The NSW project for the Phase I upgrade of the ATLAS Muon Spectrometer (focusing on Micromegas)

ATLAS EXPERIMENT

Dimitris Fassouliotis

National and Kapodistrian UNIVERSITY OF ATHENS

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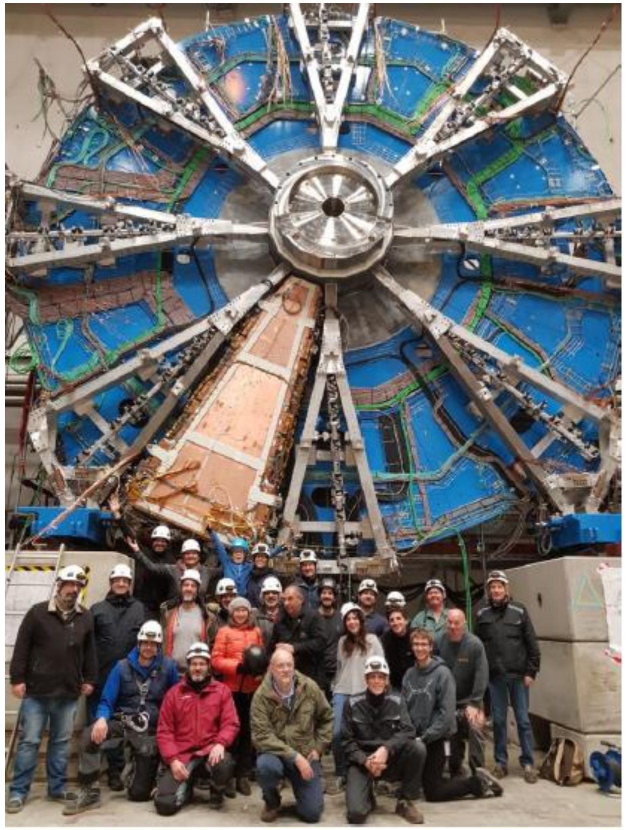
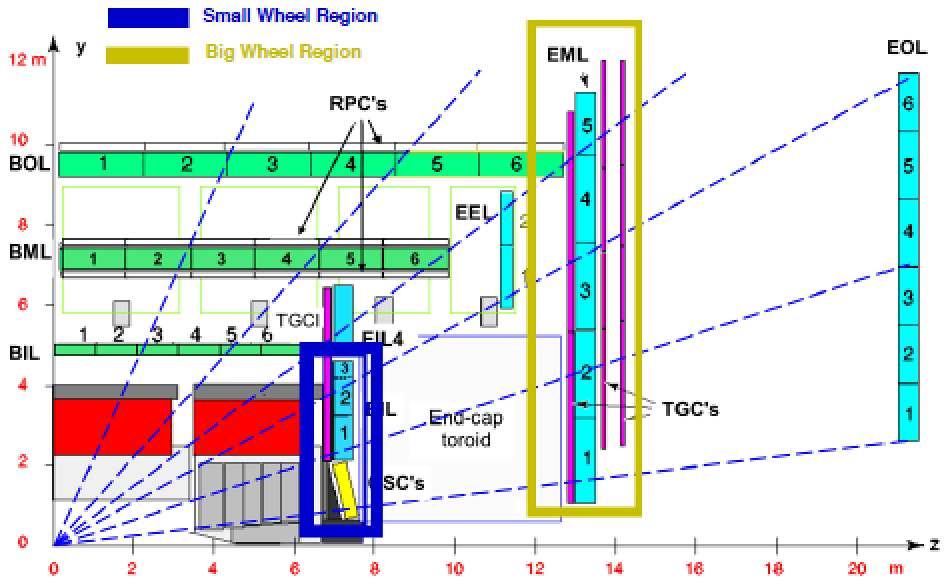
- MM Quality assurance and commissioning

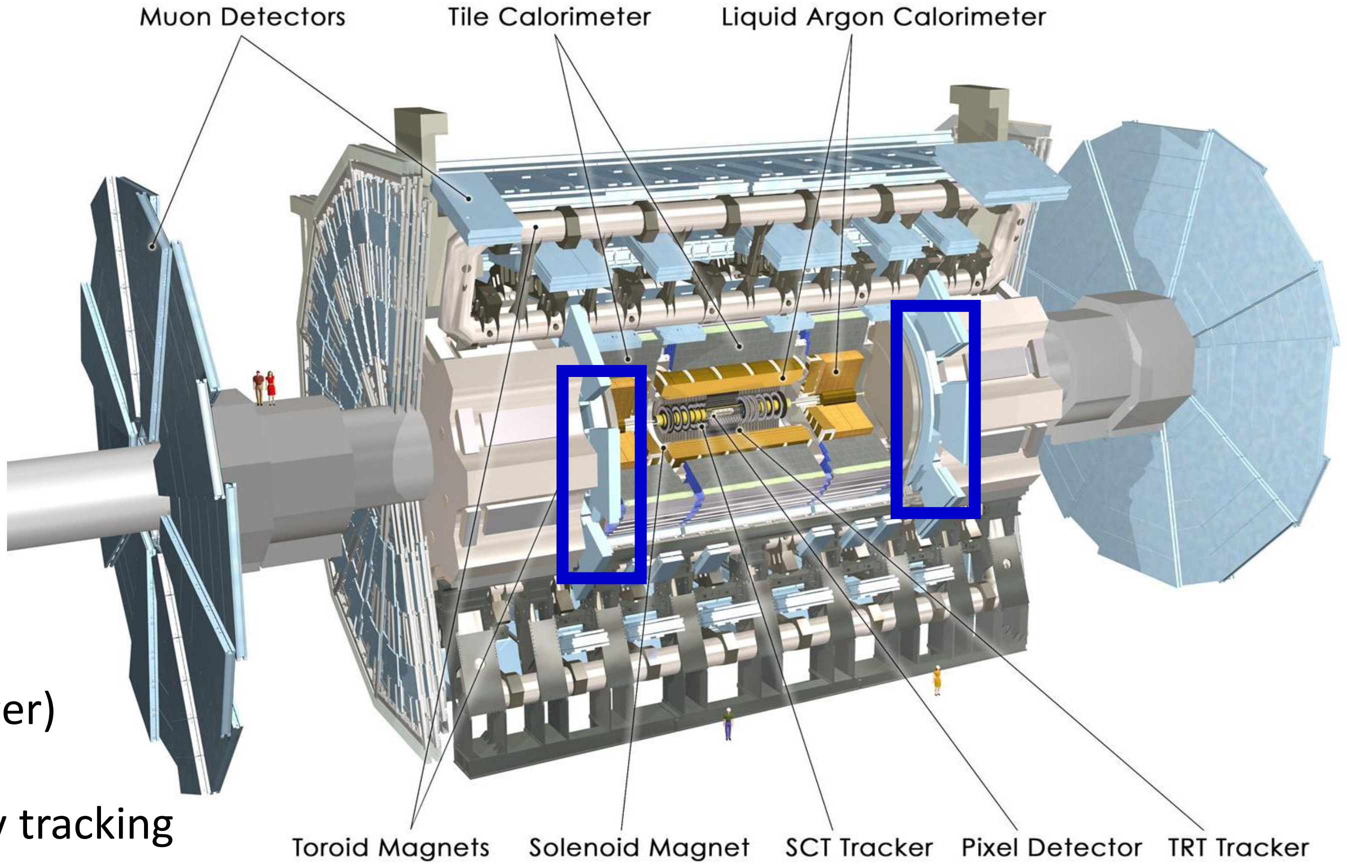


... more details

- ***I. Mesolongitis***, **S. Maltezos** Design of a Differential Safety Mechanism (DSM) Dedicated to the NSW Micromegas Wedges
- ***T. Geralis*** Research activities of the ATLAS NCSR Demokritos group
- **A. Kourkoumeli-Charalampidi**, Surface commissioning of the Micromegas detectors for the muon spectrometer NSW of the ATLAS experiment
- **S. Maltezos**, Methods used for Gas Tightness Test and percent Oxygen Monitoring of the NSW Micromegas Detectors of LHC-ATLAS Experiment
- **I.M. Maniatis**, Construction and operation of large scale Micromegas detectors for the ATLAS Muon upgrade
- **M.Perganti**, Performance of the final New Small Wheel Micromegas sectors for the ATLAS Muon Upgrade
- **O. Zorba**, ATLAS NSW Upgrade – sTGC Trigger and Commissioning
- **F. Trantou**, A program to drive the ATLAS Local Trigger Interface (ALTI) at the ATLAS experiment
- **P. Tzanis**, The Detector Control System of the New Small Wheel for the ATLAS experiment
- **S. Tzanos**, The Detector Control System for the magnetic field sensors of the sTGC detector in New Small Wheel Phase I upgrade of ATLAS detector
- **I. Drivas-Koulouris**, Implementation of the DCS System for the validation of MM HV Boards and the DCS System of the new BIS78 Chambers for the upgrade of muon system of the ATLAS Experiment
- **M. M. Prapa**, The Fake Sector Logic for the ATLAS Muon Trigger system

Introduction: The New Small Wheel





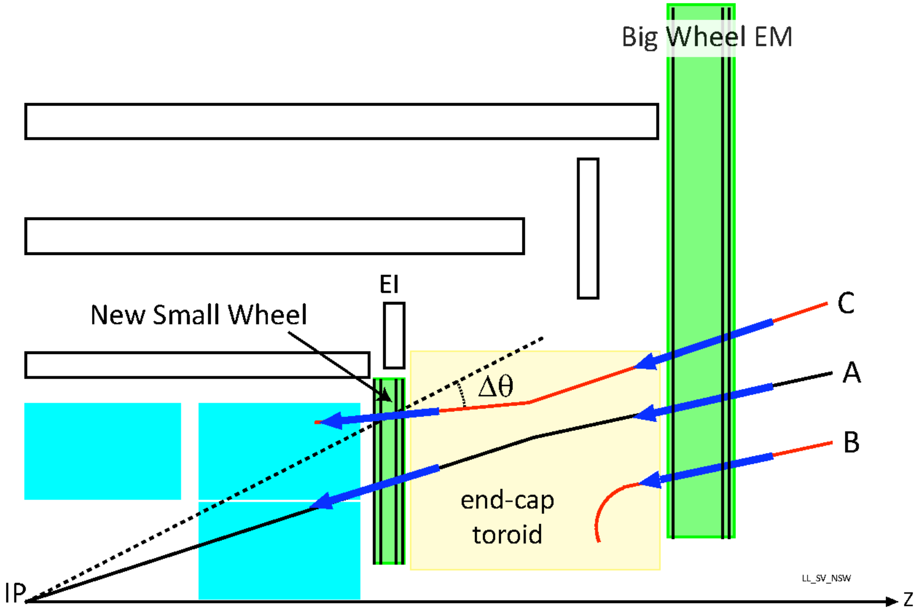
Current Small Wheel → CSC, MDT (tracking), TGC (trigger)
NSW →
Micromesh Gaseous Structure (Micromegas) primarily tracking
Small strip Thin Gap Chambers (sTGC) primarily trigger

- Main ATLAS very challenging upgrade during the Long Shutdown 2 (Phase-I)
- Designed to operate also at HL-LHC luminosity $\gtrsim 5\times10^{34}$ $cm^{-2}s^{-1}$
- Angular coverage: $1.3<|\eta|<2.7$
- 10 meter diameter - Located at *z* 7m from IP

Introduction: NSW motivation

Current Small Wheel

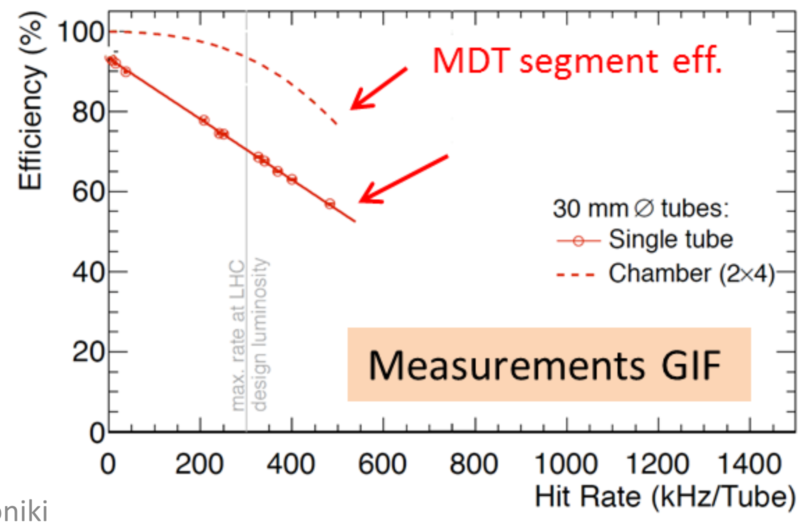
- Single muon trigger suffers from large amount of fakes
- MDTs loose resolution and efficiency when going significantly beyond original LHC design luminosity
- CSC loose tracking efficiency from limitation of 4 layers



NSW : 1mrad segment angle resolution at L1

NSW

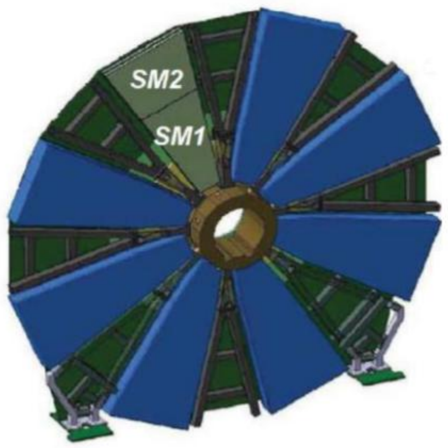
- ➢ Reduce substantially single muon trigger fake rate
- ➢ Maintain excellent efficiency and resolution of tracking at very high rates
- ➢ 16 active layers → redundancy for tracking and pattern recognition



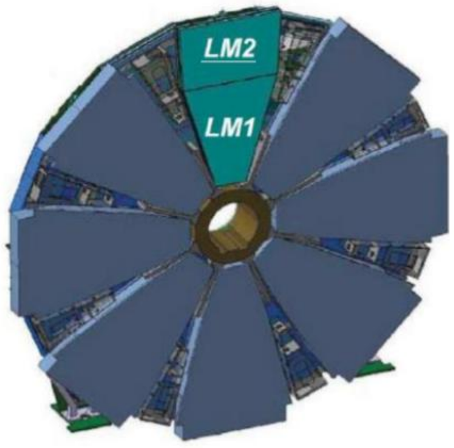
NSW ~2,5million readout-channels ≈ full muon spectrometer

Introduction: NSW layout

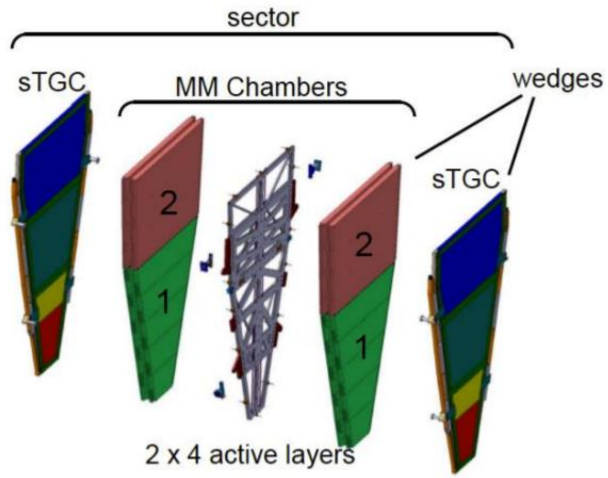
- NSWs preserve the geometry and segmentation of present SWs
- 8 Large and 8 Small sectors with Micromegas and sTGC on each side
- Installed on mechanical support which combines the NJD steel disk (shielding, flux return) and aluminum structure (spokes) bolted on it
- Spokes support the detectors and hold the alignment bars
- Installation plan: First the Small sectors - Then the Large sectors
- Each sector consists of 2 sTGC and 2 Micromegas wedges
- The two Micromegas wedges are placed on an aluminum support (spacer frame) to make a double wedge

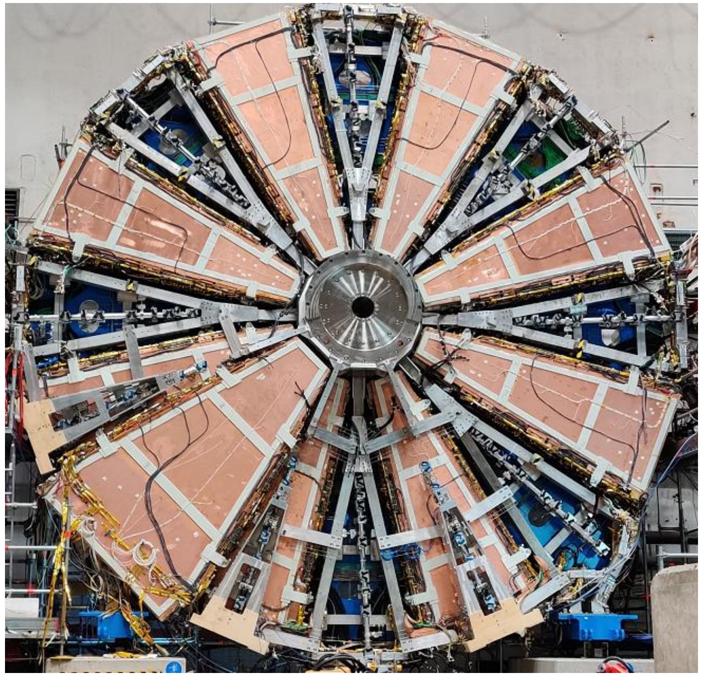


Small sectors

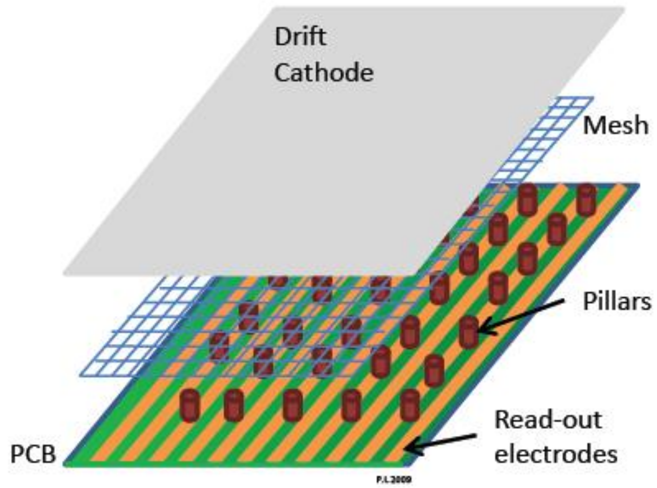


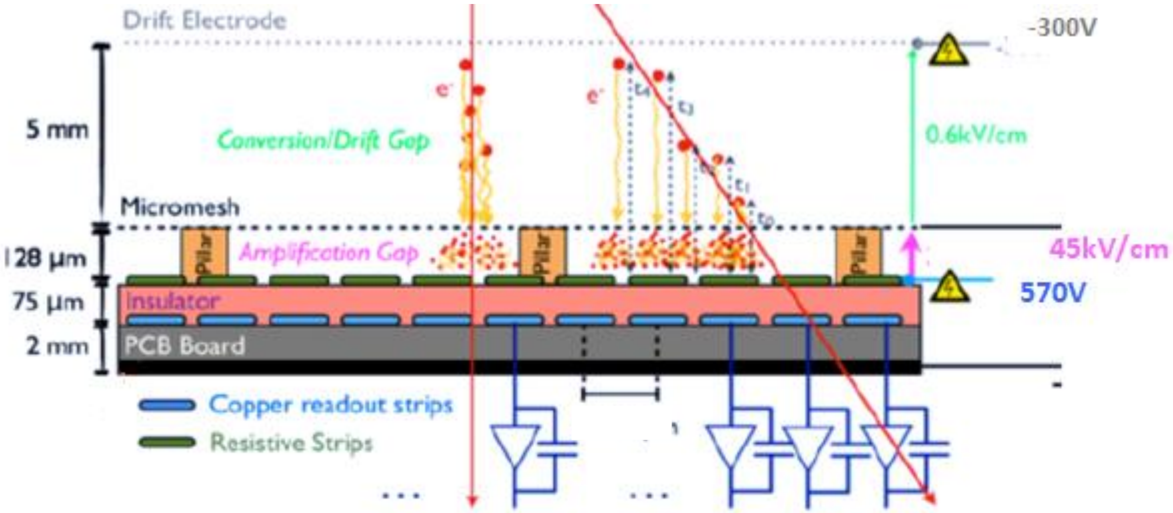
Large sectors

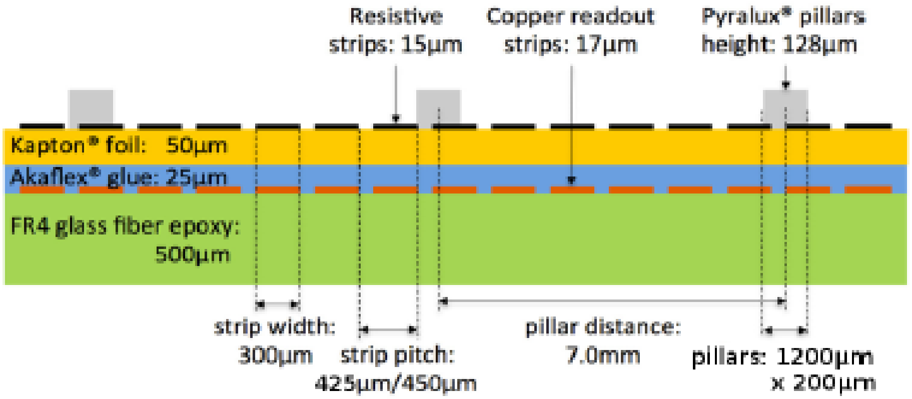




Introduction: Micromegas Operational principle





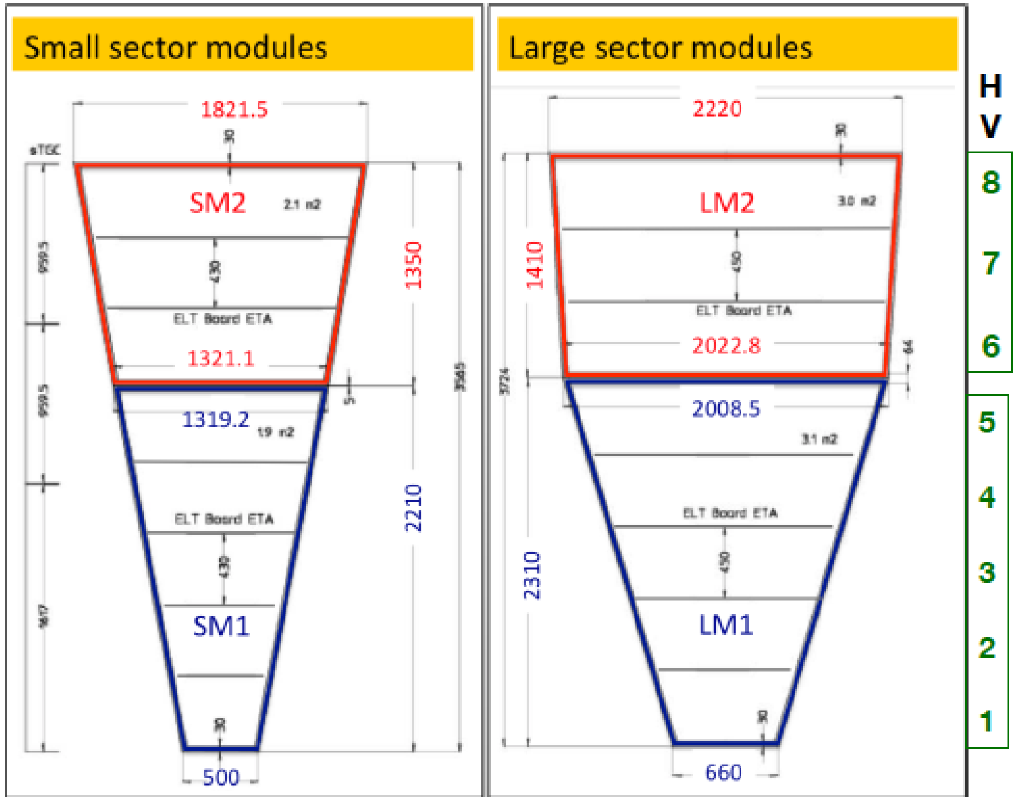


ATLAS Micromegas characteristics

- **NSW Micromegas** are **resistive for spark protection**. Cu strips are covered by a Kapton layer with resistive screen pattern (graphite) printed on it. HV is applied on the resistive layer.
- The mesh is integrated in the drift panel structure and not coupled with the pillars
- Strip width 300 µm (pitch 425-450 µm)
- The mesh is at ground potential
- Drift gap (5 mm), HV_{drift}= -300V , E_C = 600 V/cm
- Amplification gap (128 µm), **HV_{RO} = 570 V**, E_A = 45 kV/cm
- Baseline gas mixture: 93% Ar - 7% CO_2

Chamber production: Layout

- Each Mixcromegas Double Wedge is composed by 2 wedges with 4 layers each
- 4 η layers for measuring the η coordinate
- 4 stereo layers with inclined strips (+/-1.5°) to provide 2nd coordinate
- Each wedge has 2 modules (quadruplets) 1 & 2



2210 mm + 1350 mm = 3560 mm   2310 mm + 1410 mm = 3720 mm

Construction of the Micromegas modules

Large Module 1 (LM1):
France
CEA, Saclay

Large Module 2 (LM2):
Greece, Russia
Thessaloniki, Dubna, CERN

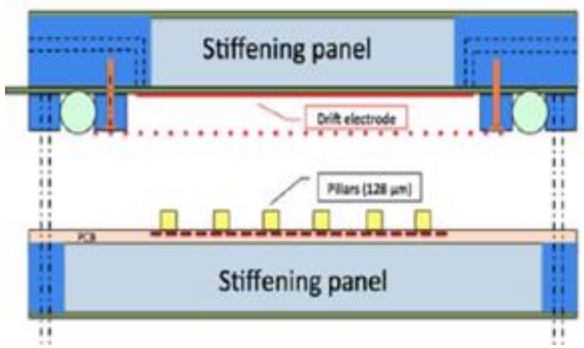
Small Module 1 (SM1):
Italy/INFN
Pavia, Rome1, Rome3, Frascati, Lecce, Cosenza, Napoli.

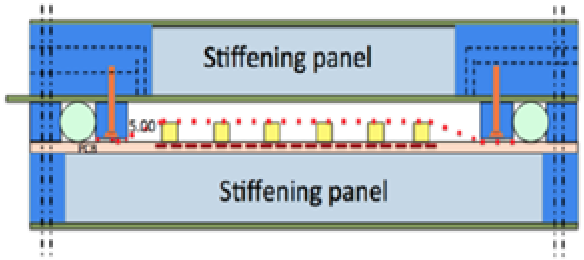
Small Module 2 (SM2):
Germany
Munich, Freiburg, Würzburg, Mainz.

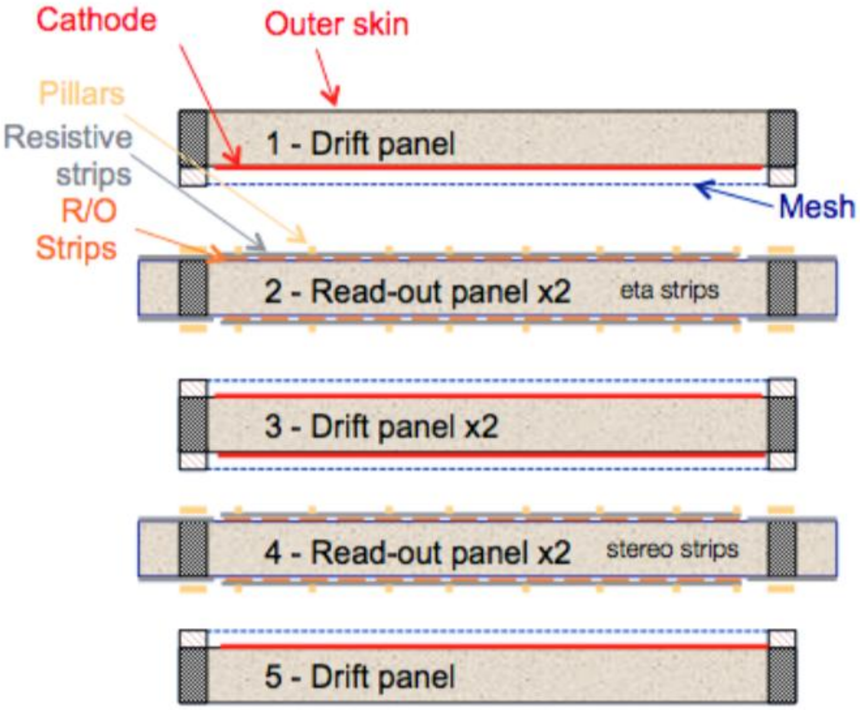
- 128 modules of 4 different types
- Surface /module /layer 2-3 m^2
- Total area larger than 1200 m^2 → **The largest Micromegas project**

Chamber production: Construction

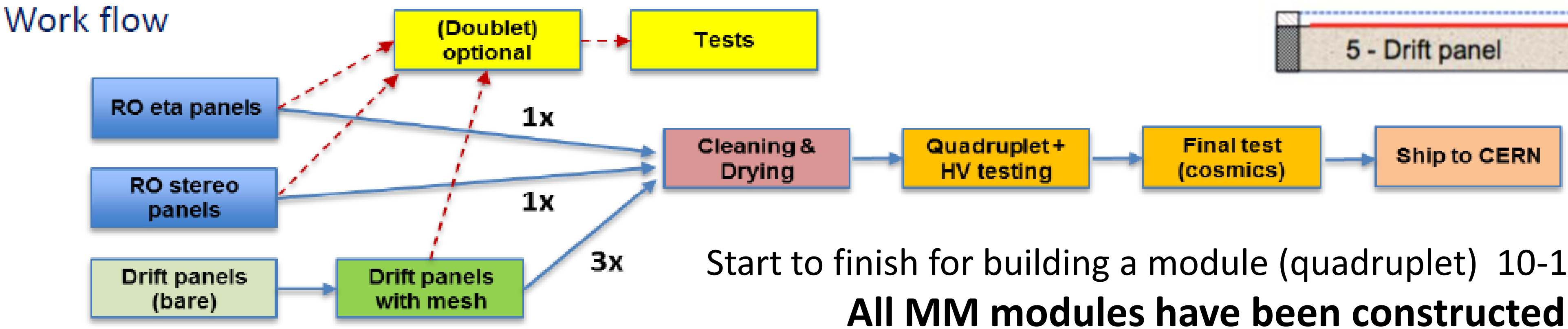
Cathode (*drift*) and anode (*read-out*) planes built on sides of five panels stiffened through the use of honeycomb structures







Careful QA/QC program implemented to check all parts of production steps



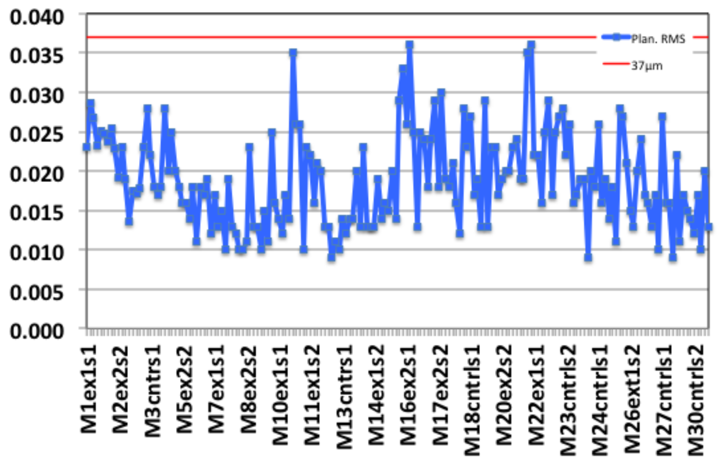
Start to finish for building a module (quadruplet) 10-12 weeks

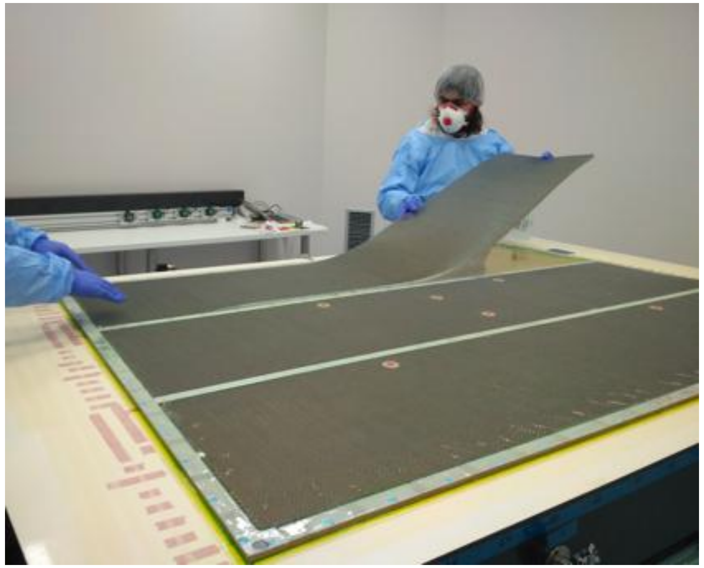
All MM modules have been constructed

LM2 drift panels construction @ Thessaloniki

- The production and test of **96+9 Drift panels** equipped with mesh sent to Dubna for the chamber assembly (quadruplet)
- New Laboratory for detector construction established (360 m^2)
- New Clean Room (145 m^2, *Grade D*)
- **Production started July 2017 – ended January 2020**

Panel Planarity (<37μm)

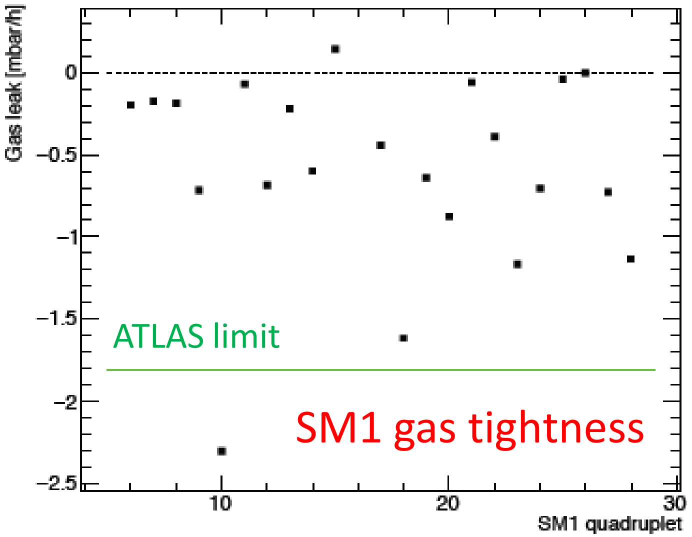




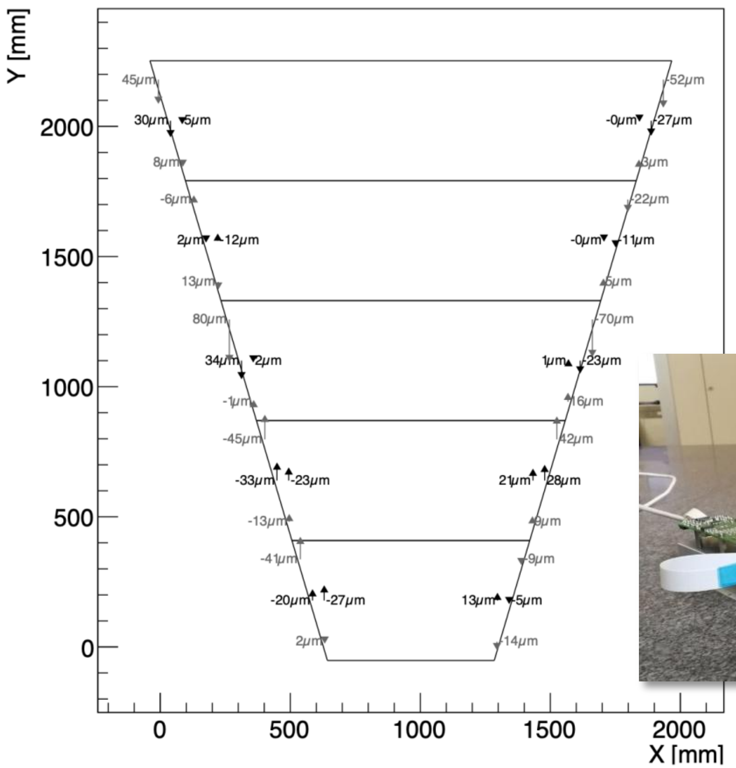
Chamber production: Quality control

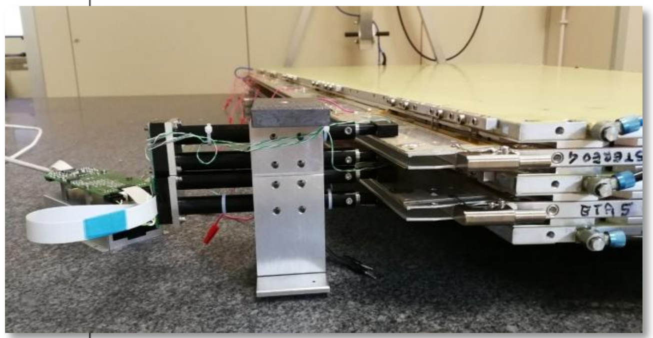
QA/QC per panel and / or quadruplet

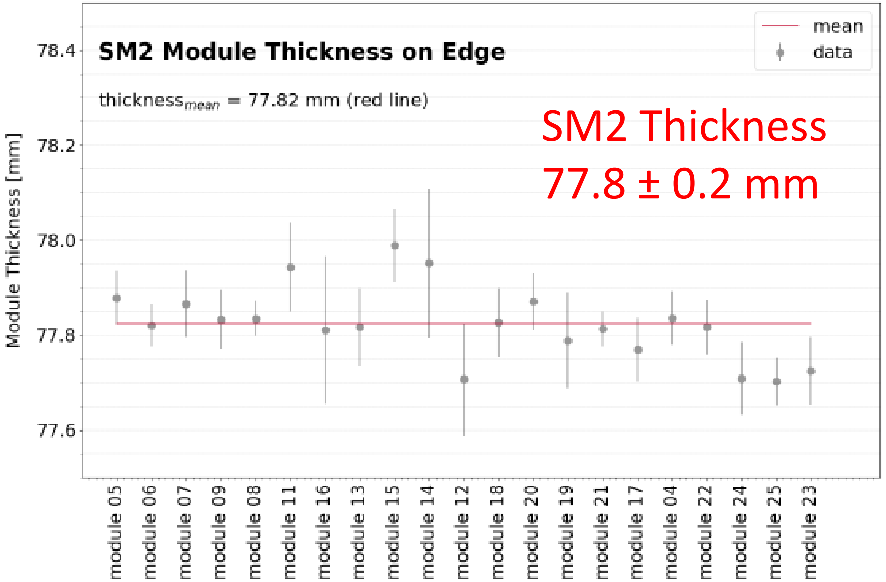
- Thickness
- Planarity
- Gas tightness
- Alignment
- HV stability
- Efficiency
- Gain homogeneity

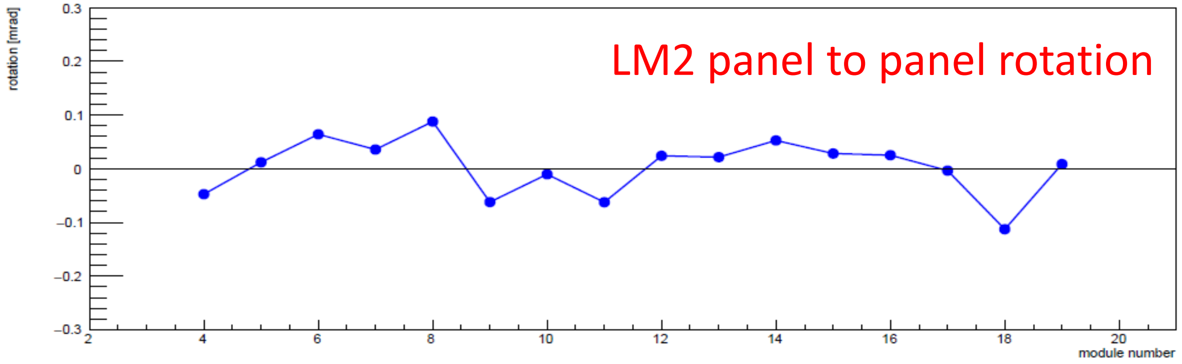


LM1 example of RasFork alignment measurement

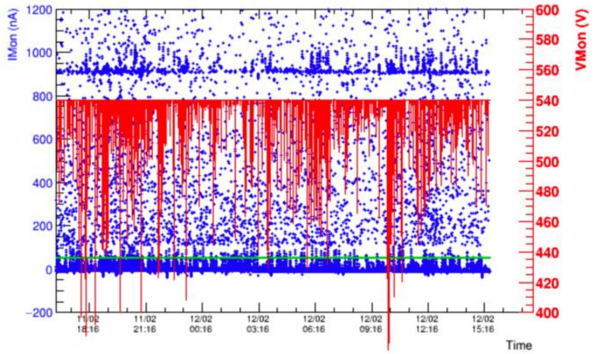








Chamber production: HV stability



End 2017 → Issues of HV Stability with first production MM NSW Quadruplet
High currents and discharges - concern for possible permanent damages
Jan 2018 → R&D focused on the cause of sparks and possible means of protection

Spark causes

- Residual material humidity
- Residual ionic contamination
- Mesh mechanical imperfections
- Other imperfections

→

- **Detailed quality control of PCBs targeting imperfections**
- **Thorough cleaning/ drying of panels prior to assembly**
- **Polishing of mesh**
- Reduce relative humidity inside chamber ≤ ~15%

- **Jan 2019**: Evidence of discharge happening close to the boundary of the active area

→

Insufficient spark suppression due to low resistivity in localized spots

Spark protection

- **Act on the resistive layer**
- **Increase HV granularity**
- ***Modify gas mixture (under validation)***

→

Passivation of a region along the sides of the PCB through deposit of a thin layer of araldite, in order to increase the minimum resistivity of the active area

Performance and commissioning of HV

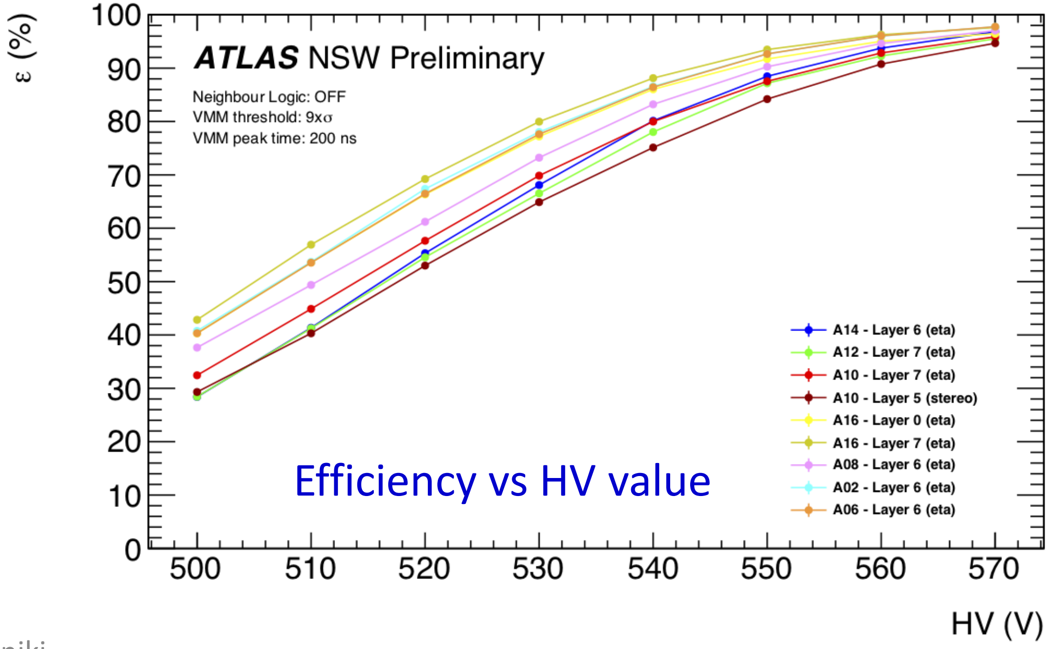
Several tests to ensure stability under HV operation

Nominal HV is 570 V (with $ArCO_2$ 93:7 gas)

- **128 HV sections per sector**
- Test are performed by ramping the HV and recording the current & the spark rate
- Modules which presented issues were sent for irradiation scan
- Categorize HV sections on their quality --- Nominal, reduced, disconnected sections
- **Average DW efficiency per layer has to be higher than 85%**
- **Finalize the HV configuration and confirm efficiency from cosmic**
- **Validate HV stability once again at 191 after installation on NSW**

➢ In the initial HV configuration 16 HV positive channels (1/layer/module) and 4 HV channels for hospital lines were designed

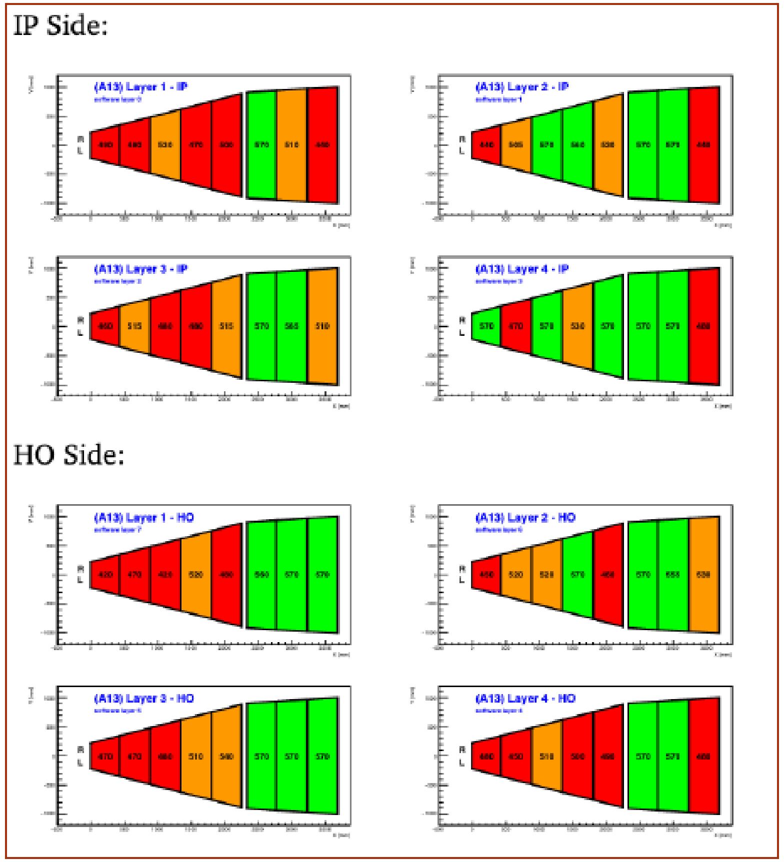
➢ **In the final configuration 64 HV channels are used (1/PCB)**



Study of gas to Ar-Co_2-isobutane 93:5:2

Motivation: Performance of old (non-passivated) A13 DW (studied at BB5) – Similar behavior was verified with other DWs
Decision after: Irradiation of 1-2 chambers @ 5-10 HL-LHC years and 3-4 chambers @ 1 HL-LHC year at GIF++

Ar:CO_2 93:7 vol%
nom. HV: 570 V



insufficient performance

green: sector is on nominal HV

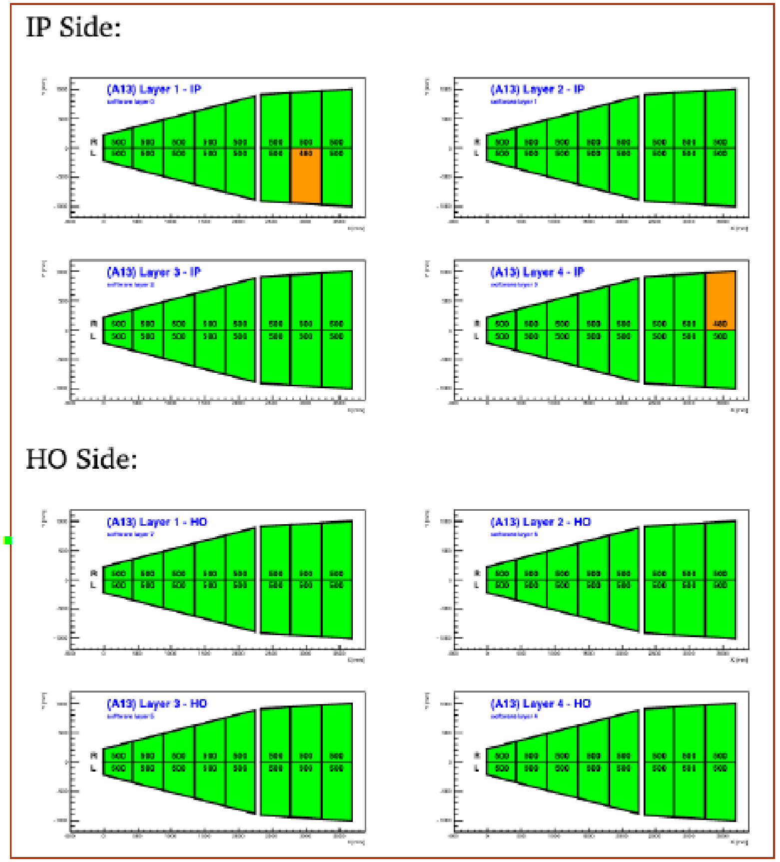
red: sector is below nominal HV

-2% of CO2

+2% of Isob.

non-burning
non-explosive
gas-mixture

Ar:CO_2:iC_4H_{10} 93:5:2 vol%
HV: 500 V



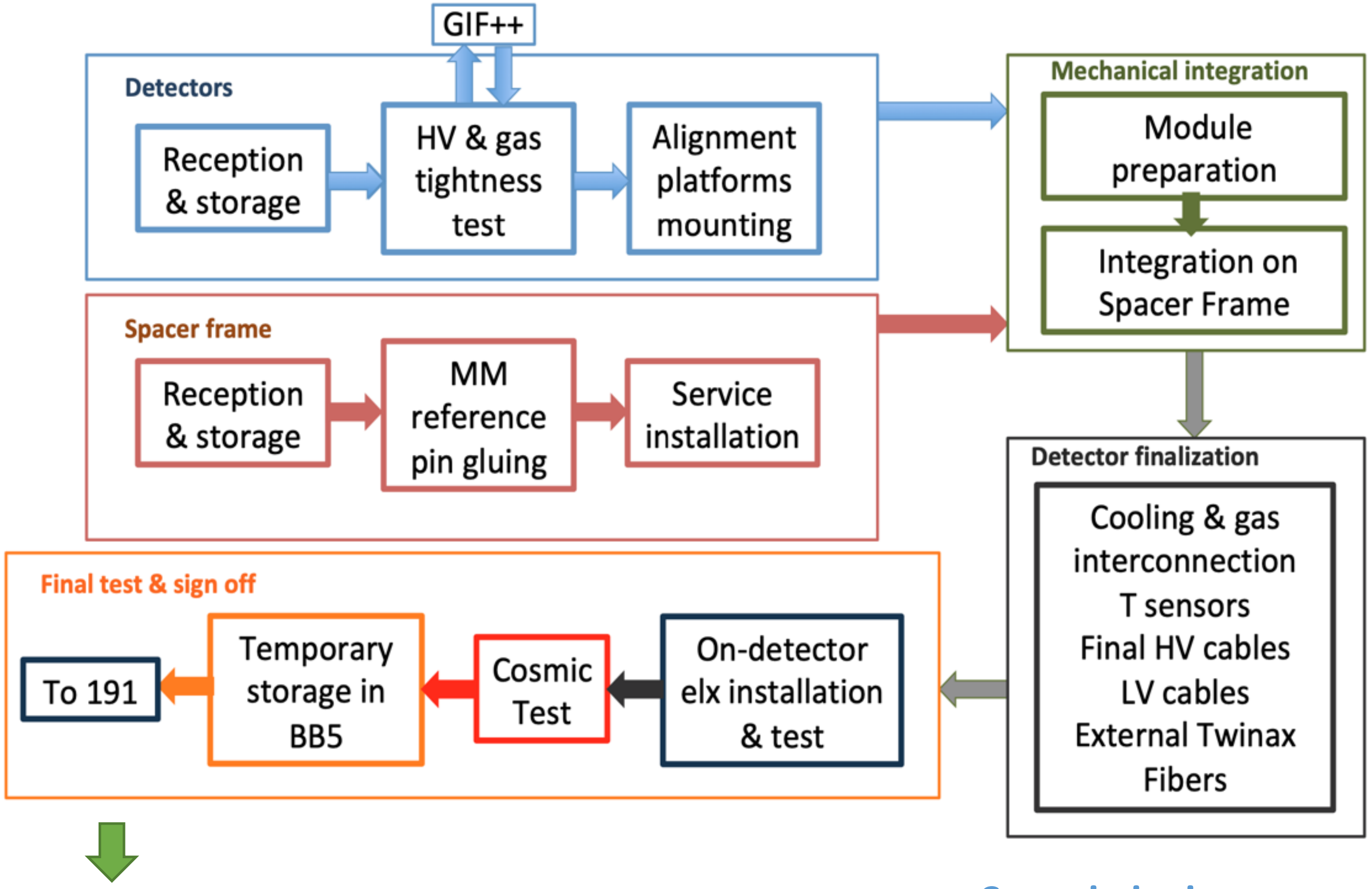
almost perfect performance
similar efficiency @ cosmics

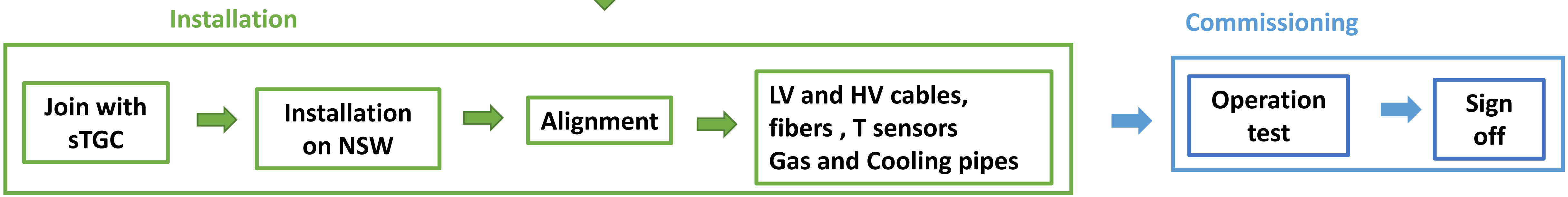
Integration and commissioning

Integration and commissioning activities are performed at CERN in parallel in two buildings

BB5
- Components tests
- Mechanical assembly
- Integration
- Elx test and calibration
- Cosmic rays test

191
- Installation on NSW
- Services connection
- Surface commissioning





Commissioning: Data Acquisition

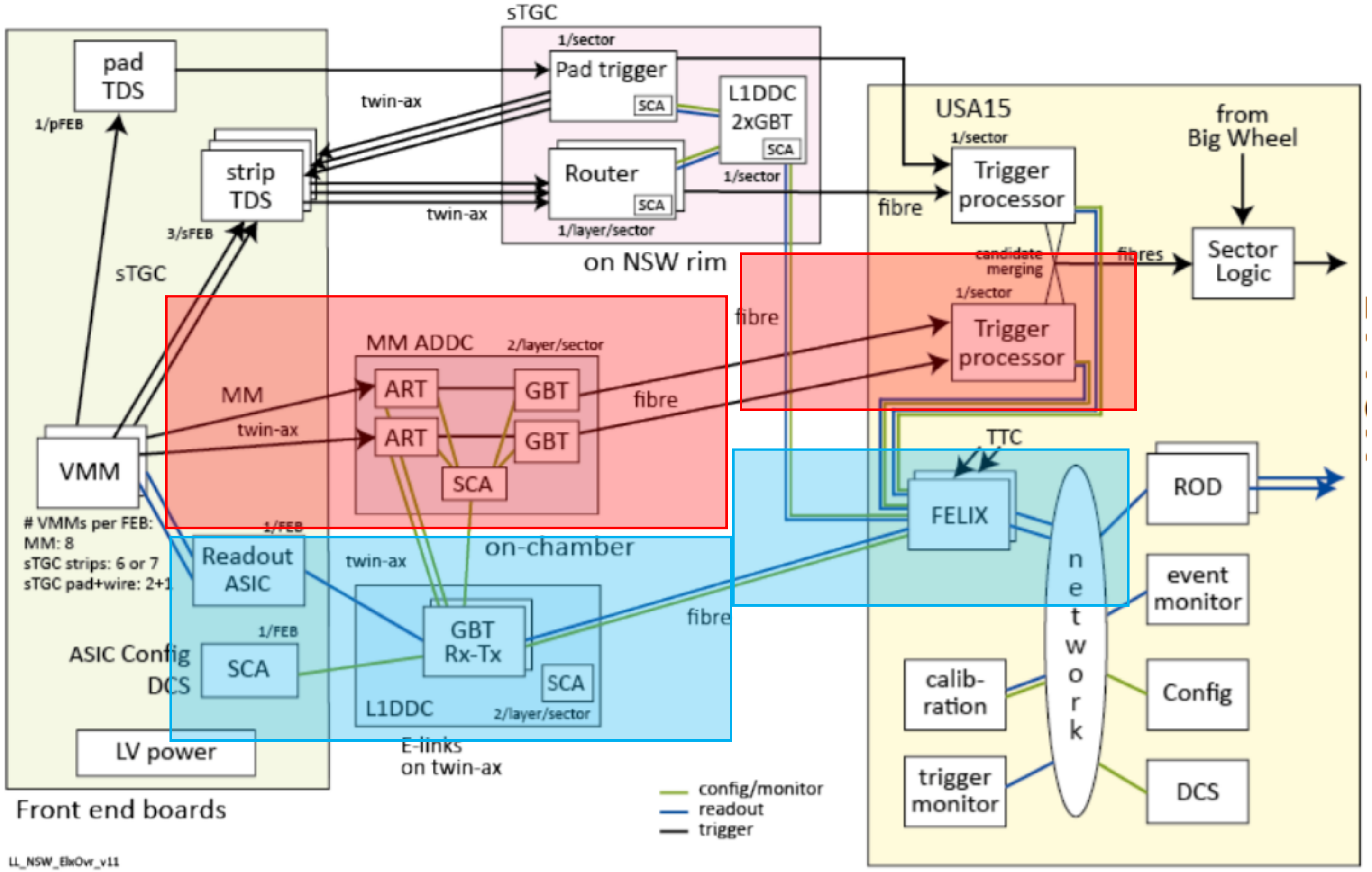
The NSW DAQ architecture lies on the newly introduced readout scheme of ATLAS
It uses the final FELIX based readout system for all the data taking

Read-out Validation
65536 read out channels / sector

Read out for LHC Run III, detector quality control

Read out for HL-LHC

Trigger path



The data acquisition system is fully functional for the needs of the commissioning

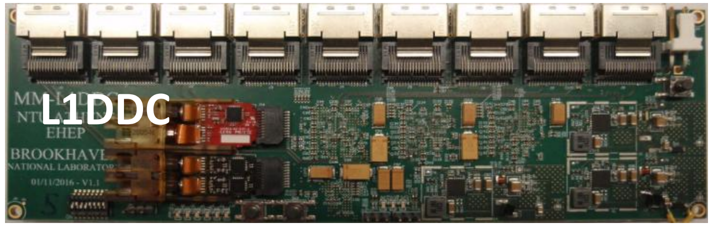
Integration: Electronic boards

Each Micromegas double-wedge

Has 65536 read out channels

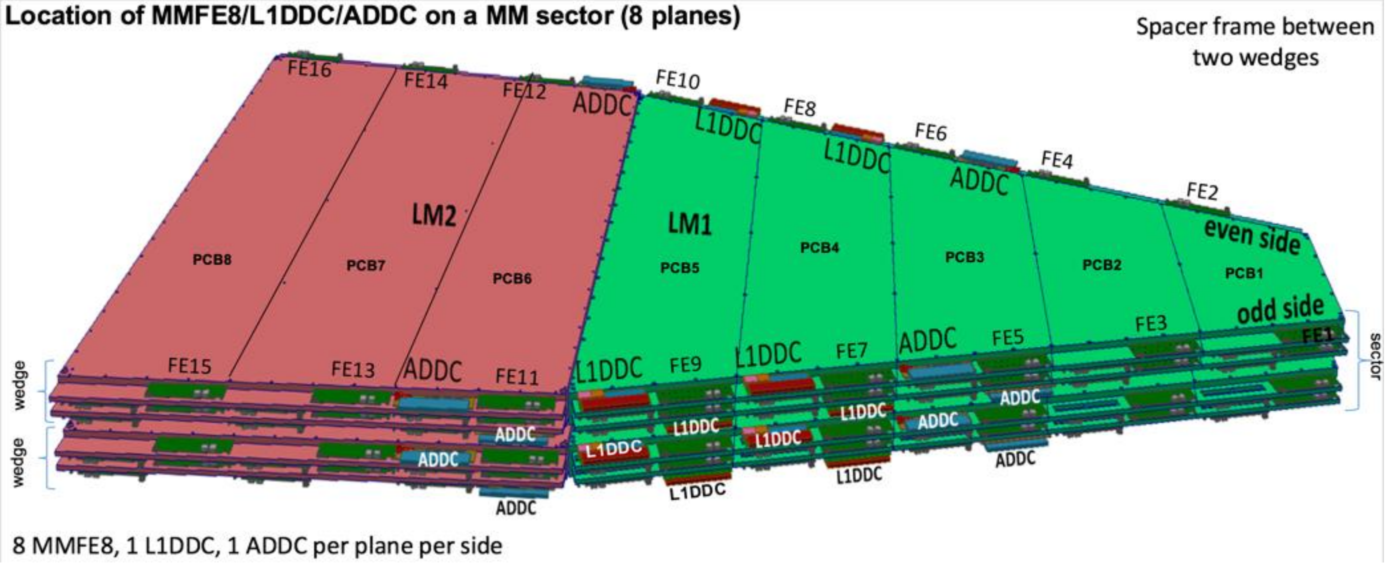
Combines 4 different types of elx boards

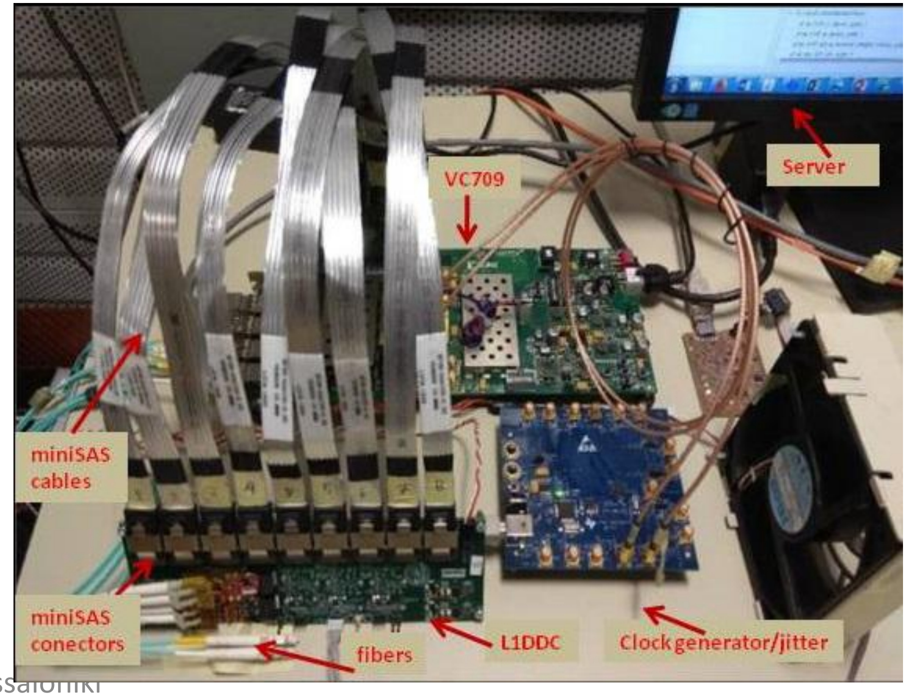
- 128 MMFE8 -- MicroMegas Front-End
- 16 L1DDC -- Level-1 Data Driver Card
- 16 ADDC -- Address in Real Time Data Driver Card
- 16 LVDB -- Low Voltage Distribution Board



All the cards are fully tested on the bench before installation on the detector

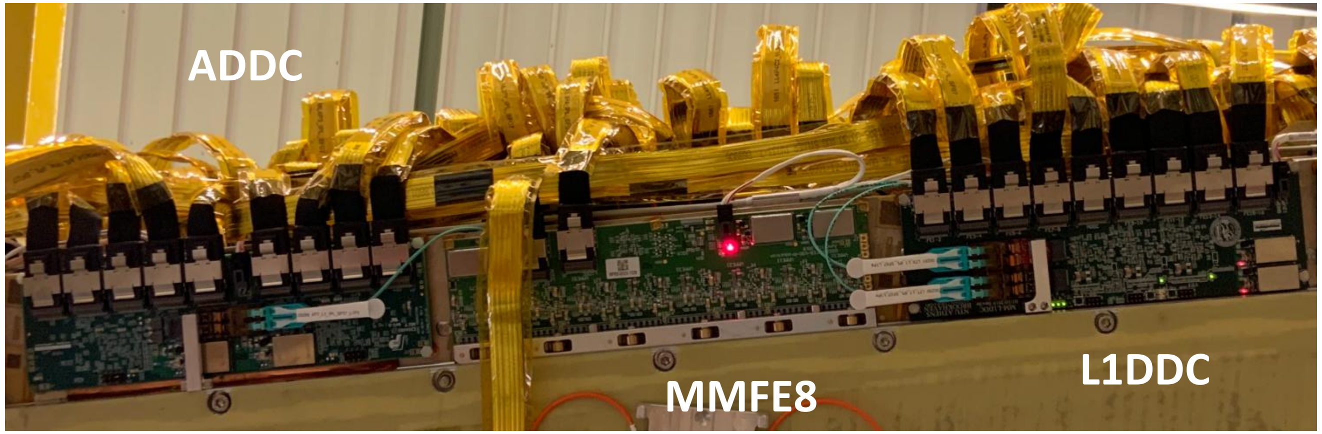
ADDCs and L1DDCs (for both MM and sTGCs) were validated in 2019 by NTUA, NCUA, Univ. of WA and NCSR Demokritos teams



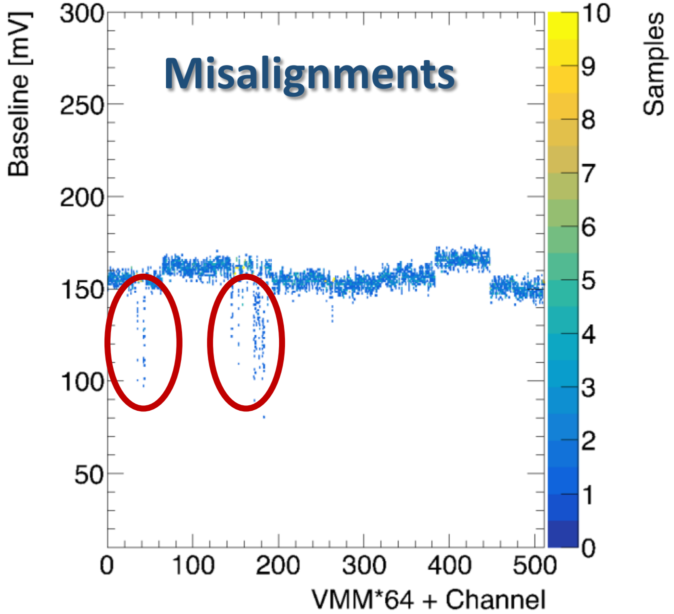


Integration: Electronic boards

Alignment of MMFE8 channels with the strips of the detector proved to be another great challenge



Combination of the quality of:
- Chamber alignment pins
- PCBs
- MMFE8 alignment sockets
- Zebra connectors



Even after the development of the MCAT special tool

MMFE8 Check Alignment Tester

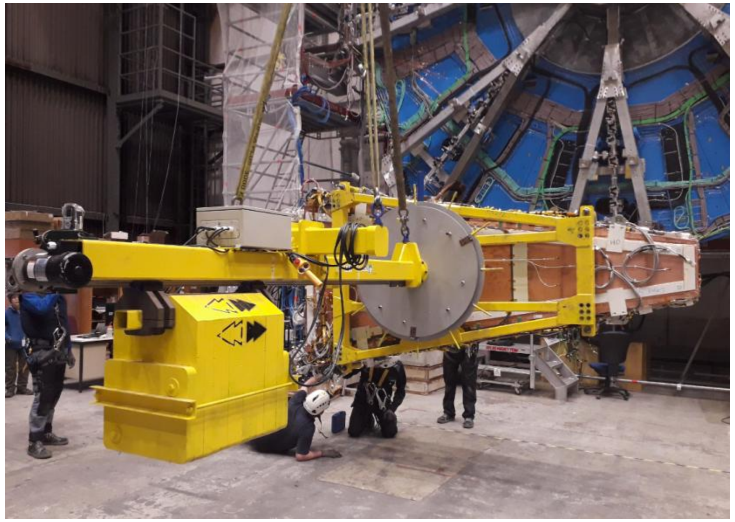
it requires on average 3-4 days for 2 persons

1st Sector Installation

12/2019

Grabbing of the sector

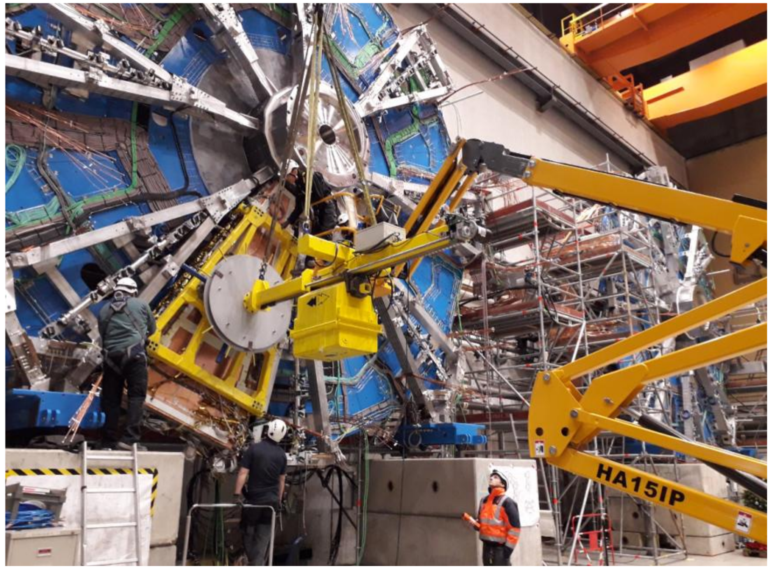
Adjusting center of gravity



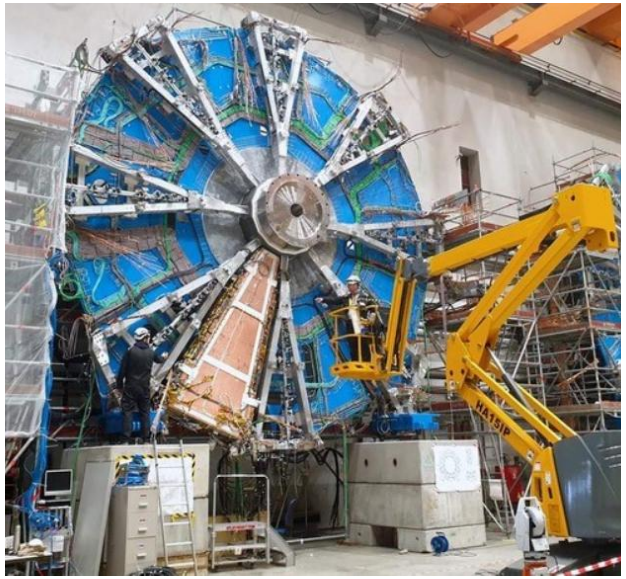
Moving towards the wheel

Set orientation to 22.5 deg

Installation Fixation on NSW A



Ready for survey

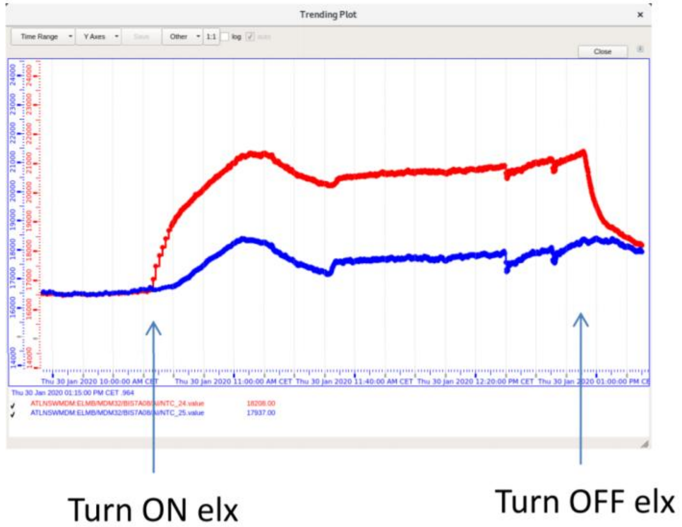


Services connection and validation

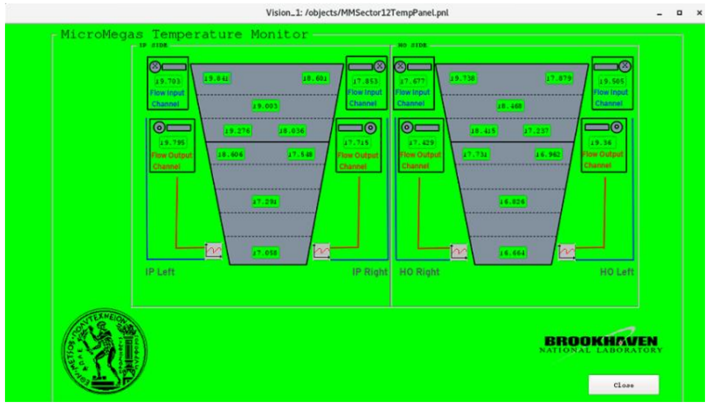
Connections
- Cooling system
- Gas system
- Low voltage cables (40 with 248 pins/sector)
- High voltage cables (8 with 144 pins /sector)
- Read out fibers (48 pairs/sector)
- Temperature sensor cables

Validation
- Survey and alignment
- Cooling system
- Gas tightness measurement
- Monitoring of electronics
- Temperature, current monitoring of LV system
- Read out fibers
- Cable routing and envelop specifications

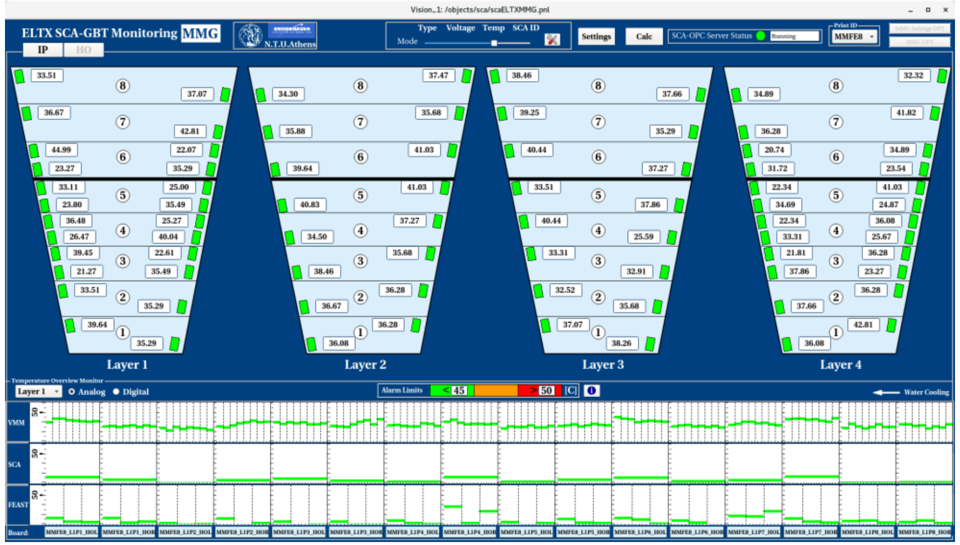
Water input and output temperatures



Temperatures on detector



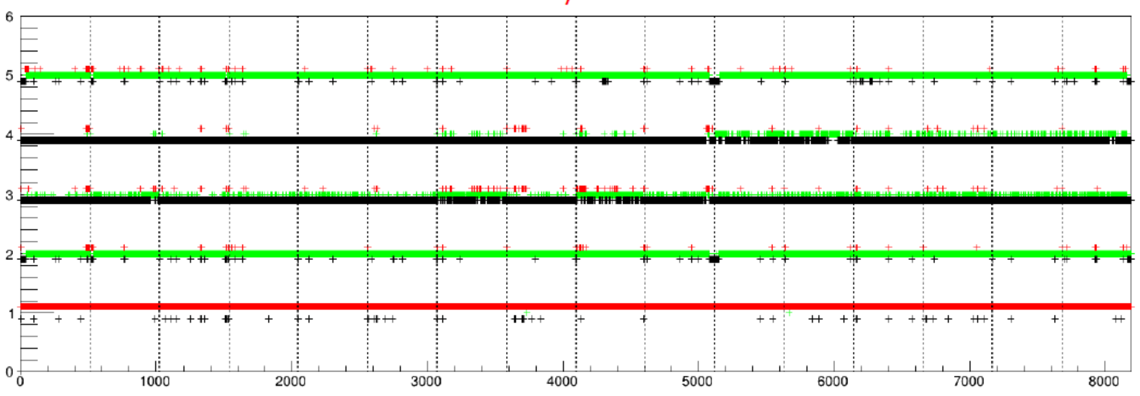
Electronic components monitoring



Commissioning of 1st test sector on NSW

Commissioning of the 1st sector on NSW

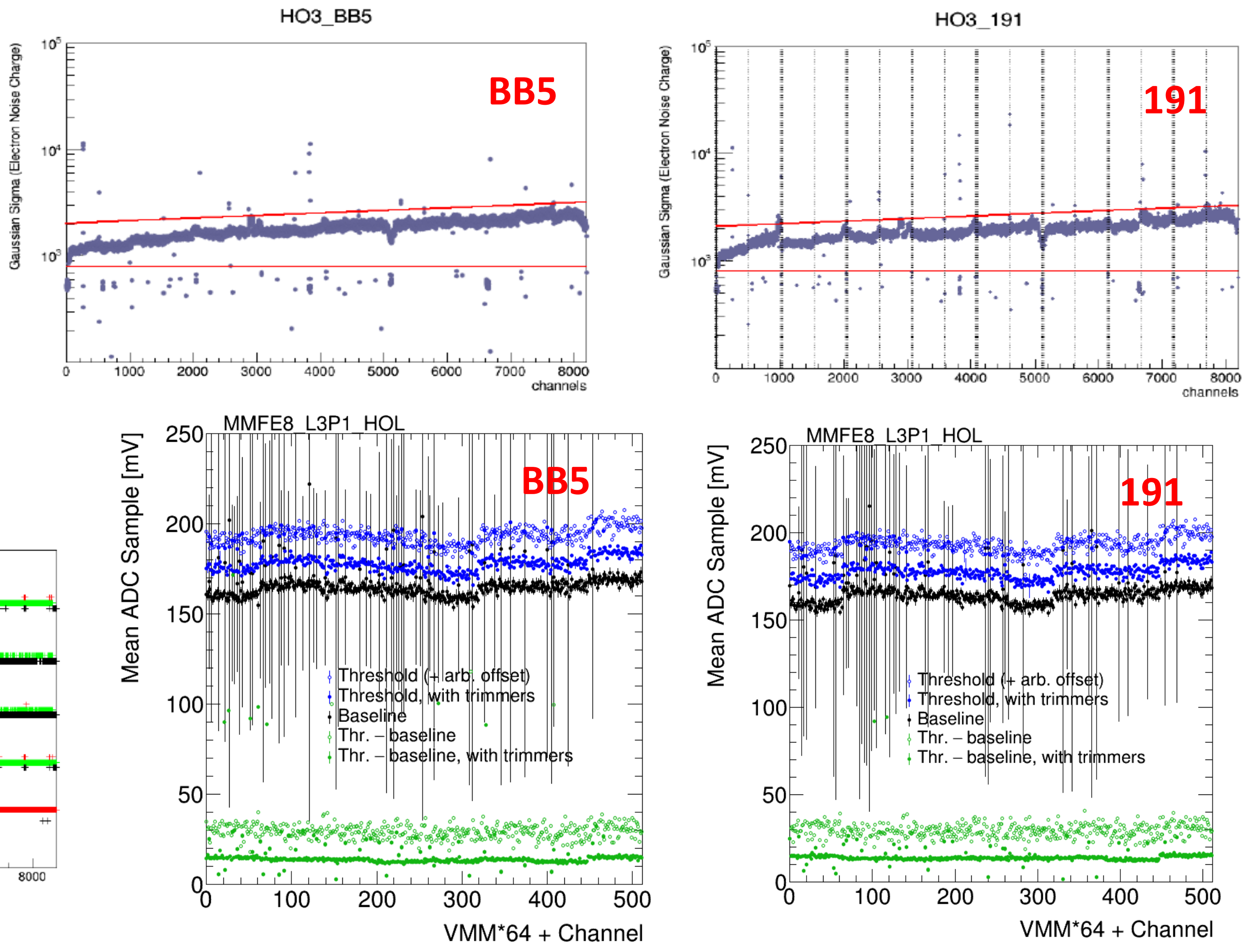
- Confirmed the installation procedure
- Confirmed similar electronics performance after the installation
- Confirmed similar HV operational behavior
- Finalized the steps of the commissioning
- Optimized several preparatory details
- Improved software for the data analysis
- Gained confidence that certain issues can be treaded after installation



1) Pulse
2) Baselines
3) Noise thrx9
4) Noise thrx12
5) BB5 cosmic run

- Low occupancy
- Normal
- High occupancy

Comparison at integration and after installation



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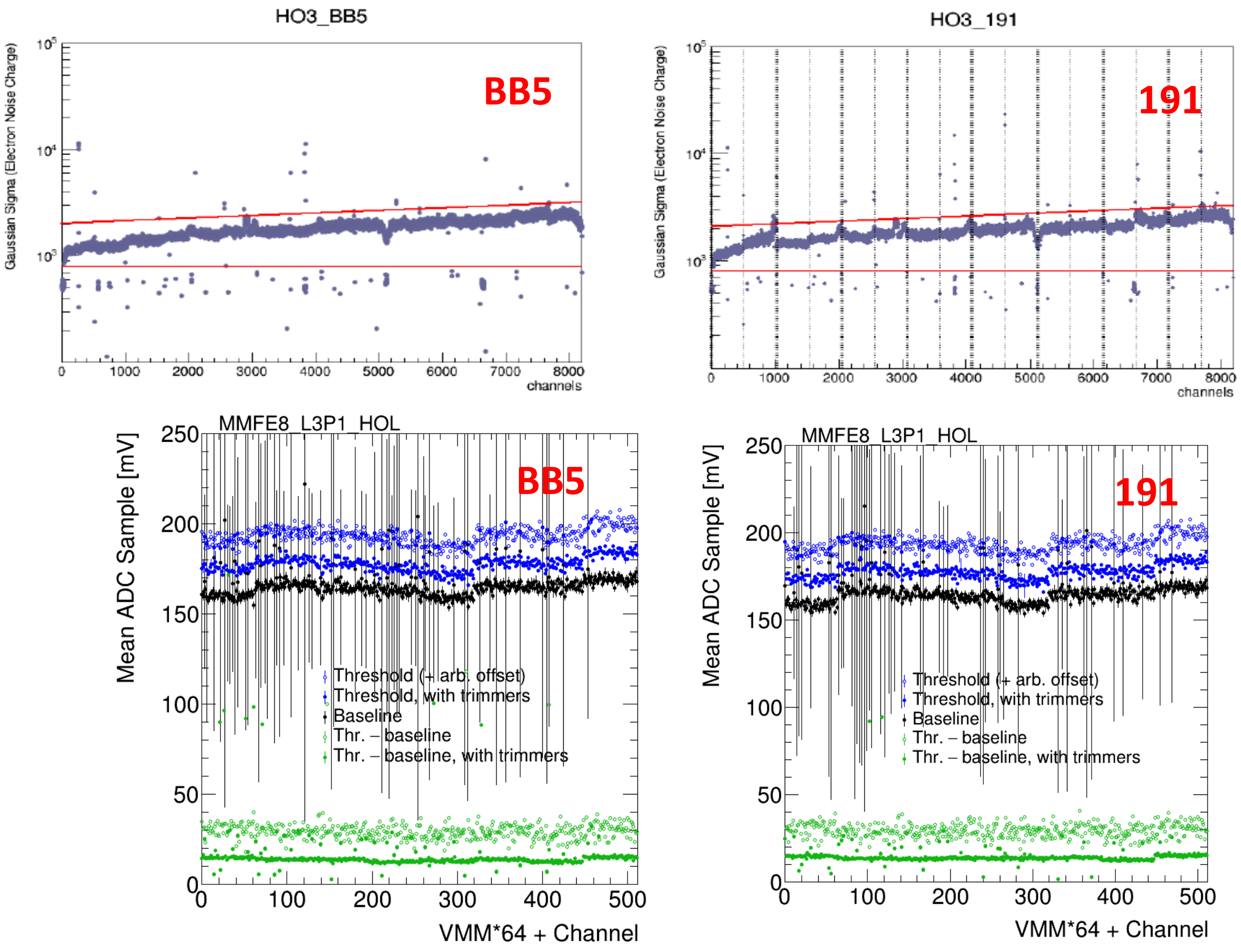
Comparison at integration and after installation

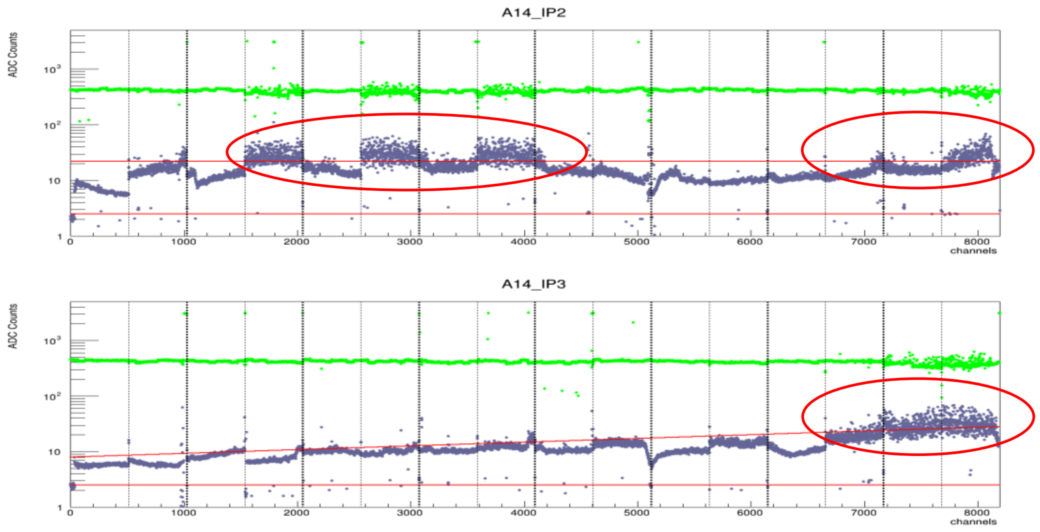


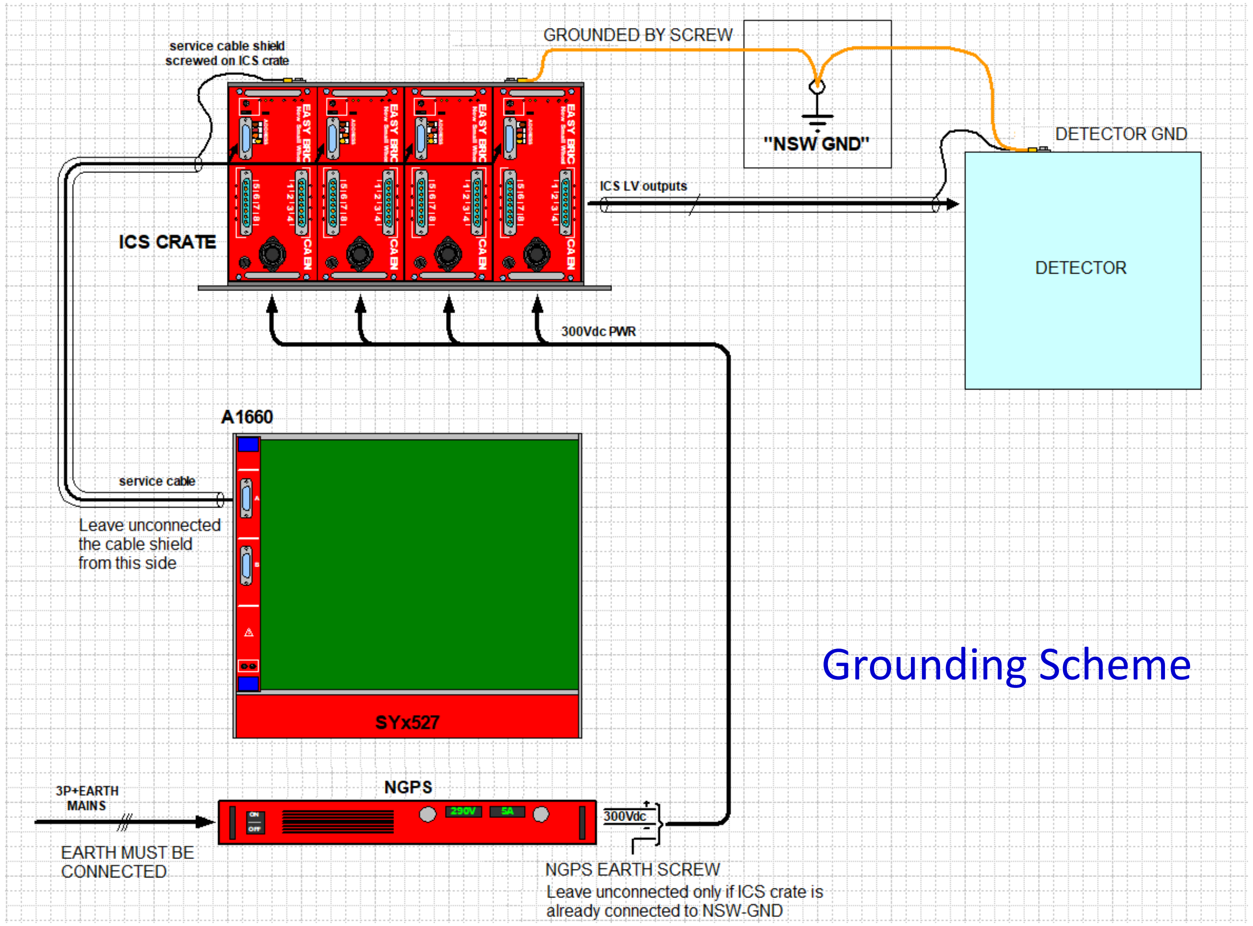
However, at the time:

- Not the final LV power supply (ICS not available)
- Not the final LV cables routing

An unexpected challenge

1) With the final LV power supplies and the final cable routing →
The noise levels have increased a lot in specific areas





Grounding Scheme

Multi-parametric problem:
- Grounding scheme LV PS
- Grounding scheme detector
- Ground loops with sTGC
- ICS Power supply
- NGPS and controller
- Cable shielding
- Cable routing
- Emitted noise
- Elec. contacts through mount points
- Other effects

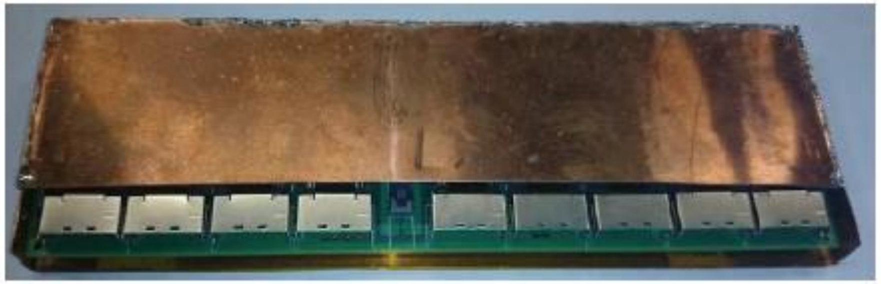
Commissioning of 2 first sectors on NSW

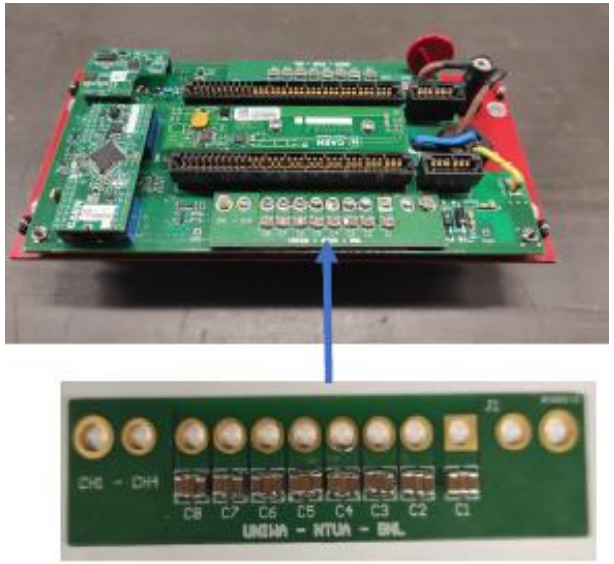
Increased noise levels - Challenge and solutions

Huge amount of efforts to scrutinize every aspect of the issue

- Insufficient shielding of the feasts of ADDCs → Induced noise on surrounding MMFE8s → Faraday cage around ADDCs
- Improve Digital ground on DWs
- Improve cable shielding
- Reinforce ground connections on DWs with extra clamps
- **Improve noise filtering of ICS by introducing additional filter capacitors**

Refurbishment of all side A DWs



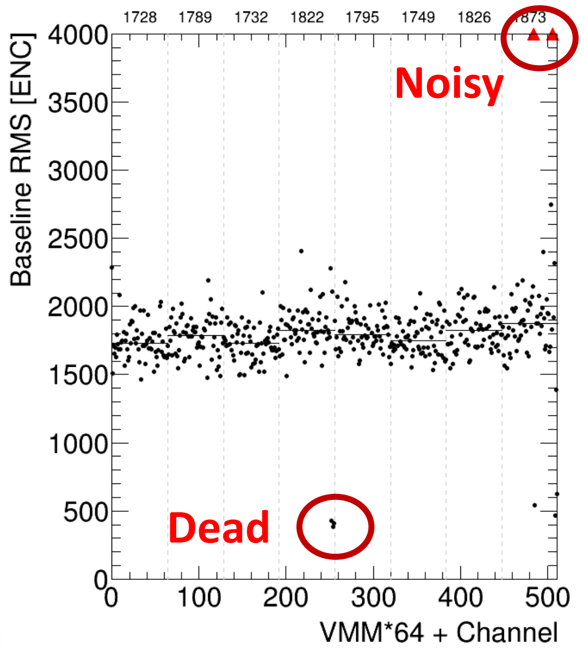


Mezanine filter board

Commissioning: Baselines / Threshold setting

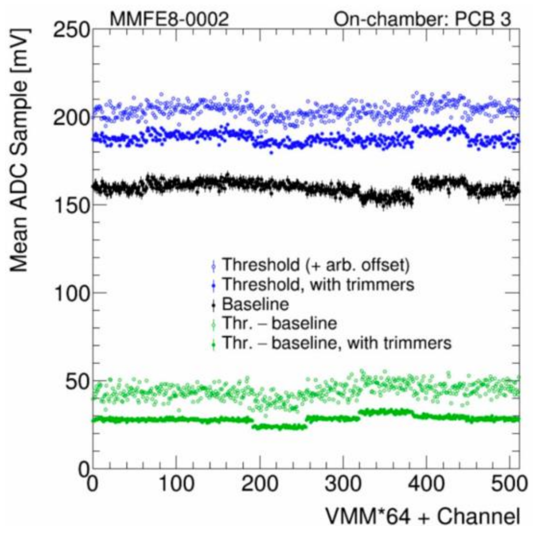
Baselines are studied in order to

- Identify and correct misalignment between chamber and board strips causing sorts between neighboring channels (making them unusable)
- Check for noisy or dead channels
- Baselines are measured again at 191 after installation to ensure that no one board or connector was moved and evaluate the noise conditions on NSW
- Estimate the dead and noisy channels



For every channel a different threshold is set

- VMM is the first level readout having 64 channels
- Each VMM has a slightly different response
- For each VMM a global threshold is set
- Then for each channel the threshold can be further calibrated up to 30 ADC counts (trimming)
- 3 sets of thresholds of different tightness are produced



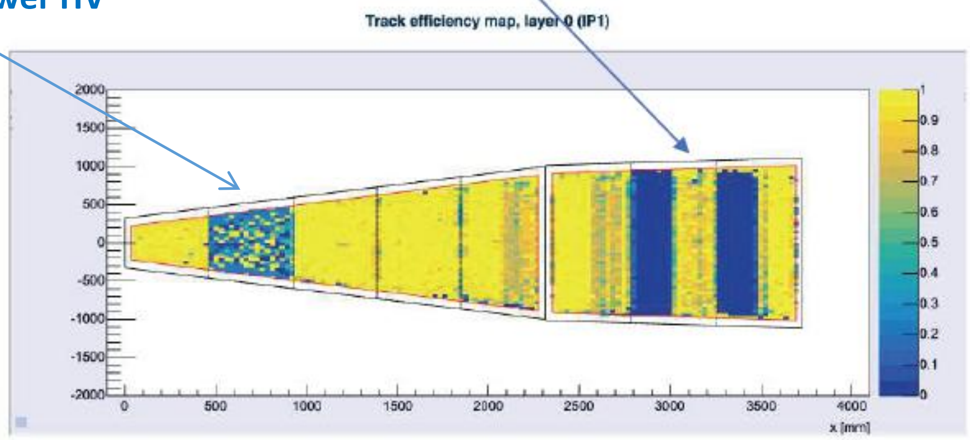
Commissioning: Different sets of data taking

Different kind of data taking runs are performed

- Noise runs - varying thresholds, trigger frequency
- Pulse runs - varying pulse height, channels
- Cosmic runs - varying thresholds
- Runs to validate the trigger path

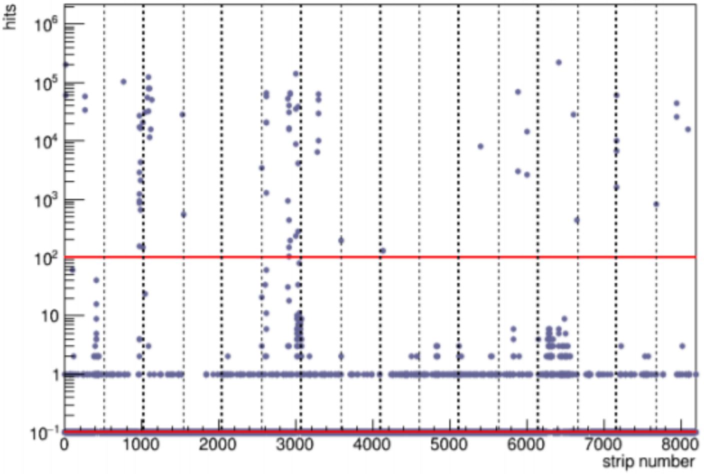
In order to

- ➢ Identify dead-noisy channels
- ➢ Check electronics response
- ➢ Check detector performance

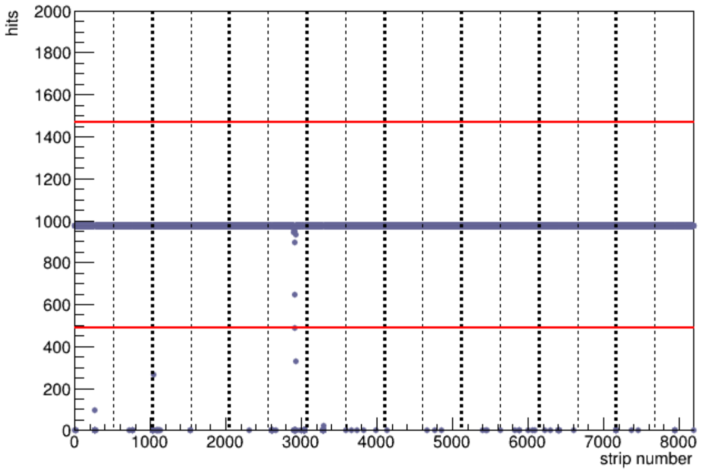


Efficiency map from cosmic run

Occupancy - noise run



Occupancy - pulse run

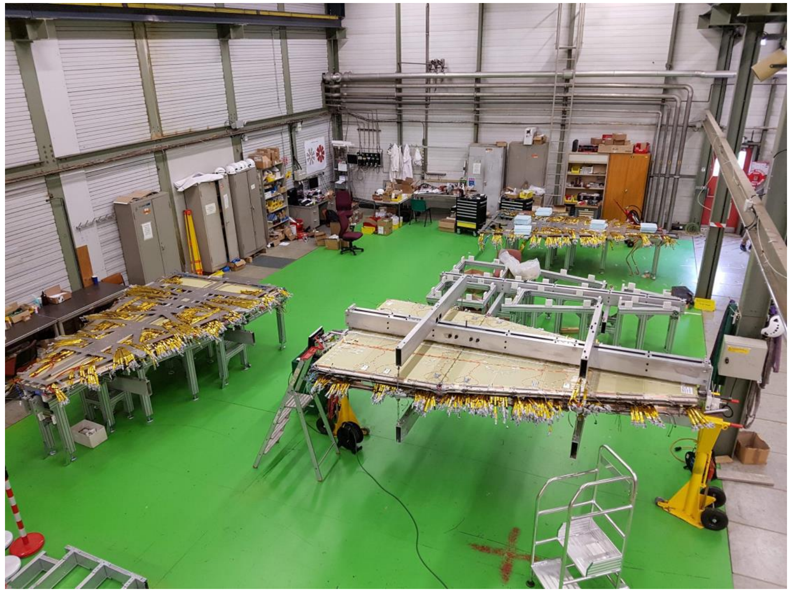


Present status

Double wedge Assembly and integration at BB5

S. Kompogiannis
Muon Week 3/6/2021

- 2 integration tables Large DWs
- 5 rotation stations in use
- All SFs are finished
- All but 2 DWs of side C are left for mechanical assembly
- **All but 3 DWs of side C are left for service completion**



T. Alexopoulos
Muon Week 3/6/2021

- 3 rotation stations in use for elx integration and validation
- 6 SS and 1 LS of side C have been validated
- **End of integration of all side C sectors by August 2021**

Sector Commissioning at 191

[A. Kourkoumeli-Charalampidi
Muon Week 3/6/2021]

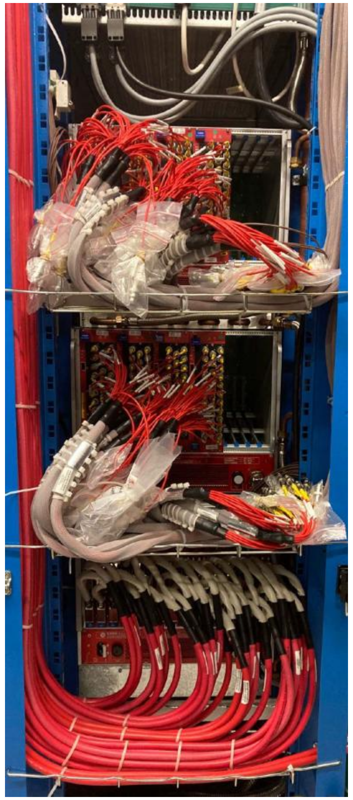
• Last large sector installed on May 28th
Despite noise issues that delayed commissioning
• All SS side A have been commissioned
• 5 LS side A have been commissioned
• Commissioning preparation has started on side C
• **Side A will be fully commissioned in two weeks**

Commissioning at P1

K. Ntekas
Muon Week 1/6/2021

- NSW-A expected to be installed in the cavern mid of July
- All the equipment needs to be configured, tested and commissioned before connecting to the detector
- Only production software and tools should be used at P1
- New DCS architecture and its integration with the muon DCS has been finalized
- **NSW A will be commissioned at P1 in parallel with NSW C at 191**

Racks for HV



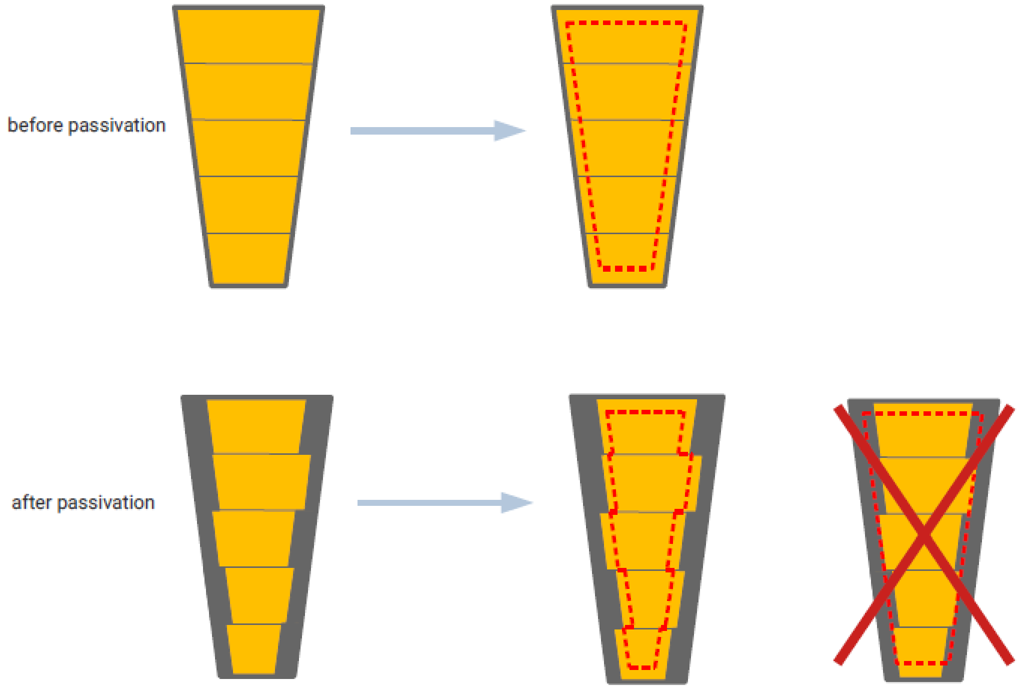
Racks for DAQ

Racks for DCS

NSW software upgrade

S. Angelidakis
Muon Week 2/6/2021

- Byte-stream to RDO conversion (both MM and sTGC)
- Mapping between online and offline IDs
- **Common tool to be used by DAQ and Athena is implemented**
- Include passivation in digitization and reconstruction
- **Preliminary implementation of passivation already in Athena**



Summary

- **ATLAS NSW is (a) the largest ATLAS phase I upgrade and (b) the larger Micromegas project curried out so far.**
- **In the last three years huge effort has been set to understand and overcome a variety of challenges.**
- **Passivation, increase of HV granularity is approved and possible modification of operation gas used to mitigate HV stability issues.**
- **All the detector modules have been produced. Most of them have been mechanically assembled and will be fully integrated by ~ August 2021.**
- **Having solved the noise issues, installation and commissioning proceeds at full speed.**
- **Side A will be fully commissioned at 191 in a few days and be moved to P1 at mid July.**
- **Schedule for side C is still very tight (10/2021) but feasible.**
- **Next big challenge is the commissioning of NSWs at P1.**

This work was supported by the European Union and the ESPA 2014-2020 National Fund for Research Infrastructures DaTanet

Back up slides

Introduction: Motivation

Table 1.1: Expected Level-1 rate (based on 2011 data at 7 TeV) for luminosity $3 \times 10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$, $\sqrt{s} =$ 14 GeV and 25 ns bunch spacing for different p_T threshold with and without the NSW upgrade. The extrapolation uncertainty to 14 TeV is also shown.

L1MU threshold (GeV)	Level-1 rate (kHz)
$p_T > 20$	60 ± 11
$p_T > 40$	29 ± 5
$p_T > 20$ barrel only	7 ± 1
$p_T > 20$ with NSW	22 ± 3
$p_T > 20$ with NSW and EIL4	17 ± 2

ATLAS Run 201289 [LB 96-566], LHC Fill 2516, Apr. 15 2012, 50ns spacing

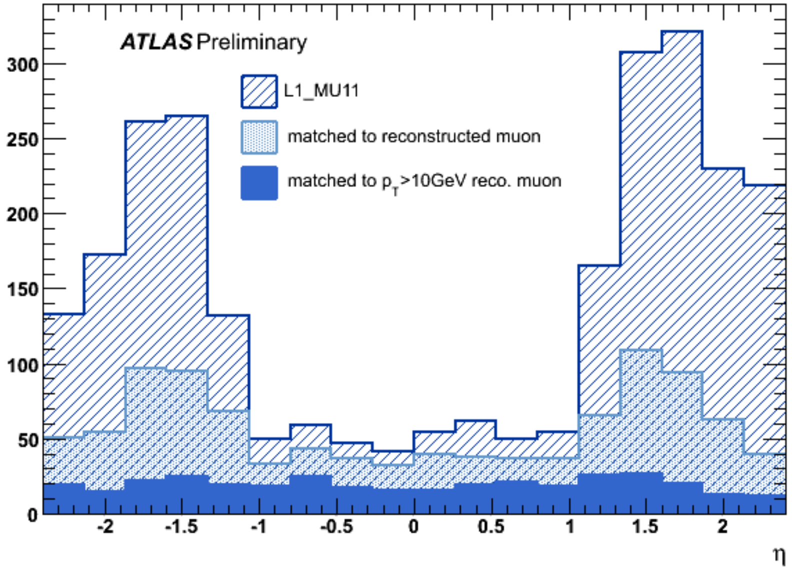


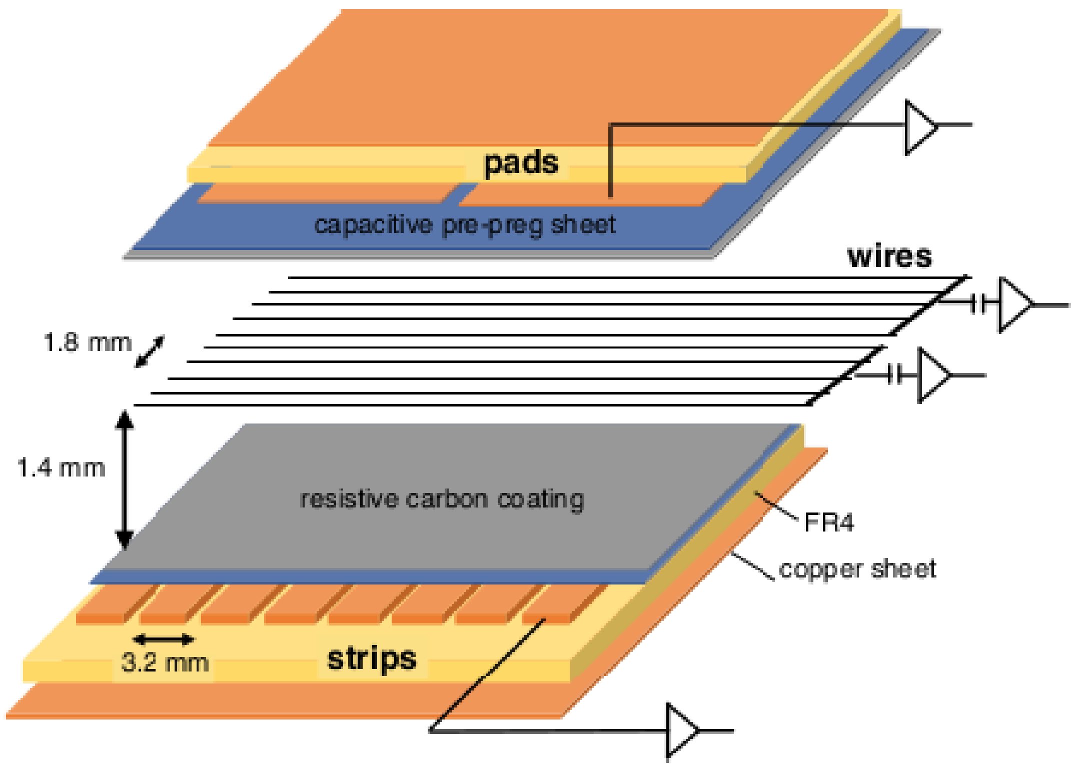
Table 1.2: The efficiency for WH associated production $pp \to WH$ with $W \to \mu\nu$ and two decay modes of a 125 GeV SM Higgs boson to $H \to b\bar{b}$ and $H \to W^+W^- \to \mu\nu qq'$.

L1MU threshold (GeV)	$H \to b\bar{b}$ (%)	$H \to W^+W^-$ (%)
$p_T > 20$	93	94
$p_T > 40$	61	75
$p_T > 20$ barrel only	43	72
$p_T > 20$ with NSW	90	92

Introduction: sTGC operational principle

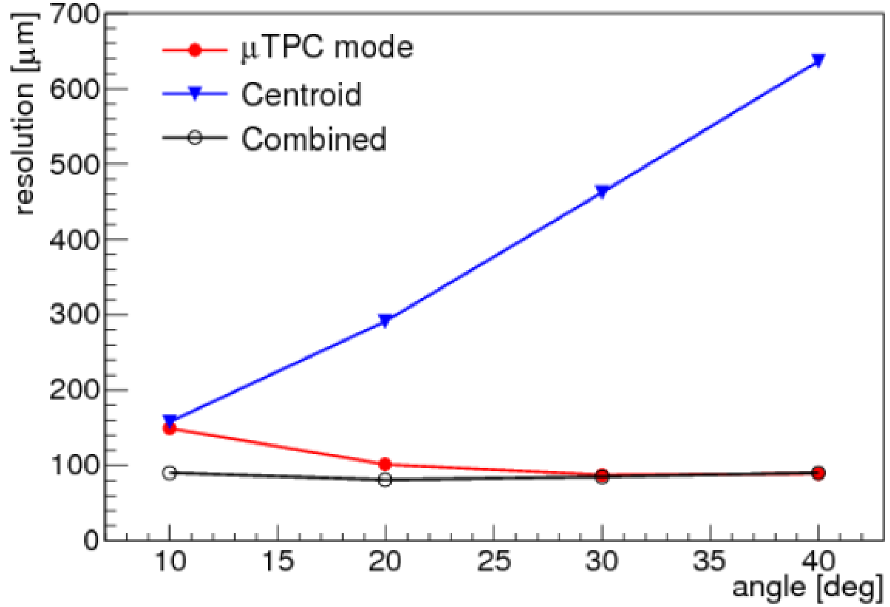
Schematic diagram of sTGC

- Primarily used for triggering;
- CO_2-n-pentane gas (55%:45%);
- Wire, pad, and strip readouts;
- Strip pitch, 3.2 mm, much smaller than TGC, hence "small";
- Pads for local triggering;
- Good timing resolution with short drift time for electrons;
- **Construction sites:** Canada, Chile, China, Israel, Russia.

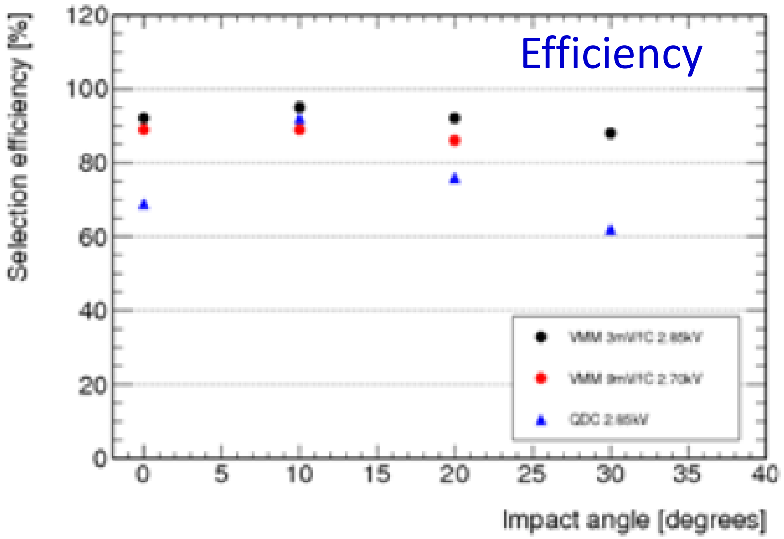


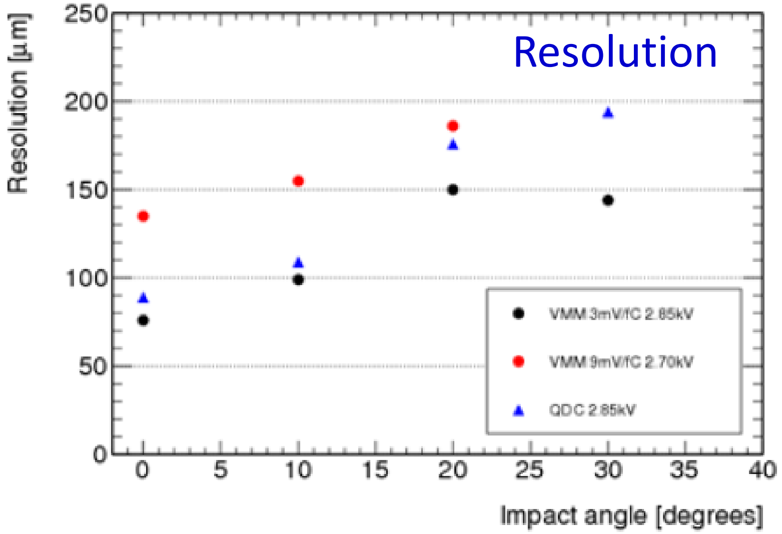
Introduction: Test beam results

Micromegas



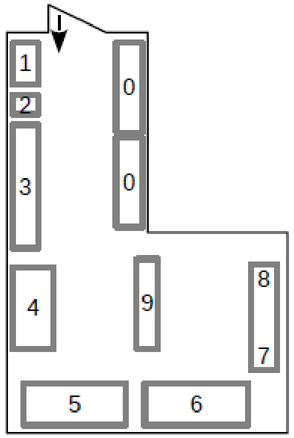
sTGC





Chamber production: PCB quality control

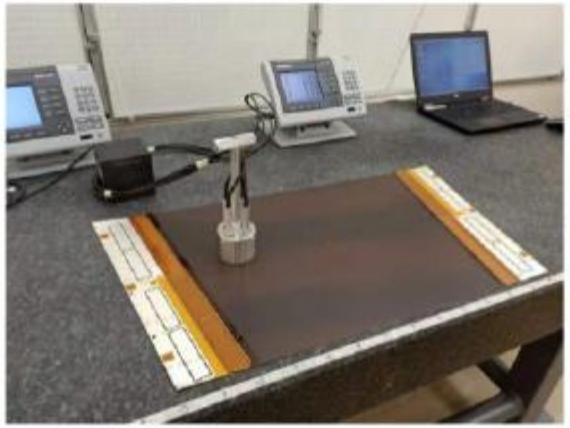
Dedicated lab at CERN for PCB QA/QC

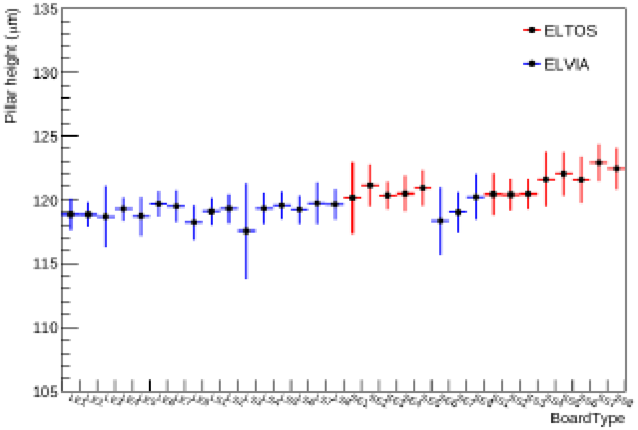


0. shelf & table
   unwrapping
1. computer table
   logistics
2. tool chest

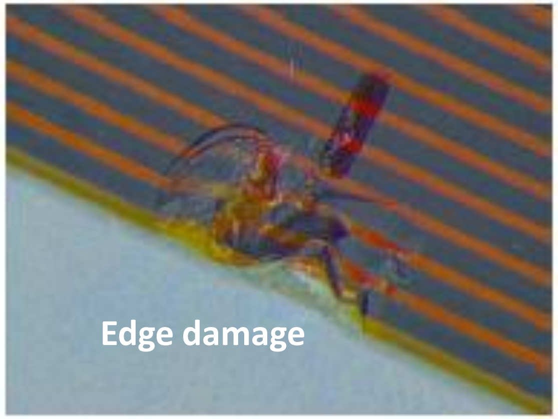
QC tests

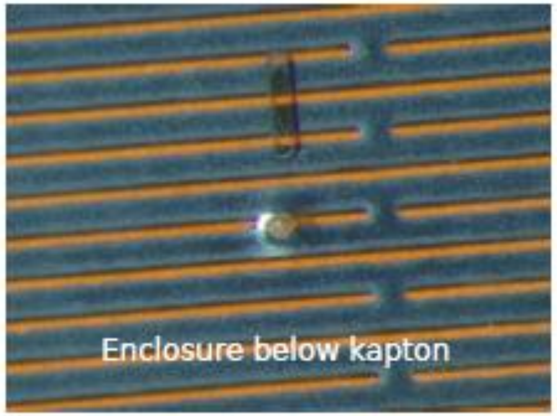
3. top light table
   visual inspection, electrical tests, repairs
4. back light table
   agreement btw. holes & Cu pattern,
   edge precision & straightness, pillar pattern
5. rasmask granite table
   absolute dimensions & shape O(30μm)
6. granite table
   pillar height measurement
7. table
   resistivity mapping
8. table
   strip capacitance measurement
9. self
   storage of boards when QC has finished





Pillar height mapping as a function of the board type

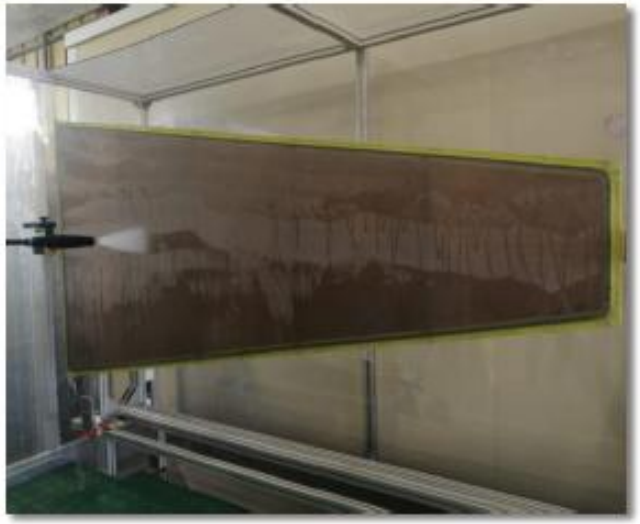




Cleaning protocol at production sites

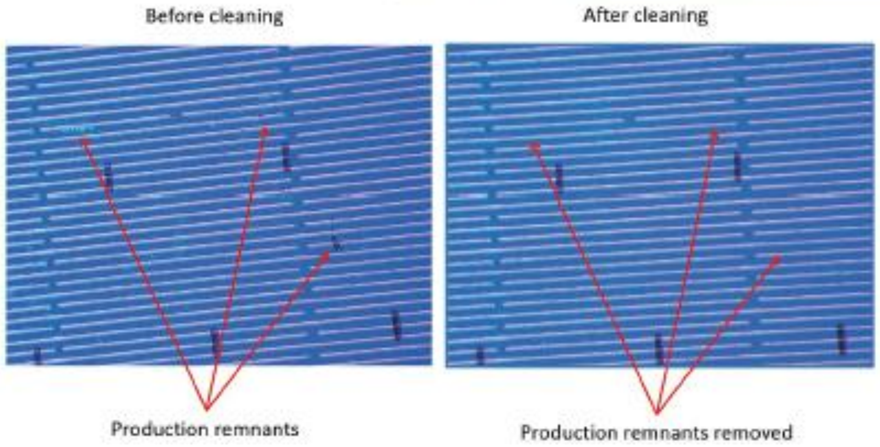
Micropolishing cleaning procedure:

- Hard and soft brushes to distribute detergents
- Accurate washing with hot and demineralized water
- Drying in a box with a ventilation system at ~40°



Main purpose of wet cleaning (and scrubbing):

- remove remnants from the PCB production: dirt and solid deposits from the RO boards -> mostly responsible of "ionic component"
- remove dirt from the mesh (and trapped wires/chips)



LM2 drift panels construction @ Thessaloniki

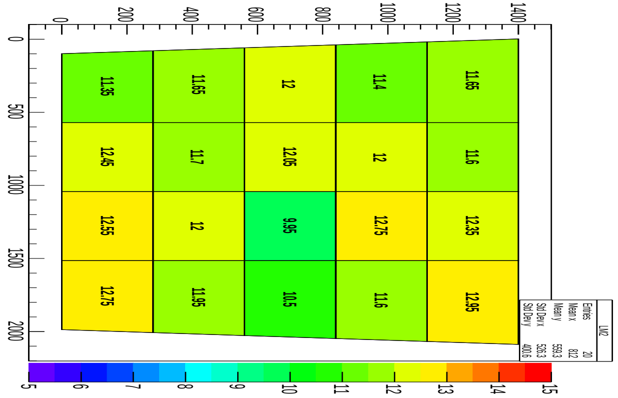
- Steps of construction:
  1. Assembly and gluing of the aluminum frame → Trapezoidal frame with three sub-areas
  2. Panel gluing is a one step process using the vacuum table method
  3. Under-pressure of about 100 mbar on vacuum tables → PCBs mimicking table's planarity
  4. Kapton tape attached along PCB junctions to reassure sealing
  5. 3 kg of glue is distributed on aluminum frame and PCBs
  6. Honeycomb is placed inside frame's sub-areas
  7. Second table (movable) is rotated and placed on top of the first one standing on ten high precision spacers
  8. 20 hours glue curing with under-pressure

Quality control
- Planarity
- Thickness
- Gas tightness
- Mesh tension

- Steps after gluing:
  1. PCB excesses remove
  2. Sealing PCB junction to prevent gas leaks
  3. Mesh frame gluing
  4. Interconection drift spacers gluing
  5. Gas pipes gluing
  6. HV conectors gluing
  7. Mesh stretch to a certain mechanical tension
  8. Mesh gluing on a transfer frame (mandatory for movement from stretcing machine to bare panel)
  9. Perforation of mesh around the interconection area
  10. Mesh gluing on bare panel
  11. Mesh excesses remove

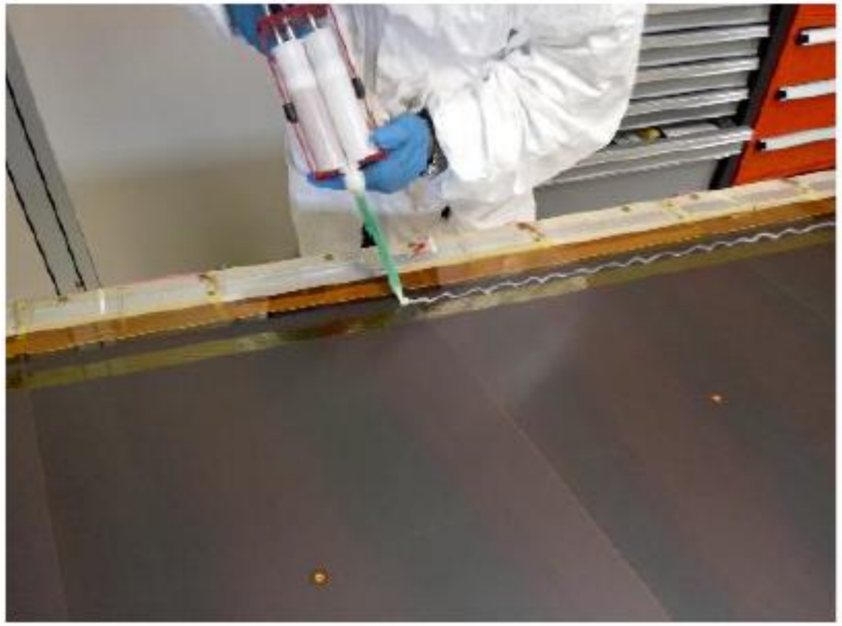
Mesh tension mapping

Uniformity better than 10%

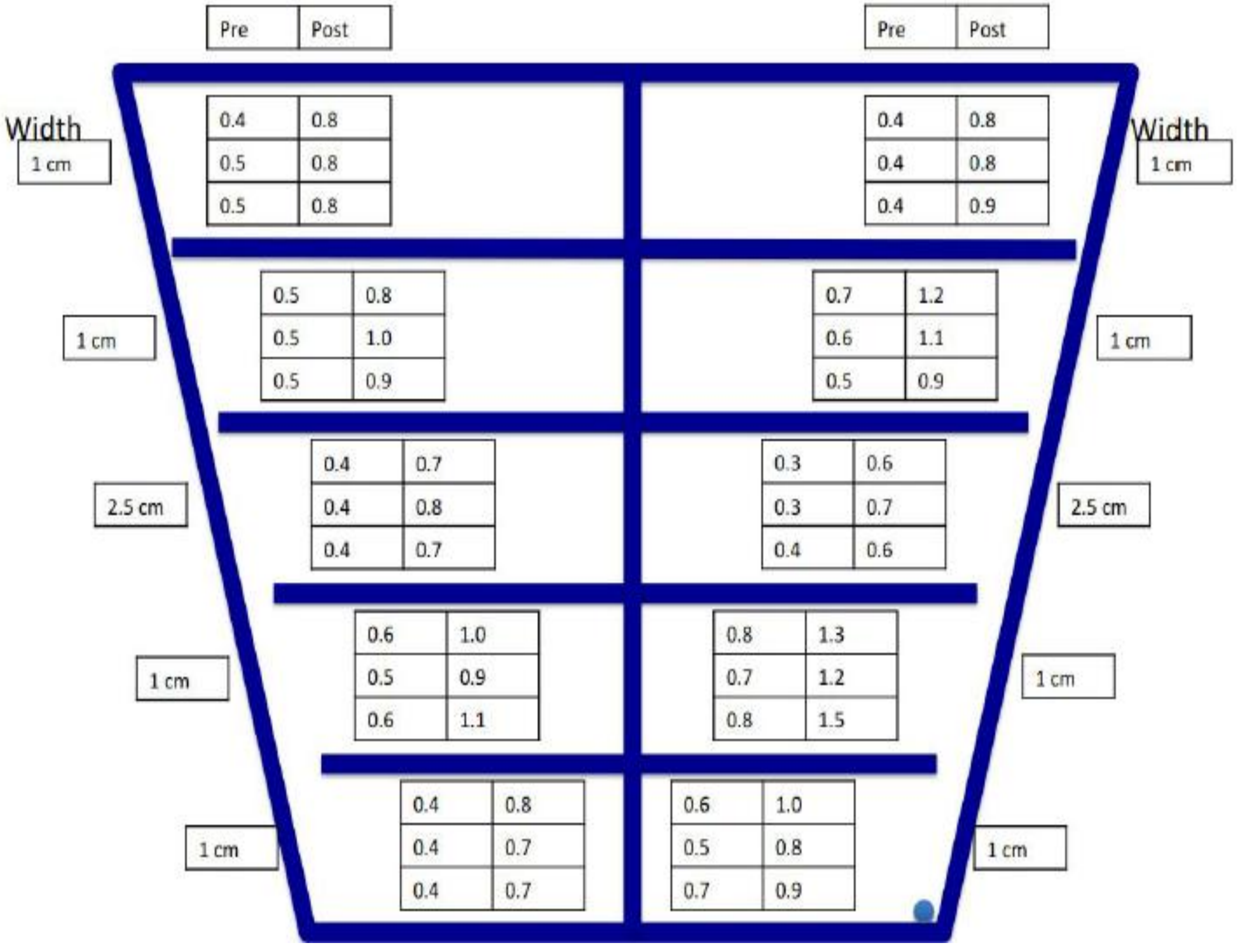


Chamber production: HV stability - Passivation

Passivation is performed using a thin Araldyte film



Width of passivated area such that R>0.8 MΩ



Chamber production: HV stability - Passivation

- The method of passivation was used for all the modules from one point and on, to mitigate the HV stability issues
- As a result there is a small decrease of the active area in the overlapping small – large sector regions