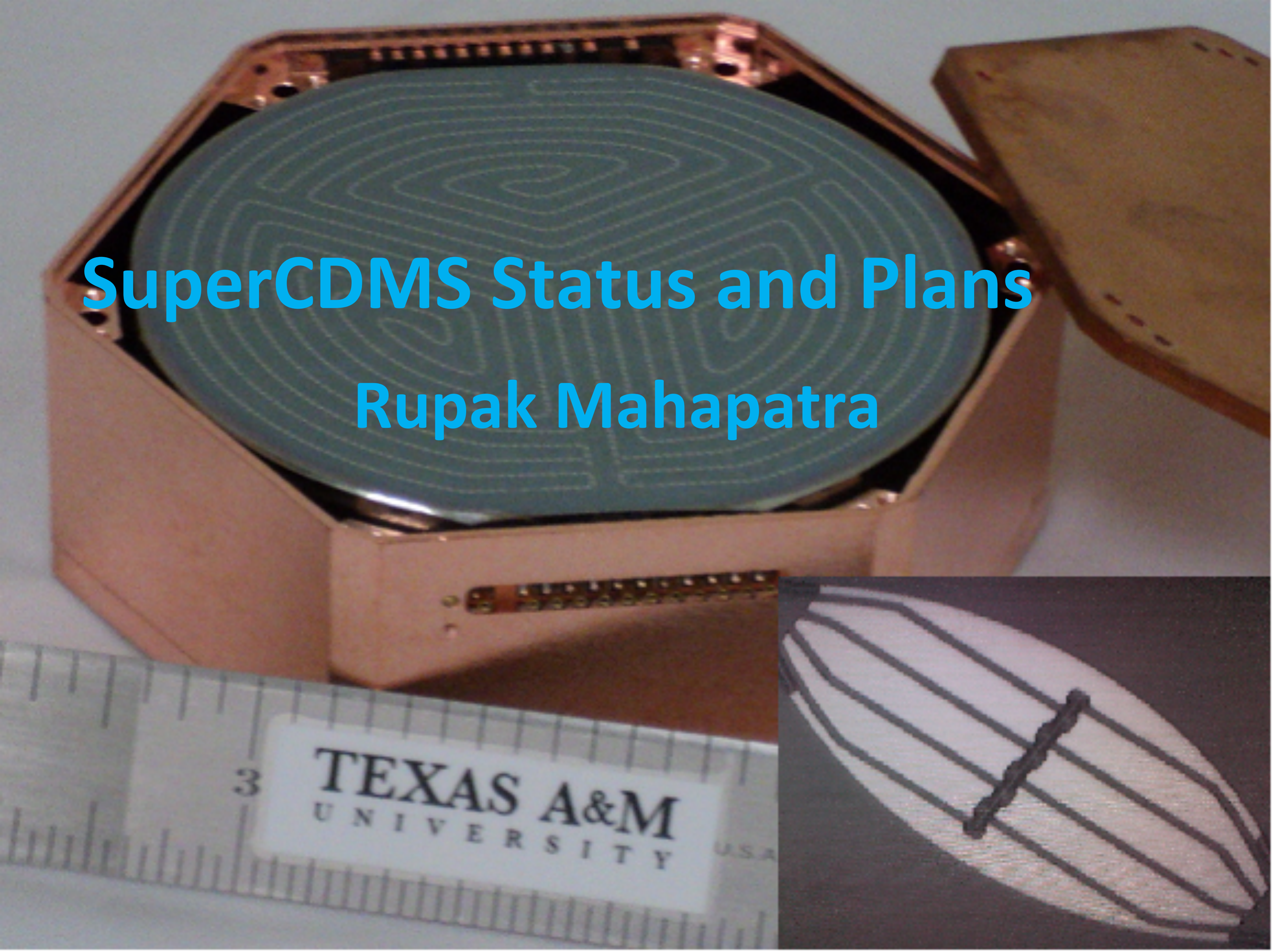
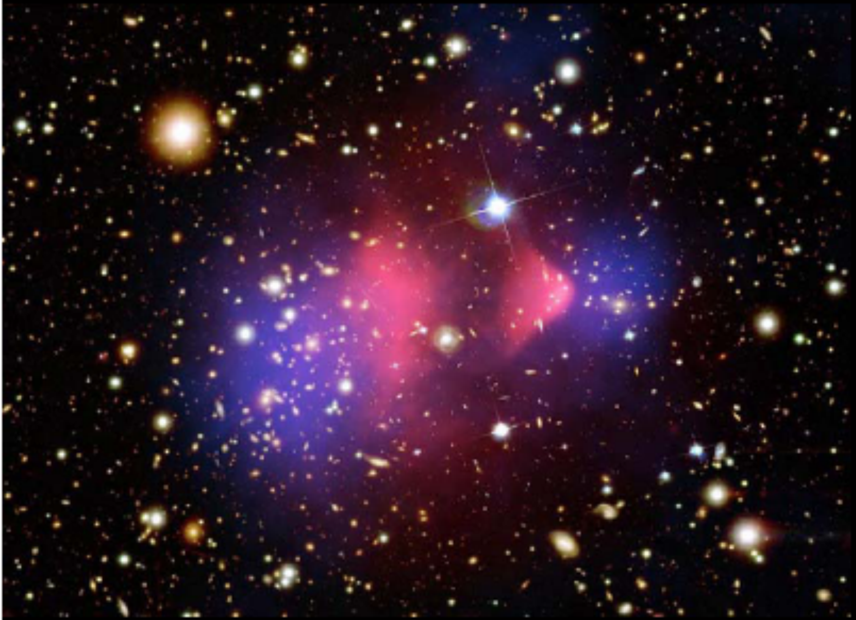
SuperCDMS Status and Plans

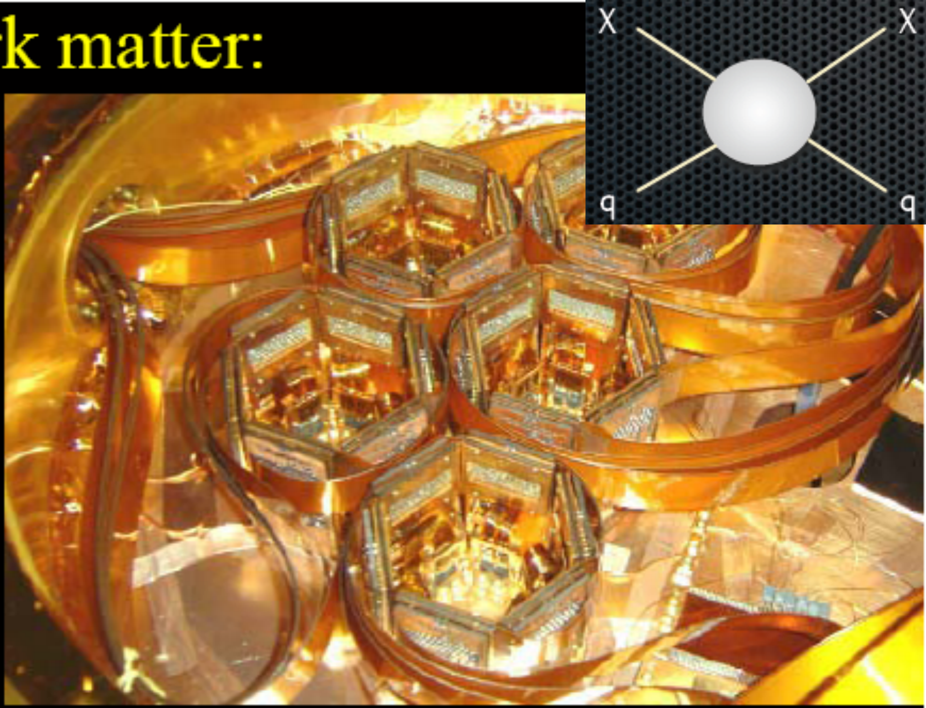
Rupak Mahapatra



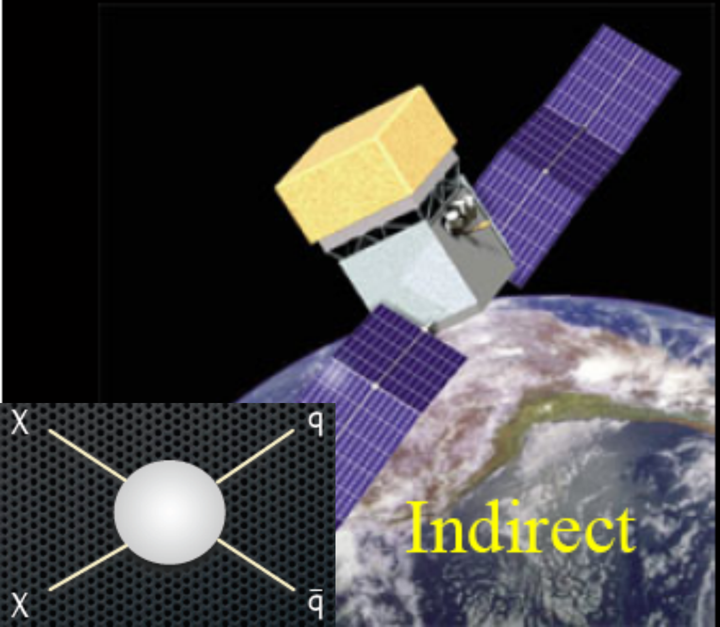
Four roads to dark matter:



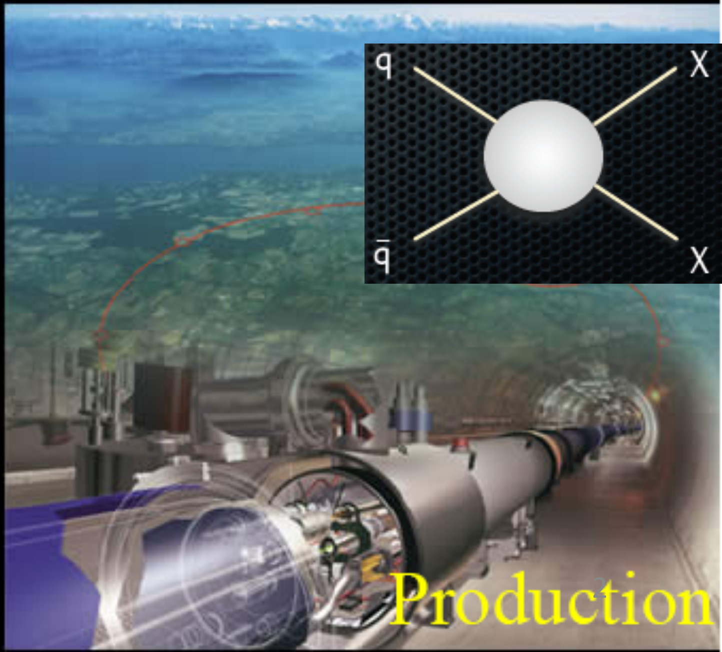
Gravitational



Direct



Indirect

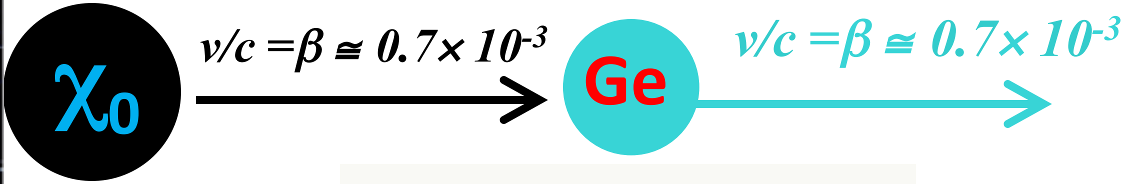


Production

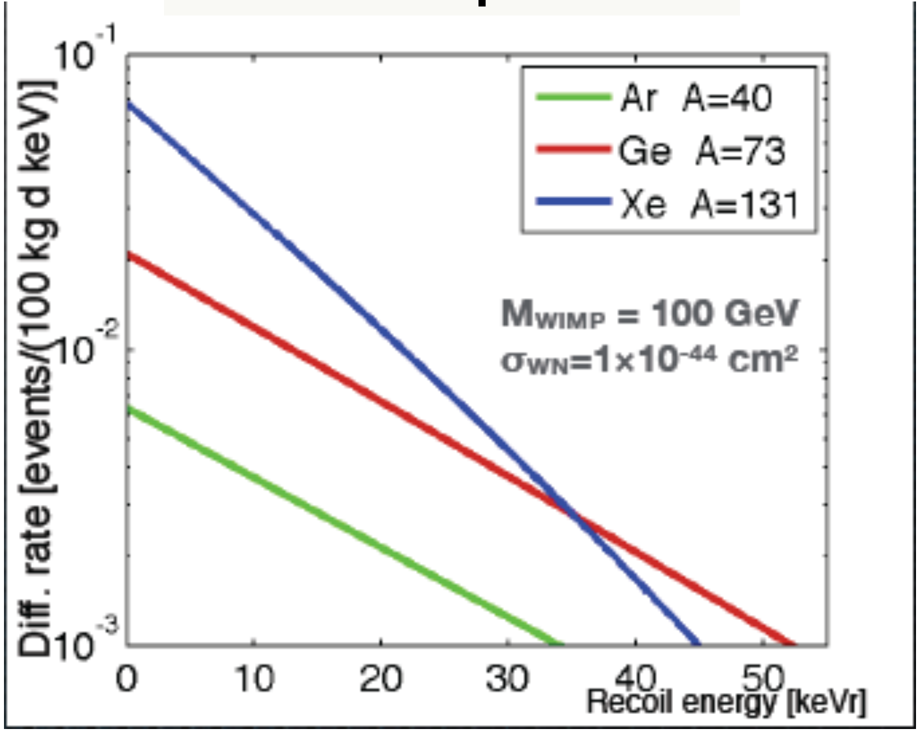
WIMP Hunting

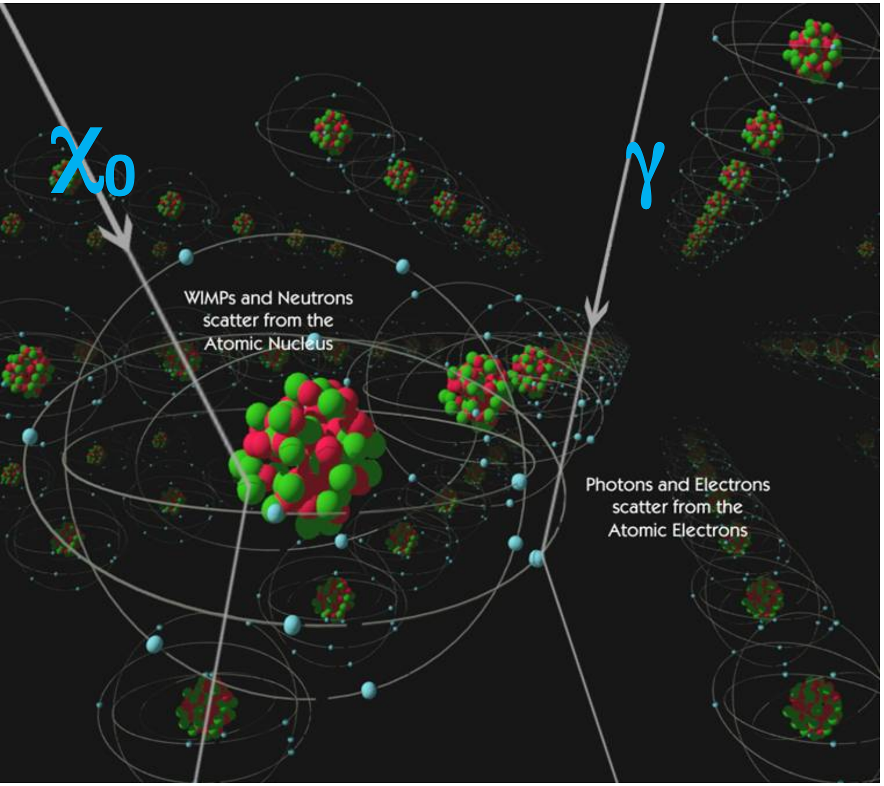
Out there & may interact on earth

$E_R \approx \mu^2 v^2/m_{Ge} \approx 10$ keV



Rate = N ϕ σ



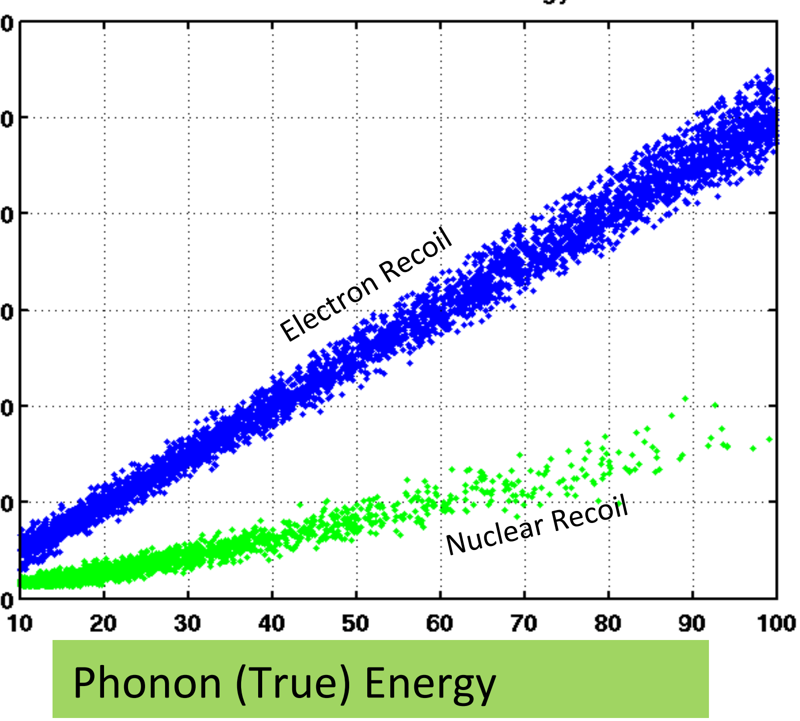


Recoil difference provides rejection

- Expected rate <.01/kg-day
- Huge Radioactive background
- Reduction and Rejection strategy

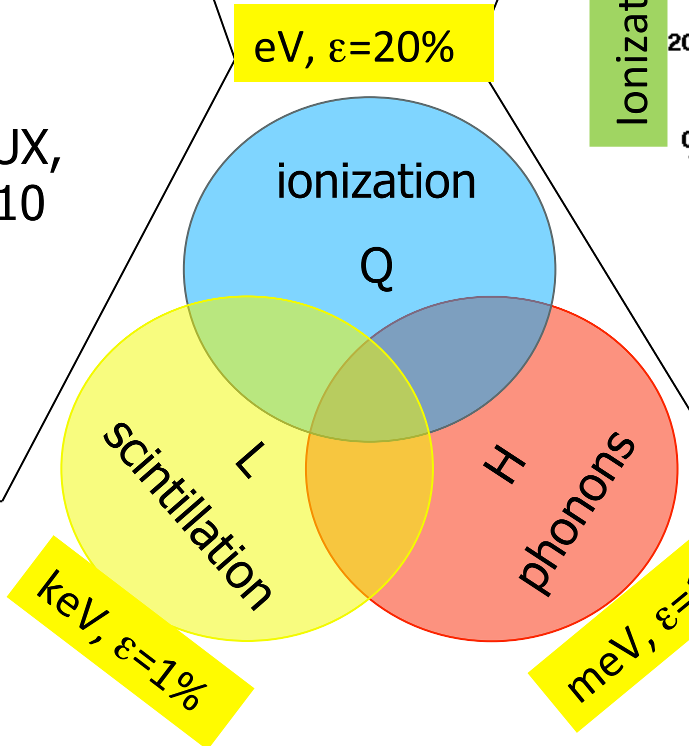
Detection and Discrimination Methods

IGEX,
DRIFTI, II



CDMS, EDELWEISS

ZEPLIN II, III, LUX,
XMASS, XENON10



NAIAD, ZEPLIN I,
DAMA

CRESST II,
ROSEBUD

CRESST,
PICASSO,
COUPP

At 1 keV – Million phonon quanta vs 0 light quanta. Huge statistics.

The SuperCDMS Collaboration

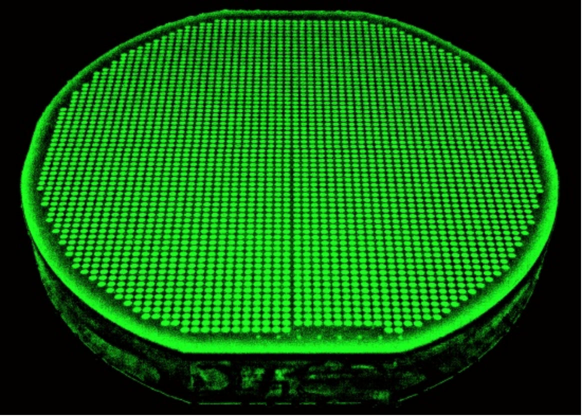
California Inst. of Tech.
CNRS-LPN
FNAL
Mass. Inst. of Tech.
NIST Inst. of Tech.
PNNL
Queen's University
Santa Clara University
SLAC
Southern Methodist U.
Stanford University
Syracuse University
Texas A&M University
U. Autónoma de Madrid
U. British Columbia
U. California, Berkeley
U. Colorado Denver
U. Evansville
U. Florida
U. Minnesota
U. South Dakota

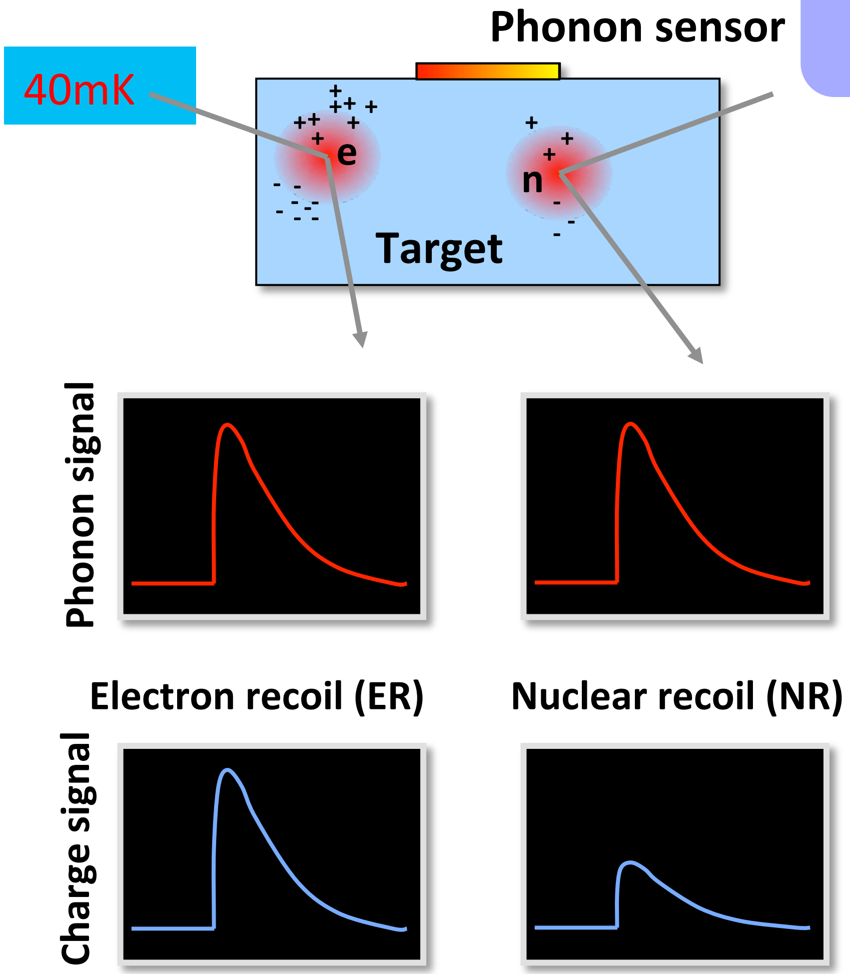
Labs - $3M in funds and $2M in donated instruments

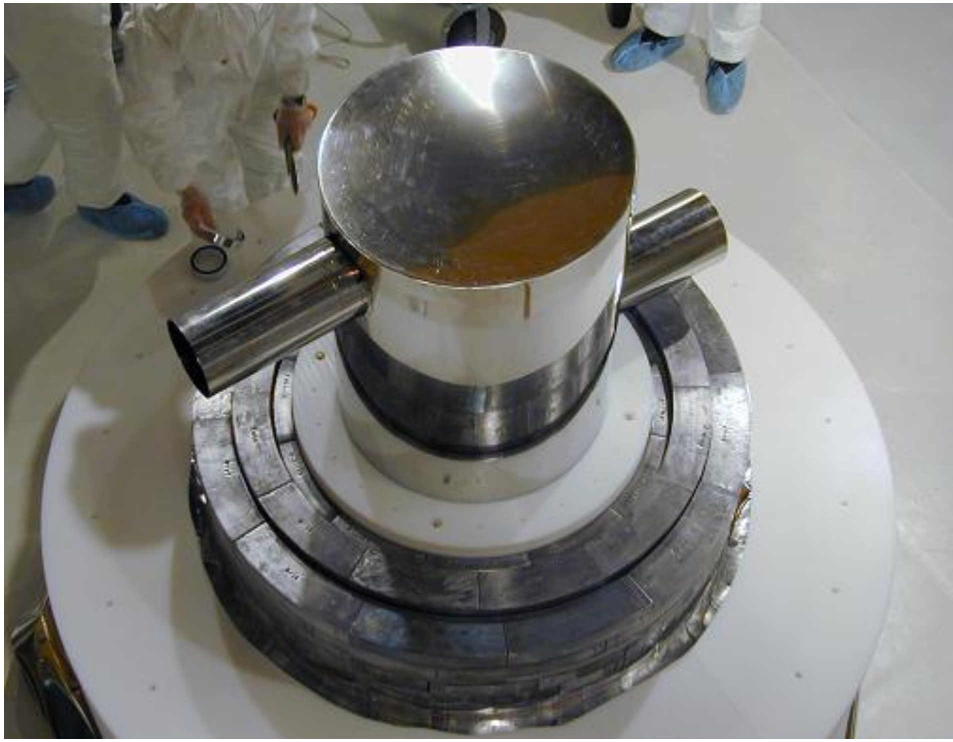
Instruments Donated by: Maxim Integrated Products
DOE (Career) and NSF (DUSEL) and TAMU Startup funds

CDMS: The Big Picture

Cryogenically cooled Ge/Si detectors with photo lithographically patterned Transition Edge Sensors for good energy and position resolution







- Passive Shielding (Pb, poly, *depth*)
- Active Shielding (muon veto shield)

SuperCDMS technique — the iZIP

Interleaved ionization & phonon sensors

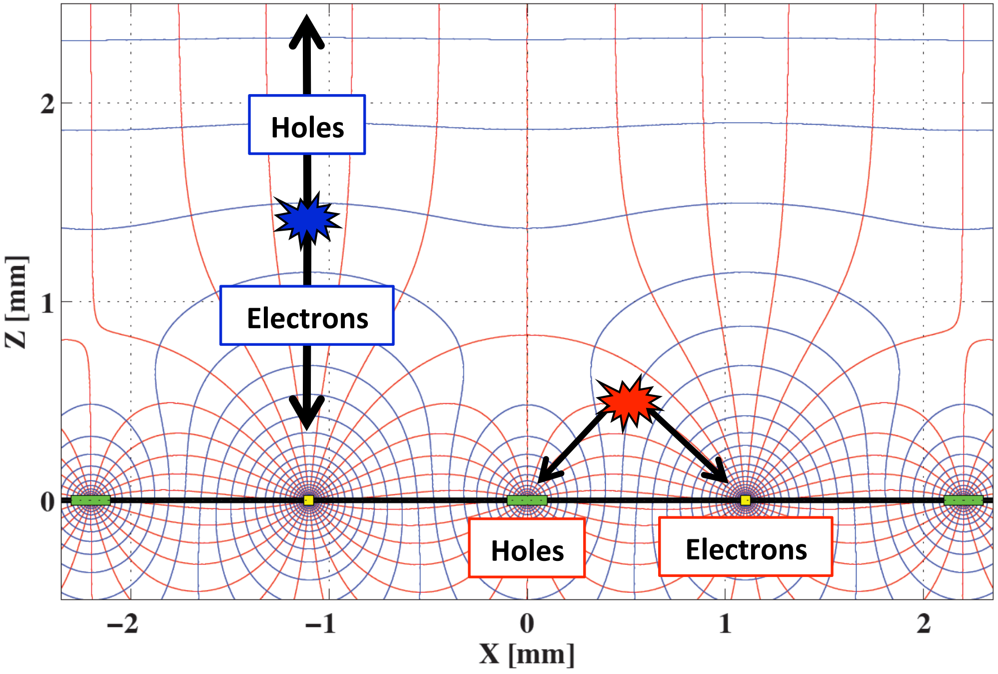
Bulk event → Side-symmetric Ionization signal

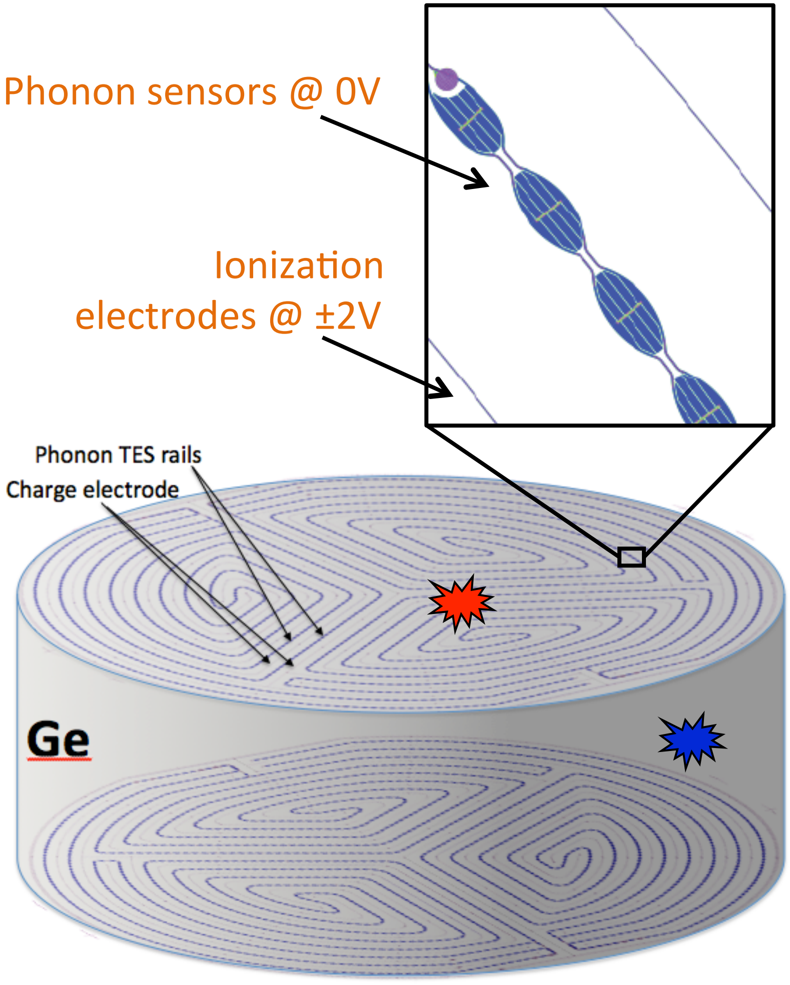
+

Surface event → Asymmetric ionization signal

=

Significantly improved face-event rejection




Phonon sensors @ 0V

Ionization electrodes @ ±2V

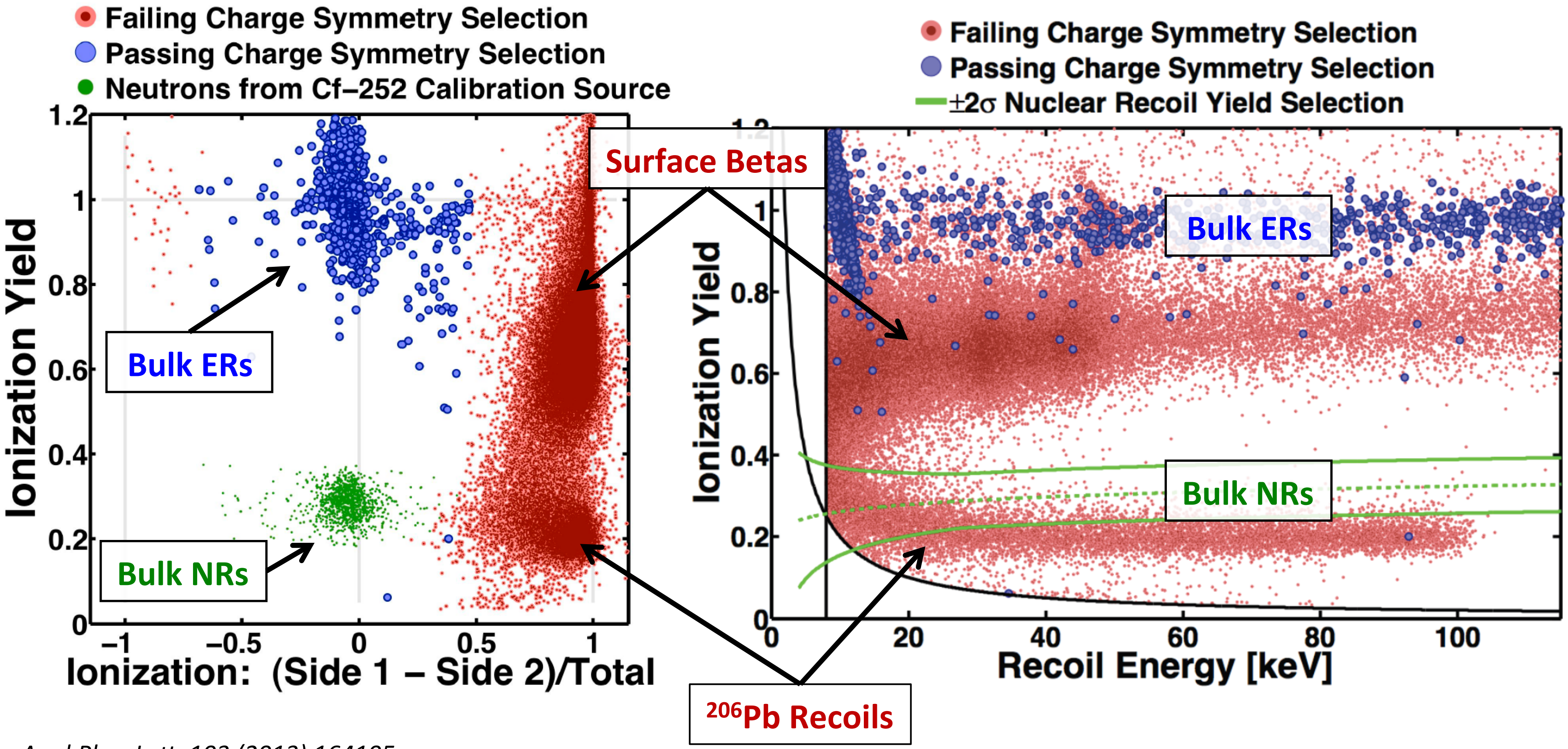
SuperCDMS background rejection

Surface-event Rn-daughter sources placed above and below 2 detectors (*in situ* @ Soudan)

50 live days → 0 of 132,968 leaked surface events in (symmetric) NR signal region

→ Good enough rejection for proposed SuperCDMS SNOLAB

(100 kg, $\sigma_{\chi\text{-N}} < 8 \times 10^{-47}$ cm^2 for 60 GeV/c^2 WIMP)

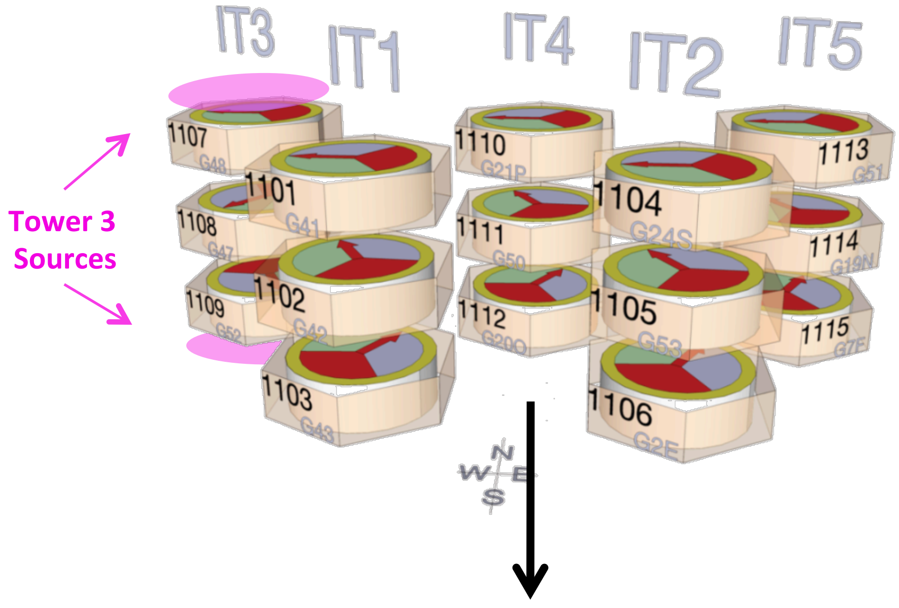


Appl.Phys.Lett. 103 (2013) 164105
[arXiv:1305.2405]

SuperCDMS Soudan

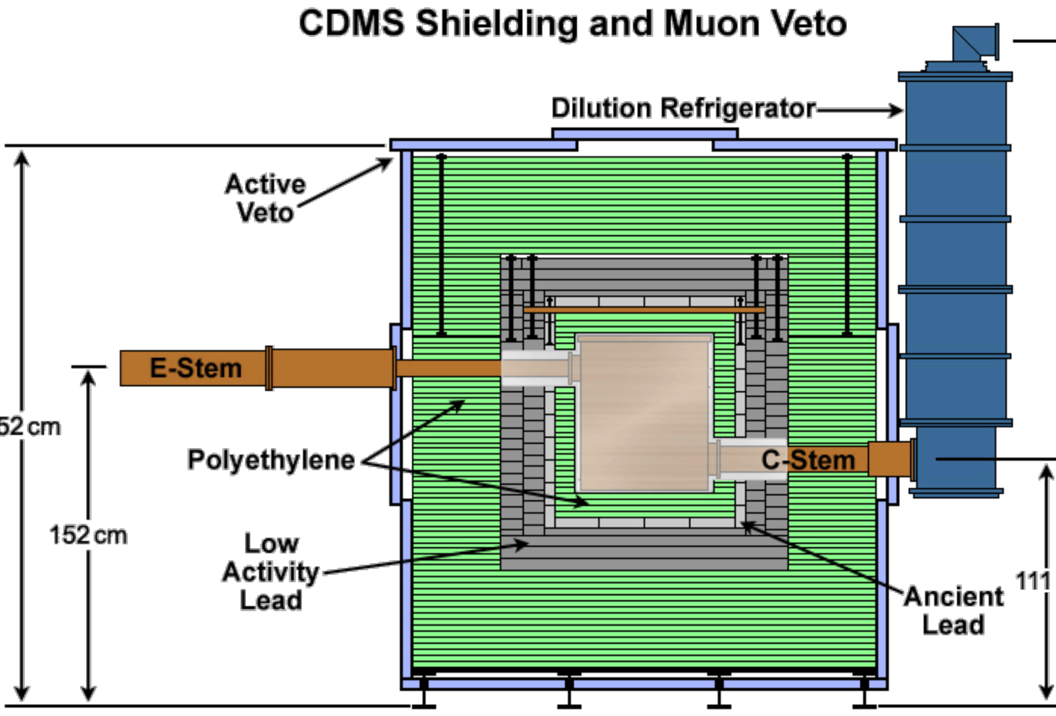
<u>5 Super Towers of Ge iZIPs</u>

- 3 iZIPs per tower → total mass of ~9 kg
- Installed in CDMS II shielding end of 2011
- Fully operational since early 2012
- Currently recording WIMP-search data!
- Expect to run for 2–3 years



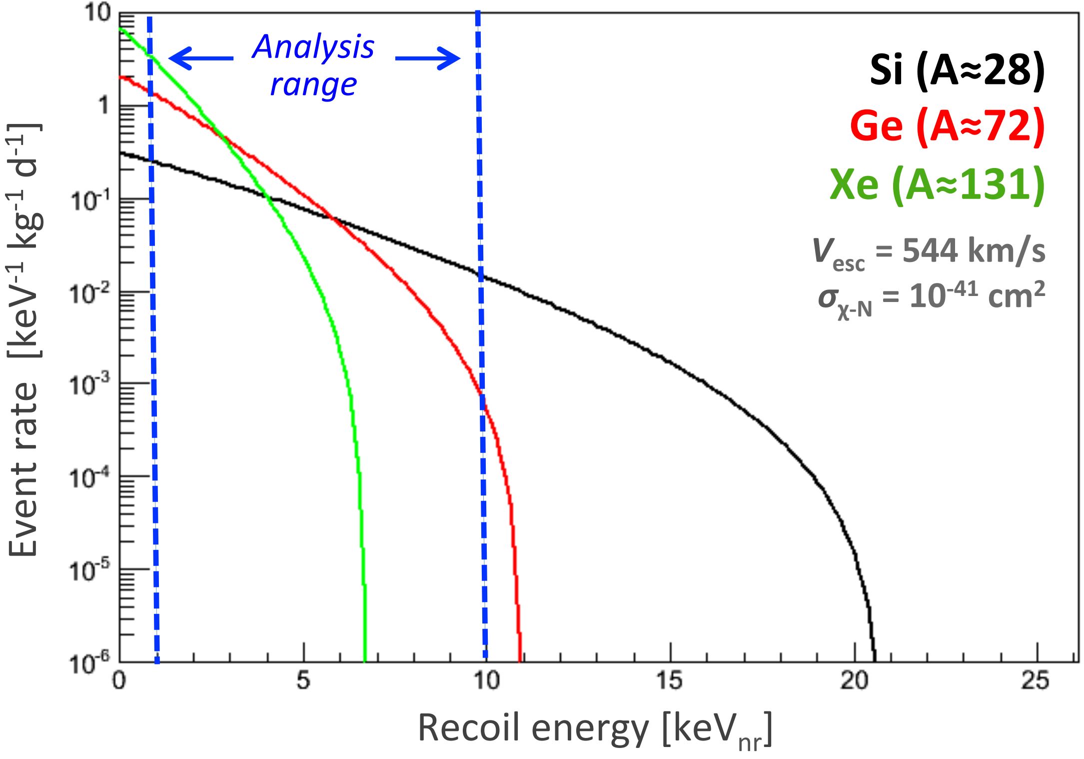
<u>WIMP-search strategies</u>

- CDMSlite →
  - Special bias configuration & readout
  - Light WIMP masses: < 10 GeV/c^2
- Low-threshold (LT) analysis →
  - Subset of array w/ best trigger thresholds
  - Light WIMP masses: < 20 GeV/c^2
- Near-zero background analysis →
  - Full detector array & exposure
  - Higher thresholds to prevent background from resolution effects
  - Heavier WIMP masses: > 10 GeV/c^2


CDMS Shielding and Muon Veto

Searching for light WIMPs

Experiments with lighter targets and lower thresholds have the advantage when looking for WIMPs with mass < 10 GeV/c^2



7 GeV/c^2 WIMP-induced recoil spectrum

Our strategy

Ge is a relatively heavy target, so go as low in threshold as possible

- CDMSlite search → < 1 keV$_{nr}$
- LT analysis → ≈1.6 keV$_{nr}$

Backgrounds more difficult to reject below 10 keV$_{nr}$

- CDMSlite → extra-low threshold
- LT analysis → use improved iZIP fiducialization capability to reject as much background as possible

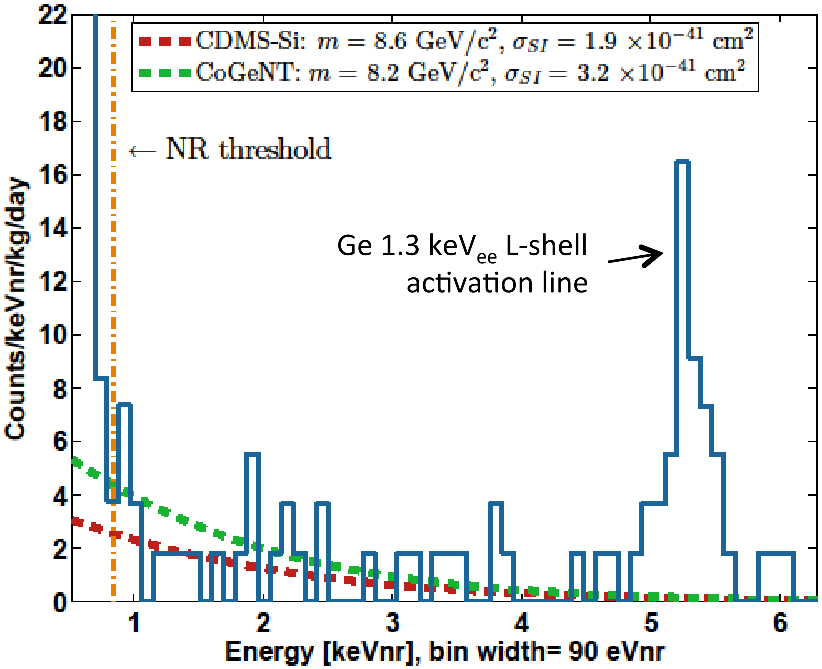
We expect background events in the signal region…
tradeoff is greater sensitivity to low mass WIMPs.

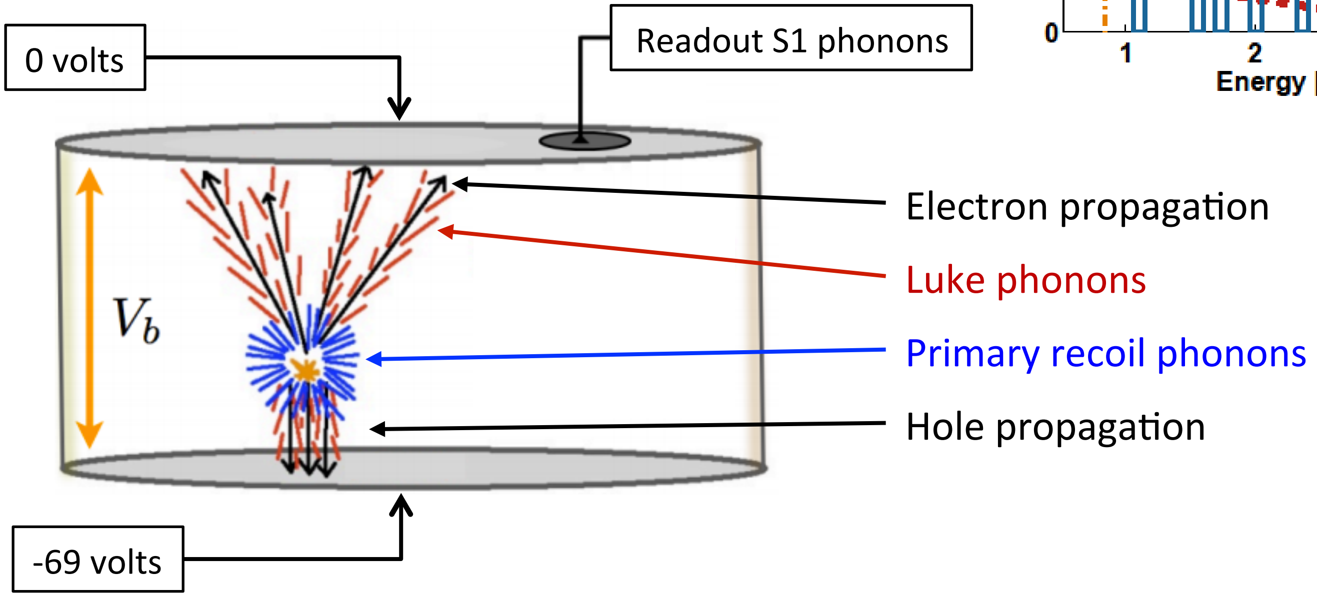
SuperCDMS Soudan — CDMSlite

Luke-amplified ionization-energy measurement

- 24x amplification of ionization energy via phonons
  - → 10x lower threshold for ERs
  - → ≈ equal noise performance

  ***vs.* normal ±2V mode**
- No event-by-event ER-NR discrimination
  - → But near perfect signal efficiency
- Fall 2012 search for light WIMPs
  - → Single-detector 10-day exposure (5.9 kg-days)
  - → Observed rate → 1.2±0.2 events /keV$_{nr}$ /kg-d





0 volts

Readout S1 phonons

Electron propagation

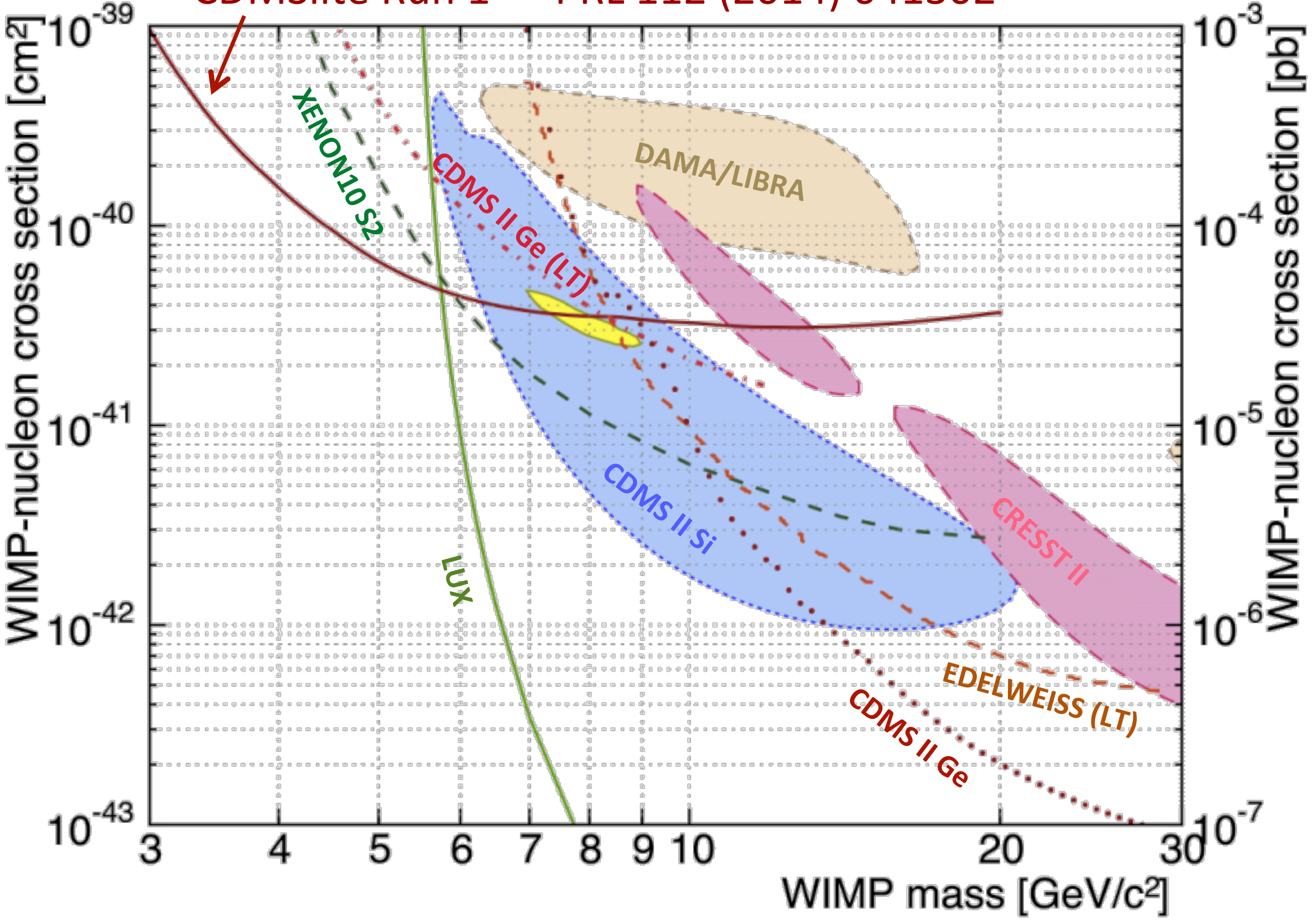
Luke phonons

Primary recoil phonons

Hole propagation

-69 volts

CDMSlite result


CDMSlite Run 1 — PRL 112 (2014) 041302

6-month CDMSlite Run 2 with electronics upgrade in progress! (≈½ complete)

SuperCDMS SNOLAB CDMSlite: even lower threshold by optimizing detector geometry

→ Easy 2x improvement (*e.g.*, not dual-sided phonons, of which only 1 is read out)

→ Increasing bias voltage will lower threshold even further

SuperCDMS Soudan — LT analysis

Normal ±2V bias configuration

WIMP search → Oct 2012 – July 2013

- 577 kg-day ***blinded*** exposure
- ER calibration throughout via ^{133}Ba
- NR calibrations via ^{252}Cf
  - → 97 kg-day open dataset

7 detectors w/ lowest trigger thresholds

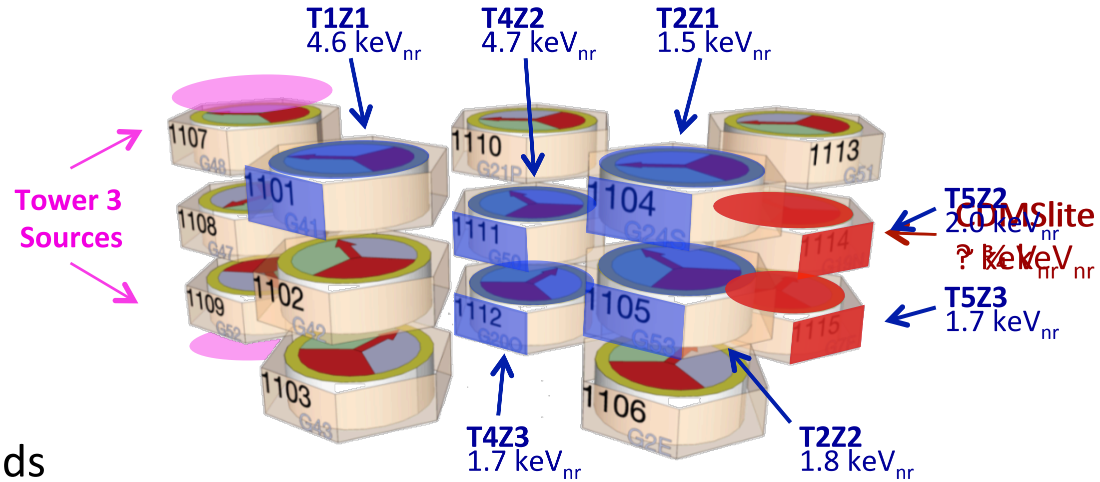
- → ~1.6 to 5 keV$_{nr}$ (detector & time dependence)

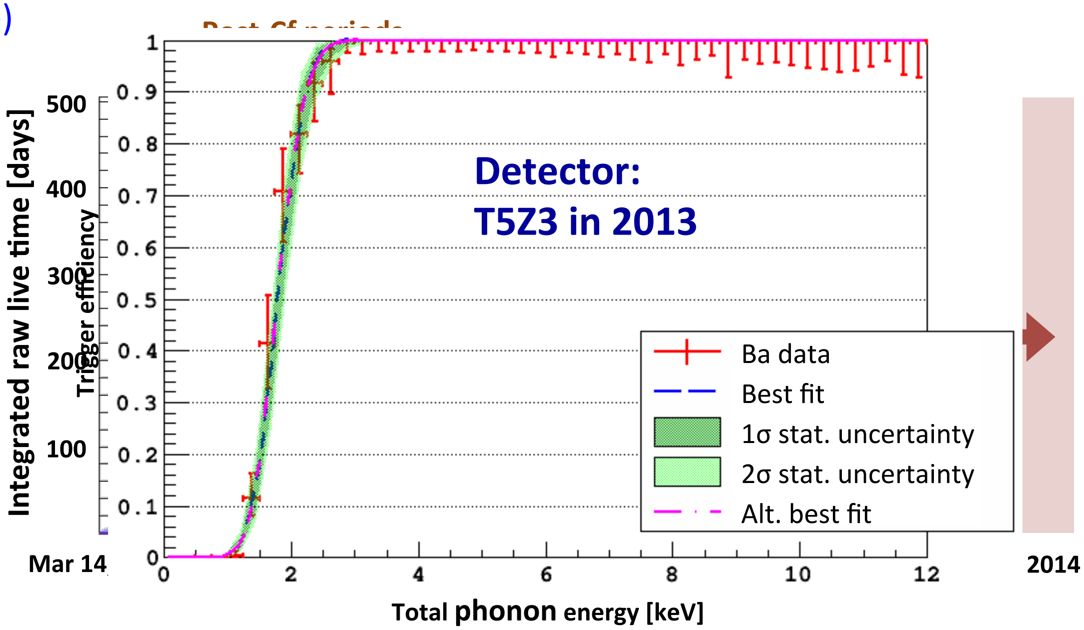
Expect background in signal region at lowest energies where ionization is ≈ consistent with electronic noise

- → But some discrimination still possible

Note: 2 special-case detectors

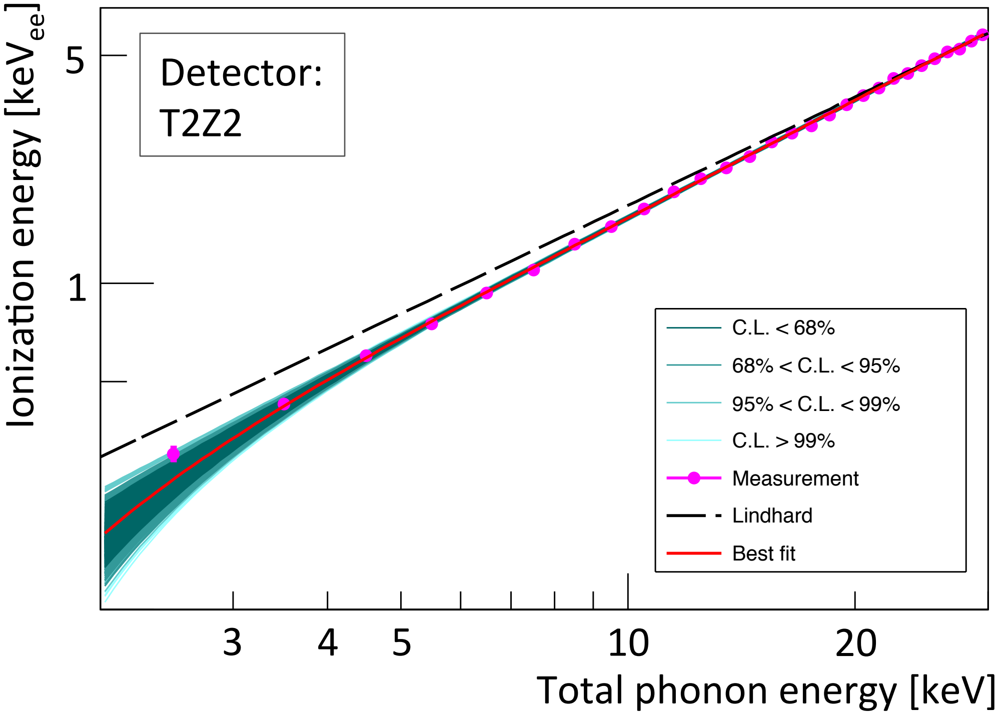
- → T5Z2 in 2013 had noisy S1 Q guard
- → T5Z3 has S1 Q guard not biased





LT-analysis energy scale

Ionization for nuclear recoils measured from ^{252}Cf data



Total phonon energy =

$E_{total} = E_{Luke} + E_{recoil}$

E_{total} is measured with phonons

NR equivalent energy =

$E_{total} - E_{Luke,NR}$

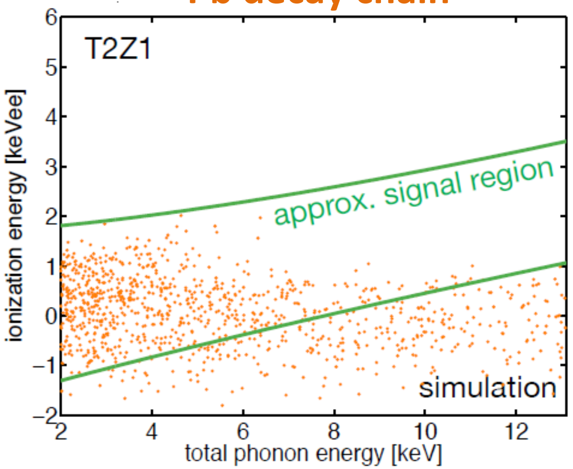
$E_{Luke,NR}$ estimated from mean NR ionization, varies with E_{total}

(same as CDMS II low-energy analysis)

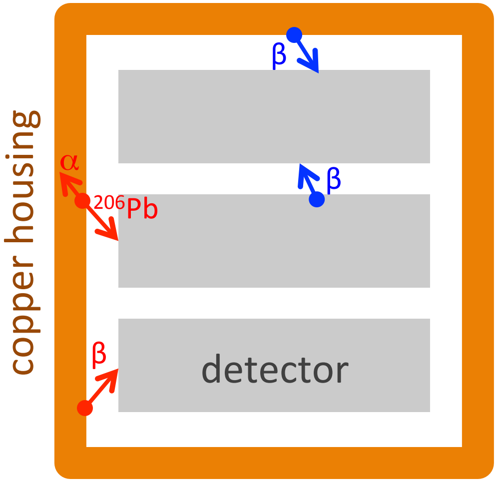
Note: we sometimes approximate mean ionization with Lindhard theory because measured values are detector-dependent. This is labeled "Lindhard nuclear recoil energy"; difference is a few %.

LT-analysis backgrounds

^{210}Pb decay chain

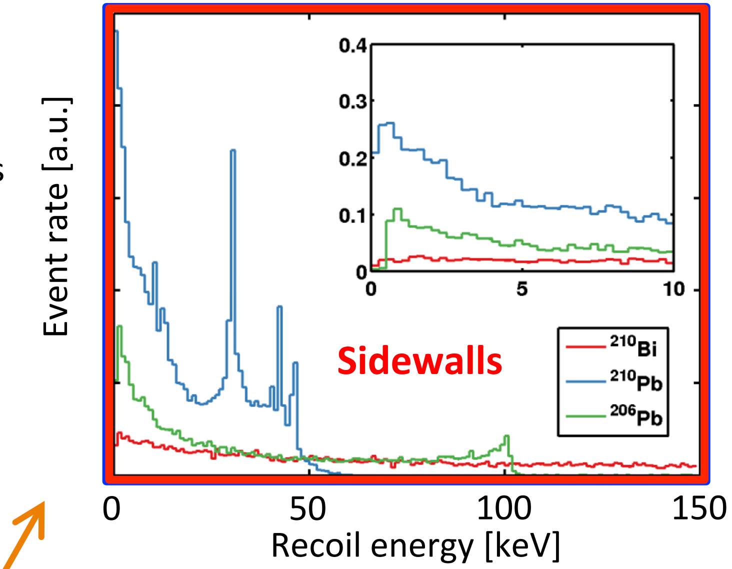


- ^{210}Pb, ^{210}Bi → β's & X-rays
- ^{210}Po decays → ^{206}Pb recoils
- Divide by location:
  - → detector **faces**
  - → detector **sidewalls**

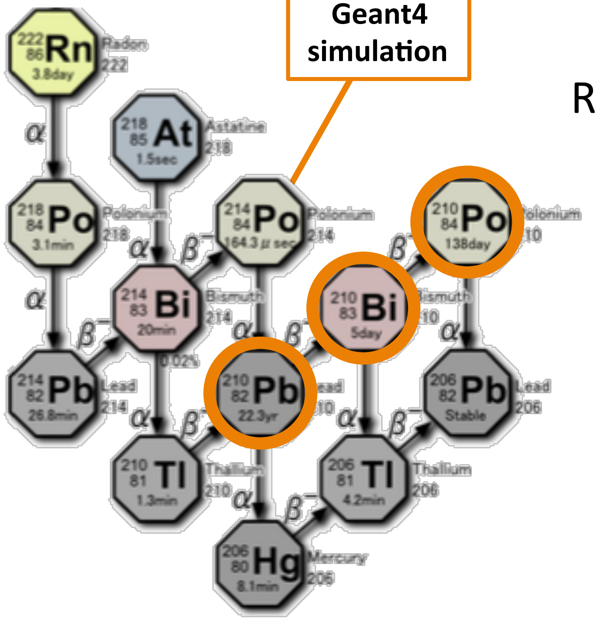


"Pulse Simulation"

Simulate low-energy detector response by combining noise traces w/ template pulses taken from higher-energy sidebands & scaled to give MC energy spectrum



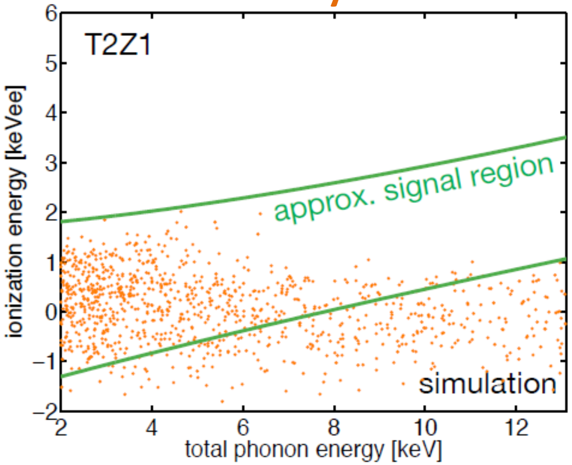
Geant4 simulation



Rn progeny plate-out onto detector & copper surfaces, creating long-lived ^{210}Pb source

LT-analysis backgrounds

^{210}Pb decay chain



- ^{210}Pb, ^{210}Bi → β’s & X-rays
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- Divide by location:
  → detector **faces**
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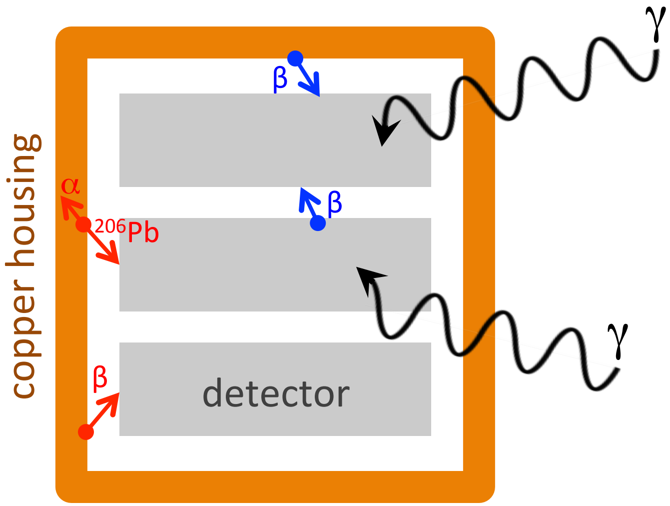
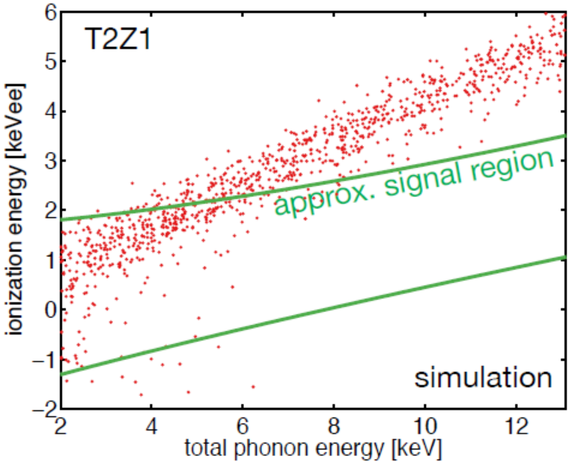


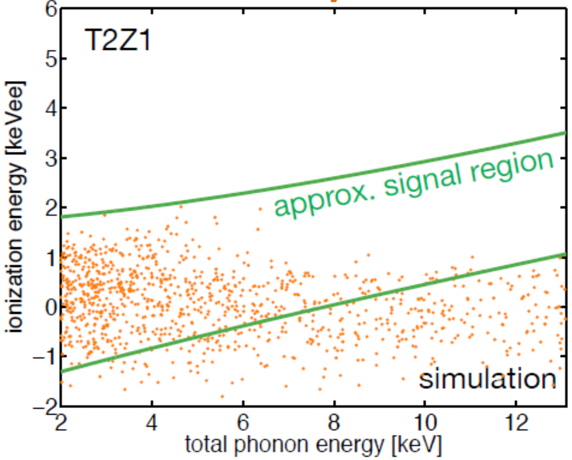
External Gammas



- External gammas from radioactivity in shielding & cryostat
- Detector response via pulse simulation

LT-analysis backgrounds

^{210}Pb decay chain



- ^{210}Pb, ^{210}Bi → β’s & X-rays
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- Divide by location:
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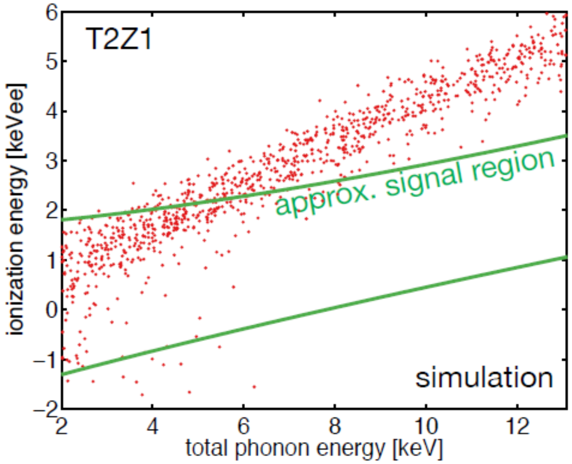
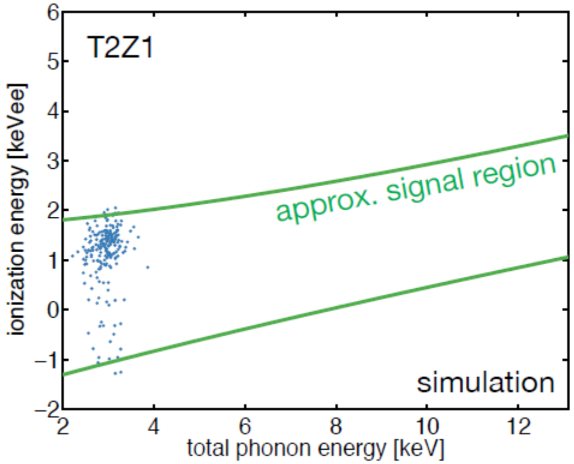
External Gammas

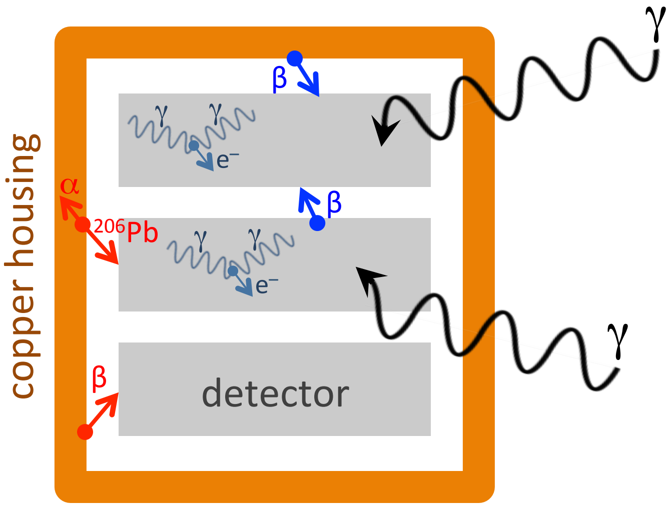


- External gammas from radioactivity in shielding & cryostat
- Detector response via pulse simulation

Internal Activation Lines

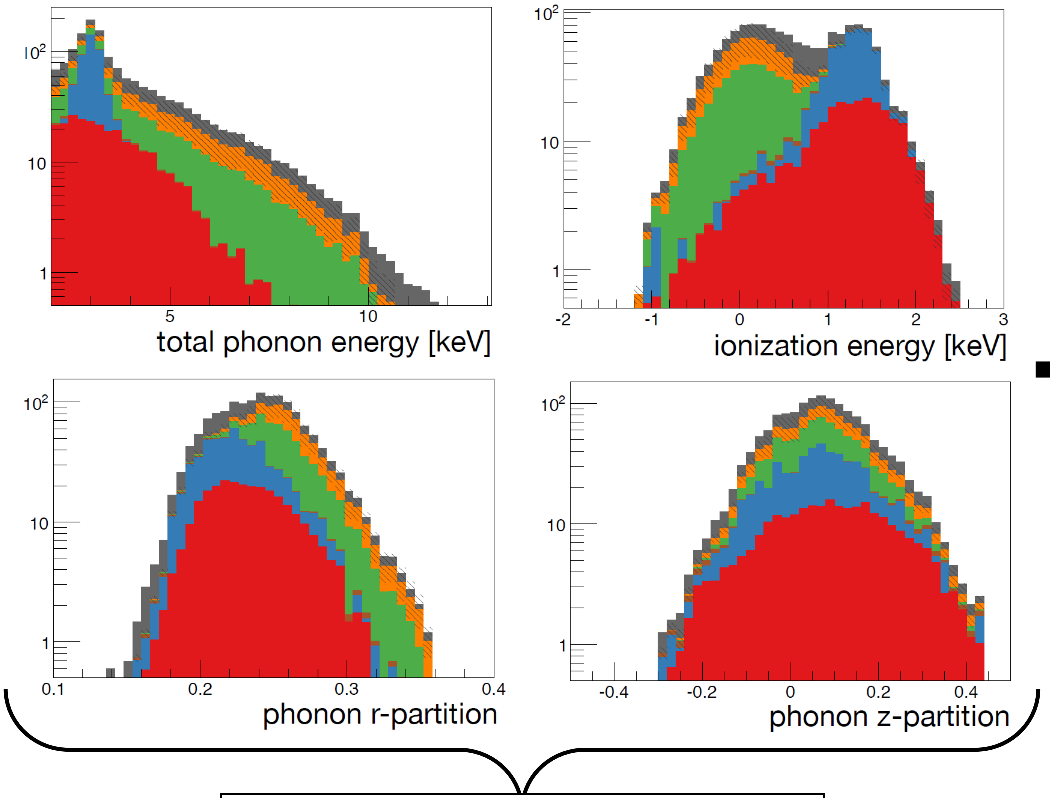


- Detector activation from cosmics & thermal-neutron capture
- X-rays & Auger electrons from ^{68,71}Ge, ^{65}Zn, ^{68}Ga L-shell e⁻ capture
- Detector response via pulse simulation



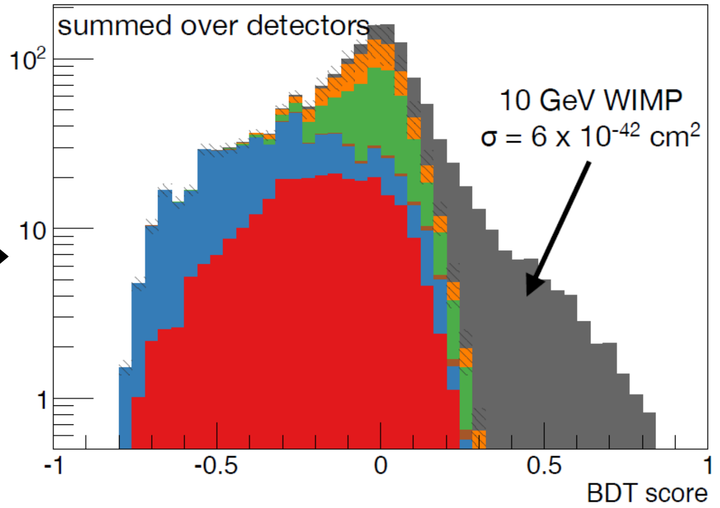
- Also, radiogenic & cosmogenic neutron backgrounds
  - → but irreducible & rate is very low
- Signal region blinded & no calibration for ^{210}Pb-sourced sidewall events
  - → ^{210}Pb decay-chain simulation systematics not yet understood in detail
  - → Before unblinding, chose to set upper limit based on any candidates

LT-analysis BDT



Boosted Decision Tree — inputs

Boosted Decision Tree — Output



⬛ → Expected WIMP signal (10 GeV/c^2 shown here)

🟧 → Sidewall ^{206}Pb recoils

🟩 → Sidewall β's & X-rays

🟫 → Face β's & X-rays

→ ^{210}Pb-sourced

🟦 → 1.1–1.3 keV L-shell activation lines

🟥 → External gammas ("Comptons")

Train BDT with:

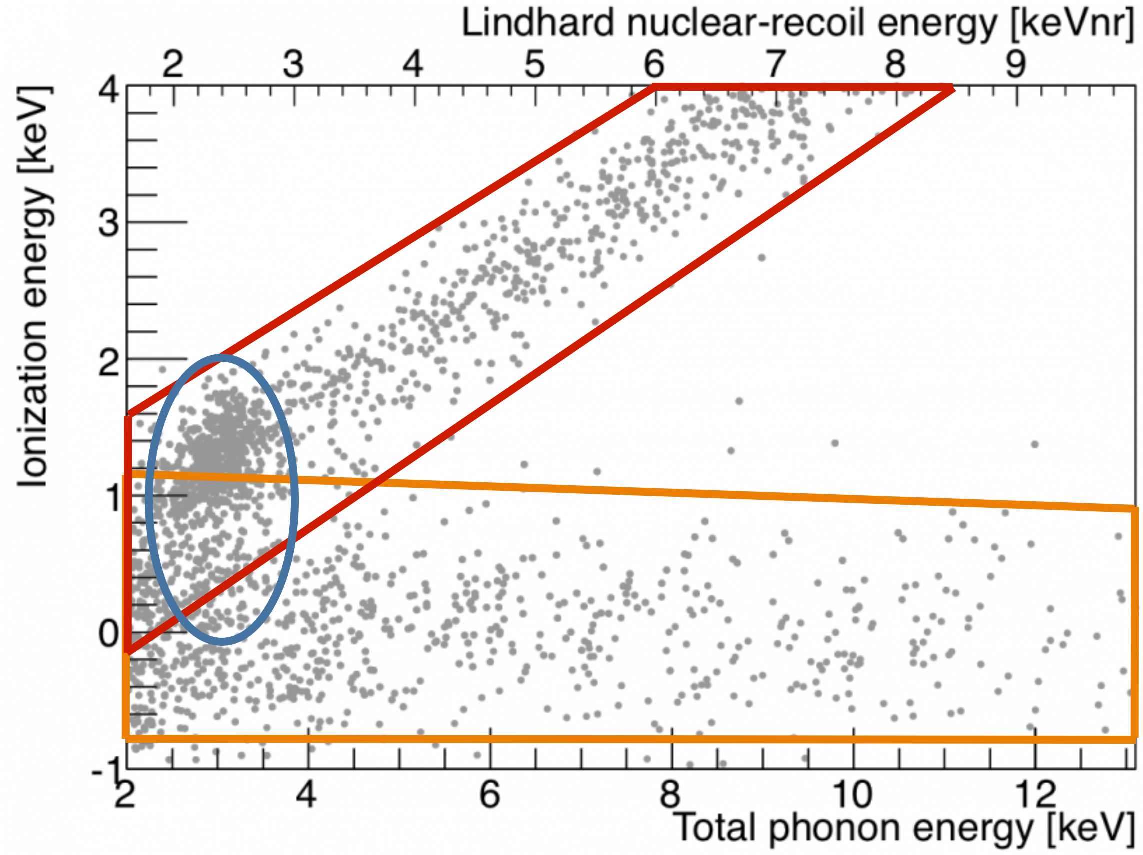
- Background events from pulse simulation
- Signal from ^{252}Cf NRs reweighted to expected energy spectra for 5, 7, 10 & 15 GeV/c^2 WIMPs

Create 1 BDT per detector per WIMP mass

Optimize BDT-score cuts simultaneously across detectors to minimize expected 90% C.L. upper limit separately for each WIMP mass

OR across WIMP masses to accept events that pass one or more of 4 cuts

LT-analysis unblinding (before BDT)



All events passing:

- Quality &
- Thresholds &
- Preselection (except NR ionization)

3 background components evident:

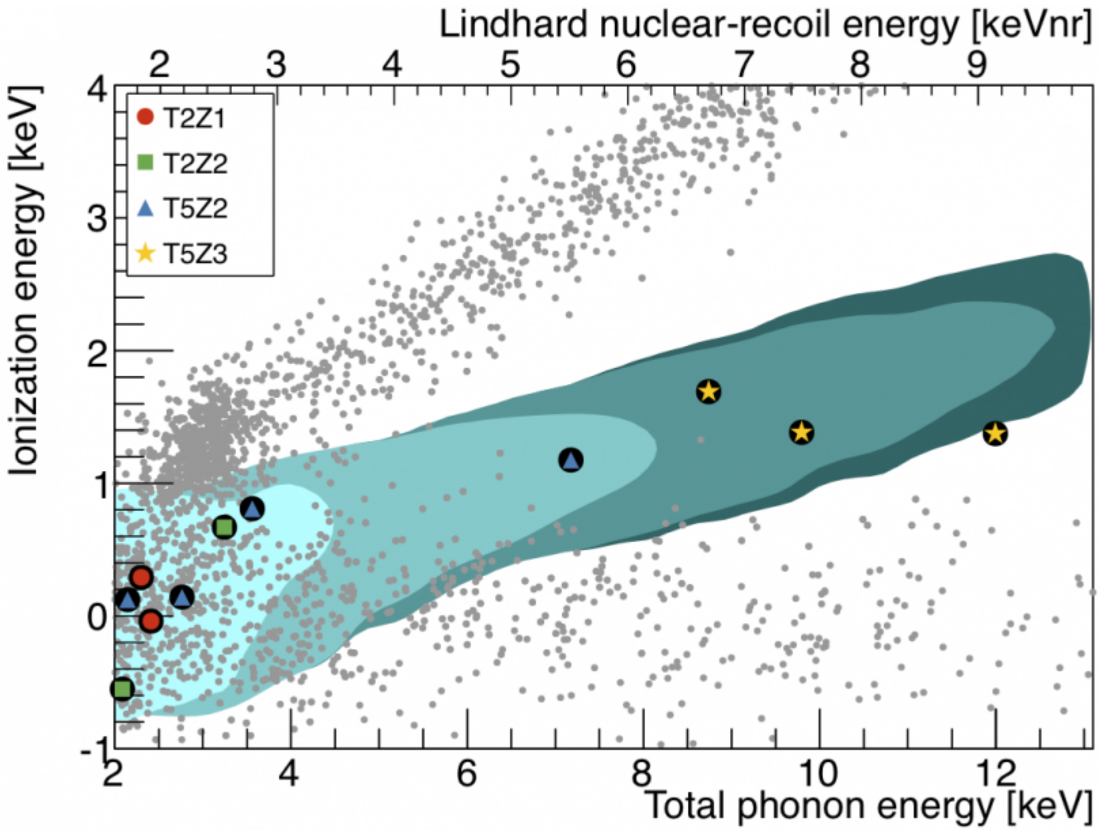
- ^{210}Pb-sourced surface events
- External gammas ("Comptons")
- Internal activation lines

Expected background after BDT:

$6.1^{+1.1}_{-0.8}$ (stat. & syst.)

Also, 0.10 ± 0.02 neutrons

LT-analysis unblinding (after BDT)



11 candidate events pass all cuts!

($6.1^{+1.1}_{-0.8}$ expected)

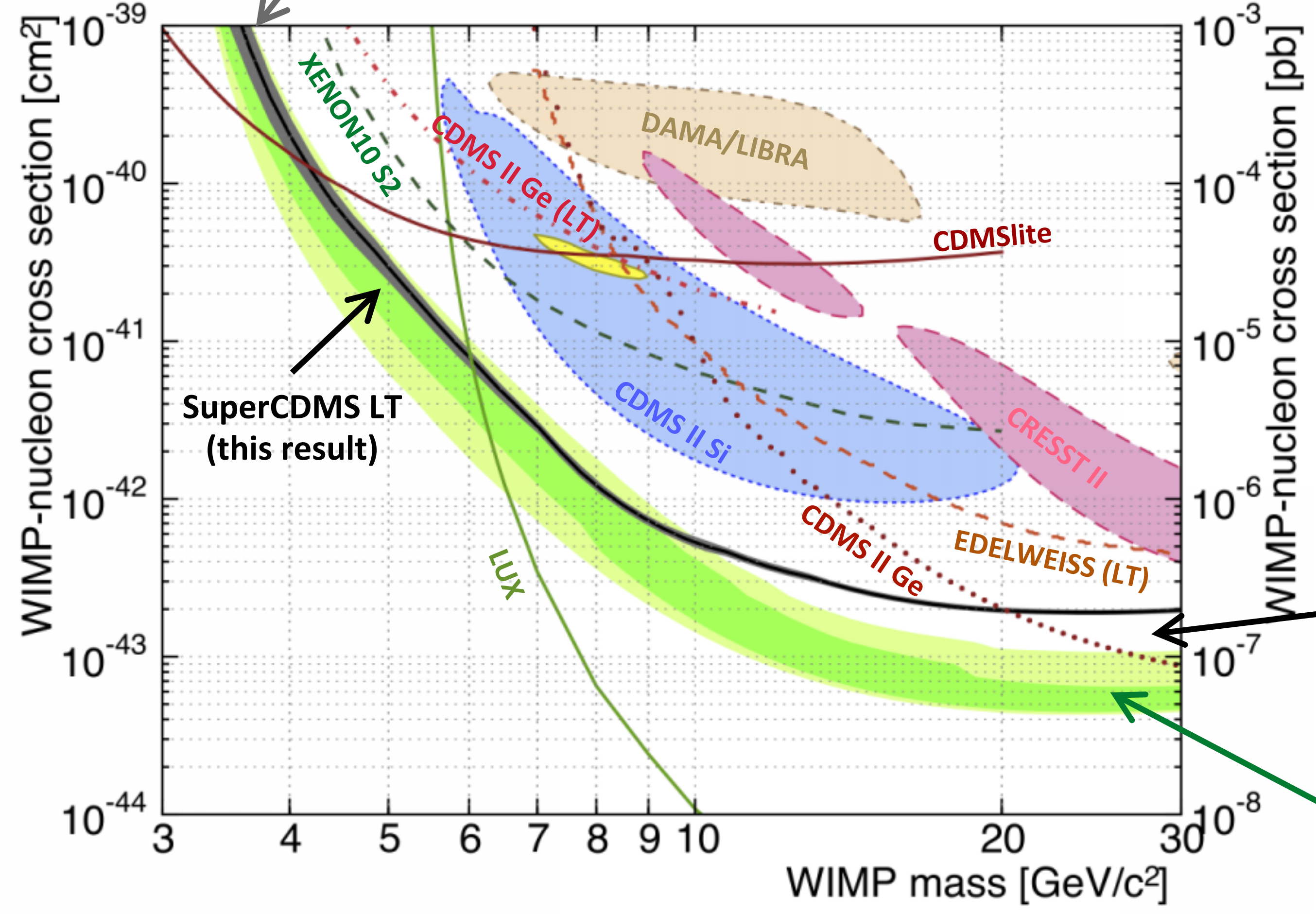
3 with unexpectedly (from model) high energies

→ all in T5Z3 w/ altered E-field

95% confidence contours for expected signal from **5**, **7**, **10** & **15** GeV/c^2 WIMPs

LT-analysis result

95% C.L. uncertainty band
(trigger, energy scale, fiducial volume)



SuperCDMS LT
(this result)

difference due to T5Z3
high-energy events

Expected sensitivity
at 68 and 95% C.L.

[arXiv:1402.7137] (submitted to PRL)

SuperCDMS Soudan full exposure

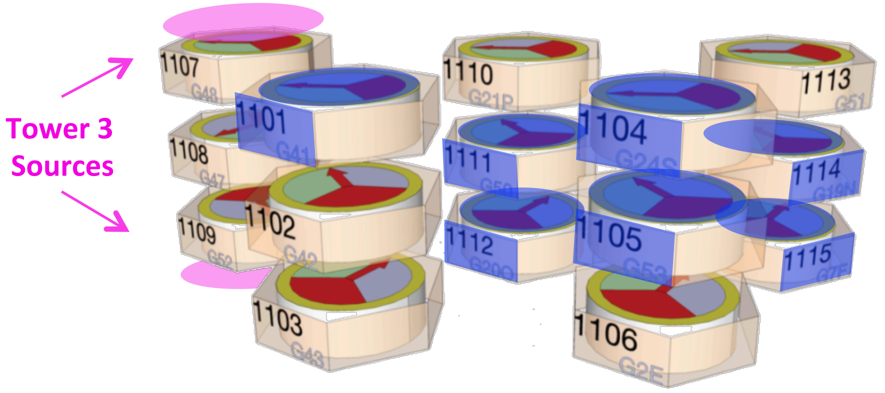
Near-zero background WIMP-search

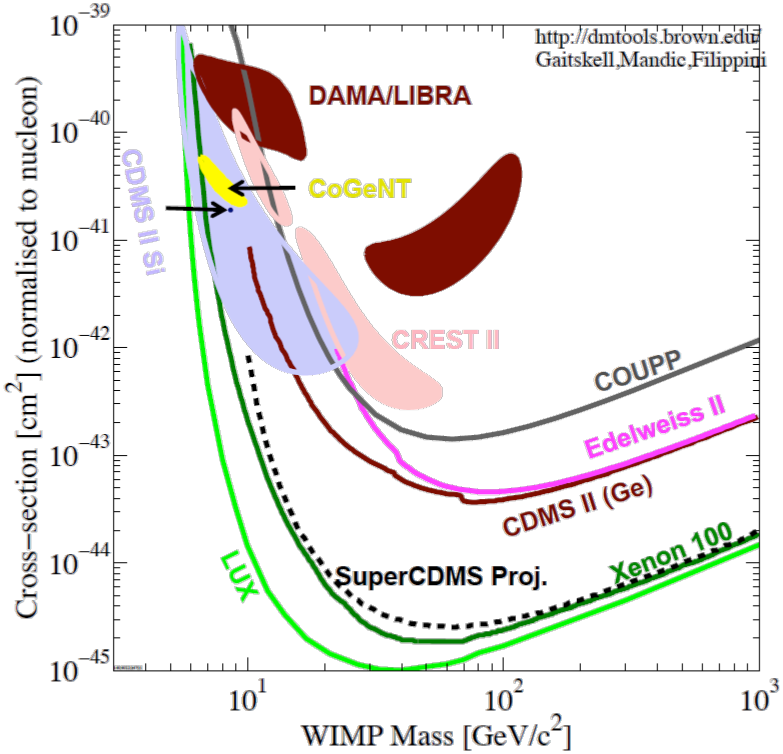
Different strategy:

- → higher thresholds
- → larger exposure (≈3000 kg-days)
- → background from low-rate tails of of surface-event distributions
- → expect larger fiducial volume

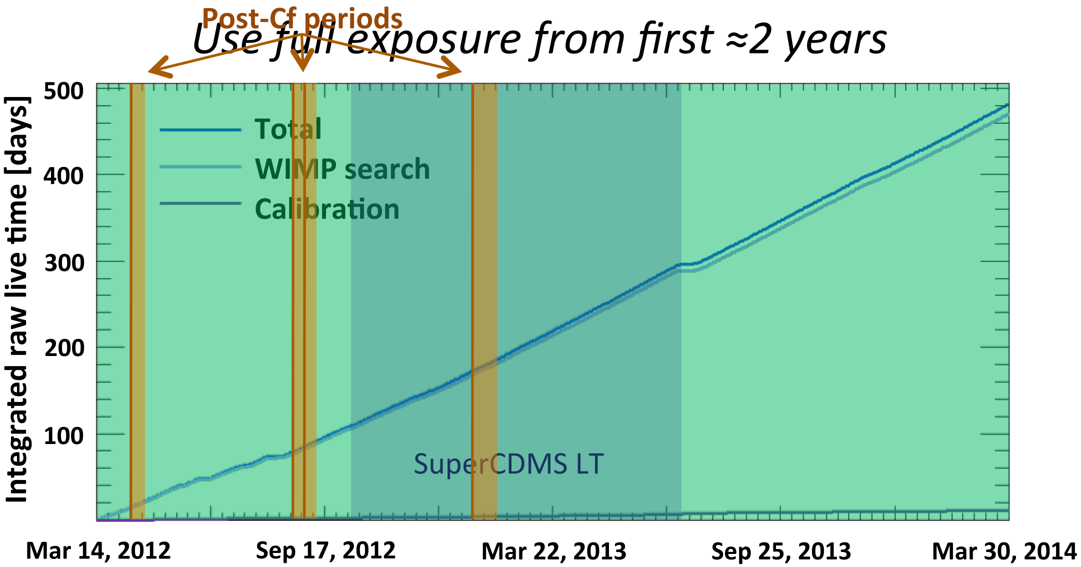
Analysis effort ongoing!

Use full detector array





Use full exposure from first ≈2 years



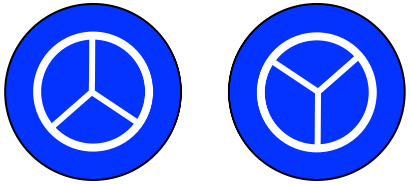
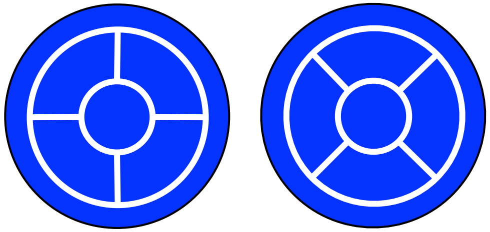
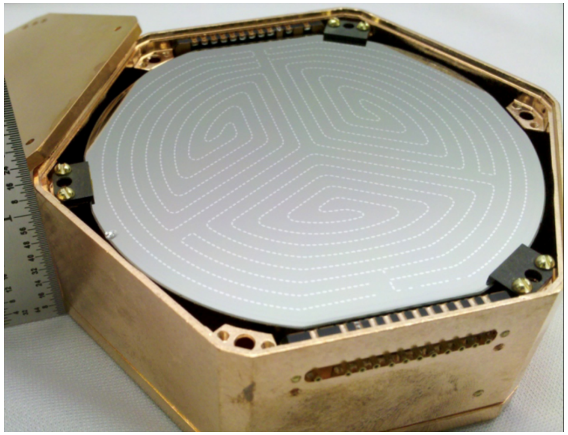
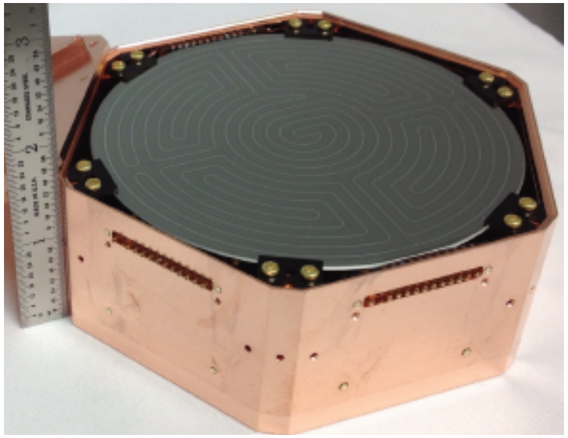
Next generation → SuperCDMS SNOLAB

Larger 110 kg target mass:
- More & larger iZIPs
- Cryostat large enough for 400 kg
- **Si & Ge crystals**
- 1 tower in CDMSlite configuration
  - → also with Si & Ge

Lower background:
- New facility at deeper site
- Cleaner materials selection
- Active neutron veto

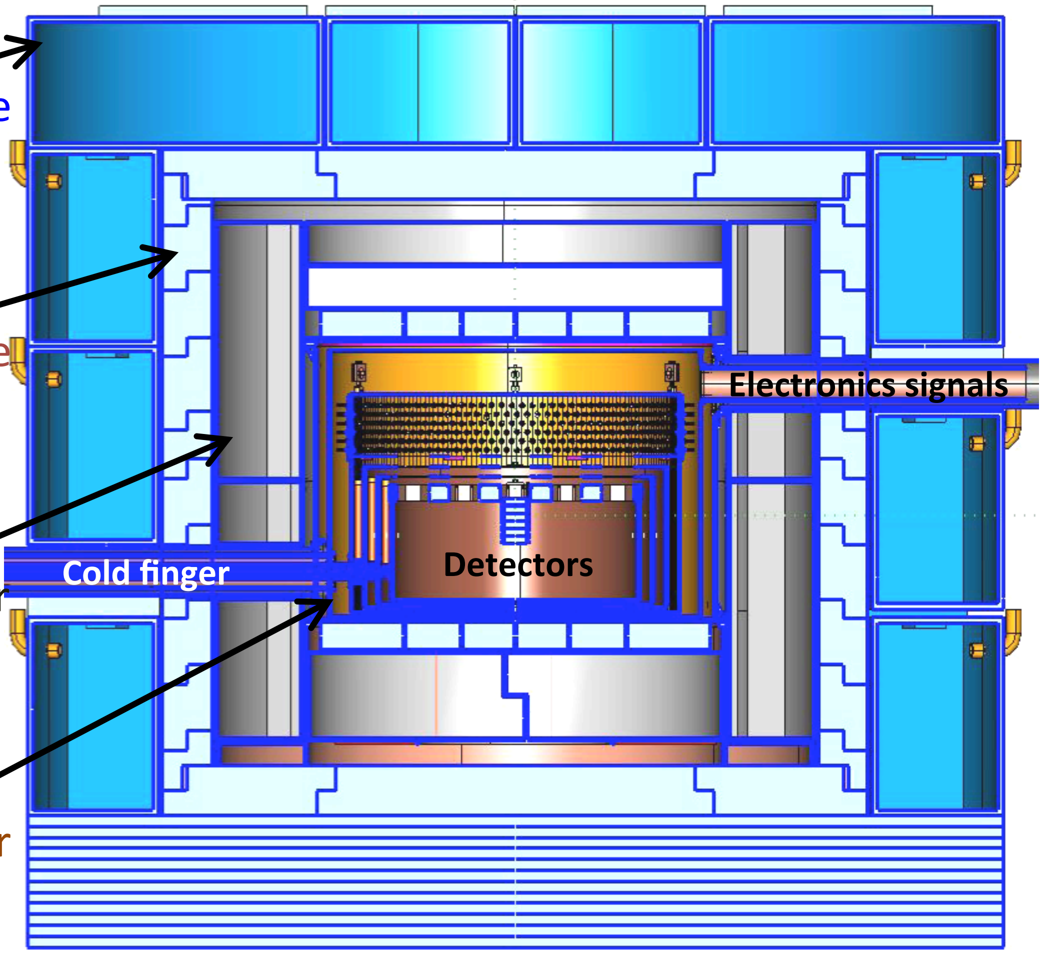
Improved signal readout:
- Phonons → new SQUID arrays
- Ionization → switch to HEMTs
- Improved tower design

Improved resolution:
- $\sigma_{phonon} \propto T_c^3 \rightarrow$ lower operating temp
- 42 eV demonstrated (>4x better)
- Improved cryogenics could give
  - >100x improvement!

SuperCDMS Soudan	**SuperCDMS SNOLAB**
2.5 cm thick 3"diameter 600 g Ge	3.3 cm thick 4"diameter 1.4 kg Ge / 615 g Si
2 ionization + 2 ionization 4 phonon + 4 phonon	2 ionization + 2 ionization 6 phonon + 6 phonon
	
5 towers of 3 iZIPs each	15 towers of 6 iZIPs each
	

All Si detectors for the experiment to be fabricated at Texas A&M

SuperCDMS SNOLAB shielding



Outer shielding (neutrons & gammas):
→ 60 cm water or polyethylene

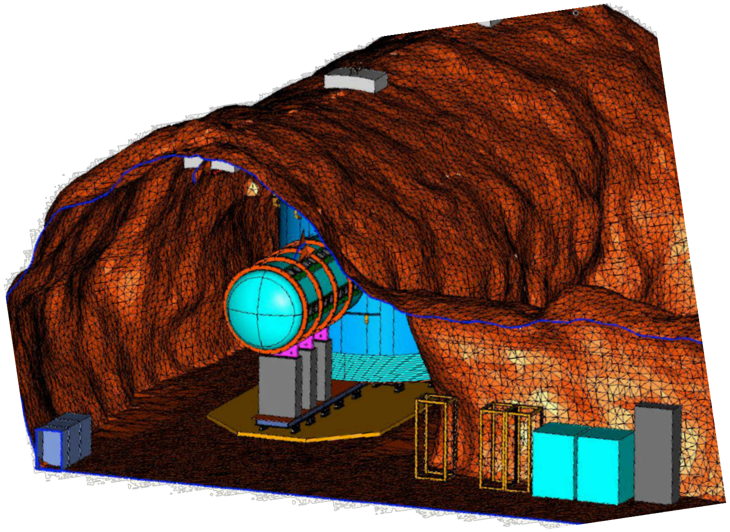
Inner passive shielding (gammas):
→ 23 cm lead with radon purge

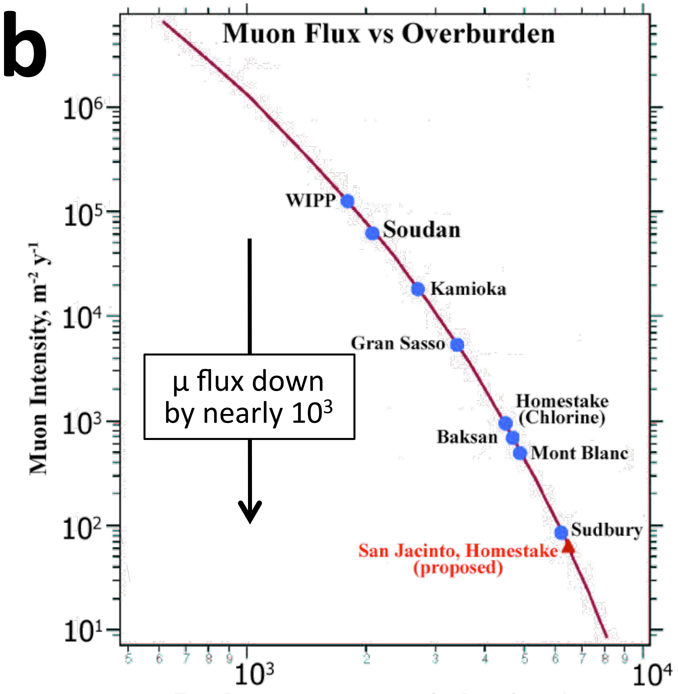
Active shielding (neutrons):
→ 40 cm doped scintillator

Nested cryostat (gammas):
→1/2–3/8” low-activity copper

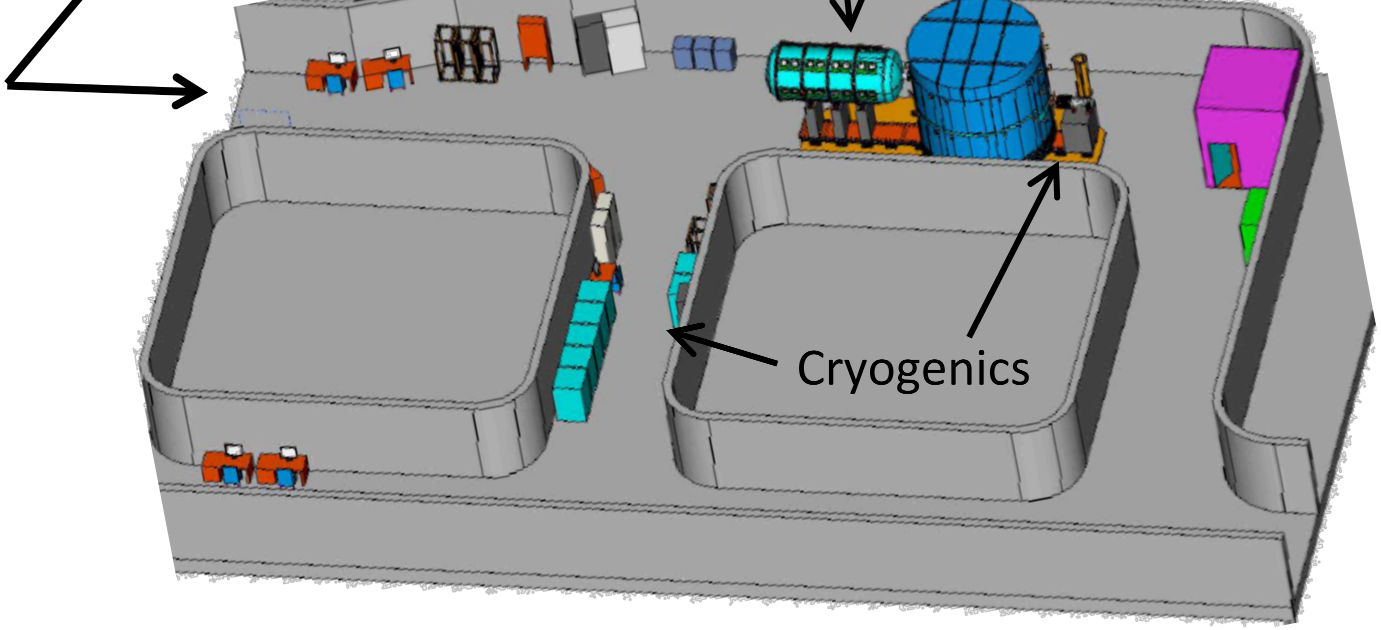
Assumed bulk contaminant levels no lower than measured by other experiments for easily available radiopure materials

SuperCDMS SNOLAB ladder lab





μ flux down by nearly 10^3

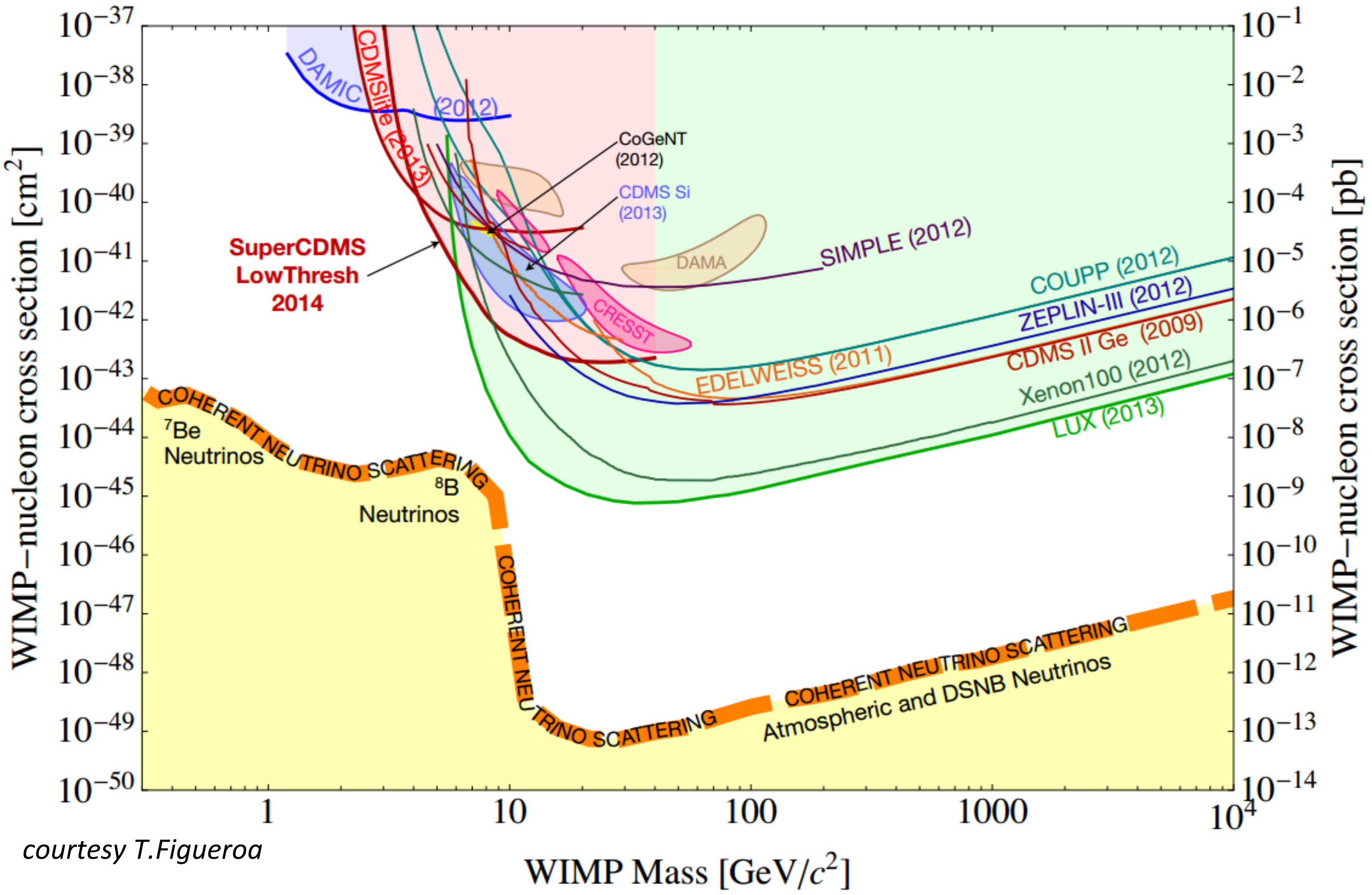


Shielding

Electronics

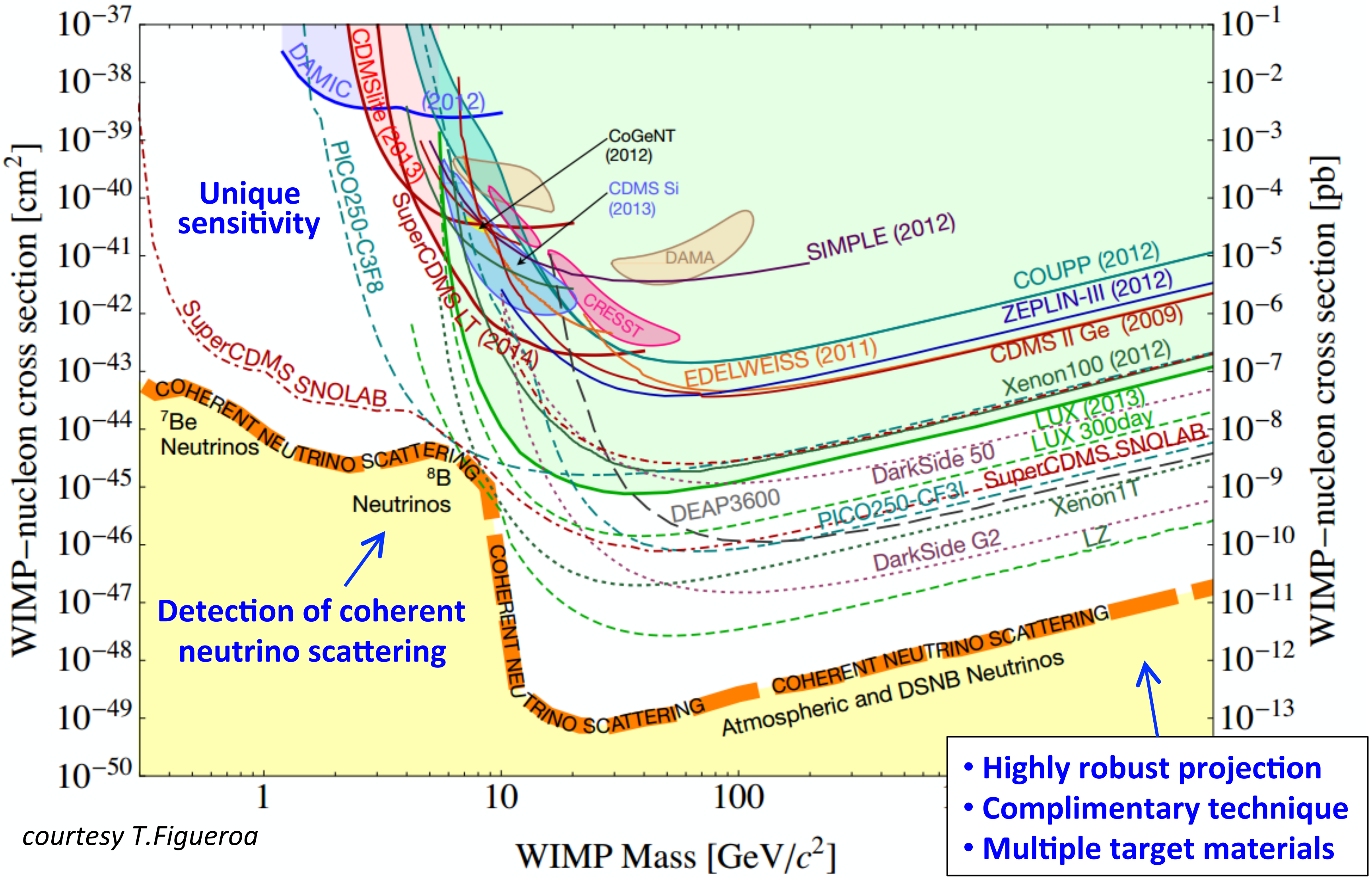
Cryogenics

SuperCDMS SNOLAB expected sensitivity



courtesy T.Figueroa

SuperCDMS SNOLAB expected sensitivity



Unique sensitivity

Detection of coherent neutrino scattering

- **Highly robust projection**
- **Complimentary technique**
- **Multiple target materials**

courtesy T.Figueroa

Conclusions

SuperCDMS Soudan

CDMSlite Run 1 demonstrates utility of Luke-amplified phonons for light WIMPs

→ *PRL 112 (2014) 041302*

→ Better measure of backgrounds with Run 2 (in progress!)

577 kg-day low-threshold analysis sets 90% C.L. limit of 1.2×10^{-42} at 8 GeV/c^2

→ Rules out WIMP interpretation of CoGeNT excess, also for standard-halo spin-independent interpretations of CDMS II Si, DAMA/LIBRA & CRESST

→ Rules out new parameter space for masses < 6 GeV/c^2; *[arXiv:1402.7137] (Accepted by PRL)*

Larger ≈3000 kg-day exposure in hand:

→ near-zero-background WIMP-search analysis ongoing

SuperCDMS SNOLAB

G2 Process underway and outcome expected soon.

Upgraded technology, site depth, materials screening, shielding, and active neutron veto:

→ 5 years of operation with 0.2 total expected background for WIMP masses > ~10 GeV/c^2

Low backgrounds, improved resolution, upgraded electronics:

→ unique discovery potential for WIMP masses 1–10 GeV/c^2

CDMSlite tower with high-gain, low-noise operation:

→ extremely low thresholds for world leading light-WIMP sensitivity from 0.3–5 GeV/c^2