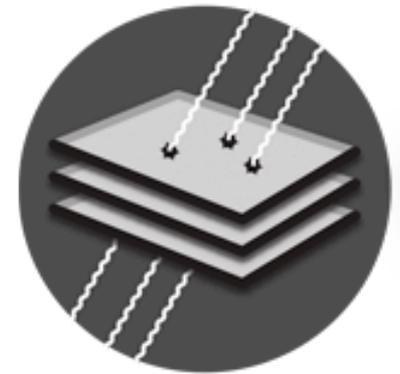




Characterization of low energy ionization signals from Compton scattering in a CCD Dark Matter detector

Karthik Ramanathan

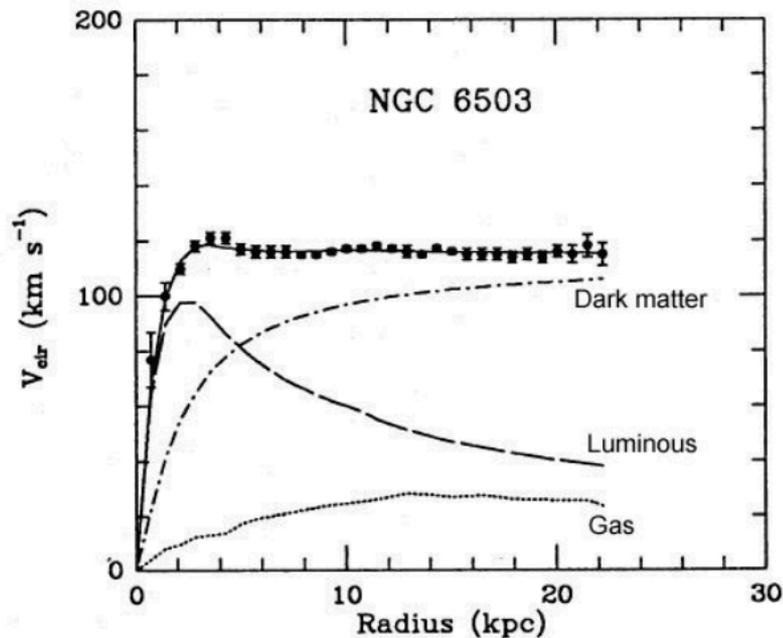
University of Chicago



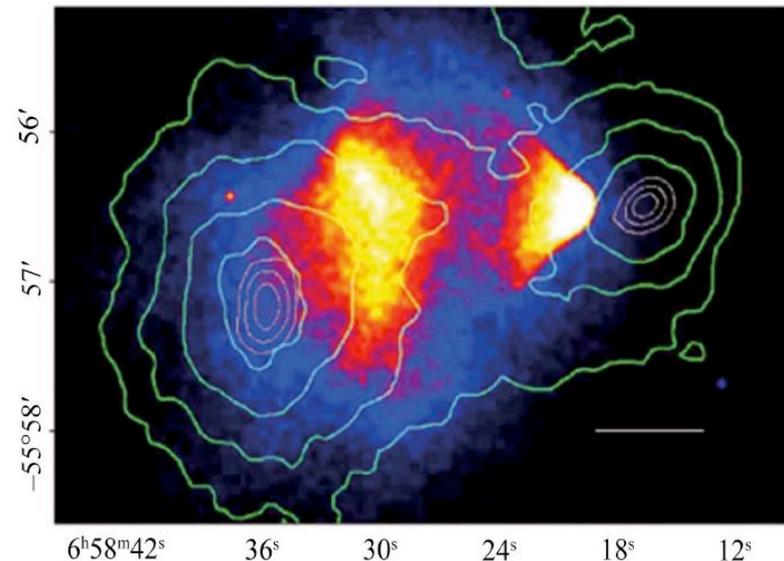
Fermilab New Perspectives 2017

Dark Matter

- ▶ Evidence from galactic rotation, structure formation, gravitational lensing etc.
 - ▶ Missing mass problem → **Dark Matter**
 - ▶ Λ CDM → **~26%**



Begeman et al. (1991)



Clowe et al. (2006)

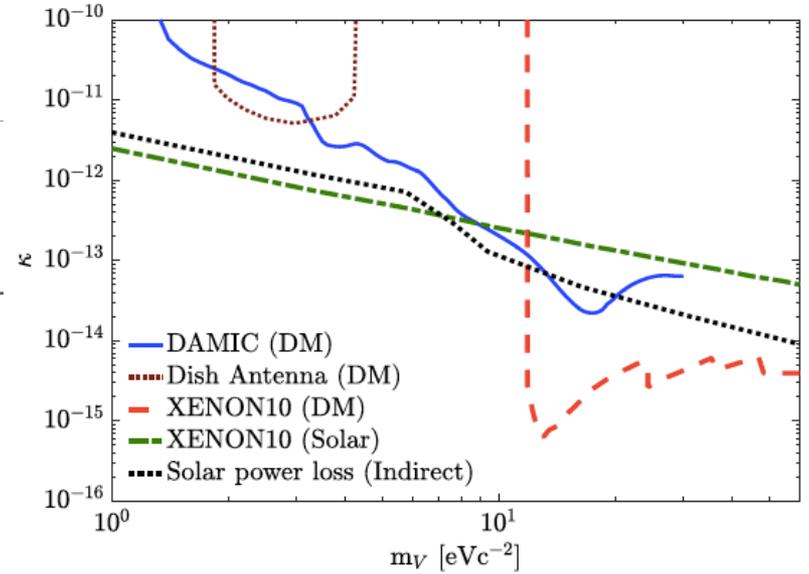
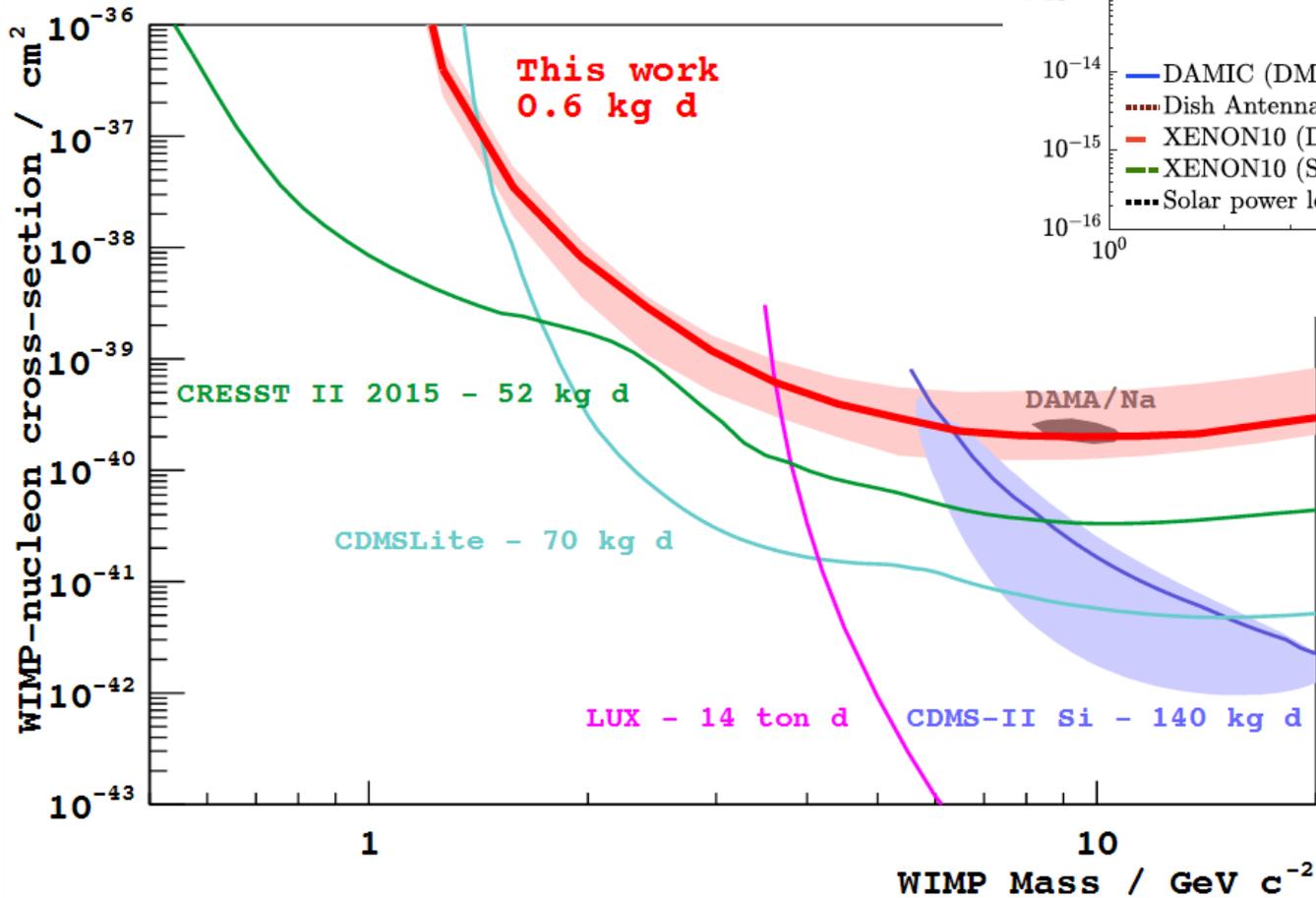
DAMIC in brief

- ▶ DAMIC – **D**ark **M**atter **I**n **C**CDs
- ▶ Exploit properties of CCDs (like the one in your pocket) to detect & analyze particles
- ▶ Dominant DM paradigm WIMPs (Weakly Interacting Massive Particle) → Nuclear Recoil
- ▶ Lots of alternative candidates (e.g. Axion Like Particles, Hidden Photons)
- ▶ DM-E scattering + interactions
- ▶ DAMIC-100 detector currently deployed at SNOLAB

DAMIC Collaboration

- FERMILAB
-  ➤ U Chicago
- U Michigan
-  ➤ SNOLAB
-  ➤ UNAM (Mexico)
-  ➤ FIUNA (Paraguay)
-  ➤ UFRJ (Brasil)
-  ➤ U. Nacional del Sur
- Centro Atomico Bariloche
-  ➤ U. Zurich
-  ➤ LPNHE (Paris 6/7)
- 11 institutions
- 8 countries
- 39 collaborators

Latest Exclusion Plots

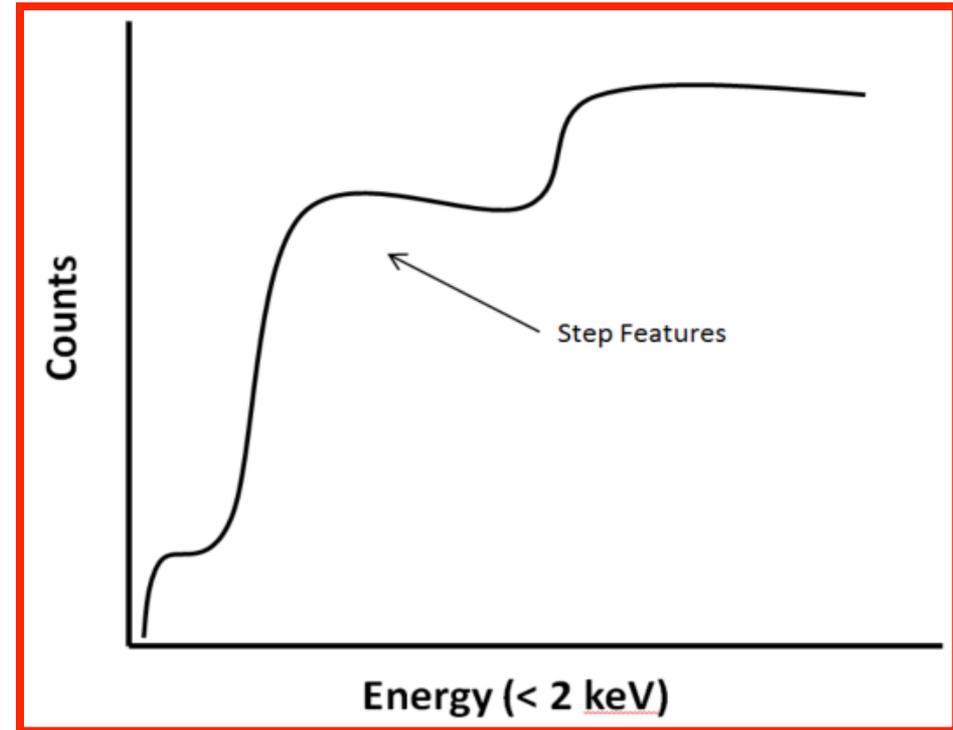
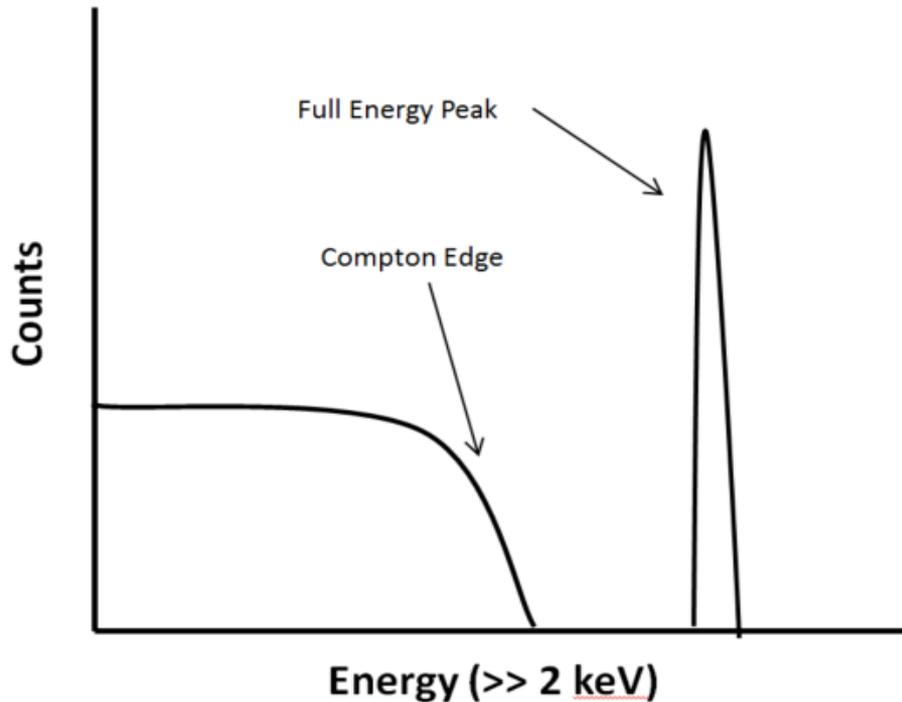


Motivation & Approach I

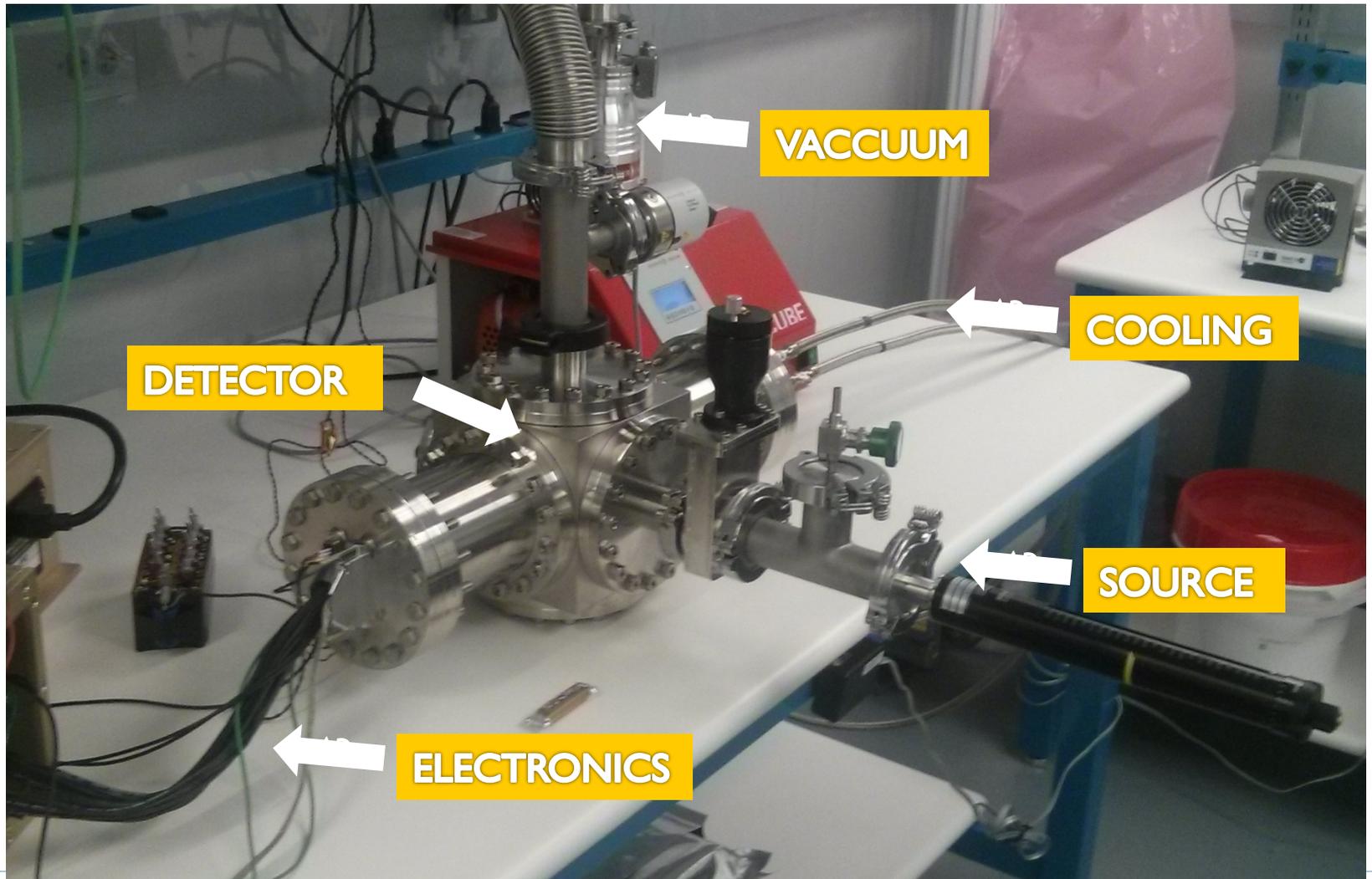
- ▶ At low energies of our searches (2-100 e-) dominant background from environmental radiation are low-energy electron recoils due to small-angle Compton scattering of external gammas.
- ▶ Flux is orders of magnitude higher than fast neutrons – the usual consideration for external source of signals
- ▶ Irreducible ER background → potential DM can only be identified by spectrum.
- ▶ Need complete understanding of low-energy spectral features.
 - ▶ Expose detector to ^{57}Co (~130 keV) and ^{241}Am (~60 keV)

Motivation & Approach II

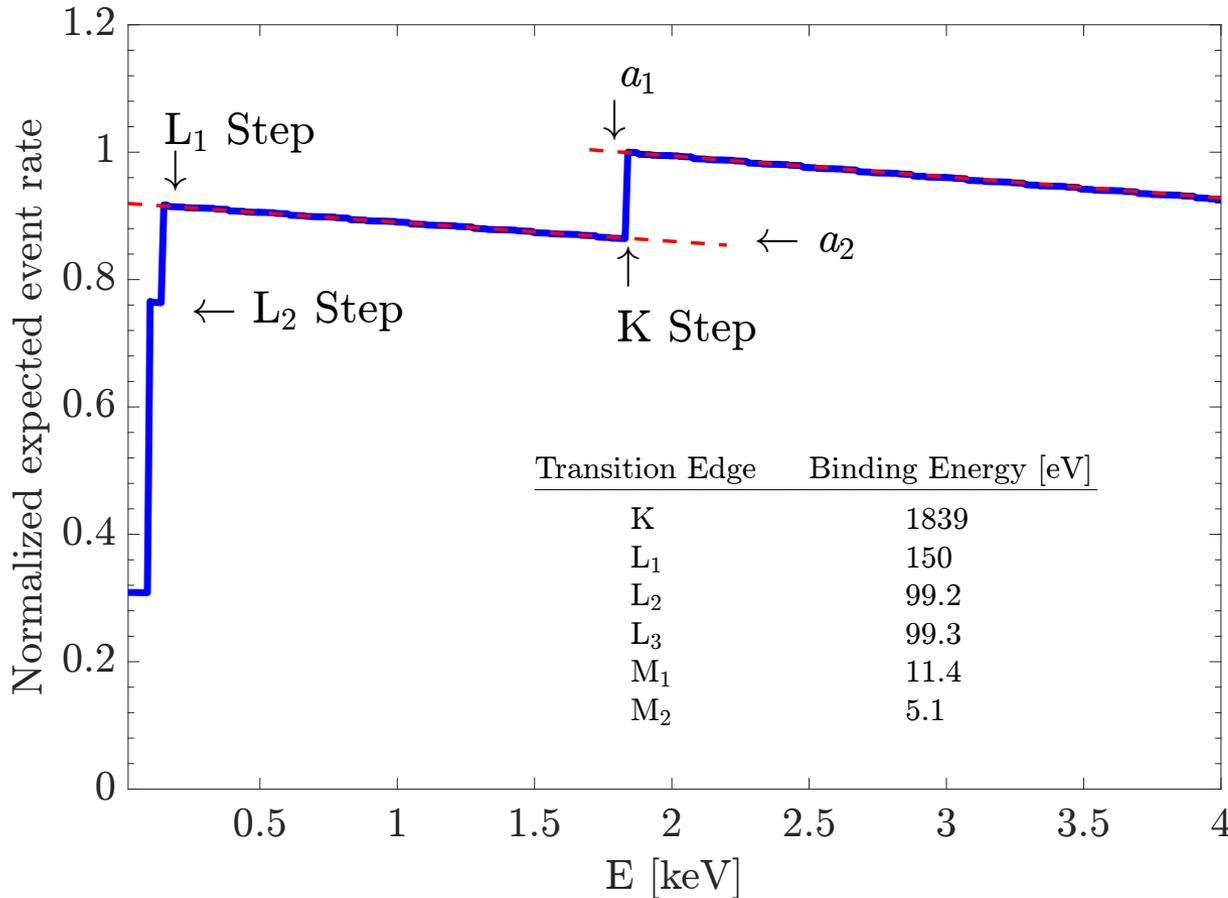
- ▶ Expose to γ -ray source
 - ▶ Compton features + ?



Testbed (UChicago)

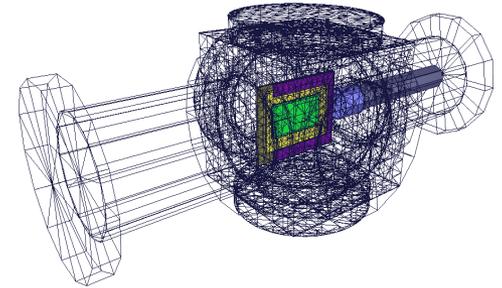
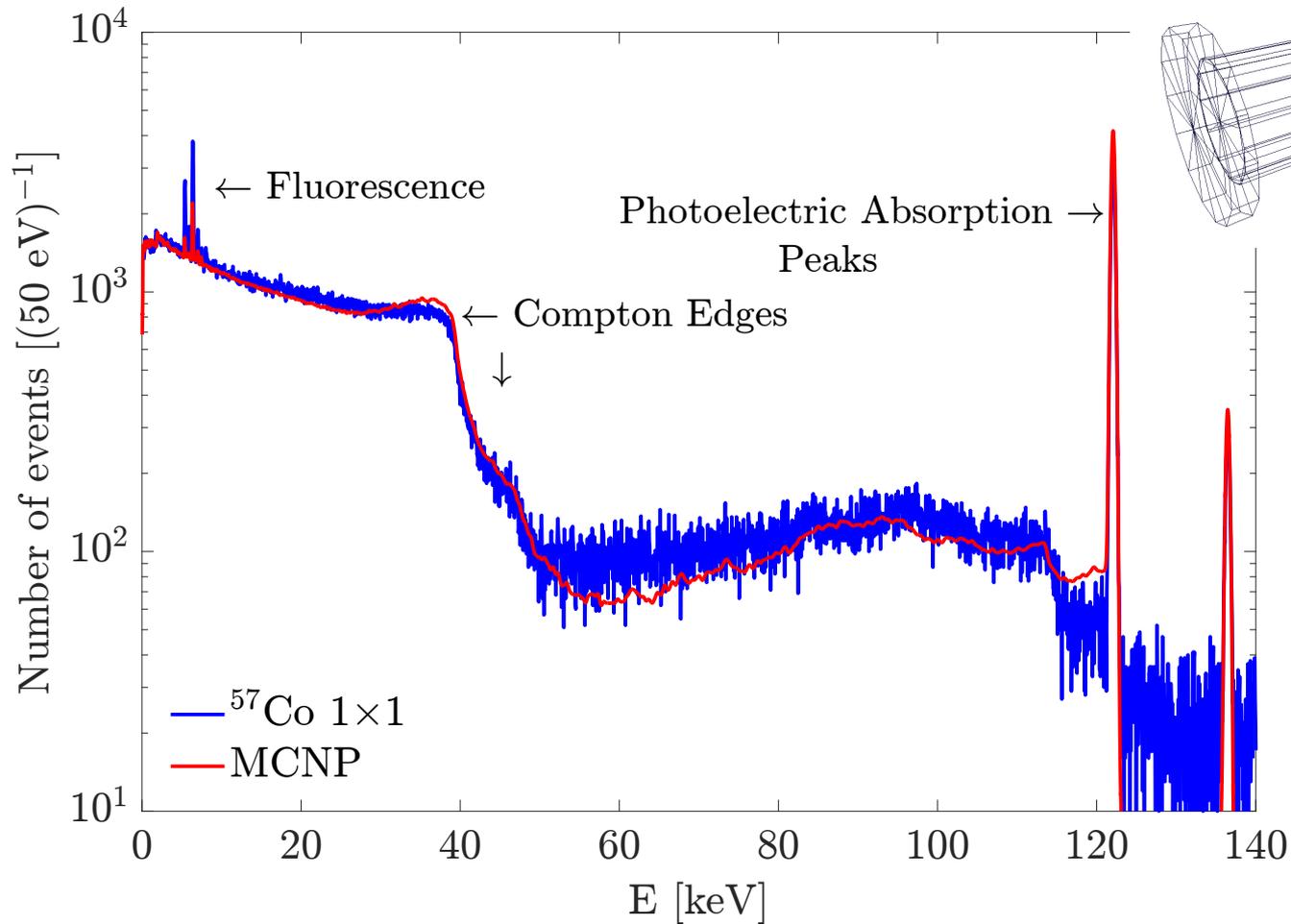


Expected Spectrum

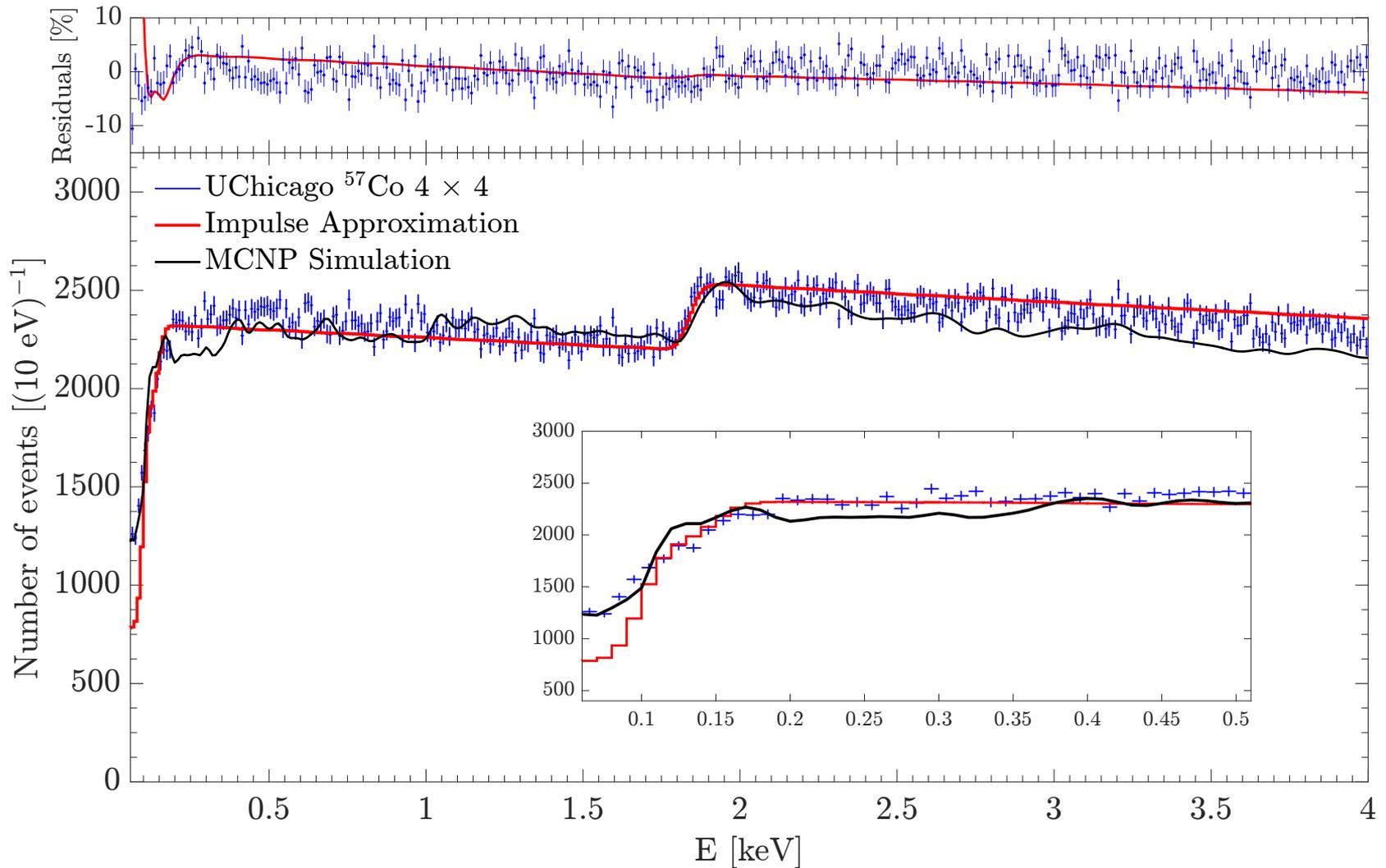


- ▶ Visible Step features
- ▶ From Impulse Approximation
- ▶ Silicon Binding Energies
- ▶ Fit with simple 3 parameter model

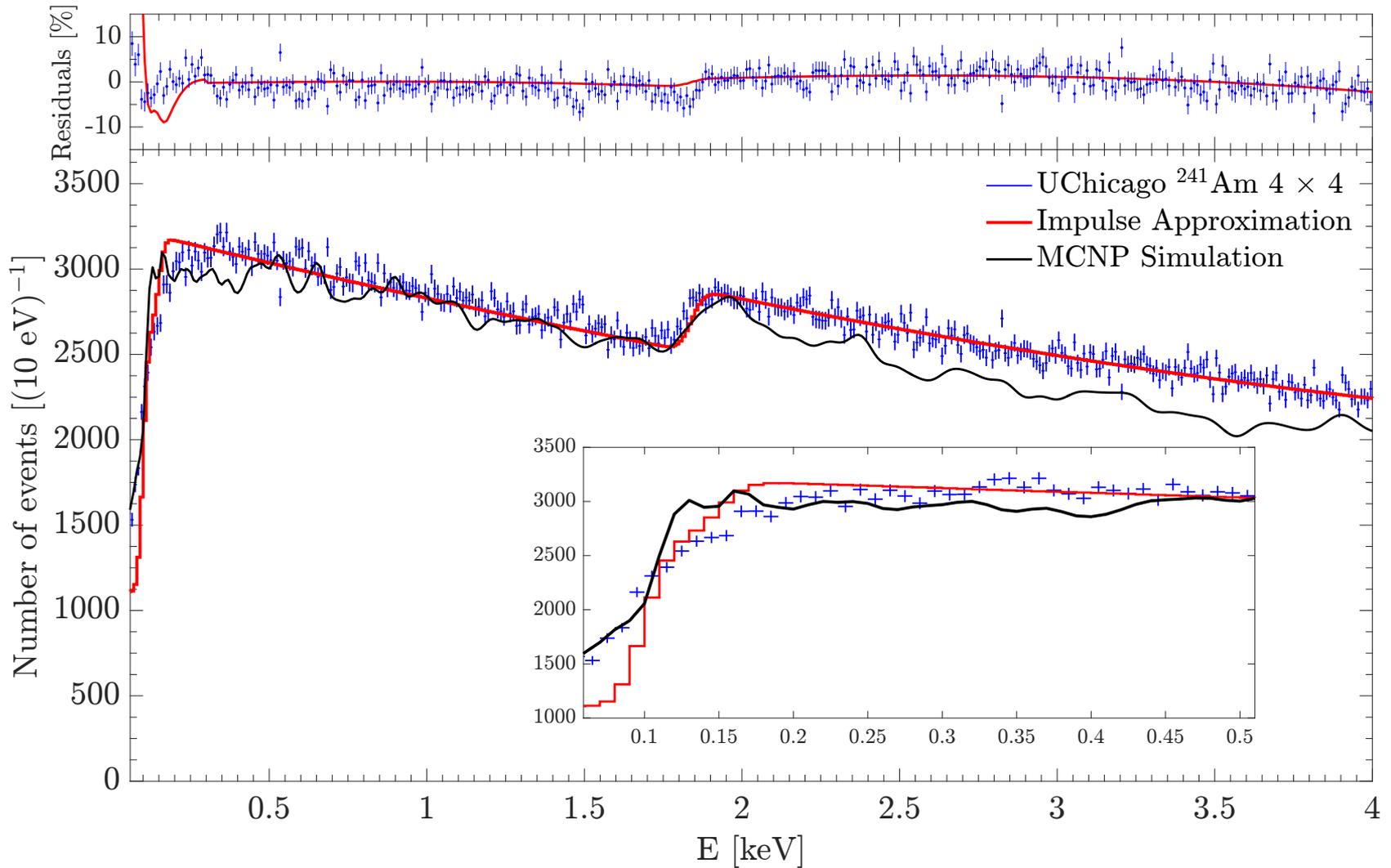
MCNP Simulation Model



Results - Cobalt

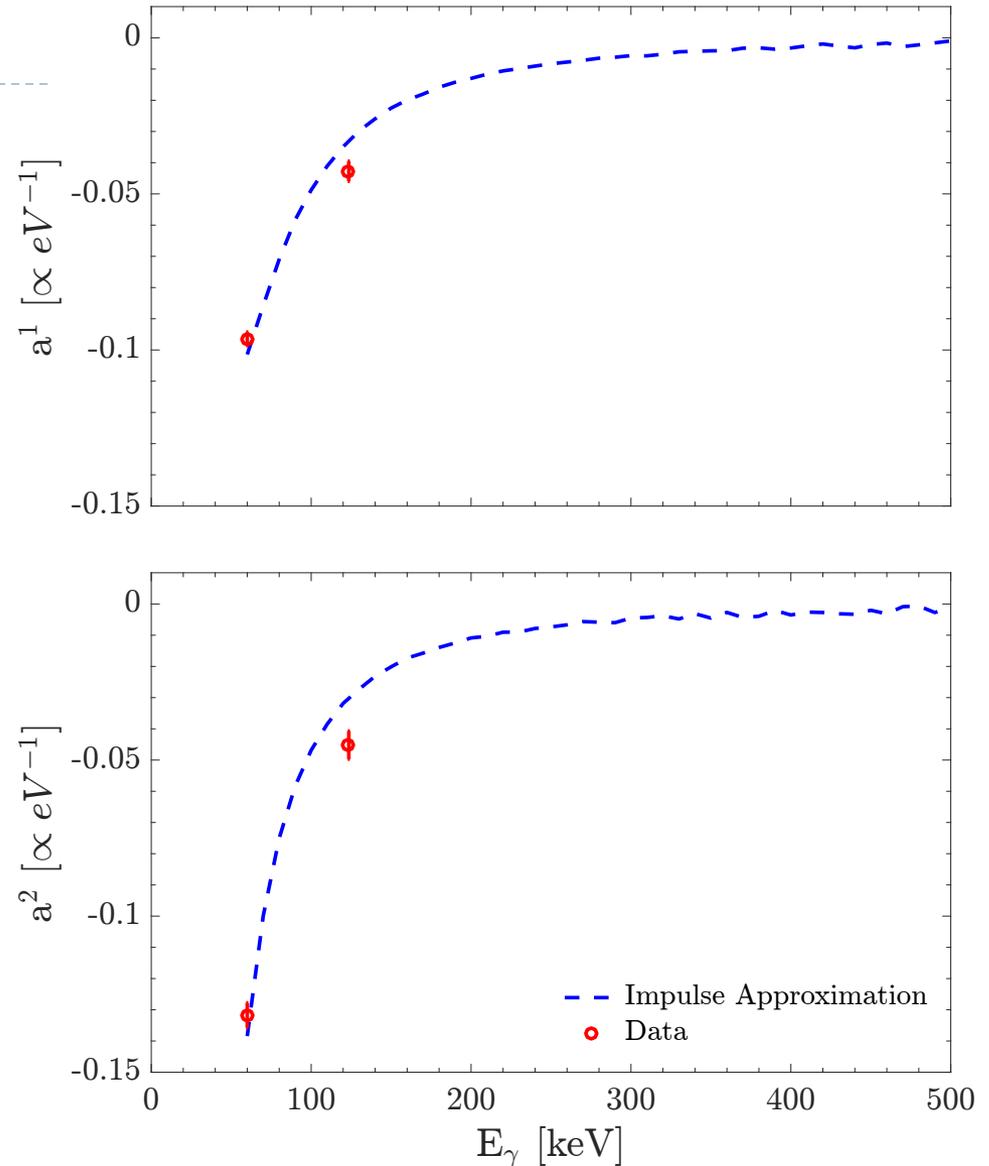


Results - Americium

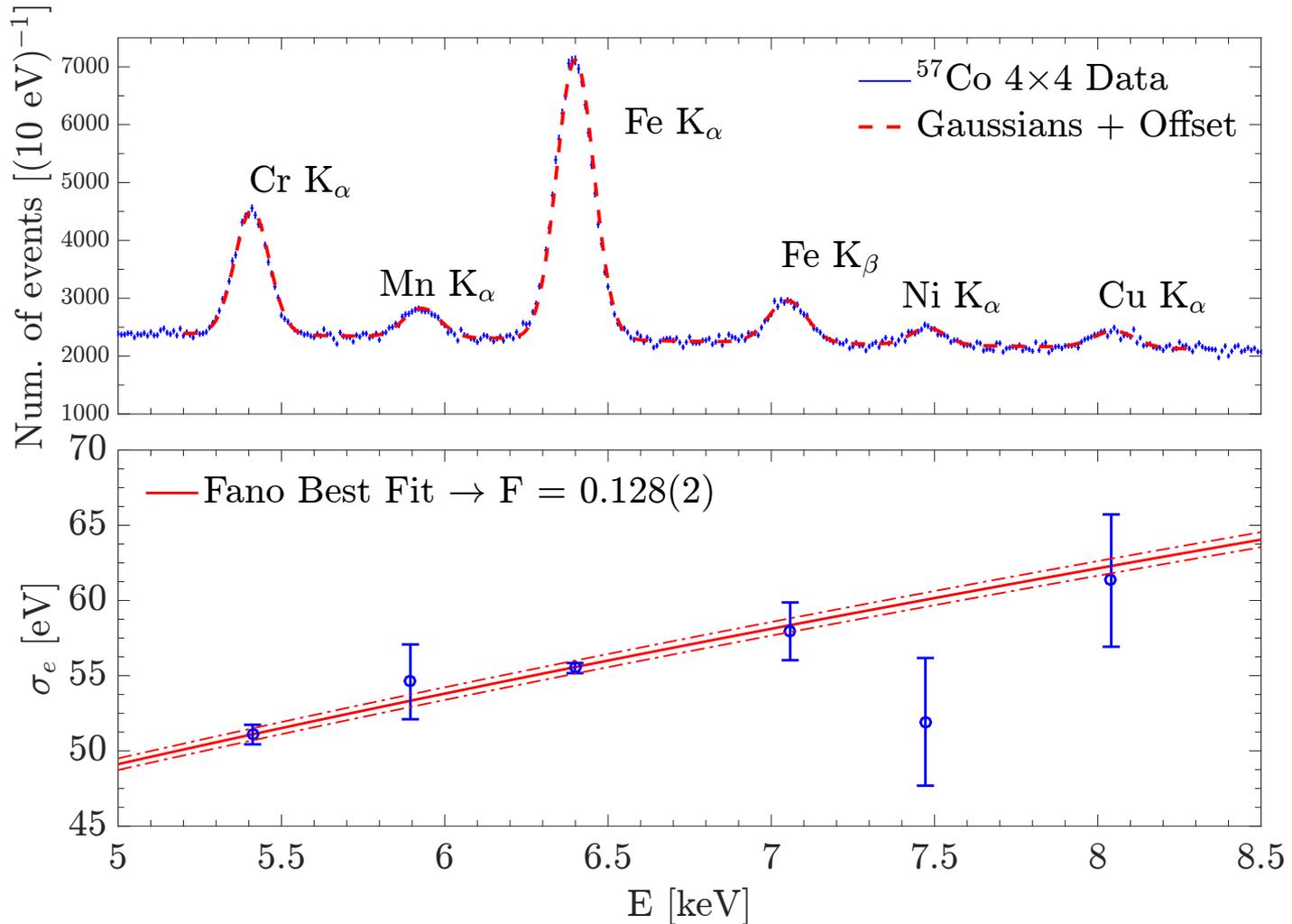


Model

- ▶ 3 parameter model
→ 2 linear slopes
(+1 scale factor).
Able to model fit
in 1-10 keV range
without accurate
background
knowledge.
- ▶ Flattens out at high
 γ energies



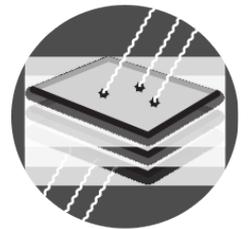
Fano Factor (@ 130 K)



Takeaway

- ▶ Demonstrate DAMIC's resolution down to ~ 60 eV
 - ▶ + Fano Factor
- ▶ Characterize the spectrum of low-energy ionization signals from electrons Compton scattered by radiogenic γ -rays, **vital for future DM searches**
- ▶ Validate applicability of very simple linear model

Questions?

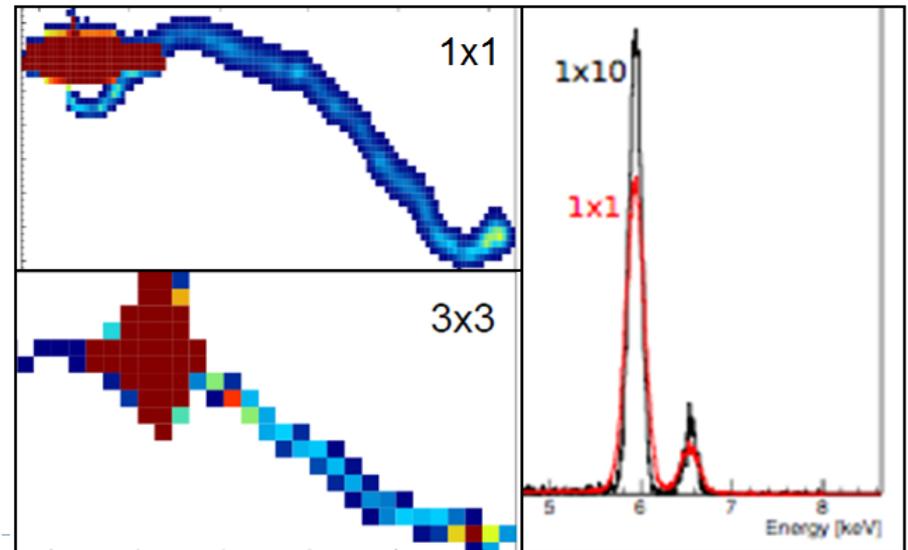


DAMIC

Backup - Data & Binning

Binning	Source	N images	V_{sub} [V]	Event density [keV ⁻¹]
1×1	⁵⁷ Co	1981	45	3.5×10^4
	Background	1235	45	4.3×10^3
	²⁴¹ Am	971	45	4.7×10^4
4×4	Background	2062	45	2.4×10^3
	⁵⁷ Co	1981	127	2.5×10^5
	Background	10276	127	2.6×10^2
	²⁴¹ Am	9828	127	2.5×10^5
	Background	2062	127	1.1×10^3

Charge of several pixels can be added together before moving it to the readout node. Some loss of spatial resolution but improved signal to noise (same readout noise but more charge in a binned pixel)



Backup - Impulse Approximation

- ▶ Each atomic shell treated independently. Bound electrons are modeled as free with constrained momentum distribution derived from bound-state wave function.

$$\left[\frac{d^2\sigma}{dE_s d\Omega} \right]_{IA} = r_0^2 \frac{m}{|\vec{q}|} \frac{E_s}{E_i} \frac{1 + \cos^2(\theta)}{2} J(p_z)$$
$$p_z = \frac{E_i E_s (1 - \cos(\theta)) - m_e c^2 (E_i - E_s)}{|\vec{q}| c^2}$$
$$|\vec{q}| = \frac{1}{c} (E_i^2 + E_s^2 - 2E_i E_s \cos(\theta))^{\frac{1}{2}},$$