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Detection of single photons with THickGEM-based counters

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ABSTRACT

Cherenkov imaging counters requiring large photosensitive areas, the capability to stand high rates and to operate in magnetic field environments could benefit from the use of photon detectors based on THick Gaseous Electron Multiplier (THGEM) coupled to a solid state CsI photo-cathode.

A systematic study of the THGEM detector response as a function of its geometrical parameters and electrodes' applied voltage has been performed. Dedicated electrostatic calculations to optimize the detector design have been accomplished. Data obtained from small photon detector prototypes operating in single photon detection mode are presented and discussed. In particular the key aspect of photo-electron extraction from the photo-cathode surface is investigated via the timing spectrum response of the detector for different electric field conditions at the photo-cathode: a comparison of the measured time distributions and the simulation results is illustrated.

1. THGEM electron multipliers

The THGEM [1,2] is a robust gaseous electron multiplier based on GEM principle scaling the geometrical parameters. It is obtained via standard PCB drilling and etching processes making possible the economic production of large series and large size devices. THGEM geometrical parameters cover wide ranges; typical values are as follows: PCB thickness from 0.3 to 1 mm; holes diameter from 0.2 to 1.0 mm; hole pitch from 0.4 to 1.5 mm. The rim, the clearance region around the hole, ranges from 0 to 0.4 mm. The active area can be enlarged theoretically from few squared centimeters, as in the case of the prototypes used for the studies presented here, without limitations. These detectors can stand high rates up to 10 MHz/mm^2, provide fast signals and reach high gains up to 10^6 and more in triple stack configuration when detecting UV light. Due to the production technology the material budget is not particularly low and they do not offer a space resolution as good as GEMs. These aspects are not a limitation when detecting single photons in Cherenkov imaging counters. A THGEM-based photon detector usually consists of a structure of triple THGEM layers (see Fig. 1), where the first one, coated with a CsI film, acts as reflective photo-cathode [3,4]. The electric fields 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.

The reader is referred to Refs. [5,6] for a detailed description of the tests performed to study the role played by the different geometrical parameters characterizing the THGEMs, for the

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production technology method chosen and for the discussion of the obtained result.

The detector optimization studies, measurement and test are the main topics in this paper.

2. Gain issues and thickness role

As reported in Refs. [3–6] high gains larger than 10^5 are reachable with single or cascaded CsI-THGEM electrodes. When single photons are detected, the corresponding single photon–electron amplitude spectrum is exponentially distributed. Good signal to background ratio and a good gain stability of the detector are mandatory requirements in order that the threshold setting does not result in a critical issue.

In particular, large gains can be obtained multiplying electrons by THGEM with large rims but the gain stability versus time strongly depends on the rim size. Gain variations below 20% are observed when the rim is not present while huge ones (up to a factor of 5 and more) are visible when the rim is large [5].

A possible way to overcome the gain instabilities due to large rim, preserving the high gain performance, is to increase the detector thickness and avoid the use of rim. The maximum gain achievable using a single THGEM stage for different gas mixtures and geometries is shown in Fig. 2. Details of the maximum gain test are described in Ref. [5]. The maximum gain obtained with

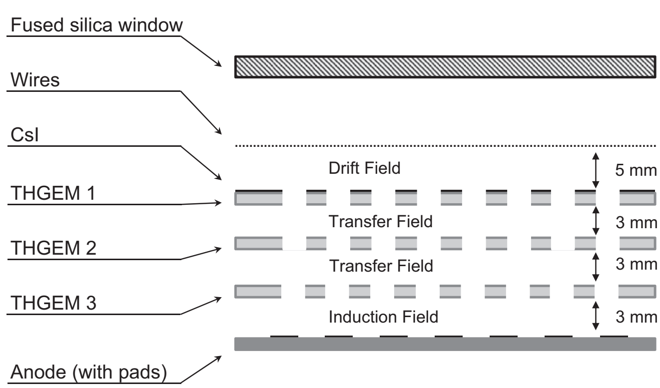

Fig. 1. Structure of a THGEM-based photon detector: the first layer is coated with a CsI photon converting film (not to scale).

the 20 μm rim, 0.4 mm thickness is recovered using a THGEM with no rim and double thickness. The hole diameter and pitch is the same for the three THGEMs tested.

3. Photo-electron extraction from the CsI layer

The effective photon detection efficiency of a THGEM based photon detector strongly depends, among other parameters, on the photo-electron extraction and on the subsequent photo-electron collection efficiency [8]. The last was studied in the present work both via electrostatic simulations and dedicated tests: the most favorable condition requires zero drift field as described in Ref. [5] and will not be discussed furthermore here.

The electric field on the photo-cathode surface, orthogonal to the THGEM surface (E_z), generated by the dipole field of the THGEM holes must be large enough to ensure an effective photo-electron extraction. The values of E_z for which the effective extraction efficiency is greater than 85% depend on the gas mixture used and correspond to values greater than 500 V/cm in pure methane gas [8]. The same effective extraction is ensured by an Ar–CH_4 mixture with methane fraction larger than 30%.

The layer where the CsI film is deposited can be further optimized by choosing an *ad hoc* geometry, as explained in the next lines, which is favorable to achieve high values of E_z also in the farthest area from the holes' center, the center of the triangle having as vertexes' three holes' center (critical point). The z component of the electric field, normal to the surface and in the critical point (E_{zc}), is simulated with COMSOL Multiphysics® [9], as a function of the hole diameter d, for different values of the pitch p, keeping the ΔV applied to the THGEM electrodes fixed. The competing requirements of keeping an active surface area larger than 80% and a value of $|E_z|$ larger than ~ 0.6 kV/cm bound the ratio of diameter and pitch to be $\sim 1/2$. Simulations, when fixing $d/p = \sim 1/2$, also show that the E_{zc} component increases decreasing the THGEM thickness, i.e. allowing the dipole field of the THGEM hole to extend more outside the near hole region. Different configurations of the d/p ratio result in an abrupt decrease of E_{zc}: for a diameter and thickness of 400 μm a change in pitch from 600 to 700 μm results in a decrease from ~ 0.8 kV/cm to ~ 0.4 kV/cm for E_{zc} when applying a $\Delta V = 1.5$ kV. These results point towards the use of a less thick first stage THGEM electrode with respect to the next ones where the parameter to be optimized is gain.

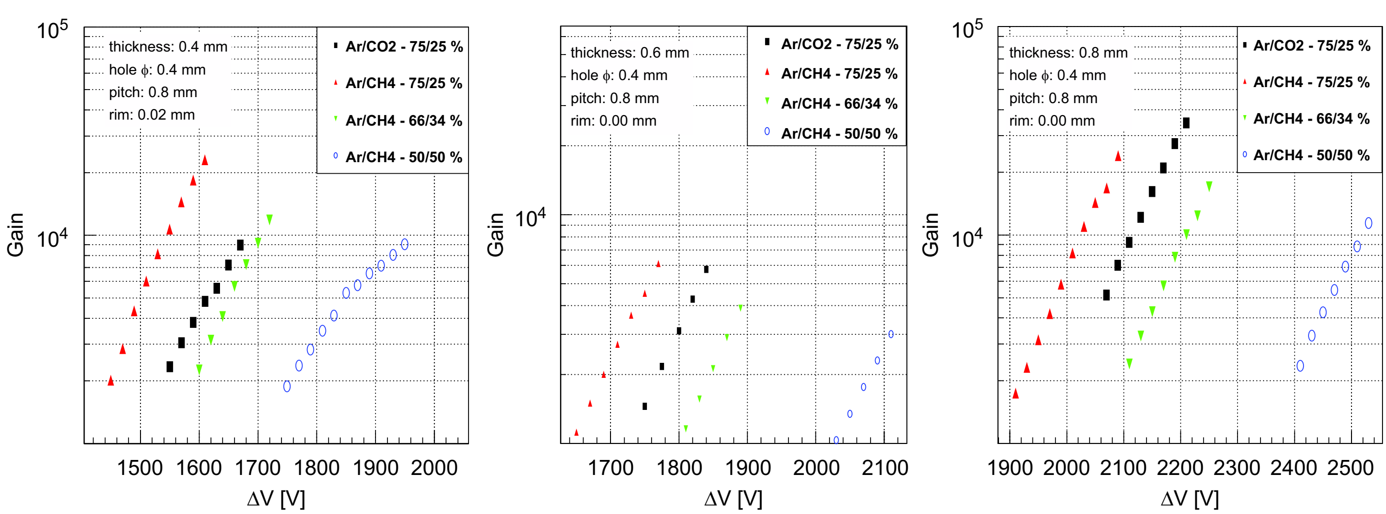

Fig. 2. Maximum gain achievable for different gas mixtures and different THGEMs. On the left: THGEM parameters: 0.4 mm thickness, 0.4 holes' diameter, 0.8 mm pitch and 20 μm rim, maximum gain $\sim 2 \times 10^4$. Center: THGEM parameters 0.6 mm thickness, 0.4 holes' diameter, 0.8 mm pitch and no rim, maximum gain $\sim 7 \times 10^3$. Right: THGEM parameters 0.8 mm thickness, 0.4 holes' diameter, 0.8 mm pitch and no rim, maximum gain $\sim 2 \times 10^4$.