

Cryogenic Detectors ... or... Come To The Cold Dark Side



Prof Miriam Diamond
GRIDS, June 2026

University of Toronto, Dept of Physics and Dept of Astronomy & Astrophysics
Arthur B. McDonald Canadian Astroparticle Physics Research Institute



FROZEN: The Dark Version

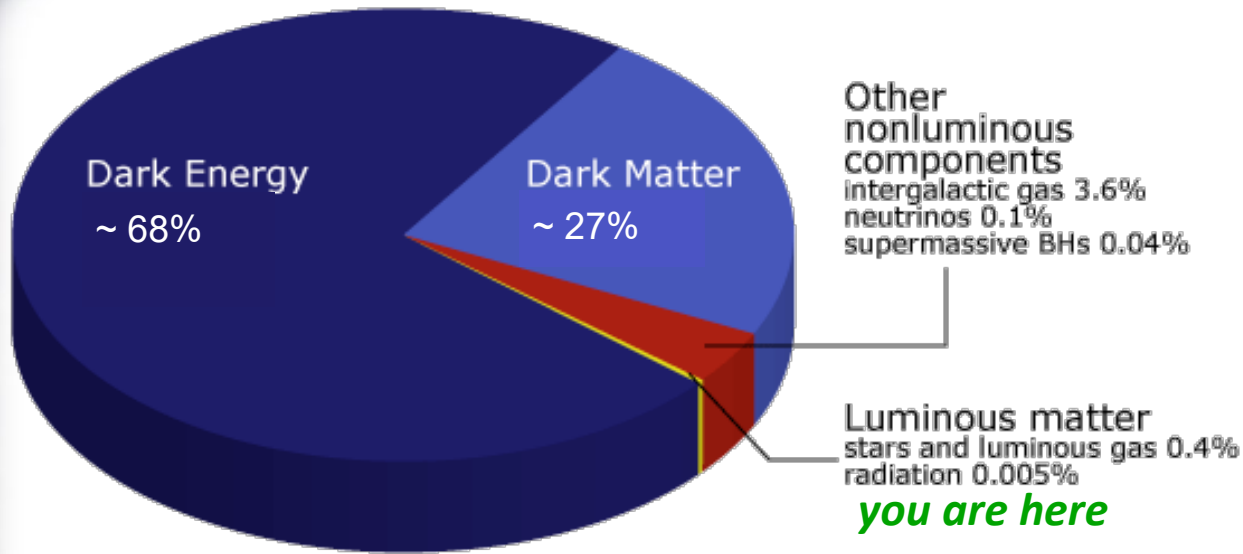
- **Overview: DM candidates & search strategies**
- **Overview: “exotic” neutrino physics**
 - **$CE\nu NS$, $0\nu\beta\beta$**
- **Current / next-gen cryogenic detectors**
 - **CCDs, semiconductor crystals, liquid nobles**
- **Neutrinos vs DM signals in cryogenic detectors**
- **Cryogenic infrastructure**
 - **Dilution fridges, adiabatic demagnetization fridges, cryostats**
- **Backgrounds & calibrations in cryogenic detectors**



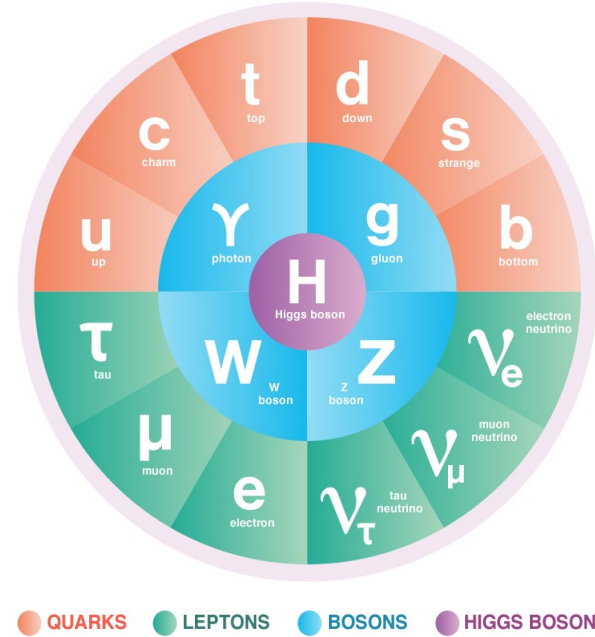
DM Candidates & Search Strategies



The Dark Matter Question



=



+



So far, evidence for existence of DM comes from astrophysics
 Meanwhile, HEP theory tells us Standard Model is incomplete

Targeting “Beyond the Standard Model” Searches

DM searches → look for BSM particle(s) with particular properties:

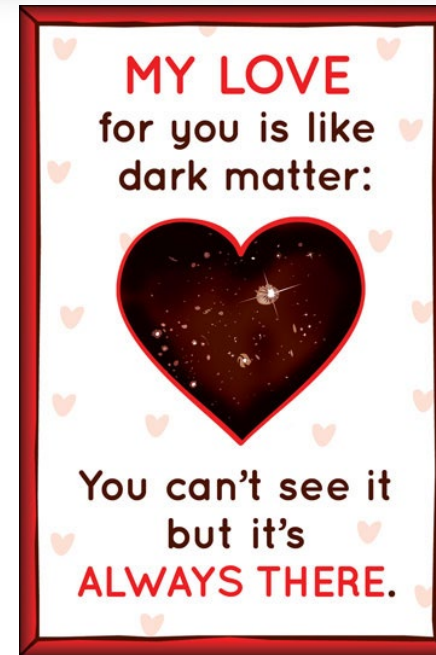
- Cold (non-relativistic)
- Stable on cosmological timescales
- Gravitationally interacting
- Feeble, if any, non-gravitational self-interactions
- Feeble, if any, non-gravitational interactions with luminous matter

What mass scale?

What interactions with SM?

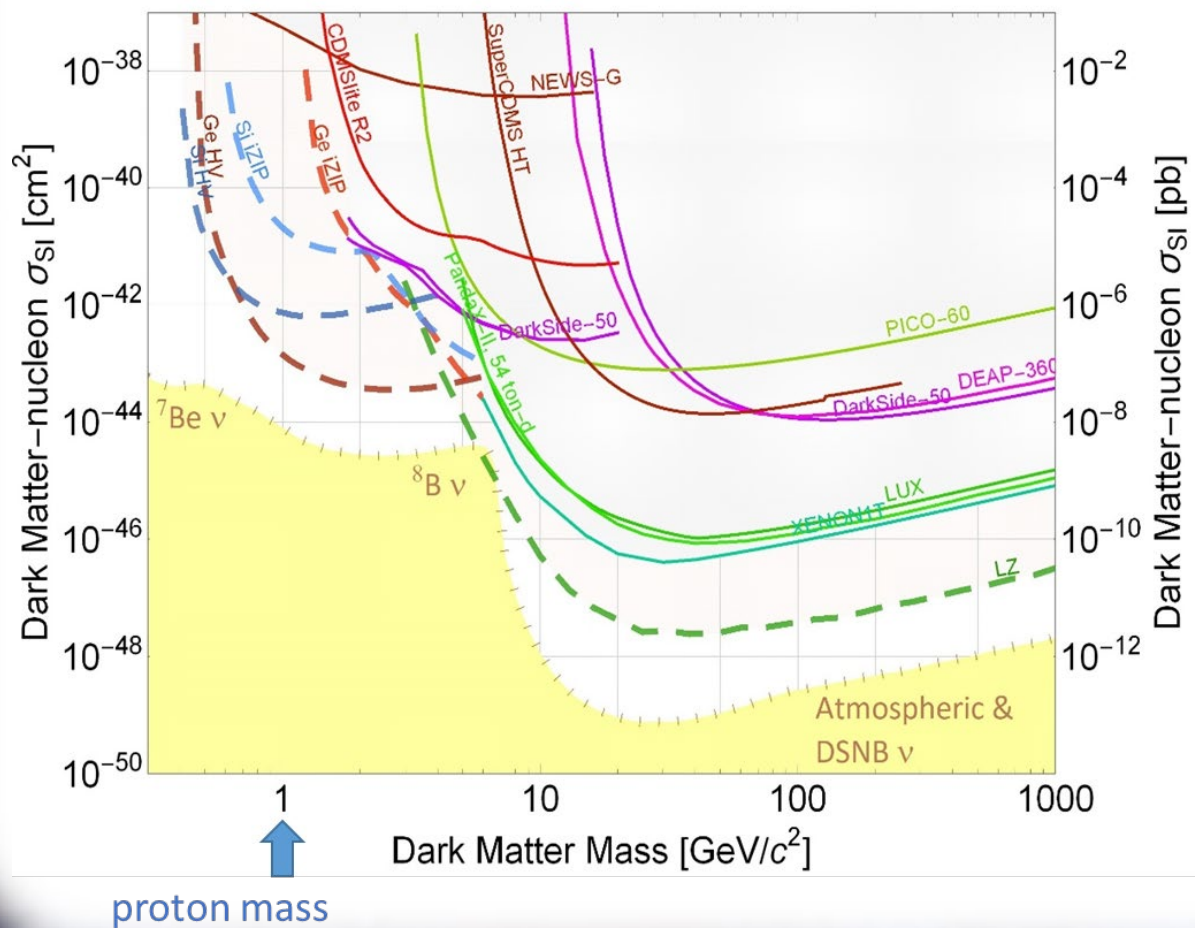
Are there “dark forces”?

How many new particle species?



Weakly Interacting Massive Particles: WIMPing out?

Decades of searches *where we most expected to find WIMPs* haven't found them!

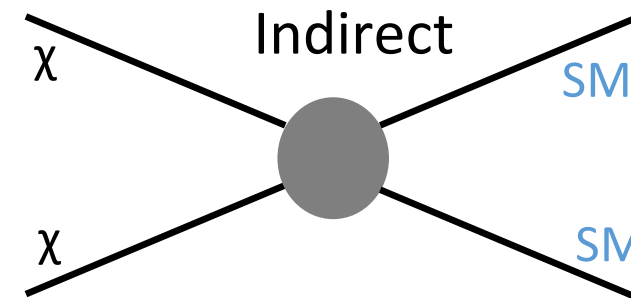
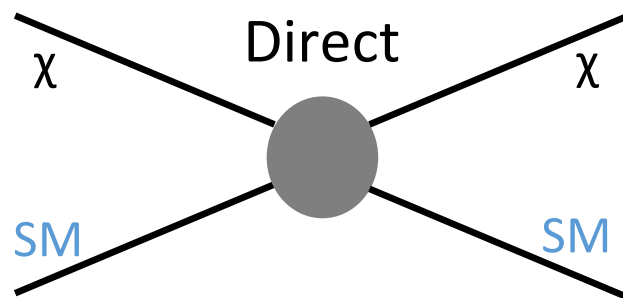
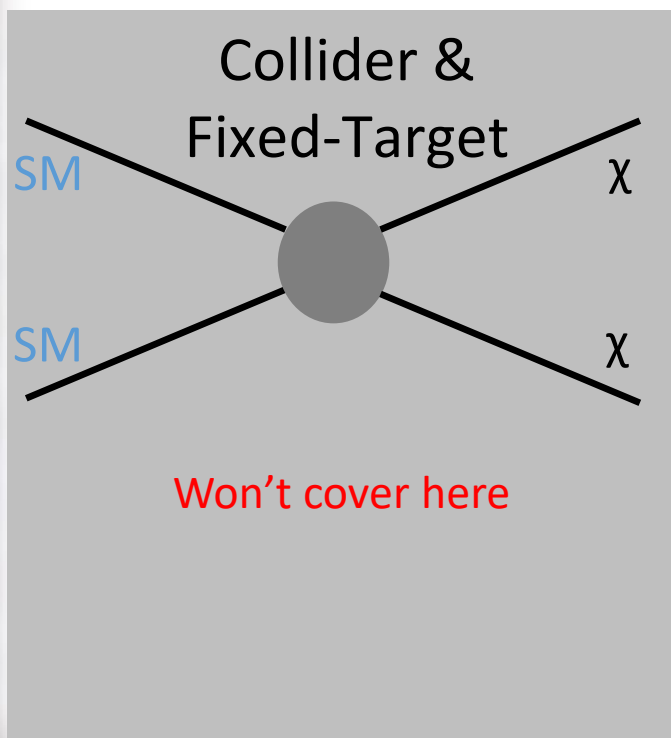


What now? Options include:

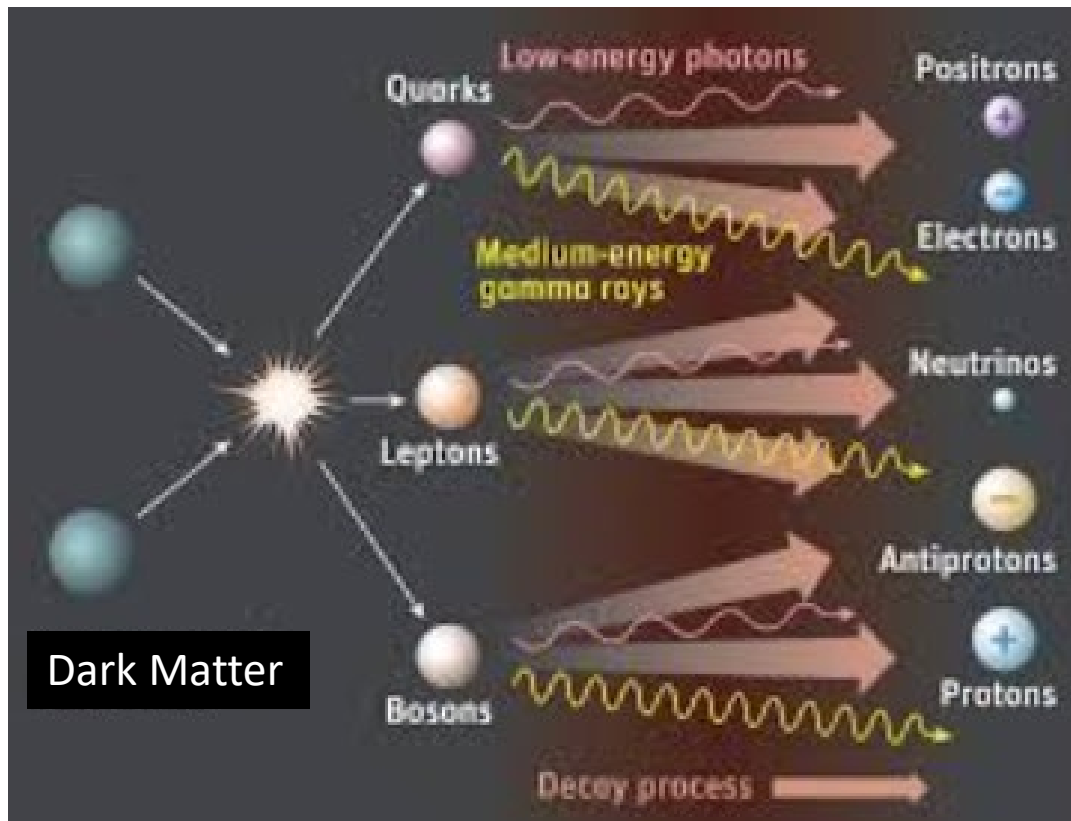
- Very feebly-interacting WIMPs
- Sub-GeV WIMP-like particles
- Low-mass dark photons (sub-GeV)
- Lightly-ionizing / millicharged particles (sub-GeV)
- Axion-like particles (sub-eV)

DM Search Strategies

Complementarity between different types of experiments

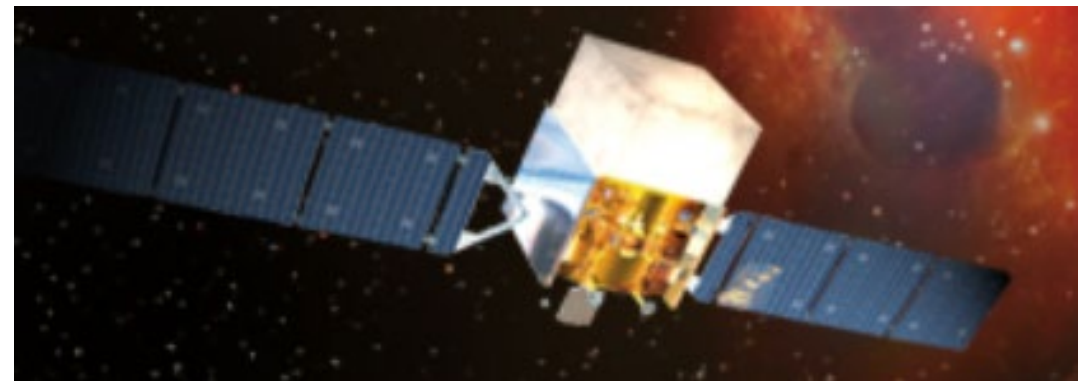


Indirect Detection of DM

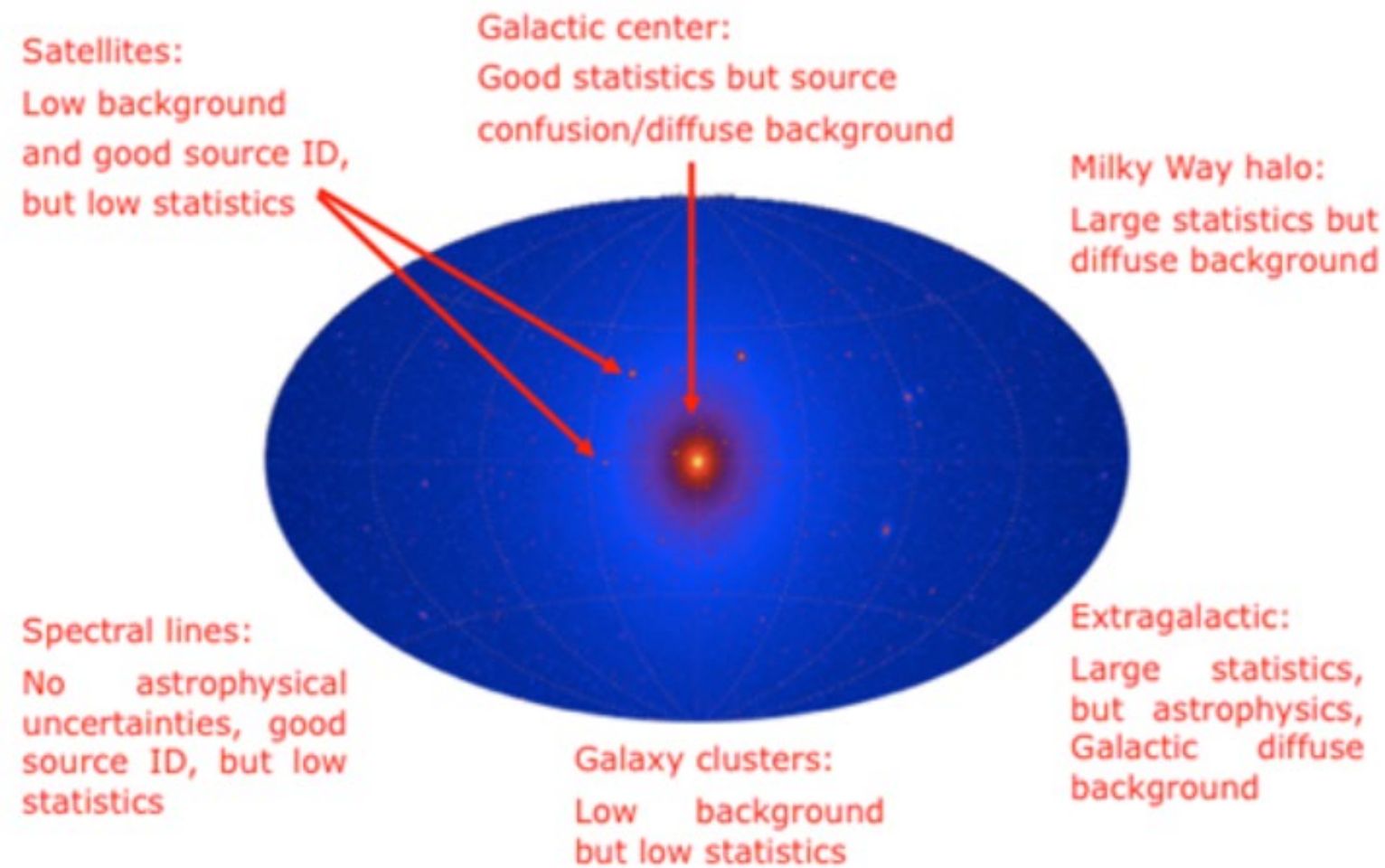


Collisions of WIMPs in outer space could produce SM particles that travel to Earth

“Signals” (e.g. excess photons of a certain frequency) detected by ground- or space-based telescopes



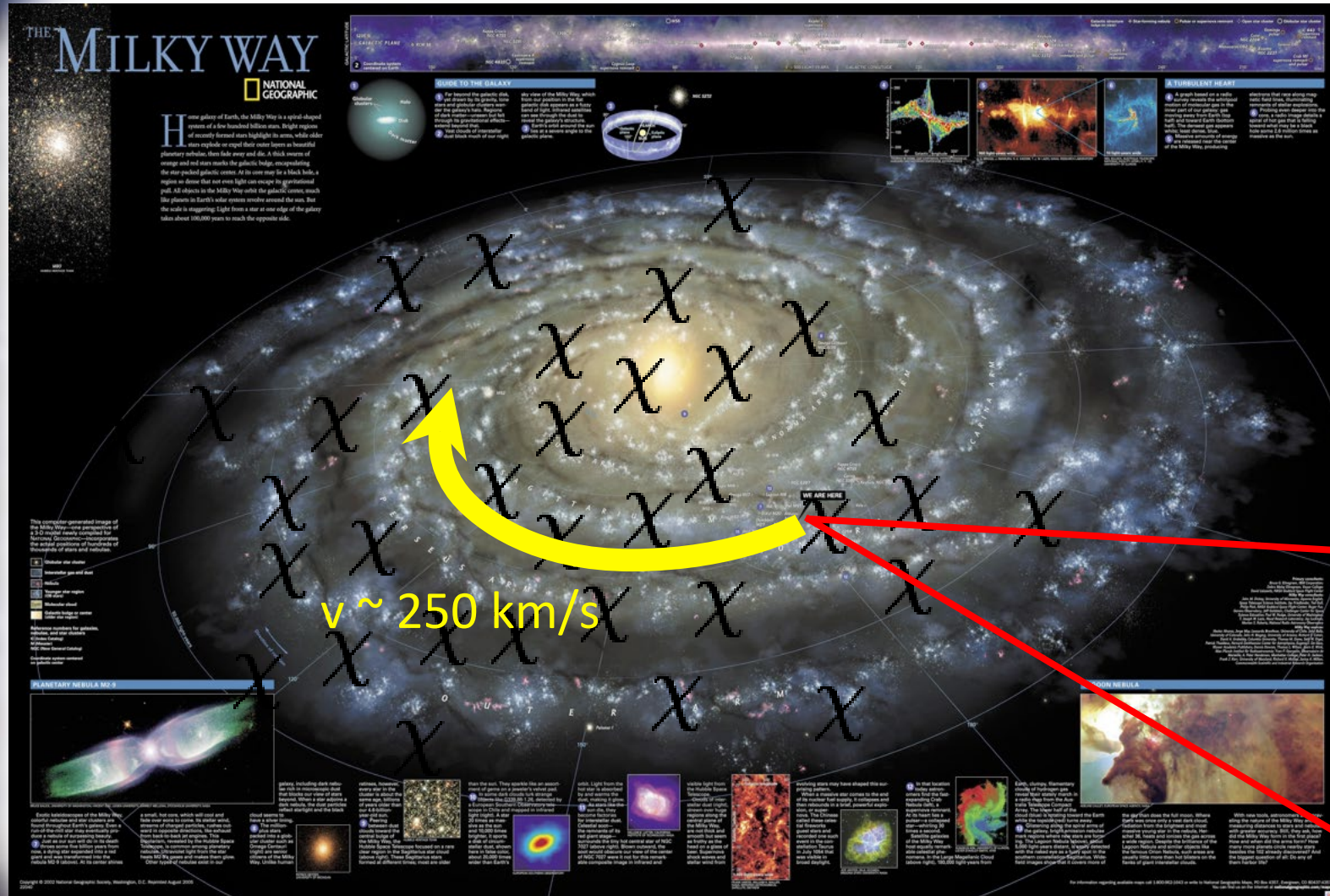
Indirect Detection of DM



Expect some cosmic neighborhoods to have more DM than others

But some also give off more backgrounds

Direct Detection of DM

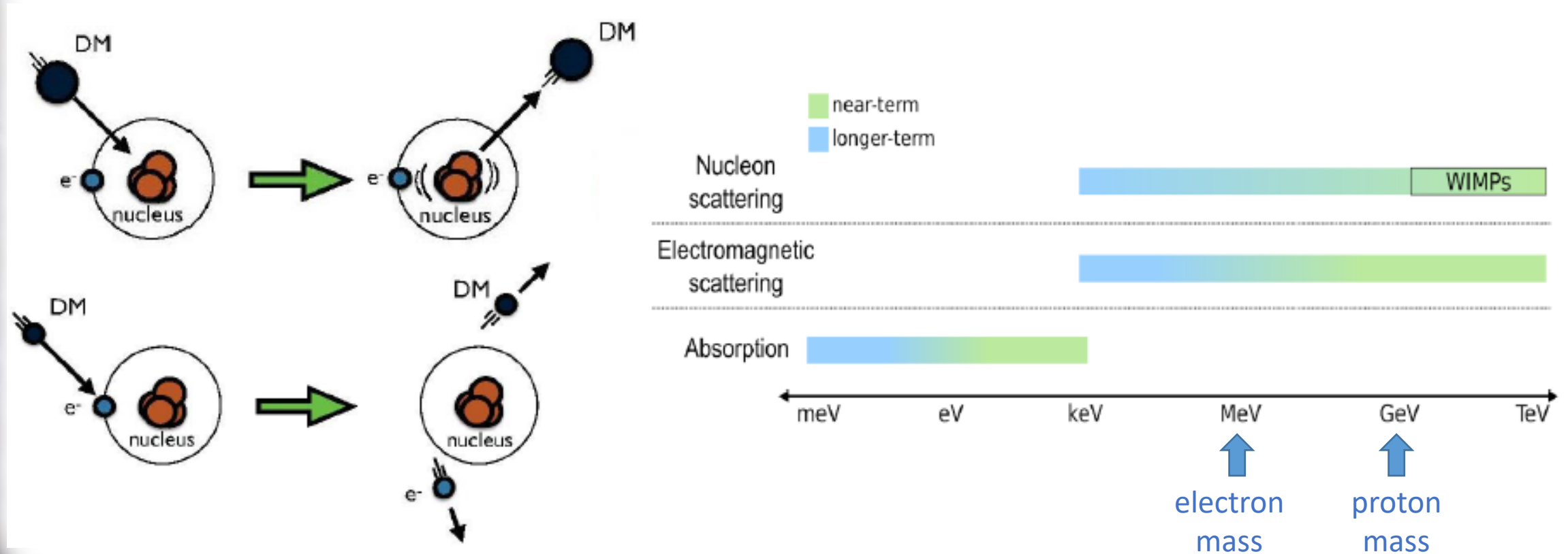


Collisions of galactic DM with SM particles in detector on Earth



Direct Detection: Interaction Types

DM particles collide with SM particles in detector “target” and are absorbed, or cause nuclear and/or electronic recoils



Direct Detection: DM Event Rate

particle theory nuclear structure local properties of DM halo

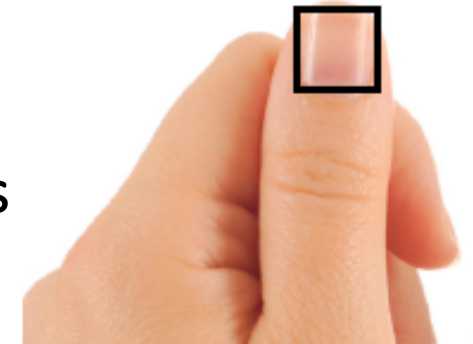
$$\frac{dR}{dE_R} = \frac{\sigma_o}{m_\chi} \frac{F^2(E_R)}{m_r^2} \frac{\rho_o T(E_R)}{v_o \sqrt{\pi}}$$

recoil energy of nucleus

$m_r = \frac{m_\chi m_N}{m_\chi + m_N}$ reduced mass of DM-nucleon system

Local $\rho_{DM} \approx 0.4 \text{ GeV/cm}^3$
 $v_{DM} \approx 250 \text{ km/s}$ (non-relativistic)

For $m_{DM} \approx 1 \text{ GeV}$:
 $\text{flux}_{DM} \approx 10 \text{ million / cm}^2\text{s}$



Direct Detection: DM Event Rate

	particle theory	nuclear structure	local properties of DM halo
$\frac{dR}{dE_R} =$	$\frac{\sigma_o}{m_\chi}$	$\frac{F^2(E_R)}{m_r^2}$	$\frac{\rho_o T(E_R)}{v_o \sqrt{\pi}}$

- Simplest case: Spin Independent interactions
- The scattering amplitudes from individual nucleons interfere.
- For zero momentum transfer collisions (extremely soft bumps) they add coherently:

$$\sigma_o = \frac{4m_r^2}{\pi} [Zf_p + (A - Z)f_n]^2$$

$$\sigma_o \simeq \frac{4m_r^2}{\pi} fA^2$$

coupling constant

Enormous enhancement for heavy nuclei target!

Slide credit: Enectali Figueroa-Feliciano

Direct Detection: DM Event Rate

	particle theory	nuclear structure	local properties of DM halo
$\frac{dR}{dE_R} =$	$\frac{\sigma_o}{m_\chi}$	$\frac{F^2(E_R)}{m_r^2}$	$\frac{\rho_o T(E_R)}{v_o \sqrt{\pi}}$

$$F(E_R) = \left[\frac{3J_1(qR_1)}{qR_1} \right]^2 \exp(-(qs)^2) \quad \text{“Woods-Saxon Nuclear Form Factor”}$$

J_1 = Bessel function of the first kind, cylindrical harmonic

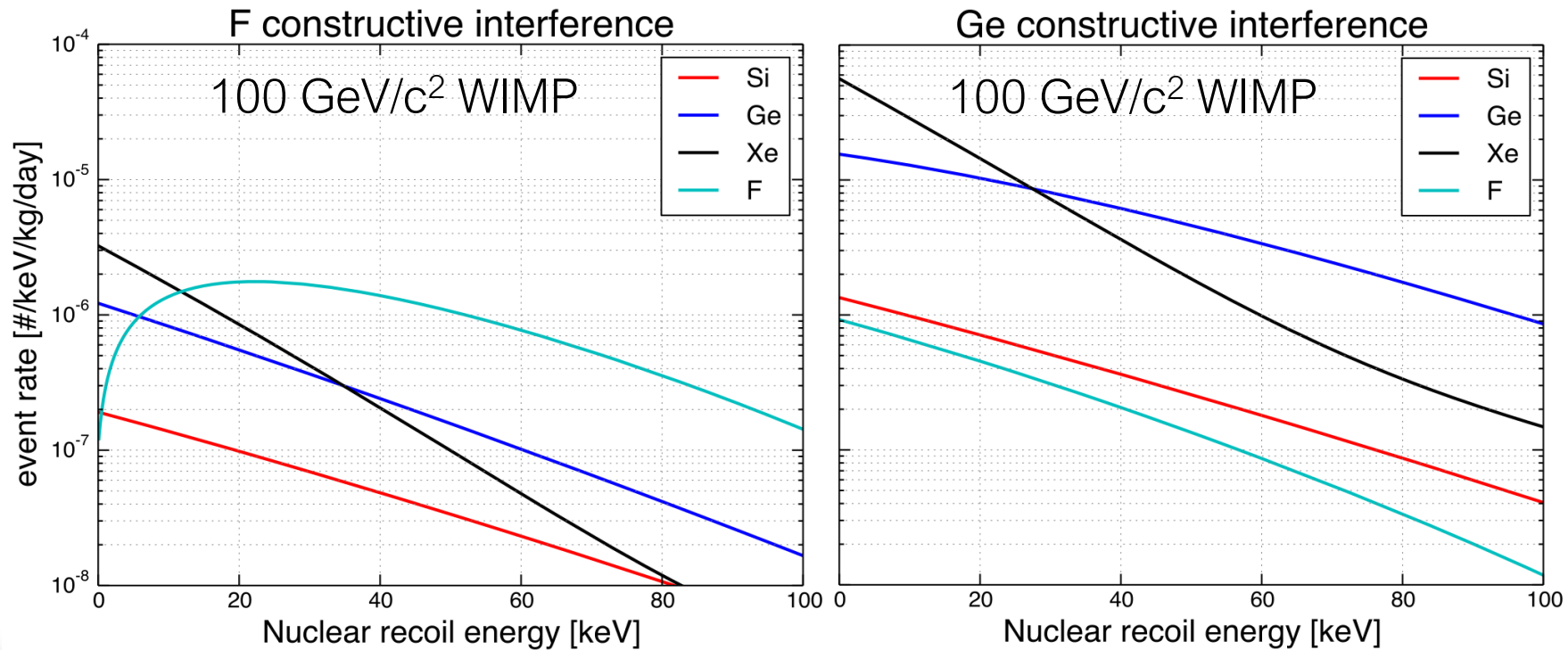
q = momentum transferred

s = effective “nuclear skin thickness” (distance through which charge density of nucleus drops to 0, not a step function due to QM effects)

Slide credit: Enectali Figueroa-Feliciano

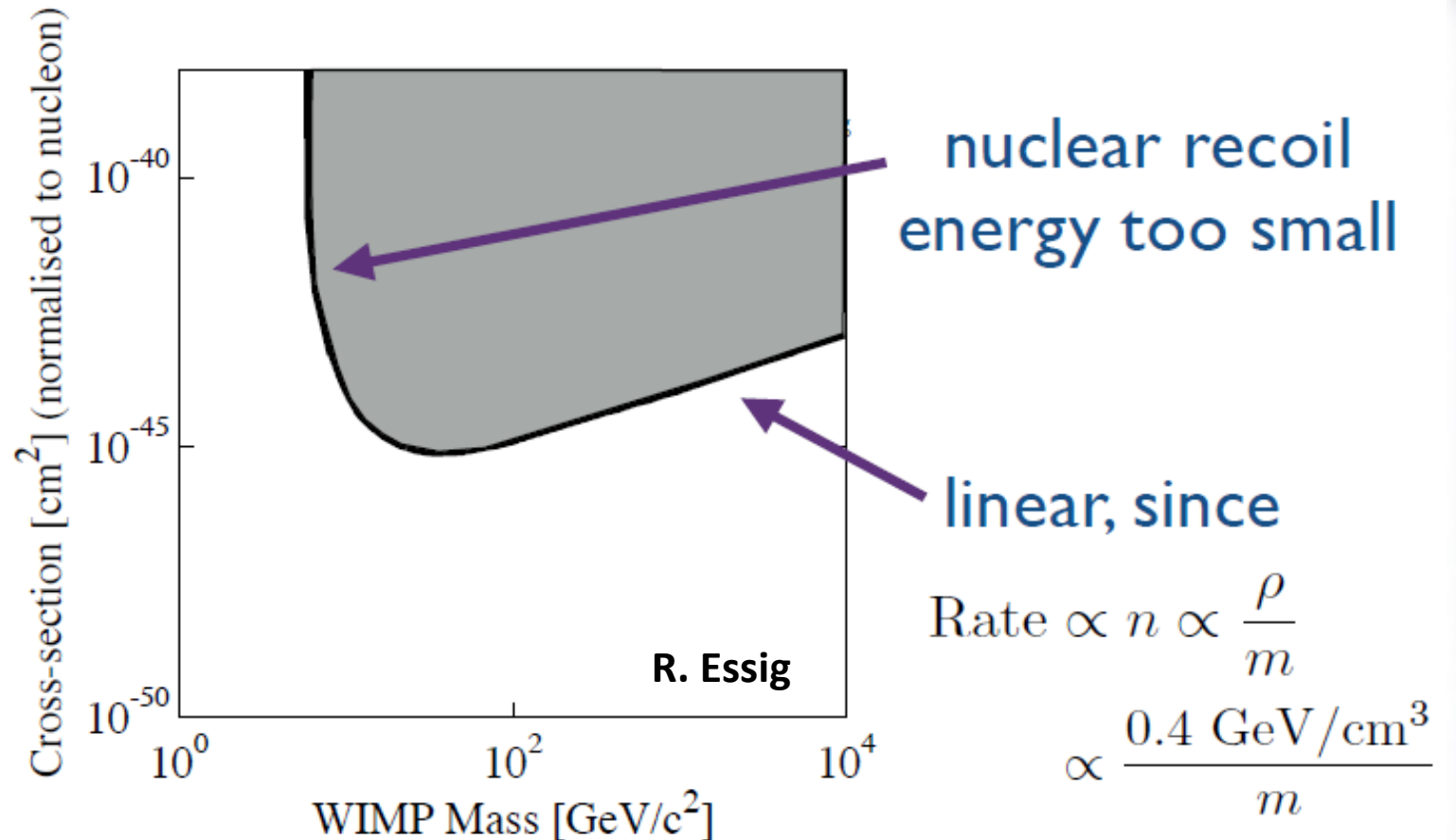
Direct Detection: Choice of Target Material

- More complicated interactions could lead to different rates (and different spectral shapes) in different target materials
- Robust program with multiple targets necessary to determine which (Effective Field Theory) operators are contributing to any detected signal



The GeV-Scale & Sub-GeV DM Direct Detection Challenge

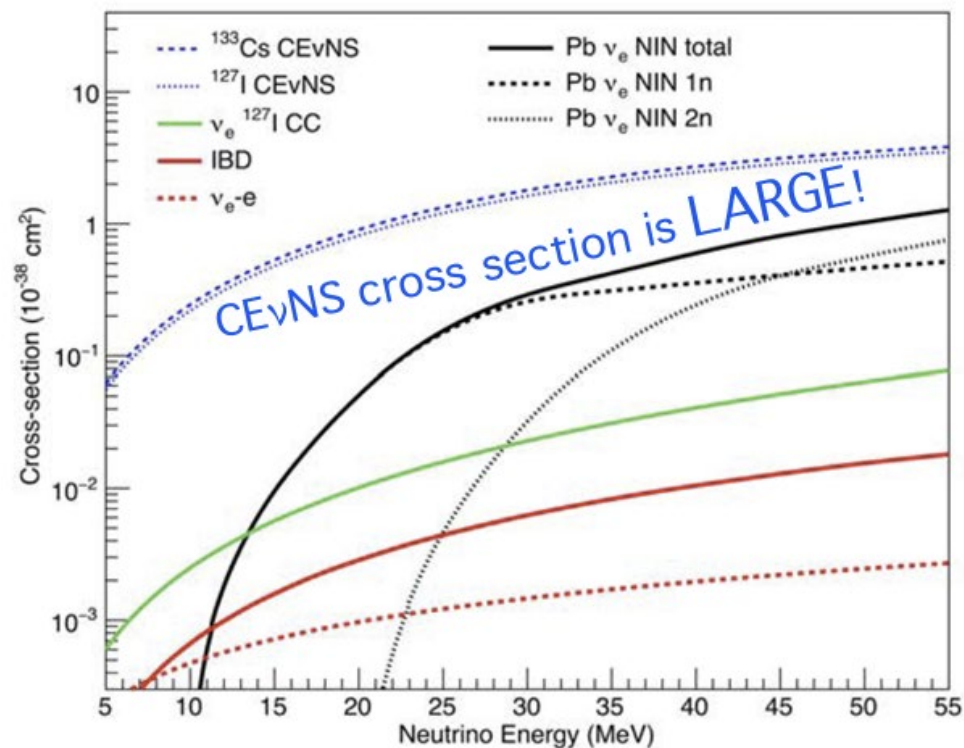
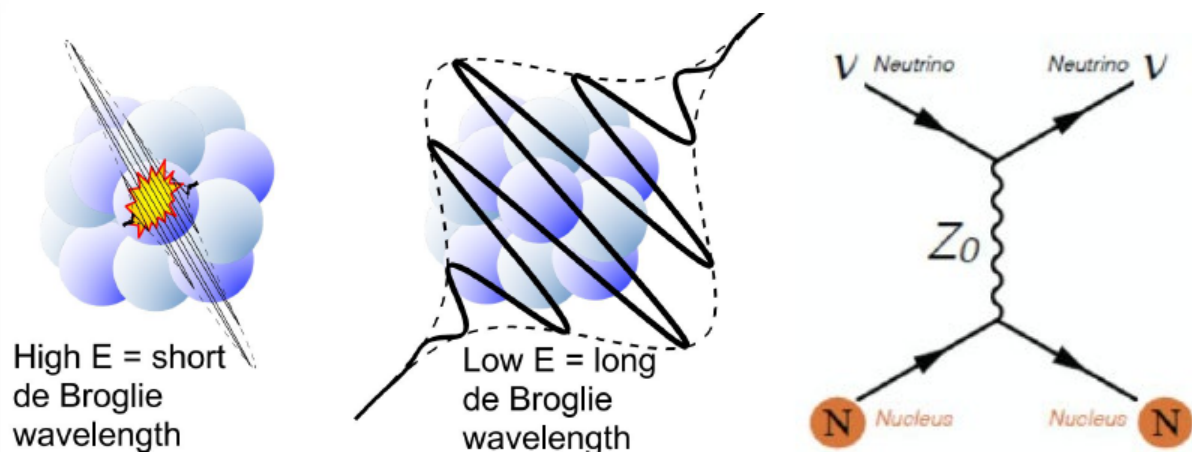
- **Low-mass DM stretches traditional WIMPy direct detection searches**
- **Can rely on elastic NR signal for DM masses down to ~ few GeV**
- **But not for sub-GeV DM: inefficient momentum & energy transfer**
- **Alternatives: inelastic processes, electron recoils**



“Exotic” Neutrino Physics

Coherent Elastic Neutrino-Nucleus Scattering

- CEvNS cross-section gets N^2 enhancement compared to other ν interactions
- Allows for kg-scale (not ton-scale) detectors
- First measured by COHERENT at spallation neutron source with CsI[Na], Ar, and Ge detectors
- Could be measured at nuclear reactors in future



D. Akimov et al. (COHERENT). Science 357, 1123–1126 (2017)

Coherent Elastic Neutrino-Nucleus Scattering

Fermi constant (SM parameter) Kinematics Nuclear Form Factor: F=1 full coherence

$$\frac{d\sigma}{dT} = \frac{G_F^2 M}{4\pi} \left(1 - \frac{MT}{2E_\nu^2} - \frac{T}{E_\nu}\right) Q_W^2 [F_W(q^2)]^2 + \frac{G_F^2 M}{4\pi} \left(1 + \frac{MT}{2E_\nu^2} - \frac{T}{E_\nu}\right) F_A(q^2)$$

Weak nuclear charge

$$Q_W = [Z(1 - 4 \sin^2 \theta_W) - N]$$

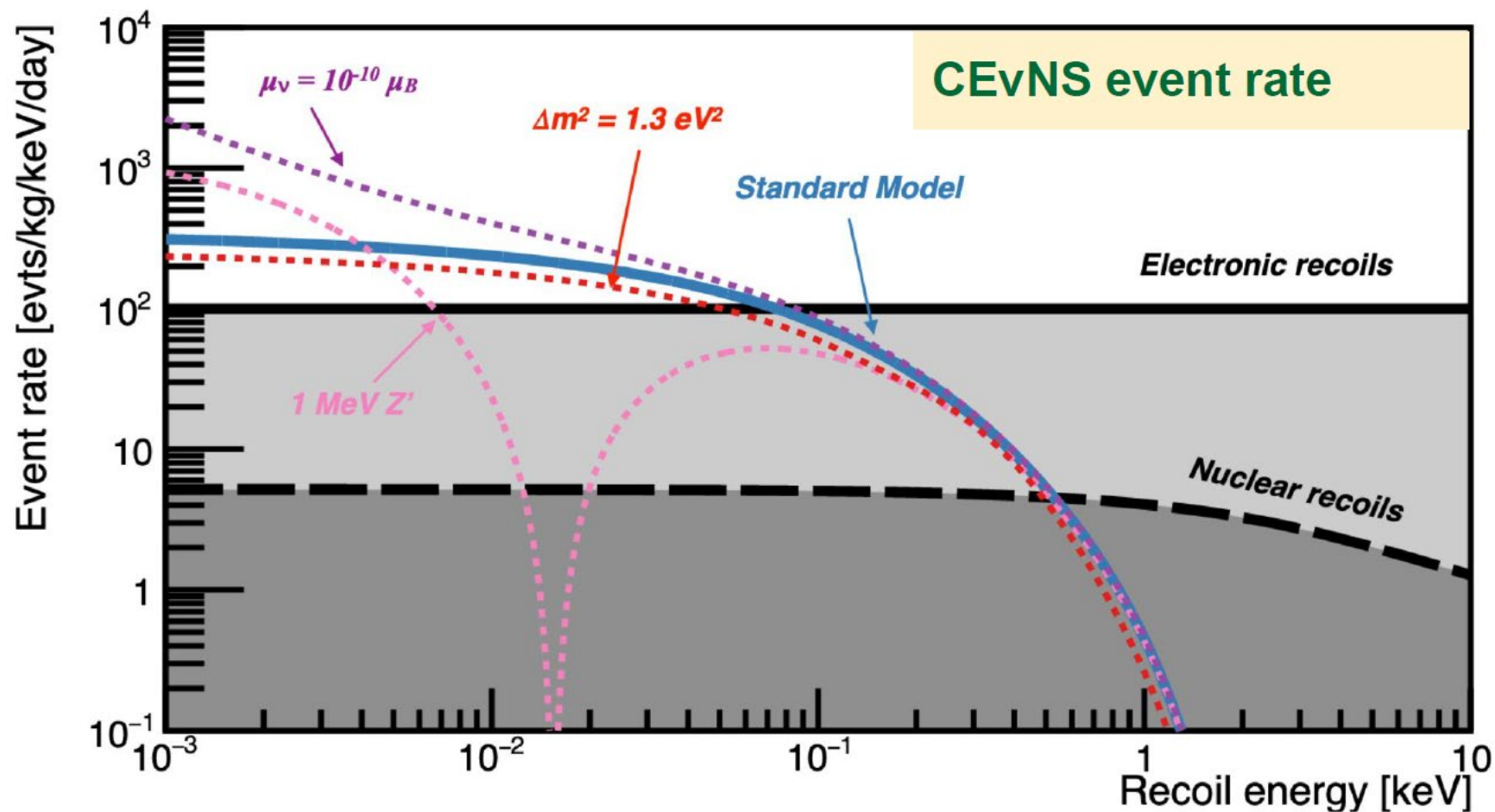
$\sin^2 \theta_W = 0.23 \rightarrow$ protons unimportant
Neutron contribution dominates

- E_ν : is the incident neutrino energy
- M: the nuclear mass of the detector material
- 3-momentum transfer $q^2 = 2MT$

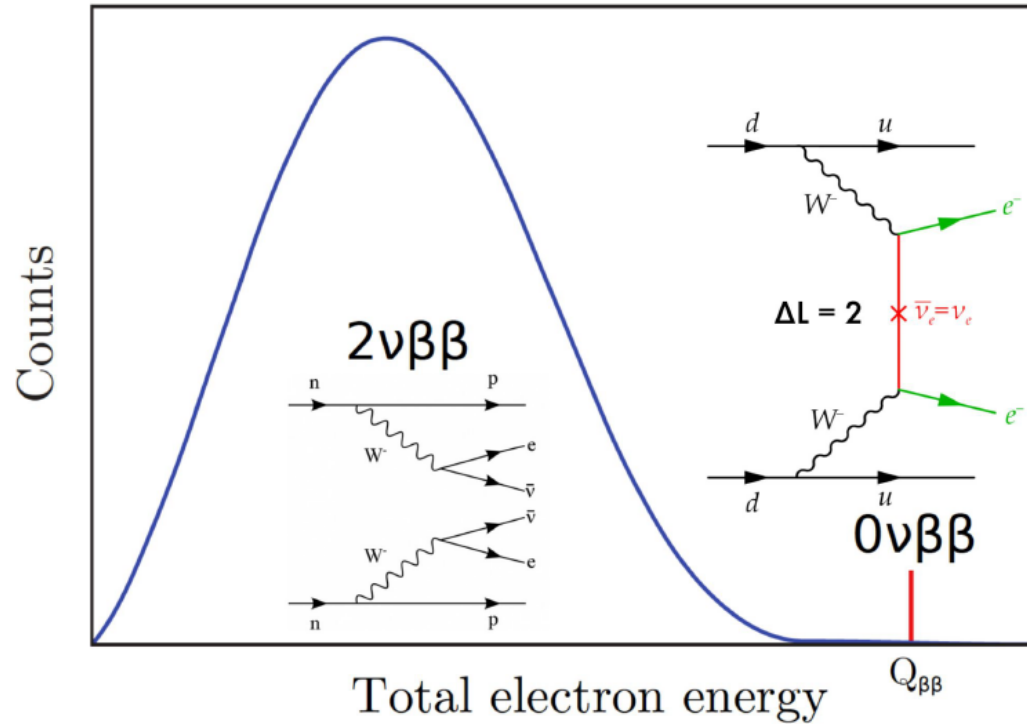
Axial contribution is small for most nuclei, spin-dependent.
It vanishes for nuclei with even number of protons and neutrons

Coherent Elastic Neutrino-Nucleus Scattering

Various BSM scenarios change spectral shape at low momentum transfers



Neutrinoless Double Beta Decay



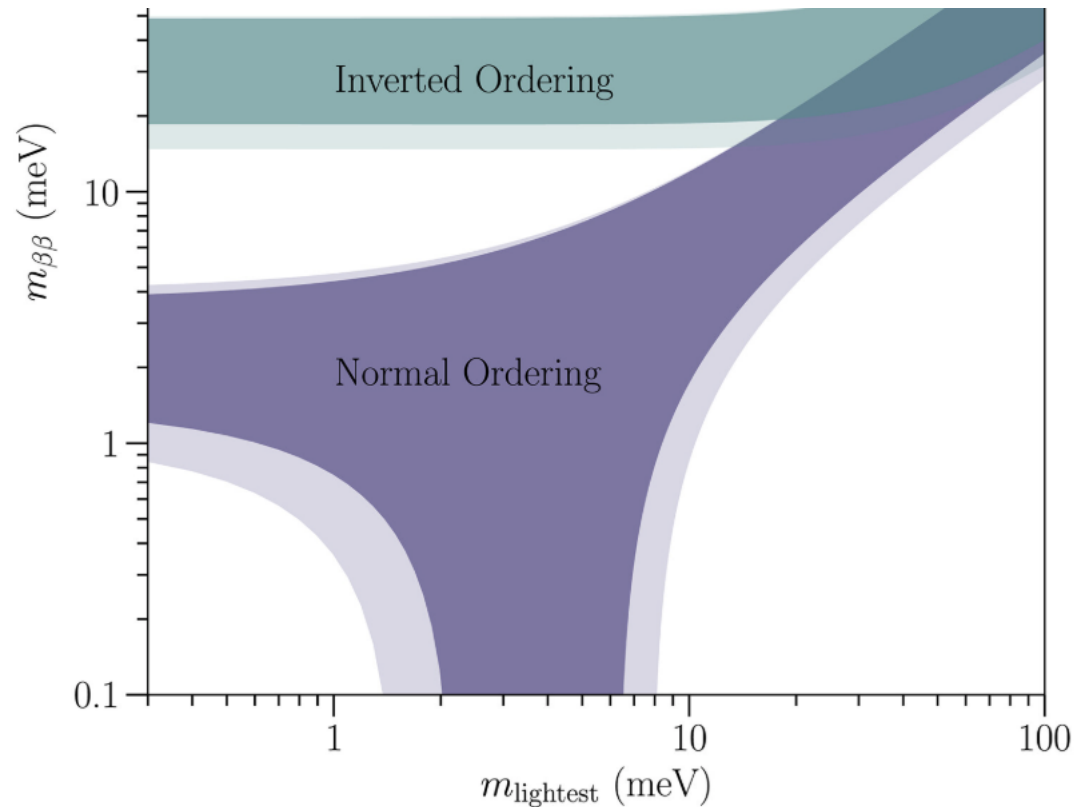
- Double beta decay: rare SM process in which 2 neutrinos are emitted
 - Broad energy distribution
 - Observed half-lives $\tau > 10^{19}$ years
- Neutrinoless version ($0\nu\beta\beta$): hypothetical, as-yet-unobserved process that can only occur if lepton number is violated in neutrino sector
 - Tiny peak at high edge of $2\nu\beta\beta$ spectrum
 - Majorana mass for neutrinos?
 - Explanation for universe's baryon asymmetry?

Image credit: Bradford Welliver, TAUP 2021 conference

Neutrinoless Double Beta Decay

Parameter space: effective Majorana mass vs lowest neutrino mass eigenstate

Experiments have just begun to probe Inverted



Only a few isotopes make good candidates, based on their $Q_{\beta\beta}$

(circled ones to be mentioned later)

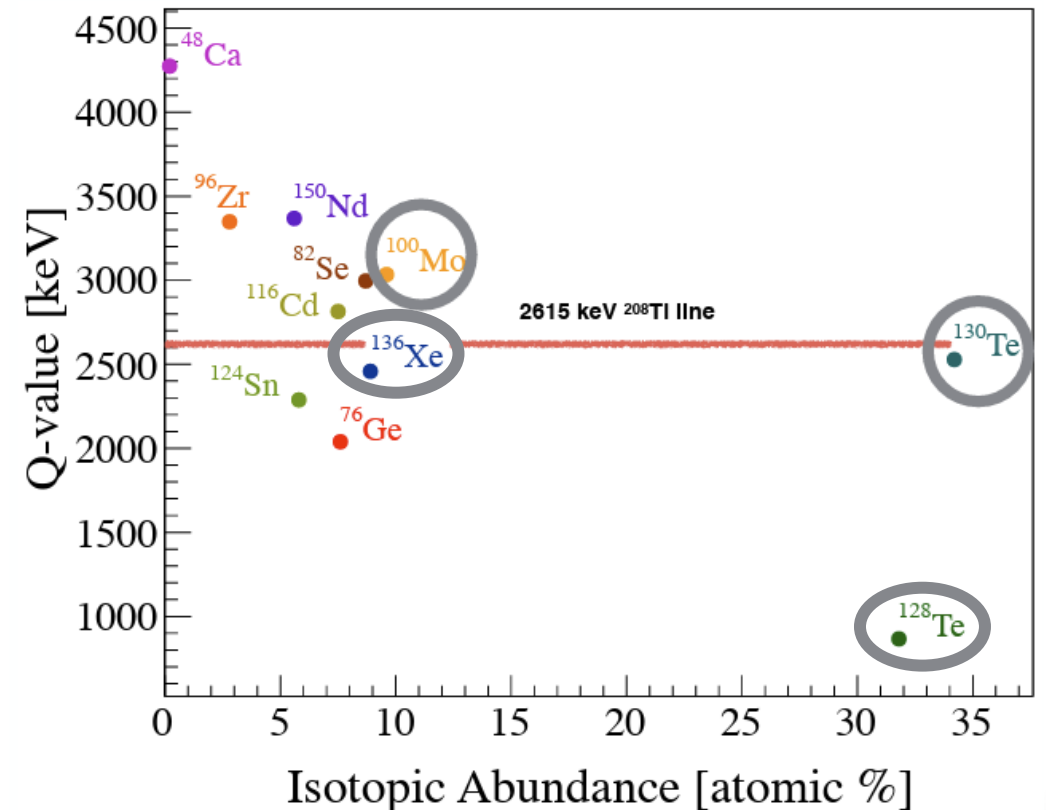


Image credit: Bradford Welliver, TAUP 2021 conference

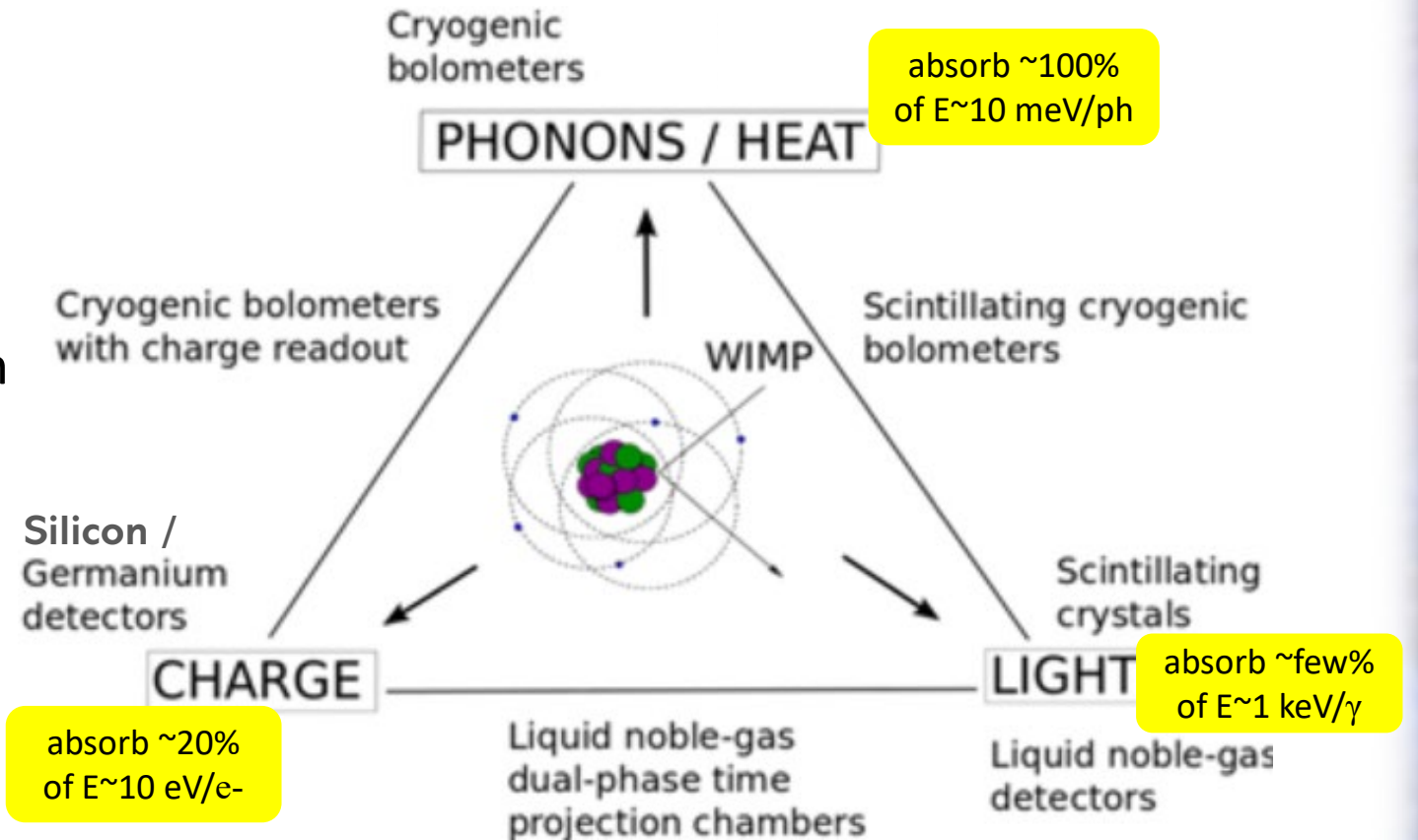
Cryogenic Detectors for DM Direct Detection & Neutrino Studies



Rare Event Searches: 3 Basic Detection Channels

DM searches and neutrino experiments share same basic “rare event search” needs:

- 1: Large Exposure (Target Mass x Time)
- 2: Low Energy Threshold
- 3: Good Energy Resolution
- 4: Low Backgrounds
- 5: Signal vs. Background Discrimination



Leads to some joint development of cryogenic detectors

[arXiv:1509.08767](https://arxiv.org/abs/1509.08767)

Solid-State:
Charge-Coupled Devices (CCDs)
and Semiconductor Crystals

CCDs for Rare Event Searches

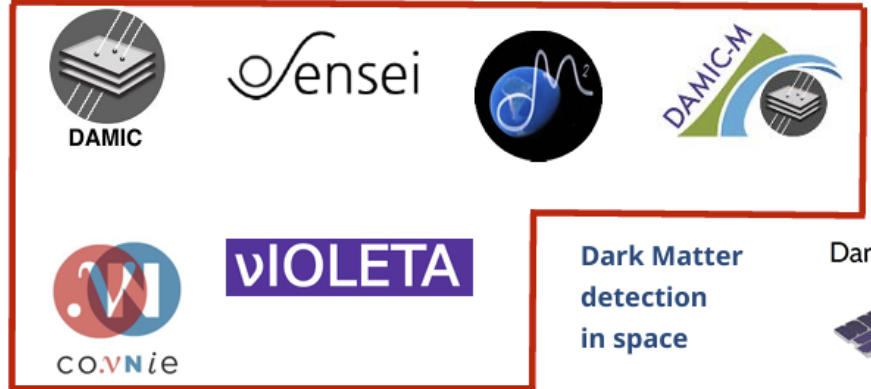
Multiple generations, for multiple applications

Run warm (~80 K, liquid nitrogen cooled) compared to semiconductor crystals

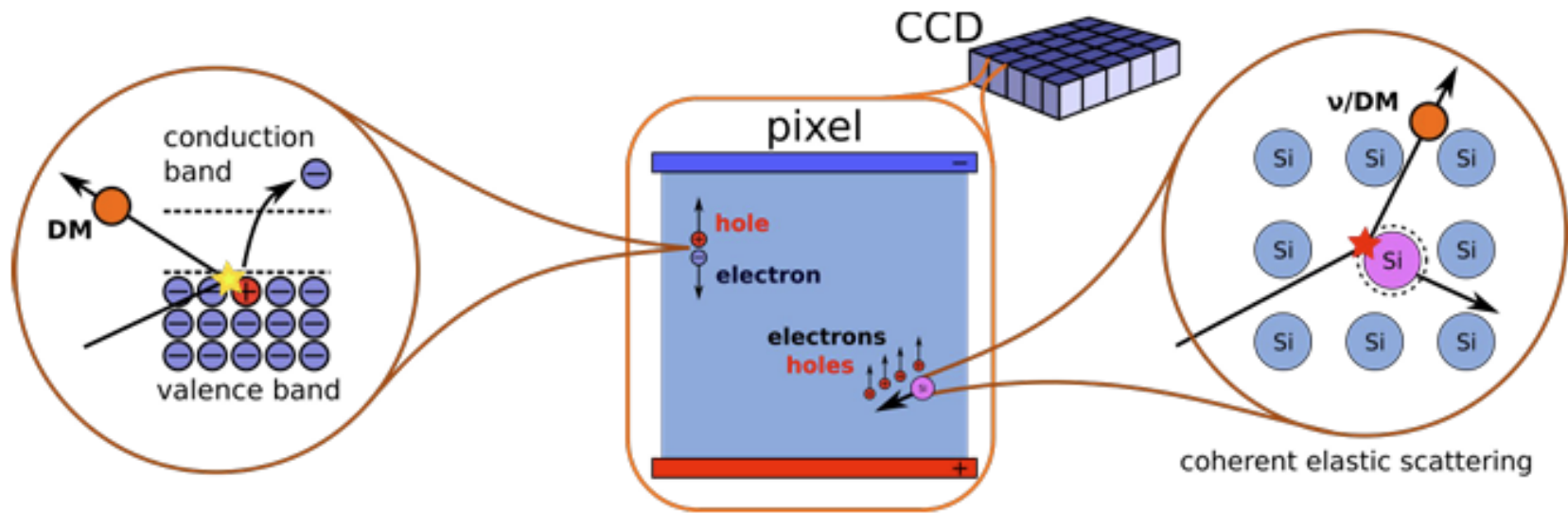
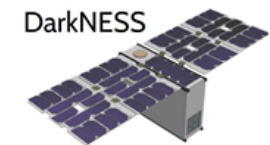
currently commissioning/operational

Halo Dark Matter direct detection (< 1 GeV mass)

Nuclear reactor CEvNS and mCPs



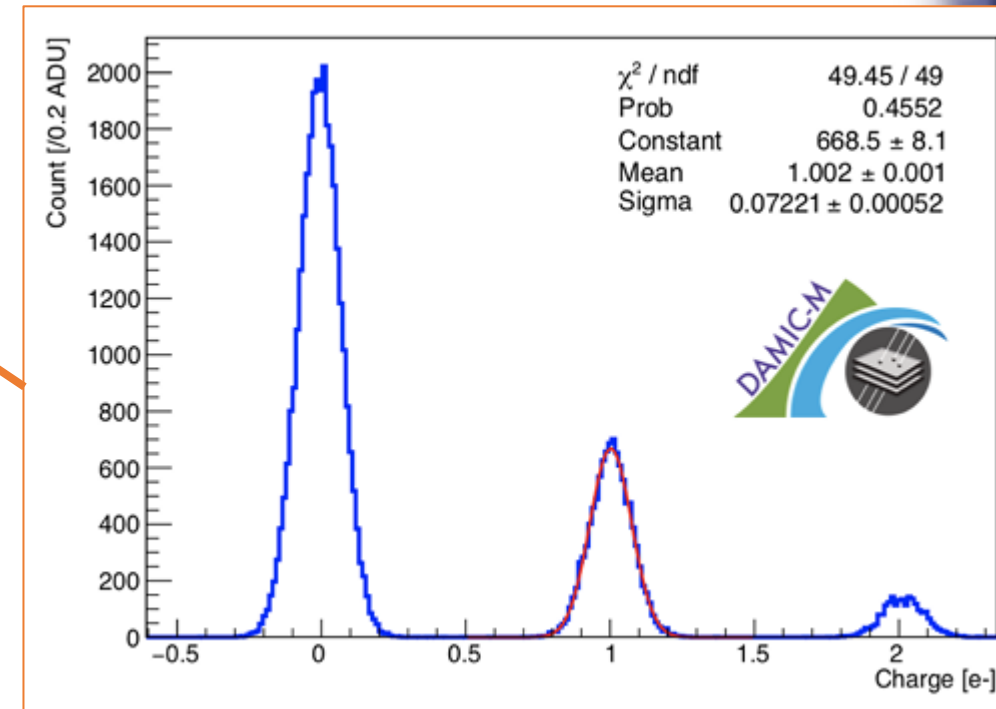
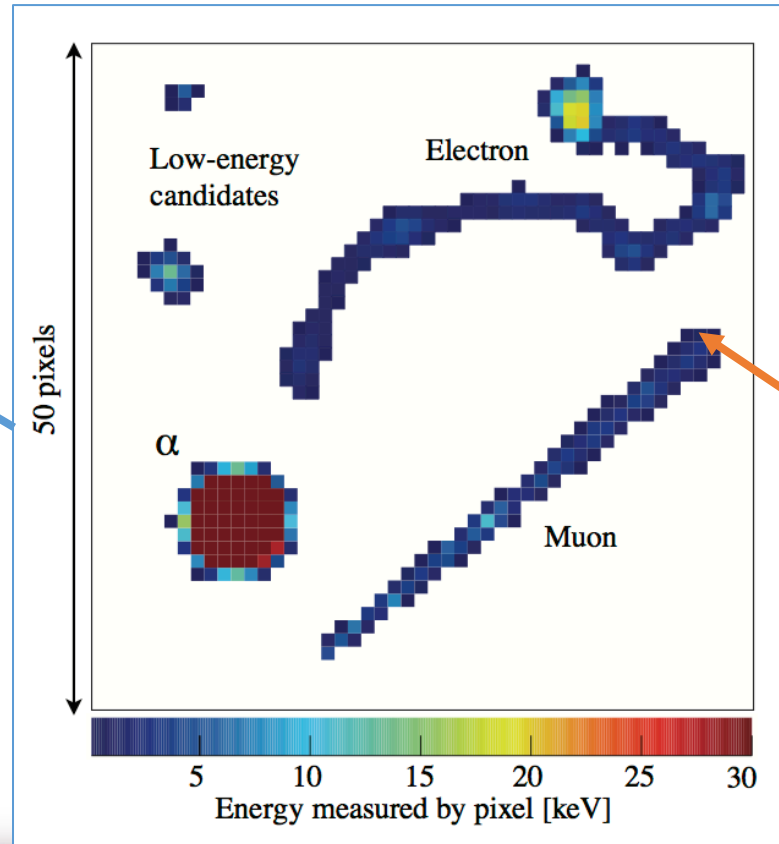
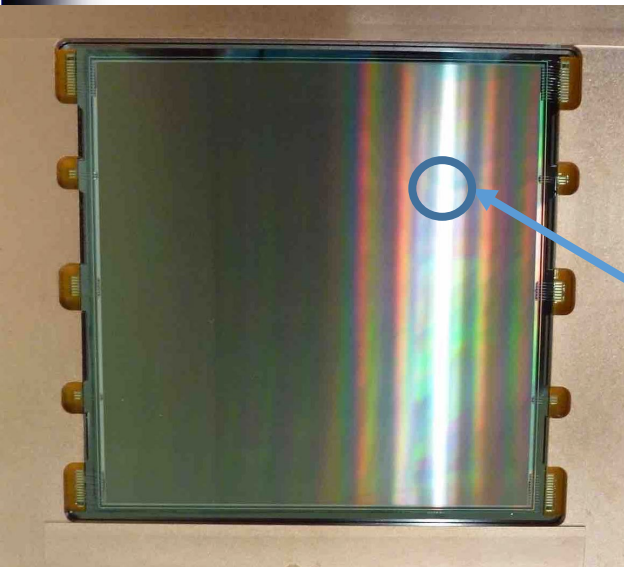
Dark Matter detection in space



Images credit: Ana Martina Botti

CCDs for Rare Event Searches

- Pixels $\sim 15 \times 15 \mu\text{m}^2$, hundreds of μm thick
- “Skipper” CCDs reliably detect excitations as small as 1 electron in a pixel

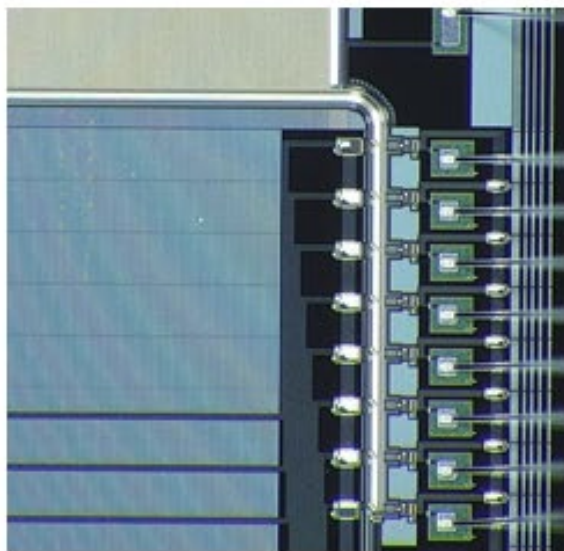


<https://damic.uchicago.edu/detector.php>

CCDs for Rare Event Searches

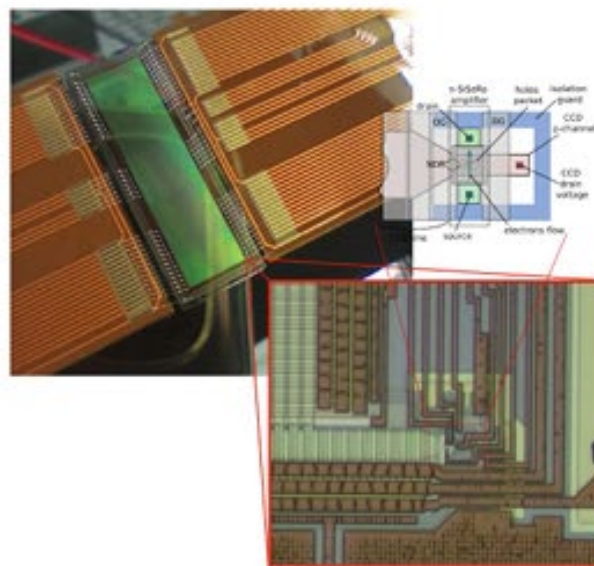
R&D for specialized CCDs still ongoing

MAS-CCD



IEEE Transactions on Electron Devices, vol. 71, no. 6, pp. 3732-3738 (2024).

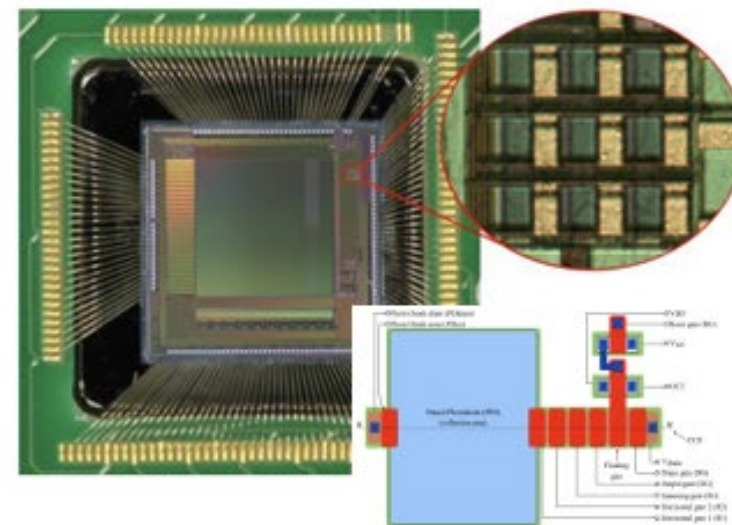
Sisero-CCD



5x2.5 μm

Phys. Rev. Lett. 133, 121003

Skipper-CMOS



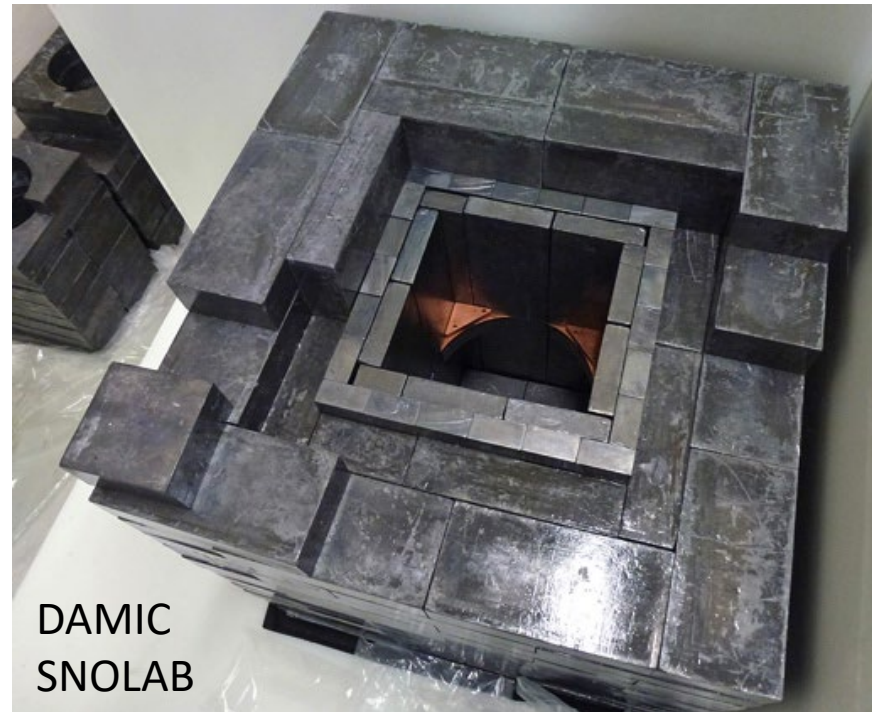
IEEE Transactions on Electron Devices, vol. 71, no. 11, pp. 6843-6849, 2024

Slide credit: Ana Martina Botti

CCDs for DM Direct Detection

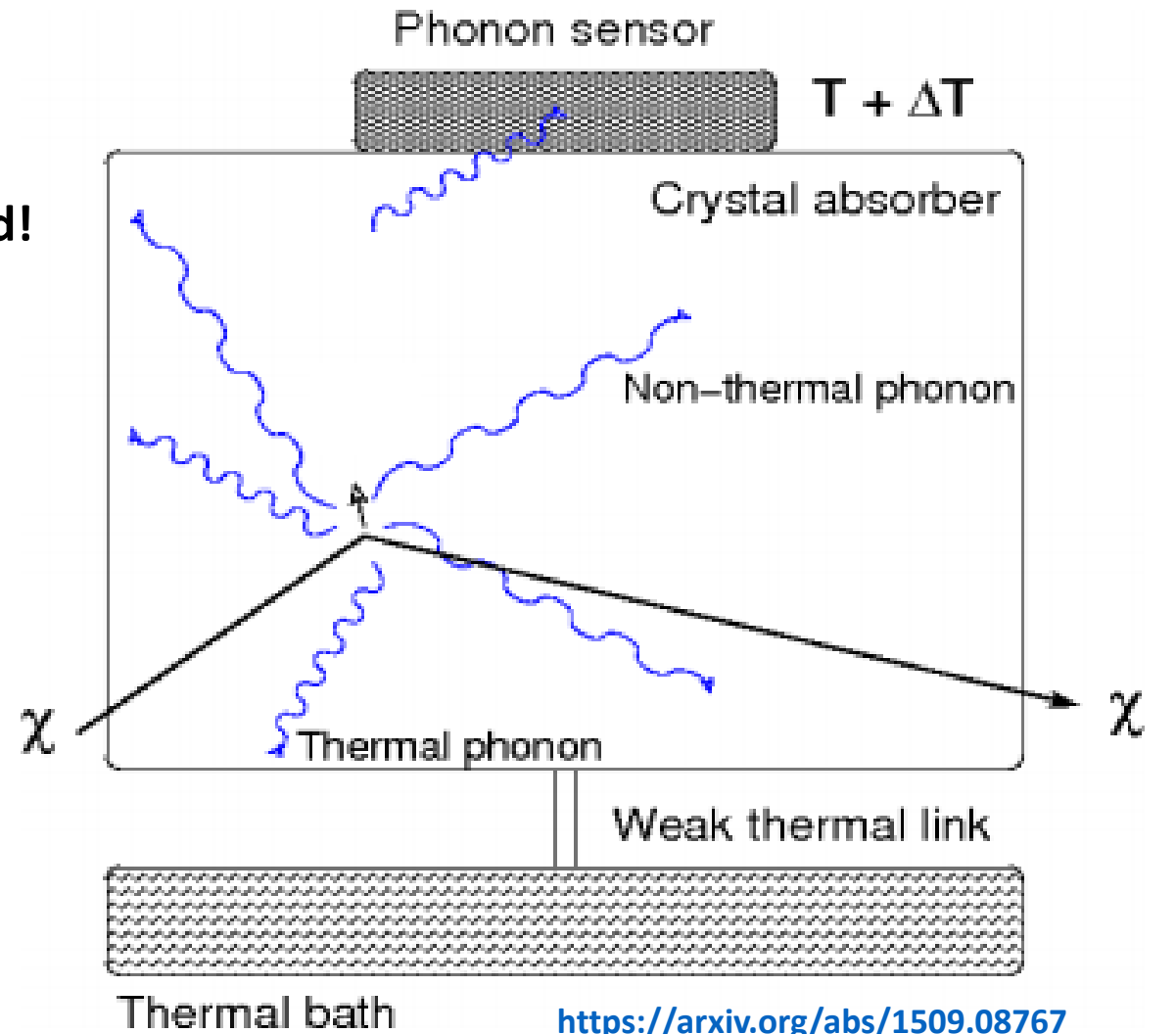
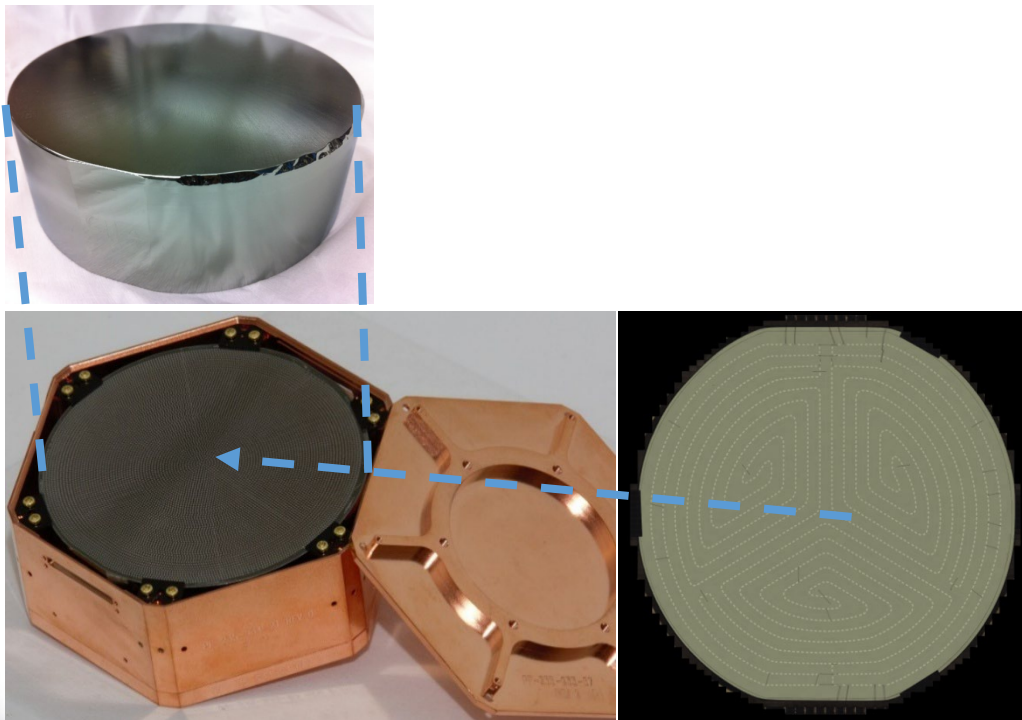
Hour[s] of “exposure time” per “image”

- DAMIC (Dark Matter in CCDs) @SNOLAB
- SENSEI (Sub-Electron-Noise Skipper-CCD Experimental Instrument) @SNOLAB
- DAMIC-M @Modane
- OSCURA (Observatory of Skipper CCDs Unveiling Recoiling Atoms) collaboration



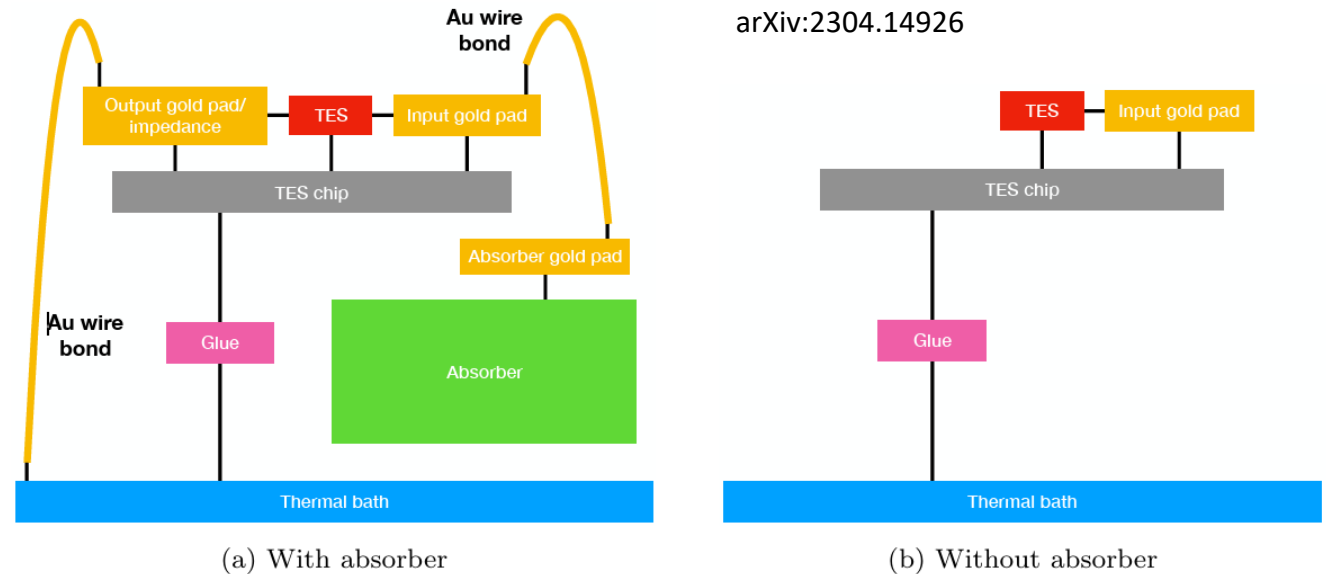
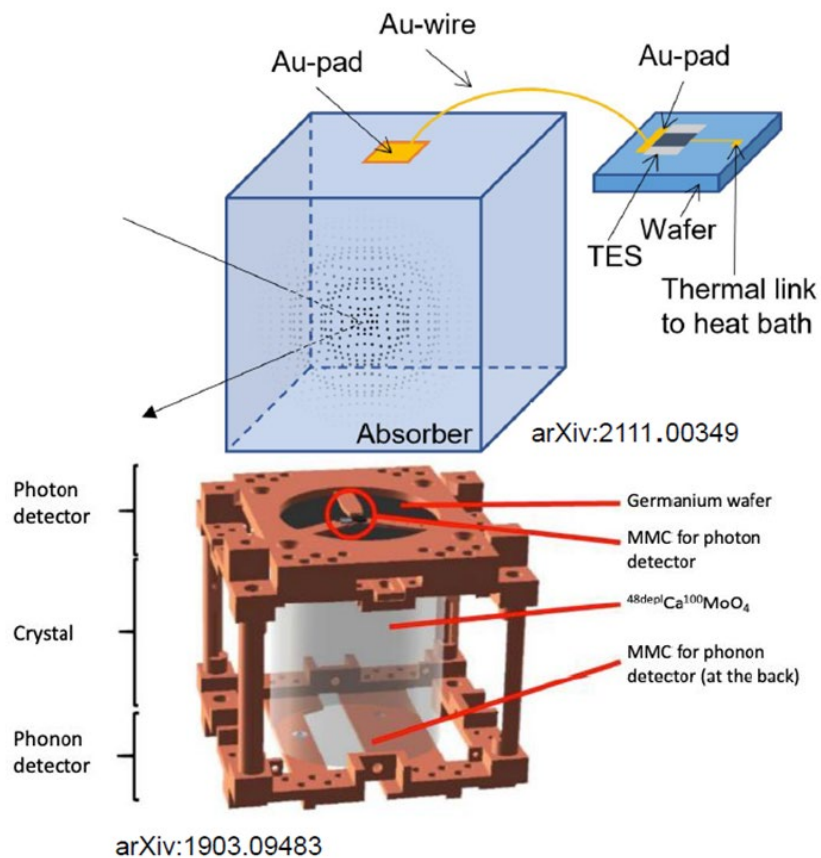
Cryogenic Crystal Detectors

- Collect phonons [plus electrons or photons]
- Calorimetry, not tracking/imaging
- Operated at tens of mK: liquid He cooling required!



Cryogenic Crystal Detectors: Modular Design

Decoupling thermometer from crystals for ease of fabrication: an alternative to depositing thermometer directly onto crystal surface
 e.g. Ricochet (for CEvNS):



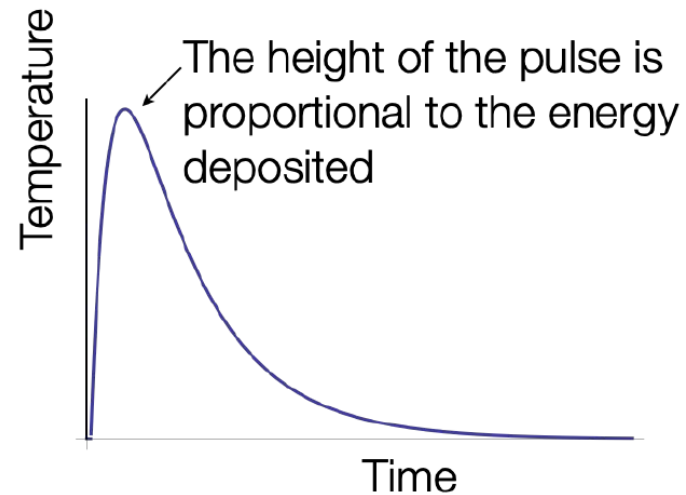
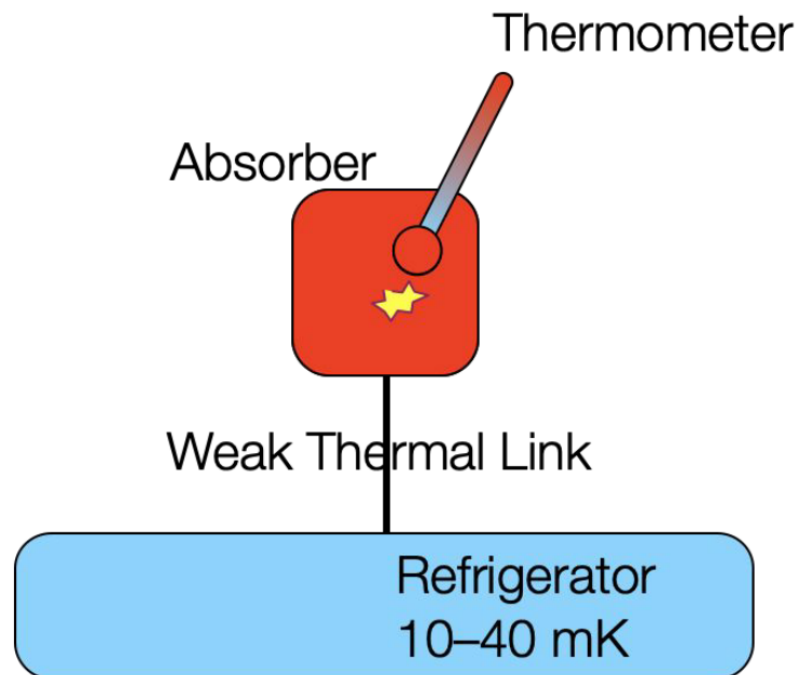
Thermal conduction facilitated by a gold wirebond
 Can be coupled to a variety of target materials

Slide credit: Ziqing Hong

Cryogenic Crystal Detectors: Basic Model of Phonon Channels

Thermometer types include:

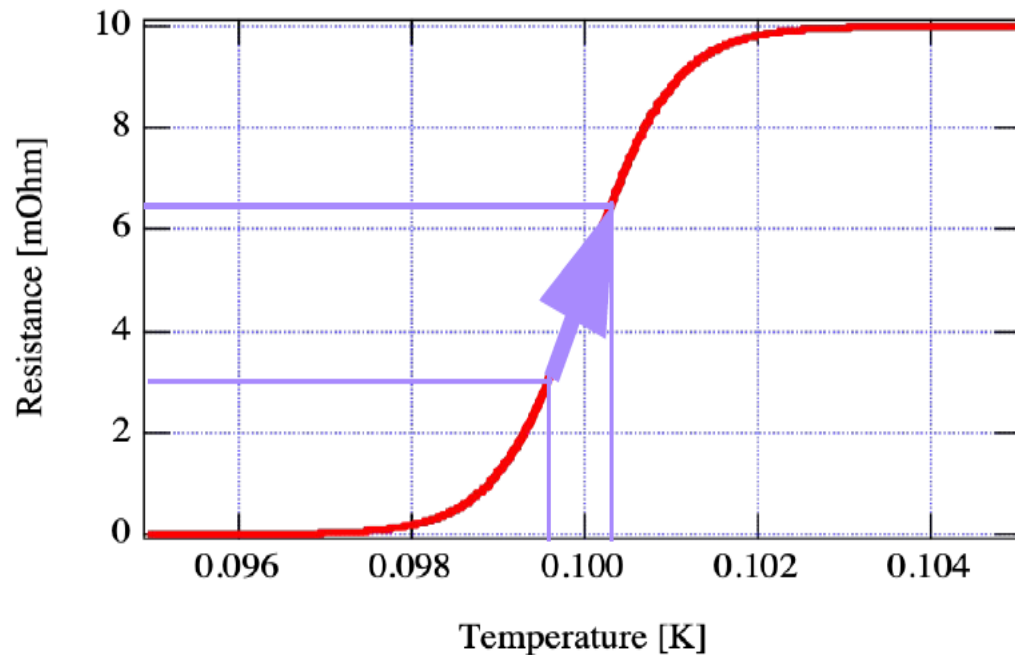
- Transition Edge Sensors
- Neutron Transmutation Doped Thermistors
- Metallic Magnetic Calorimeters
- Microwave Kinetic Inductance Detectors



Slide credit: Ziqing Hong

Cryogenic Crystal Detectors: Basic Model of Phonon Channels

Using Transition Edge Sensors (TESs) as example



$$\alpha = \frac{T}{R} \frac{dR}{dT} \quad 50 < \alpha < 1000$$

Superconductor biased in its transition

- Elemental, e.g.: W, Al, Re, Pb
- Paramagnetic impurity doped, e.g. : Al/Fe, Al/Mn
- Bi-layers, e.g. : Mo/Au, Mo/Cu, Ti/Al

Low resistance allows readout with Superconducting Quantum Interference Devices (SQUIDs)

Cold reduces transition width (parameterized via α), improves detector sensitivity

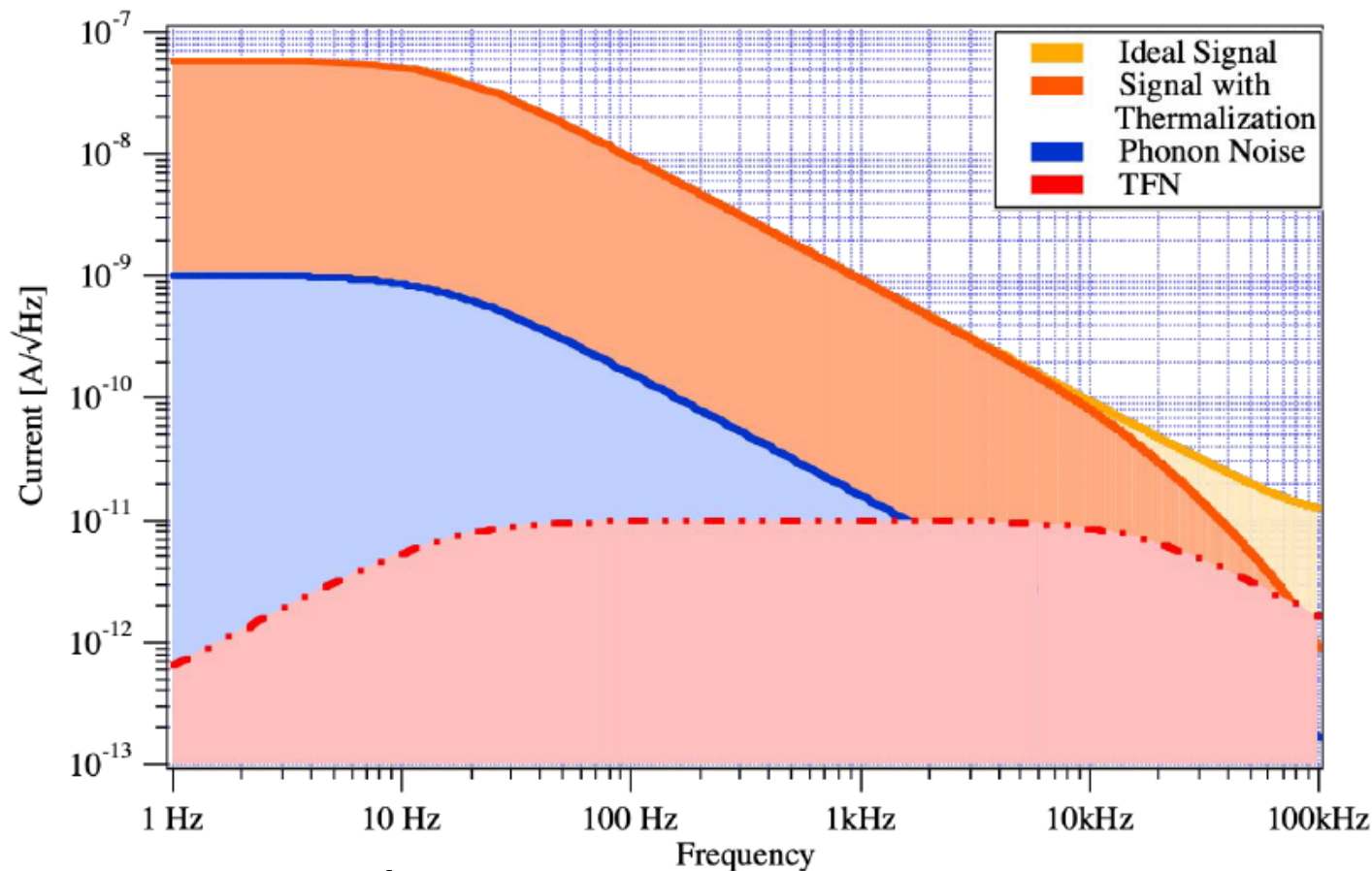
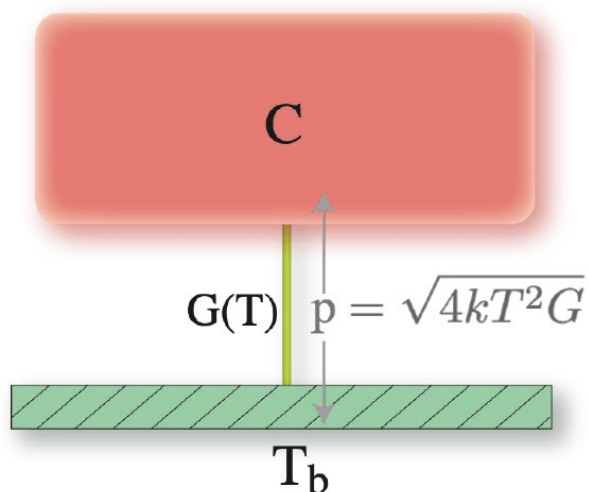
Slide credit: Ziqing Hong

Cryogenic Crystal Detectors: Basic Model of Phonon Channels

Key performance parameters:

- Signal-to-noise ratio
- Energy resolution

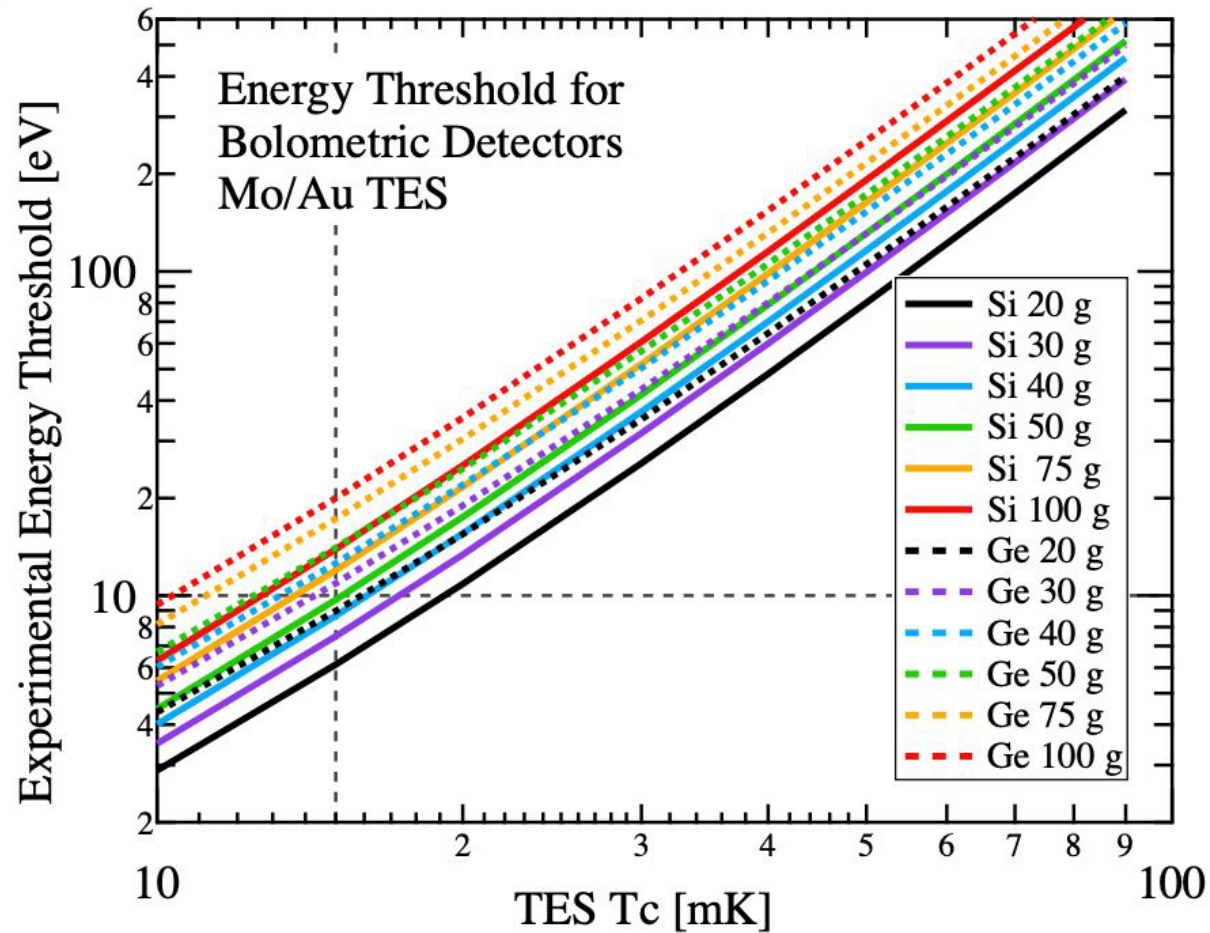
$$\Delta E_{rms} = \sqrt{kT^2C}$$



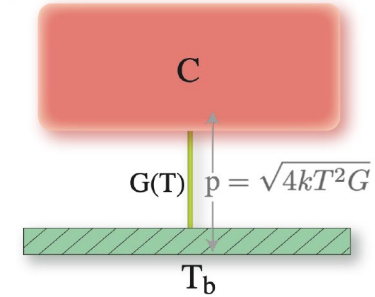
Cold reduces noise, improves energy resolution

Slide credit: Ziqing Hong

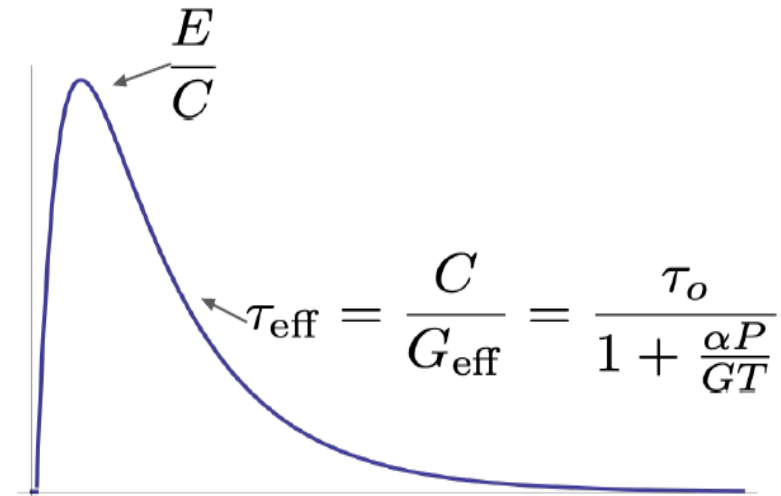
Cryogenic Crystal Detectors: Basic Model of Phonon Channels



$$\alpha = \frac{T}{R} \frac{dR}{dT}$$



Signal pulse (schematic): want tall & narrow



Cold reduces heat capacity, lowers energy threshold

Slide credit: Ziqing Hong

Cryogenic Crystal Detectors for $0\nu\beta\beta$

CUORE (Cryogenic Underground Observatory for Rare Events), Gran Sasso: tonne-scale, using ^{128}Te & ^{130}Te

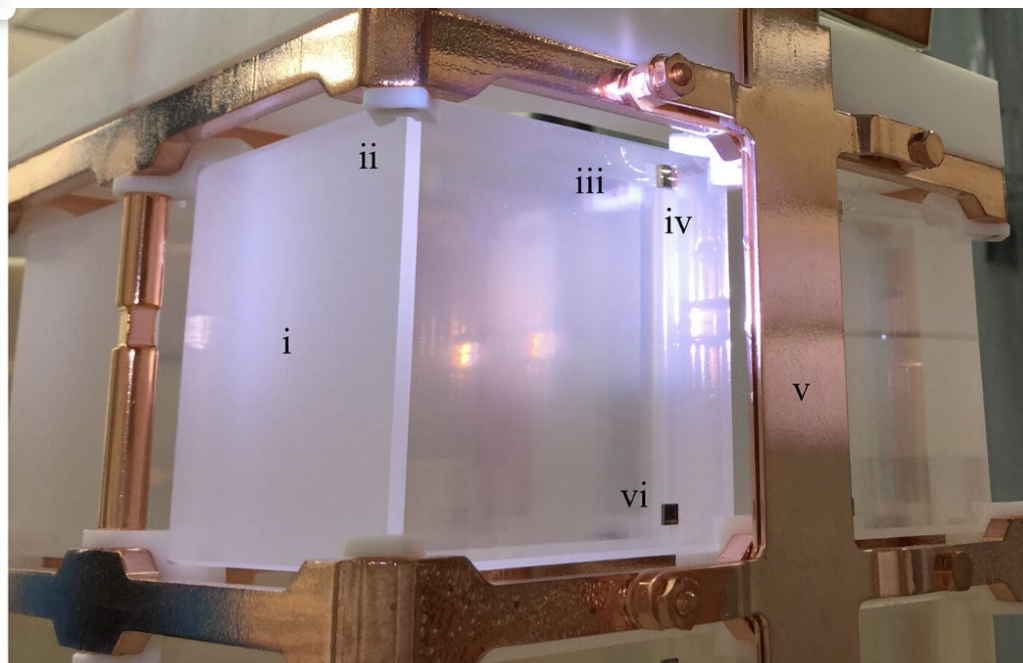
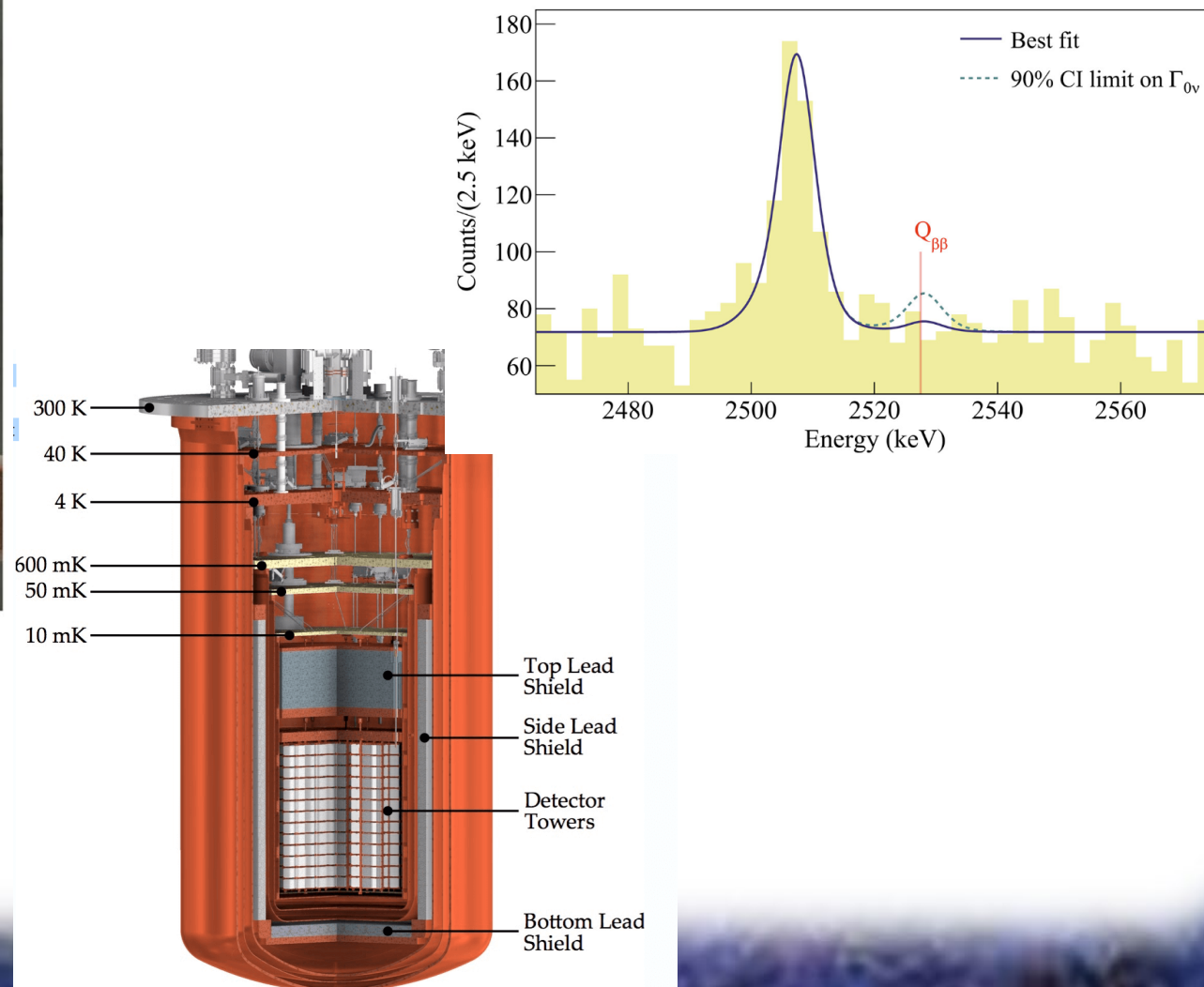


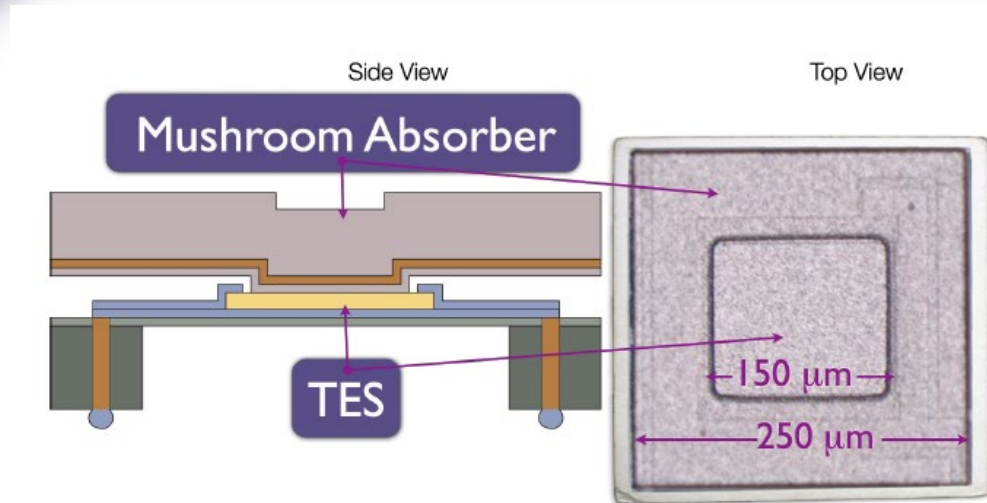
Fig. 1. CUORE calorimeter.

Shown are (i) the absorber (TeO_2 crystal of 5 by 5 by 5 cm size); (ii and iii) weak thermal couplings (PTFE spacer and Au wire, respectively); (iv) temperature sensor (NTD Ge thermistor); (v) heat sink (Cu frame); and (vi) auxiliary Joule heater (Si chip). A spotlight was used to increase the visibility of the 25- μm wires used for electrical connection.



DOI: [10.1126/science.adp6474](https://doi.org/10.1126/science.adp6474)

Cryogenic Microcalorimeters for DM Indirect Detection



Arrays of eV-resolution sensors can be used as ultra-sensitive X-ray detectors

Widely used in Earth-based telescopes, rocket & satellite-based probes

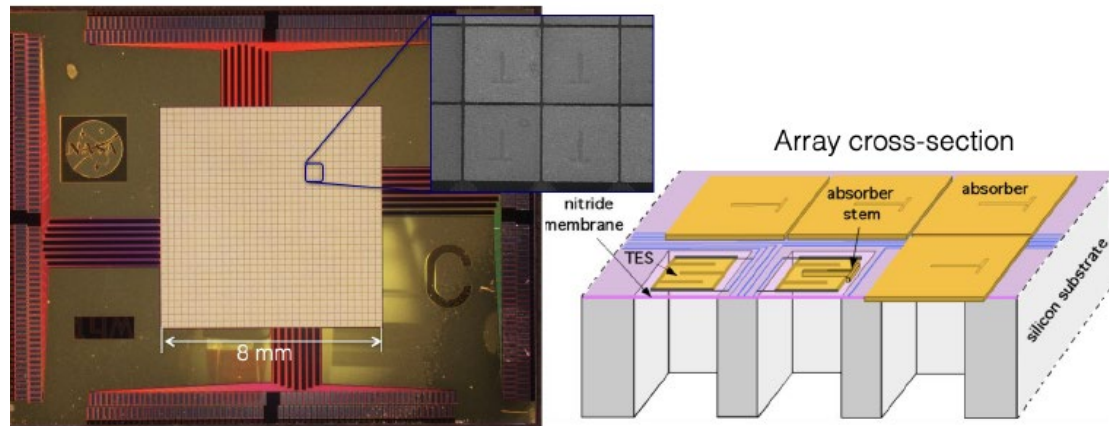


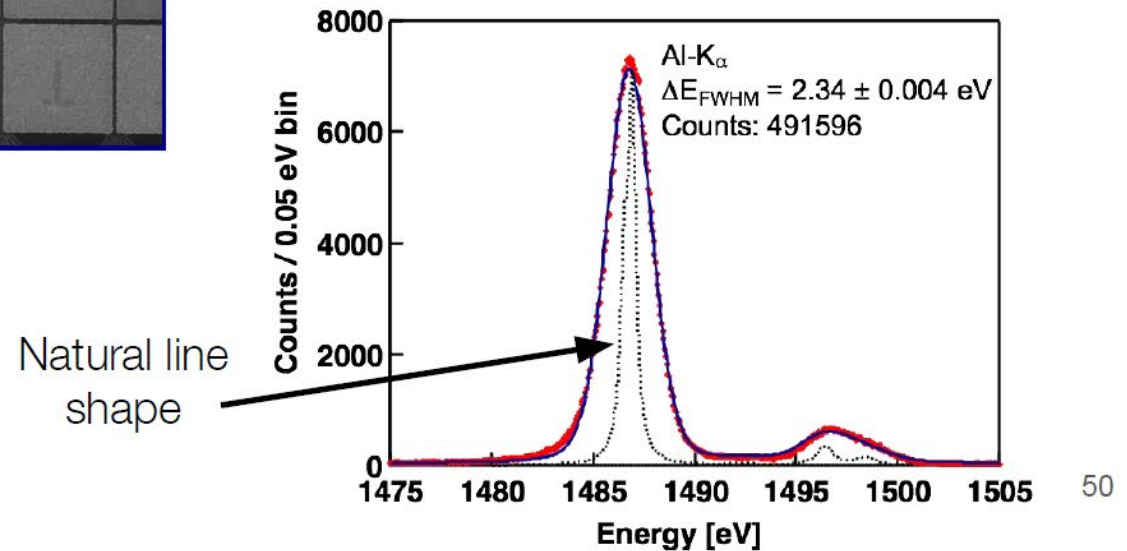
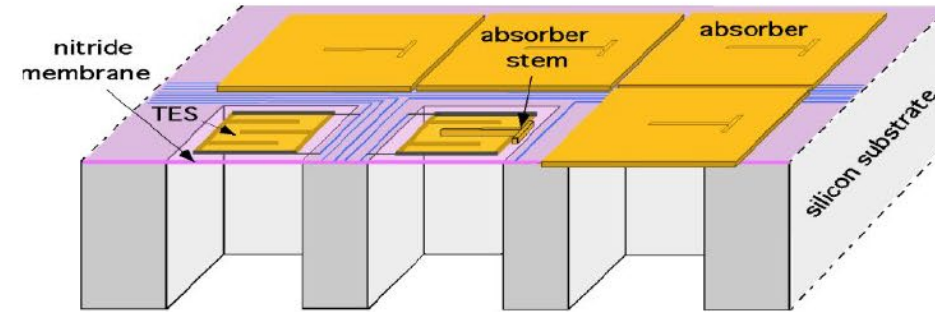
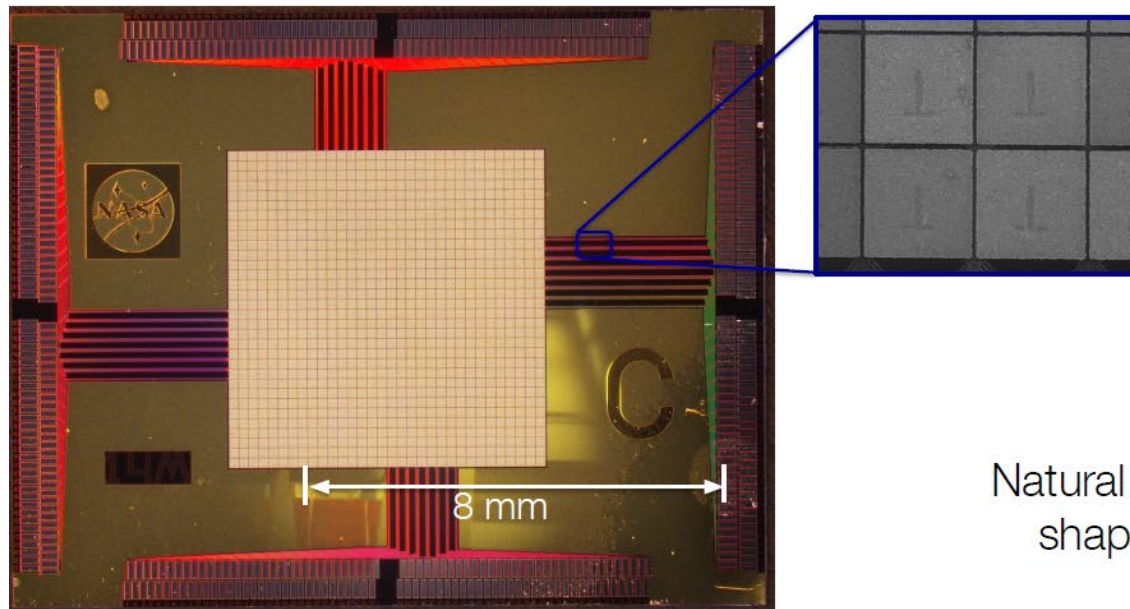
Fig. from E. Figueroa, COFI PIRE 20017

Cryogenic Microcalorimeters for DM Indirect Detection

Transition-edge sensor arrays

- NASA Goddard Space Flight Center TES Arrays

Fully wired 32x32 array (8x8 mm²) with 64 pixels connected to bond pads on each side



Slide credit: Ziqing Hong

Cryogenic Crystals with Phonon Amplification for DM Direct Detection

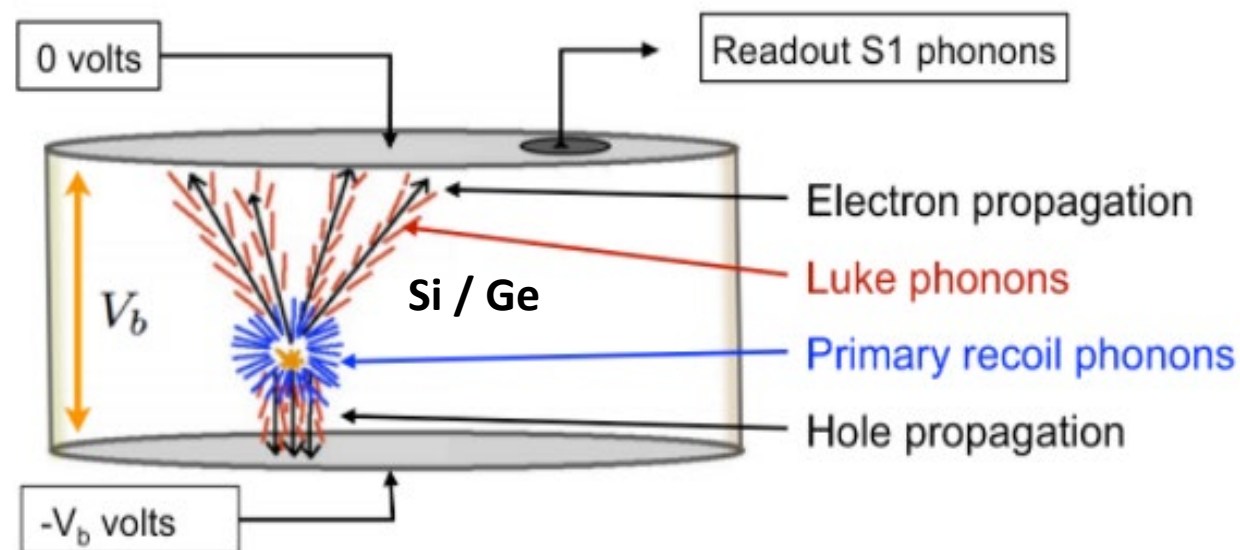
- Drifting charges across a V_b generates cascade of “Luke phonons”
- Lowers recoil energy threshold
- But “true calorimetry” lost

$$E_t = E_r + n_{eh}qV_b$$

Total
phonon
energy

Primary
recoil
energy

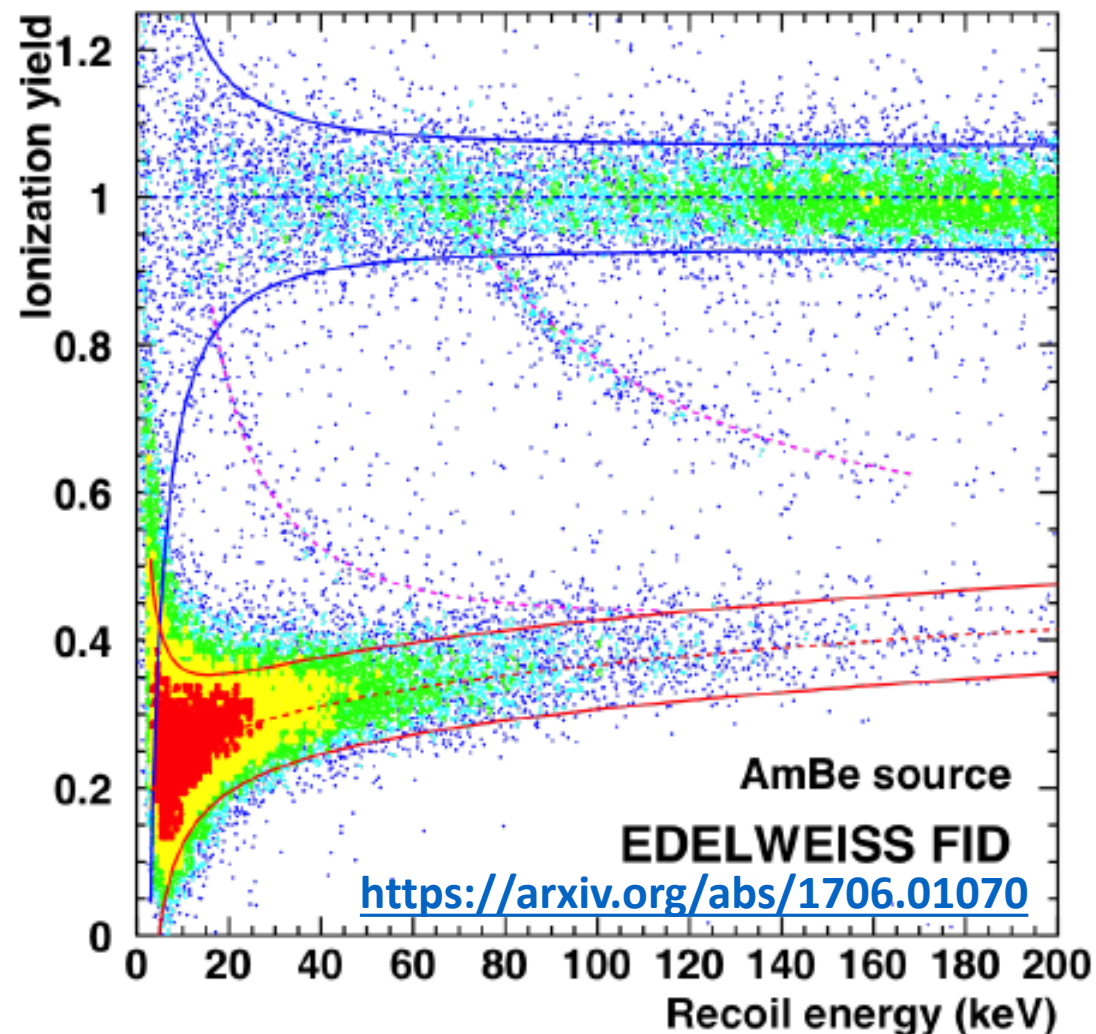
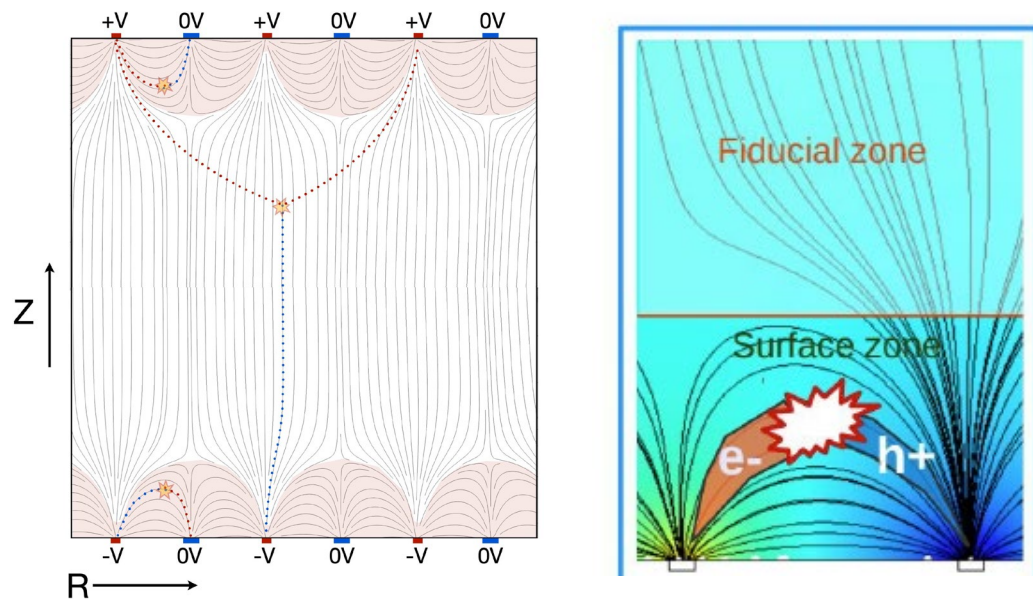
Luke phonon
energy



- EDELWEISS (Expérience pour Detecter Les WIMPs En Site Souterrain) @ Modane
- SuperCDMS (Cryogenic Dark Matter Search) “High Voltage”

Cryogenic Crystal Detectors with Charge Channels: Phonons + Ionization

Combination of phonon and ionization channels allows **NR** vs **ER** discrimination



Cryogenic Crystals with Charge Channels for DM Direct Detection

- EDELWEISS
- SuperCDMS "iZIP" (Interleaved Z-sensitive Ionization & Phonon)

Transition Edge Sensor (TES)
phonon readout
High Electron Mobility Transistor
(HEMT) ionization readout

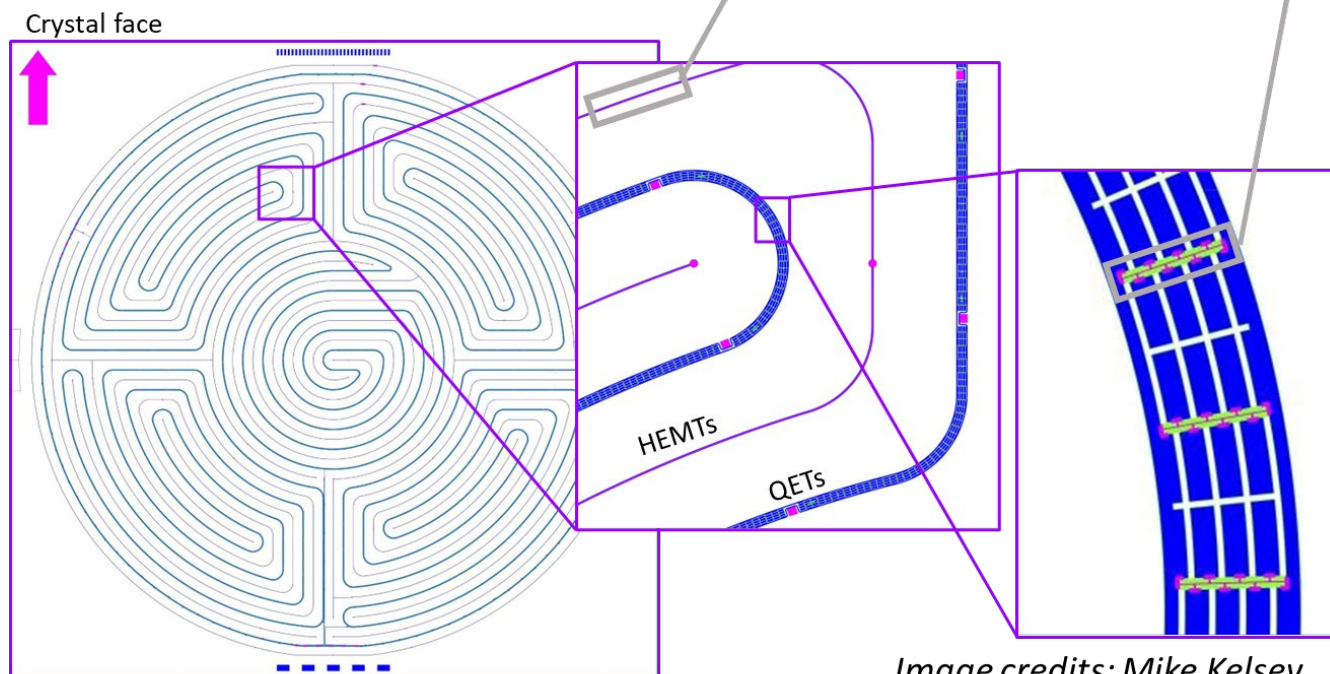
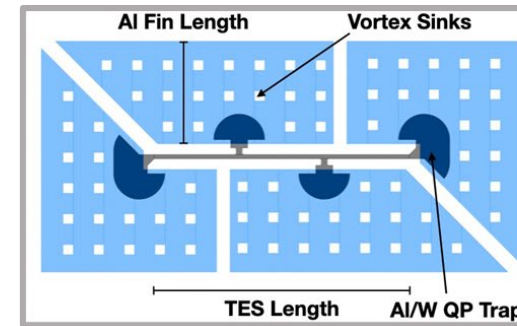
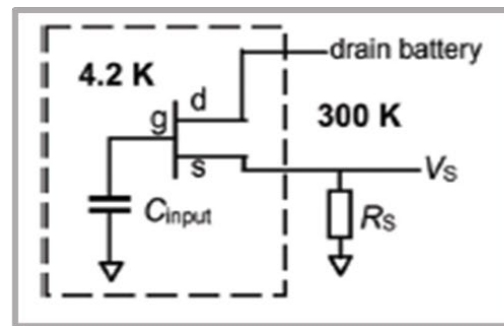
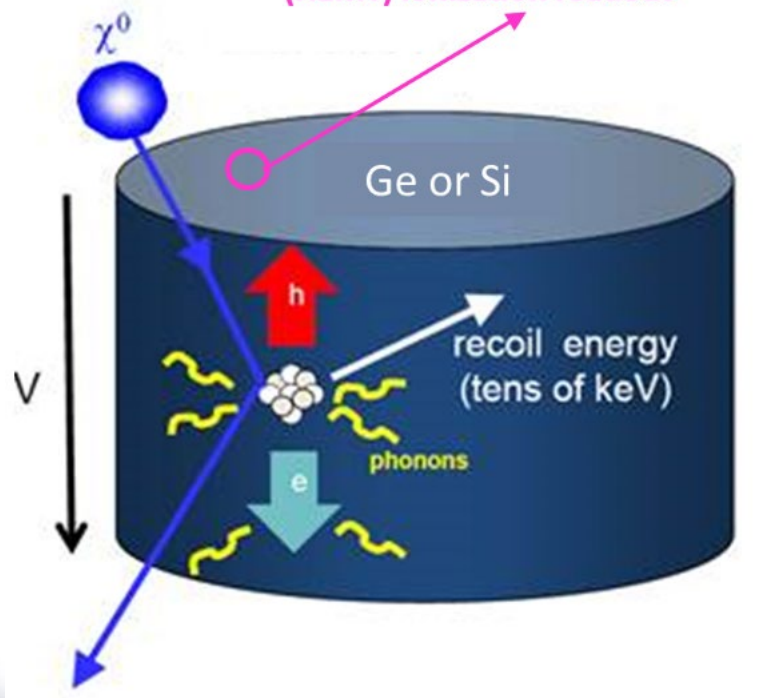


Image credits: Mike Kelsey

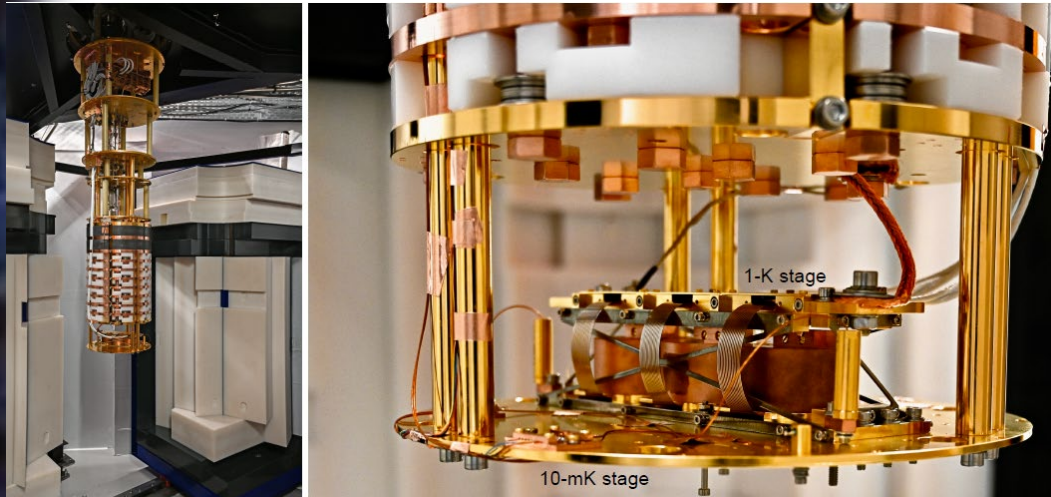
Cryogenic Crystal Detectors with Charge Channels for CEvNS

Ricochet: array of Ge crystals, 42g each, at Institut Laue-Langevin reactor

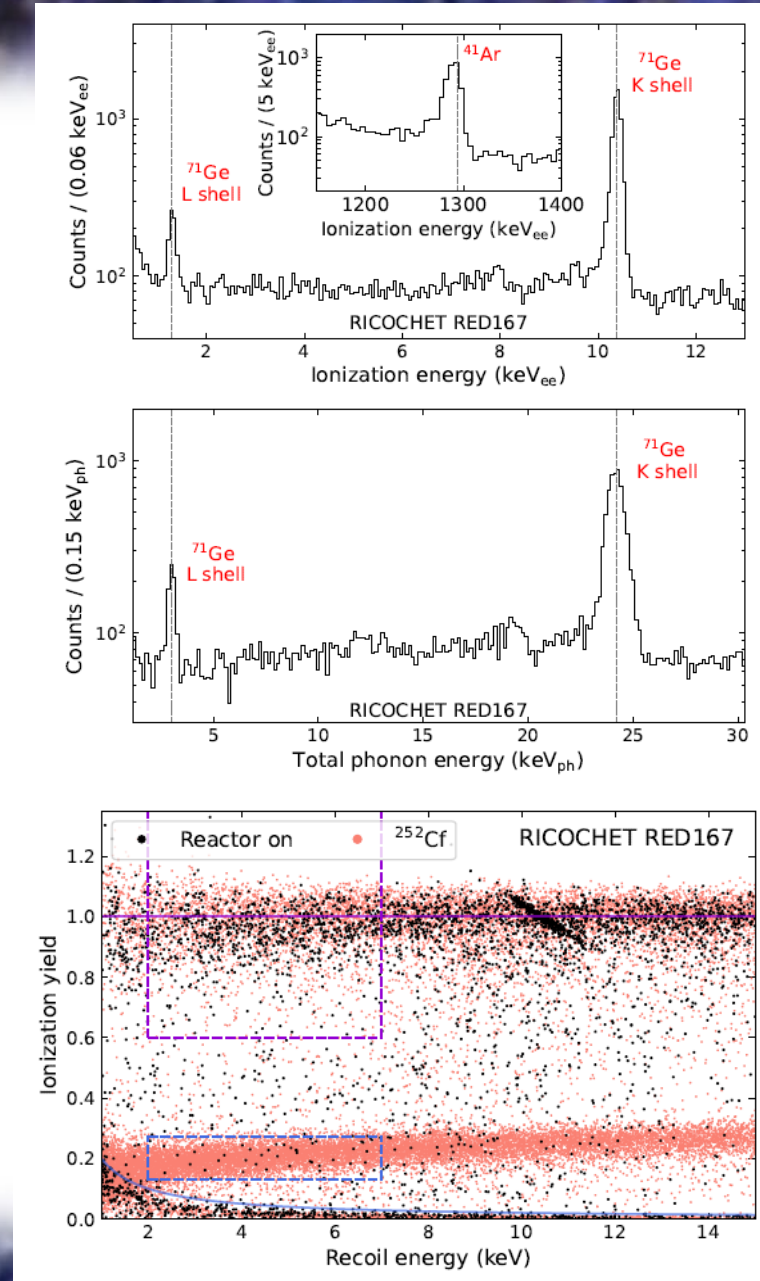
Operates at $\sim 8\text{-}9\text{ mK}$, during reactor-on and reactor-off cycles

3-crystal demonstration run, 2024

Planned 18-crystal setup



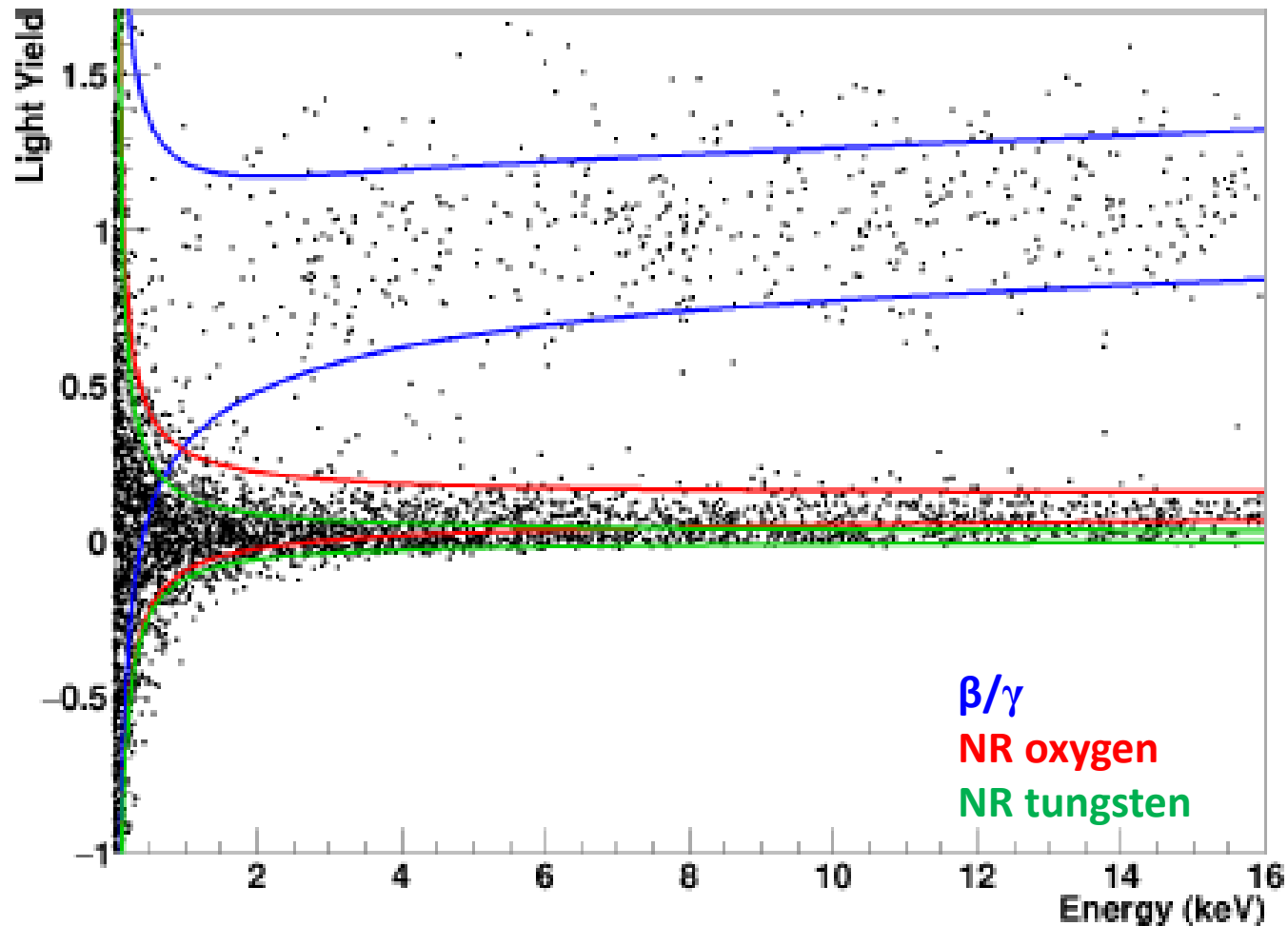
arXiv:2507.22751



Cryogenic Scintillating Crystals: Phonons + Light

Along with phonon signal: instead of collecting electrons in semiconductor crystals, collect light in scintillating crystals

Combination of phonon and light channels allows **ER & gammas** vs **NR** discrimination

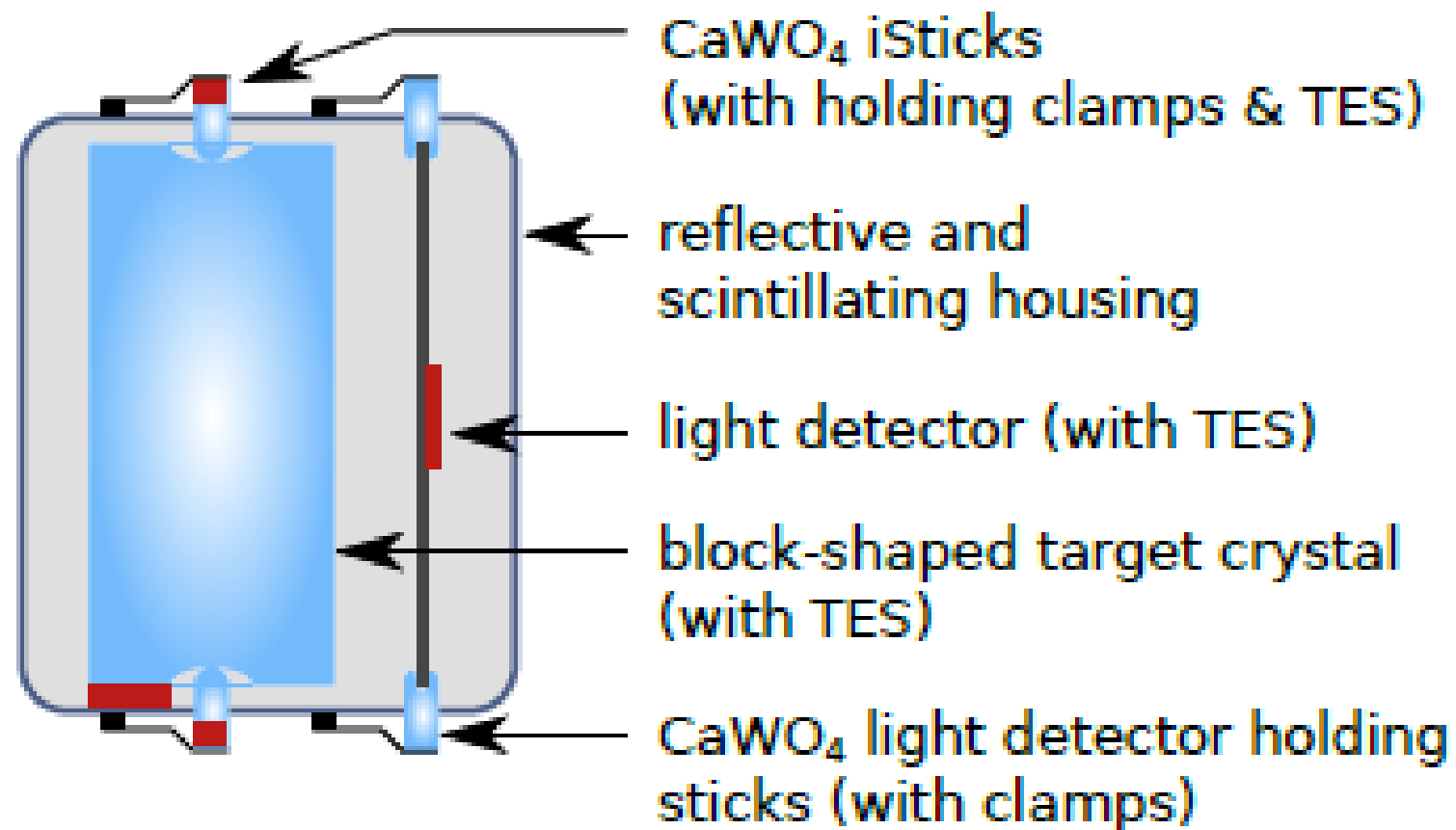


<https://arxiv.org/abs/1904.00498>

Cryogenic Scintillating Crystals for DM Direct Detection

e.g CRESST-III (Cryogenic Rare Event Search with Superconducting Thermometers):
calcium tungstate crystals

Operated at ~ 5 mK @LNGS



<https://arxiv.org/abs/1904.00498>

Cryogenic Scintillating Crystals for $0\nu\beta\beta$

e.g. CUORE Upgrade with Particle ID (CUPID):

$\text{Li}_2^{100}\text{MoO}_4$ (LMO) crystals, at Gran Sasso

- NTD Ge sensors
- 20 LMO crystals, ~ 200 g each

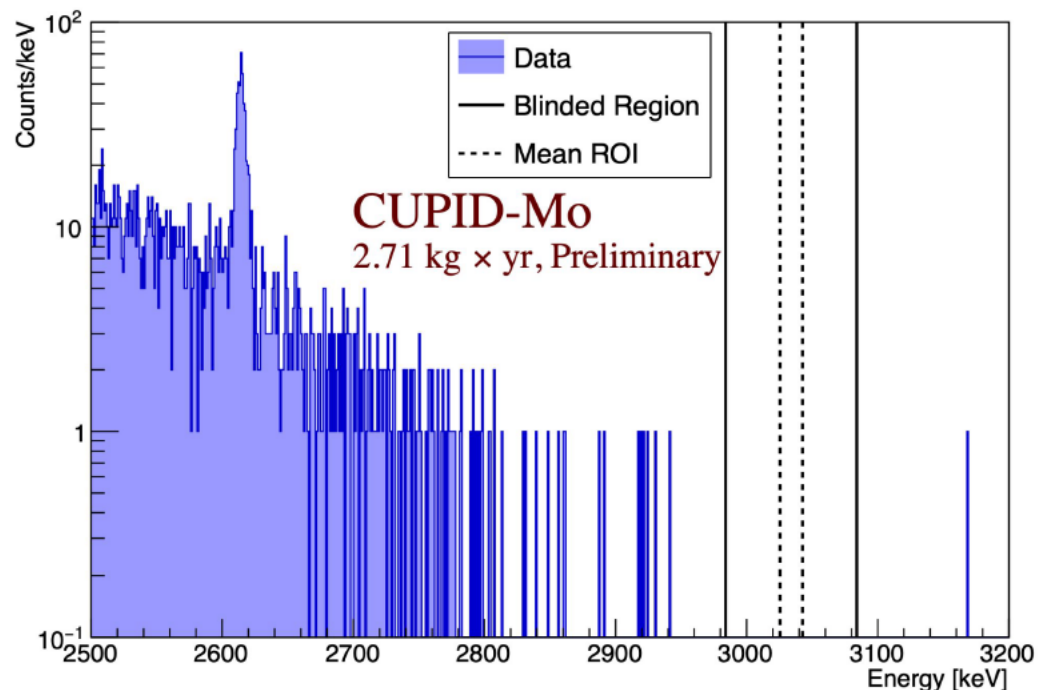
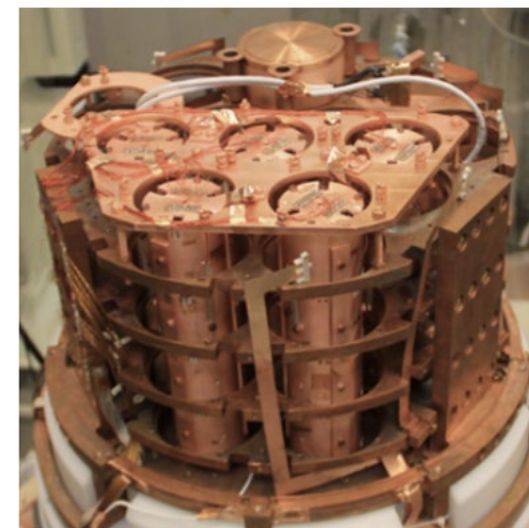
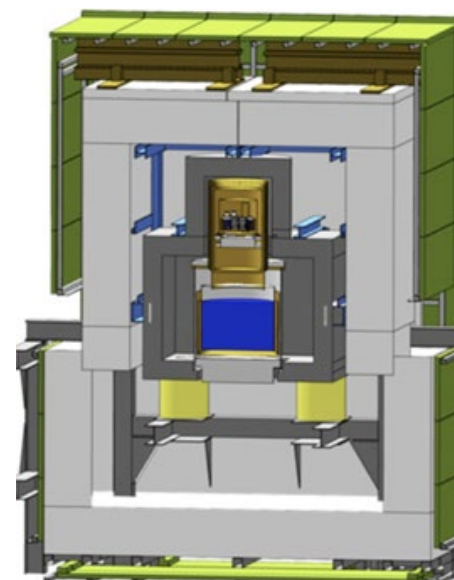
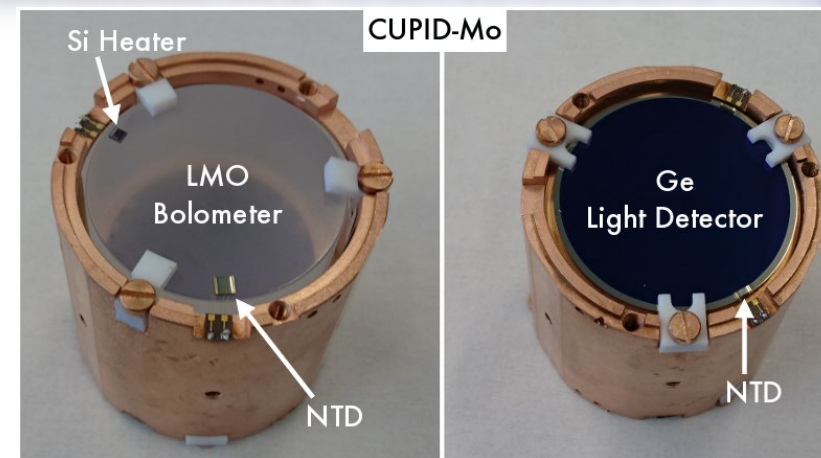


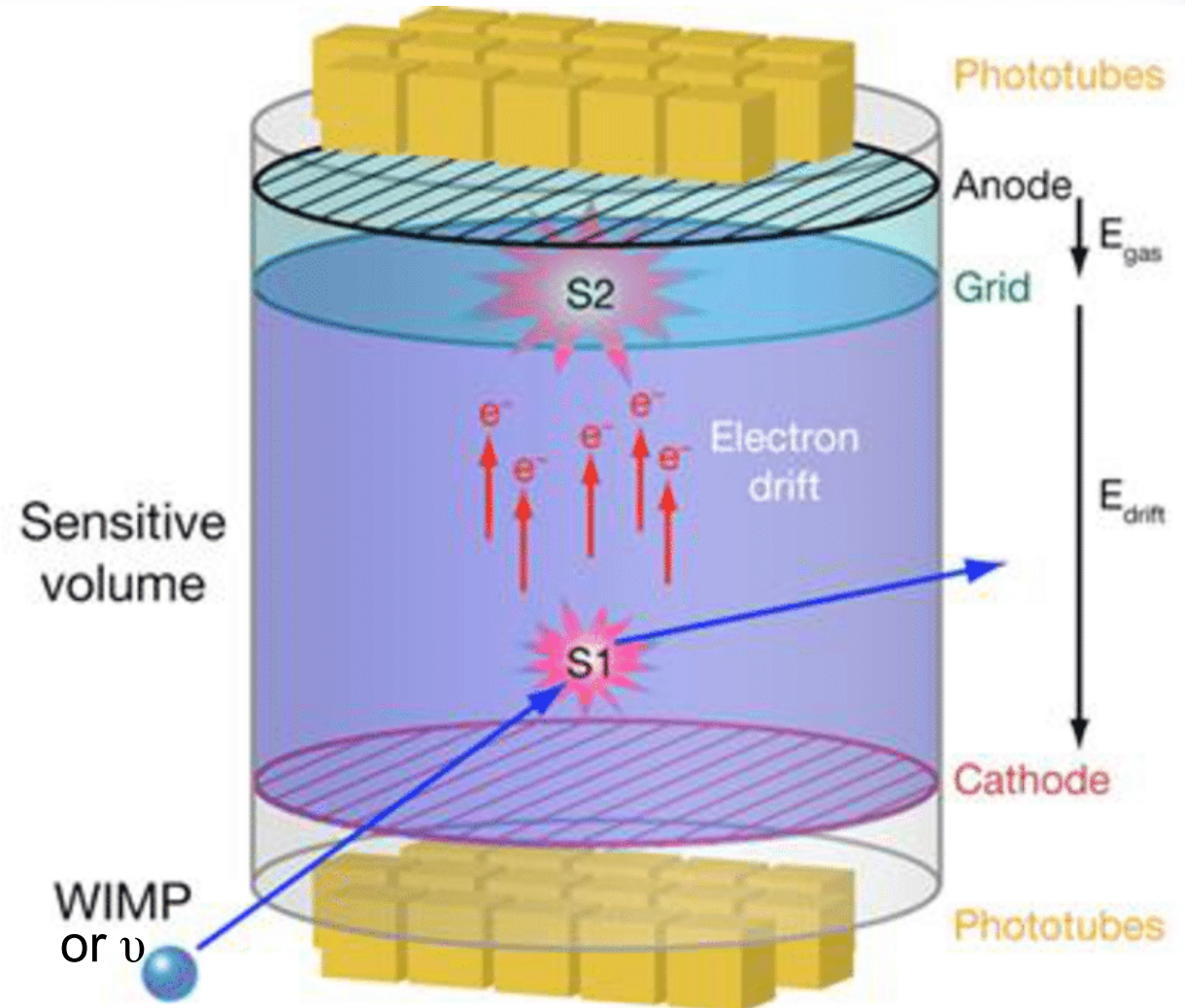
Image credits: Bradford Welliver, TAUP 2021 conference



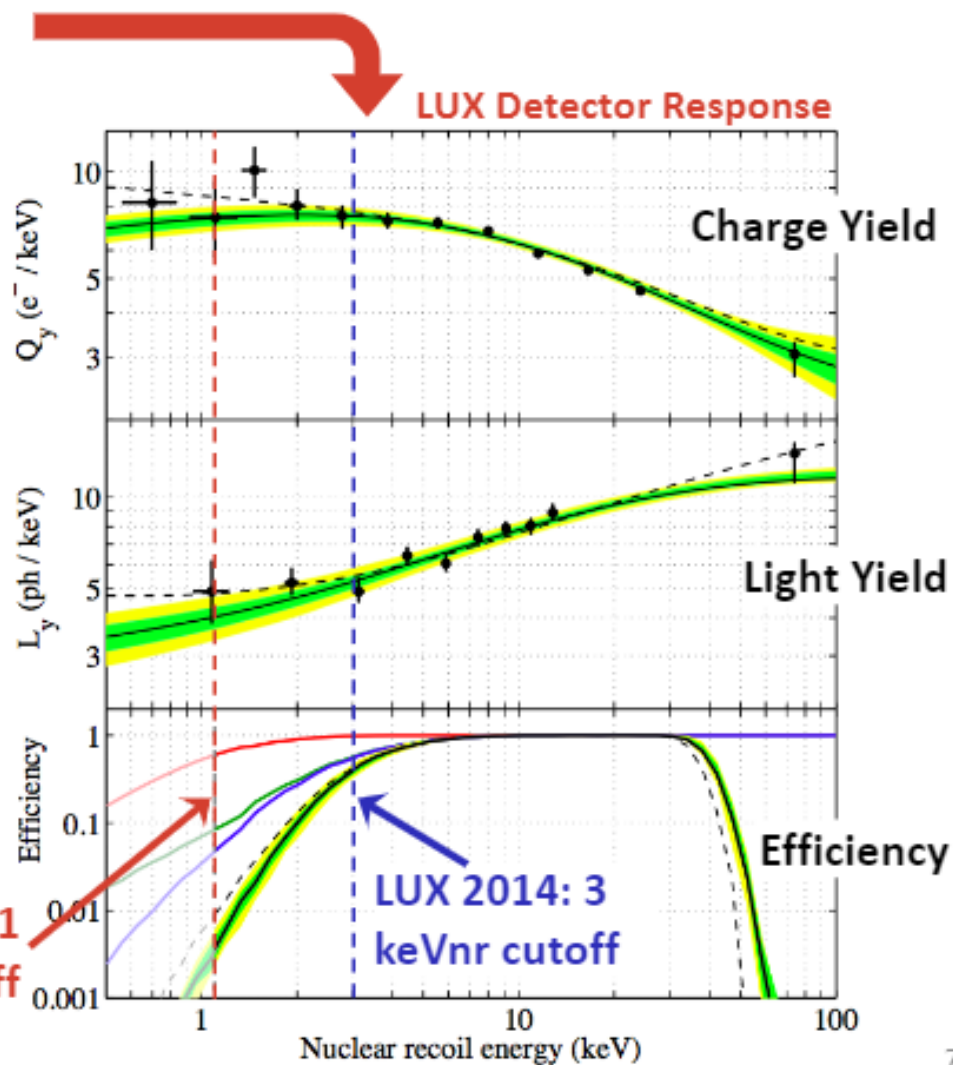
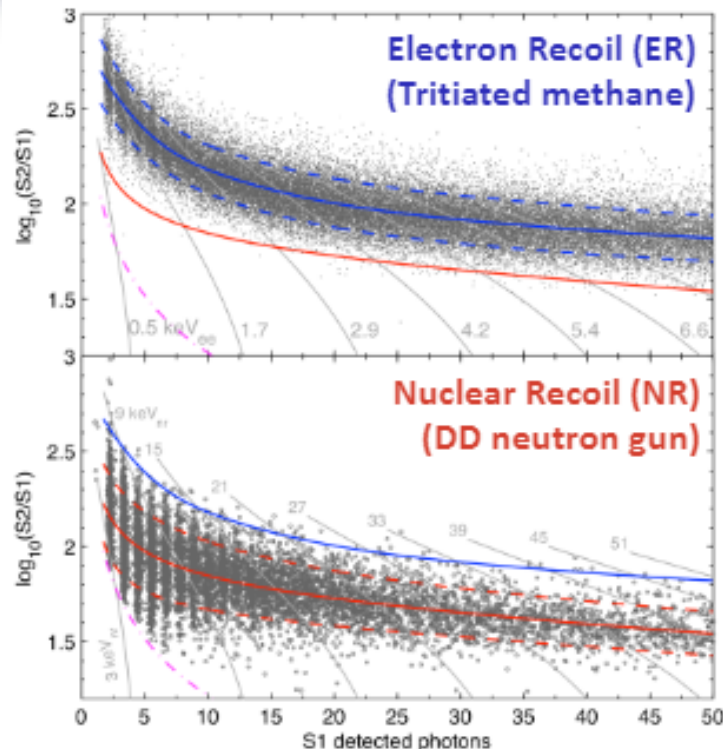
Liquid Nobles

Noble Liquid Detectors: Time Projection Chambers

- Large tank of liquid noble element (xenon or argon) attached to sensors for light and ionization energy of particle interactions
- May also have gaseous layer (“dual-phase”)
- Shielded, and often underground, to avoid interference from cosmic rays and ambient radiation
- Run warm ($\sim 85\text{K}$ for LAr, $\sim 175\text{K}$ for LXe) compared to crystals
- DM direct detection, $0\nu\beta\beta$, $\text{CE}\nu\text{NS}$, and other neutrino measurements (e.g. flavour oscillations, multi-messenger astro)



Noble Liquid Detectors: Time Projection Chambers



LUX 2015: 1.1 keVnr cutoff

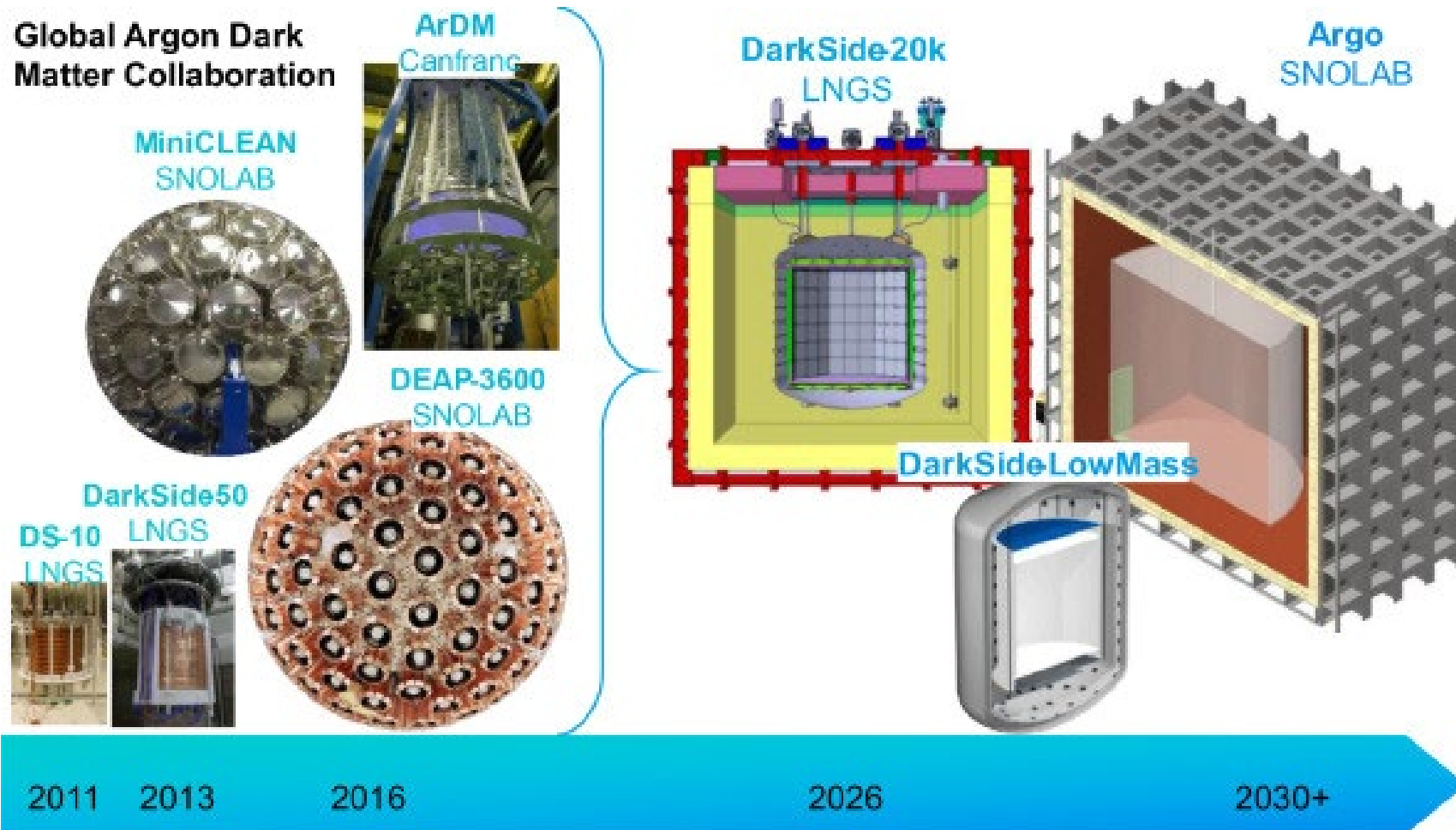
LUX 2014: 3 keVnr cutoff

[May also use "pulse shape discrimination" for Particle ID, won't get into this here]

arXiv: 1512.03506

Liquid Noble Detectors: Argon Program

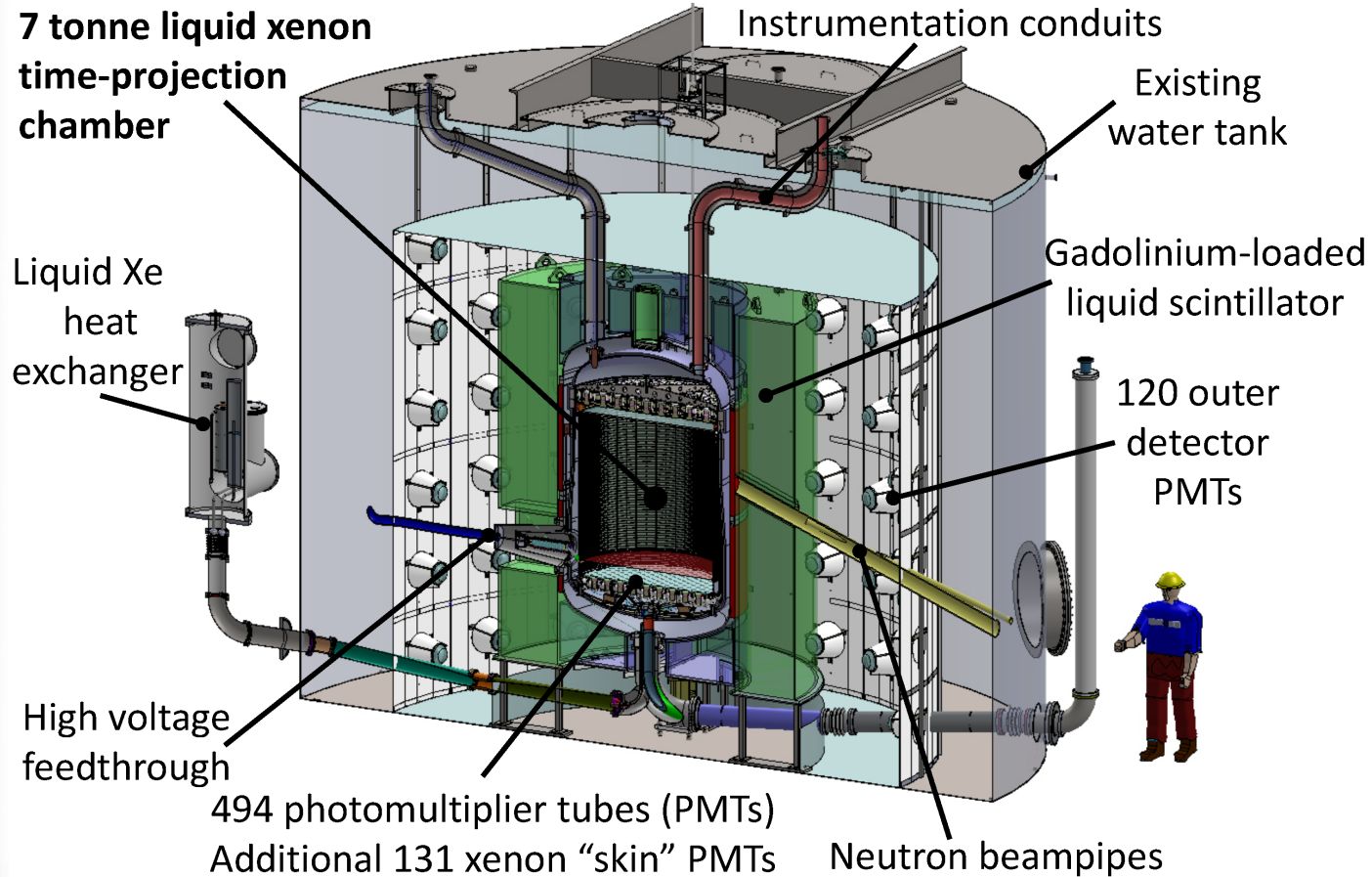
Several generations of LAr experiments for DM direct detection, growing in target mass



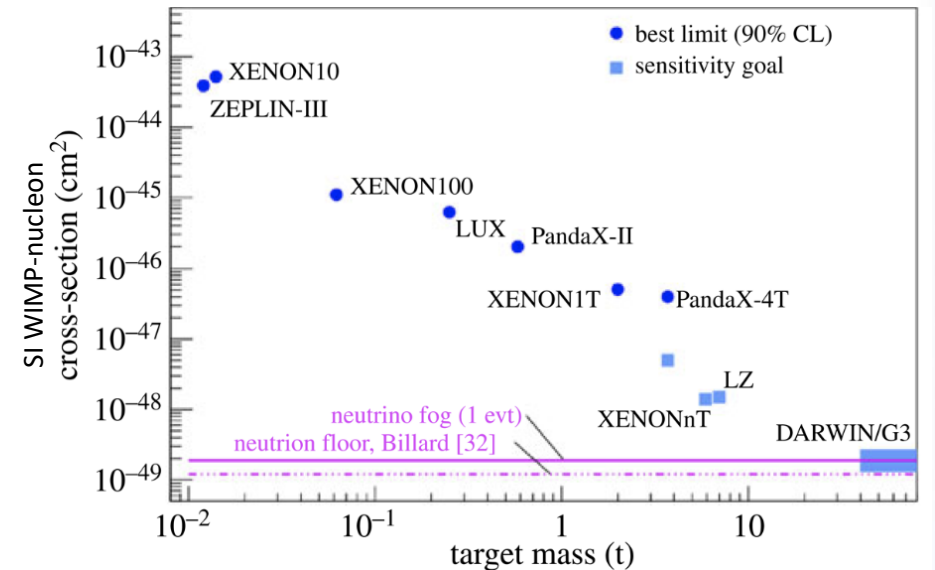
Slide credit: Art McDonald

Liquid Noble Detectors: Xenon Program

The LZ Detector



Several generations of LXe-TPCs for DM direct detection since early 2000s: ZEPLIN, XENON, LUX/LZ, Panda-X



<https://doi.org/10.1098/rsta.2023.0083>

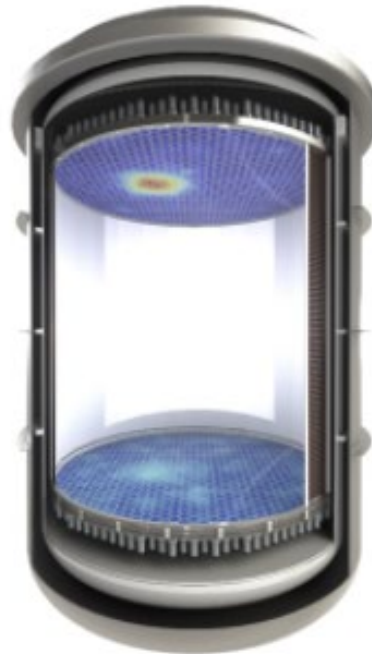
Plus, neutrino detection!

Liquid Noble Detectors: Xenon Program

Next gen: XLZD would feature 60 tonnes active mass (~3m diameter x 3m height)

Dark Matter

WIMPs
Sub-GeV
Inelastic
Axion-like particles
Planck mass
Dark photons



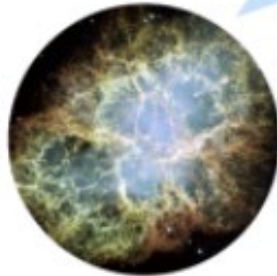
Neutrino nature

Neutrinoless double
beta decay
Neutrino magnetic
moment
Double electron
capture



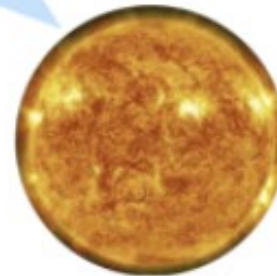
Supernovae

Early alert
Supernova neutrinos
Multi-messenger
astrophysics



Sun

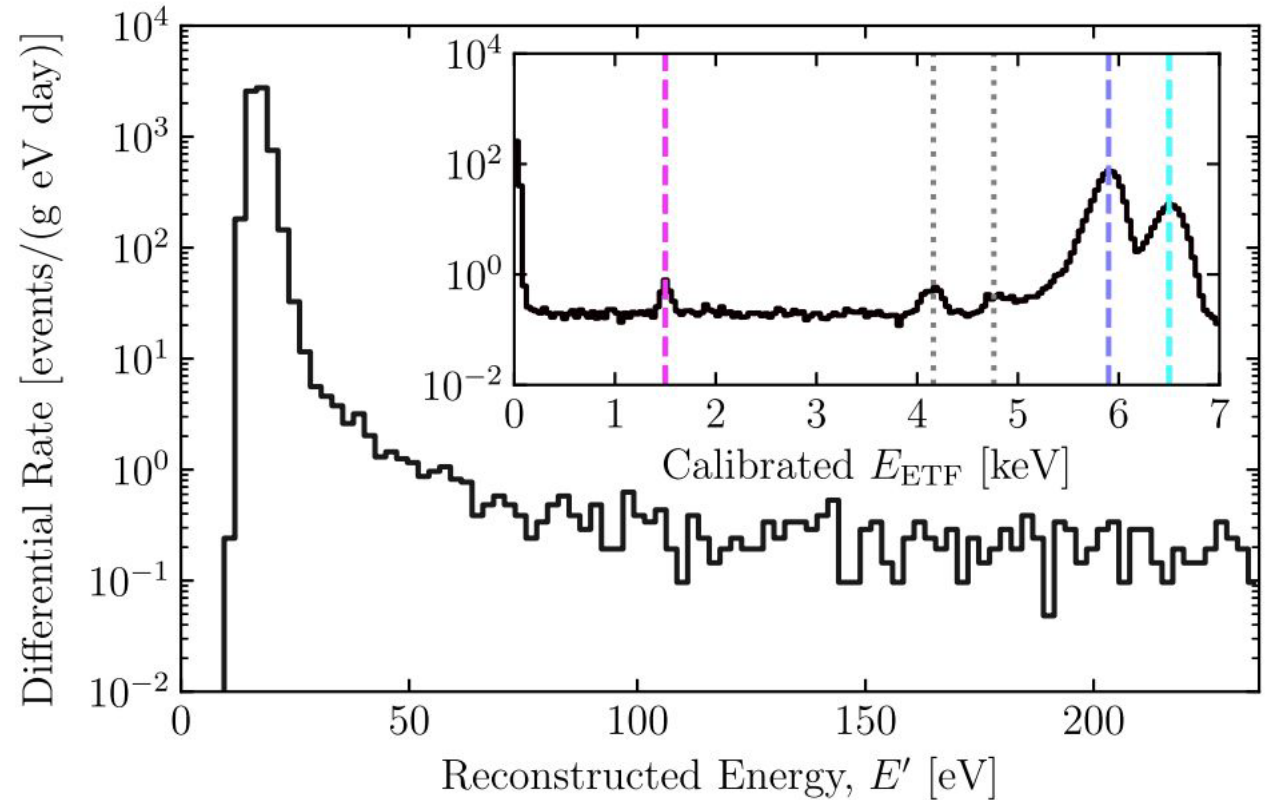
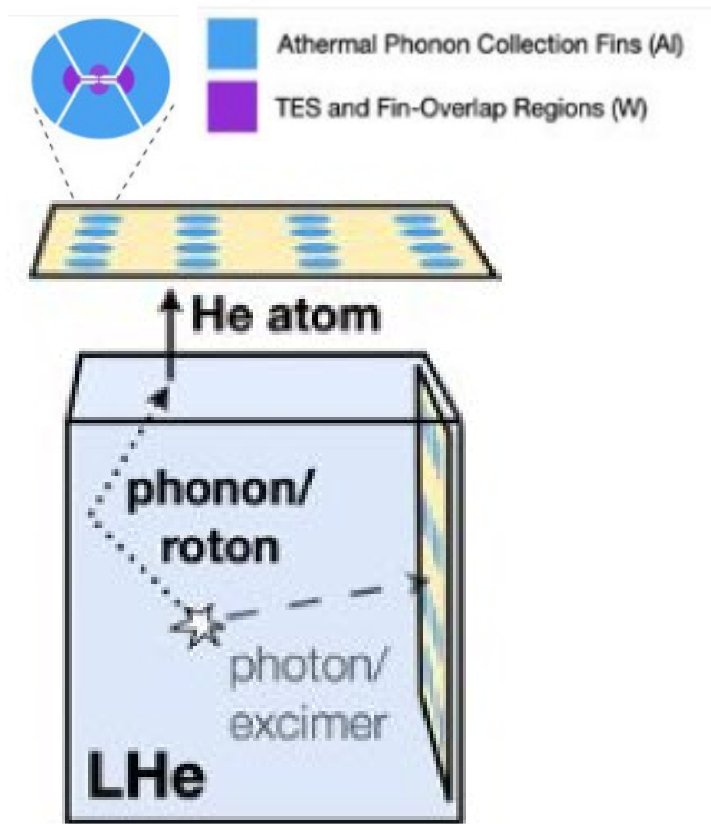
pp neutrinos
Solar metallicity
 ${}^7\text{Be}$, ${}^8\text{B}$, hep



arXiv:2410.17137

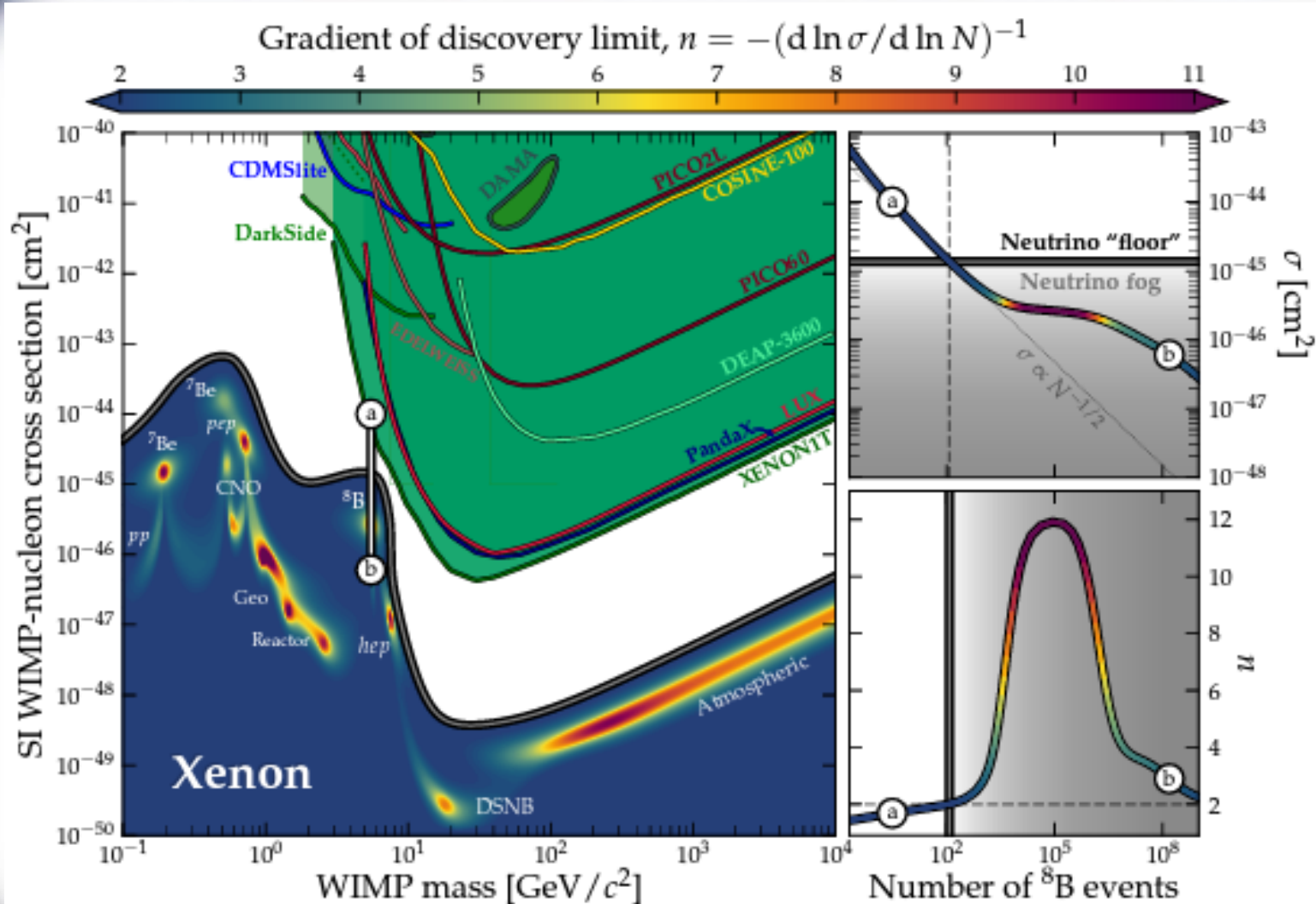
Noble Liquid Detectors: Helium

TESSARACT: currently in prototyping stage, for DM direct detection
gram-scale TES-based detectors



Neutrinos vs DM in cryogenic detectors

Neutrino “Floor” or “Fog” in DM Searches



arXiv:2109.03116

ν **floor** traditionally defines region of parameter space where DM signals get hidden under “irreducible” ν bg

- under arbitrary choices of exposure, threshold

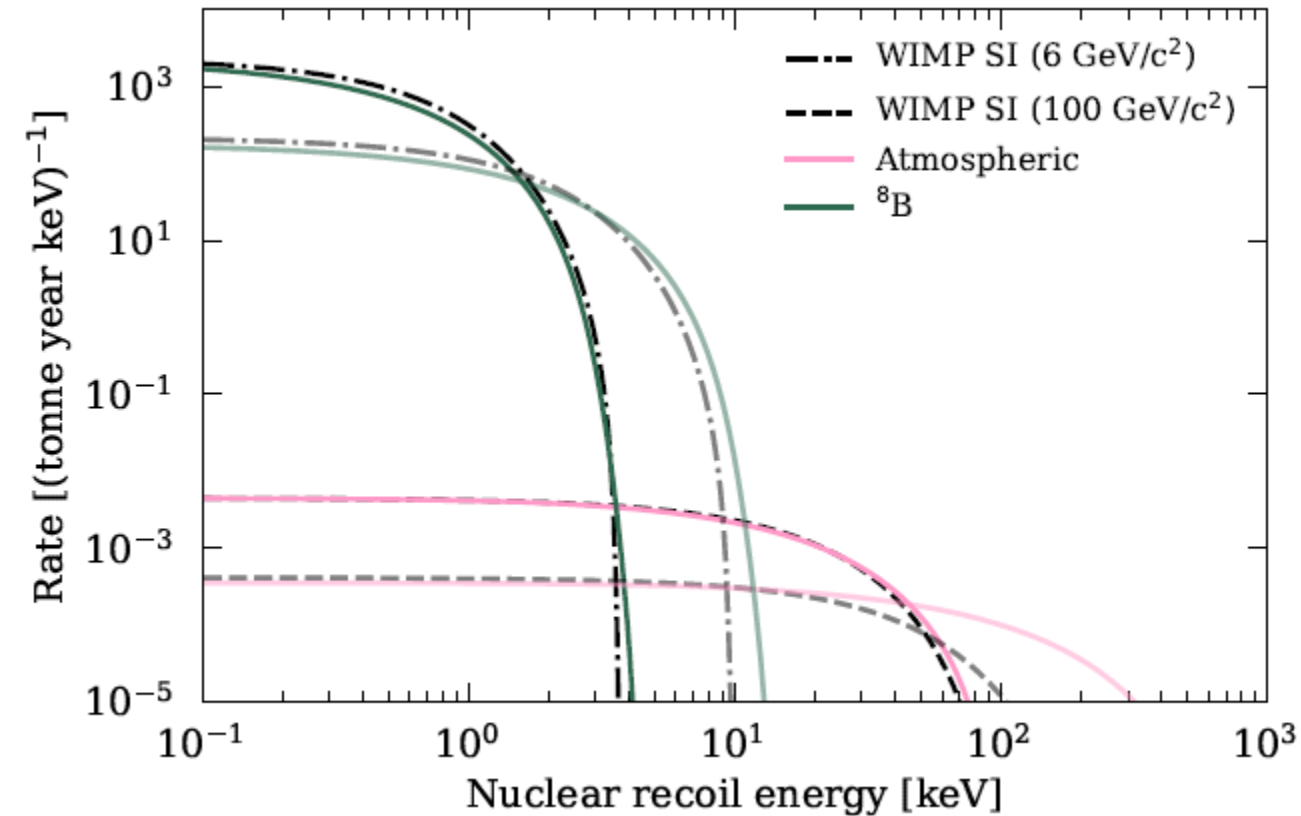
New definitions proposed, e.g. :
 n = index in scaling of *discovery limit* σ with #bg events N ,
fog = $n > 2$ regime

Still:

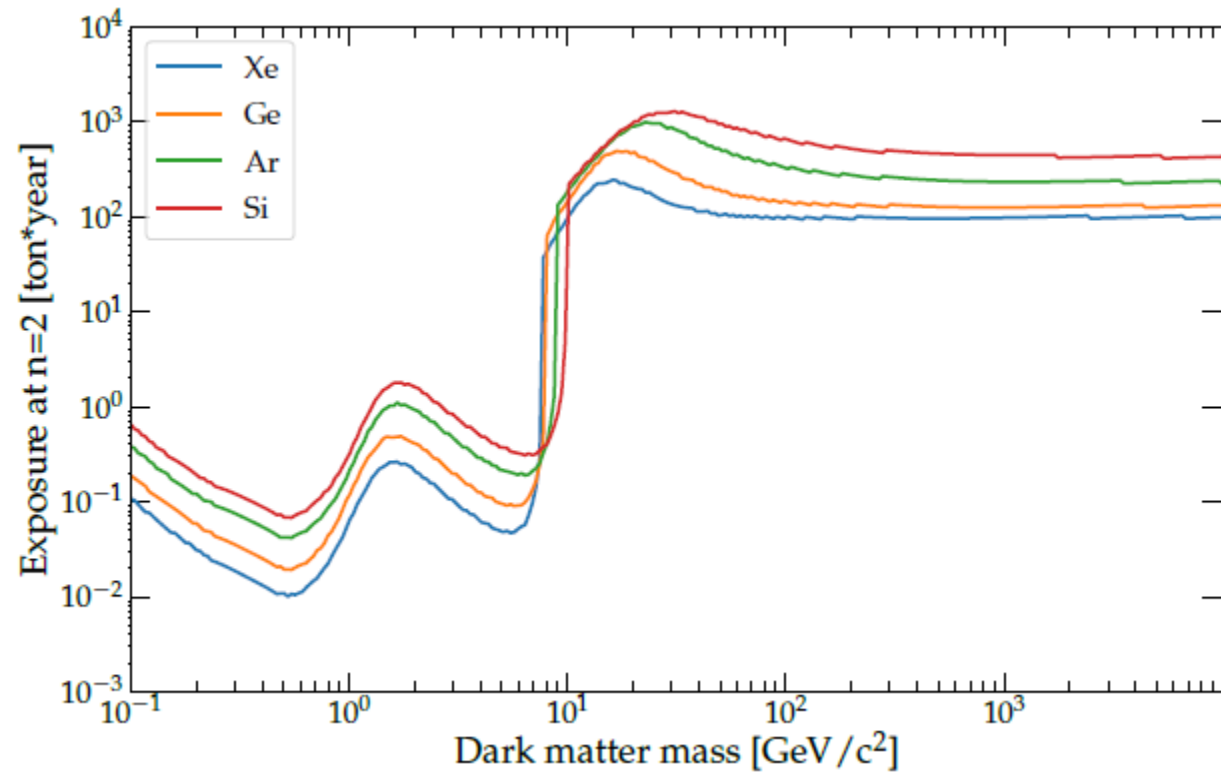
- Depends on target material
- Influenced by systematic uncertainties on ν flux normalization

Neutrino "Floor" or "Fog" in DM Searches

ν NRs on Xe (darker colour) and Ar (lighter)



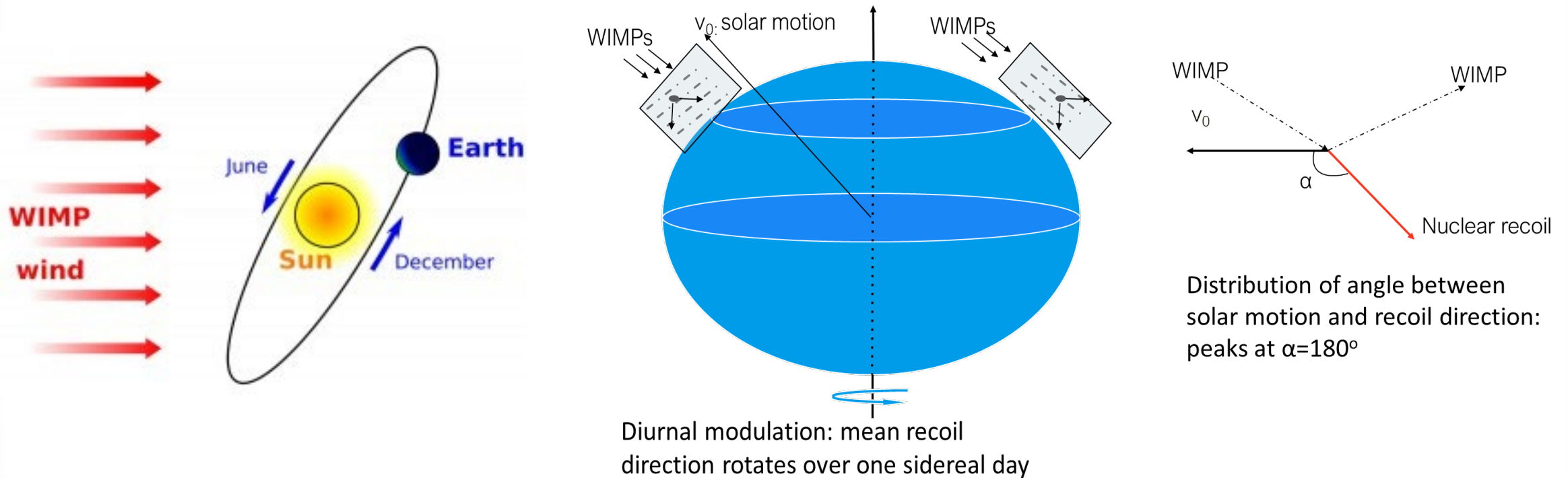
Exposure required to reach $n=2$
(systematic-limited) SI ν fog



arXiv:2109.03116

DM Directional Detection?

Look for annual or daily modulation signal to bypass constant backgrounds

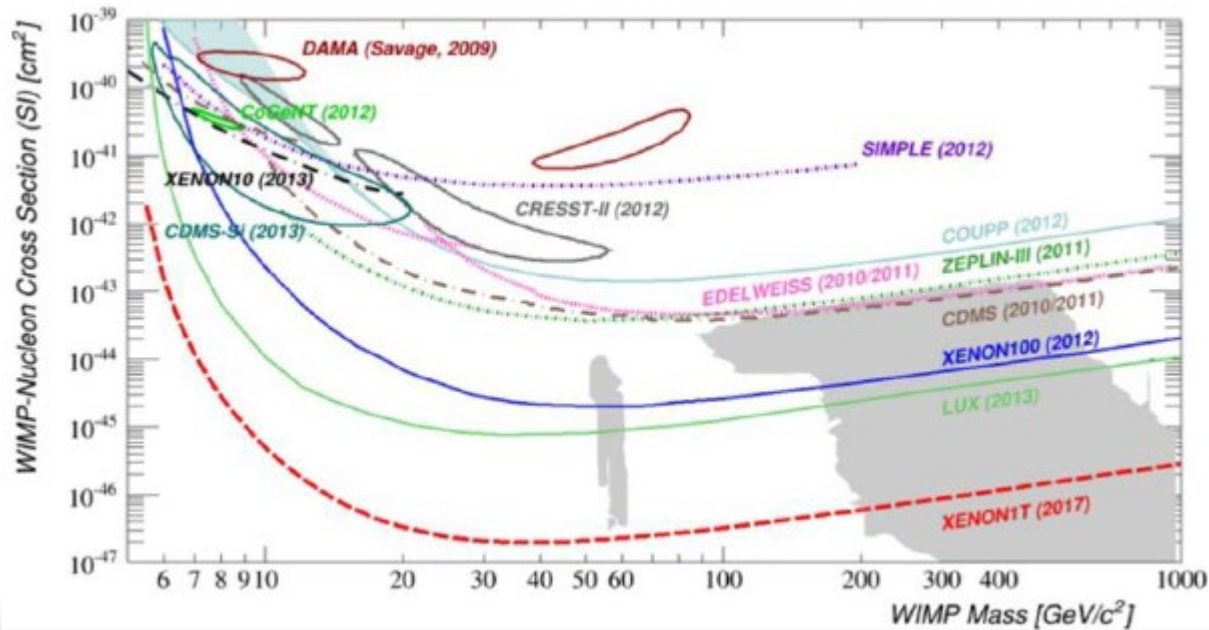
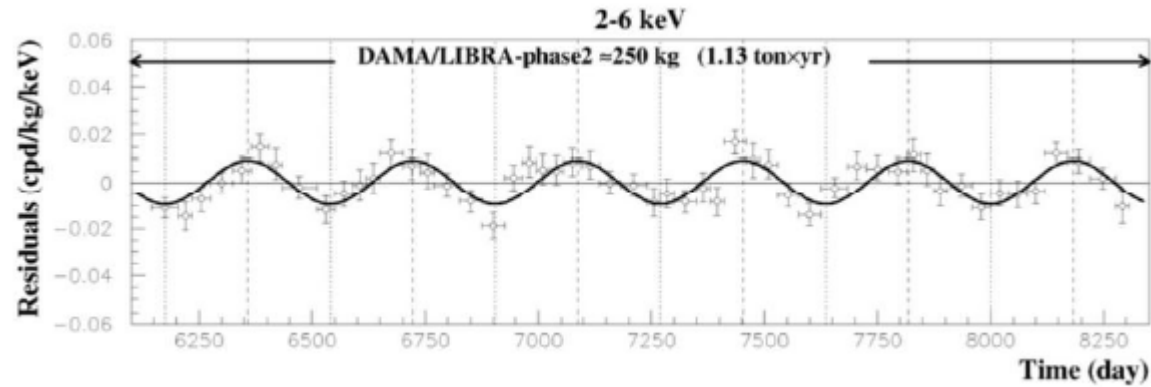


Slide credit: Enectali Figueroa-Feliciano

And Now For Something Confusing... DAMA

DAMA/LIBRA sees 12-sigma “annual modulation” signal, incompatible with null-results from direct detection experiments that use background subtraction / modelling!

See also, lack of replication by COSINE and ANAIS

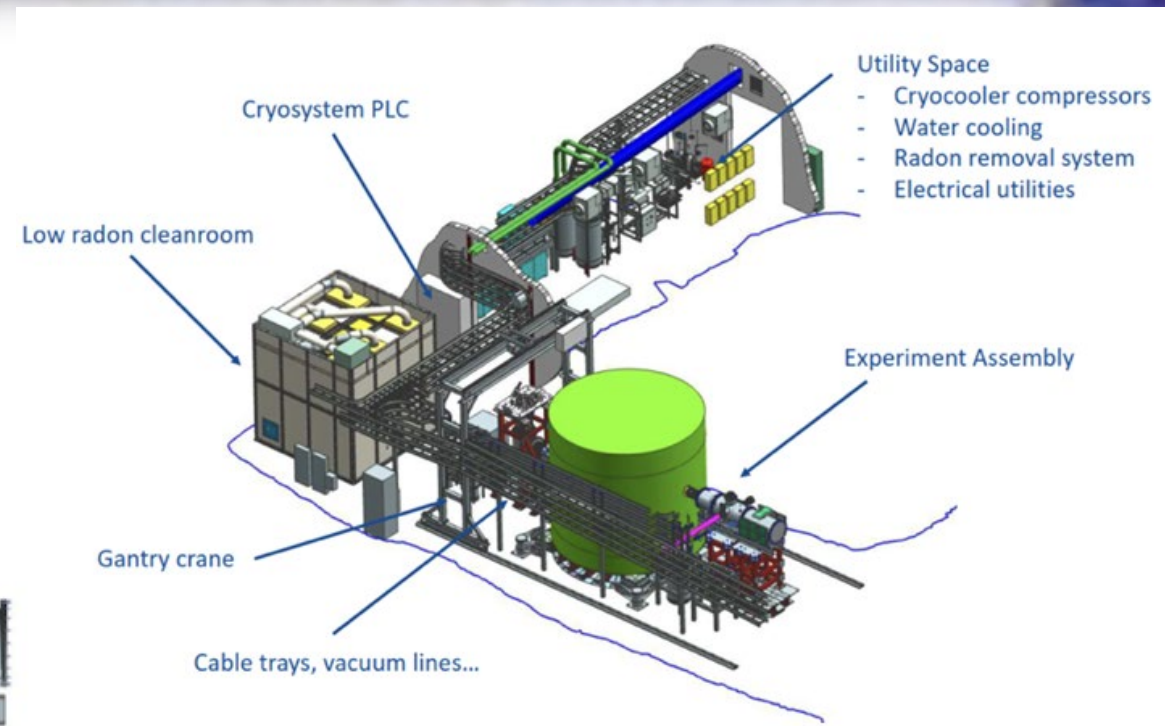
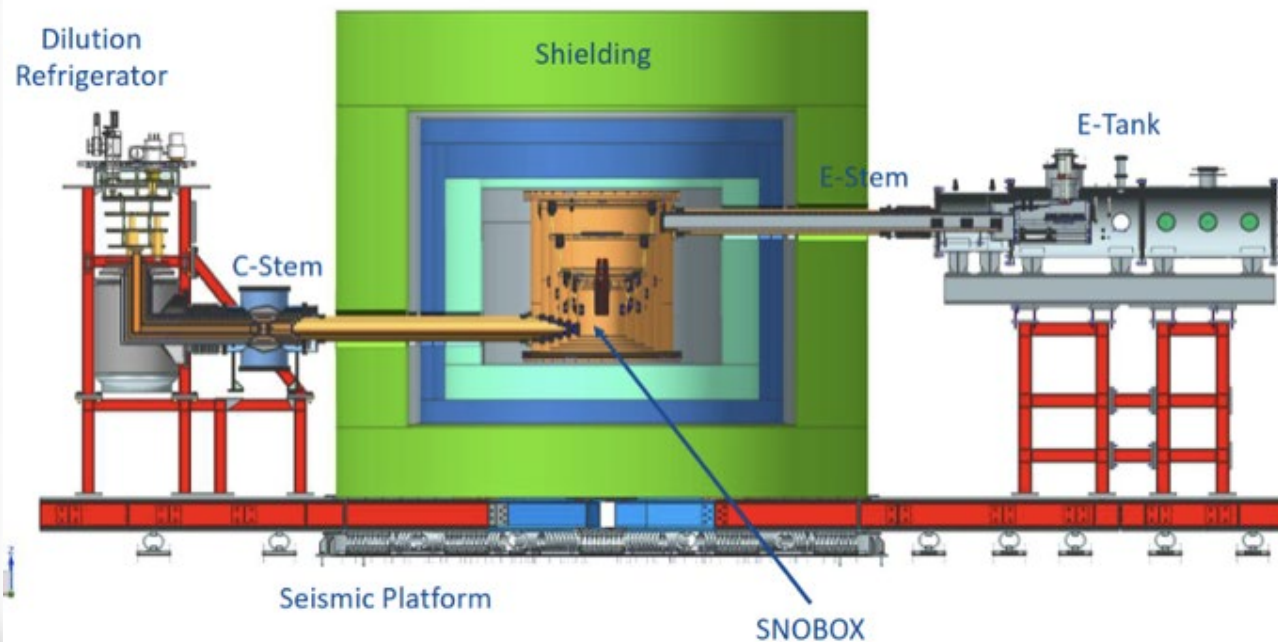


Cryogenic Infrastructure

Cryogenic Detectors Require Lots of Infrastructure

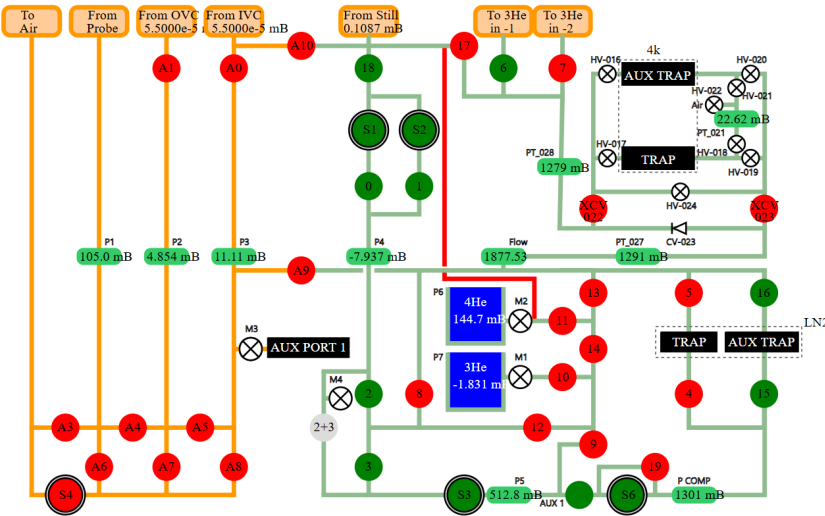
e.g. SuperCDMS SNOLAB:

Dilution fridge and readout electronics outside detector shield, “C-Tank” & “E-Tank” larger than cryostat itself

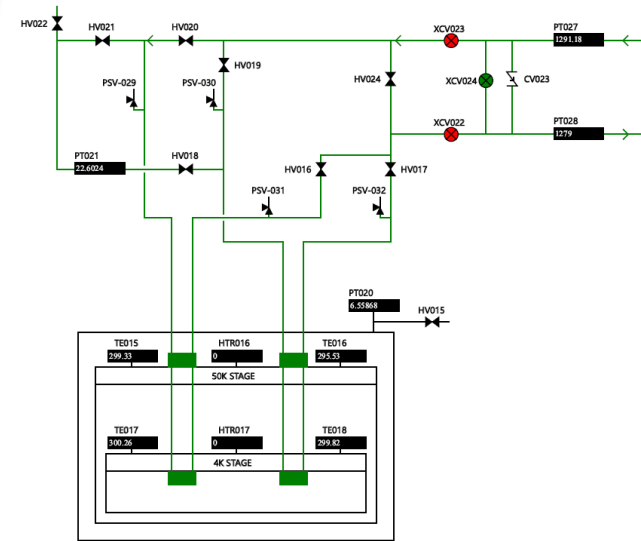


Cryogenic Detectors Require Lots of Infrastructure

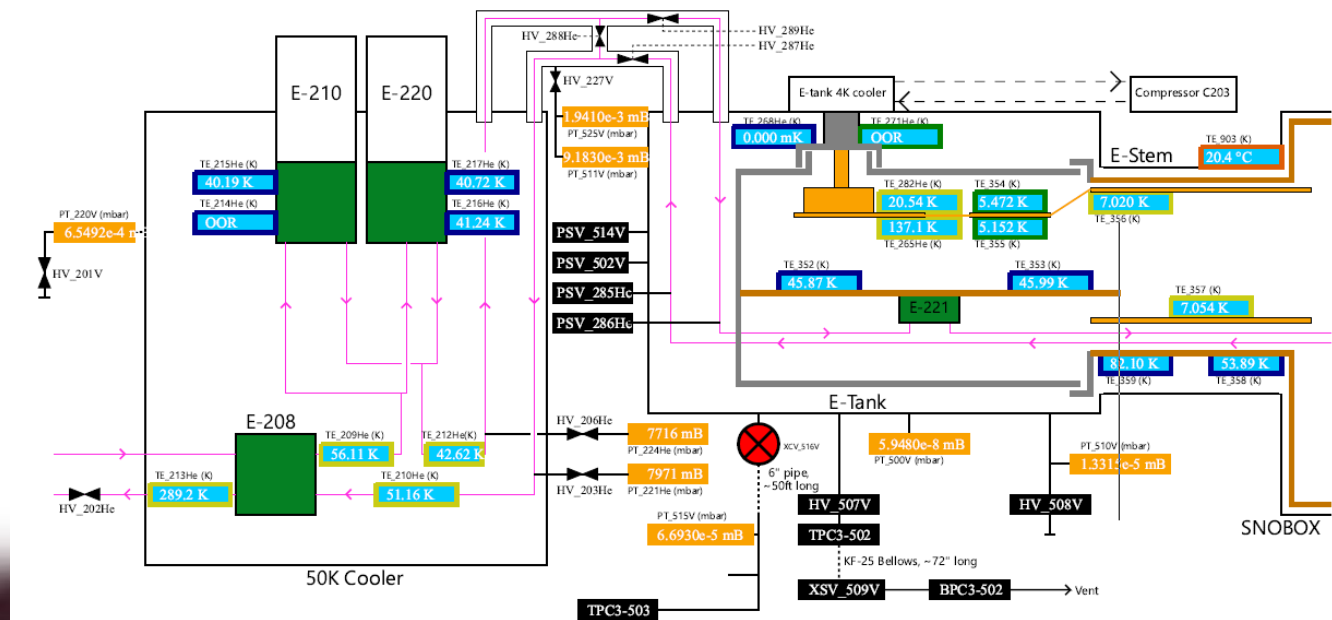
Fridge:



4K "trap":

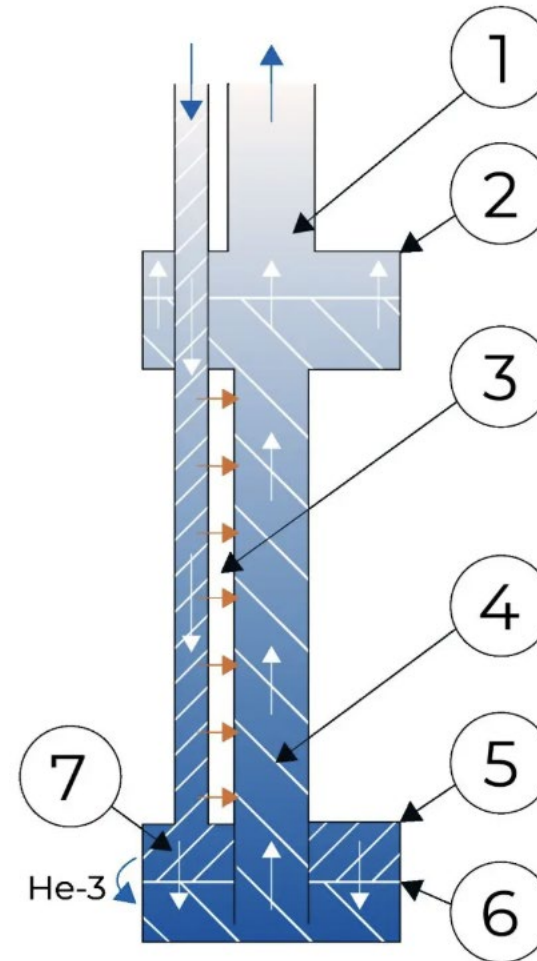
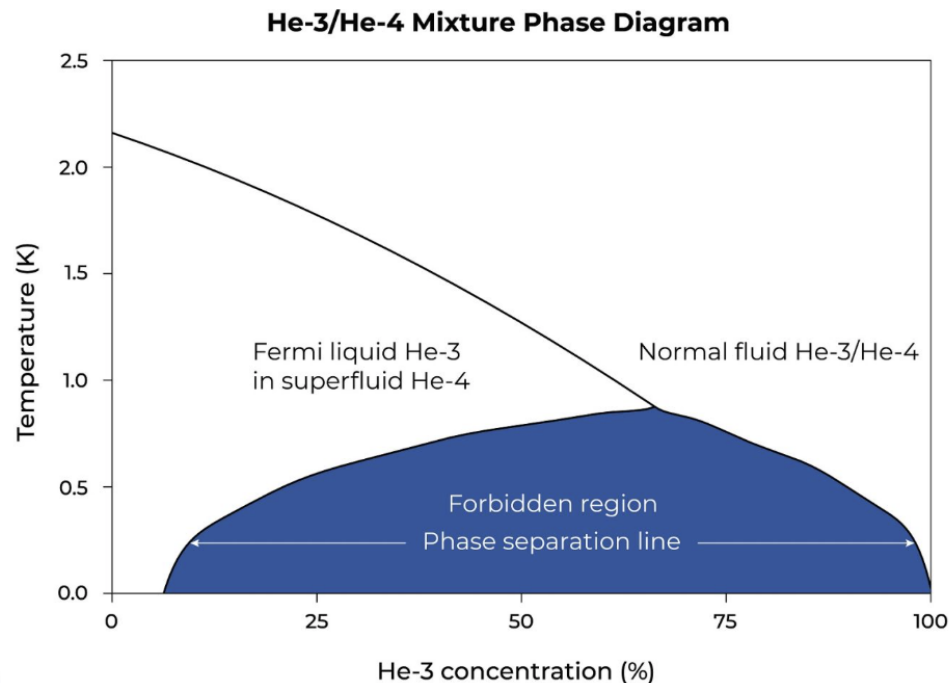


E-tank+50K:



LHe Dilution Refrigerators

- Approaching 0K, “concentrated” phase becomes pure He-3, “dilute” He-4 rich phase maintains ~6.6% of He-3.
- $H_{\text{He3}}(\text{dilute}) > H_{\text{He3}}(\text{concentrated})$, so moving He-3 from concentrated to dilute phase takes thermal energy



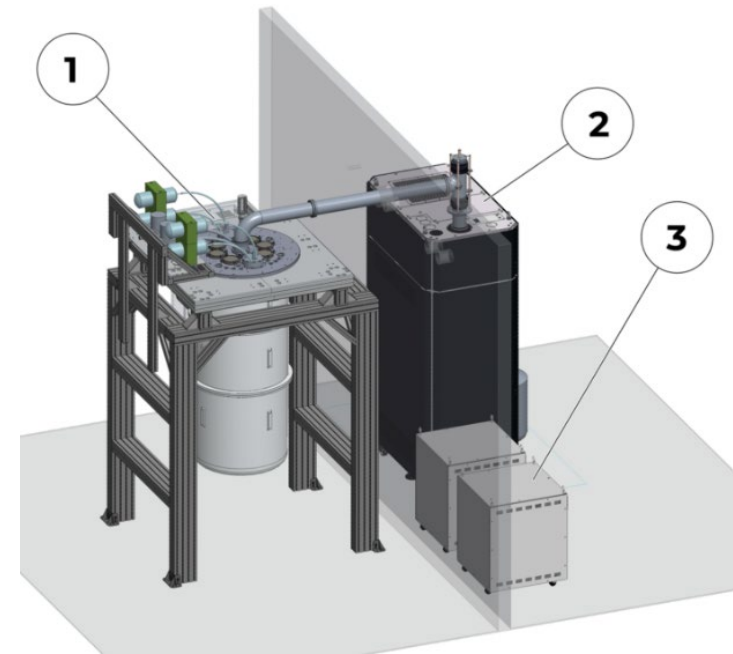
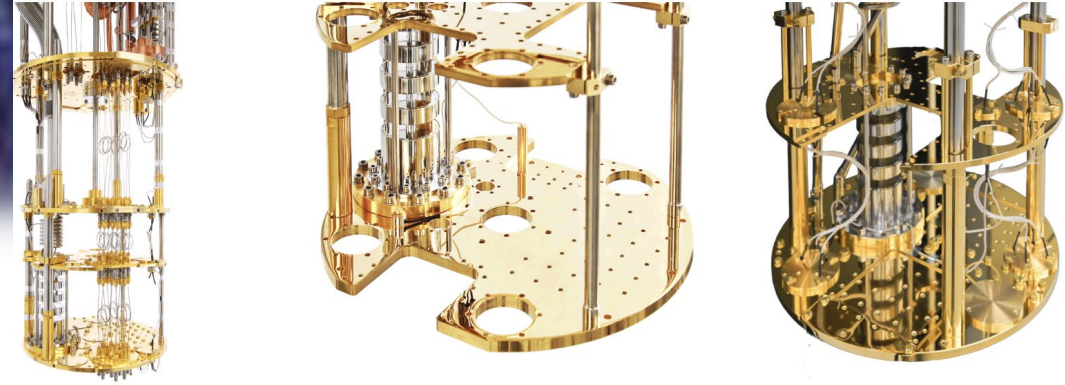
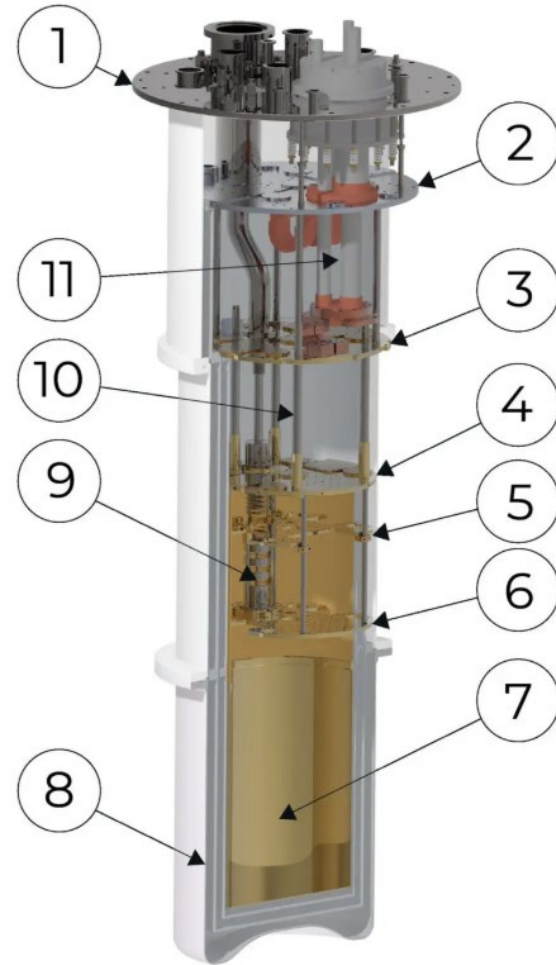
1. He-3-rich gas phase
2. Still
3. Heat exchangers
4. He-3-poor phase
5. Mixing Chamber
6. Phase separation
7. He-3-rich phase

(courtesy of BlueFors)

LHe Dilution Refrigerators

e.g. BlueFors:

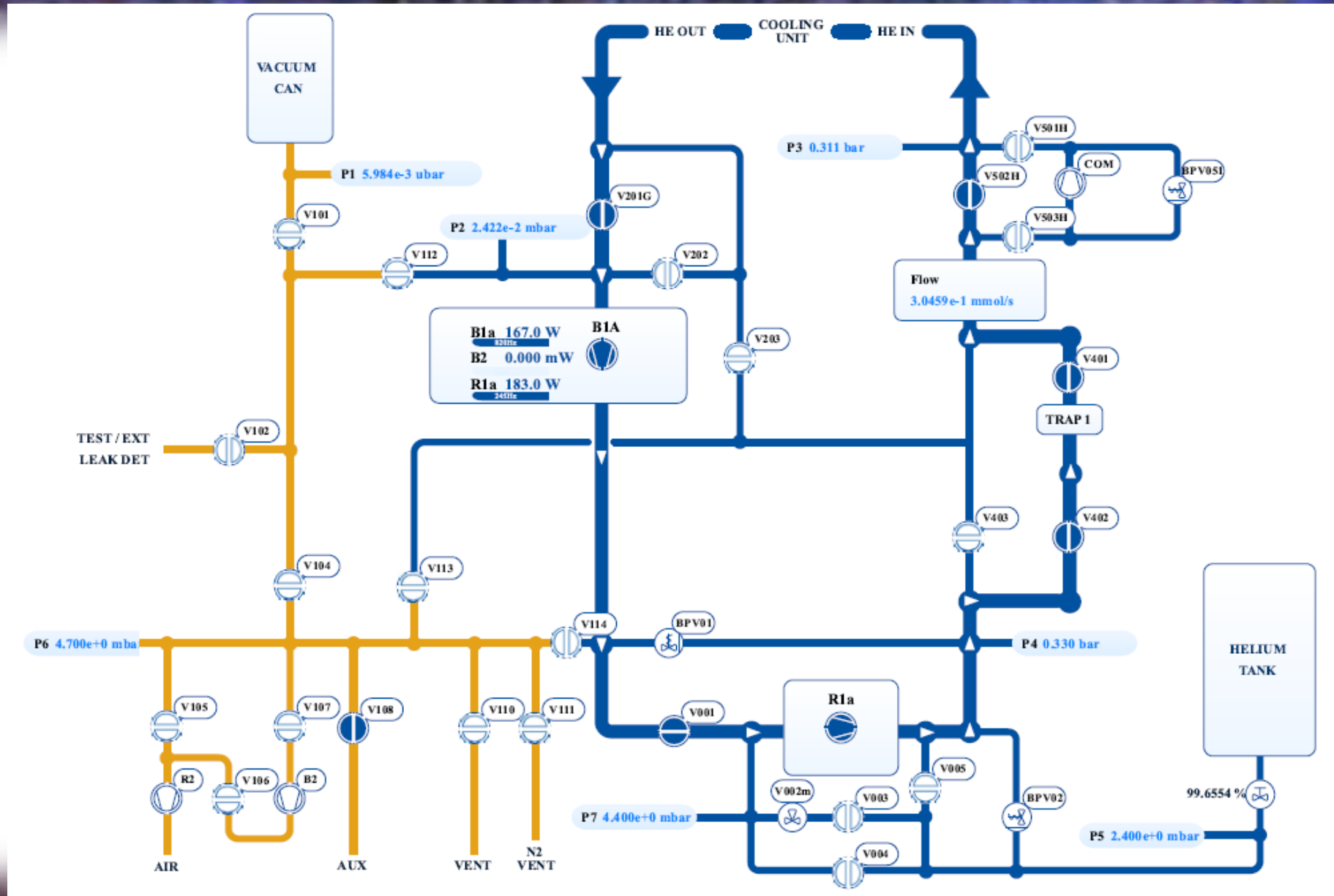
1. Room Temp Flange
2. 50K Flange
3. 4K Flange
4. Still Flange
5. Cold Plate
6. Mixing Chamber Flange
7. Experimental space
8. Vacuum enclosure & radiation shields
9. Dilution unit
10. Heat Switch
11. Two-stage pulse tube



1. Fridge on its support frame
2. Gas Handling System
3. Pulse Tube compressor

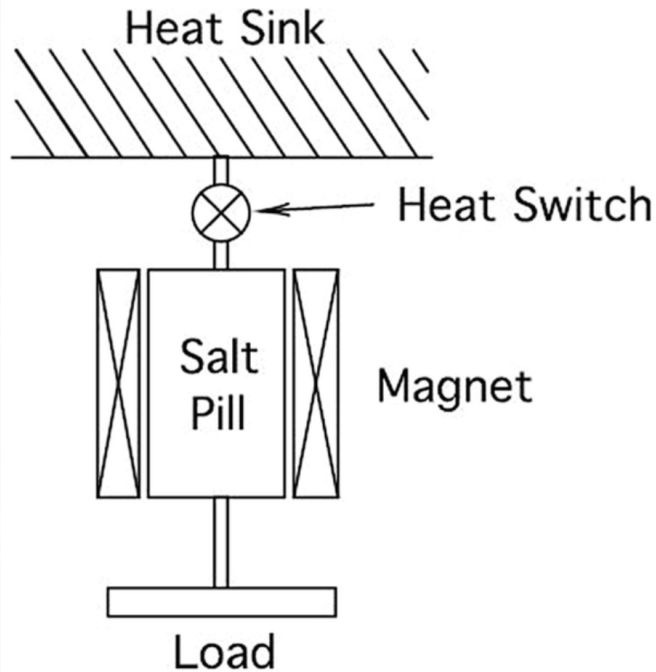
LHe Dilution Refrigerators

e.g. BlueFors:

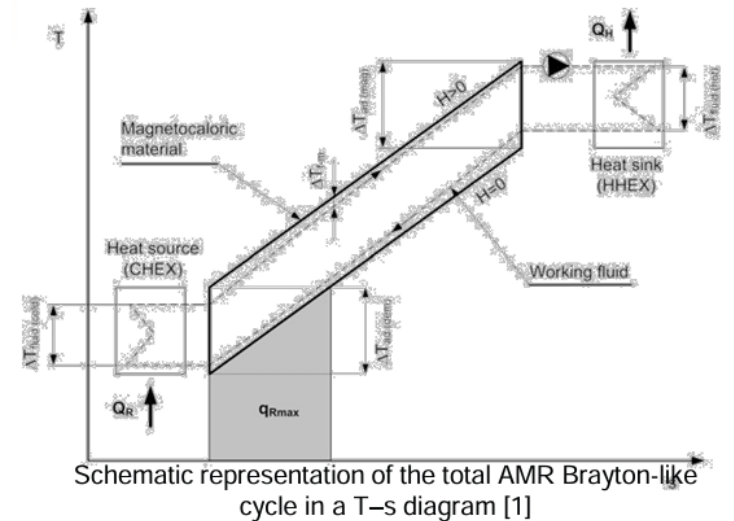
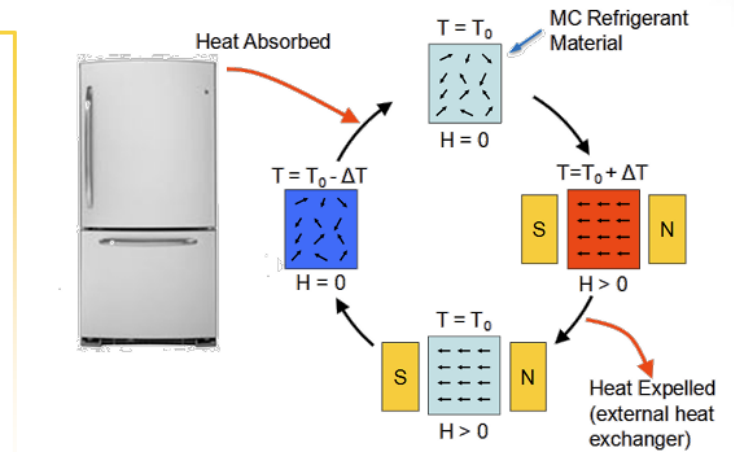


Adiabatic Demagnetization Refrigerators

Uses magnetocaloric (MC) material: “salt pill”



- Cycle starts with MC material (MCM) at T_0
- MCM is placed inside a higher magnetic field resulting in MCM temperature increase to $T_0 + \Delta T$
- Heat is rejected from the MCM to ambient while inside the higher magnetic field, reducing its temperature to T_0
- MCM is removed from the higher magnetic field; resulting in reduced temperature to $T_0 - \Delta T$
- Heat is absorbed by MCM from refrigerated compartment; increasing its temperature to T_0 , and the cycle is repeated



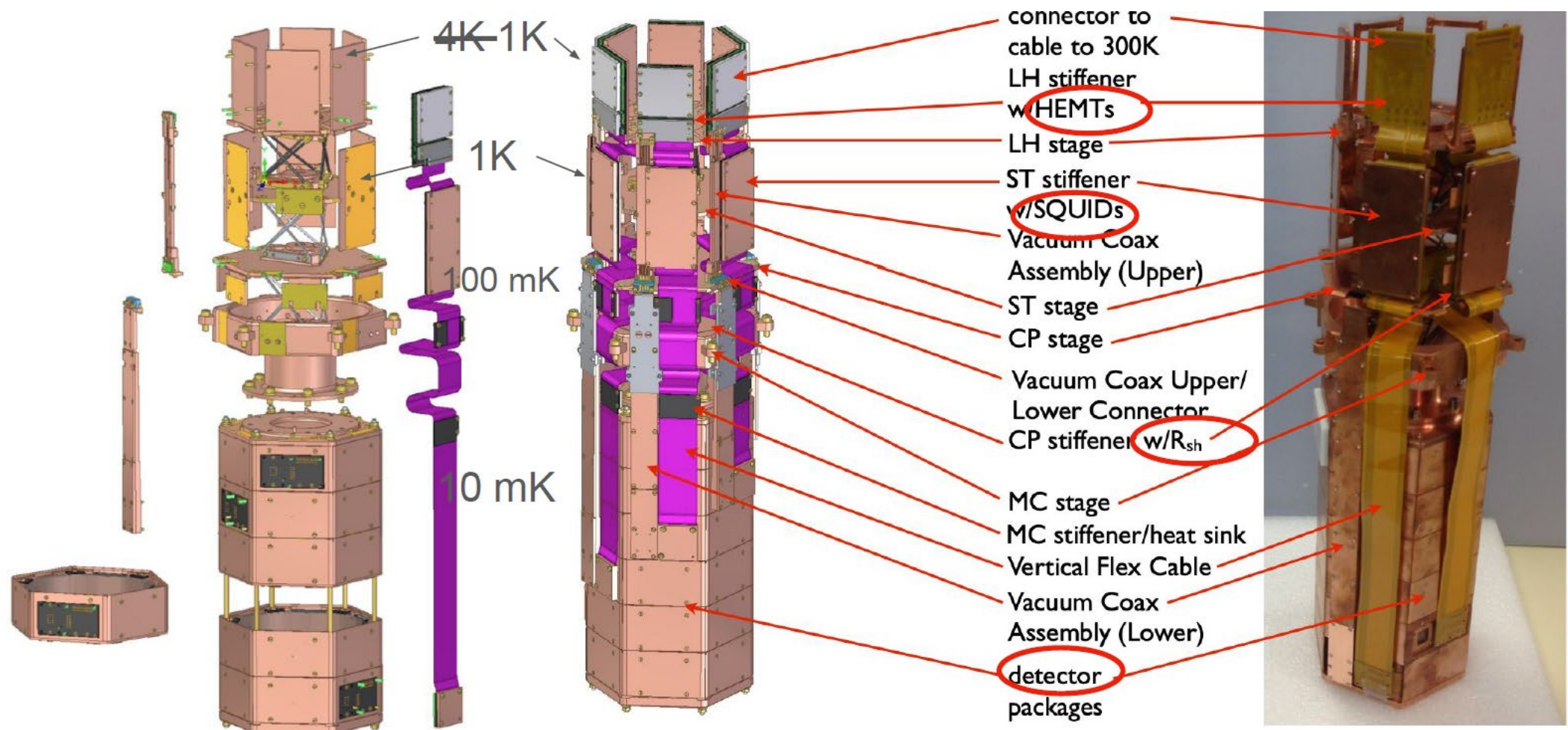
“Wet fridge” uses a lot of LHe

Can only run for ~hours before salt pill must “regenerate” (spins must re-set)

But may be more portable & less expensive than dilution fridges

“Stages”: matching temperatures to components

e.g. SuperCDMS:



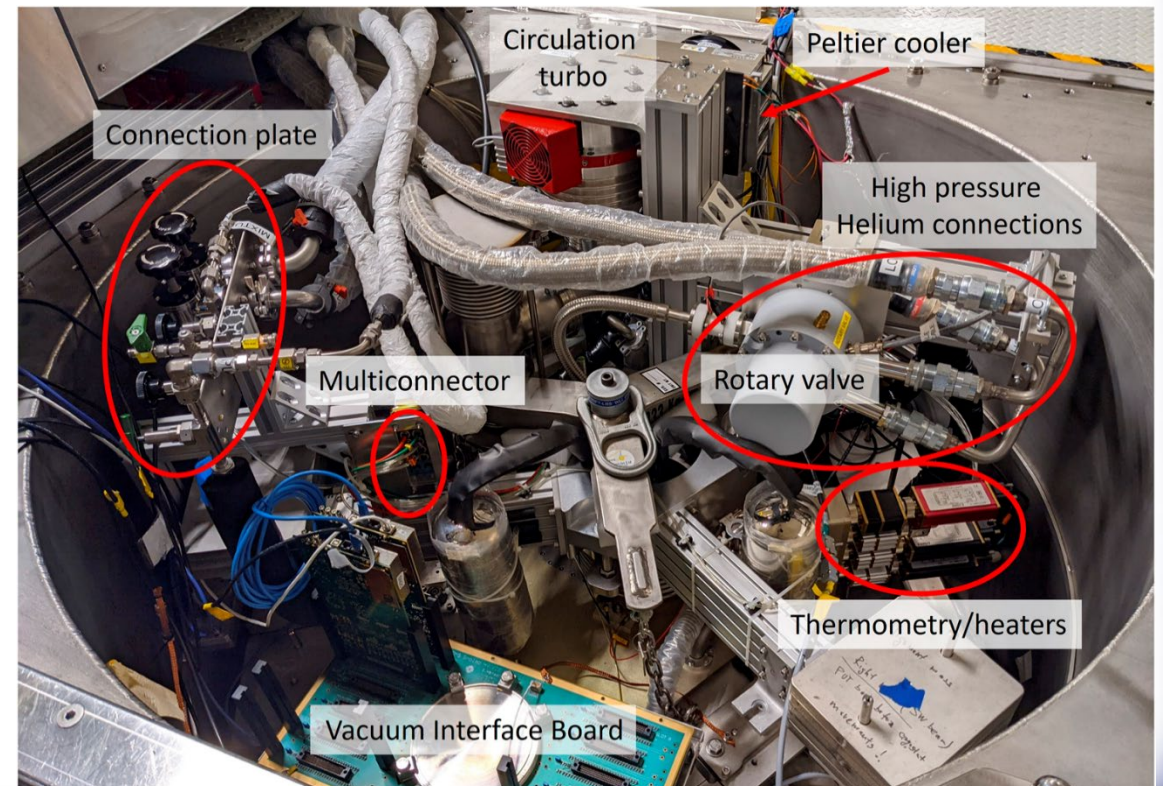
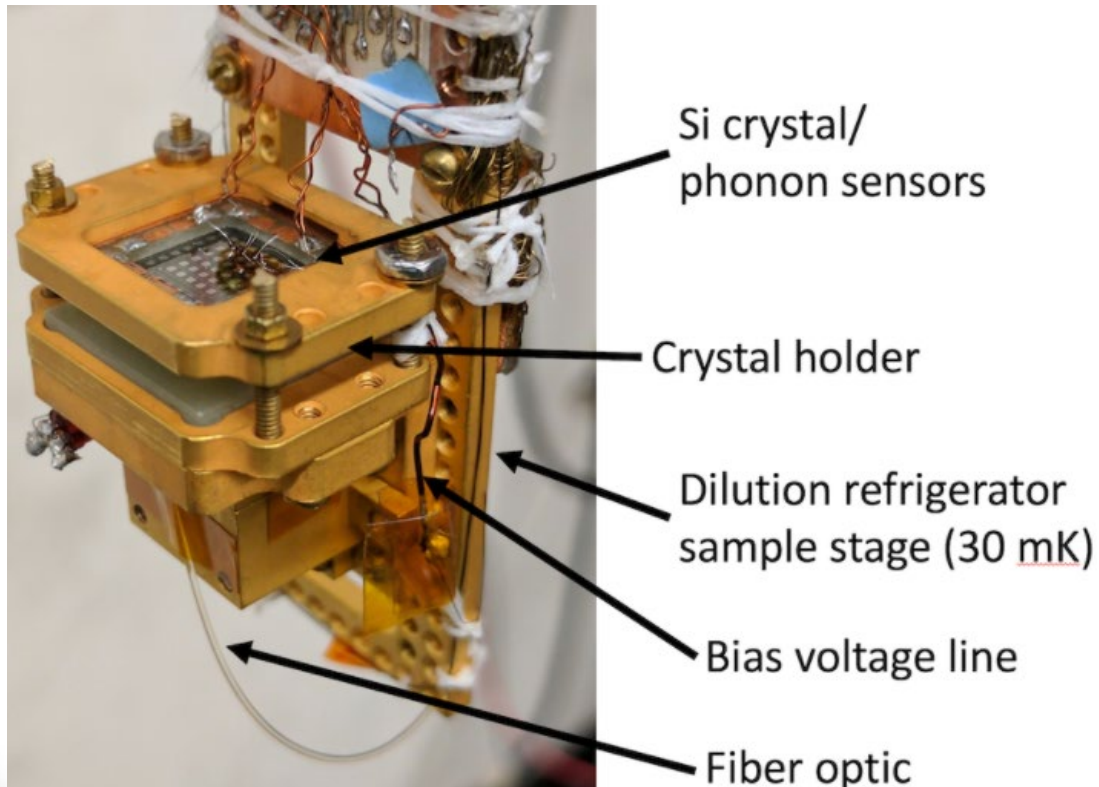
Cryostats

Beware of all the connections! Light leaks, He leaks, electrical discontinuities, ...

Size & complexity varies widely depending upon detector “payload”, e.g.

SuperCDMS test facility for prototypes

Cryogenic Underground Test (CUTE) @SNOLAB



Backgrounds & Calibrations

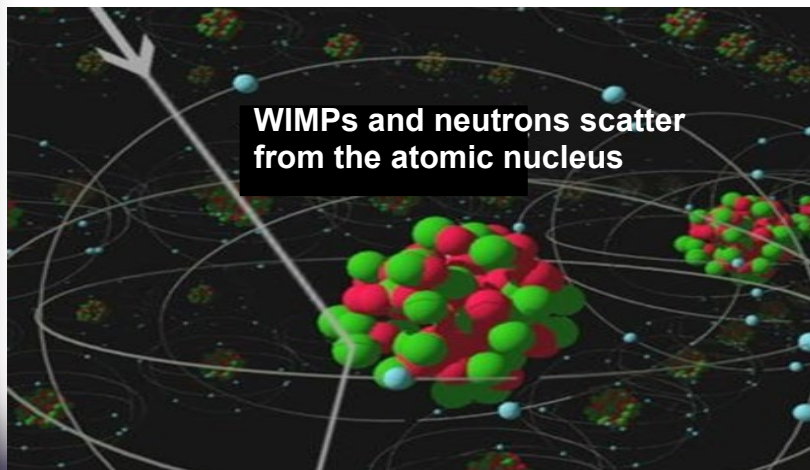
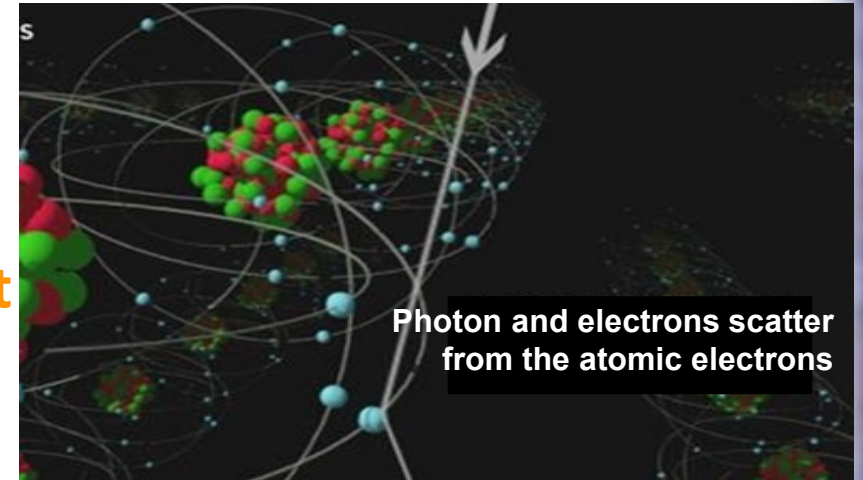
The most troublesome backgrounds

Most from trace radioactivity, or cosmogenic (cosmic ray muons produce fast neutrons via spallation, difficult to shield against)

ER

γ : Most prevalent

β : on surfaces or in the bulk



NR

n: often indistinguishable from WIMP

α : on surfaces

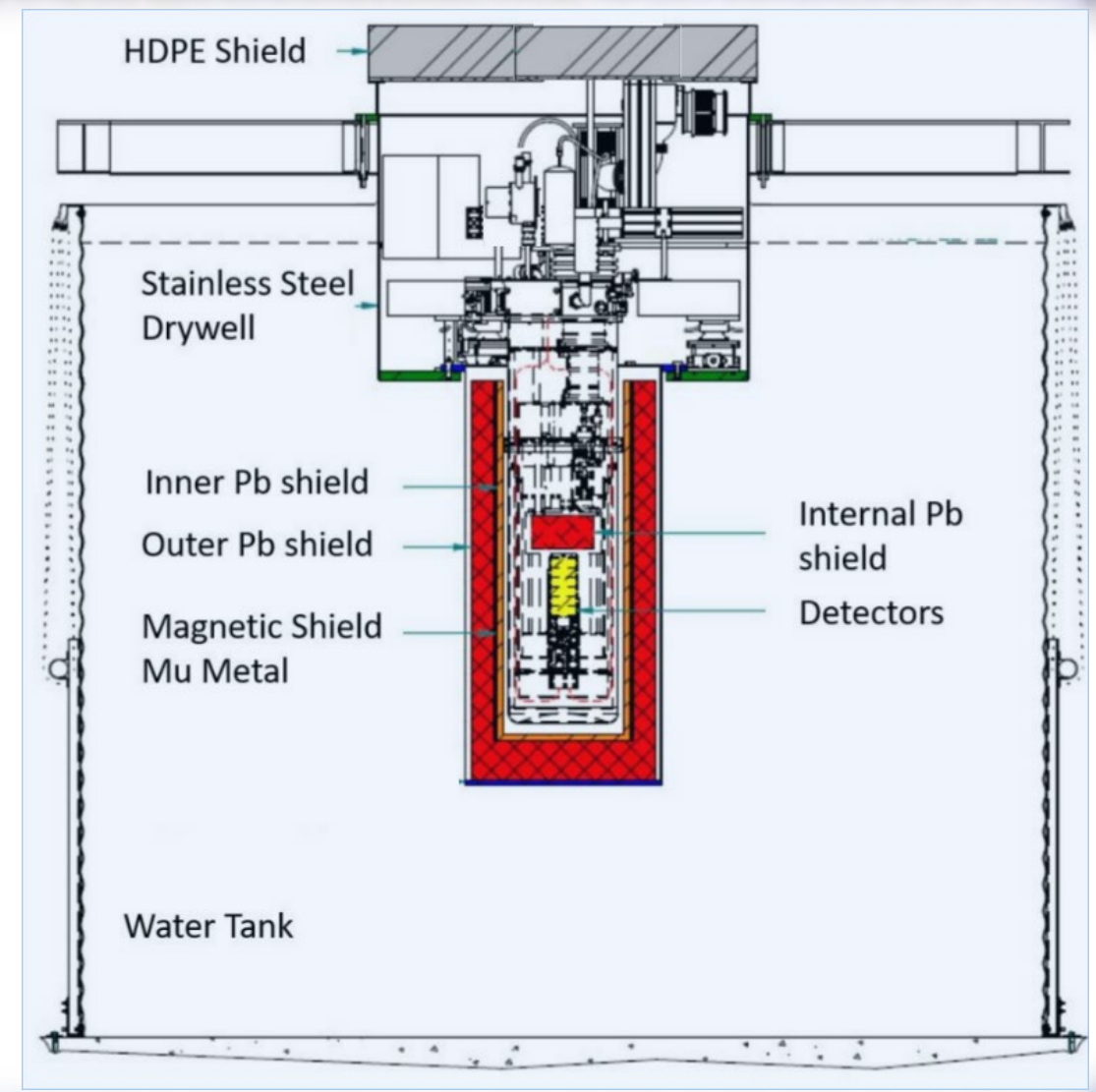
Recoiling nucleus: another surface event

Passive shielding to help reduce backgrounds

e.g. CUTE (Cryogenic Underground Test) facility @SNOLAB:



- 2 km rock overburden
- ~ 10 cm low activity Lead in drywell
- Mu-metal reduces external B-field ~x50
- ~1.5 m water, 20 cm Polyethylene lid
- 15 cm Lead “plug” inside cryostat
- Active low Ra air purge in drywell



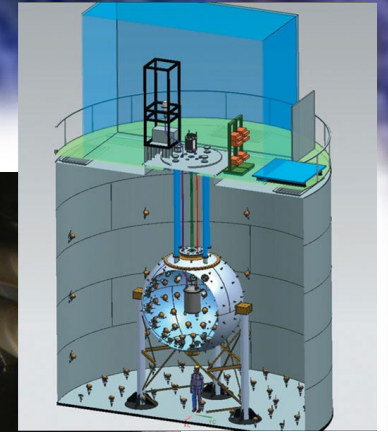
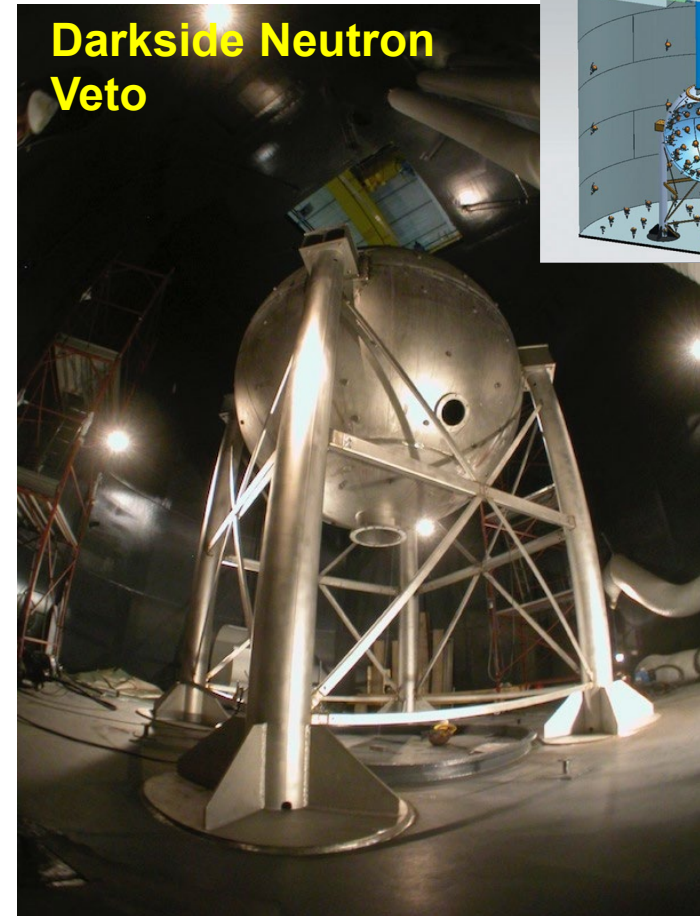
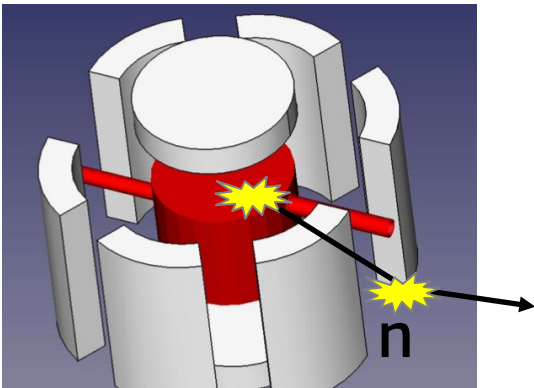
Slide credit: Andrew Kubik

Active shielding to help reject backgrounds

Muon Veto: water Cherenkov or scintillator, tags muons passing through/near experiment

Neutron Veto: liquid scintillator doped with isotope w/ high neutron capture cross-section; tags radiogenic neutrons originating from contaminated material

Proposed SuperCDMS neutron veto



Slide credit: Enectali Figueroa-Feliciano

Calibrations: Getting the Energy Scale Using n or γ Sources

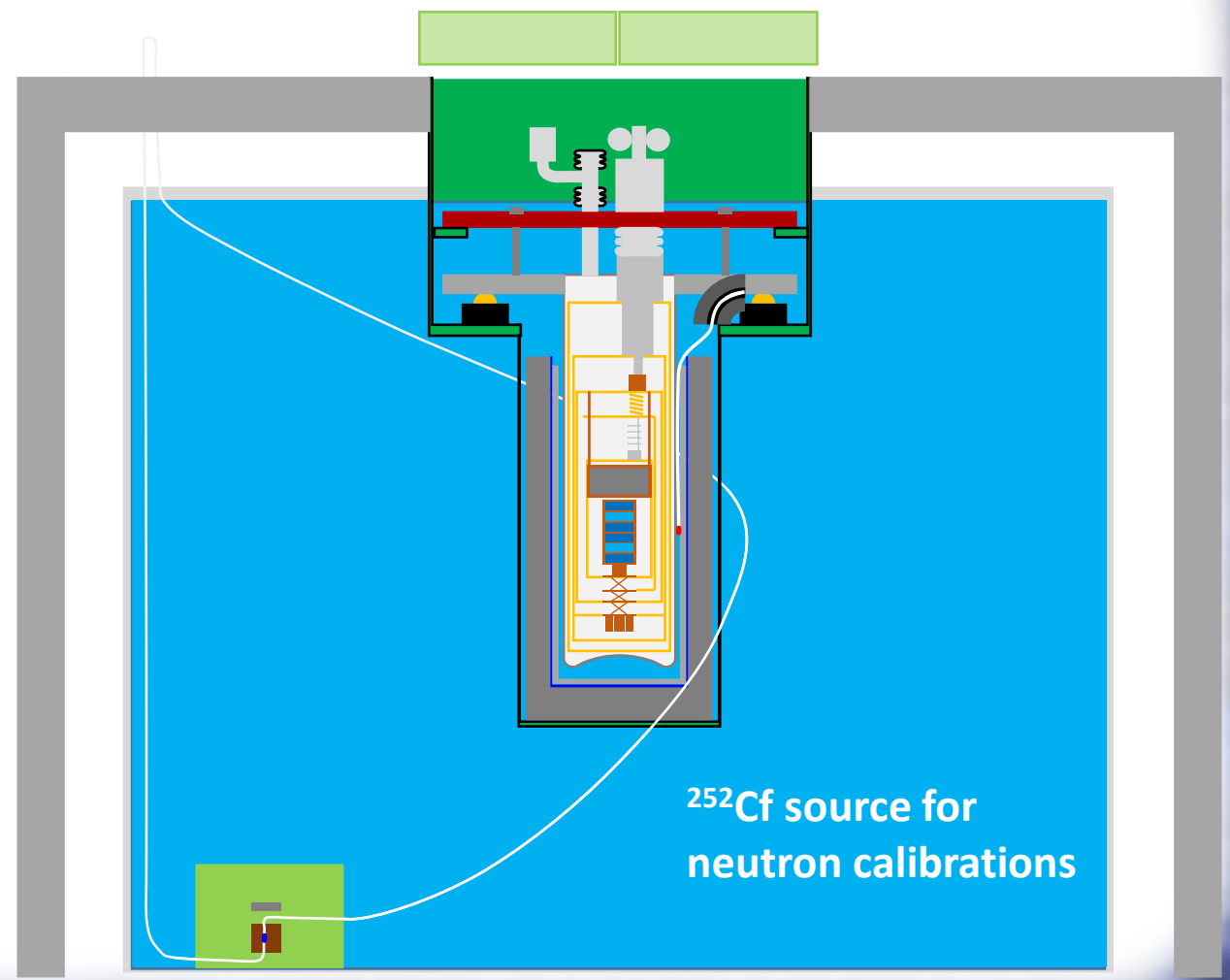
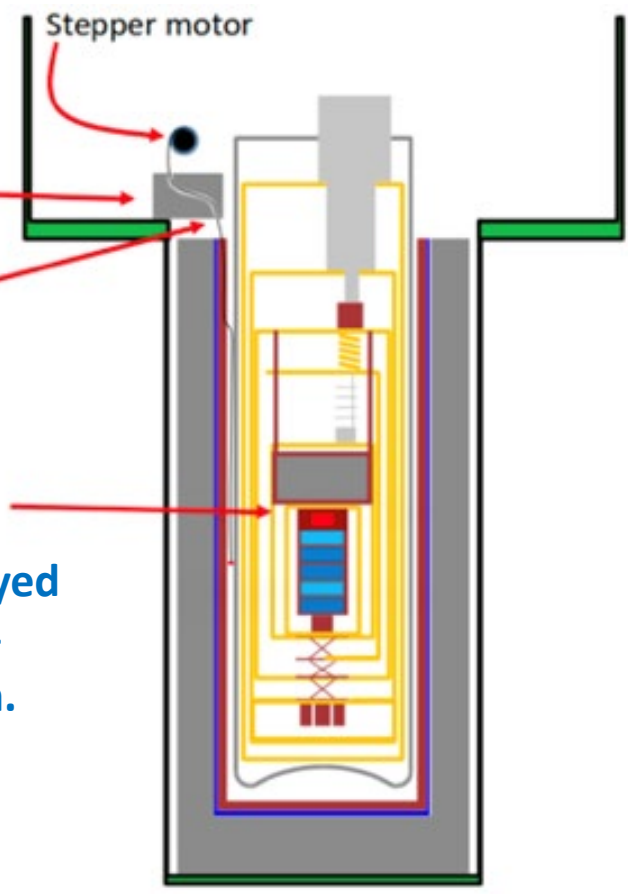
e.g. CUTE:

^{133}Ba gamma source deployable inside shielding

Storage - Pb or HDPE
Source chain

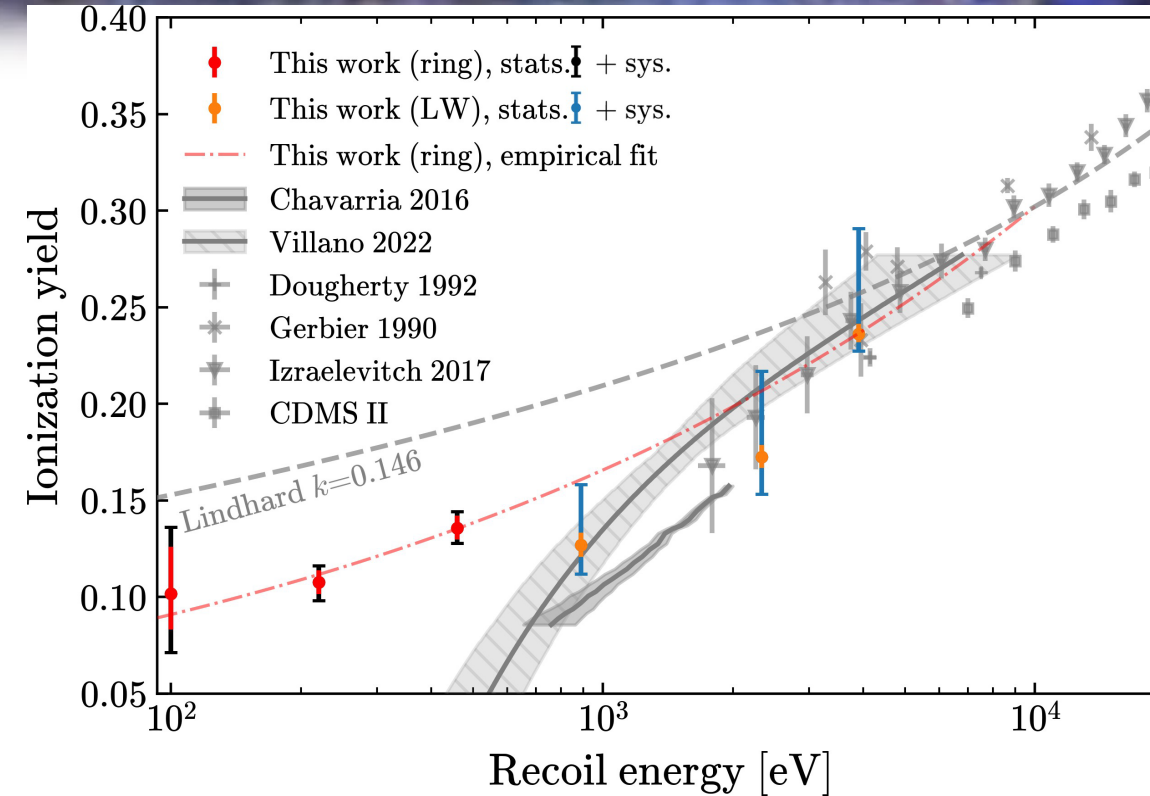
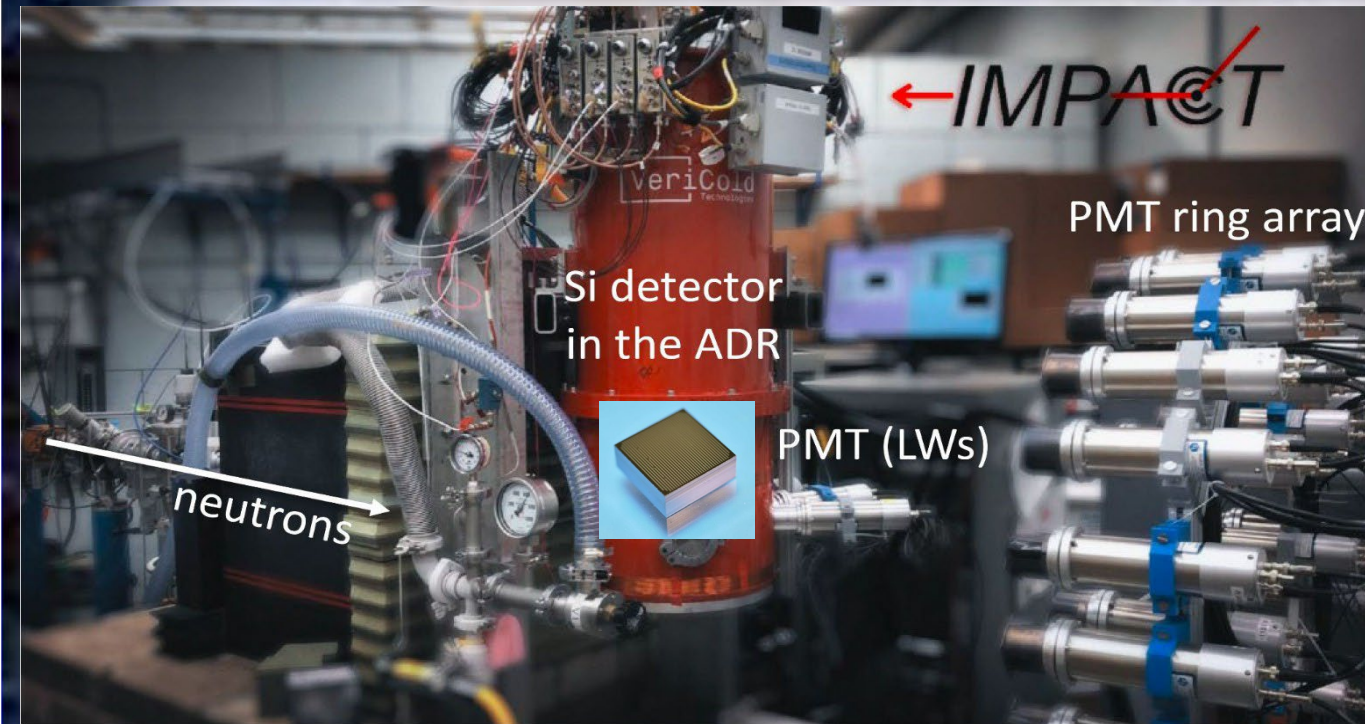
Internal source

^{55}Fe can be deployed internally for low-energy calibration.



^{252}Cf source for neutron calibrations

Dedicated Calibration Campaigns: Ionization Yield for Nuclear Recoils



- Ionization yield (Y) measurement down to 100 eV with Si calorimeter in a neutron beam
 - ▶ Significant deviations from “Lindhard model”
 - ▶ No indication for ionization threshold in Si
- Ge yield measurement in preparation

Total phonon energy and yield

$$\begin{aligned}
 E_t &= E_r + (N_{eh} \cdot e \cdot V_b) \\
 &= E_r \cdot (1 + e \cdot V_b / \varepsilon_{\text{pair}} \cdot Y(E_r))
 \end{aligned}$$

Slide credit: Stefan Zatschler