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Study of discharge properties in cascaded gaseous detectors

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Abstract. In this work we describe simulation and experimental studies of the possible reasons for the observed increase of the maximum gain in multi-GEM devices. Two main hypotheses are analyzed: first, a diffusion-dominated charge spread reducing the density in individual holes, acting as independent amplifiers and therefore an increase of the discharge limit with the number of cascaded electrodes; second, the possibility that total avalanche charge before transition to a discharge (Raether limit) strongly depends on the field value and is therefore much higher in cascaded than in single-stage systems.

1. Introduction

Several GEMs in a cascade allow to increase significantly the effective gain of a detector as compared to single-stage systems. As was demonstrated in [1], the addition of each GEM boosts the discharge limit by more than a factor of ten (see Fig.8 in [1]). However, a detailed study of the mechanism of such enhancement was not performed and the exact reason of this behavior of a cascaded system is not clear.

In the present work we analyze two hypotheses of the observed increase of gain limit with cascaded GEMs: first, a diffusion-dominated charge spread over a number of holes acting as independent amplifiers and therefore an increase of the discharge limit with the number of multipliers; secondly the possibility that total avalanche charge before transition to a discharge (Raether limit) strongly depends on field value and is therefore much higher for a GEM cascade.

2. Electron diffusion in GEM cascades

To test the first hypothesis we performed a simulation of electron transport through a triple-GEM cascade, analyzing the width of avalanche after each GEM. Electric fields in GEMs, calculated with ANSYS [2], are imported into GARFIELD++ [3] where a calculation of electron transport is performed. The GEMs are shifted arbitrary with respect to each other. The gaps between GEMs and corresponding field values are shown in Table 1. All conditions are kept similar to those in [1], including the gas composition (Ar-CO_2 (70%-30%)). The voltages across GEMs are equal and provide gain value of $\sim$10 for each GEM.

The results along one direction are shown in Figs. 1a, 1b, 1c for the first, second and third GEM respectively.

Table 1. Gaps between GEMs and electric field values in the simulations.

Gap name	Thickness, mm	Electric field, kV/cm
Drift	3	2.0
First transport	2	3.5
Second transport	2	3.5
Induction	2	3.5

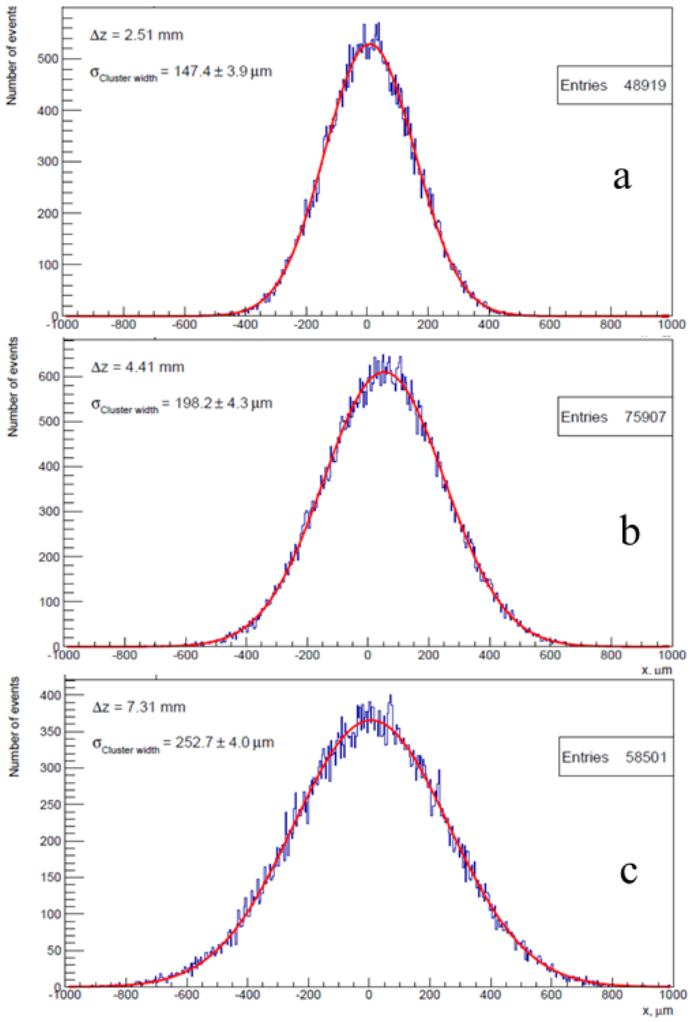

Figure 1. Distribution of electrons in X-direction after GEM1 (a), GEM2(b) and GEM3(c).

The final result for both directions is shown in Fig. 2. From the data we can conclude, that the avalanche width is increased only by a factor ∼3.2 after GEM3, compared to single-GEM case. While a full estimate of the charge density in each direction has not been performed, this increase is definitely not sufficient to explain the observations.

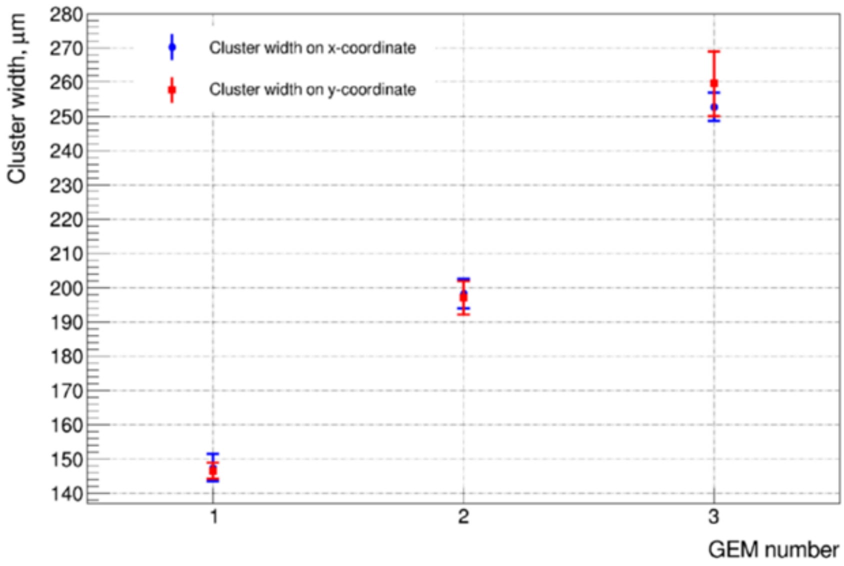

Figure 2. Electron cluster width (sigma of Gaussian fit) for both coordinates after GEM1, GEM2 and GEM3.

3. Study of discharge limit dependence on field value.

For the study of the possible modification of the discharge limit with electric field we have injected a variable amount of electrons into a parallel-plate amplification (PPA) gap with known uniform field. In order to study the discharge limit in a wide range, the injected charge has to be varied as well. The detector used for these measurements includes a double-GEM cascade and PPA gap below the second GEM (Fig. 3). The first GEM plays the role of preamplifier and the second GEM, operated in the transmission mode, is used as the top mesh electrode of the PPA gap. The drift cathode is made with a 0.5 mm thick G10 plate coated on the inner side with a 15 μm copper layer. Since this electrode is not transparent to 5.9 keV photons of ^{55}Fe, a ^{109}Cd source was used, emitting 22-24 keV and 88 keV photons. All the measurements are performed with Ar+10%i-C_4H_{10} mixture at atmospheric pressure.

In Fig. 4 the current measured on the anode is shown as a function of voltage across GEM1. For this measurement the anode and both electrodes of GEM2 have been connected together to be sure that all electrons that escape GEM1 are collected. As expected with this gas mixture GEM1 allows to get high charge flow and change it in a wide range.

Modification of voltage at GEM2 affects significantly the anode current in a wide range of GEM2 voltages (Fig. 5). However, below 80 V the GEM2 transparency starts to drop quickly and above 120 V we clearly see the beginning of amplification.

For the measurement of discharge limit the field in PPA gap was gradually increased, keeping voltages between all other electrodes constant. The measurement was stopped when the frequency of discharges reached the range between 0.1 Hz and 0.01 Hz. From the current source on the power supplies we could observe discharges only between bottom electrode of GEM2 and the anode. Also it was checked many times that the discharges were associated

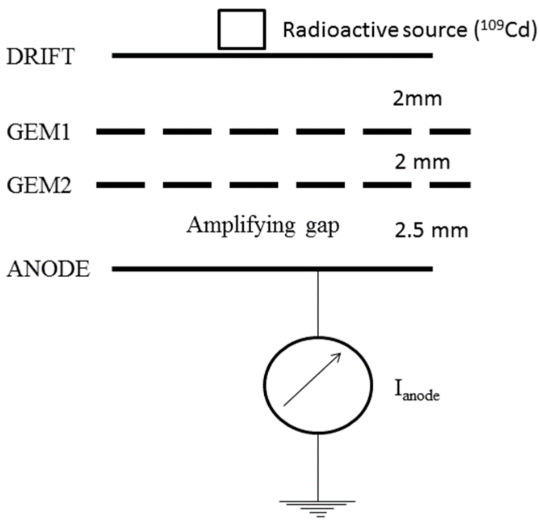

Figure 3. Detector used for the measurements of discharge limit.

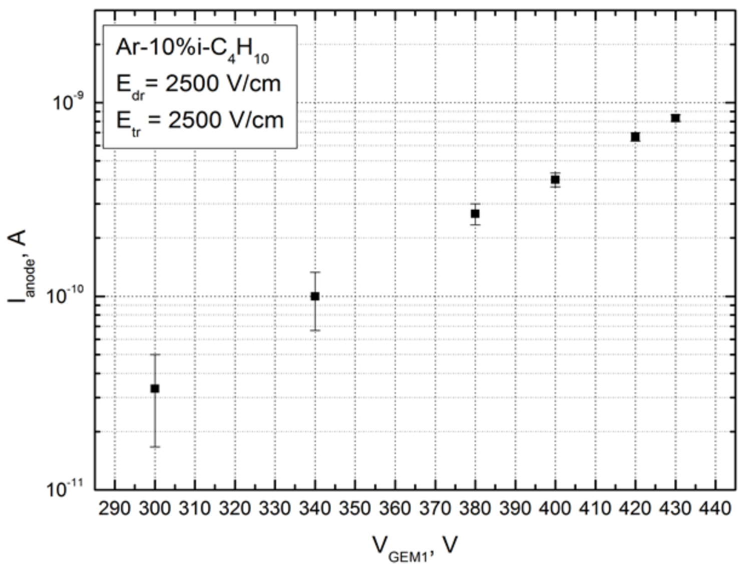

Figure 4. Dependence of anode current on the voltage across GEM1

with irradiation and stop when the radioactive source is removed. The results of several sets of measurements are shown in Fig. 6 and Fig. 7 for 200V and 120V across GEM2 respectively.

The end points of all data sets from Fig. 6 and Fig. 7 corresponding to discharge limits are

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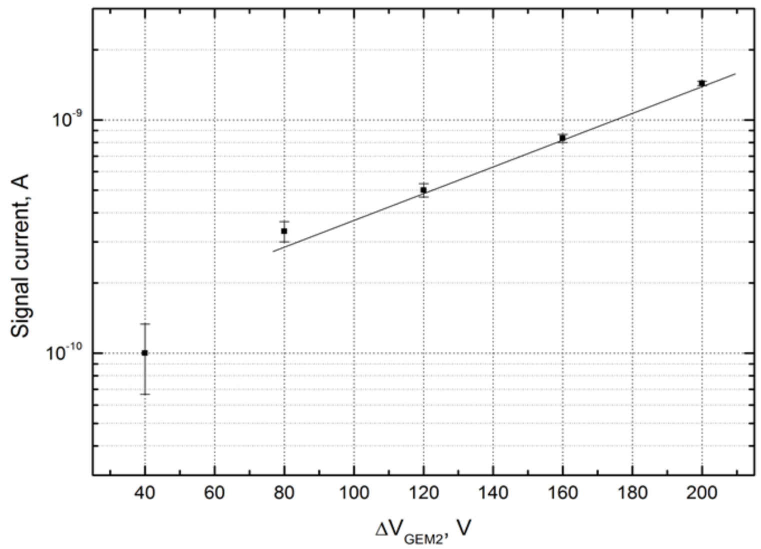

Figure 5. Anode current as a function of GEM2 voltage. E_{dr} and E_{tr} are equal to 2500 V/cm and the field in PPA gap is 4000 V/cm.

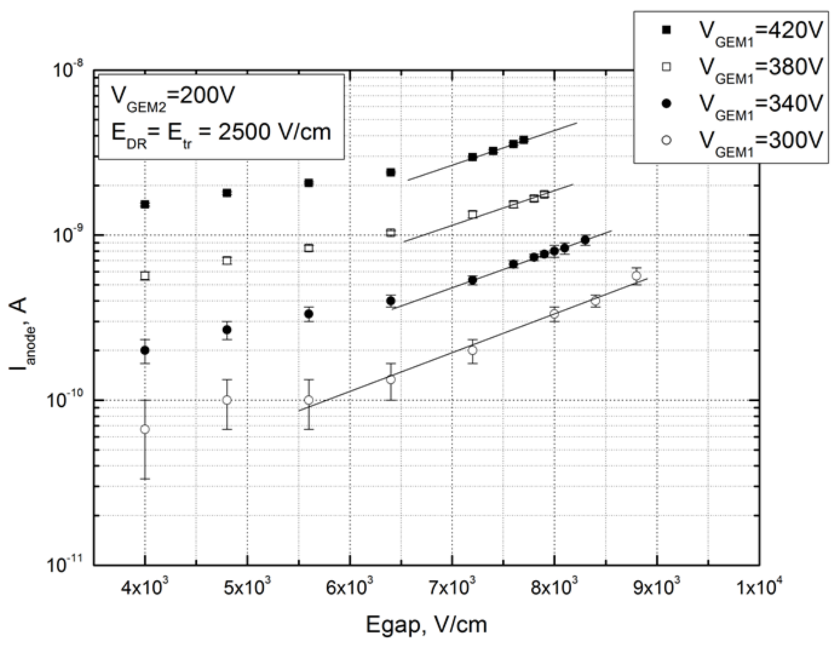

Figure 6. Anode current as a function of PPA gap field for different voltages across GEM1 and 200V at GEM2.

collected in Fig. 8; the result demonstrates that the discharge limit significantly depends on the field. In this particular case it is increased by a factor of $\sim$7 when the field drops by only 15%.

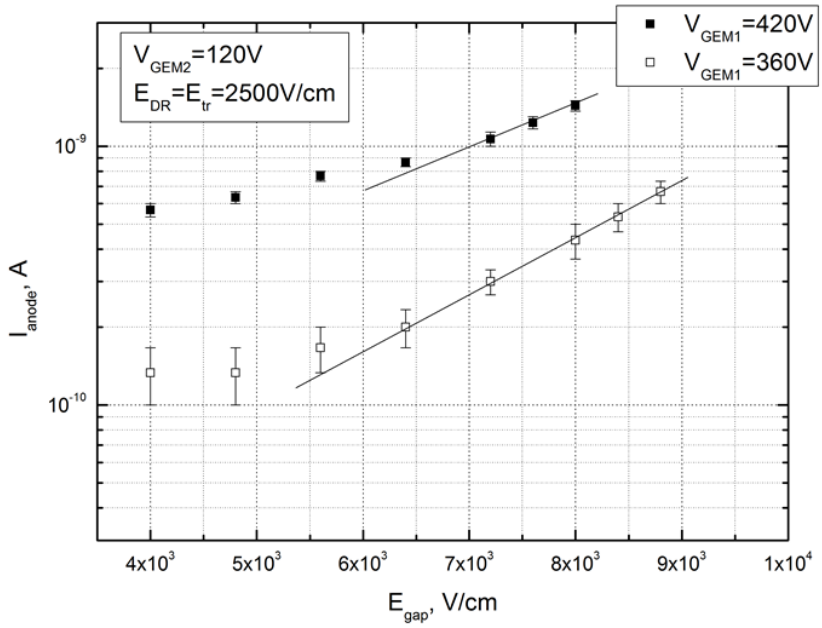

Figure 7. Anode current as a function of PPA gap field for different voltages across GEM1 and 120V at GEM2.

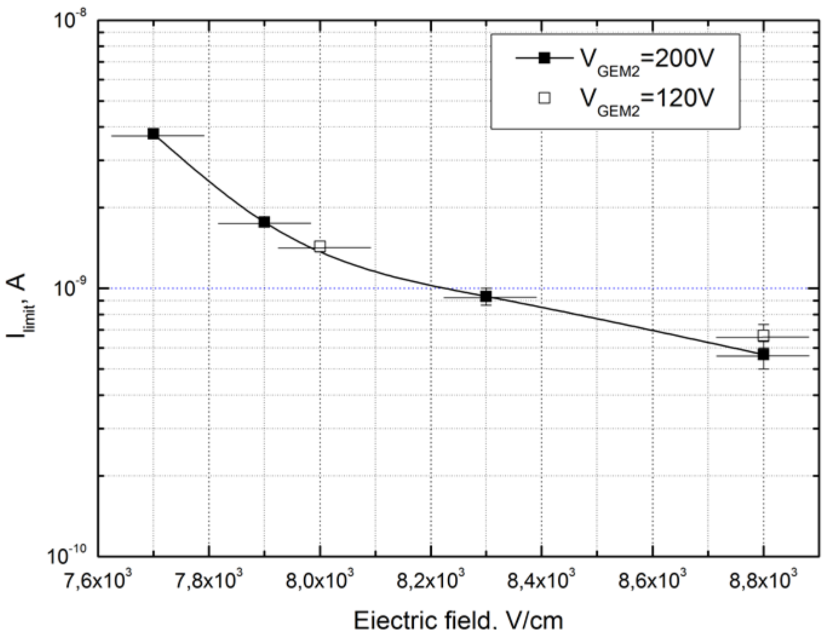

Figure 8. Discharge limit as a function of PPA gap field.

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