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Optimisation of the Gas Electron Multiplier for high rate application

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ABSTRACT

The construction and performance of large size GEM detectors for the COMPASS experiment is described. Based on the experience gained during the operation of these detectors in high rate muon, proton, and pion beams we discuss the suitability of their use in harsh radiation environments.

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1 Introduction

The gas electron multiplier (GEM) [1] is made of a thin polymer–foil, metal clad on both sides and perforated with a high density of holes (fig. 1). Upon the application of a potential difference between the metal electrodes, it acts as an amplifier for the electrons released in the gas volume above the GEM. With an optimized geometry gas gains up to 10^4 have been reached [2]. A good fraction of the charge is transferred to a readout structure, which might be a simple PCB board equipped with charge collecting electrodes.
In Double GEM detectors as shown in figure 2, two multiplying foils are operated in a cascade. These detectors give higher gain factors compared to Single GEM detectors. A given gain necessary in a specific application can be reached at lower voltage applied to each GEM foil and therefore a safer operation of the device is possible. Double GEM detectors have excellent properties for the application as tracking detectors in high energy physics experiments. The detection of minimum ionizing particles at an efficiency $> 98\%$ is possible and a comfortable plateau length is reached. A spatial resolution of better than 40 μm and a time resolution of 20 ns FWHM have been measured [3]. GEM detectors are also well suited for the operation at high rates. No drop of the gain up to particle fluxes of 10^5 Hz/mm^2 has been observed [4] and no sign of aging was found up to an integrated charge of 12 mC/cm [5]. It has been demonstrated that a two-dimensional readout can be implemented in the readout structure [6]. These properties have led to the decision to use GEM detectors in the small area tracker of COMPASS [7], a fixed target experiment that will be operated at the SPS at CERN. The physics program requires the operation in very high intensity muon ($10^8 s^{-1}$) and proton beams ($2 \times 10^7 s^{-1}$) at a maximum particle flux of $\sim 10^5$ mm^{-2}s^{-1}. The active area of the detectors is 31 × 31 cm^2. They will be exposed directly to the beam, therefore a detector design is necessary that allows to deactivate the central region in high intensity runs. This is necessary to avoid occupancy problems making a track reconstruction impossible in the experiment.

2 Prototype detectors for the COMPASS experiment

A schematic view of Double GEM detectors built as prototypes for the COMPASS experiment is given in figure 3. The gap widths are 3, 1, and 1 mm for the drift, transfer, and induction gap, respectively. The pitch of the holes in the GEM foils is 140 μm, their diameter 70 μm. A two-dimensional readout structure is implemented on a printed circuit board. As shown in the figure, the GEM foils are segmented, with each foil divided in 5 electrically independent sectors. The central region being an individually powered segment can be deactivated in high intensity runs, but activated in low intensity runs, a

useful feature for calibration and alignment studies (fig. 4). The segmentation is also an important measure to allow their safe operation, as it limits the capacitance of the system, and therefore the energy released in case of a discharge. To guarantee the flatness of the foils and therefore the homogeneity of the electric fields in the gaps, an insulating frame with thin bridges serving as spacers is used (fig. 5). A picture of a prototype detector during a test beam experiment at PSI (see section 3.2) is shown in figure 6.
To define the working point of the detector we measured the gain using X–rays. With β–particles from a ^{90}Sr-source we determined the gain necessary to reach full efficiency for the detection of minimum ionizing particles (fig. 7). The PreMux128–chip [8] has been used for these measurements. Its characteristics are similar to the APV25–chip [9] which is foreseen for the experiment, but not yet available. The efficiency plateau is reached at a gain of ~2500 per coordinate. For the two-dimensional readout of the detectors, a total gain at the working point in the experiment of ~5000 is therefore needed.

3 Results of test beam experiments

We extensively tested Double GEM detectors in different beam lines. The first tests have been performed at the M2–beam at CERN, the nominal beam line for the COMPASS experiment. Further tests were made at the πM1–beam at PSI[1], a beam that matches the environment expected in future LHC experiments [10].

3.1 Performance at the M2–beam at CERN

A full size prototype has been tested during several weeks at the M2–beam. With the target included, the environment during the tests corresponds to that expected in the course of the experiment. After an initial phase at moderate intensities for gain studies the detector has been exposed to the muon beam at an intensity of 10^8 s^{-1} and the proton beam at an intensity of 2×10^6 s^{-1}. For the muon beam the maximum particle flux was 2×10^5 Hz/mm^2. A pulse height spectrum recorded at moderate intensity is given in figure 9. The voltage applied to each GEM was 420 V, this corresponds to a total gain of 6000, sufficient for an efficient detection of minimum ionising particles on both coordinates of the two–dimensional readout. At this gain a low rate of discharges has been observed during voltage scans performed at full intensities of the μ and proton–beam (fig. 10). Note, that during these measurements the whole chamber including the central region has been activated. In further long term

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measurements the absolute rate of discharges was about one every five hours. Discharges are harmless to the detectors, although the same may not be true for the readout electronics.

3.2 Performance at the πM1–beam at PSI

To make a study of possible suffering of the detectors from damages induced by discharges an even more stringent test has been performed at the πM1–beam at PSI. There, pions at a rate of up to 5×10^7 s^{-1} are delivered continuously to the experimental area, the maximum particle flux corresponds to about 10^4 Hz/mm^2. We tested the COMPASS-prototype already operated at the M2–beam and a smaller size, fully equipped Double GEM detector with an active area of 10×10 cm^2. This detector owns also a two–dimensional readout. The PreMux128–chip has been used to record the signals. A pulse height spectrum recorded with the smaller detector is given in figure 11. The probability of a discharge as a function of the GEM–voltage is shown in figure 12, together with the efficiency for the detection of minimum ionising particles measured with respect to the trigger from scintillators. After an irradiation of the detector with 10^{12} π at highest intensity no discharges have been observed up to a voltage of 400 V applied to both GEM foils. These voltages correspond to a gain of about 3000, sufficient for the detection of minimum ionizing particles for a detector with one–dimensional readout. For the working point of the tested detector, equipped with a two–dimensional readout (V_{GEM}= 420 V) a rate of one single discharge during an irradiation with 10^9 π has been observed. This result is in agreement with the discharge rate measured at the M2–beam. Both detectors have been operated for some time during the test beam experiment at gains exceeding a value of 10^4. In the course of these tests the detectors experienced several thousand discharges. The detectors withstood these discharges, kept fully operational until the end of the test beam experiment, and are still in use for laboratory measurements. A careful analysis revealed that also the PreMux128–chips did not suffer: no electronic channel was damaged during the test–beam experiment. Details about both test beam experiments described and their analysis can be found in [11].

Currently, we test the COMPASS–prototype connected to the APV25–chip. We turn special attention to tests of the input protection of that chip and its resistance to discharges. To minimize possible risks we also study methods to further reduce the probability for discharges and to prevent the propagation of the discharges to the readout–board.

References

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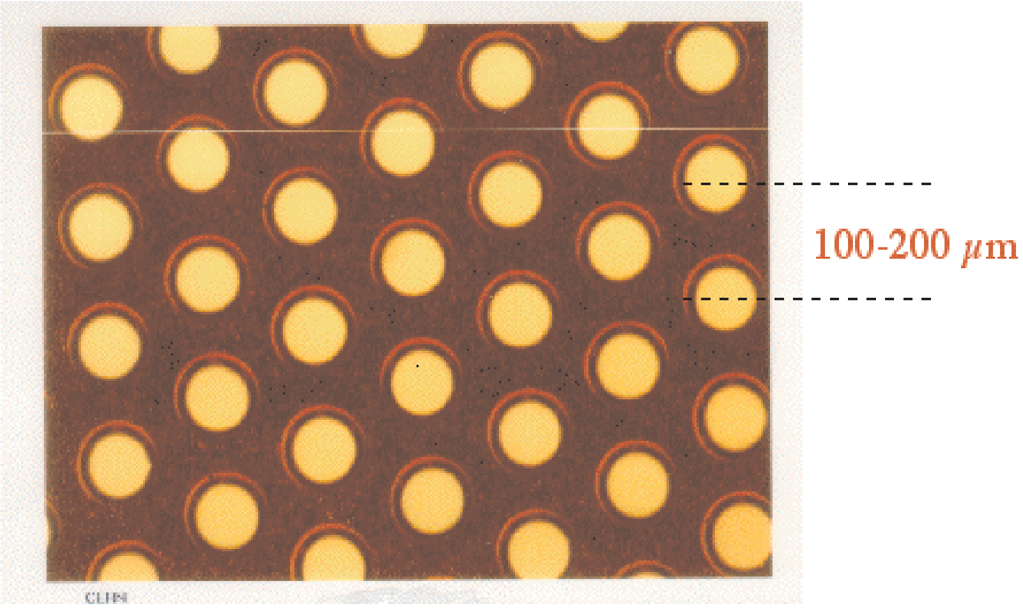

Figure 1. Photography of a GEM foil, typical dimensions are indicated. It is made of a 50 μm thick Kapton foil, the metal layers are made of copper.

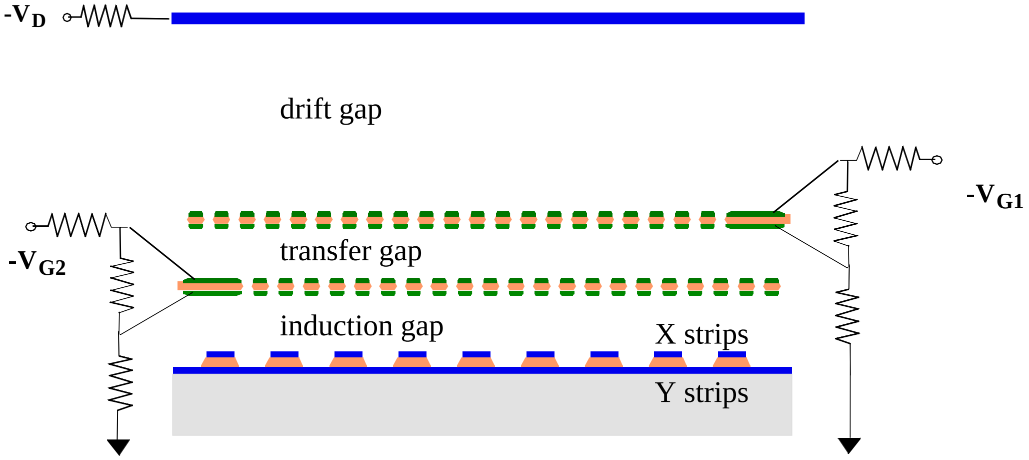

Figure 2. Cross section of a Double GEM detector.

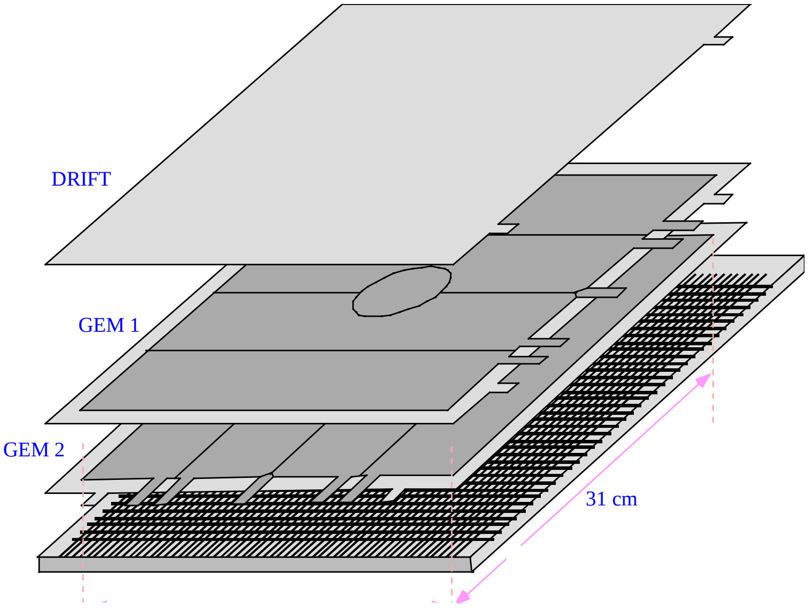

Figure 3. A schematic view of the detector.

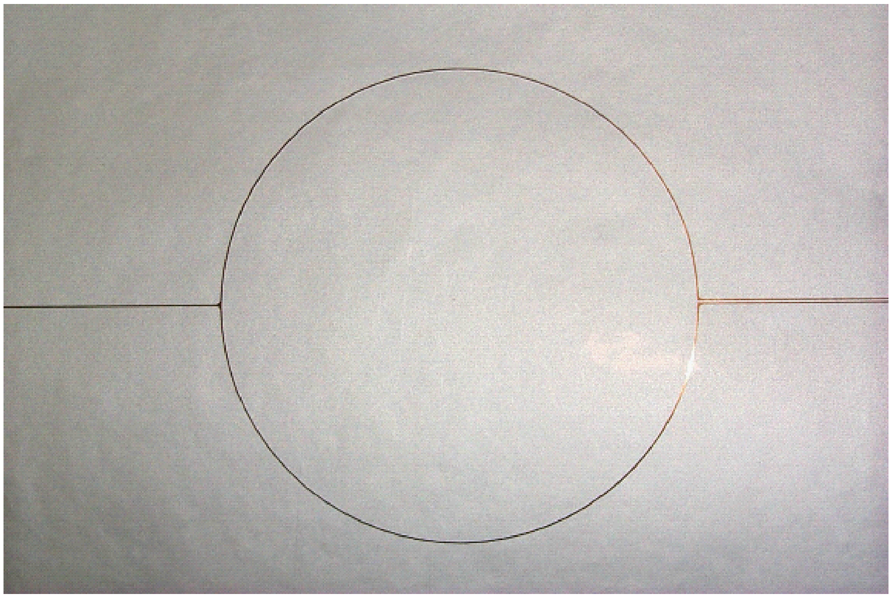

Figure 4. Realization of the segmented central region of a GEM foil. The diameter of the central region is 5 cm. Through the thin line on the right of the photograph the central region is supplied with high voltage.

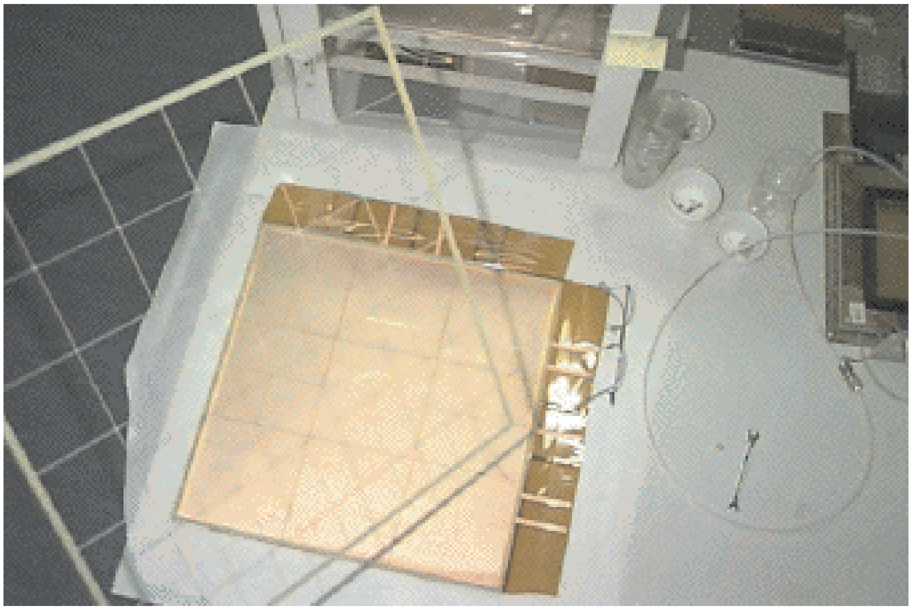

Figure 5. A frame made of Stesalit with thin bridges serving as spacers.

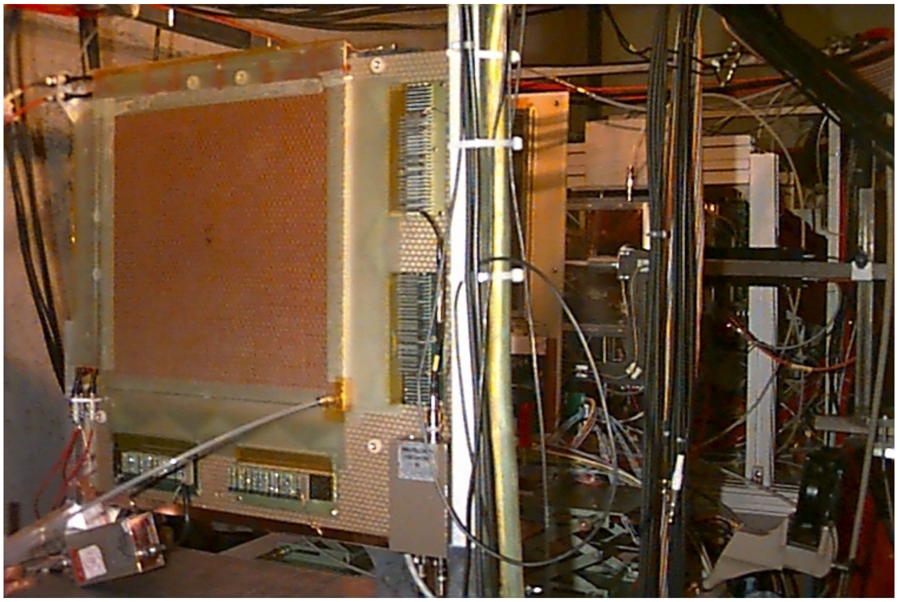

Figure 6. Photography of a prototype Double GEM detector during a test beam experiment at PSI.

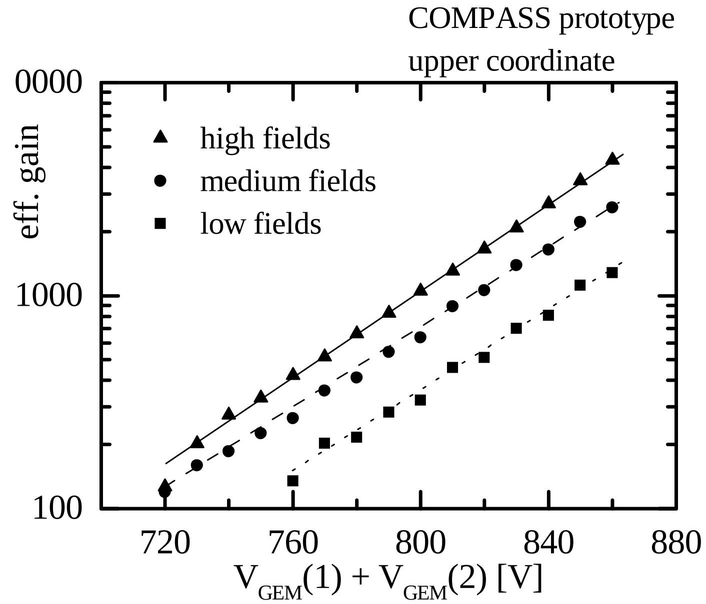

Figure 7. Effective gain measured using X–rays:
High fields: E_{drift} = 3 kV/cm, E_{trans}= 4 kV/cm, E_{ind} = 7 kV/cm
Medium fields: E_{drift} = 3 kV/cm, E_{trans} = 4 kV/cm, E_{ind} = 4 kV/cm
Low fields: E_{drift} = 3 kV/cm, E_{trans} = 2 kV/cm, E_{ind} = 4 kV/cm

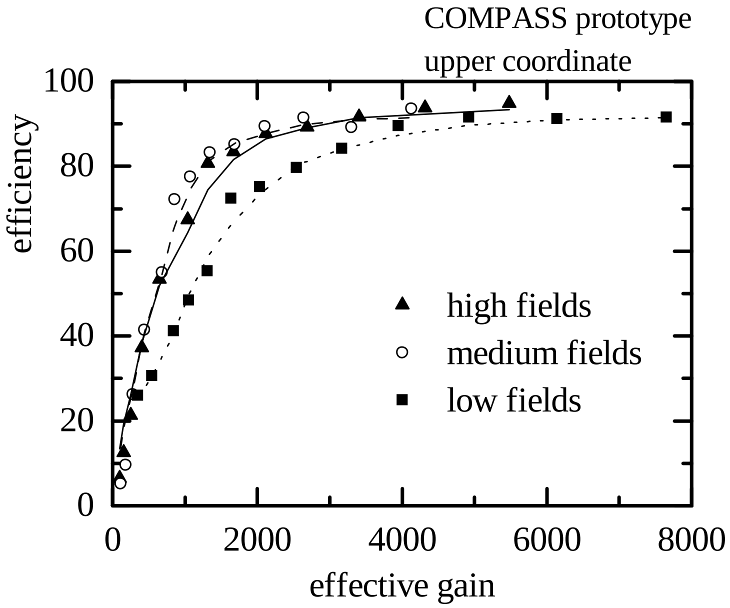

Figure 8. Efficiency obtained from β–particles versus gain. The gain calibration is taken from figure 7. The efficiency is measured with respect to a trigger signal from scintillators. The absolute value of the efficiency estimated by this method is underestimated as some fake triggers from the scintillators cannot be suppressed.

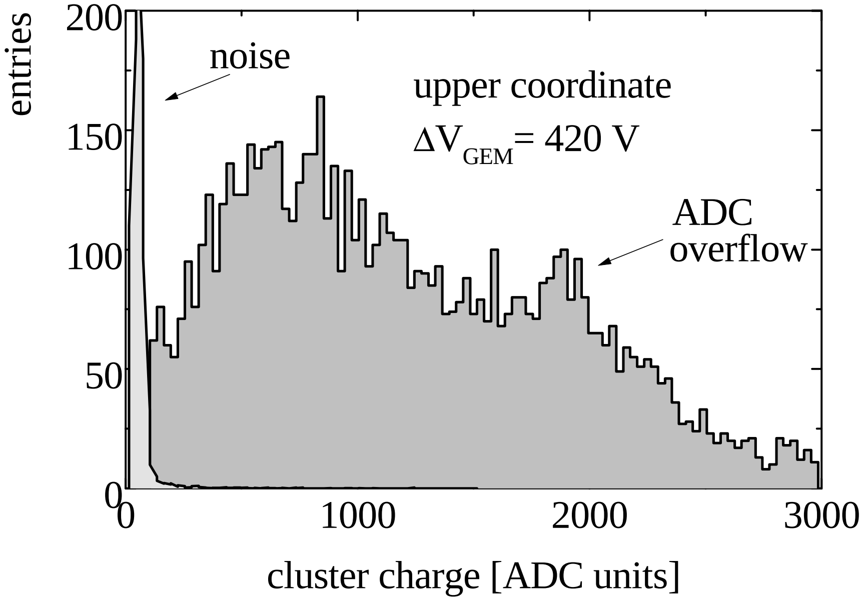

Figure 9. Pulse height spectrum measured with the COMPASS prototype at the M2 beam at CERN.

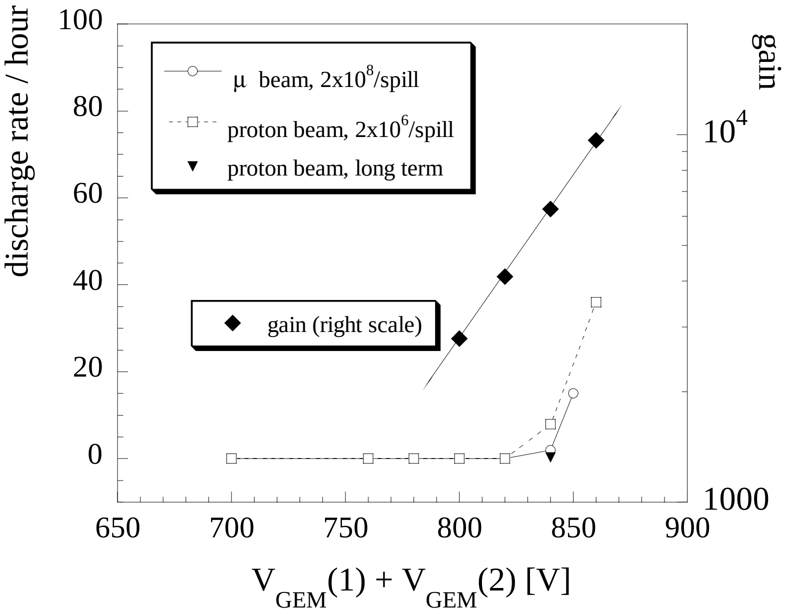

Figure 10. Left: Discharge rate and gain observed during the same test-beam experiment.

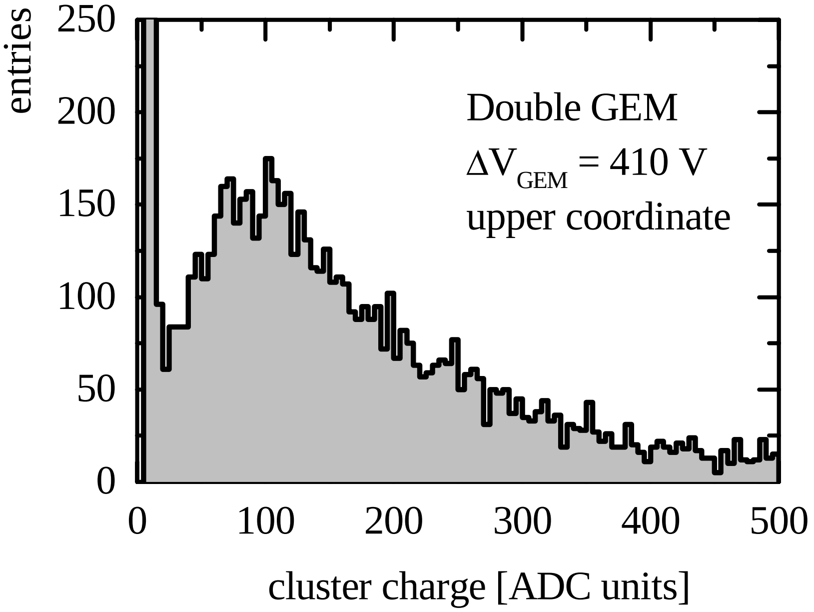

Figure 11. Pulse height spectrum measured at the πM1–beam at PSI.

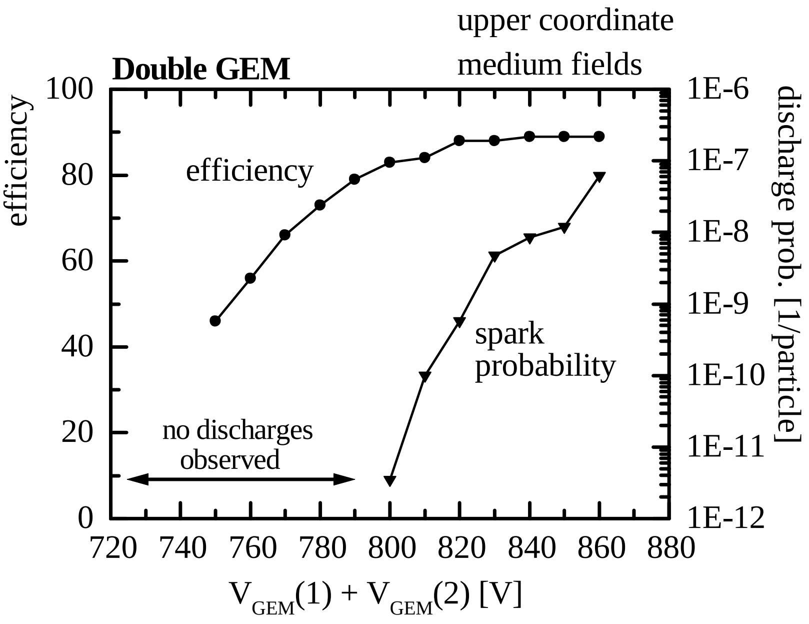

Figure 12. Discharge rate and efficiency for the detection of minimum ionising particles.