Qualification of Eco-Friendly Gas mixture for Avalanche Mode Operation of RPC

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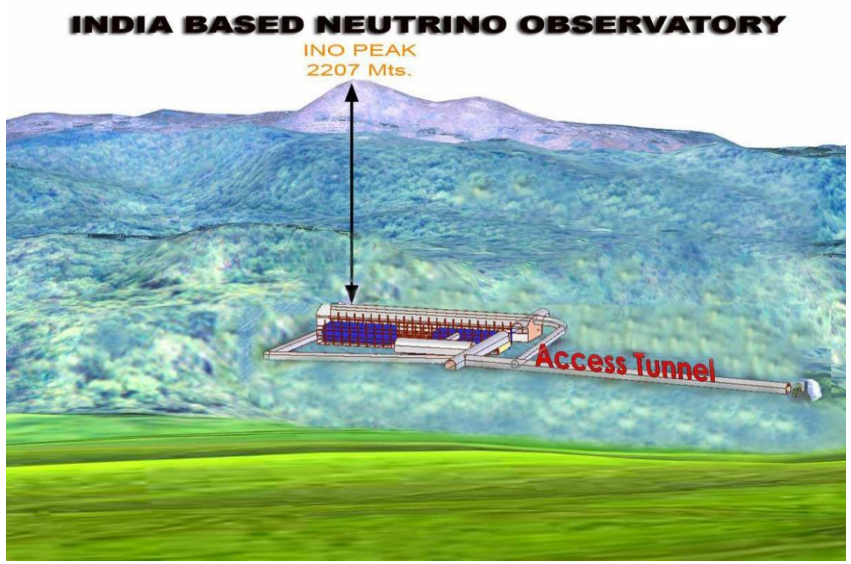
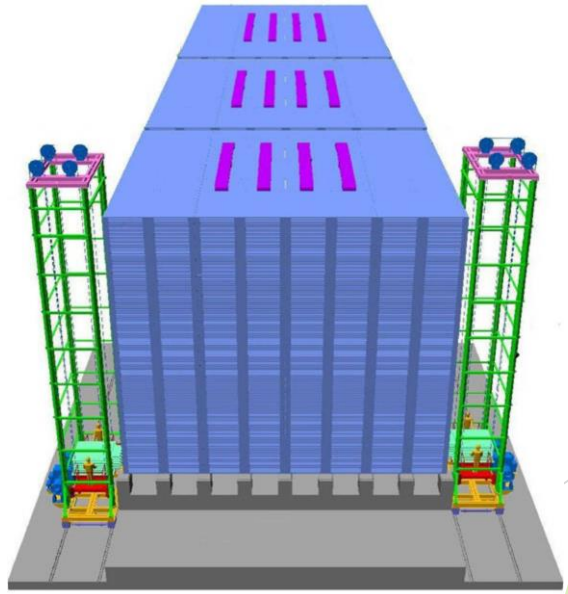
INO-ICAL and RPC

- India based Neutrino Observatory (INO) is an under ground research facility for neutrino physics.
- One of the experiments, which are going to come up in this facility, is mass hierarchy experiment. The detector for this experiment will be a magnetized iron calorimeter(ICAL).
- The active part of the detector will be Resistive Plate Chambers(RPC).
- Nearly 30000 RPCs will be set up in the cavern.



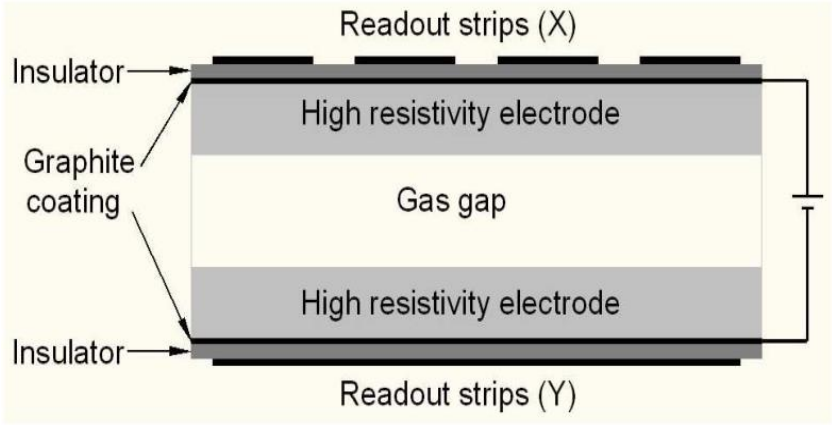


Resistive Plate Chamber(RPC)

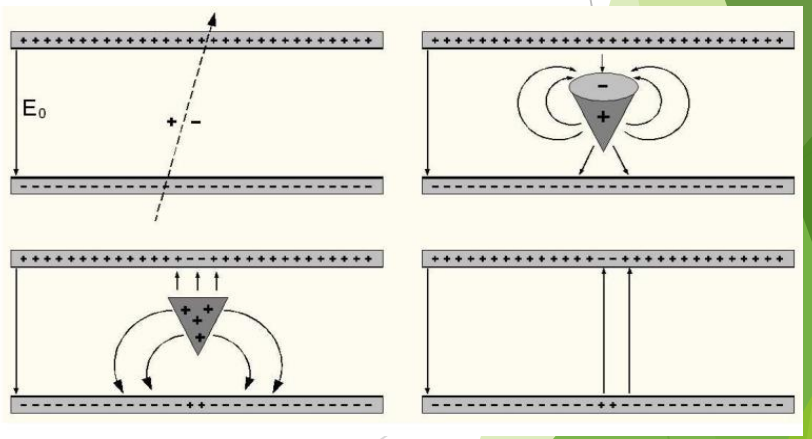
- Resistive Plate Chamber is a gaseous detector.
- Charged particle while going through it ionizes the gas, emitted electrons then move along the electric field and ionizes more molecules, thus giving the signal.
- RPC can run in two modes-

1. Avalanche mode, the detector is in proportional region.
2. Streamer mode, the proportionality is not present. Moreover the spatial resolution goes bad.

- In INO RPC are designed to run in avalanche mode and the gas mixture contains R134a, Iso-Butane, SF_6.



Schematic diagram of RPC



Schematic diagram of avalanche formation in RPC

Present and Substitute Gas Mixture

- The present RPC gas mixture contains R134-a(Tetrafluoro ethane) : Iso-Butane : SF_6 = 95.5 : 4.2 : 0.3
- Both R134-a and SF_6 are potential pollutant. Global warming potential of these gases are 1430 and 22300 respectively.
- Recent environment treaty says Global Warming Potential(GWP)>150 should not be used.
- The present mixture GWP is 1403. That's why we need to substitute it with a more eco friendly one.
- We are testing a Argon, CO_2 based gas mixture which can replace the present gas mixture.
- Ar:CO_2 =80:20 has GWP 0.2 .

Gas	Atmospheric lifetime (years)	GWP (100 years)
R-134A	13.8	1430
Isobutane	774	3.3
SF_6	3200	22300
Argon	87	0
CO_2	variable	1 (reference)

Streamer Formation

- The formation and rapid spread of a highly ionized zone near the discharge anode is called streamer.
- The criteria for streamer development is, the radial field of the positive space charge from the avalanche should be of the same order of the applied field. [Physical Review, 57(1940)722]
- The quantitative criteria given by J.Meek is

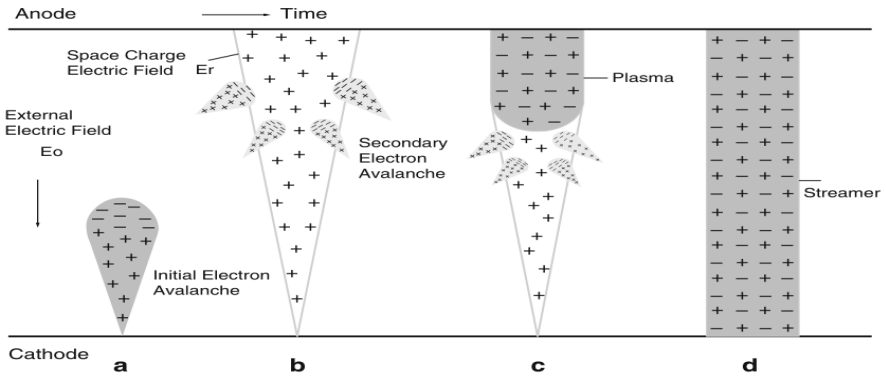
$$\alpha d + \ln\frac{\alpha}{P} = 14.5 + \ln\frac{E}{P} + \frac{1}{2}\ln\frac{d}{P}$$

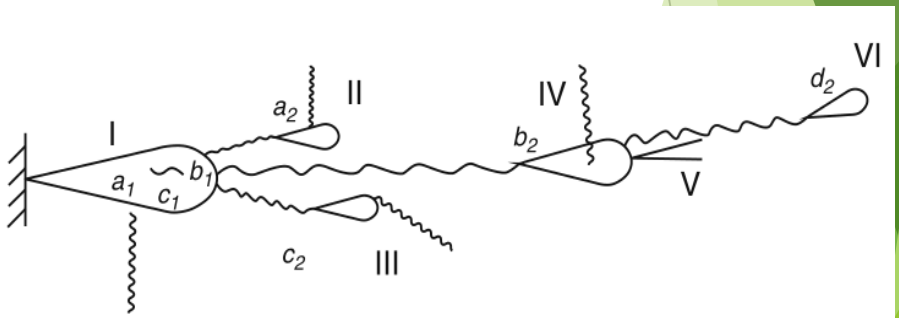
here α is Townsend coefficient, d is the gap length, P is pressure, E is applied electric field.

- Criteria given by H.Raether is

$$\alpha x_c = 18.4 + \ln x_c$$

here α is Townsend coefficient and x_c is the critical distance where streamer starts.





Avalanche to streamer transition

Streamer Probability Check

- The present gas mixture of RPC gives good efficiency, position and time resolution. The streamer probability is also small.
- The new gas mixture should have this properties also.
- To have an idea about the streamer probability of the new gas mixture is helpful to identify the components, their proportion and operating regime.
- To check the streamer probability we are taking help of an available code by M.Rabie and C.M.Franck. [J. Phys. D: Appl. Phys. 49 (2016) 175202]

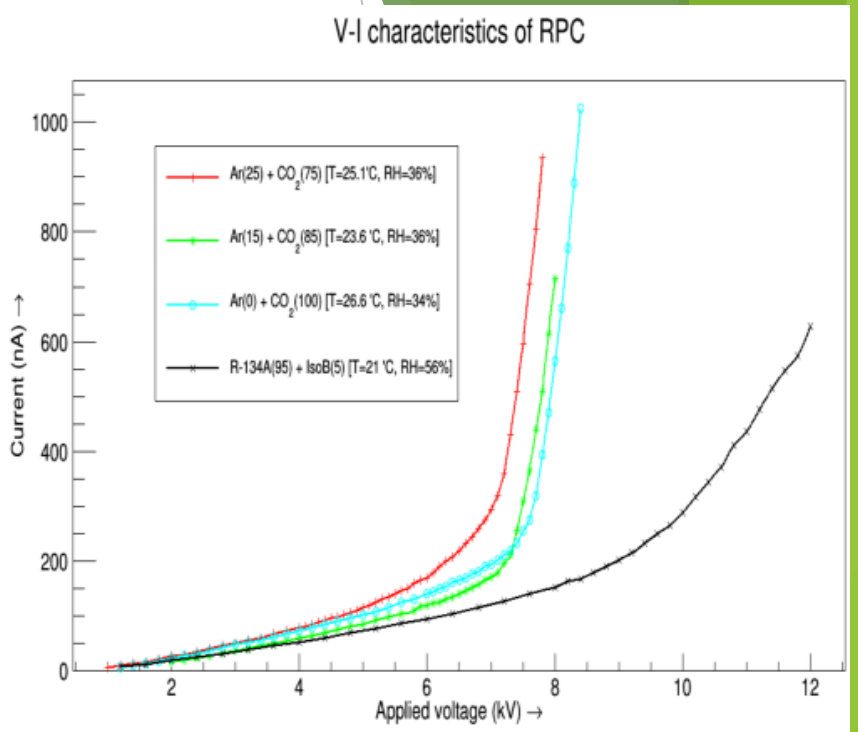


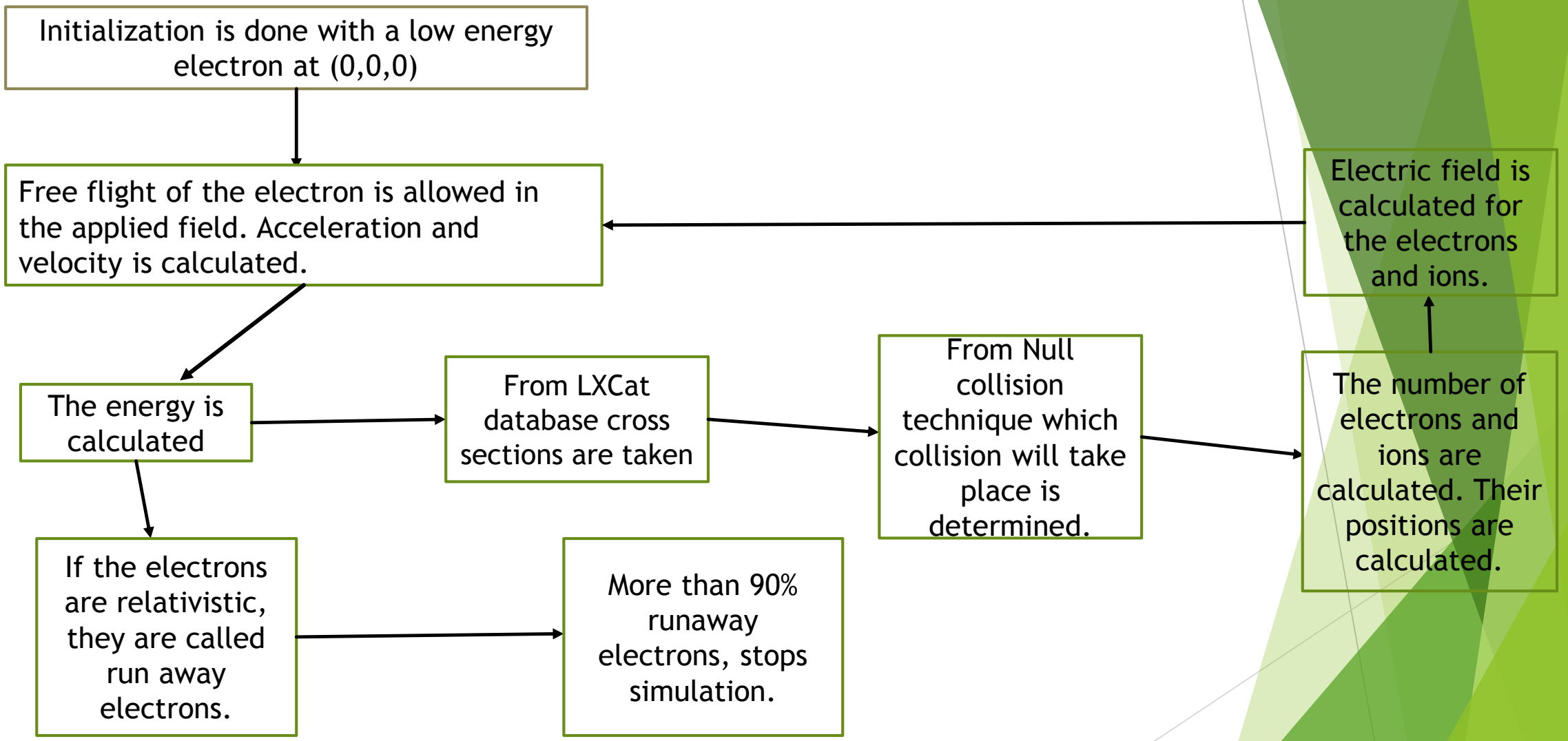
Fig: V-I plot of RPC for different gases.

- The code uses Particle in a Cell and Monte-Carlo method for interactive simulation.
- To solve the Poisson equation for the space charges, the code uses a 3D Poisson solver.
- The code can investigate avalanche to streamer transition over a wide pressure and homogeneous background field.

Physics behind and computational resource

- The avalanche to streamer transition must include electron and ion kinetics and collision with background particles.
- Mobility and Diffusion coefficient is calculated using Nernst-Townsend-Einstein equation.
- Boltzmann equation for charged particles is solved to find the position and velocity.
- The force on the particles are simple Lorentz force.
- For simulation process 2.56GHz, 56GB CPU is used.

Algorithm


Initialization is done with a low energy electron at (0,0,0)
Free flight of the electron is allowed in the applied field. Acceleration and velocity is calculated.
The energy is calculated
From LXCat database cross sections are taken
From Null collision technique which collision will take place is determined.
The number of electrons and ions are calculated. Their positions are calculated.
Electric field is calculated for the electrons and ions.
If the electrons are relativistic, they are called run away electrons.
More than 90% runaway electrons, stops simulation.

Parameters used to define Streamer

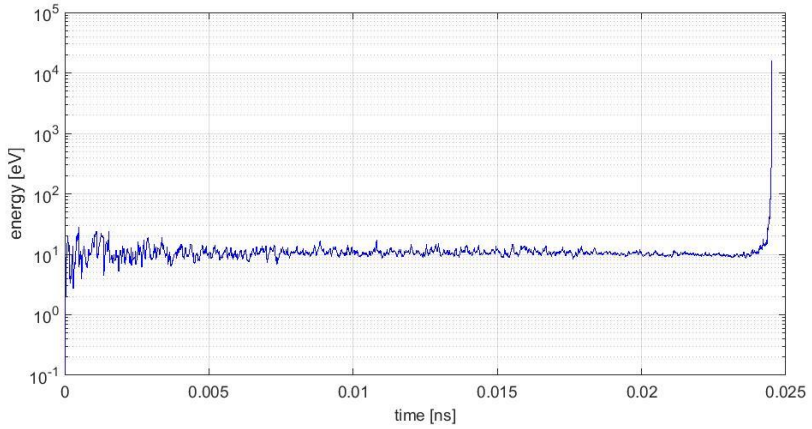
- Though by Raether and Meek a quantitative idea of streamer formation is given, in this code the streamer regime is defined by some other parameters.

1) Distortion of Background field.
2) Deviation of the electron density profile from Gaussian.
3) Occurrence of high energy electron.
4) Sudden increase in the electron number.
5) Sudden increase in the average energy of the electrons.

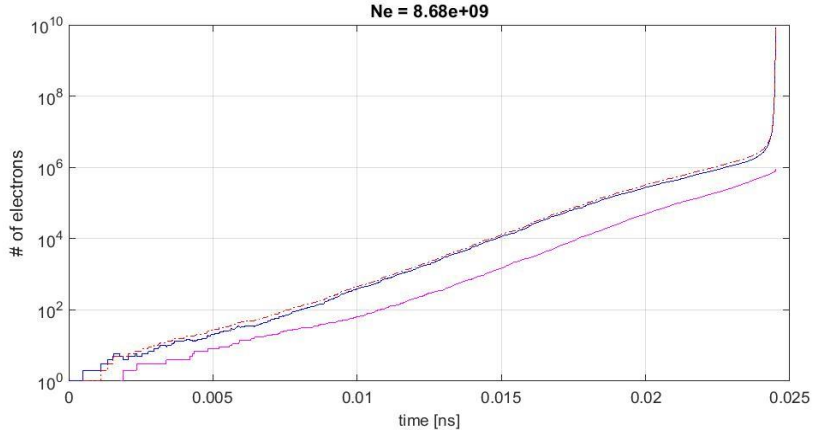
- Though we have simulated using this code but there are some dispute between our experimental situation and the simulation input.

1) The code assumes low energy electrons, which is not likely for ionization of 1GeV muon. Ionization electrons have energy more than 100keV, where as they have taken the initial electron has energy few eV.
2) It starts with only one electron, but practically ionization can occur in 2, 3 places and every time cluster will form. HEED, CERN provides the information of primary ionization.
3) No detector geometry is taken as input, but as homogeneous field is taken, we are assuming that it will work fine for our detector also.

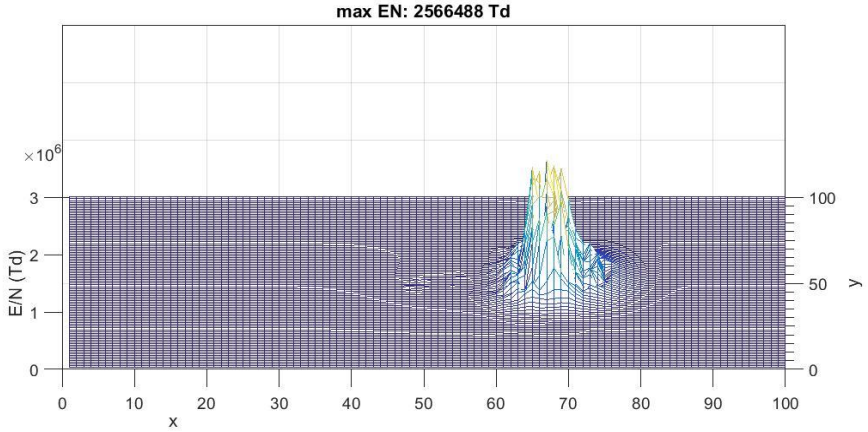
Results for SF_6



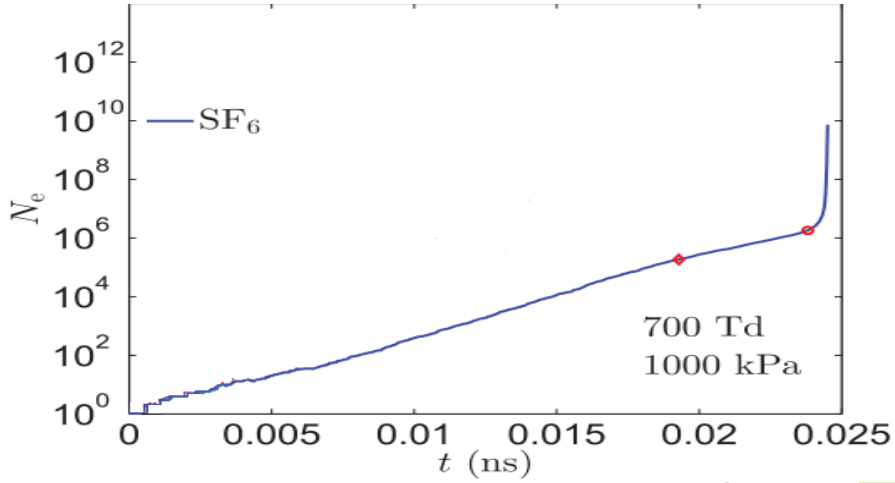
Average energy of electrons vs. time



Number of charged particles vs. time

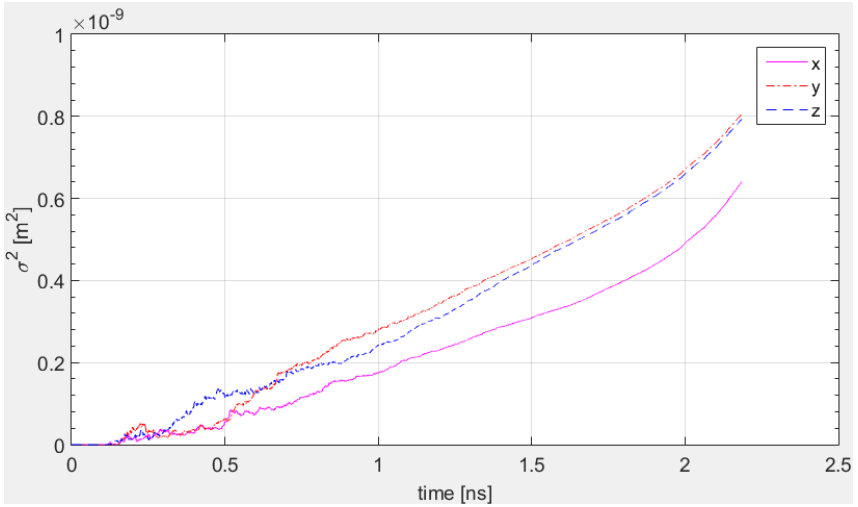


E/N spatial plot

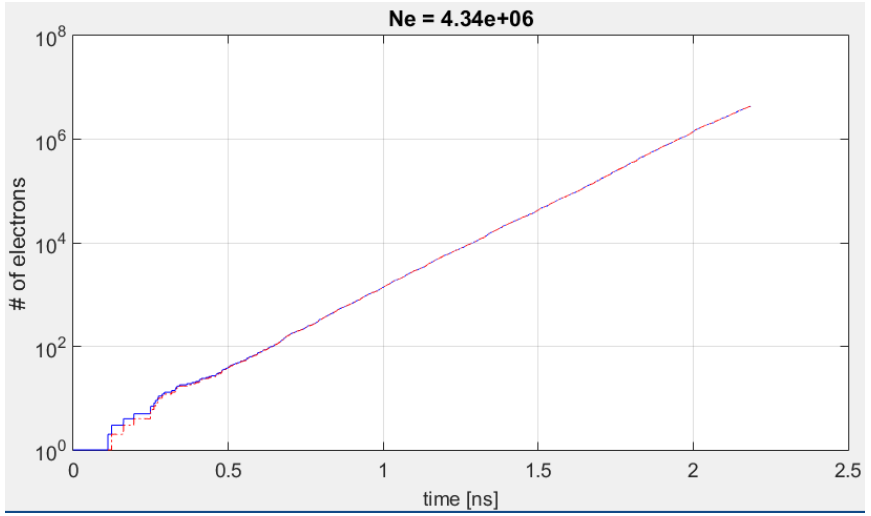


Result obtained by the authors

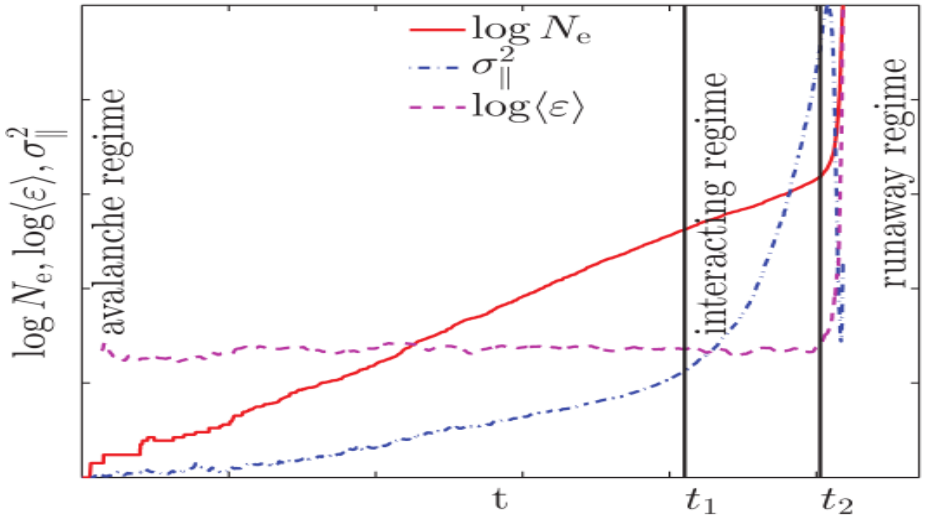
Results for Ar-CO_2 Mixture



Sigma of the electron distribution



Number of charged particles vs. time



Development of parameters for avalanche to streamer transition

A Different Approach

- To see the streamer probability in new gas mixture a different approach is being pursued.
- We are trying to model the problem using COMSOL Multiphysics.
- But still now we have not succeeded to model it perfectly.
- For the modelling we are using guideline given by Prof. Paulo Fonte.[Notes for the RD51 Simulation School, CERN, Jan. 19-21 2011].
- He has modeled a Gas Electron Multiplier streamer in this model.
- Our case the detector will be different so the geometry will be different but the ion transport physics and electrostatics will be same.
- We will be able to check our obtained result from the simulation code with this model.

Future Steps

- We have to modify the code to consider the high energy electron as seed electrons.
- The code should take the primary ionization into the consideration. So modification is needed in that direction.
- As the code does not include detector geometry, just tells the temporal development of the avalanche or streamer, we have to find a proper criteria so that we can say that whether the streamer will be formed or not inside the detector.
- Modelling a RPC with COMSOL Multiphysics and simulate the streamer. Thus we will be able to cross check our results, and make a comparison.

Acknowledgement

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Thank You