Micropattern Gaseous Photon Detectors for Cherenkov Imaging Counters

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***Abstract*–RICH counters for PID in the high momentum domain and in large acceptance experiments require photon detectors covering extended surface of several square meters and able to accept Cherenkov photons in a wide angular range. An ideal approach is represented by gaseous photon detectors, which allow covering wide surfaces at affordable costs.**

Novel gaseous photon detectors using closed geometry, as those possible with multistage arrangements of micropattern gaseous detectors, can overcome the limitations observed in present gaseous photon detectors with solid CsI photocathode, which are due to the ion bombardment of the photocathode.

We have started an R&D programme to develop a Thick GEM-based photon detector and we report about the status of this project.

I. -INTRODUCTION

So far, the photon detectors used in Ring Imaging CHerenkov (RICH) counters are vacuum-based ones, namely photomultiplier tubes, in standard or hybrid version, or gaseous detectors coupled to photon converters. The latter ones allow to cover wide surfaces at affordable costs and, thanks to their reduced material budget, they can be placed in the apparatus acceptance region.

For the first generation of these detectors photoconverting vapours were added to the detector gas mixtures. These photon detectors have given a key contribution in establishing RICH counters as solid, reliable tools for physics experiments,
as tested by the RICH detectors of E605 [1], DELPHI [2], OMEGA [3] and SLD [4]. The use of photoconverting vapours results in specific requirements to the experimental devices. When TMAE (Tetrakis Dimethylamine Ethylene) is used at room temperature long conversion regions are needed; alternatively, heated photon detectors can be adopted, in which the gaseous detectors with TMAE are kept at 40 ^{0}C or higher temperature to increase the vapour content of the gas mixture. Photons in the very far UV domain, below 165 nm, can be converted with TEA (Triethylamine). These features represent clear limitations and photoconverting vapours are being progressively abandoned. Presently, the Cleo III RICH [5] is the only imaging Cherenkov counter in operation making use of photoconverting vapours.

The first gaseous photon detector with a solid state photoconveter has been developed within the RD26 research programme [6]: it is a MWPC where a cathode plane is formed by a PCB segmented in pads and coated with a CsI layer. These photon detectors have been selected in several experiments: NA44 [7], HADES [8], COMPASS [9], STAR [10], JLab-HallA [11], ALICE [12]. In spite of the remarkable success of proving that solid state photoconverters can operate in gaseous atmospheres, MWPCs with CsI photocathodes suffer because of some performance limitations. Aging, resulting in a sever decrease of the quantum efficiency, is reported after a collected charge of the order of some mC/cm^2 [13]. The presence of the CsI layer causes electrical instabilities of the MWPCs accompanied by long recovery time (about 1 d) [9]: the detectors must be operated at low gain, limiting the single photoelectron detection efficiency. Both these features are related to the bombardment of the CsI layer by the positive ions generated in the multiplication process: they flow back to the photocathode elements.

New developments in the field of photon gaseous detectors must result in detectors where the photocathode ion

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bombardment is reduced. Gaseous detector architectures developed more recently look promising under this respect: when a multilayer structure of electron multipliers is used, a good fraction of the ions is trapped in the intermediate layers and do not reach the photocathode.
The threshold Cherenkov counter Hadron Blind Detector (HBD) [14] of the Phenix experiment represent the first application of these ideas: the photon detectors are triple GEM counters operated at low gain (about 5000). For imaging counters, where the effective detection of single photons is required, larger gains are needed.

We are developing a large gain gaseous photon detector characterized by a closed geometry architecture and based on the use of THick GEM (THGEM) electron multipliers. We report about the status of this R&D project.

II. THE THGEM ELECTRON MULTIPLIER

THGEMs [15], [16] are electron multipliers derived from the GEM design, scaling the geometrical parameters and changing the production technology. The Cu-coated kapton foil of the GEM multipliers is replaced by standard PCBs and the holes are produced by drilling. The conical shape of the GEM holes that forms uncoated polyamide rings around the holes themselves are replaced by a clearance ring, the rim, surrounding the hole and obtained by Cu etching. Typical values of the geometrical parameters are PCB thickness of 0.4-1 mm, hole diameter ranging between 0.3 and 1 mm, hole pitch of 0.7-1.2 mm and rim width between 0 and 0.1 mm (Fig.1). Large gains have been reported for detectors with single or double THGEM layers, as well as good rate capabilities [15].

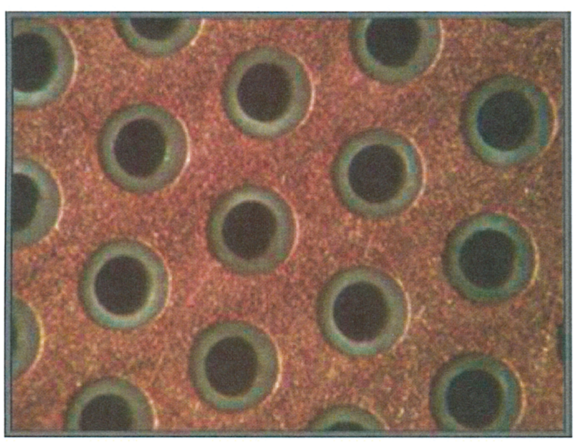


Fig. 1. Detail of a THGEM PCB.

It is expected that THGEMs can be produced in large series and large size with standard PCB technology, in spite of the requirement for a large number of holes: some millions per square meter. THGEMs have intrinsic mechanical stiffness, and they are robust against damages produced by electrical discharges. Due to the technology used, the material budget of THGEM-based detectors is not particularly reduced and they cannot offer space resolution as pushed as GEM-based detectors.

The features of THGEM-based detectors, shortly mentioned above, match very well the requirements of photon detectors for Cherenkov imaging applications; the large gain, the robustness, the production technique and the mechanical characteristics are advantages, while the material budget and resolution aspects do not represent a limit. Moreover, thanks to the reduced gaps between the multiplication stages, these detectors can be successfully used in magnetic field.

The basic architecture of a THGEM-based photon detector consists in double or triple THGEM layers, where the first layer is coated with a CsI film and acts as a reflective photocathode. This configuration is preferred to architectures with semitransparent photocathode, as it results in a larger photoconversion rate. In fact, a semitransparent photocathode requires the application of a thin metallic film, which absorbs photons, to keep the entrance window at a fix potential; also the probability of photoelectron absorption is lower in a reflective photocathode than in a semitransparent one as the conversion probability is the highest at the entrance surface of the photoconveter.

It is worthwhile to mention other fields, where the THGEM-based detectors can be envisaged: they can be used as the active elements in hadron sampling calorimetry and muon tracking; in these applications, large surfaces have to be instrumented, while space resolution in the mm range is fully adequate.

III. THGEM CHARACTERIZATION

The first phase of our R&D activity has been dedicated to understanding the role of the various geometrical parameters of the THGEM multipliers. The study has been performed via the characterization of about 30 THGEM prototypes, inserted in single layer detectors and tested using X-ray sources. A voltage ΔV is applied between the two THGEM faces. An electric field E_{drift} is established in the region above the so-called top THGEM face (lower potential), in order to focus the ionization electrons through the THGEM holes. It is obtained applying a potential lower than the one at the top THGEM face to a plane electrode parallel to the THGEM itself. An electric field $E_{induction}$ is applied in the region below the so-called bottom THGEM face (higher potential) to guide part of the electrons created in the multiplication process to the anode electrode, namely a conductive plane surface parallel to the THGEM PCB. In our investigation we collect the amplitude spectra of the anode signals and we measure the currents absorbed by all the electrodes (cathode, THGEM top, THGEM bottom and anode). To perform the latter exercise, we have designed and built cheap and low consumption current meters with about 1pA resolution, powered via batteries in order to operate at high voltage. The measurement protocols include the optimisation versus gain of the E_{drift} and

$E_{induction}$ values and the long term (days) measurements of the detector gain stability. Gain versus rate has also been measured for a subset of the THGEMs characterized. All the results reported below have been obtained with a gas mixture of Ar : CO_2 = 70 : 30.

The most relevant results are summarized in Figs. 2 to 5. The gain stability in time strongly depends on the rim size. Gain variations ≤ 20% are observed when the rim is absent, while huge variations are clearly observed when the rim is large (Fig. 2). These variations depend on the irradiation rate when the detector is powered. In Fig. 3(a) the short time gain variations of a THGEM with large rim are presented for two extreme cases: irradiating for a few minutes after the THGEM has been kept for 10 hours at nominal voltage without irradiation, and irradiating for a few minutes at voltage switch-on after 1 day with no voltage. Large variations in the measured gain and totally different behaviors are observed. On the contrary, for a THGEM with no rim (Fig. 3(b)) the same measurements show that the gain has almost no dependence on the previous ΔV and irradiation history. This behavior is interpreted as caused by the displacement of charges in the PCB fiberglass plate when the high voltage is applied. This phenomenon is slow (it takes h or d) and the resulting charge distribution is not screened in the rim region. When the detector is irradiated, the effective field due to this charge distribution is partially screened by the accumulation of charged particles (ions or electrons) on the free dielectric surface. The different irradiation rate thus results in different charge distribution and, consequently, in different detector gain. The huge gain variation and its dependence on the irradiation history clearly indicate that the use of large rim THGEMs must be avoided, at least for all those application that require stable detector gain.

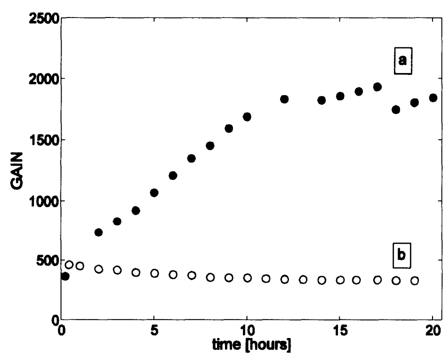


Fig. 2. Gain behavior versus time for two THGEMs with the following geometry: thickness 0.4 mm, pitch 0.8 mm and hole diameter 0.4 mm (common parameters); different parameter: 0.1 mm rim for (a), no rim for (b). Continuous detector irradiation; ΔV: 1750 V for (a) and 1330 V for (b).

In Fig. 4, the maximum gain that can be obtained varying the THGEM geometrical parameters is reported. The gain increases with the rim size and with the PCB thickness. The gain variation versus other geometrical parameters is illustrated in Fig. 5. The pitch has limited influence on the gain, while the hole diameter plays a major role and, at fixed voltage, larger gain is observed using smaller diameters.

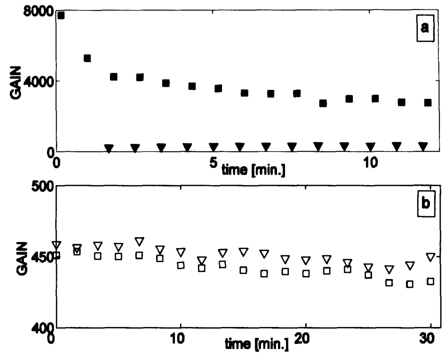
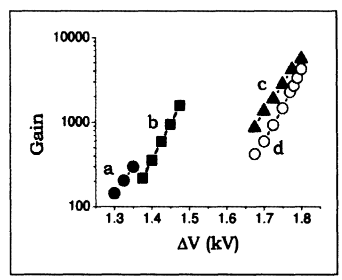


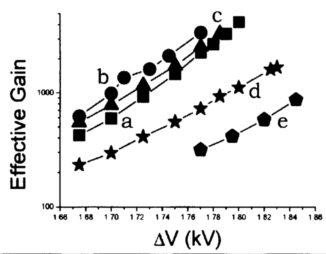
Fig. 3. Gain versus time for the THGEMs (a) and (b) described in 2. Full (empty) square points represent the gain measured irradiating the THGEM with large (no) rim after it has been for 10 h at nominal voltage without irradiation. Full (empty) triangle points represent the gain measured irradiating the THGEM with large (no) rim immediately after switching on the high voltage, after it has been switched off for 1 day.



THGEM	Diameter (mm)	Pitch (mm)	Rim (mm)	Thick (mm)
a	0.3	0.7	0	0.4
b	0.3	0.7	0.01	0.4
c	0.3	0.7	0.1	0.4
d	0.3	0.7	0	0.6

Fig. 4. Gain versus applied ΔV obtained with THGEMs of different geometry: rim width and thickness.

No rate dependence of the gain up to rates of at least 100 kHz/mm^2 has been observed for THGEM without rim (Fig. 6), while gain variations versus rate are detected when a large rim is present.



THGEM	Diameter (mm)	Pitch (mm)	Rim (mm)	Thick (mm)
a	0.3	0.7	0	0.6
b	0.3	0.6	0	0 6
c	0.3	0.5	0	0.6
d	0.4	0.7	0	0.6
e	0.5	0.7	0	0.6

Fig. 5. Gain versus applied ΔV obtained with THGEMs of different geometry: hole diameter and hole pitch.

IV. THGEM PRODUCTION ASPECTS

We have tested THGEMs produced with 5 different procedures and several different rim width up to 100 μm, including samples with no rim.

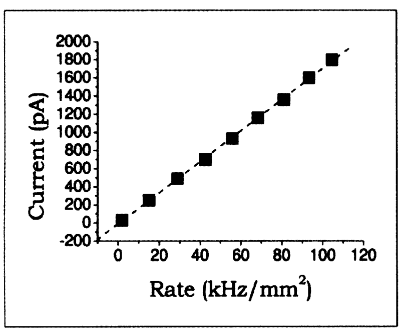


Fig. 6. Anode current versus X-ray rate for a THGEM with the following geometry: thickness 0.4 mm, pitch 0.8 mm. hole diameter 0.3 mm, no rim.

In the procedure elaborated by the Weizmann group [17], the rim is formed with standard PCB lithographic image transfer and etching techniques before drilling; this approach can result in off-centered rims. R. de Olivera, at CERN, [18] has proposed a production techniques without image transfer: a photoresistive layer is applied before drilling; after drilling, etching attacks Cu from the unprotected surface created by drilling at the hole edges producing a rim with an uniform width around the whole; the photoresistive layer is then removed (Fig. 7a). More THGEM prototypes have been produced by ELTOS [19] with three alternative techniques. The first one consists in drilling as first step; then, a photoresistive layer is applied and image transfer is performed using the holes as position reference; the rims obtained are well centered (Fig. 7b). The global etching technique proposed by ELTOS is a simplified version of R. de Olivera's procedure: no photoresistive layer is used; after drilling, etching attacks the copper at the hole edges and at the surface; this approach is adequate to produce small rims (about 10 μm or less) (Fig. 7c). When large THGEM have to be produced, the global etching is still possible replacing the standard etching with micro etching techniques. Rims have been obtained also with a pure mechanical process, by a triple drilling procedure: the rim surface is inclined by about 120 degrees respect to the PCB surface (Fig. 7d).

The different THGEM samples have been tested to measure, in nitrogen atmosphere and without radiation sources, the maximum voltage that can be applied between the two PCB faces, before a regime of frequent discharges is observed. As expected, the maximum voltage strongly depends on the rim size and substantially higher voltage can be applied to large rim samples. Comparing samples with the same rim size, a mild dependence of the maximum voltage from the production technique is reported and the samples produced with the global etching procedure give the best results.

A clear advantage of the procedures used to produce rims is the copper hole edge smoothing due to the chemical attack. On the base of this considerations and taking into account our results on the gain stability, for the next steps of our R&D programme, we have chosen THGEM geometries with very small rims (<10 μm).

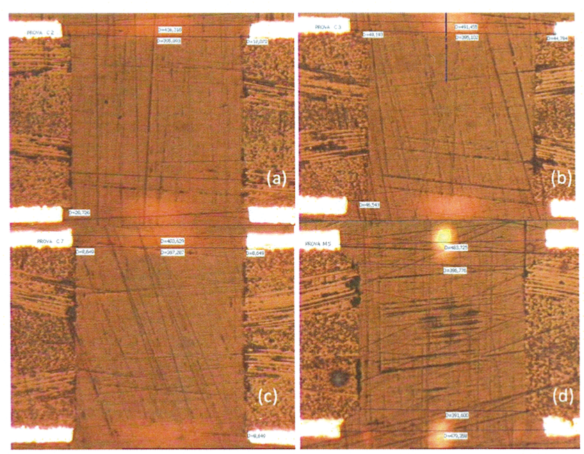


Fig. 7. Metallographic cross-sections of THGEM PCBs produced with different procedures. The details of the different production processes are given in the text.

V. DETECTION OF SINGLE PHOTONS.

We are performing a set of exploratory studies of different aspects specific to the use of THGEM for single photon detection. These studies are meant to familiarize with the issues posed by the use of THGEM electron multipliers for photon detection and to plan the systematic studies to be performed as a following step.

The high gain needed for effective detection of single photons has to be obtained with a THGEM multilayer architecture. Using THGEM prototypes with 0.4 mm hole diameter, 0.8 mm pitch, 0.4 mm thickness and 10 µm rim, we have compared the maximum gain obtained in detecting X-rays using a single, double or triple THGEM configuration: the gains are, respectively, 3000, 20000 and > 50000. One of THGEM prototypes described above has been coated with a CsI layer and mounted in a double THGEM configuration. UV light injected via a fused silica window has been detected. The fit of the exponential amplitude spectrum, illuminating in single photoelectron mode, allows to determine the gain (Fig. 8): gains as large as 60000 have been observed.

A preliminary scheme of the device for photon detection can be derived from the outcomes of the characterization studies and the prototype production by industry. The photon detector is a chamber equipped with three or four layers of THGEM with no or reduced rim to obtain a gain above 10^5, optimizing the stability of the detector response and keeping the ion feed back at a few percent level. The upper layer is coated with a CsI film, to act as a reflective photocathode. The photons enter the chamber via a fused silica window. A PCB segmented into pads with a typical pitch of a few mm collects the signal. A digital read-out system with high sensitive front-end stage and good time resolution is coupled to the detector. The active surface of a single unit can easily be larger than 50 x 50 cm^2 and the dead zone kept below 15% of the surface.

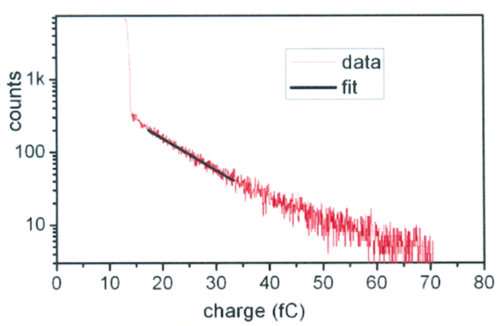


Fig. 8. Amplitude spectrum obtained with a double layer THGEM detector with CsI photocathode illuminating the detector with UV light in single photoelectron mode.

We have design a first prototype of a large surface detector (60 x 60 cm^2) as an exercise to attack the engineering aspects of a large size THGEM-based photon detector. The components have been produced and we are assembling the detector (Fig. 9).

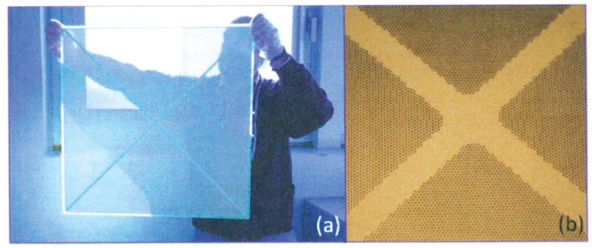


Fig. 9. One of the first prototypes of large size THGEM PCB; the useful surface is 60 x 60 cm2; (a): the whole PCB; (b): detail of the central zone.

VI. Outlook and Conclusions

In view of the development of a large gain gaseous photon detector based on THGEM electron multipliers, we have characterized in a systematic way a large number of THGEMs with different geometrical design and production parameters. We have gained insight in the role of the various geometrical parameters and have selected those geometries, which are promising for our application.

We have started the second phase of our R&D activity, namely to address the specific requests posed by the detection of single photons. Exploratory studies have been performed: they are a preliminary step needed to plan a more systematic investigation.

In parallel, we are studying the engineering aspects of large surface THGEM-based photon detectors and we are assembling a 60 x 60 cm^2 prototype.

The exercises performed so far provide encouraging results and no stopping point for the development of a TGEM-based photon detector has been identified.

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