Resistive Micromegas for the Muon Spectrometer Upgrade of the ATLAS Experiment

Ourania Sidiropoulou

on behalf of the ATLAS Muon Collaboration

MPGD 2017
Outline

Introduction:
- ATLAS NSW project overview
- Detector requirements

Construction of Micromegas Detectors:
- NSW Micromegas detectors
- Anode panels & QA/QC
- Drift panels
- Quadruplet assembly

Results of first NSW prototypes
The ATLAS New Small Wheel (NSW) project

- Upgrade of the ATLAS innermost end-cap muon stations during LHC Long Shutdown 2 (2019/2020)
- Operation up to and including High Luminosity LHC

Pseudorapidity coverage: $1.3 < |\eta| < 2.7$

Each sector consists of **Micromegas & sTGC** arranged in quadruplets (high redundancy)

Both detector technologies with triggering and tracking capabilities:
- Micromegas: primary tracking detector
- sTGC: primary for trigger

Disk like design:
- 8 small sectors
- 8 large sectors

~10 m
Detector Requirements

- Spatial resolution for up to 32° track inclination:
  - 100 μm in precision coordinate ($\eta$)
  - ~mm in azimuthal coordinate ($\varphi$)
- 1 mrad angular resolution (from HL-LHC L1 trigger requirement)
- Bunch crossing identification
- Efficiency > 98%
- Rate capability up to 15 kHz/cm$^2$
- Good ageing properties

$T$ type bulk resistive Micromegas chamber

- strip pitch = 400 μm, strip width = 300 μm
- pillar diameter = 500μm, pillar pitch = 5mm
- amplification gap = 128 μm, drift gap = 5mm
**NSW Micromegas detectors**

**Construction of MM quadruplets is distributed over 5 countries & CERN**
- 4 different types (SM1, SM2, LM1, LM2)
- For each type 32 chambers (128 in total)

In each quadruplet:
- 2 (η) layers with parallel readout strips
- 2 (φ) layers with readout strips inclined by ±1.5°

Challenge in construction: alignment of the strips on each detection layer
- 30 μm RMS in η
- 80 μm RMS in z

The largest Micromegas-based project ever built
Micromegas Detector Design

Anode & Drift panel:
- Based on stiff but lightweight panels
- Cathode on drift panel
  - Mesh (to ground) is mechanically supported by the drift panel in order to facilitate cleaning & simplify commissioning
- Anode on readout (R/O) panel
  - Resistive layer for spark protection

When the detector is closed the mesh is resting on the pillars and kept in position by electrostatic force
Anode Panels
Micromegas Anode Boards

Production done in industry

Raw Materials
- kapton, resistive paste

Industry:
- Matsuda (Japan)

Kobe & Tokyo
- QA/QC

Raw Materials
- FR4, coverlay, silver paste

CERN
- QA/QC & logistics
- material storage

Construction Sites
- (DE, IT, FR, RU)

Industry:
- Elvia (FR)
- Eltos (IT)

The side of the anode boards on one dimension is limited (width=60cm) due to the available machines in companies. For this reason the Micromegas panels are made from different boards.
Anode (Readout) Boards

- Copper readout strips (photo-lithography etching)
- 50μm Kapton® foil with resistive strips (screen-printing)
- 25μm solid glue (Krempel Akaflex®)
- High temp. and high pressure gluing
- Polymer Silver contact (screen-printing)
- Pillars creation: 2x64 μm Pyralux® coverlay (lamination)

Kapton® foil: 50μm
Akaflex® glue: 25μm
FR4 glass fiber epoxy: 500μm

Strip width: 300μm
Strip pitch: 425μm/450μm
Pillar distance: 7.0mm
Pillars: 1200μm x 200μm

(depend on the board type)
Resistive strips foils

- Screen-printed resistive strips on kapton (Matsuda - Japan)

- Same width and pitch as the copper strips
- Ladder structure for a homogeneous impedance between the high voltage supply point and each position on the anode

Main production of resistive foils completed!
Long pillars (1.2 mm x 0.2 mm) running perpendicular to the readout strips do not affect the detector performance, while ensuring larger attachment surface.

Presented yesterday at the poster session:
“Characterization of Micromegas detector with elongated pillars”
Readout Boards: Meeting requirements

2015

- Enclosures and bubbles

2016/17

- Great improvement:
  - Technological transfer
  - Procedure and work-flow optimization

- Silver line HV connection

Delicate procedure → vast improvement
Readout Boards: Meeting requirements

- **Edge Cutting**

- **Resistive vs readout strip alignment**

Great improvement:
- Procedure and work-flow optimization

Improved with design changes allowing for an easier alignment during stacking and check after gluing.

Mass production started in January 2017
Board expansion during Series Production

Elongation observed consistently due to humidity uptake

**Solution:**
- Copper etching mask rescaled according to measured expansion (<500μm/m)
- Wait for the expansion of the boards (4 weeks) before cutting, milling & drilling
On-line QC form

Readout Boards: QA/QC at CERN

0) **table**: unwrapping
1) **table**: logistics
2) **tool chest**: tools, gloves, wipes & chemicals
3) **top light table**: visual inspection, etching quality, electrical tests
4) **back light table**: agreement holes & Cu pattern, edge precision & straightness, agreement resistive & Cu pattern, pillar pattern
5) **rasmask granite table**: absolute dimensions & shape O(30μm)
6) **granite table**: pillar height measurement
7) **table**: resistivity mapping
8) **shelf**: final storage
9) **table**: strip capacitance measurement
Readout panel construction

Mechanical requirement is very strict in order to reach a position accuracy of 100 μm in a single detector layer

- Panels, sandwiches of FR4 PCB sheets with an aluminum honeycomb core, must reach a surface planarity better than 37 μm RMS

- Horizontal deviation of readout strips must not exceed 30 μm RMS

\[ \text{planarity transferred with the use of granite tables} \]

\[ \text{readout PCBs are positioned on reference surfaces; exact position is done via alignment pins-holes or precision washers} \]
Readout panel construction

- Position and alignment of PCBs on granite table
- Sucking to granite table and sealing with tape → planarity transfer
- Glue distribution on PCBs
- Placing aluminum bars and honeycomb
- Placing second readout panel (sucking to stiffback)

well defined panel thickness
Planarity measurement

Planarity is measured with a triangulation distance laser sensor mounted on a Coordinate Measurement Machine (CMM).

1. side

2. side

thickness @ assembly holes: 11.559±0.032 mm  (11.564 design)
Drift Panels
An ideal mesh would be:

- **as thin as possible and almost flat**
- **sufficiently robust** to be stretched over large areas and counteract deformations under the electrostatic forces
- creating **independent electrical fields** in both volumes (shielding the fields)
- completely **transparent to electrons** traversing the low drift field into the amplification field but fully absorbent to ions drifting in the other direction
- Allowing **gas exchange** between volumes

Detailed studies performed:

Micro-mesh selected:
plain weave mesh
with 71μm aperture,
30μm wire diameter
and 250 lines per inch

**Production finished in June 2016!**
Drift panel construction

- Mesh stretching and gluing on transfer frame

Mesh tension ~10 N/cm

- Similar construction concept as for the readout panels (granite table, vacuum)

Average mesh tension: 11.66 ± 0.38 N/cm (RMS)
Quadruplet assembly
Quadruplet assembly is done with a dedicated tooling to help keeping panels in vertical position and to avoid the bending of panels under their own weight.
Example from SM1 M0 Italy

1st Panel - Drift
2nd Panel – Readout Stereo
3rd Panel – Central Drift
4th Panel – Readout Eta

Alignment of readout panels

Assembly completed

May. 24 2017
O. Sidiropoulou
Results of first NSW prototypes
SM1 module-0 (INFN)

First M0 completed in May 2016 and first test-beam in June

Spatial resolution

**Precision coordinate**
from Layer1-Layer2
Difference /√2

\[ \sigma_{\text{gaussian}} = 81 \mu\text{m} \]

Evts in Fit range = 95%
*Well within requirements*

\[ \chi^2 / \text{ndf} = 27.54 / 9 \]
Prob = 0.001139
Constant = 489.9 ± 11.8
Mean = 0.02562 ± 0.00158
Sigma = 0.08136 ± 0.00141

**2nd coordinate**
from the stereo planes,
compared with y-coordinate from reference chambers

\[ \sigma_{\text{gaussian}} = 2.4 \text{ mm} \]

Evts in Fit range = 95%
*Good agreement with expectations*

\[ \chi^2 / \text{ndf} = 52.51 / 39 \]
Constant = 140.3 ± 3.5
Mean = -0.7924 ± 0.0472
Sigma = 2.408 ± 0.041
After refurbishing of the readout boards some HV issues that were observed during test-beam were solved.

- Alignment within a maximum deviation of ± 80 μm
- Indication of layer-to-layer rotation or strip pattern global deformation
  - Now 20 C-CCD cameras were installed for alignment checks when stacking the panels for assembly

**Very good performance!**

NOTE: Empty bins correspond to layers that are operated in lower HV
Chamber was completed in November 2016 → joined effort by CERN, Dubna, Thessaloniki

- Readout PCBs as the other M0 had a number of issues and repaired as much as possible before assembly

- During first operation some HV sectors had high currents

---

**Pillar recreation**
Chamber re-opened after Christmas break for further investigation:

- Signs of local discharges of few cm$^2$ found in the HV sectors that had high currents (up to 20μA localized in few cm$^2$)

- Indication of reduction of the amplification gap (shorter pillars)

- Scanning Electron Microscope analysis on two samples (clean & spark region) did not show any pollution other than damage on carbon matrix:
LM2 module-0 (CERN, Dubna, Thessaloniki)

- After reparation and cleaning, quadruplet reassembled in April 2017.
- On-going measurements in the RD51 GDD laboratory (X-Rays and cosmics)
Conclusions

- Construction methods of the NSW Micromegas detectors have been established
- Production of mesh and resistive foils have been completed
- Mass production of the readout boards have started
- Construction of the Micromegas quadruplets is about to start

Thank you!
Additional Slides
Anode (Readout) Boards

I. Copper pattern creation by photolithography
   (PCB material: FR4 0.5mm, 17μm Cu clad double-sided)
   - PCB material thickness accurate to < ±50μm
   - Copper pattern accuracy: ±30μm (short side), <100μm/m (long side)
   - Strip linearity better than 60μm over up to 2m strip length
   - Line and space accuracy 20% referring to the finest design feature
   - Maximum 1% of interrupted copper lines, not on neighboring lines
   - Maximum 0.1% of shorts between two lines, no more than two successive lines connected

II. Selective plating on connector pads
   - Ag-Layer thickness > 0.70μm

III. Cutting of Kapton® foils with resistive pattern
   - Cutting accuracy shall be better than ±1mm

IV. High pressure Gluing of Kapton® foil on the PCB
   - Alignment accuracy better than ±0.5mm
   - No enclosures between the PCB and the Kapton® foil

V. Connection of HV input line and resistive strips
   (screen printed with silver conductive paste)
   - Position accuracy on the copper pattern < ±1mm
   - Resistance of the silver HV connection line < 10Ω

VI. Pillar creation (2x 64μm Pyralux® Coverlay)
   - Pattern absolute position accuracy < ±1mm
   - Accuracy of the dimensions of the pillars ± 25μm
   - Missing pillars maximum 0.1% in total, no neighboring missing pillars
   - Max. 10 extra coverlay structures of a size < 1mm²
   - The mean height of the pillars in different 25x25cm² regions homogeneous on a level of <5μm
   - Coverlay insulation over HV distributor guaranteed at 1kV

VII. Edge milling and drilling of assembly holes
   - Milling absolute accuracy referring to the copper pattern < ±100μm
   - Holes position accuracy referring to the copper pattern < ±100μm

QC during production
Base Material QC at CERN and Kobe
Raw Material QC by the supplier
Polymer Silver conduct (ESL 1901 SD)
25μm glue (Krempl Akaflex® CDF 25)
Kapton® foil with resistive pattern
2x64μm coverlay (Pyralux® PC1025)
Acceptance QC at CERN
Drift panel QA/QC

1) Visual inspection
2) Holes position/dimension: boards are compared with reference boards to ensure superimposition of assembly holes through precise plugs
3) Board-to-board joint cut quality
4) Height measurement with caliper
5) Back-to-back test: symmetry w.r.t. center