Dark matter detectors

Dark matter & the Universe, lecture 5 illustrative slides

Ed Daw

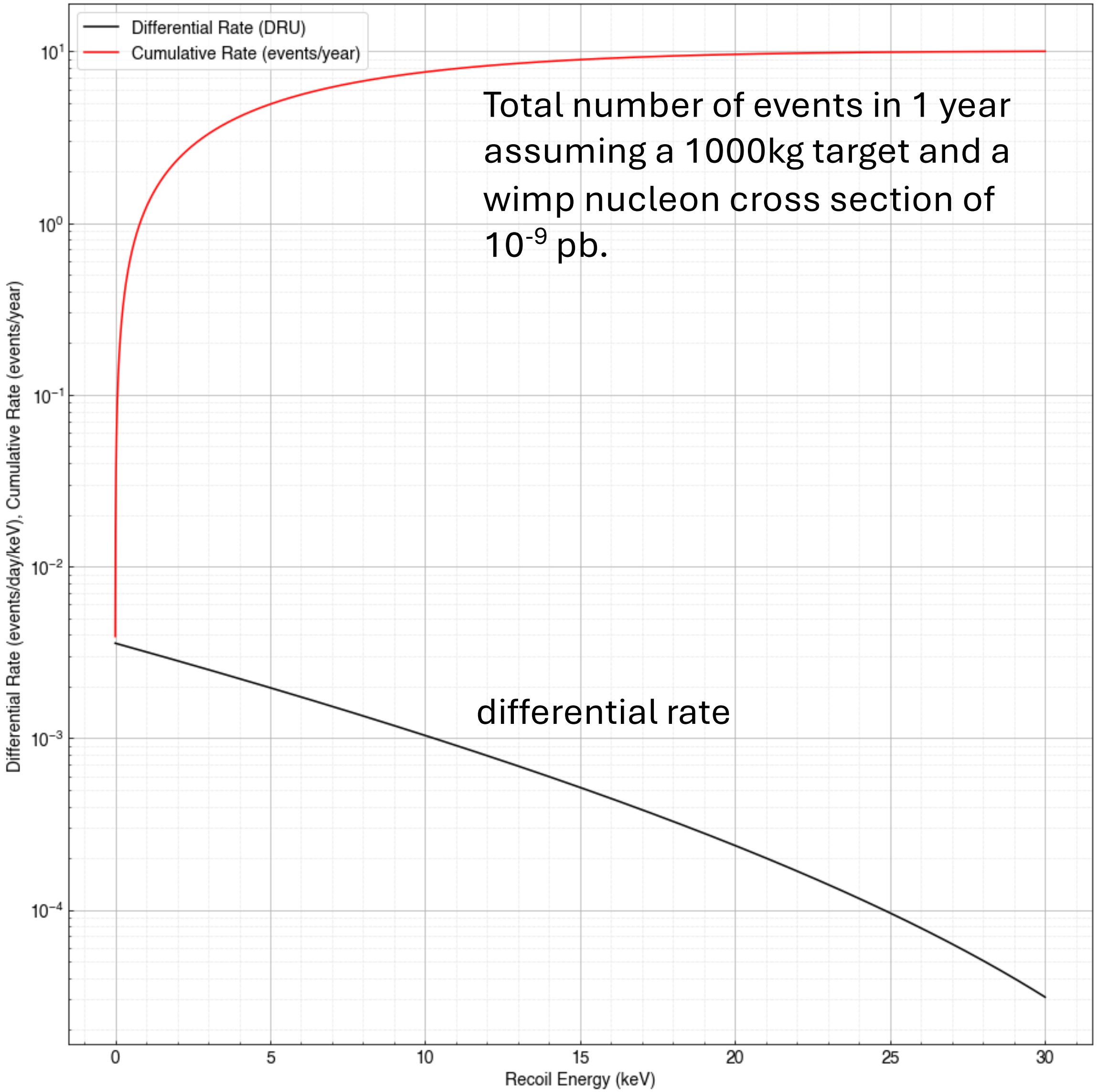
Differential WIMP scattering rate

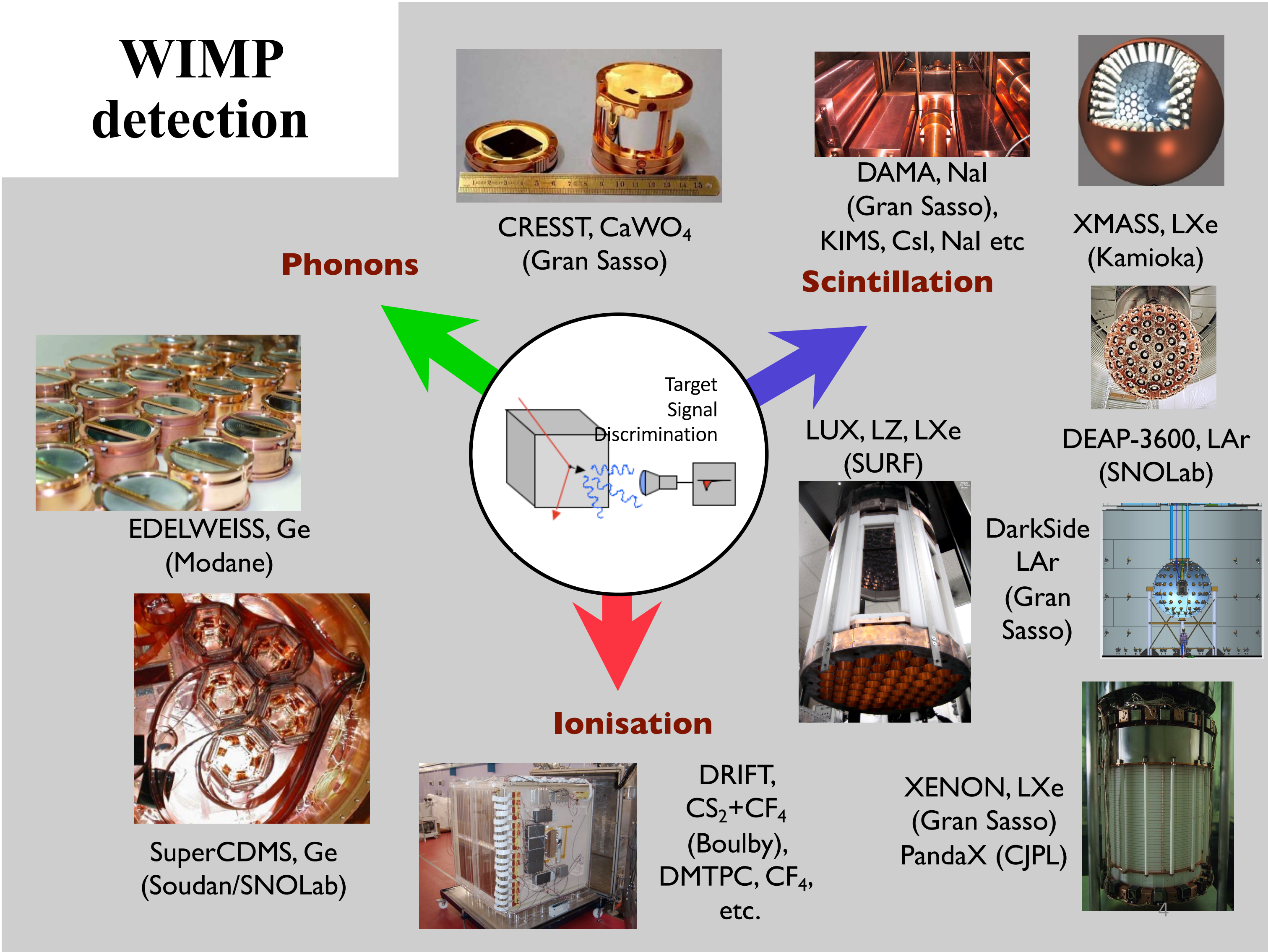
In lecture 4 we derived the differential rate for WIMP nucleon elastic scattering. Per kg of detector,

$$\left(\frac{1}{M_D}\frac{dR}{dE_R}\right)\ [\mathrm{D.R.U.}] = \frac{0.87F^2(E_R)A^2\sigma_{\mathrm{N}}\rho_{\mathrm{H}}m_N}{\mu^2 m_w\left(\frac{v_0}{c}\right)}\exp\left(\frac{-m_N E_R}{2\mu^2\left(\frac{v_o}{c}\right)^2}\right)$$

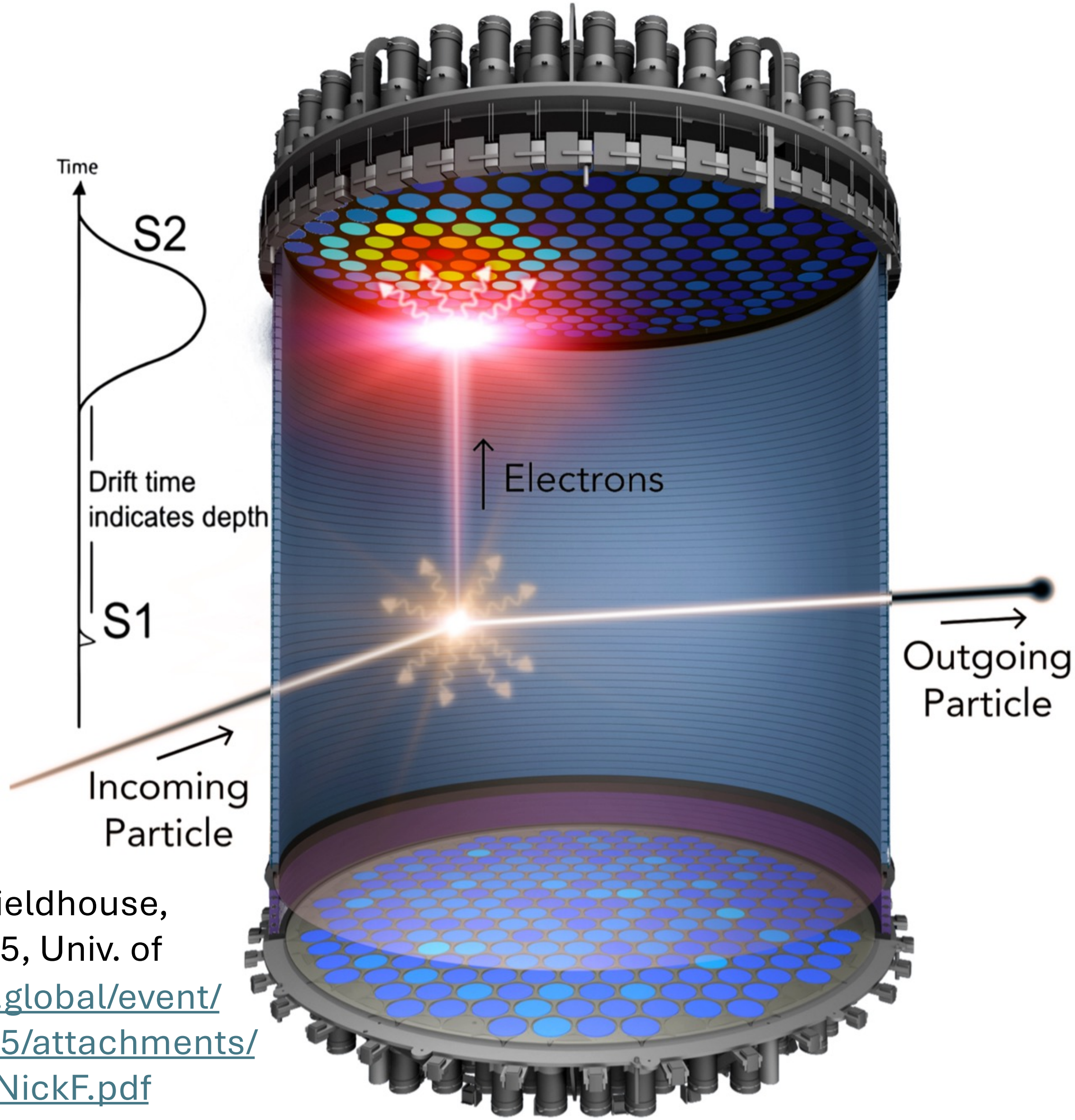
The differential rate is plotted here assuming a 10^{-9} pb WIMP nucleon elastic scattering cross section, a 1000kg detector consisting of Xenon, A=131, and a 100GeV/c^2 wimp with a halo density of 0.45 GeV/c^2.

Also shown is the total rate up to 30keV recoil energy, where the differential rate has dropped by two orders of magnitude. There are a total of 10 events, of which 5 are below a recoil energy of 5keV.

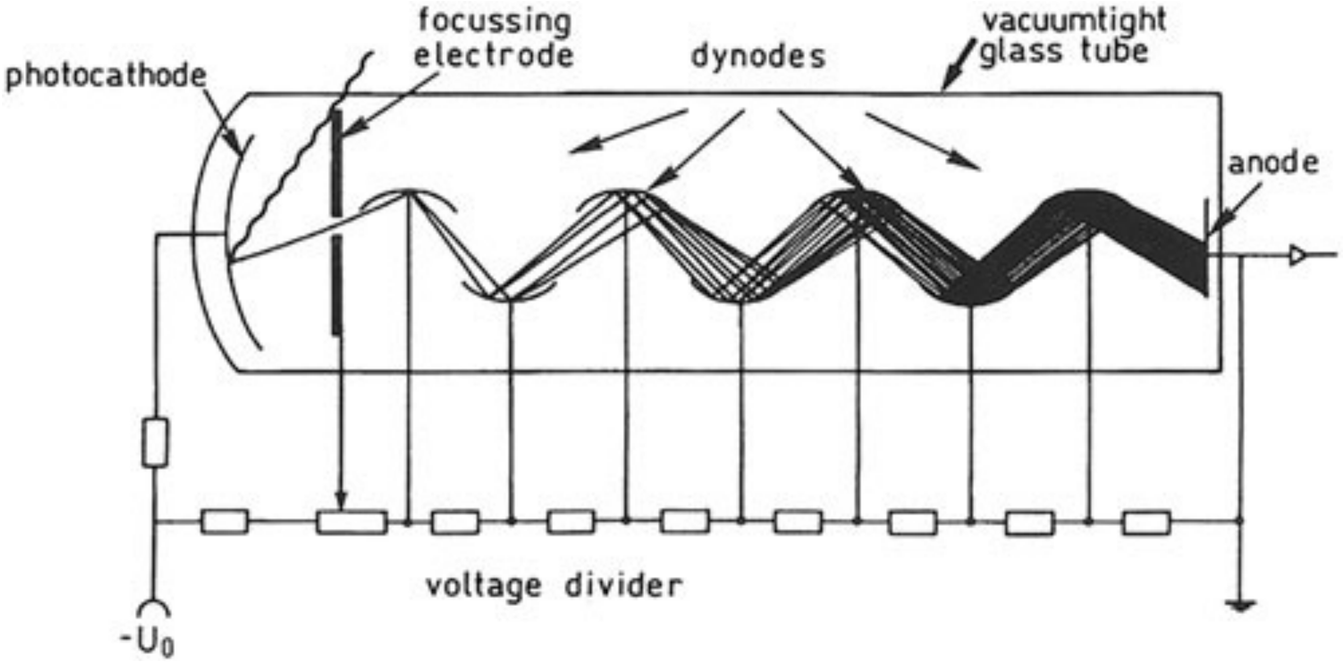




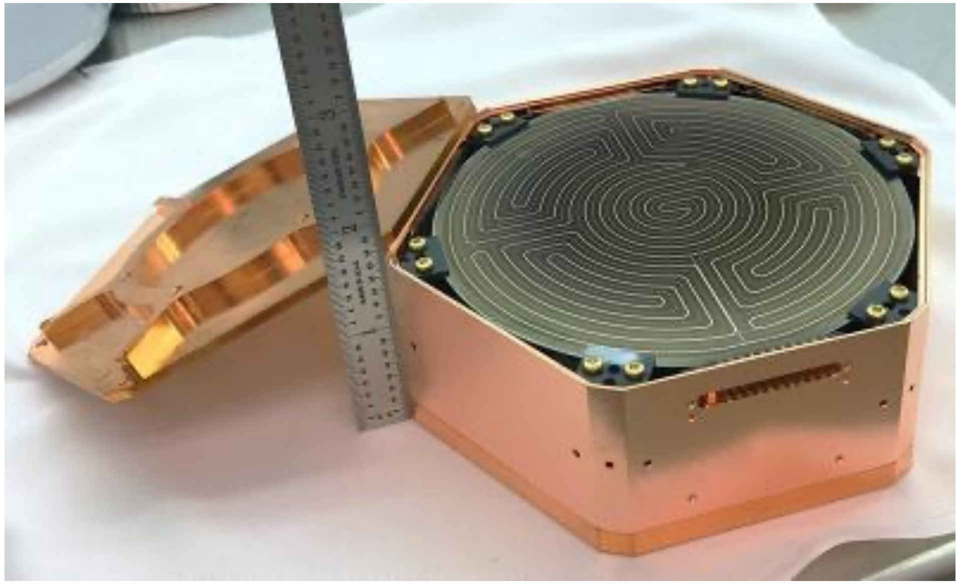
from V.A. Kudryavtsev, Dark Matter and the Universe course notes, private communication (2025)

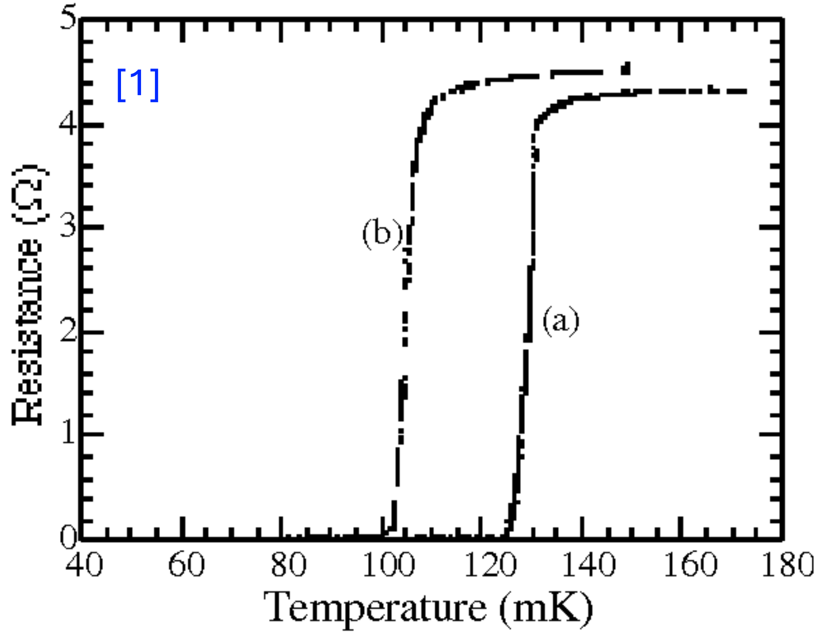


From the talk by Nicholas Fieldhouse, DMUK meeting, 1st Dec 2025, Univ. of Birmingham. https://indico.global/event/15936/contributions/140215/attachments/64983/125724/LZUpdates-NickF.pdf



https://www.researchgate.net/publication/344039122/figure/fig18/AS:940738644811795@1601300979276/Working-principle-of-a-photomultiplier-The-electrode-system-is-mounted-in-an-evacuated.ppm





Bias the film with a constant voltage. The heating of the resistor is V^2/R where R is the resistance.

When the temperature rises, the resistance rises, so the heating drops and the film cools again. In this way, you can use a constant voltage to stabilize the film at a temperature part way up its superconducting / normal conducting transition curve.

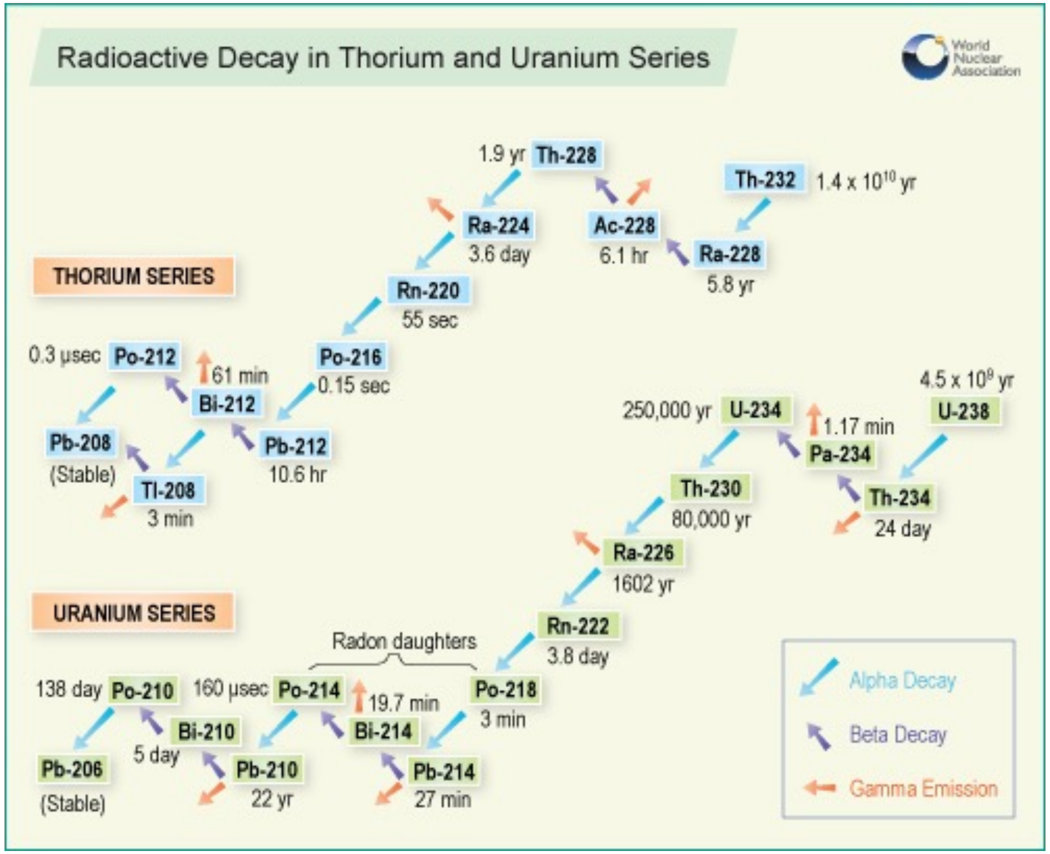
phonon signals manifest themselves as small pulses in the voltage caused by small energy depositions giving rise to transient heating of the tungsten film.

[1] TUNING OF TUNGSTEN TRANSITION EDGE SENSORS USING IRON IMPLANTATION
https://api.semanticscholar.org/CorpusID:18675720

Sources of background

- Dominated by radiation entering the cavity.
- Neutrons and gamma rays are the most problematic
- Cosmic rays can act as a source of neutrons
- The detector itself can contain radioactive nuclides
- The environment surrounding the detector.
- In underground labs, radon is a particular issue.

Backgrounds: radioactivity



- Uranium and thorium decay chains.
- ^{40}K is present in natural potassium.
- ^{60}Co and other radioisotopes produced by cosmic rays at the surface and in other nuclear reactions (nuclear power plants, accidents, nuclear explosions).

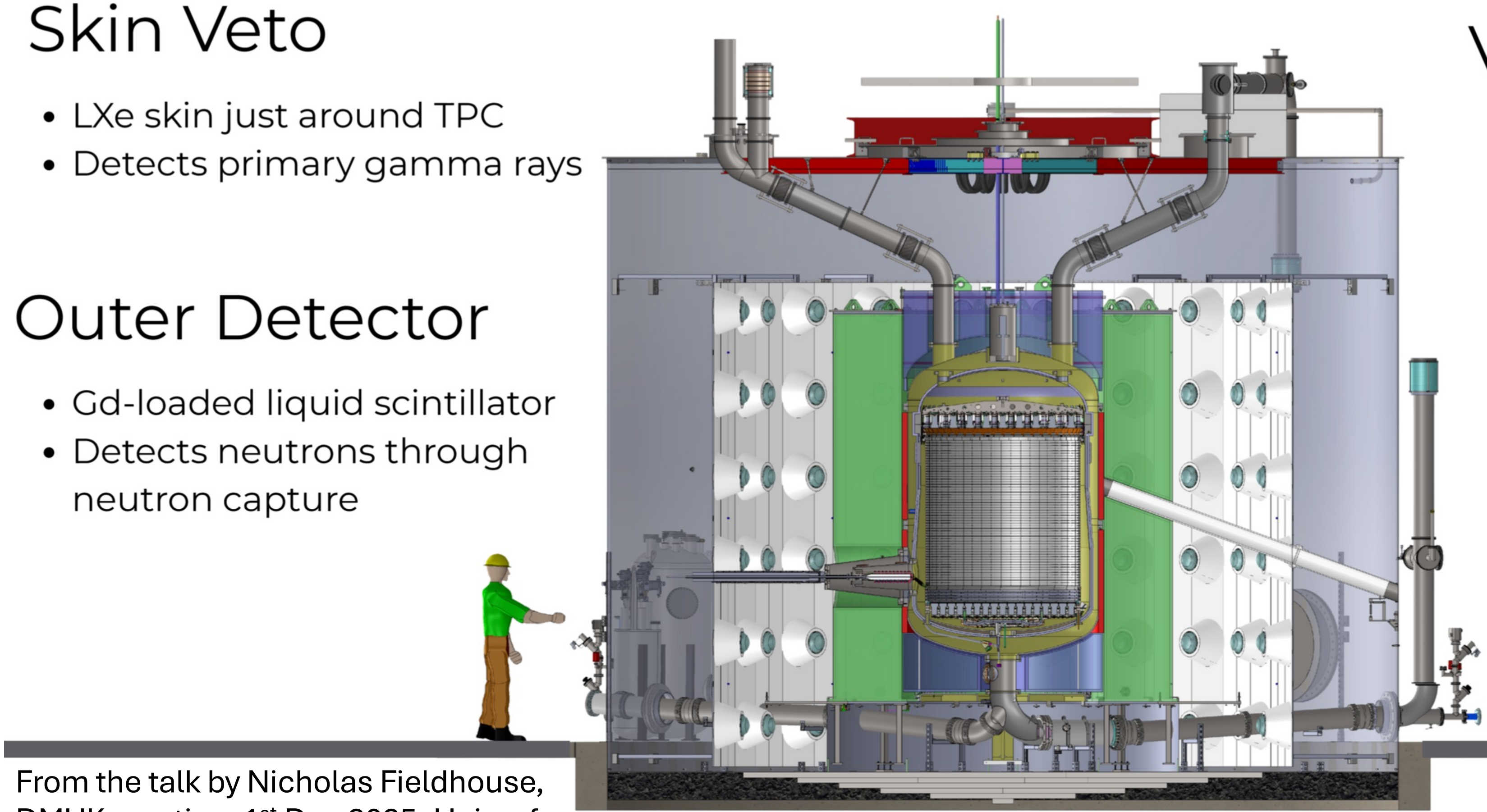
from V.A. Kudryavtsev, Dark Matter and the Universe course notes, private communication (2025)

Skin Veto

- LXe skin just around TPC
- Detects primary gamma rays

Outer Detector

- Gd-loaded liquid scintillator
- Detects neutrons through neutron capture



Veto Efficiency

89 ± 3 %
from AmLi calibrations

92 ± 4 %
from simulations of neutron backgrounds

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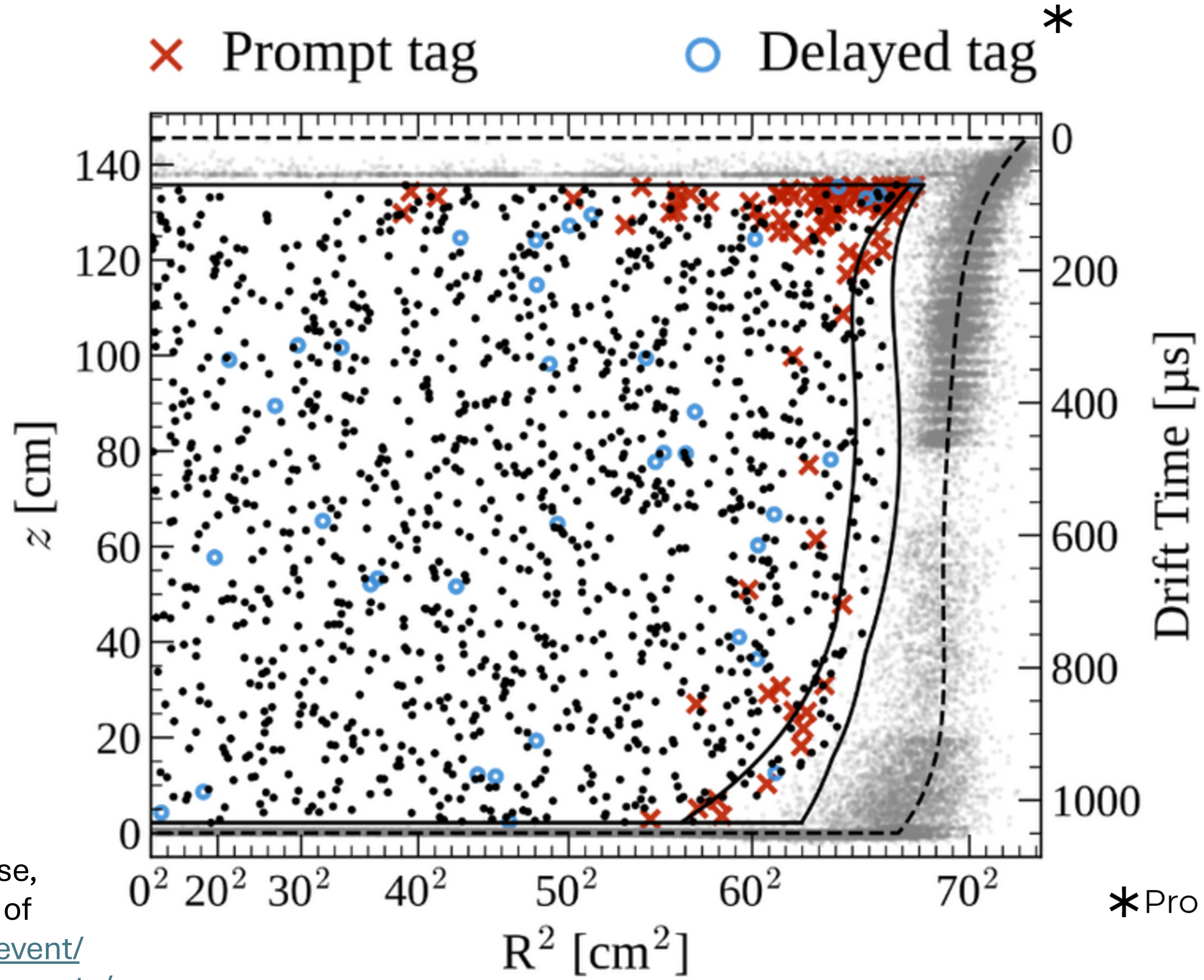

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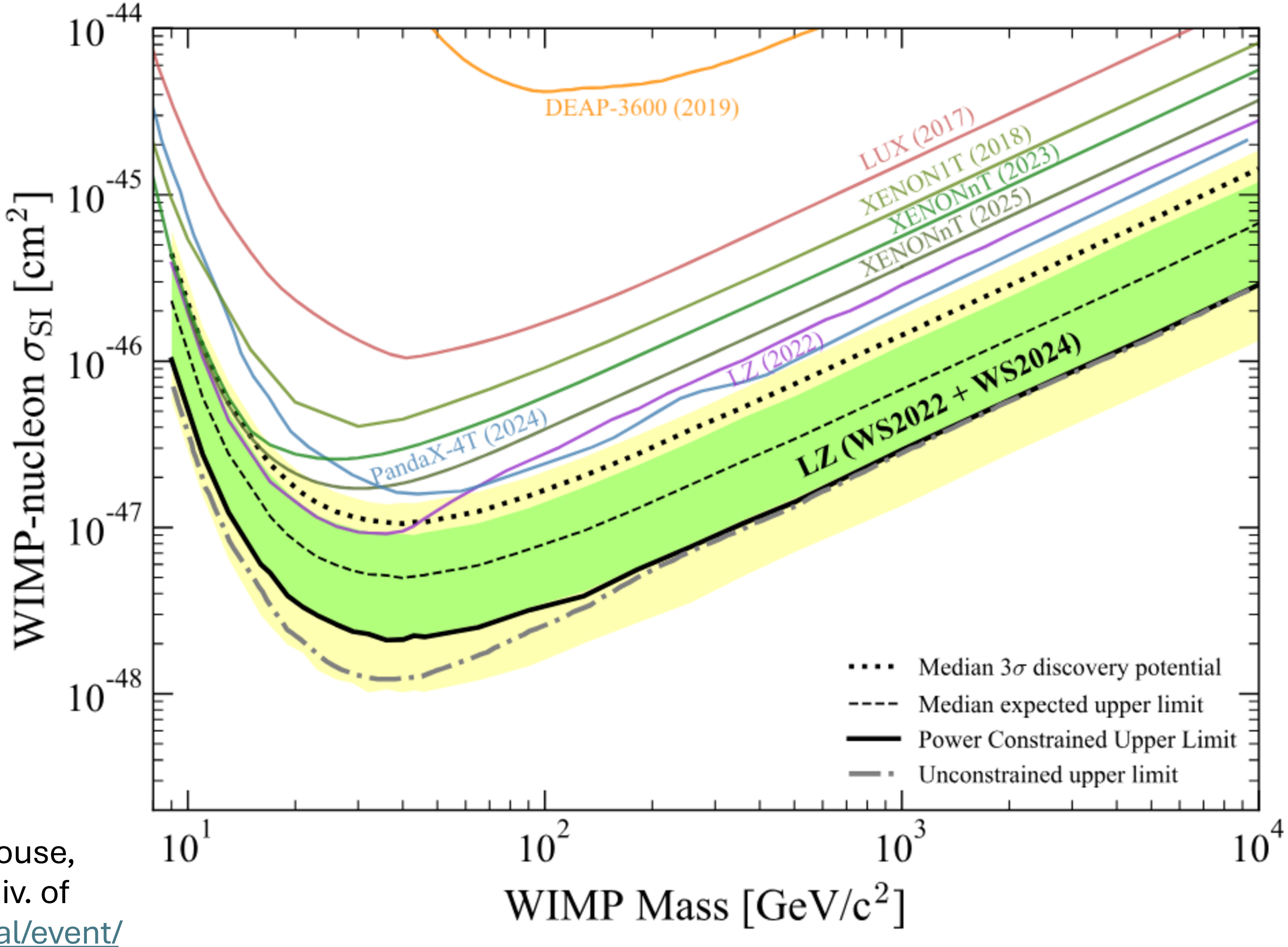

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Summary

- Nuclear recoils carry keV of kinetic energy into a detector.
- This energy can be converted into observable signatures – in particular scintillation light, ionization electrons and phonons (heating of the crystal)
- Radioactive background can mask and mimic signals.
- Underground operation is necessary to suppress cosmic rays.
- The detector itself and the surrounding environment are also radioactive to some extent.
- Shielding and vetoes are additional defences to suppress noise.
- The detector can be fiducialised to eliminate events occurring near its surface.
- Modern detectors have excluded WIMPs in our local halo with exquisite sensitivity, current limits are at the 2×10^{-12} pb level!