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Abstract. In 2016 we have upgraded the COMPASS RICH by novel gaseous photon detectors based on MPGD technology. Four new photon detectors, covering a total active area of 1.5 m^2, have been installed in order to cope with the challenging efficiency and stability requirements of the COMPASS physics programme. The new detector architecture consists in a hybrid MPGD combination: two layers of THGEMs, the first of which also acts as a reflective photocathode thanks to CsI coating, are coupled to a bulk Micromegas on a pad-segmented anode. These detectors are the first application in an experiment of MPGD-based single photon detectors. Presently, we are further developing the MPGD-based PDs to make them adequate for a setup at the future EIC collider. All aspects of the COMPASS RICH-1 Photon Detectors upgrade are presented: R&D, engineering, mass production, QA and performance; the on-going development for collider application is also presented.

1. Introduction

COMPASS [1] is a fixed target experiment located at CERN SPS; it investigates nucleon structure and performs hadron spectroscopy. Many physics channels require en efficient particle identification (PID) over a large momentum range and over a large acceptance; this goal is successfully achieved thanks to the large Ring Imaging Cherenkov (RICH) counter called RICH-1 [2]. Cherenkov photons are generated in a 3 m long C_4F_{10} radiator and focalised on a 5.5 m^2 detection surface. The photosensitive plane, originally made of 16 CsI coated MWPC, underwent two major upgrades which replaced the four innermost photon detectors (PDs) with Multi-anodePMTs (MAPMTs) and four other PDs with MPGD based hybrid chambers [3]. This article is dedicated to the latter upgrade which is the result of a eight year long R&D programme.

2. The Architecture of the Hybrid Detector

Figure 1. (a) schematic view of the hybrid detector, (b) schematic view of a single resistive pad and (c) its equivalent circuit

The basic structure of the hybrid module (Fig.1 (a)) consists of three multiplication layers: two layers of THGEMs [4, 5] and a final Micromegas [6] one. The architecture is completed by two planes of wires. UV light sensitivity is obtained via a thin (300 nm) CsI film deposited on the top of the first THGEM electrode which acts as a reflective photo-cathode. The detectors are operated with $Ar : CH_4 = 50 : 50$ gas mixture. Electrons extracted by Cherenkov photons on the CsI surface are guided into the holes of the first THGEM where the first avalanche occurs. The electron cloud is then driven to the second THGEM where, thanks to complete misalignment of the holes with respect to the first THGEM, the charge is distributed. Finally the charge is guided to the bulk Micromegas where the last multiplication occurs. The signal generated on the anode pad is capacitively transferred to a second pad, parallel to the first one and buried inside the PCB. The two pads are separated by a fiberglass layer 70 μm thick (Fig.1 (b) and (c)).

The intrinsic ion blocking capabilities of the Micromegas as well as the arrangements of the THGEM geometry and electric fields configuration grant an ion back flow to the photocathode surface lower or equal to 3%. Concerning the figures of ion backflow rates, this hybrid architecture has resulted more effective than the use of triple staggered THGEMs [7].

3. Building and commissioning of the final detectors

All THGEMs have the same geometrical parameters: thickness of 470 μm, total length of 581 mm and width of 287 mm. The holes are arranged in a hexagonal matrix formation having diameter of 400 μm and pitch of 800 μm. The holes are produced by mechanical drilling and have no rim.

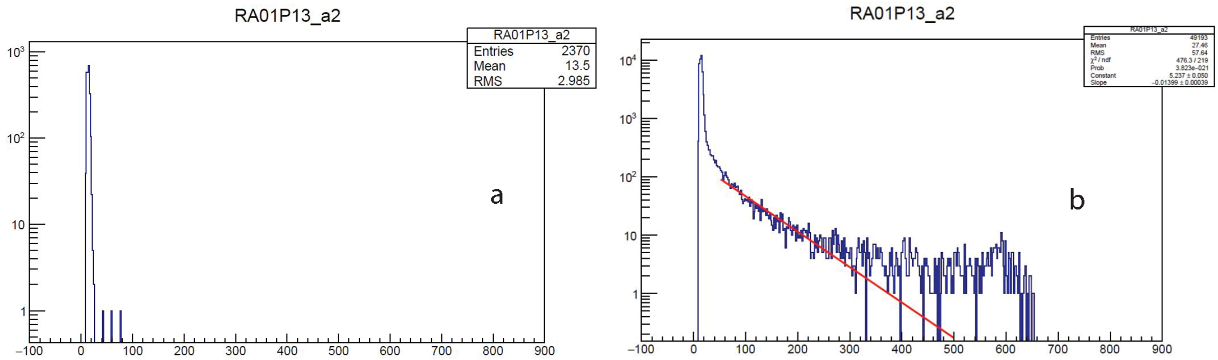

Figure 2. Amplitude spectrum from one of the hybrid PDs; each entry is the response of an anode pad with amplitude above threshold; (a) no beam (random trigger); (b) with beam (physics trigger)

The THGEMs are produced following a dedicated protocol [8], which is one of the results of the dedicated R&D project. The protocol includes raw material selection, THGEM production, quality assessment, characterization, CsI coating, storage and installation.

The Micromegas were produced by bulk technology [9] at CERN EP/DT/EF/MPT workshop over the pad segmented multilayer PCBs. The 600×600 mm^2 PDs were built by mounting two 300×600 mm^2 modules side by side in the same frame.

The deposition of the solid photoconverter for the hybrid photocathodes was performed at CERN Thin film Laboratory following the procedure described in [10]. The assembled PDs were then installed on COMPASS RICH-1 and equipped with front-end electronics, low voltages, high voltages and cooling services.

4. The performance of the novel detectors

The new hybrid detectors were commissioned during the COMPASS data taking period from May to October 2016. The observed average equivalent electron noise is $\sim 900e^-$. After ensuring accurate timing, the amplitude spectra for noise and signals have been collected. With no beam and random trigger the noise part of the amplitude spectrum is observed (Fig.2 (a)). With physics triggers the amplitude spectrum shows the noise part, a prominent single photon exponential part and a tail due to charged particle signals (Fig.2 (b)). A typical discharge rate of few events per day is observed.

Important gain variations with environmental conditions (pressure and temperature) are expected in a multilayer gaseous detector. During the R&D phase these effects had been studied in order to introduce an automated high voltage correction system to compensate for the effect and to stabilize the PD gain response [11]. In figure 3 (c) the measured PD gas pressure and temperature curves are shown. The effective gain stability can be seen in the lowermost plot.

In order to estimate the number of photons per Cherenkov ring the fit function (1) has been used:

$$N_{\theta_{ch}} = p_0 \cdot sin^2\theta_{ch} + p_1 \cdot \theta_{ch} \tag{1}$$

where $N_{\theta_{ch}}$ is the average number of detected photons per Cherenkov ring for a particular Cherenkov angle θ_{ch}, p_0 and p_1 are the fit parameters for the Cherenkov photon part according to the Frank and Tamm distribution and for the background part of the data, respectively. Background is assumed linear in the angle as suggested by geometrical considerations. The fit

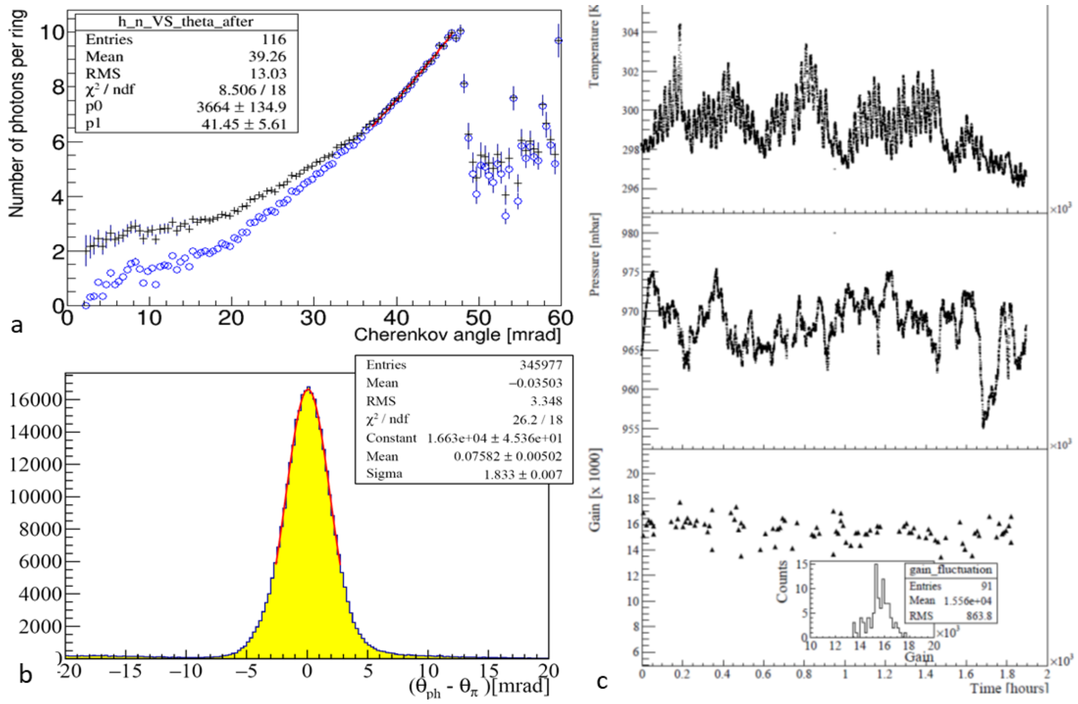

Figure 3. (a) number of Cherenkov photons per ring as a function of the angle (b) distribution of the difference between calculated and measured Cherenkov angle for a pion sample (c) temperature, pressure and effective Gain fluctuations over 2017 COMPASS data taking period

estimation indicates 12.9 photons per ring at Cherenkov saturation angle ($\sim$ 55.2 mrad); the signal part is 10.3 ± 0.4 and background part is 2.6 ± 0.3 (Fig.3 (a)).

Single photon resolution has been evaluated in order to complete the characterization of the RICH PDs. For a sample of identified pions, knowing momentum and refractive index allows to calculate the angle of the Cherenkov photons θ_{π}; for the same sample the angle of the photons, θ_{ph}, is measured. The distribution of the difference of these two angles is plotted in figure 3 (b) (all four hybrid PDs combined) and the residual angular resolution is $\sim$ 1.83 mrad.

5. Future perspectives

The described hybrid PDs can be exploited by the future gaseous RICHes that will be built in next years. Among others, the experiments at the future Electron Ion Collider (EIC) [12] could profit from this technology. However, the challenging environment of a collider needs some adaptations: in a compact geometry a reduced lever arm requires a higher space resolution for ensuring an efficient PID, which translates in a modification of the detector design.

A prototype similar to the COMPASS PDs has been designed and built [13]; it features a pad size reduced to 3×3 mm^2 with 3.5 mm pitch, resulting in 1024 pads covering an active area of 10×10 cm^2. The prototype is fully modular, with front-end electronics and almost all services contained within the active area: detectors covering larger surfaces could be designed by replicating the basic module represented by the prototype. The internal structure of the modular minipad prototype presented in figure 4 (a) and it reproduces the basic scheme of the hybrid MPGD implemented for COMPASS RICH-1.

The detector components have been prepared adopting procedures and protocols similar to those used for COMPASS PDs. The prototype has been tested at INFN Trieste laboratories and in 2018 in a test beam at CERN SPS. The beam particles, alternatively π and μ, traversed

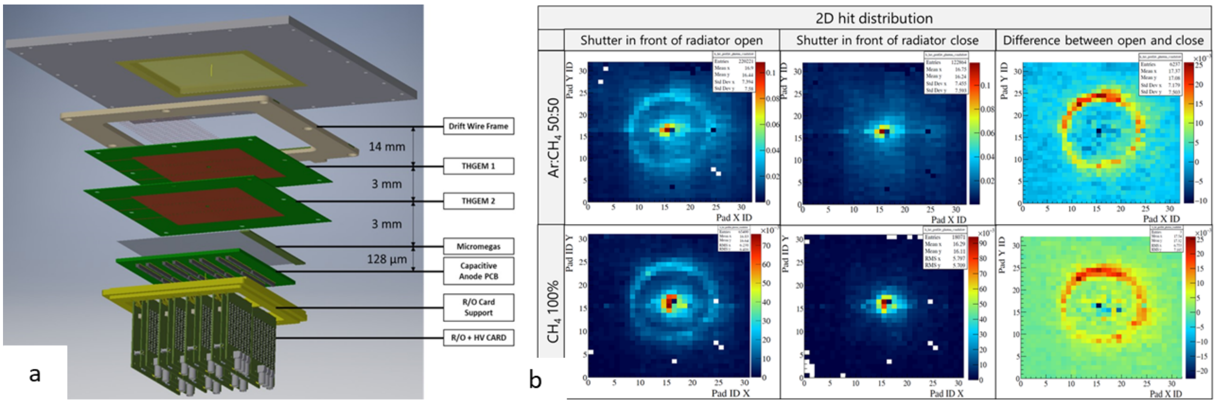

Figure 4. (*a*) Exploded view of Mini-PAD hybrid, (*b*) results of 2018 test beam (see text)

a truncated cone fused silica radiator aligned with the center of the pad plane, generating Cherenkov photons. A shutter sitting between the radiator and the detector made possible to collecte data including Cherenkov photons or excluding them. Figure 4 (*b*) shows the hit map: in left figures the radiator shutter is open, both Cherenkov photons and beam particles are detected; in central figures the radiator shutter is closed, only beam particles are detected; right figures show the difference between the two previous plots. Cherenkov rings are clearly visible.

Non uniformity in gain among pads has also been observed, probably due to different input capacitance for different pads; this effect will be studied in a dedicated prototype currently under development.

6. Conclusions

Novel MPGD-based hybrid single photon detectors, representing the state of the art in the MPGD technology, have been designed, engineered, built, tested and operated in a RICH detector. They are the first application in an experiment of THGEMs and resistive Micromegas, as well as the first application of an MPGD based photon detector. The four chambers have been stably operated during COMPASS data taking periods, matching the physics requirements; they will be a crucial element also for 2021 run. The hybrid technology has proven to be successful and robust, paving the way to further applications in more challenging environments, such as the experiments at the future EIC. The R&D program ongoing in INFN Trieste laboratories moves in this direction, aiming at reducing the detector pad size for improving the space resolution. Up to now, a prototype has been designed, built and tested, giving encouraging results.

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