RD51 Collaboration Meeting, 19–21 Jun 2023, CERN

Parallelization of Garfield++ and neBEM to simulate space charge effects in RPCs

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Collaborative Institutes

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June 20, 2023

Outline

1. Goal or Motivation
2. Uncorrelated and parallel random number generation using TRandom3 and OpenMP
3. Calculation of space charge electric field with line charge model
4. Example of space charge effect in a trigger RPC using Garfield++
5. Example of space charge effect in a timing RPC
6. Summary
7. Future Outlook

Goal or Motivation

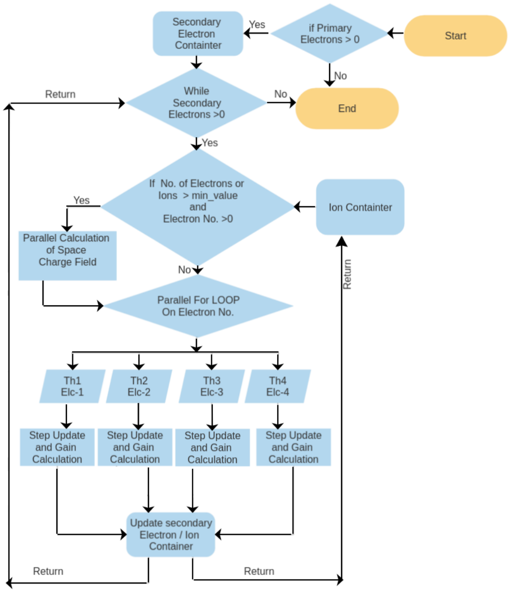
1. Generation of 3D Avalanche with Space charge effect in any gaseous detectors with Garfield++.
2. Parallelization of the avalanche process with space charge effect to reduce the computation time.
3. Study device physics of RPC and other gaseous detectors.

Garfield++

Introduction :

1. A C++ based software.
2. Used to study the detector physics of particle detectors like RPC,GEM etc..
3. Basic Methods to generate Avalanche
   - i. Microscopic tracking. Class Name: AvalancheMicroscopic.
   - ii. Monte Carlo tracking. Class Name: AvalancheMC
4. Built-in field solver : neBEM
5. **Our contribution** :
   - i. Added a new class pAvalancheMC to generate avalanche with space charge effect.
   - ii. Applied Multithreading technique OpenMP to speed up avalanche process.
   - iii. pAvalancheMC is based on Monte Carlo tracking.
   - iv. Use of OpenMP version of neBEM.

Flow of algorithm of pAvalancheMC



Uncorrelated random numbers using Trandom3 and OpenMP

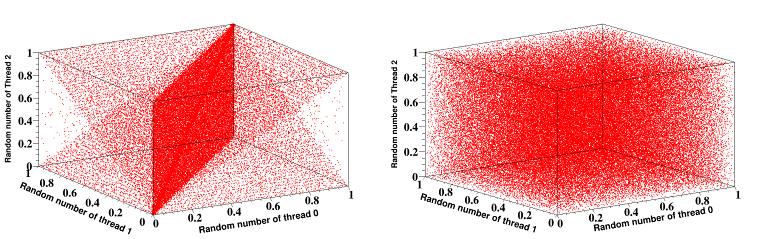


Figure 1: Correlation between random numbers generated by individual threads when 3 threads are used

1. All threads generate random number from different TRandom3 object and different seed.
2. Random number generated by three thread are un-correlated.

Example of the electron & ion cluster [1]

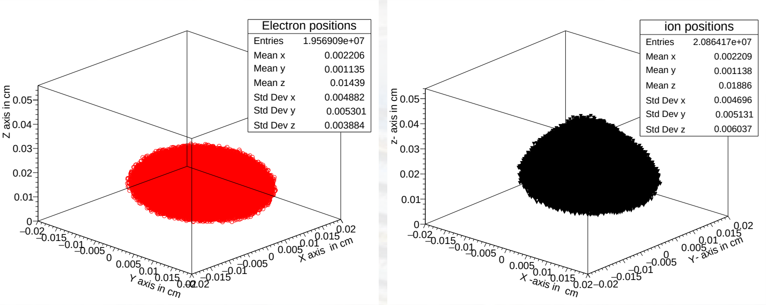
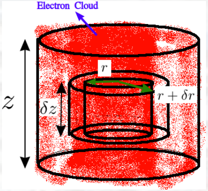


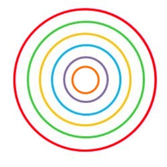
Figure 2: (a) Left electron distribution. (b) Right side ion distribution [1]

Steps of modeling of space charge region as charged rings and lines

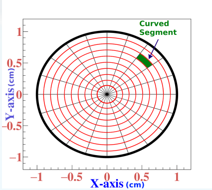
Step1: Dividing Z space into several δz element.



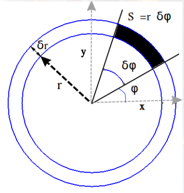
Step2: $\delta z \to 0$ & radial space divided into several co-centric rings of increasing radius r & thickness δr.



Step3: Divide rings into several curved segments.



Step4: Small $\delta\phi$ so that curved segment becomes a line.



Example of an avalanche with space charge effect

1. Electrode thickness = 2mm.
2. Gas-gap = 2mm.
3. Electrode material = bakelite.
4. Gas-Mixture = Ar (80%),CO_2 (20%).
5. Constant Electric Field = 23.5kV/cm.
6. The step size of time has been taken as 0.1 ns.

Results (Avalanche Saturation in presence of space charge effect) [2]

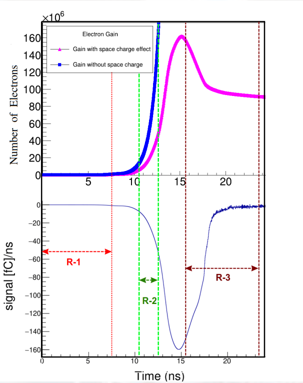
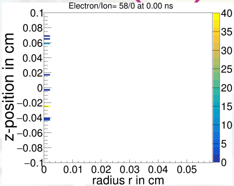
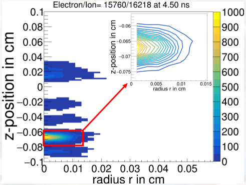


Figure 3: Variation of electron number with and without space charge effect and signal with space charge effect

1. We will analyse the gain in following three different regions:
   a. R1: Non space charge region: 0 ns to 7.46 ns
   b. R2: Space charge region started: 10.46 ns to 13.46 ns
   c. R3: Near the peak value to saturated region: 15.46 ns to 23.46 ns

Propagation of electron cloud from 0 ns to 7.46 ns (R1)





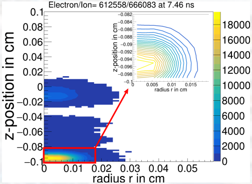
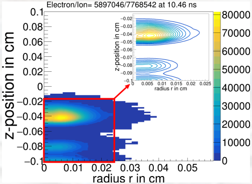
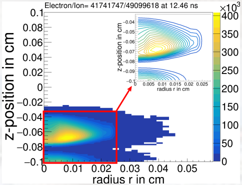


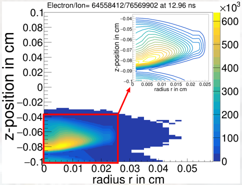
Figure 4

1. At 0 ns 58 primary electrons distributed in 7 cluster.
2. As time grows clusters size are increasing.
3. Clusters are gradualy merging with time.
4. At center yellow region is max charge density.

Propagation of electron cloud from 10.46 ns to 13.46 ns (R2)







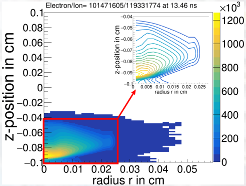


Figure 5

1. All Clusters merged.
2. At 10.46ns max charge density shifted from the r=0 because of space charge field.
3. Max charge location shifted again to r=0 due to the radial component of ion field.

Changing of shape of electron cloud from 15.46 ns to 23.46 ns (R3)

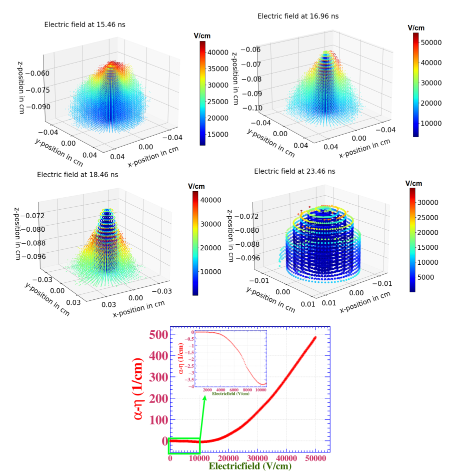


Figure 6

1. The shape of electron cloud changing form spherical to cone.
2. At 23.46 ns the cone become some co-centric cylinder.
3. At 23.46 ns the gain of the avalanche is saturated because the rate of ionisation compensate rate of attachment process.

Avalanche simulations inside the RPC with $C_2H_2F_4$(97%), i-C_4H_{10} (2.5 %), and SF_6 (0.5 %) gas mixture

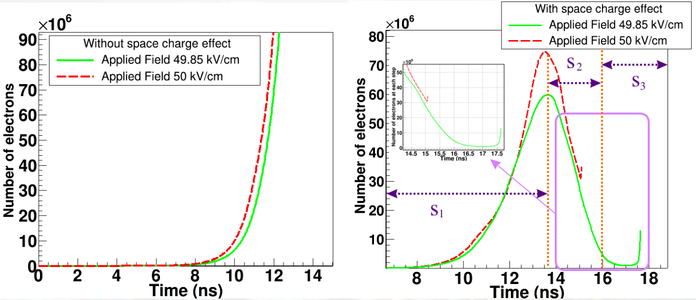


Figure 7

Variation of magnitude of maximum space-charge field with time

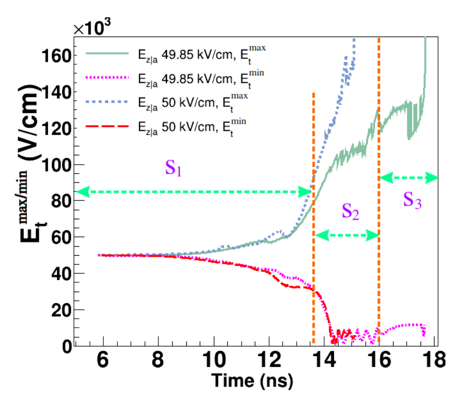


Figure 8

Example of space charge effect in a timing RPC

1. Electrode thickness =2mm.
2. Gas-gap =0.3mm.
3. Electrode material = bakelite.
4. Gas-Mixture = R134a (85%),ISOBUTANE (5%),SF6 (10%).
5. neBEM field solver used to calculate applied field.
6. Avg Electric Field inside the gas gap = 43 kV/cm (1720 V).
7. The step size of time has been taken as 0.01 ns.

Electron gain distribution

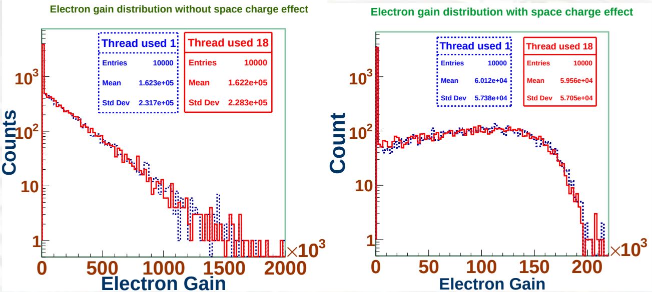


Figure 9: Electron gain distribution (a)without space charge effect (left) (b) with space charge effect (right)

1. A set of 10K avalanche generated from a single electron placed near the negative electrode (z=0.02 cm).
2. The shape of the electron gain distribution is modified.
3. The avarage value of the gain is reduced by a factor 10.

Timing Performance

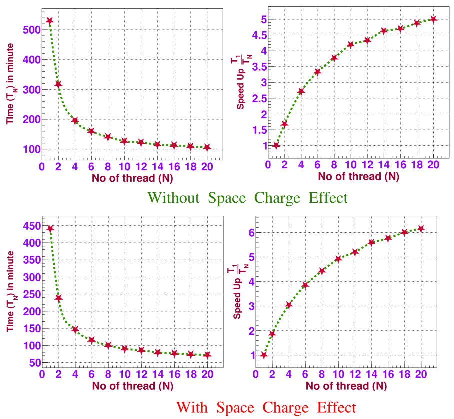


Figure 10

1. Time to complete 10K avalanche is reducing with increament of thread number.
2. Maximum 5 times speed up is observed for 20 thread without space charge effect.
3. Maximum 6 times speed up is observed for 20 thread with space charge effect.

Summary

1. Proposed a numerical line charge model to calculate the field of space charge inside the RPC.
2. Compared the results of line model with the field solver neBEM and ring models available in the literature and shows a good agreement.
3. Implemented the line model in the Garfield++ software.
4. Implemented the multithreading technique to parallelize Garfield++ and neBEM.
5. Performed a realistic avalanche with space charge effect inside an RPC and with realistic field map generated by neBEM.
6. Calculate the induced charge distribution with space charge effect.

FUTURE OUTLOOK

1. Implement photon transport model in Monte Carlo simulation.
2. Simulate avalanche to streamer transition.
3. Simulate rate effect in an RPC.
4. Test the line model with other gaseous detectors.

Collaborators

1. Tanay Dey (INO, VECC, Kolkata, India).
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5. Abhishek Seal (Regent Education and Research Foundation, Kolkata, India)
6. Subhasis Chattopadhyay (VECC, Kolkata, India)

Acknowledgement

The author acknowledges all the respective institutes and universities for their help and support.

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[2] T. Dey, P. Bhattacharya, S. Mukhopadhyay, N. Majumdar and S. Chattopadhyay, *Parallelization of garfield++ and nebem to simulate space charge effects in rpcs (Under Review)*, .

[3] T. Dey, S. Mukhopadhyay, S. Chattopadhyay and J. Sadukhan, *Numerical study of space charge electric field inside resistive plate chamber*, *Journal of Instrumentation* **15** (nov, 2020) C11005–C11005.

Thanks For Your Attention!
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Field of uniformly charged line[3]

$$E_x^B = \frac{\bar{\lambda}(x-\bar{r})}{4\pi\epsilon_0 P^2}\left[\frac{(y+\frac{S}{2})}{\sqrt{(y+\frac{S}{2})^2+P^2}} - \frac{(y-\frac{S}{2})}{\sqrt{(y-\frac{S}{2})^2+P^2}}\right]$$

$$E_y^B = -\frac{\bar{\lambda}}{4\pi\epsilon_0}\left[\frac{1}{\sqrt{(y+\frac{S}{2})^2+P^2}} - \frac{1}{\sqrt{(y-\frac{S}{2})^2+P^2}}\right]$$

$$E_z^B = \frac{\bar{\lambda}(z-\bar{z})}{4\pi\epsilon_0 P^2}\left[\frac{(y+\frac{S}{2})}{\sqrt{(y+\frac{S}{2})^2+P^2}} - \frac{(y-\frac{S}{2})}{\sqrt{(y-\frac{S}{2})^2+P^2}}\right]$$

where,
S=length of the line.
$P = \sqrt{(z-\bar{z})^2+(x-\bar{r})^2}$, and if Q_{st} is the total charge of this straight line then, $\bar{\lambda} = \frac{Q_{st}}{S}$.

Comparison of neBEM and line approximation [1]

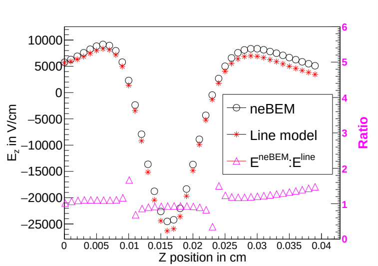

Figure 11: Comparision of total z-directional field (source+image) with neBEM. [1]

Back ups

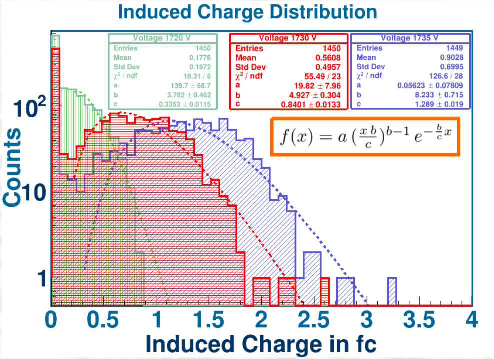

Figure 12: Induced charge distribution with space charge effect at voltages ±1720 V,±1730 V and ±1735 V