SuperCDMS and Beyond

Search for low mass dark matter
With cryogenic detectors

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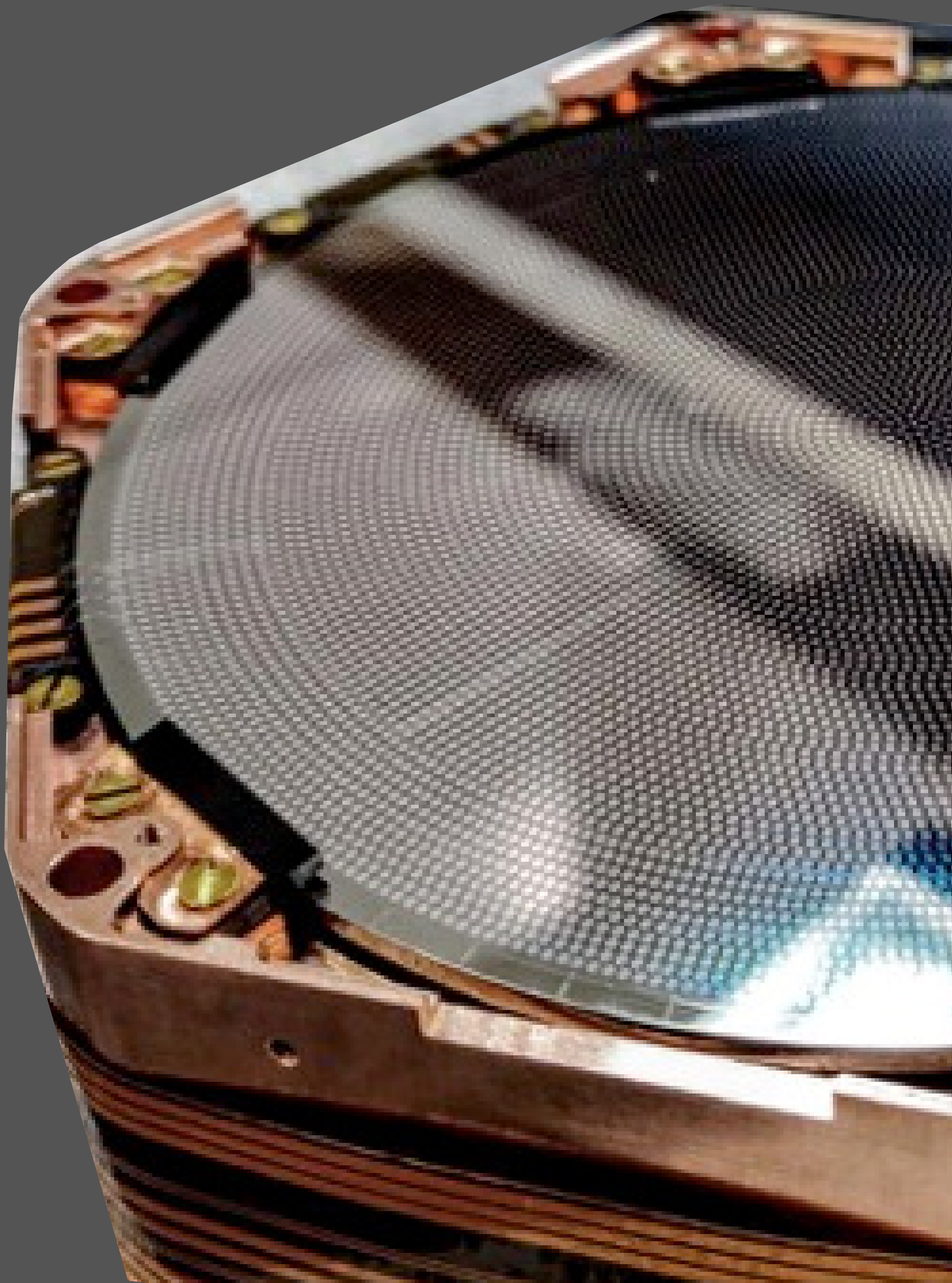
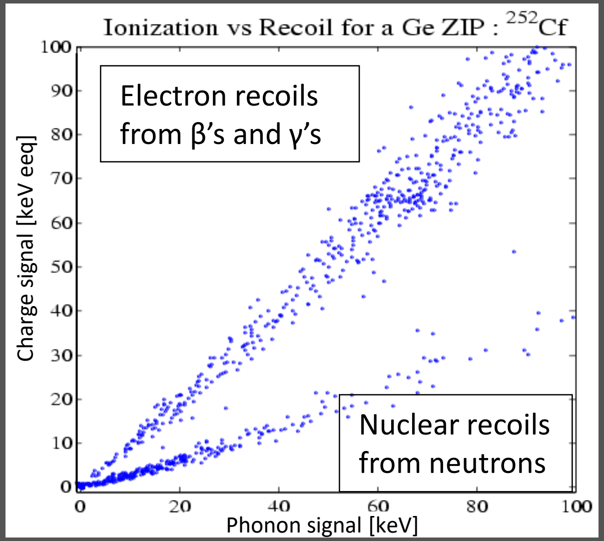


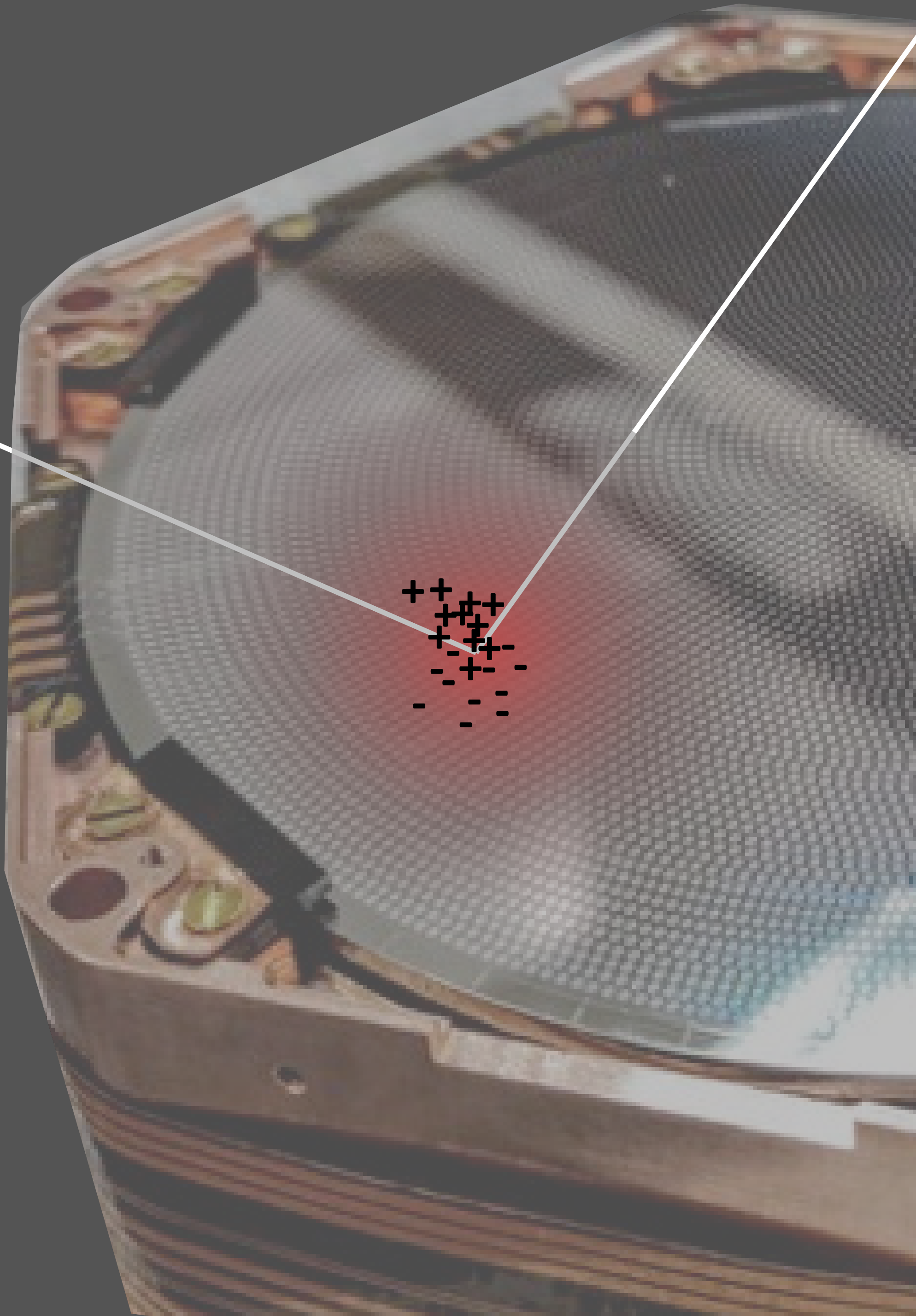
Overview

- SuperCDMS basics
- SuperCDMS SNOLAB and CUTE
- Low mass candidate search at Soudan
- Very low mass electron-interacting candidate search
- Prospects for very low mass nuclear-recoil search
- SuperCDMS SNOLAB goals
- Pushing thresholds with new materials

SuperCDMS Basics

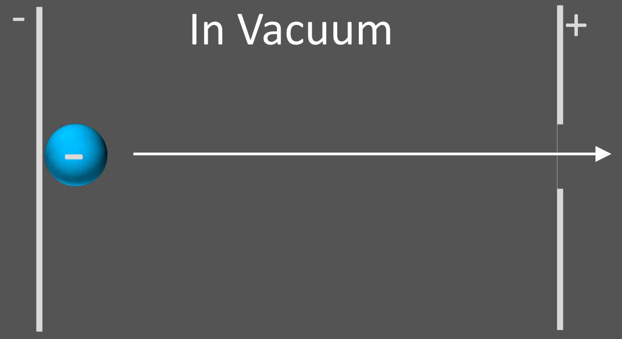
- Particle deposits energy
- Phonons (lattice vibrations) spread
- Electron-hole pairs are produced
- Ratio (phonon : charge) depends on interaction (electrons vs. nuclei)



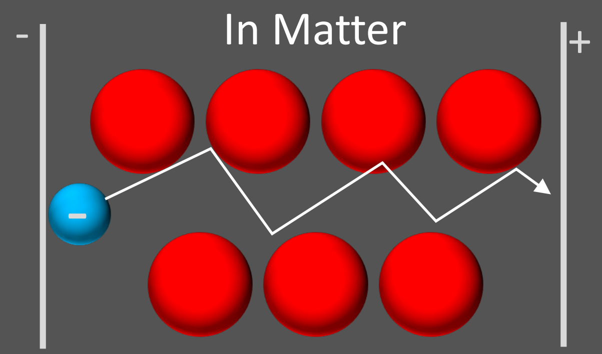


SuperCDMS Basics

Neganov-Trofimov-Luke Effect



Electron gains kinetic energy
(E = q · V → 1 *e*V for 1 V potential)



Deposited energy in crystal lattice:
Neganov-Luke phonons

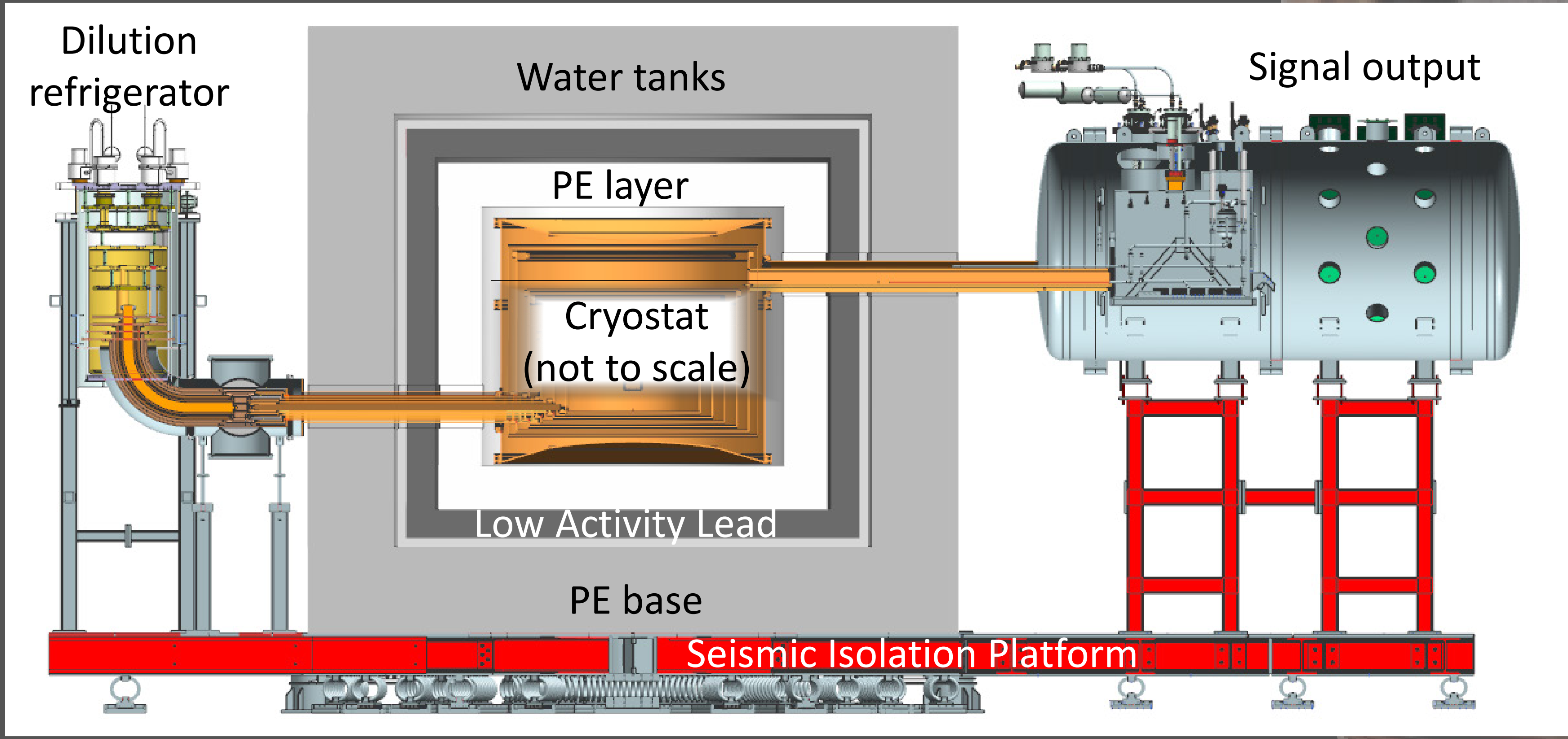
$\propto$ V, # charges

- Mixing charge and phonon signal → reduced discrimination
- High voltage → large final phonon signal, measures charge!!
- ER much more amplified than NR
  → gain in threshold; dilute background from ER

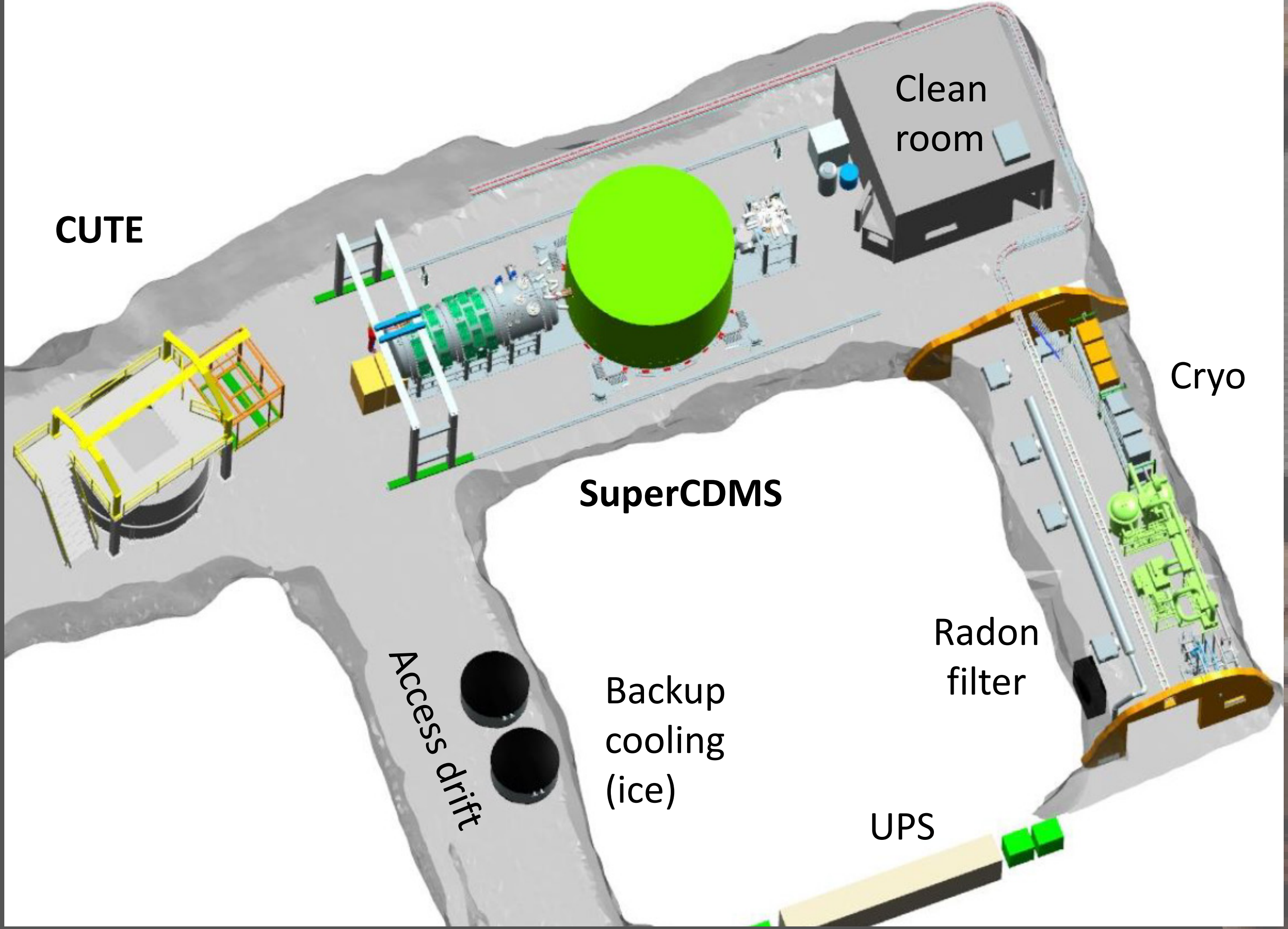
SuperCDMS SNOLAB

- Two detector materials: Ge and Si
- Detector size: ∅ 10 cm; height: 3.3 cm (1.4 kg Ge/0.6 kg Si)
- Two detector concepts:
  - iZIP: Charge/Phonon sensors (interleaved) with good position sensitivity for best background suppression
  - HV: O(100 V) bias voltage for strong NTL effect; optimized phonon sensors for low energy threshold
- Initial payload: 4 stacks (“towers”) of 6 detectors each (2 x iZIP, 2 x HV; overall 6 Si and 18 Ge detectors)
- New low-noise readout electronics
- Multilayer shielding (PE, low-activity Pb, water)
- Under construction; to be completed in 2021
- First science data in 2022

SuperCDMS SNOLAB



SuperCDMS SNOLAB

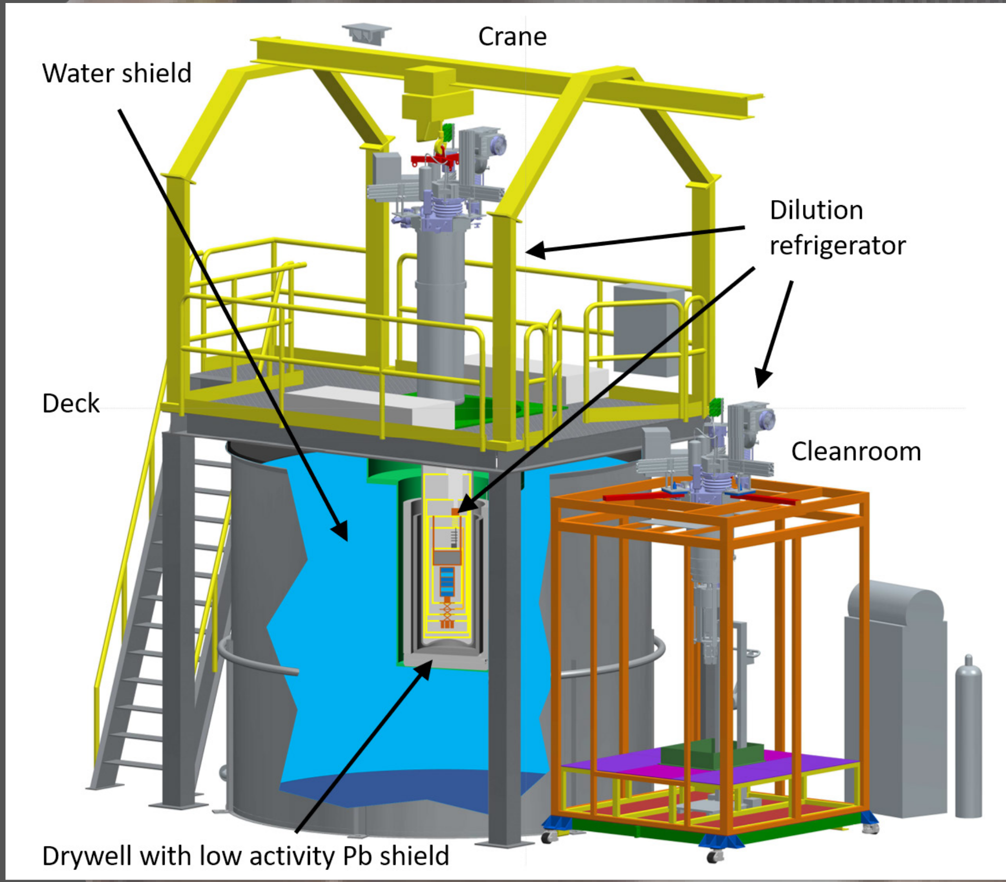


Cryogenic Underground TEst facility

CUTE

- Dilution refrigerator (13 mK) in centre of 3-m water tank with additional ~12 cm of low-activity Pb
- Vibration isolation
- Low-Rn cleanroom for payload change
- Holds up to 6 new SuperCDMS detectors

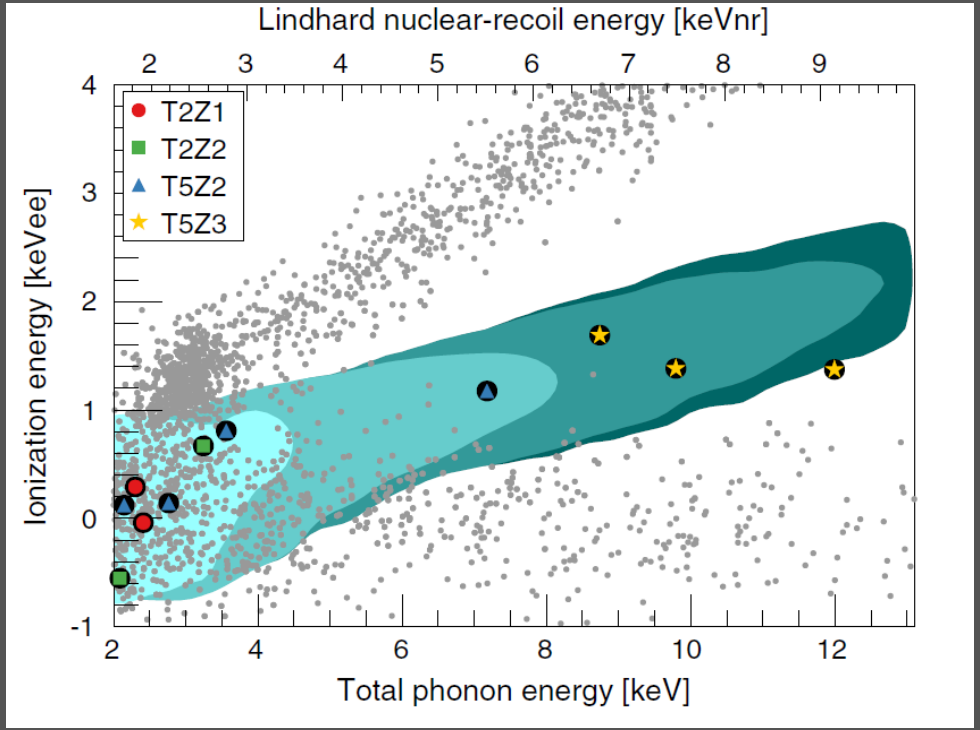
- Test new SuperCDMS detectors
  (~1 week turnaround time; no cosmogenic activation)
- Possibly early DM search
  (facility BG O(10) evts/keV/kg/day above 10 keV)
- FACILITY IS RUNNUING
  presently testing Soudan detectors and prototype detectors (big and small)

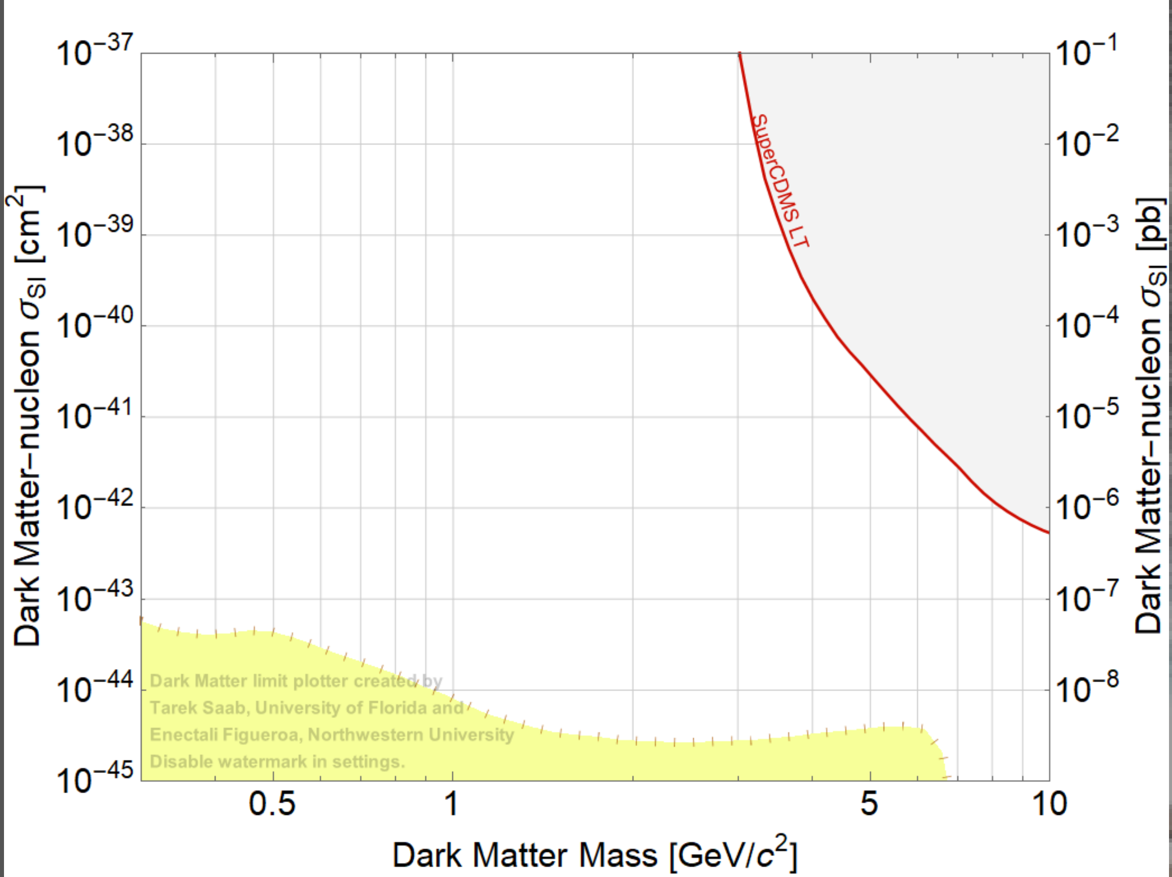


Low Mass Candidate Searches at Soudan

Low Threshold analysis

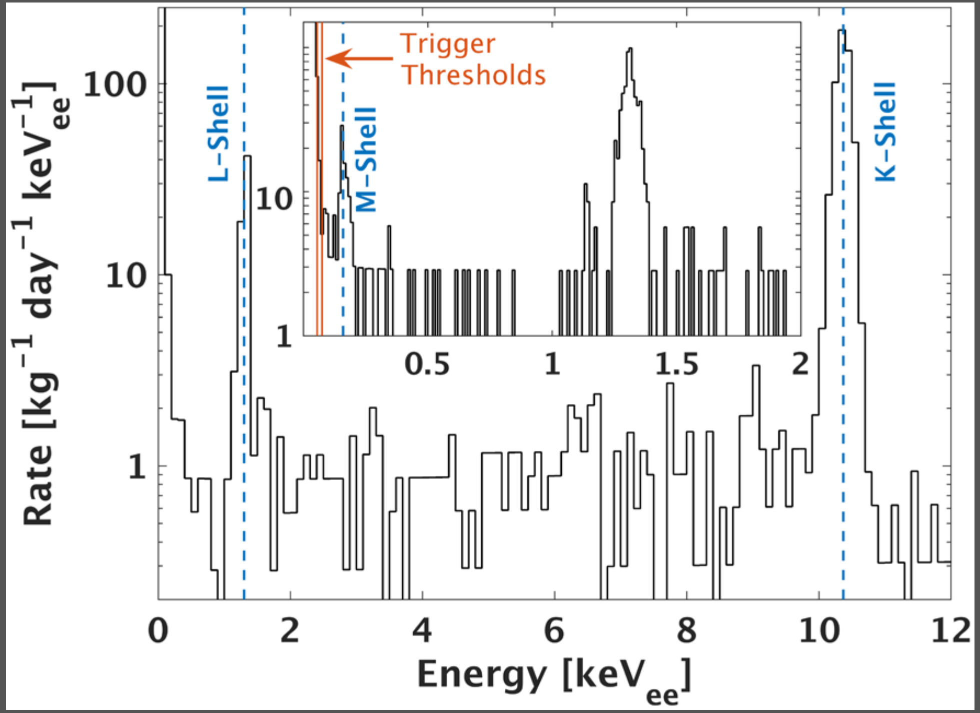
- Select detectors with best low-energy performance
- Push discrimination limit – accept background
- “High”-energy background from detector with broken channel

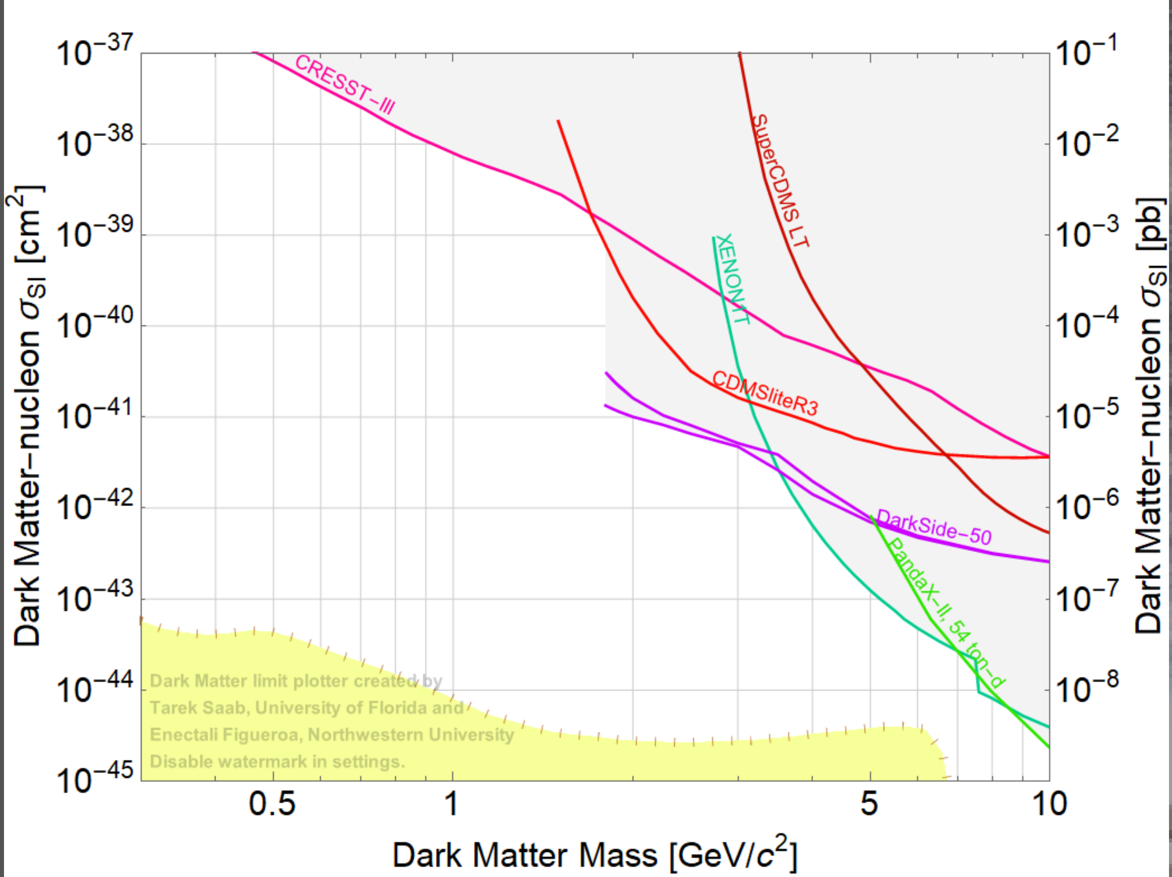




Low Mass Candidate Searches
CDMSlite

- Re-wire single detector for straight electric field
- Apply ~70 V to enhance NTL effect (regular is 4 V)
- Radial fiducial volume cut
- Energy threshold: 56 eV_{ee} (during best period) (correspond to a few hundred eV for NR)



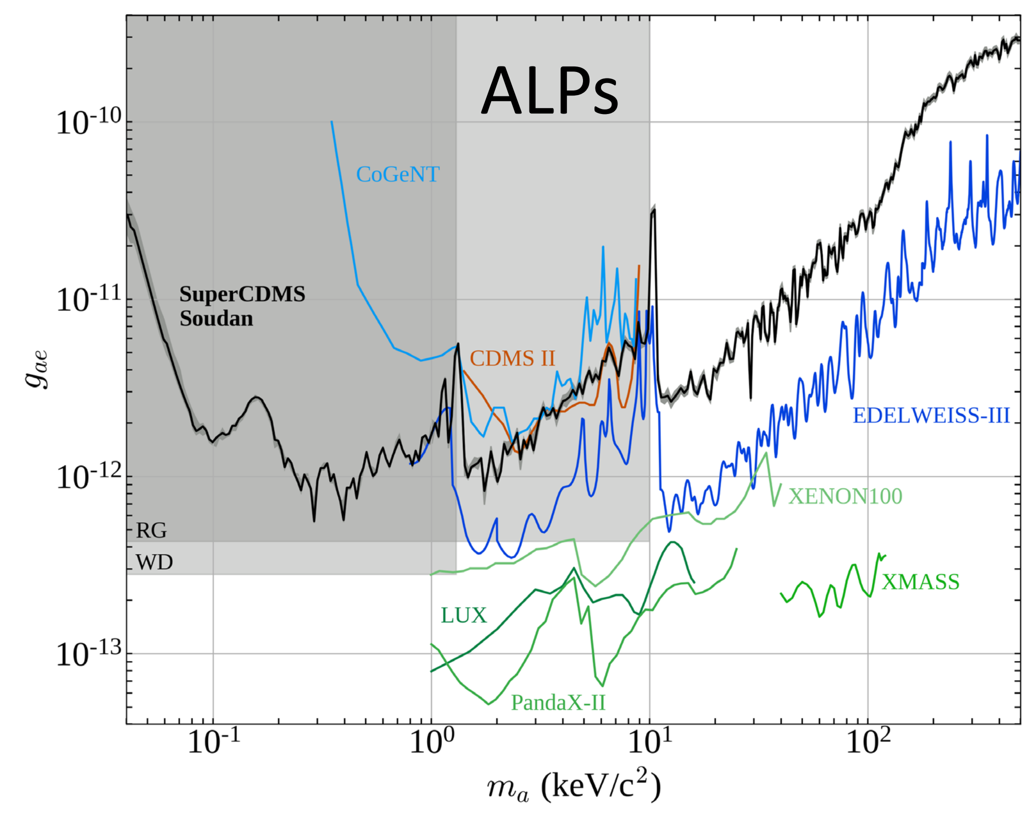


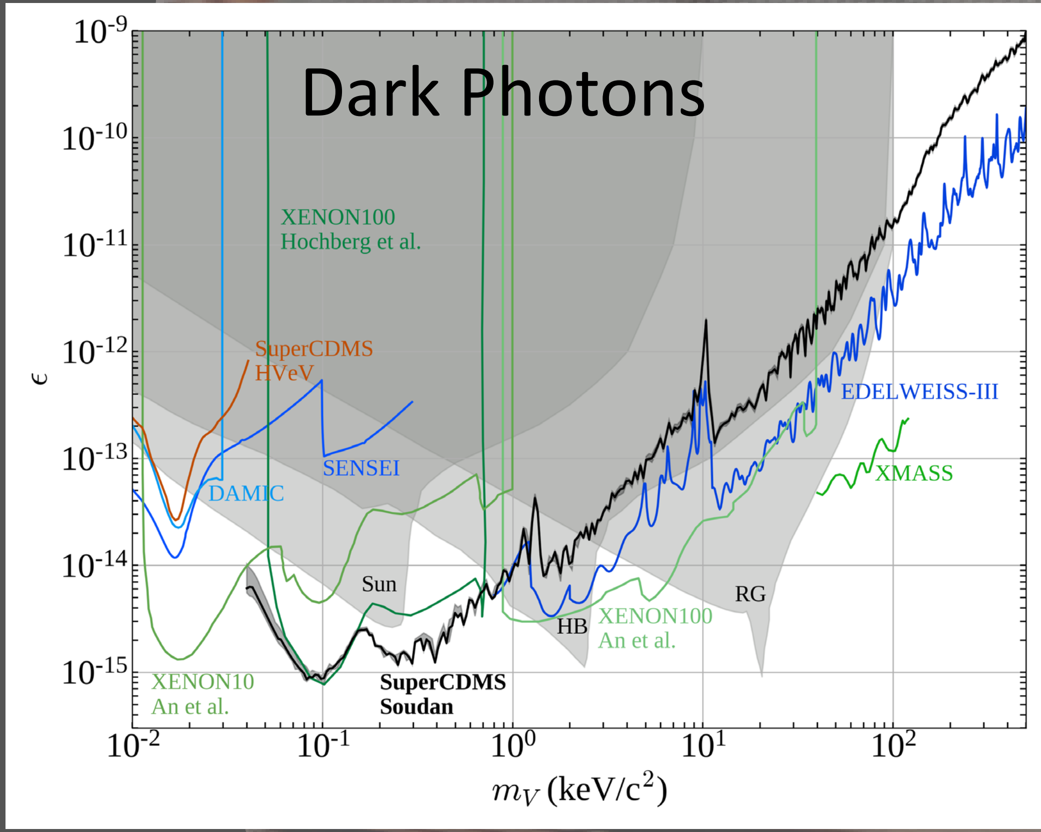
Low Mass Candidate Searches

Dark Absorption

- Dark Photons and Axion-like Particles can be absorbed (analogue to photoelectric effect)
- Galactic DM is non-relativistic: absorption produces peak at $E = m_{DM}c^2$ with width given by detector resolution
- Reanalyze SuperCDMS Soudan data (both CDMSlite and iZIP): extend energy range (CDMSlite); determine efficiency (iZIPs); reassess energy resolution; new method of combining information from different detectors
- Cover energy range from 40 eV to 500 keV;
  world leading below about 1 keV (ALPs) / 200 eV (DP)

Low Mass Candidate Searches
Dark Absorption

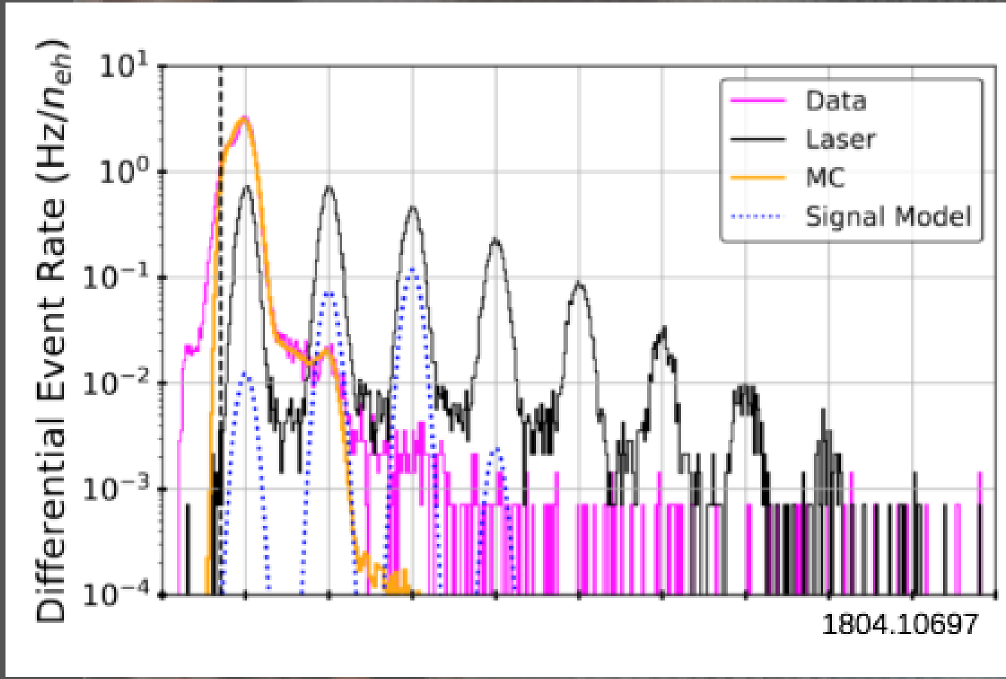


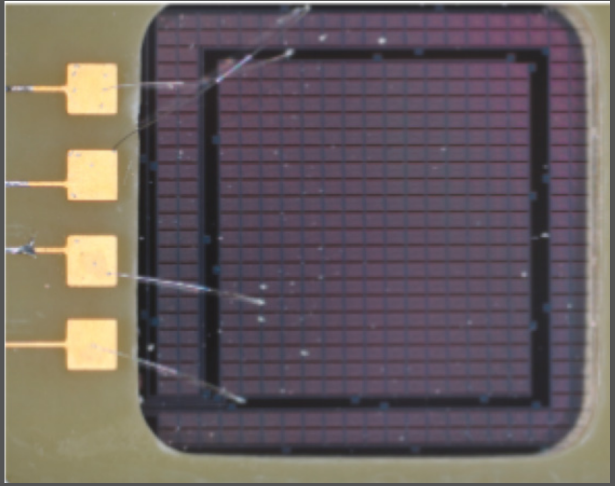


Very Low Mass

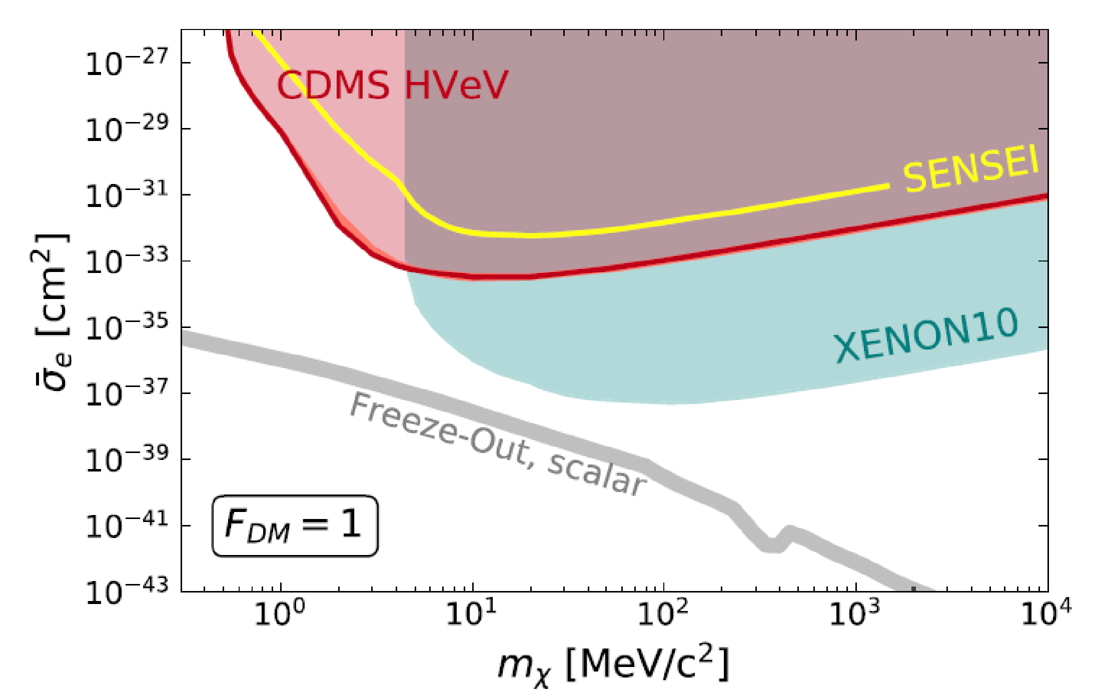
Electron-Interacting Candidates

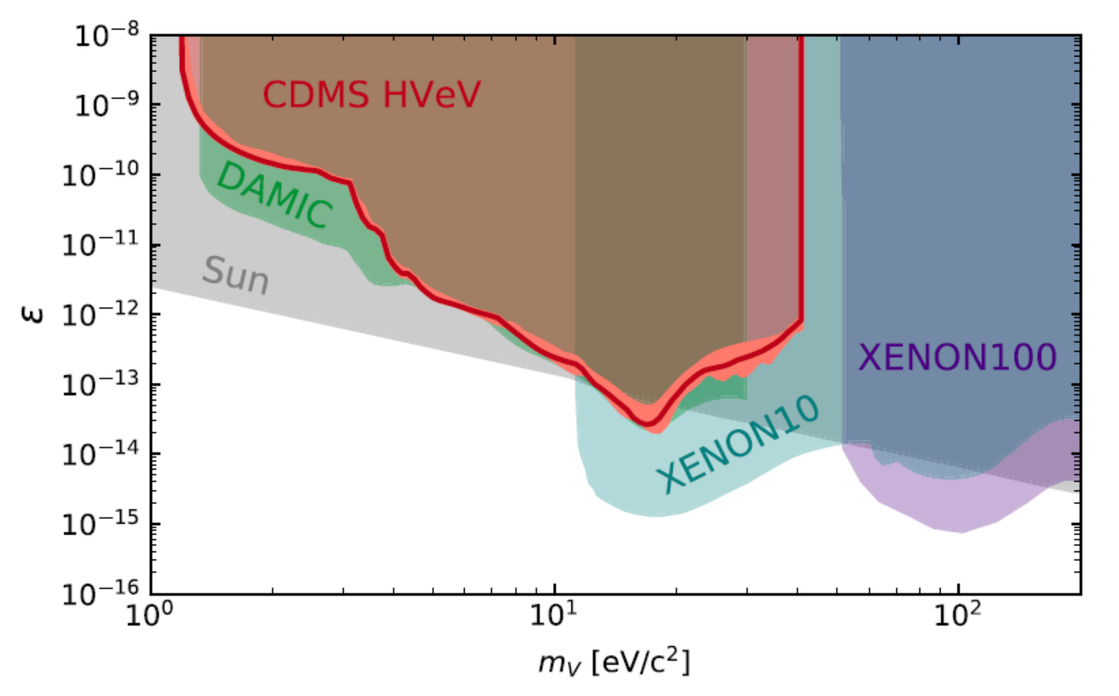
- Very low mass Si detector: 10 x 10 x 4 mm (~1 g)
- Developed for measuring NR ionization yield at low energy
- Only phonon measurement
- Intrinsic energy resolution O(10 eV) (newer version: 2-3 eV)
- High bias voltage (~100 V)
- Effective energy resolution: 0.07 eh pairs (0.1 eV)
- Calibration using optical photons (laser)





Very Low Mass
Electron-Interacting Candidates

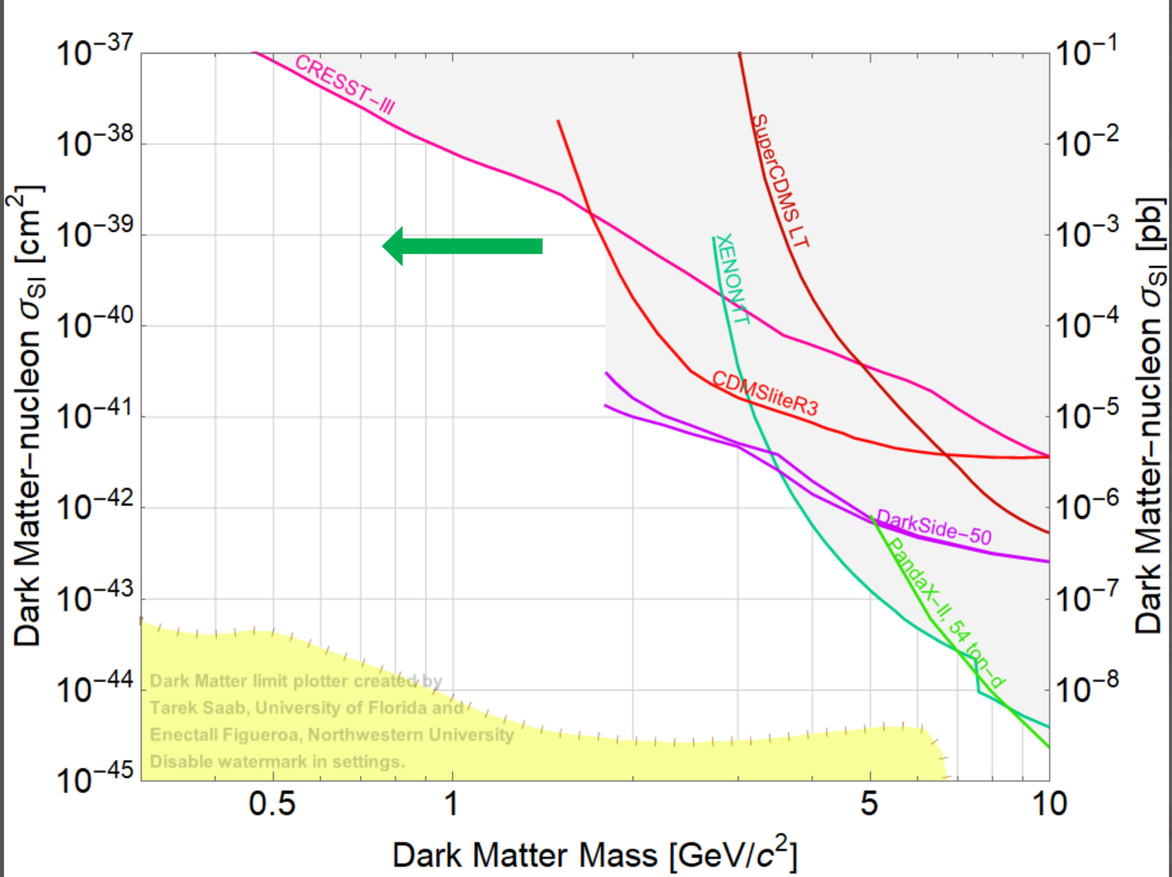




Prospects for Very Low Mass

Nuclear Recoil Searches

- Low mass Si detector: ∅ 7.5 cm, 1 mm thick, 11 g
- Developed as light detector for cryogenic scintillating veto (concept detector)
- Only phonon measurement
- Intrinsic energy resolution O(3 eV)
- NO bias voltage
- Calibration with low-energy radioactive source (keV)
- Sensitivity to very low energy nuclear recoils
- Data from surface facility under analysis
- Plans to repeat test at CUTE (potential for interesting limit)

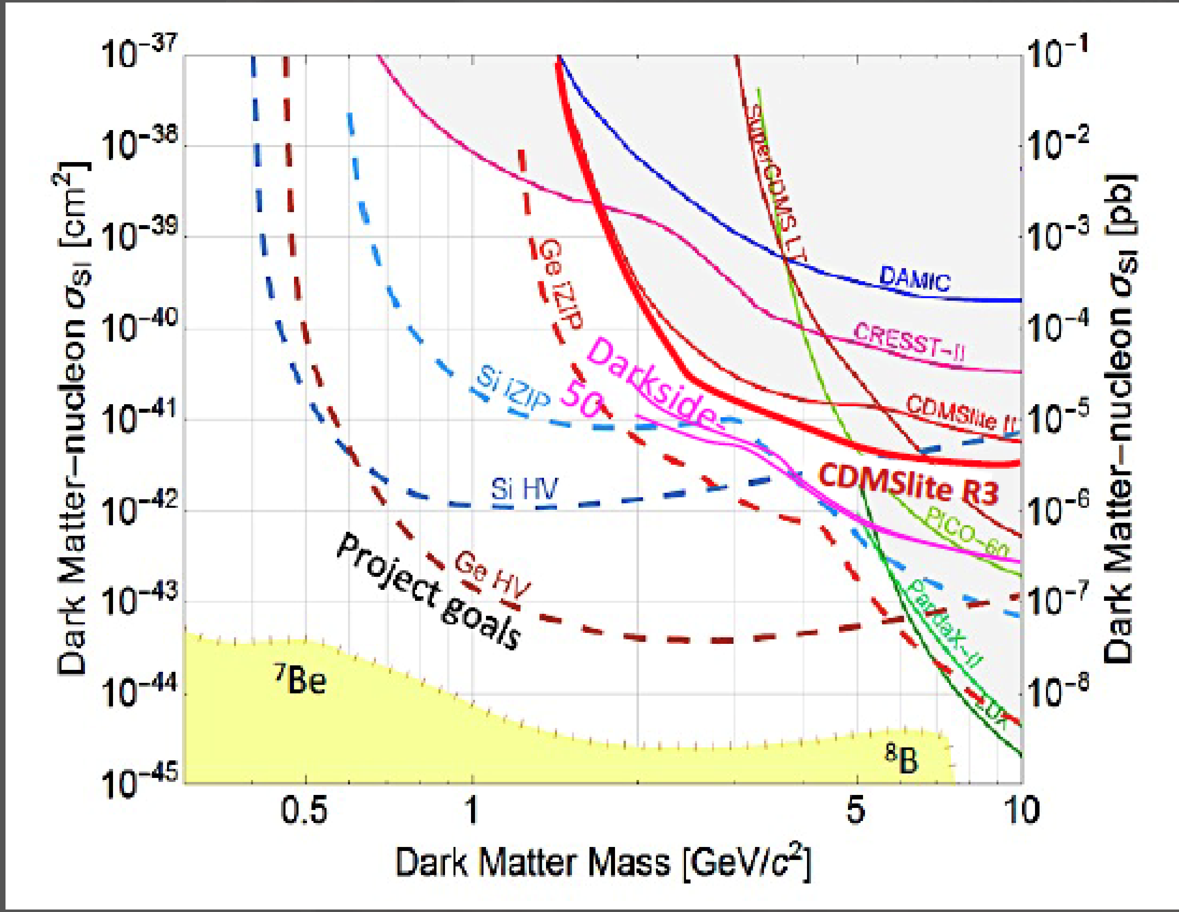


SuperCDMS SNOLAB Goals

Nuclear Recoil Searches

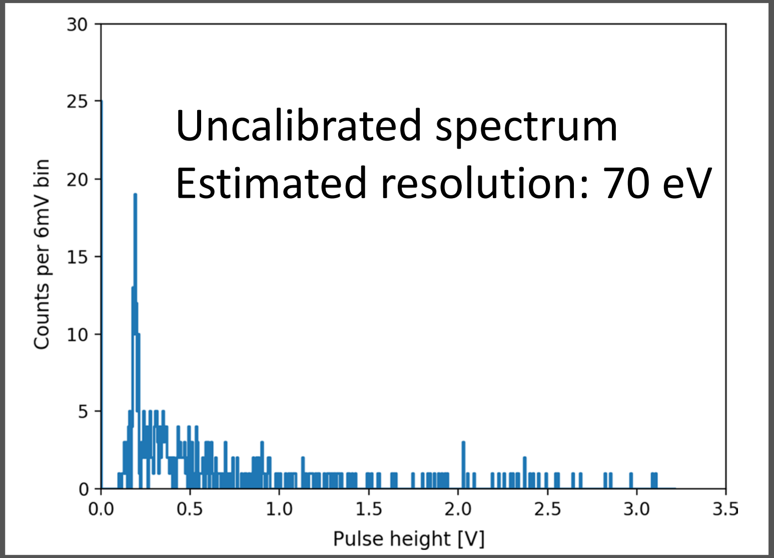
- Projections for 4 years of running
- Background limited (no modelling/subtraction)
- Further improvements expected with background models and Profile Likelihood analysis

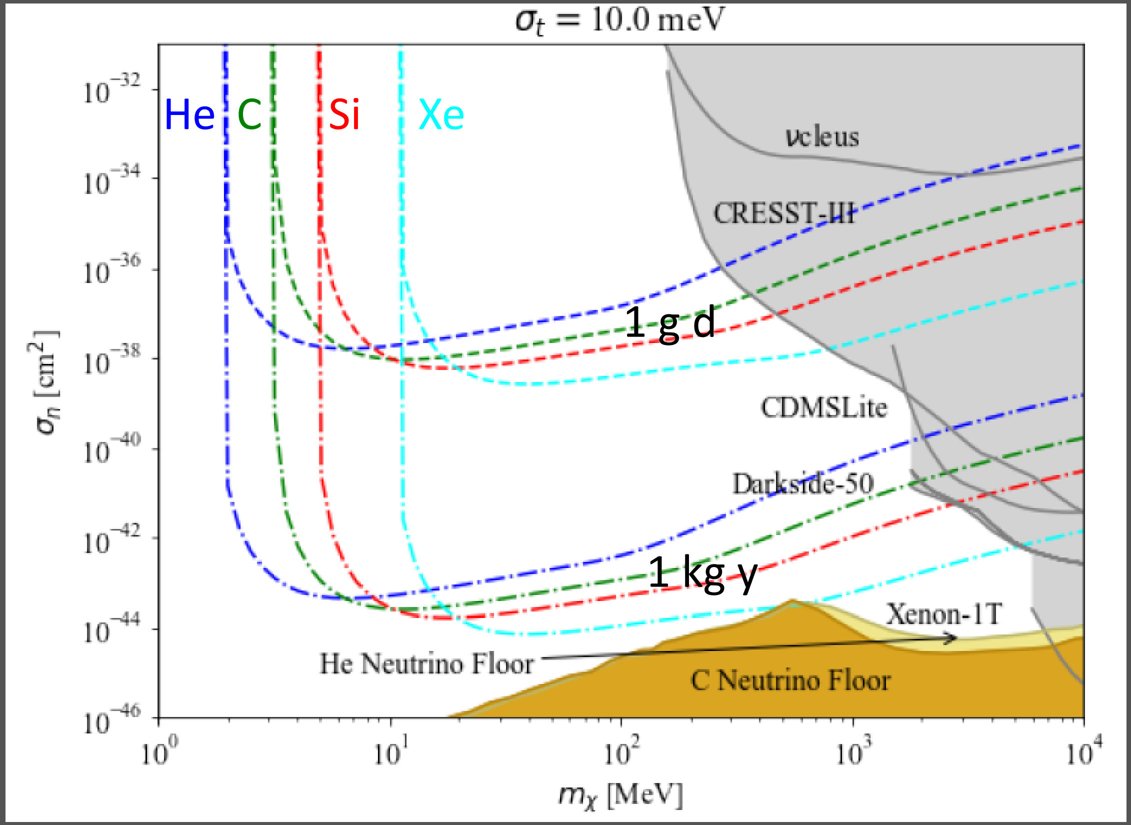
- Will also address alternative searches:
  - Electron recoils
  - Dark absorption
  - Lightly Ionizing Particles
  - …



Pushing Thresholds with New Materials
Diamond

- Low Z matched better to low-mass candidates (NR)
- Excellent phonon properties for low threshold
- Detector naturally small (few mm)
- Sensitivity study by N. Kurinsky et al. (arxiv: 1901.07569)
- First real attempt: L. Canonica et al. (J Low Temp Phys; Feb 2020)

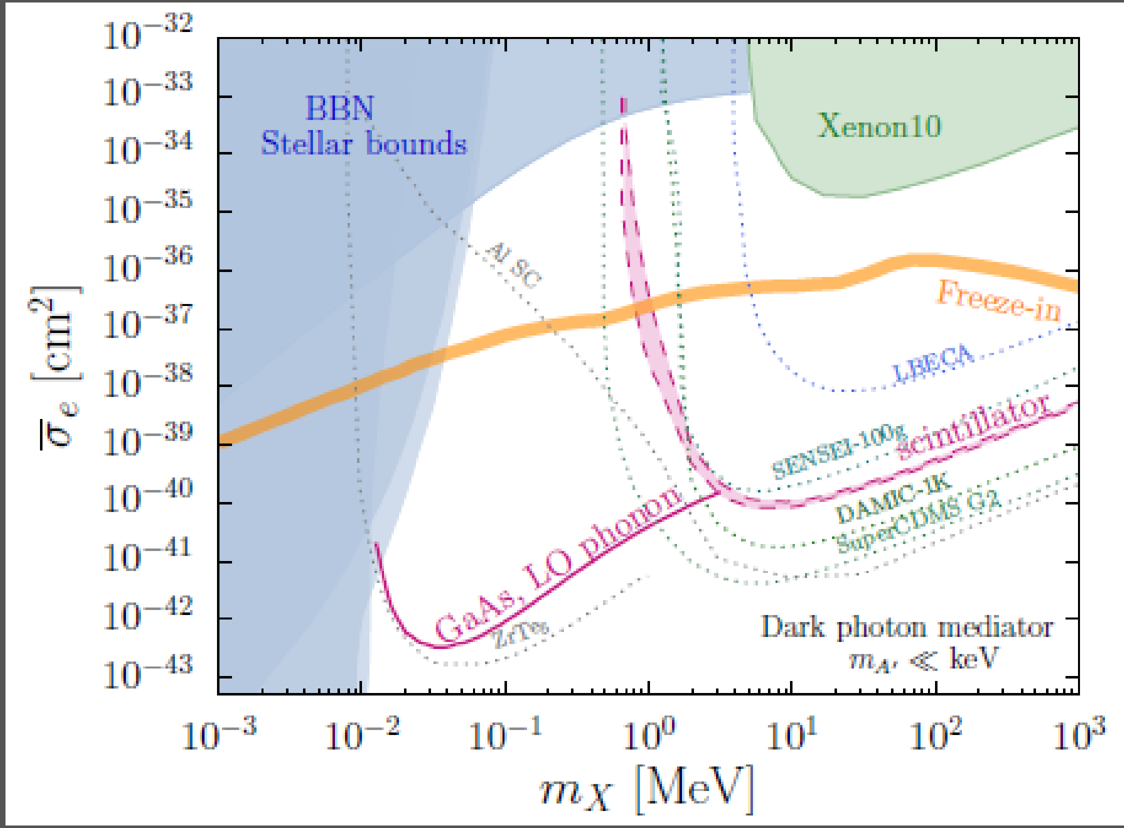




Pushing Thresholds with New Materials

Polar Crystals (e.g. GaAs)

- Optical phonons in polar crystals couple to EM waves
- Energy/momentum of optical phonons well matched for DM candidates in MeV range and below
- Dark Photons in this range could produce single optical phonons
- Conceivable to reach energy threshold for single phonon detection
- S. Knapen et al. (incl. M. Pyle) (arxiv 1712.06598)



Conclusion

- SuperCDMS is preparing for the next round
- CUTE is up and running – chance for 'early' DM searches with small devices and single SuperCDMS detector towers
- Cryogenic detectors hold great promise for testing new parameter space in the low mass range (few GeV down to eV)