Backgrounds in Low-Threshold Direct Detection Experiments

INT 22-2b
Dark Matter in Compact Objects, Stars, and in Low Energy Experiments

9th August 2022

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UC San Diego

Introduction

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- Strong evidence for the existence of dark matter through its gravitational interactions

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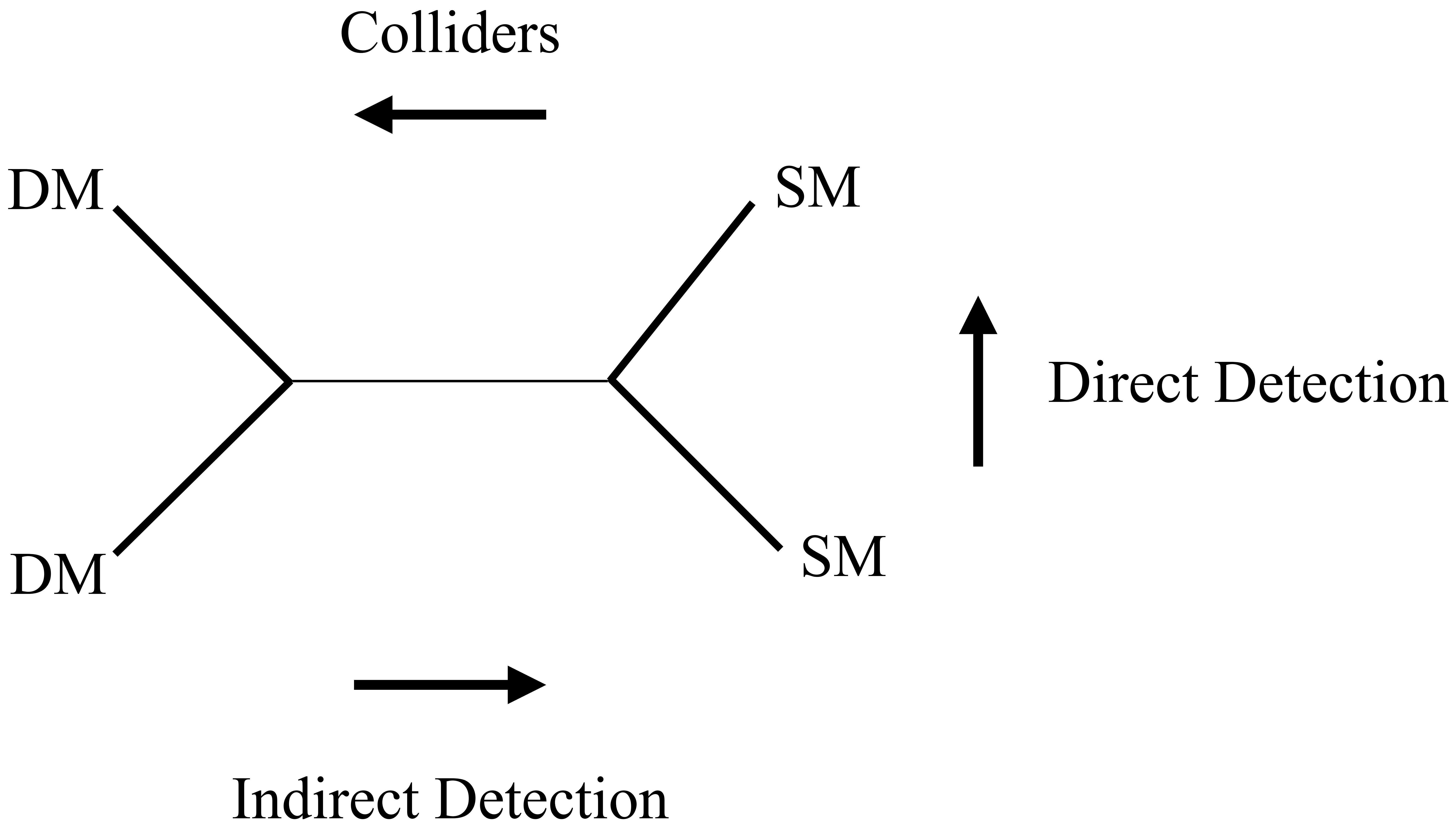
- The big question: does dark matter interact with SM particles through forces other than gravity?

- Several experiments have been probing various models of dark matter in different ways

Dark Matter (DM) Detection Strategies



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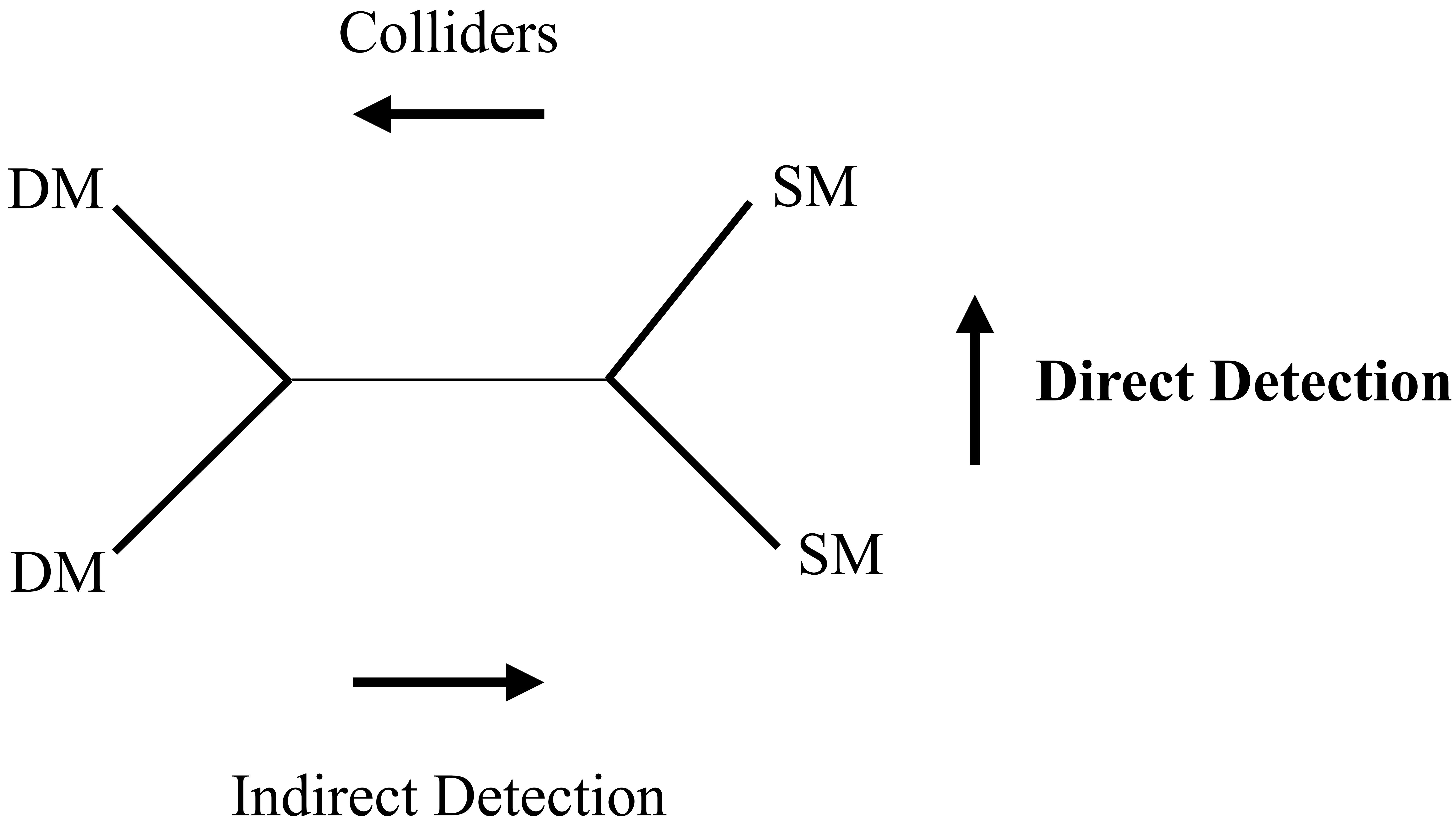
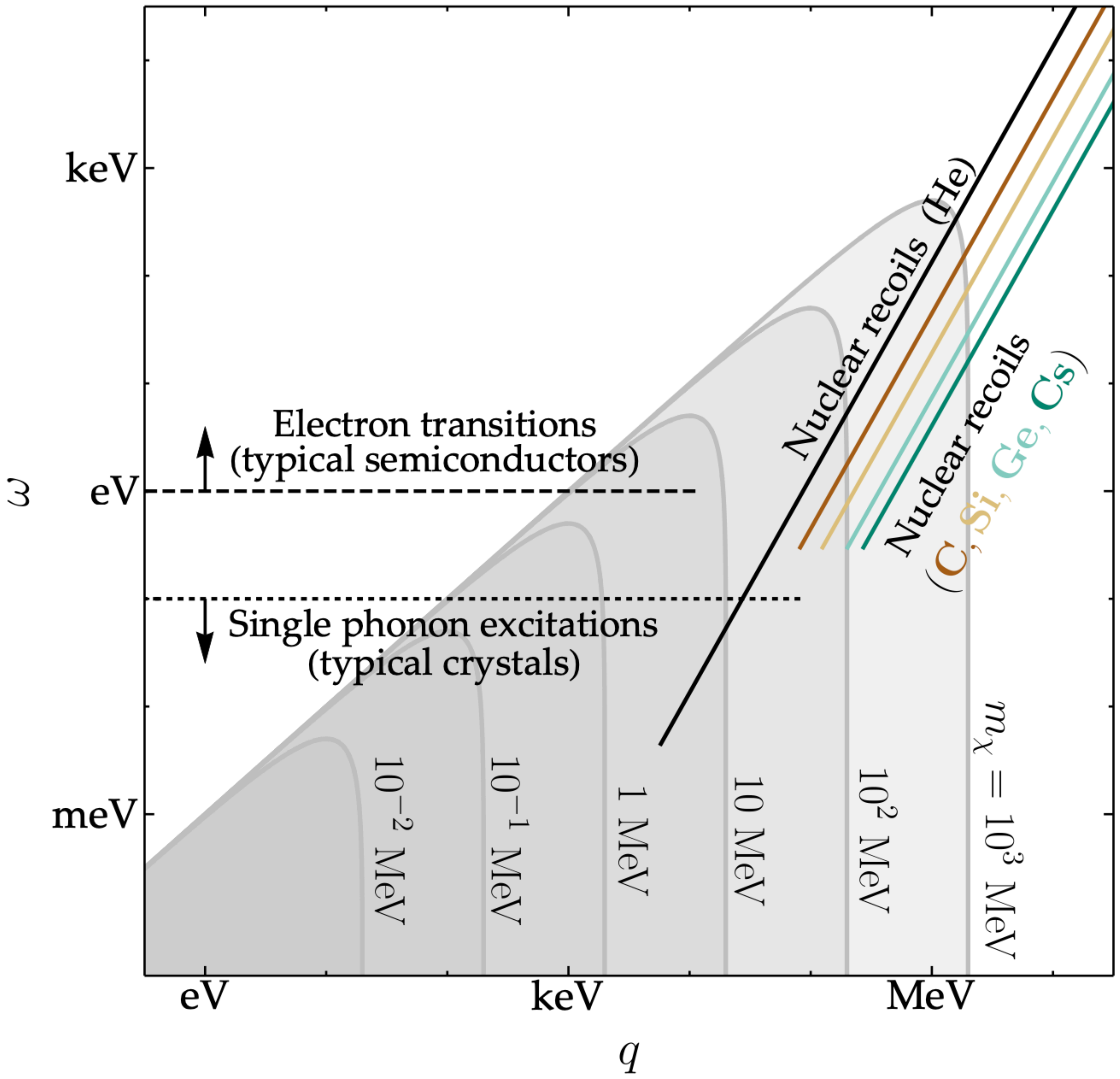


Channels of Direct Detection



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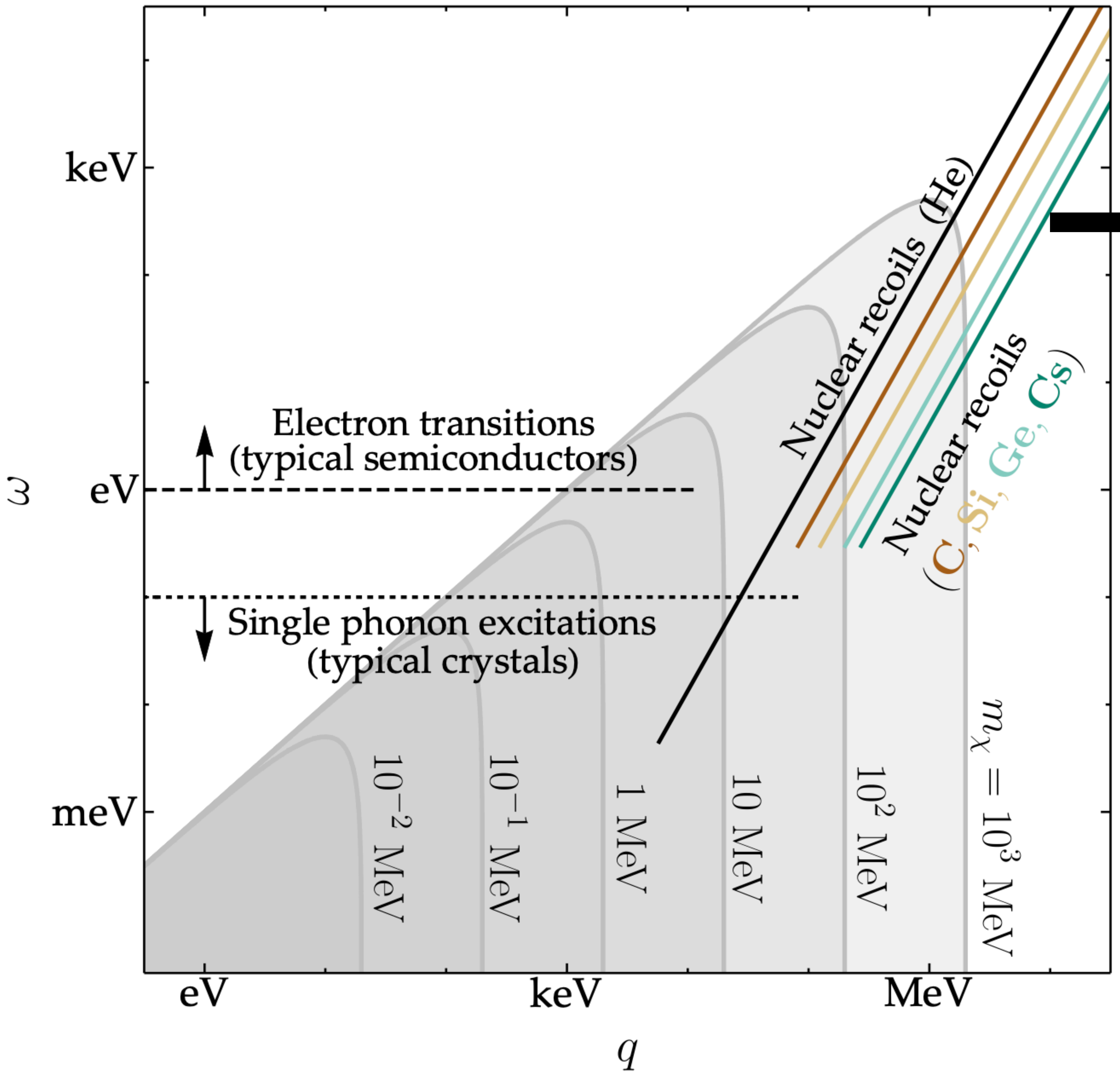

Traditional Detection Method (~ GeV DM mass and above)

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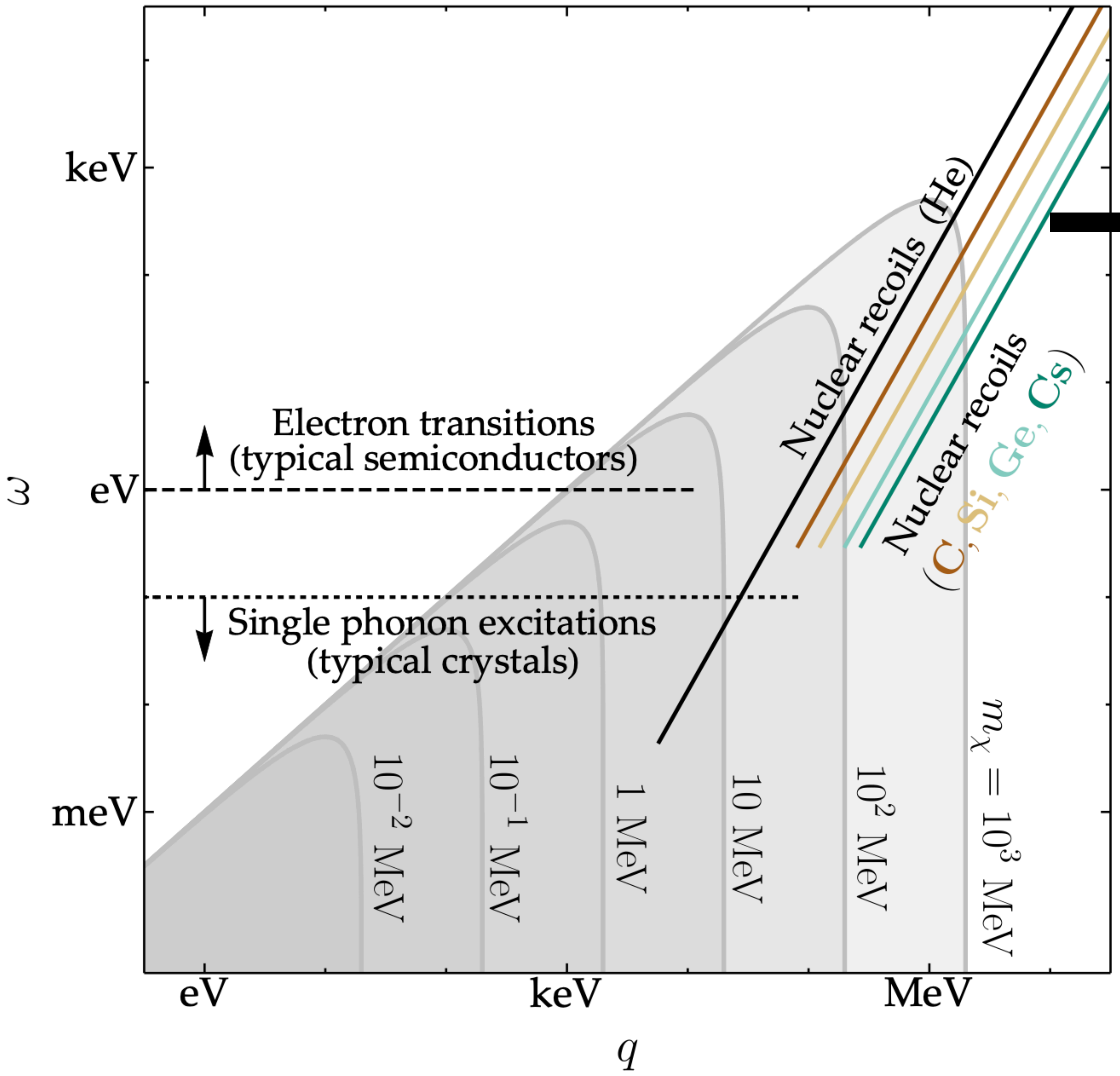

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Well-Understood Radiogenic and Cosmogenic Backgrounds above ~ keV recoils

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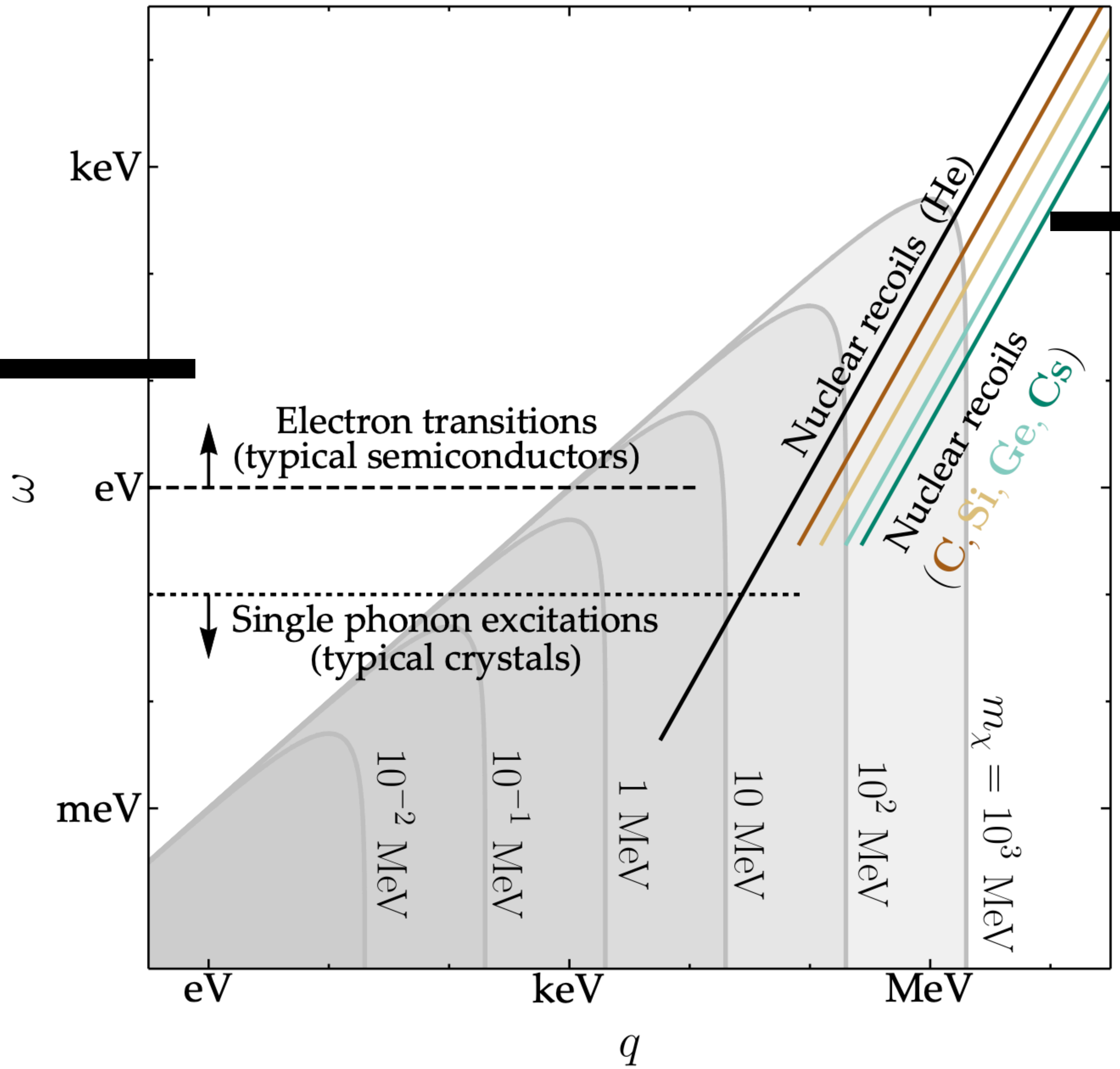
Recent Detection Method (probe sub-GeV DM)



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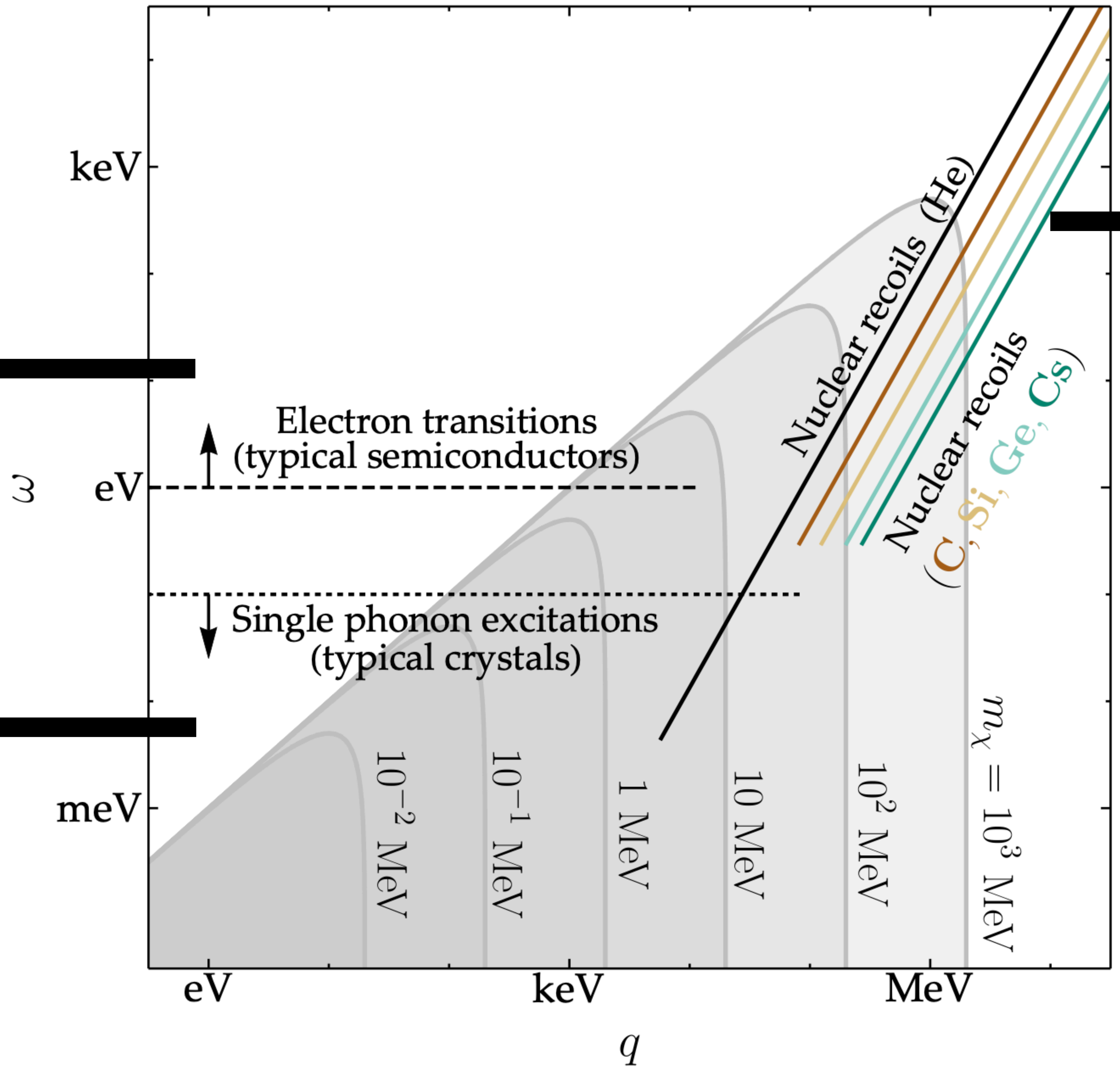

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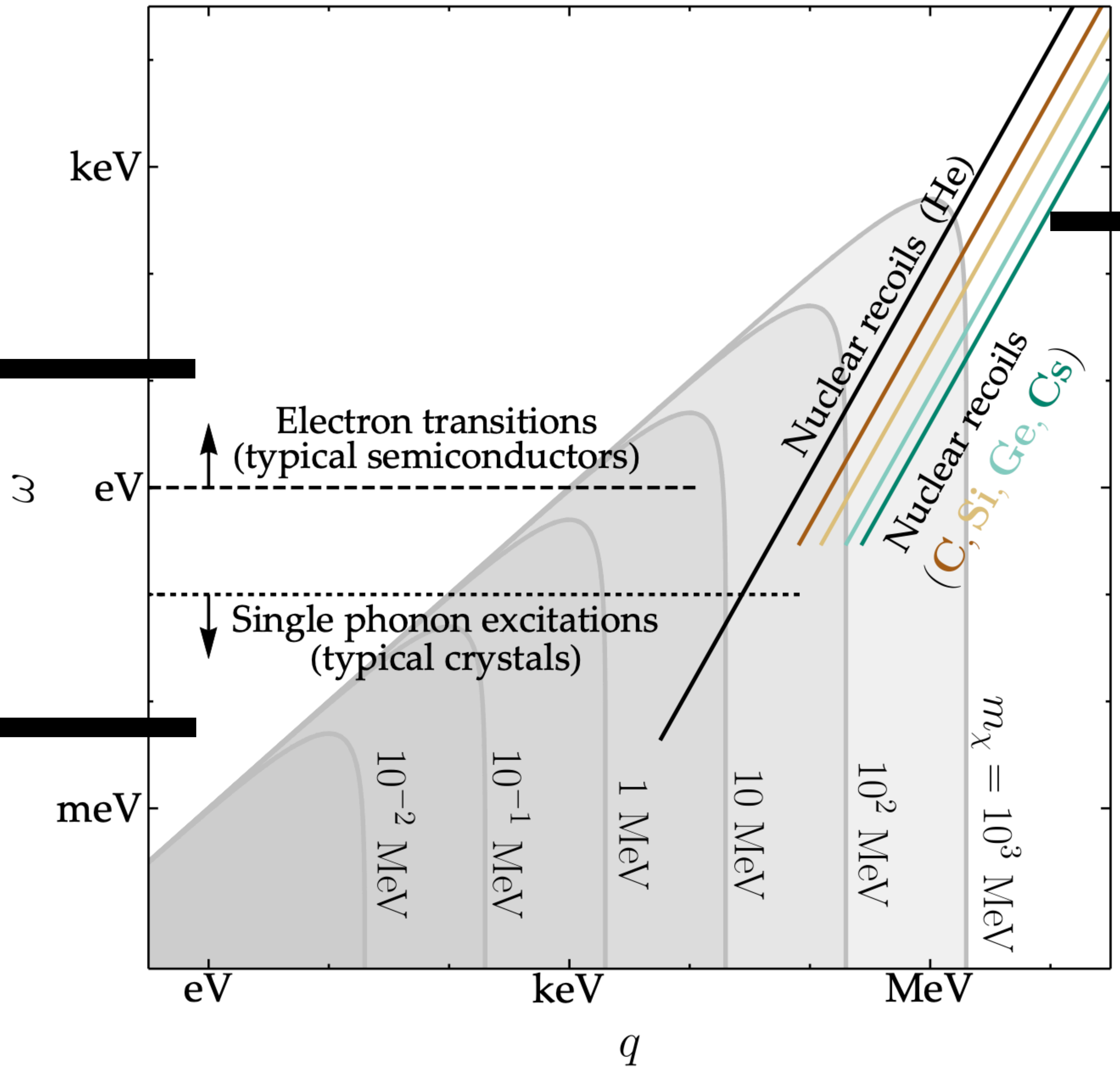

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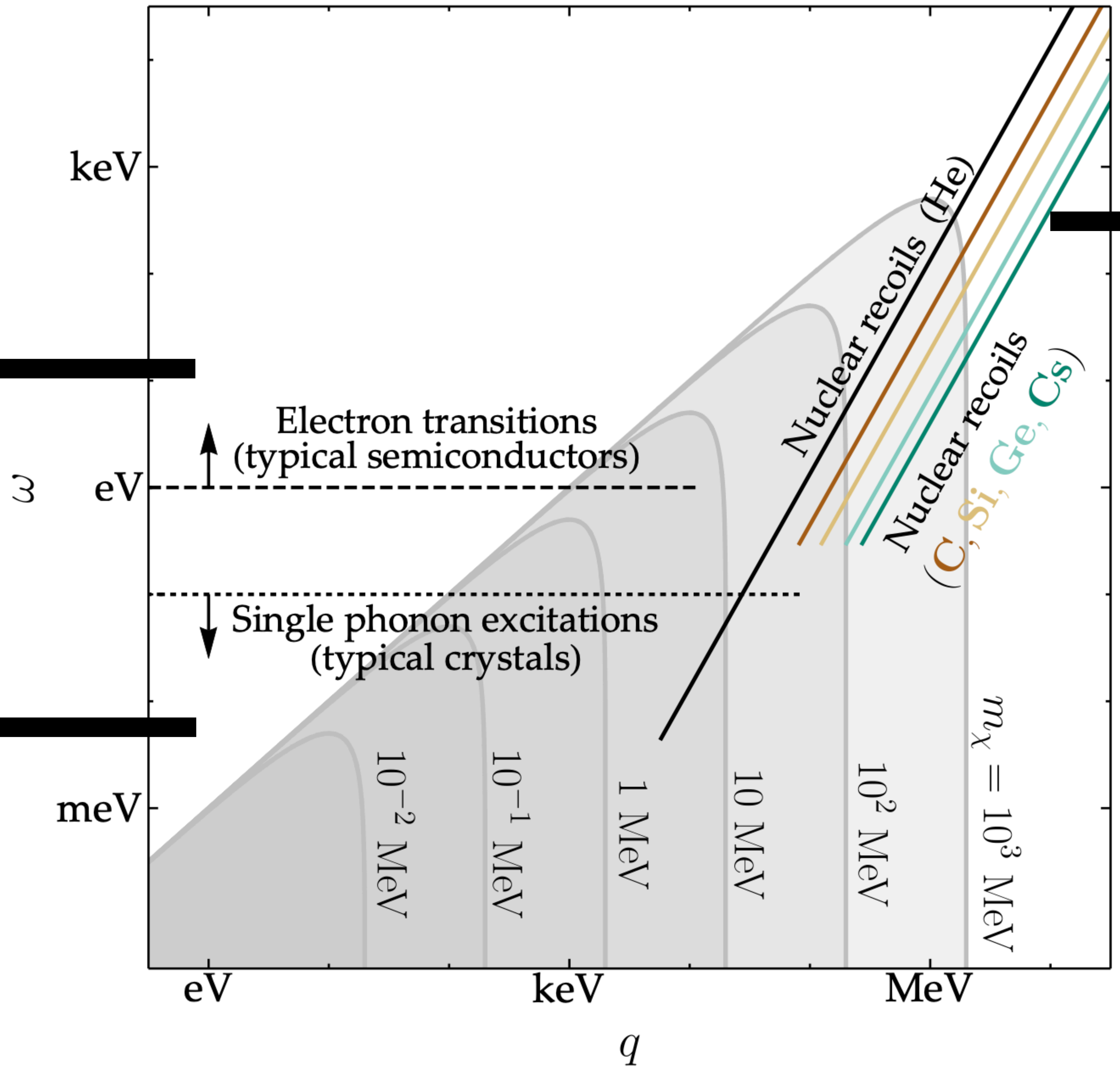

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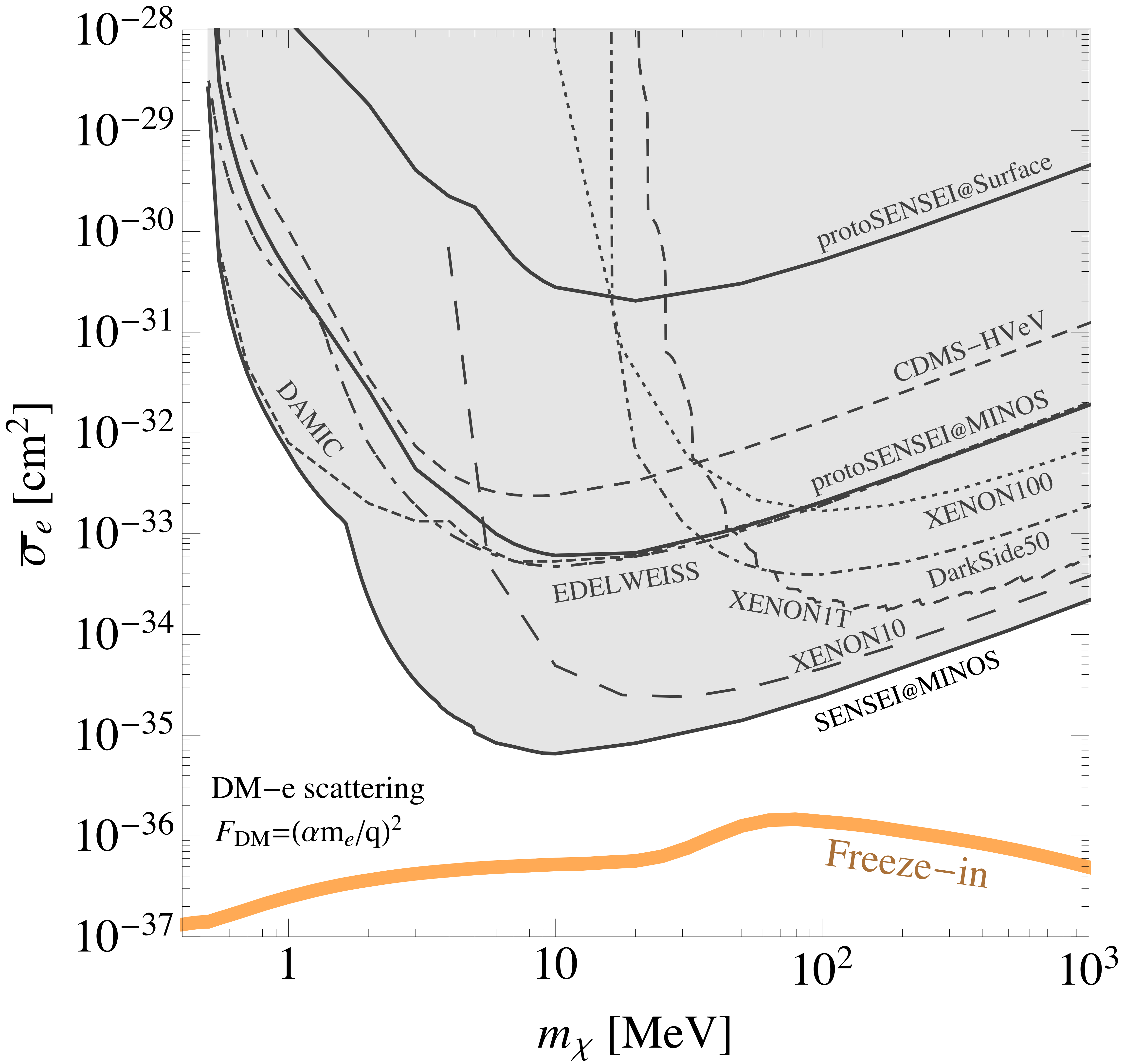

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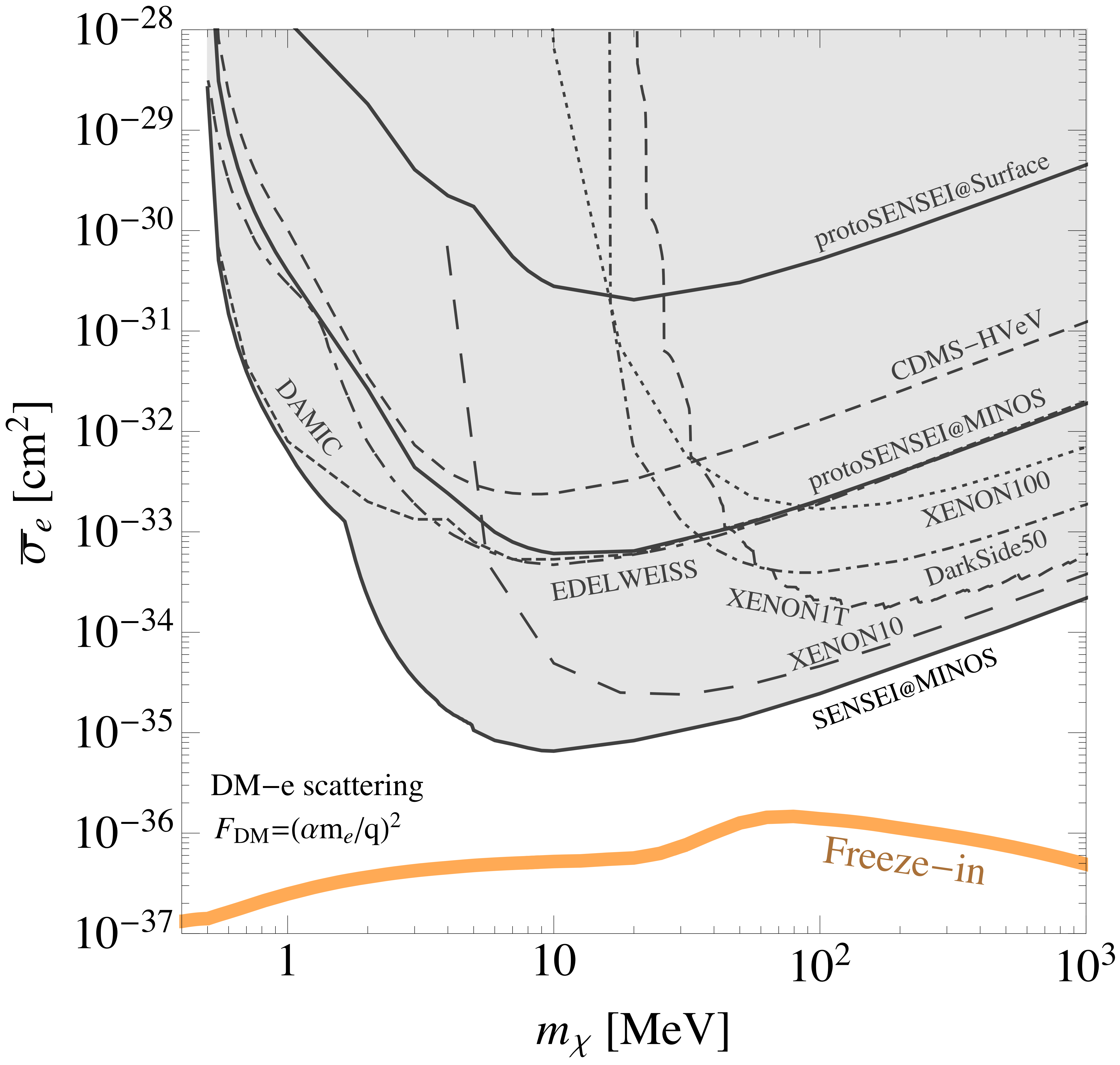

Well-motivated targets in sub-GeV parameter space

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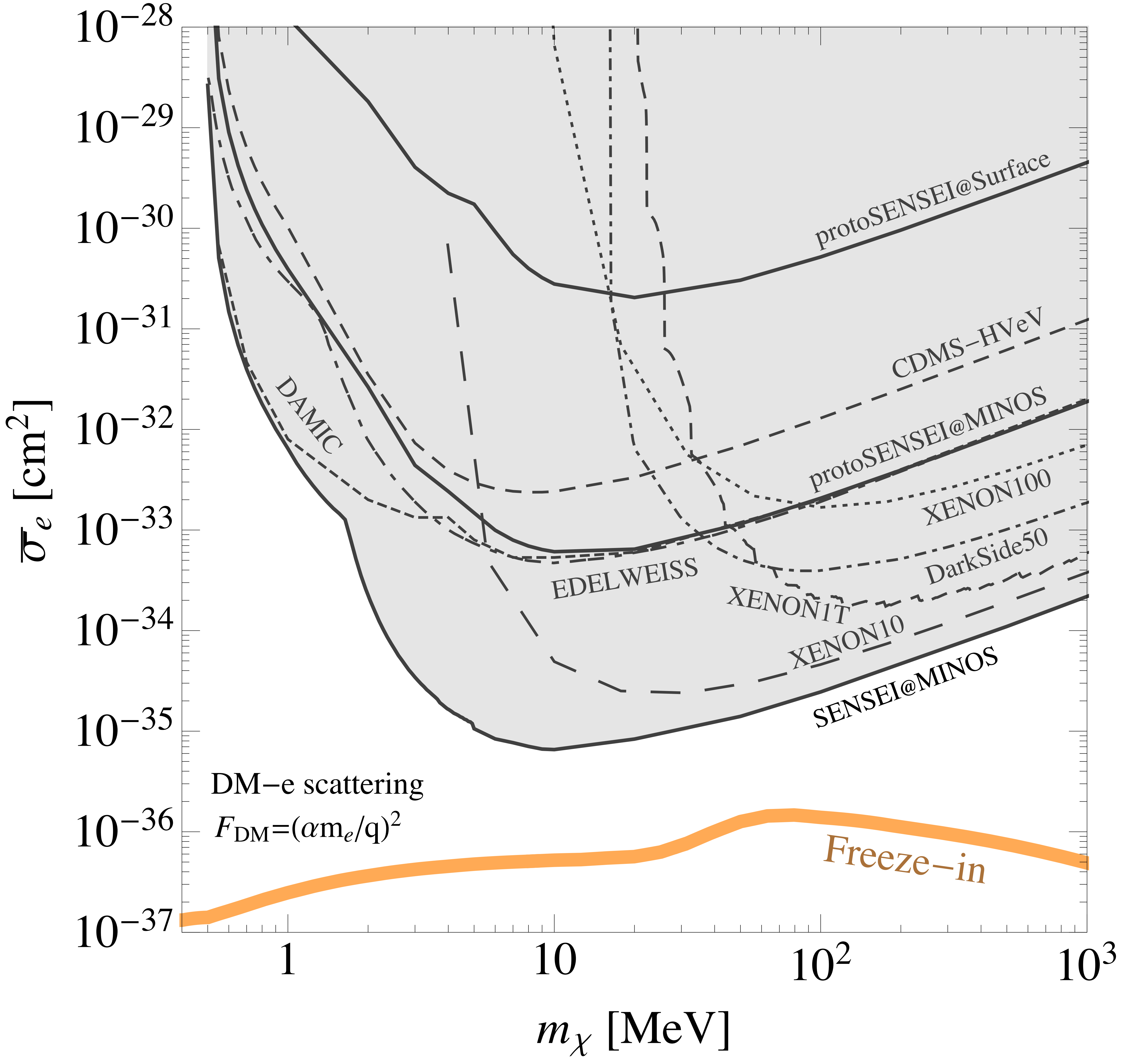
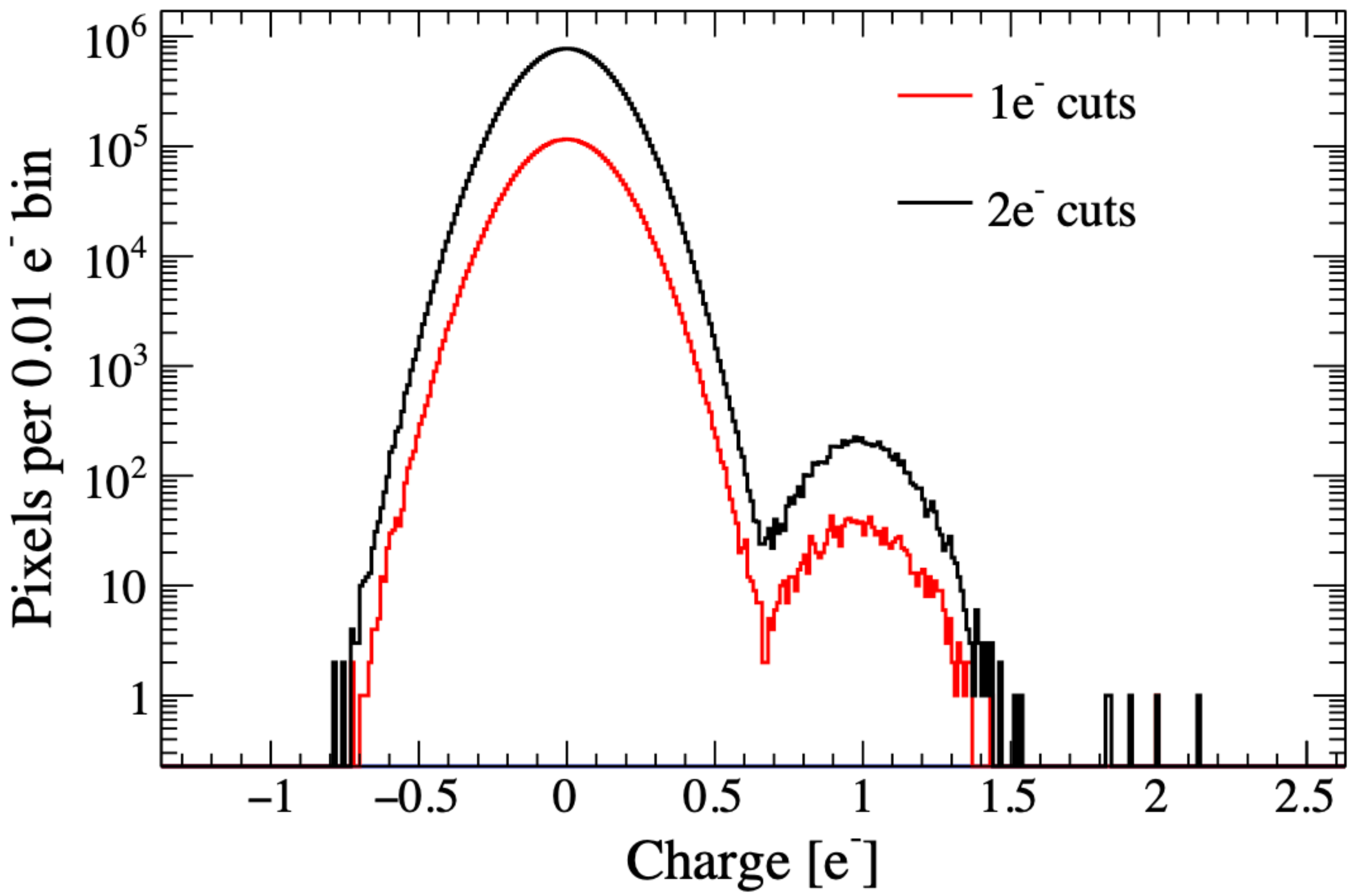


Well-motivated targets in sub-GeV parameter space

Sensitivities could be limited by backgrounds

Excesses in Low-Threshold Dark Matter Searches

- Several experiments observe a sizable number of low-energy events
- For example, searches for electron recoils like SENSEI:



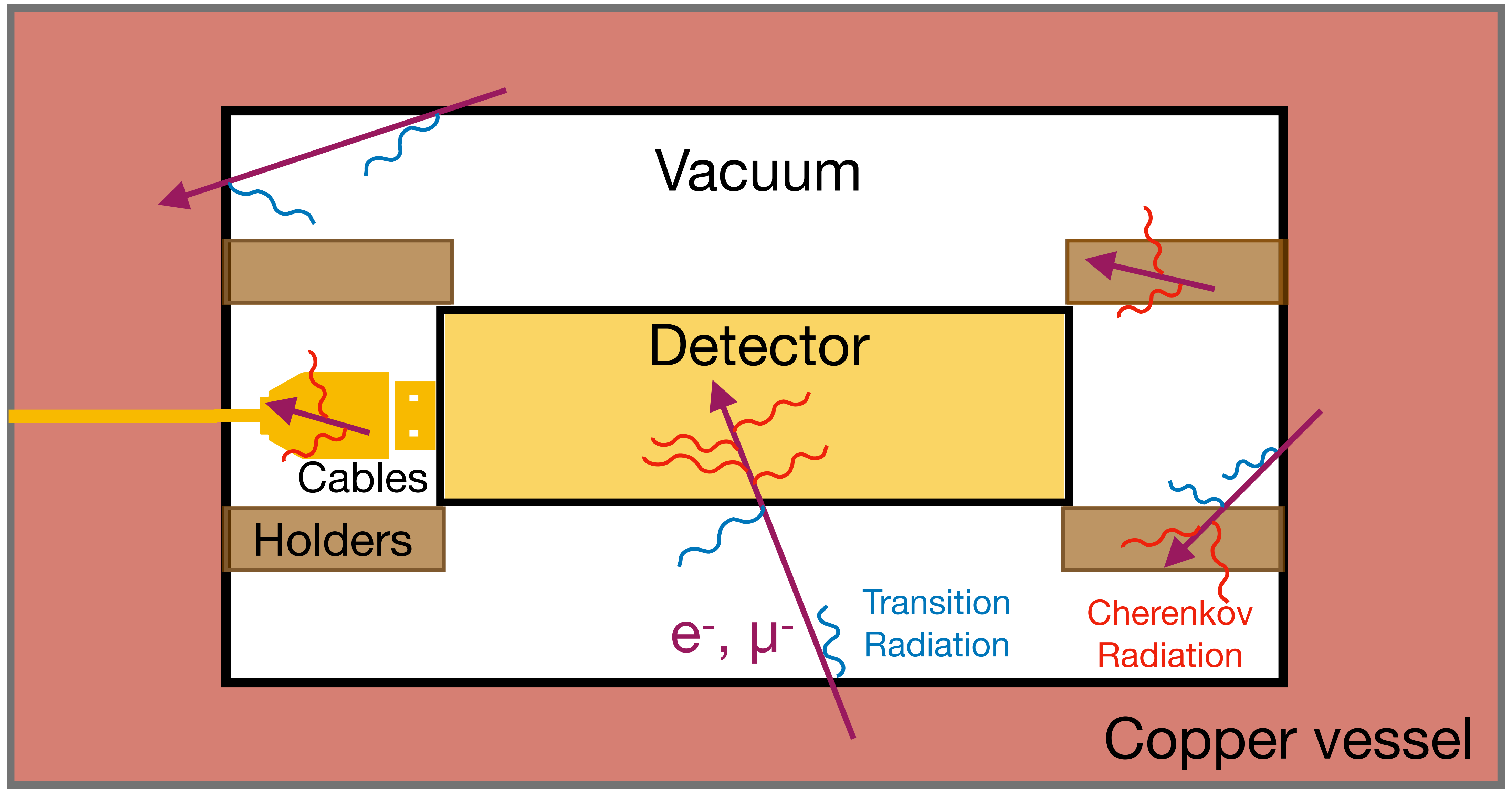
**SENSEI, 2020*

SENSEI
(Si, Skipper-CCD)

Hypothesis

*arXiv:2011.13939 Du, Egana-Ugrinovic, Essig, **MS**

- High energy particles can interact to create low-energy photons
- These photons can be absorbed to produce low-energy electronic recoil events

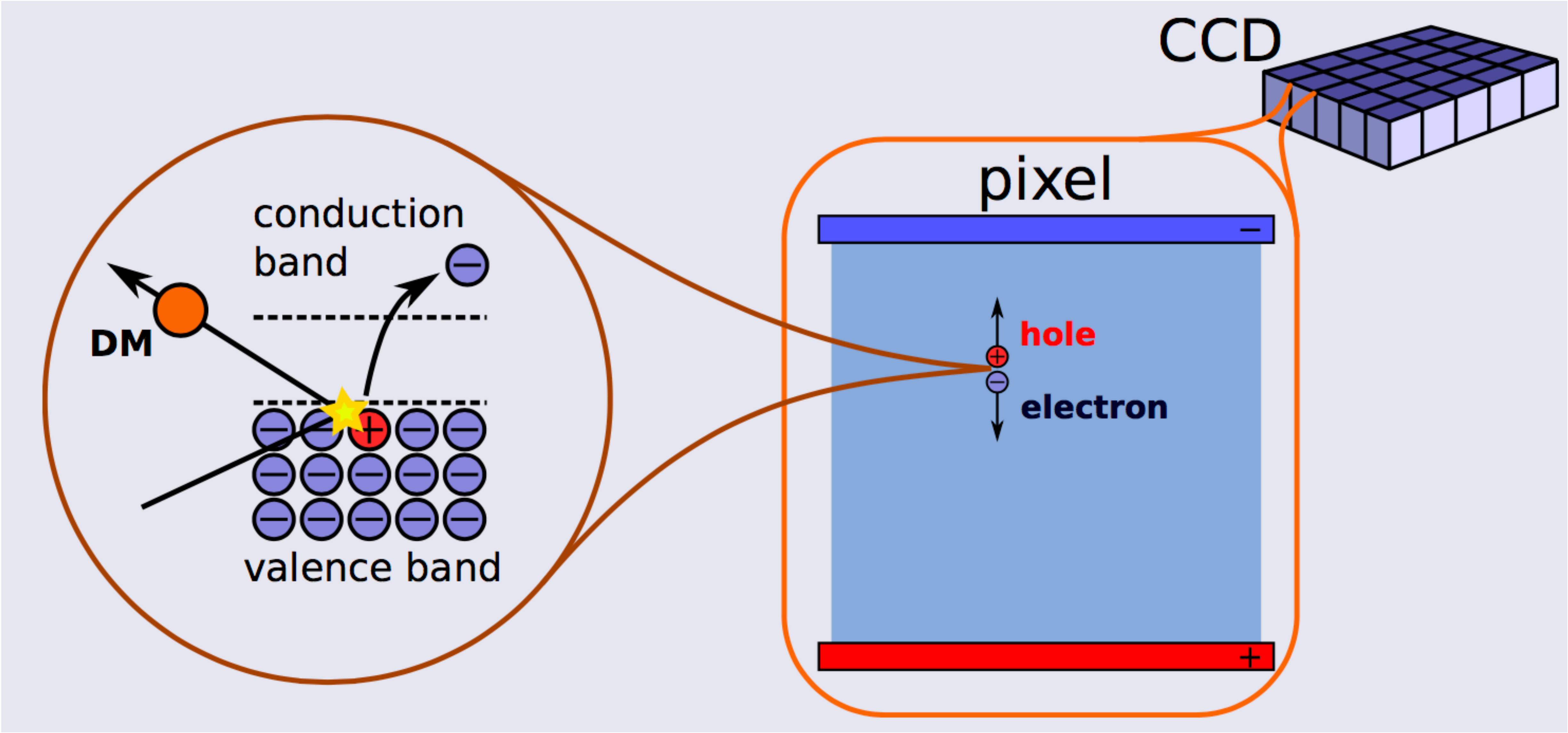


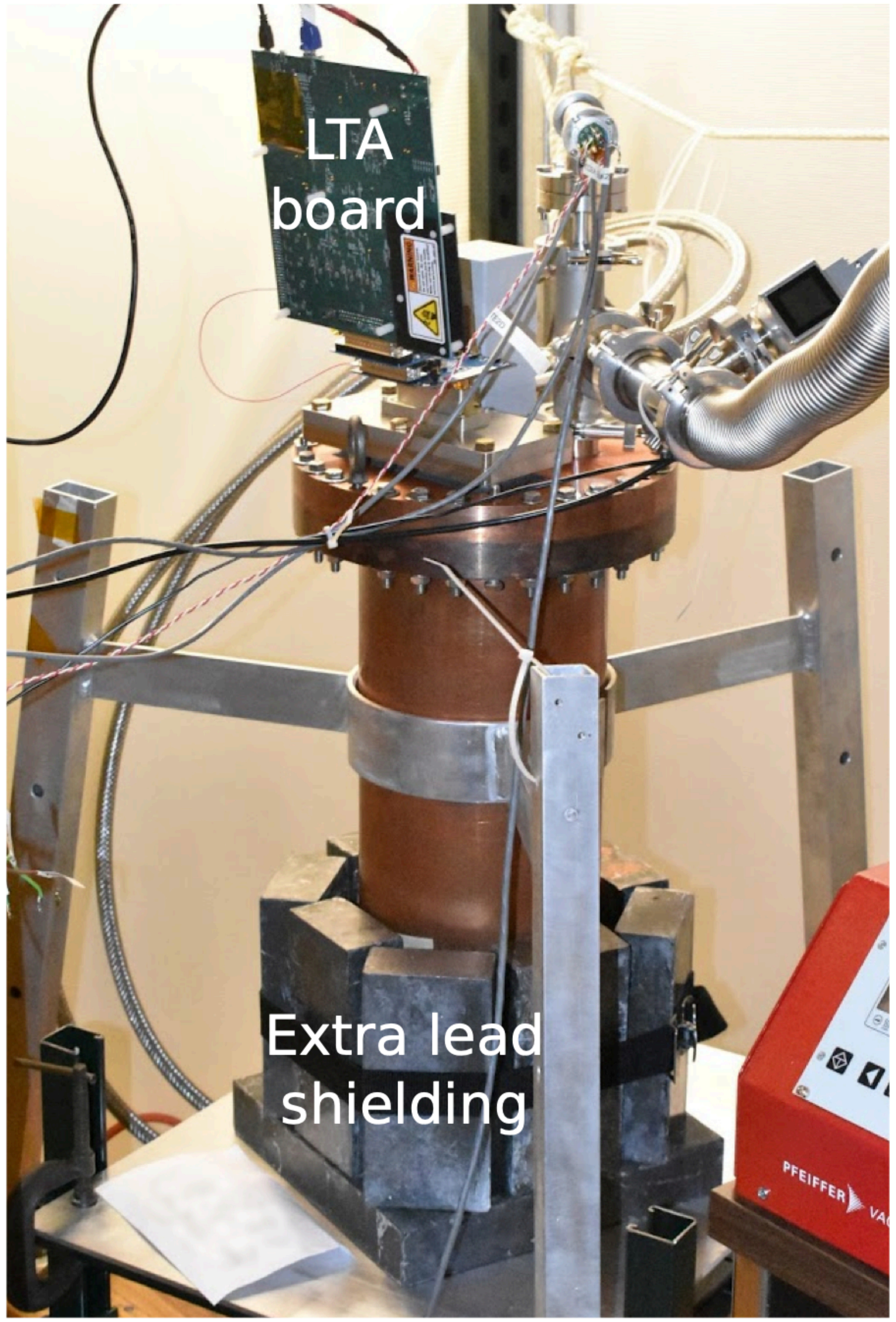
- **Cherenkov Radiation**
- Transition Radiation

Concrete Example: SENSEI at MINOS

SENSEI overview:

- Uses silicon Skipper-CCDs to probe sub-GeV DM by precisely measuring ionization



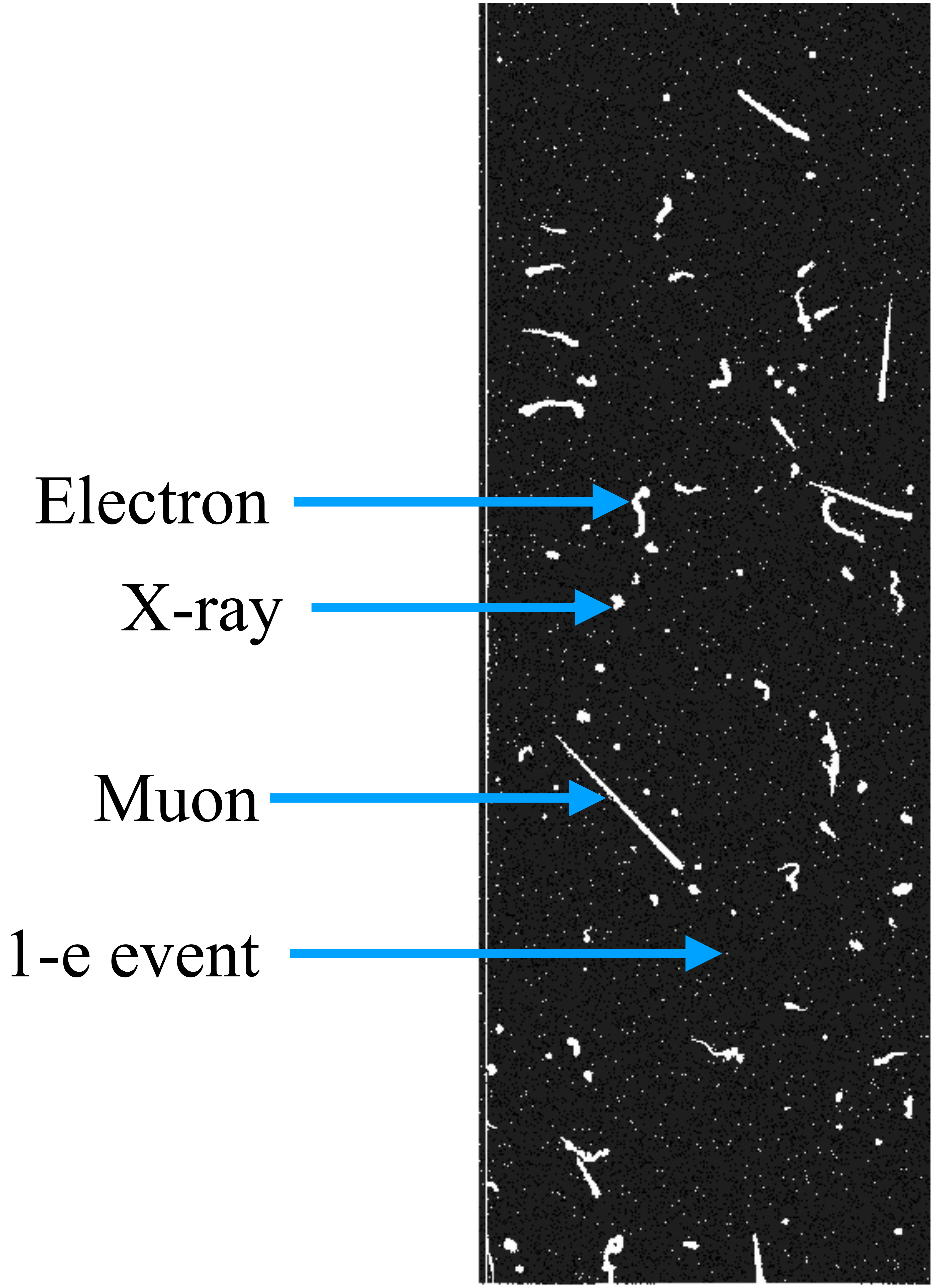


**SENSEI, 2020*

SENSEI at MINOS

SENSEI data:

- **Excellent spatial resolution**



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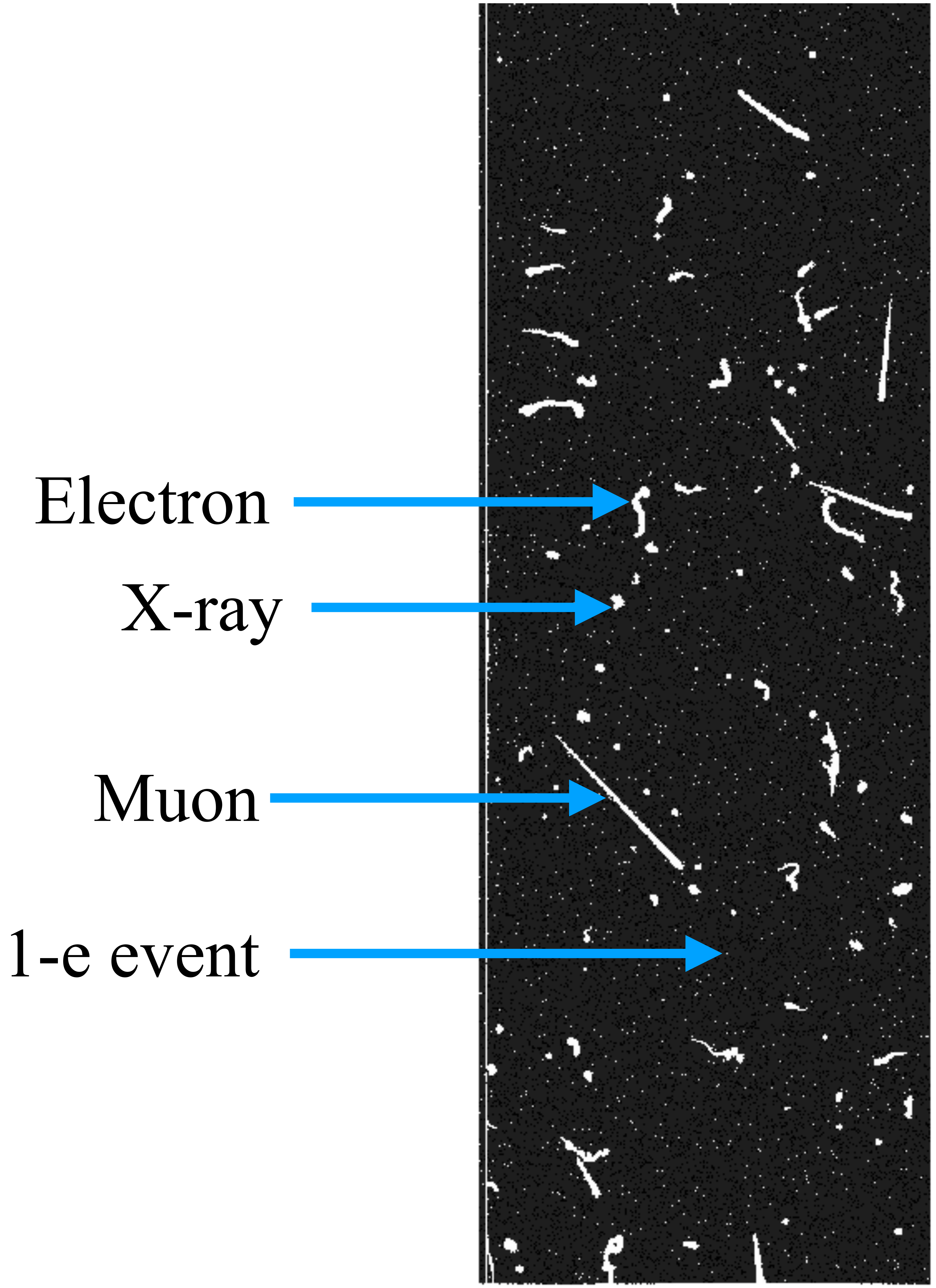
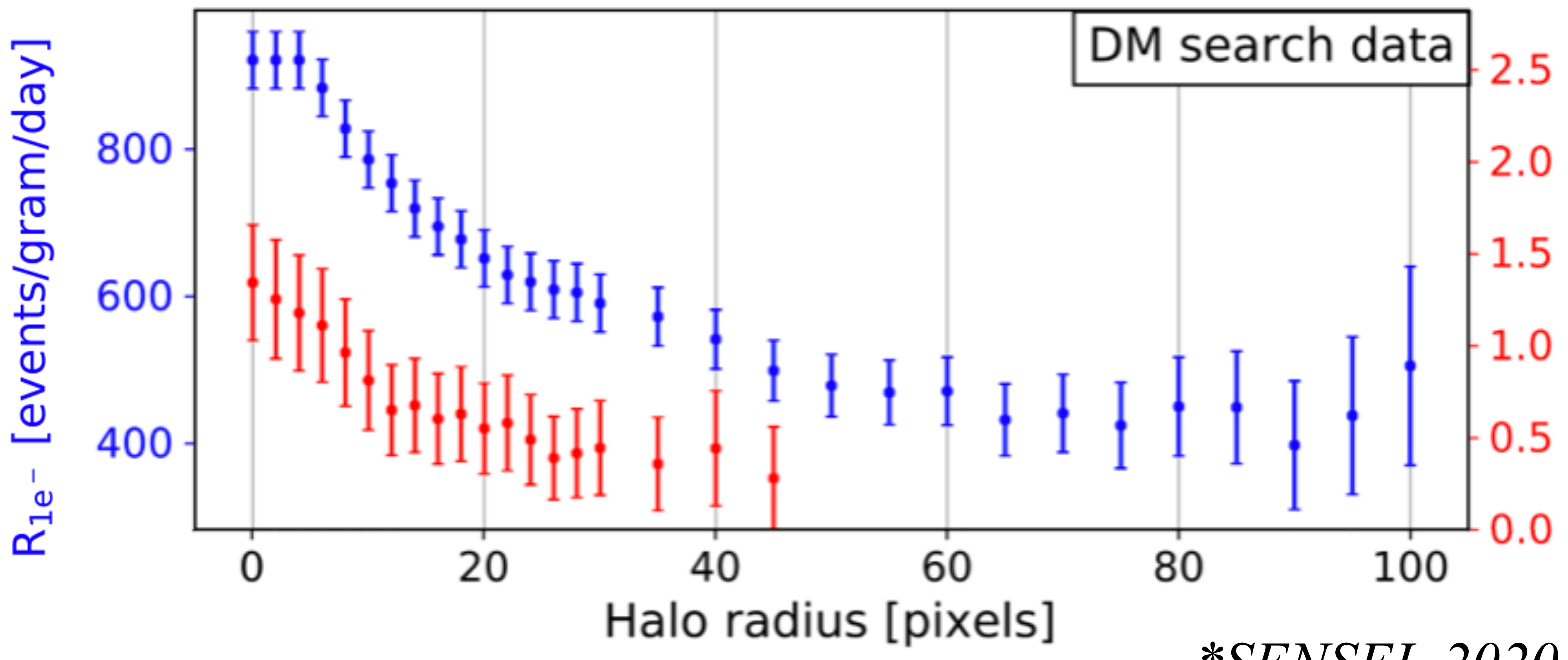


SENSEI at MINOS

SENSEI data:

- **Excellent spatial resolution**
- Can place cuts based on the position of events relative to the positions of high-energy tracks
- Observed ~ 450 1-e events per (gram*day) after applying a 60-pixel (~900 µm) halo-mask cut



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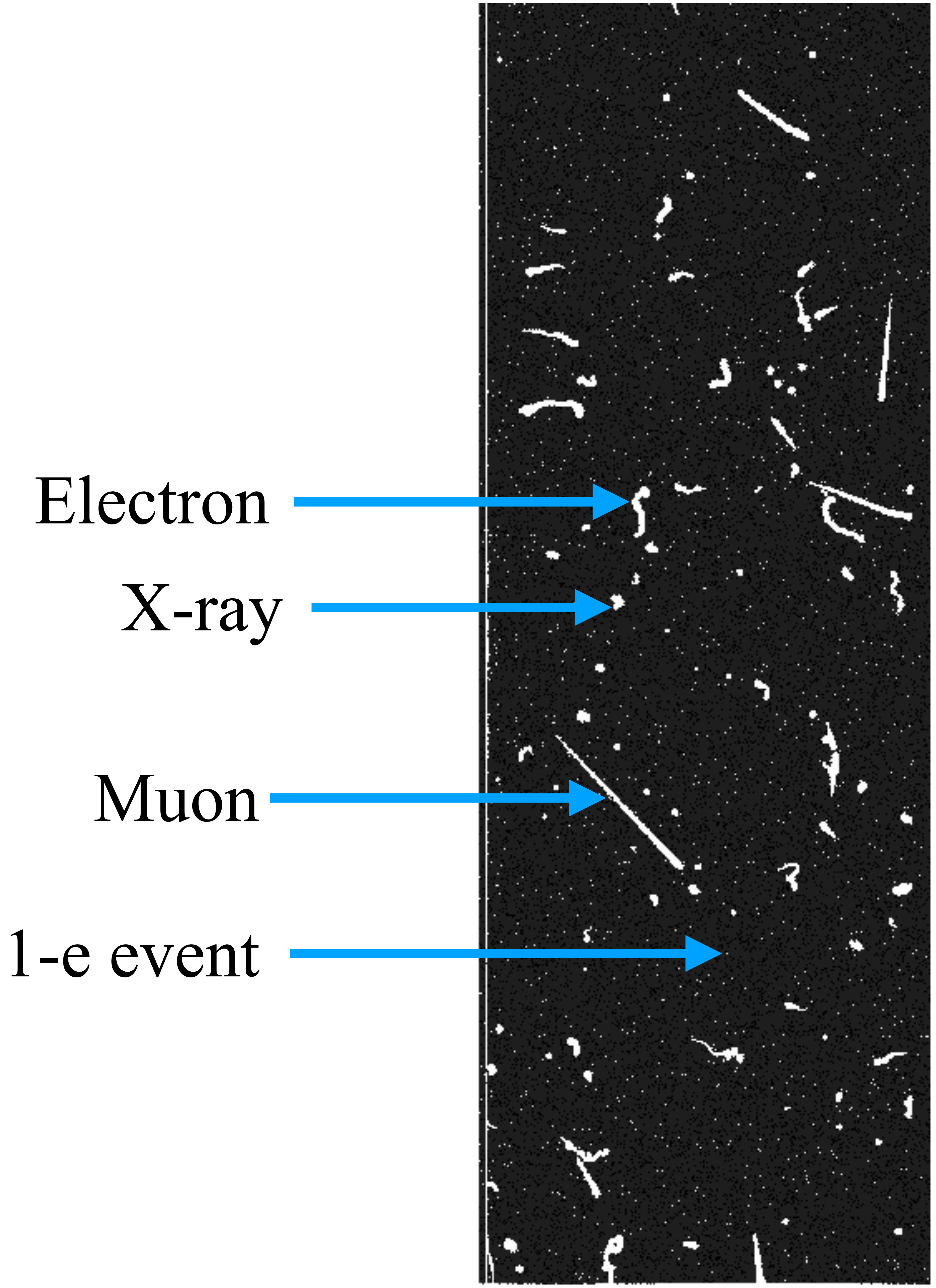
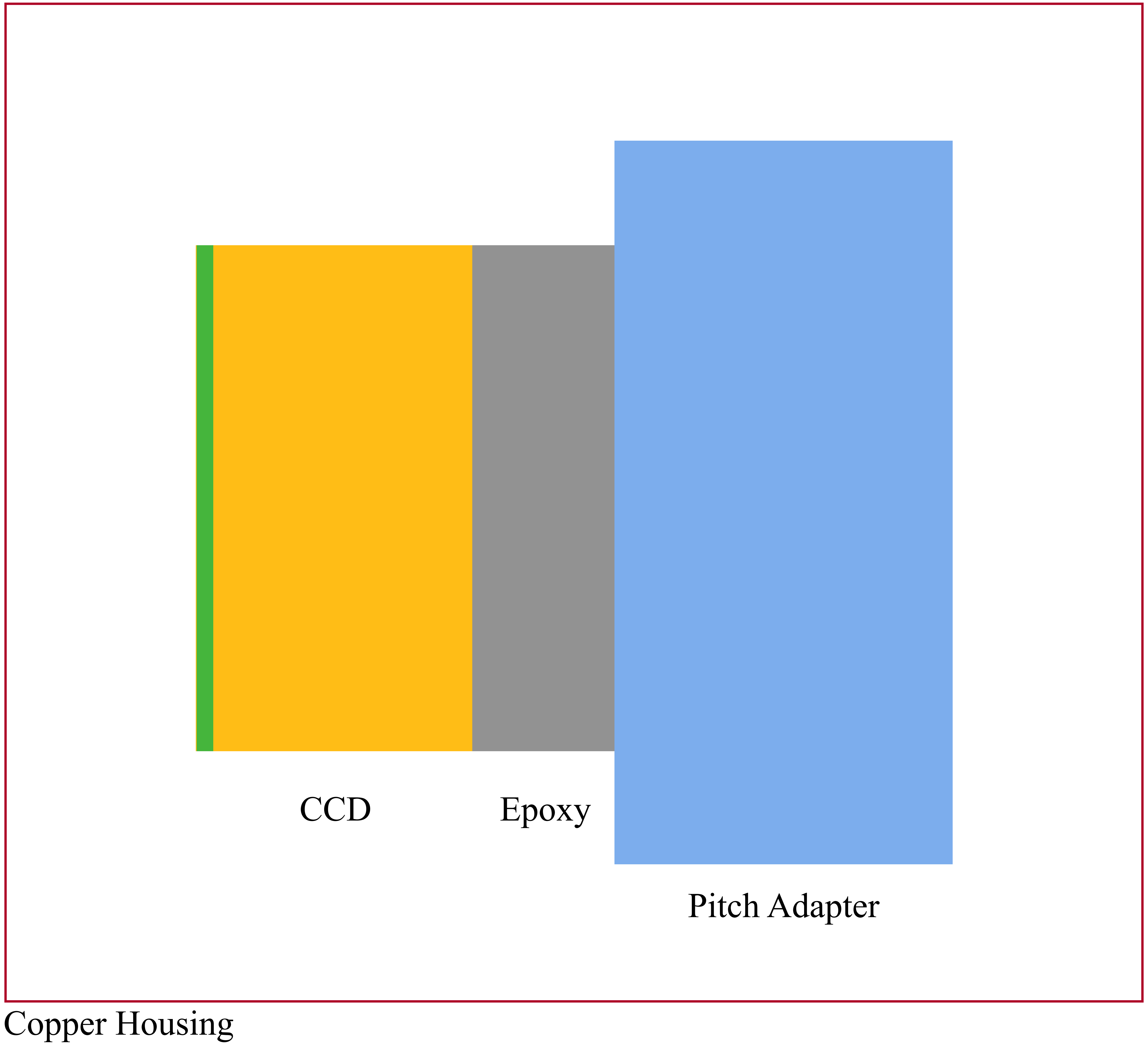


Radiative Processes Simulation for SENSEI

*paper in prep: Du, Egana-Ugrinovic, Essig, **MS**



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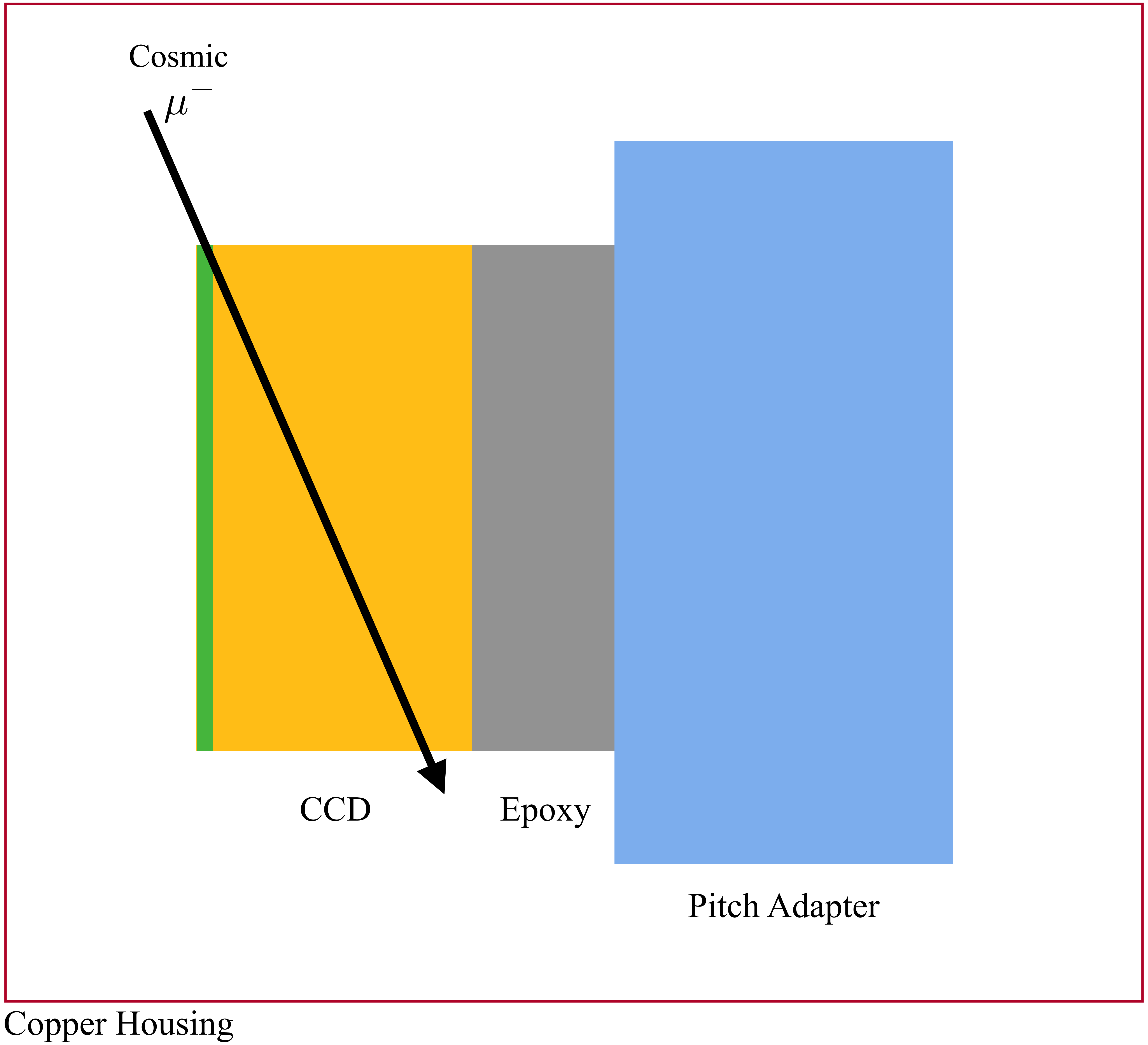

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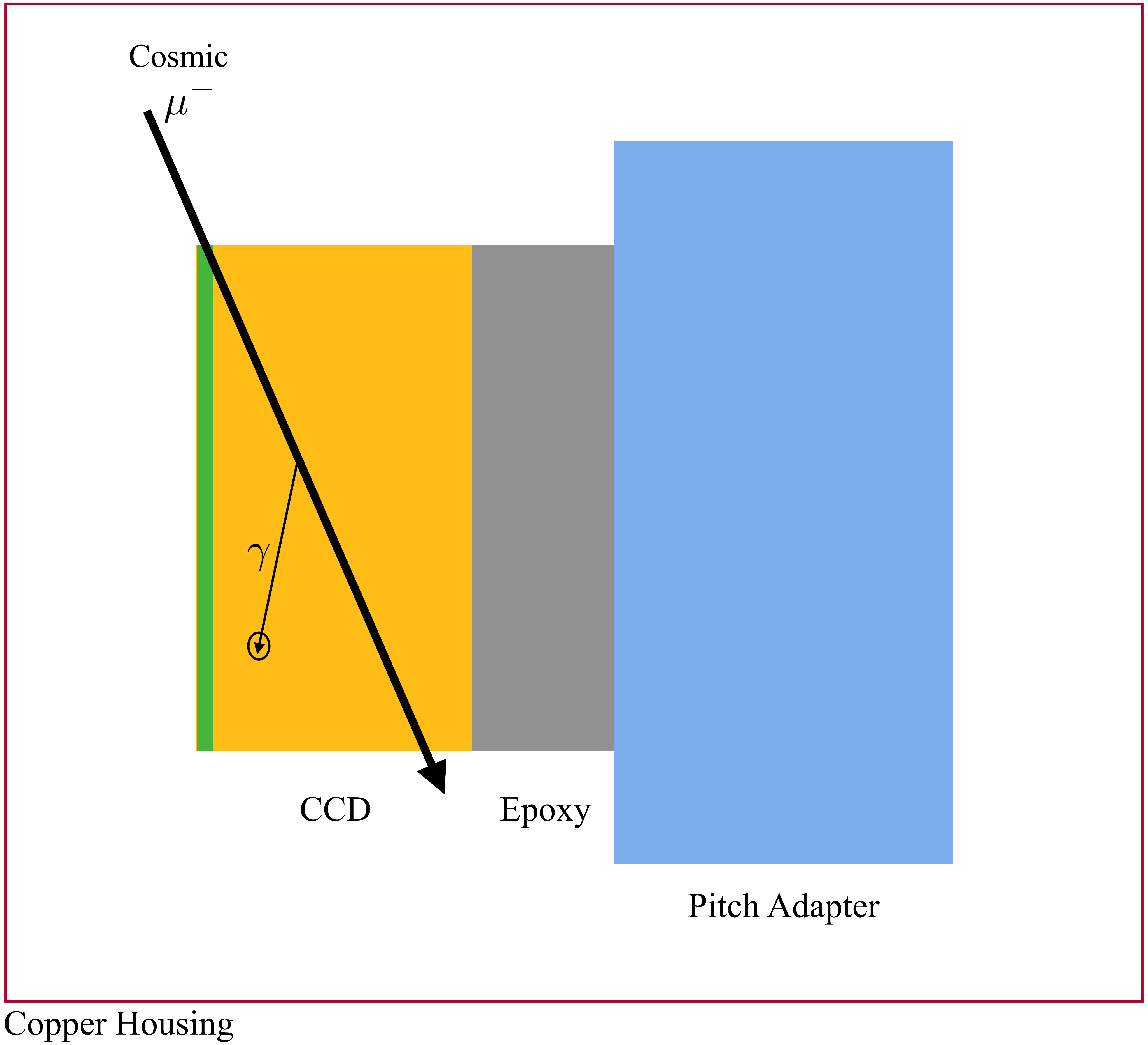

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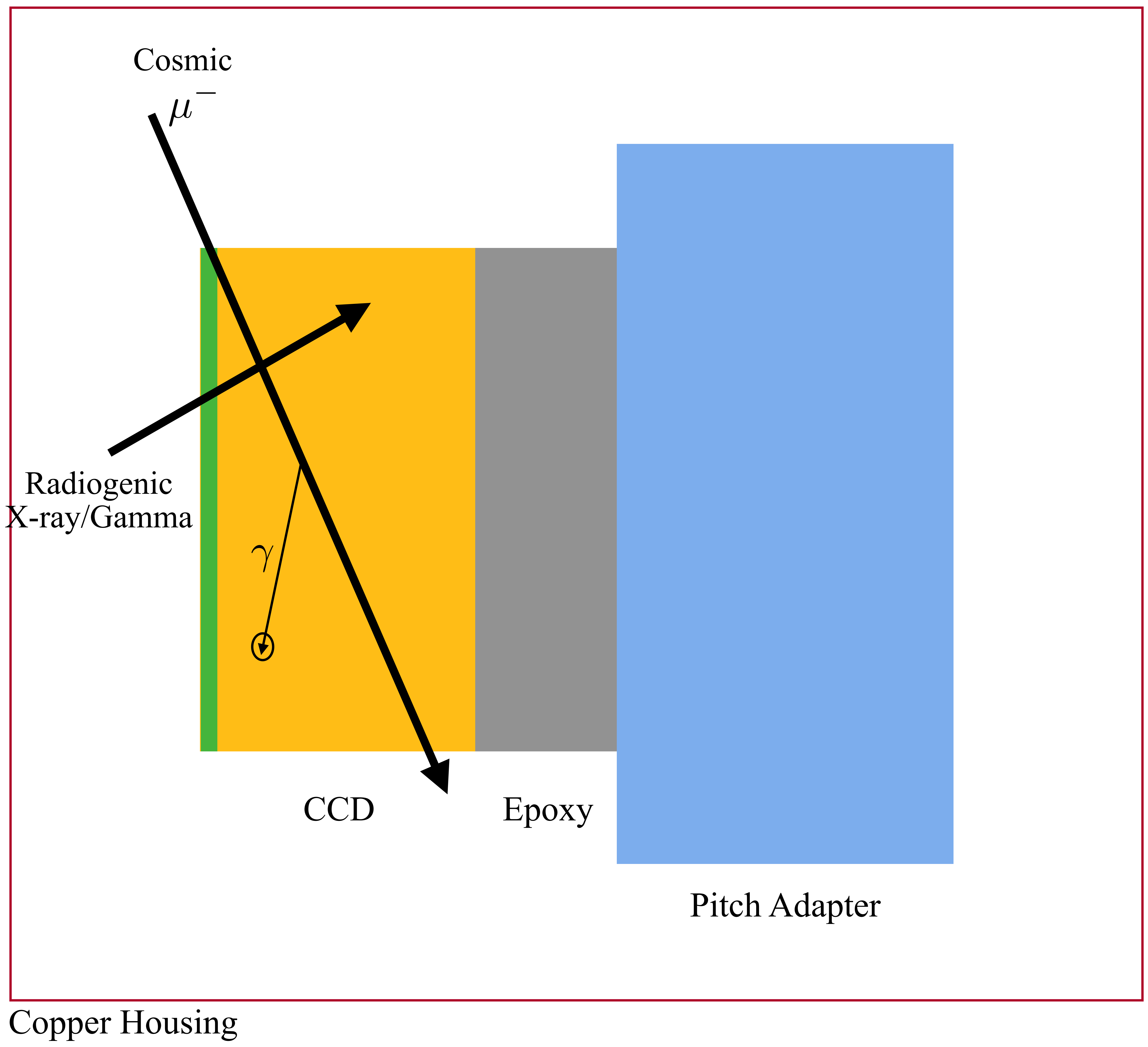

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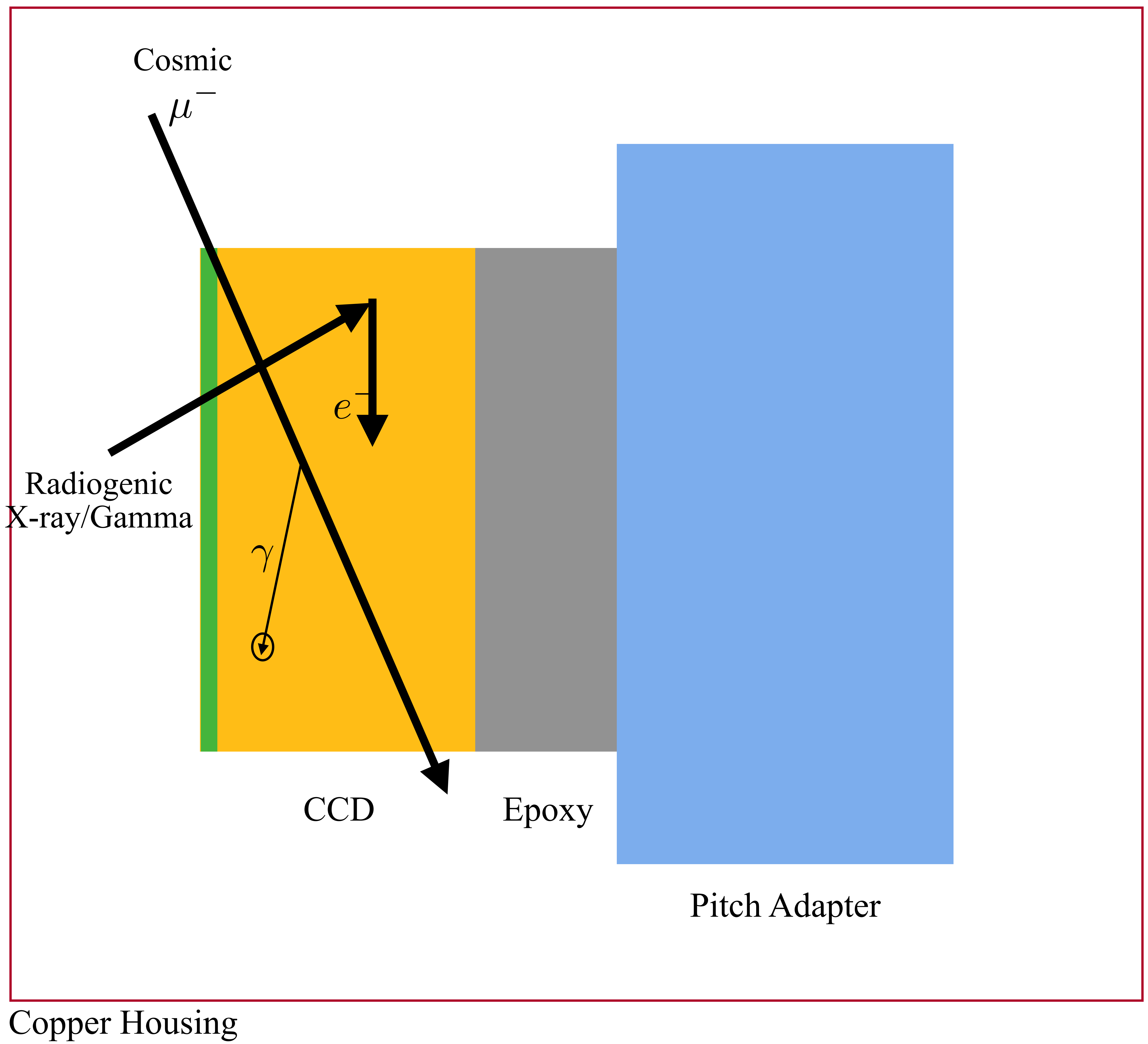

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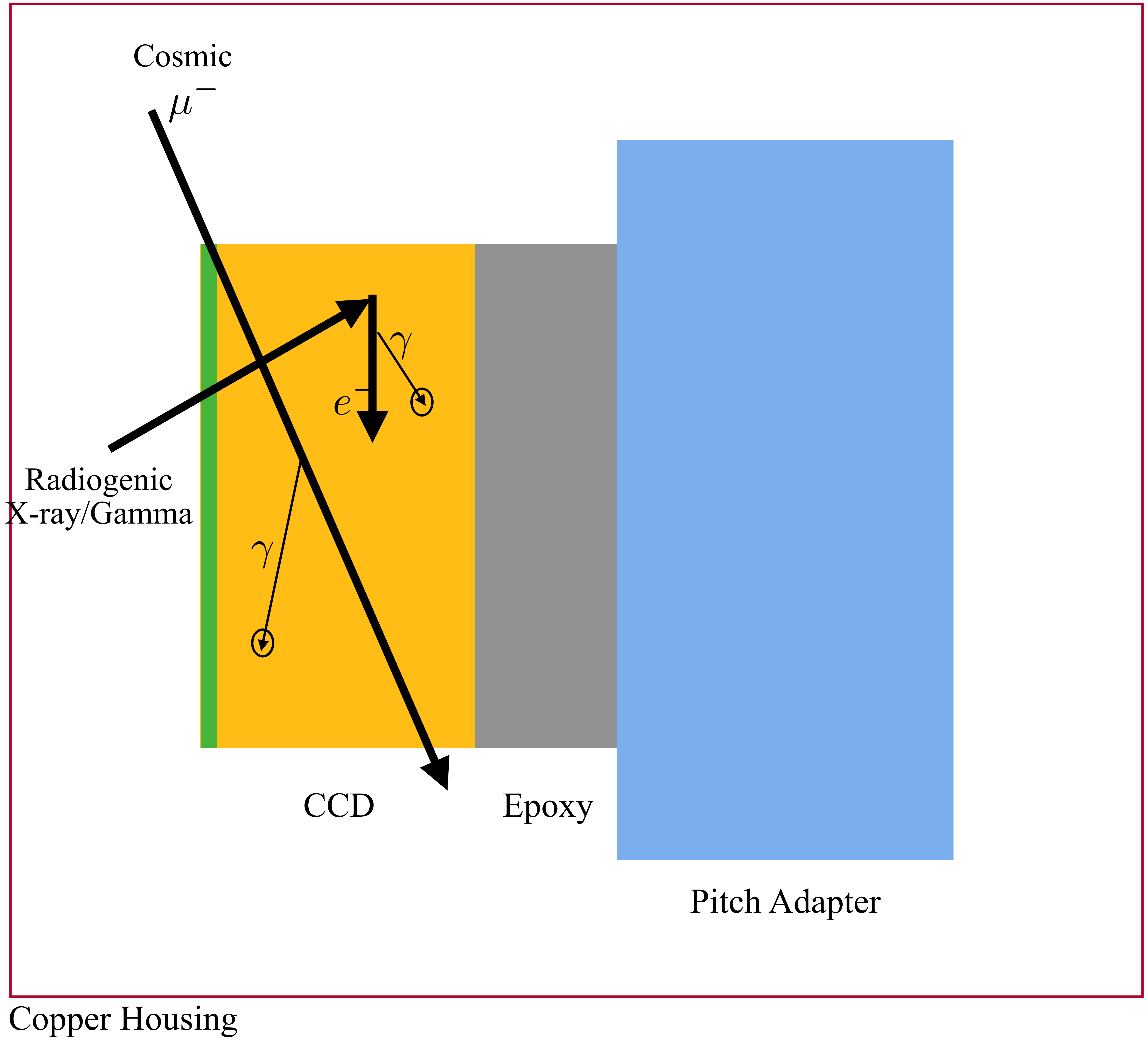

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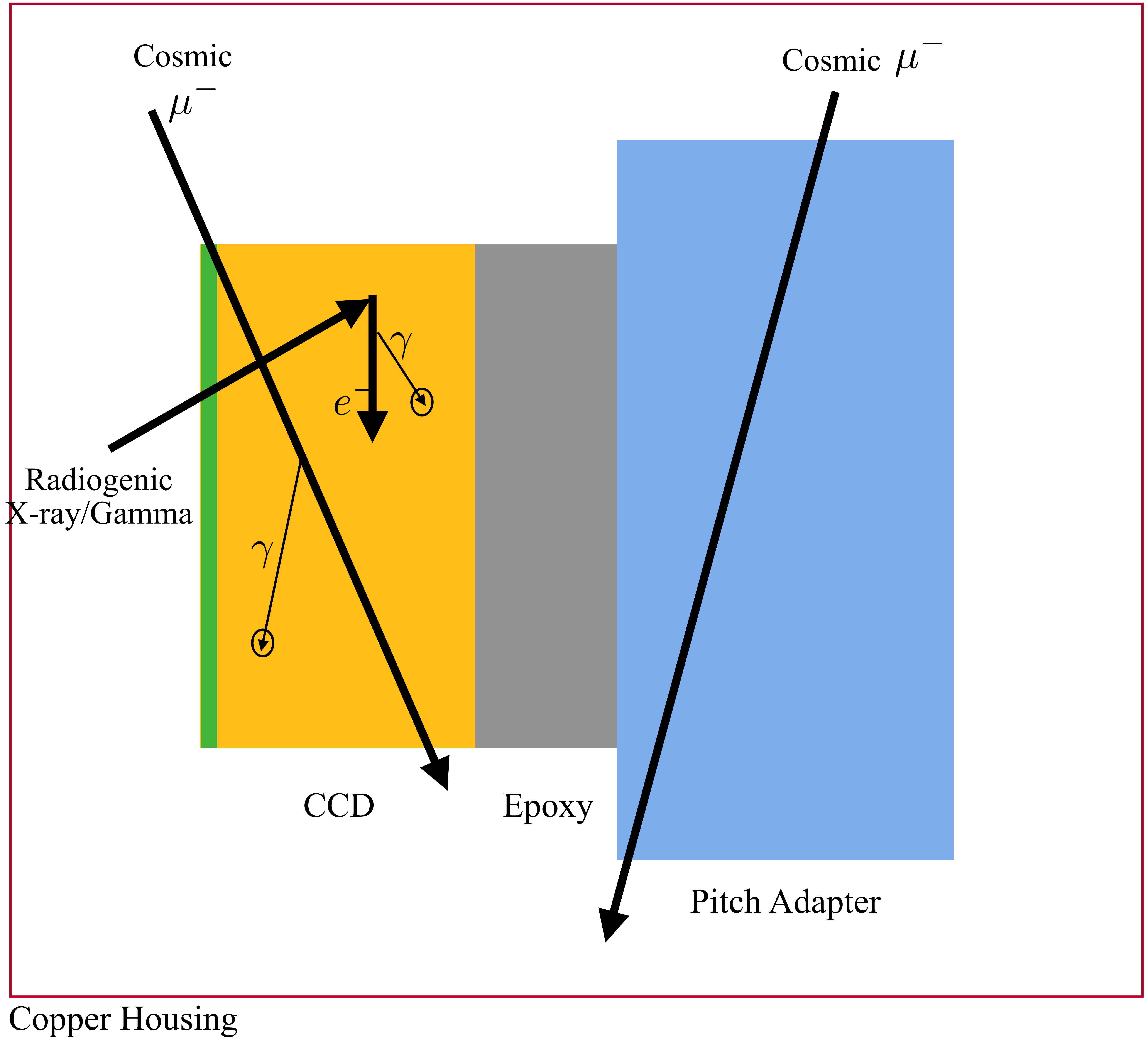

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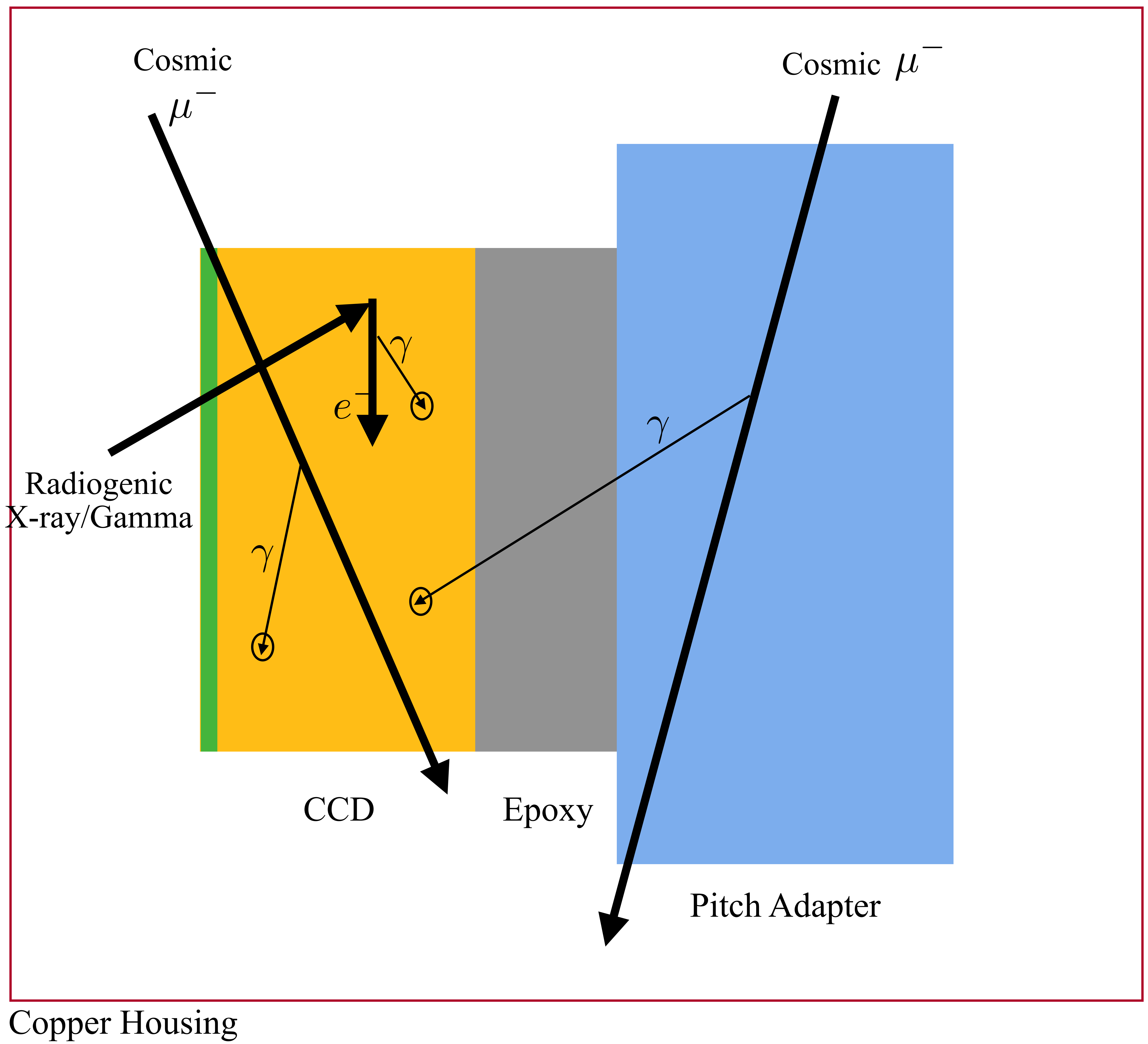

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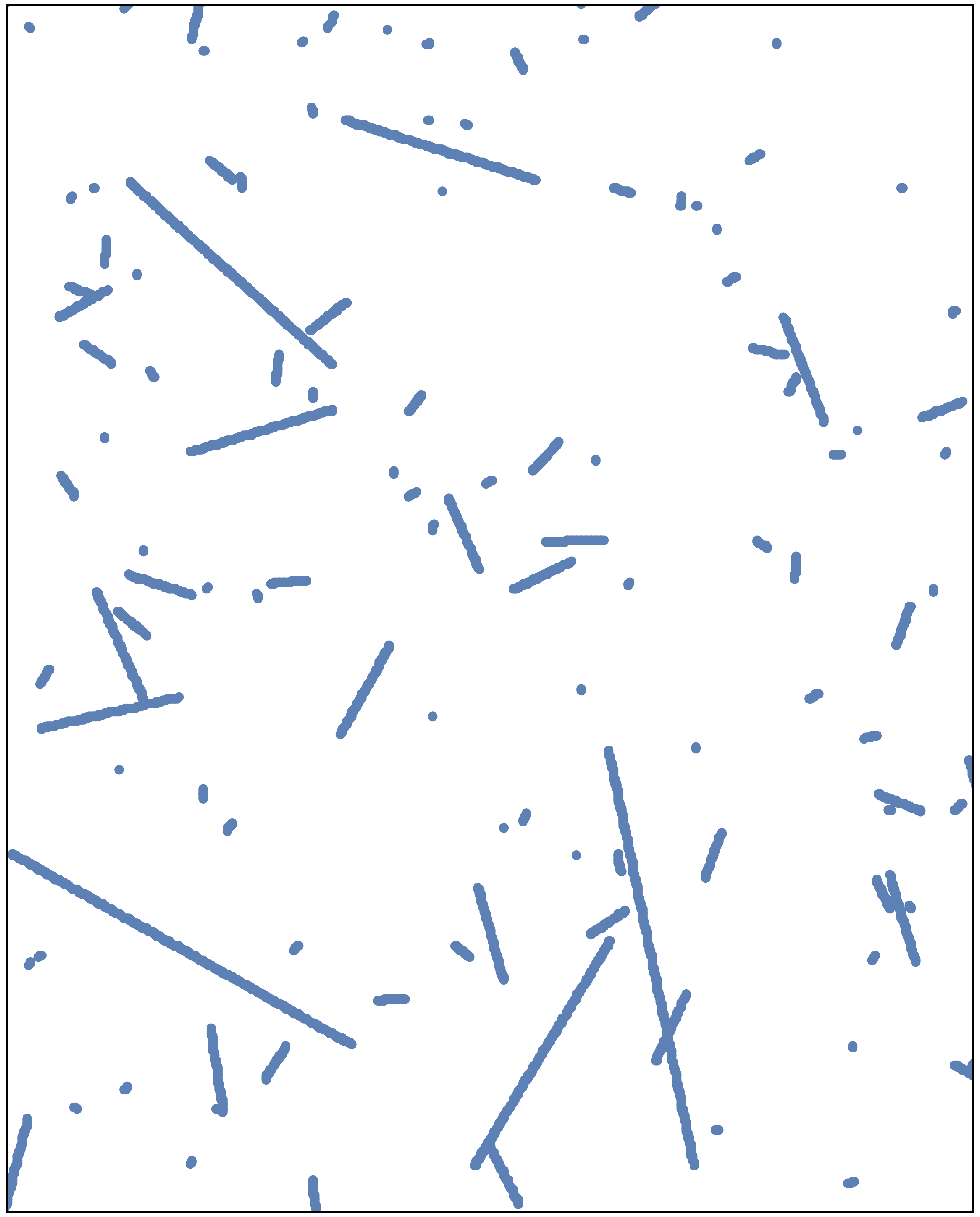
Simulated Tracks



SENSEI data

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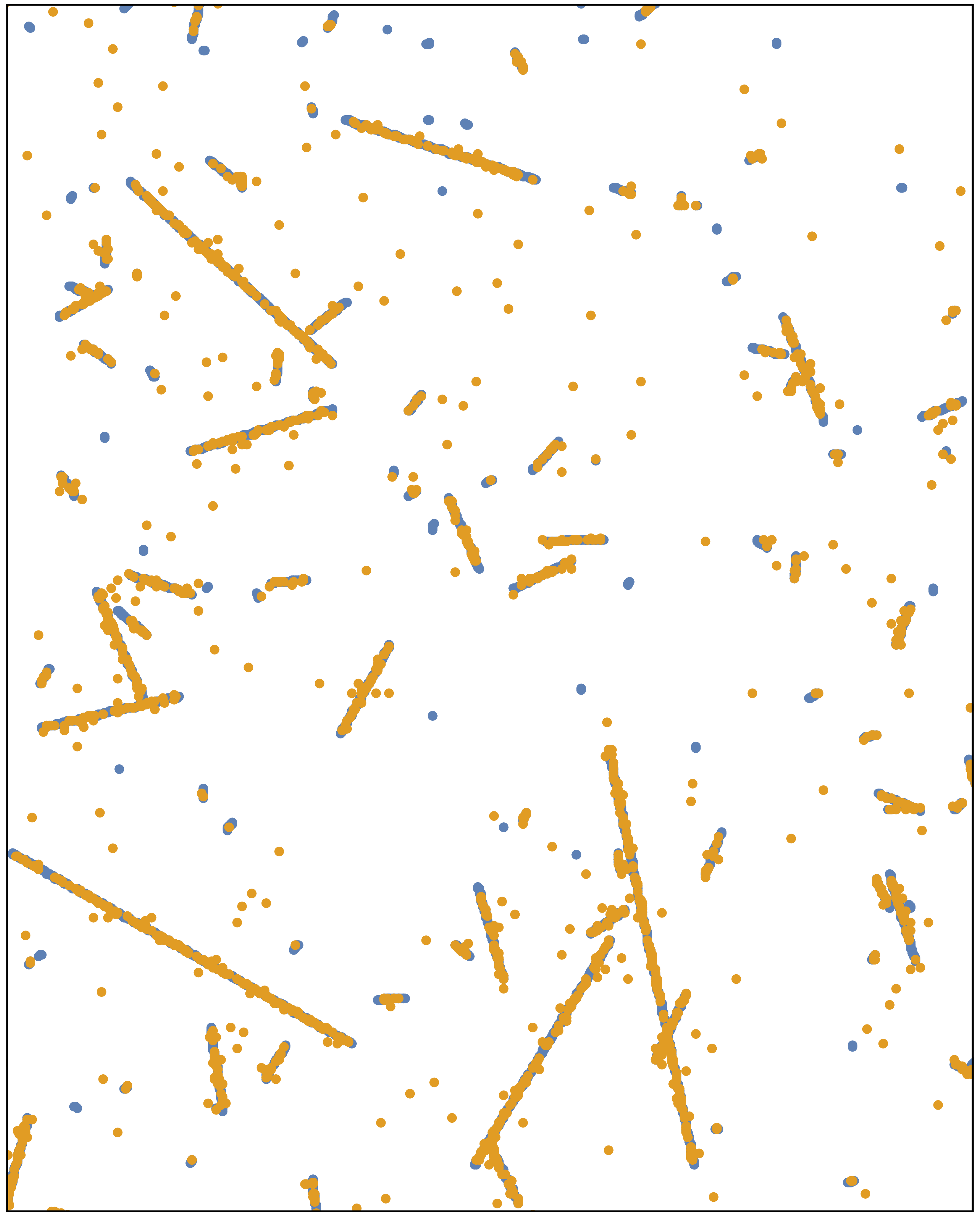
Simulated Tracks + Cherenkov



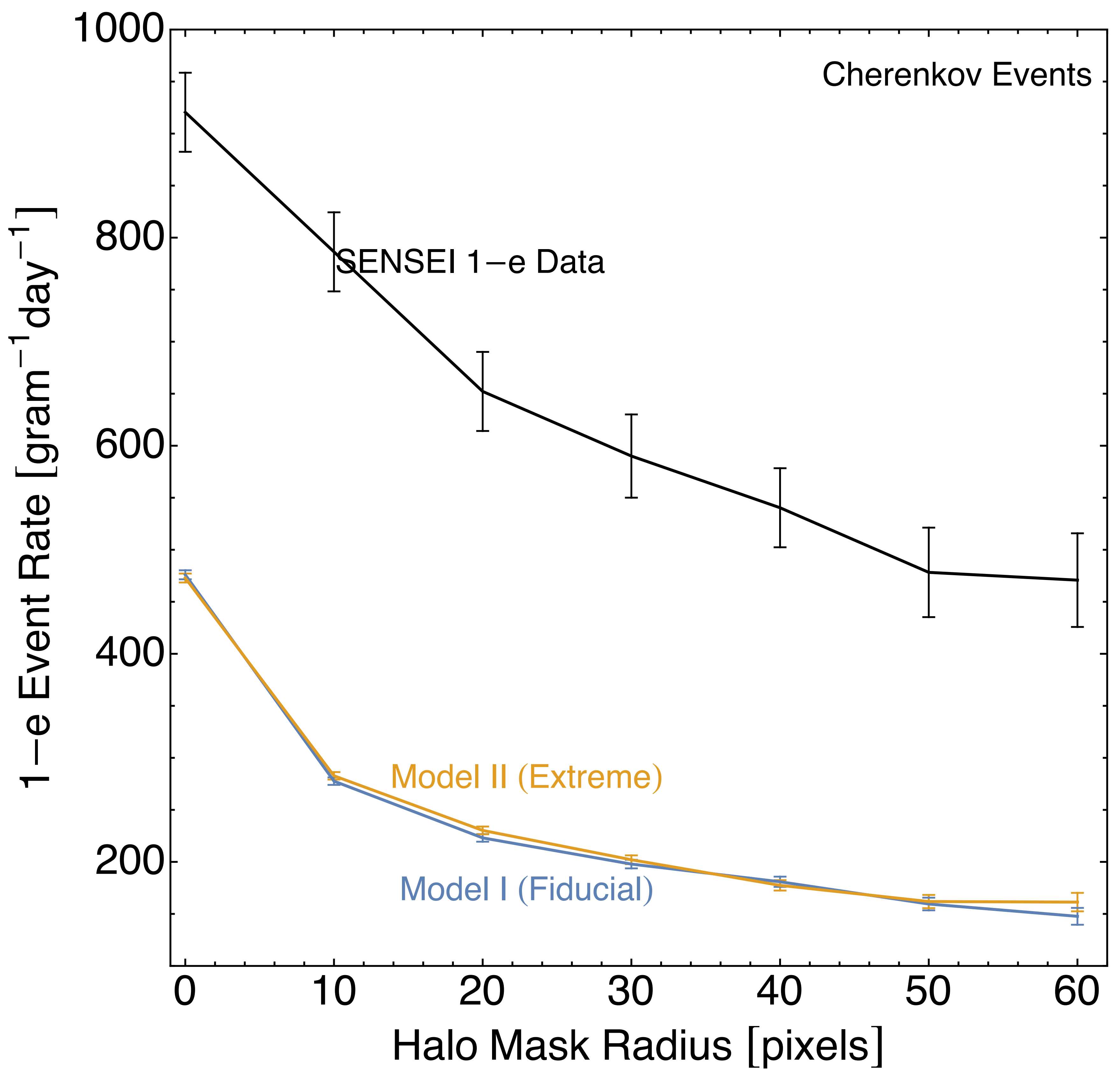
SENSEI data

Radiative backgrounds in SENSEI

*paper in prep: Du, Egana-Ugrinovic, Essig, **MS**

Results:

- SENSEI rate after a 60-pixel halo-mask cut: **450 ± 45 / (gram*day)**
- Estimated Cherenkov contribution: **150 ± 40 / (gram*day)** (including systematics)



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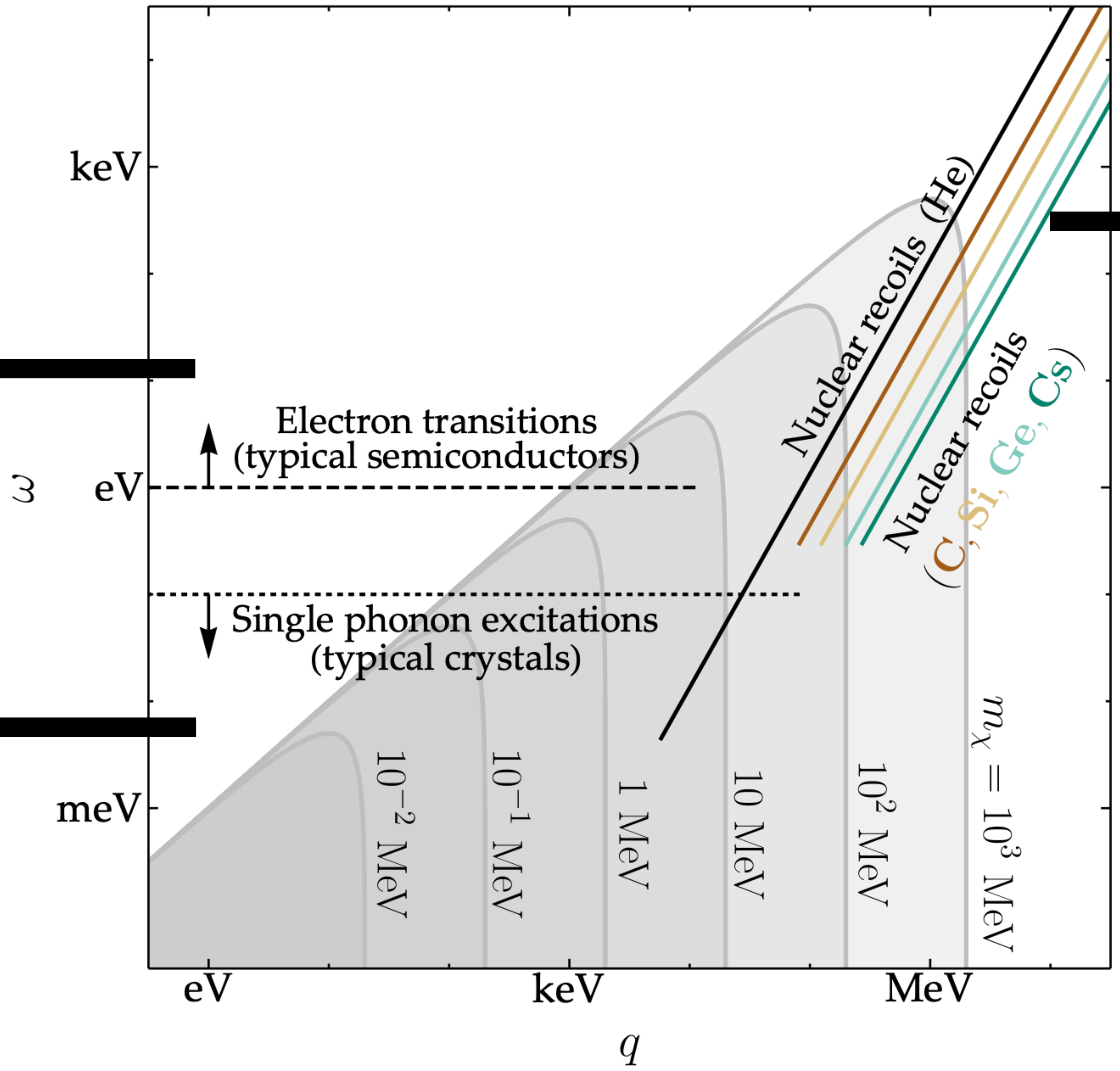

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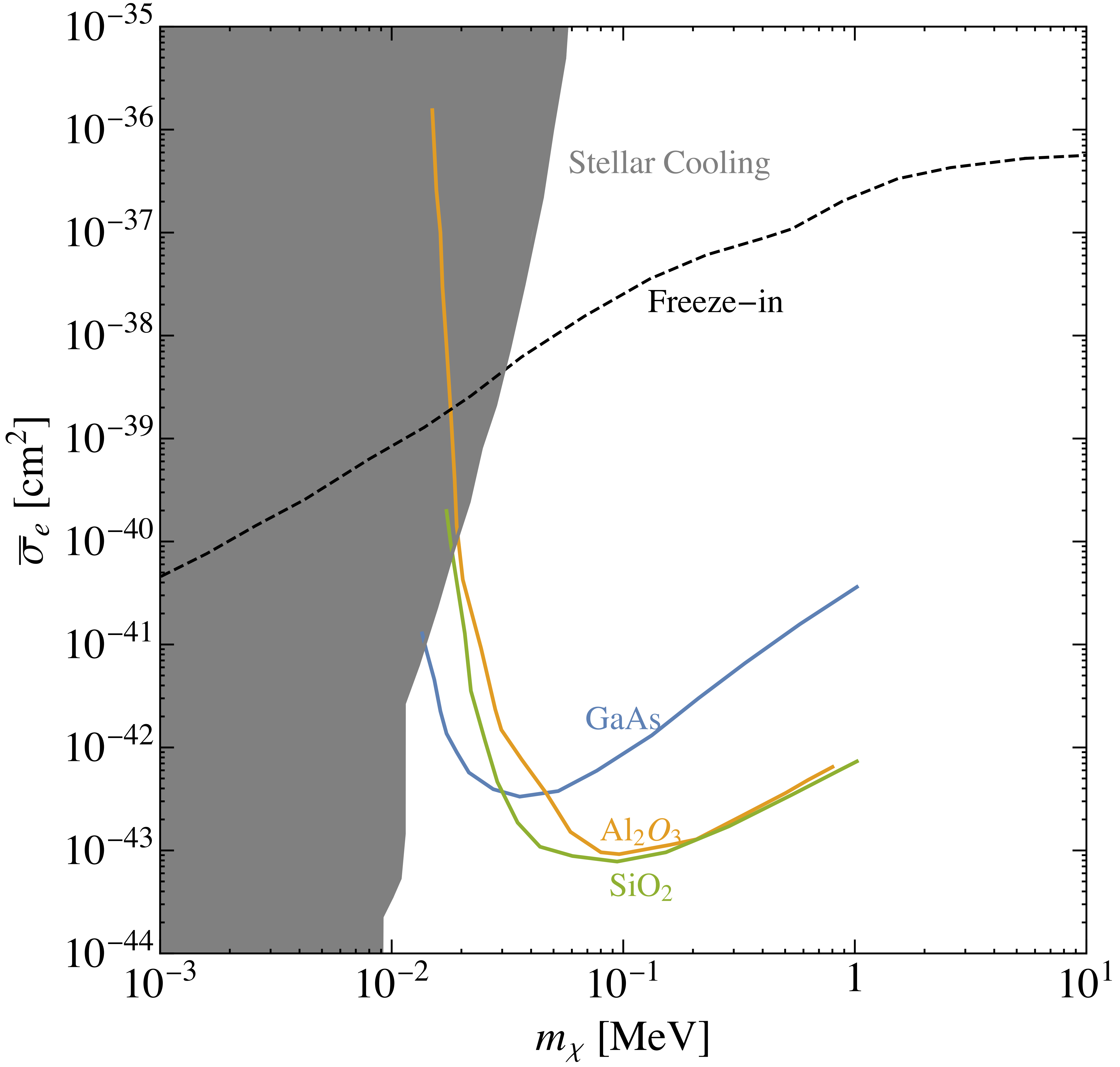


*arXiv:2108.03239 Kahn, Lin

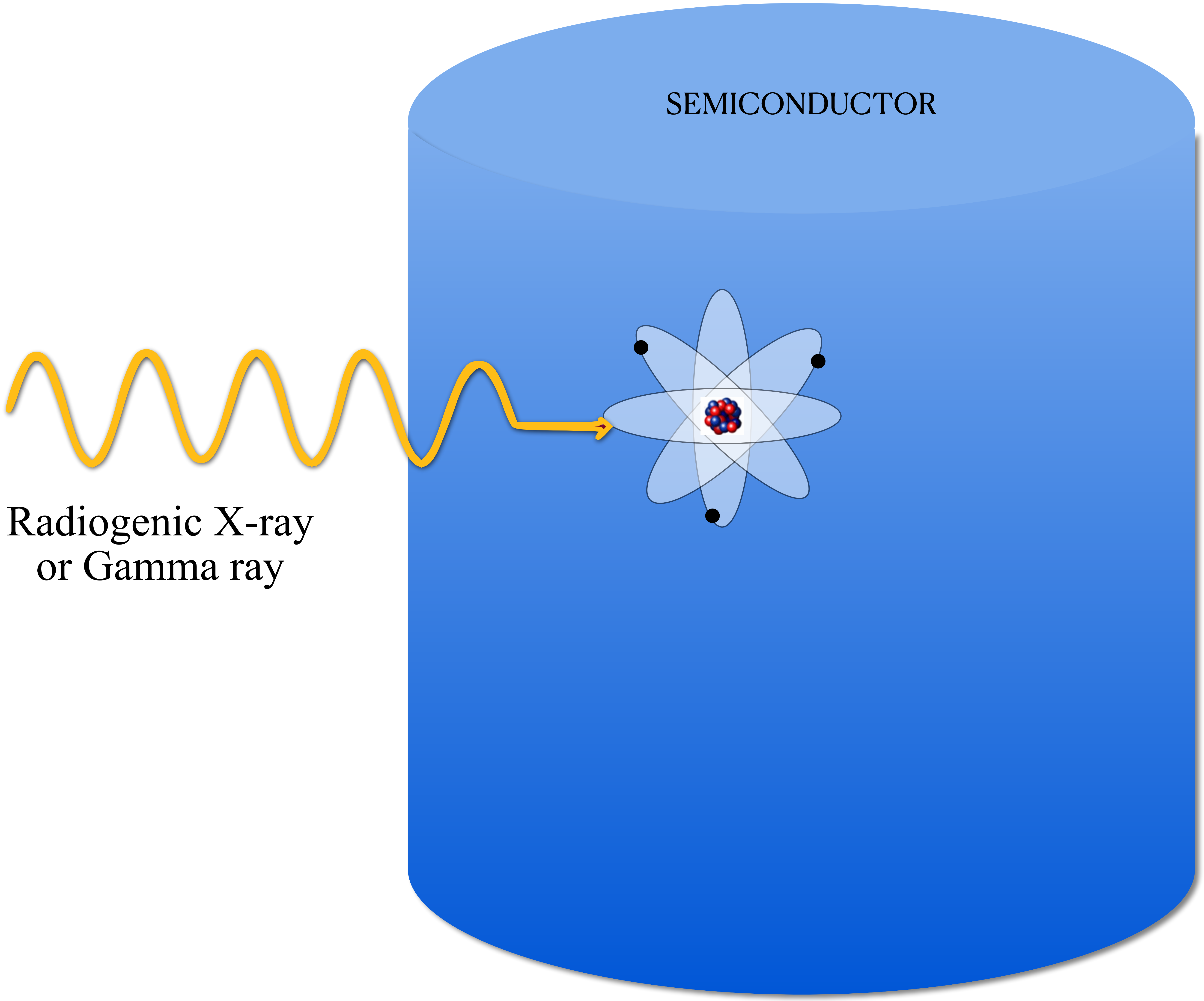
Well-motivated targets in sub-MeV parameter space

Sensitivity projections assuming **background-free** kg-year exposure

Important to estimate backgrounds in these future detectors

Photon Background

*arXiv:2112.09702 Berghaus, Essig, Hochberg, Shoji, **MS**



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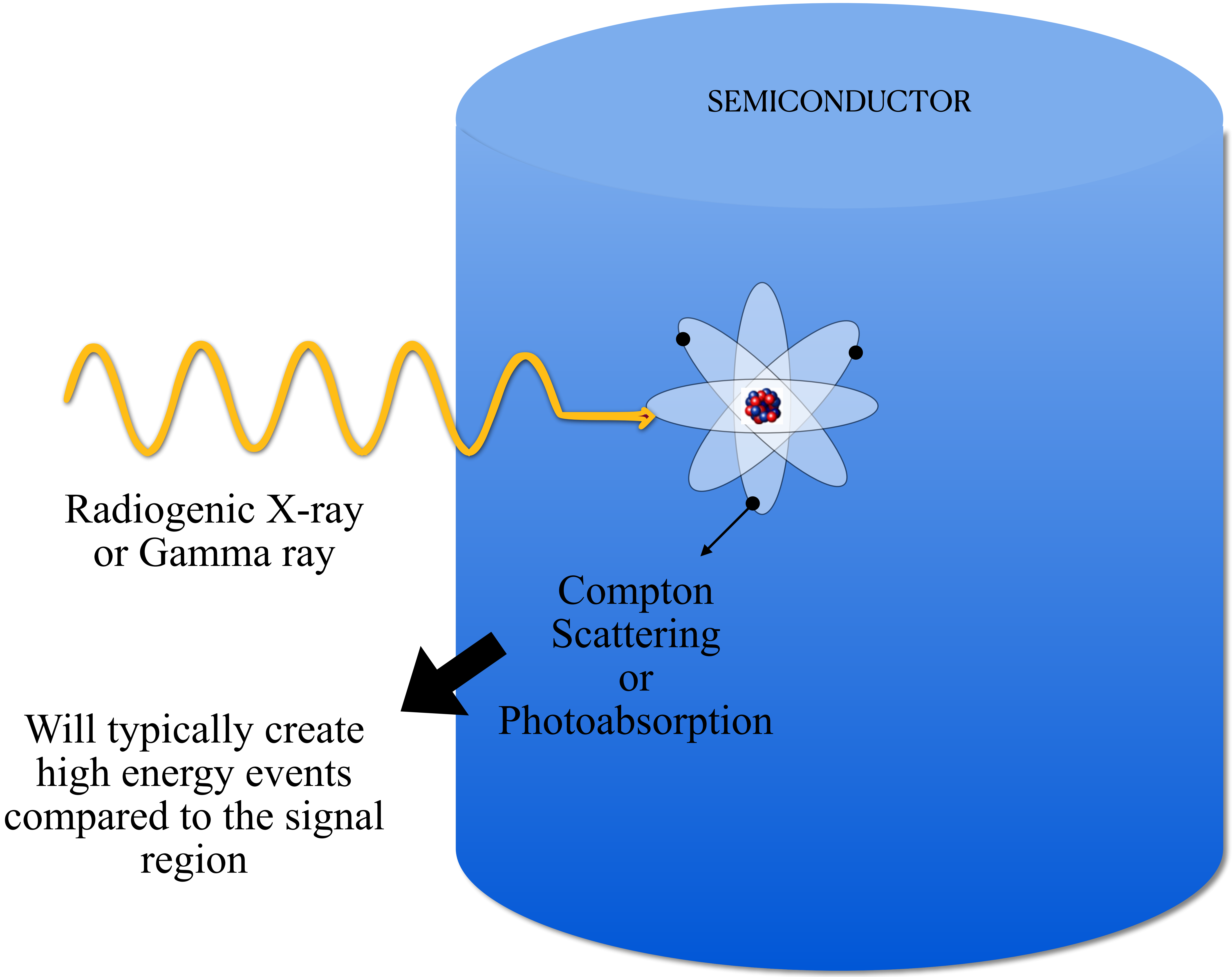

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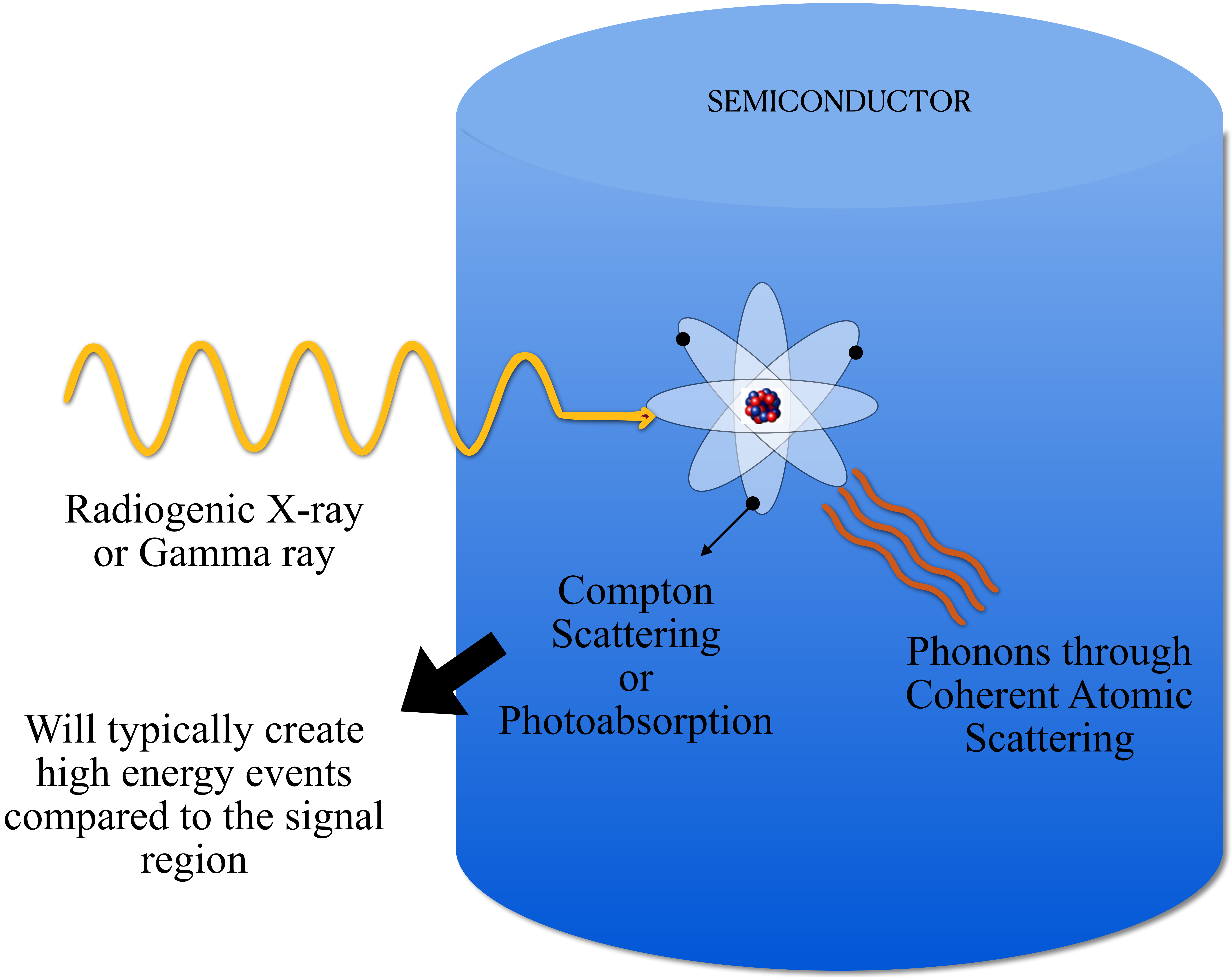

Phonons from Coherent Atomic Scattering

$$\frac{d\sigma}{d\Omega d\omega}(q, E_\gamma, \omega) = \frac{d\sigma}{d\Omega}(q, E_\gamma) S(q, \omega)$$

*H. Schober 2014

Coherent Atomic Scattering
Cross Section

Dominated by Thompson Cross section
with individual electrons

$$\frac{d\sigma_T}{d\Omega}(q, \theta) \simeq \frac{\alpha^2}{2m_e^2}\left(1 + \cos^2\theta\right)|g(q)|^2$$

Structure Function

$$S(\vec{q}, \omega) = \sum_f |\langle f| e^{i\vec{q}\cdot\vec{r_N}}|i\rangle|^2 \delta(E_i - E_f - \omega)$$

Can be evaluated in terms of the
phonon density of states of
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Final Rate: $$\frac{dR}{d\omega}(\omega) = N_T \sum_i \int d\Omega \frac{d\sigma}{d\Omega d\omega}(q, E_{\gamma_i}, \omega) n_{\gamma_i} v$$

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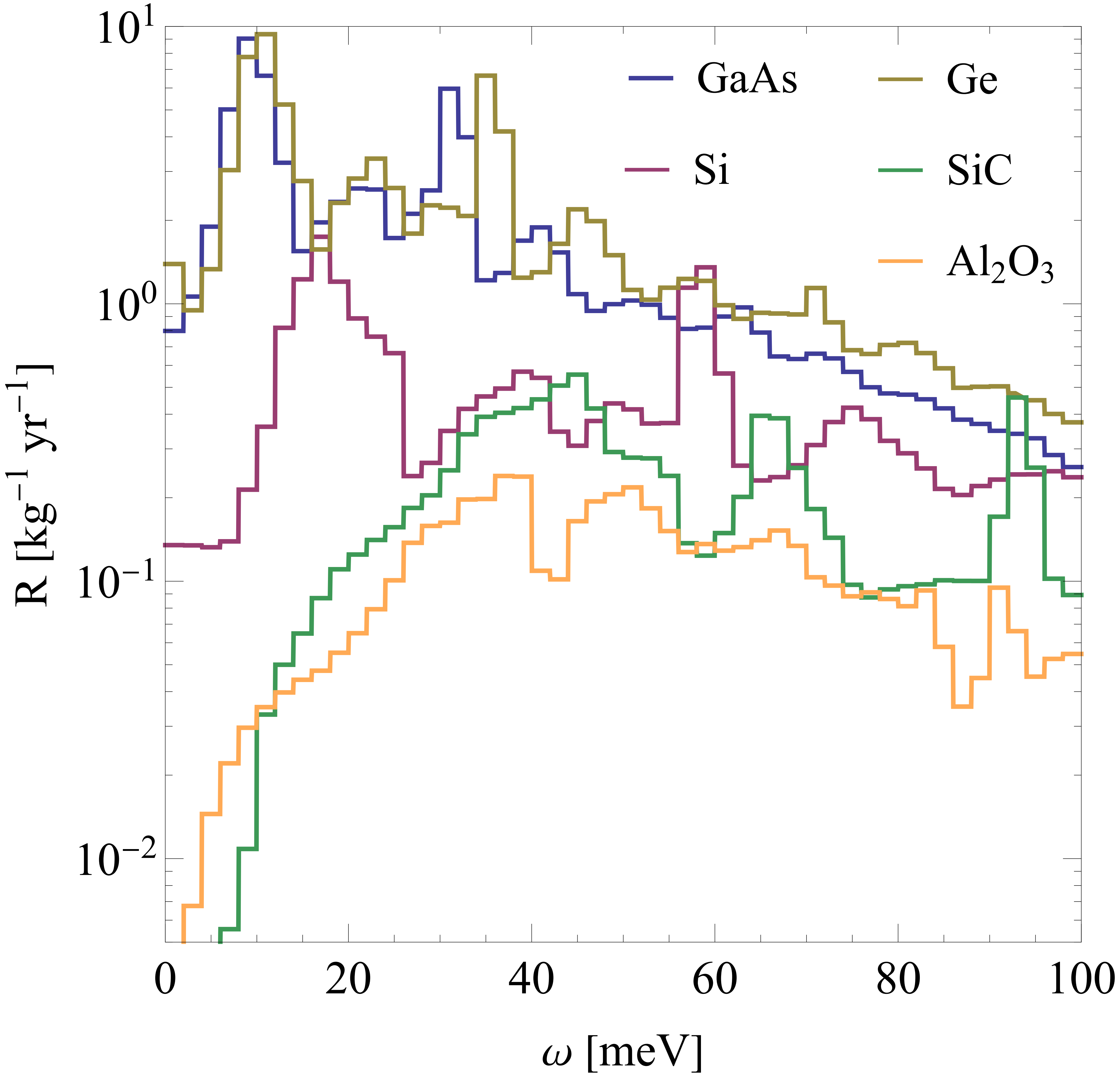

Phonon rates assuming
a typical photon background measured
in a well-shielded
EDELWEISS detector

Could be as high as
~ 100 events per kg.year

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- Mitigation strategies: Increase passive shielding (less high energy photons, muons etc.), Active shielding (correlated high energy events) with timing, Multiple detectors