

Hybrid MPGD-based Detectors of Single Photons for the upgrade of COMPASS RICH-1

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Abstract—A seven year-long R&D programme has been performed and the resulting detector architecture is a hybrid MPGD including two Thick GEM (THGEM) multiplication stages followed a MICROMEAS. The first THGEM board forms the photocathode support: its upper face is CsI coated. The properties of THGEM-based photocathodes have been studied in details. The two THGEM layers act as pre-amplification stages and, thanks to a staggered configuration, namely by the misalignment of the holes of the two THGEMs, the electron shower produced in the pre-amplification phase is distributed onto a larger surface portion of the following MICROMEAS unit, where the final multiplication takes place: it is so possible to operate at gains as high as 10^5 and more even in radioactive environments. COMPASS RICH-1 is a large-size Cherenkov imaging counter with gaseous radiator for hadron identification up to 50 GeV/c. The construction of a set of large-size (unit size: $60 \times 60 \text{ cm}^2$) gaseous photon detectors based on the hybrid MPGD architecture for the upgrade of COMPASS RICH-1 is ongoing and the upgraded detector will be in operation in 2016.

The R&D studies, the engineering aspects and the construction challenges are presented.

Index Terms—RICH; COMPASS; Photon detection; Micropattern gas detector; Thick GEM.

I. INTRODUCTION

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THE Cherenkov imaging technique for Particle Identification (PID) has been established as a robust, reliable experimental approach thanks to the use in several experiments. The effectiveness of visible and UV single photon detection is at the basis of the successful operation of these counters. So far, only vacuum-based and gaseous photon detectors have been adopted. In particular, 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. Novel gaseous photon counters must overcome the limitations of the present generation of gaseous photon detectors: large gains, intrinsically fast response and reduced Ion Back Flow (IBF) to the photocathode are required; appropriate MicroPattern Gaseous Detectors (MPGD) can match these requirements.

RICH-1[1] is a gas-radiator Cherenkov imaging counter characterized by large angular acceptance providing hadron identification up to 50 GeV/c to the COMPASS experiment[2] at CERN SPS. From 2002 to 2004, RICH-1 photon detection has been provided by MWPC with CsI photocathodes[3]. The photon detectors have been successively upgraded: from 2006 onwards a faster detection system has been adopted. The central photon detector part is affected by the largest amount of uncorrelated background, and has been equipped with high time resolution MAPMTs. In the peripheral region (75% of the active area) the MWPC have been left unchanged, equipped with a new read-out system based on the APV25 chip[4] to obtain better time resolution. The present upgrade aims at replacing the first generation gaseous photon detectors with solid state photocathodes, namely the MWPCs with CsI photoconverter with the novel MPGD-based photon counters, adequate for the increased rates of the COMPASS experiment.

II. THE R&D FOR THE NOVEL PHOTON DETECTOR

A seven year-long R&D programme has been performed and the resulting detector architecture is a Hybrid MPGD (H-MPGD) including two Thick GEM (THGEM)[5] multiplication stages followed a MICROMEAS[6] (Fig.1).

The upper face of the first THGEM 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

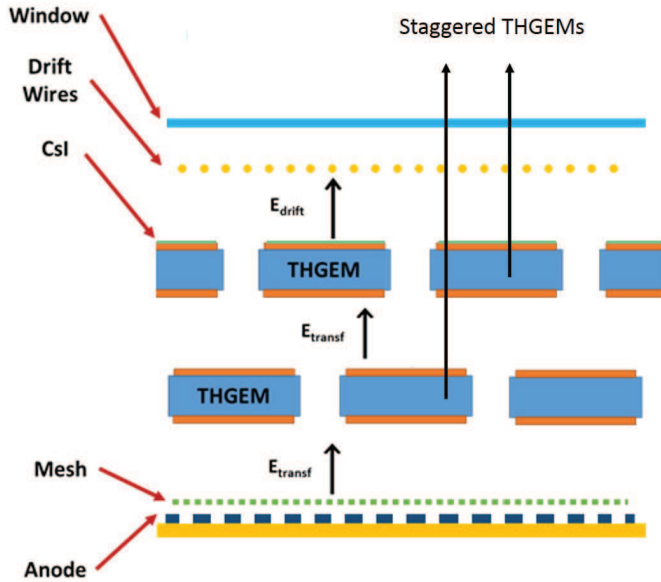


Fig. 1. Scheme (not to scale) of the hybrid detector architecture including two staggered THGEM layers (thickness: 0.4mm; hole diameter: 0.4mm; pitch: 0.8mm), and a MICROME GAS (128 μm gap, multi-pad anode).

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; a second transfer field is applied between the bottom face of the last THGEM and the MICROME GAS mesh. The signals are collected at the MICROME GAS anode plane, formed by a PCB segmented in pads. Thanks to a staggered configuration, namely by the misalignment of the holes of the two THGEMs, the electron shower produced in the pre-amplification phase is distributed onto a larger surface portion of the following MICROME GAS unit, where the final multiplication takes place: it is so possible to operate at gains as high as 10^5 and more even in radioactive environments; this gain-figure has to be compared with the gain-values of the MPGDs operated in experiments so far, which are always lower than 10^4 .

The R&D studies[7] included a first phase dedicated to establish the THGEM properties as electron multiplier with particular care to those aspects which are related to single photon detection; studies dedicated to the hybrid architecture have followed. The development has been performed using single and multiple THGEM arrangements and hybrid detector prototypes to detect ionizing particles or UV photons in laboratory and test beam exercises (Fig. 2); the measurement campaigns have been accompanied by extensive calculations of the electrical configuration provided by the different architecture and some simulation exercises. The main R&D outcomes are summarized in the following.

A. The role of the rim, namely the clearance ring without metallic layer around the holes

The rim has been introduced in THGEMs to increase the maximum gain that can be obtained. The main motivation for the increased gain is due to a deposited charge collected at the free dielectric voltage surface, which is formed within a

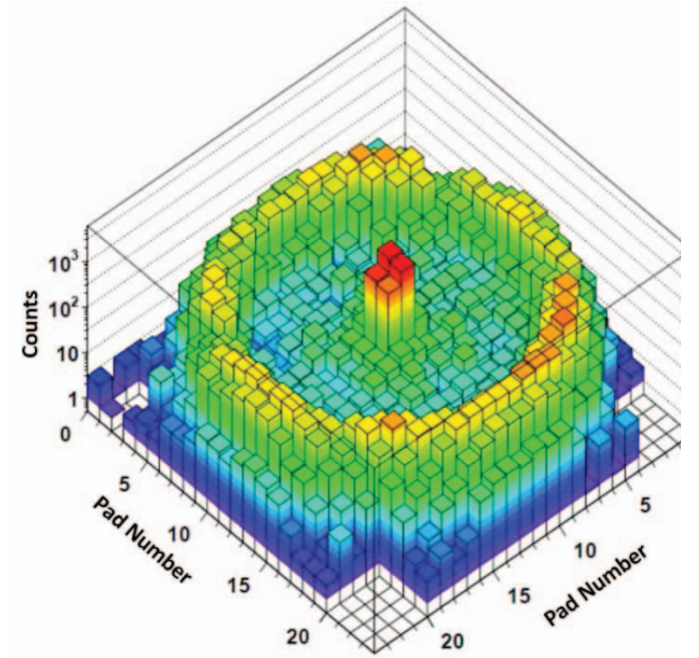


Fig. 2. Cherenkov ring obtained by superimposing events in a $30 \times 30 \text{ cm}^2$ triple-layer THGEM detector.

few minutes after applying the bias voltage and modifies the electric field in the THGEM hole and surrounding regions resulting in a larger gain. The price to pay is a substantial gain dependence over time due to the ion motion inside the substrate (fiberglass): for large rim size, namely for annulus width in the order of 100 μm , gain variations up to a factor of five have been observed over a few days of continuous application of the voltage bias. Also, THGEMs with large rim exhibit relevant gain dependence versus rate. Moreover, we could show that the complete collection of the ionization charge is not obtained when a large rim is present. On the basis of these facts, we have selected THGEM without rim.

B. The role of the THGEM thickness

Increasing the THGEM thickness it is possible to stably operate at higher multiplier gain because the multiplication region is longer. When the thickness is increased, the dipole field created biasing the THGEM is more concentrated in the holes and, correspondingly, the electric field at the external THGEM surface decreases, reducing the efficiency of the effective photoelectron extraction from the photocathode. We have chosen to use THGEM of moderate thickness (0.4 mm) recovering the gain by the multiple multiplication stages.

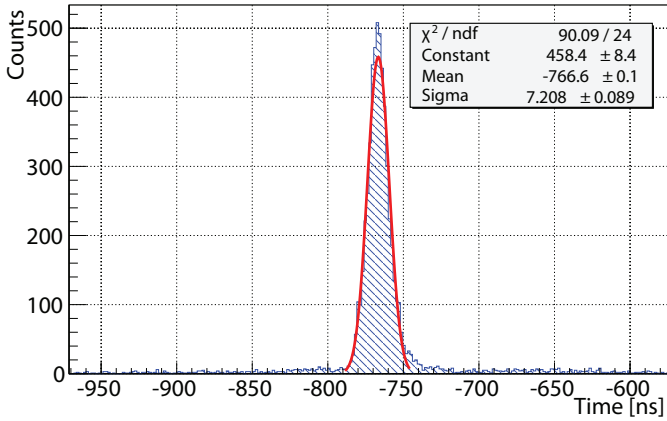


Fig. 3. Time distribution of Cherenkov photon detected in a H-MPGD; the solid line is the gaussian fit to the distribution.

C. The time response of THGEM-based detectors and the H-MPGDs

When the photoelectron extraction is effective, the time resolution of triple THGEM arrangements or of the H-MPGD is always below 10 ns and typical values of 7 ns have been easily obtained using both architectures (Fig. 3). If the photoelectron extraction is poor, namely, the electric field in front of the photocathode is too low (below about 800 V/cm), the drift velocity of the photoelectron is reduced, severely spoiling the time resolution: therefore, measurements of the time resolution are also a powerful diagnostic tool to verify the effectiveness of the photoelectron extraction.

D. The role of the gas mixture and of the electric bias to obtain effective photoelectron extraction efficiency from the CsI photoconverting film coated on THGEM photocathodes

Our measurements have confirmed that the best gas atmosphere to guarantee effective photoelectron extraction from CsI in a gaseous detectors is methane. We have proved that argon-methane mixtures rich in methane (at least 40 %) are equally good. The required electric field to ensure the effectiveness is at least 700-800 V/cm and it has to be provided by the dipole field obtained biasing the THGEM. The drift field applied in front of the photocathode cannot contribute, as it has to be very low, almost null: in fact, a large positive field would suck the photoelectrons to the plane of wire place above the photocathode instead of letting them enter the THGEM holes, while a negative drift field would compete with the dipole field decreasing it. This aspects have been studied by detailed calculations of the electric configurations, by collection efficiency measurements in laboratory and at test beams and, finally, by fine granularity maps of efficiency obtained using a UV scanning system known as leopard[8].

E. IBF rates in triple THGEM arrangements and in the H-MPGD architecture

IBF rates as low as 5% and below have been obtained using both architectures. In a triple THGEM detector the IBF suppression requires that the holes of the three THGEMs are staggered, namely the full misalignment of the holes of

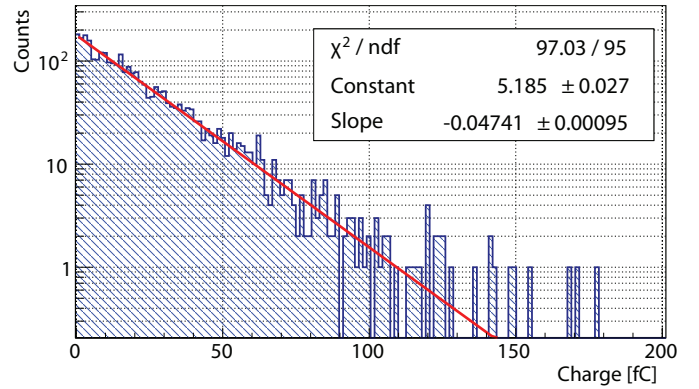


Fig. 4. Amplitude spectrum of the signal produced by Cherenkov photons in an H-MPGD detector operated at a gain of 10^5 .

the central layer and a strong transfer field (of the order of 5 kV/cm) between the second and the third THGEM. In the H-MPGD architecture the intrinsic property of ion trapping in the multiplication gap, which is a characteristic of the MICROME GAS, guarantees similar figures for a transfer field between the second THGEM and the MICROME GAS mesh of the order of 1 kV/cm and a field of at least 35 kV/cm in the MICROME GAS multiplication gap.

F. The maximum detector gain compatible with a stable operation of the detector also in presence of a radioactive background

This parameter supports the choice of staggered THGEM holes, both in the triple THGEM configuration and in the H-MPGD: in fact, it is so possible to spread the electron avalanche over a larger surface of the last multiplication stage making it less probable to locally reach discharge conditions. In general, the H-MPGD allows operating at higher gains and it is stable at least up gains as high as 10^5 (Fig. 4).

III. THE ENGINEERING AND CONSTRUCTION OF THE NOVEL PHOTON DETECTORS

The H-MPGD photon detector, which is the outcome of the R&D, can satisfy all the requirements posed to overcome the limitation of the present gaseous photon detectors and match the needs of experiments at higher and higher rates: their engineered version will be used to upgrade the photon detection system of COMPASS RICH-1. The construction of a set of large-size (unit size: 60×60 cm²) H-MPGDs is ongoing and the upgraded detector will be in operation in 2016. These detectors are built taking into account the developments of the engineering phase, described in this section.

A. The THGEM design

The THGEM holes are distributed according to a repeated pattern, where the base unit cell is a equilateral triangle; the hole pitch is 0.8 mm, the hole diameter is 0.4 mm, the thickness is 0.4 mm and rim-less design has been chosen. The 60×60 cm² surface is covered by two THGEMs of unit size 60×30 cm² each, including more than 300 thousand holes,

segmented into 12 longitudinal sectors separated by non-metalized strips 0.7 mm wide. The segmentation is introduced to limit the discharge energy when occasional discharges take place; moreover, in case of local damages to a THGEM during operation, the segmentation makes it possible to reduce the voltage of a limited portion of the detector. The width of the strips between segments is the result of dedicated studies: it guarantees not to propagate discharges between adjacent segments via the PCB surface. The electric field in the THGEM holes at the periphery of the active region is larger as indicated by calculations and measurements performed with the leopard scanning system: a more uniform electric field is obtained increasing to 0.5 mm the diameter of the holes at the periphery of the active region.

B. THGEM production

Hole drilling requires industrial production: the THGEM PCBs are produced at ELTOS. The final polishing, that has to match stringent requirements, non-typical in the industrial production of PCBs, is performed at the home laboratory following an optimized protocol. The procedure includes heating in oven at 160 °C in order to complete epoxy curing, polishing with fine grain pumice powder, smoothening of the hole edges in ultrasonic bath with Sonica PCB solution (PH11), rinsing with distilled water, residual removing by high pressure water and final drying in vacuum. Large-surface THGEMs with uniform gain are obtained when (i) the hole diameter and pitch are constant and (ii) the thickness is uniform. Requirement (ii) is provided by using high-technology industrial drilling machines, while requirement (i) is matched by the selection of the fiberglass foils: the thickness of a foil is measured by sampling at 1300 points and a foil is accepted when the pick-to-pick thickness variation is smaller than 15 μm . The THGEMs are individually validated: for this purpose they are temporary used in single layer detectors. The Quality Assessment (QA) protocol imposes very stringent requirements concerning the electrical stability: discharge rates below 1 discharge per hour in operative condition (gas mixture, HV) are requested. Gain maps are collected detecting X-rays and, typically, the ratio of the gain standard deviation over the average gain is in the range 5-7%. THGEMs are accepted when this figure is below 10%.

C. Resistive MICROMEGAS by discrete component

We have adopted an approach inspired by the development for the ATLAS-MAMMA project[9]: resistive anodes have been introduced to limit the discharge energy, which results in a protection of the detector itself and of the front-end electronics and, even more relevant, in a substantial reduction of the detector dead-time; in fact, a non-negligible dead-time is present at high discharge rates due to the time required to re-establish the operational high voltage after a discharge event. The resistive anodes have been obtained by photolithography or screen printing or sputtering [39] technologies, which are being developed towards a full maturity. The signals are then collected from electrodes with capacitive coupling to the

resistive anode. By this scheme it is possible to bias the anode at HV, while the MICROMEGAS mesh is grounded.

Due to the time scale of the COMPASS RICH-1 upgrade and taking into account that the pad size is $8\times 8\text{ mm}^2$, we have designed a resistive MICROMEGAS where the anode pads are powered via individual resistors, while the signal is collected by the pads of a second plane, internal to the anode PCB. The anode and the signal pads are parallel and form a capacitor that allows the signal transmission with a signal amplitude reduction lower than 20%. In the H-MPGD, grounding the micromesh offers one more advantage: the THGEM multiplication layers and the MICROMEGAS stage are electrically separated. The choice of the resistive anode by discrete elements results in an anode plane which is a standard multilayer PCB: it is so possible to build the MICROMEGAS multiplication gap using the fully mature bulk MICROMEGAS technology[10] mastered at CERN, where the MICROMEGAS gap for the COMPASS RICH-1 upgrade are produced. Similarly to the THGEM case, the $60\times 60\text{ cm}^2$ active surface is covered by two MICROMEGAS of unit size $60\times 30\text{ cm}^2$ each. The QA of the MICROMEGAS includes testing the electrical stability in operative condition (gas mixture, HV) and the measurement of the gain uniformity using MICROMEGAS as standalone multiplication stage: gain maps are produced detecting X-ray. The ratio of the gain standard deviation over the average gain is typically around 5%. THGEMs are accepted when this figure is below 10%.

IV. PERSPECTIVES

The constructions for the upgrade of COMPASS RICH-1 by novel photon detectors with H-MPGD architecture is progressing according to the schedule and it is accompanied by an intense QA activity performed according to detailed protocols.

RICH-1 will be operated in the upgraded version during the 2016 COMPASS data taking: it will be the first RICH counter making use of MPGD-based photon detectors.

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