Straw signal parametrisation based on Garfield++ simulation studies

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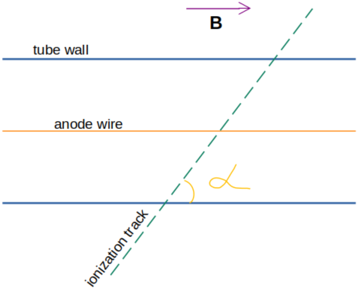
Motivation

1. Current SPD ROOT tracker simulation uses simplified straw responce without accounting for magnetic field, track-to-wire distance and track angle;
2. Our goal is to develop realistic parametrisation accounting for the magnetic field and for tracks with different angles with respect to the straw axis;
3. Last year results were obtained using Fortran Garfield, now we use Garfield++ (details about Garfield++ simulation see in the poster presented by Assel Mukhamejanova);
4. Garfield prediction for straw signal is interfaced to an LTSpice model of realistic readout electronics including noises, signal shape, etc.

Simulation parameters (SPD setup)

1. Straw diameter: 10 mm
2. Anode diameter: 30 mkm
3. HV: 1750 V
4. Gas mixture: Ar+CO2 / 70:30 [%]
5. Gas mixture temperature: 20 celsius
6. Gas mixture Pressure: 1 atmosphere
7. Ionization particle: muon 1 GeV
8. Track angle α: 90°, 13°.
9. Magnetic field: 0, 1.3 T
10. Gas Gain is fixed $= 4.5 \cdot 10^4$ (Penning coefficient is 0)



Layout diagram of ionising particle, track angle, and magnetic field vector

See details in the poster presented by Assel Mukhamejanova

Garfield++ transition from Fortran Garfield

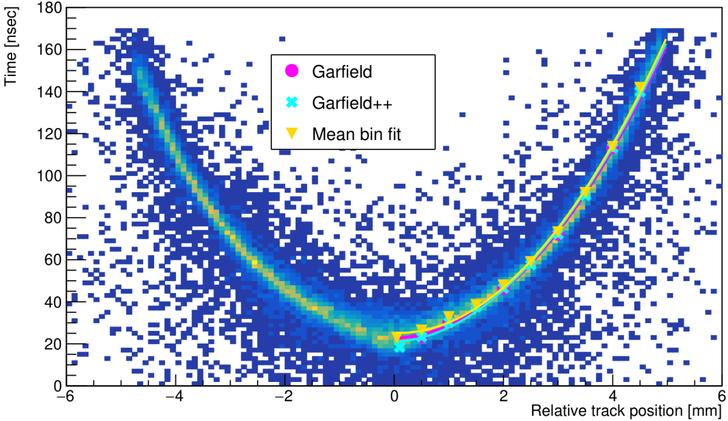
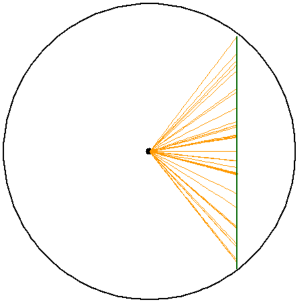
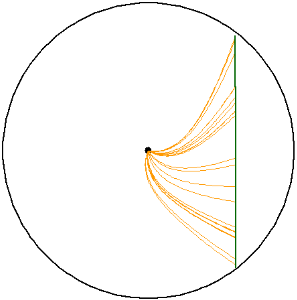


Figure: Fortran Garfield and Garfield++ with VMM3 compared to NA62 data (CARIOCA chip)

Drift Line Examples



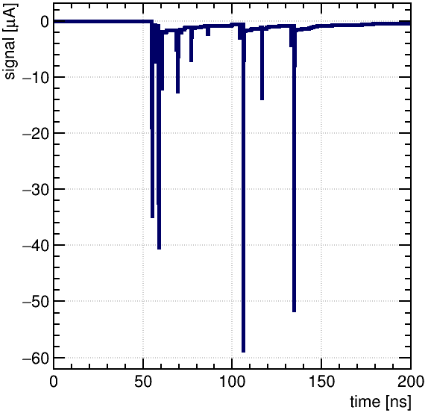
a) Electron drift lines without magnetic field.



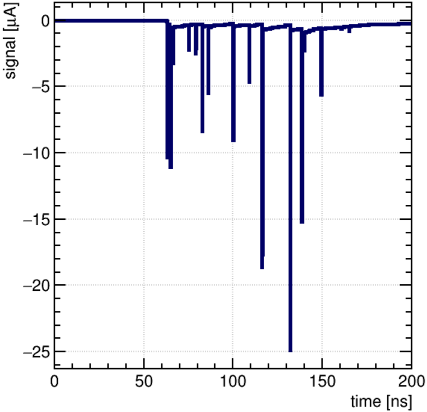
b) Drift lines with magnetic field, B = 1.3 T. Electrons (yellow) twist in magnetic field

Figure: Visualization of drift lines in straw. Green line shows an 1 GeV muon, crossing the straw at the distance 3 mm from the wire.

Example of signals before LTSpice



a) Signal example, no magnetic field

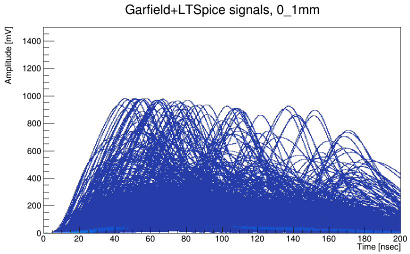


b) Signal example, with magnetic field, B = 1.3 T

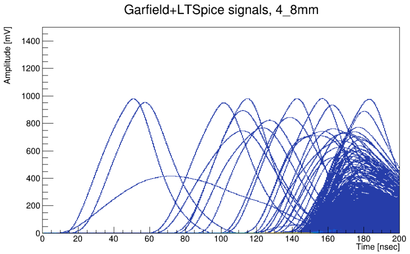
Figure: Example of a straw response to a single muon crossing the straw at the distance of 3 mm from the anode wire

Set of signals after LTSpice

The signals from Garfield++ are interfaced to the VMM3-based readout model implemented in LTSpice. Parameters: peaking time 25 ns, signal amplification 3 mV/fC, noise implemented here is 0e, threshold 10 mV.



a)



b)

Figure: Examples of signals after the LTSpice modeling for 0.1 mm (a) and 4.8 mm (b) between the track and wire

Gas gain in Garfield++

For electron drift lines, multiplication is taken into account in the signal calculation. For this purpose, after calculating a drift line, the number of electrons and ions, n_e, at each point of the line is calculated by integrating the Townsend and attachment coefficient, α and η, along the line. For a given starting point, the number of electrons at the end of the drift line is thus given by

$$n_e = \exp\left(\int(\alpha - \eta)ds\right) \tag{1}$$

The multiplication factor can be set directly. In order to take fluctuations of the avalanche size into account in the signal calculation the number of electrons in the avalanche can be sampled from a Pólya distribution

$$\overline{n}P_n = \frac{(\theta+1)^{\theta+1}}{\Gamma(\theta+1)}\left(\frac{n}{\overline{n}}\right)^{\theta}\exp\left(-(\theta+1)n/\overline{n}\right) \tag{2}$$

Gas gain in Garfield++ (continue)

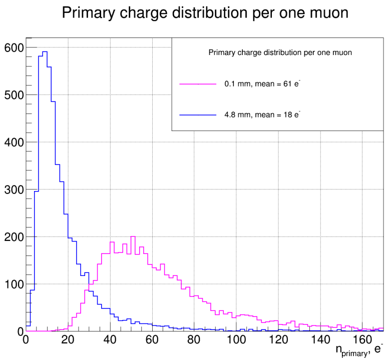
Signal generation steps:

1. Muon enters into a straw volume,
2. Primary ionisation of the gas results in $n_{primary}$ electrons,
3. Avalanche development with a given average gas gain given for every primary electron $G = 4.5 \cdot 10^4$,
4. The signal induced at the electrodes corresponds to the total charge of n_{total} electrons.

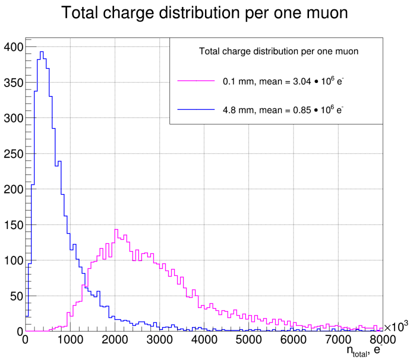
The number of electrons arrived to the wire is proportional to the number of electrons in primary ionisation clusters:

$$n_{primary} \cdot G = n_{total} \tag{3}$$

Charge distributions, $\alpha = 90^\circ$

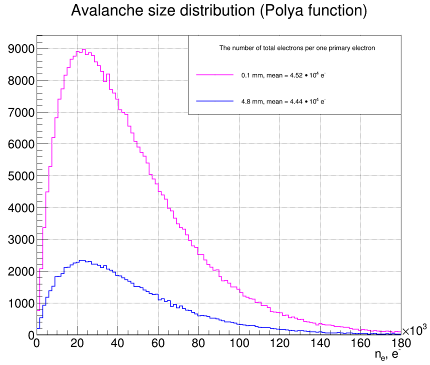


a) Primary charge distribution per one muon

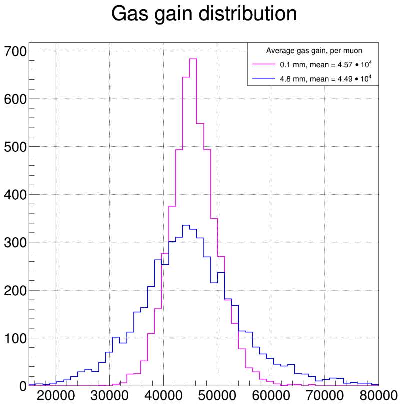


b) Total charge distribution per one muon

Gas gain: $4.5 \cdot 10^4$



a) The number of total electrons per one primary electron (Polya function)



b) The total charge divided by primary charge

Threshold crossing time for the 10 mV

Threshold crossing time for the signals from LTSpice. Threshold value is 10 mV

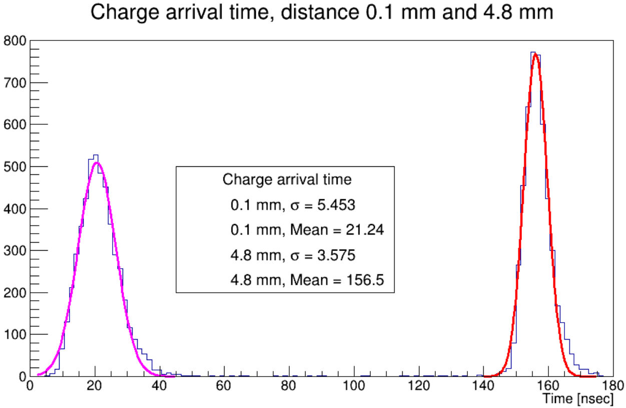
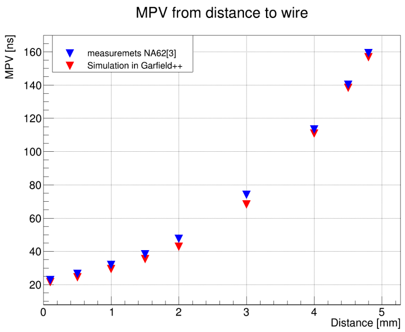
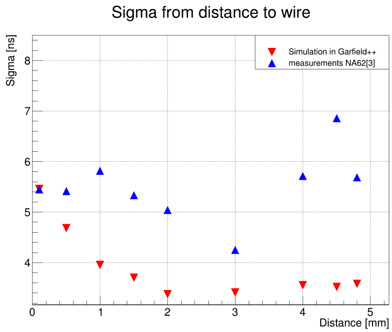


Figure: Threshold crossing time for 0.1 mm and 4.8 distances. $B = 0$ T, $\alpha = 90^{\circ}$ (Mean (ns) is the most probable value (MPV), σ (ns) is the distribution width)

Time distribution most probable value (MPV) and time distribution width (σ)



a)



b)

Figure: (a) The most probable value of the threshold crossing time (b) The width of the threshold crossing time distribution.
The values are shown as functions of the distance between a track and the anode wire and compared to the performance of the NA62 straw tracker readout with CARIOCA chip.

MPV & σ distributions for different cases

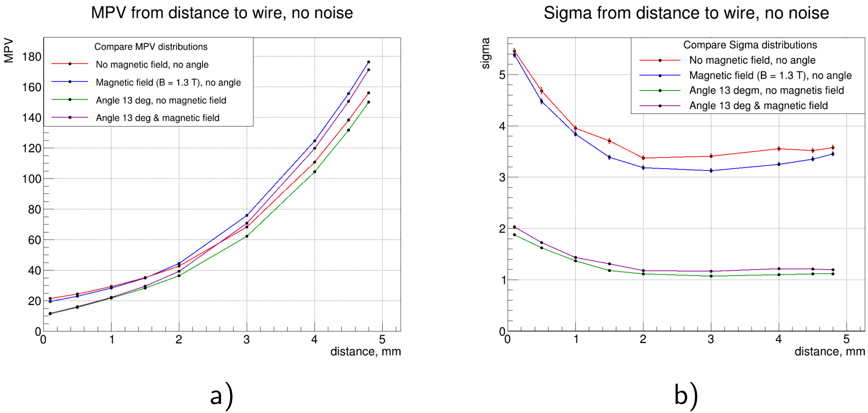
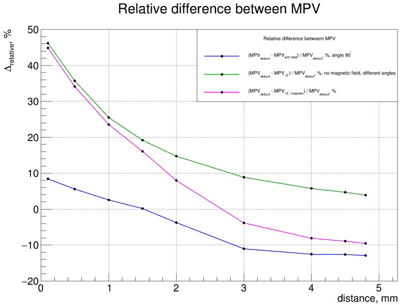
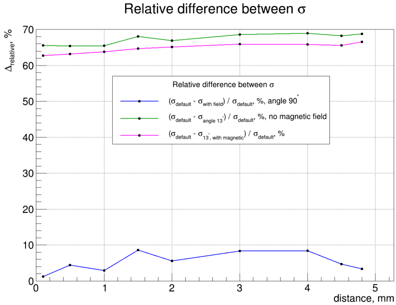


Figure: (a) MPV (ns) from distance to wire (b) Sigma (ns) from distance to wire

Relative difference between MPV and σ

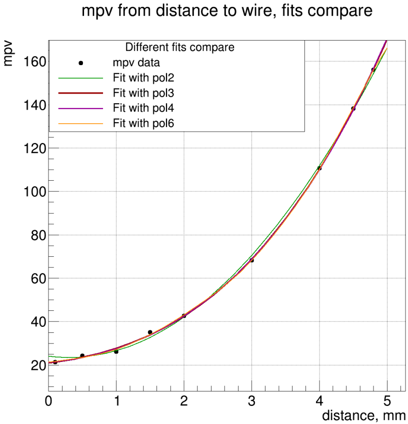


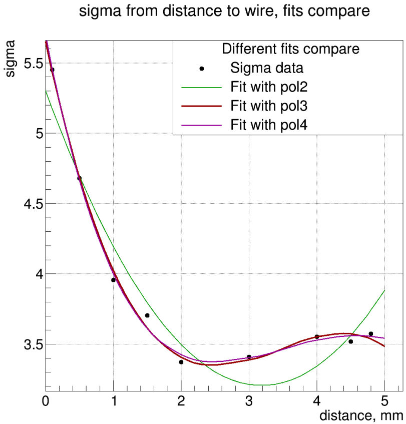


Relative difference between MPV for different cases. $MPV_{default}$ is for 90° angle and without magnetic field

Relative difference between σ for different cases. $\sigma_{default}$ is for 90° angle and without magnetic field

MPV & sigma parametrisation



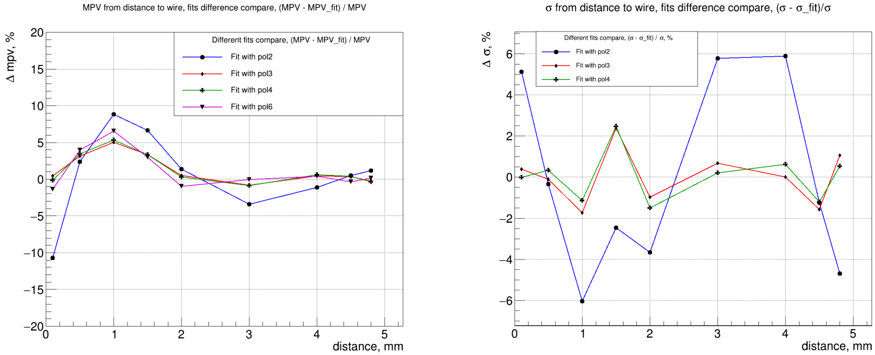


a) Different MPV parametrisations for no field no angle case

b) Different σ parametrisations for no field no angle case

Figure: (a) MPV (nsec) from distance to wire parametrisation (b) σ from distance to wire parametrisation

MPV & sigma parametrisation (continue)



a) b)

Figure: (a) $\Delta MPV = (MPV_{model} - MPV_{fit})/MPV_{model}$ for different fitting functions (b) $\Delta\sigma = (\sigma_{model} - \sigma_{fit})/\sigma_{model}$ for different fitting functions

Conclusion

1. We have done transition from Fortran Garfield to Garfield++
2. TDR results obtained with Fortran Garfield have been reproduced in Garfield++
3. There is a good description of the drift time in Garfield/Garfield++, but avalanche multiplication needs tuning. We used a quick fix to reproduce straw signal charge and shape in order to provide realistic signals for processing with LTSpice
4. Straw response parametrisation for the simple case without magnetic field and slope angle has been done. The maximal deviation of the parametrization function is less than 10
5. Studies for the magnetic field and different track angles are started
6. A procedure of adding electronics noise to signals is established, the results will be updated accounting for a realistic noise level
7. Further studies with different ionizing particles and different particle momenta are planned