The New Small Wheel Project for the ATLAS Muon Spectrometer

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On behalf of the ATLAS Muon Collaboration

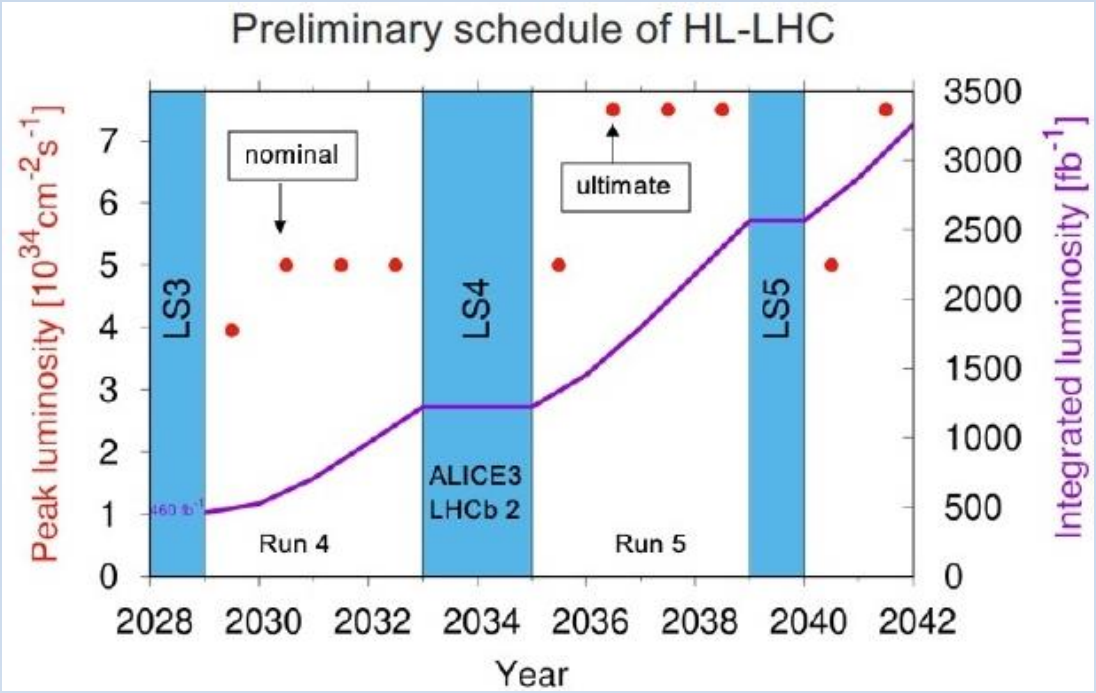
Vienna Conference on Instrumentation – 2022

Outline

- ATLAS and LHC upgrades
- Introduction to the NSW
  - Resistive strip Micromegas
  - Small-strip Thin Gap Chambers
- Detector integration at CERN
- Surface commissioning
- Status in ATLAS cavern
  - MM
  - sTGC
  - DAQ and DCS
  - Trigger processor
- Summary

ATLAS and LHC upgrades

- The ***Large Hadron Collider*** will undergo several major upgrades **until 2032**:
  - From LS2 until end of Run 3: $L \gtrsim 2\times10^{34}\ cm^{-2}s^{-1}$, $L_{int} \sim 500\ fb^{-1}$
  - **From LS3 until end of Run 4:** $L \gtrsim 5\times10^{34}\ cm^{-2}s^{-1}$ and $L_{int} \sim 1500\ fb^{-1}$

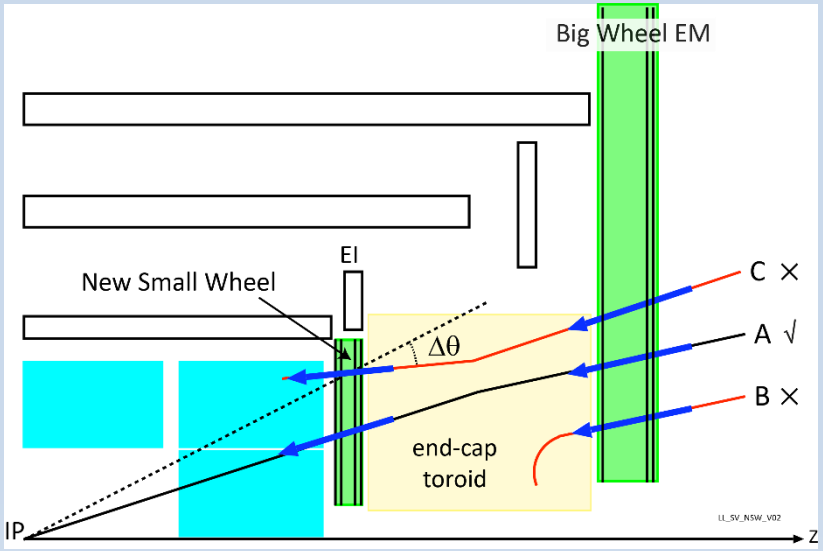


- The experiments will have to undergo upgrades in order to handle the significant increase in event-rate and keep high efficiency.
- The largest detector upgrade for ATLAS during the Long Shutdown 2 was the replacement of the innermost muon endcaps:

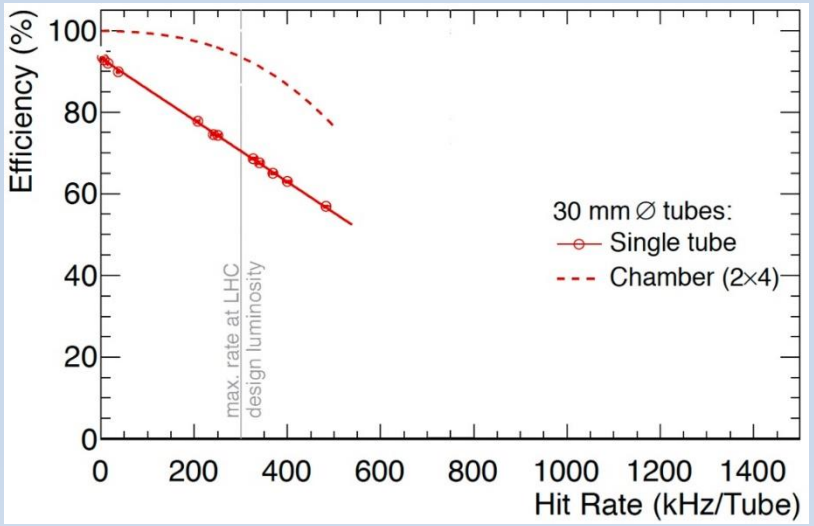
Small Wheels → **New Small Wheels**

The New Small Wheel Upgrade

- **“Old” Small Wheels** employed Monitored Drift Tubes (**MDT**), Cathode Strip Chambers (**CSC**) and Thin-Gap Chambers (**TGC**).
- Significant degradation expected at high luminosity:
  - **MDT efficiency drops significantly** (down to ~70%) at the **expected rate** for an instantaneous luminosity of $1x10^{34}cm^{-2}s^{-1}$
  - **More than 80%** of Level–1 muon trigger rate are **fake triggers** not re-constructible offline (cavern background).



Schematic of ATLAS muon trigger. Existing trigger accepts all three tracks. The fake tracks (B and C) can be rejected in the trigger by the addition of the New Small Wheel.



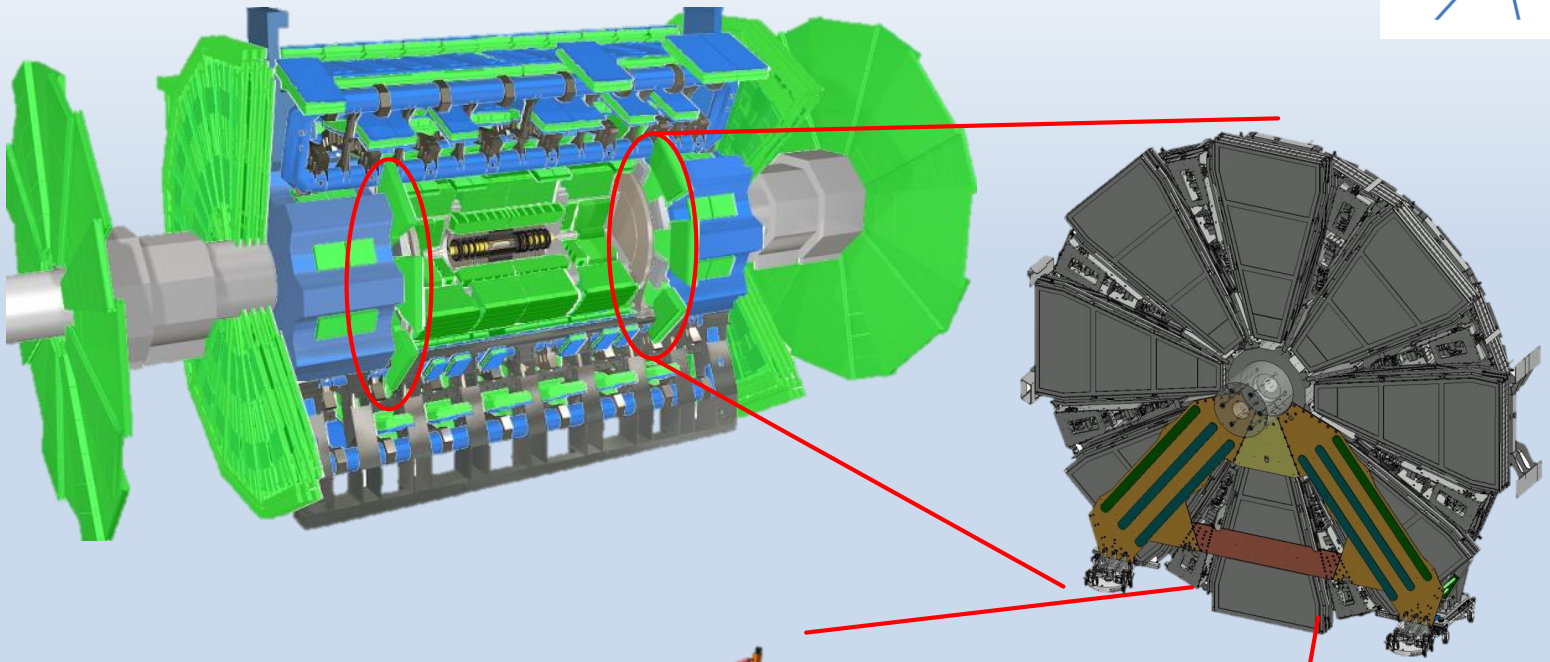
MDT single tube and chamber efficiency vs rate

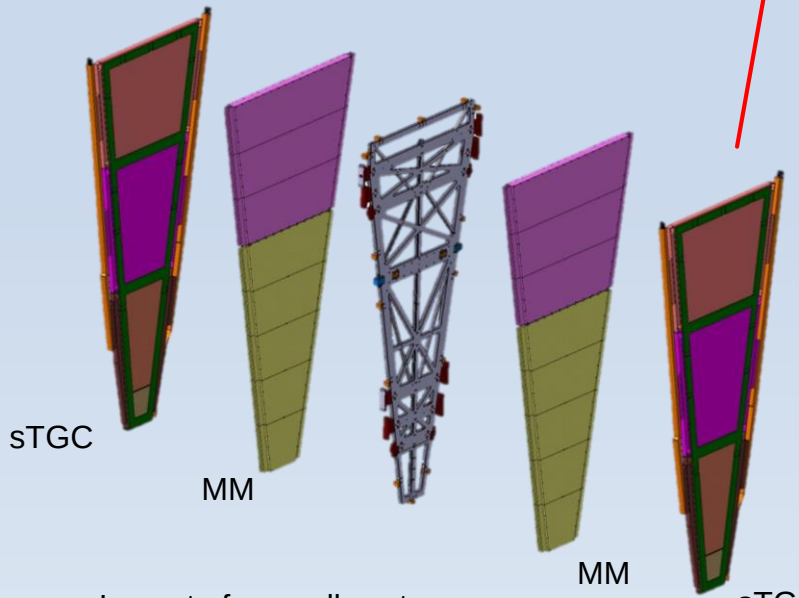
Mandatory to improve the tracking and triggering performance of the muon detectors to match the requirements of the future High Luminosity LHC

The New Small Wheel Upgrade

Composed of:

- 2 Innermost Muon end-cap Stations
- 16 sectors (8 small, 8 large) each.
- 16 detector planes in two multilayers.
- Each multilayer: four **small-strip TGC (sTGC)** and four **Micromegas (MM)** detector planes.
- Precision tracking and trigger detectors able to work at high rates.





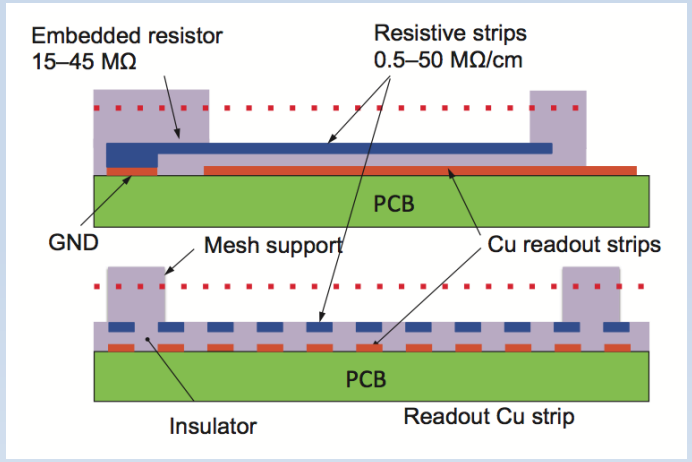
Layout of a small sector

Novel Electronics:

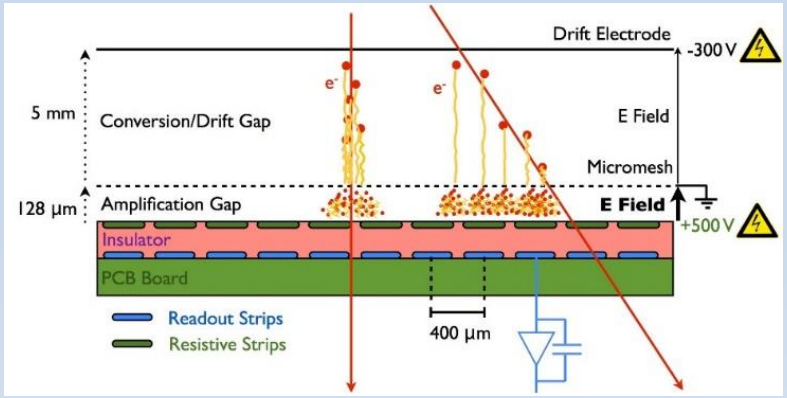
- NSW consists of 2.4M analog channels. ATLAS Muon spectrometer 1.2M.
- Custom rad-hard ASICs were designed and produced for NSW:
  - –VMM3a (frontend ASIC)
  - –Read Out Controller (ROC)
  - –Trigger Data Serializer (TDS)
  - –Address Real Time (ART)

The resistive-strip Micromegas

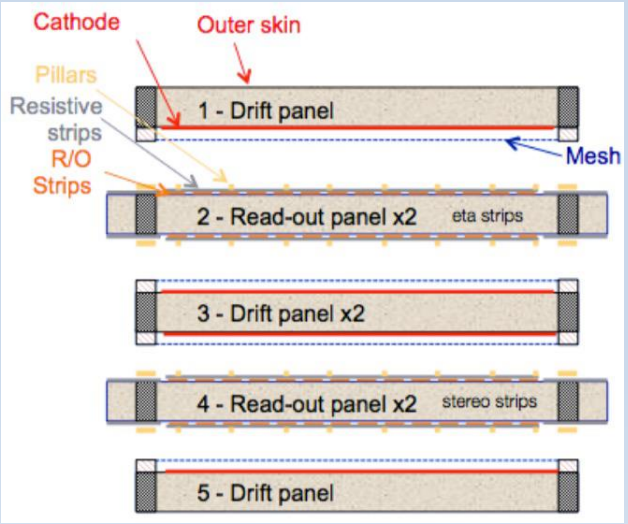
- Significant dedicated R&D to address the shortcomings of standard Micromegas (high spark rate and HV voltage breakdown)
- Resistive strips scheme:
  - Strips with ρ ≳ a few MΩ/cm on top of readout strips, with a 50μm kapton layer in between.
  - Signal induced by capacitive coupling on RO strips.
  - Resistive strips instead of a resistive layer to limit the spread of charge to neighboring strips.
  - Stacked in four layers per detector (spatial resolution <100μm)
- Efficient protection of sparks also in very harsh environment.



Cross sections of a MM layer



Electrical diagram of a MM layer

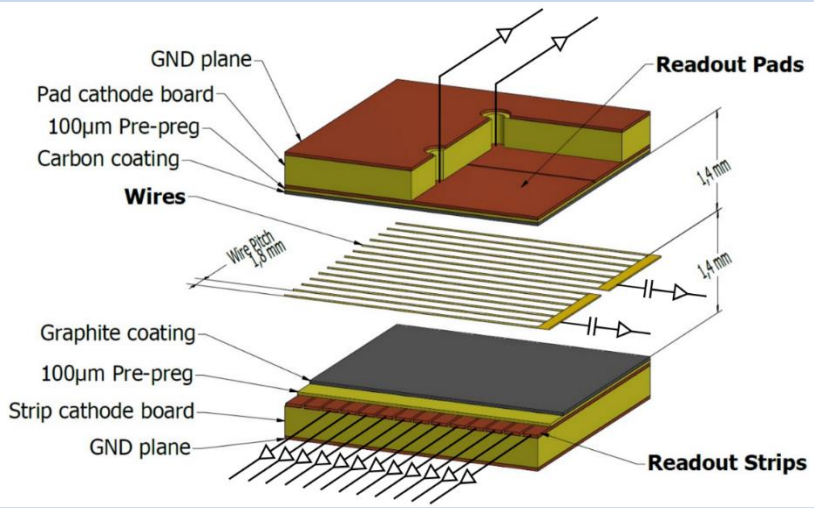


Stacking of four MM layers

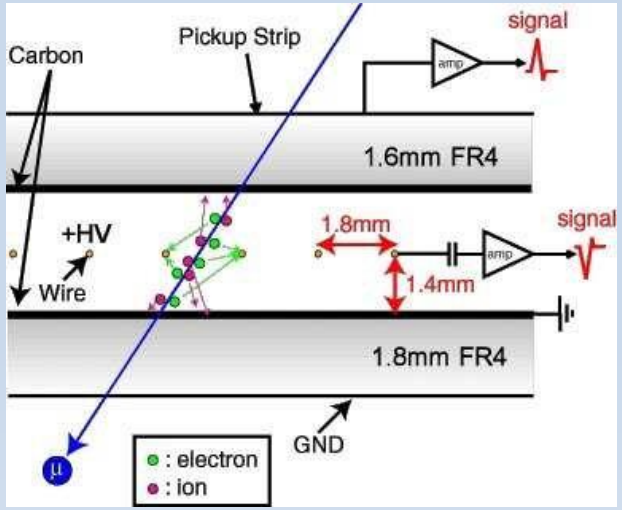
- Produced in 5 countries in 4 different flavor for Small Sectors and for Large Sectors.

The small-strip Thin Gap Chambers

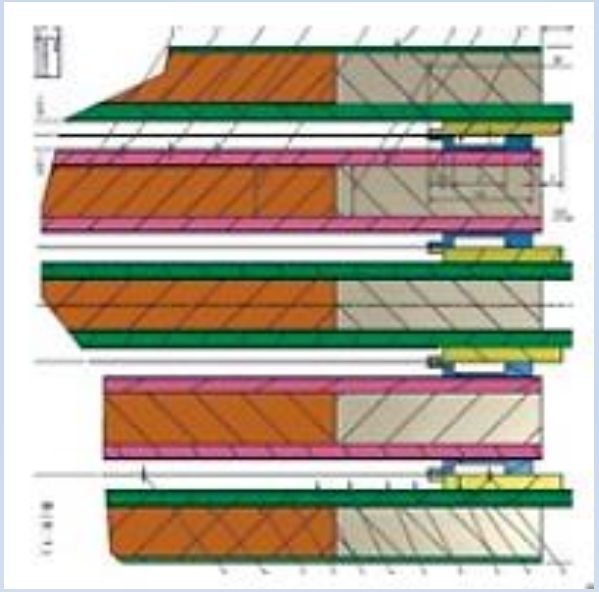
- Inheriting from well established and successful TGC detector technology.
  - Good timing characteristics.
  - Pad readout provides fast pre-trigger to determine the strips to be sent to the Trigger Processor.
  - Precision strips for muon track reconstruction at level of ~100μm at high event rates.
  - Stacked in four active layers per detector.



Section of a sTGC layer with relevant components



Electrical diagram of an sTGC layer



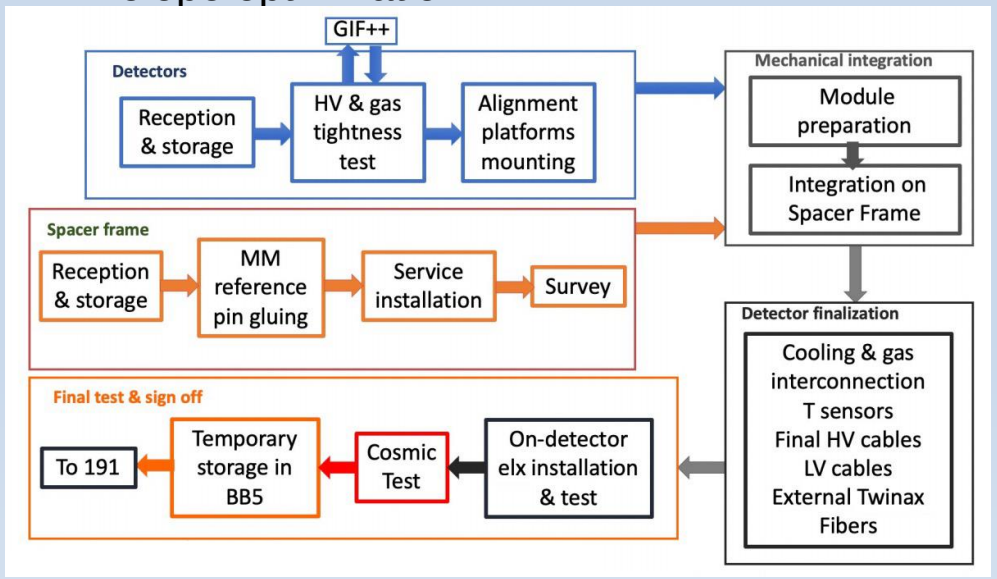
Stacking of four sTGC layers

- Produced in 5 countries in 6 different flavors for Small Sectors and for Large Sectors.

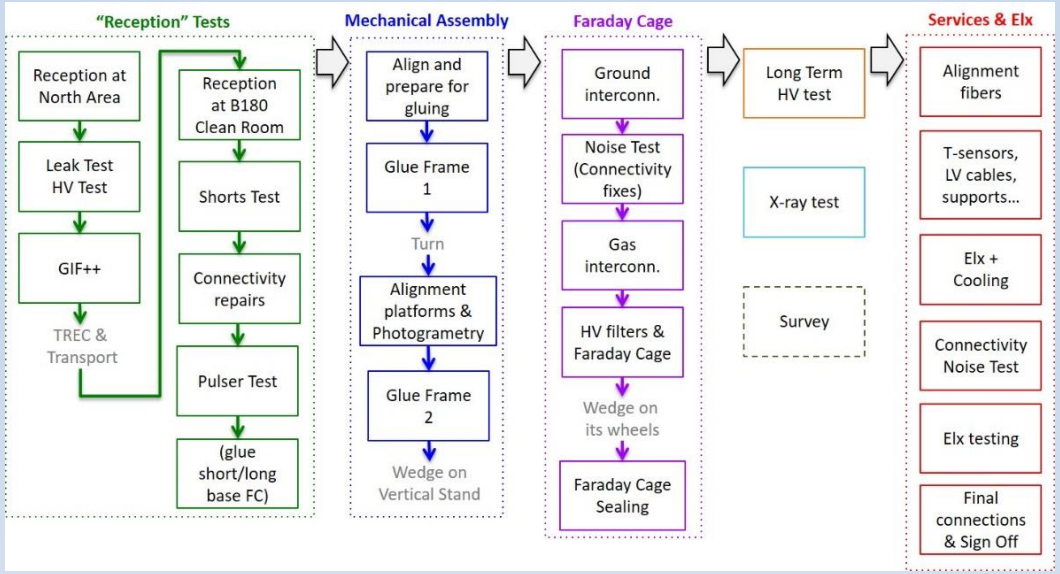
Detector Integration at CERN

- MMs and sTGCs detectors were then sent to CERN for integration into wedges.
- Workflows and testing procedures showed several chambers needed fixes when arriving from Construction Sites.
  - Gas tightness (higher than specified leak rates…)
  - HV problems (large leak currents, discharges..) → conditioning, fixes
  - Electrical grounding (different implementation from construction sites…) → reduce noise
  - Envelope optimization.

For MM, if chambers did not fulfill the specs: reopening, repairing and testing again → hospital facility



MM integration workflow at CERN

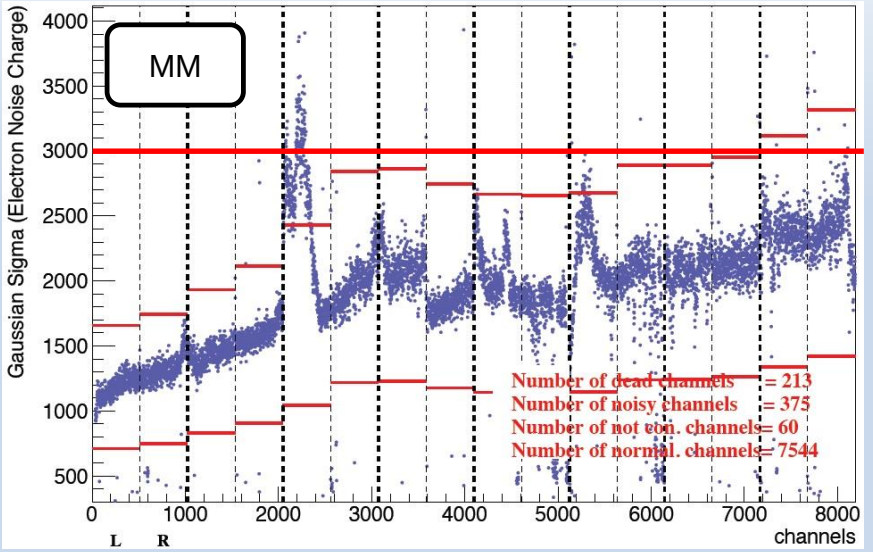


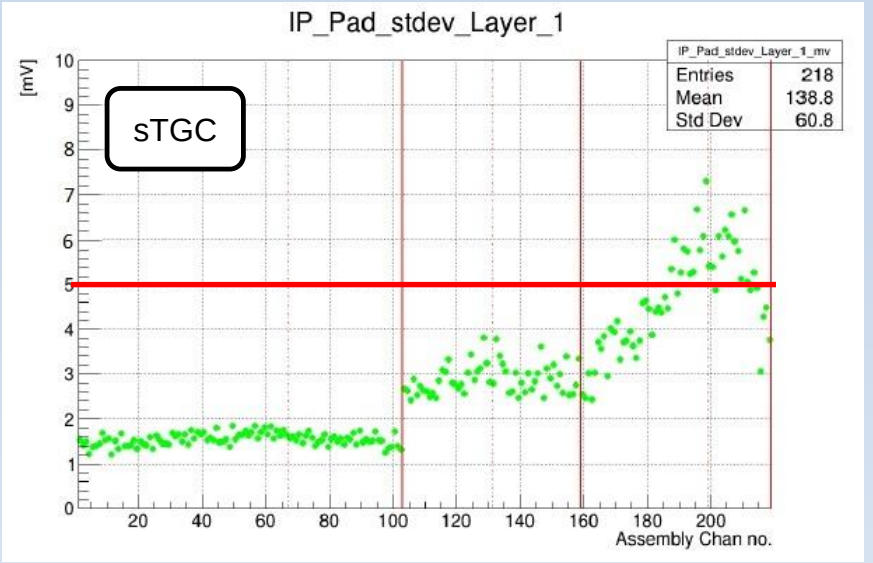
sTGC integration workflow at CERN

- **In total**: **70 sTGC** wedges integrated (few spare wedges), **64 MM** wedges integrated (no spares).

Surface commissioning

- Very high noise was observed on MM and large sectors of sTGC after installation.
- **MM:** traced to implementation of FEASTs on ADDC cards.
  - Coupling between ADDC cards and detector structure.
- **sTGC:** implementation of grounding on adapter boards varied from CS
  - Large susceptibility to any electronic noise source.
- **Noise task force established to address issue.**
- Several important recommendations:





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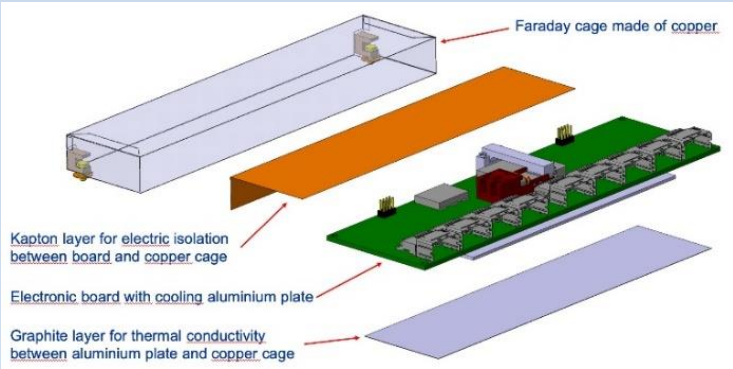
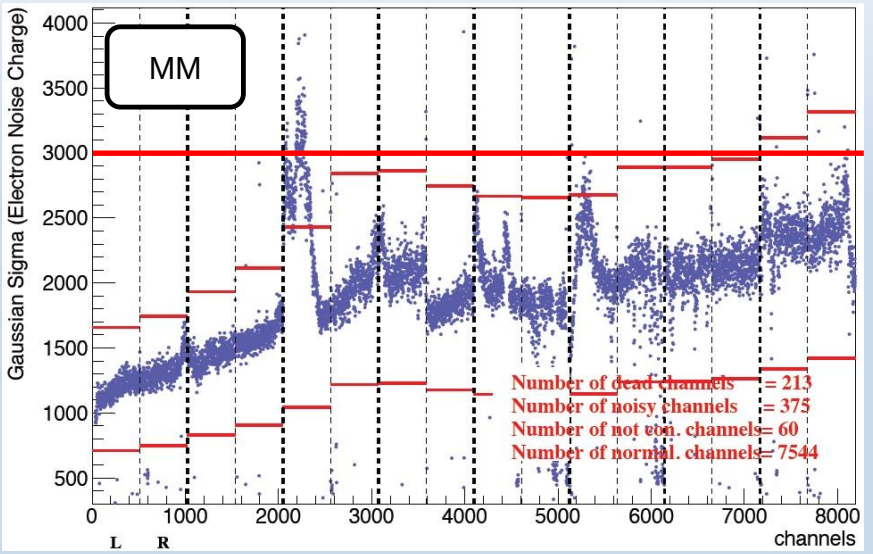
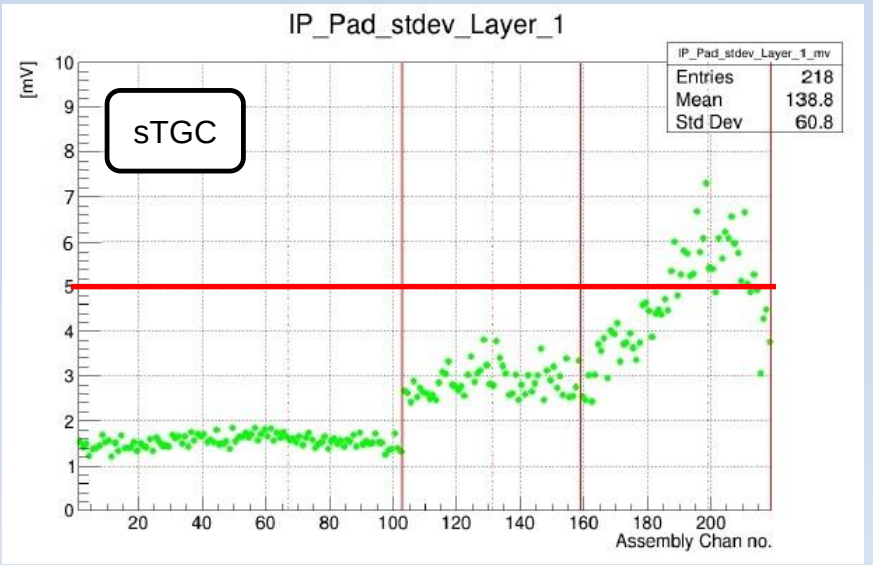
Faraday cage on ADDC cards







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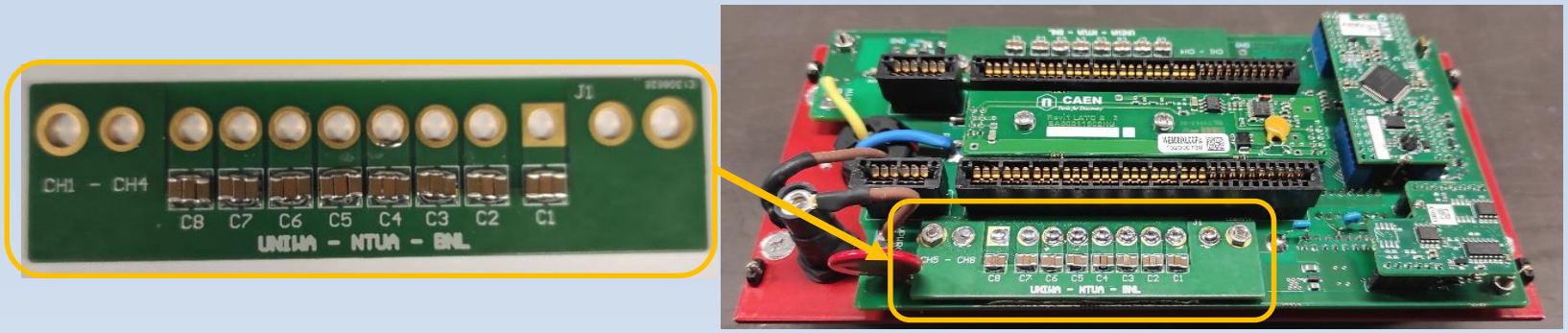
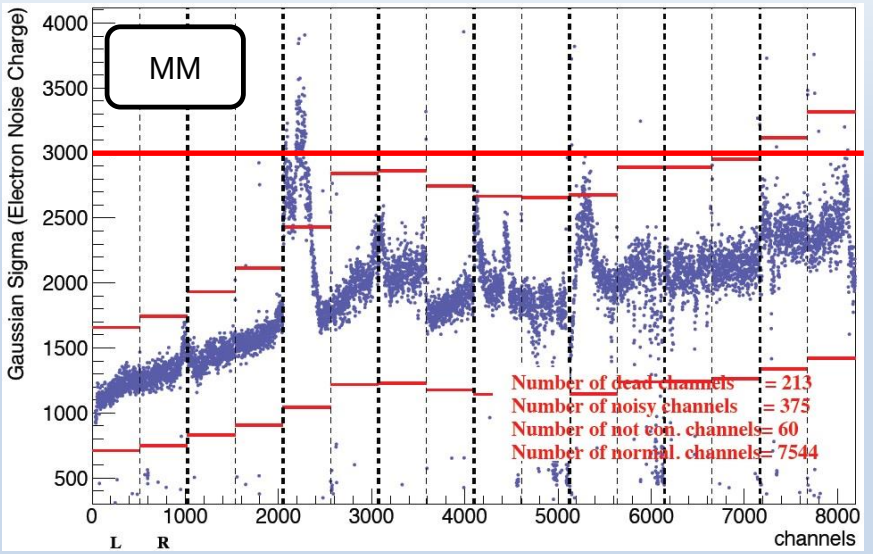
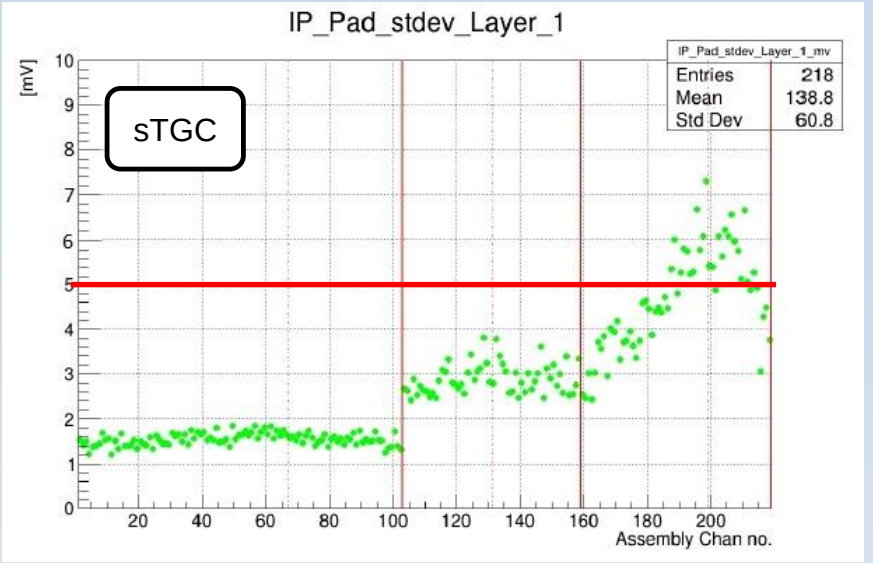
Added filtering to ICS outputs







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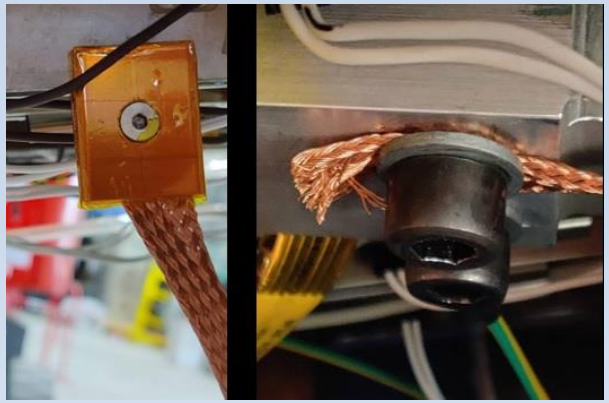
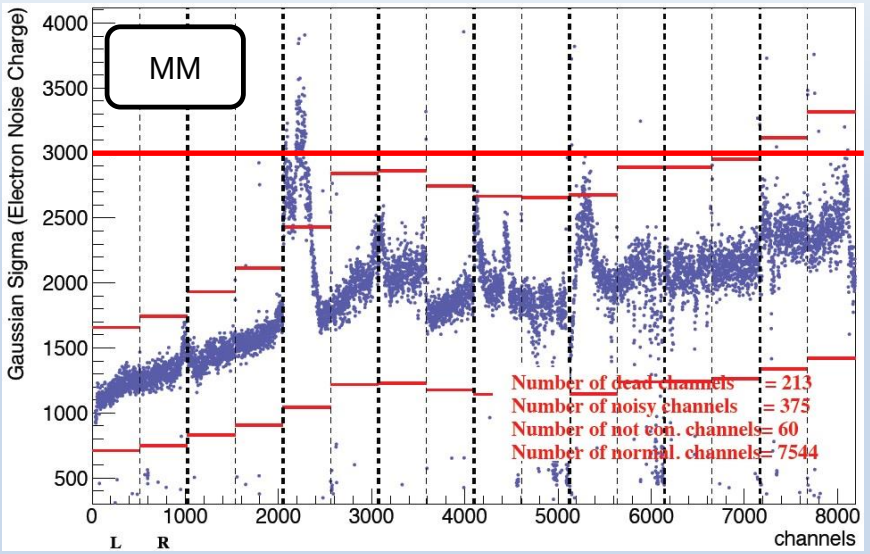
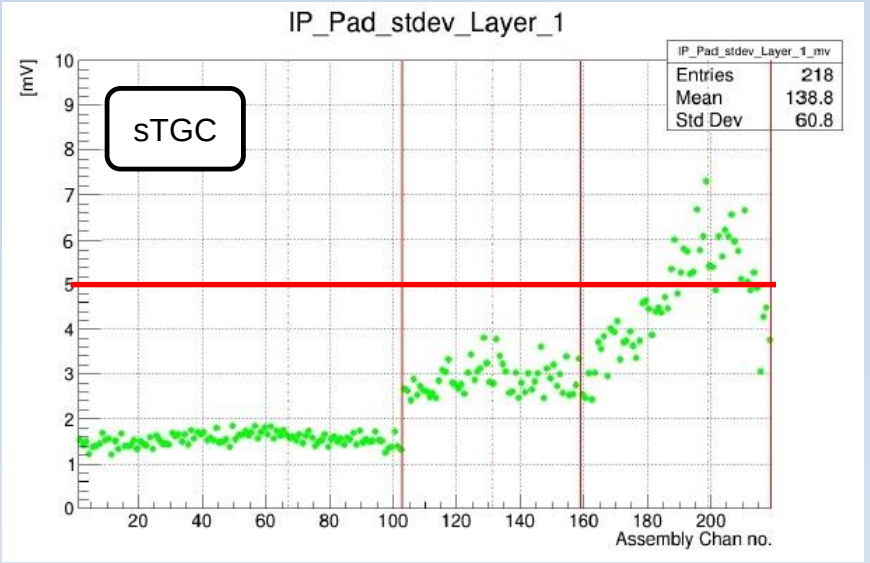
- Several important recommendations:

MM grounding braids to spacer frame







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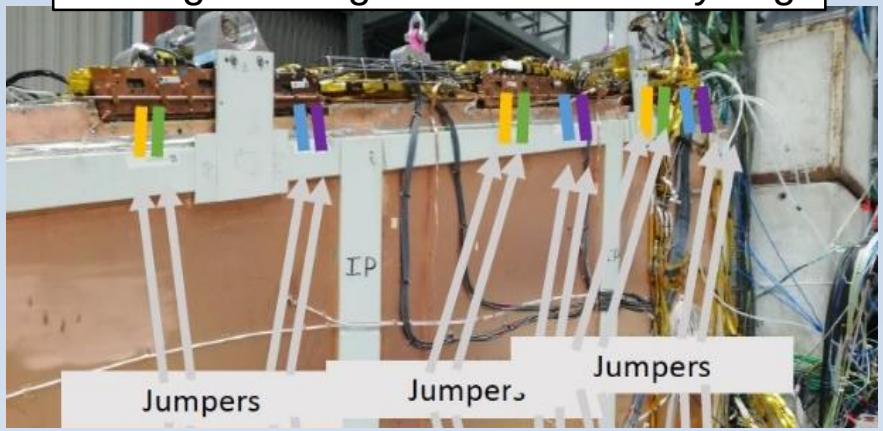
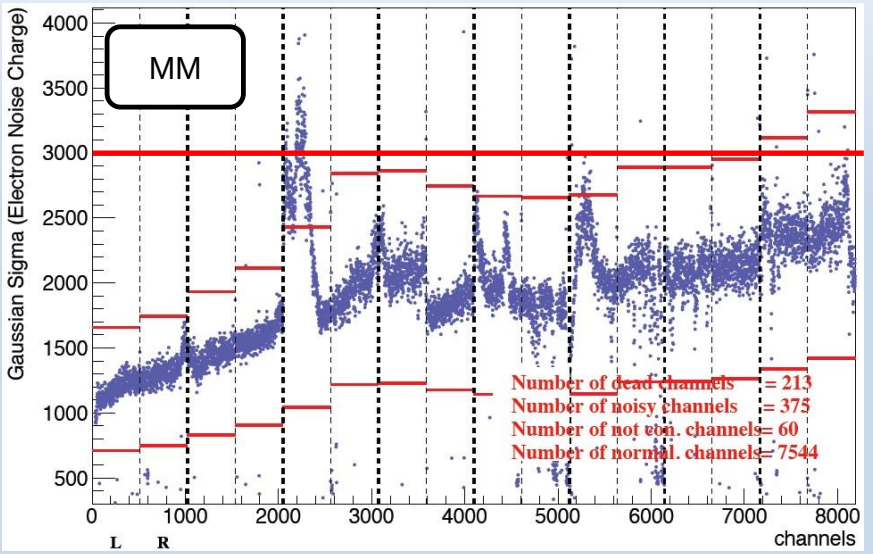
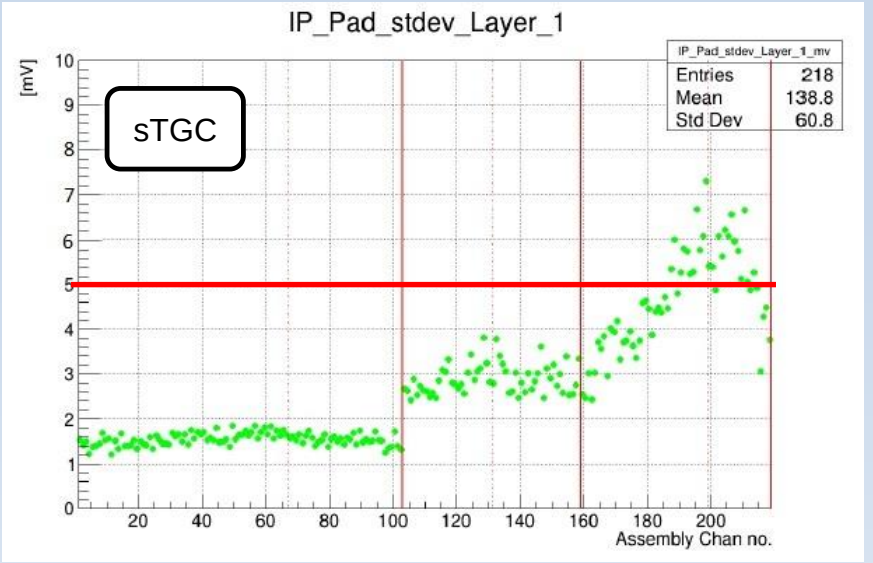
- Several important recommendations:

sTGC grounding braids to Faraday cage







Surface commissioning

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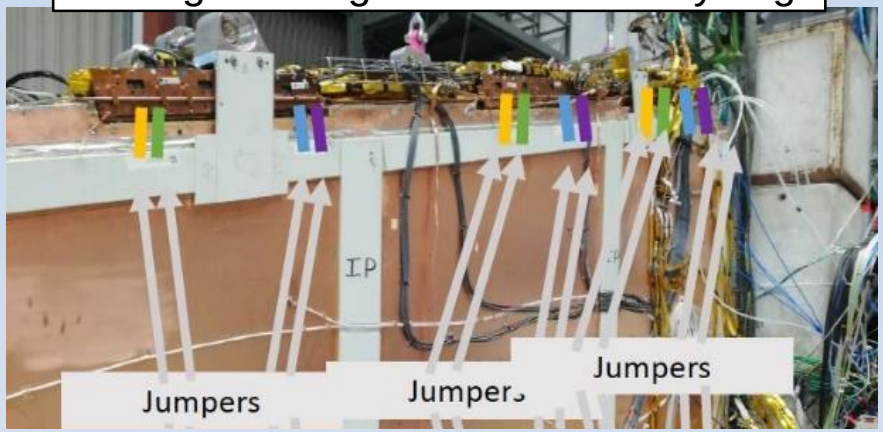
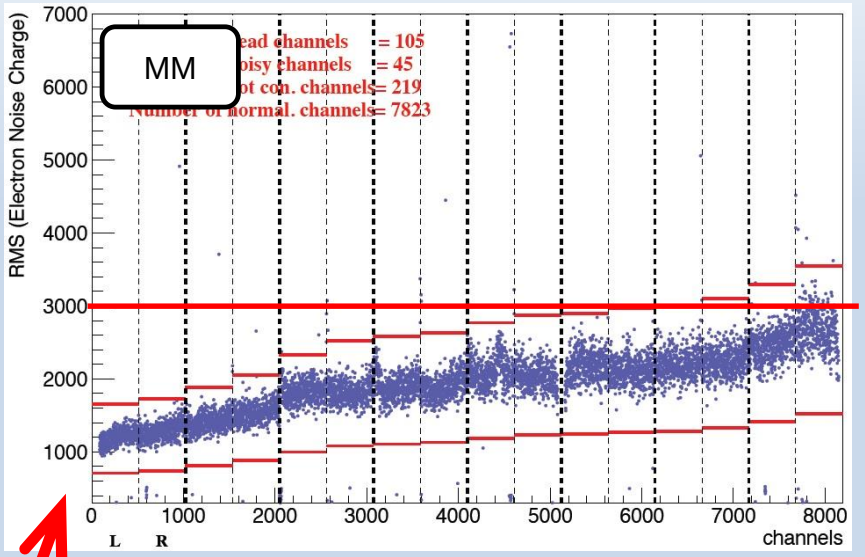
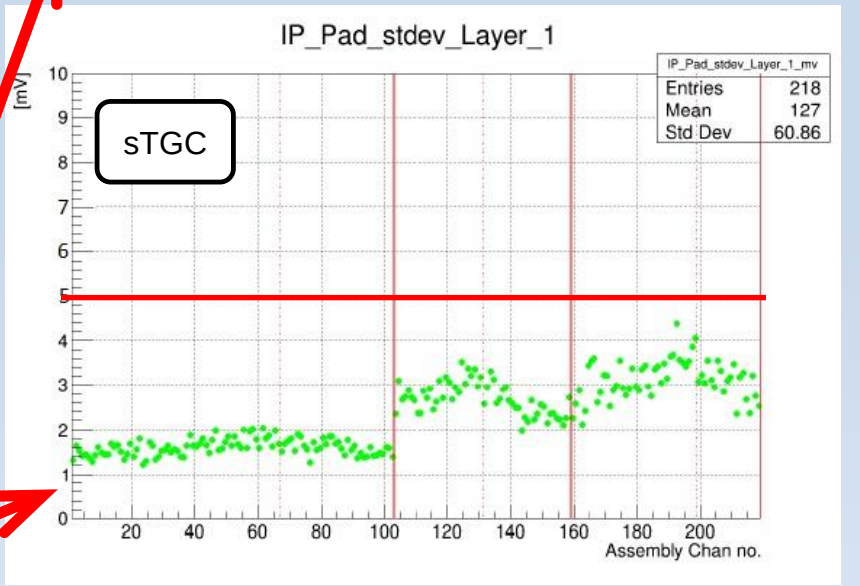


- Decision was taken to refurbish all sectors and all ICS modules.





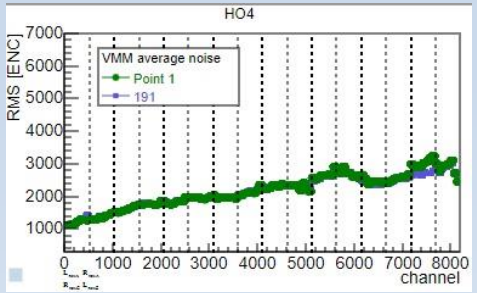
Successful intervention significantly reduced noise to operating levels

ATLAS cavern – MM

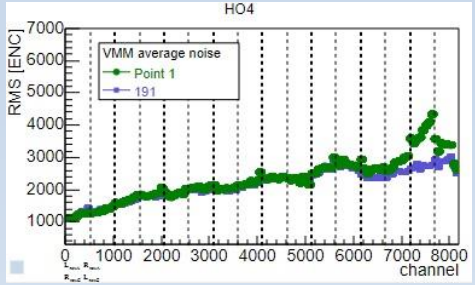
- **NSW-A** installed mid-July, 2021; **NSW-C** installed early-Nov, 2021
- Both wheels with gas since their installation and HV on as much as possible.
- Connectivity checked and cooling tuned for both wheels.
- Baselines and calibrations taken on sectors continuously and simultaneously for many sectors and continuously to monitoring.

LV/ELX

- **NSW-A:**
  - 4 LVBDs not working.
  - Some sectors see slight noise increased after movement to run position.
  - Investigation ongoing.

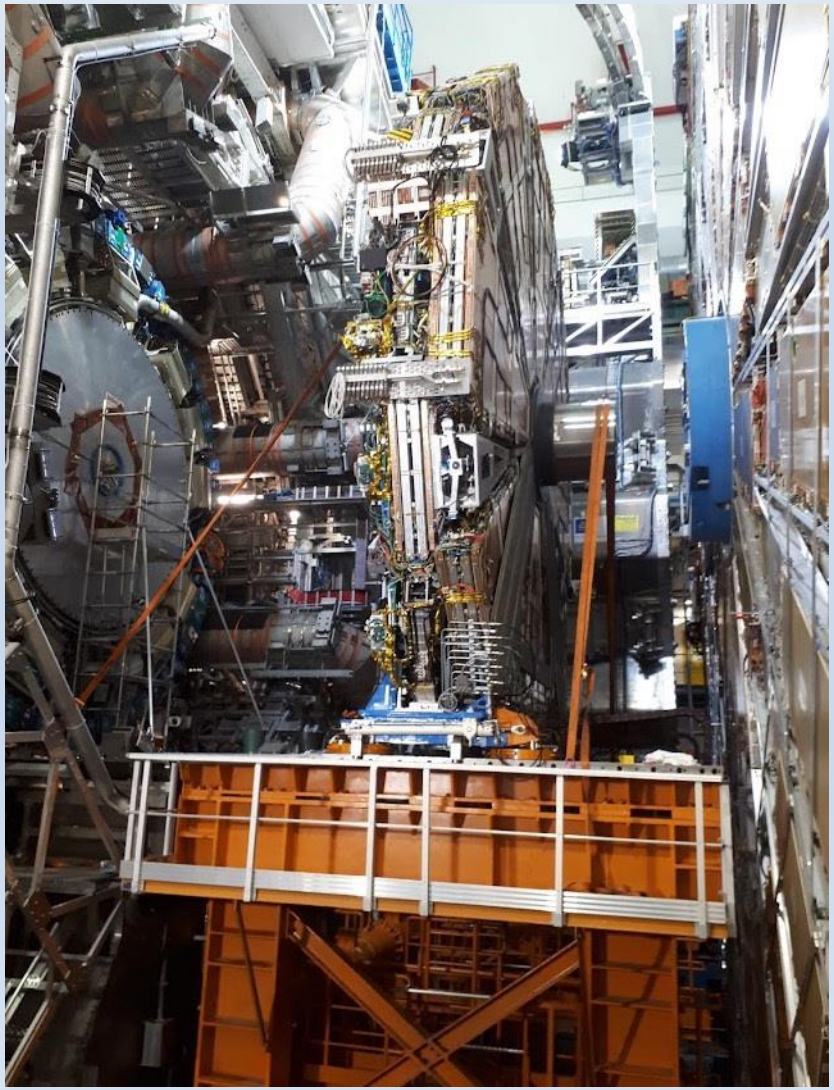


A05 pre-movement



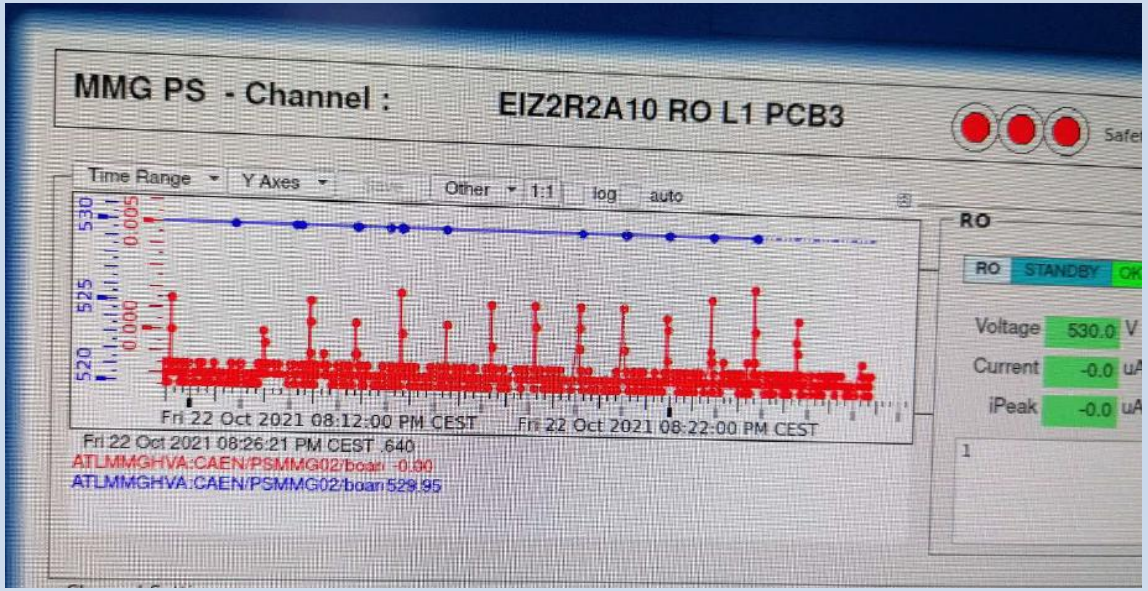
A05 after movement

- **NSW-C:**
  - All LVDBs working.
  - No increase of noise observed after movement to run position.

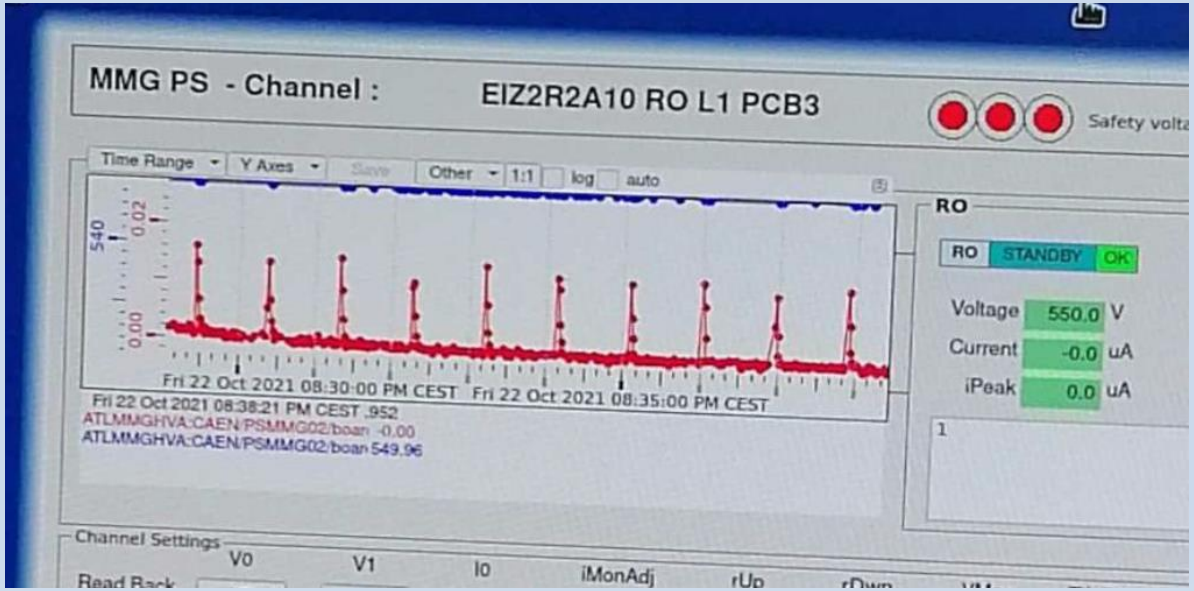


ATLAS cavern – MM

- Began ramping up voltage early-October on all the chambers to 550V (nominal: Ar:CO_2 93:7 - 570 V <–> Gain~6500).
- Lowered all chambers to 530V in preparation for pilot beam.
- First beam splashes on MM of NSW-A on 22nd Oct @530V.



A10 SM2 – IP L1 PCB3 @530V
Train of splashes peaks at ~5nA



Ramped to 550V
Train of splashes peaks at ~20nA

ATLAS cavern – MM

- However, overall HV picture remained as observed during surface commissioning.
- Status during surface commissioning in Ar:CO_2 HV_{op}>550V (very similar to situation in P1):

ATLAS cavern – MM

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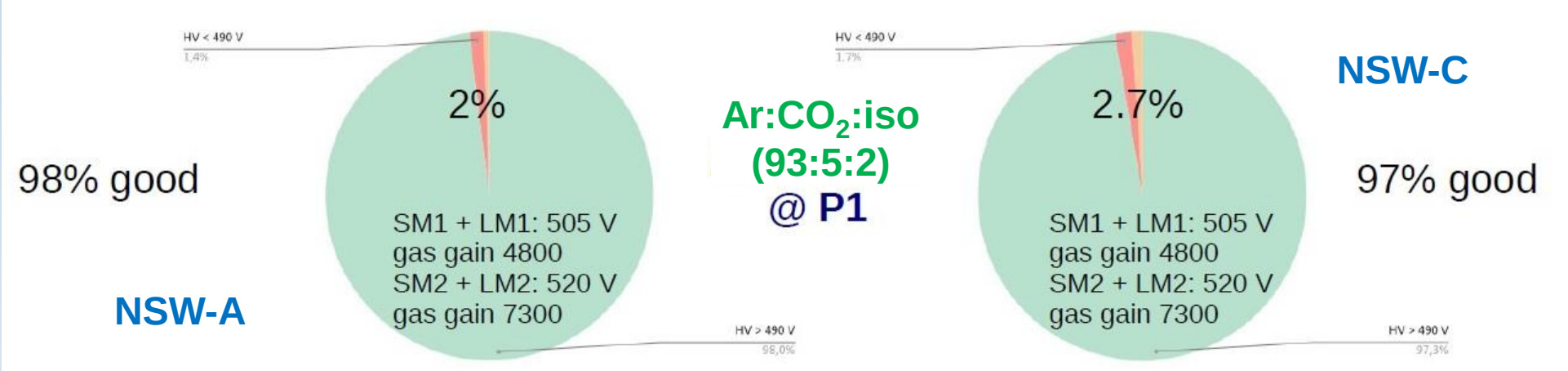
- Status during surface commissioning in Ar:CO_2 HV_{op}>550V (very similar to situation in P1):

- Switching to admixture of 2% of isobutane (Ar:CO_2:iC_4H_{10}):



ATLAS cavern – MM

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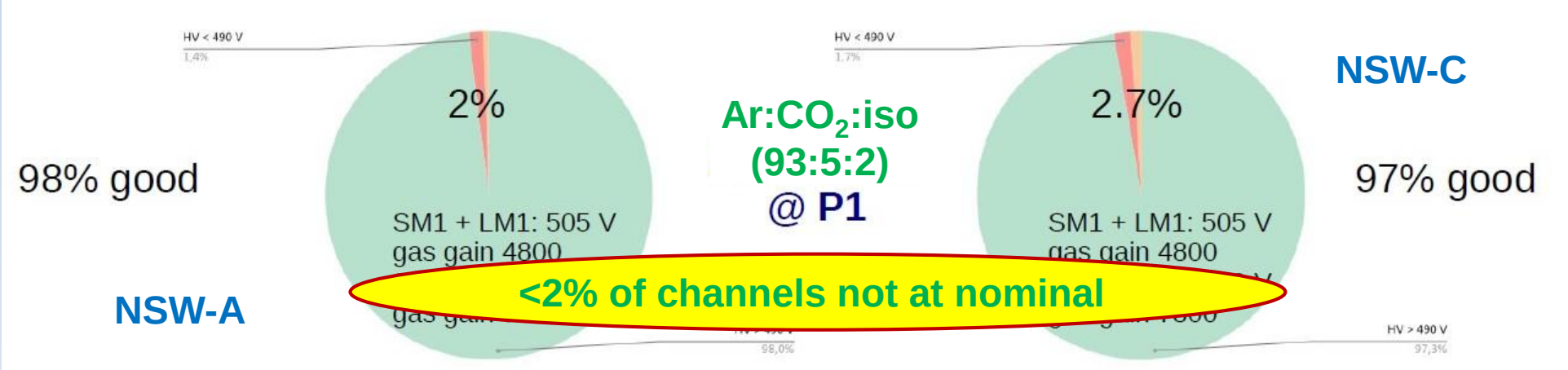


Alternative NSW gas mixture – MM

- Not all HV sectors of the NSW MM quadruplets are capable to run at 570V (nominal working point) in Ar:CO_2 (93:7):
  - Sudden discharges and fatal degradation of sectors had been observed (experimental setups and in production quadruplets)
  - Quadruplets operating under nominal conditions in Ar:CO_2 are at the limit.

- Proposal to switch to an Ar:CO_2:iC_4H_{10} (93:5:2) gas mixture:
  - Re-enables the safe operation of otherwise faulty sectors.
  - Lower amplification voltages to reach better performance.
  - Need to evaluate aging issues with isobutane admixture.

- Intense aging test campaigns ongoing with the new gas since long.

  No indication of aging observed so far (~10y HL-LHC equivalent has been reached in GIF++ on spare MM modules).

- Final review on gas choice for Run 3 took place on 2nd of February. Review outcome received:

The panel recommends to start Run 3 with Ar-CO2-iC4H10 93-5-2.

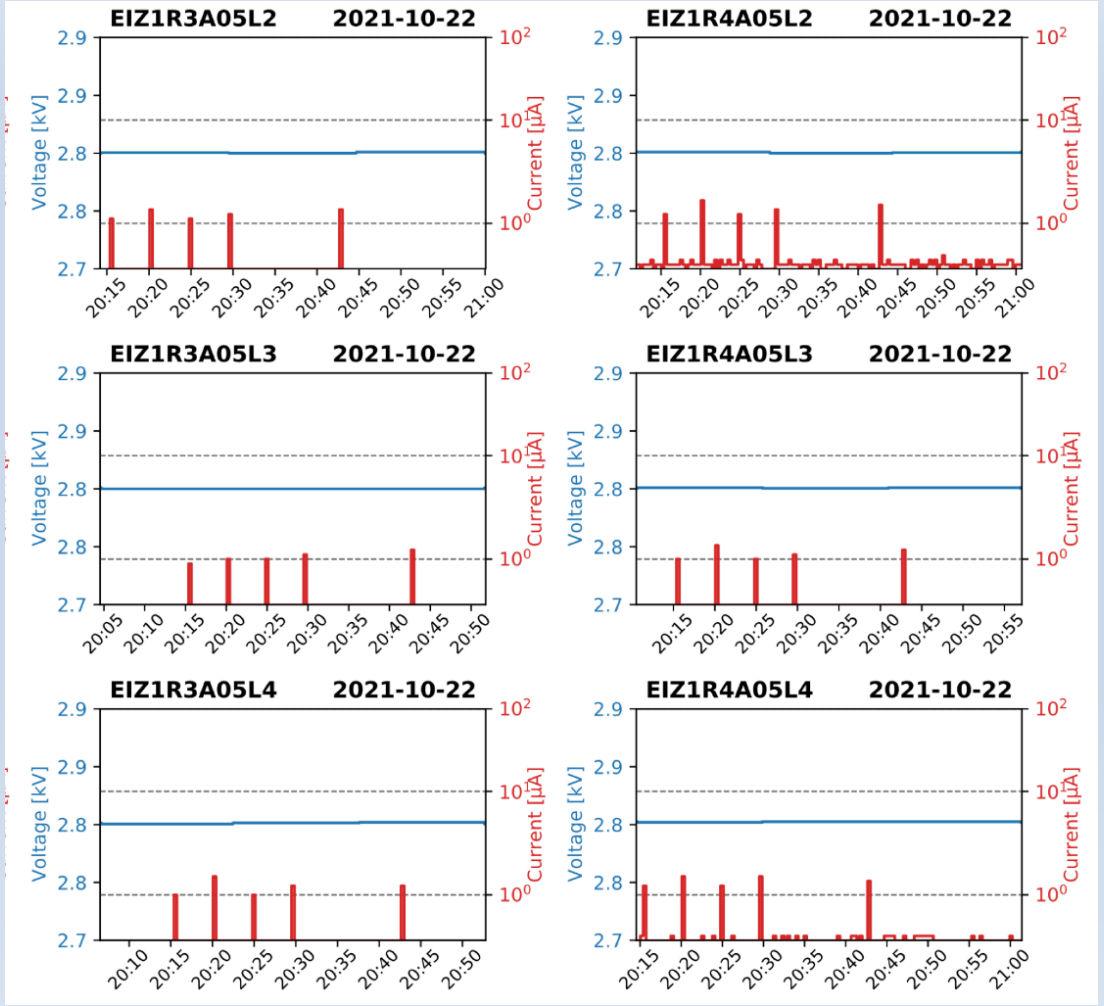
The ATLAS MM team has gained an incredible amount of knowledge, analysis and reaction capacity. The MM detector is in good hands.

ATLAS cavern – sTGC

- Working gas mixture (CO_2/n-pentane) running in chambers since end of Oct.
- First splashes on sTGC on the 22nd Oct @2.8kV.

- Peaks of current of a few μA registered on current plots.
- Current approximately the same and in time across layers!

- Recent monitoring and archiving issue of HV data overcome:
  - Update rate in DCS monitoring of 2s during Pilot beam
  - Prevented debugging and recording I/V for some layers.
  - Added one more branch controller per side.



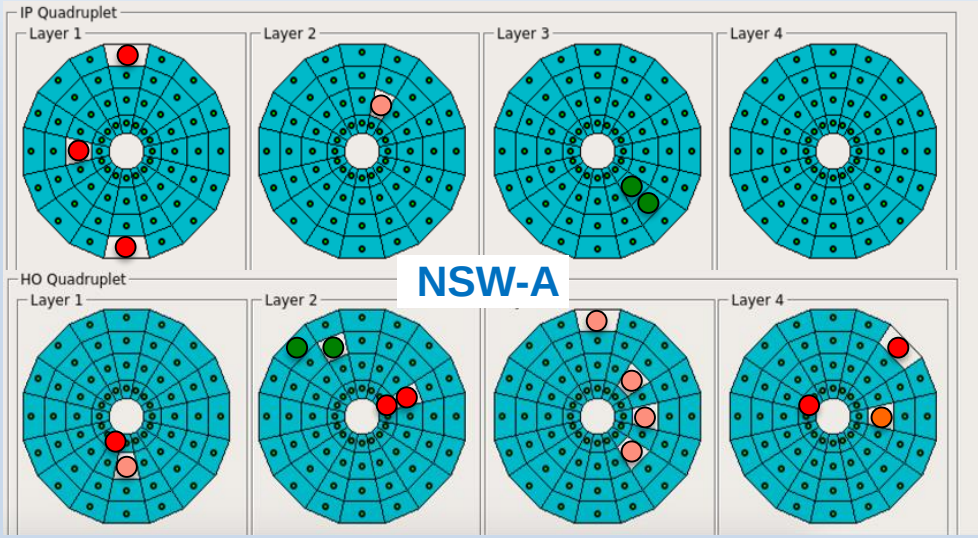
ATLAS cavern – sTGC

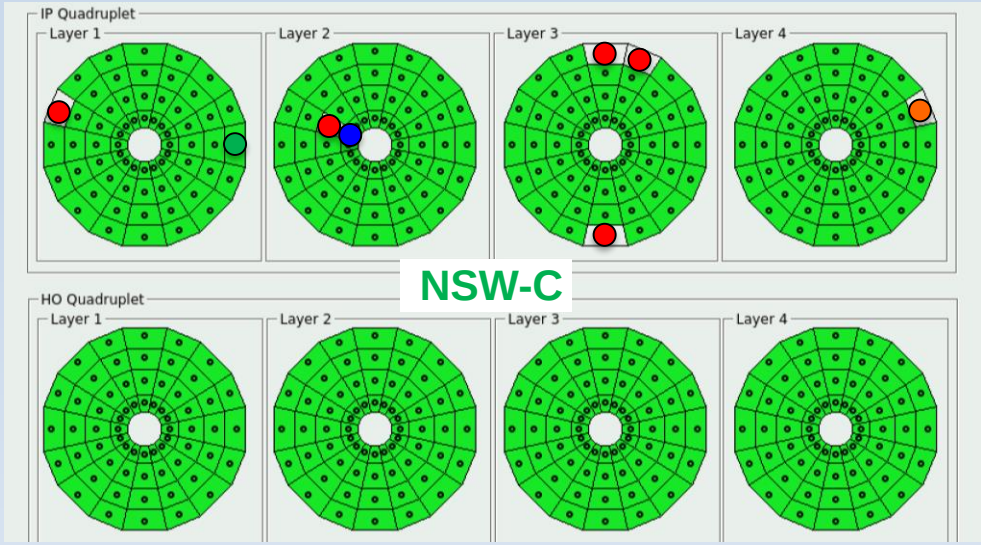
High Voltage

- **NSW-A:**
  - 4 quad layers recovered.
  - 8 quad layers not usable (6.2% of total)
- **NSW-C:**
  - 1 quad layer recovered.
  - 6 quad layers not usable (4.7% of total)

LV/DAQ

- 1 FEB was recovered.
- All rim crates (part of sTGC trigger path) tested.
- Baselines and trimmers taken for all sectors → no increase in noise observed.
- Trimmer code to be reviewed to improve performance.

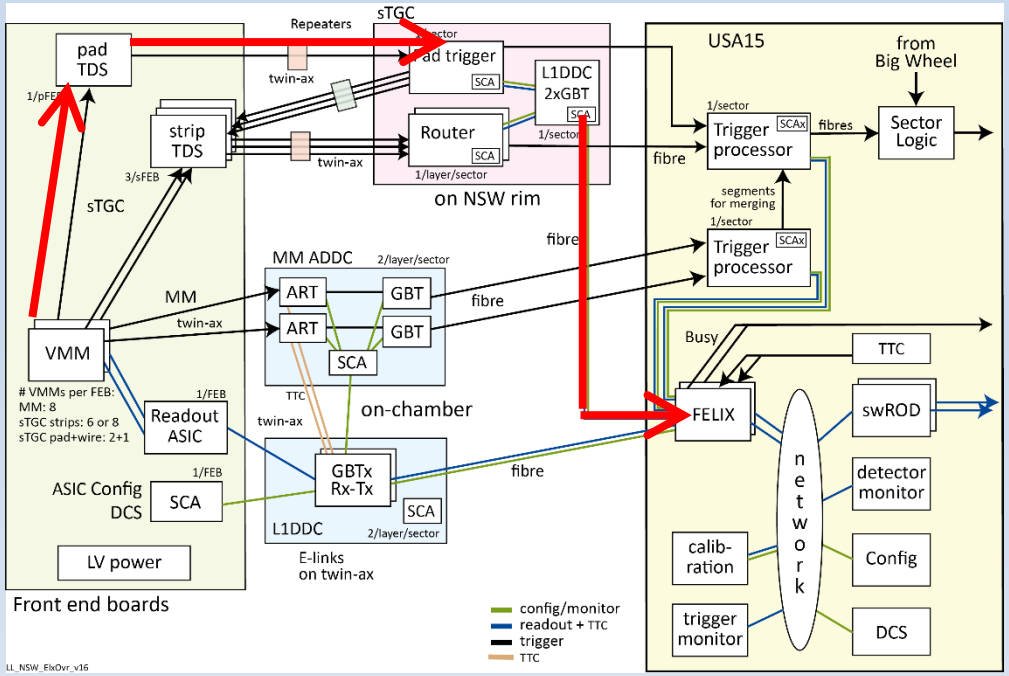


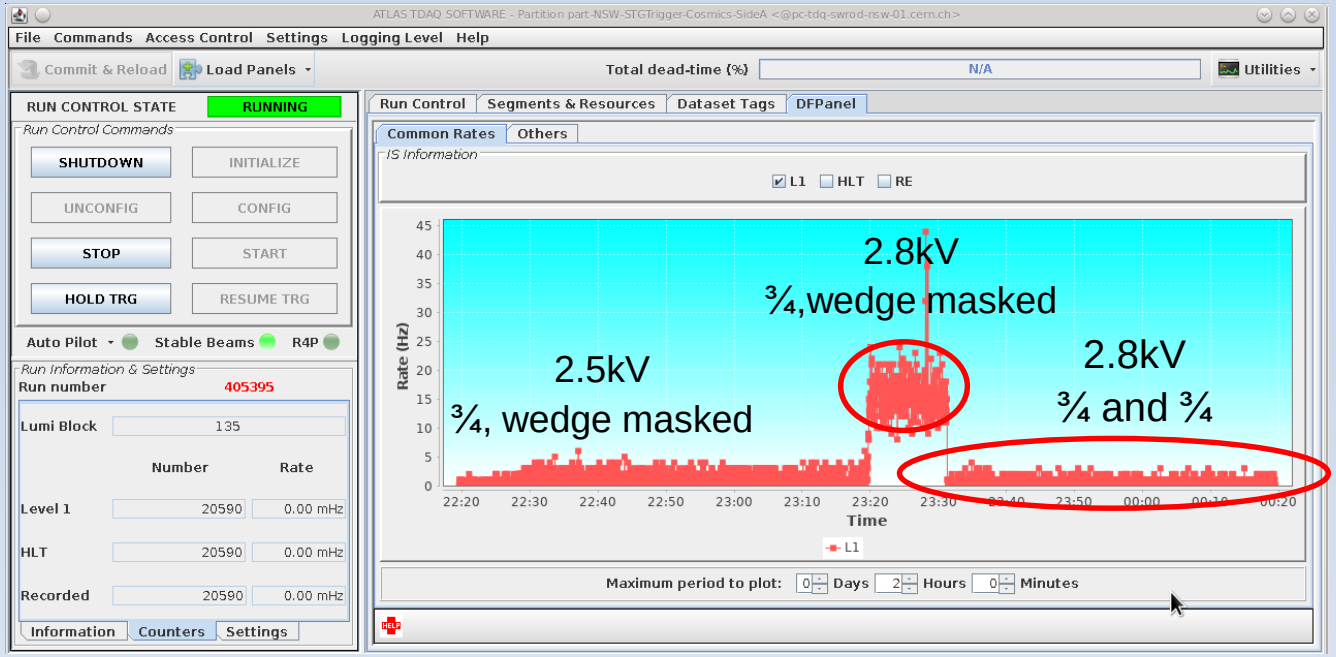


ATLAS cavern – sTGC

Test of the Pad Trigger module with real tracks.

- Significant developments on trigger logic implementation on Pad Trigger.
- Pad Trigger is a pre-trigger to determine which strips data to be sent to the Trigger Processor.
- Implemented ¾ and ¾ logic.
- Readout Pad Trigger module in self-trigger mode to check the Pad Trigger module's functionality with real tracks.
- Test showed that Pad Trigger find real tracks and not false coincidences from noise.





Sector 15 self-trigger rate

Self-trigger rate of 2 to 3 Hz !!!

ATLAS cavern – DAQ and DCS

- Significant effort from DAQ experts to have NSW part of ATLAS partition during pilot beam.
- Encountered stability problems with FELIX system (FELIXcore not maintained by TDAQ).
- Implemented “watchdog” to detect when links becomes invisible and reconfigures it.
- Moving to a more stable system (migrating to improved FELIXstar).

Hardware

- All FELIX, SBCs, ALTIs and ROD BUSY installed, connected. 2 PCs replaced since Dec.

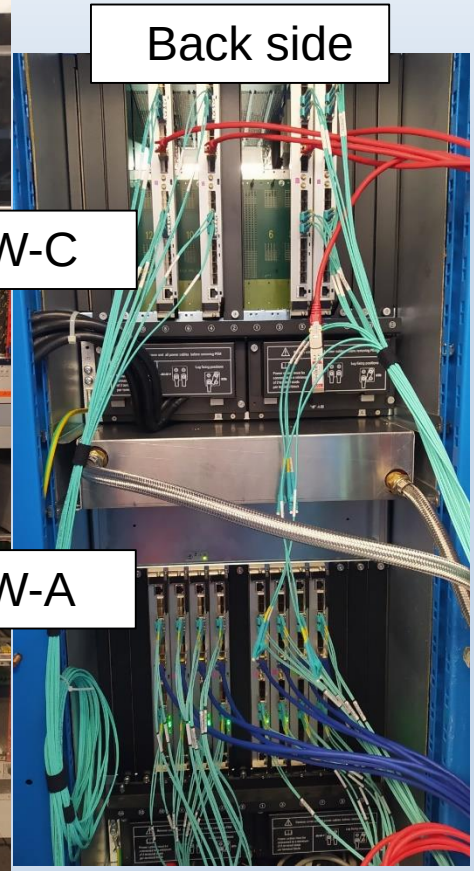
- **NSW DCS architecture and it’s integration with the Muon DCS** → finalized**.**
  - Important and continuous feedback from experts and users for optimization of alarms, panels, scripts, features, bugs, etc.
- Various DCS projects currently under review with Central DCS.
  - No show stoppers have been identified.
- **DCS for Trigger Processor:**
  - ATCA panels and tools for monitoring and logging have been developed.
  - Thresholds of sensors on carriers/mezzanines being defined and set.

Trigger Processor Status

Hardware milestones

- **NSW-A:**
  - All 8 sets installed and used for detector commissioning.
  - Optical measurements of links from detector to the TP boards performed.
- **NSW-C:**
  - 4 out of 8 sets installed in USA15 and used for detector commissioning.
  - Successfully checked cabling, link quality and stability of inputs
  - 4 sets require follow-up.

Fibers from detectors & to sector logic



Fibers to/from FELIX

Trigger Processor Status

Hardware milestones

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  - All 8 sets installed and used for detector commissioning.
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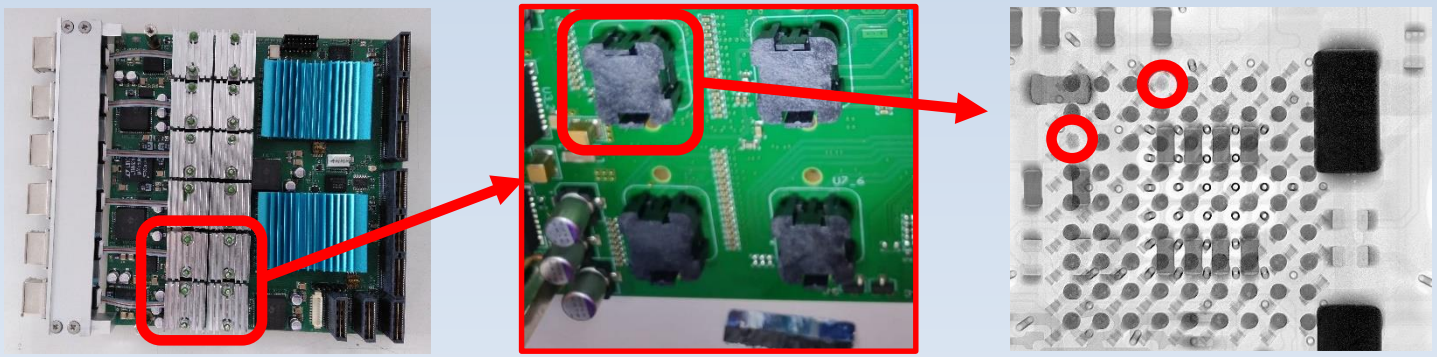
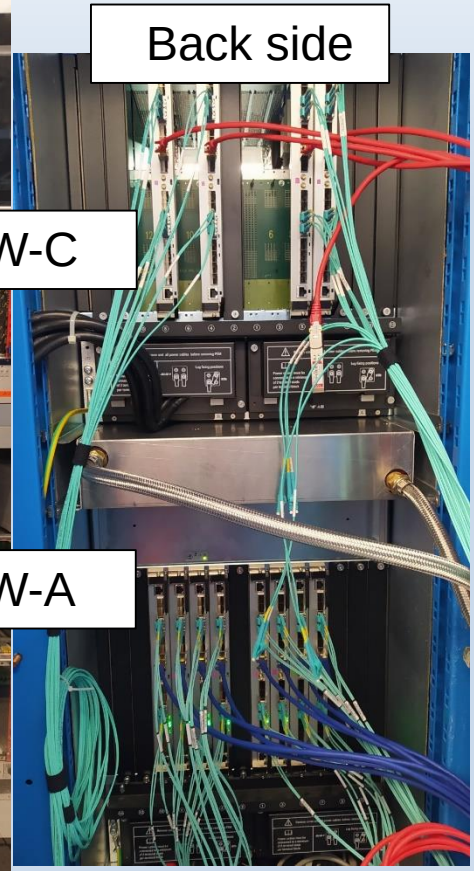
  - 4 out of 8 sets installed in USA15 and used for detector commissioning.
  - Successfully checked cabling, link quality and stability of inputs
  - 4 sets require follow-up

- Quality issues on MicroPOD sockets on Mezzanines cause broken links.
- Implementing fix (see extra slides).



Fibers from detectors & to sector logic



Fibers to/from FELIX

Missing balls from ball array

Summary

- NSW-A installed mid-July, 2021 → in run position since mid-Jan, 2022.

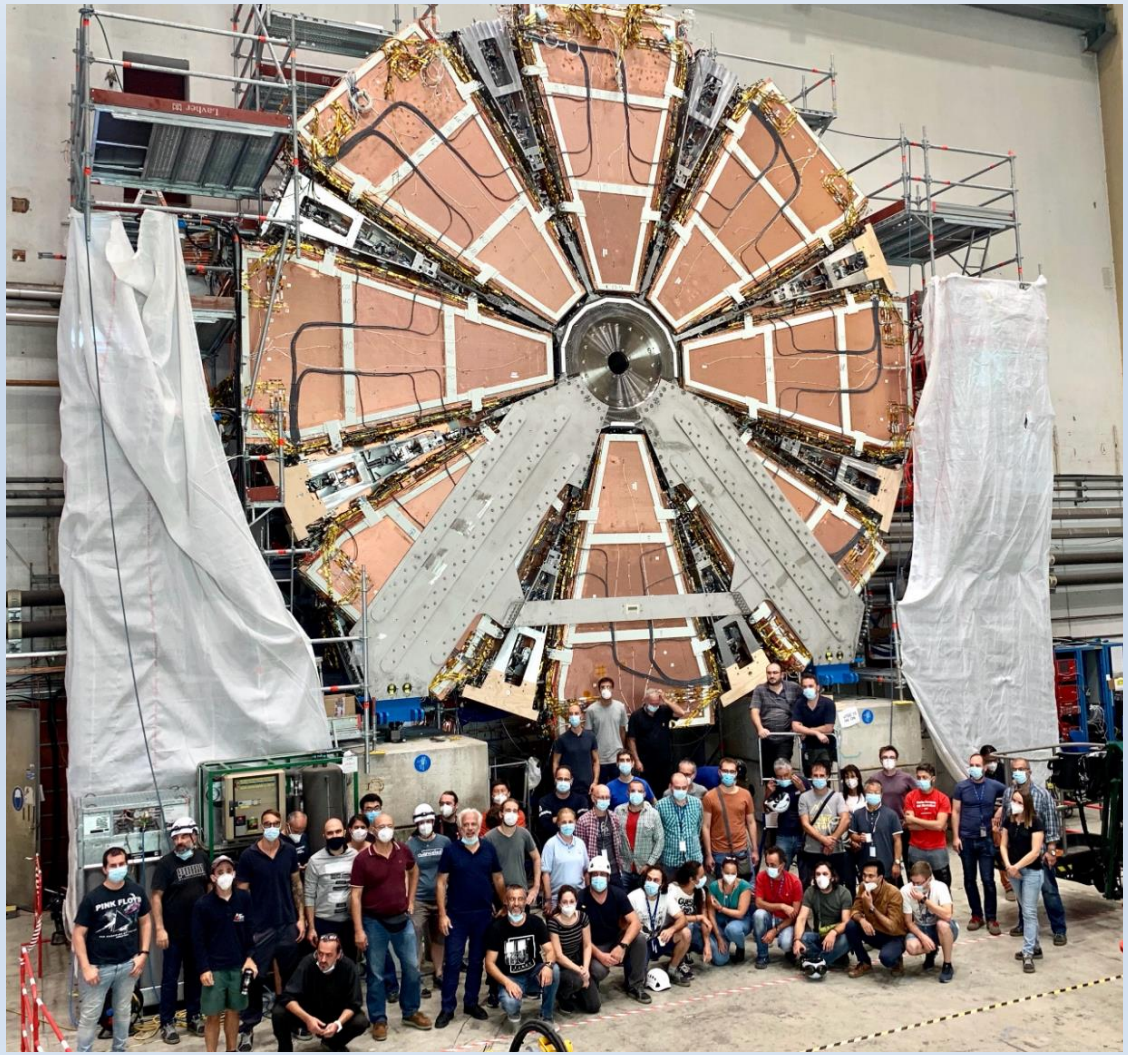
- NSW-C installed early-Nov, 2021 → in run position since end-Jan, 2022.

- System commissioning and debugging well under way.
- Expect to migrate to Felixcore at large scale

- Besides the problems described major hurdles successfully overcome but not mentioned:
  - Edge passivation of Micromegas.
  - sTGC signal repeater implementation.
  - Warped VMMs packaged by a specific company.
  - sTGC Safety Envelope leaks.
  - …

- Working hard for the first muons of 2022 and start of Run 3.

Thank you



Extra slides

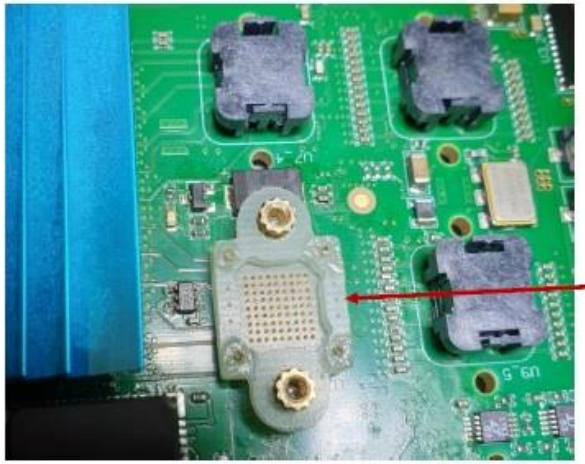
MicroPOD socket issue

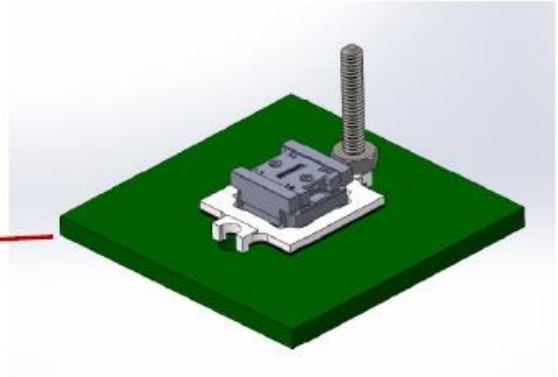
Addressing the Micropod Socket Issue 2/2

3) Remaining Mezzanine cards (3 boards) cannot be used without additional work on them due to too many broken channels
   - The decision was made to repair them with an interposer and gold pins
   - Successfully demonstrated in one board to fix issues
   - The tin-gold interface has long term reliability concerns (not known how short "long term" can be)

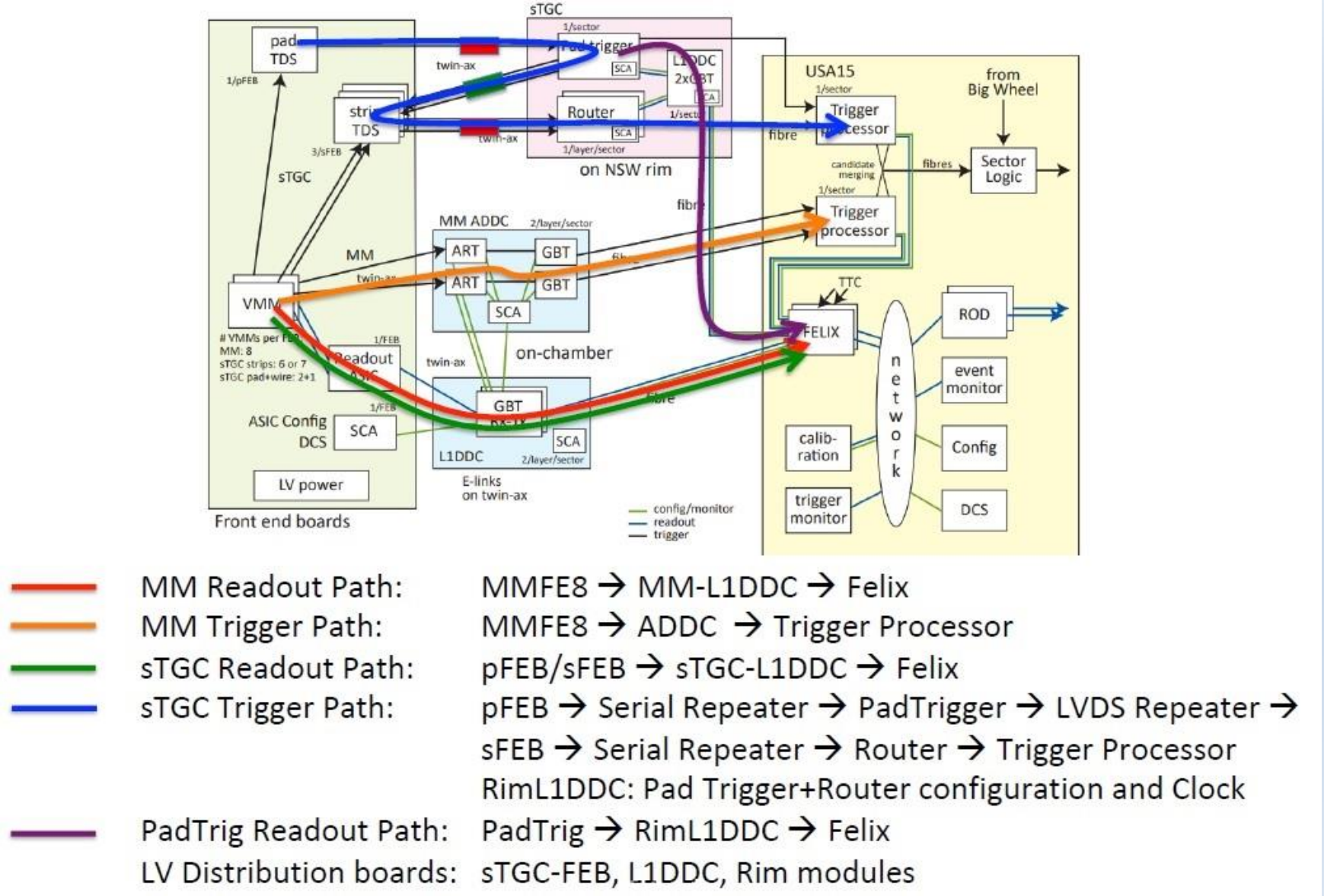
These Mezzanines are planned to be used in development test stands and not in USA 15

Four pre-production boards currently in test stands could be used as spares





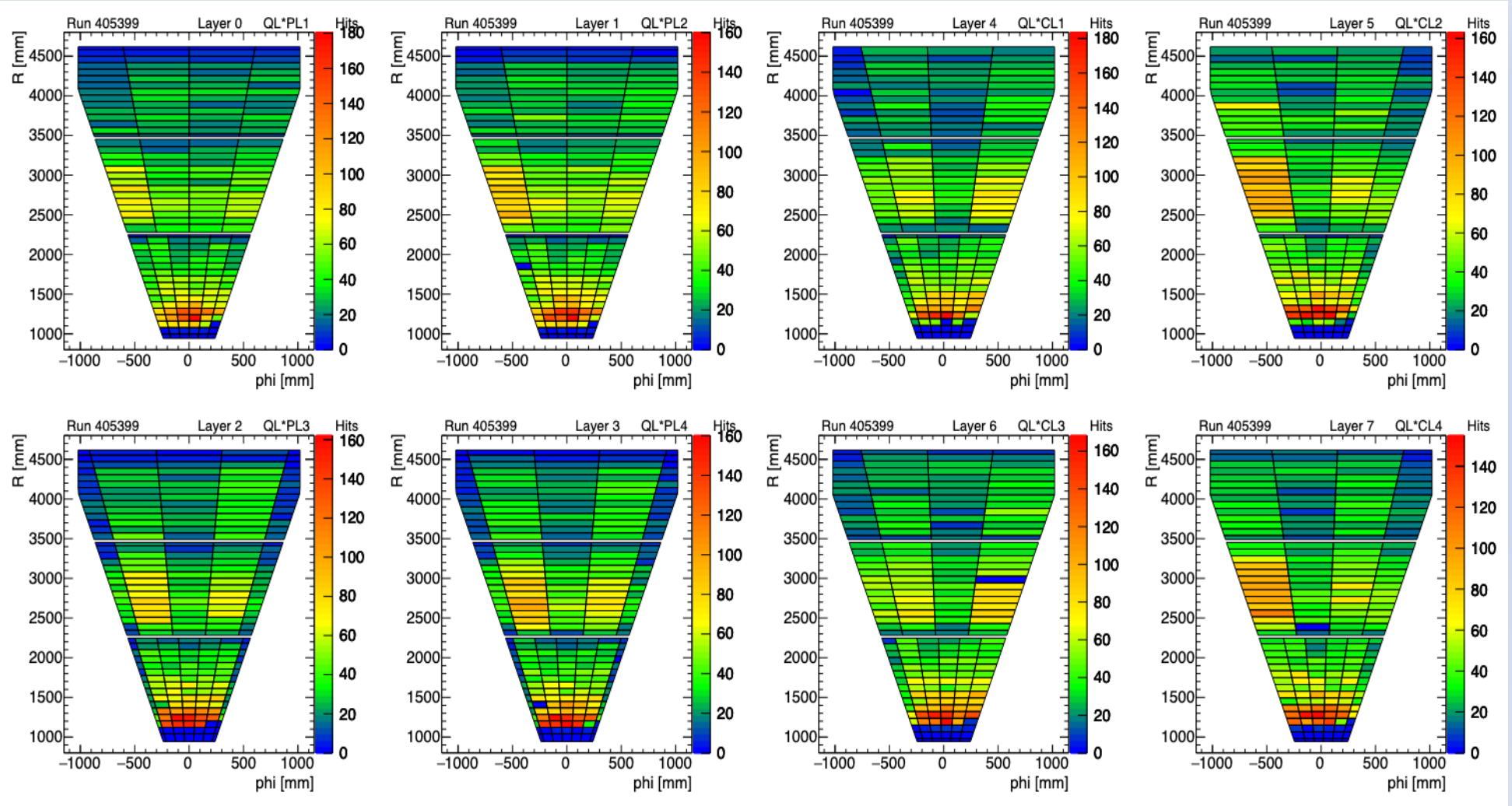
NSW Readout and Trigger Electronics Scheme



MM Readout Path:	MMFE8 → MM-L1DDC → Felix
MM Trigger Path:	MMFE8 → ADDC → Trigger Processor
sTGC Readout Path:	pFEB/sFEB → sTGC-L1DDC → Felix
sTGC Trigger Path:	pFEB → Serial Repeater → PadTrigger → LVDS Repeater → sFEB → Serial Repeater → Router → Trigger Processor RimL1DDC: Pad Trigger+Router configuration and Clock
PadTrig Readout Path:	PadTrig → RimL1DDC → Felix
LV Distribution boards:	sTGC-FEB, L1DDC, Rim modules

sTGC – Readout of the Pad Trigger Module

- Heat maps on an sTGC large sector with beam.



sTGC – Readout of the Pad Trigger Module

- A few coincidences observed during pilot beam.