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

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Abstract

Novel gaseous detectors of single photons for RICH applications have been developed and installed on COMPASS RICH-1 in 2016. They have a hybrid architecture consisting of two staggered THGEM layers (one equipped with a CsI photoconverting layer) and a bulk Micromegas; they cover a total area of 1.4 m\(^2\) and operate stably and efficiently. They provide a single photon angular resolution of \(\sim 1.8\) mrad and about 10 detected photons per ring at saturation. The main aspects of their construction and commissioning, their characterization and performance figures 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 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 (\(\pm 200\) mrad), at high rates.

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: Multi Wire Proportional Chambers (MWPCs) with CsI photocathodes, Multi Anode Photo-Multipliers Tubes (MAPMTs) and novel Micro Pattern Gaseous Detectors (MPGDs) based PDs.

COMPASS RICH-1 was designed and built between 1996 and 2001 and is in operation since 2002. It was originally equipped with MWPCs hosting 16 CsI-coated photocathodes, each having an active area of about 600\(\times\)600 mm\(^2\); in 2006, to cope with the high particle flux of the central region, 4 of the 16 CsI-coated photocathodes 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): this configuration provides good stability for large area PDs operating in harsh conditions too.

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

2. The novel Hybrid MPGD-based Photon Detectors

![Sketch of the hybrid single photon detector](image)

Figure 1: 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.1 consists in a combination of two layers of THGEM fol-
lowed 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 $\sim 100$ ns.

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

Figure 2: 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 MM (Fig. 2) were produced at CERN using the bulk technology on a custom, pad segmented anode; they have a 128 $\mu$m gap and a square array of $300 \mu$m diameter pillars with 2 mm pitch.

The THGEMs (Fig. 3) are made from standard PCB material and their geometrical parameters are: thickness = 470 $\mu$m (400 $\mu$m dielectric, $2 \times 35 \mu$m copper), hole diameter = 400 $\mu$m, pitch = 800 $\mu$m; 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 G$\Omega$) resistor. The two THGEMs are staggered, providing maximal misalignment between the two set of holes: this configuration increases the PD electrical stability.

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 ($5\mu$m) and Au ($0.2\mu$m) (see Fig. 3), 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 $\sim 3\%$ r.m.s. within a photocathode and $\sim 10\%$ between different photocathodes.

To preserve the QE all operations of transport and installation are performed under controlled atmosphere, in dedicated glove-boxes (Fig. 4.

The hybrid PD anode is segmented in $7.5 \times 7.5$ mm$^2$ pads with $0.5$ mm interpad clearance and each pad is biased at positive voltage ($\sim 620$ V) via an individual (470 M$\Omega$) 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 $\sim 4\%$) and allows restoring the nominal voltage in few seconds. It also allows normal operation of the detector even in the case one 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 $\mu$m 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 on COMPASS RICH-1 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 $\leq 3\%$ (see Fig. 5).
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 frequency the voltage and current values of all the 136 channels; it counts the discharges (events with $\geq 20$ 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 only and the operating conditions are recovered in $\sim 10$ s; their rate is $\sim 1$/h per chamber; discharges in the two THGEM layers are fully correlated, while those observed in the MM are mostly correlated with THGEM ones. No high voltage power supply protection trips were observed during data taking.

The front-end electronics \cite{5}, 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 FP-GAs performing on-line zero suppression with common-mode correction send the detector data to the COMPASS DAQ for data storage and monitor. A cooling system using underpressure water flow assures efficient removal of the heat produced by the readout. The average noise level is $\sim 800$ 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 ($\geq 90\%$) 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 to remain stable at a level of 5% over several months of continuous operation. The ring images provided by the novel detectors are clean and almost background-free: typical examples are presented in Fig.\ref{fig6} 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.

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.\ref{fig7} where the expected exponential behavior is observed over more than two orders of magnitude. The extracted value for the effective gain is $\sim 14000$. 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 $\sim 13$, 9 and 120.

The single photoelectron detection efficiency, estimated from the measured effective gain and the threshold applied to the signals, is $\geq 80\%$; the level of background hits in the ring coronas, originated by the electronic noise, is expected to be $\leq 20\%$: 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 $\sim 1.85$ mrad, as can be seen in Fig.\ref{fig8} where the difference

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{fig5.png}
\caption{Dedicated measurement of ion back-flow fraction to the THGEM photocathode at four different values of the UV light intensities.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{fig6.png}
\caption{Examples of fully contained and shared rings}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{fig7.png}
\caption{Signal amplitude distribution}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{fig8.png}
\caption{Signal amplitude distribution}
\end{figure}
between the Cherenkov angle calculated from the reconstructed momentum of the particle track and the measured Cherenkov angle for each photon candidate cluster is shown: this value fully matches the expectation. 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 crosses represent the measured quantity, while the open circles represent the numbers corrected for the effect of the non negligible probability of a statistical outcome of zero photons when the average is very 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.

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 ($\beta = 1$) can be reliably extracted. The curve shown in Fig. 9 provide a value of $\sim 13 \text{ hits at a Cherenkov angle value of 55.2 mrad}$, which is the traditional reference Cherenkov angle value at saturation for CsI photoconverter and a C$_3$F$_{10}$ radiator at s.t.p.; the number of detected photons from the fit is $\sim 10.5$ and the background contribution is $\sim 2.5$.

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.

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 $\sim 15000$, a noise level of $\sim 800$ equivalent e$^-$ r.m.s., providing a single photon angular resolution of $\sim 1.85 \text{ mrad}$ and about 10 detected photons per ring at saturation.

![Figure 8: Detector angular resolution for single Cherenkov photons](image)

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.

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