PARSIFAL

parametrized simulation of triple-GEM and μ-RWELL response to a charged particle

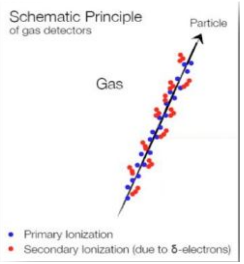
R. Farinelli on behalf of the working group

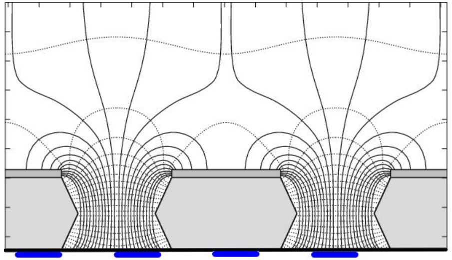
Outline

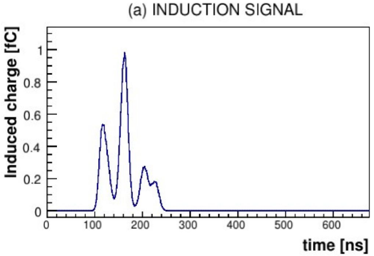
1. Starting point: GARFIELD++
2. From the parametrization to PARSIFAL
3. Detector simulation

MPGD detectors: triple-GEM and μ-RWELL

Micro Pattern Gaseous Detector measure the ionization signal released by charged particle and it reconstruct time and position. The detection technique is similar:



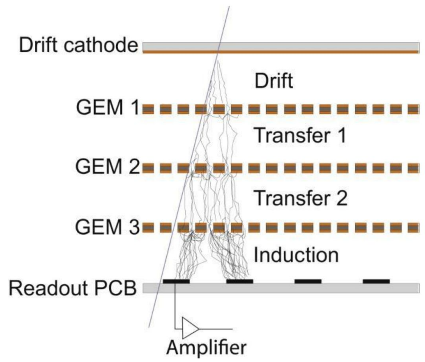


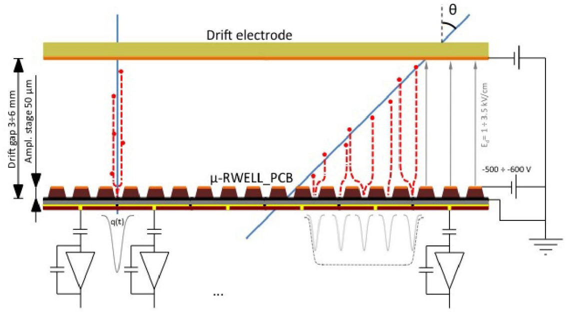


Ionization

Drift and amplification

Induction





Triple-GEM peculiarities:
- three amplification stages

μ-RWELL peculiarities:
- single stage amplification
- resistive layer before the readout

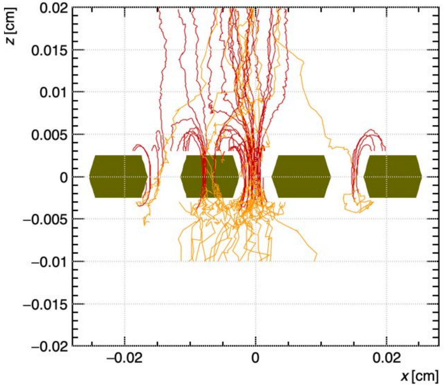
State of art for gas detectors simulation

Garfield++ is a toolkit for the detailed simulation of detectors which use gases or semiconductors as sensitive medium.

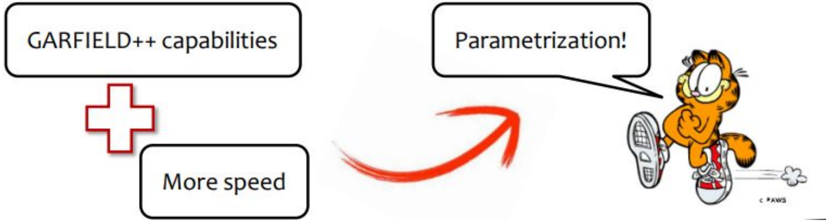
Ionisation -> Heed generates ionisation patterns of fast charged particles

Electric fields -> interfaces with the finite element programs (Ansys, Elmer, Comsol and CST) which can compute approximate fields in nearly arbitrary 3D configurations with dielectrics and conductors

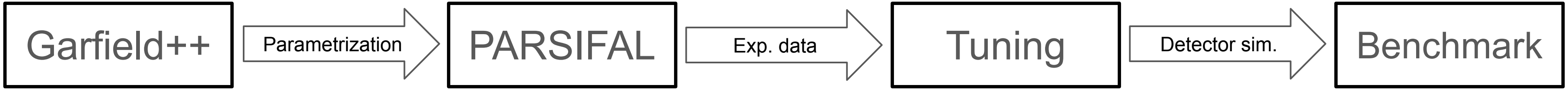
Transport of electrons -> Magboltz is used for computing electron transport and avalanches in nearly arbitrary gas mixtures



We tried to run the complete simulation of a triple-GEM but it took about **one day** for a triple-GEM



PARSIFAL in a nutshell



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 <u>main processes</u>
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. Let’s check the goodness of the simulation.

Ionization

Electron drift

Amplification

Resistive

Induction

Readout

Reconstruction

The next slides will summaries

the **parametrization**

of the **main processes**

involved in an MPGD

The parametrization

Ionization

Electron drift

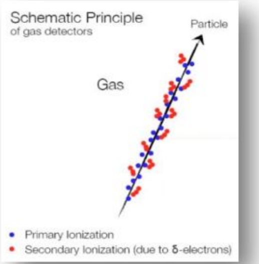
Amplification

Resistive

Induction

Readout

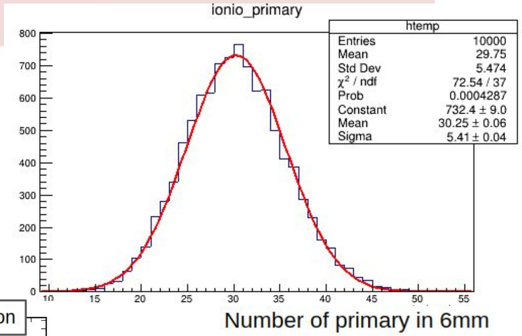
Reconstruction



- **primary ionization** – Poissonian process
  → *relative position* from exponential distribution
  → the number of the ionizations follows
- **secondary ionization** – from tables [F.Sauli (1977) *Principles of Operation of Multiwire Proportional and Drift Chambers*; A. Sharma *Properties of some gas mixture used in tracking detectors*]
  → consistent with GARFIELD++ simulations

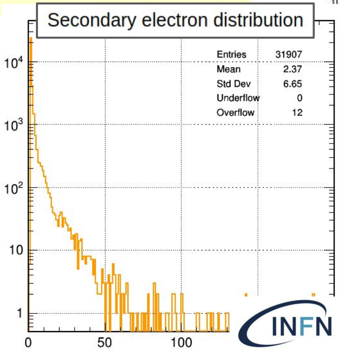
Simulations

Electron clusters were extracted for M.I.P. (150 GeV/c muons) → will be extended to other particles and energies



Two approximations

- ionization electrons generated only in the drift gap
- secondary electrons with the same origin of the primaries



The parametrization

Ionization

Electron drift

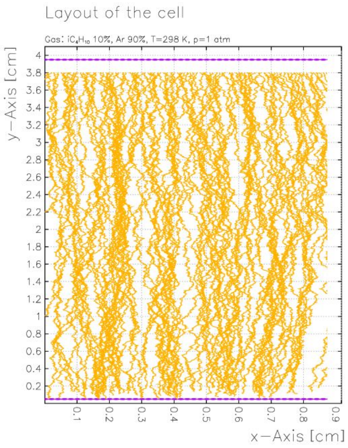
Amplification

Resistive

Induction

Readout

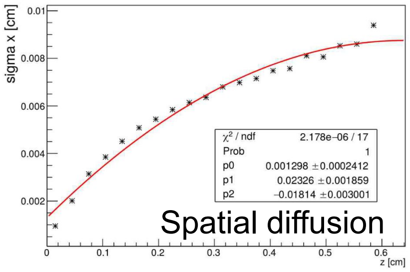
Reconstruction

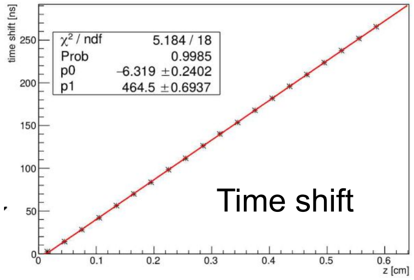


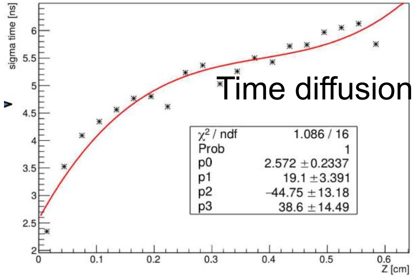
Drift gap

- The ionization position is different from electron to electron → **z dependence** of spread and sigma of position distribution

- Analogous behavior for time distribution







The parametrization

- Ionization
- Electron drift
- **Amplification**
- Resistive
- Induction
- Readout
- Reconstruction

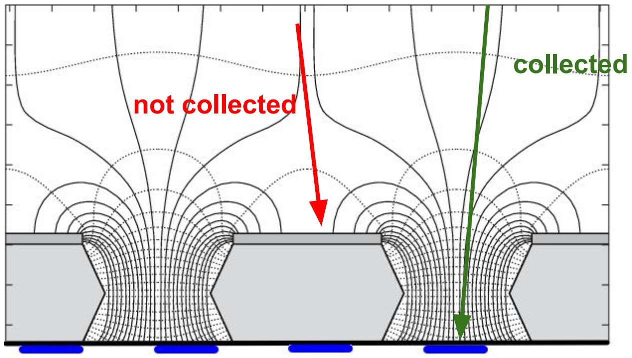
Gain fluctuations → Polya distribution

[G. Iakovidis PhD Thesis, Research and Development in Micromegas Detector for the ATLAS Upgrade]

$$P(G) = C_0 \frac{(1+\theta)^{1+\theta}}{\Gamma(1+\theta)} \left(\frac{G}{\overline{G}}\right)^{\theta} \exp\left[-(1+\theta)\frac{G}{\overline{G}}\right]$$

$\overline{G}$ = intrinsic gain mean value

θ → connected to variance



ELSEVIER
Available online at www.sciencedirect.com
ScienceDirect
Nuclear Instruments and Methods in Physics Research A 566 (2006) 281–285
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

The parametrization

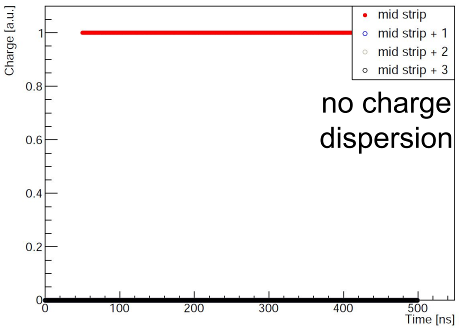
Simulating the charge dispersion phenomena in Micro Pattern Gas Detectors with a resistive anode

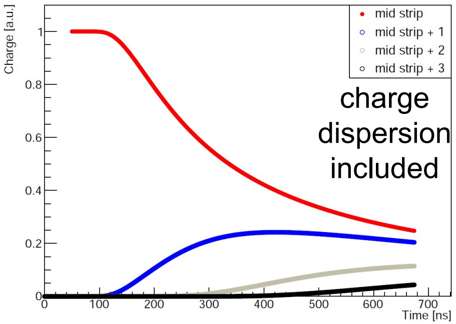
M.S. Dixit[a,b,*], A. Rankin[a]

- Ionization
- Electron drift
- Amplification
- **Resistive** — ONLY μ-RWELL
- Induction
- Readout
- Reconstruction

customized for strip 1D

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





The parametrization

Ionization

Electron drift

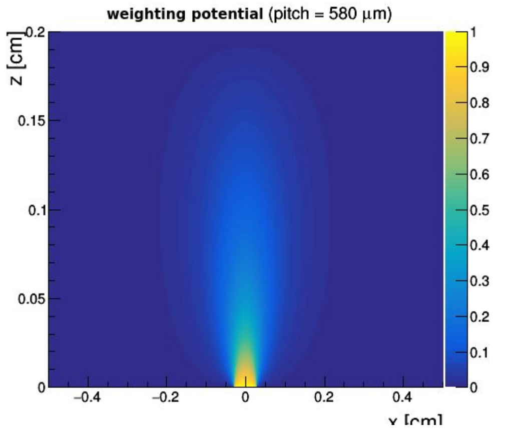
Amplification

Resistive

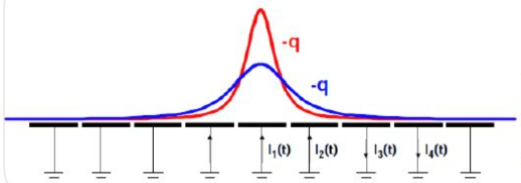
Induction

Readout

Reconstruction



$$i_{ind}(t) = e \cdot \overline{v}_{drift}(t) \cdot \overline{E}_w(t)$$



[W. Riegler, CERN seminar]

The current induced on a strip on the anode:
- depends on the position
- ends when the electron arrives on the strip

The parametrization

Ionization

Electron drift

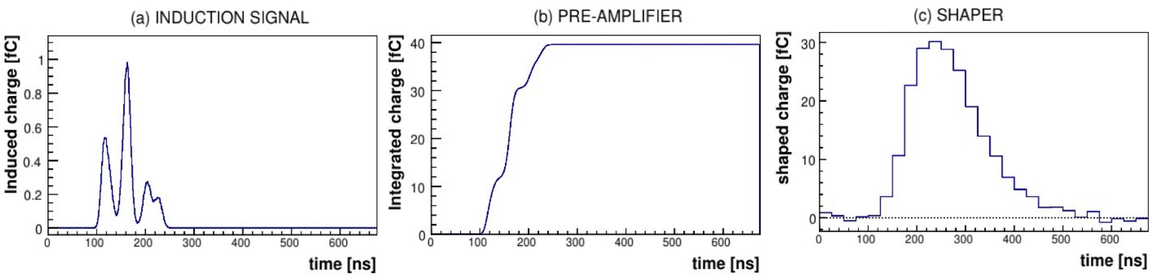
Amplification

Resistive

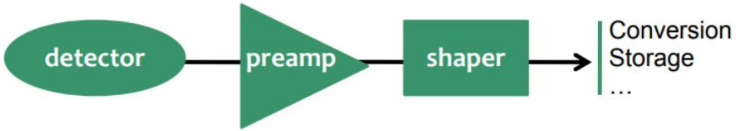
Induction

Readout

Reconstruction



APV-25 ASIC simulation



1. **Detector induction** → simulate the induced *dq* in 1 ns time steps
2. **Pre-amplifier** → ∀ time step, add *dq* to the integrated charge
3. **Shaper** → create 27 functions (one for each APV-25 time bin, 25 ns each)

CR-RC with τ = 50 ns $h(t) = S_p \times \frac{t-t_0}{\tau} exp(-\frac{t-t_0}{\tau})$

→ get the induced charge in each 25 ns and apply the transfer function

∀ time bin, evaluate all the previous function @ t_i and sum them up!

Compute noise → ∀ time bin, sample from Gaussian (μ, σ) → add to the charge

The parametrization

Ionization

Electron drift

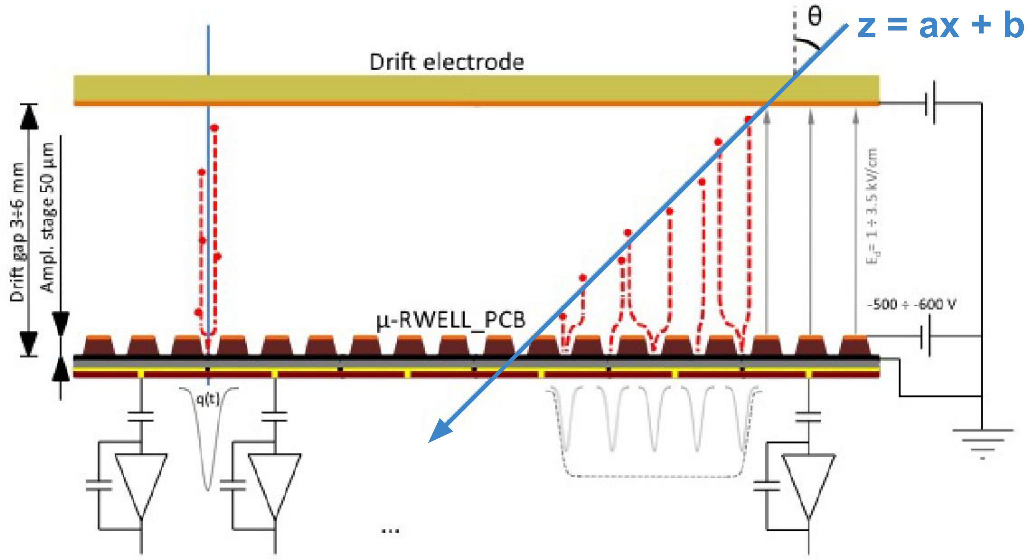
Amplification

Resistive

Induction

Readout

Reconstruction



$$x = \frac{\sum x_i * q_i}{Q_{TOT}}$$

$$x = \frac{\frac{gap}{2} - b}{a}$$

Now **simulate** a lot of events

and

compare the detectors performance with a **testbeam**

to

tune the simulation on the experimental data

RD51 testbeam
- H4 beam line, SPS-NA (CERN)
- GOLIATH dipole magnetic field
- 150 GeV/c muons

Triple-GEM tuning: gain and diffusion

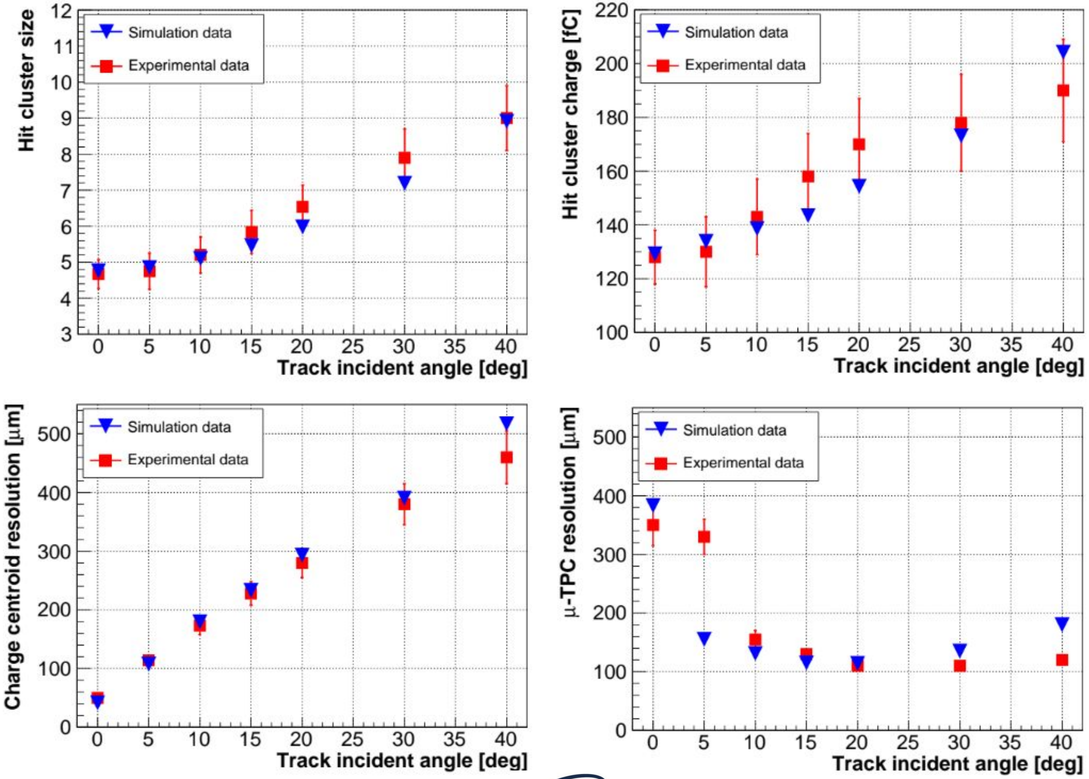
triple-GEM specifics
- planar triple-GEM, 10 x 10 cm²
- double view readout, APV-25
- gas: Ar:*i*-C_4H_{10} (90:10)
- HV: 275/275/275 V
- fields: 1.5/2.75/2.75/5 kV/cm
- magnetic field *off* or *on* (B = 1T)
- incident angle: 0°, 5°, 10°, 15°, 20°, 30°, 45°

Let's focus on the tuning on the **detector response** agreement between data and simulation.

Check the consistency between simulation and real data, due to various approximations applied.

Measure **four reconstructed variables of interest** to tune the detector gain and the electron diffusion.

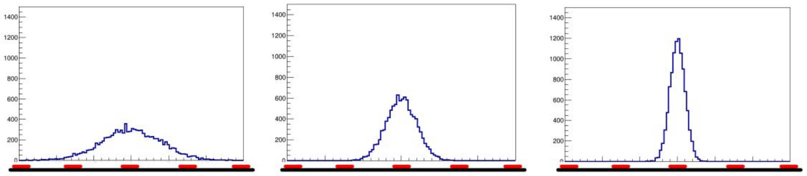
The performance study is performed **as a function of the incident angle** to access at the behavior of interest.



μ-RWELL tuning: resistivity

Charge distribution example

low ρ

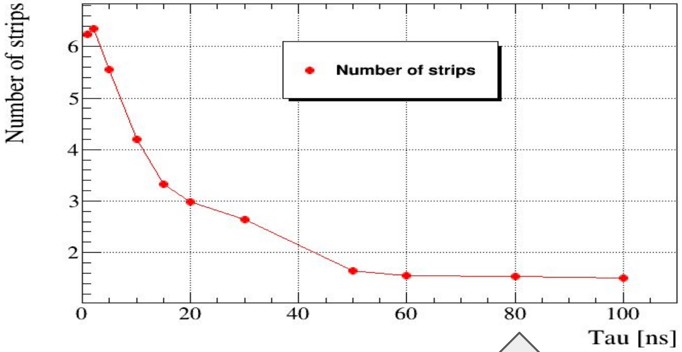


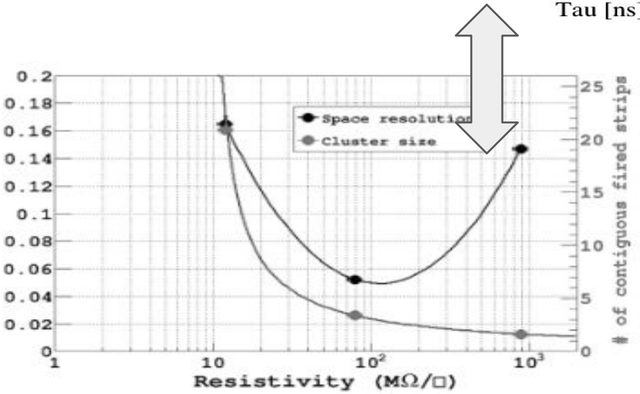
high ρ

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.



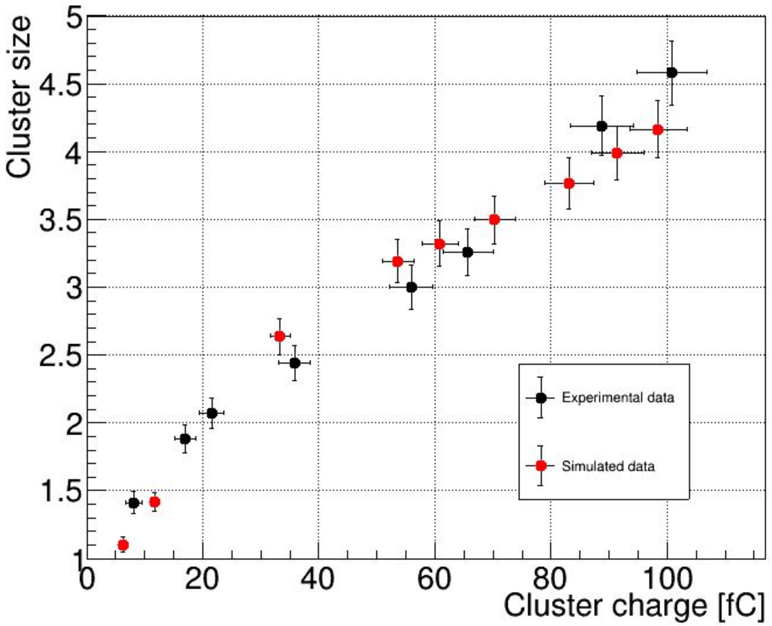


μ-RWELL tuning: resistivity

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.



- email
- GIT
- article

Conclusion

PARSIFAL, a simulation tool for **MPGD**: triple-GEM and μRWELL.

Its output has been **tuned** with experimental results and the agreement is good.

PARSIFAL **time consumption is much lower** than GARFIELD++ one, due to less detail in physics process description.

Fast simulation of MPGD with similar configurations can be used to study the detector performance and physics decay benchmarks.

Actually PARSIFAL is used to simulate several MPGD detectors:

1. Cylindrical Triple-GEM as Inner Tracker for BESIII/BEPCII
2. Cylindrical μ-RWELL as Inner Tracker for tau-charm factories
3. Pre-shower and muon system for IDEA/FCC-ee

Thank You

This research is funded by the following Grants agreement ID

AIDAinnova: 101004761
EURIZON H2020: 871072
FEST: 872901

European Commission

eurizon
European network
for developing new horizons for RIs