Simulation studies of μ-RWELL with APV and TIGER

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Outline

1. PARSIFAL recap
2. Resistive simulation
3. Ion tail
4. White noise
5. Single muon
6. APV simulation
7. APV tuning
8. TIGER simulation
9. TIGER tuning

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PARSIFAL in a nutshell

1. **Define** the main physical processes in an MPGD
2. Simulate the single process in **Garfield++** and parametrized it
3. Sample from the parametrization and **check** the agreement with Garfield++ in each process
4. Built **PARSIFAL** from the parametrization of main processes
5. Simulate the detector response and **tune** it with experimental data

This approach reduces the time consumption of a single event to 1-2 seconds

Ionization

Electron drift

Amplification

Resistive

Induction

Readout

Reconstruction

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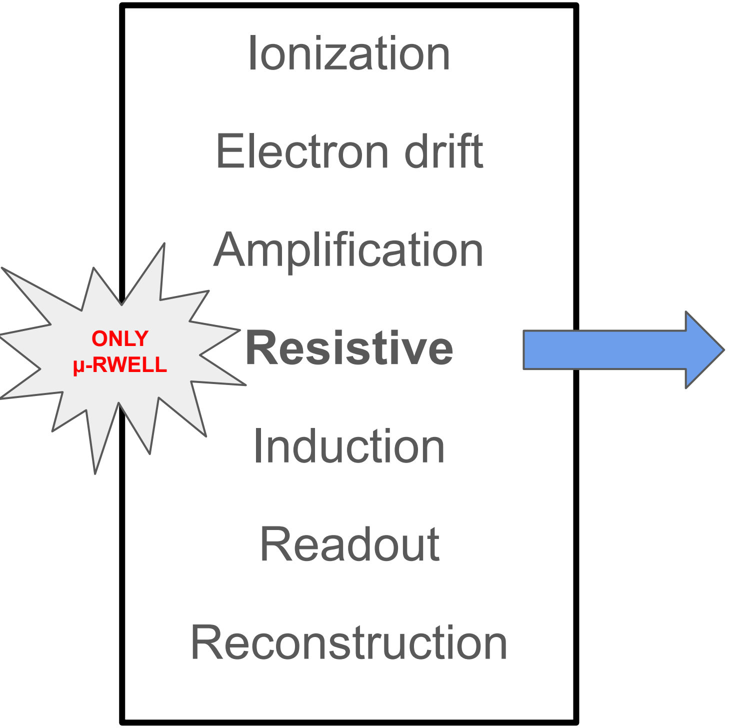
The parametrization

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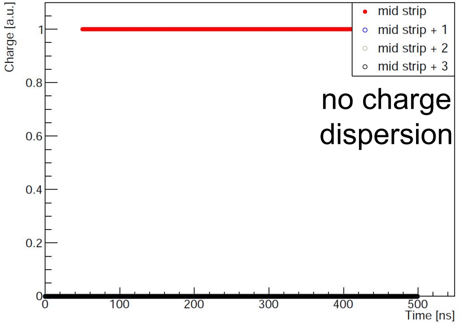
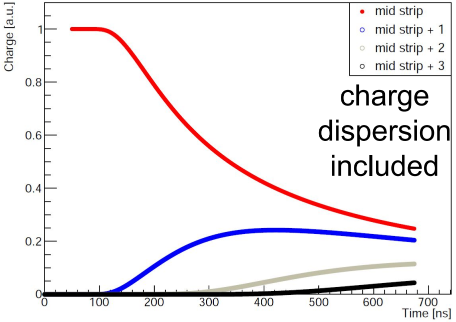
Simulating the charge dispersion phenomena in Micro Pattern Gas Detectors with a resistive anode

M.S. Dixit[a,b,*], A. Rankin[a]

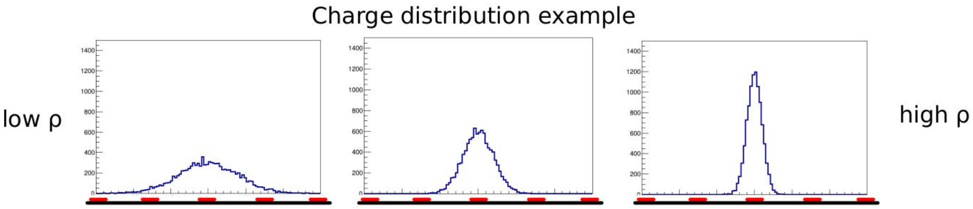
customized for strip 1D

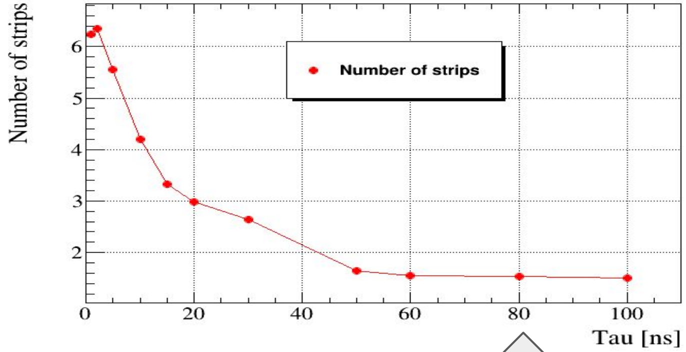
$$
\begin{aligned}
Q(t) &= \int_{x_1}^{x_2} \rho(x,t)\mathrm{d}x \\
&= \frac{q}{\sqrt{2\pi}\left[\sigma_0\left(1+\frac{t-t_0}{\tau}\right)\right]} \int_{x_1}^{x_2} \exp\left[-\frac{(x-x_0)^2}{2\sigma_0^2\left(1+\frac{t-t_0}{\tau}\right)^2}\right] \Theta\left(t-t_0\right)\mathrm{d}x \\
&= \frac{q}{2}\left[\mathrm{erf}\left(\frac{x_2-x_0}{\sqrt{2}\sigma_0\left(1+\frac{t-t_0}{\tau}\right)}\right) - \mathrm{erf}\left(\frac{x_1-x_0}{\sqrt{2}\sigma_0\left(1+\frac{t-t_0}{\tau}\right)}\right)\right]\Theta\left(t-t_0\right)
\end{aligned}
$$

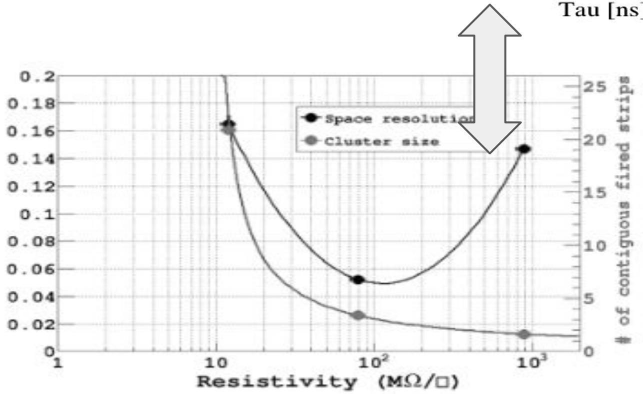




µ-RWELL tuning: resistivity







The µ-RWELL tuning has to confirm the **charge sharing** simulation technique.

The **charge spread** depends on the resistivity (or Tau) of the µ-RWELL and this impact on the number of strips above threshold.

Once the **Tau** (resistivity) is **tuned** on the data then a check on the four variables is performed.

Latest update on μ-RWELL + electronics

- Ion tail on the induction
- White noise implementation

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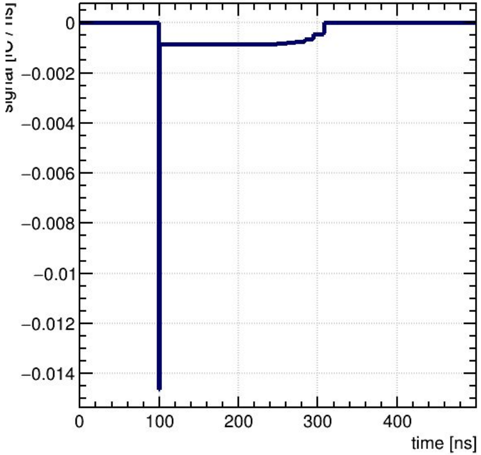
Single electron/ion induction

Ground model for the induction is to inject a pulse of 1ns and 1.6e-4fC once the electron reach the readout plane of the µRWELL.

To improve the reliability of the induction, the ion tails needs to be considered.
A simulation of 1 e- and 1 Ar+ drift along +60µm and -60µm together the relative induction of a plane is reported.



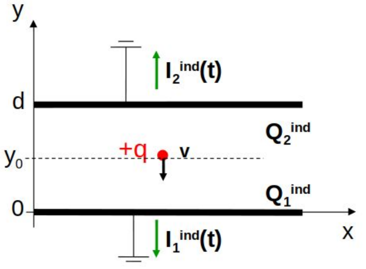
Single electron/ion induction

electron+ion peak amplitude = -0.01463 fC/ns
after 1ns the bump goes down to the ion tail

ion tail amplitude = -0.00085 fC/ns
ion tail duration = 140ns @ fix value + 70 ns to go zero

time bin size	ratio e+I / I
1ns	0.058 (1 bin)
0.1ns	0.060 (10 bin)

The induced current depends on the ionization place



$$y(t) = y_0 - vt \qquad \frac{dy(t)}{dt} = -v \qquad 0 < t < \frac{y_0}{v}$$

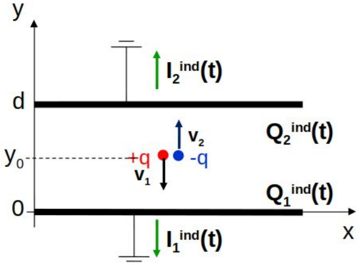
$$I_1(t) = -\frac{q}{V_w} E_1(y(t)) \frac{dy}{dt} = q\frac{v}{d}$$

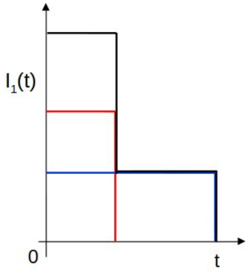
$$I_2(t) = -\frac{q}{V_w} E_2(y(t)) \frac{dy}{dt} = -q\frac{v}{d}$$

$$I_1(t) + I_2(t) = 0$$

Total induced charge on electrode 1

$$Q_{1tot}^{ind} = \int_0^{y_0/v} I_1(t)dt = \frac{q}{V_w}[\psi_1(0) - \psi_1(y_0)] = q\frac{y_0}{d}$$





Two charges +q, -q moving from y_0 to the electrodes with velocities v_1 and v_2, arriving at the electrodes at times t_1 and t_2

$$t_1 = \frac{y_0}{v_1} \qquad t_2 = \frac{d - y_0}{v_2}$$

Induced currents

$$I_1(t) = q\frac{v_1}{d}\Theta(t_1 - t) + q\frac{v_2}{d}\Theta(t_2 - t) \qquad I_2(t) = -I_1(t)$$

$$I_2(t) = -I_1(t)$$

Total induced charges

$$\begin{aligned} Q_{1tot}^{ind} &= \int_0^{\infty} I_1(t)dt \\ &= \frac{q}{V_w}[\psi_1(0) - \psi_1(y_0)] - \frac{q}{V_w}[\psi_1(d) - \psi_1(y_0)] \\ &= q \end{aligned}$$

In all physics processes, pairs of charges with opposite sign are produced at the same position, which results in the fact that the total induced charge is equal to the charge that has arrived at the electrode, once ALL charges have arrived at the electrodes.

If you wait enough time, the total charge is Q, where Q=Ne*gain.

The fast (electron) and slow (ion) contribution is not 50-50. A precise number can be extracted from the weighting field evaluation. On RPC this fraction is 5:95 while on MicroMegas is 15:85.

We can assume a Micromegas-like signal induction.

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The induced current depends on the ionization place

I decided to use 15% fast component and 85% slot component based on similar studies conducted on MicroMegas.

This value needs to be carefully measured.

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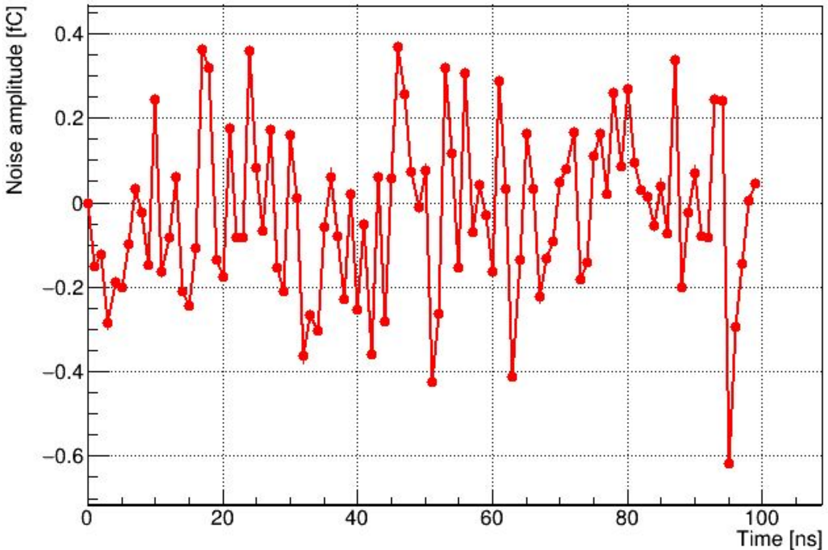
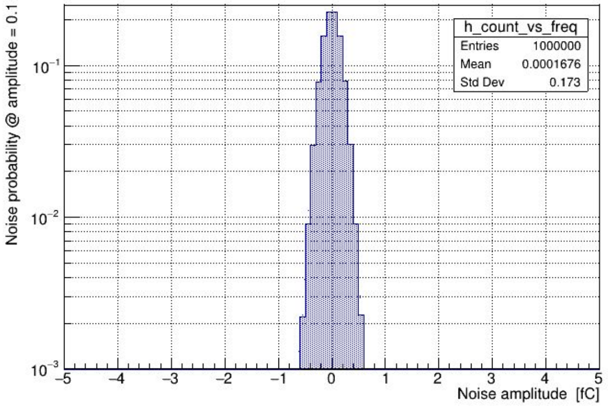
(White) Noise implementation

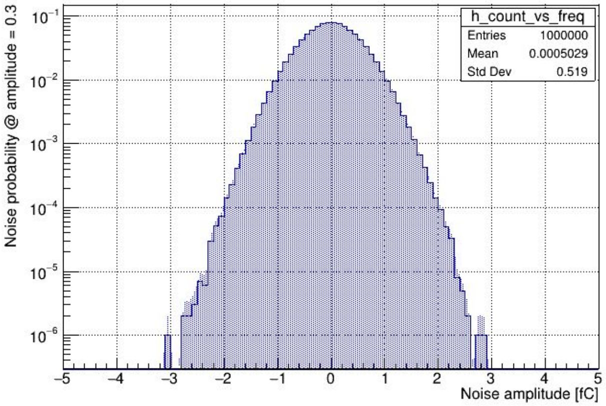
```
const int n_freq = 50;
float freq_amplitude[n_freq];
float freq_value[n_freq];
float freq_phase[n_freq];
void init_freq(){
  for(int i=0;i<n_freq;i++) {
    freq_amplitude[i]=r->Gaus()*max_amplitude();
    freq_value[i]=r->Uniform(min_freq,max_freq);
    freq_phase[i]=r->Uniform(0,6.283);}
  //for(int i=0;i<n_freq;i++) cout<<freq_amplitud
}
```

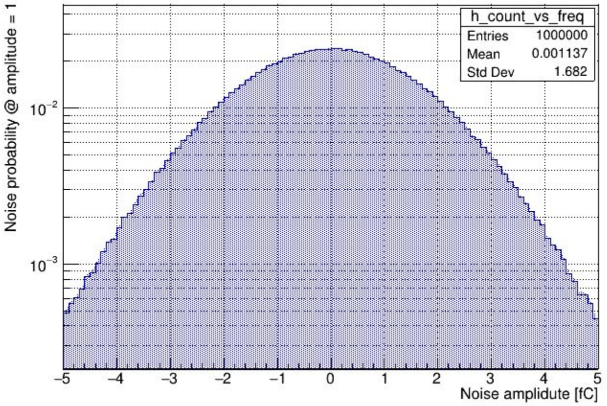
```
// 1/f noise function. It has 5 frequency choosen to reduce the calculation time and for each timebin randomize an amplitude value for each frequency
float one_over_f_noise(int itime){float output=0; for(int ifreq=1;ifreq<max_freq;ifreq*=10){output+=r->Gaus()*max_amplitude()*sin(6.283*itime*ifreq);} return output;}
// white noise function
float white_noise(int itime){float output=0; for(int i=0;i<5;i++){int ifreq= r->Uniform(1,1e0);output+=r->Gaus()*max_amplitude()*sin(6.283*itime*ifreq);} return output;}
// one freq noise function
float one_freq_noise(int itime){float output=0; output+=max_amplitude()*sin(6.283*itime*1e3); return output;}
// fixed amplitude white noise
float fixed_amplitude_white_noise(int itime){float output=0; for(int i=0;i<n_freq;i++){output+=freq_amplitude[i]*sin(6.283*itime*freq_value[i]+freq_phase[i]);} return output;}
```



White noise implementation







The noise distribution sigma depends on the noise current amplitude

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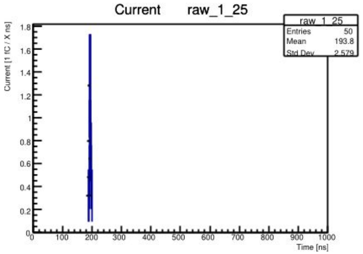
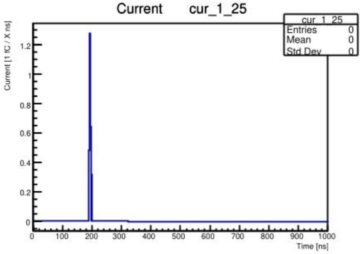
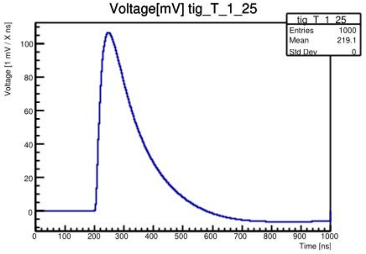
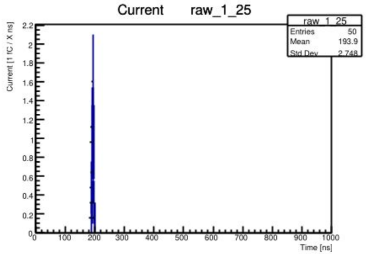
White noise implementation - 1 electron - no noise

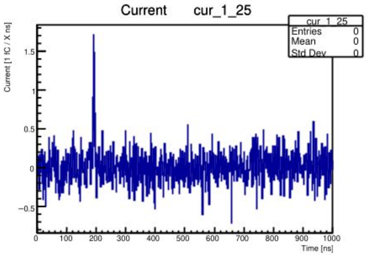


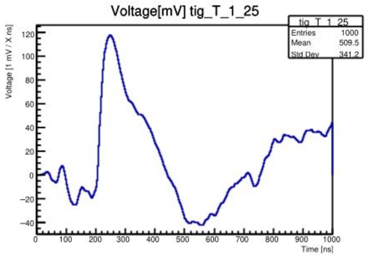




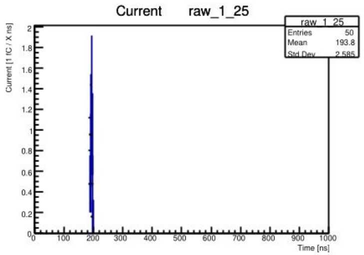
White noise implementation - 1 electron - amplitude 0.1

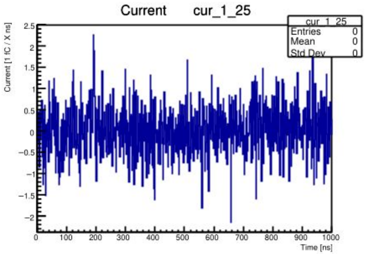


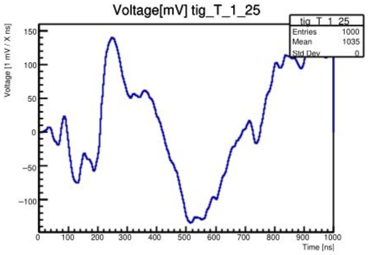




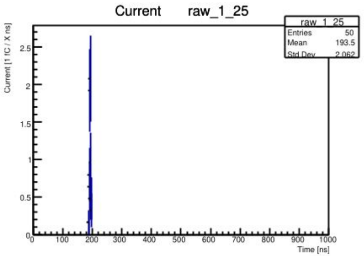
White noise implementation - 1 electron - amplitude 0.3

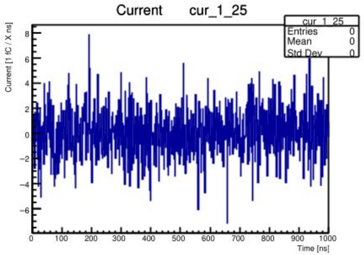


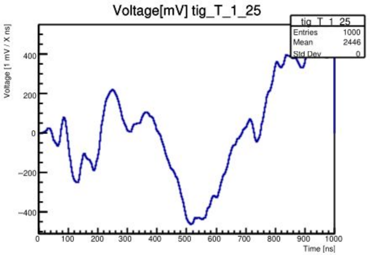




White noise implementation - 1 electron - amplitude 1

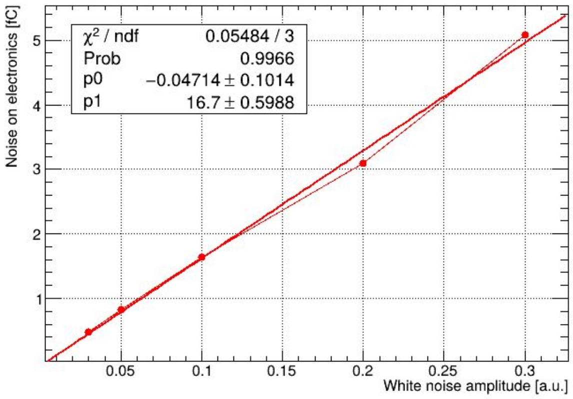




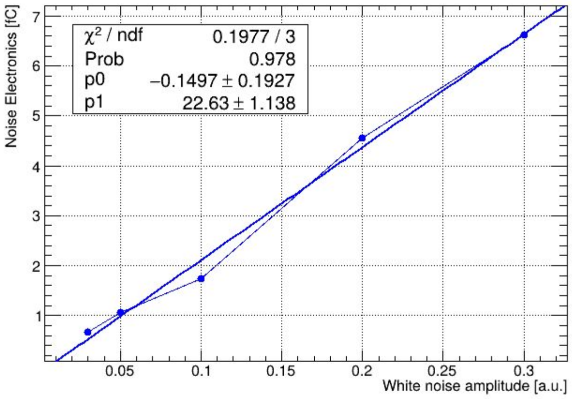


Noise calibration in PARSIFAL

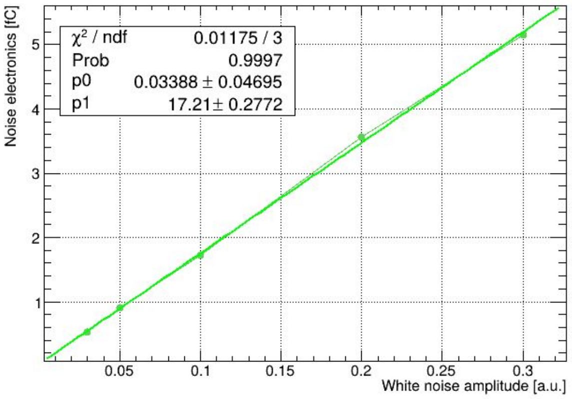
APV



TIGER
E-branch



TIGER
T-branch

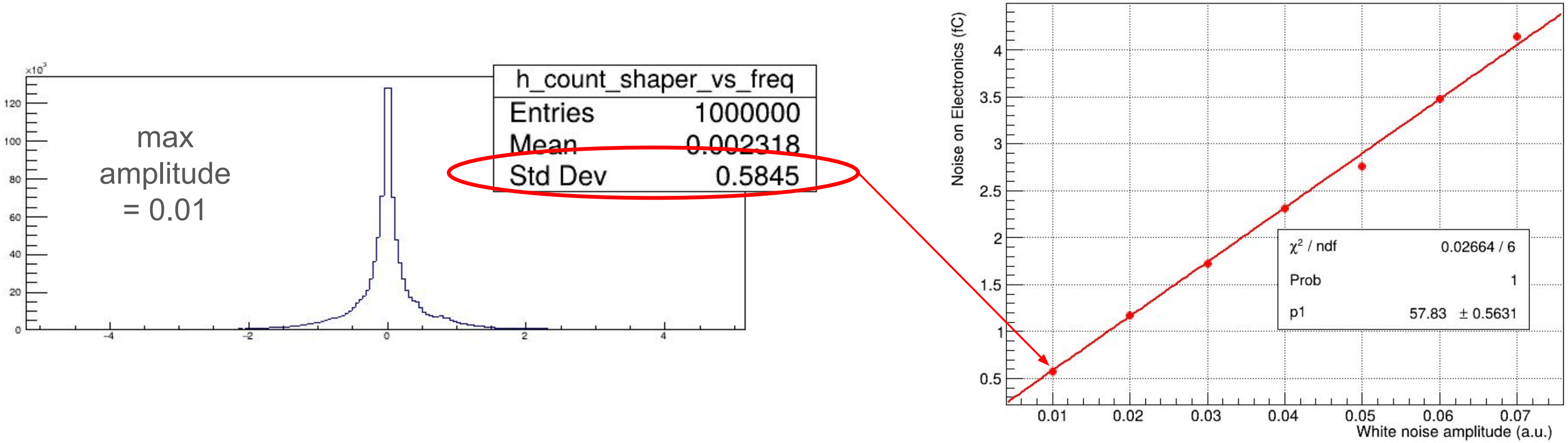


Given the same white noise amplitude, the noise collected on the E-branch of the TIGER is the larger.
In general, the longer is the shaping time, the larger is the noise amplitude.

Noise calibration curve @ 50ns shaping time

For each max_amplitude as input, the shaper amplitude STD is evaluated.

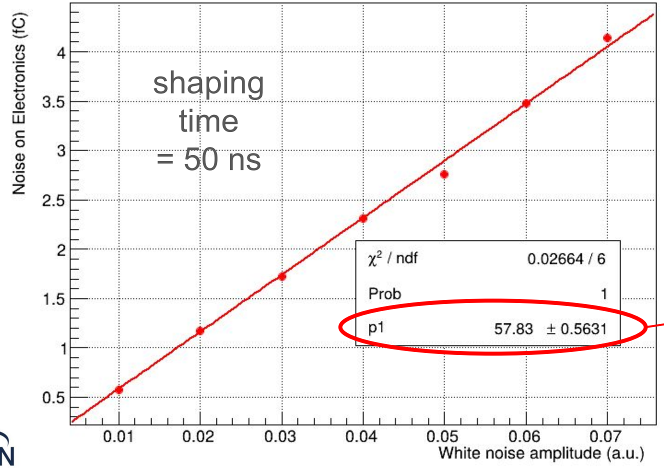
No Gaussian fit are used due to large tails in the distribution.

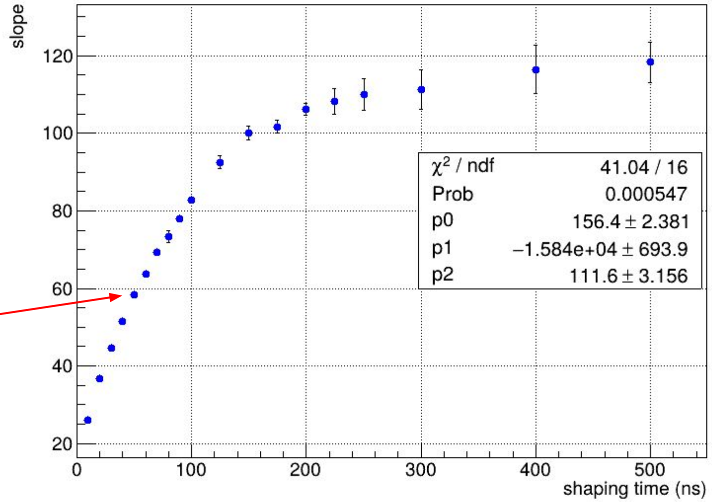


Noise calibration curve @ different shaping time

For each given shaping time, a given slope is measured.

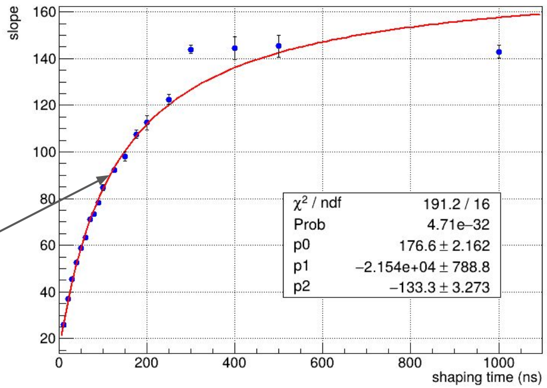
The larger is the shaping time and the higher is the STD in the noise measured by the shaper given the same input noise current.

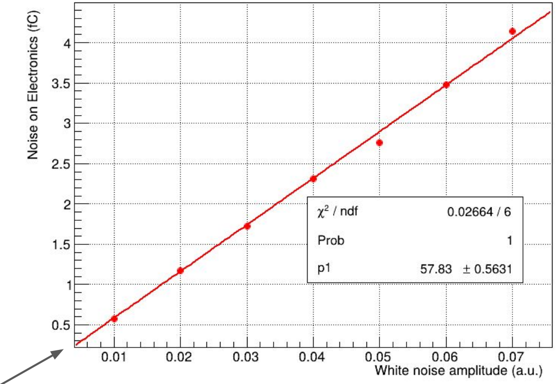




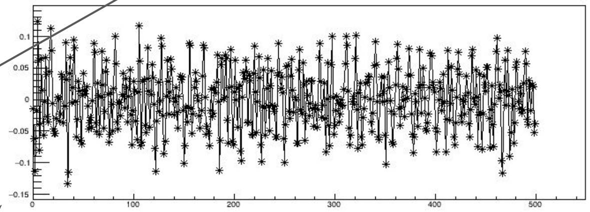
Updating noise

The following parametrization is used to calibrate the noise input as a function of the expected noise amplitude:

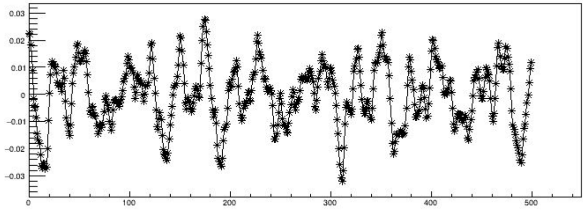




$$slope = 176.6 - \frac{21539.4}{ShapingTime + 133.3}$$

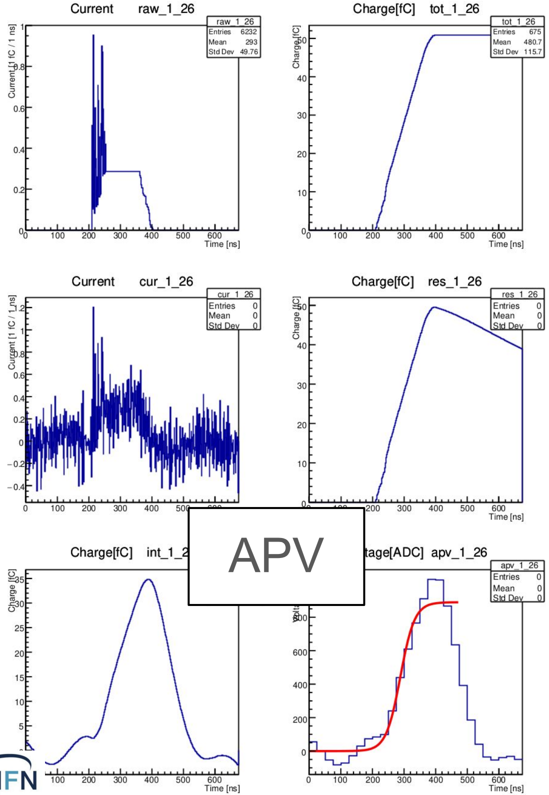


Graph



$$STD\,noise\,fC = noise\,Current\,Amplitude \times slope$$

Single muon simulation

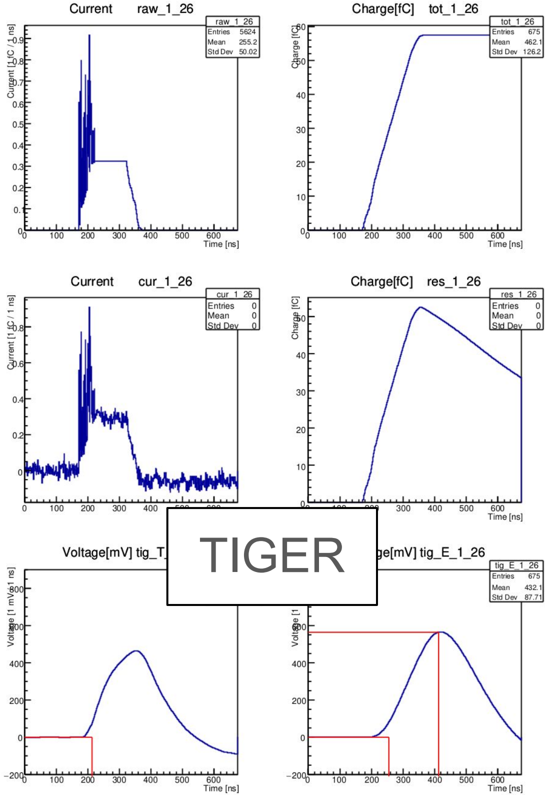


APV thr = 45 fC

Time measured = 291.25 ns

Charge measured = 34.18 fC

Max charge collected = 50.87 fC



Tiger T thr = 0 mV

Tiger E thr = 0 mV

Time measured = 213.62 ns

Charge measured = 44.41 fC

Voltage at Qmeas = 564.04 mV

Time at Qmeas = 412.50 ns

Time at thr_E = 255.00 ns

Max charge collected = 57.48 fC

Parsifal results

I. Experimental data from TB 2021 and pitch 0.4 mm

II. APV tuning (gain, resistivity, noise)

III. APV final results

IV. TIGER stuff

Tuning parameters

Resistivity:

-> increase the cluster size

Noise:

-> increase the cluster size

-> worsen the resolution

-> worsen the efficiency

Gain:

-> increase the charge/saturation

-> increase the cluster size

-> improve the resolution

APV simulation and tuning

Look at the **experimental**

APV
TB 2021
Ar:CO2:CF4
Pitch 400 µm
Resistivity 80 MΩ/❒
HV scan 520-670 V
Gain scan ~ 460-12000

Check it in the simulation

Gain scan [200-15000]

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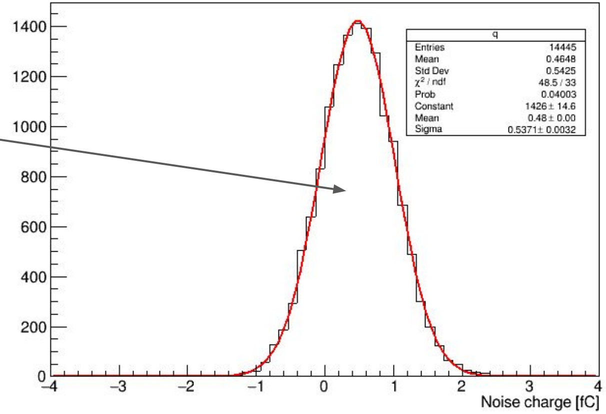
Noise from random trigger run_101/2021

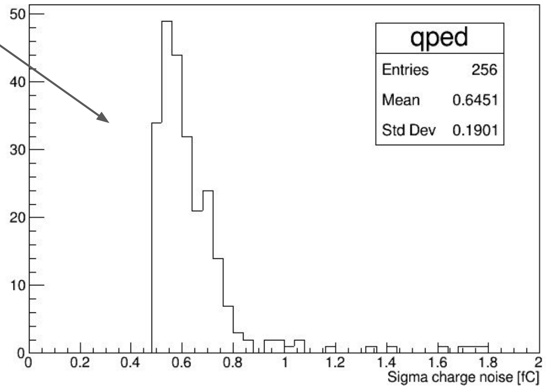
A noise of 0.5 fC is measured from data.

A similar number is evaluated from the pedestal file.

Those information are used in the simulation of the noise and the APV hit selection

- Channel is removed if
  - $Sum(Q_{tb})/Ntb < Pedestal\_stddev * user\_factor$
  - N_{tb} – number of time bins
  - $Q_{tb} = Ped_{mean} - Q_{raw}$
  - user_factor – defined in GUI



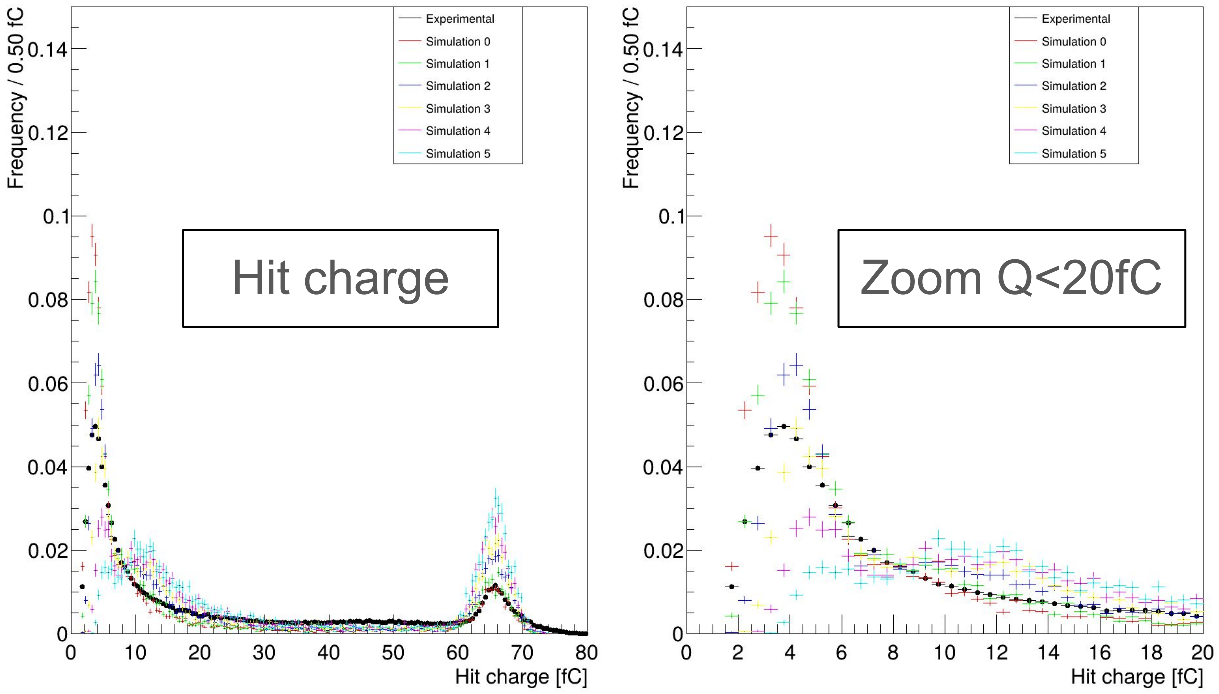


Noise and threshold tuning

It is important to reproduce the hit charge distribution at low charge.

A scan between 0.5 and 5 fC is shown.

1-1.5fC reproduce the effective threshold



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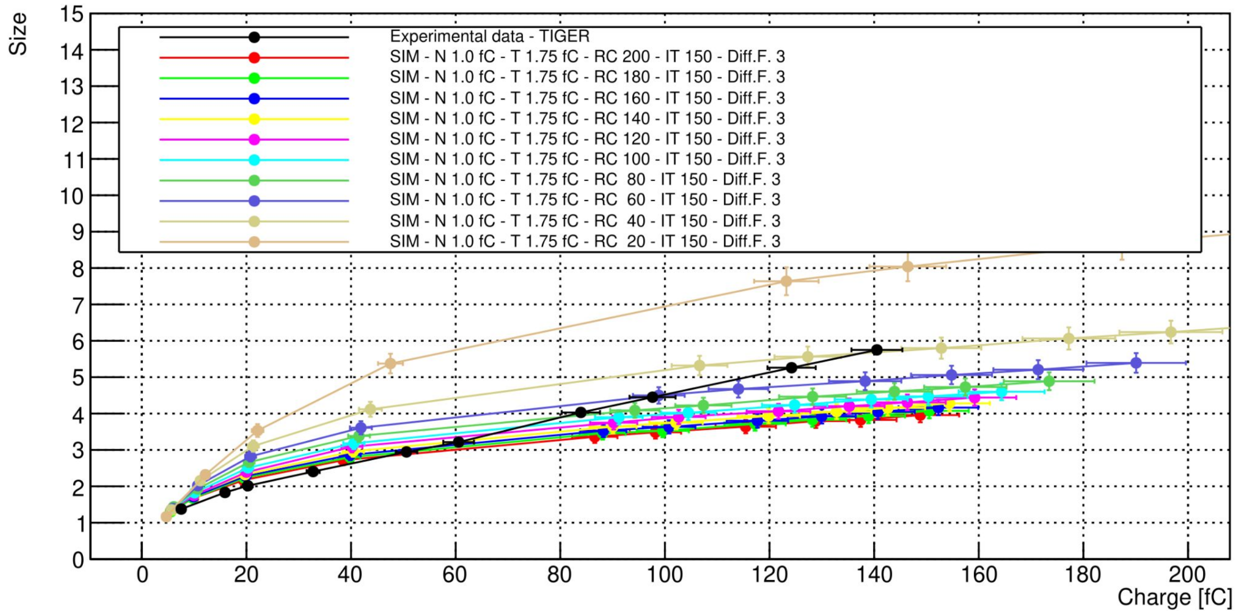
Noise APV

Set APV noise to 1fC

Resistivity scan APV

The larger is the resistivity and the higher is the size.

A fixed value of resistivity cannot reproduce the data…



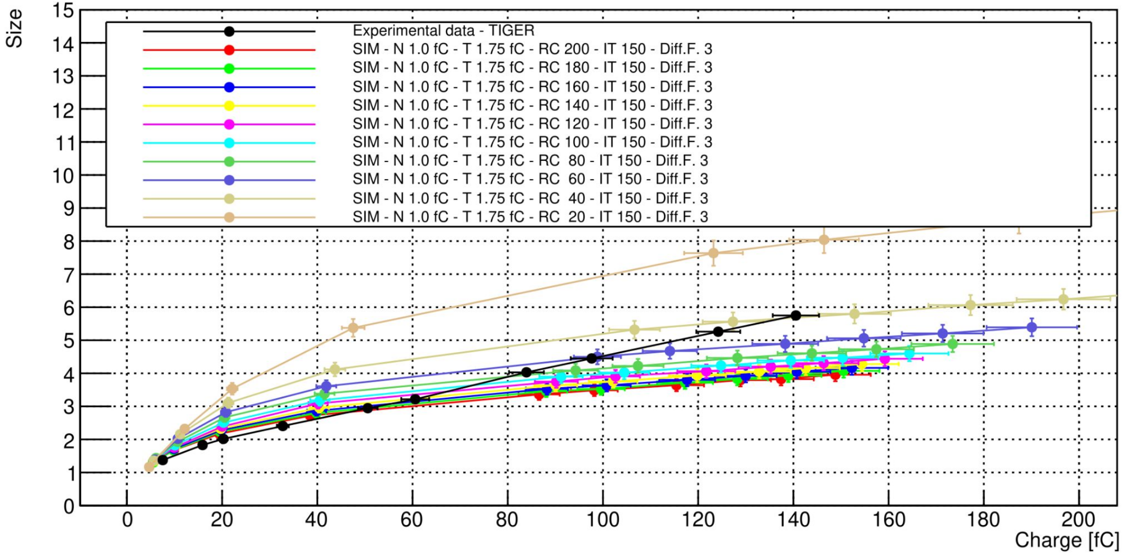
Resistivity scan APV

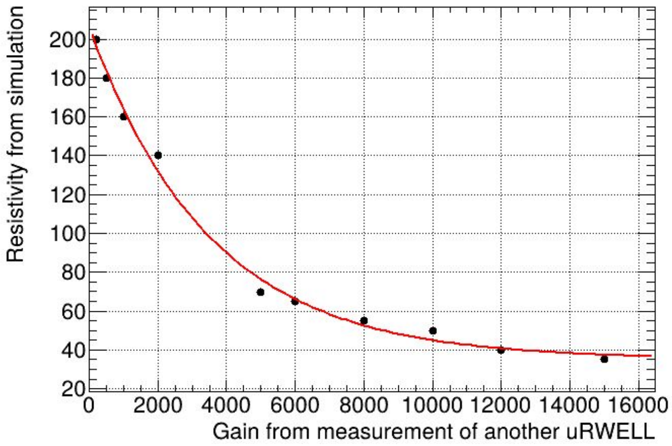
... but different values for resistivity can do it

What happens if the evolution of the charge in the resistive layer depends on the amplitude of the signal?

This behavior is described with an exponential function

It must be discussed with Djunes



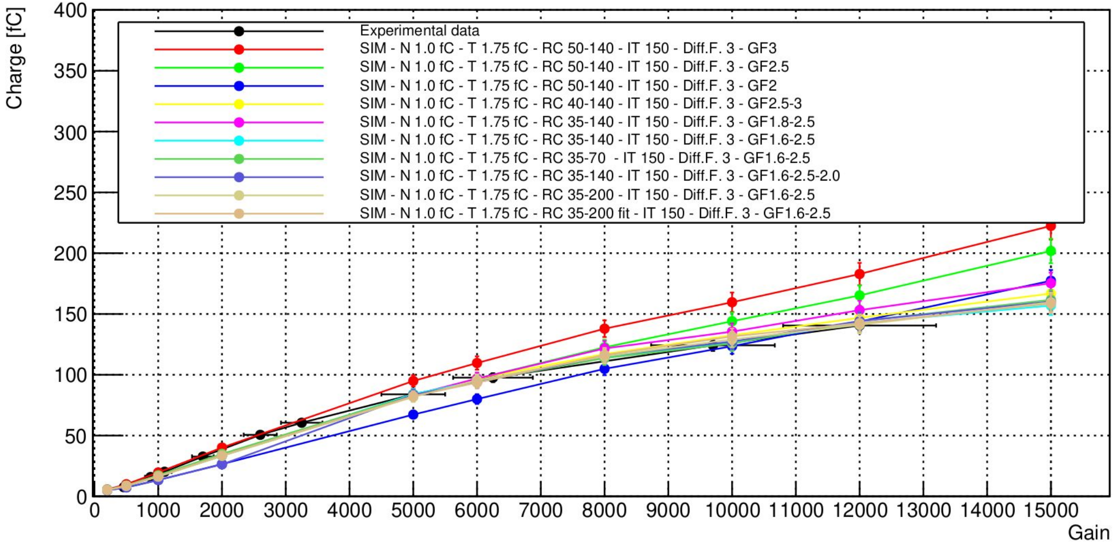


Gain factor tuning

A gain factor of 2.5 was used in triple-GEM

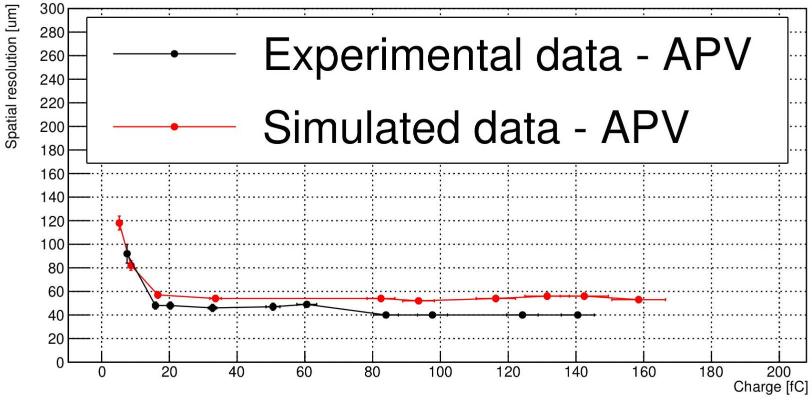
Here a variable value between 2(blue) and 3(red) is needed.

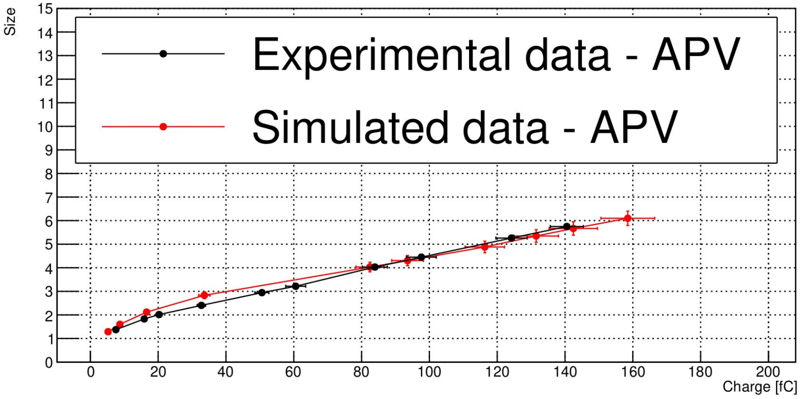
This gain factor differences can be absorbed by the this assumption.

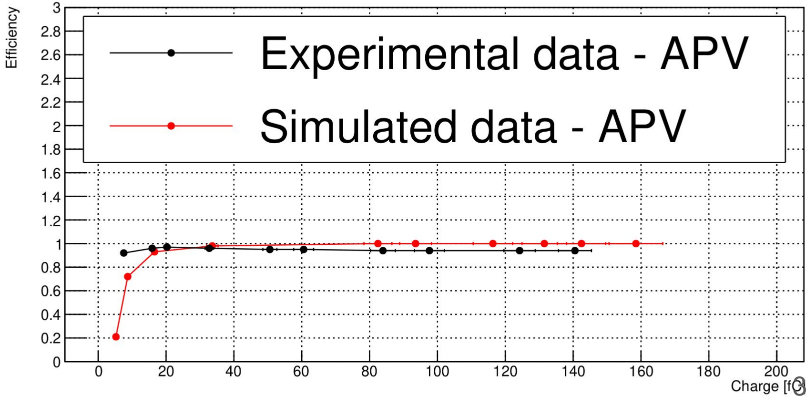


Results APV

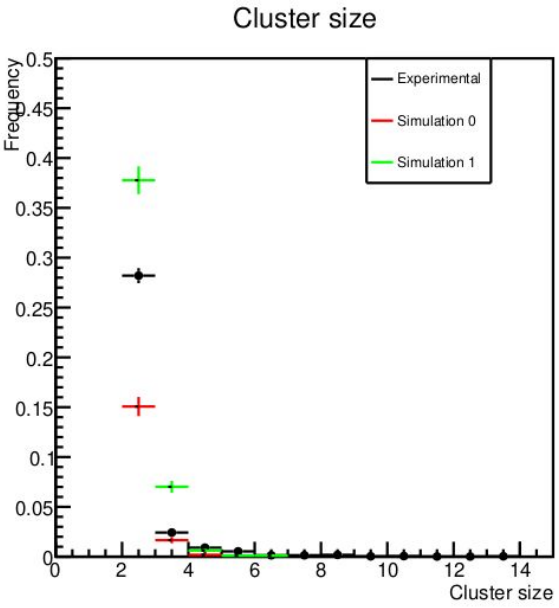
Small discrepancies in the efficiency behavior but charge, size and resolution look nice

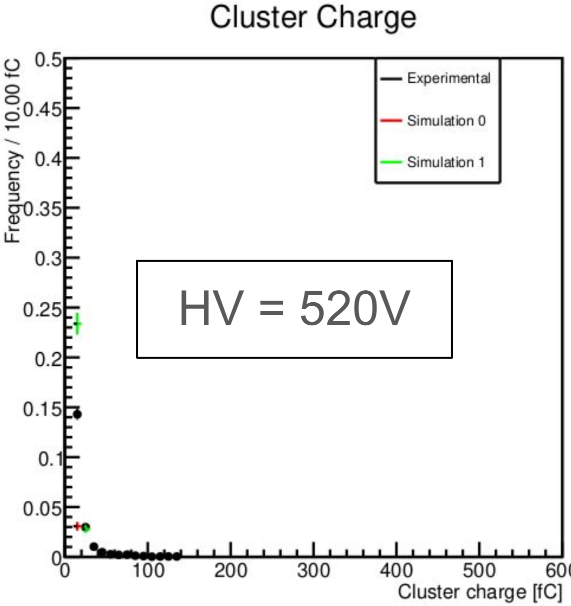


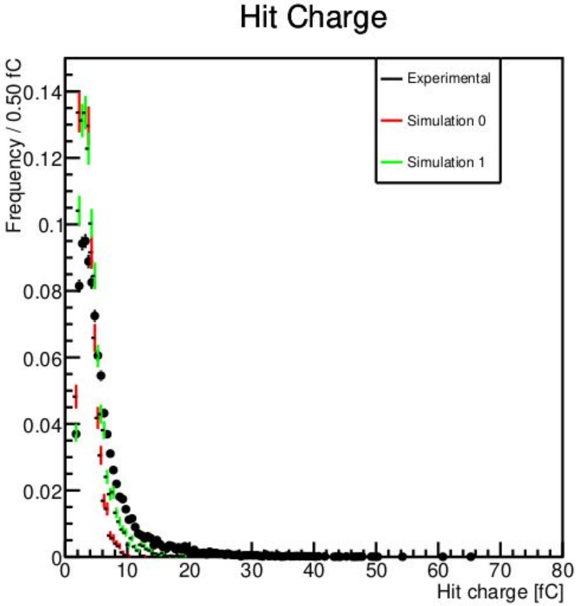




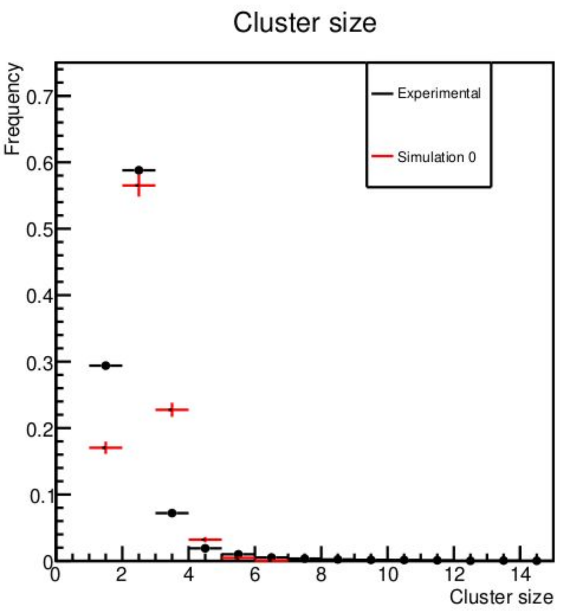
Distribution check on the cluster and hit distribution

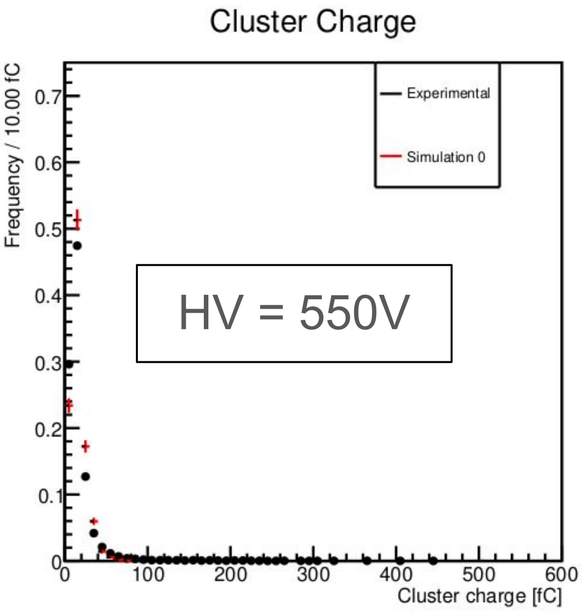


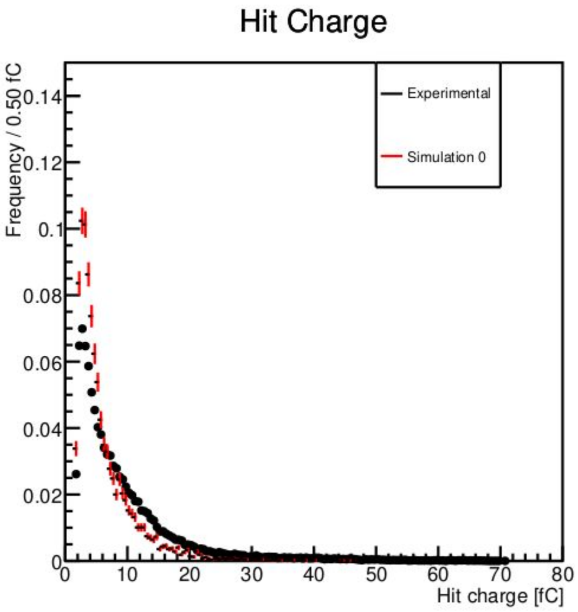




Distribution check on the cluster and hit distribution







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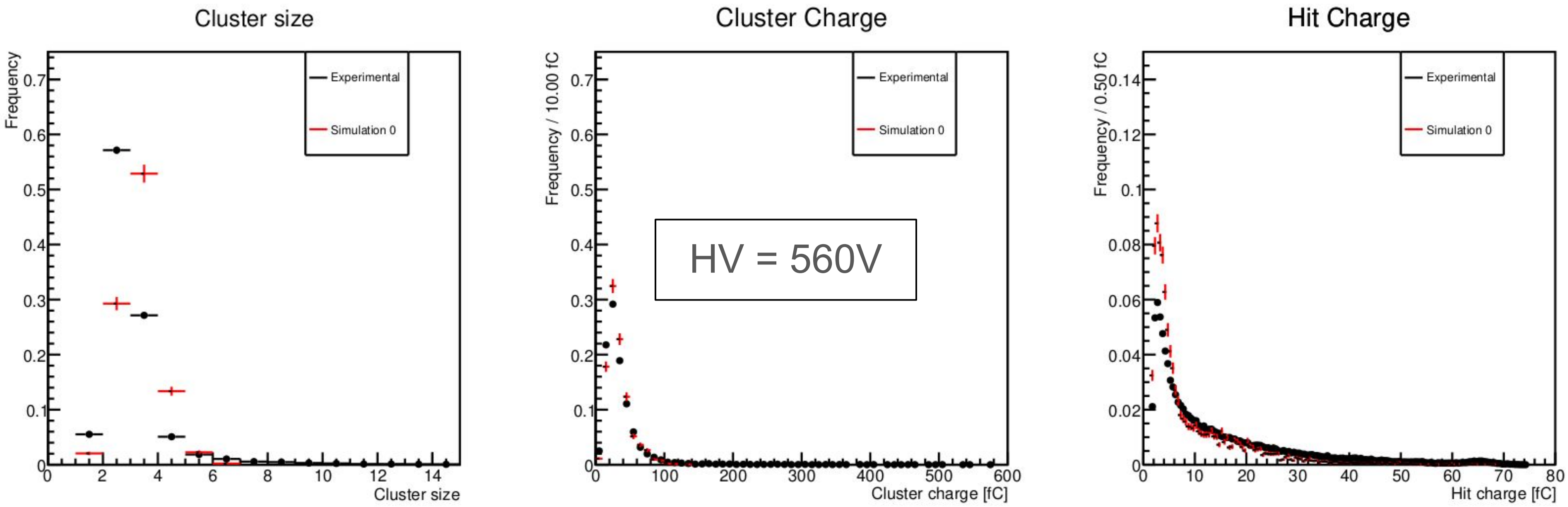
Distribution check on the cluster and hit distribution



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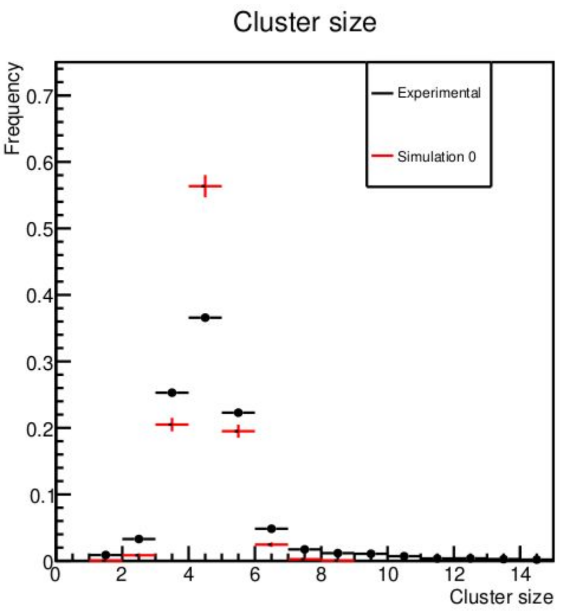

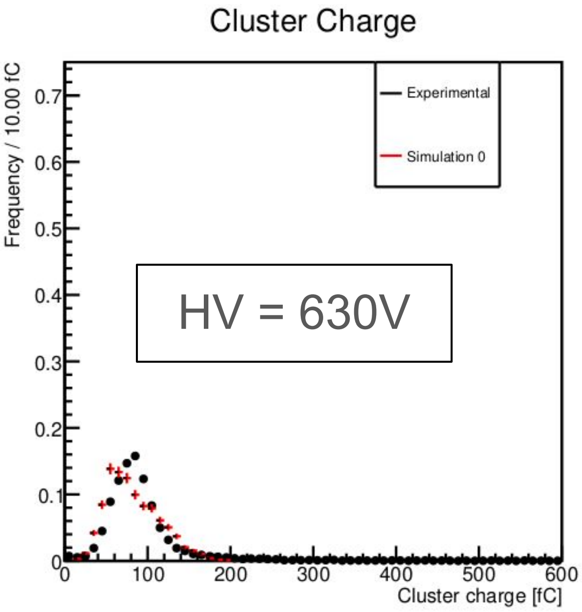

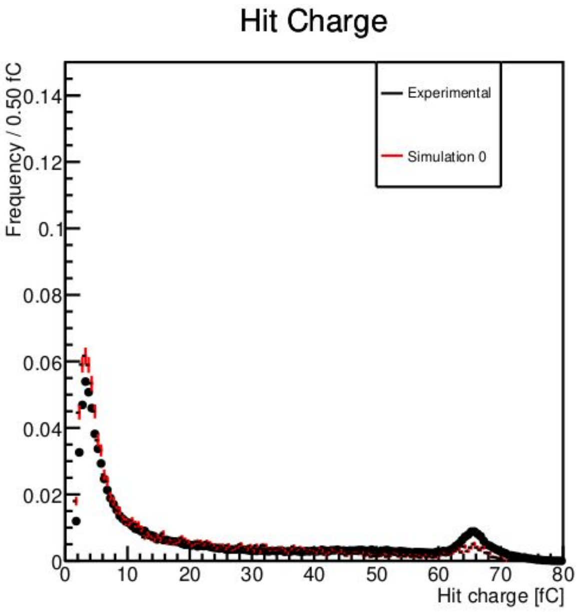

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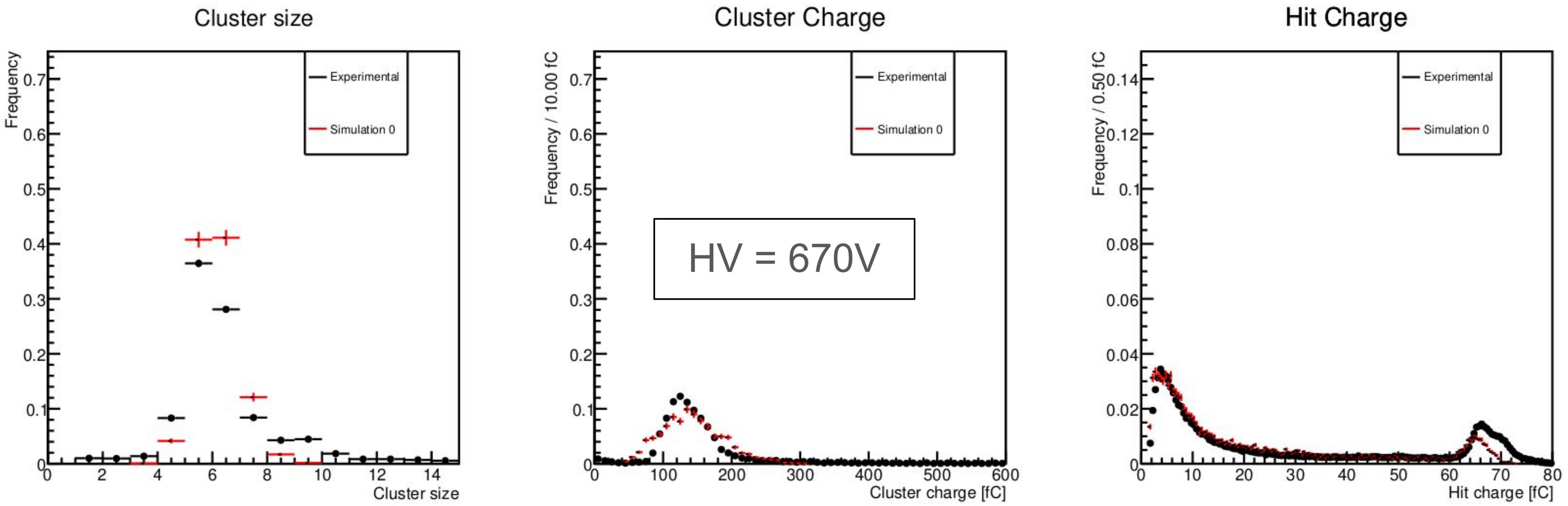
Distribution check on the cluster and hit distribution



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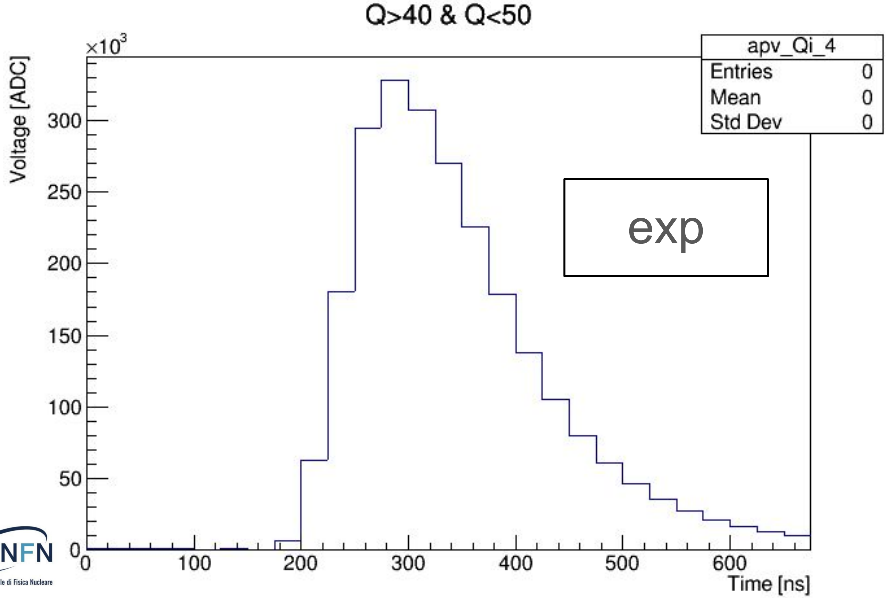
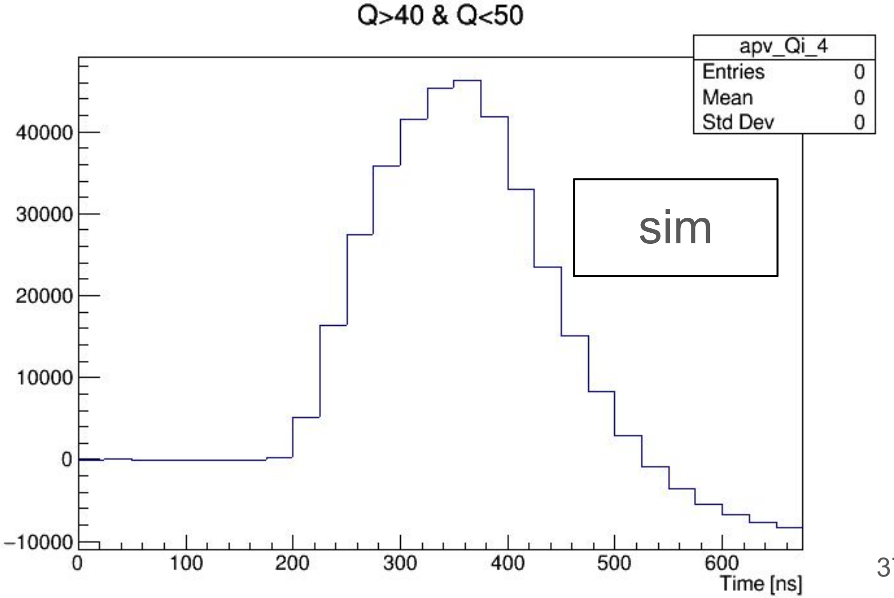
Signal shape APV

The APV samples the hit charge in 27 bin, this allows to check the signal shape.

The signal shape of the two is not properly the same.
Experimental data have a shorted rising edge and a longer falling edge.





Resistive simulation equation

To be tested a different equation, i.e. the one from T2K

$$
\begin{aligned}
Q(t) &= \int_{x_1}^{x_2} \rho(x,t)\mathrm{d}x \\
&= \frac{q}{\sqrt{2\pi}\left[\sigma_0\left(1+\frac{t-t_0}{\tau}\right)\right]} \int_{x_1}^{x_2} \exp\left[-\frac{(x-x_0)^2}{2\sigma_0^2\left(1+\frac{t-t_0}{\tau}\right)^2}\right] \Theta(t-t_0)\,\mathrm{d}x \\
&= \frac{q}{2}\left[\mathrm{erf}\left(\frac{x_2-x_0}{\sqrt{2}\sigma_0\left(1+\frac{t-t_0}{\tau}\right)}\right) - \mathrm{erf}\left(\frac{x_1-x_0}{\sqrt{2}\sigma_0\left(1+\frac{t-t_0}{\tau}\right)}\right)\right] \Theta(t-t_0)
\end{aligned}
$$

Charge diffusion function:

$$
Q_{pad}(t) = \frac{Q_e}{4} \times \left[erf\left(\frac{x_{\text{high}}-x_0}{\sqrt{2}\sigma(t)}\right) - erf\left(\frac{x_{\text{low}}-x_0}{\sqrt{2}\sigma(t)}\right)\right] \times \left[erf\left(\frac{y_{\text{high}}-y_0}{\sqrt{2}\sigma(t)}\right) - erf\left(\frac{y_{\text{low}}-y_0}{\sqrt{2}\sigma(t)}\right)\right]
$$

$$
\sigma(t) = \sqrt{\frac{2t}{RC}}
$$

- Obtained from Telegrapher's equation for charge diffusion.

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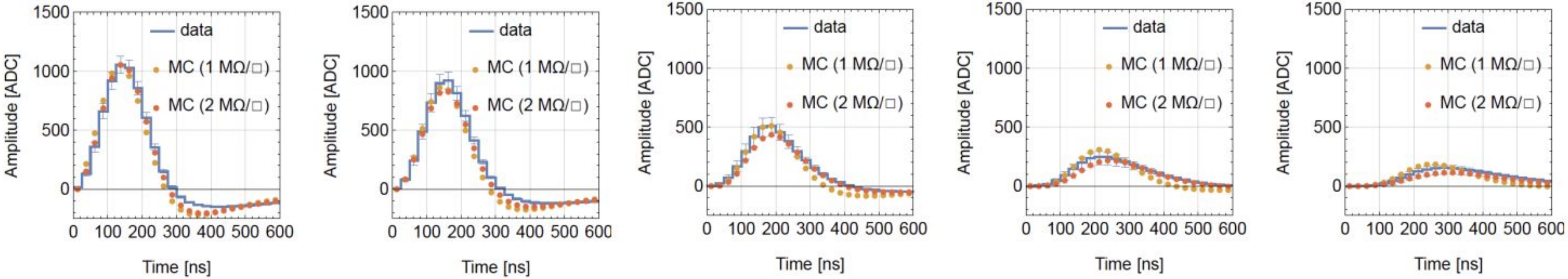
Example from Djunes



TIGER stuff

Experimental data

APV
TB 2021
Ar:CO2:CF4
Pitch 400 μm
Resistivity 80 MΩ/❐
HV scan 400-680 V
Gain scan ~ 30-15000

Keep the same resistive values measured with APV

Procedure:

I. Tune the threshold T and E branches (not present in APV)
II. Tune the gain factor
III. Tune the noise

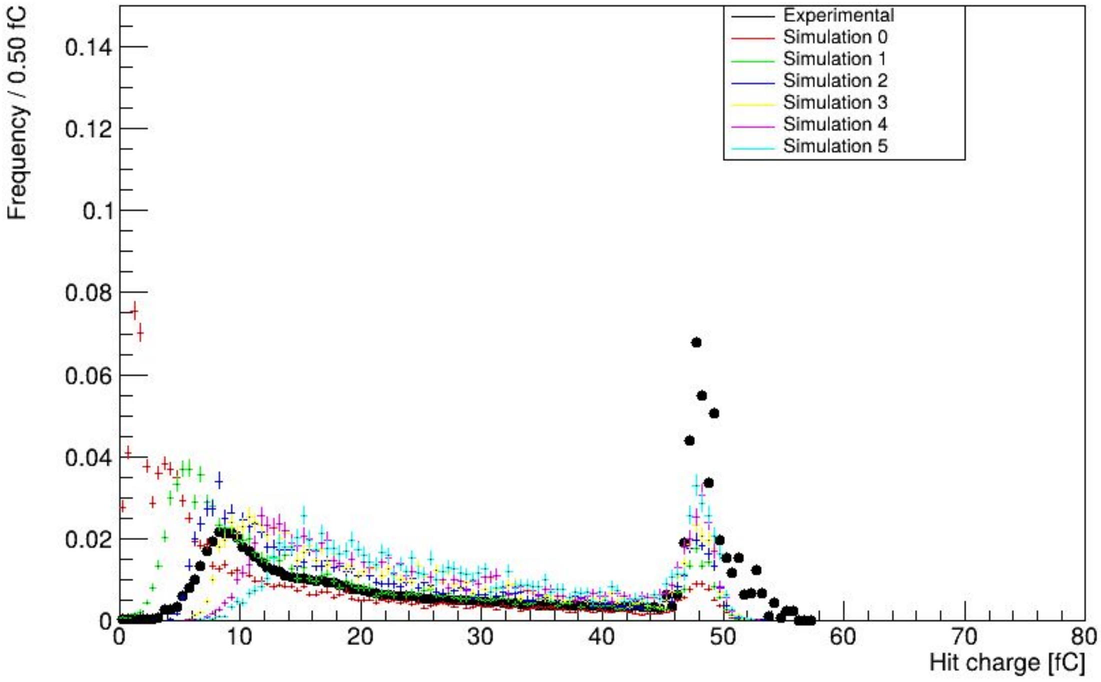
Threshold TIGER E/T branches

Use the hit charge distribution to define the threshold
-> this is **not** the **noise**

The saturation peak is not well described

The threshold of 4-6 fC describe better the data

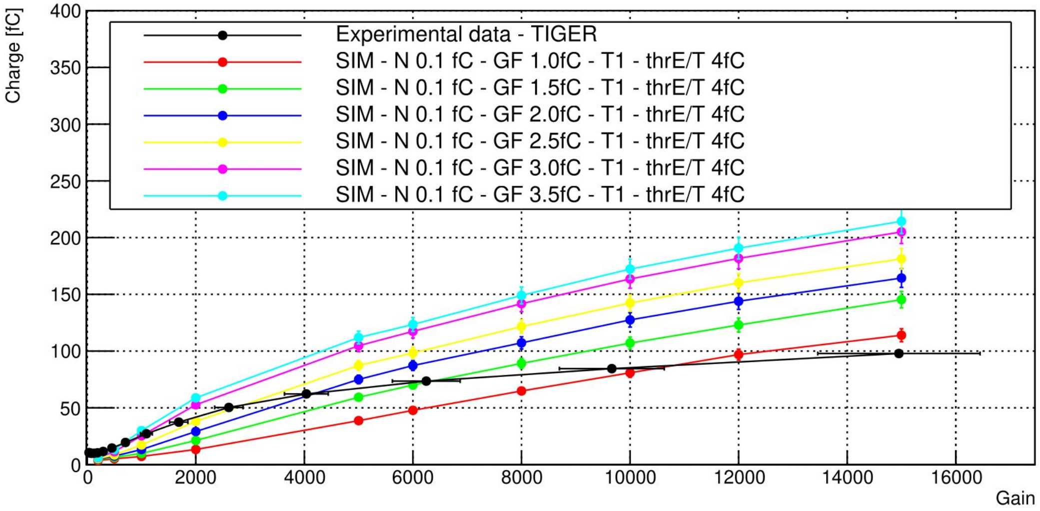
-> **Set the threshold to 6 fC**



Gain factor tuning

Looking at the Charge vs Gain curve a unique gain value cannot be used but several ones.

A value between 1 and 3.5 is chosen as in the APV tuning procedure



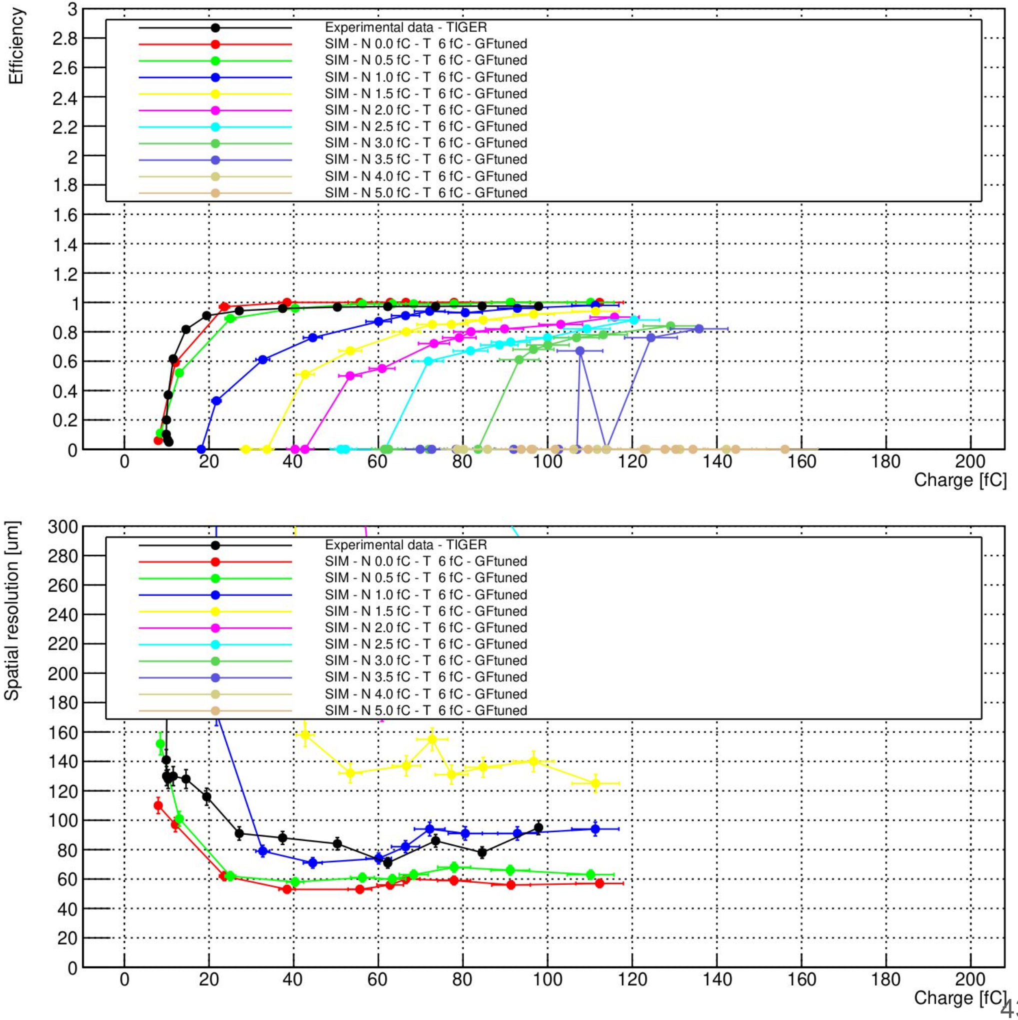
Noise TIGER

Several plot can be used to tune the noise.

Every small change in noise/gain/threshold has an impact on all the variable used as benchmark: charge/size/efficiency/resolution

A value between 0.5 and 1 fC noise is chosen.

I need to check the noise calibration curves for the TIGER. This value **could be 3.5 time larger**.



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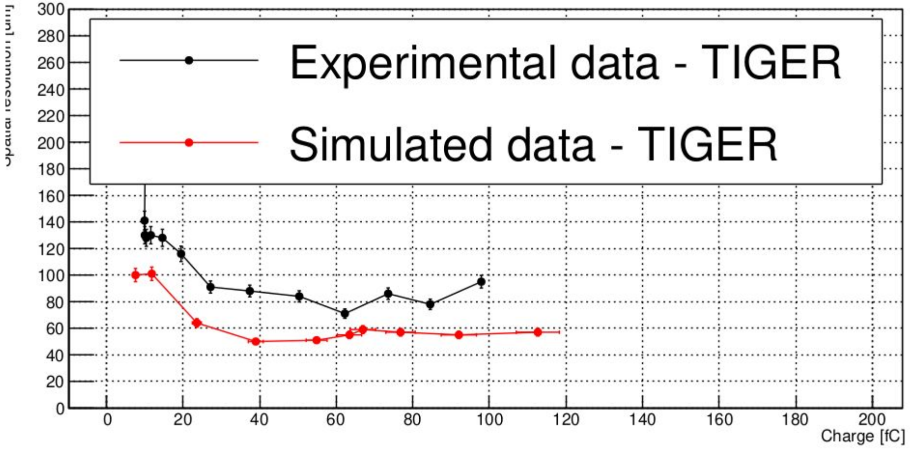
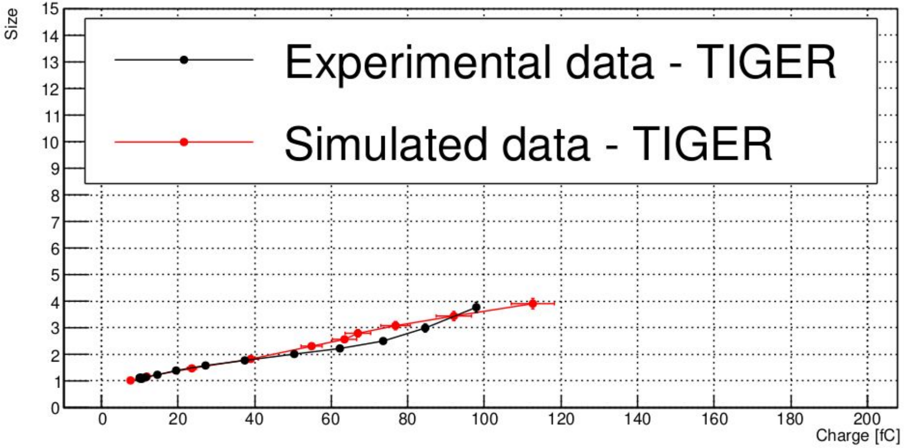
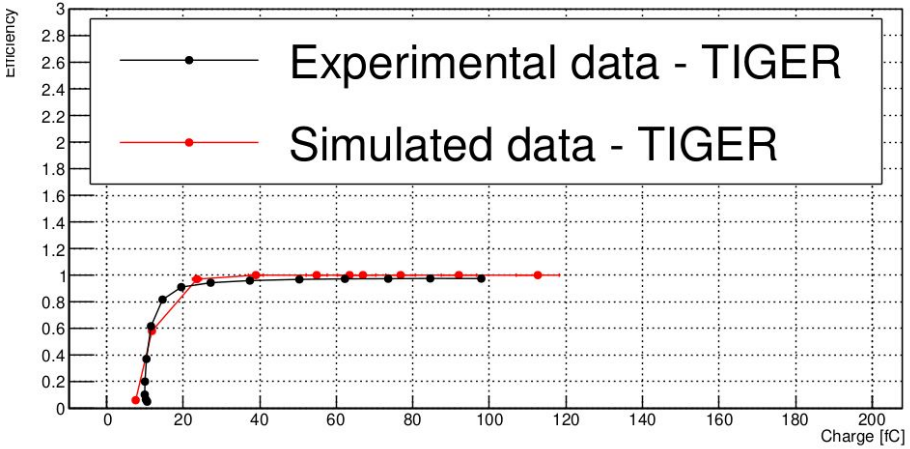
Results TIGER







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Next step on APV side

1. Extend the tuning of the APV to the other dataset
    a. Pitch 0.4 / 0.8 / 1.2 / 1.6 mm
    b. Resistivity 10 / 40 / 80 MΩ/❒

… comments?

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Next step TIGER

2. Scan in sampling time (Tpeak) and electron drift velocity
   a. noise
   b. charge collected linearity
   c. time-walk
   d. performance (eff, σ_space, σ_time)
3. Charge dynamic range
   a. saturation
   b. charge collected linearity
   c. performance (eff, σ_space, σ_time)

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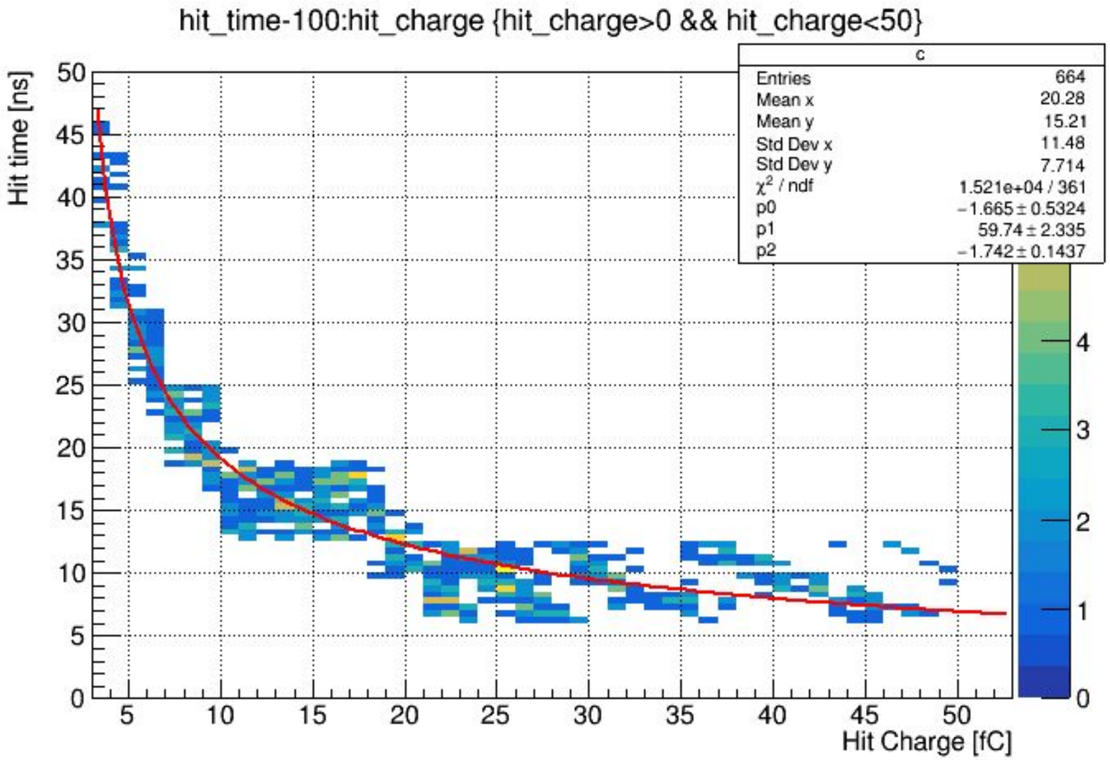
Next next

4. Pole-zero cancellation
5. Multi sampling like electronics (APV)
    a. shaping time scan
6. Time measurement with double threshold
    a. time-walk measurements
7. Time bin (≠6.25 ns)
8. Charge sensibility (≠10 bit)

µRWELL+TIGER: timewalk studies



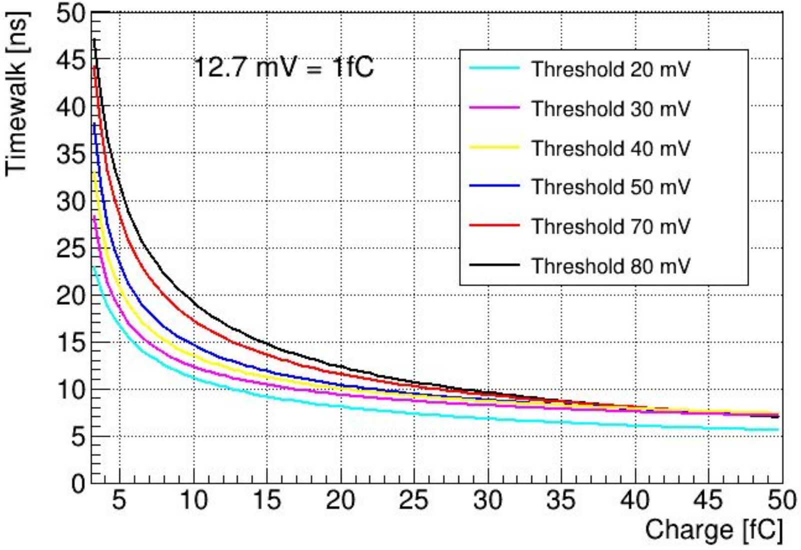
Simulation of a single electron ionization at fixed time and different gains.

The fitting line describe the time shift due to the time-walk.

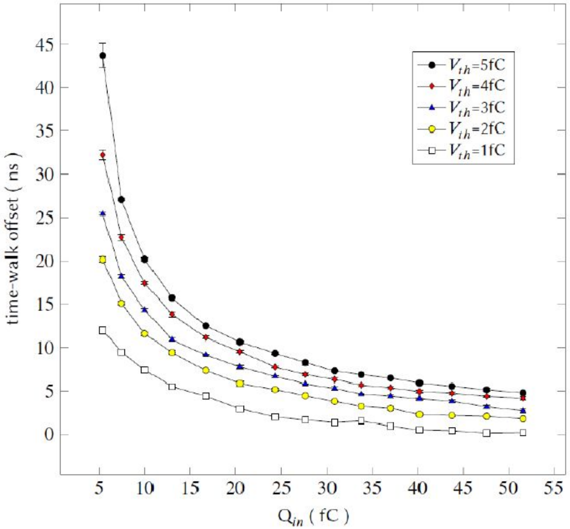
Threshold used: 80-80

μRWELL+TIGER: timewalk studies

SIM

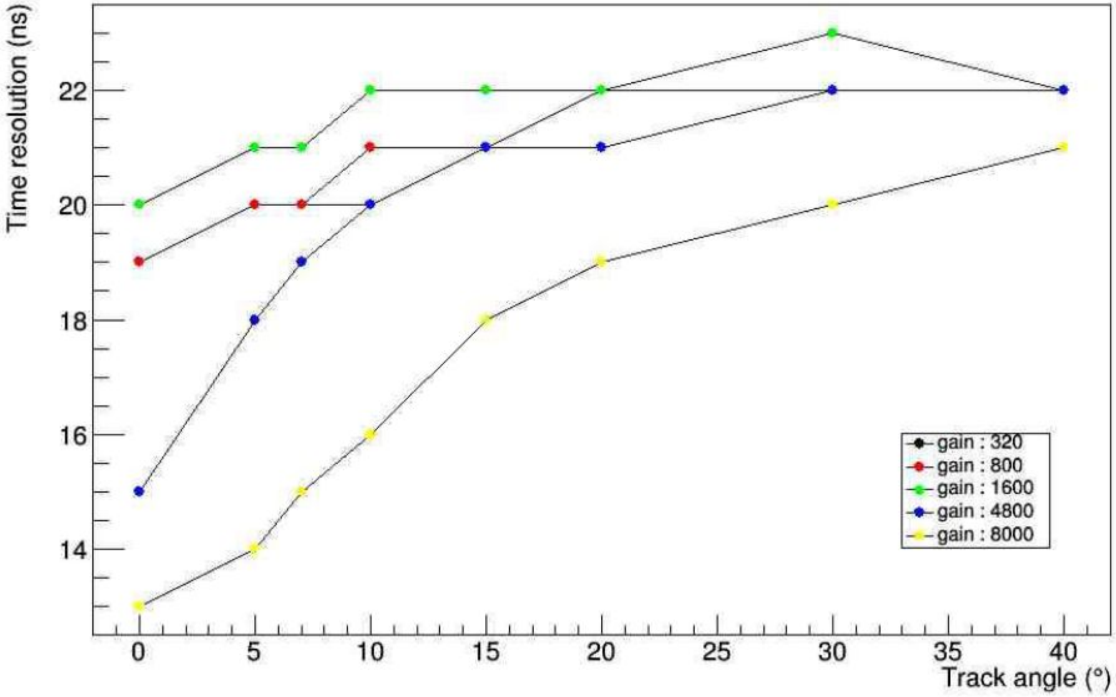


DATA

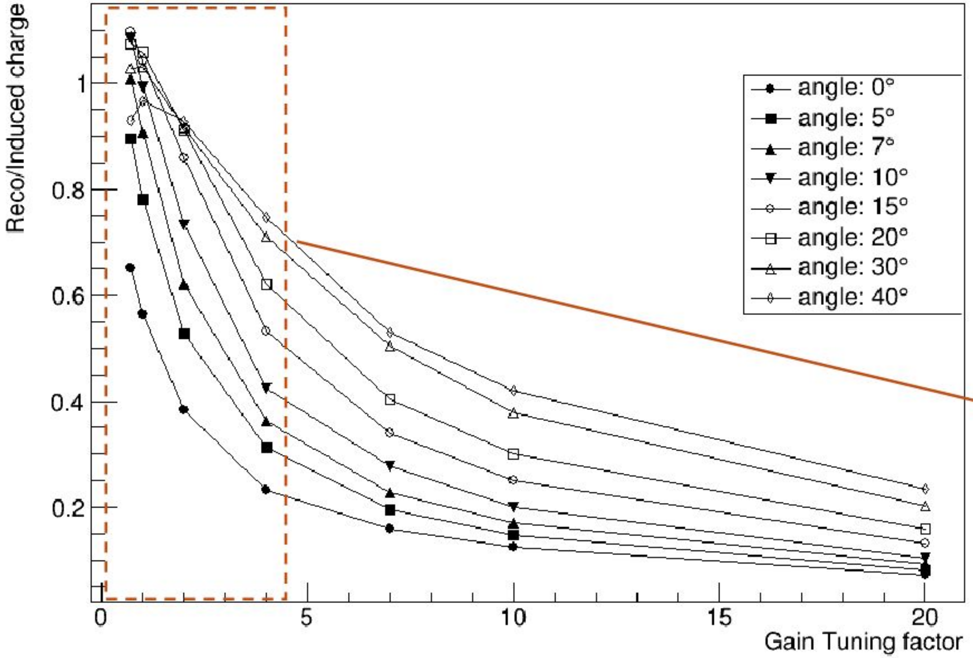


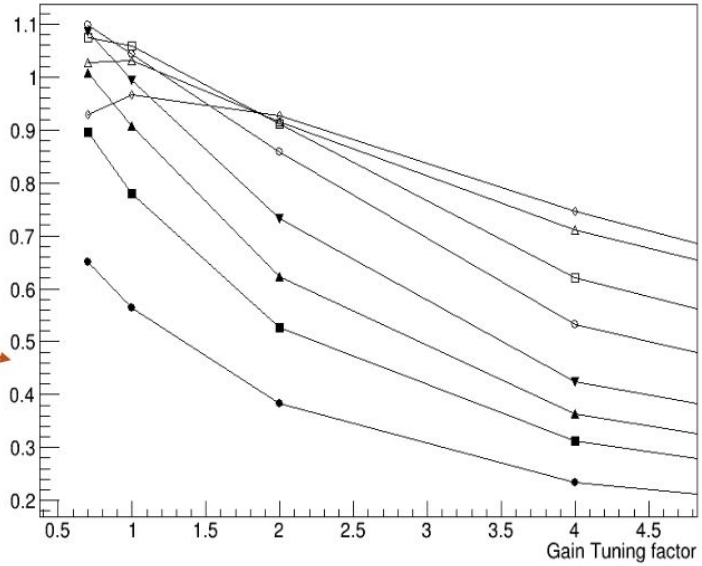
Compatible results have been obtained.

Time resolution



Reconstructed/Induced charge vs Gain





Conclusion

- A first **parametrized simulation** of a **μ-RWELL** detector with APV and TIGER electronics has been completed.

- The simulated results show **good agreement** with experimental data in terms of charge, cluster size, efficiency, and spatial resolution—both in average values across the HV scan and in the cluster/hit distributions for individual runs.

- The simulation relies on **two key assumptions** used to tune the data, which require further discussion within the DRD1 community.

- Additional improvements are expected by **refining the resistive modeling** of the signal shape for individual events (APV response).

- This simulation framework will be used in **upcoming studies to optimize** the performance of candidate readout electronics for μ-RWELL detectors.

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