Ionization yield for nuclear recoils in silicon at TUNL

Émile Michaud

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Ionization yield

Ionization yield (Y) : ratio of the number of electron-hole pairs produced by a nuclear recoil over an electronic recoil

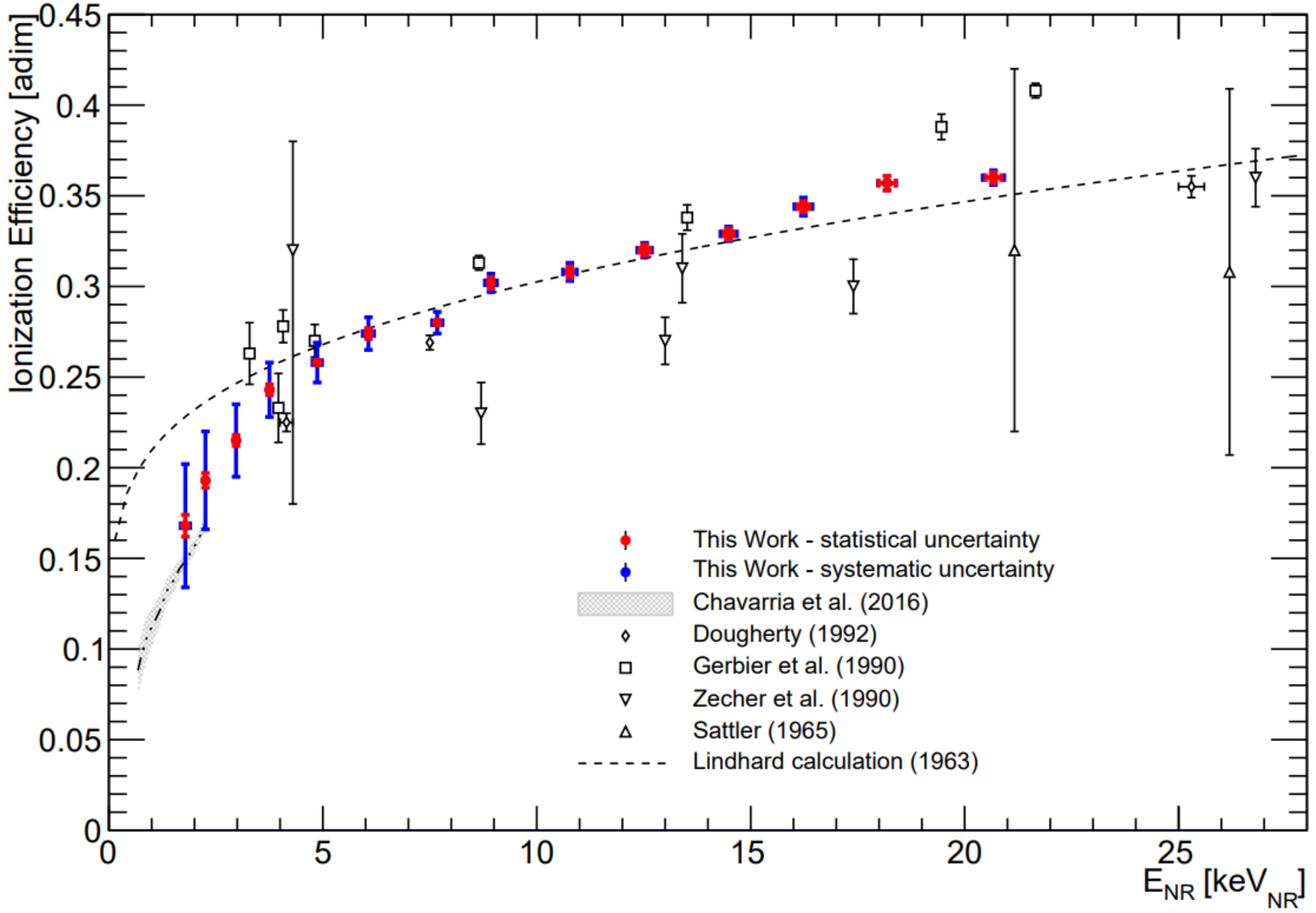
$$Y = \frac{Q_{nr}}{Q_{er}}$$

For the same amount of energy deposited, a particle that hits the nucleus (E_{nr}) will excite less e^-h^+ pairs than if it hits the electron (E_{er}).

Low mass WIMPS are expected to interact via nuclear recoil and deposit $E_{nr} \sim$ 1keV.

To reconstruct the E_{nr} of dark matter in SuperCDMS detectors (Cryogenic Dark Matter Search), we need to know the ionization yield Y

Unreliable yield (different from Lindhard) below ~ 3 keV



Ionization yield in silicon for energies between 0.6 keV and 27 keV

F. Izraelevitch, et al., *A measurement of the ionization efficiency of nuclear recoils in silicon*, J. Inst., 12, P06014 (2017)

SuperCDMS detectors (HVeV)

Incoming particles hit the detector which produces electron-hole pairs and recoil phonons if it's a nuclear recoil (eg. Neutron)

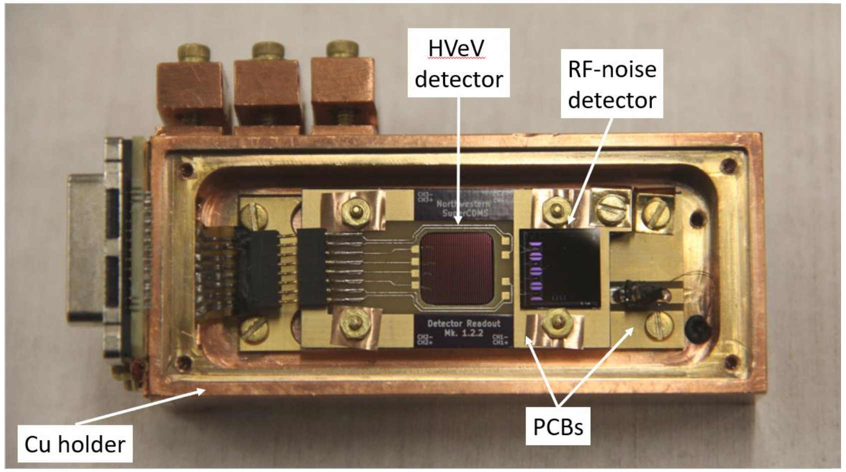
Drifting charge carriers produce additional phonons via the Neganov-Trofimov-Luke (NTL) effect because of the applied voltage ($\sim$ 100V)

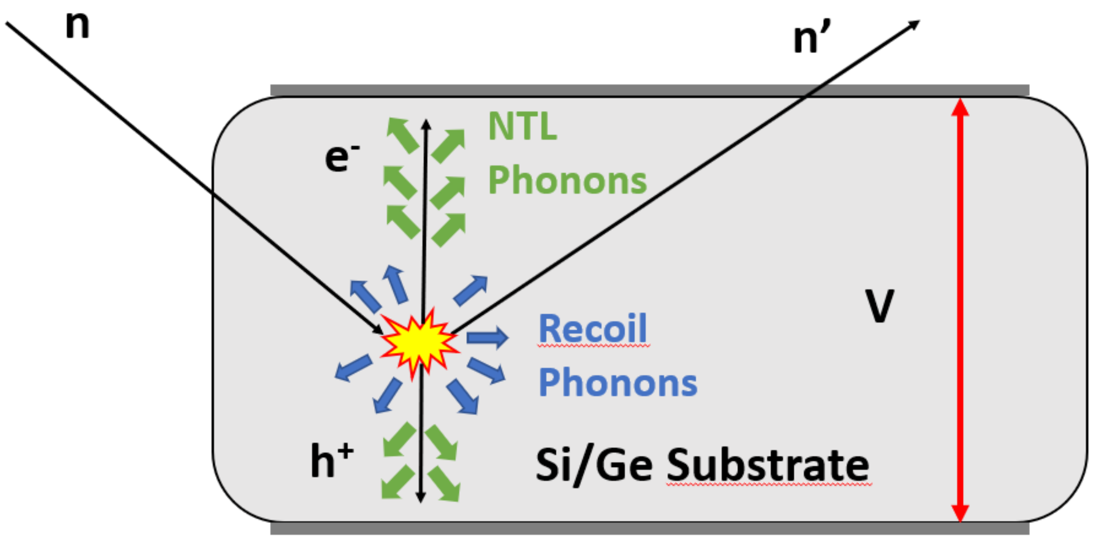
Total phonons energy : $E_{ph} = E_r + n_{eh} \cdot e \cdot V$

Where E_r is recoil energy, n_{eh} the number of electron-hole pairs produced, e the electric charge and V the voltage.

$$n_{eh} = Y \frac{E_r}{\epsilon_{eh}}$$

ϵ_{eh} is the average energy needed to excite one electron-hole pair (3.7 eV in Si)





Schematic of the phonon production in the HVeV detectors

Single e^-h^+ pair sensitivity

Calibration data with 1.95 eV photons (635 nm laser pulsed) and 100 V bias

1 g silicon detector

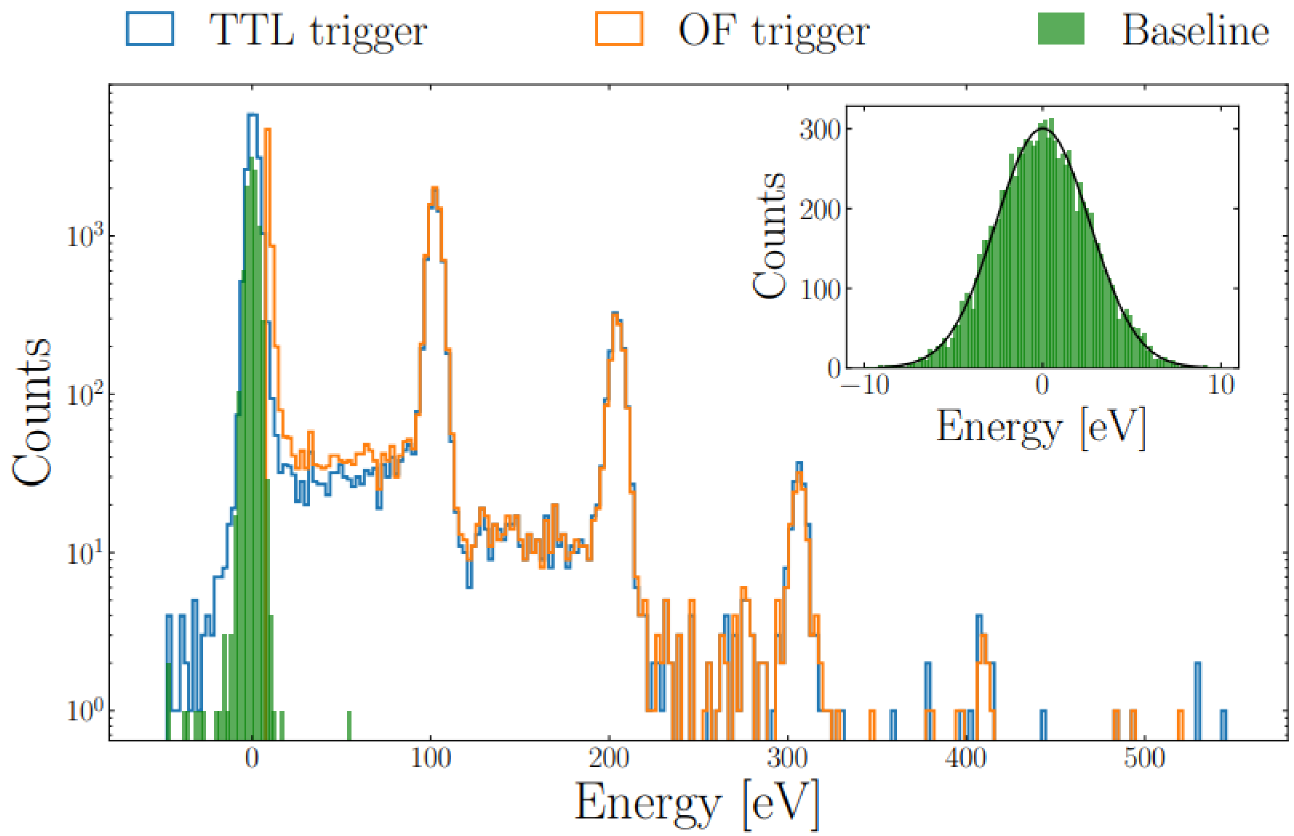
Crystal dimensions : 1cm x 1cm x 4mm

Detector cooled down to ~ 50 mK

Able to measure 1 e-h+ pair in Si crystal

By applying high voltage we can obtain eV resolution thus the name : High Voltage eV (HVeV)

$$E_{ph} = E_r + n_{eh} \cdot e \cdot V$$



R.Ren et al. : Design and characterization of a phonon-mediated cryogenic particle detectorwith an ev-scale threshold and 100 kev-scale dynamic range, 2021. arXiv:2012.12430

Experimental Setup

Ionization Measurement with Phonons at Cryogenic Temperature (IMPACT) measures the Ionization yield in silicon at energy between 0.1 and 4 keV

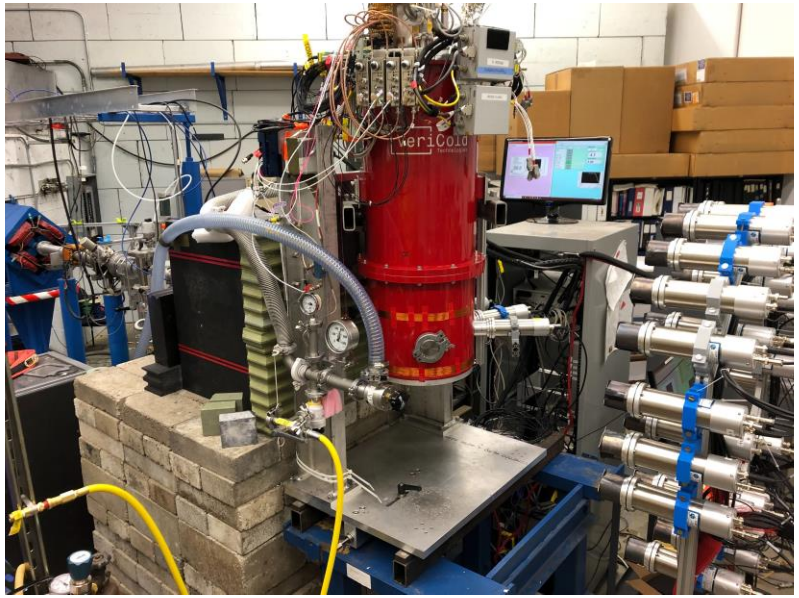
The incoming neutrons scatter on the HVeV detector and are then captured by the liquid scintillator backing array

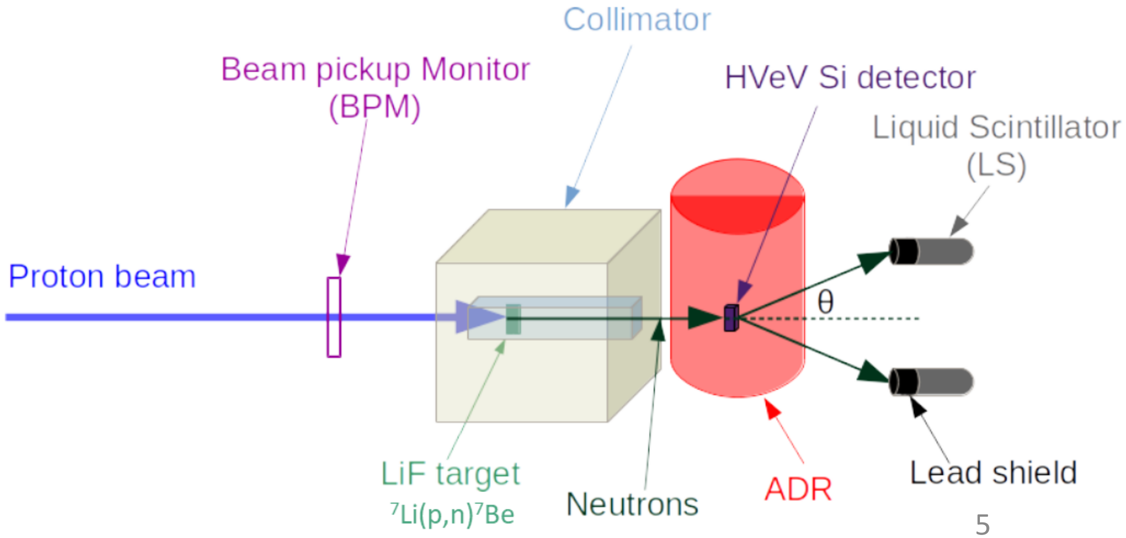
We then compare the energy measured by the Si detector (E_{ph}) to the expected recoil energy (E_r) given by the scattering angle ϴ :

$$E_R = 2E_n \frac{m_n m_T}{(m_n + m_T)^2} (1 - \cos\theta)$$

E_n : neutron energy
m_n : neutron mass
m_T : target mass (Si)

We use the time of flight between a hit in the HVeV and the LS to find coincident events



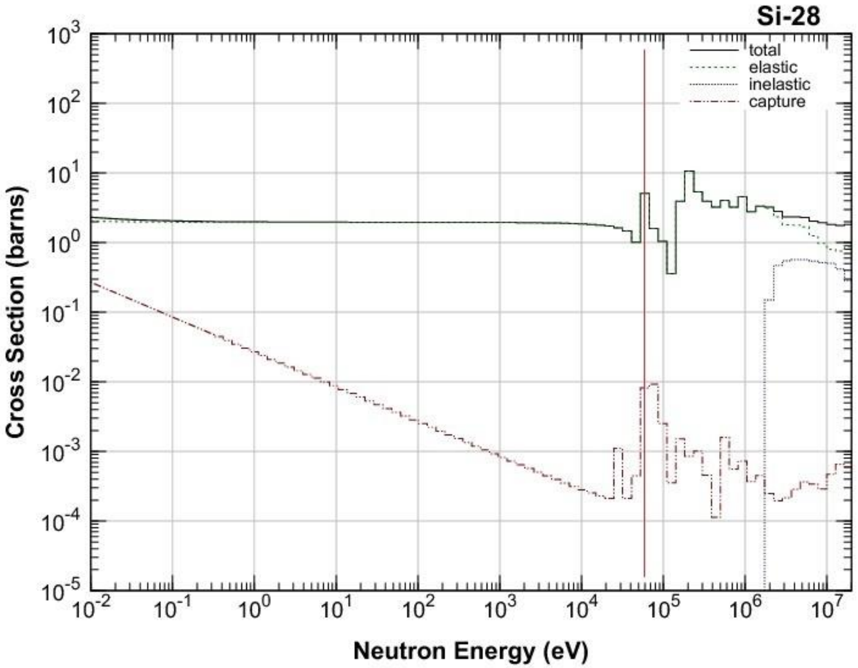


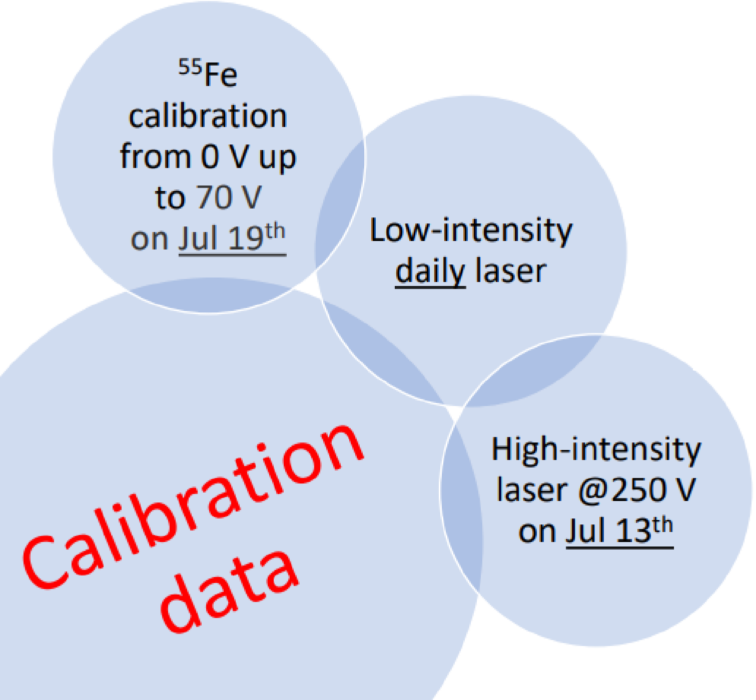
HVeV detector (calibration and datasets)

Ran the beam July 2019 for approximately 1 month

Neutron beam energy of 55.7 keV because of Neutrons ^{28}Si resonance:

Higher cross section and thus higher signal/noise rate



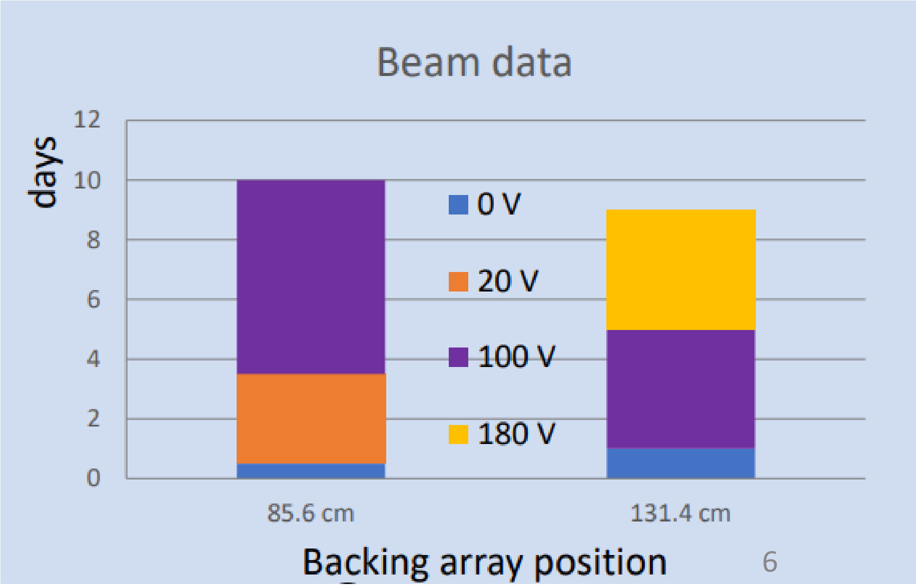


Different voltages applied on the HVeV detector:

-0V, 20V, 100V and 180V

-0V is used to infer the cuts and make sure the beam is working before unblinding

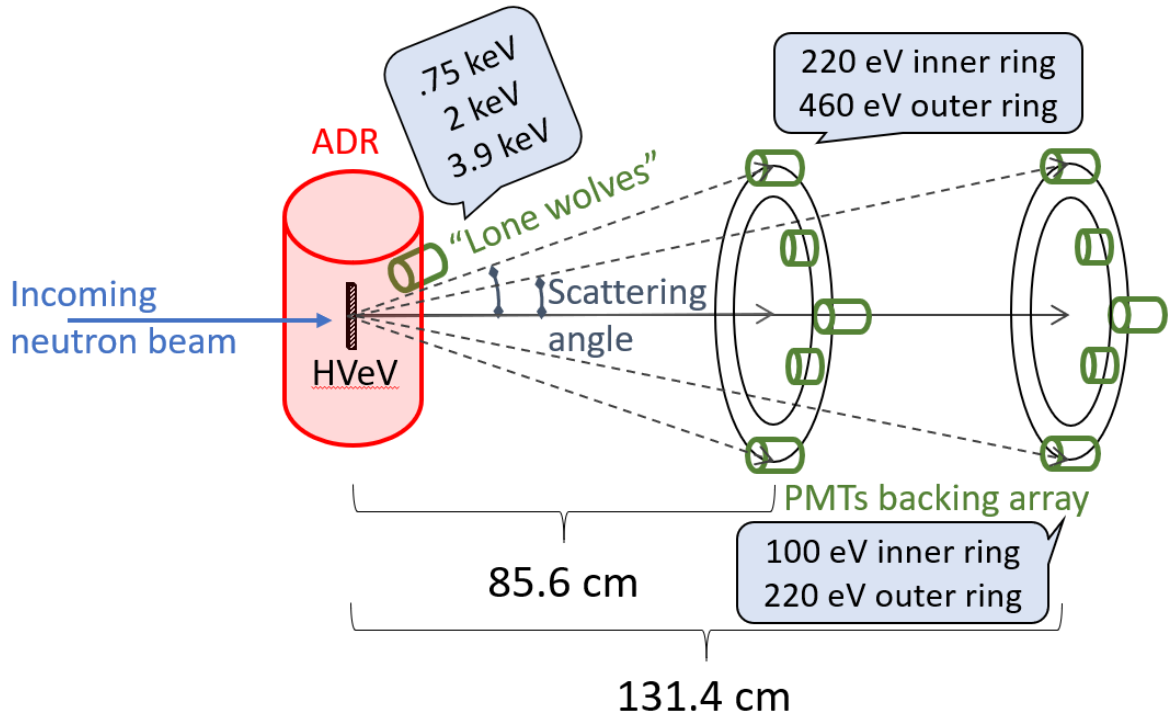
-Other voltages used to extract the ionization yield

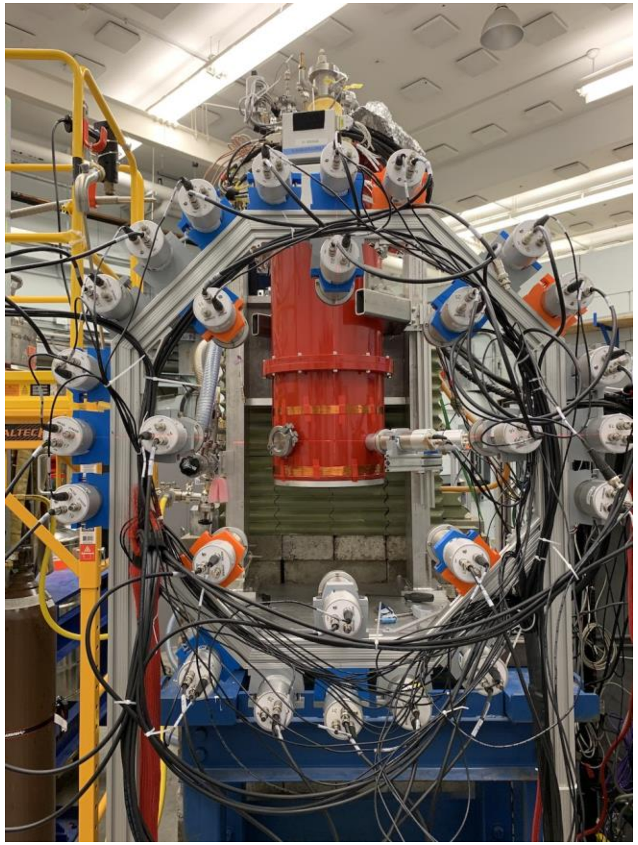


Liquid scintillators

We used 29 EJ309/EJ 301 liquid scintillators placed at 6 scattering angles.

Corresponds to the 6 following recoil energies :
100 eV, 220 eV, 460 eV, 750 eV, 2.0 keV and 3.9 keV





Summary

We used a neutron beam of 55.7 keV at TUNL on our HVeV superCDMS detector with single electron-hole pair sensitivity to measure the ionization yield for nuclear recoils in silicon between 0.1 and 4 keV.

We used a backing array of liquid scintillators at various angles to take advantage of coincidence and compare the energy deposited in our detector to the expected energy based on the scattering angle.

We are still working on analyzing our data and adjusting our quality cuts before unblinding

-We expect to publish this summer

We will repeat the experiment at Université de Montréal but with a lower neutron energy this summer

Merci / Thank you!