Searching for low-mass dark matter particles with the SuperCDMS experiment

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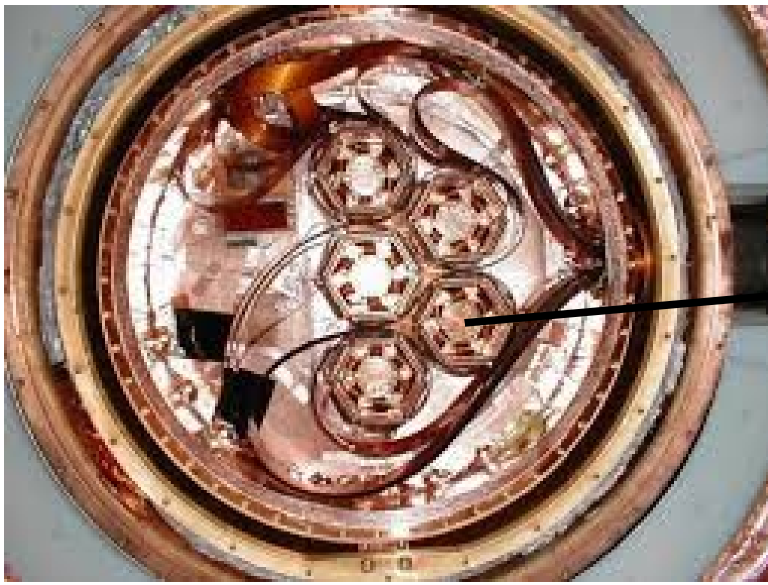
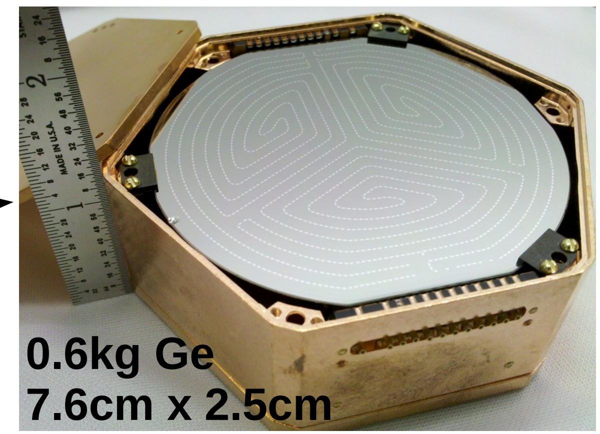
Lake Louise Winter Institute 2017

SuperCDMS Soudan: Overview

Underground laboratory at SOUDAN:

~800m deep, ~2090 m.w.e.



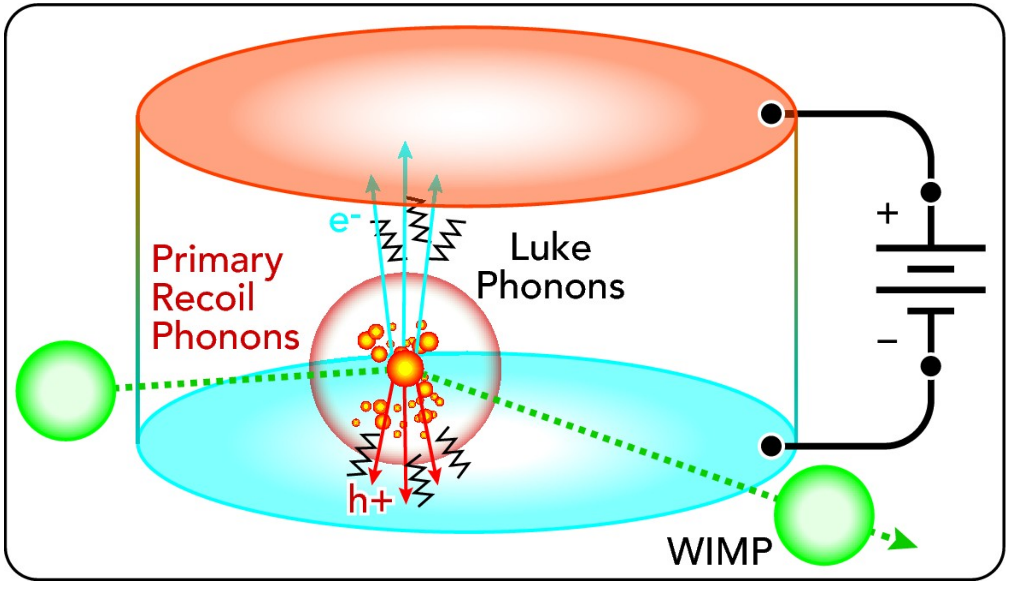


- 15 detectors in 5 towers.
- 9kg Ge total.
- iZIP detectors:
  - Ionization and Phonon signal.
  - Operated in normal and **HV mode**.
- HV mode data: **CDMSlite**.

- SuperCDMS Soudan operational until late 2015.
- SuperCDMS SNOLAB construction starting 2017:
  - Will be deeper, larger, more sensitive!

CDMSlite Detection Principle

lite: **l**ow **i**onization **t**hreshold **e**xperiment



Standard iZIP mode

- Primary phonon and ionization signal:

  => allows NR/ER discrimination.

  NR, ER: **N**uclear **R**ecoil, **E**lectron **R**ecoil

CDMSlite: HV mode

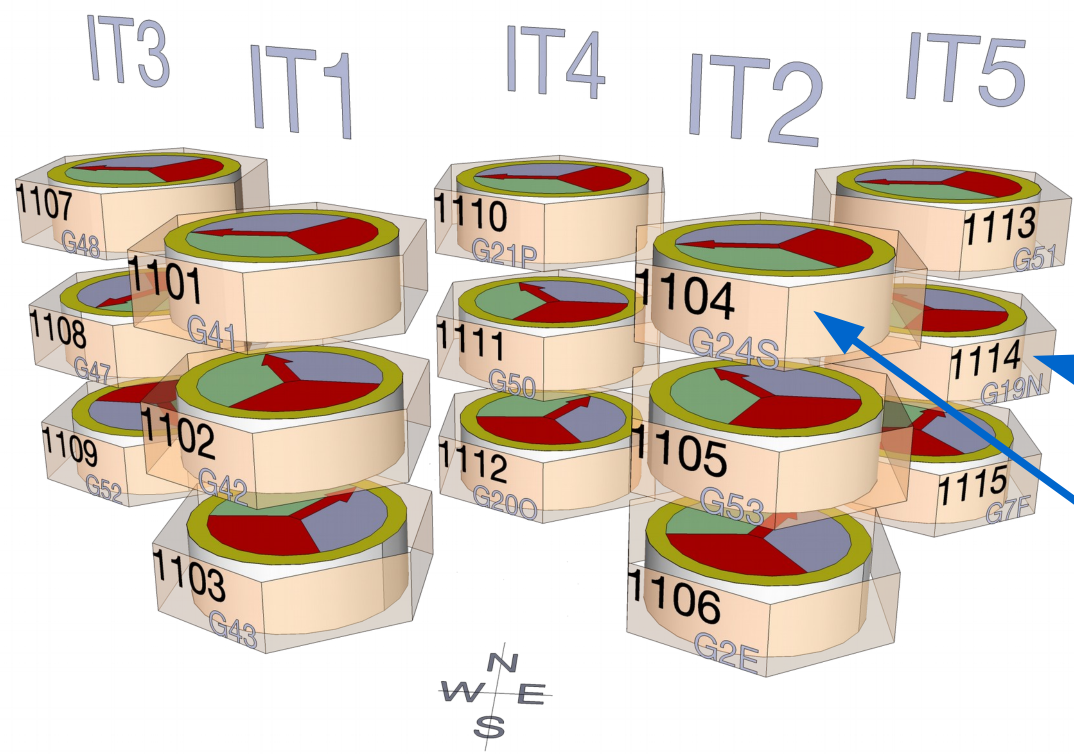
- e^-/h^+ produce extra phonons as they drift to electrodes: Neganov-Trofimov-Luke phonons (NTL).
- **#NTL phonons ∾ V_{bias}:**

  => large V_{bias} yields large *phonon* amplification of *ionization* signal.

NTL amplification enables very low thresholds => low WIMP masses.

Trade-off: NTL phonons mix ionization and phonon signal => no NR/ER discrimination.

CDMSlite Data from 3 Runs



One iZIP in HV mode for CDMSlite:

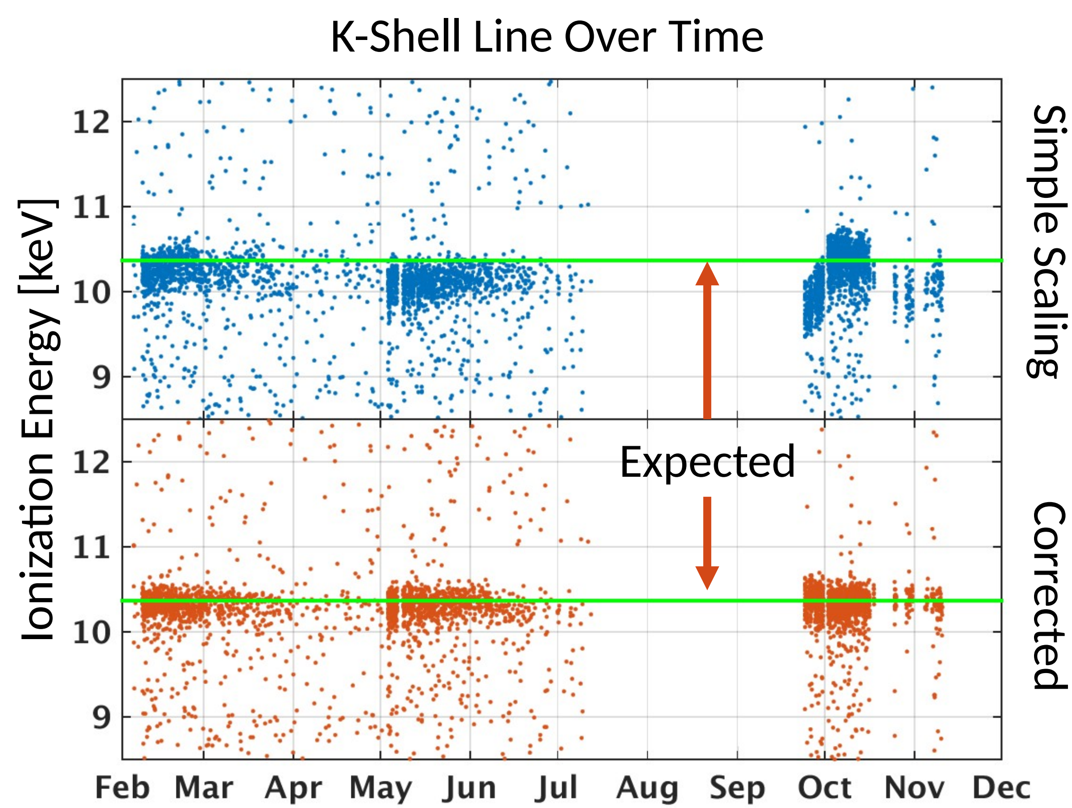
Run 1-2

Run 3

- Run 1: Aug. - Sep. 2012
- **Run 2a: Feb. - July 2014**
- **Run 2b: Sep. - Nov. 2014**
- Run 3: Feb. - May 2015

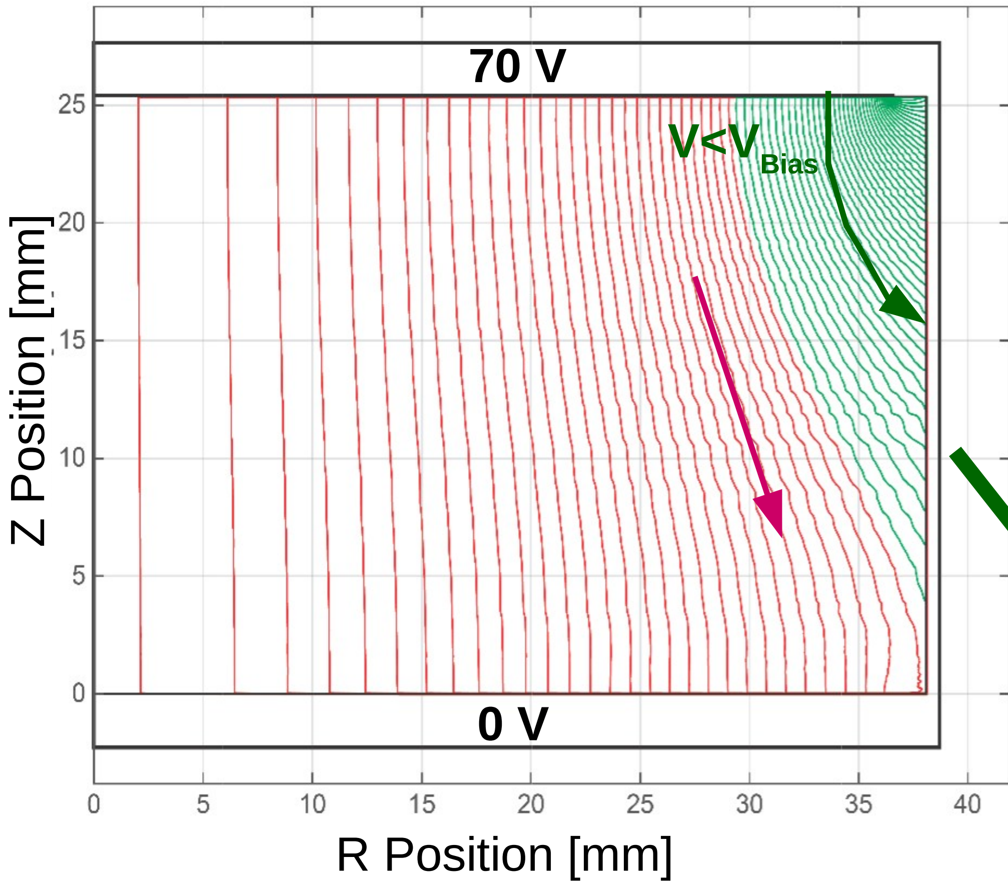
Ionization Energy Scale Calibration
(Run 2)

- ^{252}Cf neutron source:
  - $^{70}Ge + n \rightarrow {}^{71}Ge$.
  - ^{71}Ge decays via electron-capture.
  - Well-known energy released in K-, L- and M-shell captures:
    - K-shell (BR ≲88%): 10.37 keV.
    - L-shell (BR ≲11%): 1.30 keV.
    - M-shell (BR ≲2%): 0.16 keV.
- High-statistics K-shell capture used for calibration.

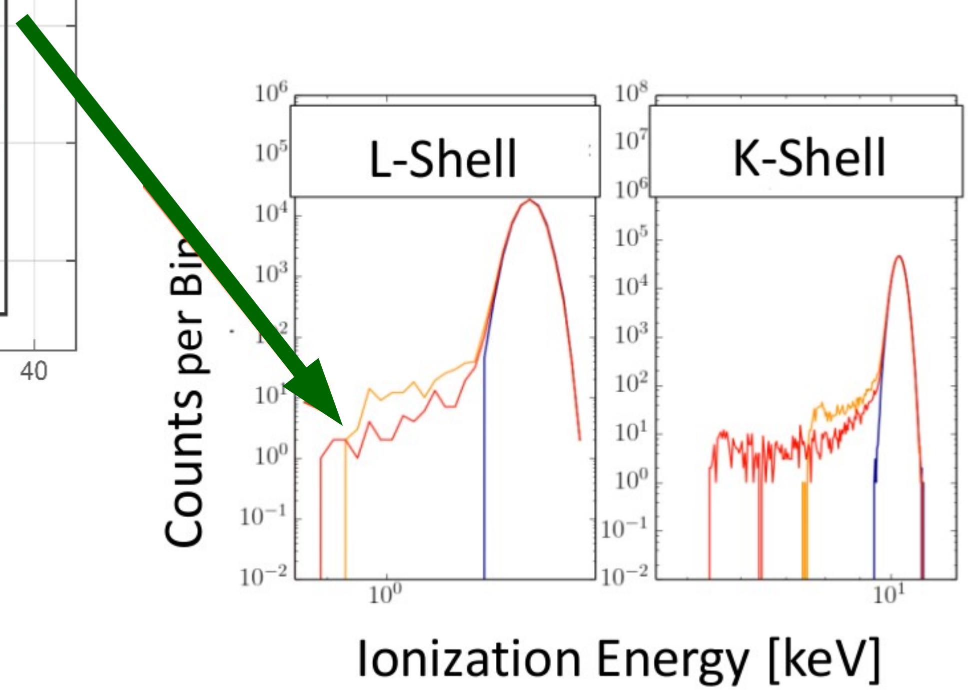


- Correcting for changes in environmental and operational conditions:
  - Base temperature.
  - Parasitic resistances.
  - Position dependence.

Fiducial Radius



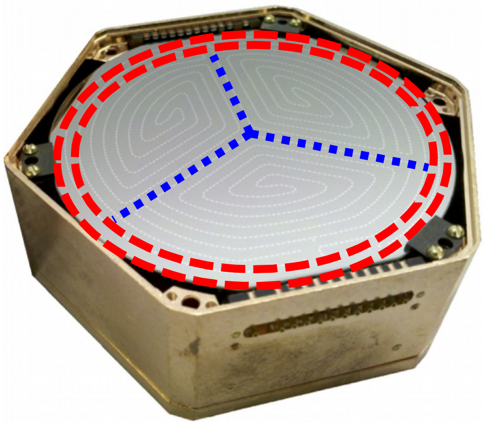
- Grounded sidewall and one-sided readout:
  - e/h pairs created at large radii traverse V< V_{bias}.
    - Reduces NTL amplification.
    - Adds low energy tail to spectrum.



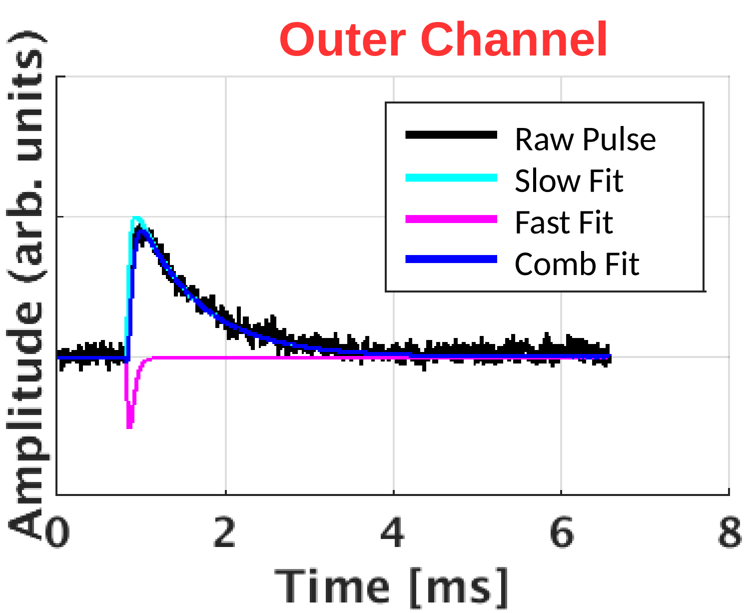
Empirical Radial Parameter

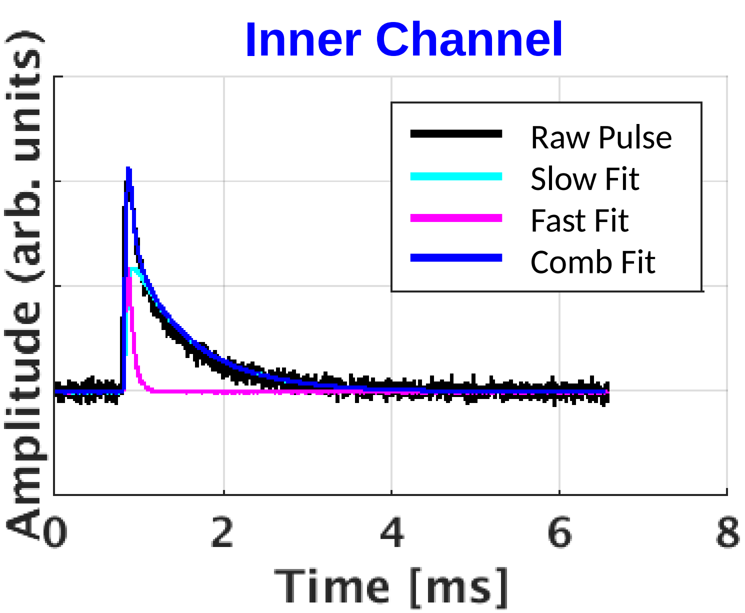
1 Outer Phonon Channel

3 Inner Phonon Channels

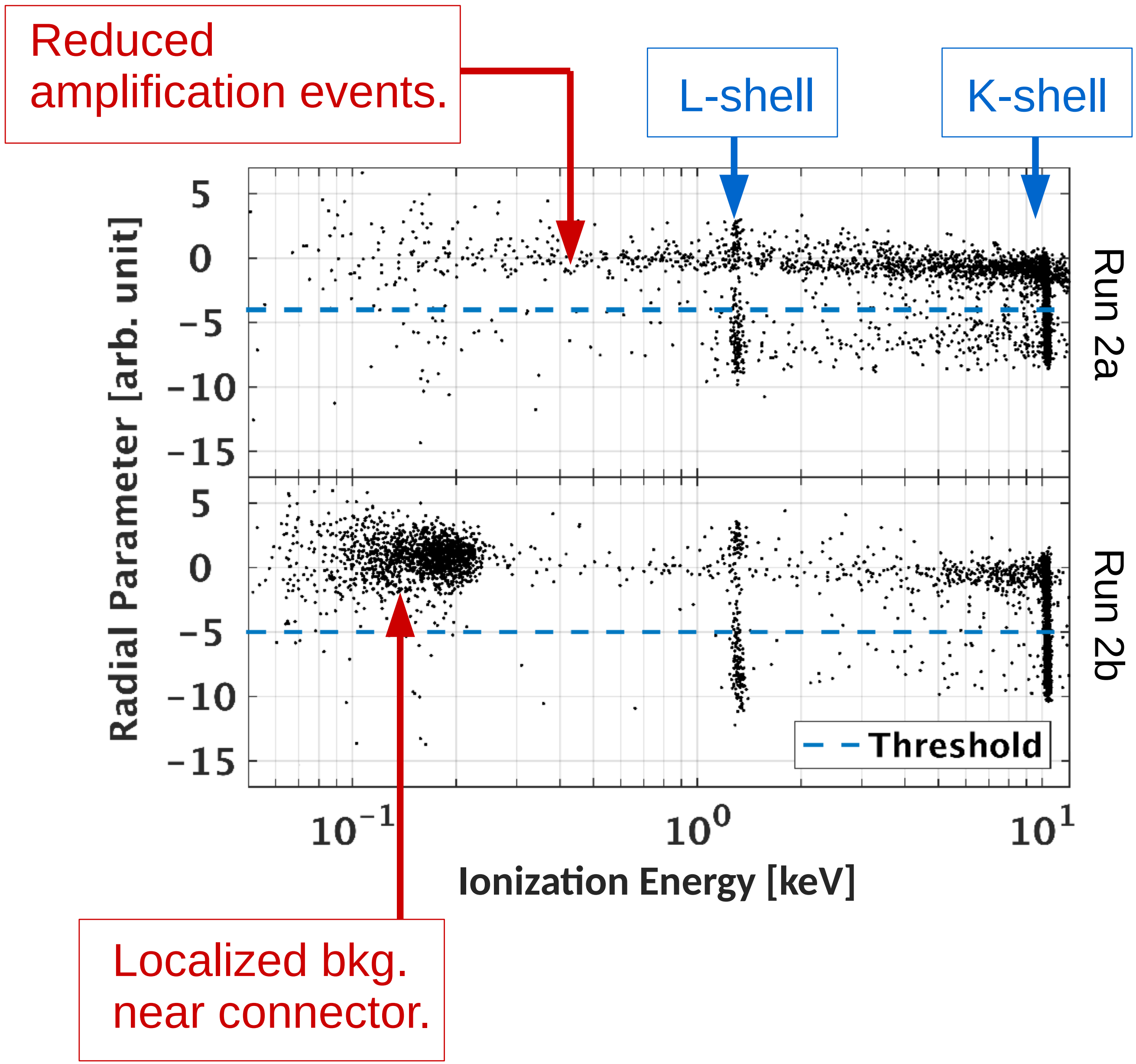


- 2-Template Fit:
  - Use difference in fast component to derive empirical radial parameter.



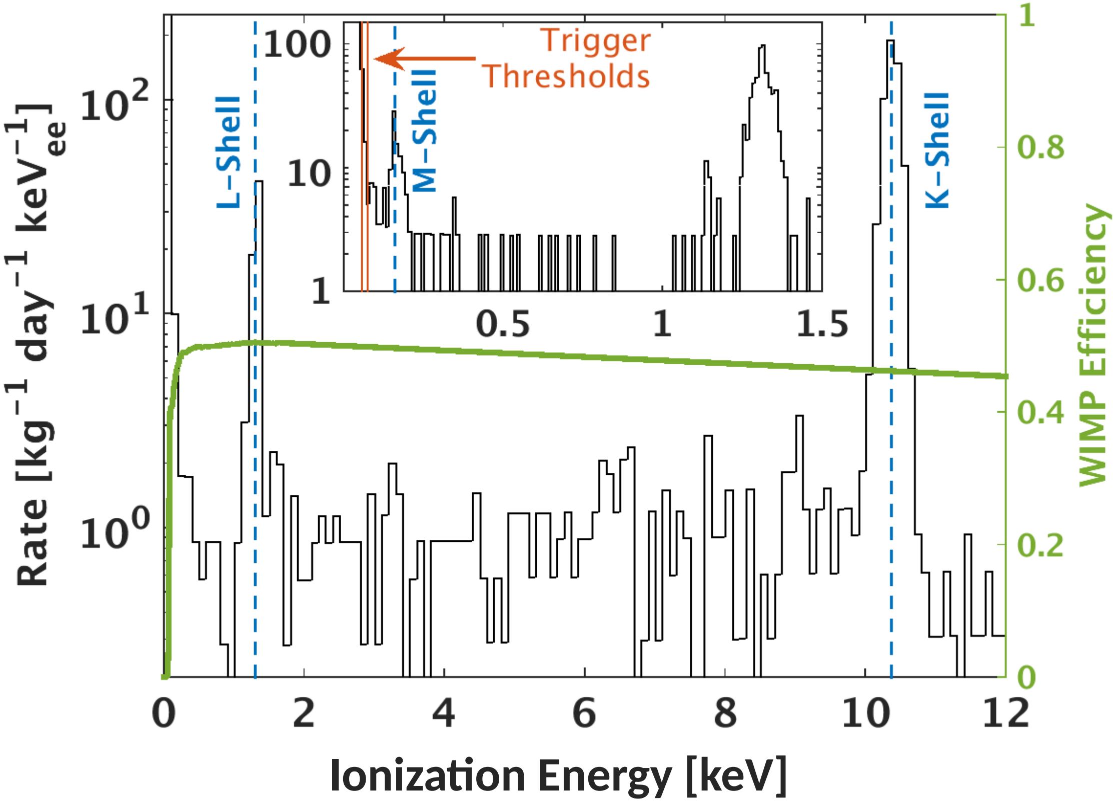


Fiducial Radial Cut



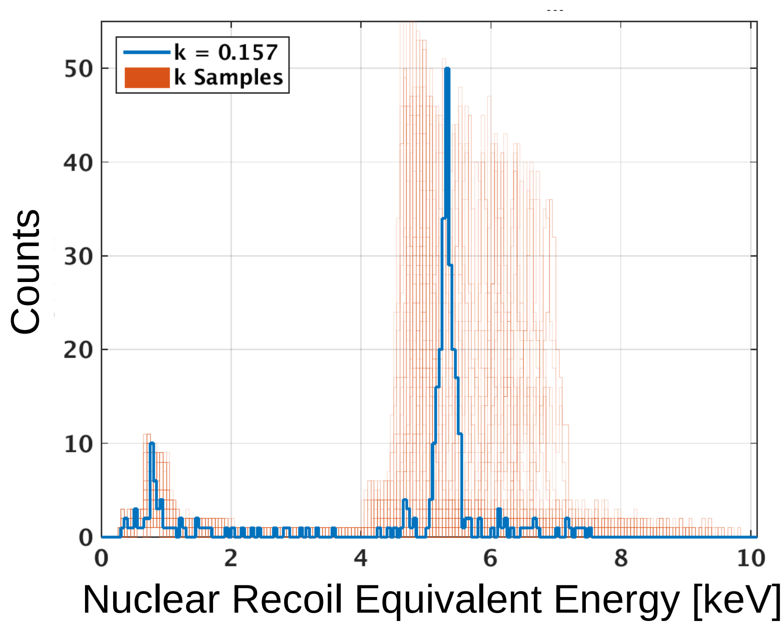
- >90% of reduced amplification events removed by cut.
- Tighter cut in Run 2b.

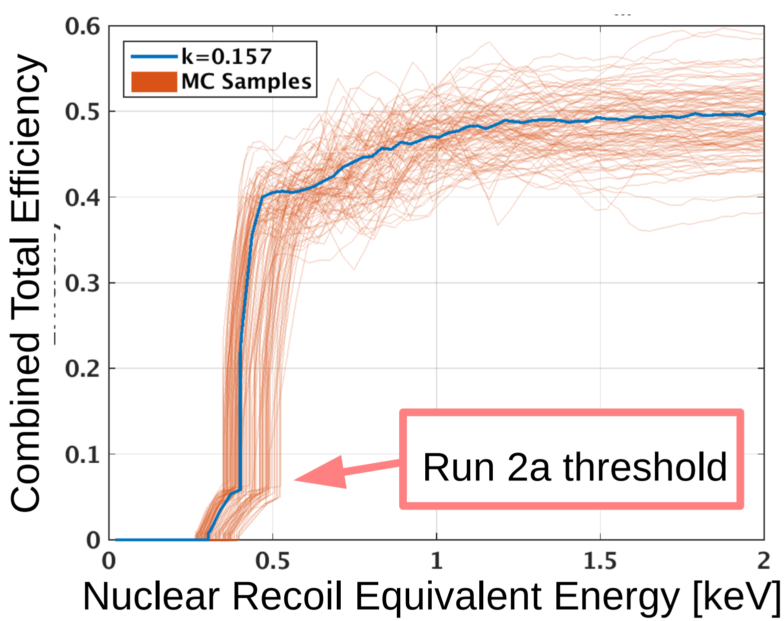
Energy Spectrum (Run 2)



- Corrected for all efficiencies, except trigger.
- ~1 count/(keV·kg·d) between K- and L-peaks.
- Trigger threshold (i.e. 50% trigger efficiency) at:
  - 75^{+4}_{-5} eV (Run 2a).
  - 56^{+6}_{-4} eV (Run 2b).

Setting the Limit (Run 2)





- Using Optimal Interval* with no background subtraction.
- Converting to Nuclear Recoil (NR) equivalent energy using Lindhard model:

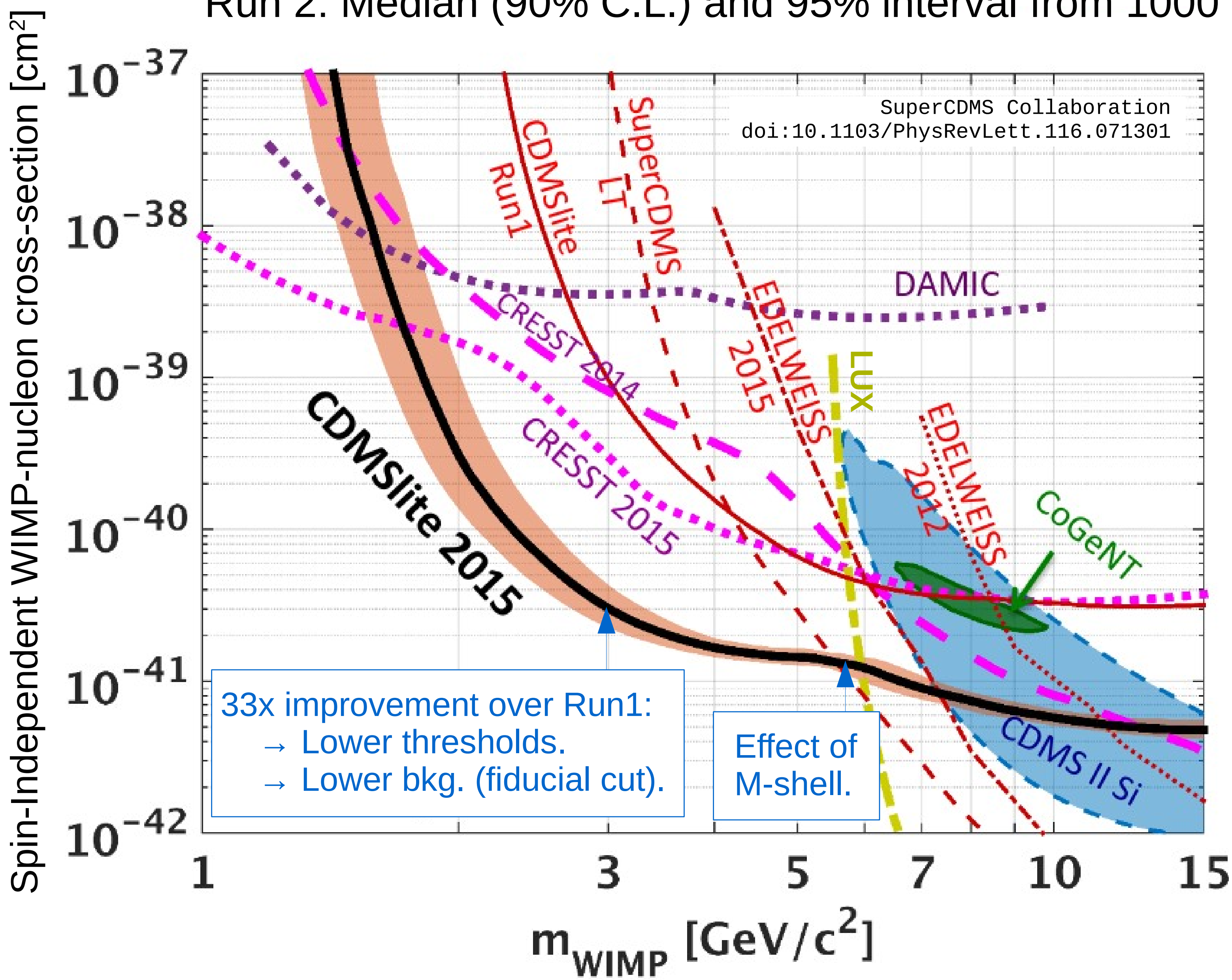
$$Y\left(E_{\mathrm{nr}}\right) = k\left(Z,A\right)\cdot\frac{g\left(E_{\mathrm{nr}},Z,A\right)}{1+k\left(Z,A\right)\cdot g\left(E_{\mathrm{nr}},Z,A\right)}$$

- Creating 1000 samples with input parameters drawn from uncertainty distributions.
  - *k(Ge)* = 0.157, scanned over [0.1, 0.2].
  - Final result given by median.
  - Uncertainty given by distribution.

*S. Yellin, Phys. Rev. D 66, 032005 (2002).

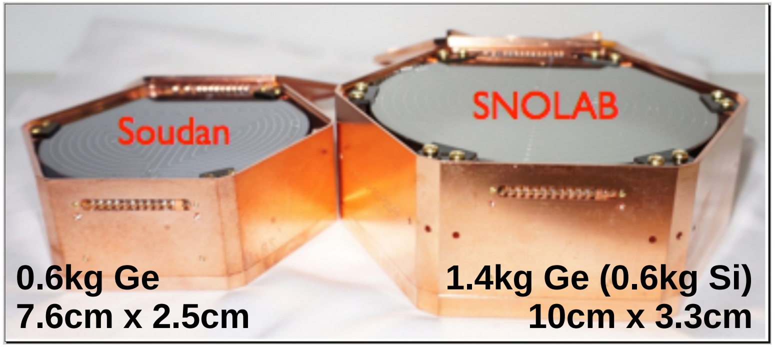
CDMSlite Run 2 WIMP limit

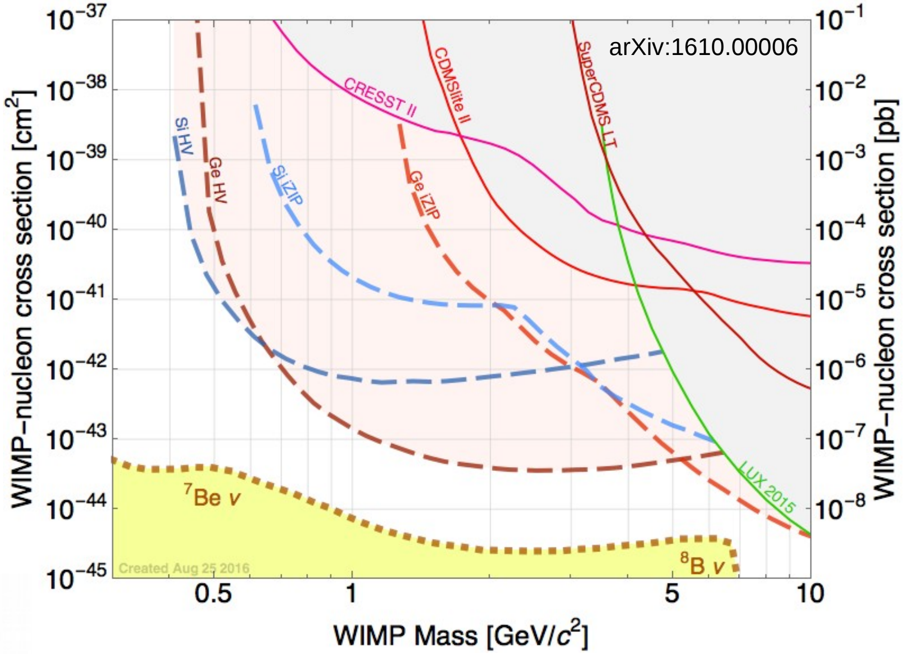
Run 2: Median (90% C.L.) and 95% interval from 1000 samples.

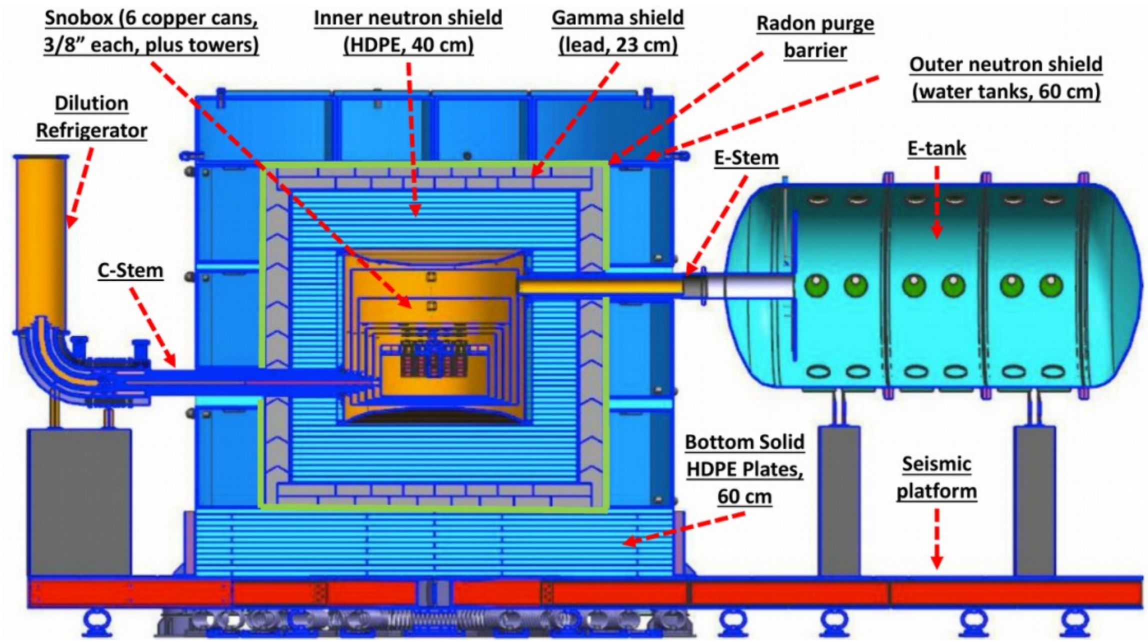


Outlook: SuperCDMS SNOLAB

Initial program: 5 yrs of operation (2020-2024), 80% livetime







Initial payload:

- 24 detectors in 4 towers.
- 25kg Ge, 3.6kg Si total.
- 12 iZIP and 12 dedicated HV detectors.

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

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

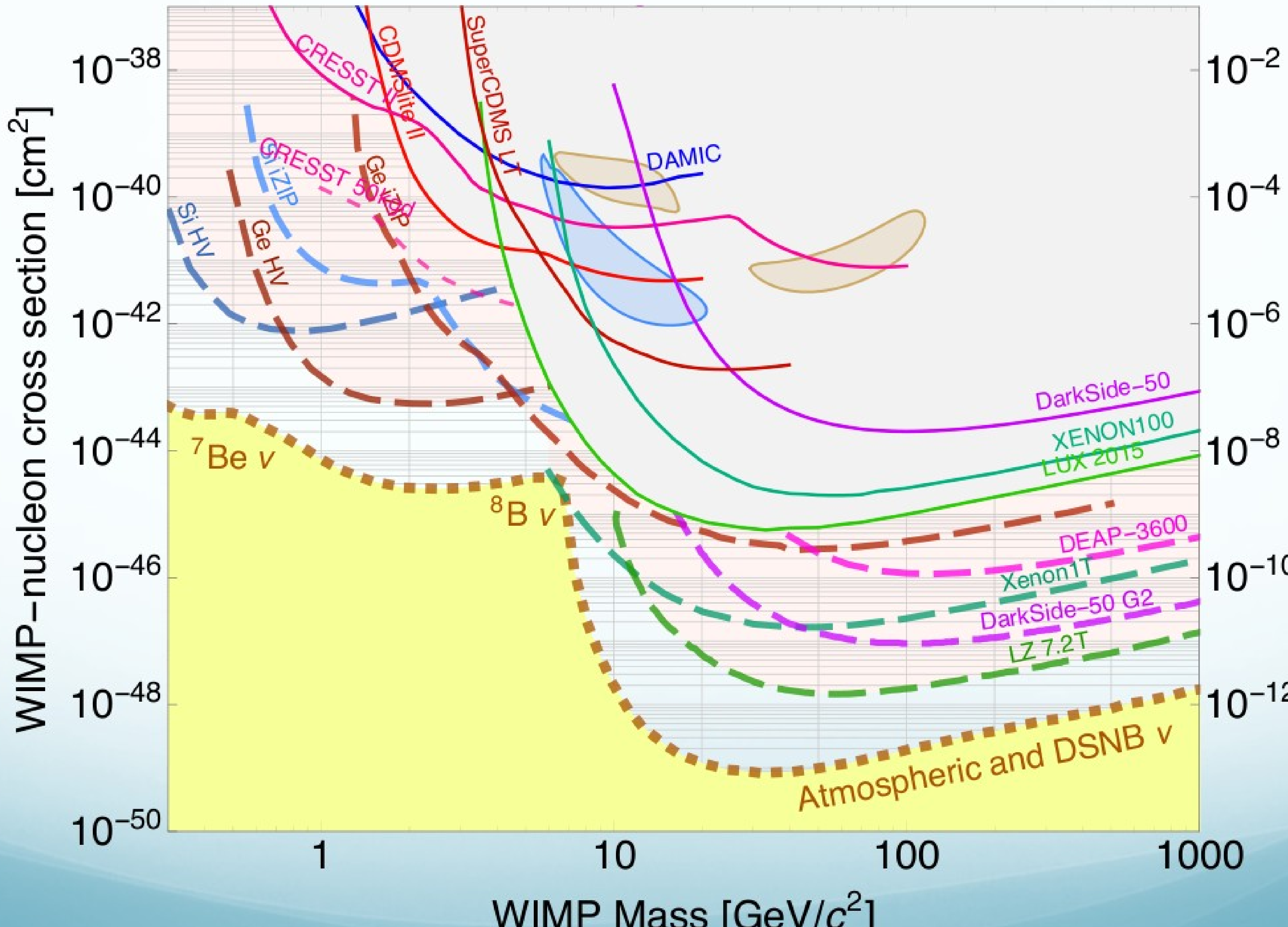
SMU | Santa Clara U. | South Dakota SM&T | Stanford University | Texas A&M University | U. British Columbia

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

* Associate members

Back-up Slides

SuperCDMS SNOLAB Sensitivity



Recoil Energy Calculation

total phonon energy including primary and Neganov-Luke phonons

recoil energy in SuperCDMS detectors

$$E_{recoil} = \frac{E_{total}}{1 + Y_{ionization} \cdot \frac{eV_{bias}}{\varepsilon}}$$

bias voltage, ~70V for CDMSlite

energy for e/h pair, 3eV in Ge

ionization yield, =1 for ER, <1 for NR

$$Y_{ionization} = \frac{E_{ion}}{E_{recoil}}$$

Accurate E_{recoil} measurement requires knowledge of $Y_{ionization}$:

- For iZIP detectors measurement of $Y_{ionization}$ on an event-by-event basis.
- **For HV detectors direct measurement of $Y_{ionization}$ not possible!**

→ CDMSlite results to date use Lindhard theory (k=0.157).

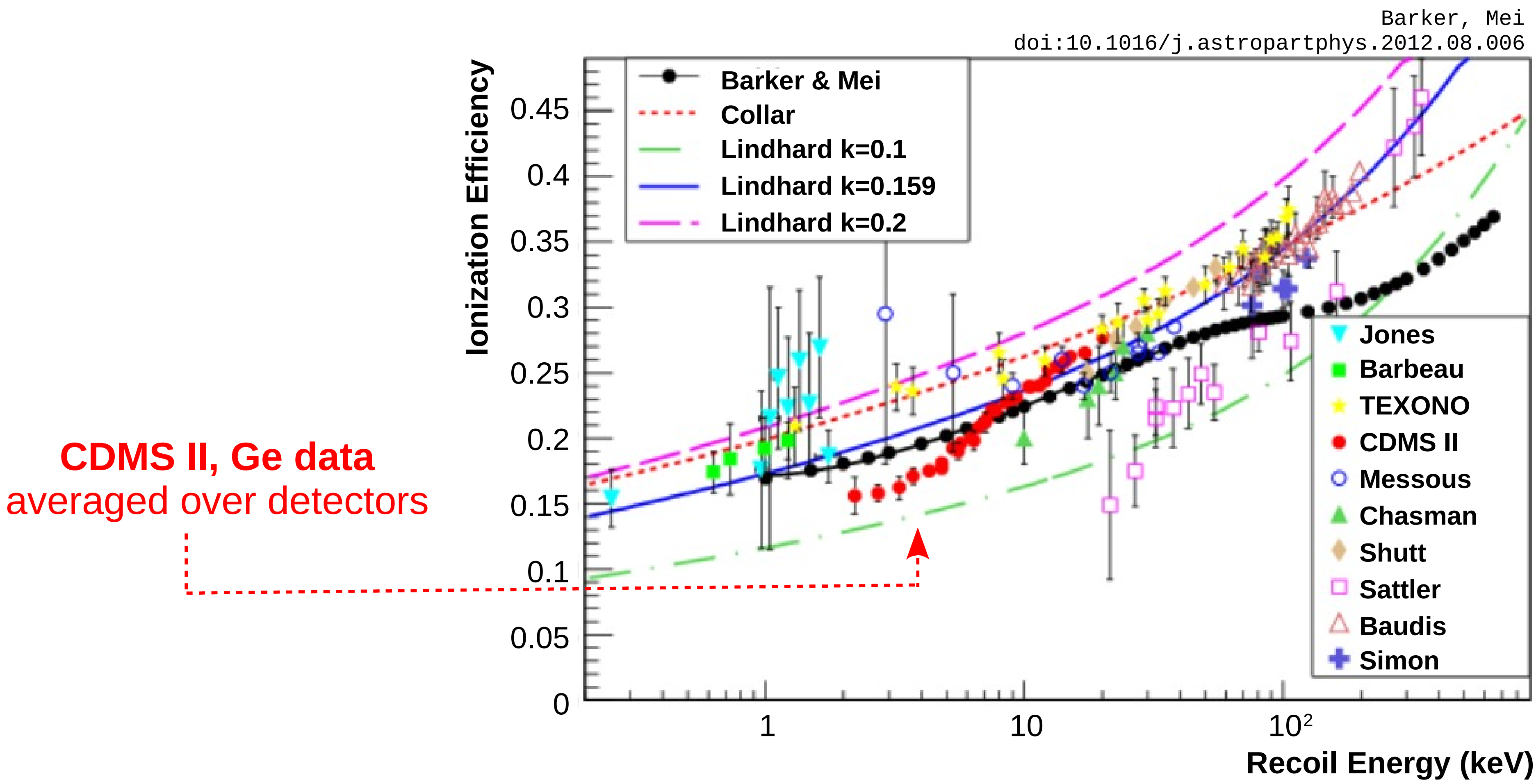
Ionization Yield: Lindhard

Lindhard:

$$Y\left(E_{\text{recoil}}\right) = k\left(Z,A\right)\cdot\frac{g\left(E_{\text{recoil}},Z,A\right)}{1+k\left(Z,A\right)\cdot g\left(E_{\text{recoil}},Z,A\right)}$$

$$k_{\text{Ge}} = 0.157$$

Ge:
Z=32, A=72.64



Outlook: Run 3

- Run conditions compared to Run 2:
  - Higher bias voltage: 75 V instead of 70 V.
  - Less exposure: ~40 kg-d instead of ~59 kg-d (Run 2a) + ~11 kg-d (Run 2b).
  - BUT lower threshold: $\gtrsim$50 eV instead of 56 eV (Run 2b).
  - Different detector in different tower.

- Ongoing efforts:
  - "Salting" of data for unbiased analysis.
  - Calibration of nuclear energy scale with photoneutron sources.
  - Development of low-energy background model.
  - Improvement of 2-template fit and radial parameter.