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Production and quality control of Micromegas anode PCBs for the ATLAS NSW upgrade

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Abstract: To exploit the full discovery potential of the Large Hadron Collider an upgrade towards high luminosity (HL-LHC) is scheduled for 2024–25. Simultaneously to the accelerator, the experiments have to adapt to the expected higher particle rates and detector occupancy. Within the next long shutdown in 2019-20 the innermost end-cap regions of the ATLAS Muon spectrometer will be replaced by the New Small Wheels (NSW) including Micromegas detector modules of several m^2 size.

The Micromegas readout anode boards, representing the core components of the detector, are manufactured in industry, making the NSW Micromegas the first Micro Pattern Gaseous Detector (MPGD) for a major LHC experiment with a crucial industrial contribution. Production of the up to 2.2 m long boards is a serious challenge for industrialization technology and quality control methods.

Keywords: Detector design and construction technologies and materials; Manufacturing; Materials for gaseous detectors; Micropattern gaseous detectors (MSGC, GEM, THGEM, RETHGEM, MHSP, MICROPIC, MICROMEGAS, InGrid, etc)

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Contents

1 Introduction

The two innermost forward detector wheels of the ATLAS Muon spectrometer [1] will be replaced by New Small Wheels (NSW) [2]. They comprise Micromegas and small Thin Gap Chamber (sTGC) detectors in an overlapping structure of eight large and eight small sectors (figure 1). Each sector hosts two quadruplet-structures (4 detection planes per quadruplet) of each technology. The Micromegas [3] cover an active area of 1280 m^2, divided in 128 quadruplets of 4 different module types and comprise more than 2 million channels in total.

Given the dimensions of the detectors, industrial production of its components becomes a prerequisite for successful construction of the NSWs. The industrialization of the anode printed circuit boards (PCBs) is a major challenge for industrial suppliers on the production side and for the collaboration regarding quality assurance aspects.

We reported on the design, production methods and quality control applied during the production of PCBs for full scale test-module (Module 0) construction throughout 2015 in [4]. Therefore this publication is focused on changes between the pre-series and final NSW PCB layout (section 2) and quality control methods (section 3). An overview on the production process and quality requirements is given in appendix A.

2 Layout of the NSW Micromegas anode PCBs

The NSW sectors cover a radial distance of more than 3.5 m. Since standard PCB production equipment is limited to 60 cm board width, the readout structure of each sector is segmented into 8 boards in radial direction (figure 1). They are grouped in inner modules (SM1 / LM1) comprising 5 PCBs and the 3 boards wide outer modules (SM2 / LM2).

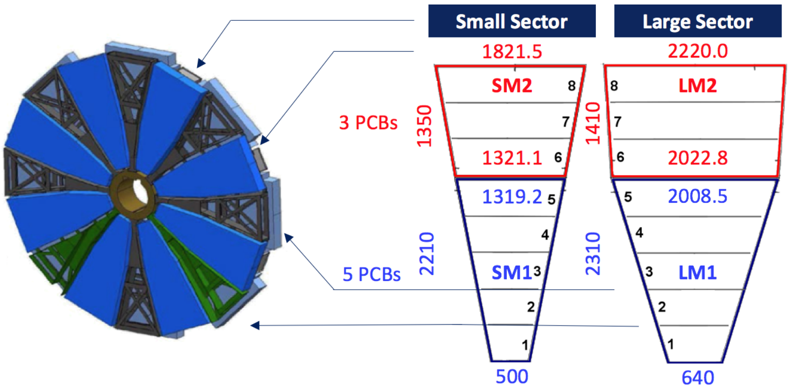

Figure 1. The New Small Wheel subdivision in small (S) and large (L) sectors and the division of the sectors' readout planes into 8 anode PCBs grouped in two modules. (Dimensions in mm.)

The four quadruplet layers contribute to the Muon track reconstruction with a spatial resolution of O(100 µm) in the radial direction, as required for the NSW tracking detector [2]. To measure the second coordinate with O(2 mm) resolution, the strips on two planes are inclined by $\pm 1.5°$, forming a stereo pattern when mounted in back-to-back configuration [5]. This segmentation results in 32 different types of anode PBCs. A total of 2048 boards is required to construct all Micromegas modules for two New Small Wheels.

2.1 Cross-section of the resistive anode PCBs

The anode board carrying the copper readout structure, the protective resistive anode [6] and the amplification gap defining pillars is the most complex component of the Micromegas. Its stacked structure is shown in figure 2 and the layout of each layer is described in the subsequent paragraphs. A precision on 10 µm level or better is required for the thickness and the lateral extend of these structures.

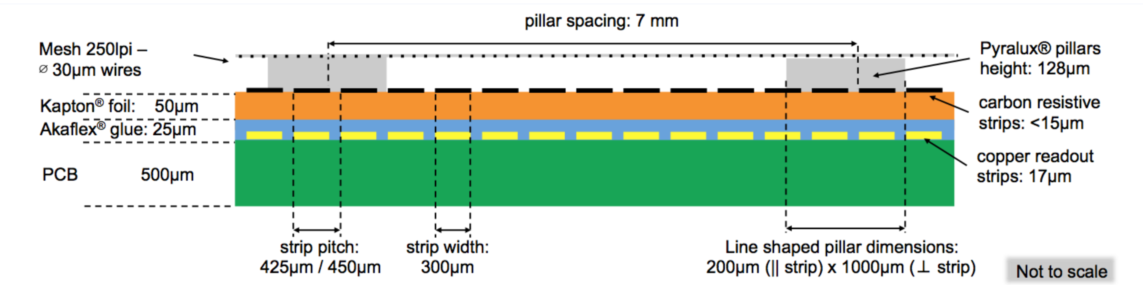

Figure 2. Schematic of a NSW Micromegas anode PCB (cross-section).

2.2 Copper pattern layout

The boards can be divided into an active area, suitable for particle detection, and rim areas on the left and right of each board (figure 3) and additionally on the top / bottom on the largest / smallest board of each module.

The active area is covered with 1022 readout strips of 300 µm width and a pitch of 425/450 µm for small/large sector boards. Although each PCB could accommodate for 1024 strips according to its width, the first and the last strip have been removed to allow a larger mechanical clearance for edge cutting and joining of the PCBs to a readout plane. The large extend of the modules calls for central stiffening screws, to counteract mechanical deformation (e.g. due to gas over-pressure). The positions for these interconnections have been revised with respect to the pre-series to minimize the deformation. Now they are all located within the active area, not anymore along the board edges. The readout strips are not interrupted by these interconnection holes, but guided around as shown in figure 3 (B).

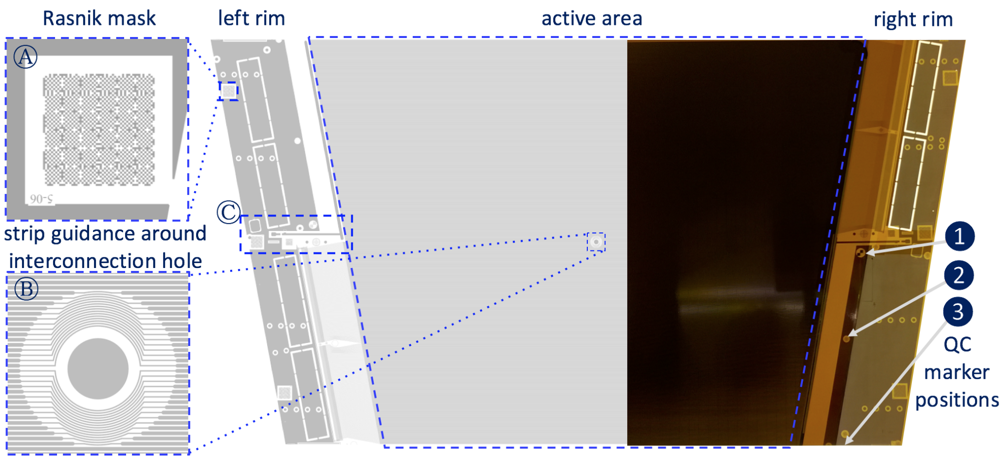

Figure 3. Drawing of a Micromegas anode PCB copper pattern (left) and picture of the finalized board (right). The location and structure of Rasnik masks (A), strip routing around holes (B) and the center of the rim area (C) (see figure 4) are shown, as well as the location of three quality control markers (see figures 5, 6 and 7).

The strips are routing half-and-half to the right and left rim where the front-end electronic is connected by elastomeric connectors, avoiding soldering. Aside these connection regions, cut-outs are foreseen to establish direct contact of the electronics with the cooling channel, embedded in the panel. The boards' position references are located in the center of the rim, surrounded by different targets for precise board-to-board alignment (see section 2.5). This area furthermore contains soldering pads for ground, high voltage supply and electronic components as displayed in figure 4. In total each side rim carries four Rasnik masks [7] (figure 3 (A)) for precise measurement of the boards dimensions and position.

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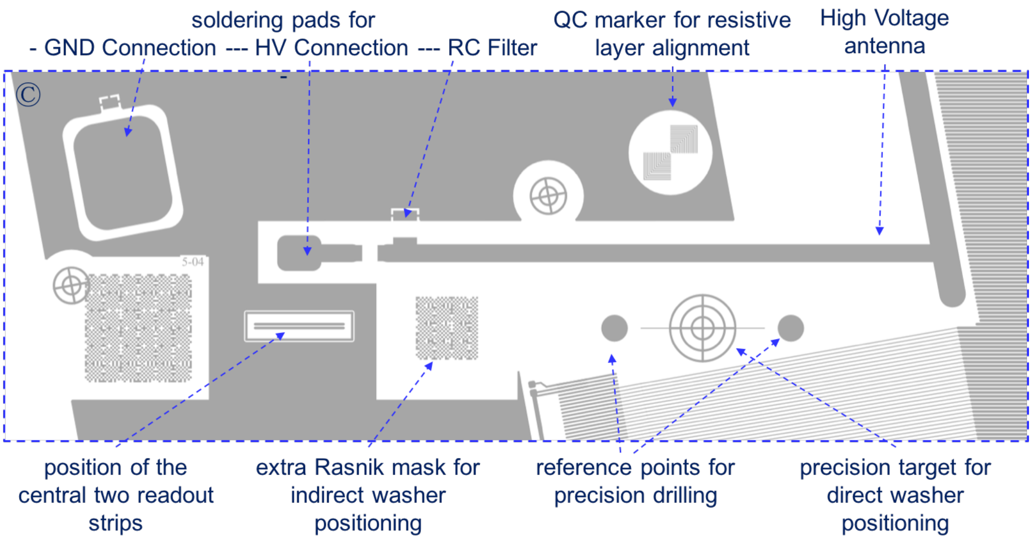

Figure 4. Copper pattern at the rim center of the NSW Micromegas anode PCBs with the positions of several references (bottom), soldering pads and a quality control marker (top).

2.3 Design of the resistive anode

The resistive pattern is screen-printed on an insulating Kapton® foil, which is glued on top of the readout structure. The resistive pattern consists of strips congruent to the readout layer, but with an array of bridges connecting each strip alternating with its top or bottom neighbor every 10 mm. This yields a more homogeneous surface resistivity which is less effected by damages of single lines. The strips are interrupted in their center to divide the surface into two high voltage sectors, each of them supplied through a broad distribution line along the rim, interconnecting all resistive lines.

2.4 Structure of the pillar array

A pattern of Pyralux®-coverlay pillars with precise height is developed on top of this stack. The pillars are arranged in a triangular lattice with 7 mm spacing. Mechanically supporting the mesh in the Micromegas, the amplification gap height is defined by the height of this pillar layer. Additionally to the pillars covering the area, a frame of coverlay is surrounding the active area of the joint detection plane to ensure the correct height of the mesh along its circumference.

Deviating from the original design of 230 µm diameter cylindrical pillars, line shaped pillars of 1000 µm length and 200 µm width have been chosen and positioned perpendicularly to the strips. This increases the contact surface between the anode and the pillar thus ensuring adhesion of the pillar on the Kapton® foil and consequentially reduces the risk of missing pillars during production.

2.5 In-plane alignment of single PCBs

Each readout plane is composed of several PCBs and therefore the total accuracy of the detector module crucially depends on the precise positioning of the readout strips in the plane. The position and orientation of a board is defined by one reference hole (right) and one slot (left) along the boards long direction [8]. To transfer the intrinsic accuracy of the copper pattern (verified to 30 µm in radial direction, see section 3) to a mechanical hole and slot pair, the copper pattern includes a pair of targets aligned with the board axis and the strip pattern. These targets are accompanied by different reference markers (figure 4) to be utilized as references by different mechanical methods: precision holes can be drilled directly into the target by referring to the two equidistant points aside the target. Alternatively precision washers can be glued on the target either directly using telocentric optics for the washer positioning or by indirect reference utilizing the Rasnik masks. Although the three methods are interchangeable, different module construction consortia rely on the different techniques. All three methods have proven to be feasible and yield the required accuracy of better than 50 µm.

3 Quality control and quality assurance

The quality control (QC) and quality assurance (QA) scheme for the NSW Micromegas anode PCBs (see appendix A) relies on stringent material control and immediate testing during production. Nevertheless a comprehensive acceptance control of the finalized product is of major importance to cross-check industry-QC measurements and ensure flawless functional efficiency of each single board.

3.1 Acceptance quality control at CERN

Given the quantity of boards to be produced and tested, the quality control methods need to be:

- Quick and accurate
- Reproducible and operator independent
- Documented and traceable

To assure traceability, each board carries an in-erasable ID, composed of its type and a unique three-digit number. The ID will remain visible during each step of detector assembly and on the final modules, allowing cross-checking of the detector component with the QC results. All quality control measurements are documented and accessible via a web browser interface. The results of several dedicated measurement programs (dimension QC, etching quality test, resistivity mapping, pillar height control) can directly be interpreted by the interface. The application can exchange board ID based information with the CERN QC Database (DB) for long-term data storage, the Kobe QC DB to access results on first Kapton® foil QC and the NSW Logistics DB.

3.2 QC markers for quick and reliable measurements

Different types of QC markers have been developed and implemented to speed up and simplify PCB testing. They allow a quick and accurate visual QC of different characteristics of the board geometry.

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Copper pattern — resistive layer alignment (figure 5). A pattern of 100 µm wide lines and gaps is included in the copper layer while a double-square marker is printed with the resistive pattern. The markers are placed congruently on both layers and cover each other if the layers are perfectly aligned and their dimensions are in agreement with the design. Each visible line or gap indicates a misalignment of 100 µm. The difference of the misalignment observed on two distant markers sheds light on the relative dilatation of the two patterns.

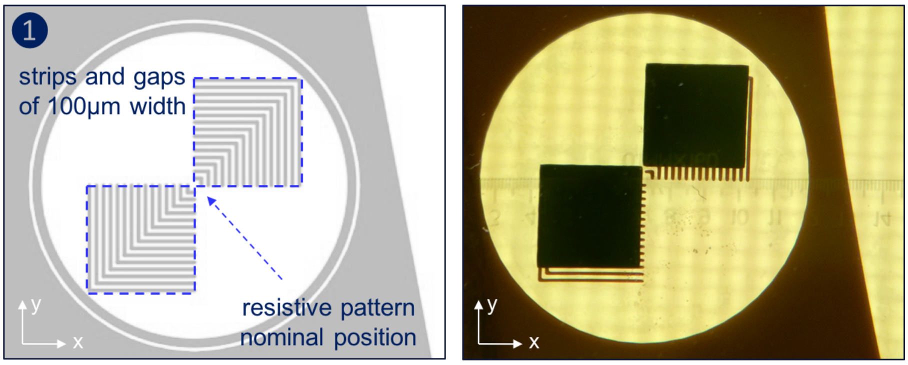

Figure 5. Left: concept of the layer-to-layer alignment QC marker with the pattern of 100 µm wide lines and gaps on the copper pattern and the nominal position of the covering squares. Right: exemplary picture showing a misalignment of +400 µm in vertical and -150 µm in horizontal direction.

Hole positioning (figure 6). A copper ring of 100 µm thickness is positioned concentric with the nominal drilling position. The hole radius is 150 µm smaller than the copper ring radius. Once drilled, the hole position can be validated on ±100 µm precision if the copper ring is not touched by the hole. The board is disqualified if the ring is completely ruptured, proving a position inaccuracy of ≥200 µm.

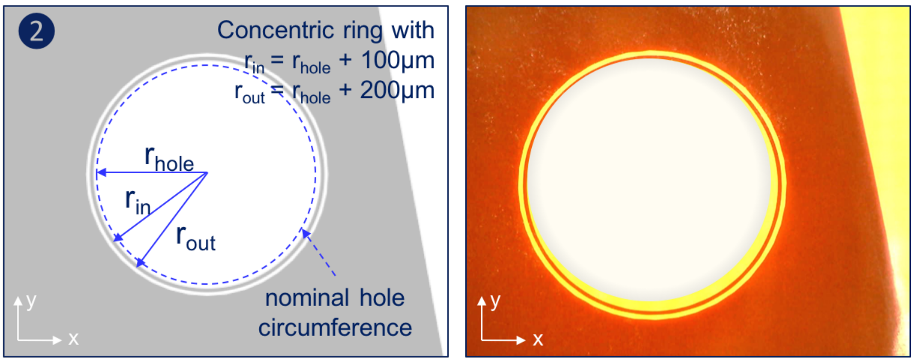

Figure 6. Left: concept of the hole position QC marker with a concentric 100 µm thick copper ring around the nominal hole circumference. Right: exemplary picture showing a deviation of the hole position of ≥100 µm but ≤200 µm referred to the copper pattern.

Edge milling accuracy (figure 7). A set of four ladder-patterns with 100 µm lines and gaps are placed across the milling line and shifted by ±50 µm to each other. By counting the not-removed lines the milling precision can be assessed on a ≤50 µm-level. Combined with a straightness measurement along the edge, performed with a rectified ruler on an illuminated table, two markers on the left and right are sufficient to judge the overall milling accuracy.

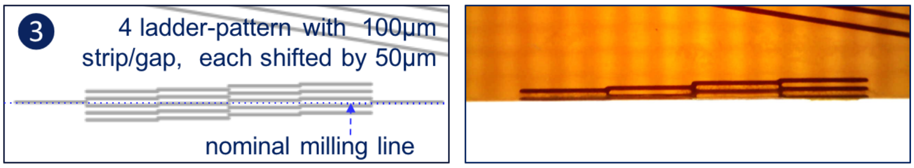

Figure 7. Left: concept of the edge accuracy QC marker comprising four ladder-patterns with 100 µm strips and gaps positioned across the nominal cutting line. Right: exemplary picture showing a cut slightly too far inside the board with ≤50 µm deviation from nominal.

4 Conclusion: status of NSW Micromegas anode board production

To speed up production throughput and mitigate the risk of delay, the production of the anode PCBs for the NSW is split between two manufactures: ELVIA (France) and ELTOS (Italy). Both companies participated in the Module 0 test production during the last 18 month and optimized their procedures in production and quality control. Based on this experience several small but nevertheless important changes to the design have been implemented to cope with occurred problems like missing pillars, and to optimize QC processes utilizing QC markers. The first boards of the series production have been produced and are compliant with all quality requirements. The production of the more than 2000 boards will continue until end 2017.

Acknowledgments

Our sincere thanks to R. de Oliveira and his team at the CERN PCB workshop for their invaluable expertise and advice during design, technology transfer and production follow-up. We thank our industrial partners ELVIA and ELTOS for the close exchange and fruitful collaboration.

A PCB production and quality requirements

The production process follows a multi-step processing that has been introduced in [4] and is graphically summarized in figure 8. While all individual processes are standard in PCB industries their uncommon combination, the large size of the PCBs and the stringent requirements for accuracy and quality (listed in figure 8) result in a serious challenge. The detailed QC scheme in-between production steps ensures high quality and optimized yield throughout the production and allows to detect occurring problems with minimal delay.

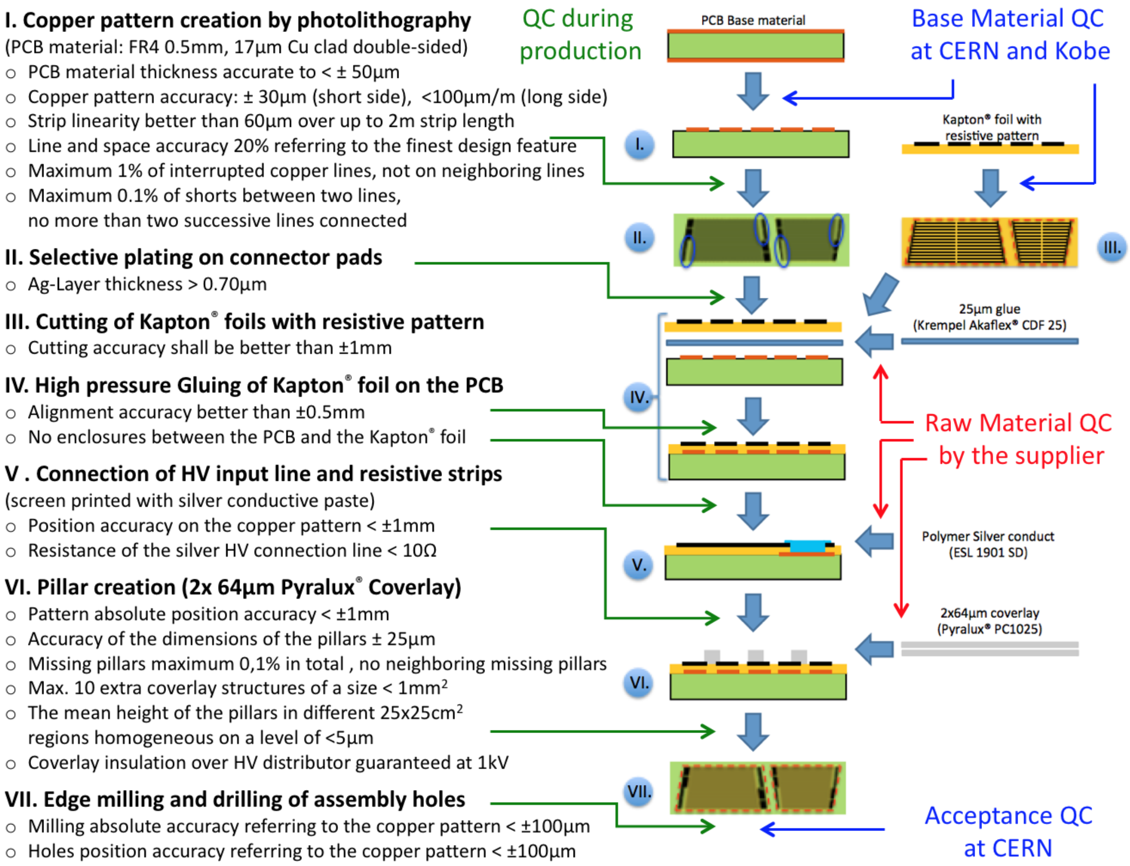

Figure 8. Multi-step workflow during NSW Micromegas anode PCB production (left) and quality requirements for each process (right). Quality control steps performed by the PCB producer (green), other industrial suppliers (red) and our collaboration (blue) are indicated. Updated figure based on [4].

All production steps and quality requirements are explained in detail in [4]. It should be noted that the selective plating on the connector pads (step II.) is not bound to the processing order displayed above and can be shifted in-between any subsequent production steps.

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