A gas avalanche photomultiplier with a CsI-coated GEM

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Abstract

We describe the operation principle and properties of a CsI-coated GEM photodetector.This type of detector performs photon detection with reflective photocathodes, which are easy to produce and have high quantum efficiency. In the proposed configuration, the detector is practically free of avalanche-induced photon feedback effects. The influence of the GEM voltage and the electric fields close to the CsI-GEM electrode on the photon detection efficiency are studied. Conditions for obtaining full extraction of photoelectrons from the photocathode and their transfer through the GEM apertures are presented.

Key words: GEM, CsI photocathodes, single electron detection, gaseous photomultiplier
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1 Introduction

Gaseous avalanche photomultipliers (GPMT) [1] allow for the efficient localization of single UV photons over very large area (square meters), are tolerant to magnetic fields, have good time ($\leq$ 1 ns) and position (sub-mm) resolution.

Coupling a semitransparent photocathode to a Gas Electron Multiplier (GEM) [2] was recently shown to reduce ion- and photon-feedback processes and allow for high gain operation even in noble gas mixtures [3]. This paves the way for

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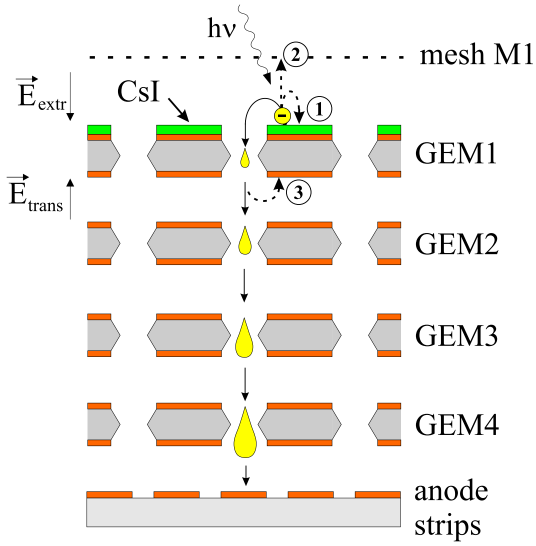

Fig. 1. A quadruple GEM photon detector with the photocathode evaporated on the top face of GEM1. The dashed arrows illustrated the different photoelectron loss mechanisms: backscattering (1), transfer to top mesh (2) and collection at the backside of the GEM (3).

designing large area position sensitive GPMTs for high precision imaging of light, with a single photon sensitivity, over a wide spectral range.

In a recent publication [4] we reported on the first efficient operation of a GEM-based GPMT having a reflective photocathode evaporated on the surface of the topmost electrode of a multi-GEM detector (fig.1).

We present here some new results of recent systematic investigations of the operation parameters and the detector efficiency. All measurements presented in this work were made with a 50 μm thick GEM, having single conical hole geometry with 140 μm pitch and hole diameters of 70 μm on the CsI-side and 100 μm on the GEM backside.

A more complete discussion of detector efficiency and operation parameters, including the influence of the GEM hole geometry and the counting gas, will be discussed in a following article [5].

2 General properties

Evaporating the CsI photocathode on the top GEM1 surface, instead of using a semitransparent photocathode, has two major advantages. Firstly, thick reflective photocathodes can be used, which are easier to produce and have superior quantum efficiency (QE). We measured an absolute QE of 35% at 150nm in vacuum, for a CsI photocathode evaporated on top of a GEM hav-

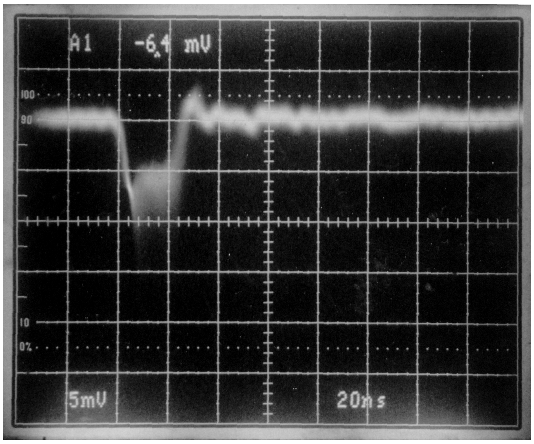

Fig. 2. Single electron pulses measured in $Ar{:}CH_4$ (20:80).

ing a 77% metallic surface [4]. Secondly, the detector is free of photon-feedback as the photocathode is fully concealed by the GEM structure from secondary photons generated in the avalanche process.

Total gains of up to 10^6 were reached in a quadruple GEM detector operated in atmospheric $Ar{:}CH_4$ (20:80). This gain is ample for the detection of single photoelectrons. Fig.2 shows single electron pulses taken with a fast (1 ns rise-time) amplifier, presenting a fast rise-time of 5 ns.

3 Optimization of the GPMT parameters

An efficient photon detection requires that each photoelectron emitted from the photocathode surface is transfered into GEM1 aperture, multiplied and further transfered towards the next amplification element. There are three main mechanisms of possible photoelectron losses in the detector (see fig.1):

- **Backscattering** of photoelectrons to the photocathode due to elastic collisions with gas molecules.
- Transfer of electrons towards the **top mesh M1** rather than into GEM1 apertures.
- Losses of electrons to the **lower GEM1 electrode**.

Each of the above depends on the voltage across GEM1, ΔV_{GEM}, the electric fields E_{extr} above and E_{trans} below GEM1, the GEM aperture and the choice of the counting gas. To evaluate the dependence of the detector efficiency on the operation parameters we replaced GEM2–GEM4 of fig.1 by a MWPC and measured the counting rate. We further mounted a MWPC above the mesh M1 of fig.1, and operated it as a "reference" detector with the CsI-coated GEM acting as a reflective photocathode. Normalizing the counting rate of

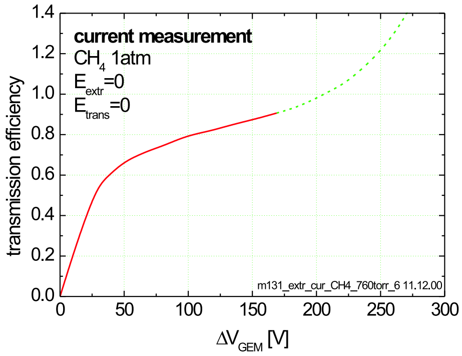

Fig. 3. Influence of ΔV_{GEM} on the transmission efficiency in atmospheric CH_4. Current measurement provides meaningful transmission efficiency only for $\Delta V_{GEM} \leq 150V$.

the GEM-based detector to the one measured in the "reference" detector, allowed us to determine the transmission efficiency, namely the probability of a photoelectron released from the photocathode to be transfered through a GEM hole, multiplied and further transfered towards the next element. The transmission efficiency multiplied by the QE gives the overall photon detection efficiency of this detector.

In some cases we measured current on the backside of GEM1, with reversed E_{trans}. This measurement is meaningful only for small GEM voltages and no GEM amplification, otherwise the photocurrent is masked by the much larger currents originating from the avalanche process. Nevertheless, the current mode provides some insight into the charge transfer mechanism, as it is sensitive to efficiency losses due to backscattering and losses on M1 but not to efficiency losses due to bad electron extraction from the hole. Thus the current measurement allows to distinguish between the different electron loss mechanisms.

A more detailed description of the measurement methodology is given in [4,6].

3.1 Influence of ΔV_{GEM}

Fig.3 presents the transmission efficiency versus ΔV_{GEM}, measured in current mode. The initial fast rise is due to the increase of the electric field on GEM1 surface, leading to a decrease in electron backscattering. For GEM voltages higher than 200V the electric field within the GEM holes is high enough for gas amplification in CH_4, resulting in an exponential increase of the current, and the measurement is no longer valid.

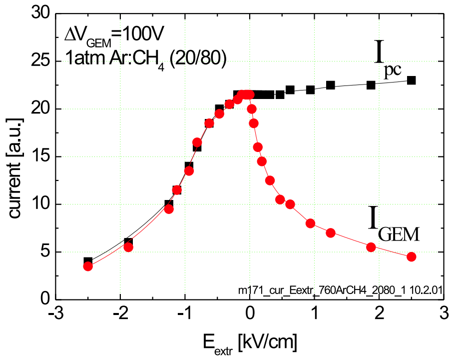

Fig. 4. Influence of E_{extr} on the transmission efficiency in 1 atmosphere of Ar:CH_4 (80/20).

One should note, that already at GEM voltages of 100V, about 80% of the photoelectrons created are extracted and transfered into GEM1 apertures.

3.2 Influence of E_{extr}

In order to evaluate the influence of the extraction field, E_{extr}, on the operation, the current on the photocathode, I_{PC}, and on the backside of GEM1, I_{GEM}, were measured simultaneously (fig.4). For reversed E_{extr} both currents coincide and drop with increasing the reversed E_{extr}; this is due to the reduction of the field strength on the photocathode surface and the consequent increase of photoelectron losses by backscattering. On the other hand, if the mesh is at a positive potential with respect to the photocathode, a fraction of the photoelectrons will drift towards mesh M1 rather than being transfered into the holes. Indeed, I_{PC}, namely electrons leaving the photocathode, is independent of E_{extr}, while I_{GEM}, namely electrons arriving to the bottom GEM1 electrode, drops with increasing E_{extr}.

The optimal condition for an efficient detector operation is at $E_{extr} \simeq 0$. For higher GEM1 voltages the influence of E_{extr} is less pronounced and one can allow for slightly positive values to prevent space charge accumulation in the gap between M1 and GEM1. Such small positive fields above the photocathode will considerably reduce the collection of ionization electrons induced by charged particles. This is of considerable importance in application of photon detectors in particle physics experiments, particularly in RICH.

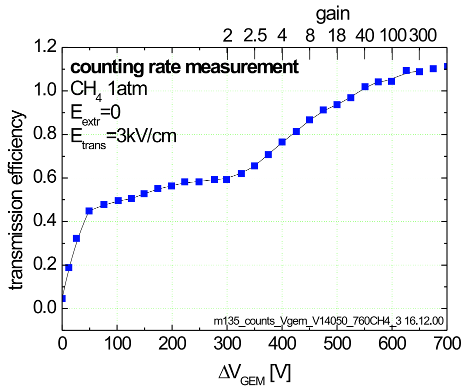

Fig. 5. Influence of ΔV_{GEM} on the transmission efficiency in atmospheric CH_4 in the pulse-counting mode.

3.3 Influence of E_{trans}

Due to the particular topology of the dipole field configuration in the GEM apertures, a fraction of the electrons leaving a GEM hole is always collected on the lower GEM electrode rather than being transfered to the next GEM [6,7]. This fraction depends almost linearly on the transfer field E_{trans}. In most applications this simply reduces the visible gain [7]. However, for single electron detection, in the absence of a "saturated" pulse-hight spectrum, losing part of the amplified charge means loosing a fraction of the events and thus reducing the detector efficiency. Fig.5 shows the transmission efficiency versus ΔV_{GEM}, measured in pulse-counting mode. Similarly to fig.3 (current mode) we observe an initial fast rise of the transmission efficiency followed by a plateau. Comparing with the data of fig.3 we note the difference in the hight of the first plateau. This is clearly the effect of E_{trans}, to which the current mode is not sensitive at all. In the pulse-counting measurements, the true plateau value is measured, and is 50% at ΔV_{GEM}=100V, compared to 80% falsely measured in current mode. Below 200V the GEM gain is 1, so each electron lost to the bottom electrode of GEM1 reduces the transmission efficiency. At ΔV_{GEM}=100V and E_{trans}=3kV/cm we loose approximately one third of the electrons transmitted through the GEM hole to the lower GEM side. For higher GEM voltages, at gains $\geq$100, these charge losses do not imply loss of the event as the electron cloud is large enough. This explains the second rise of the counting rate seen in fig.5, starting at ΔV_{GEM}=300V (gain 2) and reaching a second plateau at full transmission (gain $\geq$100). We therefore conclude, that operation at high GEM1 gain and high E_{trans} (the first parameter depends on the second one) is required in order to obtain full detector efficiently. However we should always keep in mind, that too high E_{trans} may reduce the electron transparency of the following GEM element [7].

4 Conclusions

We presented new results for a GEM-based photodetector with a reflective photocathode. This detector can operate at high gain and is sensitive to single photons. We have demonstrated that a correct evaluation of the detector efficiency for single photoelectrons can obtained only by the pulse-counting technique. We shortly discussed the role of the various fields on the detector performance. It is shown that it is possible to find operation conditions with full transmission efficiency and thus maximal photon detection efficiency:

- **High ΔV_{GEM}** — creates high fields at the photocathode surface that reduces backscattering and guarantees a large enough avalanche to compensate for any charge losses to the GEM lower face.
- **Zero or very low E_{extr}** — allows for an efficient electron focusing into the GEM holes. A slightly positive E_{extr} makes the detector practically blind to direct particle-induced ionization.
- **High E_{trans}** — extracts the majority of electrons produced within the GEM holes and thus reduces the gain required in GEM1 to reach full transmission efficiency.

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