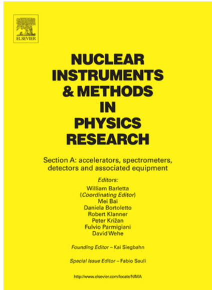
Accepted Manuscript



The hybrid MPGD-based photon detectors of COMPASS RICH-1

J. Agarwala, M. Alexeev, C.D.R. Azevedo, F. Bradamante, A. Bressan, M. Büchele, C. Chatterjee, M. Chiosso, A. Cicuttin, P. Ciliberti, M.L. Crespo, S. Dalla Torre, S. Dasgupta, O. Denisov, M. Finger, M. Finger Jr., H. Fischer, M. Gregori, G. Hamar, F. Herrmann, S. Levorato, A. Martin, G. Menon, D. Panzieri, G. Sbrizzai, S. Schopferer, M. Slunecka, M. Sulc, F. Tessarotto, J.F.C.A. Veloso, Y. Zhao

PII: S0168-9002(19)30111-1
DOI: https://doi.org/10.1016/j.nima.2019.01.058
Reference: NIMA 61832

To appear in: *Nuclear Inst. and Methods in Physics Research, A*

Received date : 21 November 2018
Revised date : 21 December 2018
Accepted date : 17 January 2019

Please cite this article as: J. Agarwala, M. Alexeev, C.D.R. Azevedo et al., The hybrid MPGD-based photon detectors of COMPASS RICH-1, *Nuclear Inst. and Methods in Physics Research, A* (2019), https://doi.org/10.1016/j.nima.2019.01.058

The Hybrid MPGD-based photon detectors of COMPASS RICH-1

J.Agarwala[a,j], M.Alexeev[b], C.D.R.Azevedo[c], F.Bradamante[d], A.Bressan[d], M.Büchele[e], C.Chatterjee[d], M.Chiosso[b], A.Cicuttin[a,j], P.Ciliberti[d], M.L.Crespo[a,j], S.Dalla Torre[a], S.Dasgupta[a], O.Denisov[f], M.Finger[g], M.Finger Jr.[g], H.Fischer[e], M.Gregori[a], G.Hamar[a], F.Herrmann[e], S.Levorato[a], A.Martin[d], G.Menon[a], D.Panzieri[h], G.Sbrizzai[d], S.Schopferer[e], M.Slunecka[g], M.Sulc[i], F.Tessarotto[a,*], J.F.C.A.Veloso[c], Y.Zhao[a]

[a] *INFN, Sezione di Trieste, Trieste, Italy*
[b] *INFN, Sezione di Torino and University of Torino, Torino, Italy*
[c] *I3N - Physics Department, University of Aveiro, Aveiro, Portugal*
[d] *INFN, Sezione di Trieste and University of Trieste, Trieste, Italy*
[e] *Universität Freiburg, Physikalisches Institut, Freiburg, Germany*
[f] *INFN, Sezione di Torino, Torino, Italy*
[g] *Charles University, Prague, Czech Republic and JINR, Dubna, Russia*
[h] *INFN, Sezione di Torino and University of East Piemonte, Alessandria, Italy*
[i] *Technical University of Liberec, Liberec, Czech Republic*
[j] *Also at Abdus Salam ICTP, 34151 Trieste, Italy*

Abstract

Novel gaseous detectors of single photons for RICH applications have been developed and installed on COMPASS RICH-1 in 2016, covering a total area of 1.4 m^2. They have a hybrid architecture consisting of two staggered THGEM layers (one equipped with a CsI photoconverting layer) and a bulk Micromegas and operate stably and efficiently, providing a single photon angular resolution of ~ 1.8 mrad and about 10 detected photons per ring at saturation. The main aspects of their construction, commissioning, characterization and performance are presented.

Keywords: Photon detection, gaseous detectors, RICH, MPGD, THGEM, CsI photocathode

1. Introduction

The RICH-1 [1] detector of the COMPASS Experiment [2] at the CERN SPS is a large gaseous Ring Imaging Cherenkov counter providing hadron identification in the range of momenta between 3 and 60 GeV/c, over a large angular acceptance (±200 mrad), at high rates (beam rate up to 100 MHz, trigger rate up to 100 kHz).

It consists of a 3 m long C_4F_{10} radiator, a 21 m^2 large focusing VUV mirror surface and Photon Detectors (PDs) covering a total active area of 5.5 m^2. Three photodetection technologies are used in RICH-1 (Fig. 1): Multi Wire Proportional Chambers (MWPCs) with CsI photocathodes, Multi Anode Photo-Multipliers Tubes (MAPMTs) and novel Micro Pattern Gaseous Detectors (MPGDs) based PDs.

The COMPASS RICH-1 was designed and built between 1996 and 2001 and is in operation since 2002. It was originally equipped with 16 PDs consisting in MWPCs hosting a CsI-coated photocathode, each having an active area of about 600×600 mm^2; in 2006, to cope with the high particle flux of the central region, 4 such PDs were replaced by detectors consisting of arrays of MAPMTs coupled to individual fused silica lens telescopes.

In parallel, an extensive R&D program [3], aimed to develop MPGD-based large area PDs, established a novel hybrid technology combining MicroMegas (MM) and Thick Gas Electron Multipliers (THGEMs), providing good stability in harsh operating conditions.

In 2016 The COMPASS RICH-1 was upgraded by replacing 4 MWPCs-based PDs with detectors resulting from the newly developed MM+THGEM hybrid technology [4]. MPGD-based detectors of single photons are used for the first time in a running experiment.

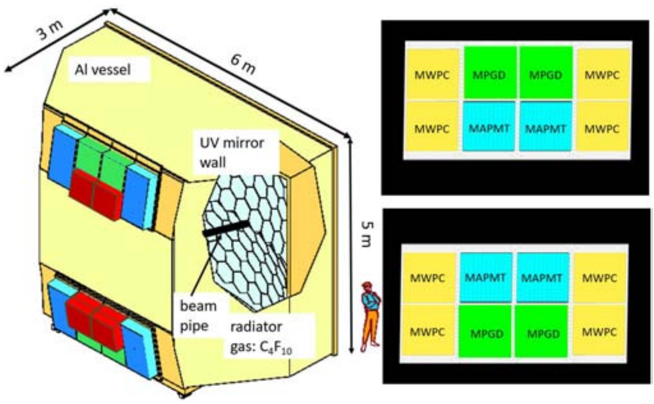


Figure 1: Artistic view of the COMPASS RICH-1 (left) and scheme of the PD arrangement (not in scale) (right).

*corresponding author, email: fulvio.tessarotto@ts.infn.it

2. The novel Hybrid MPGD-based Photon Detectors

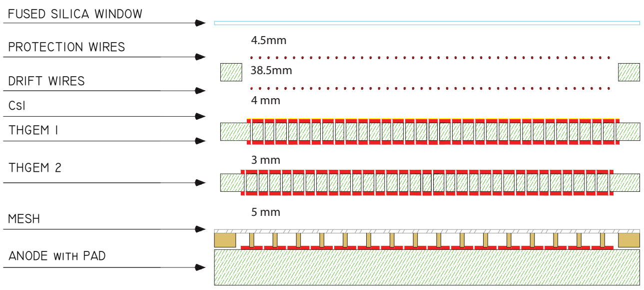


Figure 2: Sketch of the hybrid single photon detector: two THGEM layers are coupled to a MM. Drift and protection wire planes are shown. Image is not to scale.

The novel Hybrid MPGD-based PD architecture, sketched in Fig.2, consists in a combination of two layers of THGEM followed by a MM; the top of the first THGEM is coated with a CsI film and acts as a reflective photocathode. In this configuration the feedback from photons generated in the multiplication processes is suppressed by the presence of the THGEM layers and the large majority of the ions from the MM multiplication are collected at the MM mesh. The signal development time is about 100 ns.

Each of the four new COMPASS RICH-1 PDs has 600 × 600 mm^2 and is formed by two identical modules (of 600 × 300 mm^2) arranged side by side.

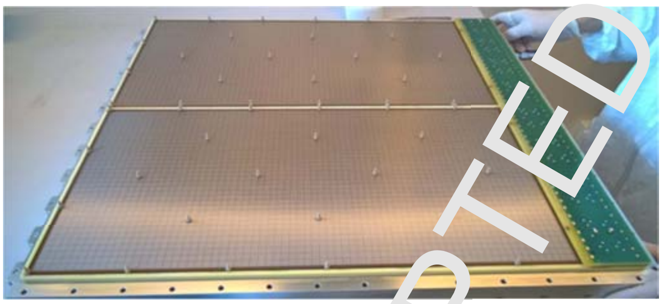


Figure 3: Two Micromegas mounted side by side in a PD. The pillars that preserve the distance between the micromesh and the THGEM above it are also visible.

The MMs (Fig.3) were produced at CERN using the bulk technology [5] on a custom, pad segmented anode; they have a 128 μm gap and a square array of 300 μm diameter pillars with 2 mm pitch.

The THGEMs (Fig.4) are made from standard PCB material and their geometrical parameters are: thickness = 470 μm (400 μm dielectric, 2 × 35 μm copper), hole diameter = 400 μm, pitch = 800 μm; the holes are rimless. The THGEM top and bottom electrodes are segmented in 12 parallel sectors, separated by 0.7 mm clearance, each biased via an individual (1 GΩ) resistor. The two THGEMs are staggered, providing maximal misalignment between the two set of holes: this configuration increases the PD electrical stability.

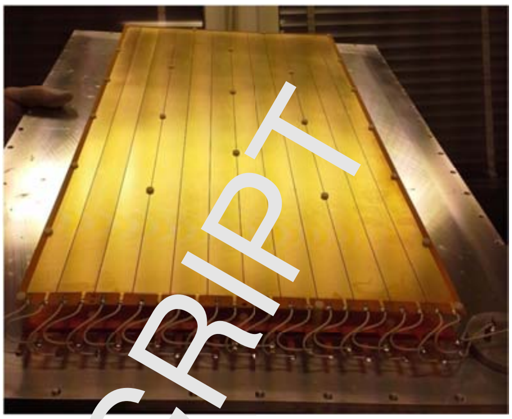


Figure 4: A Au coated THGEM ready for insertion in the CsI evaporation plant.

A specific protocol for production and validation of the THGEMs has been applied, consisting in: preselection of raw PCB material for homogeneous thickness, polishing after drilling with fine pumice powder, cleaning with high pressure water and ultrasonic bath with a basic (pH11) solution, detailed optical inspection, test of electrical strength, measurement of gain uniformity and long test of discharge rates under illumination by X-rays. The selected THGEMs were then coated with Ni (5 μm) and Au (0.2 μm) (Fig.4); half of them were subject to a further coating with a 300 nm CsI layer to become reflective photocathodes. The quantum efficiency (QE) of the CsI photocathodes is measured inside the evaporation plant after the coating process: the uniformity level is ≈ 3% r.m.s. within a photocathode and ≈ 10% between different photocathodes. To preserve the QE all operations of transport and installation are performed under controlled atmosphere, in dedicated gloveboxes.

The hybrid PD anode is segmented in 7.5 × 7.5 mm^2 pads with 0.5 mm interpad clearence and each pad is biased at positive voltage (≈ 620 V) via an individual (470 MΩ) resistor; the MM micromesh, being the only non-segmented electrode, is kept at ground potential. This configuration prevents occasional discharges from propagating to neighboring pads, limits the voltage drop suffered by the pads surrounding a tripping one to about 2 V, (corresponding to a gain drop ≈ 4%) and allows restoring the nominal voltage in few seconds. It also allows normal operation of the detector even when an anodic pad is shorted to ground potential (a few cases appeared during the runs 2016 and 2017, resulting in a total of less than 0.1% dead MM area). The signal is transmitted from the anode pad via capacitive coupling to a readout pad facing it, buried inside the anode PCB (at 70 μm distance from the anode pad) and connected to the front-end board connector. The resistive-capacitive pad scheme dumps the effects of discharges and protects the front-end electronics.

The novel hybrid PDs are operated with an Ar/CH_4 = 50/50 gas mixture. The ion back-flow to the THGEM photocathode, in the standard operating conditions has been measured to be ≈ 3% (Fig.5) by recording the currents on each electrode of the hybrid PD using a set of custom, fully floating, picoammeters.

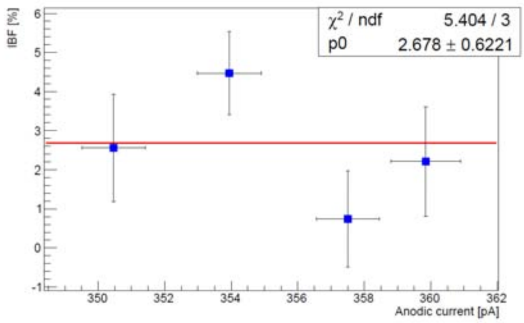


Figure 5: Dedicated measurement of ion back-flow fraction to the THGEM photocathode at four different values of the UV light intensities.

3. The commissioning of the MPGD-based PDs

The new PDs have been installed on COMPASS RICH-1 during Spring 2016, commissioned during the 2016 run, and operated stably and efficiently during the 2017 run too. The high voltage is provided by commercial power suppliers (CAEN A1561HDN and A7030DP HV modules, hosted in two SY4527 mainframes); each chamber is divided into 4 independent sectors and has 9 different electrode types, each one having specific requirements.

The HV control system (custom made, using C++ and wxWidgets) monitors and records at 1 Hz fequency the voltage and current values of all the 136 channels, counts the discharges (events with ≥ 20 nA current increase) and readjusts automatically the specific voltage bias in case the discharge rate exceeds the allowed limit. It also measures the variation of environmental parameters (pressure and temperature) and provides automatic voltage adjustment to compensate for it, in order to preserve the stability of the PD gain. Discharges typically affect single sectors, reach a maximum current of about 100 nA and need ~ 10 s to restore the operating conditions. Their rate is about 1/h per chamber. Discharges in the two THGEM layers are fully correlated, and those observed in the MM are mostly related with the THGEM ones. No high voltage power supply protection trips (I ≥ 100 nA for more than 10 s) were observed during data taking.

The front-end electronics [6], is based on the APV25-S1 chip, and provides three amplitude samples per trigger for each channel. Digitizer boards hosting 10 bit flash ADCs and FPGAs performing on-line zero suppression with common-mode correction send the detector data to the COMPASS DAQ for data storage and monitoring. A cooling system using underpressure water flow assures efficient removal of the heat produced by the readout. The average noise level is ~ 800 equivalent e^- r.m.s, highly stable during the running periods. A clustering algorithm is applied in the analysis to provide coordinates and amplitudes of "photon candidate" clusters; the majority (≥ 90%) of clusters however receive contribution from a single pad only.

The average effective gain of the 16 sectors was tuned to be the same (at 1% level) and remained stable at a level of 5% over several months of continuous operation thanks to the automatic voltage adjustment to compensate for pressure and temperature changes. The ring images provided by the novel detectors are clean and almost background-free: typical examples are presented in Fig.6, where a ring fully contained in one of the new PDs (left) is shown together with a "shared" ring (right), namely a ring with photons detected partly by the new PD and partly by the MAPMTs. In both cases the reconstruction and identification efficiency is satisfactory.

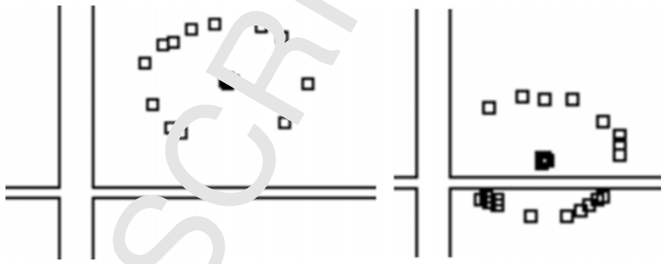


Figure 6: Examples of fully contained and shared rings

4. Preliminary performance results

A preliminary characterization of the hybrid THGEM-MM PD response has been performed from the analysis of data collected during two days of dedicated RICH calibration runs in september 2017; during this period the radiator gas consisted in a mixture of $C_4F_{10}/N_2 \sim 75/25$.

Photon candidate clusters contributing to the rings of identified particles are selected to obtain pure samples of Cherenkov photoelectron signals: an example of their amplitude distribution is presented in Fig.7 where the expected exponential behavior is observed over more than two orders of magnitude. The extracted value for the effective gain is ~ 14000. The respective contributing factors from the three layers (first THGEM, second THGEM and MM) of electron multipliers to the effective gain are estimated to be ~ 13, 9 and 120.

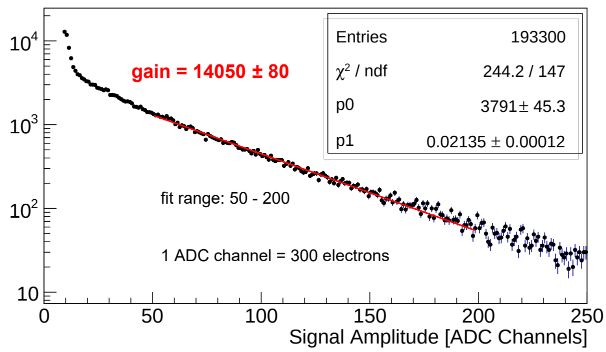


Figure 7: A typical signal amplitude distribution

The single photoelectron detection efficiency, estimated from the measured effective gain and the threshold applied to the signals, is ≥ 80%; the level of background hits in the ring coronas, originated by the electronic noise, is expected to be ≤ 20%: the observed deviation of the hit amplitude distribution from a pure exponential at very small amplitudes confirms this expectation.

Selecting identified pion rings, the detector angular resolution for single Cherenkov photoelectrons has been measured to be ∼ 1.85 mrad, as can be seen in Fig. 8, where the difference between the Cherenkov angle calculated from the reconstructed momentum of the particle track and the measured Chenekov angle for each photon candidate cluster is shown: this value fully matches the expectation. The use of a preliminary alignment results in an offset of 0.44 mrad.

The average number of detected photons per ring depends quadratically on the Cherenkov angle, according to the Frank-Tamm equation: the observed number of detected clusters shows the expected behavior, as can be seen in Fig. 9, where the points marked by triangles represent the measured quantities and the open circles include the correction for the effect of the non negligible probability of a statistical outcome of zero photons when the average is small. To increase the statistical accuracy of the estimate, the shared rings are used too, provided at least half of the ring corona is contained in the active area of the novel hybrid PD. The limited kinematic range of the pion data sample (momentum = 4.5 ± 1.4 Gev/c) and the effective refractive index of the radiator (∼ 1.00127) provide a maximum observed Cherenkov angle of ∼ 50 mrad. The reconstructed rings with large, unphysical angles are due to background hits and have a low number of photons per ring.

A fit of the corrected distribution with a quadratic (Frank-Tamm) + linear (random background proportional to the corona area) function is then performed in the range of Cherenkov angles where high statistical accuracy and small correction effects are present: since the quality of the fit is good and the level of background obtained from the fit agrees with the expectation, a preliminary estimate for the number of detected photons for tracks at saturation (β=1) can be reliably extracted. The curve shown in Fig. 9 provides a value of ∼ 13 hits at a Cherenkov angle value of 55.2 mrad, which is the traditional reference Cherenkov angle value at saturation for CsI photoconverter and a C_4F_{10} radiator at s.t.p.; the number of detected photons from the fit is ∼ 10.5 and the background contribution is ∼ 2.5.

A complete characterization of the new detectors is still ongoing, but from the preliminary results a clear indication of a very stable and reasonably high effective gain, low noise level, good angular resolution and large photoelectron detection efficiency is obtained.

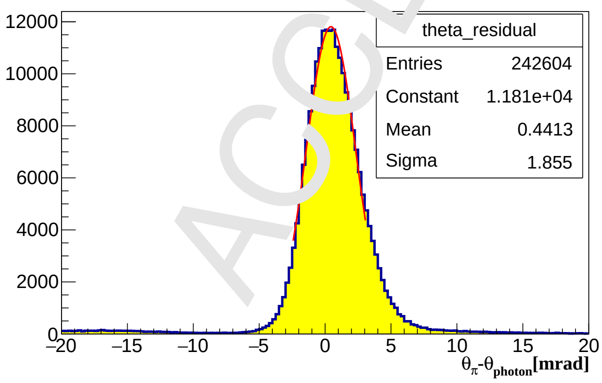


Figure 8: Detector angular resolution for single Cherenkov photons

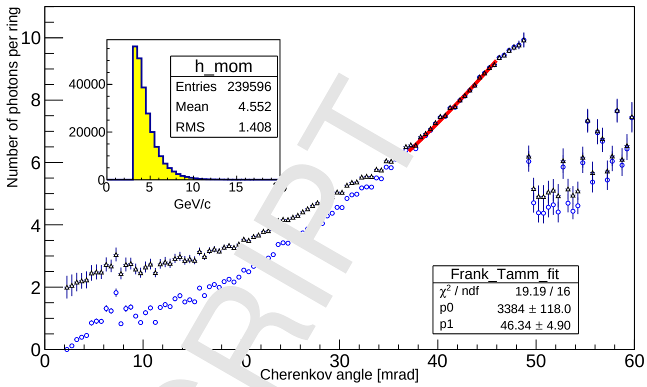


Figure 9: The average number of detected photons per ring as function of Cherenkov angle in a hybrid PD for identified pions. Triangular markers: measured values, open circles: corrected values. Top left box: distribution of the momenta of the identified pions

5. Conclusions

Novel large area gaseous detectors of single photons, based on a hybrid combination of THGEMs and Micromegas, have been developed and installed on COMPASS RICH-1 in 2016. They operate stably and efficiently with an effective gain of ∼ 15000, a noise level of ∼ 800 equivalent e^- r.m.s., providing a single photon angular resolution of ∼ 1.85 mrad and about 10 detected photons per ring at saturation.

They represent a remarkable technological achievement, since gaseous PDs are the most effective approach to instrument large surfaces with detectors of single photons at affordable costs, and they have a very low magnetic sensitivity.

MPGD-based photon detectors are a promising option for future RICH applications too.

Acknowledgements

The authors are grateful to the colleagues of the COMPASS Collaboration for continuous support and encouragement.

This work is partially supported by the H2020 project AIDA-2020, GA no. 654168.

References

References

[1] E.Albrecht, *et al.*, *Status and characterisation of COMPASS RICH-1*, Nucl. Instrum. Meth. A **553** (2005) 215; P.Abbon *et al.*, *Read-out electronics for fast photon detection with COMPASS RICH-1*, Nucl. Instrum. Meth. A **587** (2008) 371; P.Abbon *et al.*, *Design and construction of the fast photon detection system for COMPASS RICH-1*, Nucl. Instrum. Meth. A **616** (2010) 21; P.Abbon *et al.*, *Particle identification with COMPASS RICH-1*, Nucl. Instr. and Meth.A **631** (2011) 26; F.Tessarotto *et al.*, *Long term experience and performance of COMPASS RICH-1*, JINST **9** (2014) C09011.

[2] P. Abbon *et al.*, *The COMPASS Experiment at CERN*, Nucl. Instr. and Meth. A **577** (2007) 455; P. Abbon *et al.*, *The COMPASS setup for physics with hadron beams*, Nucl. Instr. and Meth. A **779** (2015) 69.

[3] M.Alexeev *et al.*, *The quest for a third generation of gaseous photon detectors for Cherenkov imaging counters*, Nucl. Instr. and Meth. A **610** (2009) 174; M.Alexeev *et al.*, *THGEM based photon detector for Cherenkov imaging applications*, Nucl. Instr. and Meth. A **617** (2010) 396; M.Alexeev *et al.*, *Progress towards a THGEM-based detector of single photons*, Nucl. Instr. and Meth. A **639** (2011) 130; M.Alexeev *et al.*, *Development of THGEM-based Photon Detectors for COMPASS RICH-1*, Physics Procedia 37 (2012) **781**; M.Alexeev *et al.*, *MPGD-based counters of single photons developed for COMPASS RICH-1*, JINST **9** (2014) C09017; M.Alexeev *et al.*, *Long term experience with CsI photocathodes in gas photon detectors*, JINST **9** (2014) P01006; M.Alexeev *et al.*, *The gain in Thick GEM multipliers and its time-evolution*, JINST **10** (2014) P03026.

[4] M.Alexeev *et al.*, *The MPGD-based photon detectors for the upgrade of COMPASS RICH-1*, Nucl. Instr. and Meth. **A** *876* (2017) 96.

[5] I.Giomataris *et al.*, *Micromegas in a bulk*, Nucl. Instrum. Meth. **A 560** (2006) 405.

[6] P.Abbon *et al.*, *Fast readout of the COMPASS RICH CsI-MWPC photon chambers*, Nucl. Instr. and Meth. **A 567** (2006), p. 104.