Modelling signal induction for detectors with resistive elements

EP R&D

GDD
Gas Detectors Development Group

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1 Introduction

Resistive detector designs utilize materials with finite conductivity to achieve enhanced robustness or improved their performance. We employ a Finite Element Method (FEM) approach in conjunction with Garfield++ [1] to simulate induced signals across a wide range of devices in this category:

- Multi-gap Resistive Plate Chambers (MRPCs)
- μ-Resistive WELL
- Resistive Micromegas (ATLAS NSW MM, PICOSEC)
- Resistive Silicon Detectors (RSDs)
- 4D Diamond Sensor

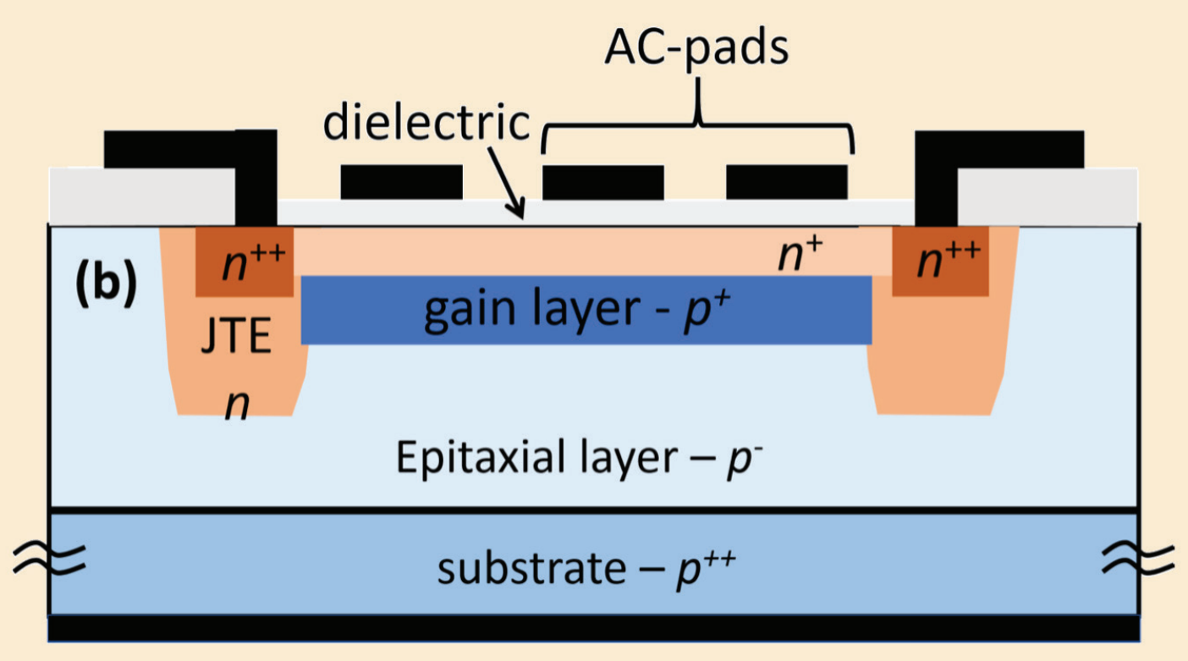
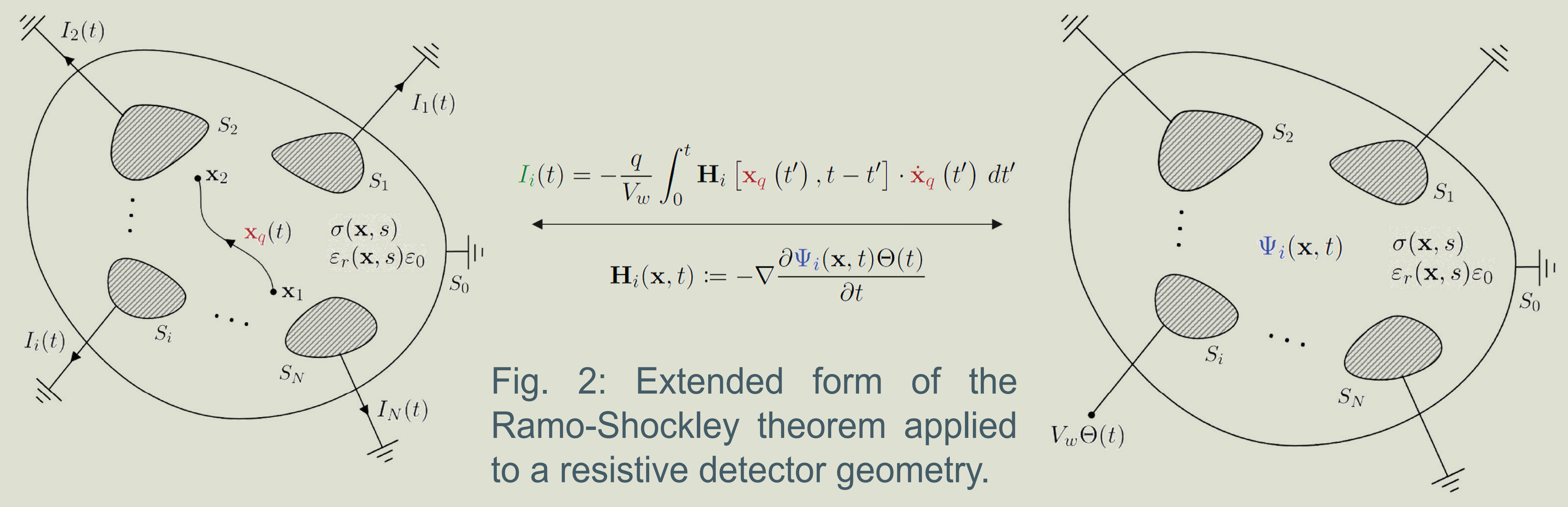


Fig. 1: Resistive silicon detector [2].

2 Dynamic weighting potential

The works of W. Shockley [3] and S. Ramo [4] describe the induction of current on grounded electrodes from moving charge carriers by using static so-called weighting potentials, defined by removing the drifting charges and applying a constant voltage on the electrode under study while keeping all others grounded. Due to the medium's finite conductivity, these weighting potentials become time-dependent for geometries containing resistive materials [5,6].



$$I_i(t) = -\frac{q}{V_w}\int_0^t \mathbf{H}_i\left[\mathbf{x}_q\left(t'\right), t-t'\right]\cdot\dot{\mathbf{x}}_q\left(t'\right)\,dt'$$

$$\mathbf{H}_i(\mathbf{x},t) := -\nabla\frac{\partial\Psi_i(\mathbf{x},t)\Theta(t)}{\partial t}$$

Fig. 2: Extended form of the Ramo-Shockley theorem applied to a resistive detector geometry.

3 Simulation methodology

We developed a numerical method to model the time dependence of the signals in resistive readout structures by employing a FEM solver [7]. Garfield++ then uses the resulting weighting potentials to calculate the signal on the electrodes induced by the drifting charge carriers [8].

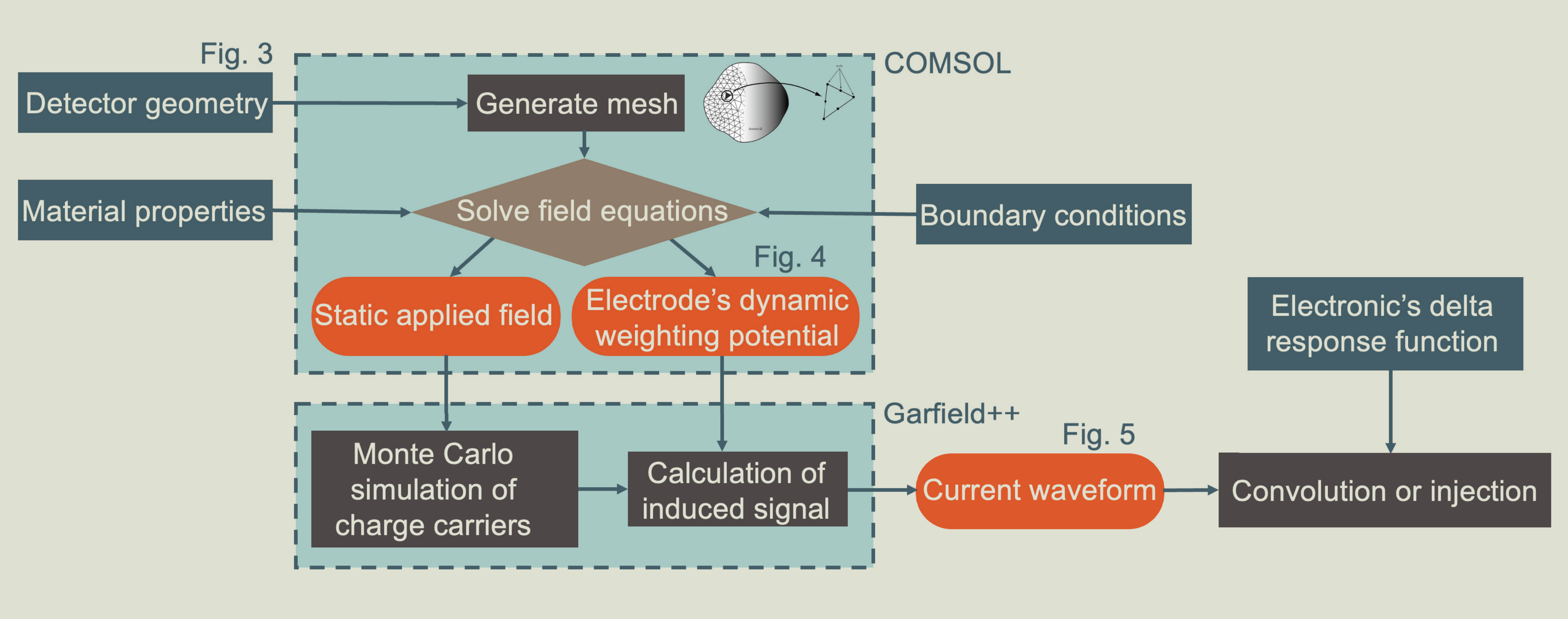


Fig. 3
Detector geometry
Generate mesh
COMSOL
Material properties
Solve field equations
Boundary conditions
Fig. 4
Static applied field
Electrode's dynamic weighting potential
Electronic's delta response function
Garfield++
Fig. 5
Monte Carlo simulation of charge carriers
Calculation of induced signal
Current waveform
Convolution or injection

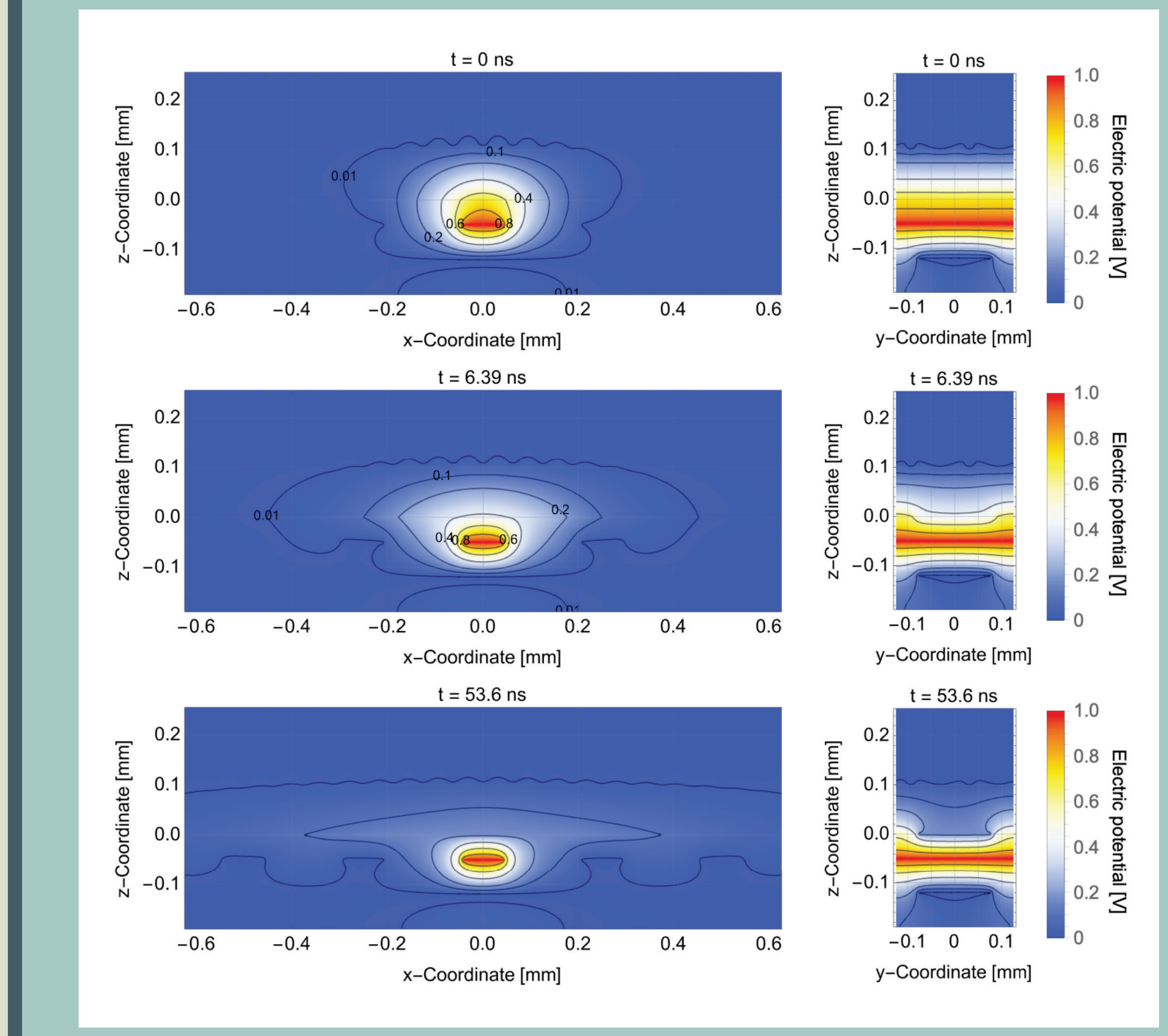


Fig. 4: Time slices of the dynamic weighting potential cross-sections of an x-strip electrode in the xz-plane (left) and yz-plane (right).

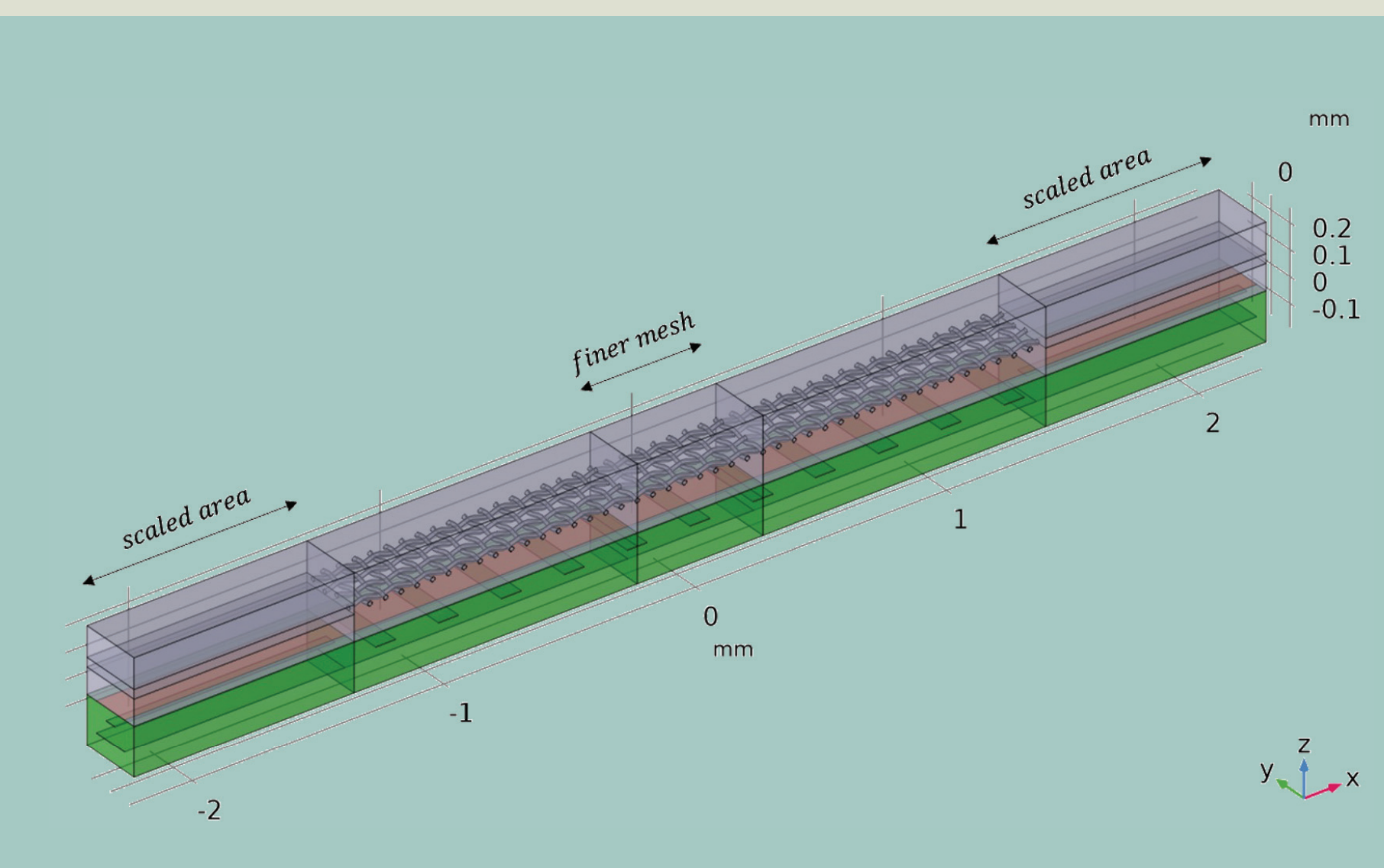


Fig. 3: Model of a 2D-readout resistive strip MM.

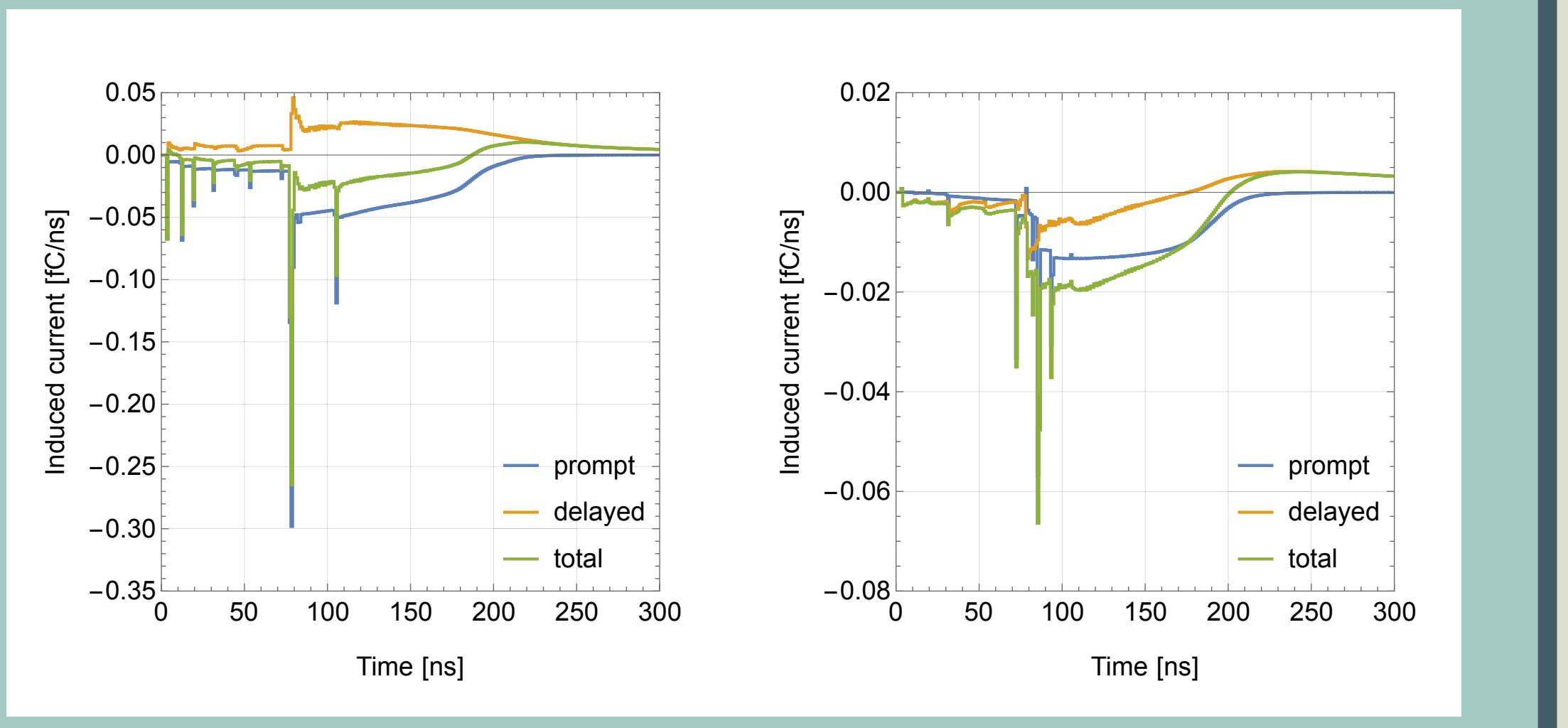


Fig. 5: Induced current on the leading and neighboring x-strips due to the movement of the charges (prompt) and resistive material (delayed).

4 Results

By employing an extended form of the Ramo-Shockley theorem, we studied the induced current response of various devices. These models were systematically validated against toy-model results and experimental data. Notably, a benchmark was conducted using the resistive strip MM [9], demonstrating strong agreement between simulations and experimental findings.

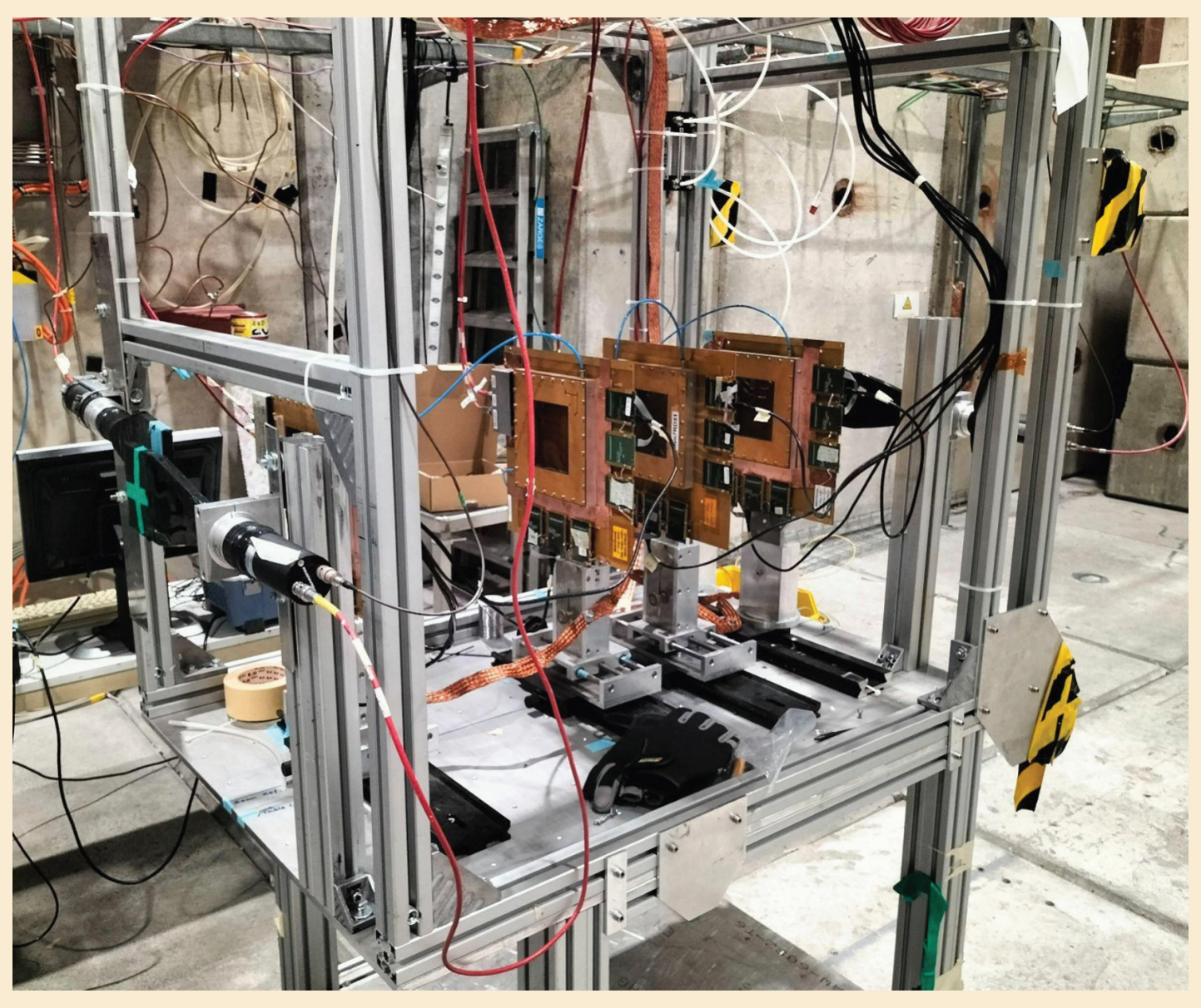


Fig. 6: Image of the test beam tracker at the CERN SPS H4 beamline for the measurement of the average current response of the resistive strip MM.

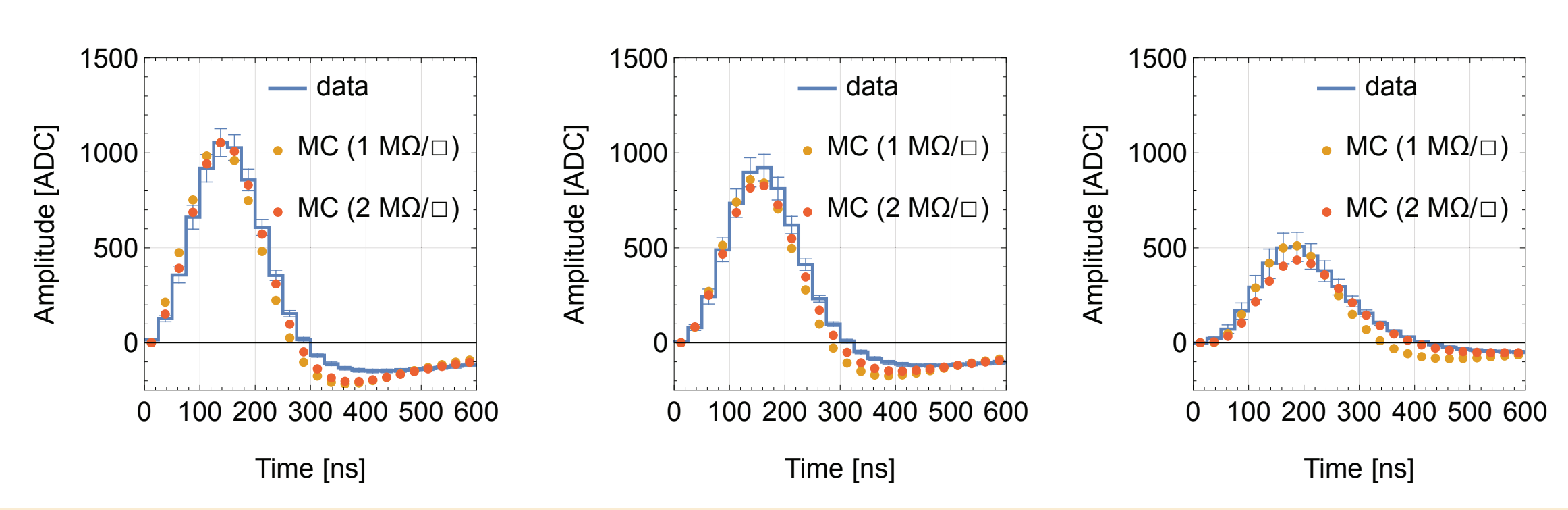


Fig. 7: Comparison between the simulated and measured average induced current of three adjacent x-strips in a resistive strip MM.

5 Conclusion

Through simulation and measurement, we have explored novel solutions in MRPCs, Micro Pattern Gaseous Detectors, and solid-state sensors incorporating resistive elements [10]. These studies can be employed to advance the design and optimization of future detectors and be tailored to meet the specific demands of HEP experiments.

References

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[4] S. Ramo, Proc. Ire. 27 (1939) 584
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Resulting works

[8] D. Janssens et al., NIM-A 1040 (2022) 167227
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