Simulation and reconstruction of charged particle trajectories in an atypic time projection chamber

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Outline

1. Track simulation
2. Track reconstruction
3. Energy reconstruction

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Track simulation

- We use Garfield++ for track simulation
  - Primary relativistic particle simulated using Heed program [1]
  - Secondary ionization electrons can be simulated using Monte Carlo (gas table calculation necessary)
  - Alternative approach is microscopic tracking (uses equation of motion)
    - A bit slower, more precise especially for small structures.
- Currently we have only one track for testing purposes
- Soon, more microscopic tracks will be simulated on MetaCentrum to test the reconstruction

Simulated track example (microscopic tracking)

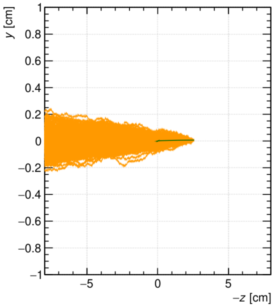


Figure: Diffusion front view

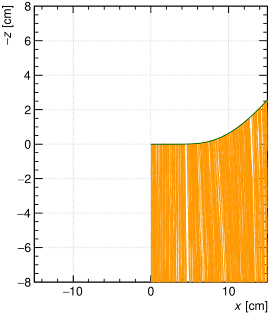


Figure: Electron drift

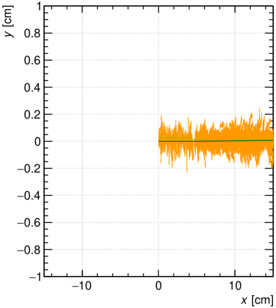


Figure: Diffusion top view

Ionization electrons map simulation

- In the experimental setup TPC detects secondary ionization electrons (after multiplication on triple GEM)
- These electrons drift at constant velocity towards the readout plane
- We can use simulation of evenly spaced electrons for reconstruction (time consuming – run on MetaCentrum)

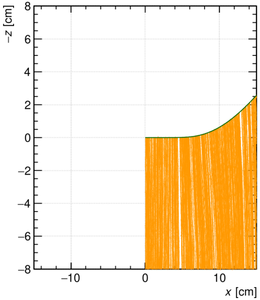
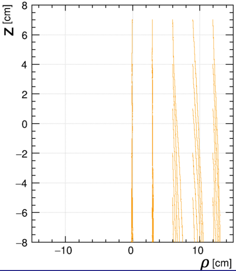


Figure: Electron drift

Ionization electron map simulation

- As a result we get an approximation of a mapping from initial coordinates of the electrons (x, y, z) to the readout coordinates (x', y', t)
- By interpolating the resulting readout coordinates (we know the respective initial coordinates) we can get an approximation of the initial coordinates for any point (we get the inverse map)
- We can use the inverse map to finally create mapping from our discrete readout values (channel number, time) to voxels of the primary track



Ionization electron map simulation

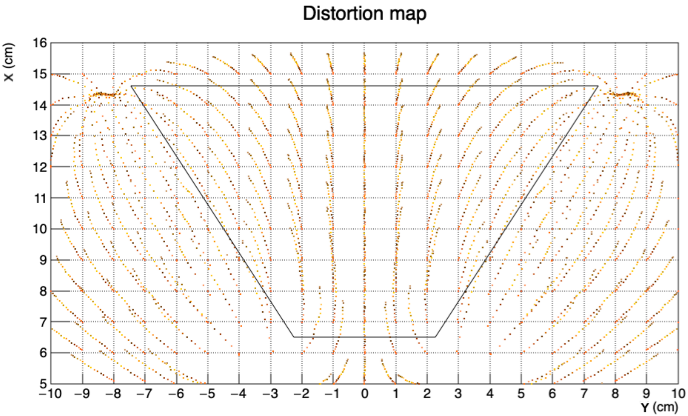


Figure: The average readout coordinates x and y of ionization electrons generated at different z values denoted by color (Credit: Hugo Natal da Luz).

Ionization electron map simulation

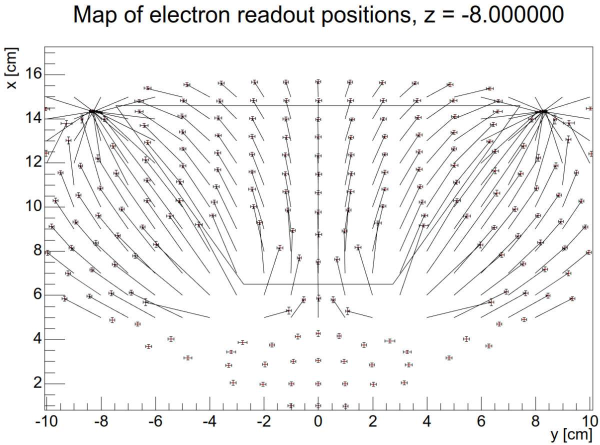


Figure: The average readout coordinates x and y of ionization electrons generated for maximal initial distance from readout. The tail of each arrow denotes the initial coordinates.

Ionization electron map simulation

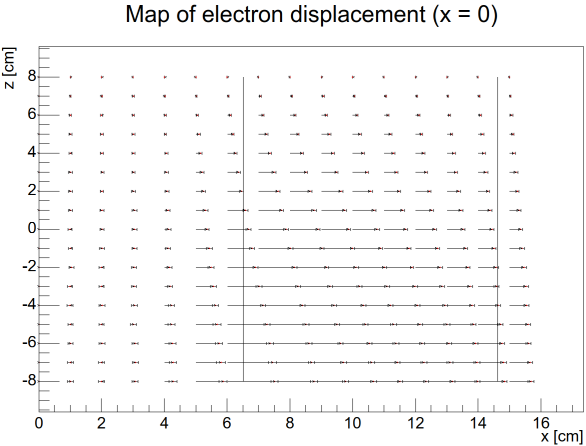


Figure: The average readout x-coordinate of ionization electrons generated for different initial x and z coordinates ($y = 0$). The tail of each arrow denotes the initial coordinates.

Ionization electron map simulation

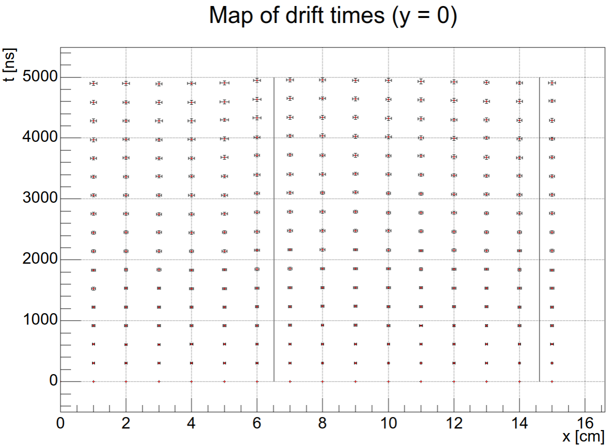


Figure: The average readout coordinates x and t of ionization electrons generated for different initial x and z coordinates ($y = 0$).

Ionization electron map simulation

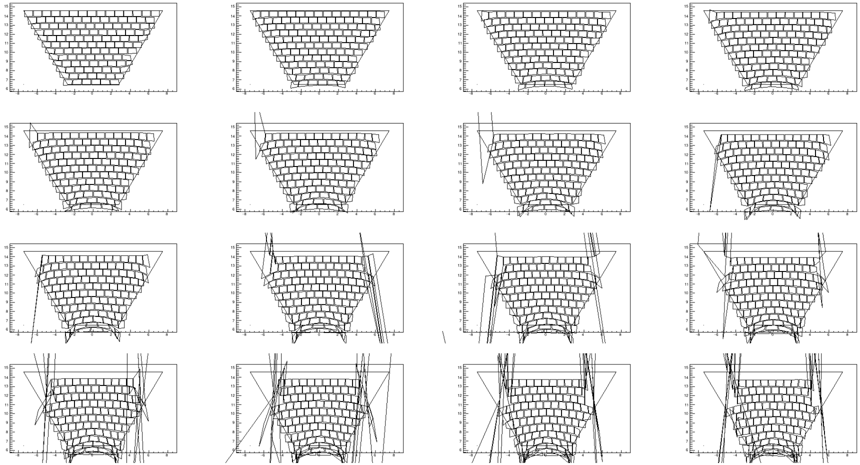


Figure: Pad voxel boundaries for different times (picture of the first attempt). Errors might be caused by attempted interpolation outside the simulated grid.

Outline

Track reconstruction

- Preliminary attempts using the inverse map (not accounting for readout pads - we assume we know the coordinates exactly)
- These attempts were used to test the map (see residues on the next slide)

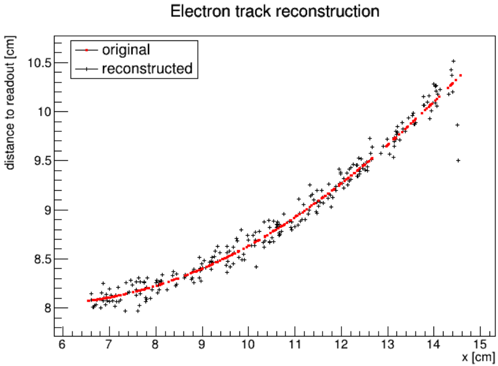


Figure: Original and reconstructed interaction points on the simulated track

Track reconstruction

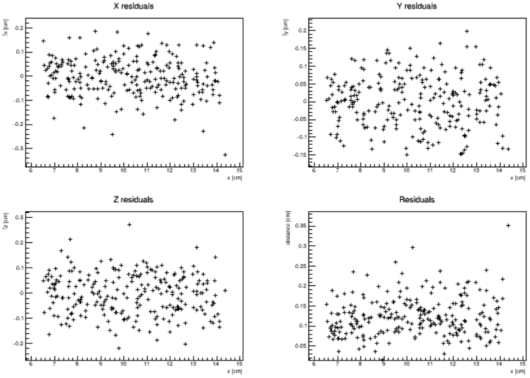


Figure: Residues (x, y, z and combined) of the interaction point reconstruction using the map displayed as a scatter plot along the tracks original direction x.

Track reconstruction

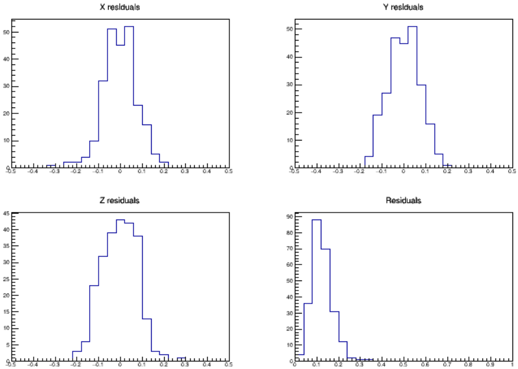


Figure: Residues (x, y, z and combined) of the interaction point reconstruction using the map displayed as a histogram.

Outline

Energy reconstruction

- With or without pads
- We are counting the number of electrons as charge of the pad
- Initial fit with smoothly attached circular arc with straight lines (expected in homogeneous field)
    - Fitted parameters:
        - radius, direction of bending, starting point of the circle and length of the circle
    - Orientation and position of the first line is fixed in the fit
    - The magnetic field in the middle of the chamber (where the track crosses the middle x-coordinate) is used as B value
    - Reconstruction of energy tested on Runge-Kutta generated tracks with random initial parameters (no pads)
- Energy is then refined using the Runge-Kutta 4th order fit (assuming known direction)

Energy reconstruction

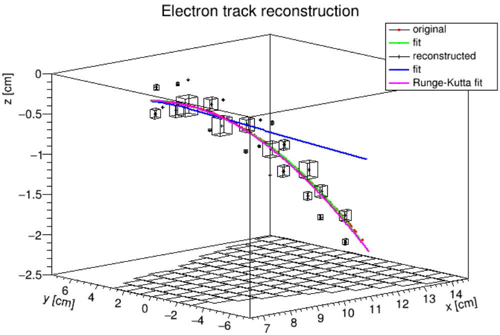
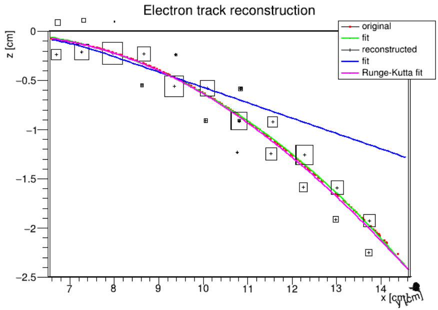
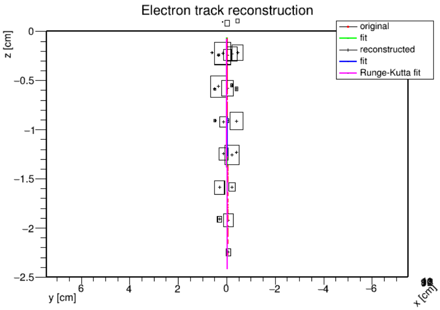


Figure: Original and reconstructed (with pads) 7.49 MeV track fitted with the lines and circle fit (both original and reconstructed, not yet tuned for pads). Reconstructed track is also fitted by the Runge-Kutta fit. Initial reconstructed energy is 7.55 MeV for the original fit and 8.86 MeV from the reconstructed. Refined energy with Runge-Kutta fit (with pads) is 7.374 ± 0.037 MeV.

Energy reconstruction





Energy reconstruction - circle fit test with Runge-Kutta sample

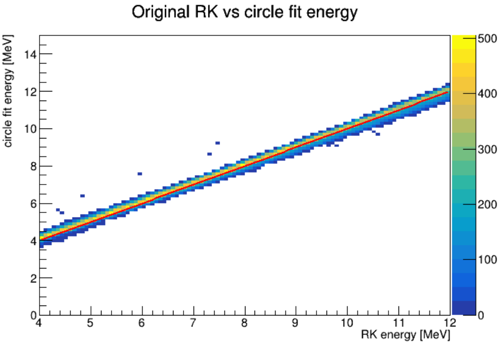


Figure: Simulated vs reconstructed energy of the Runge-Kutta generated tracks. Function $y = x$ displayed in red for reference.

Energy reconstruction - circle fit test with Runge-Kutta sample

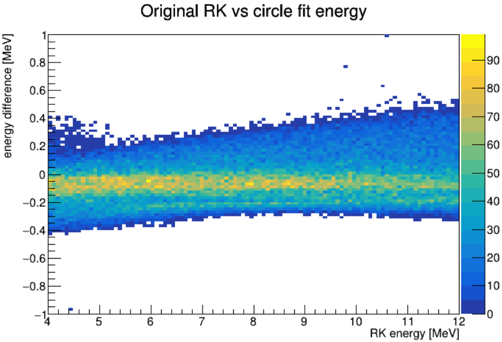


Figure: Dependence of the difference in the simulated and reconstructed energy (absolute error) on the simulated energy.

Energy reconstruction - circle fit test with Runge-Kutta sample

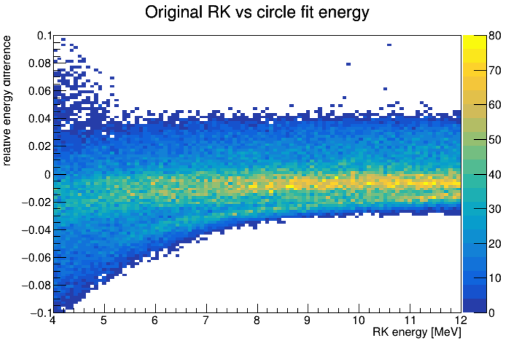


Figure: Dependence of the relative difference in the simulated and reconstructed energy (relative error) on the simulated energy.

Thank you for your attention.

References I

[1] I. B. Smirnov.
Modeling of ionization produced by fast charged particles in gases.
Nucl. Instr. Meth. A, 554:474–493, 2005.