Evaluation and reduction of ion back-flow in multi-GEM detectors

D. Mörmann *, A. Breskin, R. Chechik and D. Bloch 1

Department of Particle Physics, The Weizmann Institute of Science,
76100 Rehovot, Israel

Abstract

In gaseous photomultipliers, avalanche generated ions back-flowing to the photocathode can drastically limit the detector operation and lifetime. This is especially the case for photocathodes with low electron emission threshold, where impinging ions induce ion feedback effects by secondary electron emission.

We present ways of reducing ion-backflow to the photocathode, and thus suppress ion-feedback effects in multi-stage Gas Electron Multiplier (GEM) detectors. We studied the effect of the various electric fields on the ion transport in the detector and present our results on active ion gating with a dedicated gating electrode.

Key words: GEM, gaseous detectors, gaseous photomultiplier, ion back-flow, ion feedback, ion gating

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1 Introduction

The operation of gas avalanche detectors is often limited by secondary effects, originating from avalanche-induced photons and ions, generating electrons in the gas or on the detector’s electrodes. The aim of the present work is to investigate ways of reducing ion-induced secondary effects in Gas Electron Multiplier (GEM) [1] based detectors. Multi-GEM electron multipliers have been proposed and are extensively studied [2] for Gaseous Photomultipliers (GPMTs) in the UV- and visible light range. Their high gain [3], suppressed photon-feedback [4] and operation in noble-gas mixtures [5] make them potentially attractive for the fast and efficient imaging of single photoelectrons.

* Corresponding author. Email: moermann@wicc.weizmann.ac.il
1 Summer student from the Technion, Haifa, Israel

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As an example, Fig. 1 schematically shows a 4-GEM gaseous photomultiplier (GPMT) developed in our group [6]. Photoelectrons emitted from a photocathode deposited on the top face of GEM1 are focused into the GEM holes and undergo gas amplification in the successive GEM stages before being collected on the anode. The anode can be patterned to provide an accurate localization of the avalanche [7,8]. Gains exceeding $10^6$ for single photoelectrons are typically achieved with this detector in various gas mixtures. This is possible because photon-induced feedback effects on the photocathode are largely suppressed in multi-GEM detectors, due to the opacity of the GEM element, and photon-mediated processes in the gas are suppressed due to the confinement of the avalanche into the GEM holes [5]. However, it was found that the gain limit in these detectors is also dictated by avalanche ions back-flowing to the photocathode, yielding secondary electrons. This is particularly manifested in detectors with visible-sensitive photocathodes, having a very low electron emission threshold [9]. Ion impact on the photocathode also gradually damages its surface, resulting in loss of quantum efficiency. Ions back-drifting into the drift volume affect the operation of TPC devices as well, by creating space charge effects [10].

A better understanding of the ion transport properties, usually drifting in opposite direction to the electrons, is of importance for the detector’s optimization and stability of operation.

While ion feedback is the common general terminology for the secondary effects caused by the ion impact (e.g. electron emission), we use the notion of
ion back-flow to quantify the fraction of avalanche-generated ions reaching the photocathode. The minimization of ion back-flow is therefore a prerequisite for keeping the ion feedback at the lowest possible level. As discussed in some previous works [11–15], the ion back-flow to the ionization region or to a photocathode, in multi-GEM detectors, depends upon the GEM geometry, gas, pressure, electric fields etc.

We studied mainly the role of the various electric fields within the multi-GEM detector and their effect on the ion backflow, while maintaining the detector performance in terms of maximum achievable gain and stability. We have also investigated ion back-flow suppression by the incorporation of ion-gating electrodes, as commonly used in multiwire-based TPCs [10].

2 Ion back-flow in a 4-GEM detector

2.1 Methodology and experimental setup

All GEMs used within this study have a 30×30mm$^2$ active area and a hexagonal aperture array of 140μm pitch and 55/70μm (inner/outer) hole diameter, in a 50 micron thick copper-cladded Kapton. The topmost GEM has an additional thin (< 1μm) gold plating, to prevent possible chemical reactions of the metal electrode with the 250nm thick CsI photocathode evaporated onto it.

The cathode and anode mesh electrodes (we use a mesh anode instead of the segmented one shown in Fig. 1) are made of 50μm diameter crossed stainless steel wires, 0.5mm apart (81% optical transmission). All elements were stretched and mounted on G10 frames. The schematics of the detector setup and the distances between the elements are indicated in Fig. 1. The detector was placed within a vacuum vessel, evacuated to 10$^{-5}$ Torr by a turbomolecular pump prior to the gas filling. The system is operated in a gas flow mode, using mass-flow controllers, differential pumping and a regulated pressure control. Unless otherwise indicated, we used Ar/CH$_4$ (95:5) at 760 Torr as counting gas; we currently use this mixture in sealed gas photo-multipliers. In current mode operation, a UV Hg(Ar)-lamp was illuminating the photocathode through a quartz window, resulting in a constant flux of emitted photoelectrons. In pulse-mode operation we used a H$_2$ discharge lamp emitting large bursts of UV photons; it resulted in several hundreds of photoelectrons ejected by the photocathode per light pulse. In all cases, the total current collected on the anode was kept below 5nA, to prevent space charge effects.

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Fig. 2. Ion transfer through a GEM can be divided in two steps: from region 1 to region 2 it is governed by the ratio $\Delta V_{\text{GEM}}/E_1$ and from region 2 to region 3 is governed by $\Delta V_{\text{GEM}}/E_2$.

In measurements with ion gating we used a gating electrode mounted on a G10 frame, with 50$\mu$m diameter stainless steel wires, 1mm apart and alternatingly interconnected. The pulses applied to the gate wires were generated with dedicated electronics, designed and successfully used for TPC gating by the LHC-ALICE experiment [16].

Similarly to the transfer of electrons and ions through a wire mesh [17,18], the charge transfer in GEM detectors depends on the electric field ratios below, within and above the GEM electrode, as shown for electrons, for example, in [12]. Electrons arriving at a GEM are either transferred into the GEM holes or are lost to the top GEM electrode. A combination of high potential across the GEM, $\Delta V_{\text{GEM}}$, and low electric field value above the GEM generally ensures a high electron transmission into the holes. At the GEM hole exits, a fraction of the electrons is collected on the bottom GEM electrode and is not transferred to the next detector stage. A high electric field below the GEM ensures that a large fraction of the electrons leaving the hole is extracted and transferred into the next GEM. In multi-GEM detectors the electric fields between successive GEMs (generally denoted as transfer field, $E_{\text{trans}}$) have to be optimized to satisfy good electron extraction from the hole exit of a given GEM while ensuring a high electron transmission into the holes of the next GEM element.

The situation is very similar for the ion transfer in multi-GEM detectors. Fig. 2 shows schematically the possible drift paths of ions, originating from the GEM avalanche and from subsequent GEM stages below it. It also shows the three field regions of fields $E_1$, $E_{\text{GEM}}$ (represented by the GEM potential $\Delta V_{\text{GEM}}$) and $E_2$. In analogy to measured electron transport in such geometry we expect the following dependence of the ion transport on the electric fields: Ions arriving from region 1 have a probability of entering the holes which increases with $\Delta V_{\text{GEM}}/E_1$. At lower $\Delta V_{\text{GEM}}/E_1$ values a larger fraction of ions ends on the bottom GEM electrode. Similarly for ions leaving the GEM holes, the higher the ratio $E_2/\Delta V_{\text{GEM}}$, the larger the fraction of ions leaving the GEM and drifting to the preceding GEM. For low $E_2/\Delta V_{\text{GEM}}$ values, a larger fraction of ions is neutralized on the top GEM electrode. Obviously the
terms “low” and “high” have only a relative meaning; the absolute values will not only depend on the potentials but also on the GEM geometry, gas mixture and pressure.

We have varied the various detector potentials and studied their influence on the ion back-flow. It was seen that field ratios in the detector can only be varied by a factor 2-5 before drastically changing the electron transport through the GEMs and limiting the overall detector performance (maximum gain, stability, etc.); being roughly proportional to these field ratios, the ion back-flow is expected to change by approximately the same factor. Of particular role is the drift field in the vicinity of the photocathode. In a 3-GEM detector with semi-transparent photocathode it was shown that ion back-flow can be as low as $2 \cdot 10^{-3}$ for a very low drift field of 100 V/cm, and further decreased for even smaller fields \cite{11}. This could solve the problem of ion back-flow in GEM-based TPCs but it is not applicable for GPMTs having solid photocathodes. For both reflective and semi-transparent ones strong electric fields are required close to the photocathode in order to overcome backscattering of photoelectrons to the photocathode \cite{19}. The ions, inevitably following this field, are accelerated and end on the photocathode where they can induce secondary effects.

In the present work, we chose a configuration which is insensitive to the drift field $E_{\text{drift}}$. All measurements were performed with a GPMT having a reflective photocathode deposited on the top face of GEM1, interconnected with the cathode mesh ($E_{\text{drift}} = 0$) and keeping a constant $\Delta V_{\text{GEM}} = 350$V. These conditions were found to be optimal for this detector configuration in Ar/CH$_4$ (95:5) at atmospheric pressure \cite{20}, yielding full photo-electron extraction from the photocathode and their efficient transmission into the GEM1 holes. The detector electrodes were either powered with a voltage dividing resistor network (resulting in variable transfer fields, of 2-3kV/cm in the range of operation) or individually through a 22M\Omega protective resistor. The experimental scheme with the resistor network is shown in Fig. 1.

The cathode-mesh + photocathode ion current, normalized to the electron current collected on the anode, is defined as the ion back-flow in the detector; it represents the fraction of ions created in the detector that leave the holes of the top GEM, and are collected at the photocathode and the cathode mesh. To eliminate the error in the anode electron current due to electron losses on the GEM4 bottom electrode, we operated the detector with interconnected anode mesh and GEM4 bottom electrode, and used this current for normalization. The ion current was measured with a pico-ampermeter while the electron current was measured by the voltage drop over a 10M\Omega resistor with a floating multimeter.
2.2 Symmetric GEM powering

We first measured the ion back-flow in a “standard” operation mode, namely with equal $\Delta V_{GEM}$ values (with the exception of a constant $\Delta V_{GEM1}=350\text{V}$) and equal transfer fields. For that purpose, GEM2, GEM3 and GEM4 were powered by a resistor network (shown in Fig. 1); the transfer fields ($\sim 2$-$3\text{kV/cm}$), yielded good electron transport at high gains.

In Fig. 3 we show the exponential gain increase with the voltage on the resistor network, $V_{res}$, and the ion back-flow variation. Due to the electrode powering with a resistor network and to the fixed potential on GEM1, the transfer fields at low $V_{res}$ values are too small to allow for a good electron transport between the GEM stages. In these conditions, ion transport is more efficient than electron transport resulting in values of ion back-flow larger than 1. The ion back-flow drops rapidly with increasing $V_{res}$ and stabilizes at $\sim 35\%$ for high total gains. We may conclude that in standard operation mode, not optimized for low ion back-flow, about two thirds of the ions are neutralized on the various electrodes of the detector and do not reach the photocathode.

![Graph showing gain and ion back-flow as function of resistor network voltage](image-url)
2.3 Influence of the transfer field

For more careful optimization of the detector potentials and electric fields, we have replaced the resistor network by individual power supplies. Fig. 4 shows the influence of $E_{\text{trans}3}$, the transfer field between GEM3 and GEM4, on the ion back-flow and on the total gain, while keeping the two other transfer fields at 2.5kV/cm and the potential differences on GEMs 2, 3 and 4 at 280V. $E_{\text{trans}3}$ values larger than 0.5kV/cm are required for good electron transport from GEM3 to GEM4; for $E_{\text{trans}} < 3kV/cm$, the gain is hardly influenced by this field; for higher fields, the avalanche extends further into the transfer gap resulting in the observed gain increase. The ion back-flow increases with the field for values below 1kV/cm due to an improved ion extraction from the GEM4 holes into the transfer gap above it (region 2 → region 3 in Fig. 2), while for high $E_{\text{trans}3}$ values the ion back-flow starts dropping again, as ions start to be neutralized on the GEM3 bottom electrode and do not enter GEM3 holes (region 1 → region 2 in Fig. 2). We may conclude that by choosing high $E_{\text{trans}3}$ field, the ion back-flow reduces from 30% in normal operation mode ($E_{\text{trans}} \sim 2kV/cm$) to $\sim 20\%$.

2.4 Asymmetric GEM powering

The ion transport within the detector can be modified also by powering differently two consecutive GEMs, e.g. GEM3 and GEM4. In order to keep the total gain of the detector constant, reduced potentials on one GEM were compensated for by raising the potential on the adjacent one. It should be noted
Fig. 5. Influence of the voltage difference between \( \Delta V_{GEM4} \) and \( \Delta V_{GEM3} \) on the ion back-flow. The detector potentials were as follows: \( \Delta V_{GEM4} + \Delta V_{GEM3} = 560 \text{V} \), \( \Delta V_{GEM2} = 280 \text{V} \), \( \Delta V_{GEM1} = 350 \text{V} \) and \( E_{\text{trans1/2/3}} = 2.5 \text{kV/cm} \).

that there is not much freedom in varying \( \Delta V_{GEM1} \), as its increase would lead to higher ion back-flow, while its decrease may lead to loss of primary photo-electrons that are not extracted into the GEM1 holes. Therefore GEM1 was kept constant at its optimal potential while varying GEM3/GEM4 voltages.

With increasing \( \Delta V_{GEM4} \), a larger fraction of ions produced in GEM4 ends on its top face. Also, as the potential across GEM3 is lowered, the fraction of ions ending on the GEM3 bottom electrode increases. Both effects lead to a decreasing ion back-flow with increasing asymmetry of the GEM powering which is clearly visible in Fig. 5. Nevertheless, the improvement compared to the symmetric GEM powering is marginal (from 25% to 20%) and does not justify the detector instability caused by operating GEM4 close to its breakdown limit.

### 2.5 Influence of the induction field

Another possibility investigated for ion back-flow reduction, is the operation of the induction gap (see Fig. 1) in parallel-plate avalanche mode. In this mode the majority of the ions is produced in this gap, where the final avalanche takes place; applying high induction field \( E_{\text{ind}} \) will result in low ion transmission through GEM4 (region 1 \( \rightarrow \) region 2 in Fig. 2); therefore, in a reduction of ion back-flow. For this measurement the anode mesh was disconnected from the resistor network and powered separately through a 22M\( \Omega \) resistor. The anode current was measured by the voltage drop over this resistor. Fig. 6 shows the
Fig. 6. Influence of the induction field on the ion back-flow for a) $\Delta V_{GEM4}=200V$ and b) $\Delta V_{GEM4}=300V$.

variation of the detector gain and the ion back-flow with the induction field $E_{ind}$ for two different values of $\Delta V_{GEM4}$. Parallel-plate amplification in our gas mixture starts at $E_{ind} \sim 5kV/cm$. The slight increase in gain for smaller values of $E_{ind}$ is due to improved electron extraction from the GEM4 holes and due to avalanche extension out of the GEM4 holes into the induction gap.

In both cases the ion back-flow drops with increasing $E_{ind}$ due to improved electron extraction to the anode. But for a given $E_{ind}$ the ion transmission through GEM4 is low for $\Delta V_{GEM4}=200V$ (region 1 $\rightarrow$ region 2 in Fig. 2) and high parallel plate gains ($\sim 10^3$) can be reached at high values of $E_{ind}$ compared to $\Delta V_{GEM4}=300V$. This explains why for $\Delta V_{GEM4}=300V$ we reach an ion back-flow of 20%, while for $\Delta V_{GEM4}=200V$ the ion back-flow reaches $\sim 10\%$ for $E_{ind} \geq 9kV/cm$. 

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Although, compared to “standard” 4-GEM operation, one reaches a reduction of ion back-flow by a factor ~3, this operation mode is more vulnerable to discharges. In addition the signal contains a slow ion component, usually not present in GEM detectors, which could be of disadvantage.

3 Ion gating

Electron gating by pulsed field modifications in gas detectors was introduced for event selections in cascaded avalanche chambers [21]; ion gating was introduced for suppressing space-charge effects in time projection chambers (TPCs) [10]. We adopted the method to suppress ion feedback in GPMTs. As ion drift velocities are typically 2-3 orders of magnitude smaller than electron drift velocities, one can use the fast electron signal on the anode to trigger a potential change in the detector while the ions are still close to their production point. The gate is realized by a set of parallel wires, alternatingly interconnected as shown in Fig. 7. In open-gate mode, all wires are kept at the same potential, $V_{Gate}$, and electron and ion transport through the detector is therefore uninterupted. To close the gate, the potentials on the wire sets are changed to $V_{Gate} \pm \Delta V_{Gate}$ respectively. The switching of two wire sets with pulses of equal shape and amplitude but of opposite polarity, considerably reduces the capacitive pick-up on the detector’s readout electrode. Ions drifting towards the closed gate are neutralized on the “negative” wires, preventing any further transport towards the cathode. Fig. 8 shows simulated ion drift lines for the two conditions of open and closed gate.

3 Performed with Garfield software package [22]
Fig. 8. Simulated ion drift lines (starting from the bottom of the pictures) and equi-potential lines (horizontal lines) in the vicinity of the gating electrode. The wires (50μm in diameter, 1 mm apart) are shown as black dots. (a) In open mode (ΔV\text{gate} = 0V) ions can pass through the gating grid, while in (b) closed mode(ΔV\text{gate} = 275V) all ion drift lines end on the gate wires.

The majority of ions is generated in the holes of the last GEM and the spatial extension of the ion cloud is of the order of the GEM thickness. For typical ion drift velocities at atmospheric pressure gases, this corresponds to a spread in the ions arrival time to the gate of ~10μs. The gate has to be closed for at least this time period for each event, which introduces a certain dead-time and imposes a counting rate limit of ~ 10^5 Hz, still high enough for most applications. Larger counting rates may be reached by subdividing the gate and the anode electrode into many independent segments.

The gating performance was tested in two modes, by current measurement and by pulse recording.

3.1 Current mode measurements

The electron transfer through the gate, in “gate-open” mode, the gate wires equally polarized, was measured with a DC UV-lamp in a setup schematically shown in Fig. 9. For a constant electric field E_1, the electron current I_{ mesh } was measured on the mesh as a function of E_2, normalized to I_{ gate } previously measured with a slightly reversed electric field E_2. Fig. 10 shows that the field ratio of E_1/E_2 has to be ≥1.5 in order to satisfy full electron transmission through the open gate electrode. In all further measurement the field conditions were chosen accordingly.

Ion transmission through the gate in its “gate-closed” mode was measured, using the setup depicted in Fig. 11. A DC UV-lamp is directed at the photo-
Fig. 9. Schematic experimental setup for measuring the electron transmission through the gate.

Fig. 10. Electron transmission through open gate ($\Delta V_{Gate} = 0$) as a function of the ratio of $E_1/E_2$, the field below and above the mesh.

cathode and the emitted photoelectrons are multiplied on the anode wires of a MWPC. A fraction of the avalanche-generated ions drift across the top multiwire cathode mesh towards the gate electrode, and across it towards the top cathode mesh. The current induced by this constant ion-flow is measured on the top cathode mesh as a function of the gating voltage $\Delta V_{Gate}$, the voltage offset of the wires from their value at “gate-open” condition.

The ion transmission through the gate depends on the value of $\Delta V_{Gate}$ and on the electric fields ($E_1, E_2$) on both sides of the gate as can be seen in Fig. 12a. But it mainly depends on $\Delta V_{gate}/E_1$, as seen from Fig. 12b. An ion backflow suppression of $10^4$ is demonstrated.
3.2 Pulse mode measurement

Observation of ion-induced secondary pulses (ion feedback pulses) is required for fully evaluating the effectiveness of the ion gating in pulsed mode. They could not be observed under normal atmospheric conditions with CsI photocathodes in GEM-based GPMTs; but a low pressure operation (e.g. 40Torr of Ar/CH\(_4\) (95:5)) results in an increased ion drift velocity, leading to apparent ion feedback [4]. Moreover, under optimized operation of the detector with a reflective photocathode deposited on a GEM, the field at the photocathode surface is rather high (~20kV/cm close to the GEM holes), resulting in energetic ions impinging on the photocathode and inducing feedback electrons. We used a setup comprising a GEM with reflective CsI photocathode followed by a MWPC (see Fig. 13); it is a simple double-stage device, operating stably at high gains. Electrons emitted from the photocathode under pulsed UV-lamp illumination, are multiplied in the GEM apertures and further at the MWPC. The majority of the ions are produced close to the anode wires; they drift upwards through the gate, into the GEM holes and acquire high kinetic energy in the strong electric field at the vicinity of the photocathode. A fraction of the back-flowing ions induce secondary electrons; they yield, after multiplication in the detector stages, secondary after-pulses on the MWPC anode, as shown in Fig. 14a for an “gate-open” condition. Additional secondary pulses follow the first one, due to a repeated feedback process; their delay reflects the ion drift time from the MWPC wires to the photocathode. Under such intensive feedback effect, a higher gain would lead to a diverging total charge and to a discharge.

Fig. 14b and 14c show anode pulses for two \(\Delta V_{\text{Gate}}\) values; a full suppression of ion feedback pulses is very clear in Fig. 14c, for \(\Delta V_{\text{Gate}}=80\) V. In Fig. 15 we show the ion feedback suppression in pulse mode as a function of \(\Delta V_{\text{Gate}}\). It is defined as the ratio of the pulse height of the first after-pulse to the
primary pulse. One observes the same behavior as in the DC mode measurements described above (Fig. 12), namely a very fast drop of the feedback with increasing $\Delta V_{\text{Gate}}$. A direct comparison between the two is not possible as the conditions (pressure, electric fields) were different; moreover in the pulse mode measurement the ion-feedback is also reduced, as the secondary electrons are also stopped by the gate and do not reach the MWPC.
3.3 Gated 4-GEM operation

We operated a 4 GEM detector, incorporating the ion-gating electrode described above. As only ions produced below the gate are stopped, it would be best placed between GEM1 and GEM1. Due a limit in DC voltage the high
Fig. 15. The ion feedback suppression as a function of $\Delta V_{\text{Gate}}$ in pulse mode. For $\Delta V_{\text{Gate}} = 80$V no secondary pulses were observed.

Voltage pulser used by us could supply to the gating electrodes, the gate was placed between GEM3 and GEM4 instead (Fig. 7). The detector was operated at 100 Torr of CH$_4$, in order to initiate ion-feedback effects on the CsI photocathode (see sec. 3.2). The pulsed H$_2$ lamp induced $\sim 1000$ photoelectrons per light-pulse impinging on the photocathode. These were further multiplied in the four successive GEM stages. At a total gain of $> 10^5$ the detector electronics is sensitive to single-photo-electrons and ion-induced SEE was observed as a series of feedback single electron pulses spread over a time window of $\sim 10\mu$s and appearing $\sim 45\mu$s after the original pulse (Fig. 16). At this relatively low pressure the avalanche is no longer confined in the GEM holes but extends out of the holes; this explains the time spread of the ion-induced pulses observed in Fig. 16. The delay of $\sim 45\mu$s in the appearance of the secondary pulses is in good agreement with their drift time from GEM4 to the photocathode, estimated to be $40\mu$s.

Using a digital oscilloscope, a dedicated data acquisition system and analyzing software, we measured the average number of feedback-induced after-pulses within a $10\mu$s long time window, $45\mu$s after the appearance of the main pulse, as a function of the gating voltage, $\Delta V_{\text{Gate}}$. The ion feedback (defined as the average number of feedback pulses over threshold, divided by the same number at $\Delta V_{\text{Gate}} = 0$) is plotted in Fig. 17. The suppression of ion feedback is caused by a reduced ion back-flow and by the non-transparency of the gate to ion-induced secondary electrons. A direct comparison of this result with the previous ones is not possible due to the different transfer fields and gas pressures used. Nevertheless one recognizes the fast drop of the ion feedback with the gating voltage $\Delta V_{\text{Gate}}$ already noted in Fig. 15 and in Fig. 12 measured in current.
Fig. 16. A single-event pulse recorded on the 4-GEM anode, induced by a multiple photon burst hitting the photocathode of the detector shown in Fig. 7. Four ion-induced feedback pulses are clearly seen \( \sim 40\mu s \) after the primary pulse. The primary pulse is not shown in full height. Time scale: 10\( \mu \)s/div.

Fig. 17. The relative ion feedback as a function of \( \Delta V_{Gate} \) in pulse mode in a 4-GEM detector operated at 100Torr CH\(_4\) with transfer fields of 0.5kV/cm and equal GEM voltages of 260V.

At a voltage of 80V these after-pulses were \( 10^4 \) times less frequent than with an “open” gate. Higher ion suppression factors could not be measured in this work due to statistical limits of our measuring system.
Ion back-flow has been investigated in a 4-GEM gaseous photomultiplier with a reflective photocathode deposited on the first GEM. Attempts were made to minimize it by varying different electric fields within the cascaded multiplier, namely the transfer field, the induction field and the potential across the GEM. Our results clearly indicate, that the ion back-flow could be reduced at best to a 10% level, in a DC operation mode. The relatively high back-flow is due to an efficient ion collection at the photocathode surface; it is caused by the high surface electric fields, required to assure high photoelectron emission conditions (low backscattering on gas molecules). Furthermore as ions follow the same electric field lines as the electrons, it is hardly possible to reduce the ion back-flow in a DC mode without severely changing the electron transport in the detector. The only exception to this, as noted, is if one can allow for very low drift fields above the first GEM, resulting in collection of a large fraction of back-drifting ions on the top electrode of the first GEM stage. This could be applicable in GEM-based particle trackers, other radiation imaging detectors and TPCs.

As recently demonstrated, the ion back-flow in multi-GEM detectors could be further reduced, by incorporating a Micro Hole and Strip Plate (MHSP) element [23] as the last amplification stage in the cascade. In such a configuration, part of the avalanche ions are collected on neighbouring electrodes, resulting in an ion back-flow reduction in a DC mode down to a level of ~2% [24].

We have shown in this work, that the ion back-flow could be reduced by four orders of magnitude with active ion gating. This was reached by incorporating a pulsed gating electrode with alternatingly polarized wires. Higher suppression factors are expected at higher gating voltages but these could not be measured due to limitations in our experimental setup. Nevertheless the demonstrated ion back-flow levels are sufficient for most applications. The gating will slightly affect the rate capability of the detector due to the dead-time caused by a closed gate; however segmented anode and gate electrodes would reduce this problem. Further measurements in multi-GEM GPMTs with visible-sensitive photocathodes, incorporating gating electrodes, are foreseen in the near future. As recently demonstrated, the ion feedback in these conditions is more critical, due to the lower electron emission threshold of bi-alkali photocathodes [9].

The effects of the gas mixture on the probability for ion induced feedback is also under intensive investigations [25]. First results, in GPMTs combining GEMS with bi-alkali photocathodes, indicate that the maximum attainable gain before ion feedback onset can vary by at least two orders of magnitude.
by a proper choice of the gas mixture.

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