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

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Outline

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Motivation

- Measurement of anomalies in angular correlation of electron and positron internally produced in excited ^{8}Be and ^{4}He
- For energy reconstruction, tracks in the time projection chamber (TPC) will be used
  - Atypical TPC (magnetic field is perpendicular instead of parallel to electric)
  - This interferes with the direction of the drift of electrons
  - Energy can be determined using curvature of the track in the inhomogeneous magnetic field
  - Magnetic field data from simulation is used

X17 detector

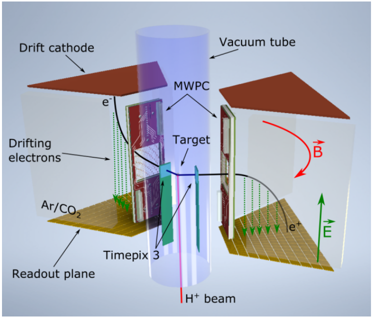

Figure: A diagram of the X17 detector. You can see two out of the six TPC chambers.[1]

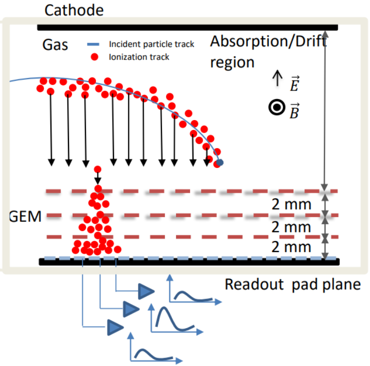

Figure: Working principle of TPC with triple gas electron multiplier (GEM) readout.[1]

Outline

Track simulation

- We use Garfield++ for track simulation
  - Primary relativistic particle simulated using Heed program [2]
  - 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 simulate only one track at a time for testing purposes

Simulated track example (microscopic tracking)

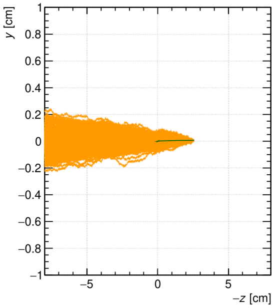

Figure: Diffusion front view

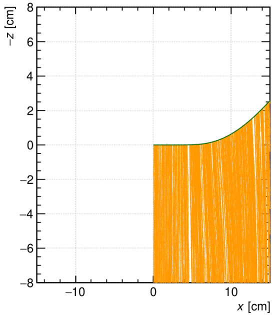

Figure: Electron drift

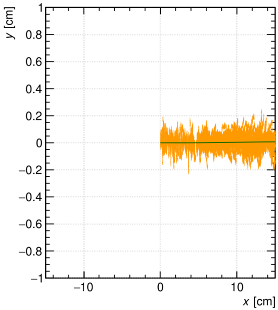

Figure: Diffusion top view

Ionization electrons map simulation

- In the experimental setup TPC only 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)

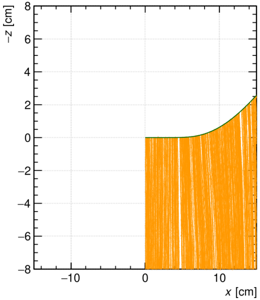

Figure: Electron drift

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 we can 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

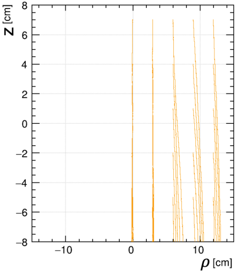

Figure: Partial simulation of the map

Ionization electron map simulation

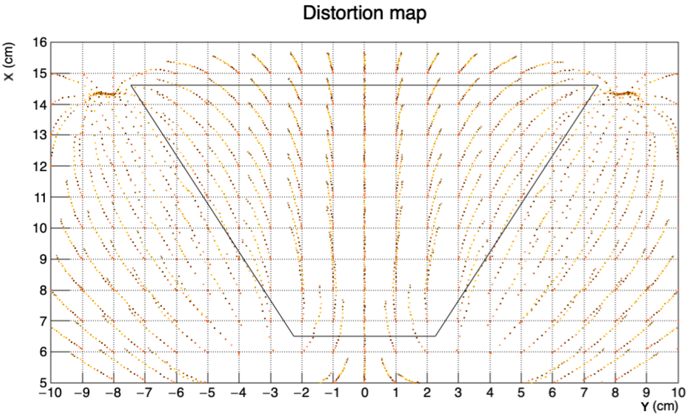

Figure: x and y coordinate distortion at different z values (Credit: Hugo Natal da Luz).

Ionization electron map simulation

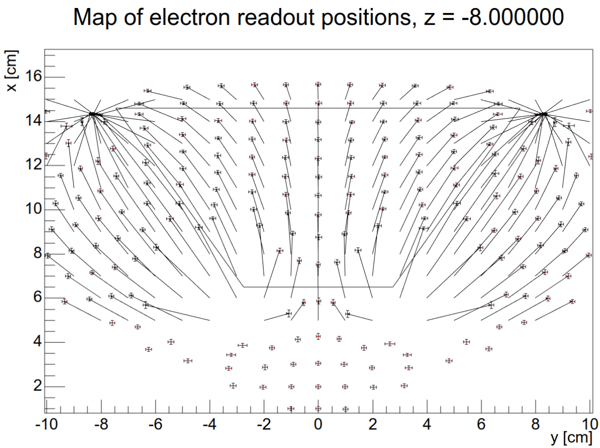

Figure: x and y coordinate distortion for maximal initial distance from readout

Ionization electron map simulation

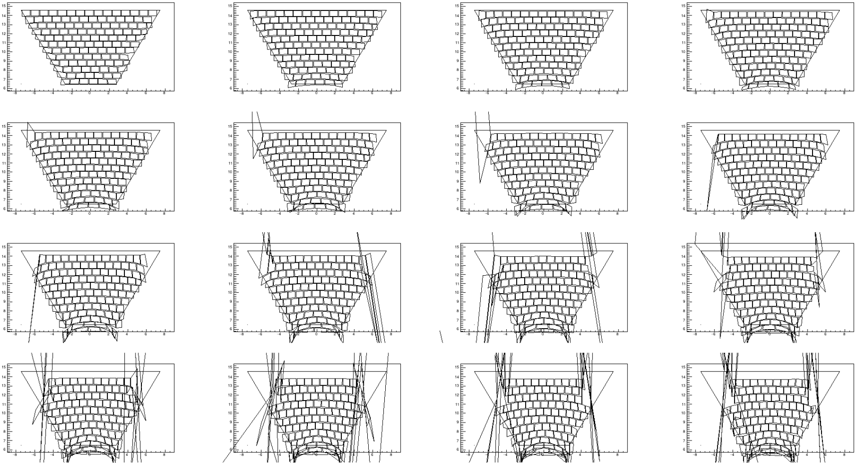

Figure: Pad voxel boundaries for different times (picture of first attempt).

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Track reconstruction

- So far only preliminary attempts using the inverse map have been made (not accounting for readout pads)

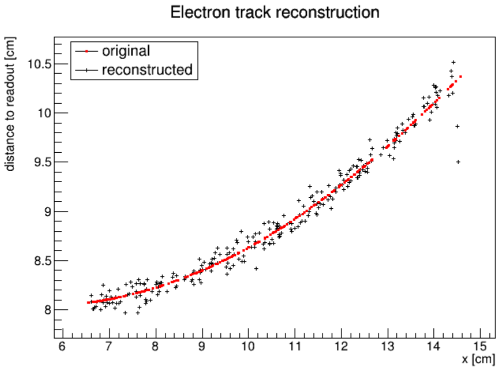

Figure: Original and reconstructed interaction points on the simulated track

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Energy reconstruction

- So far only preliminary attempts
- Best result for track fit with smoothly attached circular arc with straight lines (expected in homogeneous field)
- This or similar approach might be used as initial guess for the actual reconstruction

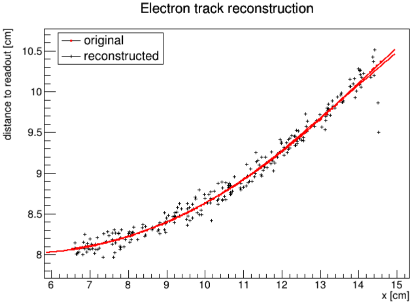

Figure: 8 MeV simulated electron energy reconstruction from both original and reconstructed interaction points. Results are 8.27 and 7.93 MeV.

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Summary

- Several tracks have been simulated for testing purposes
- The map of secondary electron positions and drift times has been generated
- The map has been tested by preliminary track reconstruction
- First attempts for energy reconstruction that might be useful as initial guesses

Future

- Account for GEM in simulation, charge distribution between pads
- Account for pads and discrete time in track reconstruction (irregular voxels)
- Use Runge-Kutta integration for energy reconstruction
  - Reasonable initial guess of track parameters
  - Likelihood optimization (voxels)
- Simulate many tracks with random initial parameters to test the reconstruction

Thank you for your attention.

References I

[1] A.F.V. Cortez, H. Natal da Luz, R. Sykora, B. Ali, L. Fajt.
Measurement of anomalies in angular correlation of electron and positron internally produced in excited 8Be and 4He.

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