# Extending Garfield++ for Efficient Multi-Stack MRPC Simulation with Space-Charge Effects and Differential Readout

**Yingjie Zhou**[1], **Dongdong Hu**[1], **Yiding Zhao**[1], **and Ming Shao**[1]

[1]*Department of Physics, University of Science and Technology of China, Hefei, Anhui 230026, China*

## Abstract

We present a simulation framework for avalanche development, signal formation, and timing studies in a multi-stack resistive plate chamber (MRPC). The detector model has four stacks of six gas gaps and five strip-readout planes.

Cosmic-ray muon tracks generated with CRY are supplied to TrackHeed to simulate primary ionization in the detector gas. Early avalanches are treated with microscopic electron transport, after which the electrons are transferred to a grid-based calculation including diffusion and space-charge effects[1,2]. Weighting potentials for readout strips are calculated with a two-dimensional neBEM model and imported as interpolation maps. A reference-strip solution is translated to the remaining strips to avoid repeated field calculations. Targeted refinements were introduced in Garfield++ to preserve disconnected strip boundaries in neBEM calculations and to consistently initialize transport properties for gas gaps not populated by the initial avalanche.

Signals from corresponding strips on the five readout planes are propagated to a common reference plane and combined to construct the differential response. Leading-edge crossing times and time-over-threshold values are then extracted and used for time-walk correction. Preliminary studies demonstrate physically consistent signal formation and enable systematic studies of thresholds, cluster size, efficiency, and timing.

## Simulation chain

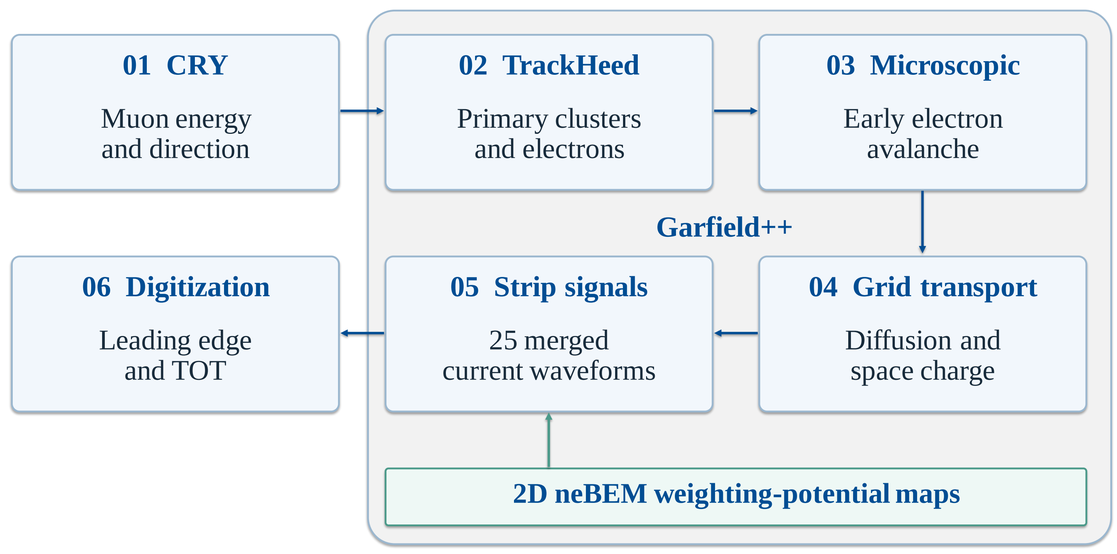
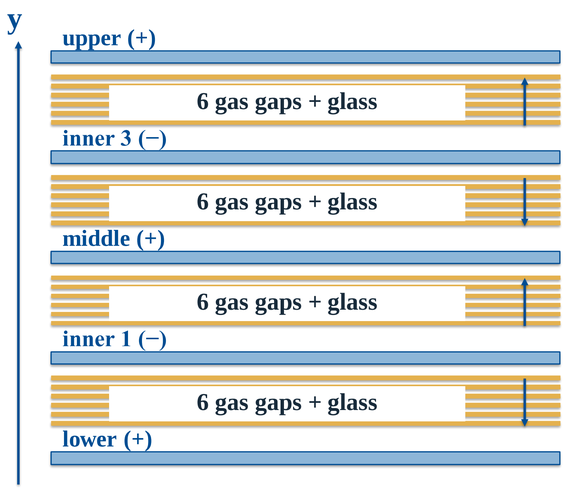



**Fig. 1. Simulation chain.** CRY is used to sample cosmic-ray muons, and TrackHeed generates the primary electrons. Microscopic avalanche transport is applied up to 0.2 ns, followed by grid transport including diffusion and space-charge effects [1]. Strip weighting-potential maps are calculated using neBEM[2] in Garfield++, and the induced signals are subsequently digitized.

## Detector model

Four stacks, 24 gas gaps and five strip-readout planes




**Gas gap**
0.15 mm
**Glass / PCB**
0.57 / 1.20 mm
**Strip width / gap**
7 / 3 mm
**Gas field magnitude**
≈126 kV/cm
**Gas mixture (90 : 5 : 5)**
$C_2H_2F_4$ / $SF_6$ / iso-$C_4H_{10}$
293.15 K, 1 atm

**Fig. 2. Stack cross-section.** Fields alternate between stacks; not to scale.

## Weighting potentials and refinements

Some modifications were made to the Garfield++ software to ensure its stable operation.

**Disconnected strips**
Preserve disconnected collinear strip boundaries to prevent incorrect neBEM geometry construction.

**All gas gaps initialized**
Initialize geometry, field and transport state even when a gap has no initial electrons, that could cause the program to terminate abnormally.

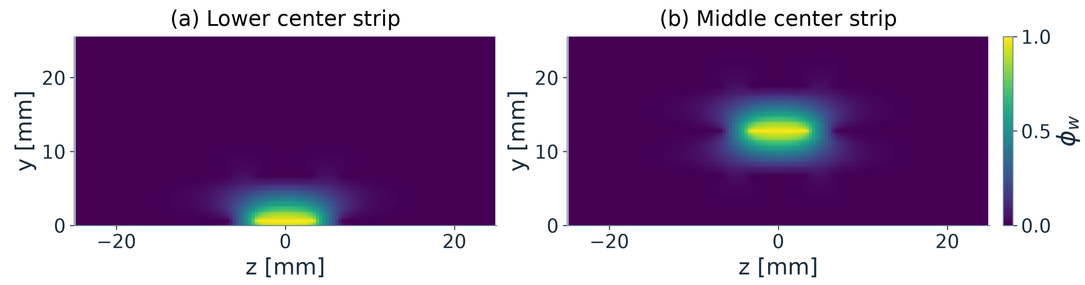



**Fig. 3. Weighting potentials of the lower (a) and middle (b) center strips**. With the modifications described above, the weighting fields were successfully generated using neBEM, enabling stable MRPC simulations.

## Differential readout and signal formation

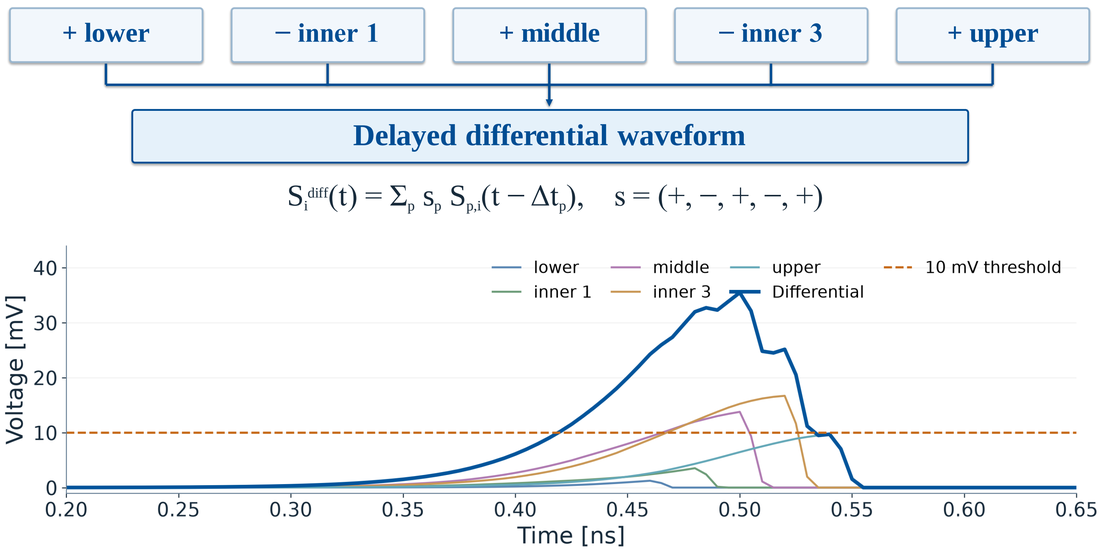



**Fig. 4. Simulated signal graph.** The signals from the five readout strips are corrected for propagation delays and then combined differentially to obtain the total signal amplitude. The dashed line represents a threshold of 10 mV, which is used for triggering the over-threshold condition.

## Threshold and timing performance

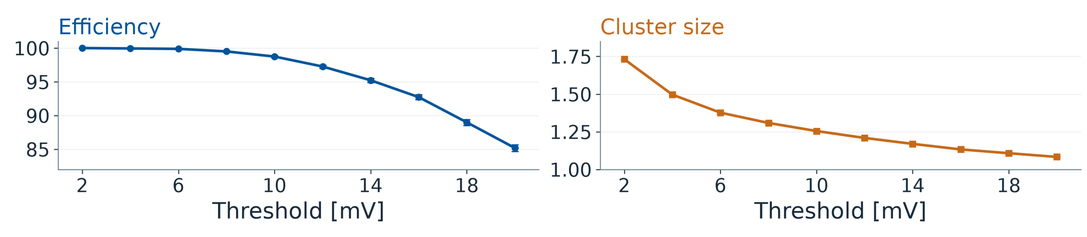



**Fig. 5. Threshold response.** Simulated detection efficiency and mean cluster size as functions of threshold.

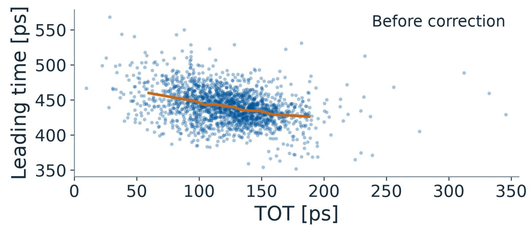



**Fig. 6. TOT correction.** Simulated leading time versus TOT before correction.

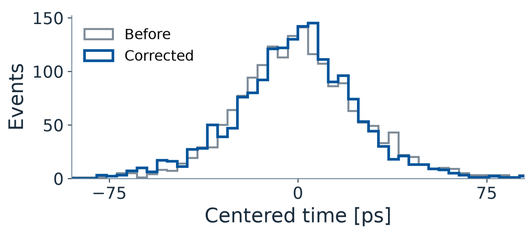



**Fig. 7. Time resolution.** Simulated time distributions before and after TOT correction. Gaussian fits give time resolutions of 21.60 ps before correction and 19.46 ps after correction. The threshold is 10 mV.

## Conclusion

A complete simulation framework has been developed for multi-stack MRPCs, covering avalanche transport, weighting-field calculation, signal formation, and differential readout. The Garfield++ modifications enable stable simulations of the full detector geometry. Preliminary results reproduce the expected threshold behavior and demonstrate improved timing after TOT correction. Future work will include a realistic front-end electronics response and direct comparison with experimental data. The development and refinement of the simulation and analysis code were assisted by OpenAI's GPT-5.6 Sol model.

**References**

[1] C. Lippmann and W. Riegler, "Simulation of space charge effects in resistive plate chambers," IEEE Trans. Nucl. Sci. 50 (2003) 797–802.

[2] N. Majumdar and S. Mukhopadhyay, "Simulation of 3D electrostatic configuration in gaseous detectors," JINST 2 (2007) P09006.

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https://github.com/Yingjie-Zhou/MRPCSim