Sources of Low-energy Backgrounds in SENSEI

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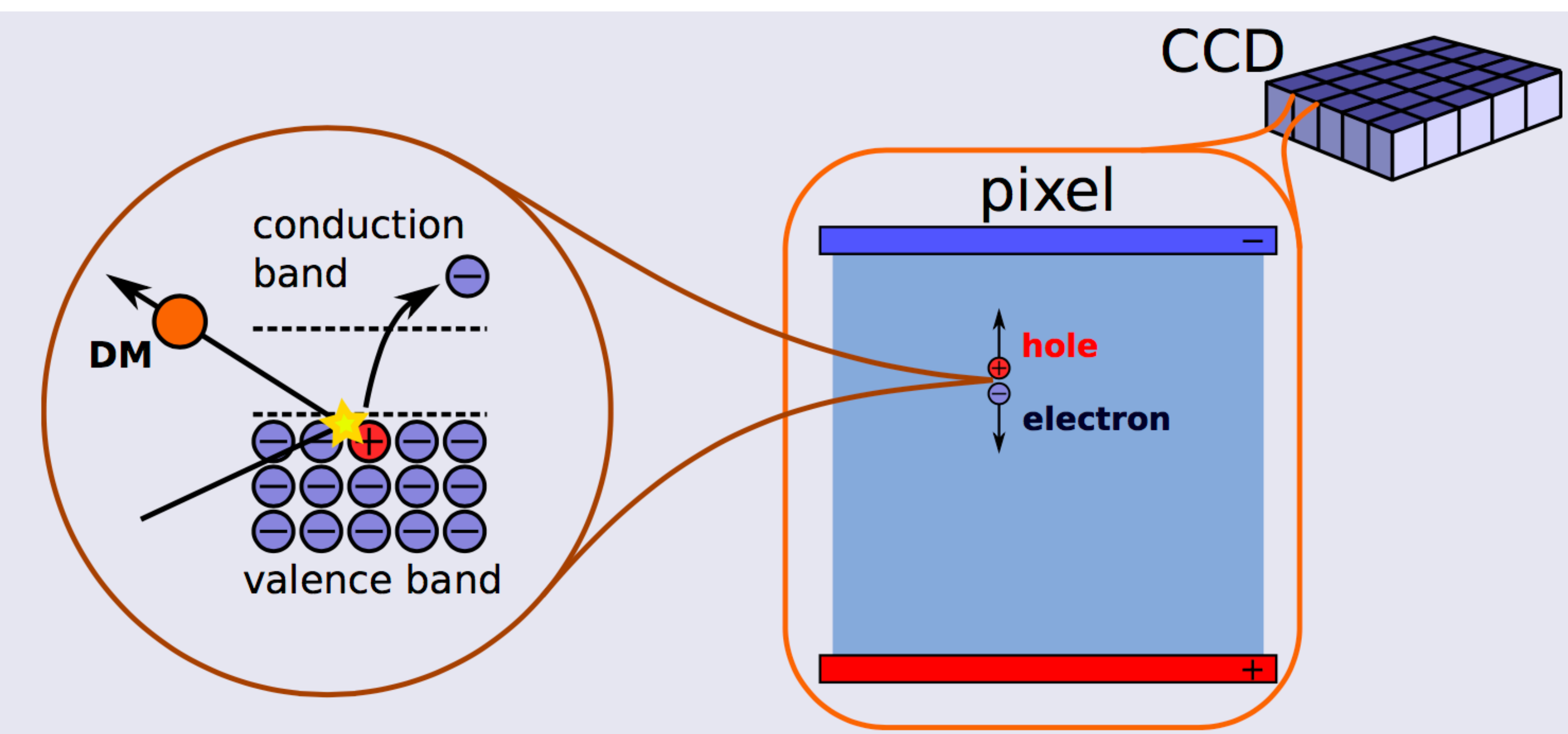
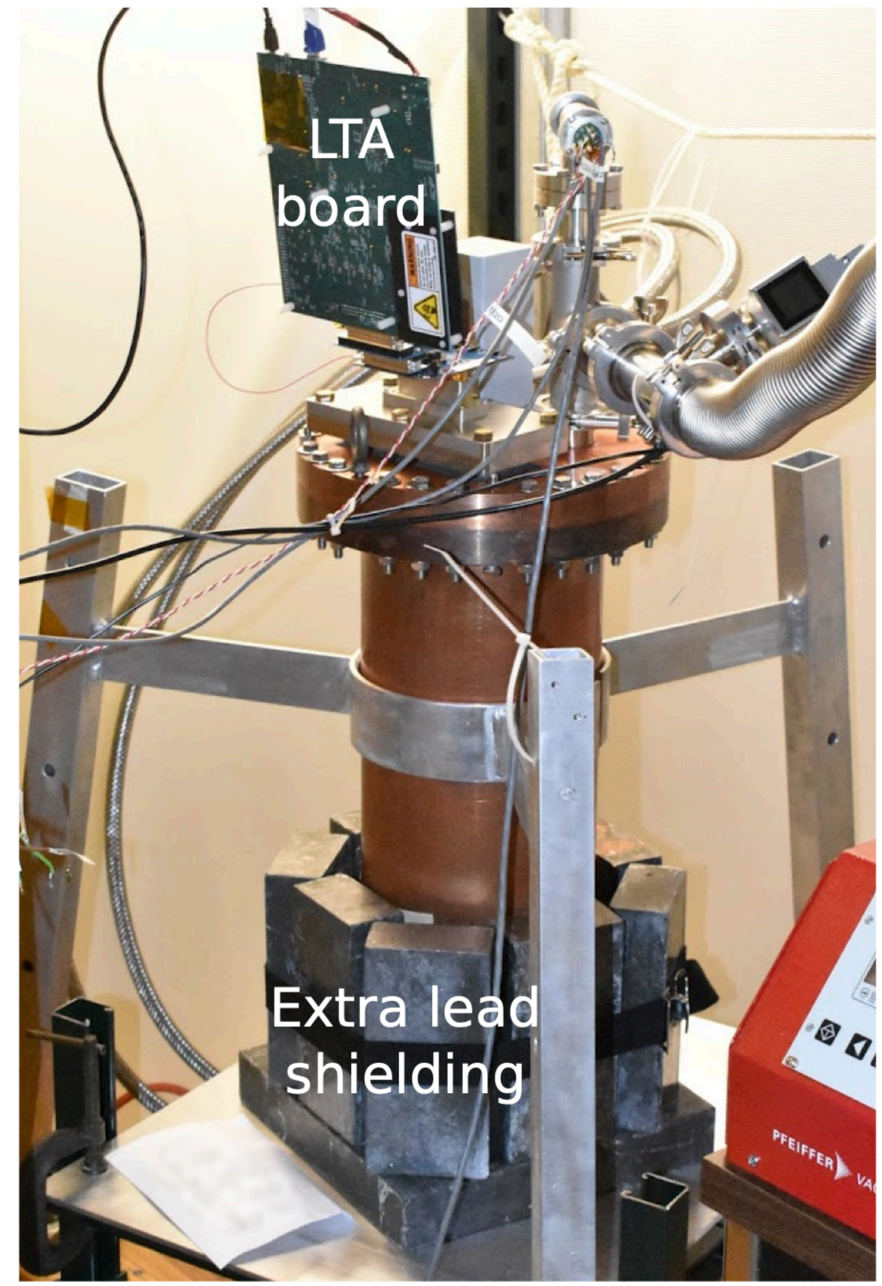
SENSEI at MINOS

Overview:

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

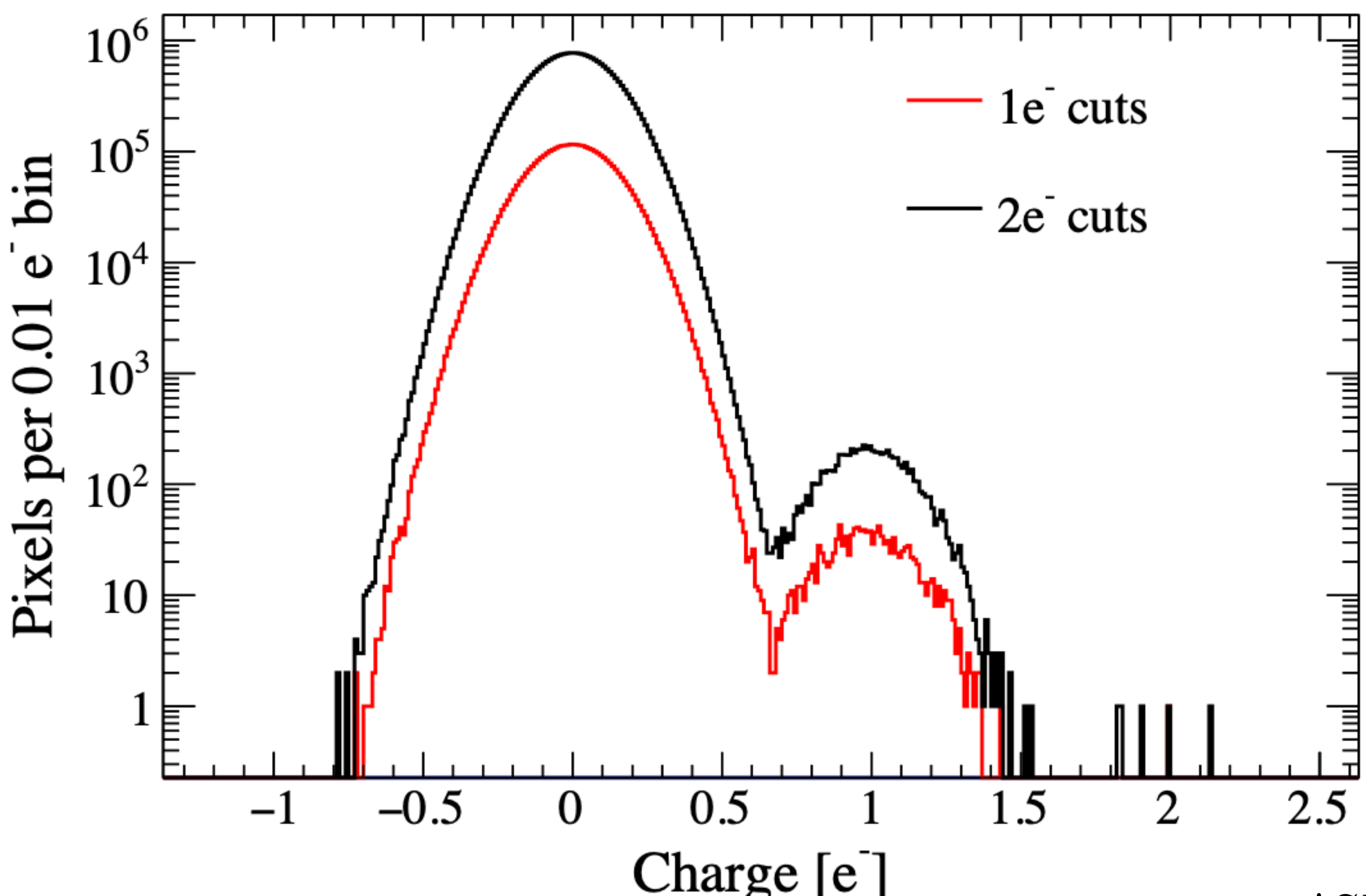




**SENSEI, 2020*

Excess Low Energy Events in SENSEI

- SENSEI observed a sizable number of 1-e events
- Cannot be explained by previously explored backgrounds

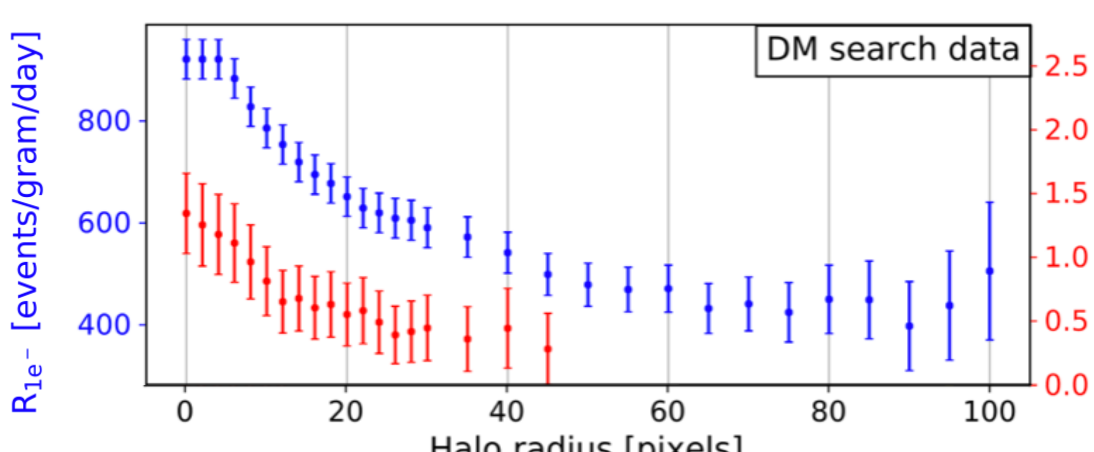


**SENSEI, 2020*

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 a correlation in positions of 1-e events and the positions of high energy events
- Observed ~ 450 1-e events per (gram*day) after applying a 60-pixel (~900 µm) halo-mask cut



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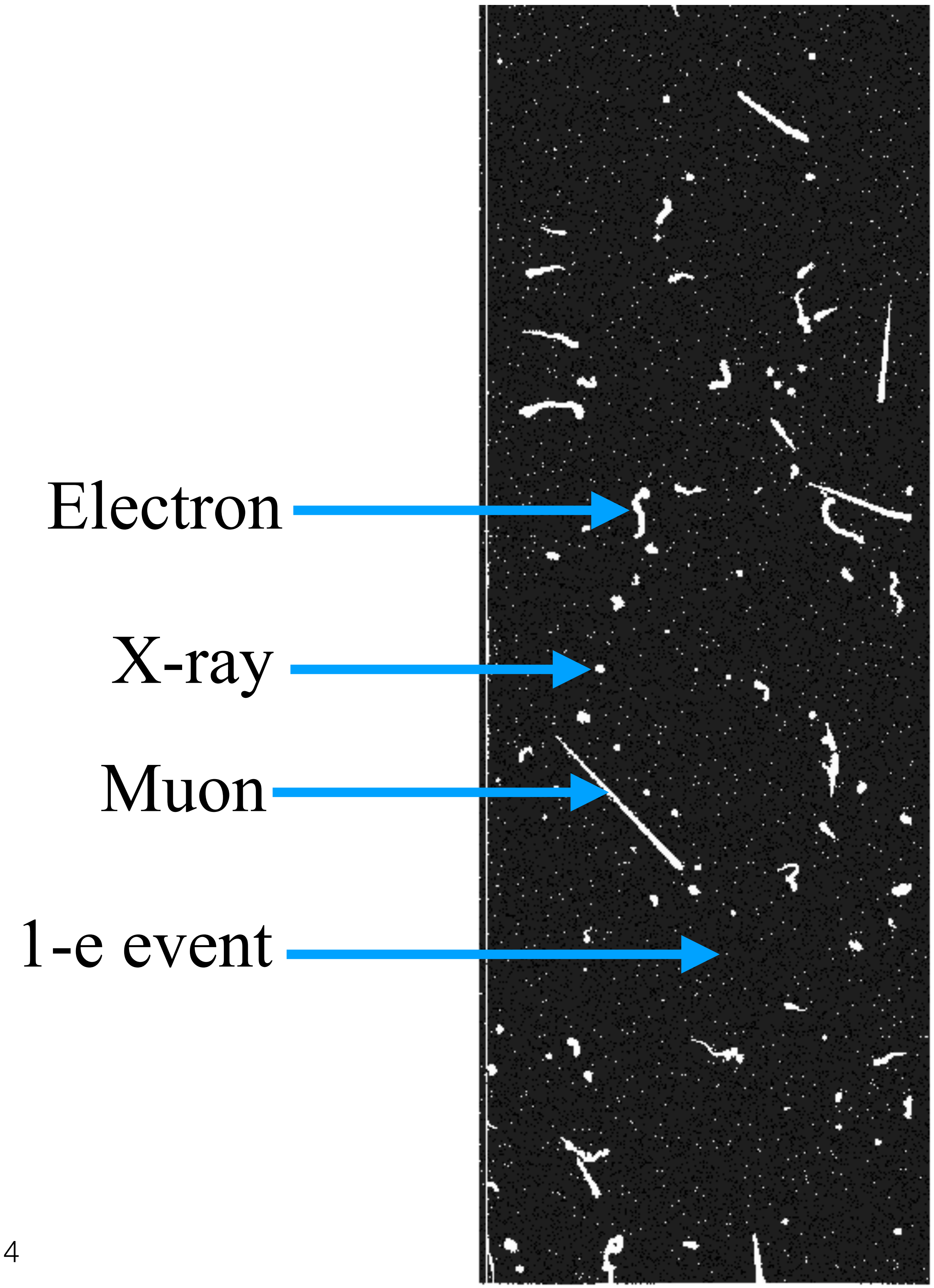

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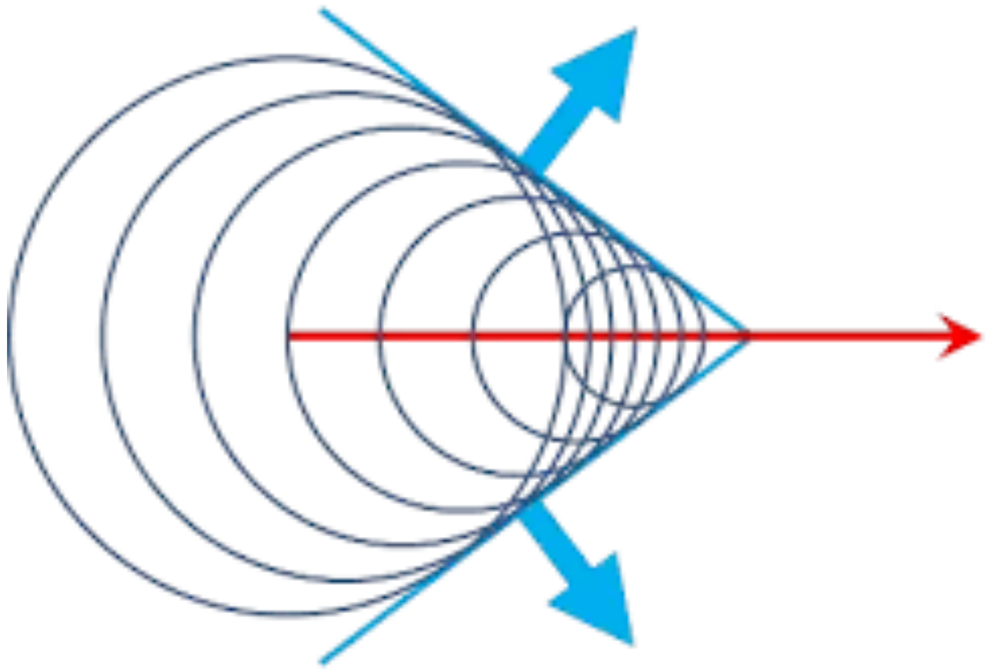
- Can account for a significant fraction of 1-e events

Cherenkov Radiation

- Cherenkov radiation is the spontaneous emission of radiation by a charged particle passing through a dielectric material, when the speed of the particle exceeds the speed of light in the material



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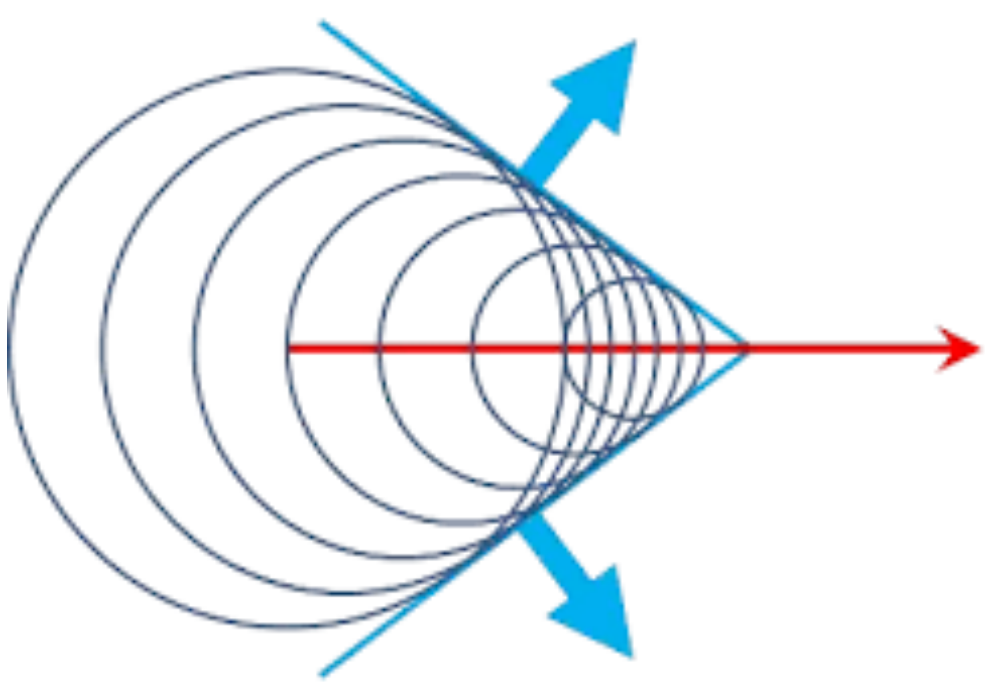
$\epsilon(\omega)$: Dielectric Function as a function of photon frequency ω

$$v^2 \mathrm{Re}\ \epsilon(\omega) > 1$$



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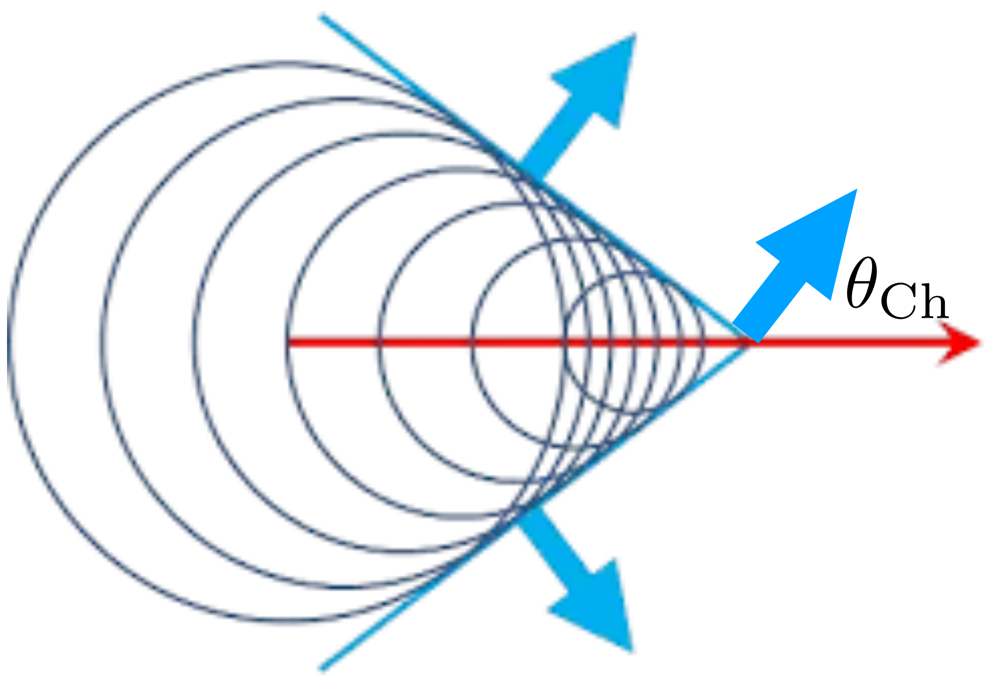

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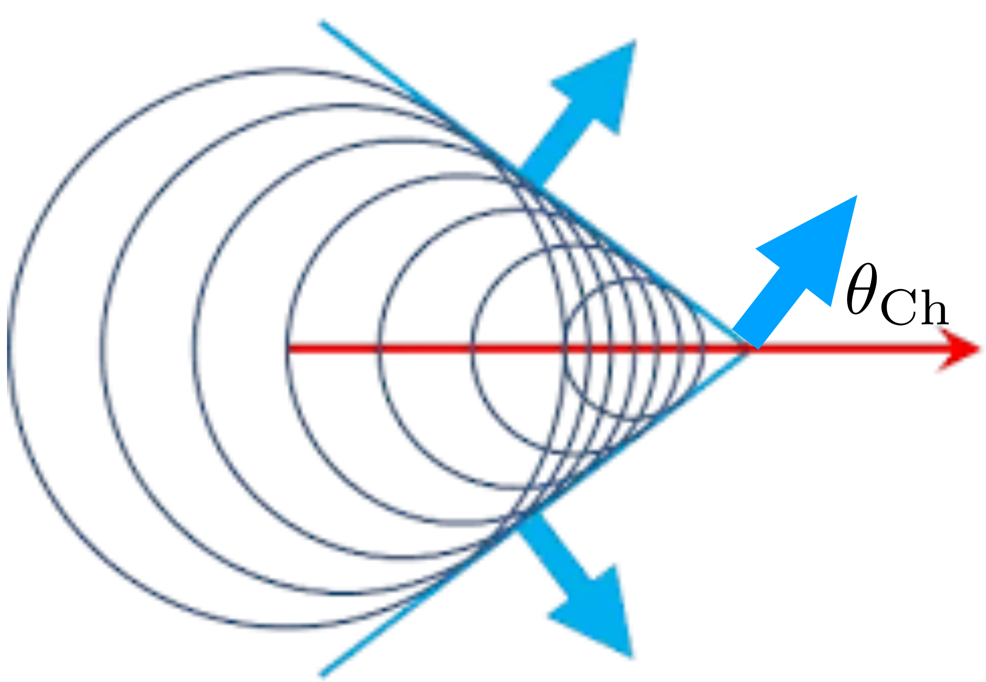


$$\cos\theta_{\mathrm{Ch}} = \frac{\sqrt{\mathrm{Re}\ \epsilon(\omega)}}{v|\epsilon(\omega)|}$$

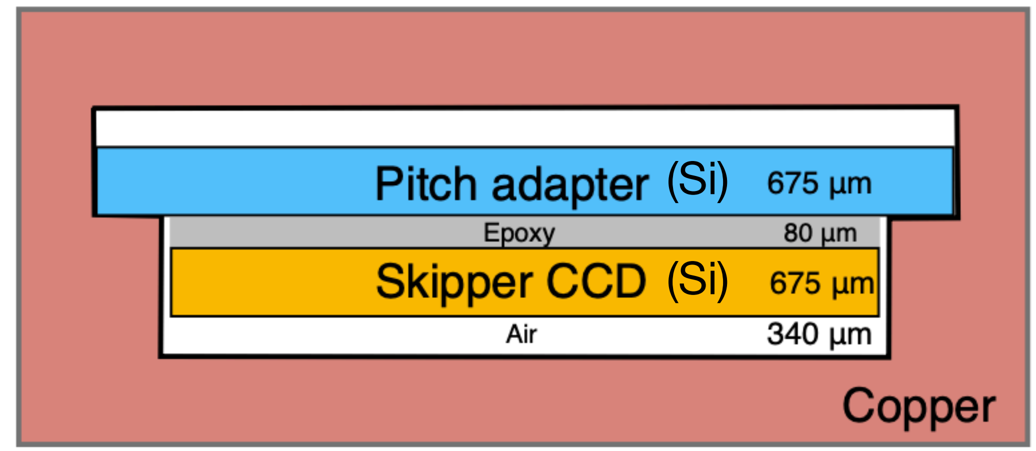
$$\frac{d^2N}{d\omega dx} = \alpha\left(1 - \frac{\mathrm{Re}\,\epsilon(\omega)}{v^2|\epsilon(\omega)|^2}\right)$$

Cherenkov Radiation as a Background in SENSEI

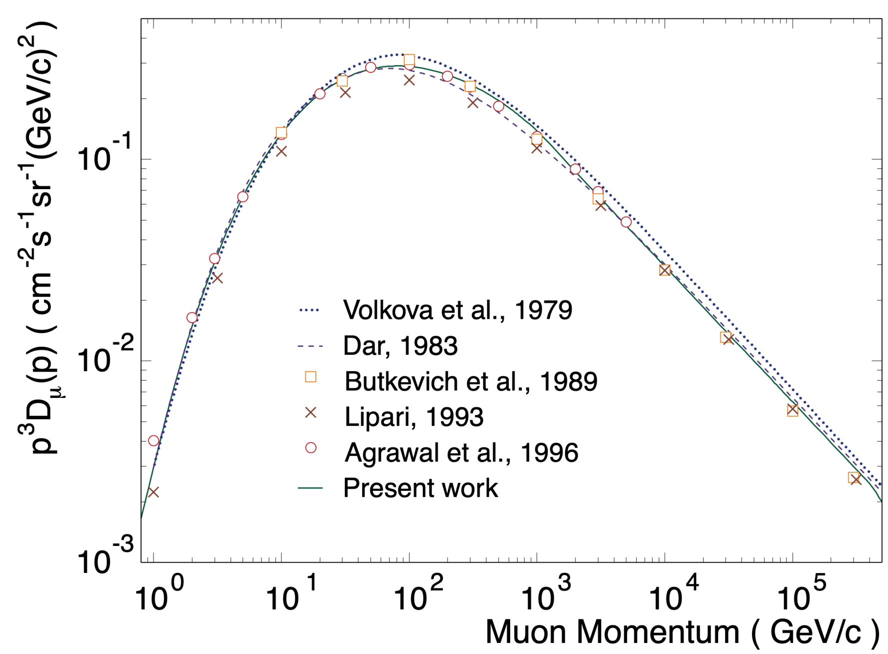
Materials that can emit Cherenkov:

- **Silicon CCD (675 μm)**
- **Silicon in pitch adapter (675 μm)**
- Epoxy-glue (80 μm)

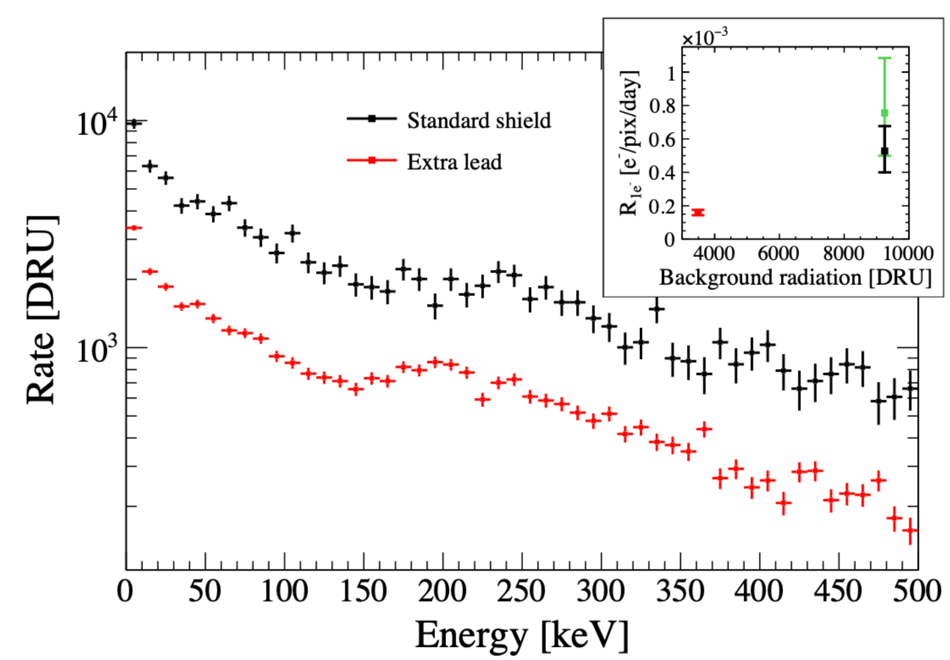
Side view



High-energy Particles	Cherenkov Energy Threshold (Si)
Electrons	20 keV
Muons	4.1 MeV



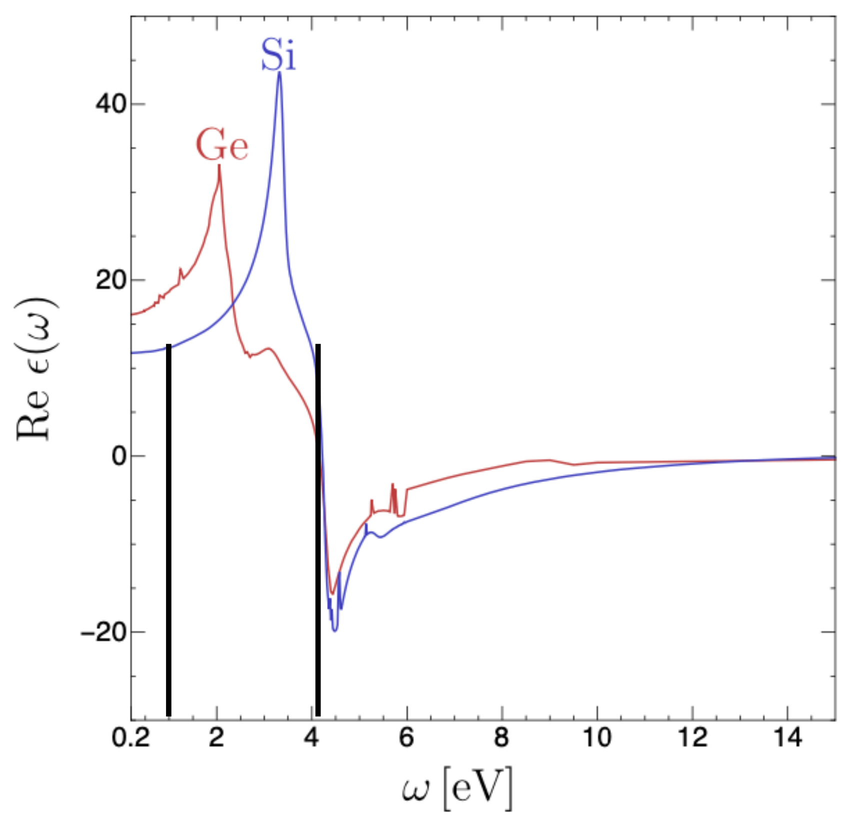
 Bugaev et.al., 1998



**SENSEI, 2020*

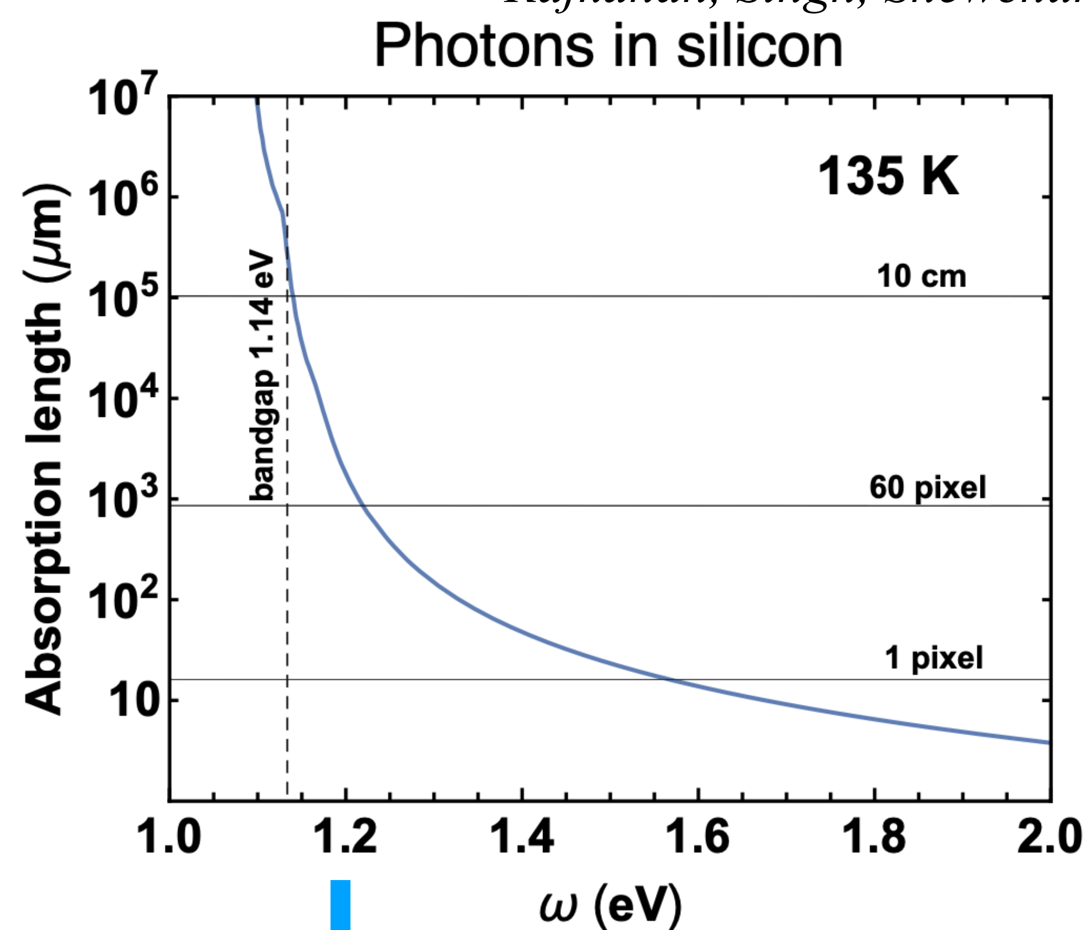
Cherenkov Radiation as a Background in SENSEI

Dielectric function



Emitted Cherenkov photons can be absorbed to produce 1-e event

**Rajkanan, Singh, Shewchun, 1978*

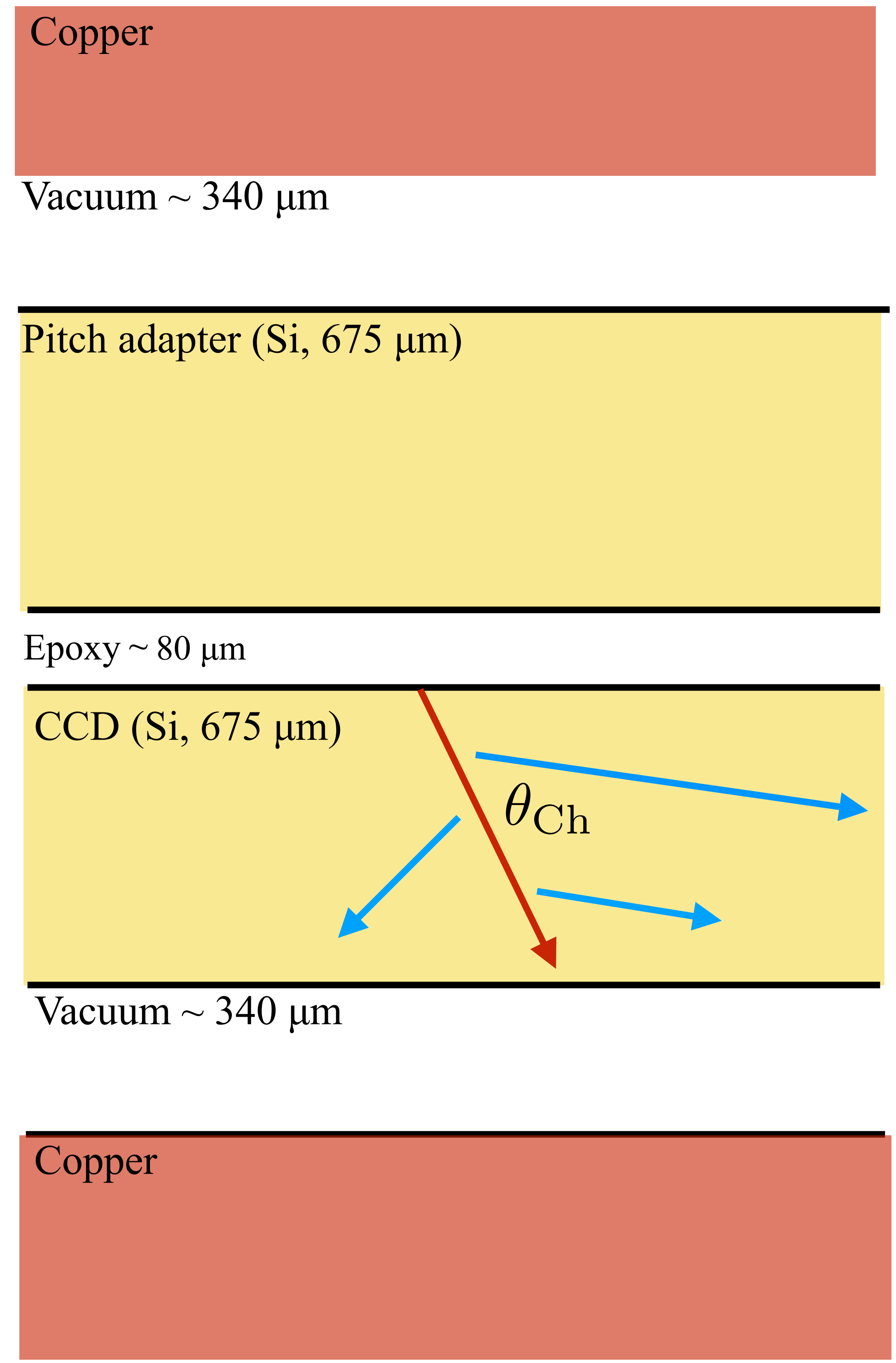


Can evade 60-pixel halo-mask if energy is close to bandgap

Cherenkov Radiation as a Background in SENSEI

Simulate Cherenkov background:

- Simulate high-energy particle tracks
- Tracks in CCD or pitch-adapter will emit Cherenkov photons
- Include reflections, refractions, and thin-film interference at interfaces, and reflections from copper housing



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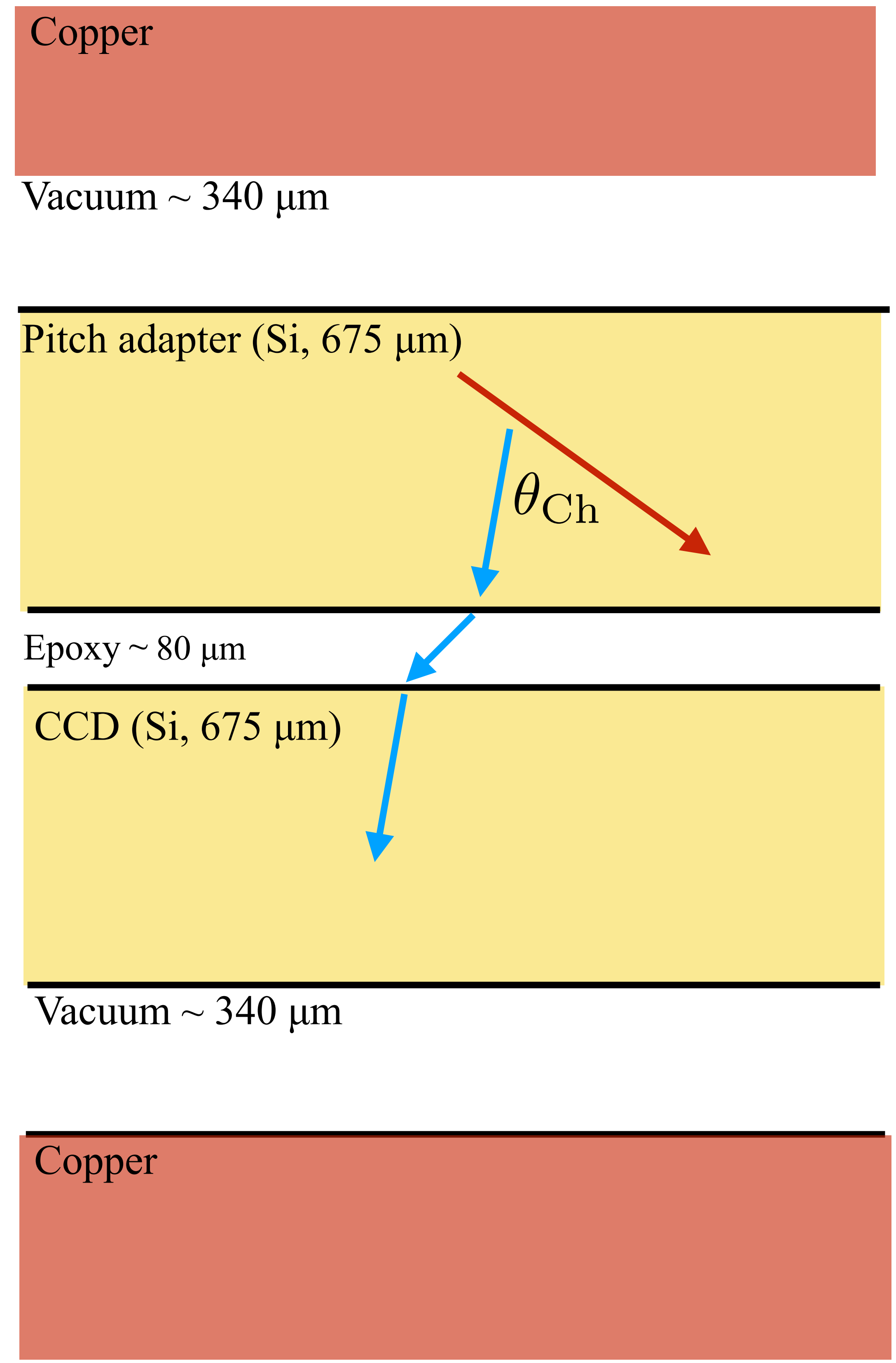

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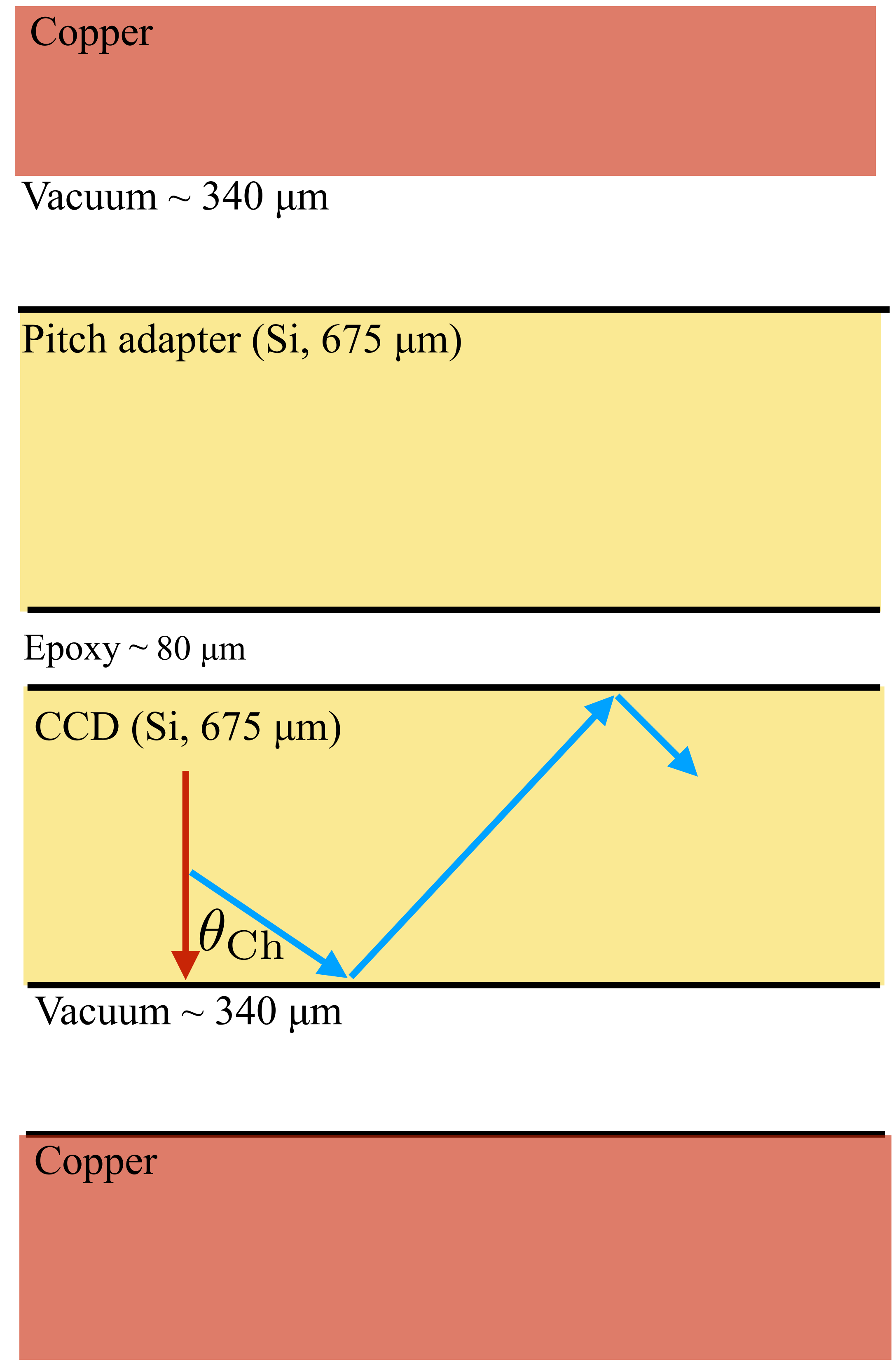
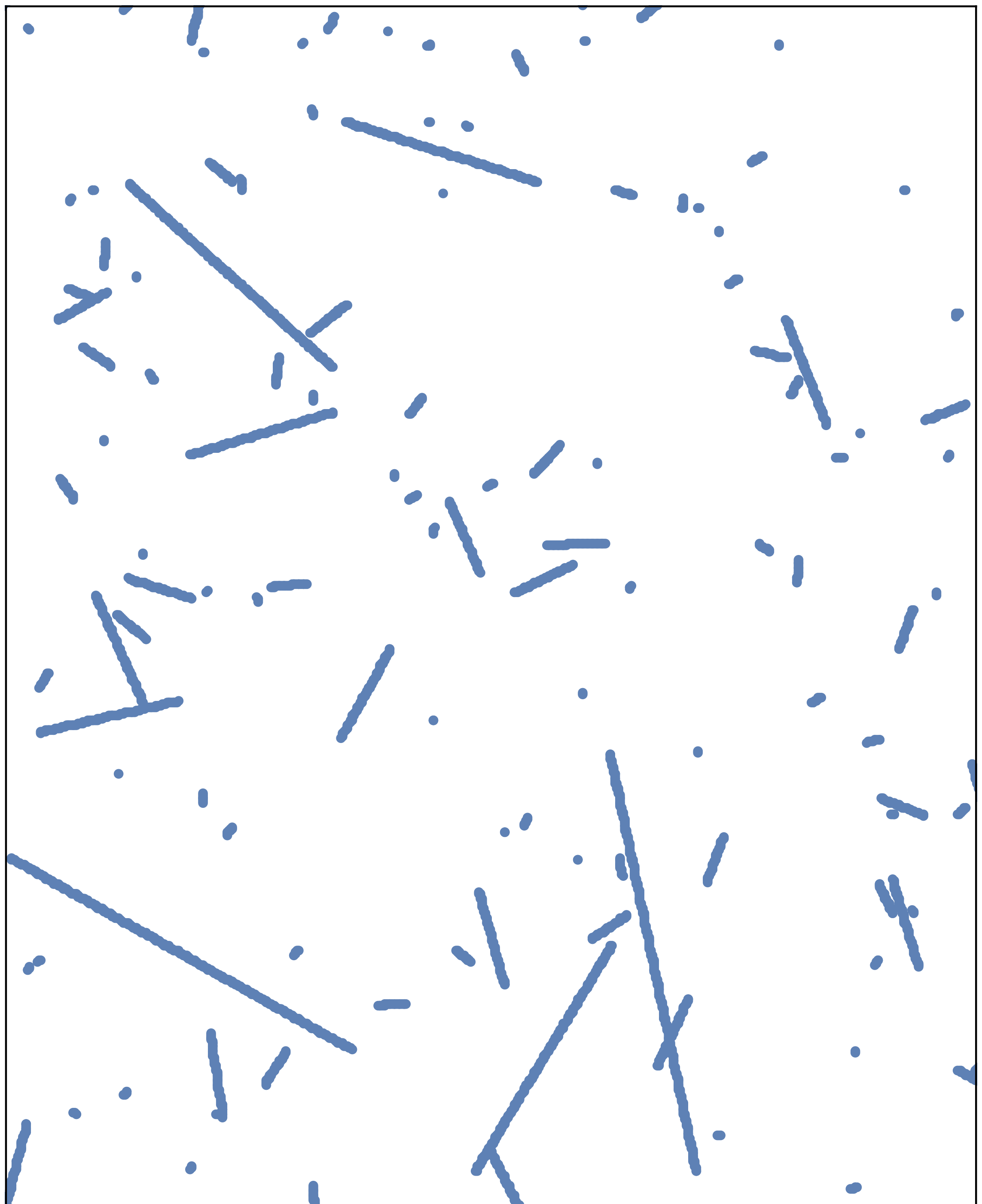
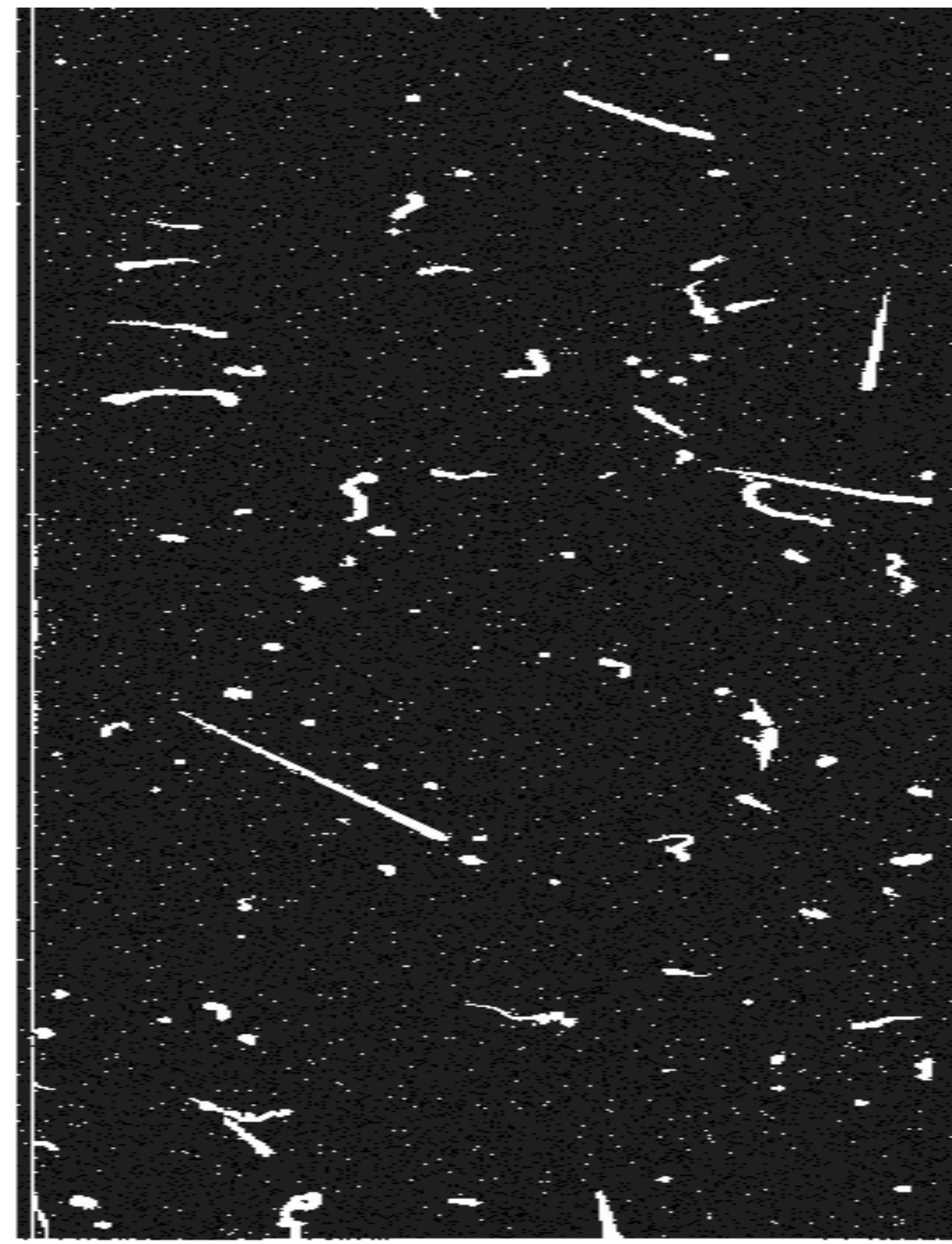


SENSEI Images

Simulated Tracks

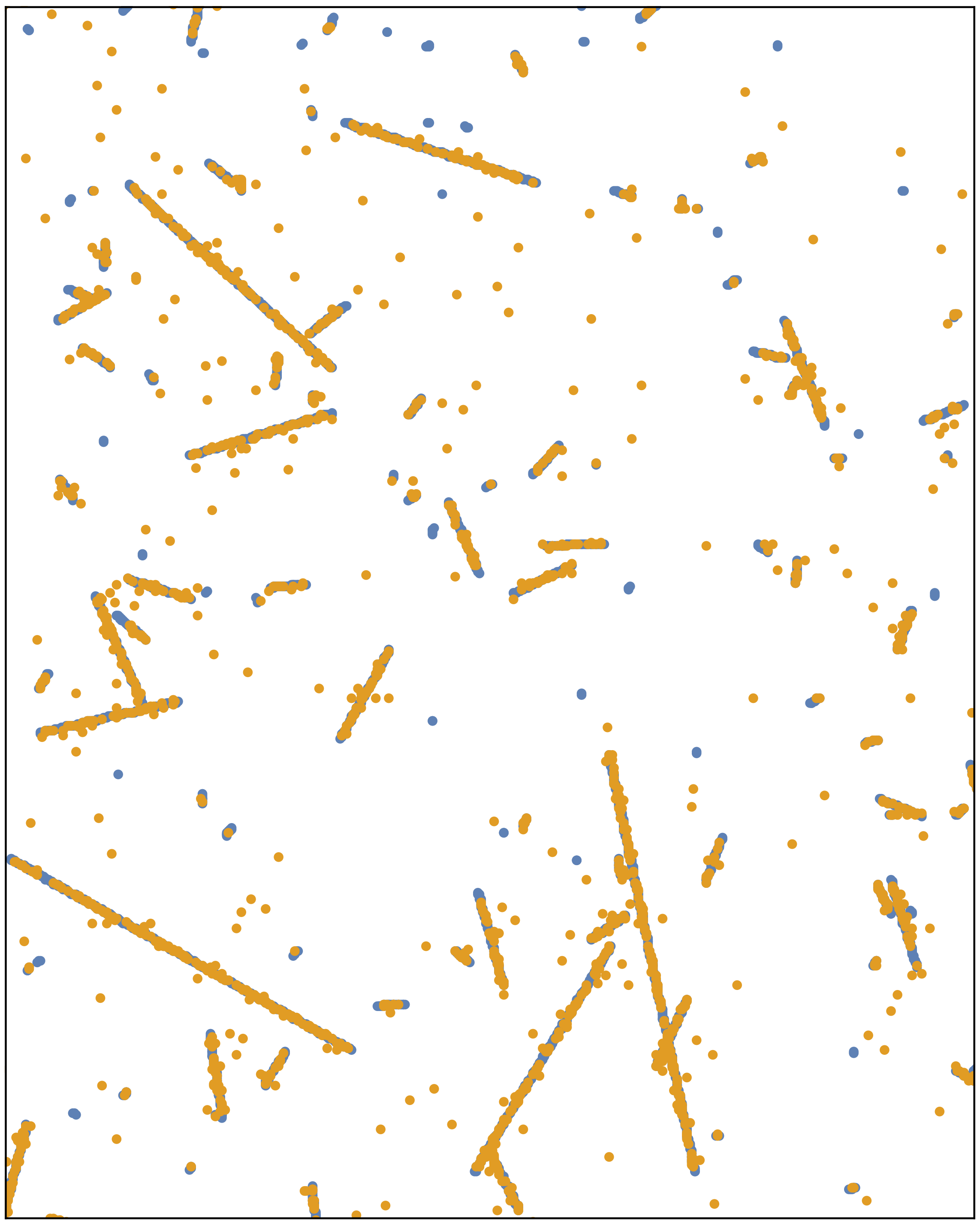


SENSEI data



SENSEI Images

Simulated Tracks + Cherenkov



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    - Behavior of electron-hole pairs and photons in the doped CCD Backside
    - CCD surface roughness

Summary and Conclusions

- We have identified an important and unexplored background for low-threshold DM detectors: Cherenkov radiation
- Likely explains a sizable fraction of low-energy events observed in SENSEI
- Evaluation of systematic uncertainties and other unexplored radiative backgrounds is in progress