Photoneutron calibration of SuperCDMS detectors

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CAP Congress 2016

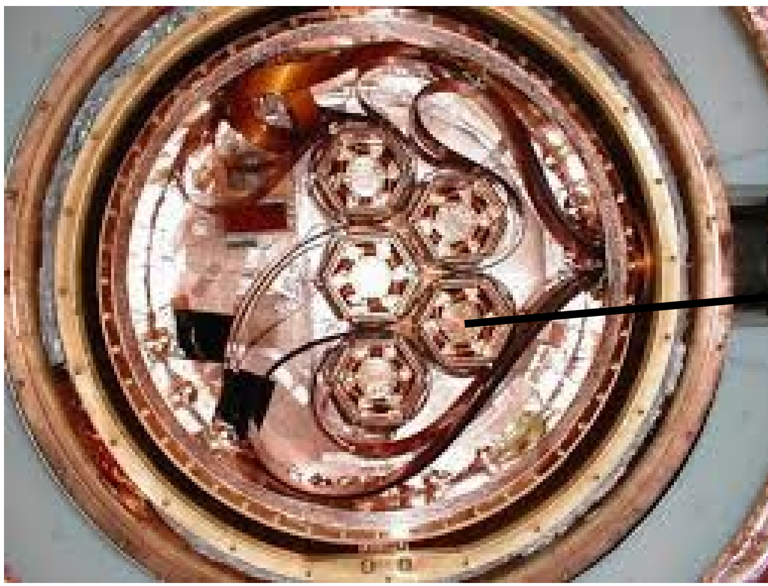
The SuperCDMS Experiment

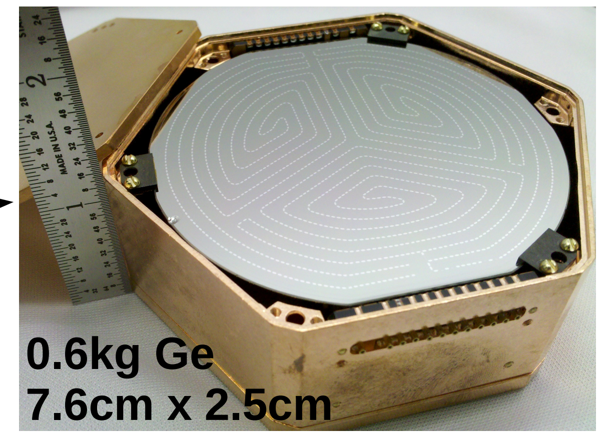
(Cryogenic Dark Matter Search)

SuperCDMS Soudan: Overview

Underground laboratory at SOUDAN:

~800m deep, ~2090 m.w.e.



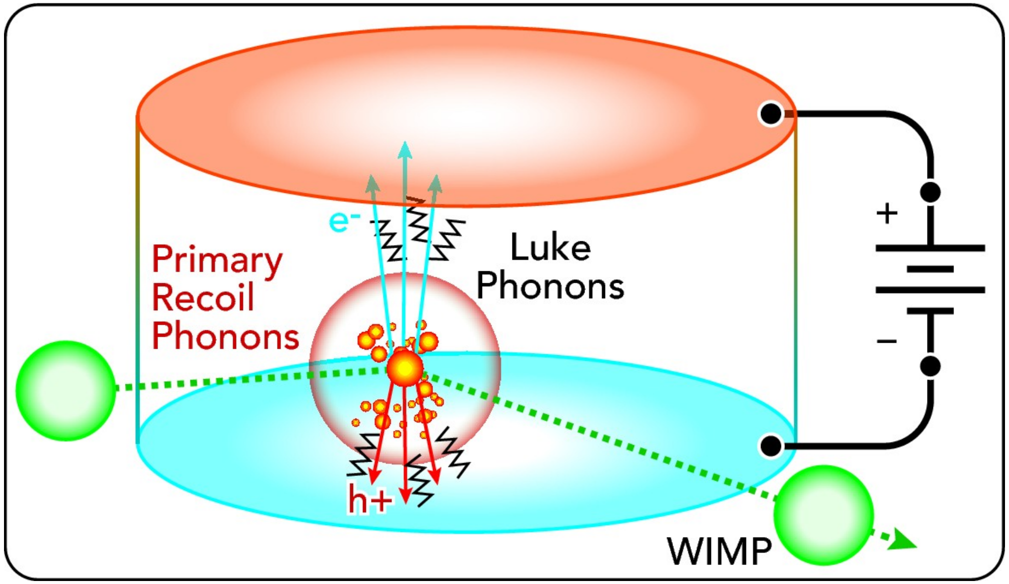


- 15 detectors in 5 towers.
- 9kg Ge total.
- iZIP detectors:
  - Ionization and Phonon signal.
  - Operated in normal and **HV mode**.
- Photoneutron data taken summer/fall 2015.

- SuperCDMS Soudan operational until late 2015.
- SuperCDMS SNOLAB construction starting 2017:
  - Will be deeper, larger, more sensitive!

CDMSlite (HV) Detection Principle

lite: **l**ow **i**onization **t**hreshold **e**xperiment



Standard iZIP mode:

- Primary phonon and ionization signal:

  => allows NR/ER discrimination.

  NR, ER: **N**uclear **R**ecoil, **E**lectron **R**ecoil

HV mode:

- e^-/h^+ produce extra phonons as they drift to electrodes (Neganov-Luke phonons).
- **#Neganov-Luke phonons ∾ V_{bias}:**

  => large V_{bias} yields large *phonon* amplification of *ionization* signal.

Neganov-Luke amplification enables very low thresholds => low WIMP masses.

Trade-off: Neganov-Luke phonons mix ionization and phonon signal => no NR/ER discrimination.

Recoil Energy Calculation

total phonon energy including primary and Neganov-Luke phonons

recoil energy in SuperCDMS detectors

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

bias voltage, ~70V for CDMSlite

energy for e/h pair, 3eV in Ge

ionization yield, =1 for ER, <1 for NR

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

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

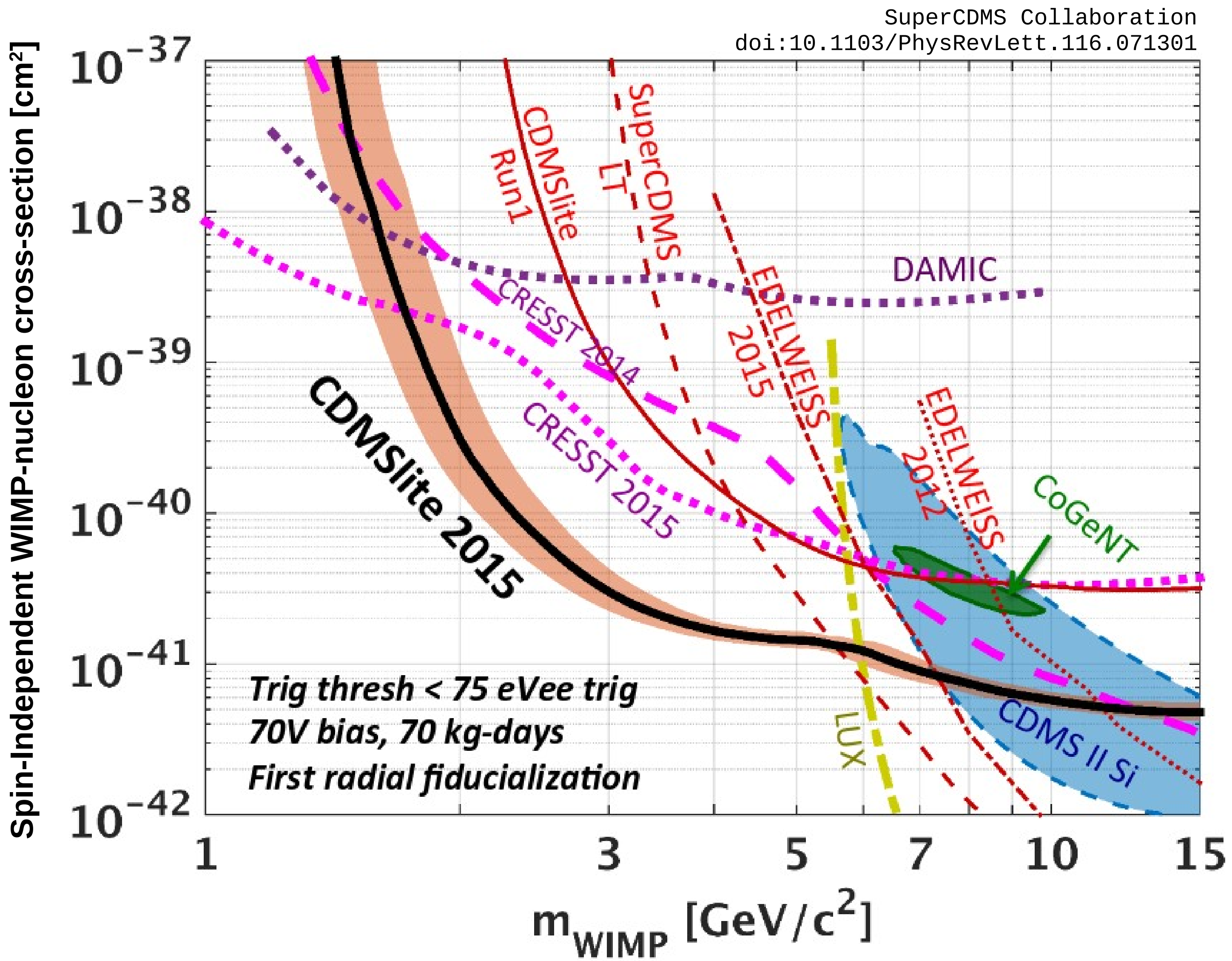
- For iZIP detectors measurement of $Y_{ionization}$ on an event-by-event basis.
- **For HV detectors direct measurement of $Y_{ionization}$ not possible!**

→ CDMSlite results to date use Lindhard theory (k=0.157).

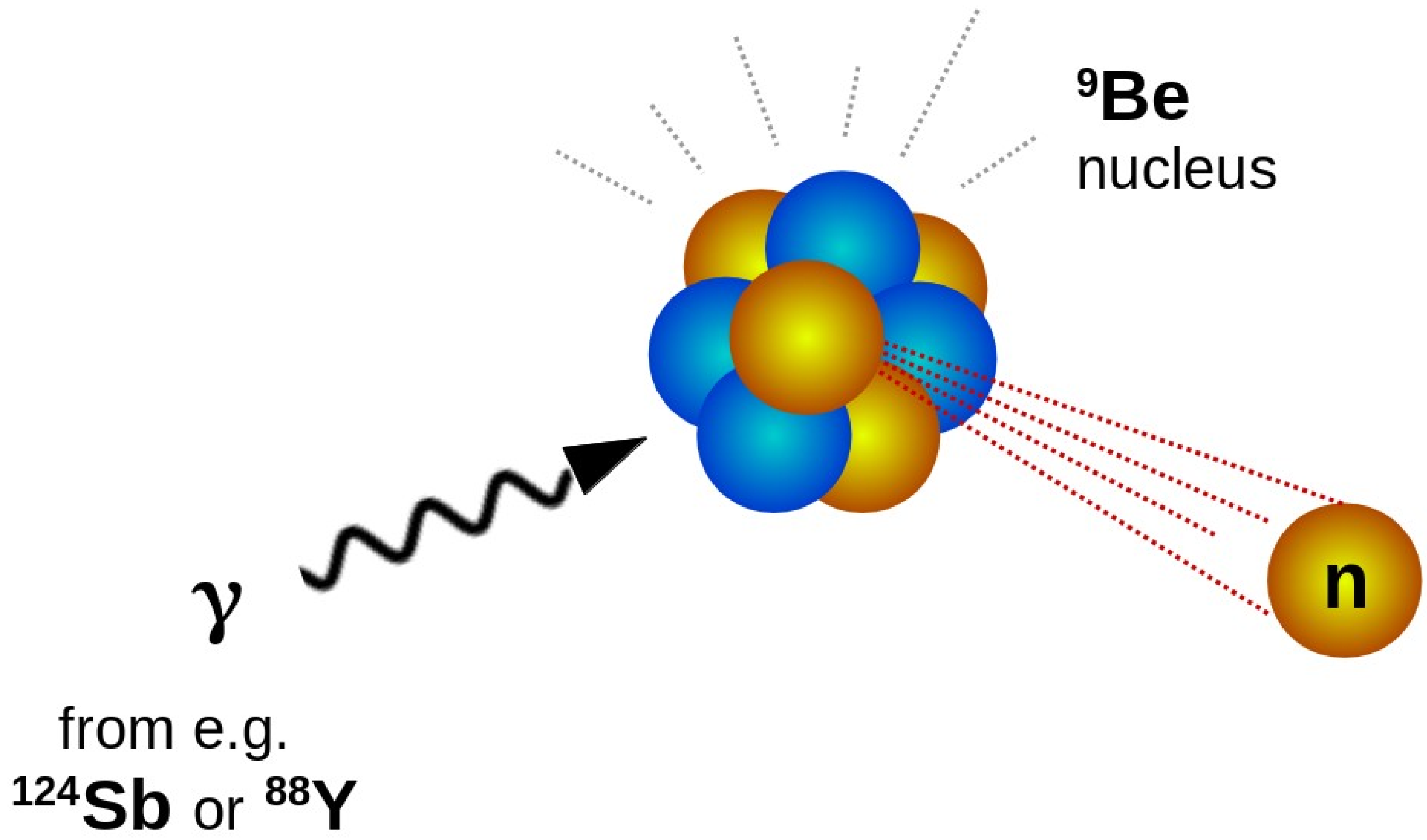
Impact of Recoil Energy Uncertainty on CDMSlite (Run II)

- Results to date use Lindhard model with *k*=0.157 for central value.
- Uncertainty band dominated by $Y_{ionization}$ uncertainty at <3GeV/c^2.

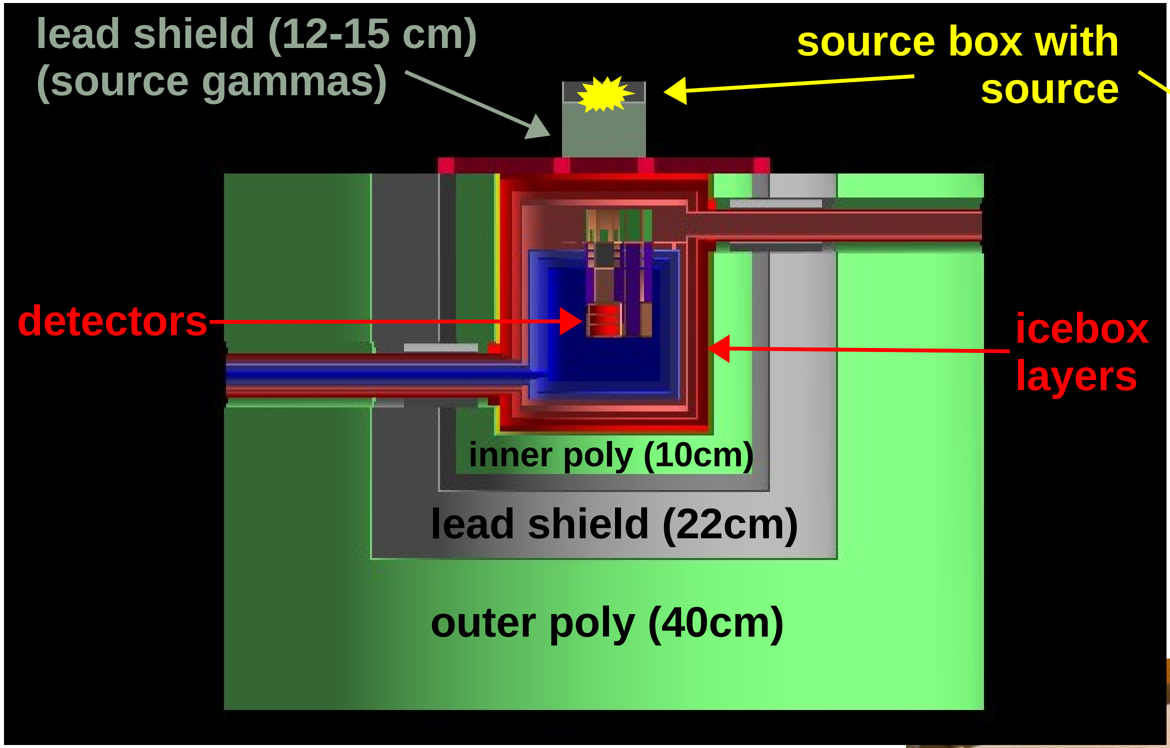
  → Encompasses Lindhard-like parameterization with "k" = [0.1, 0.2].



Photoneutron Calibration



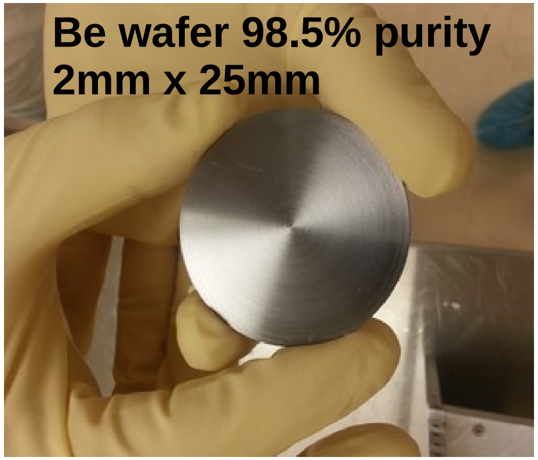
Set-up at Soudan

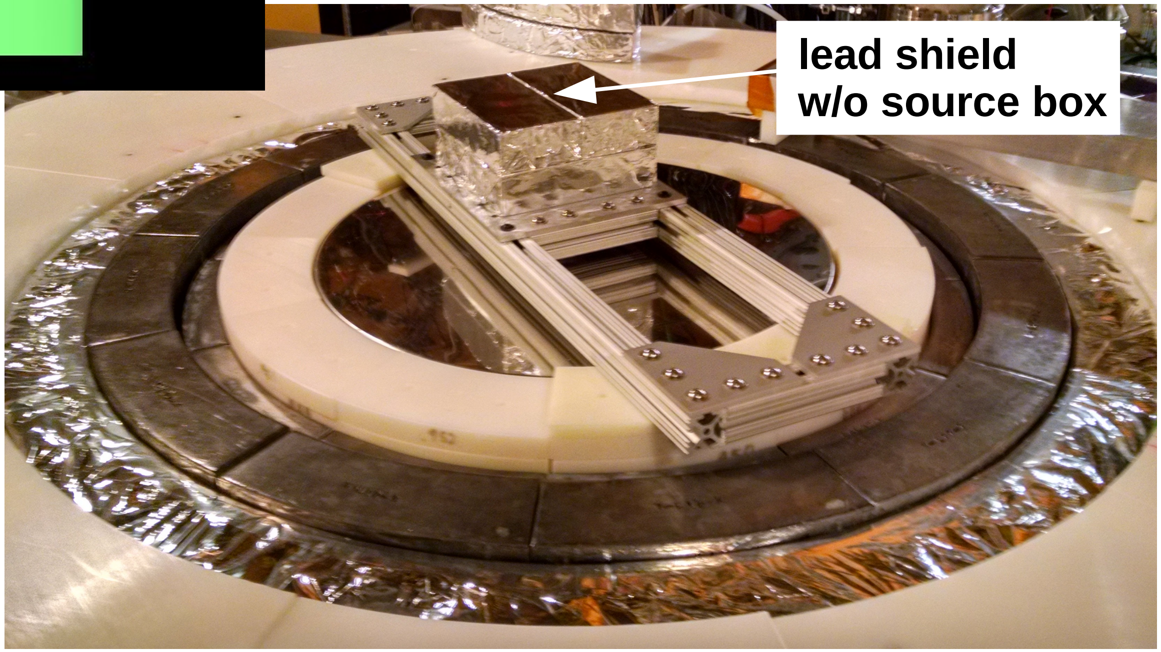


Courtesy of A. N. Villano

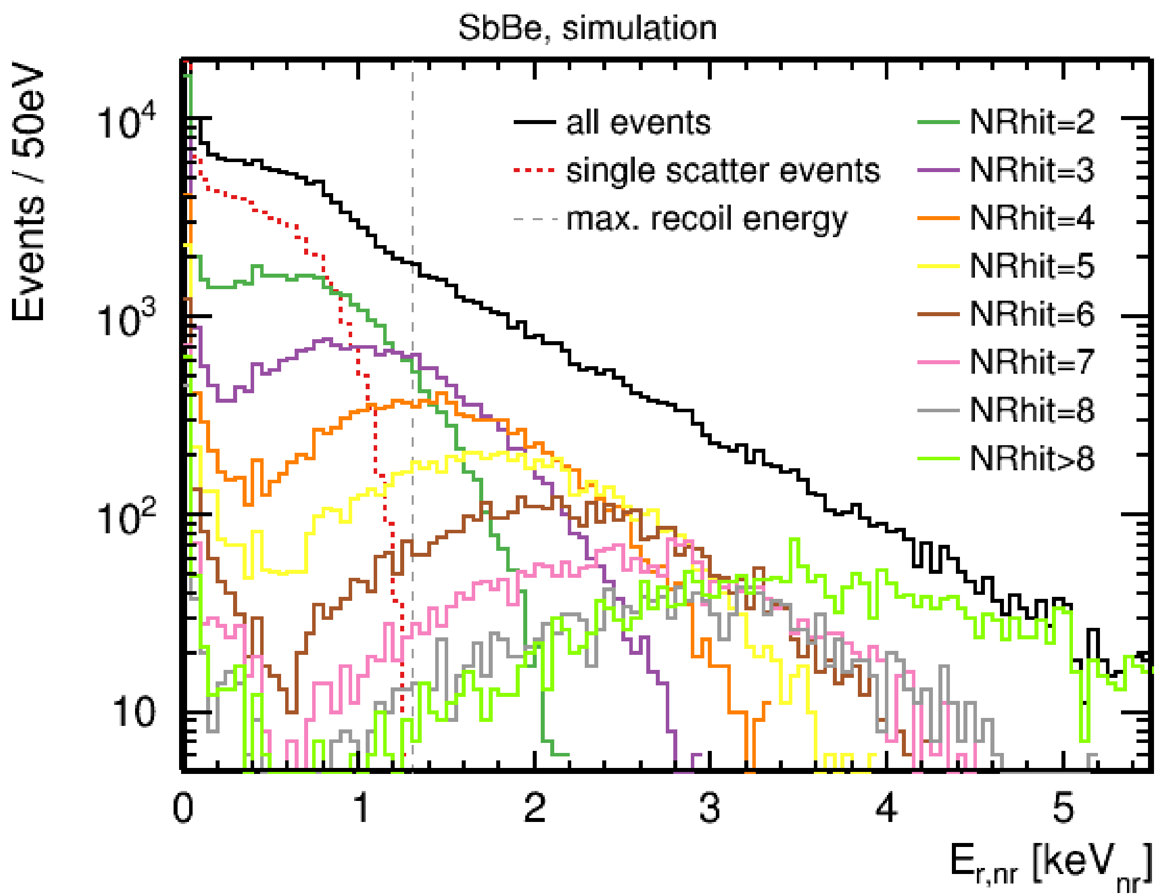
γ source and Be wafer in fixed position:

Shifters could (re)place γ source precisely wrt detectors.





Photoneutron Calibration: Concept

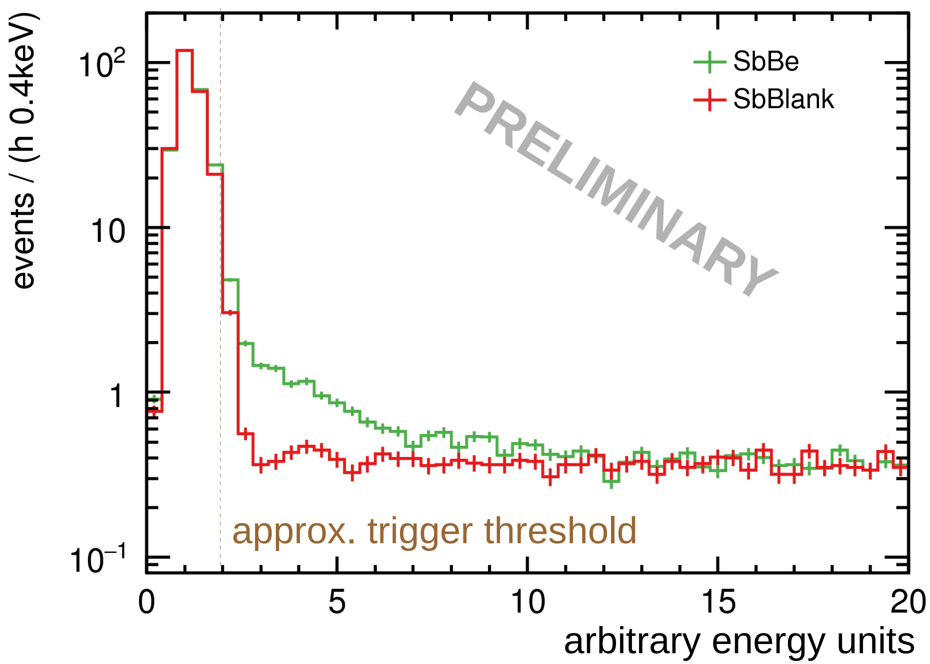


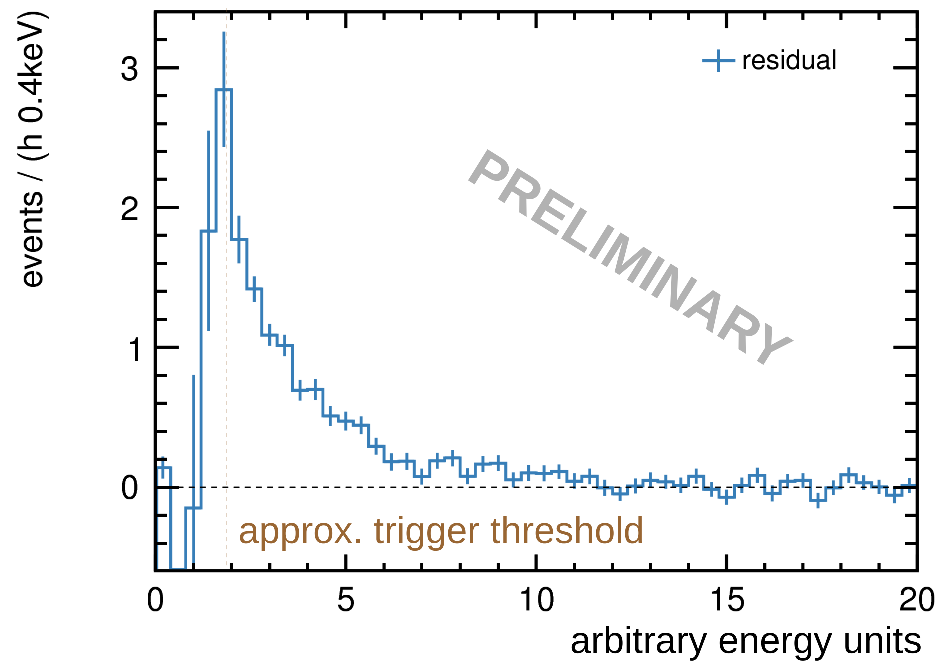
- Quasi mono-energetic neutrons from **SbBe** and YBe source with $E_{kin} \approx$ **24keV** and 152keV.
- Max. elastic scattering shoulder off Ge at ~**1.3keV** and 8.1keV.
- Shoulder provides identifiable feature of known energy:
  => Can check NR energy scale
  and thus $Y_{ionization}$.

Complications:

- Multiple neutron scatters in same detector blur max. elastic scatter shoulder.
- Initial gamma rate much higher than neutron rate => large ER background.

Preliminary CDMSlite SbBe spectra

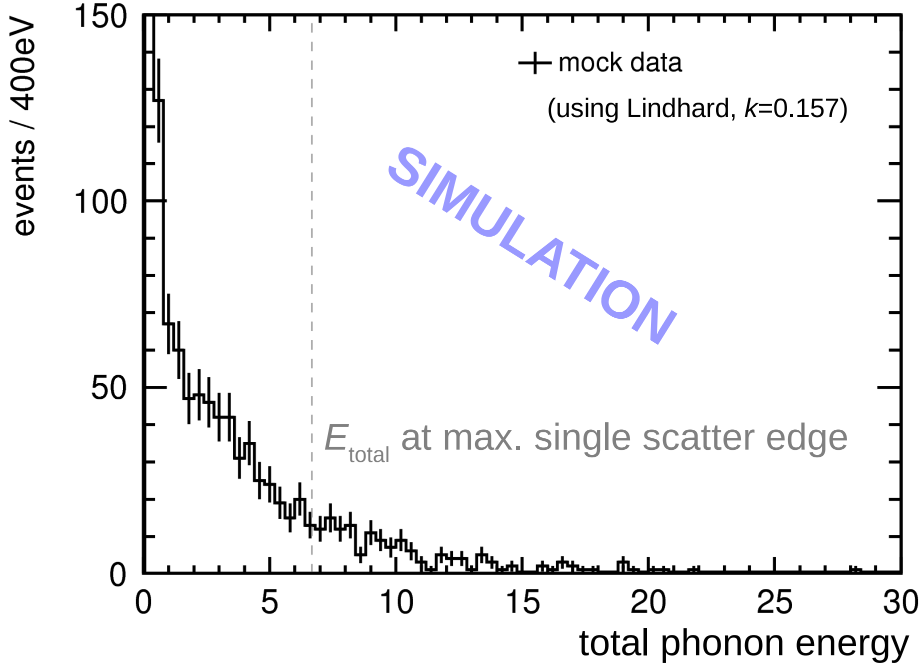


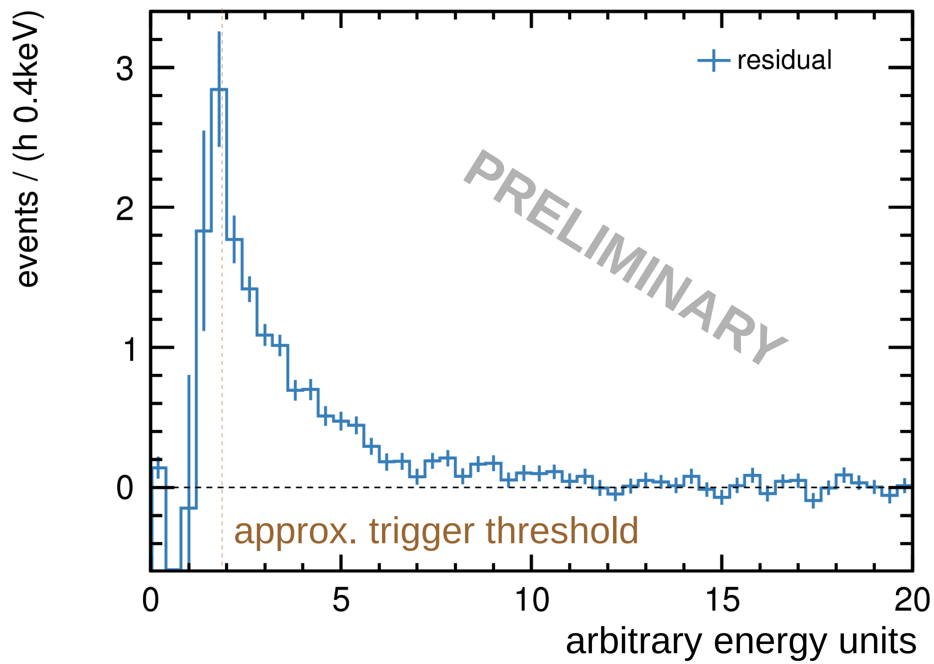


- Data taken with AND without Be wafer:
  - SbBe: NR's plus ER's.
  - SbBlank: ER's only.
- Spectra are normalized by livetime to obtain rates.
  - Rates to be corrected for cut and trigger efficiencies.
- Residual spectrum dominated by NR's.
- Uncertainties shown are statistical.

x-axis units shown are not calibrated but same scale.

Preliminary CDMSlite SbBe spectra





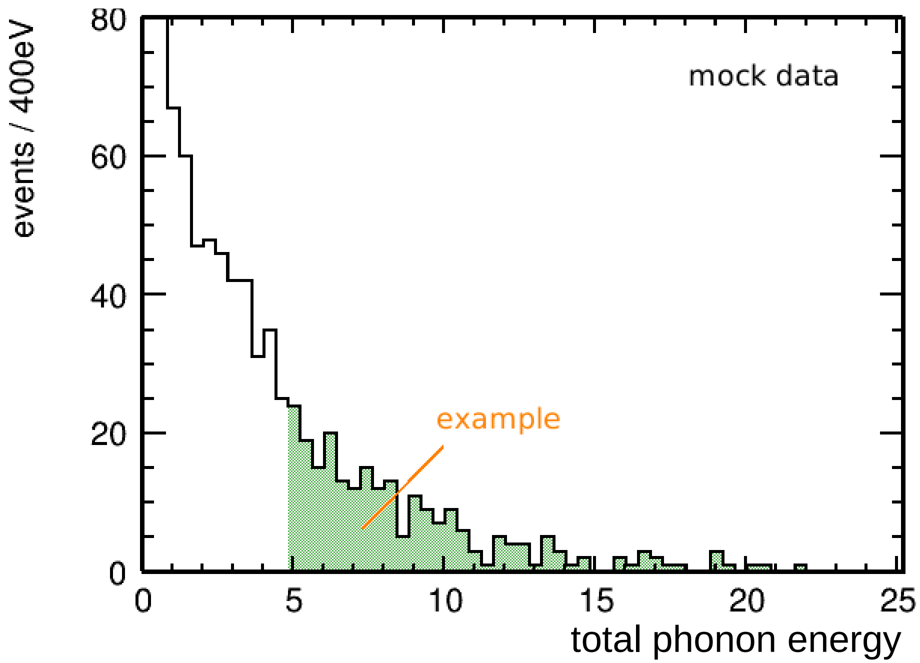
- Mock data created **from simulated nuclear recoil spectrum** using Lindhard.
- Total event number randomly reduced.

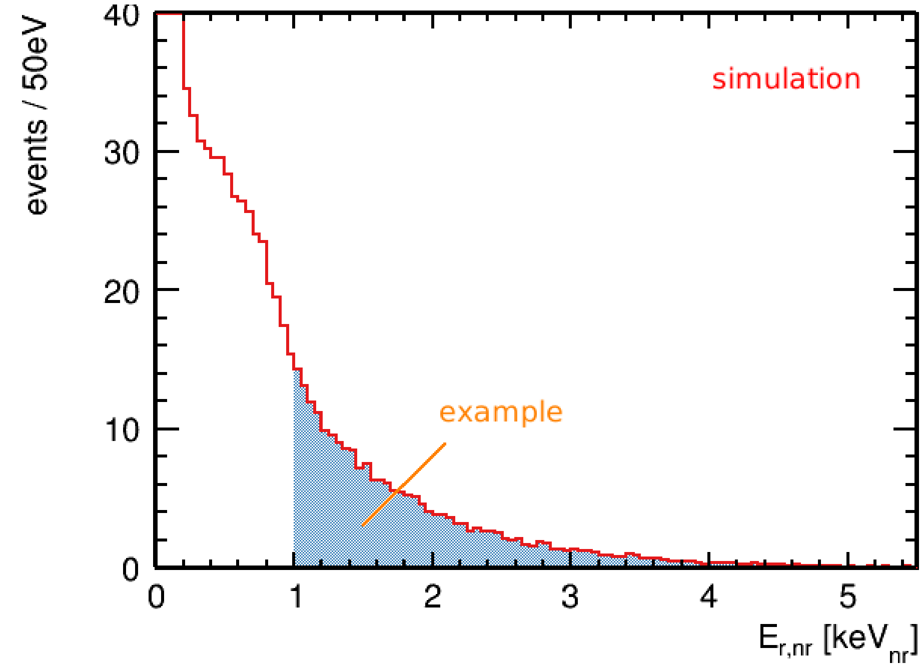
- Residual spectrum dominated by NR's.
- Uncertainties shown are statistical.

Ongoing analyses pursuing two approaches:

- Spectral fit of simulation to data in likelihood analysis (normalization as free parameter).
- "Integral test" (depends amongst others on how well normalization can be constrained).

Integral Test





- Integral above a certain measured **total phonon energy** is expected to be (about) the same as the integral above the corresponding **nuclear recoil energy**.
- Multiple scatter events complicate this relation!

Summary

- SuperCDMS Soudan probes WIMP-nucleon coupling through a combination of iZIP and CDMSlite (HV) detectors.

- To complement the sensitivity, we need to measure $Y_{ionization}$ at unprecedented low recoil energies,
  - particularly for CDMSlite detectors.

- Several months of $^{124}Sb^{9}Be$ and $^{88}Y^{9}Be$ data have been taken at Soudan.

- By comparing photoneutron data to simulation, we expect to be able to constrain $Y_{ionization}$ in CDMSlite detectors down to ~1keV$_{NR}$
  - This will be the first direct measurement of $Y_{ionization}$ in CDMSlite.

- The presented data and simulation spectra look promising, but work is ongoing.

Stay tuned…!

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

* Associate members

Back-up Slides

Ionization Yield: Lindhard

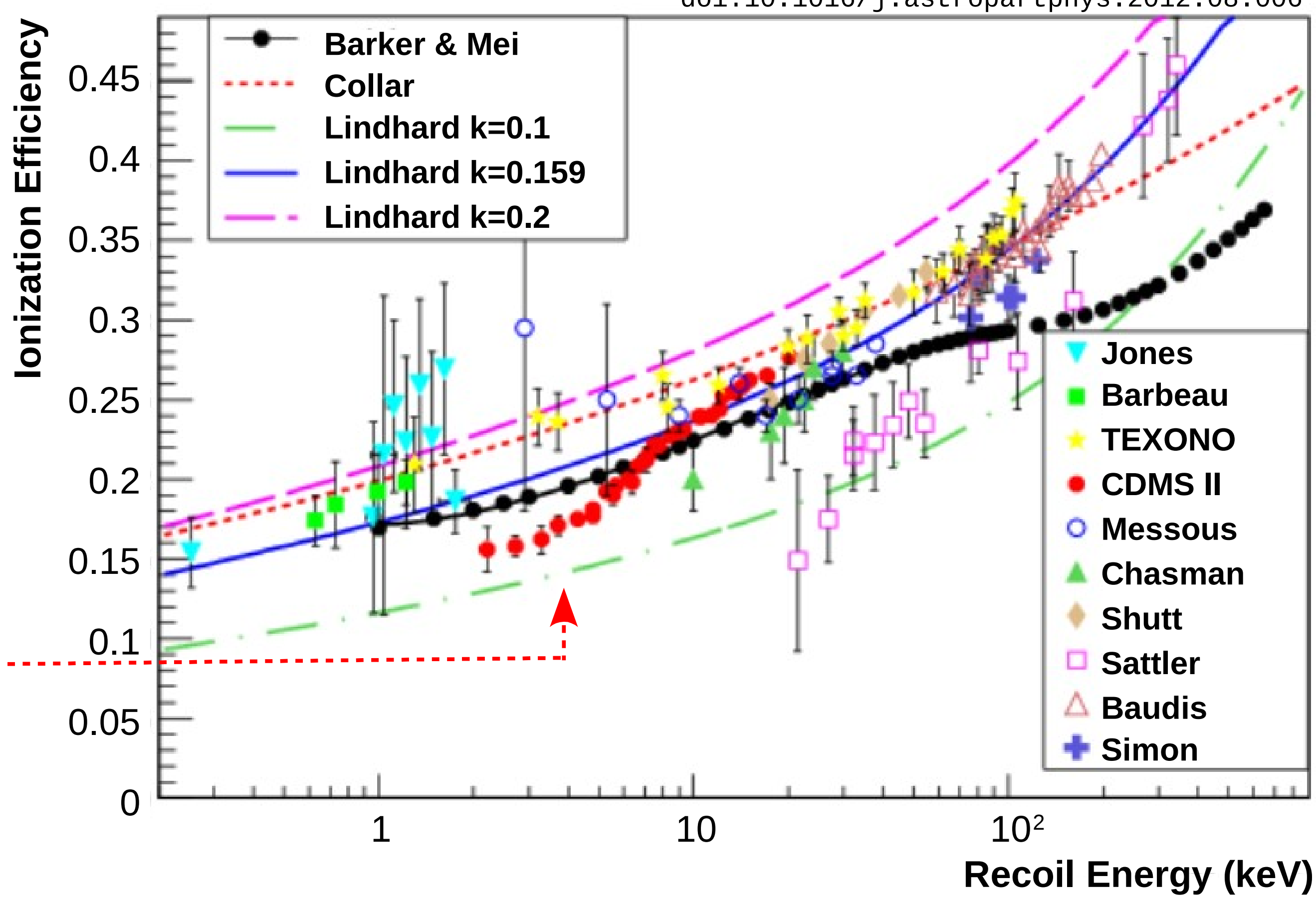
Lindhard:

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

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

Ge:
Z=32, *A*=72.64

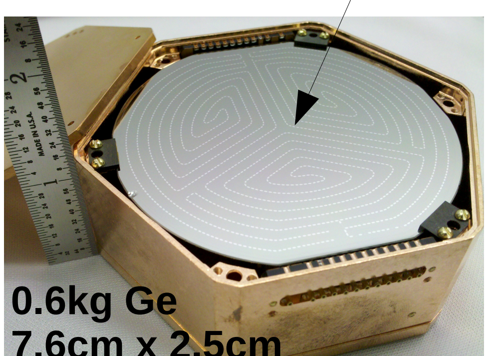
Barker, Mei
doi:10.1016/j.astropartphys.2012.08.006



CDMS II, Ge data
averaged over detectors

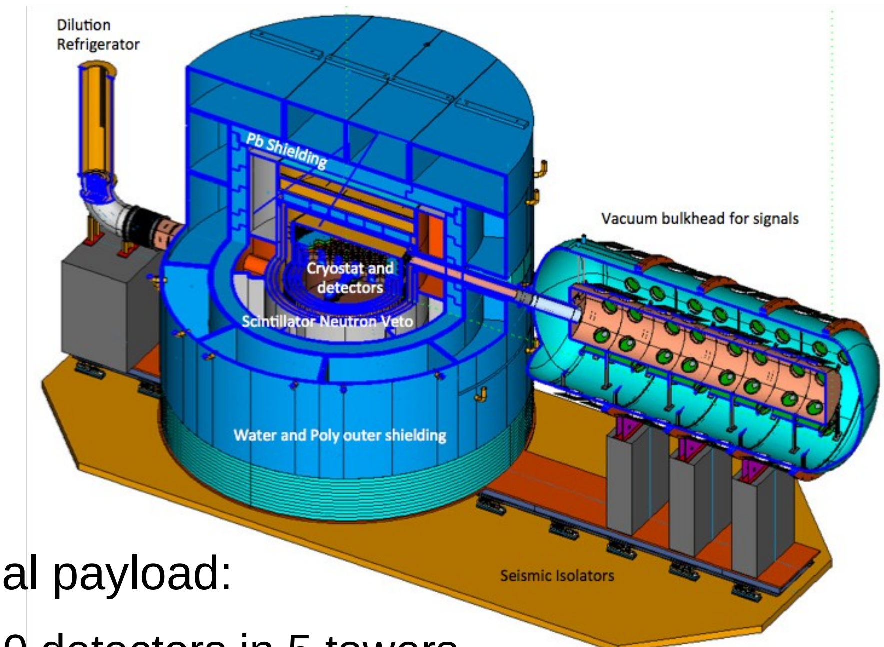
SuperCDMS Overview

SOUDAN
(~800m deep, ~2090 m.w.e.)



- 15 detectors in 5 towers
- 9kg Ge total
- all iZIP detectors (normal and HV mode)
- operational until late 2015

SNOLAB
(~2000m deep, ~6010 m.w.e.)



Initial payload:

- 30 detectors in 5 towers
- 29.4kg Ge, 5.5kg Si total
- iZIP and dedicated HV detectors
- construction starting 2017