TAUP VIENNA 2023

Measurement of low-energy Compton and neutron scattering in Si CCDs with single-electron resolution

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for DAMIC-M Collaboration

Measurements relevant for DM searches:

1. Compton scattering,
2. Ionization efficiency of nuclear recoils,
3. Defects by nuclear recoils.

Work by DAMIC-M and also R&D for OSCURA

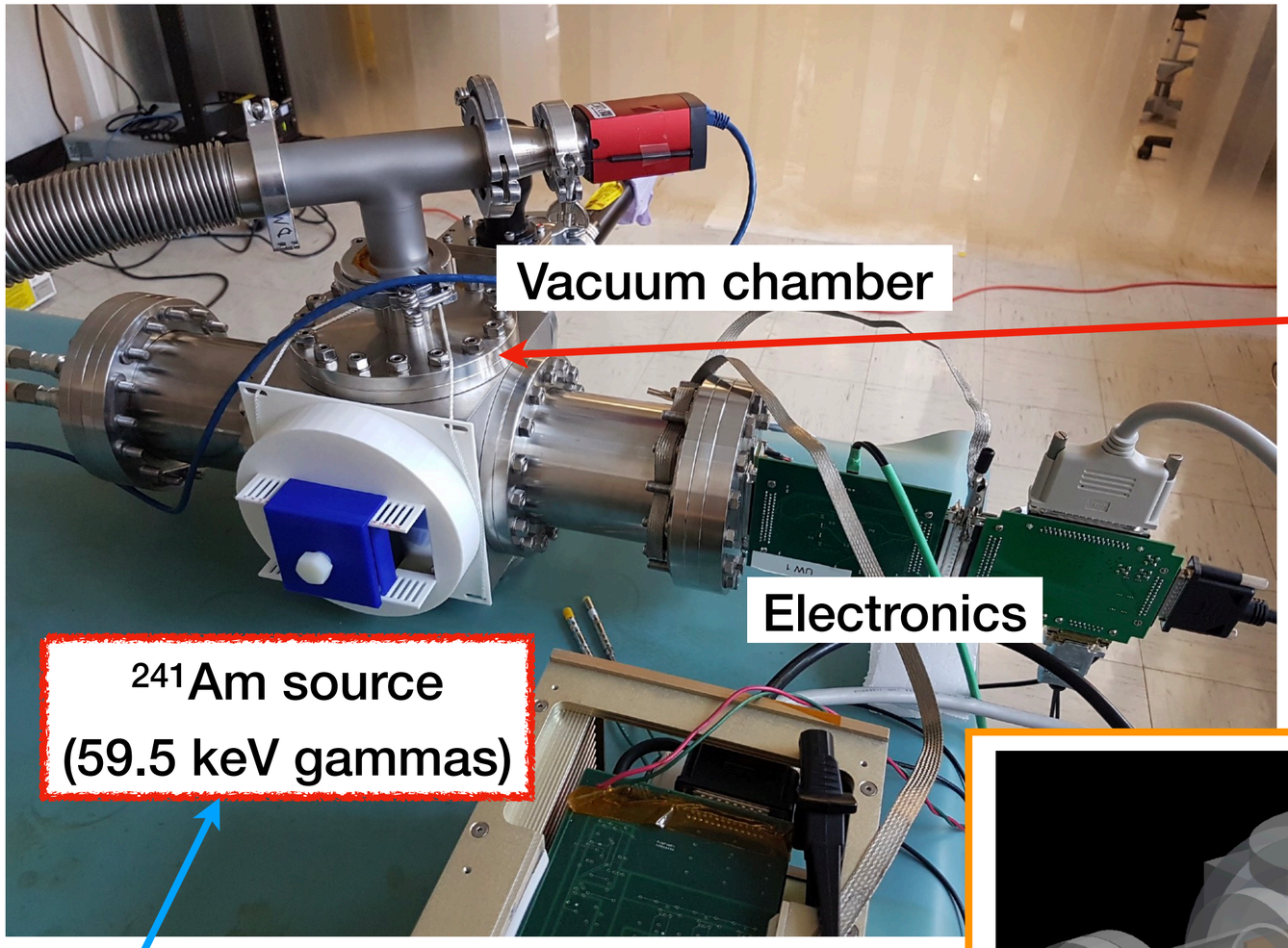
1. Compton scattering in Si

Motivation:

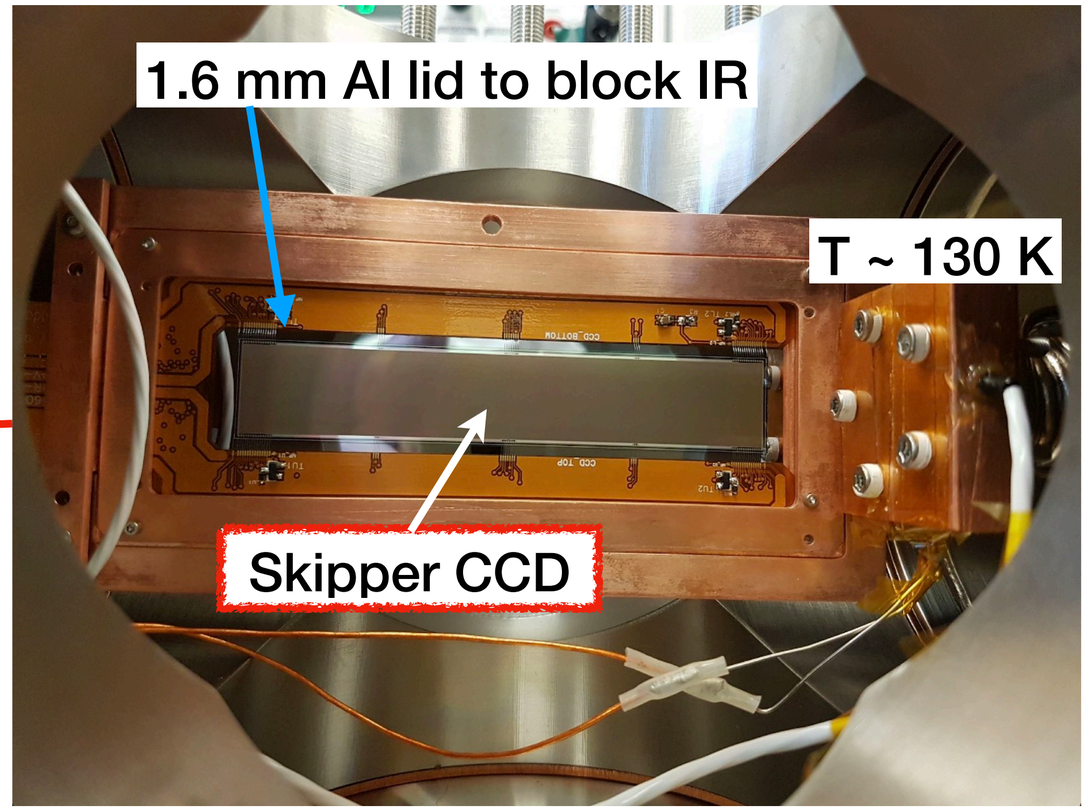
- High-energy γs are challenge for background models, because they produce low-energy electrons in the bulk of a detector.

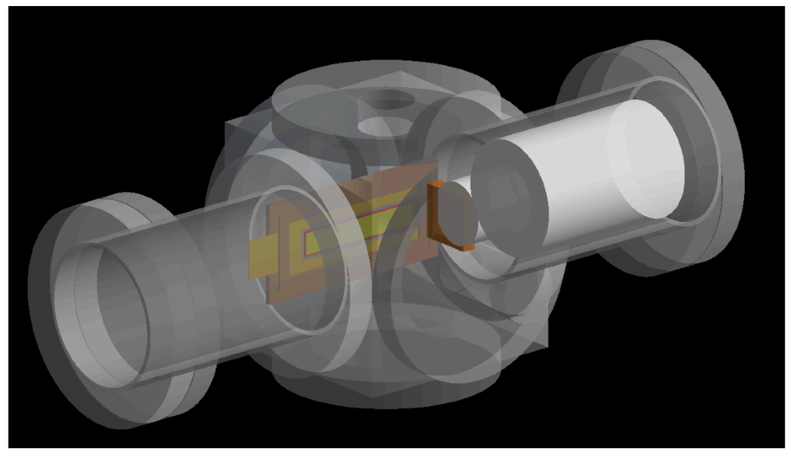
- Understanding of gamma scattering with electrons bound in semiconductors is relevant for DM-e^- scattering.

Experiment at UChicago



13 mm Al blocks 10-35 keV lines



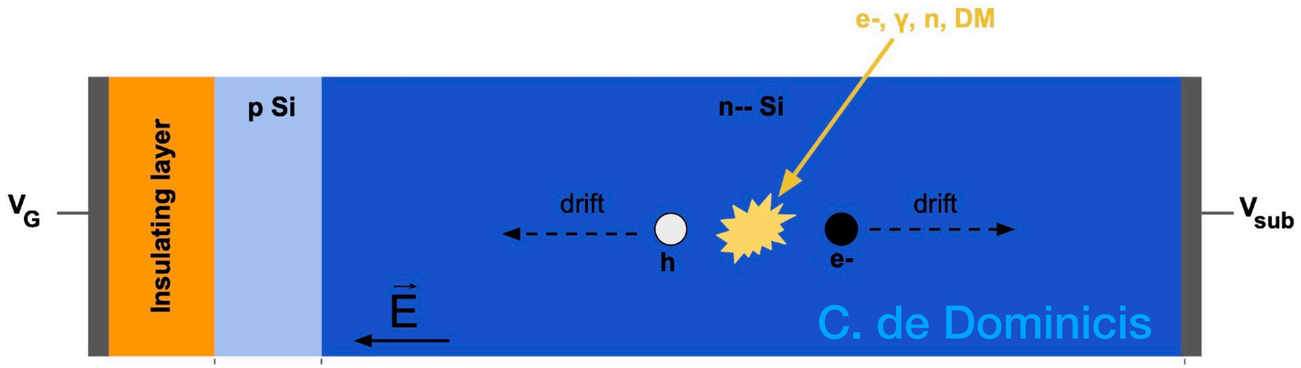


GEANT4 simulation of the whole experiment including the CCD

Skipper CCD

DAMIC-M prototype CCD

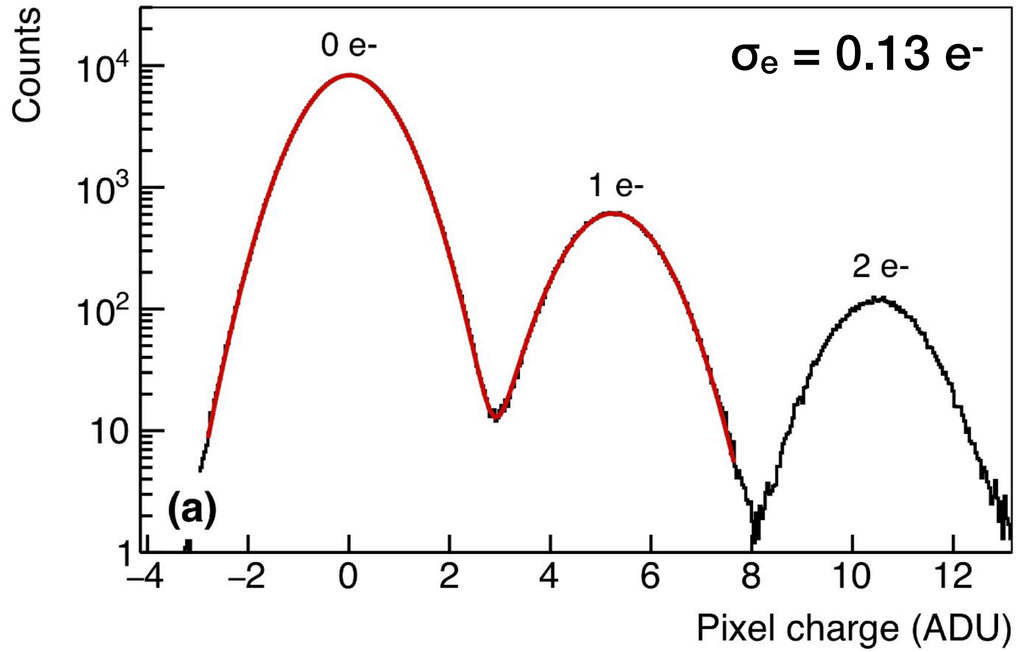
- skipper readout amplifiers,
- 6M pixels,
- pixel size 15 μm × 15 μm,
- 670 μm thick bulk depleted with $V_{sub} \geq 40$ V.



Charge collected in pixels during exposure is clocked to skipper readout amplifiers.

Talks about skipper CCDs at TAUP 2023: A. Aguilar-Arevalo, A. M. Botti, M. Cababie, P. Privitera, N. Saffold, M. Traina.

PRD 106 (2022) 092001



Single electron resolution thanks to multiple non-destructive charge measurements (skips).

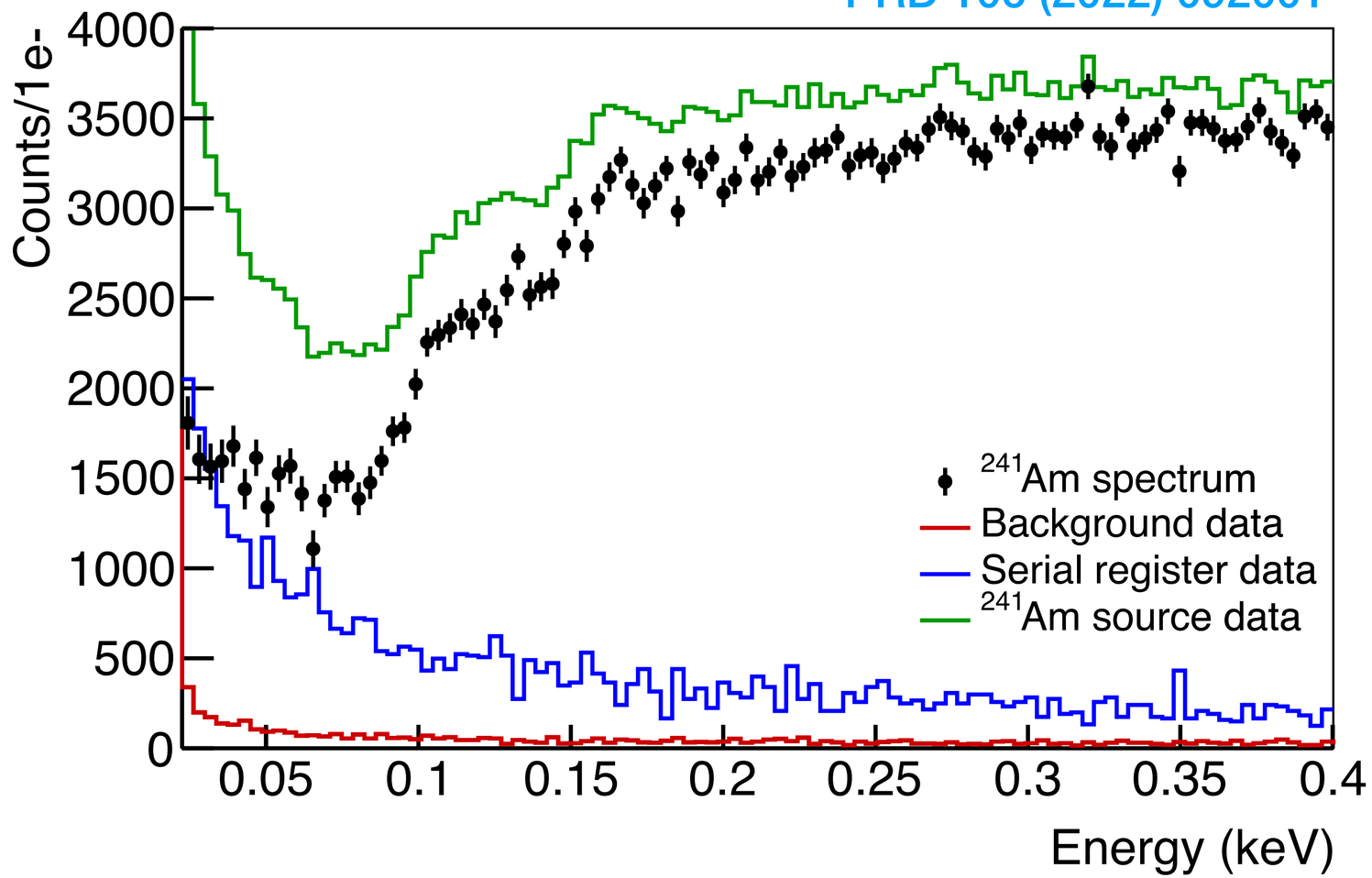
Data taking and analysis

Data:

- ^{241}Am source (total exposure 105.5 d),
- two background data sets (total exposure 60 d).

Correct background subtraction was critical to reach the energy threshold of only 23 eV.

PRD 106 (2022) 092001

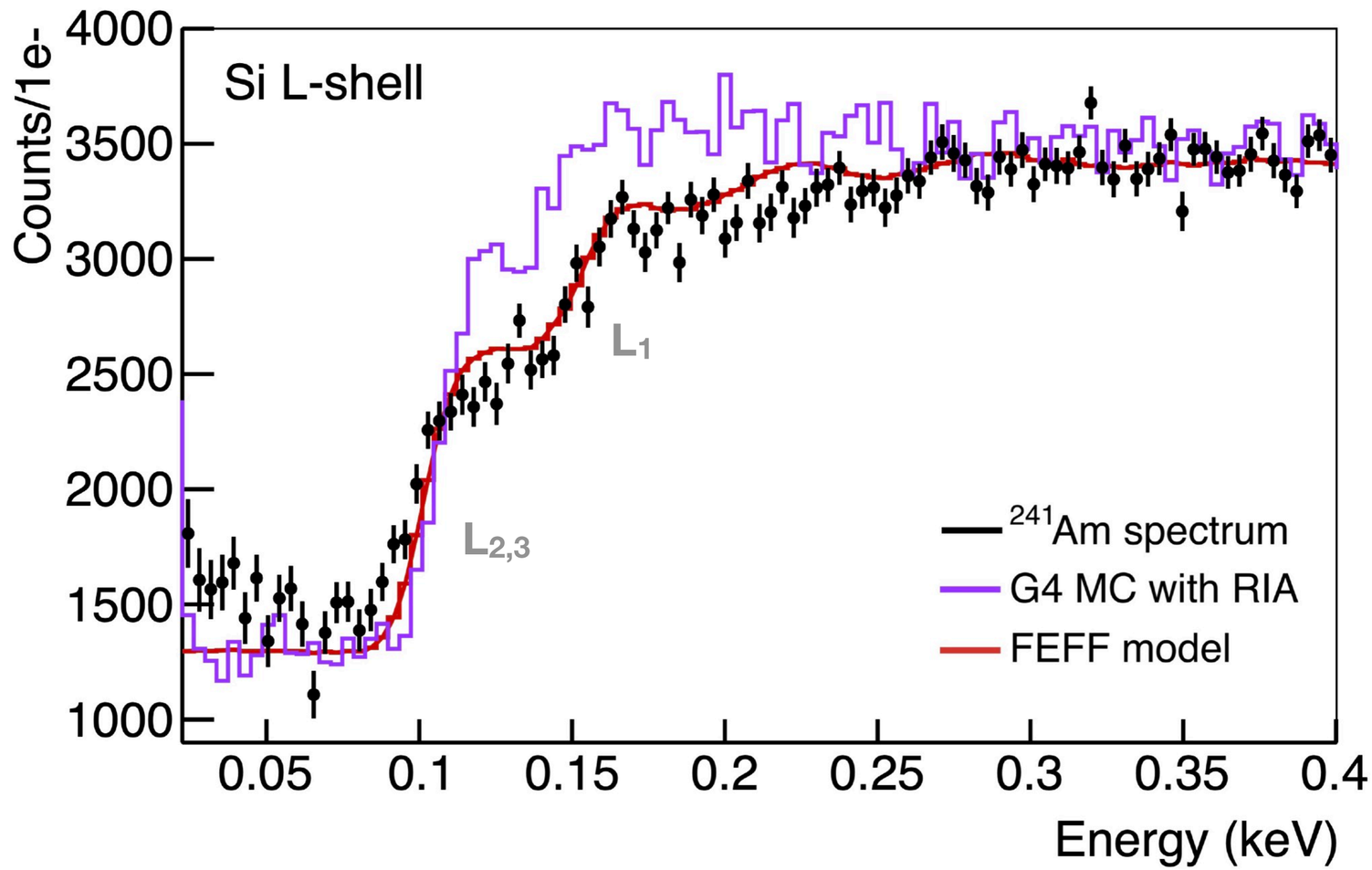


Compton scattering results

1. First measurement of Compton scattering on valence e^- below 100 eV.

2. Clear identification of steps associated with Si L_1 (150 eV) and $L_{2,3}$ (99 eV) shells.

3. Commonly used relativistic impulse approximation (RIA) fails to reproduce the spectrum in the L-shell region and overestimate rates by up to 20%.



Much better agreement with full QM calculation (FEFF model).

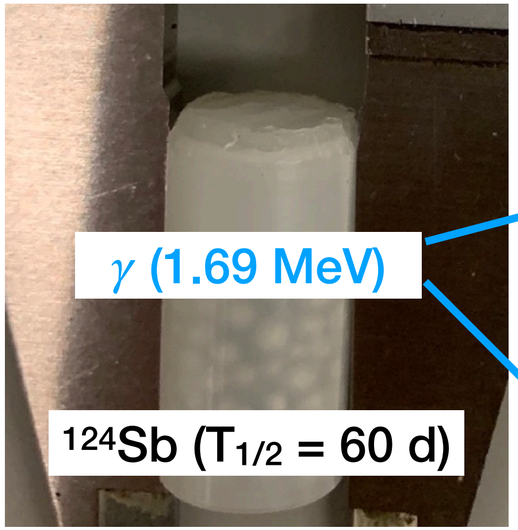
Details in PRD 106 (2022) 092001.

2. Ionization efficiency of nuclear recoils

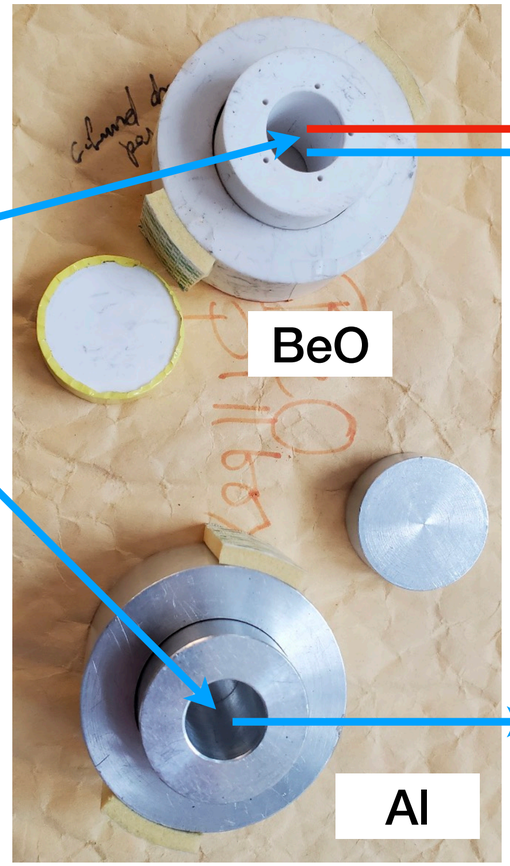
Experiment at UChicago

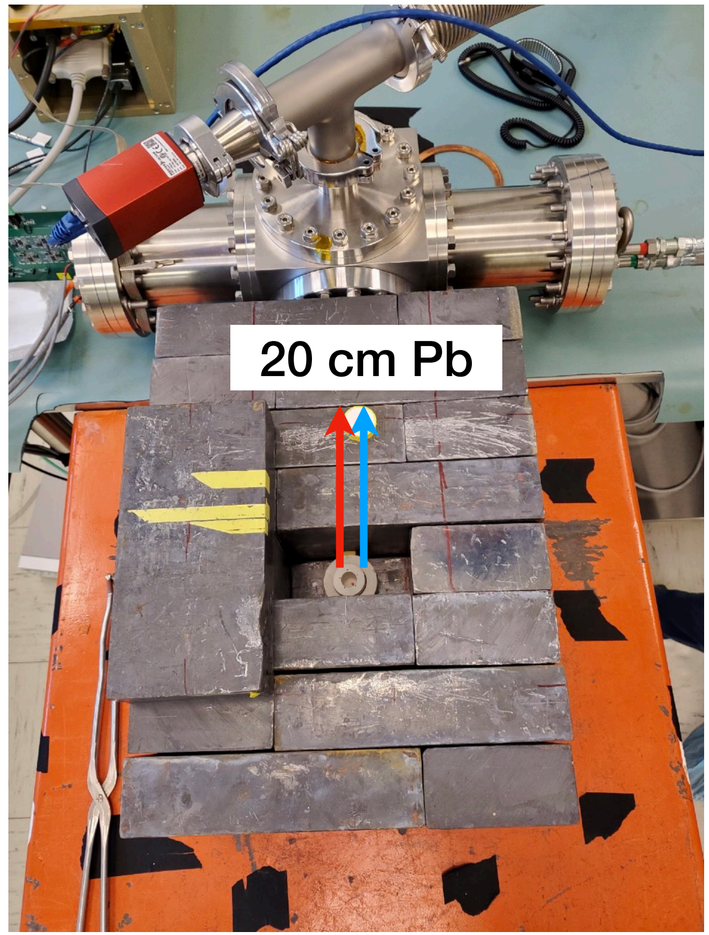
photo-disintegration:

γ + ^{9}Be —> ^{8}Be + n (24 keV)



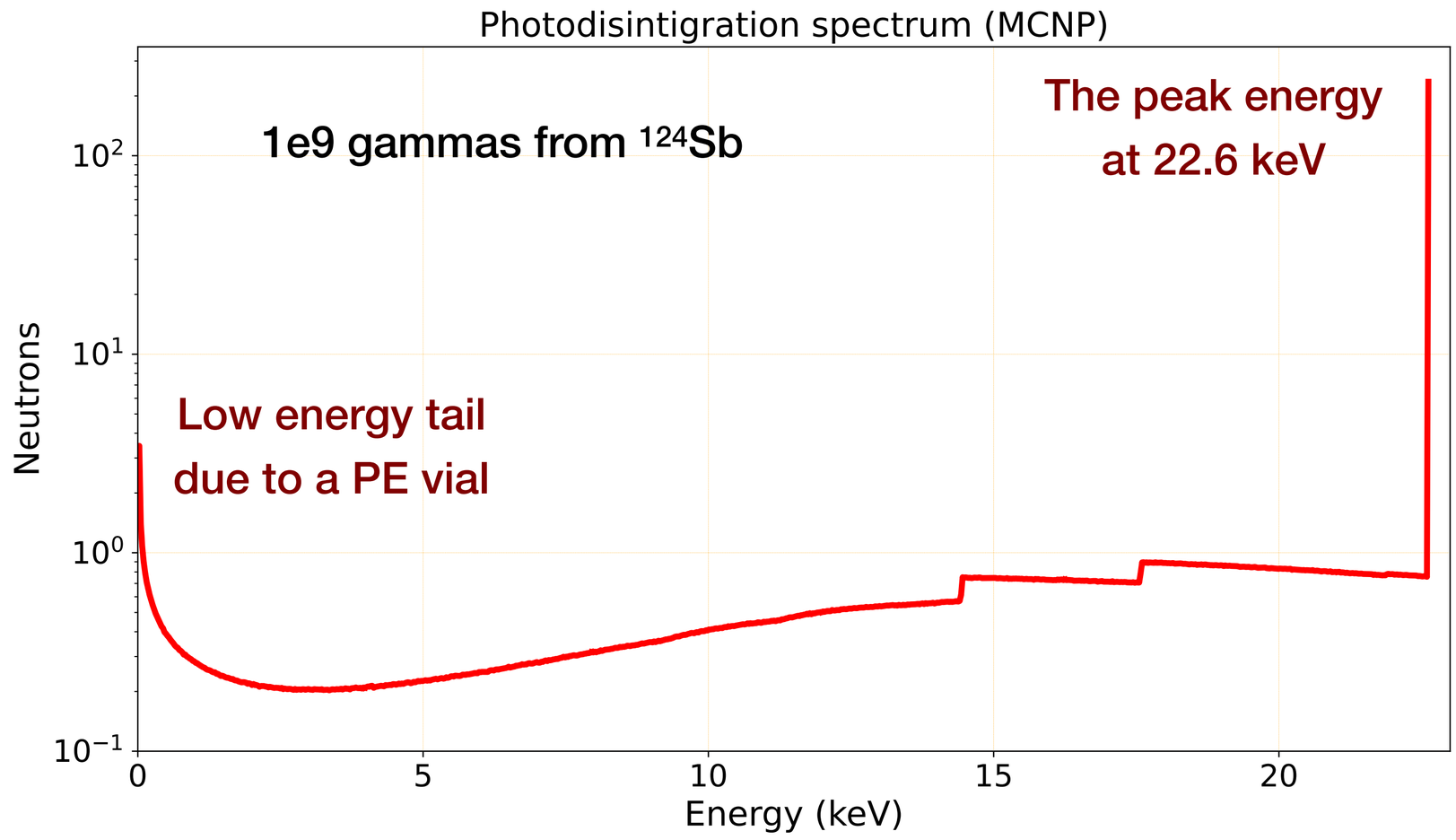
^{124}Sb sources activated at Oregon State Univ.





Data collected with the source either in BeO (neutrons) or Al (gamma background), plus no-source data.

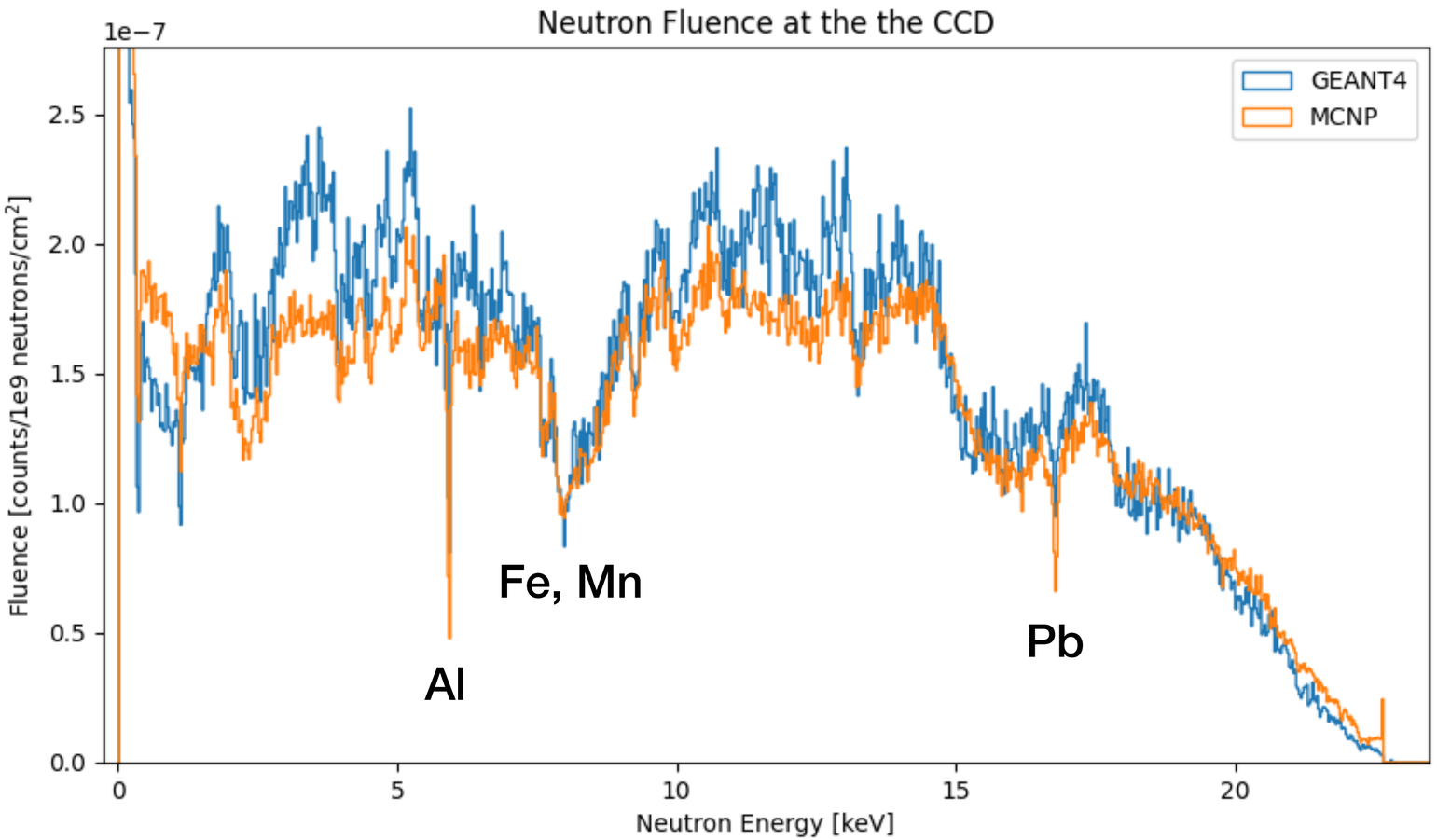
Neutron spectrum from the source



MCNP simulation uses the photo-disintegration cross section from PRC 94 (2016) 024613.

Neutron sources were calibrated with ^{3}He detector (~9000 n/s).

Neutron flux

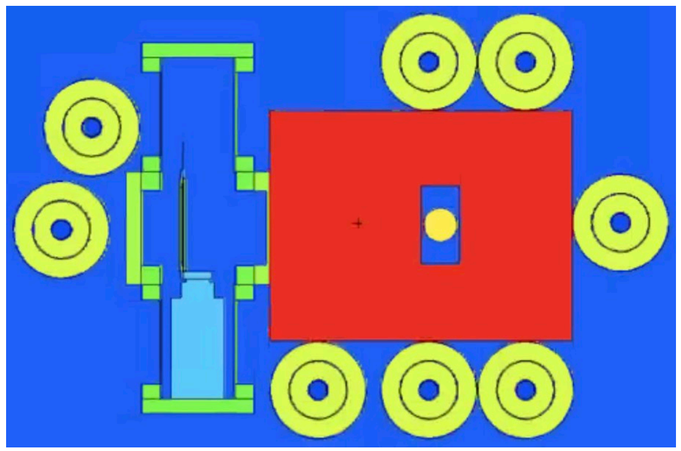


Neutron flux at the CCD

Moderated by different materials (shielding, vacuum chamber, …)

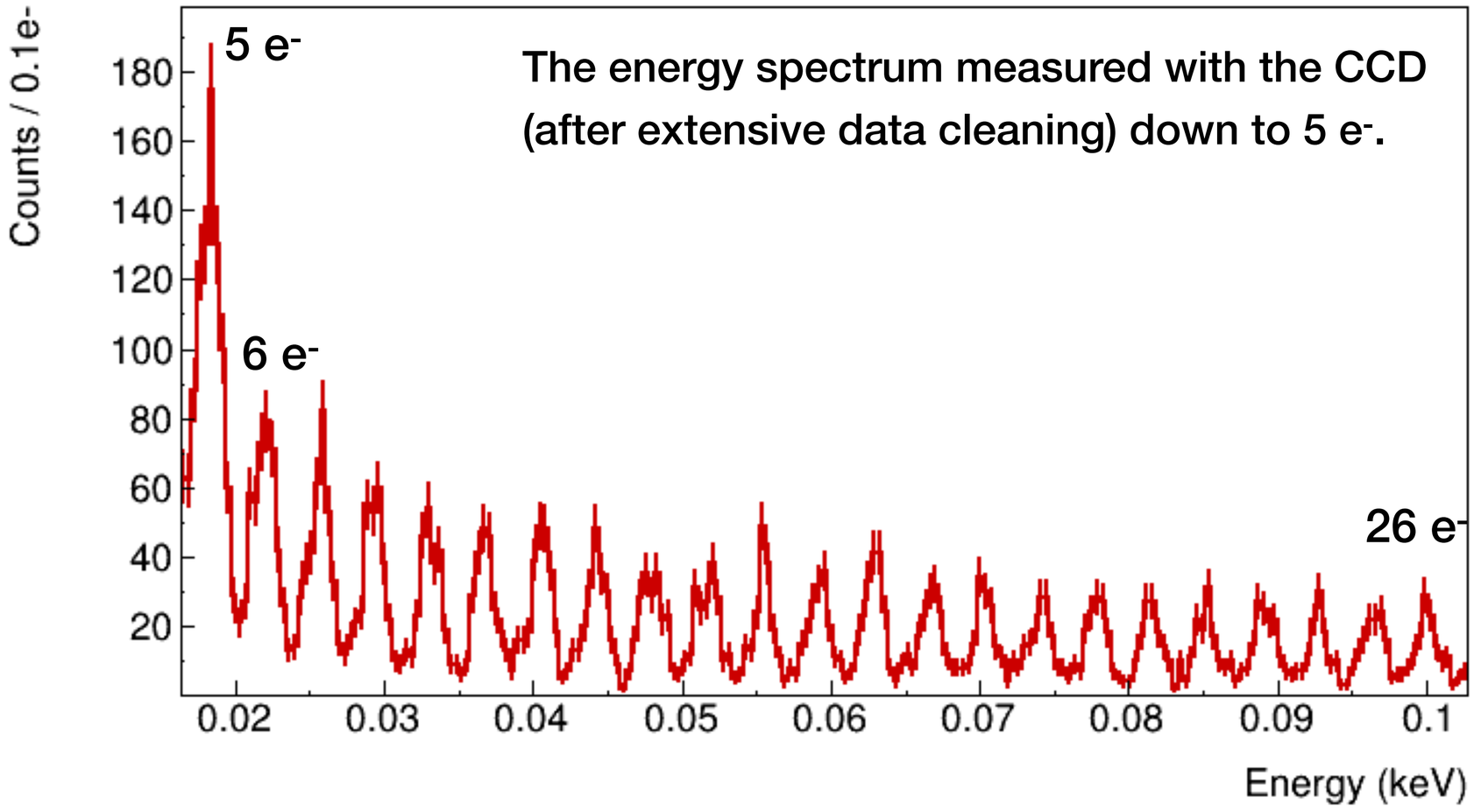
GEANT4 and MCNP simulations agree pretty well. Differences are under investigation.

To check simulations, the neutron flux was measured with ^{3}He counter in several positions.



Work in progress

The analysis has not been finished, yet, so no result on the nuclear recoil ionization yield can be shown.



The energy spectrum measured with the CCD (after extensive data cleaning) down to 5 e^-.

3. Nuclear recoil defects

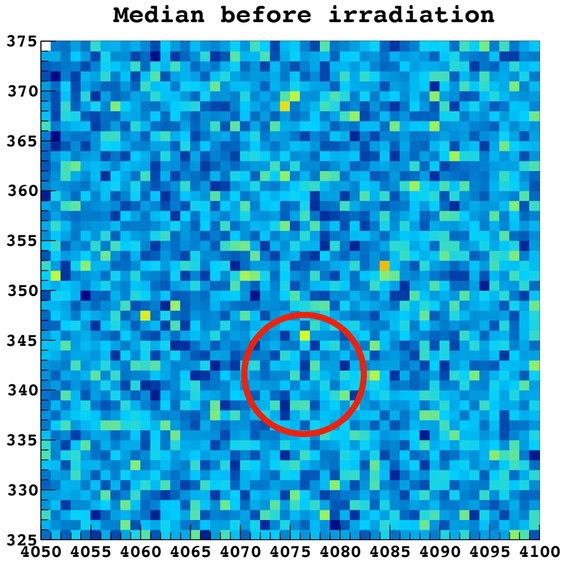
Experiment at University of Washington under DOE DM New Initiatives

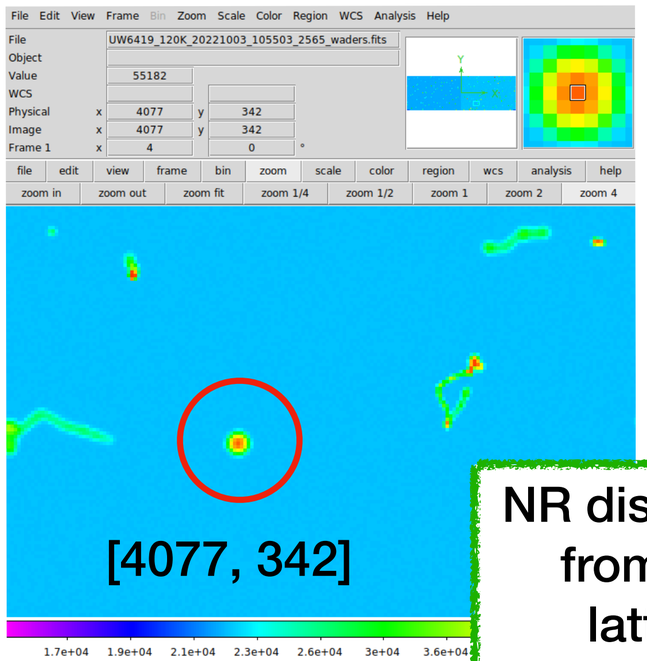
Nuclear recoils (NR) in CCDs

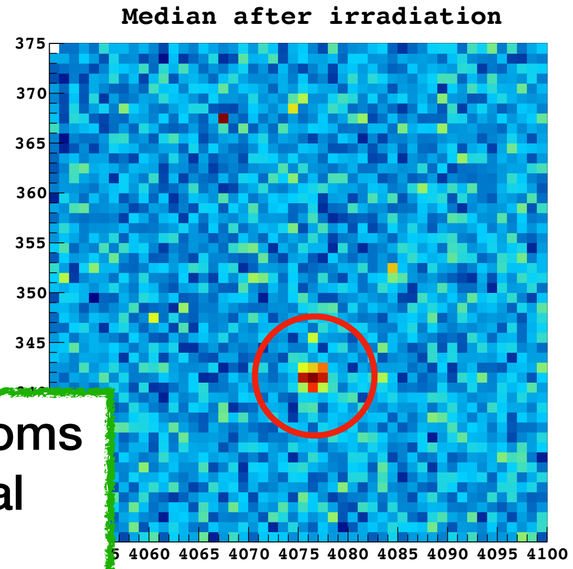
Idea: Distinguishing NR signals from electronic recoil (ER) backgrounds could enhance the sensitivity of future CCD experiments.

Experiment at U. Washington

Series of warm images (223 K) to identify existing defects → Cold images (147 K) during irradiation with AmBe source (4.2 MeV neutrons) to identify primary ionization events → Series of warm images (223 K) to identify new defects



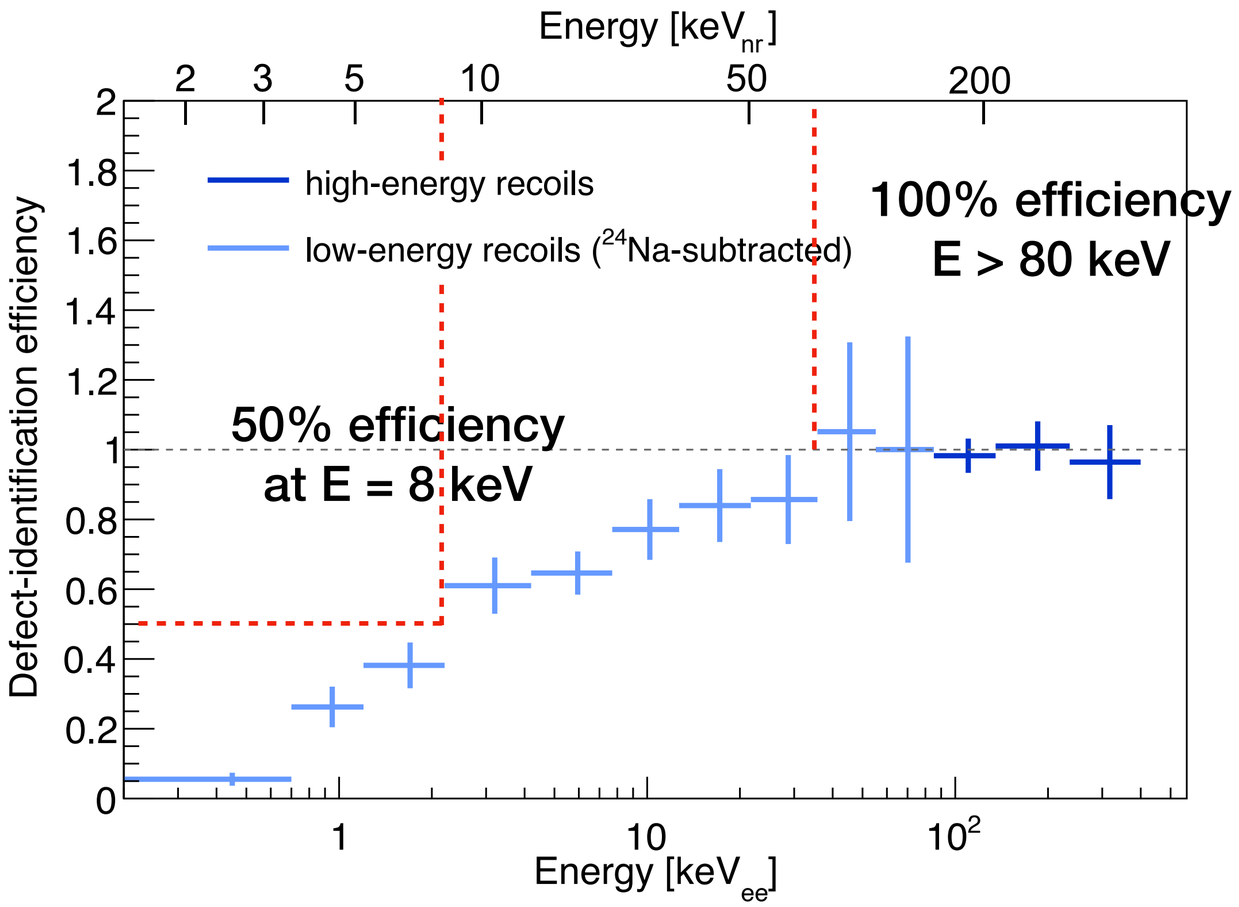




NR dislocates atoms from the crystal lattice, which produces a defect

Stable for at least 12 h

Results and Outlook

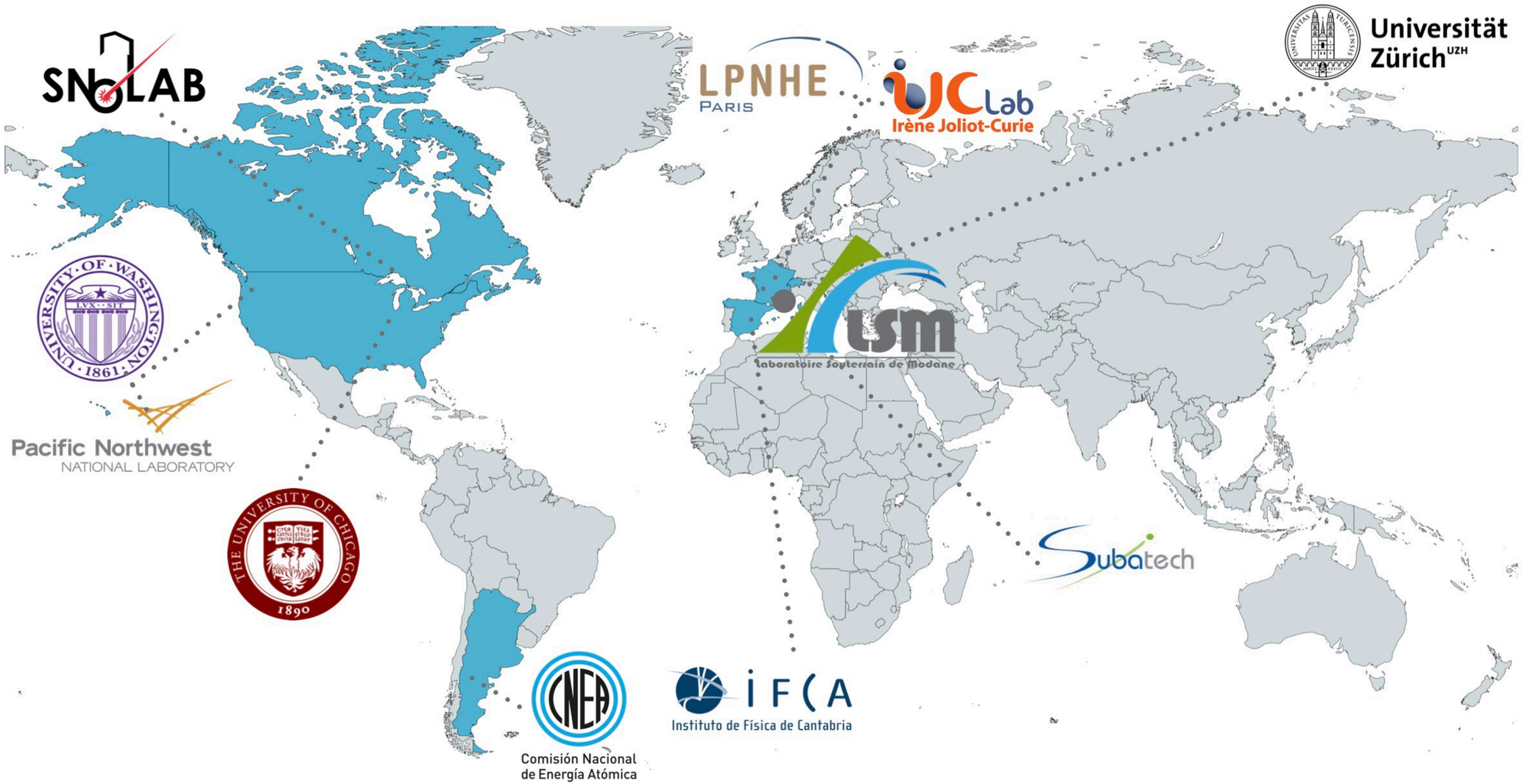


<0.1% of ER with E < 85 keV are spatially correlated with a defect

This is only the first attempt at NR/ER discrimination in CCDs. We have yet to optimize the thermal stimulation strategy, explore optical stimulation, etc.

Future CCD experiments DAMIC-M and OSCURA will have NR/ER discrimination!

The DAMIC-M Collaboration



https://damic.uchicago.edu/