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Detection of single photons with hybrid ThickGEM-based counters

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Architectures based on multiple layers of thick gas electron multipliers offer an answer to the quest for novel gaseous counters with single photon detection capability able to overcome all the limitations of the present generation of gaseous photon detectors. A systematic R&D programme has been performed to achieve a deep understanding of the characteristics of these multipliers and to optimize their parameters in view of the photon detection application. Recently a new hybrid approach has been considered: an architecture where the last multiplication stage is obtained by using a MICROMEGAS structure.

The characteristics of the hybrid detector are discussed and preliminary results obtained with a first prototype are reported.

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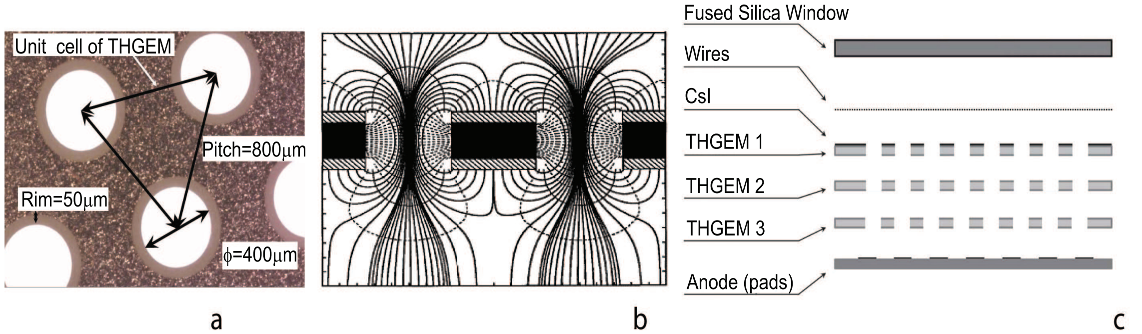

Figure 1: a: Image of a THGEM detector; the main geometrical parameters namely the holes diameter, the pitch and the rim are indicated. b: Field lines obtained by a calculation exercise. c: Sketch of a triple THGEM photon detector arrangement (not to scale).

1. Introduction

We have performed an intensive R&D activity programme dedicated to the development of a new generation of advanced imaging Cherenkov detectors. Our goal is the upgrade of the gas photon detector system of the RICH-1 counter[1] of the COMPASS experiment[2] at CERN SPS. A parallel development [3] is ongoing for the future VHMPID of the ALICE experiment at CERN LHC. The requirements imposed by these experiments include high sensitivity to single photoelectron usually in a harsh ionizing-radiation background environment, operation in magnetic field, as well as the possibility of covering large detection areas at affordable production cost.
Photon detectors based on THick Gas Electron Multipliers (THGEM)represent an answer to this quest, provided the right choice of the geometrical parameters and the production techniques.
THGEM electrodes, introduced in parallel by several groups[4] are robust electron multipliers, characterized by high gain. These devices are built by standard PCB techniques, namely by industrial drilling and chemical etching processes and standard PCB materials are used. The thickness of the fibreglass material, the hole diameter, the holes pitch and the rim size (Fig. 1 a) are the main mechanical parameters characterising the electron multiplier.
The working principle is similar to GEM[5] one: the dipole field obtained conveniently biasing the two electrodes, namely the two THGEM faces (Fig. 1 b) is, inside each hole, large enough to start a multiplication process whenever an electron enters the hole. Electrons transportation into and out of the holes is obtained by suitably electric fields. The use of stacked THGEM architectures, namely detectors with multiple multiplication stages, results in an important increase of the total gain. A THGEM-based photon detector usually consists in a structure of triple THGEM layers (Fig. 1 c), where the first one, coated with a CsI film, acts as reflective photo-cathode[6]. The electric field between the drift wires and the top face of the first THGEM (the photo-cathode), between two THGEM layers and between the third THGEM bottom face and the read out anode are indicated as drift field, transfer field and induction field respectively.

A four-year long systematic R&D programme [7] has been performed to achieve a deep understanding of the THGEM characteristics and to optimise their parameters in view of photon detection applications by studying more than 50 THGEMs 30 mm $\times$ 30 mm wide, where different geometrical parameters and production techniques have been selected. The laboratory activity has been complemented computing the electrostatic field configurations by finite element method software tools[1]. Prototypes of optimised photon detectors have being built and tested and they have provided positive results.

Recently we have obtained very promising results by coupling THGEM multiplication stages to a MICROMEGAS stage (Fig. 2). MICROMEGAS [8] consists in an ionization stage, often called drift gap, followed by a parallel plate avalanche chamber with a very narrow amplification gap (typically of about 100 μm) defined by the anode plane, where the signals are collected, and by a micromesh plane separating the drift and amplification gap. The parallelism between the micromesh grid and the anode is guaranteed by spacers of 150 μm diameter, placed every 2 mm. They are etched on a thin epoxy substrate by conventional lithography of a photosensitive film. The thickness of the film defines the amplification gap. Large detectors with excellent uniformity and energy resolution over the whole surface have been obtained.

A gas photon detector with hybrid architecture, namely a single or double THGEM layer followed by a MICROMEGAS presents several advantages. In fact, a new generation of gaseous photon detectors must match four basic requirements. Reduced photon back-flow and Ion Back Flow (IBF) rates are needed in order to overcome ageing. Good signal to background ratio and good stability of the detector gain are required in order that the electronic threshold does not result in a critical issue. Intrinsically fast signal generation is a prerequisite to obtain detectors adequate for even extremely high rate environments. A major request is the possibility to have good effective quantum efficiency on the whole reflective photo-cathode surface of the device. The combined use of a THGEM stage and a MICROMEGAS paves the way towards the realization of a stable and reliable detector satisfying all these requirements.

In the followings the key aspects of the hybrid detector are discussed and preliminary results are presented.

2. The hybrid detector

2.1 Ion Back Flow

In this article, we define the IBF rate as the fraction of the ions created in the avalanche process that flow back and are collected at the photocathode, where their bombardment causes the photocathode ageing and induce secondary photon emission resulting in feedback pulses that limit the detector performance.

The IBF rate in triple THGEM arrangements can be made smaller than 5% by staggering the alignment of the holes of the three layers and at the price of using very high transfer field between the second and third layer [9].

An interesting property of the MICROMEGAS is represented by the electric field shape close to the micromesh. The electric field is homogeneous in both the amplification and the conversion gaps and exhibits a funnel like shape around the openings of the micromesh separating the two regions: when the values of the electric field in the two gaps is very different, the field lines originating in the drift region are highly compressed towards the middle of the micromesh openings and mostly

[1]COMSOL Multiphysics package

continue in the amplification region; the large majority of the field lines of the amplification region, where the line density is largely higher, end at the micromesh electrode. Both the compression of the drift field lines in the hole and the large fraction of the amplification field lines ending at the micromesh depend on the ratio of the fields between the two MICROMEGAS gaps $\xi = E_{Mult}/E_{Drift}$. When ξ is large enough, the electrons present in the drift volume are efficiently focused into the openings of the micromesh and enter the multiplication volume, while the ions generated in the avalanche process are quickly collected at the micromesh. A value of the parameter $\xi > 20$ allows for full electron transparency and nearly 100% ion collection.
In a hybrid photon detector, the two different processes namely the photon conversion and the multiplication can be separated: the THGEM, acting also as support of the photoconverting layer, is optimised to guarantee the maximum photoelectron extraction and collection efficiency, providing also a moderate pre-amplification stage, while the MICROMEGAS acts as multiplier for which the IBF is naturally suppressed. The photon feedback is suppressed thanks to the closed geometry of the THGEM layer.

2.2 Gain issues

The highest gain at which a detector exhibits stable performance is a key issue for a large number of applications: large gains ensure good detection efficiency and less demanding requirements for the read-out electronic system. In particular, when single photons are detected in a gas counter, namely the multiplication chain starts from a single photoelectron, the amplitude spectrum of the signals is almost always exponential: necessarily, the electronic threshold cuts part of it. At high gain, the lost portion can be kept low; when the gain is uniform and stable, the detection efficiency is, correspondingly, uniform and stable.
MICROMEGAS has been tested with a large variety of gas mixtures and gains as high as 10^5 have been obtained. Unfortunately, they are accompanied by high levels of discharge probabilities: in practice, for the applications in experiments, the gains are limited to about 10^4.
Like MICROMEGAS, THGEMs can provide very high gains, larger than 10^4 in a single-THGEM configuration when single photoelectrons are detected. Larger gains up to $\approx 10^6$, can be achieved using multiple THGEM stages; nevertheless, the space charge issue forces to operate these detector at lower gain values ($\approx 10^5$) when a spark free regime is required.
In a hybrid detector, the gain limitations illustrated above can be overcome: the photoelectron undergoes in the THGEM a preamplification (of the order of ≈ 100) and the resulting electrons are then drifted towards the MICROMEGAS amplification region. Thanks to the shape of the THGEM dipole field outside the hole region (Fig. 1 b) combined with the electron diffusion, the electrons are distributed over a volume large enough to trigger different avalanches in the MICROMEGAS. When the anode read-out elements are large enough, the charge from a multiple avalanche is detected as a unique signal, allowing to reach larger effective gain values, without entering the discharge regime. This possibility provides extremely good single photoelectron sensitivity.
Both THGEM-based detectors and MICROMEGAS provide fast signal generation and can stand high rate particle fluxes: it is expected that the hybrid detector presents similar performance.
Another interesting aspect of the hybrid structure is the reduced HV values to be applied: assuming the use of an Ar-CH_4 mixture with a CH_4 content of the order of 40% (Subsec. 2.3), a total ΔV

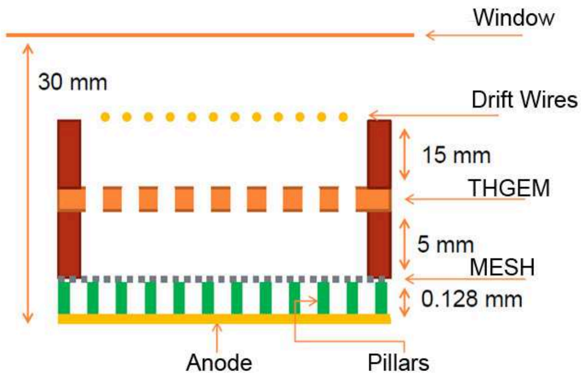

Figure 2: Scheme of a hybrid detector (not to scale). The geometrical parameters refer to the detector used to obtain the results presented in sec. 3

of about 4 kV is required, to be compared to the about 8 kV needed in a triple THGEM-based detector. The requirements for insulation issues, HV power supply procurement and operation, and the protection against discharges of the front-end electronics can be relaxed.

2.3 Photoconversion issues

The photoconversion is provided by the CsI film present at the top face of the THGEM and good photoelectron extraction fully depends on the THGEM geometrical and operational parameters as well as by the choice of the detector atmosphere. We have studied these issues for the development of THGEM-based photon detectors [7] by laboratory exercises and electrostatic calculations and, here, we recall the main features.

Good photoelectron extraction depends on the gas and the electric field at the photoconverter surface. The best extraction is obtained in methane atmospheres; the same effective extraction is ensured by Ar-CH_4 mixtures with methane fraction larger than 30%. The electric field at the photocathode surface, orthogonal to the THGEM surface E_z, generated by the dipole field due to the bias applied to the THGEM, must be large enough to ensure an effective photo-electron extraction: this requirements imposes $E_z > 500$ V/cm to obtain an effective extraction efficiency $> 85\%$.

Electrostatic calculations indicate that, for a given bias voltage, E_z increases when the ratio r of the hole diameter and the hole pitch is large. At the same time, when r is large, the fraction of the THGEM surface that can be coated is reduced; for r = 0.5, this faction is 78%. The two competing requests dictate a strong constrain on the ratio value and suggest to adopt geometries with r = 0.5.

The electrostatic calculations also show that, when r = 0.5 is imposed, the average E_z component increses decreasing the THGEM thickness, i.e. allowing the dipole field of the THGEM hole to extend more outside the hole. These results points towards the use of a thin THGEM as first detector stage: our choice is $\approx$0.4 mm.

The transfer field below the THGEM must be chosen so to guarantee good transfer efficiency of the electrons from the THGEM to the following multiplying stage: values of $\approx$ 1.5 kV/cm are required. As a consequence, to obtain $\xi \approx 20$, the field required in the MICROMEGAS multiplication stage is $\approx$30 kV/cm.

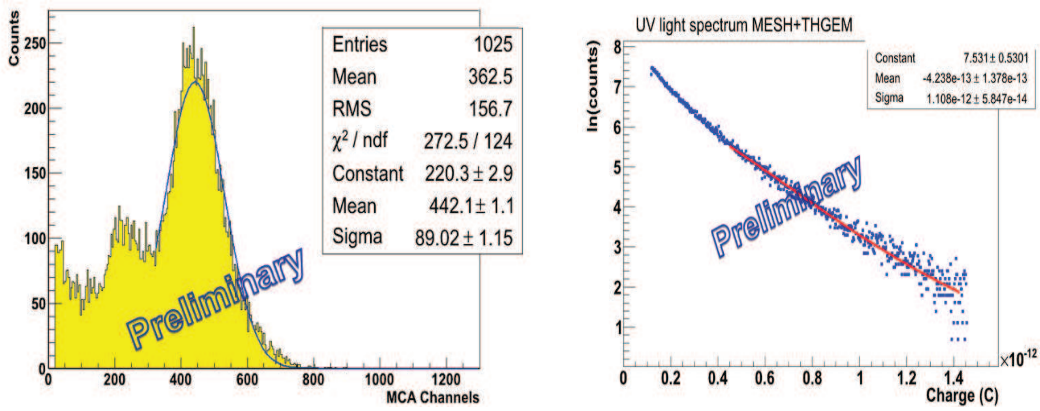

Figure 3: Amplitude spectra obtained with the hybrid detector prototype. Left: using the ^{55}Fe source; estimated gain: $2.5{\cdot}10^5$. Right: illuminating in single photon detection mode; estimated gain: $\approx 1.2 \cdot 10^6$

3. Preliminary results

The hybrid structure (Fig. 2) makes use of a Bulk MICROMEGAS[10][2] with the following characteristics: micromesh-anode distance is 128 μm, the space diameter and pitch is 300 μm and 2 mm respectively. The micromesh is a stainless steel grid of 18 μm diameter woven wires separated by a distance of $\approx 80\mu$m. 5 mm separate the mesh from the bottom layer of the THGEM, characterised by 0.4 mm holes, 0.8 mm pitch and 0.6 mm thickness and no rim. In this preliminary test the THGEM thickness as well as the distance to the MICROMEGAS are not optimized. The wires of the drift plane placed above the THGEM, which are needed to define the electric field in the space above the multiplier, have 100 μm diameter and to 2 mm pitch; the plane is at a distance of 15 mm from the top THGEM layer. The test is performed using Ar/CO_2 (70/30%) and detecting either ionizing particles using an ^{55}Fe source or single photons provided by a pulsed UV LED with 245 nm wavelength. The signals are processed by a read-out chain composed by a CREMAT[3] CR110 preamplifier, an Ortec[4] 672 amplifier and an MCA8000A digitizer by Amptek[5]. The drift field applied is adjusted according to the source type, as specified in the following.

Before assembling the hybrid detector, the MICROMEGAS detector has been characterised to evaluate its response in terms of energy resolution and gain as function of the voltages applied and of the parameter ξ. These measurements, compared with the results obtained with the hybrid detector, allow to check that the MICROMEGAS detector performance is preserved also in presence of the THGEM layer.

Fig. 3 left shows the spectrum collected using the hybrid detector exposed to the ^{55}Fe source. The voltage applied to the mesh electrode is V_{mesh} = 625 V, the transfer field is E_{trans} = 450 V/cm, the bias voltage across the THGEM layers is ΔV = 1550 V, the drift field is E_{drift} = 650 V/cm. The corresponding gain is estimated to be $2.5{\cdot}10^5$. Detecting the photons from the UV LED and

[2]Courtesy of the CEA Saclay COMPASS group
[3]Cremat, Inc., Watertown, Massachusset, USA
[4]ORTEC Advanced Measurement Technology, Inc, Oak Ridge, Tennessee, USA
[5]Amptek Inc., Bedford, Massachusset, USA

biasing the electrodes to obtain the following conditions: E_{drift} = 0 V/cm, $E_{mesh} \approx$ 30 kV/cm, E_{trans} = 1.2 V/cm, ΔV = 1575 V, it is possible to achieve a stable gain of $\approx 1.2 \cdot 10^6$ in single photo-electron mode (Fig. 3 right).
It was possible to estimate the IBF rate, by inserting picoammeters in the supply lines to all the detector electrodes. The measured value is 4%, confirming that the ions are mostly trapped at the mesh.
It is clear from these preliminary results that the hybrid detector is very promising exhibiting extremely good performance in terms of achievable gain and IBF values. Further tests need to confirm the results, to optimize the parameters, to check the long term operation as well as the behaviour of larger-size detectors.

4. Aknowledgements

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