# The Search for Light WIMPs with CDMSlite and SuperCDMS SNOLAB

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# SuperCDMS Collaboration

California Inst. of Tech. | CNRS-LPN* | Durham University | FNAL | NISER

NIST* | Northwestern U. | PNNL | Queen's University | SLAC

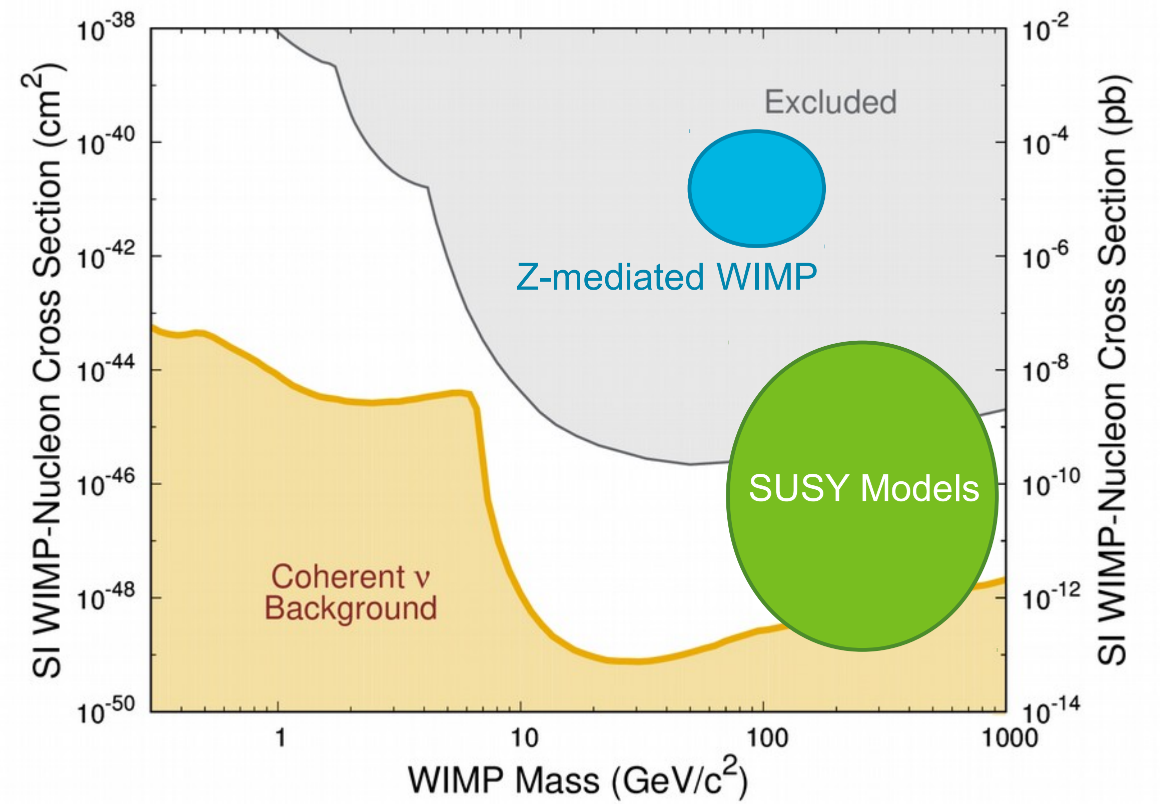
SMU | Santa Clara U. | South Dakota SM&T | Stanford University | Texas A&M University | U. British Columbia

U. California, Berkeley | U. Colorado Denver | U. Evansville | U. Florida | U. Minnesota | U. South Dakota

* Associate members

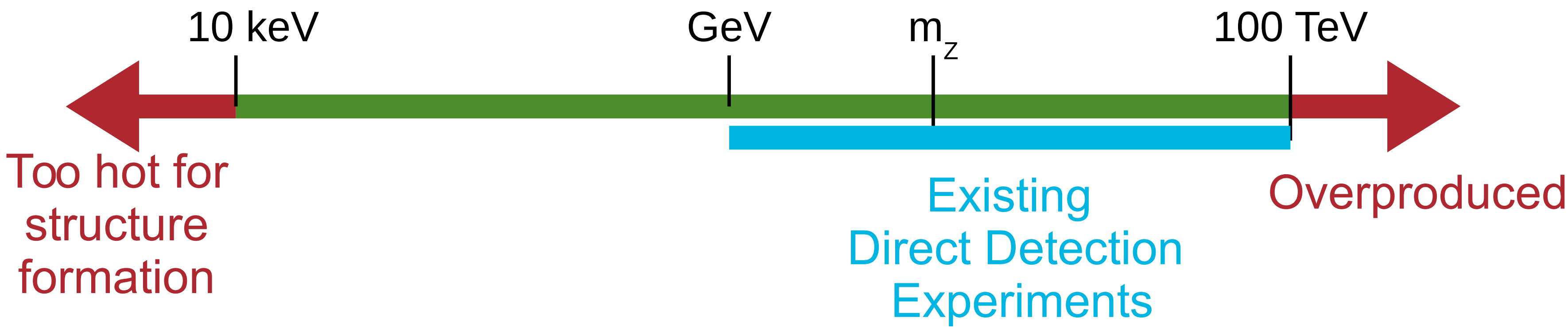
# Weakly interacting massive particles (WIMPs)

- Why 100 GeV/$c^2$ WIMPs?
  - WIMP miracle – weak scale couplings and mass match thermal freeze-out relic abundance – being excluded by LHC and liquid Xe experiments.



# Why Light WIMPs?

- What could a thermal relic mass be?

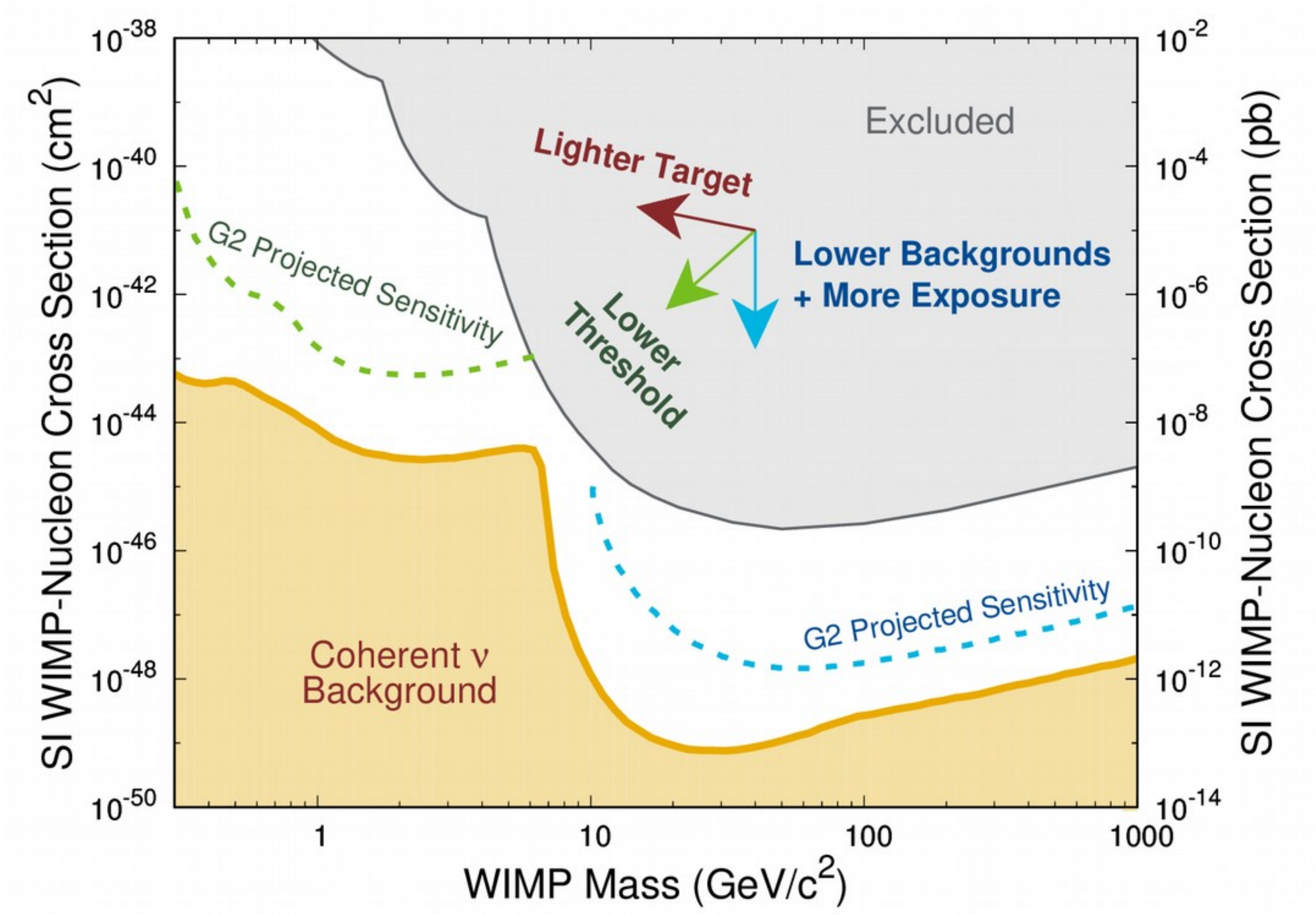



- Well motivated models exist
  - Asymmetric DM
    - Models related to the matter/antimatter asymmetry
  - Hidden sector
    - New U(1) field that mixes kinematically with the photon
    - Consistent with muon g-2 anomaly

See Gordan Krnjaic, FNAL Users Meeting 2016

# Dark Matter Direct Detection

- Different types of searches required at low vs. high mass.



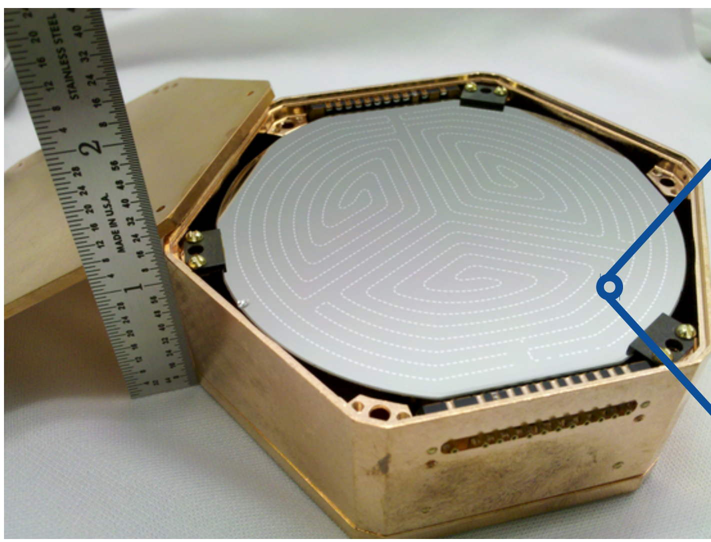
# Light WIMP detectors

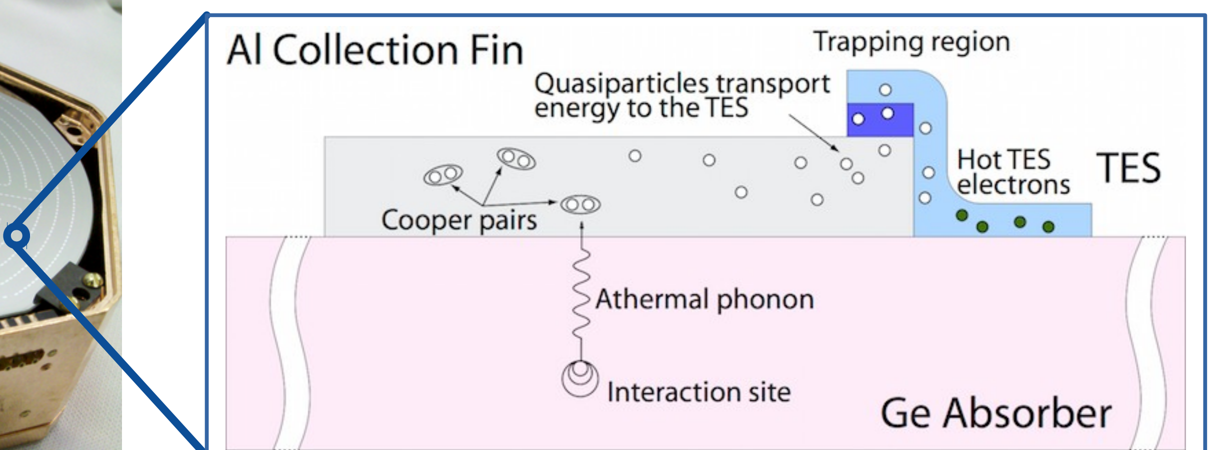
- Experimental approaches
  - SuperCDMS & EDELWEISS
    - Cryogenic (mK) Ge & Si with charge and phonon sensors
  - CRESST
    - Cryogenic scintillators with phonon and light sensors
  - DAMIC
    - Ultra-low noise CCD measuring charge
- Phonons provide more information
  - Average energy of information carriers
    - ~20 eV per scintillation photon
    - ~3 eV per electron/hole pair
    - ~0.001 eV per athermal phonon

# SuperCDMS Soudan (2010–2015)

Ge iZIP (interleaved Z-sensitive Ionization and Phonon sensors)

- Measure **phonons** and **ionization**
  - Athermal phonons measured with Transition Edge Sensors
  - $e^-/h^+$ pairs drifted across ±2 V bias.
  - 15 detectors, 0.6 kg each at ~50 mK

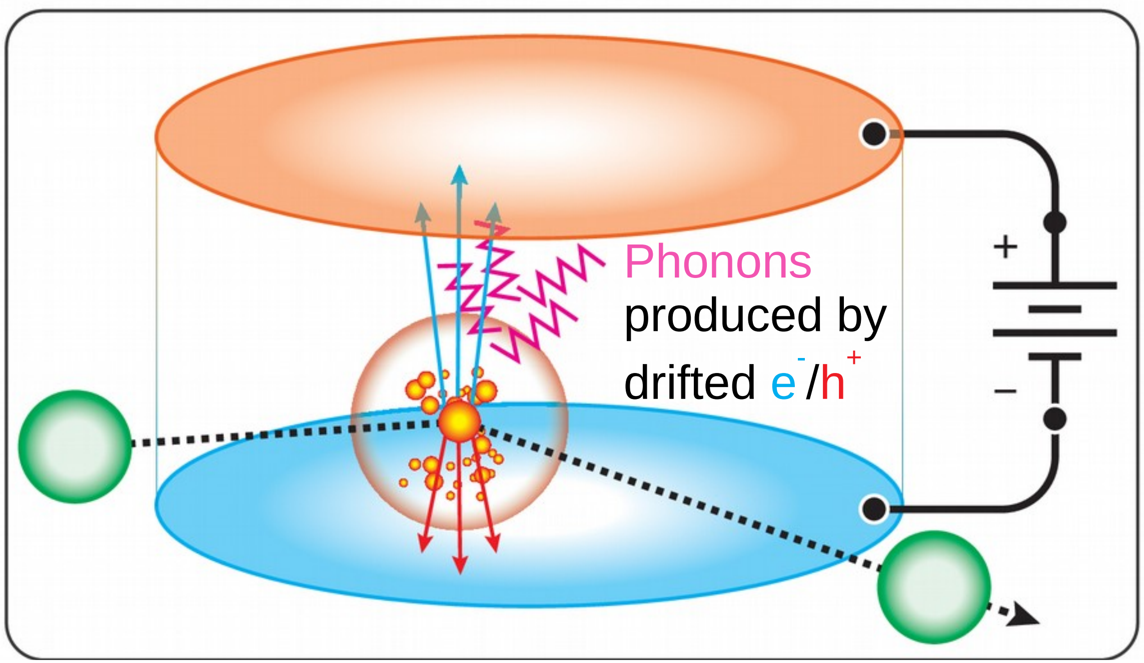




# CDMS Low Ionization Threshold Experiment

How do we optimize resolution?

- Internal amplification of ionization
  - Drift across bias voltage creates additional phonons
- Data at Soudan w/ retrofitted iZIPs at 70V bias.




Phonon energy
$= E_r + n_{eh} e\Delta V$

Recoil Energy
# of e-/h+ pairs
Bias potential

# Exploiting Differences in Ionization Yield

- Electron recoils produce 1 $e^-/h^+$ per 3 eV.
- Nuclear recoils produce <1 $e^-/h^+$ per 20 eV below 300 eV.
  - ER backgrounds are boosted out of low-energy region.
  - Potential for ER/NR discrimination if single $e^-/h^+$ are resolved

Phonon energy
$= E_r + n_{eh} e\Delta V$

Recoil Energy
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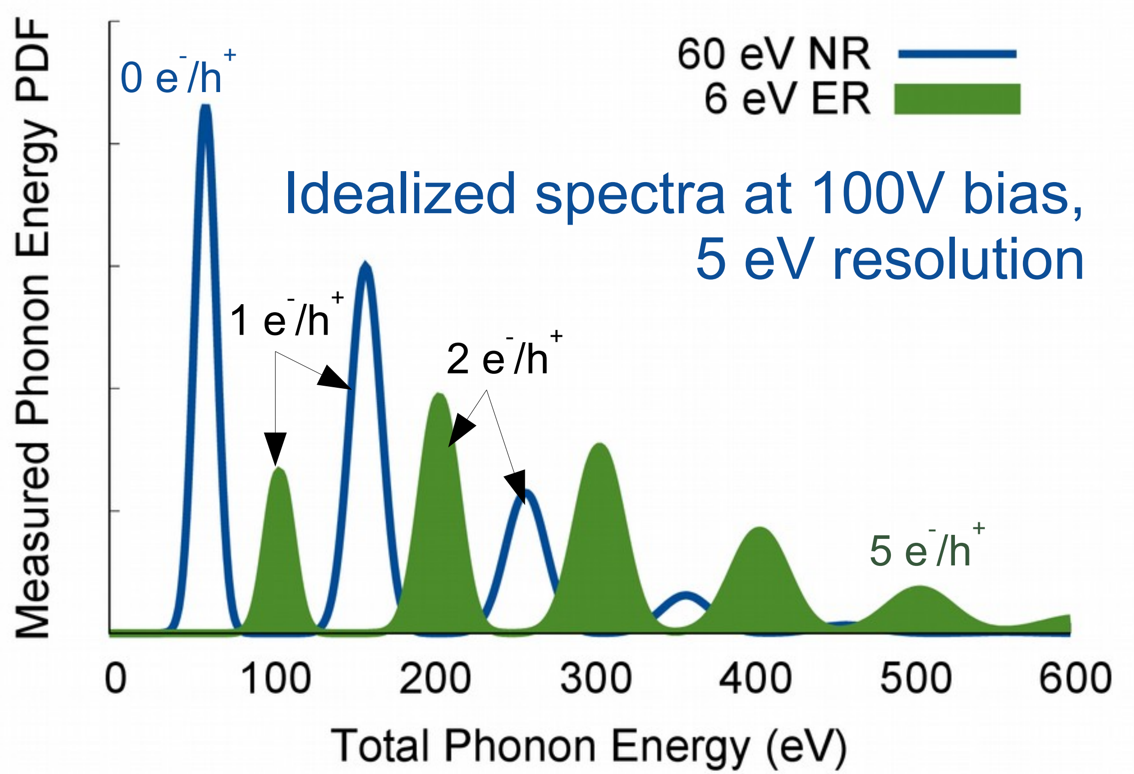
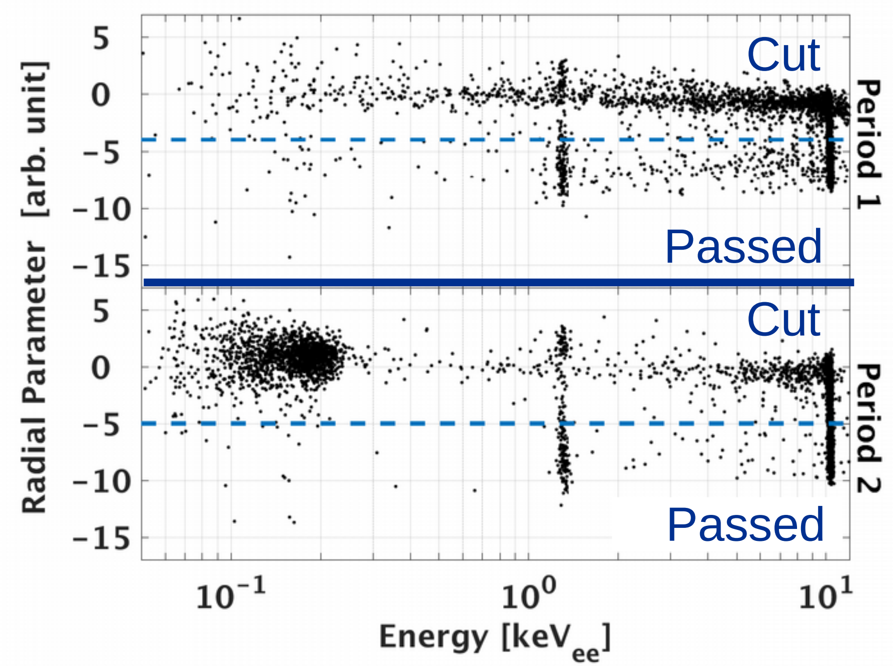
Bias potential

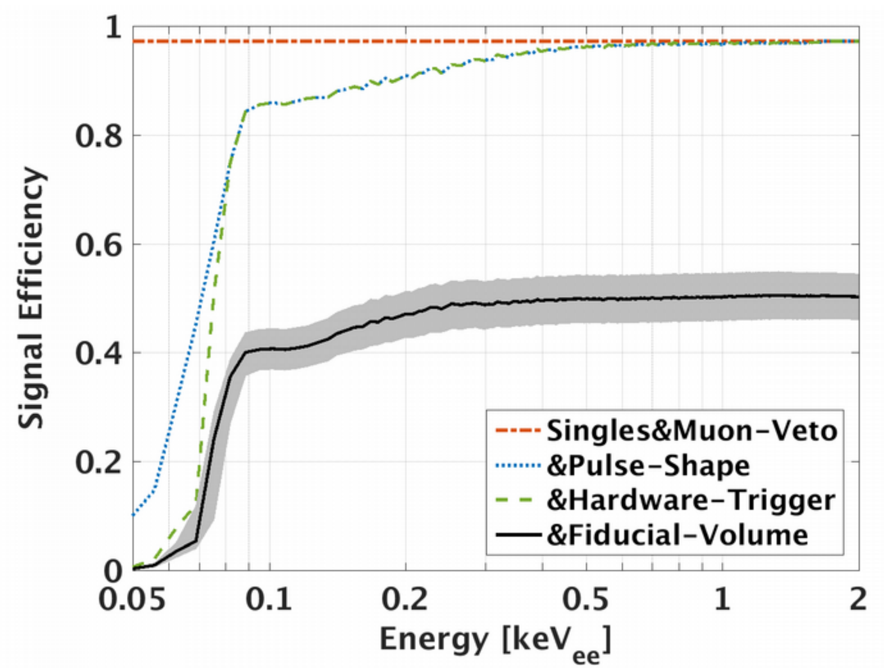


# CDMSlite Analysis

PRL **116** 071301 (2016)

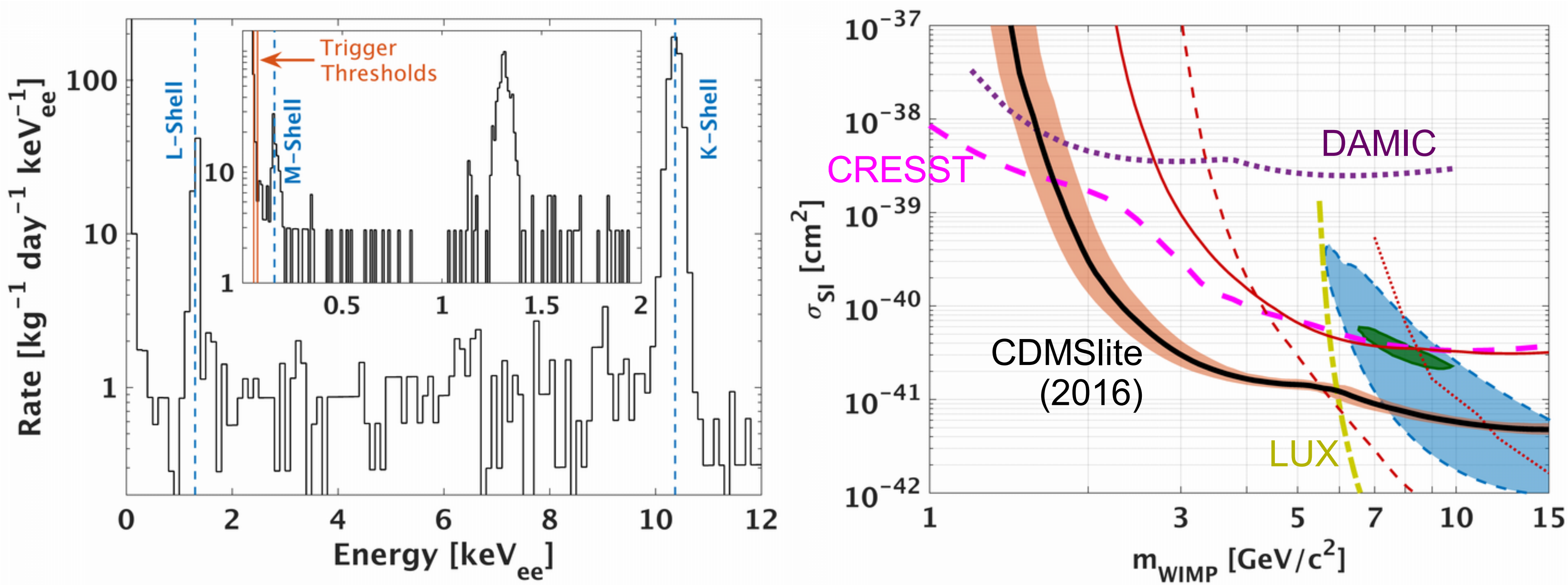
- Thresholds at 75 $eV_{ee}$ (period 1) and 56 $eV_{ee}$ (period 2) limited by low-frequency vibrations.
- Fiducial volume limited by high radius events.



# CDMSlite Analysis

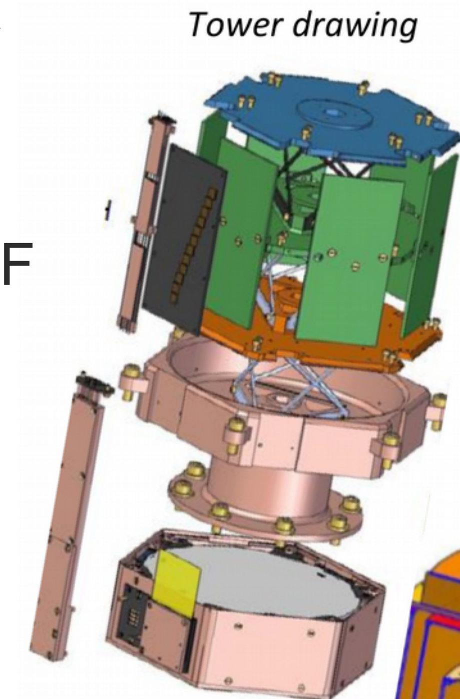
- World leading low-mass WIMP limits.

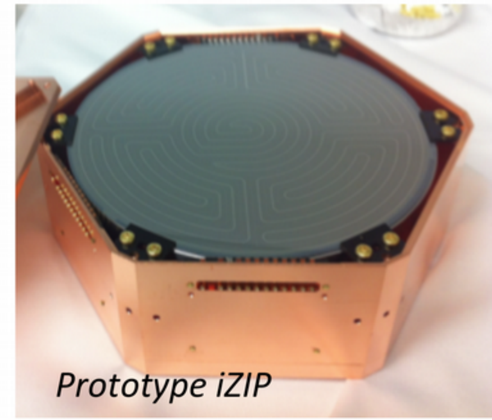


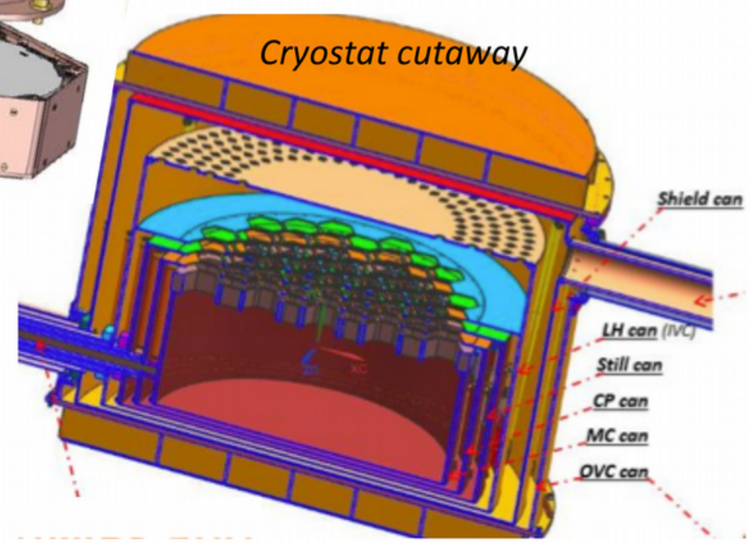

- Final data set, with lower hardware threshold, under analysis.

# SuperCDMS SNOLAB

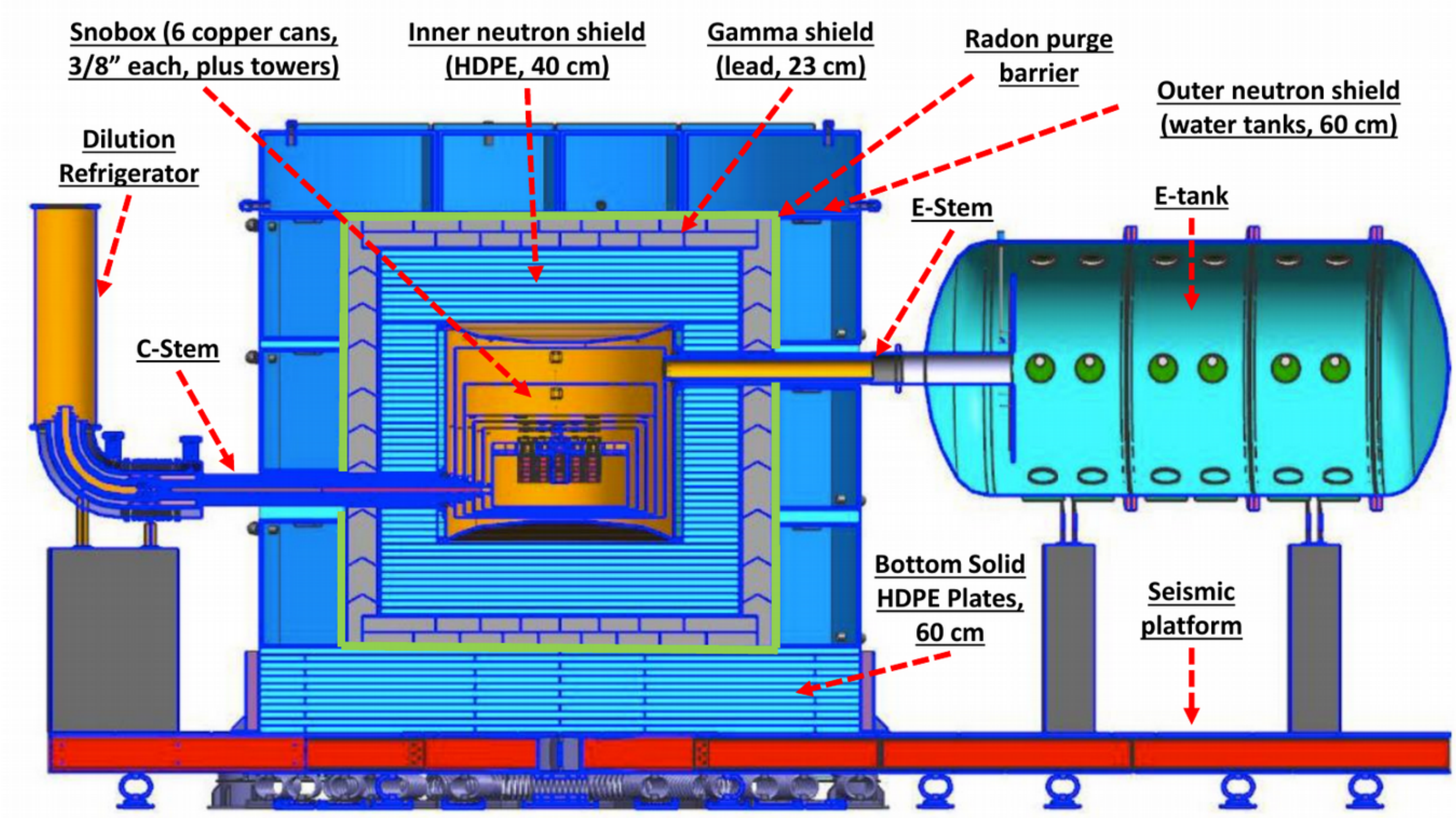
- Generation 2 dark matter direct detection experiment
  - Supported by DOE, NSF & CFI (USA & Canada)
- Facility designed to support later generation detectors



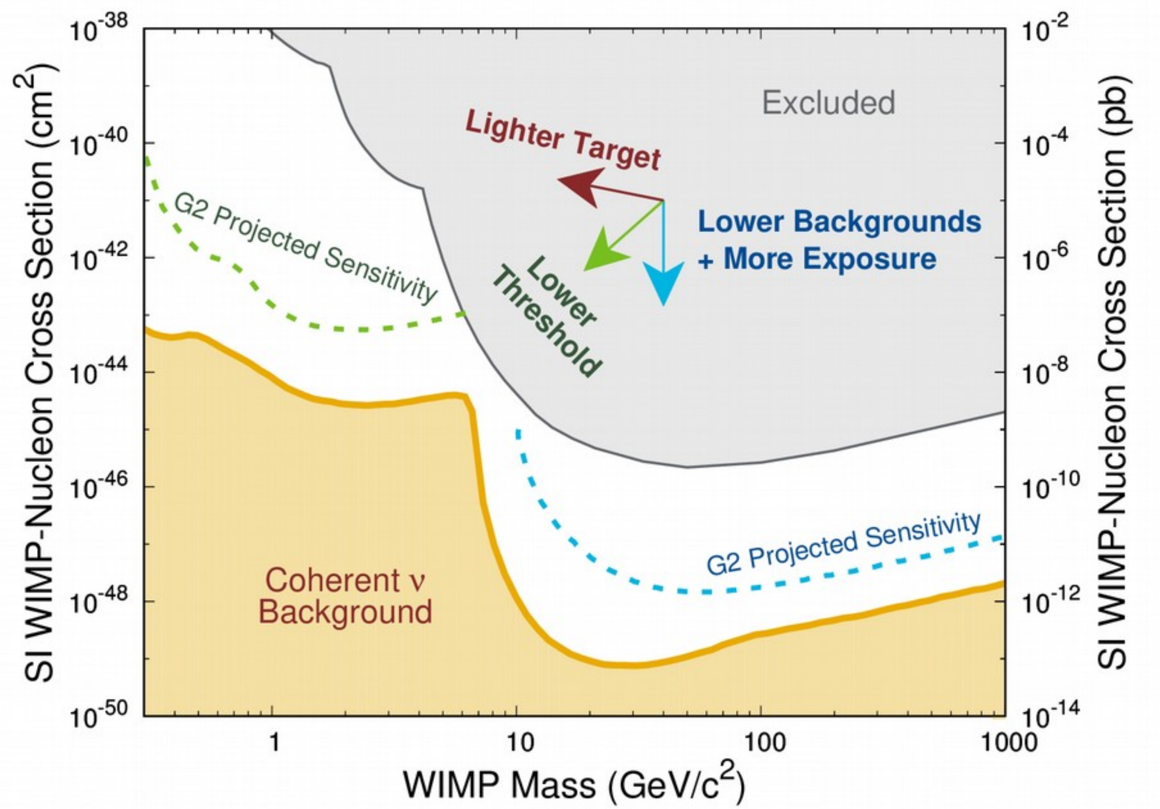



# SuperCDMS SNOLAB Conceptual Design



# SuperCDMS SNOLAB

- Lower threshold
  - Phonon optimized HV detectors with 5 eV resolution
- Lighter Si Target
  - In addition to Ge detectors
- Lower backgrounds
  - Remaining cosmogenic ER backgrounds dominate at low mass



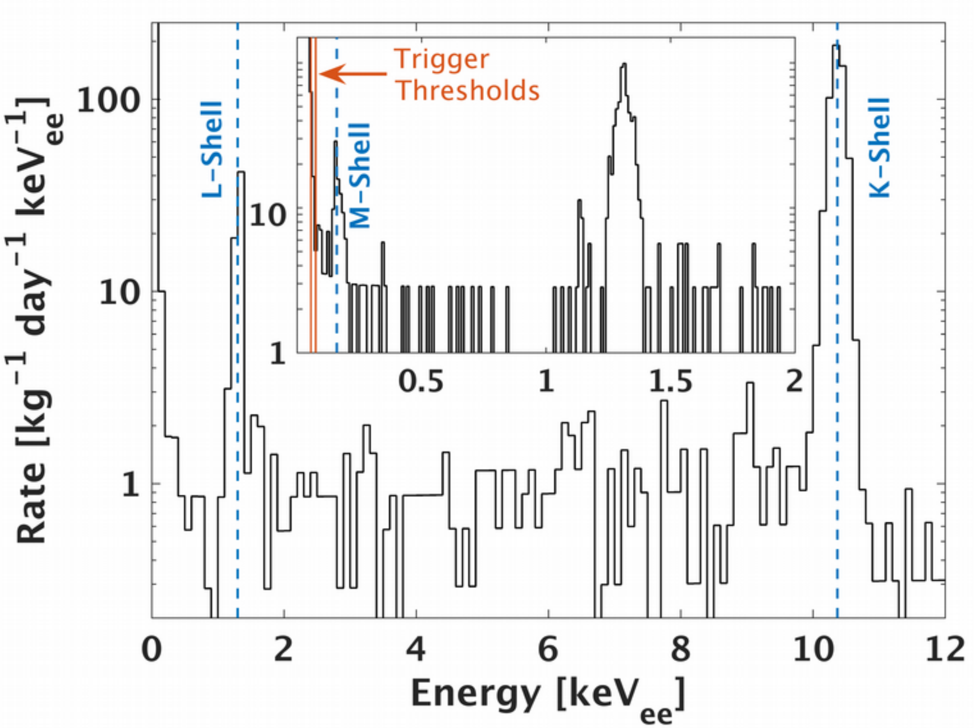
# Improved Phonon Resolution

- Optimized design of sensor and detector bandwidths
  - Athermal phonon collection time
    - Maximize collection area
  - Quasi-particle collection time
  - TES heat capacity / thermal conductance to bath
  - Electronics
- Limiting Resolution $\propto T^3$
  - 15 mK base temperature vs. >50 mK at Soudan
- Design resolutions
  - 5 (10) eV for Si (Ge) HV
  - 25 (50) eV for Si (Ge) iZIP

# Si-32 and Tritium Backgrounds

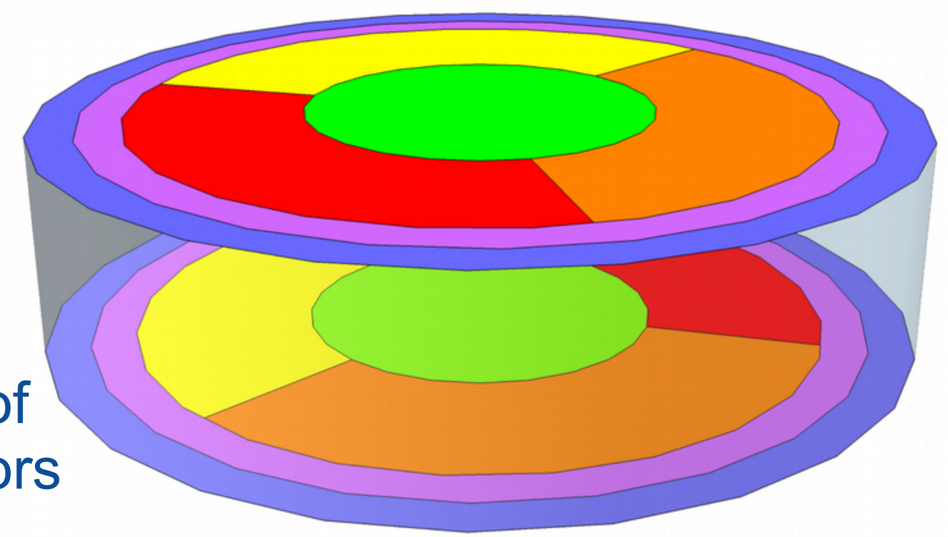
$^{32}Si$ & $^{3}H$ Low-energy β continuum

- Dominant backgrounds for SuperCDMS SNOLAB HV
- DAMIC measured $^{32}Si$ $80^{+110}/_{-65}$ (90% conf.) counts/kg/day
- EDELWEISS measured 82±21 $^{3}H$ atoms/kg/day produced at sea level
  - Consistent with CDMSlite background & calculations
    - publication in preparation



# Radioactivity in materials

- Environmental background contolled to below the $^{3}H$ contribution of ~21 counts/kg/keVee/yr
  - Surface events
    - Limited radon exposures
    - Rejection based on phonon partition and pulse timing
  - Gammas
    - Limited above ground cosmogenic exposures
    - Material screening
  - Cavern environment
    - Shielding
    - Deep underground site

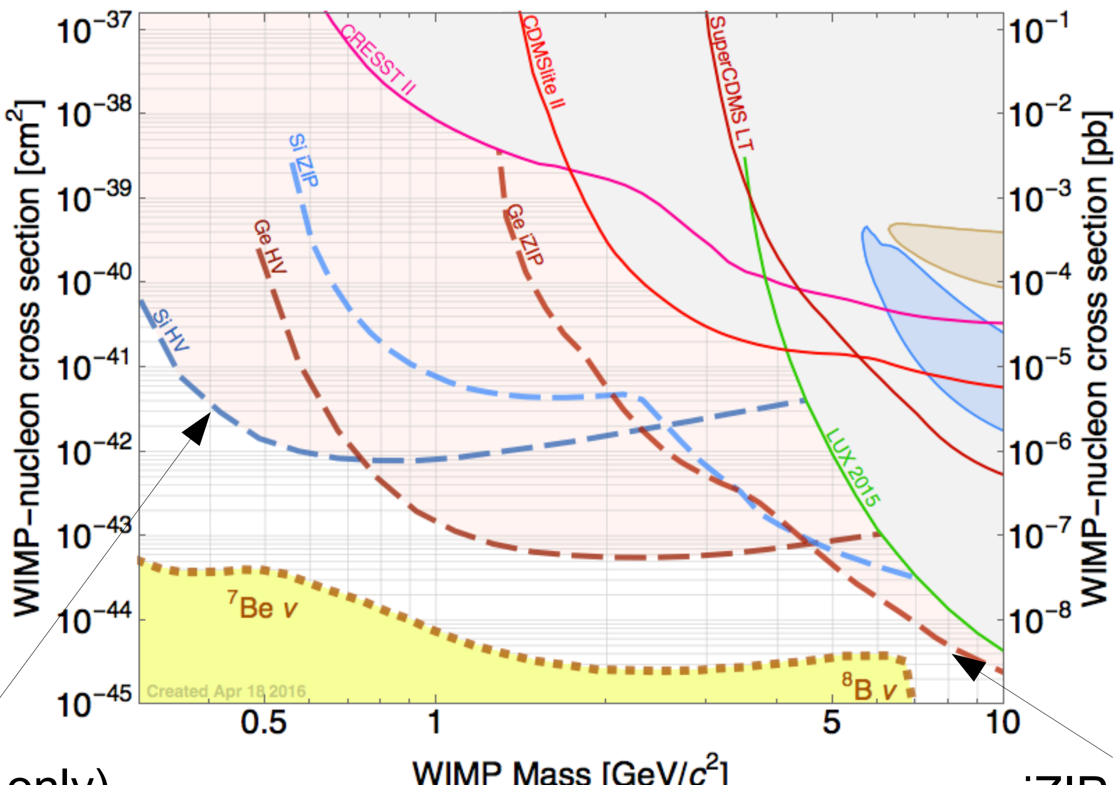


Phonon sensor layout of HV detectors

# SuperCDMS SNOLAB Reach

Expect world's best sensitivity for <10 GeV WIMPs

- Updated sensitivity projections to be released this month.



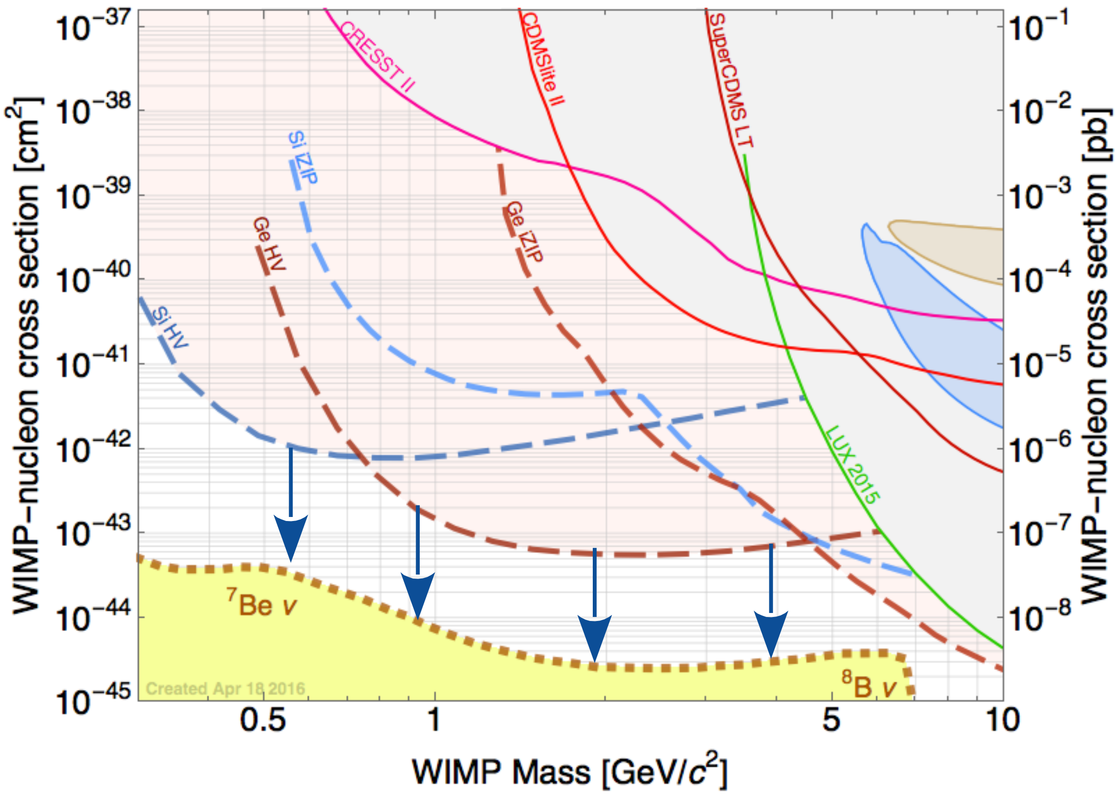

HV (phonon only) detectors will be background limited

Previously released projection

iZIP detectors will be exposure limited

# SuperCDMS SNOLAB Upgrades

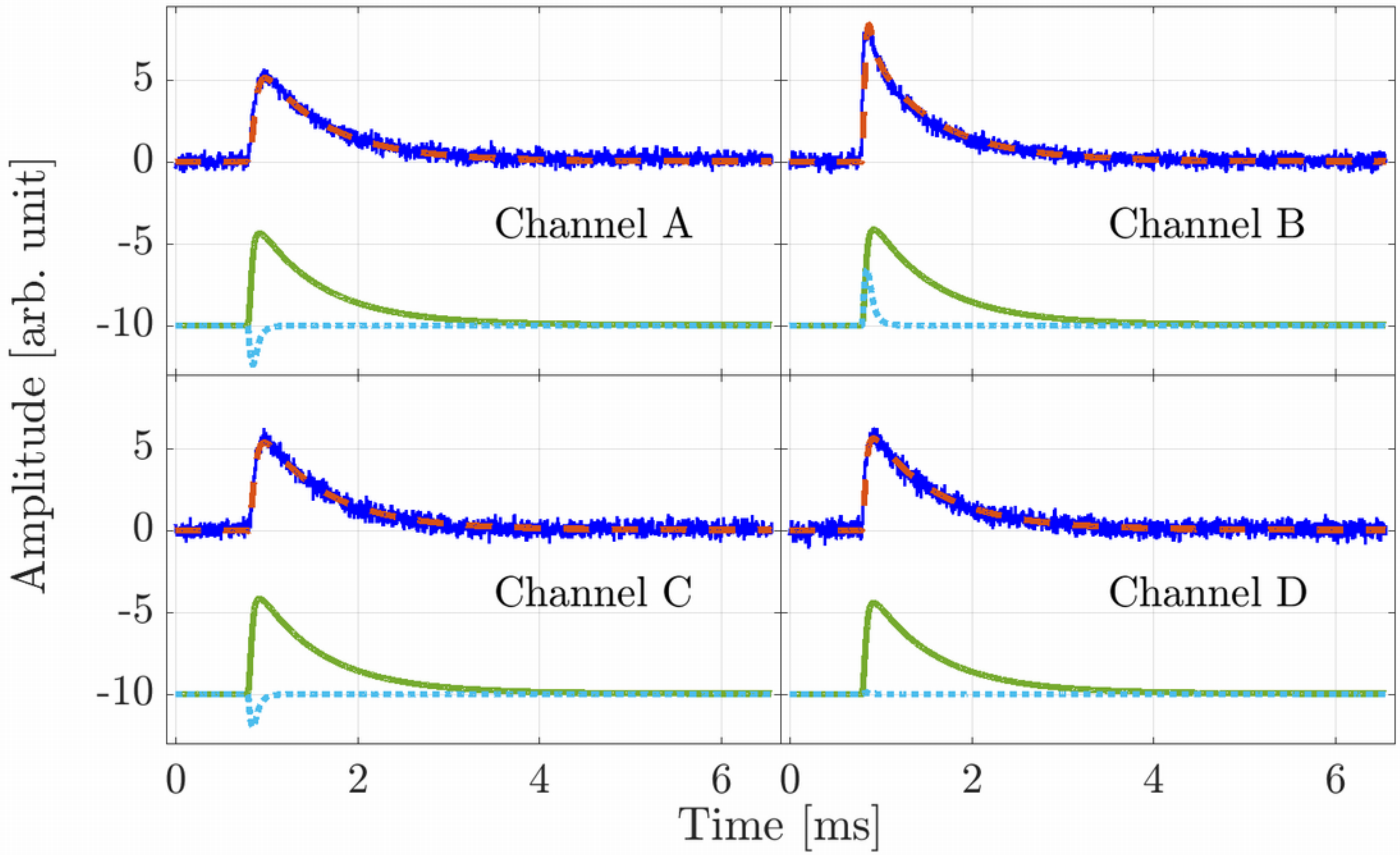
- Facility designed to host an upgraded experiment to reach the neutrino floor.
  - Requires background reduction and/or demonstrated ER/NR discrimination in HV detectors.



# Extra Slides

# Phonon Pulse Shape

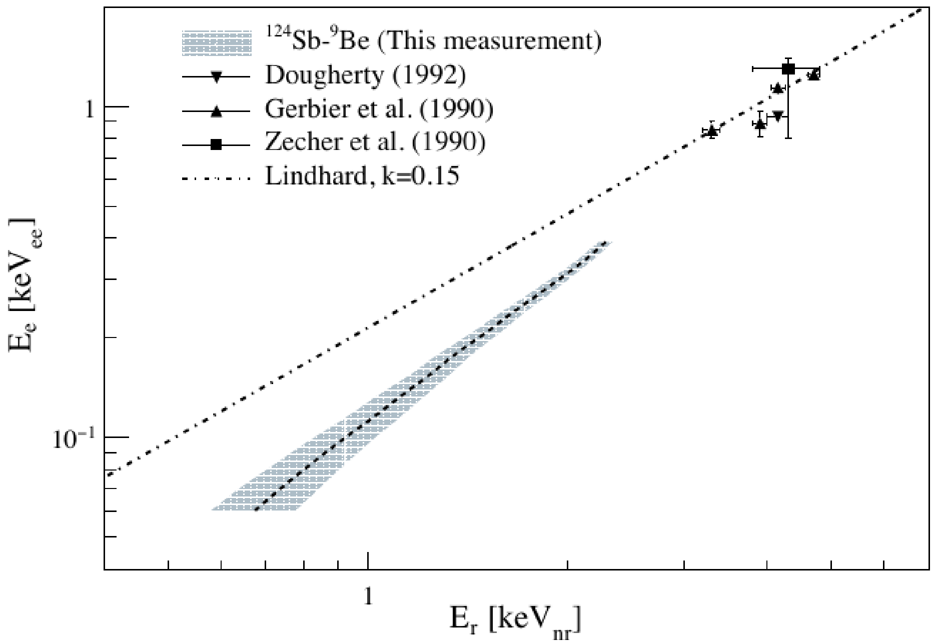
Fast (diffusive) and slow (ballistic) phonon absorption



# Ionization Yield Calibrations

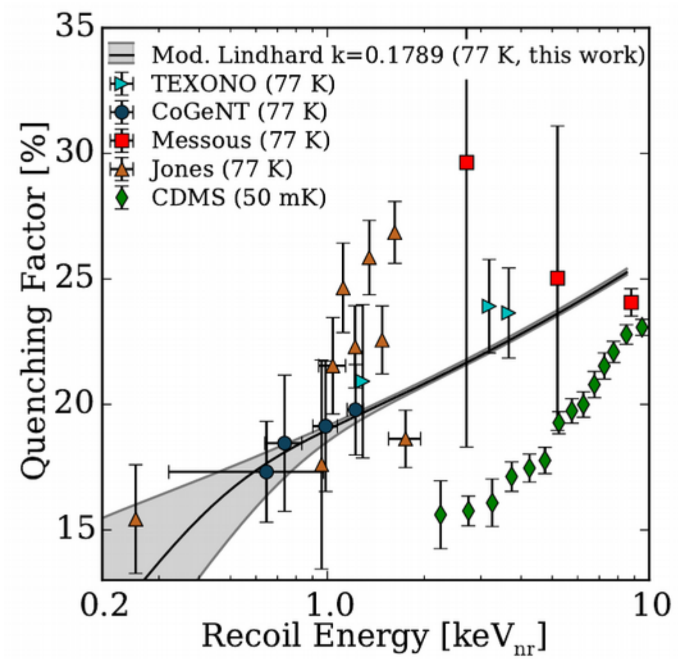
- Response to nuclear recoils at low energy requires calibration
  - Photoneutron sources
  - Thermal neutron capture recoils
  - D-D neutron scattering calibration planned

Ionization yield in Si




Chavarria et al., arXiv:1608.00957

Ionization yield in Ge




Scholtz et al., arXiv:1608.03588