LAB 8 and 9: Detector Simulations

Advanced Simulations in Gaseous Detectors: From Field Configurations to Signal Induction

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Introduction to simulations

Simulations play a crucial role in the design, optimization, and analysis of devices and physical phenomena across multiple disciplines.

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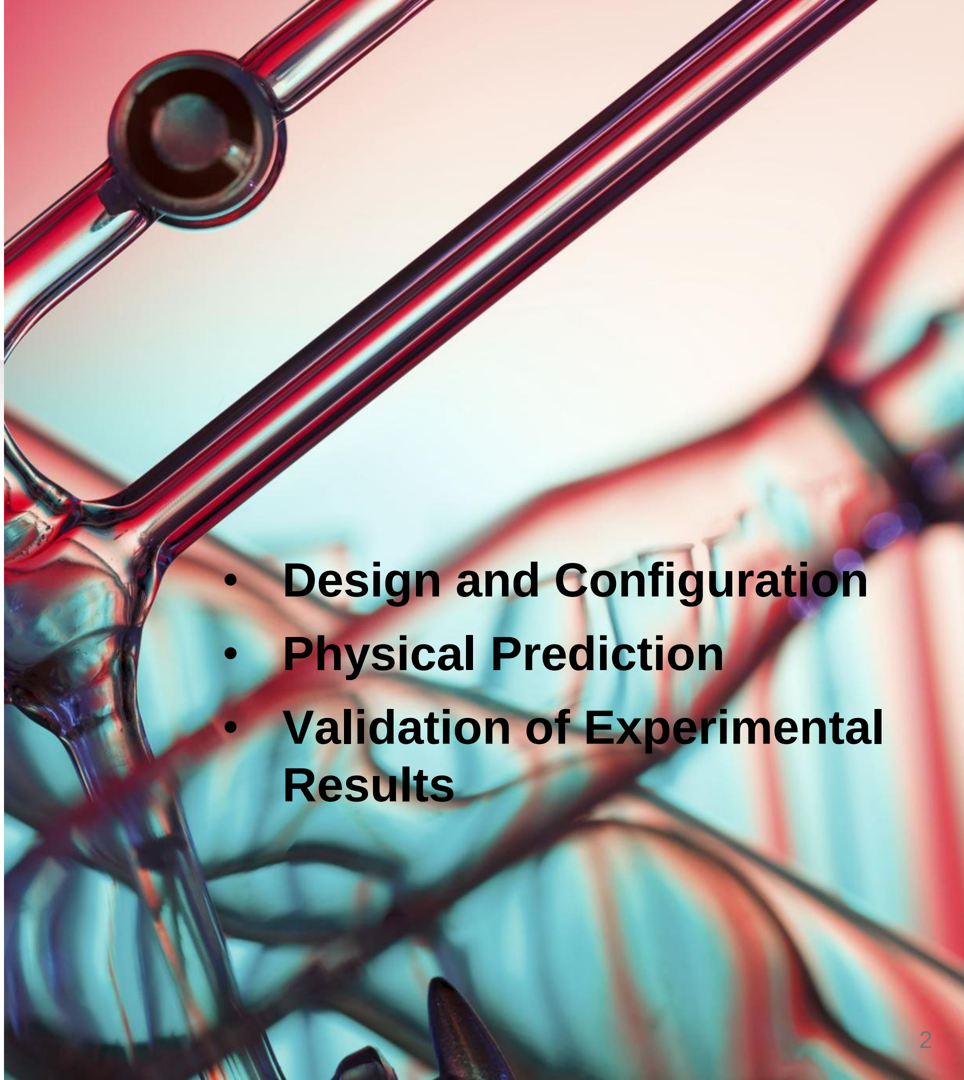
In the case of particle detectors, they enable the prediction and study of interactions between particles and materials without relying solely on expensive or challenging experiments.



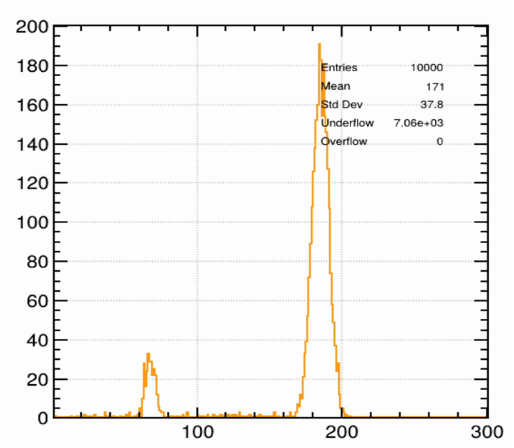
- **Design and Configuration**
- **Physical Prediction**
- **Validation of Experimental Results**

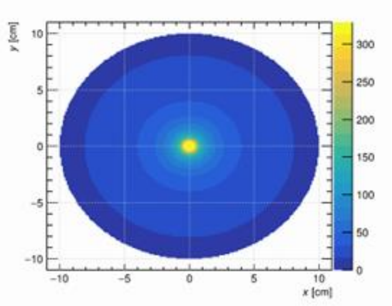
Garfield++

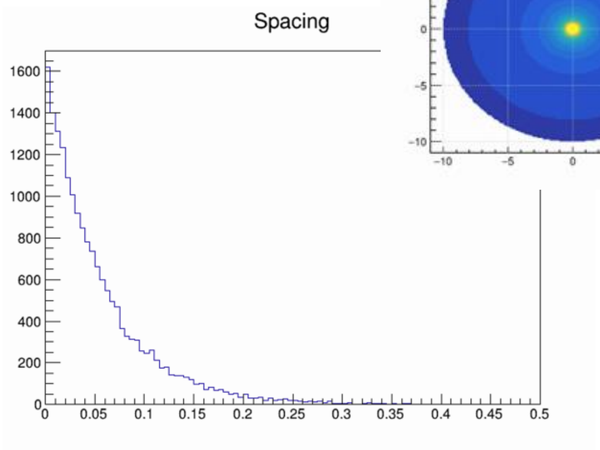
- Toolkit designed specifically to model and analyze the behavior of ionization detectors, both gaseous and semiconductor-based. it is widely used in particle physics research to study complex processes, from the initial particle interaction to the final detected signal.
- **Core Applications**

1. **Event Detection:**
    - Simulation of electron avalanches to study efficiency and time resolution in detectors like RPCs (Resistive Plate Chambers).
    - Optimization of design and operating parameters for Micromegas and other detectors.
2. **Visualization and Analysis:**
    - Graphical representation of geometries, electric fields, and particle trajectories.
    - Detailed analysis of induced signal shapes and timing.
3. **Integration with Additional Tools:**
    - Integration with Magboltz for gas transport calculations.
    - Use of Python and ROOT for extended analysis capabilities.

Garfield++ Basics







- **Electric Field Configurations**
  - Simulations of parallel plate chambers, wire chambers, and GEMs.
  - Gas setup (Argon/CO2) and electric field visualization.
  - Generation of potential and electric field line plots

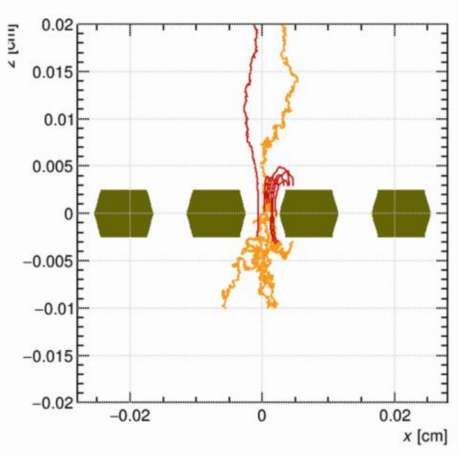
Gas Ionization
  - Study of primary ionization caused by charged particles.
  - Simulation of spatial distributions of primary and secondary clusters.
  - Statistical analysis of deposited energy and generated electrons.

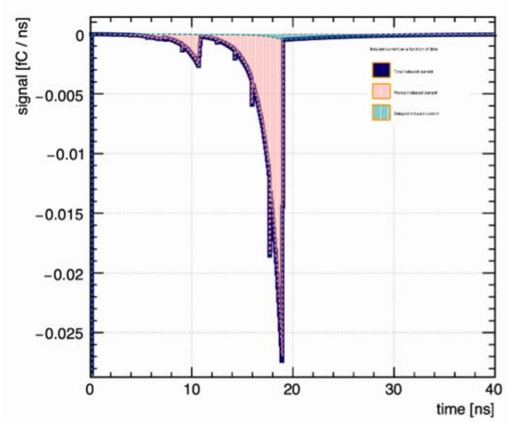
X-Ray Conversion
  - Simulation of photon absorption from Fe55 in a gas volume.
  - Analysis of primary electrons produced and comparison with experimental data.

- **Electron Drift and Diffusion**
  - Investigation of electron drift velocity and diffusion in different gases.
  - Comparison of deterministic (Runge-Kutta) and probabilistic methods.

Advanced Processes and Results

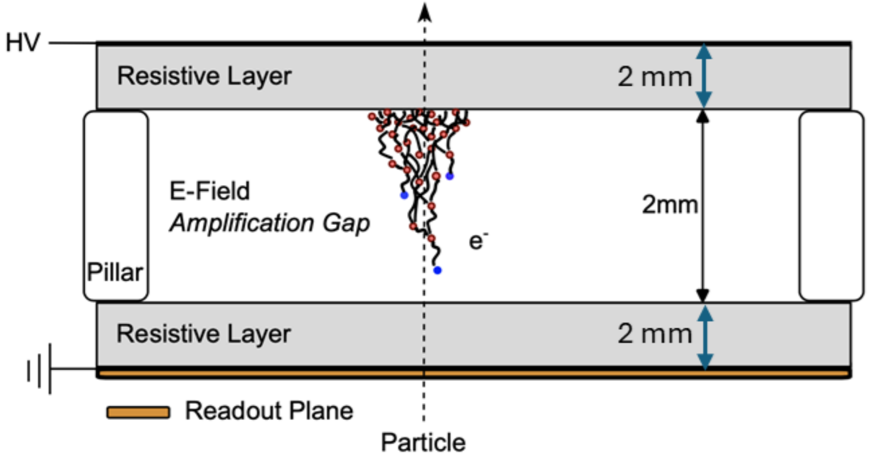
- **Electron and Ion Drift**
  - Simulation of particle drift in an ionization chamber.
  - Analysis of how gas properties affect diffusion.
- **Electron Amplification**
  - Simulation of electron avalanches in a resistive plate chamber (RPC).
  - Evaluation of detector gain as a function of applied voltage.
- **Signal Induction**
  - Study of current induction on a readout electrode by moving electrons.
  - Simulation of electronic response using a transfer function.





RPC: setup

- **Single Gap RPC** with a readout plane electrode
- **0.2 cm** gas gap, support pillars were not modelled. **ΔV=-8.8 kV** voltage between planes.
- $\mathbf{C_2H_2F_4/C_4H_{10}/SF_6}$ (95.2%/4.5%/0.3/) gas mixture loaded from file.



Objectives:

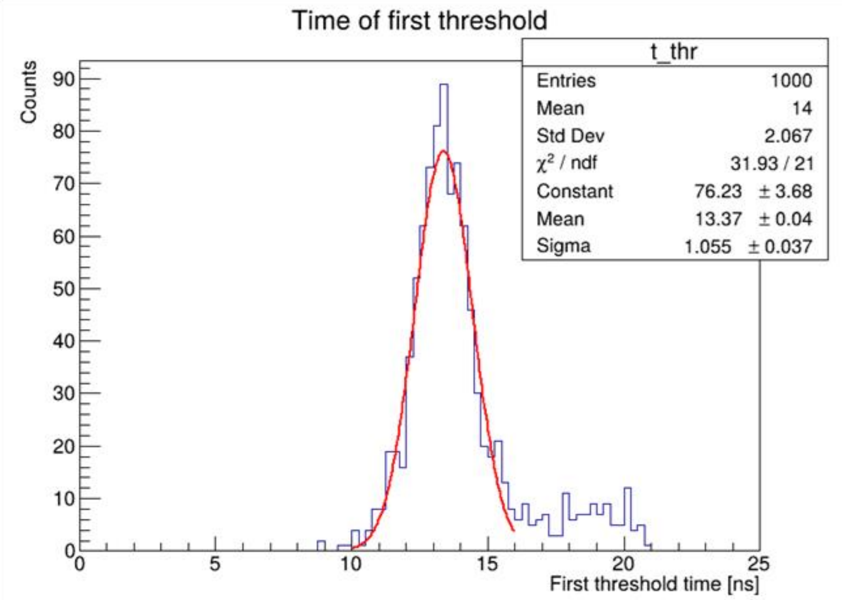
- Simulating electron avalanches from a track
- Extracting detector efficiency and time resolution

RPC time resolution

- Simulating 100 GeV μ perpendicular to the planes
- Efficient avalanche simulation with AvalancheMicroscopic + AvalancheGrid
- Estimated time resolution at ΔV=-8.8 kV:

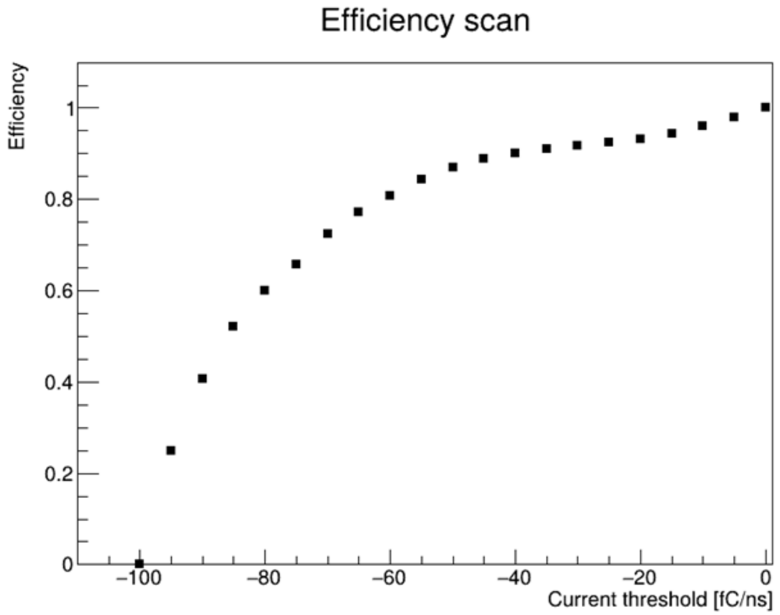
$$\sigma_t = \frac{1.28}{(\alpha - \eta) \cdot v} \simeq 1.4 \text{ ns}$$

- Threshold at -10 fC/ns → spread in rise times has deviation with respect to estimated σ_t value



RPC efficiency

- RPC efficiency estimated as: $\epsilon \equiv \frac{N_{selected}}{N_{tot}}$
- Scan of RPC efficiency for ΔV=-8.8 kV at different signal thresholds
- Plateau in the -40 to -20 fC/ns threshold interval.

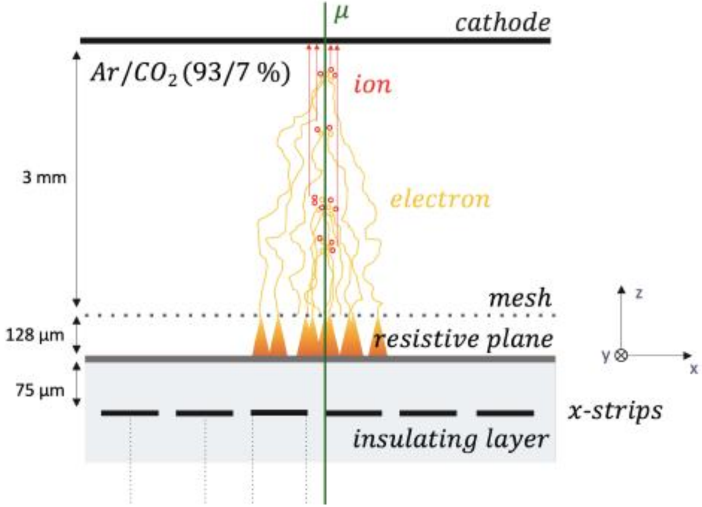


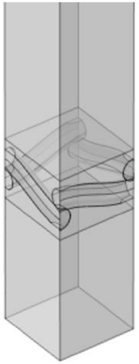
Micromegas: setup

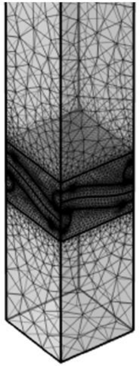
Schematic representation of a Micromegas with an infinite expanding resistive plane and strip readout

Woven mesh

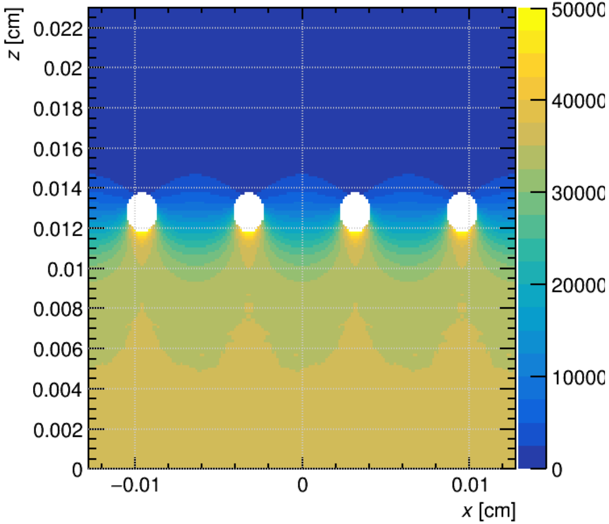
Electric field calculation using the Finite Element Method (COMSOL)

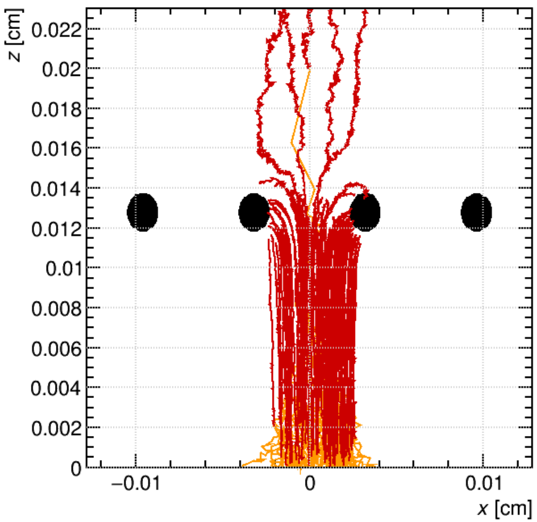






Micromegas: electric field and gain





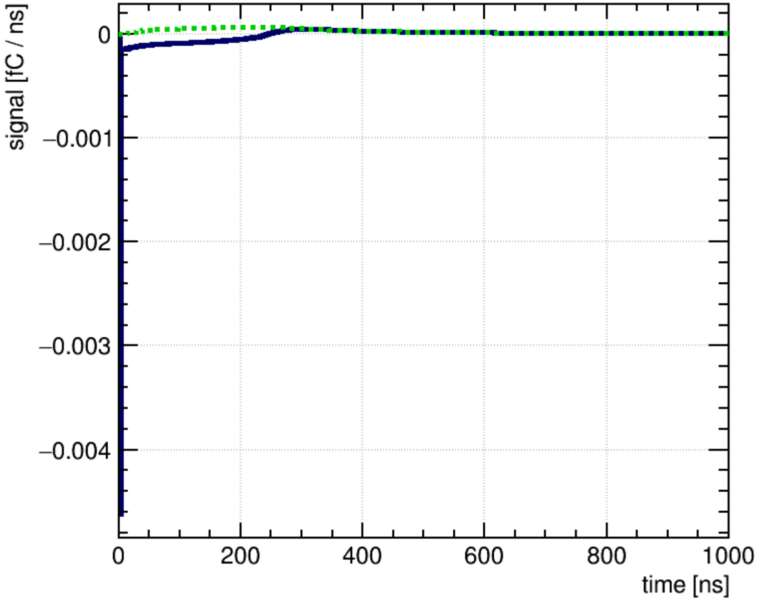
Representation of the electric field inside the Micromegas

Use of AvalancheMicroscopic to simulate the gain of the detector

Micromegas: signal induction

FEM solutions of time-dependent weighting potentials to calculate the induced signals on the readout strips

The simulated signal exhibits the characteristic features of a Micromegas signal: a sharp electron peak followed by a long ion tail.



Conclusions

Explored the features of Garfield++ for the simulation of gas detector physics:

- Made use of multiple field solvers: analytical fields, ANSYS and COMSOL field maps, etc.
- Extracted relevant distributions for the ionization processes
- Single Gap RPC: studied the time resolution and efficiency behaviour
- Micromegas geometry from COMSOL: studied the signal production with a time-dependent weighting potential.
- GARFIELD++ is a reliable tools for studying the detector features and efficiency.

Acknowledgements

DRD1 Gaseous Detector school organizers, tutors, and collaboration