New Approaches to Very Low-energy Calibration of Cryogenic Detectors

Rau, W.[2]; Ghaith, M.[1]; Galema, M.[1] ; Di Stefano, P.[1] ; Fascione, E.[2] ; Germond, R.[2] ; Underwood, R.[2]
[1]Department of Physics, Engineering Physics and Astronomy, Queen's University
[2]Canada's Particle Accelerator Centre, TRIUMF

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Abstract

The search for dark matter candidates using cryogenic detectors, pushes towards a lower energy thresholds at each development stages. Consequently new approaches for detector calibration at the proposed energy scales are necessary. In the case of SuperCDMS SNOLAB, energy thresholds in the range of a few eV are expected. In this poster, we are presenting R&D work for new ideas to calibrate cryogenic detector in the eV range, using LEDs of various wavelengths operated at cryogenic temperatures.

Motivation

The Super Cryogenic Dark Matter Search (SuperCDMS) uses cryogenic Ge and Si detectors operated at a few 10s of mK to search for dark matter. The new generation of SuperCDMS at SNOLAB [1] pushes towards very low energy thresholds where calibration with external radioactive sources is difficult. We are developing new calibration methods covering the eV energy range based on LEDs operated at cryogenic temperatures, and we study the operational parameters of LEDs at these temperatures.

Pulsed LED at 40 mK

LEDs operated near detectors could be used for several reasons such as, monitoring detector stability, low-energy calibration (if intensity can be controlled) and to produce electron-hole pairs in the detectors for the eV scale calibrations. As first step, we studied the operation of 1650 nm LEDs at cryogenic temperatures.

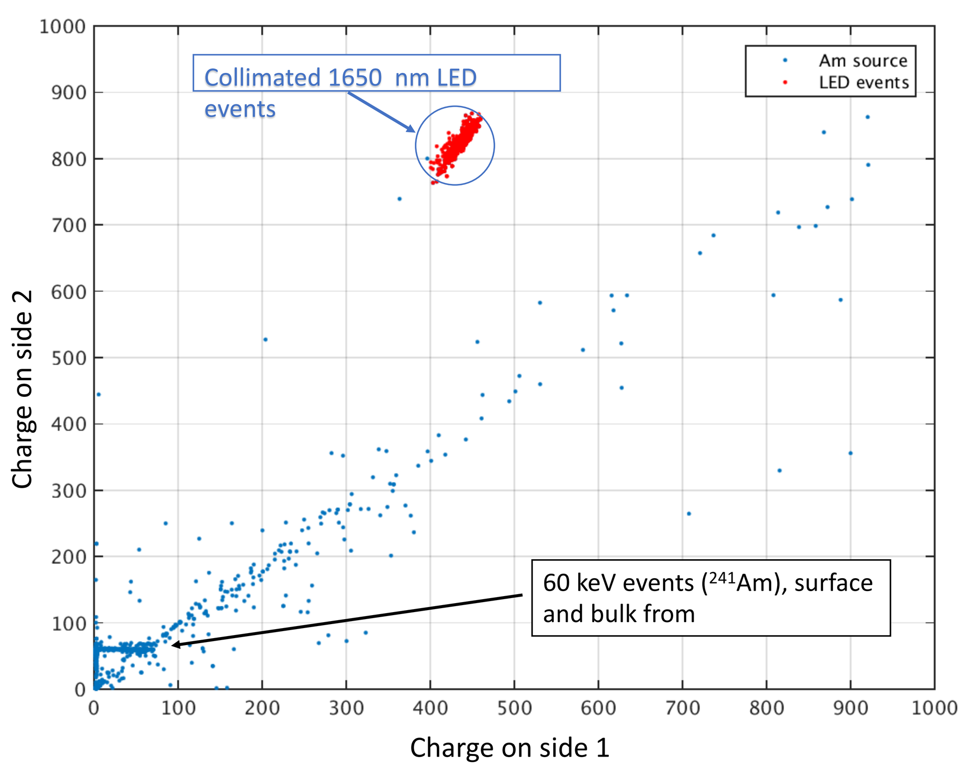


Figure 1: Particle-like events in a 2.5 cm thick SuperCDMS Ge detector, produced by a pulsed LED (nominal peak wavelength 1650 nm) operated at ~40 mK] (red dots). The signal distribution between sensors on both sides of the detector (~2:1) indicates a penetration depth of <1 cm, in tension with the 17 cm reported by EDELWEISS [2]. Other events are from background (diagonal) and a low-energy gamma source (bottom left).

Temperature Dependence of LED

Temperature dependence of the LED characteristics may contribute to the discrepancy in absorption length. We measured the temperature dependence of the cut-in voltage (proportional to the bandgap) and the emission wavelength. Varshni's formula describes the temperature dependence of the bandgap: $E_g(T) = E_0 - \frac{\alpha T^2}{T+\beta}$ [3].

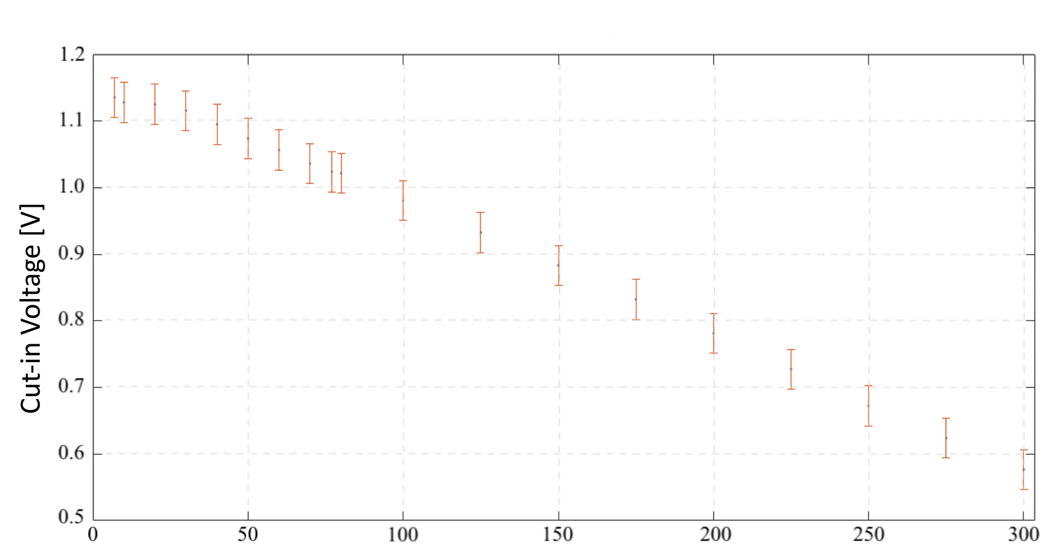
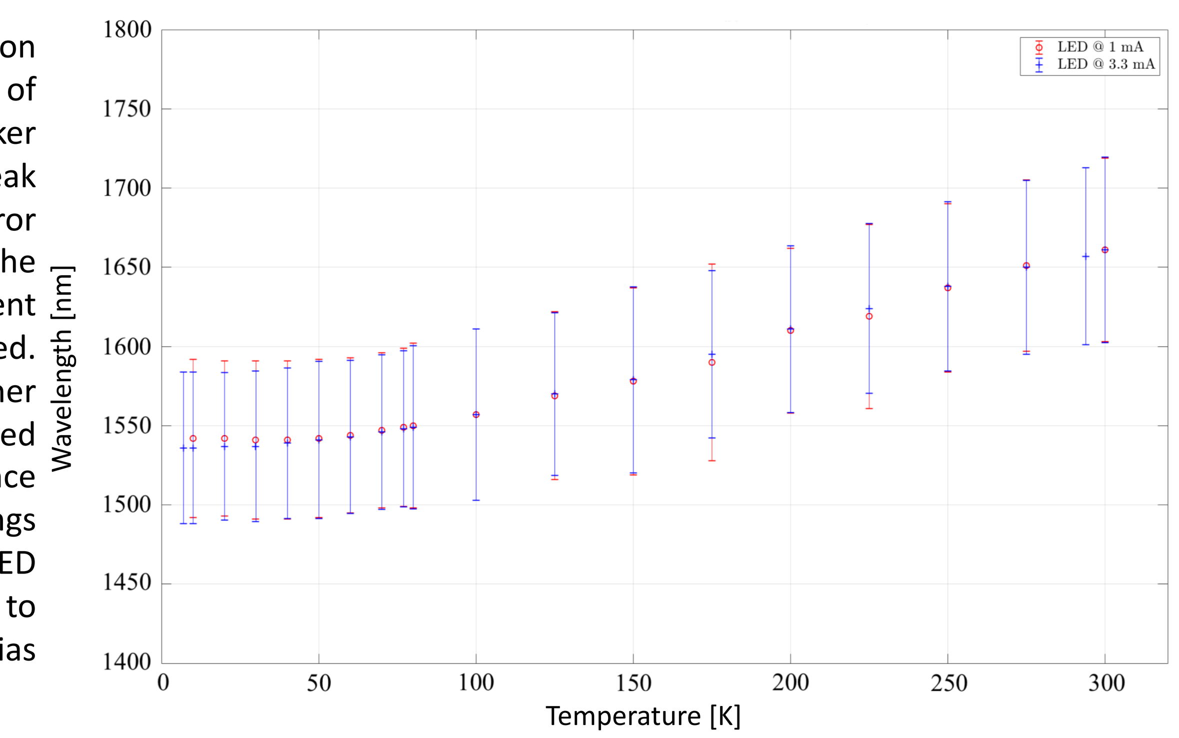


Figure 2: Measured cut-in voltage as function of temperature for the 1650 nm LED, with fit. Error bars indicate the 95 % CL of the measurement.

The temperature dependence of the cut-in voltage V_c (proportional to the bandgap energy E_g) was extracted from IV-curve measurements and is shown in Fig. 2, together with a fit corresponding to Varshni's formula (in voltage instead of energy, and with the energy E0 replaced by the voltage V0).
The temperature dependence of the emission wavelength is shown in Fig. 3.

Figure 3: Emission wavelength as function of temperature. The marker indicates the peak position and the error bars the width of the distribution. Two different bias settings were used. The plateauing at higher temperature (compared to Fig. 2, and difference between bias settings indicates an increased LED temperature due to heating from the bias current.



Conclusion

LEDs can be operated at mK temperatures to produce particle-like pulses in Ge detectors. The expected shift in wavelength as function of temperature must be considered when interpreting the data. This could contribute to the observed discrepancy in absorption length between our measurements and EDELWEISS [2], since the nominal wavelength is just at the Ge bandgap energy, but the wavelength at low temperature is well above. Other contributing factors could be impurity levels affecting the penetration of sub-bandgap photons.

e-Gun: Conceptual Design

As a more versatile calibration tool for very low energies we are developing an electron gun (schematic in Fig. 4). Electrons are produced by the photoelectric effect using a UV LED shining at an Al surface (see Fig. 5); the emitted electrons can be filtered by energy and then accelerated to a moderate energy (10s of eV) before hitting the detector.

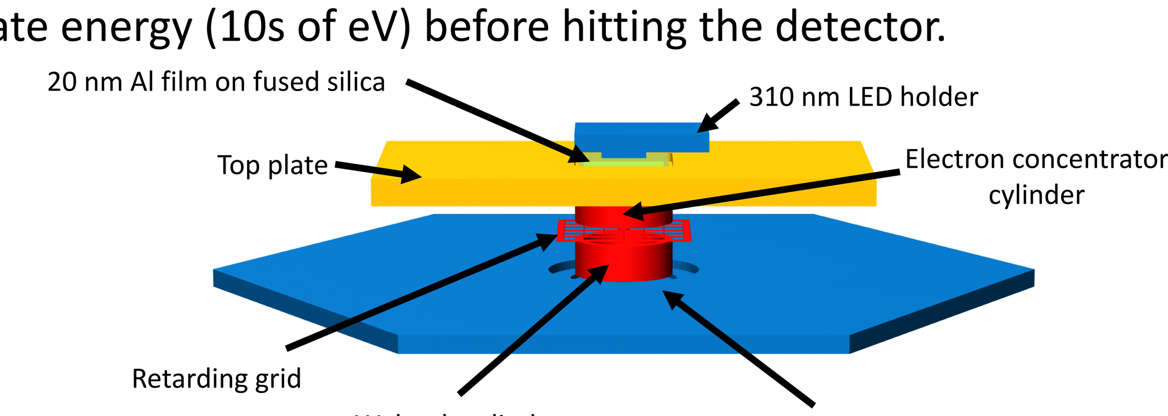


Figure 4: A schematic for the different parts of the e-gun. Different colors indicate different electric potentials (blue: ground; red: accelerating voltage; orange: defines the retarding potential for filtering)

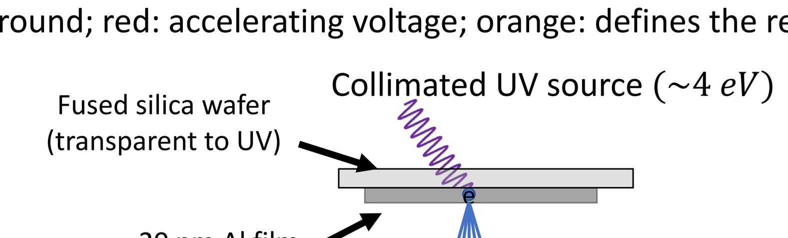


Figure 5: Geometry for electron production by the photoelectric effect (not to scale)

e-Gun Simulation

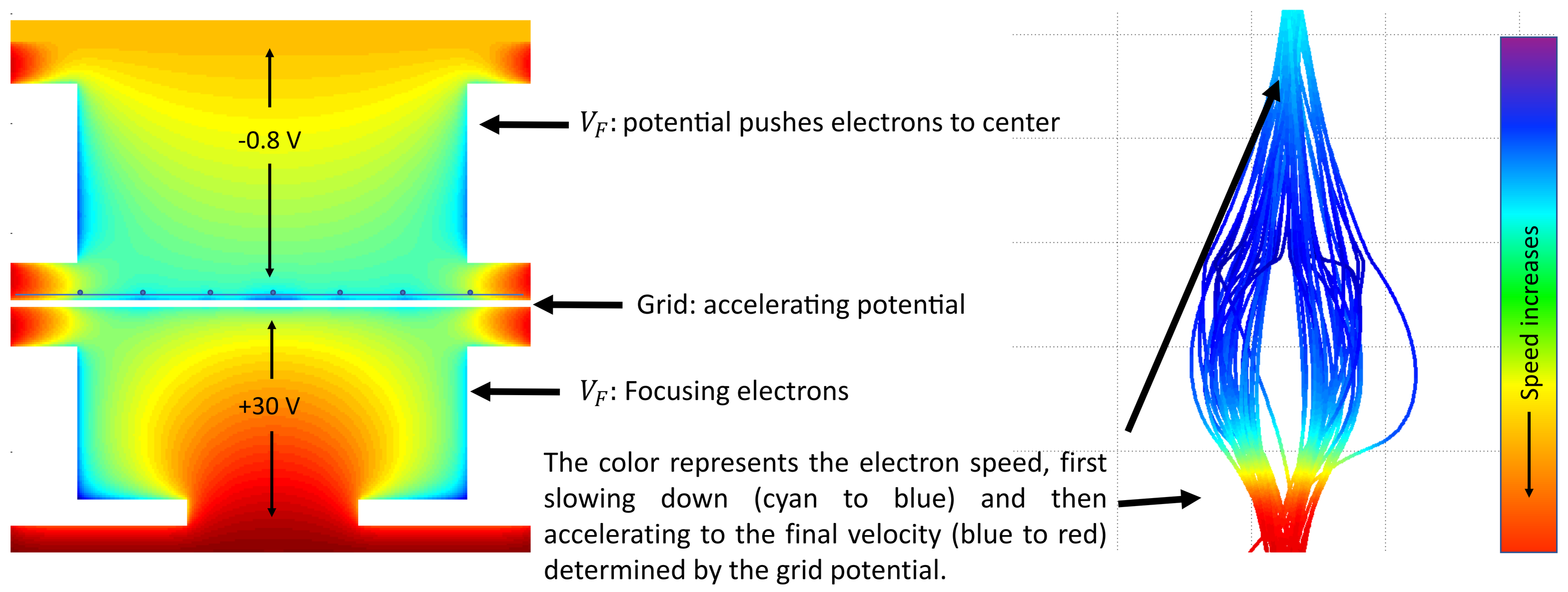


Figure 6: *Left:* Simulation for the E-field mapping. *Right:* Simulation for the electrons' paths through the electron concentrator, the retarding grid and the Wehnelt cylinder.

The primary electron emission spectrum is unknown. A spectrum linearly decreasing to 0 between 0 and 1 eV was assumed for the simulation. With the given potentials, the electron transmission is of order of one percent.

Preliminary Tests

A first version of the e-Gun was produced.

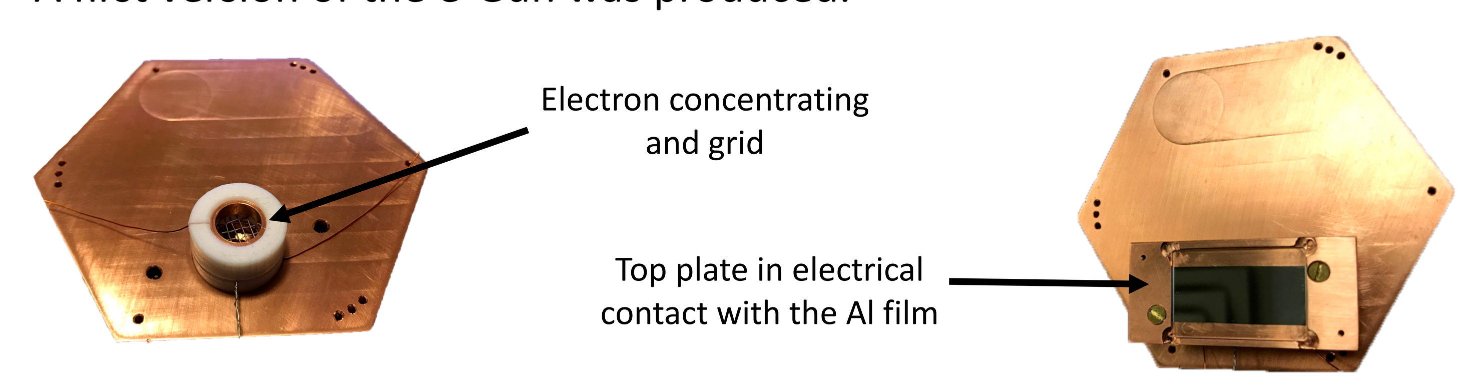
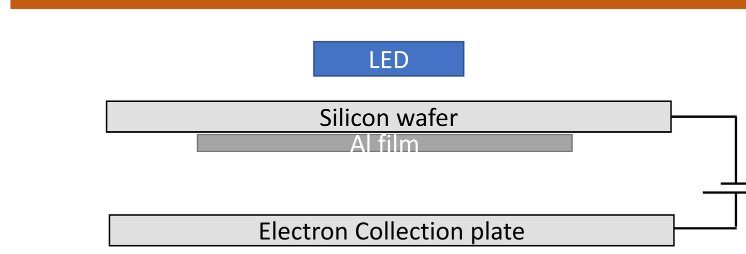
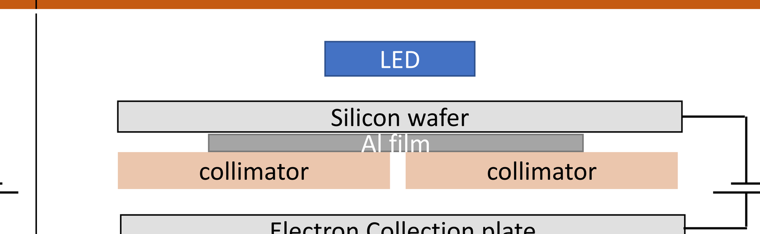


Figure 7: e-Gun as built. *Left*: Electron concentrating cylinder with grid mounted above Wehnelt cylinder and ground plate. *Right*: Fused silica wafer with Al film mounted in top plate.

First tests for the electron emission from the Al were performed in vacuum at room temperature with the LED at 80 % of maximum emission. The emitted electrons were collected on a Cu plate at a 12.5 V collection potential.

Without Collimator		With collimator	
			
Measured current	1.5 pA	Measured current	0.2 pA

The measured current with collimator corresponds to ~600 electrons/50 us pulse. With the 1 % transmission from the simulation, this corresponds to an average of 0.6 electrons per pulse. This is in an acceptable range.

References

[1]. *Agnese R et al. Physical Review Letters, 121(5), 2018.*
[2].*Domange J el al. AIP Conference Proceedings 1185, 314 (2009).*
[3] *K. P. O'Donnell et al, Applied Physics Letters, vol. 58, pp. 2924, (1991).*

muad.ghaith@queensu.ca