Markov Modeling of Performance Deterioration in irradiated RPCs

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1 Introduction

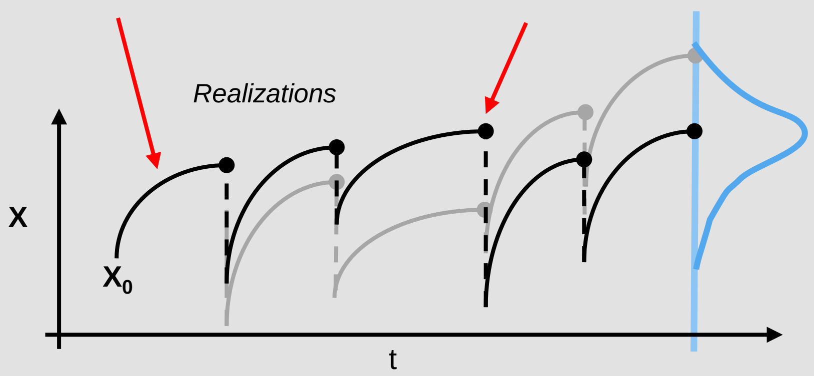
- Eco-friendly gas mixtures in RPC possess the disadvantage that their efficiency plateau significantly reduces under background irradiation [1,2]. Two promising eco-friendly gas mixture candidates, ECO2 and 3 (~2% / 100 Hz/sqcm), are around a factor of two worse compared to the trigger-RPC standard mixture (~0.7% / 100 Hz/sqcm).
- Modelling rate capability still relies on Monte Carlo methods, whereas analytical approaches (mostly *Campbell theorem* [3,4]) struggle to describe the high-action regime (high-rate or high-charge) [3,4].

2 Piecewise Deterministic Markov Process (PDMP)

- Modelling the high-action regime must include correlation between two background events. In some cases, such as the single-cell model with constant permittivity, the mechanism has the Markov property and can be described using a PDMP [5,6,8].
- The stationary gap voltage spectrum (light blue Fig. 1) is essential to determine the performance deterioration.

Piecewise deterministic: $\frac{d\mathbf{X}_t^{(i)}}{dt} = \Phi_i(\mathbf{X}_t)$

Markov Process: $\mathbf{X}_t \sim q(\cdot\,|\mathbf{X}_{t\_})$



e.g.: $\mathbf{X} = V_{\text{gap}}(\boldsymbol{x})$, $\Phi_i \propto \frac{1}{RC}$, and $q \propto \rho(Q|V_{\text{gap},t^*_-})$

Fig. 1. Principle of PDMP with deterministic evolution between events and random jumps with Markov property (jump only dictated by the previous state). The light blue curve indicates the resulting voltage spectrum.

3 Single Cell Model – three-layer single-gap

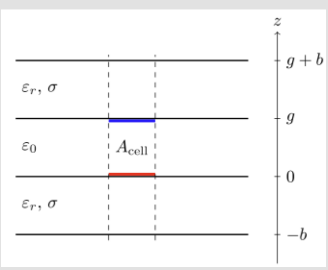
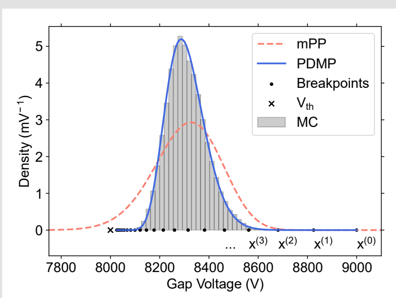


Fig. 2.1. Sketch of the single cell model.

- Divides RPC into cells and represents the local voltage drop through its RC-equivalent circuit [7].
- Cell size reflects *area of influence*, and results depend on it.

Fig. 2.2. Gap voltage spectrum calculated with three different methods.



- The PDMP differential equations (blue) match the Monte Carlo simulations (gray). The spectrum based on Campbell's theorem (red) deviates and predicts too large field fluctuations.
- Works for any smooth charge distribution function.

4 Rate Induced Efficiency Plateau

- Based on two Γ-distributions, the total charge spectrum of the background irradiation, including streamer discharges, is modelled. The mean charge follows a piecewise linear function.

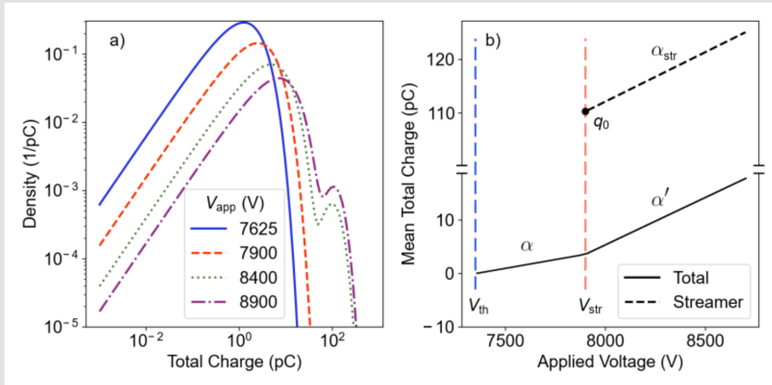


Fig. 3.1. a) Charge distribution including large charge events and b) the average charge deposited at the respective voltage.

- As the separation between avalanche and streamers ($V_{\text{str}} - V_{\text{th}}$) increases, the efficiency plateau drops. The accumulated charges depress the average voltage drop disproportionately, acting like a barrier.
- On the other hand, the increase of the streamer charges increases the barrier-effect.

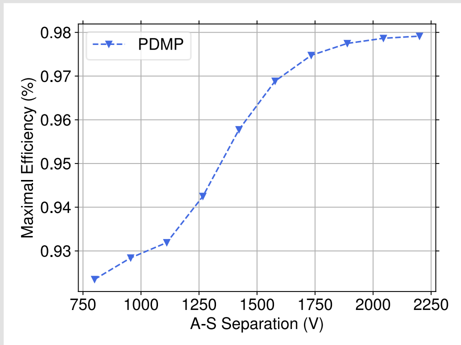


Fig. 3.2. Maximal efficiency as a function of the avalanche to streamer separation. Fixed rate and streamer charges.

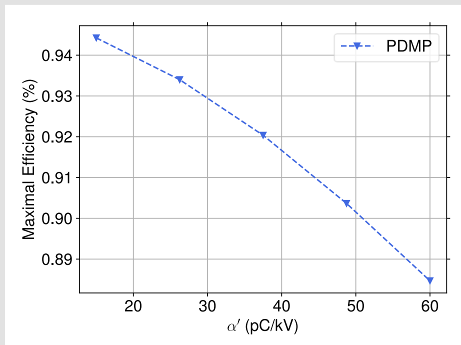


Fig. 3.3. Maximal efficiency as a function of the streamer charge slope. Fixed rate and a-s separation.

5 Conclusion

- Analytical model (PDMP) describing the strong correlation between two subsequent background events. Captures the deviation from previous work solely based on Campbell's theorem. Very fast (up to 100 times faster) and accurate compared to Monte Carlo simulations.
- PDMP can be applied to other RPC geometries. Also works for more realistic models without imposing the cell division (see my talk on Wednesday!)
- PDMP works for arbitrary charge spectra, no sampling needed.
- Large charge events, like those from streamers, suppress the maximal reachable efficiency. Essential for finding eco-friendly mixtures!

6 Acknowledgements

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