Simulation and reconstruction of charged particle trajectories in an orthogonal fields time projection chamber (OFTPC)

Martin Vavřík

martin.vavrik@cvut.cz
IEAP CTU PRAGUE

4th - 8th December, 2023

Outline

Outline

Motivation

- Measurement of anomalies in angular correlation of electron and positron internally produced in excited ^{8}Be and ^{4}He

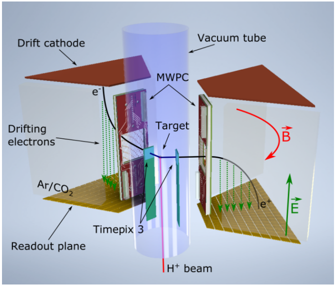


Figure: Two out of the six TPC chambers.[1]

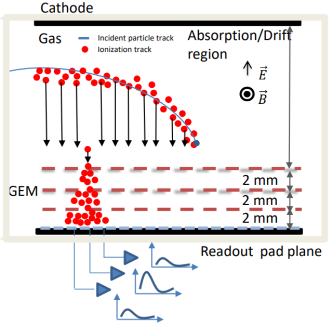


Figure: TPC with triple gas electron multiplier (GEM) readout.[1]

X17 detector

- 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
- Less information about how TPCs work, more information about reasons for OFTPC.

Outline

Track simulation

- We use Garfield++ for track simulation
  - Primary relativistic particle simulated using Heed program [2]
  - Secondary ionization electrons simulated using microscopic tracking (uses equation of motion)
    - Relatively slow (typically 5-30 CPU hours per track), very precise especially for small structures.
- Batches of 9702 tracks with different initial parameters simulated on MetaCentrum
  - Electron or positron
  - 11 different energies (from 3 MeV to 11 MeV)
  - 21 different angles φ and 21 different angles θ (see picture on next slide)

Track simulation

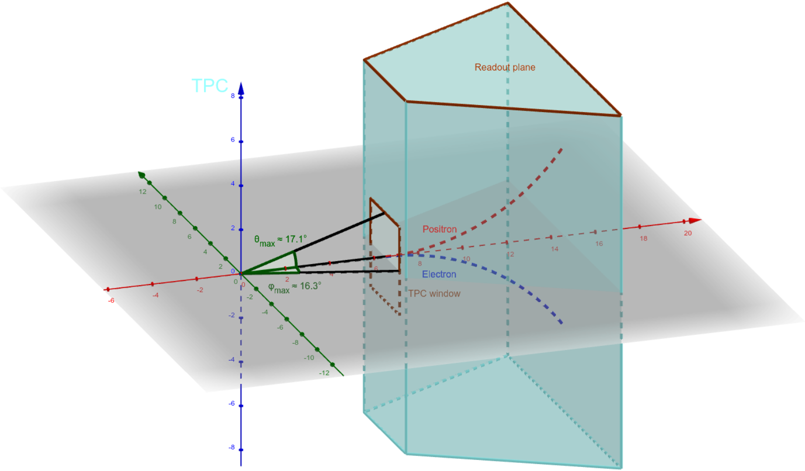


Figure: Diagram of the batch simulation parameters, $\theta \in [-17.1°, 17.1°]$, $[-16.3°, 16.3°]$, $E_k \in [3, 13]$ MeV.

Simulated track example (microscopic tracking)

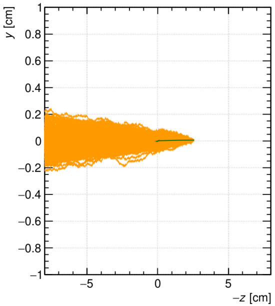


Figure: Diffusion front view

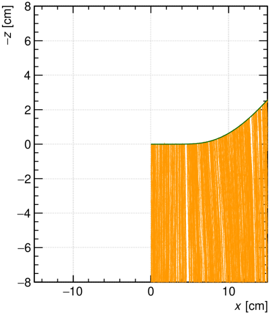


Figure: Electron drift

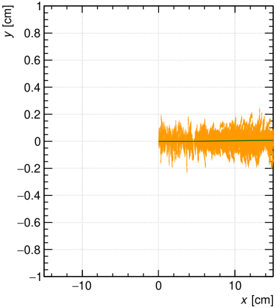


Figure: Diffusion top view

Ionization electrons map simulation

- In the experimental setup TPC only detects secondary ionization electrons (after multiplication on triple GEM)
- These electrons drift at a constant velocity towards the readout plane
- We can use a simulation of evenly spaced electrons for the reconstruction (time consuming – run on MetaCentrum)
    - Current spacing 5 mm, 100 electrons simulated in each location with 0.1 eV energy in a random direction

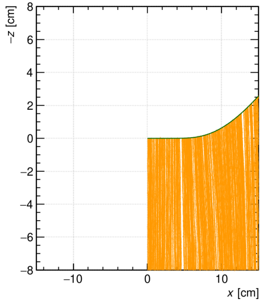


Figure: Electron drift

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

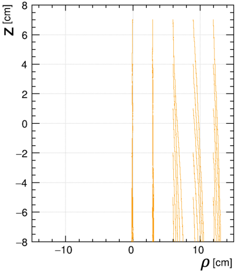


Figure: Partial simulation of the map

Ionization electron map simulation

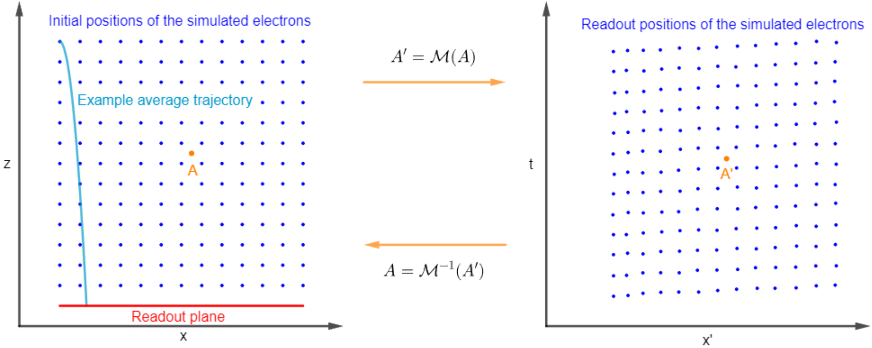


Figure: 2D visualization of the simulated mapping $\mathcal{M}$ and inverse mapping $\mathcal{M}^{-1}$.

Ionization electron map simulation

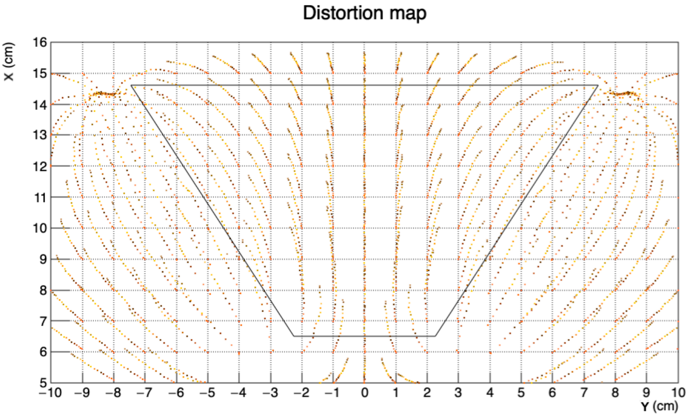


Figure: x and y coordinate distortion at different z values (Credit: Hugo Natal da Luz).

Ionization electron map simulation

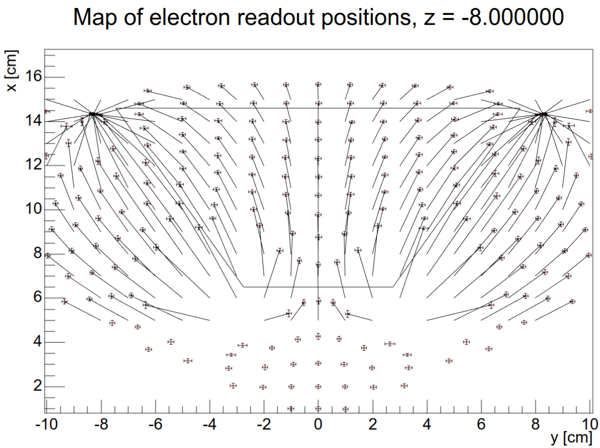


Figure: x and y coordinate distortion for maximal initial distance from readout

Ionization electron map simulation

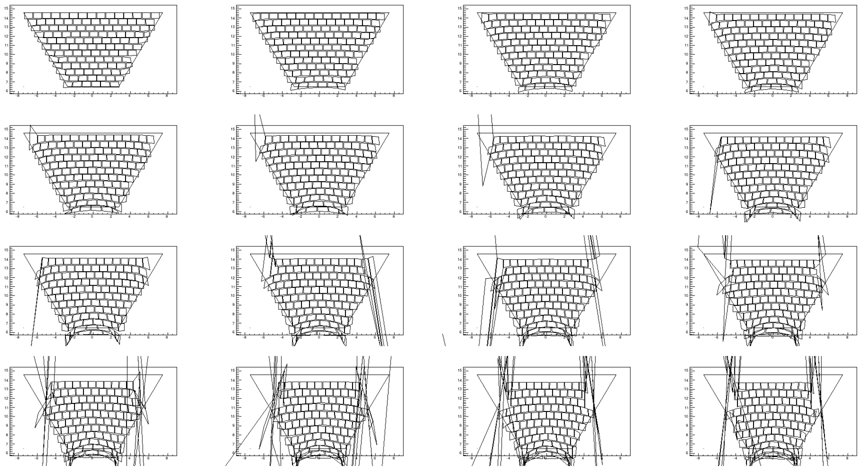


Figure: Pad voxel boundaries for different times (picture of first attempt).

Outline

Track reconstruction

- First attempts using only the inverse map (not accounting for readout pads)
- Simple reconstruction with pads and time bins, counting the number of electrons in each bin

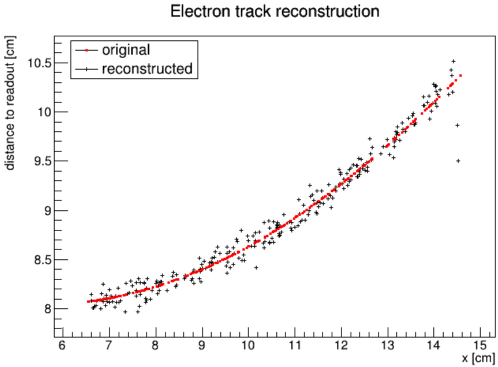


Figure: Original and reconstructed interaction points on the simulated track

Outline

Energy reconstruction

- Prefit with circle with smoothly attached lines
- One parameter (kinetic energy) fit with 4th order Runge-Kutta fit
- In both steps known initial position and direction of the particle assumed
- Currently cca 0.3 CPU seconds per track

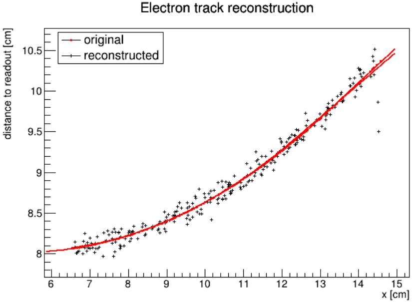
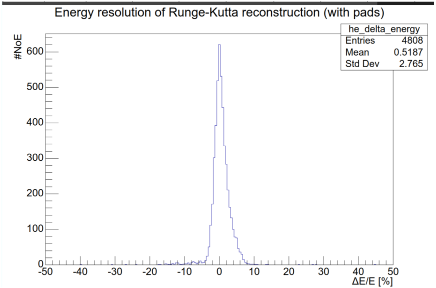


Figure: 8 MeV simulated electron energy reconstruction from both original and reconstructed interaction points. Results are 8.27 and 7.93 MeV.

Energy reconstruction precision

Electrons



Positrons

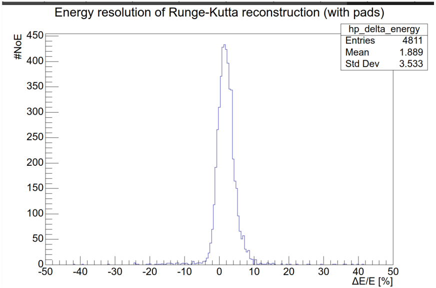


Figure: Relative reconstruction deviation of the kinetic energy of electron and positron tracks. These histograms represent the best possible resolution for our detector.

Outline

Summary

- Several batches of 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
- Testing of the energy reconstruction has begun, first attempts of determining the resolution of our detector were made

Future

- Account for parasitic tracks caused by high energy secondary electrons
- Account for GEM in simulation, charge distribution between pads
- Optimize Runge-Kutta integration fit with likelihood approach (instead of least squares) if needed
- Write a faster simulation method for secondary electrons using the map
- Fix the systematic error of reconstruction discovered using the simulated tracks

Notes (what else to mention)

- Magnetic field simulation.
- Better simulated track example pictures?
- Extra slide with the whole process summary?
- Better description than pad voxels.
- Better description of interpolation?
- Residues on first attempts of track reconstruction?
- Change energy reconstruction figure!
- More energy reconstruction resolution figures.
- ATOMKI slide

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.