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The high voltage system of the novel MPGD-based photon detectors of COMPASS RICH-1 and its development towards a scalable High Voltage Power Supply System for MPGDs

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ABSTRACT

The COMPASS RICH-1 detector has undergone a major upgrade in 2016 with the installation of four novel MPGD-based photon detectors. They consist of large-size hybrid MPGDs with multi-layer architecture composed of two layers of Thick-GEMs and bulk resistive MicroMegas. A dedicated high voltage power supply system, based on CAEN HV modules, has been built and put in operation: it controls more than 100 HV channels. The system is required to protect the detectors against errors by the operator, monitor voltages and currents at a 1 Hz rate and automatically react to detector misbehavior. It includes also a HV compensation system against environmental pressure and temperature variation to grant the detector stability. The operation of a MPGD based single photon detector poses challenging requirements to the high voltage power supply systems employed in terms of high-resolution diagnostic features and dynamic voltage control. Systems satisfying all the needed features are not commercially available; for this reason a novel single channel high voltage system matching the MPGD needs has been designed and realized. In this article the COMPASS RICH-1 MPGD HV system implementation is described as well as its performance in terms of stability of the novel MPGD-based photon detectors during the physics data taking at COMPASS. The design, implementation and performance of a novel HV power supply system based on DC to DC converters and controlled by a FPGA device is presented. The capabilities of the first prototype of the new single HV channel power supply are illustrated when operated with a MPGD based single photon detector during a test beam exercise. The preliminary result of the multi channel system are briefly discussed.

1. Architecture of the COMPASS RICH-1 gaseous micro pattern photon detectors

During the 2015–2016 winter shut-down of the COMPASS [1] experiment, approximately 1.4 m² of the active area of the RICH-1 [2–4] Photon Detectors (PD) was upgraded by novel detectors based on Micro Pattern Gaseous Detector technologies. Four new PDs (unit size: 600 × 600 mm²) now replace the MWPC-based PDs in order to cope with the challenging efficiency and stability requirements of the new COMPASS measurements.

The architecture of the novel detectors, illustrated in Fig. 1, combines in a hybrid MPGD arrangement two layers of Thick GEMs [5] (THGEM) to a MicroMegas [6] (MM). The top surface of the first THGEM is coated with a CsI film which acts as a reflective photocathode. THGEMS are 0.4 mm thick, hole diameter and pitch are 0.4 mm and 0.8 mm respectively. The MM uses a pad segmented anode with a pad size of 7.5 × 7.5 mm² and 8 mm pitch. Each hybrid detector is made by two 600 × 300 mm² modules placed side by side to form a single unit. The bulk MM adopts an original implementation making use of discrete resistive elements: HV is applied to the anode

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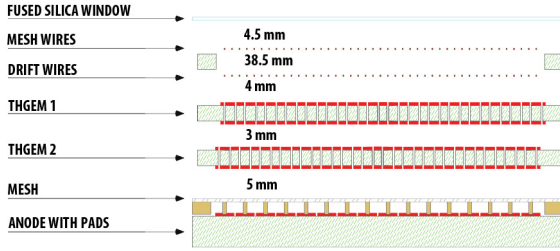


Fig. 1. Sketch of the hybrid single photon detector: two staggered THGEM layers are coupled to a bulk MicroMegas. The drift wire and protection plane are visible. Image not to scale.

pads, each one protected by an individual 470 M Ω resistor, while the signals are collected from a second set of pads, parallel to the first ones, embedded in the anode PCB, where the signal is transferred by capacitive coupling. The large-value resistance decouples each pads from the neighboring ones in case of occasional discharges limiting the voltage (gain) drop to 2 V (4%) [7]. The 4760 pads of a detector are supplied by four HV units, each one providing bias to 1190 pads.

Both surfaces of each THGEM [8] unit ($600 \times 300 \text{ mm}^2$) are divided into 12 electrodes, referred as segments. The segments of the top and bottom THGEM face are grouped by six forming two sectors per THGEM unit, namely four per THGEM plane in a detector. A sector is powered via a single HV channel through a distribution scheme employing a 1 G Ω resistors and fast 20ETS12S¹ diodes to prevent the current flow from a segment to the others in case of a discharge. The detectors are operated with the gas mixture Ar: CH₄ = 50: 50, selected for optimal extraction of the photo-electrons from the converting CsI film to the gaseous atmosphere. The typical voltages applied to the detector electrodes are 1270 V across THGEM1, 1250 V across THGEM2, and 620 V to bias the MM. The drift field above the first THGEM is 500 V/cm, the transfer field between the two THGEMs is 1000 V/cm and the field between the second THGEM and the MM micromesh is 1000 V/cm. This corresponds to effective gain-values for the three multiplication layers around 12, 10 and 120 for a total effective gain of $\approx 15\text{k}$. The distance between the aluminum structural frames at ground and the multiplication electrodes is minimized to reduce the detector dead area, requiring the presence of auxiliary electrodes at sides of the detector frames to restore the optimal electric field configuration. These shaping electrodes, embedded in the Tufnol 6F/453 insulator, count for a total number of four electrodes per detector.

2. The HV system and its control software

The HV system requirements are dictated by the need of current monitoring with fine resolution to control MPGD operation and by the multistage architecture of the novel detectors where the applied voltages are strongly correlated. Further complexity comes from the electrode segmentation resulting in a not trivial control of the system. The implementation of automatic protocols to react to occasional misbehavior of the detectors and to adapt the supply voltages to the environmental changes in pressure (P) and temperature (T) in order to maintain the detector gain constant complete the overall scheme. A user-friendly graphical interface is needed to support the operator in controlling the whole system of about 140 HV power supply channels. Two different power supply units by CAEN² have been selected: THGEM electrodes as well as the protection wires, the drift wires and the lateral auxiliary electrodes are powered by A1561HDN 12-channel fully floating power modules, characterized by a low voltage ripple, typically 5 mV pp from 10 Hz to 100 MHz at full load, fine voltage

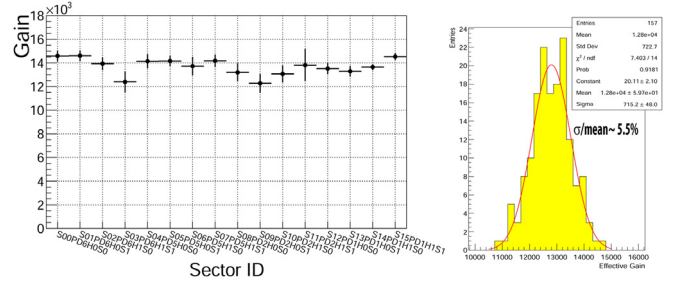


Fig. 2. Left: gain in the sectors of the hybrid detectors. Every four points belong to one hybrid detector, corresponding to four sectors for each detector. Right: a single sector gain measured during the data taking with P and T compensation enabled.

resolution, 100 mV for setting and 10 mV for monitoring, and the fine current resolution, 500 pA for setting the maximum current and 50 pA for monitoring. These figures have been confirmed in operation. MM pads are supplied by A7030DP 12-channel fully floating modules. The typical ripple is <15 mV, 20 mV maximum in the range 10–1000 Hz and <5 mV typical, 10 mV maximum above 1000 Hz. The voltage resolution is 50 mV for setting and 10 mV for monitoring. These modules present a 2 nA current resolution for monitoring. During the detector operation an unexpected variation of the off-set of the current monitoring has been observed. The temperature and pressure measurement is performed via the ADT7420³ sensor, with ± 0.25 °C accuracy, and the MS5611-01BA03⁴ barometric pressure sensor with an accuracy of ± 2.5 hPa. Eight couples of sensors are read, one at the entrance one at the exit of the gas lines of each detector.

The detector gain stability is obtained by the controlled voltage variation operated via the software system according to the equations:

$$G = e^{\frac{\Delta V - \Delta V_c}{dV}} \quad (1)$$

$$\frac{\Delta V}{\Delta V_0} \approx 1 + \alpha \left(\frac{P}{P_0} \frac{T_0}{T} - 1 \right)$$

ΔV is the voltage bias applied to THGEMs or MMs and ΔV_0 , P_0 and T_0 are fixed reference values. The gain G depends on the bias voltage applied to a gaseous detector according to equations Eq. (1), where ΔV_c is the voltage where the extrapolated gain is equal to 1. For the THGEM with the geometric parameters employed for the RICH-1 PD an increase of 1 V will result in a 1% gain increase, while for MM it will result in a 2% gain increase for the gas mixture employed. The detector gain as function of T and P has been measured in laboratory exercises operating the detector at gain values of $\approx 15\text{k}$. The P/T dependence can be approximated with a linear function and its slope extracted from data using equation Eq. (1) where α is the fit parameter. The extracted value of α is 0.55 [7]. A temperature variation of 5 K requires a voltage compensation of about $\approx 1\%$ for each multiplication stage, while it would cause a gain variation of $\approx 40\%$ if not compensated. Similarly, a variation of 10 mbar can be compensated by a $\Delta V = 0.5\%$, while it would cause a gain variation of $\approx 20\%$ if not compensated.

An excellent gain uniformity has been reached over the segments of the detectors by the fine adjustment of the single amplification stages as illustrated in Fig. 2 left. The gain stability of a single sector shows a standard deviation of approximately 5.5%, an excellent result despite the possible limitations related to the temperature non uniformity of the gas in the detector and the linear approximation of Eq. (1)-(2). A dedicated High Voltage Control System (HVCS) software package was designed in order to power the COMPASS RICH Hybrids, taking into account the requirements as specified above. In particular, it handles more than hundred HV electrodes, it continuously performs the gain correction required by the modification of the environment

¹ VS-20ETS12S-M3 Series - Vishay.

² CAEN www.caen.it.

³ ADT7420 - Analog Devices.

⁴ The MS5611-01BA03 - MEAS.

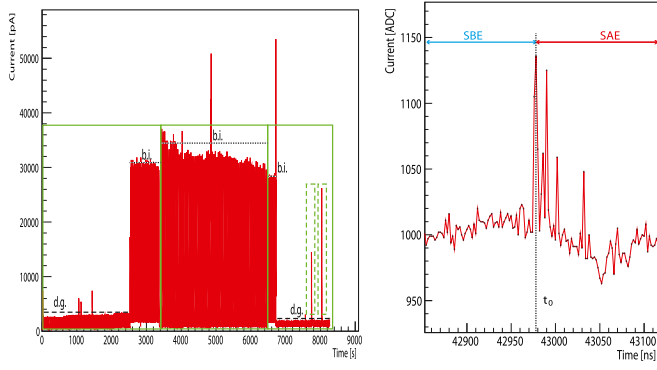


Fig. 3. Left: The current versus time as measured by the HVPSS at the test beam, where the detector was experiencing different beam setting condition and detector working parameters. The areas in the three rectangles highlight the different beam duty cycle, the dotted lines marked with the letters b.i. correspond to different beam intensity conditions, the dashed lines marked with the letters d.g. correspond to different detector operating conditions, the areas in the dotted rectangles highlight two examples of high current surge related to detector discharges. Right: the 500 MHz waveform is collected when a surge current is detected. The number of points before and after the event can be selected by the user.

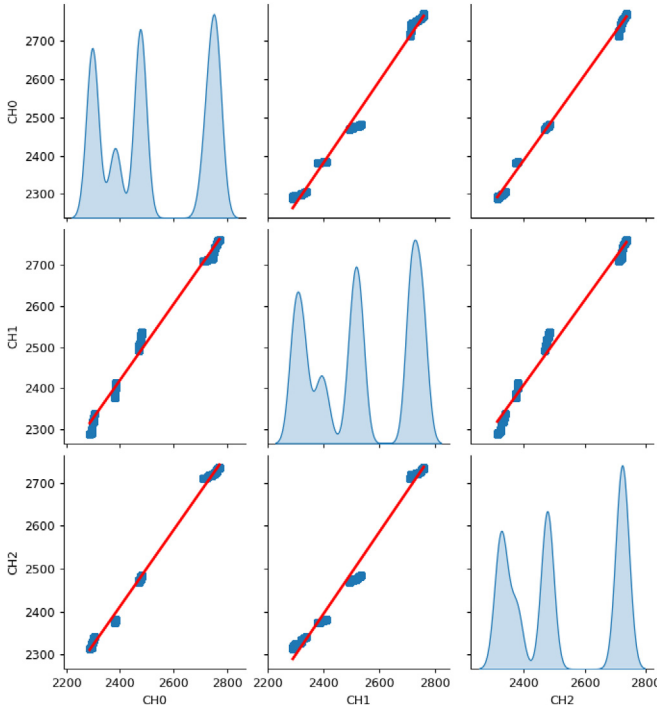


Fig. 4. Pairwise scatter plot matrix of discharge times of three neighboring HV channels.

parameters, checks the detector's electrical stability and reacts to the possible detectors misbehavior, connects to the slow control system of the experiment Detector Control System (DCS) system and offers the experts control and log of the full detector system data via the Distributed Information Management (DIM) servers at 1 Hz rate.

3. The high voltage power supply system for MPGD

The development of a High Voltage Power Supply System (HVPSS) [9] suited for the MPGD technologies originates from the experience gained in upgrading COMPASS RICH-1 with MPGD-based single photon detectors. The system has been designed and built to match all the requirements for the complete monitoring and the accurate handling

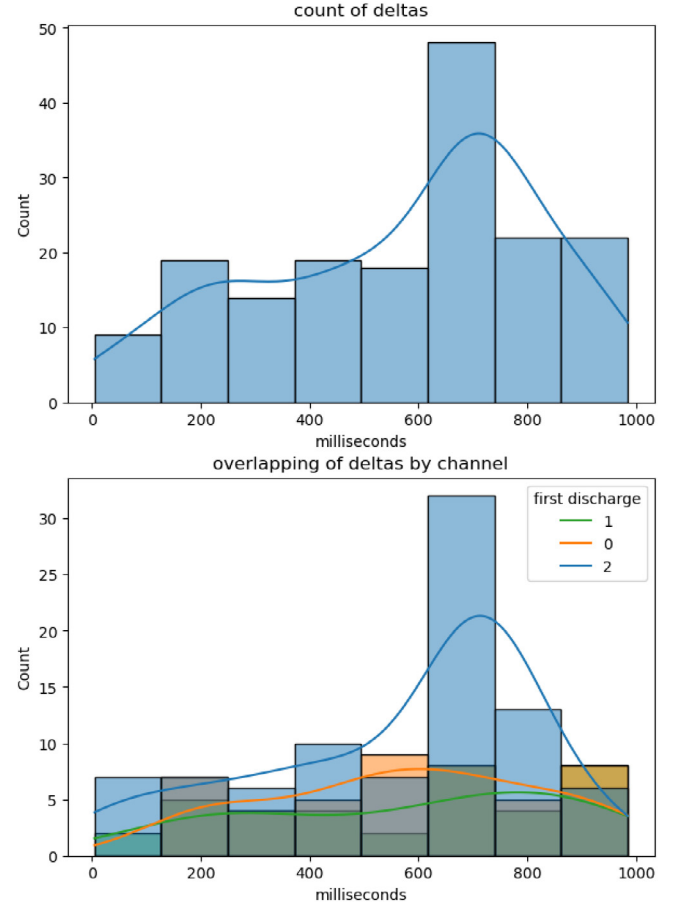


Fig. 5. Histogram of time difference (deltas) after primal discharge in a one-second window and the contribution of each channel into the discharges.

of MPGDs, also those that cannot be satisfied using commercial power supply systems. In particular it allows to perform MPGD R&D when the monitoring of the voltage and current parameters in the order of few ns is needed. The possibility to prevent and limit discharge events requires the use of high-speed electronics with re-configurable capabilities able to take decisions using environmental variables and information broadcast from neighboring independent channels.

The HVPSS is composed of a commercial DC/DC converter based on the ISEG⁵ BPN4010512 module capable to deliver up to 4 kV. The voltage control of the DC-to-DC converter is obtained via a 16-bit DAC MAX5216⁶ and galvanically isolated through a high-performance quad-channel digital isolator ISO7841DWW⁷ with 8 kV peak isolation voltage. A custom made picoammeter board (pA) is built around a AD549LHZ⁸ operational amplifier operated in trans-conductance mode. A dedicated data acquisition board for high speed Analog to Digital Conversion (ADC) has been built employing the low power 8-bit high speed 500 MSPS ADC08500 device. The current resolution of the picoammeter coupled with this ADC spans from 3.9 pA at 0.95 MHz to 65.2 pA at 250 MHz, within a full range of 60 nA.

The CIAA-ACC, an open hardware industrial System-on-Chip (SoC) carrier designed by the Argentinian International Institute of Industrial Technology, has been selected for data acquisition and system operation handling. It houses a Xilinx Zynq 7030 FPGA and micro-processor SoC in a high pin count (HPC) FMC carrier compliant with

⁵ ISEG www.iseg-hv.com.

⁶ MAX5216 <https://www.maximintegrated.com/>.

⁷ ISO7841DWW <https://www.ti.com/>.

⁸ AD549LHZ - ANALOG DEVICES.

the ANSI VITA 57.1 standard [10]. Logic cores designed and implemented in the FPGA subsystem handle the data acquisition and time-deterministic tasks such as raw data sampling, timestamping, signal analysis and diagnostics, hardware peripheral control, and the communication between the FPGA and microprocessor [11,12].

The microprocessor subsystem handles the slow control and communication with an external PC for each channel. The reading of the pressure and temperature sensors and the calculation of the corresponding HV compensation adjustment are carried out by the microprocessor as well without the intervention of the FPGA.

4. The high voltage power supply system performance

A fully assembled system has been employed during a test beam exercise in October 2018 at CERN SPS H4 beam line [13]. The system has been operated for nearly two weeks powering one of the electrodes, in particular the MicroMegas mesh of the last multiplication stage of a hybrid prototype for single photon detection, identical but in the size of the RICH-1 hybrid photon detector described in this paper. During the two week operation, the system has recorded the current provided to the micro-mesh at the sampling rate of 156 Hz and has recorded several discharge events storing the full waveform at 500 MHz sampling rate. The HVPSS monitoring capabilities are illustrated in Fig. 3 (left) where the measured current versus time is plotted. The data points in the plot correspond to the mean value of the histogram generated in the FPGA. Each peak in the figure is correlated to the beam extraction, during which the electron multiplication processes occurs in the MPGD and, therefore, the power supply system must provide current to preserve the correct electrode voltage. During the measurement the detector experienced different beam setting conditions and detector working parameters that can be clearly identified in the plot of the current, as detailed in the figure caption. In Fig. 3 (right) a waveform sampled at 500 MHz is collected when a surge current is detected, i.e. the slope of the current exceeds a threshold values set by the user. The number of data points collected before (SBE) and after (SAE) the surge, can be defined by the user via dedicated registers. The waveform is sent to the remote connected PC for offline analysis.

A three channel HVPSS system has been operated connected to independent segments of the first THGEM layer of a hybrid photon detector. Multichannel time synchronization has been obtained via Precision Time Protocol (PTP) through a high voltage isolation buffer network interface [14]. The electrodes have been biased 10% more than the typical operating voltage resulting in a large rate of discharges between the top and bottom layer of the THGEM. A comparison of the current spikes as a function of the detection time taken during several minutes is plotted for the three different channels in Fig. 4. The red line corresponds to fully correlated events. The diagonal shows a kernel density estimation plot of the time distribution of the electrical discharges on each channel. By choosing an electrical discharge as

primal and measuring the elapsed time for the next one in a one-second window, a principal value of around 600 to 700 ms can be seen in Fig. 5. As shown in the plot, one of the three channels presents a higher contribution to these events. The results illustrated are obtained in an abnormal working condition of the detector and are shown only to illustrate the system's capabilities.

Systematic tests are ongoing at the time this article has been written, improving the 20 ns maximum time uncertainty measured between the different HVPSS system synchronization systems via the PTP protocol.

5. Outlook

The preliminary tests performed with a multi channel system have proven the possibility to operate the HVPSS connected to a MPGD detector to measure the discharges and to verify the possible correlations between the different electrodes. A 7 channels system has been realized and will be operated with a MPGD based single photon detector as in [13] in order to study its final performance. The master-slave scheme, as described in [9] poses few limits in terms of scalability. Improvement of the HVPSS form factor are still to be addressed as well as the radiation hardness, that will be matter of future investigations.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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