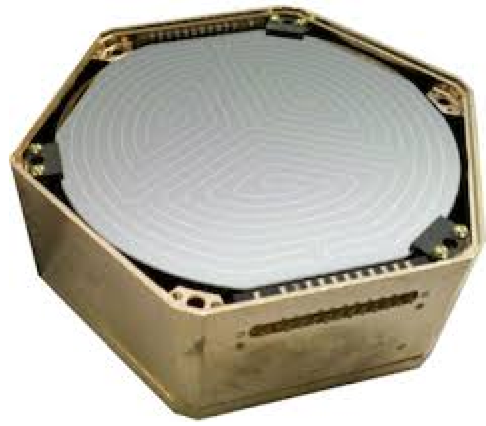


July 13, 2017 – TRIUMF – Science Week

BELINA VON KROSIGK (BKROSIGK@PHYSICS.UBC.CA)

SEARCHING FOR DARK MATTER PARTICLES WITH SuperCDMS AT SNOLAB

THE SuperCDMS COLLABORATION

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

* Associate members

SuperCDMS

(Cryogenic Dark Matter Search)

PAST AND FUTURE OF (Super)CDMS

SUF:
10 mwe

Soudan:
2000 mwe

SNOLAB:
6000 mwe

CDMS @ SUF

1998 - 2002

CDMS II @ Soudan

2003 - 2009

SuperCDMS @ Soudan

2009 - 2014

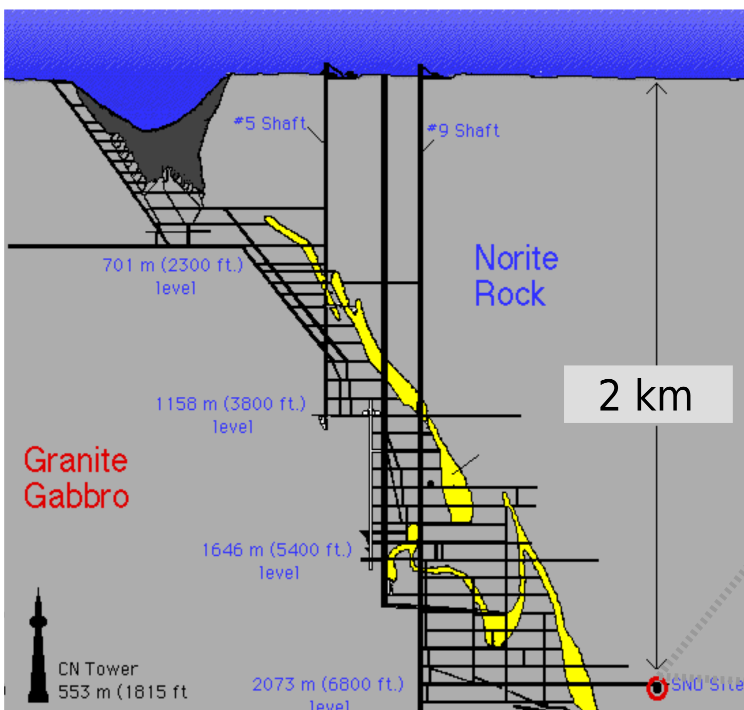
SuperCDMS @ SNOLAB

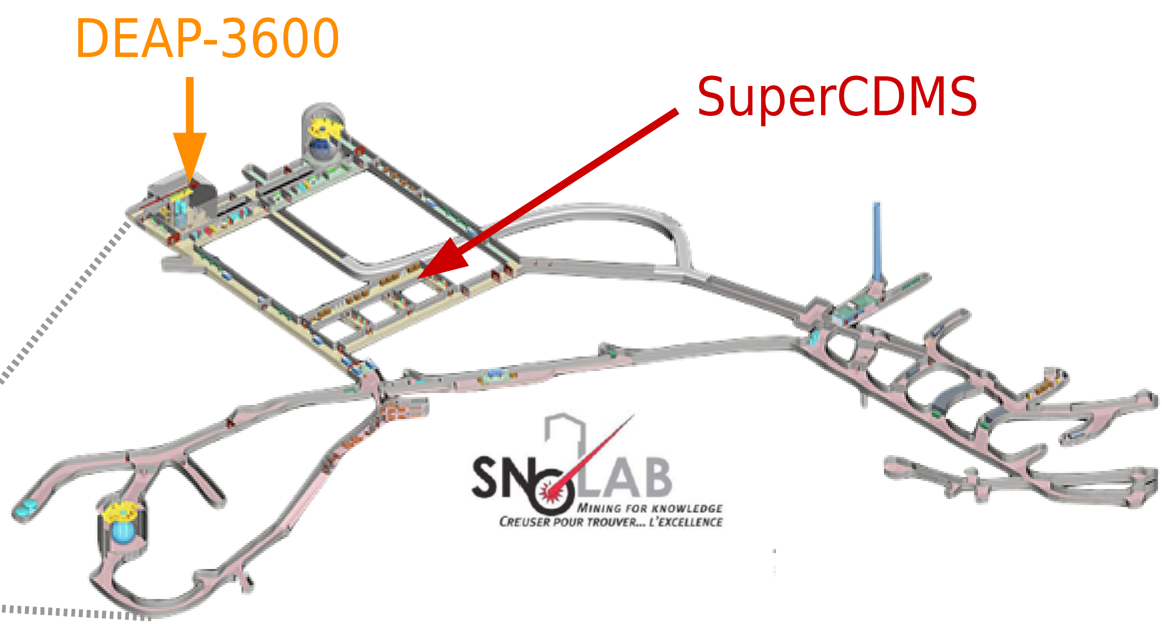
2020 - 2024

2024 - ...

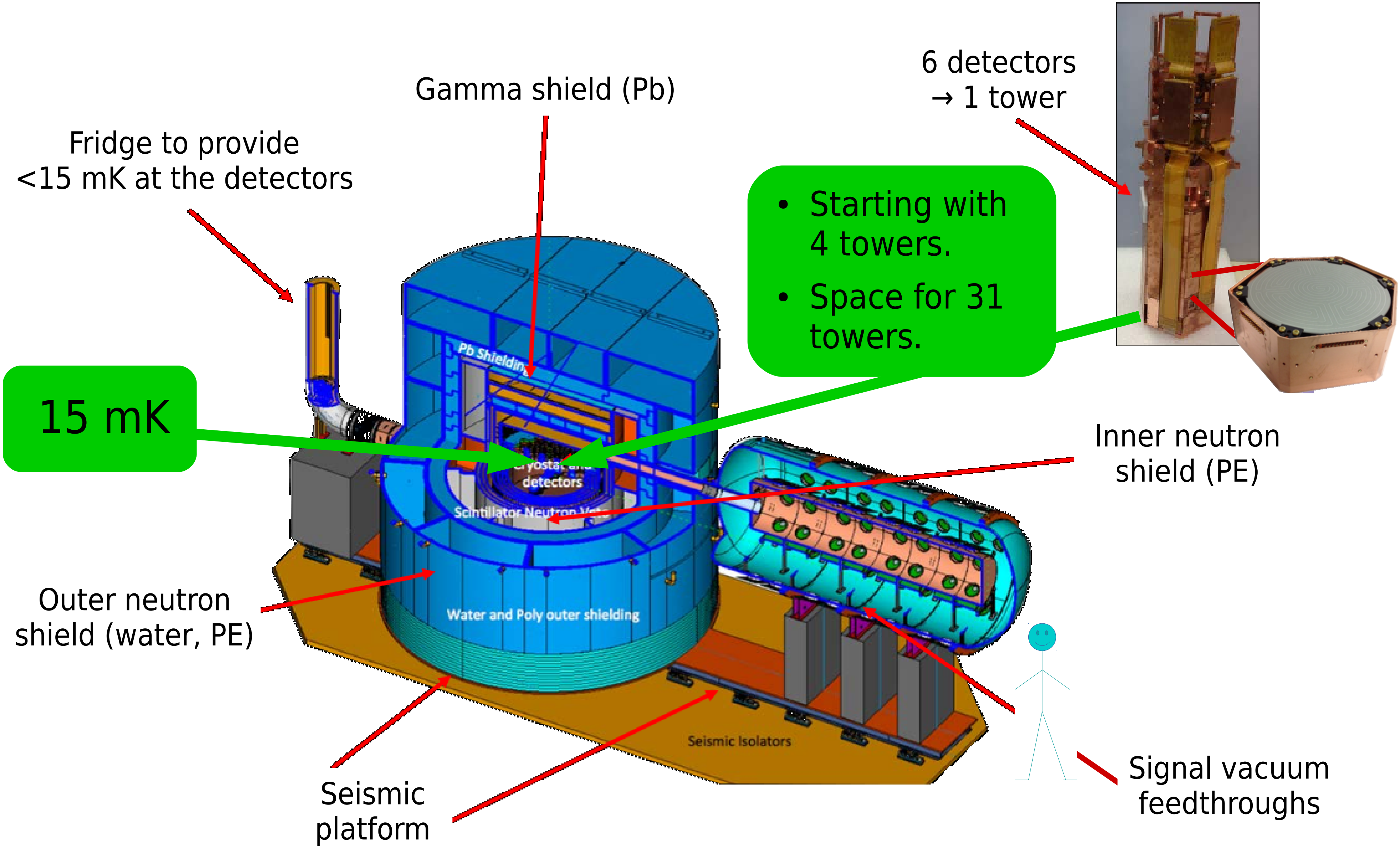
SuperCDMS AT SNOLAB

- Greater Sudbury, Ontario.
- ~2 km deep underground in an active mine.
  - ~6000 mwe overburden.
- Cleanroom class 2000.
- Home to ~10 experiments.

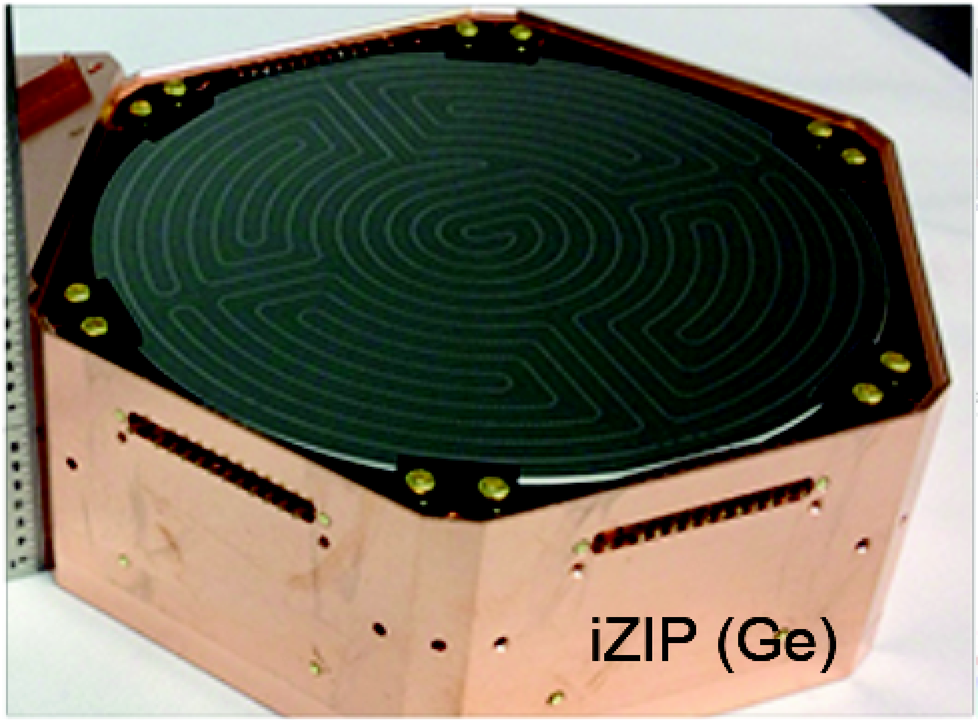


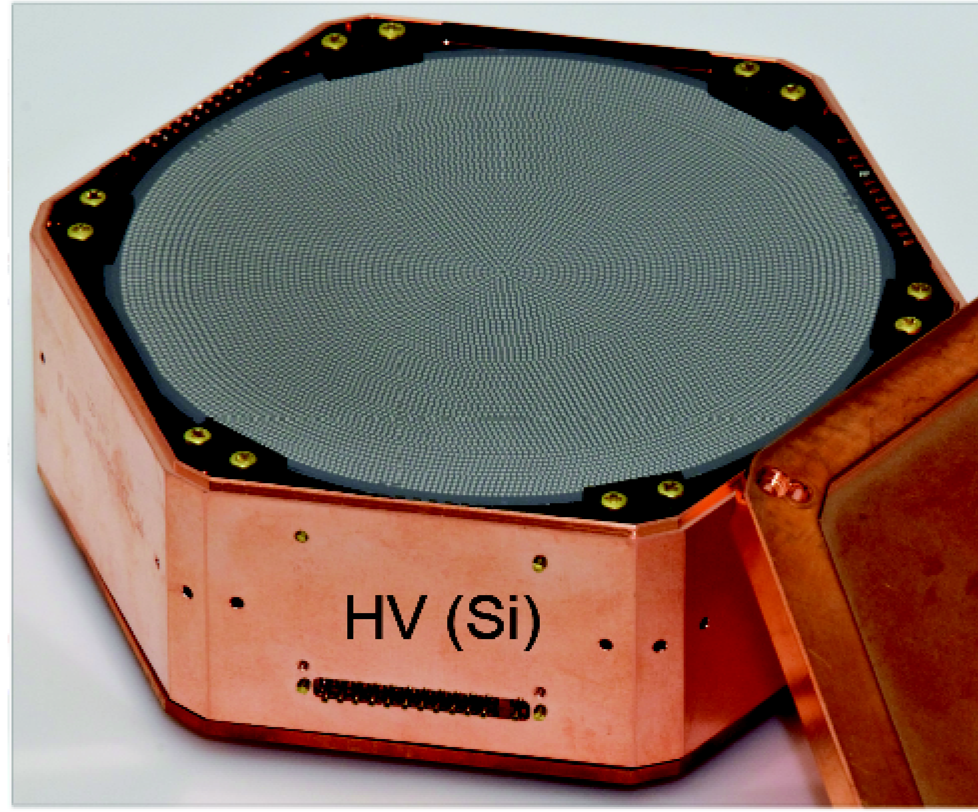


THE SuperCDMS EXPERIMENT



THE SuperCDMS DETECTORS

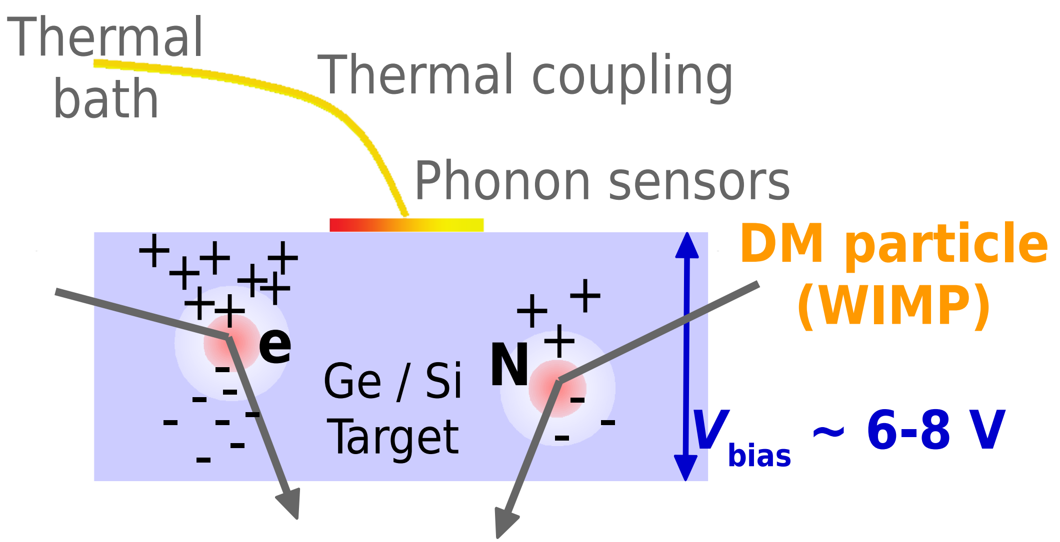


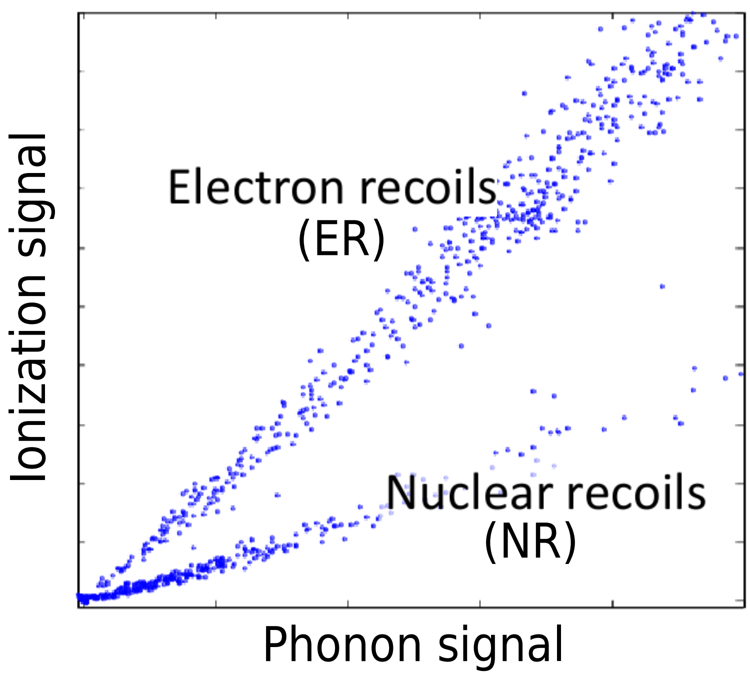


- Size of about an Ice Hockey puck.
- Two crystal types:
  - Germanium: 1.4 kg per detector.
    ~ 25 kg total.
  - Silicon: 0.6 kg per detector.
    ~ 3.6 kg total.
- Two detector types:
  - 12 iZIP detectors.
  - 12 HV detectors.

iZIP DETECTORS

interleaved **Z**-Sensitive **I**onization and **P**honon detectors.



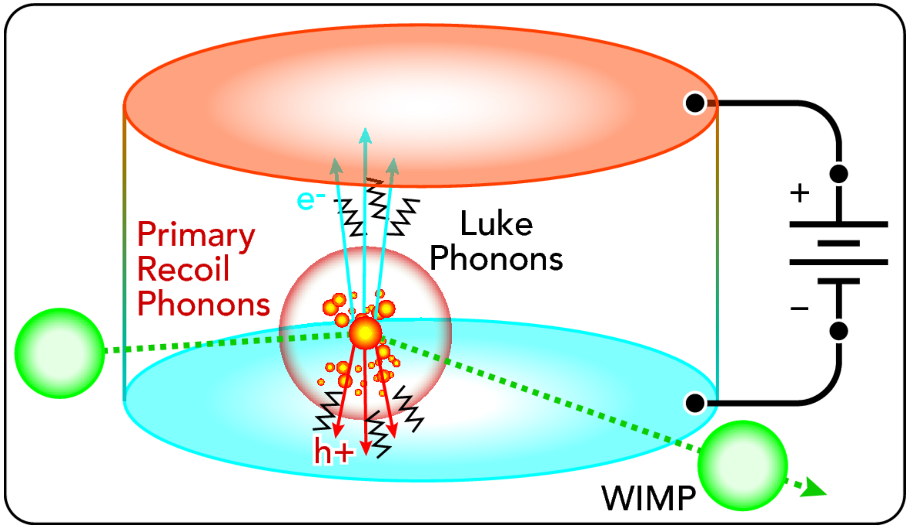


- **Phonon signal**: Heat / energy deposition.
- **Ionization signal**: e^-/h^+ pair production.
  - Reduced for nuclear recoil.
- Combination: Efficient discrimination between nuclear and electron recoil events.

HV DETECTORS

CDMSlite: **l**ow **i**onization **t**hreshold **e**xperiment.

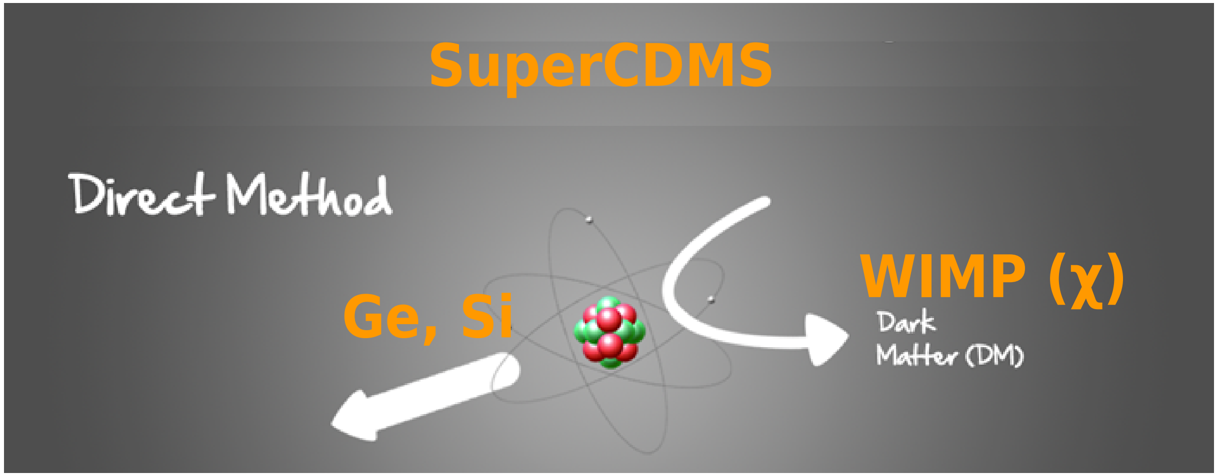
$V_{bias} \sim 100$ V



- e^-/h^+ produce extra phonons as they drift to electrodes.
  - Neganov-Trofimov-Luke phonons.
  - Large V_{bias} => large **phonon amplification of ionization signal**.

- **Effective threshold of one/few e^-/h^+ pairs.**
- Trade-off: no discrimination between electon recoil and nuclear recoil.

DARK MATTER SEARCH STRATEGY

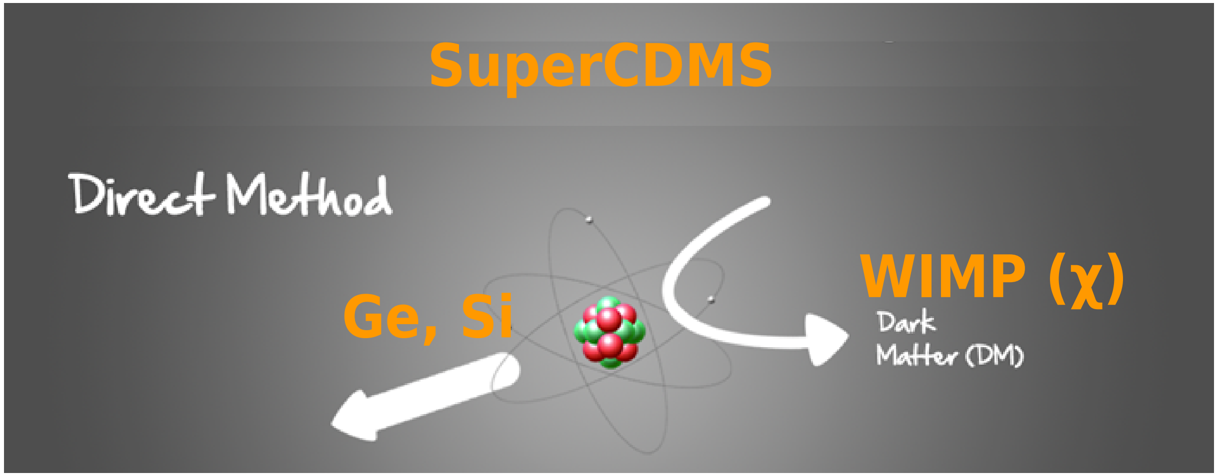


Interaction Rate [events/keV/kg/day]

$$\frac{dR}{dE_R} = \frac{\sigma_o}{m_\chi} \frac{F^2(E_R)}{m_r^2} \frac{\rho_o\, T(E_R)}{v_o\, \sqrt{\pi}}$$

E_R → Recoil energy of nucleus.

DARK MATTER SEARCH STRATEGY



astrophysics properties

Interaction Rate [events/keV/kg/day]

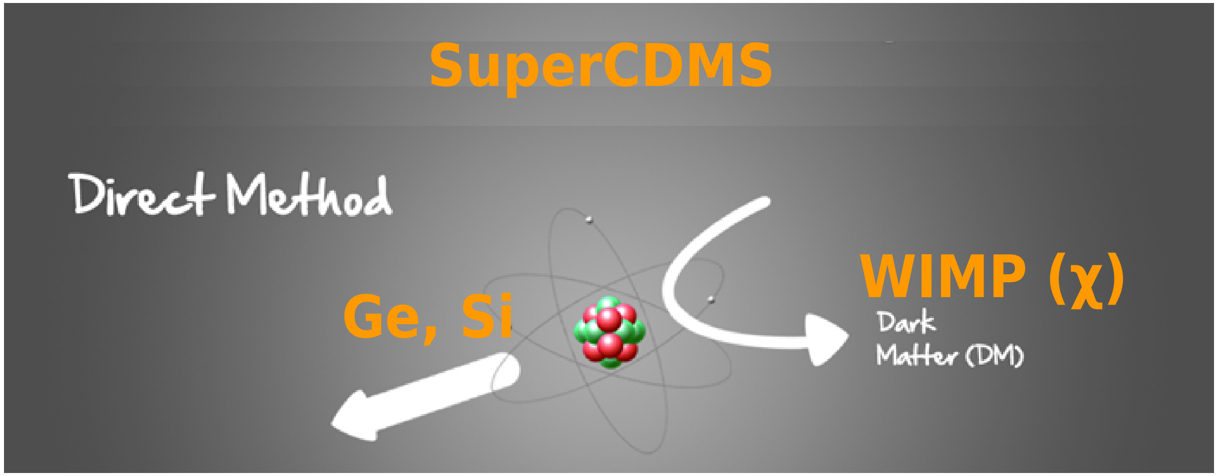
$$\frac{dR}{dE_R} = \frac{\sigma_o}{m_\chi} \frac{F^2(E_R)}{m_r^2} \frac{\rho_o \, T(E_R)}{v_o \sqrt{\pi}}$$

ρ_0: Local dark matter density.

T: Integral over local dark matter velocity distribution.

v_o: Large-radius asymptotic Galactic circular velocity.

DARK MATTER SEARCH STRATEGY

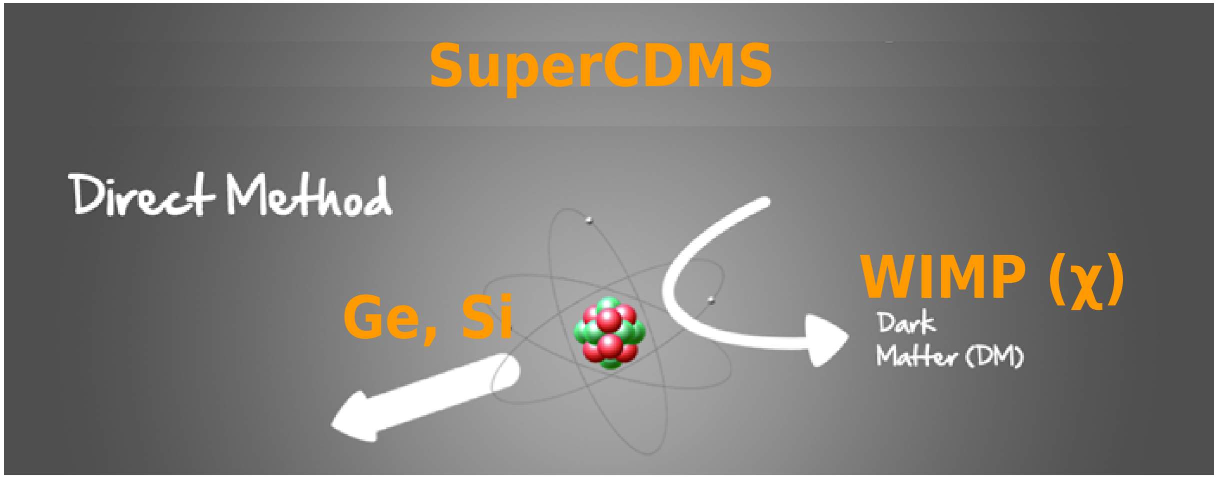


	nuclear structure	astrophysics properties
Interaction Rate [events/keV/kg/day] $\frac{dR}{dE_R} = \frac{\sigma_o}{m_\chi}$	$\frac{F^2(E_R)}{m_r^2}$	$\frac{\rho_o\, T(E_R)}{v_o \sqrt{\pi}}$

$$\frac{dR}{dE_R} = \frac{\sigma_o}{m_\chi} \frac{F^2(E_R)}{m_r^2} \frac{\rho_o\, T(E_R)}{v_o \sqrt{\pi}}$$

F: Form factor (quantum mechanics of interaction with nucleus).
m_r: Reduced mass (WIMP, nucleon).

DARK MATTER SEARCH STRATEGY



particle theory	nuclear structure	astrophysics properties

Interaction Rate [events/keV/kg/day]

$$\frac{dR}{dE_R} = \frac{\sigma_o}{m_\chi} \frac{F^2(E_R)}{m_r^2} \frac{\rho_o\, T(E_R)}{v_o \sqrt{\pi}}$$

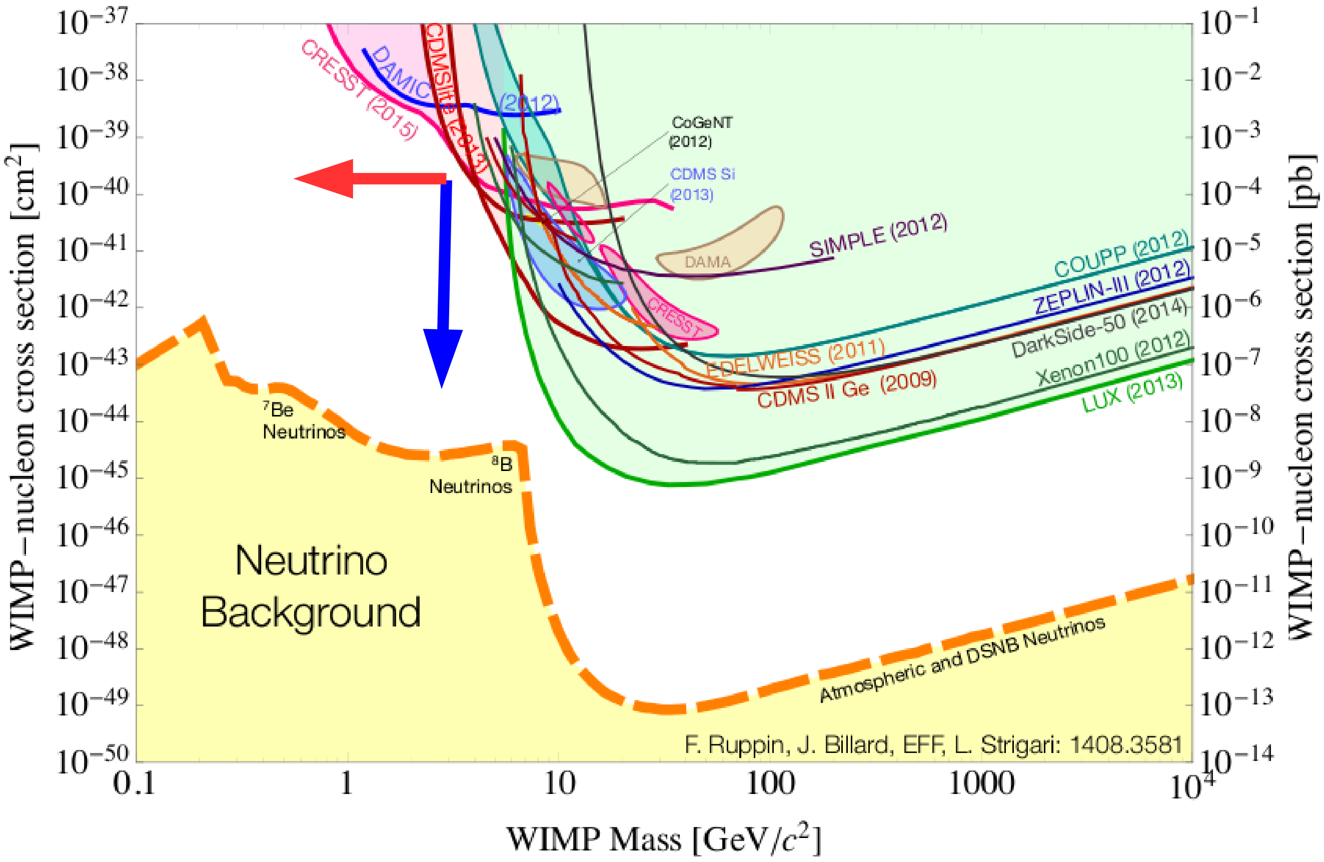
σ_o: WIMP-nucleon scattering cross-section.

m_χ: WIMP mass.

MAIN SCIENCE GOAL OF SuperCDMS

Lower threshold

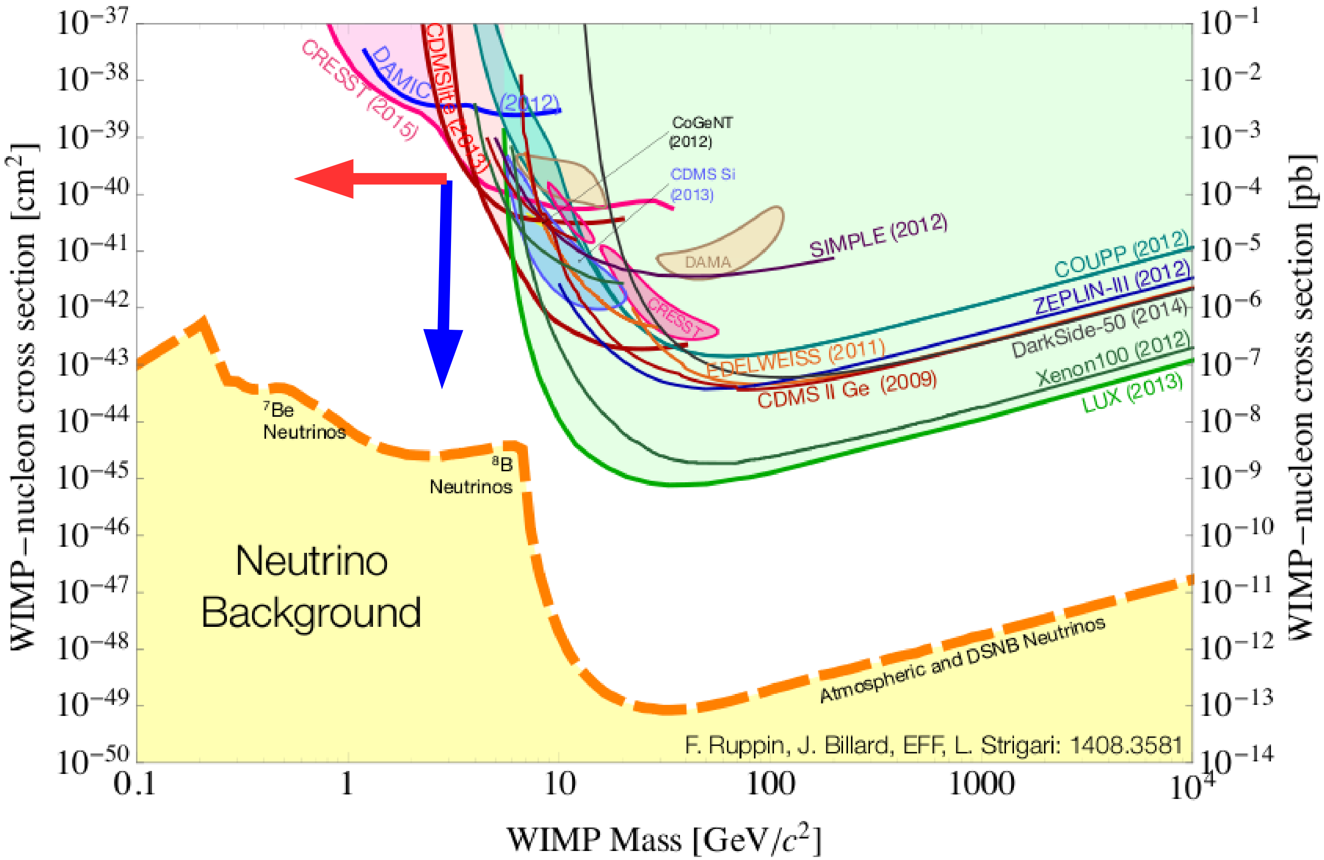
Lower background + more exposure



MAIN SCIENCE GOAL OF SuperCDMS

Lower threshold

Lower background + more exposure



→ **Build dedicated low threshold detectors** (HV detectors).

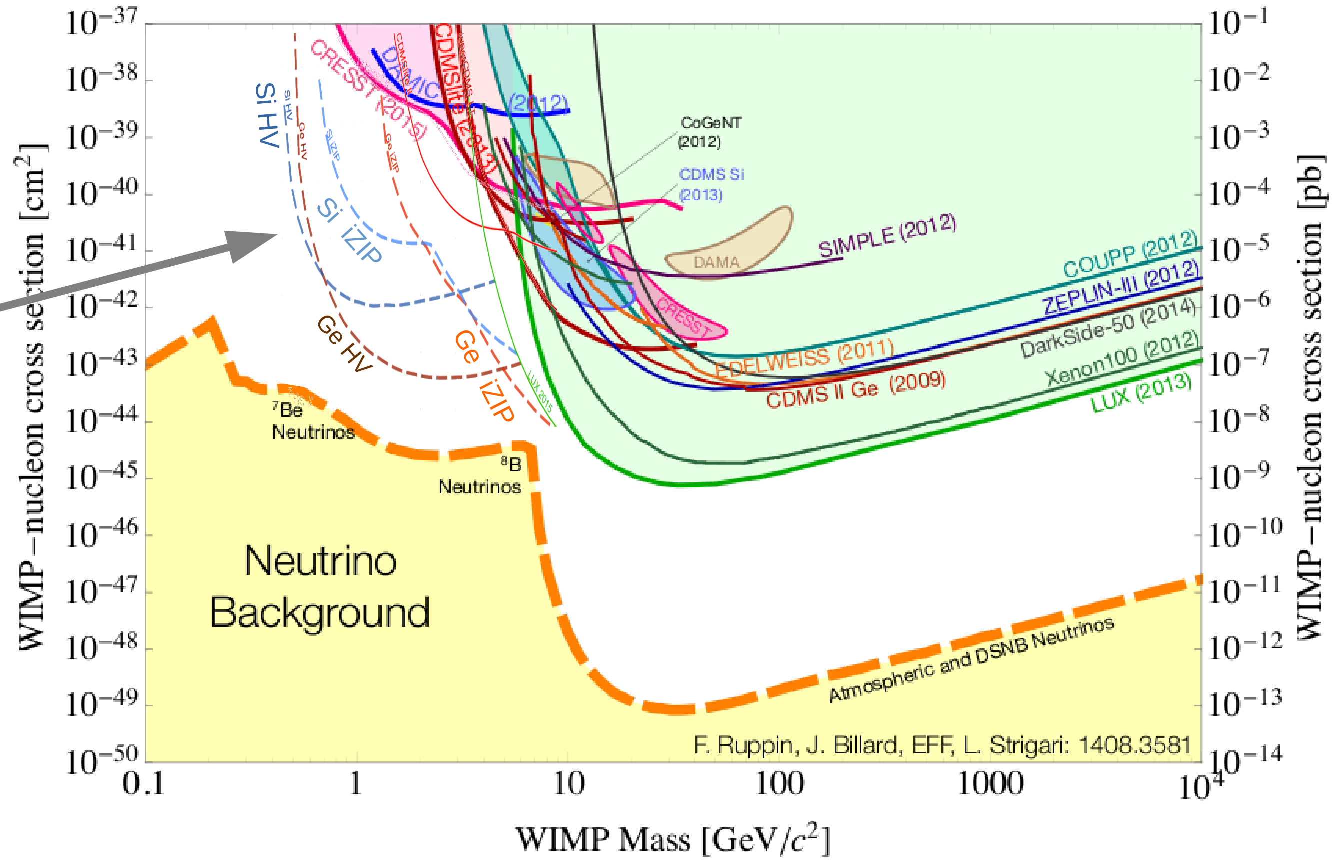
→ **Go deeper:** 6000 mwe (SNOLAB) instead of 2000 mwe (Soudan).

→ **Build bigger:** 100 kg·yr Ge + 14.4 kg·yr Si instead of 6.8 kg·yr Ge.

MAIN SCIENCE GOAL OF SuperCDMS

SuperCDMS projected sensitivity

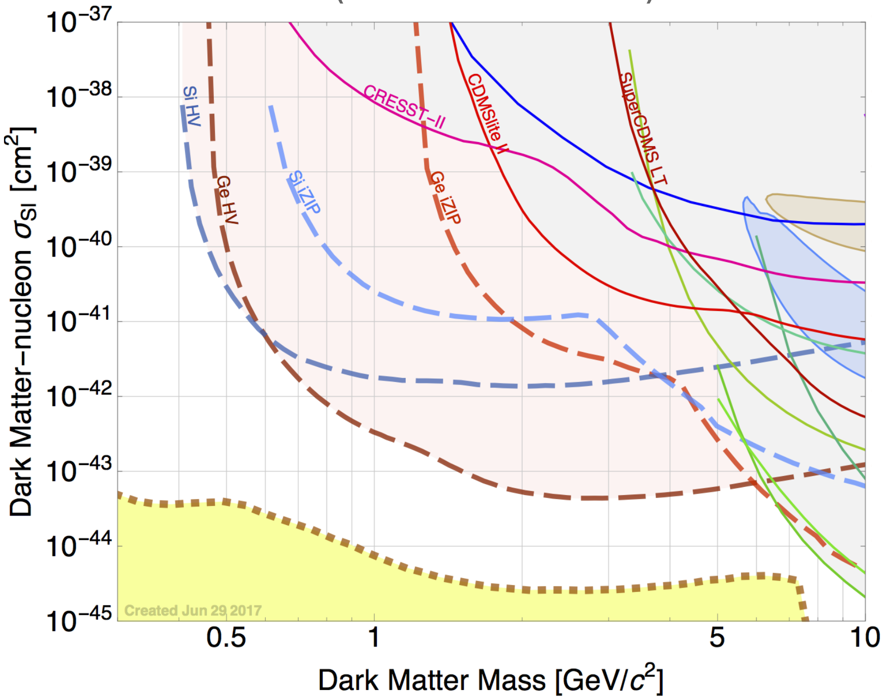
(2020-2024)



- Observe WIMPs of mass $m_\chi \sim$ GeV/c².
- Or (if nature is less generous):
  - Improve sensitivity x10 for $m_\chi \leq 10$ GeV/c² over existing limits.
  - Probe WIMP masses well below $m_\chi = 1$ GeV/c².

COMPLEMENTARITY WITH DEAP-3600

SuperCDMS
(all dashed lines)

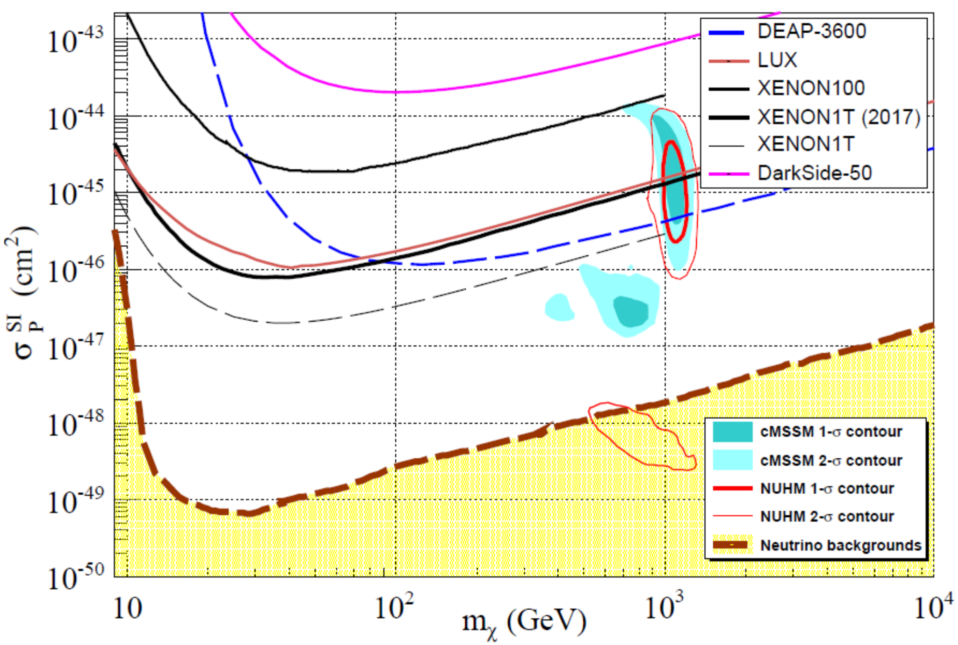


$\leq$ 10 GeV

Low-mass WIMPs.

High-mass WIMPs.

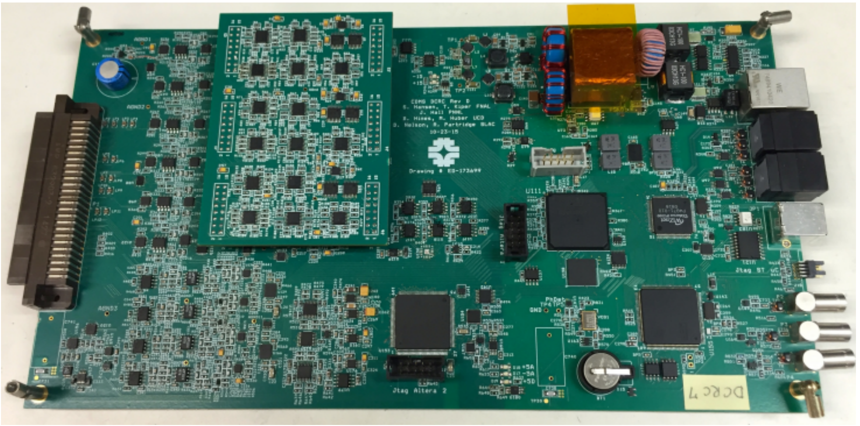
DEAP-3600
(blue dashed line)



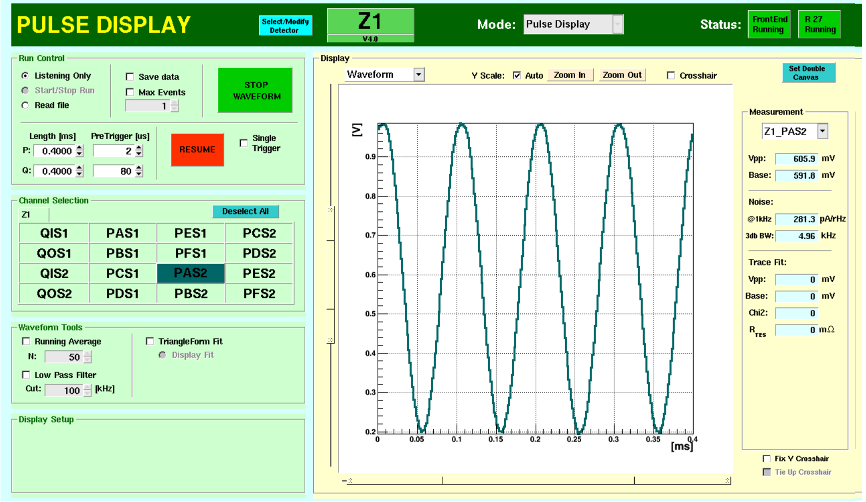
$\geq$ 10 GeV

DAQ: DATA ACQUISITION SYSTEM

Prototype detector control and readout card:



Online pulse display:



- To achieve science goals, design DAQ with:
  - Deadtime-free trigger.
  - Optimal filtering of noise at trigger level.
  - Ultra-low threshold.
  - High throughput.
  - Online data quality and environmental monitoring.
- Standardized DAQ at all test facilities.
- Milestone: Successful test of core DAQ programs at SLAC, Aug. 2016.

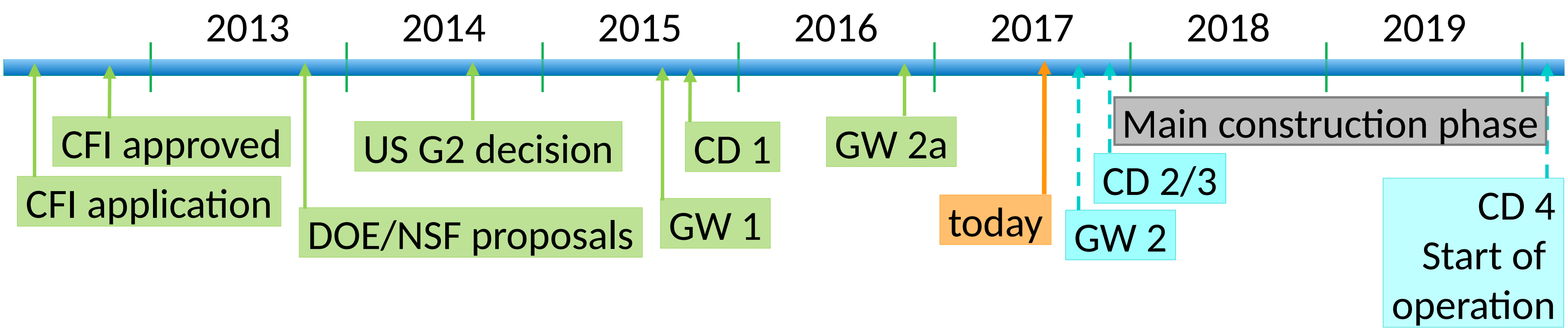
DAQ: Data AcQuisition system

New SuperCDMS DAQ software based on MIDAS.

- Modern Data Acquisition Software package.
- Developed at PSI and TRIUMF.
- Used around the world in over 80 locations.
  - Including DEAP and T2K.

SuperCDMS will benefit from over 20 years of development, experience and the close collaboration with MIDAS experts at TRIUMF.

SCHEDULE AND FUNDING



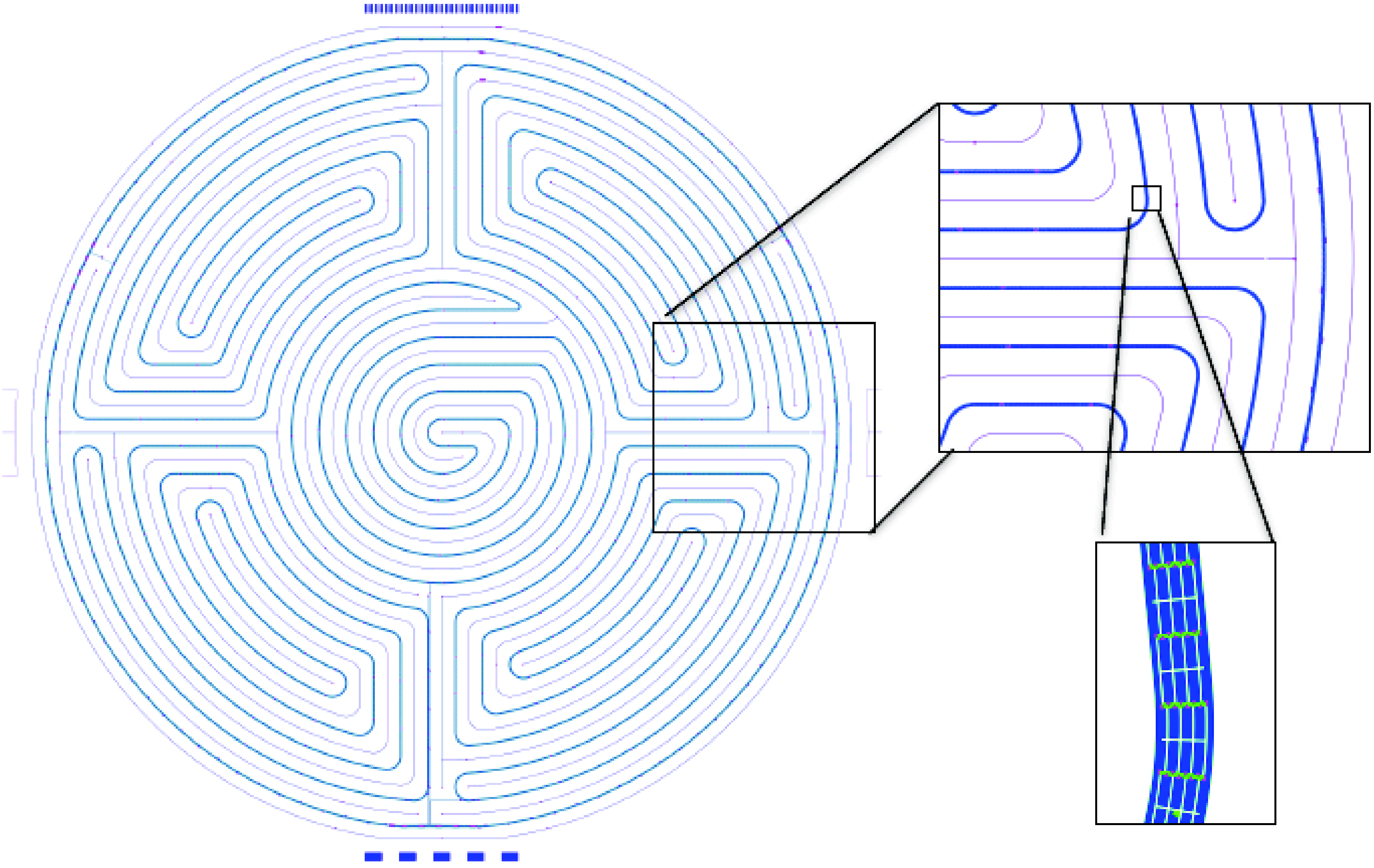
- Funding approved (CFI: 2012, DOE/NSF: 2014).
- DOE/NSF review process:
  - Passed: CD 1 - conceptual design review.
  - Upcoming end of 2017: CD 2/3 - technical design review/ready for construction.
- Reviews at SNOLAB:
  - Passed: Gateway 1 – space allocation.
  - Passed: Gateway 2a – early construction.
  - Upcoming fall 2017: Gateway 2 – construction.
- Total project costs ~$30M.

SUMMARY

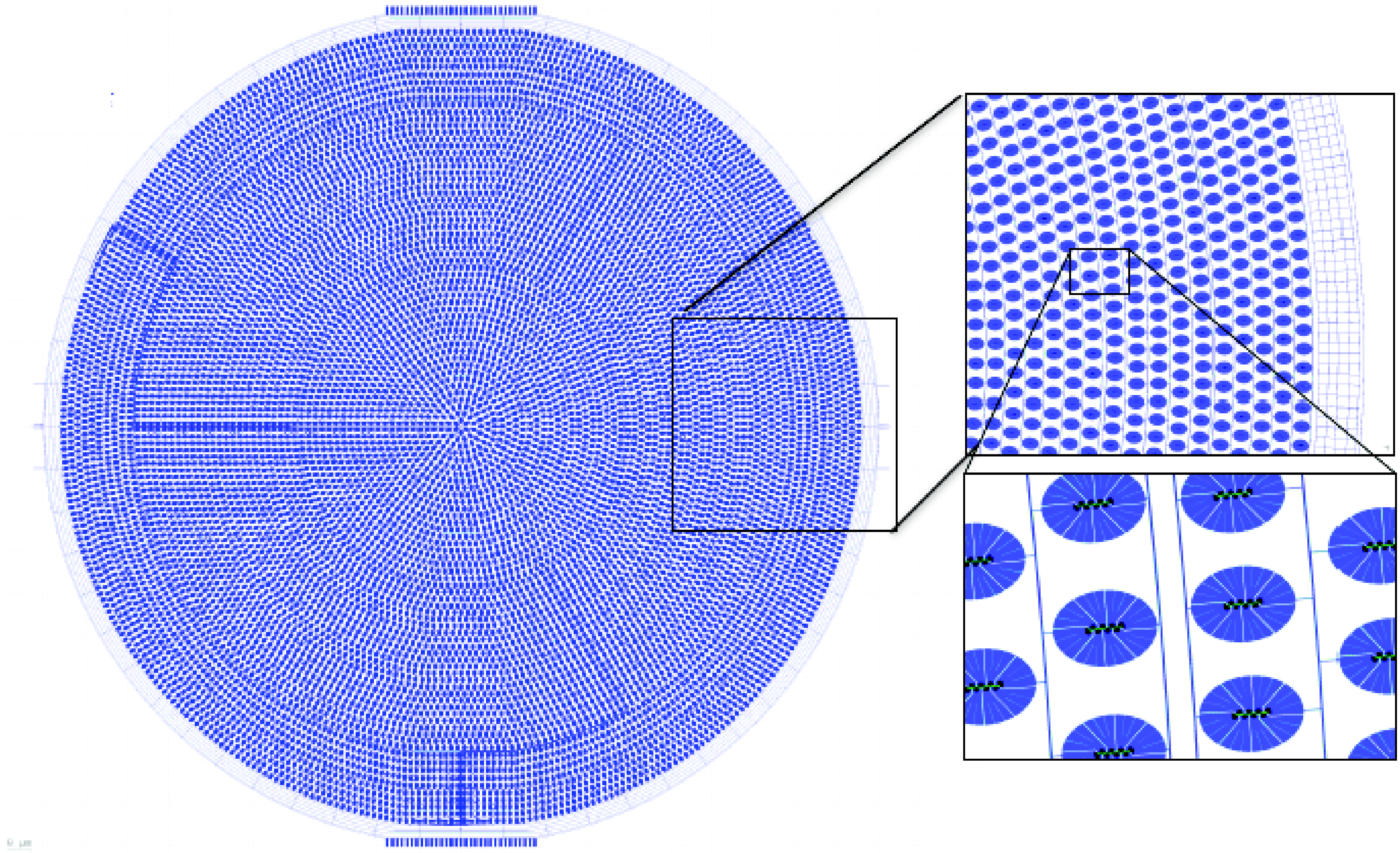
- SuperCDMS is an international experiment with a strong Canadian contribution.
- The new SuperCDMS experiment will be located at SNOLAB in Sudbury, Ontario.
- The main construction phase will start in a few months.
- The detector technology is based on Ge and Si crystals operated at cryogenic temperatures.
- The SuperCDMS SNOLAB projected sensitivity to spin-independent WIMP-nucleon scattering is world-leading at low masses.
- A sophisticated DAQ which enables an ultra-low threshold and helps to reduce backgrounds is crucial to reach this goal.
- The SuperCDMS group at TRIUMF/UBC is leading the MIDAS-based DAQ development.

BACK-UP SLIDES

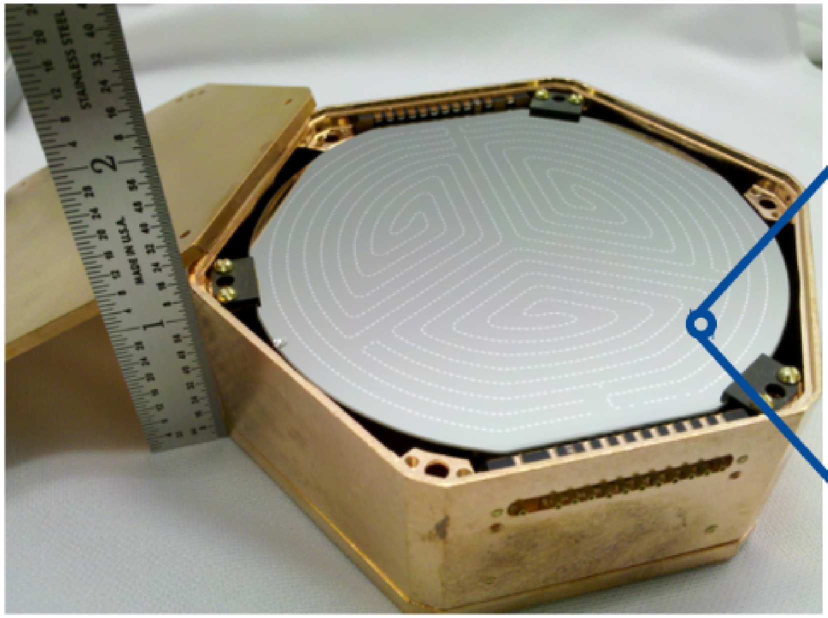
iZIP DETECTOR SENSOR LAYOUT

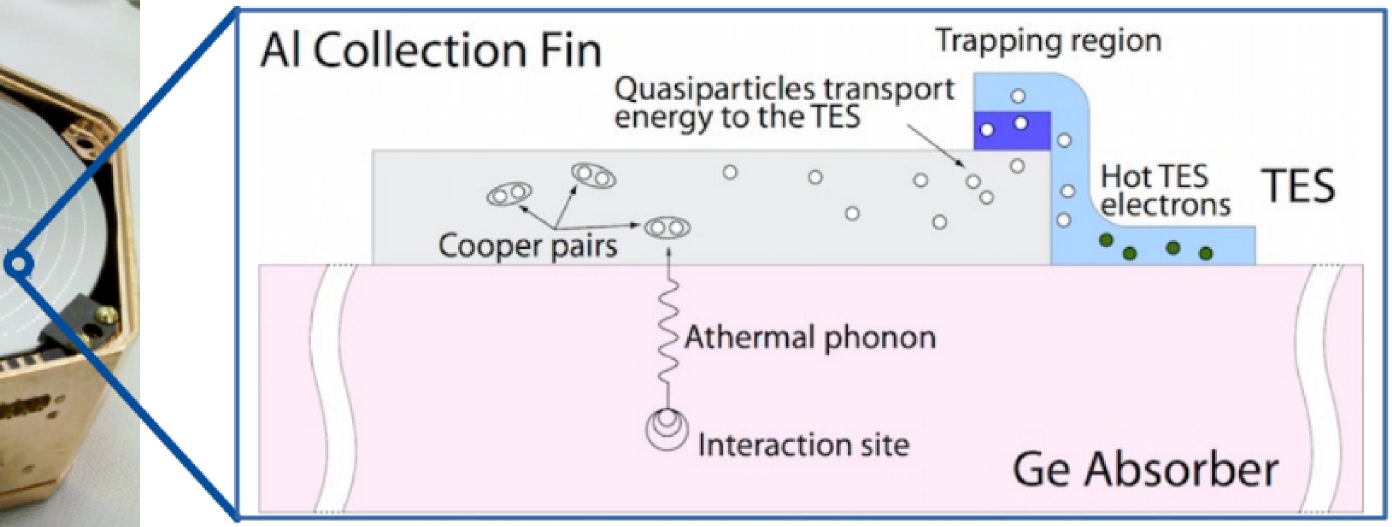


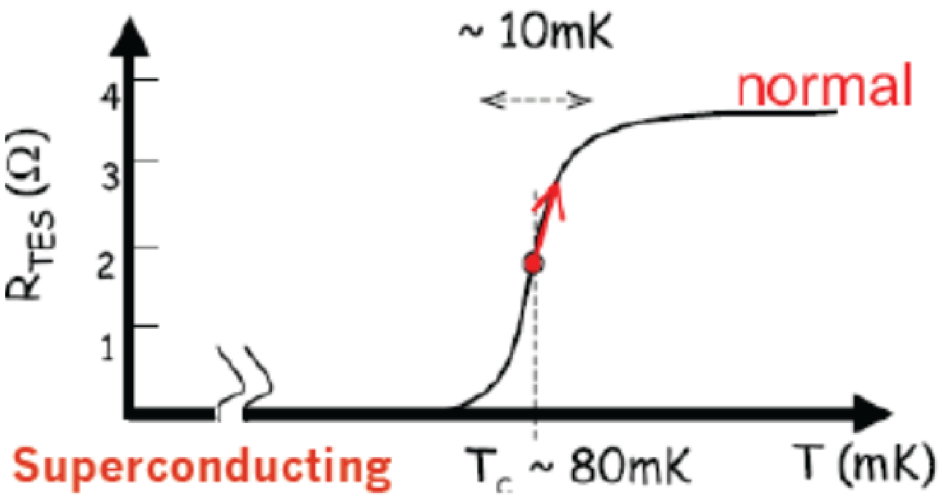
HV DETECTOR SENSOR LAYOUT



PHONON MEASUREMENT

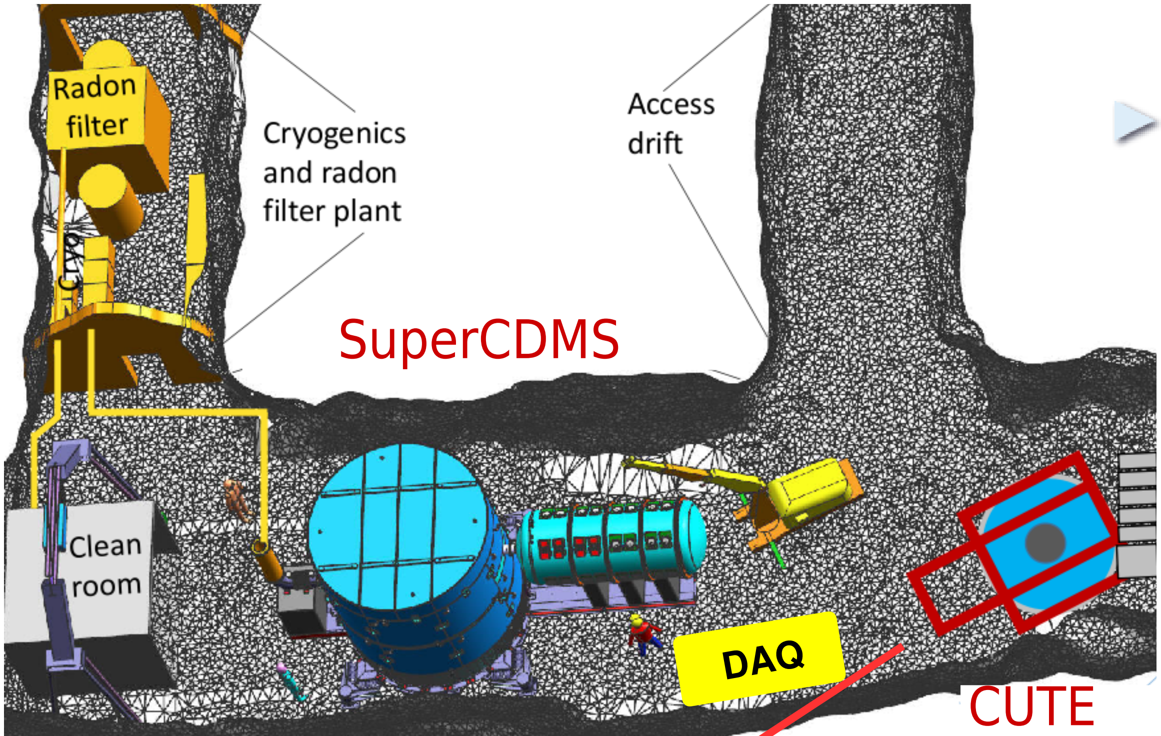


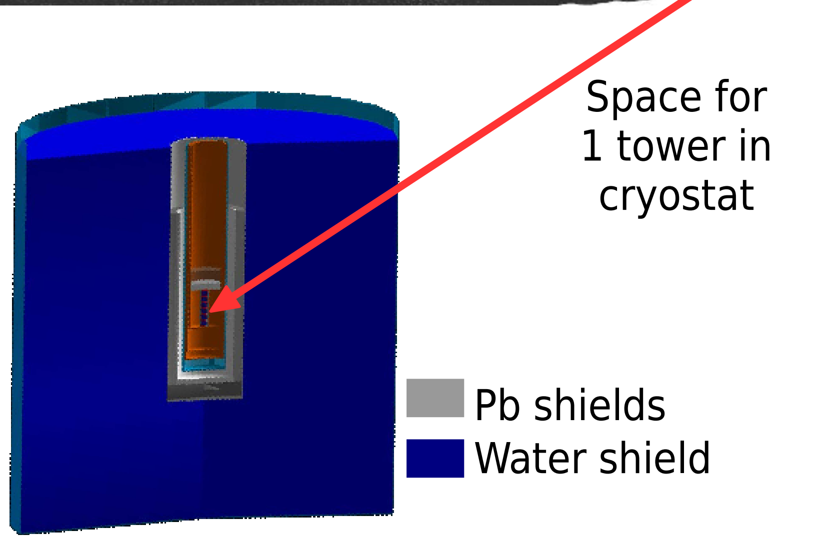




- Athermal phonons collected in Al fins on surface.
- Breaking of Cooper pairs in fins creates quasi-particles.
- Quasi-particles travel to tungsten TES, heating it.
- Heat quickly alters the resistance, supplying the signal.

CUTE: A CRYOGENIC UNDERGROUND TEST FACILITY





- Motivation:
  - Detector performance tests.
  - Background studies.
  - Nuclear recoil energy scale.
  - Test of EURECA detectors (possibility to join forces).
  - Potentially Dark Matter physics.

Commissioning scheduled towards end of 2017.

RECOIL ENERGY CALCULATION

Observed total phonon energy (incl. primary and NTL phonons).

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

Recoil energy in SuperCDMS detectors.

Energy for e^+/h^- pair,
3 eV in Ge,
3.6 eV in Si.

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

Ionization yield,
≡1 for electron recoil,
<1 for nuclear recoil.

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

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

IONIZATION YIELD

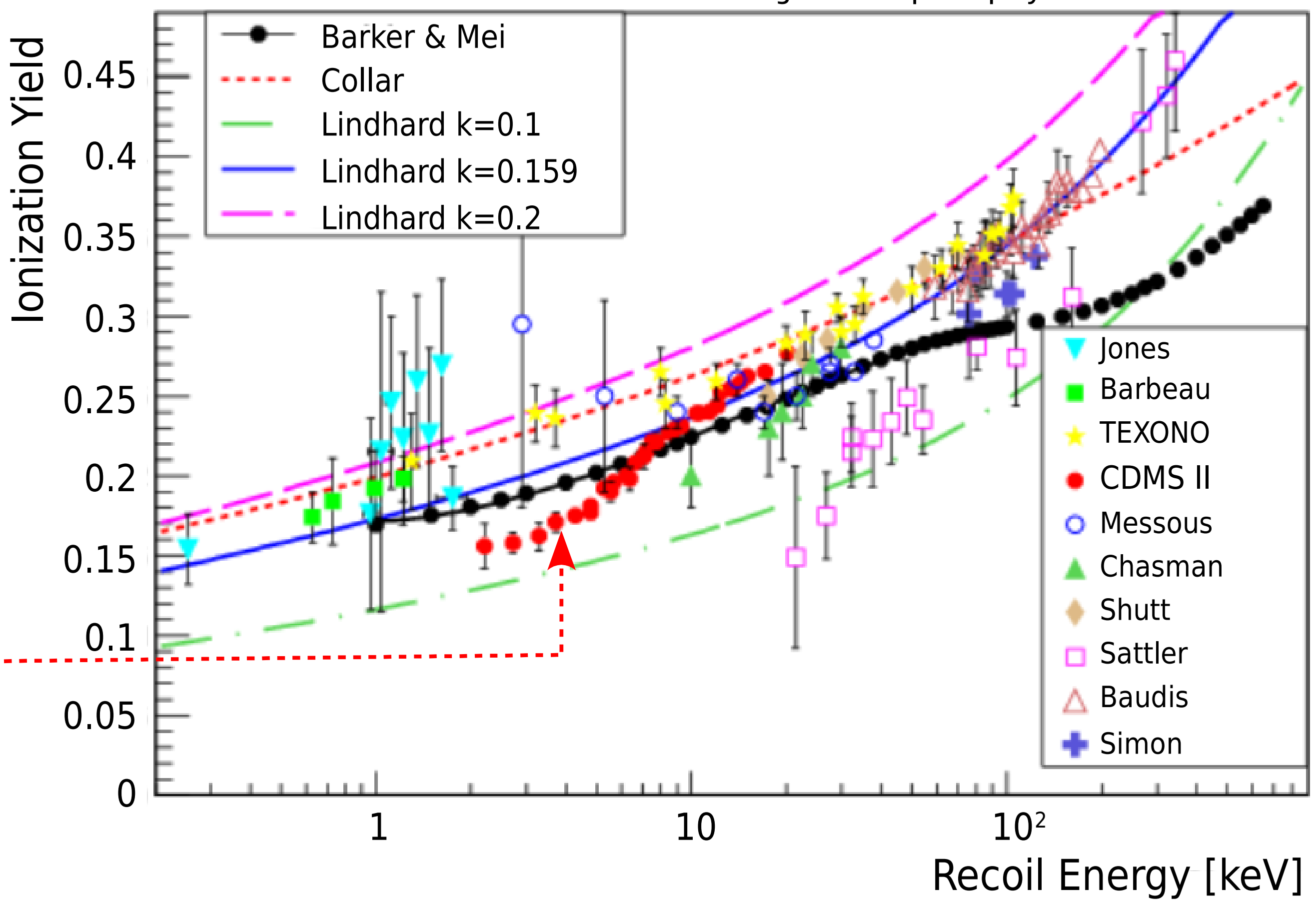
Lindhard model:

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

Ge:
$Z=32$, $A=72.64$

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

Barker, Mei
doi:10.1016/j.astropartphys.2012.08.006

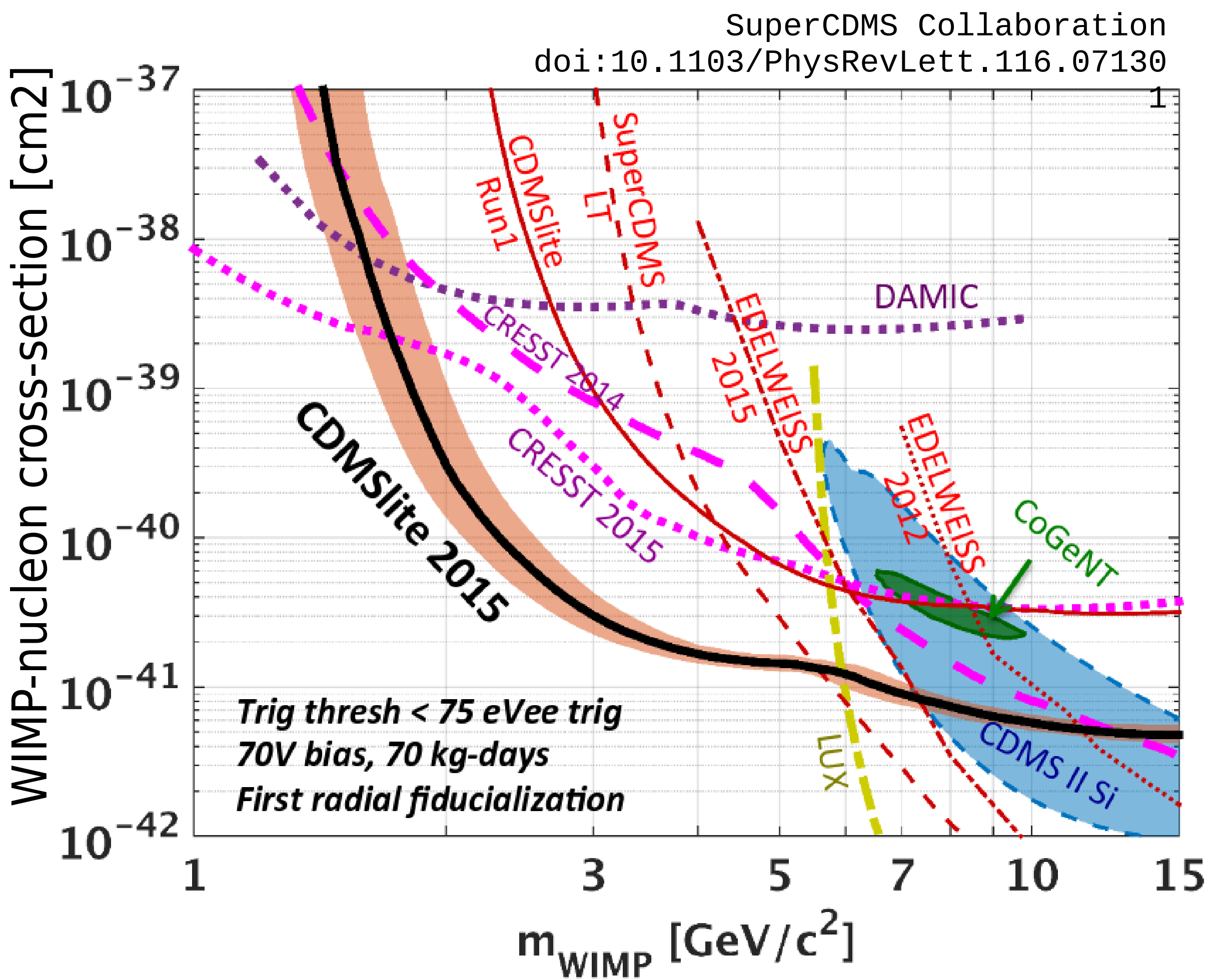


CDMS II, Ge data
averaged over detectors

IMPACT OF RECOIL ENERGY UNCERTAINTY

- CDMSlite (HV) results use Lindhard model with *k*=0.157.

- Uncertainty at <3 GeV/c^2 dominated by $Y_{ionization}$ uncertainty.



- Encompasses parameterization with *k* = [0.1, 0.2].