IL NUOVO CIMENTO Vol. 34 C, N. 6 Novembre-Dicembre 2011
DOI 10.1393/ncc/i2011-11045-2

Colloquia: IFAE 2011

Single-photon detection with THGEM-based counters

S. Levorato(1), M. Alexeev(4), R. Birsa(1), F. Bradamante(2), A. Bressan(2), M. Chiosso(8), P. Ciliberti(2), S. Dalla Torre(1), O. Denisov(9), V. Duic(2), A. Ferrero(11), M. Finger(7), M. Finger Jr(7), H. Fischer(5), M. Giorgi(2), M. Gregori(2), B. Gobbo(1), F. H. Heinsius(5), F. Herrmann(5), K. Königsmann(5), L. Lauser(5), A. Maggiora(9), A. Martin(2), G. Menon(1), A. Mutter(5), F. Nerling(5), K. Novakova(1), D. Panzieri(4), G. Pesaro(2), J. Polak(6), E. Rocco(10), C. Santos(3), G. Sbrizzai(2), P. Schiavon(2), C. Schill(5), S. Schopferer(5), M. Slunecka(7), F. Sozzi(2), L. Steiger(2), M. Sulc(6), S. Takekawa(9), F. Tessarotto(1) and H. Wollny(5)

(1) *INFN, Sezione di Trieste - Trieste, Italy*
(2) *INFN, Sezione di Trieste and Università di Trieste - Trieste, Italy*
(3) *I3N, Physics Department, University of Aveiro - Aveiro, Portugal*
(4) *INFN, Sezione di Torino and Università del Piemonte Orientale - Alessandria, Italy*
(5) *Universität Freiburg, Physikalisches Institut - Freiburg, Germany*
(6) *Technical University of Liberec - Liberec, Czech Republic*
(7) *Charles University - Praga, Czech Republic and JINR - Dubna, Russia*
(8) *INFN, Sezione di Torino and Università di Torino - Torino, Italy*
(9) *INFN, Sezione di Torino - Torino, Italy*
(10) *European Organization for Nuclear Research - Geneve, Switzerland*
(11) *CEA-Saclay, DSM-Irfu-SpHN - 91191 Gif-sur-Yvette, France*

(ricevuto il 29 Luglio 2011; pubblicato online il 29 Novembre 2011)

Summary. — An R&D project was started to develop a gaseous detector of single UV photons, able to stably operate at high gain and high rate, and to provide good time resolution and insensitivity to magnetic field, as required by the next generation of Ring Imaging Cherenkov Counters. The detector is based on the use of a novel and robust electron multiplier, the THGEM, arranged in a multilayer architecture, where the first layer is coated with a photosensitive CsI film. A systematic study of the response of single layer THGEMs with various geometries and different conditions was performed and several small photon detector prototypes have been built, tested in laboratory and operated in test beam exercises during 2009 and 2010 at the CERN H4 beam line. Evidence for the efficient detection of Cherenkov photons has been obtained, with stable operation in the test beam environment; the typical gain was about 10^5 and the time resolution was better than 10 ns.

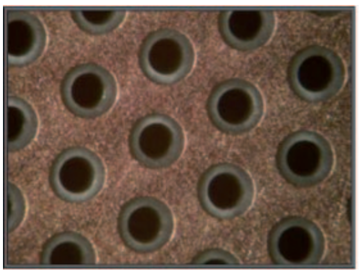
PACS 85.60.Ha – Photomultipliers; phototubes and photocathodes.
PACS 42.79.Pw – Imaging detectors and sensors.
PACS 29.40.Ka – Cherenkov detectors.

1. – The THGEM electron multiplier

THGEMs are electron multipliers derived from the GEM [1-3] 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 mechanical drilling. The rim, a metal-free clearance ring surrounding the hole, is produced by Cu etching (see fig. 1) and corresponds to the uncoated polyamide ring around the GEM holes, due to their conical shape. The THGEM geometrical parameters cover wide ranges; typical values are: PCB thickness from 0.2 mm to 1.2 mm, hole diameter between 0.2 mm and 1.0 mm, hole pitch from 0.4 mm to 1.6 mm and rim width between 0 (no rim) and 0.12 mm. THGEMs can be produced in large series and large size with standard PCB technology, they have intrinsic mechanical stiffness and are robust against damages produced by electrical discharges. On the other hand, due to the technology used, THGEM-based detectors cannot be built with very low material budget and cannot offer as good a space resolution as GEM-based detectors can. THGEMs could be used for various detector applications besides photon detection: as active elements of sampling calorimeters or muon trackers, for instance, and in general when wide areas need to be instrumented and space resolution in the mm range is acceptable. The small gaps between the multiplication stages allow these detectors to be used in the presence of a magnetic field. A THGEM-based photon detector consists in a structure of double or triple THGEM layers, where the first layer is coated with a CsI film and acts as a reflective photocathode.

2. – THGEM characterization

As a first step, a comparison of different THGEM production procedures was performed: a set of many small size (30 mm × 30 mm active area) THGEM samples has been produced using different production methods, various geometrical parameters (thickness, hole diameter and pitch) and different rim widths up to 100 μm, including samples with no rim. 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 sample thickness and on the rim size: substantially higher voltage can be applied to thicker or large rim samples. More than 50 different THGEMs have been characterized using soft X-ray sources and a standard, non-flammable gas mixture (Ar : CO_2 = 70 : 30). The samples to be tested are mounted



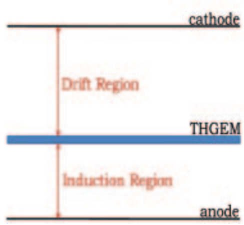
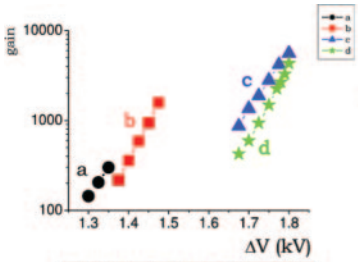
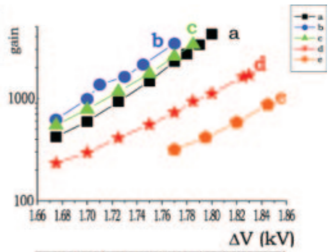


Fig. 1. – Left: Image of a THGEM with holes of 0.3 mm diameter, pitch of 0.7 mm and rim size of 0.1 mm. Right: Scheme of the THGEM test arrangement.



THGEM	Rim [μm]	Thickness [mm]
a	0.0	0.40
b	10.0	0.40
c	100.0	0.40
d	0.0	0.60



THGEM	Diameter [mm]	Pitch [mm]
a	0.3	0.7
b	0.3	0.6
c	0.3	0.5
d	0.4	0.7
e	0.5	0.7

Fig. 2. – Left: Effective gain *versus* applied ΔV for THGEMs with holes of 0.3 mm diameter and 0.7 mm pitch, having different rim widths and thicknesses. Right: Effective gain *versus* applied ΔV for THGEMs with 0.6 mm thickness and no rim, having different hole diameters and pitches.

in single layer mode between two electrodes in the configuration sketched in fig. 1. A multiplication voltage ΔV is applied between the two THGEM faces; an electric field E_{drift} is established in the region above the top THGEM face (lower potential), in order to focus the ionization electrons through the THGEM holes; it is obtained applying to the cathode electrode a potential lower than the one of the top THGEM face. An electric field $E_{induction}$ is applied in the region below the bottom THGEM face (higher potential) to guide part of the electrons created in the multiplication process to the anode electrode. Amplitude spectra of the anode signals are collected and the currents absorbed by each electrode (cathode, THGEM top, THGEM bottom, anode) are measured. The characterization protocol includes a set of measurements in different conditions, to find the optimal configurations of the E_{drift} and $E_{induction}$ fields and the detector response (currents, effective gain and energy resolution) for different multiplication voltages. Long-term (days) measurements of the detector gain stability are performed for each sample. The gain stability in time strongly depends on the rim size [4]: gain variations up to a factor 10 are seen with large rim samples, while gain variations $\leq 20\%$ are observed when the rim is absent.

In fig. 2 on left side, the effective gain as function of the multiplication voltage ΔV is displayed for THGEM samples with different rim and thickness: the maximum stably attainable gain increases with the rim size and with the PCB thickness. Figure 2 (right side) illustrates the dependence of the gain on other geometrical parameters: the hole diameter plays a major role (larger gain is observed using smaller diameters) while the pitch has almost no influence on the effective gain. For a subset of the characterized THGEMs the gain *versus* rate has been measured, too: using soft X-rays (releasing about 300 ion pairs per conversion) no rate dependence of the gain up to rates exceeding 100 kHz/mm^2 has been observed for THGEMs without rim. This characterization exercise clearly indicates that small rim sizes are preferable in order to guarantee stable detector response, in spite of the enhanced gain performance obtained with large rim THGEMs; on the other hand, either thicknesses ≥ 0.5 mm or a rim size $\approx 10\,\mu$m is needed to achieve large gain values.

3. – Photon detector prototypes

Photon detector prototypes, consisting in multi-layer THGEM arrangements with CsI coating on the top of the first THGEM (see fig. 3), have been built and operated in various

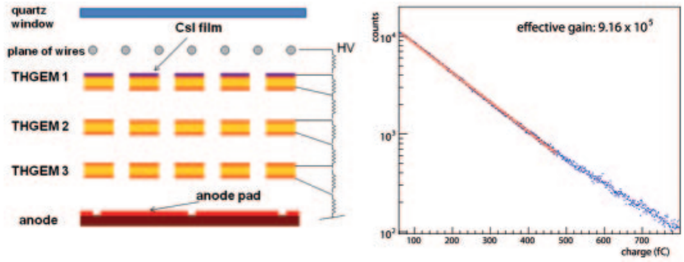


Fig. 3. – Left: Scheme of a THGEM-based photon detector. Right: Single-photoelectron amplitude spectrum measured with the THGEM detector described in the text.

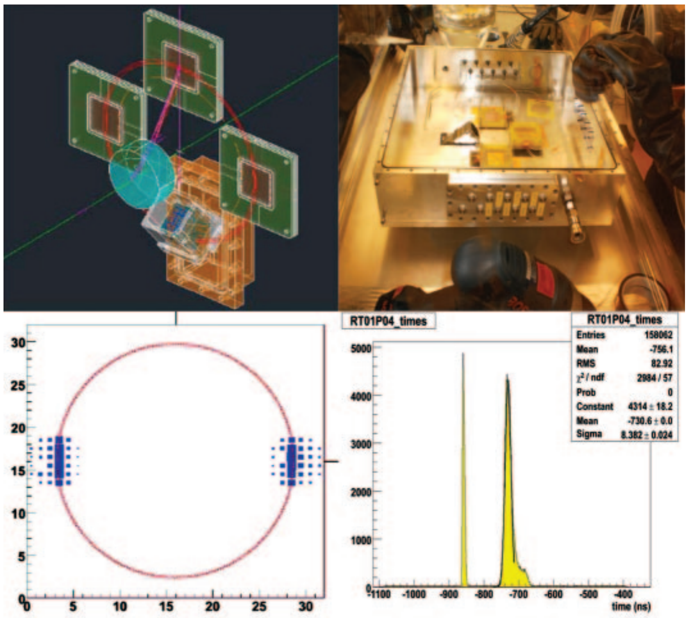


Fig. 4. – Top left: Schematic drawing of the radiator and the test beam chamber structure. Top right: The internal structure of the test chamber during assembly. Bottom left: Superposition of event images; the dotted ring represents the nominal Cherenkov ring. Bottom right: Time distribution of signals from MAPMT and THGEM-based photon detectors.

configurations. The anodic electrode of the detector is a PCB segmented in pads, allowing either analog or digital readout to be mounted on the detector. Several tests have been performed in the laboratory using either a continuous (D_2) UV lamp or a pulsed UV LED source with 600 ps long light pulses([1]), with attenuated light in order to establish the single photoelectron condition. The most extensively used prototype detector consisted in a triple-layer configuration of identical THGEMs having 0.4 mm thickness, 0.8 mm pitch, 0.4 mm hole diameter and 10 μm rim. It was operated with various gas mixtures,

([1]) Obtained powering an UV LED by the PDL 800-B pulsed power supply by PicoQuant GmbH, Berlin, Germany.

including methane-rich argon mixtures. A single-photoelectron spectrum obtained with this prototype detector and a gas mixture of $Ar : CH_4 = 50 : 50$ is shown in fig. 3: effective gains around 10^6 are routinely obtained in laboratory tests. During 2009 and 2010 prototypes of THGEM-based photon detectors, with the geometrical parameters given above, have been operated in a test beam at the CERN H4 beam line, arranged in different configurations. In one of them a fused silica radiator on the beam line was focusing the Cherenkov light produced by beam particles onto a ring illuminating at the same time the central pixels of a MAPMT and of three THGEM-based detectors, inside the same chamber volume (see fig. 3). Special care was put in the manipulation of the CsI coated THGEMS, in order to always avoid exposure to air during transport and installation: the assembling of the detectors was performed inside a glove box with controlled atmosphere (see fig. 3). Stable behavior of the detectors has been observed at gain of $\sim 10^5$ with a $150\,\mathrm{GeV}/c$ π beam rate of 10^3/s and beam $\sigma_x = \sigma_y = 20\,\mathrm{mm}$. The MAPMT and two THGEM-based photon detectors inside the chamber were operated at the same time, using an electronic readout chain based on the MAD-4 front-end chip [5] and the F1 TDC [6], fully described in [7]. In fig. 4 the superposition of collected events is shown: the spatial distribution of the signal and the observed number of detected photons is in agreement with expectation, indicating an efficient detection of the Cherenkov photons. The time distribution of the Cherenkov photons detected by the THGEMs is shown in fig. 4 together with the time distribution of the signals from the MAPMT: a difference in the formation time of 120 ns is seen, in agreement with the expectations from the known drift velocity of electrons in the detector gas mixture. The time resolution of the THGEM-based detector is about 8 ns in the standard configuration, namely without any optimization of the time response.

4. – Conclusion

In view of the development of a THGEM-based photon detector for RICH applications more than 50 THGEMs with different geometrical and production parameters have been characterized in a systematic way. This allowed to gain insight in the role of the geometrical parameters and to identify values which are suited for the envisaged application. Small prototypes of photon detectors have been built and operated in the laboratory at gains close to 10^6. Evidence for efficient detection of Cherenkov photons has been achieved at a test beam, with a measured time resolution better than 10 ns.

REFERENCES

[1] Breskin A. *et al.*, *Nucl. Instrum. Methods A*, **598** (2009) 107, and references therein.
[2] Bidault J. M. *et al.*, *Nucl. Phys. B*, **158** (2006) 199.
[3] Sauli F., *Nucl. Instrum. Methods A*, **386** (1997) 531.
[4] Alexeev M. *et al.*, *Nucl. Instrum. Methods A*, **610** (2009) 174.
[5] Gonnela F. and Pegoraro M., CERN-LHCC-2001-034, p. 204.
[6] Fischer H. *et al.*, *Nucl. Instrum. Methods A*, **461** (2001) 507.
[7] Abbon P. *et al.*, *Nucl. Instrum. Methods A*, **587** (2008) 371.