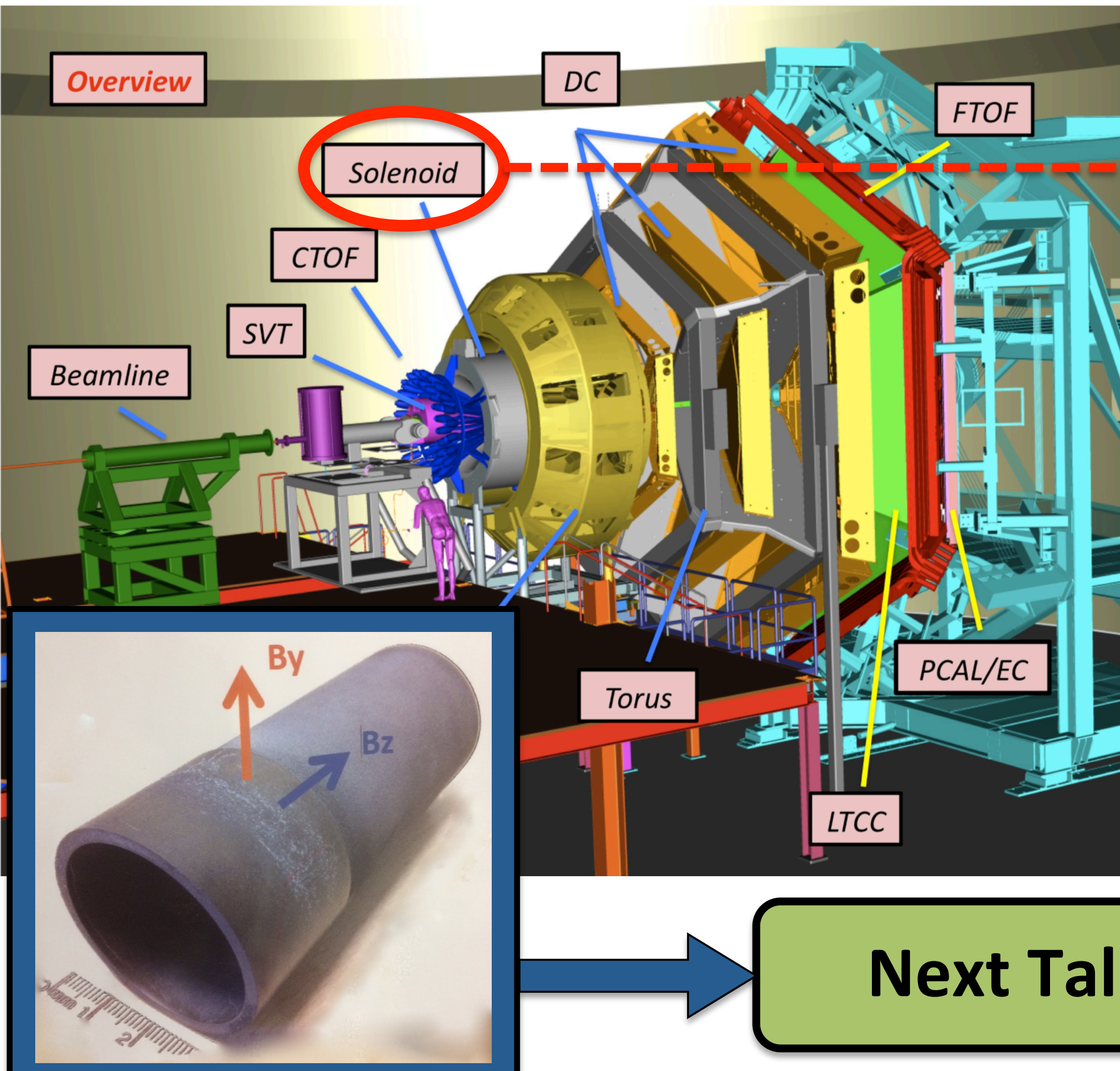


Beam on HDice expected next year!

Summary

- HDice has been successfully used with photon beams; now expanding into its use with electron beams (eHD).
  - Three "high impact" proposals to use HDice with electrons in CLAS-12.
- Charged particle beams present a new challenge for HDice.
- UITF eHD tests will allow for a study of the effects of an electron beam on the target as well as how to mitigate them.
- eHD running at UITF can be directly related to running HDice in CLAS-12.

Maintaining a Transverse Holding Field Within the CLAS-12 Solenoid



Next Talk!

HDice

Jefferson Lab

END

eHD Luminosity

$\mathcal{L}$ [cm^{-2} s^{-1}] = dN/dt [s^{-1} in a perfect detector] • 1/σ_T [cm^{-2}]

= (0.2 x 10^{33}) • T_{HD}(cm) • I_e(nA)

for 2.5 cm long cell and I_e = 2 nA ➔ 10^{33}

Room for future improvements in Al thermal conductivity

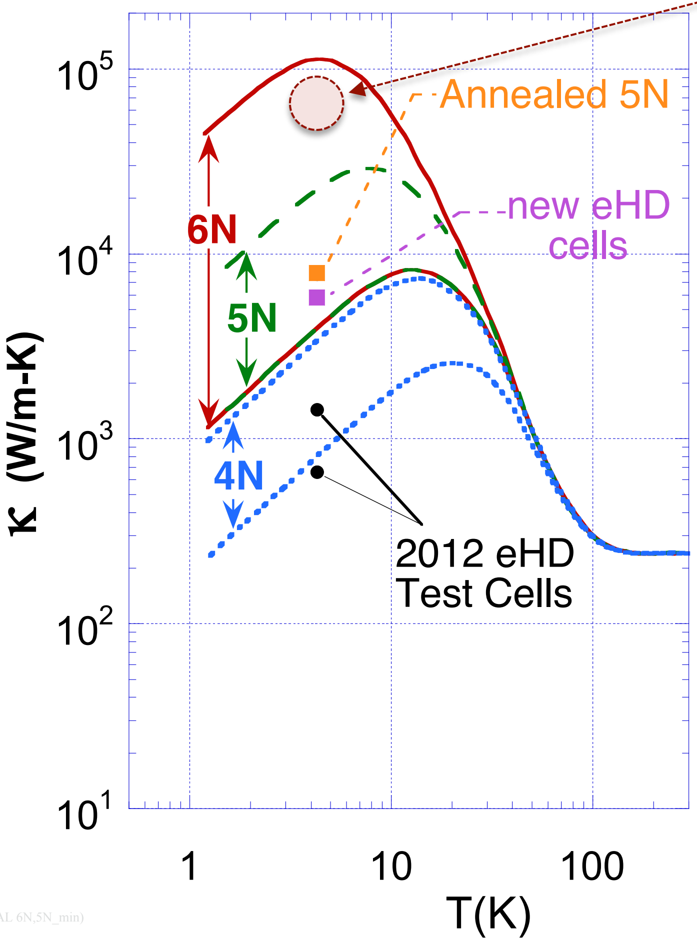
HDice data: (• ■ ■)

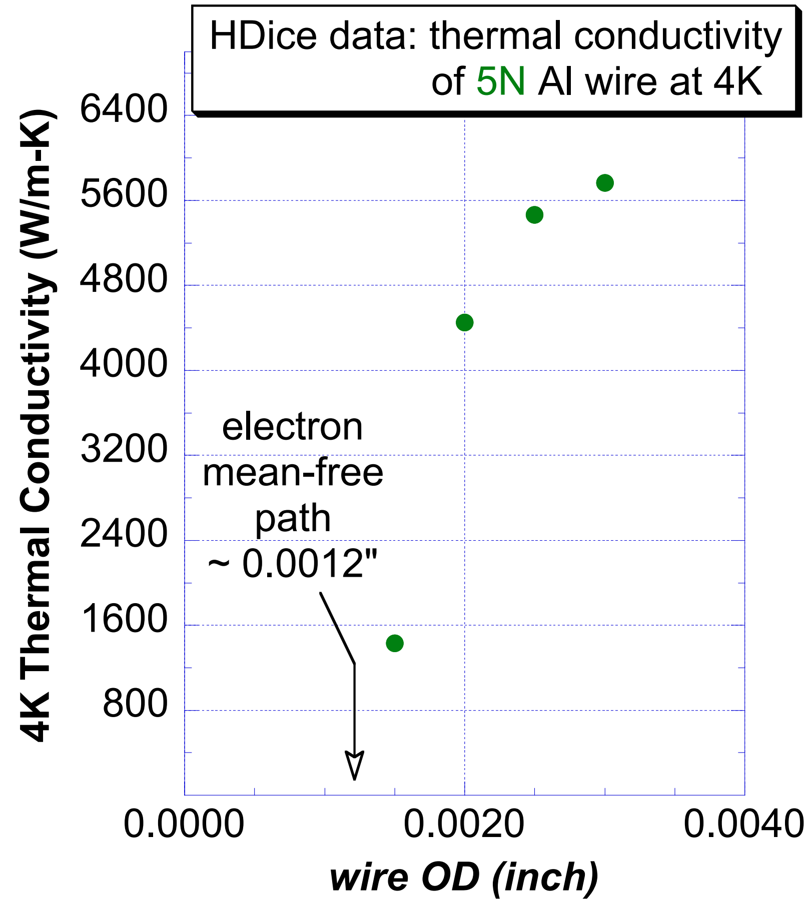
curves: —— 6N, —— 5N, —— 4N

Thermal Conductivities for pure Aluminum

A.L. Woodcraft, Cryogenics **45** (2005) 626

high 6N (99.9999%) Al wire could triple the target length





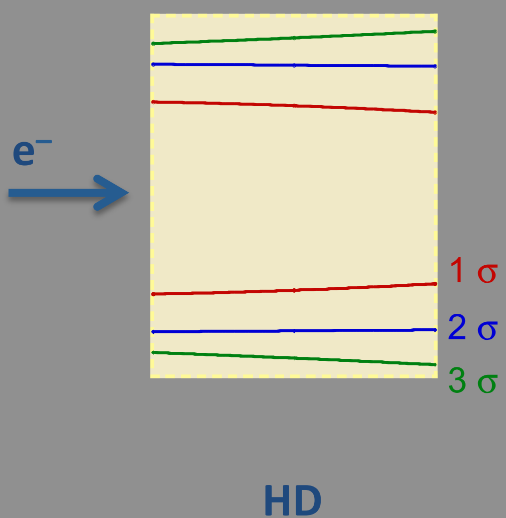
UITF vs Hall B

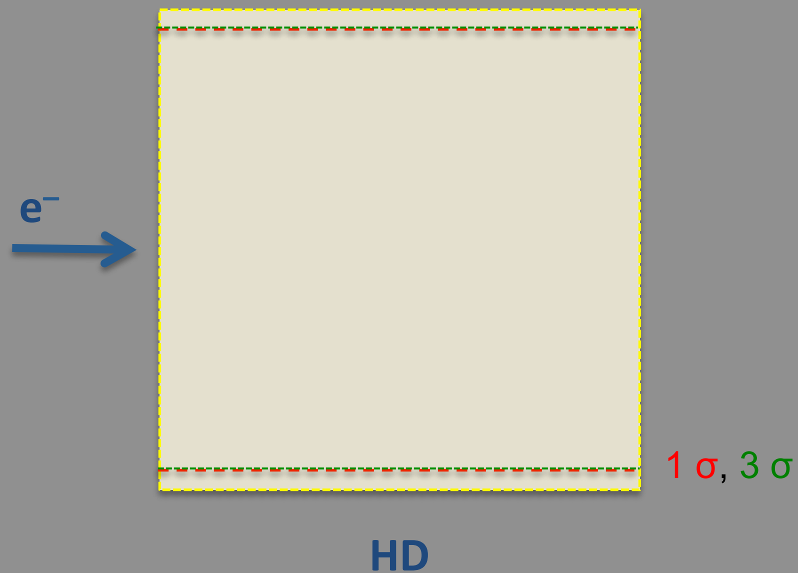
UITF

E_e = 7.86 MeV
Beam diameter = 17 mm, with tails
(*maximum size*)
HD diameter = 19 mm
(*1 mm clearance at 3 σ*)
HD length = 12.5 mm
(*max for quasi-uniform pwr*)

Hall B

E_e = 10 GeV
Beam diameter = 23 mm, no tails
HD diameter = 25 mm
HD length = 25 mm





UITF vs Hall B

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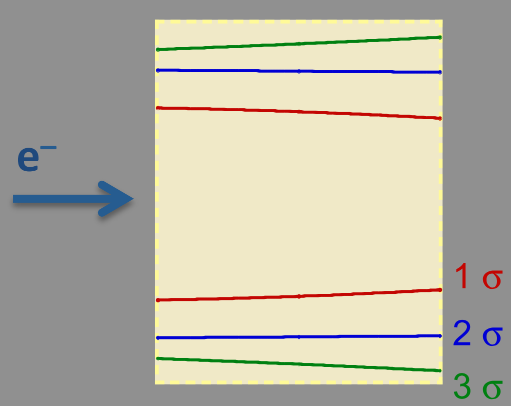


Power density at 1 nA

0.53 mW/cc (1 σ)

0.16 mW/cc (3 σ)

greater challenge! ⇔

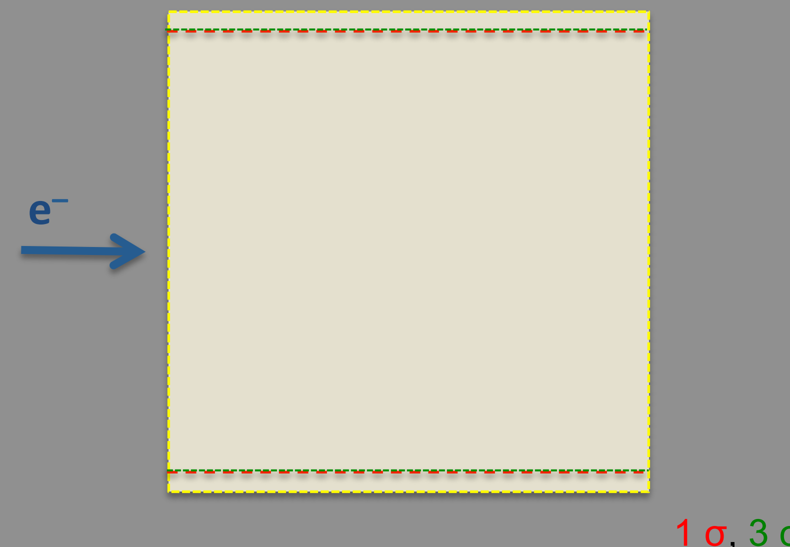
Hall B

E_e = 10 GeV

Beam diameter = 23 mm, no tails

HD diameter = 25 mm

HD length = 25 mm



Power density at 1 nA

0.13 mW/cc (1 σ, 3 σ)