SuperCDMS SNOLAB Status & Prospects

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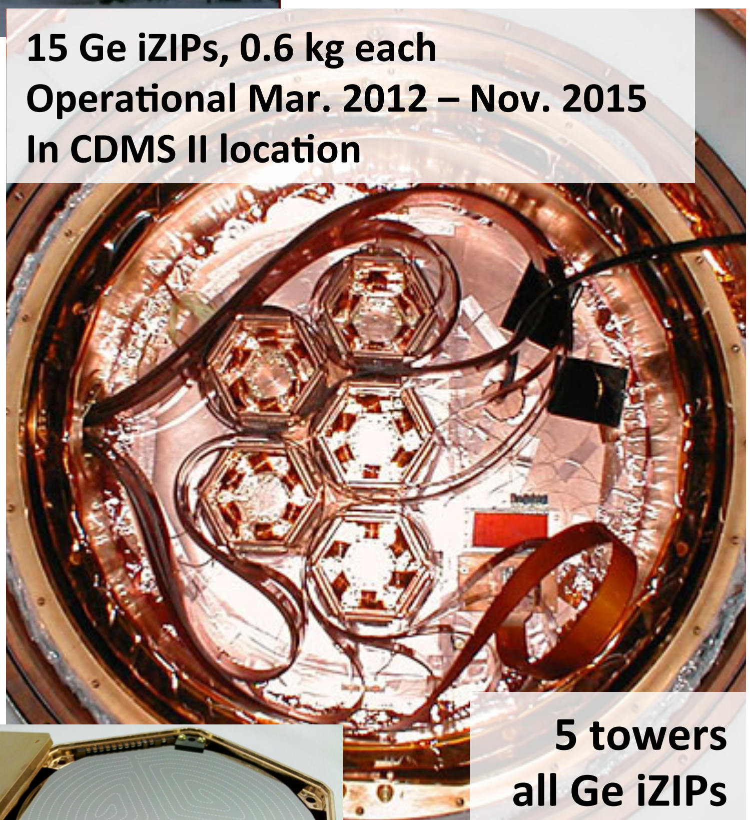
SuperCDMS

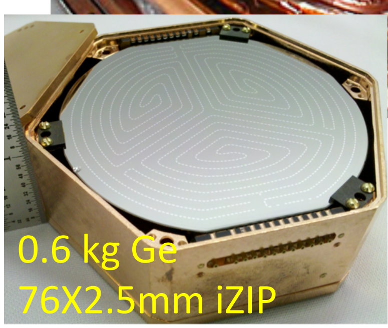
SOUDAN

Leading limits published on low mass WIMPs



15 Ge iZIPs, 0.6 kg each
Operational Mar. 2012 – Nov. 2015
In CDMS II location

5 towers
all Ge iZIPs

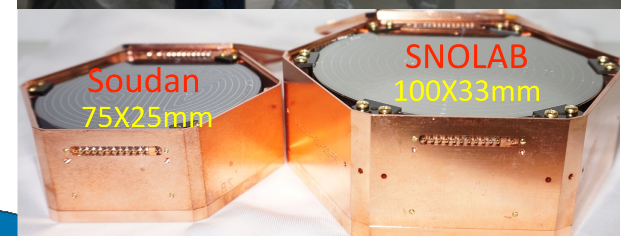


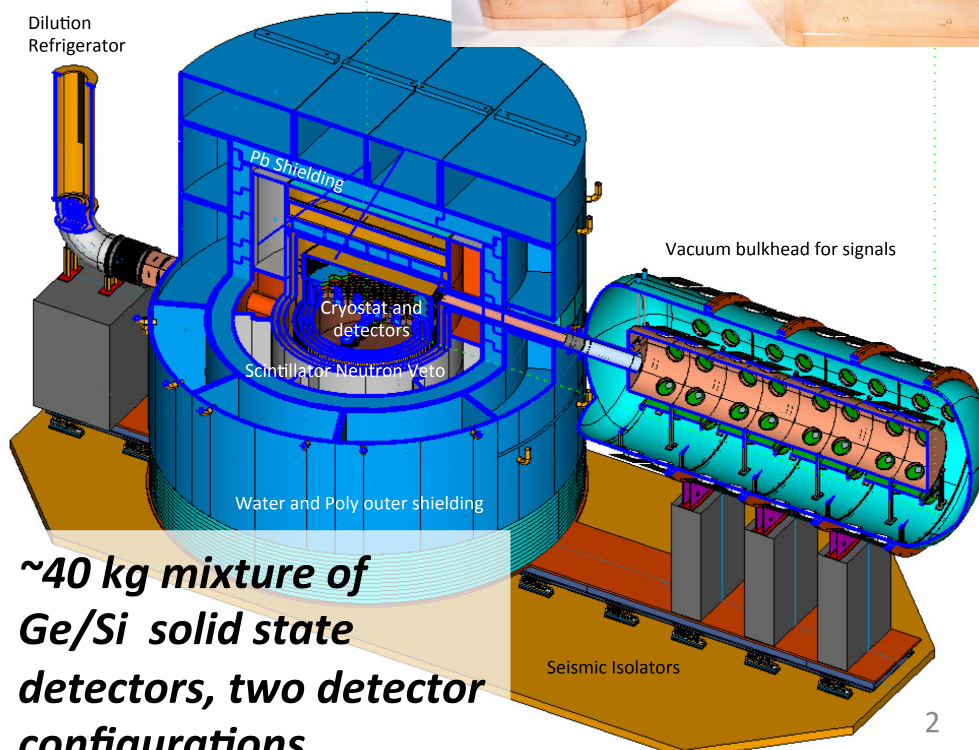
Operation ended late 2015

SNOLAB

Generation-2 experiment, beginning ~2019

Aiming for unique sensitivity to low mass WIMPs



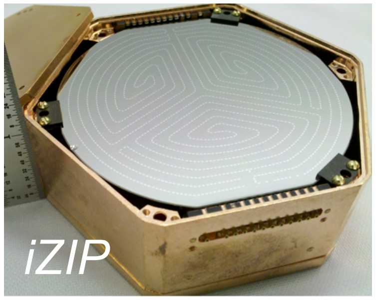


~40 kg mixture of Ge/Si solid state detectors, two detector configurations

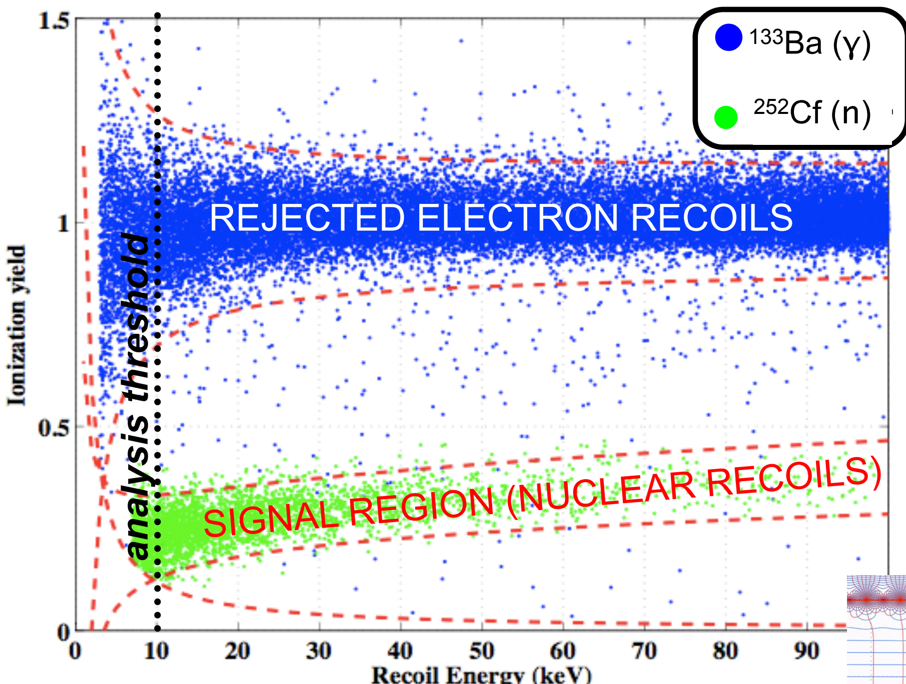
The SuperCDMS Collaboration

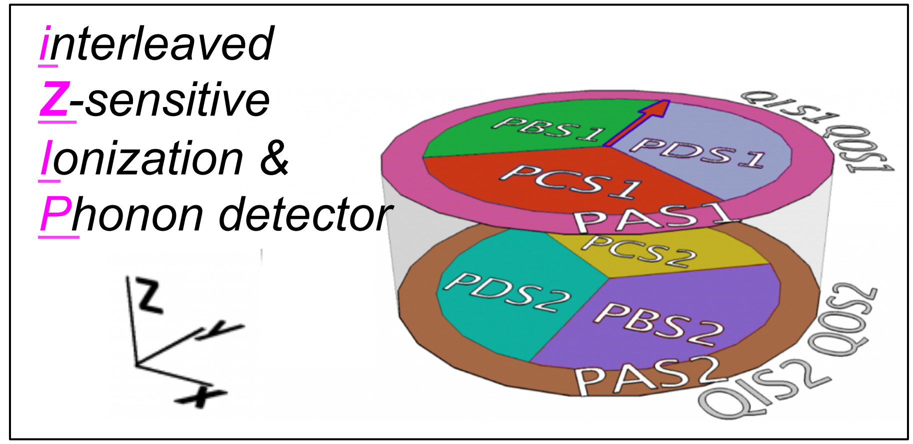
California Inst. of Tech.
CNRS-LPN*
Durham University
FNAL
NISER
NIST*
Northwestern U.
PNNL
Queen's University
SLAC
SMU
Santa Clara U.
South Dakota SM&T
Stanford University
Texas A&M University
U. British Columbia
U. California, Berkeley
U. Colorado Denver
U. Evansville
U. Florida
U. Minnesota
U. South Dakota
U. Toronto

* Associate members



iZIPs: Ionization & Phonon Detectors

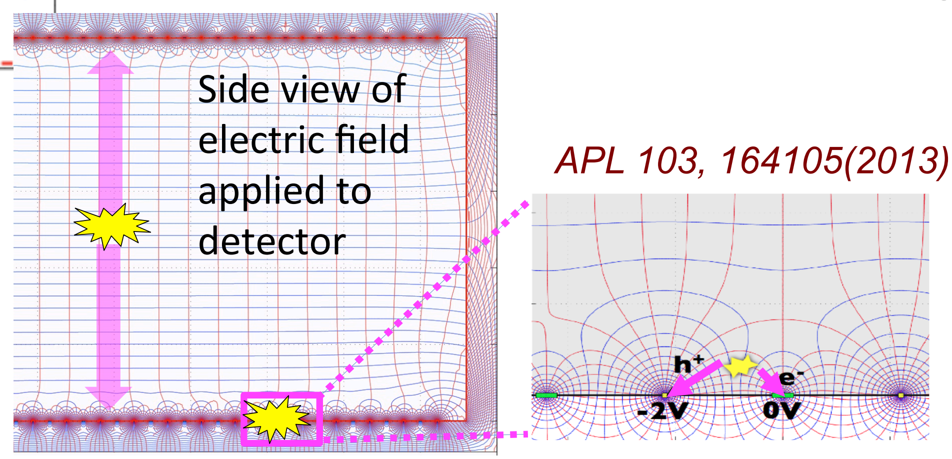




3-D fiducialization in both ionization and phonon energies allows for efficient rejection of external backgrounds down to very low energies

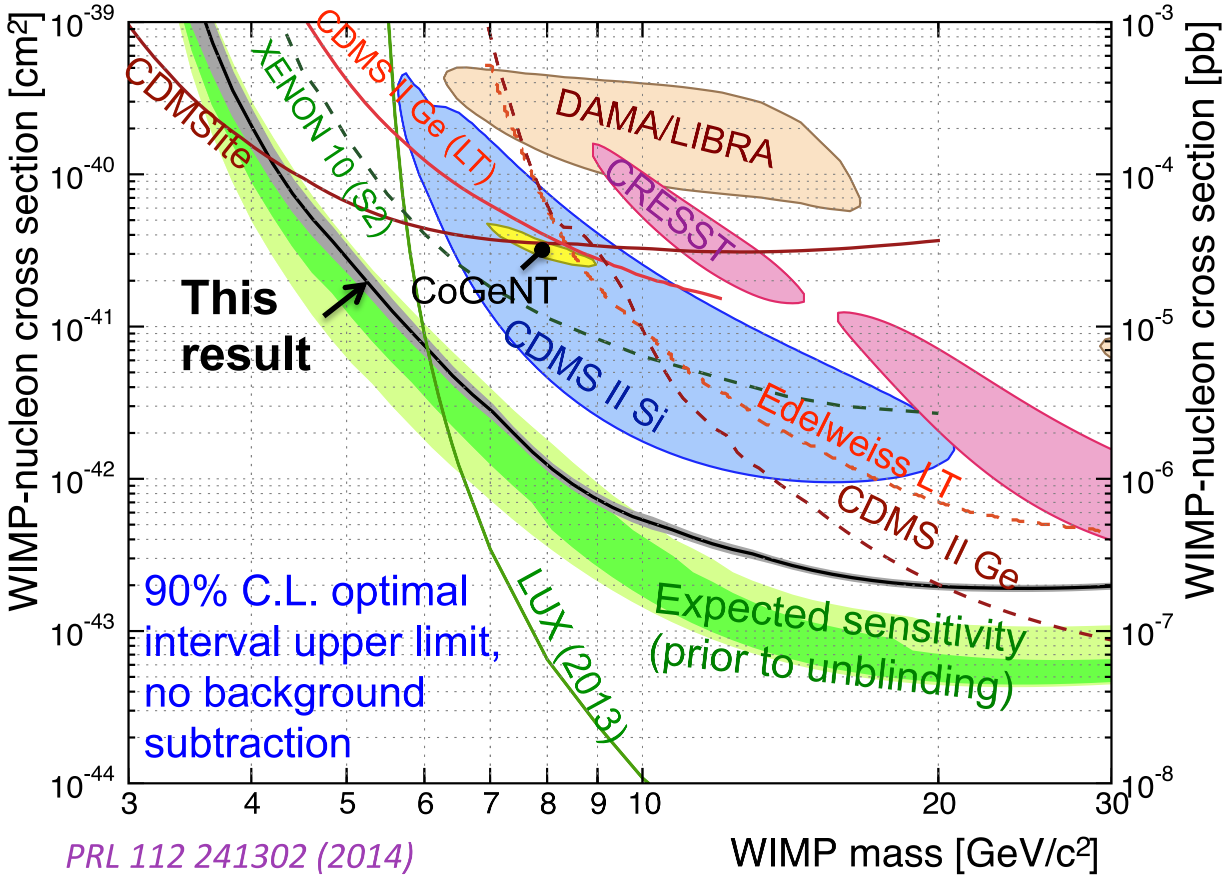
Simultaneous measurement of ionization and phonons provides better than 1:10^6 separation between NR and bulk ER

Operated at low bias (4V) to extract recoil energies on event-by-event basis



First iZIP results from SuperCDMS Soudan

Results from 7 iZIPs with lowest trigger thresholds (577 kg-days), using full power of background rejection from iZIPs, sets strong constraints on light WIMPs in 2014



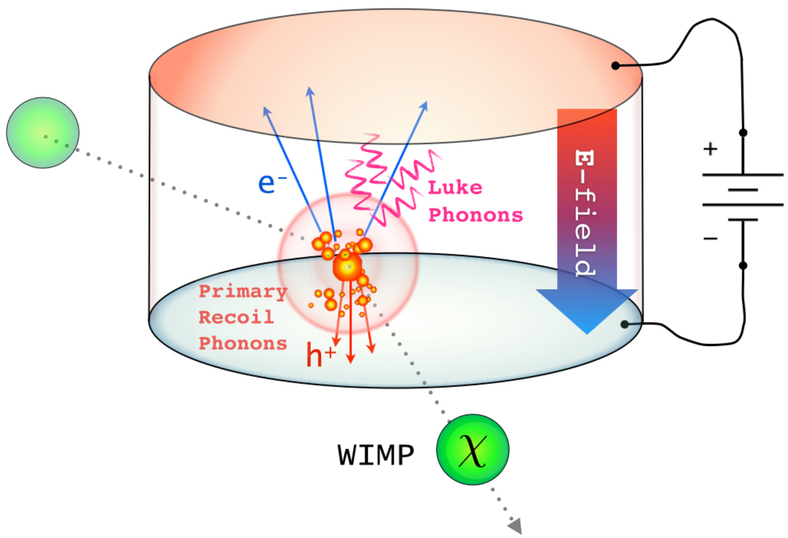
PRL 112 241302 (2014)

Eleven events observed; treating all as candidates set competitive constraints below 10 GeV/c^2 at the time of publication

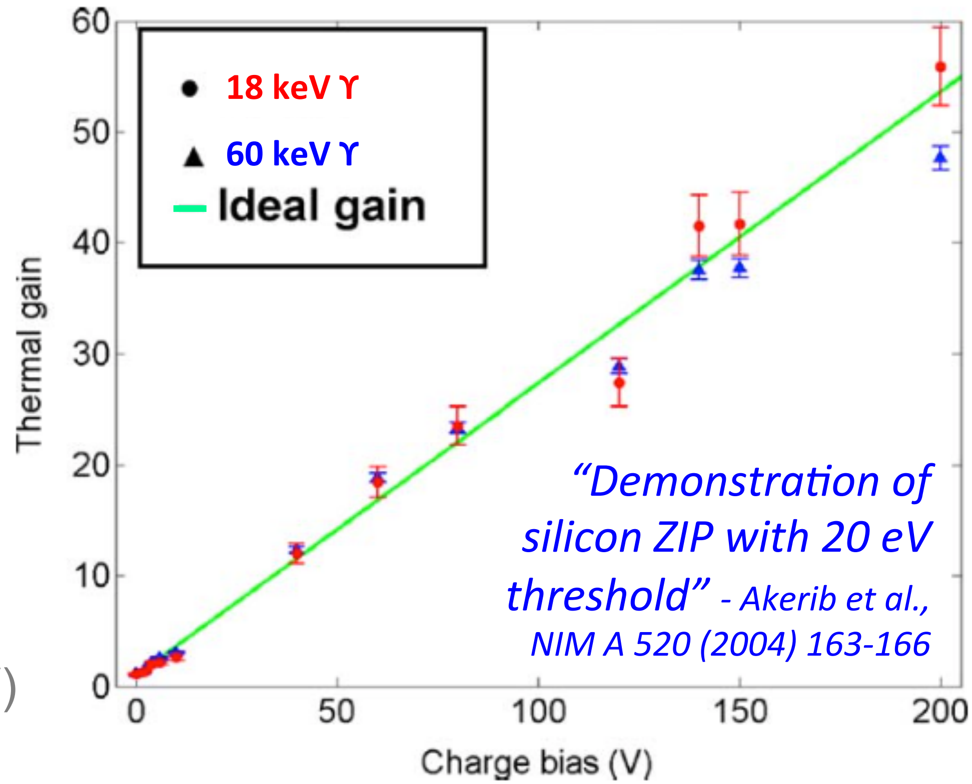
See A. Robinson's parallel talk for details

(Ultra) Low Ionization Threshold Experiment: **CDMSlite (a.k.a. HV)**

Neganov-Luke amplification of phonon response allows operation at very low energy thresholds



Electrons and holes radiate phonons proportional to V_{bias} as they drift to the electrodes. ➔Apply large V_{bias} (~100V) to amplify ionization signal



"Demonstration of silicon ZIP with 20 eV threshold" - Akerib et al., NIM A 520 (2004) 163-166

Ionization and phonon measurements are redundant in this mode; trading-off background rejection for lower thresholds

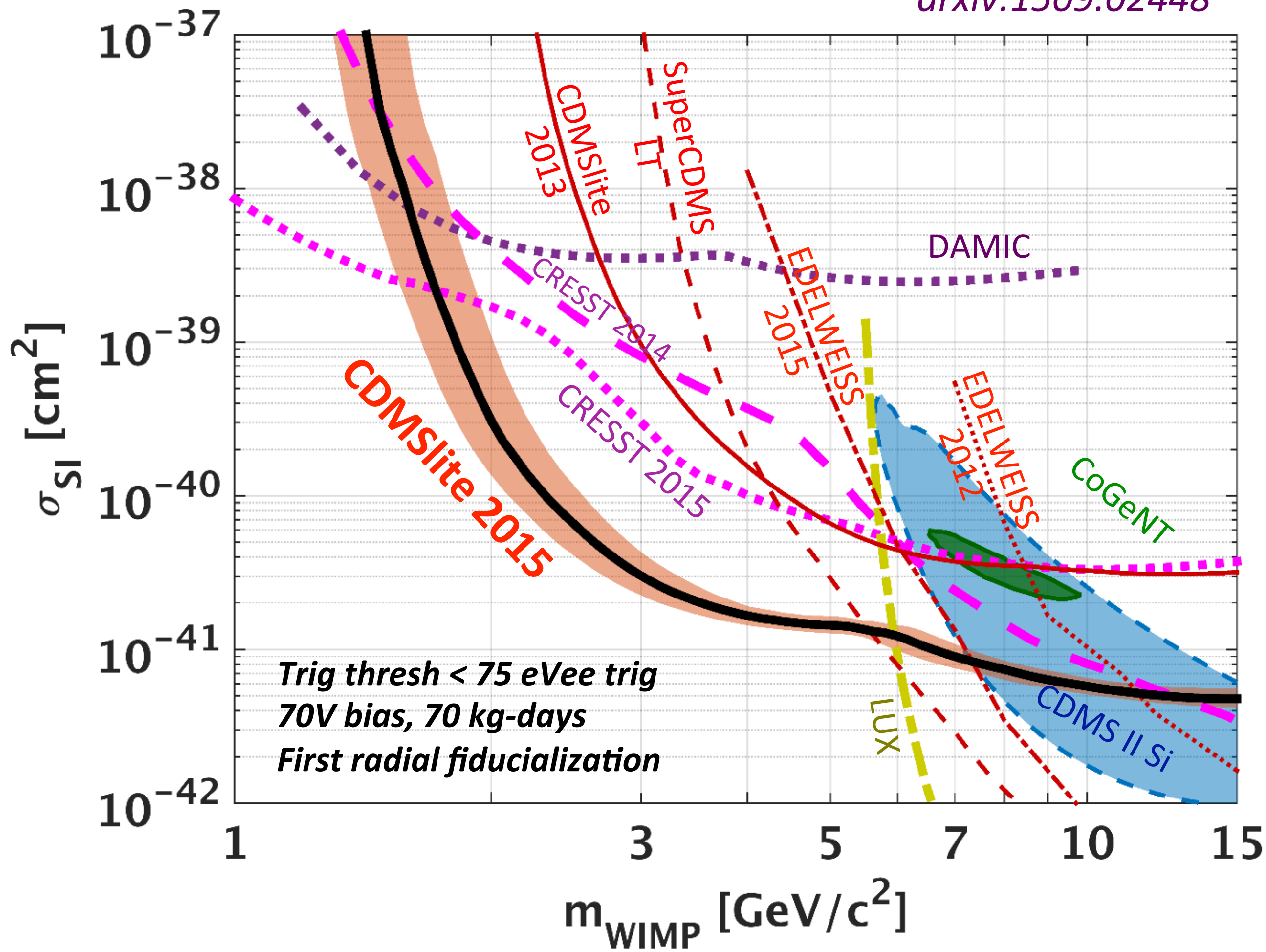
CDMSlite Results from Soudan

- First Run (2013): single detector, < 1 keV nuclear recoil threshold demonstrates operation and set world-leading limits with 10 days of data!

- Second run (2015): improved trigger threshold+ radial fiducialization + longer exposure time

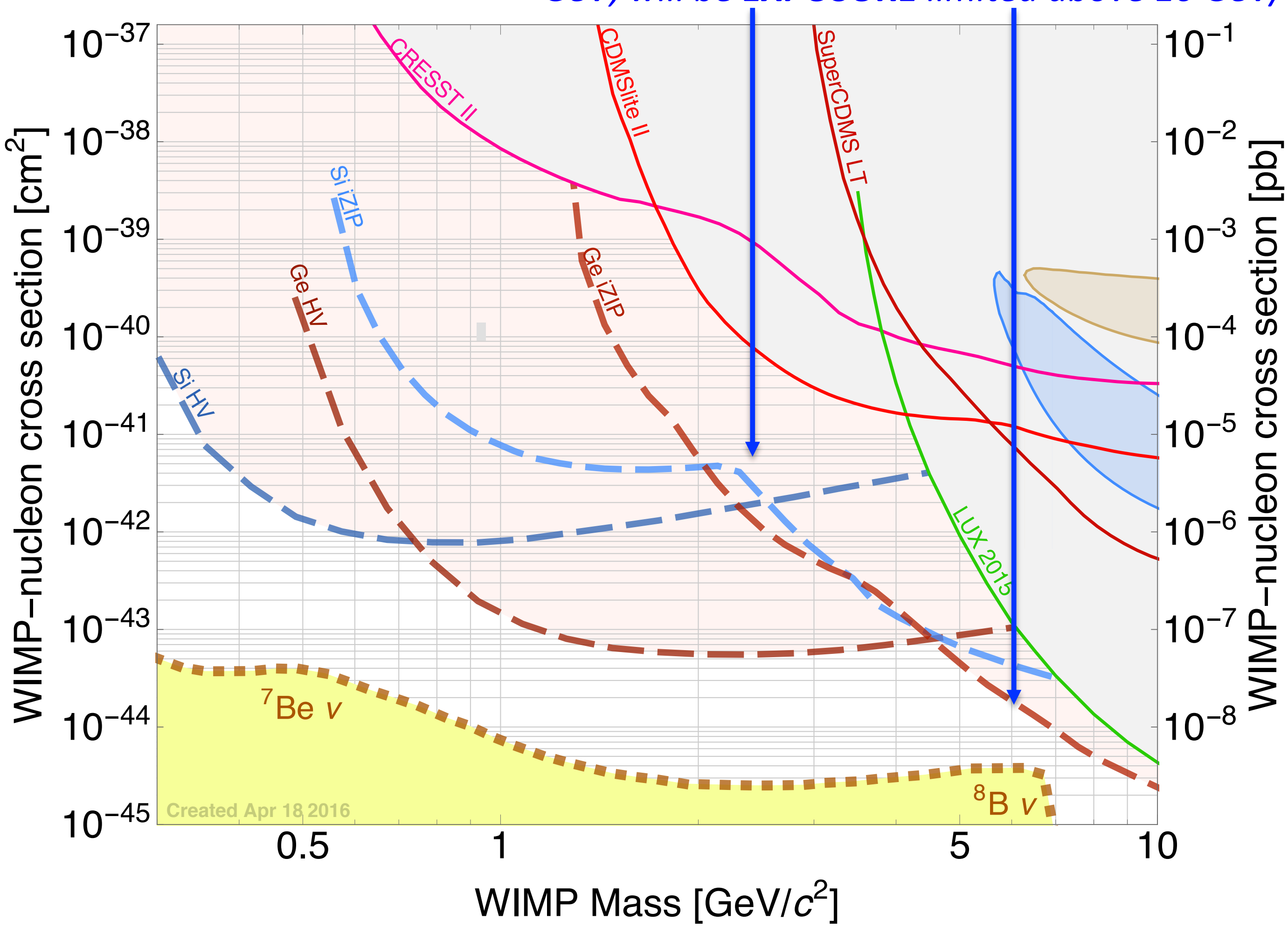
See A. Robinson's parallel talk for details

arxiv:1509.02448

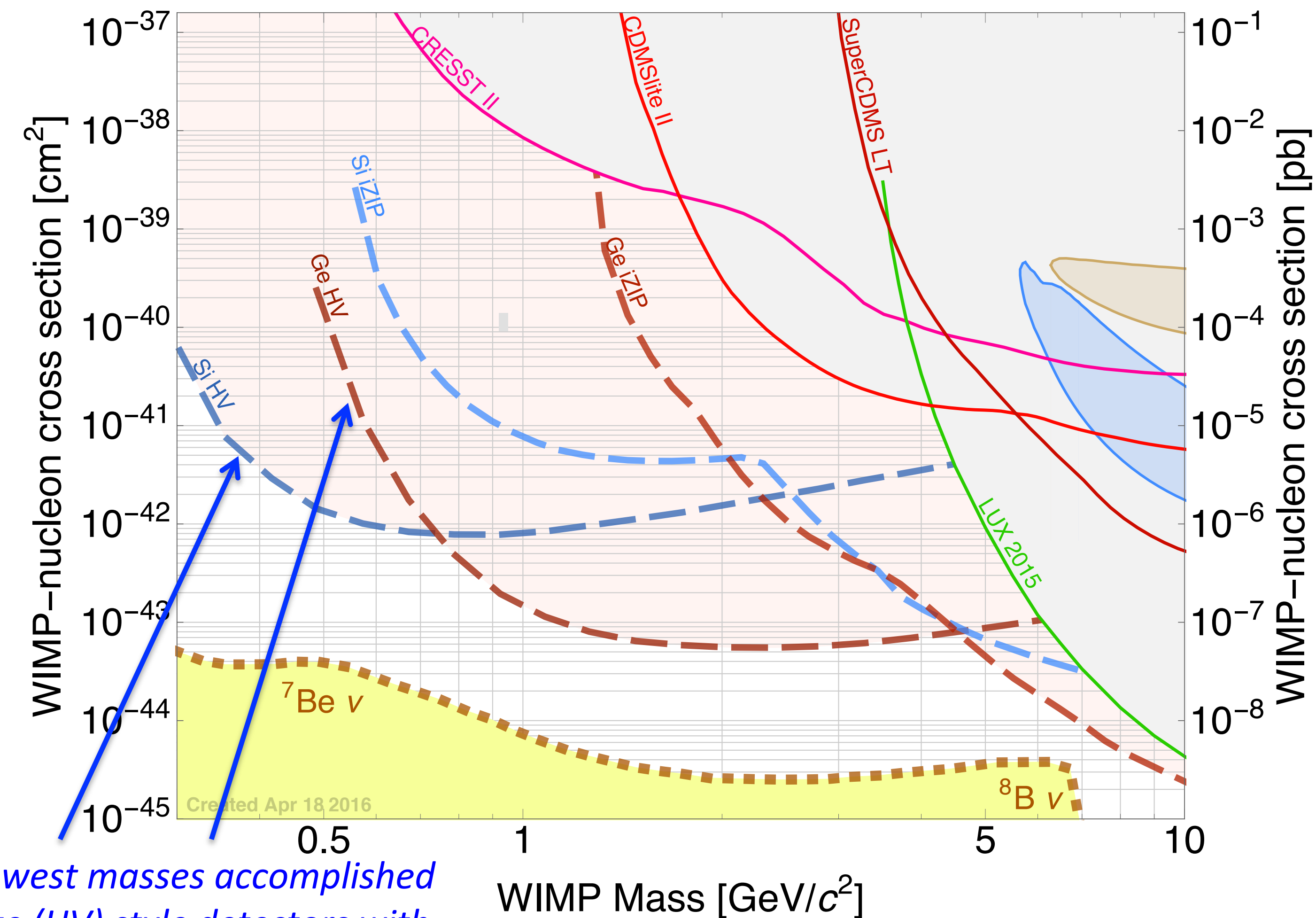


SuperCDMS SNOLAB Projections

*iZIPs provide nearly background-free sensitivity down to a few GeV; will be **EXPOSURE** limited above 10 GeV/c^2*



SuperCDMS SNOLAB Projections

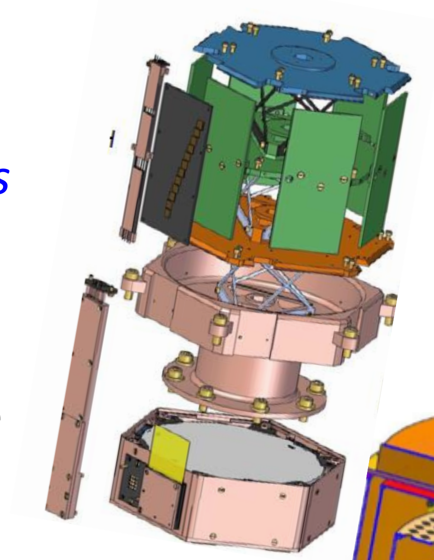


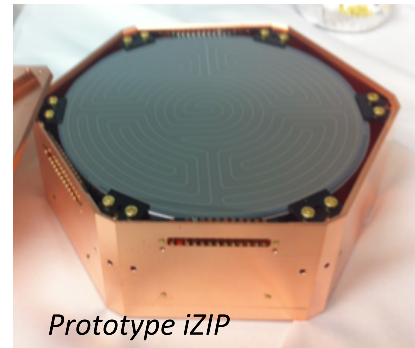
*Reach at lowest masses accomplished w/ CDMSlite (HV) style detectors with ultra-low (< 100 eV) threshold; will be **BACKGROUND** limited*

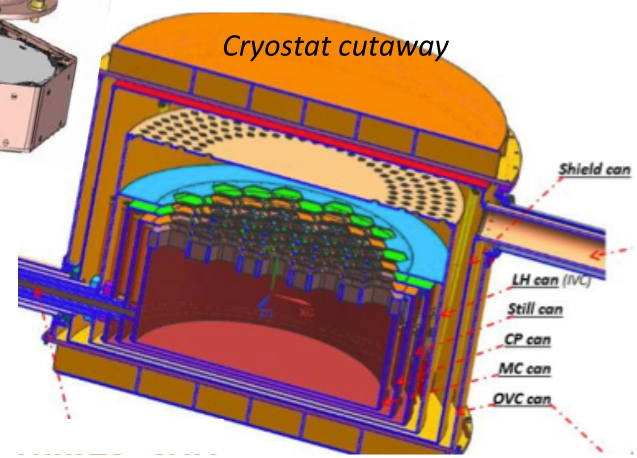
Improvements for SNOLAB

- **10X(4X) better resolution** in phonon channels for CDMSlite(iZIP) detectors; *thresholds as low as ~50 eV_{nr} allow for much better sensitivity to light particles*
- **Much Cleaner:** reduces intrinsic sources of radioactive background by screening for levels demonstrated in published literature
- **Deeper:** at 2 km, SNOLAB is 2X deeper than Soudan and has 100X lower muon flux
- **Bigger detectors:** reduce surface events, lower fabrication costs; provides path to scale-up if WIMPs seen at high mass

Tower drawing

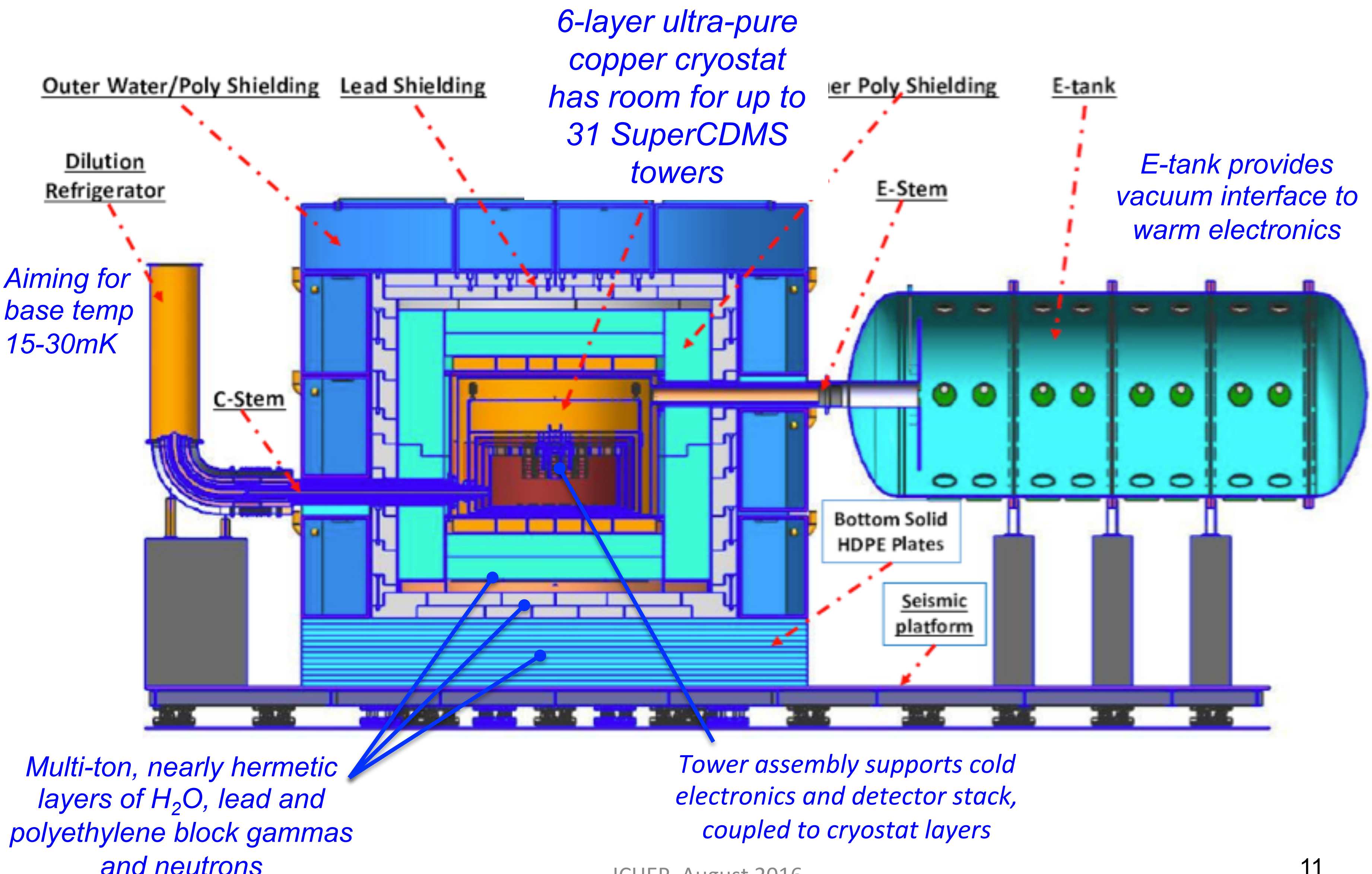






Silicon provides better sensitivity to light WIMPs (light target) and can cross check CDMS II Si result; Ge improves sensitivity where Si detectors are background limited and provides complementary target information

SNOLAB Experiment Layout



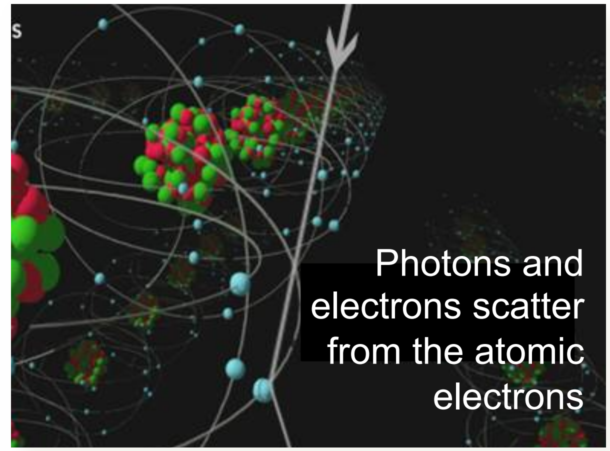
Most Prevalent Backgrounds

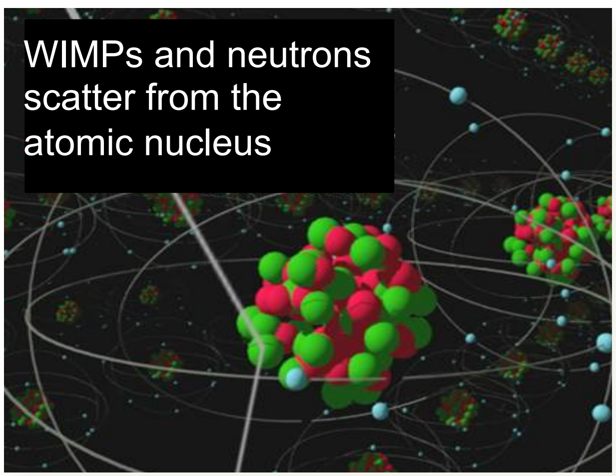
Expected WIMP scattering rate is <10^7 times lower than radioactivity of common materials

ELECTRON RECOILS (ER)

Gamma: most prevalent environmental background

Beta: common "surface events" but also prevalent in detector bulk from cosmogenic activation





NUCLEAR RECOILS (NR)

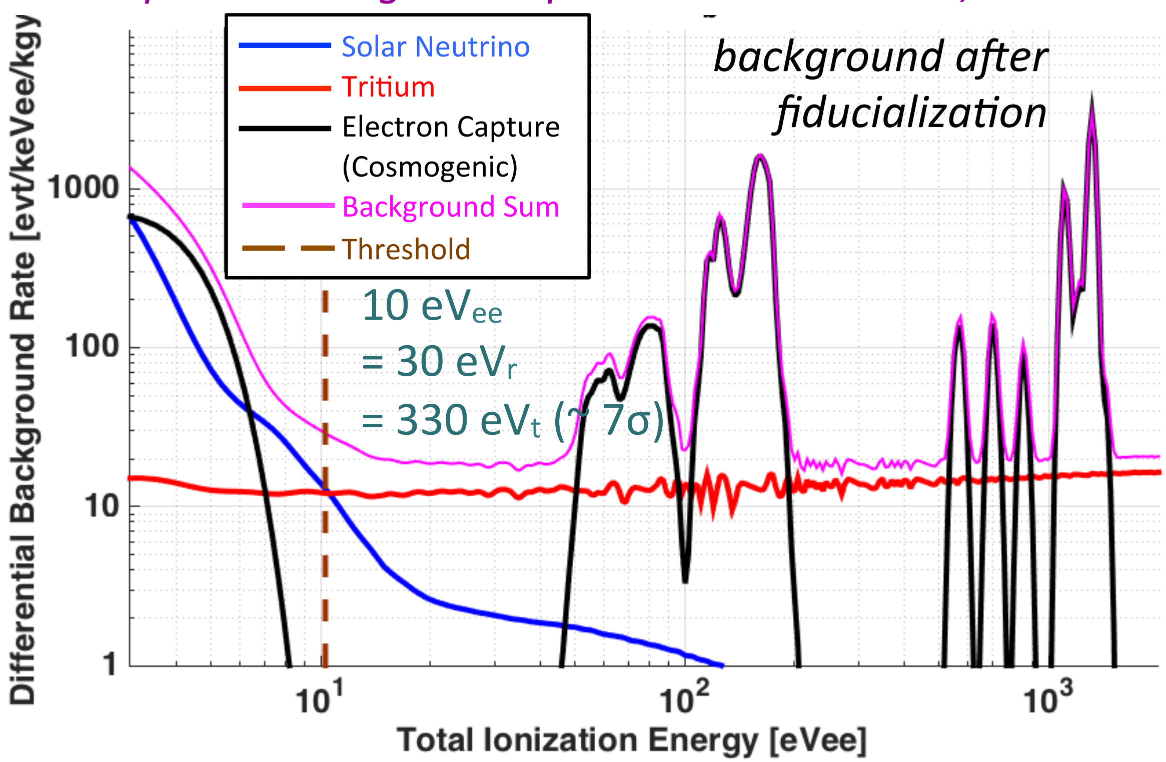
Neutron: rare but single-scatters NOT distinguishable from a WIMP signal

Alphas and Pb recoils (both mostly products of radon)

Background Control Critical

- Gamma background ~200x lower than Soudan via more exhaustive material screening
- Reduced beta's, alphas and Pb recoils originating in copper detector housing by tracking Rn exposure (detectors ok already!)
- HV detector background dominated by cosmogenics! ^3H by spallation in both Ge and Si detectors, also ^{32}Si in Si detectors from atmospheric Ar

Ge HV expected background spectrum at V_b = 100V, σ_t = 50 eV



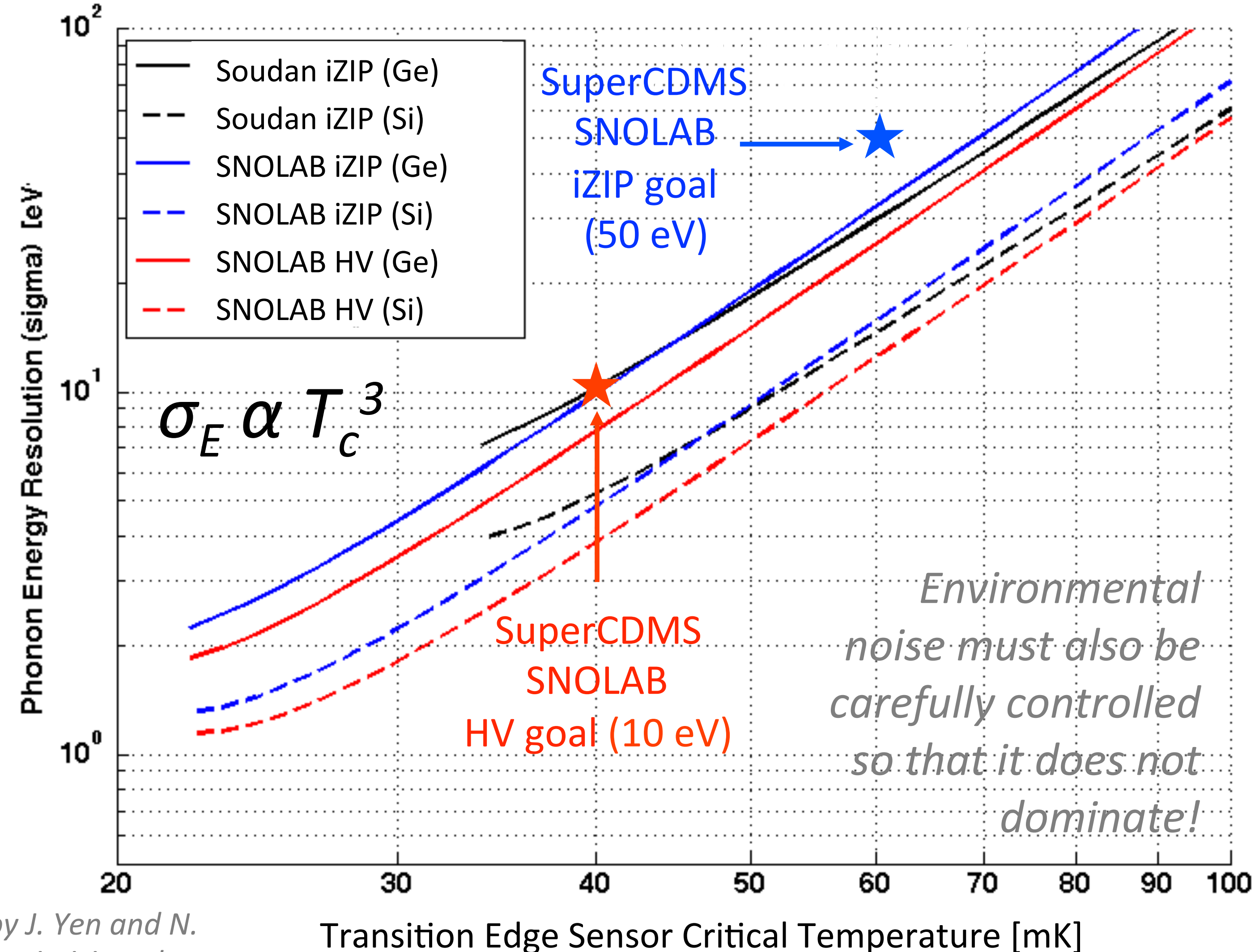
Cosmogenic background estimates assuming These surface exposure times:

	days
detectors (^3H)	120
housings/tower (^{60}Co)	90
cryostat (^{60}Co)	180

See poster by D. Barker on modeling background at low energy for SuperCDMS

Phonon Resolution is Critical

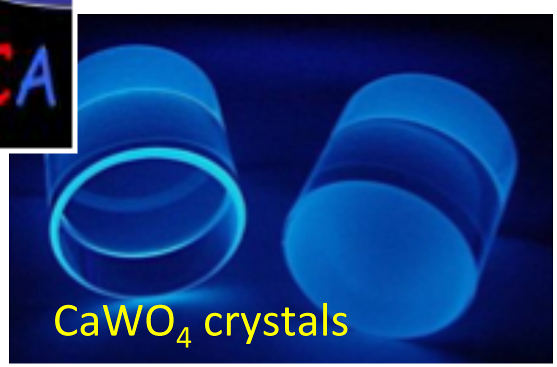
SNOLAB will achieve markedly improved phonon resolution (and hence threshold) by reducing the critical temperature of the TES sensors



See posters by J. Yen and N. Kurinsky on optimizing phonon sensors for SuperCDMS SNOLAB

SuperCDMS/EURECA

Cryostat will be sized to hold much more than initial G2 payload; offers prime real-estate in the sub-40 mK, ultra-low radioactive background, ultra-low noise zone!



- Active development in adapting SuperCDMS cryogenics, towers and readout to EURECA specifications
- EURECA: next-generation "cryogenic" dark matter experiment; joint collaboration between present-day EDELWEISS (Ge) and CRESST ($CaWO_4$).
- Positioned to expand payload to explore high mass WIMPs if a signal is seen, *OR upgrade with improved detectors to reach neutrino floor in 1-10 GeV/c^2 region.*

SuperCDMS Rough Timeline

2012-2014: Ongoing R&D

July 2014: Selected as a next-generation dark matter experiment by DOE & NSF (!)

Fall 2015: CD-1
Fall 2015: End of Soudan Operations

We are here

2016-2017: Design, work towards DOE CD-3

2018-19: Construction

2020: commissioning and first science running

Beyond 2024: Upgrade to multi-100 kg or merge with EURECA

Summary

Using two styles of detectors, SuperCDMS SNOLAB will have unique sensitivity to WIMPs with mass < 10 GeV/c^2

SuperCDMS Soudan demonstrated potential to detect low mass WIMPs, with several recent publications on iZIP and CDMSlite

Background control and improved phonon resolution will be key to SuperCDMS SNOLAB sensitivities

SuperCDMS SNOLAB selected by DOE and NSF for Generation 2 dark matter program; will have sensitivity many orders of magnitude better than present-day experiments – stay tuned!

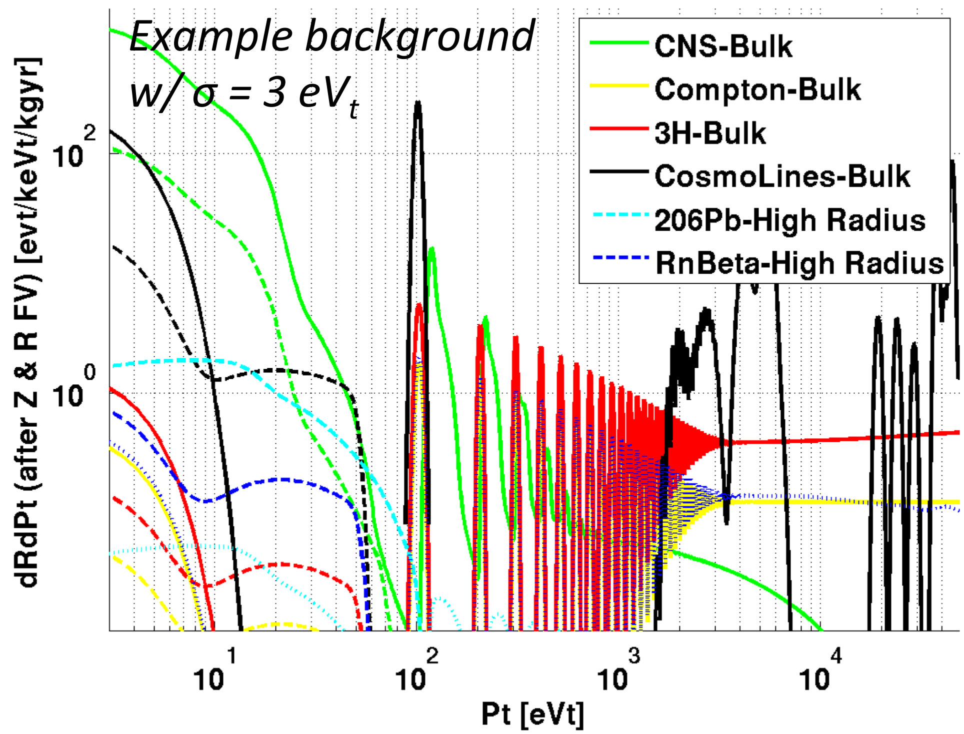
Thank You!

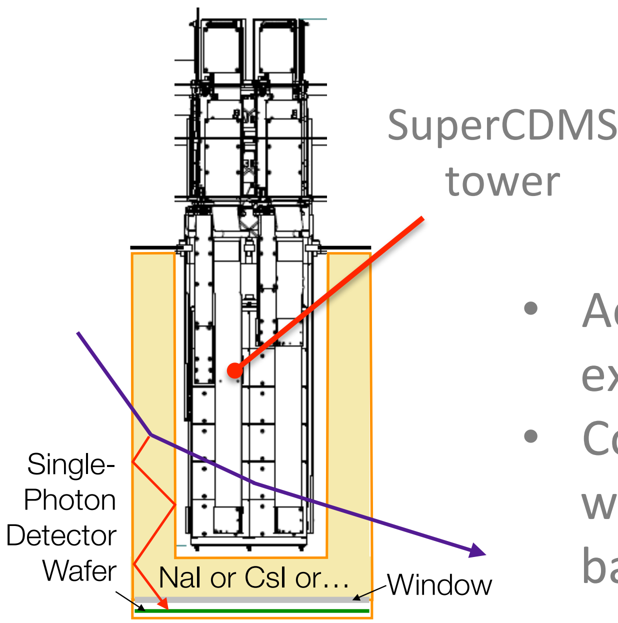
Backup slides

R&D Towards the Neutrino Floor

Background reduction will be key to extending reach down to the neutrino floor

- Phonon resolution of $\sigma = 3eV_t$ enables HV detector to resolve ER spectrum into individual peaks for e-h pairs
- NRs would appear in the space between; *this recovers NR rejection in HV mode!*





- Active vetos around tower can effectively reduce external backgrounds
- Concept: NaI or CsI scintillating "buckets" instrumented with cryogenic photon detectors to minimize backgrounds and optimize signal to noise

SuperCDMS SNOLAB Backgrounds Budget

Cosmogenic backgrounds dominate the background budget for the HV detectors

Rates /kg keV yr	Ge HV	Si HV
Cosmogenic* Activation	20	325
Radiogenic Contamination	4.1	17
Environmental Radiation	< 0.18	< 0.75
Coherent Neutrino Interactions	0.35	0.33
Other NR backgrounds	< 0.01	< 0.01
Bulk Total	25	343
Surface Activity before fiducial cuts	~20	~40

Preliminary background budget for the SuperCDMS SNOLAB HV detectors.

Review of recoil energy calculation

In SuperCDMS detectors, recoil energy is measured from total phonon energy after correcting for Neganov-Luke phonons:

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

~4V for iZIP
~70V for CDMSlite

energy for e/h pair = 3 eV in Ge

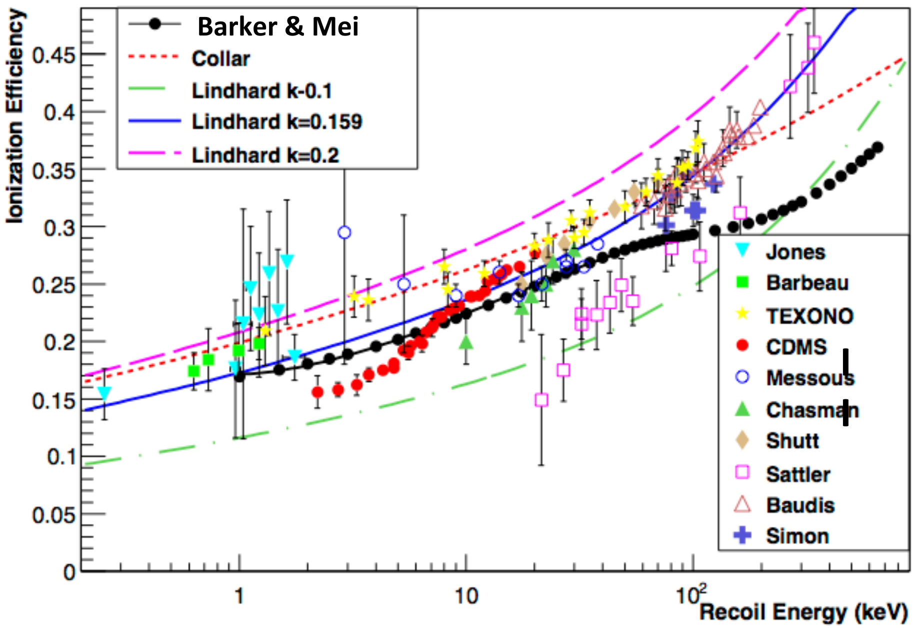
Accurate recoil energy measurement requires knowledge of ionization yield (quenching factor) for given recoil type

$$Y_{ionization} = E_{ion}/E_{recoil}$$

$Y_{ionization}$ is measured directly with iZIPs on an event-by-event basis during exposure to gamma and neutron sources. But this is not the case for HV detectors. $Y_{ionization}$ must be determined independently in order to extract E_{recoil}

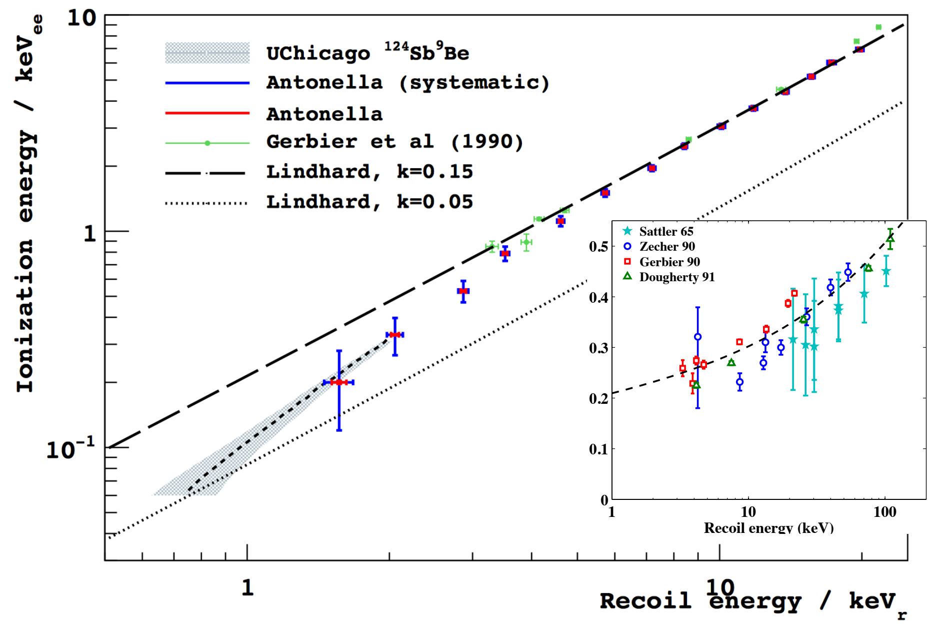
Current status on ionization yields

Germanium



In addition to how much the yield differs from Lindhard, at some point we expect a physical turnoff in ionization yield. Where this cutoff is can have large implications.

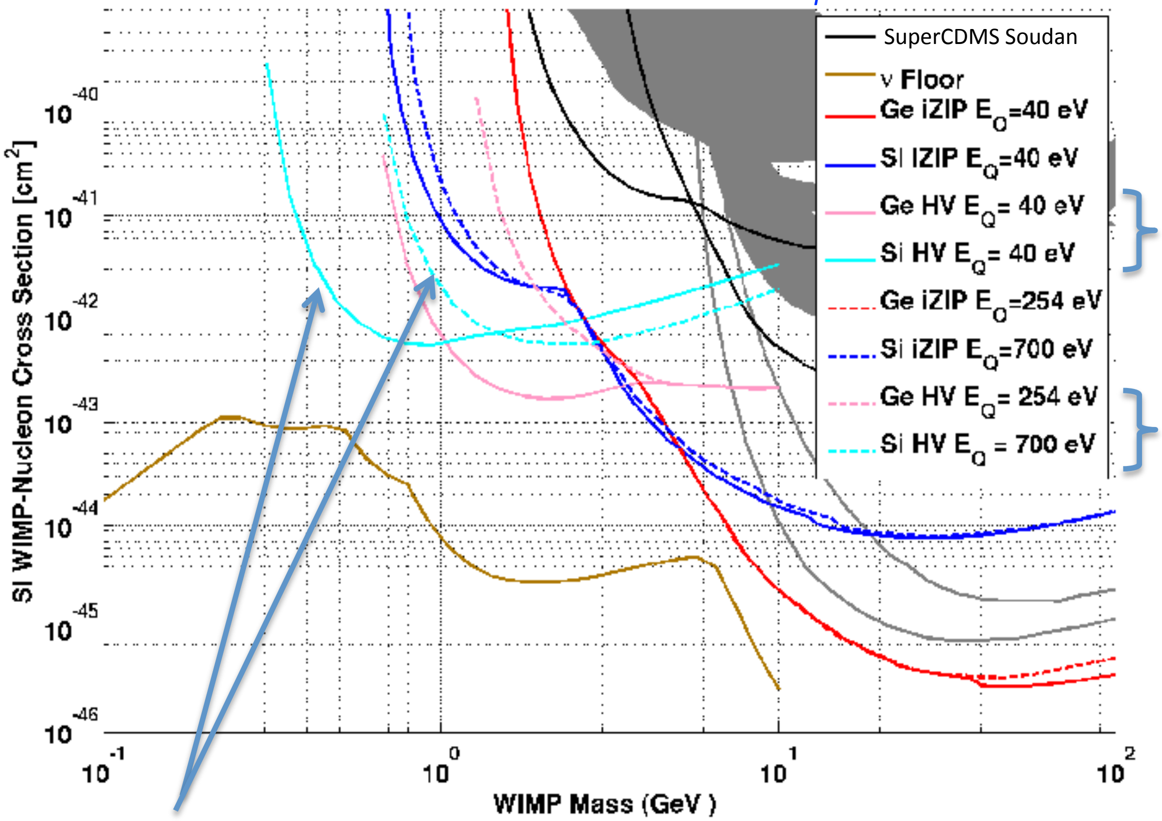
Silicon



Note sensitivities on previous slide assumed 40 eV ionization threshold and that ionization yield follows Lindhard down to that point.

Example 1: effects of ionization yield cutoff

Conservative resolution case: σ_{pt} = 50(25) eV for Ge (Si), HV = 50V
Hardware threshold assumed to be $7*\sigma_{pt}$ = 350(175)eV



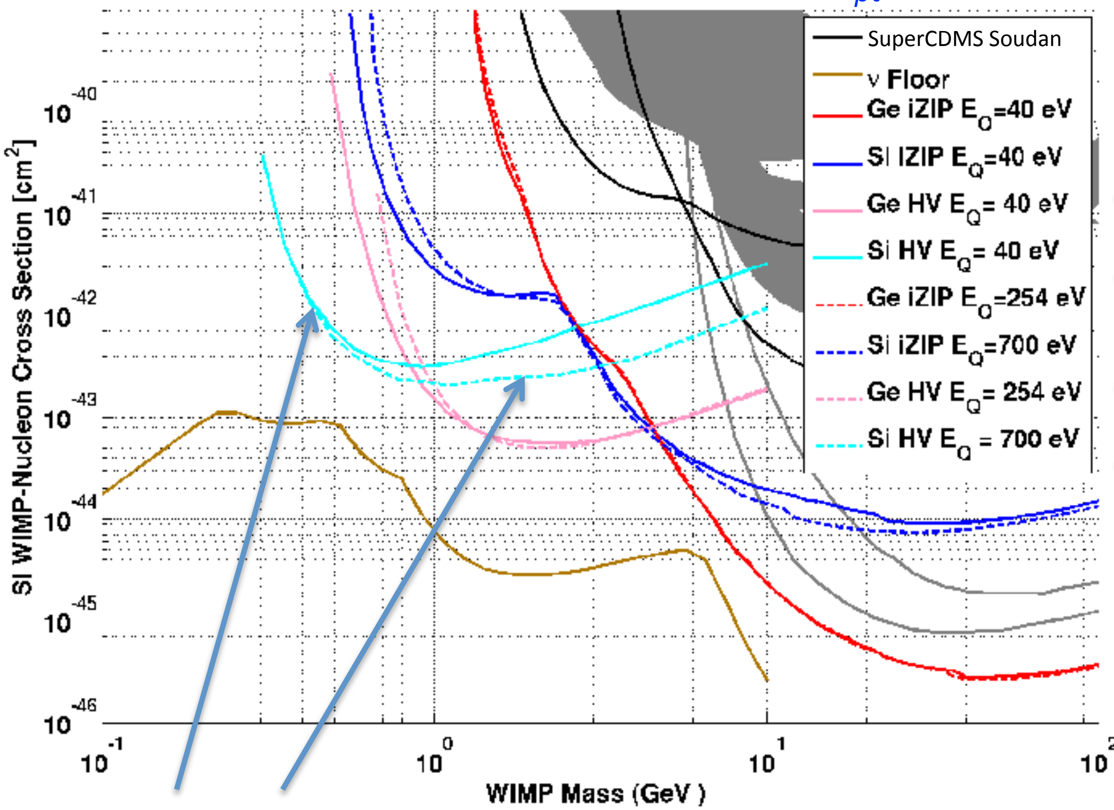
Optimistic cutoff: roughly based on ion dislocation energy

Worst case: cutoff is zero below lowest energy of existing measurements

Here, ionization threshold makes a large difference in sensitivity for HV detectors. The difference arises from hardware threshold being below (optimistic case) versus above (worst case) the ionization threshold and hence where Luke phonons exist to amplify the NR signal.

Example 2: effects of ionization yield cutoff

SuperCDMS goal resolution case: σ_{pt} = 10(5) eV for Ge (Si), HV = 100 V
Hardware threshold assumed to be 7σ_{pt} = 50(35) eV*



Optimistic cutoff: roughly based on ion dislocation energy

Worst case: cutoff is zero below lowest energy of existing measurements

Here, effect is less severe bc the hardware threshold is so low it's already below the ionization threshold in both scenarios (for Si) so there's no difference in NR thresholds between optimistic and worse case. In fact, Luke gain is no longer useful for reducing threshold, instead use it to tune what ER backgrounds wind up in the signal NR region.