HydroX: Hydrogen-doped Liquid Xenon to Search for Sub-GeV/c^2 Dark Matter Particles

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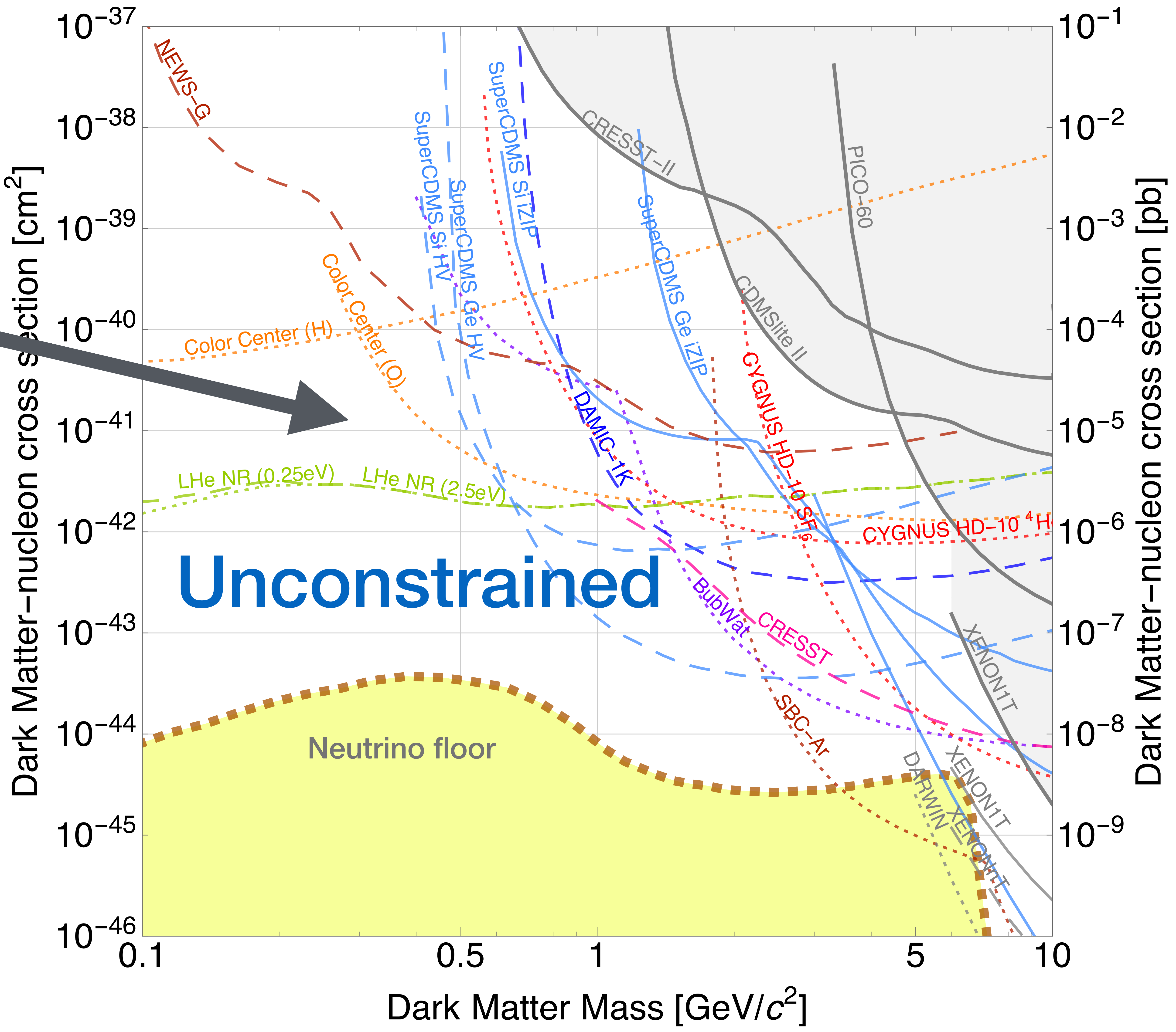
Low mass dark matter

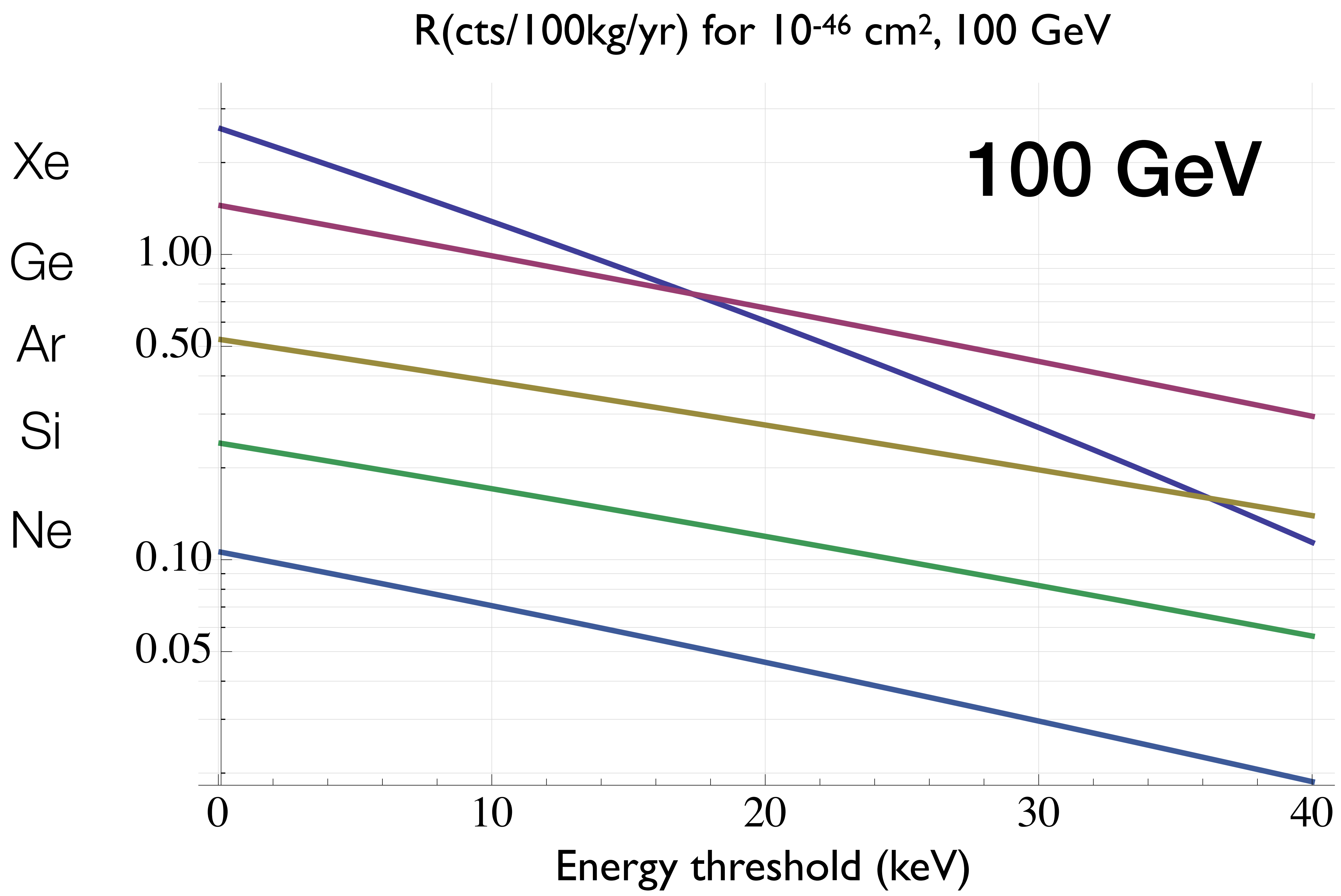
From Cosmic Visions (1707.04591)

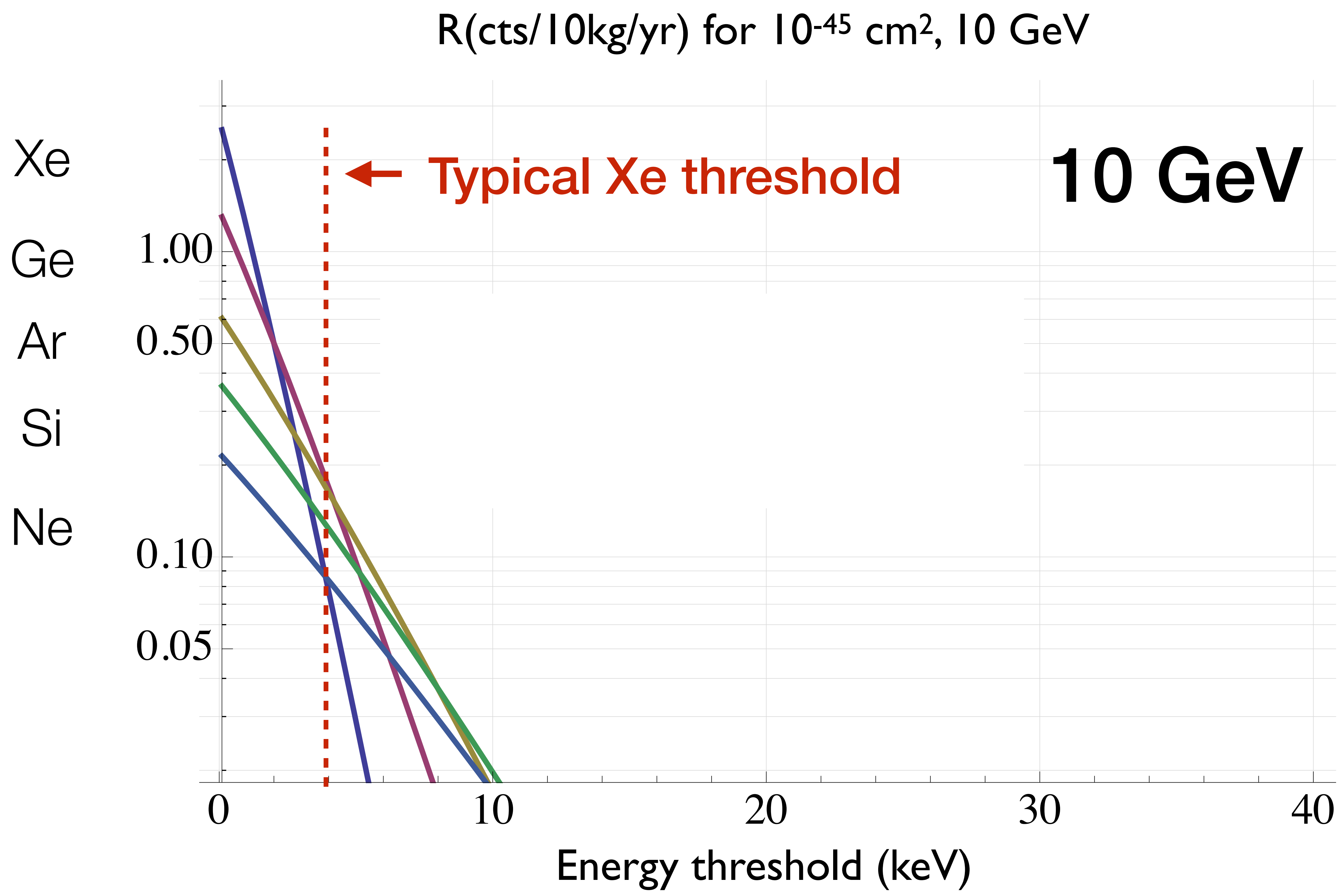
Many new proposed experiments aimed at <5 GeV/c²



Existing liquid noble searches are in 10s-100s GeV/c²

Low mass dark matter rate





For low mass sensitivity, need:
(1) low threshold
(2) lighter target for better kinematic match to DM mass

Low mass dark matter detectors

Challenge		Solution
Kinematics	→	Match target-DM mass
Low energy depositions	→	Low energy threshold
Extremely rare interaction	→	Large/scalable target mass
Environmental backgrounds	→	Underground / shielding
Detector backgrounds	→	Self-shielding, discrimination, radiopurity
Impurities	→	Purification
Unknown particle physics	→	Sensitivity to multiple interaction types

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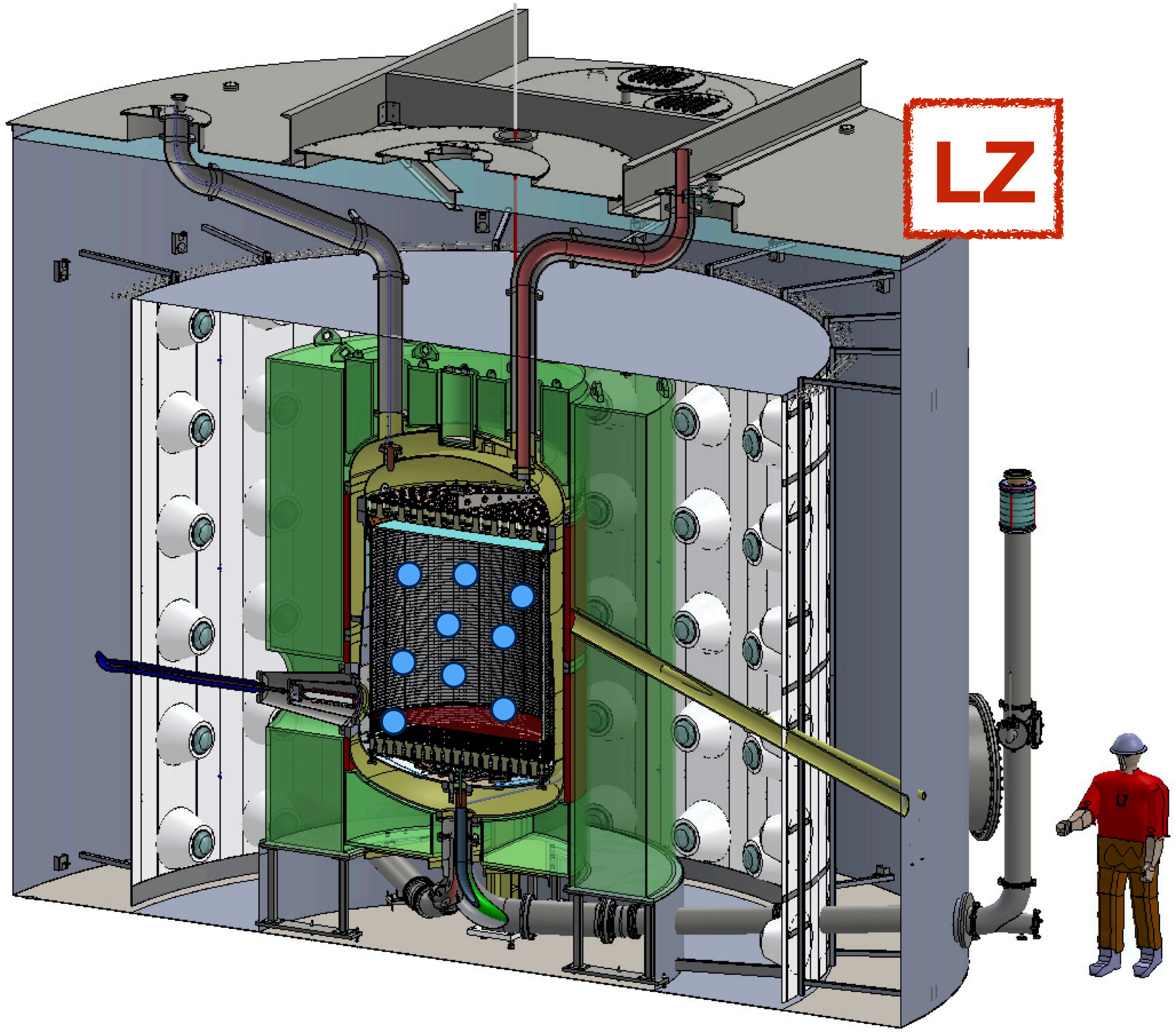
But LZ has a heavy target (Xe)

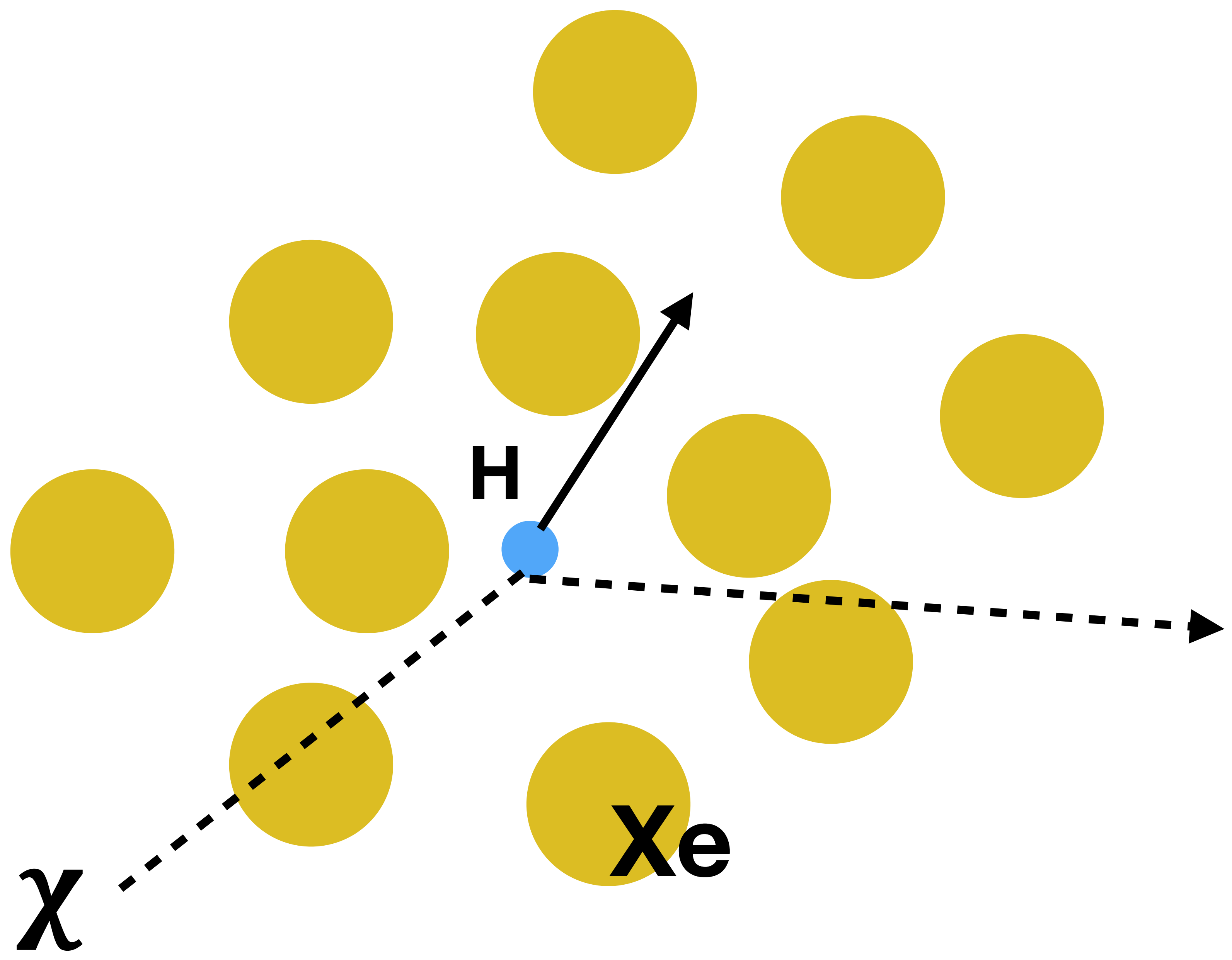
Put a low-Z target in LZ,
while retaining benefits of Xe

HydroX: Hydrogen-doped Xenon

1. Dissolve H_2 into LXe

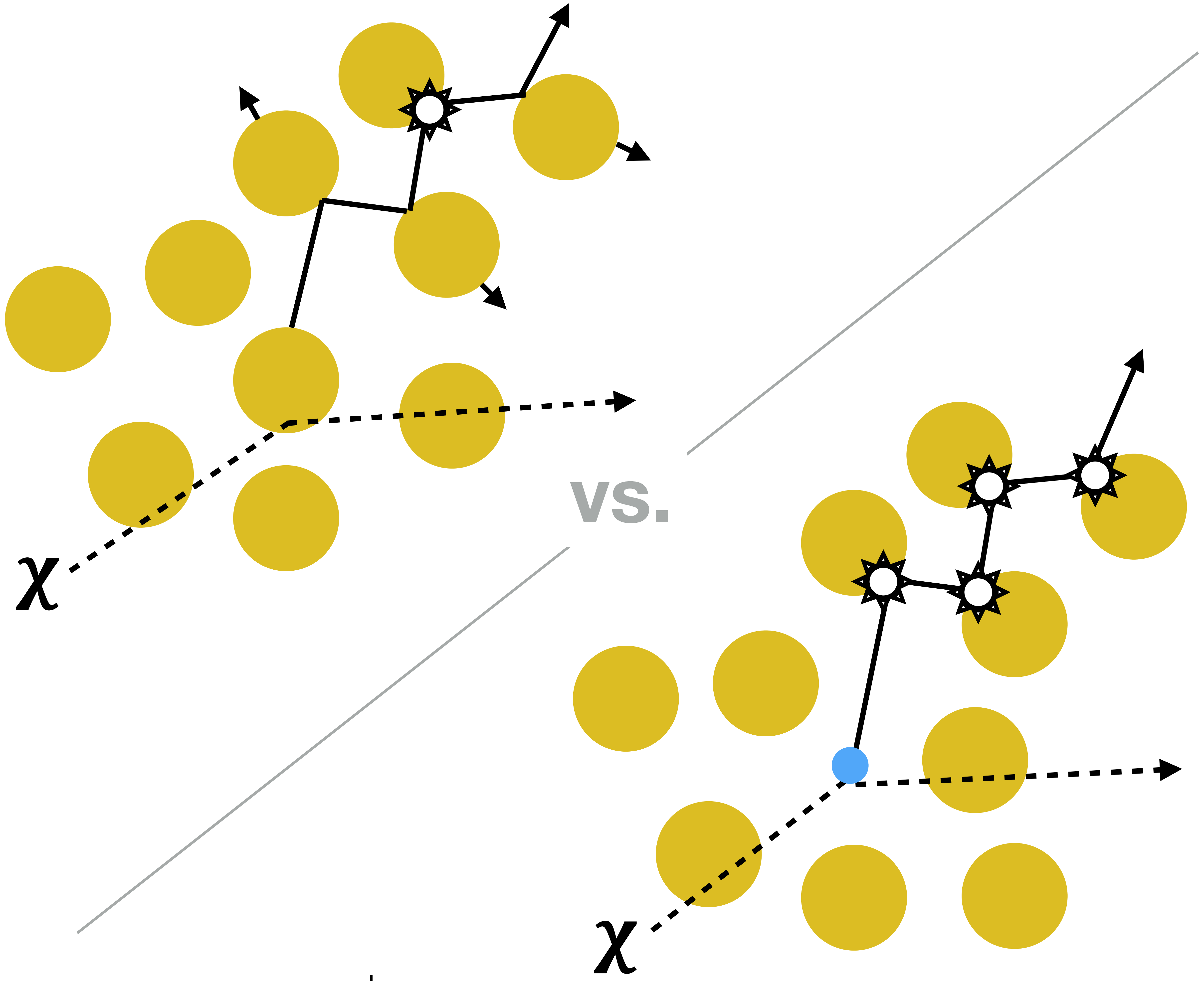


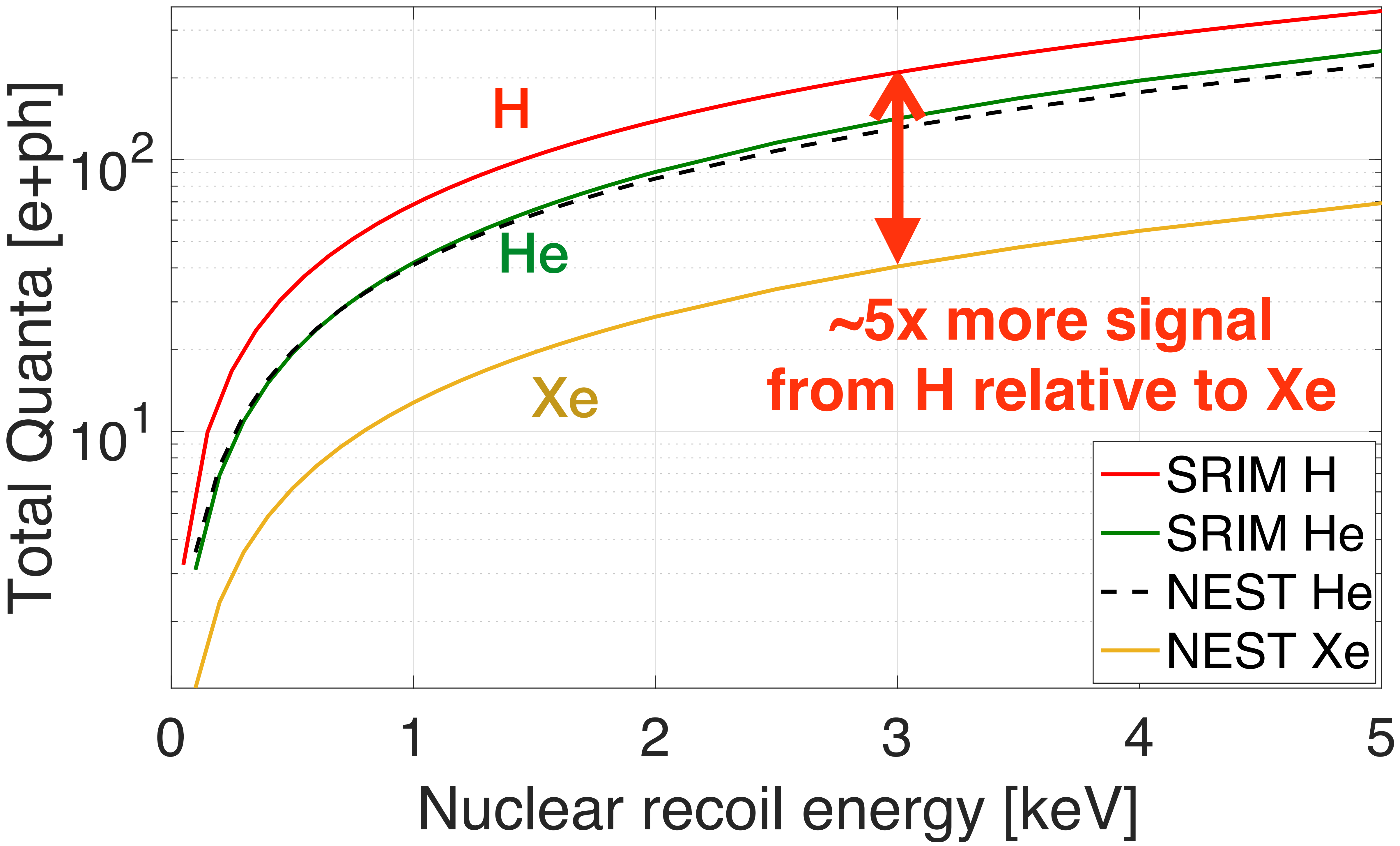
2. Look for recoiling proton



HydroX advantages: signal yield

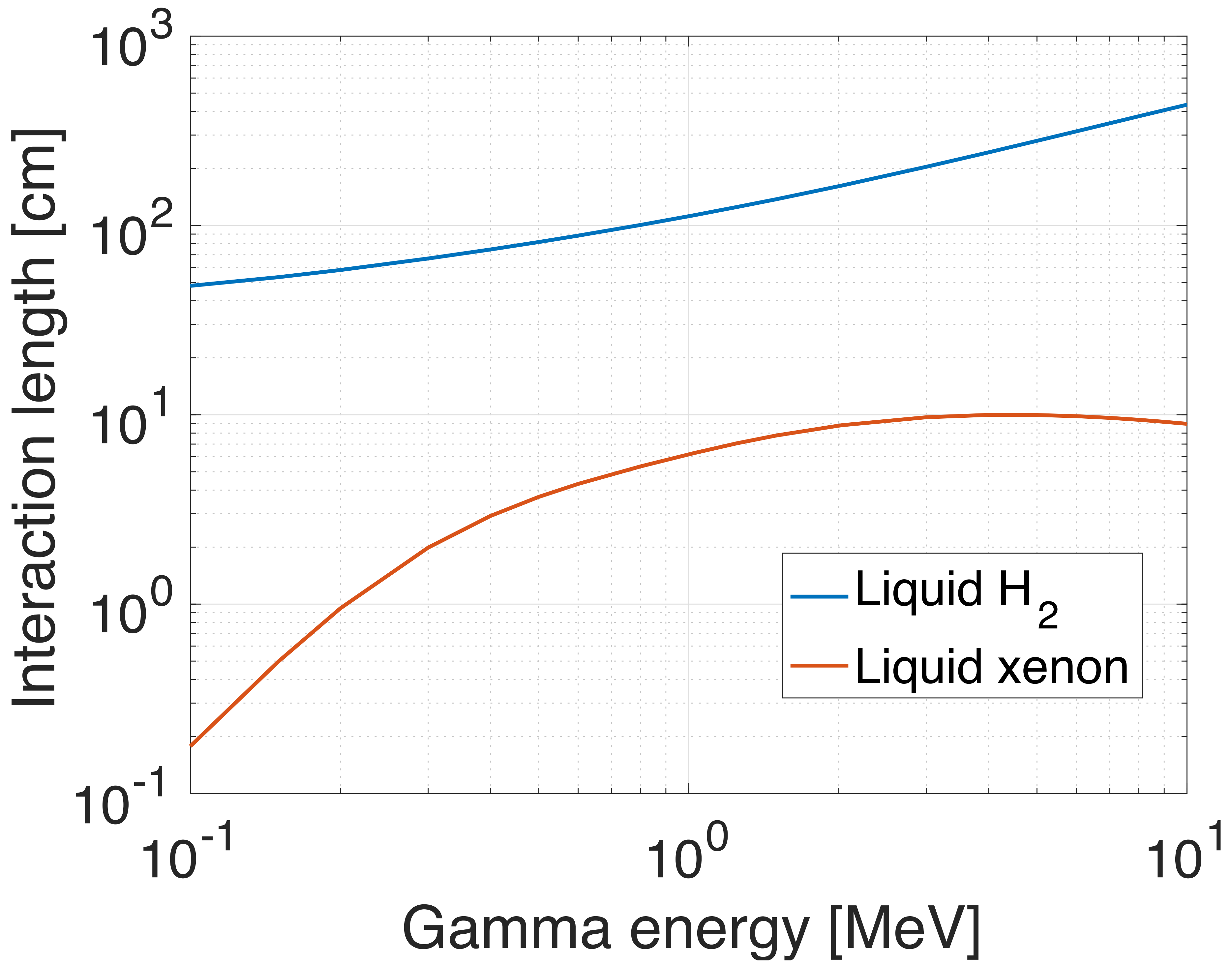
- Xe recoil: $m_{Xe}=m_{Xe}$ → energy lost to heat (Lindhard) → O(20%) of energy is observable
- H_2 recoil: $m_p \ll m_{Xe}$ → all electronic excitations → ~100% of energy is observable



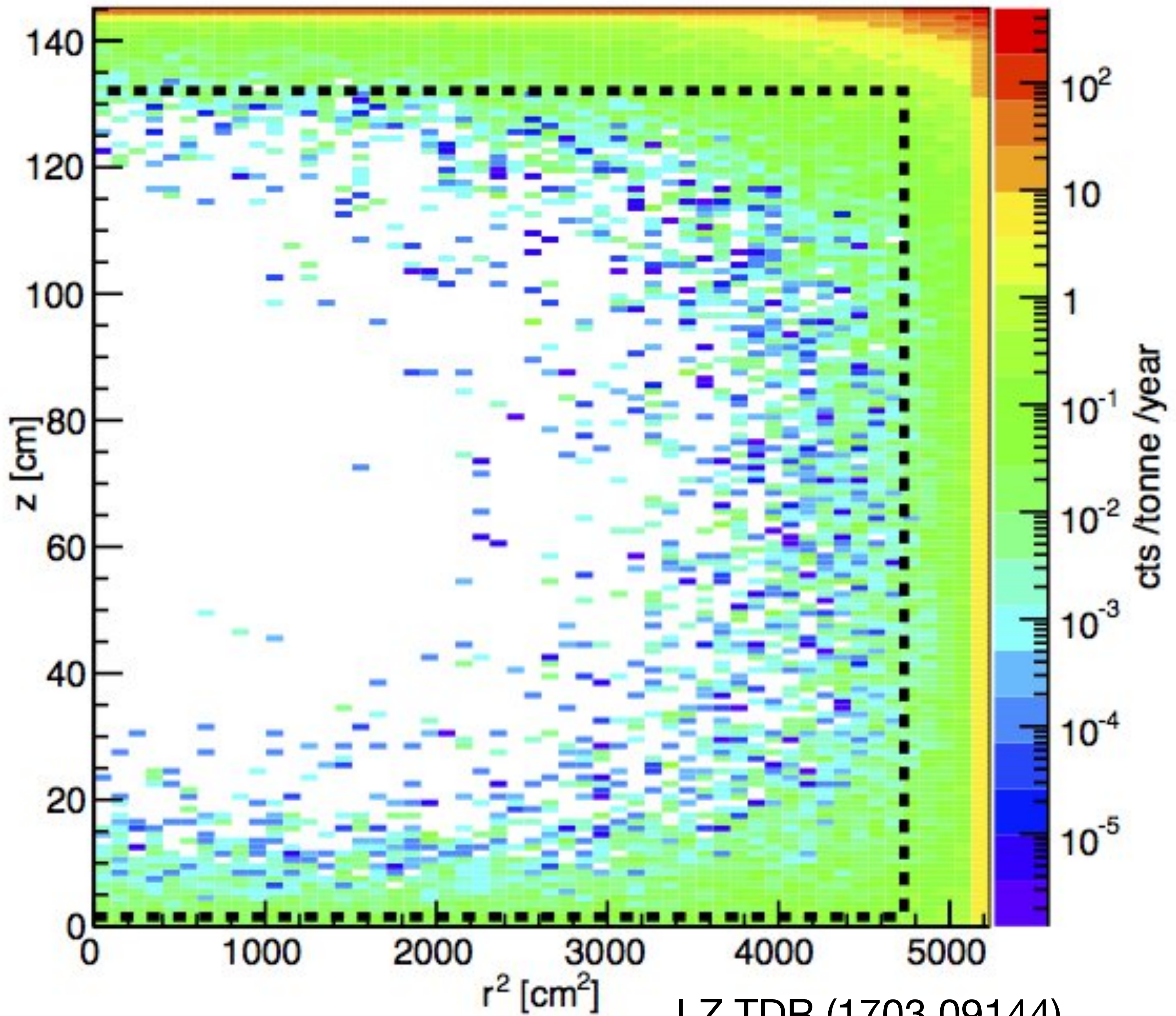


HydroX advantages: BG mitigation

- Retain self-shielding of LXe
- Vetoes, water tank, intensive radio-cleanliness of LZ
- Fully characterized BG model from LZ



LZ ER+NR backgrounds (external)

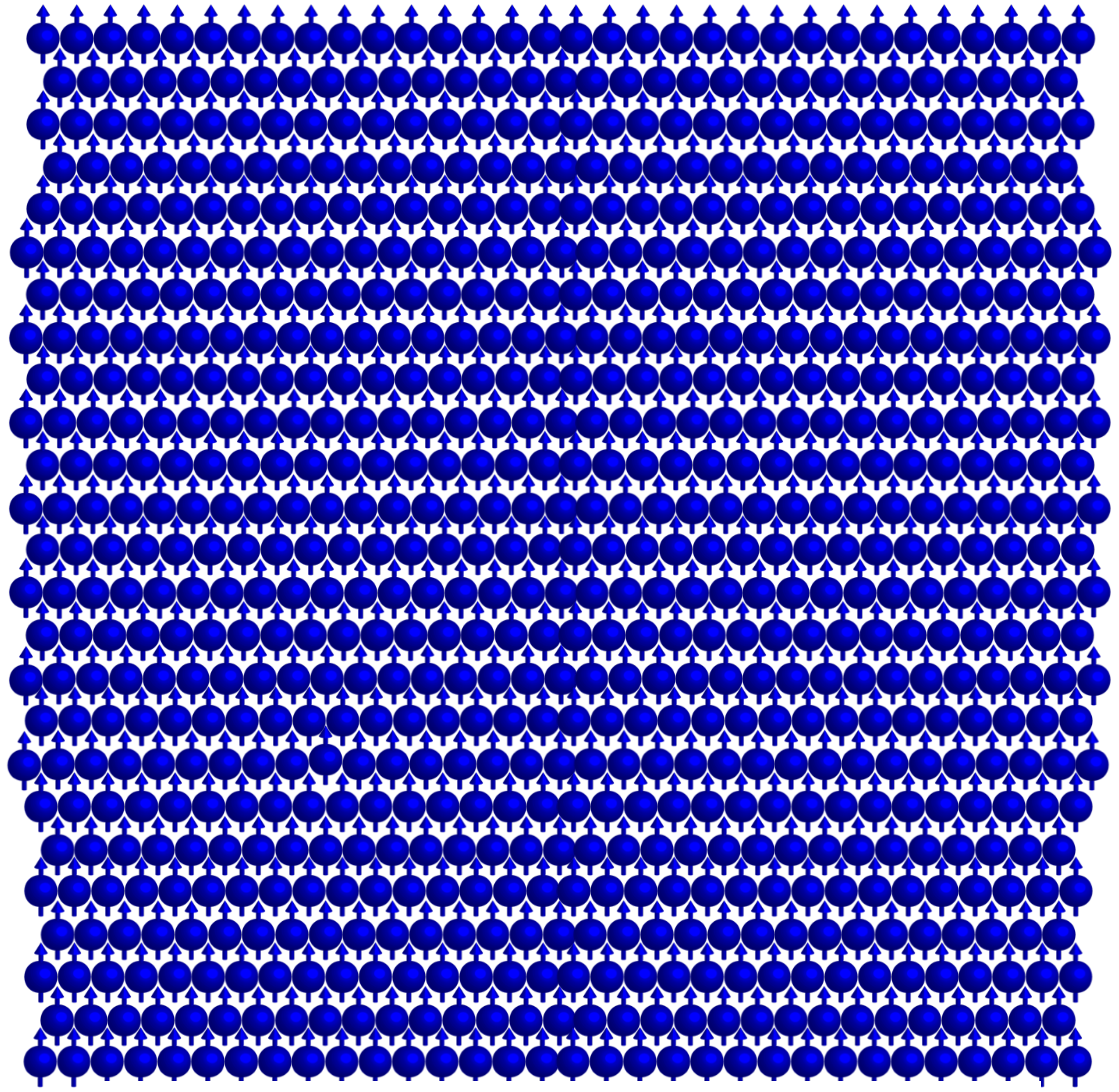


LZ TDR (1703.09144)

HydroX advantages: SD sensitivity

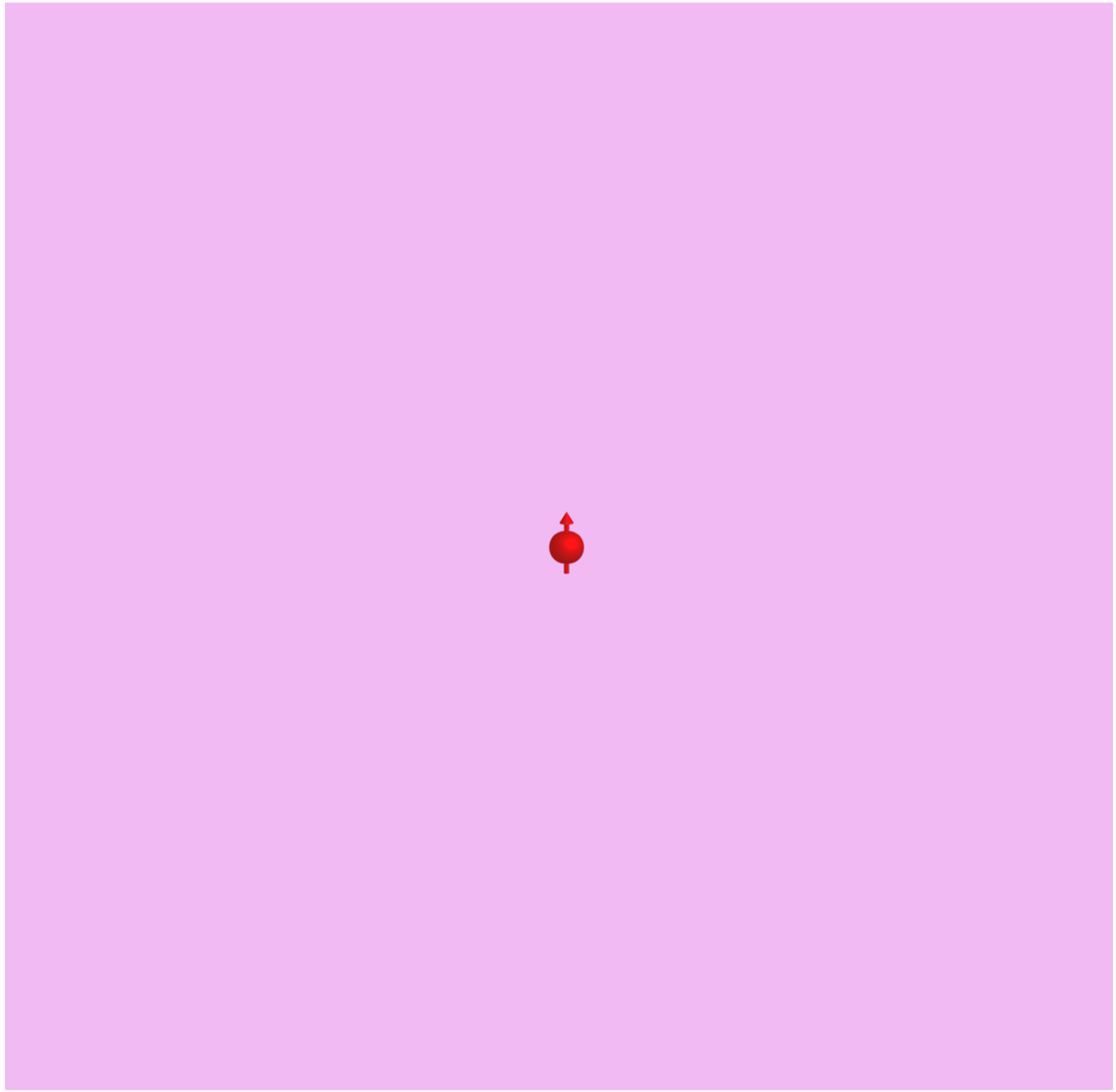
For equivalent masses of H and Xe:

^{1}H



unpaired proton spin

^{nat}Xe



unpaired neutron spin

^{1}H has 820x more SD sensitivity per kg than ^{nat}Xe

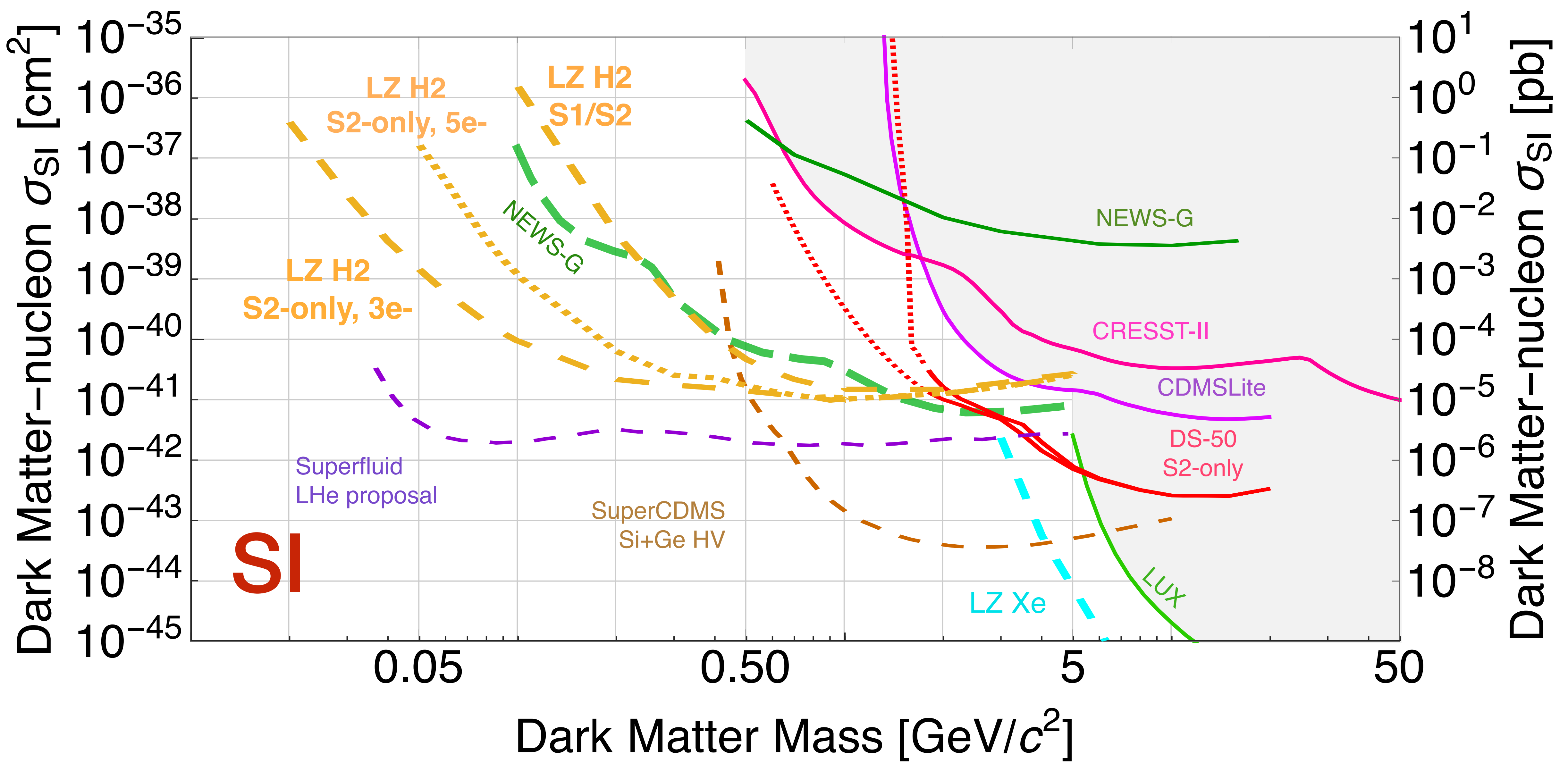
In addition, use **deuterium**: gives both DM-p and DM-n sensitivity

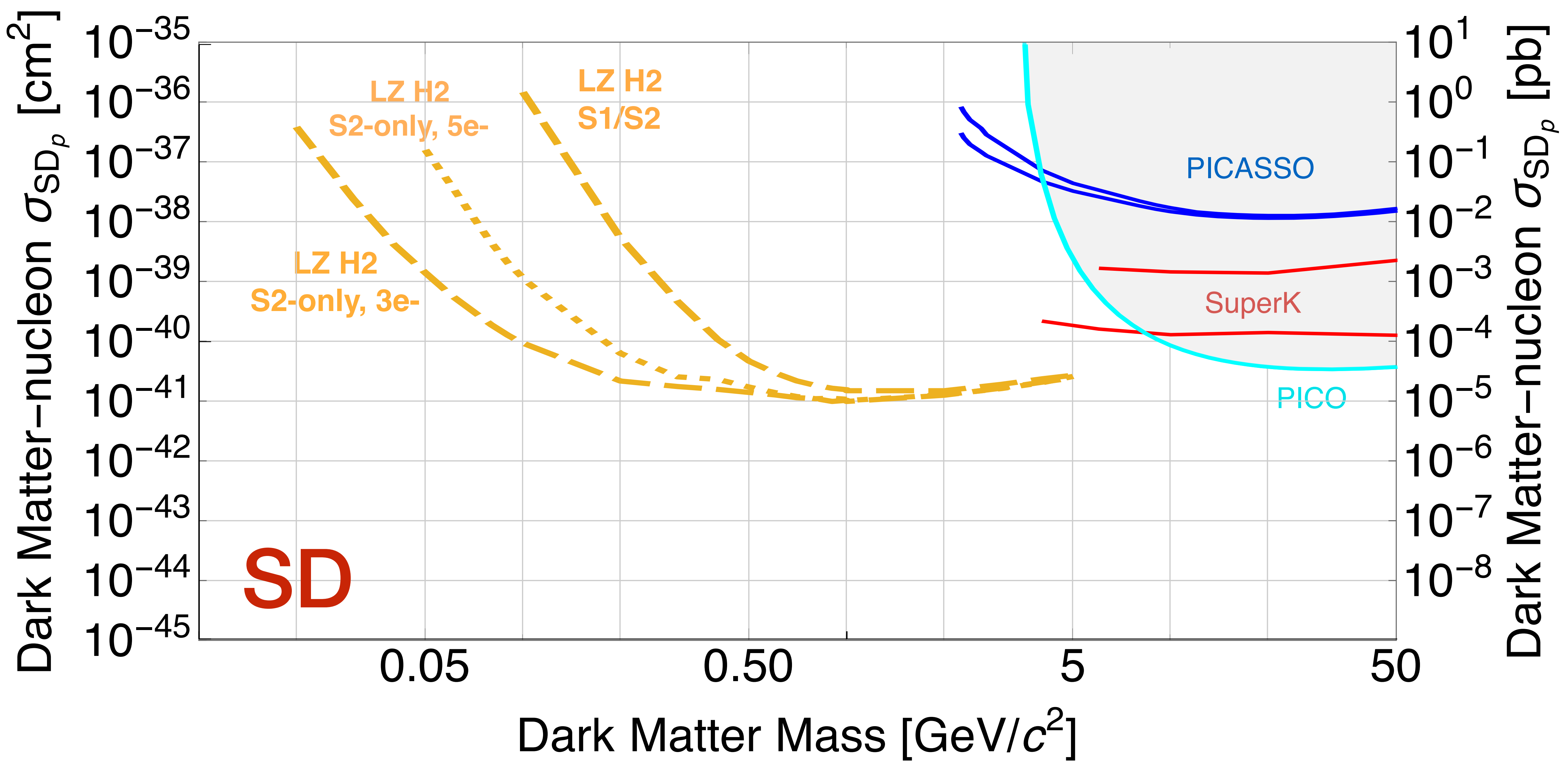
HydroX sensitivity

Assumptions:

- Signal yields from SRIM + LZ detector model
- 2.2 kg of H_2 in LXe (2.6% mol fraction)
- Proton recoil S2/S1 is ER-like (no discrimination)
- 250 live-day exposure

SD sensitivity at low mass is unique



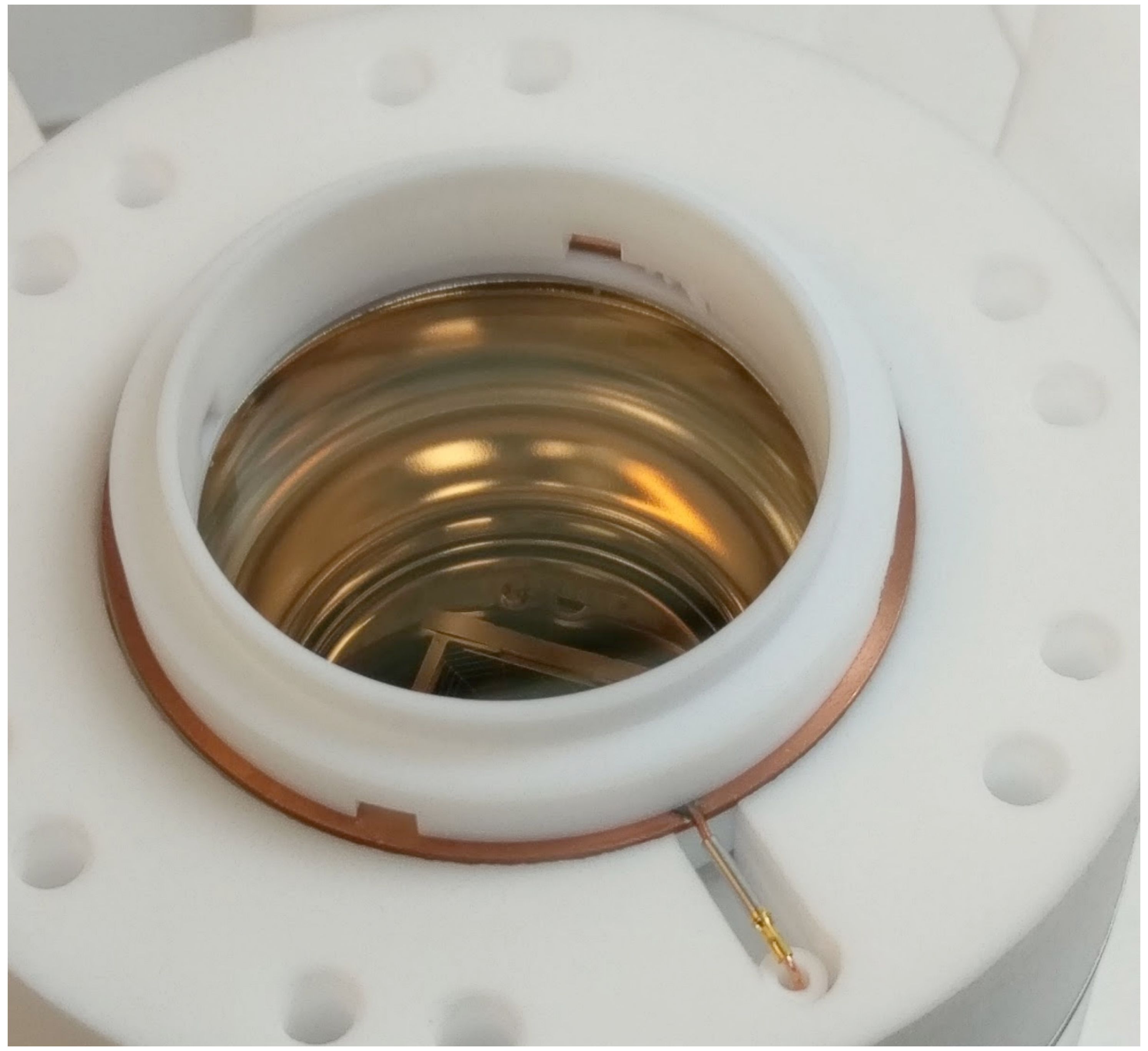


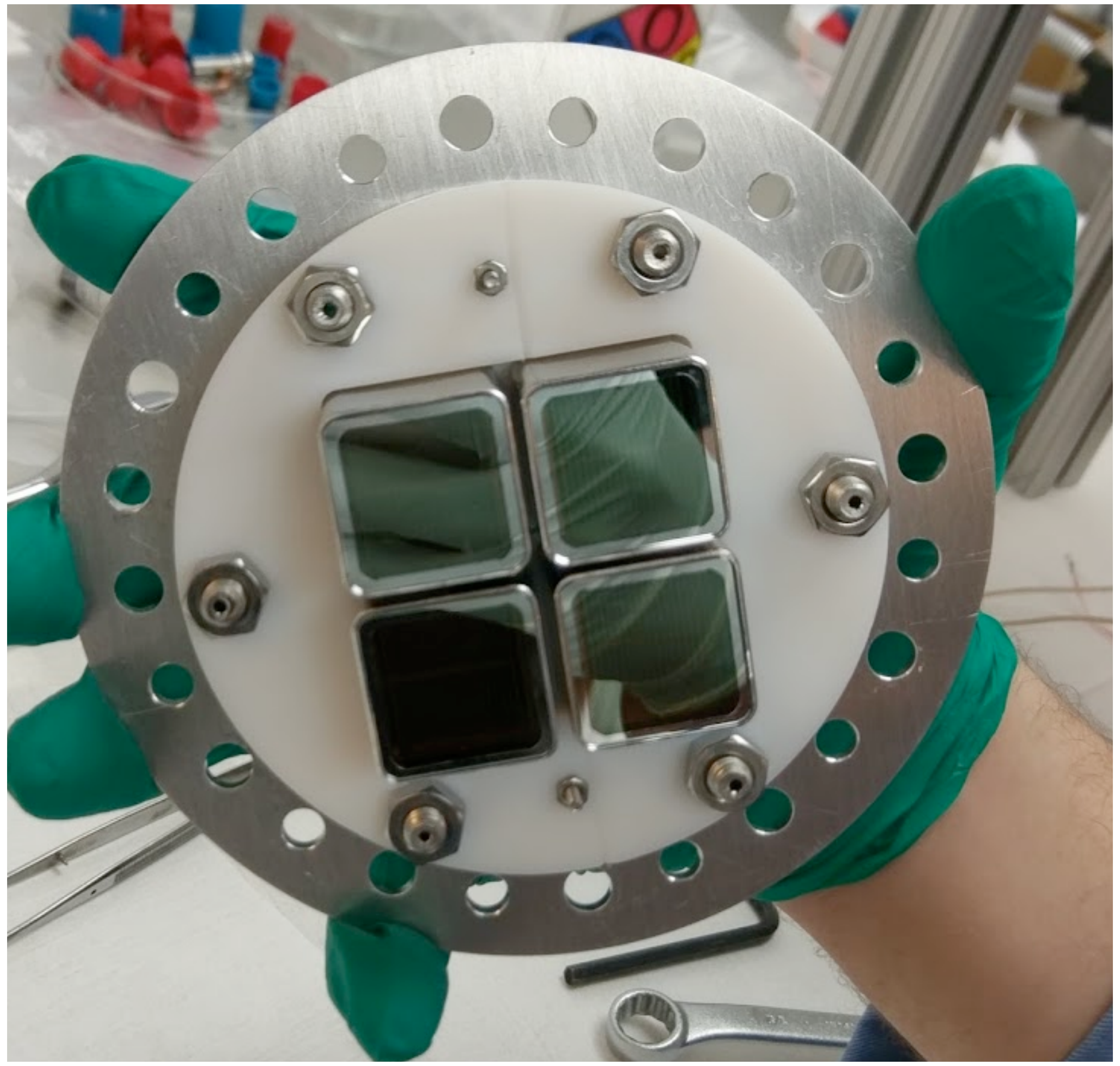
R&D

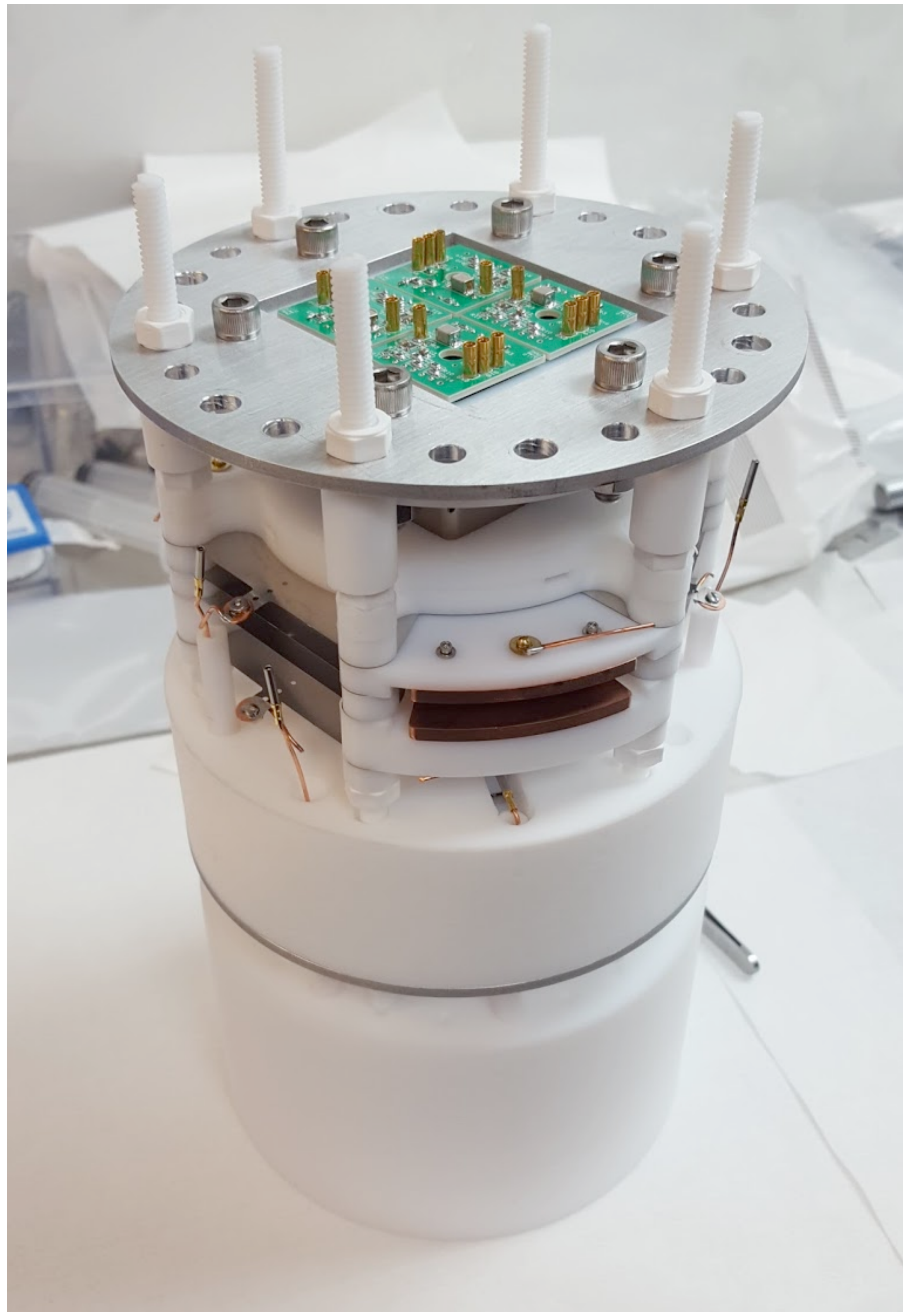
- **Will it work?**
  - What is Henry coefficient?
  - Effect on signal generation (light and charge)
  - Circulation and cryogenics
  - Purification removes H_2
  - Ti embrittlement
  - H_2 leakage into PMTs
- **How do we calibrate?**
  - Ultra low energy proton recoils in LXe
  - Effect on discrimination
- **How do we make it work in LZ?**

Injecting H_2 into LXe

- XELDA: small TPC constructed at Fermilab
  - Originally for measuring ER discrimination for inner shell e-, now for H_2-doping
- One 3” PMT facing four 1” PMTs
- Gas phase circulation, inject H_2 at the condenser

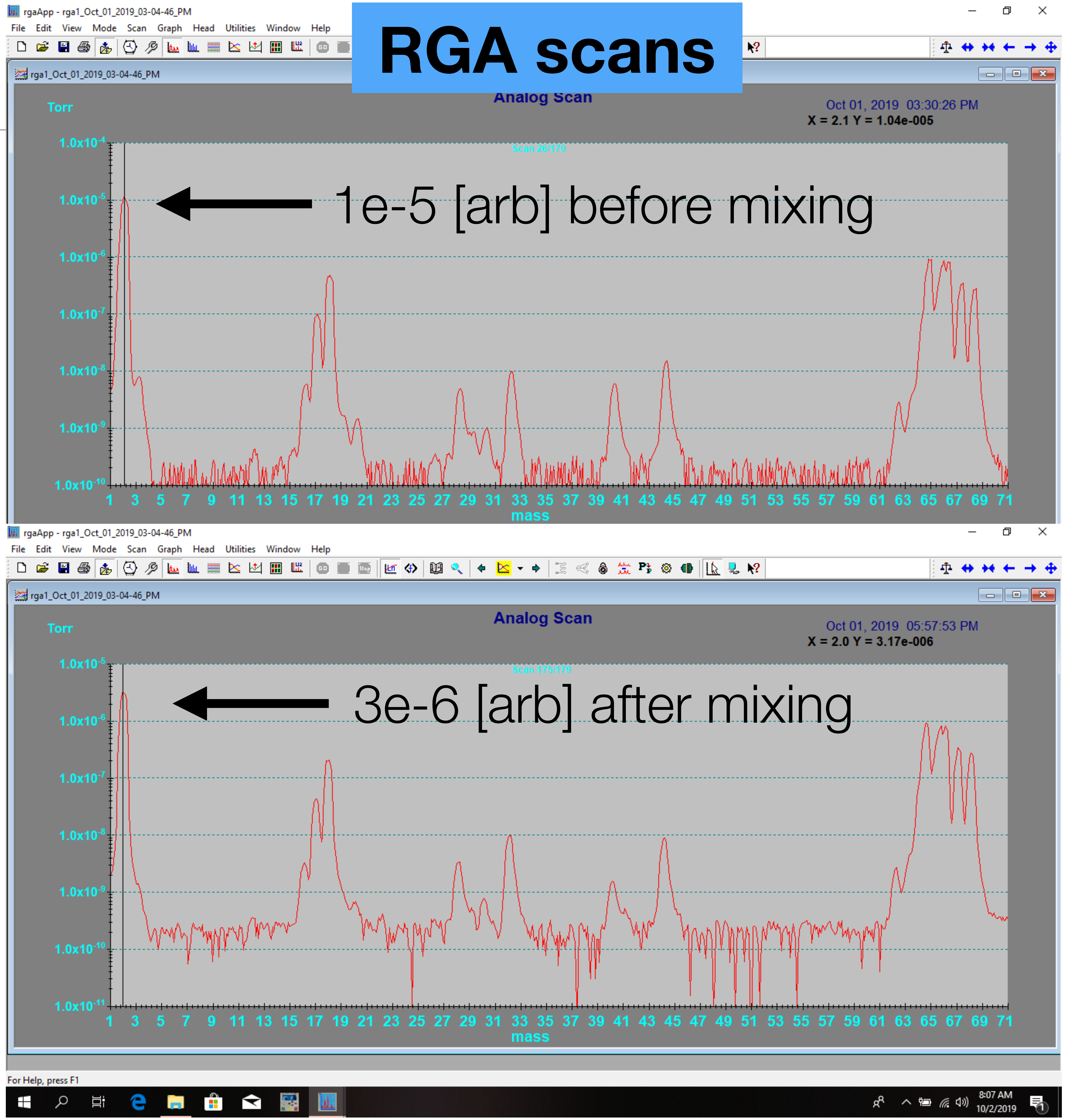






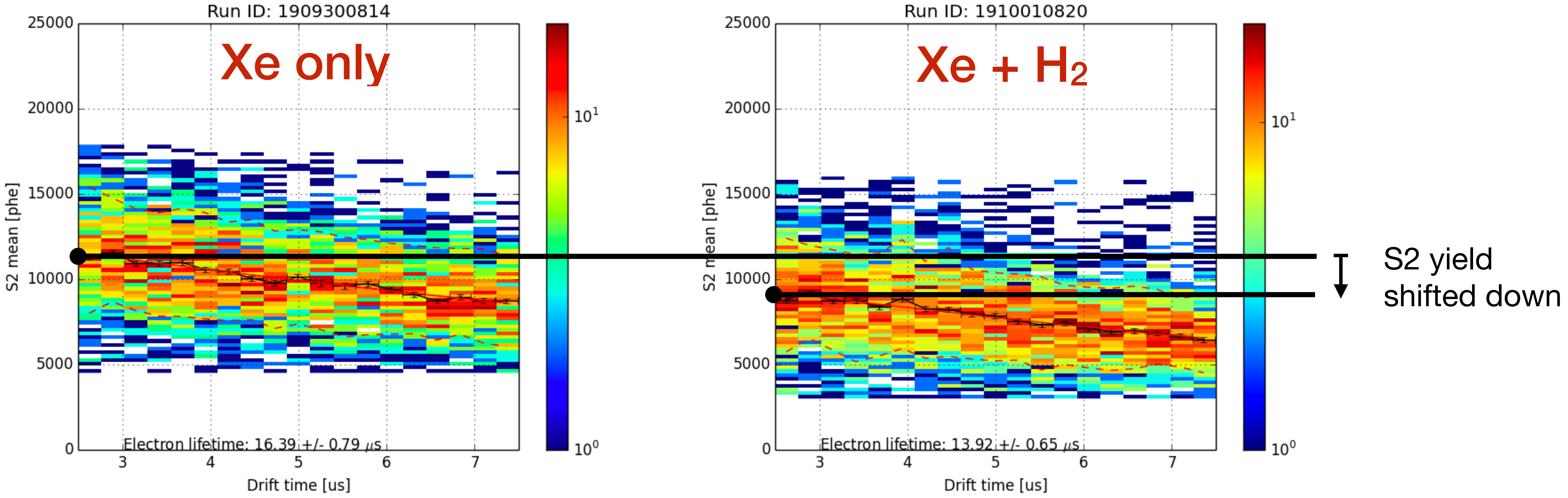
Injecting H_2 into LXe

- Is H_2 in the liquid?
- YES, though hard to say how much
  - Measure H_2 in gas space after injection, before and after inducing mixing (circulating)
  - H_2 level in gas space goes down, (by factor 2-3) → H_2 is in the LXe



Injecting H_2 into LXe

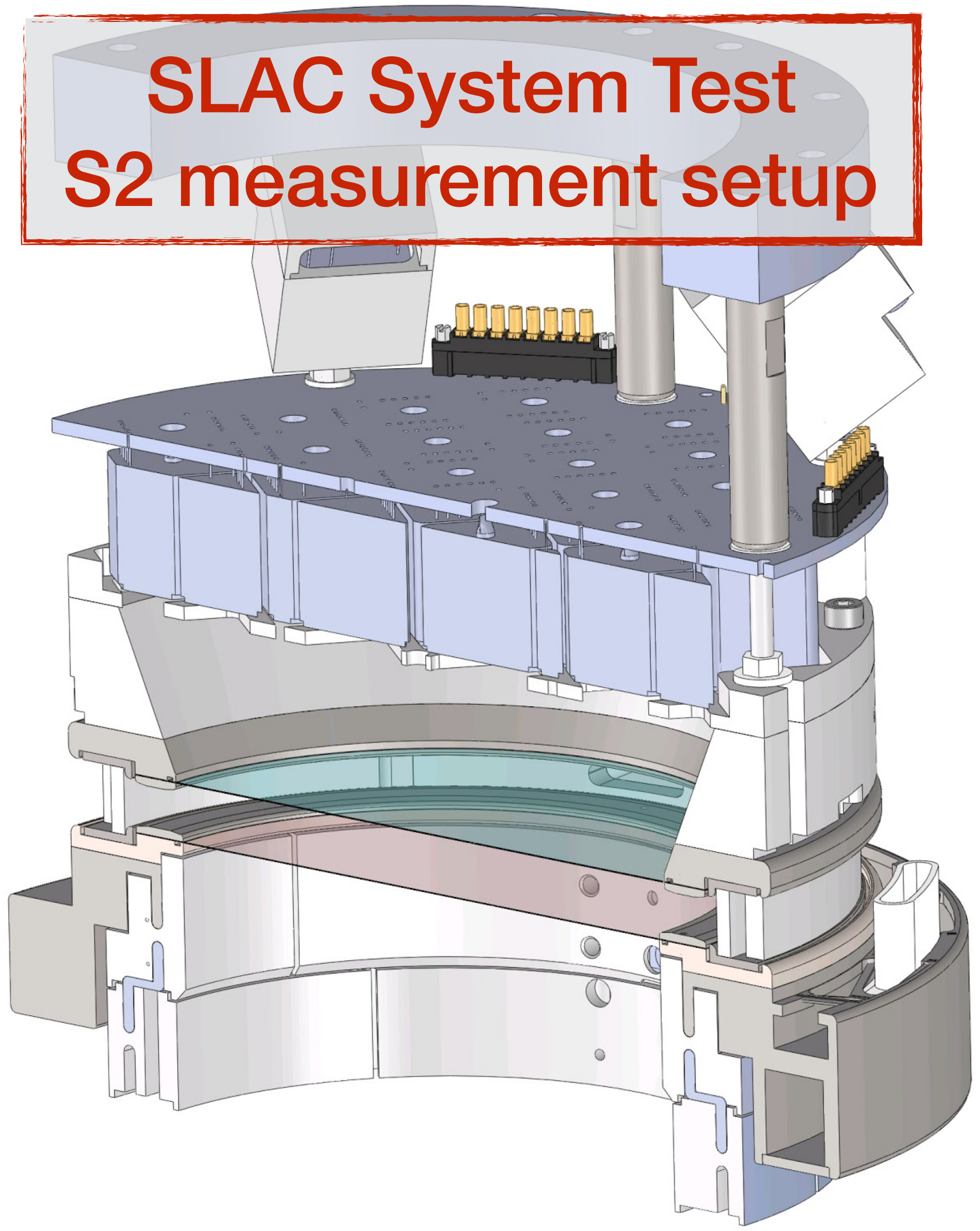
- TPC still working!
  - S1s and S2s still being produced and can see them
- Loss of S2 yield (as predicted)
- Possible decrease in S1 yield (~10%)



Immediate next steps

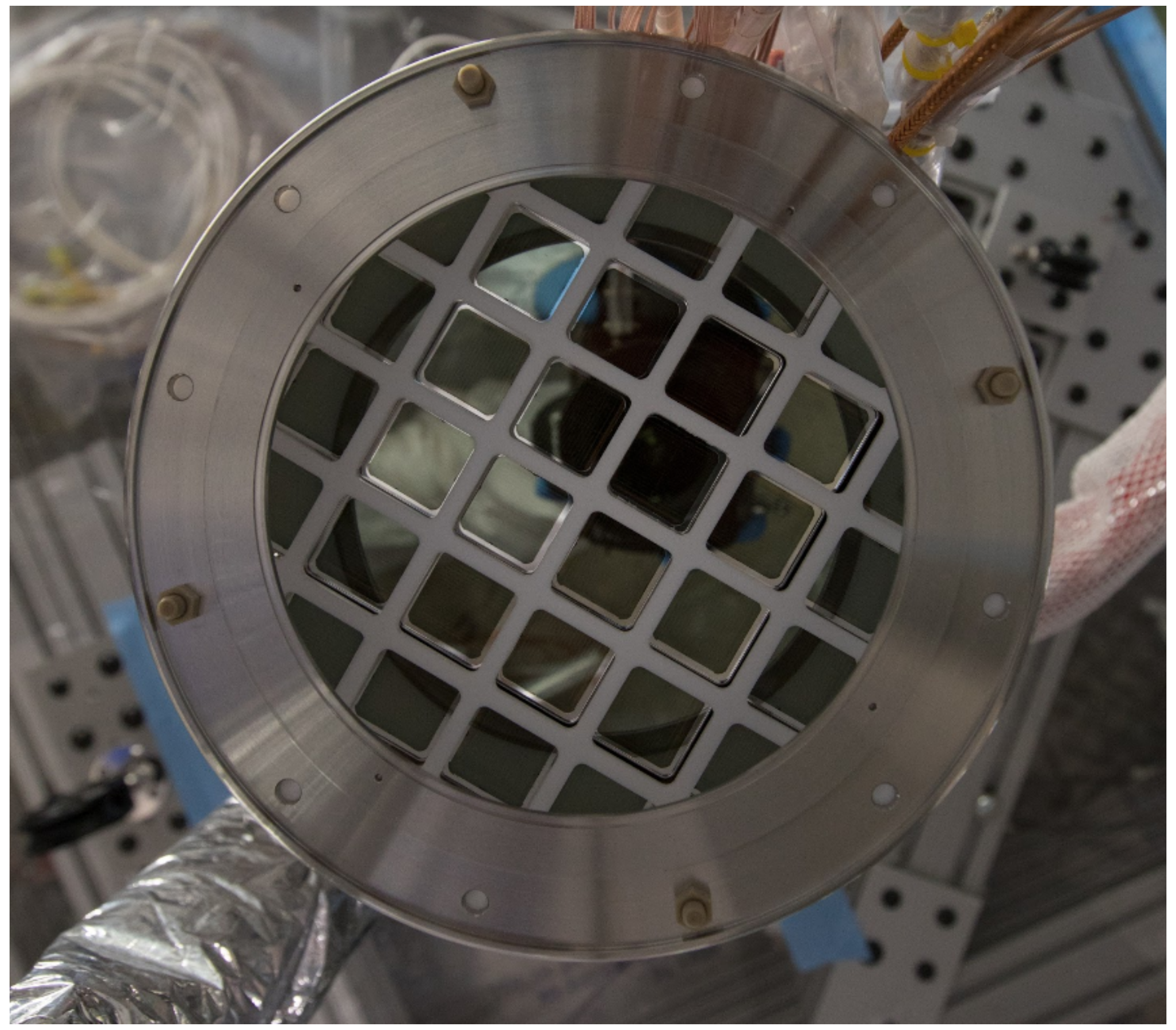
XELDA Run 2

- Improved gas analysis
- Inject more H_2
- S1-only mode to measure S1 loss more carefully
  - S2s difficult to measure well in XELDA setup with H_2



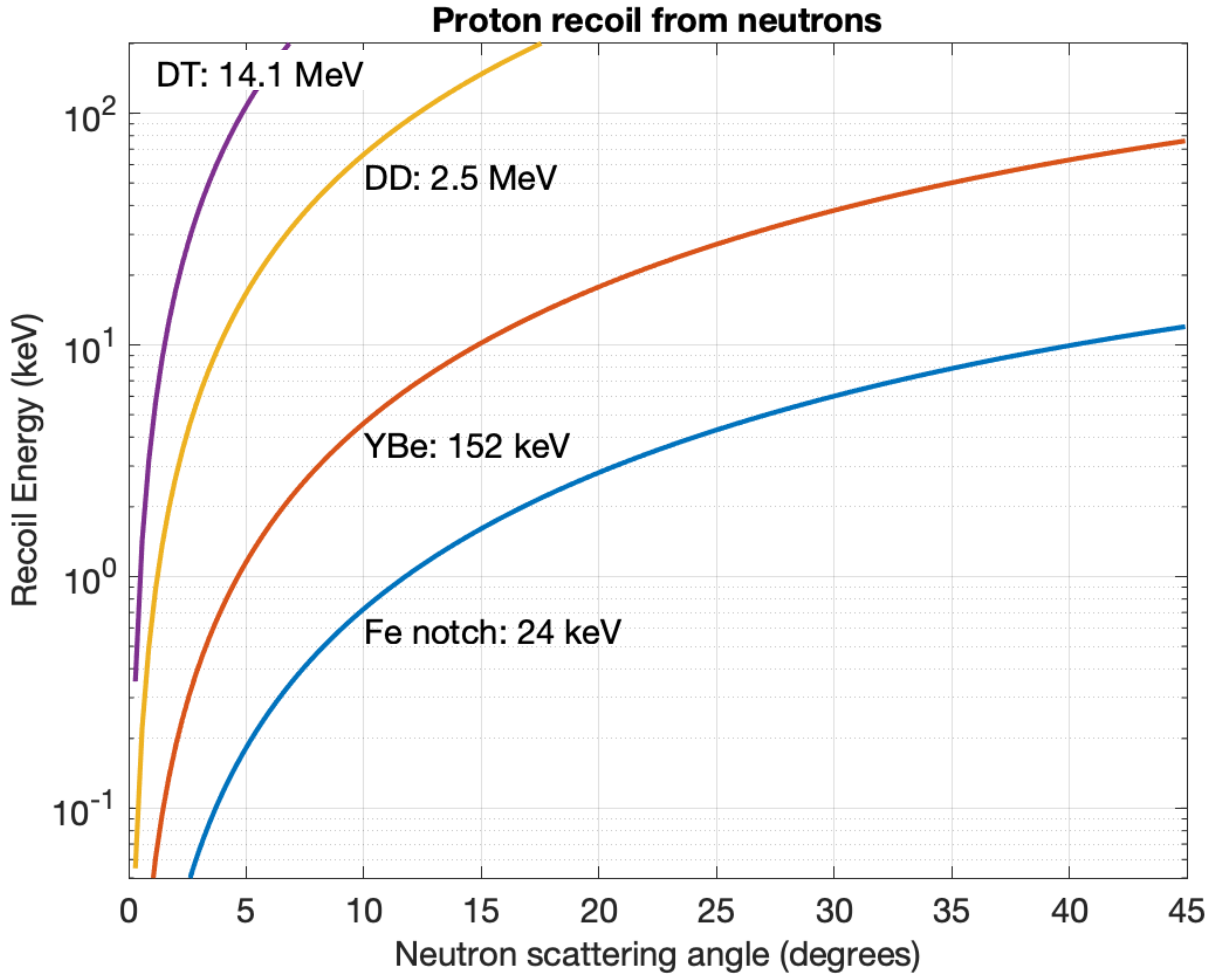
H_2+GXe at SLAC

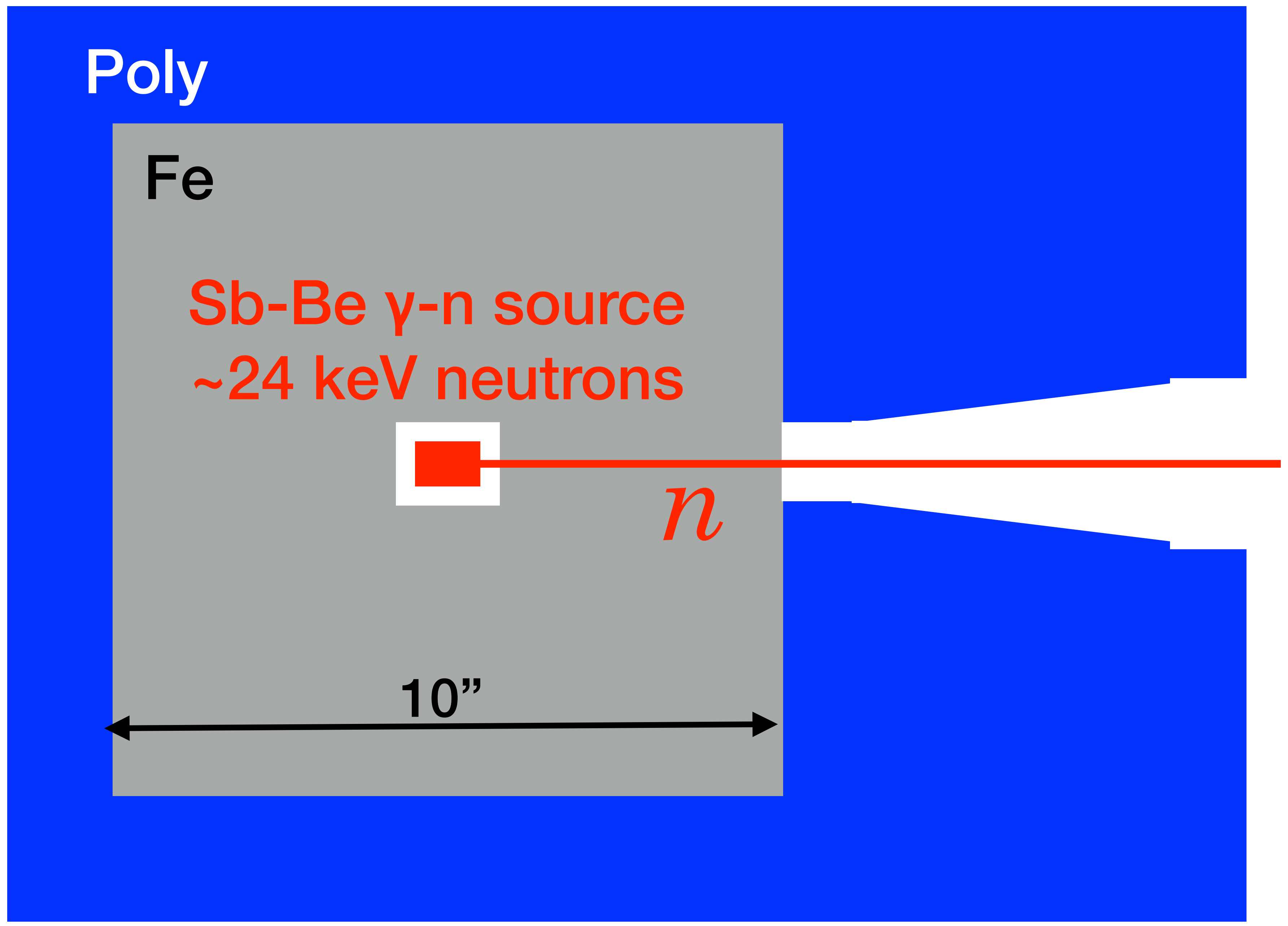
- Use SLAC System Test in room temperature gas-only mode
  - Used extensively for electron emission studies (see R. Mannino's talk)
- Measure effect on S2 yield more carefully



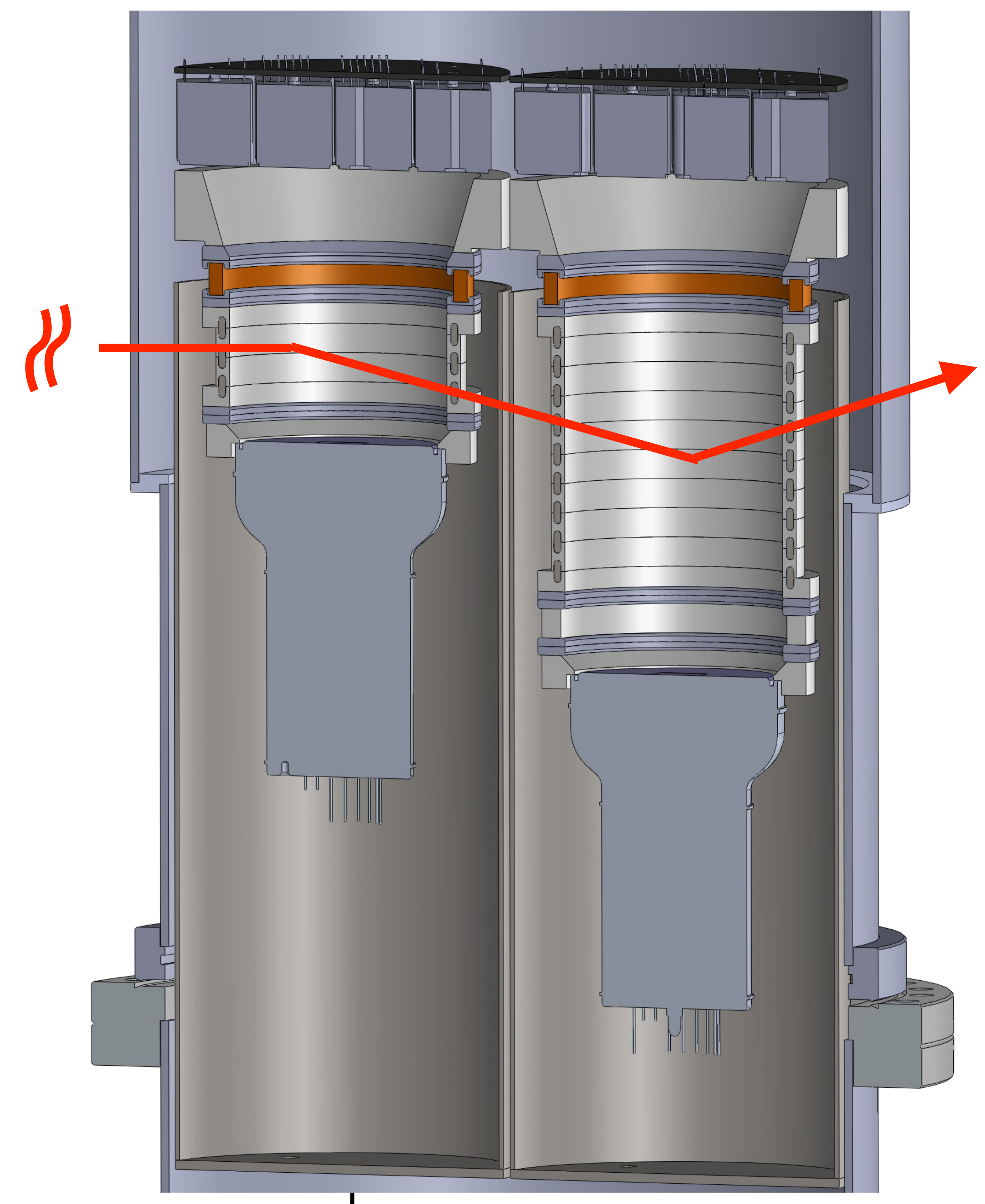
Low energy recoil calibration

- Classic neutron scattering setup: scattering angle gives recoil energy
- Low energy neutron source: 24 keV neutrons from ^{124}Sb-^{9}Be source
- TPCs for both target and neutron tagger



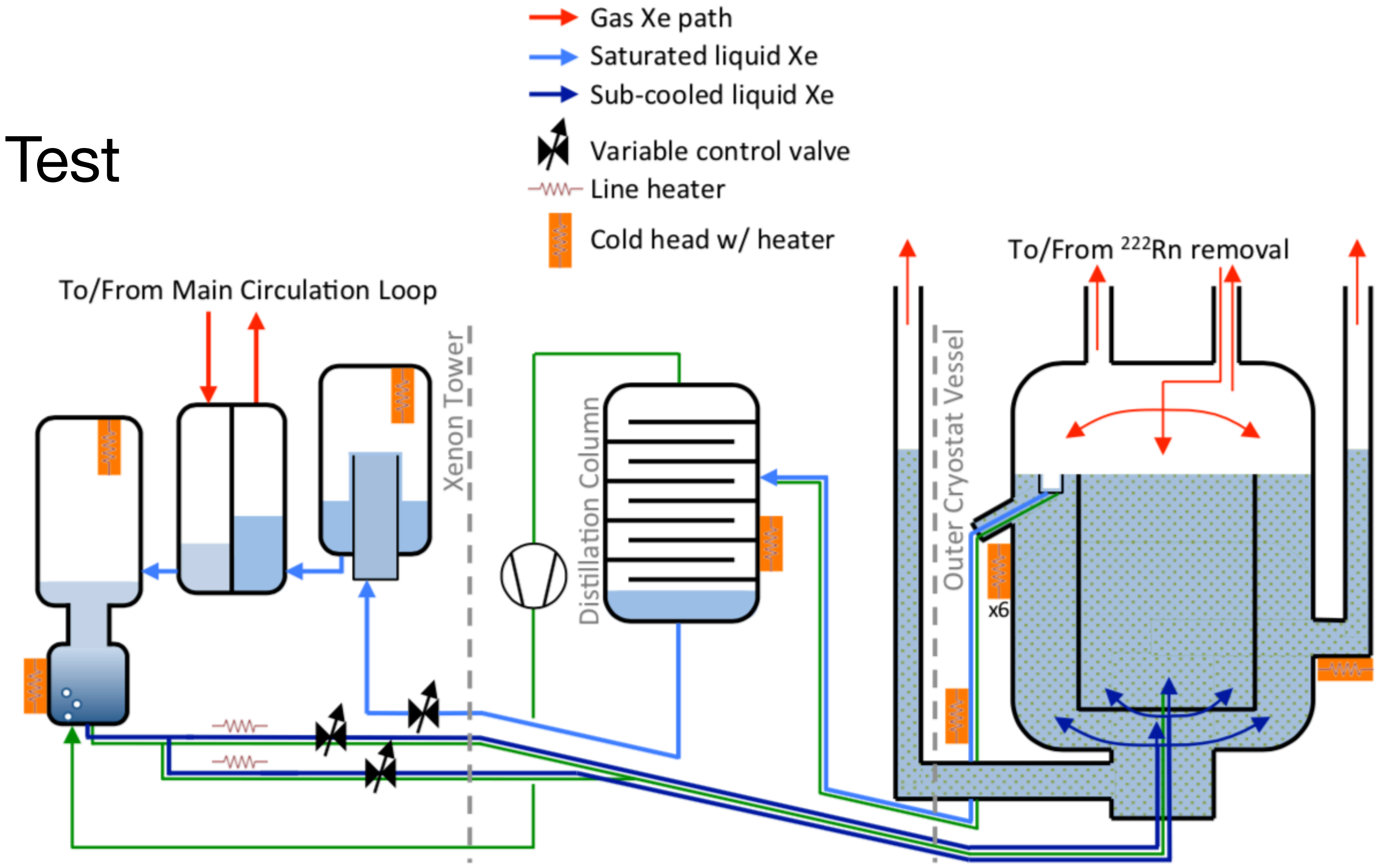


keV Iron Neutron source (keVIN)



Cryogenics and circulation with H_2-doped Xe

- LZ purifier will remove H_2 → Inject and remove H_2 continuously, around purifier
- Options for removing H_2:
  - Distillation column
  - Sparging
- Test at O(100 kg) of Xe using SLAC System Test



Summary

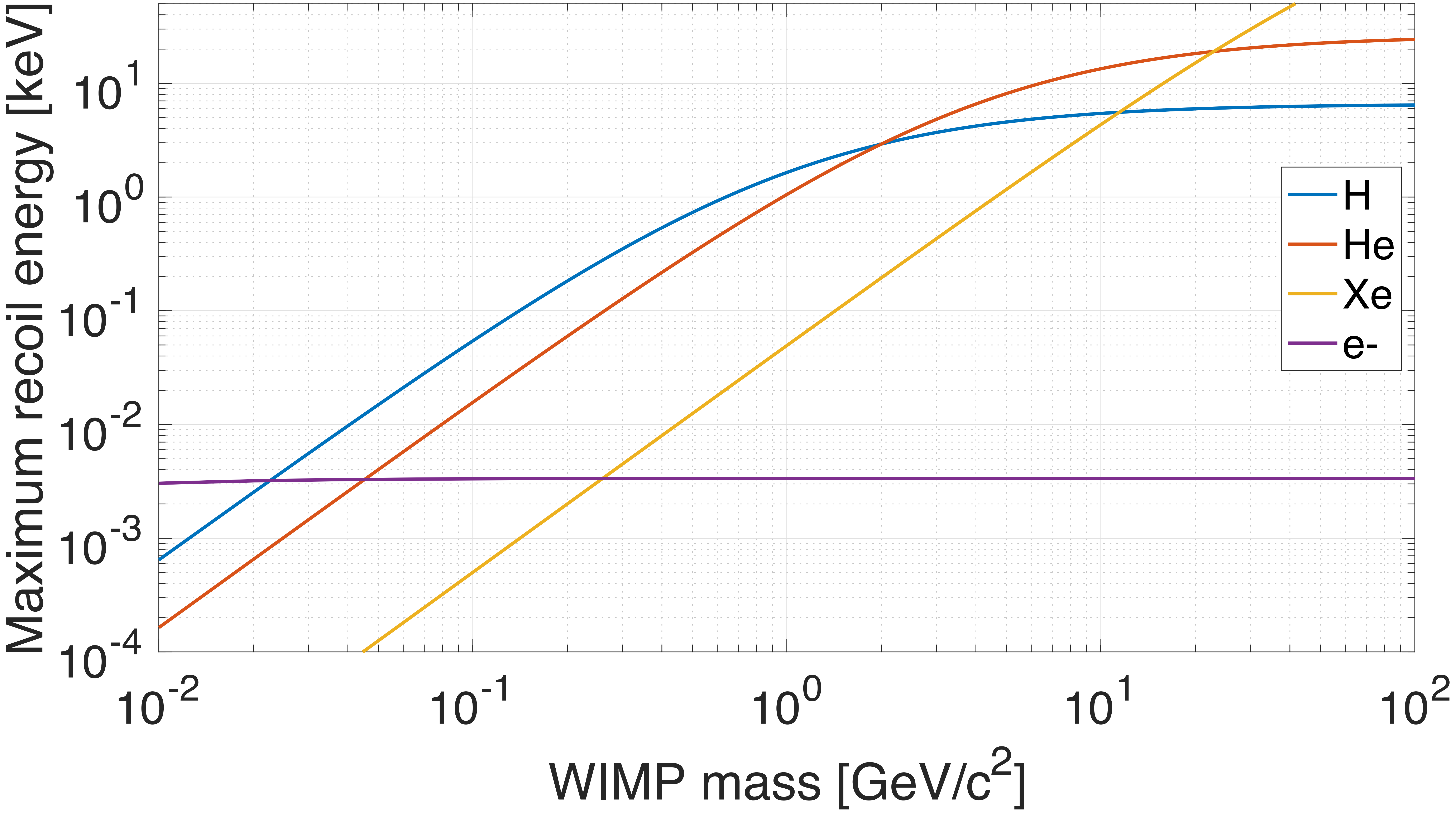
- Many new searches for low mass dark matter
- HydroX is a novel new effort
  - Hydrogen-doped LXe
  - Optimize kinematic matching for low mass DM (0.1-5 GeV/c^2)
  - SI and SD sensitivity
  - Leverage success of conventional LXe TPCs
- R&D needed; already underway
- First proof that TPC works with H_2+Xe

The original HydroX

Backup

Low mass dark matter detection

$$\frac{dR}{dQ} = \frac{\rho_0}{m_\chi} \times \frac{\sigma_0 A^2}{2m_p^2} \times F^2(Q) \times \int_{v_m}^{v_{esc}} \frac{f(v)}{v} dv$$



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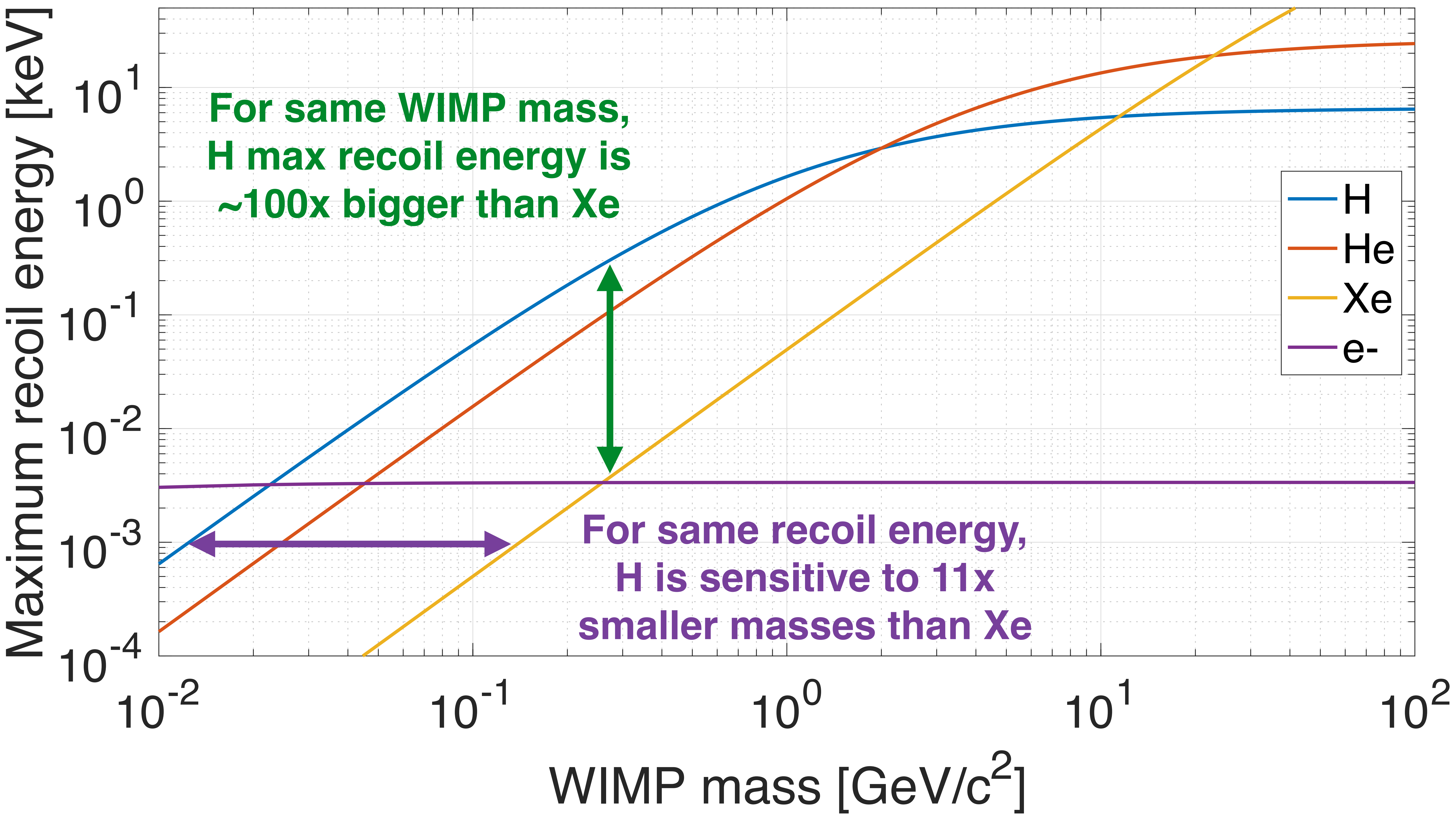
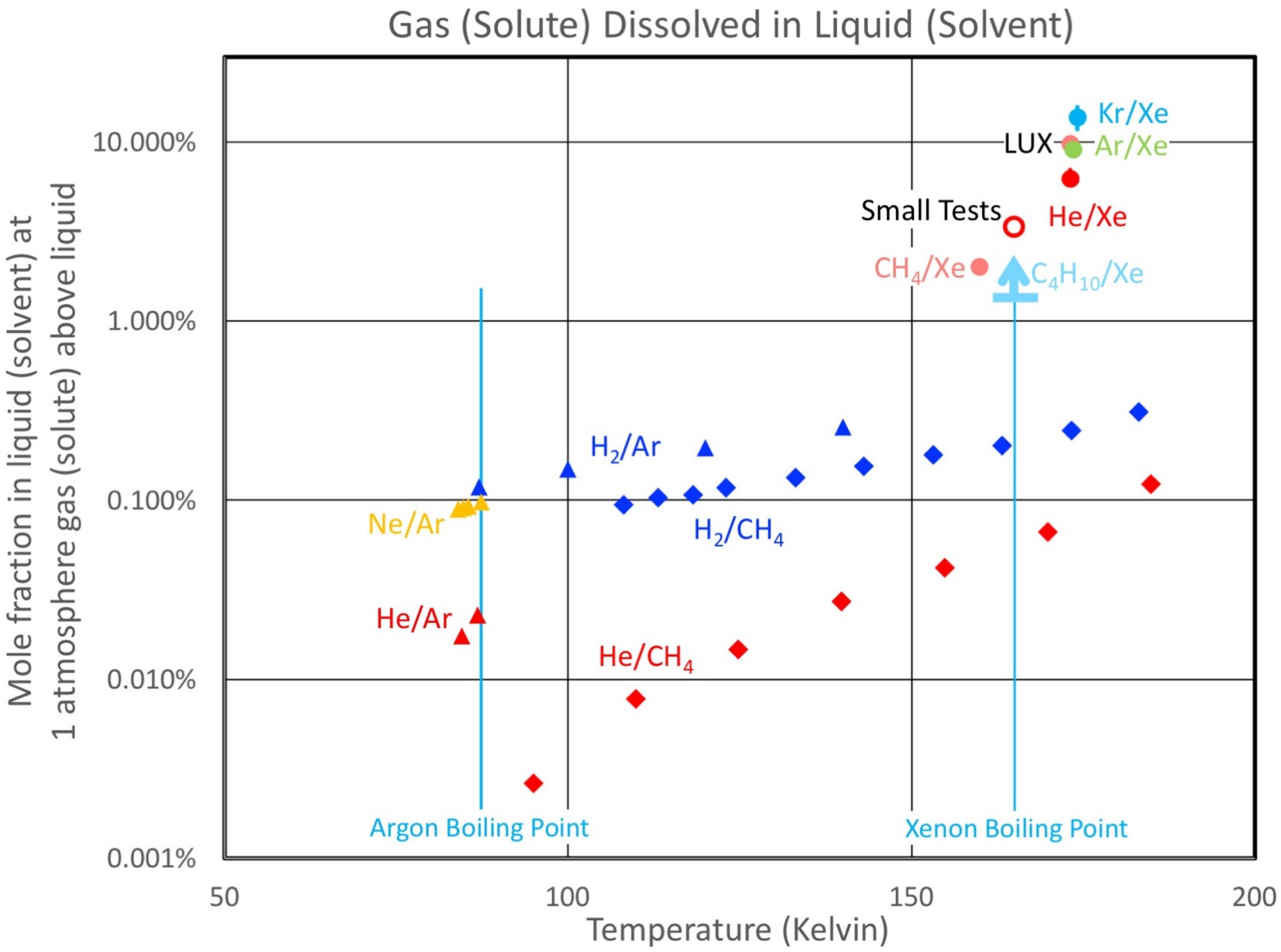


Solubility in LXe

- Dissolving H_2 in LXe has not previously been done
- But lots of other stuff has
- LXe is an efficient solvent



keV Iron Neutron source (keVIN)

- ^{124}Sb-^{9}Be source gives 24 keV neutrons + gammas
- Surround source with Fe: stops gammas and passes neutrons (“notch” at 24 keV)
- Alternate configuration to get 2 keV neutrons:
  - Degrade neutron energy down with poly
  - Exploit 2 keV notch in scandium (^{21}Sc)