SuperCDMS Compton step calibration study

SuperCDMS collaboration

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WNPPC

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@SuperCDMS

Direct search for dark matter

Goal:

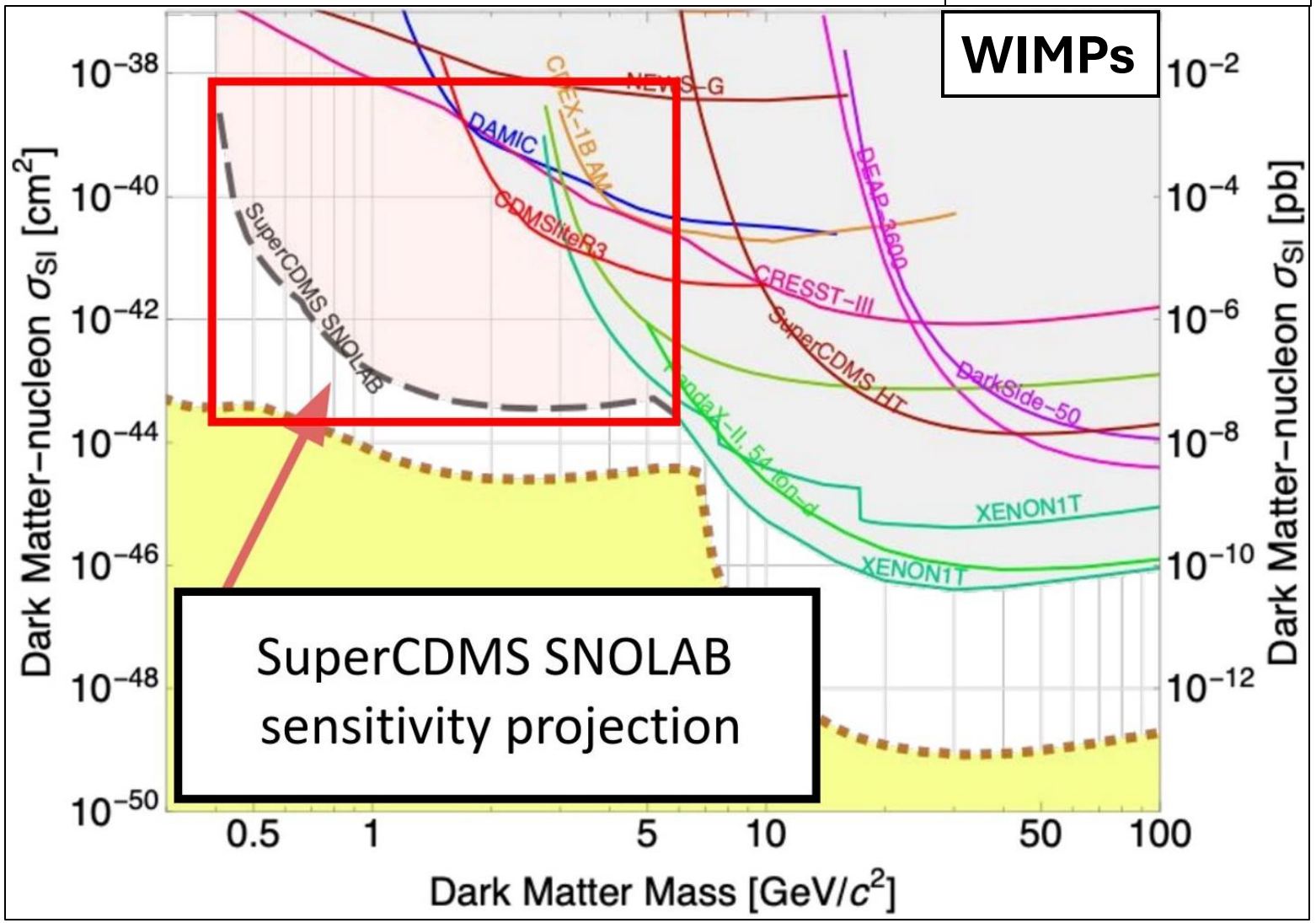
- Observe or reject dark matter models.

Procedure:

- Dark matter model.
- Background model.
- Experiment data.
- A statistical test.
- Any indication for dark matter in data?

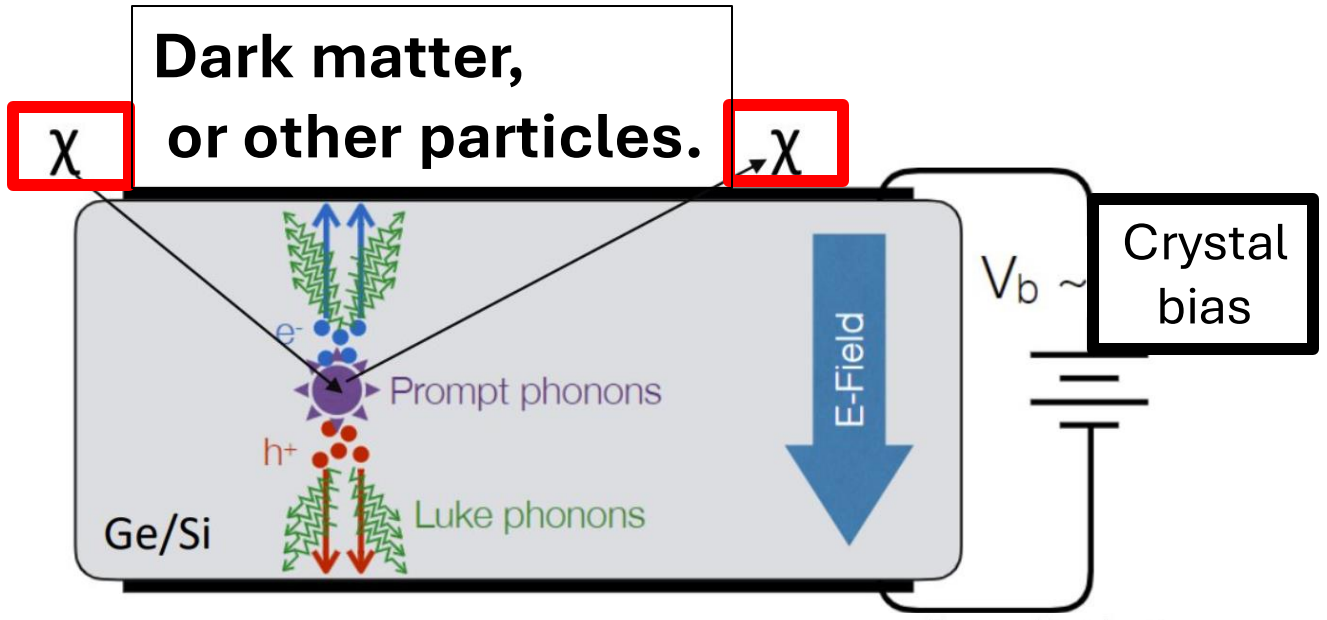
First need detector calibration.

arXiv:1610.00006



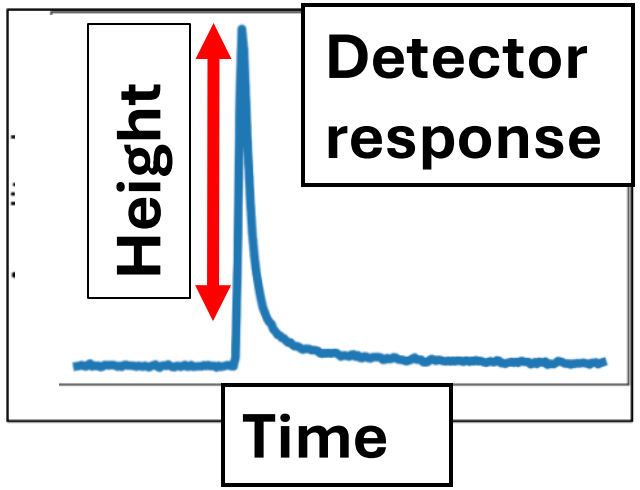
What is calibration

- Choose calibration sources with signatures at known energies.
- Identify the signatures in data.
- Extract the calibration function.

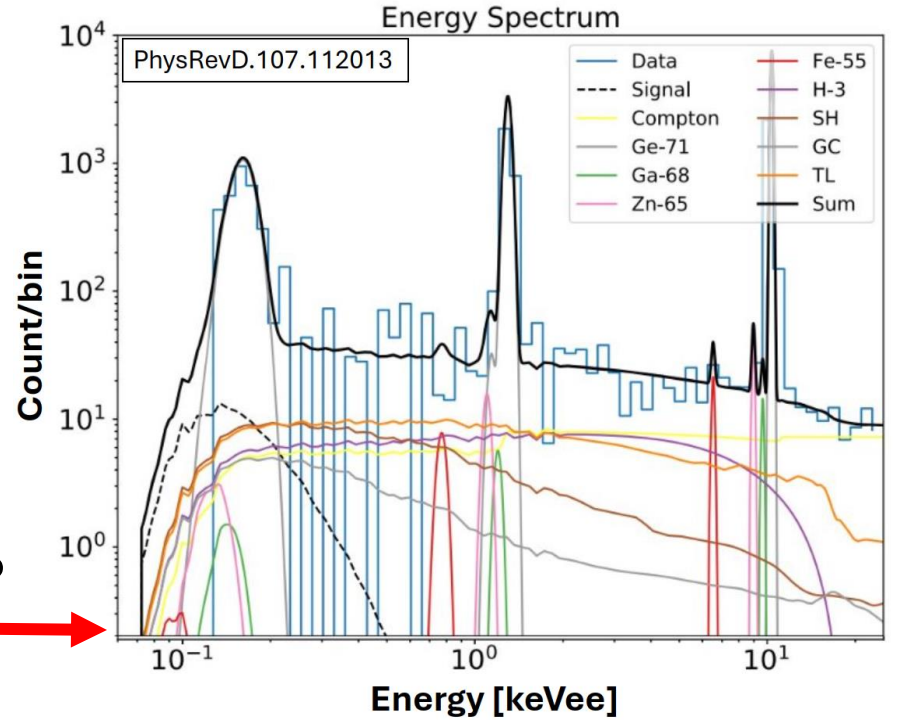


Final goal:

Function(Height) = Energy



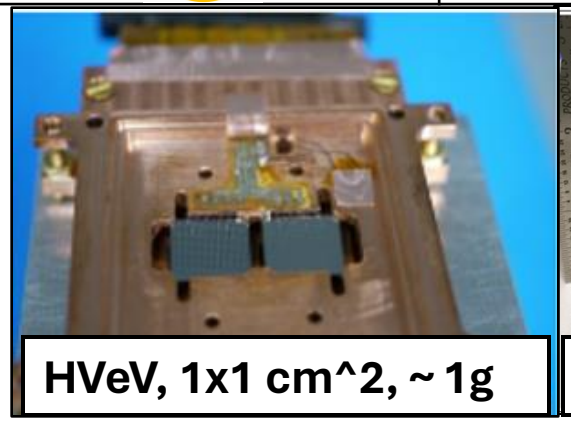
?



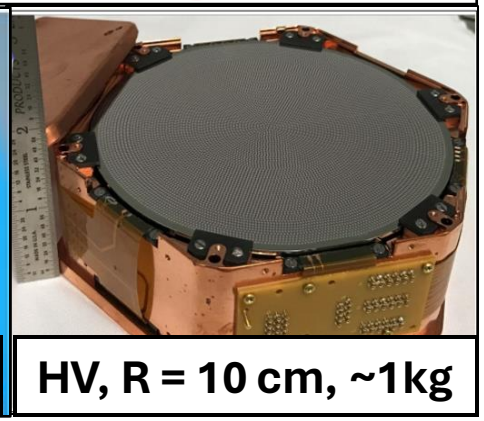
Calibration methods

Energies		Low (few eV)	Intermediate (up to 10keV)	
Procedure		Optical photons	Compton steps	Intrinsic activation lines
Ge	HV (~10eV resolution)	✗	✗	✓
Si	HV (~10eV resolution)	✗	!	✗
	HVeV (~eV resolution)	✓	?	✗

- **Today**: Si-HVeV is under investigation. ?
- **Future**: Si-HV is the final goal. !



HVeV, 1x1 cm^2, ~ 1g



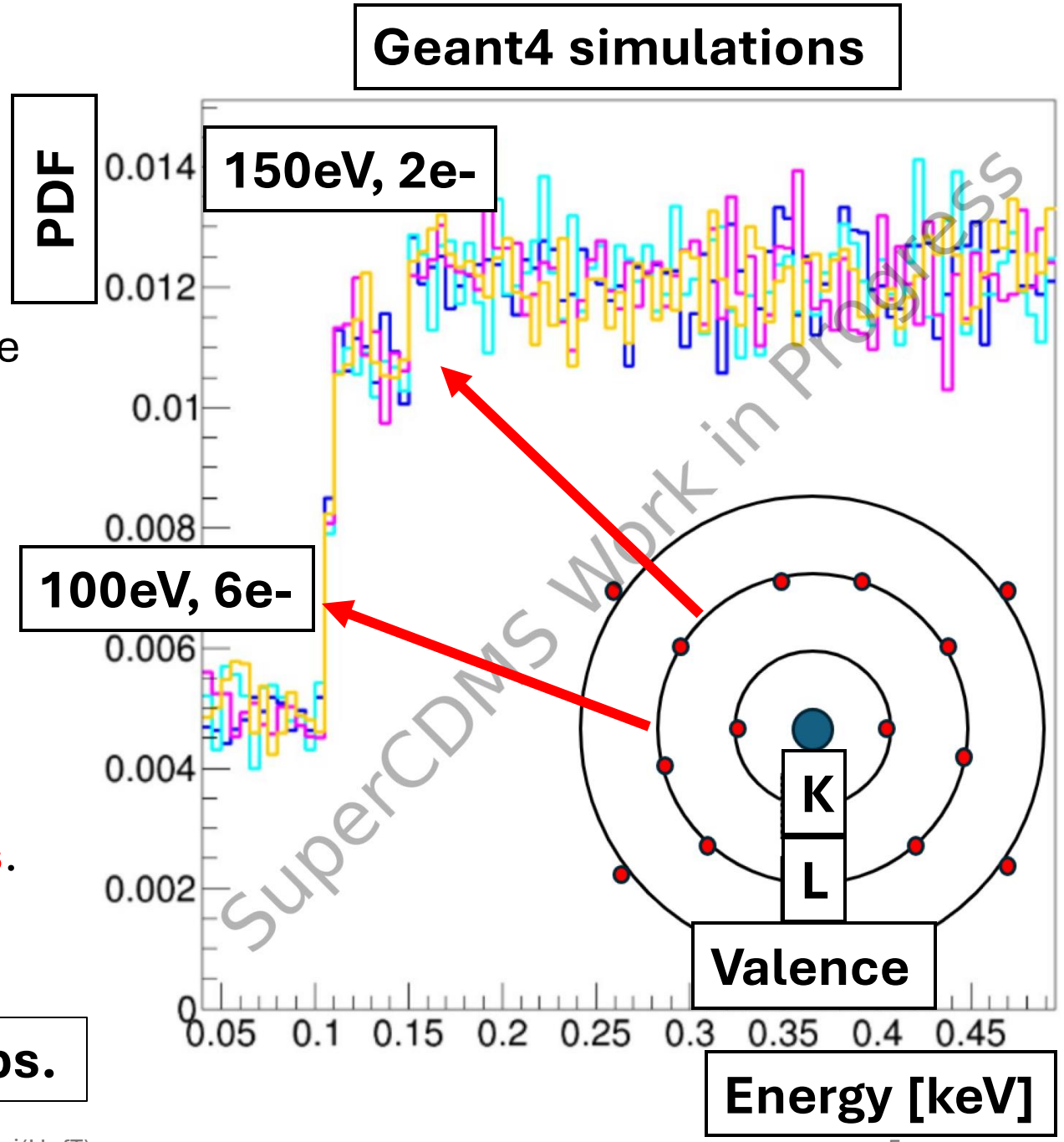
HV, R = 10 cm, ~1kg

Silicon L-shell steps

Compton steps:

- Irradiate with O(100) keV gamma rays to produce Compton scatters.
- Electromagnetic interactions.
- The binding energy of the electron limits the minimum required energy for scattering.
- Scattering **probability** ∝#**accessible electrons**.

Right: L-step simulations, 2S and 2P steps.

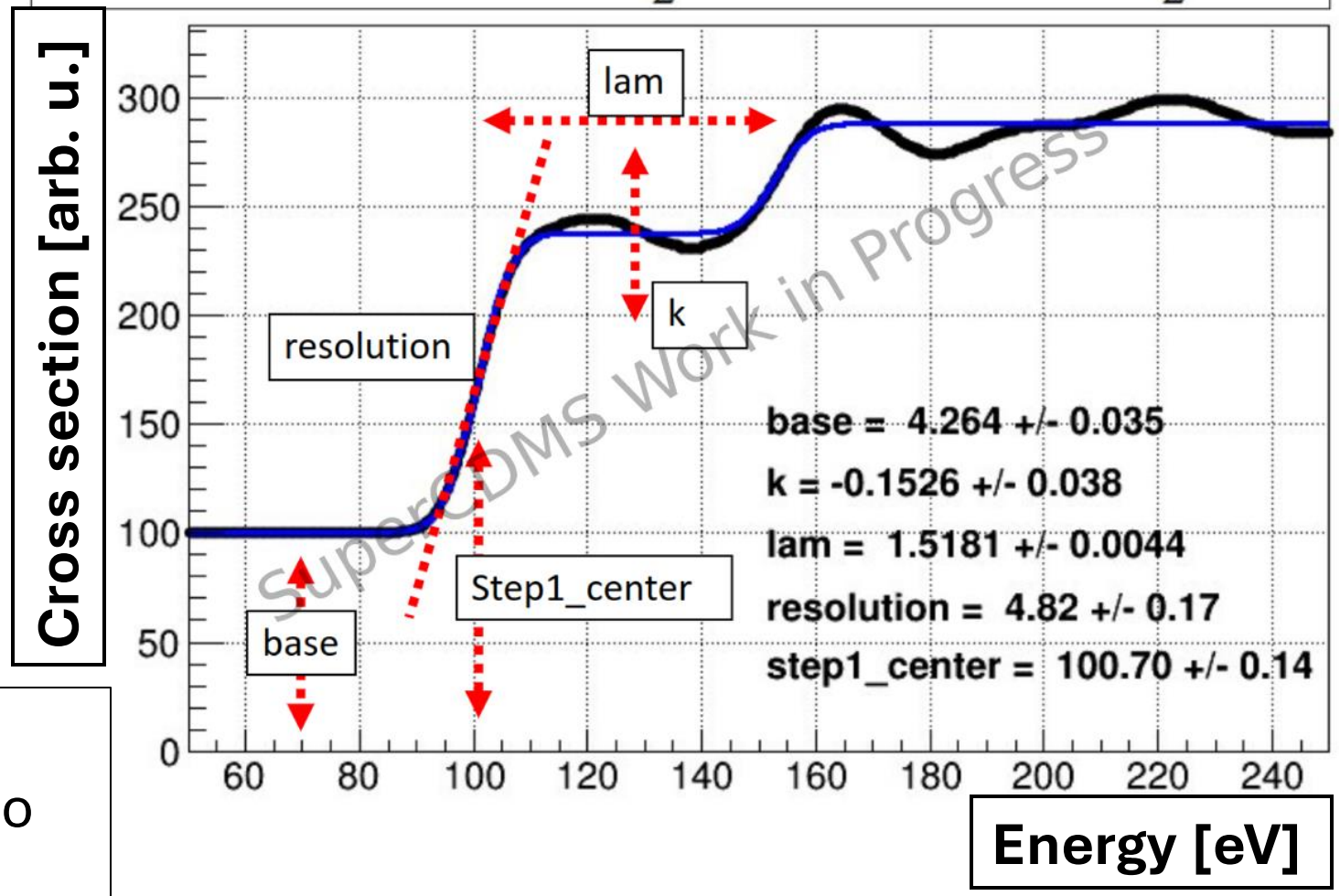


L-shell calibration

1. Need a step detection system.
2. Perform simulations.
3. Take data.
4. Compare simulation to data.

Black line: **FEFF** simulation.
Blue line: **Analytical model** fitted to simulations.

$$f(x|\theta) = base + (6+k)\frac{1+Erf(\frac{x-x_1}{\sqrt{2}\sigma})}{2} + (2-k)\frac{1+Erf(\frac{x-\lambda x_1}{\sqrt{2}\sigma})}{2}$$

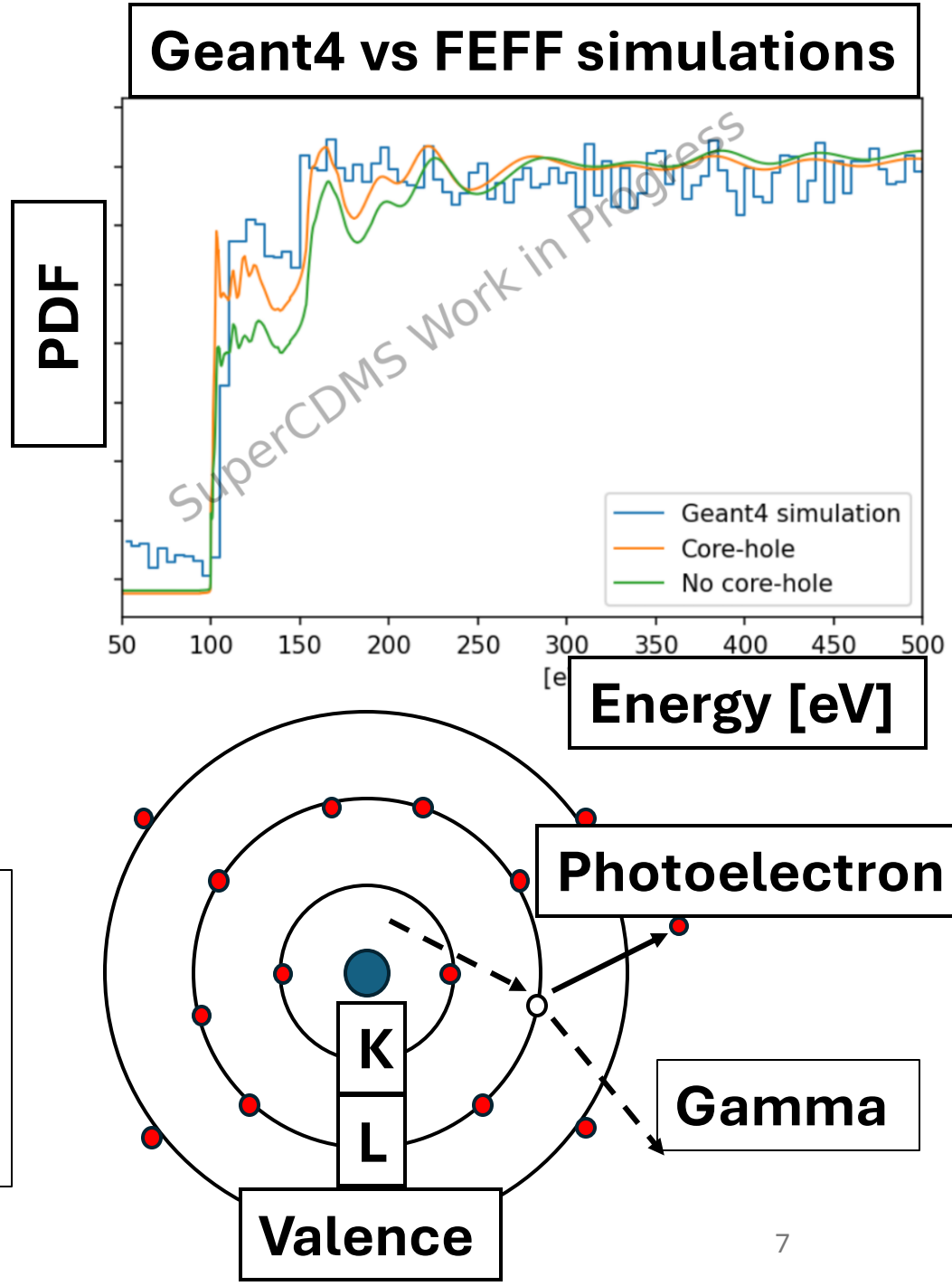


L-shell simulations

Different simulation packages:

1. Geant4 simulations:
   - Based on impulse approximation for E&M scatters.
   - Not trustworthy near Compton steps.
   - Monte Carlo based.
2. FEFF simulation:
   - No impulse approximation.
   - Deviates from Geant4 simulations.
   - Ab initio calculation of cross section.

Impulse approximation:
- Ignore the **external potential** on the photoelectron **during the scattering** process.
- Valid when: **Transferred energy** >> **Binding energy**.
- In other words: Scattering **time scale** << **Atomic response**.



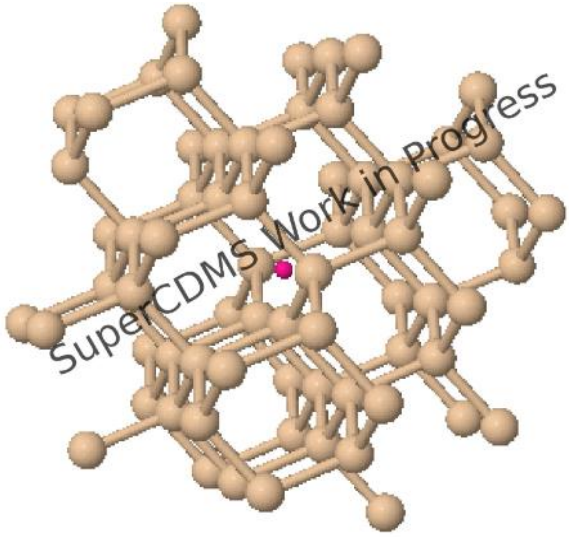
FEFF simulations

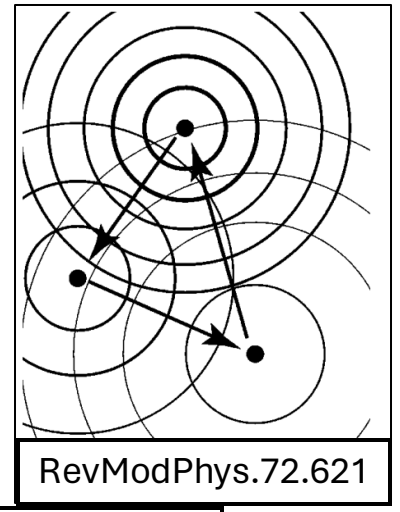
FEFF calculations:

- Model the external potential on the photoelectron.
- Thus, need the arrangement of atoms. (Si crystal)
- And a target atom. (Pink dot)
- Each electron shell -> Separate Calculation.

Cross section **oscillation** in FEFF:

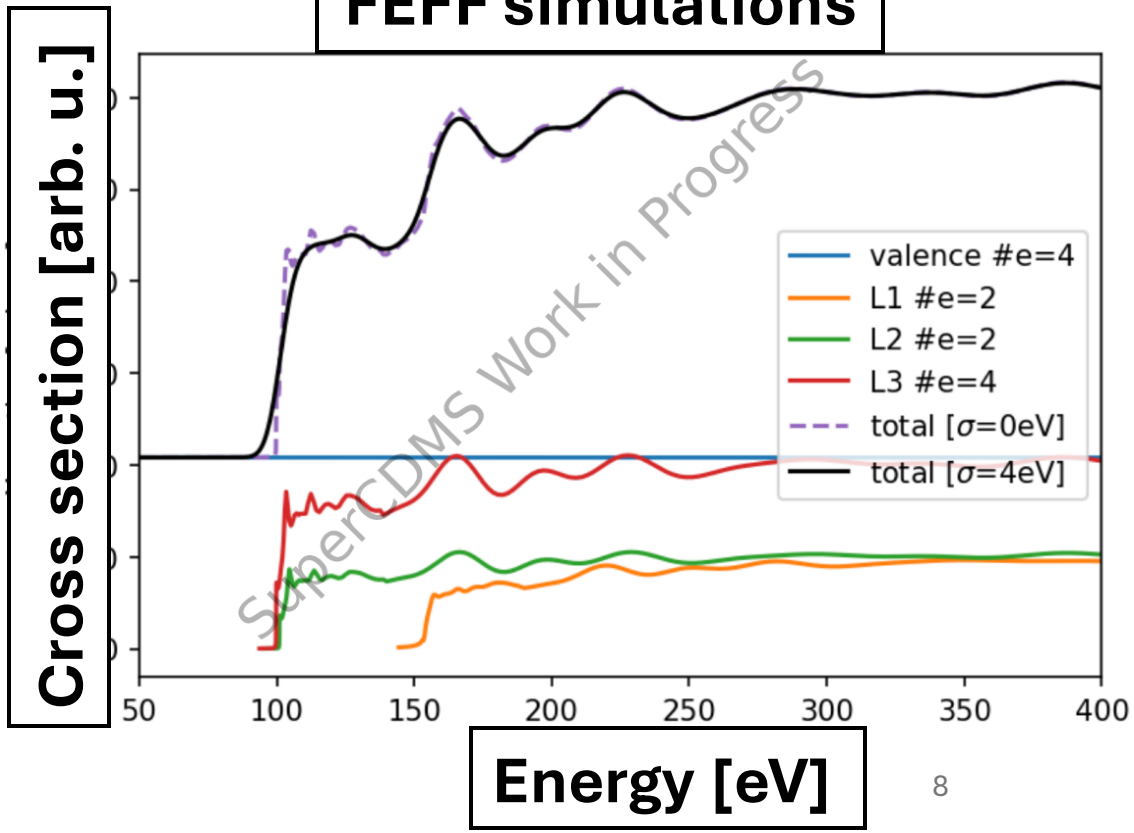
Constructive and **destructive interference** patterns of the **photoelectron** wave **depending** on **wavelength** and **atomic spacing** (top right).





RevModPhys.72.621

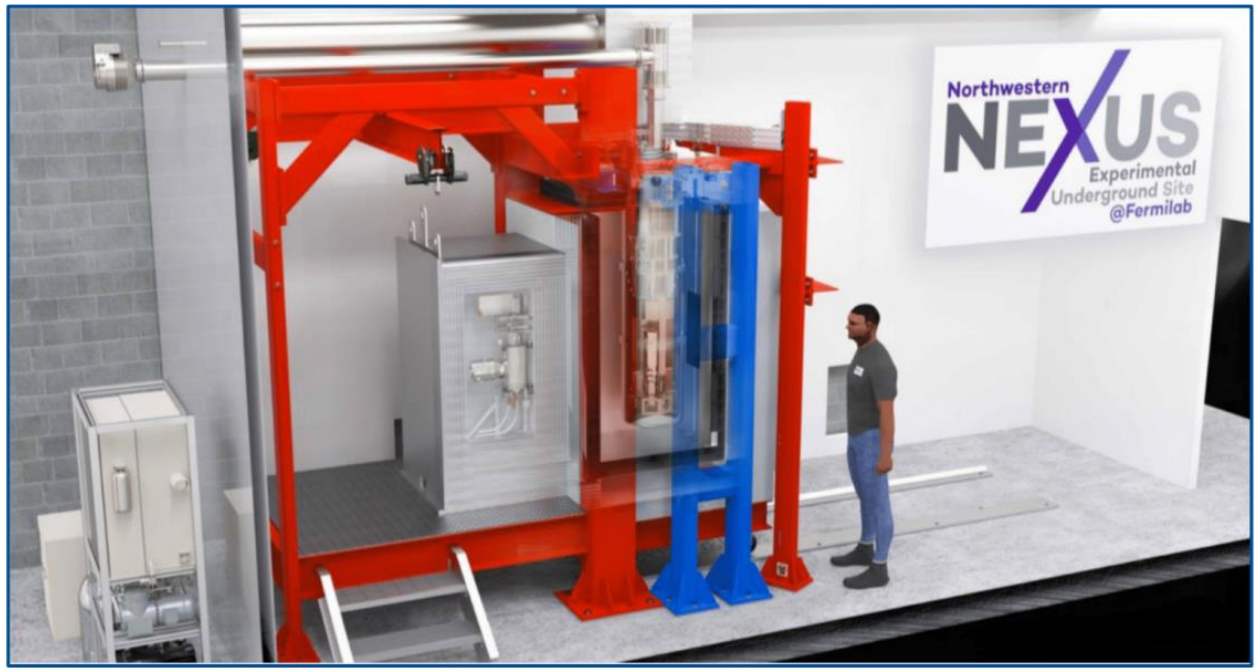
FEFF simulations



Compton calibration data

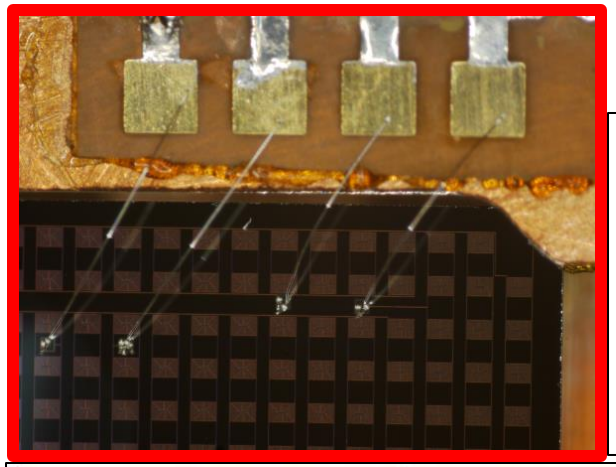
Compton step Calibration data:

- Facility: NEXUS at Fermilab.
- Overburden: 100m.
- Detectors: Si-HVeV prototype/R&D.
- Calibration source: Cs-137 (662keV gamma rays).

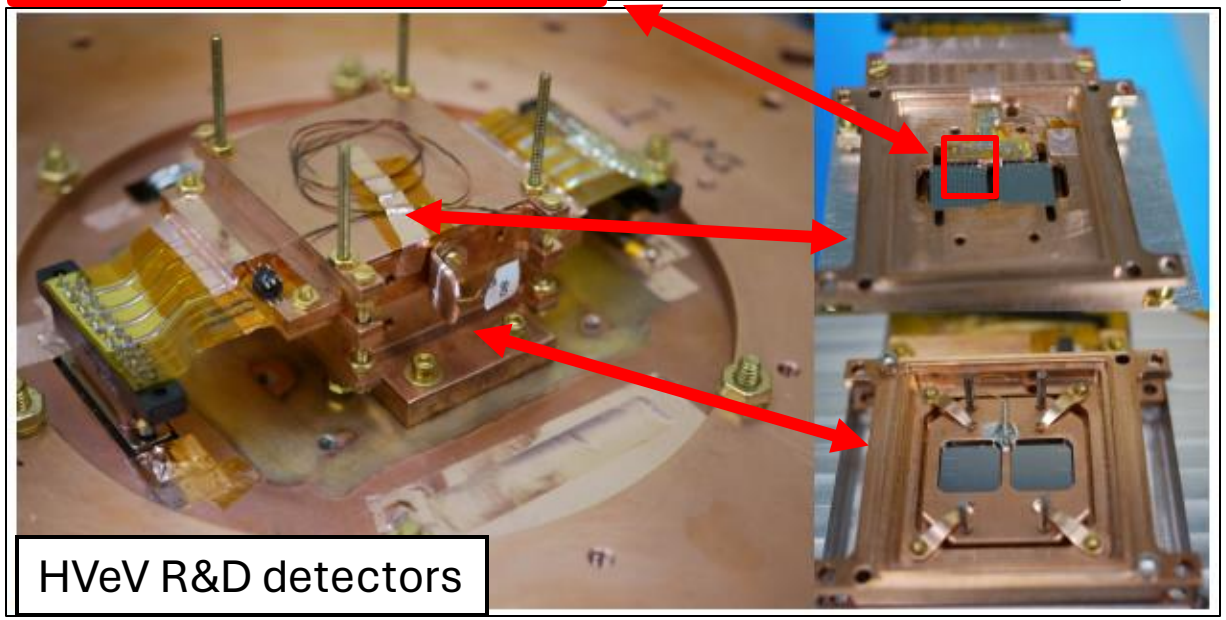


Next steps

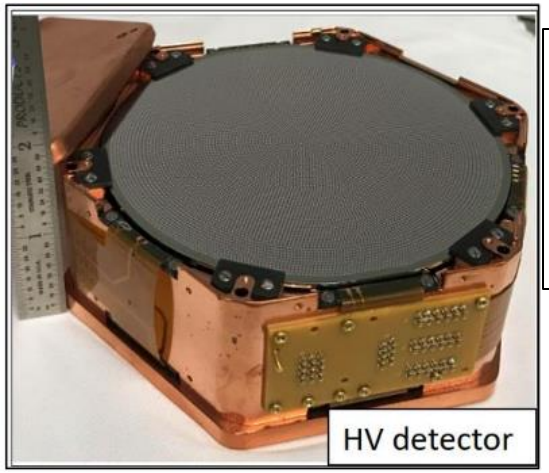
- Compton step analysis for HVeV detectors is going through SuperCDMS internal review. (Oops, no data today!)
- Looking forward to use the developed calibration scheme for HV detectors.



HVeV
10x10x4 mm^3
Silicon
~1g



HVeV R&D detectors



HV detector

R = 10cm, H=3cm
Silicon or germanium
~1kg

Thanks!

@SuperCDMS

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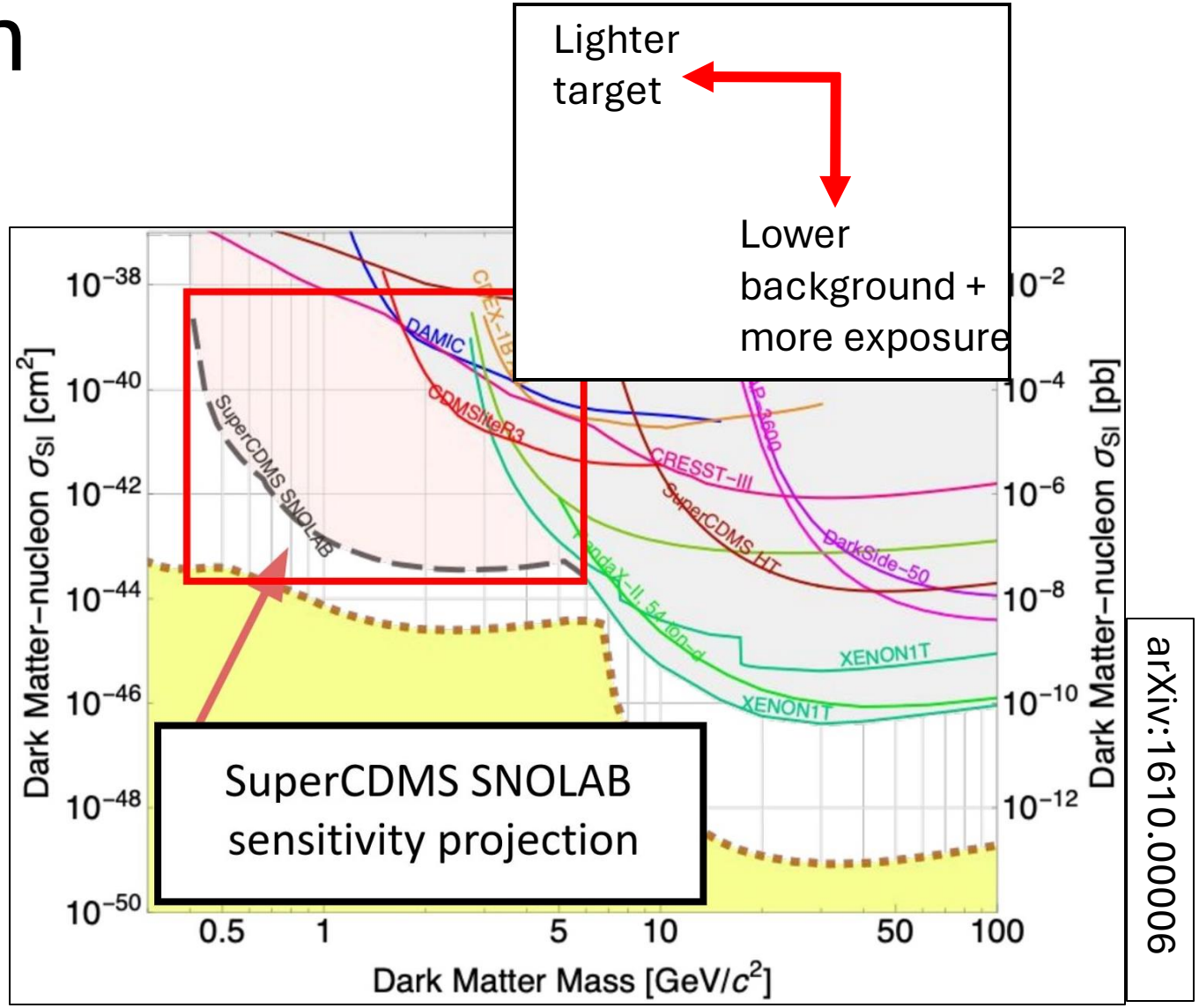
Backup

WIMP direct detection

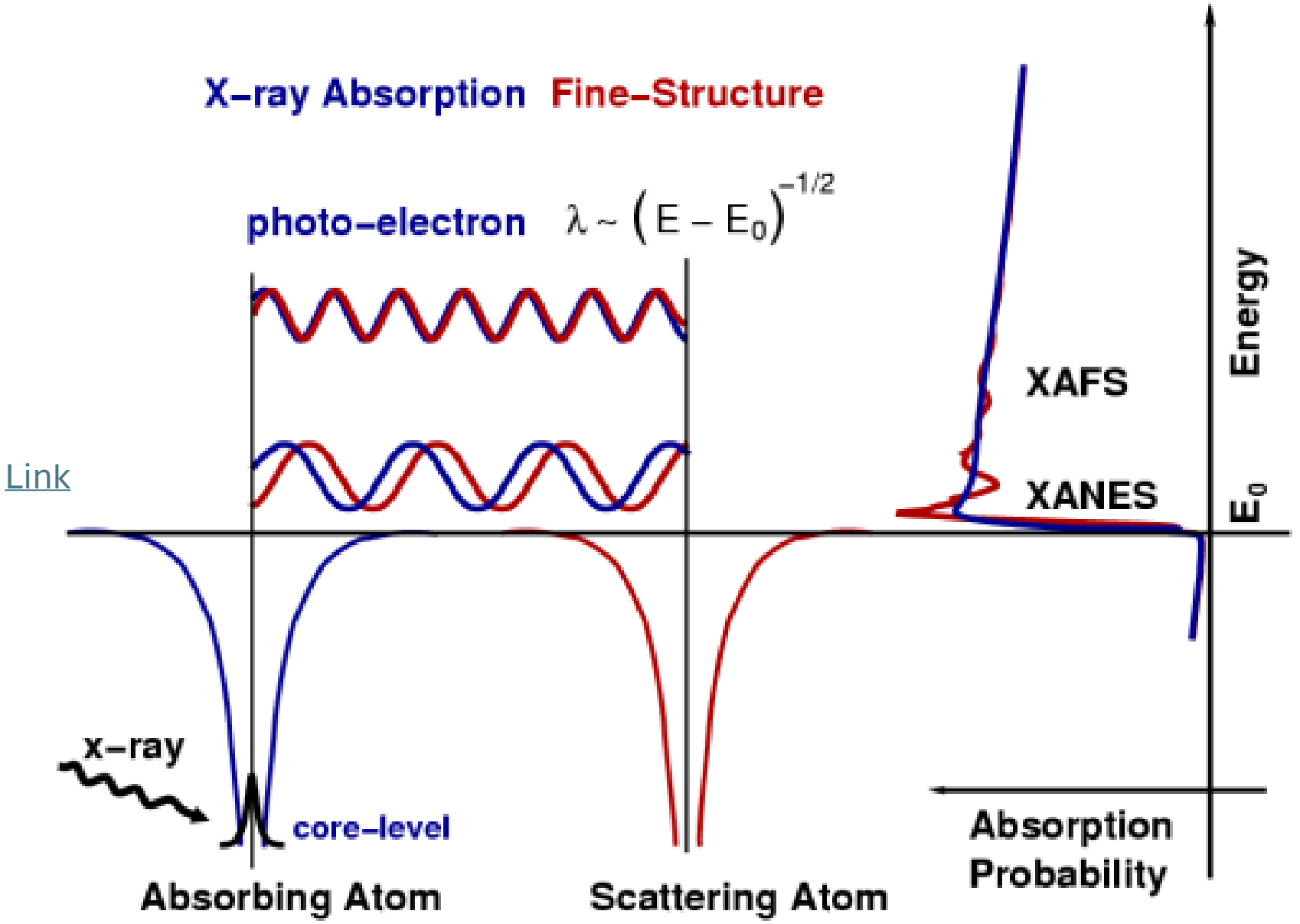
Cryogenic semiconductor detectors:

- Assuming known backgrounds.
- More exposure->Lower cross section.
- More sensitive detector -> Lower mass.

First need detector calibration.

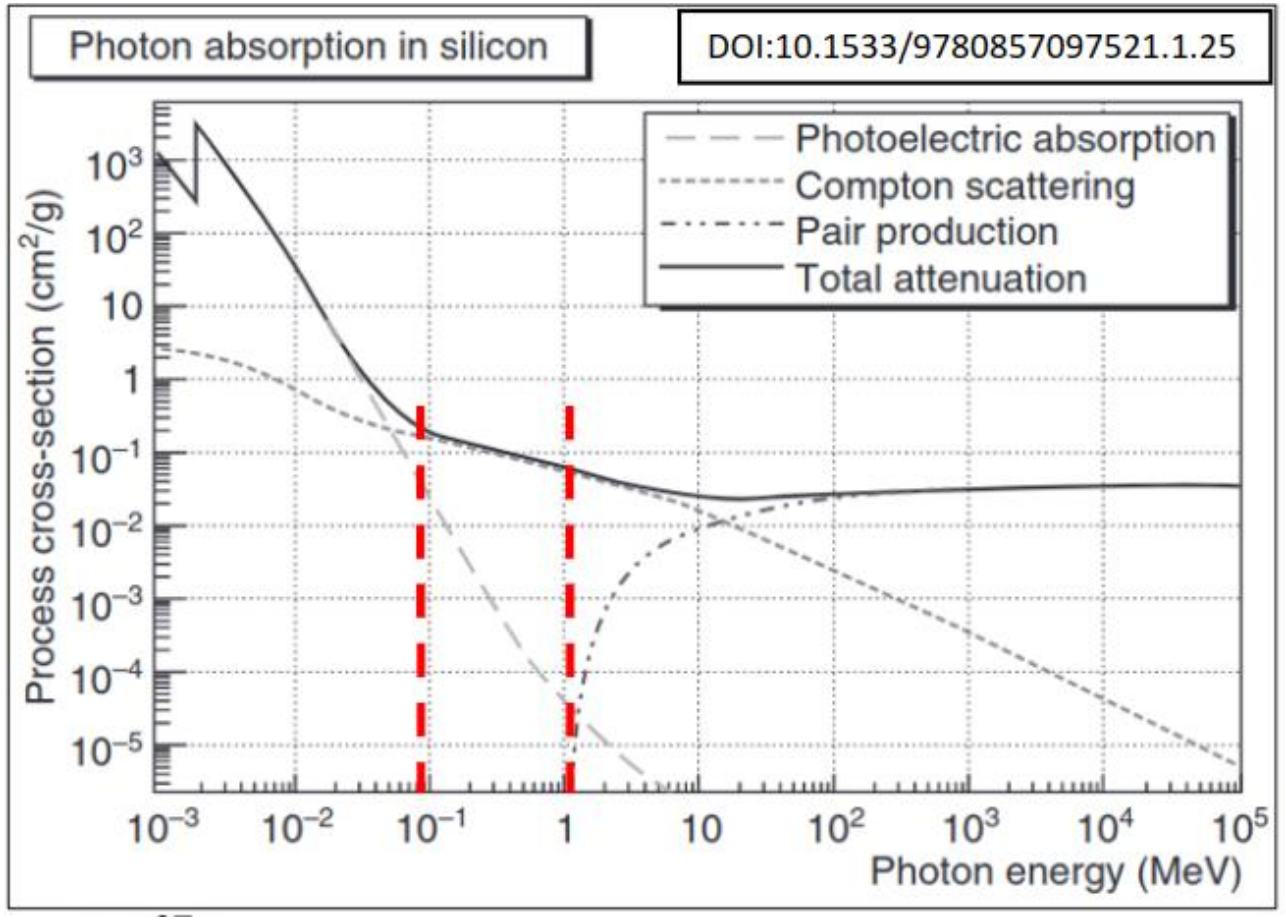


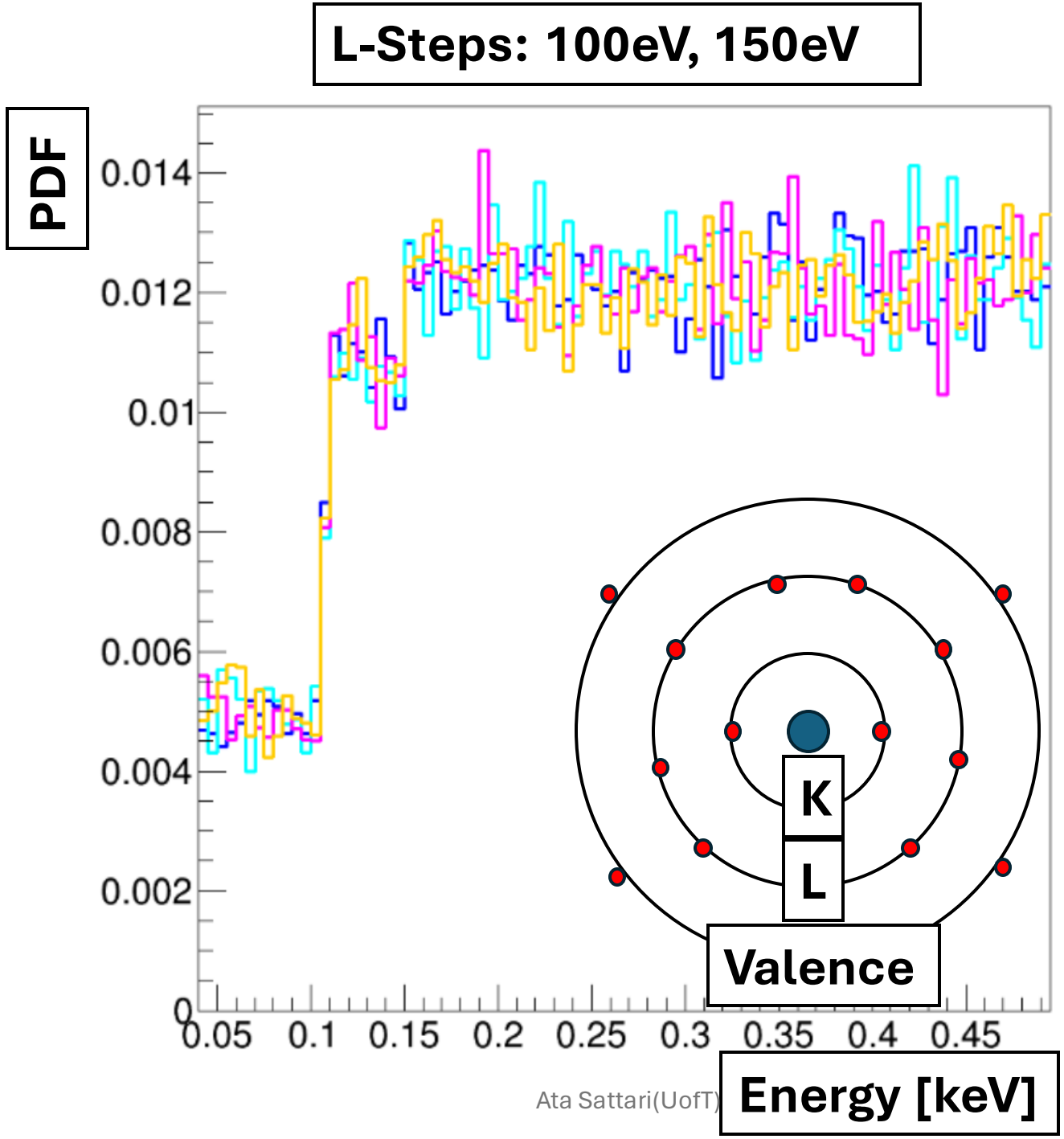
arXiv:1610.00006


X-ray Absorption Fine-Structure
photo-electron
$\lambda \sim (E - E_0)^{-1/2}$
XAFS
XANES
Energy
E_0
x-ray
core-level
Absorbing Atom
Scattering Atom
Absorption
Probability

Link

Silicon absorption length




L-Steps: 100eV, 150eV
PDF
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
K
L
Valence
Energy [keV]

Geant4 geometry