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

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Outline

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Motivation: ATOMKI measurements

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

OFTPC: Detector Configuration

- Time Projection Chamber with Orthogonal Fields – electric and magnetic field perpendicular

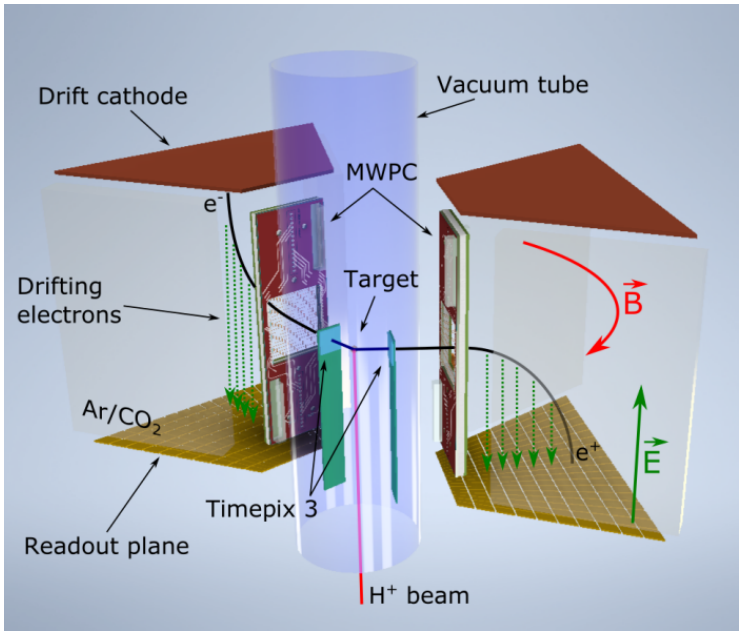


Figure: Two out of the six TPC chambers. [1]

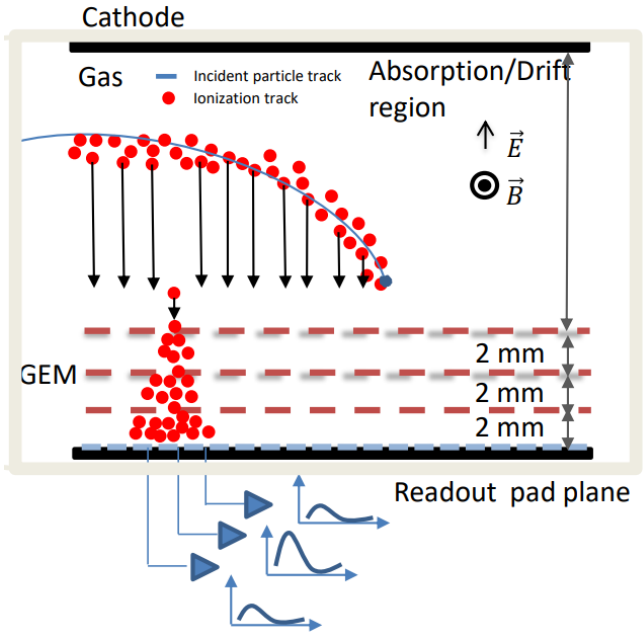


Figure: TPC with a triple gas electron multiplier (GEM) readout. [1]

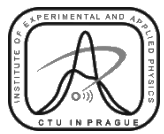
OFTPC: Reasons and Complications

- No solenoid – permanent magnets used to generate the field
- Space constraints – granularity of the TPC readout limited in order to fit one SAMPA/SRS hybrid in each of the six sectors
  - Parallel fields would bend particles parallel to readout, requiring much larger number of pads
  - These trajectories would extend to more than one sector, requiring alternative architecture of the detector
- Inhomogeneous magnetic field (simulated using Maxwell Add citation!)
- This interferes with the direction of the drift of secondary electrons
- Curvature of the track is not constant in this field (deviation from circle)

Outline

Track simulation

- Garfield++ used for track simulation
  - Primary relativistic particle simulated using the HEED program [2]
  - Secondary ionization electrons simulated using microscopic tracking (uses equations 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 a grid (MetaCentrum [3])
  - Electrons and positrons
  - 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

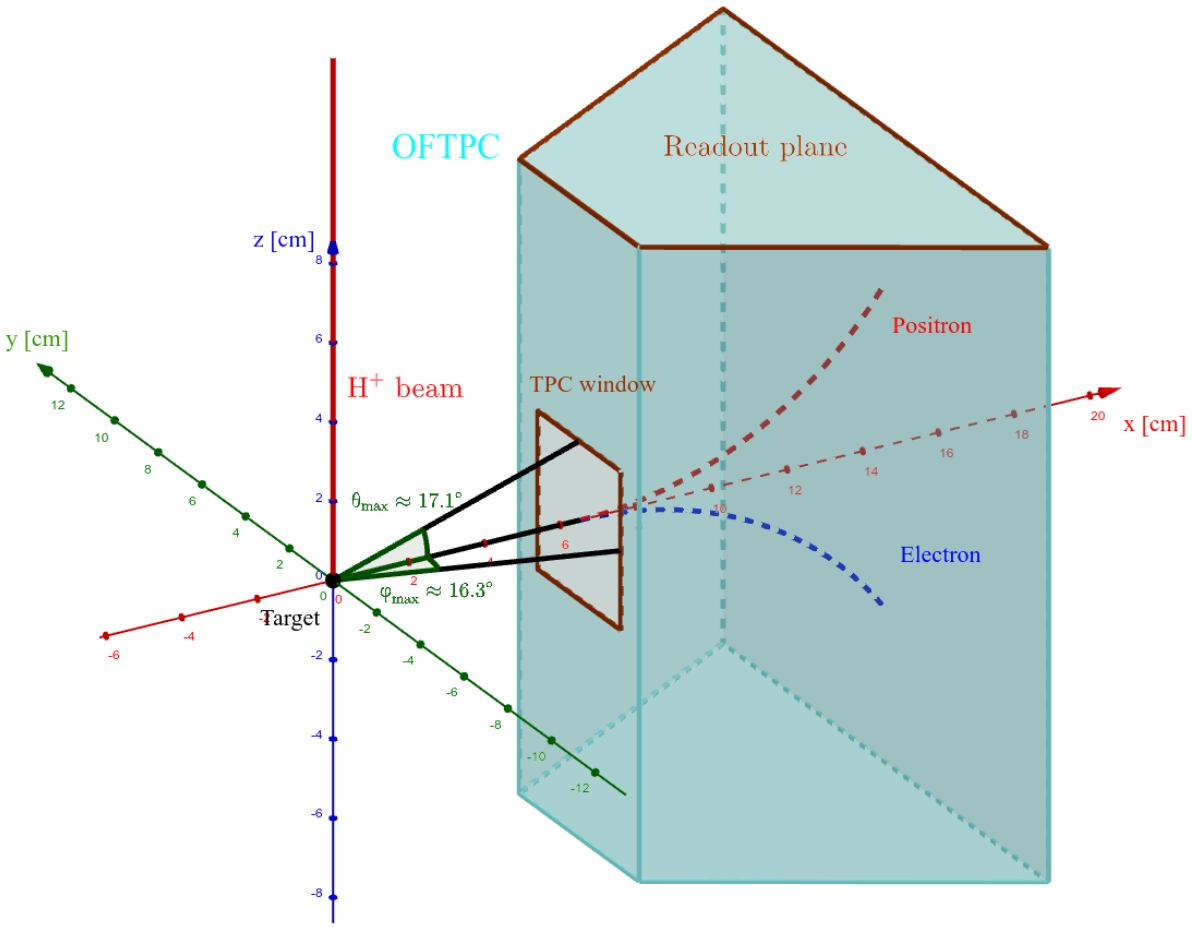


Figure: Diagram of the batch simulation parameters, θ and ϕ are spherical coordinates with respect to z: $\theta \in [-17.1°, 17.1°]$, $\varphi \in [-16.3°, 16.3°]$, $E_k \in [3, 13]$ MeV.

Simulated track example (microscopic tracking)

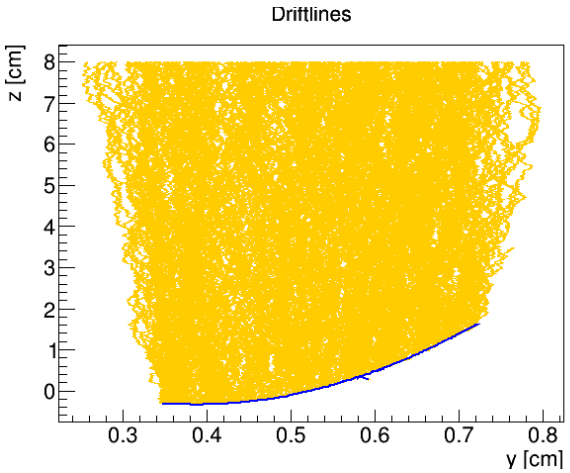


Figure: Diffusion front view

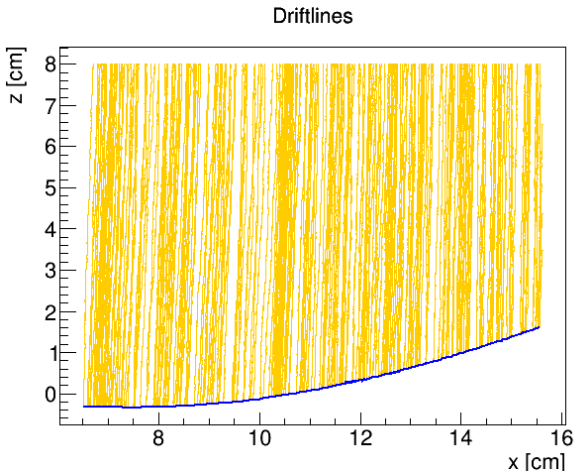


Figure: Electron drift

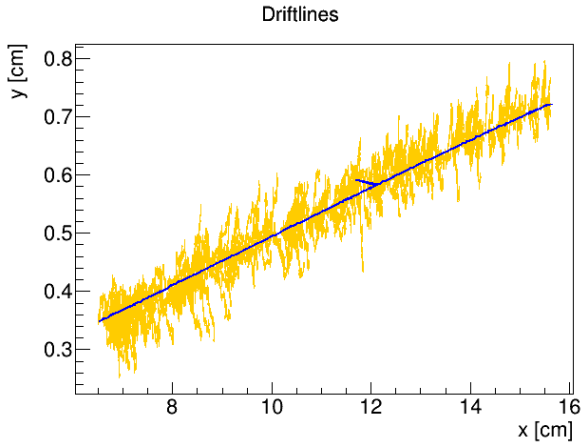


Figure: Diffusion top view

Ionization electrons map simulation

- In the experimental setup the OFTPC 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
  - Current spacing 5 mm, 100 electrons simulated in each location with 0.1 eV energy in a random direction

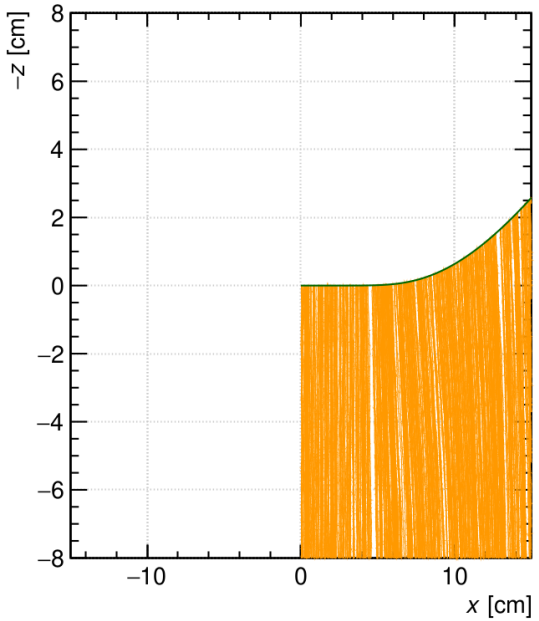


Figure: Electron drift

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

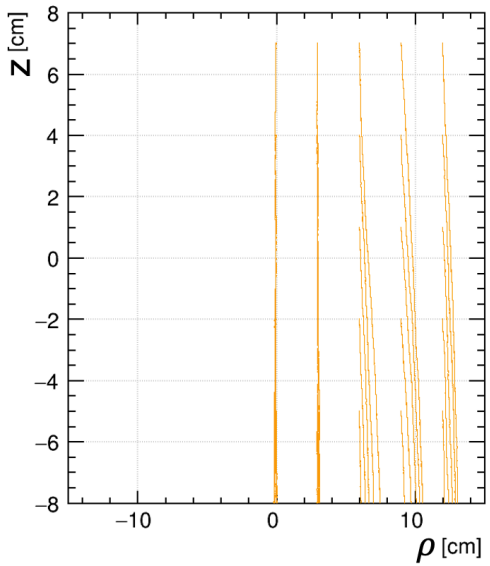


Figure: Partial simulation of the map

Ionization electron map simulation

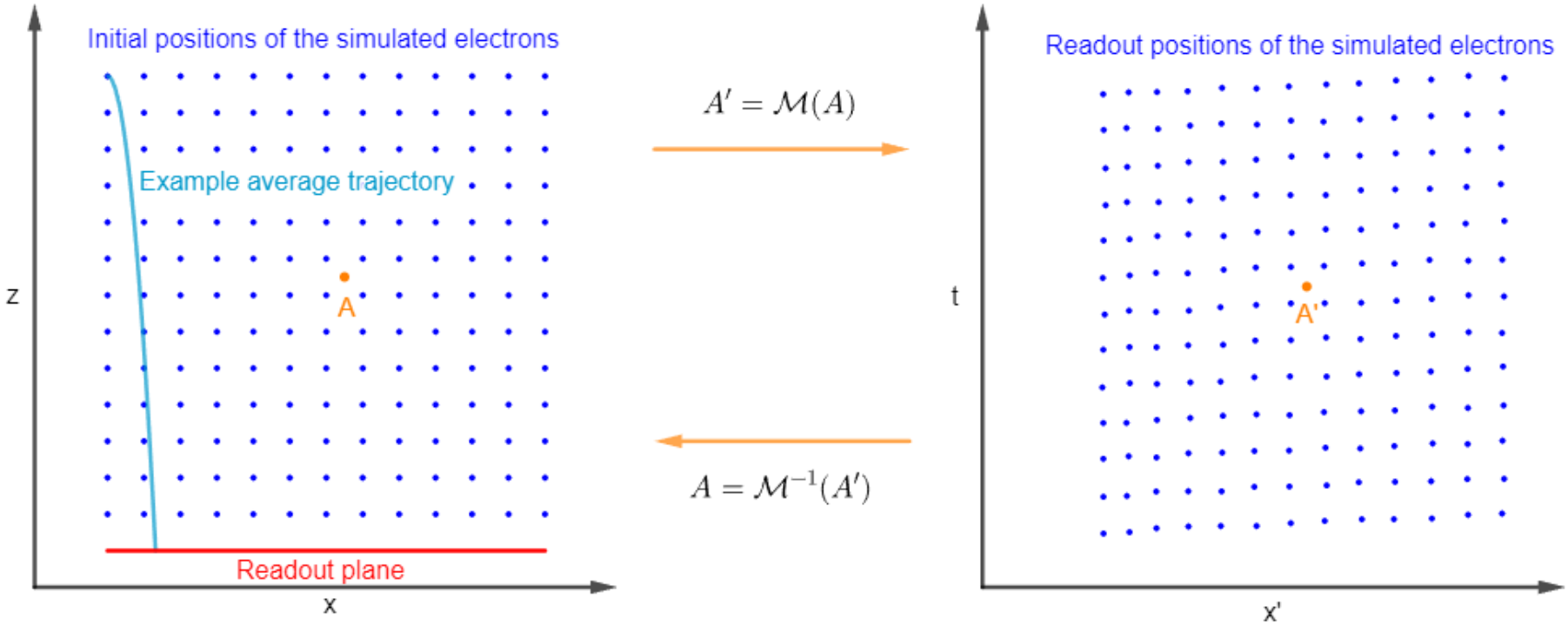


Figure: 2D visualization of the simulated mapping $\mathcal{M}$ and inverse mapping $\mathcal{M}^{-1}$.

Ionization electron map simulation

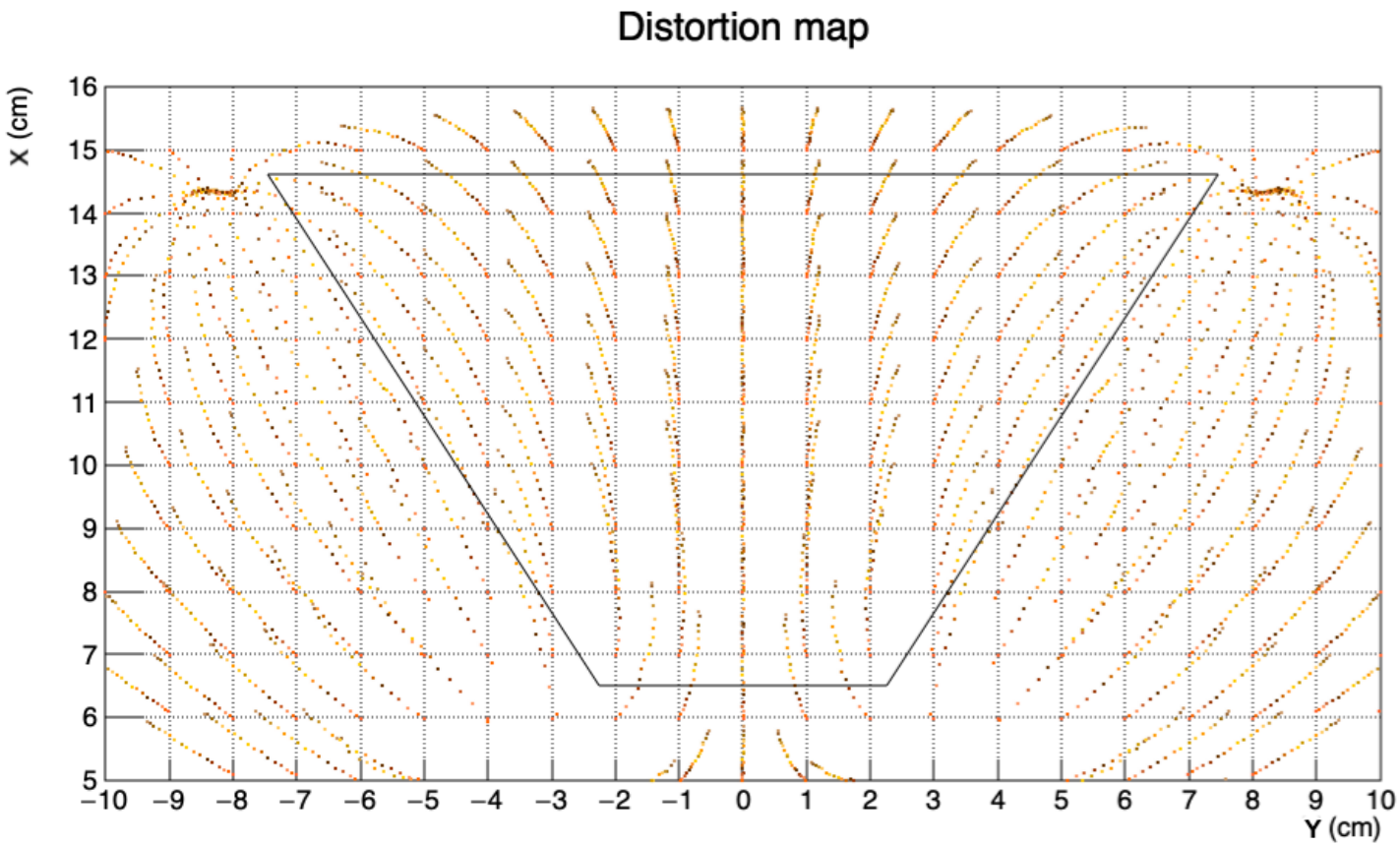


Figure: x and y coordinate distortion at different z values (Credit: Hugo Natal da Luz).

Ionization electron map simulation

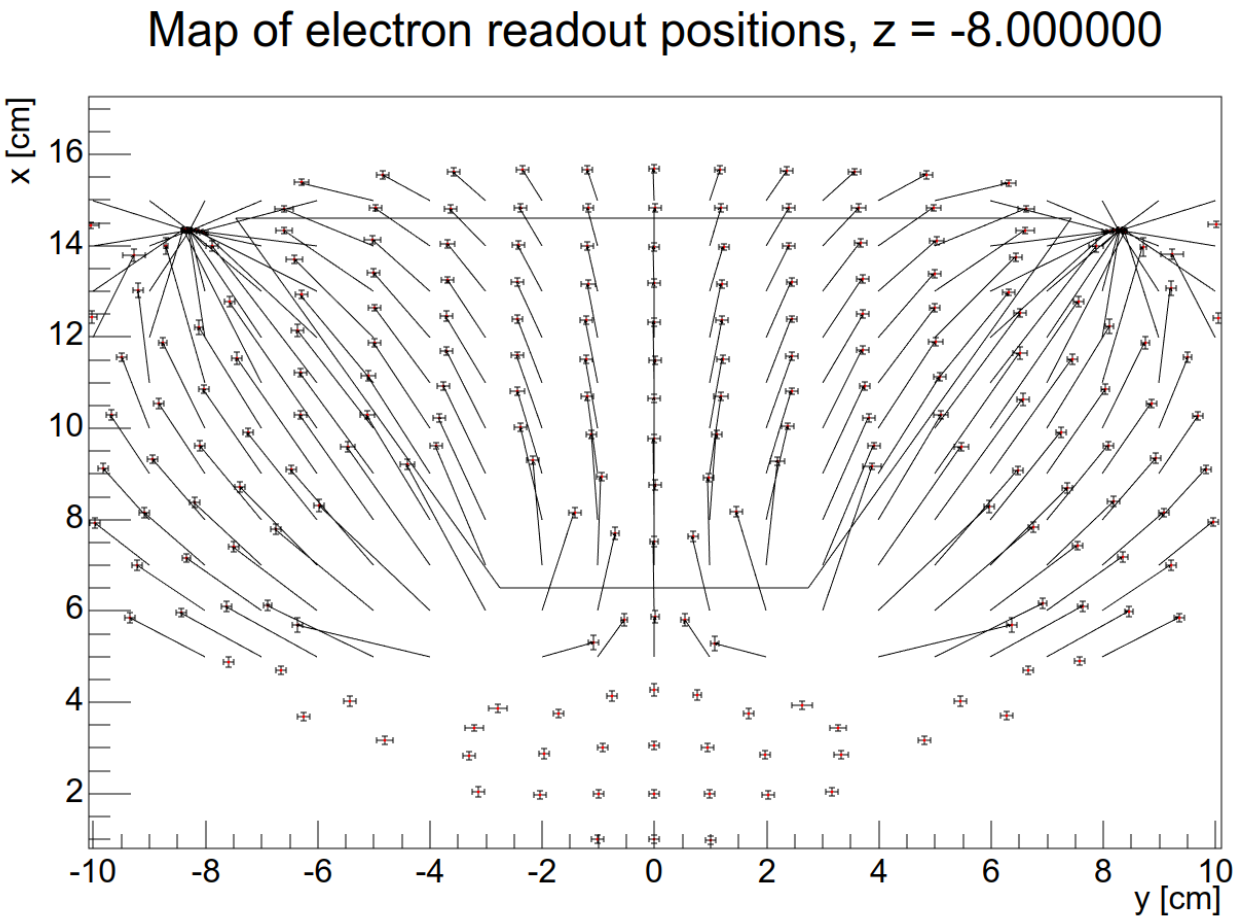


Figure: x and y coordinate distortion for maximal initial distance from readout

Ionization electron map simulation

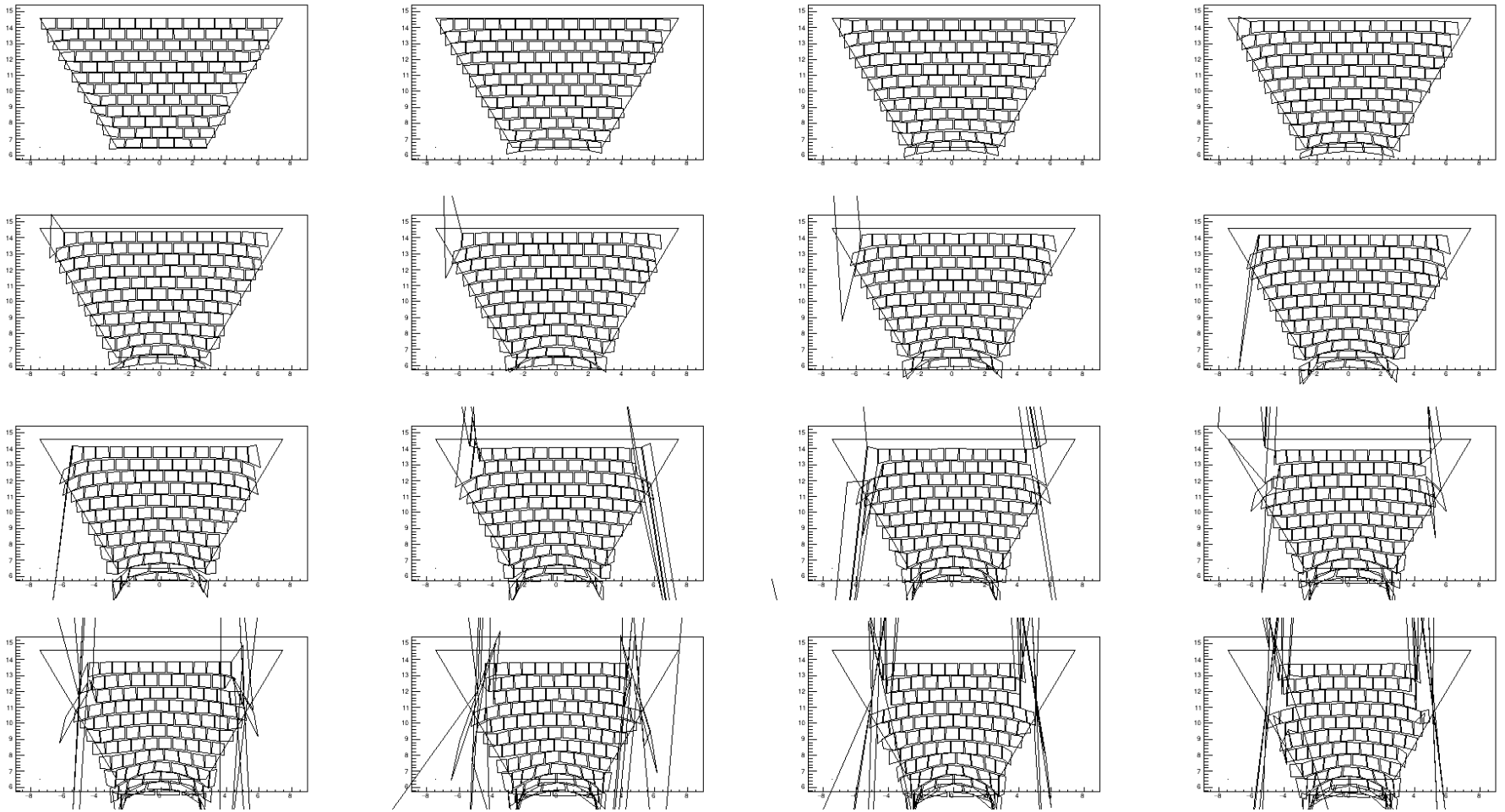


Figure: Pad voxel boundaries for different times (picture of first attempt).

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

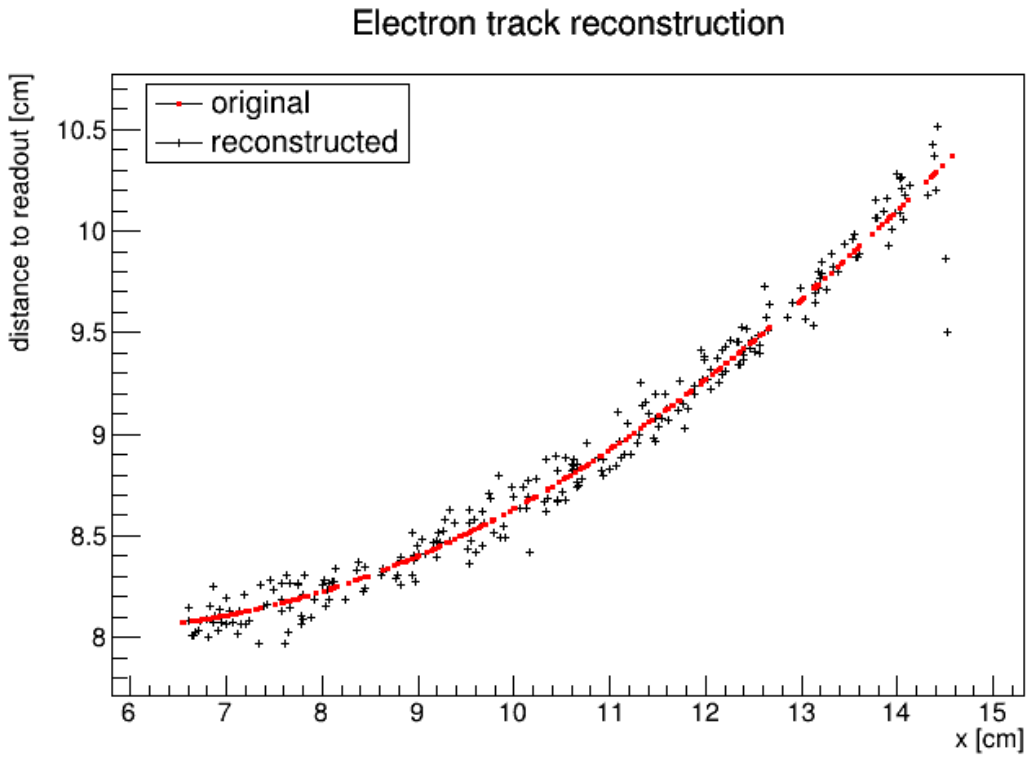


Figure: Original and reconstructed interaction points on the simulated track

Outline

Energy reconstruction

- Prefit with circle with smoothly attached lines
- Kinetic energy fit with 4^{th} order Runge-Kutta fit
- Known initial position and direction of the particle assumed
- Currently cca 0.3 CPU seconds per track

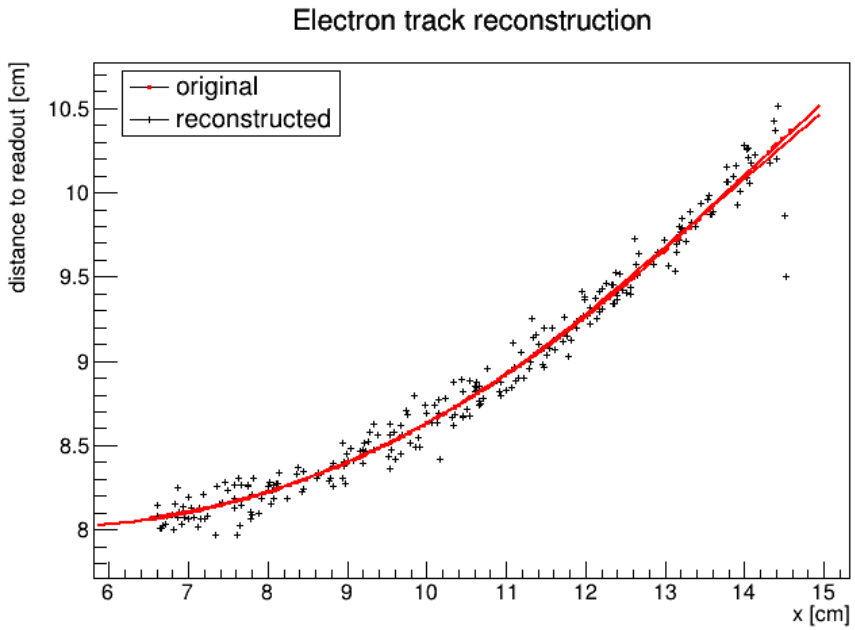
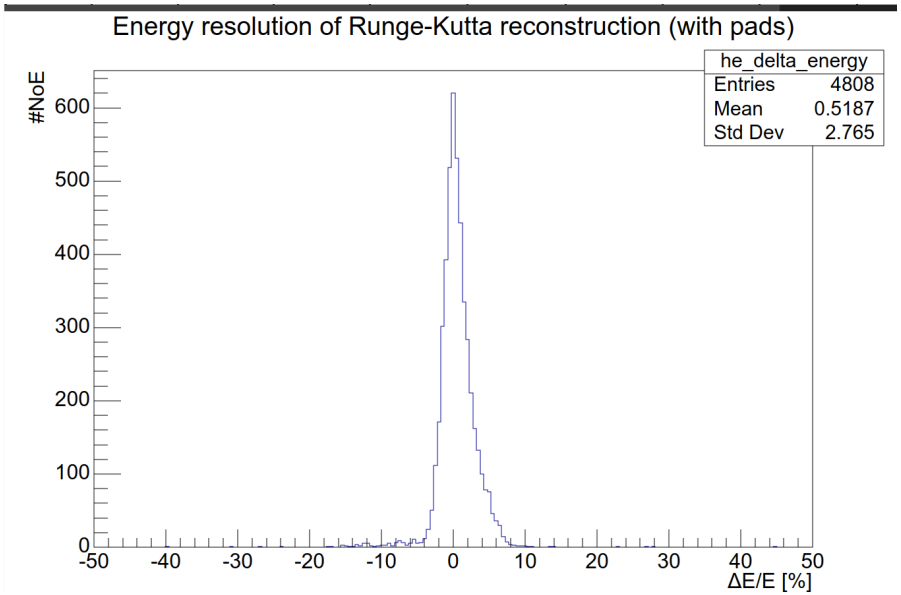


Figure: 8 MeV simulated electron energy reconstruction from both original and reconstructed interaction points. Results are 8.27 and 7.93 MeV.

Energy reconstruction precision

Electrons



Positrons

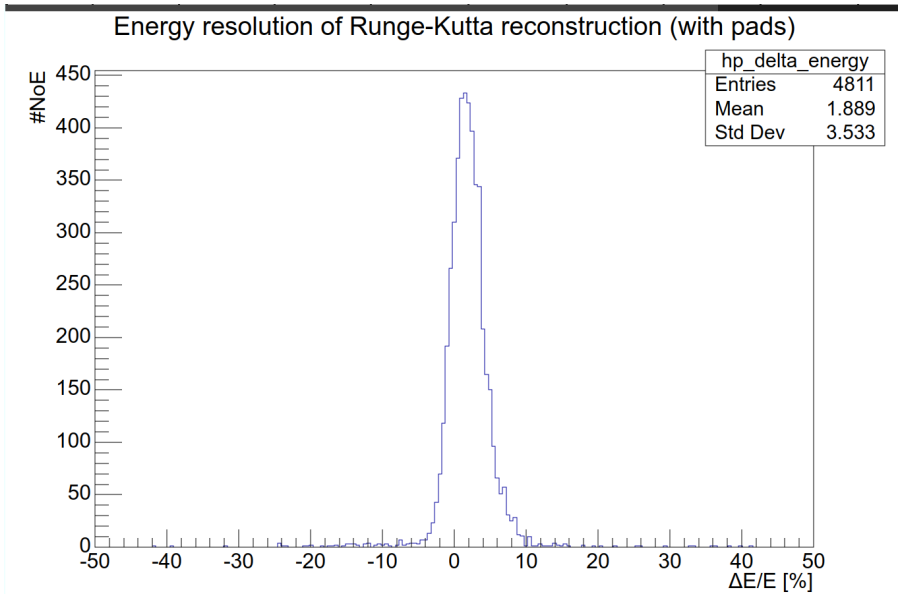


Figure: Relative reconstruction deviation of the kinetic energy of electron and positron tracks. These histograms represent the best possible resolution for our detector.

Outline

Summary

- Several batches of tracks have been simulated for testing purposes.
  - $\theta \in [-17.1°, 17.1°]$, $\varphi \in [-16.3°, 16.3°]$, $E_k \in [3, 13]$ MeV
- The map of secondary electron positions and drift times has been generated.
- The map has been tested by preliminary track reconstruction.
- First results suggest that:
  - Best possible resolution $\frac{E_{rec}-E}{E} \approx 3.5\%$, positrons have worse resolution.
  - OFTPC works well on a simulation level.

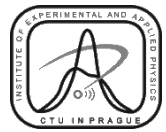
Future Steps

- 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 observed systematic error of reconstruction

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.

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.

[3] MetaCentrum.
Computational resources were provided by the e-INFRA CZ project (ID:90254), supported by the Ministry of Education, Youth and Sports of the Czech Republic.
https://metavo.metacentrum.cz/en.