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First measurement of low-energy He & e^- recoil discrimination for sub-GeV dark matter searches in doped LXe TPCs (HydroX)

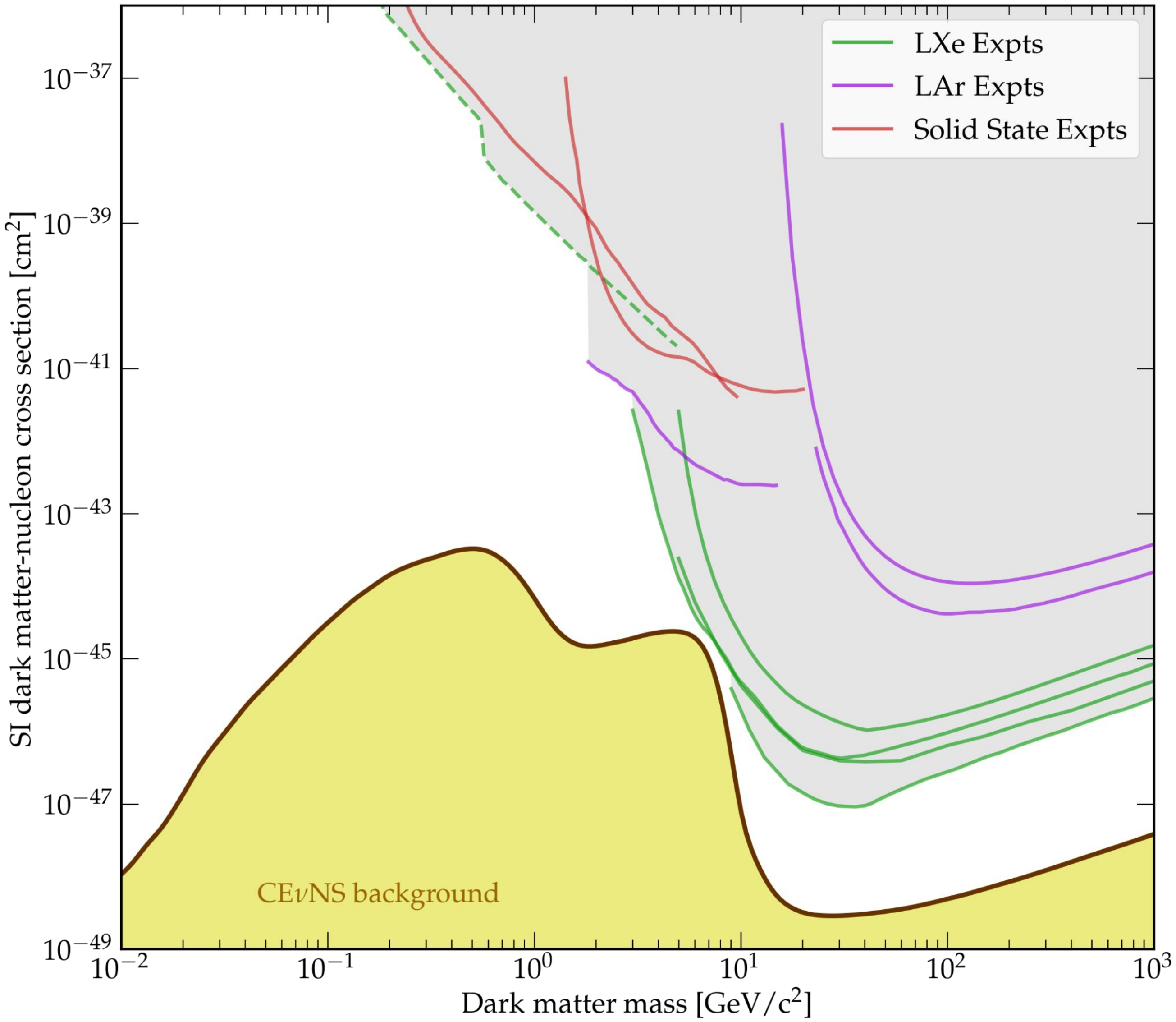
Scott Haselschwardt (LBNL)

On behalf of…
LBNL team: R. Gibbons, H. Chen, S. Kravitz, A. Manalaysay, P. Sorensen, and Q. Xia
and our HydroX collaborators

UCLA DM 2023
March 31, 2023

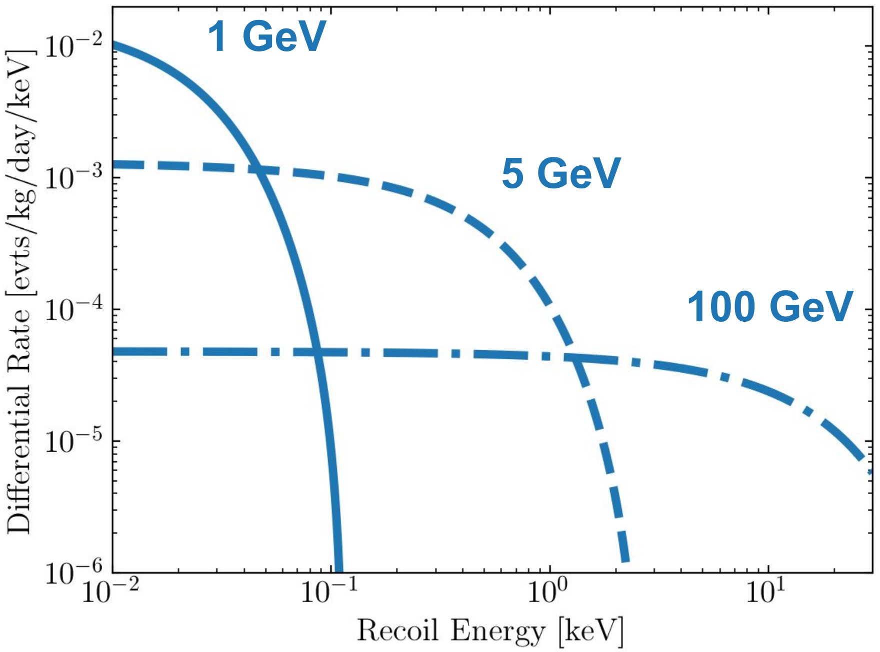
Direct Detection Landscape

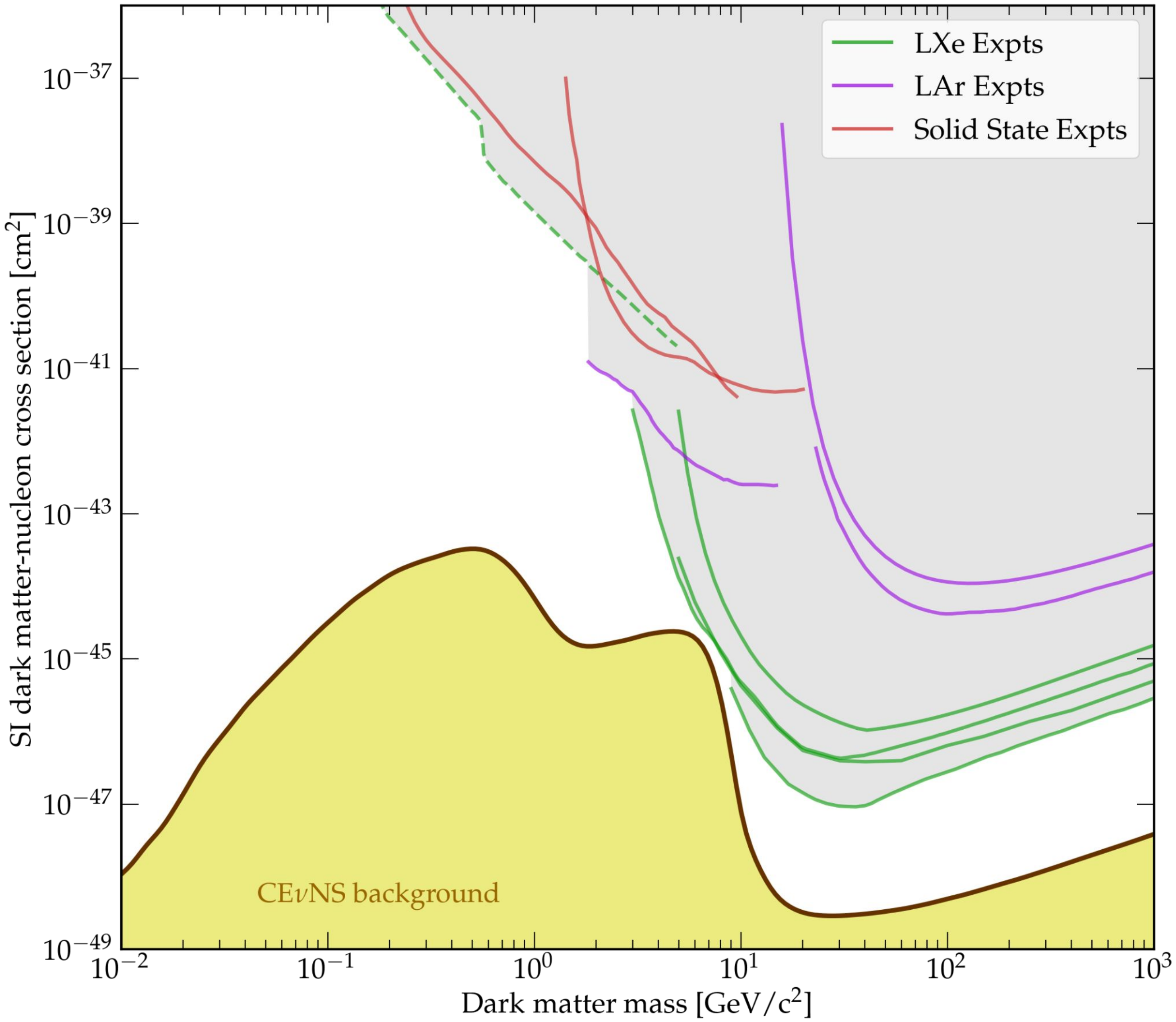
Liquid xenon TPCs lead the search for >5 GeV dark matter



Direct Detection Landscape

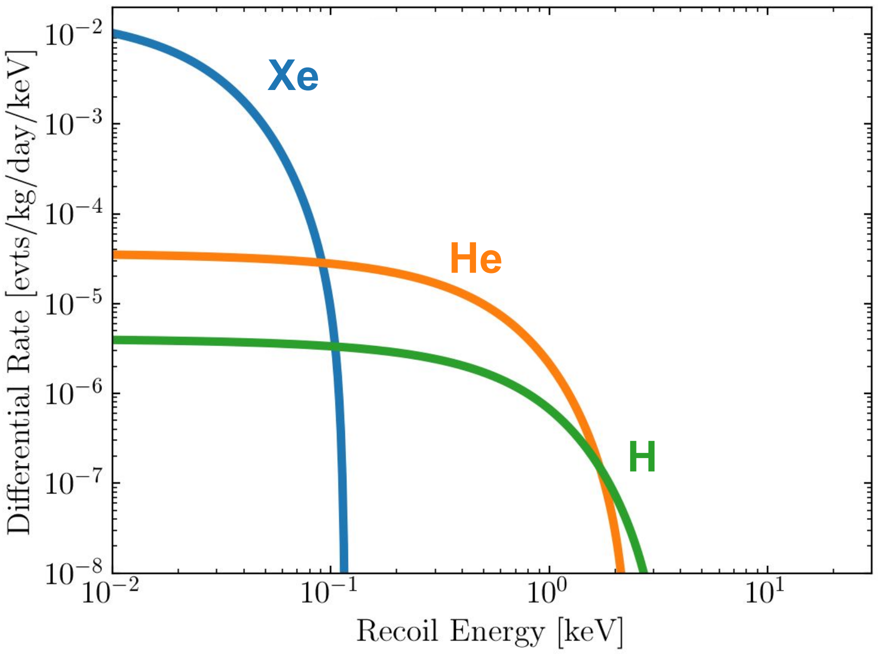
but inefficient kinematics and detector threshold limit low-mass reach…

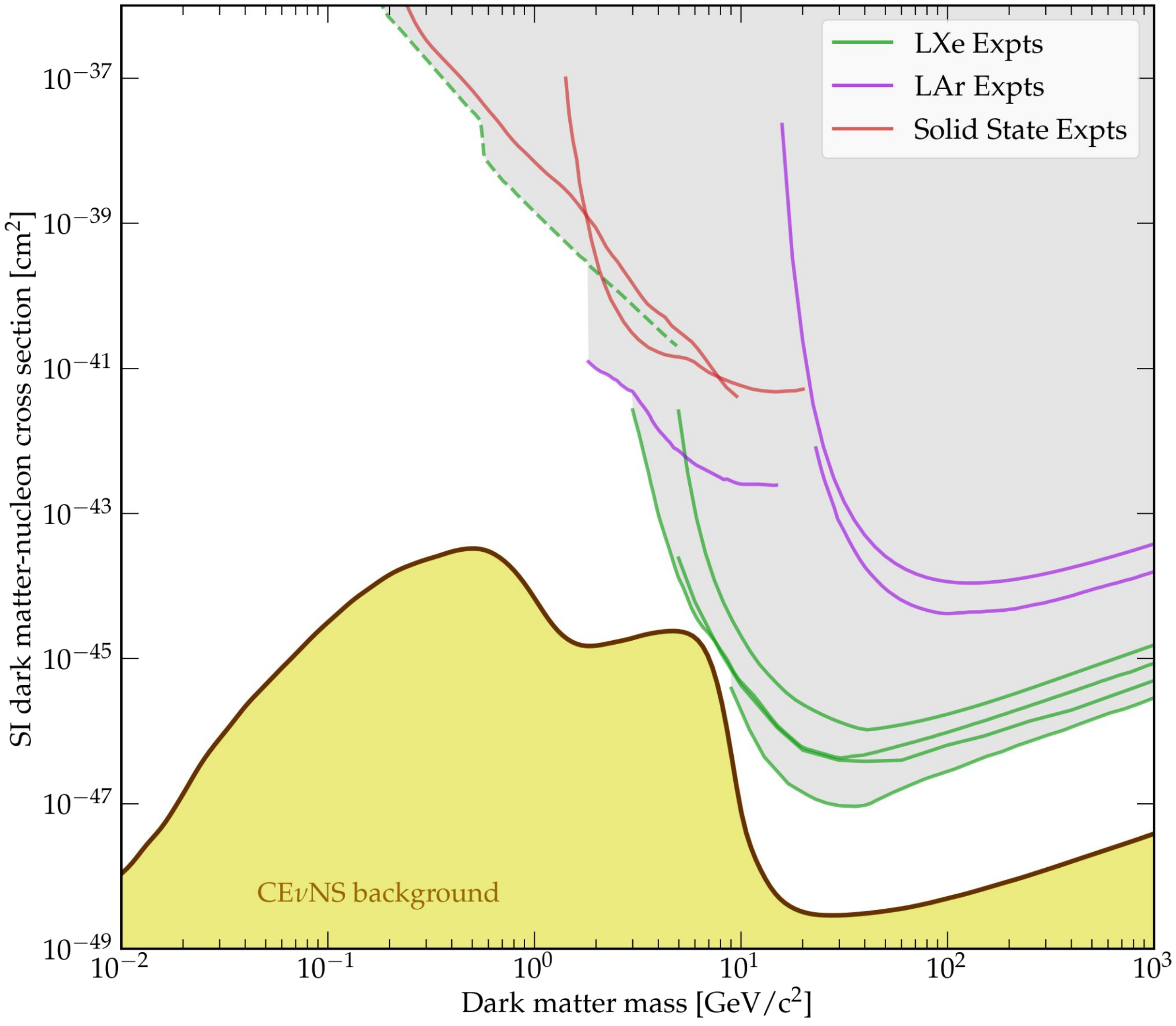




Direct Detection Landscape

Idea: dissolve a light species in LXe to serve as the DM target!

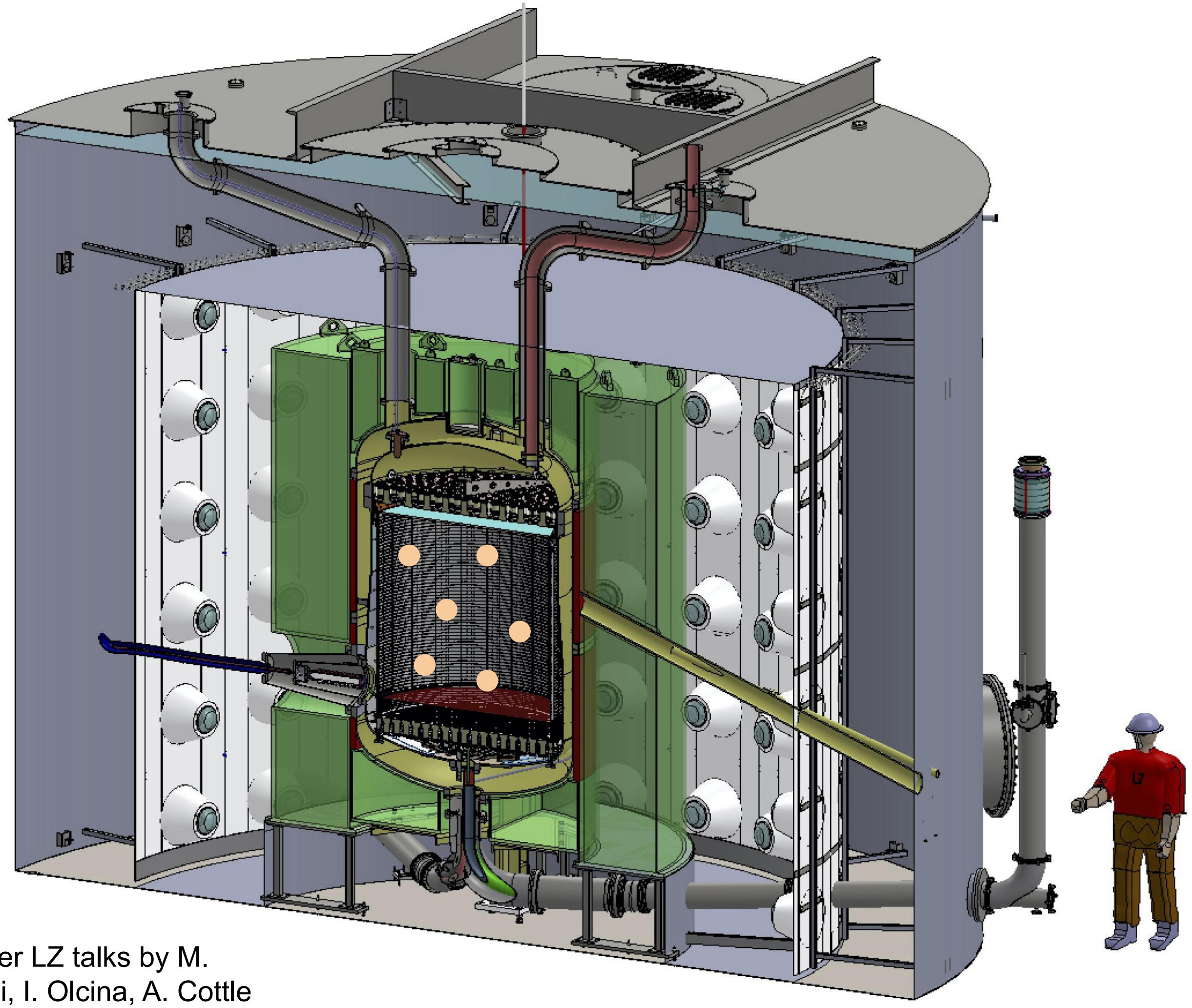


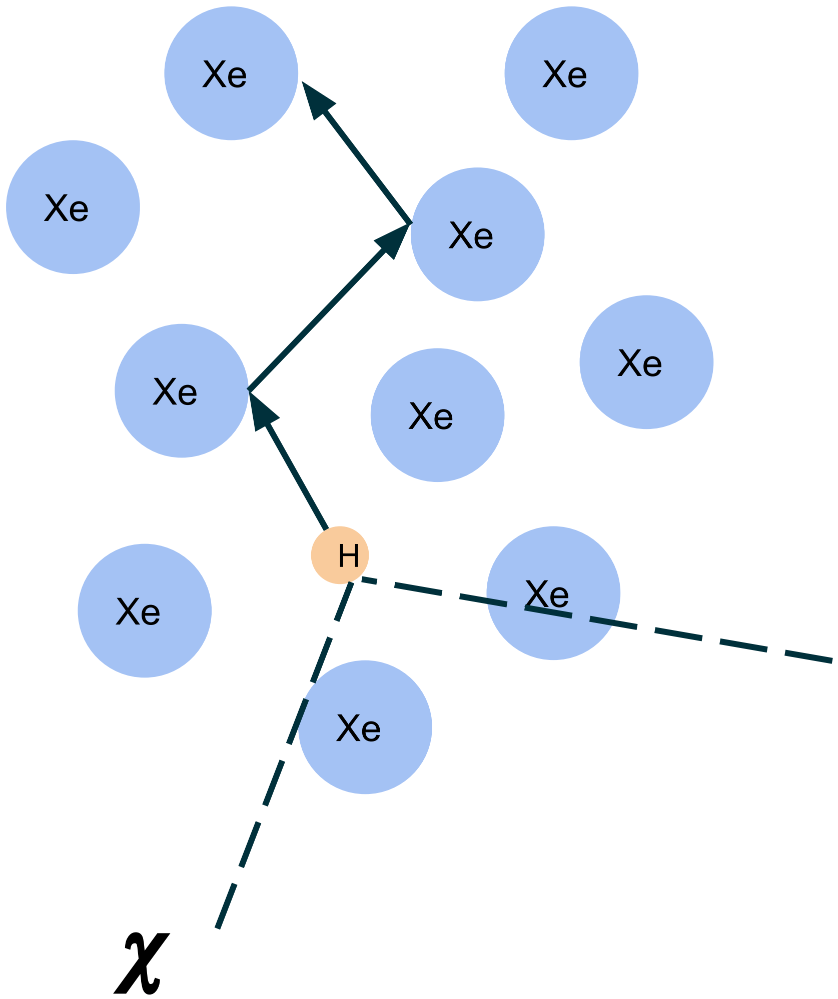


HydroX: proposed LZ upgrade to dissolve H_2 into the LXe

Dissolved **hydrogen** nuclei become the **dark matter target**

Xenon is the **sensor**





See other LZ talks by M. Monzani, I. Olcina, A. Cottle & J. Bang

Why HydroX?

Most of the experiment is built!

Utilize well-understood LZ background environment

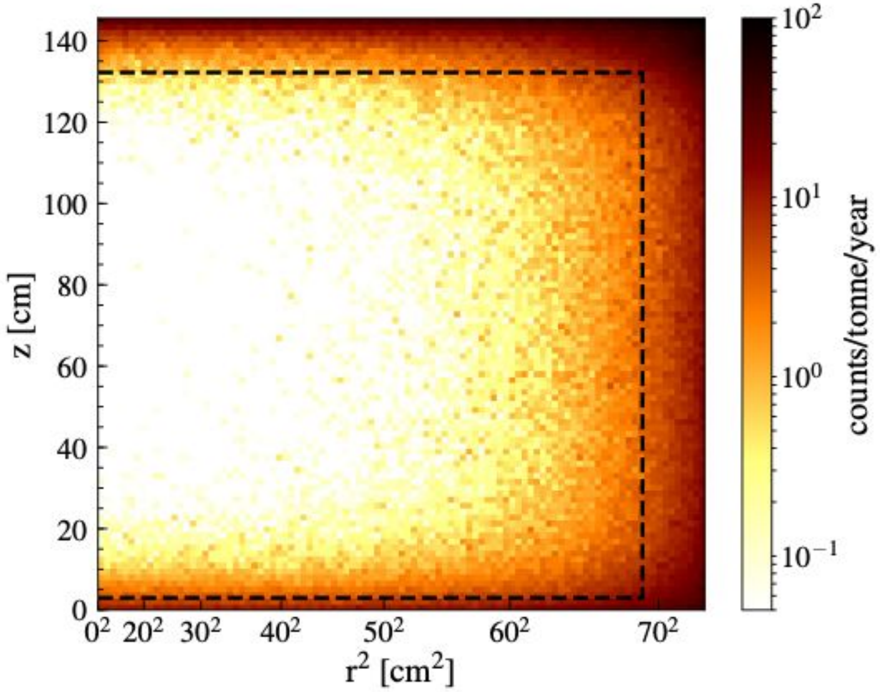
- "self-shielding" of external backgrounds
- veto systems + water tank + extreme cleanliness

Expected high signal yield

- H or He recoils expected to give largely electronic excitations (less to heat)

High spin-dependent sensitivity

- Lone proton for SD_{proton}
- Deploy deuterium for $SD_{neutron}$ reach

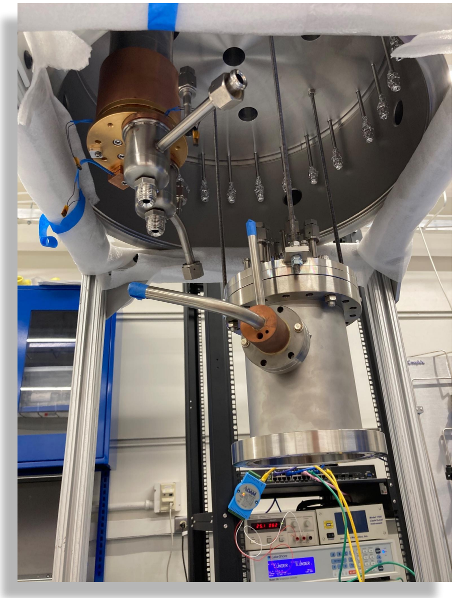


Current HydroX Efforts and R&D

HydroX Institutions:

UCSB	Penn State
LBL	Michigan
SLAC	Imperial College London
SURF	Northwestern

UC SANTA BARBARA



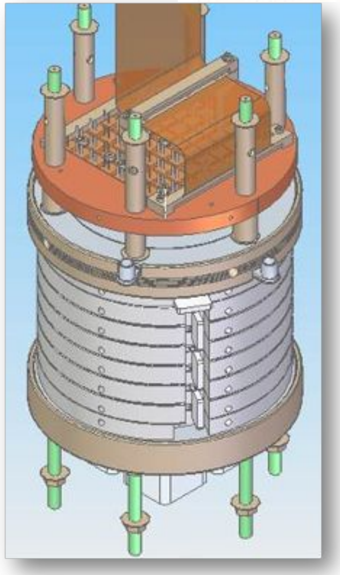
Henry Machine @ UCSB:

Measure Henry coeff. for light elements in LXe & LAr

Understand cyro properties of light gas mixtures

Tests of injection/extraction

Imperial College London

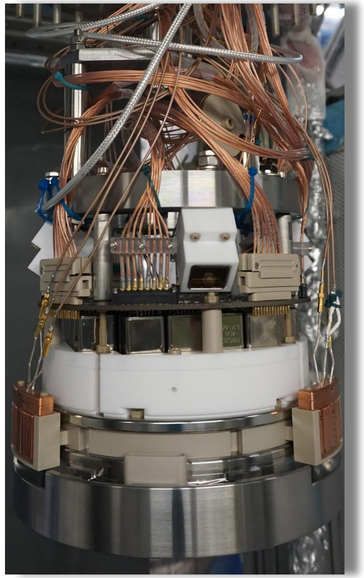


XENIA @ Imperial:

high granularity SiPM readout (σ_r~150 μm)

Measure electron transport/drift properties in H_2-doped LXe TPC for improved 0νββ sensitivity

SLAC



HydroX @ SLAC:

Measure impact of H_2 on TPC signals:

Impact on S2 (charge) signal

Purification + circulation with mixed H_2+LXe

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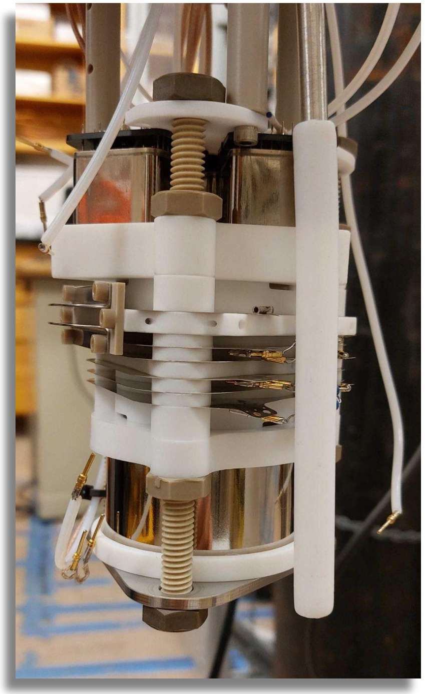
HydroX @ LBNL:

Low-energy DM signal calibration:

Measure light and charge yields of recoiling He and H in doped LXe TPC



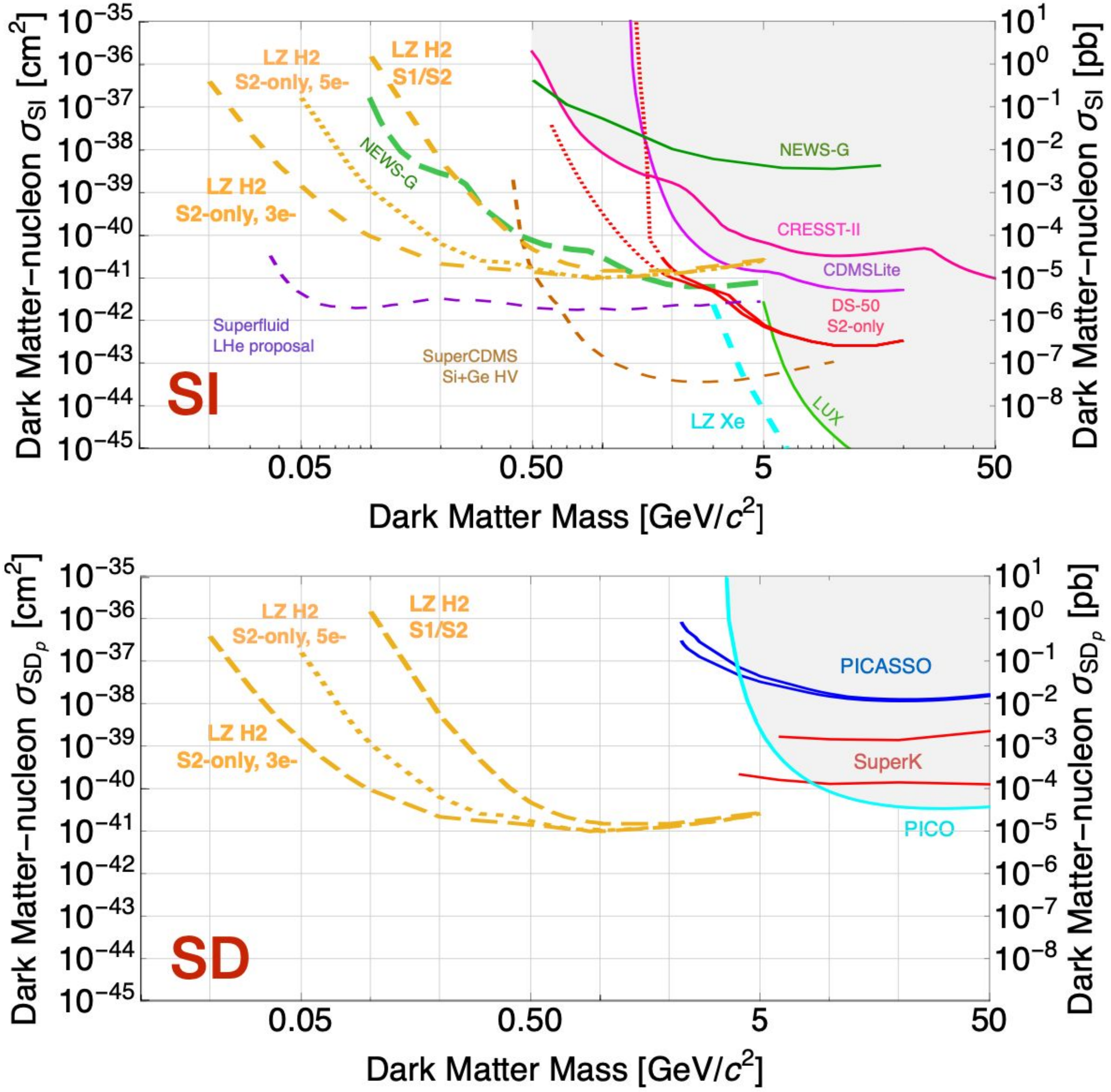
Projected Physics Reach

250 livedays

2.2 kg of H_2 in LXe (2.6% mol fraction)

Signal yields from SRIM + LZ detector response

No discrimination between ER backgrounds and H-recoil signals assumed!



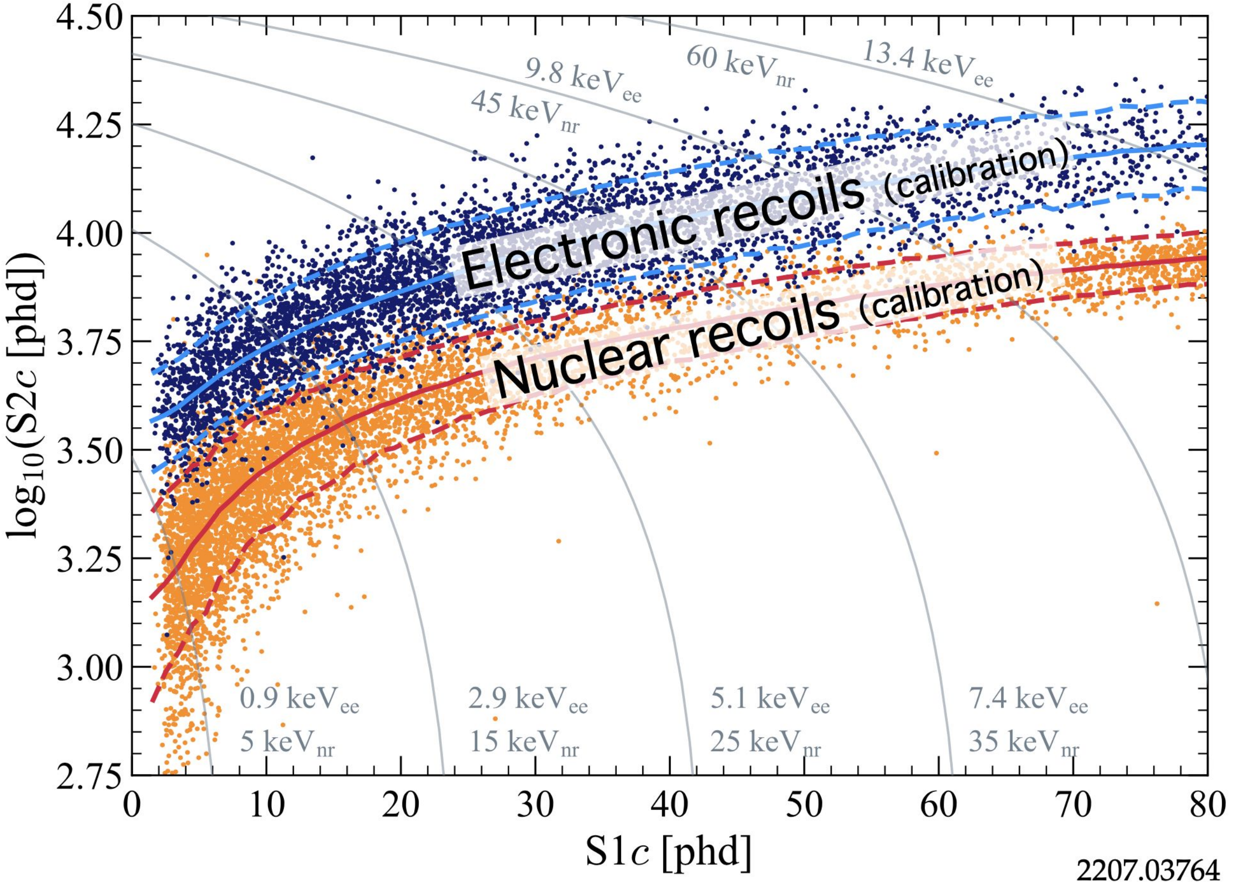
Is there ER/light-element discrimination in LXe?

<u>Rest of this talk:</u>

Results from development of a "degraded alpha" (**He-recoil**) source

Provide **first look** at what we can expect for discrimination in a LXe TPC

LZ calibration data



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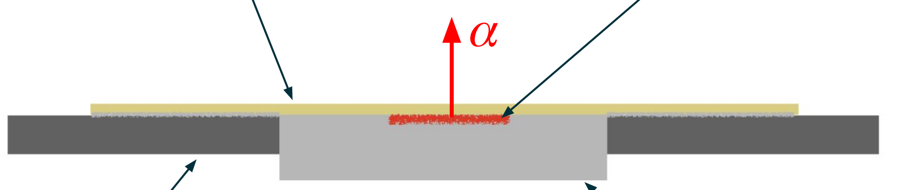
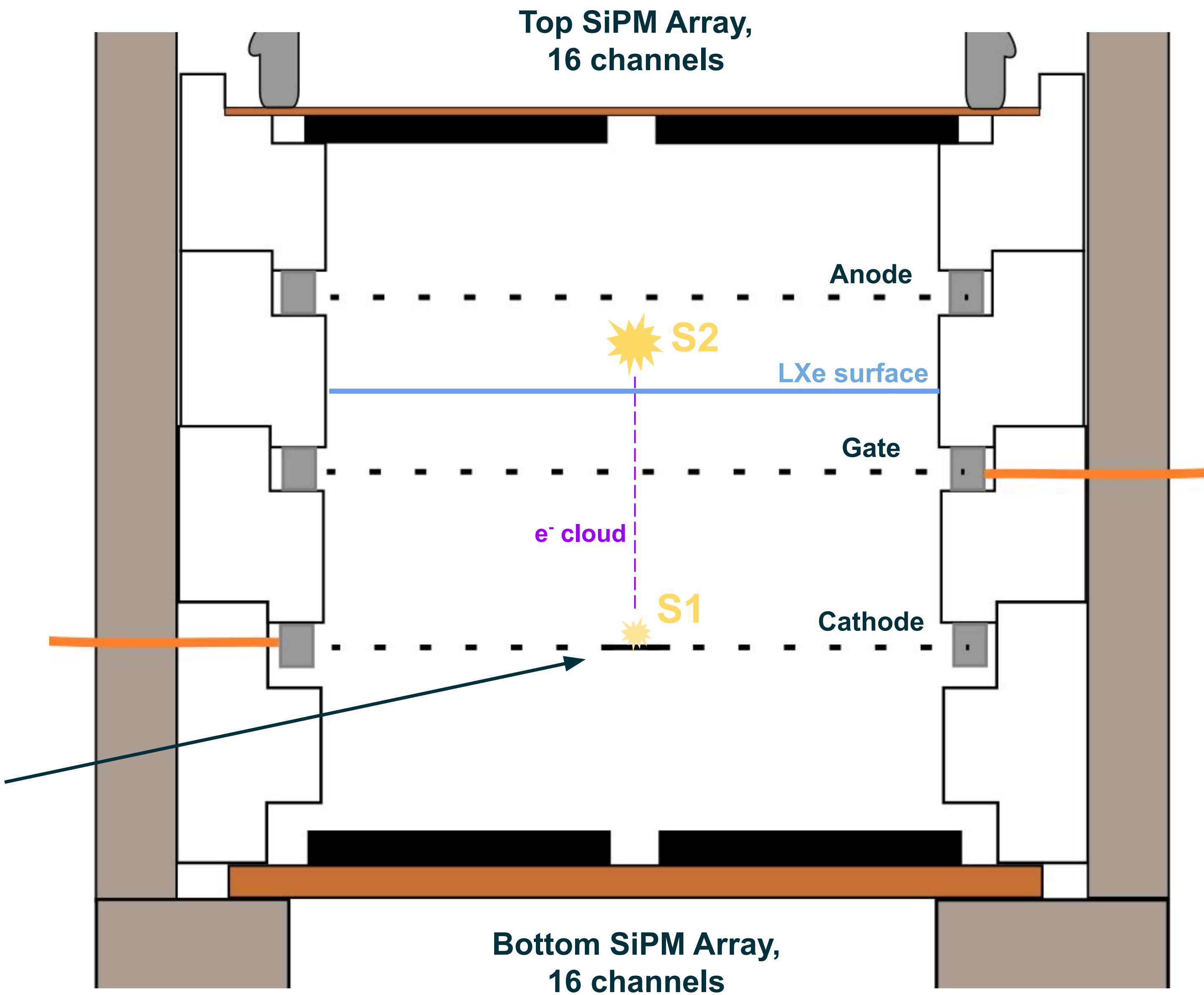
Measurement Overview

Custom cathode source

5.3 MeV α's 'degrade' in continuum energy spectrum down to 0 keV

Repeat with β source for calibration
- ^{99}Tc w/ endpoint = 300 keV

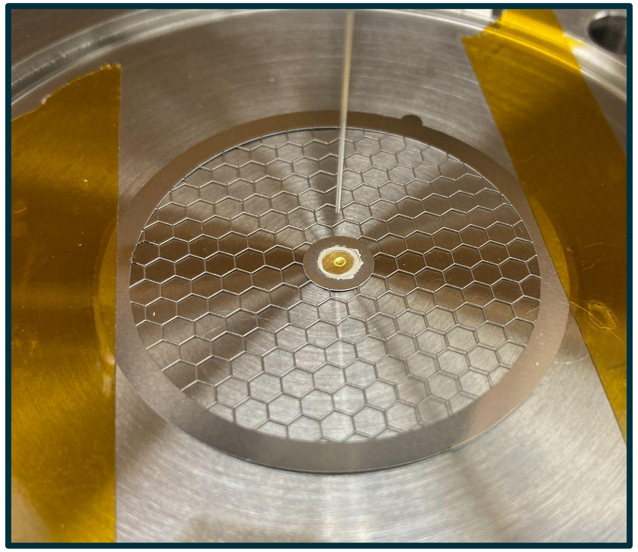


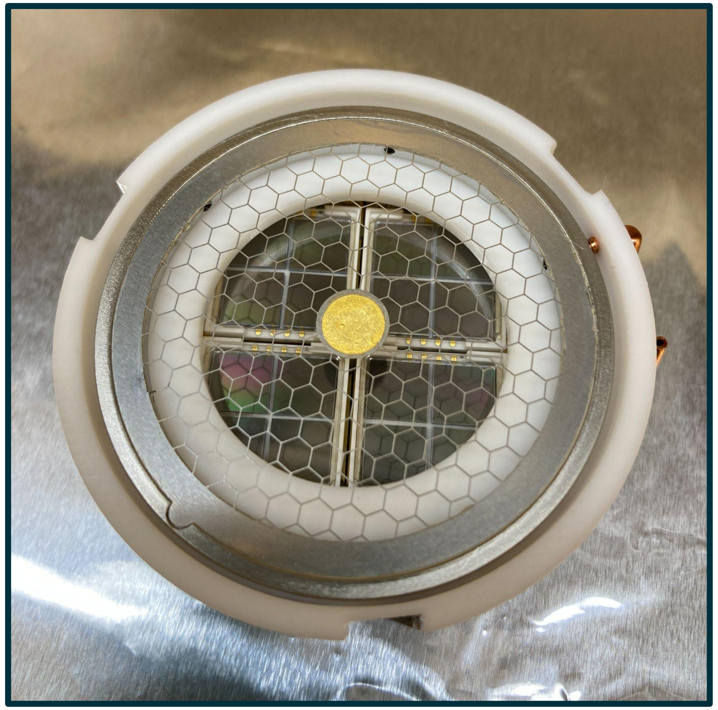


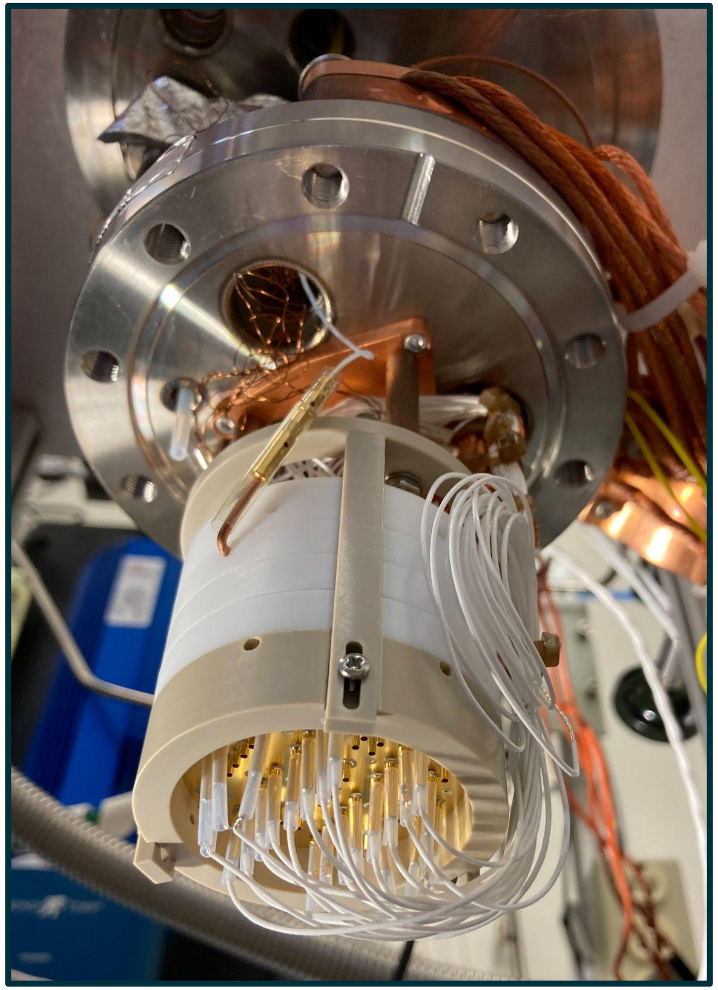
See Hao Chen's CrystaLiZe talk using same TPC @ LBNL

Source Details

Activity deposited on gold foil







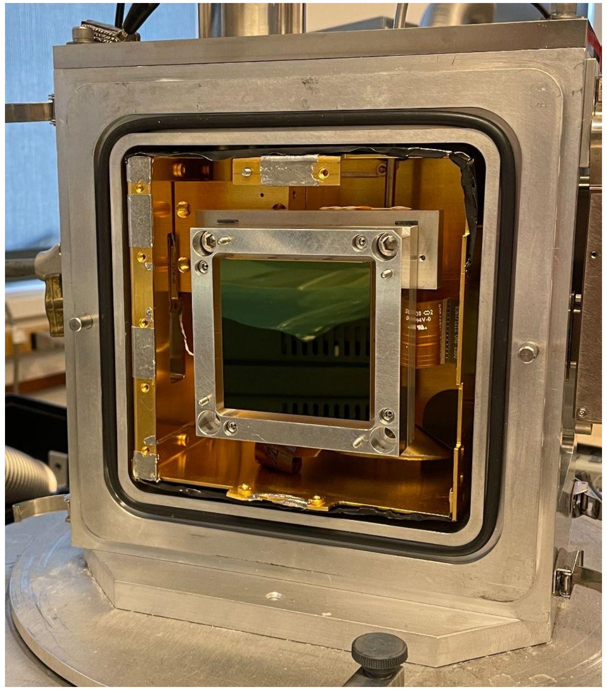
Sealed and installed in LBNL TPC

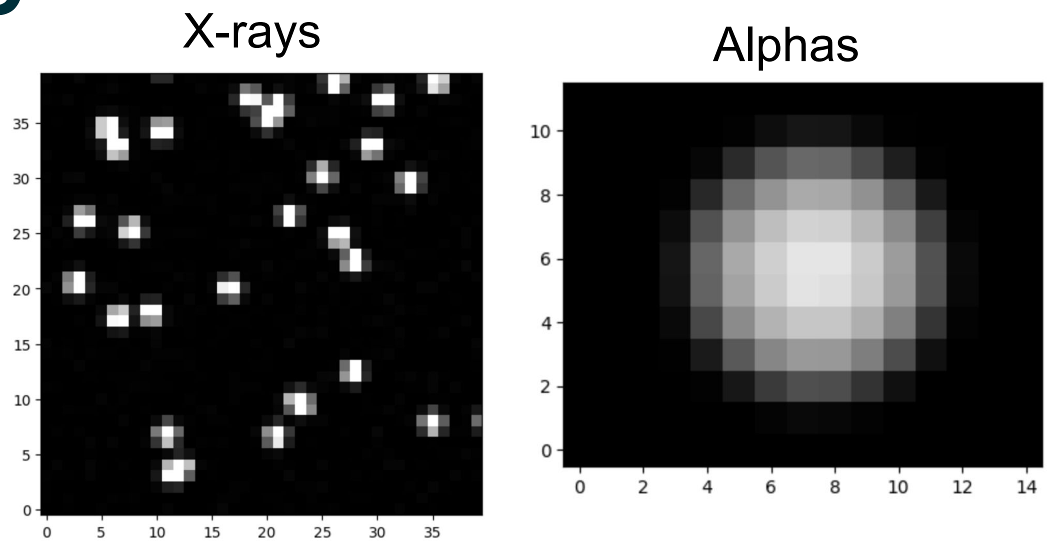
Source characterization in a CCD

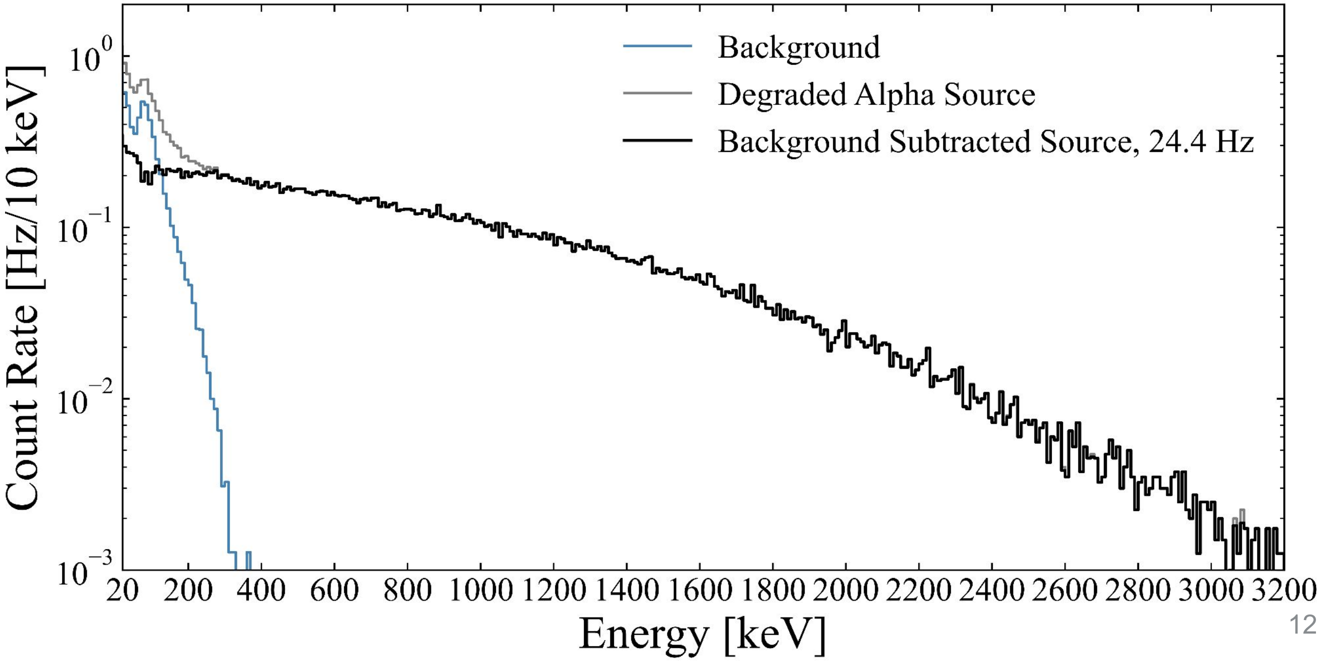
DESI CCD w/ ~180 nm dead layer & 250 μm active

>20 keV α's penetrate dead layer

Continuum α energy down to 0 keV







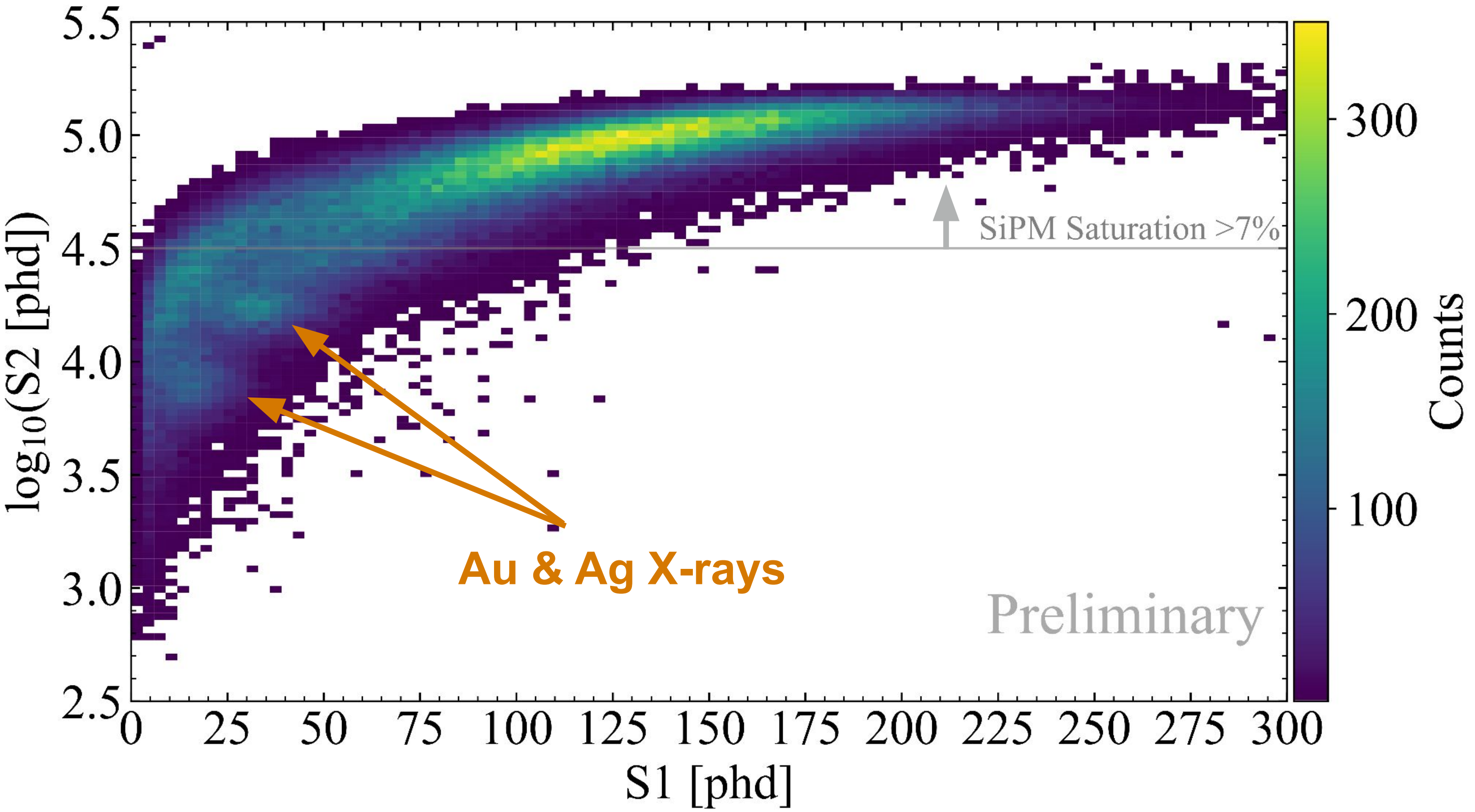
^{99}Tc β Source Calibration

Overall β shape agrees with Geant4 prediction

X-ray peaks from gold foil (~10 keV) and silver epoxy (~22 keV) used to tune NEST

- Fit electric field = 774 ± 75 V/cm agrees with field simulation
- Provides expectation for ER & Xe NR

Surface effects produce extra charge above X-ray peaks



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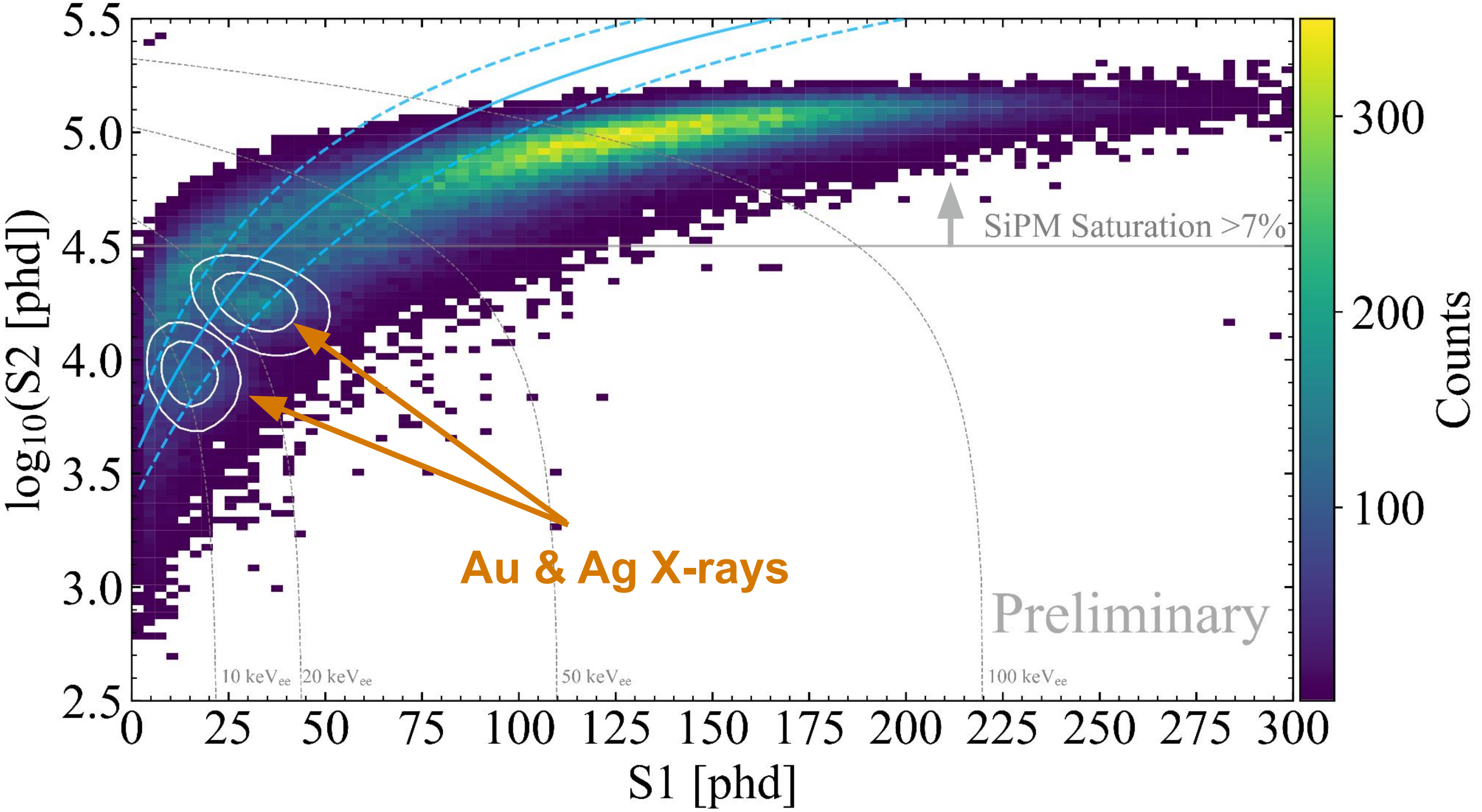
Blue band: NEST flat ER expectation

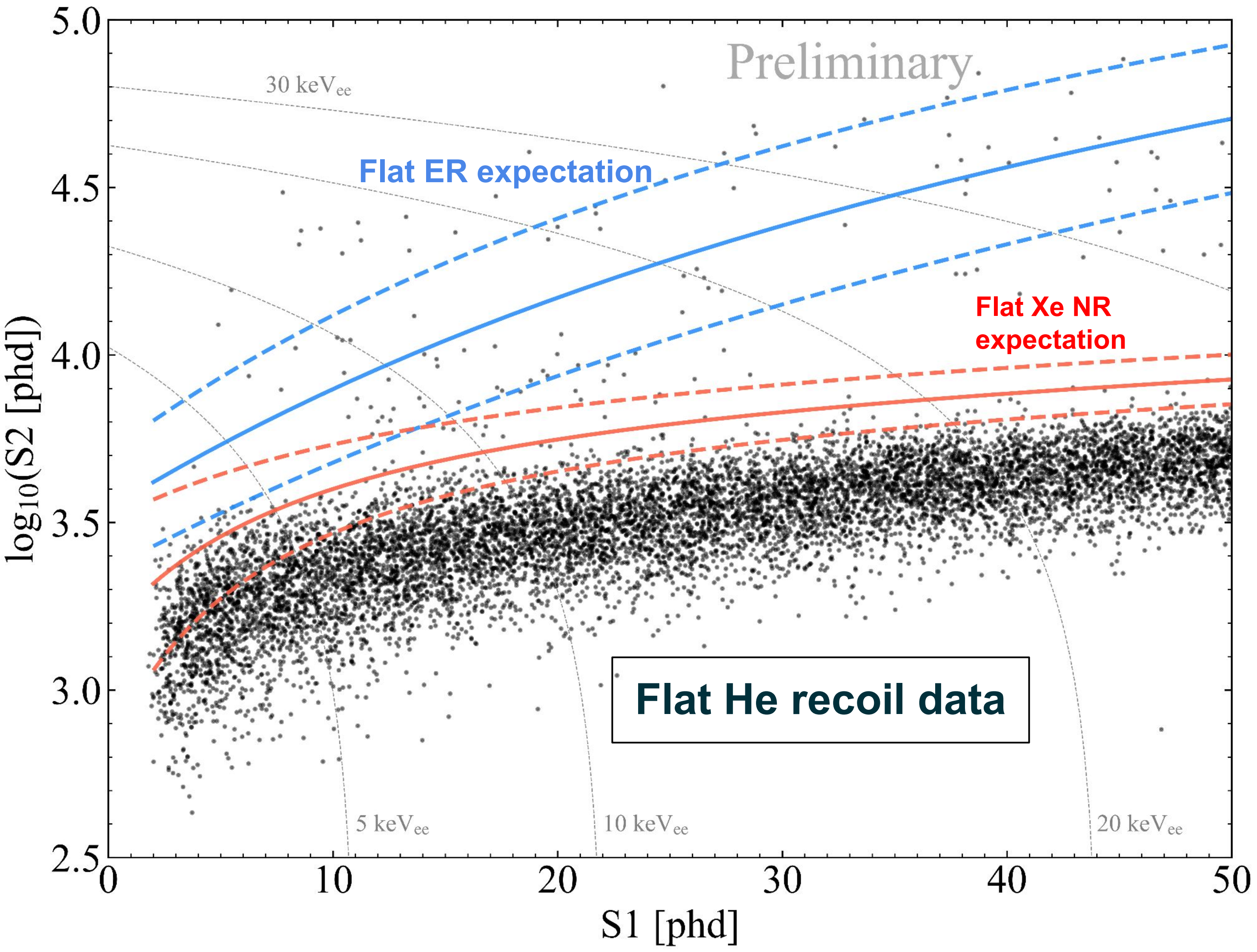


Degraded α (He) source data

Low-energy He recoils **well separated** from ER and Xe recoils!

Background ER's in α source data agree with β band prediction

Impact of cathode surface to be understood



Summary

- HydroX: a well-motivated proposal to search for low-mass DM by dissolving the lightest nuclei (H_2, He) in the LZ LXe TPC
- Leverages success and advantages of large, LXe TPCs
- R&D across multiple institutions underway
- **New measurements suggest good discrimination of He recoils from electron-recoil backgrounds - promising results for HydroX!**

Extra slides

Liquid Xenon TPC Operational Principle

High voltage grids provide electron drift to liquid surface

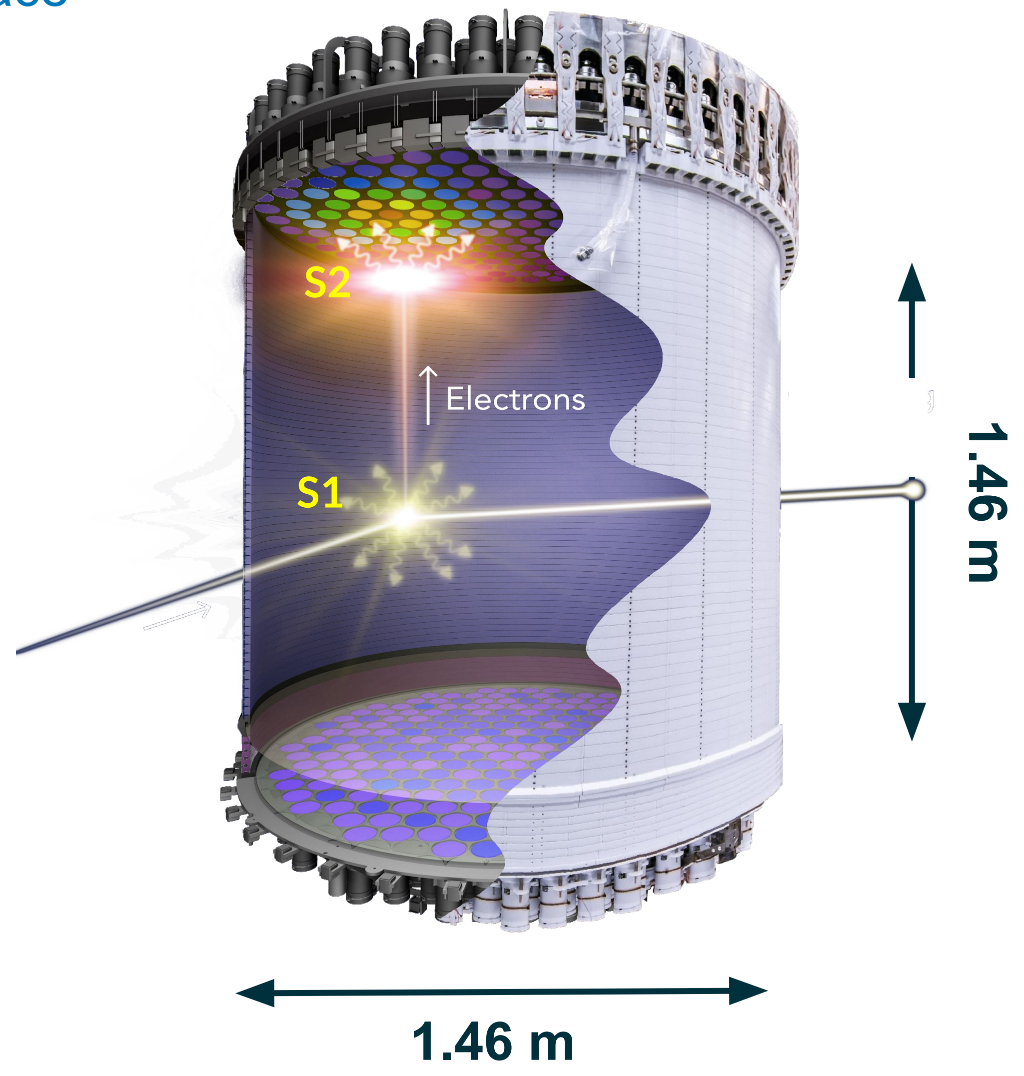
Top PMT array hit pattern gives (x,y)

Time between S1 & S2 gives depth

S2/S1 ratio gives
particle ID between:

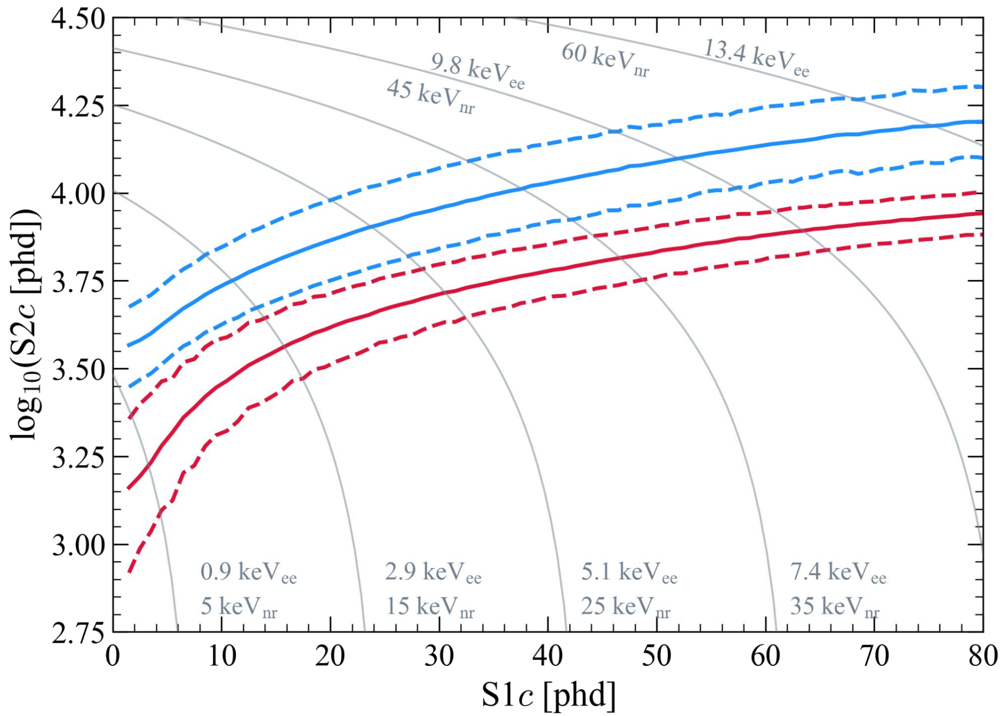
Nuclear Recoils - **neutrons**
WIMPs

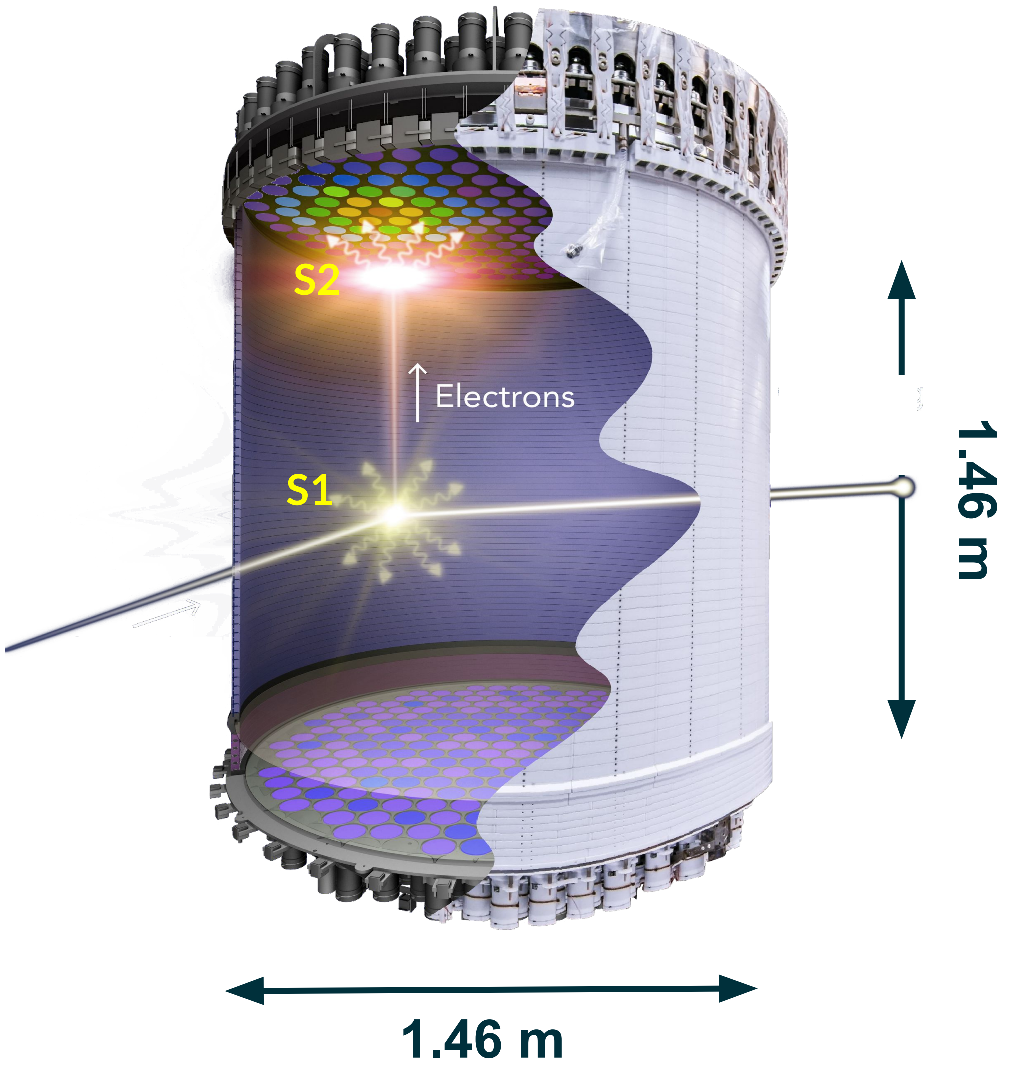
Electron Recoils - ***β*** **& EC decays**
Compton Scatters



Scott Haselschwardt, LBNL

Liquid Xenon TPC Operational Principle





Nuclear Recoils - neutrons, WIMPs

Electron Recoils - β & EC decays, Compton Scatters

Solubility Data

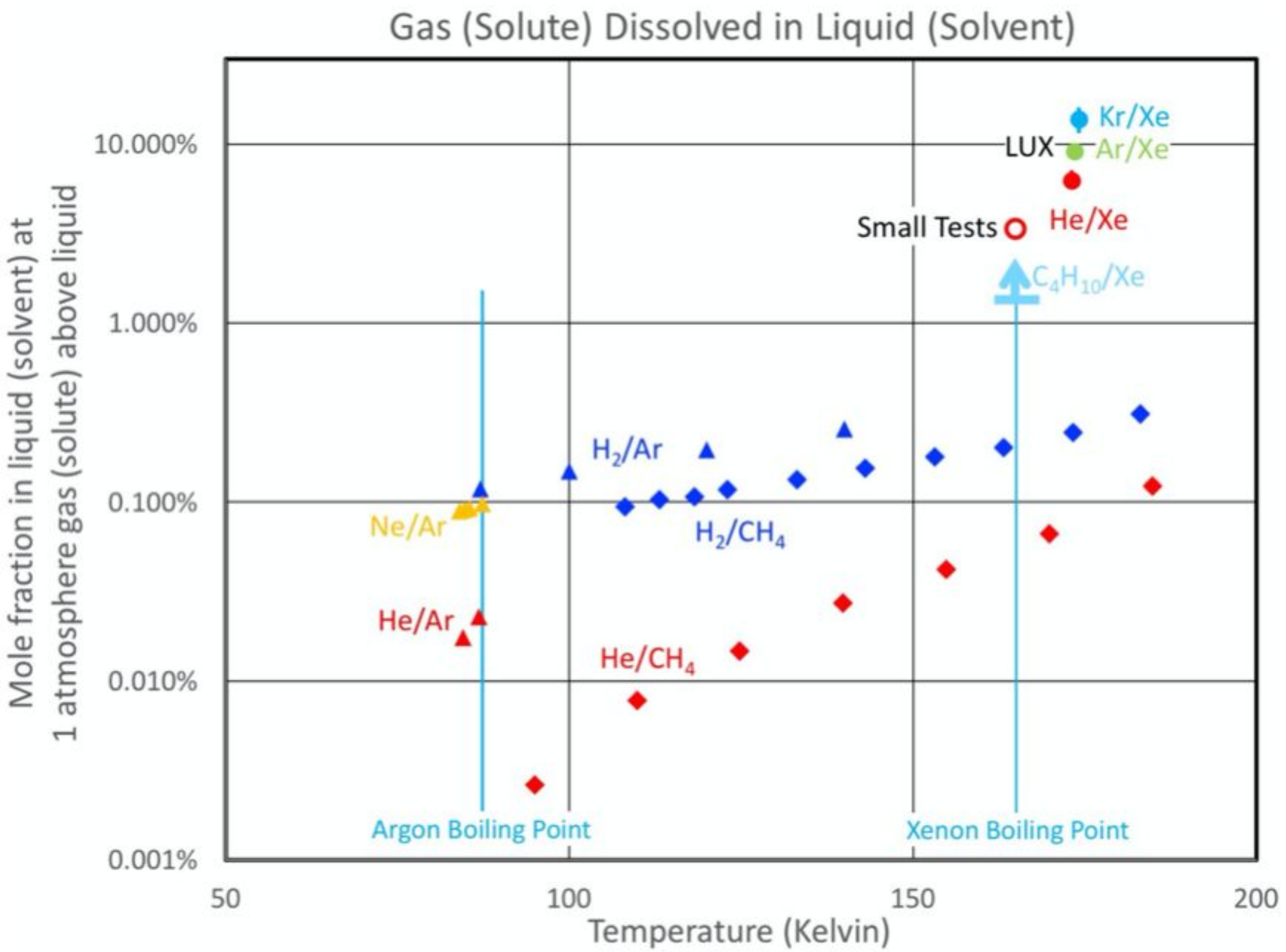
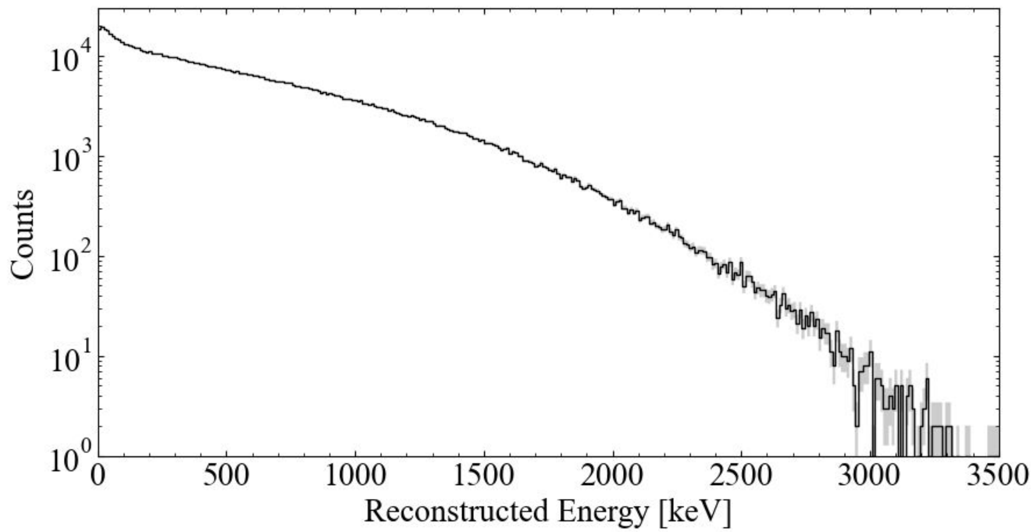


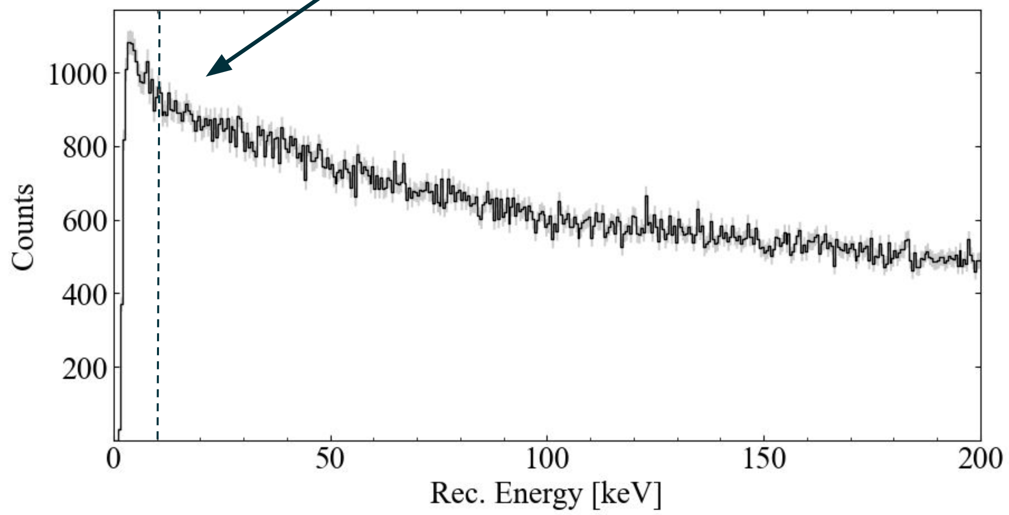
Figure 3: Solubilities of various gases in cold liquids as a function of temperature. Methane(Argon/Xenon) as a solvent are shown in diamonds(triangles/circles). The various solutes are labeled and distinguished by color. The solubilities in liquid xenon measured by LUX and associated small setups are substantially higher than those in methane and argon.

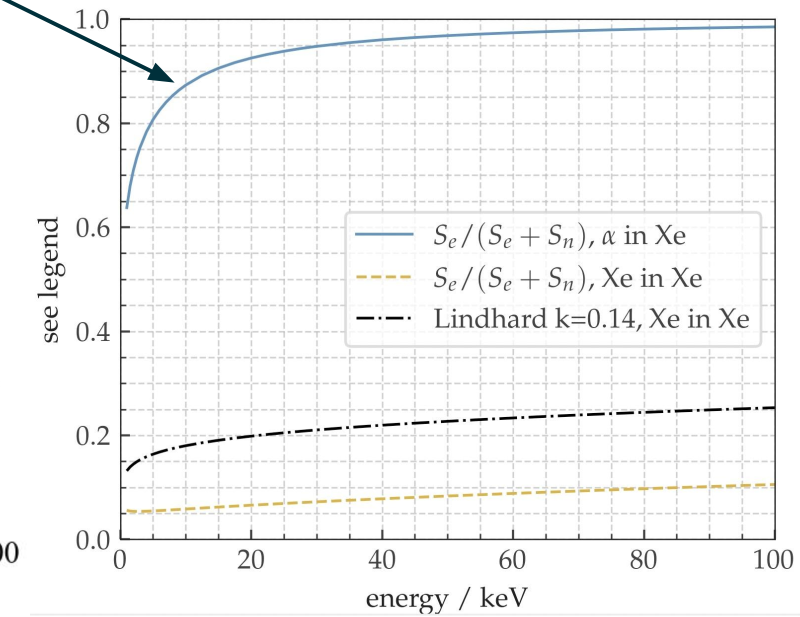
Estimates on alpha energy scale



expected flat(ish) source spectrum has upward inflection at ~10 keV

Right where electronic fraction of total stopping power has downward inflection





Estimates on alpha energy scale

~72 quanta (electron-like)

~40 quanta; 57% quenched

So 5 keVee ~ 9.0 keV_{Helium}