Construction and Quality Assurance of Large Area Resistive Strip Micromegas for the Upgrade of the ATLAS Muon Spectrometer

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Outline

1 Motivation for the ATLAS NSW Upgrade Project

2 Construction of NSW Micromegas Quadruplets
   - Design of the Micromegas Quadruplets
   - Requirements for Micromegas Detectors
   - Panel Construction
   - Alignment of the Readout Boards

3 Quality Assurance of NSW Micromegas Quadruplets
   - Planarity Measurement of the Panels
   - Verification of Strip Alignment
   - High Rate Irradiation Tests

4 Summary
LHC high luminosity upgrade

- 2021: Run 3: $2 \times \mathcal{L}_{\text{design}}$
- 2026: Run 4: $5 - 7 \times \mathcal{L}_{\text{design}}$

upgrade of inner end-cap region of Muon Spectrometer (Small Wheels) before Run 3
Motivation for the ATLAS NSW Upgrade Project

- full inclusion of New Small Wheel in trigger
- 90% of trigger are fake in end-cap region
  - A track pointing to IP (good muon track)
  - B no hit in Small Wheel (fake)
  - C background event: not pointing to IP (fake)
- MDT efficiency loss:
  \[ L > L_{\text{design}} \implies \varepsilon < 90 \% \]
  \[ L > 2L_{\text{design}} \implies \varepsilon < 60 \% \]
- maintain current excellent momentum resolution for higher luminosity:
  \[ \Delta p_T \approx 15 \% @ p_T = 1 \text{ TeV muons} \]

\[ \implies \text{New Small Wheel needs trigger and high rate capable new technology:} \]
- sTGC and
- Micromegas
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4 Summary
Layout of the New Small Wheel

- disk-like design:
  - eight large sectors
  - eight small sectors

- sector: two Micromegas wedges sandwiched by two sTGC wedges
  - eight layers of sTGCs (trigger)
  - eight layers of Micromegas (tracker)

- Micromegas wedges subdivided in two Micromegas quadruplets

Micromegas quadruplet strip layout
Design of the Micromegas Quadruplets

2-3 m² Micromegas

Micromegas quadruplets:
- three drift panels
- two readout panels
- four meshes mounted on drift panels
- four gas volumes between panels are the active Micromegas layers
Resistive Strip Micromegas

single active plane of a quadruplet:
- cathode
- grounded micro-mesh
- anode strip structure

position reconstruction:
- charge centroid over strip-cluster
- track reconstruction via \( t_{\text{drift}} = f(\text{strip}) \)
Production of Resistive Strip Readout Boards

- PCB with copper readout strips
- Kapton foil with resistive pattern aligned to readout strips with markers
- Kapton foil glued on top of readout strips
- Silver connection between HV connector and resistive pattern
- 128 \( \mu \text{m} \) coverlay pillars as mesh support
Requirements for Micromegas

maintain current excellent momentum resolution for higher luminosity:
\[ \Delta p_T \approx 15\% \atop p_T = 1 \text{ TeV} \text{ muons} \]
\[ \implies 100 \, \mu m \text{ spatial resolution in a single plane} \]

- 30 \, \mu m alignment accuracy of readout strips on the individual PCBs
  and particularly the alignment within a quadruplet
- 80 \, \mu m accuracy perpendicular to the plane
Panel Construction in two Gluing Steps: Step 1

1. PCBs placed and aligned on granite table
2. Vacuum applied to granite table and sealed with tape
3. Glue distributed on PCBs
4. Aluminum bars and honeycomb placed on top of halfpanel
5. Halfpanel cures overnight in vacuum bag
6. Halfpanel removed and sucked to stiffback
7. Second set of PCBs placed on granite table
8. Glue distributed on PCBs
Panel Construction in two Gluing Steps: Step 1

- PCBs placed and aligned on granite table
- sucked to granite table and sealed with tape
  \[\Rightarrow\] planarity transfer
- glue distributed on PCBs

Diagram:
- vacuum
- granite table
- sealing tape
- glue
- halfpanel cures over night in vacuum bag
- halfpanel removed and sucked to stiffback
- second set of PCBs placed on granite table
- glue distributed on PCBs
Panel Construction in two Gluing Steps: Step 1

- PCBs placed and aligned on granite table
- Sucked to granite table and sealed with tape
  $\Rightarrow$ planarity transfer
- Glue distributed on PCBs
- Aluminum bars and honeycomb placed on top
- Halfpanel cures over night in vacuum bag
Panel Construction in two Gluing Steps: Step 2

- PCBs placed and aligned on granite table
- Sucked to granite table and sealed with tape
- Glue distributed on PCBs
- Aluminum bars and honeycomb placed on top
- Halfpanel cures overnight in vacuum bag
- Halfpanel removed and sucked to stiffback
- Second set of PCBs placed on granite table
- Glue distributed on PCBs

PCBs placed and aligned on granite table
⇒ Planarity transfer

Philipp Lösel (LMU)
Panel Construction in two Gluing Steps: Step 2

- PCBs placed and aligned on granite table
- sucked to granite table and sealed with tape
  $\Rightarrow$ planarity transfer
- glue distributed on PCBs
- aluminum bars and honeycomb placed on top
- halfpanel cures over night in vacuum bag
- halfpanel removed and sucked to stiffback
- second set of PCBs placed on stiffback
- glue distributed on PCBs
- stiffback with halfpanel placed on distance pieces
  $\Rightarrow$ well defined panel thickness
Panel Construction in one Gluing Step

main difference: no halfpanel, only PCBs sucked to stiffback

all other steps as before
Panel Construction in one Gluing Step
Alignment of the Readout Boards

- Eta Readout Plane
- SE8
- SE7
- SE6

V-spacer
L-spacer

global alignment

precision washer circular
precision washer oval

relative alignment

precision target well aligned to strips

top view
precision target

24 masks
Two Versions of Alignment: Precision Holes or Washers

- Planar precision plates
- Well aligned
- Pins + precision holes

- Accuracy < 5 μm

- Washer gluing

- Accurate alignment frame
- Global alignment on granite table
- Relative alignment using pins
Two Versions of Alignment: Precision Holes or Washers

- Precision hole
- Planar precision plates
- Well aligned
- Pins + precision holes

- Precision washer
- Glued
- @ position of target
- Accurate alignment frame
- Global alignment on granite table
- Relative alignment using pins

- 10 precision pins
- Precision pins fixed on the granite table
- The RO PCBs are laying with the pillars against the granite table
- Round and long-hole washers have been glued precisely aligned onto the precision markers
- The PCBs are pre-aligned
Two Versions of Alignment: Precision Holes or Washers

- Planar precision plates
- Well aligned
- Pins + precision holes

- Precision washer glued at position of target

- Accurate alignment frame
- Global alignment on granite table
- Relative alignment using pins

10 precision pins

- Precision pins fixed on the granite table
- Aligns the 3 PCBs relative to precision pins using a V and L spacer
- Aligns the 3 PCBs relative to each other by bushes and pins

- Brass bushes, stainless pins fit into the precision washers
Mesh Stretching and Mounting

Mesh stretching:
- in cleanroom
- pneumatic clamps
- 1. step: glued on transfer frame
- 2. step: glued onto mesh frame
- tension $\approx 11 \text{ N/cm}$
Mesh Stretching and Mounting

**mesh stretching:**
- in cleanroom
- pneumatic clamps
- 1. step: glued on transfer frame
- 2. step: glued onto mesh frame
- tension ≈ 11 N/cm

Average mesh tension: 11.66 ± 0.38 N/cm (RMS)
deformation of drift region for outer detector layers due to 2 mbar overpressure in gas volumes
\[\Rightarrow\] 4-7 interconnections integrated in Micromegas quadruplets

example: LM1
ANSYS FEM simulation

max. deformation 115 \(\mu\)m
O(mm) without interconnections
Precision Assembly using Dedicated Pins

pins and bushes precisely glued into the panel using precision templates
\[\Rightarrow\] perfect alignment of both readout panels
Fully Assembled Micromegas Quadruplet

pressure sensors and micrometer adjustment units
\[\Rightarrow\] assembly free of forces
\[\Rightarrow\] free movement of pins in bushes
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4 Summary
Planarity Measurement of the First SM2 Readout Panel

1. side

2. side

thickness @ assembly holes: 11.559±0.032 mm (11.564 design)

pillars + coverlay
eltx. region (as expected)

active area σ=17μm

eltx. region pillars coverlay

active area σ=15μm

eltx. region pillars coverlay
Verification of Strip Alignment using Coded Masks

- 5 × 8 coded masks on each readout plane
- Contact CCDs mounted on reference jig
- Position and rotation of coded masks can be calculated
  \[ \Rightarrow \text{verification of strip alignment} \]

Accuracy: \( O(\mu m) \)

- Yellow squares: coding info
- Red squares: position where lines with coding info cross

C-CCD
Verification of Alignment of the two Surfaces of a Panel

- measure coded masks (Rasmasks) on two opposite sides of the panel
- no contact between tool and panel
- reconstruct positions with respect to each other
- can also be used on whole quadruplet or with global reference masks
- calibration with one transparent mask
Calibration using Cosmic Muons, Alternative: X-Rays

2 external tracking references (2 MDTs)
study of principle:

- 1 m² prototype detector with two readout boards
- no alignment tool used for gluing of anode structure

Muon tracks show:

- variation of gap size between PCB plates during gluing
- **shift**: 100 μm
- **rotation**: 350 μm/m

**NSW-MM**: elimination of this effect by precise tooling
High Rate Behavior: GIF++

- Gamma Irradiation Facility (GIF++) at CERN
  - 14 TBq $^{137}\text{Cs}$ source
  - 662 keV gamma flux $\approx 6 \times 10^7$ Hz/cm$^2$
- high rate irradiation tests of all modules
construction of Micromegas quadruplets for the ATLAS NSW Upgrade:

- mechanical requirement can be fulfilled
- precise alignment of readout boards using precision templates
- planarity transfer from granite table using vacuum technique
- interconnections to prevent chamber deformations

quality assurance of NSW Micromegas quadruplets:

- planarity measurements using laser triangulation heads
- verification of strip and surface alignment using coded masks
- calibration with cosmic muons or X-Rays
- high rate irradiation test in GIF++
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- high energy testbeam campaigns @ CERN to check spatial resolution, efficiency, etc.
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THANK YOU
Backup
Alignment of Resistive Pattern to Readout Strips

Copper pattern on the PCB

Resistive pattern on Kapton foil

Kapton on top of PCB
Precision Washer glued on PCBs

very precise alignment frame mounted on granite table

- 2 external pin for global alignment
- 6 pins for relative PCB alignment
- washer gluing with telecentric camera
Alternative Method: SM2/LM1

- 5 precision plates
- well aligned
- pins + precision holes

precision holes drilled in PCB

- 10 precision pins
- drilled @ position of target
**LMU surveyor**

- Minimal head with C-CCD
- Cone
- Slotted cone

**Plug-in for cable to driver**
- 89.9mm
- Camera head

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**LMU surveyor**

- Constructed and calibrated by Brandeis
- Arrived at LMU (KW 40, 2016)
- Surveyor is precise in x and y
Rasnik Analysis I

Rasnik analysis

- Rasnik mask: coded mask, every 9th row/column contains coding info - deviation from chessboard pattern
- Rasnik analysis within LWDAQ software from Brandeis finds rasnik pattern and marks it
  - Yellow squares: coding info
  - Red squares: position where lines with coding info cross
Picture of SACLAY mask from C-CCD

- Position of RP on mask [μm]
- Mask coordinates x, y
- Magnification
- Rotation [mrad]
- Uncertainty on x, y
- Square size 220μm
- Reference point (RP) = center of C-CCD

Orientation code = 4

0: no analysis
1: perform rasnik analysis

Flash time of the 4 LEDs [s]

Private network
Contact IP address

C-CCD is connected to driver socket 6
Module05 – Read-Out panels – I

• Strip alignment (will be used for Mod05 panels):
  • **C-CCDs** inserted on table and stiffback plates: 20 masks per panel will be read-out;
  • Cameras & minimal heads tested, software finalized;
  • **Calibration procedure**
    • **Jig** built and precision spheres measured in Freiburg;
    • **Surveyor** is at Pavia
two Monitored Drift Tube (MDT) reference chambers
⇒ two reference tracks

- two trigger scintillator hodoscopes
  ⇒ second coordinate
  ⇒ segmentation of test Micromegas in 10 cm wide segments

- 34 cm iron absorber ⇒ $E_\mu > 600$ MeV
- active area $9 \text{ m}^2$, $\Theta \in [-30^\circ, 30^\circ]$

⇒ investigation of the whole active area of 2-3 $\text{m}^2$ large Micromegas
resistive strip technology

**active area**: \(0.92 \times 1.02 \text{ m}^2\)

two readout boards with in total **2048 strips**

**pitch**: 0.45 mm

**Ar:CO_2 93:7 vol\% @ atmospheric pressure**

16 APV25 front-end boards
57.6 mm wide (y - coordinate)

10 scintillator segments
100 mm wide (x - coordinate)

\[\Rightarrow\] subdivision of detector in 16 APV \times 10 \text{ scintillators} = 160 partitions

\[\Rightarrow\] calibration and alignment for each of the 160 partitions
measurement of y position (perpendicular tracks):
residual via centroid method:
\[ \text{res} = y_{\text{measured}} - y_{\text{predicted}} \]
\[ \Delta y = \text{res} \]

measurement of z position (inclined tracks):
\[ \Delta z = \frac{\text{res}}{\tan \alpha} \]
\[ \text{res} = m_y \cdot \Delta z \]
with \( m_y = \tan \alpha \)

fit with a straight line
\[ \Rightarrow \Delta z = \text{slope} \]
\[ \Delta y = \text{intercept} \]
Verification of Strip Alignment: X-Rays

- The measurement is performed recording data with random triggers while the detector is irradiated with an X-ray gun.
- Two sets of data ($0^\circ$ and $180^\circ$) to compensate for possible misalignment between the X-Ray gun and the detector surface.

\[
\delta_{1-2} = \left( \frac{\sigma_1^0 + \sigma_1^{180}}{\sigma_2^0 + \sigma_2^{180}} \right)
\]

For MMSW $\delta_{1-2} < 15 \, \mu m$ (single point measurement)

- Huge statistic is needed (several millions events, after selection cuts), requiring at least 2-3 hours for each position.
A complete map of the detector surface would take quite a long time.
The same test with lower statistics demonstrated not to provide a resolution $<20 \, \mu m$ as required.
Plane to Plane Alignment – Mechanical Measurement

- readout panel alignment before assembly
- verification on both sides with laser tracker