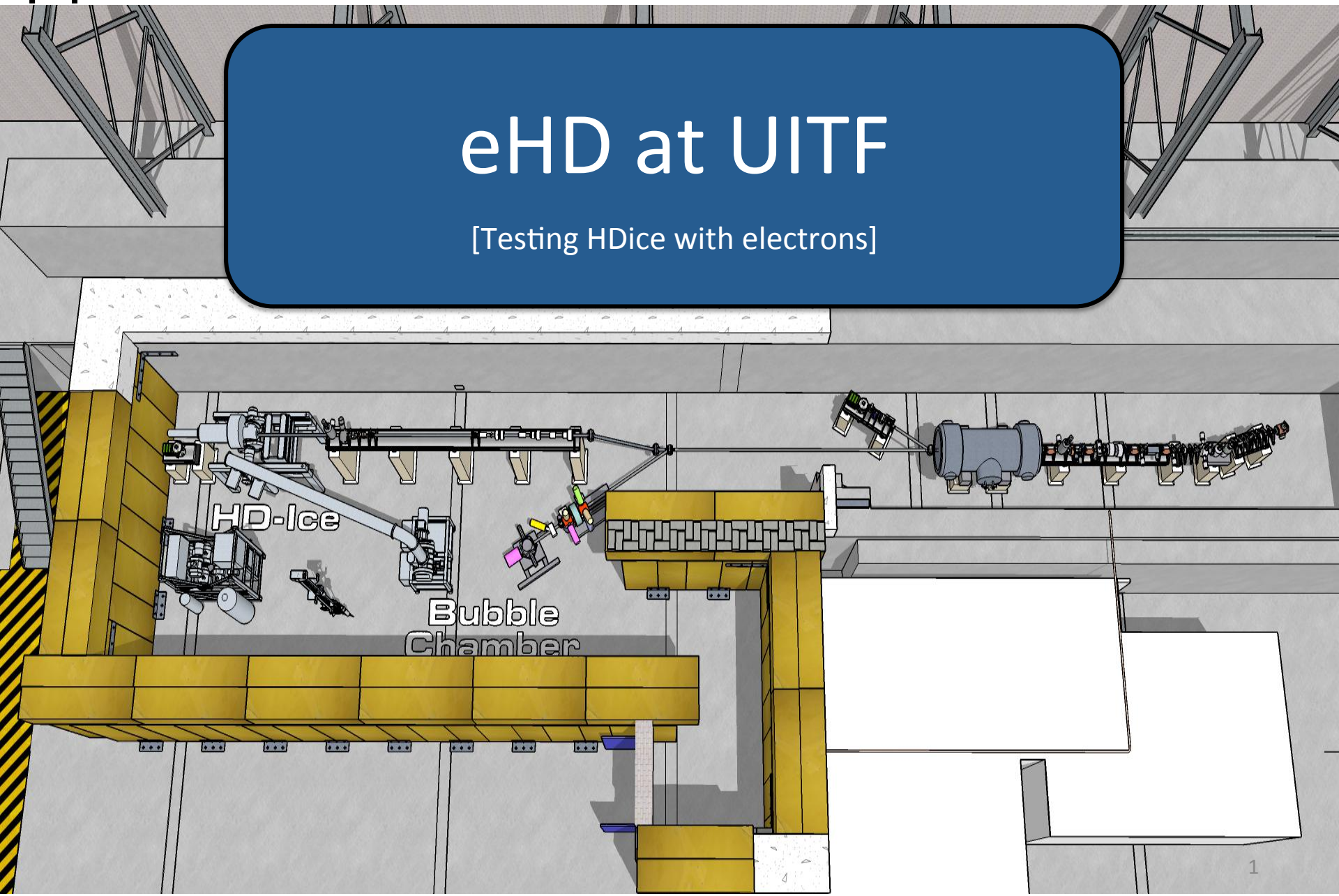
eHD at UITF

[Testing HDice with electrons]



Outline

- Lessons from 2012 eHD tests
- Challenges of using MeV electrons with IBC
- Plan for running with MeV electrons
- Translation to GeV running
- Status and schedule

2012 eHD Test in Hall B

- Results attributed to three possible depolarization mechanisms:

1) Beam-induced chemical changes
   - HD molecule is ionized and becomes highly reactive
   - A chain of reactions begin:
     - ➔ Temperature spikes occur from "recombination flashes"
       - Also seen in g14 photon runs (from $e^+ e^-$ pairs) with low frequently but with no apparent effect.
     - ➔ 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 (analysis may not have had required resolution)

2012 eHD Test in Hall B

- Results attributed to three possible depolarization mechanisms:

2) Hyperfine mixing of unpaired electrons with 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

- Results attributed to three possible depolarization mechanisms:

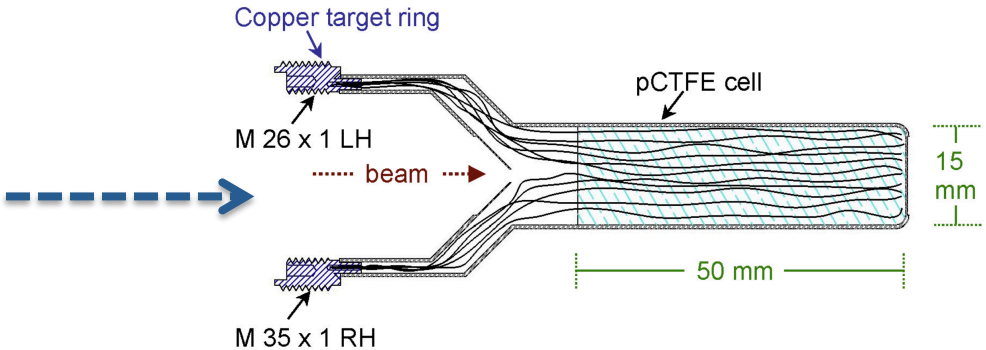
3) Beam unpairs 1s electron in target material
   - Electron may be unpolarized (depends on temperature)
   - If unpolarized (or has low polarization), flips with frequency that has harmonics at nuclear Larmor frequencies of H and D
   - Depolarization of local HD begins
   - Depolarization spreads to rest of HD crystal

Solution:

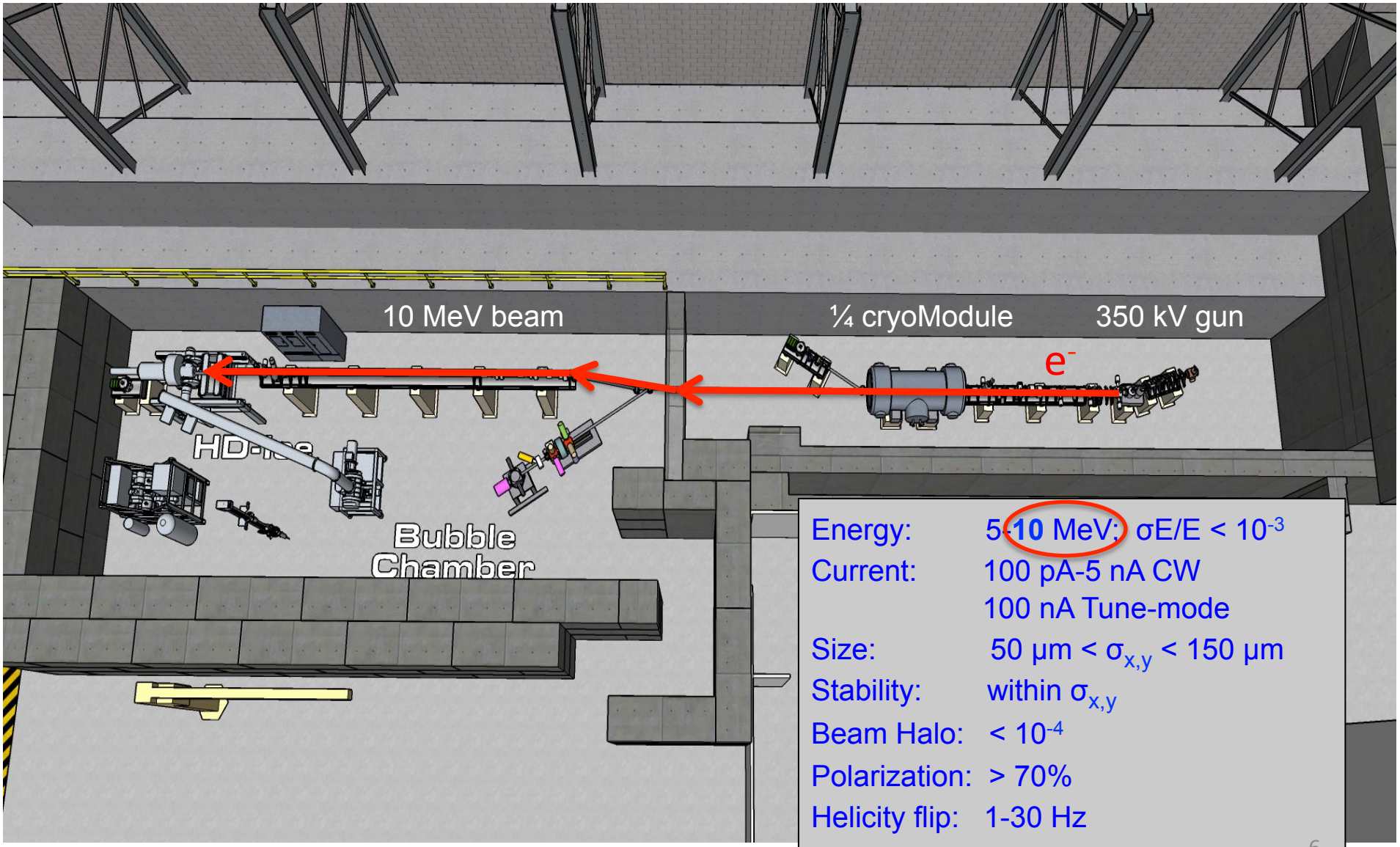
Suppress this effect through mitigation of beam heating.

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

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

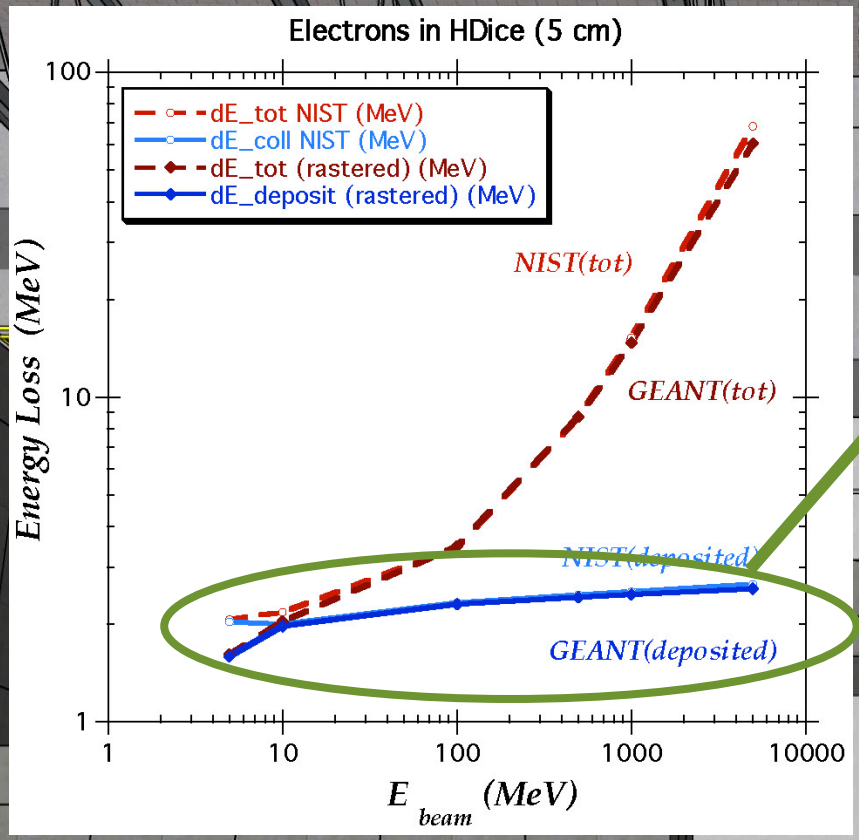


eHD Tests in UITF



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

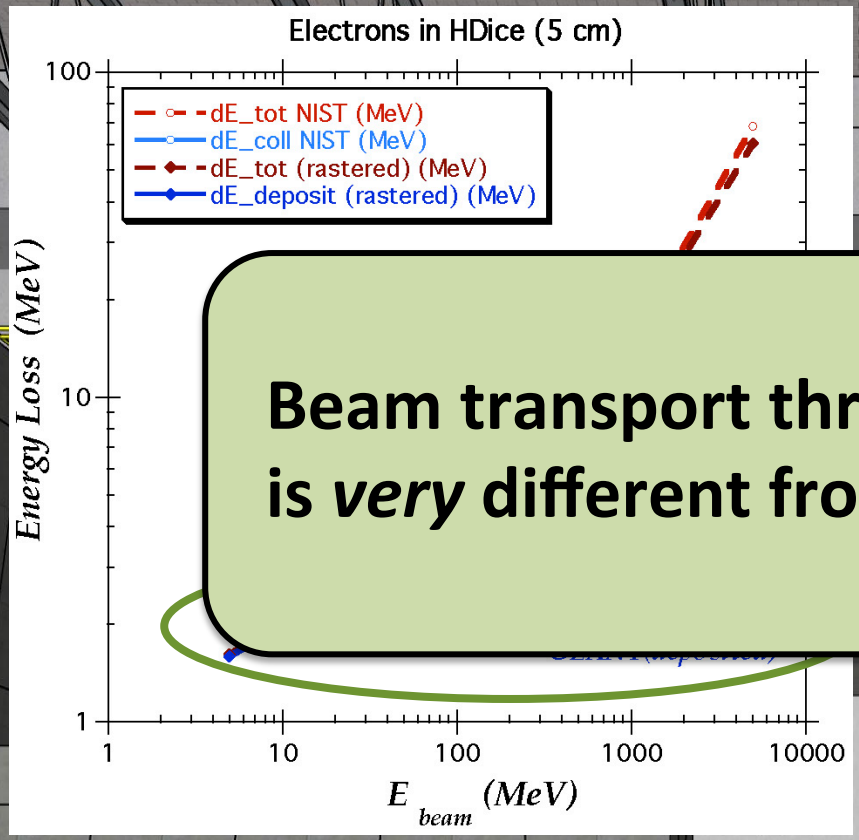


Ionization and energy deposition are approx independent of E_{beam}

UITF at 10 MeV ≃ Hall B at 10 GeV

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



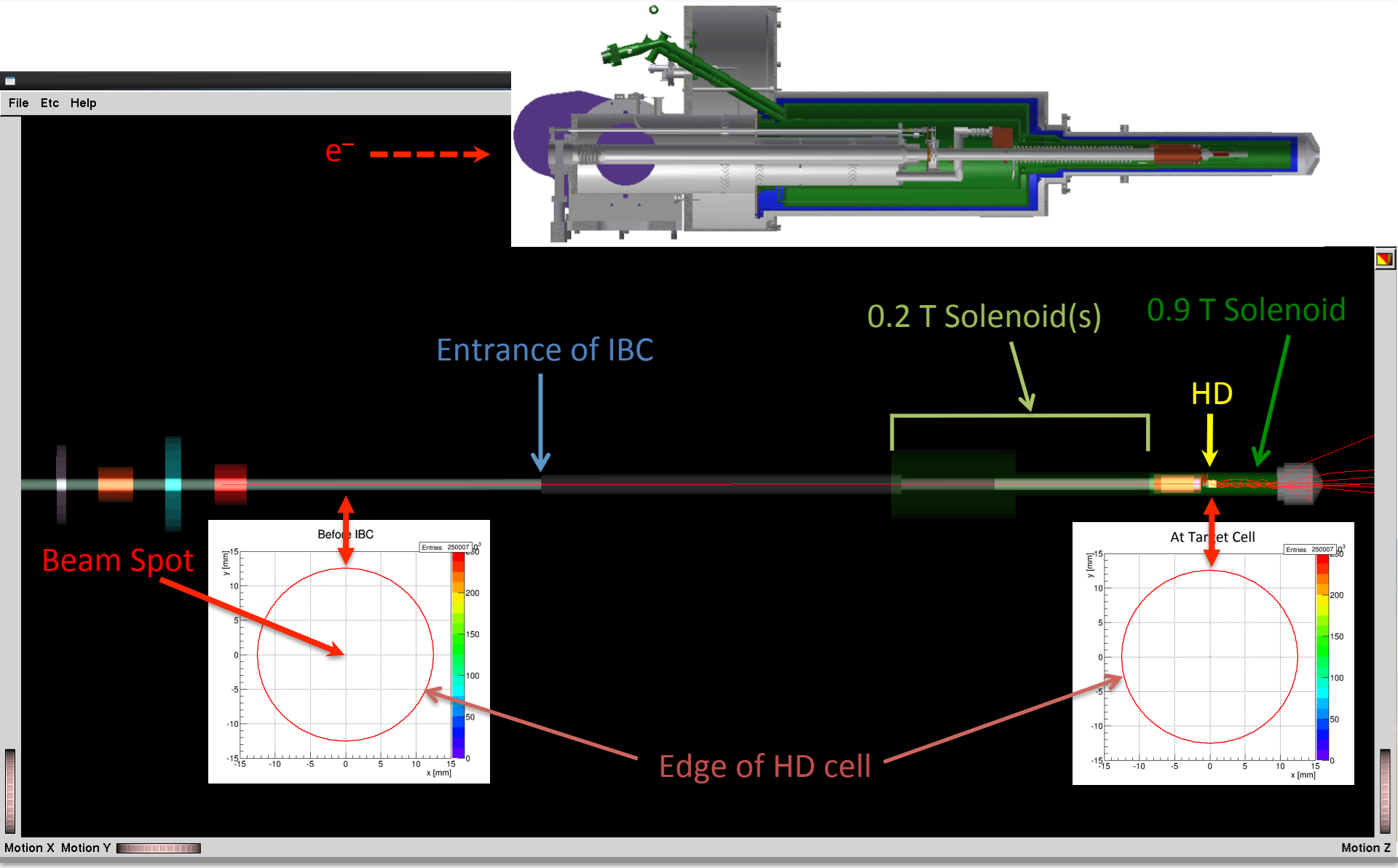
Ionization and energy deposition are approx independent of E_{beam}

at 10 GeV

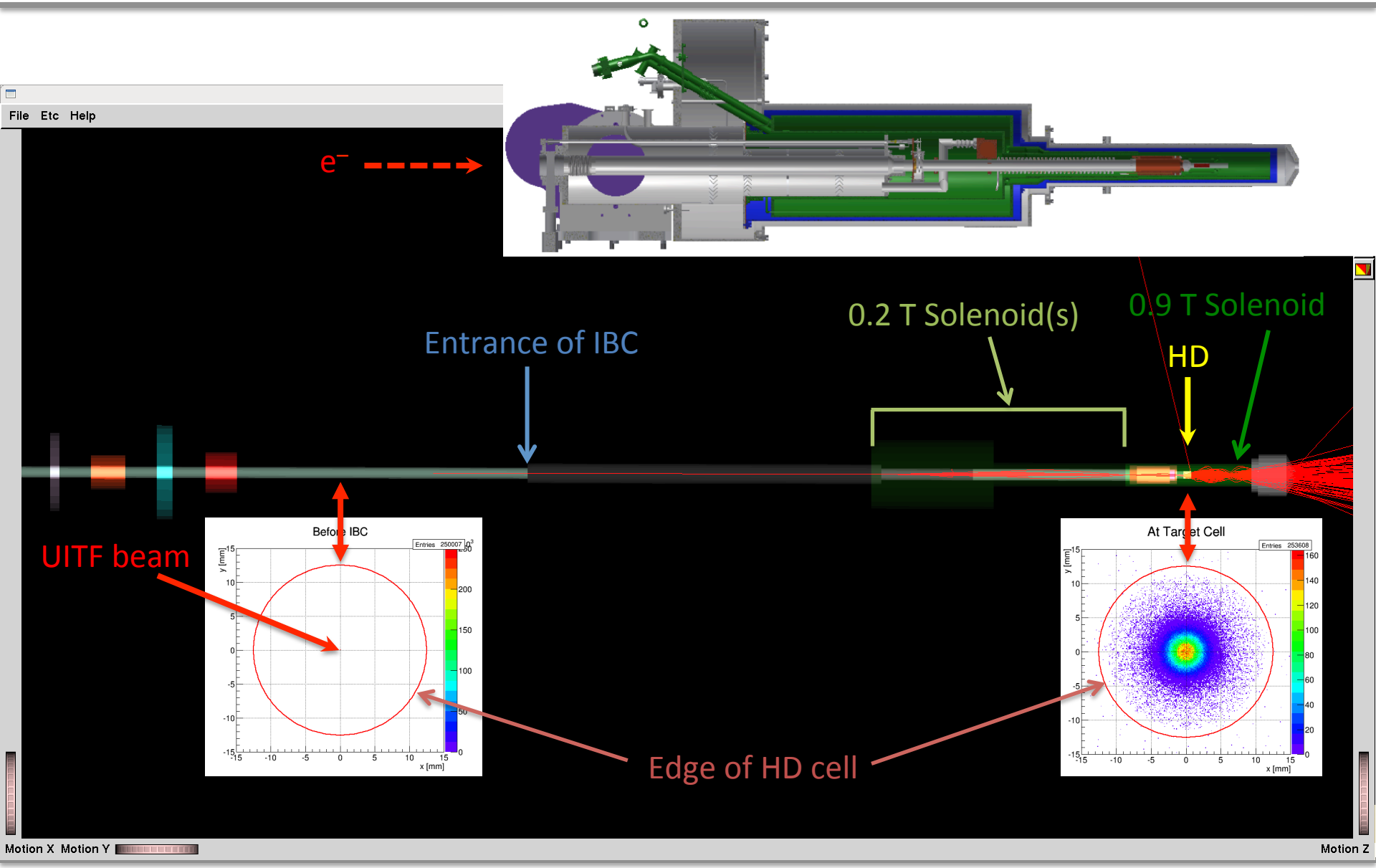
Beam transport through IBC at 10 MeV is *very* different from 10 GeV!!!

Energy:	5-**10** MeV; $\sigma E/E < 10^{-3}$
Current:	100 pA-5 nA CW
	100 nA Tune-mode
Size:	50 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

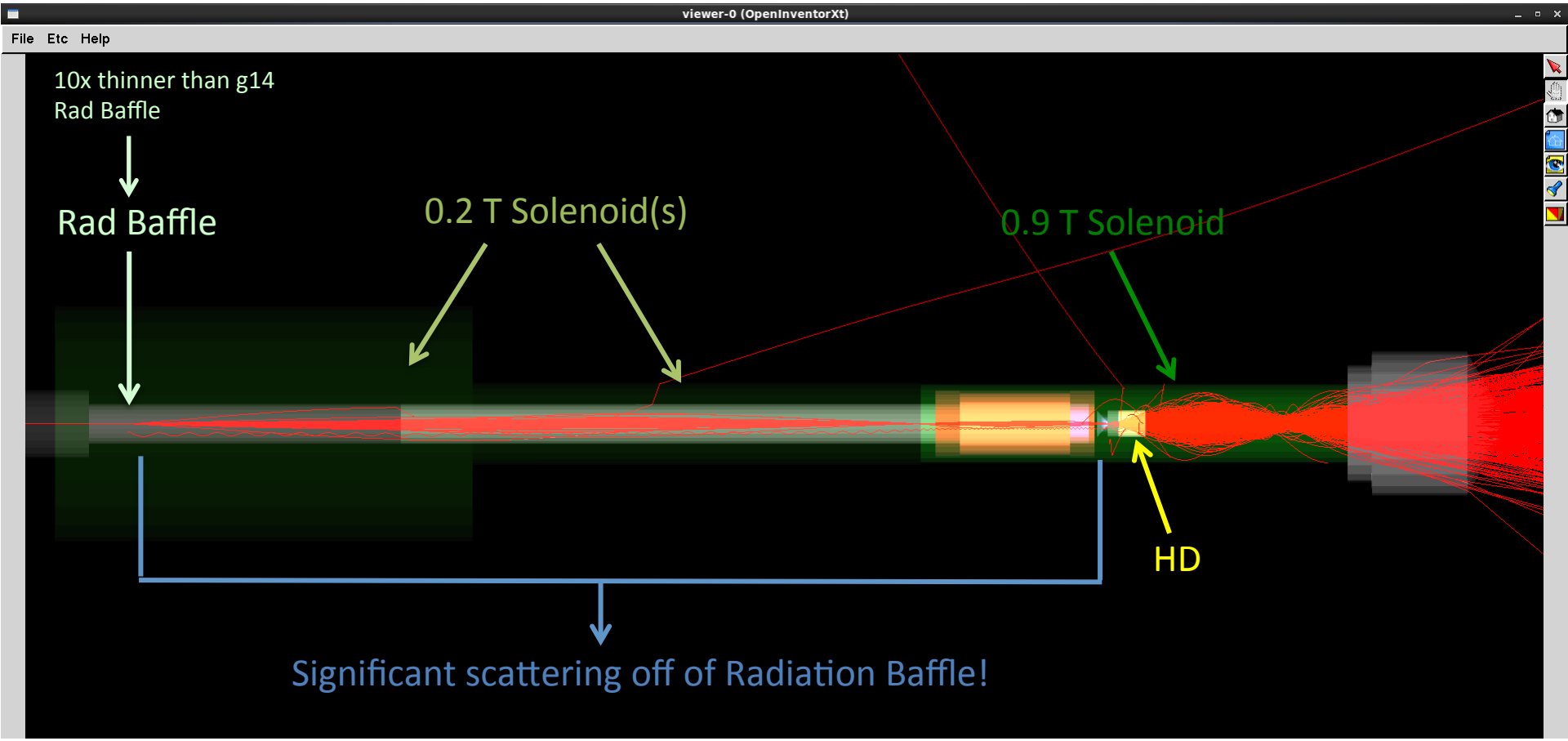


Pencil beam into IBC with normal orientation at <10 MeV



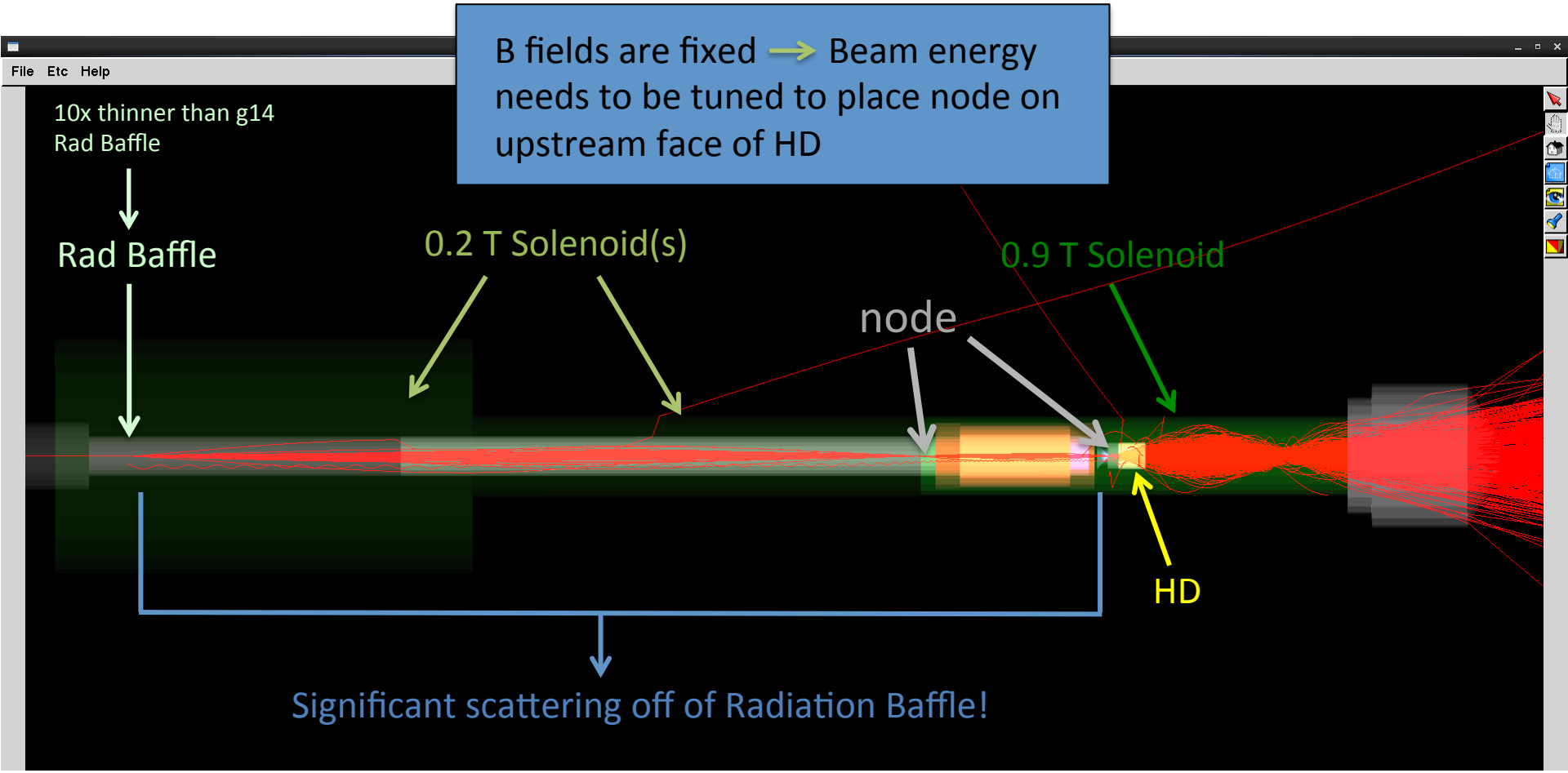
Pencil beam into IBC with normal orientation at <10 MeV

…… a closer view

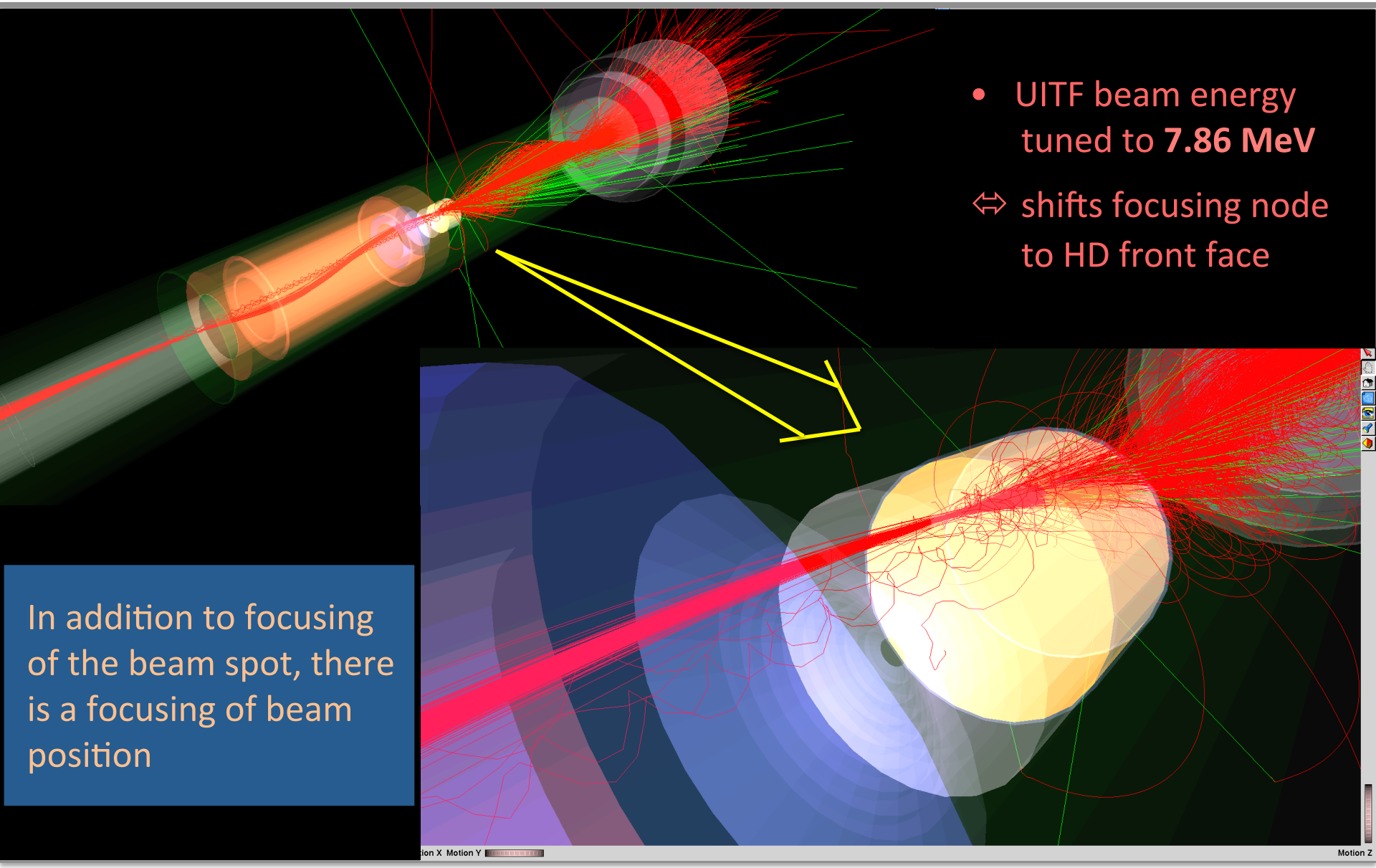


Pencil beam into IBC with normal orientation at <10 MeV

…… a closer view



(UITF) Pencil beam into IBC with 14 mm offset



- UITF beam energy tuned to **7.86 MeV**

⇔ shifts focusing node to HD front face

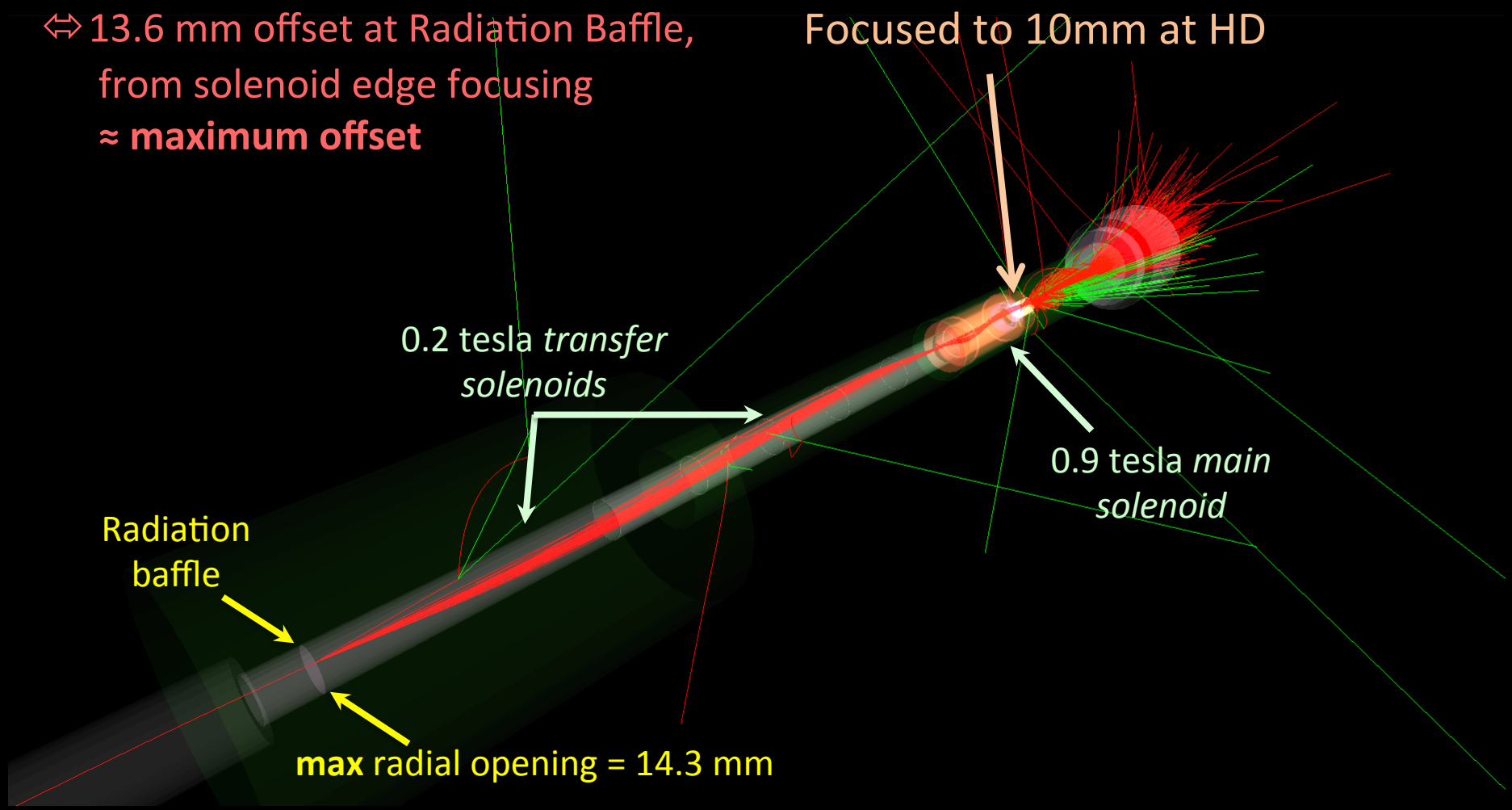
In addition to focusing of the beam spot, there is a focusing of beam position

(UITF) Pencil beam into IBC with 14 mm offset

Pencil beam offset 14 mm at launch

⇔ 13.6 mm offset at Radiation Baffle, from solenoid edge focusing

≈ maximum offset

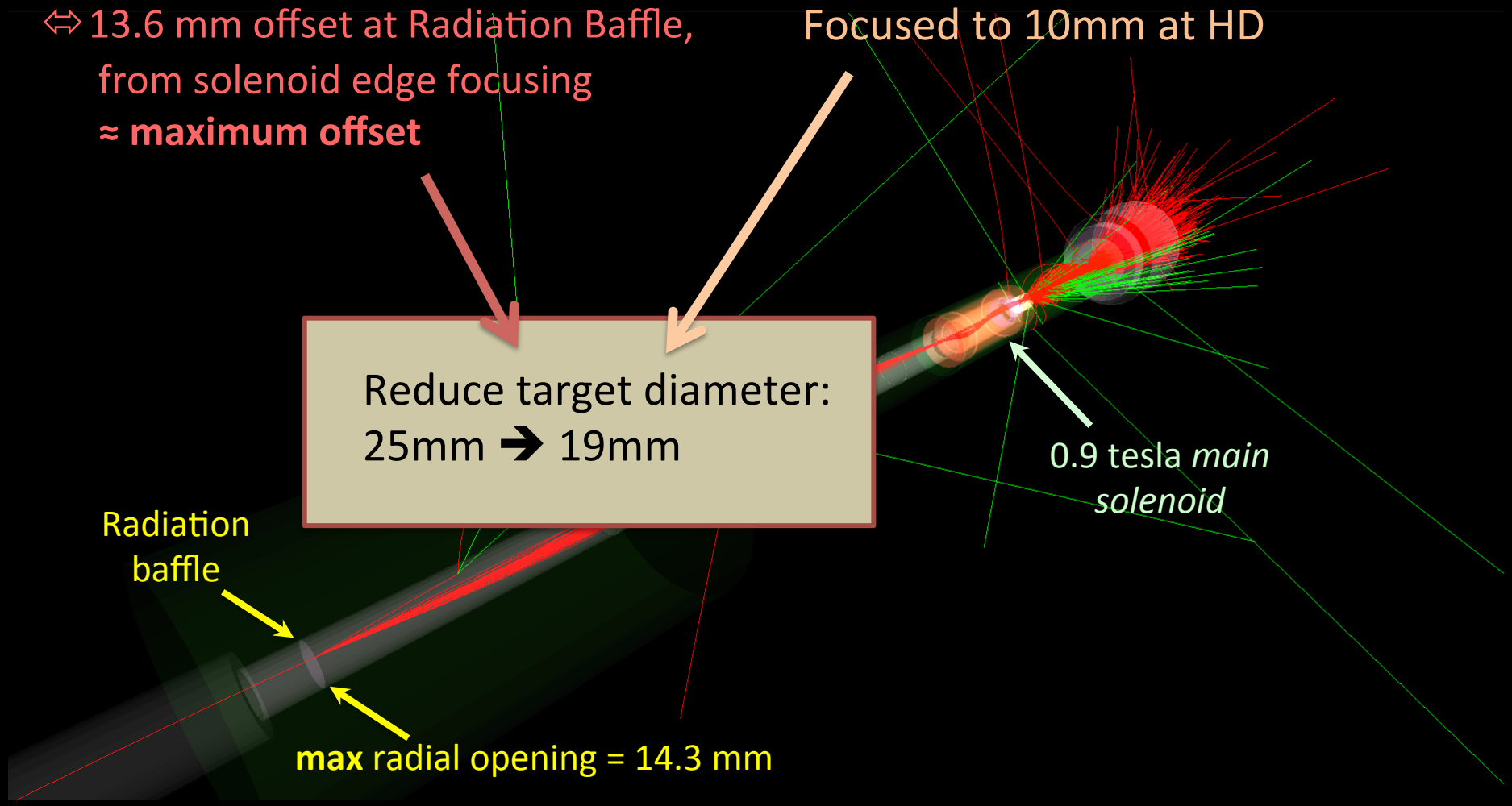


(UITF) Pencil beam into IBC with 14 mm offset

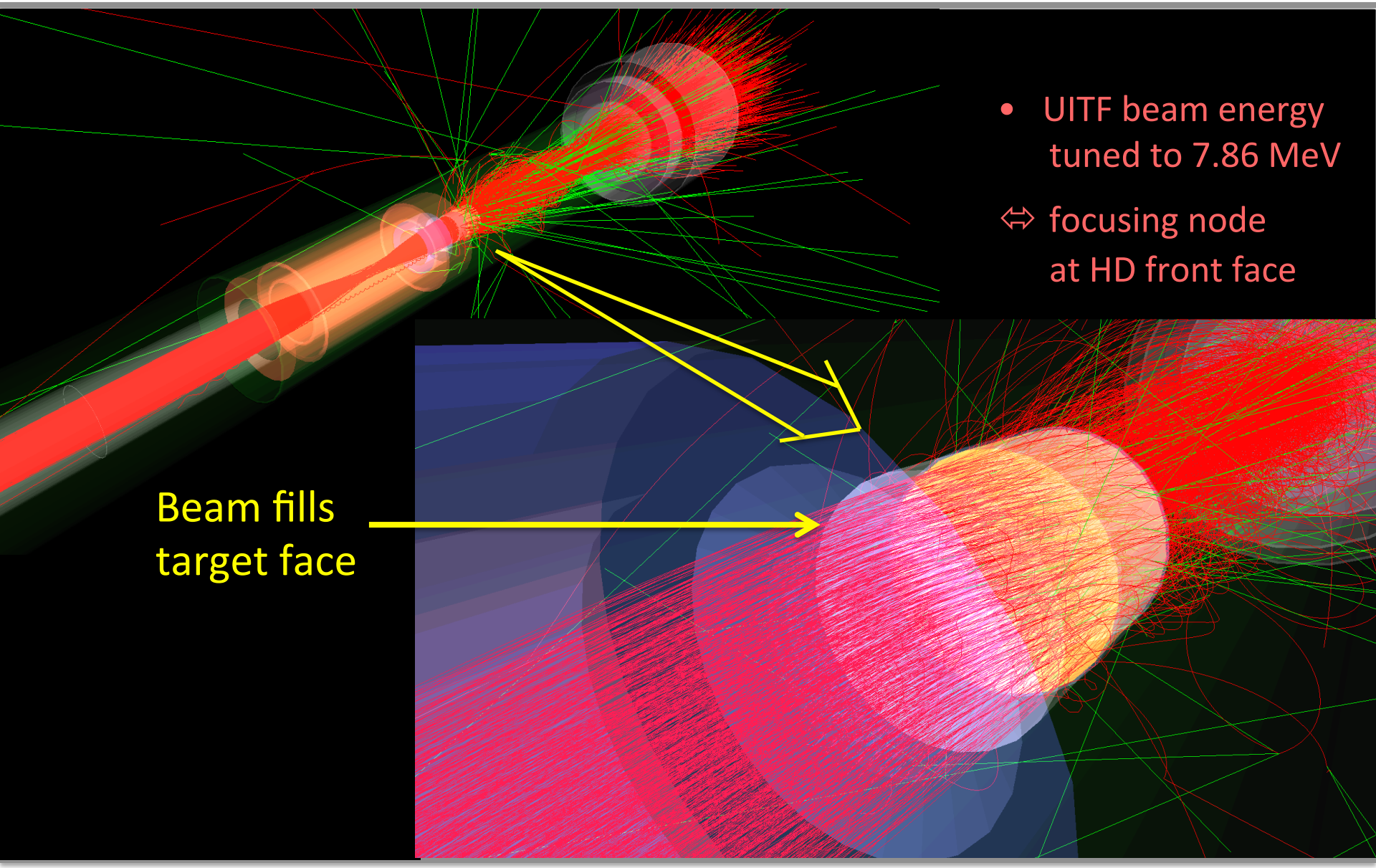
Pencil beam offset 14 mm at launch

⇔ 13.6 mm offset at Radiation Baffle, from solenoid edge focusing ≈ **maximum offset**

Focused to 10mm at HD



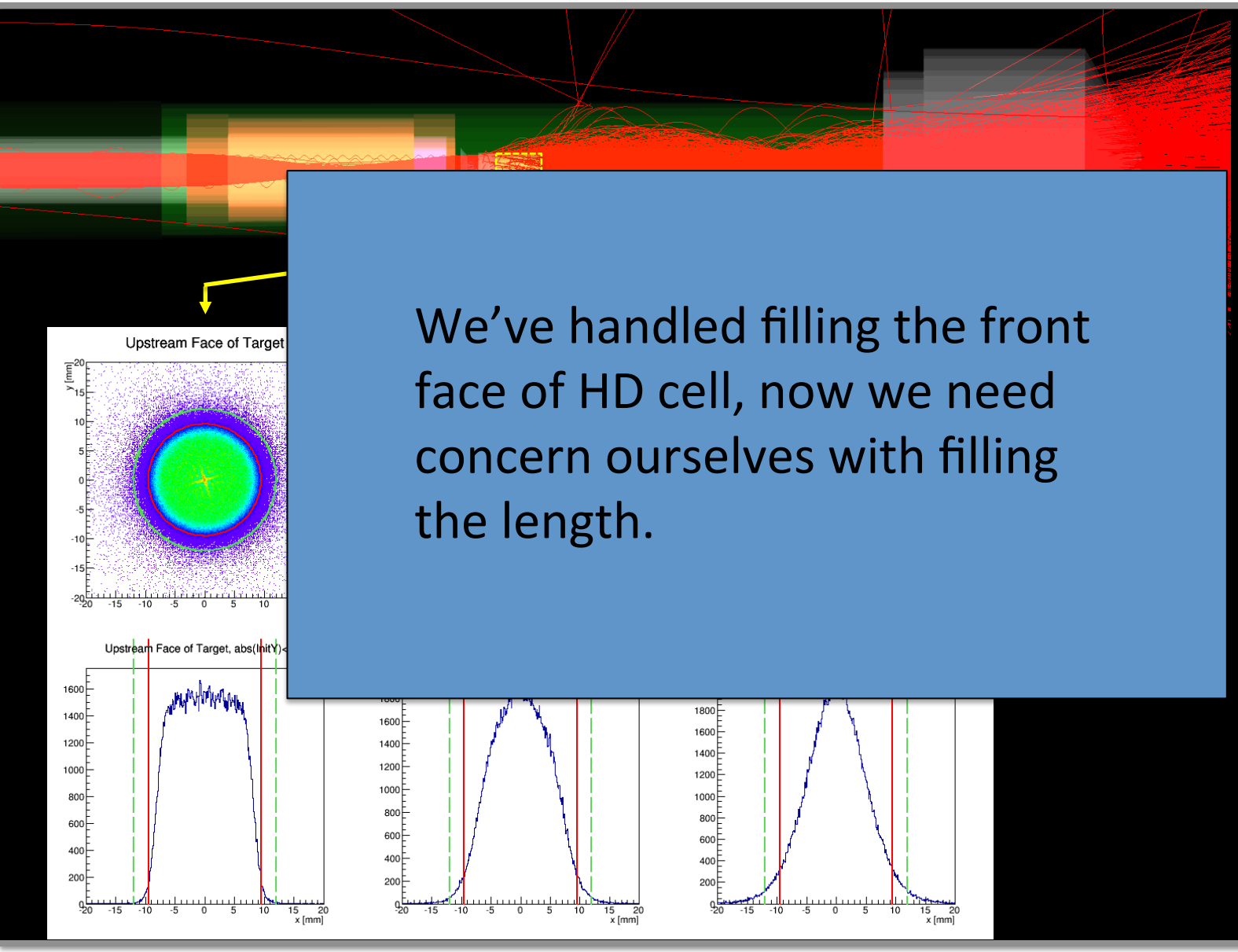
(UITF) Uniform rastered beam into IBC



- UITF beam energy tuned to 7.86 MeV

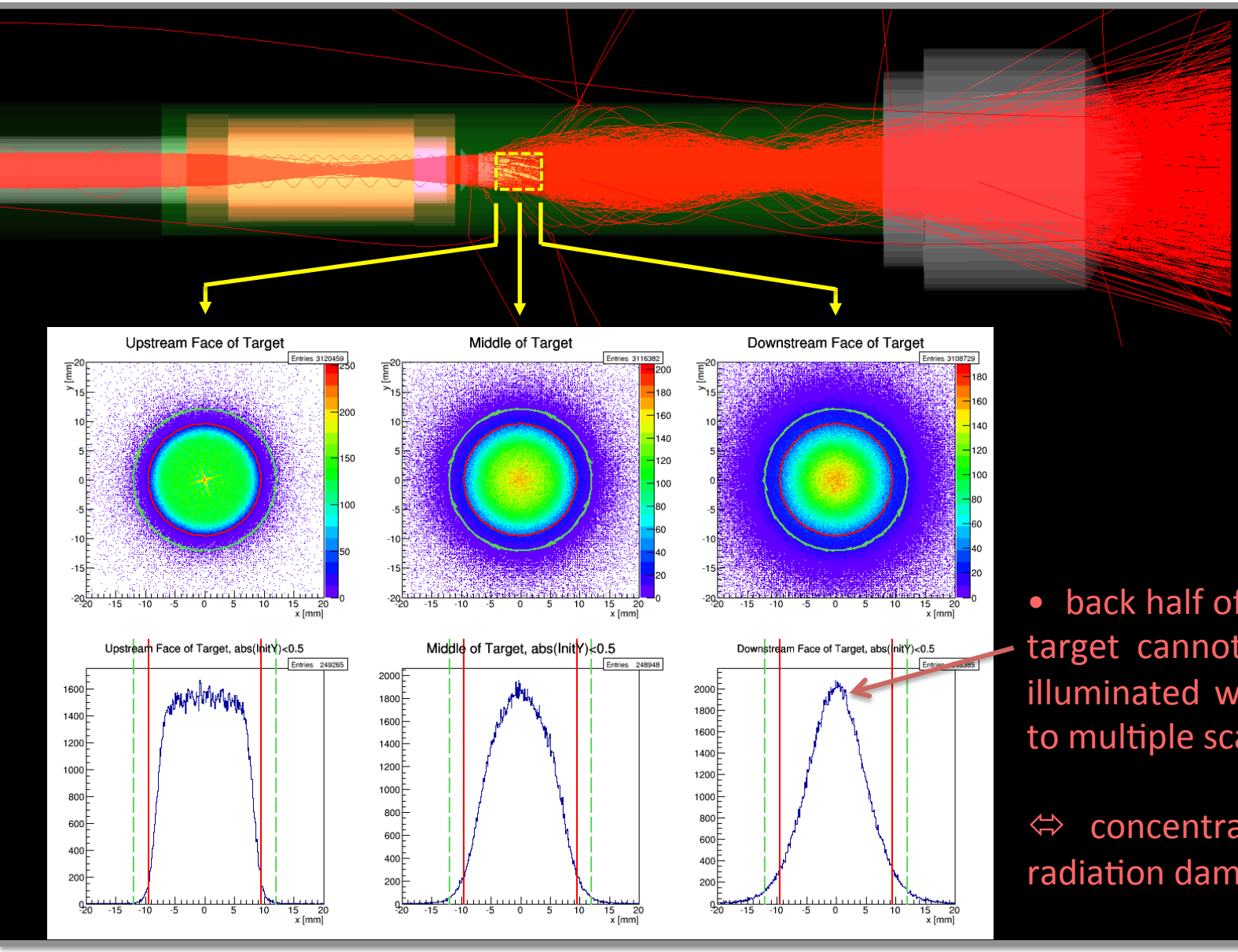
⇔ focusing node at HD front face

Rastered beam profiles on 25 mm long target



We've handled filling the front face of HD cell, now we need concern ourselves with filling the length.

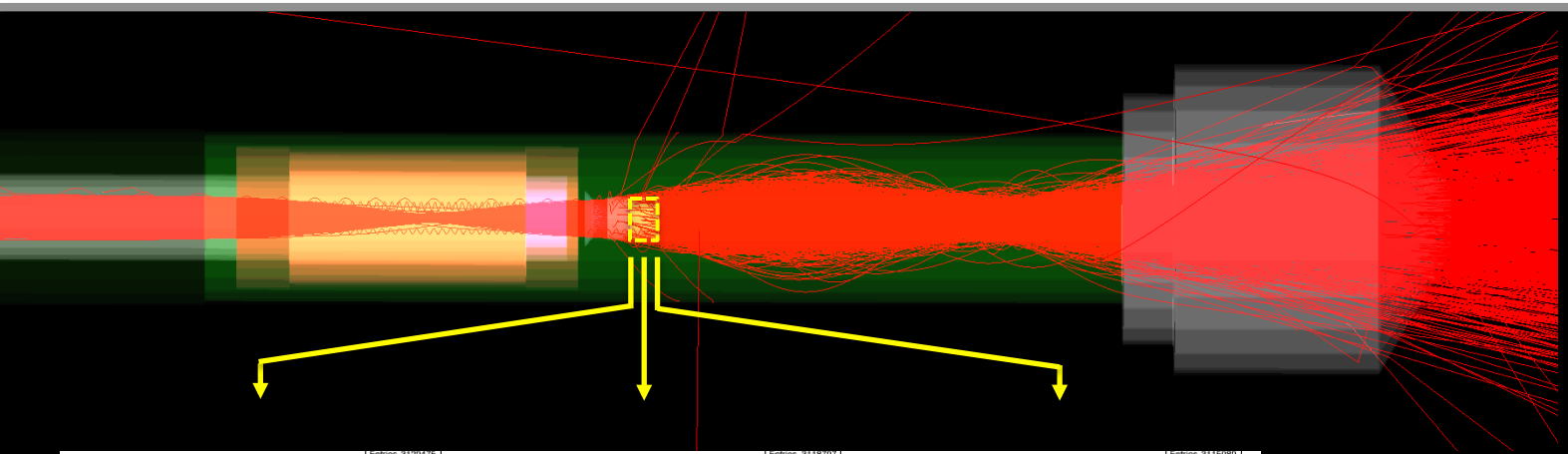
Rastered beam profiles on 25 mm long target

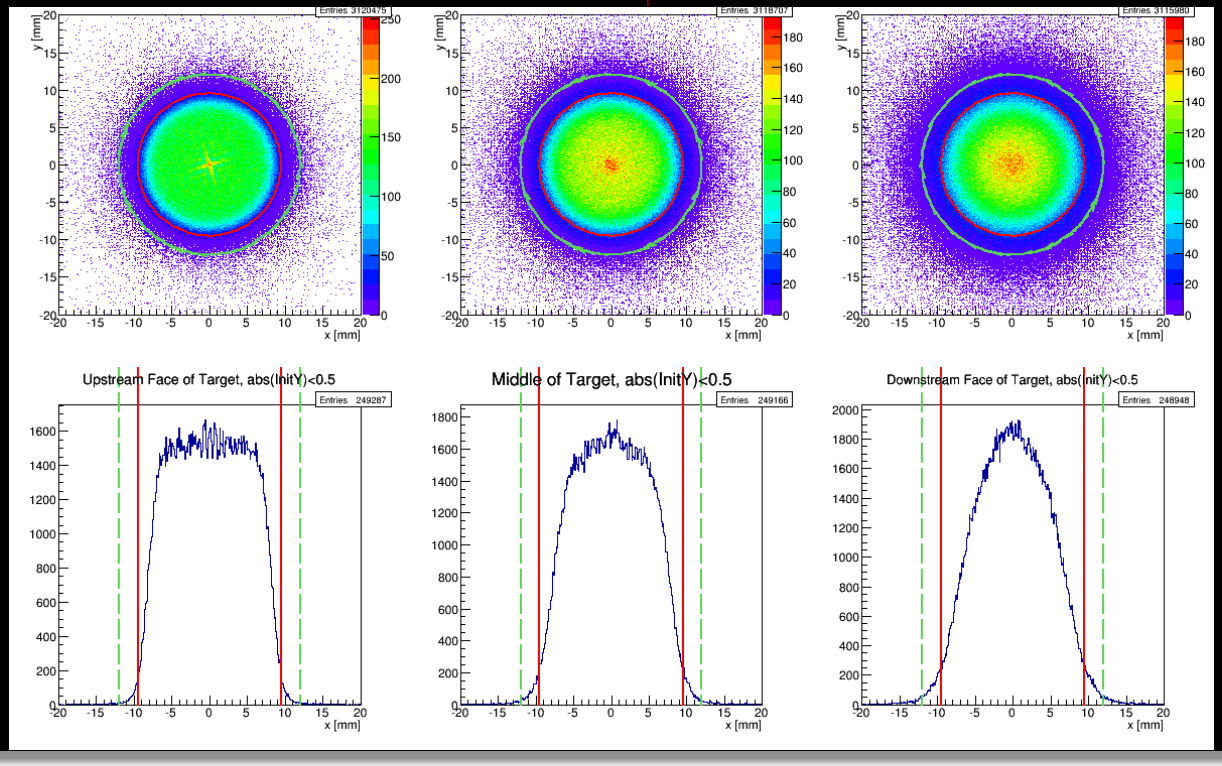


- back half of a 25 mm long target cannot be uniformly illuminated with beam, due to multiple scattering

⇔ concentrates heat and radiation damage

Rastered beam profiles on 12.5 mm long target





- compromise on ½ target length to distribute beam quasi-uniformly

⇔ *most of the 12.5 mm target length* can be filled with beam

Based on results from simulation of UITF beam:

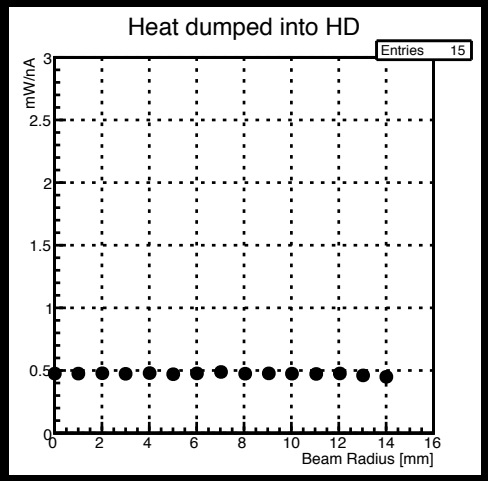
- Scattering off of Rad Baffle and focusing from fringe fields give rise to nodes
  ➔ tune beam energy to 7.86 MeV ➔ shifts node to front face of HD

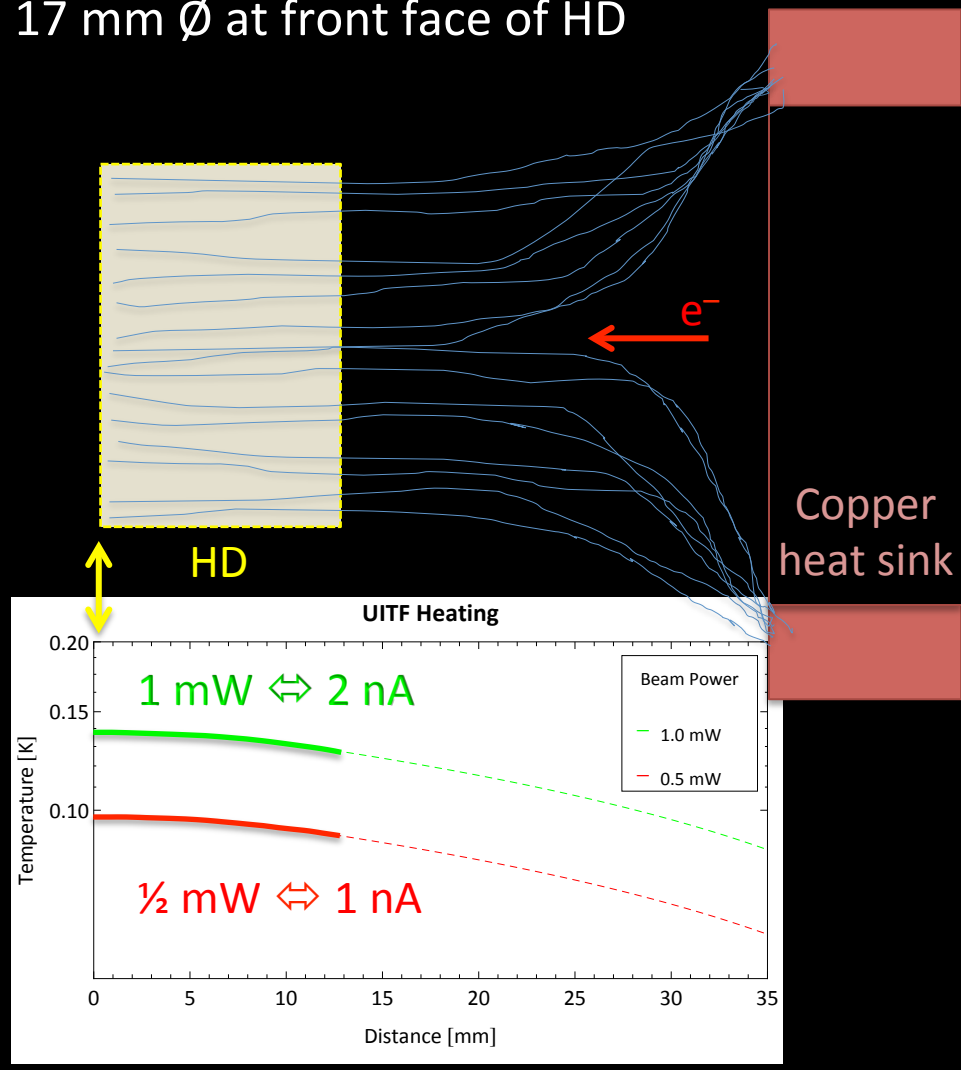
- Focusing from fringe fields also affects beam position
  ➔ 12.0 mm radius at launch focused to 8.5 mm radius on target front face
  ➔ to fill target face as much as possible, but allow for misalignments,
  max HD radius = 9.5 mm

- Multiple scattering creates an enhancement in the center of the target that grows with z
  ➔ for a quasi-uniform illumination of the target with electrons,
  max HD length = 12.5 mm

Heat load on HD from **UITF** beam

- E_e = 7.86 MeV, rastered uniformly over 24 mm Ø at IBC entrance
  ⇔ 17 mm Ø at front face of HD
- HD length = 12.5 mm
- heat dumped in HD = 0.5 mW/nA
- Heat conducted away
  by 960 x 3 mil Ø Al (5N) wires





Heat load ➔ polarization of molecular electrons

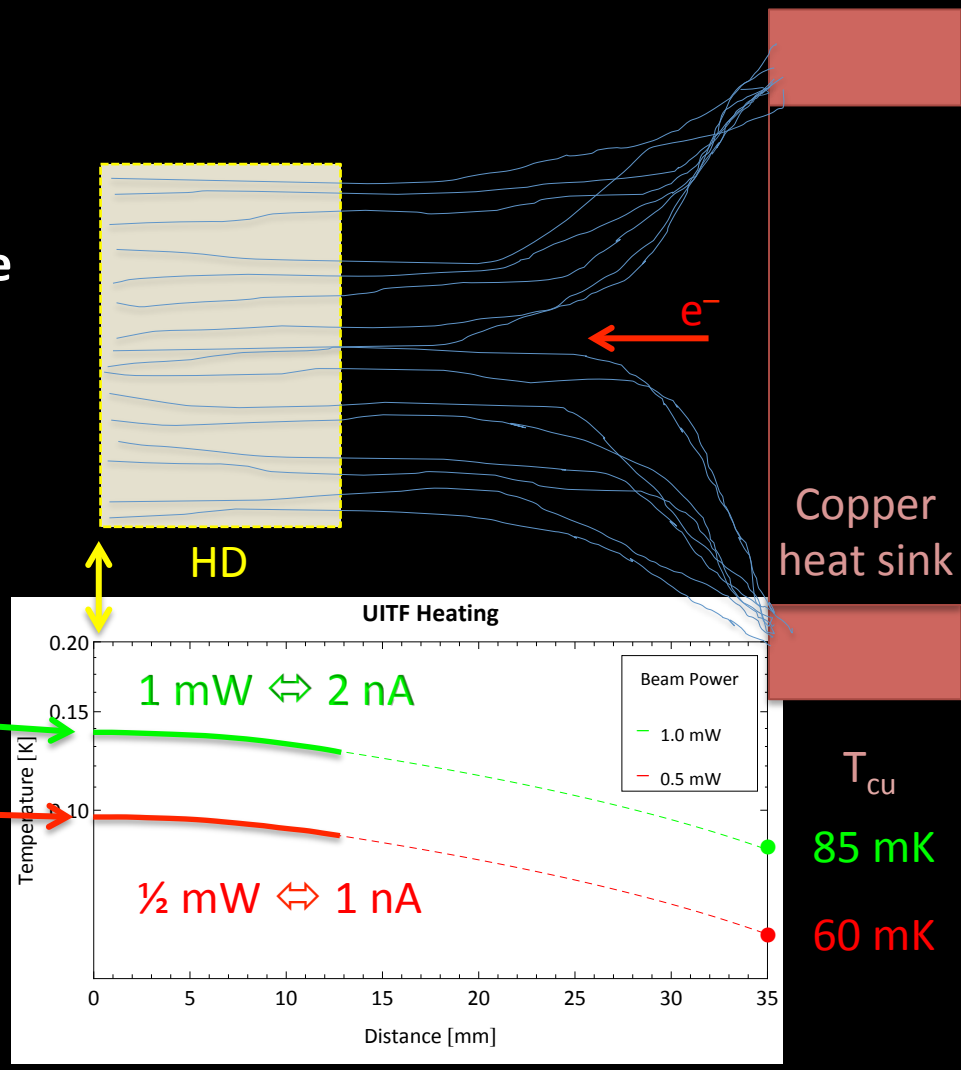
- Depolarization mechanism: beam ionizes HD, breaking paired *1s* electrons

- unpaired electrons will be inert if they polarize in the 0.9 T IBC field

⇔ **polarization depends on temperature**

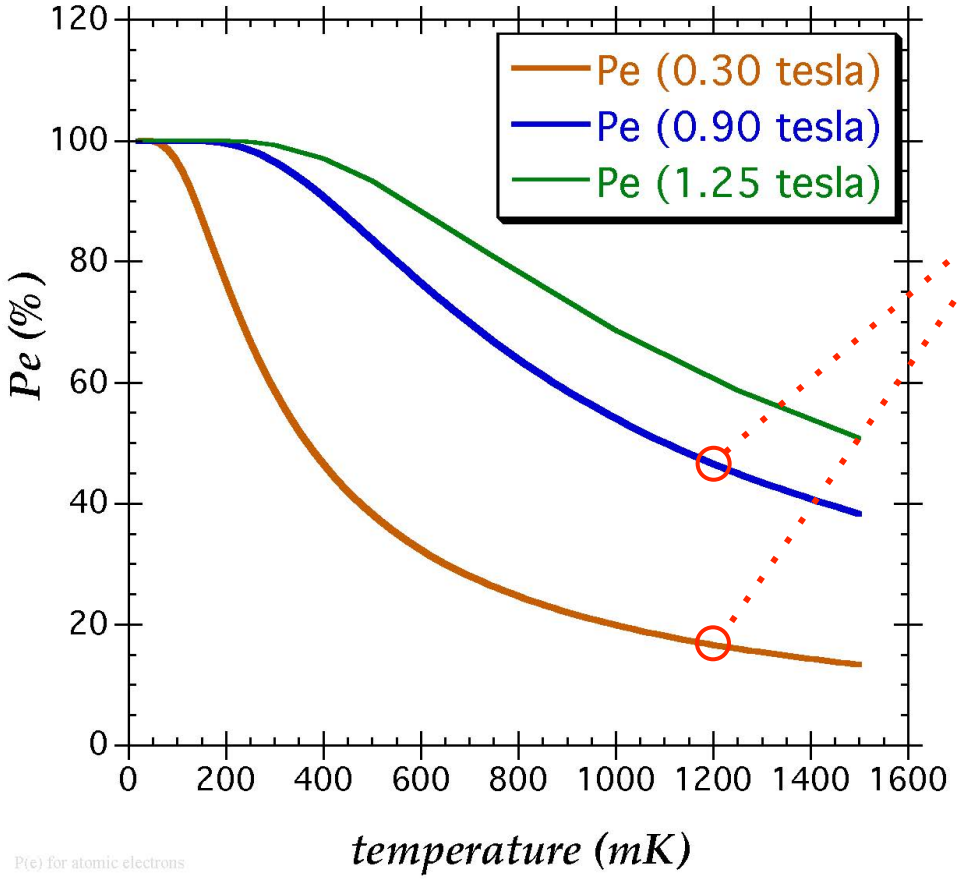
- HD temp depends on deposited beam power & temp of Cu heat sink (⇔ cooling pwr of IBC refrigerator)

P_e	I_e	Q_{HD}	T_{HD}^{max}
0.99977	2 nA	1 mW	138 mK
0.99999	1 nA	½ mW	98 mK



⬆ very promising !

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 ~ 20-50%

at $P_e = 0.2$

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

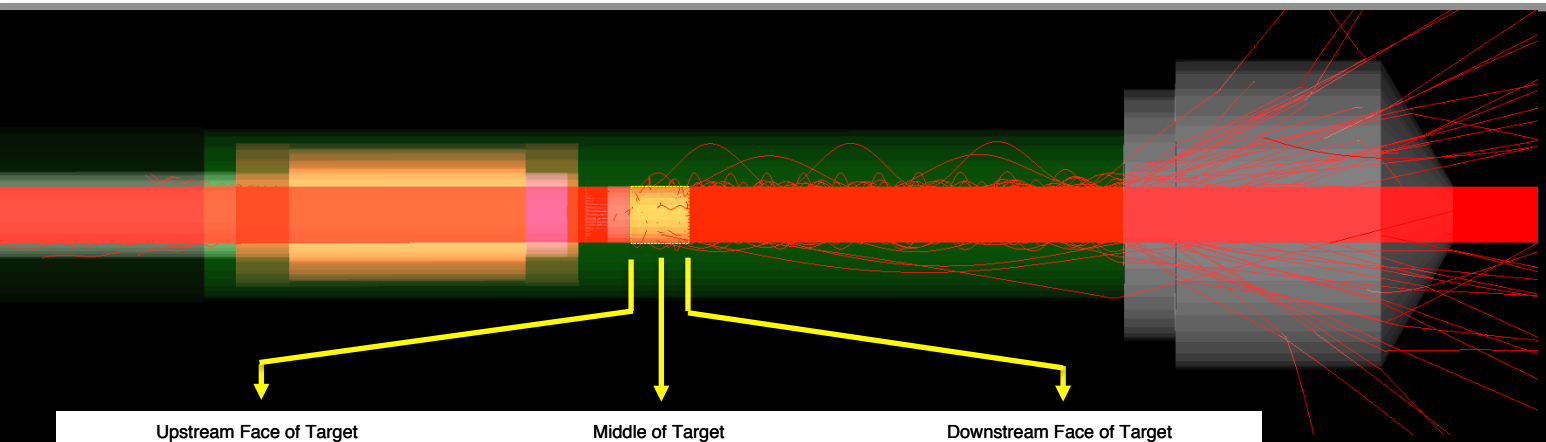
and T_1 ~ 4 hr

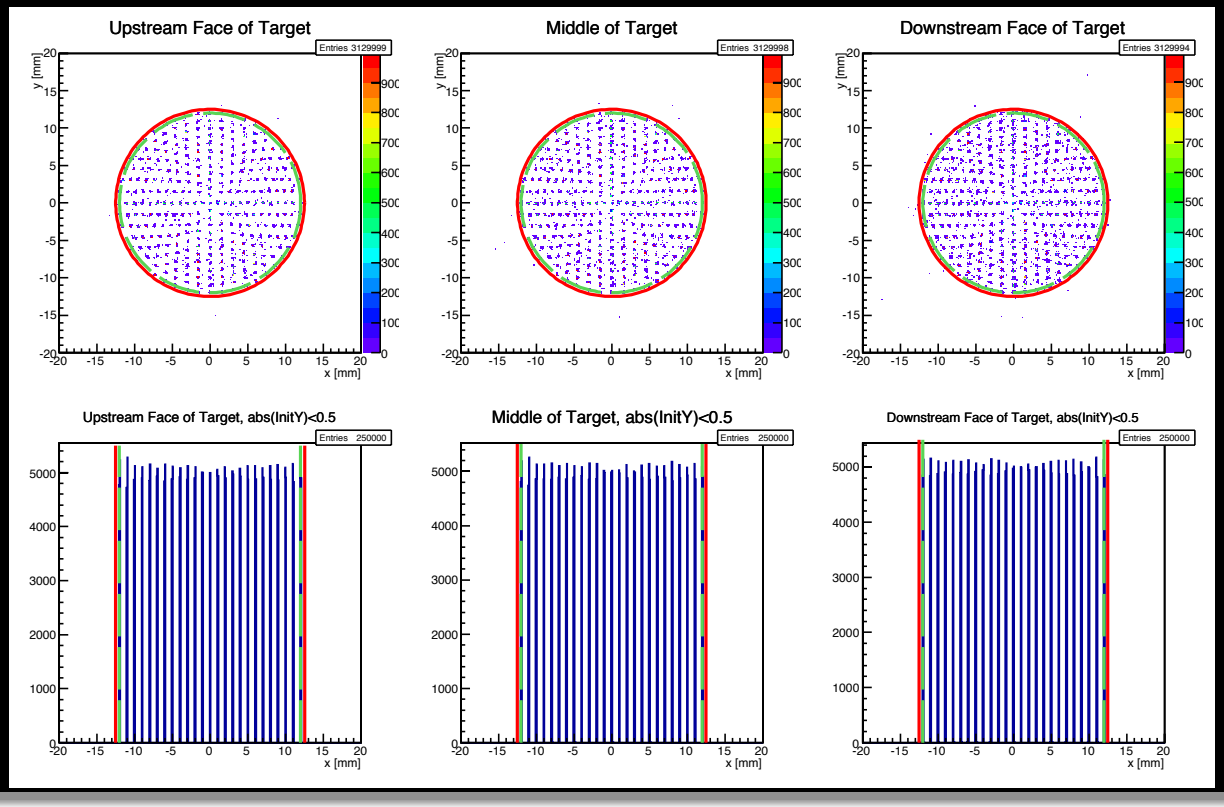
➔ at Pe = 0.999

⇔ e- population $N_- = 0.001$

and T_1 should be 400 hr

Rastered **10 GeV** beam profiles on 25 mm long target



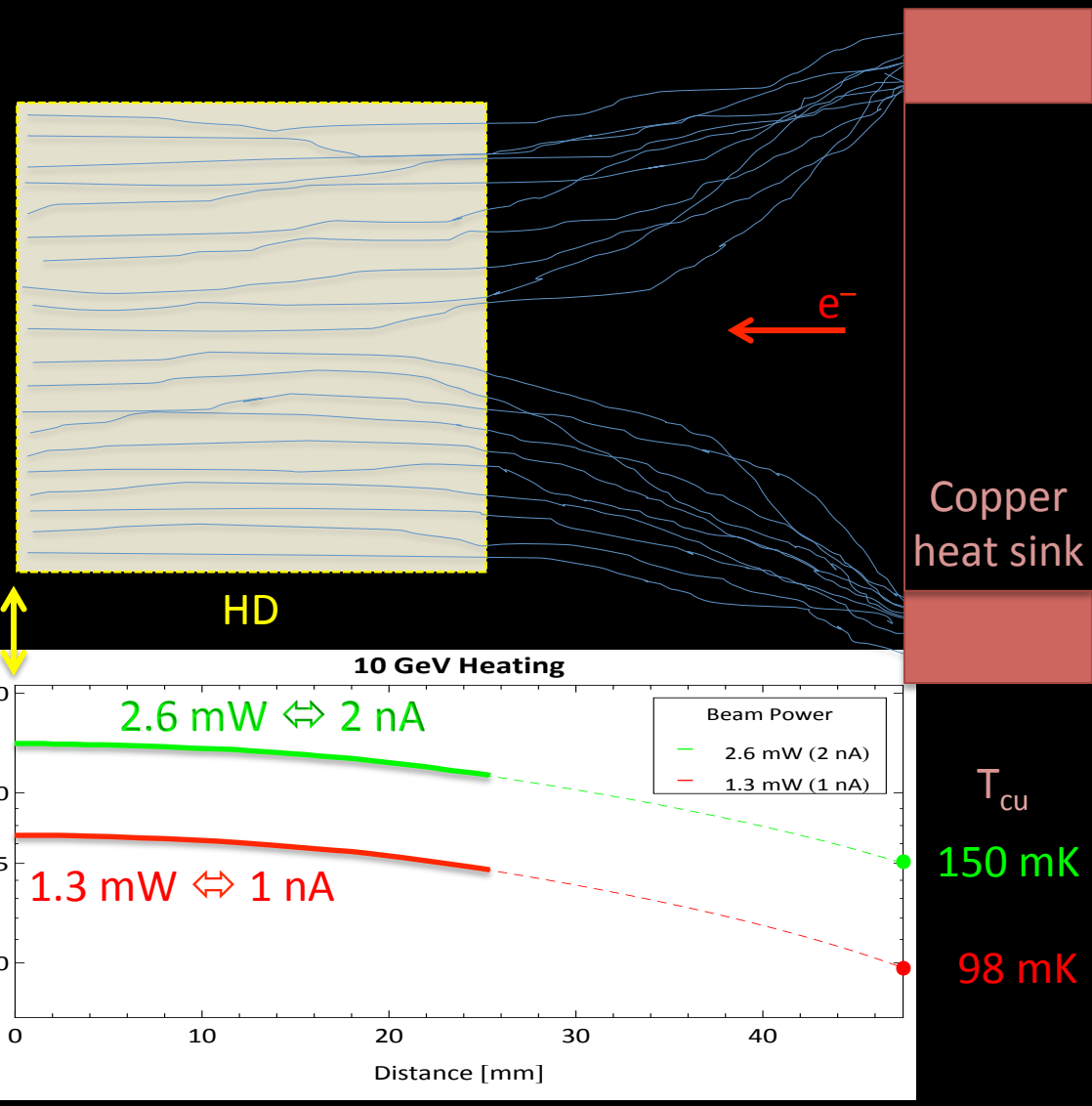


- solenoid focusing and multiple scattering are both irrelevant
- beam uniformly illuminates the full target cell

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

- 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

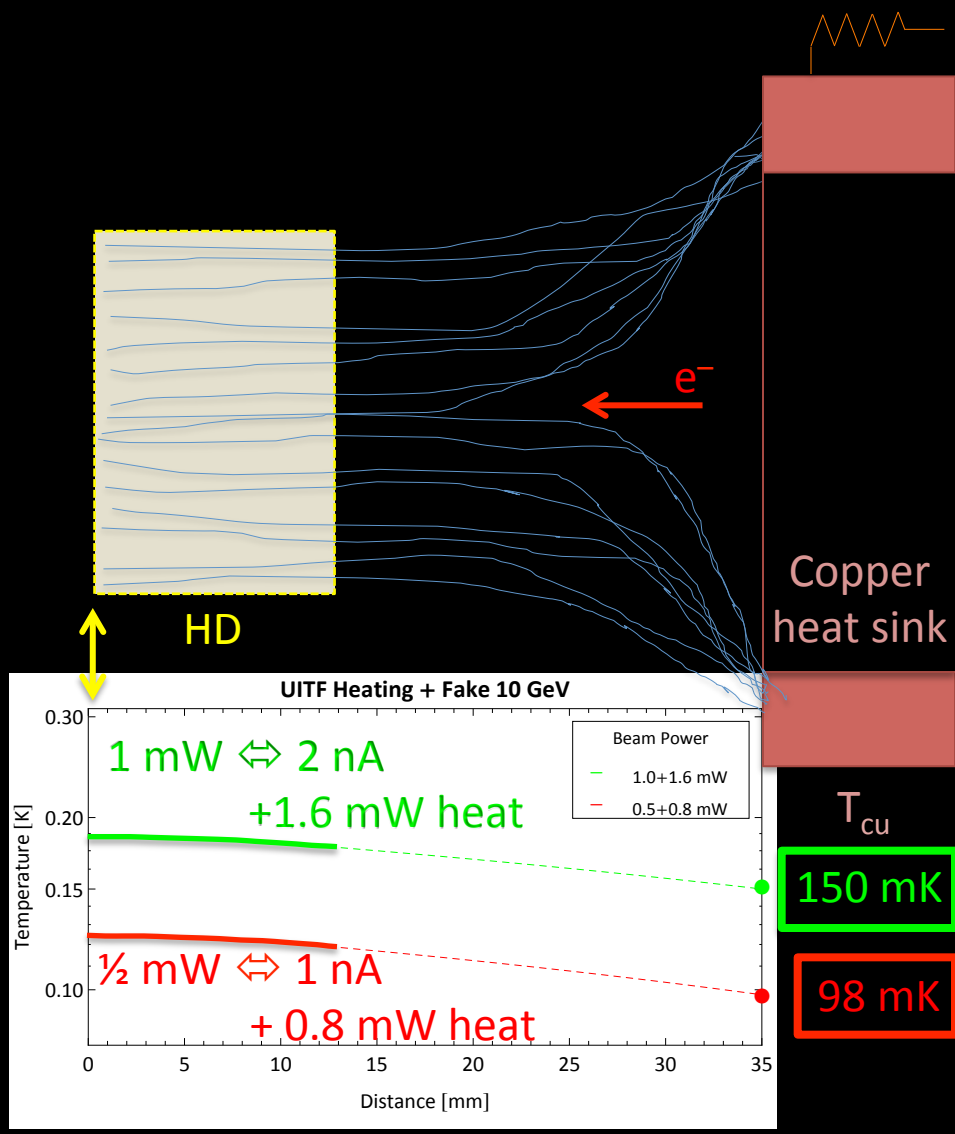


Simulating **10 GeV** heat load & polarizations at **UITF**

- **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



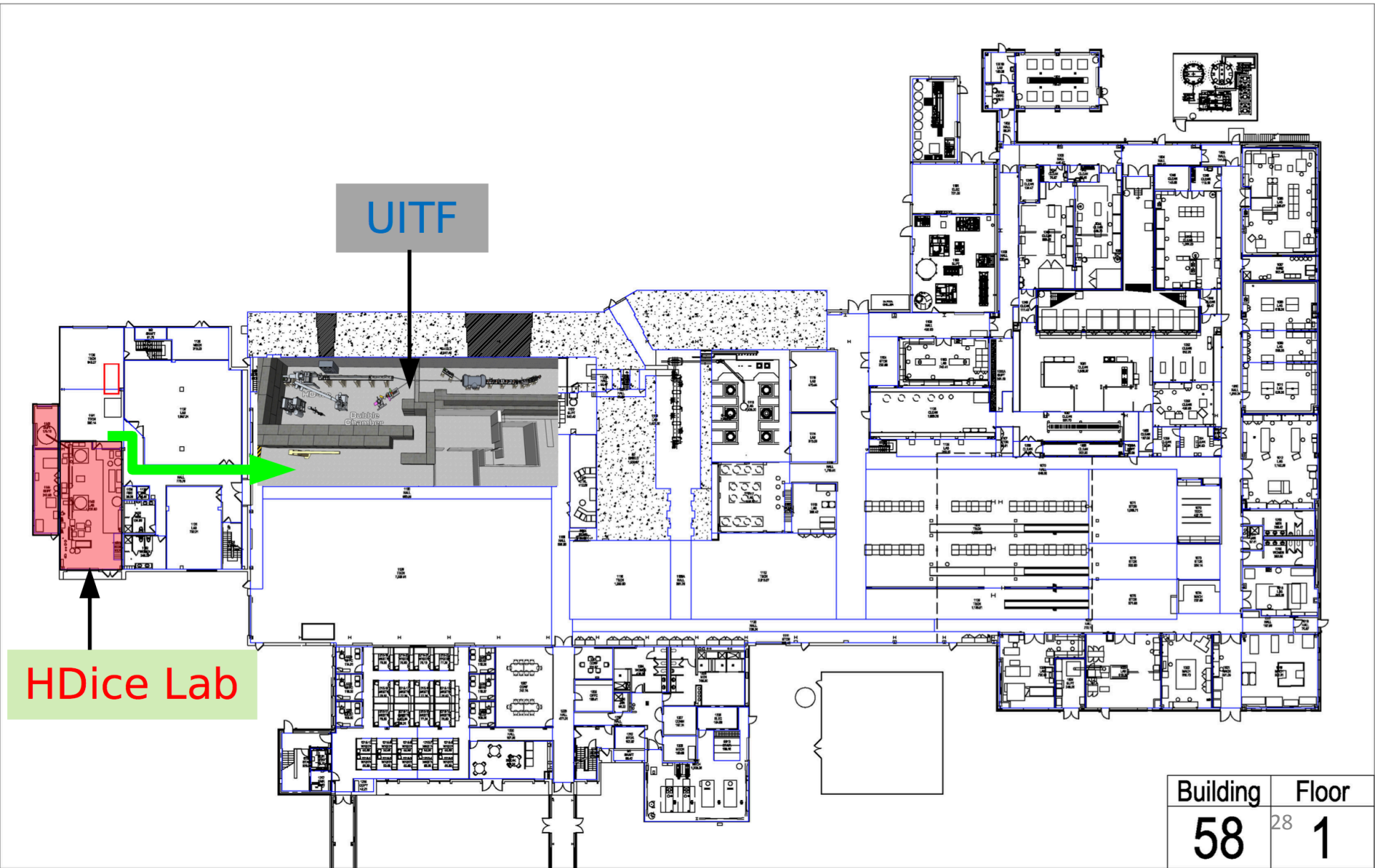
eHD Luminosity

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

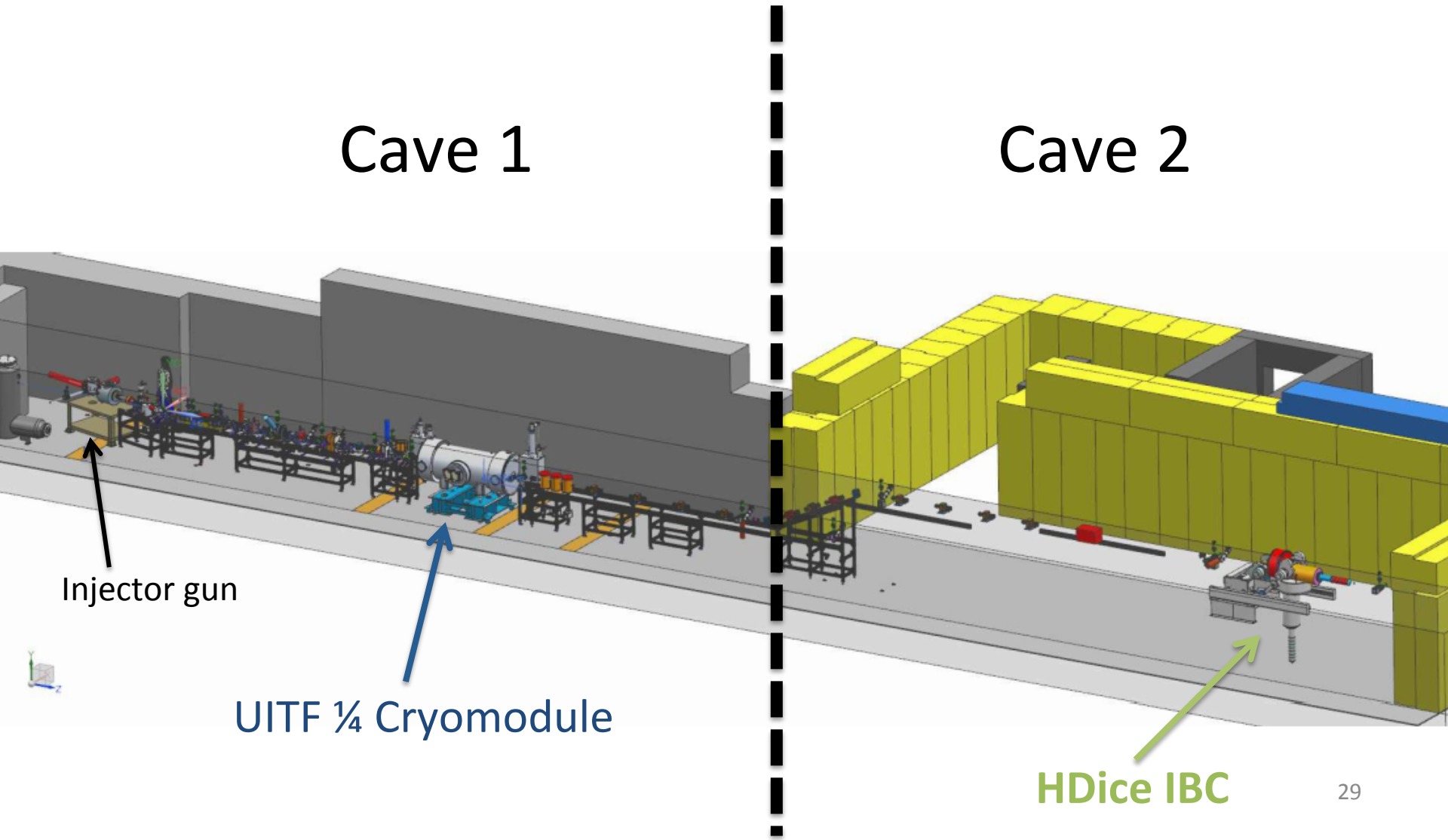
= (0.2×10^{33}) • T_{HD}(cm) • I_e(nA)

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

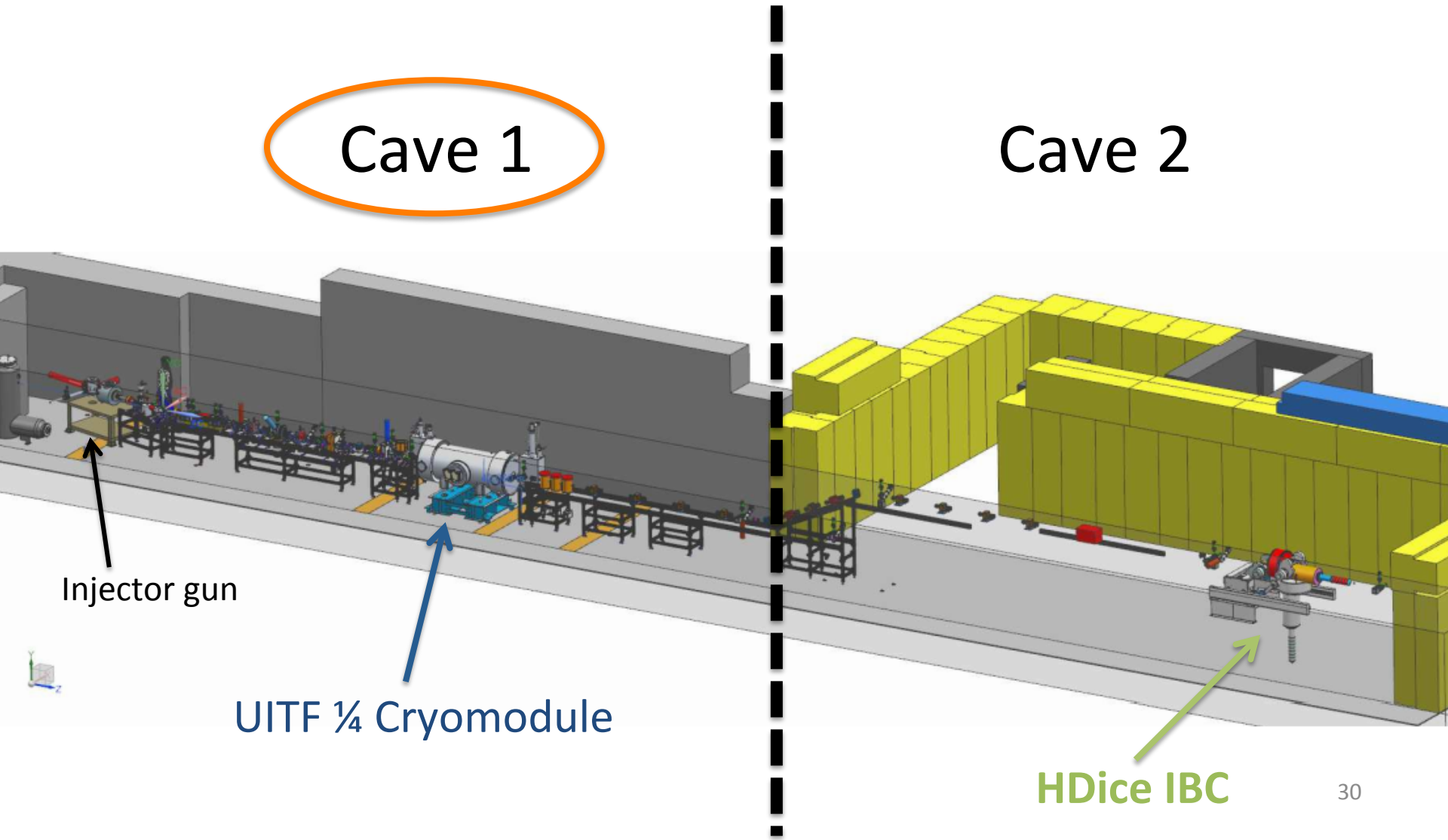
UITF Status



Preparing for eHD



Preparing for eHD: Cave 1



Preparing for eHD: Cave 1

Concrete wall removed prior to construction of Cave 2

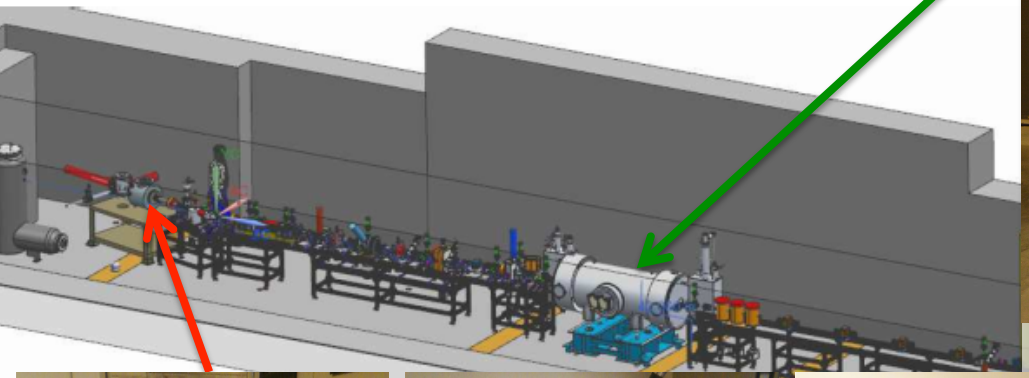
- Cave 1 cleared out, cleaned

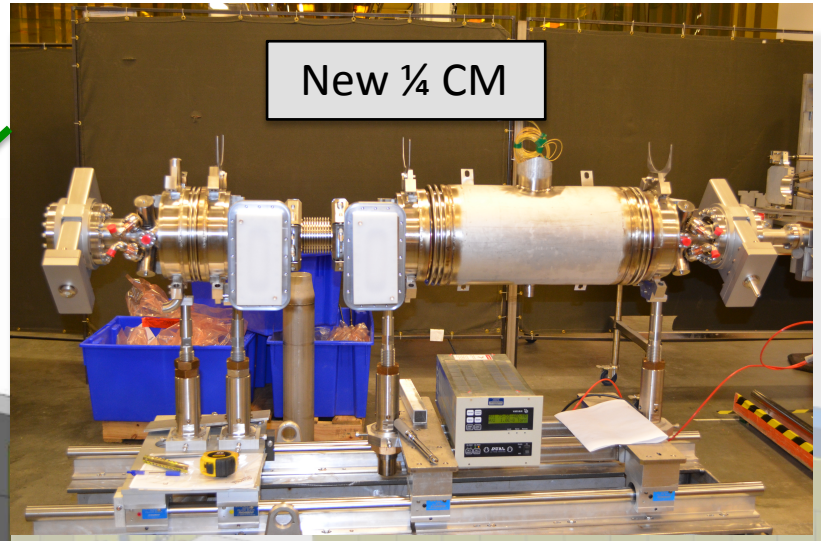
- Plumbing installed
  (LCW, compressed air, GN2)
- Beamline beginning to form

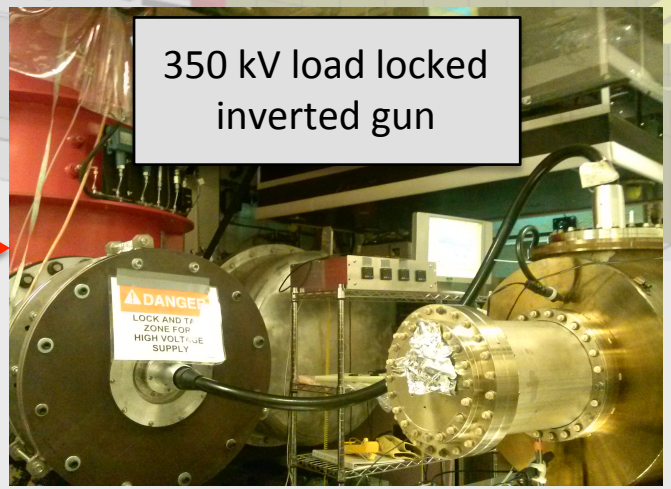
UITF Gun

- Gun built with (mildly) conductive insulator, optimized shielding electrode
- Polishing complete
- Tested up to 325 kV

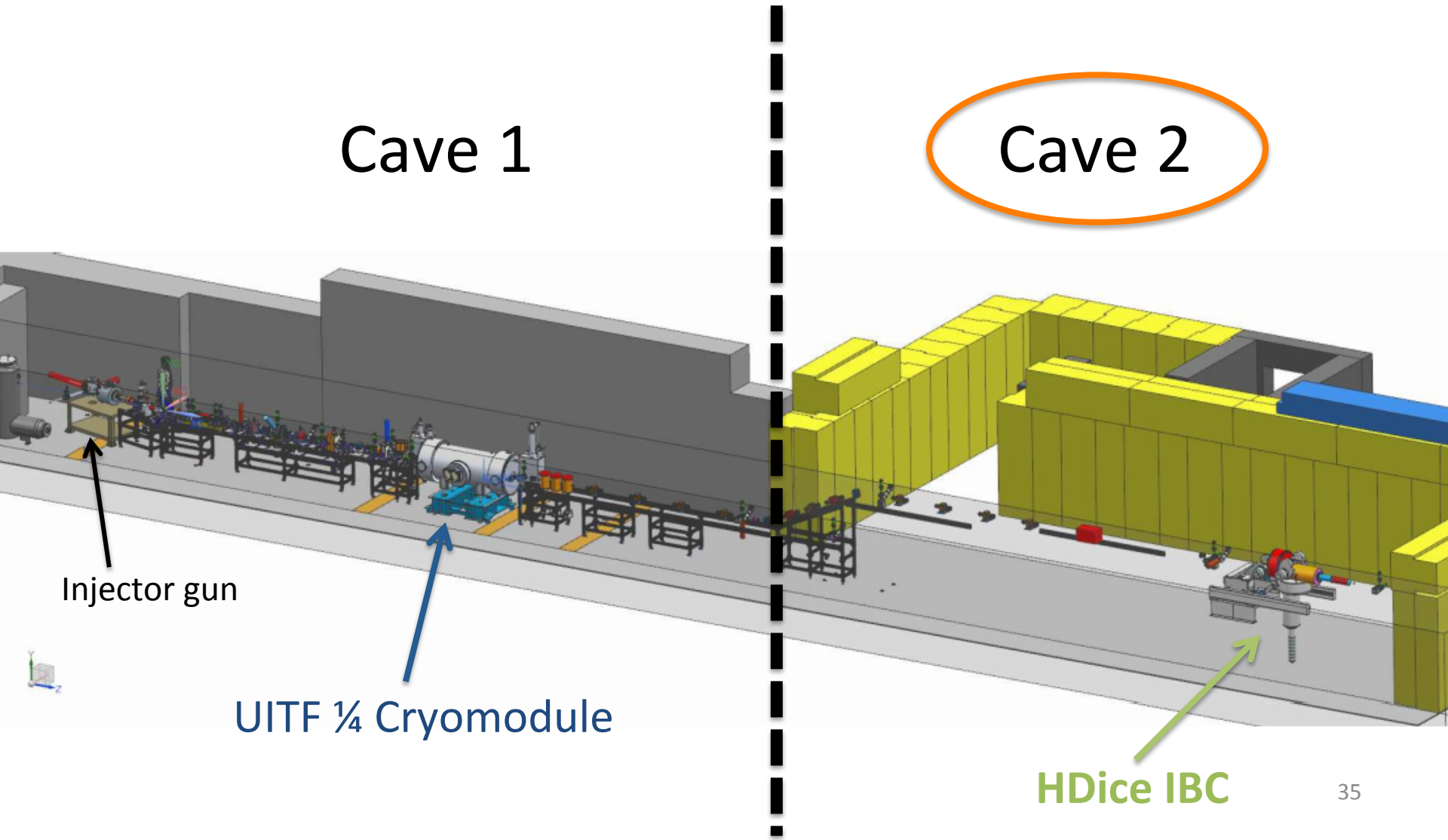
Preparing for eHD: Cave 1





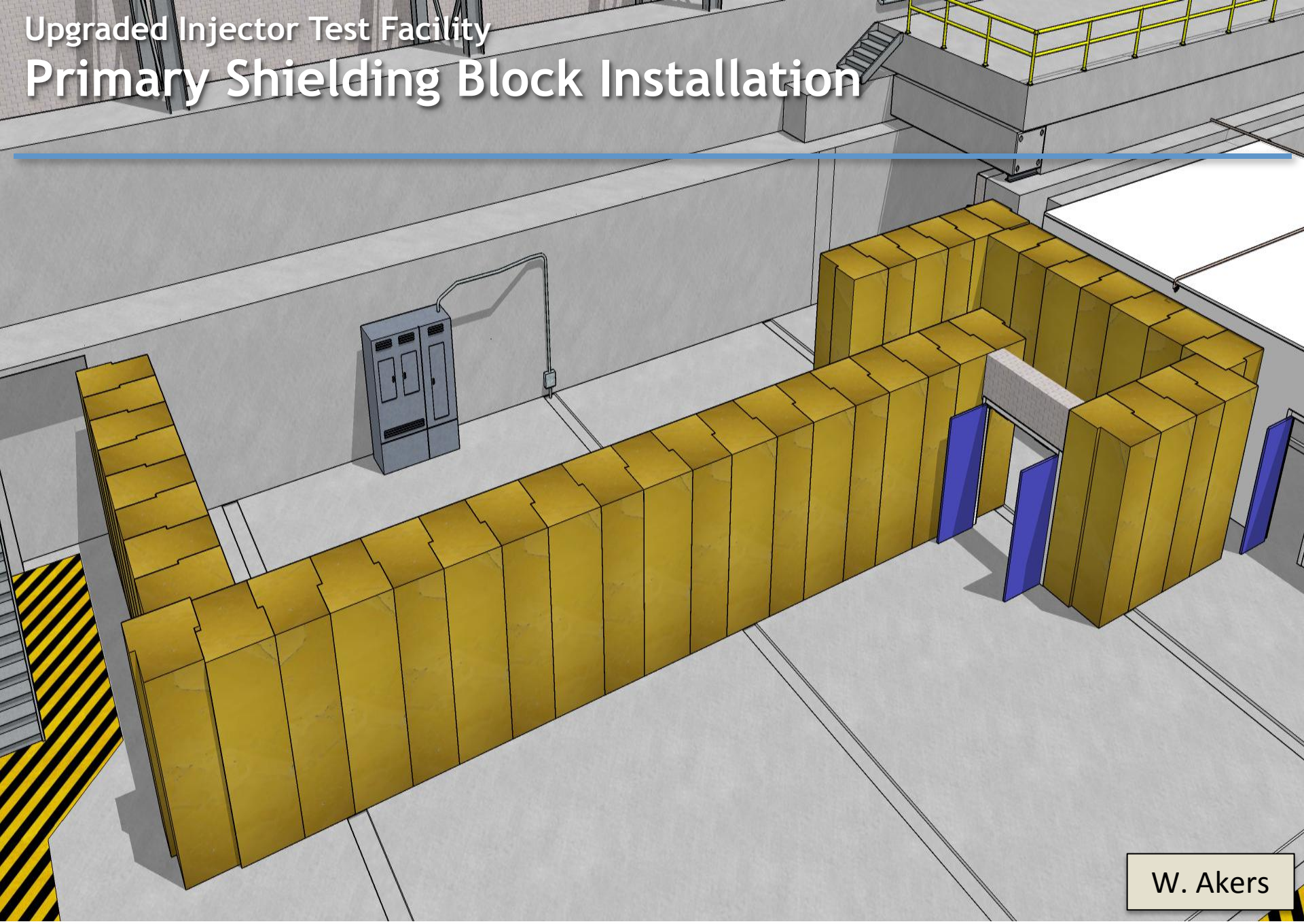


Preparing for eHD: Cave 2



Upgraded Injector Test Facility

Primary Shielding Block Installation



W. Akers

Upgraded Injector Test Facility

Installation of Upper Level Shielding

W. Akers

Upgraded Injector Test Facility

Installation of Roof Beams

W. Akers

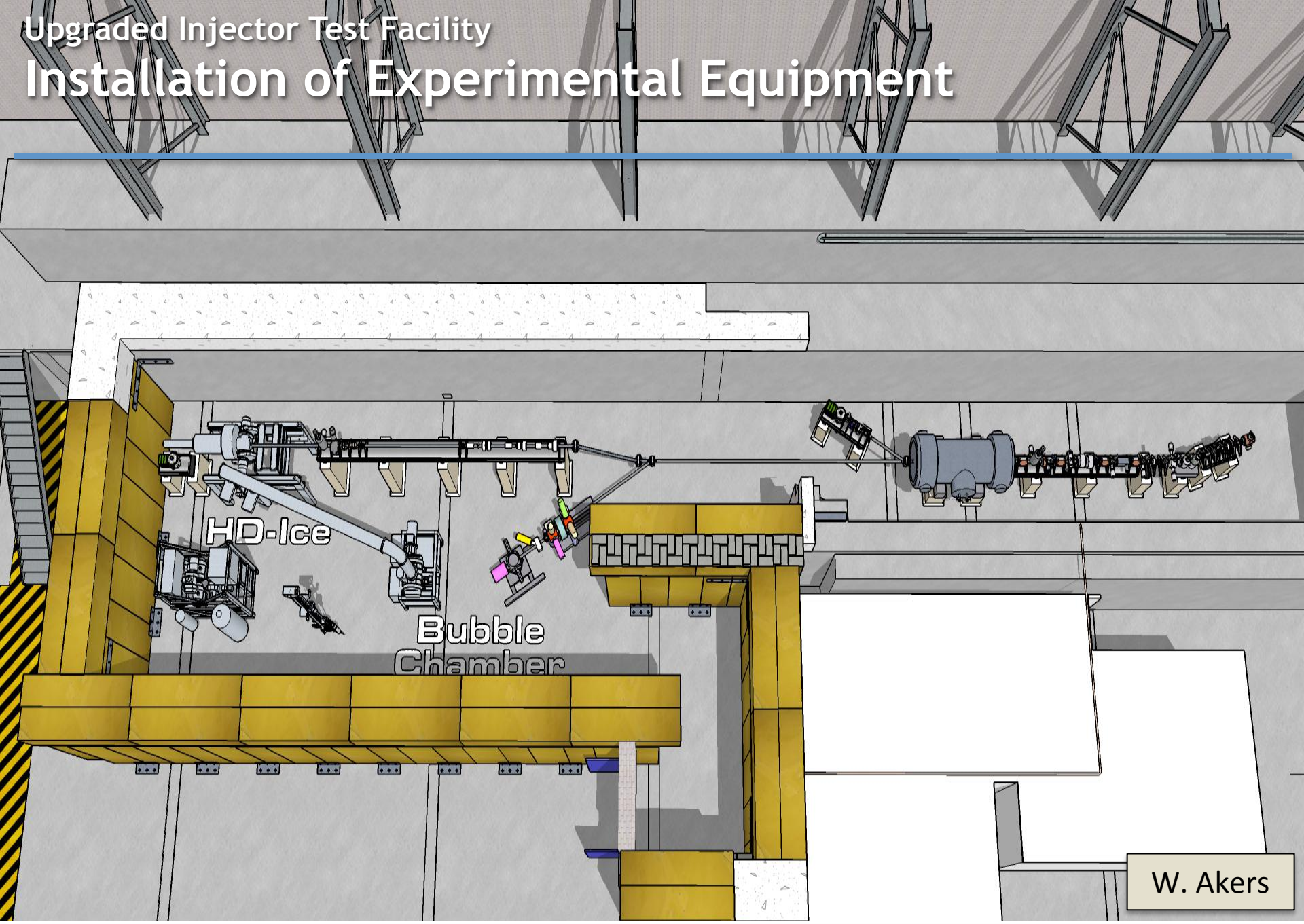
Upgraded Injector Test Facility

Installation of Roof Beams

W. Akers

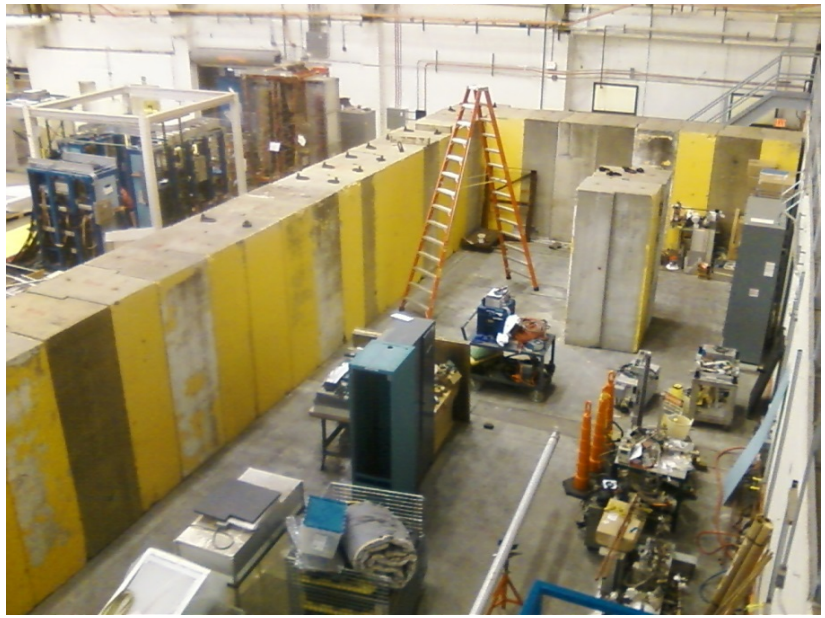
Upgraded Injector Test Facility

Installation of Experimental Equipment



W. Akers

Preparing for eHD: Cave 2



Preparing for eHD

Electronics racks installed above Cave 1

Associated cable trays have also been installed

UITF and eHD schedule (as of Friday 1/29/16)

- Klystrons and control modules installed above cave 1 - March/16
- Cryo and RF to location of ¼ cryomodule in cave 1 - April/16
- **FM completes cave 1 enclosure and construction of Cave 2 with roof - July-August/16**
- **install *new* ¼ cryomodule (can use 200 keV gun) - August/16**
- build MeV beam line in cave 2 - August/16
- install LHe transfer line from CTF to HDice buffer location in cave 2 - September/16
- make first keV beam in cave 2 - September/16
- **deliver 1st test MeV beam to cup in front of HDice position in cave 2 - September/16**

  ⇔ *UITF Capital Equipment Project is complete in FY'2016*
- **test *new* 350 keV gun (needed for later use with *old* ¼ cryomodule) - October/16**
- **install HDice IBC on beamline in cave 2 and connect to CTF - November/16**
- **1st cool down of HDice IBC at UITF - January/17**
- **1st MeV beam to IBC with an empty cell, unpolarized HD - Febuary/17**
- **1st beam on polarized HD - April/17**

Summary

- Lessons were learned during the 2012 eHD tests carried out in Hall B.
- These lessons have resulted in a redesigning of the target cell and experimental procedure.
- Simulations (using g4beamline) regarding eHD running have revealed complications from the use of MeV electrons with the IBC.
- Based off of the simulations, a balance between beam, target, and cryostat effects has been reached.
- Preparation for the eHD tests in the UITF are well underway.

END

Room for future improvements in Al thermal conductivity

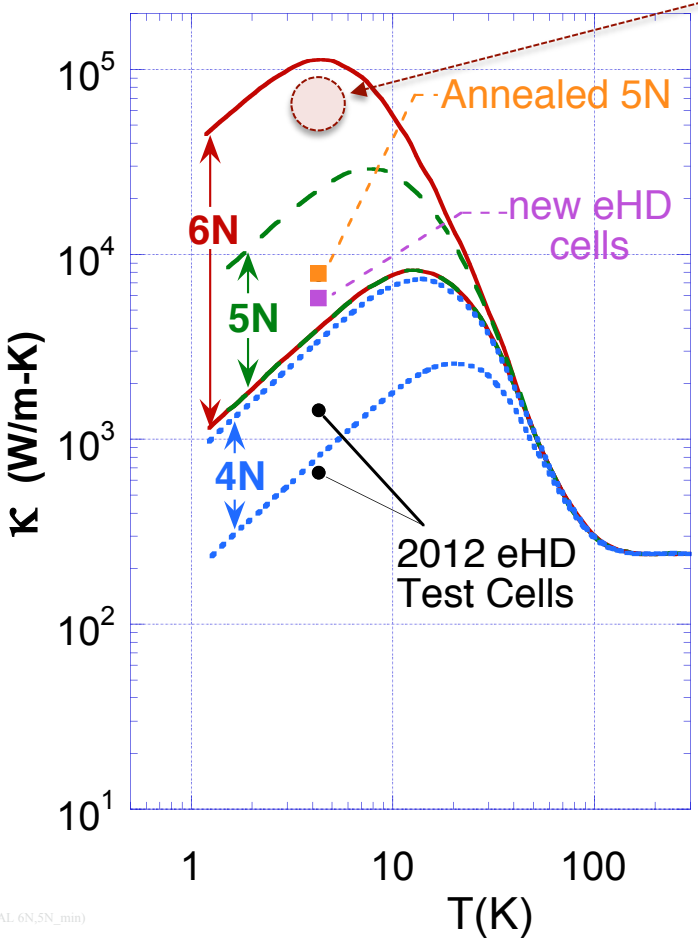
HDice data: (● ■ ■)

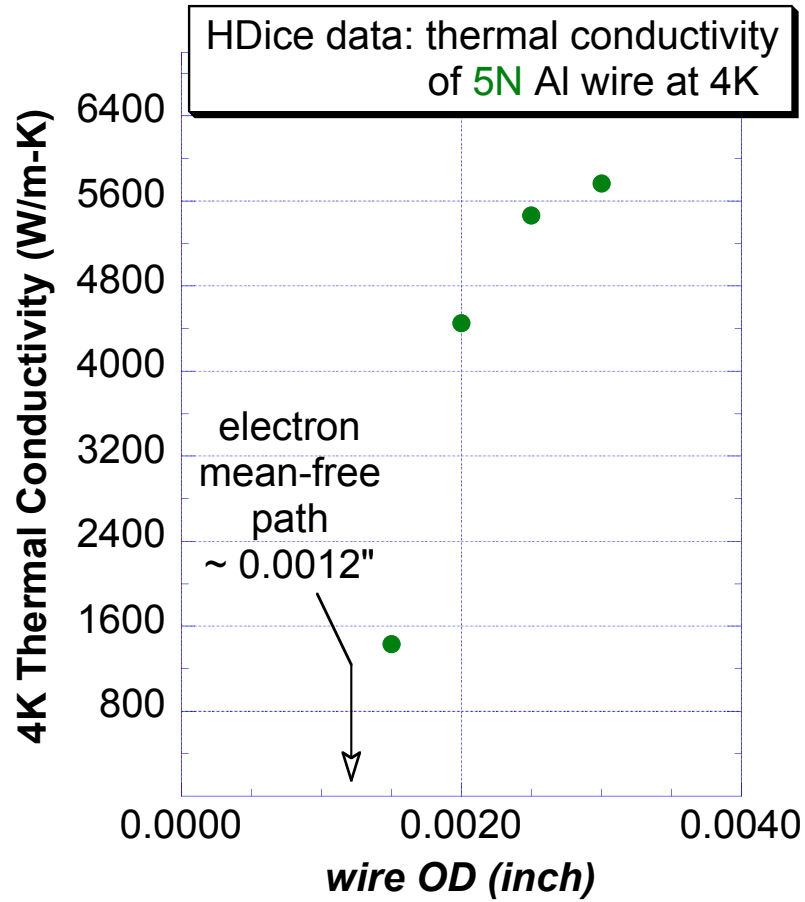
curves: 6N, 5N, 4N

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***)

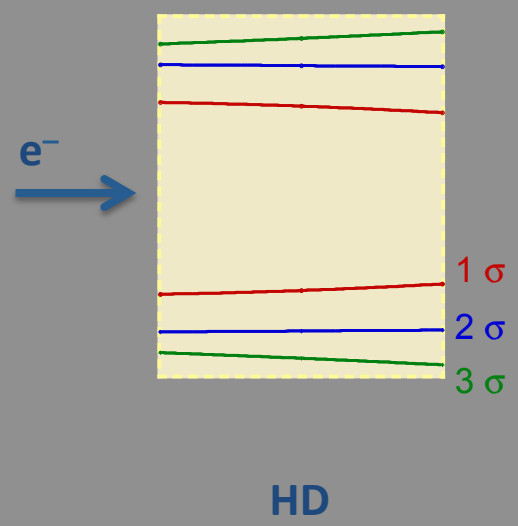
Hall B

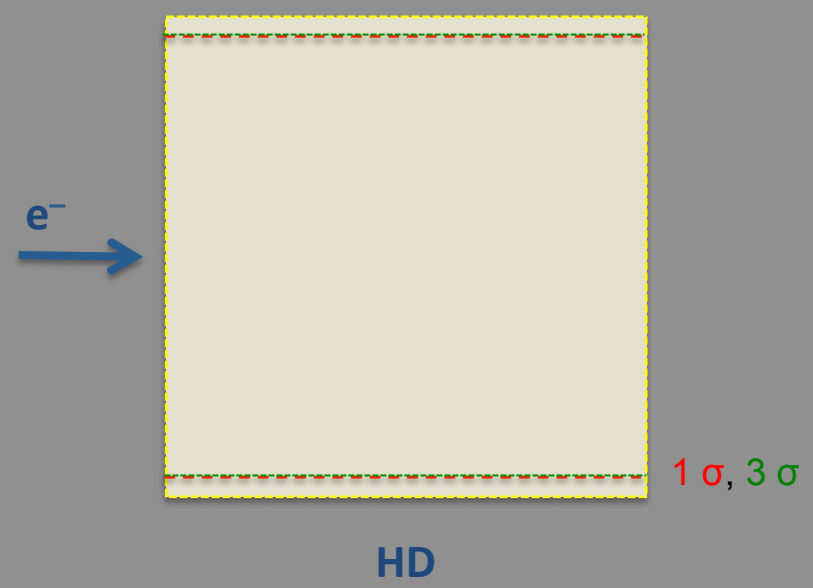
E_e = 10 GeV

Beam diameter = 23 mm, no tails

HD diameter = 25 mm

HD length = 25 mm

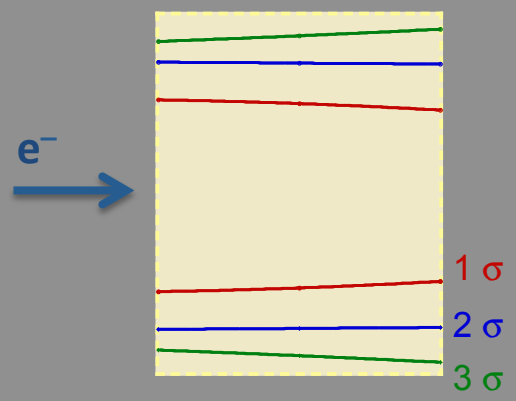




UITF vs Hall B

UITF

E_e = 7.86 MeV
Beam diameter = 17 mm, with tails
HD diameter = 19 mm
HD length = 12.5 mm



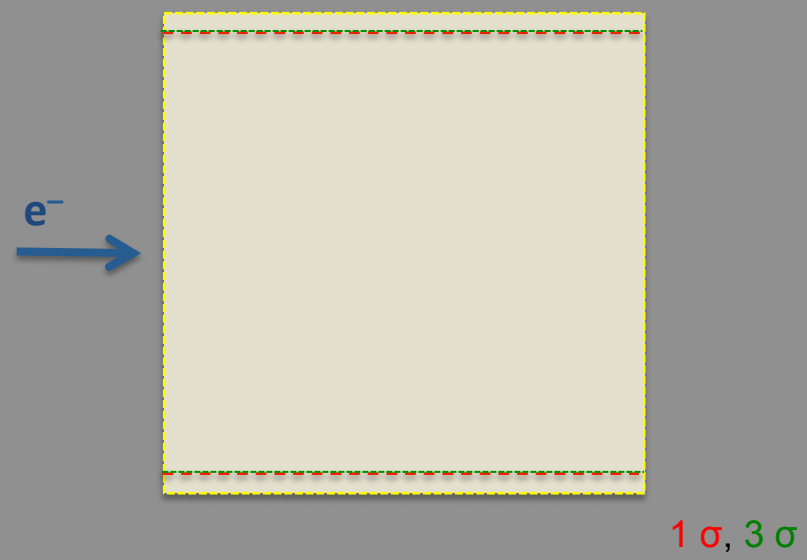
Power density at 1 nA

0.53 mW/cc (1 σ)

0.16 mW/cc (1 σ)

Hall B

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



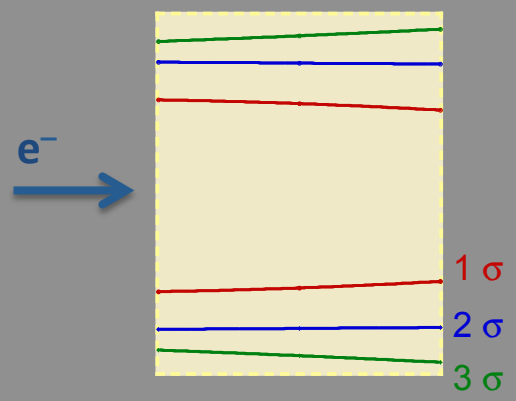
Power density at 1 nA

0.13 mW/cc (1 σ, 1 σ)

UITF vs Hall B

UITF

E_e = 7.86 MeV
Beam diameter = 17 mm, with tails
HD diameter = 19 mm
HD length = 12.5 mm



Power density at 1 nA

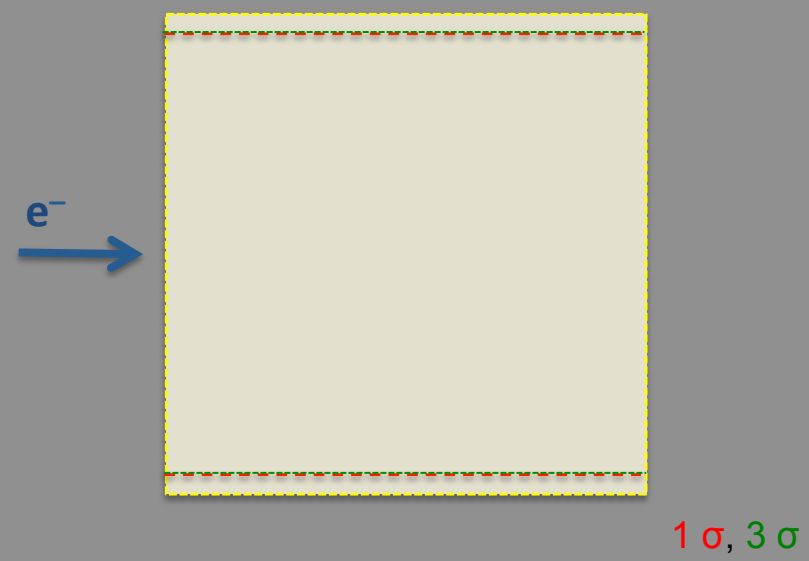
0.53 mW/cc (1 σ)

0.16 mW/cc (1 σ)

greater challenge ⇔

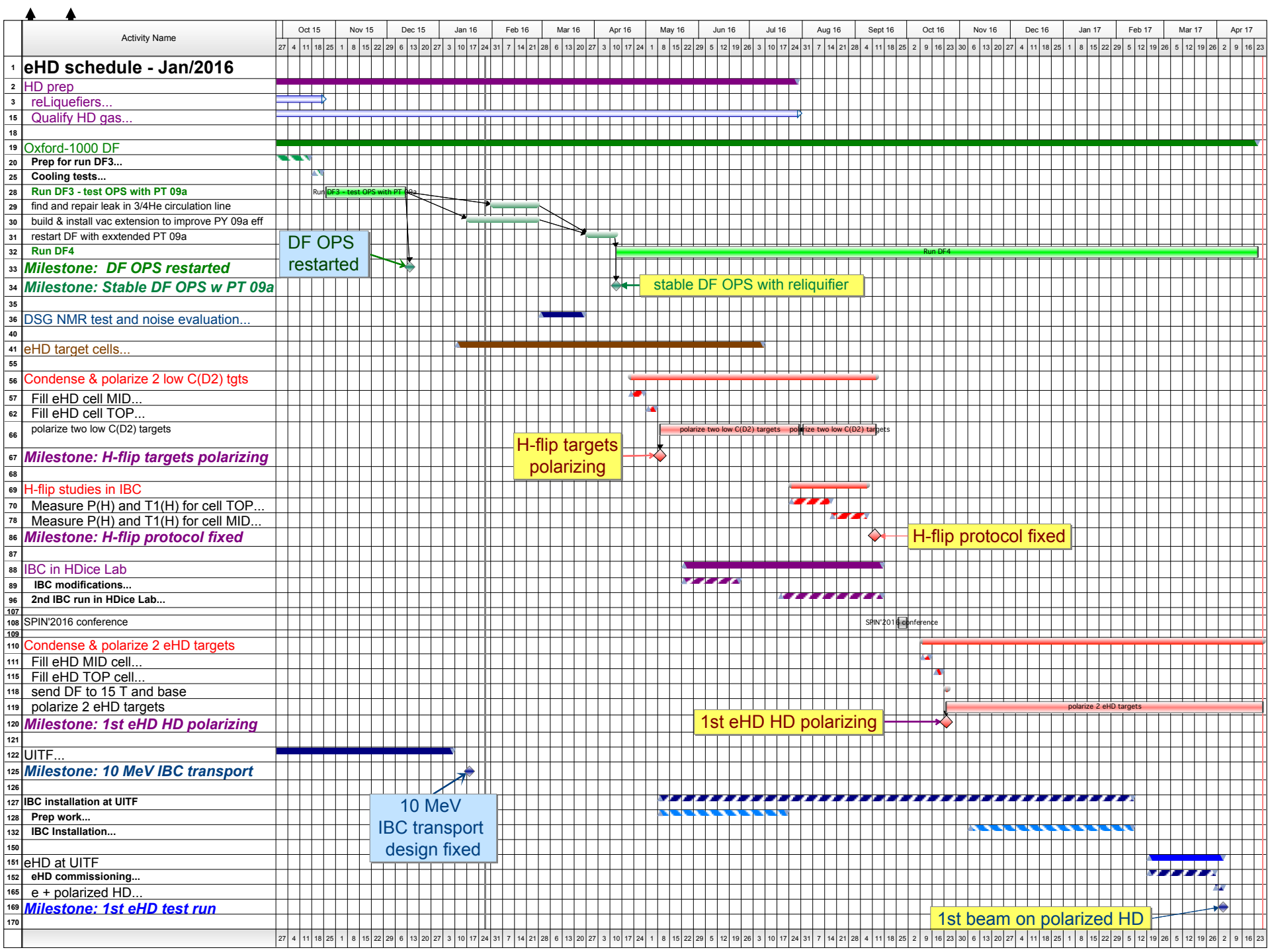
Hall B

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, 1 σ)


Activity Name
Oct 15
Nov 15
Dec 15
Jan 16
Feb 16
Mar 16
Apr 16
May 16
Jun 16
Jul 16
Aug 16
Sept 16
Oct 16
Nov 16
Dec 16
Jan 17
Feb 17
Mar 17
Apr 17
1 eHD schedule - Jan/2016
2 HD prep
3 reLiquefiers...
15 Qualify HD gas...
19 Oxford-1000 DF
20 Prep for run DF3...
25 Cooling tests...
28 Run DF3 - test OPS with PT 09a
29 find and repair leak in 3/4He circulation line
30 build & install vac extension to improve PY 09a eff
31 restart DF with exxtended PT 09a
32 Run DF4
33 Milestone: DF OPS restarted
34 Milestone: Stable DF OPS w PT 09a
36 DSG NMR test and noise evaluation...
41 eHD target cells...
56 Condense & polarize 2 low C(D2) tgts
57 Fill eHD cell MID...
62 Fill eHD cell TOP...
66 polarize two low C(D2) targets
67 Milestone: H-flip targets polarizing
69 H-flip studies in IBC
70 Measure P(H) and T1(H) for cell TOP...
78 Measure P(H) and T1(H) for cell MID...
86 Milestone: H-flip protocol fixed
88 IBC in HDice Lab
89 IBC modifications...
96 2nd IBC run in HDice Lab...
108 SPIN'2016 conference
110 Condense & polarize 2 eHD targets
111 Fill eHD MID cell...
115 Fill eHD TOP cell...
118 send DF to 15 T and base
119 polarize 2 eHD targets
120 Milestone: 1st eHD HD polarizing
122 UITF...
125 Milestone: 10 MeV IBC transport
127 IBC installation at UITF
128 Prep work...
132 IBC Installation...
151 eHD at UITF
152 eHD commissioning...
165 e + polarized HD...
169 Milestone: 1st eHD test run
DF OPS restarted
stable DF OPS with reliquifier
Run DF4
H-flip targets polarizing
H-flip protocol fixed
1st eHD HD polarizing
10 MeV IBC transport design fixed
1st beam on polarized HD

END END