Parametrized simulation of the micro-RWELL response with PARSIFAL software

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Abstract. PARSIFAL is a software tool originally implemented to reproduce the response of a triple-GEM interacting with a charged particle, which describes the main physical processes with a parametrization. Reliable software as GARFIELD++ is widely used to simulate a gaseous detector with great accuracy, but it is CPU-time consuming. The implementation of PARSIFAL was driven by the need to reduce the processing time, while maintaining the precision of a full simulation. The software is initialized with parameters extracted from a GARFIELD++ simulation, run only once. Then, PARSIFAL can be run independently to provide a reliable simulation by sampling from a set of functions which describe the physical effects and depend on the input parameters. The simulation of the triple-GEM was tuned on experimental results from a testbeam. Recently, PARSIFAL was extended to the μ-RWELL technology, with the implementation of the charge dispersion effect generated by the resistive layer. A fine tuning of the simulation for the μ-RWELL is ongoing, following a strategy similar to the one validated for the triple-GEM, with a special attention to the tuning of the resistivity of the resistive layer. An illustration of the general code, setting the focus on this latest implementation will be described.

1. Introduction

During the R&D on a detector for high energy physics, both the hardware and software sides must be addressed, for a full understanding of the detector underlying mechanisms. Concerning the software implementation, three main topics must be considered: the Monte Carlo simulation of the interaction of the particles in the detector materials, the simulation of the response of the detector to the passage of those particles and the reconstruction algorithms. For the first point, dedicated libraries, as Geant4 [1], are used, depending on the specific particles and the energy regime. For the last, reconstruction algorithms are usually customized on the detector specific characteristics. This paper sets the focus on the second issue and presents the software tool PARSIFAL [2, 3], originally developed for the simulation of a triple-GEM response to the passage of charged particles, now updated for the simulation of another Multi-Pattern Gaseous Detector (MPGD), the μ-RWELL [4].

2. PARSIFAL description

PARSIFAL (PARametrized SImulation) is a software implemented in C++ and based on ROOT [5], that simulates the main physics effects which have a role in the formation of the signal in a MPGD. The version written for the triple-GEM is based on [6], where the authors state that the complete simulation of the detector can be obtained by simulating separately four steps: ionization, GEM properties, gas and magnetic field effects, signal formation and noise.
A detailed description of the code can be found in [2, 3]. The working principle is the following. A complete set of simulations is first run with GARFIELD++ [7], the robust and widely used software for the simulation of gas and semiconductor based detectors, just one time, to extract the necessary parameters to describe each effect. Then, the parameters are fed as input to PARSIFAL, where functions and histograms describe the diffusion, the gain and the other effects, without the microscopic simulation as GARFIELD++ does, which is heavily time consuming. This allows the user to simulate high statistics samples in a much shorter time and with the same accuracy. The accuracy is granted by a procedure called *tuning*, during which a direct comparison of the results from the analysis of simulation and experimental data collected at testbeam is conducted, to evaluate and improve the matching between them. In this procedure, the GEM gain is multiplied by a tuning factor, since GARFIELD++ underestimates it, and the transverse spatial diffusion is corrected in order to obtain consistent results between simulation and real data. A very good match was obtained on the four sentinel variables that were chosen, i.e. the cluster charge (a cluster is a set of contiguous firing strips in the segmented anode), the cluster size (the number of strips in the cluster) and the spatial resolution of the cluster position reconstructed with two methods, the charge centroid and the μTPC mode (see [8] for more details on these quantities).

3. The μ-RWELL description

The μ-RWELL belongs to the family of MPGD. It is a single amplification-stage, resistive, spark protected gas-based tracker. Figure 1 shows the layout of the μ-RWELL, which is composed by a copper cathode, sealing the conversion gas gap, and a anode PCB which embeds the multiplication stage. The amplification stage consists of a well patterned single copper-clad polyimide (Apical ©) foil, where thousands of holes with a diameter of 50 (70) μm are obtained by photo-lithographic technique. On the opposite side with respect to the copper, a layer of Diamond Like Carbon (DLC) is sputtered on the polyimmide. The DLC is a very thin resistive layer (< 0.1 μm) with a surface resistivity ρ ranging from 10 to 100 MΩ/□. Under the DLC, a layer of pre-preg is glued on the readout PCB electrode, which can be segmented in pads or strips. The chamber is filled by the gas mixture Ar:CO_2:CF_4 (40:15:45). The DLC is electrically grounded and a potential difference is applied between the cathode and the ground, to drive the

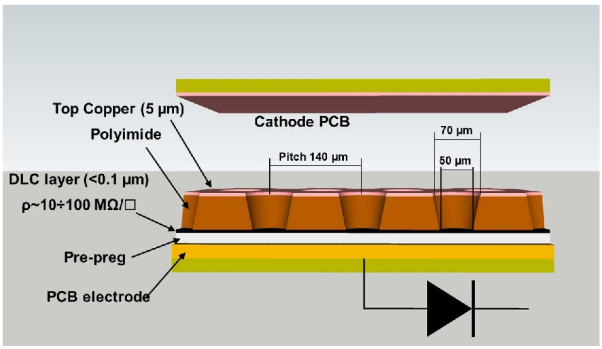

Figure 1. μ-RWELL layout [9].

electrons from gas ionization into the multiplication holes. An additional potential difference of some hundreds of Volts is applied between the top copper layer of the amplification stage and the DLC, to create an electric field in the holes intense enough to trigger avalanche multiplication an amplify the signal.

4. The μ-RWELL simulation

It is clear from Section 3 that the simulation of the response of a μ-RWELL can be obtained from the simulation of the triple-GEM already implemented in PARSIFAL with some adjustments. In fact, the functioning principles of the triple-GEM and the μ-RWELL are basically the same, but in the μ-RWELL there is a single multiplication stage, instead of the three, and there is the additional resistive layer which modifies the signal.
Concerning the modeling of the resistive layer, a mathematical treatment of its effect is reported in [10, 11]. The charge density spread on the resistive layer can be written as:

$$\rho(x,y,t) = \frac{Nq_e}{2\pi(2ht+w^2)}\ exp[-(x^2+y^2)/2(2ht+w^2))] \tag{1}$$

where N is the number of electrons in the avalanche, q_e is the electron charge, $h = 1/RC$ is the inverse of the time constant due to the surface resistivity and the capacitance per unit of area, t is the time, w is the width of the avalanche and x, y are the position coordinates.
An adaptation of Equation (1) for the case of an anode segmented in strips, hence for a one-dimensional readout, was implemented in the code, as:

$$\rho(x,t) = \frac{q}{\sqrt{2\pi}\sigma_0(1+\frac{t-t_0}{\tau})}\ exp\Big[-\frac{(x-x_0)^2}{2\sigma_0^2(1+\frac{t-t_0}{\tau})^2}\Big]\ \Theta(t-t_0) \tag{2}$$

where q is the charge of the avalanche, x_0 is the electron starting position, σ_0 is the width of the avalanche, t_0 is the starting time of the induction and $\tau = RC$ is the time constant.
In order to be able to compare the results with experimental data collected on a testbeam where the μ-RWELL chambers were readout by the APV-25 ASIC, the response function of the chip was also implemented in the simulation as:

$$Q_{shaped} = Q_{preamp}\Big(\frac{t-t_0}{\tau_{APV}}\Big)exp\Big[-\frac{t-t_0}{\tau_{APV}}\Big] \tag{3}$$

where Q_{preamp} is the integrated charge, t_0 is the starting time of the induction and τ_{APV} is the shaping time of the APV-25 (50 ns).
Figure 2 shows a simulation of the readout charge as a function of the time when a single

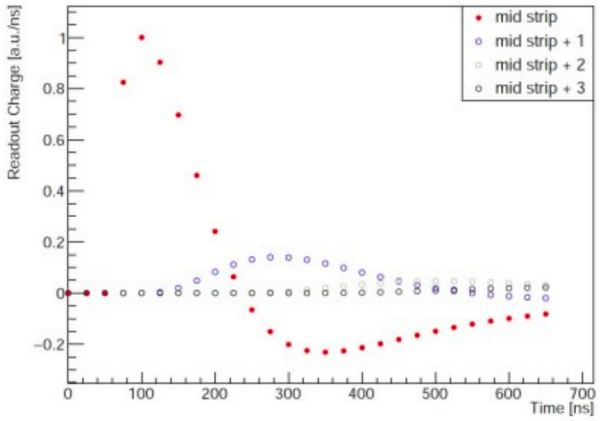

Figure 2. Readout charge simulated as the convolution of Equation (2) and (3) in response of an injected charge of one electron injected on the middle strip: the red dots correspond to the middle strip, the blue, grey and black dots to the middle strip first, second and third neighboring strip.

charge $q = 1$ is injected at $t = 0$ on a strip and the effect of the charge spread is simulated by Equation (2) with $\tau = 10$ ns. The strip on which the charge was injected shows the highest readout charge (red dots), which then flows on the neighboring strips, which show a delayed and lower readout charge. The shown results are obtained by the convolution between the charge spread and the APV-25 response function.

This description of the resistive layer and of the APV-25 was added to the existing simulation of the physical effects (ionization, diffusion and gas gain) already implemented for the triple-GEM and opportunely modified, in order to test the full μ-RWELL digitization with realistic events. As a first test, simulations with different values of the time constant for the charge spread were run, by generating ten thousand minimum ionizing particle events for each chosen τ. Figure 3 shows the cluster size, i.e. the number of contiguous firing strips, as a function of τ, related to the resistivity. If the resistivity is low ($\tau < 20$ ns), then the charge dispersion is large and the charge is induced on a few millimeters (the strip pitch size is 400μm). On the other hand, if the resistivity is large ($\tau > 60$ ns), then the charge dispersion is too small and it does not exceed the strip pitch size, hence it does not impact the cluster size.

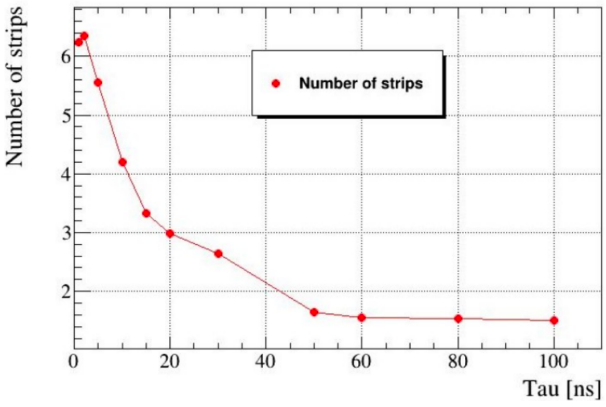

Figure 3. Cluster size as a function of the charge spread time constant τ.

5. Conclusion

A software originally designed to simulate the response of a triple-GEM, PARSIFAL, was developed within the project for the new Cylindrical GEM Inner Tracker for the BESIII experiment. The code was tested on triple-GEM detectors and the simulation was finely tuned to experimental data collected at testbeam. Recently, PARSIFAL has been extended

to the simulation of the μ-RWELL, thanks to the modular structure of the code, as they share with GEMs various characteristics, particularly the amplification method which is based on the MPGD technology. PARSIFAL important feature is that it allows the user to obtain reliable simulations of a triple-GEM and of a μ-RWELL, reducing significantly the CPU-time with respect to full physics simulators, as GARFIELD++. The implementation of the resistive layer specific of the μ-RWELL technology was completed and the tuning on test beam data is ongoing.

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