Results from the second CDMSlite run and plans for SuperCDMS SNOLAB

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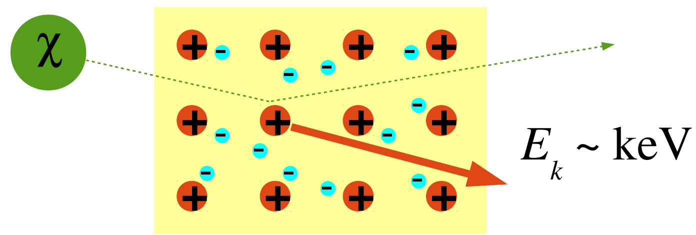
on behalf of the SuperCDMS Collaboration

Rencontres de Moriond, 18th of March 2015

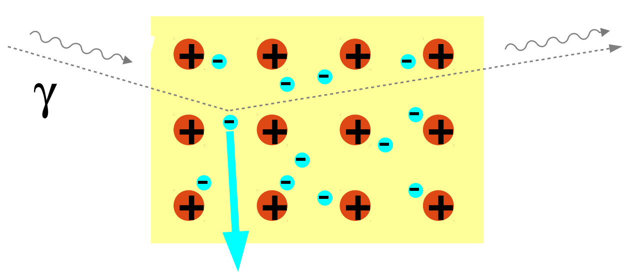
INTRODUCTION

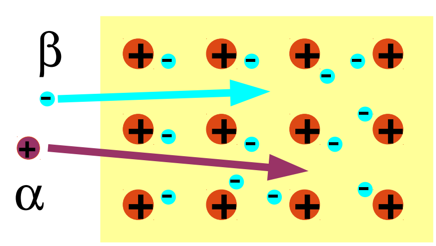
Signal: **atomic nuclei** recoiling after interacting with galactic WIMPs

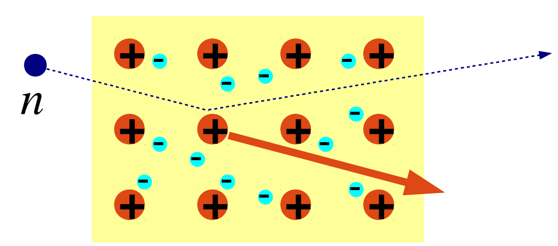


Backgrounds: from environmental radioactivity and cosmic muons:

1) **Electrons** recoiling after X-ray or γ-ray interactions
2) **Charged particles** from nuclear disintegrations (mostly α and β decays)
3) **Atomic nuclei** recoiling after neutron interactions (same as signal if single-scattering)

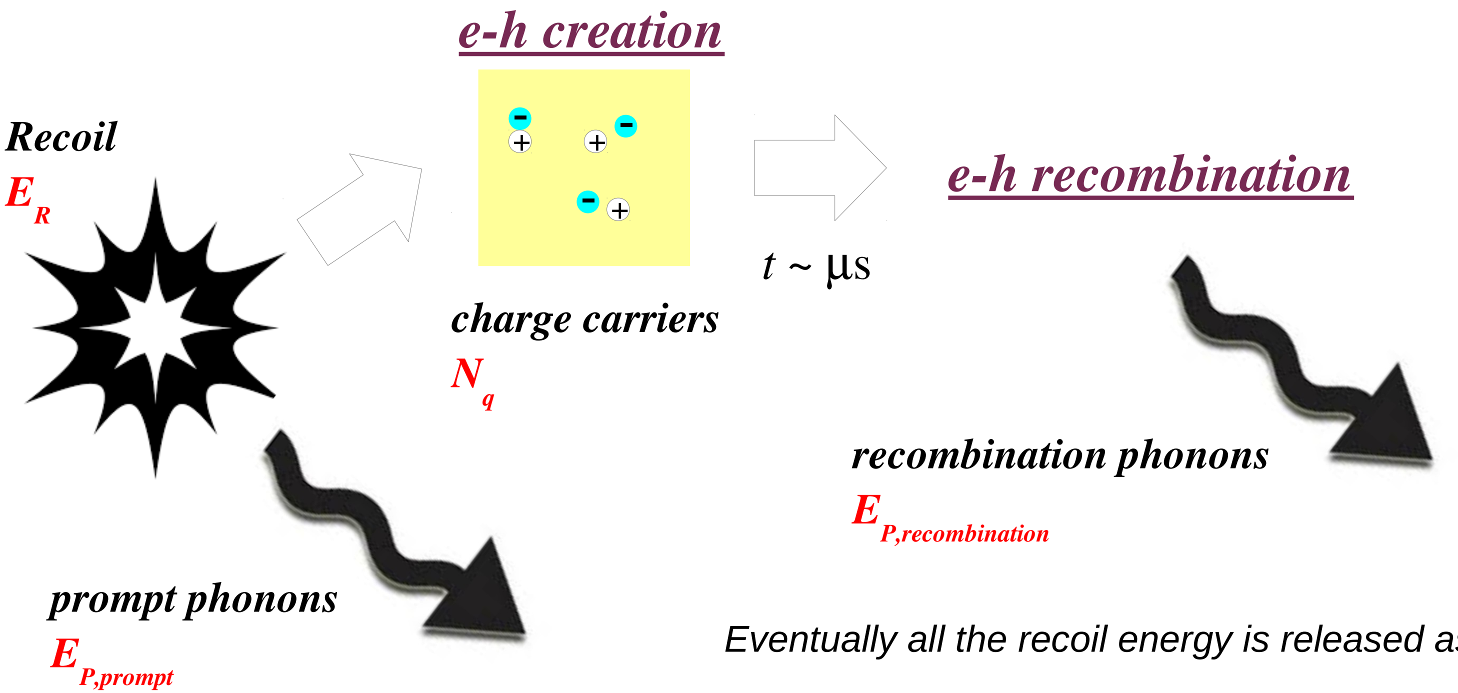






SEMICONDUCTOR DETECTORS

SuperCDMS detects recoiling nuclei using **semiconductor technology**



*Eventually all the recoil energy is released as phonons (**heat**)*

$$N_q = Y\frac{E_R}{\epsilon}, \quad \epsilon(\mathrm{Ge}) = 3.0\ eV$$

$$E_P = E_{P,prompt} + E_{P,recombination} = E_R$$

Y (**ionization yield**) depends on the type of the recoiling particle ⇒ useful for particle-ID

	Y
Recoiling electron	~1
Recoiling Ge nucleus	~0.3

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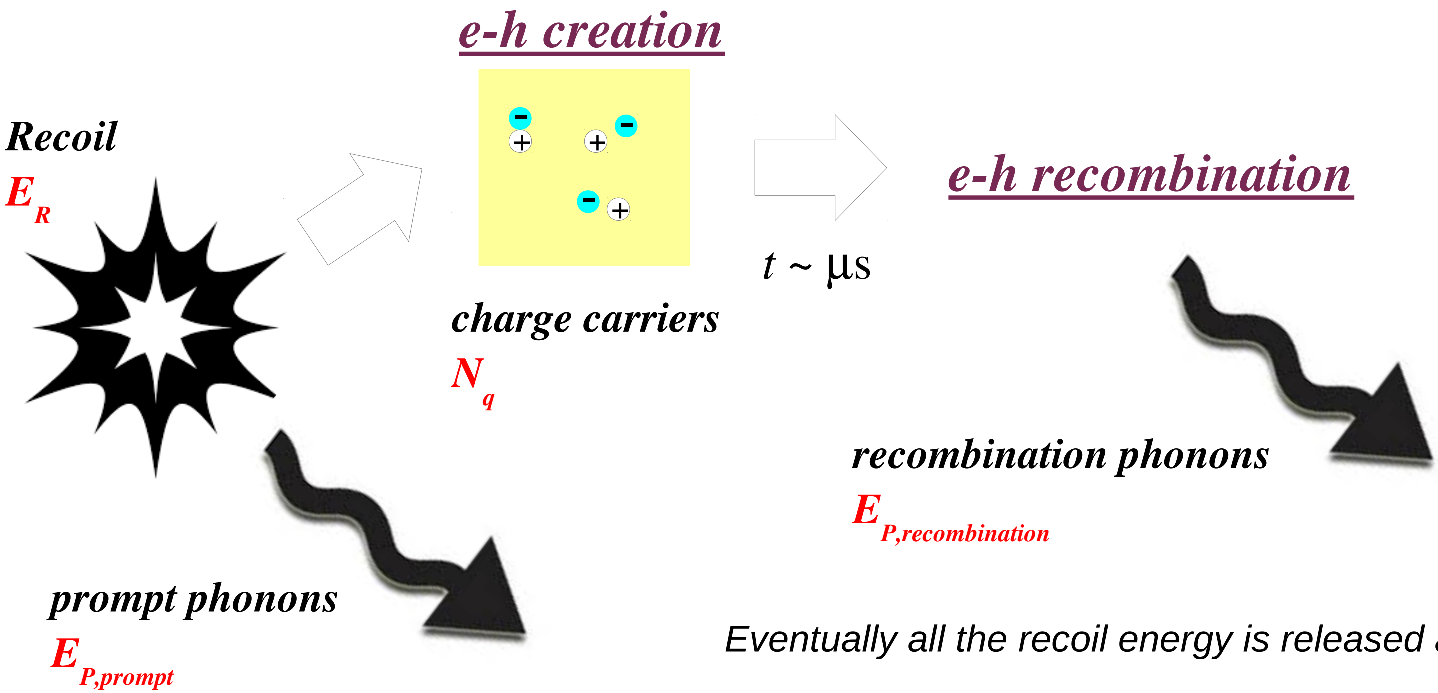

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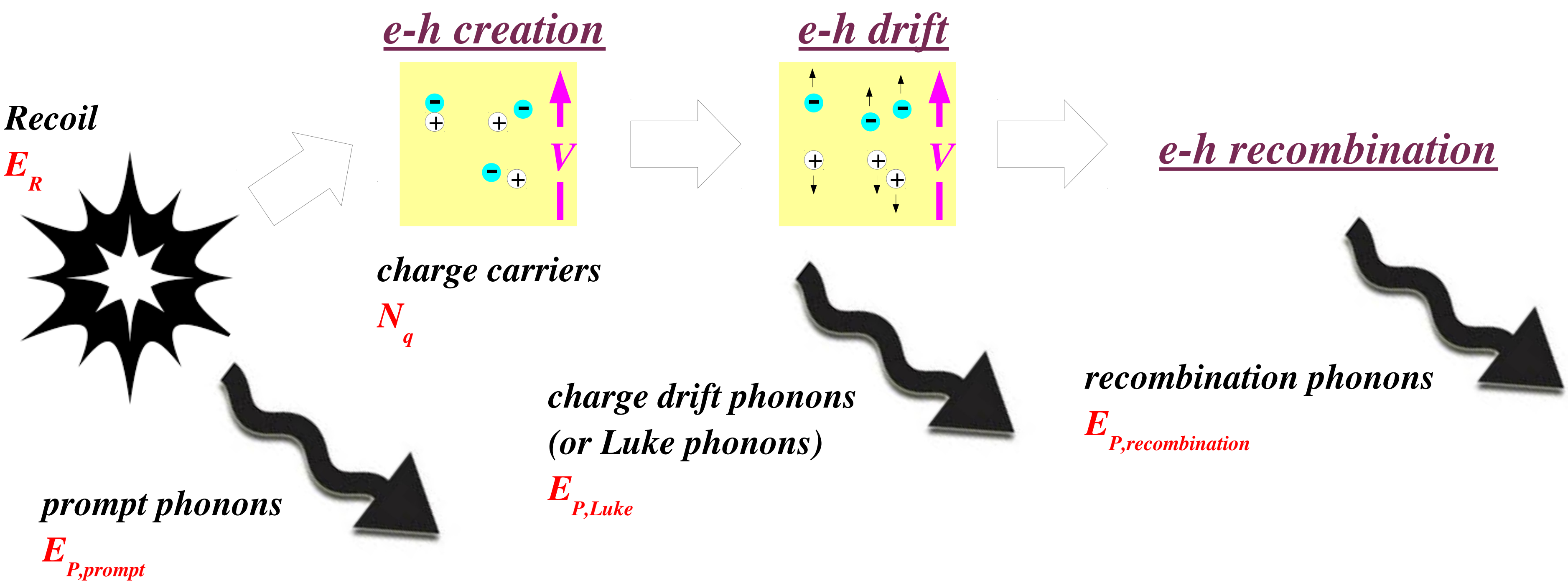
$$N_q = Y\frac{E_R}{\epsilon}, \qquad \epsilon(\mathrm{Ge}) = 3.0\ eV$$

$$E_P = E_{P,prompt} + E_{P,recombination} = E_R$$

It's possible to know E_R and Y from E_P and N_q

SEMICONDUCTOR DETECTORS

A **voltage bias** (*V*) creating an electric field is required to separate the charge carriers



$$N_q = Y\frac{E_R}{\epsilon}, \quad \epsilon(\mathrm{Ge}) = 3.0\ eV$$

$$E_P = E_R + \boxed{q_e V N_q} = E_R(1 + Y\frac{q_e V}{\epsilon})$$

Note that $E_P > E_R$ if voltage bias is applied

$$E_P = g(V)\, E_R$$

SEMICONDUCTOR DETECTORS

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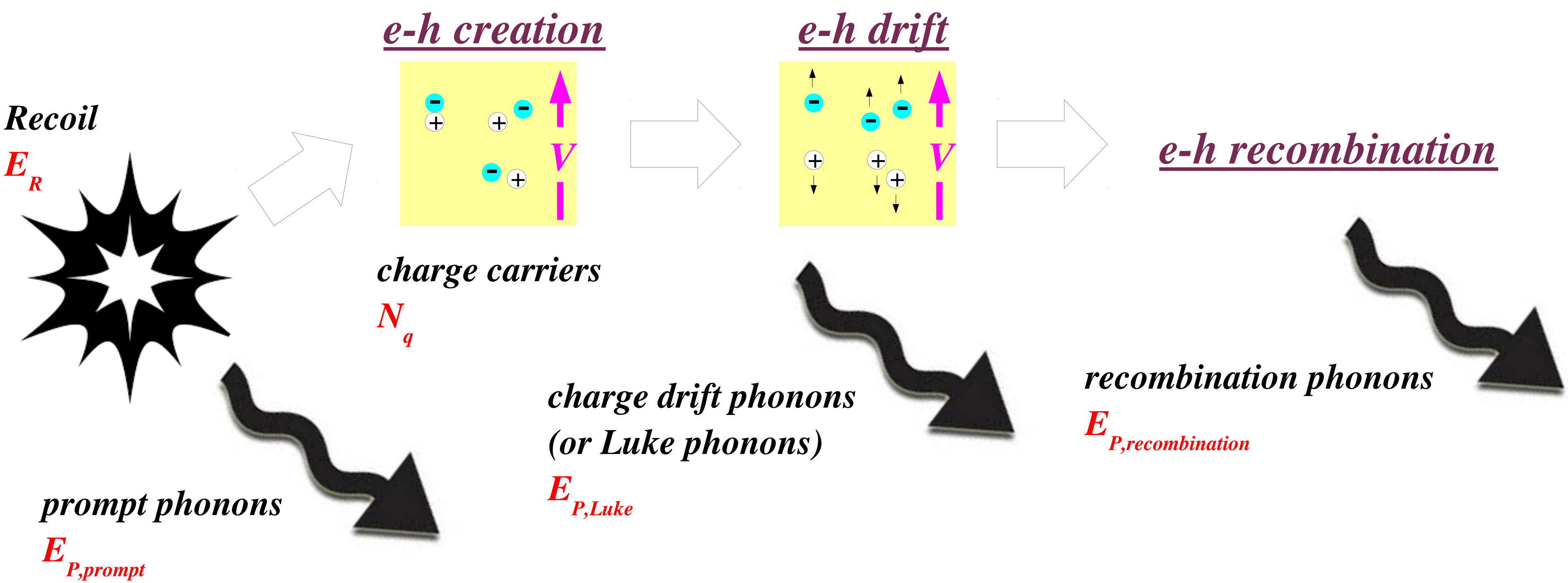


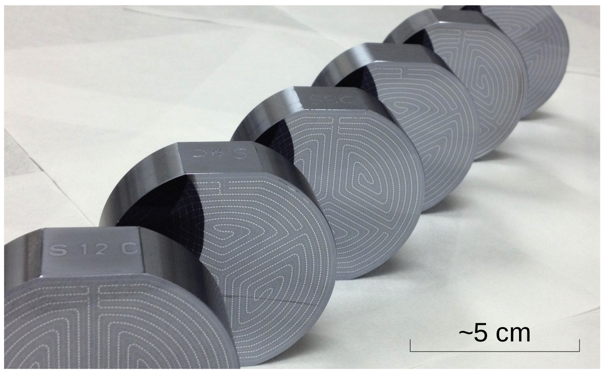
$$N_q = Y\frac{E_R}{\epsilon}, \qquad \epsilon(\mathrm{Ge}) = 3.0\ eV$$

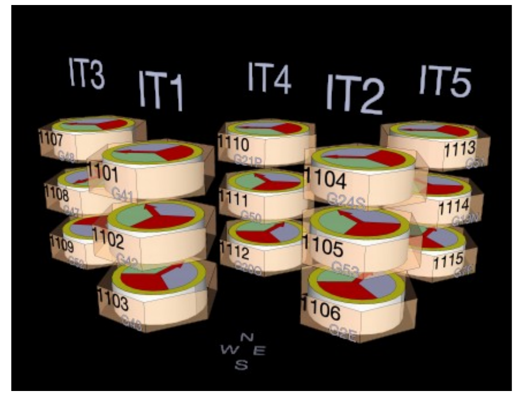
$$E_P = E_R + q_e V N_q = E_R\left(1 + Y\frac{q_e V}{\epsilon}\right)$$

Again, it's possible to know E_R and Y from E_P and N_q

THE SUPERCDMS EXPERIMENT

Detectors: 15 cylindrical **Ge** monocrystals, **~9 kg total**

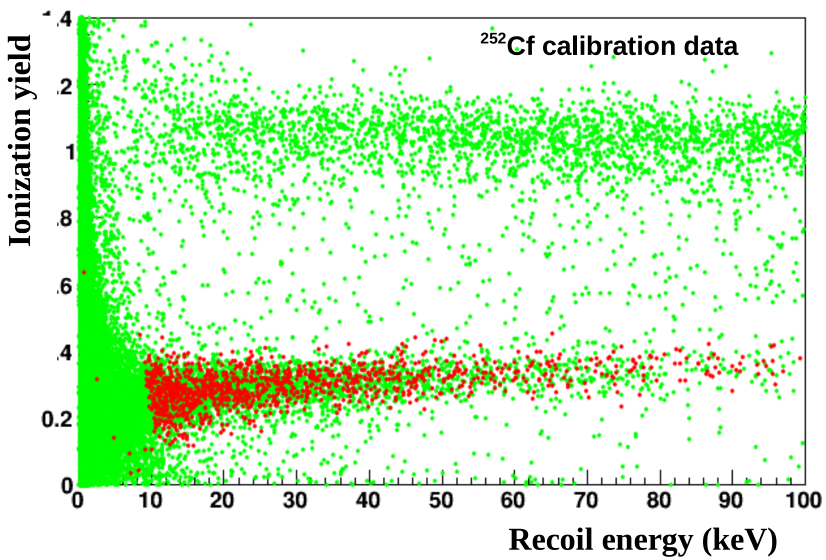




Detectors operating at 50 mK

Applied 4 V voltage bias (nominal)

Measuring both N_q and E_P ⇒ capable of determining both E_R and Y



Recoiling electrons from γ's (Y = ~1)

Recoiling Ge nuclei from n's (Y ~ 0.3)

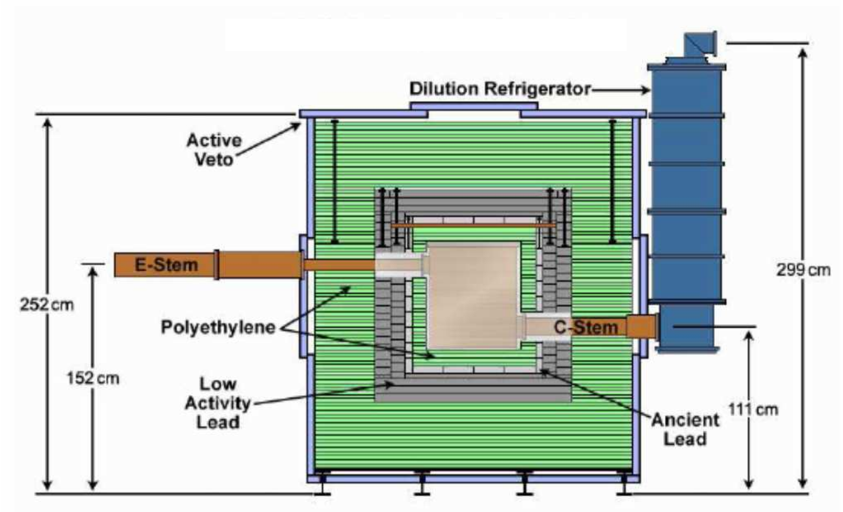
THE SUPERCDMS EXPERIMENT

Surface event rejection (fiducialization): enabled by the applied **electric field** and the **segmented read-out** configuration

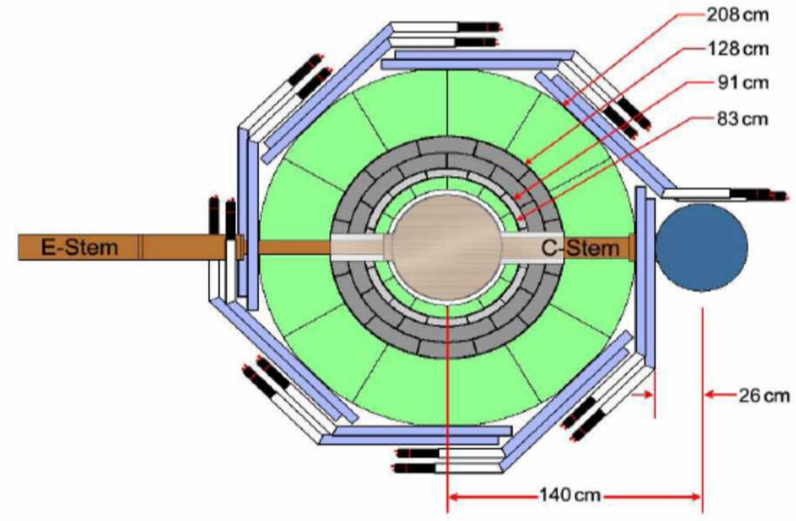
Neutron background suppression:

- Deployed at **Soudan Underground Laboratory** (714 m depth)
- Active shielding (muon showers): **scintillating plastic**, full solid angle
- Passive shielding: **polyethylene**; also lead for γ's
- Structures within shielding: **radiopure Cu**

Side view



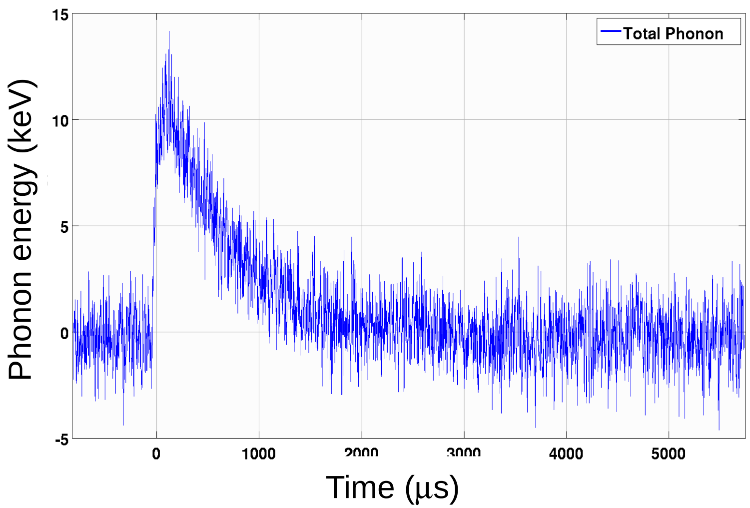
Top view



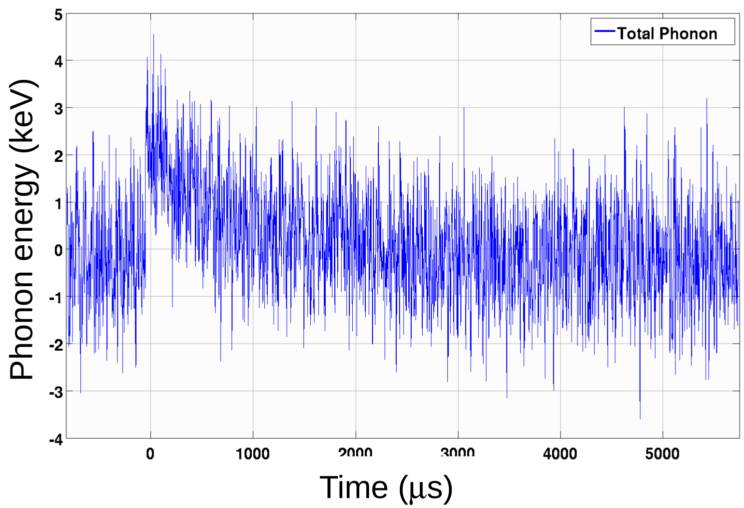
THE CDMSLITE APPROACH

Electronic noise limits the lowest accessible E_R (therefore the lowest accessible M_χ)

noise < E_R



noise ~ E_R



Under nominal operation conditions, E_R threshold is ~2 keV (⇒ $\boldsymbol{M_\chi > 10}$ **GeV**)

(And still interesting WIMP models below 10 GeV: asymmetric DM, etc)

However: **Phonon signal can be amplified by increasing the applied electric field**

⇓

CDMSlite

THE CDMSLITE APPROACH

If voltage bias *V* applied,

$$E_P = E_R + \boxed{q_e V N_q} = E_R(1 + Y\frac{q_e V}{\epsilon}) = g(V)E_R$$

contribution from applied electric field

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contribution from applied electric field

$g(V) > 1$

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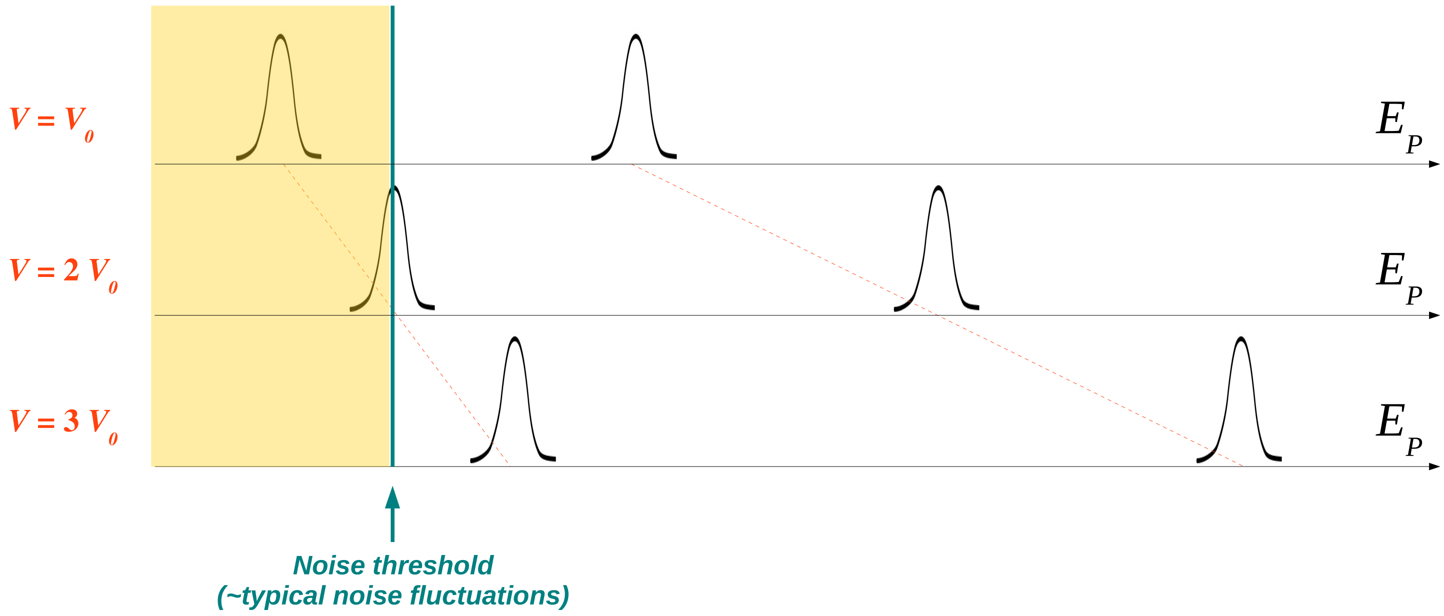


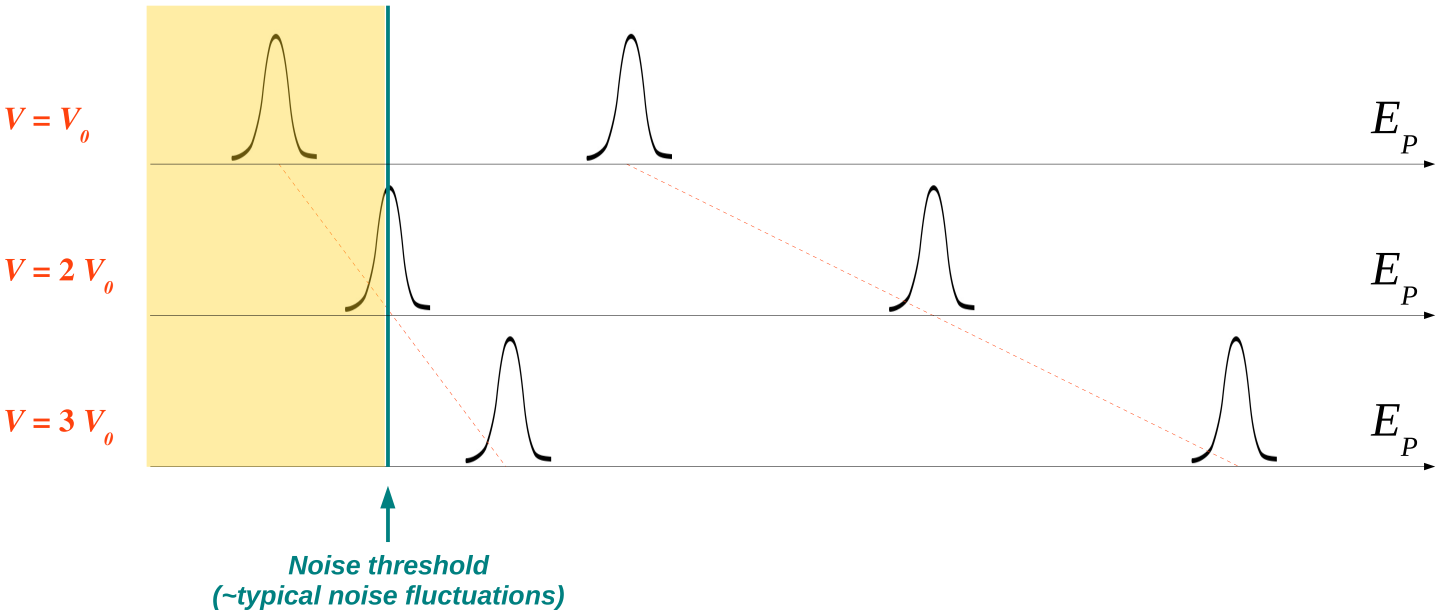
THE CDMSLITE APPROACH

If voltage bias V applied,

$$E_P = E_R + \boxed{q_e V N_q} = E_R\left(1 + Y\frac{q_e V}{\epsilon}\right) = \boxed{g(V)} E_R$$

contribution from applied electric field

$g(V) > 1$



However, note that only E_P can be amplified, not N_q

Particle-ID & fiducialization compromised, reconstruction of E_R requires assumptions on Y

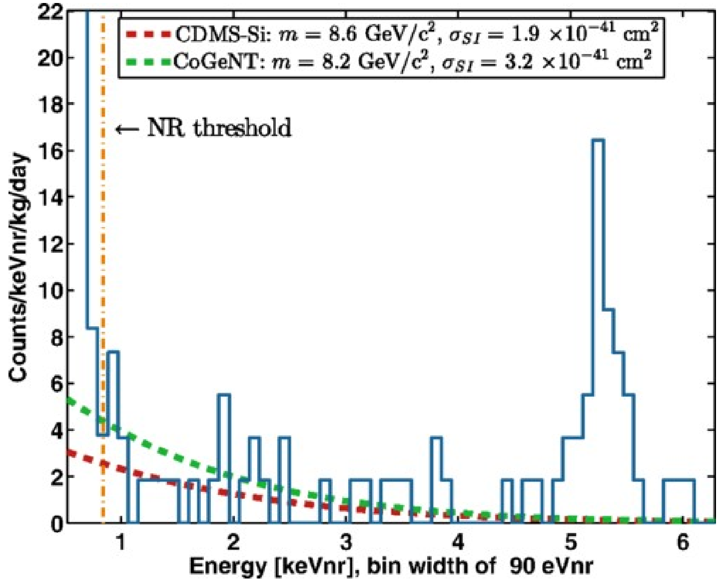
CDMSLITE RUN 1

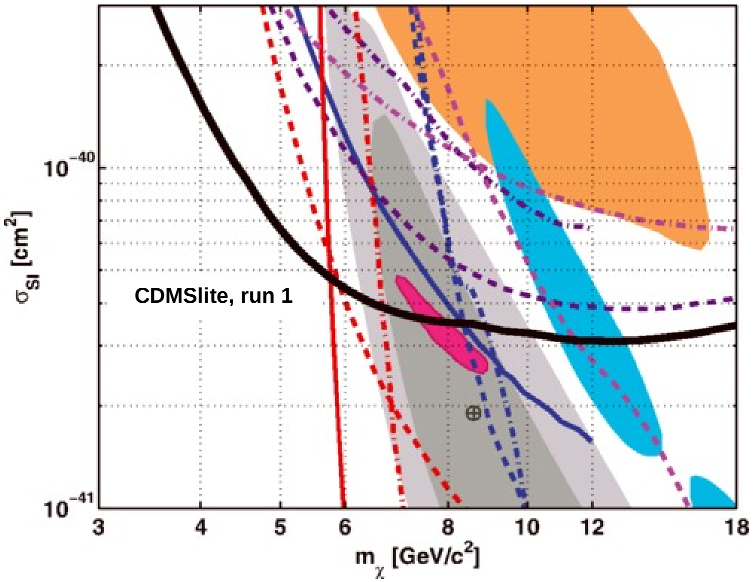
Used 1 detector only: **6.25 kg day** exposure (Aug. 2012)

Voltage bias: 69 V (nominal: 4 V) ⇒ $g(V) = 8$ for NR, 24 for ER

<u>**0.8 keV threshold**</u> for NR, no background rejection

Exclusion limit calculated by assuming all events in signal region to be WIMPs



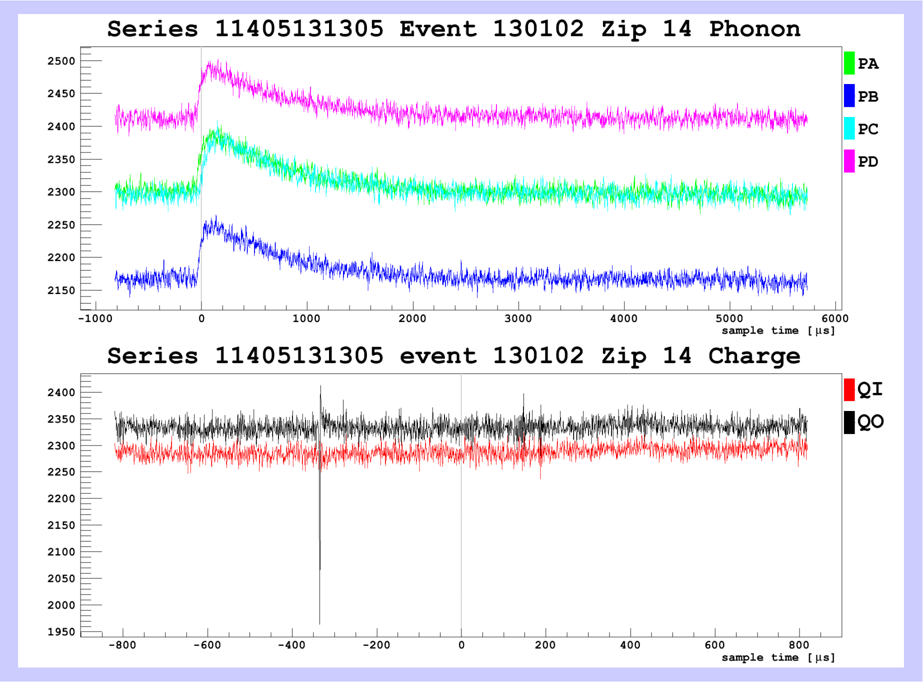


CDMSLITE RUN 1

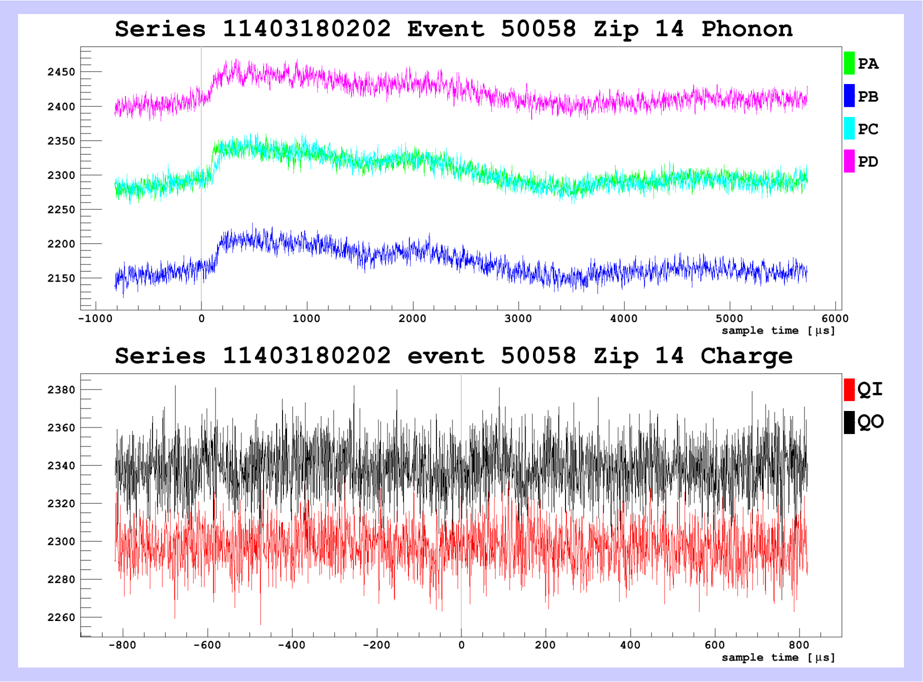
Limitations:

- **Acoustic noise** in addition to intrinsic electronic noise ⇒ increased energy threshold
- **No fiducialization, no particle-ID** ⇒ background limited with very little exposure

Real pulse



Acoustic noise



Acoustic noise is produced by components of the cryogenics system

CDMSLITE RUN 2

Used 1 detector only (same as run 1): **115.59 kg day** exposure (Feb. 2014-Nov. 2014)

Voltage bias: 70 V (similar to run 1)

0.26-0.35 keV threshold for NR

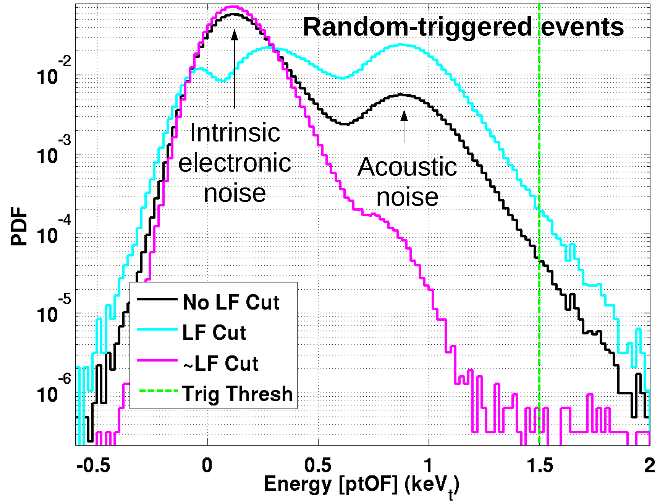
With respect to run 1, exposure increased by a factor 20, threshold decreased by a factor 2.5

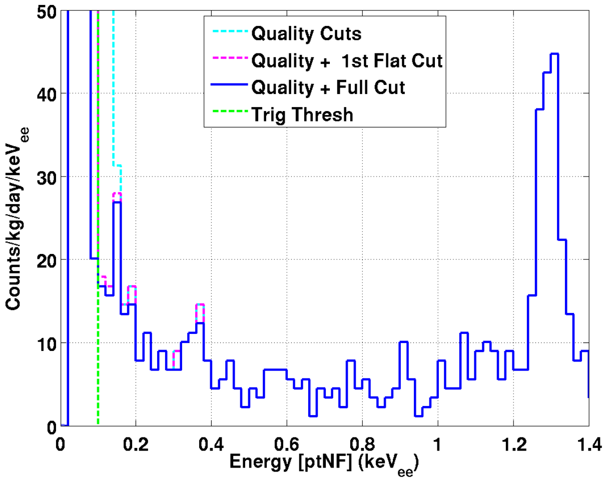
Modifications with respect to run 1:

- Hardware and mechanical improvements
- **Better rejection of acoustic noise** ⇒ lower threshold, sensitive to smaller M_χ
- **Pulse-based radial fiducialization** ⇒ increased exposure, sensitive to smaller σ_χ

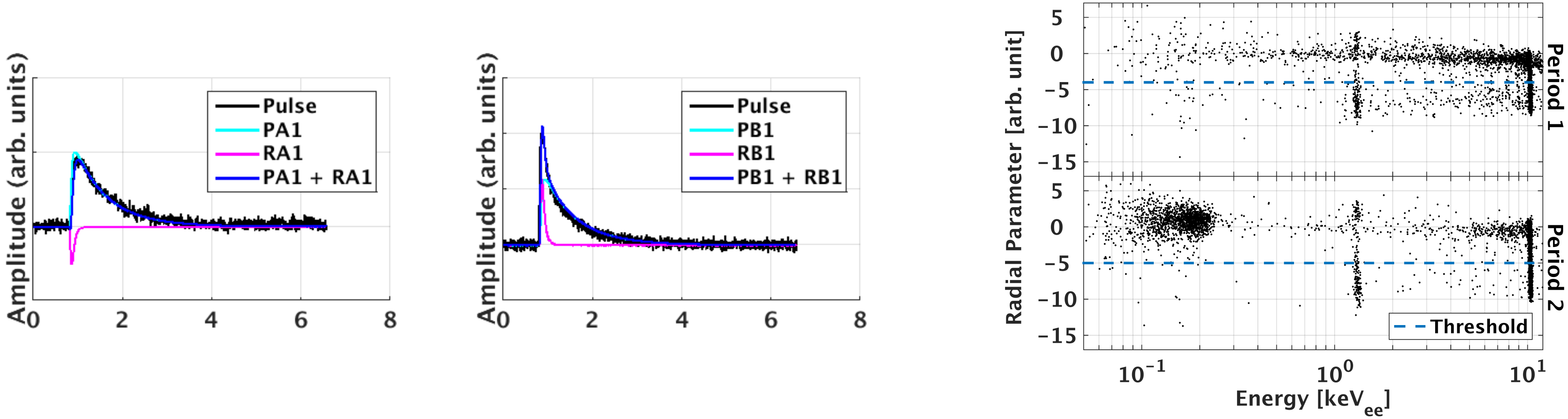
CDMSLITE RUN 2

The acoustic noise is rejected using **pulse-shape discrimination**





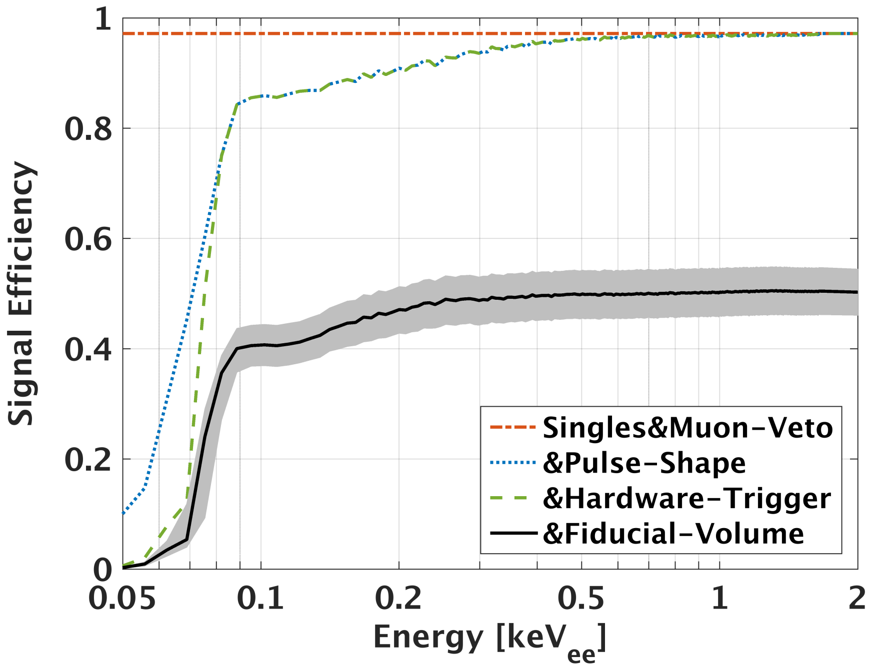
The **fast phonon component** is used to construct an estimator of the radial position



CDMSLITE RUN 2

Event selection:

- **Single-scattering** (no signal above noise in the other 14 detectors)
- **No muon-induced** (no signal above noise in the outer scintillating veto)
- **Good data quality**
- **No acoustic noise**
- **Fiducialized** in the radial direction



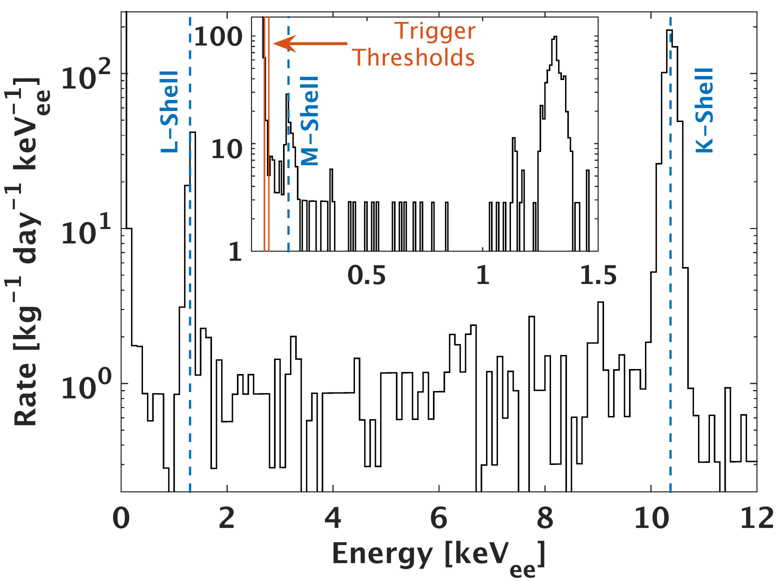
- *Efficiency of acoustic noise cut calculated using MC simulations*
- *Efficiency of radial fiducial cut calculated with events from ^{71}Ge electron capture*

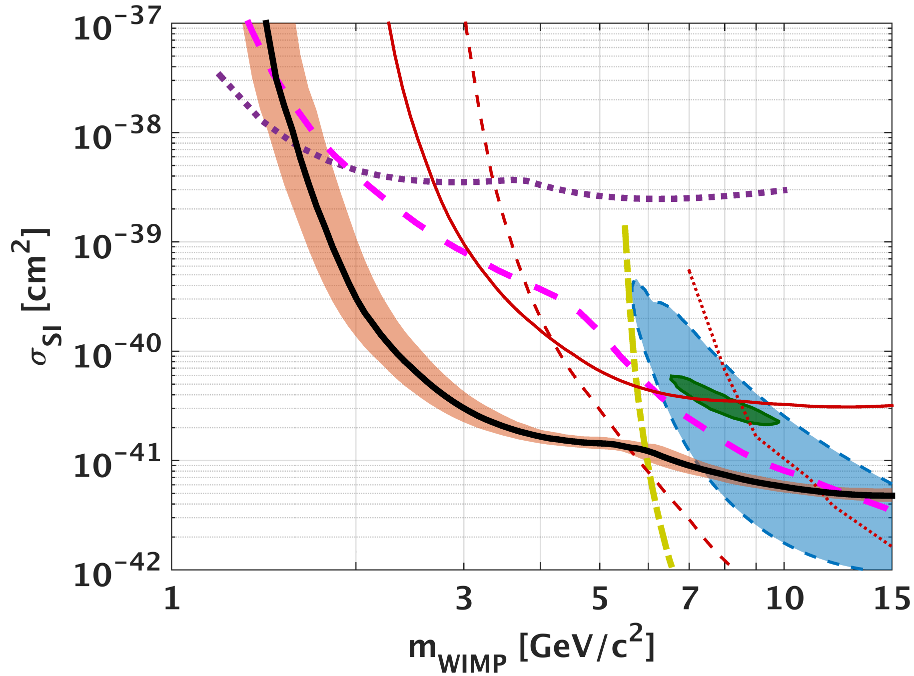
CDMSLITE RUN 2

<u>Background</u> dominated by **electrons recoiling in the bulk**, due to X-rays from ^{71}Ge electron capture and Compton scattering of radiogenic γ-rays

<u>Uncertainty</u> dominated by the **assumptions used to reconstruct E_R**

Reconstruction of E_R assumes Lindhard model for Y



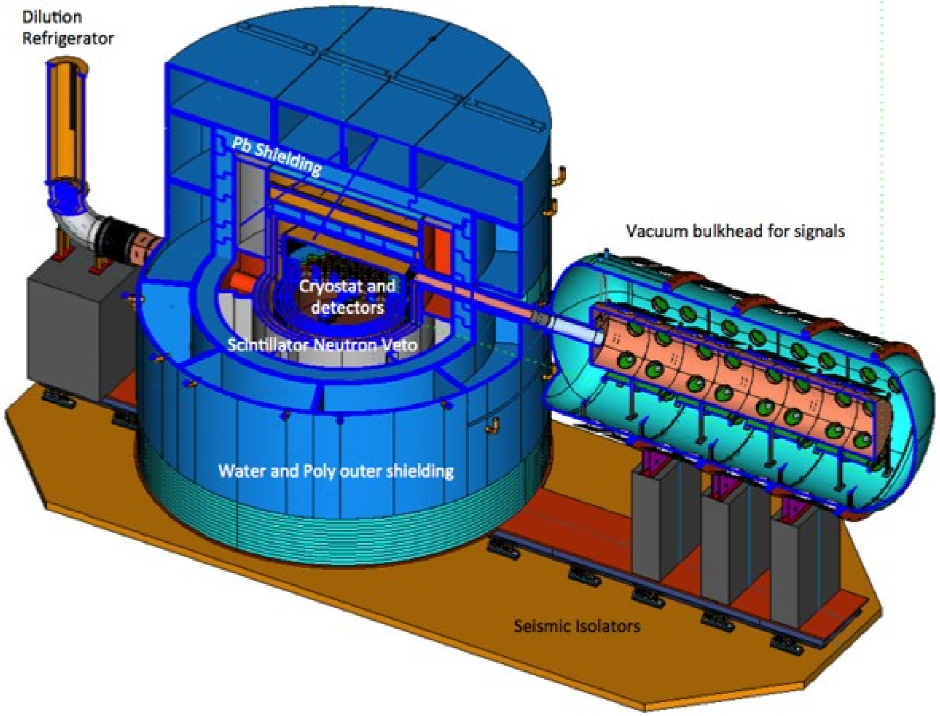


Exclusion limit calculated by assuming all events in signal region to be WIMPs

New parameter space excluded between 1.6 and 5.5 GeV

FUTURE PLANS: SUPERCDMS SNOLAB

- **Deeper laboratory** (SNOLAB, 2070 m depth) ⇒ suppressed cosmogenic background
- Increased **radiopurity** ⇒ decreased radiogenic background
- Improved **energy resolution**
- Impressive **fiducialization** capabilities (already demonstrated in SuperCDMS Soudan)

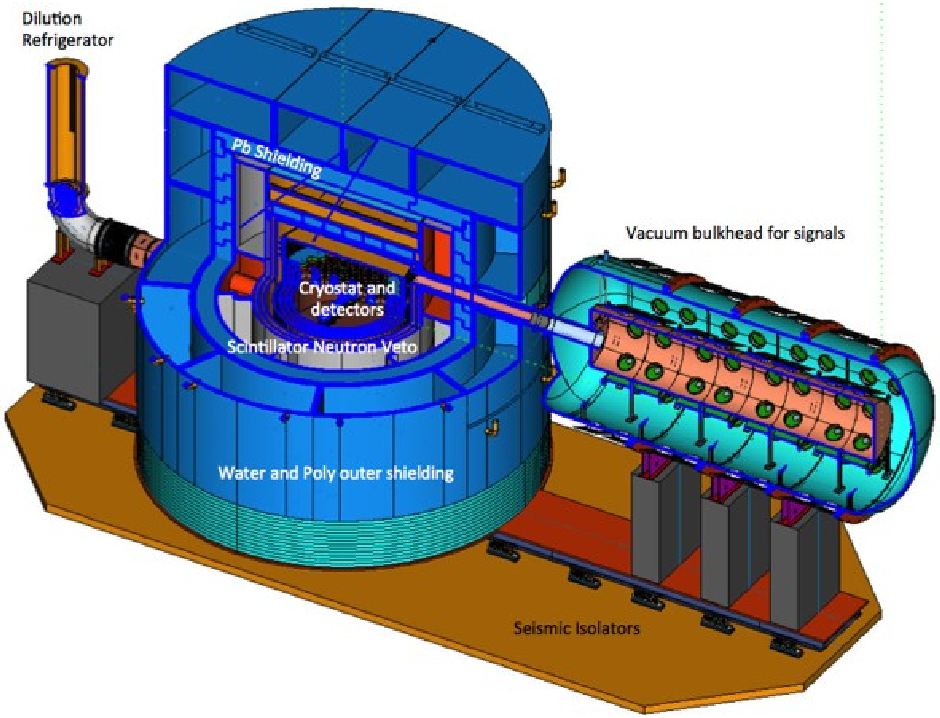


FUTURE PLANS: SUPERCDMS SNOLAB

30 detectors, arranged in 5 stacks:

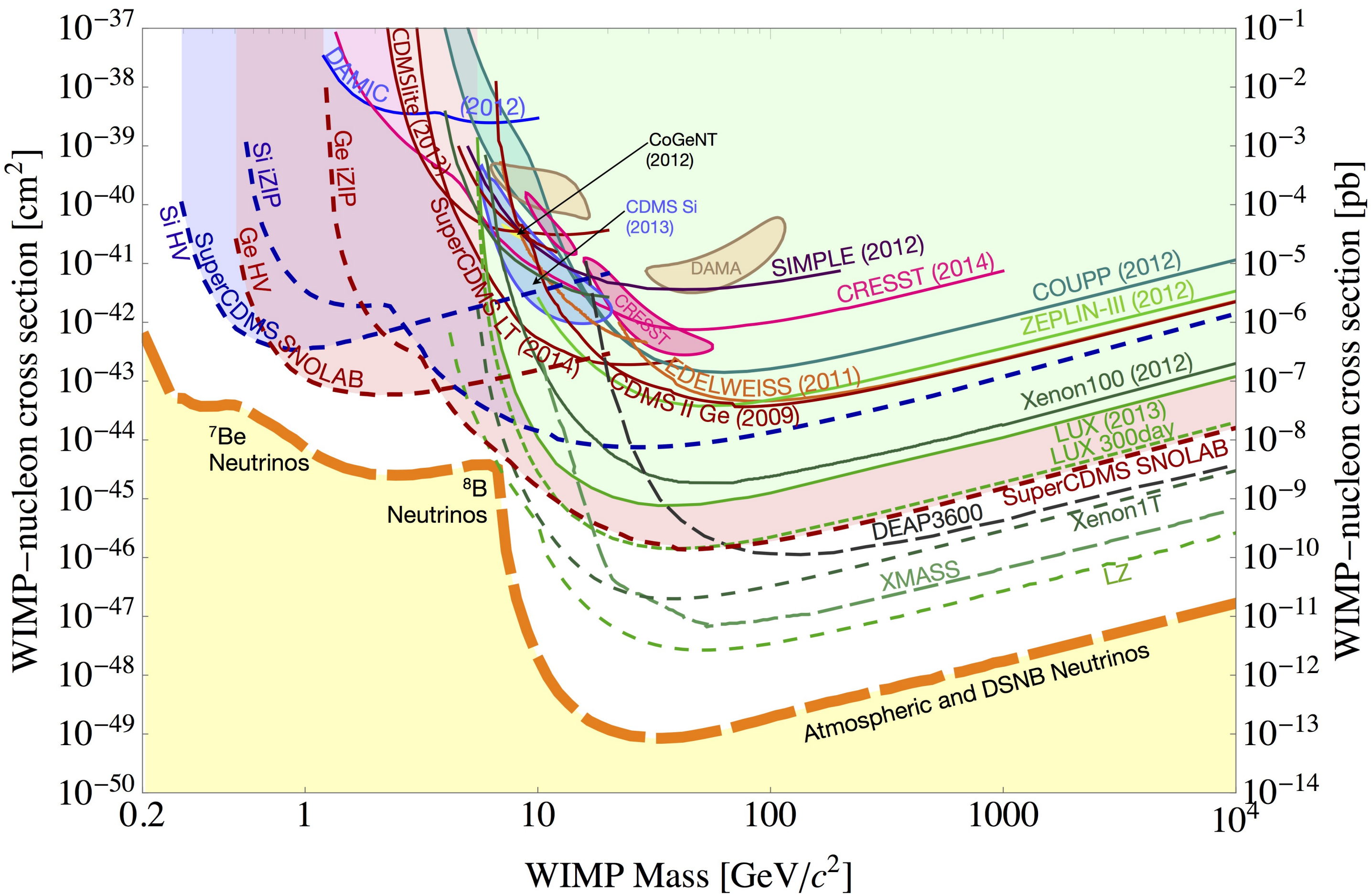
- 3 **Ge** stacks (**~50 kg**)+1 **Si** stack (**~4 kg**)
- 1 stack operating at **high-voltage** (HV): 4 **Ge** (**~5.6 kg**)+2 **Si** (**~1.4 kg**) detectors

Approved by US DOE and NSF as a next-generation dark matter direct detection experiment, with a focus on low-mass WIMPs



FUTURE PLANS: SUPERCDMS SNOLAB

Expected to be sensitive to **coherent neutrino scattering** from solar (^8B) neutrinos



SUMMARY

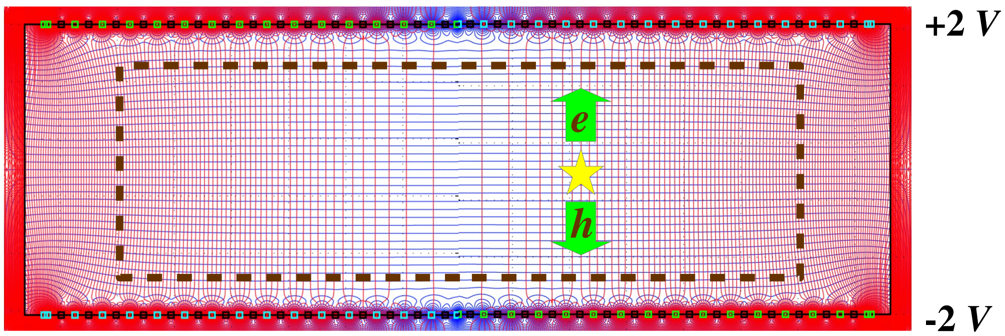
- SuperCDMS based on semiconductor technology, measuring both E_P and N_q
- In CDMSlite the recoil energy threshold is lowered by amplifying the phonon signal. Not possible to amplify the charge signal ⇒ compromised background rejection capabilities, reconstruction of E_R requires assumptions on Y
- The analysis of the second CDMSlite run data allowed to suppress the mechanical noise, and included some fiducialization.
- New parameter space has been explored for WIMP masses between 2 and 5 GeV
- SuperCDMS Soudan ended operations on November 2015, SuperCDMS SNOLAB is already approved by DoE and currently under development

THANK YOU…

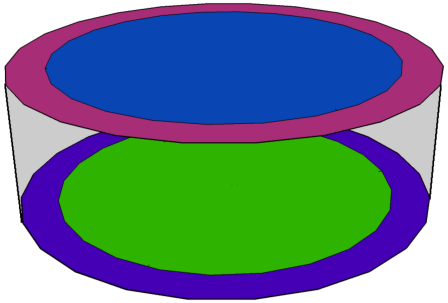
Backup

THE SUPERCDMS EXPERIMENT

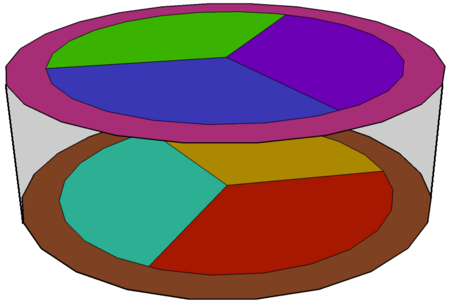
The applied electric field and the read-out configuration enable **fiducialization**



Charge read-out channels



Phonon read-out channels



Fiducialization allows to reject surface events from charged particles