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

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 $\mu$m < $\sigma_{x,y}$ < 150 $\mu$m
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 $E_{\text{beam}}$

UITF at 10 MeV $\simeq$ Hall B at 10 GeV

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eHD Tests in UITF

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

Beam transport through IBC at 10 MeV is very different from 10 GeV!!!
Pencil beam into IBC with normal orientation at 10 GeV
Pencil beam into IBC with normal orientation at <10 MeV

- Entrance of IBC
- Edge of HD cell
- UITF beam
- 0.2 T Solenoid(s)
- 0.9 T Solenoid
- HD
Pencil beam into IBC with normal orientation at <10 MeV

...... a closer view

10x thinner than g14 Rad Baffle

Rad Baffle

0.2 T Solenoid(s)

0.9 T Solenoid

HD

Significant scattering off of Radiation Baffle!
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

10x thinner than g14 Rad Baffle

Rad Baffle

0.2 T Solenoid(s)

0.9 T Solenoid

node

Significant scattering off of Radiation Baffle!

HD
(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

\[ 13.6 \text{ mm offset at Radiation Baffle, from solenoid edge focusing} \]

\[ \approx \text{maximum offset} \]

Focused to 10 mm at HD

0.2 tesla *transfer solenoids*

0.9 tesla *main solenoid*

max radial opening = 14.3 mm
(UITF) Pencil beam into IBC with 14 mm offset

Pencil beam offset 14 mm at launch

.slant 13.6 mm offset at Radiation Baffle, from solenoid edge focusing ≈ maximum offset

Focused to 10mm at HD

Reduce target diameter: 25mm → 19mm

max radial opening = 14.3 mm

0.9 tesla main solenoid
(UITF) Uniform rastered beam into IBC

- UITF beam energy tuned to 7.86 MeV
- focusing node at HD front face

Beam fills target 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 $\varnothing$ at IBC entrance
  $\Leftrightarrow$ 17 mm $\varnothing$ 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 $\varnothing$ Al (5N) wires

- Heat dumped into HD
- Heat dumped into Al Wires (Volume B)
- Heat dumped into Al Wires (Volume C)
- Heat dumped into Cu Ring and Mixing Chamber
- Heat dumped into Section 1 of IBC Beampipe
- Heat dumped into Section 2 of IBC Beampipe
- Heat dumped into Section 3 of IBC Beampipe
- Heat dumped into Section 4 of IBC Beampipe
- Heat dumped into Section 5 of IBC Beampipe
- Heat dumped into remaining 292.09 mm section of IBC Beampipe
- Heat dumped into Rad Baffle
- Heat dumped into largest IBC Beampipe

**Graphs and Diagrams**

- Heat dumped into HD
- UITF Heating

**Notes**
- Copper heat sink

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**Equations**

- $e^{-}$
- $e^{-}$
- $E_e = 7.86$ MeV, rastered uniformly over 24 mm $\varnothing$ at IBC entrance
  $\Leftrightarrow$ 17 mm $\varnothing$ 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 $\varnothing$ Al (5N) wires
Heat load \(\Rightarrow\) 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

\[ \Leftrightarrow \text{polarization depends on temperature} \]

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

\[
\begin{array}{cccc}
P_e & I_e & Q_{\text{HD}} & T_{\text{HD}}^{\text{max}} \\
0.99977 & 2 \text{ nA} & 1 \text{ mW} & 138 \text{ mK} \\
0.99999 & 1 \text{ nA} & \frac{1}{2} \text{ mW} & 98 \text{ mK} \\
\end{array}
\]

\[ \uparrow \text{very promising!} \]
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 T₁ ~ 4 hr

⇒ at P_e = 0.999
⇒ e⁻ population N⁻ = 0.001
and T₁ 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

<table>
<thead>
<tr>
<th>$P_e$</th>
<th>$I_e$</th>
<th>$Q_{HD}$</th>
<th>$T_{HD}^{max}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.99831</td>
<td>2 nA</td>
<td>2.6 mW</td>
<td>245 mK</td>
</tr>
<tr>
<td>0.99993</td>
<td>1 nA</td>
<td>1.3 mW</td>
<td>168 mK</td>
</tr>
</tbody>
</table>

10 GeV Heating

- 2.6 mW $\Leftrightarrow$ 2 nA
- 1.3 mW $\Leftrightarrow$ 1 nA

Copper heat sink

- $T_{cu}$
  - 150 mK
  - 98 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

<table>
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<th>$I_e$</th>
<th>$Q_{HD}$</th>
<th>$T_{HD}^{\text{max}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.99757</td>
<td>2 nA</td>
<td>1+1.6 mW</td>
<td>186 mK</td>
</tr>
<tr>
<td>0.99991</td>
<td>1 nA</td>
<td>½+0.8 mW</td>
<td>125 mK</td>
</tr>
</tbody>
</table>

$\uparrow$ ~ same $P_e$ as 10 GeV and 1.25 T
eHD Luminosity

\[ \mathcal{L} \text{ [cm}^{-2} \text{ s}^{-1}] = \frac{dN}{dt} \text{ [s}^{-1} \text{ in a perfect detector]} \cdot \frac{1}{\sigma_T} \text{ [cm}^{-2}] \]

\[ = (0.2 \times 10^{33}) \cdot T_{HD}(\text{cm}) \cdot I_e(\text{nA}) \]

for 2.5 cm long cell and \( I_e = 2 \text{ nA} \Rightarrow 10^{33} \]
Preparing for eHD

Cave 1

Cave 2

Injector gun

UITF ¼ Cryomodule

HDice IBC
Preparing for eHD: Cave 1

Cave 1

Cave 2

Injector gun

UITF ¼ Cryomodule

HDice IBC
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

- 350 kV load locked inverted gun
- New ¼ CM
Preparing for eHD: Cave 2

Cave 1

Cave 2

Injector gun

UITF ¼ Cryomodule

HDice IBC
Upgraded Injector Test Facility
Primary Shielding Block Installation
Upgraded Injector Test Facility

Installation of Upper Level Shielding

W. Akers
Upgraded Injector Test Facility
Installation of Roof Beams
Upgraded Injector Test Facility

Installation of Roof Beams

Removable roof for target transfers
Upgraded Injector Test Facility
Installation of Experimental Equipment
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 - February/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

HDice data: thermal conductivity of 5N Al wire at 4K

electron mean-free path ~ 0.0012"

2012 eHD Test Cells

Annealed 5N

new eHD cells

Kappa(Al 6N, 5N_min)
**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 $\sigma$)*
- 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

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Hall B

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Power density at 1 nA
0.53 mW/cc ($1 \sigma$)  
0.16 mW/cc ($1 \sigma$)

Power density at 1 nA
0.13 mW/cc ($1 \sigma$, $1 \sigma$)
**UITF vs Hall B**

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**Hall B**

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**Power density at 1 nA**

- **UITF:** 0.53 mW/cc (1σ)
- 0.16 mW/cc (1σ)
- 0.16 mW/cc (1σ, 3σ)

- **Hall B:** 0.13 mW/cc (1σ, 1σ)

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*greater challenge*
END END