RD51 Collaboration Meeting

Simulating MRPCs with Garfield++

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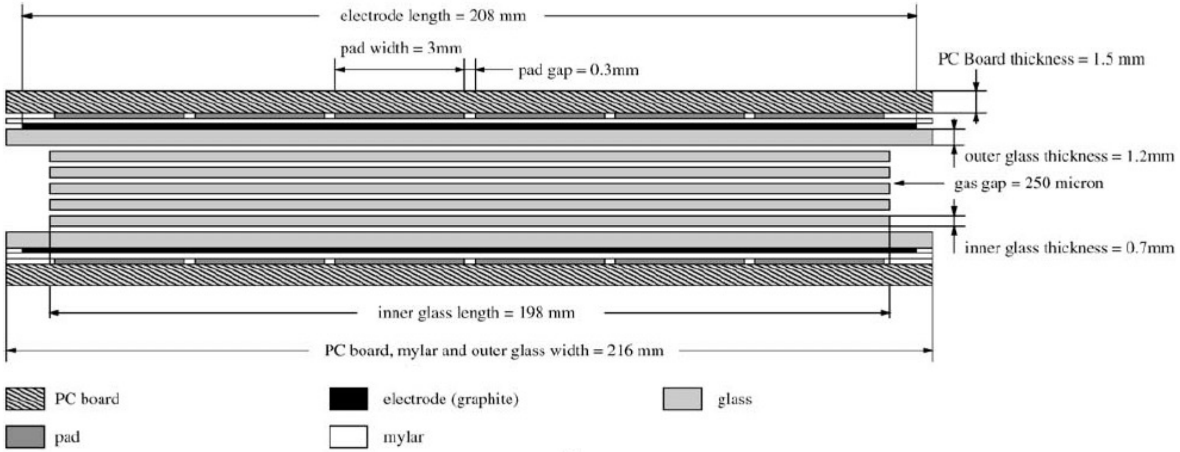
Overview

The large number of charges involved in forming an avalanche in multi-gap resistive plate chambers (MRPC) makes microscopic tracking time-consuming. Instead, another approach is used to speed-up the calculations.

Outline:

- Grid-based simulation of avalanche development
- The semi-analytical weighting potential for N-layer geometry
- An example of a MRPC
- Summary

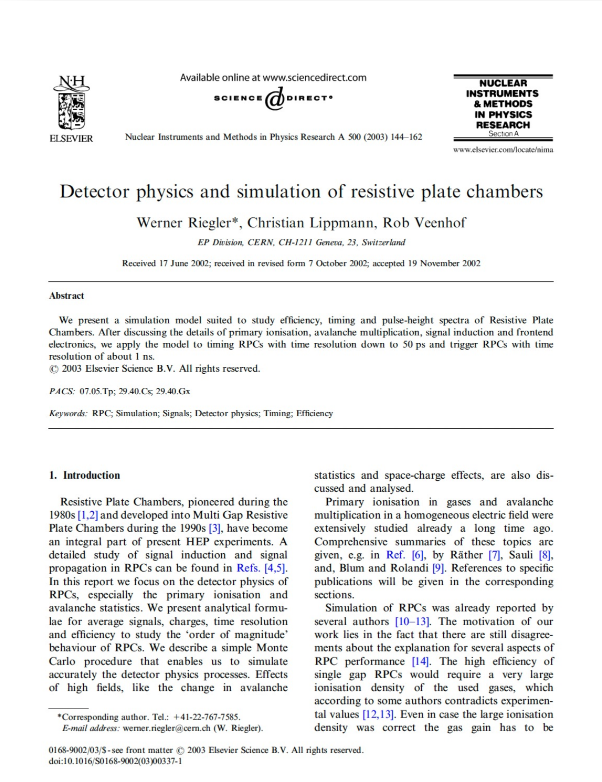


M. Shao, et al., Nucl. Instr. and Meth. A: Vol. 492, Issue 3 (2002) 344

See also presentation of Dario Stocco.

Measurement using a resistive small-pad MM

This simulation recipe for MRPCs leans heavily on two works describing a one-dimensional description of the avalanche dynamics and the signal formation in multi-layer parallel plate type detectors.



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Detector physics and simulation of resistive plate chambers

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Abstract

We present a simulation model suited to study efficiency, timing and pulse-height spectra of Resistive Plate Chambers. After discussing the details of primary ionisation, avalanche multiplication, signal induction and frontend electronics, we apply the model to timing RPCs with time resolution down to 50 ps and trigger RPCs with time resolution of about 1 ns.

PACS: 07.05.Tp; 29.40.Cs; 29.40.Gx

Keywords: RPC; Simulation; Signals; Detector physics; Timing; Efficiency

1. Introduction

Resistive Plate Chambers, pioneered during the 1980s [1,2] and developed into Multi Gap Resistive Plate Chambers during the 1990s [3], have become an integral part of present HEP experiments. A detailed study of signal induction and signal propagation in RPCs can be found in Refs. [4,5]. In this report we focus on the detector physics of RPCs, especially the primary ionisation and avalanche statistics. We present analytical formulae for average signals, charges, time resolution and efficiency to study the 'order of magnitude' behaviour of RPCs. We describe a simple Monte Carlo procedure that enables us to simulate accurately the detector physics processes. Effects of high fields, like the change in avalanche statistics and space-charge effects, are also discussed and analysed.

Primary ionisation in gases and avalanche multiplication in a homogeneous electric field were extensively studied already a long time ago. Comprehensive summaries of these topics are given, e.g. in Ref. [6], by Räther [7], Sauli [8], and, Blum and Rolandi [9]. References to specific publications will be given in the corresponding sections.

Simulation of RPCs was already reported by several authors [10–13]. The motivation of our work lies in the fact that there are still disagreements about the explanation for several aspects of RPC performance [14]. The high efficiency of single gap RPCs would require a very large ionisation density of the used gases, which according to some authors contradicts experimental values [12,13]. Even in case the large ionisation density was correct the gas gain has to be

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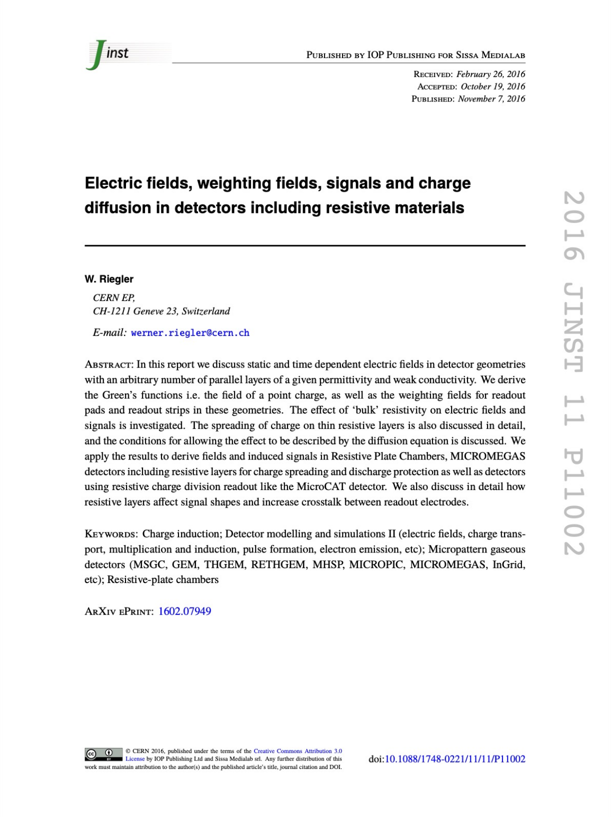

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Electric fields, weighting fields, signals and charge diffusion in detectors including resistive materials

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ABSTRACT: In this report we discuss static and time dependent electric fields in detector geometries with an arbitrary number of parallel layers of a given permittivity and weak conductivity. We derive the Green's functions i.e. the field of a point charge, as well as the weighting fields for readout pads and readout strips in these geometries. The effect of 'bulk' resistivity on electric fields and signals is investigated. The spreading of charge on thin resistive layers is also discussed in detail, and the conditions for allowing the effect to be described by the diffusion equation is discussed. We apply the results to derive fields and induced signals in Resistive Plate Chambers, MICROMEGAS detectors including resistive layers for charge spreading and discharge protection as well as detectors using resistive charge division readout like the MicroCAT detector. We also discuss in detail how resistive layers affect signal shapes and increase crosstalk between readout electrodes.

KEYWORDS: Charge induction; Detector modelling and simulations II (electric fields, charge transport, multiplication and induction, pulse formation, electron emission, etc); Micropattern gaseous detectors (MSGC, GEM, THGEM, RETHGEM, MHSP, MICROPIC, MICROMEGAS, InGrid, etc); Resistive-plate chambers

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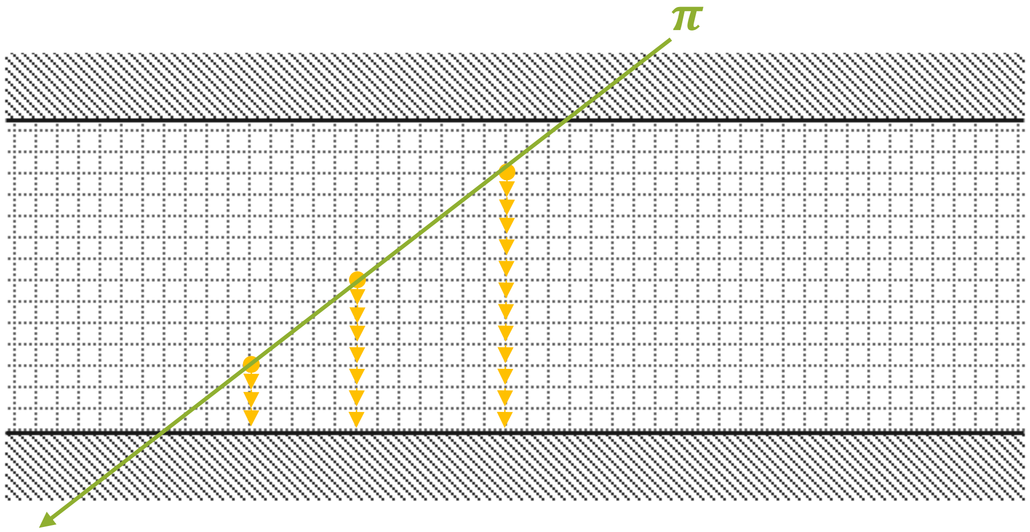
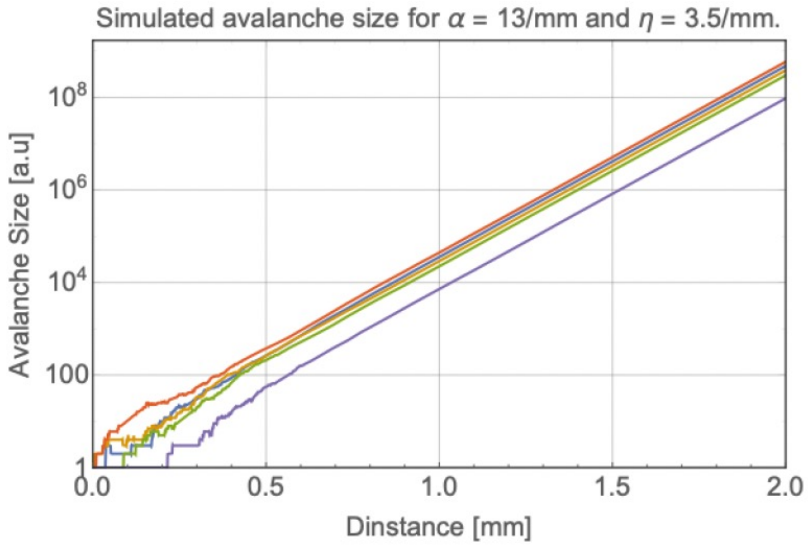
In addition to Marcello Abbrescia et al., Nucl. Instr. and Meth. A 431 (1999) 413.

Grid-based avalanche calculation

The gas volume is subdivided using a 3D grid, on the nodes of which the electrons are snapped and propagated in the direction of drift. This is the **Legler model**. The probability of an avalanche containing n electrons after a distance x after starting with only one is given by:

$$P(n,x)=\begin{cases} k\frac{\bar{n}(x)-1}{\bar{n}(x)-k}, & n=0 \\ \bar{n}(x)\left(\frac{1-k}{\bar{n}(x)-k}\right)^2\left(\frac{\bar{n}(x)-1}{\bar{n}(x)-k}\right)^{n-1}, & n>0 \end{cases} \text{, where} \quad \bar{n}(x)=\mathrm{e}^{(\alpha-\eta)x}, \quad k=\frac{\eta}{\alpha}.$$



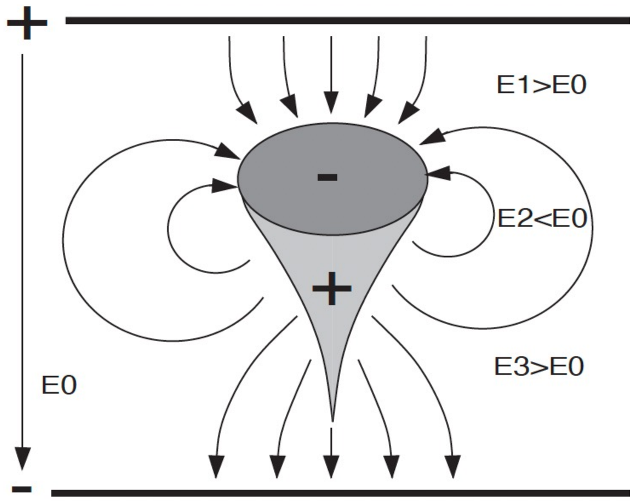


Marcello Abbrescia et al., Nucl. Instr. and Meth. A 431 (1999) 413.
Werner Legler, Z. Naturforschung. 16a (1961) 253.

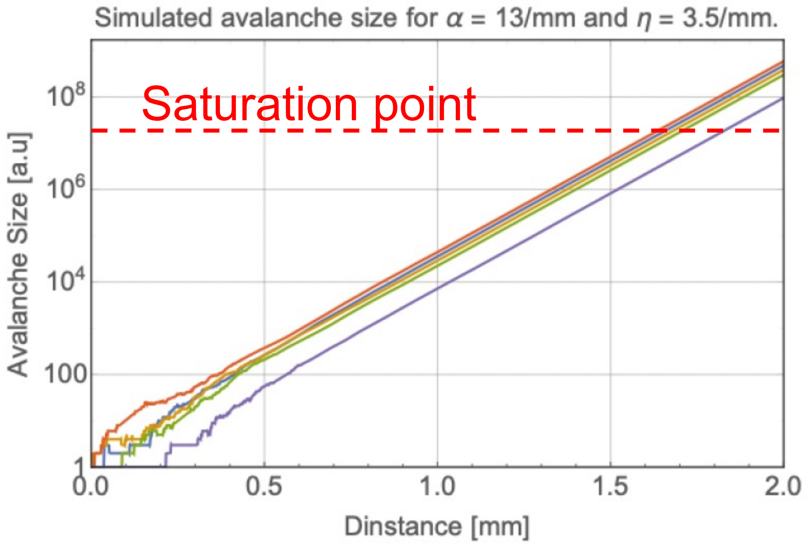
Grid-based avalanche calculation

Given the large amount of charge produced in the avalanches its growth will be suppressed.

To take this into account, a crude approximation is made by stopping the growth after having reached 1.6*10^7 electrons.



C. Lippmann et al., NIM-A 517 (2004) 54–76



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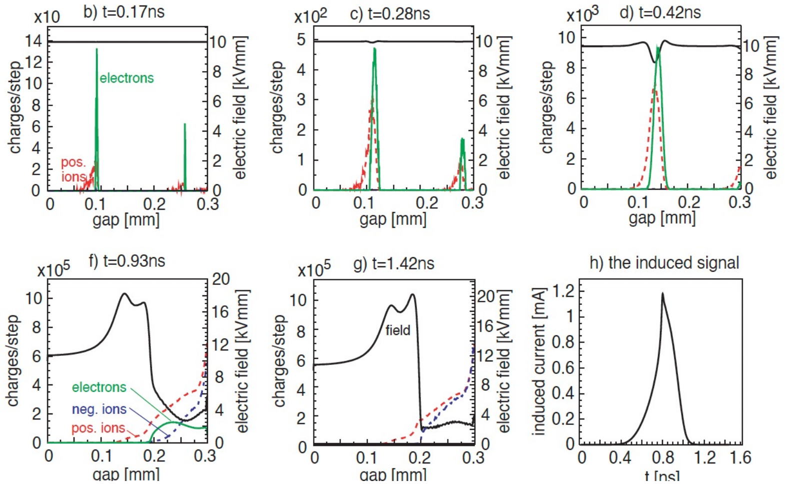
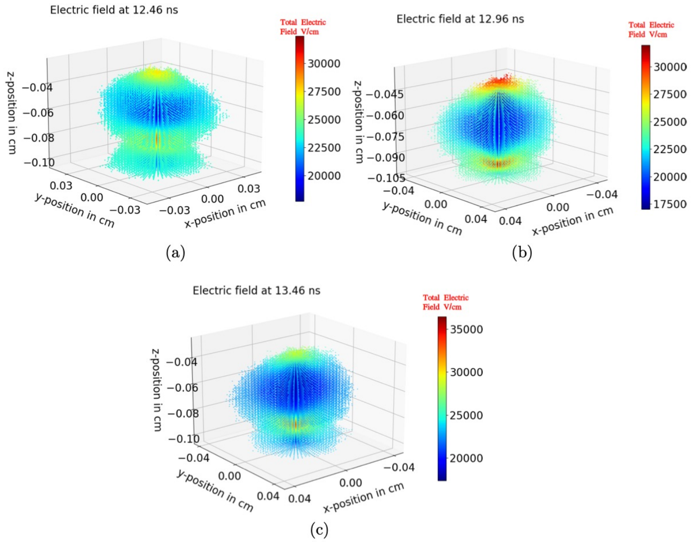
M. Abbrescia, et al., Nucl. Phys. B (Proc. Suppl.) 78 (1999) 459.
R. Camarri, et al., Nucl. Instr. and Meth. A 414 (1998) 317.

Grid-based avalanche calculation

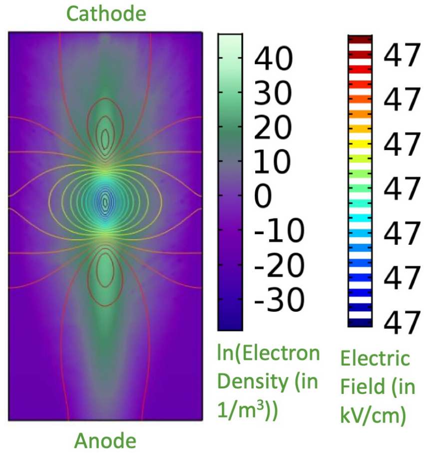
However, more sophisticated approaches are available for modeling the space-charge effect:



C. Lippmann, W. Riegler, NIM-A 517 (2004) 54–76
See also presentation of Dario Stocco.



See presentation of Supratik Mukhopadhyay.
Also: arXiv:2211.06361v1 [physics.ins-det]

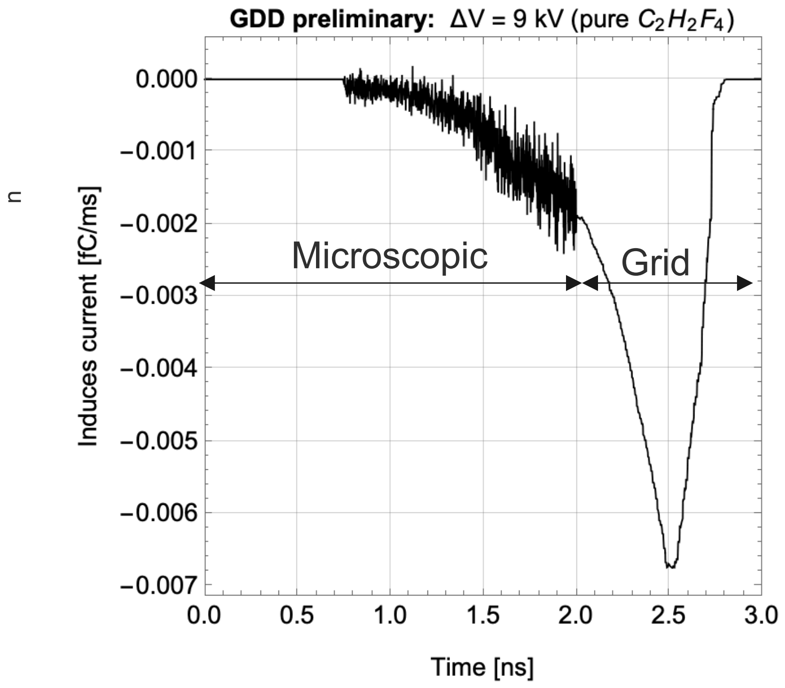


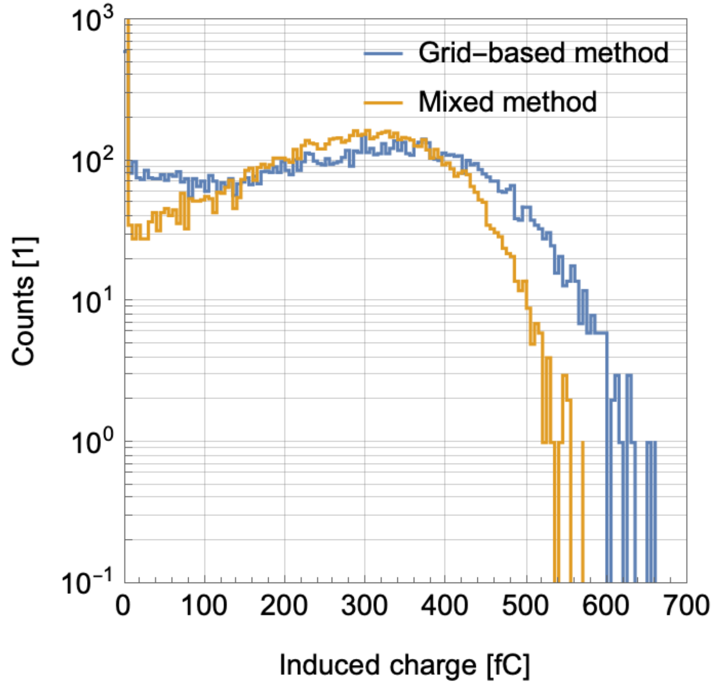
A gaussian distribution of primary electrons is used as the seed to initiate the avalanche.

RD51–NOTE-2011-005, by Paulo Fonte
RD-51 Open Lectures by Filippo Resnati.
Also: Jaydeep Datta’s presentation.

Grid-based avalanche calculation

Given the importance of the early fluctuations to the eventual induced charge distribution, this is more reliably represented by the microscopic tracking in Garfield++. After a set time the switch is made to the Legler model, giving a “mixed method”.



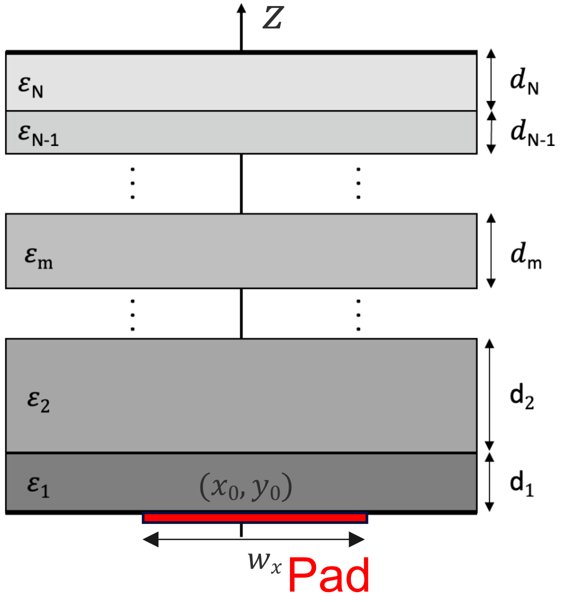


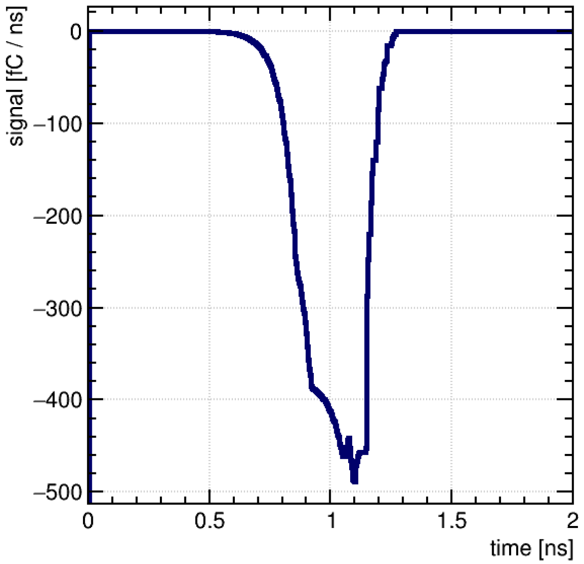
Signal formation in a MRPC

Given a rectangular electrode in an N-layer parallel plate geometry, then the static weighting potential is given by:

$$\phi^w(x_0, y_0, z_m) = \frac{4V_w}{\pi^2} \int_0^\infty \int_0^\infty \cos(k_x x_0) \sin\left(\frac{k_x w_x}{2}\right) \cos(k_y y_0) \sin\left(\frac{k_y w_y}{2}\right) \frac{1}{k_x k_y} \frac{\varepsilon_1}{k} \frac{\partial f_{m1}(k,z)}{\partial z}|_{z=z_0} dk_x dk_y$$

Due to the typically high volume resistivities of O(10^9 - 10^{12}) Ωcm found in RPCs, the delayed component is negligible.





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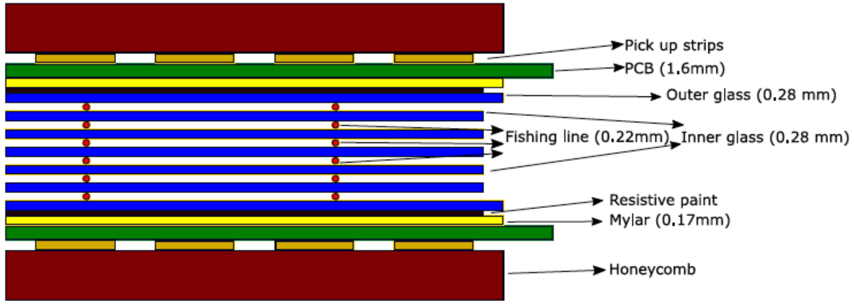
Signal formation in a MRPC

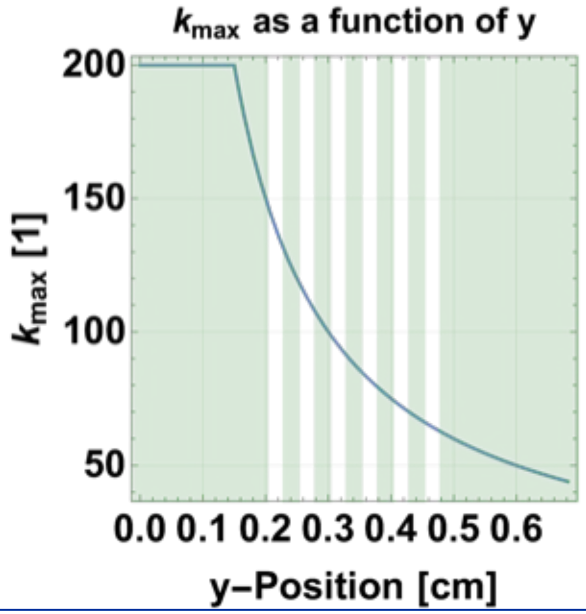
Moving further away from the readout the contribution from the small values of k start to dominate. We can take the as cut-off k_{max}(m) = p/(z-z_0), with p >10 determining the accuracy of the calculation.

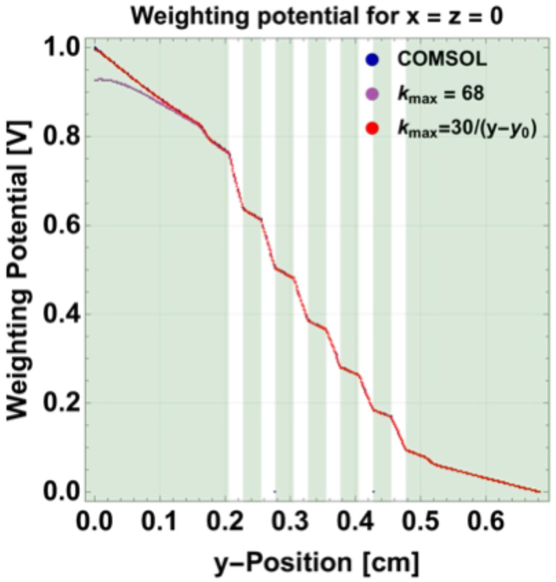
$$\phi^w(x_0,y_0,z_m) = \frac{4V_w}{\pi^2}\int_0^\infty\int_0^\infty \cos(k_x x_0)\sin\left(\frac{k_x w_x}{2}\right)\cos(k_y y_0)\sin\left(\frac{k_y w_y}{2}\right)\frac{1}{k_x k_y}\boxed{\frac{\varepsilon_1}{k}\frac{\partial f_{m1}(k,z)}{\partial z}}|_{z=z_0}dk_x dk_y$$

For large k $\propto e^{-k(z-z_0)}$



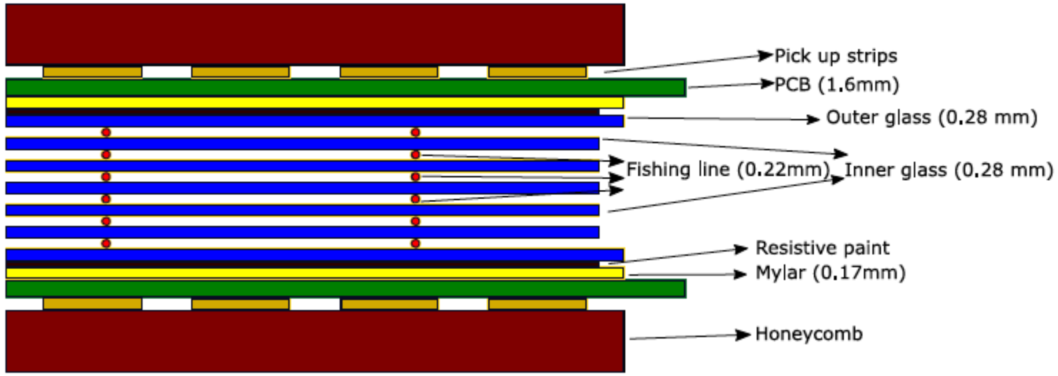
Z. Liu et al., NIM-A 908 (2018) 383-387



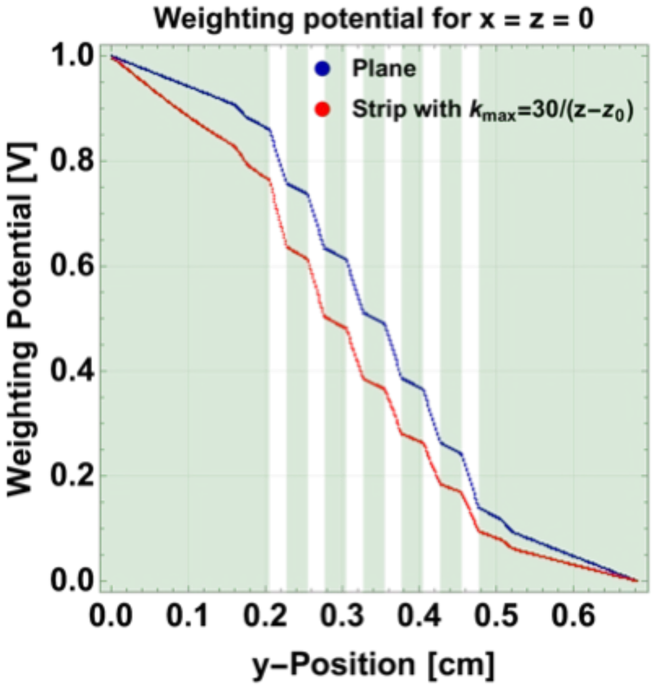


Signal formation in a MRPC

Each gap contributes equally to the signal formation for a readout plane electrode. This is not necessarily the case for a strip of pad electrode since the weighting field in gaps further removed from the readout is smaller.



Z. Liu et al., NIM-A 908 (2018) 383-387



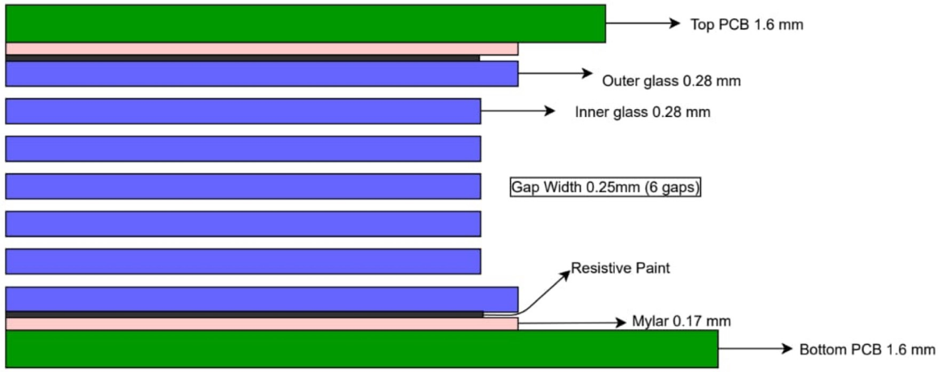
An example MRPC

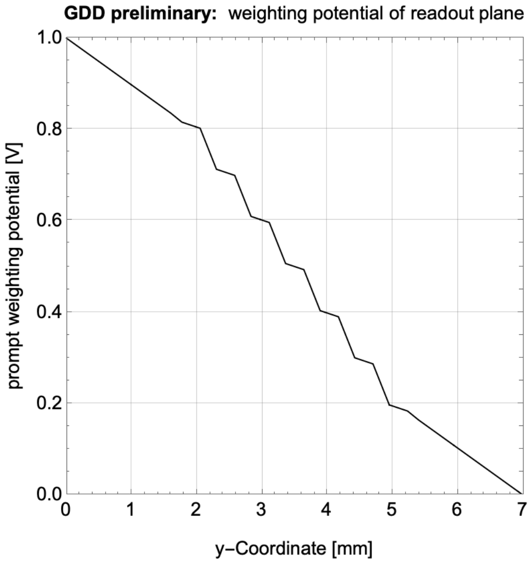
The field, weighting potential calculations and geometry information is contained in the *ComponentParallelPlate* class.

Take a 6-gas gap geometry, i.e. N = 17, that is read out from the bottom using a plane electrode.

```
ComponentParallelPlate* RPC = new
        ComponentParallelPlate();
RPC->Setup(N, eps, thickness, voltage);

std::string label = "anode";
RPC->AddPlane(label);
```





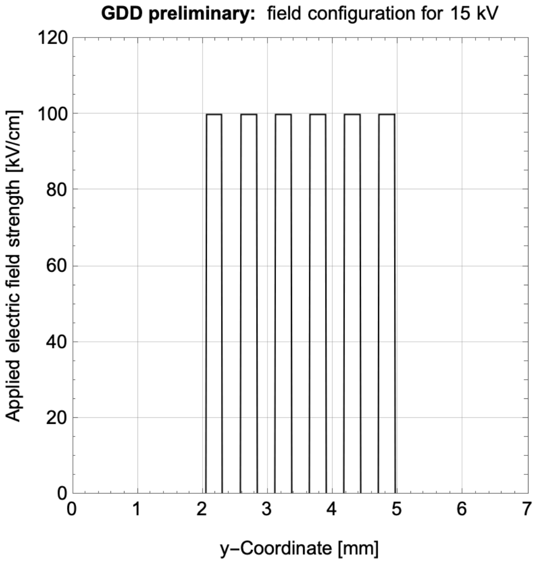


Image of the MRPC is coutacy to Cecilia Uribe Estrada

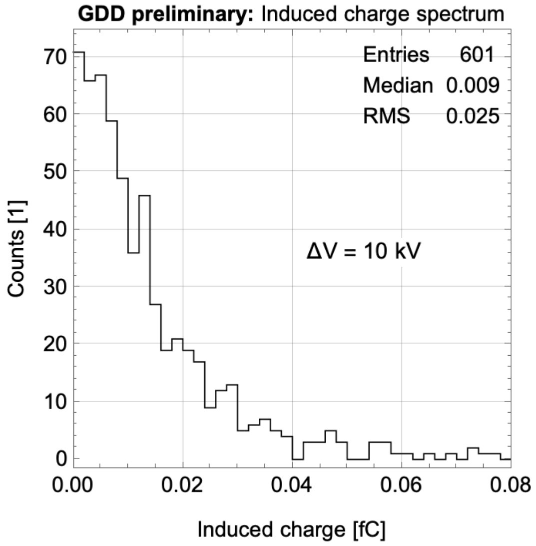
An example MRPC

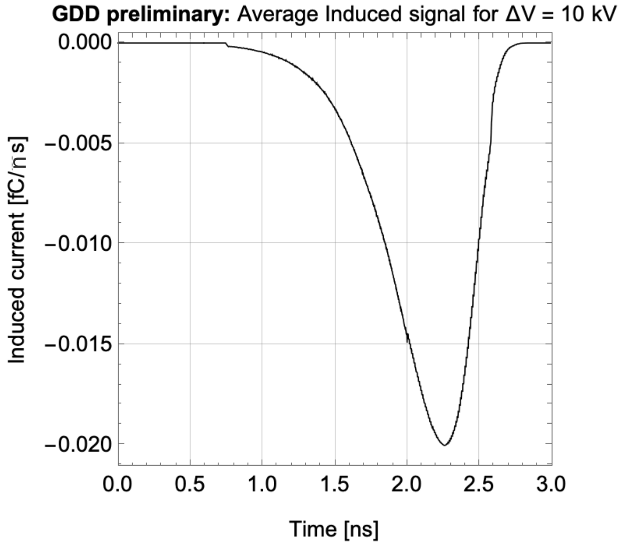
The grid-based Monte Carlo simulation is contained in the *ComponentParallelPlate* class.

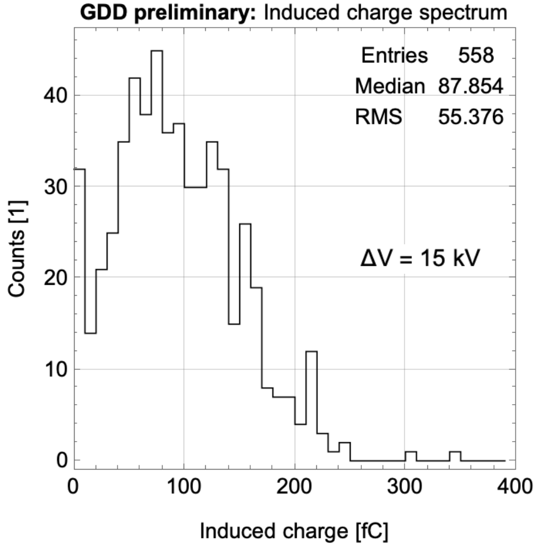
The mixed method transition time is set using tMaxWindow.

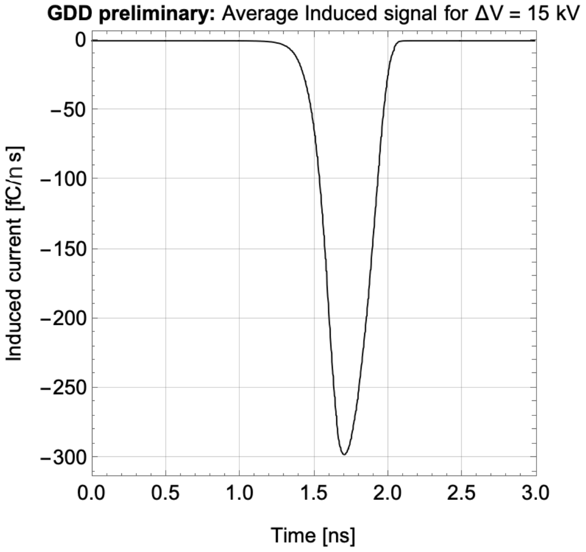
```
AvalancheMicroscopic aval;
…
aval.SetTimeWindow(0., tMaxWindow);

AvalancheGrid avalgrid;
…
avalgrid.SetAvalancheMicroscopic(&aval);
avalgrid.SetGrid(x_min,x_max, n_x, y_min,y_max,
         n_y, z_min,z_max, n_z);
…
avalgrid.GetElectronsFromAvalancheMicroscopic();
…
avalgrid.AsignLayerIndex(RPC);
avalgrid.StartGridAvalanche();
```


GDD preliminary: Induced charge spectrum


GDD preliminary: Average Induced signal for ΔV = 10 kV


GDD preliminary: Induced charge spectrum


GDD preliminary: Average Induced signal for ΔV = 15 kV

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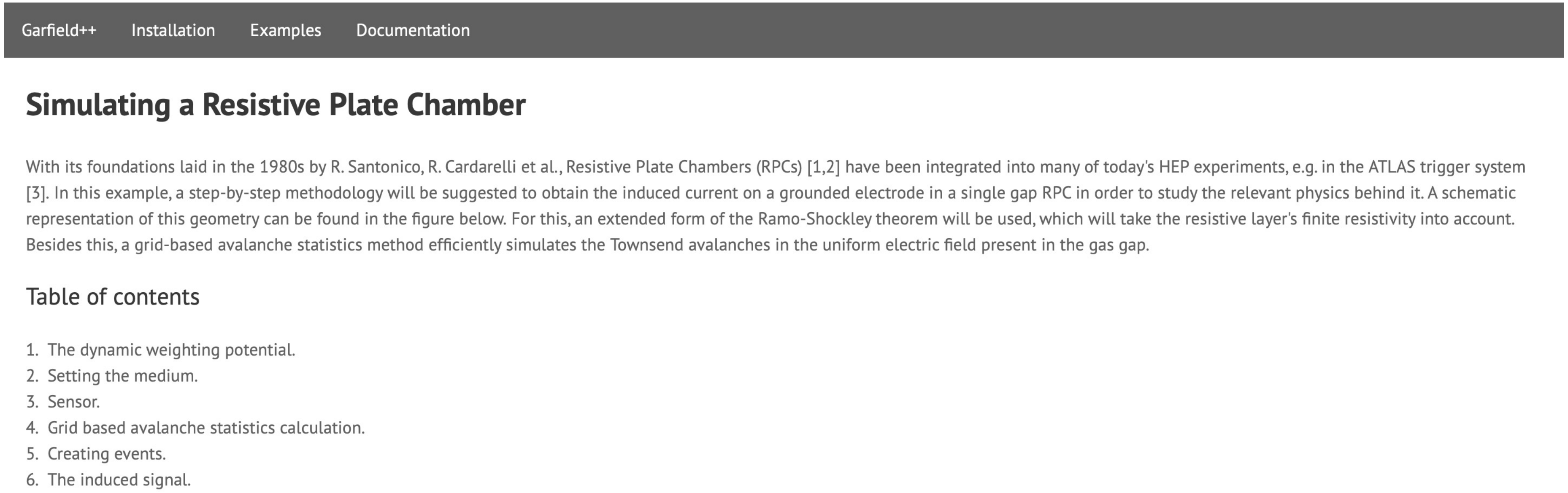
Summary

Using the weighting potential of N-layered parallel plate geometry and a grid-based Monte Carlo calculation the response of a MRPC can be studied using high statistics more easily.

Improved benchmarking efforts and extensions are under way in the context of the search for environmentally friendly RPC gases. See presentation of Dario Stocco.



Simulating a Resistive Plate Chamber

With its foundations laid in the 1980s by R. Santonico, R. Cardarelli et al., Resistive Plate Chambers (RPCs) [1,2] have been integrated into many of today's HEP experiments, e.g. in the ATLAS trigger system [3]. In this example, a step-by-step methodology will be suggested to obtain the induced current on a grounded electrode in a single gap RPC in order to study the relevant physics behind it. A schematic representation of this geometry can be found in the figure below. For this, an extended form of the Ramo-Shockley theorem will be used, which will take the resistive layer's finite resistivity into account. Besides this, a grid-based avalanche statistics method efficiently simulates the Townsend avalanches in the uniform electric field present in the gas gap.

Table of contents

Garfield++ webpage example: https://garfieldpp.web.cern.ch/garfieldpp/examples/rpc/