Garfield++ simulations: HPTPC v1

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Garfield++ simulation of the HPTPC and an ALICE ROC

- These is a compilation of slides shown in the last two RHUL group meetings. Showing how I simulate gas gain and waveforms for a HPTPC like geometry and energy deposits in an HPTPC like detector volume
- Recently I started to look into garfield++ simulations of signals once more
- All the code for the following plots can be found here: `https://gitlab.cern.ch/adeistin/garfield-dune-hpgtpc-code/-/blob/master/README.md` – in case someone wants to play. The *readme* should be enough to get started. Contains:
  - Mock up RHUL HPTPC with three anodes
  - ALICE ROC
  - Pull and play with *cmake* on my Mac – not jet tested on other platforms (needs Garfield++)

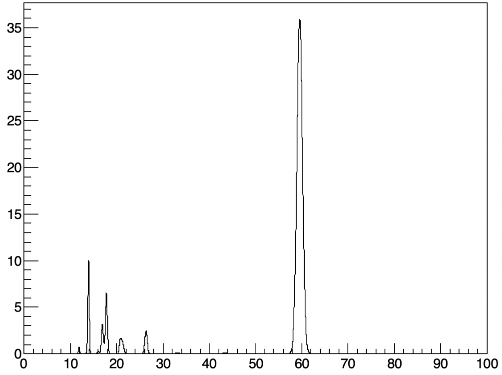
Strategy – gas gain and signals

1. Simulate x-ray absorptions in the gas volume, *i.e* how likely are they absorbed and in case they are absorbed: How many ionisation electrons do they free. Currently ^{241}Am and ^{55}Fe x-rays are implemented.
2. Simulate the gas gain. This is done independently of step 1. – the goal is to get enough statistics to parametrise the gas gain by a Polya and take it from there
3. Signal generation: Based on the gas gain data, signals are calculated. These are then convolved with a preamp response function.
   Matching signals to the primary electrons contained in said signals will hopefully allow to establish an additional function to apply to the gas gain's polya

- Use the information from steps 1. to 3. to build up a realistic spectrum

Step 1. and 2. are currently under control, the main difficulty is to get decent statistics. Step 3. is still running. Furthermore I did not jet test pure-Ar. (The higher the gain, the longer the run-time – for first tests a pure noble gas seemed to be unwise.)

Step 1: x-ray absorption for ^{241}Am



- ^{241}Am has plenty of x-rays and 2 γ-rays – most of them with a low yield per decay
- I build up a function taking into account all these values, then the energy of a photon is drawn from this function and given to *heed*. *Heed* which knows about our detector geometry, the gas, and so on.
- As long as there not yet 10000 converted x-rays in the gas, I continue to draw energies form the function and evaluate these with *heed*

- 7.12 % of the x-rays/γ-rays convert. The contribution of the γ-rays is negligible

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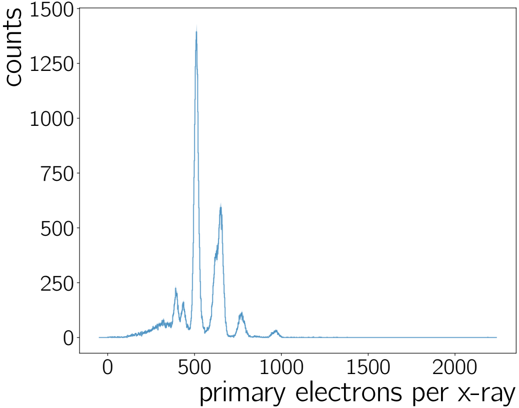

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Interlude: Energy deposit simulations

- Simulating the spectra of energy deposited in the detector to compare to the measured spectra
- Goal: Confirm the (– or help to build a new –) hypothesis on which peak is which

Last years status

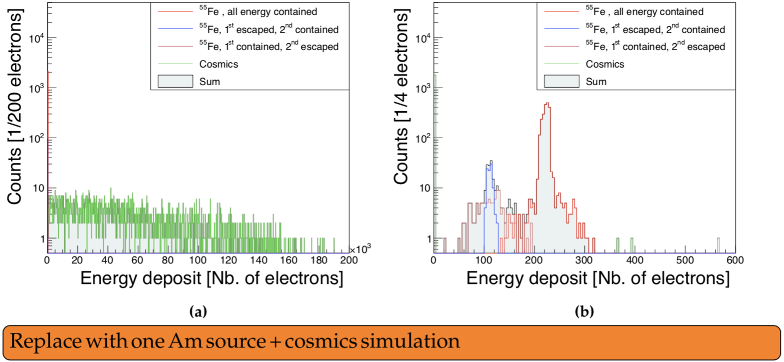


Figure 12. Expected energy deposits of ^{55}Fe decay radiation and cosmic muons inside a gas volume filled with Ar-CO_2 (98-2). This is the result of a toy Monte-Carlo using the approximate layout of the HPTPC, the HEED [22] package in GARFIELD++ [23], and the information in [20,21,24,25]. (b) shows a zoomed in view of (a).

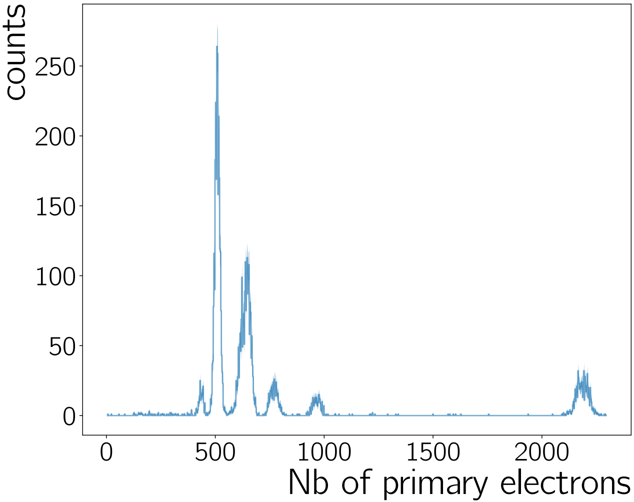
Last years status...

- The plot on the previous slide shows ^{55}Fe and cosmic μons, requiring the μs to cross the amplification region
- The volume was a $75\,\text{cm} \times 75\,\text{cm} \times 43\,\text{cm}$ cube – about $\frac{1}{4}$ of the amplification region.

... and what I did now:

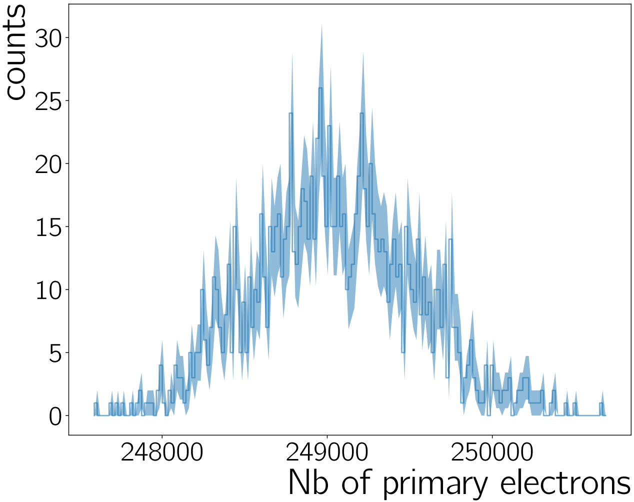
- Run again for ^{241}Am and cosmic μs, using heed and the parametrisations for ^{241}Am shown last week.
- heed can not deal very well with particles which have a momentum much lower than their rest mass. Therefore:
  - After sampling the μ energy from a cosmic μ energy distribution I reject all with $\varepsilon_{\text{kin}} < 5 \cdot m_\mu / 10^5$. The number of rejected μs is negligible.
  - In case of the α particles, the lowest momentum feasible is about 15.7 MeV. This is a factor three to four too large, however: Given the start point of the tracks and the gas volume geometry the energy deposited in the gas is 4.07 MeV (standard deviation of 8.2 keV). This is actually not so bad for the energy deposit calculation of an ^{241}Am α particle.
- The amplification region's electric fields are not taken into account for this simulation

X-rays



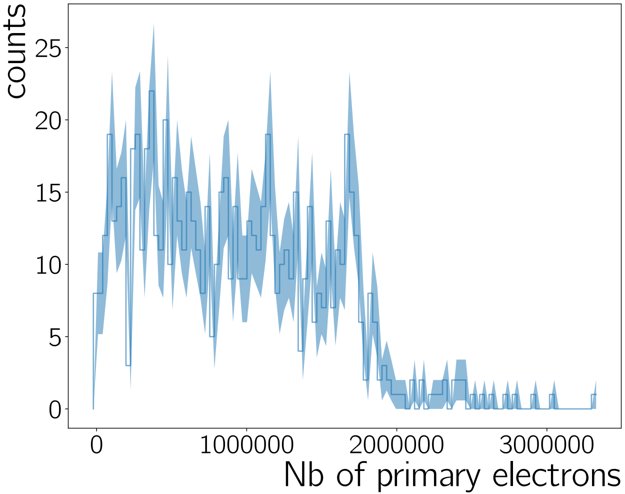
- Contains 6000 converted x- and γ-rays, which is less than 8 % of the total number of simulated photons
- Given the size of the TPC, we even see some 60 keV γs
- All x-rays are emitted from the source position in direction of the amplification region. No cuts on the x-ray location have been made. *i.e.* whether it converted before or after the amplification region

α-particles



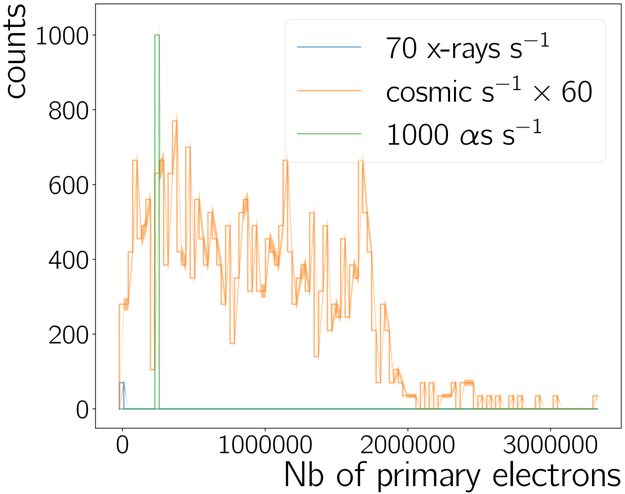
- Contains 1200 α particles, all of which leave energy in the detector.
- For a proper relative scaling of α particles to photons we would need a measurement of the source. The input we have currently is that Zach & Harrison mentioned that they were still measuring kBq a few cm from the source.)

Cosmic μons



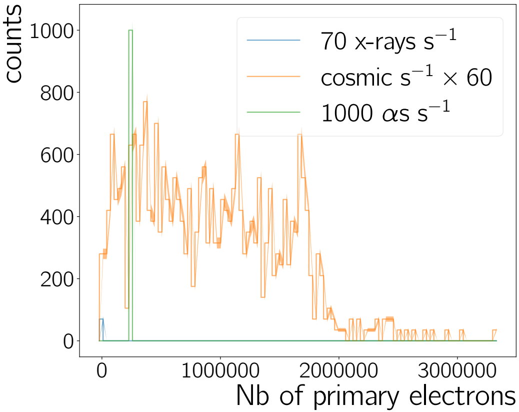
- Contains 1877 cosmics, about 750 with a energy deposit in the detector different from zero
- This is about 35 s of cosmic radiation, assuming 1 /cm^2/minute
- ☐ I still have to check why only a third leaves energy in the detector

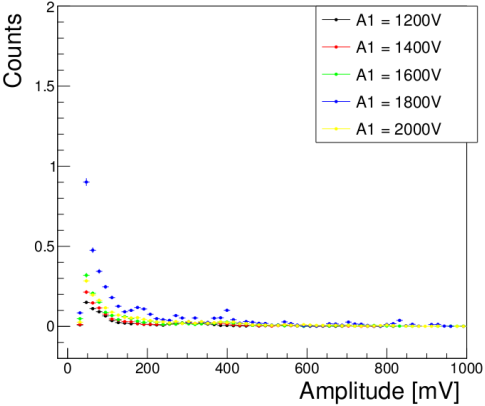
Cosmic μons



- What parts of the spectrum are visible depends on the set time in the simulation and the source rate
- In contrast to the simulation showed in the beginning, we have now the position of the alpha once more
- There are similarities with Harrison's spectra but there is still tension between this spectrum and background data / the data spectra and background data

Cosmic μons





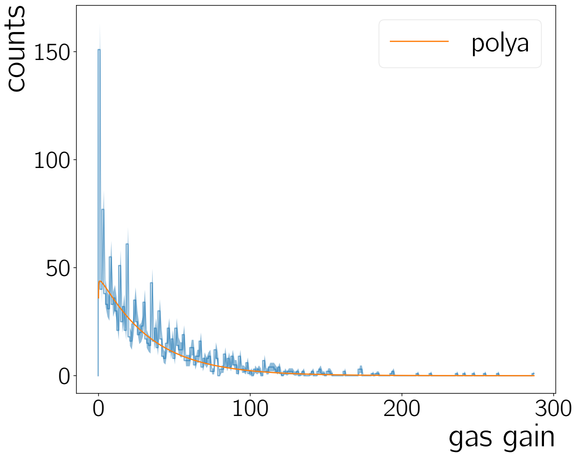
Back to the gas gain and signal simulation

- We covered step 1 already – energy deposits in the gas – and now we are having a look into simulating the gas gain and signals

Details on the simulation set-up

- For these waveform simulations three anode grids are used ($y_{\text{anode3}} = 1.0\,\text{cm}$, $y_{\text{anode2}} = 1.1\,\text{cm}$, $y_{\text{anode1}} = 1.15\,\text{cm}$, $\varnothing_{\text{anode3}} = 24\,\mu\text{m}$, $\varnothing_{\text{anode2}} = 24\,\mu\text{m}$, $\varnothing_{\text{anode1}} = 40\,\mu\text{m}$, $d_{\text{anode3}} = 101.6\,\mu\text{m}$, $d_{\text{anode2}} = 254\,\mu\text{m}$, $d_{\text{anode1}} = 254\,\mu\text{m}$, $V_{\text{anode1}} = 700\,\text{V}$, $V_{\text{anode2}} = 1500\,\text{V}$, $V_{\text{anode3}} = 3000\,\text{V}$, $V_{\text{cathode}} = -16\,000\,\text{V}$)
- The gas is Ar-CO_2 (90-10) at 750 Torr. I use the default CO^+ in CO_2 ion mobilities.
- 50 clusters of 100 primary electrons are simulated. Their initial coordinates are $x_i = 0.0$ $y_i = 1.485\,\text{cm}$ and then spread out using Gaußians with $\sigma_x \sim 0.5\,\text{cm}$ and $\sigma_y \sim 0.05\,\text{cm}$
- Reminder: `https://gitlab.cern.ch/adeistin/garfield-dune-hpgtpc-code/` – turns out that even runs on linappserv

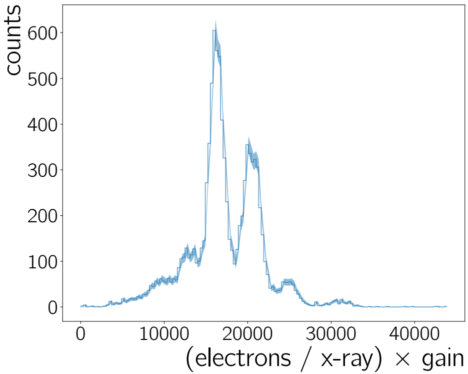
Step 2: The gas gain



- The gain displayed here is for Ar-CO_2 (90-10) at 750 Torr, room temperature and for the voltages stated on the previous slide
- For the polya fit the gas gain ≤ 1 bins have been excluded
- The fit describes the data well, *e.g.*: Here we get a χ^2 of 303 with N_{dof} of 295 A gain of 33.6 ± 0.9 with a σ of 32 ± 1 (and a normalisation factor of 2007 ± 51

Combining only step 1 and step 2:

Currently only gas gain and photon conversion information is combined. Also the polya fit is not used, but the previously shown gas gain distribution. Thus this is still very preliminary. In order to combine the gas gain and the photon data we



a) Pull randomly 10000 primary electron counts from the *primary electrons per x-ray* distribution

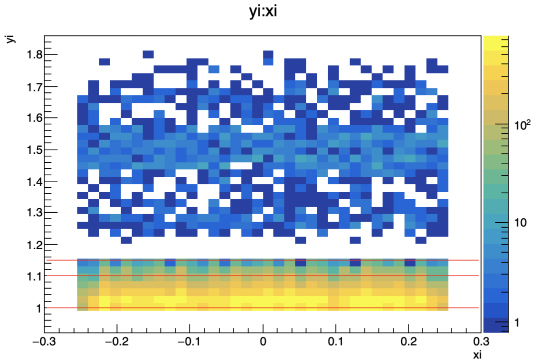
b) Lets say the primary count is N_{e-i}. Then we pull N_{e-i} gain values G_j from the gas gain distribution, and add them:

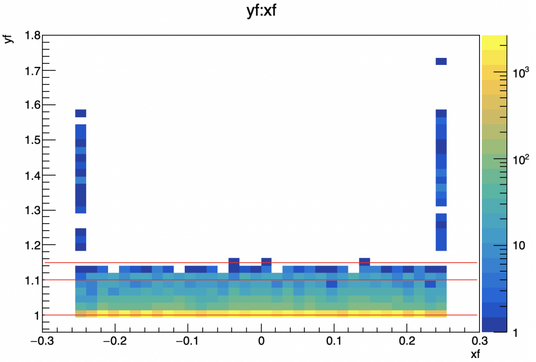
$$\text{Signal electrons} = \sum_{j=0}^{N_{e-i}} G_j$$

Plot left: resulting number of *signal electrons*

Comments on waveform simulations

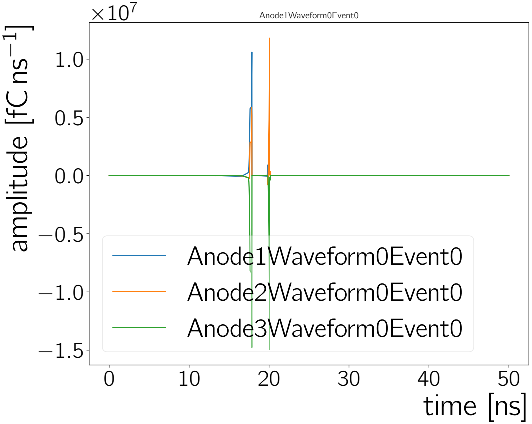
Initial (left) and final (right) electron positions

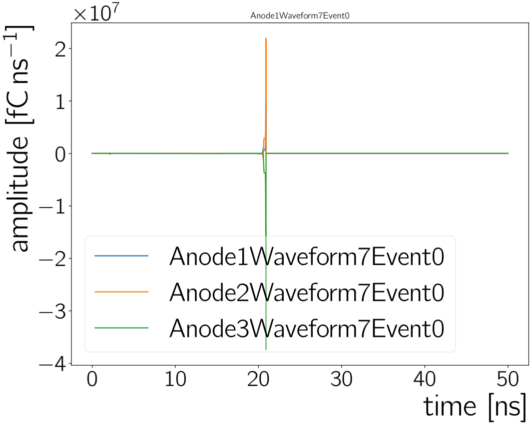




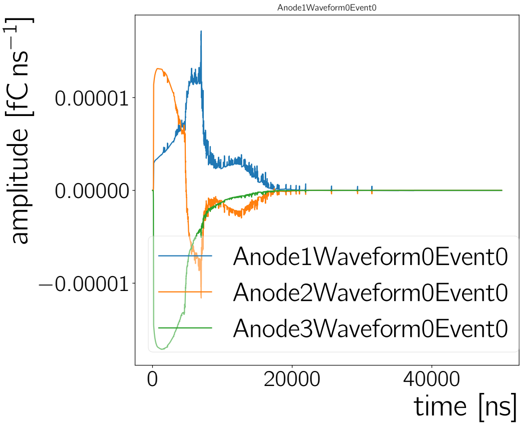
- ▶ The fact that it shows this hard transition on the edges, shows that I have chosen the sensor size too small
- ☑ I will need to re-run this once more for a larger sensor size to avoid edge effects

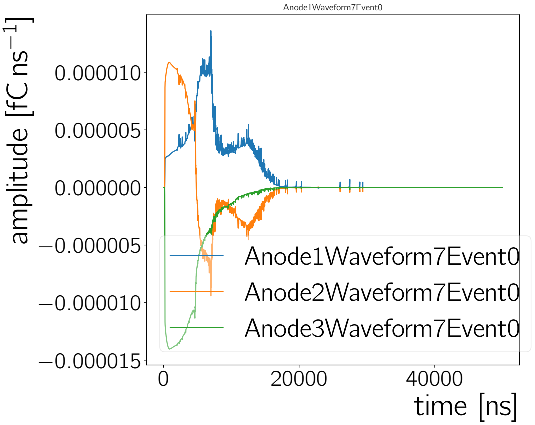
Electron signal



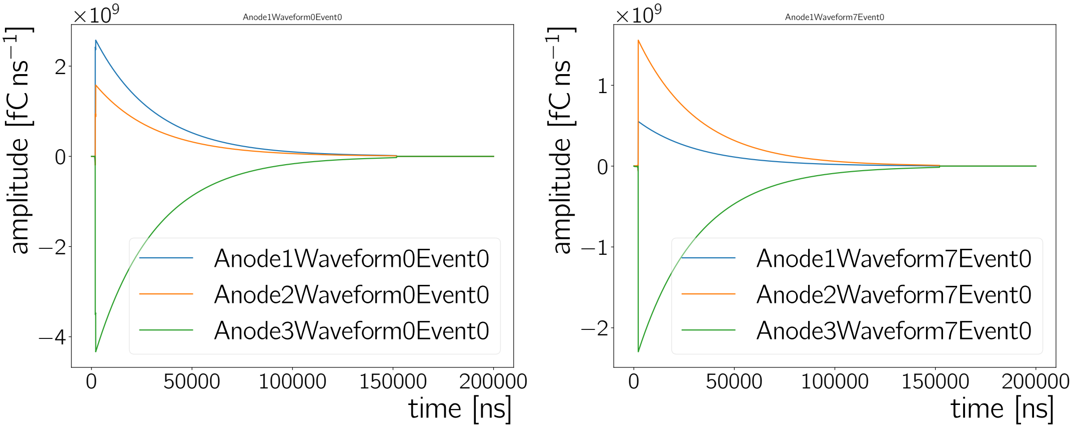


Ion signal


Anode1Waveform0Event0
amplitude [fC ns^{-1}]
0.00001
0.00000
−0.00001
0
20000
40000
time [ns]
Anode1Waveform0Event0
Anode2Waveform0Event0
Anode3Waveform0Event0


Anode1Waveform7Event0
amplitude [fC ns^{-1}]
0.000010
0.000005
0.000000
−0.000005
−0.000010
−0.000015
0
20000
40000
time [ns]
Anode1Waveform7Event0
Anode2Waveform7Event0
Anode3Waveform7Event0

Sum of the electron and ion signal, convoluted



- Vertical units are not correct
- Convolved with $13 * \exp\{-1 \cdot (1/30000 \cdot (t - 100) + \exp\{-3 \cdot (t - 100)\}\}$

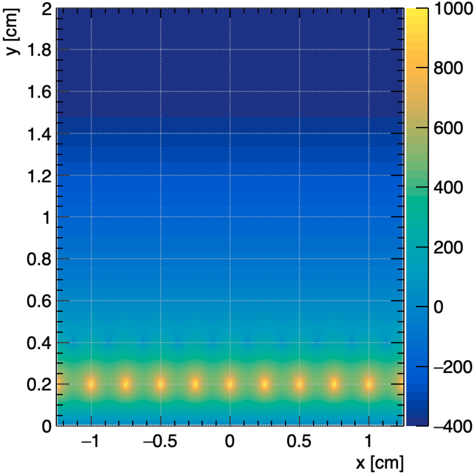
Waveform simulation summary

- As mentioned: The sensor used for the signal evaluation was too small
- The spread in signal amplitude values is quite substantial and spans several orders of magnitude
- Concerning the signal polarities: 39 of 50 signals have positive polarity on anode 1 and anode 2, negative on anode 3. So far I did not see any with a positive anode 3 signal.
- This can be qualitatively understood with having primary ionisations before the amplification region and the avalanches evolving through both inter anode gaps
- Since we do not see many events with these polarities: Where does the discrepancy come from?
- When I find some time to re-run this again, I'll give an update

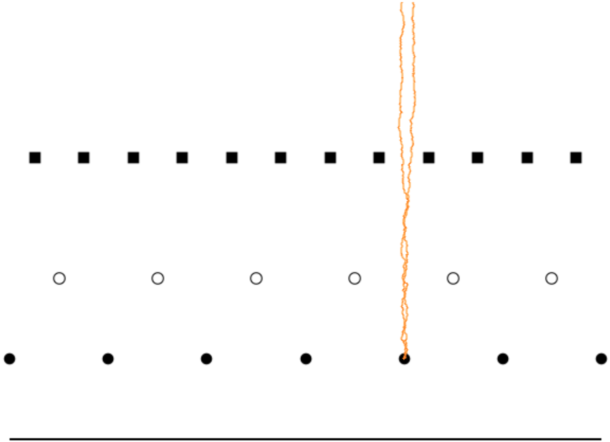
Backup

Example images and maps from the ALICE ROC simulations

Electric field map – ALICE ROC example



Electron drift – ALICE ROC example



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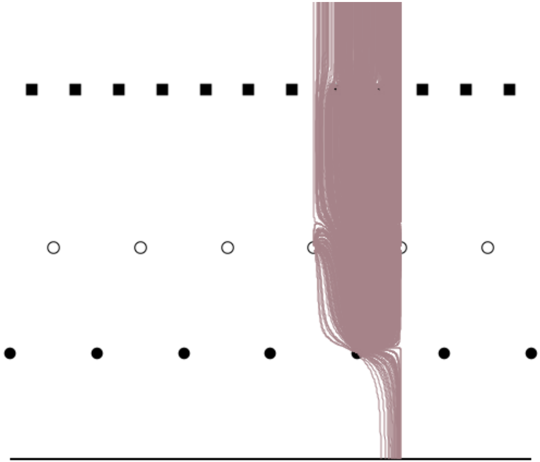
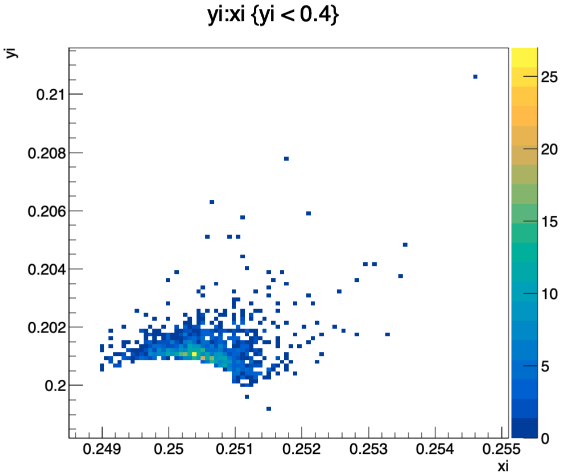


Electron initial positions close to a wire – ALICE ROC example



Electron final positions – ALICE ROC example