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
Micro Pattern Gaseous Detectors (MPGD) measure the ionization signal released by charged particles and reconstruct time and position. The detection technique is similar:

**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** \(\rightarrow\) **Heed** generates ionisation patterns of fast charged particles

**Electric fields** \(\rightarrow\) 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** \(\rightarrow\) **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.

![Garfield++ capabilities](image)

![Parametrization!](image)

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PARSIFAL in a nutshell

Garfield++ → Parametrization → PARSIFAL → Exp. data → Tuning → Detector sim. → Benchmark
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. Let’s check the goodness of the simulation.
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

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

- **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

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Drift gap

- The ionization position is different from electron to electron $\rightarrow z$ dependence of spread and sigma of position distribution
- Analogous behavior for time distribution
The parametrization

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Gain fluctuations → Polya distribution

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

\[ \bar{G} = \text{intrinsic gain mean value} \]
\[ \theta \to \text{connected to variance} \]
The parametrization

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

M.S. Dixit¹,h,*, A. Rankin¹

\[ Q(t) = \int_{x_1}^{x_2} \rho(x,t)dx \]

\[ = \frac{q}{\sqrt{2\pi} \left[ \sigma_0 \left( 1 + \frac{t-t_0}{\tau} \right) \right]} \int_{x_1}^{x_2} \exp \left[ -\frac{(x-x_0)^2}{2\sigma_0^2 \left( 1 + \frac{t-t_0}{\tau} \right)^2} \right] \Theta(t-t_0) dx \]

\[ = \frac{q}{2} \left[ \text{erf} \left( \frac{x_2 - x_0}{\sqrt{2}\sigma_0 \left( 1 + \frac{t-t_0}{\tau} \right)} \right) - \text{erf} \left( \frac{x_1 - x_0}{\sqrt{2}\sigma_0 \left( 1 + \frac{t-t_0}{\tau} \right)} \right) \right] \Theta(t-t_0) \]

customized for strip 1D

ONLY µ-RWELL

no charge dispersion

charge dispersion included
The parametrization

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\[ i_{\text{ind}}(t) = e \cdot \bar{v}_{\text{drift}}(t) \cdot \bar{E}_w(t). \]

[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
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Reconstruction

APV-25 ASIC simulation

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

$ h(t) = S_p \times \frac{t-t_0}{\tau} exp\left(-\frac{t-t_0}{\tau}\right) $  

$ \rightarrow $ 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 $\rightarrow$ ∀ time bin, sample from Gaussian ($\mu, \sigma$) $\rightarrow$ add to the charge
The parametrization

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\[ z = ax + b \]

\[ x = \frac{\sum x_i \cdot q_i}{Q_{TOT}} \]

\[ x = \frac{\text{gap}}{a} - b \]
Now simulate a lot of events and compare the detectors performance with a testbeam to tune the simulation on the experimental data.
Triple-GEM tuning: gain and diffusion

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

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.
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.
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
This research is funded by the following Grants agreement ID

AIDAinnova: 101004761
EURIZON H2020: 871072
FEST: 872901