Garfield/LTSpice studies of the straw time and charge resolution for different readout parameters

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Motivation

- We have already performed parametrisation of time resolution as a function of the distance and angle between wire and track (see Kate M. report);
- Our next step is to create signal charge parametrisation for SPDroot;
- Additionally we investigate the readout electronics parameters in order to perform charge measurements without degrading the time resolution;
- To do this, we made simulation for different readout electronics parameters such as peaking time and amplification.

Simulation parameters (SPD setup)

- Straw diameter: 10 mm
- Anode diameter: 30 mkm
- HV: 1750 V
- Gas mixture: Ar+CO2 / 70:30%
- Gas mixture temperature: 20 celsius
- Gas mixture Pressure: 1 atmosphere
- Ionization particles: muon, proton, pion, kaon, electron. 0.1, 0.3, 0.5, 1, 10 GeV/c
- Track angle α: 90^0, 26^0.
- Magnetic field: 0 T
- Mean Gas Gain value is fixed to $4.5 \cdot 10^4$, the variation is described by Polya function

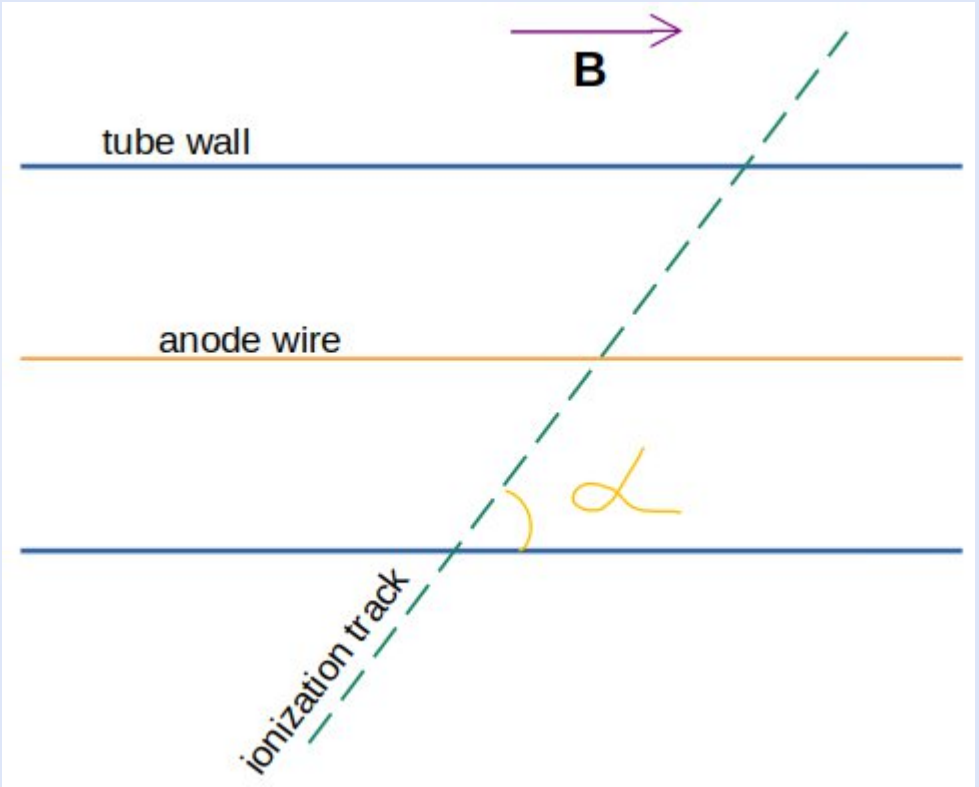
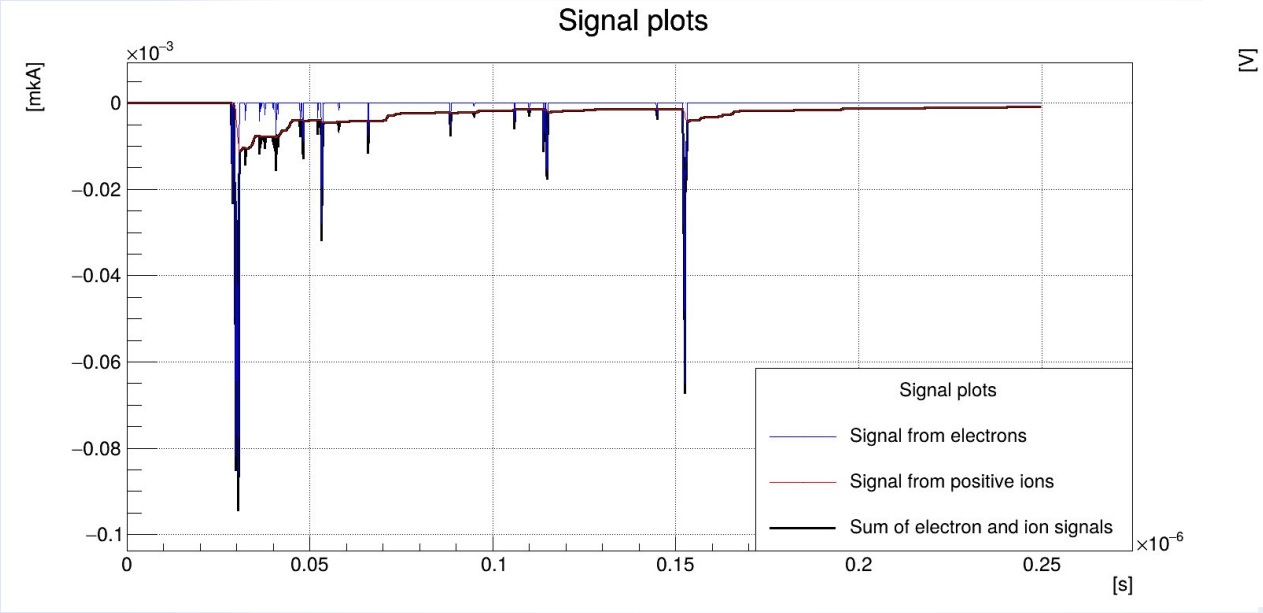
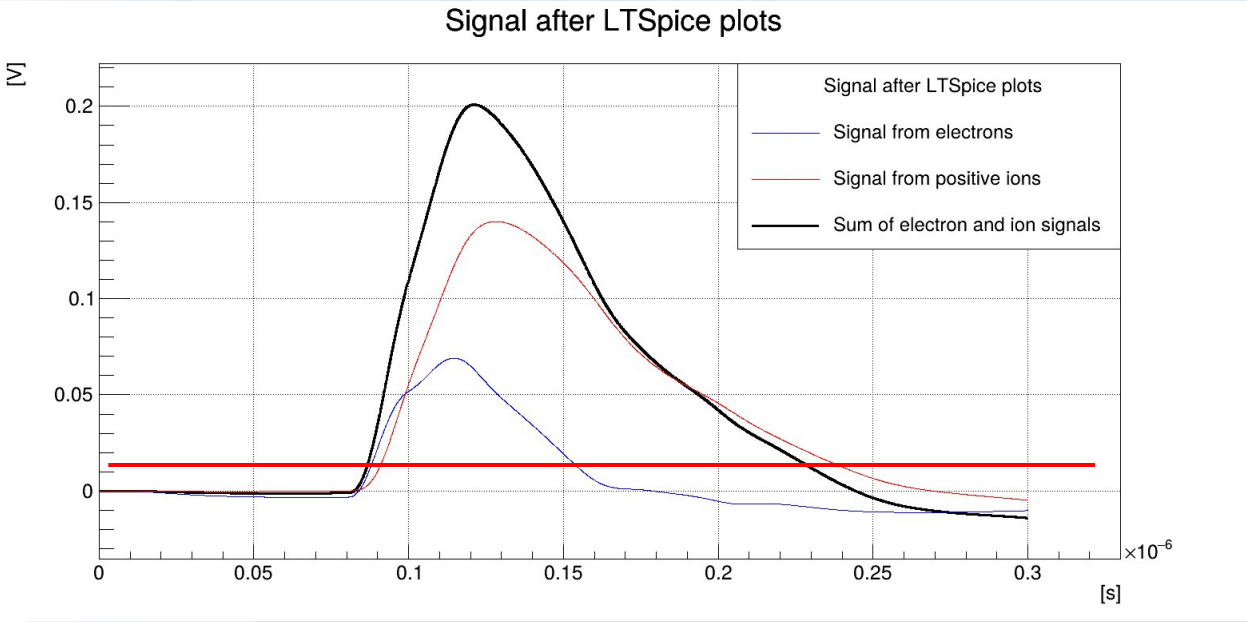


Fig. 1. Layout diagram of ionising particle, track angle, and magnetic field vector

Examples of the simulated signals



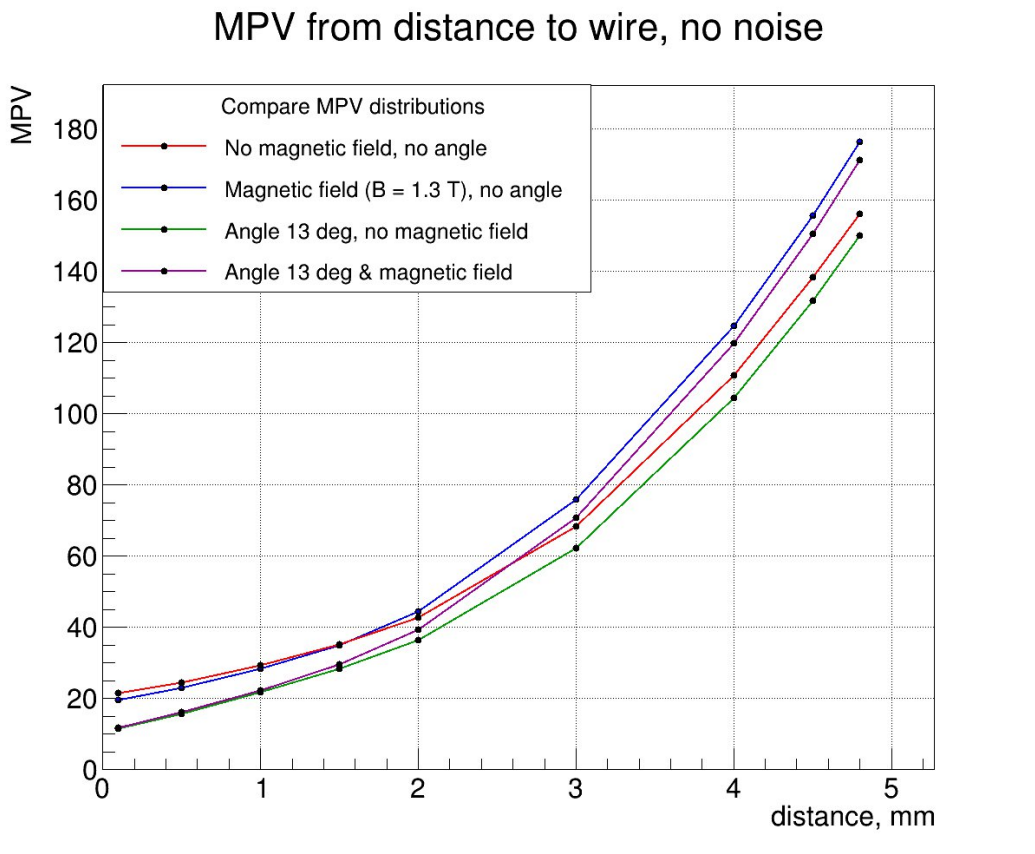
(a)



(b)

Fig. 2. (a) The signal induced at the anode wire (black) by electrons (blue) and ions (red), (b) the corresponding signal after the LTSpice readout emulation (VMM3-based model) for 25 ns peaking time, gain of 3 mV/fC and electronics noise of 1500 e as reference values.

Example of signal timing studies for SPDroot realistic simulation



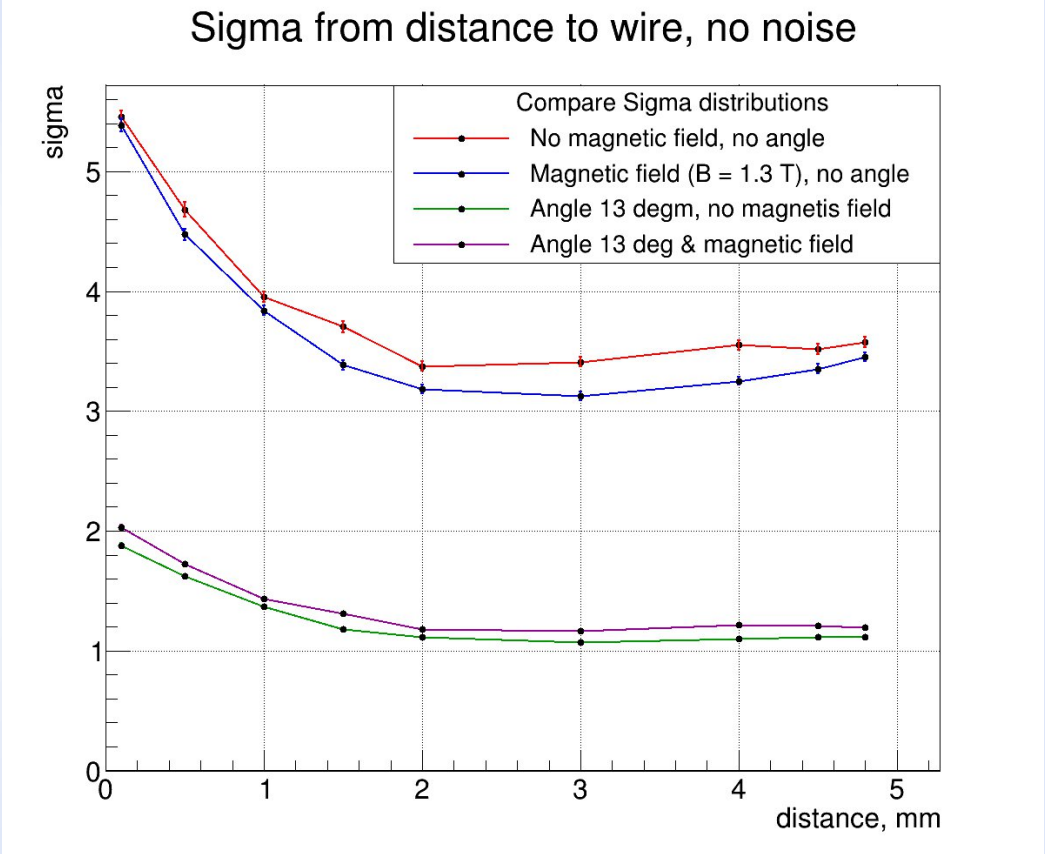


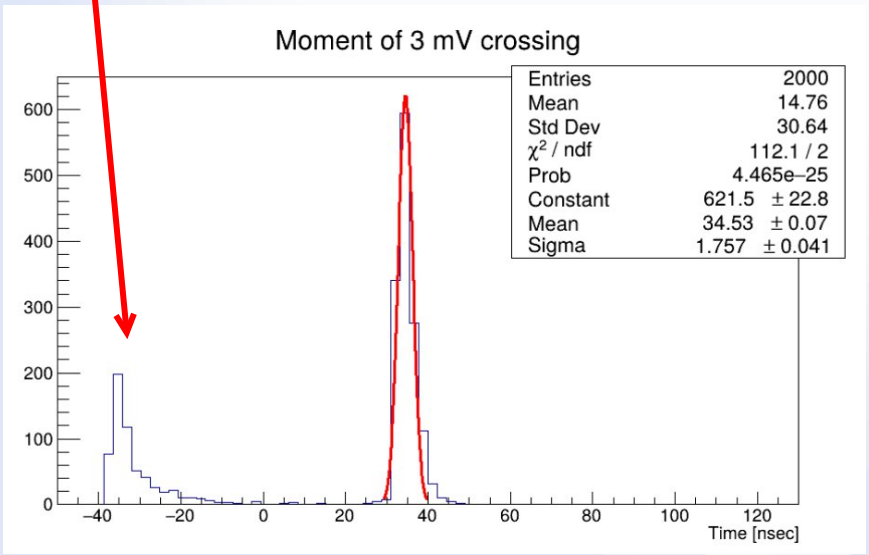
Fig. 3. (a) MPV (ns) from distance to wire (b) Sigma (ns) from distance to wire of time resolution

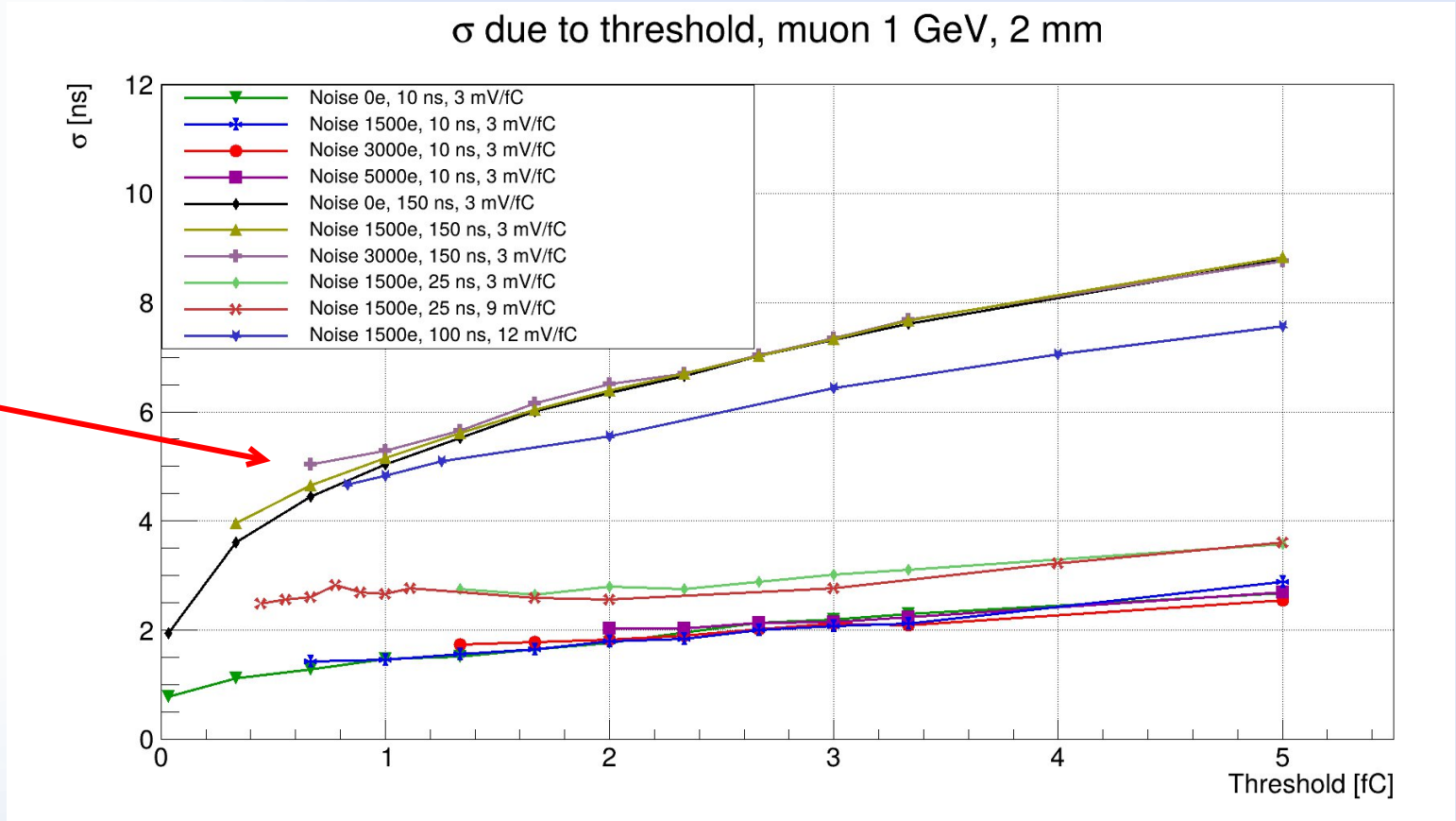
We have already done with time resolution as a function of angle and magnetic field magnitude (see Kate M. report). Now our goal is to describe charge resolution.

Additional studies of straw time resolution as a function of electronics parameters

Fig. 4. Time resolution vs discriminator threshold for:
1. Different peaking time
2. Different preamplifier gain
3. Different noise levels

Only those cases are considered when fake hit contribution is less than 15%



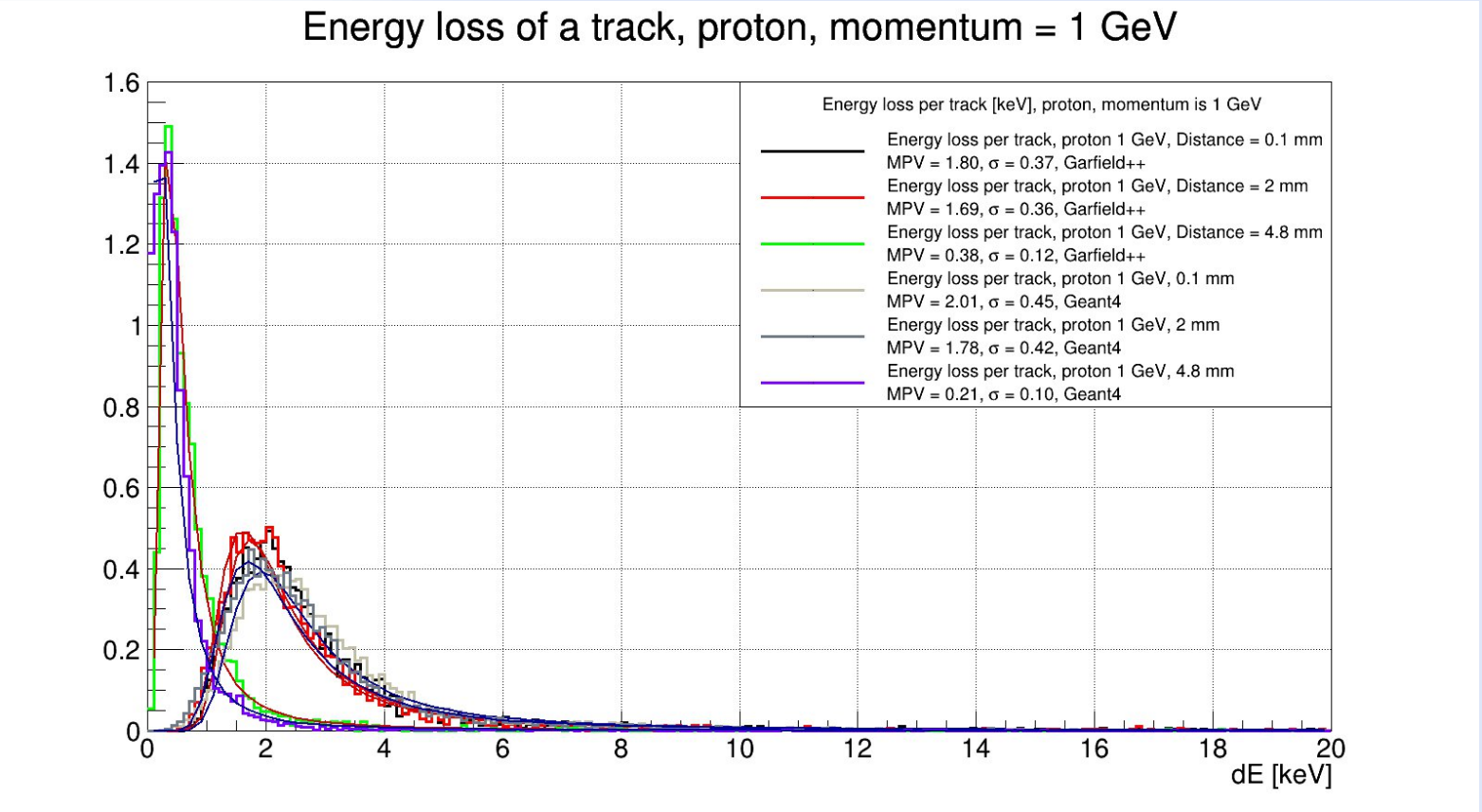


Search for optimal parameters for simultaneous time and charge measurements

- Precise time measurements require short peaking time;
- Precise charge measurements require long peaking time;
- We need to measure MIPs but also protons and kaons at low momenta. This requires large dynamic range of the readout electronics or sophisticated reconstruction routine.
- We investigate which readout electronics parameters could be optimal for these complicated requirements

Garfield++ and Geant4 cross check

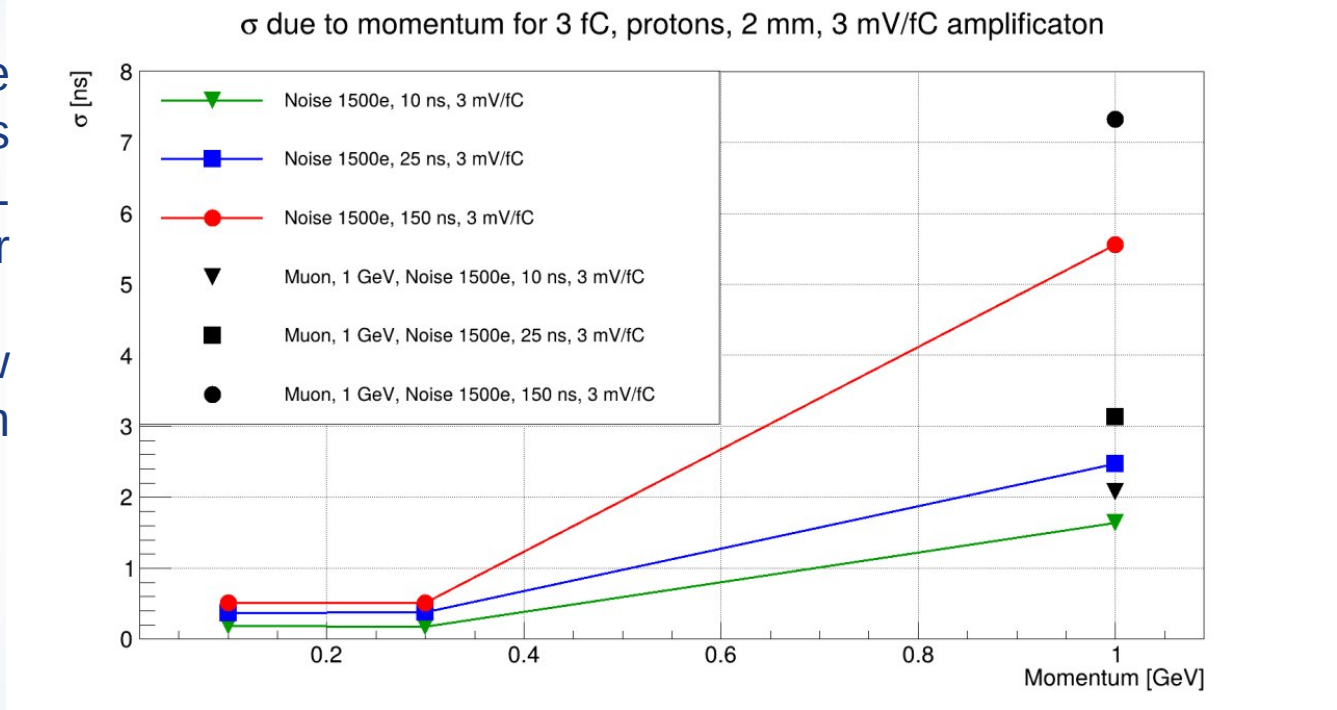
Fig. 5. Validation of Garfield++ ionization losses with respect to Geant4 (done by Demezhan Myktybekov).
We compare three distances to the wire (0.1, 2., 4.8 mm). Validation for lower momenta to be added later.



Study of time resolution for protons of different momenta

Fig. 6. σ of threshold crossing time due to particle momentum [GeV] for 10 ns, 25 ns and 150 ns peaking time. Muon and proton, 1500e noise. 1 GeV muon is a MIP, so the resolution for other particles will be better.

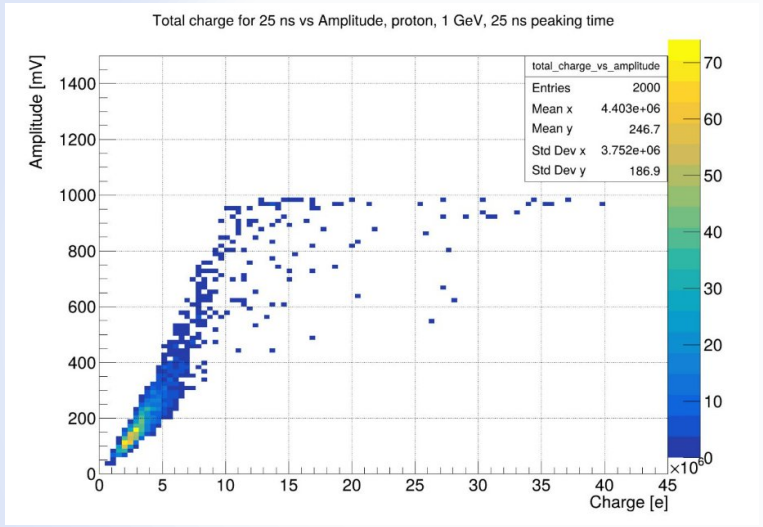
As expected, the time resolution for low momentum particles is significantly better than MIP.

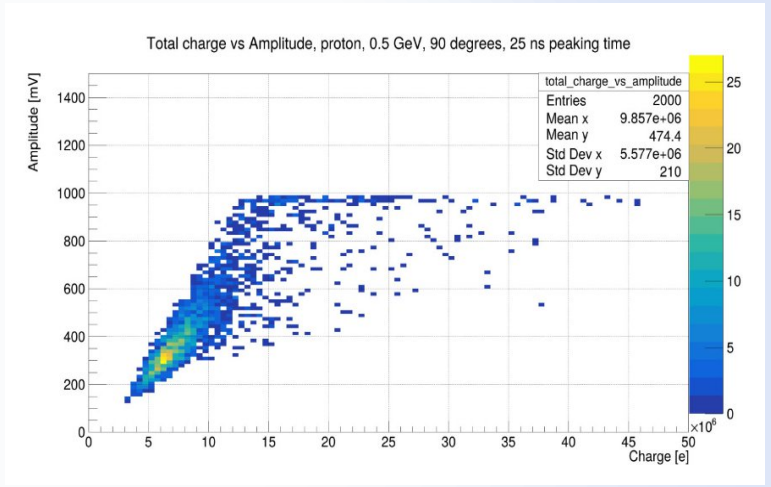


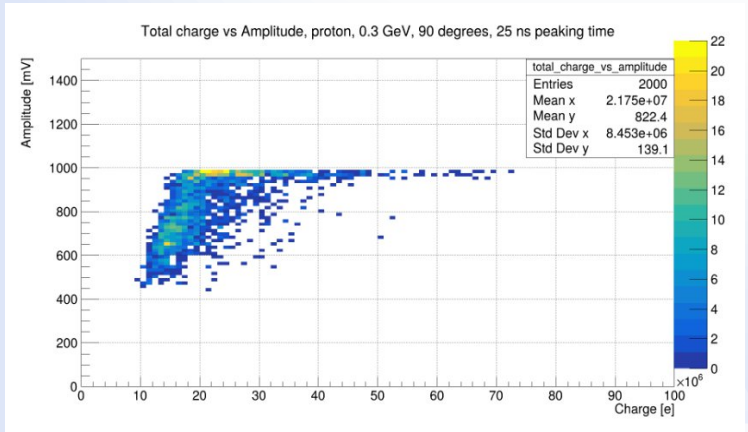
Studies of the charge resolution

- We generate signals in Garfield++ and consider the **total signal charge** to probe the internal charge resolution of the straw;
- The readout electronics will:
  - Degrade this resolution depending on the peaking time
  - Limit measurements for very large signal due to finite dynamic range
- For initial studies we consider a VMM-type analog circuit with 25 ns peaking time, gain 3 mV/fC, noise 1500e. We assume saturation for signals above 800 mV (very concervative). Studies for different parameters are also started.
- We study distribution of **signal amplitudes** as they are provided by LTSpice to study the actual charge resolution.

Correlation between the readout signal amplitude and the total charge of the straw response







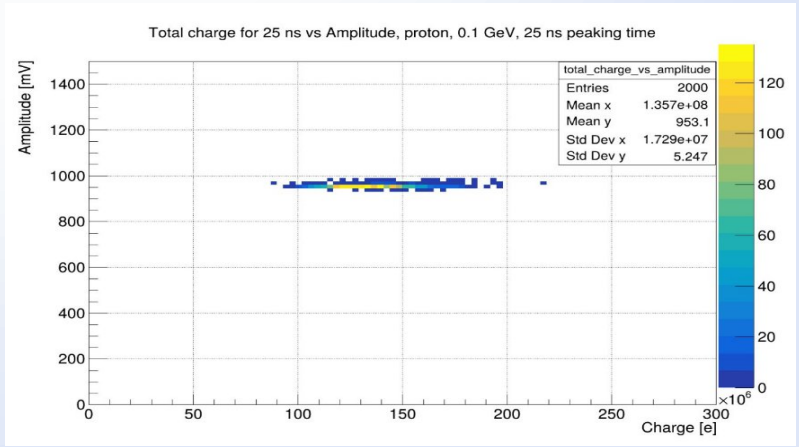
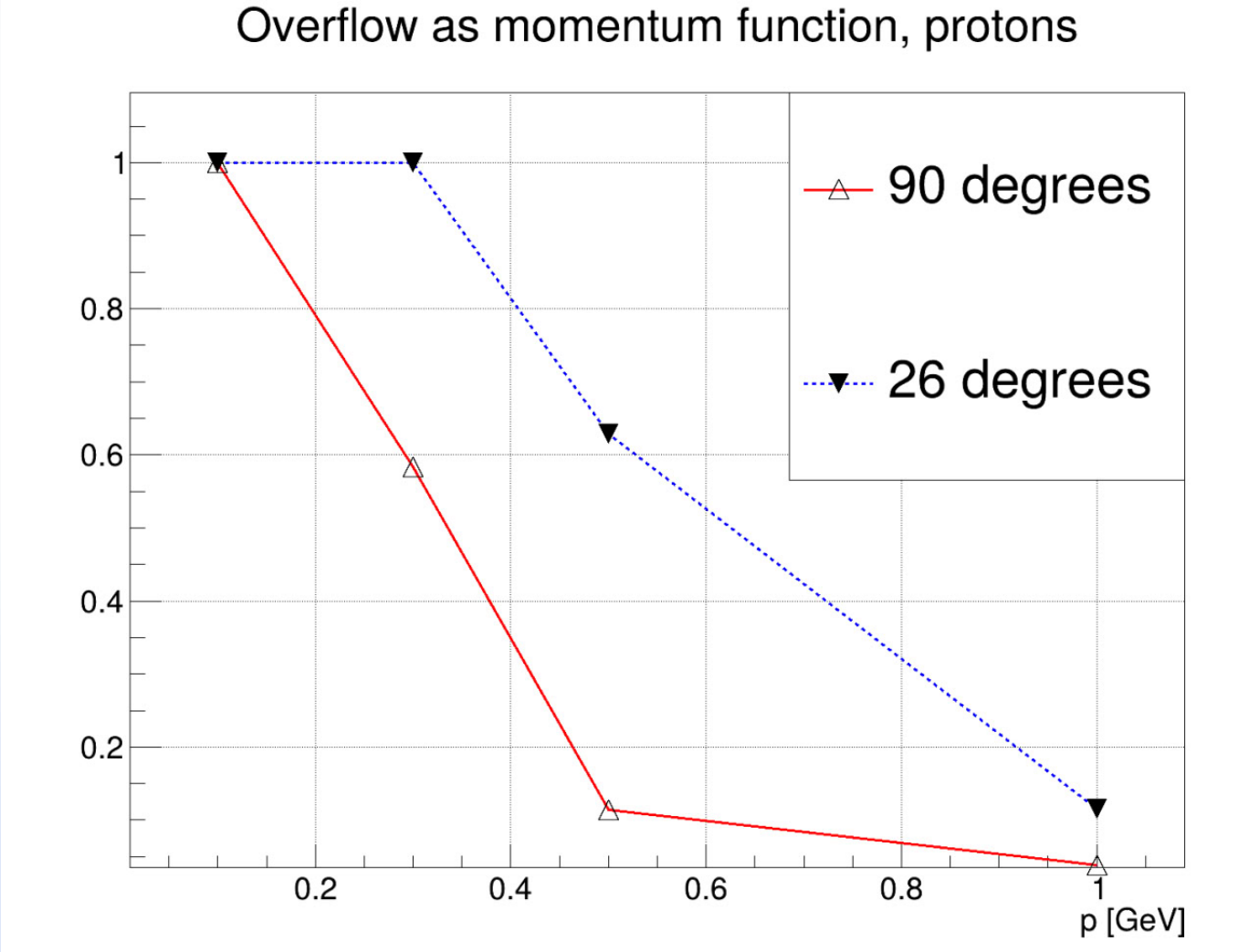


Fig. 7. For each straw response we know the total charge and the amplitude of the electronic signal. The correlation plots are shown for protons 1, 0.5, 0.3, 0.1 GeV perpendicular to wire at the distance 2 mm.

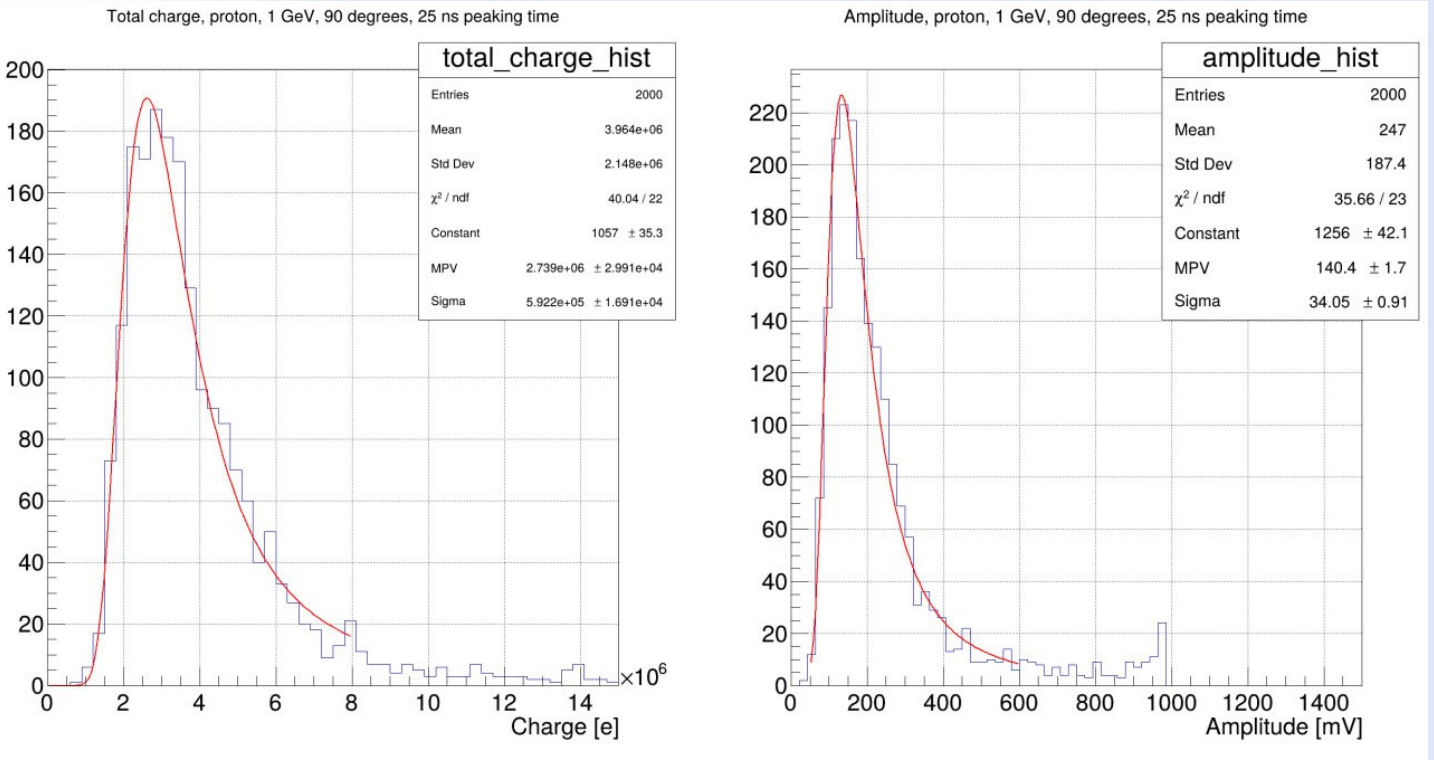
Signals with amplitude above 800 mV are considered to cause electronic saturation.

Fig.8. Fraction of signals with amplitudes above 800 mV as a function of proton momentum for tracks at 2 mm from the anode wire at the angles 90 and 26 degrees with respect to the straw.



Evaluation of the charge resolution

Fig. 9. To estimate the resolution of ionization energy losses, we fit the total signal charge distribution (internal straw resolution) and the signal amplitude distribution (resolution defined by straw + readout electronics performance).



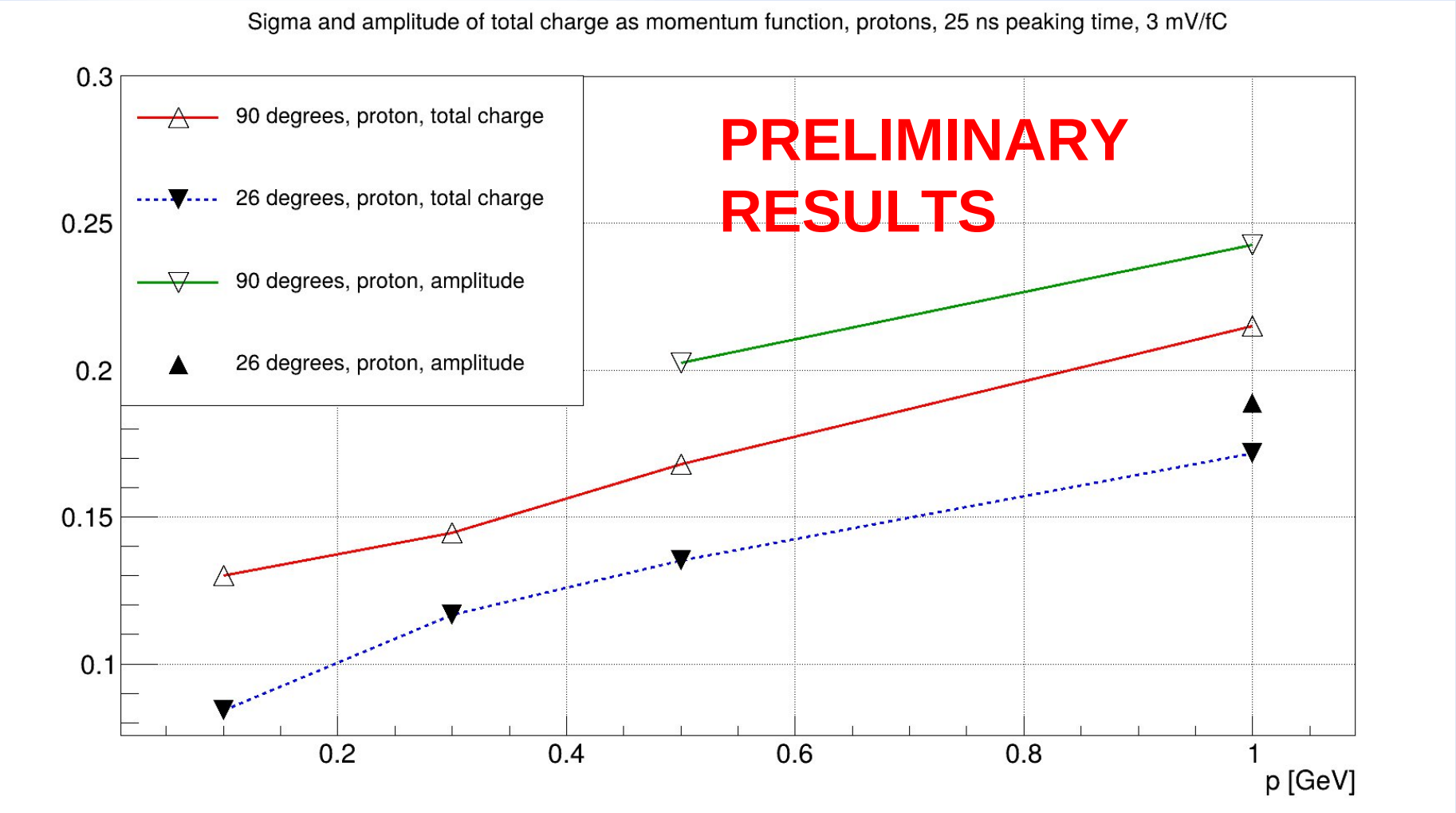


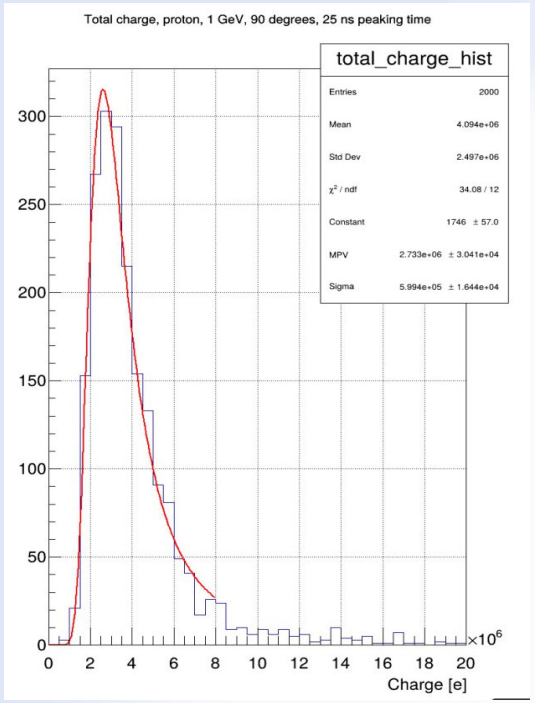
Fig. 10. Sigma/MPV for the total charge and amplitude distributions, Protons, 2 mm, 90 and 26 degrees, 25 ns peaking time 3 mV/fC, 1500e noise

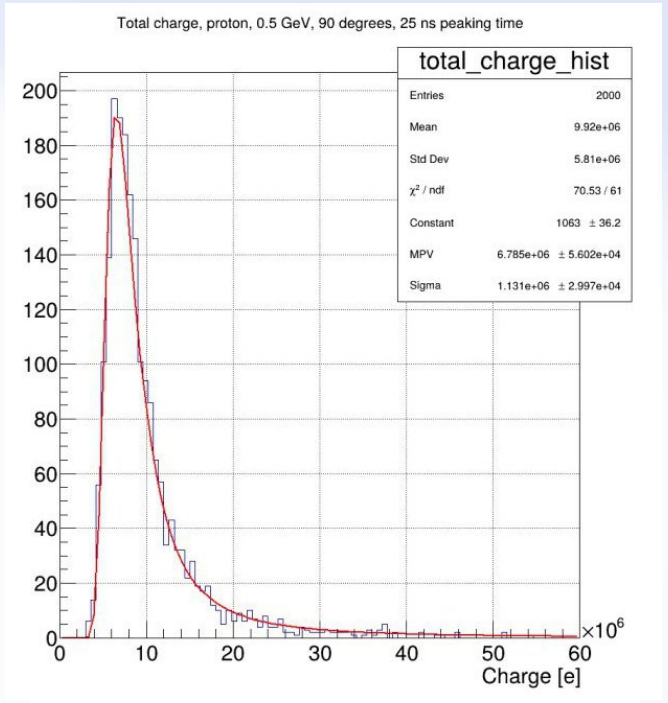
Conclusion

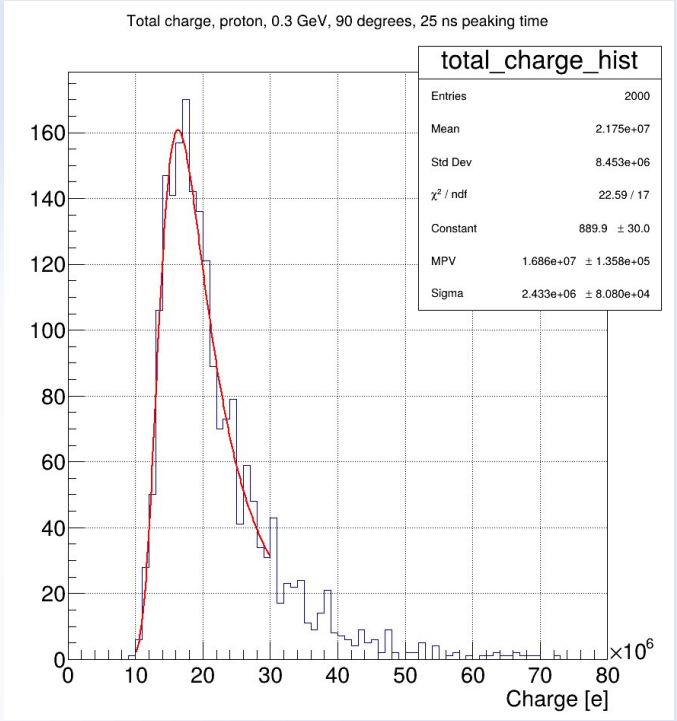
- Realistic straw time resolution as a function of track angle and distance to the wire has been studied and provided for parameterized straw response in SPDroot (see Kate M. report);
- Studies on charge measurements started.
- Studies on optimal readout electronics parameters are ongoing. At the moment we use VMM3-based model, but ready to repeat the studies for any other readout electronics models provided to us.
- Following discussion with A. Solin: next step - AST-SPD readout model with the following parameters:

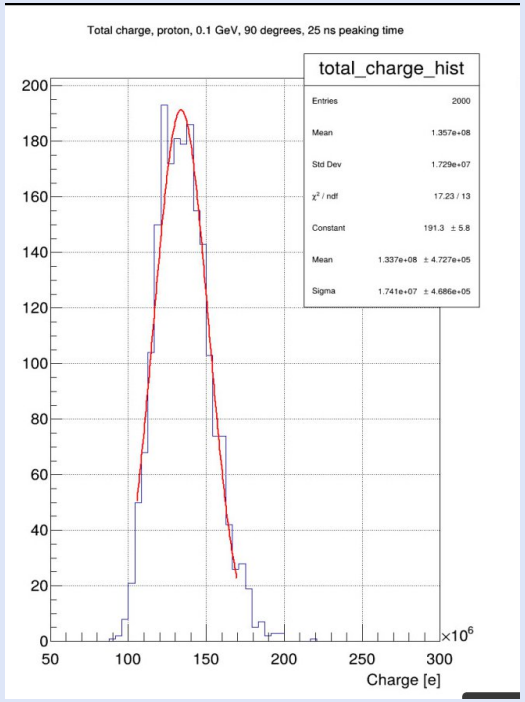
  Time measurements: 3 mV/fC, peaking time 10 ns, ENC 1500e

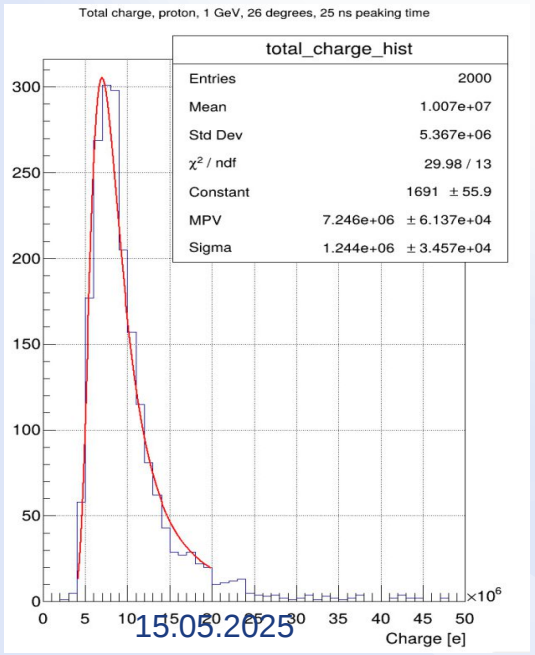
  Charge measurements: 1mV/fC, 150 ns peaking time, ENC 1000e, saturation amplitude 1.5 V

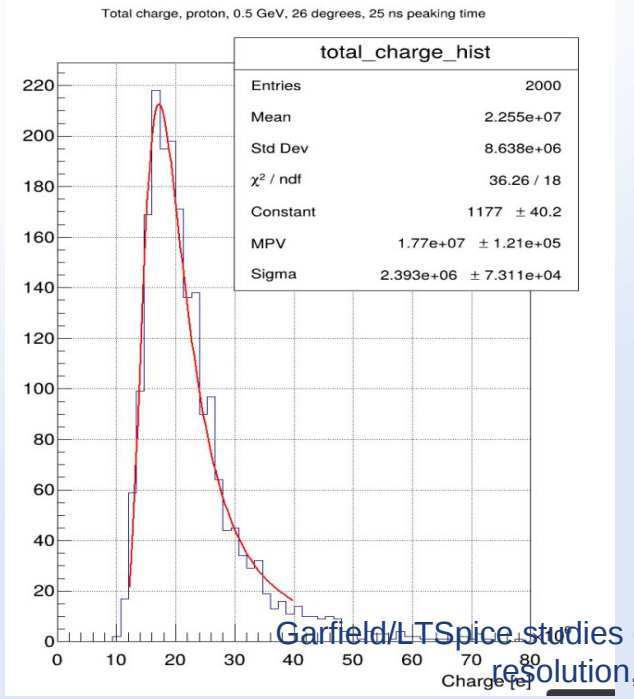

Total charge, proton, 1 GeV, 90 degrees, 25 ns peaking time
total_charge_hist
Entries 2000
Mean 4.094e+06
Std Dev 2.497e+06
χ² / ndf 34.08 / 12
Constant 1746 ± 57.0
MPV 2.733e+06 ± 3.041e+04
Sigma 5.994e+05 ± 1.644e+04
×10⁶
Charge [e]

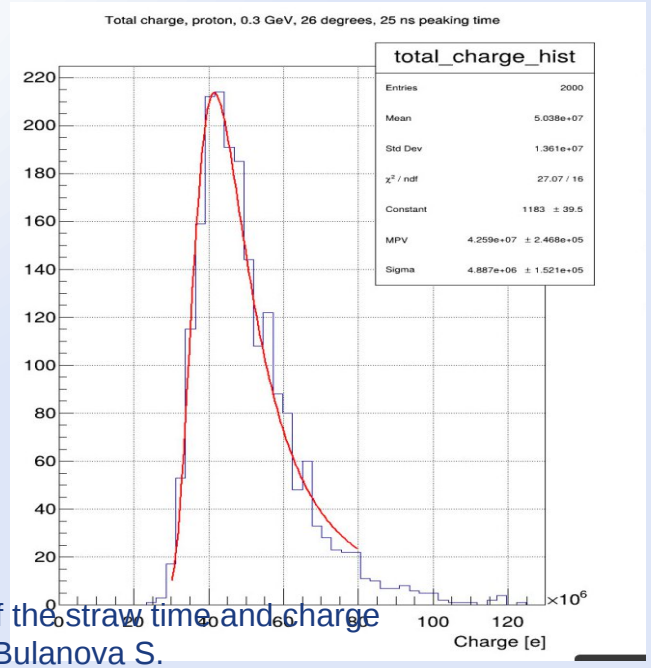

Total charge, proton, 0.5 GeV, 90 degrees, 25 ns peaking time
total_charge_hist
Entries 2000
Mean 9.92e+06
Std Dev 5.81e+06
χ² / ndf 70.53 / 61
Constant 1063 ± 36.2
MPV 6.785e+06 ± 5.602e+04
Sigma 1.131e+06 ± 2.997e+04
×10⁶
Charge [e]

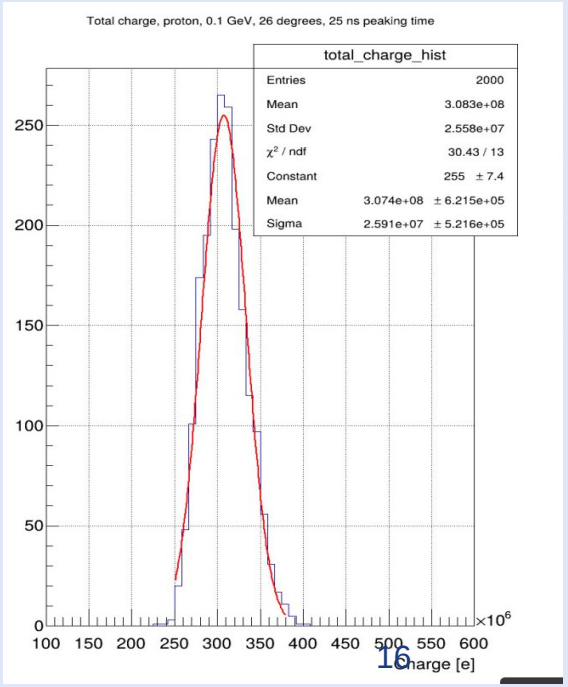

Total charge, proton, 0.3 GeV, 90 degrees, 25 ns peaking time
total_charge_hist
Entries 2000
Mean 2.175e+07
Std Dev 8.453e+06
χ² / ndf 22.59 / 17
Constant 889.9 ± 30.0
MPV 1.686e+07 ± 1.358e+05
Sigma 2.433e+06 ± 8.080e+04
×10⁶
Charge [e]


Total charge, proton, 0.1 GeV, 90 degrees, 25 ns peaking time
total_charge_hist
Entries 2000
Mean 1.357e+08
Std Dev 1.729e+07
χ² / ndf 17.23 / 13
Constant 191.3 ± 5.8
Mean 1.337e+08 ± 4.727e+05
Sigma 1.741e+07 ± 4.686e+05
×10⁶
Charge [e]


Total charge, proton, 1 GeV, 26 degrees, 25 ns peaking time
total_charge_hist
Entries 2000
Mean 1.007e+07
Std Dev 5.367e+06
χ² / ndf 29.98 / 13
Constant 1691 ± 55.9
MPV 7.246e+06 ± 6.137e+04
Sigma 1.244e+06 ± 3.457e+04
×10⁶
Charge [e]


Total charge, proton, 0.5 GeV, 26 degrees, 25 ns peaking time
total_charge_hist
Entries 2000
Mean 2.255e+07
Std Dev 8.638e+06
χ² / ndf 36.26 / 18
Constant 1177 ± 40.2
MPV 1.77e+07 ± 1.21e+05
Sigma 2.393e+06 ± 7.311e+04
Charge [e]


Total charge, proton, 0.3 GeV, 26 degrees, 25 ns peaking time
total_charge_hist
Entries 2000
Mean 5.038e+07
Std Dev 1.361e+07
χ² / ndf 27.07 / 16
Constant 1183 ± 39.5
MPV 4.259e+07 ± 2.468e+05
Sigma 4.887e+06 ± 1.521e+05
×10⁶
Charge [e]


Total charge, proton, 0.1 GeV, 26 degrees, 25 ns peaking time
total_charge_hist
Entries 2000
Mean 3.083e+08
Std Dev 2.558e+07
χ² / ndf 30.43 / 13
Constant 255 ± 7.4
Mean 3.074e+08 ± 6.215e+05
Sigma 2.591e+07 ± 5.216e+05
×10⁶
Charge [e]