Micromegas for ATLAS New Small Wheel upgrade - status report -

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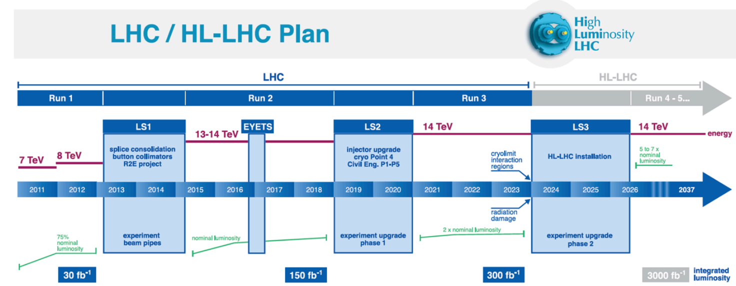
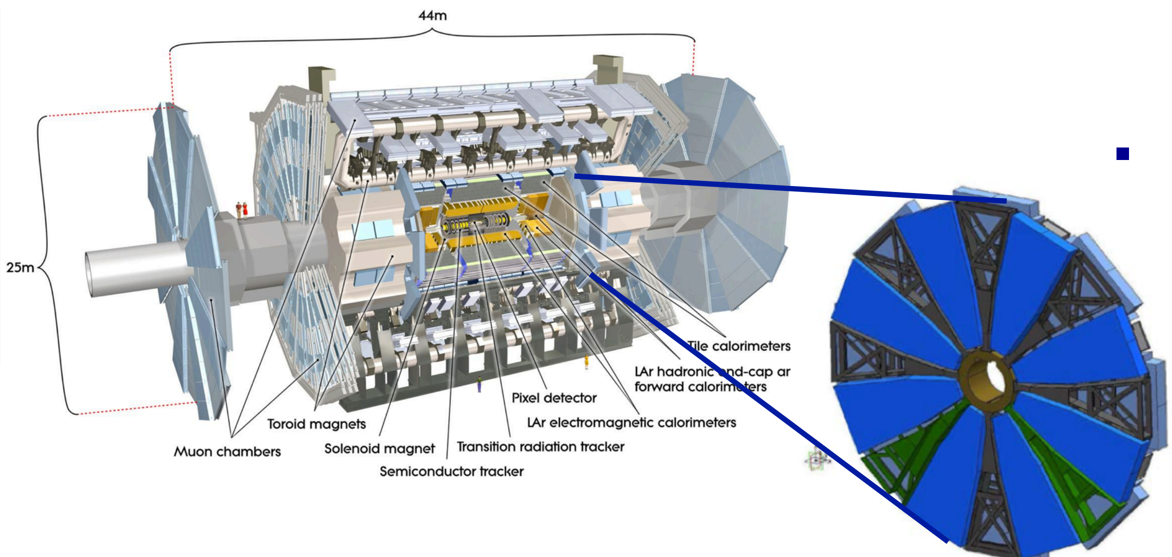
On behalf of Micromegas NSW Collaboration

The ATLAS New Small Wheel project

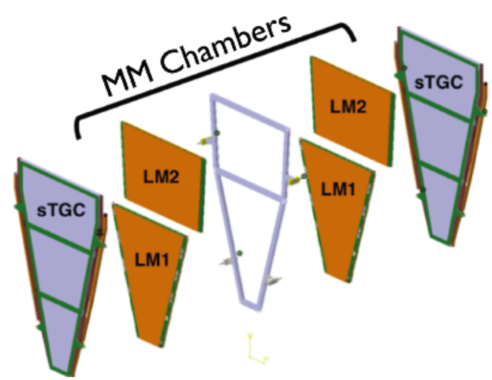
- Upgrade of the innermost forward detector wheels of the ATLAS muon system during LHC Long Shutdown 2 (2019/2020)





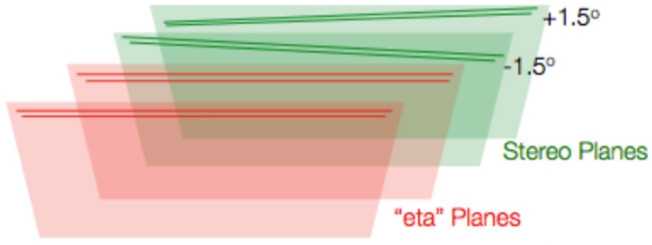
- NSW requirements
  - Spatial resolution up to 32° track inclination 100 um in precision coordinate (η) ~mm in azimuthal coordinate (φ)
  - 1 mrad angular resolution (from HL-LHC L1 trigger requirement)
  - Bunch crossing identification
  - Efficiency > 98%
  - Rate capability > 15 kHz/cm2

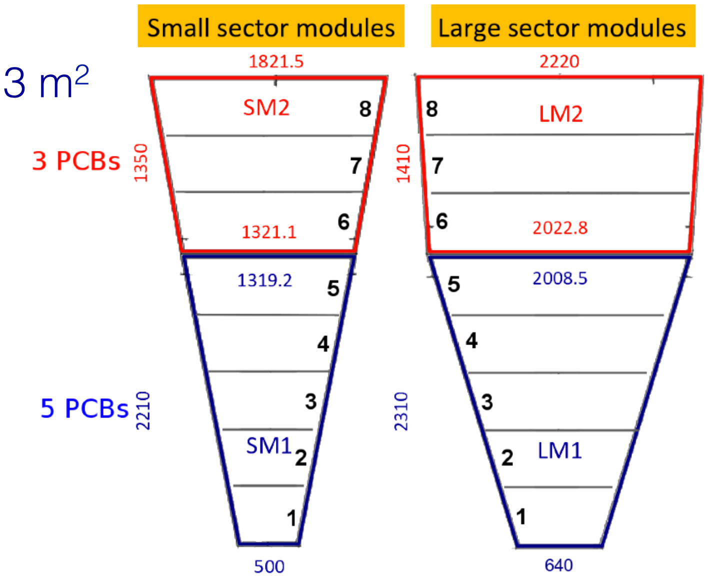
- 2 wheels ~10 m diameter
- 2 detector technologies both with triggering and tracking capabilities:
  - Micromegas: primary tracking detector
  - sTGC: primary trigger detector
- High redundancy: 8 sTGC and 8 MM layers arranged in quadruplets



Micromegas for ATLAS NSW

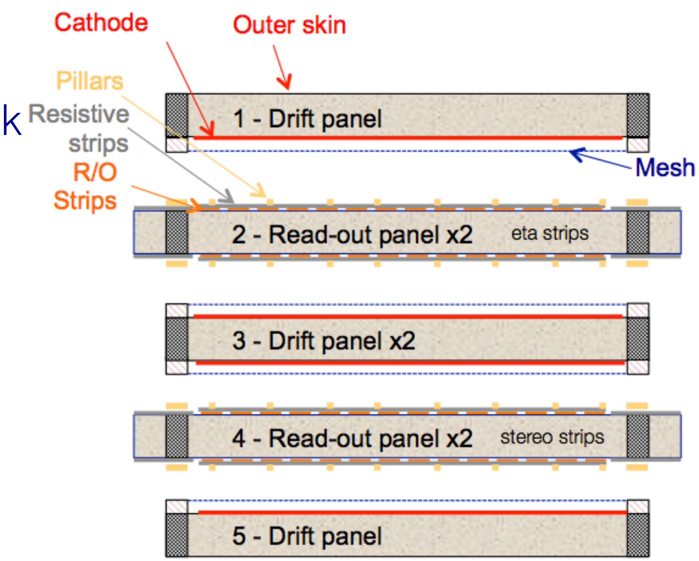
- 128 Micromegas quadruplets (modules) in total
- 4 different types (32 modules each) with surface of 2 to 3 m^2





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

- 2 doublets in back-to-back configuration (5 panels):
  - 2 readout panels
  - 2 external drift cathode panels (single)
  - 1 middle drift cathode panel (double)

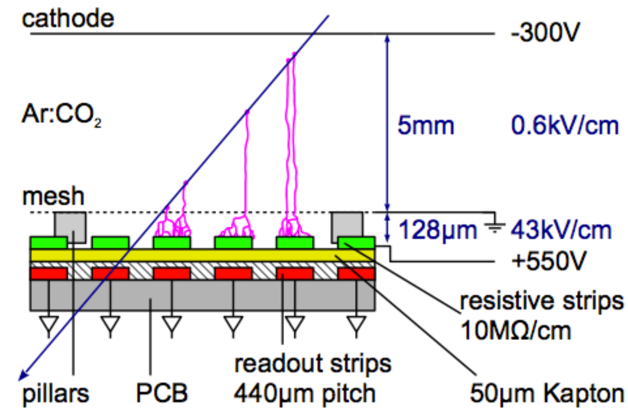


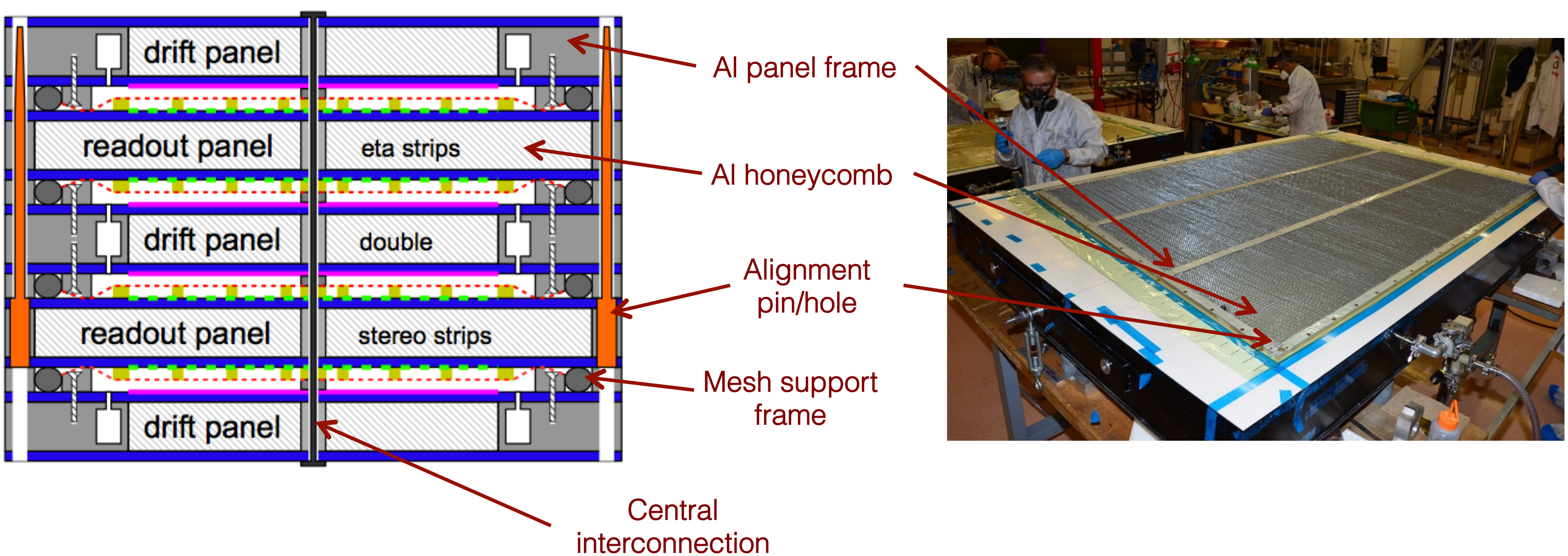
Total of >1200 m^2 of Micromegas active area

NSW is the largest Micromegas-based project ever built

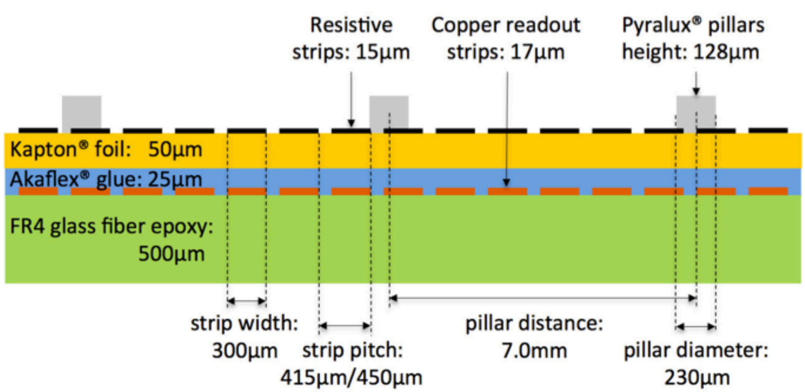
Detector design

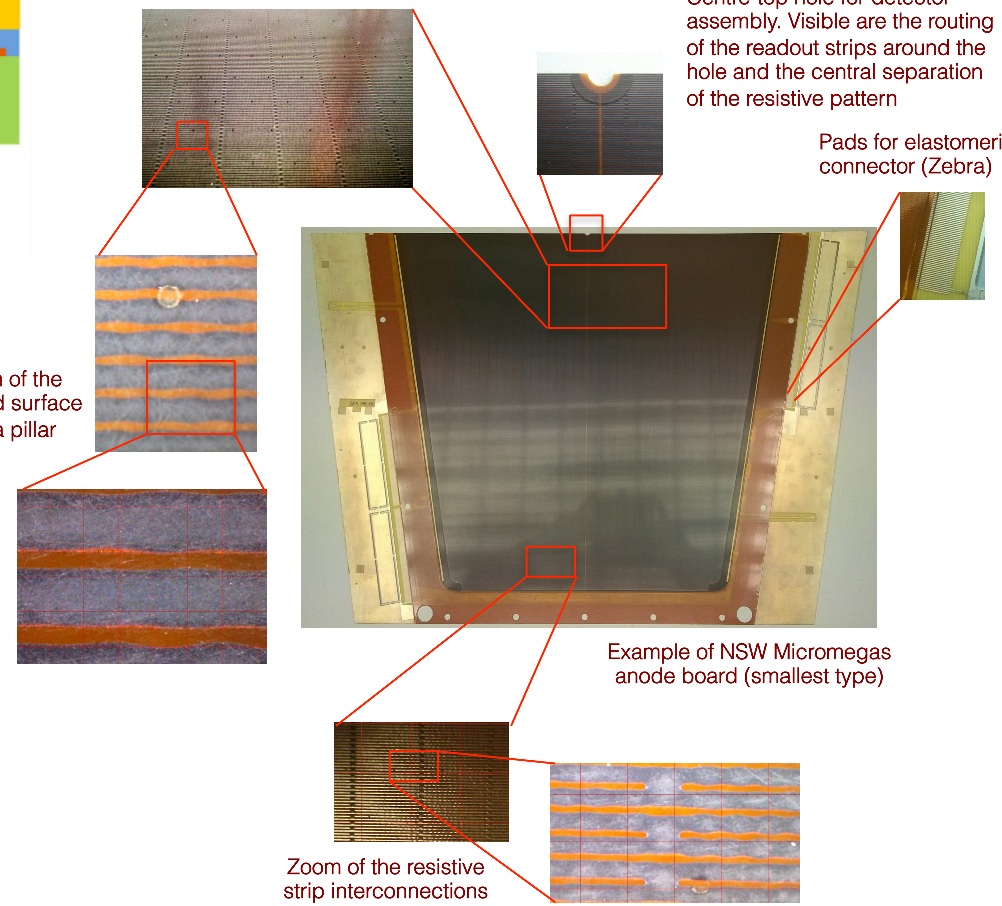
- Resistive strip layer for spark suppression
- Mesh stainless steel woven on plain weave, 30/70
  - mechanically floating (no bulk)
  - grounded, HV on resistive strips
- Panels (stiff and light):
  - 10 mm Al honeycomb with Al frames
  - Two FR4 skins (0.5 mm thick)





Readout board design





Surface structure of the board, with regular patterns of pillars and interconnections of resistive strips

Centre-top hole for detector assembly. Visible are the routing of the readout strips around the hole and the central separation of the resistive pattern

Pads for elastomeric connector (Zebra)

Zoom of the board surface with a pillar

Example of NSW Micromegas anode board (smallest type)

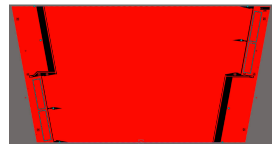
Zoom of the resistive strip interconnections

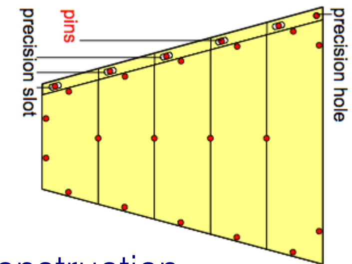
- 415/450 µm strip pitch 300 µm width
- 1023 strips/board
- Screen-printed resistive pattern (~1 MΩ/☐, 415/450 µm pitch 300 µm width, interconnections every 10 mm)
- Two HV sectors for each board: resistive strips interrupted in the middle
- Pillars 128 µm height, 280 µm diameter
- Strips routed to the left (bottom half) and right (top half) to pads for elastomeric connector (Zebra)

Requirements on mechanics

- To reach the required tracking performance the detector construction shall meet stringent requirements: strip position accuracy <30μm in η and 80μm in Z

1. Strip position (absolute) <35 μm
→ PCB fabrication

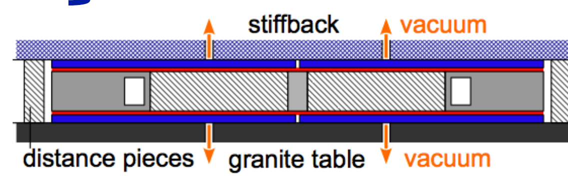




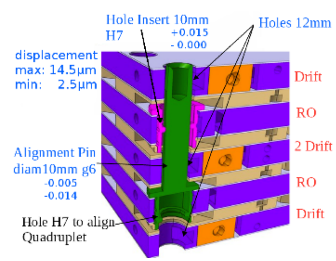
2. Alignment of two RO PCBs on the same layer <25 μm
3. Alignment of RO PCBs on the two sides of the same panels <25 μm
4. Planarity of RO and Drift panels <37 μm (RMS); <±110 μm min-max

} →Panel construction

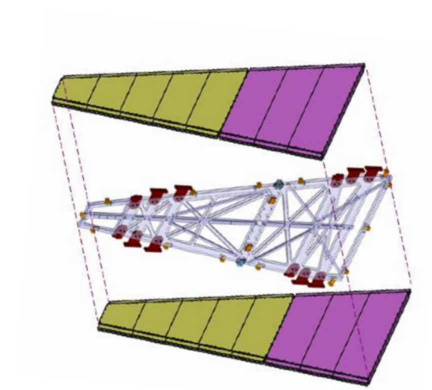
- Precision pin-slot system to align PCBs
- Optical system (C-CCD) to check alignment
- Precise marble table or stiff-back structure as surface reference



5. Alignment of two RO panels <18 μm
→ Detector assembly
- Precision pin-slot system to align RO panels
- Optical system (C-CCD) to check alignment

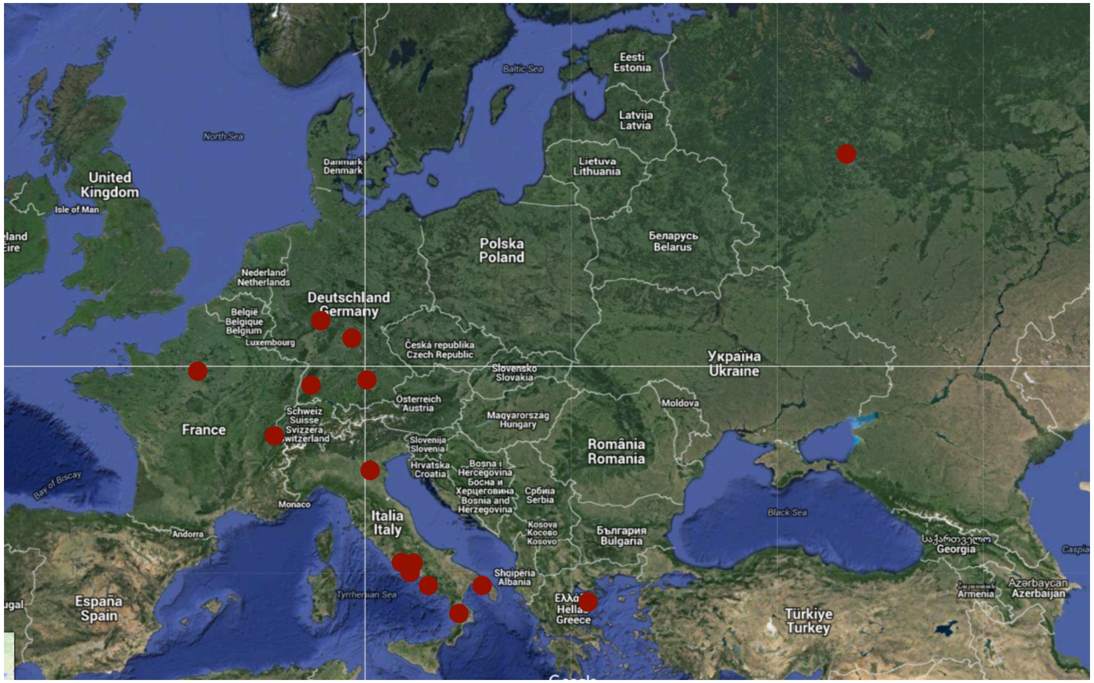


6. Alignment of MM quadruplets on the same sector <200 μm
→ Detector mounting on the support structure (spacer frame)



Construction sites and organization

- Four construction site clusters:
  - Italy INFN (Frascati, Pavia, Rome1, Rome3, Cosenza, Lecce, Napoli)
  - Geermany (BMBF; Mainz, Munich, Wurzburg, Freiburg)
  - France (CEA Saclay)
  - Russia/Greece (Dubna, Tessaloniki) with detector design, tooling development and construction and Module0 done at CERN
- Readout board QA/QC, detector commissioning and preparation at CERN



Readout board production

Production done in industry – stringent requirements

I. Copper pattern creation by photolithography

- Copper pattern absolute accuracy: <30 μm for the short side and <100 μm/m for the long side
- Line and space accuracy 20% w.r.t. the design file
- Maximum 1% of cut on the copper lines, as long as cuts are not on neighboring lines
- Maximum of 0.1% of shorts between two lines, as long as no more than two successive lines are shorted

II. Selective plating on connector pads

- Layer thickness depending on plating choice: Au/Ag/Pd

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 shall be better than ±0.5mm

V . Connection between HV input line and resistive strips (screen printed: silver conductive paste)

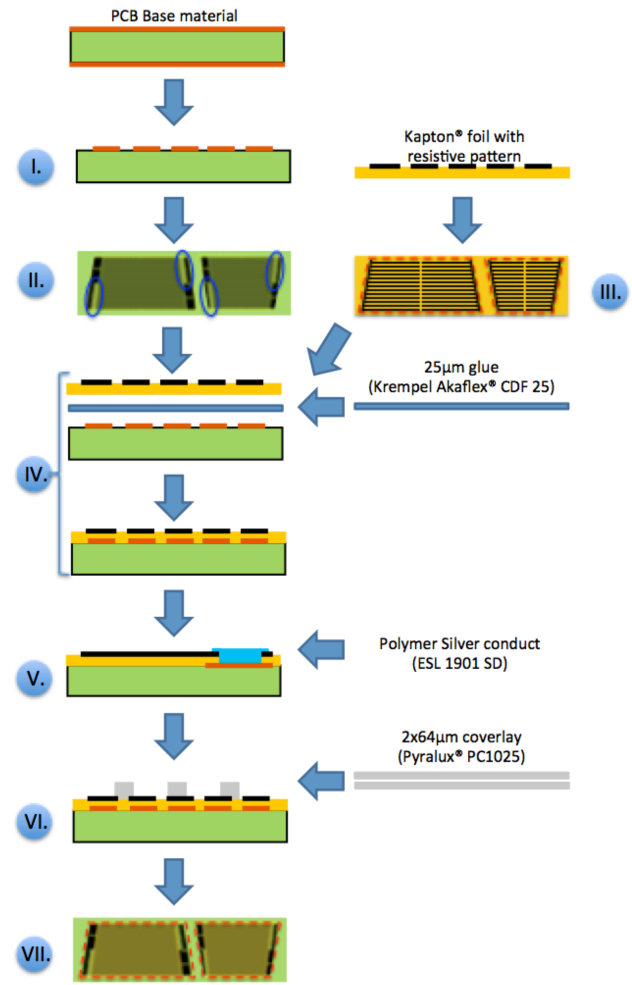
- Position accuracy w.r.t. the copper pattern < ±1m
- Resistance of the silver HV connection line < 10Ω

VI. Pillar creation (2x 64µm Pyralux coverlay)

- Coverlay pattern absolute accuracy < ±1 mm
- Accuracy of the diameter of the pillars ±25 µm
- Missing pillars maximum 0,1% of the total number, as long as no neighboring pillars are missing
- Max. 10 extra coverlay structures of a size < 1mm in each dimension are tolerated per square meter
- The mean height of the coverlay layer / pillars in different 25x25 cm^2 regions has to be homogeneous on a level of <5µm over the full surface of the board

VII. Cutting of the boards and drilling of the non-precision holes (holes for mechanical assembly and alignment)

- Cutting absolute accuracy w.r.t. the copper pattern shall be better than ±100µm
- Holes absolute position accuracy referring to the copper pattern shall be at least ±100µm



Module0 readout boards

- Boards needed for 2 pre-series detectors (Module-0) of each type:
  - 40 (10 different types) for SM1 → 20 panels
  - 40 (10 different types) for LM1 → 32 panels
  - 24 (6 different types) for SM2 → 12 panels
  - 24 (6 different types) for LM2 → 12 panels
- Order placed to two companies in Dec. 2014
  - SM1 and LM2 (64 boards, 32 panels)
  - SM2 and LM1 (64 boards, 44 panels)
- Resistive foils:
  - SM1 and LM2: screen-printing done in industry (Japan, Kobe and Tokyo groups)
  - SM2: sputtering done in industry (Japan, Kobe and Tokyo groups)
  - LM1: screen-printing done at CERN
- Base PCB material (FR4 halogen free) ordered at CERN and provided to the companies after thermal stabilization

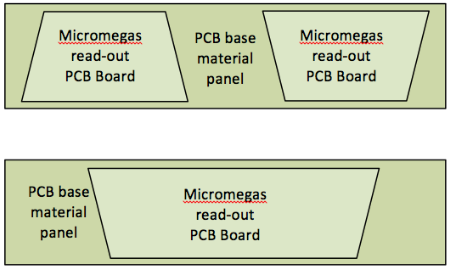


Figure 2: Top: example of two Micromegas read-out PCB boards produced from a single panel. Bottom: example of one Micromegas read-out PCB board produced from a single panel.

Foil dimension:
2180 mm x 1200mm

Module0 readout boards

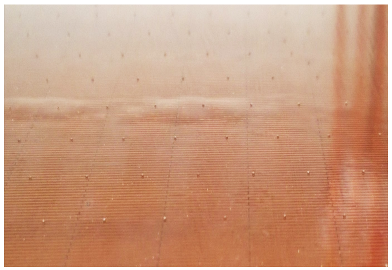
- Unexpected delay and unsatisfactory quality of the boards from both

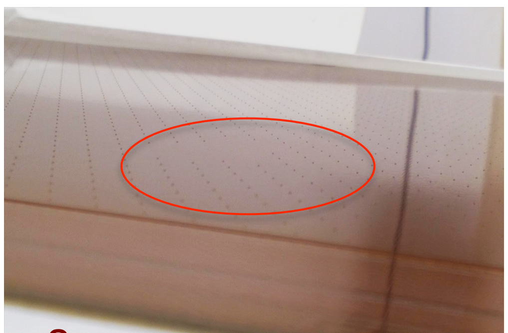
First few boards received in July/August

Main observed problems:

1. Bubbles/dust between kapton and PCB in active area
2. Deviation in the dimension of the copper pattern
3. Missing or weakly attached pillars (homogeneity of pillar heights resulted not to be an issue)
4. Inaccurate edge cutting and drilling
5. Strip cut badly repaired
6. Bad metallization/plating of the connector pad
7. Missing or bad HV connection lines

1.





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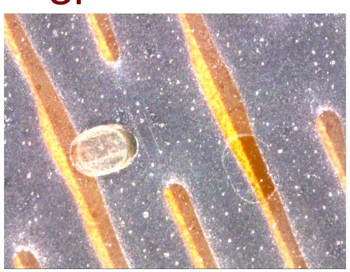

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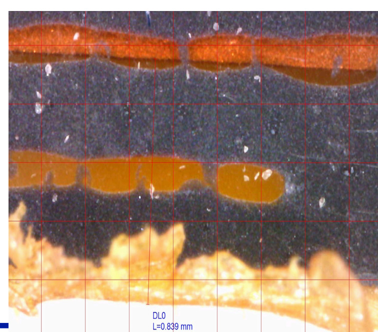

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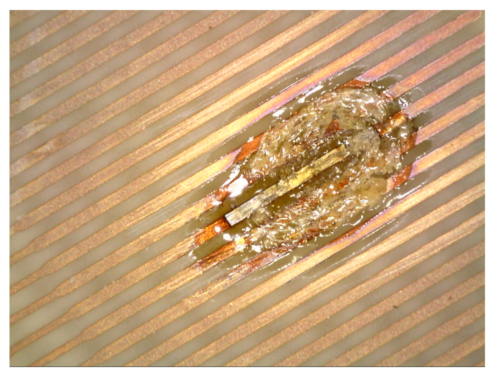

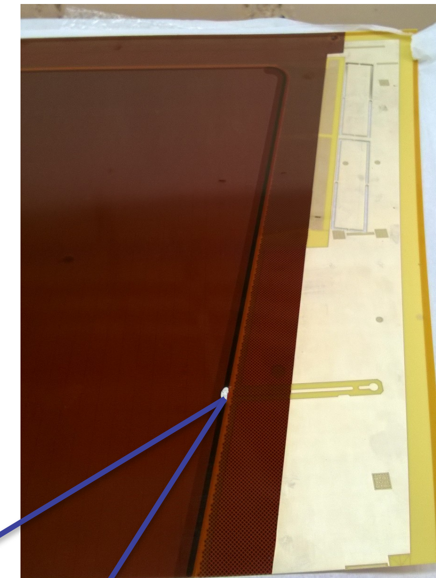

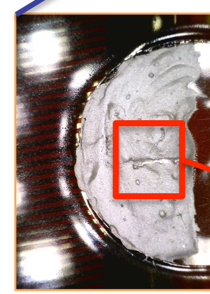

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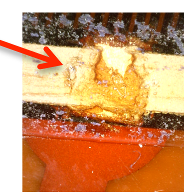
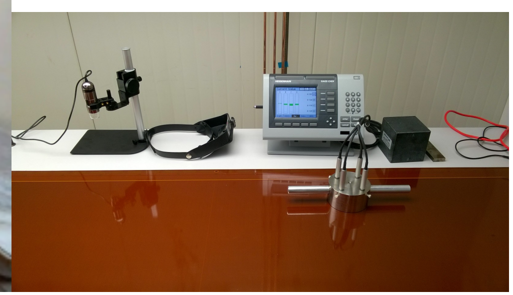


Module0 readout boards

- Actions have been taken to improve the quality of the boards after the first deliveries, including site visits to the industries
- Quality of the boards has increased, still some less severe problems observed
- Bad quality mostly related to missing quality checks during production and negligence in reading/applying our specifications, not to technical limitations of the companies

Readout board acceptance yield:
- SM1: 5 passed / 37 received
- LM2: 4 passed / 16 received
- SM2: 0 passed / 24 received
- LM1: not produced yet

A reparation campaign is ongoing to keep the boards needed for Module0

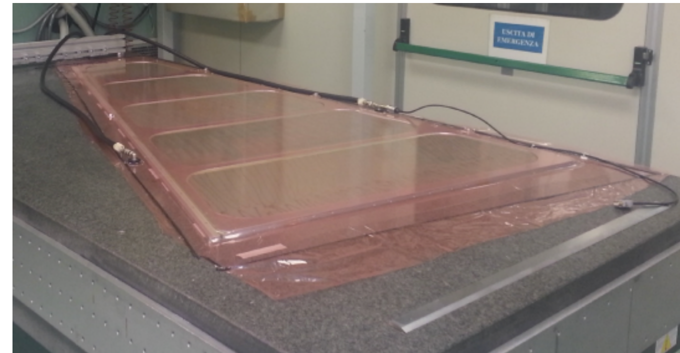


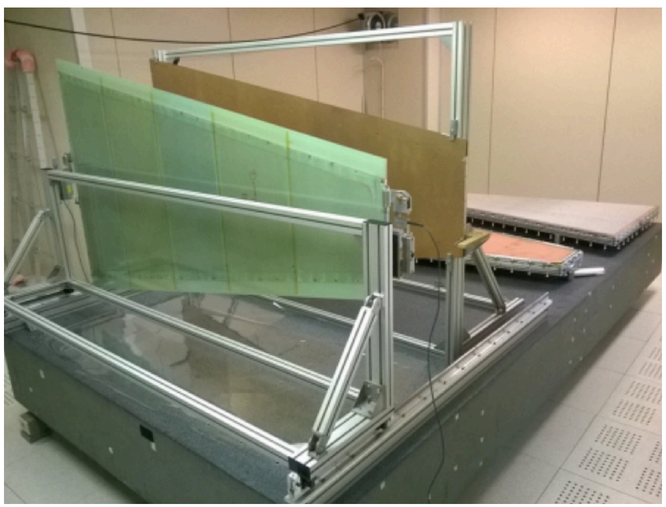
RO boards QA/QC performed at CERN in a temporary lab. The final one is being set-up

- For the mass production a tender process is in progress.
- A deeper quality check at the production company(-ies) with interfering measurements will be put in place

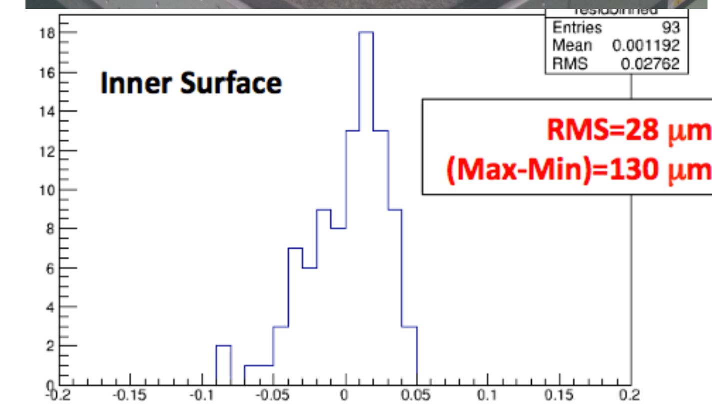
Status of Module0 construction: Italy

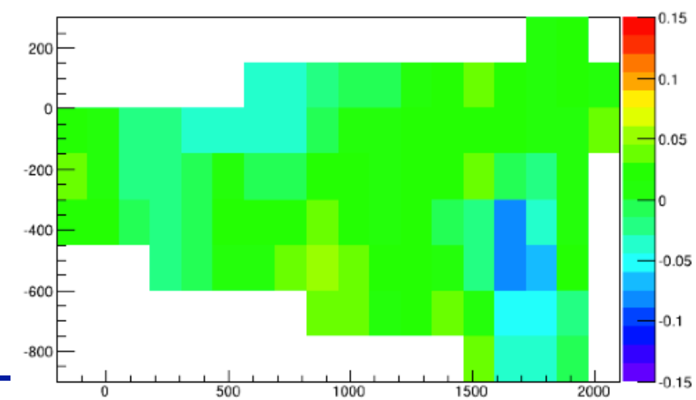
- Readout panels (Pavia): waiting for RO boards
  - Test panels built with good results
- Drift panels (Rome1): ready to be equipped with mesh (Rome3)
  - Within specs
- Quadruplet assembly (Frascati): tooling ready
- Expected completion: beginning of February





Assembly test at LNF

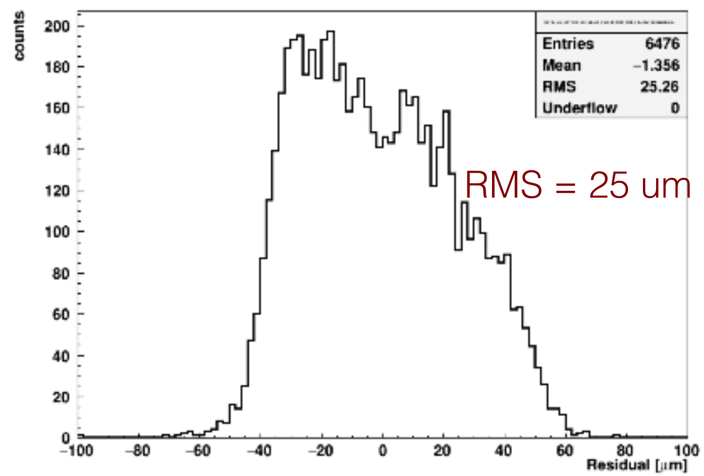


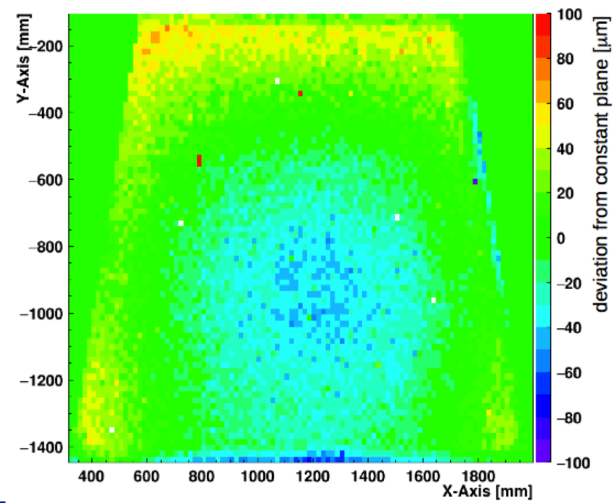


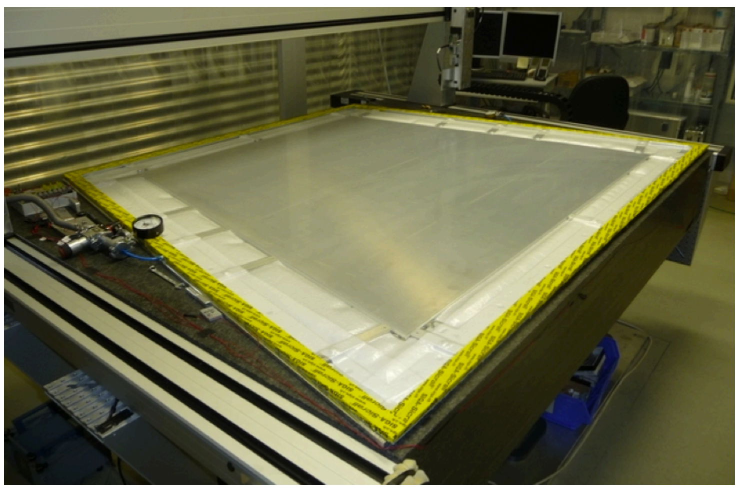
Status of Module0 construction: Germany

- Readout panels (Munich): waiting for RO boards
- Construction of first drift panel ongoing (Mainz)
- Mesh stretching tests ongoing (Wurzburg)
- Assembly tools under construction (Munich)
- Expected completion: mid March

RO test panel fulfill requirements



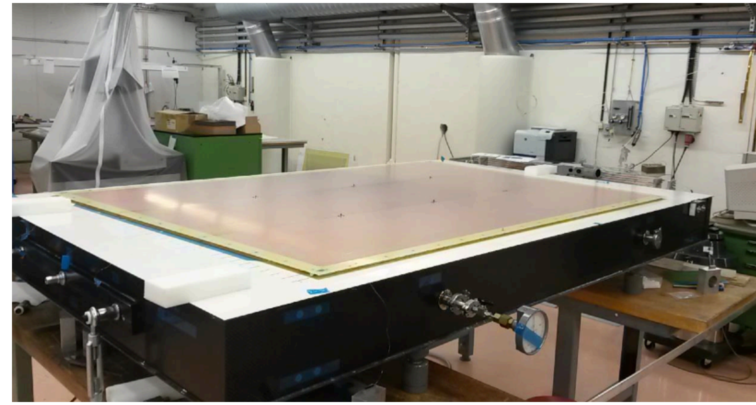


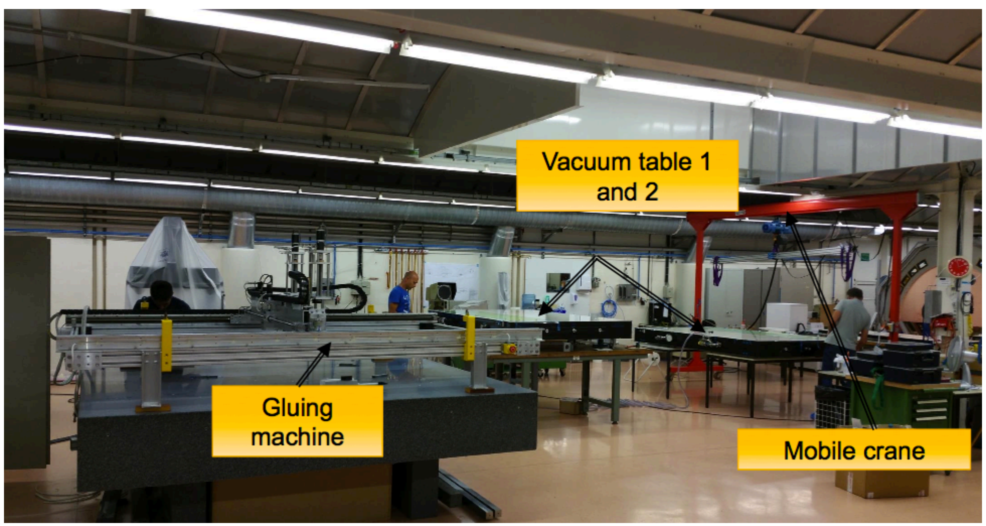


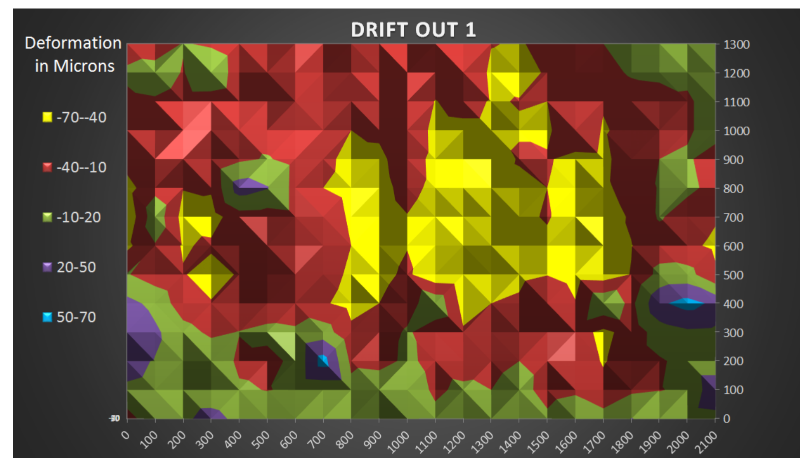
Test panel during first step of construction (vacuum bag)

Status of Module0 construction: CERN

- Readout panels: waiting for RO boards
- Drift panels: ready to be equipped with mesh
  - Within specs
- Quadruplet assembly: tooling under construction
- Expected completion: beginning of February





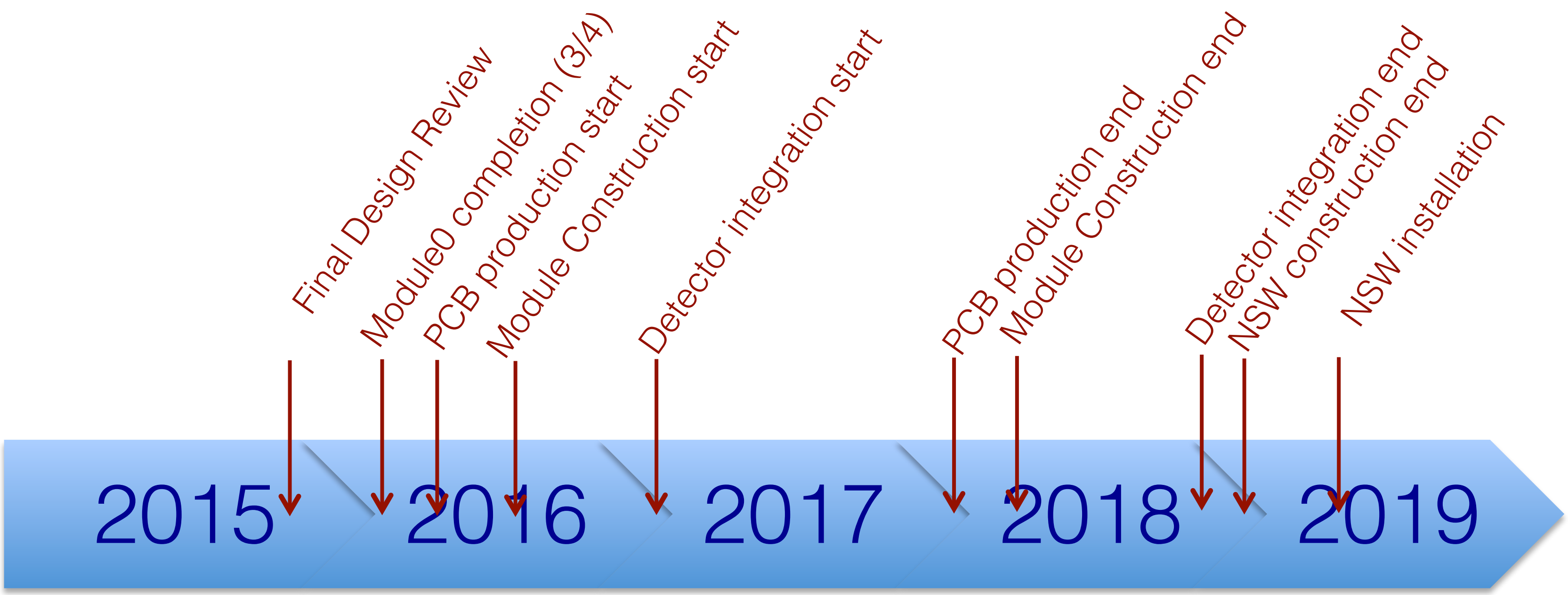


RMS = 23 um

Min-Max < 120 um

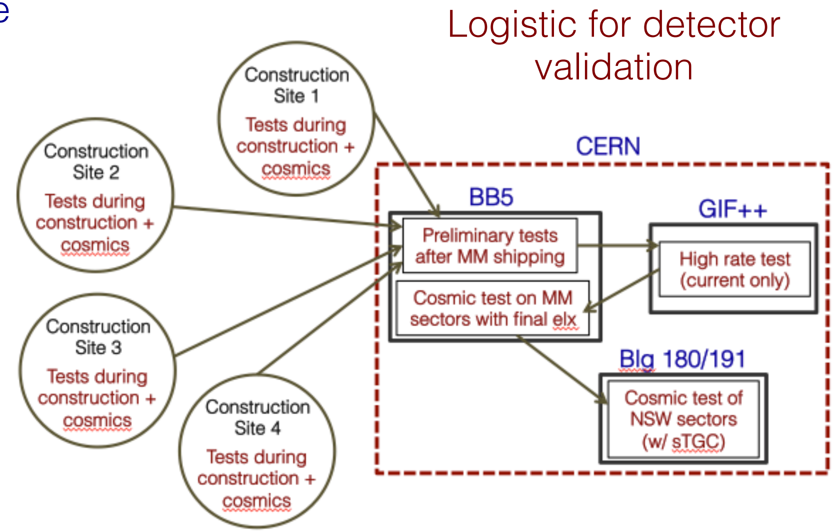
Toward mass production

- Procurement of detector components started:
  - Al honeycomb
  - Al frames
  - Mesh
  - PCB components
  - Sealing joint (O-ring)
- Tender for readout PCB production shall be finalized soon
  - PCB production to start in Spring
  - Module construction in Summer

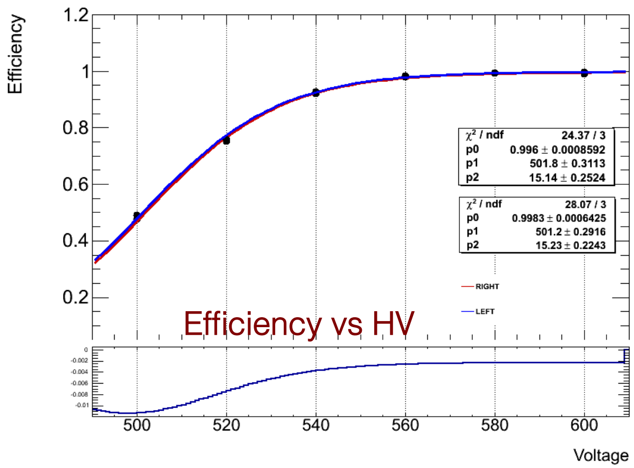


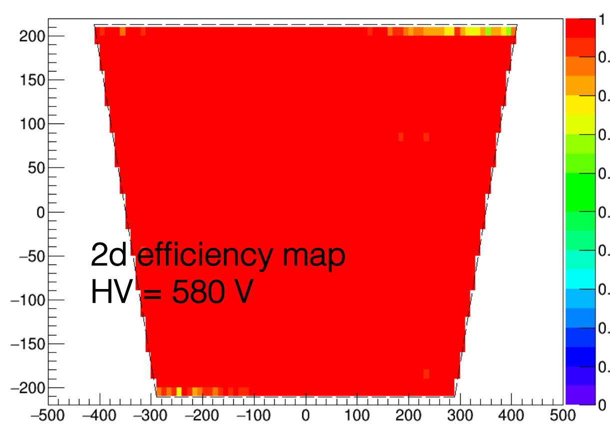
Detector validation

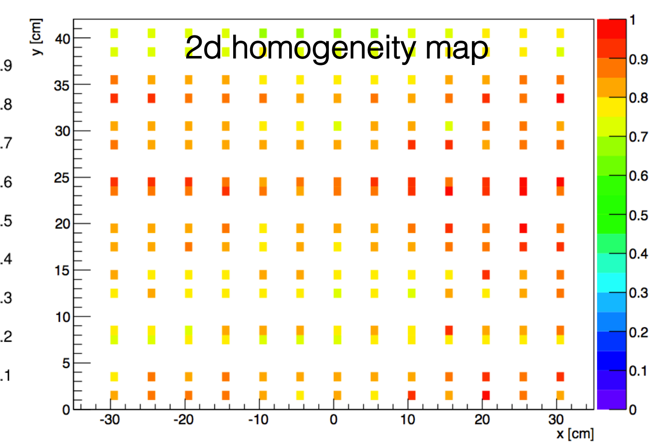
- The Micromegas validation procedure has been defined in order to have a full quality check of the detectors while spotting problems as early as possible
- Preliminary acceptance criteria, to be refined after Mod0
- Cosmic test at construction sites
  - Noise map / pedestal level / dead channels
  - Average efficiency per HV sector vs HV
  - Efficiency map per plane (@ nominal HV)
  - Gain homogeneity
- Test at integration site (CERN)
  - Integrity checks after shipping (gas tightness, HV)
  - High rate behavior: current monitor at GIF++ for few days
  - Cosmic test with final elx after detector integration on sectors



Examples from MMSW validation

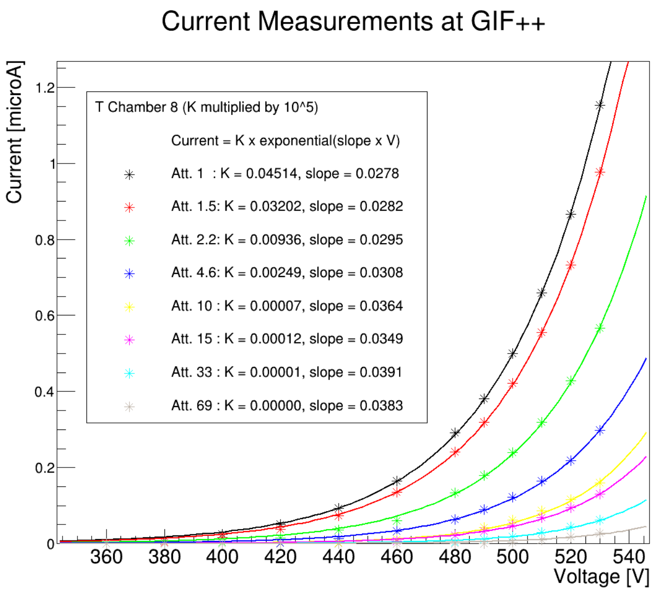


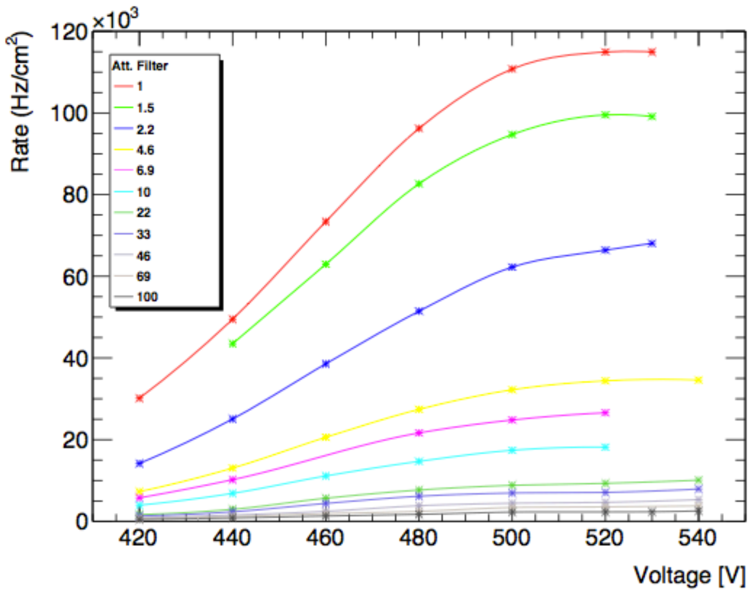




Recent results from GIF++

- Two resistive bulk-Micromegas chambers have been exposed to GIF++ photon flux (up to 64 MHz/cm^2) since May 2015
- No performance degradation observed after ~70 mC/cm^2 integrated charge
- Current behavior as expected
- Measured hit rate at full source: 0.12 MHz/cm^2
  → detector sensitivity to ^{137}Cs photons: ~1.9 10^{-3}





- Several 10x10 cm^2 floating mesh detectors built in Japan using two different Kapton types (EN and HN) have been tested too
- No difference observed between the two Kapton types. Decision to use EN (from Japan)

Conclusions

- The design of the NSW Micromegas is finalized (only few details still under discussion)
- Pre-series detectors (Module0) are under construction in ¾ construction sites
- First production of readout boards revealed a number of weaknesses
- Quality improvement already achieved with some points still under observation
- The Micromegas construction schedule, although with several delays, is compatible with the NSW general schedule