ORIGIN OF LOW-ENERGY EVENTS IN DARK-MATTER DETECTORS

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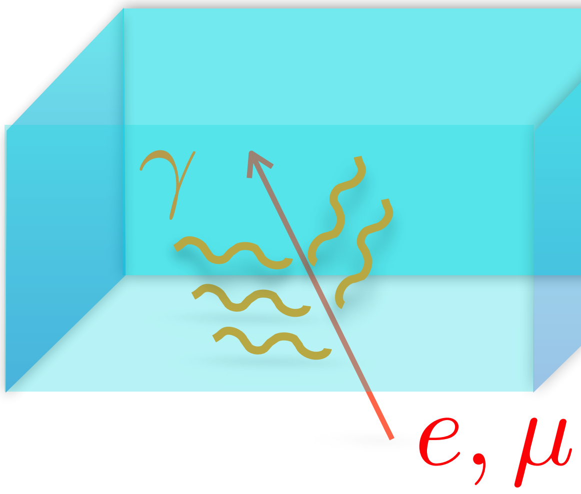
arXiv: 2011.13939 (PRX 12 (2022) 1, 011009)
and
arXiv: soon



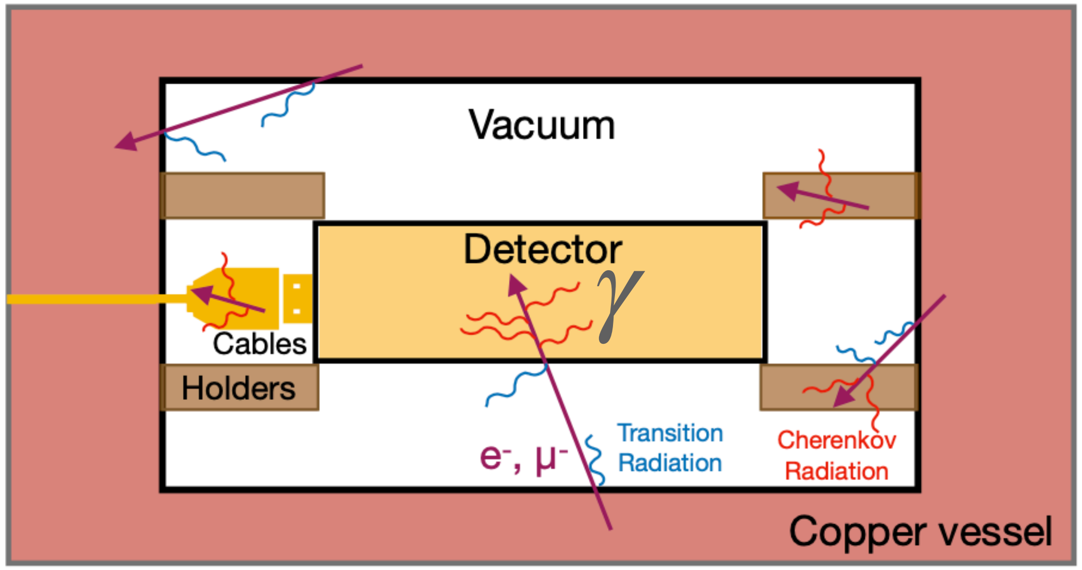
In collaboration with
Peizhi Du
Rouven Essig
Mukul Sholapurkar

TRACK-INDUCED BACKGROUNDS

Cherenkov radiation

Luminescence

DEU, Du, Essig, Sholapurkar
arXiv:2011.13939
PRX 12 (2022) 1, 011009



*~hundreds of tracks/g*day at SENSEI, ~10 thousand /g*day at SuperCDMS HVeV*

OUTLINE

1. Theory basics
    1. Cherenkov radiation
    2. Luminescence
2. Relevance at experiments
    1. SENSEI
    2. SuperCDMS HVeV
    3. LAMPOST
    4. Future: SuperCDMS SNOLAB
    5. Qubit decoherence?

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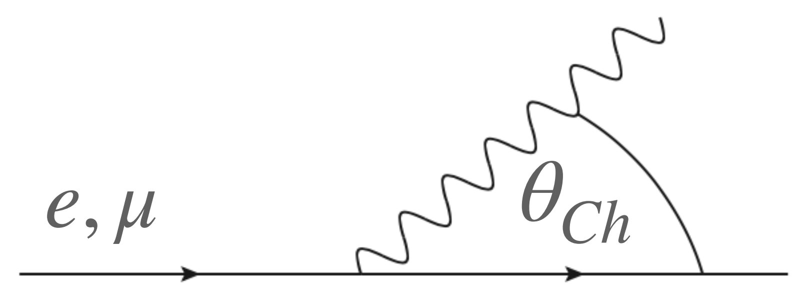
CHERENKOV RADIATION

- Is the spontaneous emission of radiation by tracks passing through non-conducting materials.



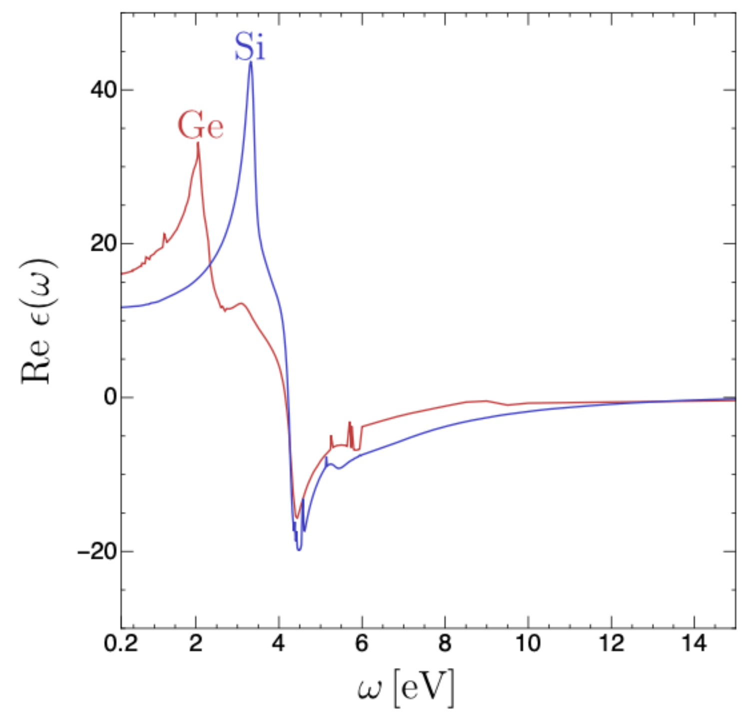
$$v^2\varepsilon(\omega) > 1$$ *Cherenkov condition*

$$\frac{dN}{d\omega dx} = \alpha\left(1 - \frac{1}{v^2\varepsilon(\omega)}\right)$$ *Rate*

WHY IS CHERENKOV RADIATION RELEVANT?

1. It leads to photons with energies matching the detector thresholds

$$v^2\varepsilon(\omega) > 1 \longrightarrow \varepsilon(\omega) > 1$$ *necessary condition*



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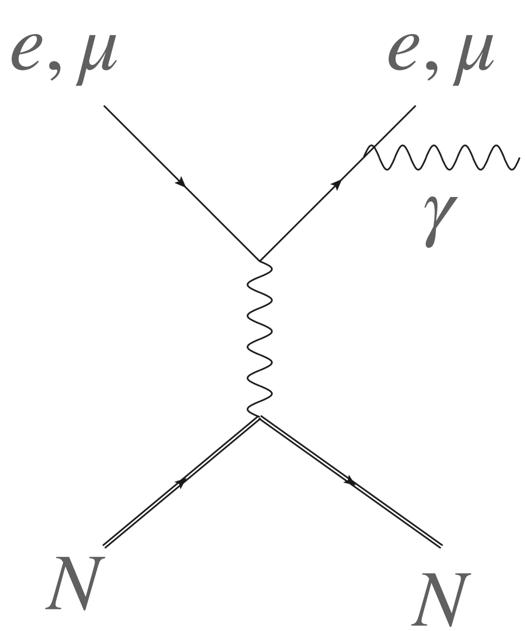
Cherenkov photons have energies $\omega \lesssim 4\,\mathrm{eV}$

WHY IS CHERENKOV RADIATION RELEVANT?

2. It arises at leading order in electrodynamics

$$\frac{dN_\gamma}{d\omega dx} \sim \alpha \qquad \textit{(for } \varepsilon(\omega) \gg 1\textit{)}$$

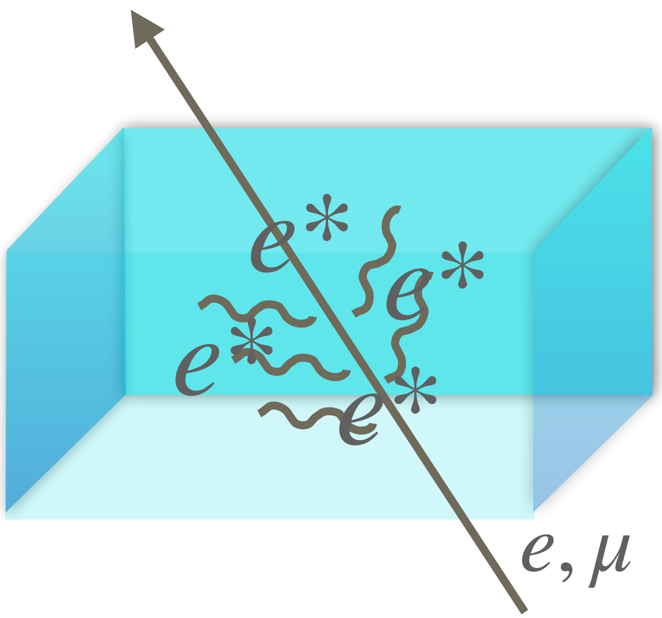
$$N_\gamma \sim 4\left[\frac{\Delta\omega}{1\,\mathrm{eV}}\right]\left[\frac{\Delta x}{100\,\mu\mathrm{m}}\right]$$



As opposed to bremsstrahlung, $\sim \alpha^3$

LUMINESCENCE

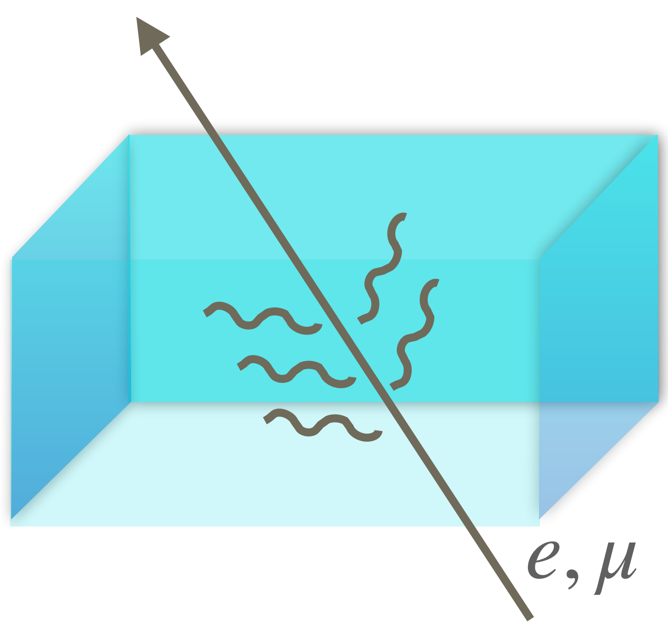
- Results in the emission of photons/phonons as excited electrons in a material return to the ground state



See also M. Pyle's talk later today

LUMINESCENCE

- Results in the emission of photons/phonons as excited electrons in a material return to the ground state

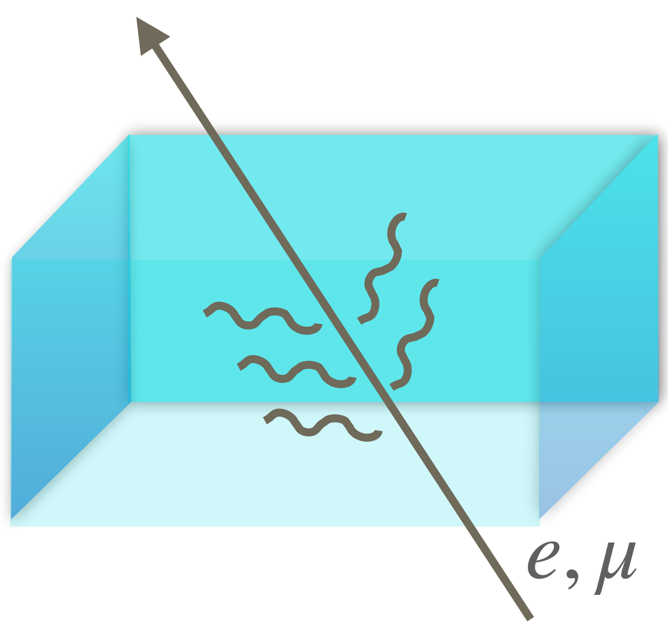


Luminescence or scintillation

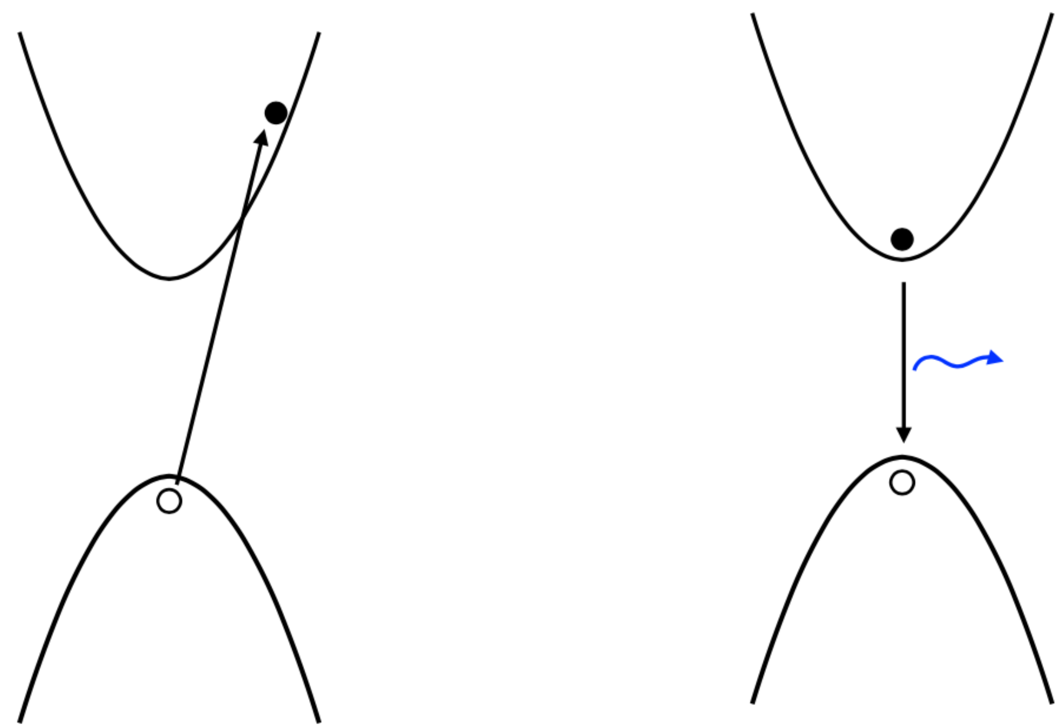
Slow: phosphorescence, afterglow

LUMINESCENCE FROM RADIATIVE RECOMBINATION

- Results in the emission of photons/phonons as excited electrons in a material return to the ground state



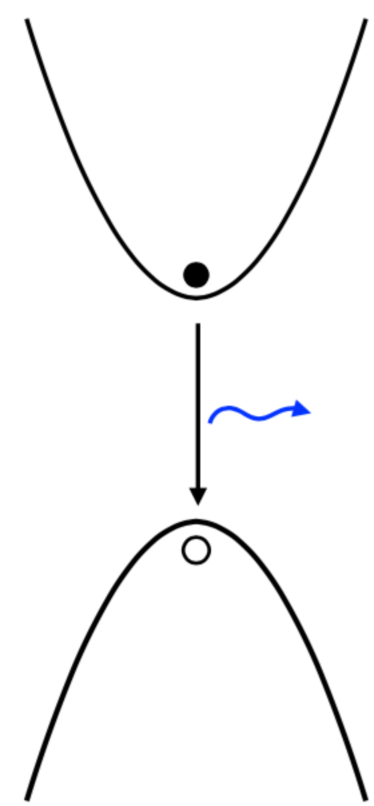
Excitation *Radiative recombination*



WHY IS LUMINESCENCE RELEVANT?

1. It leads to photons with energies matching the detector thresholds

Energy gaps in semiconductors are typically of order $\sim \mathrm{eV}$



$\omega \sim \mathrm{eV}$

WHY IS LUMINESCENCE RELEVANT?

2. Tracks leave most of their energy in materials by exciting electron-hole pairs ("ionization")

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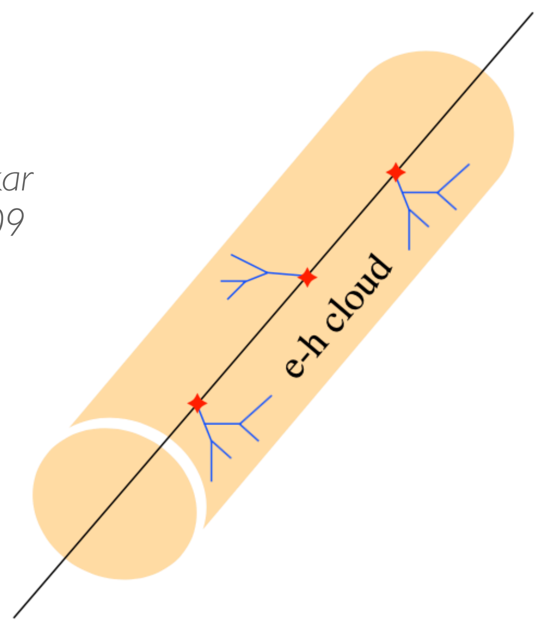

A single $\mathbf{200\,keV}$ *electron track leaves*

$$N_{eh} \sim 6 \times 10^4 \quad !!$$

$$\frac{\partial n_h}{\partial t} = -\nabla . \vec{j}_h - \Gamma_h^{\text{Auger}} - \Gamma_h^{\text{radiative}}$$

Radiative rates are highly material dependent

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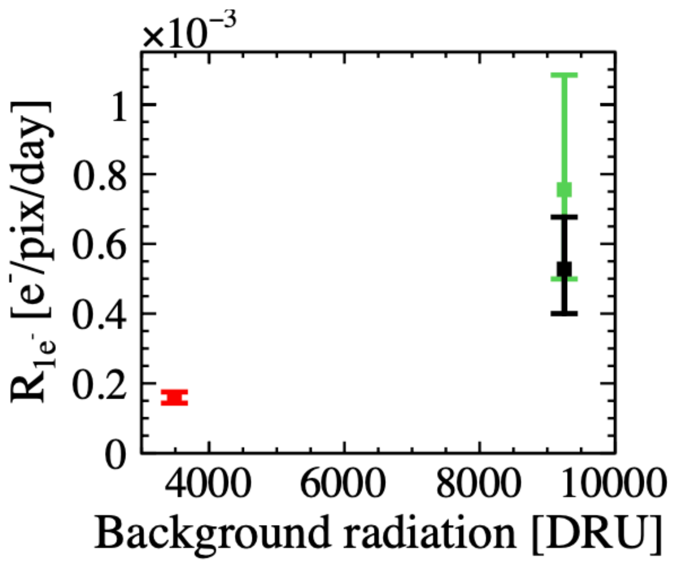
SENSEI

SENSEI (2020 DATA)

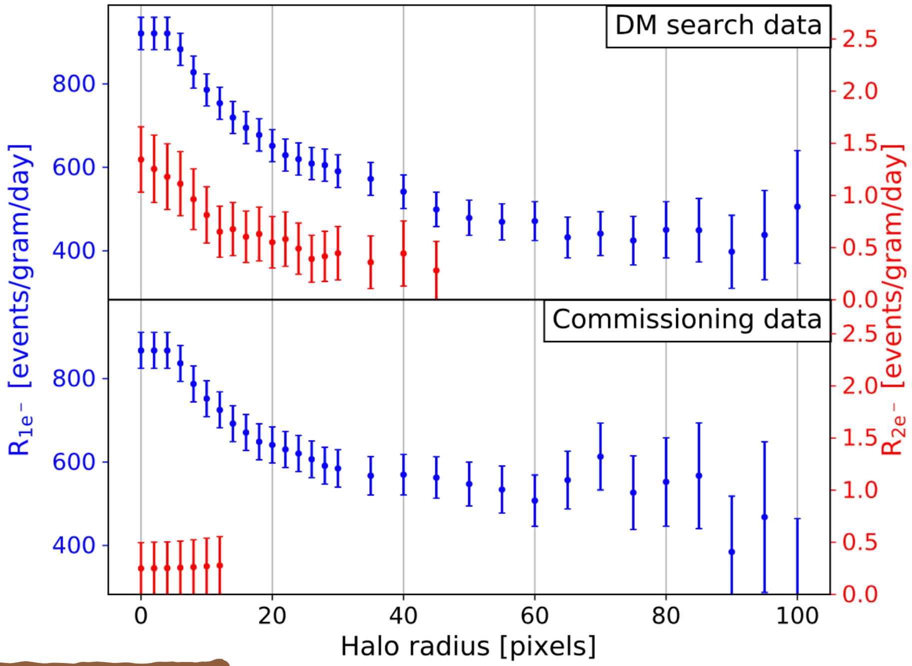
2004.11378 (SENSEI coll.)

$$R_{1e} = 450/\mathrm{g} - \mathrm{day}$$

Depends on track rate



Depends on halo mask



See also M. Cabbie's talk, and 2106.08347 (SENSEI coll.)

CHERENKOV RADIATION

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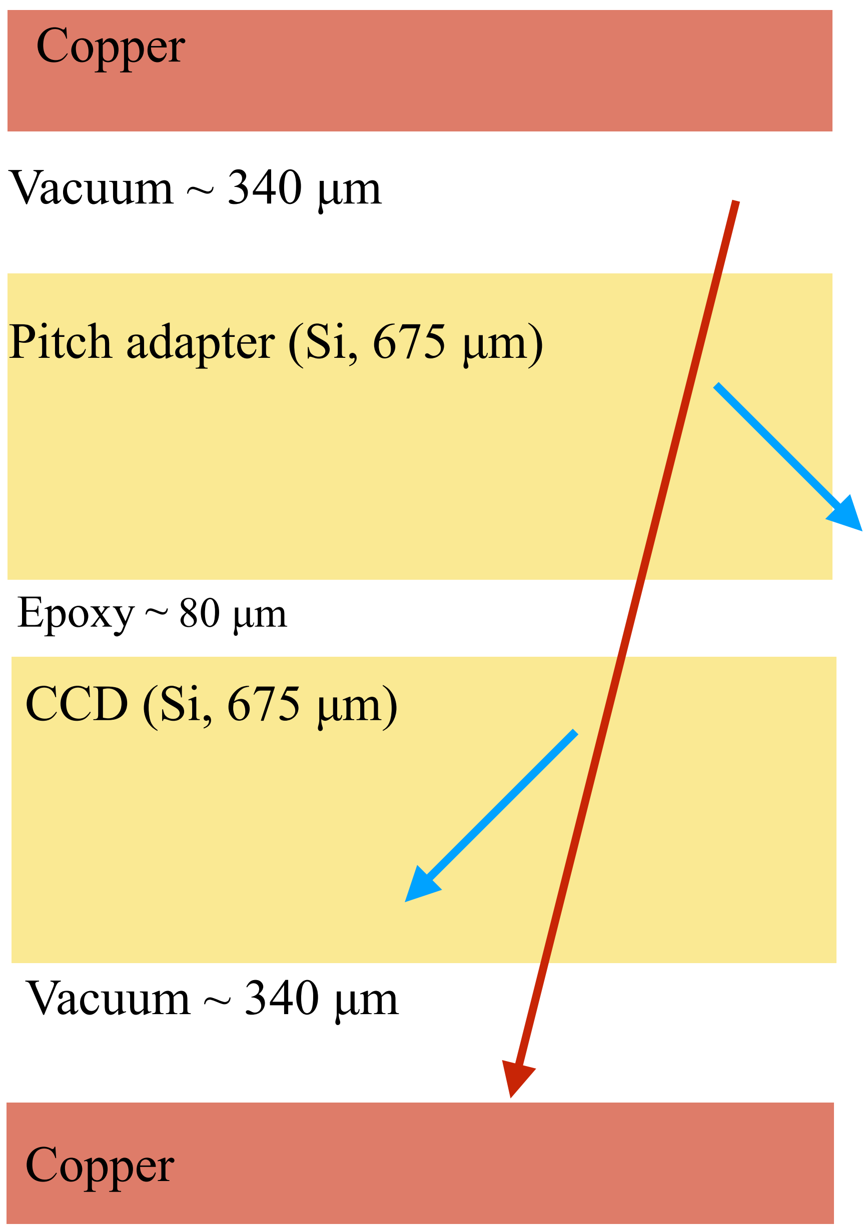
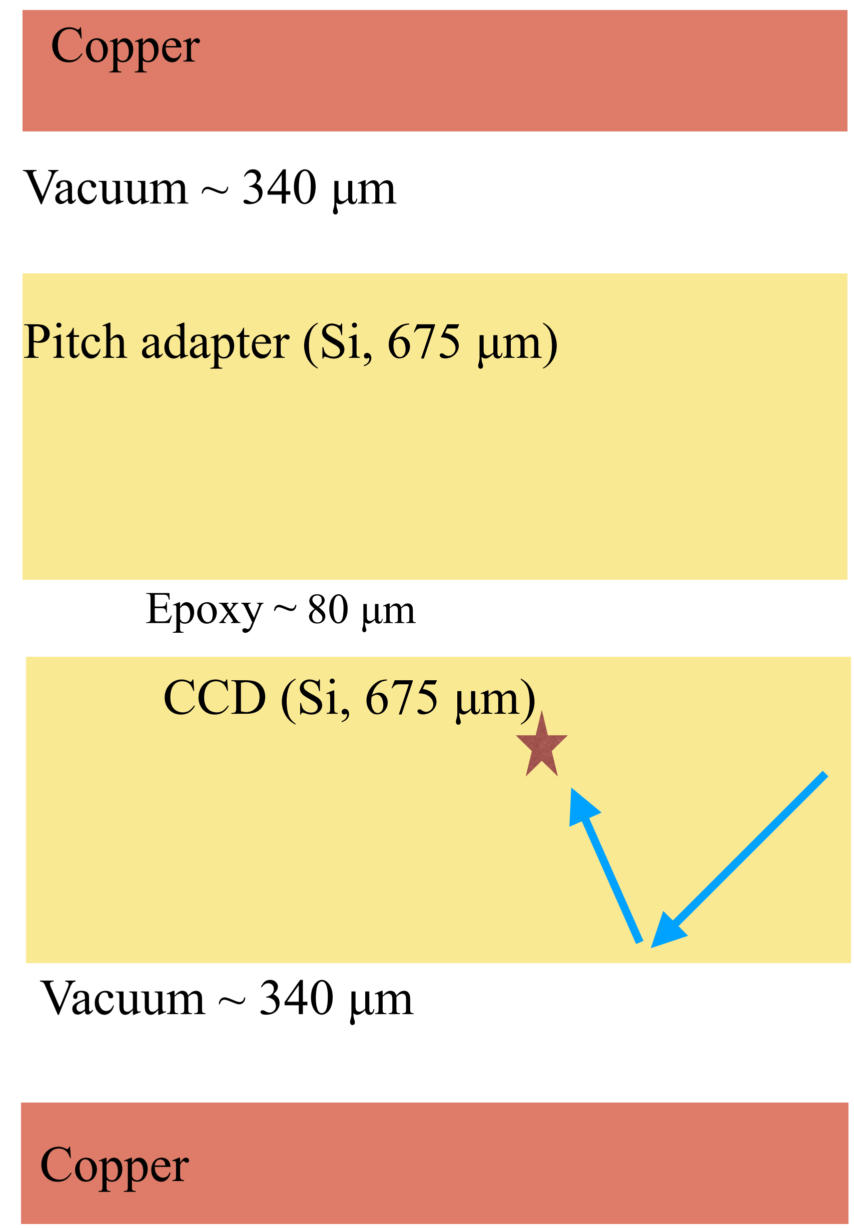
Track passage and radiation



Photons bounce around until absorbed



LUMINESCENCE (RADIATIVE RECOMBINATION)

Track passage and radiation

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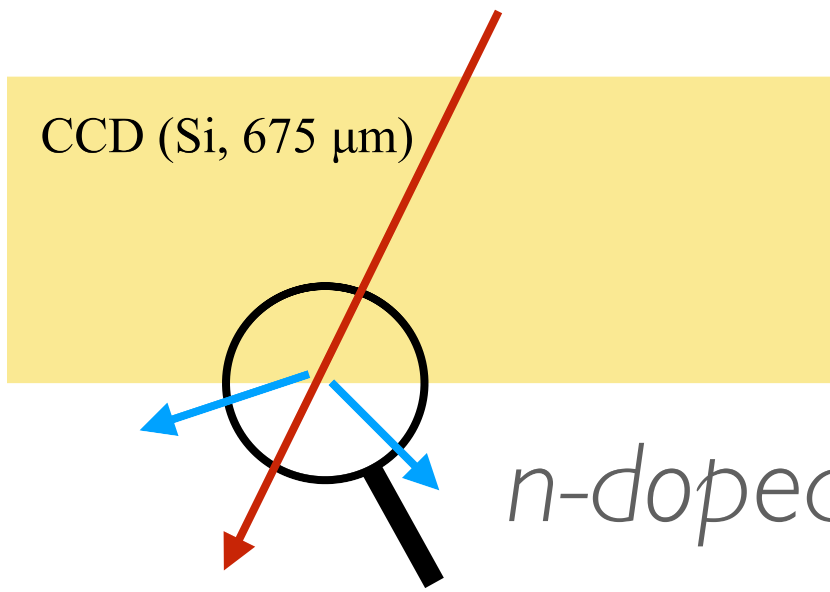
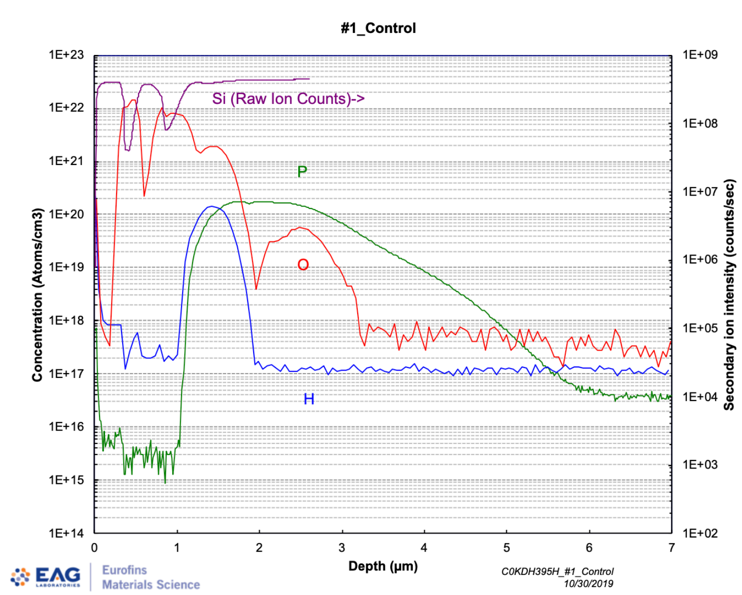
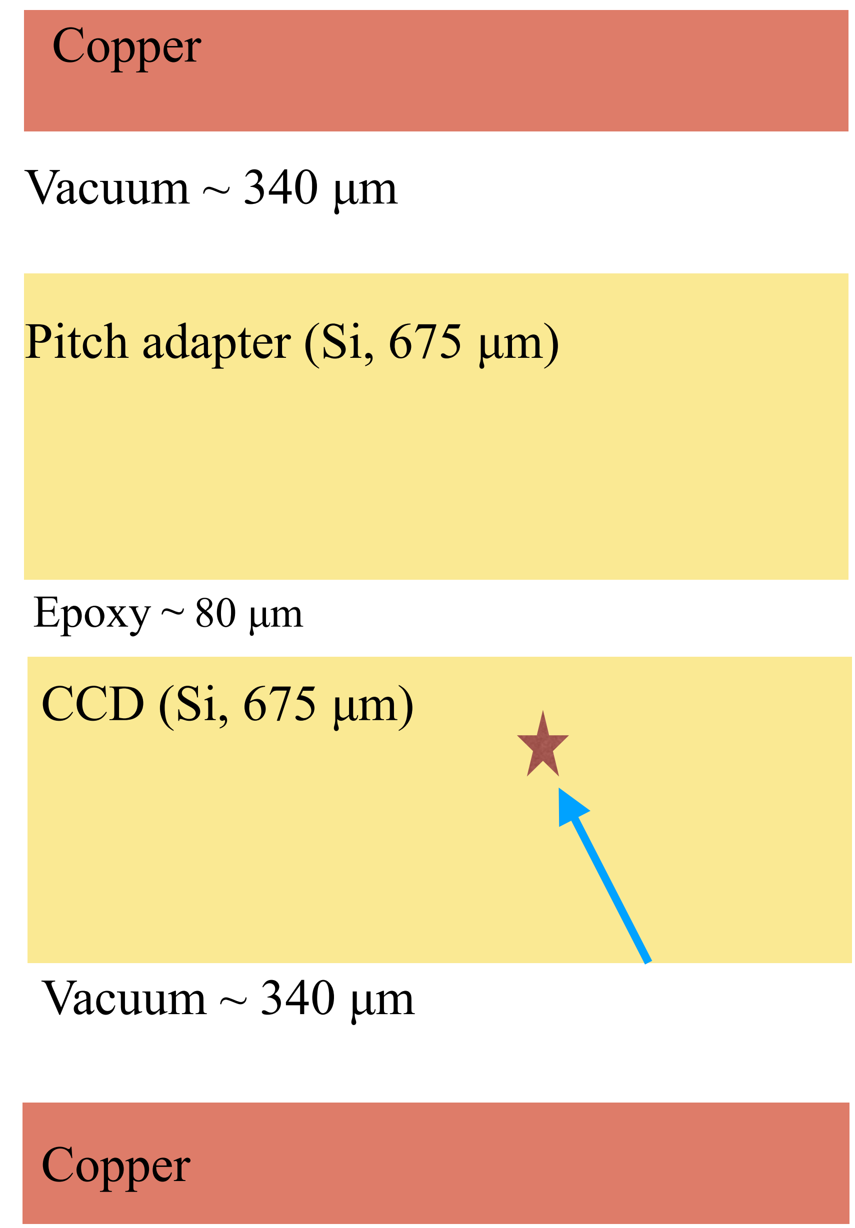
Photons bounce around until absorbed

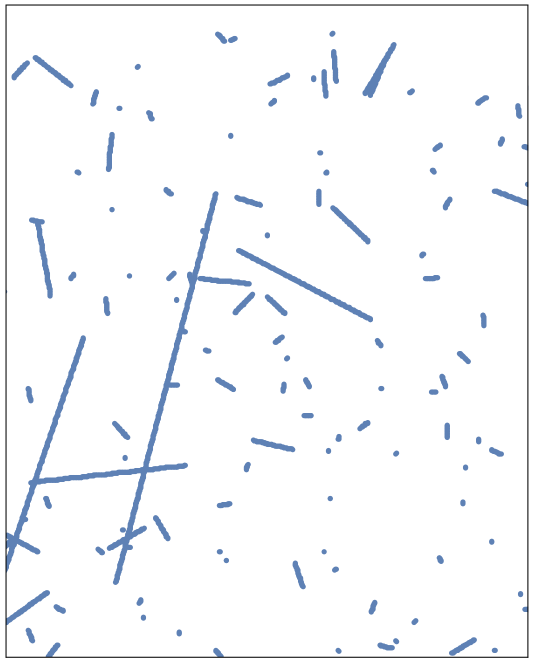


n-doped layer!

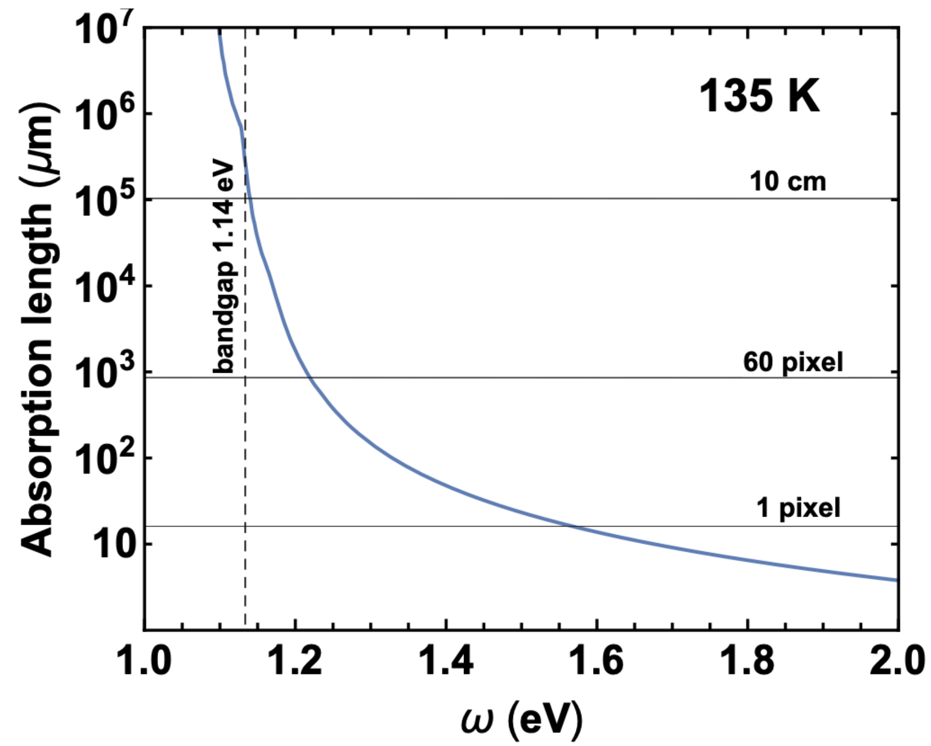




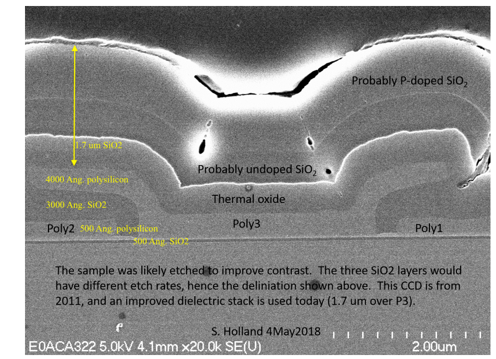
Simulated tracks



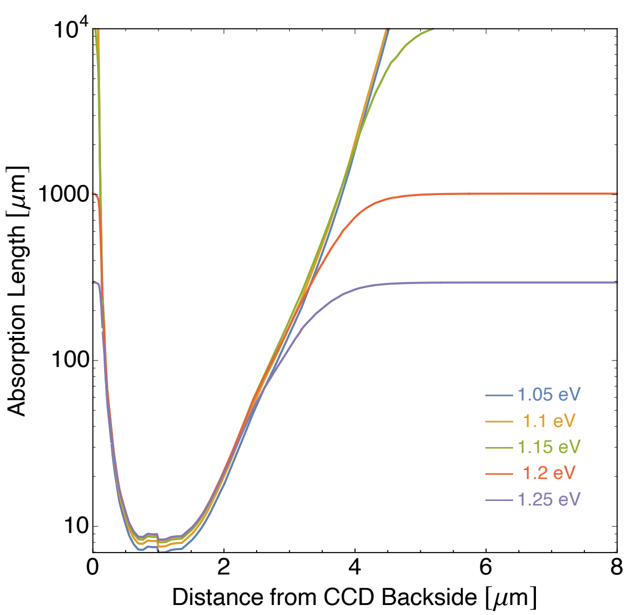
Photon absorption



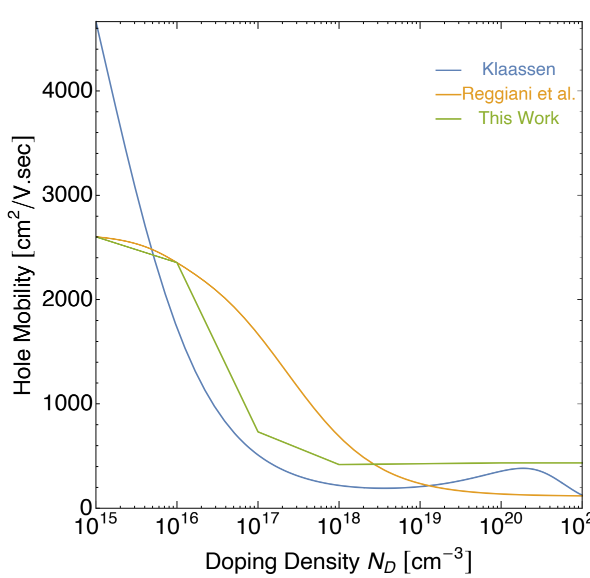
Reflection/refraction, thin-film interference



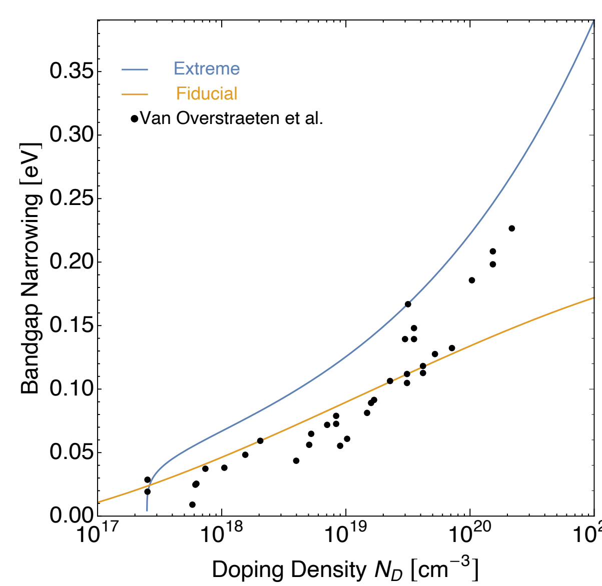
Backside absorption



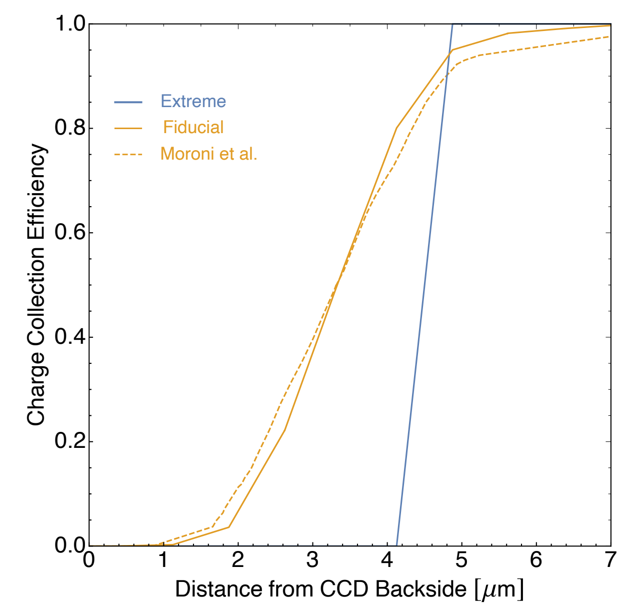
Mobility models



Bandgap gradients



Partial charge collection



etc. etc. etc.

RESULTS

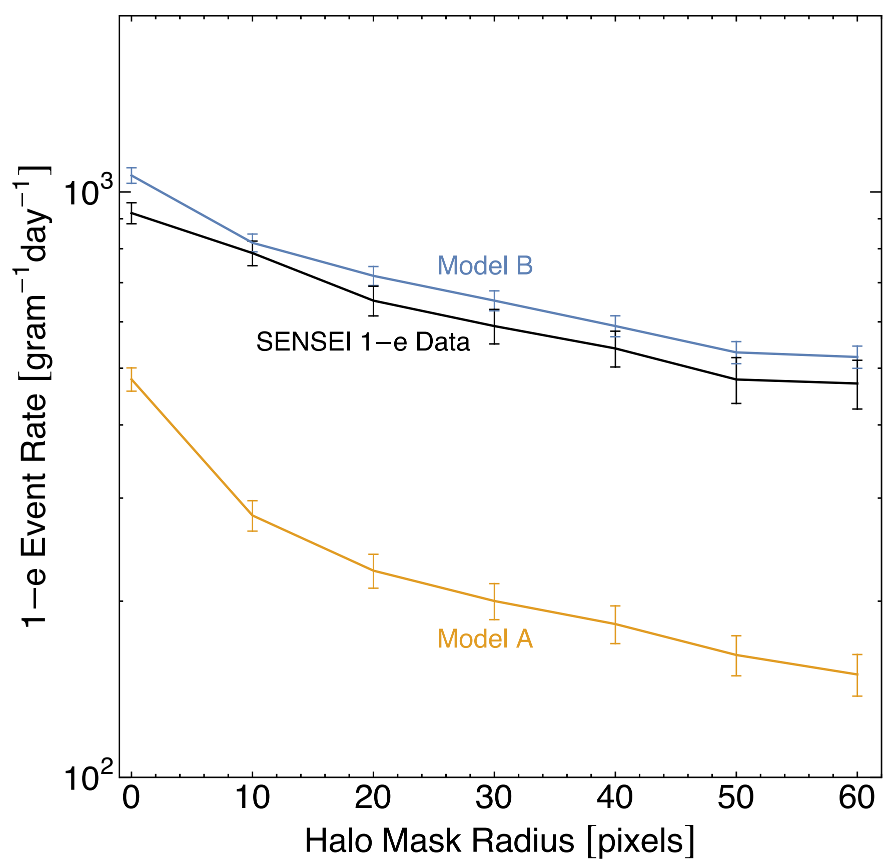
Latest simulation

$$R_{1e}^{Cherenkov} = 150/\mathrm{g-day}$$

$$R_{1e}^{Reco} = (\mathit{few} - 360)/\mathrm{g-day}$$

(to be published)

(v/s 450 observed)



DEU, Du, Essig, Sholapurkar
to be published

SUPERCDMS HVEV

SUPERCDMS HVEV (2019 DATA)

The one-electron rate is
likely generated by charge leakage *(*private communications)*

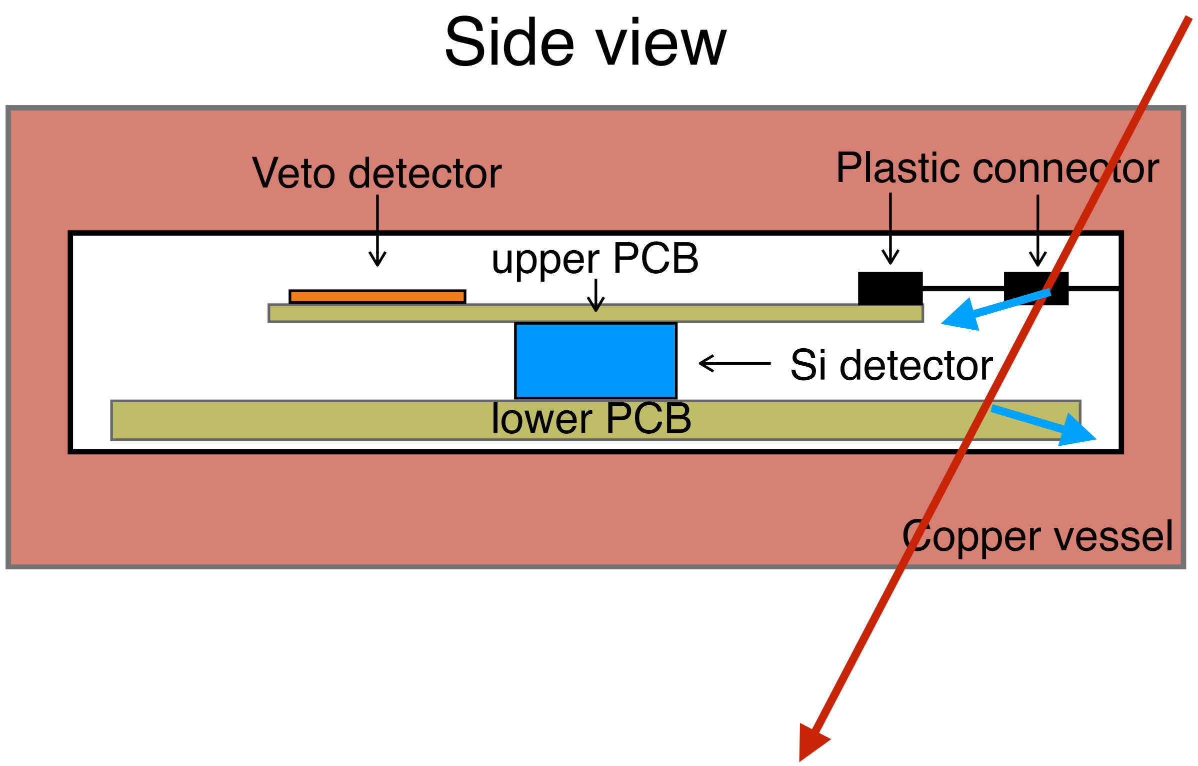
	HVeV Rates (g-day)$^{-1}$	
	100 V	60 V
R_1	$(149 \pm 1)10^3$	$(165 \pm 2)10^3$
R_2	$(1.1 \pm 0.1)10^3$	$(1.2 \pm 0.2)10^3$
R_3	207 ± 40	245 ± 86
R_4	53 ± 20	77 ± 48
R_5	16 ± 11	20 ± 25
R_6	5 ± 6	10 ± 17

See also R. Ren's talk

2005.14067 (SuperCDMS coll.)

SUPERCDMS HVEV

- But tracks passing through auxiliary materials are not vetoed.

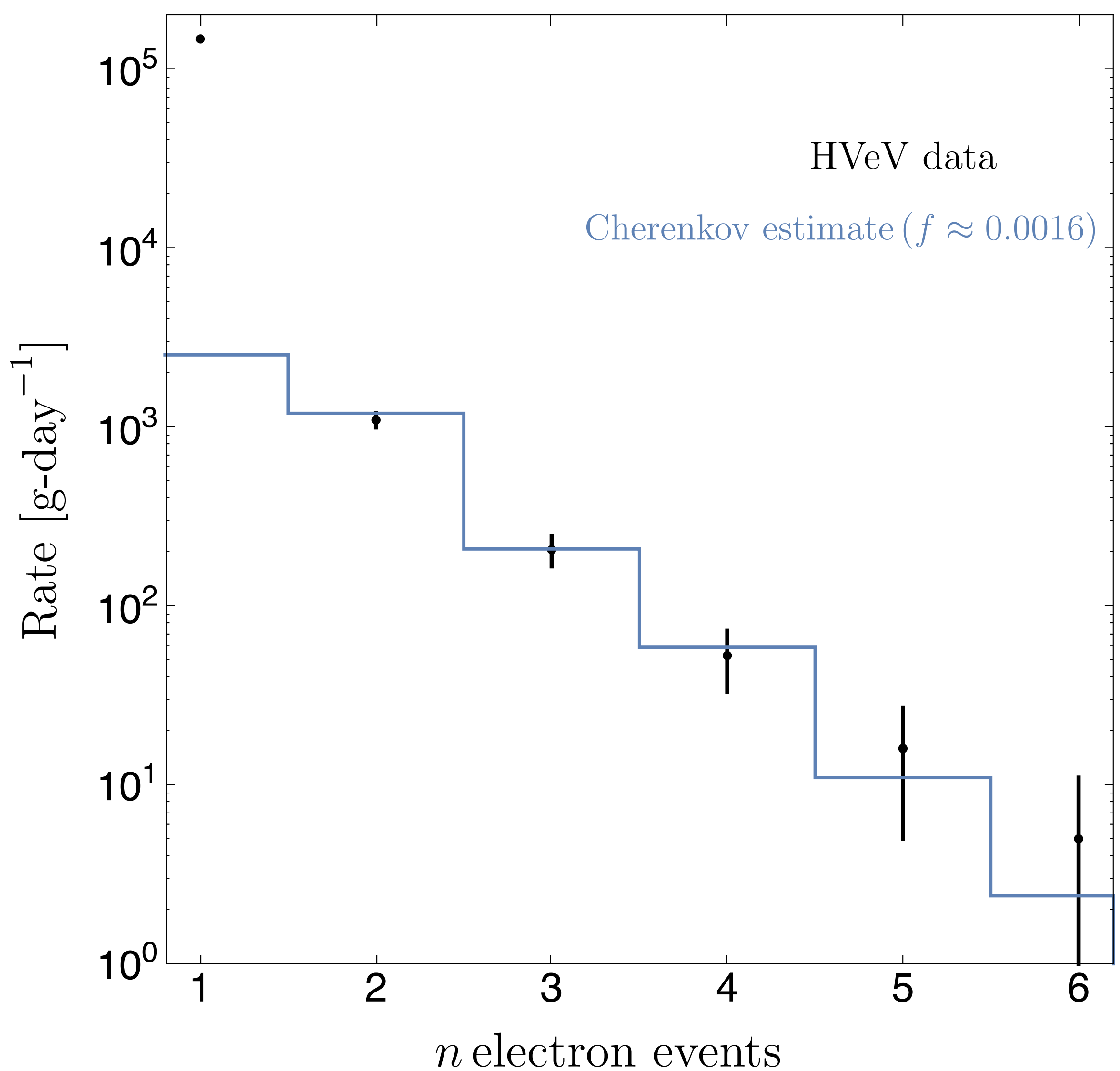


Not vetoed

Most of them from the PCBs

Cherenkovs and possibly Luminescence

SUPERCDMS HVEV



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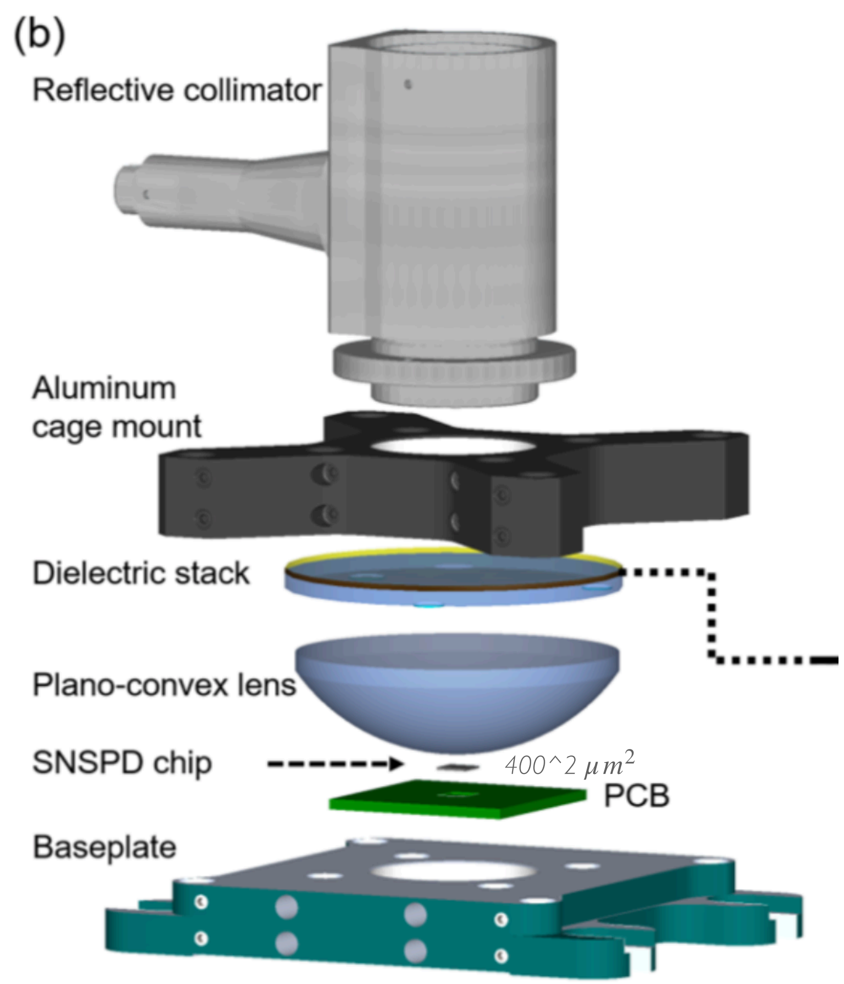
Excellent agreement of the Cherenkov hypothesis with the observed spectrum

LAMPOST

LAMPOST

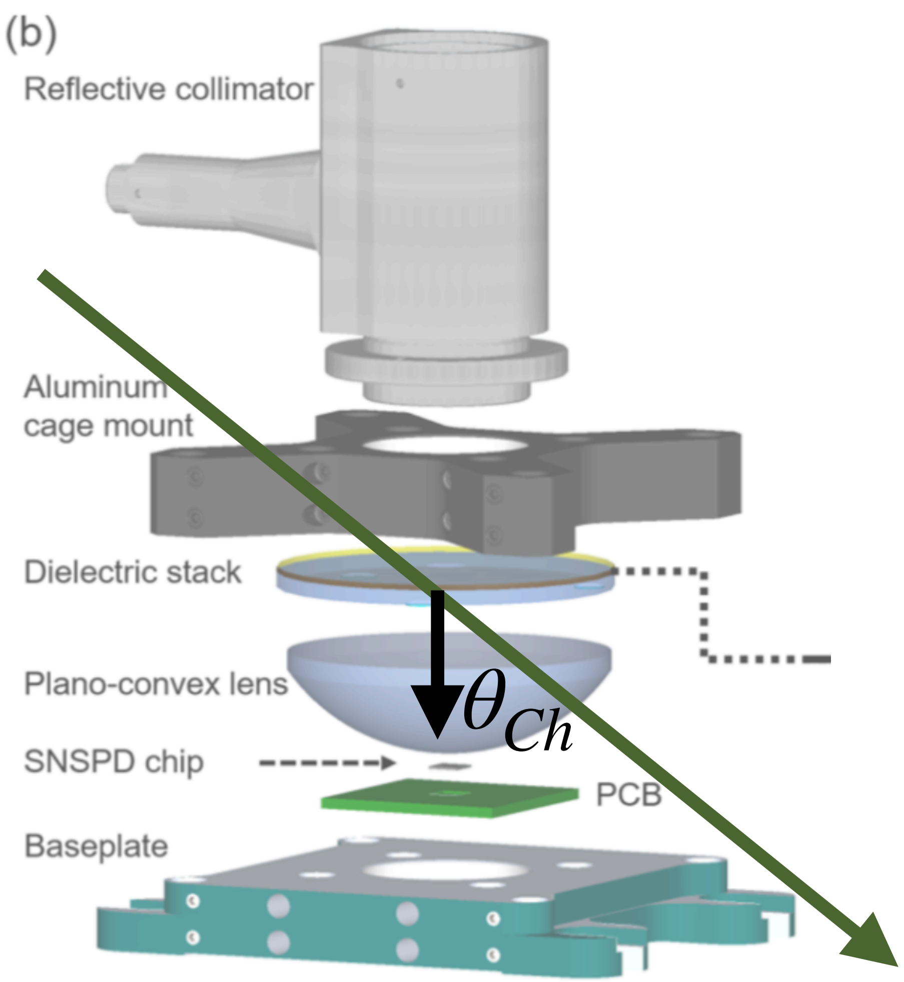
- Observes 6×10^{-6} counts/s in SNSPD detector.



2110.01582 (LAMPOST coll.)

LAMPOST

- Tracks passing through the lens generate Cherenkov photons.



From muons only

$$N_{Cherenkov} \sim 10^5/\text{day}/\text{eV}$$

(~100 per track!)

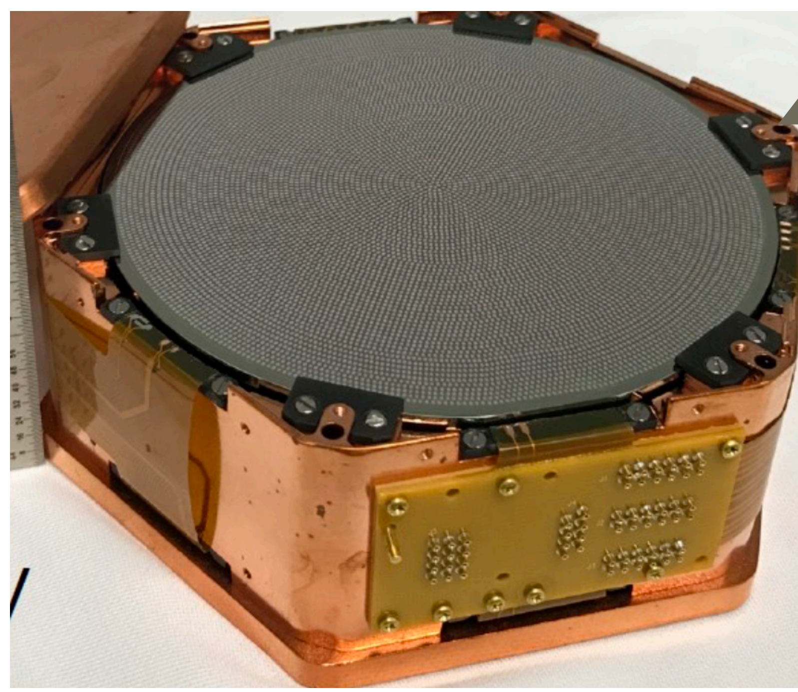
See also K. Berggren talk on Thursday

SUPERCDMS SNOLAB

SUPERCDMS SNOLAB

- High-voltage detectors are held by Cirlex clamps. Radioactive tracks from the Cirlex generate Cherenkovs.

Figure from Loer, DM 2018



Cirlex clamps

SuperCDMS coll. 1610.00006

$$N^{\text{Cirlex}}_{\text{events}} \sim 130/\text{day}/\text{tower}$$

DEU, Du, Essig, Sholapurkar arXiv:2011.13939 PRX 12 (2022) 1, 011009

Qubit decoherence?

QUBIT DECOHERENCE

- Tracks passing through substrates create Cherenkov light and eh pairs.
- Cherenkov light and luminescence generate long-lived photons that can break Cooper pairs.
- As an example, a track going over 300 μm of Sapphire substrate leads to ~10^2 eV in energy of sub-gap Cherenkov photons

⟶ 10^3 *quasiparticles/track!*

See also L. Cardani's talk on Thursday and Vepsalainen et. al. arXiv:2001.09190

CONCLUSIONS

- We discussed important backgrounds that affect a variety of low-energy threshold dark-matter detectors: Cherenkov radiation and luminescence.
- We showed that these are possible explanations for the excess events at SENSEI, SuperCDMS HVeV and LAMPOST.
- Concrete mitigation strategies can be taken towards the future: these can *significantly* improve the reach to detect dark matter.

Thanks!