Microscopic Simulation of the Ionization Track Structure within Liquid Xenon

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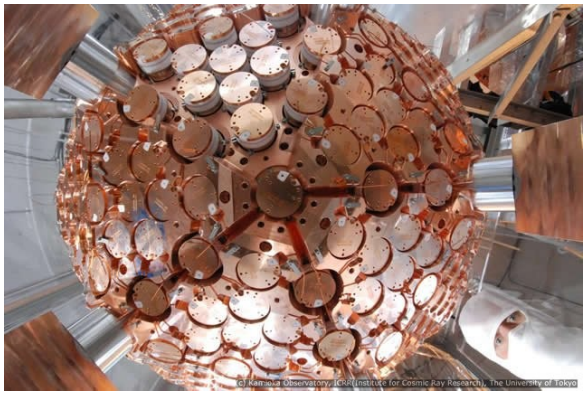
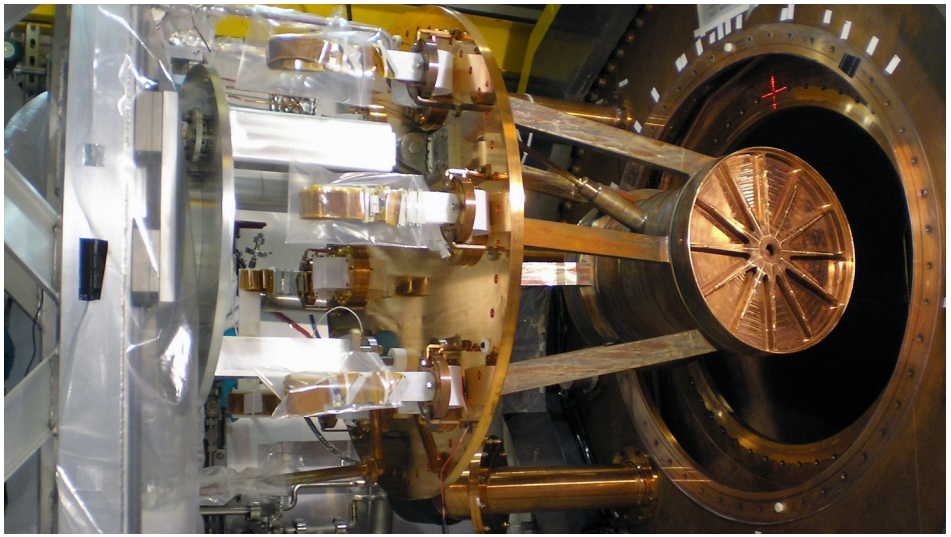
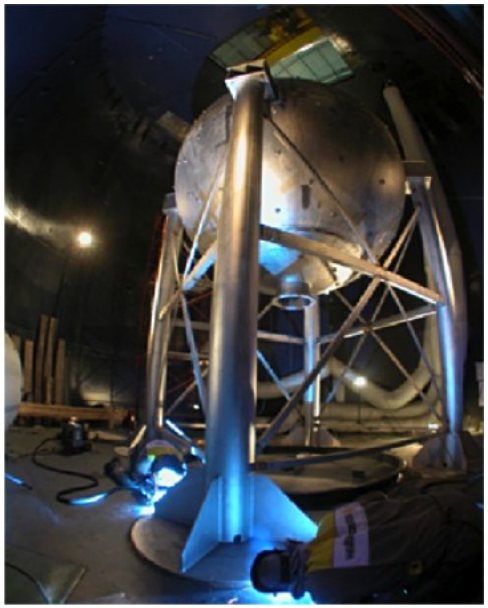
Supervised by Prof. Razvan Gornea

Motivation







Motivation

Process of interest

Fundamental particle interaction

Fast Charged Particle in medium

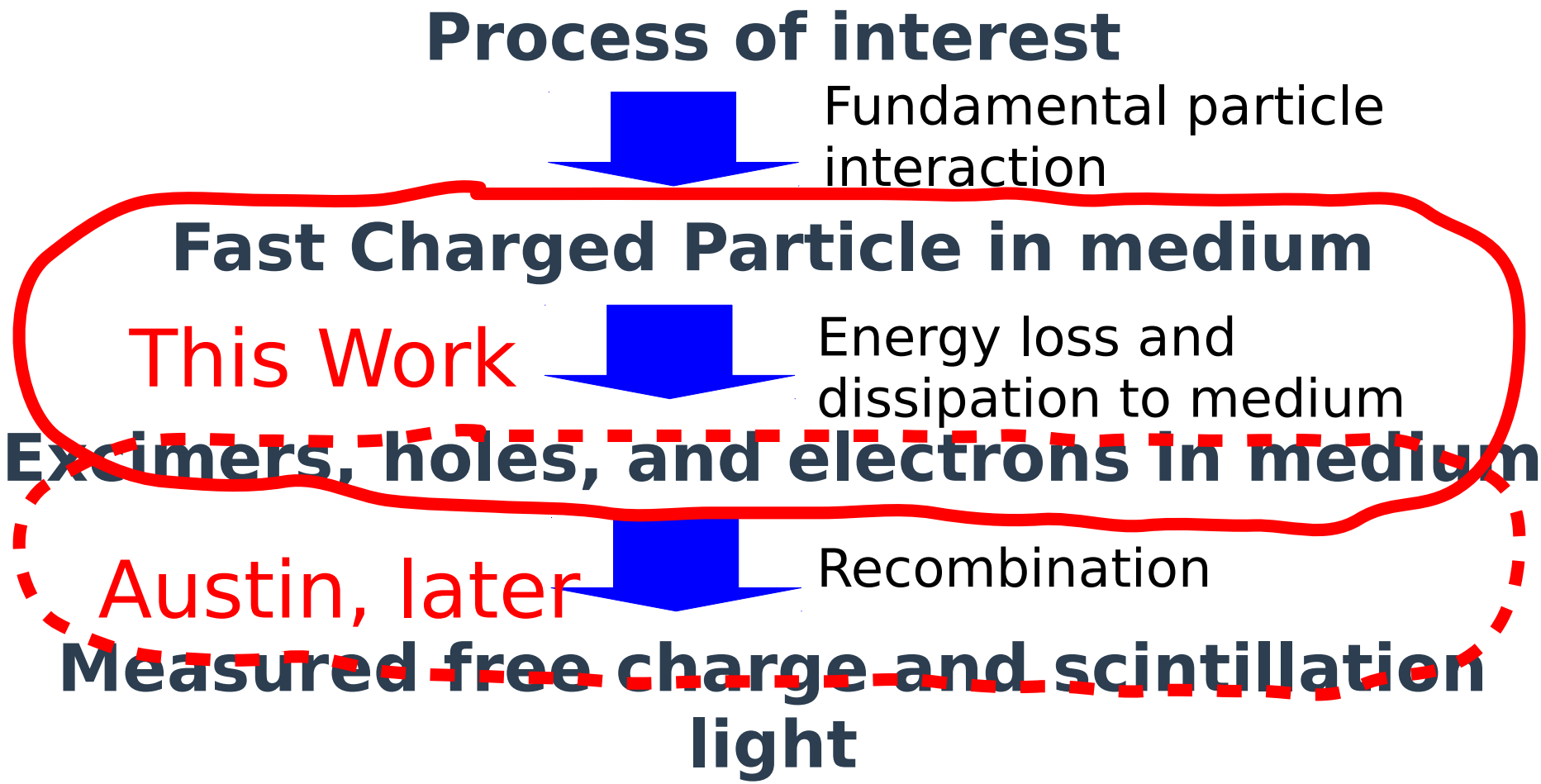
Energy loss and dissipation to medium

Excimers, holes, and electrons in medium

Recombination

Measured free charge and scintillation light

Motivation


Process of interest
Fundamental particle interaction
Fast Charged Particle in medium
This Work
Energy loss and dissipation to medium
Excimers, holes, and electrons in medium
Austin, later
Recombination
Measured free charge and scintillation light

Goals

- **Using atomic physics data and Monte Carlo simulation techniques, we can generate such a model of the ionization track structure without invoking effective models**
- **Can probe intrinsic fluctuations in produced quanta**
- **Can examine dependence on particle ID and energy**
- **Have precise spatial information crucial for recombination processes**

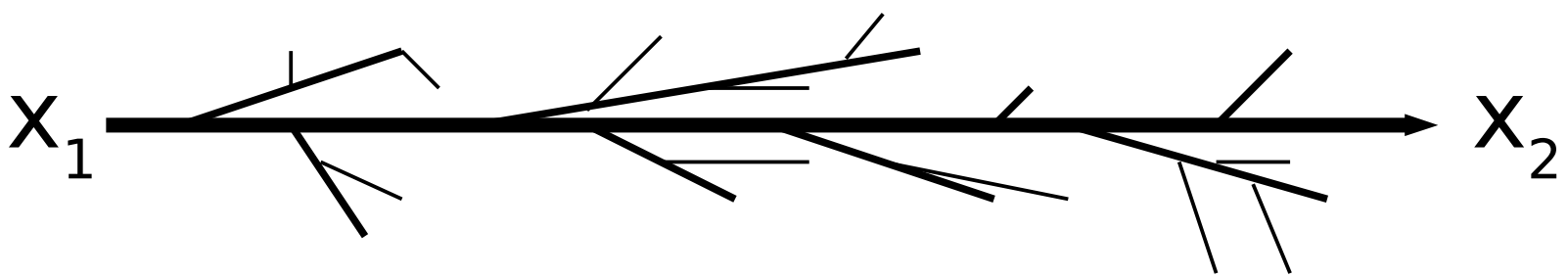
Idea

Effective Treatment:

$$\Delta E = \frac{\mathrm{d}E}{\mathrm{d}x} \cdot \Delta x \qquad Q \propto \Delta E$$

This Treatment:

$$\Delta E = \sum_i \Delta E_i \qquad Q = \sum_i q_i$$



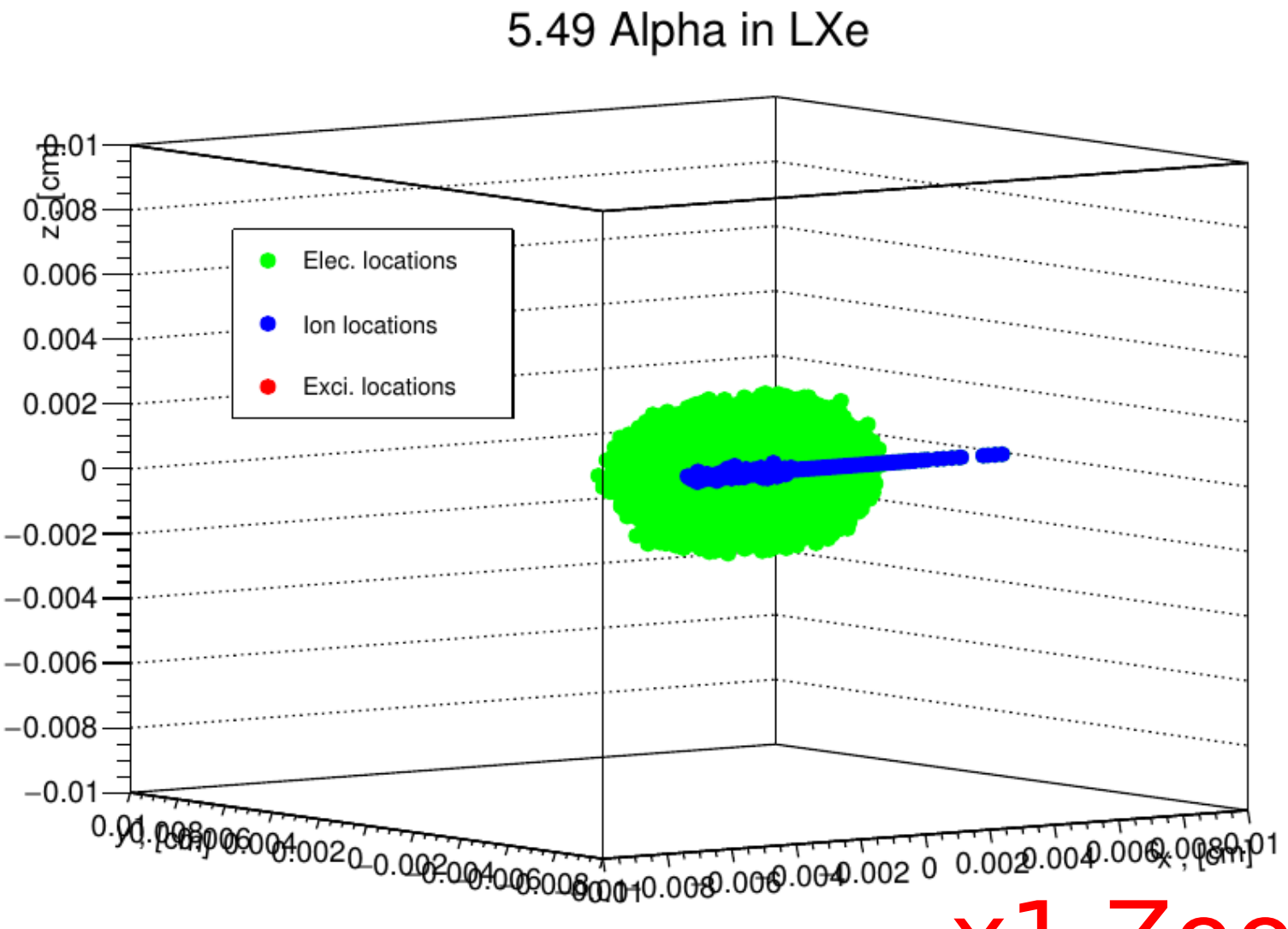
Overview of Included Physics

- **Path of track provided by Geant4**
- **Energy-loss along track handled by Allison-Cobb theory. Yields “primary” ionizations and excitations**
- **Auger cascades simulated after ionization of deep subshell according to EADL data**
- **1°, 2°, 3°… electrons tracked individually until threshold**
  - Includes E and θ-dependance of ionizations, excitations, elastic scatters
- **1°, 2°, 3°… electrons thermalized after threshold**

Implementation

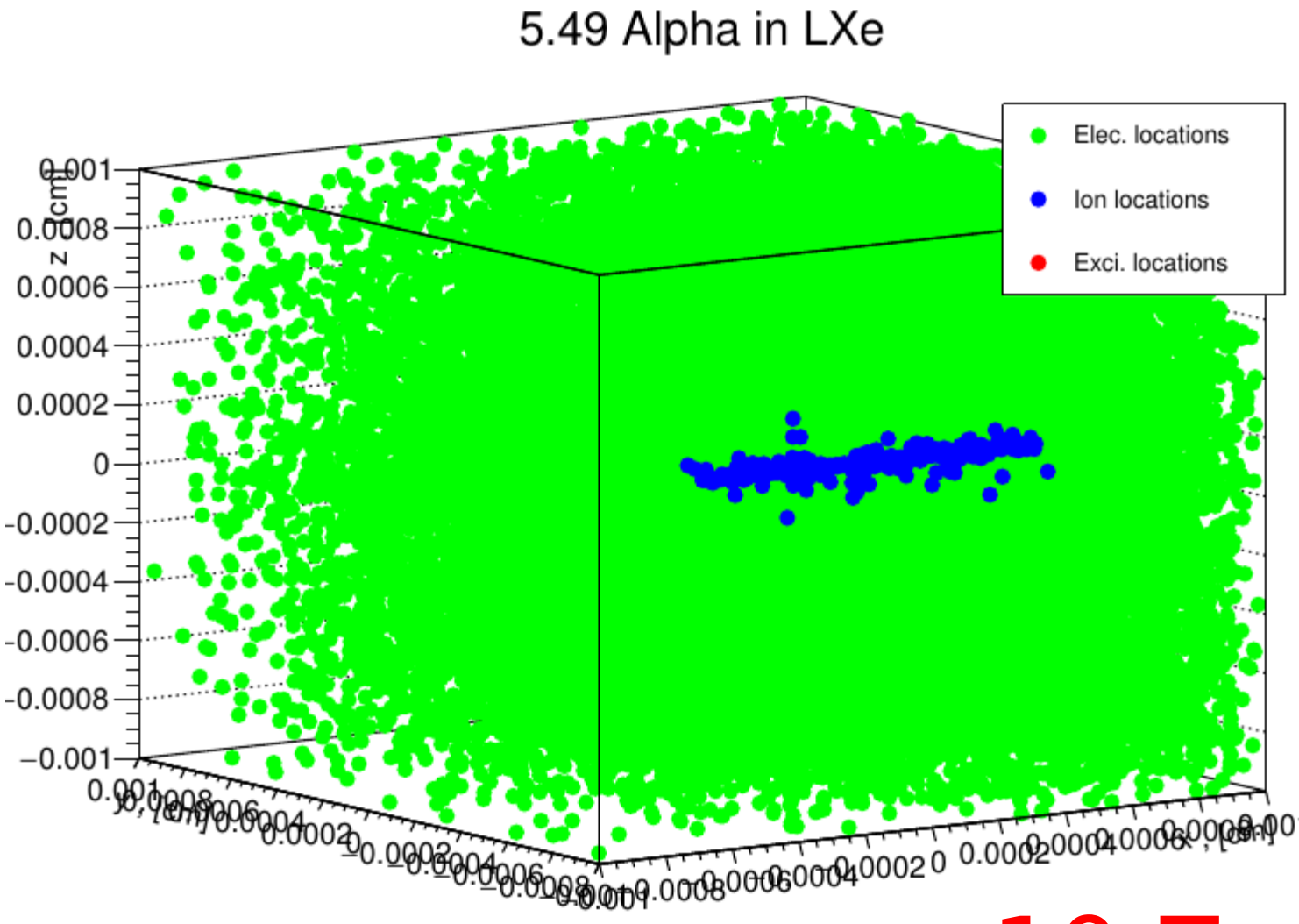
- **Monte Carlo simulation implemented in C++ with the aid of CERN/ROOT libraries and RNG's**
- **Focus on Xe: data available, of interest to EXO-200 and nEXO R&D**
- **Output provides list of final products (e.g. ions, electrons, excitations), with their time of formation, energy of formation etc.**

Exploring the Track Structure



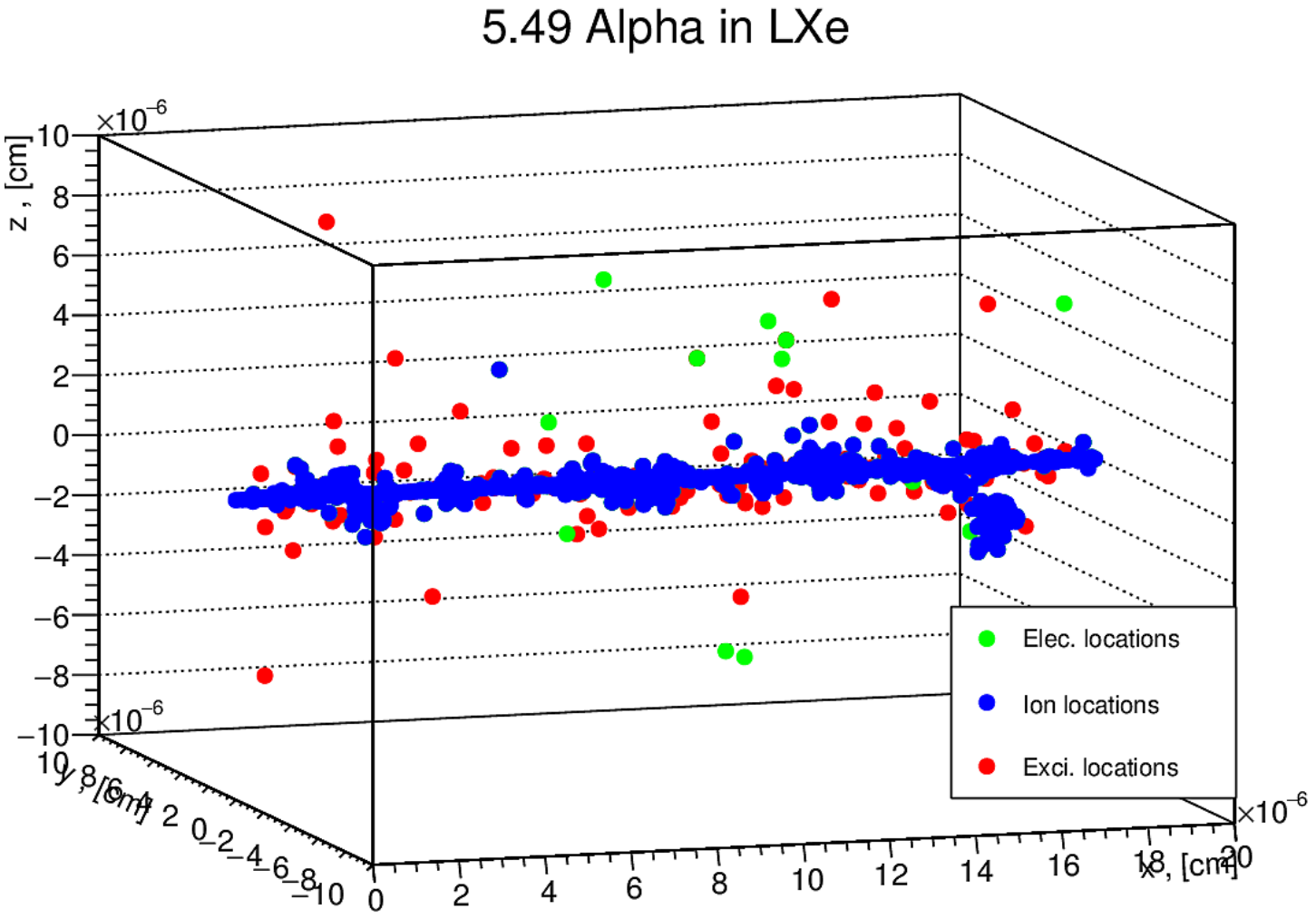
x1 Zoom

Exploring the Track Structure



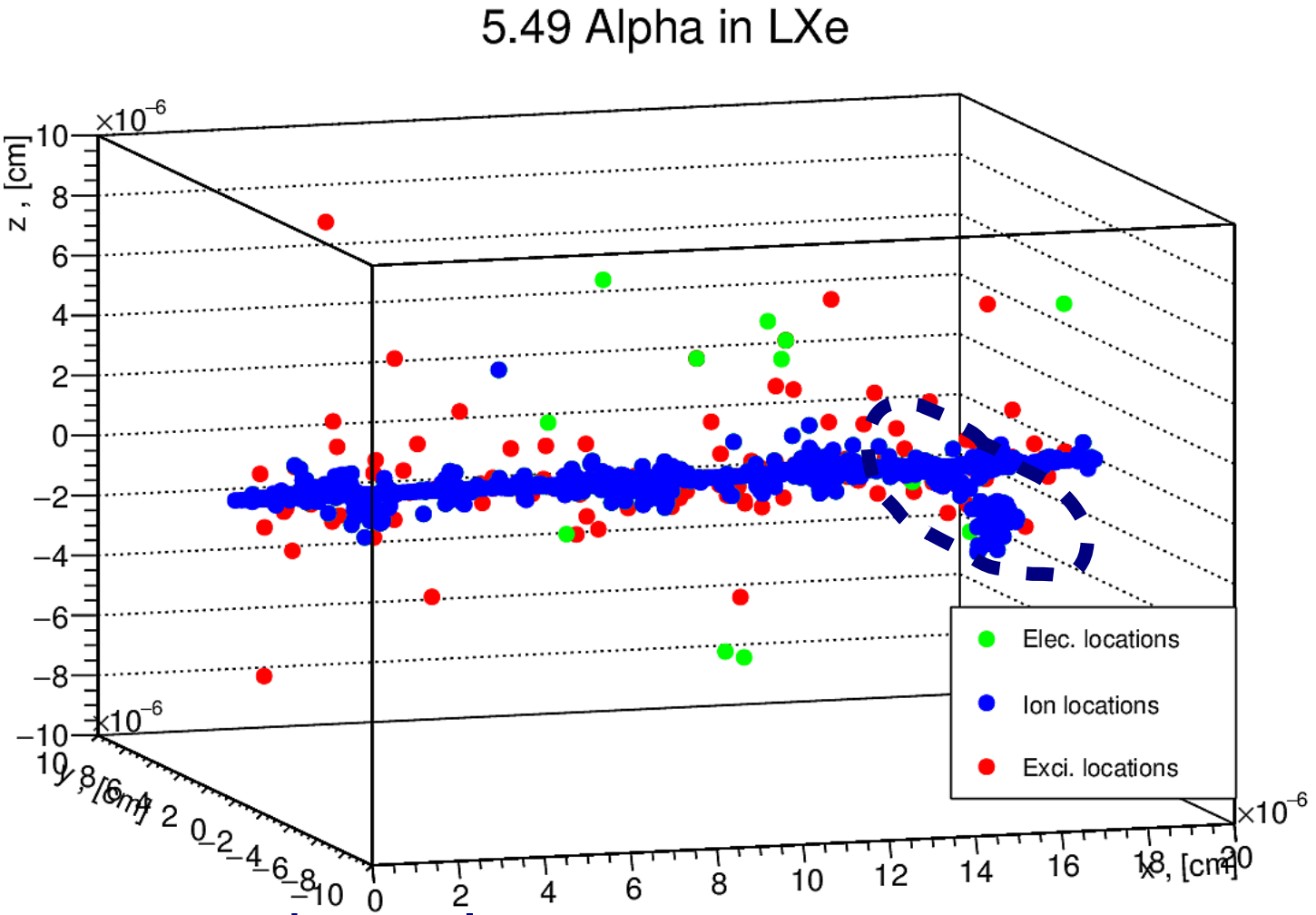
x10 Zoom

Exploring the Track Structure



x1000 Zoom

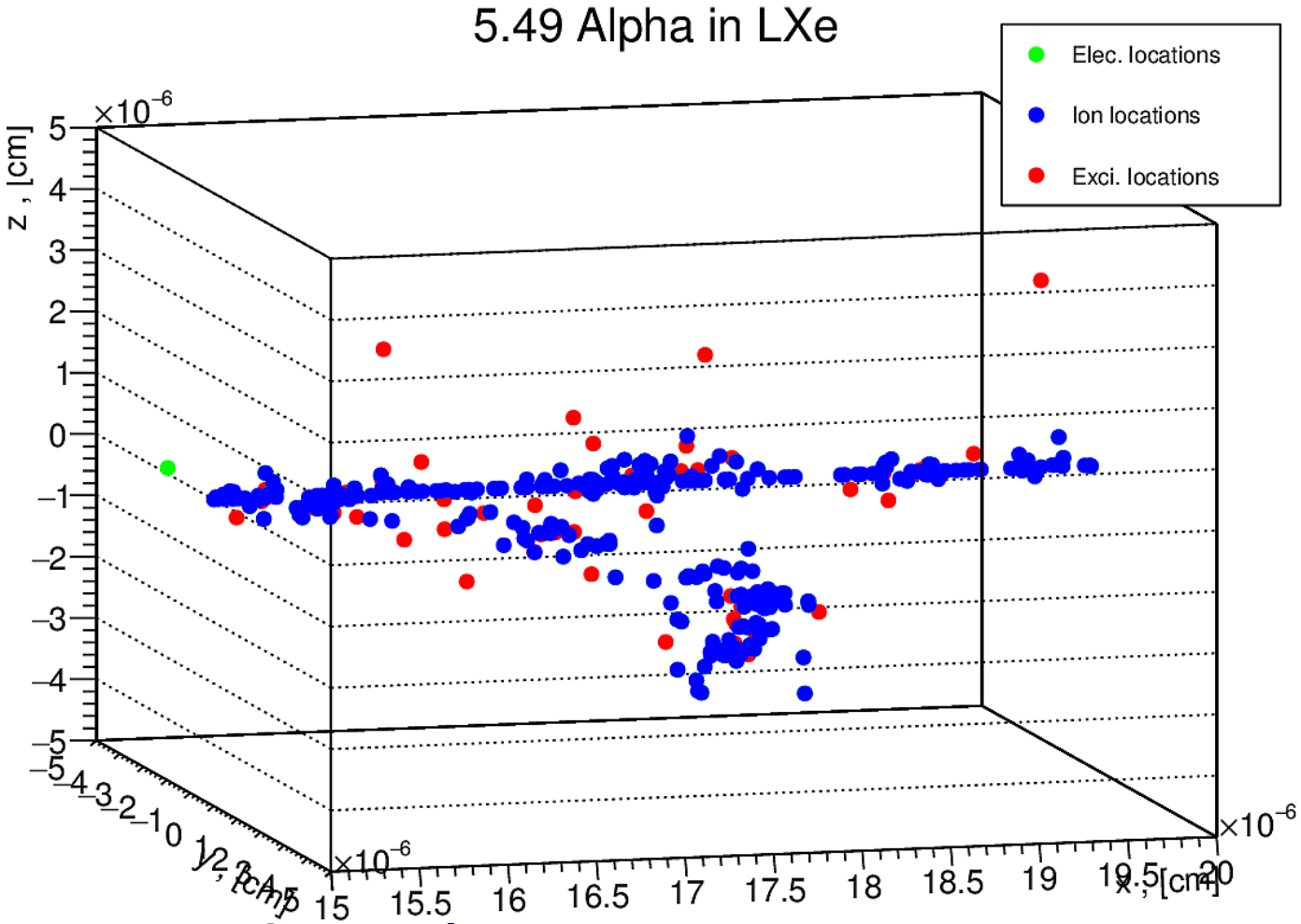
Exploring the Track Structure



~keV electron path

x1000 Zoom

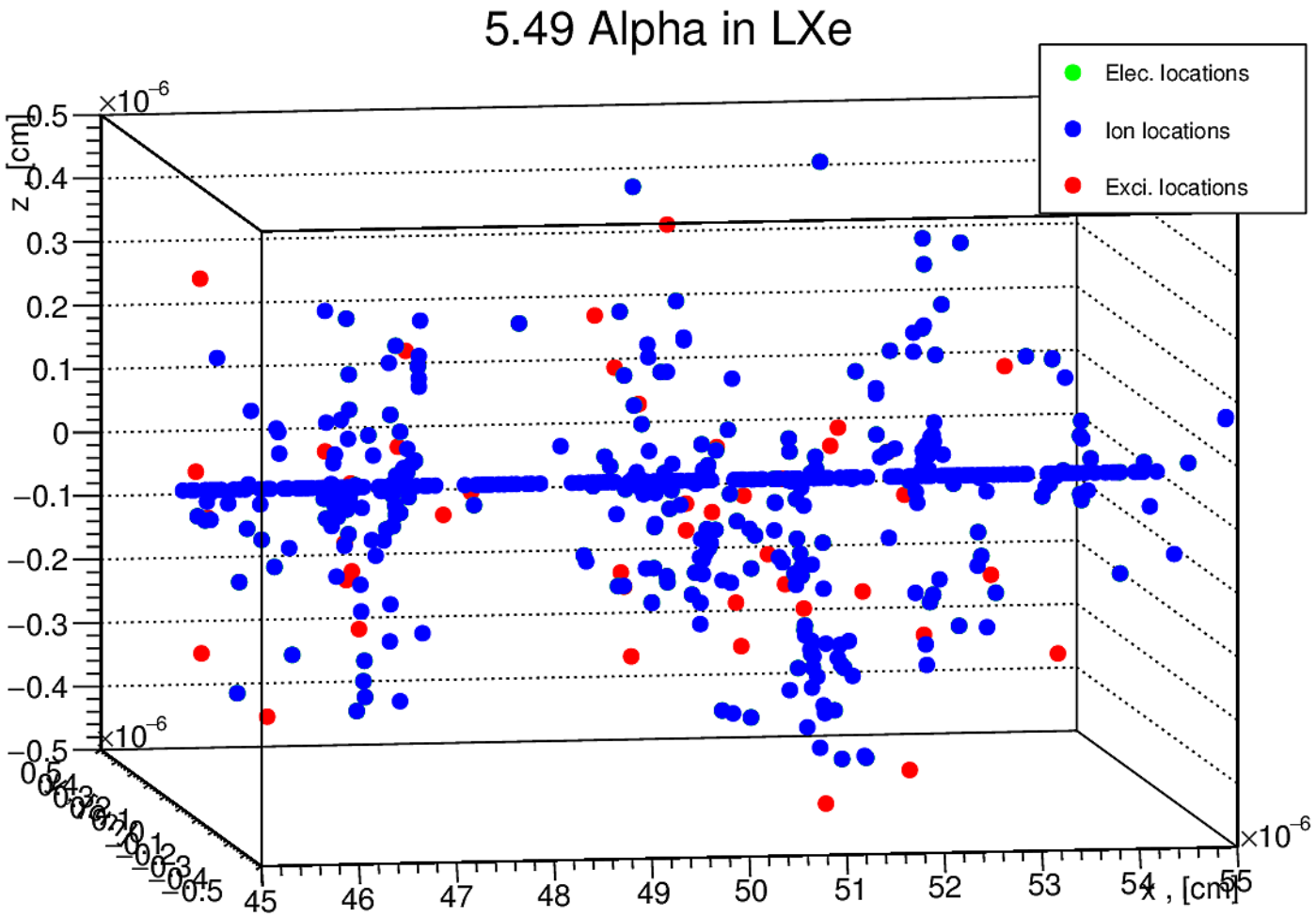
Exploring the Track Structure



~keV electron path

x5000 Zoom

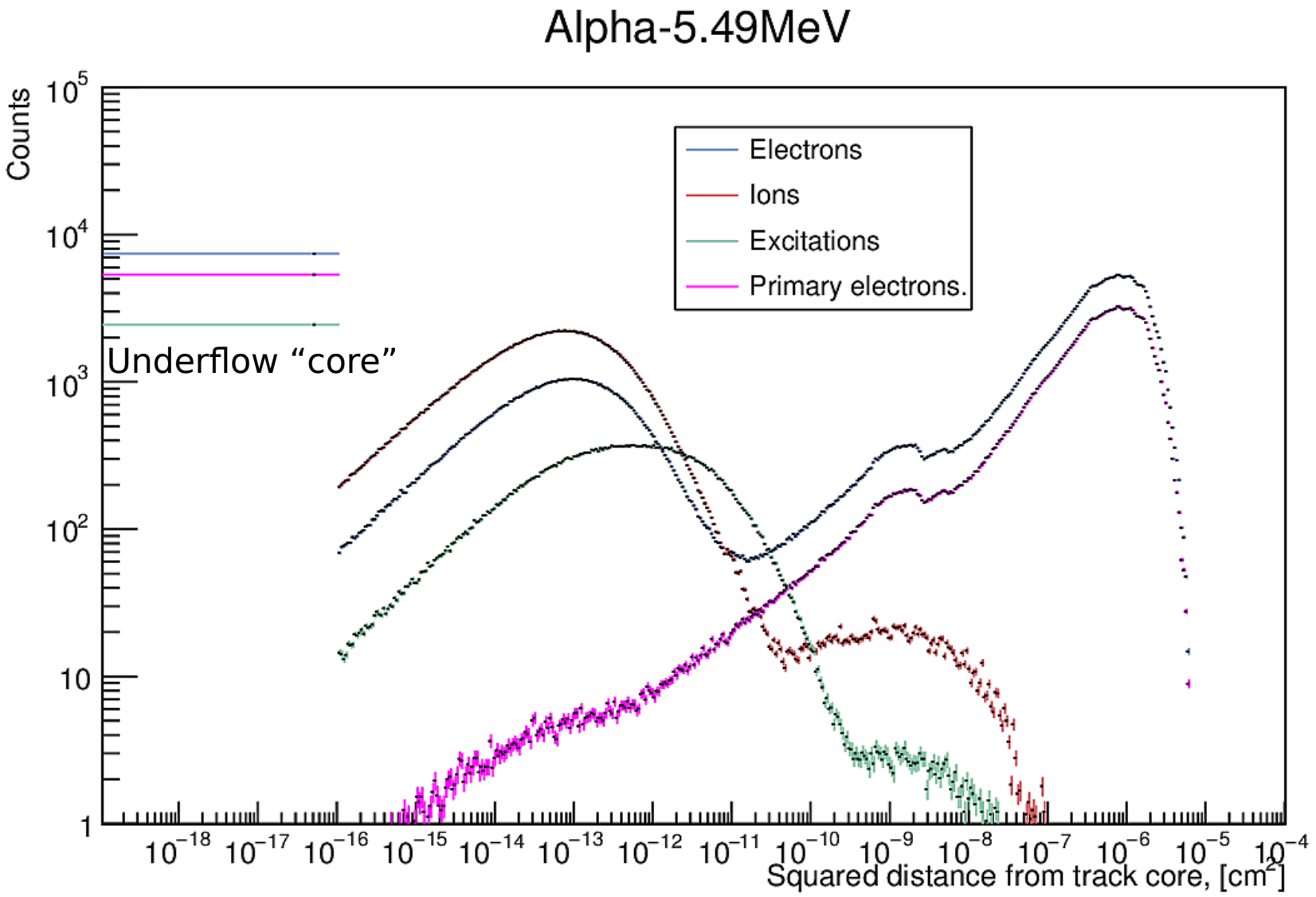
Exploring the Track Structure



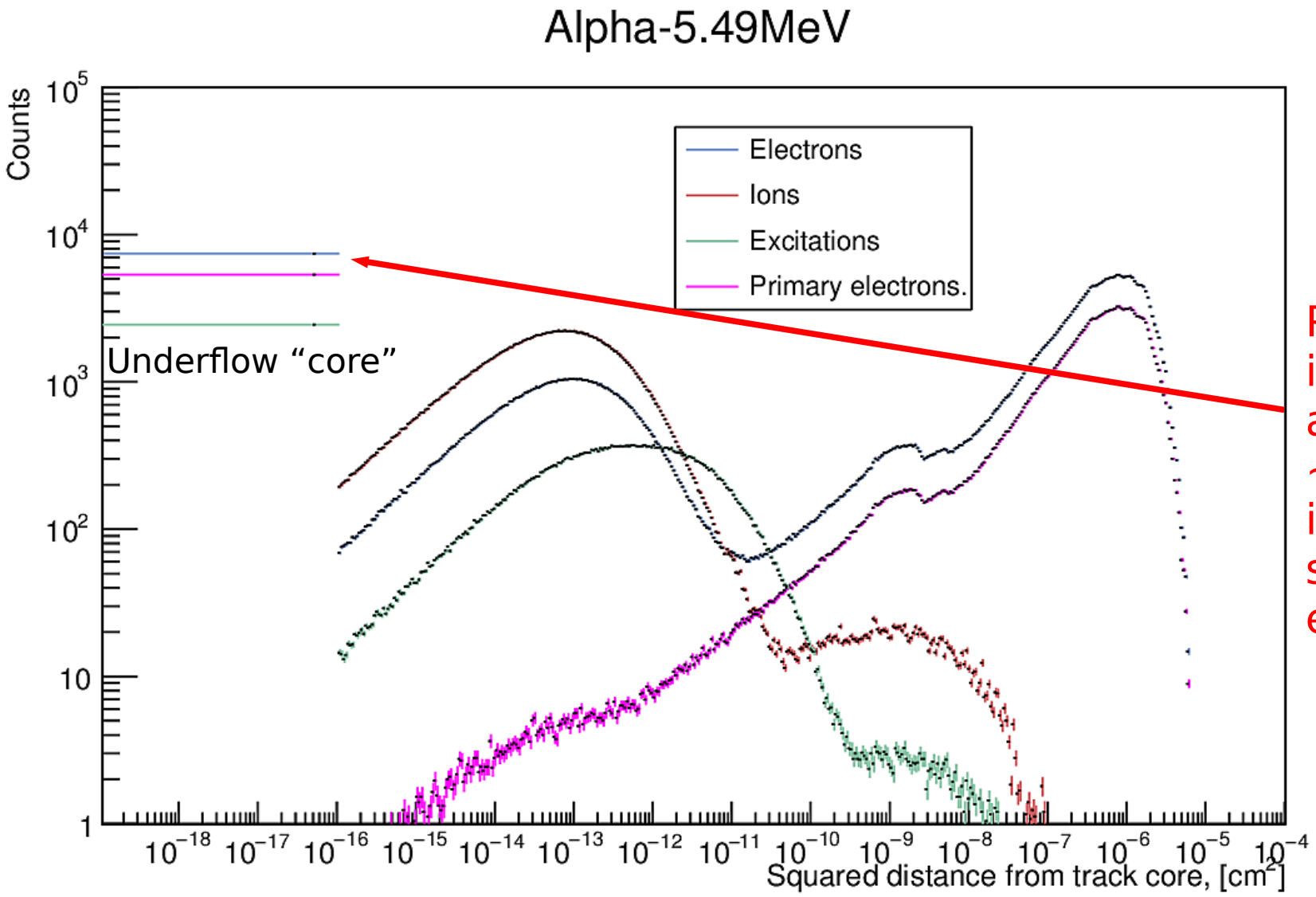
Softer electron paths

x10000 Zoom

Radial profile of products about track

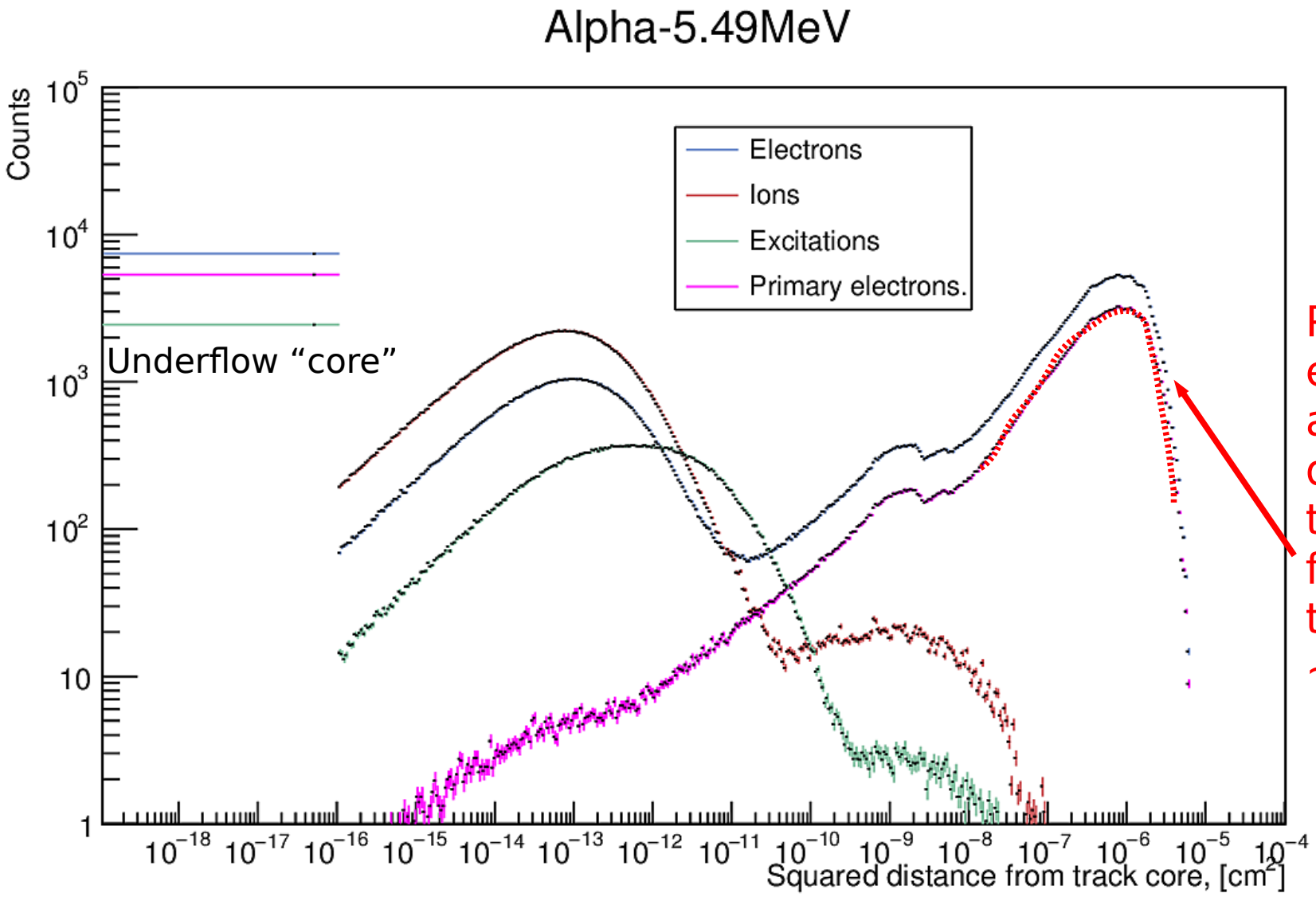


Radial profile of products about track



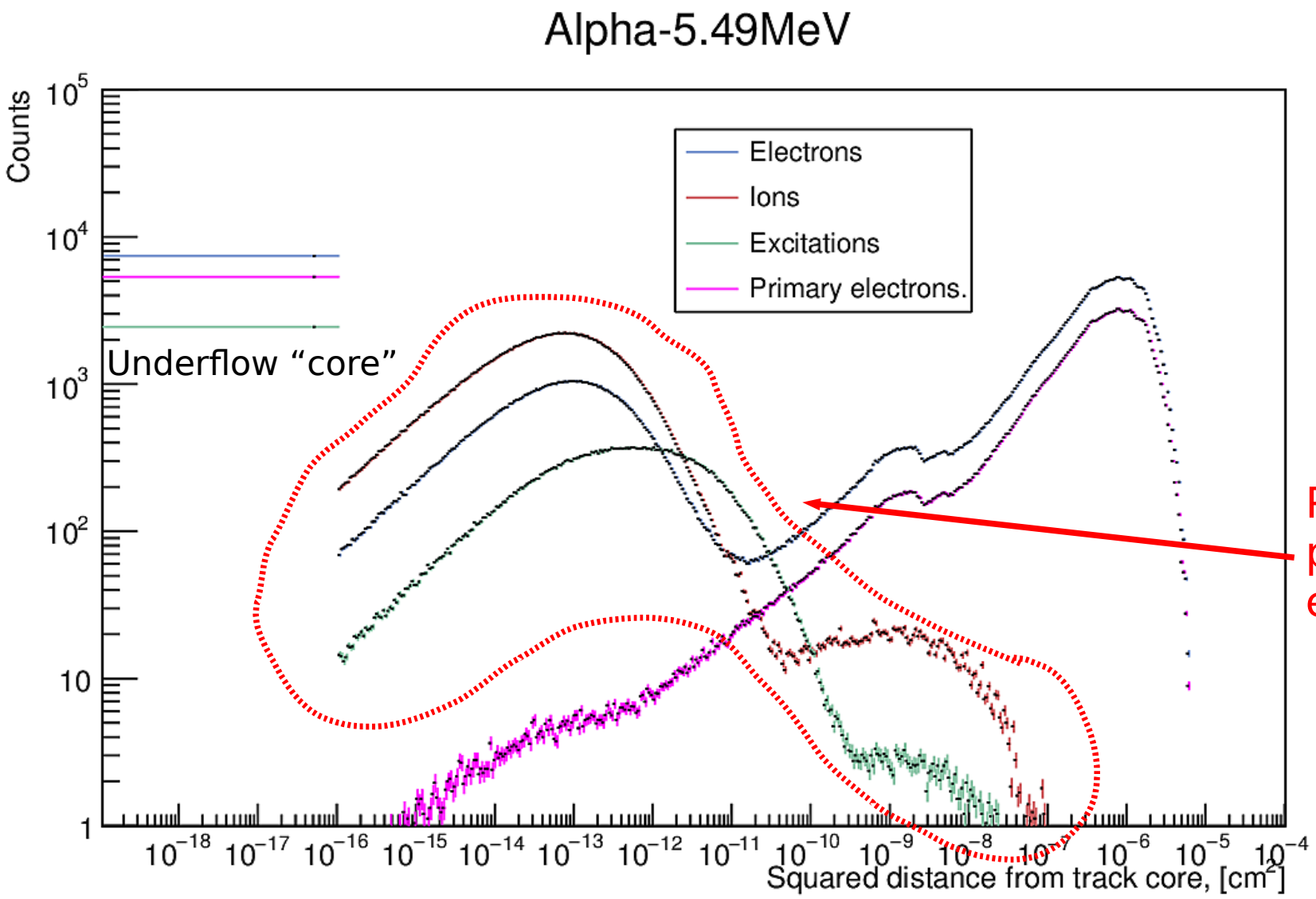
Primary ionizations account for ~45% of all ionizations; similar for excitations.

Radial profile of products about track



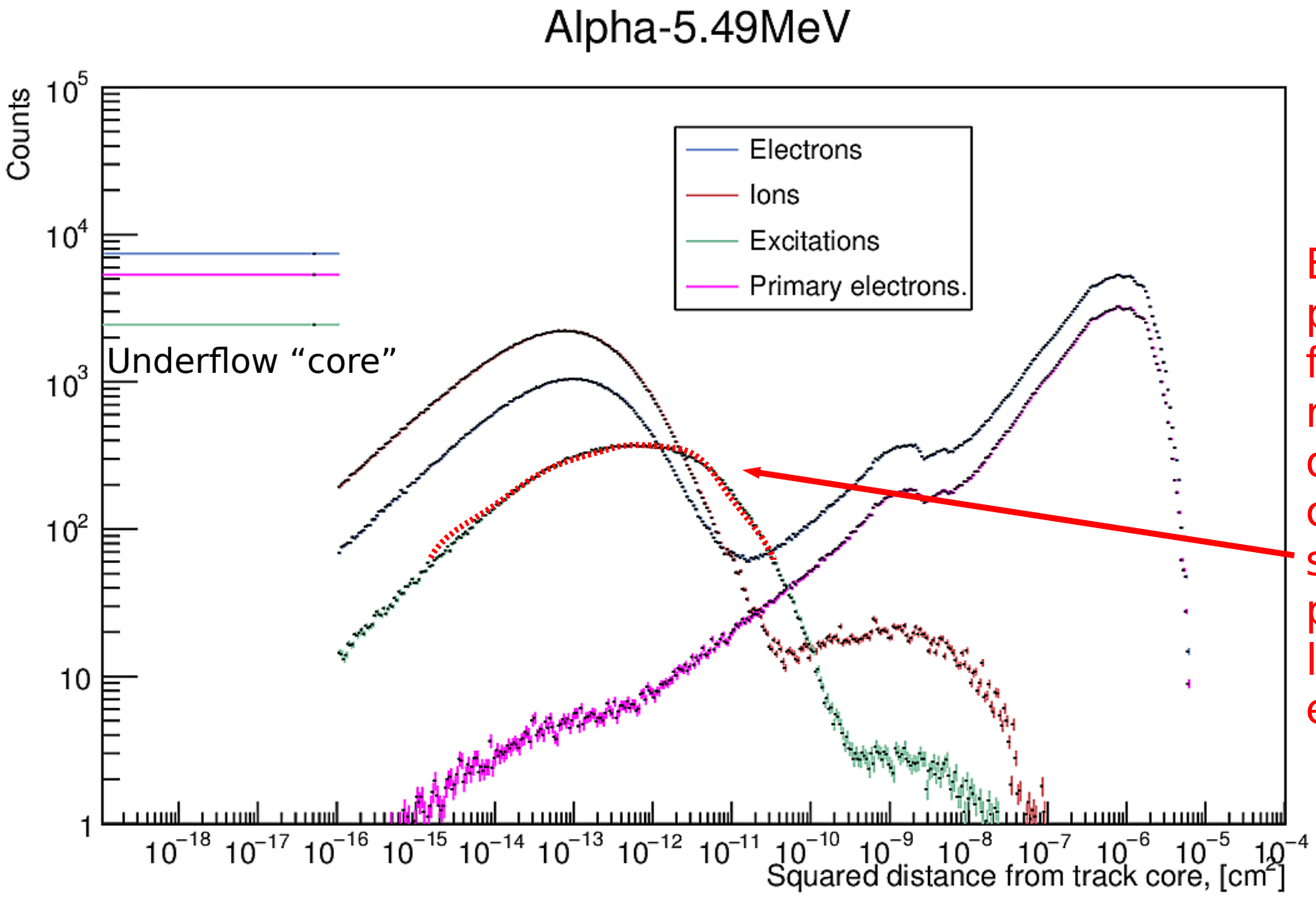
Primary electrons are displaced the furthest from the track core: ~10^{-3} cm

Radial profile of products about track



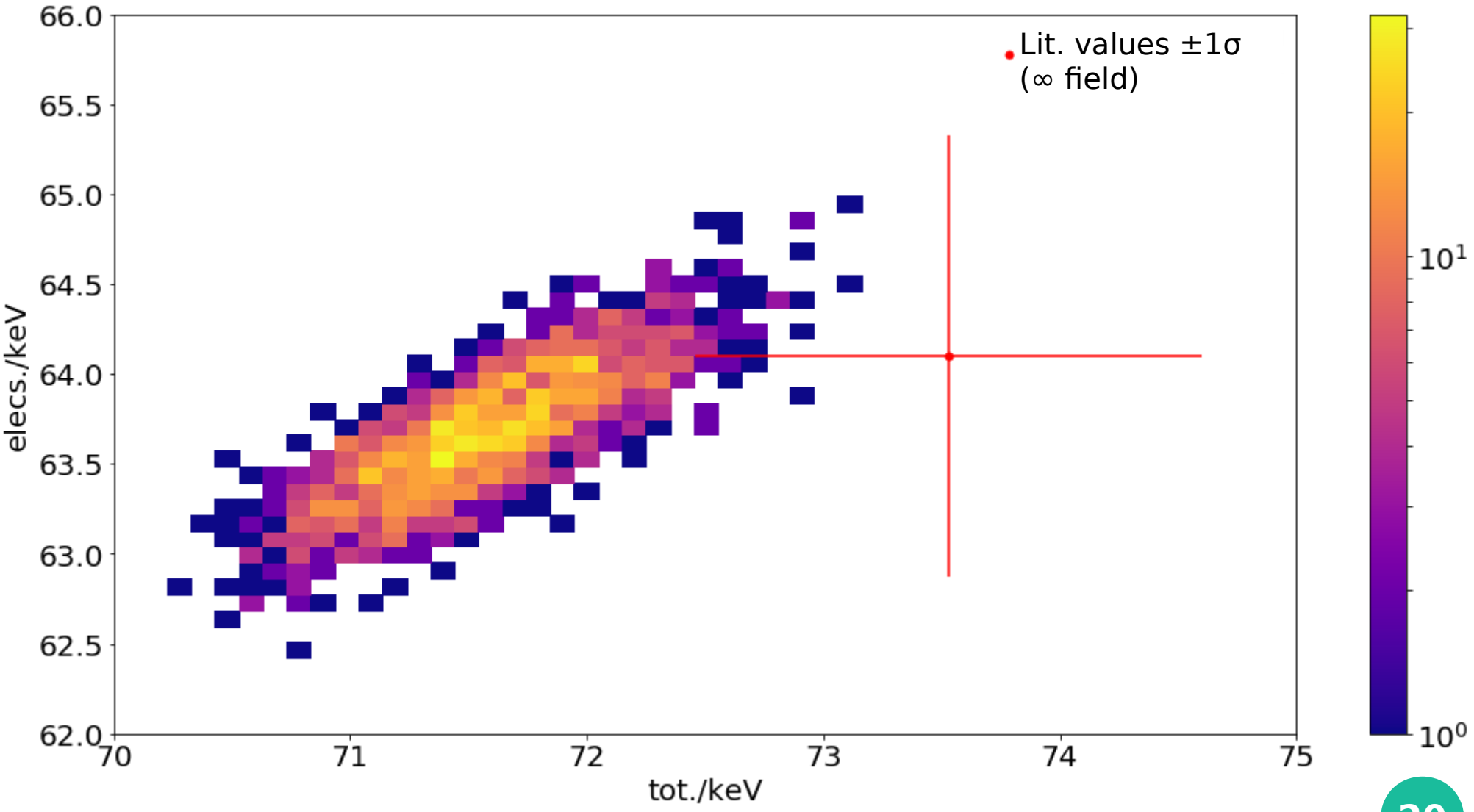
Produced by primary electrons

Radial profile of products about track



Excitations peak at further radial distance: cross-section peaks at lower energies

Charge and Total Quanta yields



Future Work

- **Remove Geant4 link**
  - Large-angle scatters by incident particle
- **Include treatment of multi-scatter energy depositions**
- **Resolve dE/dx discrepancies found between model implemented and existing codes**
- **Expand to cover nuclear recoils**
- **Review literature for Ar data to include as second medium**

Experience and Personal Growth

- **Lots of exposure to object-oriented programming**
- **Writing a simulation is v. different from just using it…**
  - What physics do you include?
  - How do you implement a process to simulate it efficiently and effectively?
- **Working with a small research group**
- **In research, things don’t always work the way you want them too ¯_(ツ)_/¯**