The Micromegas detector for ATLAS

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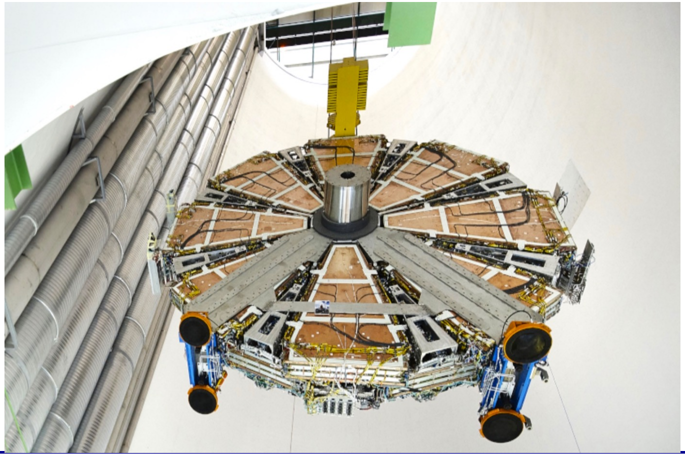
On behalf of the ATLAS Micromegas Community

ATLAS Micromegas R&D Collaboration

Evaluate possible use of micromegas for ATLAS muon chamber upgrade programme

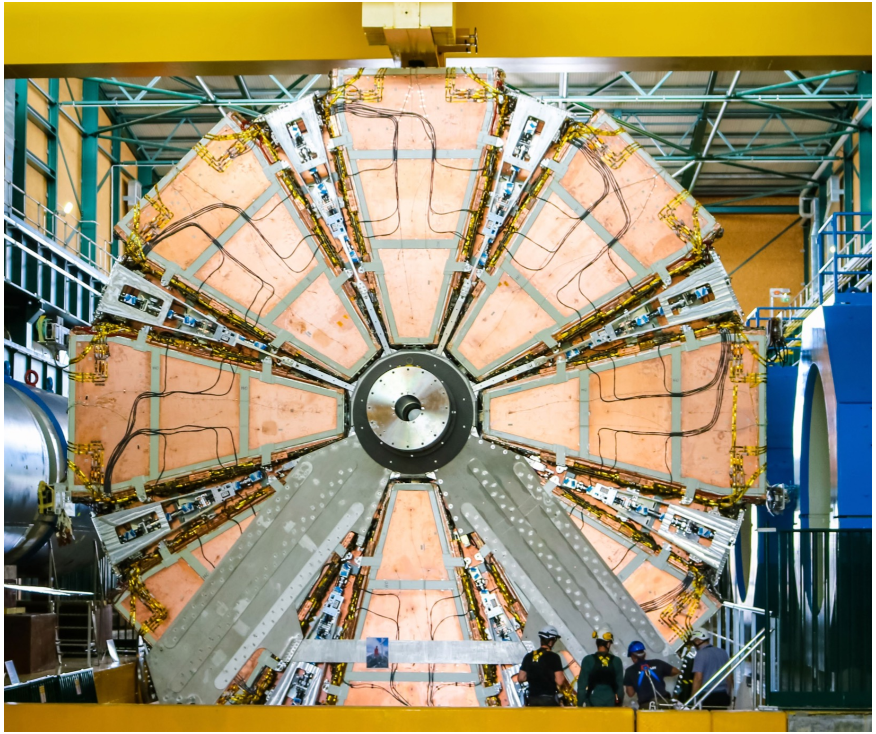
- EoI submitted in February 2007 to ATLAS Upgrade Office
- Proposal submitted in June 2007
- 11 participating Institutes so far; with growing interest ...
- Regular weekly meetings at CERN since February.
- TWiki page with agenda, contributions and minutes of all meeting plus other useful information and links:
  https://twiki.cern.ch/twiki/bin/view/Atlas/MuonMicromegas

MPGD R&D workshop 10 Sept 2007 J. Wotschack/CERN 4



Outline

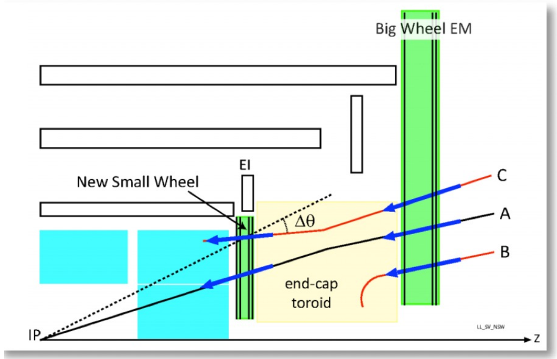
- Introduction
- Some history
- Main issues from R&D to construction
  - HV stability
  - Understanding of the problems and mitigation measures
- Some lesson learned
- Conclusions



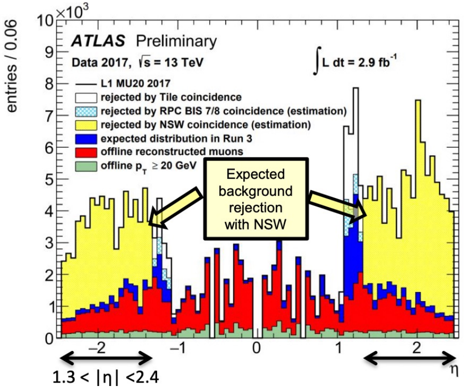
Dedicated talk on Micromegas anode board production at the June RD51 meeting and at the 2022 MPGD Conference in IL. Not covered here. Ref: *JINST* 18 (2023) 09, C09014

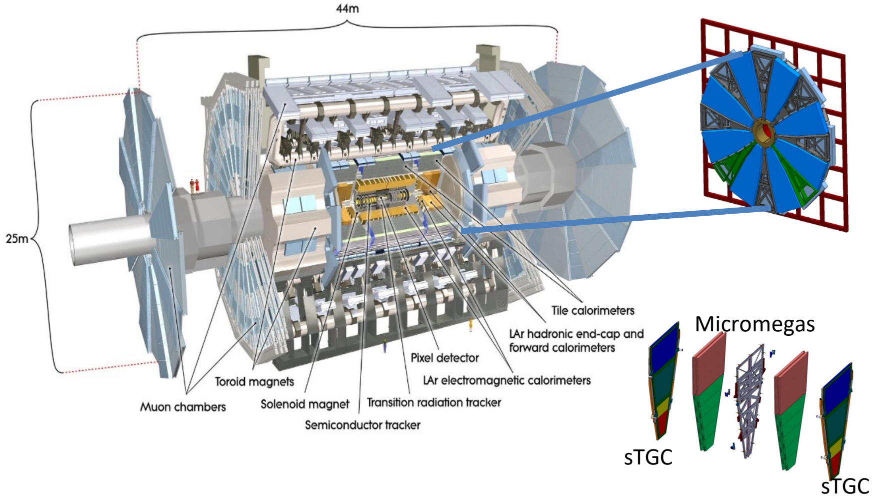
ATLAS NSW

- Major ATLAS upgrade of Phase1



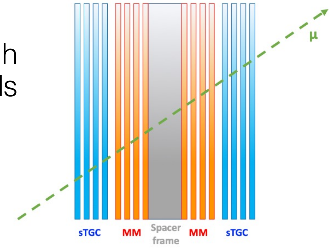
Run1 & 2: Level 1 End-Cap trigger, dominated by fake trigger events (type B e C)





Complementary technologies:

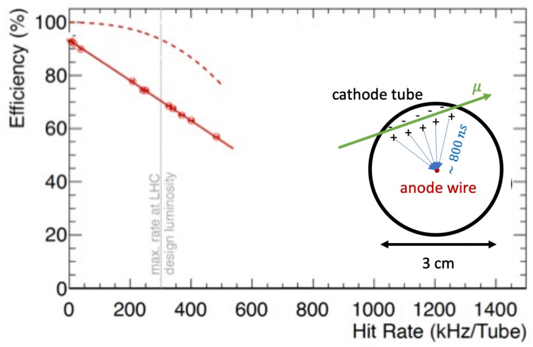
- sTGC: good bunch crossing assignment with high radial resolution and rough ϕ resolution from pads
- Micromegas: good offline radial resolution and a good ϕ coordinate due to its stereo strips
- 1280 m^2 active surface for each technology



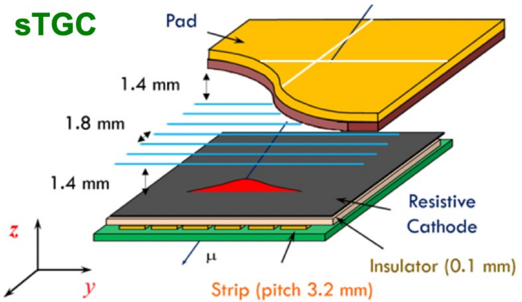
Ref: *New Small Wheel Technical Design Report*, *CERN-LHCC-2013-006*

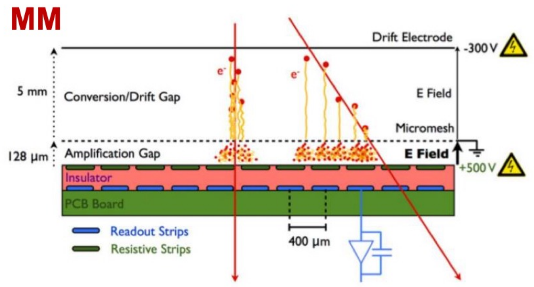
Detector requirements

- Main detector requirements for NSW detectors:
- Space resolution: O(100) um
- Good double track separation
- Trigger capability → BC identification (25 ns)
- Rate capability 20 kHz/cm2
- Longevity (aging) to stand the ATLAS lifetime (run at HL-LHC until >2040)
- Construction of large-size detectors



Efficiency vs rate for ATLAS MDT

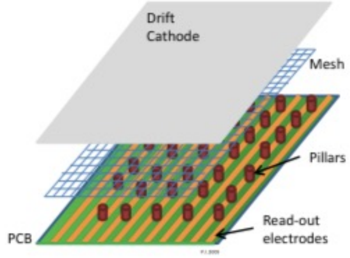


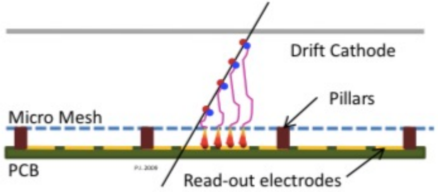


This talk focuses on NSW Micromegas

Why Micromegas?

- Gaseous detectors with excellent rate capability and ageing properties – demonstrated for non-resistive MM -, and
  - Good spatial resolution for perpendicular tracks
  - Timing performance sufficient for triggering
- But had some limiting factors for the ATLAS NSW:
  - Sparks
  - Precise tracking under angles (ability to deliver track vectors for LVL1 trigger)
  - Mass/industrial production of large-size detectors to be demonstrated.
    No Institute, included CERN, able to produce the required Micromegas boards
- R&D effort initiated in 2007 by a rather small number of physicists from few Institutes clustered in the MAMMA (Muon Atlas MicroMegas Activity) proto-collaboration





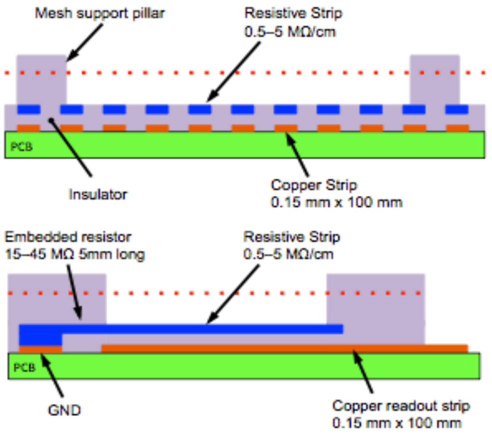
- Goal: build the largest MPGD-based system ever conceived
  - 1280 m^2 active surface
  - 2.1 M readout channels
  - 128 detectors / 4 types

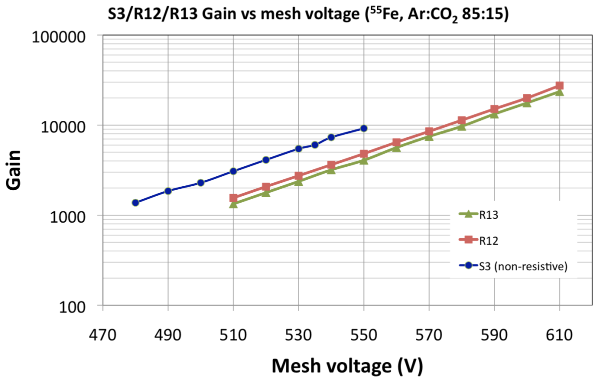
Diffuse scepticism about the feasibility of the whole project

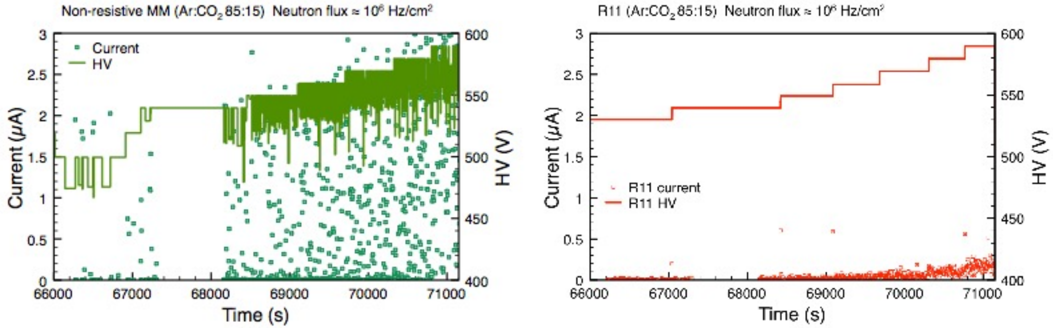
…will the dream turn into a nightmare?

Resistive Micromegas

- Development of rMM and demonstration of the principle
  - Tried both screen-printing and sputtering
  - Screen-printing judged to be more reliable and cost effective (DLC and vacuum deposition not so diffused as nowadays in our community!)
- Resistive Micromegas are spark immune:
  - Spark intensity reduced by a factor 1000



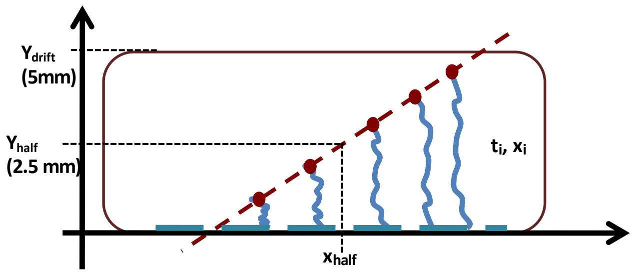




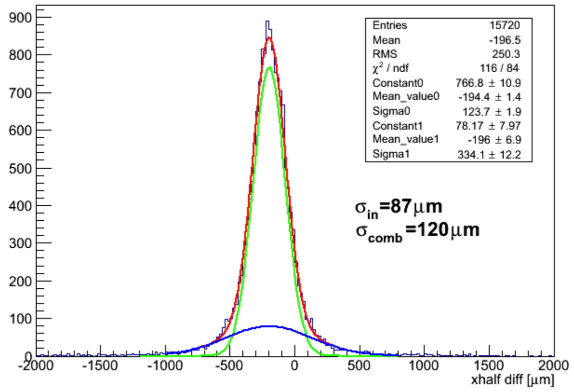
Ref: Nucl.Instrum.Meth.A 640 (2011) 110-118

Micromegas as µTPC

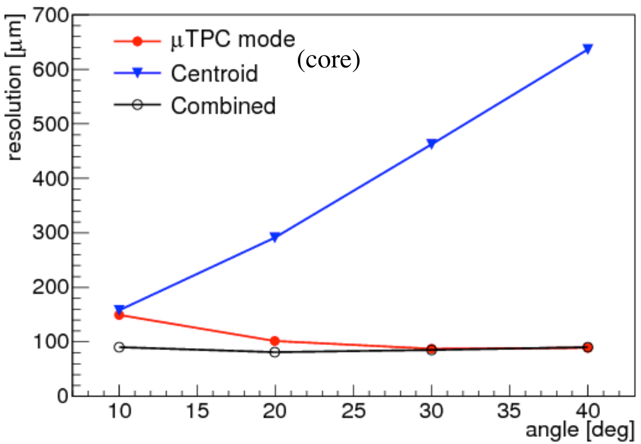
- Same principle as in TPC but on a mm scale
- Measure arrival time on readout strips and reconstruct space-points in the drift region
- Local track reconstruction in the few-mm wide drift gap possible
- uTPC technique is since then used in many applications and other MPGD as well



Position resolution vs impact angle



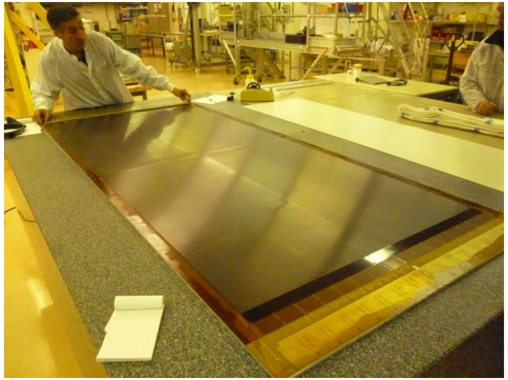
µTPC resolution at 30 deg



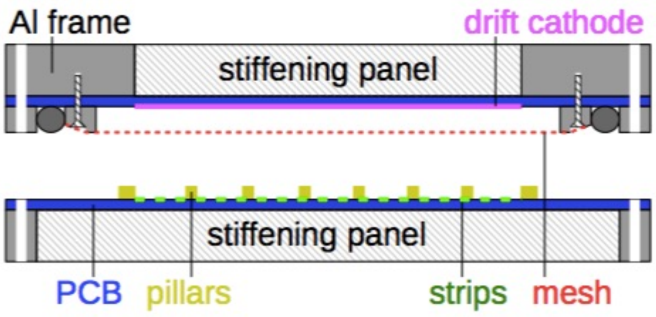
Ref: Nucl.Instrum.Meth.A 617 (2010) 161-165
Nucl.Instrum.Meth.A 937 (2019) 125-140

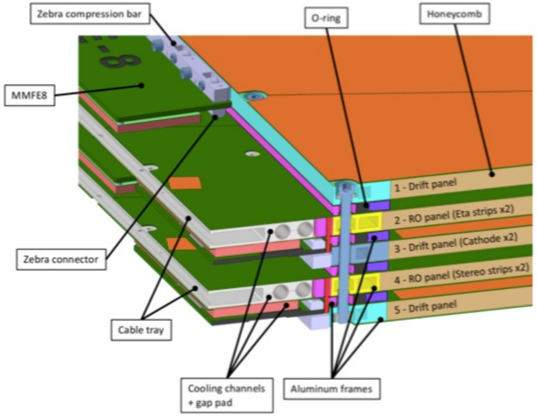
Evolution toward large-scale system

- Construction of large-size detectors using PCB techniques
  - Potential for industrialization
- Bulk-micromegas process replace by ‘floating mesh’
  - Micro-mesh mounted on the drift panel, not embedded in pillars (no bulk)
  - Mesh attracted to RO electrodes by electrostatic force
  - Possible to open the detector for cleaning if needed



Construction of a 1x2 m^2 Micromegas at CERN (in collaboration with EP-DT)

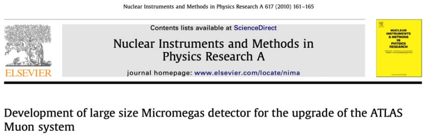




Ref: Nucl.Instrum.Meth.A 814 (2016) 117-130

From R&D to the experiment

- The results of the R&D phase together with the investigation on the industrialisation convinced us that the project was feasible
- The number of enthusiastic ‘dreamers’ increased along the way and in 2012 the ATLAS collaboration selected the Micromegas, together with the sTGC, for the NSW construction


Nuclear Instruments and Methods in Physics Research A 617 (2010) 161–165

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

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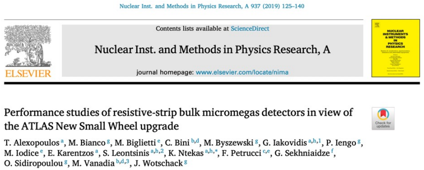
ELSEVIER

Development of large size Micromegas detector for the upgrade of the ATLAS Muon system


Nuclear Inst. and Methods in Physics Research, A 937 (2019) 125–140

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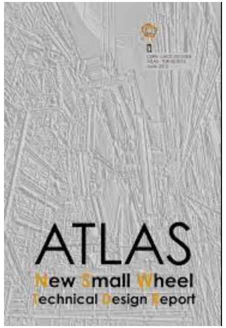
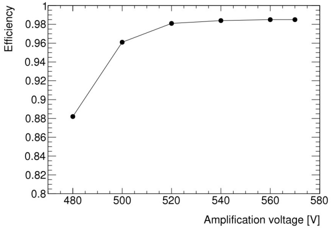
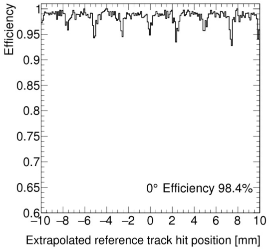
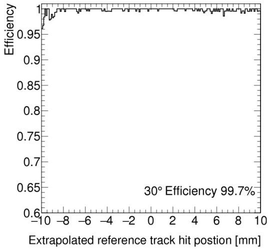
Performance studies of resistive-strip bulk micromegas detectors in view of the ATLAS New Small Wheel upgrade

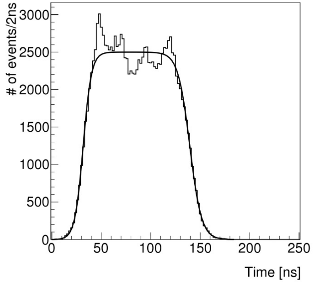
T. Alexopoulos, M. Bianco, M. Biglietti, C. Bini, M. Byszewski, G. Iakovidis, P. Iengo, M. Iodice, E. Karentzos, S. Leontsinis, K. Ntekas, F. Petrucci, G. Sekhniaidze, O. Sidiropoulou, M. Vanadia, J. Wotschack

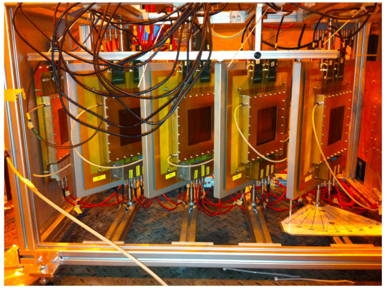








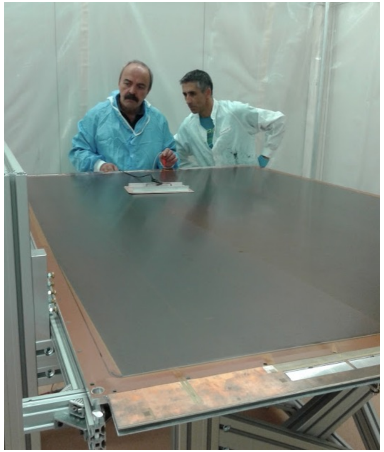


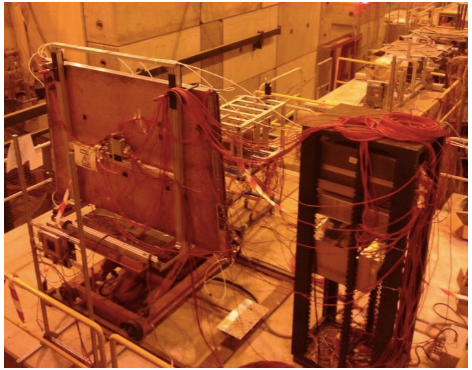


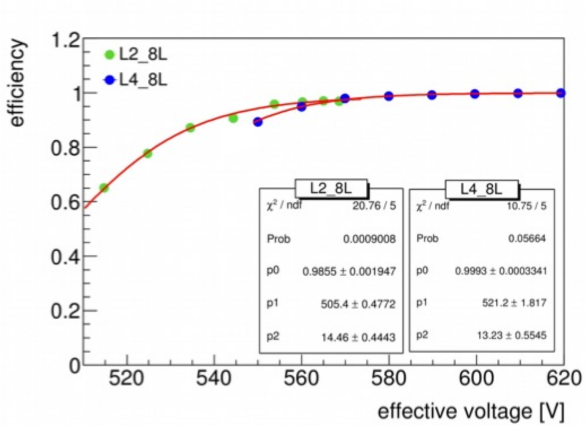
- However, most of the results based on small bulk prototypes, except few exceptions all build at CERN
  - ExMe: for mesh studies
  - MMSW: first quadruplet with sputtered strips
  - 1 m^2 and 2 m^2 prototypes

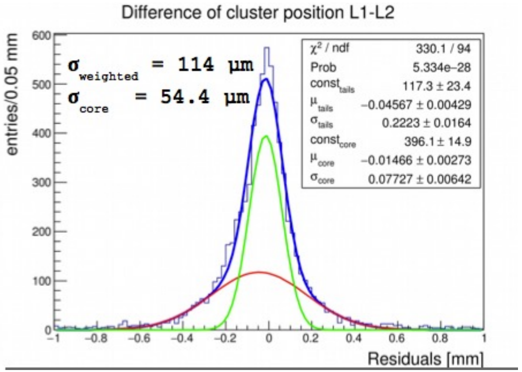
Experience with Module0

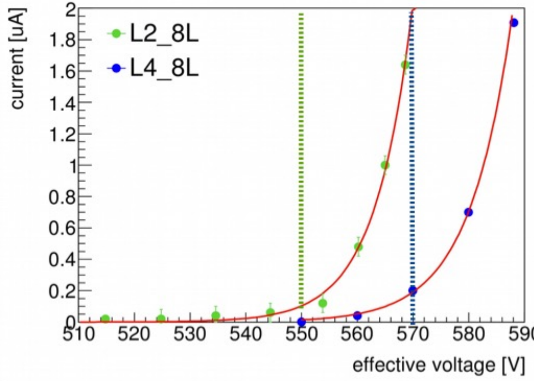
- M0 quadruplet showed good performance
  - high efficiencies
  - spatial resolution ~ 100 μm
- But with high current
  - ~stable with time
  - Attributed to low quality of the first MM boards produced in industry









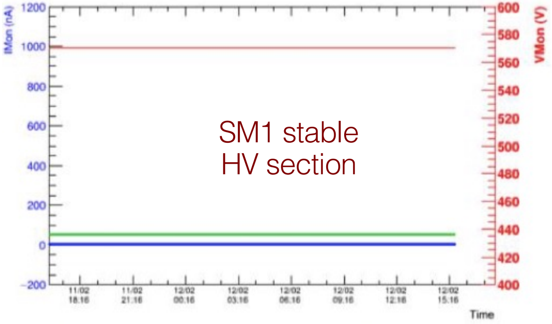


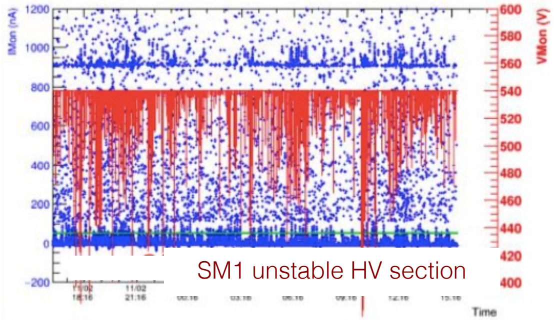
Lesson #1

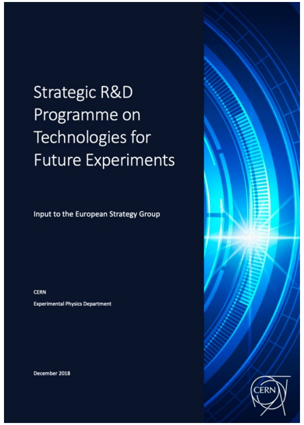
- Don't extrapolate (too much) results from small prototypes to large detectors, in particular if they are built with different components
- If you identify a problem, don't believe it is the only one until you prove it

Understanding the HV instability

- First production modules, built with boards satisfying the quality criteria showed the same (or even worst) problems than Mod0
- Actions taken & solutions implemented
  - Cleaning → establish proper cleaning procedure for anode boards and for mesh
  - Humidity → reduce humidity
  - Correlation with RO board resistivity → Passivation
  - Role of the mesh
  - Role of the gas mixture







3.2 Gas based detectors (WP2)

Gas based detection will remain a key technology in particle physics experiments. Detectors for the ILC, CLIC or FCC will rely on large area muon systems and, specifically for the ILC, on a large volume central TPC. Muon detectors will cover active areas greater than 1000 m^2 for FCC experiments. A common challenge will be the high rate capabilities. Three main lines of activities are proposed:

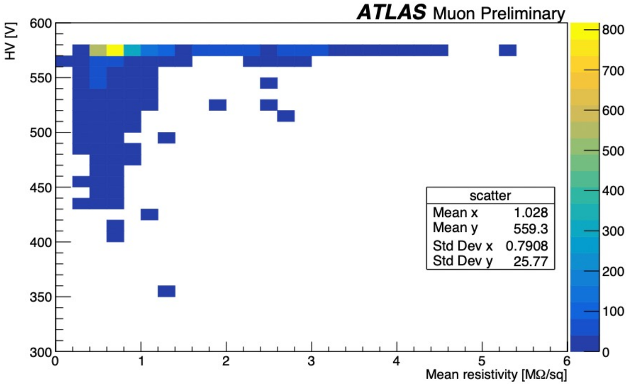
- **Large area gaseous detector systems**. Reliable and efficient mass production of all parts of large area gas based detectors is mandatory for any future detector. Recent experience during the upgrade of the LHC experiments shows that problems with mass production of the detectors can jeopardise construction schedules and bring the entire project to risk. New solutions for large area systems shall be addressed, specifications and procedures be developed, tested and documented.
- Foster **tools** required for future detector developments and for prototype design and evaluation.

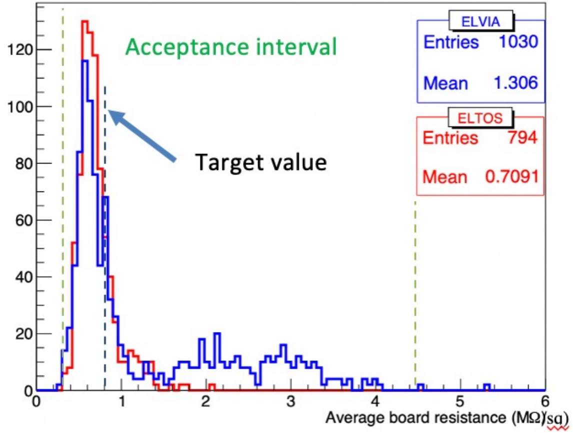
Issues of ATLAS Micromegas become a worldwide known problem…

Lesson #2

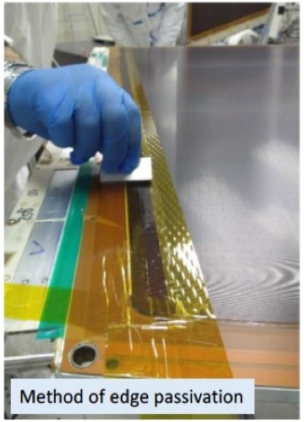
- If you write strategic documents, listed to the real experts not to gossips

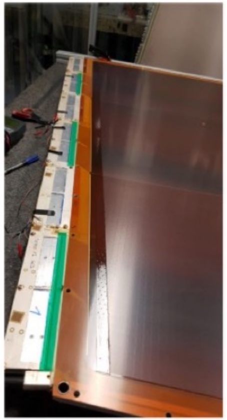
Resistivity





- Correlation between board resistivity and HV stability
- Action taken:
  - Process optimisation to increase resistivity during production
  - Passivation to increase Rmin (DOCA)

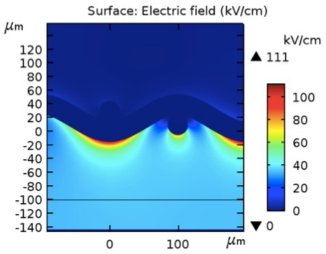


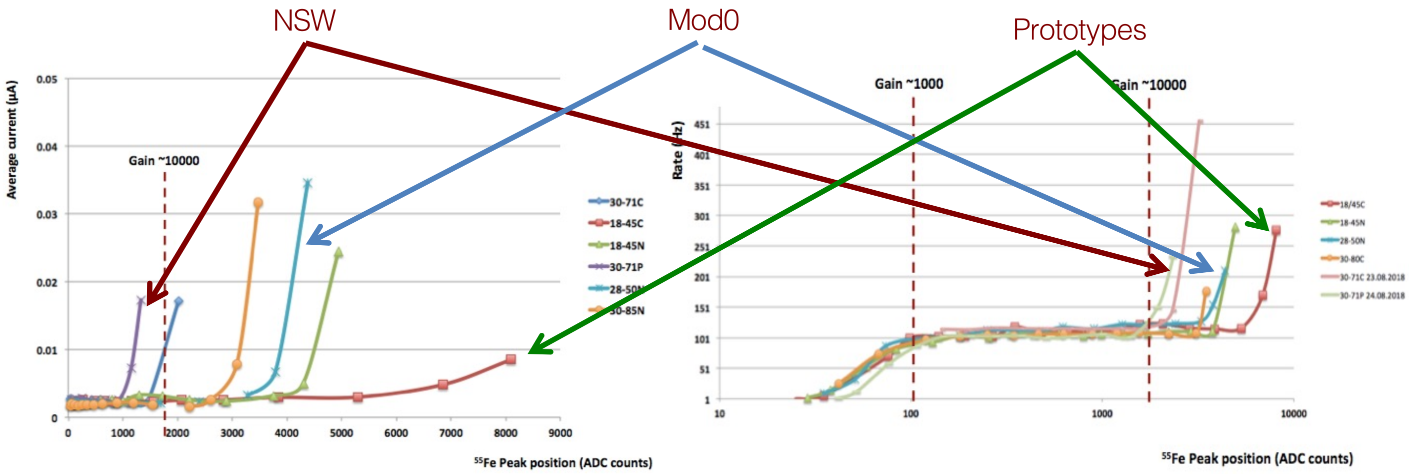


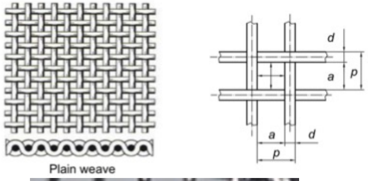
- But the produced boards are ~all within the acceptance interval for the resistivity…
- …was the target value too low? Why?

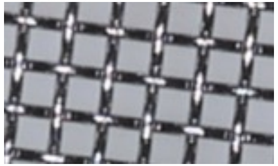
The role of the mesh

- …because it was optimized on bulk detector with 18/45 calendered mesh!
- Test campaign in 2018 to evaluate the role of the mesh geometry on HV stability
- Clear dependence of stability on geometry
  - Smaller wires perform better
  - Smaller openings give larger stability region (field uniformity)
  - Calendered meshes perform better
- Experimental results in agreement with prediction







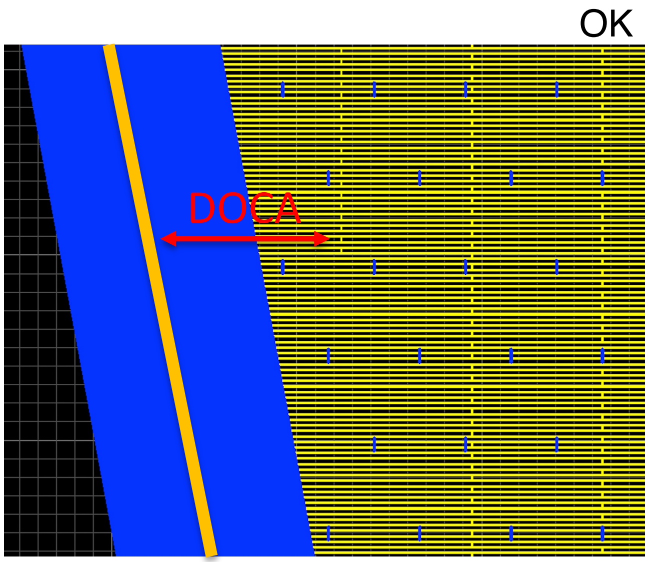


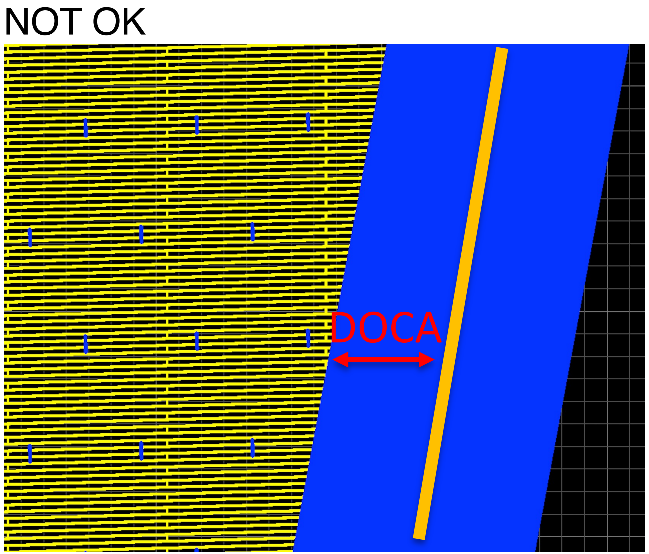
- The mesh was selected considering mechanical/physics/cost aspects
- The stability limit did not appear to be a problem

When the role of the mesh was clarified there was no consensus in the collaboration to go to the 18/45C mesh for the remaining to build detectors

Design mistake

- Some boards type (of the 32 different ones) affected by a design issue:
- Interconnections between resistive strips extending to the edge: reduce R_{min} → Passivation





DOCA = Distance Of Closest Approach

Lesson #3

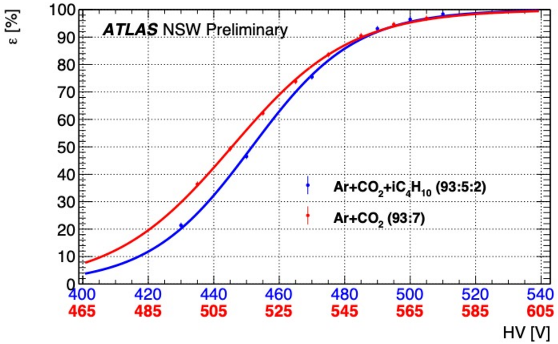
- Select well your components: saving money is not always the solution.
  It can cost you more later.
- Don’t do mistakes in the design.
  Or reduce the risk by reducing the number of different items to design

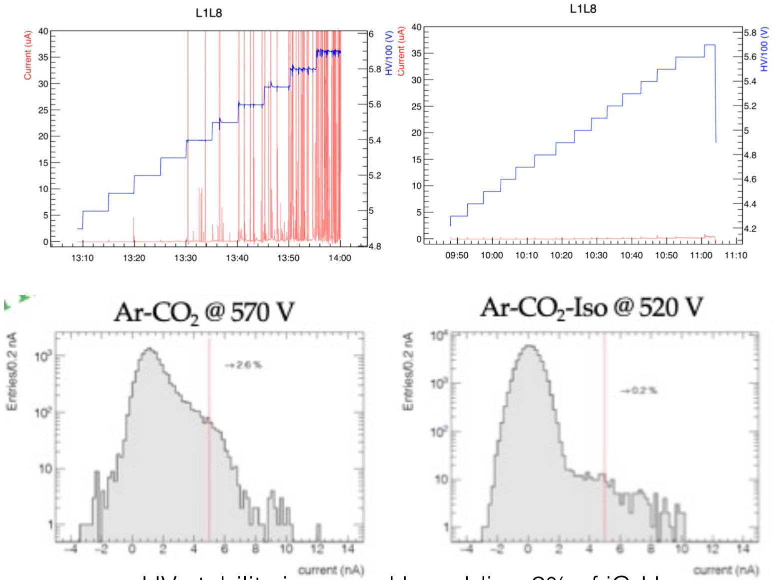
…which mesh?

Gas choice

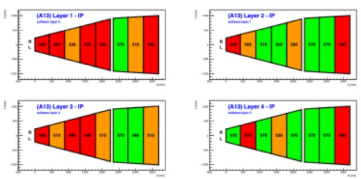
- ATLAS Micromegas were supposed to operate with Ar:CO2 93:7 mixture. The main reason for the original choice was to re-use the gas system for the MDT/CSC of the old wheel and save few kCHF
- Not an optimal gas for a parallel single-sage amplification structure
- All other MM system in use until then (e.g. COMPASS MM) used Ar-based with iC4H10
- Small bulk prototypes with 18/45 mesh worked perfectly with Ar:CO2 93:7
- Instabilities are largely mitigated with the addition of a small amount of stronger quencher
  - Lower operating voltage / larger stability plateau / suppress events with larger charge (→ discharges)

Ref: JINST 18 (2023) 07, C07005

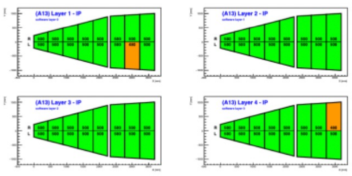




HV stability improved by adding 2% of iC_4H_{10}



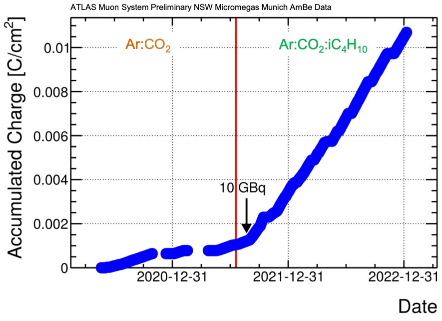
$Ar:CO_2$ 93:7

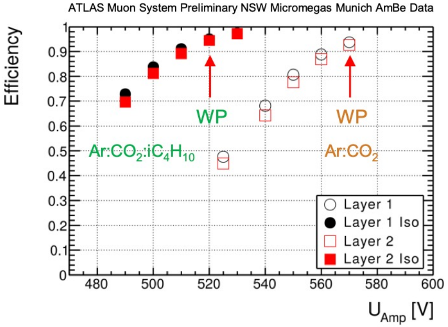


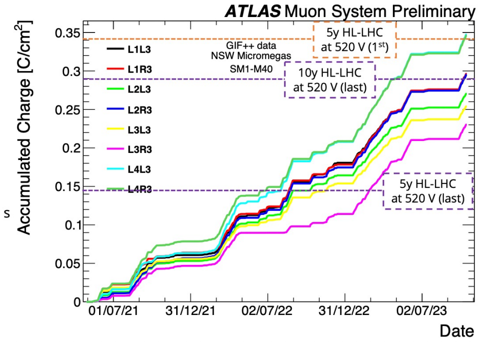
$Ar:CO_2iC_4H_{10}$ 93:5:2

Gas choice

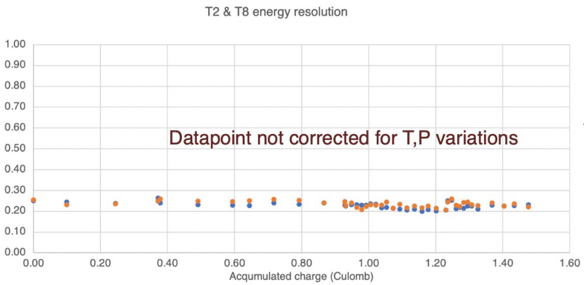
- ATLAS MM have adopted the 3-component mixture Ar:CO2:iC4H10 93:5:2
- Gas flow also matter: increased to 1 vol exchange every 4h. Further increase planned for next year
- Extensive tests performed at CERN lab with X-rays, at LMU with neutron, at GIF++ with gammas, at ATLAS with the pp particle background did not show any sign of aging or performance degradation phenomena induced by the hydrocarbons





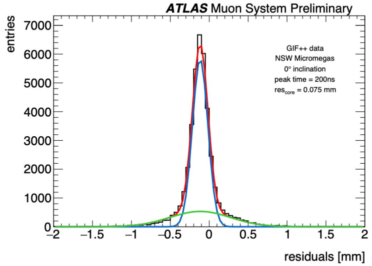


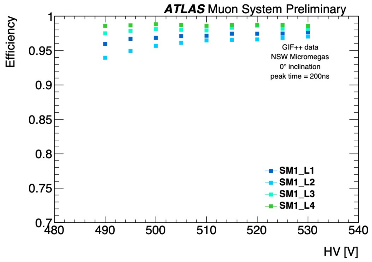
Neutron irradiation (Ref: F. Voegel 3rd Conference on gaseous detector aging phenomena



Accelerated tests with X-ray

Ref: JINST 18 (2023) 06, C06007

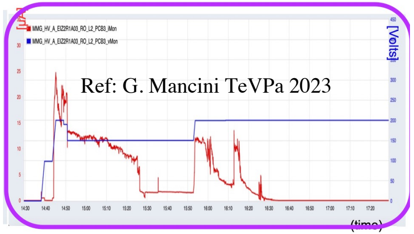




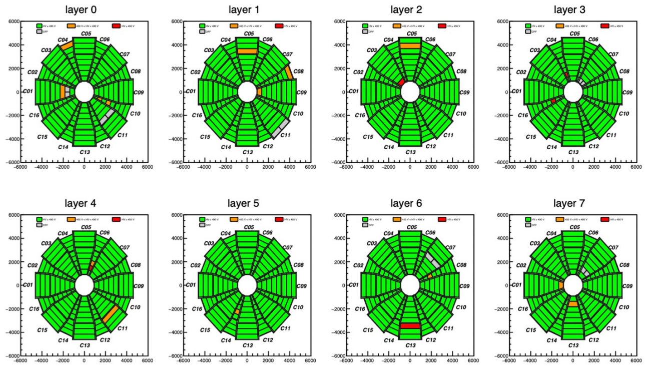
Irradiation at GIF++ (Ref: V. D;'Amico 3rd Conference on gaseous detector aging phenomena

Status

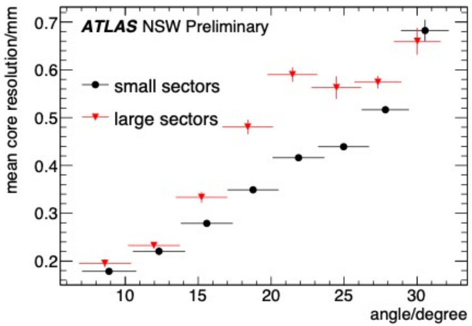
- Micromegas are stably working in ATLAS since the start of LHC Run3 at nominal voltage of 505 V (plateau)
- Ready to further increase the gain in 2024 run
- No major HV issues observed so far. Inefficient HV section at <1% level (physiological)
- Performing regular treatment with pure Ar during technical stops
- Still working to improve performance: detector alignment, time alignment, magnetic field map



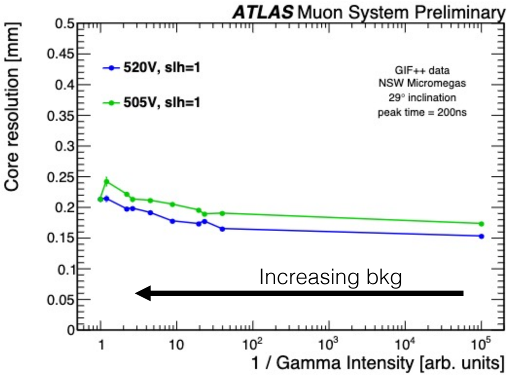
C: **HV pcb by pcb**



Ref: JINST 18 (2023) 07, C07005



Resolution vs track impact angle with cluster centroidpp collision in ATLAS (no alignment correction, no time correction)

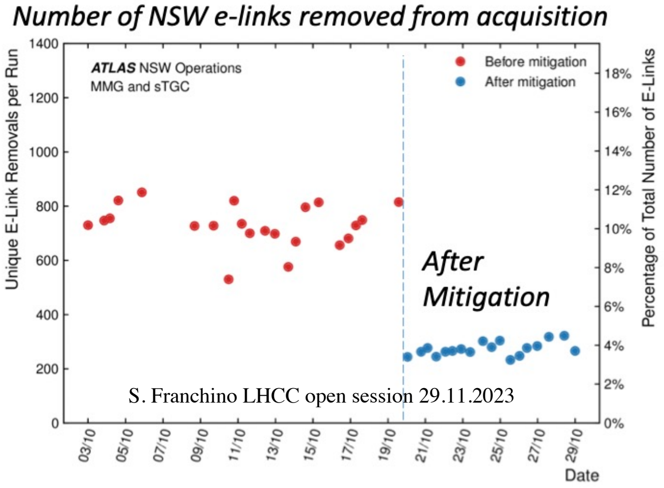


Resolution for 29deg. muon track with cluster-time projection method as function of photon background

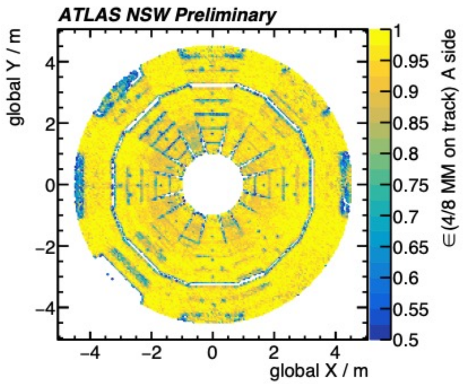
(Ref: V. D;'Amico 3rd Conference on gaseous detector aging phenomena

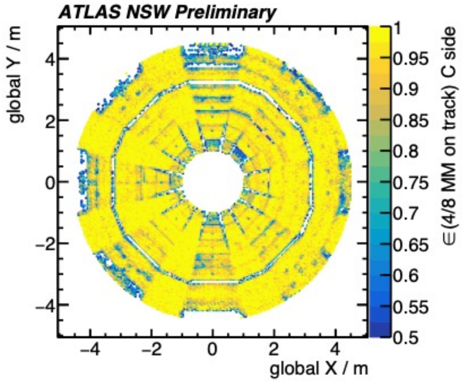
Status

- System performance still affected by
  - Failures of HW components (DC-DC converter boards, replaceable; some inaccessible LVDB)
  - Large noise level in the detectors with longer strips, affected by Bfield → intervention to improve the grounding planned in end-of-year stop
  - DAQ instabilities:
    - Mitigation recently introduced by increasing number of transitions in TTC stream to GBTx
    - Investigations to understand the underlying cause ongoing



Remaining instabilities under investigation too
We see indication of the known VTRx problem
VTRx replacement campaign ongoing for the reachable boards (sTGC trigger)

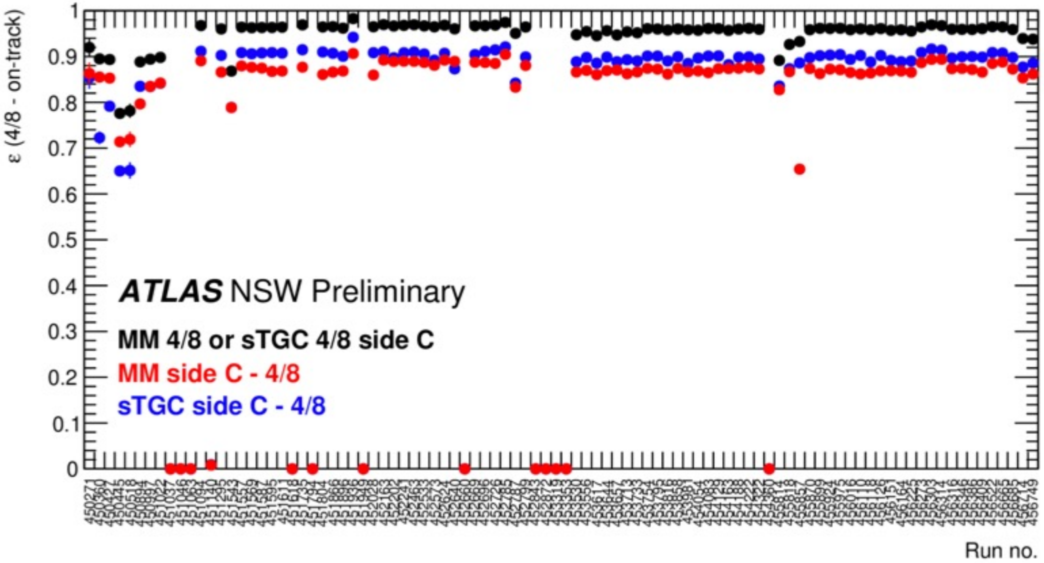




4/8 MMG efficiency

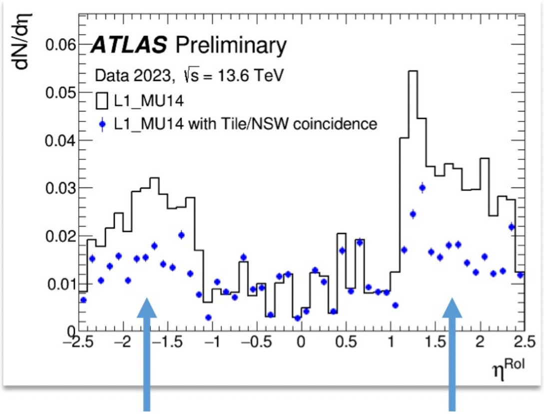
Status

- Thanks to the redundancy of the system the DAQ instability do not compromise the overall efficiency (as 4/8 majority)
- NSW effectively contributing to reduce the L1MU trigger rate with rejection of fake muon triggers
    - MMG trigger processor enabled in the last HI run



NSW efficiency vs run number in Run3

DAQ mitigation instabilities not implemented in the run shown here



*NSW **sTGC pad trigger**, rejection of fake muons in July pp data, **95% efficiency**, **75% sectors included***

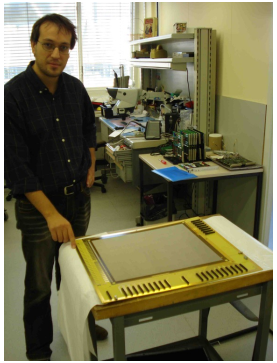
Lesson #4

- Never give up in improving your system
- Technical problems can always been overcome if there is team of motivated and dedicated people.
  Keywords: investigation-understanding-solution/mitigation

Conclusions

- The NSW Micromegas project accompanied RD51 since the beginning
  - NSW project closed in 2023 as RD51!
- The development and construction of the largest MPGD-based detector system has been full of difficulties
- Many items not covered here (mechanics, elx, services, noise etc); they would deserve dedicated talks
- The NSW Micromegas system is fully integrated in ATLAS, performance oimprovement and trigger implementation continuing
- The transition from R&D to construction revealed unexpected problems… nevertheless
- We made it! Demonstrating the feasibility or large MPGD system for the next generation experiment

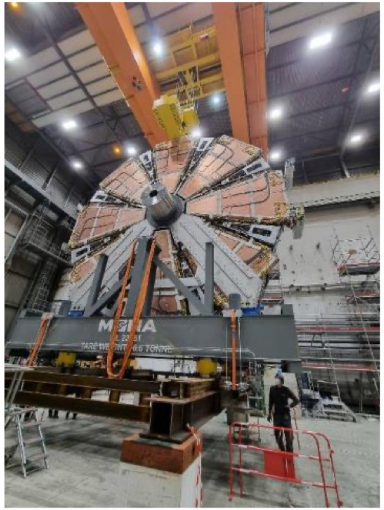
2007

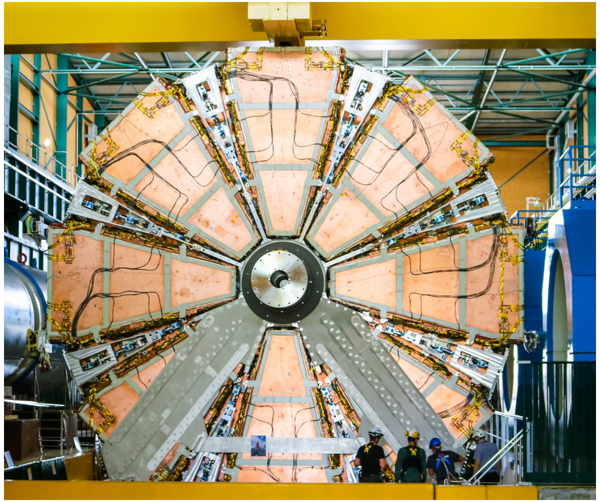


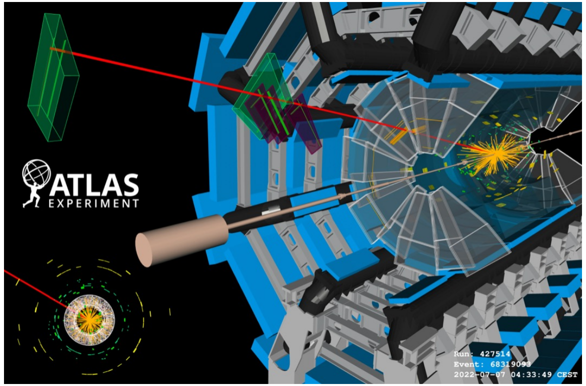
2022

Thank you!

ATLAS Micromegas







Additional Material

Cleaning

- Detailed cleaning protocol during detector construction and assembly: dust & production remnant removal (R. De Oliveira)
    - Micro crystal cleaner + NGL
    - Rinsing with war tap water
    - Claning with DI water
    - Drying in oven (humidity triggers discharges: RH<15% for safe operation)