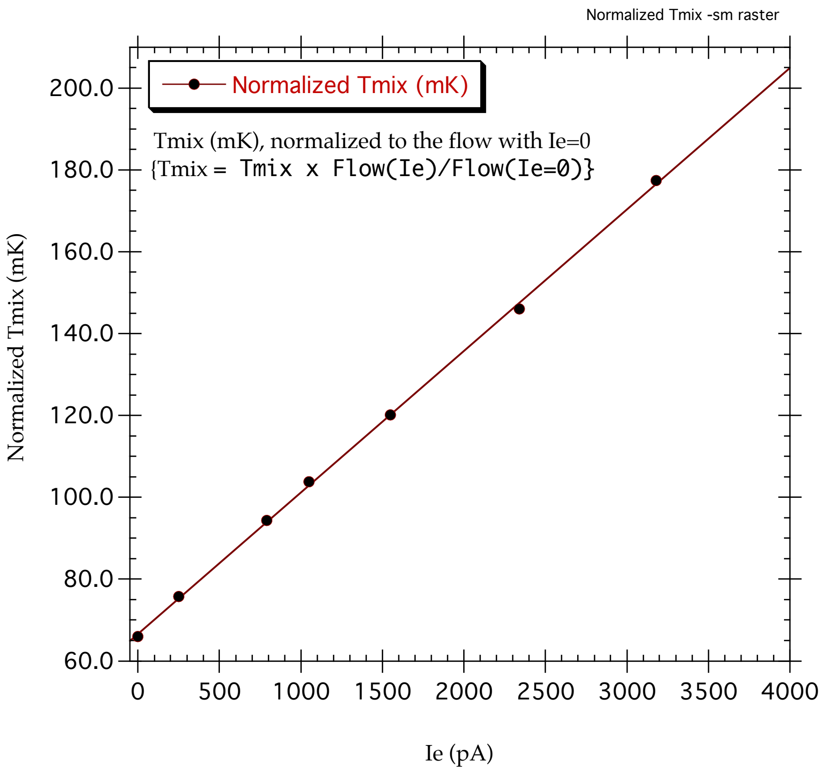
Preliminary Summary of Runs 2 & 3 – Jan 06/21

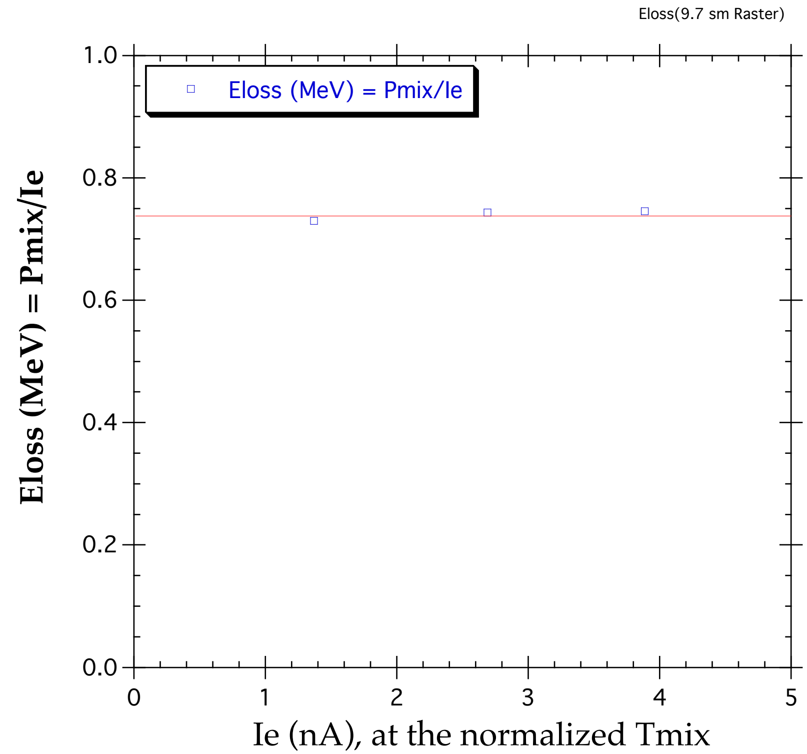
Run 2 (Oct 27 – Nov 9/2020) :

- Measure the energy loss in the target from the heat rise in the IBC
- Set the raster size to cover the target
- Tune the NMR

Preliminary Summary of Runs 2 & 3 – Jan 06/21

- *energy deposition from heat increase in the IBC* (Run 2):





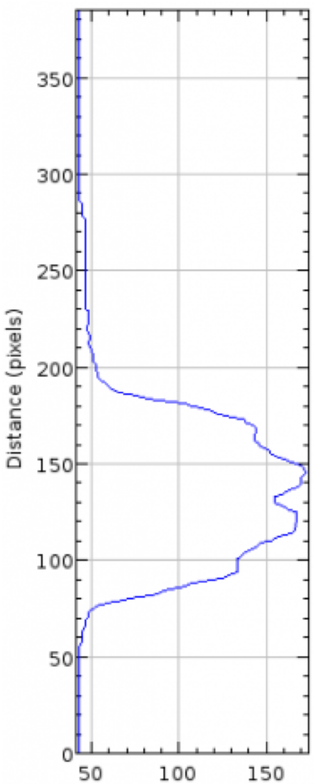
- *Eloss (10 MeV)* = 0.74 MeV/e⁻ = 0.74 mW/nA ⇔ agrees with **NIST *ESTAR***

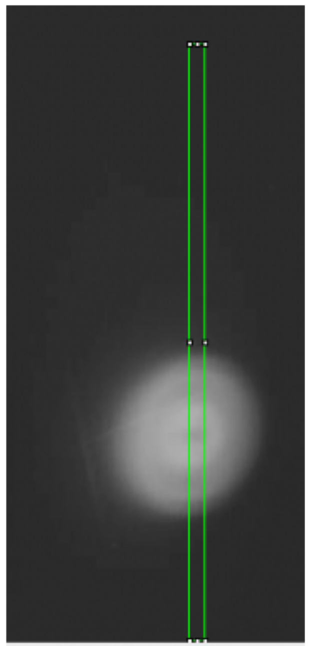
⇔ *Eloss (10 GeV)* = 0.98 MeV/e⁻ = 1 mW/nA

HDice@UITF

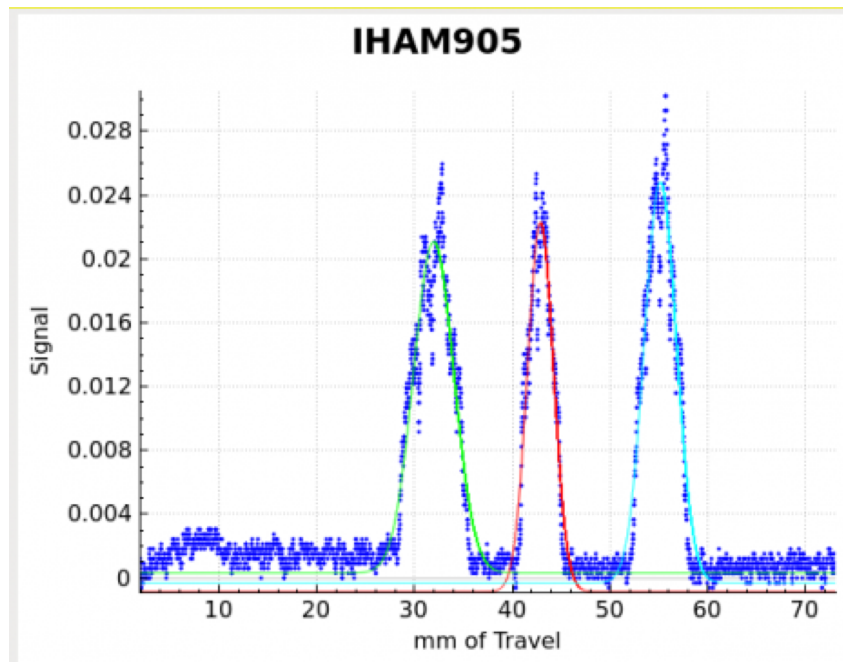
Preliminary Summary of Runs 2 & 3 – Jan 06/21

- *Sombrero Raster*: 18 – 39 KHz fundamental x 3 KHz AM (Bill Gunning)





HARP scan with *raster* set to fill HD target

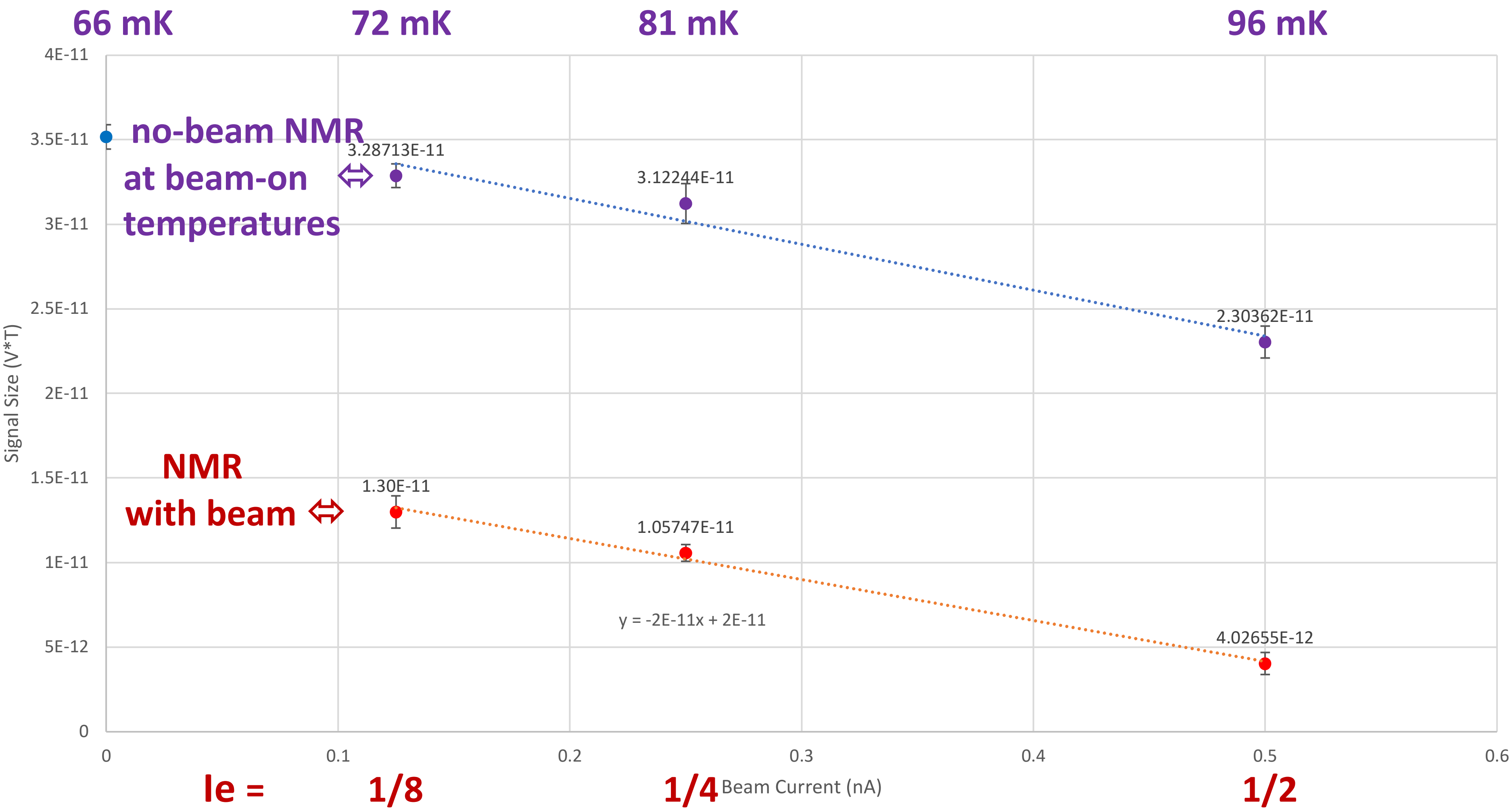


- *quasi-flat top, but with a fuzzy edge*

  ⬄ *for the present Run 3 discussion, we consider only data with P(H) > 4%*
  so that partial polarization of the outer target edge does not skew results

Preliminary Summary of Runs 2 & 3 – Jan 06/21

- from Run 2 with a short T_1 target:



Preliminary Summary of Runs 2 & 3 – Jan 06/21

Run 2 (Oct 27 – Nov 9/2020):

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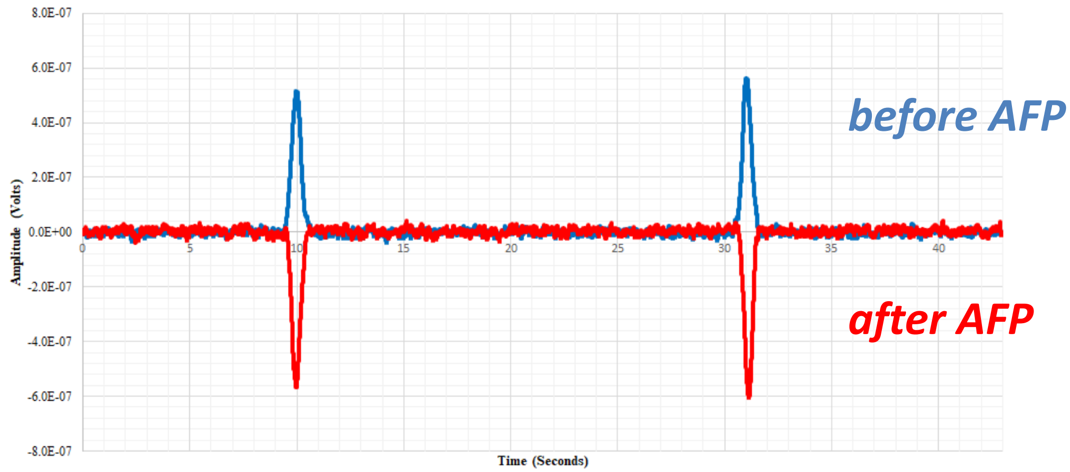
Run 3 (Nov 23 – Dec 17/2020):

- 2 frozen-spin HD targets, *eHD60 & eHD66*, both starting with P(H) ~ 30 %
- H-spins *flipped* with AFP to eliminate hyperfine dilution

Preliminary Summary of Runs 2 & 3 – Jan 06/21

- *Adiabatic Fast Passage* (**AFP**) carried out on each target to invert spin populations → aligns H spin with polarized atomic electrons → eliminates *hyperfine mixing*



$$\frac{\Delta P}{P} = \frac{1}{2}\left[1 + \frac{4\left(\mu_e - \mu_I\right)^2 B^2}{A_{HFS}^2}\right]^{-1}$$

= 0.1 % at 1.1 T; = 0.6 % at 0.45 T

athough small, HD is a quantum crystal, and spin-hopping is a known phenomenon → one e^- could dilute the polarization of multiple H-spins

⇔ eliminated by aligning H-spins with atomic electron polarization

Preliminary Summary of Runs 2 & 3 – Jan 06/21

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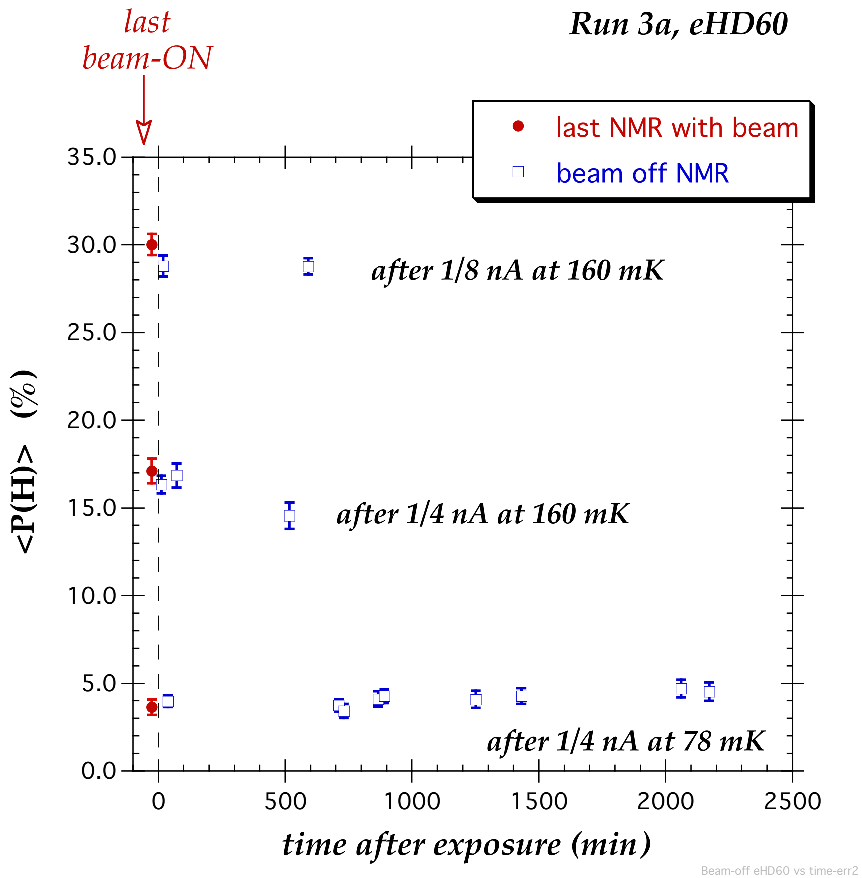
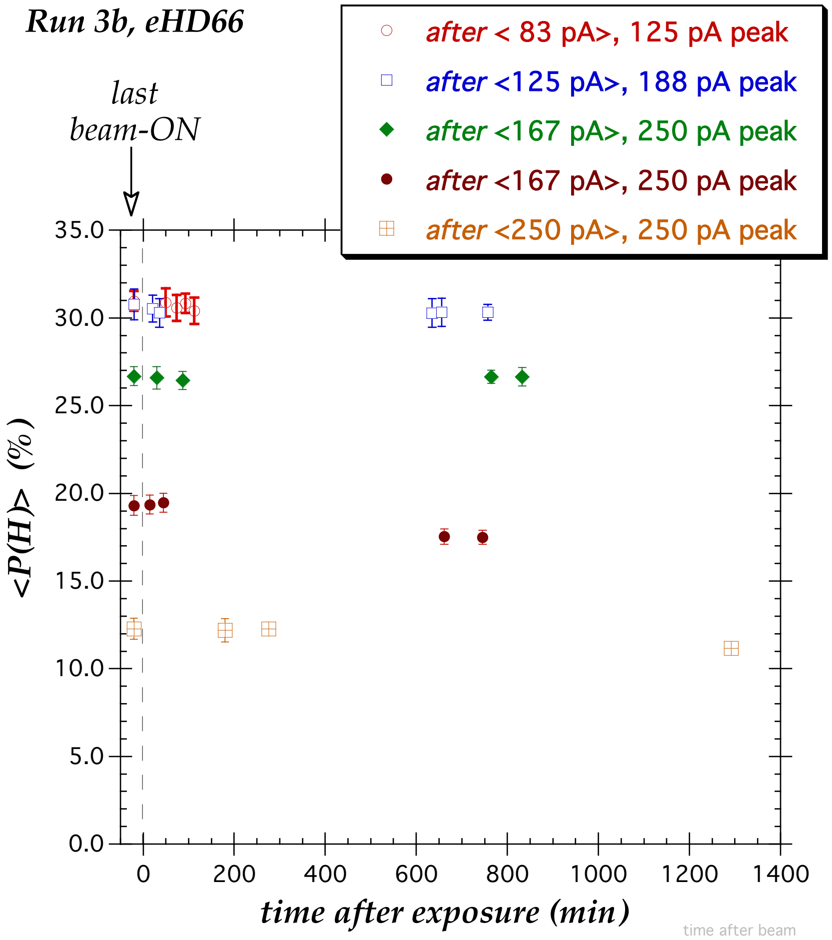
Expectations going into Run 3 (from brief 2012 tests):

- Moller electrons would create a partial screening of the NMR response
  - Run 2 reduction in NMR is either due to *screening*, or to higher HD temperatures
- chemical changes following ionization might break the frozen-spin state
- provided the beam was rastered at > 10 KHz, heat should not be the dominant issue

Preliminary Summary of Runs 2 & 3 – Jan 06/21





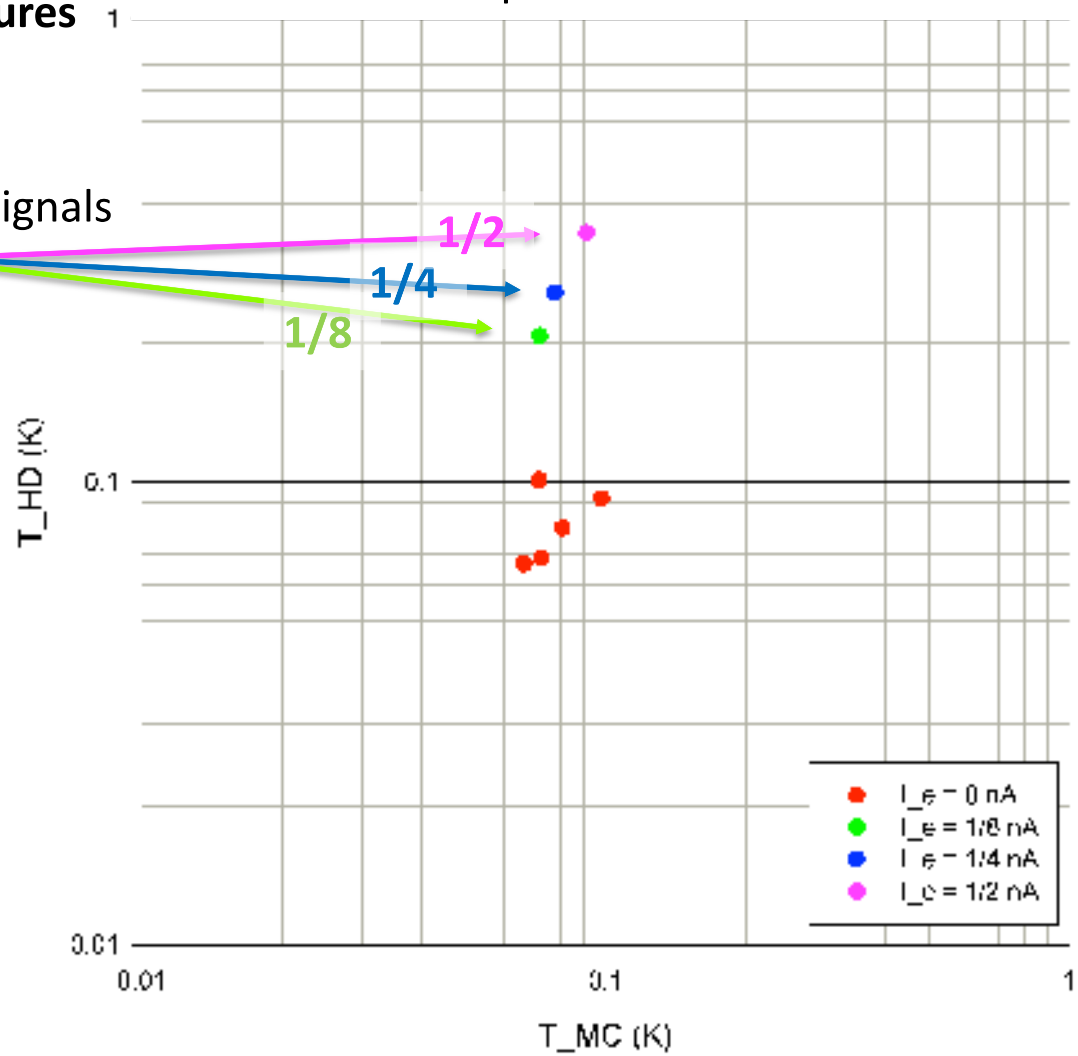
- ⬄ No evidence for screening of the NMR response
- ⬄ No evidence for permanent loss of the frozen-spin state following irradiation

Preliminary Summary of Runs 2 & 3 – Jan 06/21

⇔ **reduced NMR signals in run 2**
must reflect higher HD temperatures

- using Thermal equilibrium NMR signals
  to deduce HD temperatures

Calculated HD temperature vs IBC mixing chamber temperature at different Ie



⇔ T(IBC) < 80 mK, but
T(HD) > 200 mK

<u>heat is certainly an issue</u> !

Preliminary Summary of Runs 2 & 3 – Jan 06/21

⇔ *the consequence of higher temperatures:*

Run 3, target eHD66:

- dP/dt under different holding fields:

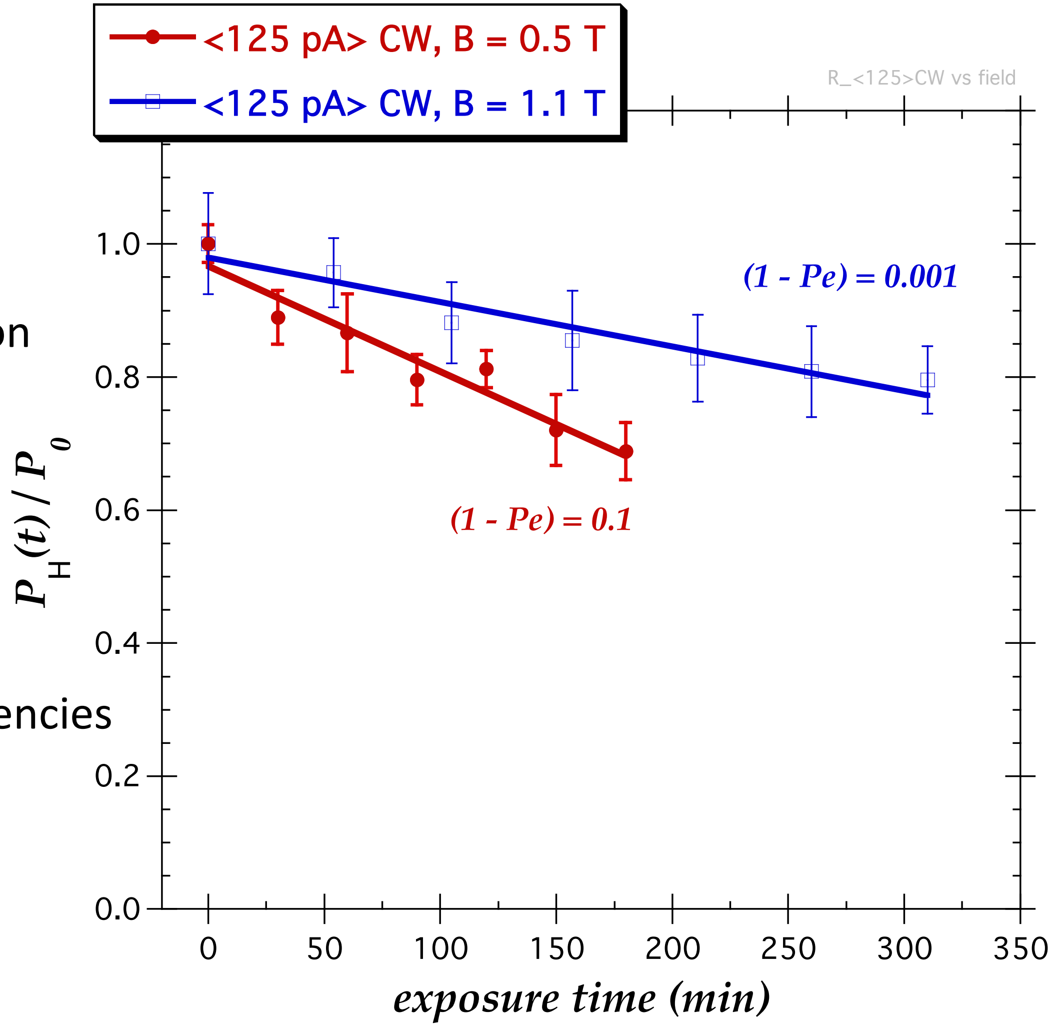
  - same current ⇔ same temperature

  ⇔ different atomic electron polarization

- **High HD temperatures (> 200 mK) result in only partial atomic electron polarization**

  ⇔ flipping electron spins have Fourier components at the H-Larmor frequencies

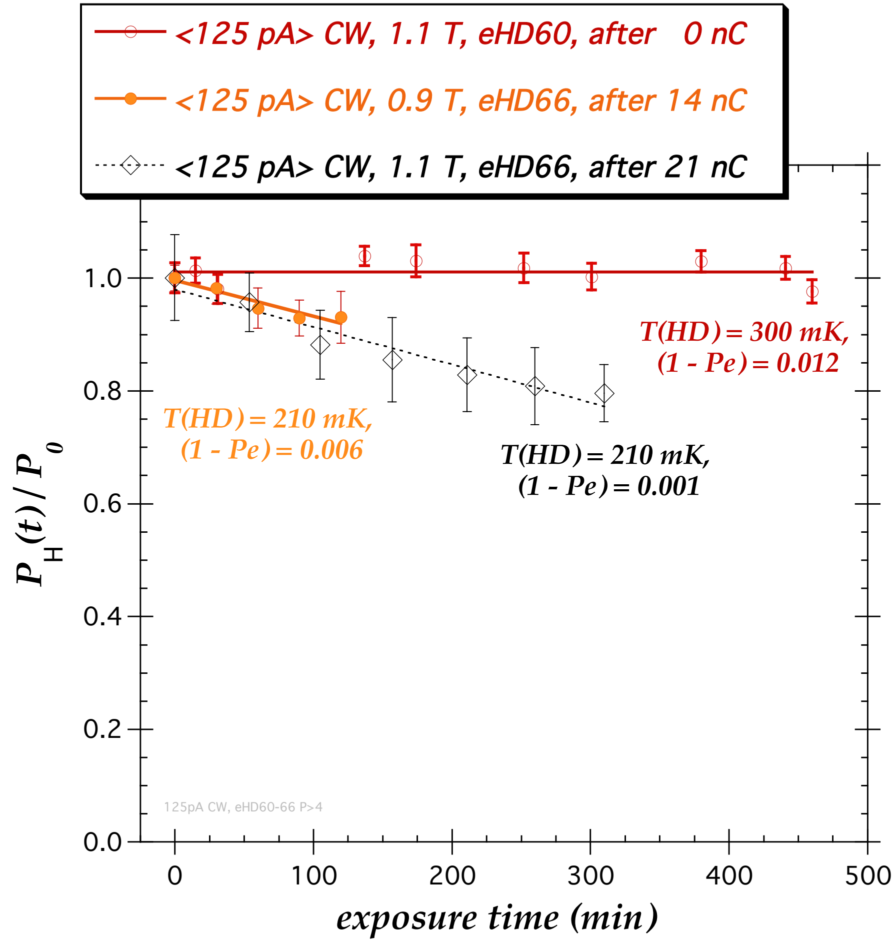
  ⇔ significant dP/dt

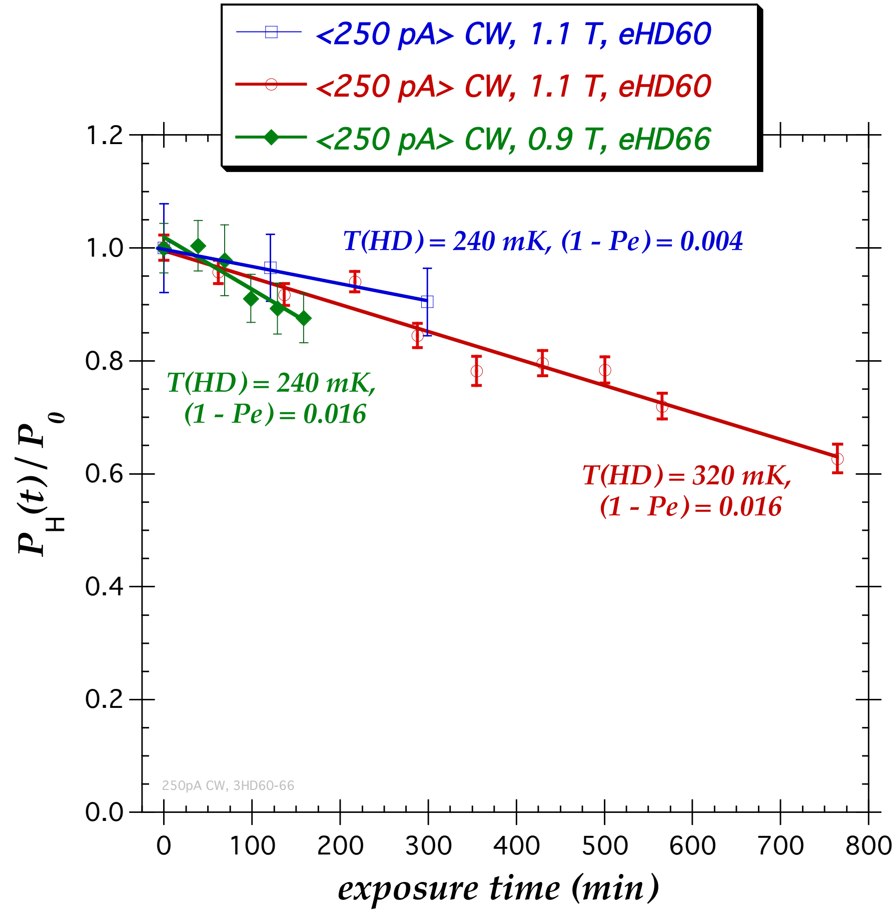


ref – intended goal:

at 100 mK & 1.1 T, (1 - Pe) = 5 e-7

Preliminary Summary of Runs 2 & 3 – Jan 06/21





- *initial* dP/dt slope is flat, but develops with dose
- but, there is no long-term effect on the frozen-spin state (P_H is steady with no beam)

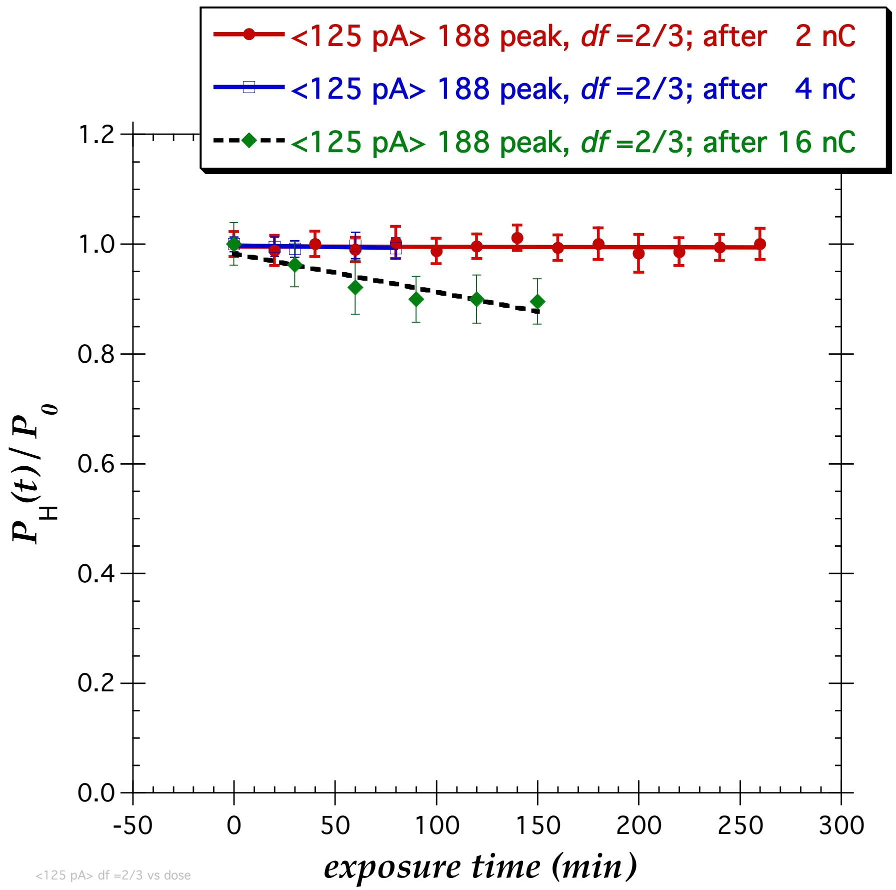
⬄ charge build-up ?

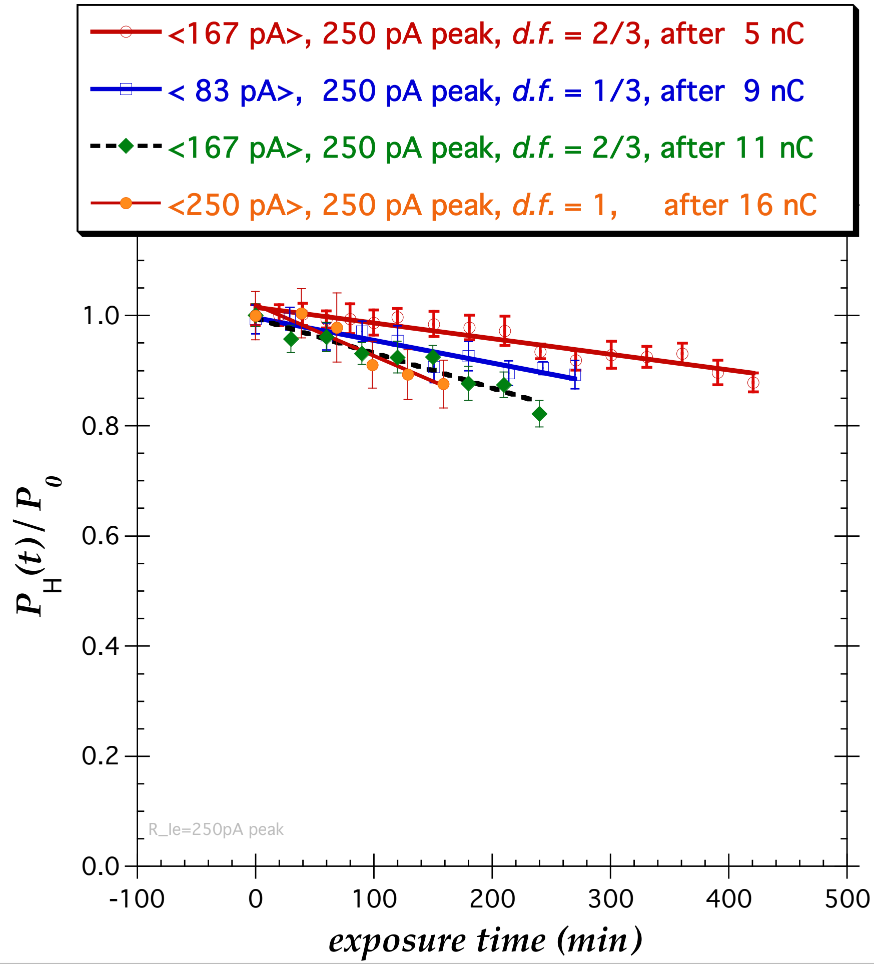
Preliminary Summary of Runs 2 & 3 – Jan 06/21

Run 3 – measurements with beam *blocked* for windows on the several ms time scale

– *d.f. = 2/3* ⇔ beam-on for 10 raster cycles + off for 5 raster cycles

– *d.f. = 1/3* ⇔ beam-on for 5 raster cycles + off for 10 raster cycles





HDice status – Jan 06/21

- the present state of HDice is not able to support the required RG-H luminosity

  ⇔ if there is another viable target technology that can provide most of the Physics reach, it should be pursued

  – if alternative options are limited, there are avenues worth investigating that may extend the viability of HDice targets, although these are R&D projects

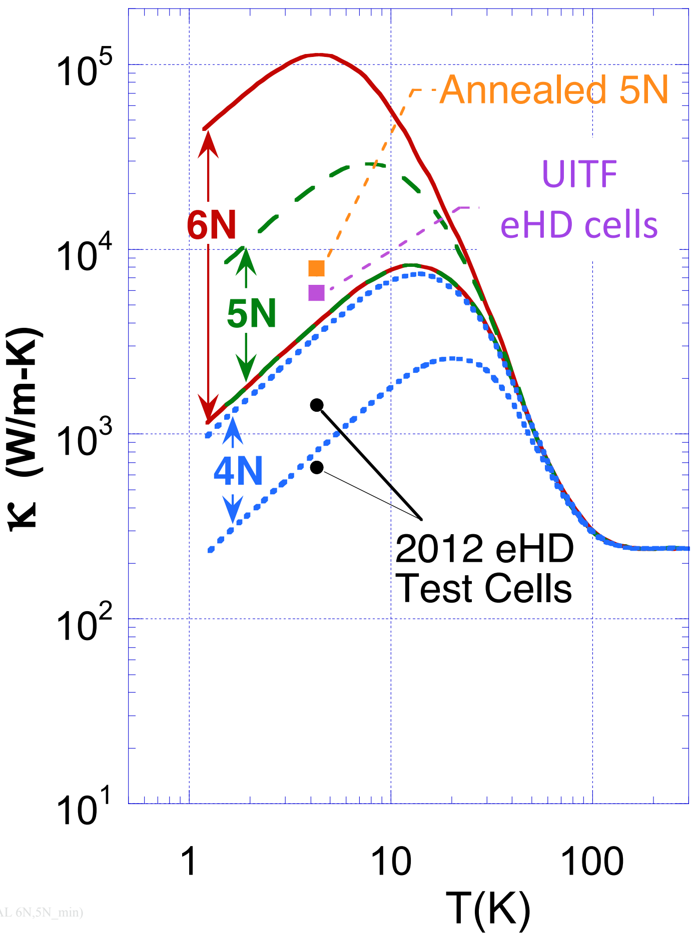
Possible HDice R&D – Jan 06/21

HDice data: (● ■ ■)

curves: —— 6N, —— 5N, —— 4N

Thermal Conductivities for pure Aluminum

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



Why is Eloss heat not getting out of the HD ?

- Tc (AL) = 1.2 K
- but Bc ~ 100 gauss

⇔ there is no data below 4 K

⇔ measure conductivity **κ** in the mK region

possible outcomes:

(α) κ(AL) deviates from extrapolated curves

⇔ the AL wires are the bottle-neck

(b) κ(AL) follows the extrapolated curves

⇔ the HD itself is the bottle-neck

Possible HDice R&D – Jan 06/21

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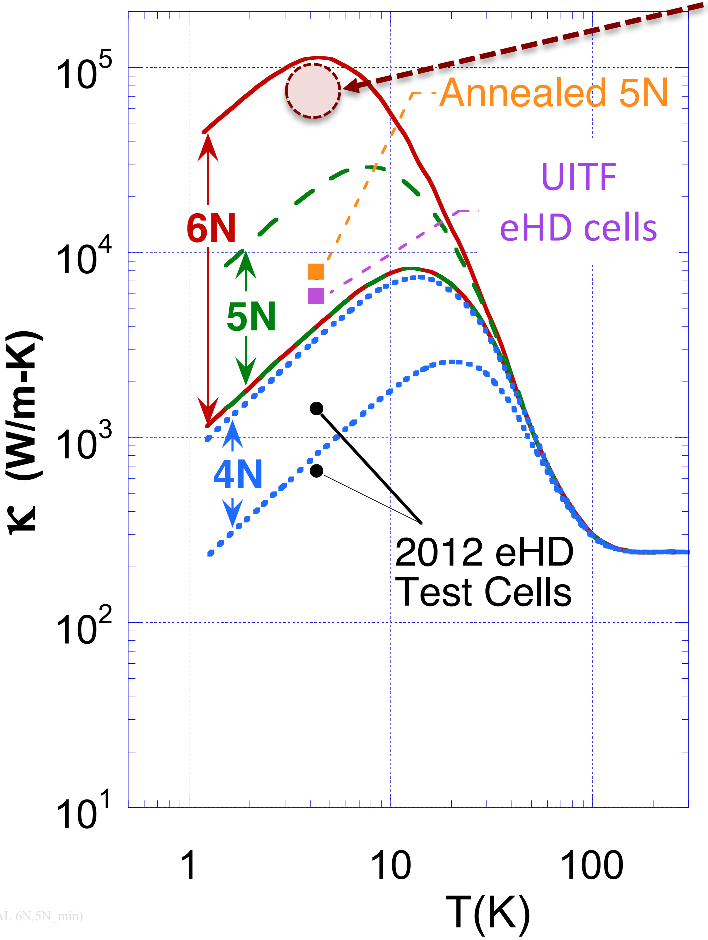

high 6N (99.9999%) Al wire could significantly improve cooling

(a) If AL conductivity is the limitation:

→ acquire ultra-high-purity AL

eg. Isotopic ^{27}Al,

purified by magnetic separation,

→ extruded into wire (by Alpha-Aesar)

Possible HDice R&D – Jan 06/21

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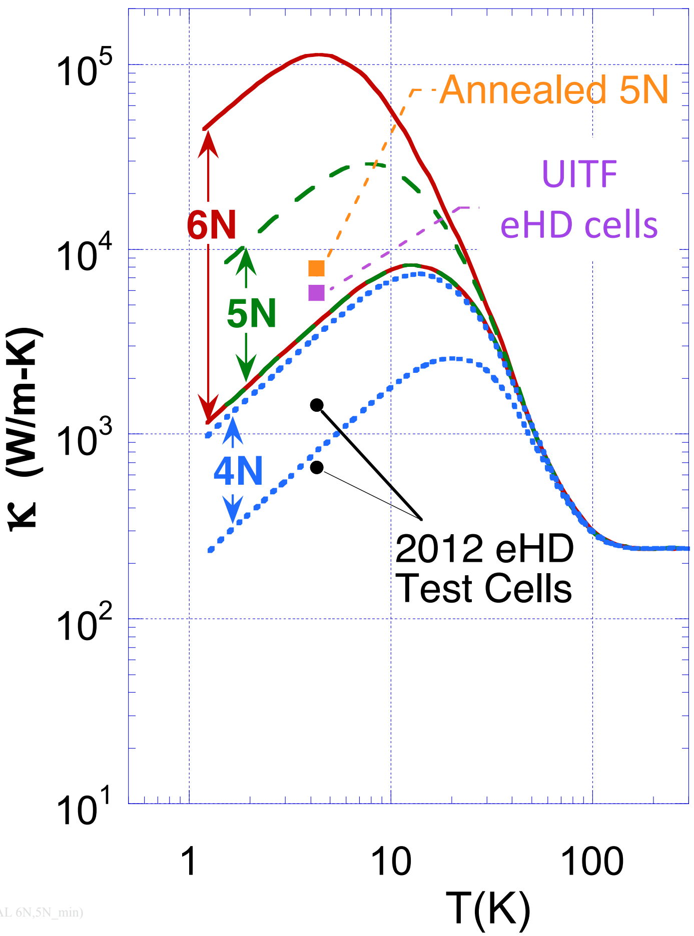
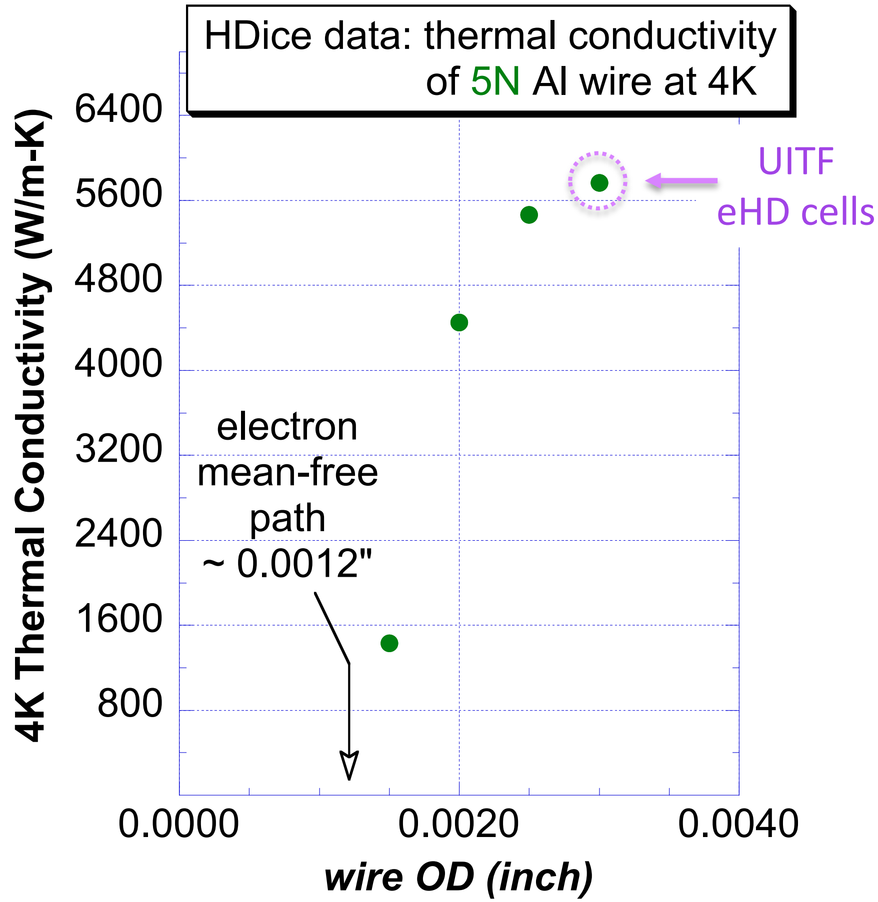
(b) If HD is the bottle-neck

→ decrease wire OD & increase number to decrease HD –to- Al distance





Possible HDice R&D – Jan 06/21

- investigate relevant time scales for charge build-up in HD:

  → with a short-T_1 HD, measure NMR with *d.f.* = 1/3 and 2/3

  → deduce equilibrium HD temperature; what dominates <Ie> or peak-current ?

  → investigate faster beam-blanking

  → possible Run 4, ~ 1 week (UITF has LHe until mid-March)