The Micromegas chambers for the ATLAS New Small Wheel upgrade

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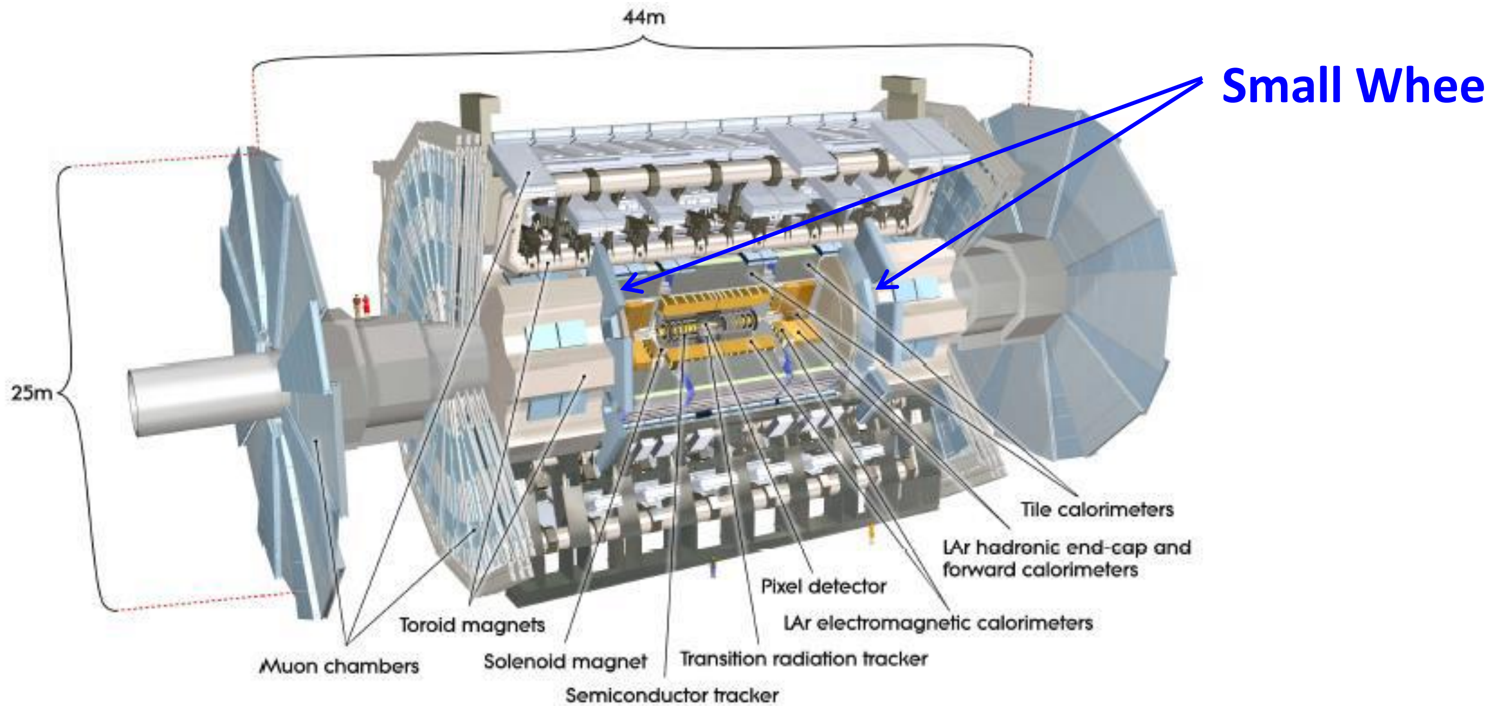
on behalf of the ATLAS Muon Collaboration

What is the New Small Wheel upgrade

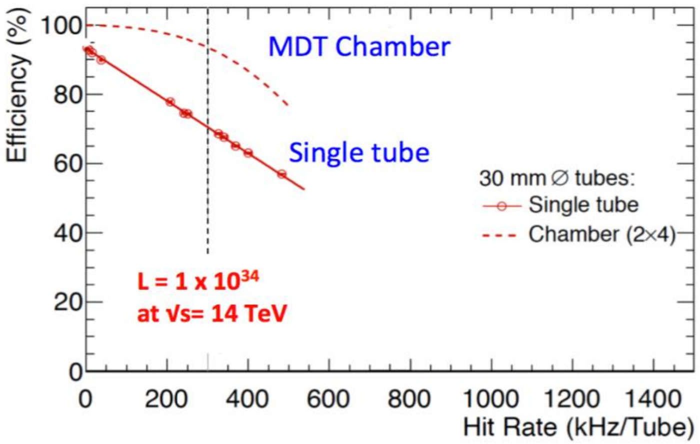


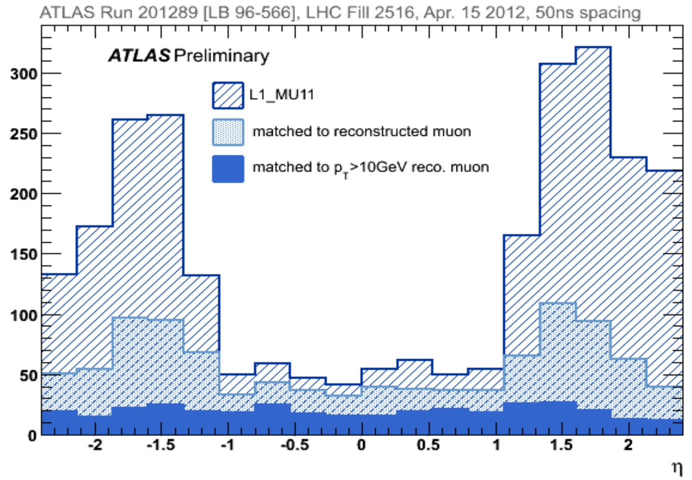
- Small Wheel – the innermost part of forward muon spectrometer

- New Small Wheels aim to replace present Small Wheels, with new detectors and electronics, which can cope with the HL-LHC pile-up and background and which can provide improved triggering

NSW upgrade: motivation

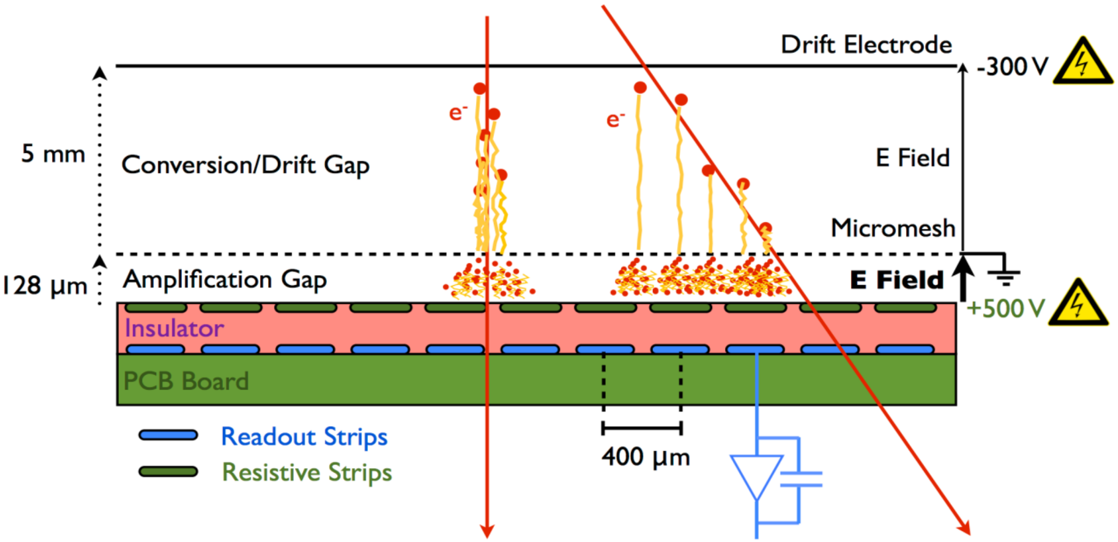
Primary aim – preserve the excellent resolution and tracking efficiency which we currently have also in the HL-LHC environment, when occupancy will rise by order of magnitude up to 15 kHz/cm^2





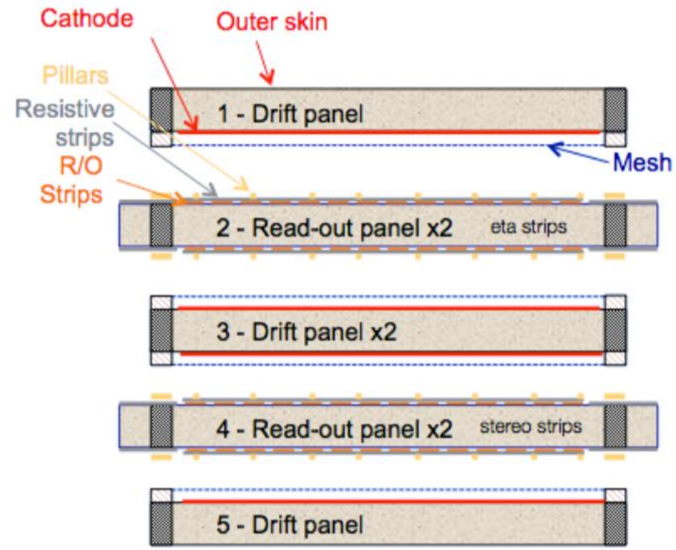
- Standard ATLAS drift tube start to loose efficiency even at LHC run-2 luminosity
  - **Replace MDT and CSC by Micromegas**
- Pattern recognition becomes more and more challenging the higher the pile up and background rates are
  - **NSW: 8 MM and 8 sTGS (16 in total) detection layers with finer granularity instead of 4 (CSC) or 6 (MDT) in the present Small Wheels.**
- Current triggering not sustainable at higher luminosity due to high fake trigger rate
  - **NSW detectors (sTGS) will be used in L1 trigger**

ATLAS NSW MicroMegas detectors

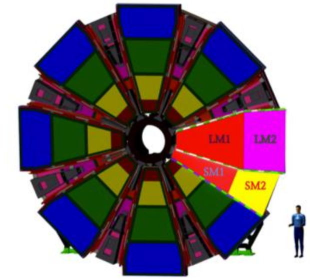


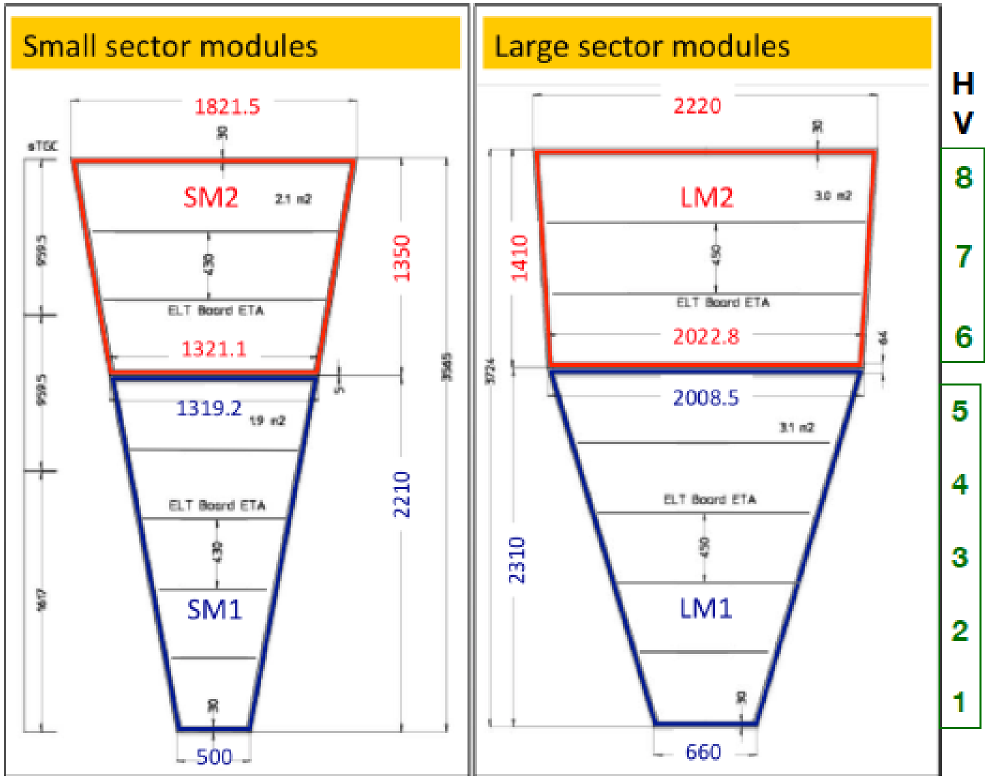
- 4 detector layers per module formed by 2 RO and 3 drift panels
- Floating mesh is integrated into drift panel
- Gas mixture: 93% Ar - 7% CO_2 (further studies ongoing)

- Large (~3m²) resistive MMs
- Cu strips are covered by a Kapton layer with resistive strip screen printed on it to limit amplitude and area of discharges
- Strip pattern resistivity $\approx 10 M\Omega/cm$
- HV is applied to resistive layers
- 128 μ pillars supporting a (floating) mesh
- Strip pitch 425-450 μ
- Convertion&drift gap 5mm



MicroMegas Modules layout





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

Large Module 1(LM1):
France, CEA, Saclay

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

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

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

- **Totally 128 MM modules in 2x16 sectors, ≈3 m^2 active area each**
- 4 modules in each double-side sectors(wedges)
- 4 Readout layers per module formed by 2 RO and 3 drift panels
- 3 or 5 precisely positioned RO boards per layer in module

Construction challenges

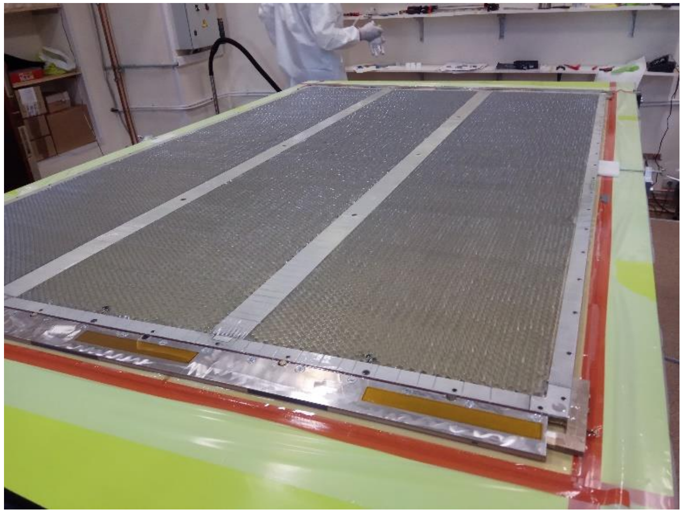
The resistive MicroMegas chambers are frontier Micro-Pattern GasDetector, designed and built for the first time on large dimensions O(m^2).

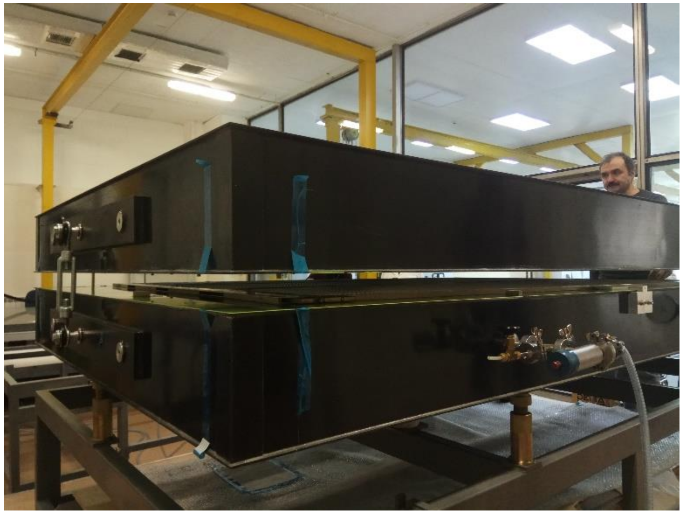
MicroMegas construction challenges:

- Very high mechanical precision in order to get ~15% p_t resolution at 1 TeV
  - strip alignment on each layer of 40 μ of precision in η over meters
  - planarity within 100 μ RMS
  - both request challenging because of the large detector dimensions
- Stability against discharges with a high electric field (~50 kV/cm) on the large surface
- **The special issue is the necessity of read-out board production in industry with extremely high quality (pillars shape, resistivity homogeneity, quality of the PCB edges)**

ATLAS MicroMegas : production

- All modules produced in a similar way with small variation depending on production site
- There are 2 major production steps: panel gluing and module assembling
- General panel gluing principle:
  - Crucial parts - PCB and alignment elements are precisely positioned with template(vacuum table) and shims
  - Support structure(not precise) - aluminum frame + honeycomb is placed in between PCB
  - (Variable) gap between support structure and PCB filled with glue
- During module assembling panels are aligned by precise holes and alignment pins.



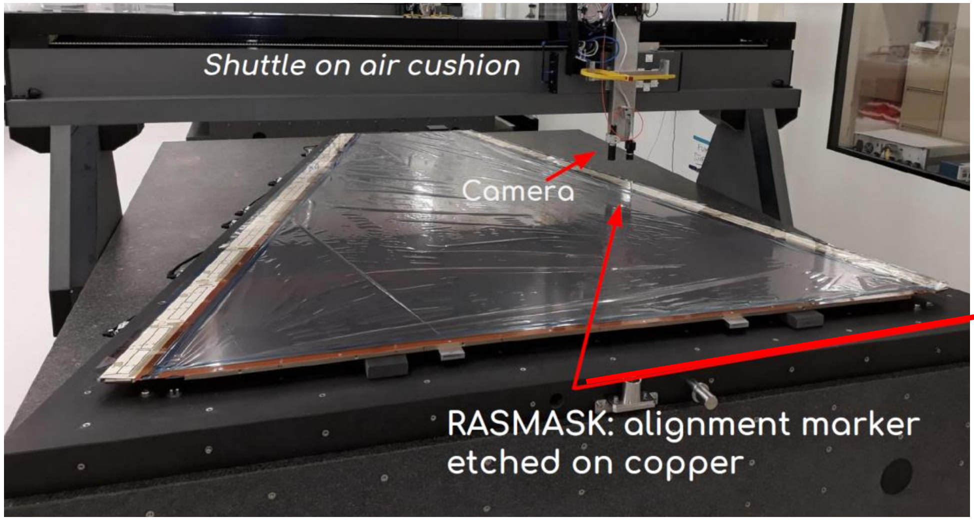


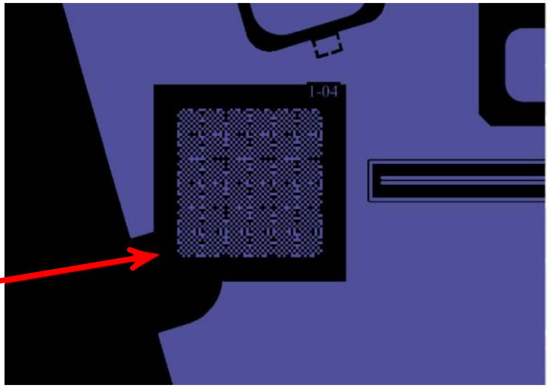
NSW MMs: strip alignment

- RO strips are precisely aligned within PCB, PCB-to-PCB position defined by template during panel gluing &assembling
- We can not completely avoid board misalignment…
  - PCB dimensions depend on humidity : 400 μ/m FR4 elongation while humidity rise from 0 to 50%
- … But we control it
- Each PCB have 6 reference mask, aligned with strips.
- Relative positions of the masks both in-plane and plane-to plane are measured with optical sensors. Board deformation as well as relative shifts are extracted and saved to use later for tracking

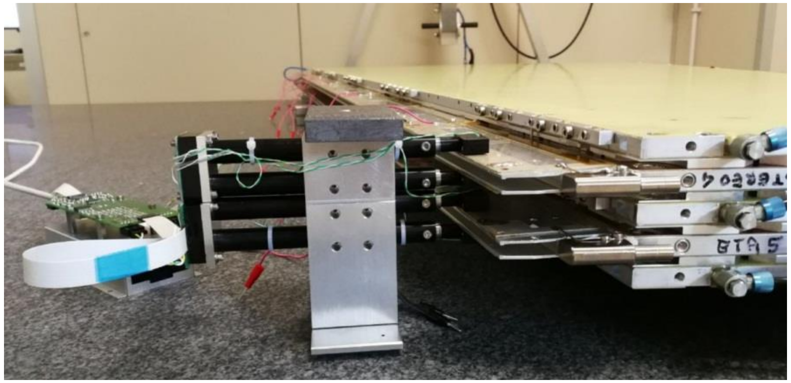
NSW MMs: alignment control

In-plane alignment control in Saclay



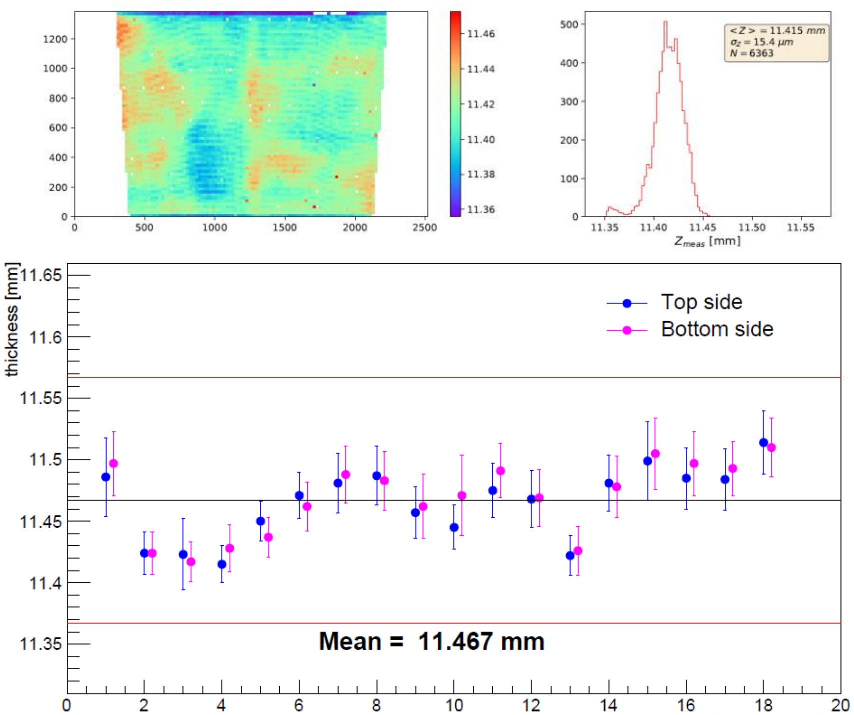


Plane-to-plane relative alignment control with calibrated ccd tower (RASFORK tool)



NSW MMs: thickness and planarity

- Due to large (≈30^0) angle of incoming tracks RO plane deviation from planarity directly contribute to the tracking inaccuracy
- Panel thickness and planarity checked after production by CNC + optical sensor



Example of thickness⊕planarity control result for single panel (top) and panel statistic in Dubna

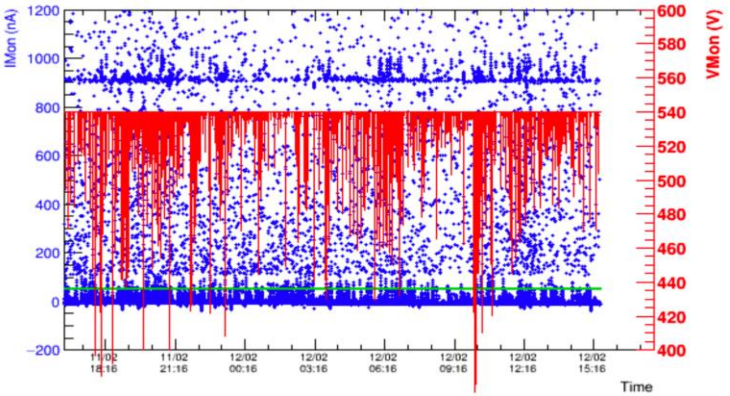
Dots and error bars represent average values and RMS for each individual panel

Red lines – 100 μ tolerance

Now all sites routinely produce modules with required accuracy

ATLAS NSW MMs: HV stability

- HV problems emerged for the first time when we had assembled module 1, and tested it - end 2017
  - High currents and discharges, with or without HV trips



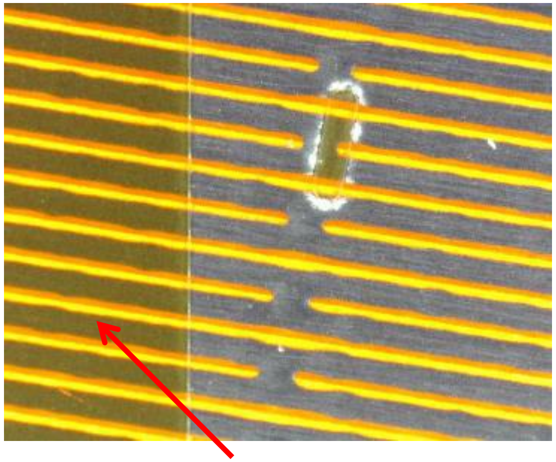
During the last year, we understood

- Thorough washing/cleaning of panels prior to assembly is crucial → dedicated multi-step protocol in place in all construction sites
- Relative humidity inside the chamber is crucial, require ≤10% to have low current. Drying in normal environment takes weeks. Special drying boxes were built by all sites.
- Margin between onset of systematic discharging and original operating point is small → nominal operating voltage lowered to 570V from 590 assumed before, keeping an efficiency well above 90%

Despite this, chambers did not pass HV acceptance criteria easily;

ATLAS NSW MMs: HV stability

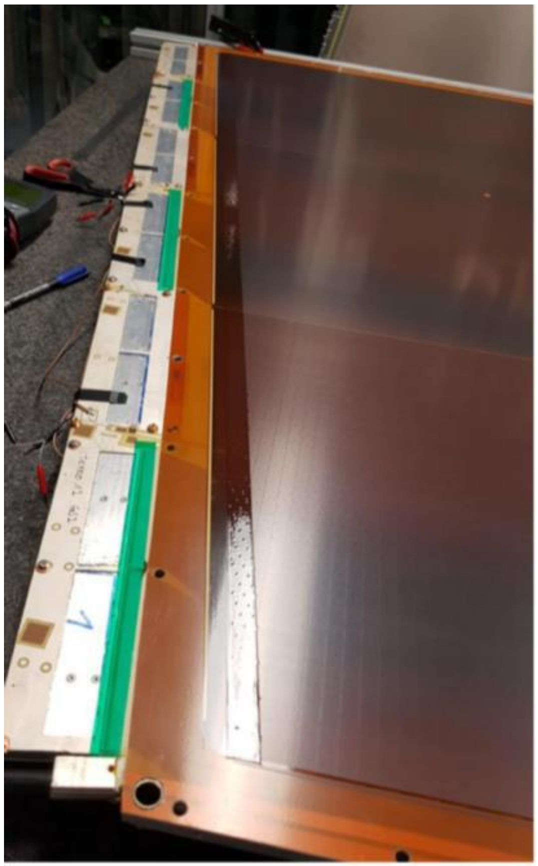
- Sectors HV stability mainly is defined PCB quality:
  - High repeatability of HV test results after module re-assembling
  - Bad sectors are concentrated on PCB of particular type
- Clear correlation was observed between low strip resistivity and sector HV instability
- Low resistivity is not a problem itself but, in combination with any other weakness/defect (mesh, impurity, surface roughness, ….) the spark quenching mechanism no longer works efficiently, and this is what we have been seeing !



coverlay

Opening and inspection of discharging chambers often showed evidence of the discharge happening close PCB edge, where the resistance to HV distribution line is particularly low

ATLAS NSW MMs: HV stability



- A procedure of "**edge passivation**" has been developed for the SM1 modules to mitigate this problem :
  - Additional 1.5 cm band is covered by thin araldite layer to ensure that minimum resistance to common HV line "seen" by any spark is above safe level. Passivation reduce overlap area, but not crucially.

- **Most of "bad HV sectors" of SM1 modules have been recovered in this way.** Method is successfully applied to all new SM1 modules (stereo panels only)
- SM1 HV stability statistic, **bad/all** sectors :
  - Without passivation : **27/140**
  - With passivation : **3/120**
- Method was successfully transferred to SM2 site, test for LM1 and LM2 are going on

- **Further studies to increase uniformly the resistivity of the boards are going in parallel**

ATLAS NSW Micromegas: status

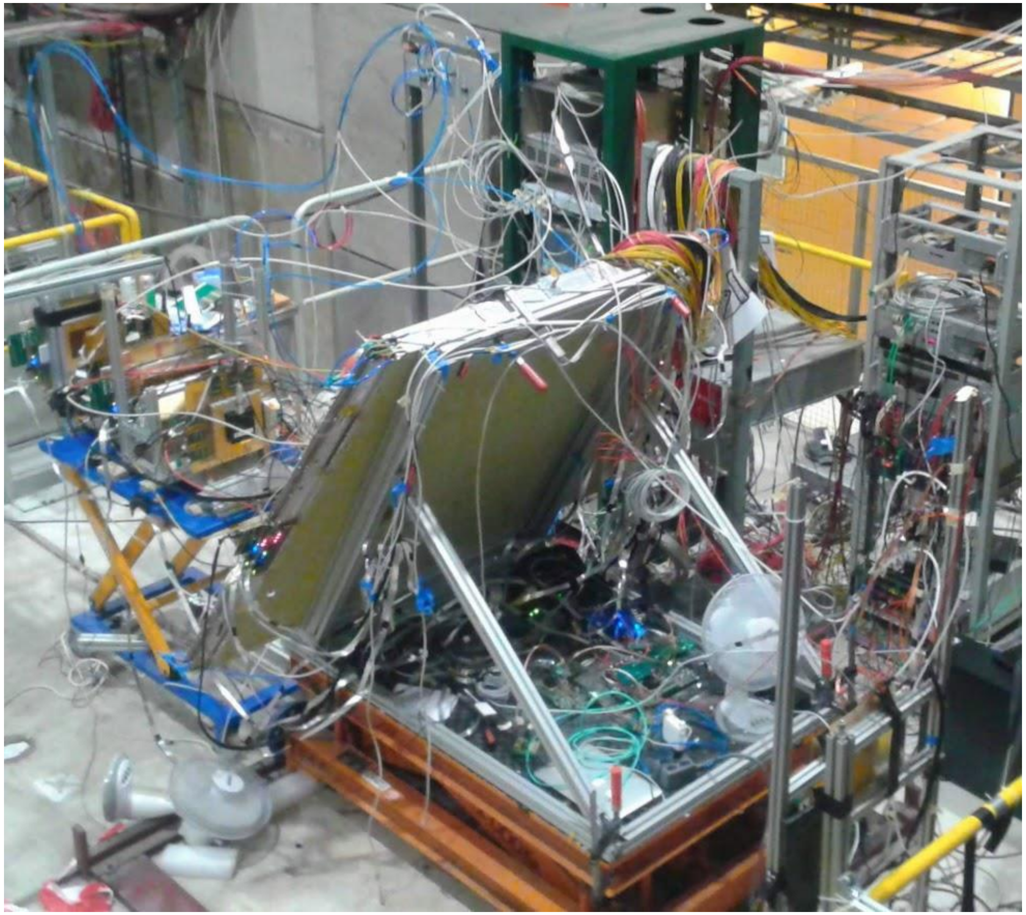
- We believe we have finally understood the origin of the HV stability issues and have found a cure.

- Most of the critical issues of Micromegas project are studied and solved. Module production has been restarted at all sites.

- Due to the accumulated delays of the NSW project (not only Micromegas) the wheel installation is planned to be done in stages :
  - NSW-side-A in 2020 resuming ATLAS Run3 with one old and one New Small Wheel
  - NSW-side-C end of 2021-beg 2022

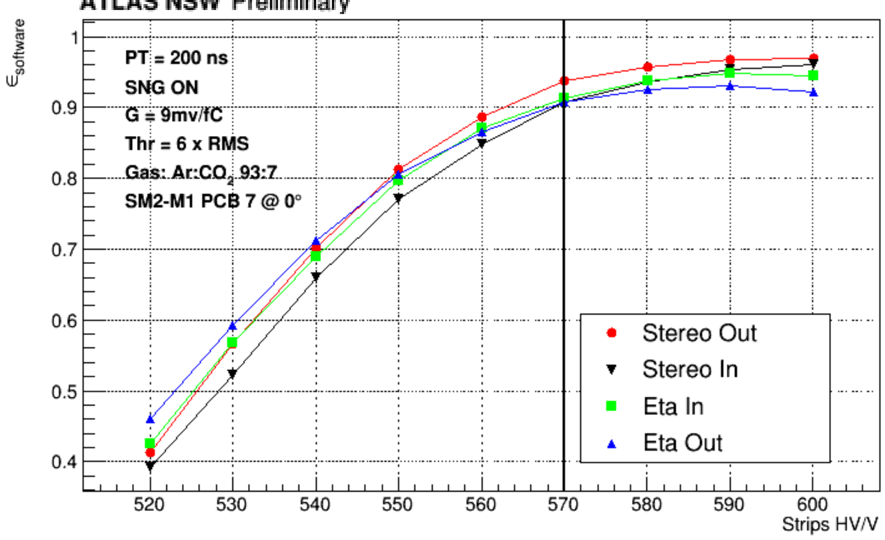
Micromegas in TestBeam: setup

- SPS H8 beamline June/July 2018
- Trigger: 2 (10x10) cm^2 scintillator
- External tracker: 3 (10x10) cm^2 MM prototype chambers
- VMM3 – based electronics (not final board)
- Test chamber: SM2 M1
- Track angle: 0^0 and 28^0

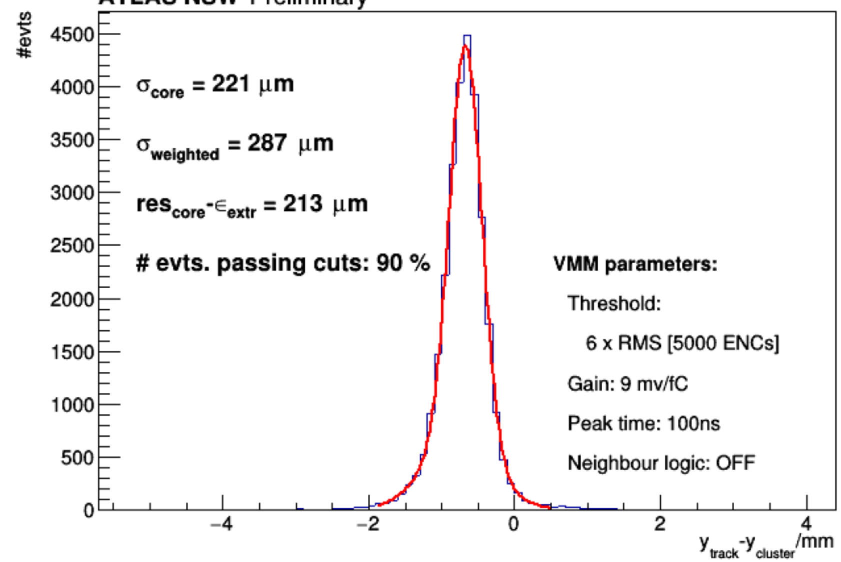


Micromegas in TestBeam: results

Efficiency vs HV scan



Resolution, 28^0 track angle



- Spatial resolution ≈ 220 µ was achieved for 28^0 tracks, while aim value is ≈100 µ. Further results improvement is expected due to
  - Noise reduction 5000 ENC → 3200 ENC obtained with new electronic boards
  - channel-by channel Time2Amplitude Convertor calibration

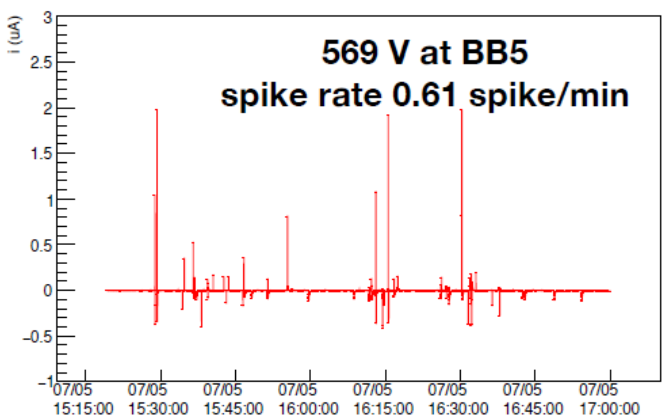
- Very good resolution ≈ 70µ was observed for perpendicular track

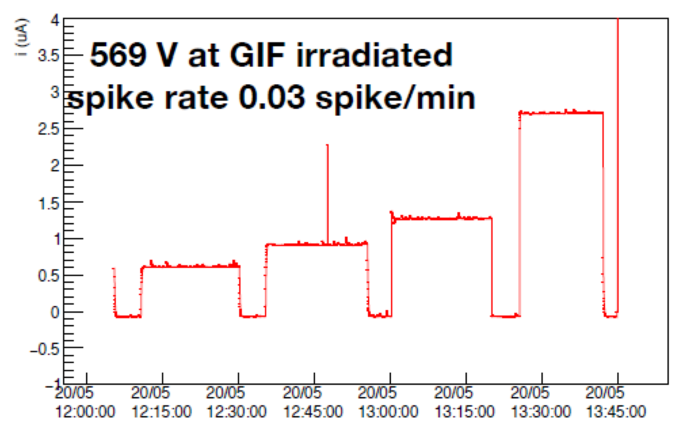
ATLAS Micromegas : GIF++ test

- Gamma ray Irradiation Facility utilize 13 TBq ^{137}Cs source to study the performance of large area detector
- GIF++ test is part of MM module QC procedure. We may consider it as first test of real ATLAS MMs in high-irradiation environment (flux up to 4.5xHL-LHC)

- Observation after first 6 months of test: except for really bad sectors
  - Current is proportional to irradiation intensity. It means there is no efficiency and gas gain degradation under fluxes up to ≈5 times one expected for HL-LHC
  - HV stability do not become worse under irradiation.

Example of sector HV behavior before and under irradiation





New Small Wheel assembling status

	Modules at CERN
SM1	10
SM2	11
LM1	4
LM2	6

- First small double wedge assembled, equipped with electronic and now is being tested with cosmic rays
- 3 small and 1 large double wedges are assembled in total (but only 1 is equipped with electronics)
- Several other modules are ready to be shipped to CERN from all construction sites

Summary

- MicroMegas chambers have been chosen for the ATLAS New Small Wheel upgrade for their great tracking performances ($\sigma \approx 100\mu$ with $\varepsilon \approx 95\%$) up to high fluxes in view of the increasing luminosity of LHC

- The construction of such large area detectors presented many challenges which have required further studies to be done

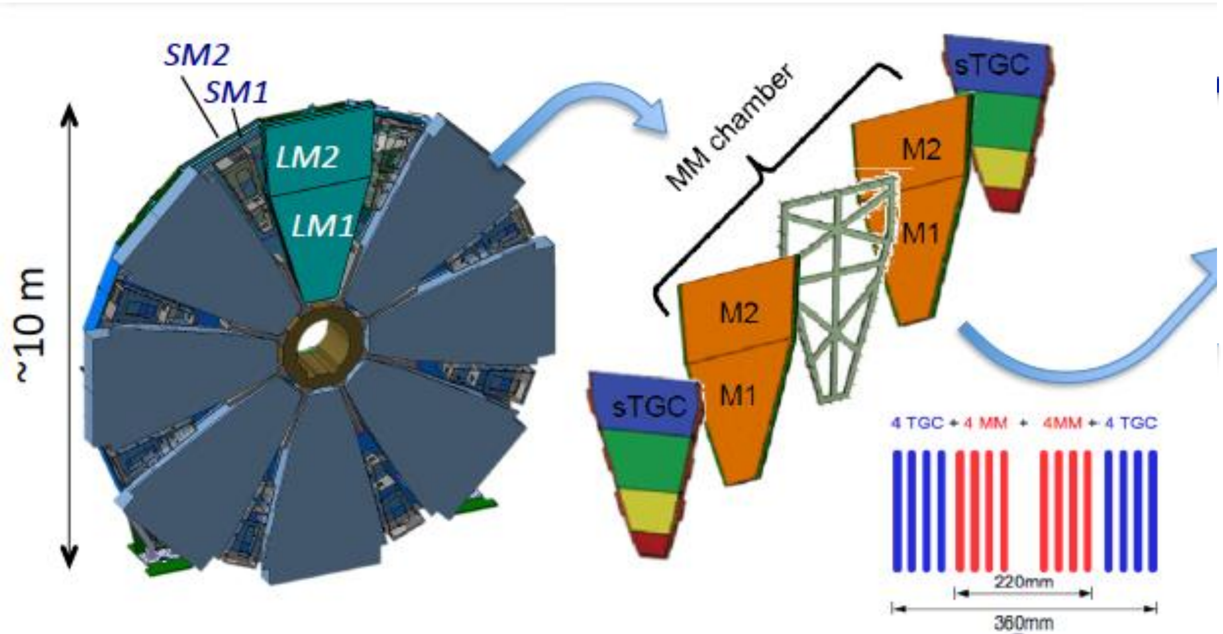
- Main issues of project have been resolved, detector production has been restarted and proceeds steadily at all construction sites

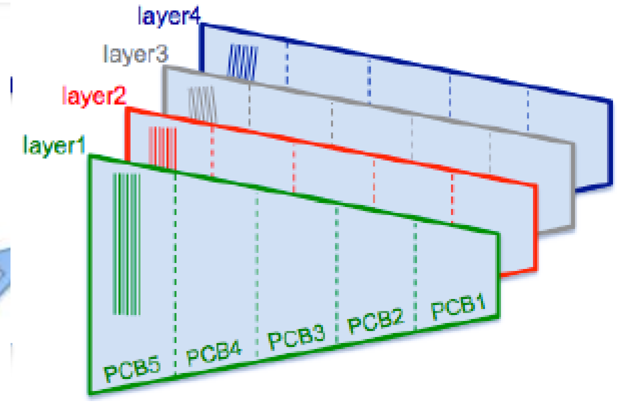
- First double wedge has been assembled, equipped and now is being tested with cosmic rays.

- Still a huge effort in front of us before the NSW can be ready for installation

Backup slides

Layout of sectors and Micromegas module





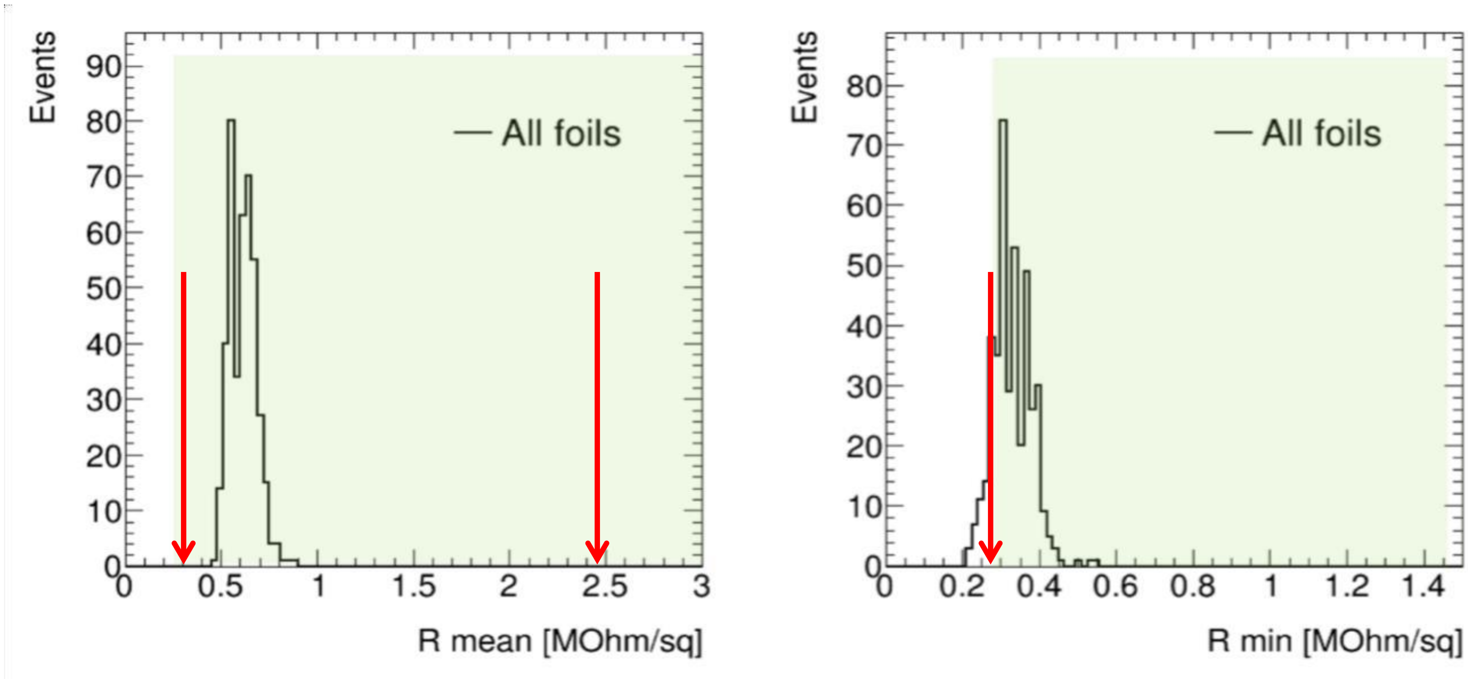
Each Sector is a sandwich of sTGC and MM quadruplets

Each NSW has 16 sectors:
8 Large + 8 Small

Each Micromegas module include 4 readout planes:

- 2 “η” planes with strips perpendicular to small wheel radius
- 2 “stereo” planes with strips inclined by $\mp 1.5^{o}$.

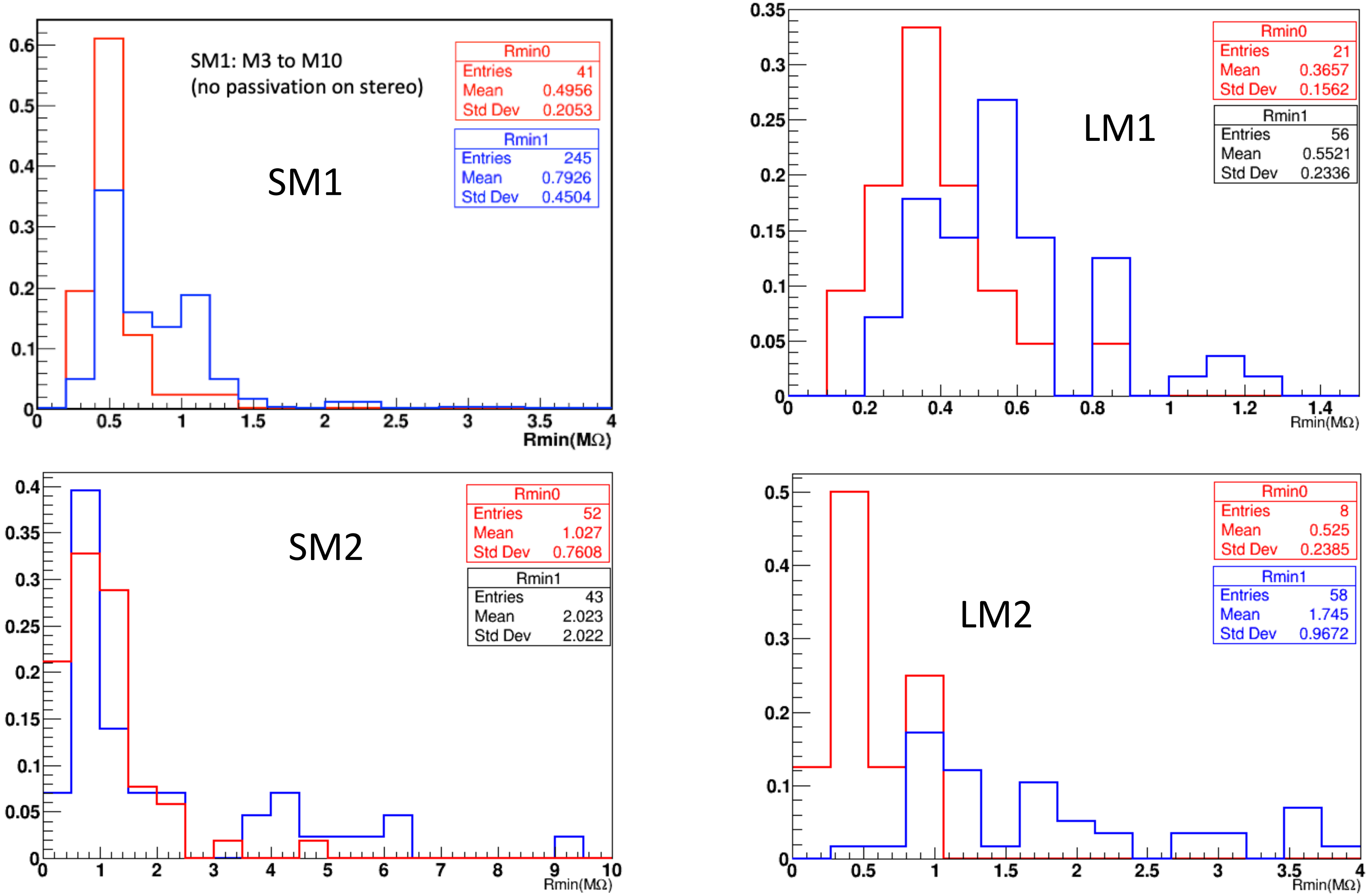
Min and average resistivity of resistive foils
Data from RO PCB QA/QC



Unfortunately we are quite close to the lower limit of 0.28 MΩ/cm, with local resistance points even below

Resistivity and HV stability

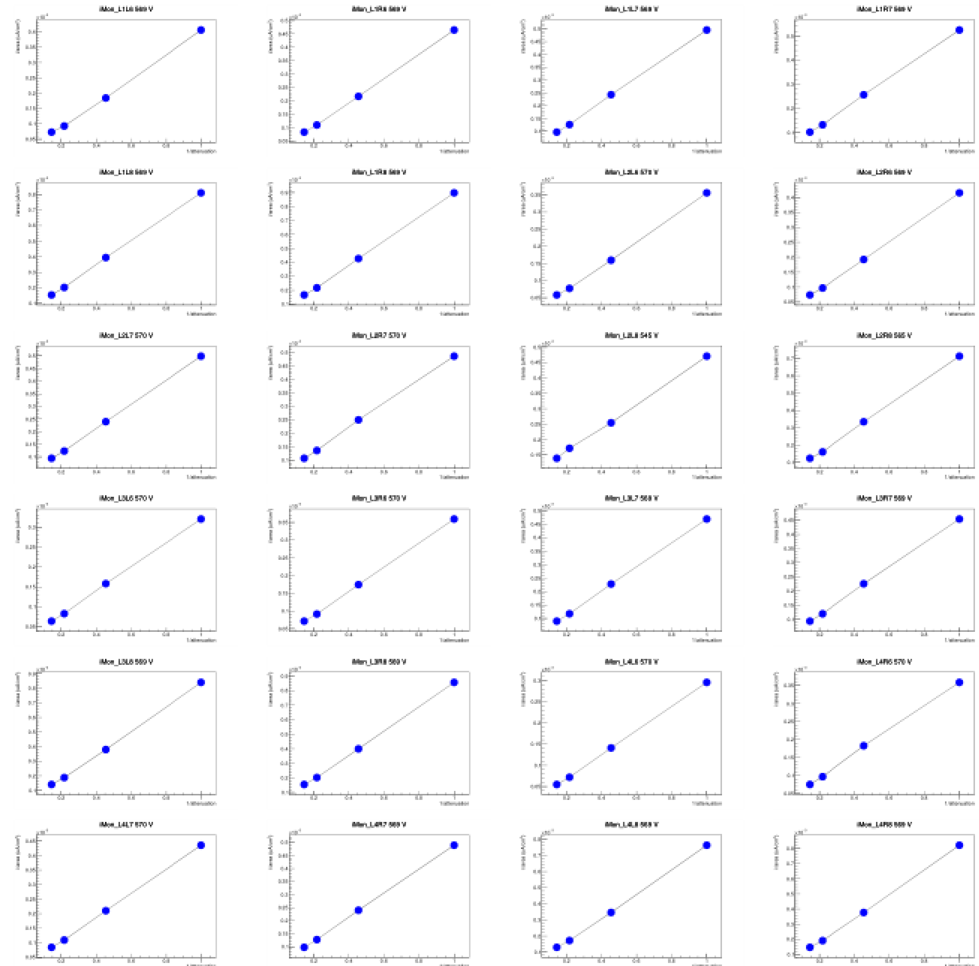
R_{MIN}, GOOD/BAD sectors



ATLAS NSW MMs : GIF++ test

Example of MM current vs irradiation flux plots for tested module. Maximum flux is approximately 4.5 of one expected for HL-LHC

Excellent linearity prove that ATLAS MMs can work at very high flux without efficiency or gas gain degradation

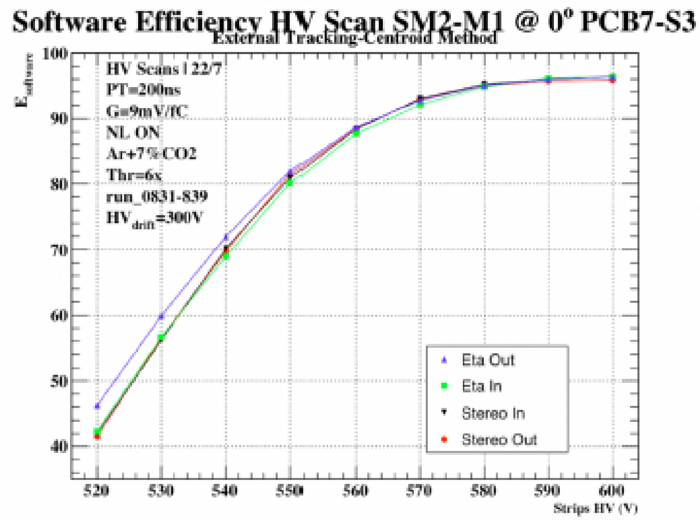


MM chamber validation criteria

The chamber acceptance criterium

Given a HV “picture“ (maximum HV per sector) obtained at the construction site a Qplet “global efficiency“ ε_G (see definition below) is evaluated
Chambers are accepted if $\varepsilon_G > 80\%$

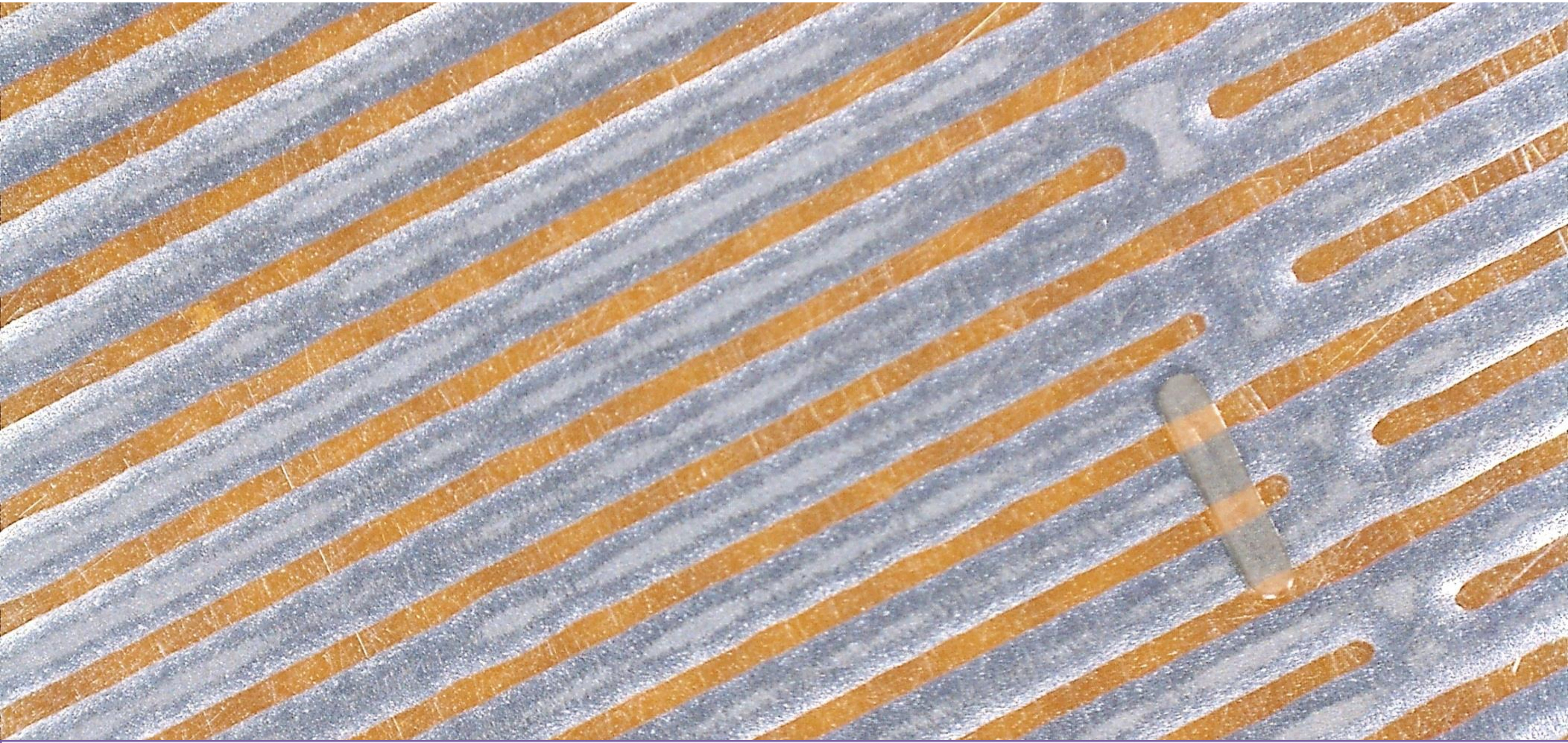
<ins>All chambers delivered to CERN respect this criterium</ins>
(more on chamber quality in Ivan’s talk later)



Definition of ε_G

At the end of the HV conditioning period, a maximum stable HV, HV_{max} , is reached for each sector. HV_{max} is defined as the maximum HV for which the sector doesn’t trip and operate with a spike rate less than 6/min, and an average current less than 50nA. A spike is defined as a current measurement in a second above 200 nA. Trip is defined by a maximum current of 2 uA and 30 s of trip time.
Once the HV picture is obtained, each HV_{max} value is converted in an efficiency applying a “universal” curve taken by the test-beam data obtained with the first production chamber. Such a curve is provided to all construction sites.
From the efficiency picture the average of all efficiencies is finally evaluated and the result is the value of ε_G .

Resistive strips, microscopic picture



- **Polishing marks are visible on resistive strips. Non-uniformity of polishing marks clearly says, that resistive strips are far from being flat. Strip pitch 425um.**