Precision Ionization Calibrations of Silicon Skipper CCDs for Dark Matter Detection

New Perspectives 2023

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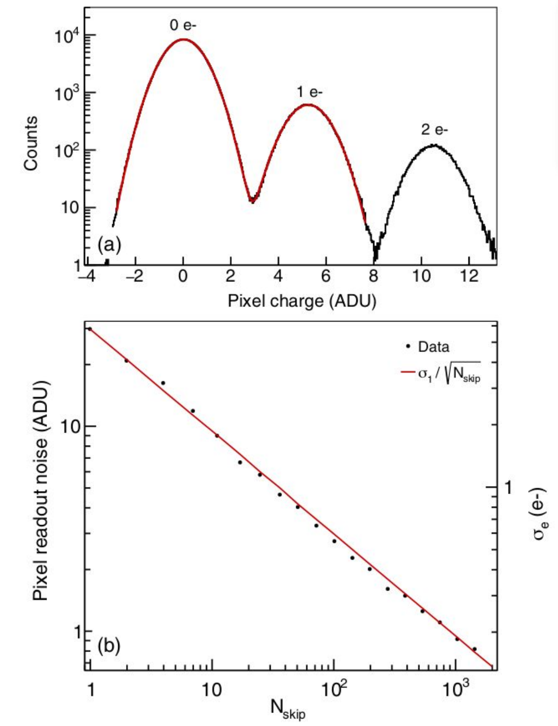
Dark matter detection with silicon CCDs

Skipper CCDs

- Measures charge multiple times when compared to conventional CCDs
- Can achieve single electron resolution
- Per each Non Destructive Charge Measurement [NDCM] the readout noise reduces by $1/\sqrt{N_{skips}}$



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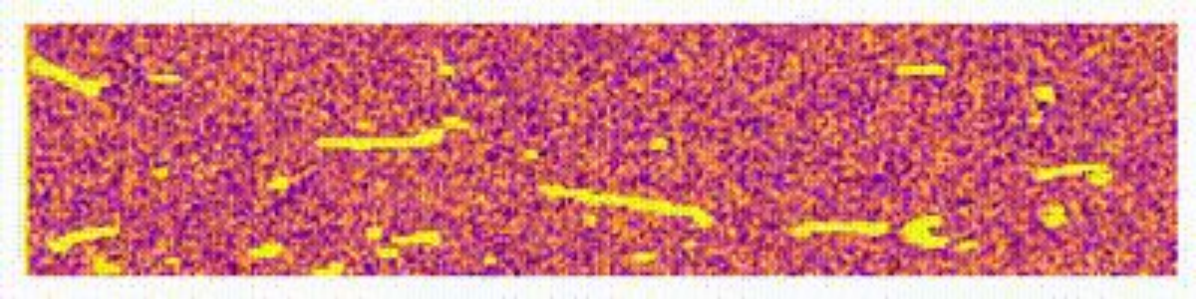
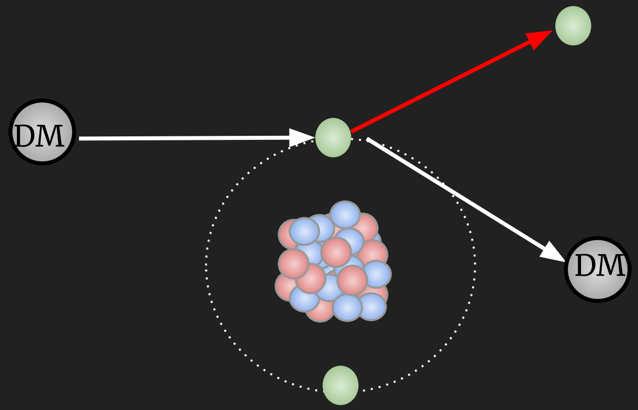


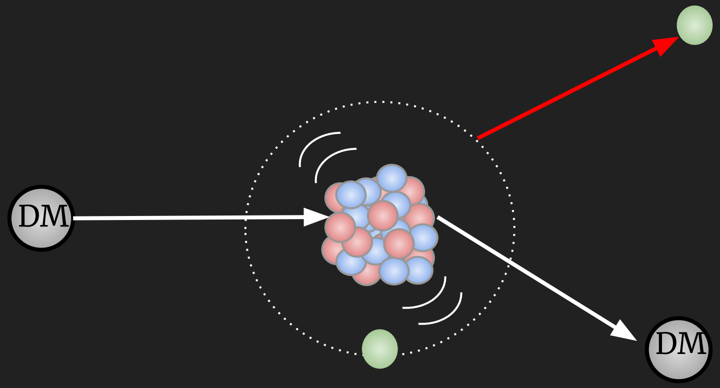
Courtesy: J.Cuevas-Zepeda

Detection

Dark matter interaction in the CCDs can occur in 2 ways:

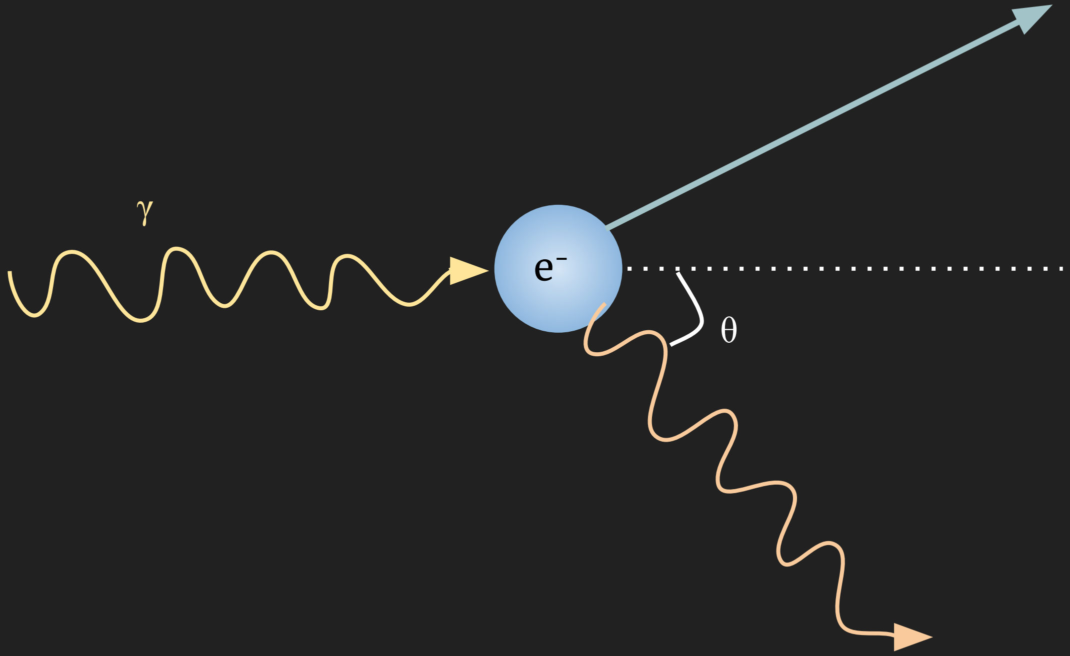
- **Electron recoil**: Resulting in the excitation of electrons from the silicon atomic and band structure. The recoil energy is directly proportional to the number of electron hole pairs generated
- **Nuclear recoil**: When a DM particle interacts with the silicon nucleus, part of the nuclear recoil energy gets transferred to ionisation of electrons. A quenching factor quantifies the relationship between the nuclear recoil energy and the ionization electrons.



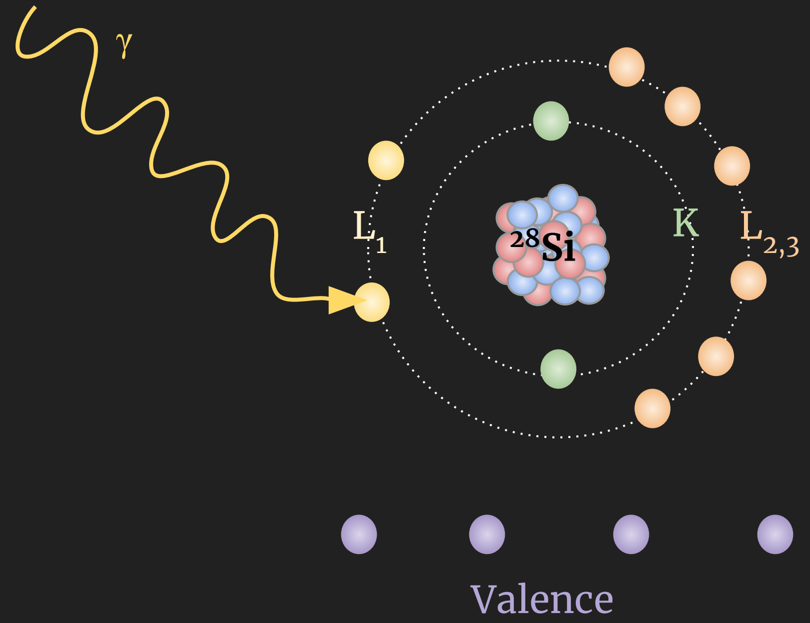


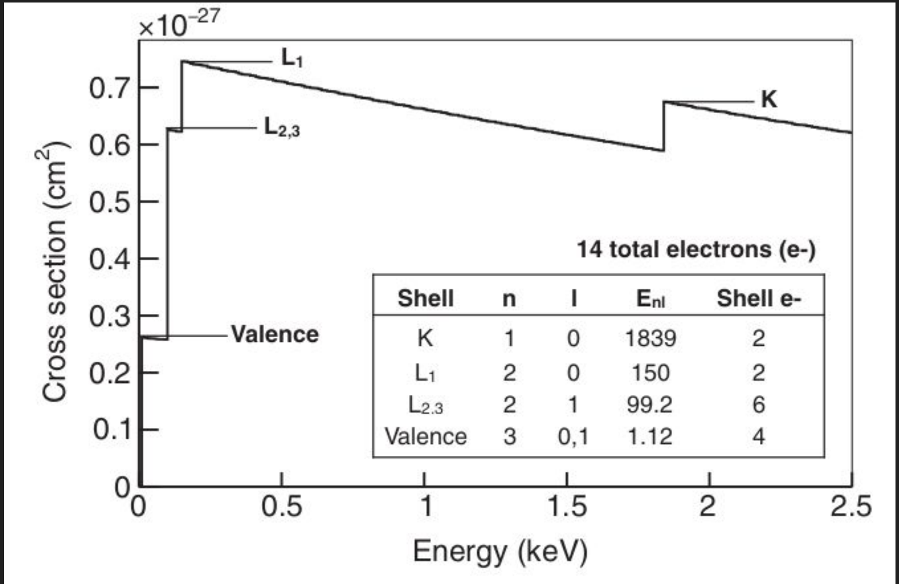
Compton scattering

- Signals from background gamma rays can mimic DM electron recoil signals.
- Hence it is important to understand the detector response to gammas low energies



Compton scattering in Silicon





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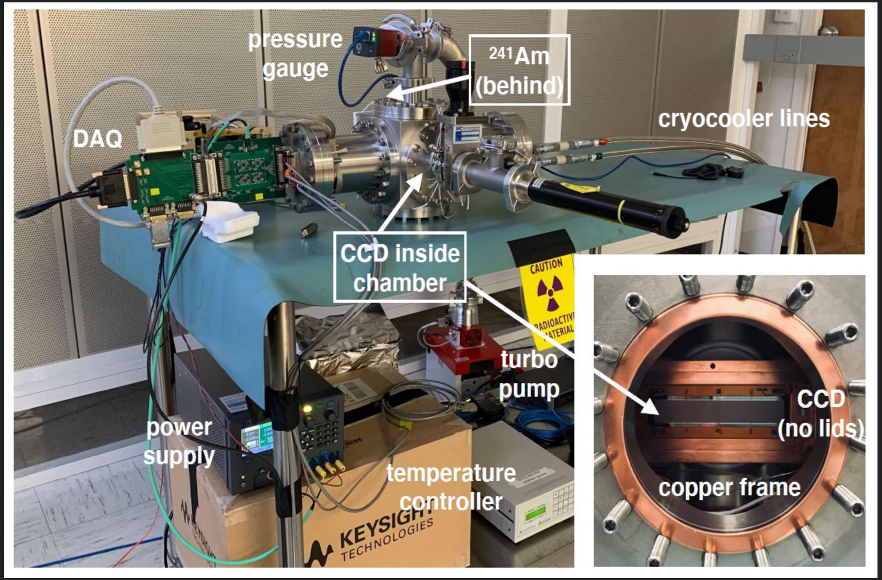
Relativistic Impulse Approximation [RIA] model

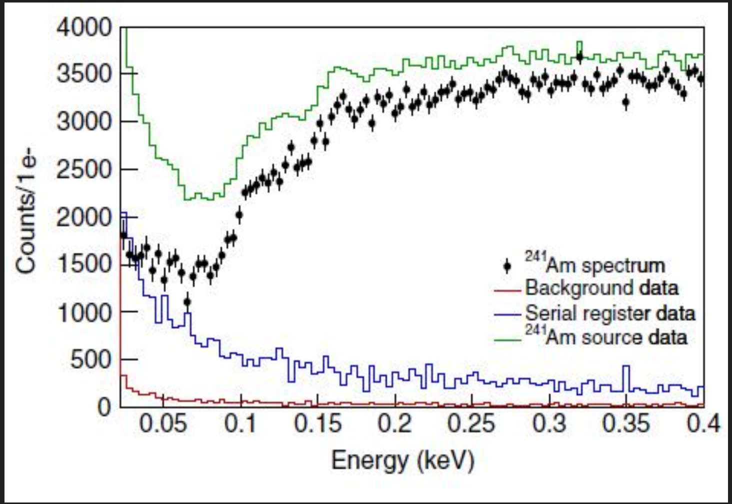
Experimental Setup and Data collection

- Skipper CCD with 1024 x 6176 pixels is used as the silicon target detector
- ^{241}Am was used as the gamma ray source, emitting 59.54 keV γ rays was mounted to illuminate the backside of the CCD
- The CCD was cooled to 126 K and under pressure of 10^{-7} mbar
- Images with N_{skip} = 64 were taken with a total exposure of 105.5 days
- Background images with no source and *serial register* images with source but clocking the CCD in the opposite direction were taken



Analysis

- Images were processed so as to reconstruct clusters of pixels associated with each event to obtain their full energy.
- Events occurring at the serial register present as *horizontal* clusters throughout the image posing as significant background.
- Exposure normalized background and serial register data were subtracted from the source data to obtain the final spectrum.



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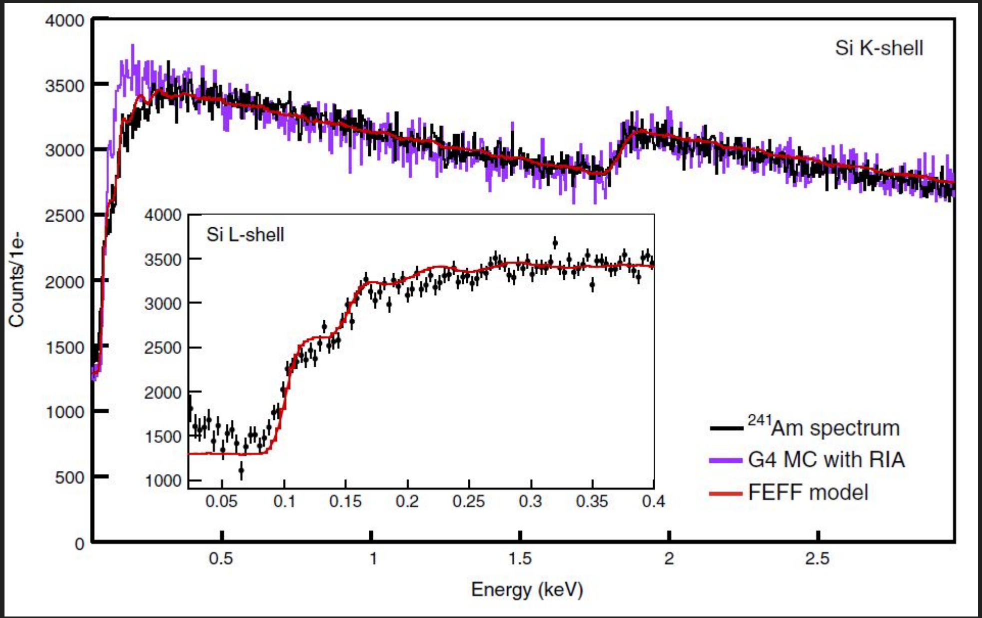
Results

- The final spectrum was compared with GEANT4 simulations.
- While the K-step showed perfect agreement with GEANT4, discrepancies arose at lower energies near the L_1 and $L_{2,3}$ steps.
- An *ab initio* calculation framework called FEFF was used to model the spectrum, which showed agreements with our measured spectrum.
- Hence we have successfully measured the compton scattering spectrum in Silicon down to 23 eV.
- This result will be used to model the uncertainties in the gamma backgrounds for DAMIC-M DM searches.



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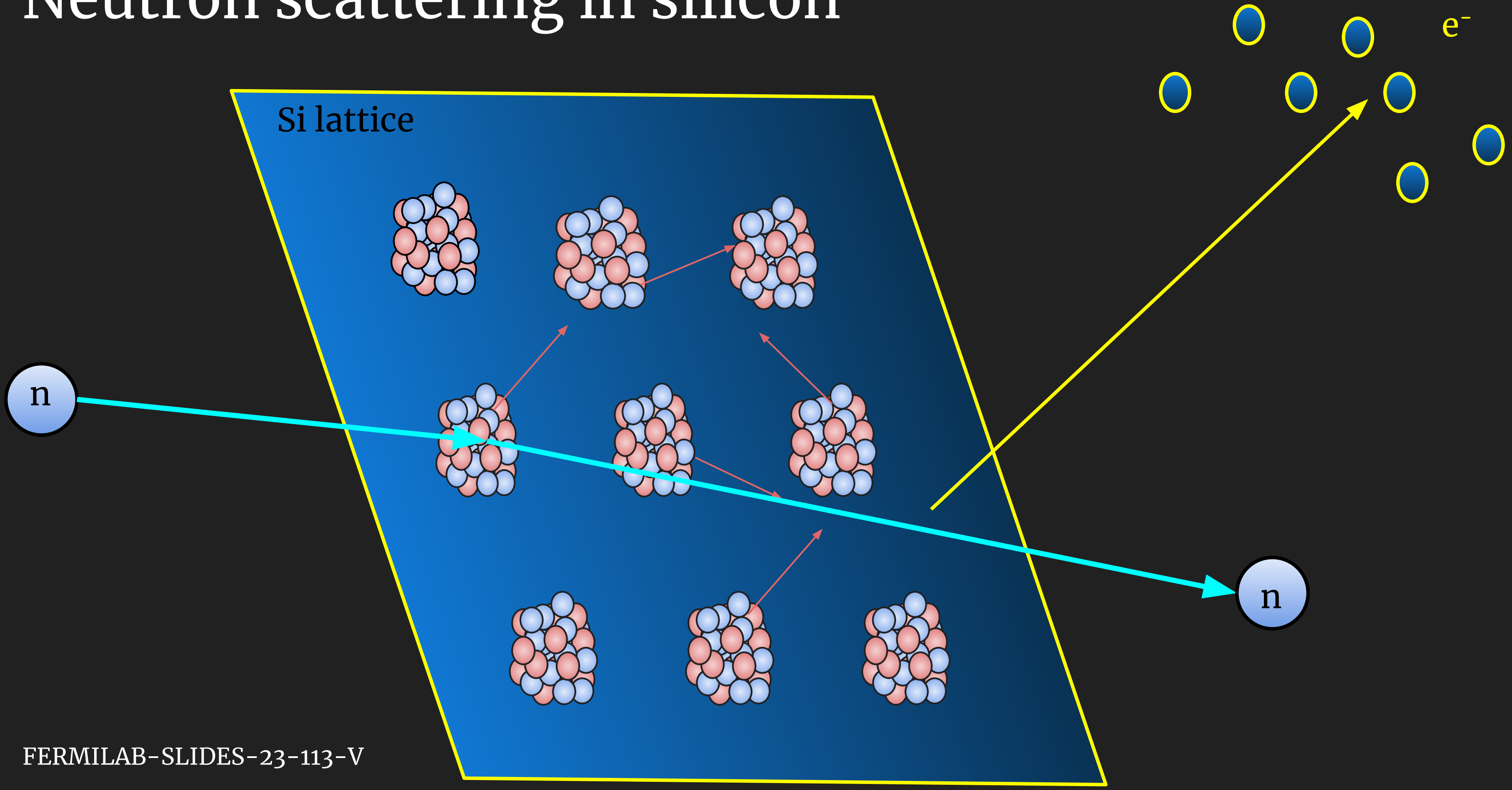
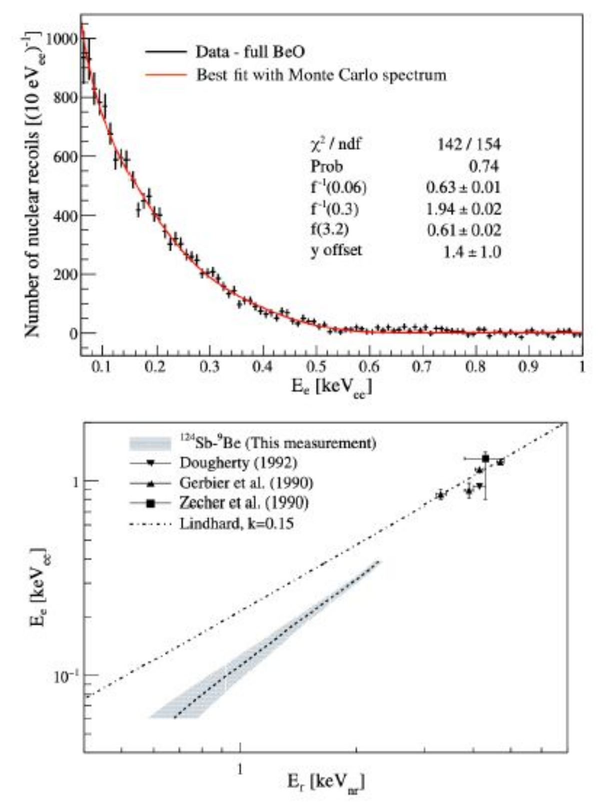
Neutron scattering in silicon



Silicon nuclear recoil measurement

- Measurement of nuclear recoil in silicon produced by low energy neutrons (<22.6 keV)
- ^{124}Sb-^{9}Be photoneutron source was used to produce the necessary neutrons
- Measurement with conventional CCDs found deviations from the lindhard model



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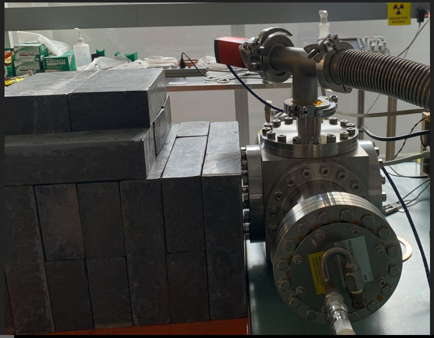
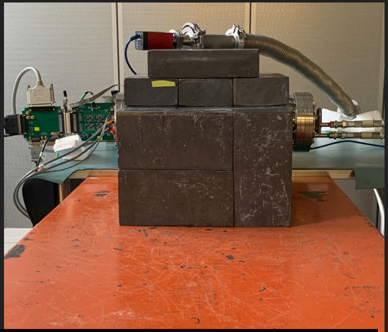
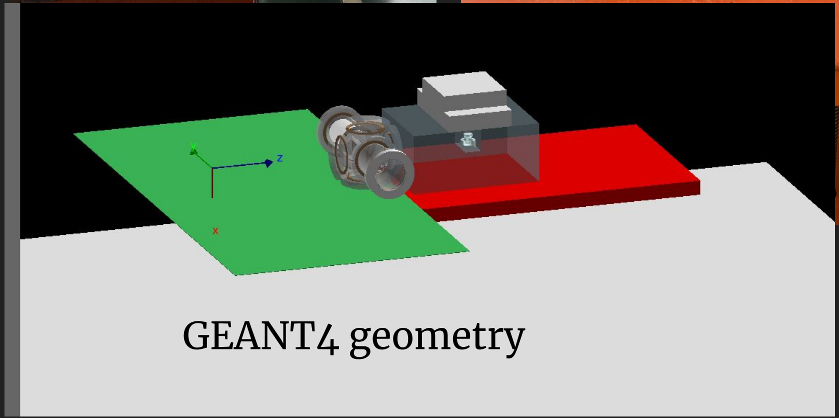
Nuclear recoil measurement setup

- Similar setup to that of Compton measurement was used.
- A lead castle was built to house the photoneutron source to shield the CCD from high energy gammas.
- The source setup was alternated between SbBe and SbAl to account for background due to gammas.

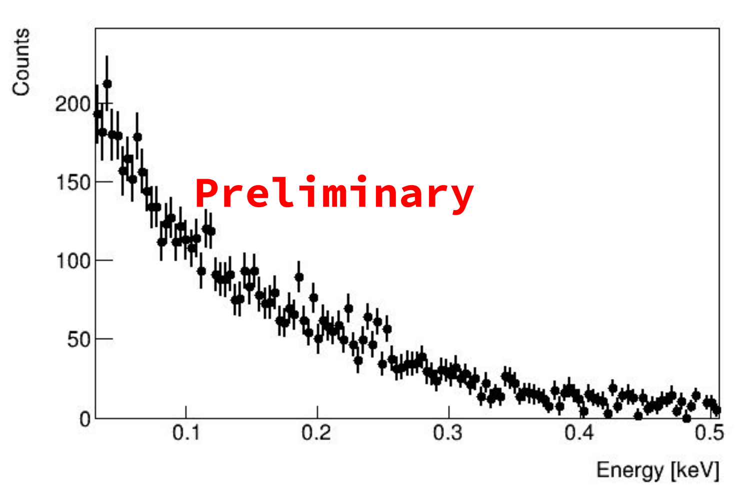




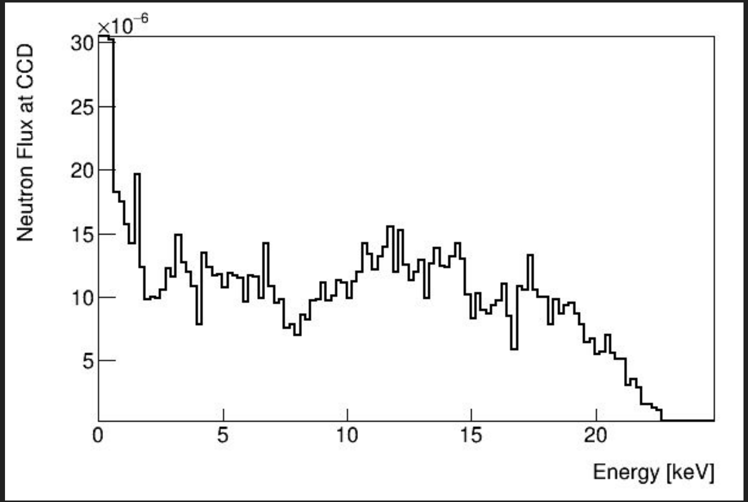


GEANT4 geometry

Preliminary results



Background subtracted nuclear recoil ionization spectrum

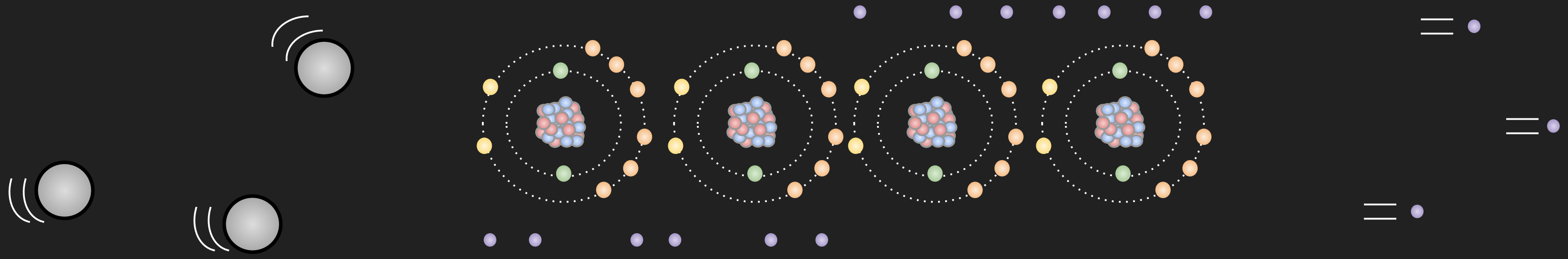


Flux of neutrons seen at the CCD as simulated by GEANT4

Obtaining the quenching factor is work in progress

Conclusions

- We have measured Compton scattering down to 23 eV
- Obtaining the nuclear recoil quenching factor at energies < 20 eV is in progress.
- These precision ionization measurements at low energies aid in calibrating the detector behaviour to backgrounds and improve limits in DM detections.



The DAMIC-M Collaboration