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Space Charge Effects on Gas Gain in Non-Uniform Field Argon-Based Detectors

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The charge carriers in the detector volume created in the gas amplification process cause a space charge effect. The fluctuation in gas amplification process is one of the main factor in the energy resolution of proportional counters. At low bias voltages only a very small number of charge carriers are generated and so the space charge effect is negligibly low. However, as bias voltage increases so does the gas amplification factor and the number of the secondary charge carriers grows, reducing the electric field strength between space charges and the anode wire. In the present work, a Monte Carlo simulation code [4] has been used in order to investigate the influence of space charge effect on the gas gain and its fluctuation for Argon based gas mixtures as a function of the applied voltage between cathode and anode at atmospheric pressure for wide range component concentrations

The purpose of any proportional detector is to measure the primary signal while introducing as small an additional fluctuation as possible. The presence of gain within the detector will reduce the relative size of fluctuations introduced by subsequent read-out electronics, but the gain process will introduce fluctuations of its own and if these are too high it may not give any overall advantage.

Gas Avalanche Gain

Gas avalanche gain is a consequence of the motion of a free electron in a strong electric-field. By increasing the field in the gas volume (above a few keV/cm) electron can gain enough energy between two collisions to produce secondary ionization. After such an ionizing collision, an electron-ion pair is produced and the primary electron continues its trajectory.

In non-uniform electric-field, the number of electrons will grow exponentially as they are drawn in a direction opposite to that of the applied field. The gas multiplication factor or gas avalanche gain is given by

$$M = \exp \int_{x_1}^{x_2} \alpha(x) dx$$

Where,
 α : First Townsend coefficient [1]
 x_1 : The coordinate at which the charge multiplication start
 x_2 : The coordinate at which the charge multiplication stop.

Furthermore, the electron may attach itself to a neutral atom, so the intensity of free electrons at the beginning, I_{oe} traversing the gas falls exponentially.

$$I_e = I_{oe} \exp(-\eta x)$$

where η is called the attachment coefficient. This coefficient depends on the incident particle energy and is strongly affected by the presence of an electric field [2].

Gain Fluctuations

The statistical fluctuation of charge carriers in the proportional counter contain two separate terms, given by following relation [4]

$$\left(\frac{\sigma_E}{E}\right)^2 = \left(\frac{\sigma_{N_i}}{N_i}\right)^2 + \left(\frac{1}{N_i}\right) \left(\frac{\sigma_M}{M}\right)^2$$

E: the measured energy deposited by the ionising particle
 σ_E : standard deviation of the E
 N_i : the average number of primary electrons
 σ_{N_i} : standard deviation of the N_i
M: the mean avalanche gain
 σ_M : standard deviation of the M

The main contribution to the fluctuations come from the second term which involves the relative variance of the gas amplification

$$f = \left(\frac{\sigma_M}{M}\right)^2$$

The magnitude of f is the most critical in determining the ultimate energy resolution of the proportional counter.

Space Charge Effect on Wire Chambers

Without space charge effect, the Townsend relation;

$$\alpha / p = A e^{-Bp/E_0}$$

With space charge effect; it will be ;

$$\alpha / p = A e^{-Bp/(E_0 + \Delta)}$$

If E_0 is the applied electrical field, then a small space charge will change it to $E_0 + \Delta$. where, Δ is space charge effect and can be obtained from the change in the potential; [3]

$$\Delta V = (E_0 - Bp/2) \frac{1}{E_0^2} \int_0^d \Delta^2 dx$$

as

$$\Delta = \frac{E_0^2}{E_0 - \frac{Bp}{2}}$$

For different gas mixture ratios, A and B gas constants have taken from [1]

Argon- methane mixtures			
Percentage of Methane	30%	50%	70%
A [$\text{cm}^{-1} \text{Torr}^{-1}$]	2.3	38.3	111.4
B [$\text{Vcm}^{-1} \text{Torr}^{-1}$]	88.4	230.1	298.5
Argon- Ethane mixtures			
Percentage of Ethane	30%	50%	70%
A [$\text{cm}^{-1} \text{Torr}^{-1}$]	24.80	40.0	164.1
B [$\text{Vcm}^{-1} \text{Torr}^{-1}$]	154.8	237.1	301.9

Simulated Results

The avalanche gain mechanism was simulated for the ALEPH ITC by tracking of individual primary electron and following the generated electrons (Fig 3). The development of the avalanche gain has been simulated for each individual electron on an interaction by interaction basis using set of cross sections for electron impact ionization and attachment computed using Magboltz program. It is clear that the avalanche gain to vary as a function of bias voltage.

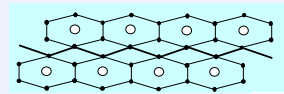


Figure1: ITC hexagonal drift cell arrays

- Anode wire
- Field wire

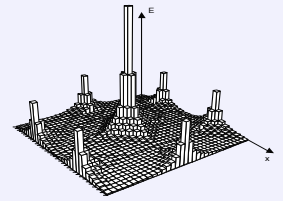


Figure2 Electric field distribution at hexagonal drift cell

Same simulation has been made for ALEPH ITC without space charge effect (Fig 4).

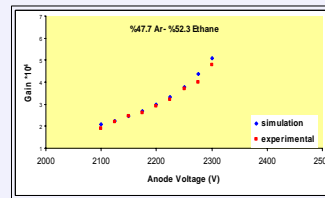


Figure 3 : Gas gain as a function of bias voltage at 50% Argon – Ethane gas mixture [4]

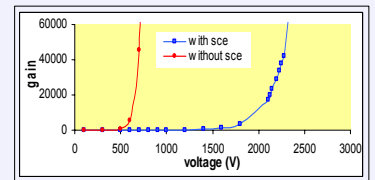


Figure 4: Avalanche gain as a function of bias voltage with and without space charge effect.

Simulation has also been performed for the same drift cell structure at different gas mixtures.

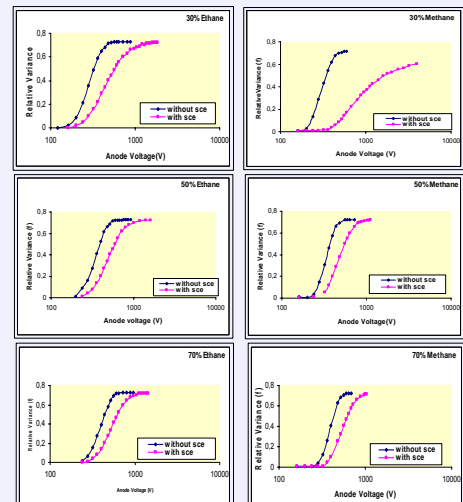


Figure 5 : Relative variance as a function of anode voltage at different Argon-Ethane and Argon-Methane gas mixtures

References

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- [2] Richard C. Fernow, Introduction to Experimental Particle Physics, Cambridge University Press, Oxford, 1986, p.211.
- [3] A.von Engel, Ionized Gases, Oxford at the Clarendon Press, 1965.
- [4] Ilhan Tapan, Nilgun Demir, Nucl. Instr. And Meth. A525 (2004) 53-56.