Calibration of SuperCDMS Detectors with a Photoneutron Source

Lauren Hsu

for the SuperCDMS collaboration

Fermilab Center for Particle Astrophysics

Calibration of Low Energy Particle Detectors

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Talk Outline

I. Review of SuperCDMS iZIP and CDMSlite(HV) detector designs

II. Review of energy scale studies with ^{252}Cf and CDMS II data

III. Photoneutron studies at Soudan

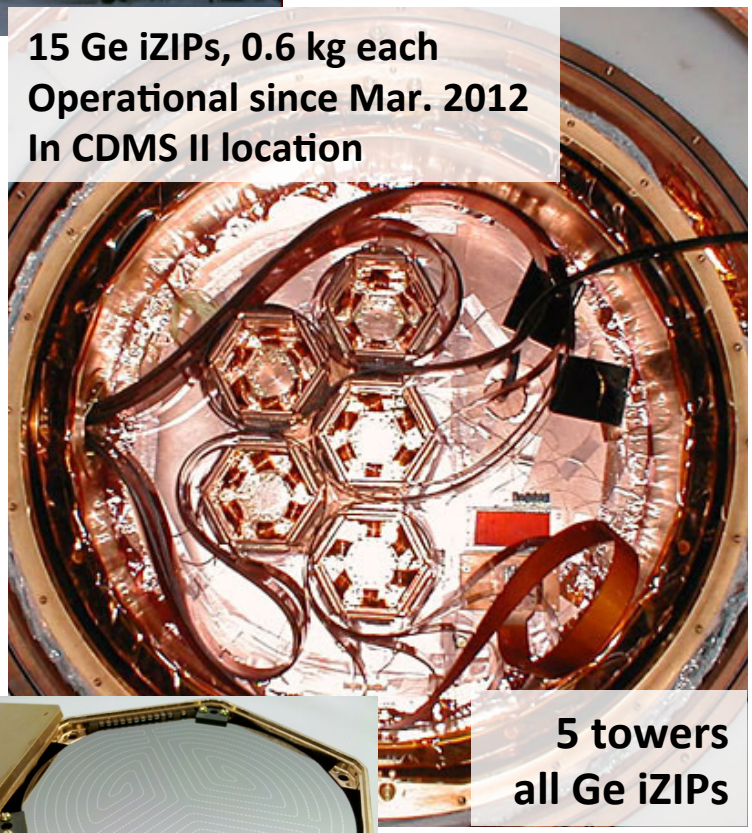
IV. Summary

SuperCDMS Overview

SuperCDMS

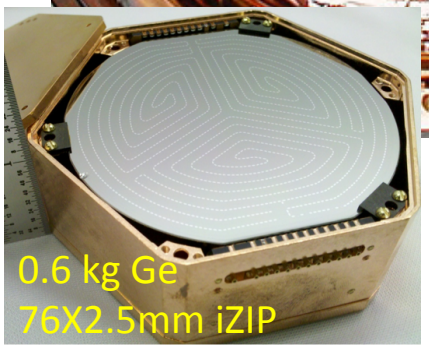
SOUDAN

Leading limits published on low mass WIMPs



15 Ge iZIPs, 0.6 kg each
Operational since Mar. 2012
In CDMS II location

5 towers
all Ge iZIPs

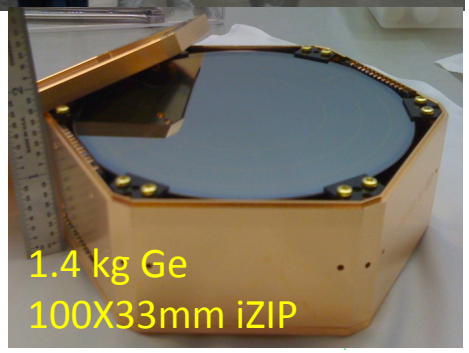


0.6 kg Ge
76X2.5mm iZIP

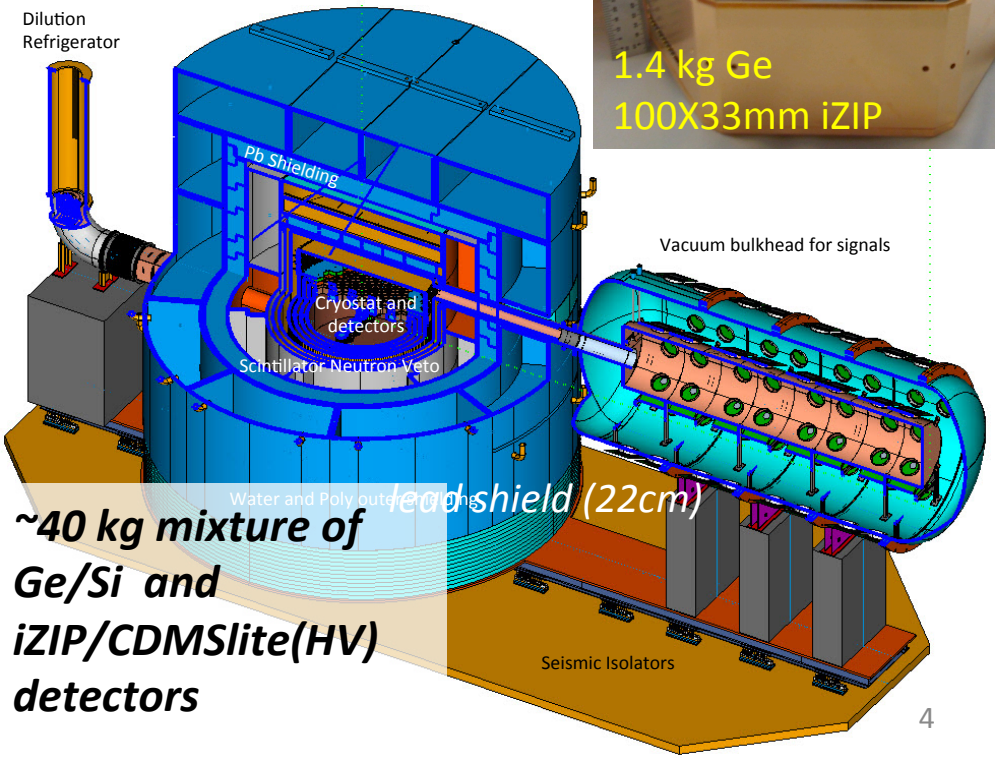
Operation ending late 2015

SNOLAB

Generation-2 experiment focusing on low mass WIMPs, to be built starting 2016

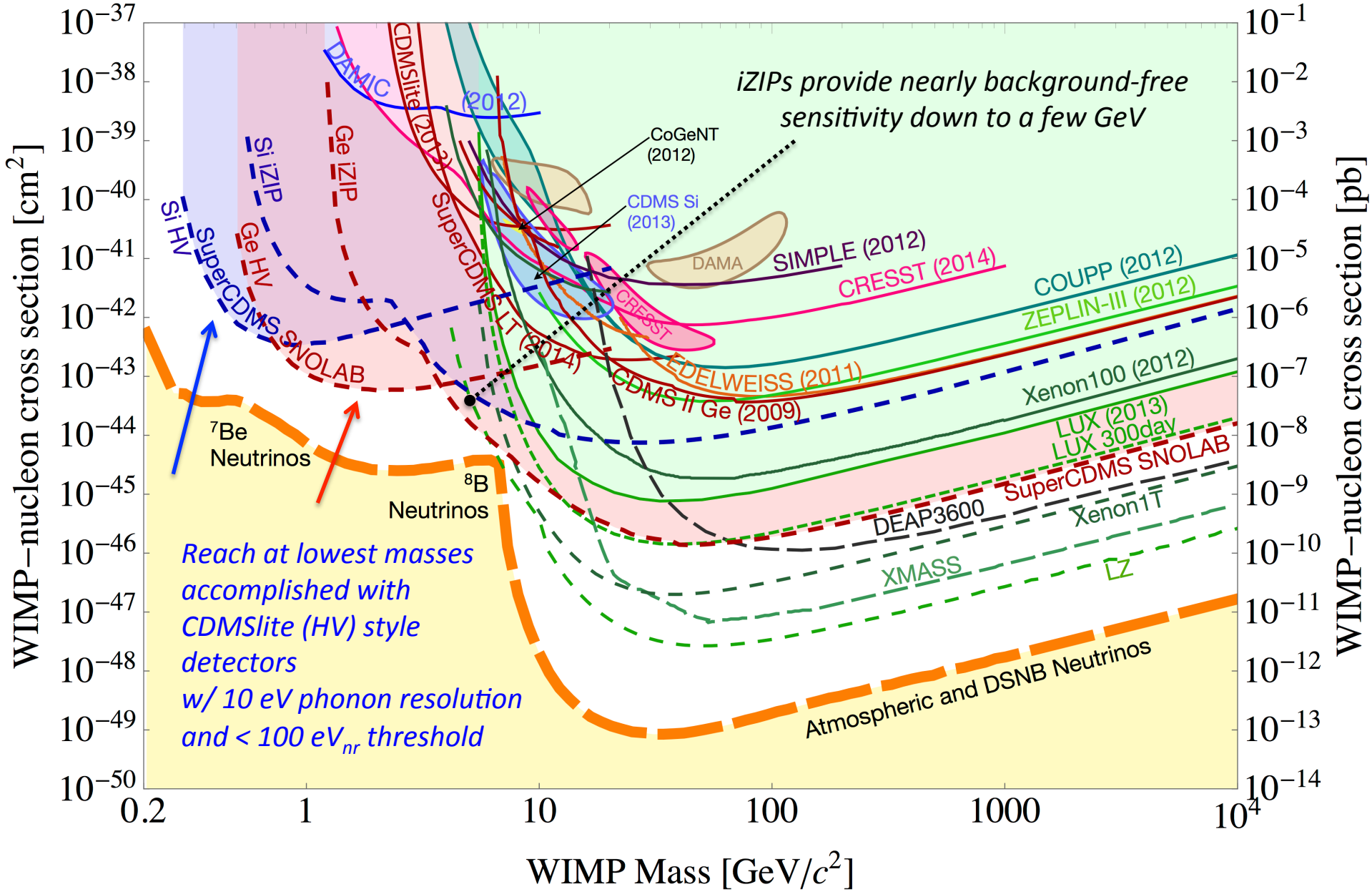


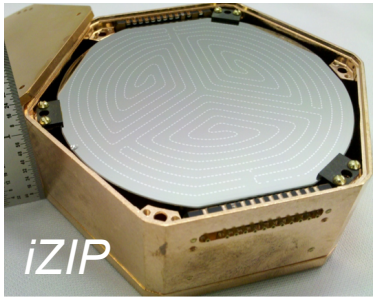
1.4 kg Ge
100X33mm iZIP



~40 kg mixture of Ge/Si and iZIP/CDMSlite(HV) detectors

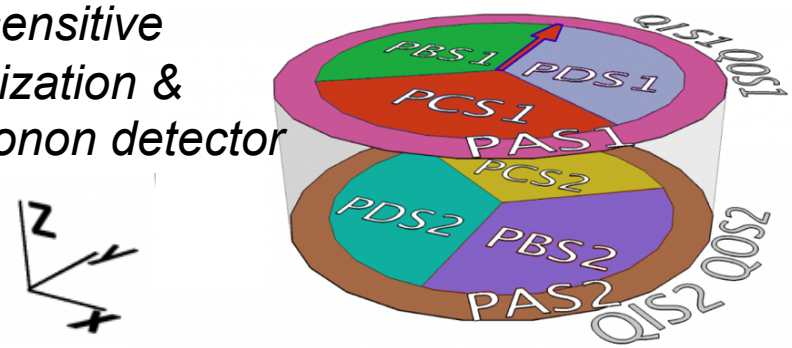
SuperCDMS SNOLAB Projections

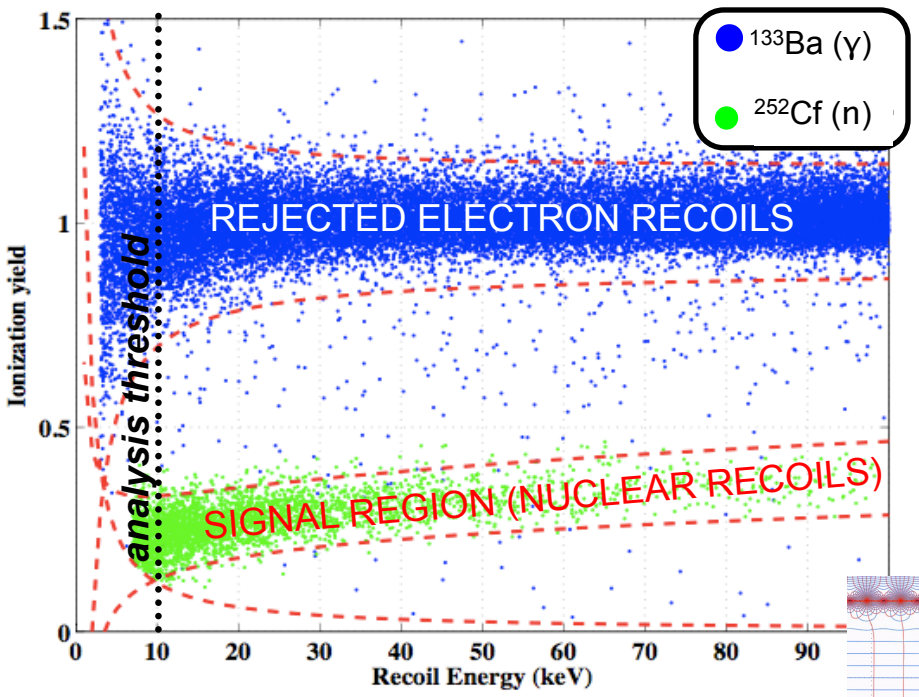




iZIPs: Ionization & Phonon Detectors

interleaved
Z-sensitive
Ionization &
Phonon detector

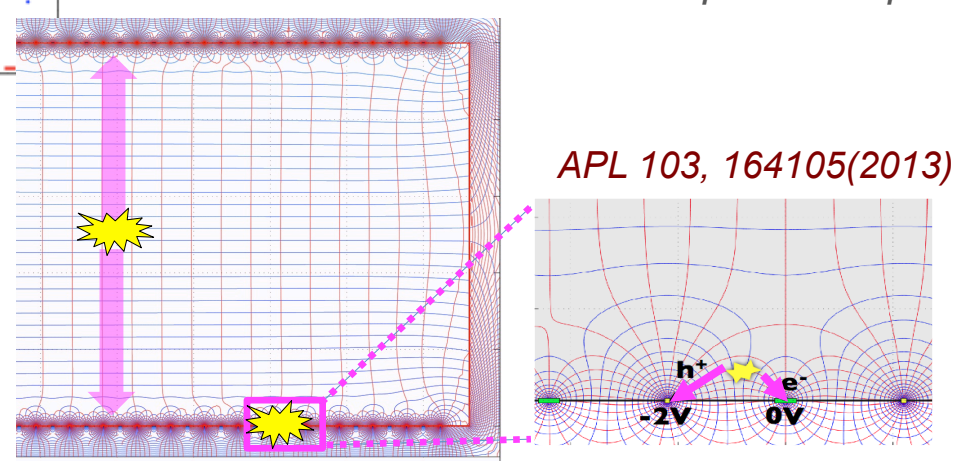




Improved fiducialization from measurement of z-symmetric ionization response
Phonon guard and z-symmetric phonon response helps too!

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

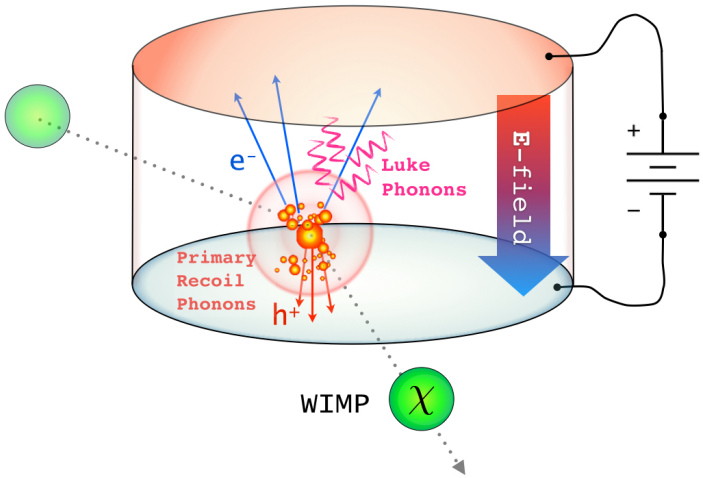
Operated at low bias (4V) to extract recoil energies on event-by-event basis



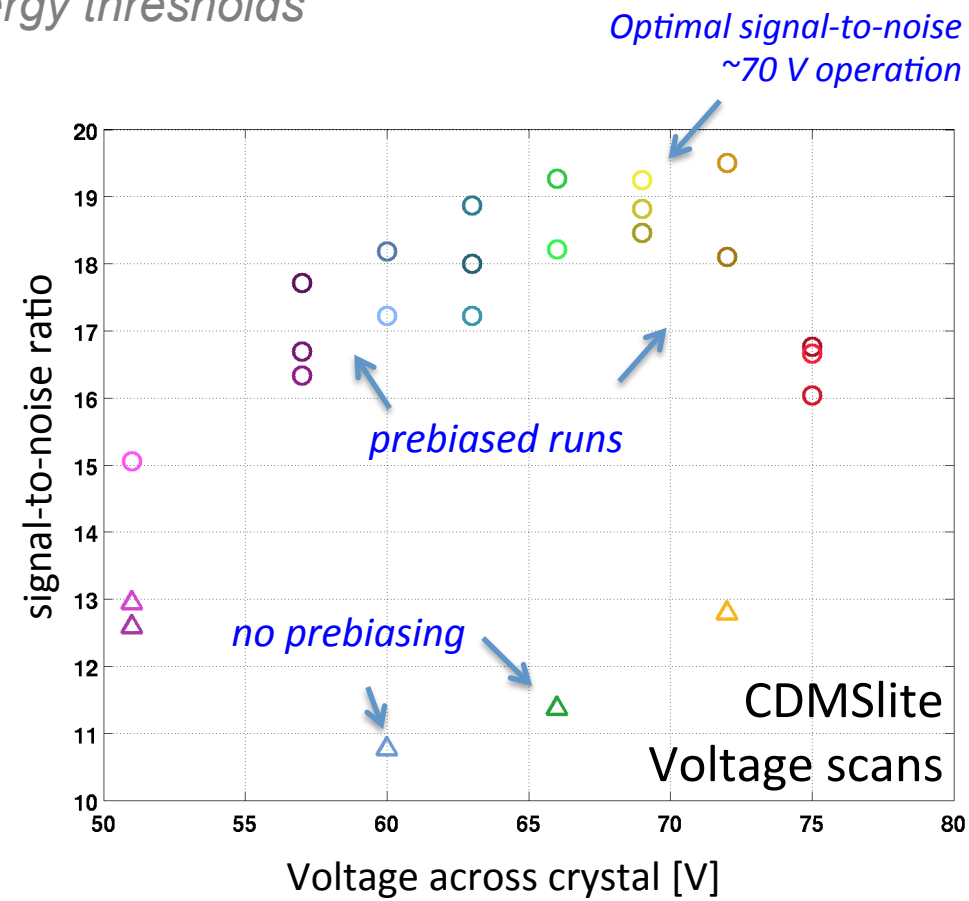
APL 103, 164105(2013)

CDMSlite (HV): Ionization Detector

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} (~70V) to amplify ionization signal



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

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

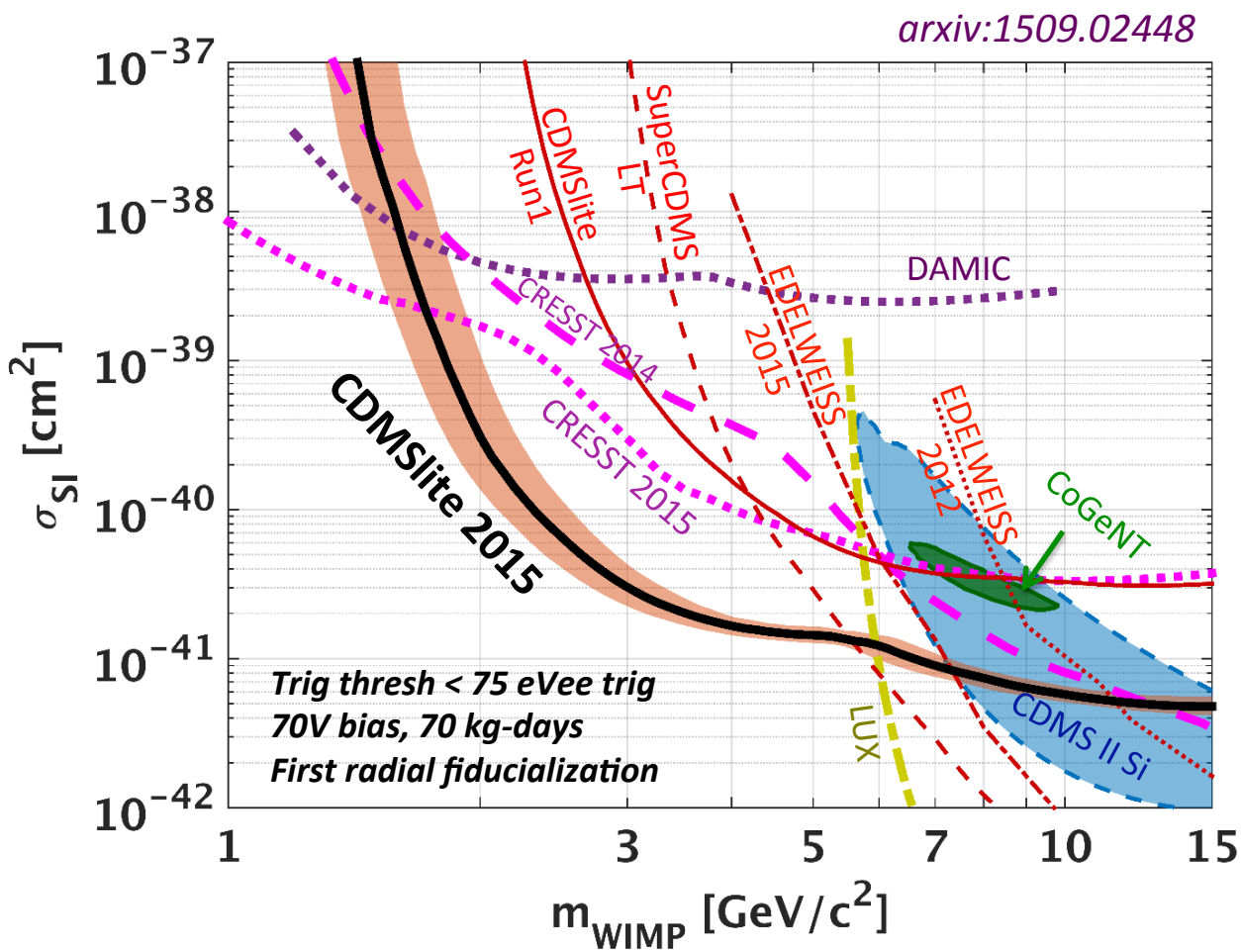
Accurate recoil energy measurement requires knowledge of ionization yield for given recoil type (ER or NR)

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

$Y_{ionization}$ 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}

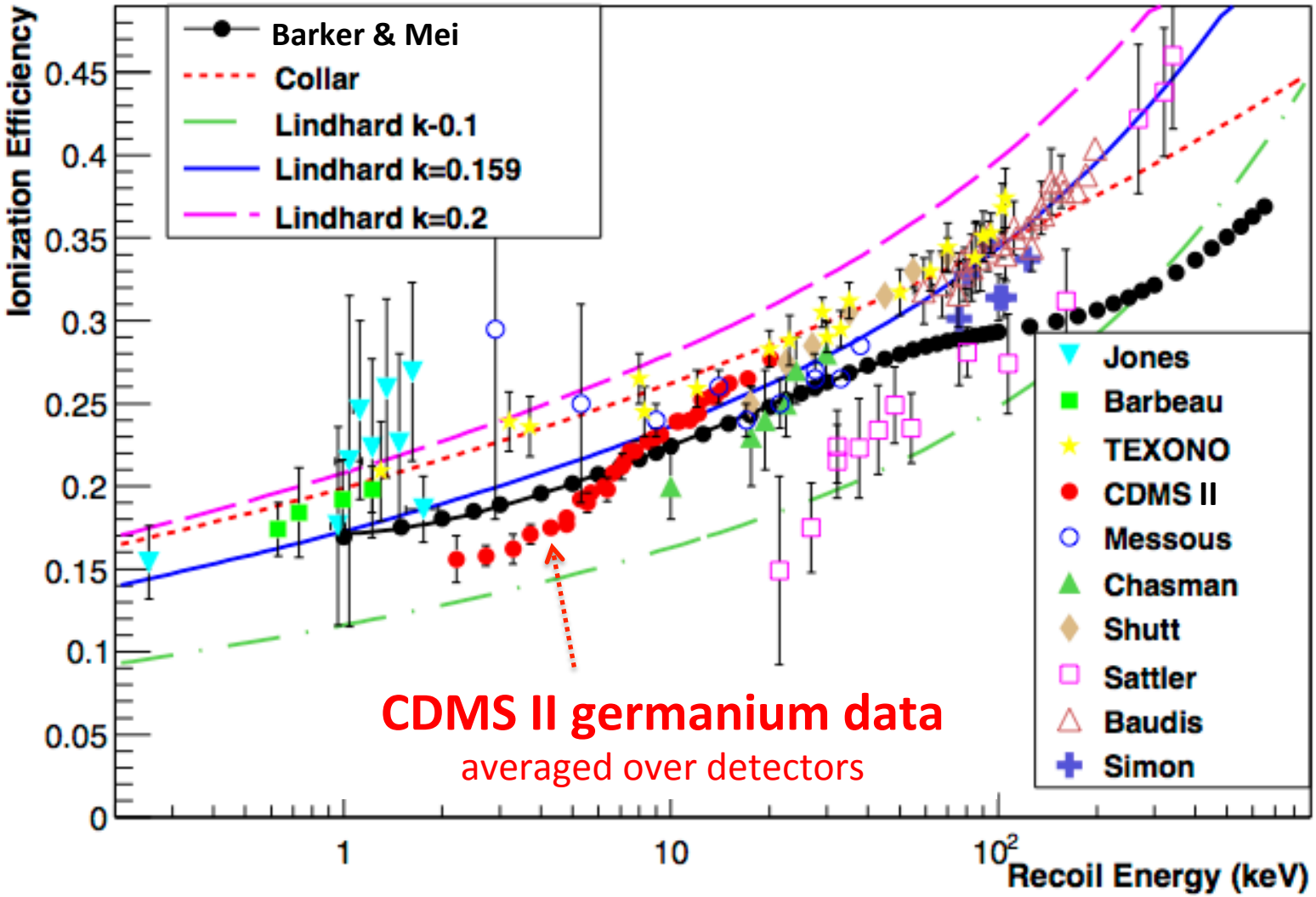
Impact of Recoil Energy Uncertainy on Run II CDMSlite

- $Y_{ionization}$ has not been directly measured in CDMSlite detectors.
- Results to date use Lindhard theory (k=0.157) for central value.
- Uncertainty band shown is dominated by uncertainty in $Y_{ionization}$ below 3 GeV/c^2; it encompasses Lindhard-like parameterization where "k" varies between 0.1 and 0.2

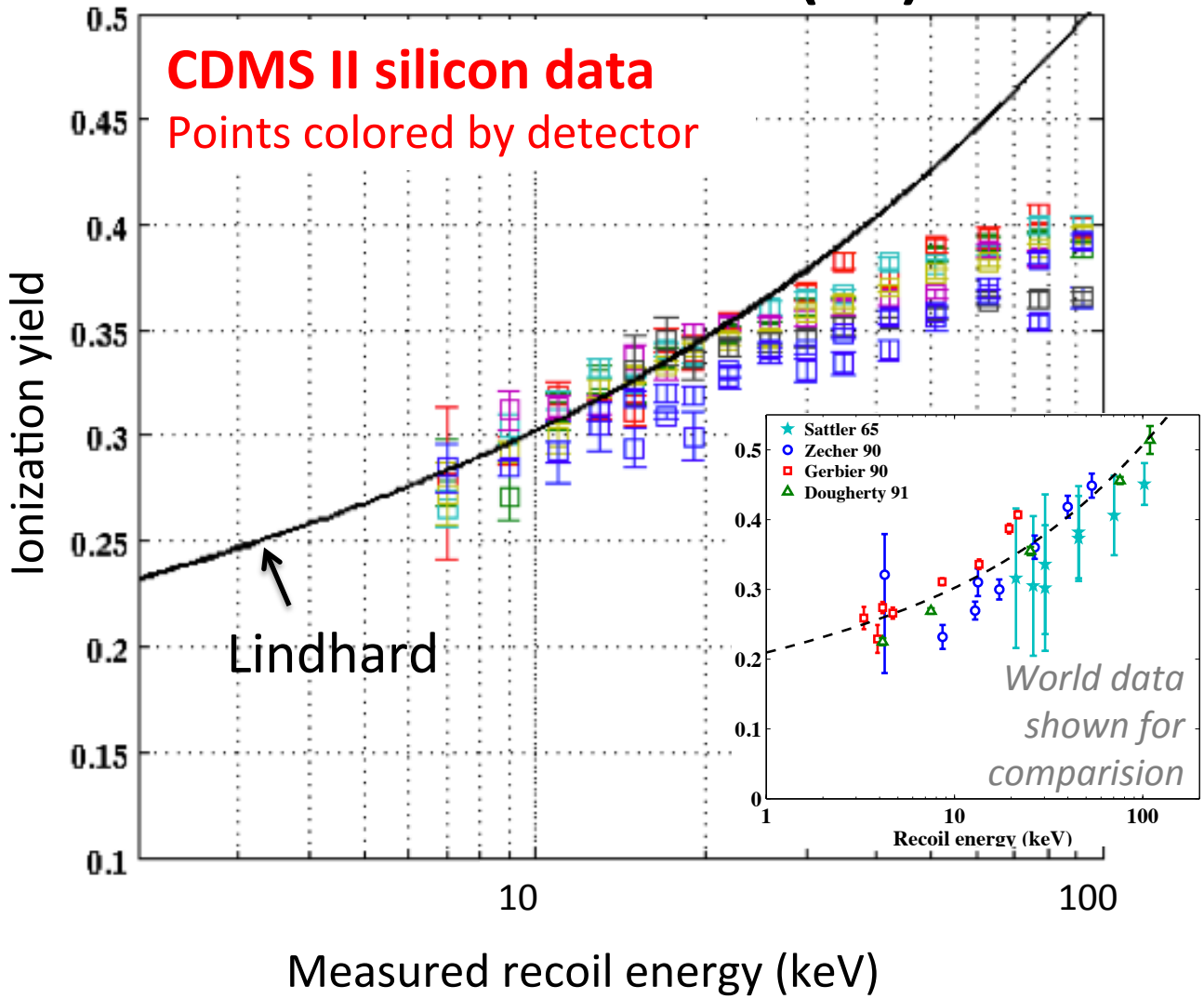


CDMS II Energy Scale studies

How does CDMS II yield compare to Lindhard (Ge)?



How does CDMS II yield compare to Lindhard (Si)?



Some Discussion

Ionization yield in CDMS II detectors does not agree with Lindhard(!)

SuperCDMS Ge iZIPs show similar discrepancies.

Does not necessarily indicate that the energy scale used for CDMS II was incorrect. *In the case of incomplete charge collection in iZIPs, ionization yield will be low wrt Lindhard, but recoil energy is still correctly calculated.*

Unlike iZIPs, charge collection issues that affect ionization yield in CDMSlite ***will*** *directly affect the recoil energy calculation.*

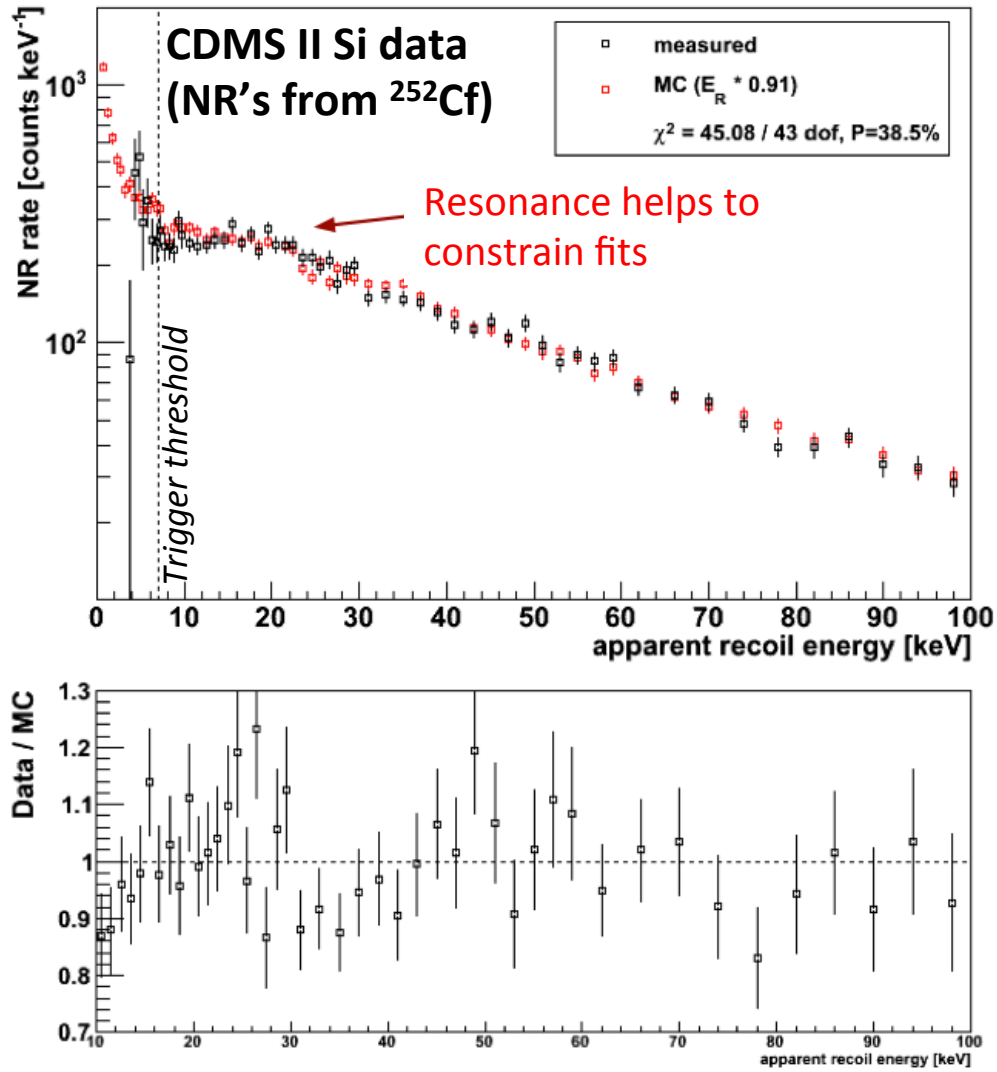
We do not a priori assume CDMSlite detectors, which are operated at much higher fields, will have the same ionization yield dependence as CDMS II detectors.

Whether its iZIP, CDMS II or CDMSlite, better to find techniques that can check the energy scale independent of the ionization yield measurements(!)

CDMS II: MC comparisons w/ ^{252}Cf data

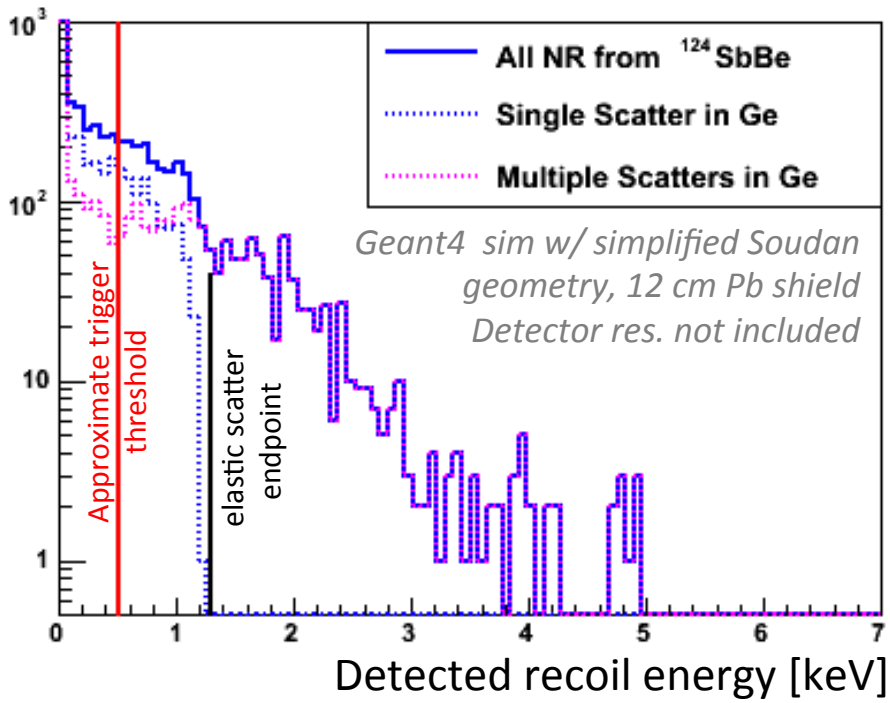
- Compare nuclear recoil spectrum of ^{252}Cf data to one generated by Geant4
- Find single-parameter scaling that minimizes χ^2 between the two spectra
- Technique works reasonably for Si due to resonance at 20 keV; *paper under preparation, see S. Fallows 2013 APS talk*
- Much harder for Ge data because there's no feature to break degeneracies between MC normalization and energy scale

Implies this technique is hard for SuperCDMS iZIPs. Also, won't work for CDMSlite because nuclear recoils can't be separated from electron recoils, both are produced by ^{252}Cf



SuperCDMS
Photoneutron studies

Photoneutron Calibration with SuperCDMS Soudan detectors



The Concept:

- Pair gamma sources, ^{88}Y and ^{124}Sb, with Be wafer to produce nearly mono-energetic neutrons of energy 152 and 23 keV, respectively.
- Look for maximum elastic scattering shoulder off Ge; **endpoints at 8.1 and 1.3 keV,** respectively from ^{88}YBe and ^{124}SbBe.
- Shoulder provides an identifiable feature to check accuracy of NR energy scale; use this to extract ionization yield for CDMSlite

Complications:

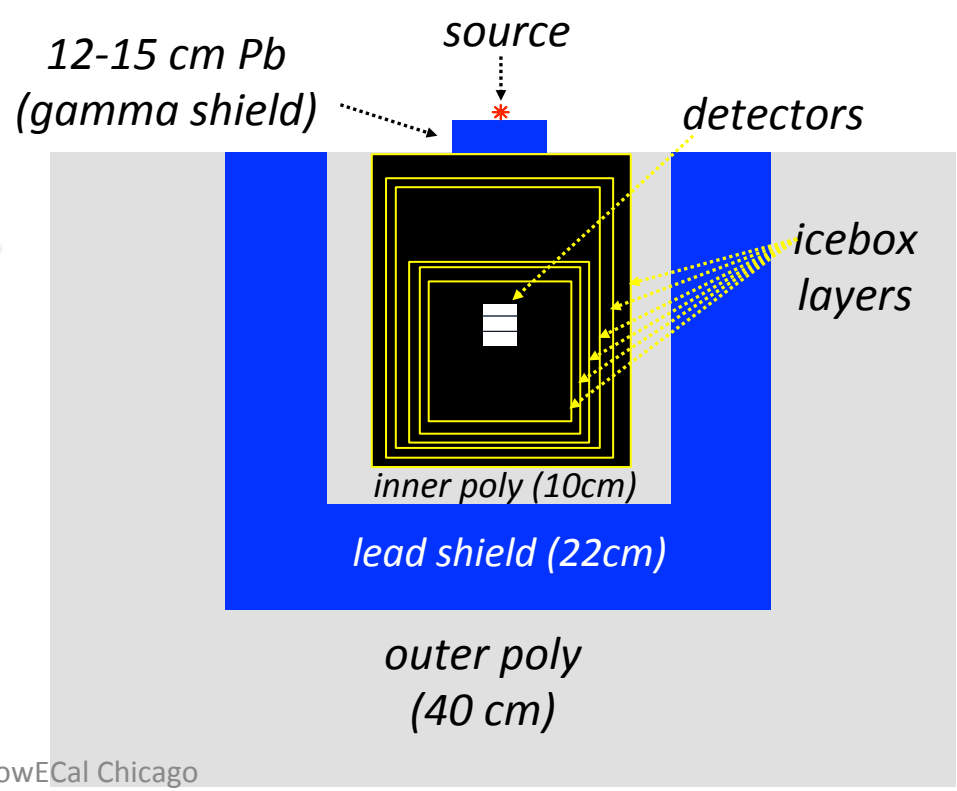
- Photon rate is ~10^5 times the neutron rate so NR's are buried in large ER background. It is necessary to bring down ER rate with lead shielding and perform ER subtraction to extract NR's.
- Neutrons that scatter multiple times within a single crystal produce a tail of events above the maximum recoil shoulder, making it more difficult to identify
- Management of pileup requires extended deployment time of several weeks to months

Simulated Setup

- Geant4 simulations were run to optimize source and shielding position, and estimate source rates.
- Simulations inform choice to deploy source on top of cryostat with a 2mm Be wafer (and predicted better spectrum from Be than BeO)
- *initial quick studies use Geant4 out of the box due to constraints of Soudan schedule. We know we can do better and we will redo more carefully now that data is in hand.*

Cartoon Schematic

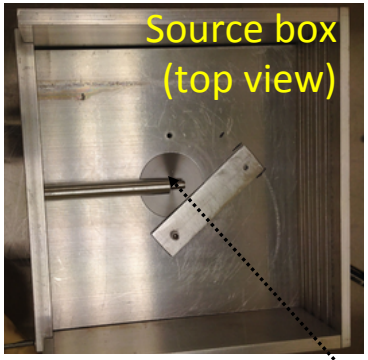
Remove top layers of SuperCDMS passive shielding to expose top of cryostat for this measurement

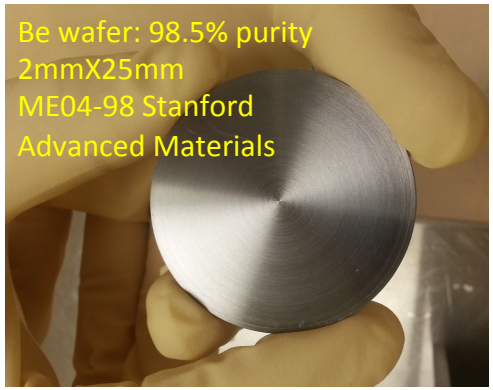


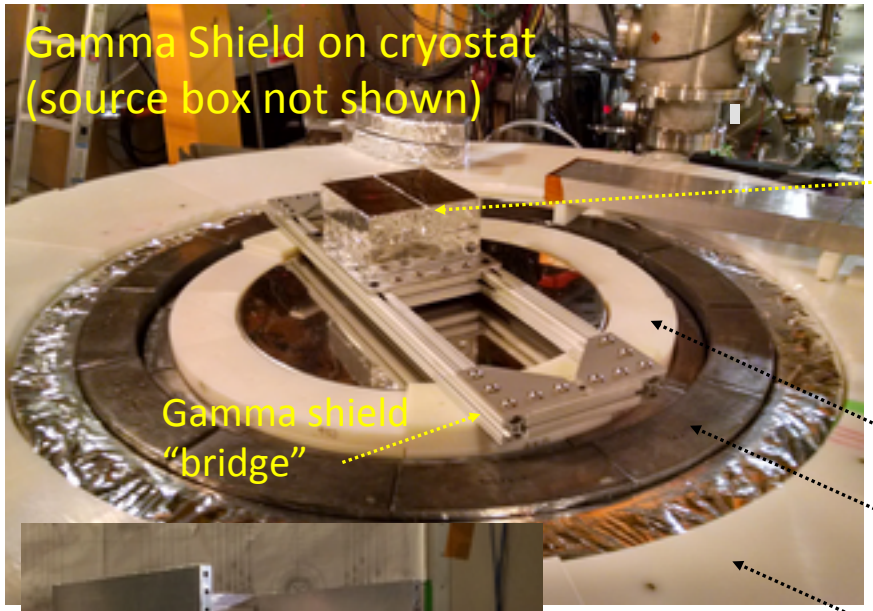
Targeting detectors T2Z1 and T5Z2; these detectors have good noise performance and both can be converted from iZIP to CDMSlite (with thresholds ~1 keV_{nr} or below)

Actual Soudan Setup

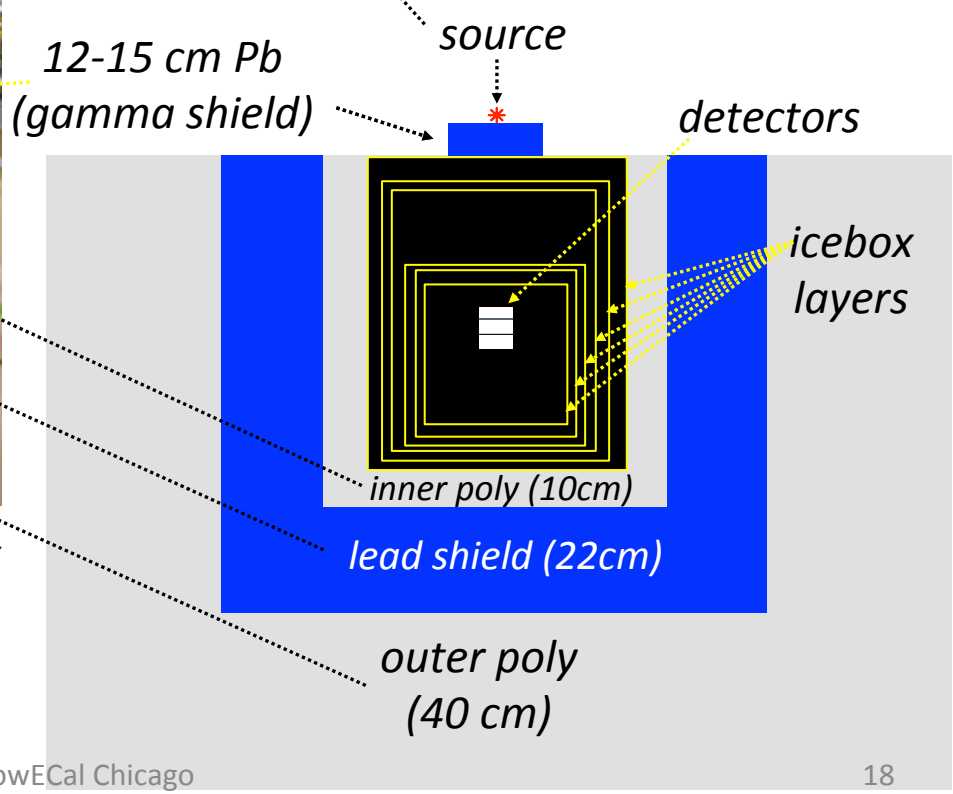
A source box was designed to hold Be wafer and gamma source in a fixed position; allows shift crews to place gamma source precisely wrt the detectors



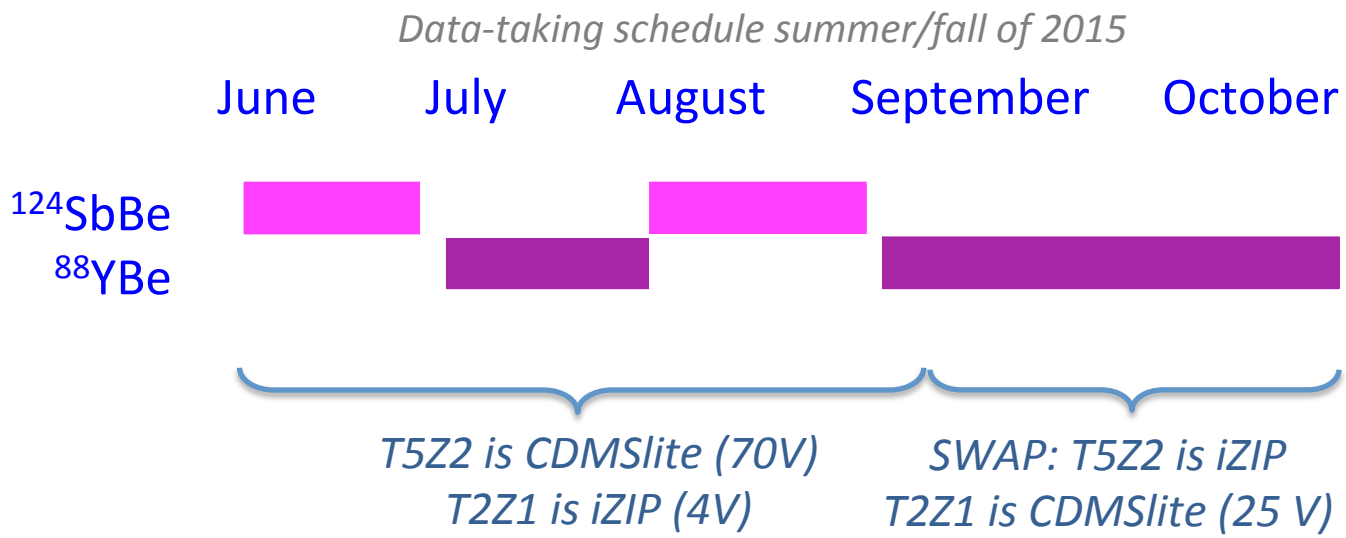




1 mCi ^{124}Sb and ^{88}Y gamma sources purchased from E&Z w/ double SS encapsulation



Data-taking Strategy

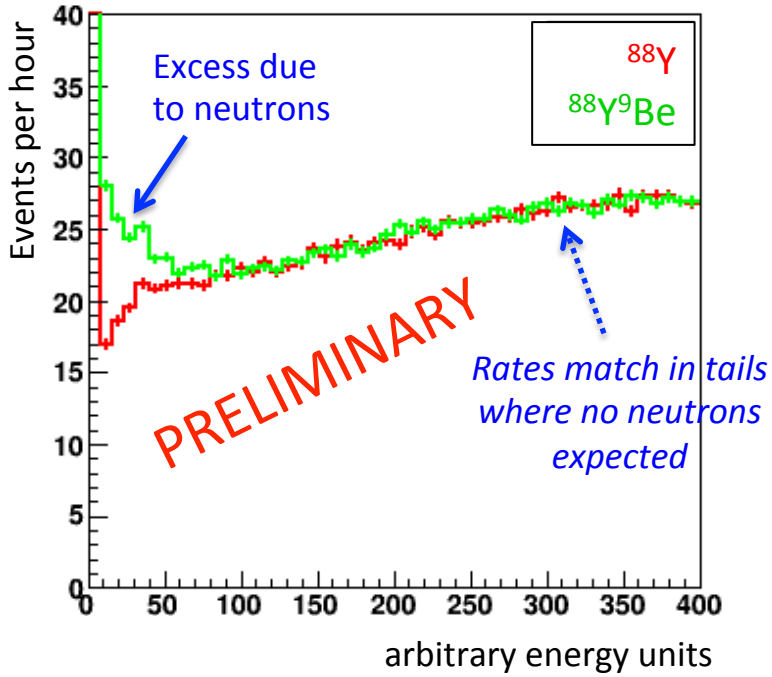


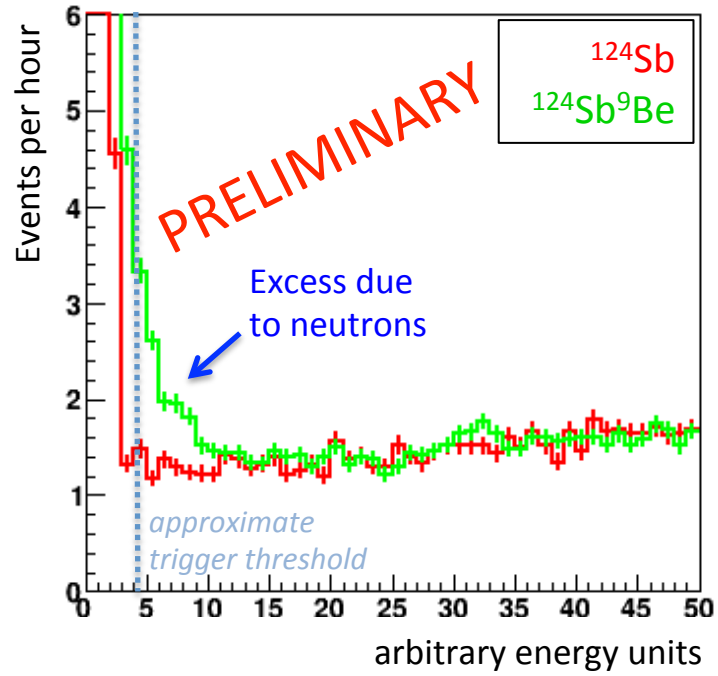
- Will use $^{88}Y^{9}Be$ dataset to compare ionization yield between CDMSlite and iZIP mode
- Neutron spectrum in CDMSlite detectors obtained by subtracting rate of "neutron-off" (no Be wafer) from "neutron-on" (with Be wafer)
- Data alternates between neutron-on and neutron-off every few days; livetime fraction is 50% or less due to other onsite activities; SuperCDMS Soudan will end in mid-Nov. ➔ *Measurement may be stats limited.*

First look at CDMSlite (unsubtracted) spectra

Comparison of on and off spectra for both sources looks reasonable (!)

Plots below are normalized by livetime to obtain rate and have basic quality cuts applied to remove bad events; rates have not been corrected for cut or trigger efficiency.

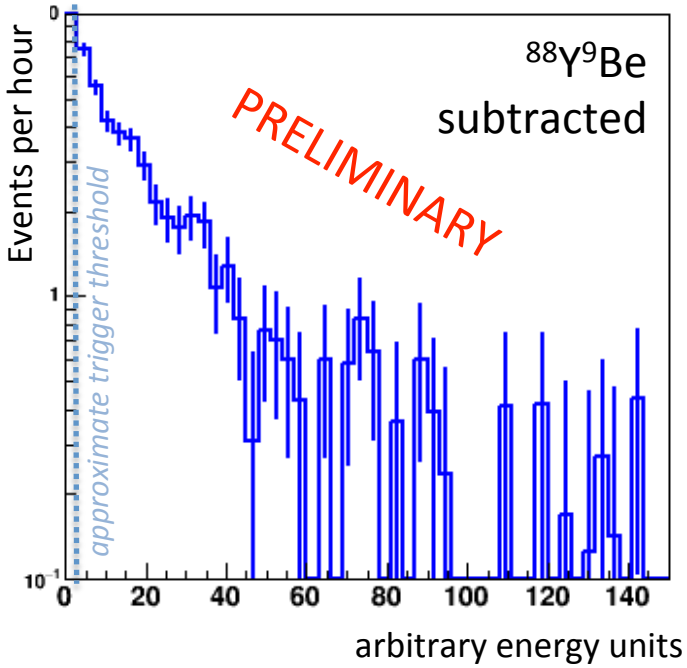


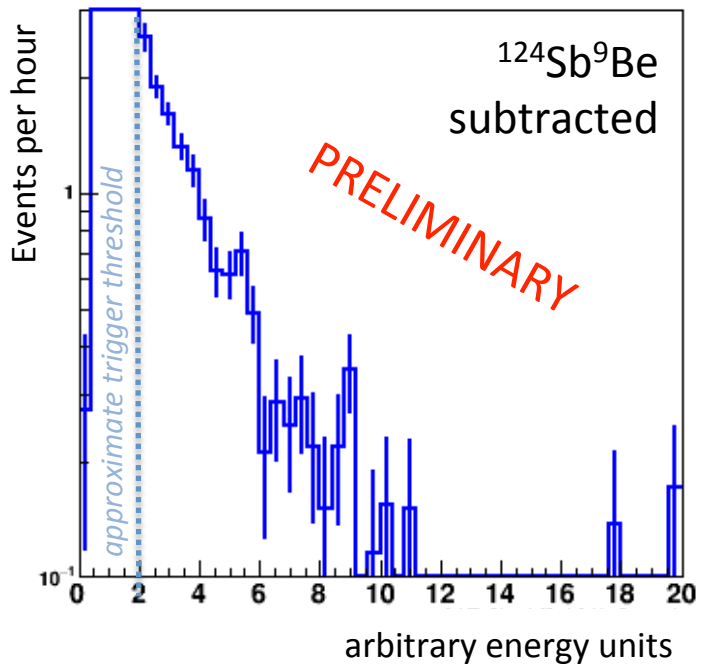


Note, final phonon energy scale does not have calibration; LHS and RHS have the same (arbitrary) energy scale

First look at subtracted T5Z2 spectra

Plots shown here are result after subtracting neutron-off from neutron-on plots shown on previous slide; these plots are not efficiency corrected.





x-axis units are not calibrated…but they are the same scale shown on previous slide.

error bars shown are statistical;
data shown is 5 weeks of Sb and 4 weeks of Y (additional data not yet analyzed)

Next steps

Goal is to extract the ionization yield for a range of energies around the elastic scattering shoulders. We expect to constrain down to ~ 1 keV$_{nr}$

Shoulder is subtle to pick out even with infinite stats. Resort to fits with simulated spectra, similar to the analysis of ^{252}Cf data done with CDMS II

- Will tune up simulations with realistic geometries and add A. Robinson's cross-section corrections to Geant4
- scattering shoulder helps to reduce systematic uncertainty in simulations

On the data analysis side of things:

- Phonon energy scale to be calibrated with 0V data; temp and leakage current corrections to be applied.
- Cut and trigger efficiency corrections to be applied
- Explore use of fiducial cuts to remove reduced field regions
- Compare results between CDMSlite vs iZIP and for different detectors

In the future, to go below 1 keV$_{nr}$, we'll need a different technique - see Tarek Saab's talk from Wednesday for future plans

Summary

SuperCDMS SNOLAB will deeply probe couplings between light WIMPs and nucleons. This will be achieved through a combination of iZIP and CDMSlite (HV) detectors

To complement this sensitivity, we need to measure the ionization yield at unprecedented low recoil energies, particularly for CDMSlite (HV) detectors

Several months of data have been gathered at Soudan using two photoneutron sources, $^{124}Sb^{9}Be$ and $^{88}Y^{9}Be$

By comparing the photoneutron data to simulated spectra, we expect to be able to constrain the ionization yield in CDMSlite detectors down to 1 keV_{nr}; If successful, this will be the first direct measurement of ionization yield in CDMSlite detectors

The data show that the photoneutron concept is working, but this is just the beginning of the work that needs to be done – stay tuned!

Thank You!

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