SuperCDMS: status and prespectives

Emanuele Michielin on behalf of the SuperCDMS Collaboration

University of British Columbia

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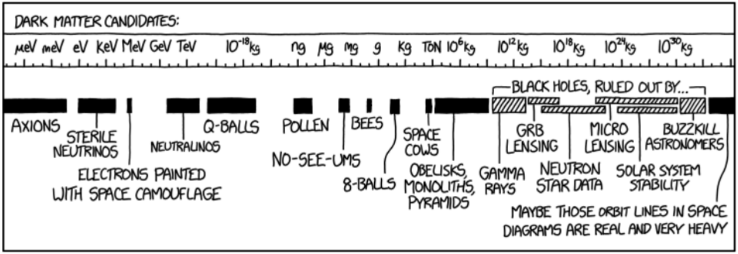
The SuperCDMS Collaboration.. during COVID times

$\sim$ 100 scientists at 27 institutions from 5 countries..

..all searching to solve one of the greatest current mysteries: where is dark matter hiding?



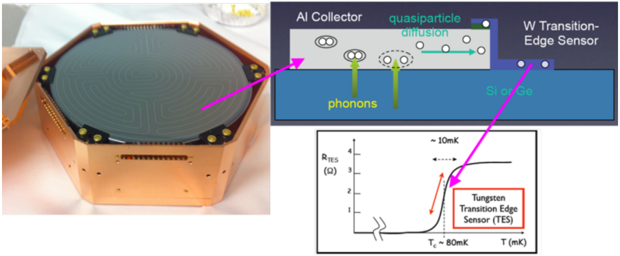
From xkcd.com

SuperCDMS is a **direct detection** experiment which looks for scattering interactions of low-mass ($< 10\,\mathrm{GeV/c^2}$) dark matter particles with standard model particles.

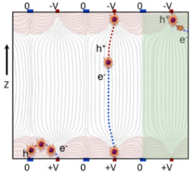
SuperCDMS detector technology

When a particle scatters in a Si/Ge crystal lattice its transferred energy is dissipated via **heat** and **ionization**. If we can measure those, we'll have a clear signature of its interaction and we can infer its properties.

- **Phonons**, measured via Quasi-particle trap assisted Electrothermal feedback Transition edge sensors (QETs)



- **Charge**, measured via interleaved electrodes



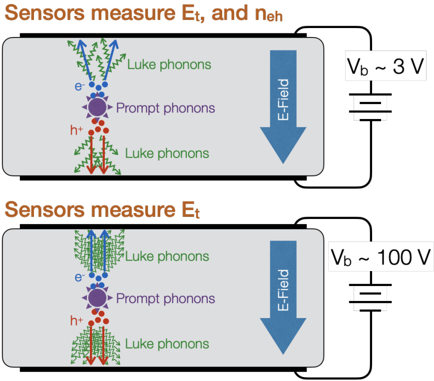
SuperCDMS detectors

Interleaved **Z**-sensitive **I**onization and **P**honon detector:

- Prompt phonon and ionization signals for discrimination between nuclear and electron recoil events
- ~ 1 **keV threshold, ER/NR discrimination power**

HV detector:

- Observed phonon energy $= E_{\text{Recoil}} + E_{\text{NTL}}$
- E_{NTL} energy from Neganov-Trofimov-Luke effect: phonons created by drifting charges
- $\boldsymbol{E_{\text{NTL}}}$ **proportional to** V_b $\left(E_{\text{NTL}} = eV_b n_{eh} = \frac{Y(E_{\text{Recoil}})}{\epsilon} eV_b\right)$
- $Y(E_{\text{Recoil}}) = \frac{E_Q}{E_{\text{Recoil}}}$ needed input, Lindhard model used but not tested at low energies
- ~ 100 **eV threshold but no ER/NR discrimination**

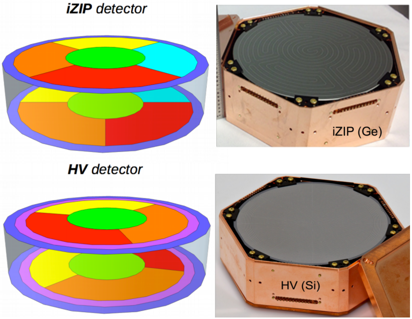


SNOLAB SuperCDMS detectors

Successful campaign in Soudan finished, now moving to SNOLAB.

Detectors improvements:

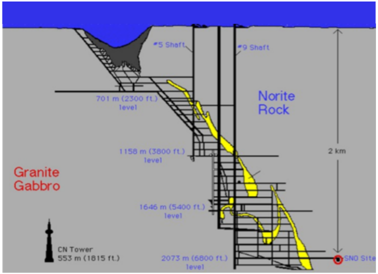
- Bigger (more fiducial volume) and higher purity (less radioactive impurities) crystals
  - Ge (1.4 kg crystals) larger exposure
  - Si (0.6 kg crystals) lower mass reach

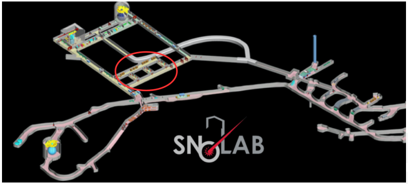


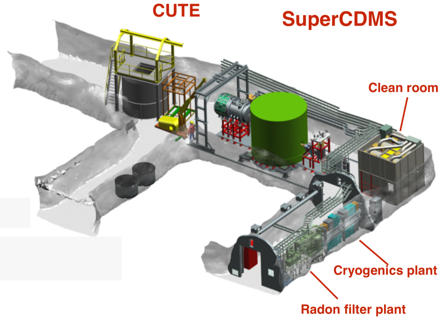
- Critical temperature Tc from 90 to 40 mK, resolution scales as Tc^3
- Newly optimized QET geometry to enhance the phonon collection efficiency
- More channels for better event position reconstruction

Moving to SNOLAB

- 2 km underground (6800 m water equivalent)
- Cleanroom (class 2000 or better)
- Muon flux from cosmic rays reduced by a factor of 100 compared to the Soudan mine

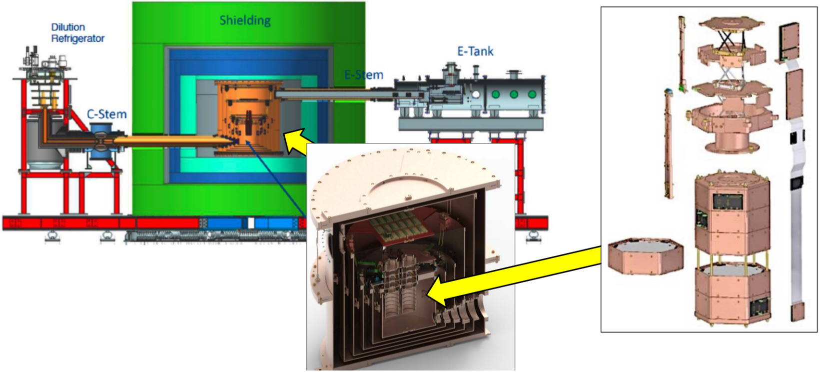






SuperCDMS SNOLAB Experiment

Initial payload: $\sim$ 30 kg total, 4 towers with 6 detectors per tower (12 iZIP, 12 HV)



- ν-dominated NR bkg
- $\mathcal{O}(0.1)$ cts/(keV kg d) γ background

- 15 mK base temperature
- Vibration isolation

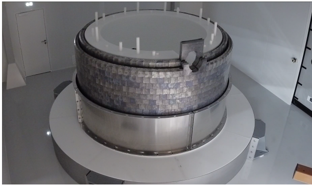
Installation is happening!

Seismic platform installed

Radon filter system

Chilled water loop

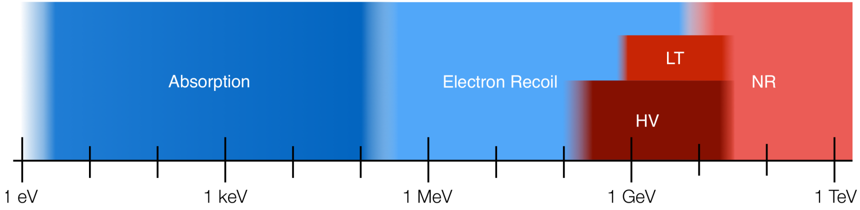
Inner lead and polyethylene shield



Plan is to start commissioning run in 2023!

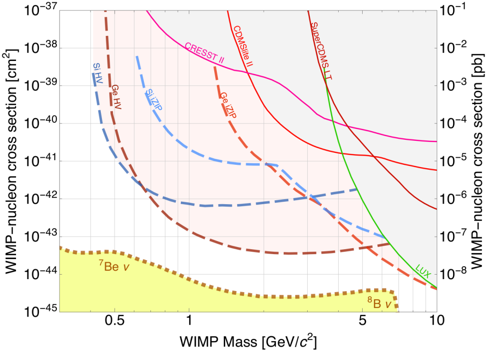
SuperCDMS sensitivity: a broadband DM search

Traditional Nuclear Recoil:	iZIP, Background free	>5 GeV
Low Threshold NR:	iZIP, limited discrimination	>1 GeV
HV mode:	HV, no discrimination,	~0.3 - 10 GeV
Electron recoil:	HV, no discrimination,	~0.5 MeV - 10 GeV
Absorption (Dark Photons, ALPs):	HV, no discrimination,	~1 eV - 500 keV (peak search)



SuperCDMS SNOLAB nuclear recoil projected sensitivity

Limits obtained with conservative optimum interval method, no background subtraction



arXiv:1610.00006

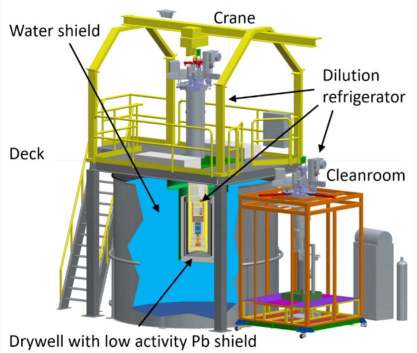
Under this condition:

- HV detectors approach these sensitivities in 2 years of operation
- IZIP detectors can run for more than 5 years without reaching background limitations

Stay tuned! Coming soon Snowmass White Paper with new projections including ER sensitivity and new detector R&D scenarios for the future

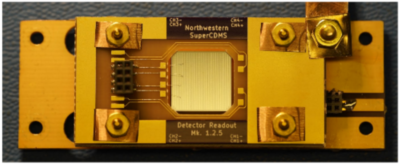
Not just installing SuperCDMS... the Cryogenic Underground TEst

- Close collaboration with SuperCDMS
- Facility background level similar to the Soudan campaign
- Running right now prototypes of HV SNOLAB detectors to study performances
- Capacity of testing 1 SuperCDMS detector tower
  - Towers 1 + 2 arrive this June
  - Towers 3 + 4 arrive this Sept
- Possibility of early science result!

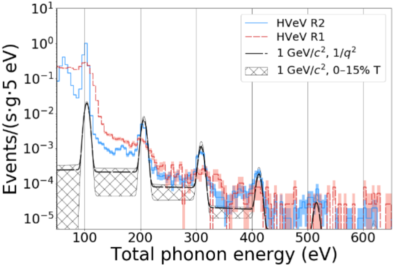


Not just installing SuperCDMS... the HVeV program

- The HVeV are small gram scale R&D detectors:
  - Single electron-hole pair resolution devices!
- Ideal for studying charge transport in Si and Ge
  - Minimize charge leakage in all SuperCDMS devices
- Sensitivity to a variety of sub-GeV DM models with gram*day exposures
- Physics runs happening now in NEXUS (FNAL) test facility
- **New results from a 0 V run coming soon!**



PRD 102, 091101, 2020



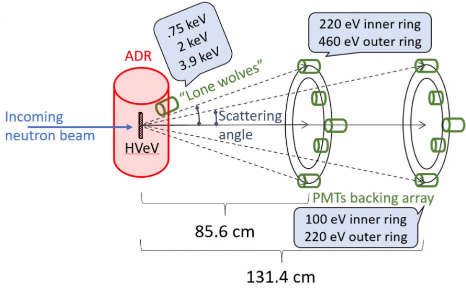
Understanding the Nuclear Recoil Scale: IMPACT

- Ionization yield $Y(E_{\mathrm{Recoil}})$ is energy dependent and not well known at lower energies
- Necessary input for our understanding of the HV detector data

IMPACT

Ionization Measurement with Phonons at Cryogenic Temperatures

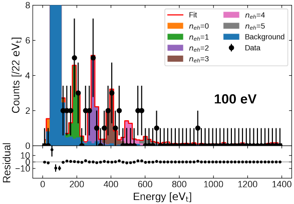
- Determination of the yield via measurement of the total phonon energy and kinematic measurement of the recoil energy via a coincident detection of the scattered neutron
- 55.7 keV neutrons beam at Triangle Universities Nuclear Laboratory
- Total phonon energy measured with Si HVeV detector at 100 V with ~ 3 eV resolution
- Set of liquid scintillator detectors coupled to 2-inch PMTs to measure scattered neutrons at various angle

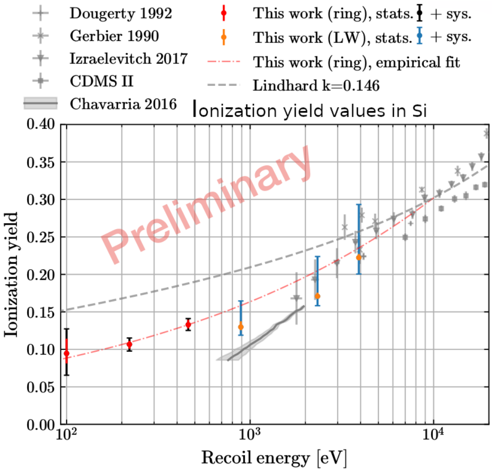


Understanding the Nuclear Recoil Scale: IMPACT

1. Measurement of total phonon energy spectrum for coincidence events
2. Simulation of recoil energy spectrum for coincidence events
3. Determine Y by fitting the simulation to the HV measurement

Example of fit, 100 eV





Paper will be out soon! Working towards a Ge HVeV measurement soon.

Understanding the Nuclear Recoil Scale: photoneutron measurement at Soudan

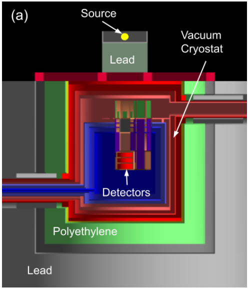
- Photoneutron sources: high rate gamma sources (^{88}Y and ^{124}Sb) on top of a ^{9}Be wafer to produce mono-energetic neutrons
- Neutrons irradiated 2 old-style Ge HV detectors, run at 70 and 25 V, at the end of Soudan campaign
- Full Geant4 simulation of neutron signal
- Electron recoil background spectrum dominated by Compton, modeled analytically and validated using source data without ^{9}Be wafer

arXiv:2202.07043

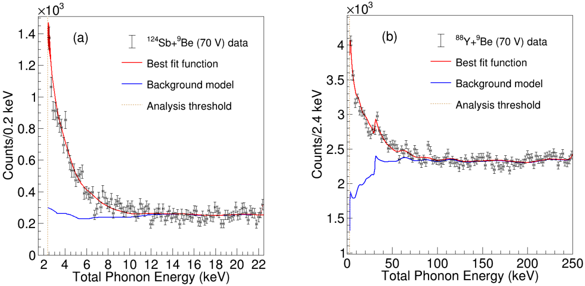
Ionization yield extract with likelihood fit to data using a linear generalization of the standard Lindhard model

$$Y_r = \frac{kg(\epsilon)}{1 + kg(\epsilon)}$$

$$k(E_r) = k_{low} + \frac{k_{high} - k_{low}}{E_{high} - E_{low}}(E_r - E_{low})$$

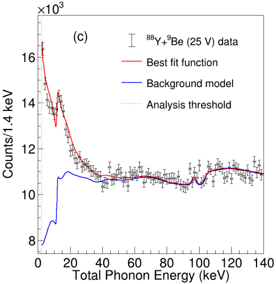


Understanding the Nuclear Recoil Scale: photoneutron measurement at Soudan

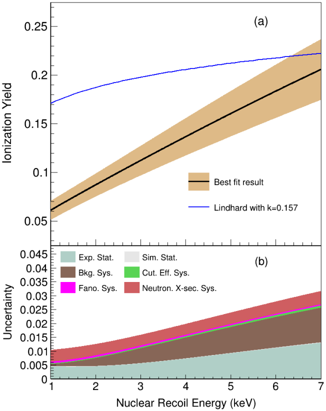


Best fit result for the 3 data sets

arXiv:2202.07043



Understanding the Nuclear Recoil Scale: photoneutron measurement at Soudan



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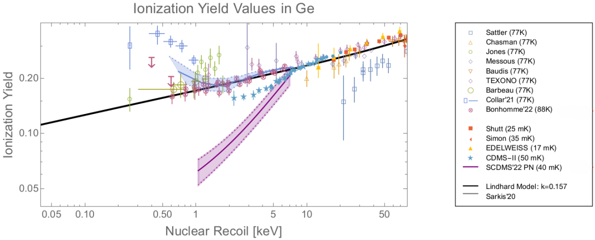
Obtained yield significantly suppressed wrt Lindhard in the few keV range



Possibility of dependence on T or V bias or type of detector.

Need for theoretical input!

Conclusion

- Exciting time ahead!
- The SuperCDMS SNOLAB Project is on track
    - Detector fab is complete and SNOLAB infrastructure is well advanced
    - Testing and characterization is happening at test facilities
    - The parameter space that SuperCDMS will explore is world-leading and unique
- Last results from Soudan era are being completed, new results will be released in the coming months!
- Begun a campaign to measure the nuclear recoil scale at low energies
- Intense and fruitful R&D effort ongoing to already develop the detector technology for the future - early science results being prepared!

$\boxed{\text{Backup}}$

SNOLAB backgrounds

- Dominant background: in-crystal ^{3}H, ^{32}Si, ^{68}Ge
- Line-of-sight contamination from ^{210}Pb
- Material and cavern contamination: ^{40}K, ^{60}Co

"Singles" Background Rates (counts/kg/keV/year)	Electron Recoil				Nuclear Recoil ($\times 10^{-6}$)	
	Ge HV	Si HV	Ge iZIP	Si iZIP	Ge iZIP	Si iZIP
Coherent Neutrinos					2300.	1600.
Detector-Bulk Contamination	21.	290.	8.5	260.		
Material Activation	1.0	2.5	1.9	15.		
Non-Line-of-Sight Surfaces	0.00	0.03	0.01	0.07	–	–
Bulk Material Contamination	5.4	14.	12.	88.	440.	660.
Cavern Environment	–	–	–	–	510.	530.
Cosmogenic Neutrons					73.	77.
Total	27.	300.	22.	370.	3300.	2900.