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

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on behalf of the ATLAS Muon Collaboration

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Instrumentation for Colliding Beam Physics

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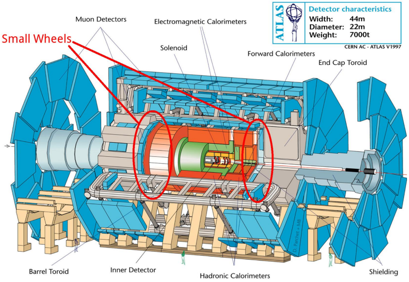
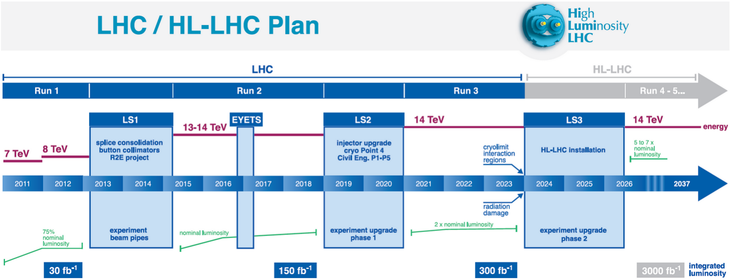
Outline

High Luminosity Upgrade of LHC

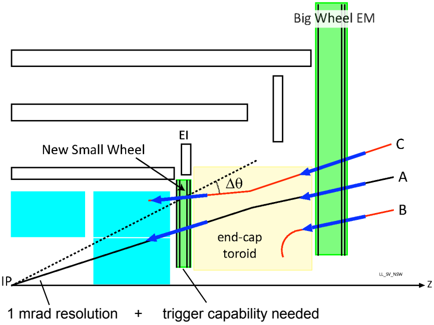
- LHC high luminosity upgrade
  - 2021: Run 3: $2 \times \mathscr{L}_{design}$
  - 2026: Run 4: $5 - 7 \times \mathscr{L}_{design}$
- upgrade of inner end-cap region of Muon Spectrometer (Small Wheels) before Run 3





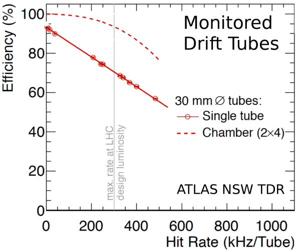
Motivation for the ATLAS NSW Upgrade Project

- 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:
  $\mathscr{L} > \mathscr{L}_{design} \Longrightarrow \varepsilon < 90\,\%$
  $\mathscr{L} > 2\,\mathscr{L}_{design} \Longrightarrow \varepsilon < 60\,\%$
- maintain current excellent momentum resolution for higher luminosity:
  $\Delta p_T \approx 15\,\%$ @ $p_T = 1\,\text{TeV}$ muons



$\Longrightarrow$ New Small Wheel needs trigger and high rate capable new technology:

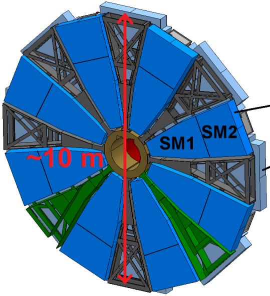
- sTGC and
- Micromegas

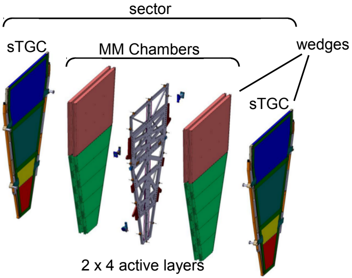


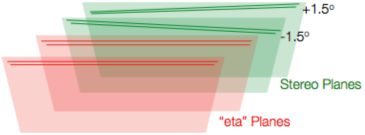
Outline

Layout of the New Small Wheel

- disk-like design:
  - eight large sectors
  - eight small sectors
- sector: two Micromegas wedges sandwiched by two sTGC wedges
  $\Longrightarrow$ eight layers of sTGCs (trigger)
  eight layers of Micromegas (tracker)
- Micromegas wedges subdivided in two Micromegas quadruplets



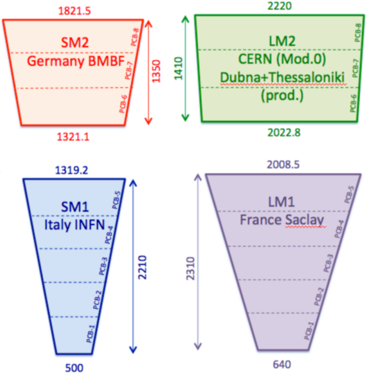


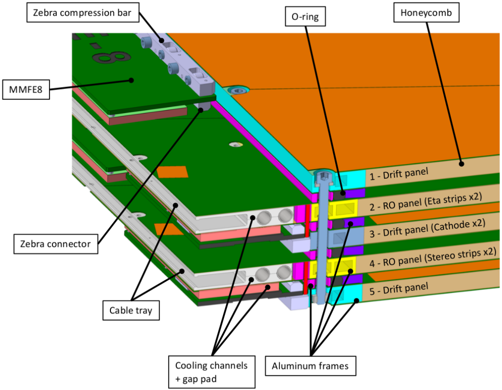


Micromegas quadruplet strip layout

Design of the Micromegas Quadruplets

2-3 m^2 Micromegas

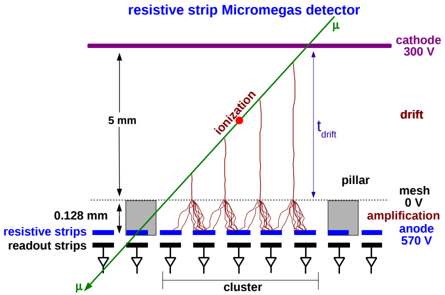




Micromegas quadruplets:

- 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

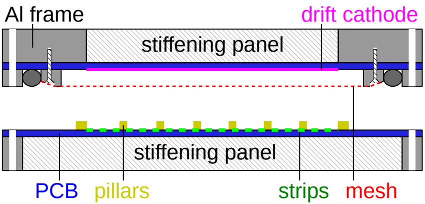


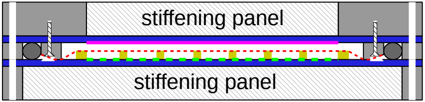
single active plane of a quadruplet:

- cathode
- grounded micro-mesh
- anode strip structure

position reconstruction:

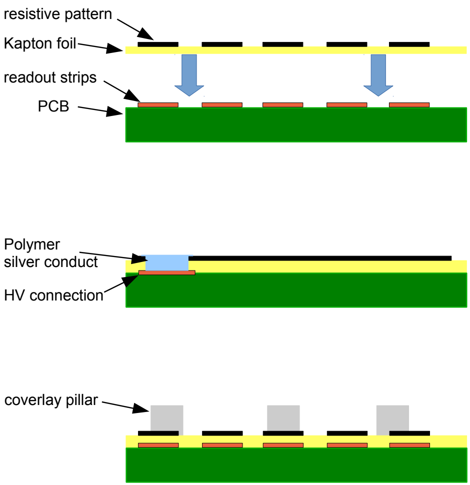
- charge centroid over strip-cluster
- track reconstruction via $t_{\text{drift}} = f(\text{strip})$





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 μm coverlay pillars as mesh support

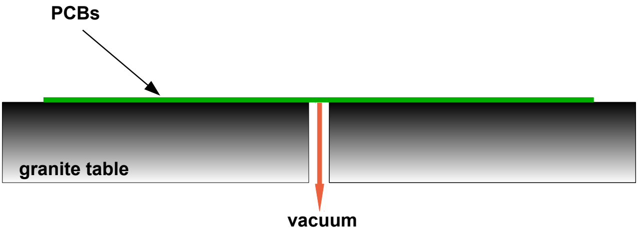


Requirements for Micromegas

maintain current excellent momentum resolution for higher luminosity:
$\Delta p_T \approx 15\,\%$ @ $p_T = 1\,\mathrm{TeV}$ muons
$\Longrightarrow$ 100 µm spatial resolution in a single plane

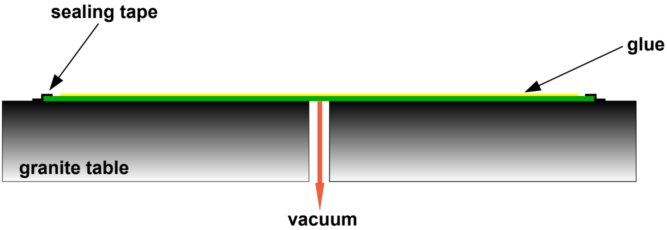
- 30 µm alignment accuracy of readout strips on the individual PCBs and particularly the alignment within a quadruplet
- 80 µm accuracy perpendicular to the plane

Panel Construction in two Gluing Steps: Step 1



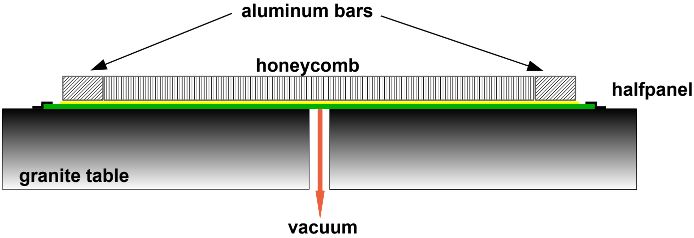
- PCBs placed and aligned on granite table

Panel Construction in two Gluing Steps: Step 1



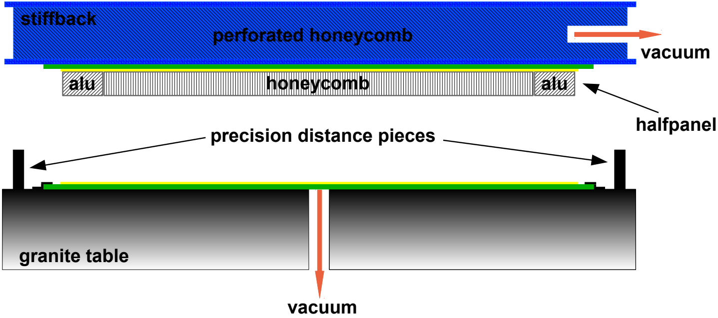
- PCBs placed and aligned on granite table
- sucked to granite table and sealed with tape
  $\Longrightarrow$ planarity transfer
- glue distributed on PCBs

Panel Construction in two Gluing Steps: Step 1



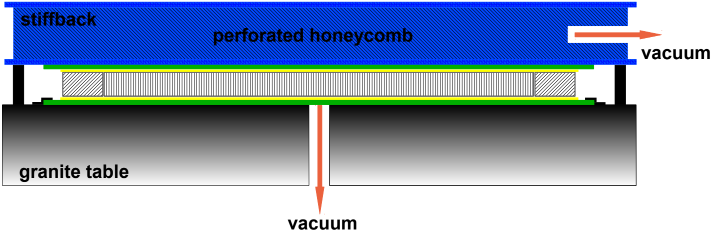
- PCBs placed and aligned on granite table
- sucked to granite table and sealed with tape
  $\Longrightarrow$ planarity transfer
- glue distributed on PCBs
- aluminum bars and honeycomb placed on top
- halfpanel cures over night in vacuum bag

Panel Construction in two Gluing Steps: Step 2



- PCBs placed and aligned on granite table
- sucked to granite table and sealed with tape
  $\Longrightarrow$ 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 granite table
- glue distributed on PCBs

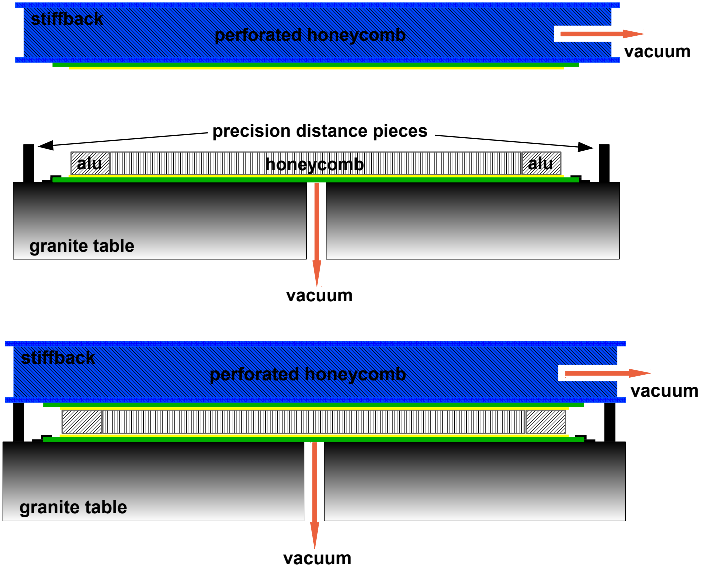
Panel Construction in two Gluing Steps: Step 2



- PCBs placed and aligned on granite table
- sucked to granite table and sealed with tape
  $\Longrightarrow$ 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 granite table
- glue distributed on PCBs
- stiffback with halfpanel placed on distance pieces
  $\Longrightarrow$ well defined panel thickness

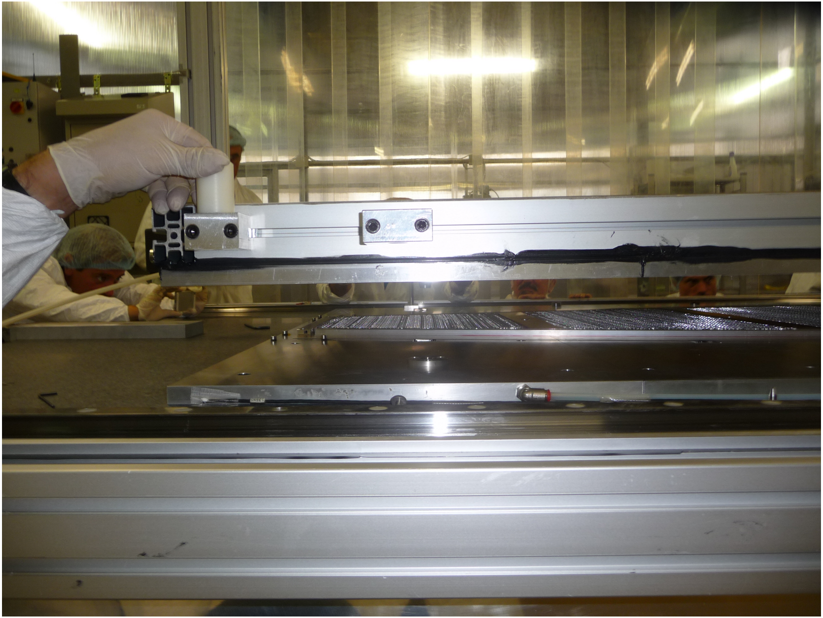
Panel Construction in one Gluing Step

main difference: no halfpanel, only PCBs sucked to stiffback

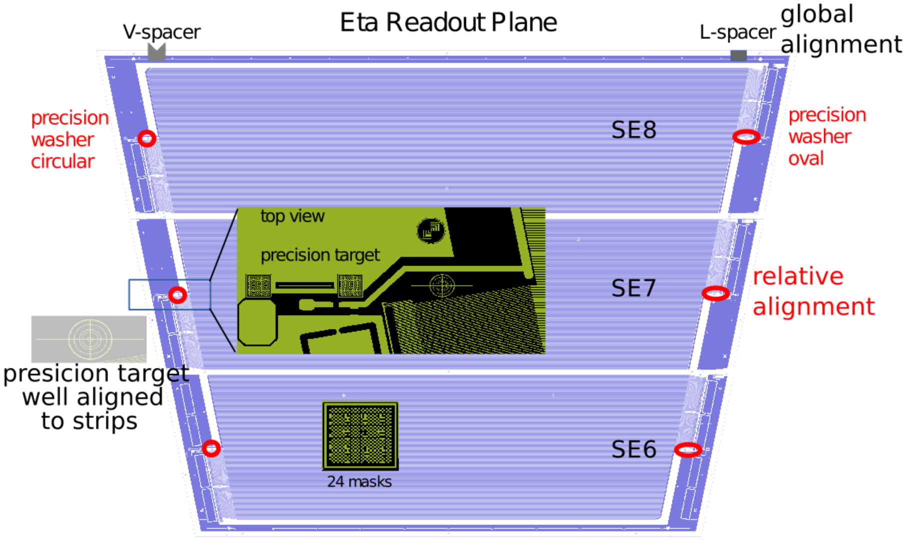


all other steps as before

Panel Construction in one Gluing Step

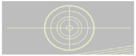


Alignment of the Readout Boards



Two Versions of Alignment: Precision Holes or Washers

precision hole



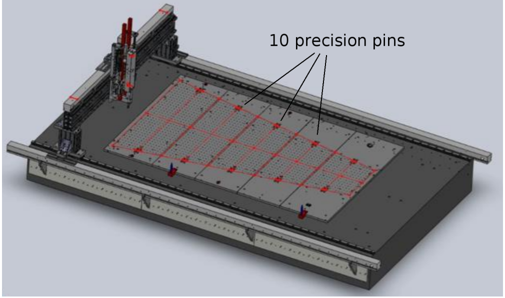
drilled @ position of target

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

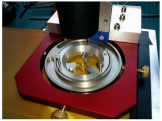
precision washer

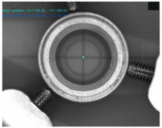
glued @ position of target

- accurate alignment frame
- global alignment on granite table
- relative alignment using pins



washer gluing

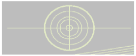




accuracy < 5 µm

Two Versions of Alignment: Precision Holes or Washers

precision
hole



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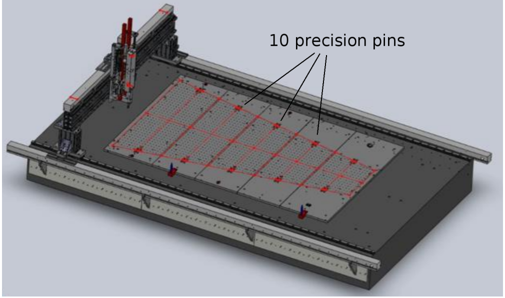

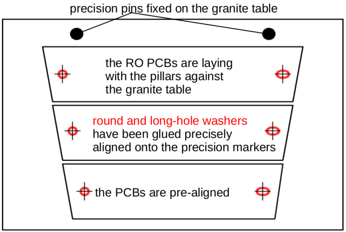

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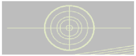

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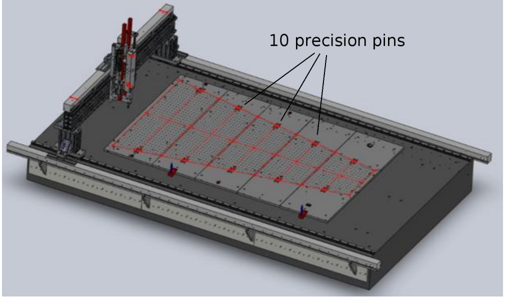
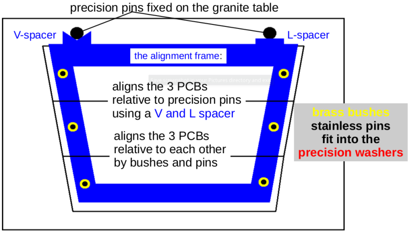
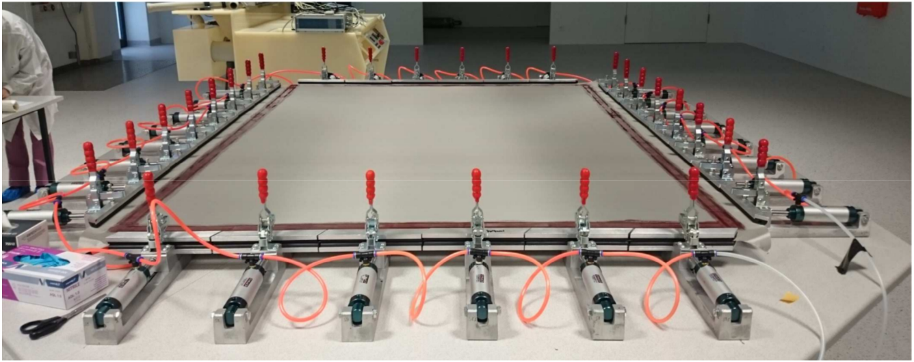


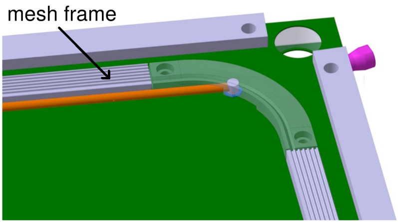


Mesh Stretching and Mounting



mesh stretching:

- in cleanroom
- pneumatic clamps
- 1. step: glued on transfer frame
- 2. step: glued onto mesh frame
- tension $\approx 11\,\mathrm{N/cm}$



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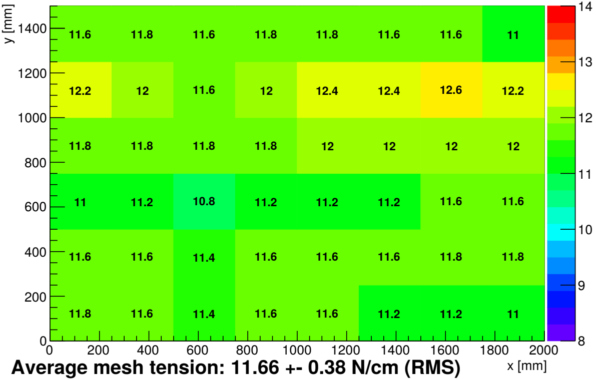
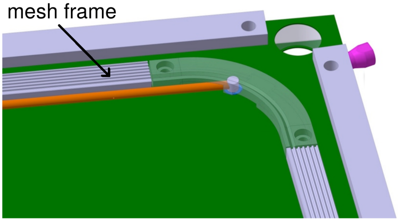


Average mesh tension: 11.66 +- 0.38 N/cm (RMS)

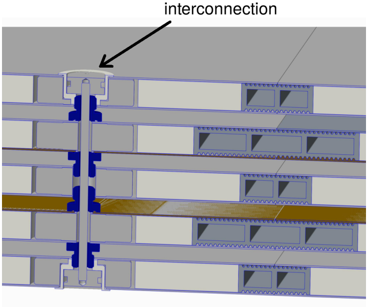
mesh stretching:

- in cleanroom
- pneumatic clamps
- 1. step: glued on transfer frame
- 2. step: glued onto mesh frame
- tension $\approx 11\,\mathrm{N/cm}$

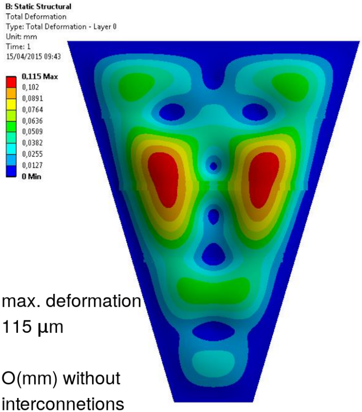


Stabilization of the Quadruplet Against Overpressure

deformation of drift region for outer detector layers due to 2 mbar overpressure in gas volumes
$\Longrightarrow$ 4-7 interconnections integrated in Micromegas quadruplets



example: LM1
ANSYS FEM simulation

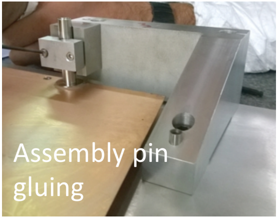


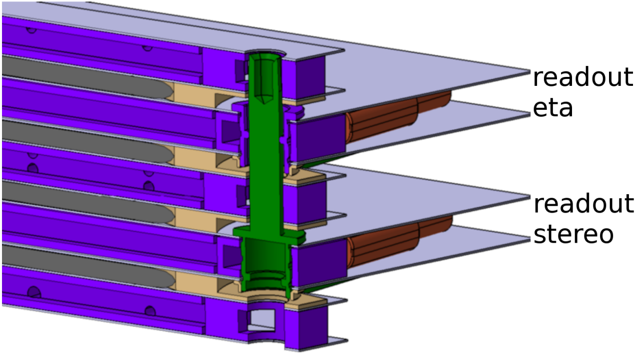
max. deformation 115 µm

O(mm) without interconnetions

Precision Assembly using Dedicated Pins

pins and bushes precisely glued into the panel using precision templates
$\Longrightarrow$ perfect alignment of both readout panels



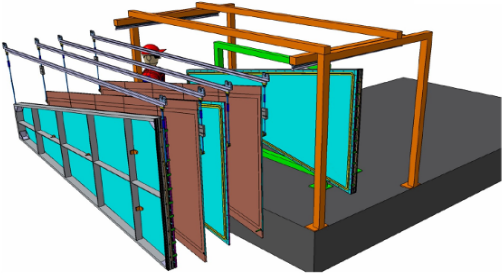


Fully Assembled Micromegas Quadruplet

pressure sensors and micrometer adjustment units

$\Longrightarrow$ assembly free of forces

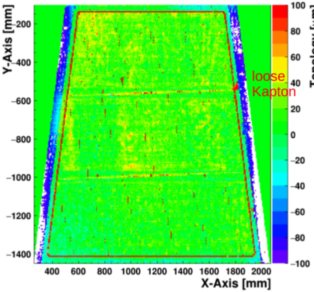
$\Longrightarrow$ free movement of pins in bushes



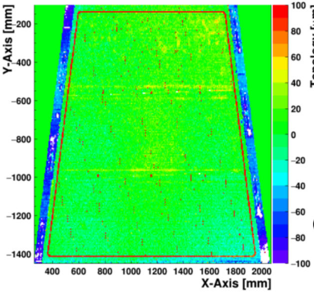
Outline

Planarity Measurement of the First SM2 Readout Panel

1. side



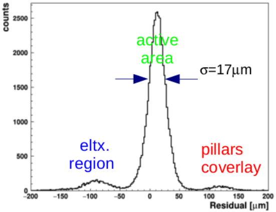
2. side

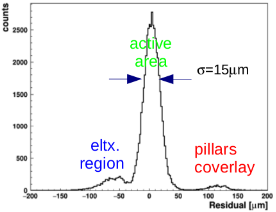


pillars
+
coverlay

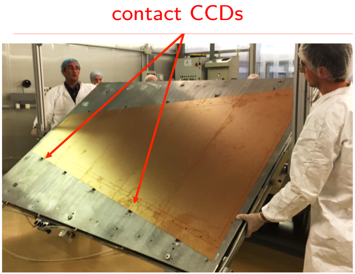
eltx. region
(as expected)

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

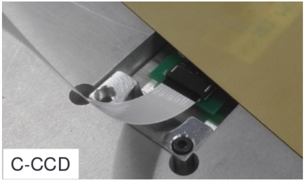


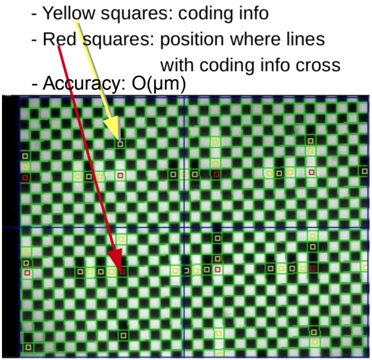


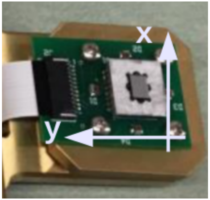
Verification of Strip Alignment using Coded Masks

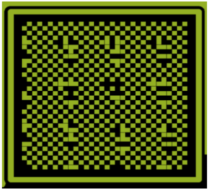


- 5 $\times$ 8 coded masks on each readout plane
- contact CCDs mounted on reference jig
- position and rotation of coded masks can be calculated
  $\Longrightarrow$ verification of strip alignment



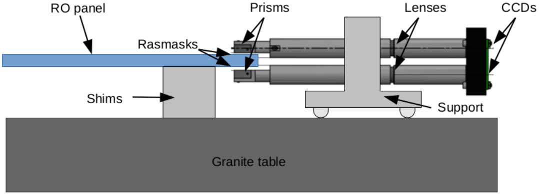


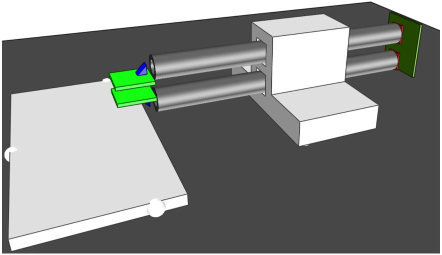




Verification of Alignment of the two Surfaces of a Panel

- 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

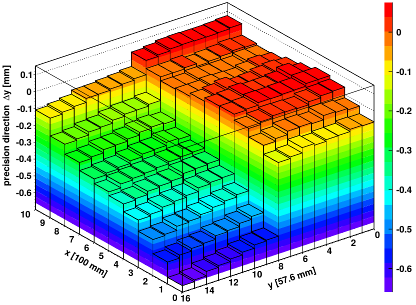
2 external tracking references (2 MDTs) study of principle:

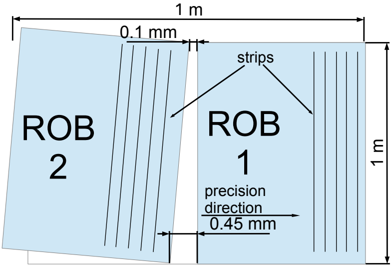
- $1\,\mathrm{m}^2$ prototype detector with two readout boards
- no alignment tool used for gluing of anode structure

muon tracks show:

- variation of gap size between PCB plates during gluing
- **shift:** $100\,\mu\mathrm{mm}$
- **rotation:** $350\,\mu\mathrm{m/m}$

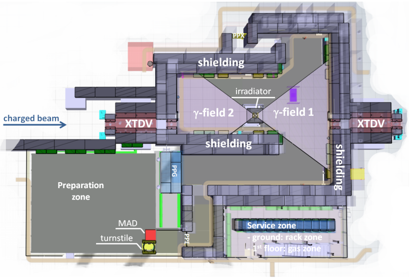
NSW-MM: elimination of this effect by precise tooling

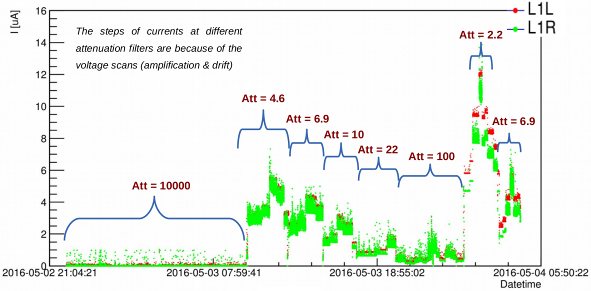


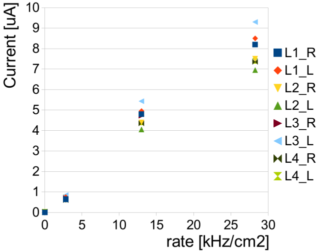


High Rate Behavior: GIF++

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







Summary

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
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Summary

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
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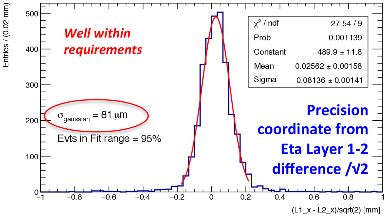
- high rate irradiation test in GIF++
- high energy testbeam campaigns @ CERN to check spatial resolution, efficiency, etc.



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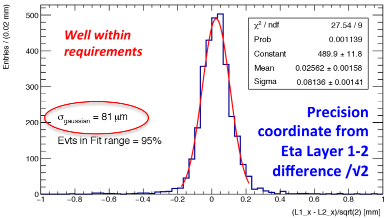
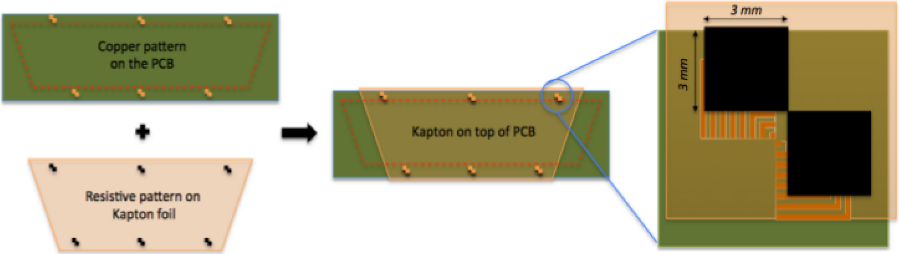
THANK YOU



Backup

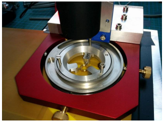
Alignment of Resistive Pattern to Readout Strips

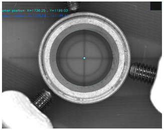


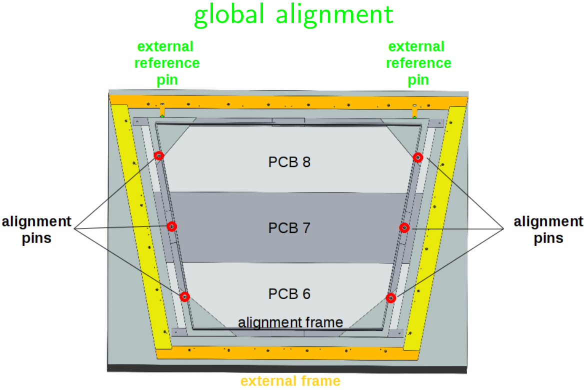
Precision Washer glued on PCBs

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





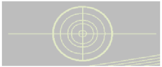


Alternative Method: SM2/LM1

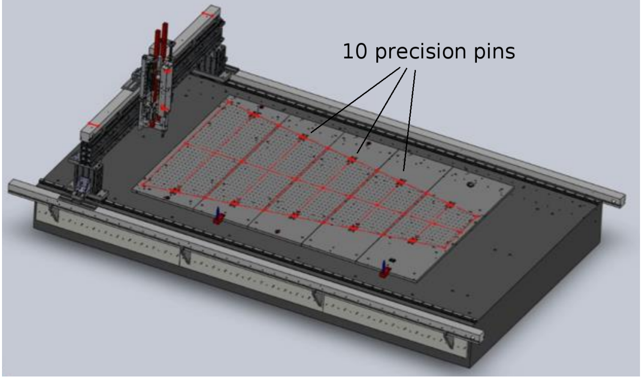
precision holes drilled in PCB

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

precision
hole

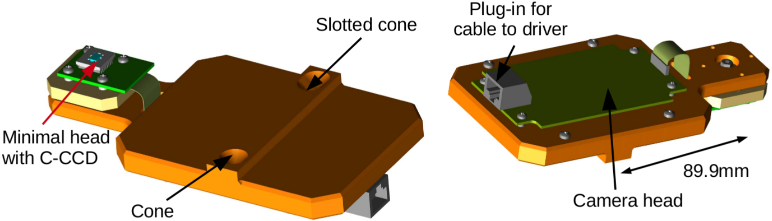


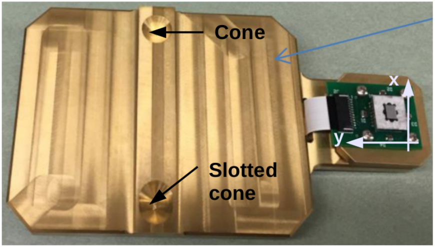
drilled
@ position
of target



C-CCD

LMU surveyor

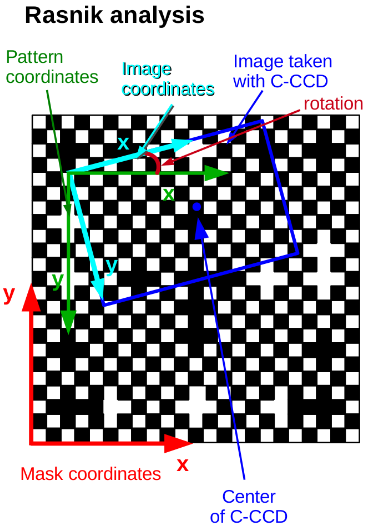




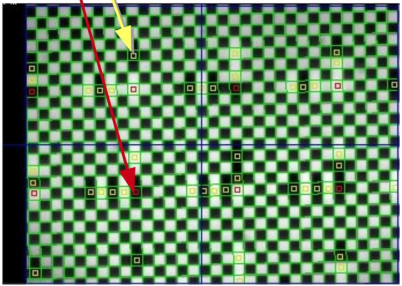
LMU surveyor

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

Rasnik Analysis I

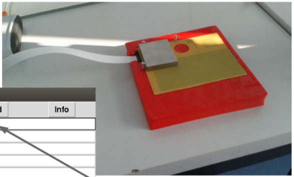


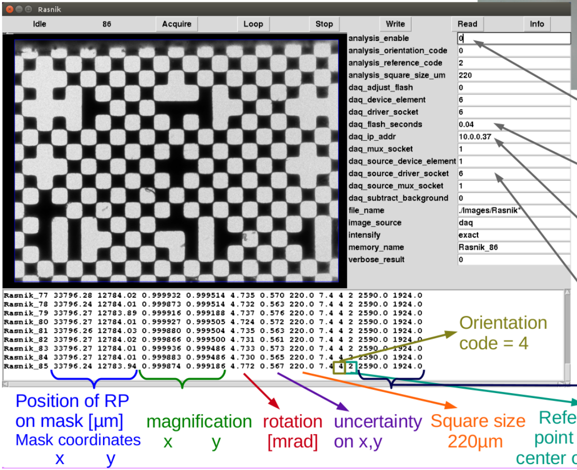
- Rasnik mask: coded mask, every 9th row/column contains coding info - deviation from chessboard pattern
- Rasnik analysis within LWDAQ software from Brandeis finds rasnik pattern and marks it
  - Yellow squares: coding info
  - Red squares: position where lines with coding info cross



Rasnik Analysis II

Picture of SACLAY mask from C-CCD

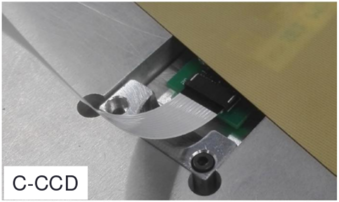


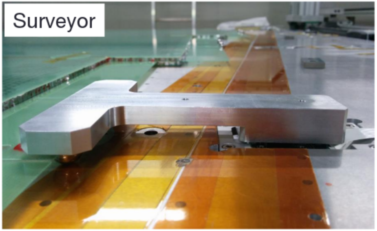


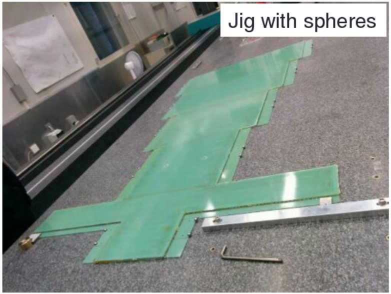
Alignment with Compact CCD

Module05 – Read-Out panels – I

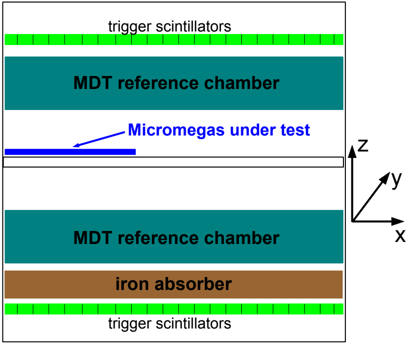
- Strip alignment (will be used for Mod05 panels):
  - **C-CCDs** inserted on table and stiffback plates: 20 masks per panel will be read-out;
  - Cameras & minimal heads tested, software finalized;
  - *Calibration procedure*
    - **Jig** built and precision spheres measured in Freiburg;
    - **Surveyor**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







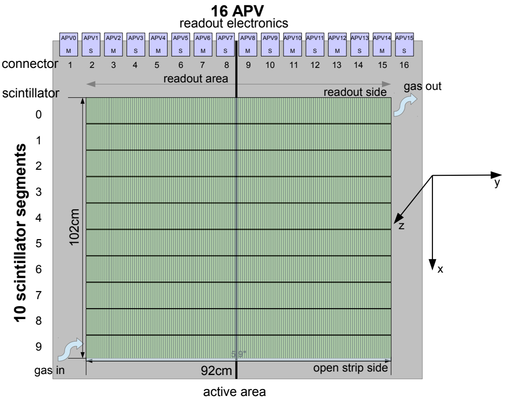
Cosmic Ray Facility, LMU Munich



- two Monitored Drift Tube (MDT) reference chambers
  $\Longrightarrow$ two reference tracks
- two trigger scintillator hodoscopes
  $\Longrightarrow$ second coordinate
  $\Longrightarrow$ segmentation of test Micromegas in 10 cm wide segments
- 34 cm iron absorber $\Longrightarrow E_\mu > 600$ MeV
- active area 9 m^2, $\Theta \in [-30^\circ, 30^\circ]$

$\Longrightarrow$ investigation of the whole active area of 2-3 m^2 large Micromegas

1 m^2 Micromegas Chamber (L1)



- resistive strip technology
- **active area**: $0.92 \times 1.02\,\mathrm{m}^2$
- 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)

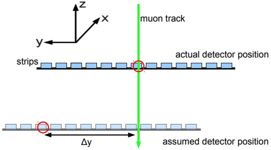
  $\Longrightarrow$ subdivision of detector in 16 APV $\times$ 10 scintillators $=$ 160 partitions

$\Longrightarrow$ **calibration and alignment for each of the 160 partitions**

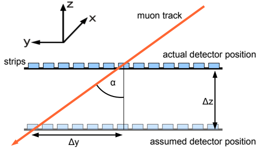
Alignment - Using Reference Tracks (160 partitions)

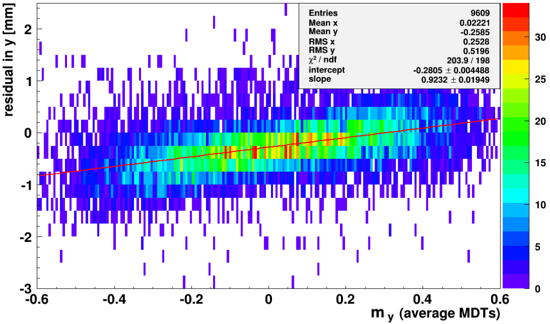
- measurement of y position (**perpendicular tracks**): residual via centroid method:
  $\mathrm{res} = y_{\mathrm{measured}} - y_{\mathrm{predicted}}$
  $\Delta y = \mathrm{res}$
- measurement of z position (**inclined tracks**):
  $\Delta z = \frac{\mathrm{res}}{\tan\alpha}$
  $\mathrm{res} = m_{\mathrm{y}} \cdot \Delta z$
  with $m_{\mathrm{y}} = \tan\alpha$
- fit with a straight line
  $\Rightarrow \Delta z = \mathrm{slope}$
  $\Delta y = \mathrm{intercept}$

measurement of y position



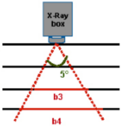
measurement of z position

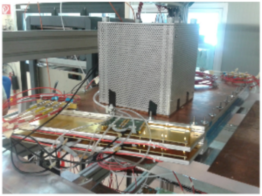




Verification of Strip Alignment: X-Rays

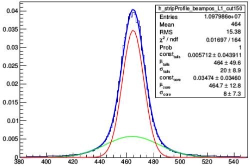
- The measurement is performed recording data with random triggers while the detector is irradiated with an X-ray gun.
- Two sets of data (0° and 180°) to compensate for possible misalignment between the X-Ray gun and the detector surface

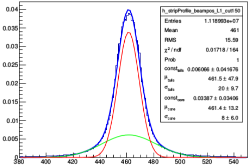




$$\delta_{1-2} = \frac{(\sigma_1^0 + \sigma_1^{180})}{(\sigma_2^0 + \sigma_2^{180})}$$

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





- Huge statistic is needed (several millions events, after selection cuts), requiring at lest 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 μm as required.

Plane to Plane Alignment – Mechanical Measurement

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