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MPGD-based counters of single photons for Cherenkov imaging counters.

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Architectures based on MicroPattern Gas Detectors (MPGD) represent a possible 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. In Cherenkov imaging counters, gaseous photon detectors are still the unique option when insensitivity to magnetic field, low material budget, and affordable costs in view of large detection surfaces are required.
A systematic R&D programme has been performed for several years to develop novel gas photon detectors base on an arrangement of multiple layers of THick-Gas Electron Multipliers (THGEM): a deep understanding of the THGEM characteristics has been achieved and their parameters have been optimised in view of the photon detection application. Large gains are required to detect effectively single photoelectrons and, after the optimisation process, the novel detectors exhibit electrical stability up to gains as high as to 1-2 x 105 also in presence of radioactive backgrounds. The delicate aspect of the photoelectron extraction from a GEM-like photocathode has been studied in detail and conditions for effective extraction have been obtained. The suppression of the signal produced by ionising particles crossing the photon detectors has been proven. In parallel with establishing the detector principle, the engineering towards large-size counters is ongoing and an intermediate size detector with 300 x 300 mm2 active surface has been successfully operated.
Recently a new hybrid approach has been considered: an architecture where the last multiplication stage is obtained by using a Micromegas arrangement.
The completed R&D studies and the engineering aspects are summarised and the characterization of the hybrid detector prototypes are reported.

Summary

Nowadays, the Cherenkov imaging technique for Particle IDentification (PID) has been established as a robust, reliable experimental approach thanks to the use in several experiments. They are used and foreseen in the experimental apparata of several future research programmes. The effectiveness of visible and UV single photon detection is at the basis of the success of these counters. So far, only vacuum-based detectors and gaseous photon detectors have been adopted. Other photon detectors being developed are interesting only for applications in the far future. Gaseous photon detectors are still the only available option to instrument detection surfaces when insensitivity to magnetic field, low material budget, and affordable costs in view of large detection surfaces are required.
The present generation of gaseous photon detectors, namely MWPC where a cathode plane is formed by a Printed Circuit Board (PCB) segmented in pads and coated with a CsI film, adopted in several experiments (NA44, HADES, COMPASS, STAR, JLab-HallA and ALICE) exhibit some performance limitations: ageing, causing a severe decrease of the quantum efficiency after a collected charge of the order of some mC/cm2, feedback pulses with a rate increasing at large gain-values, and long recovery time (about 1 day) after an occasional discharge in the detector. These limitations are related to the photon feedback from the multiplication region and to the bombardment of the CsI photocathode film by the positive ions generated in the multiplication process. They impose to operate at low gain (a few times 104), resulting in two relevant consequences: the efficiency of single photoelectron detection is reduced and rate limitations are present. Moreover, in these detectors the signal formation is intrinsically slow. There is a clear quest for novel gaseous photon detectors

with advanced characteristics, namely intrinsically fast signals and reduced photon and ion backflow to operate at larger gains and to ensure longer detector life-time.
In a multilayer structure of electron multipliers, the photons from the multiplication process cannot reach the photocathode and a good fraction of the ions is trapped in the intermediate layers. The signal is mainly due to the electron motion, namely its development is fast. GEM-based photon detectors coupled to semi transparent or reflective photocathodes have been proposed shortly after the introduction of the GEM concept. The threshold Cherenkov counter Hadron Blind Detector (HBD) of the PHENIX experiment at BNL RHIC represents the first application of these ideas, even if high gain is not required in a threshold counter.
THich GEMs (THGEM), introduced in parallel by several groups about ten years ago, are electron multipliers derived from the GEM design, by scaling the geometrical parameters and changing the production technology. Large gains and good rate capabilities have been reported for detectors with single or double THGEM layers. THGEMs can be produced in large series and large size at moderate cost with standard PCB technology, in spite of the large number of holes: some millions per square meter. THGEMs have intrinsic mechanical stiffness, and they are robust against damages produced by electrical discharges. Moreover, thanks to the reduced gaps between the multiplication stages, these detectors can be successfully used in magnetic field.
The basic architecture of the THGEM-based photon detector that we propose consists in multiple, typically triple, THGEM layers, where the top face of the first layer is coated with a CsI film and acts as a reflective photocathode. The electron multiplication takes place in the THGEM holes thanks to the dipole electric field obtained biasing the two PCB faces. A plane of drift wires defines the drift electric field above the first THGEM layer. The field between two THGEM layers acts as a transfer field; an induction field is applied between the bottom face of the last THGEM and the anode electrode. The signals are collected at the anode plane, formed by a PCB segmented in pads.
Our R&D studies performed using single and multiple THGEM arrangements to detect ionising particles or UV photons in laboratory and test beam exercises have been dedicated to explore the characteristics of the THGEM multipliers and the role of the various geometrical parameters, and to establish the guidelines towards the optimisation of the basic architecture. More than 50 different small size THGEM samples (30 x 30 mm2) have been characterised. The measurement campaigns have been accompanied by simulation studies. The main outcomes are summarised in the following.
• The rim is the clearance ring around the holes. The THGEM maximum gain is increased by more than an order of magnitude by adopting large rims, namely annulus width of the order of 100 μm. These THGEMs exhibit relevant gain dependence versus rate and over time. These gain variations are absent or negligible for no rim or small rim THGEMs. On the basis of these facts, we have selected THGEM with the minimum rim imposed by the production technology to remove the drilling residuals at the hole edge, namely annulus width smaller than 10 μm.
• The large gains ensured by sizable rims can be recovered by increasing the THGEM thickness up to 0.8-1 mm: these thickness-values are ideal for the second and third THGEM layers.
• The time response is satisfactory: the typical resolution obtained with THGEM-AGPs is 7 ns r.m.s..
• Concerning photoelectron extraction efficiency from the CsI photoconverting layer, it is clearly established that the effective extraction rate depends on the gas atmosphere in the detector and requires an electric field ≥ 1000 V/cm at the photocathode surface. At the THGEM surface, the electric field is dominated by the THGEM bias and it has a minimum at the critical point, namely the centre of the equilateral triangle, which is the unit cell of the THGEM pattern. Higher electric fields at the critical point can be obtained by reducing the THGEM thickness and values around 0.3-0.4 mm are selected: this is the thickness suggested for the photocathode THGEM.
• Photon backflow from the multiplication region to the photocathode plane is almost totally suppressed; ion backflow rate depend on the geometry details; in prototypes with staggered hole alignment it is lower than 10 %.
• Triple THGEM configurations can provide gains up to 106 when detecting single photoelectrons; the gain has to be reduced in radioactive environments. This gain reduction is made less severe by applying appropriate voltage bias in front of the photocathode to suppress the ionising particle signal: the novel detectors can operate at gains at least one order of magnitude larger than the present ones.
In conclusion, the THGEM-based photon detectors can satisfy all the requirements posed to overcome the limitation of the present gaseous photon detectors.
In parallel with establishing the detector principle, the engineering towards large-size counters is ongoing. An essential goal of the project is to provide large size detectors with minimal dead zones while preserving the optimised characteristics obtained within the R&D studies. Some samples of good quality large size THGEMs (600 x 600 mm2) have been produced proving the feasibility of large boards. The voltages applied to the electrodes can be as high as 8 kV. Minimum dead zones can be obtained with an accurate mechanical design and the correct choice of the materials for the detector vessel, and appropriate HV distribution to the many electrodes. The goal is a dead area below 10%. An intermediate size detector with 300 x 300 mm2 active surface satisfying this prescription has been successfully operated.
Recently a new hybrid approach has been considered: an architecture where the last multiplication stage is obtained by using a Micromegas arrangement. Stable operation at large gain (> 106) has been obtained detecting single photons. The hydrid detector has recently been characterized.

The R&D studies and the engineering aspects are summarised; the characterization of the hybrid architecture prototypes is also reported.

Primary author: LEVORATO, Stefano (INFN Trieste)

Presenter: LEVORATO, Stefano (INFN Trieste)

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