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Development of THGEM-based Photon Detectors for COMPASS RICH-1

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Abstract

An R&D project is presented, aimed to develop a high performance gaseous detector of single photons, for the upgrade of the Ring Imaging Cherenkov Counter RICH-1 of the COMPASS Experiment at CERN SPS. The detector has to stably operate at high gain and high rate, to provide good time resolution and insensitivity to magnetic field, and to offer the possibility to cover very large areas at affordable cost. The proposed solution is based on the use of a novel and robust electron multiplier, the Thick GEM (THGEM), arranged in a multilayer architecture, where the first layer is coated with a photosensitive CsI film. A systematic study of the response of THGEMs with various geometrical and production parameters and in different conditions was performed, leading to the choice of a set of optimal parameters. Prototypes of THGEM-based photon detectors able to efficiently detect Cherenkov photons have been built, tested in laboratory and operated in test beam exercises with typical gain of 10^5 and time resolution better than 10 ns. The engineering aspects of building large area (600×600 mm^2) THGEM-based photon detectors are presently being investigated.

Keywords: COMPASS, Photon detectors, RICH, Cherenkov detectors, THGEM, MPGD, CsI

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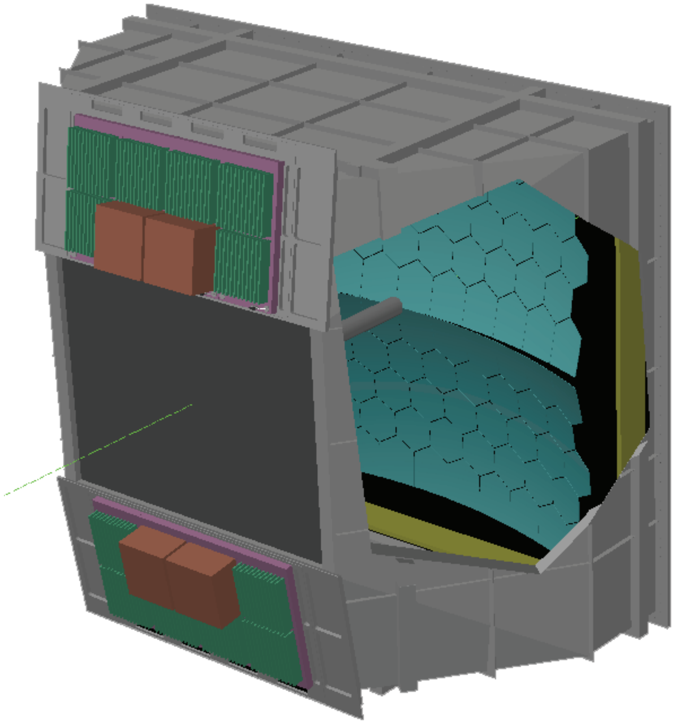

Fig. 1. Artistic view of COMPASS RICH-1.

1. Introduction

The COMPASS Experiment [1] at CERN SPS is dedicated to the study of hadron spin structure and spectroscopy. It has a high luminosity fixed-target setup with a two-stage, large angle and large momentum acceptance spectrometer [2] providing fast and high precision tracking, electromagnetic and hadron calorimetry and particle identification.

Hadron identification requirements in COMPASS are challenging: π-K separation from 3 to 55 GeV/c over a wide angular acceptance (±250 mrad in horizontal and ±180 mrad in vertical), with a beam rate of 40 MHz and trigger rates up to 50 kHz, expected to increase in the incoming years.

The COMPASS RICH-1 detector [3] (see Fig.1) provides the required PID performance using a 3 m long gaseous C_4F_{10} radiator, a 21 m^2 large focusing VUV mirror surface and photon detectors placed outside of the acceptance, covering a total surface of 5.5 m^2.

COMPASS RICH-1 is in operation since 2001, and in its original version it used as photon detectors eight MWPCs with 576×1152 mm^2 active area, equipped with CsI-coated photocathodes and pad readout.

Since 2006 the central region of the photon detectors (25% of the surface) is instrumented with matrices of MAPMTs coupled to individual fused silica lens telescopes and read out via sensitive front-end digital electronics and high resolution TDCs.

A Proposal [4] aiming to start a new series of measurements with an upgraded version of the COMPASS apparatus has been submitted to CERN in 2010 and has recently been approved.

As part of the foreseen improvements to the apparatus, an upgrade of COMPASS RICH-1 is designed, in order to cope with the requests of the future measurements: greater stability and higher efficiency will be achieved by replacing all MWPC-based photon detectors with newly developed, more performing ones, covering an active area of 4 m^2.

This replacement is needed because, in spite of their good performances, MWPCs with CsI photocathodes suffer from some limitations, all related to the photon and ion feed-back from the multiplication region to the photocathode: in experimental environments characterized by high fluxes of ionizing particles they have to be operated at moderate gain (few 10^4) to avoid electrical instabilities, which may cause discharges followed by very long recovery times (about 1 day); they experience a significant decrease of the quantum efficiency caused by aging after accumulating a collected charge of few mC/cm^2 [5]; the time characteristics of the signal are dominated by the slow drift of the positive ions. Both efficiency and rate capability are limited by these features.

In order to overcome these limitations a change in the photon detection technology is required; gaseous photon detectors however presently represent the only available option to equip at reasonable cost very large surfaces with detectors of single photons.

The new gaseous photon detectors for future RICH applications should have:

- a closed geometry to avoid photon feedback
- a reduced ion back-flow to the CsI photocathode
- signals generated by drifting electrons
- simple, robust and cheap basic elements

These requirements suggest the use of Micro-Pattern Gaseous Detectors (MPGDs).

Gas Electron Multipliers (GEMs) [7] are being successfully used in the Hadron Blind Detector [8] of the PHENIX Experiment at RHIC where a 50 cm long CF_4 radiator is directly coupled (without windows) to triple GEMs with CsI photocathodes evaporated on the top surface of the top GEMs. The detector uses CF_4 as multiplication gas and is typically operated at a gain of 4000. Signals from electrons with $\beta \approx 1$ (about 20 photoelectrons) are clearly distinguished from both the smaller signals produced by purely ionizing particles and the larger signals from e^+e^- pairs with $\beta \approx 1$.

In view of the COMPASS RICH-1 upgrade a dedicated R&D project [6] was started, aimed to develop large size gaseous detector of single photons, able to stably operate at large gain, at high rate, and to provide fast response, good time resolution and insensitivity to magnetic field.

Following the indications from previous studies [9] a multilayer structure of THick GEMs (THGEMs) [10] has been chosen as best candidate for the new detector.

This article describes the status of the R&D project to produce THGEM-based large photon detectors for the upgrade of COMPASS RICH-1.

2. Characterization of THGEMs

The THGEM is a robust gaseous electron multiplier based on GEM principle with scaled geometrical parameters; it can be industrially manufactured using standard PCB drilling and etching processes. THGEM geometrical parameters cover wide ranges, typical values being: PCB thickness from 0.3 to 1 mm; holes diameter from 0.2 to 1.0 mm; hole pitch from 0.4 to 1.5 mm. A metal-free clearance ring around the hole, the rim, has widths ranging from 0 (no rim) to 0.4 mm. THGEM-based detectors can be used for various applications [11] since they provide high gains and can stand high rates.

The first step of the COMPASS THGEM R&D project [12] has been a study of the response of different THGEMs: many small size (30 mm x 30 mm active area) THGEM samples have been produced using different production methods, various geometrical parameters (thickness, hole diameter and pitch) and different rim widths up to 100 μm, including samples with no rim.

More than 50 different THGEMs have been characterized using soft X-ray sources and a standard, non flammable gas mixture (Ar/CO_2 = 70/30). The THGEM PCB is placed between two electrodes: the anode plane which is connected to the read-out and the cathode plane, called drift plane, which is made of wires to define the electric field above the THGEM while providing good optical transparency.

Amplitude spectra of the anode signals are collected and the currents absorbed by each electrode (drift, THGEM top, THGEM bottom, anode) are measured in different conditions, to find the optimal configurations of the electric fields and determine the detector response (currents, effective gain and energy resolution) for different bias voltages ΔV (the difference between the THEM top and bottom voltages). Long term (days) measurements of the detector gain stability are performed for each sample.

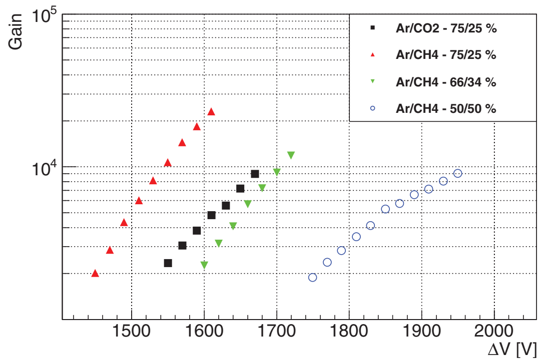

Fig. 2. Gain versus applied bias voltage ΔV for a THGEM with 0.4 mm thickness, 0.4 holes diameter, 0.8 mm pitch and 20 μm rim, for Ar/CO_2 70/30 gas mixture (black squares) and for three different Ar/CH_4 mixtures.

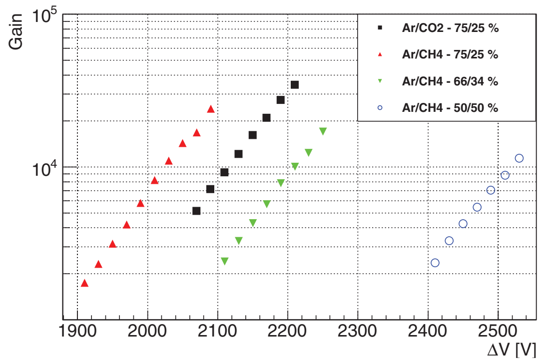

Fig. 3. Gain versus applied bias voltage ΔV for a THGEM with 0.8 mm thickness, 0.4 holes diameter, 0.8 mm pitch and no rim, for Ar/CO_2 70/30 gas mixture (black squares) and for three different Ar/CH_4 mixtures.

The response depends on the values of the external fields too and the optimal drift field is specific for each THGEM type.

The role of each geometrical parameter has been studied and in particular that of the rim, which turns out to be very critical. The THGEM performance depends on the rim production procedure and on the rim size: very large gains can be obtained using samples with large rim.

The gain stability in time strongly depends on the rim size [6]: gain variations exceeding a factor 5 are seen with large rim samples, while gain variations ≤ 20% are observed when the rim is absent.

Thicker samples with no rim are able to provide both large gains and good gain stability: this can be seen in Fig. 2 and Fig. 3 where the gain versus ΔV of two THGEMs having identical hole diameter (0.4 mm) and pitch (0.8 mm), but different thickness and rim (0.4 mm thickness and 20 μm rim in one case and 0.8 mm and no rim in the second case) are presented, for an Ar/CO_2 = 70/30 gas mixture and for three Ar/CH_4 mixtures. The maximum attainable gains are similar for these two cases but the curves of the no rim sample are more regular.

The second step of the R&D project has been an investigation of the response to UV light of THGEMs coated with a (300 nm thick) CsI photoconverting layer on the top face, acting as a reflective photocathode.

Extensive investigations have been performed in the laboratory using either a continuous (D_2) UV lamp or a UV pulsed laser diode with 600 ps long light pulses[1], with attenuated light in order to establish the single photoelectron condition [13].

Electrostatic calculations using COMSOL Multiphysics®[2] and simple simulation exercises using Ansys and GARFIELD have helped reaching a qualitative understanding of the observed THGEM behavior.

The photoelectron extraction and collection efficiency has been studied for various THGEM parameters, field configurations and gas mixtures, leading to the following choices:

- use of pure methane or methane-rich mixtures (Ar/CH_4 ≤ 70/30) to allow for efficient extraction,
- operate with an electric field at the CsI surface in all points larger than 1 kV/cm.
- use a ratio between hole diameter and pitch ≈ 0.5 (larger values of this ratio imply a low active conversion area, smaller values imply low electric field at CsI surface far from the holes)
- use a CsI coated THGEM with reduced thickness.

[1]obtained powering an UV LED by the PDL 800-B pulsed power supply by PicoQuant GmbH, Berlin, Germany
[2]COMSOL, Inc. Palo Alto, www.comsol.com

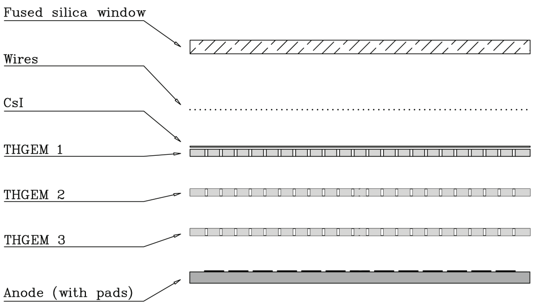

Fig. 4. Scheme of a THGEM-based photon detector

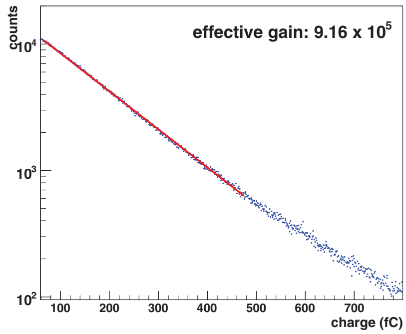

Fig. 5. Typical signal amplitude distribution measured with a triple THGEM detector with an Ar/CH_4 50/50 gas mixture.

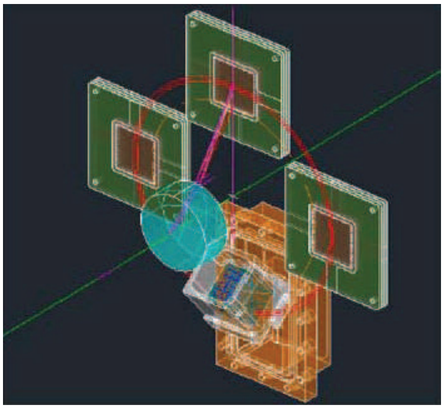

Fig. 6. Schematic drawing of the radiator and the test beam chamber structure.

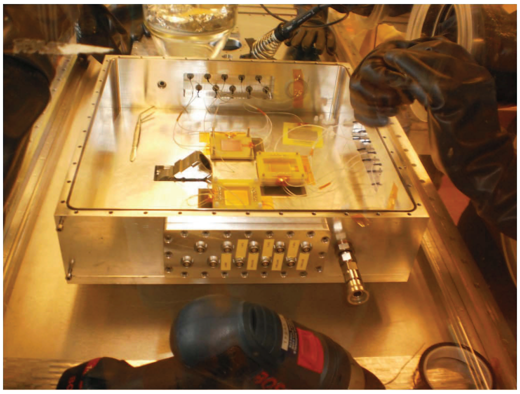

Fig. 7. The internal structure of the test chamber during assembly.

3. Photon Detector prototypes

Photon detector prototypes, consisting in chambers hosting multi-layer THGEM arrangements (see Fig. 4), with CsI coating on the top of the first THGEM, have been built and operated in various configurations. The anodic electrode of the detector is a PCB segmented in pads, allowing either analog or digital readout to be used for the measurements.

A typical signal amplitude distribution [12] for a triple THGEM and a gas mixture of Ar/CH_4=50/50 is shown in Fig. 5: the spectrum is a pure exponential and the average gain is close to 10^6, a condition which is routinely achieved in laboratory tests with small prototypes (active area of 30×30 mm^2).

During 2009 and 2010 several prototypes of triple THGEM photon detectors have been operated in a test beam at the CERN H4 beam line, arranged in different configurations. In one of them a hemispheric fused silica radiator traversed by beam particles was focusing the Cherenkov light onto a ring illuminating at the same time the central pixels of a MAPMT and of three THGEM-based detectors, inside the same chamber volume (see Fig. 6).

Special care was put in the manipulation of the CsI coated THGEMS, in order to always avoid exposure to air during transport and installation: the assembling of the detectors was performed inside a glove box with controlled atmosphere (see Fig. 7). The detectors have been stably operated at gain of $\sim 10^5$.

The MAPMT and two THGEM-based photon detectors inside the chamber were operated at the same time, using an electronic read out chain based on the MAD-4 front-end chip [14] and the F1 TDC [15], fully described in [16].

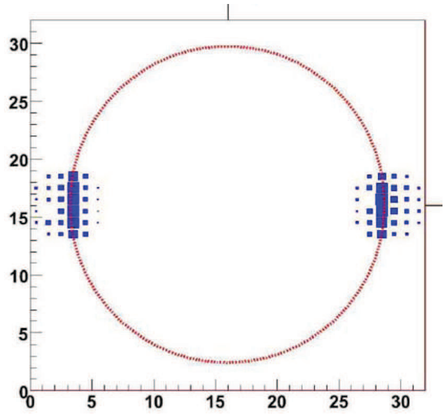

Fig. 8. Superposition of event images. The dotted ring represents the nominal Cherenkov ring

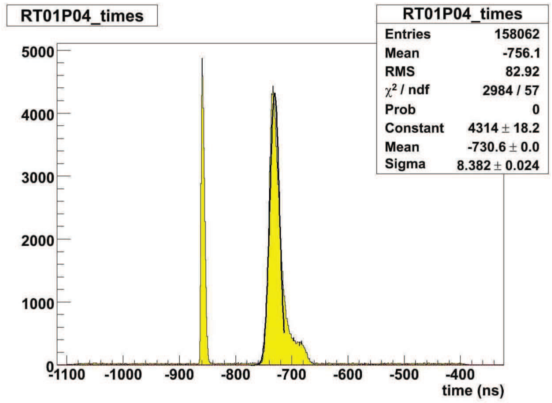

Fig. 9. Time distribution of signals from MAPMT and THGEM-based photon detectors.

In Fig. 8 the superposition of collected events is shown: the spacial distribution of the signal and the observed number of detected photons is in agreement with expectation, indicating an efficient detection of the Cherenkov photons.

The time distribution of the Cherenkov photons detected by the THGEMs is shown in Fig. 9 (right peak) together with the time distribution of the signals from the MAPMT (left peak): a difference in the formation time of 120 ns is seen, in agreement with the expectations from the known drift velocity of electrons in the detector gas mixture. Increasing the ΔV across the CsI coated THGEM improves the time resolution as can be seen from Fig. 10 reducing its standard deviation from 11 ns to 7.6 ns, and significantly decreases the fraction of signals detected at later times (from 22% to 6%). Measurements and simulations show that the electric field values which guarantee the fast photoelectron collection also provide an efficient photoelectron extraction from the CsI: it is thus possible to monitor the photoelectron extraction efficiency from the shape of the time spectrum.

Although the basic architecture of the THGEM-based photon detector has already been defined, alternative options are being considered, with the goal of achieving a significant reduction of the ion backflow: from 10% to 30% of the generated ions reach the photocathode in the present configuration.

4. Large surface Photon Detectors and engineering problems

Prototypes of larger size (100×100 mm^2 and 300×300 mm^{2}sensitive area) THGEM-based photon detectors have been built and tested in the laboratory: they provide the same response as the smaller ones, when all engineering problems related to the larger size are solved.

In view of the high absolute values of the negative voltage applied to the THGEMs (typically about -8 kV) and the large capacitance involved, a segmentation of the electrodes is needed, and a specific study of the optimal segmentation has been performed in order to minimize the maximum energy released by a discharge, the total metal-free area between segments and the number of elements. 20 pieces with different size of copper strips and interstrip spacing have been tested to determine the breakdown voltage values and the effects produced by the discharges: the use of the standard 35 μm thick copper layer on PCBs guarantees high robustness against discharges, and a 0.8 mm spacing between segments avoids propagation of local discharges to the neighboring segments.

The production of large area THGEMs with high quality and uniformity of response is under investigation: at present satisfactory samples of 300×300 mm^2 have been obtained, while a test production of samples having 600×600 mm^2 provided encouraging indications. A strict THGEM quality control protocol has been defined, including systematic optical inspection (and picture collection of potential defects), measurement of the electrostatic quality of individual segments of each sample, validation of the piece in standalone configuration inside a detector with nominal gas and voltage conditions.

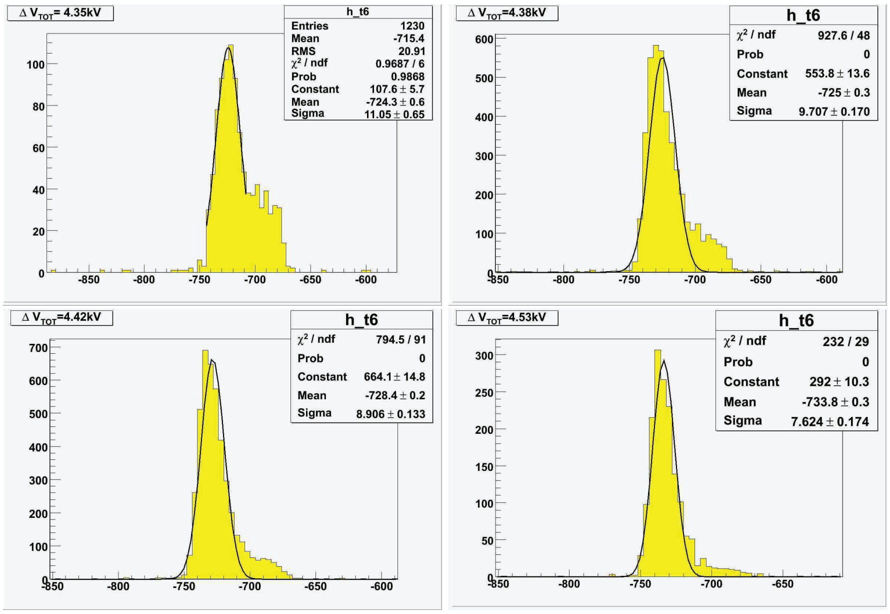

Fig. 10. Timing spectrum for different ΔV across the CsI coated THGEM. Top left: eff. gain = 0.9×10^5, top right: eff. gain = 1.1×10^5, bottom left: eff. gain = 1.4×10^5, bottom right: eff. gain = 2.0×10^5.

Different options for the HV distribution system, the gas flow between THGEM layers, the supports and positioning of THGEMs, etc. are being compared to achieve a proper definition of the mechanical and electrical tolerances and select the optimal solutions.

The minimization of the dead area between neighboring photon detectors imposes challenging constrains to the design of the support structure from both mechanical and electrical aspects: a first prototype of 300×300 mm^2 active area with minimized borders (see Fig. 11) has been produced and successfully tested with X-rays and UV light. It will be tested on the CERN H4 beam line with Cherenkov photons produced in a truncated cone fused silica radiator equipped with a remotely controlled photon interceptor (see Fig. 11) to provide a well known and tunable light yield. The prototype will later be installed and operated in the experimental area of the COMPASS spectrometer, to monitor its response in the real environment where the final detectors should be placed.

For the upgrade of COMPASS RICH-1, 12 photon detectors with 600×600 mm^2 sensitive area are needed: the design of a full scale THGEM-based photon detector has already started and dedicated tests to investigate the main engineering problems are ongoing.

5. Conclusions

The R&D project to develop large area THGEM-based photon detectors for the designed upgrade of COMPASS RICH-1 has made substantial progress.

More than 50 THGEMs with different parameters have been characterized, allowing to perform the basic choices for the detector architecture; several prototypes of photon detectors have been built, operated in the laboratory at gains close to 10^6 and studied in test beam exercises.

The time response has been investigated in detail, showing a time resolution better than 10 ns and offering a possibility to monitor the photoelectron extraction efficiency by time measurements.

The main engineering problems related to the production of large area THGEM-based photon detectors are actively being investigated.

COMPASS RICH-1 will most likely be the first large RICH equipped with THGEM-based photon detectors.

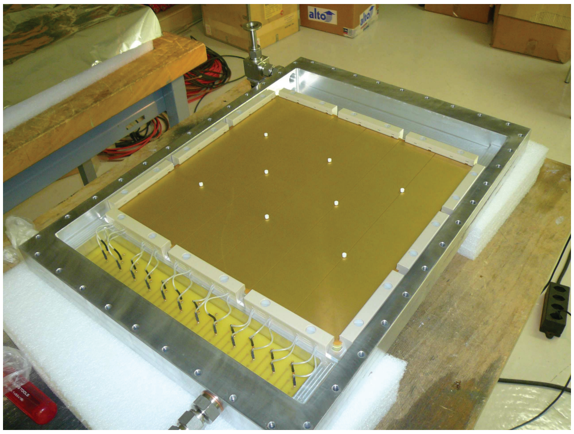

Fig. 11. Picture of the first prototype of 300×300 mm^2 active area with minimized lateral borders during the assembling phase.

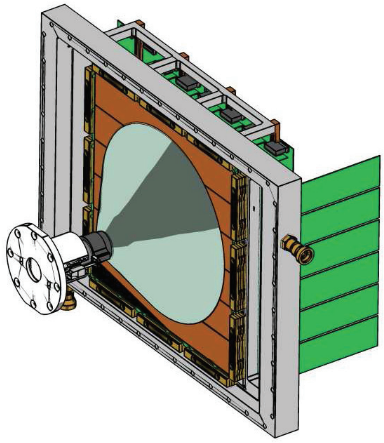

Fig. 12. Drawing of the large area prototype illuminated by Cherenkov light

Acknowledgements

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References

[1] The COMPASS Collaboration, CERN/SPSLC/96-14, SPSLC/P 297, March 1, 1996; CERN/SPSLC/96-30, SPSLC/P 297, May 20, 1996; Phys. Lett. B 612 (2005) 154; Phys. Rev. Lett. 94 (2005) 202002; Eur. Phys. J. C 41 (2005) 469; Phys. Lett. B 633 (2006) 25; Phys. Lett. B 647 (2007) 8; Phys. Lett. B 647 (2007) 330; Nucl. Phys. B 765 (2007) 31; Eur. Phys. J. C 52 (2007) 255; Phys. Lett. B 660 (2008) 458; Phys. Lett. B 673 (2009) 127; Phys. Lett. B 676 (2009) 31; Phys. Lett. B 680 (2009) 217; Eur. Phys. J. C 64 (2009) 171; Phys. Rev. Lett. 104 (2010) 241803; Phys. Lett. B 690 (2010) 466; Phys. Lett. B 692 (2010) 240; Eur. Phys. J. C 70 (2010) 39; Phys. Lett. B 693 (2010) 227.

[2] P. Abbon et al., Nucl. Instr. and Meth. A 577 (2007) 455.

[3] E. Albrecht et al., Nucl. Instr. and Meth. A 502 (2003) 112; Nucl. Instr. and Meth. A 502 (2003) 236; Nucl. Instr. and Meth. A 502 (2003) 266; Nucl. Instr. and Meth. A 510 (2003) 262; Nucl. Instr. and Meth. A 518 (2004) 586; Nucl. Instr. and Meth. A 553 (2005) 53; Nucl. Instr. and Meth. A 553 (2005) 135; Nucl. Instr. and Meth. A 553 (2005) 215; Czech. J. Phys. 56, Suppl. F (2006) 307; Nucl. Instr. and Meth. A 567 (2006) 104; Czech. J. Phys. 56, Suppl. F (2006) 315; Czech. J. Phys. 56 Suppl. F (2006) 323; Nucl. Instr. and Meth. A 567 (2007) 114; Nucl. Instr. and Meth. A 572 (2007) 419; Nucl. Instr. and Meth. A 580 (2007) 906; Nucl. Instr. and Meth. A 581 (2007) 419; Nucl. Instr. and Meth. A 587 (2008) 371; Nucl. Instr. and Meth. A 595 (2008) 177; Nucl. Instr. and Meth. A 595 (2008) 194; Nucl. Instr. and Meth. A 595 (2008) 204; Nucl. Instr. and Meth. A 595 (2008) 233; Nucl. Instr. and Meth. A 616 (2010) 21; Nucl. Instr. and Meth. A 639 (2011) 15; Nucl. Instr. and Meth. A 639 (2011) 219; Nucl. Instr. and Meth. A 639 (2011) 271.

[4] CERN/SPSC/2010-014, SPSC/P 340, May 17, 2010; CERN/SPSC/2010-022, SPSC/M 772, September 3, 2010.

[5] A. Braem et al., Nucl. Instr. and Meth. A 553 (2005) 187; H. Hoedlmoser et al., Nucl. Instr. and Meth. A 574 (2007) 28.

[6] M. Alexeev et al., Nucl. Instr. and Meth. A 610 (2009) 174.

[7] F. Sauli, Nucl. Instr. and Meth. A 386 (1997) 531.

[8] W. Anderson et al., Nucl. Instr. and Meth. A 646 (2011) 35.

[9] R. Chechik and A. Breskin, Nucl. Instr. and Meth. A 595 (2008) 116 (and references therein).

[10] P. Jeanneret, Ph.D. Thesis, Neuchâtel University, 2001; L. Periale et al., Nucl. Instr. and Meth. A 478 (2002) 377; P.S. Barbeau, et al., IEEE Trans. Nucl. Sci. NS-50(4) (2003) 1285; R. Chechik et al., Nucl. Instr. and Meth. A 535 (2004) 303.

[11] A.Breskin et al. Nucl. Instr. and Meth. A 598 (2009) 107 (and references therein).

[12] M. Alexeev et al., Development of THGEM-based Photon Detectors for Cherenkov Imaging Counters, 2010 JINST 5 P03009.

[13] M. Alexeev et al., Nucl. Instr. and Meth. A 623 (2010) 129.

[14] F. Gonella, M. Pegoraro, CERN-LHCC-2001-034, p. 204.

[15] H. Fischer, et al., Nucl. Instr. and Meth. A 461 (2001) 507.

[16] P. Abbon et al., Nucl. Instr. and Meth. A 587 (2008) 371.