Future Ideas for

SuperCDMS

at SNOLAB

Wolfgang Rau
Queen's University

for the
SuperCDMS Collaboration

SuperCDMS Collaboration

California Institute of Technology

CNRS/LPN Durham University

Fermi National Accelerator Laboratory

NISER NIST Northwestern University

PNNL Queen's University

Santa Clara University SLAC/KIPA

South Dakota School of Mines & Technology

SNOLAB

Southern Methodist University Stanford University

Texas A&M University of British Columbia/TRIUMF

University of California, Berkeley

University of Colorado Denver University of Evansville

University of Florida University of Minnesota

University of South Dakota University of Toronto

SuperCDMS Technology

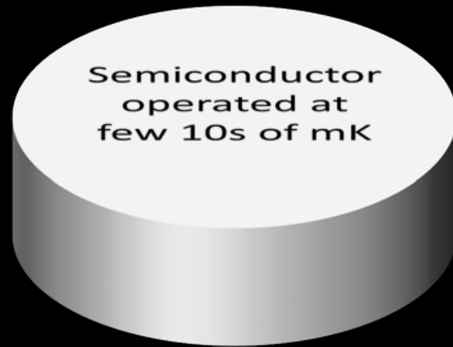
The SuperCDMS SNOLAB Project

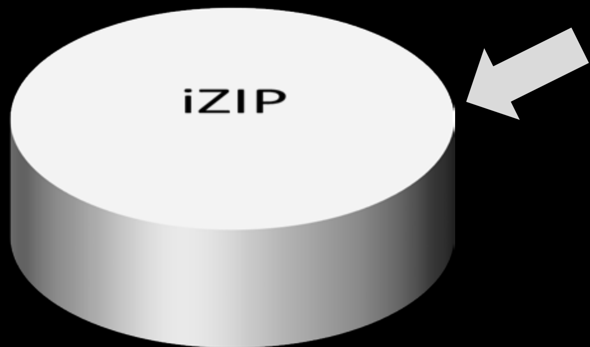
Long-term goals

Potential detector developments

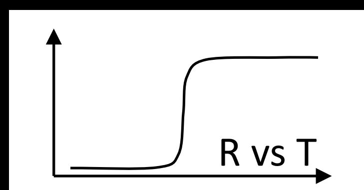
Other ideas

Detectors

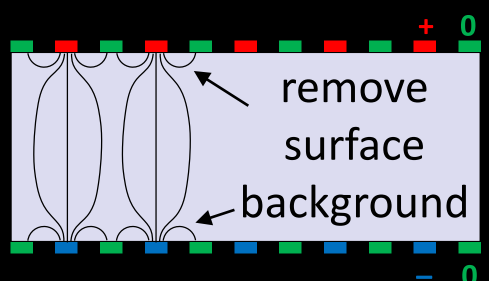




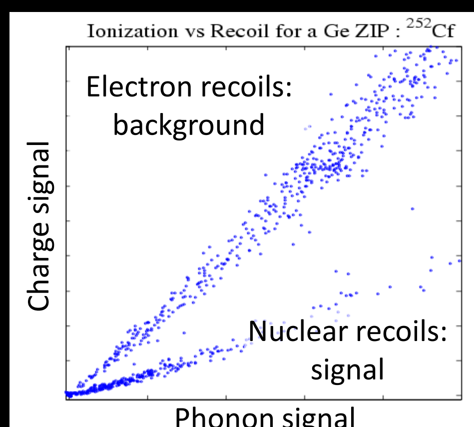
Phonon Readout:
Tungsten TES



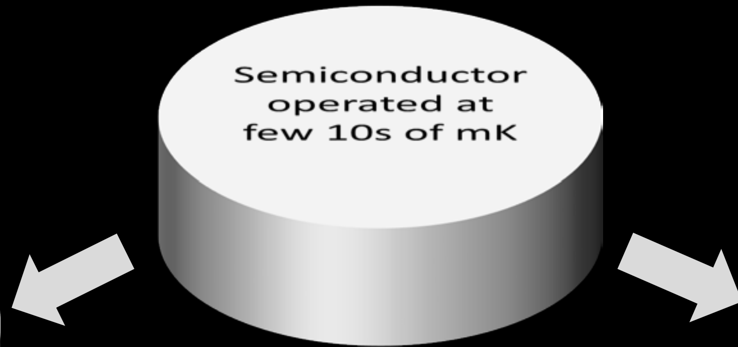
Add: charge readout (few V)
Background discrimination
Threshold < 10 keV

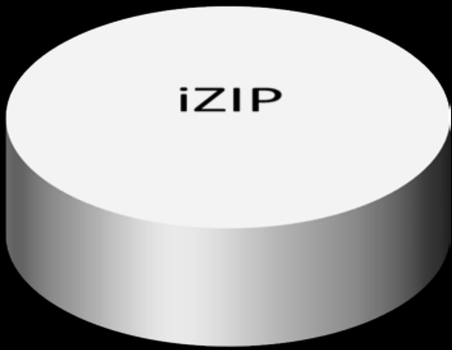


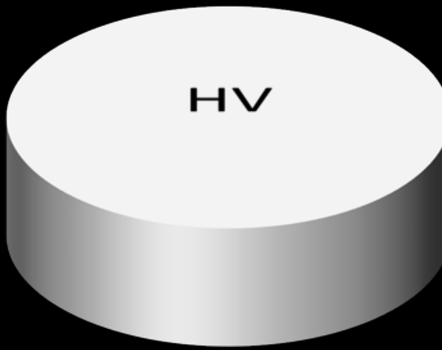
< 1 background event for whole exposure



Detectors







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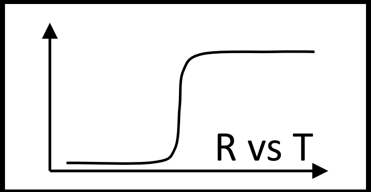

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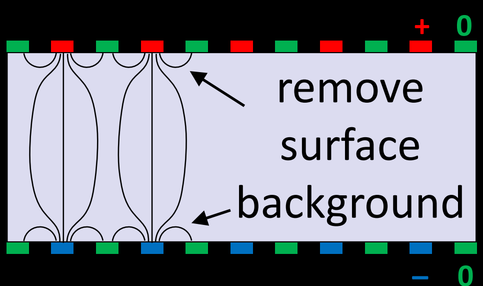

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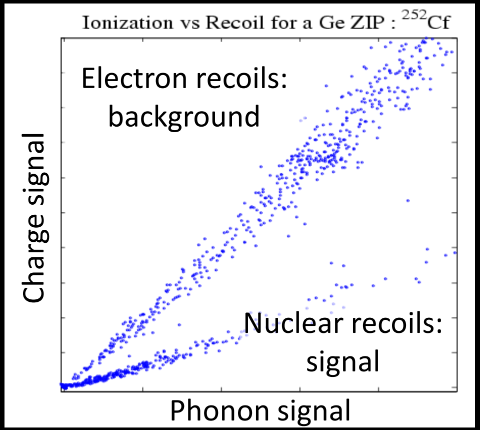
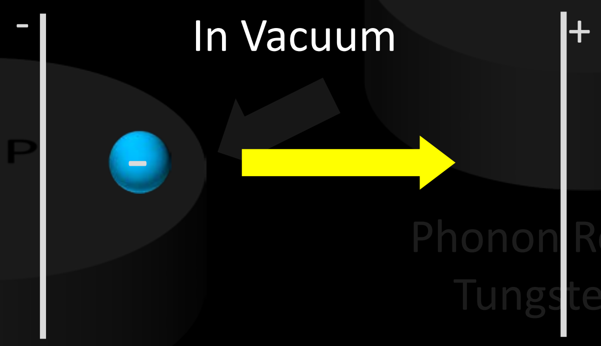
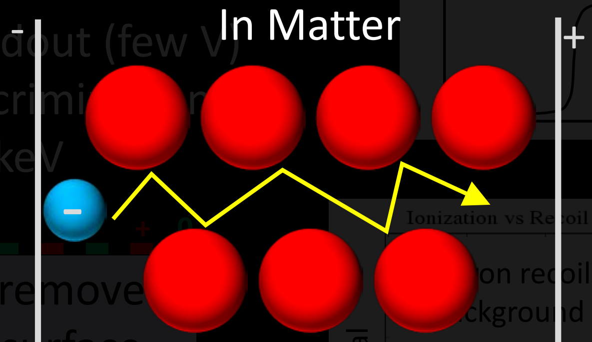


Neganov-Luke Effect



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

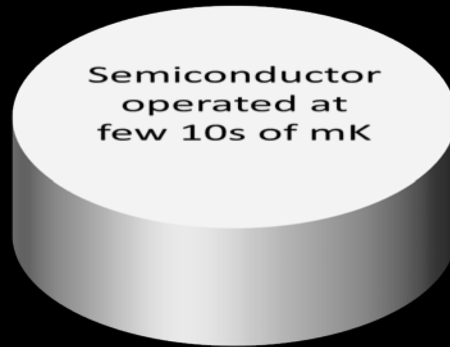


Deposited energy in crystal lattice:
Neganov-Luke phonons

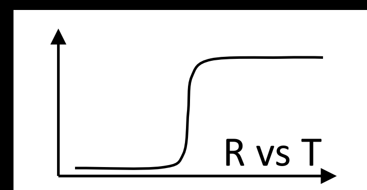
$\propto$ V, # charges

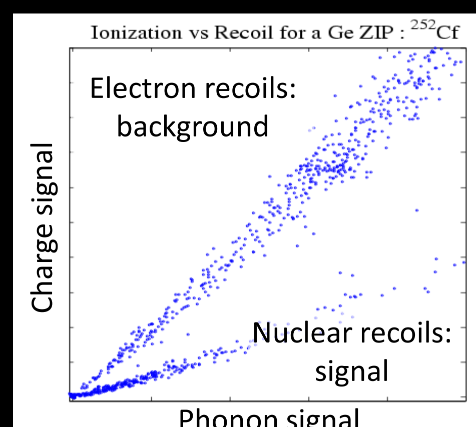
- Luke phonons mix charge and phonon signal → reduced discrimination
- Apply high voltage → large final phonon signal, measures charge!!
- ER much more amplified than NR
  → gain in threshold; dilute background from ER

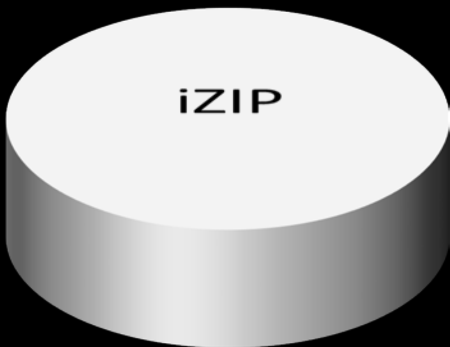
Detectors



Phonon Readout:
Tungsten TES







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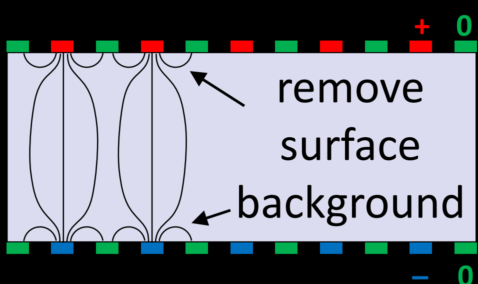
Background discrimination
Threshold < 10 keV



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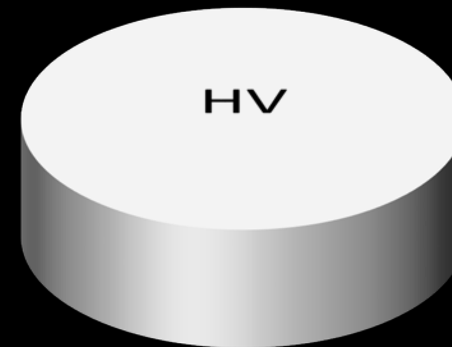
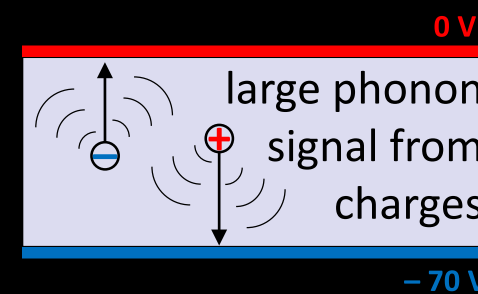
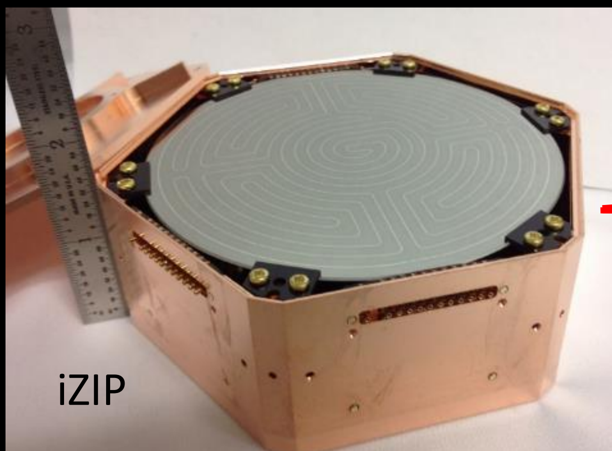


Add: high voltage (~70 V)
Phonons from drifting charges
Threshold < 0.1 keV (phonon)

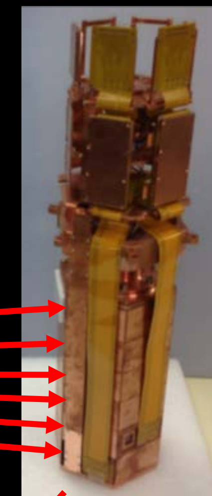


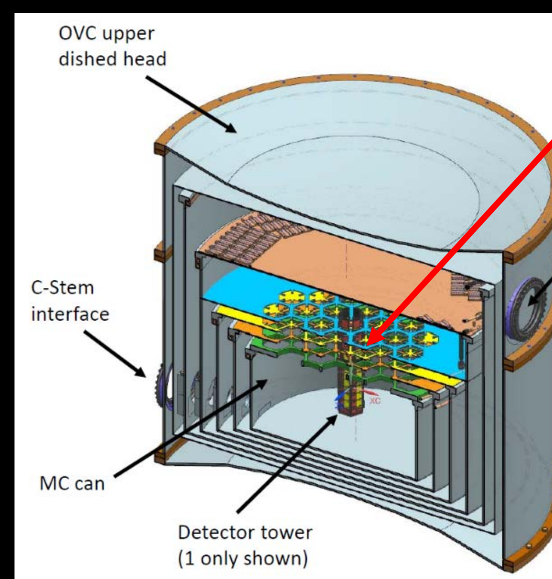
effective threshold:
few hundred eV (NR)

Implementation (SNOLAB setup)



6 detectors
→ 1 tower



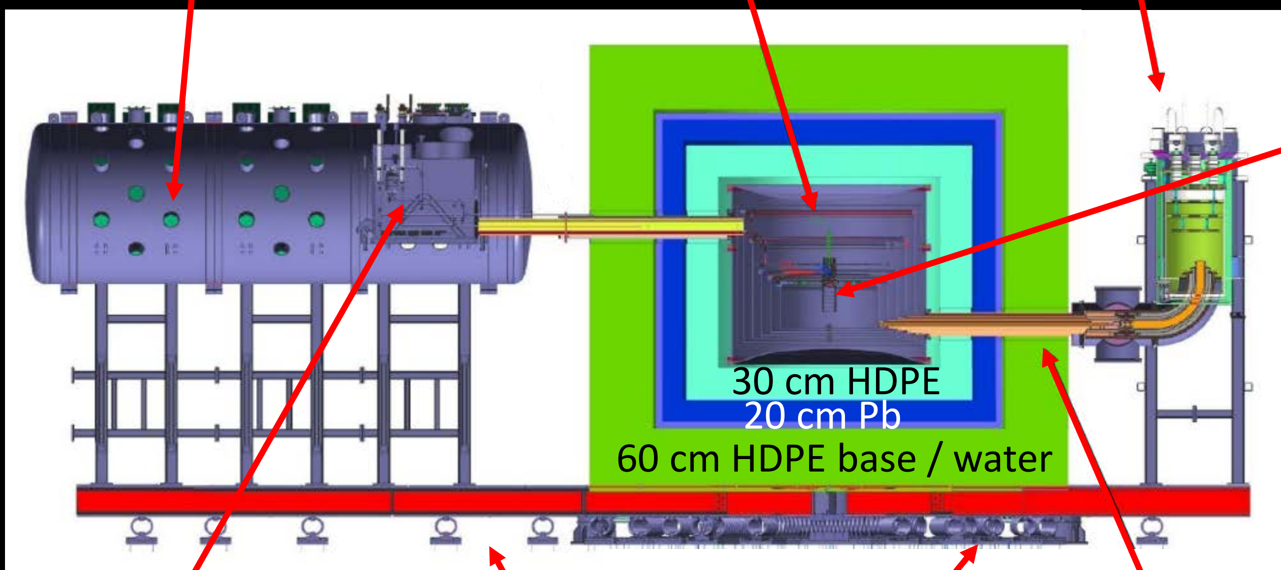


Implementation (SNOLAB setup)

Signal vacuum feedthroughs

Detector volume
(space for up to 31 “towers”)

Fridge to provide
<15 mK at the detector



6 detectors
→ 1 tower

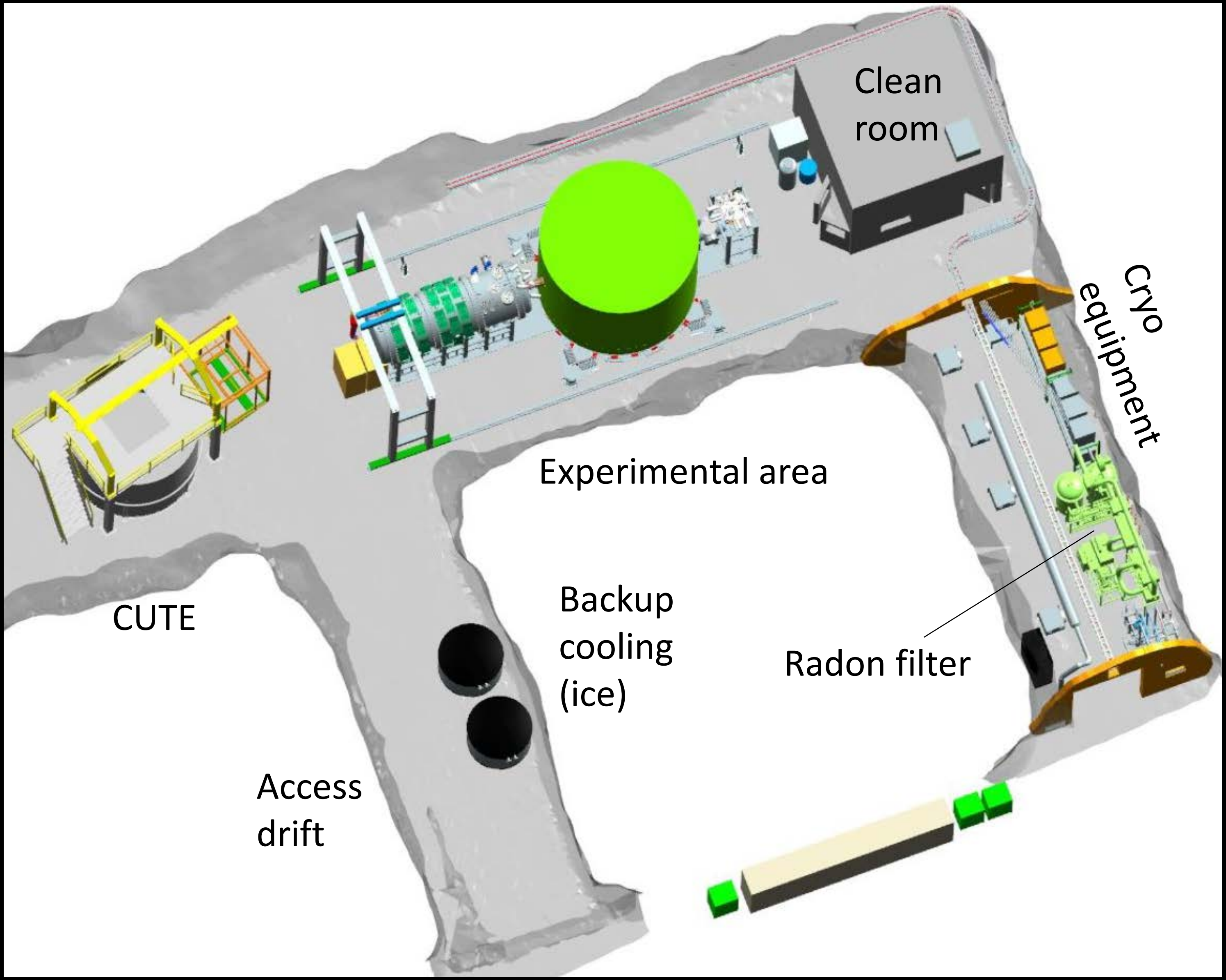
Additional cooling
(50 K/4 K)

Mounted on spring-loaded
platform (seismic isolation)

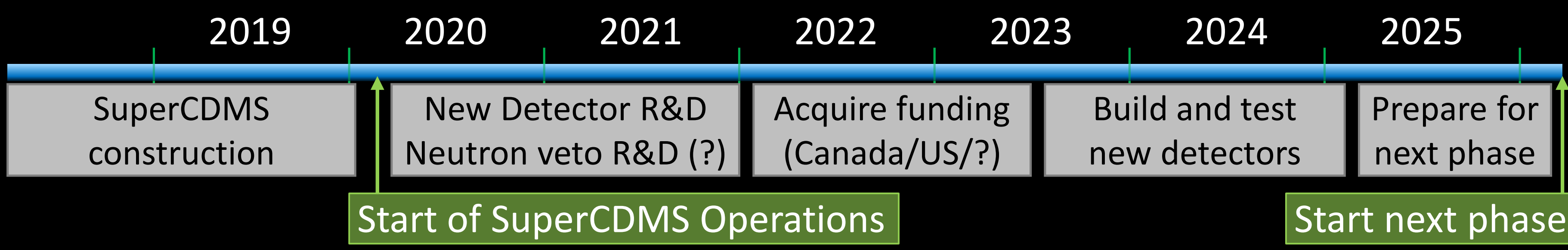
Cold finger

Initial Payload:
- 1 Ge iZIP tower (6 Ge)
- 1 Ge/Si iZIP tower
  (4 Ge/2 Si)
- 2 HV towers
  (4 Ge/2 Si each)

SNOLAB

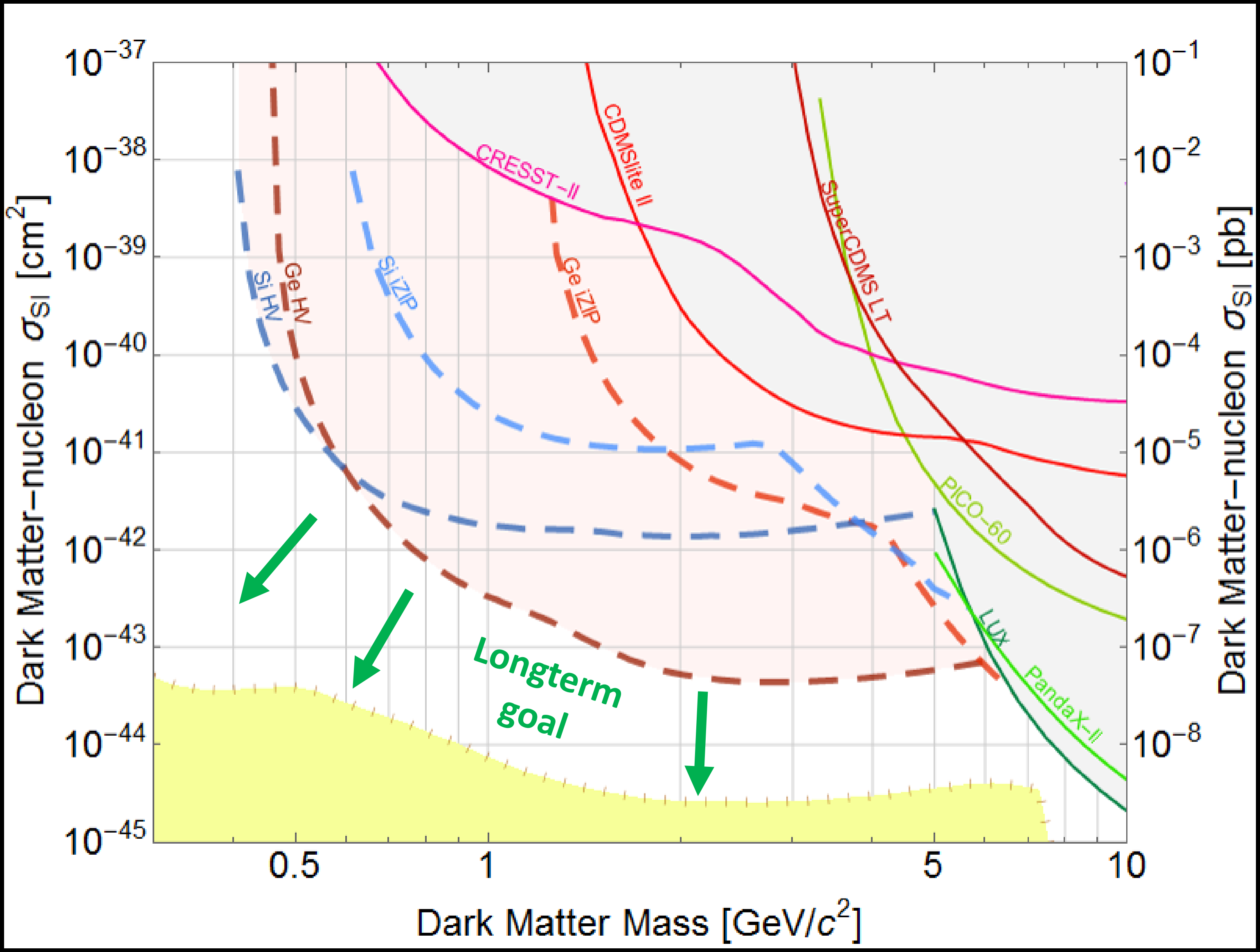

Clean room
Cryo equipment
Experimental area
CUTE
Backup cooling (ice)
Radon filter
Access drift

Tentative Schedule



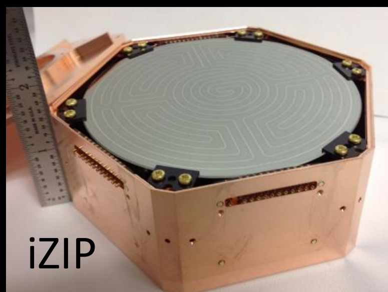
- Start operations of SuperCDMS SNOLAB in 2020
- Parallel to Operations:
  - develop improved detectors
  - acquire funding
  - produce new detectors, readout electronics etc.
- Conclusion SuperCDMS SNOLAB presently planned for 2025
- BUT: installation of improved detectors possible much earlier (e.g.: present HV detectors are expected to be background limited after about 2 year; may replace them if we have better ones by then)

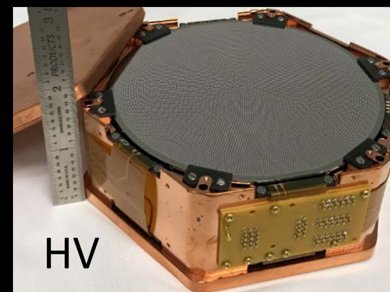
Goal

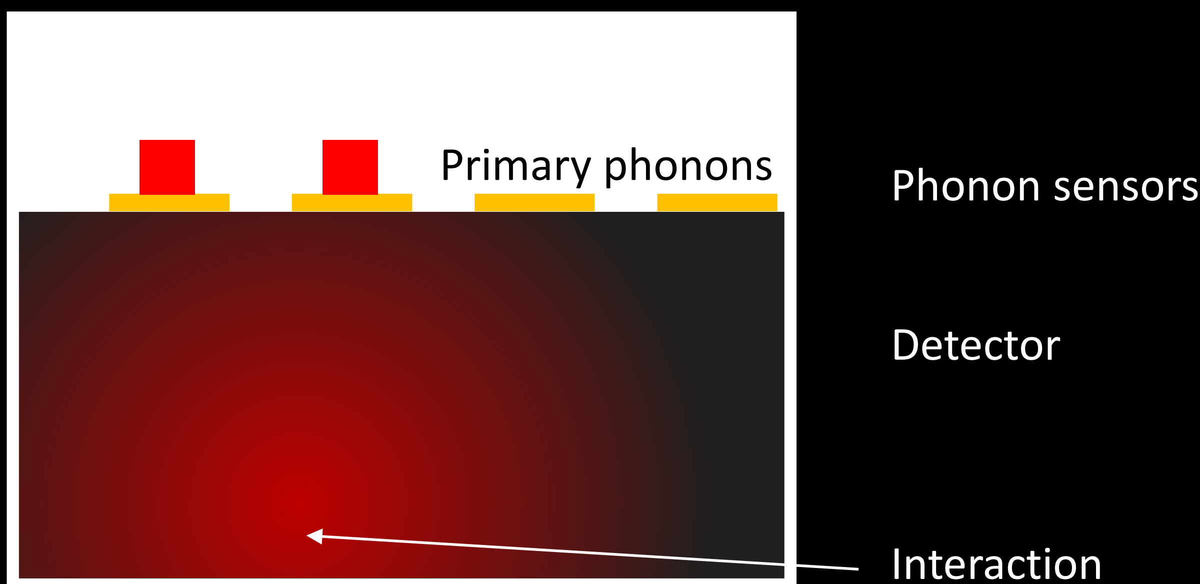

Dark Matter–nucleon σ_{SI} [cm^2]
Dark Matter–nucleon σ_{SI} [pb]
Dark Matter Mass [GeV/c^2]
10^{-37}
10^{-38}
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
0.5
1
5
10
CRESST–II
CDMSlite II
SuperCDMS LT
PICO–60
LUX
PandaX–II
Si HV
Ge HV
Si iZIP
Ge iZIP
Longterm goal

Detector Developments – Re-gain Discrimination

- Combine ideas of iZIP and HV detectors:
  Electric field configuration as in iZIP, but pure phonon readout







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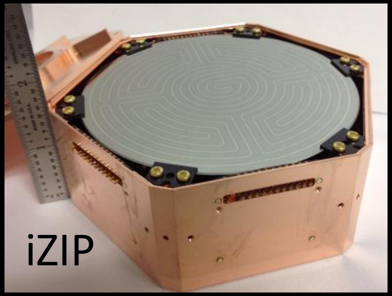
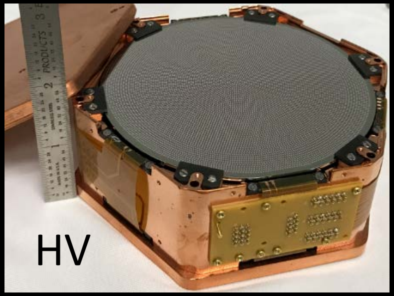
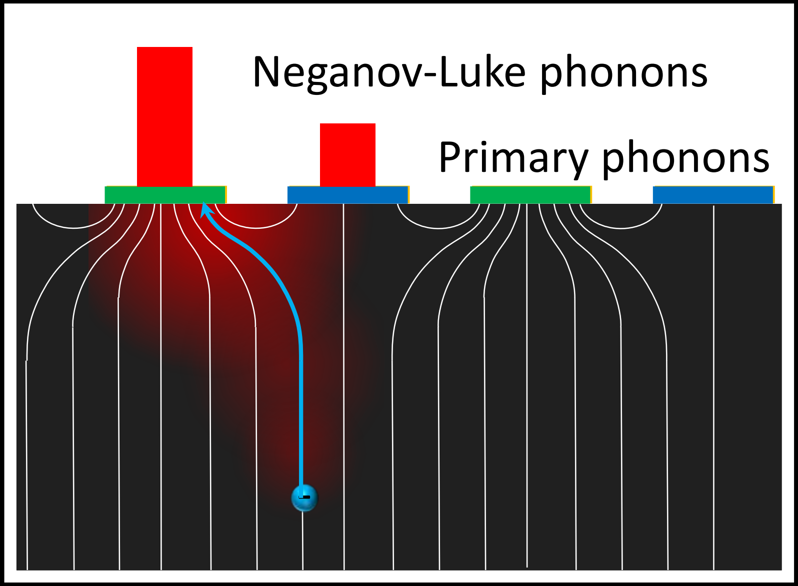






Ratio of signals gives information about ratio of primary to NL phonons

Phonon sensors – biased

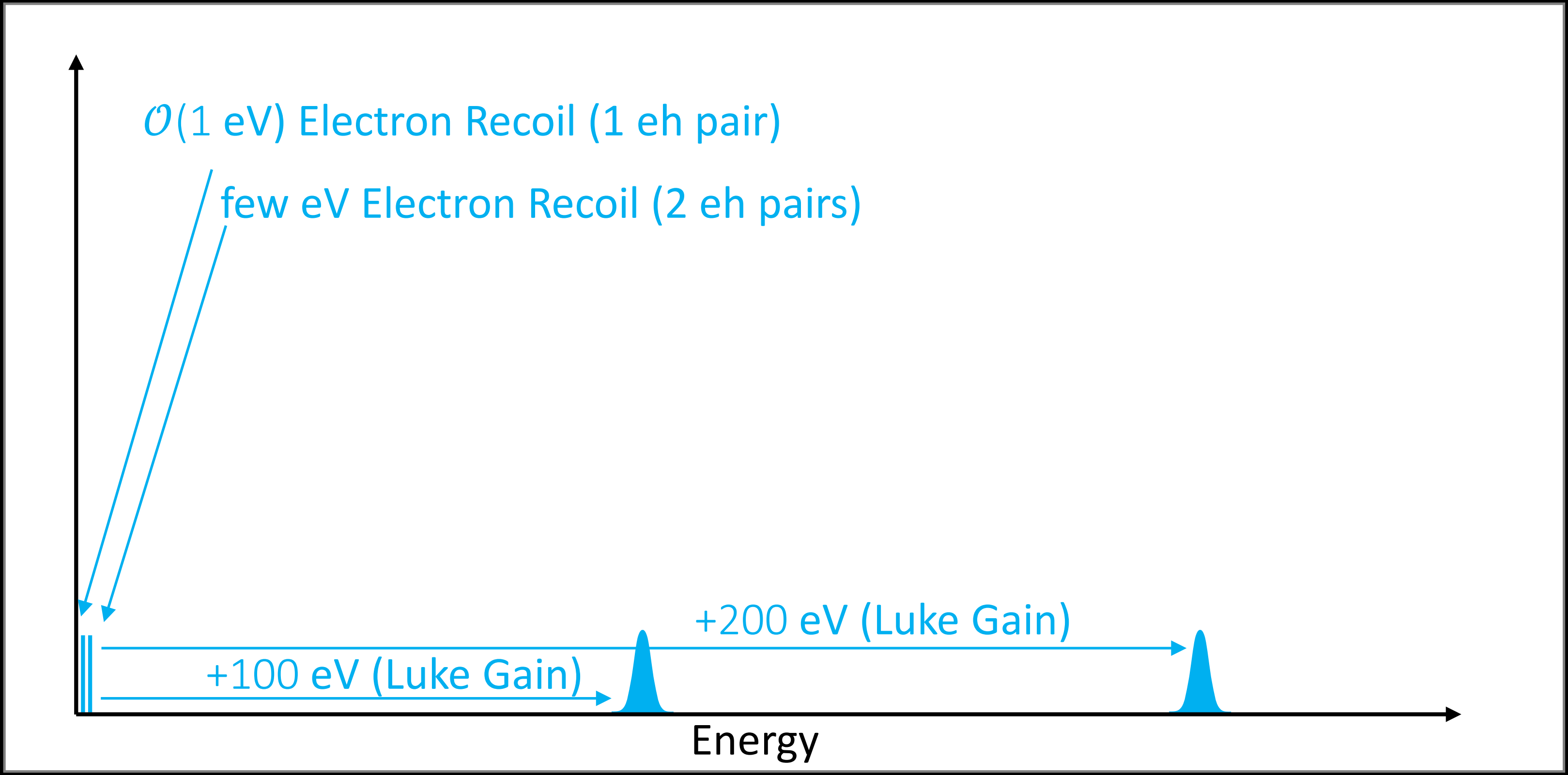
Strong field region

Detector

Weak field region

Detector Developments – Re-gain Discrimination

- Single Electron-hole Pair Luke gain (SEPL) method
- Need excellent energy resolution ($\ll e \times$ bias voltage)



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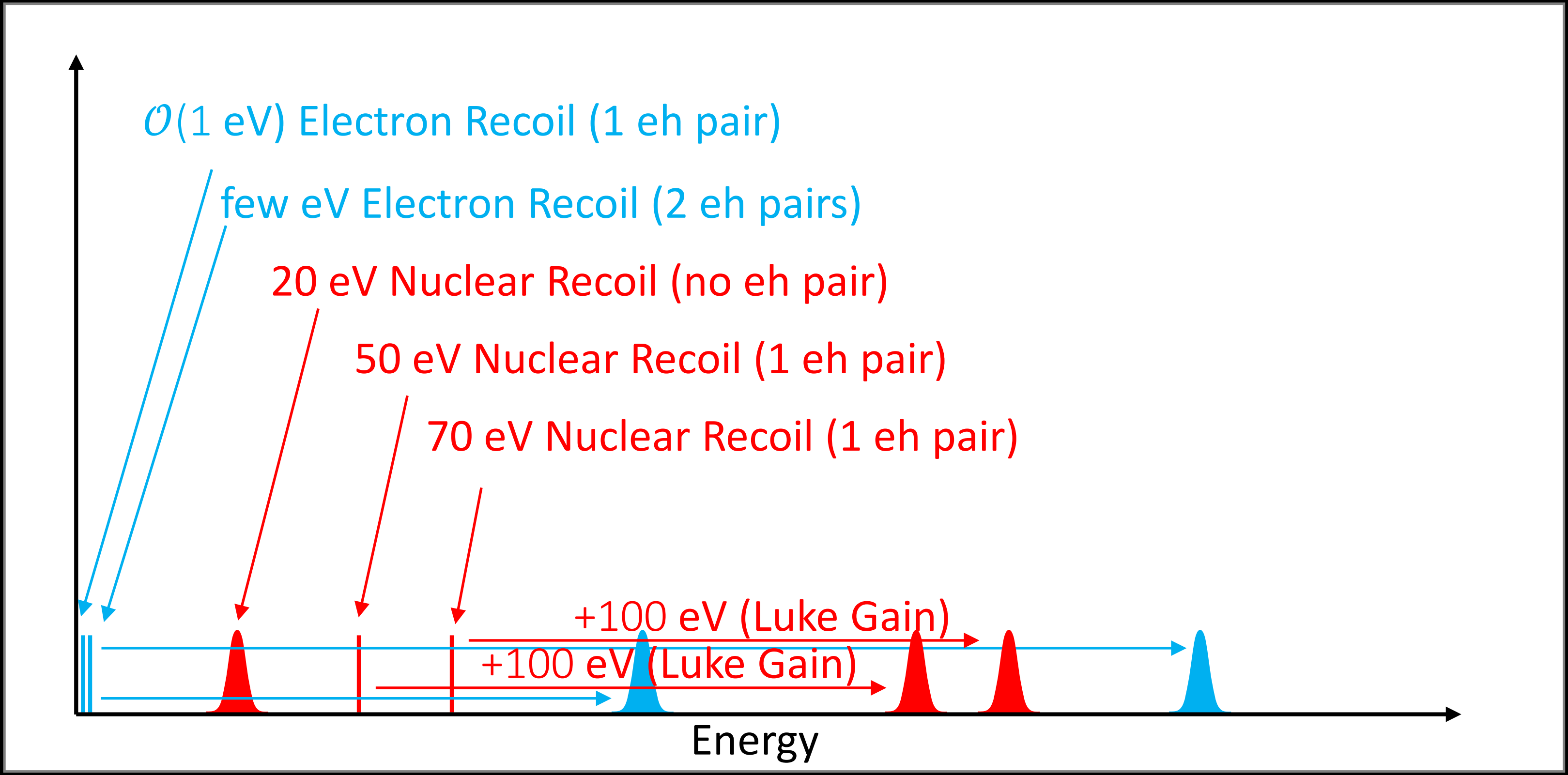

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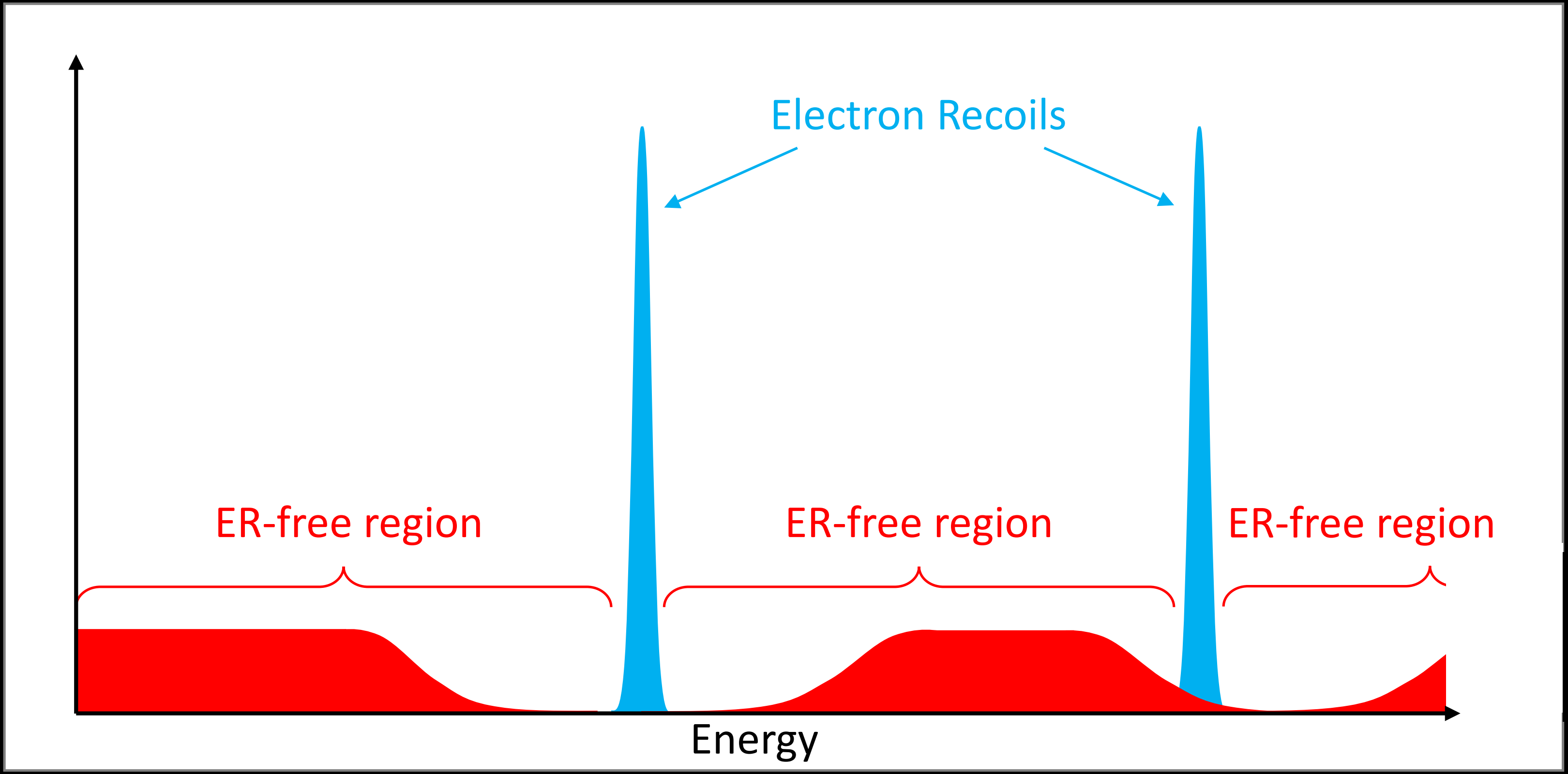
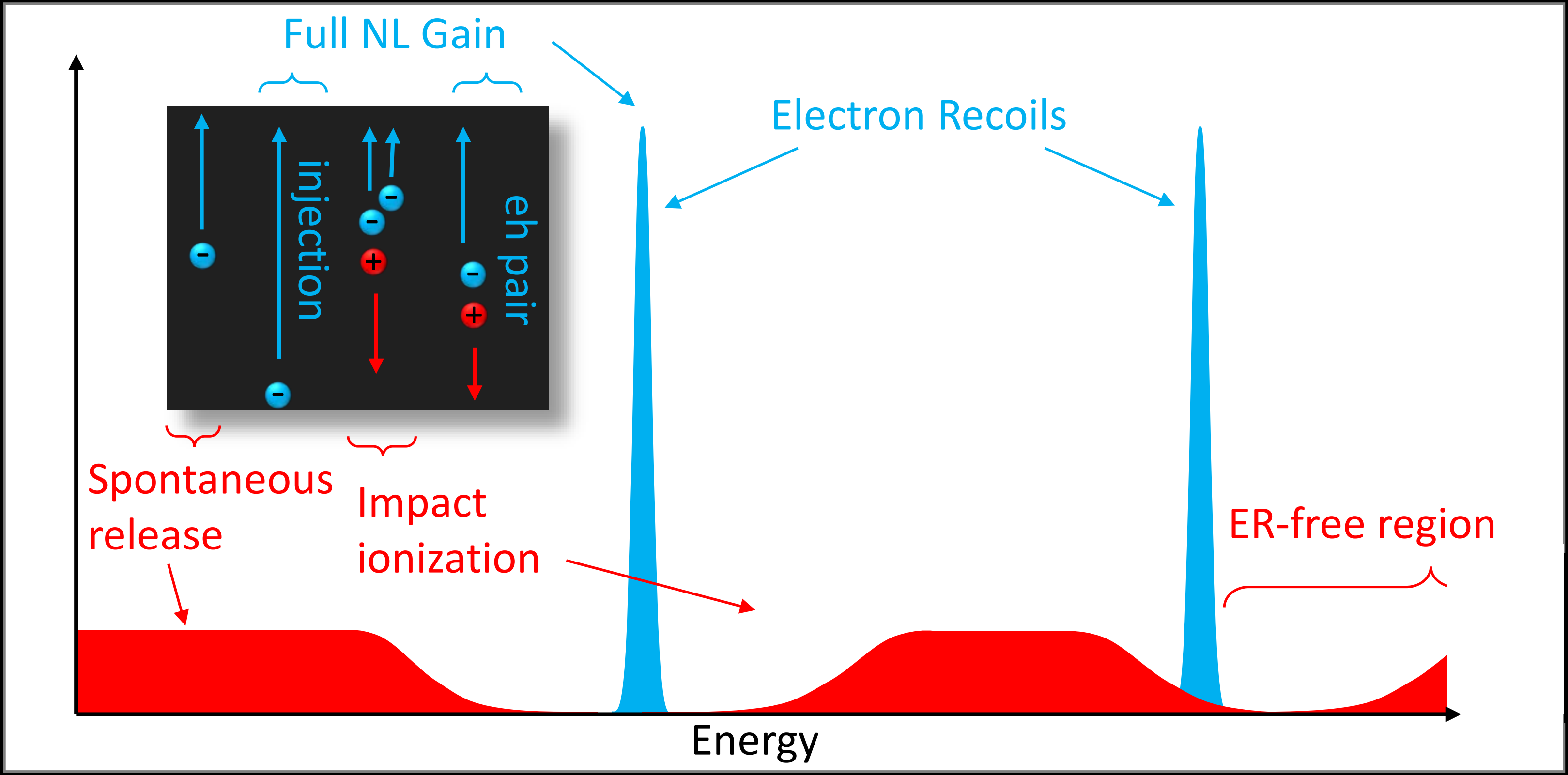


Detector Developments – Re-gain Discrimination

- Single Electron-hole Pair Luke gain (SEPL) method
- Need excellent energy resolution ($\ll e \times$ bias voltage)

Possible issues:

- Spontaneous release of trapped charges (either electrons or holes)
- Impact ionization of shallow states in the bulk



Detector Developments – Re-gain Discrimination

- Single Electron-hole Pair Luke gain (SEPL) method
- Need excellent energy resolution (≪ $e \times$ bias voltage)

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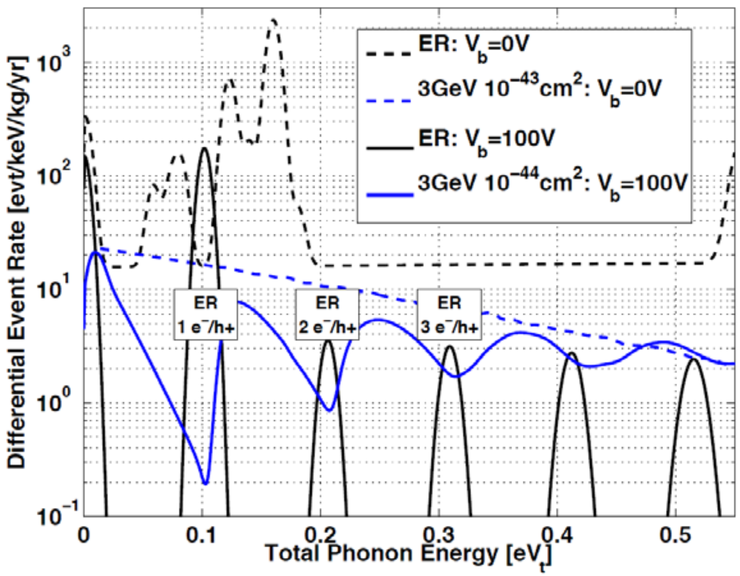
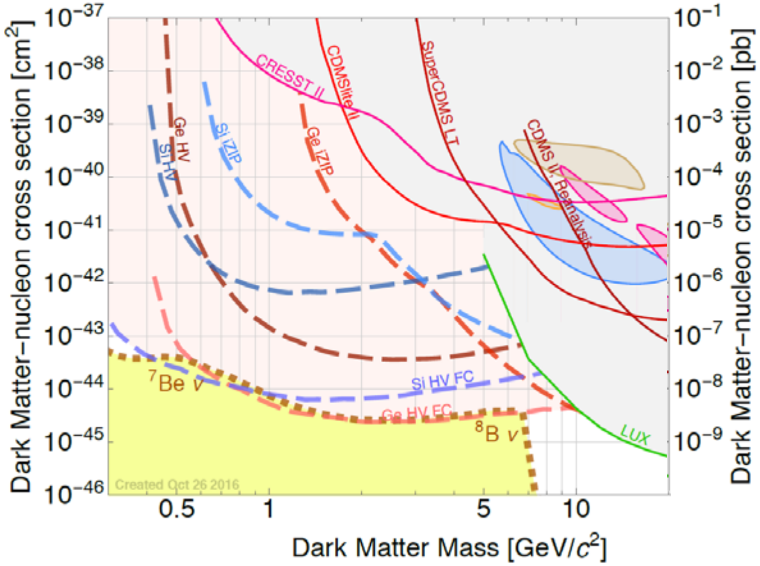
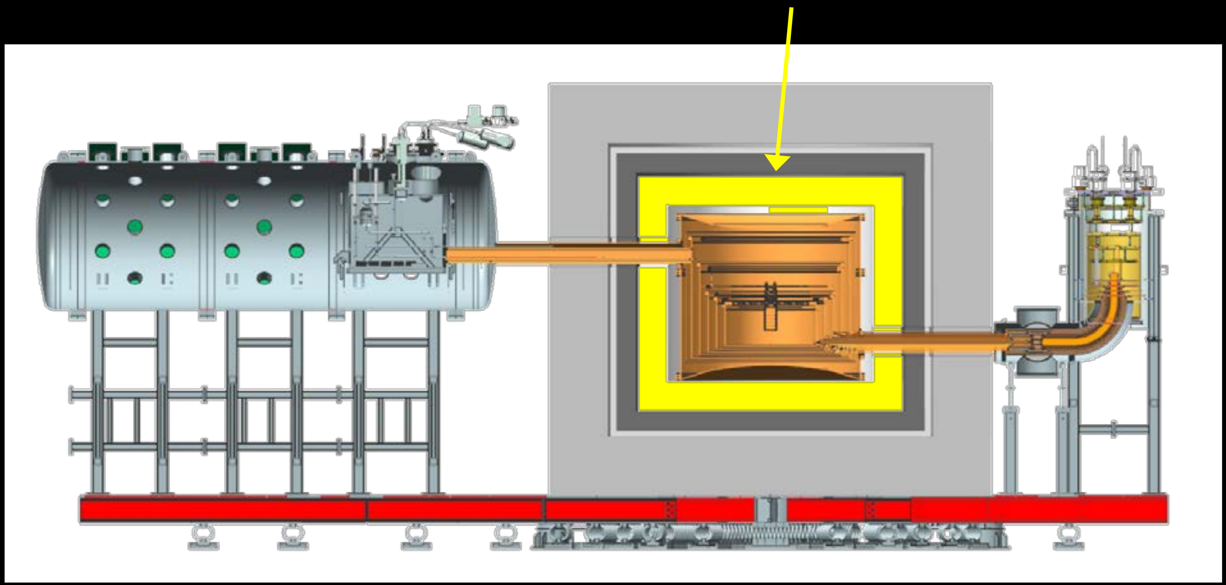




Detector Developments – Neutron Veto

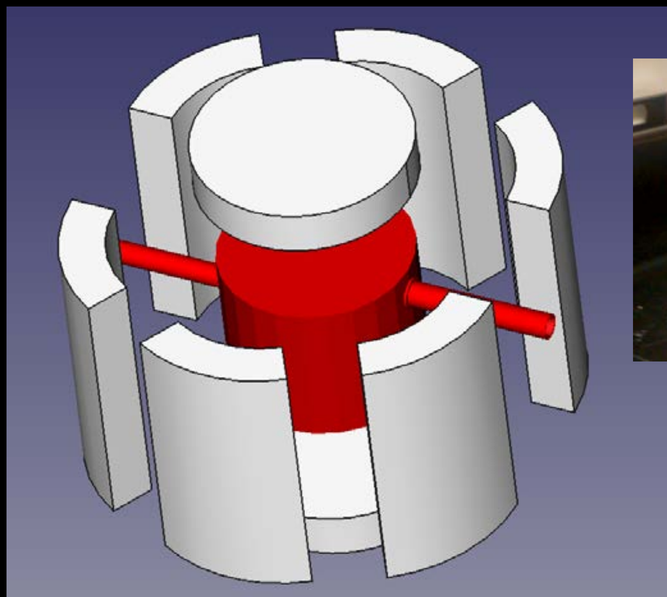
- If ER background is removed, we need to worry again about neutrons
- Replace inner neutron shield by active veto detector

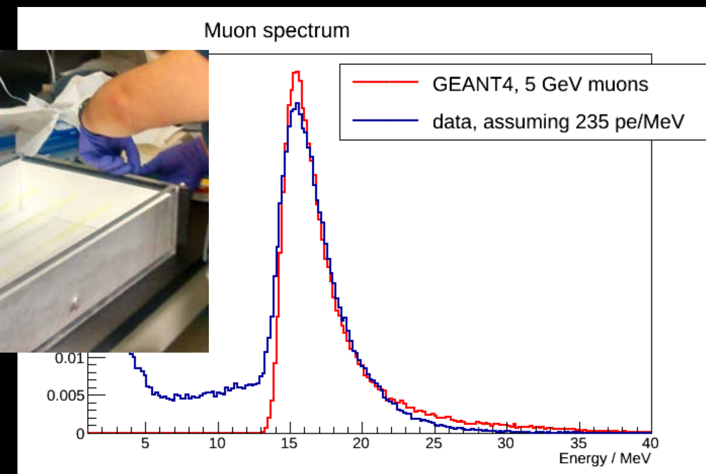


- Most important role: tag neutrons from inner part of experiment
- Additional role: tag residual neutrons from outside; muon veto
- Boron or Gadolinium loaded scintillator
- Readout with SiPM + fiber (for low radioactivity)
- Some R&D work on B-loaded scintillator is already completed

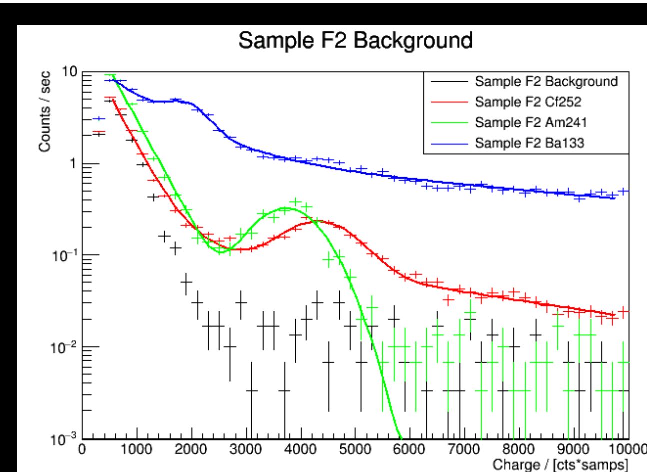
Detector Developments – Neutron Veto

- Modular tanks, LAB (organic scintillator), loaded with ~30 % trimethyl borate (TMB)
- Readout: wavelength shifting fibers coupled to SiPM (~1000; 4 fibers/SiPM)



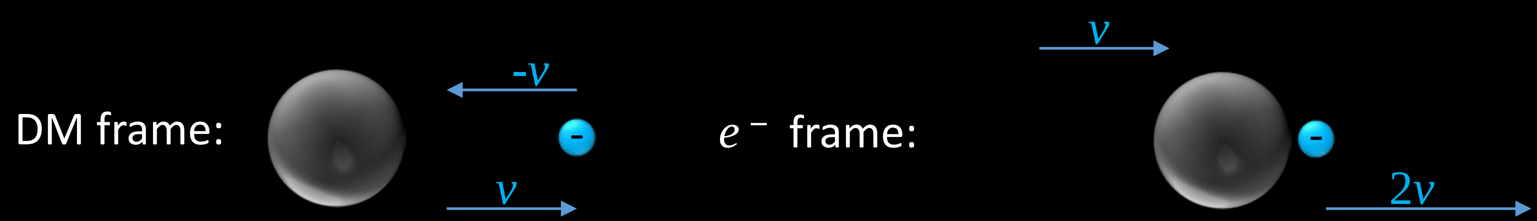


- Prototype (1/4 scale) built at Fermilab
- Performance very promising
- Alternative designs are being considered (Gd loaded liquid scintillator; solid scintillator)

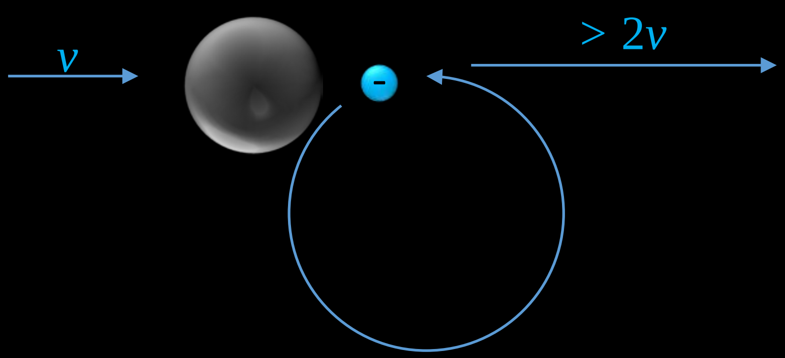


Electron Interacting Dark Matter

- With single eh-pair sensitivity we can search for Electron Interacting Dark Matter:



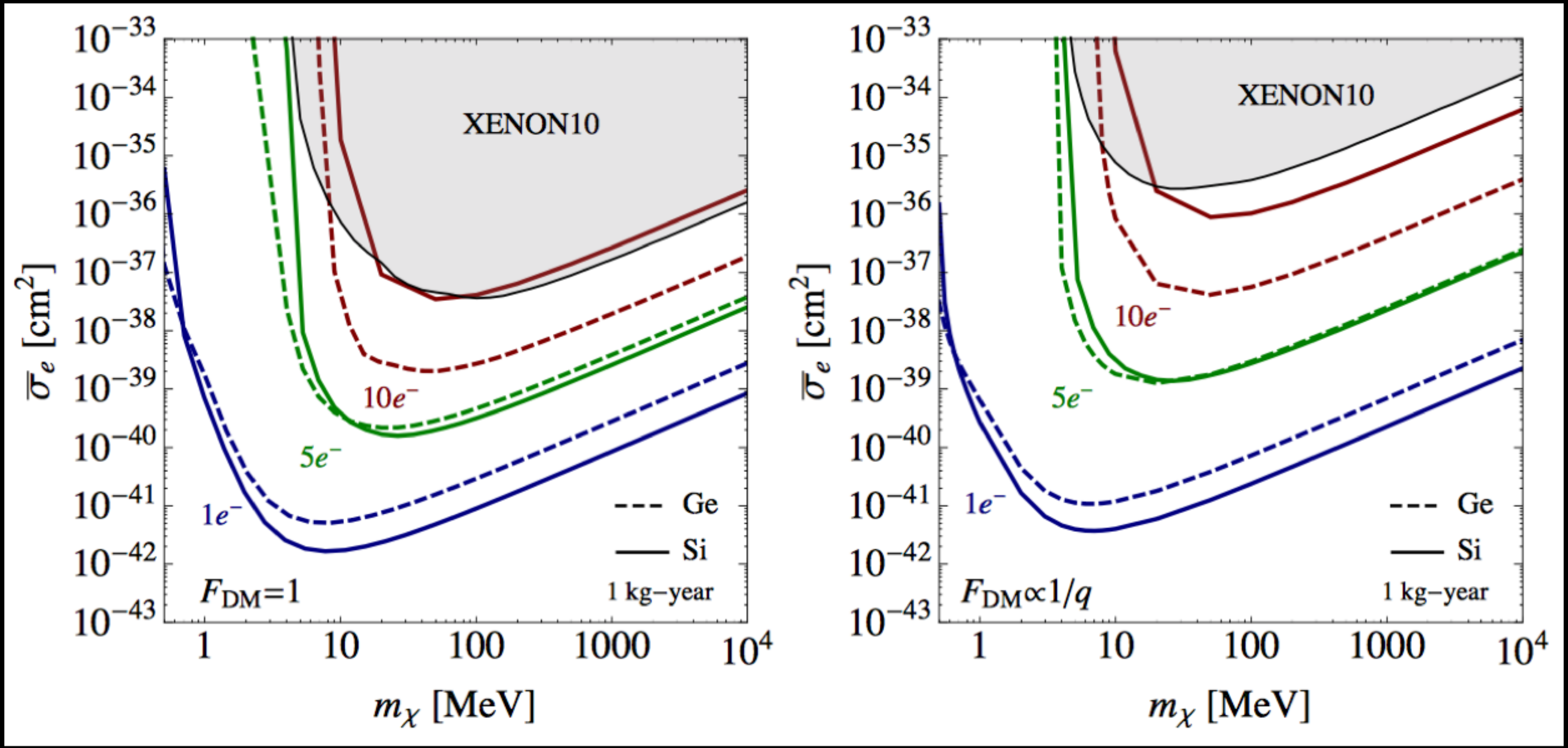
- Maximum velocity of the electron: $2 \times v_{escape} \cong 1200\ \mathrm{km/s} = 4 \times 10^{-3}\ c$
- Maximum kinetic energy: $E_e = \frac{1}{2} m_e v_e^2 = 4\ eV$
- Real world more complicated:



- Moderately higher energy transfer possible
- Requires very low leakage current (injected charge carriers look like single eh pairs) and ER background

Electron Interacting Dark Matter

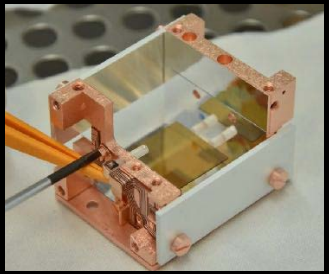
- Search for DM particles down to the MeV scale:



- Sensitivity depends on mediator mass
- Also sensitive to dark photons, axion like particles etc.

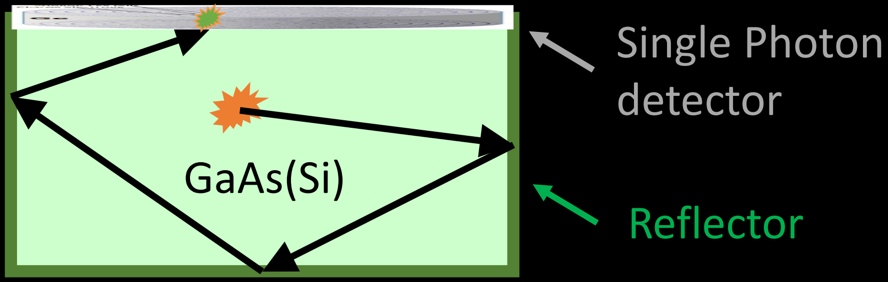
Other Detector Types

- Still in discussions with EDELWEISS and CRESST for the potential to include their detectors into the SuperCDMS setup



CRESST III: $CaWO_4$, scintillating cryo-detector
24 g/detector; cryogenic light detector
lowest energy threshold achieved so far: 20 eV
Presently at Gran Sasso; default plan is to continue, but may join if there are show-stoppers

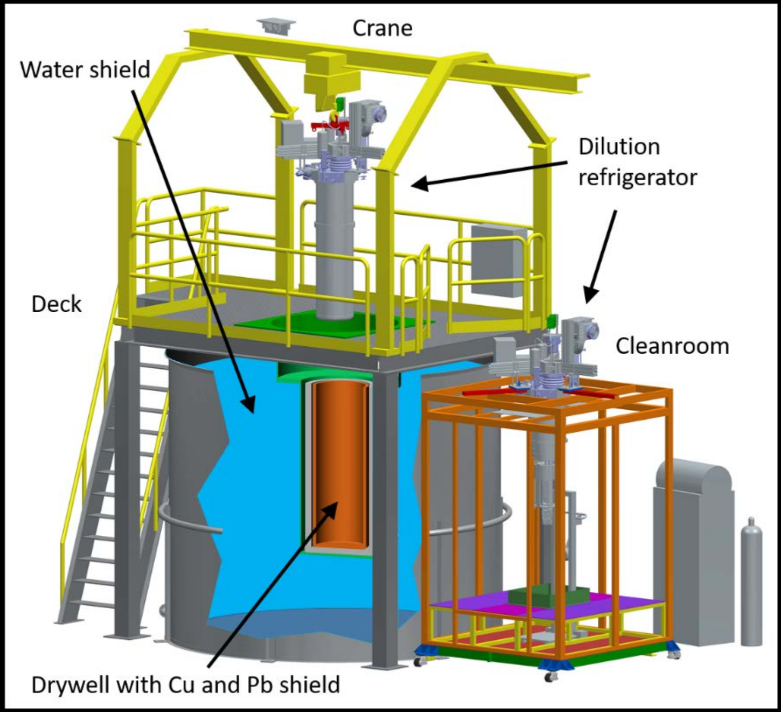
- New idea: scintillator with low band gap (GaAs(Si)) + single photon detector (setup very similar to CRESST)
  - Similar threshold as Ge/Si
  - No issue with leakage current
  - Penalty: scintillation efficiency, photon collection efficiency (factor of a few)



- Other ideas are out there – SuperCDMS is modular and adaptable to the change in the scientific landscape

Cryogenic Underground TEst facility (CUTE)

- Well shielded test facility, next to SuperCDMS
- Presently under construction
- Expected background $\mathcal{O}(5)$ events/keV/kg/day below ~10 keV



- Test all new detector concepts in low-background environment before installing in SuperCDMS
- Minimizes down-time of the experiment

Conclusions

- SuperCDMS SNOLAB: small payload, about an order of magnitude shy of the neutrino floor
- BUT: has extra capacity (up to 200 kg)
- Detector improvements may allow us to re-gain ER/NR discrimination at very low energy
- This will allow us to reach the neutrino floor (need large payload)
- At the same time: reach to lower energies and thus lower mass WIMPs
- Search for electron-interacting DM
- Discussions with EDELWEISS/CRESST about joining forces
- New detector ideas for very low mass reach, search for dark photons …