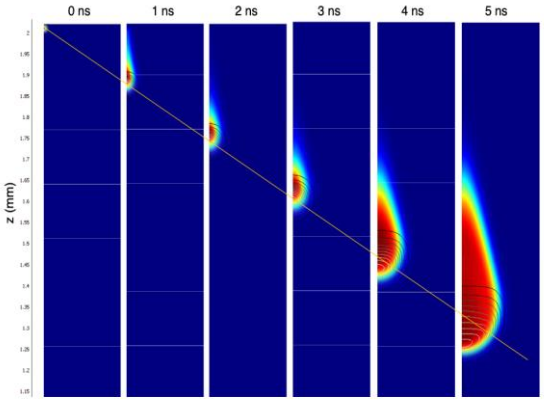

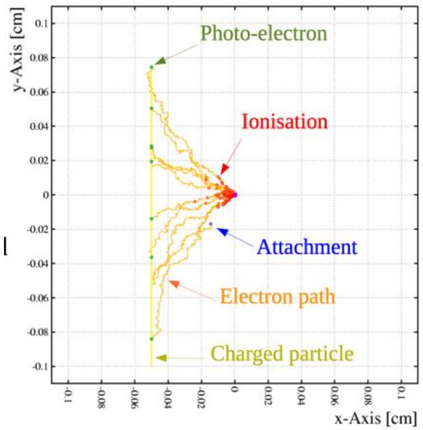

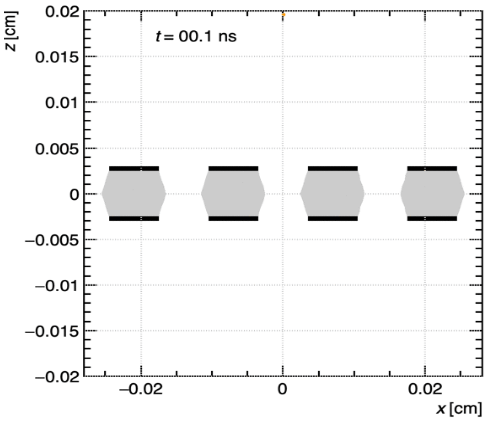

Large Avalanches & Space Charge

WG4 Working meeting

11-06-2024

Piet Verwilligen

drd1-wg4-conveners@cern.ch

Preamble

- What this meeting is about – and what it is not …
- Working meeting:
  - => would like to have ”minimal” preparation ahead
  - => but maximal work/contribution during the meeting
    - Interact in discussion
    - Express your interest
    - Search for an intent to work together on a common topic
    - Don’t feel shy if you do not have a lot of experience
      - We all started from zero some time ago
      - We are here to share knowledge – you can learn
- Idea for today:
  - Know what are the open questions - what are possibilites
  - Know what has been done in the past – what are the holes
  - Discuss into taking part in pushing the boundary of knowledge

Large Avalanches & Space Charge

- Potentially very large topic …
  - Lot of physics effects kicks in at very large charges
  - Physics of discharges understood ”qualitatively” however no simulation (quantitative) implemented
  - Simulation of (very) large avalanches can lead us to have a tool to study (& understand - later) numerically discharges
  - Intro talk by P. Fonte
    - Reference: similar talk at MPGD Stability Workshop during RD51 Collaboration Meeting in Munich 2018
    - https://indico.cern.ch/event/709670/contributions/3008591
  - Few other illustrations in my slides here below

Space Charge

- Important effect in Resistive Plate Chambers
  - Very high gain => will lead to development of space-charge
  - Space-charge will change (dramatically) the behaviour of Q
- First simulation works on space charge (*):
  - C. Lippmann & W. Riegler 2003 seminal paper
  - https://doi.org/10.1016/S0168-9002(03)00337-1

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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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Detector physics and simulation of resistive plate chambers

Werner Riegler*, Christian Lippmann, Rob Veenhof

EP Division, CERN, CH-1211 Geneva, 23, Switzerland

Received 17 June 2002; received in revised form 7 October 2002; accepted 19 November 2002

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

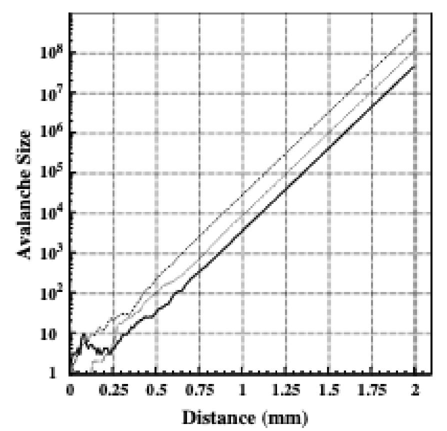
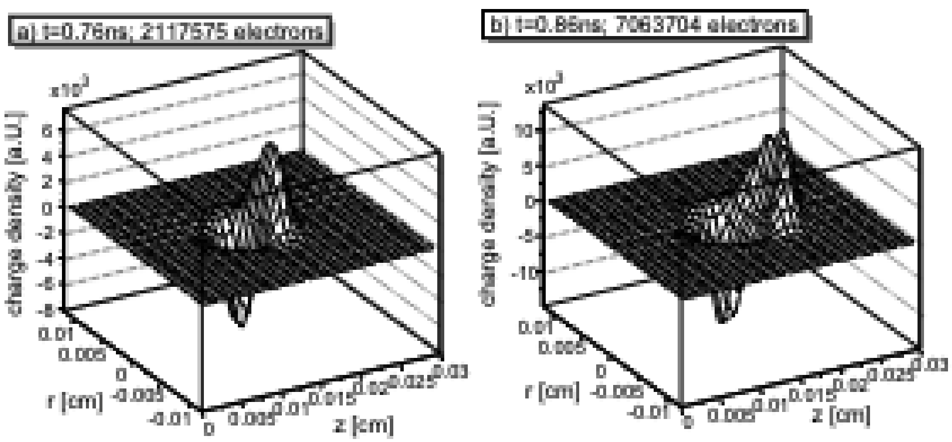


Fig. 6. Avalanches started by a single electron at $x = 0$ for $\alpha = 13/\text{mm}$, $\eta = 3.5/\text{mm}$. We see that the very beginning of the avalanche decides on the final avalanche size. Once the number of electrons is sufficiently large the avalanche grows like $e^{(\alpha-\eta)x}$.

Space Charge

- First simulation works on space charge (*):
  - C. Lippmann PhD Thesis: 1.5D and 2D (axial symmetric) models
  - https://cds.cern.ch/record/1303626
  - Private code – never made publicly available
  - Work ongoing right now to include models in Garfield++
    - Expected by September – October 2024



Space Charge

- Other approaches: Fluid-model simulation with COMSOL
  - Initiated by P. Fonte, continued by F. Resnati
    - Reference: RD51 Lectures 2017
    - https://indico.cern.ch/event/676702/contributions/2769934
  - CERN GDD group (F.Resnati) => understood gain increase at high Φ
  - Lot's of activity right now or at recent times in SINP, India (students supervised by S.Mukhopadhyay)

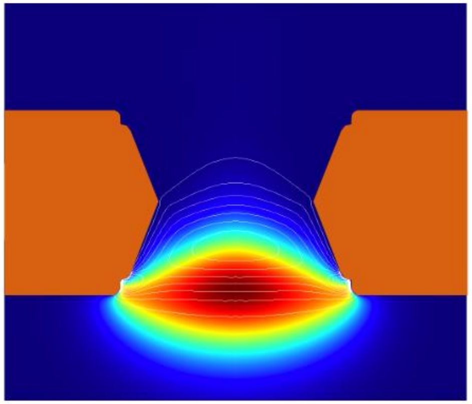
$$\frac{\partial \rho}{\partial t} = -\vec{\nabla} \cdot (\rho \vec{v} - D \vec{\nabla} \rho) + R$$

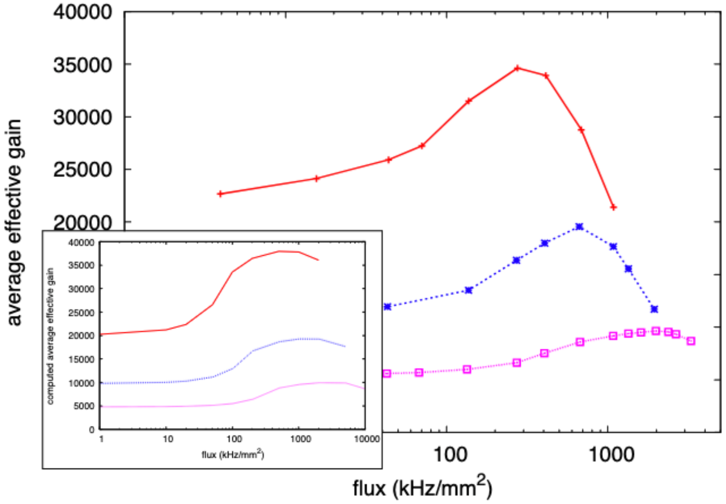
ρ is the unknown

For what concerns the boundary conditions, some examples

$\vec{n} \cdot \vec{J}^{tot} = 0$	No flux
$-\vec{n} \cdot \vec{J}^{tot} = \Phi(\vec{x}, t)$	Input flux
$\vec{n} \cdot \vec{J}^{diff} = 0$	Output
$\rho = \Psi(\vec{x}, t)$	Concentration

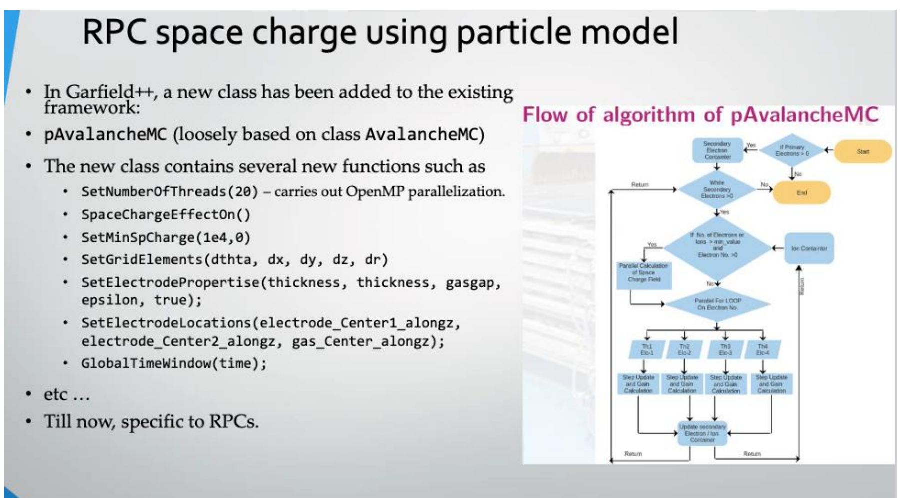
Plus symmetry and periodic conditions

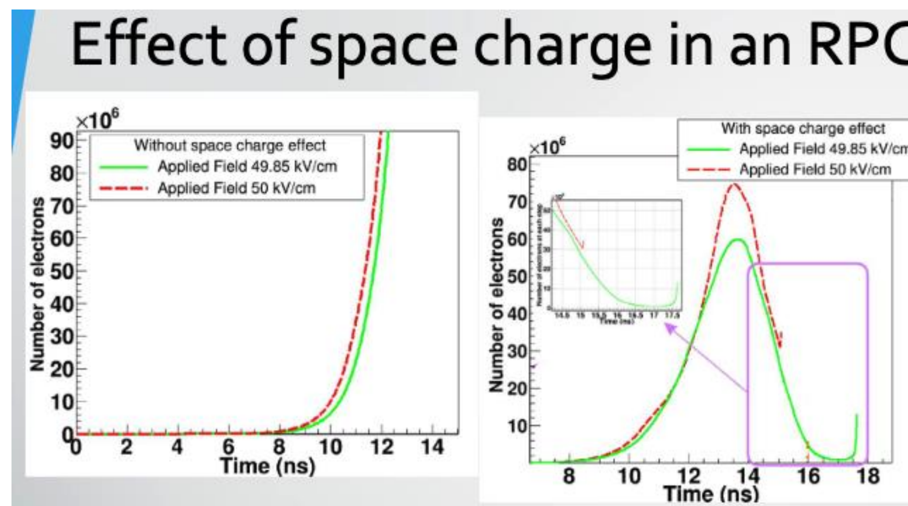




Space Charge with Garfield++

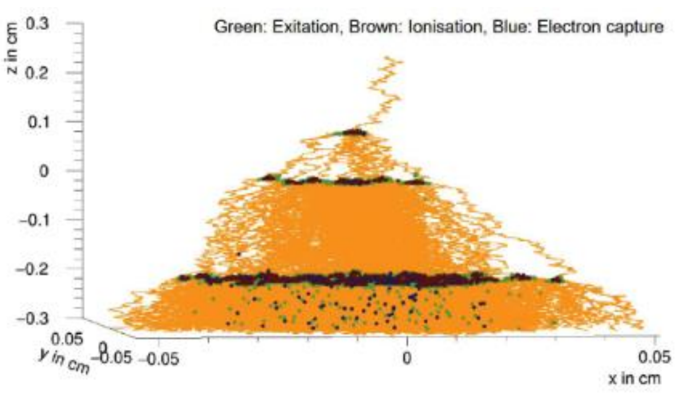
- Efforts by SINP Group (Colcatta – S.Mukhopadhyay)
- Presented at RPC Conference & Ageing WS (2023)
- Publication in Computational Physics
  - https://doi.org/10.1016/j.cpc.2023.108944
  - Code being verified / optimized before integration
  - So-far limited only to RPC – what about extension? Timescale?





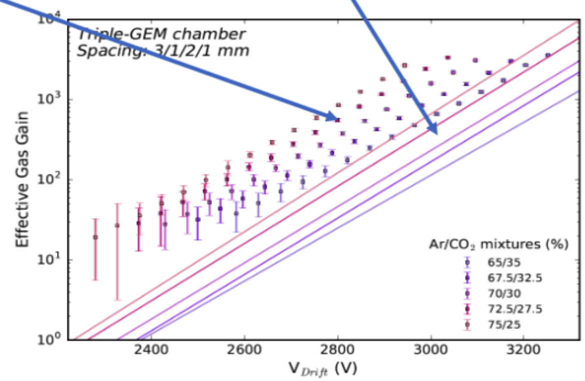
Large Avalanches & Space Charge

- Likely can play also important effect in MPGDs such as Triple-GEM detectors at large amplifications
  - Discrepancy simulated – Measured Gain in Triple-GEMs
  - Factor 2 for single-GEM, Factor 8 for Triple-GEM
  - Not the first time reported
    - Link: https://indico.cern.ch/event/843711/contributions/3556735



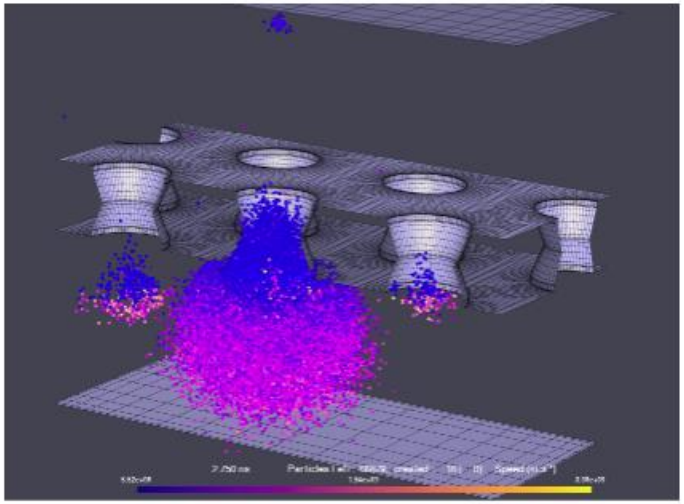
Discrepancy between gain in simulation and measurements

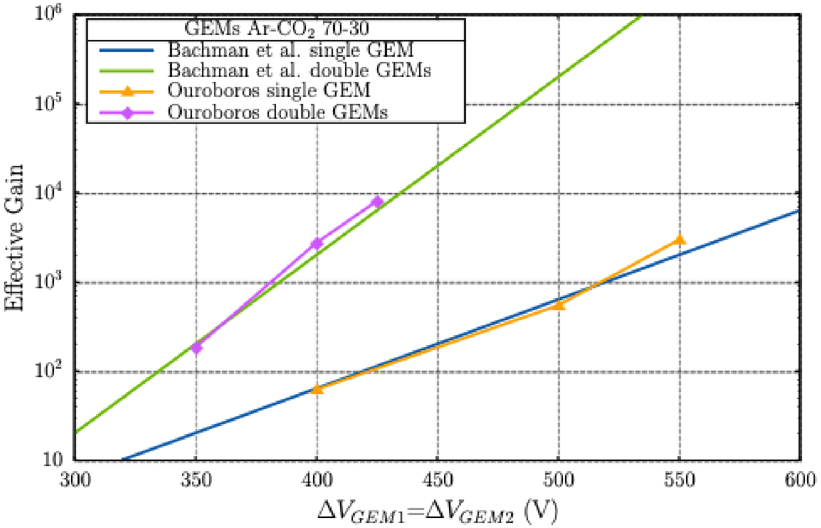
- Well-known feature that simulations give less gas gain than observed in measurements.
- Investigating microscopic simulation step



Large Avalanches & Space Charge

- Inclusion of space-charge in an ad-hoc developed software tool with Boundary-element-Method (BEM): Ouroboros-BEM
  - Reference: RD51 Collab Meeting 2019 – S.Salvador (LPC Caen)
  - https://indico.cern.ch/event/843711/contributions/3556741
  - Quite slow – even though running on cutting-edge GPU (Tesla
  - Published in JINST: 10.1088/1748-0221/17/01/P01020
  - Developed in context of Hadron-Therapy – author left field (Grav Waves)





Outlook

- DRD1 Proposal – 8 pages – lot's of ideas
  - https://cernbox.cern.ch/s/PP7BZroM3NYS2Vh
- Need for more detailed simulations
- Need for faster simulation methods
- Hybrid approaches
  - Precise & (relatively slow) for small charges
  - Approximately & fast for large charges

From DRD1 proposal

Simulation of Large Charges and Space-Charge: While the physics of small avalanches is well simulated and largely understood, the physics and statistics of large avalanches (e.g., charge spectra and time distributions) and their transformation into streamers, including realistic photonic parameters and streamer propagation and quenching are still to be understood and modelled in detail. Better understanding and modelling would not only benefit the simulation of RPCs but is also relevant for the study of discharges in MPGDs, where one would like to understand the critical charge before the breakdown, streamer formation in different detector geometries, propagating discharges and the modelling of discharges in a gem hole, including the electrode-heating and possible thermionic emission. Some possibility to model avalanche-to-streamer is already available by taking a hydrodynamic approximation to be solved using commercial FEM packages such as COMSOL Multiphysics [43]. Furthermore, the modelling and simulation of space charge within this simplified hydrodynamic approach have proven to be effective in modeling gain variations in GEM detectors observed at high particle fluxes [63]. Possible approaches within Garfield++ are grid-based avalanche statistics calculation or an extension of the particle tracking algorithm where close-by charges are clustered in deterministic behaving macro-particles or sub-avalanches when a sufficiently large number of charges is reached. The latter would preserve the statistical fluctuations in small avalanches with respect to hydrodynamical approaches that are purely deterministic. The simulation of large charge clouds in Garfield++ needs to be accompanied by the space-charge effect: Calculating the electric field induced by these charges at each step of the avalanche development can be done by interfacing a BEM or FEM solver [55] in Garfield++. Significant code improvements are required in neBEM to maintain simulations computationally feasible. Running these simulations on advanced GPUs will allow us to maintain the computational resources (memory consumption and computation time) under control. Recently a BEM solver was equipped with microscopic tracking run on a powerful GPU, and preliminary results indicate that the long-standing data Monte Carlo discrepancy for the gain in a GEM hole [64] could be resolved by including space-charge effects [65]. The software developed for the simulation of large avalanches will also be adapted and used for modelling discharge processes.

Fourth WG4 working meeting - Large Avalanches Topical Meeting

Tuesday 11 Jun 2024, 15:00 → 18:00 Europe/Zurich

Marcello Abbrescia (Universita e INFN, Bari (IT)), Maryna Borysova (Weizmann Institute of Science & KINR, NAS of Ukraine), Ozkan Sahin (Uludag University (TR)), Paulo Fonte, Piet Verwilligen (Universita e INFN, Bari (IT)), Rob Veenhof (CERN)

Videoconference WG4 working meeting Join

15:00 → 15:10 **News & Announcements** 10m

Speakers: Maryna Borysova (Weizmann Institute of Science & KINR, NAS of Ukraine), Piet Verwilligen (Universita e INFN, Bari (IT))

15:10 → 15:30 **Large Avalanches & Space Charge - an Introduction & possible goals** 20m

Speakers: Paulo Fonte (LIP Coimbra), Piet Verwilligen (Universita e INFN, Bari (IT))

15:30 → 15:50 **Algorithm for Electric Field calculation in Garfield++ with neBEM** 20m

Speakers: Supratik Mukhopadhyay (Saha Institute of Nuclear Physics (IN)), Supratik Mukhopadhyay (Saha Institute of Nuclear Physics (IN))

15:50 → 16:00 **Algorithm for large gain in Triple-GEM detectors for the Cygno Experiment** 10m

Speaker: Davide Pinci (Sapienza Universita e INFN, Roma I (IT))

16:00 → 16:10 **Algorithm for large gain in RPC detectors: adoption of Riegler-Lippman 2D algorithm in Garfield++** 10m

Speaker: Dario Stocco (ETH Zürich)

16:10 → 16:50 **Discussion Time** 40m

16:50 → 17:00 **Round Table - AOB** 10m