Resistive Micromegas for the Muon Spectrometer Upgrade of the ATLAS Experiment

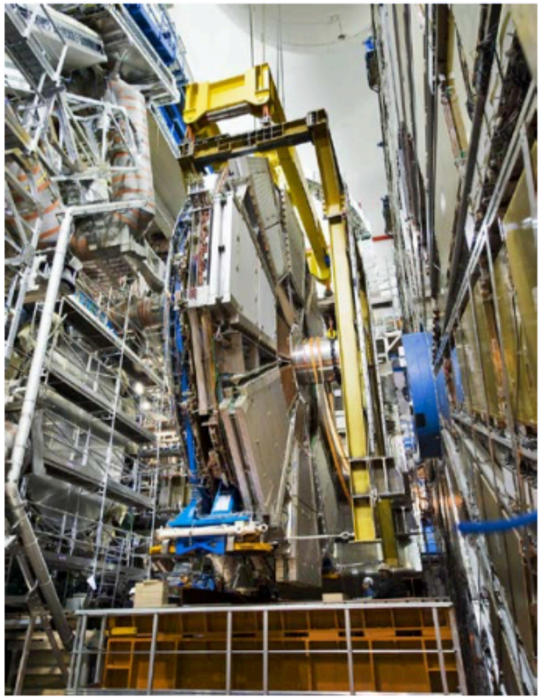
Mauro Iodice
INFN – Roma Tre
On behalf of the ATLAS Muon Collaboration

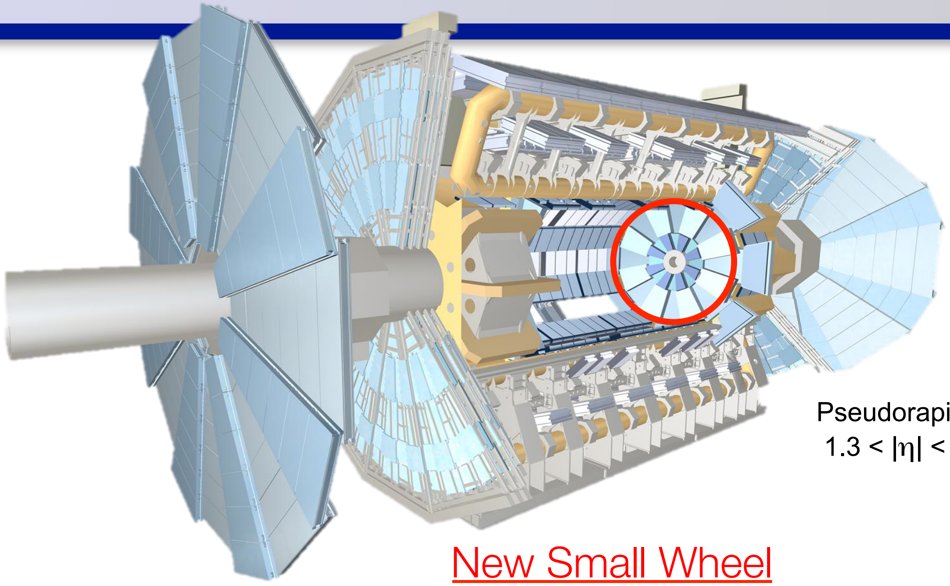
ICHEP 2016
Chicago, USA 3-10 August, 2016

OUTLINE

- The ATLAS Muon New Small Wheel Upgrade in a nutshell
- Detector Technologies and NSW Layout
- Micromegas
  - ATLAS Micromegas Design and Challenges
  - Construction of the Modules-0 prototypes
  - SM1 Module-0 Test-beam PRELIMINARY Results
- Summary

New Small Wheel Upgrade in a nutshell





- Main ATLAS upgrade during the Long Shutdown 2 (2019/20) (Phase-1)
- Will replace the present Small Wheel, not designed to exceed 10^{34} $cm^{-2}s^{-1}$
- Will operate up to HL-LHC luminosity (Phase-2)
- Expected rates up to 15 kHz/cm2

- GOALs:
  - Maintain momentum resolution: 15% P_T resolution at 1 TeV
    → ~100 μm resolution per plane on a multilayer station
  - keep single muon trigger under control
    → 1 mrad online angular resolution

New Small Wheel Detector Technologies

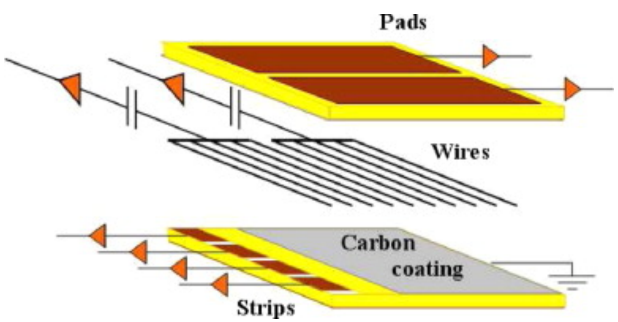
Combination of sTGC and MicroMegas detector planes

Small Strips TGC (sTGC)
primary trigger detector

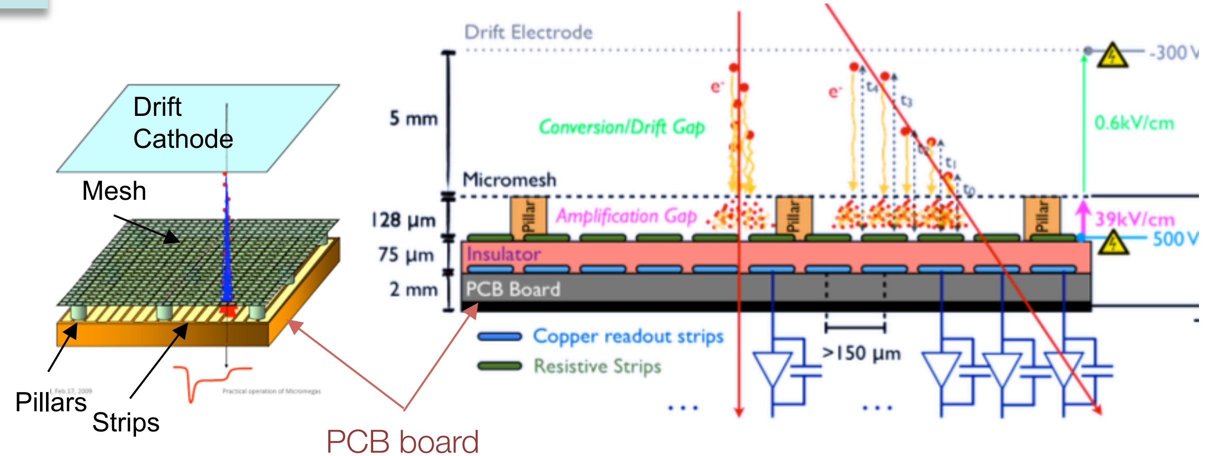
- Bunch iD with good timing resolution
- Online track vector with <1 mrad angle resolution
- pads: region of interest
- strips: track info (strip pitch 3.2 mm)
- wire groups: coarse azimuthal coordinate

Resistive strips MicroMegas (MM)
primary precision tracker

- Good Spatial resolution < 100 μm
- Good track separation (0.4 mm readout granularity)
- Resistive anode strips → suppress discharge influence on efficiency
- Provide also online segments for trigger

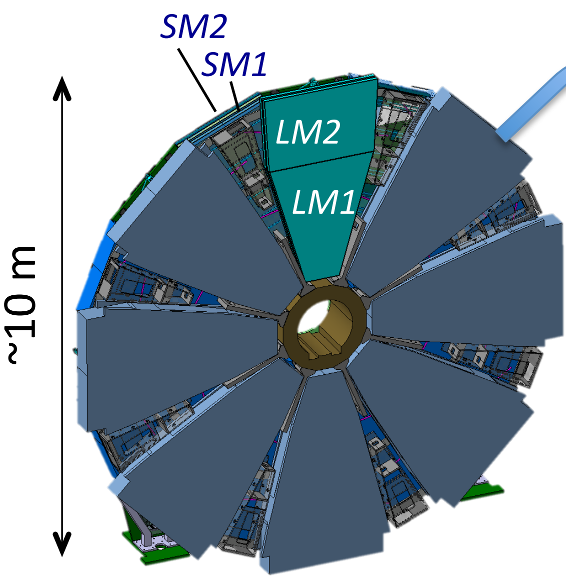


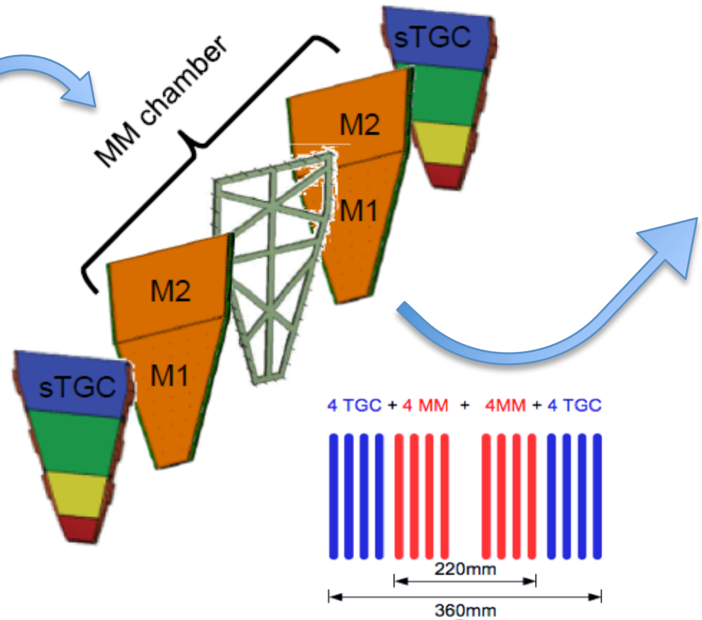
Talk by Rimsky Rojas - Aug. 6th

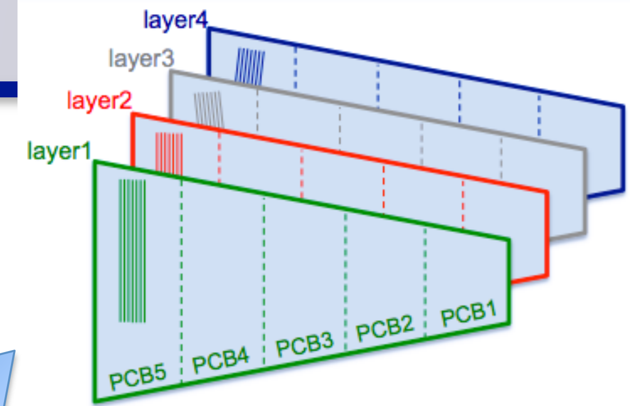


- Common front-end ASIC: VMM second prototype under tests

New Small Wheel Layout





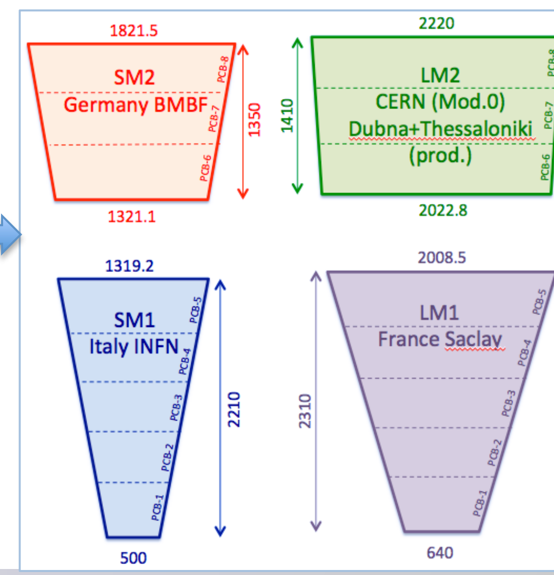


- Each MM module has 4 detection planes
- 2 planes with parallel strips (precision coordinate)
- 2 planes with +/-1.5^{o} Stereo strips (2nd coordinate)

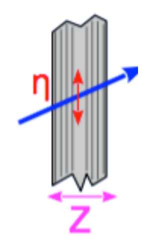
Each NSW has 16 sectors
8 Large + 8 Small

Each Sector is a sandwich of sTGC and MM quadruplets

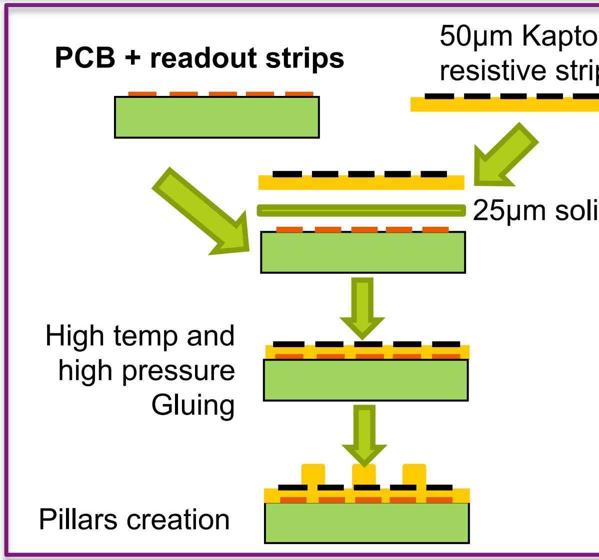
- Construction of MM Quads is distributed over several countries.

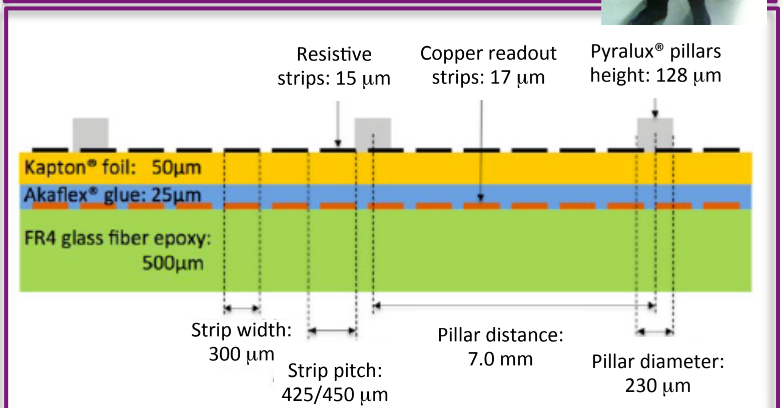


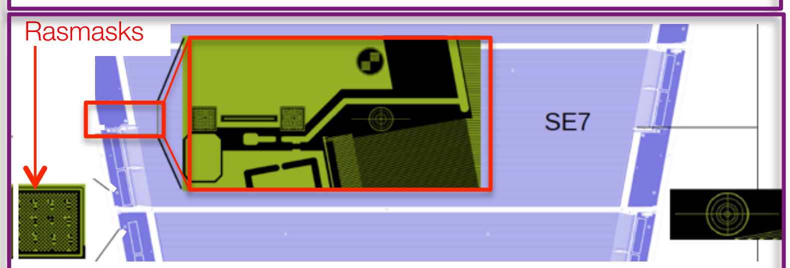
- Challenge in construction: alignment of the strips on each detection layer
  - 30 μm RMS in η
  - 80 μm RMS in z

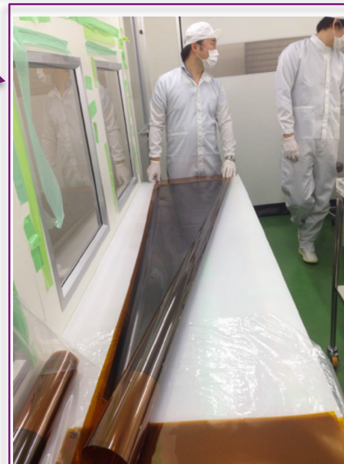


Micromegas Construction: Resistive strips Anode Boards

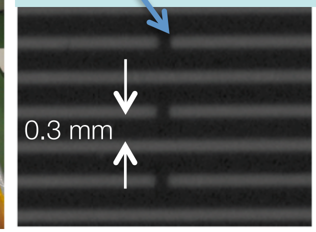








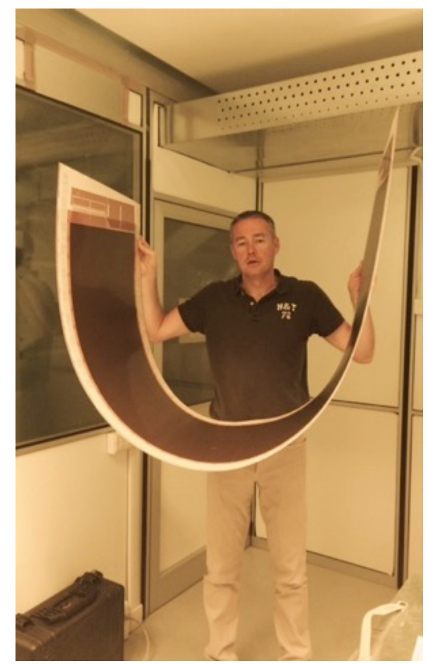
- Resistive strips on kapton by screen-printing
- "Ladder pattern" (connections every 10 mm):
  - Homogeneous resistivity (independent from distance)
  - Insensitivity to broken lines



Typical resistivity:

~ 10-20 MΩ/cm
(~800 kΩ/☐)

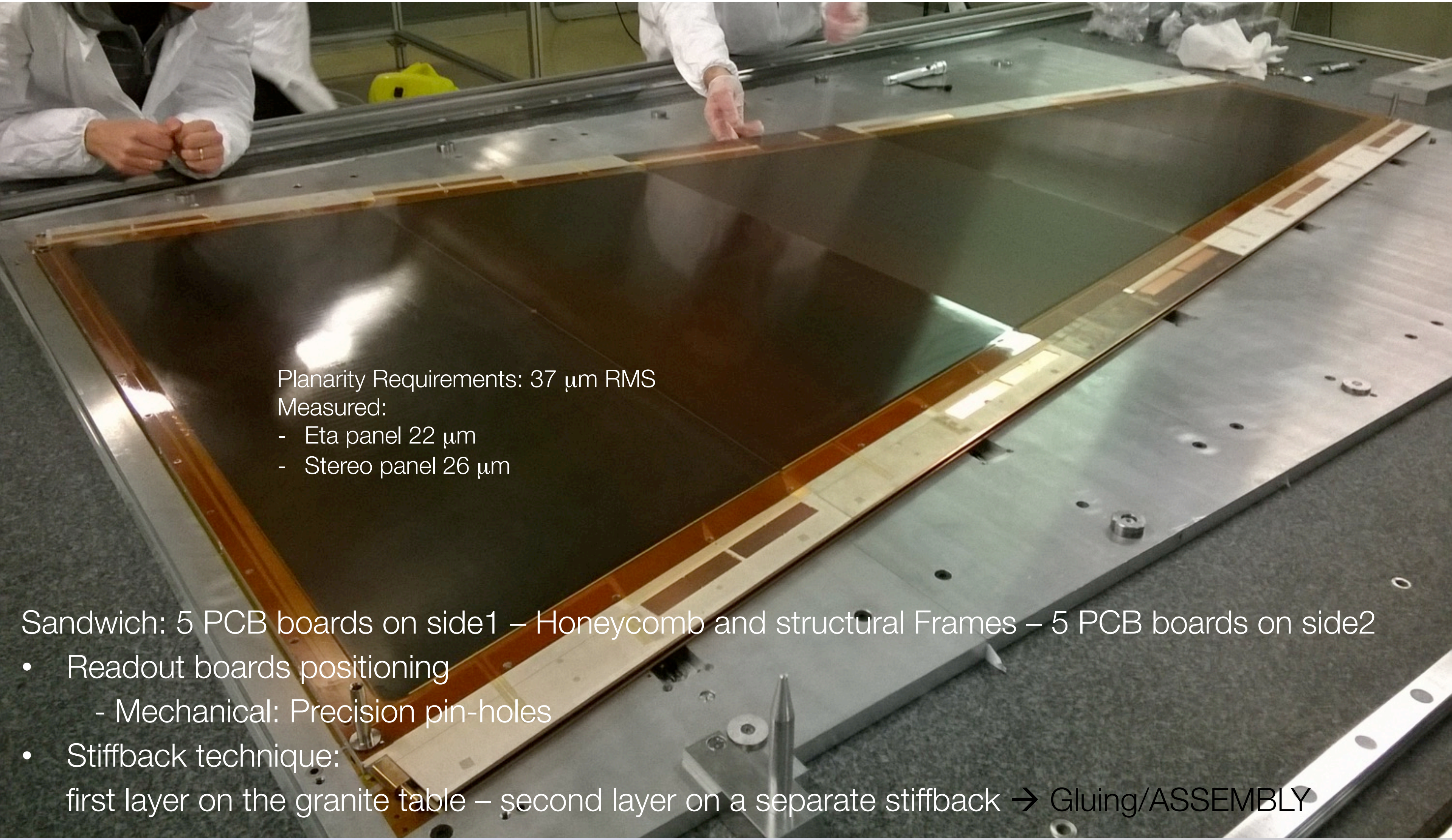
- Board dimensions:
  from 45x30 up to 45x220 cm^2
- 1022 strips/boards
- Readout strips pitch:
  425 or 450 µm
- Pillars height: 128 µm
- Several types of alignment masks



SM1 Module-0 Readout Panels Construction

INFN Pavia

Double Side Readout panel built with 5+5 Readout boards – strips alignment < 40 μm



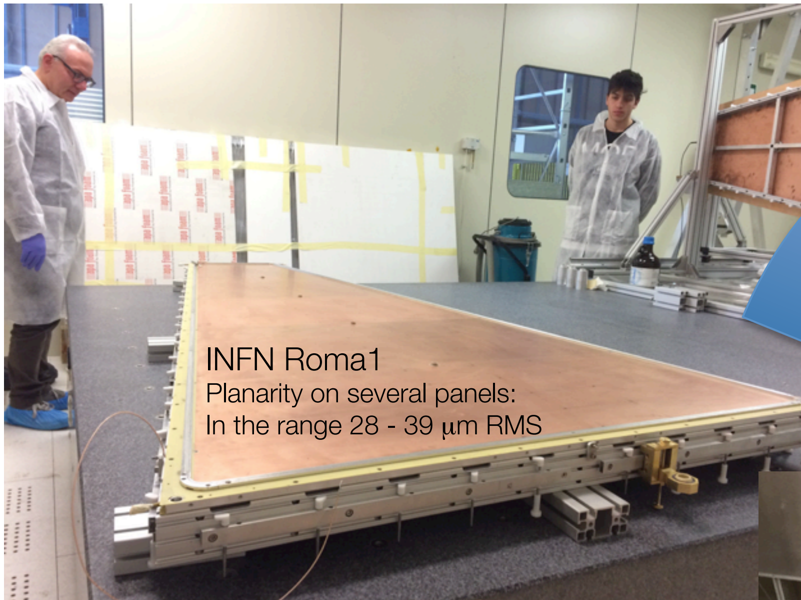
Planarity Requirements: 37 μm RMS
Measured:
- Eta panel 22 μm
- Stereo panel 26 μm

Sandwich: 5 PCB boards on side1 – Honeycomb and structural Frames – 5 PCB boards on side2

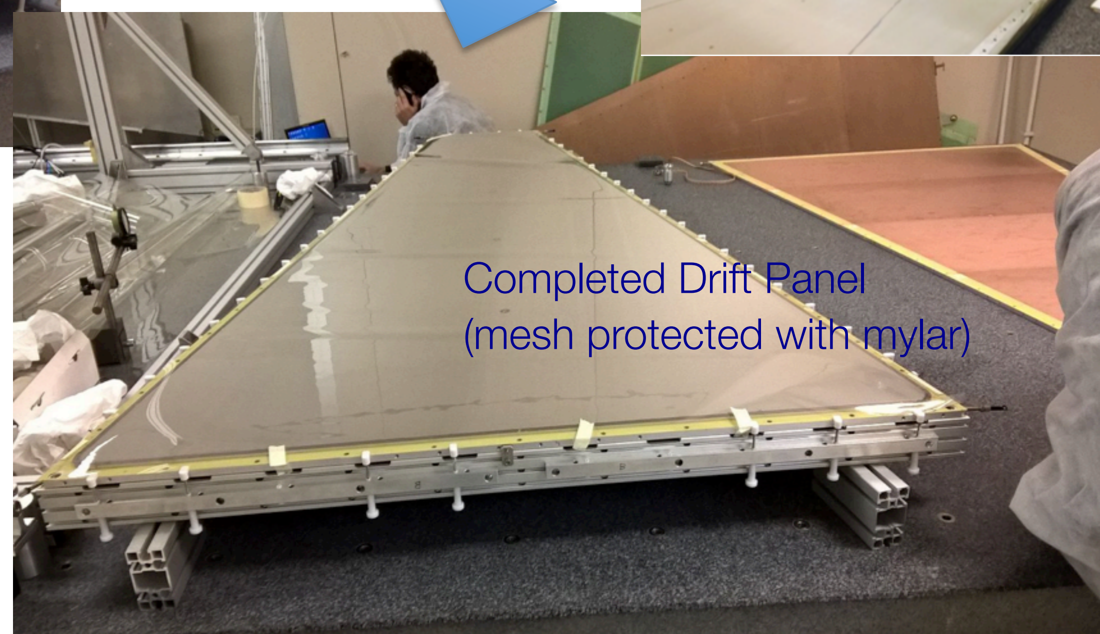
- Readout boards positioning
  - Mechanical: Precision pin-holes
- Stiffback technique:
  first layer on the granite table – second layer on a separate stiffback → Gluing/ASSEMBLY

SM1 Module-0 Drift Panels Construction

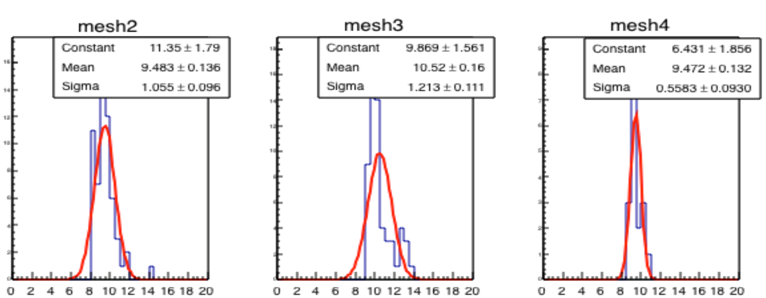
Similar construction Concept as for the readout panels



100 μm pitch (70/30)

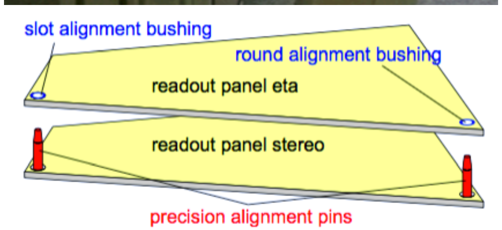


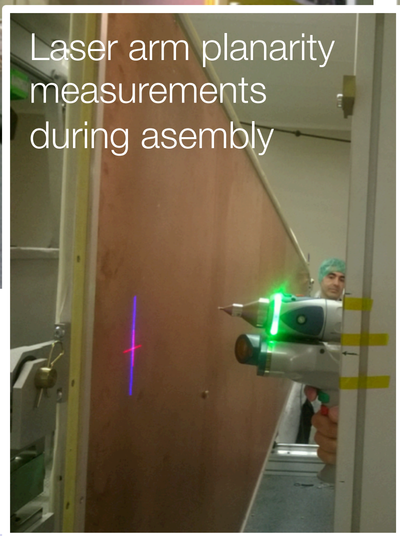
- Same planarity requirements as RO panels
- Mesh tension ~ 10 N/cm – uniformity 10%



SM1 Module-0 Quadruplet assembly

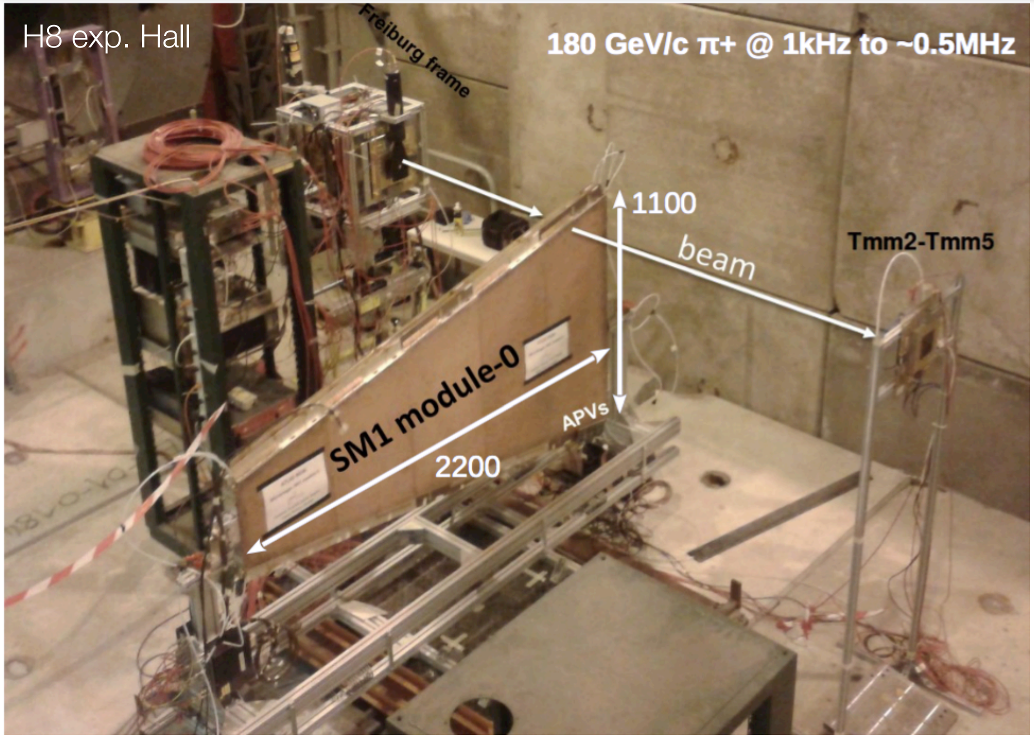
Crucial: Alignment of the two readout panels at < 60 μm precision



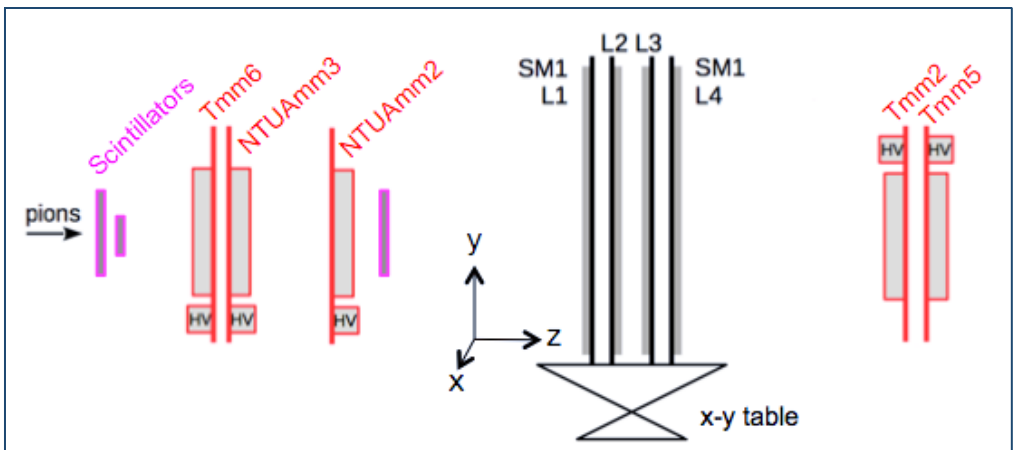


- Assembly completed in mid-May, then shipped to CERN for Test-Beam early June → superb achievement !

SM1 Module-0 Test-beam and PRELIMINARY Results

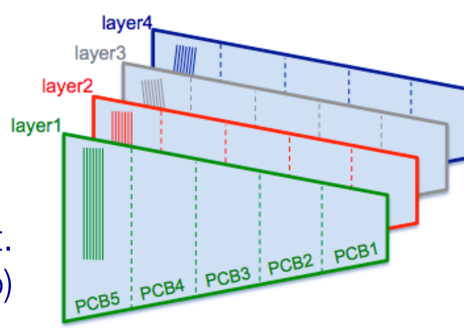


- 180 GeV/c pion beam
- Scintillators trigger
- Beam spot+trigger ~ 1x1 cm^2
- 5 micromegas with x-y readout (Tmm) used as reference
- SM1 Module-0 on a x-y scanning table
- Ar:CO_2 gas mixture (93:7)
- APV25+SRS readout (from RD51) [NOT FINAL NSW electronics]



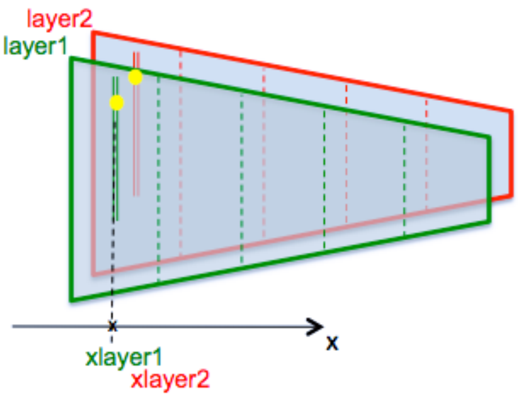
SM1 quadruplet:

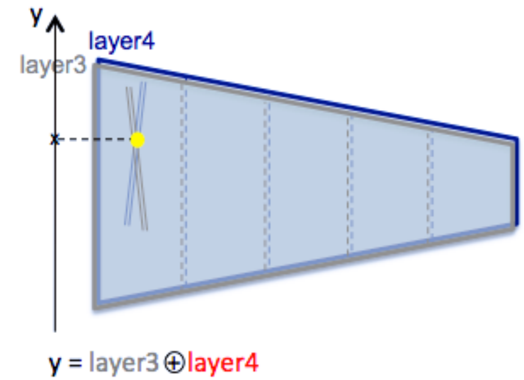
- 425 µm strip pitch
- L1 & L2 vertical strips (eta),
- L3 & L4 ±1.5° w.r.t. vertical axis (stereo)



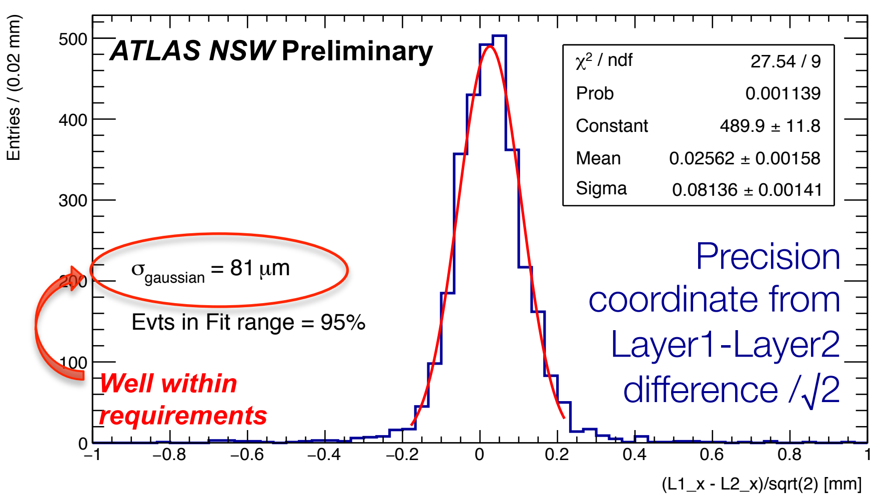
Module-0 PRELIMINARY Results on Spatial Resolution

- Perpendicular incident beam on PCB5 = longest strips
- Nominal High voltage settings:
  HV_ampl = 570 V (E= 4.4×10^7 V/cm)
  HV_drift = 300 V (E=600 V/cm)
- Ar/CO_2 93/7 @ 20 l/hour

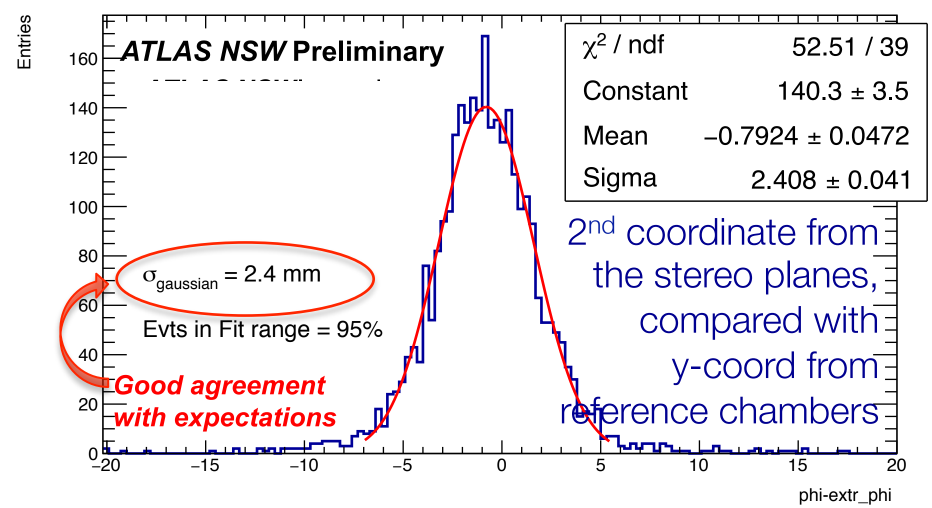




Preliminary result: Spatial Resolution of the precision coordinate



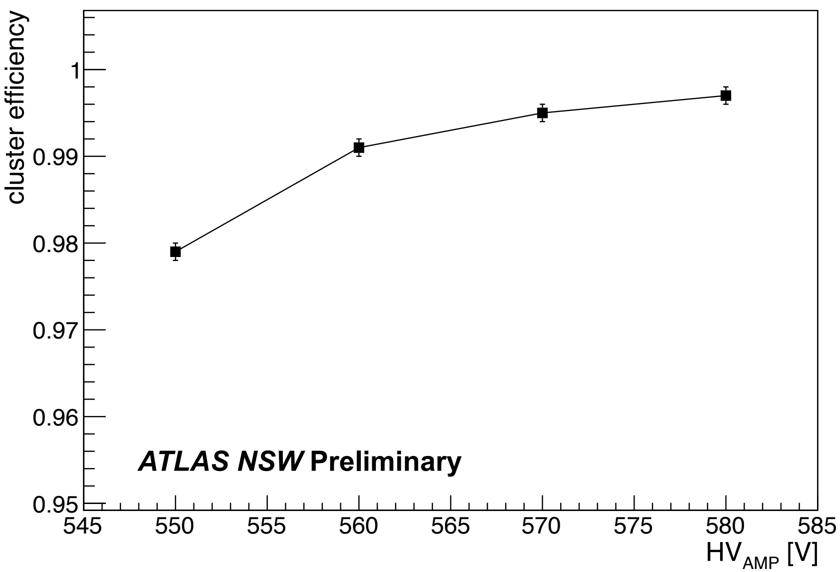
Preliminary result: Spatial Resolution of the second coordinate.



Module-0 PRELIMINAY Results on Efficiencies

- Cluster efficiency: presence of a cluster for any reference track
- Track-based efficiency: one cluster within given distance from the reference track impact on SM1

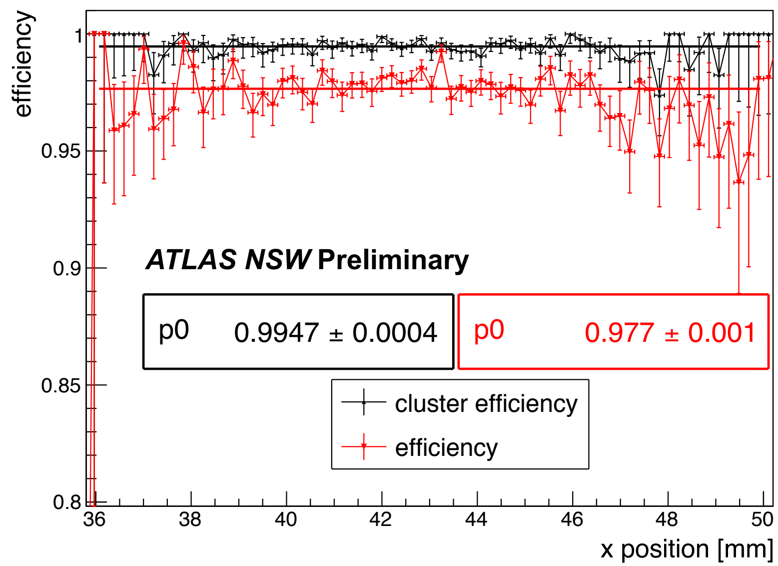
Cluster efficiency Vs Amplification HV for Layer1



- Turn-on curve saturate at a cluster efficiency very close to 100%

Efficiency at 570 V vs x-pos in the beam-spot

For Layer1

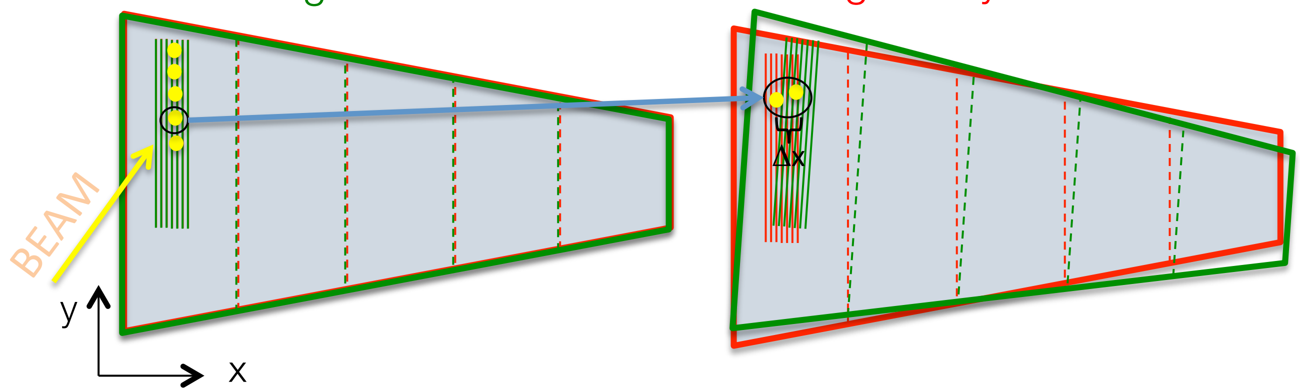


- Track based efficiency (+/-1.5 mm) ~98%
- 2% inefficiency mostly due to delta-rays

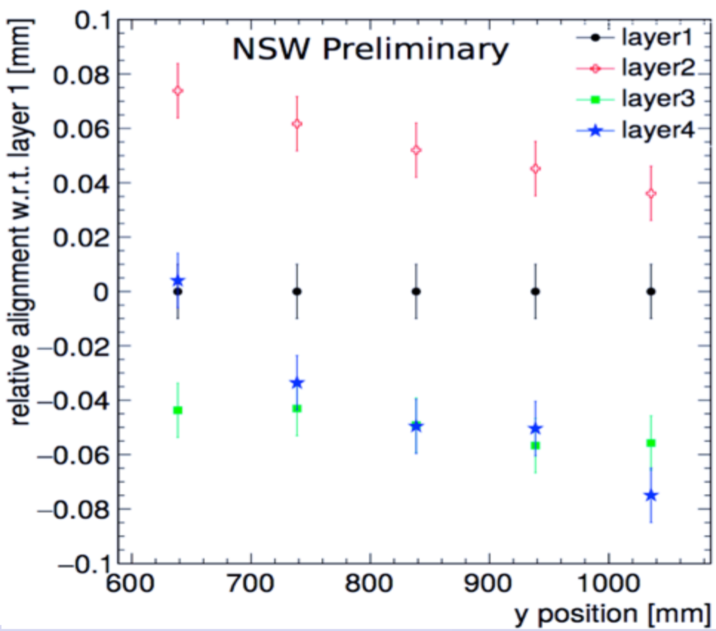
Module-0 PRELIMINARY Results on Strip Alignment

Measurements of layer-to-layer alignment

- Measurements at different vertical positions (along the strips)
- For each y-position measure Δx between *layer_i* and *layer-1* using reference tracks



$\Delta x = x_{layer\_i} - x_{layer\_1} = 0$ $\Delta x = x_{layer\_i} - x_{layer\_1} \neq 0$



Relative alignment wrt layer_1 :

- All layers aligned within a maximum deviation of +/- 80 μm
- Indication of layer-to-layer rotation or strip pattern global deformation under investigation at the construction site

Summary

- The ATLAS NSW Upgrade will enable the Muon Spectrometer to retain its excellent performance also beyond design luminosity and for the HL-LHC phase
- Large size resistive Micromegas will be employed for the first time in HEP experiments
- Micromegas design & construction methods have been refined & tested to meet the ATLAS requirements:
  - Tooling Design and quality control procedures
  - Construction and assembly methods
  - Planarity of the panels
  - Alignment of Strips and panels
- All module-0 construction are near completion
- SM1 Module-0 Completed and tested with very satisfactory results
- Ready for transition to series production in January 2017

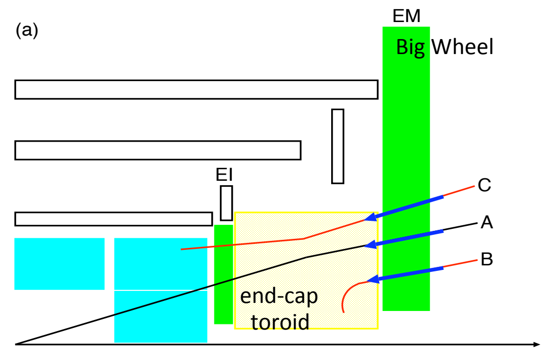
BACKUP slides

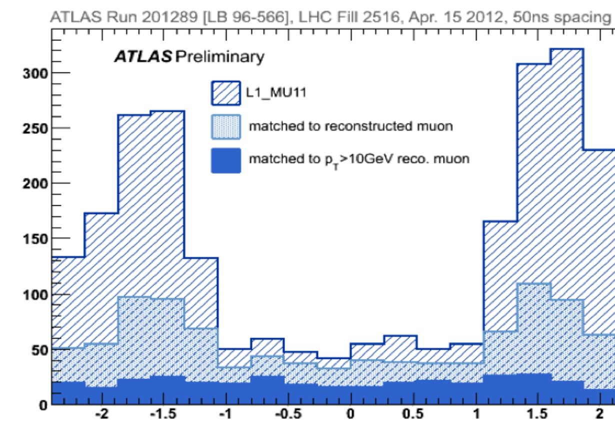
New Small Wheel – Motivations: TRIGGER

Consequences of luminosity rising beyond design values for forward muon wheels

- Present Muon L1 trigger in the EndCap relies on the Big Wheel station only: Calculating a track angle/vector and extrapolating to IP
- The Level1 Trigger rate in the EC is dominated by fake triggers
- At a 3 x 10^{34} $cm^{-2}s^{-1}$ L1MU20 (p_T>20 GeV) rate is estimated ~60 kHz, exceeding the available bandwidth (~15kHz for muons)

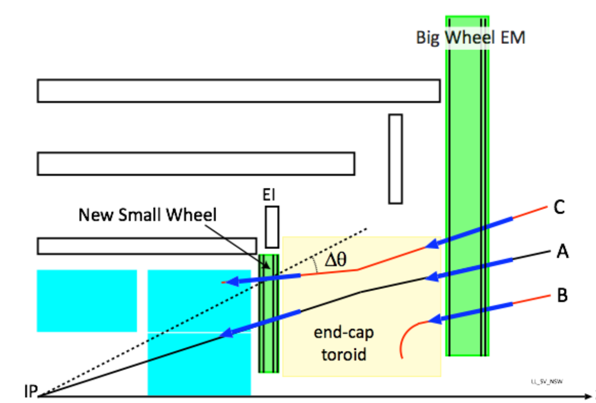
Present Level1 muon trigger





Cannot distinguish cases A (real high-pt track), B (low-pt particle created in the toroid area) and C (multiple scattering)

Upgrade L1 with NSW



Replace the Muon Small Wheels with the New Small Wheels

- Can filter out fake tracks by being able to reconstruct track vector/direction also in the endcap inner (EI) station

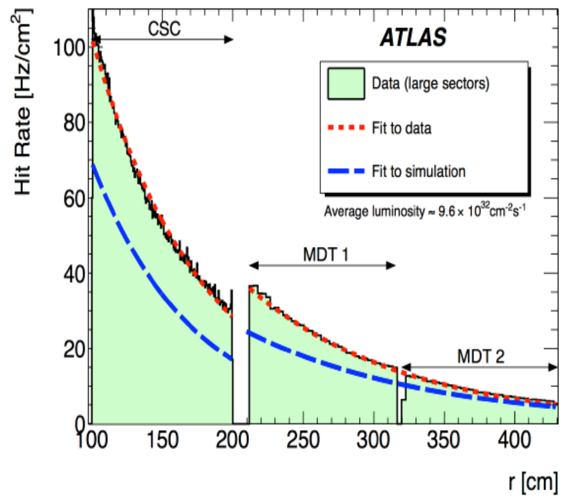
→ Extend L1 trig coverage to η = 2.6 with angular resolution of 1 mrad

NEW SMALL WHEEL – MOTIVATIONS: TRACKING

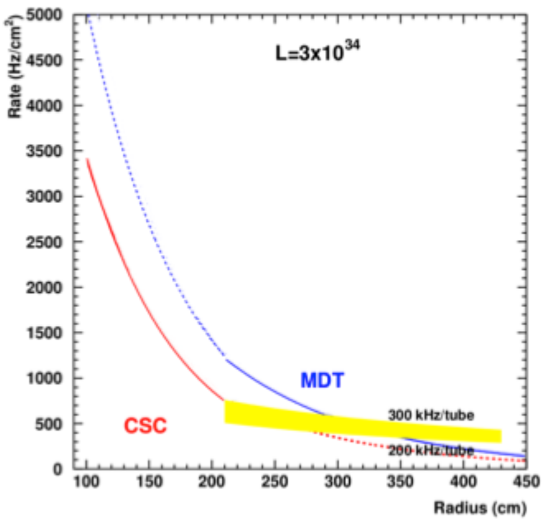
Cavern Background

- Measured hit rates in the Endcap Inner (Small Wheel) and extrapolated to 3x10^{34} cm^{-2} s^{-1}
- At 5x10^{34} cm^{-2} s^{-1} (luminosity of HL-LHC) the maximum expected rate in the NSW is about 15 kHz/cm^2 (>5 MHz/MDT_tube) (incl. Safety factor of 1.5)

Measured hit rates @ 10^{33} cm^{-2} s^{-1}

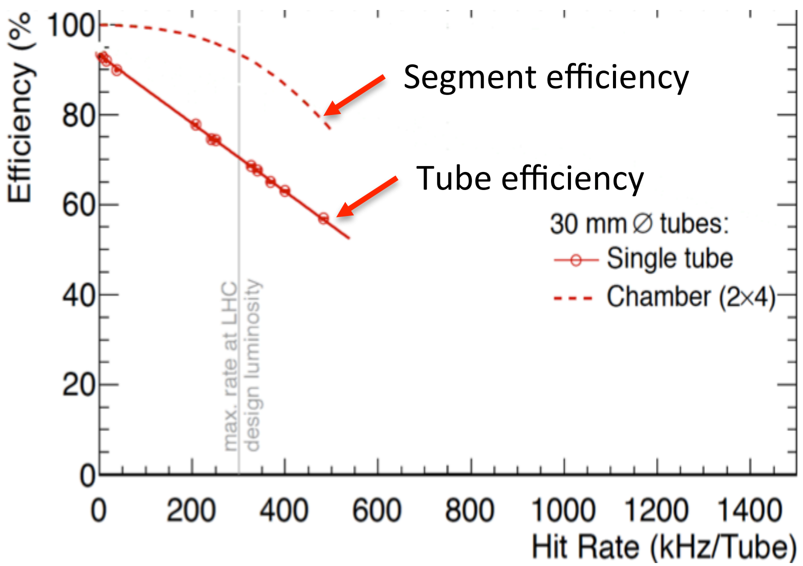


Expected rates @ 3x10^{34} cm^{-2} s^{-1}

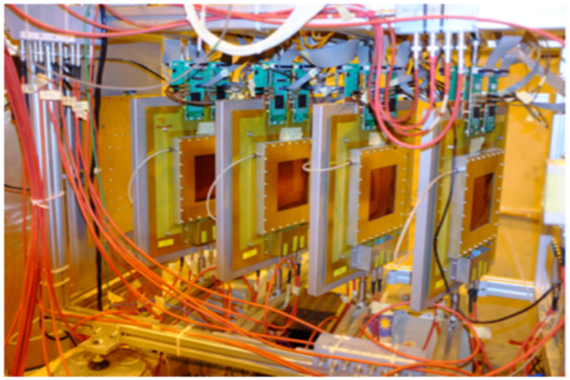


Efficiencies and resolutions

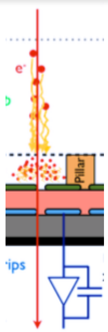
- Above 300 kHz/tube the MDT efficiency drops significantly due to dead time from background hits
- Limit for CSCs is reached even earlier, due to only 4 detection layers (instead of 6 for MDT)
- MDT Resolution degradation due to gain loss caused by space charge



Performance of Resistive Micromegas

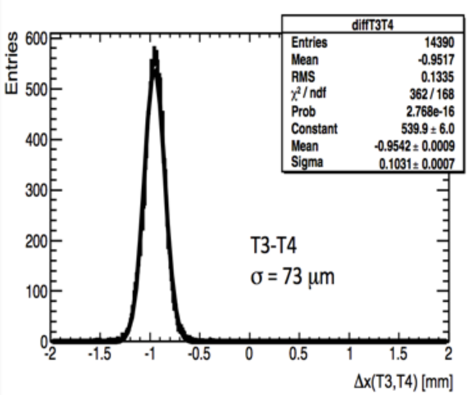


- A long R&D phase on small/Medium size Micromegas prototypes has demonstrated that resistive Micromegas fulfill the requirements for operations in ATLAS during next LHC upgrades
- Quick review on the main performance (obtained with NOT NSW elx):
  - Spatial Resolution below 100 μm independent from track angle



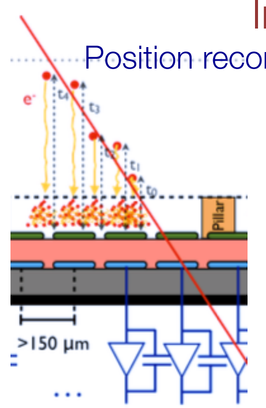
Perpendicular tracks

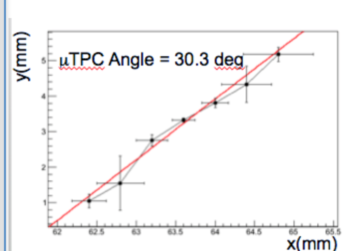
Position reconstruction: charge weighted centroid

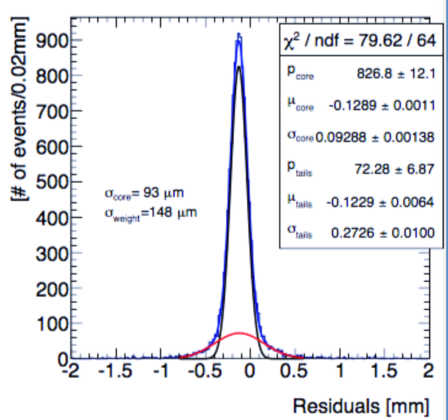


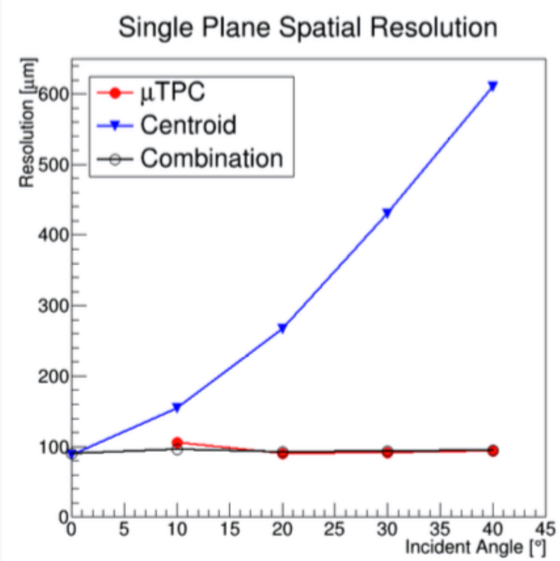
Inclined tracks

Position reconstruction: exploit time information → "micro-TPC"

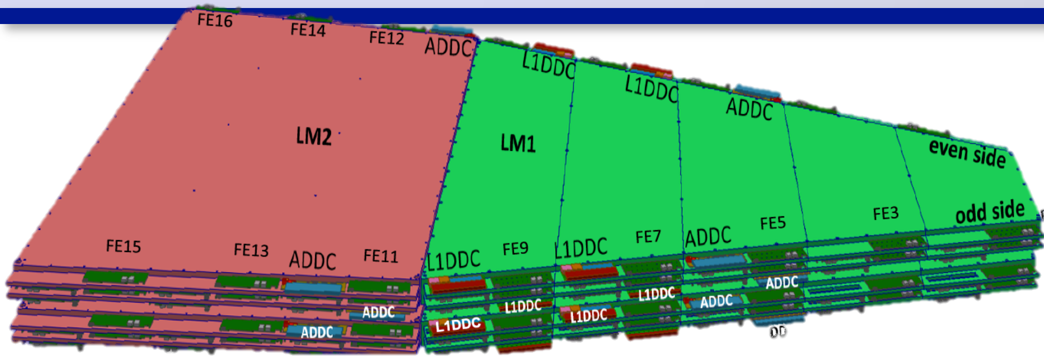






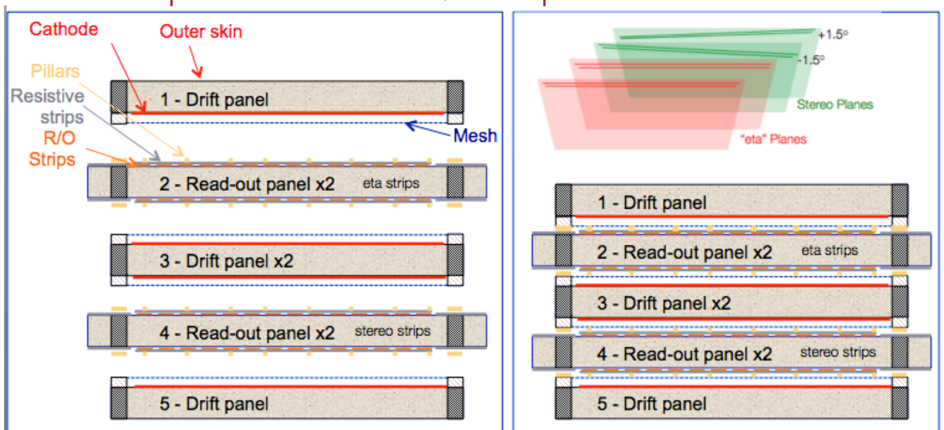


ATLAS Micromegas Design



A Large Sector of Micromegas

Main components of one Quadruplet

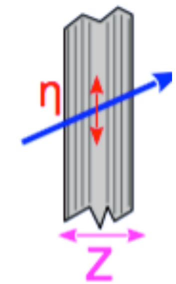


- 1 "eta-strips" double readout panel
- 1 "stereo-strips" double readout panel → Alignment is crucial
- 1 double drift cathode panels
- 2 single drift cathode panels

To achieve 15% transverse momentum resolution for 1 TeV muons :

- Alignment of the strips on each plane (RMS):

track accuracy:
30 μm in η
80 μm in z



Requirements on the construction:

Precision coordinate η

- Position of strips on planes: 40 μm (max dev.)
- Relative alignment of the two sides of the readout panel: 60 μm (max dev.)
- Relative alignment of the two readout panels: 60 μm (max dev.)

Z-coordinate

- Planarity for ALL panels:
  < 37 μm RMS
  < 110 μm max deviation wrt nominal

Micromegas Construction: Readout PCBs

I. photolithographic creation of copper pattern
standard process.
complex due to: size of board & required precision.

II. cutting of Kapton foil with resistive pattern
non-standard but simple & required accuracy only ±1mm

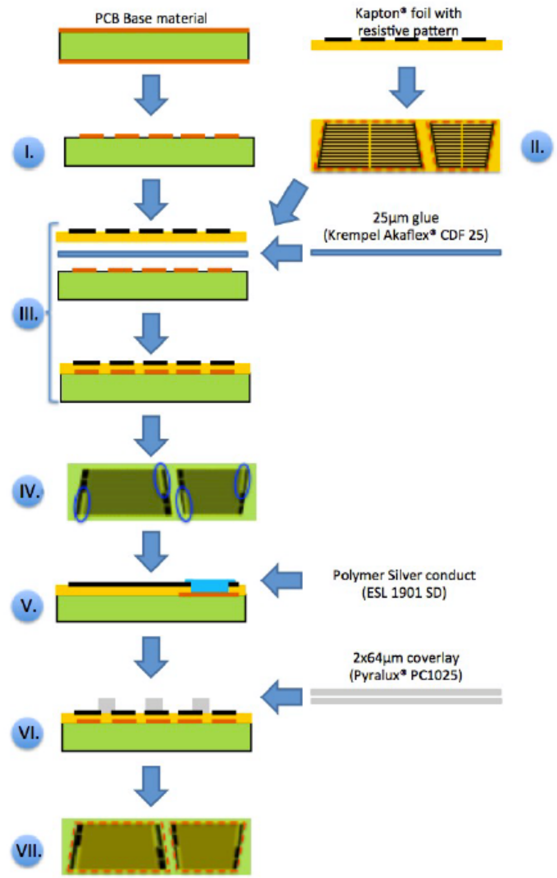
III. stacking and high-pressure & temperature gluing of Kapton foil, glue foil and board
standard process for small boards.
complex due to: size of board & required cleanliness.

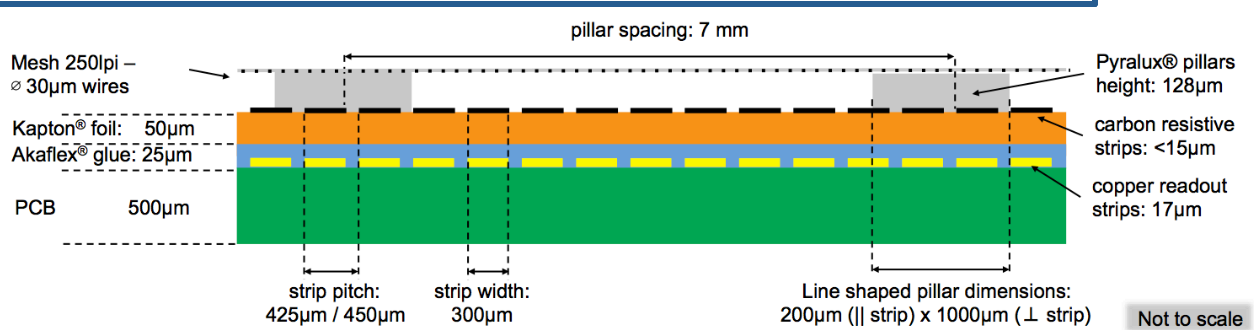
IV. chemical plating of copper pads
standard process

V. screen-printing of silver paste
non-standard but rather simple & required accuracy only ± 1mm

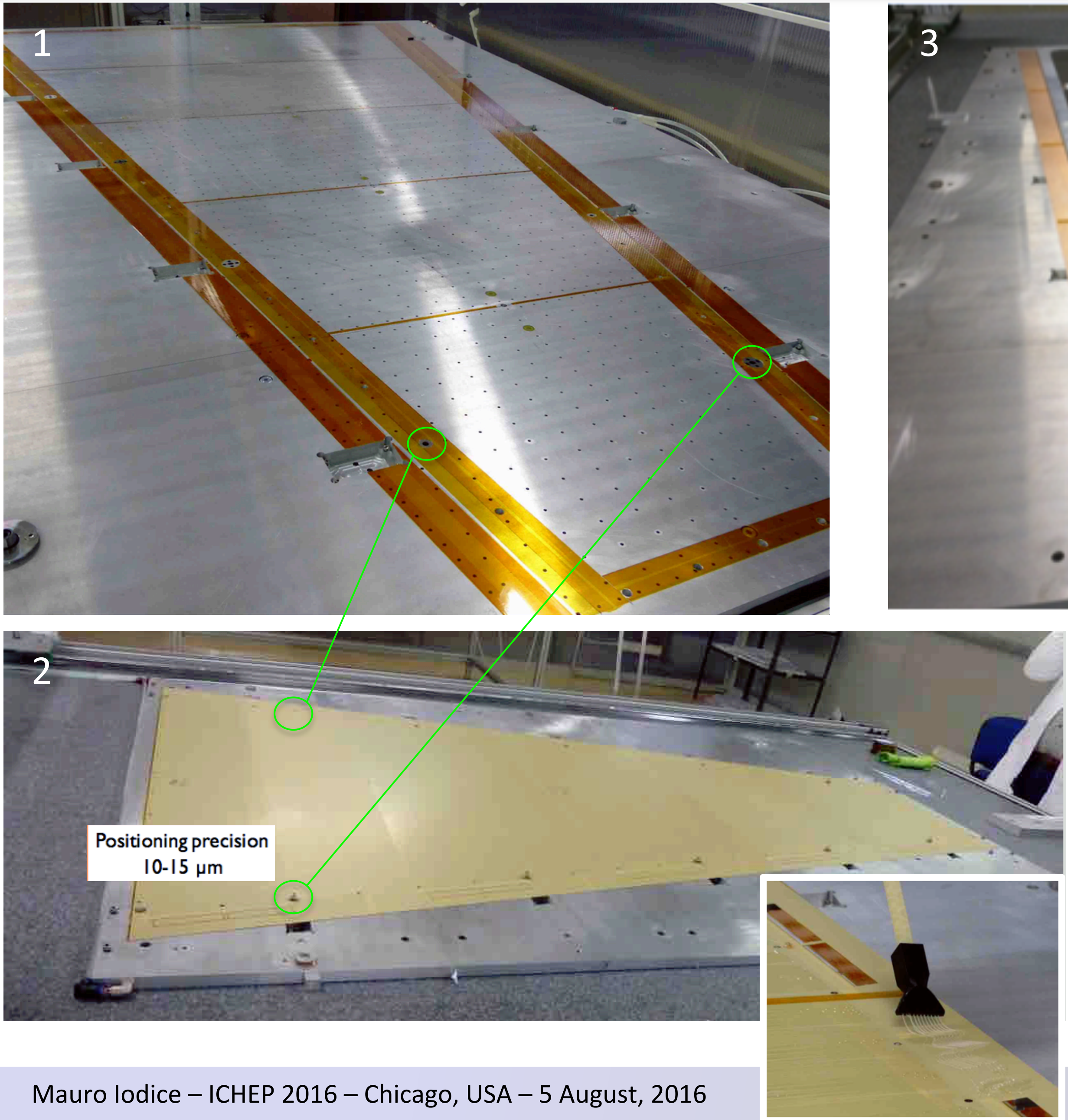
VI. lamination of coverlay & pillar creation
standard process for small boards.
complex due to: size of boards, highly non-standard pattern, required flatness

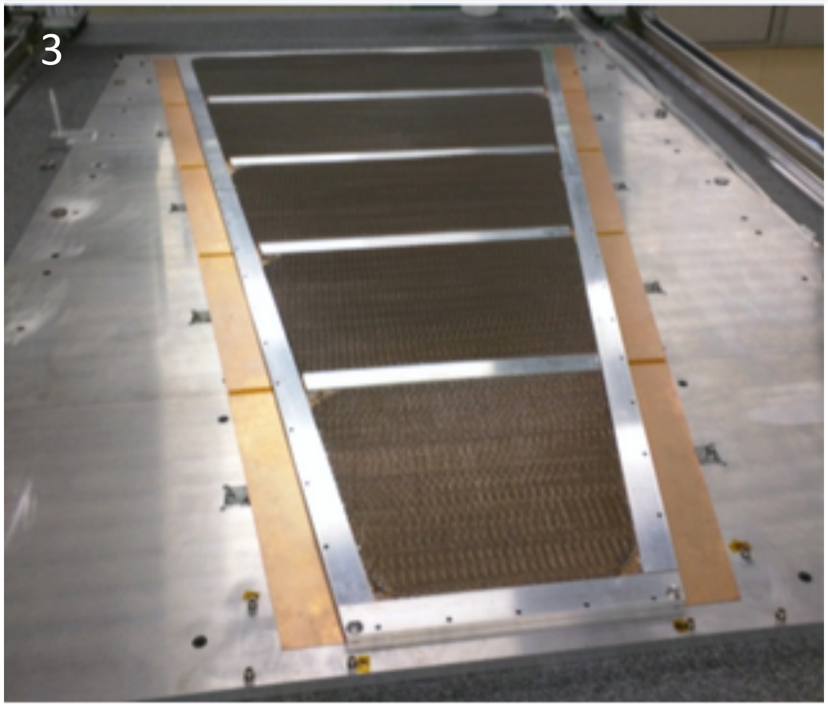
VII. cutting of boards and drilling of non-precision holes
standard process on CNC machine.
complex due to size of boards and required cutting precision





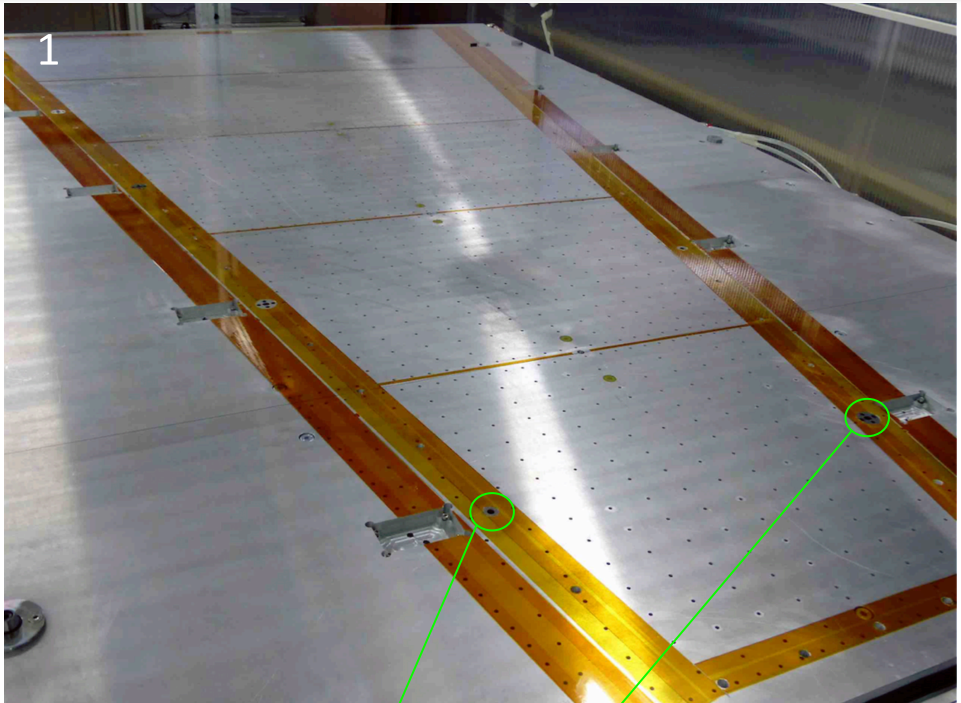
Readout Panels – Construction steps 1/2

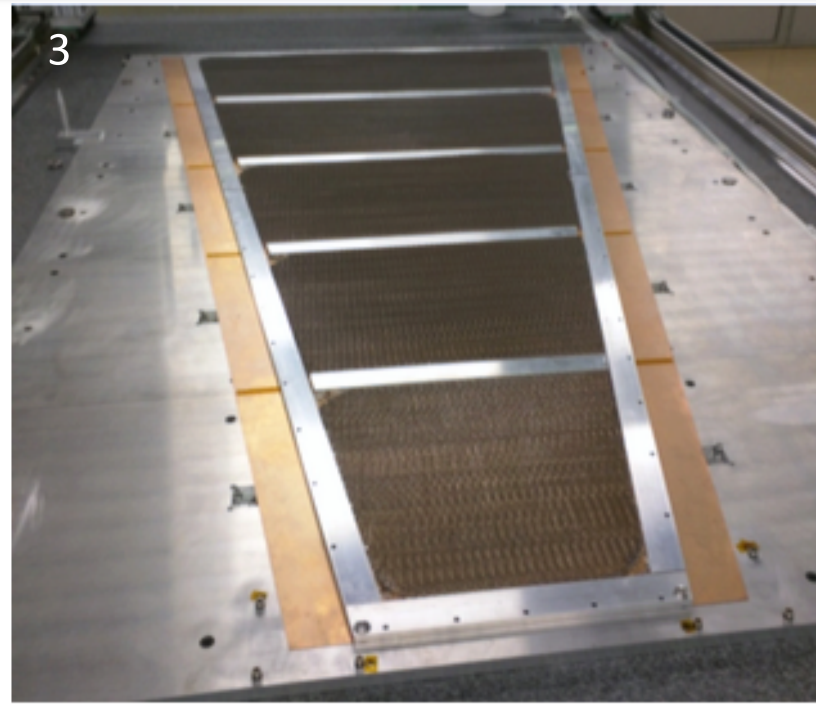


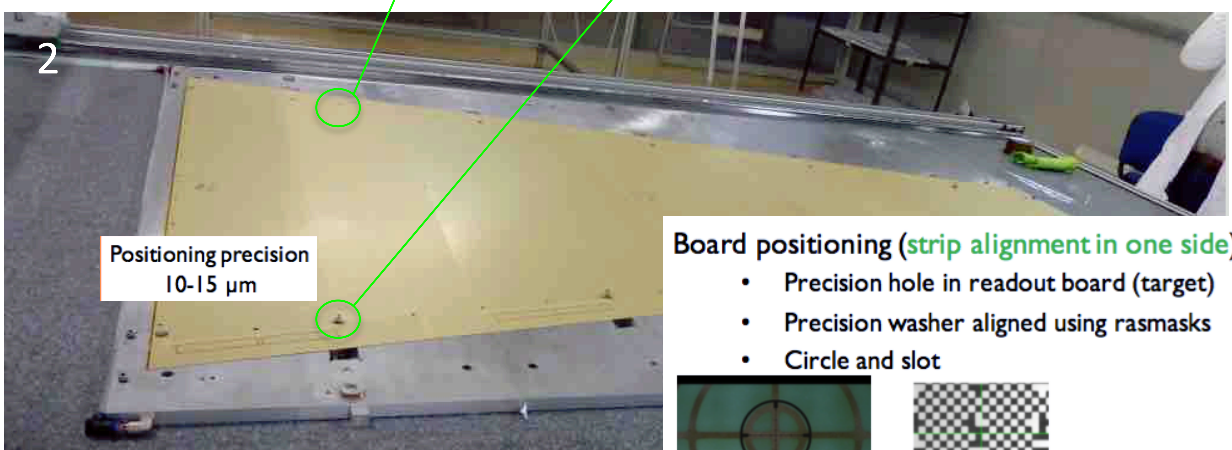


1. Align 5 Readout PCB on precision plates on the granite table with **precision pins in precision hole & slot**
2. Apply vacuum, remove pins, and apply glue
3. Place aluminum bars and honeycomb into the glue (align with Teflon pins in assembly holes)

Readout Panels – Construction steps 1/2







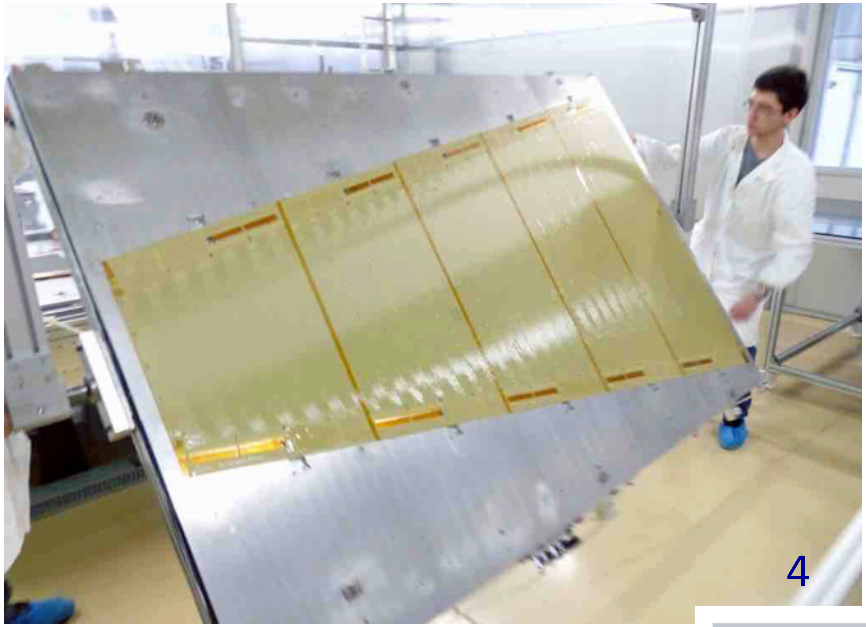
Board positioning (strip alignment in one side)

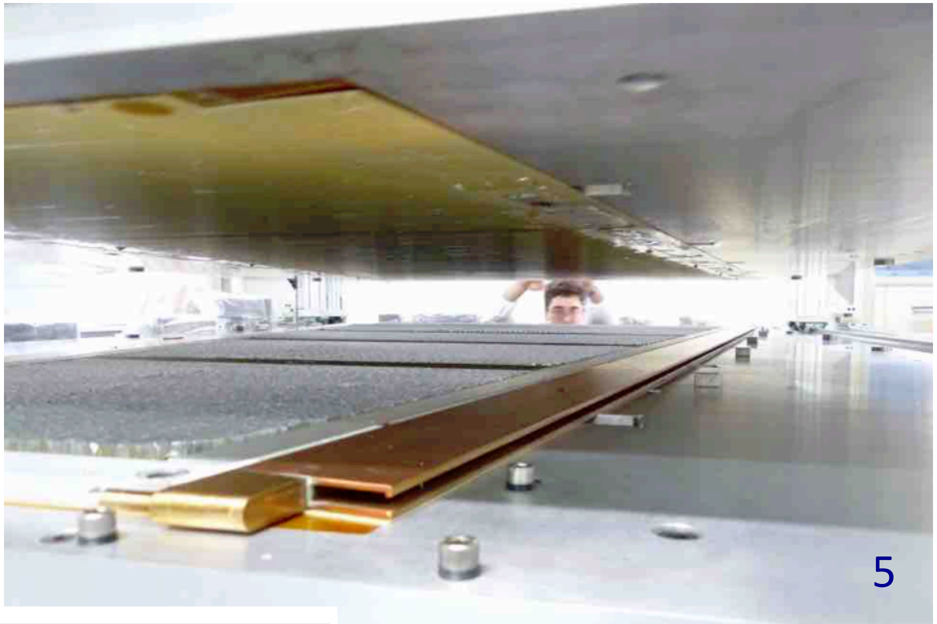
- Precision hole in readout board (target)
- Precision washer aligned using rasmasks
- Circle and slot

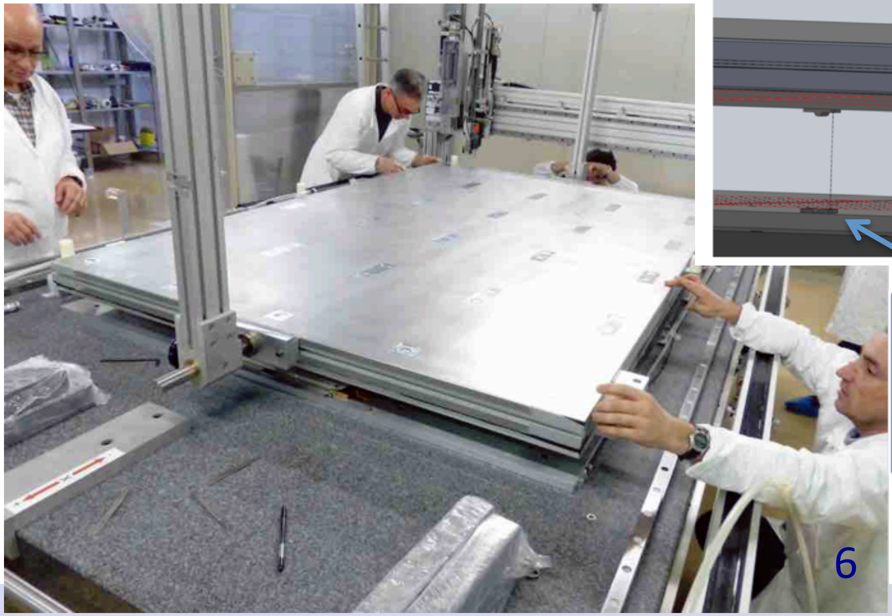
What you see with the Rasnik camera

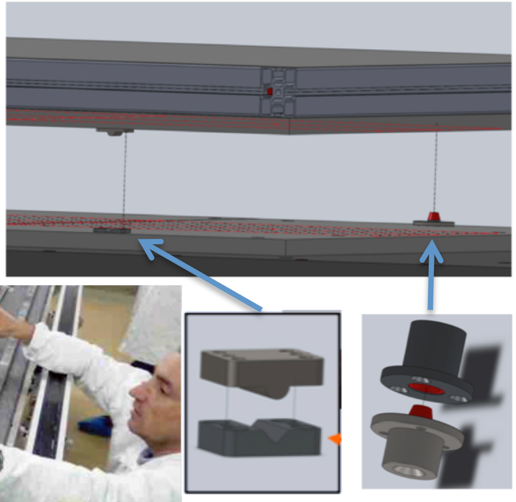
Alternative systems are used for Readout board positioning e.g. with optical method in Saclay

Readout Panels – Construction steps 2/2



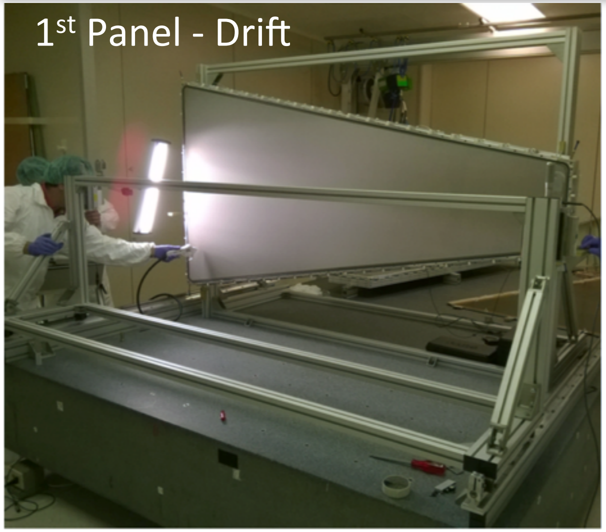


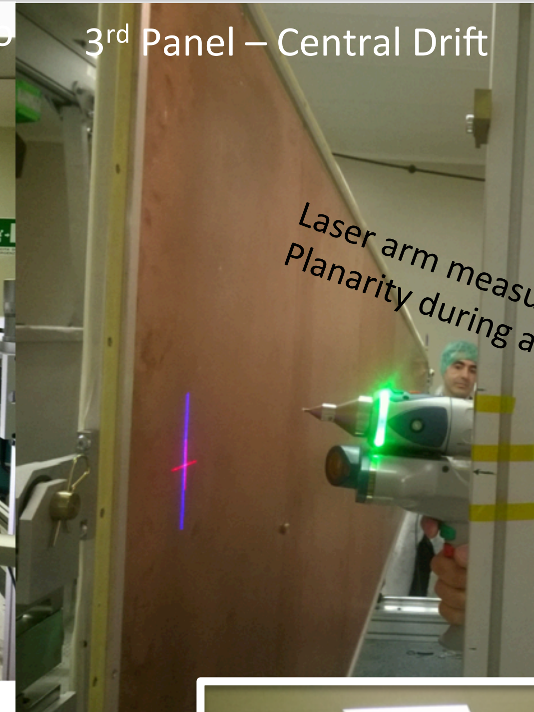


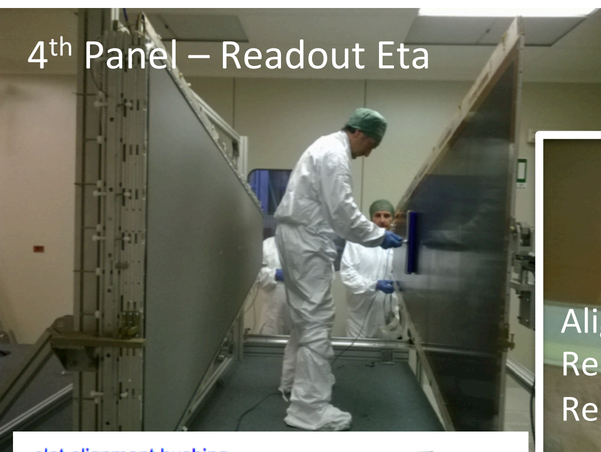


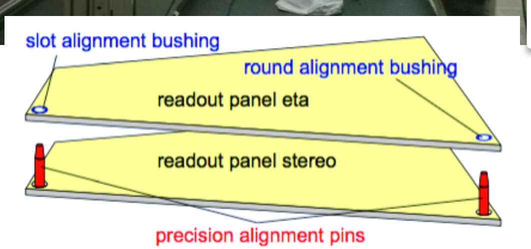
4. Align second layer PCBs with precision pins on precision aluminum plates on the stiffback
   Apply vacuum, remove pins and apply glue
5. Turn stiffback, lower towards the first side
6. Alignment of the PCB layers achieved by precision tapered and v-shaped interlocks

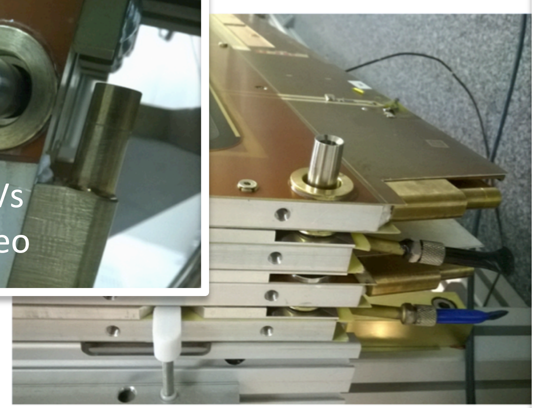
Quadruplet Assembly Steps





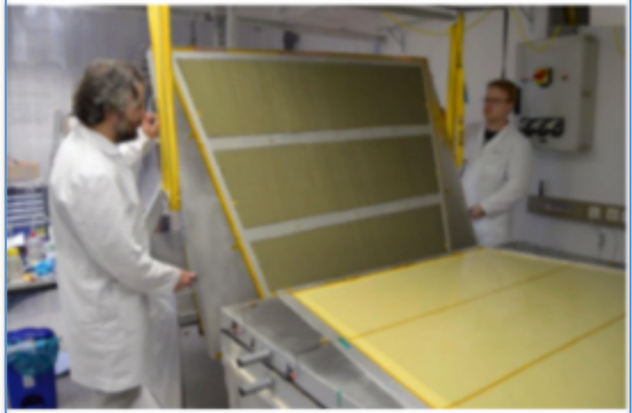
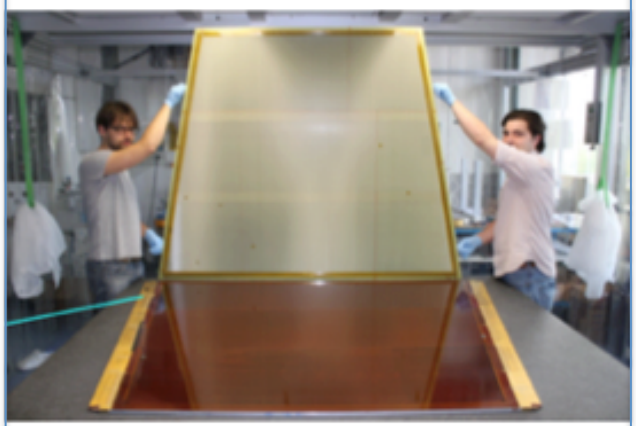






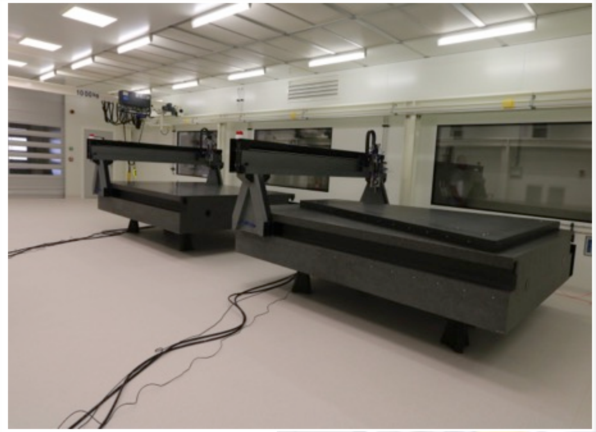
Alignment of the two readout panels at < 60 μm precision

Modules-0 Status at other Construction Sites

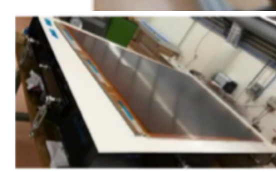
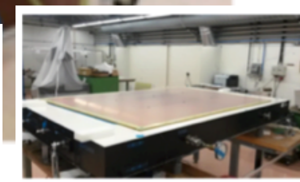
SM2 – Germany - BMBF

- All drift Panels are built – mesh stretching as well
- All Readout panels are built
- Completion module-0 in Autumn




LM1 – France - Saclay

- 2 Drift panels built
- Production tooling and new clean room ready (~20July – NEW!)
- Completion of module-0 in Autumn

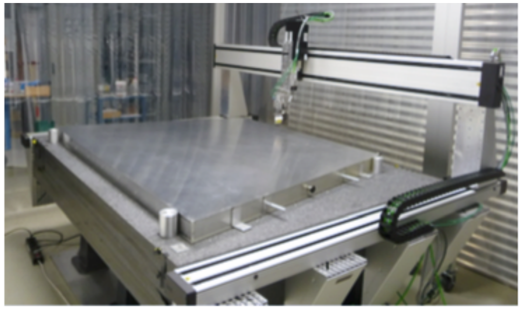




LM2 – CERN - Dubna-Thessaloniki

- All drift and readout panels built
- Quadruplet assembly ongoing (next step doublet assembly in Aug.)
- Completion module-0: in Autumn

Panels Planarity Measurements Results

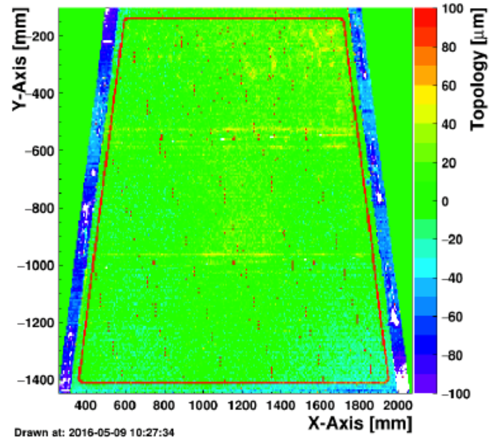
Optical measurements with coordinate measurement system @ Munich



- Laser distance sensor on a CMM
- Granite table tolerance 6 µm
- Accuracy 8 µm

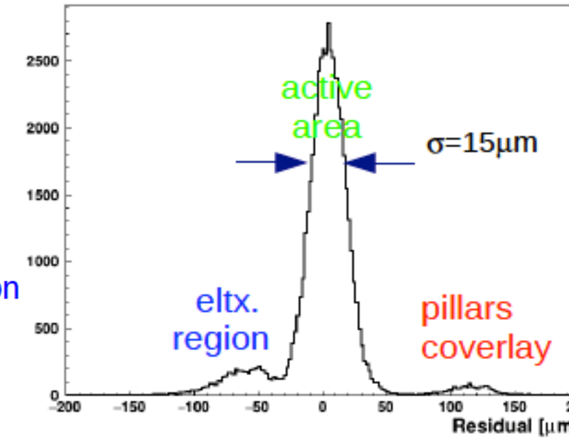
Panels flat on granite table

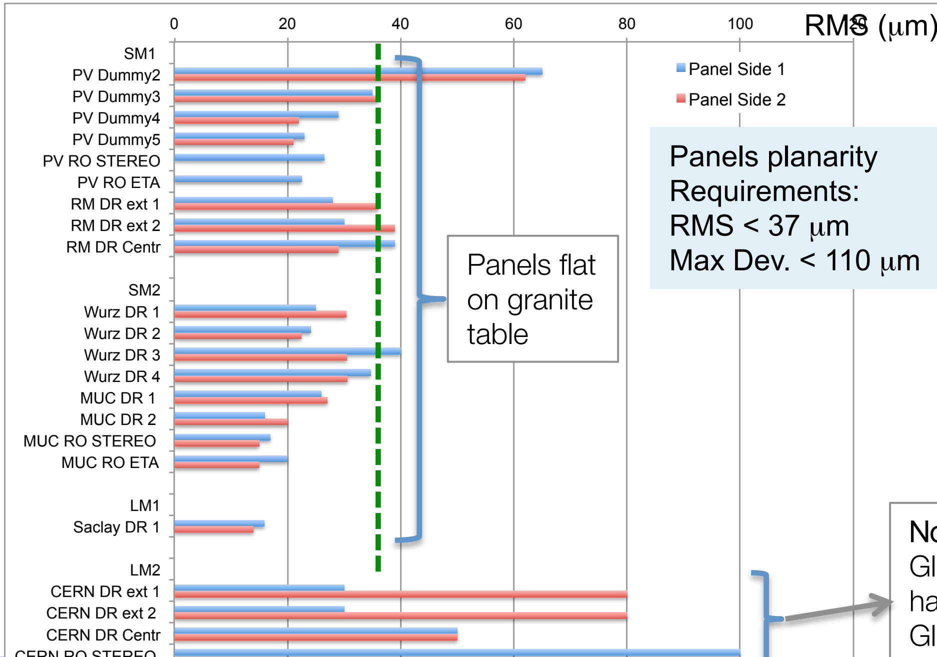
SM2 STEREO Readout Panel



pillars + coverlay

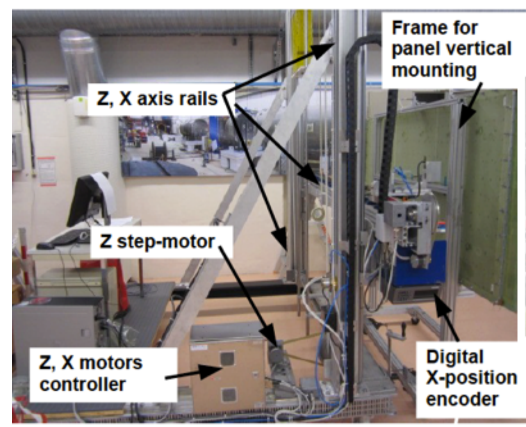
eltx. region

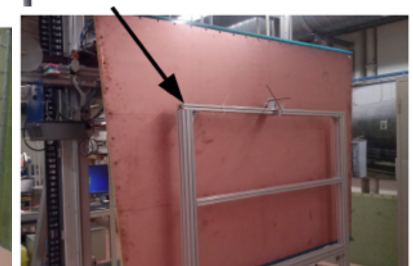




Panels planarity Requirements:
RMS < 37 µm
Max Dev. < 110 µm

Panel measurements at CERN with laser tracker in vertical position





No local inhomogeneity above 30 µm
Global deformations visible because of vertical hanging of the panels during measurements
Global deformations expected to vanish after assembly