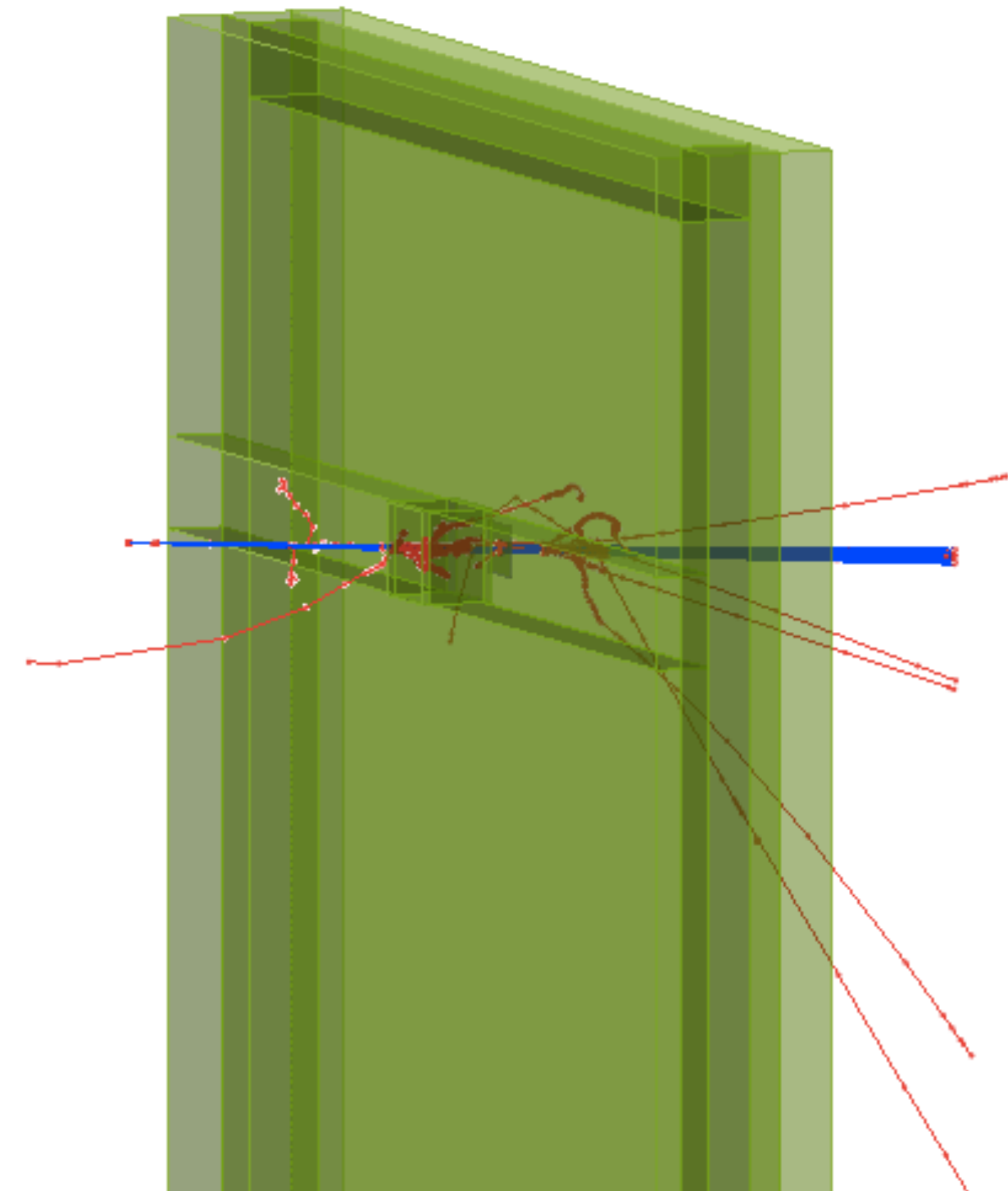


Cosmic-ray detection efficiency in cell phone camera image sensors

Alex Pizzuto

PHYS736: Final Project

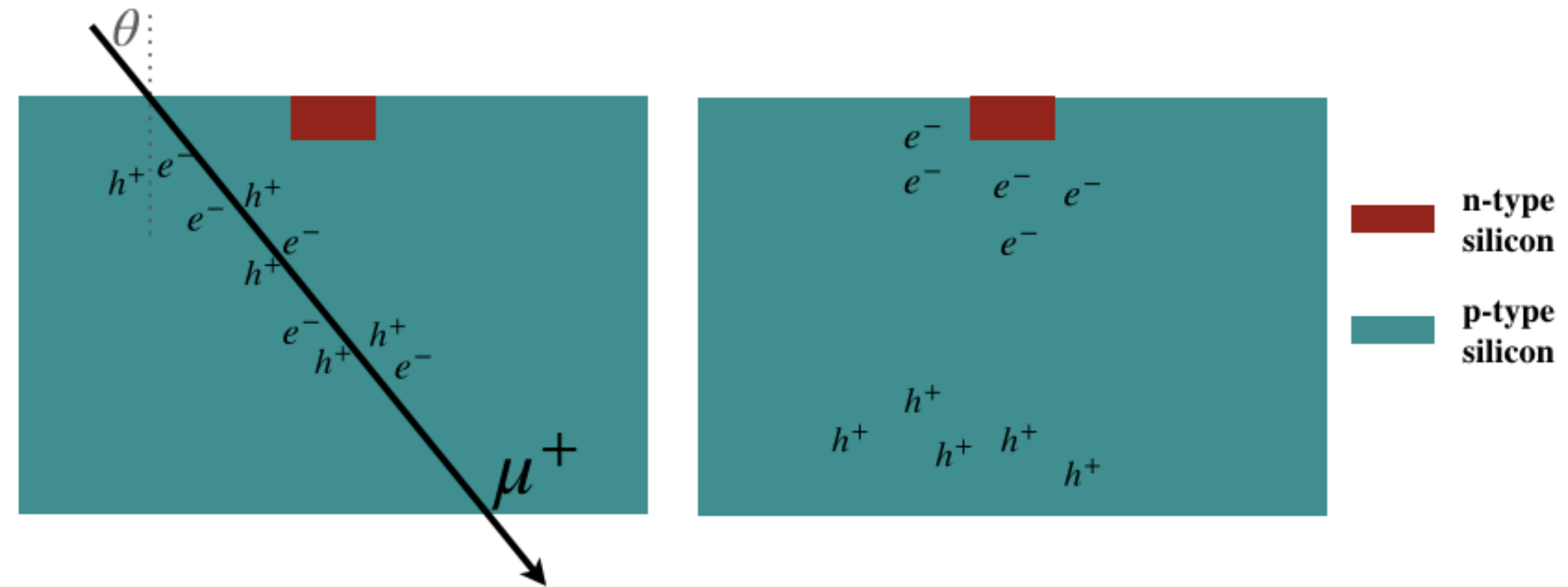


Outline

- Active Pixel Sensors & DECO
- Allpix² Simulations
- Observable Distributions
 - Photons
 - Leptons
- Systematics

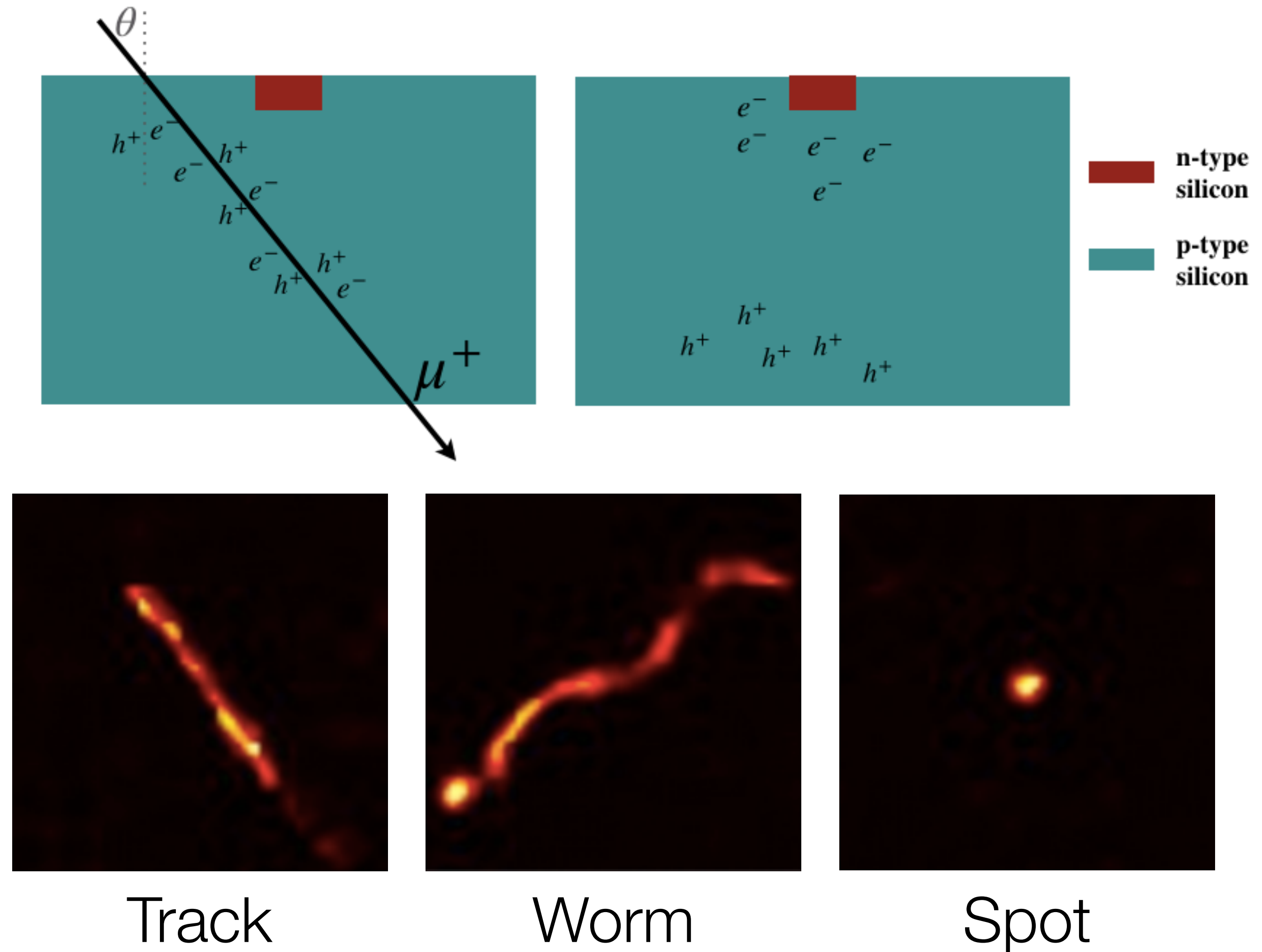
Active Pixel Sensors and the Distributed Electronic Cosmic-ray Observatory (DECO)

- Junctions of p- and n-type silicon can form diodes
- Ionizing radiation that passes through the active (depletion) region create electron-hole pairs
- The field from the junction transports the charges to readout electronics
- Different ionizing radiation leaves different signatures
- DECO uses cell phone cameras to detect this ionizing radiation, and classifies the events using a deep neural network
- To date, DECO has been mostly data-driven, there is no simulation to verify detector capabilities



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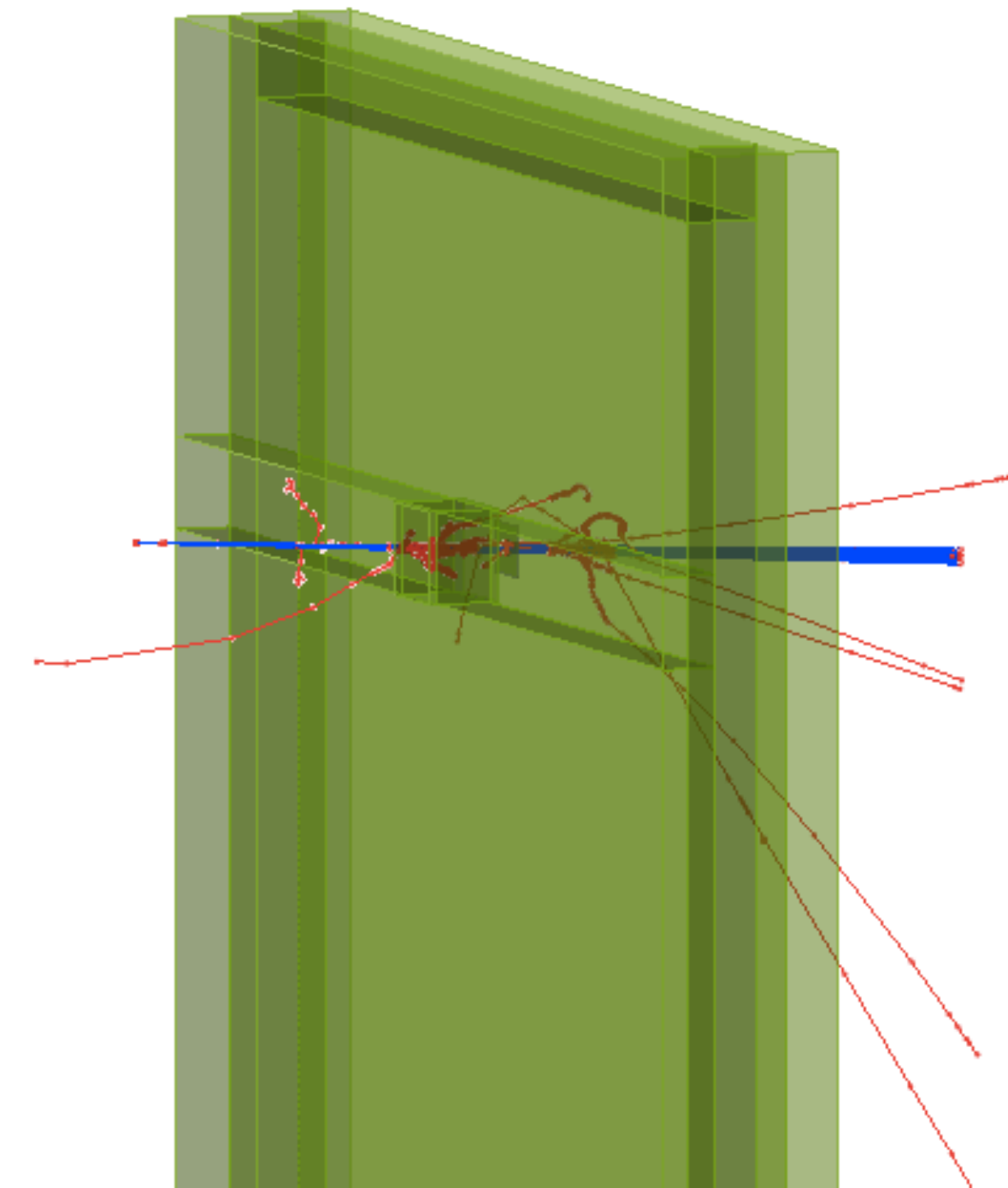


*from arXiv:1803.04493

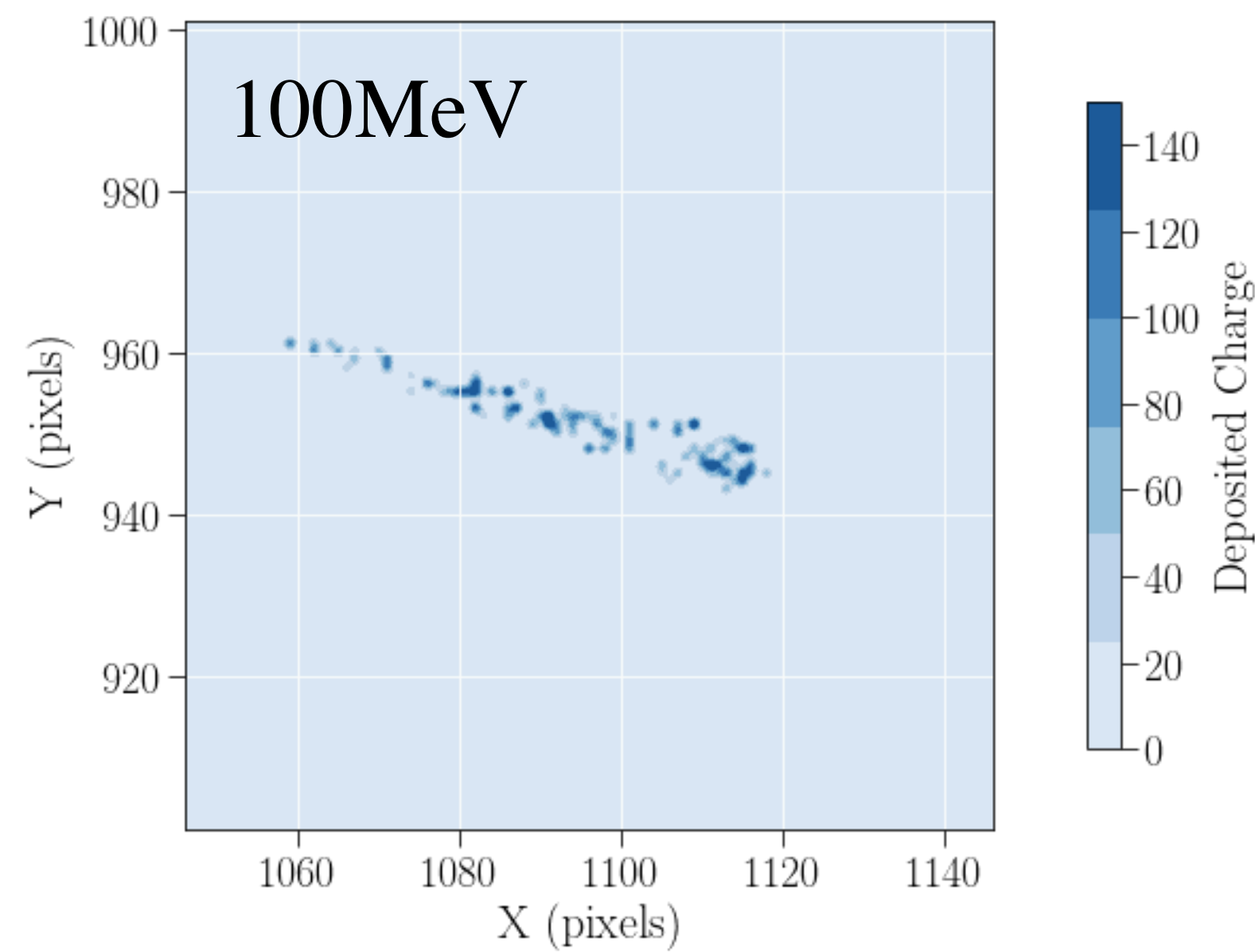
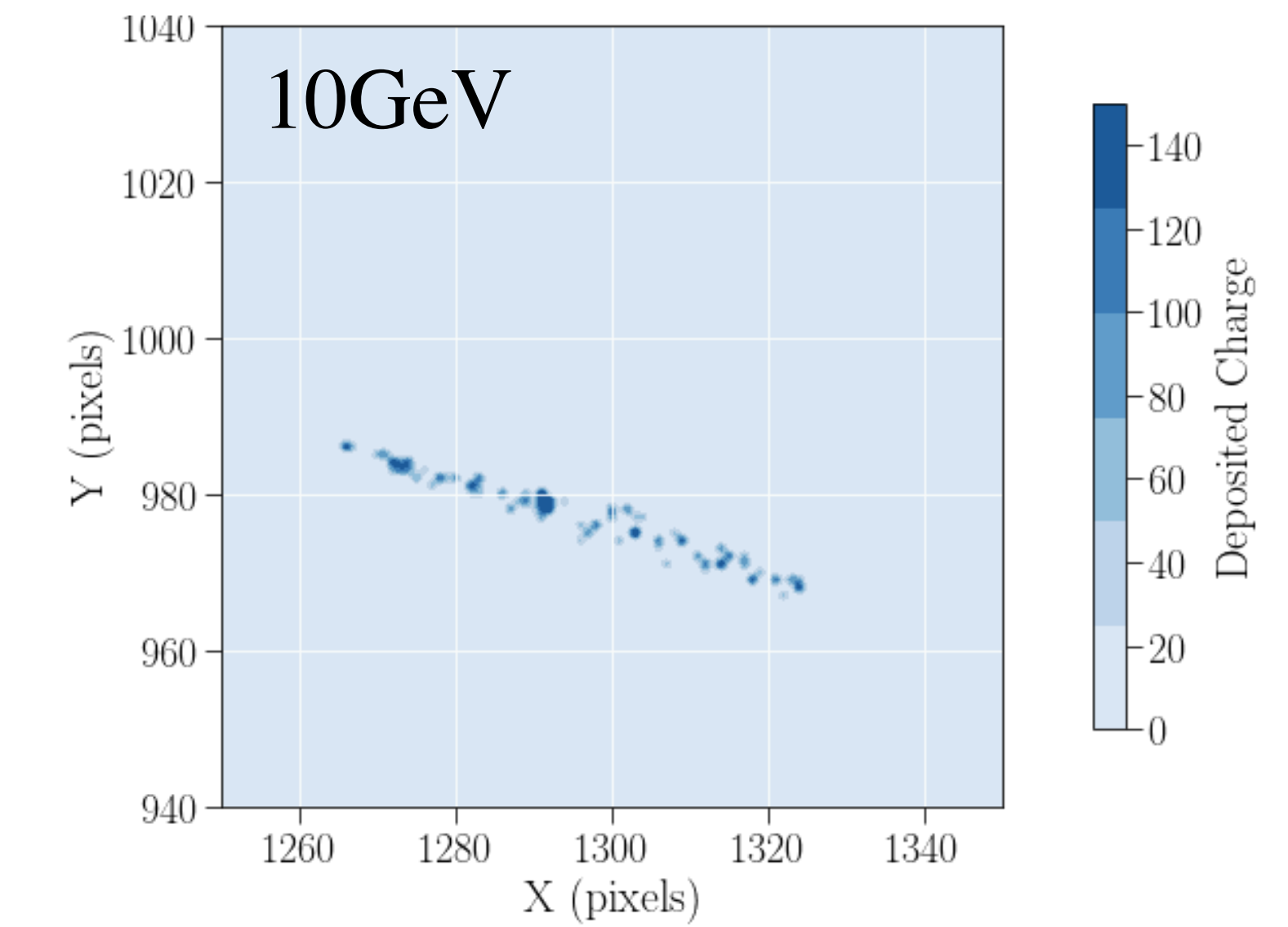
Allpix² Simulations

- GEANT4 can simulate particle interactions in matter
- Allpix² is a modular framework written on top of GEANT4 for Silicon Pixel detectors
- We combined the detector geometry using GEANT4 objects with an Allpix² pixel array
- We then simulate photons, electrons, and muons at different energies and incident angles and digitize the signal

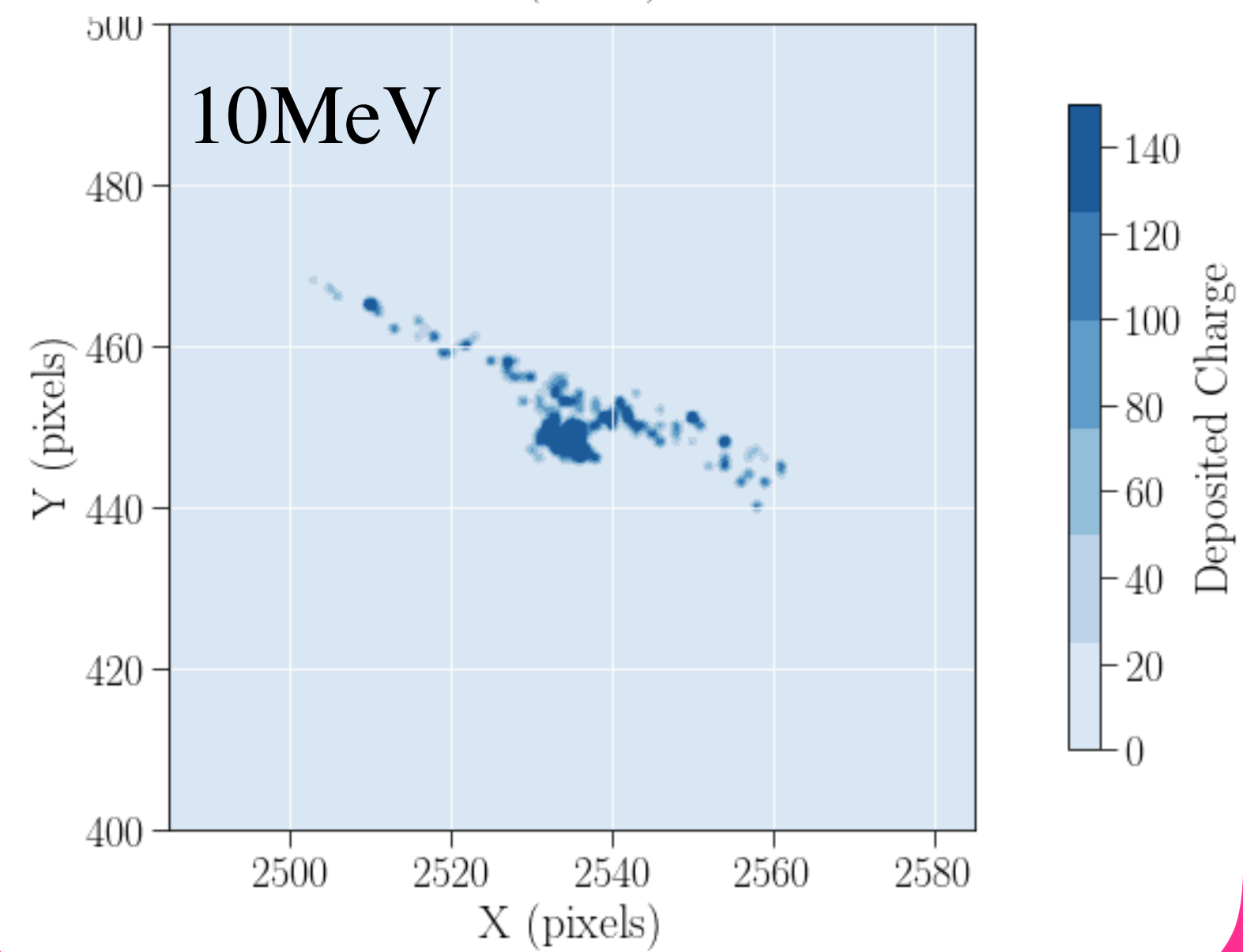
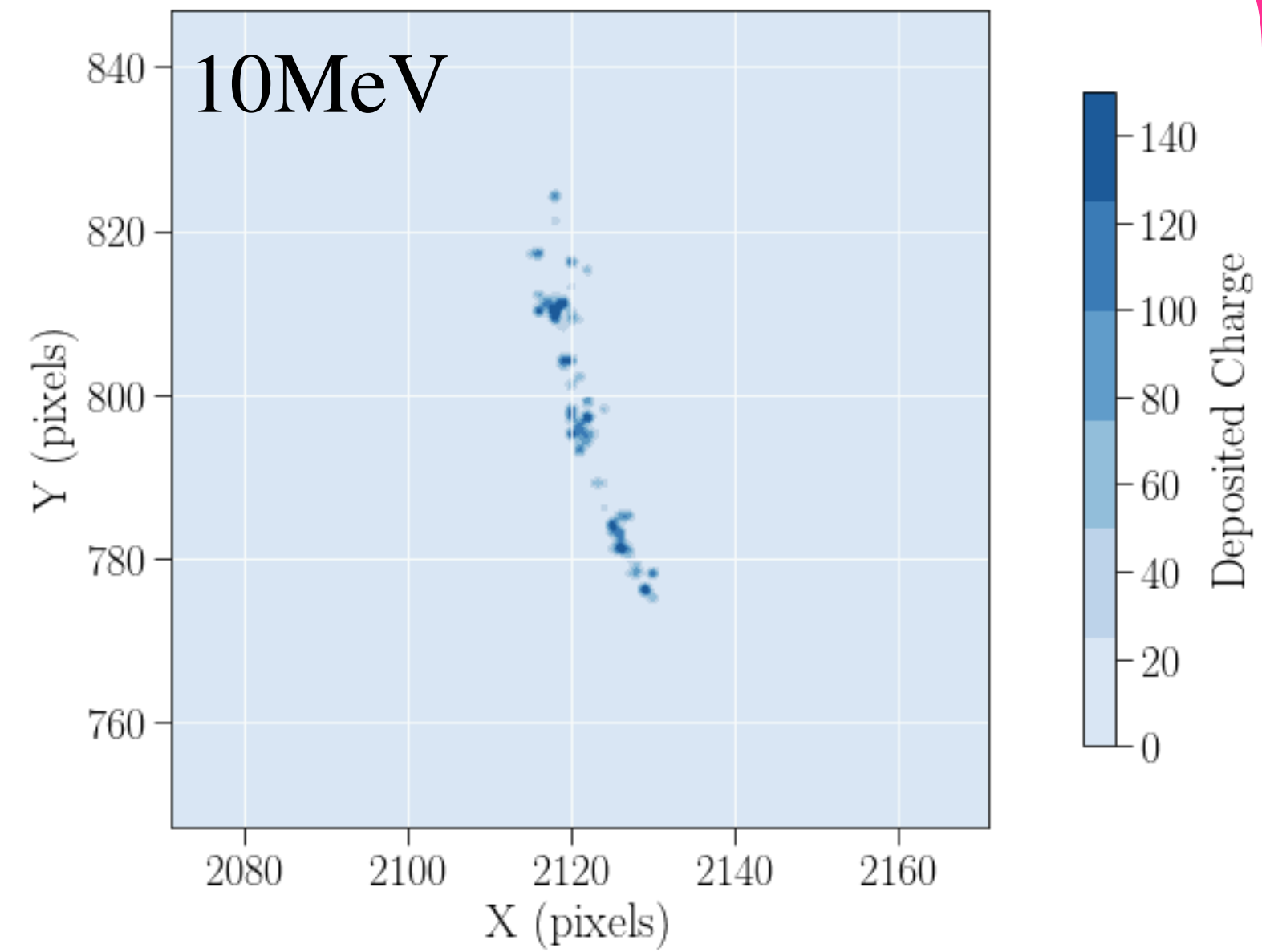
Parameter	Value
Number of Pixels	2592 × 1944 (5,038,848)
Pixel Size	0.9μm × 0.9μm
Depletion Thickness	26.3μm
Chip Thickness	10μm
Phone size	150mm × 70mm
Temperature	293K
Surrounding Material	Air



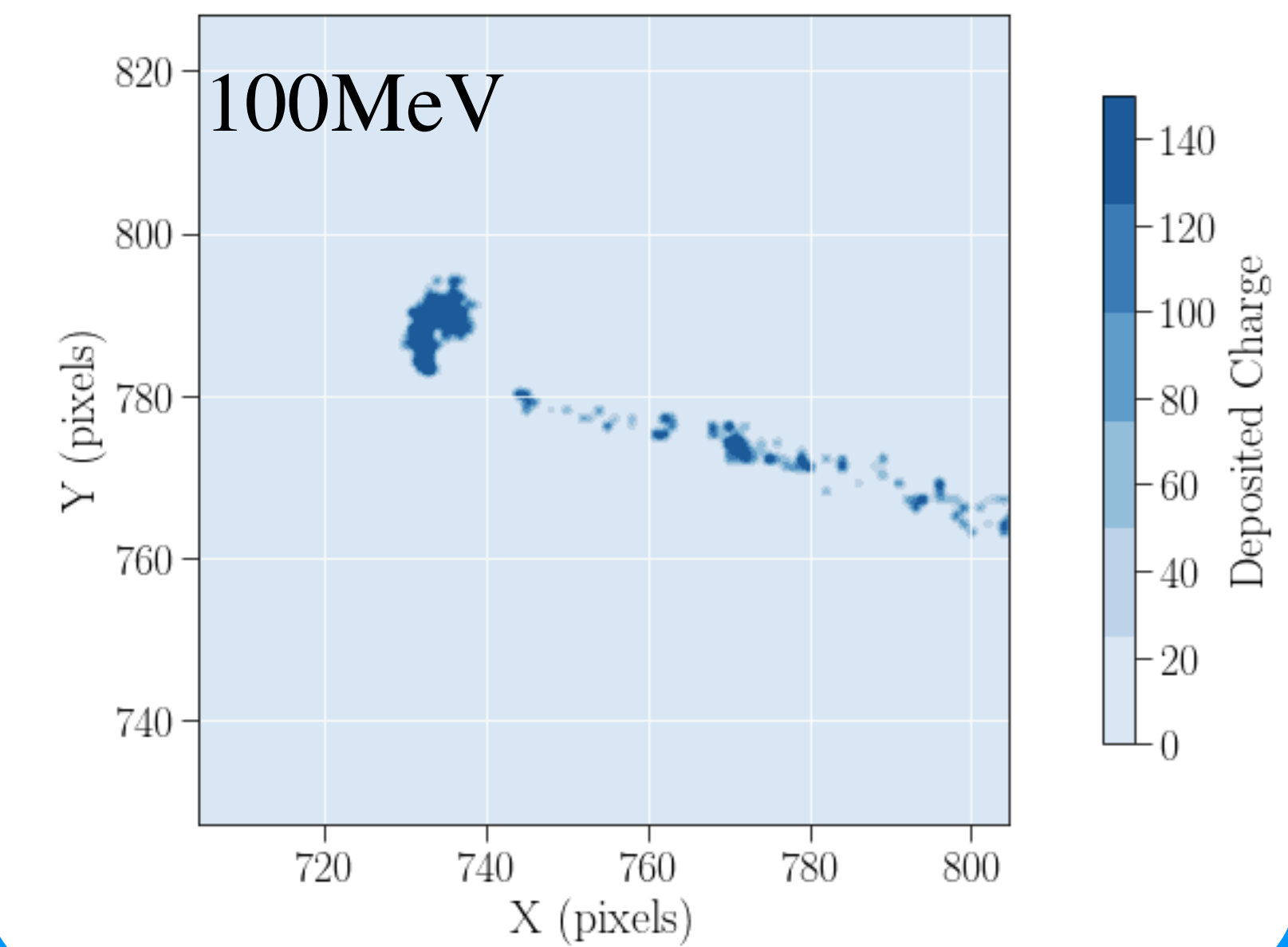
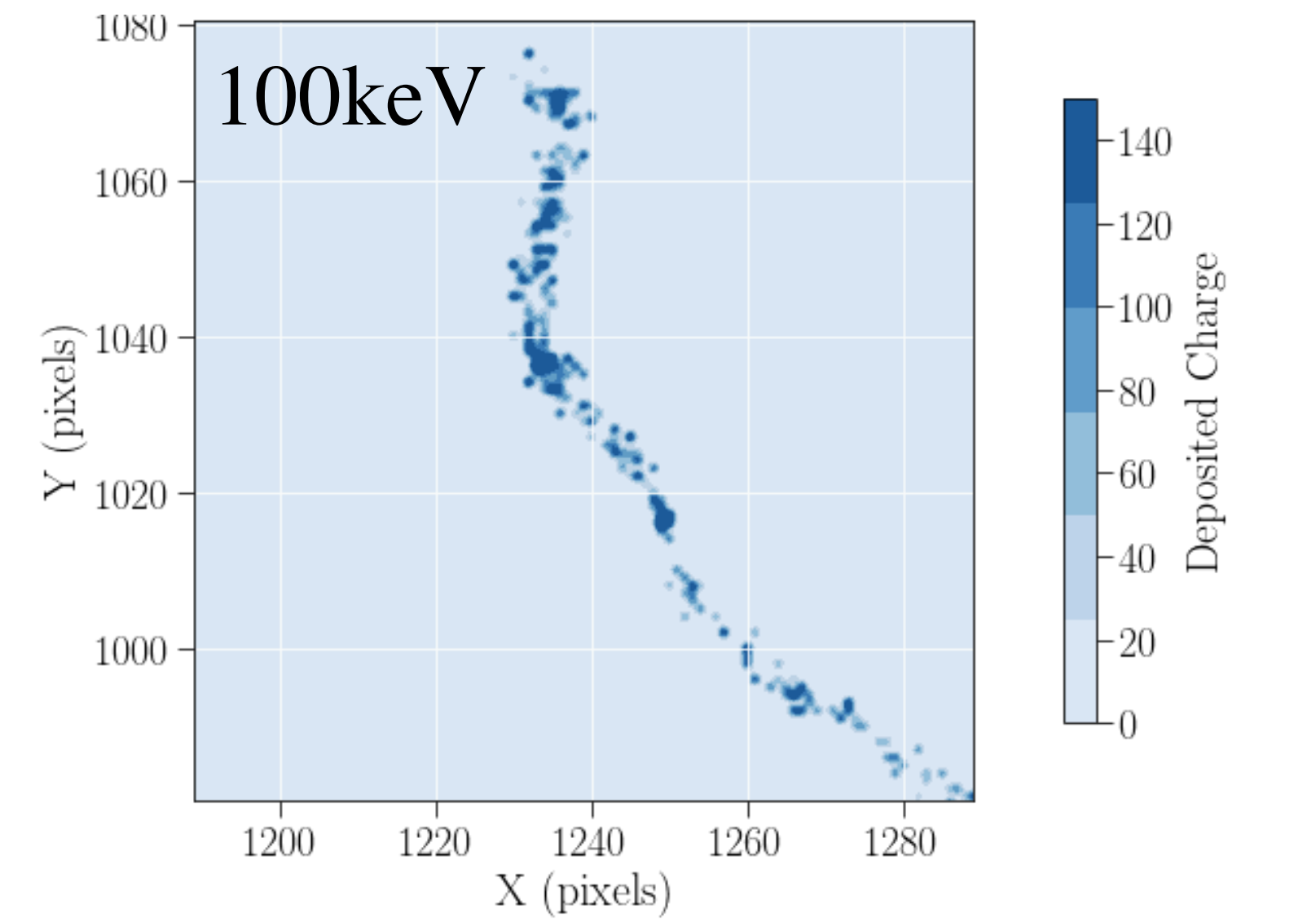
Muons



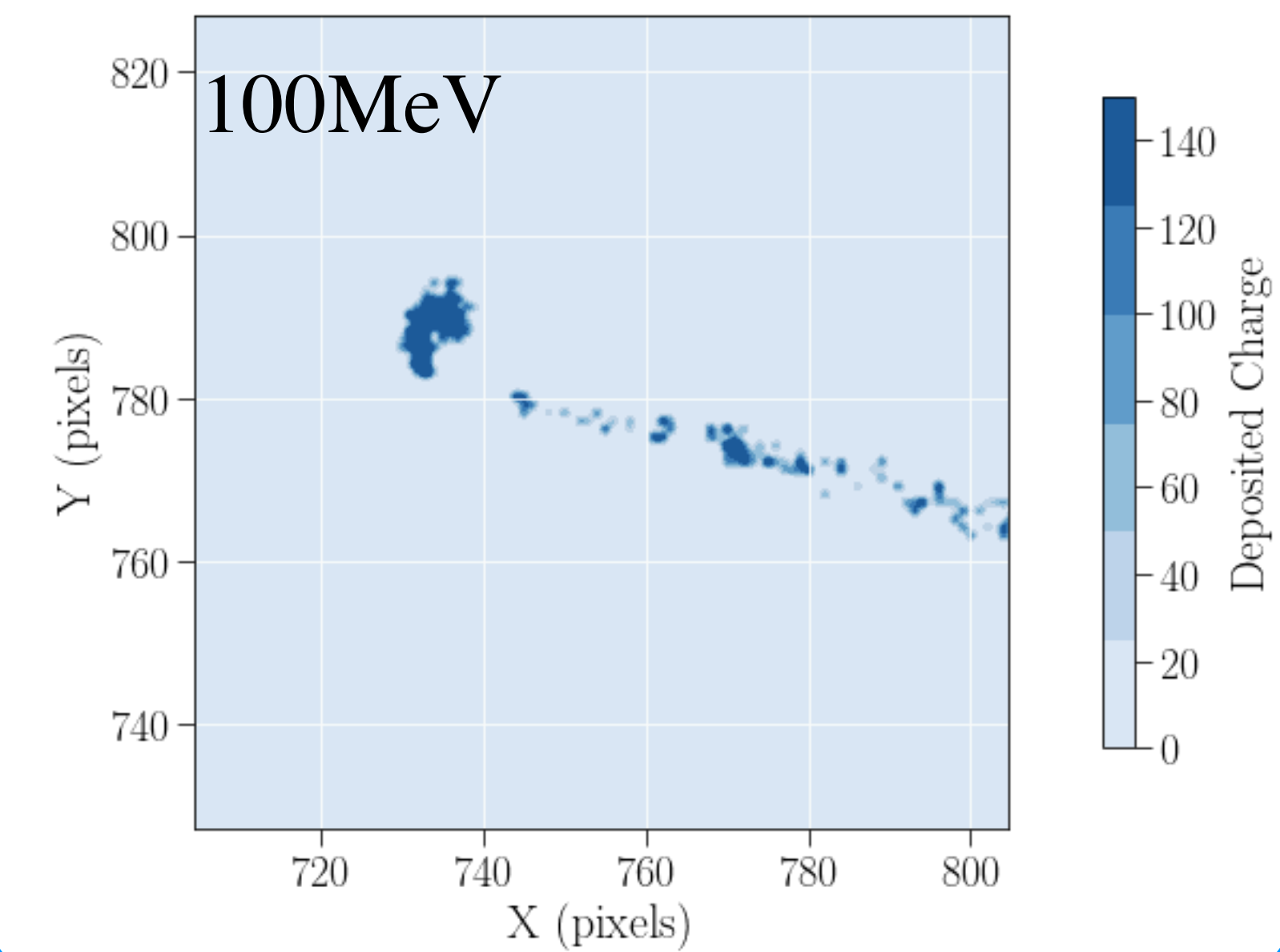
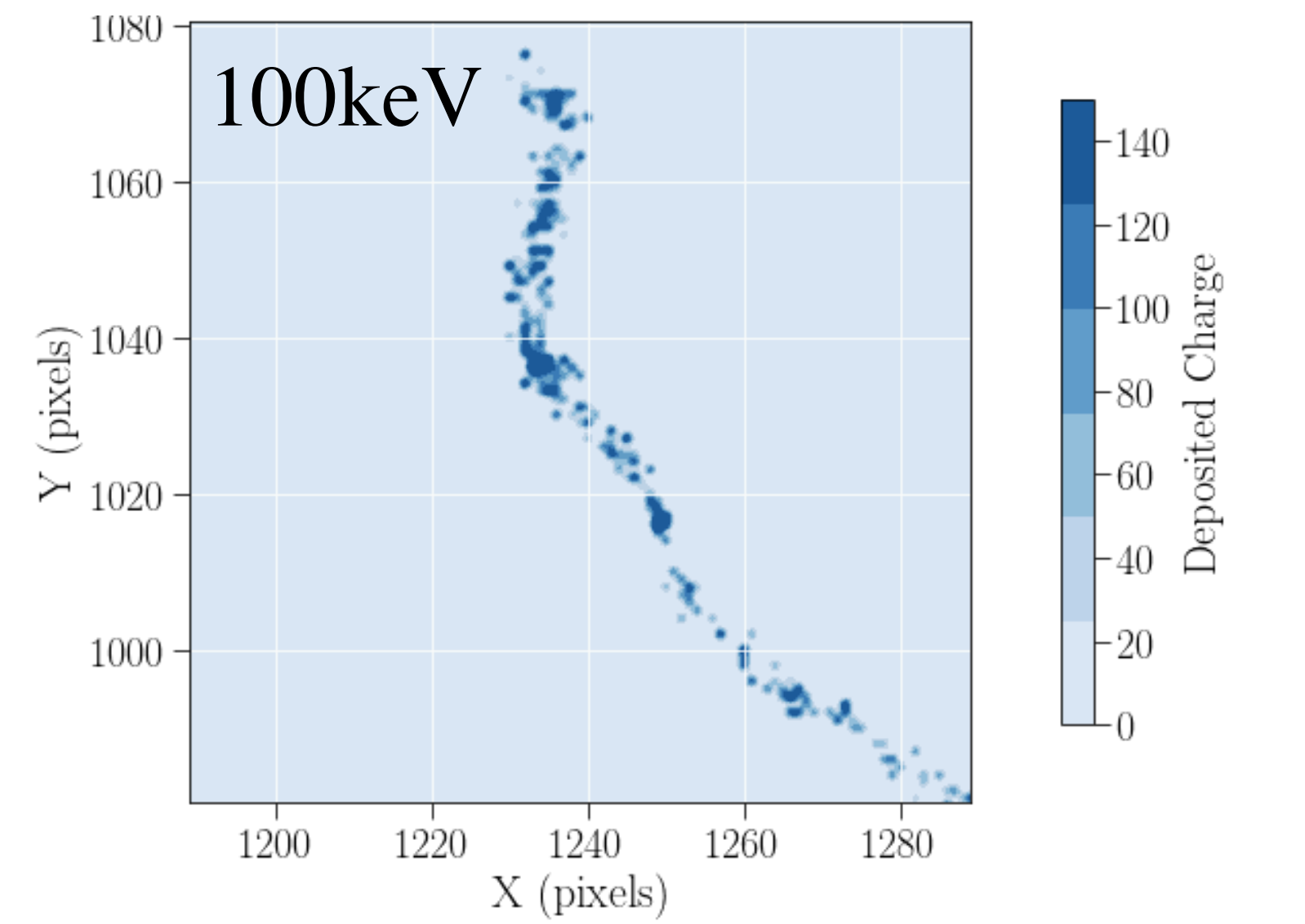
Electrons



Photons

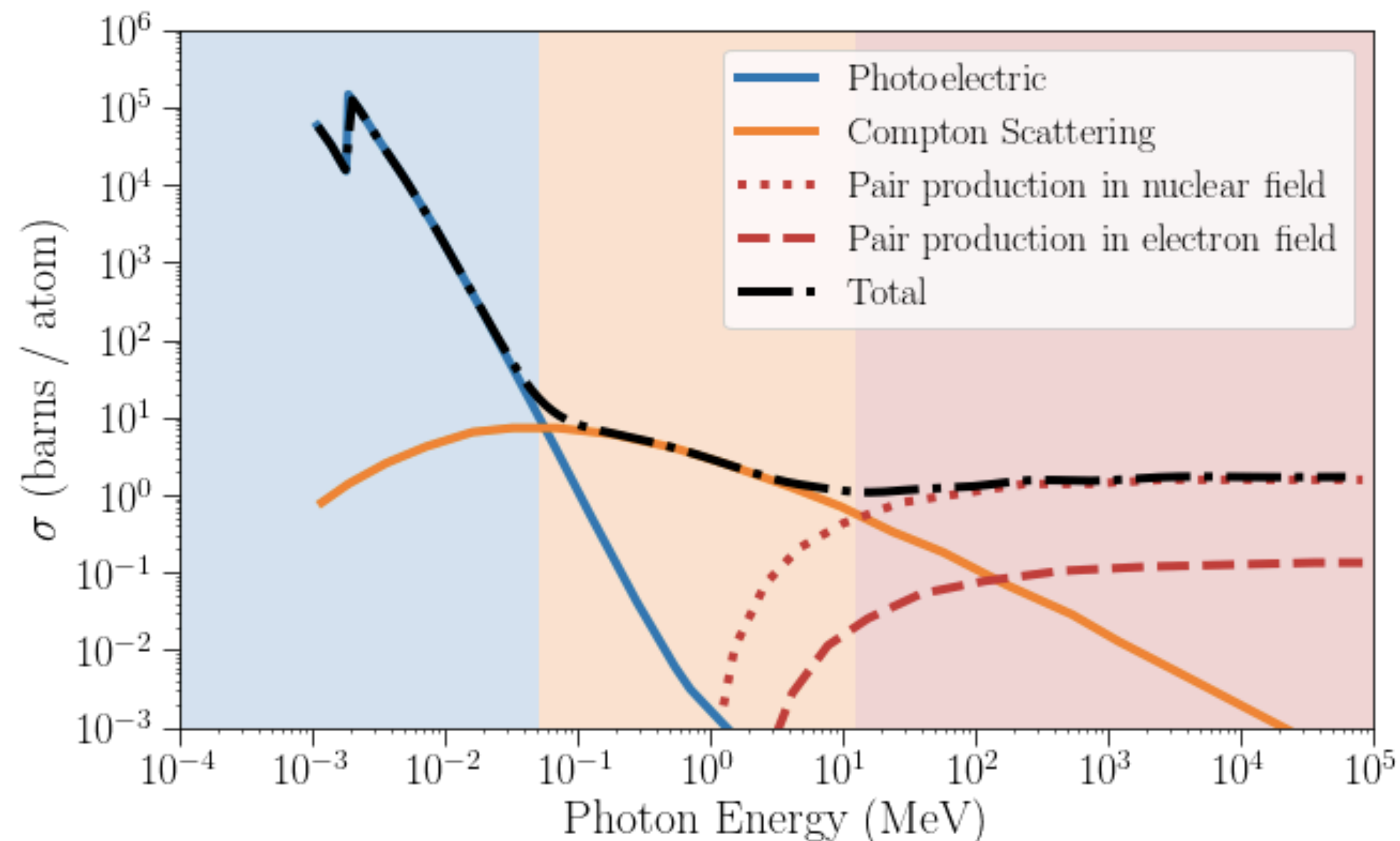


Photons



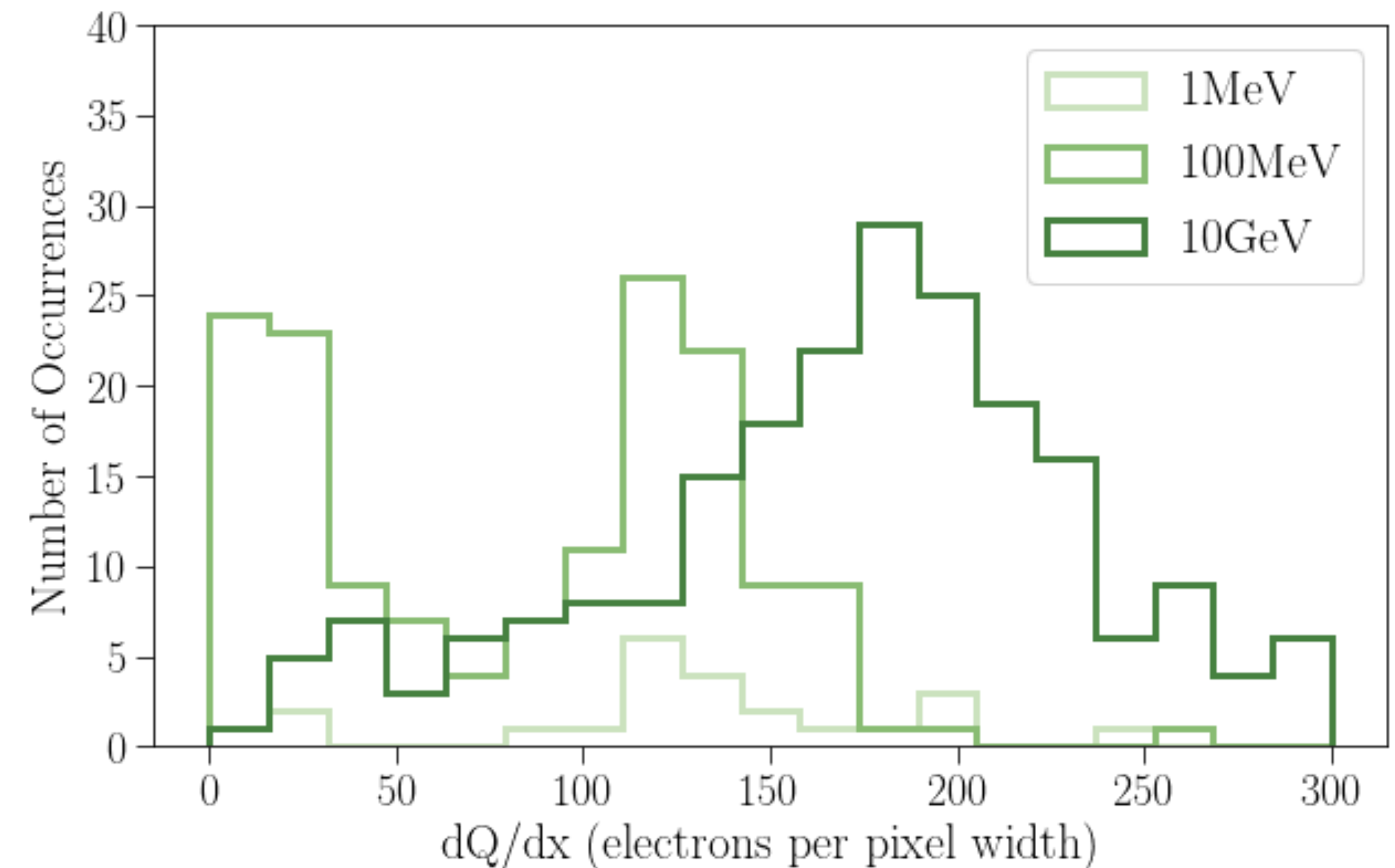
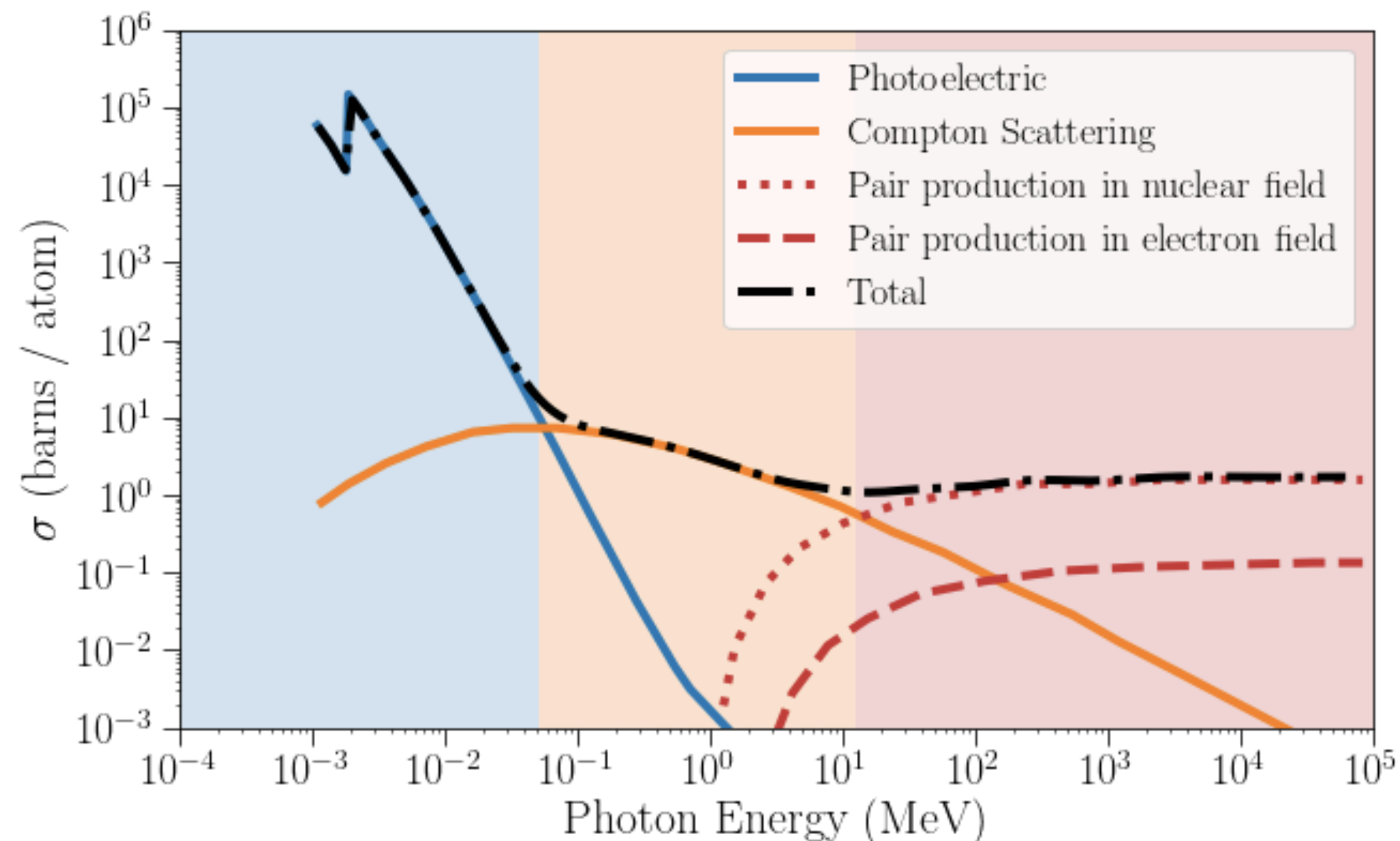
Photons

- Simulated 1,000 photons at each of 6 different incident angles at every half decade in energy from 10keV to 10GeV
- Lower energy photons dominated by photoelectric cross section (photoabsorb before reaching detector)
- Higher energy photons pair produce and then the leptons leave signatures

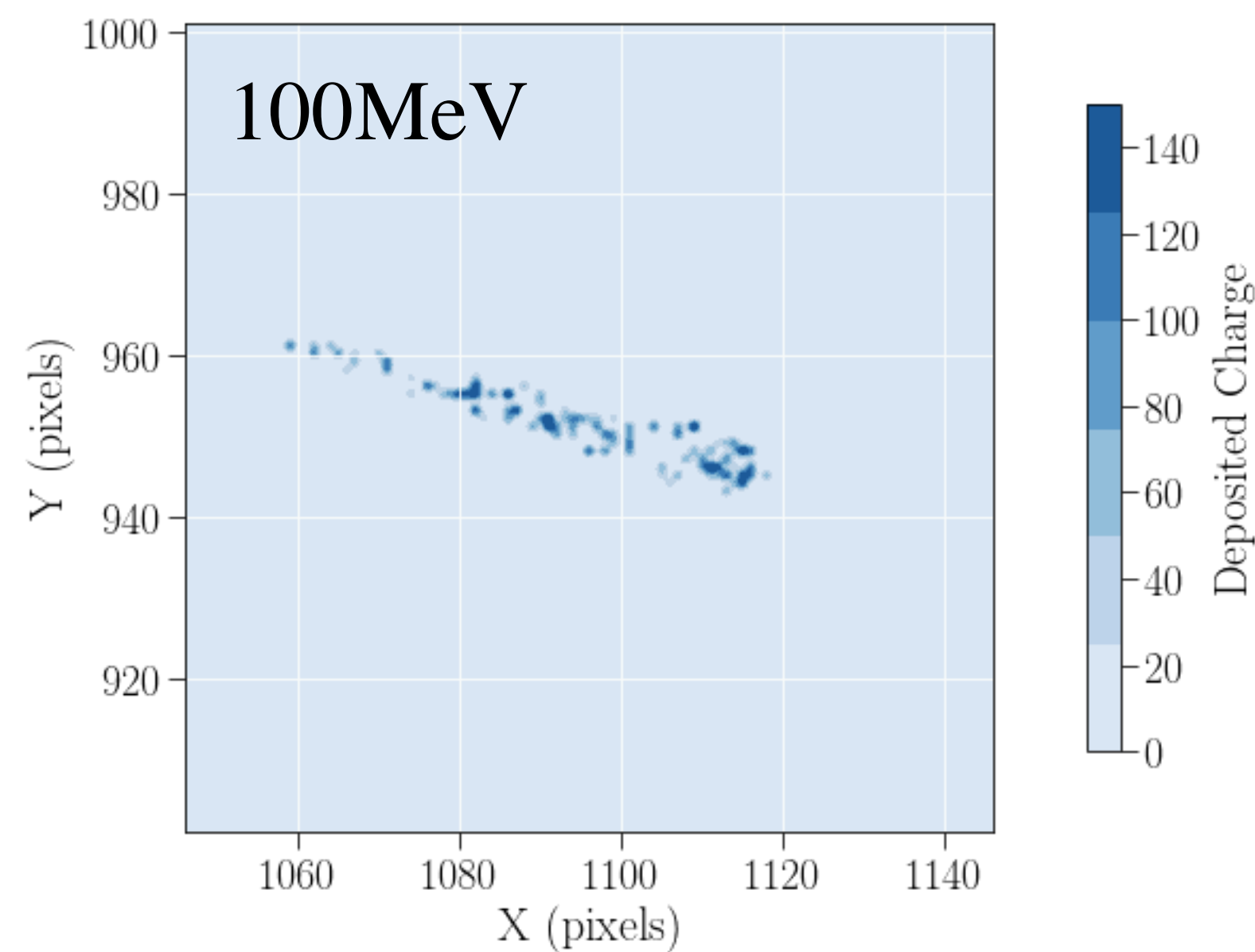
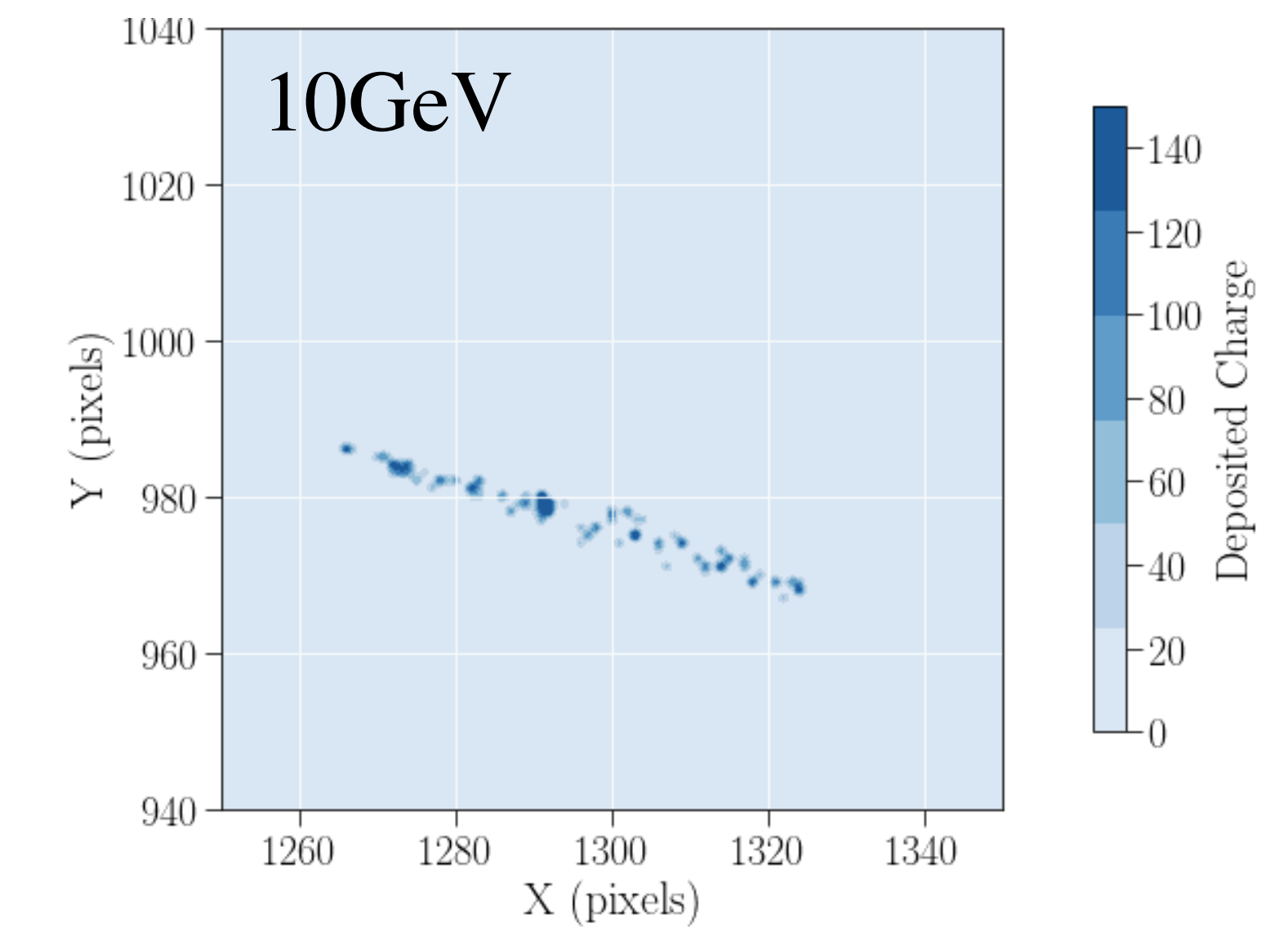


Photons

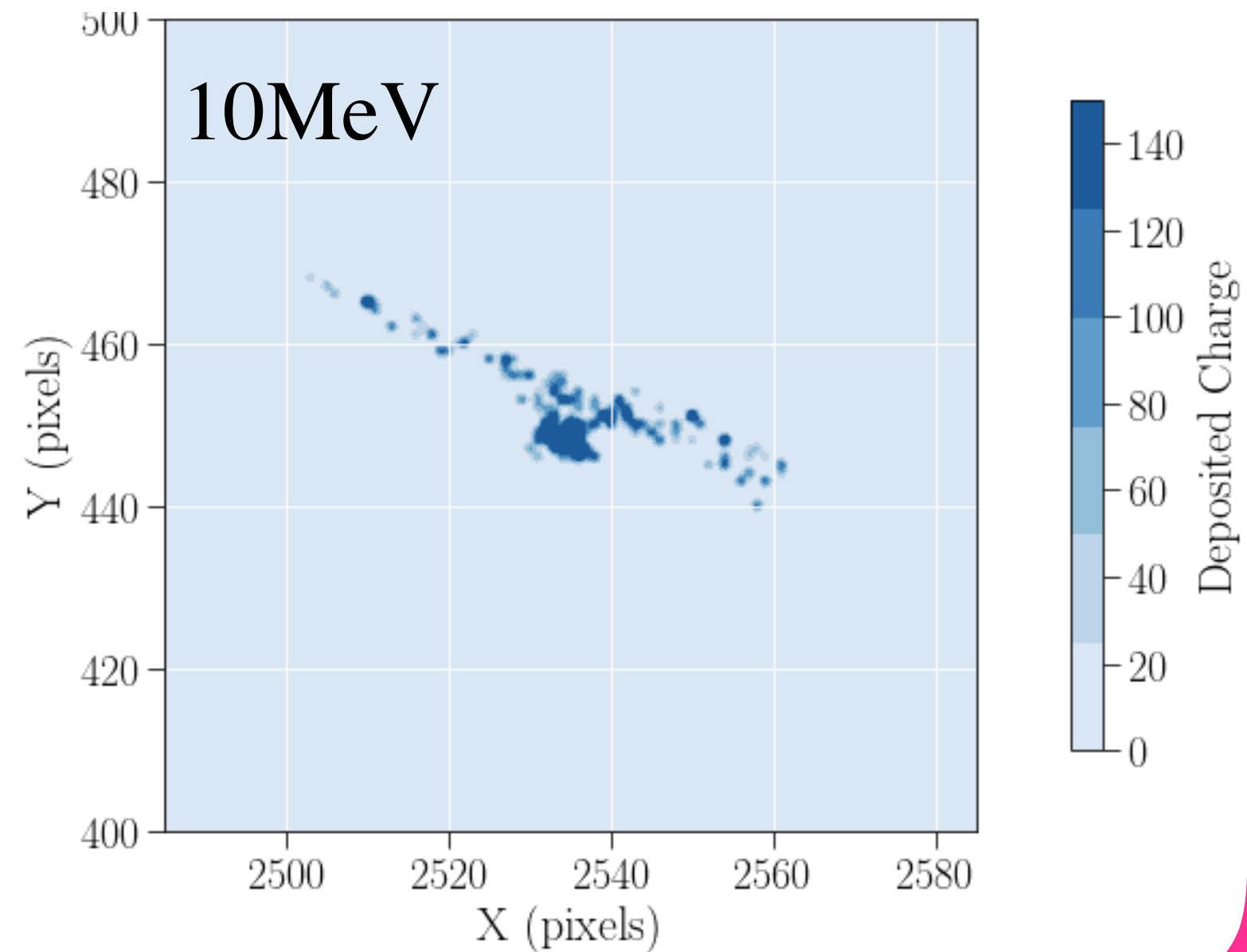
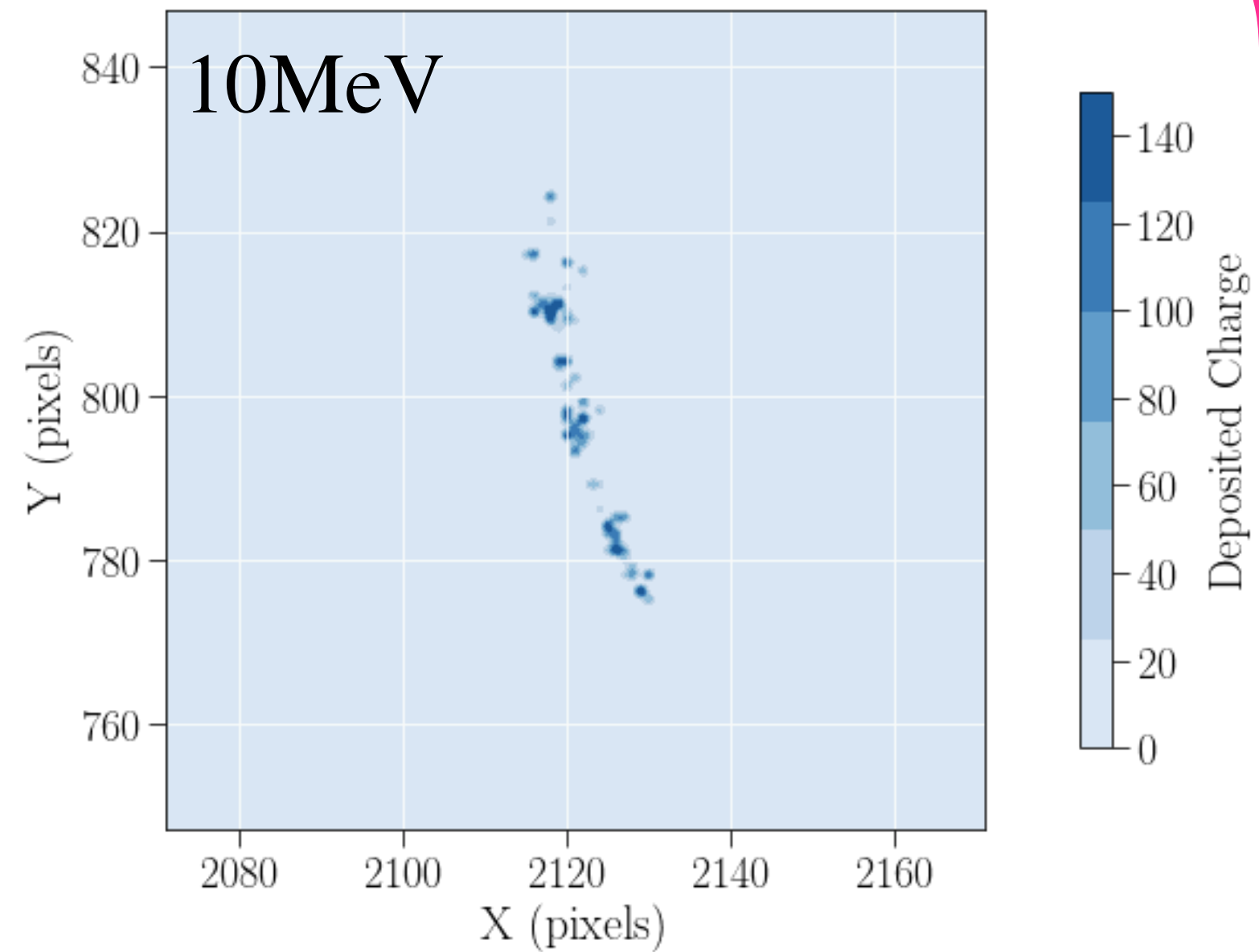
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Muons



Electrons



Finding Observable Distributions

- For each particle simulated, we record charge deposited on each pixel
- Different particles have different cross sections and energy losses in Silicon
- For minimum ionizing particles, to first order, expected signal:

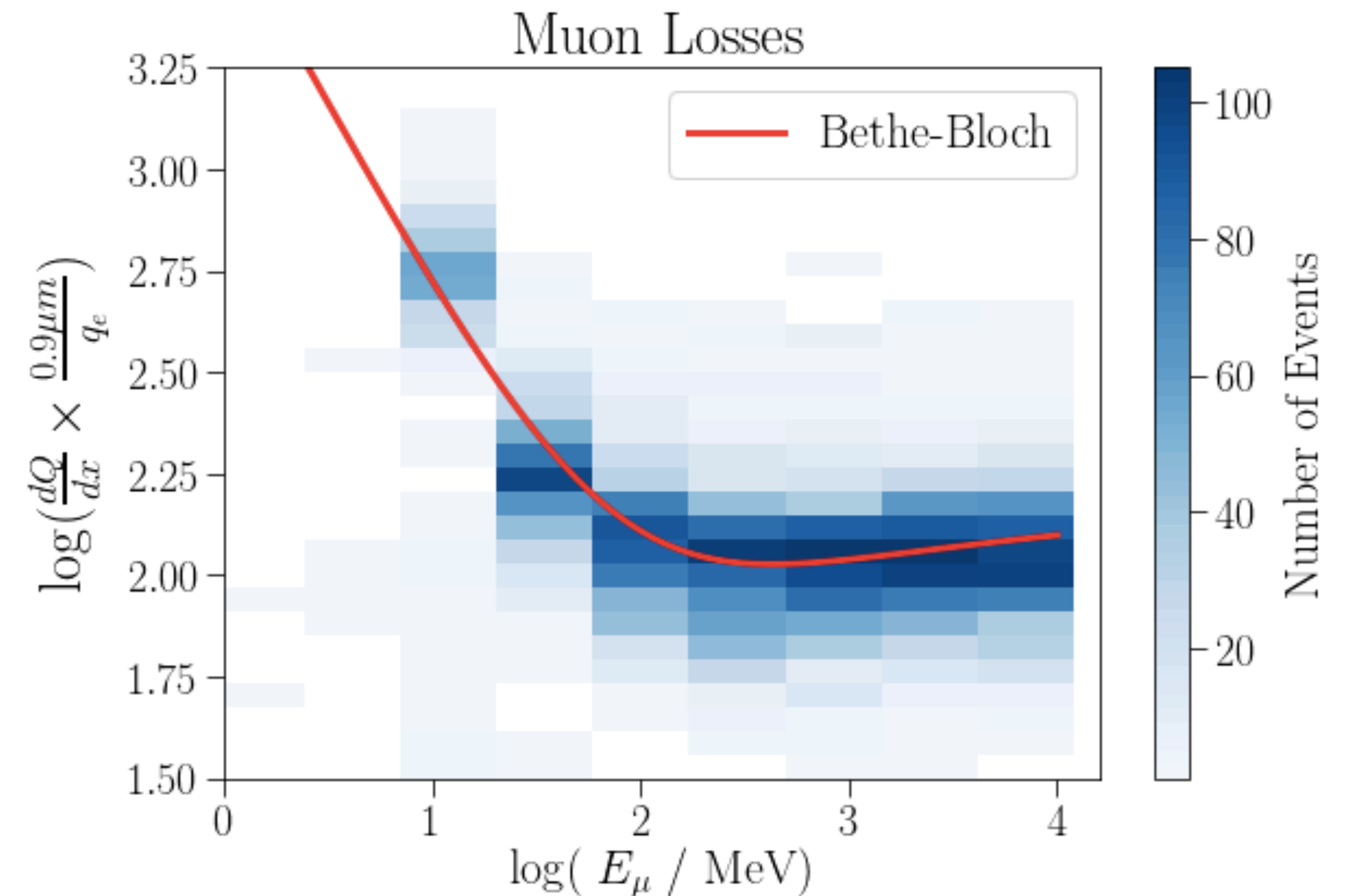
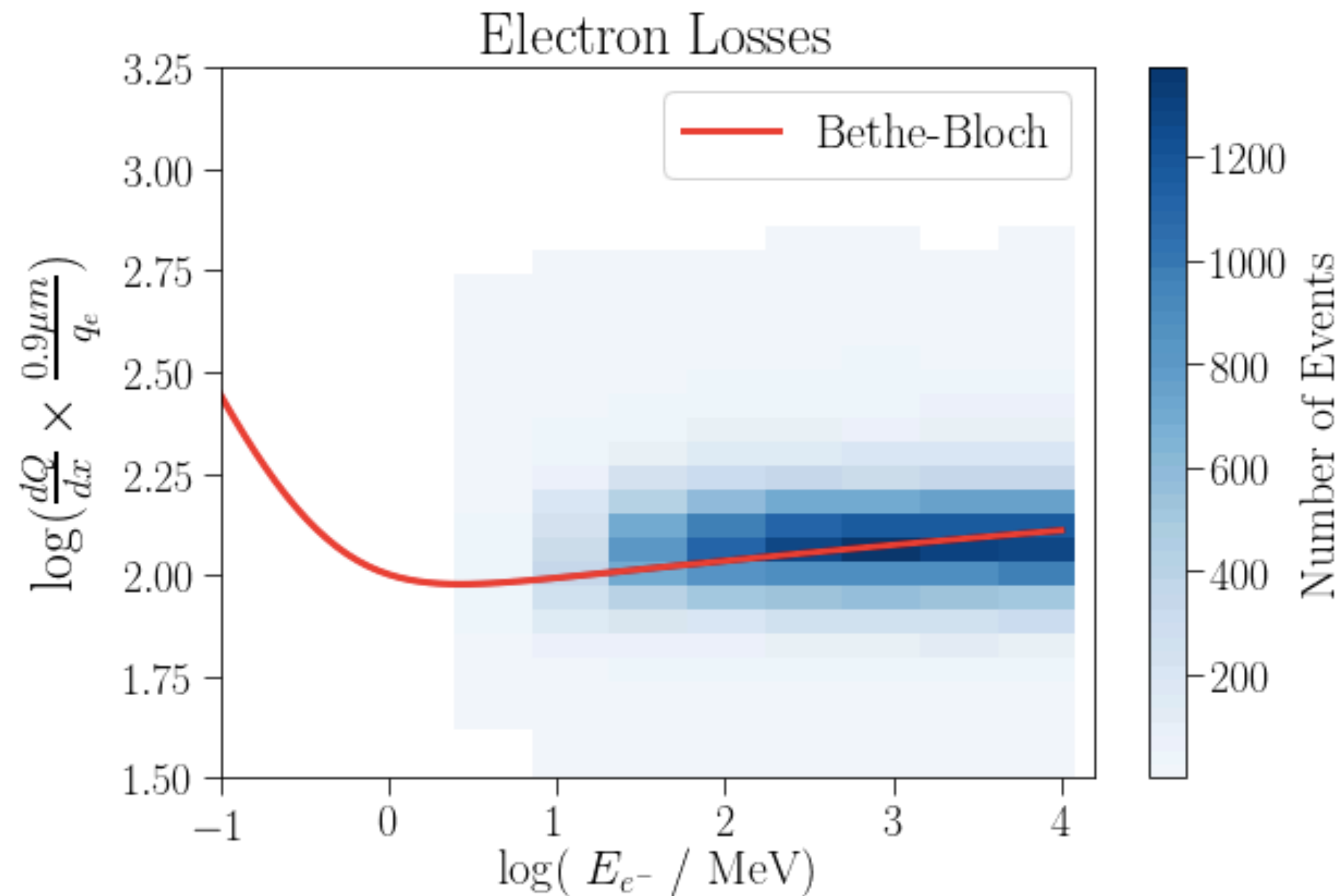
$$\frac{dE}{dx} \approx \rho \left(2\text{MeVcm}^2/\text{g} \right) \frac{Z^2}{\beta^2}$$

$$\Rightarrow E_{\text{deposit}} = 4.66 \cdot \frac{H}{\cos \theta} \quad (\text{E in MeV, H in cm})$$

$$\Rightarrow N_{\text{pair}} \leq \frac{3386}{\cos \theta}$$

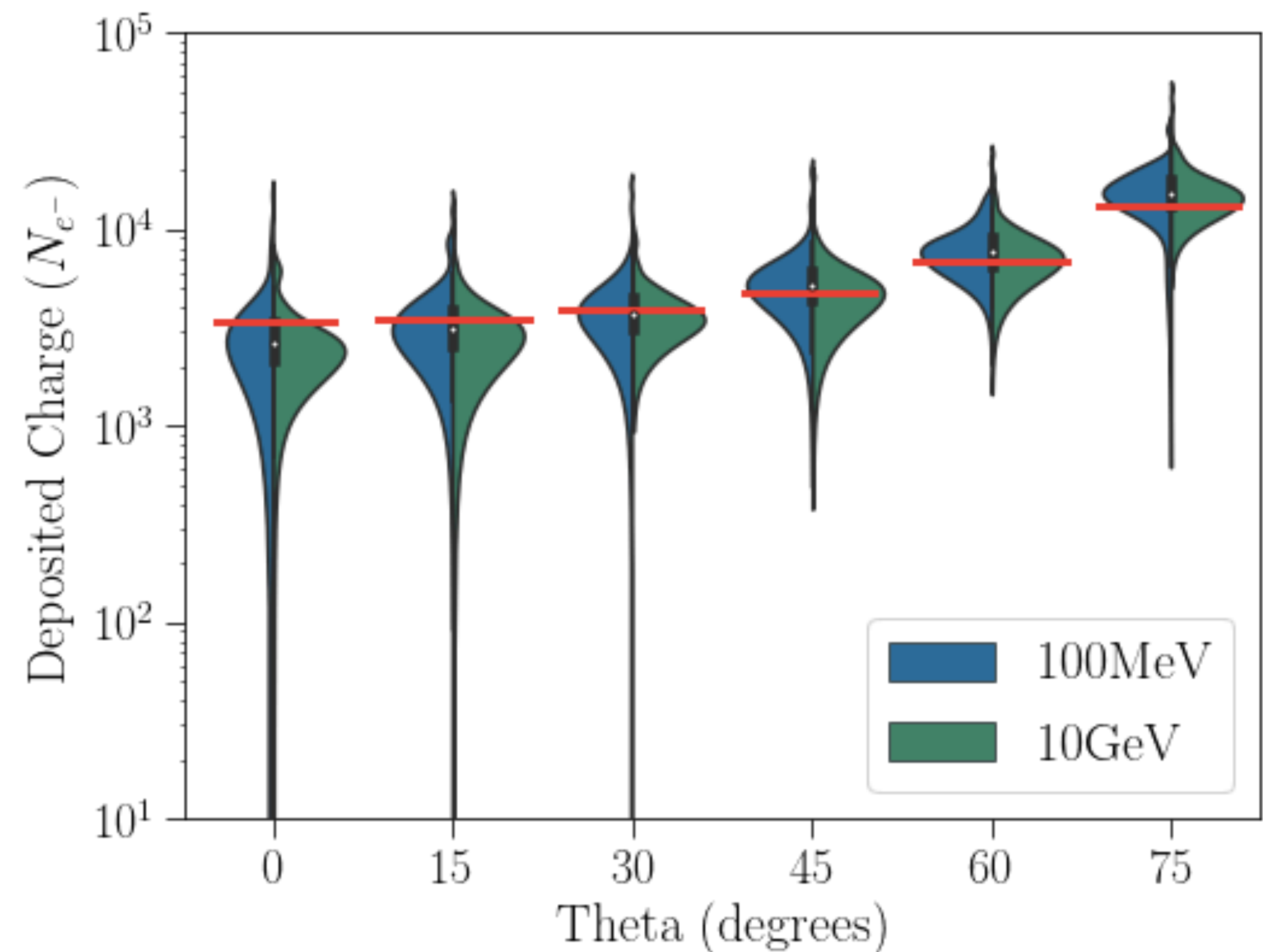
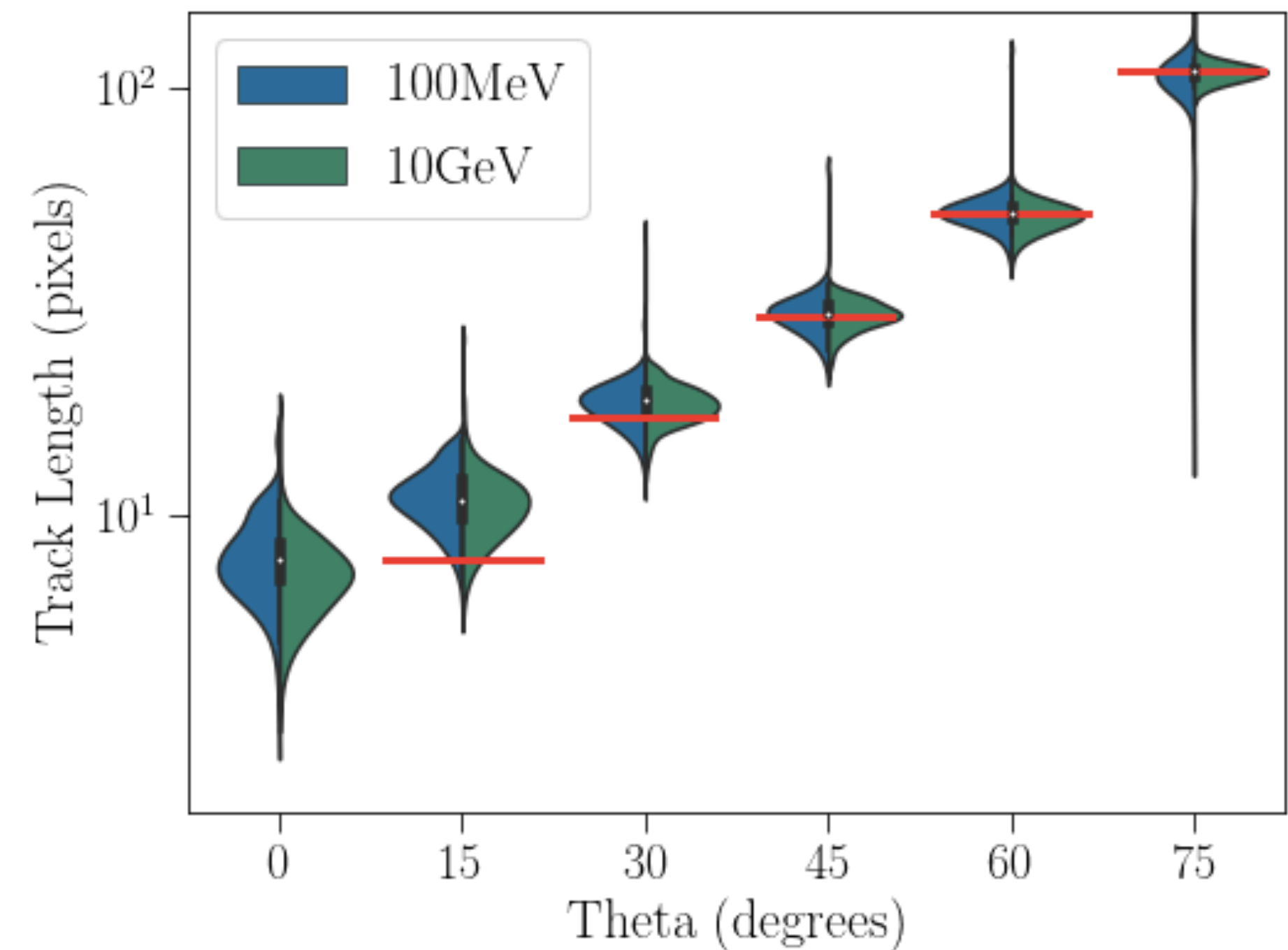
Leptons

- Electron and Muon energy losses described by Bethe-Bloch
- Observed distributions of energy losses agree well with analytical result



Dependence on Incident Angle

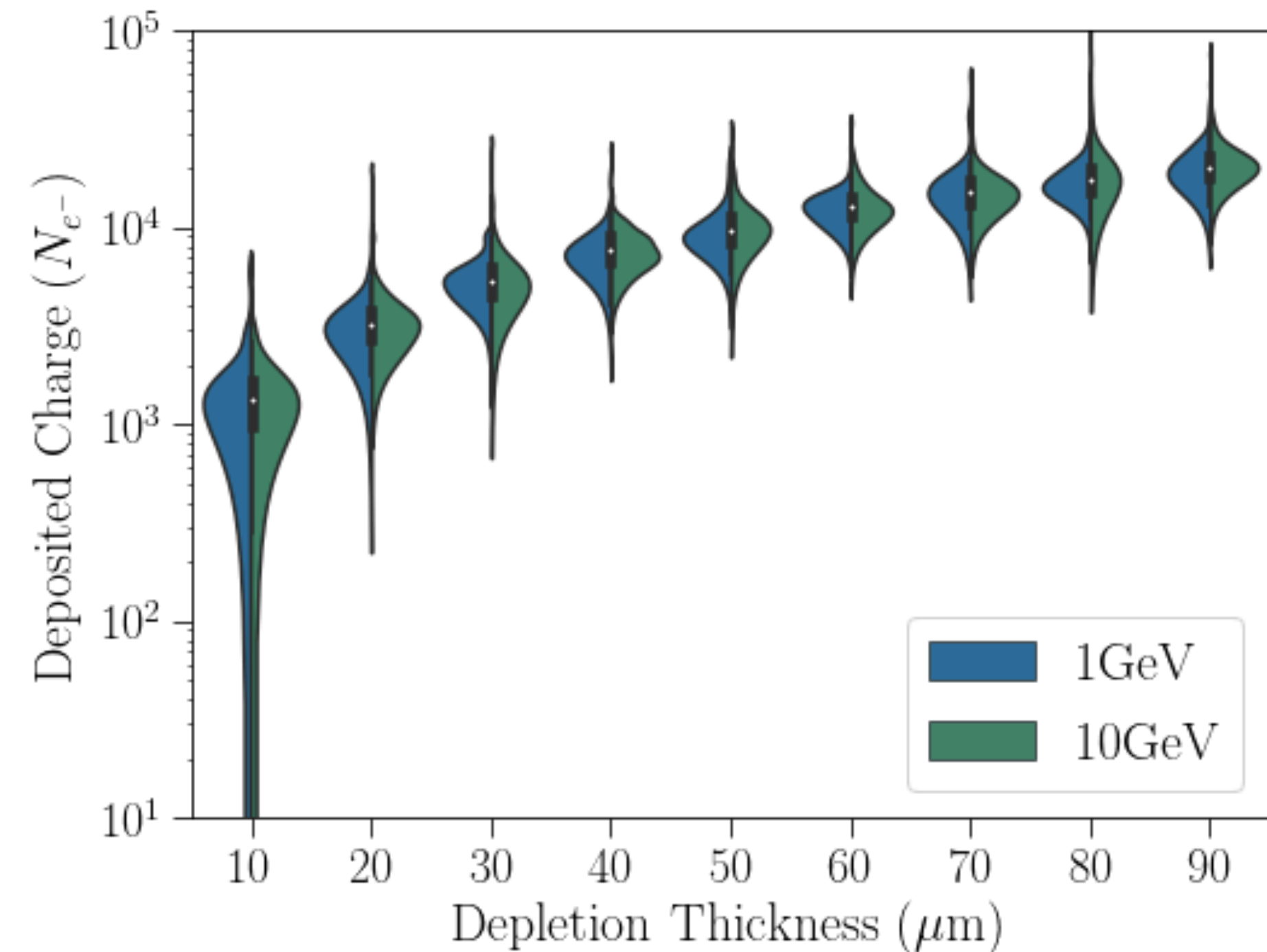
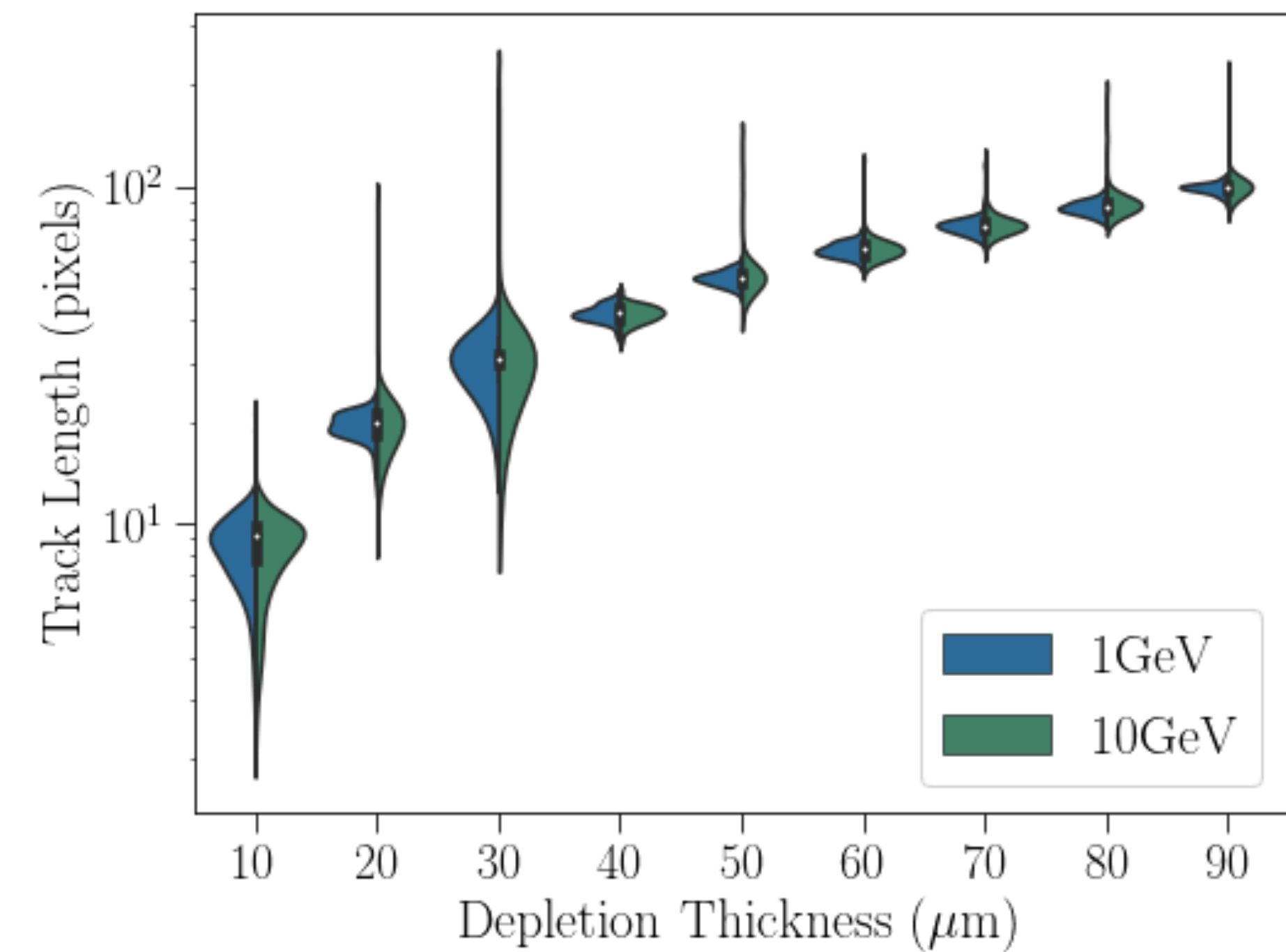
- Simulate muons at different incident angles
- Expect deposited charge to scale as trajectory length in depletion region
- Expect Track length to scale as projection onto pixel plane
- Observed distributions (blue and green) agree well with geometric assumptions (red)



Systematics: Depletion Thickness

- Investigated the effect of variable depletion thickness with fixed 45° incidence
 - This parameters in actual camera sensors is proprietary
- For small uncertainties in depletion thickness, we get uncertainty in incident angle:

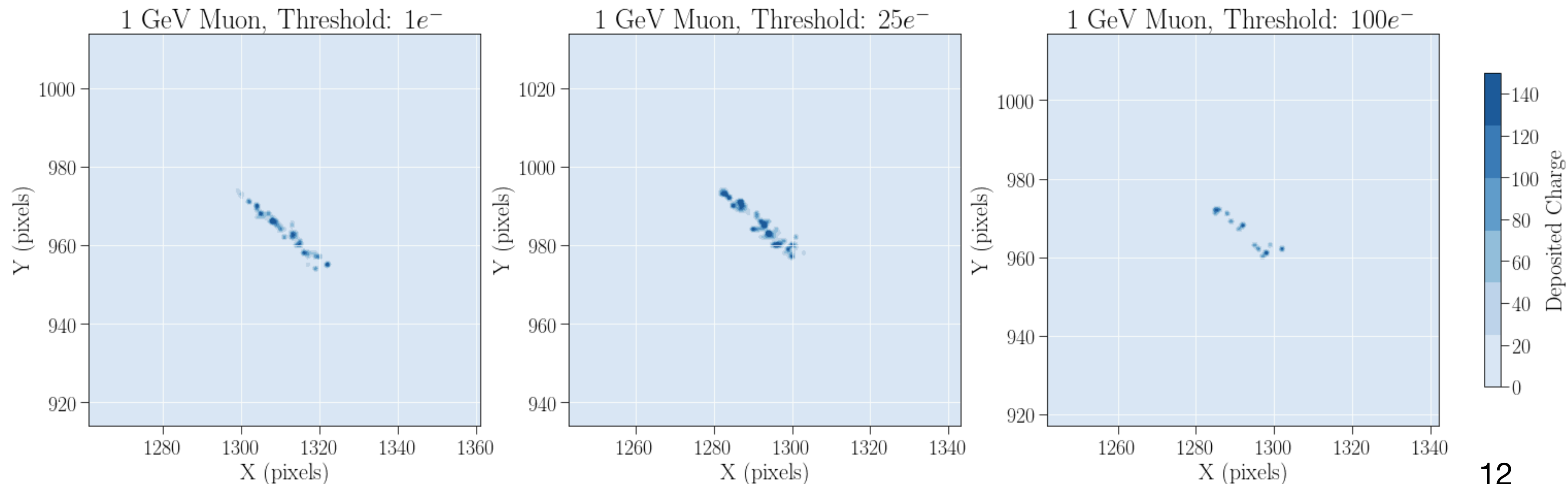
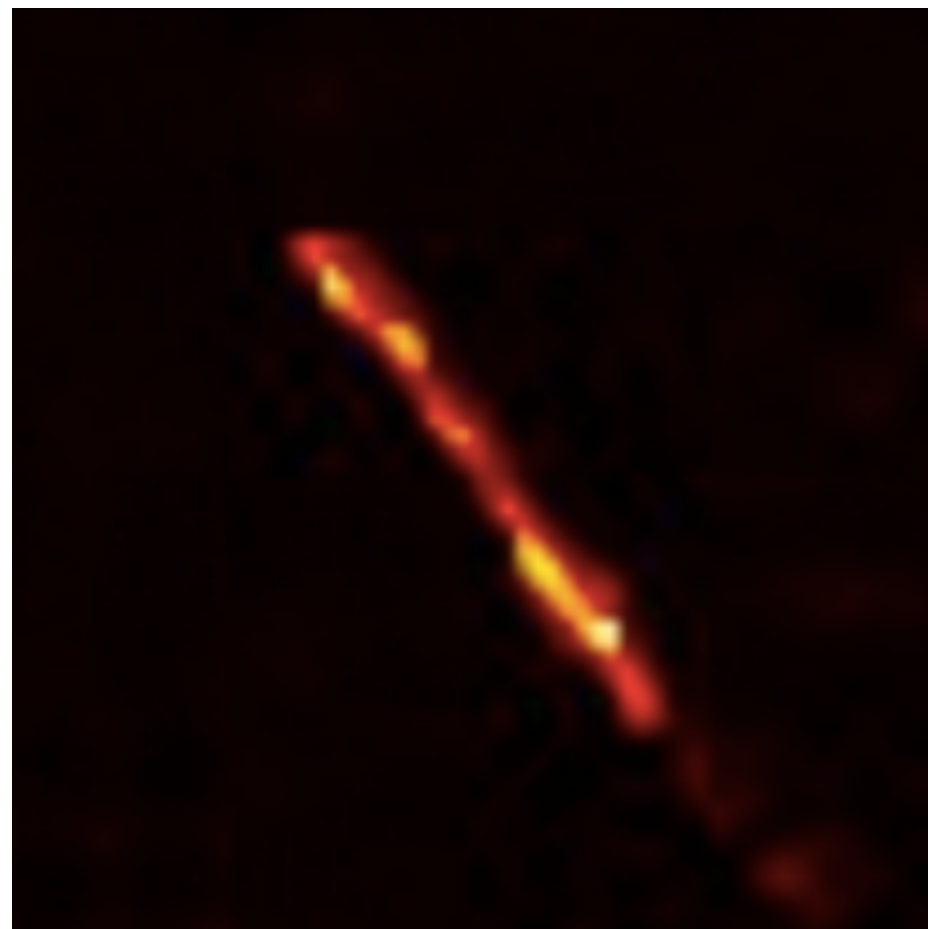
$$\begin{aligned}\theta - \phi &= \arctan \frac{l}{H} - \arctan \frac{l}{H + \delta} \\ &= \arctan \left(\frac{\frac{\delta l}{H^2 + \delta H}}{1 - \frac{l^2}{H(\delta + H)}} \right) \\ \Rightarrow \sigma_\theta &\approx \frac{l}{H^2 - l^2} \times \sigma_H\end{aligned}$$



Systematics: Trigger Threshold

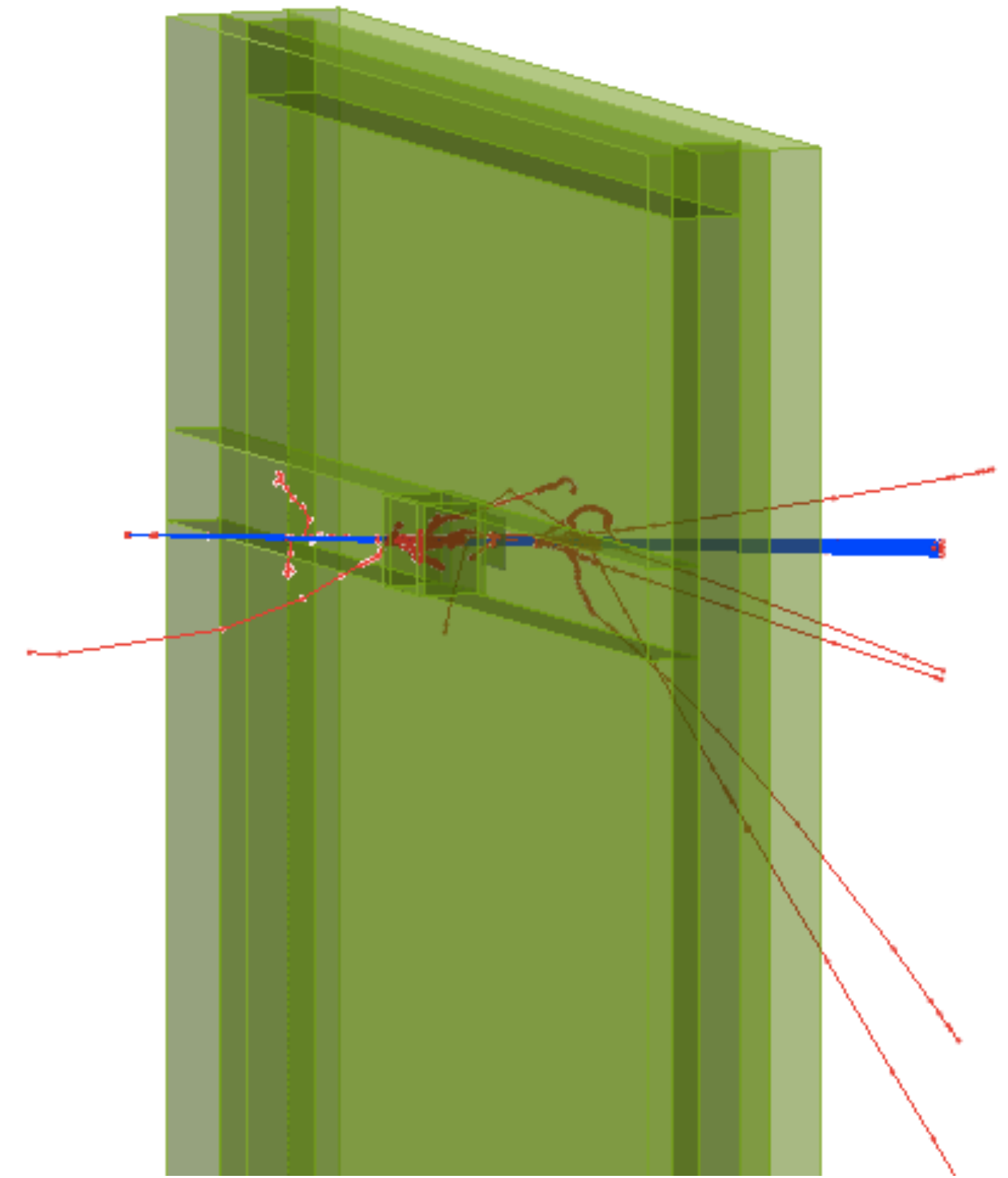
- Simulated muon tracks look less continuous than actual DECO events
- Changed trigger threshold to see if I could recover continuous tracks

DECO “Worm”



Conclusion

- Developed simulation framework for cell phone image sensors
- Deposited energy distributions agree well with known cross sections
- Particles have morphologies similar to what was expected
- Future work:
 - Fill in energy and angle parameter space
 - Model noise and imperfections

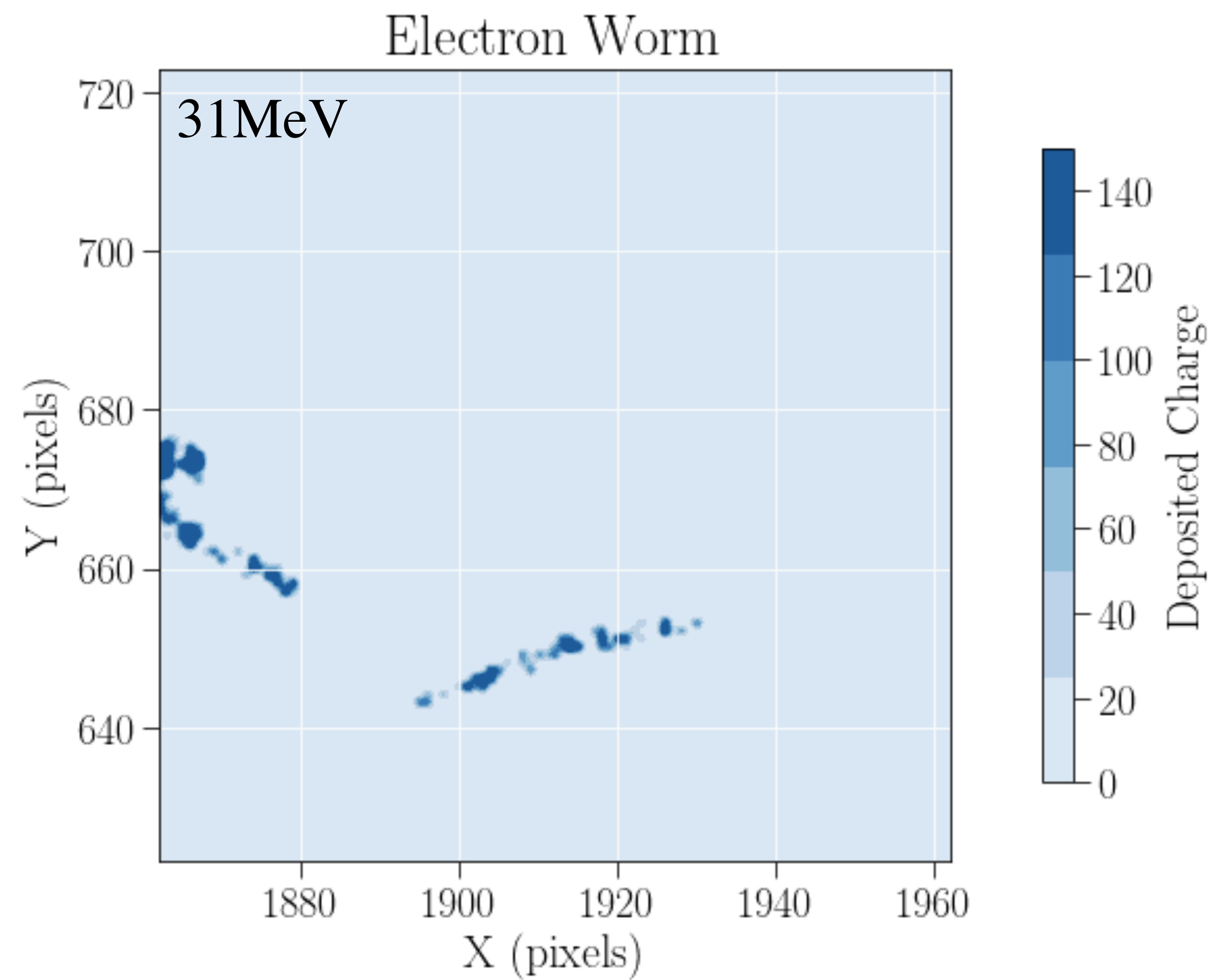
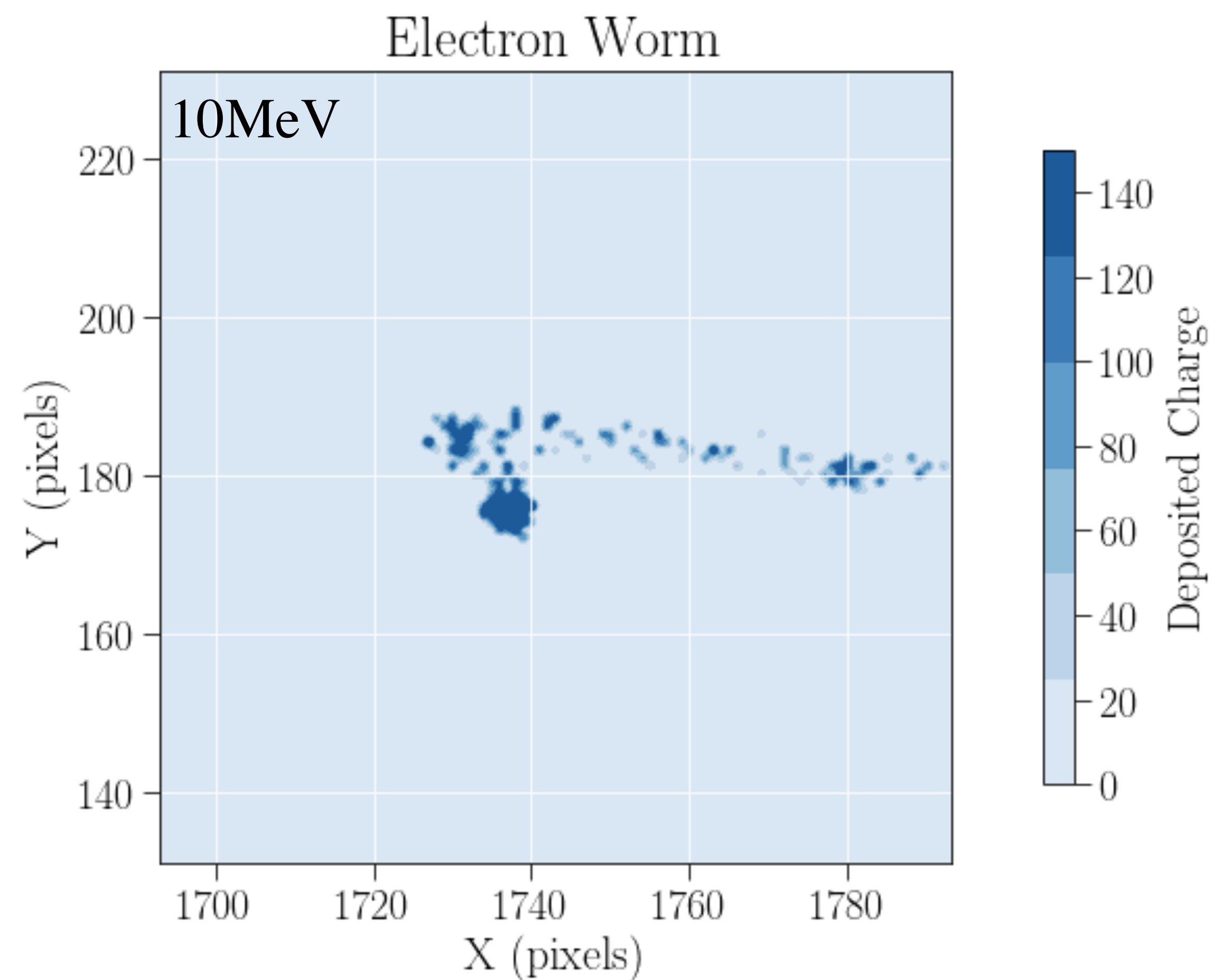


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Backup

Odd Electron Signatures



Is it just plotting formats?

maybe.

