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Fast Drift CRID with GEM*

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Abstract

The only available technique at the present time, to perform particle identification up to 40-50GeV/c in a 4π solenodial geometry using the Cherenkov ring imaging method is the use of gaseous detectors filled with either TMAE or TEA photocathodes, and a combination of the gaseous, and solid or liquid radiators. If one would consider building such a device, one may want to investigate alternative methods of building a single-electron detector. This paper investigates the feasibility of using the GEM together with a simple MWPC detector employing 33 μm diameter carbon wires to obtain a second coordinate. The results are compared to the CRID single-electron detector.

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1. INTRODUCTION

The Gas Electron Multiplier (GEM) has been recently introduced [1], and it has quickly become a source of interest in many areas of the detector field. The GEM consists of a thin Kapton foil (~50μm thick) sandwiched between two metal layers (~18μm thick copper), pierced by a regular matrix of holes, which are created using high-precision photolithographic techniques [2]. A voltage across two metal layers creates a high field causing avalanche multiplication. Coupled to a read-out device, such as MWPC, MSGC, or a simple PC-board, it was already demonstrated that the GEM electrode can work reliably in harsh background conditions [3,4].

However, until now, there were only a few attempts to use the GEM for applications trying to detect single electrons such as the Cherenkov particle identification detectors. For example, J. Seguinot has built a photon detector from a combination of the MSGC chamber and the GEM with a CsI photocathode operating at normal pressure [5]. A. Breskin et al. have tried a single GEM coupled to a MWPC, and recently also a two-GEM design, operating with a CsI photocathode at a low gas pressure [6].

This paper concentrates the effort on the quenching stability of a GEM-based detector compared to previous generations of photon detectors, such as the SLD CRID. However, there are other important detailed questions, which we have not yet fully addressed, such as the "entrance efficiency" (probability that an electron will enter the GEM hole), and the "exit efficiency" (fraction of the total GEM amplified charge drifting towards the amplifying element, such as the anode wire), etc. The "entrance efficiency" must be high to get a reasonable Cherenkov detector N_0. Low "exit efficiency" reduces the total charge produced by the GEM. A proper way to determine the "entrance efficiency" is to measure the detector response to a calibrated photon flux, and the "exit efficiency" can be determined by a proper accounting of the electrode currents. This has not been done at this point yet. Instead, we are trying to estimate these efficiencies using the 3D MAXWELL program for field calculations coupled with GARFIELD [7]. A coupling of a MWPC to the GEM reduces the GEM's exit electric field, which in turn reduces the "exit efficiency." Our simple hand calculation indicates a value of only 20-40% for the "exit efficiency" for our typical operating point. This value could be increased if a larger diameter anode wire is used, or if one would reduce the anode wire spacing.

Although we have built both single and double GEM detectors, all results reported in this paper are from the single GEM device.

2. DESIGN AND CONSTRUCTION OF THE DETECTOR

We have decided to build the GEM structure into an old BaBar Fast Drift CRID detector prototype [8]. Figures 1(a)-(b) show the detector prototype with a single GEM and double GEM electrodes respectively. The design is using the short drift cell of ~10cm drift length, repeating many times in a given modular structure. The GEM-based amplifying insert (see Figs. 2) is a MWPC chamber with the GEM foils acting as cathodes and three 33μm diameter carbon wires in the middle. The wire-to-wire distance is 3mm, and the anode-cathode distance is 3.5mm for the single GEM. The coordinate along the length of the cell is measured using drift time, the coordinate along the width is measured using a charge division using the carbon wires, and the coordinate along the 1.5 cm depth of the cell is measured using a wire address. The drift cell quartz electrodes are made of metalized strips evaporated directly on the quartz sheets.[2] Figure 3 shows the picture of the final prototype.

The GEM electrode[3] used in this test is 86μm thick, out of which the Kapton foil is 50μm thick and each copper side is ~18μm thick. The GEM double conical hole pattern has a pitch of 120μm, the Kapton hole diameter is 40μm, and the copper

[2] Strips were evaporated by A.Braem, CERN.
[3] Our GEM electrodes were made at CERN.

hole diameter is 80μm. High voltage tests in dry air indicated no problem up to a maximum voltage of ~500 V (in ethane, up to 900 V).

We use the SLD CRID amplifier with a gain of ~2.7μV/electron and a shaping time of 65ns. The amplifier motherboard strip line design gives ~0.3% cross-talk between the adjacent strips.

For the TEA application, one would have to use a CaF_2-based chamber; in that case, the chamber could be thin and may use a nonlinear resistance chain to focus photoelectrons away from the window, and chose a gas radiator sufficiently transparent in a far UV region, such as C_2F_6.

3. EXPERIMENTAL METHOD AND RESULTS

Single electrons are produced by a UV light striking the drift cathode surface (exception is TMAE, where we can ionize the gas directly). To ensure that we were dealing with single electrons, the probability of having an event per shot was set to less than 5% by attenuating the light flux. The single electrons drift over about 10 cm before entering the GEM electrode and then MWPC. We use a Xenon filled UV lamp[4] operating in a pulsed mode. A portion of the light is used to trigger a photo-diode,[5] which then provides an external trigger for the QVT. We measure the single-electron pulse height spectra using a LRS QVT-3001 operating in charge integrating mode, with an external trigger and a 600ns external gate width. All single-electron pulse height spectra plots in this paper, with the exception of Fig.7, show the so-called visible gas gain [9]. The correction factor to the total gain is about 1.5-2.0.

The gas mixing is performed using two mass flow controllers. We use an Oxisorb filter and a 13X molecular sieve during all measurements to remove the oxygen and water. The oxygen contamination at the exit of the chamber is at ~1ppm level.

3.1. Experience with ethane and 60% He+40% iC_4H_{10} carrier gases.

The first carrier gas studied was ethane, mainly because it is used successfully by CRID at SLD. Figure 4 shows the single electron pulse height spectra in ethane as a function of voltage across GEM (dV_{GEM}), while keeping V_{GEM}(in) and E_{DRIFT} constant. Similarly, Fig. 5 shows the same in ethane as a function of cathode voltage V_{GEM}(in), while keeping dV_{GEM} and E_{DRIFT} constant. A pedestal shape below zero shows a clear indication of wire to wire cross-talk, which comes from events when the single electron is amplified on neighboring anode wire. The second carrier gas investigated was 60%He+40%iC_4H_{10}, mainly because iC_4H_{10} gas component has a very good quenching capability.

3.2. Experience with TMAE and TEA photocathodes.

TMAE may reveal hidden problems, if they do exist within the detector, such as a poor quenching of the avalanche photons, HV corona, bursts of single electron charges from insulators due to the Malter effect, etc. Our present experience with the Fast Drift CRID using a single GEM, and operating with TMAE photocathode, is rather disappointing given our present GEM design choice and the selected operating parameters. Each carrier gas, ethane and 60%He+40%C_4H_{10}, yielded a similar experience. Already running with an increased detector temperature of about 45-50°C, which was the initial choice of the TMAE operation, is reducing a maximum reachable voltage across GEM by ~100-200 V. This is caused by a simple gas gain dependence on the temperature, which we measured to be a factor of two for this temperature change (the GEM does not tolerate such gain increase at our operating point). Adding TMAE further reduced the operating voltages. As a result, at high TMAE concentration (~0.18%; the TMAE bubbler at 35°C), the detector could not reach the previously set non-TMAE

[4] Hammamatsu UV lamp 2435

voltages. A detailed look at what is happening near the breakdown point revealed a large number of single electron pulses produced by the GEM; the rate of these pulses increased with the GEM voltage (dV_{GEM}) up to a point of breakdown. Furthermore, any appreciable gas gain on the GEM creates a large number of secondary photoelectrons due to photon feedback.

The TEA operation followed the TMAE operation. We have developed quite the opposite experience compared to TMAE; the chamber started to operate immediately without any problem at the non-TEA voltage settings. The TEA bubbler was set to 15°C, and the detector was operating at room temperature. Figure 6 shows the single electron pulses and spectra in 60%He+40% iC_4H_{10}+TEA (15°C). The operation with ethane, as a carrier gas, was equally smooth. All measured single electron spectra are exponential. For comparison, Fig.6 also shows the TMAE pulse height spectrum obtained at a maximum possible gas gain. Notice that the gain controlling voltages are considerably lower than non-TMAE settings.

4. COMPARISON WITH THE CRID DETECTOR

It is interesting to point out that the CRID detector worked smoothly at a comparable stage of development. For example, the CRID detector does operate equally well at the same voltages with and without TMAE, and what is more important, one can over-voltage temporarily the nominal cathode voltage by 200-300V. Figure 7 shows several examples of the CRID detector single electron pulse height spectra for various gases and anode wire diameters [10,11]; the Polya distributions have a "turnover," which we were not able to reach under any condition with the Fast Drift CRID and single GEM in this work.

5. CONCLUSION

It is not yet clear if the GEM, as it is implemented in the Fast Drift CRID prototype presently, can compete with the older photon detector designs such as SLD CRID, as far as quenching and stability. The TMAE operation, with a bubbler temperature of 35°C and a detector temperature of 45-50°C, does not provide sufficient stability; one way to improve this is to reduce the detector temperature including a reduction of the TMAE concentration, and use a double GEM design, where the outer GEM is used as a shield against the avalanche photons created from the inner GEM. On the other hand, the operation with the TEA photocathode is very stable. To increase the GEM's "exit efficiency" in our design, it is necessary to increase the GEM's exit electric field, which can be accomplished, for example, by reducing the anode wire spacing, or by increasing the anode wire diameter.

6. ACKNOWLEDGEMENTS

We would like to thank A. Sharma for her help in trying to understand our detector using the MAXWELL simulation program, and M. Hoch for help to produce the GEM electrodes.

[5] EG&G photodiode FND100

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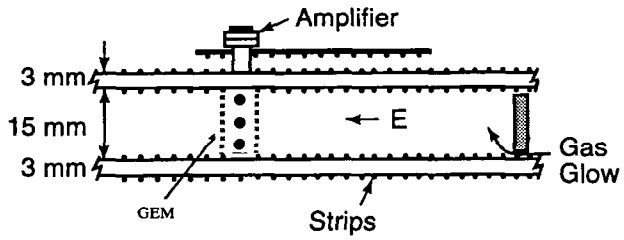
a) Single GEM:



b) Two GEMs:

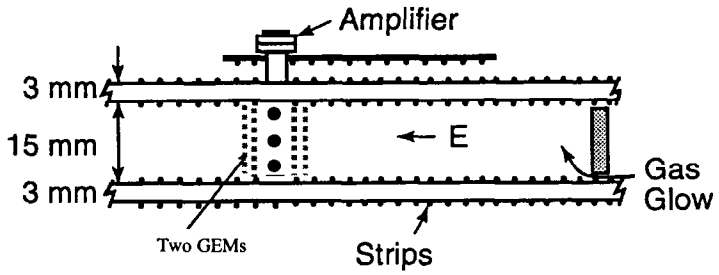


Fig. 1. Fast Drift CRID geometry with (a) a single GEM, and (b) double GEMs.

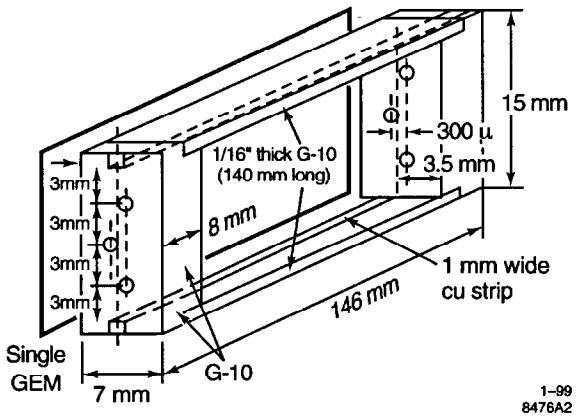


Fig. 2. Design details of the single GEM amplifier insert into the Fast Drift CRID.

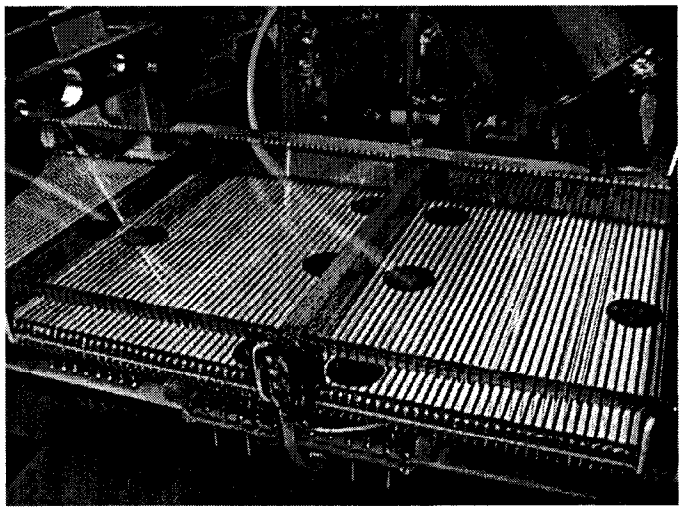


Fig. 3. Fast Drift CRID with a single GEM.

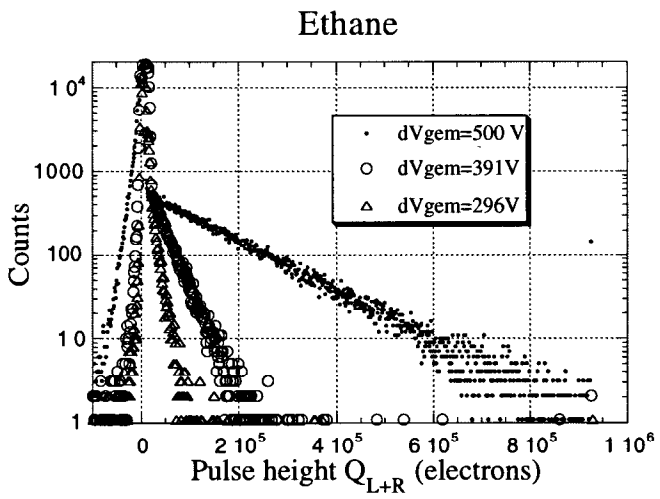


Fig. 4. Single electron pulse height spectra in ethane (no TMAE) as a function of voltage across GEM (dV_{GEM}), while keeping V_{GEM}(in) = -2.71 kV, E_{DRIFT}~500 V/cm, and V_{STRIP}=-0.503 kV constant.

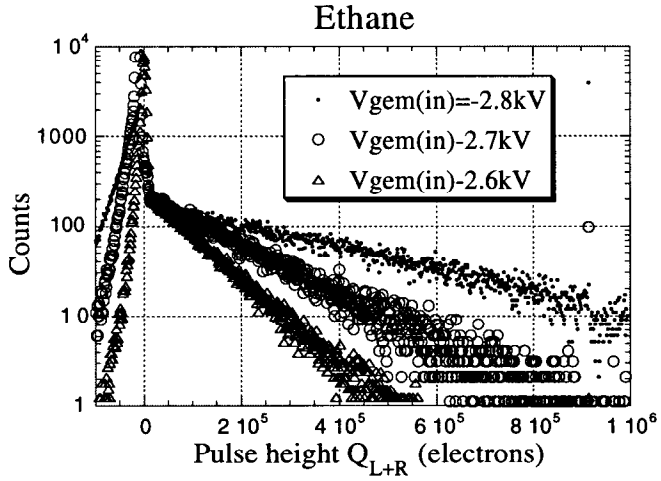
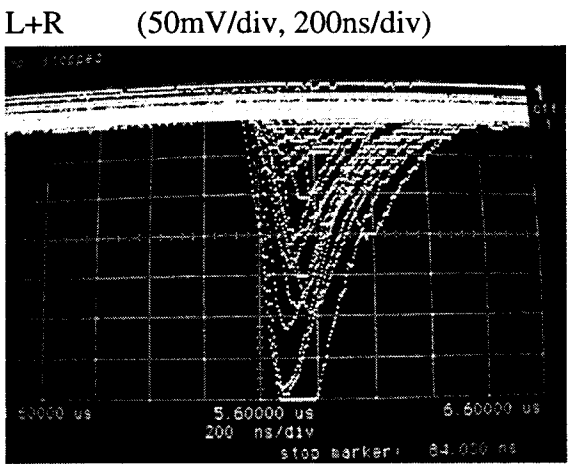


Fig. 5. Single electron pulse height spectra in ethane (no TMAE) as a function of cathode voltage V_{GEM}(in), while keeping dV_{GEM} = 500 V, E_{DRIFT} ~ 500 V/cm, and V_{STRIP} = -0.503 kV constant.

a)



b)

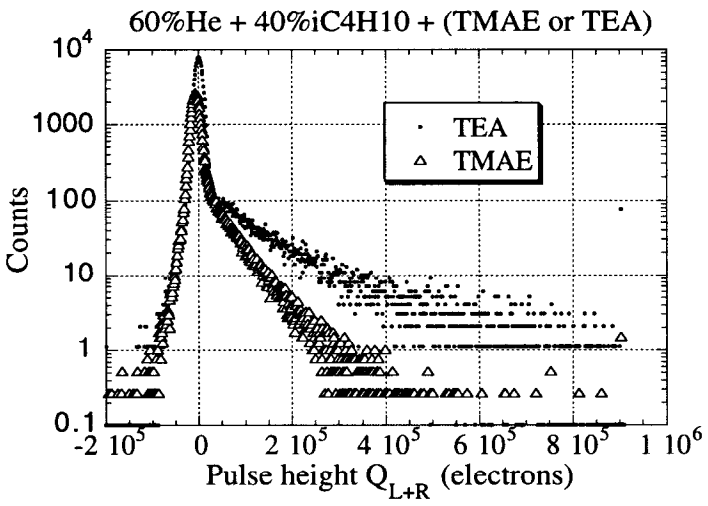


Fig. 6. (a) Single electron pulses in the Fast Drift CRID with a single GEM operating with 60%He+40% iC_4H_{10}+TEA(15°C). (b) Single electron pulse height spectra in 60%He+40% iC_4H_{10} with (i) TMAE (bubbler at 35°C, detector at 45-50°C, V_{GEM}(in) = -2.454kV, dV_{GEM}=100V, V_{STRIP}=-0.502kV, E_{DRIFT}~500V/cm), and (ii) TEA (bubbler at 15°C, detector at room temperature, V_{GEM}(in) = -2.454kV, dV_{GEMm} = 100V, V_{STRIP} = -0.502kV, E_{DRIFT} ~ 500V/cm).

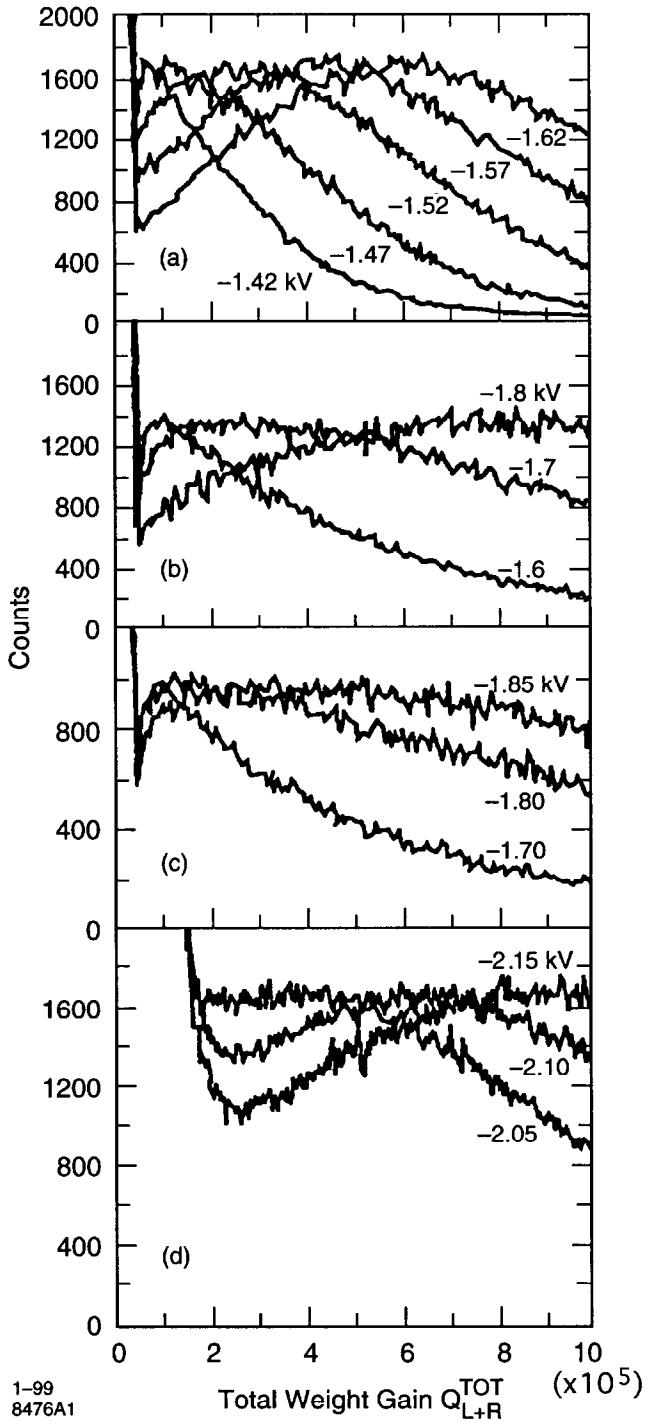


Fig. 7. Single-electron pulse height spectra in the final CRID detector from an early CRID R&D for the following conditions: C_2H_6 (7μm wire), (b) 80%CH_4+20%C_2H_6 (7μm wire), (c) CH_4 (7μm wire), and (d) C_2H_6 (33μm wire) [10, 11].