Performance of the ATLAS New Small Wheels

FABIAN VOGEL

LS SCHAILE

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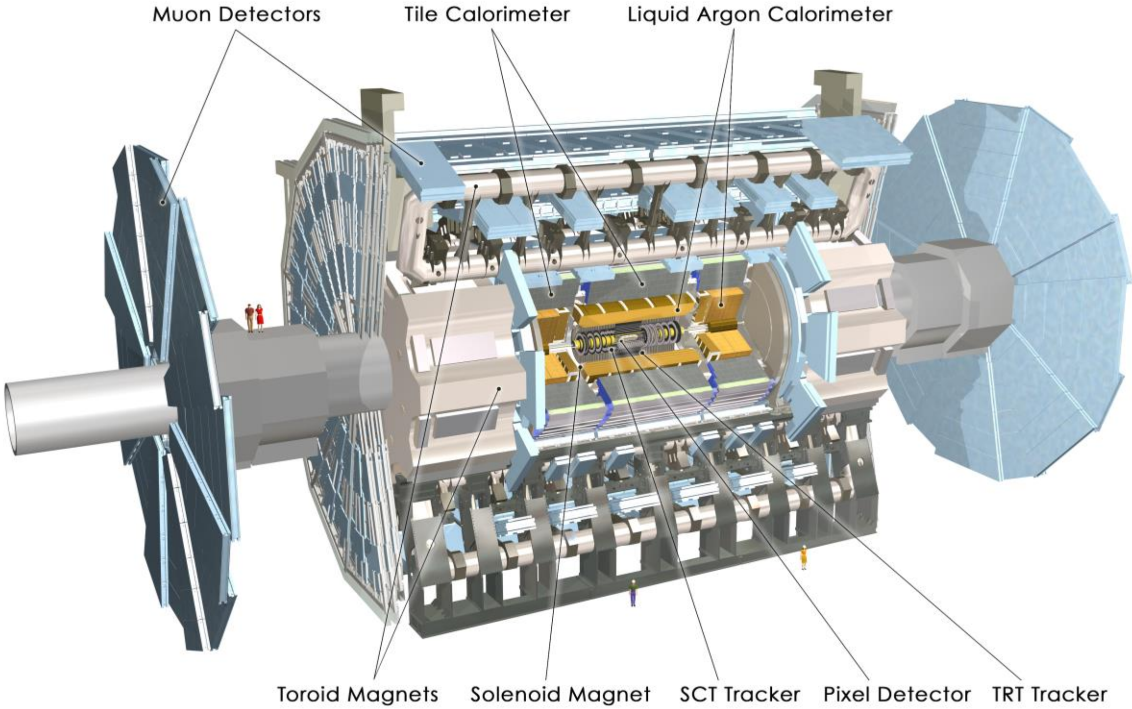
DPG FRÜHJAHRSTAGUNG GÖTTINGEN

LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Bundesministerium für Bildung und Forschung

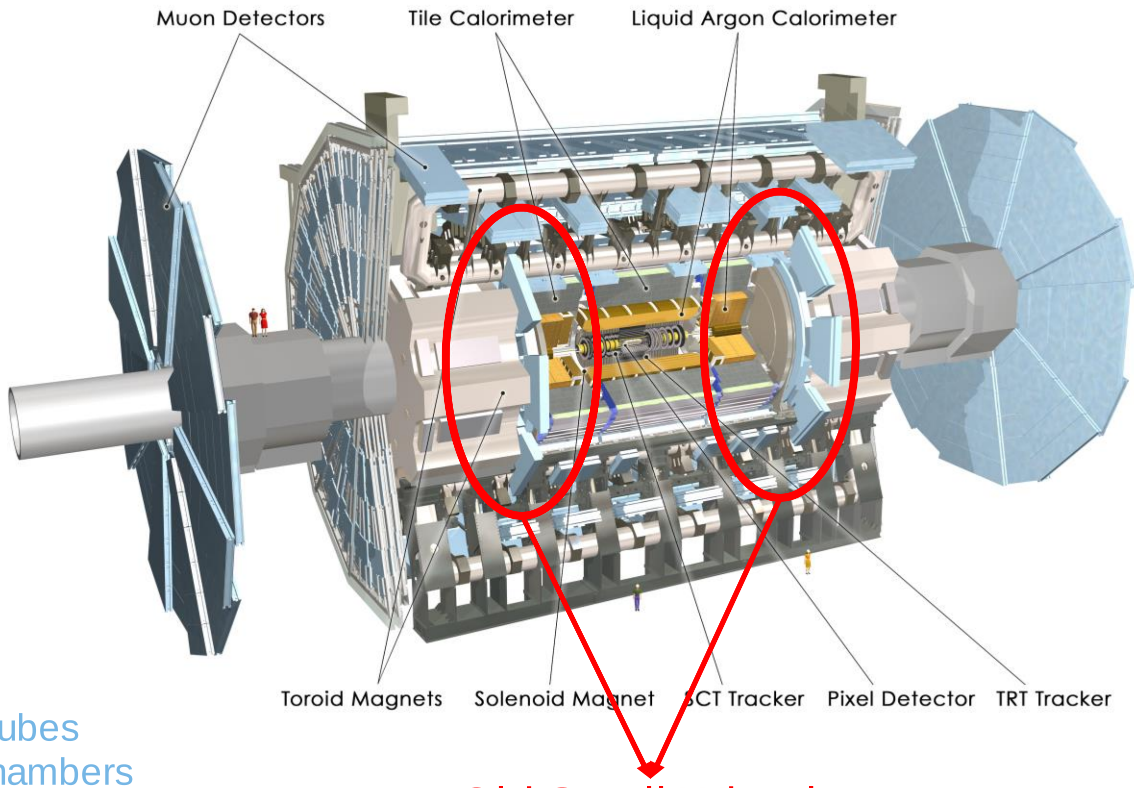
FSP ATLAS Erforschung von Universum und Materie

ATLAS Experiment



CERN-GE-0803012

ATLAS Experiment – Small Wheels



Technologies SW:
- Monitored Drift Tubes
- Cathode Strip Chambers

Old Small Wheels

Operational until 2018 at $L = 2\times10^{34}$ cm^{-2} s^{-1}

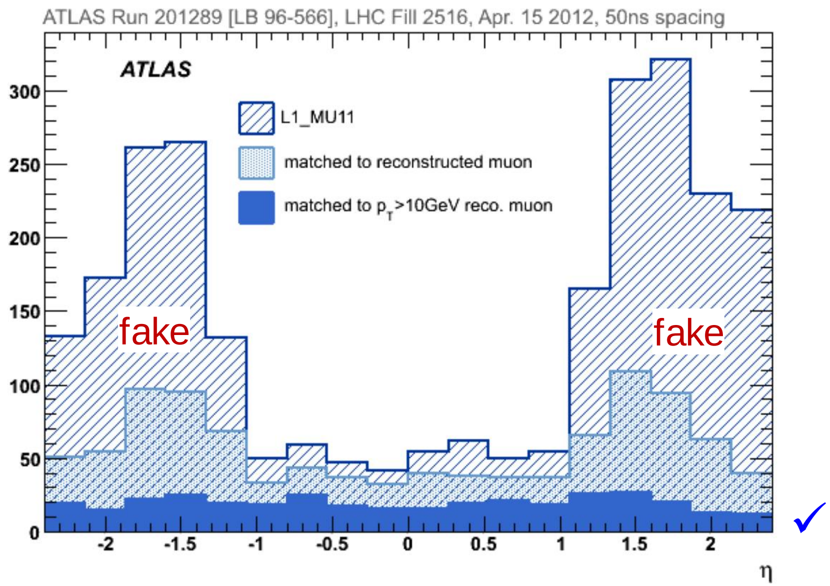
First of the 3 endcap stations

$$\frac{\Delta p_T}{p_T} < 0.1$$

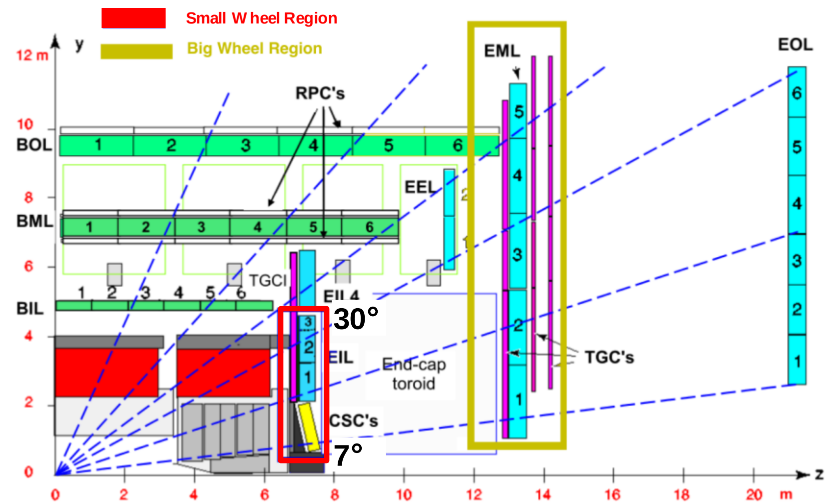
CERN-GE-0803012

Limitations of the Small Wheel

endcap endcap



9° 30° 30° 9°

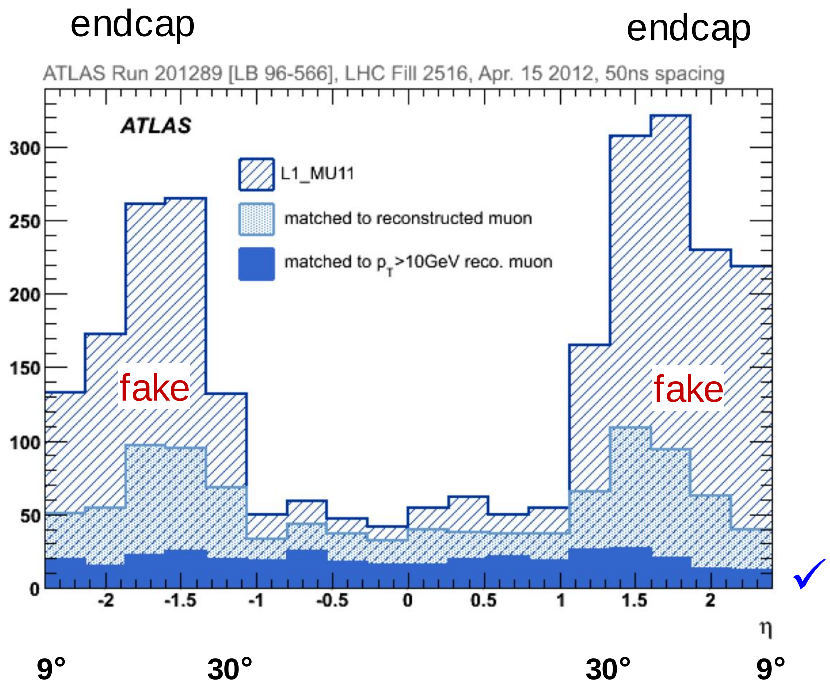


Endcap: most μ candidates are not matched to p_T > 10 GeV

Endcap region covers 1.3 < |η| < 2.7 which corresponds to 30° - 7°

ATLAS-TDR-020, adapted

Limitations of the Small Wheel



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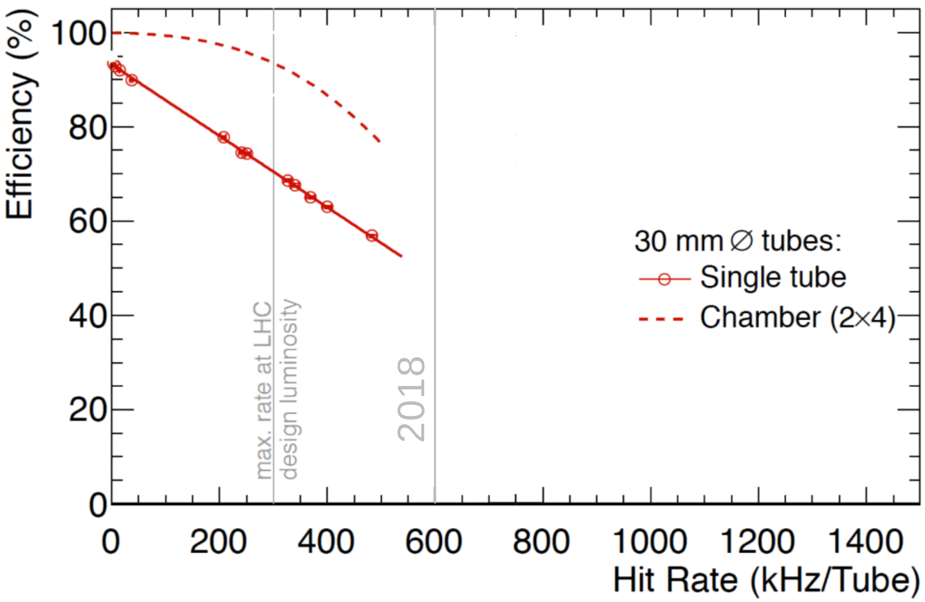
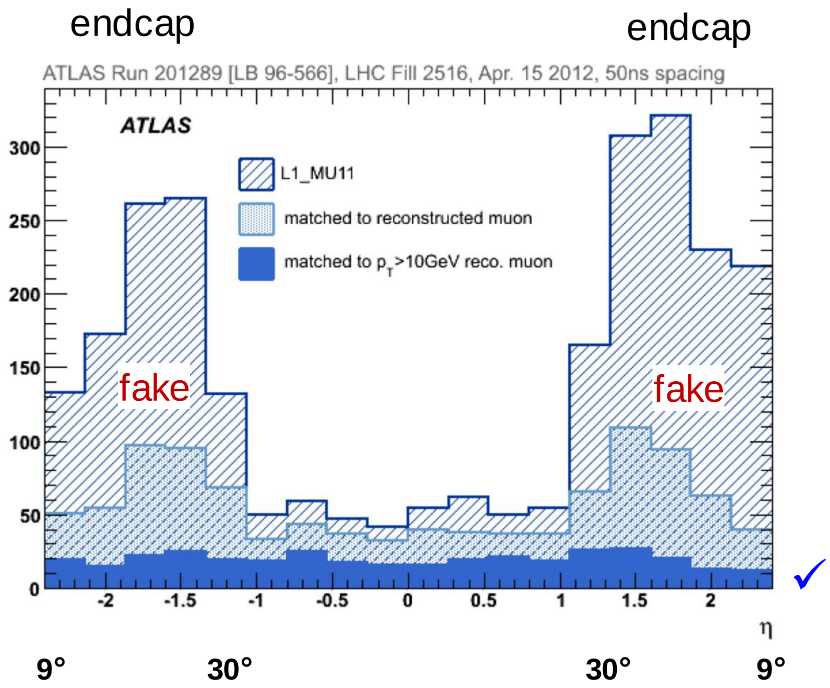


Monitored Drift Tube reconstruction efficiency decreases with hit-rate

ATLAS-TDR-020, adapted

Limitations of the Small Wheel



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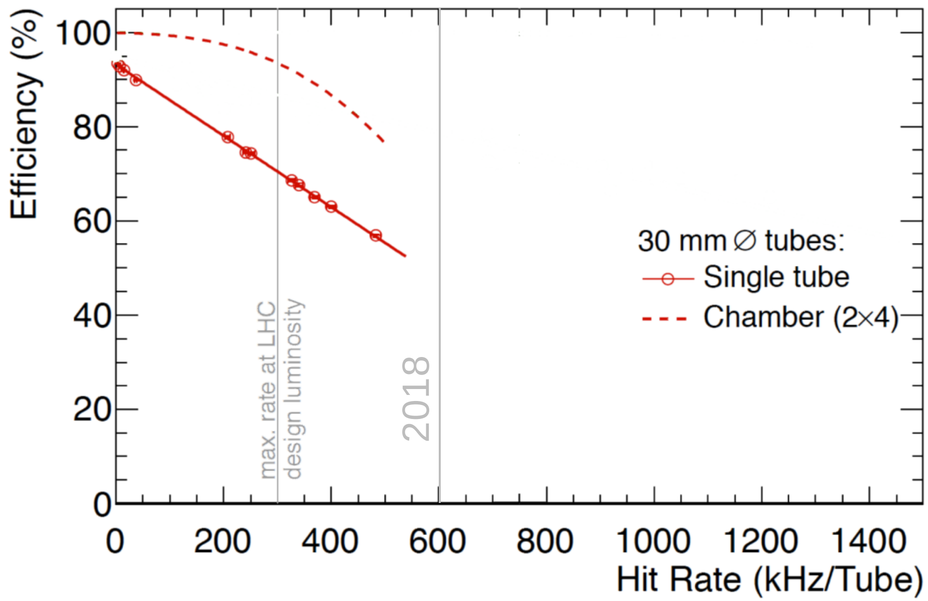

Monitored Drift Tube reconstruction efficiency decreases with hit-rate

New Small Wheels

ATLAS-TDR-020, adapted

Requirements for the New Small Wheel

Performance at High-Luminosity (HL) LHC (factor 3.75 higher) as good as SW detectors at low luminosity:

ATLAS-TDR-020

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  - Online track segment reconstruction in full η ($1.3 < |\eta| < 2.7$)

ATLAS-TDR-020

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ATLAS-TDR-020

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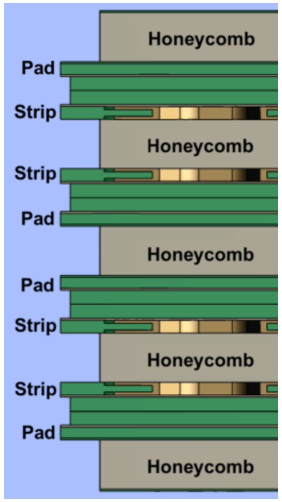
- General:
  - No detector aging (~1C/cm^2)
  - High-background tolerance 20 kHz/cm^2
  - High precision manufacturing O(40 μm)

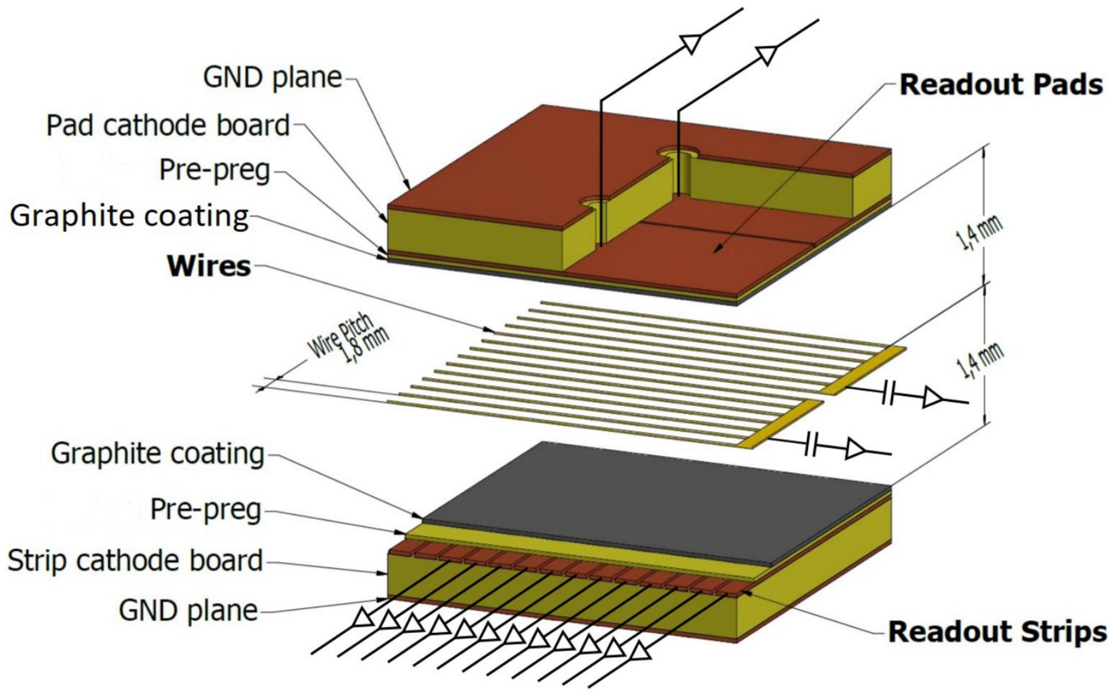
ATLAS-TDR-020

small-strip Thin Gap Chambers (sTGC)

- refined ATLAS TGCs
- 2 graphite coated cathodes
  - 1 Strip + 1 PAD plane
- Anode wires perpendicular to strip cathode operated @ approx. + 2.8kV
- 55% CO_2 + 45% n-pentane

sTGC quadruplet





not to scale

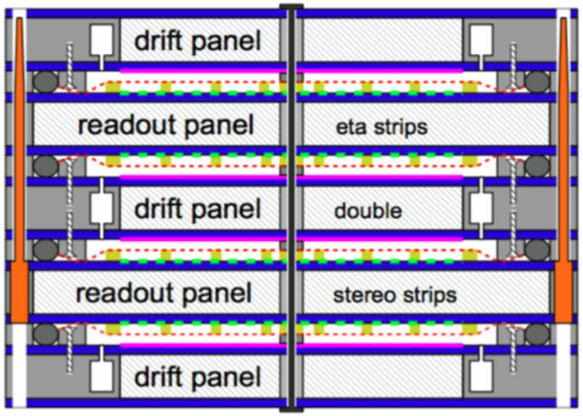
G. Aad *et al* 2024 *JINST* **19** P05063

Micro-mesh Gaseous Structure (Micromegas, MM)

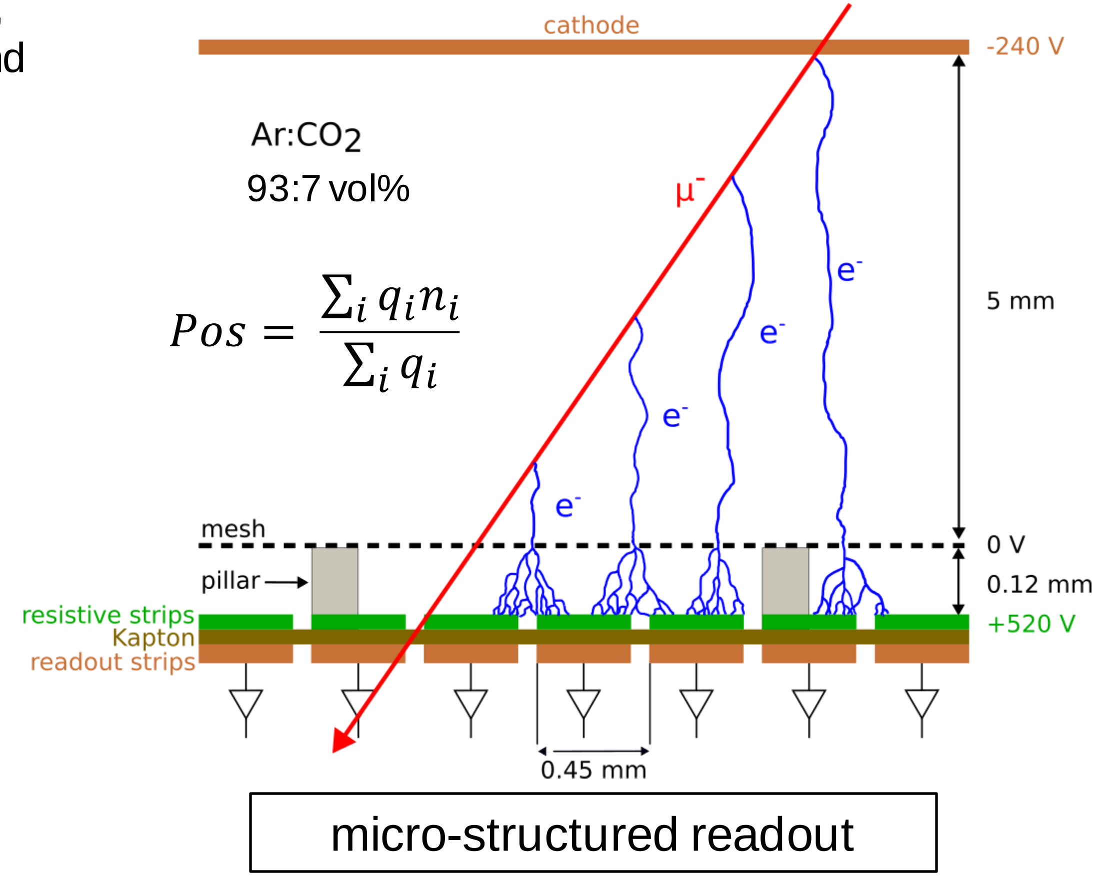
- MM: 3 planar structures (cathode, grounded stainless steel mesh and segmented anode)
- Electrons drift @ $E_{drift} \approx 480$ V/cm
- Gas Gain ≈ 5000 – 10000 @ $E_{amp} \approx 43$ kV/cm

→ Townsend avalanches

MM quadruplet



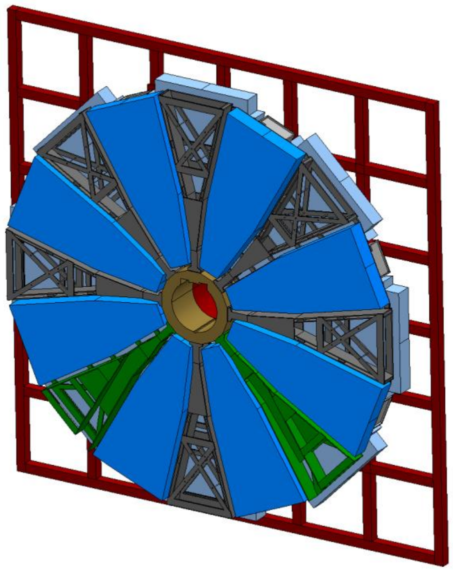
PHD O. Sidiropoulou, adapted



$$Pos = \frac{\sum_i q_i n_i}{\sum_i q_i}$$

PHD F. Vogel (LMU), adapted

Layout of the New Small Wheels



Each NSW is built from 16 sectors:
8 large sectors
8 small sectors

ATLAS-TDR-020

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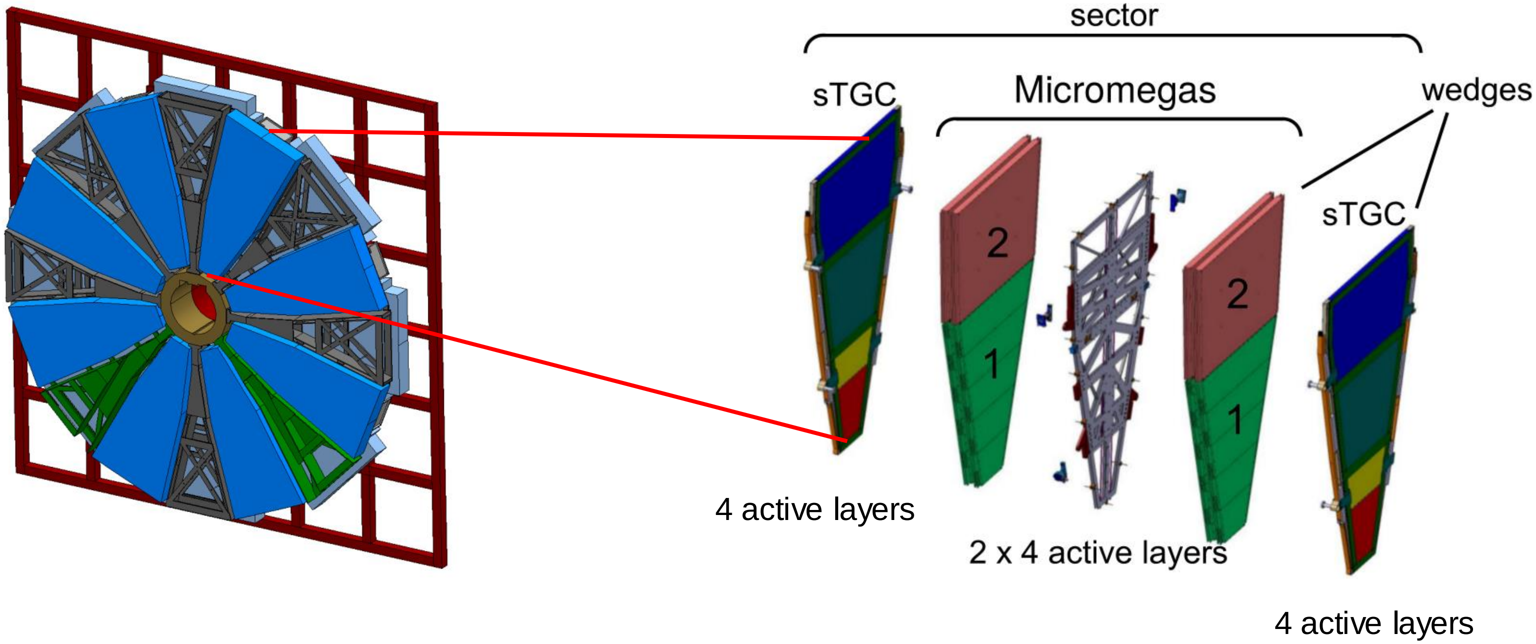
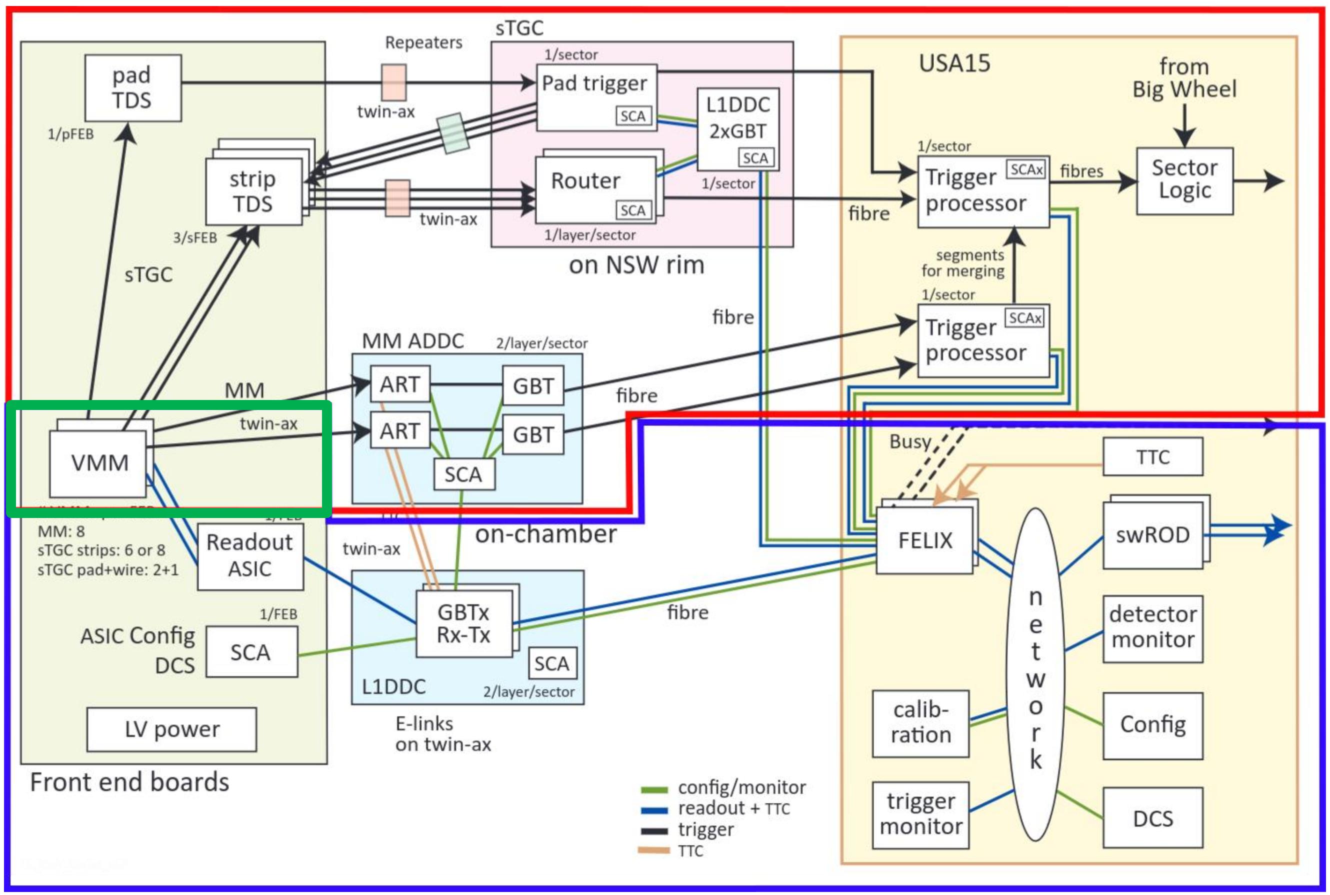


Each NSW is built from 16 sectors:
8 large sectors
8 small sectors

Each sector consists of 16 active layers:
- 8 small-strip Thin Gap Chamber and 8 Micromegas layers
- **2.5 million** readout channels
  → Custom Front-end ASIC (VMM)

ATLAS-TDR-020

Data Acquisition Implementation



Trigger: strip, time

Position: strip, time, charge

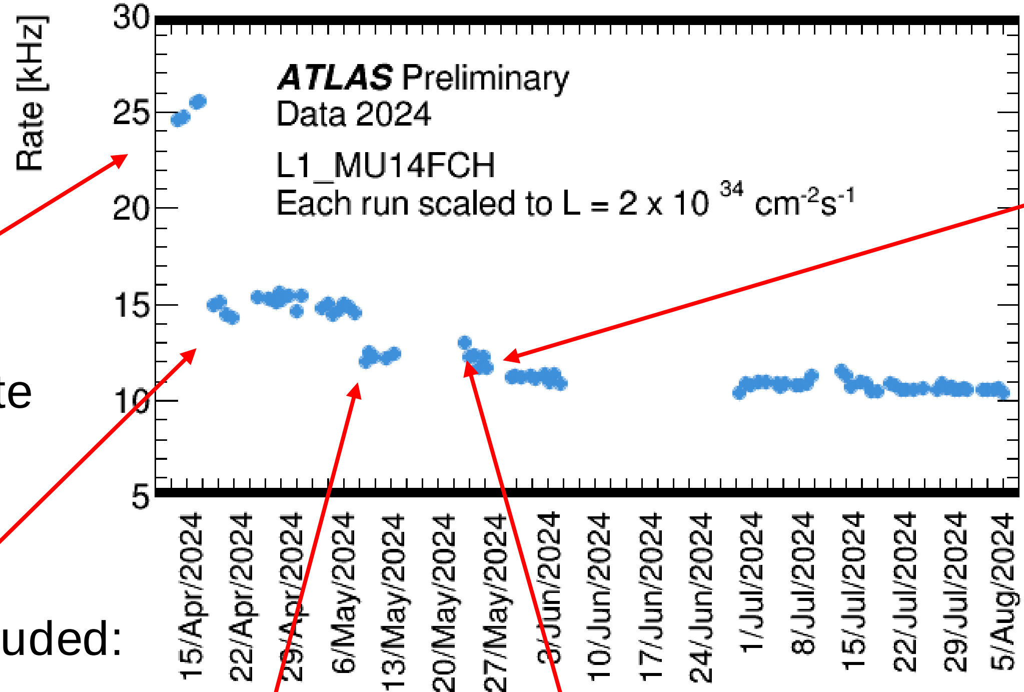
G. Iakovidis *et al* 2023 *JINST* **18** P05012, adapted

The New Small Wheel

CERN-PHOTO-202107-094-105

Part I: Trigger

Evolution of the Trigger Rate during 2024



without NSW:
25 kHz trigger rate

65% of NSW included:
-10 kHz

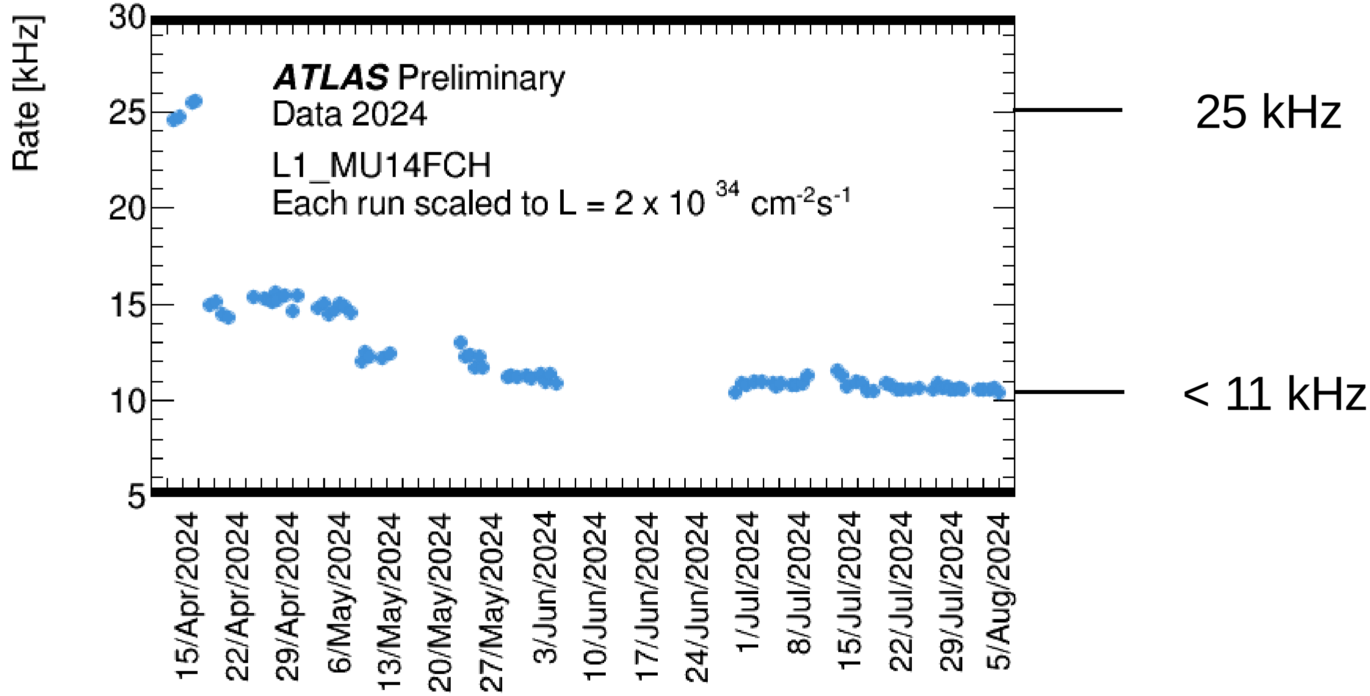
85% of NSW included:
-3 kHz

muon tracks from MM
and sTGC pads added:
+ 1kHz, + increased eff.

100% of NSW
included:
-2 kHz

ATL-COM-DAQ-2024-065

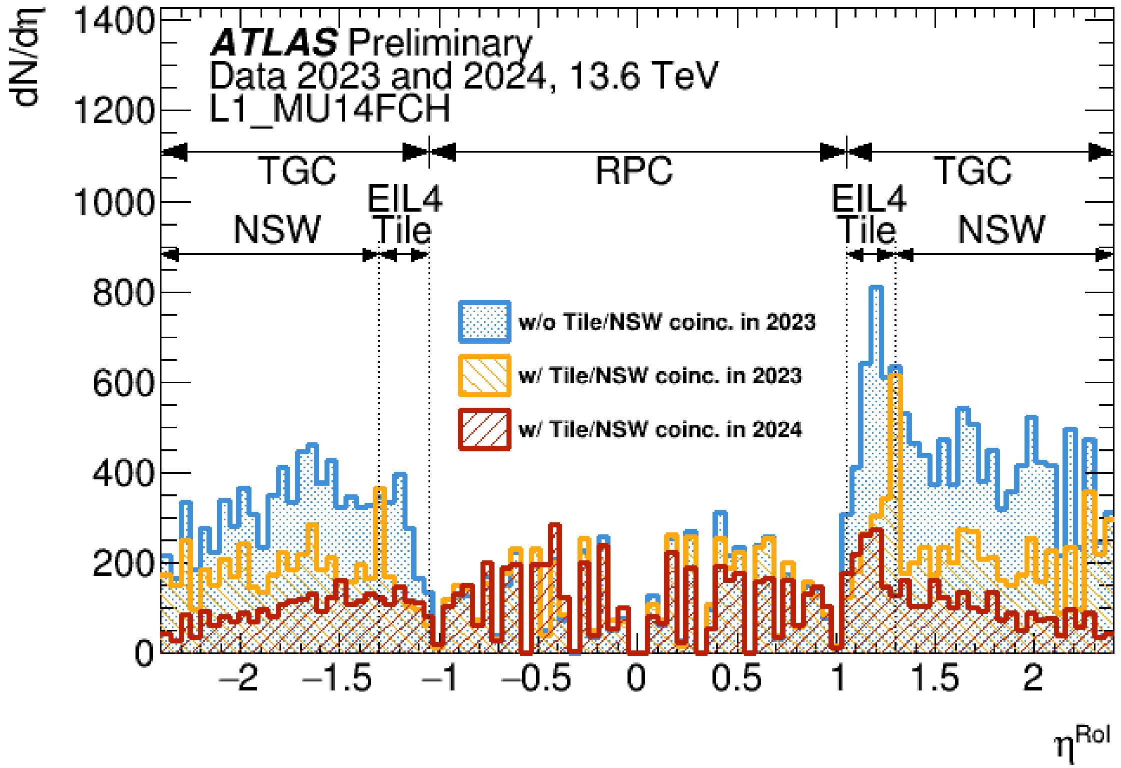
Evolution of the Trigger Rate during 2024



Overall rate reduction: -14 kHz (56%) ✓

ATL-COM-DAQ-2024-065

η-Distributions of the Trigger Rate



w/o NSW

w/ NSW

Homogeneous trigger rate along η achieved! ✓

ATL-COM-DAQ-2024-065

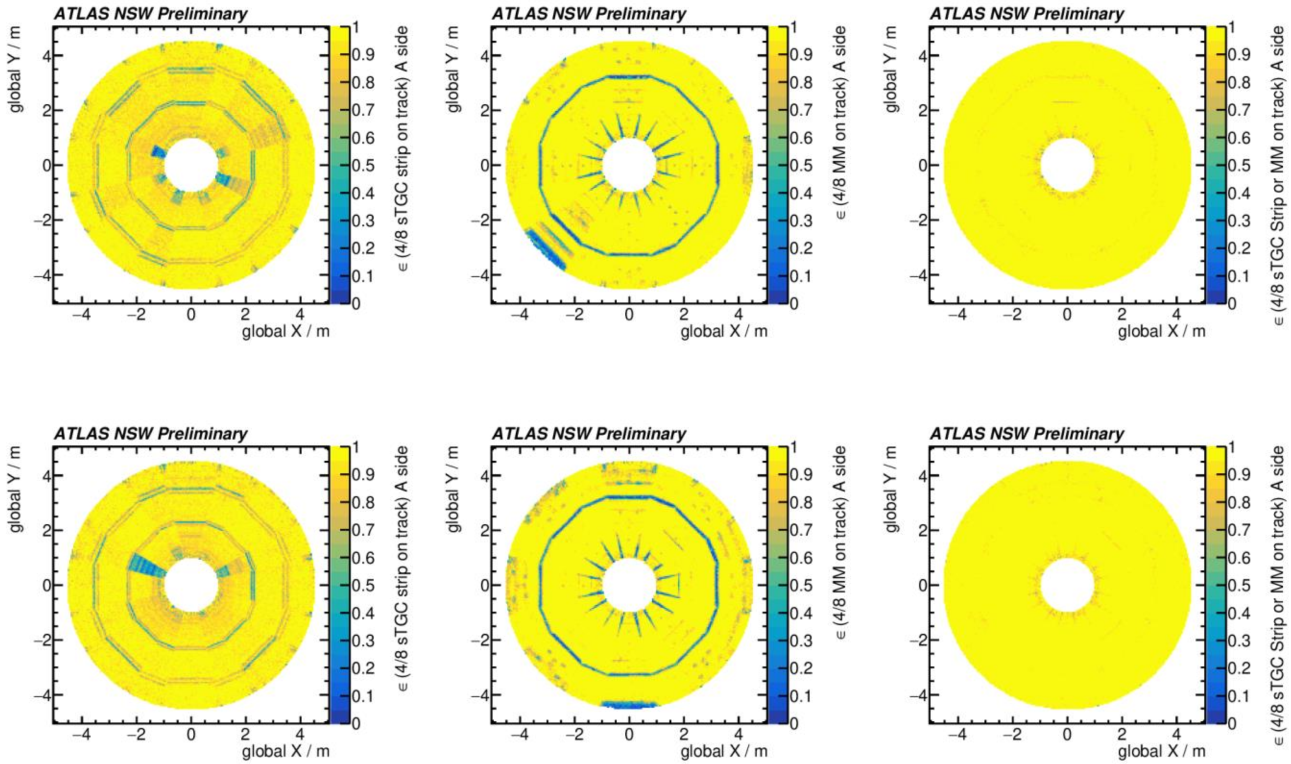
Part II: Efficiency and Resolution

Detection Efficiencies (2024)

4/8 sTGC | 4/8 MM | 4/8 MM or sTGC

NSW-A

NSW-C



construction-related inefficiencies as expected

no construction-related inefficiencies

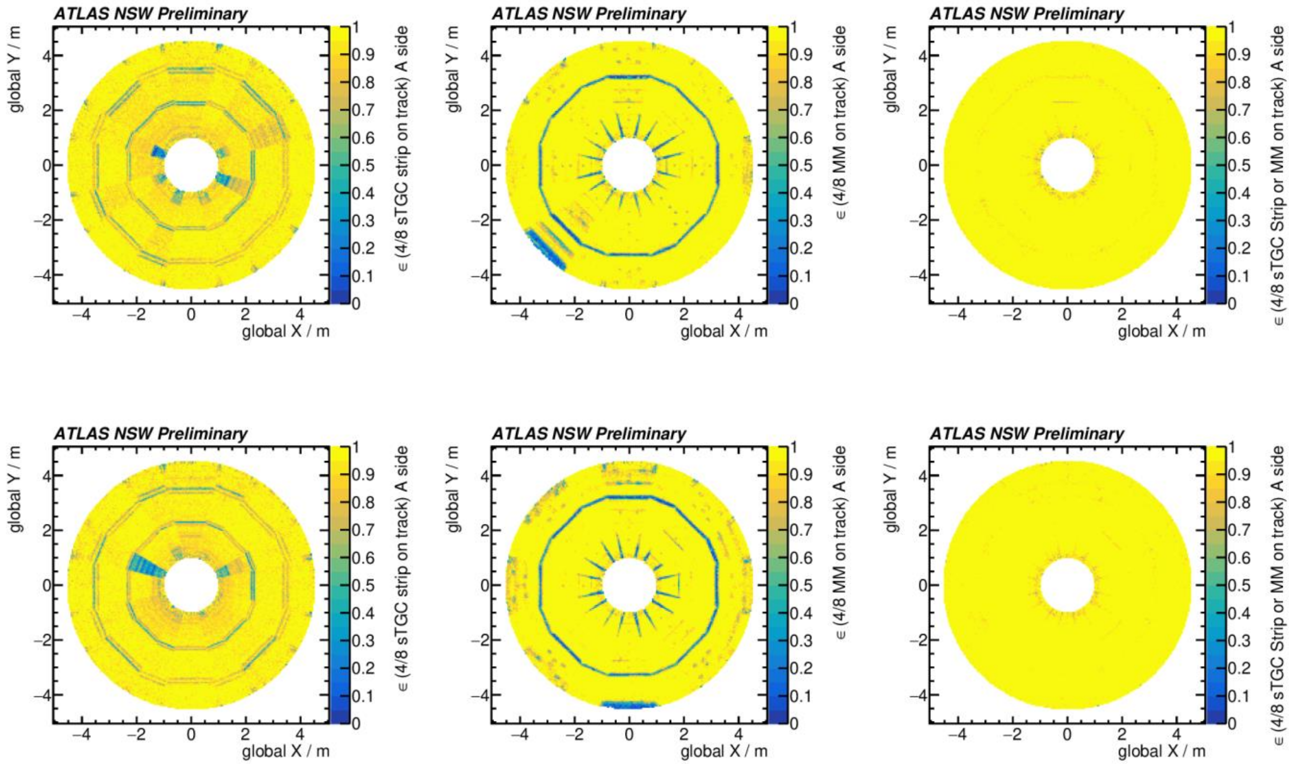
ATL-COM-MUON-2024-011

Detection Efficiencies (2024)

4/8 sTGC | 4/8 MM | 4/8 MM or sTGC

NSW-A

NSW-C



ε > 95% over both NSW surfaces ✓

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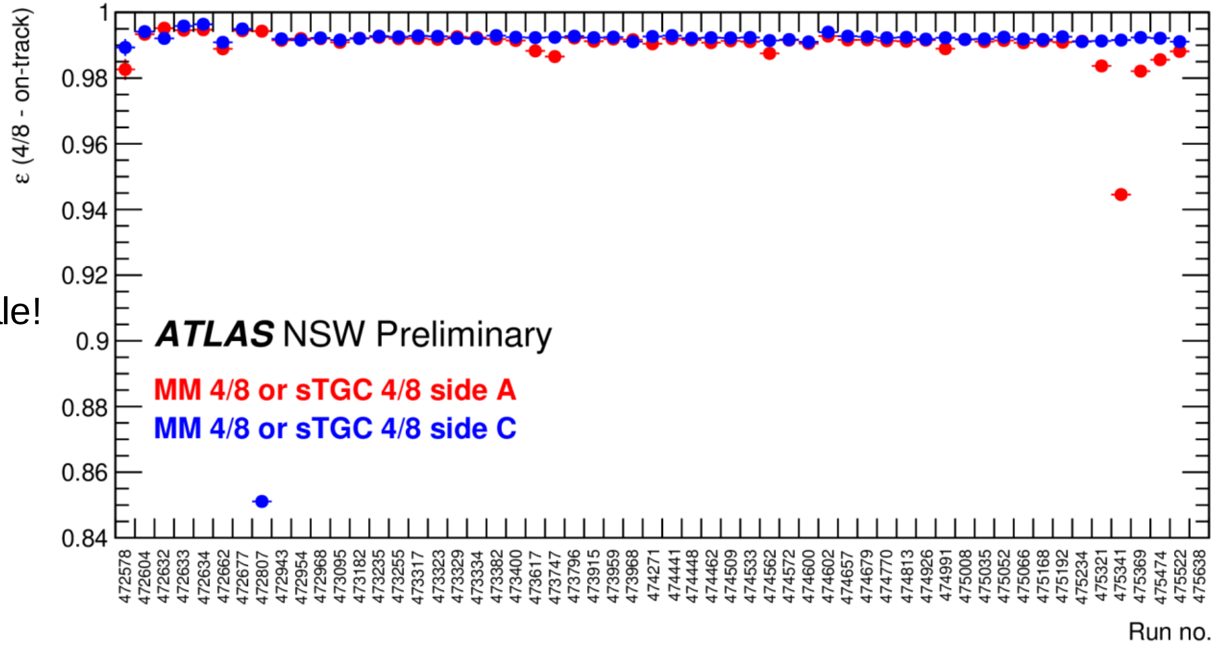
Efficiency in early 2024

expanded scale!



consistently > 98% efficiency ✓

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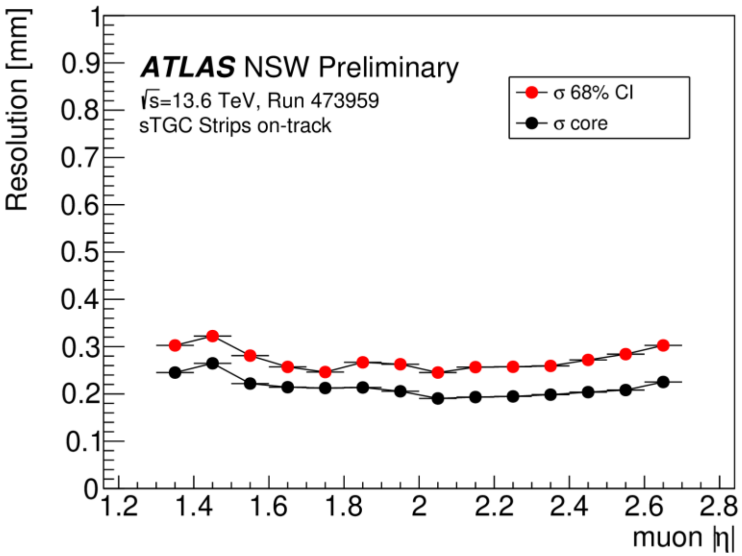
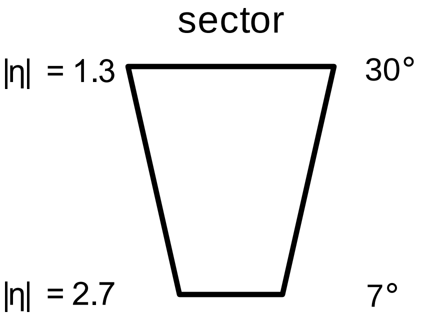
Spatial Resolution

sTGC



O(250 µm) homogeneous



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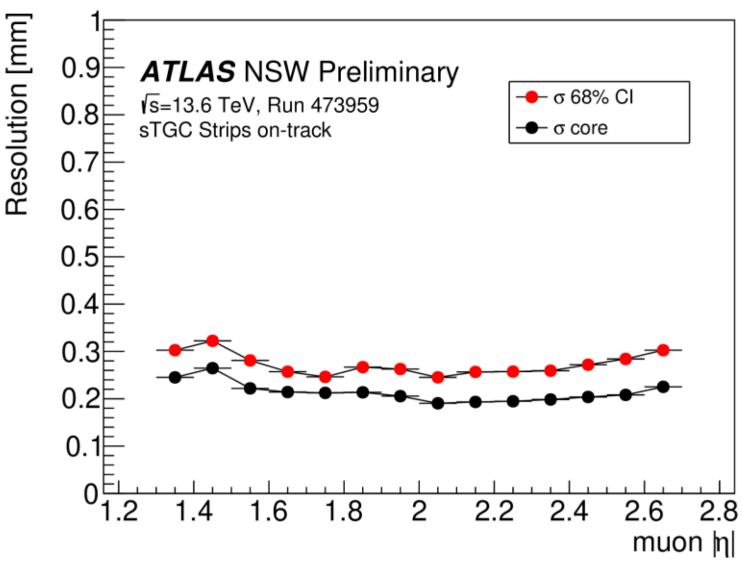

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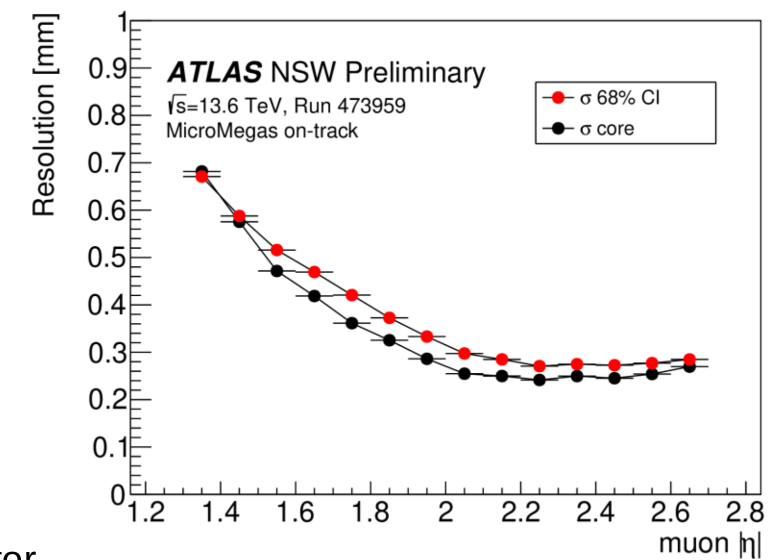
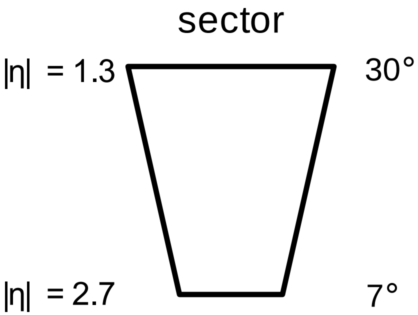
Micromegas





O(250 μm) worsening to 700 μm at large angles

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Spatial Resolution

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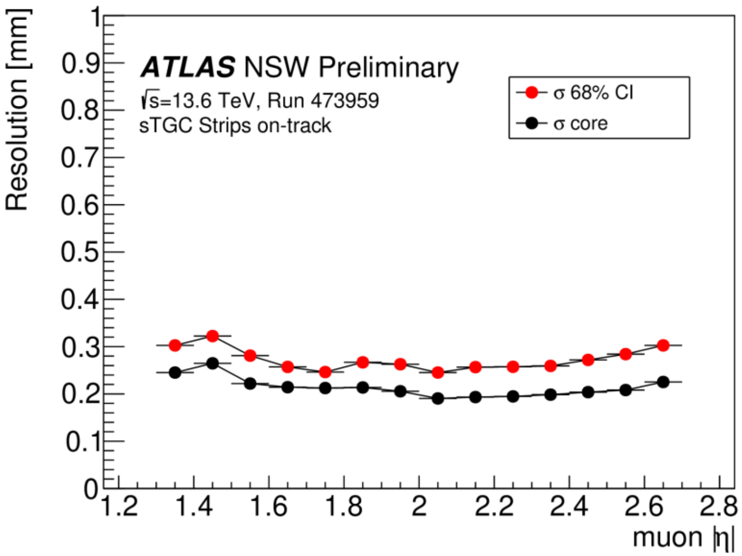

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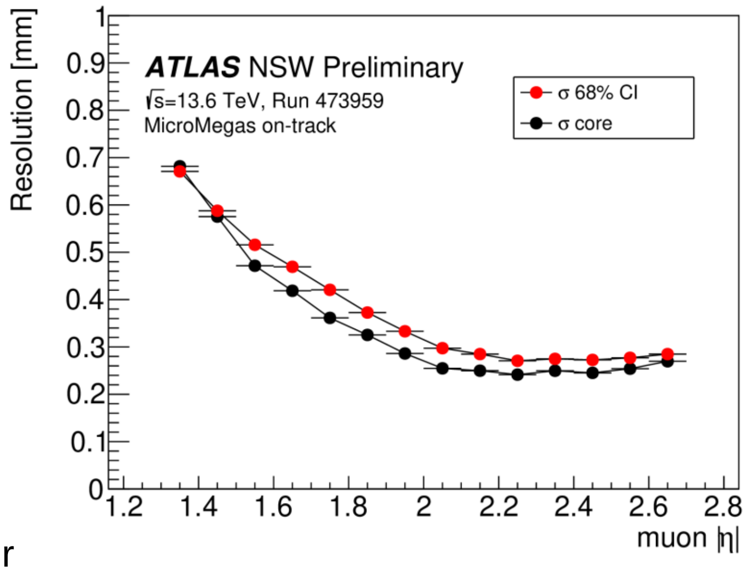

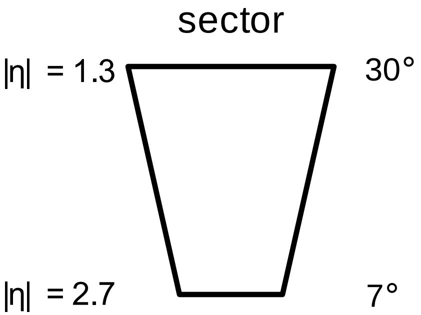

O(250 µm) worsening to 700 µm at large angles

Since:

resolution is a function of the µ angle as expected

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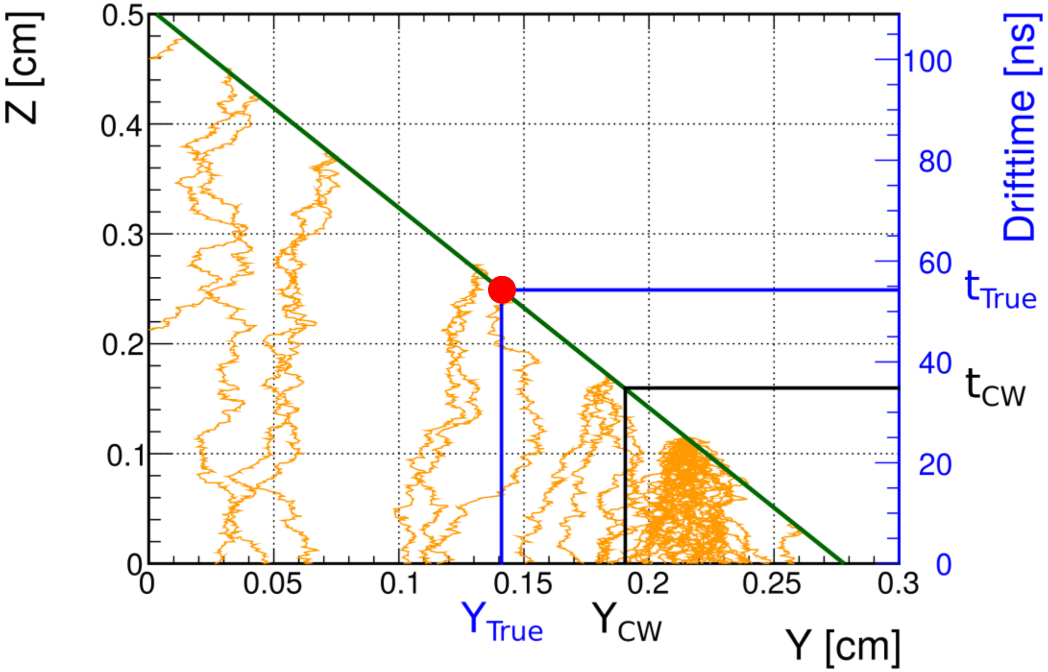
MM: Improved Position Reconstruction at large incident angles

Thin detector: inhomogeneous energy loss of the µ
(at perpendicular incident this plays no role)



Charge weighted position $$Y_{CW} = \frac{\sum_i q_i \times y_i}{\sum_i q_i}$$

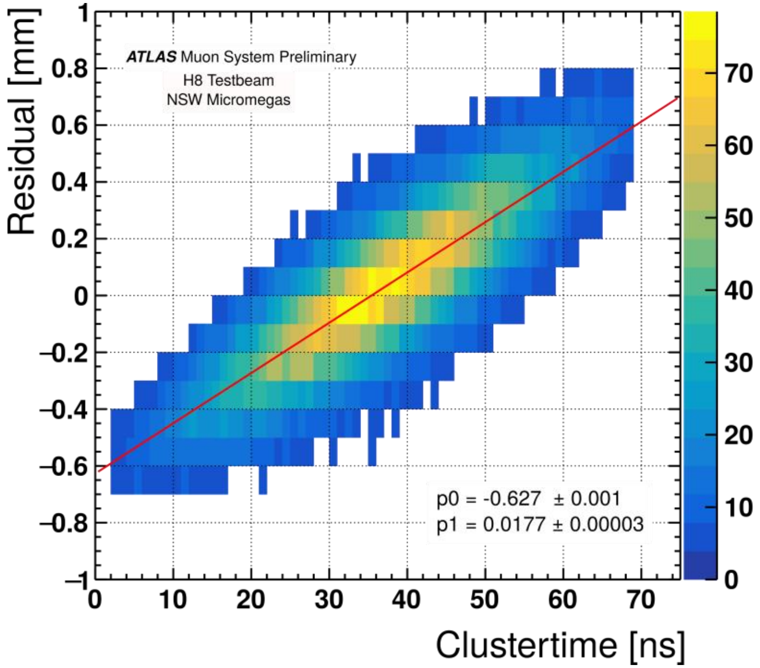
Charge weighted timing $$t_{CW} = \frac{\sum_i q_i \times t_i}{\sum_i q_i}$$

Method developed in PHD B. Flierl (LMU),
figure from PHD F. Vogel (LMU)

Position-Time Correlation

Uncorrected

Residual ∝ Position



Corrected

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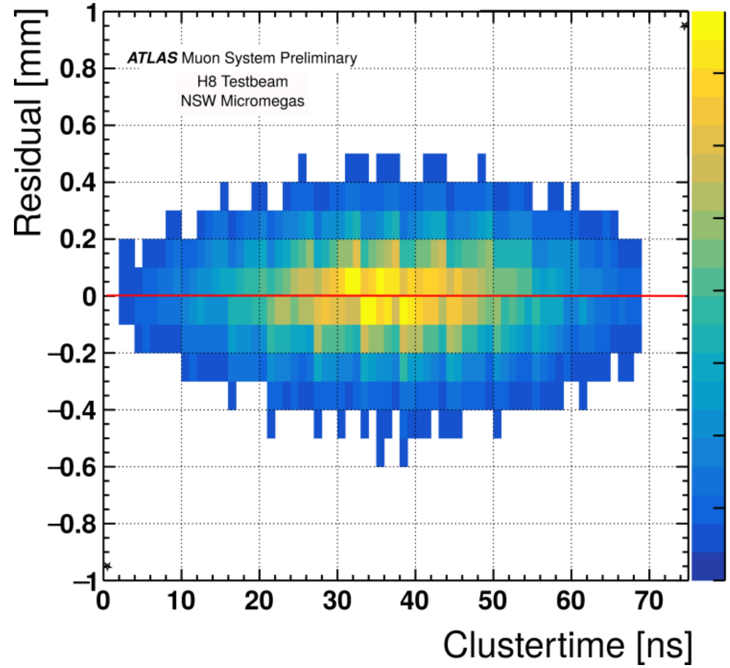

Correlation parameter p_1 is depending on η (incident angle)

→ Precise correction over the whole NSW η range

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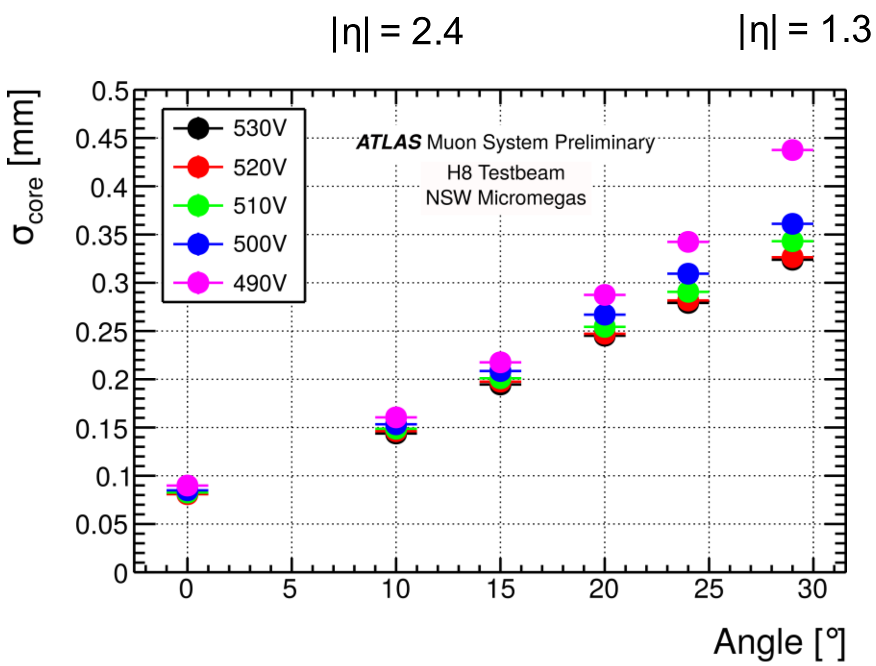
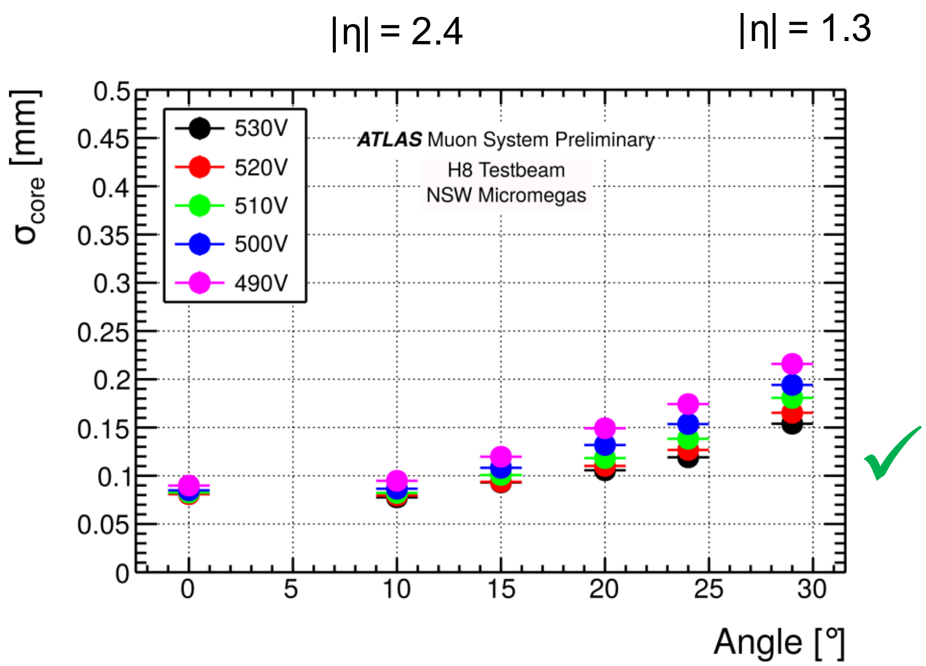
Testbeam

uncorrected Charge Weighted Position



time-corrected Charge Weighted Position



Strongly improved spatial resolution

→ Now under implementation in ATLAS

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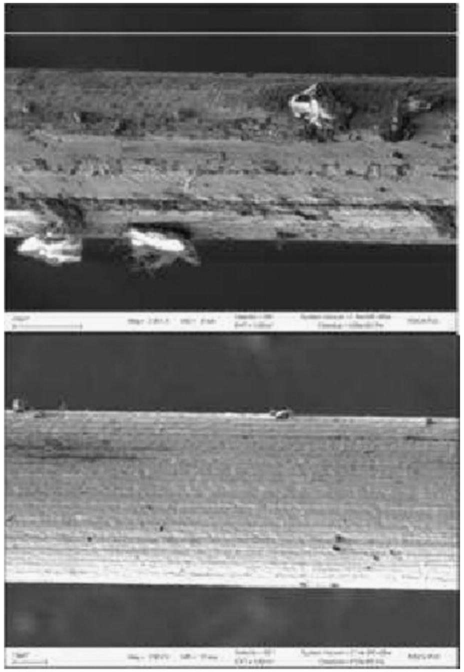
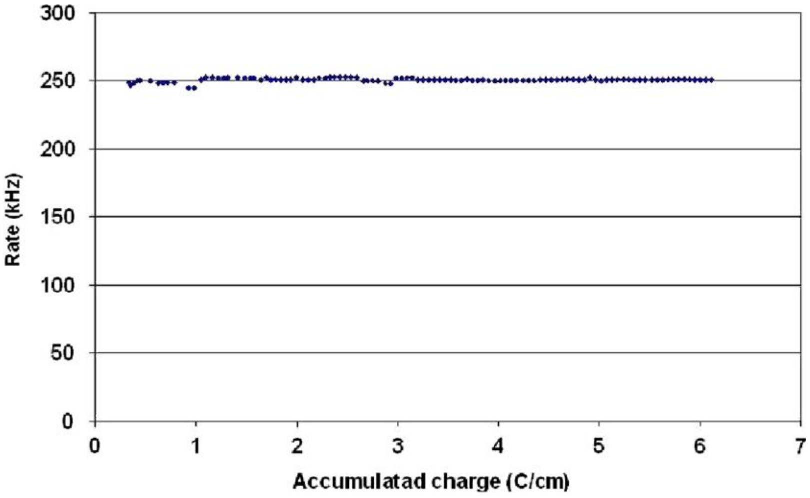
Part III: Aging

Long-term Irradiation Tests (sTGC)

Irradiation studies ~ 6 C/cm using a ^{90}Sr source (6x HL-LHC)





few wide-spread, tiny depositions

No deterioration of the detector performance ✓

DOI: 10.1016/j.nima.2010.06.311

Long-term Irradiation Tests (MM)

Prototype Irradiation with different particles

- **X-rays** (918 mC ~5y of HL-LHC; safety factor 7)
- **Cold Neutrons** (neutron flux ~5y of HL-LHC; safety factor 10)
- **Gammas** (gamma flux ~5y of HL-LHC; safety factor 3)
- **Alphas** (Detector operated at constant discharge for 66 h)

DOI:10.1088/1748-0221/8/04/P04028

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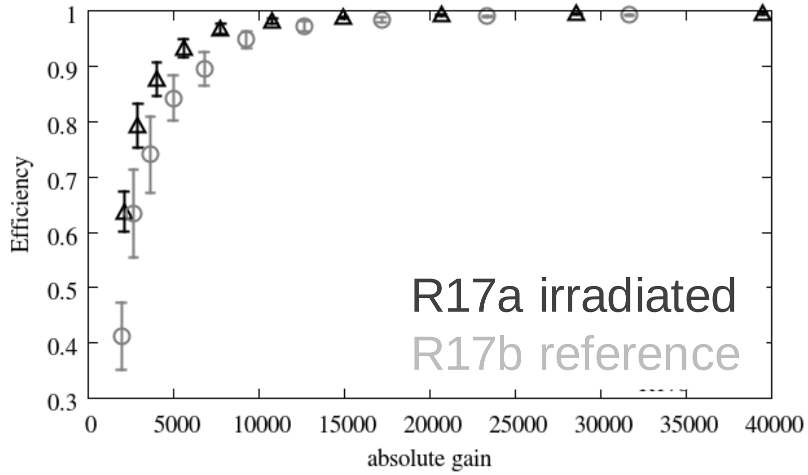
- Efficiency comparison at SPS H6 beam line ()



Perfect detection efficiency after irradiation ✓

DOI:10.1088/1748-0221/8/04/P04028, adapted

$Ar:CO_2$ 93:7 → $Ar:CO_2:iC_4H_{10}$ 93:5:2

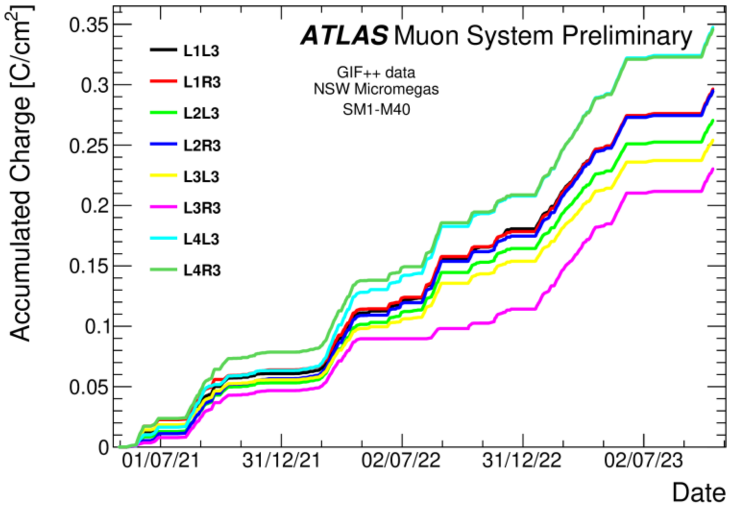
HV Stability is **improved** for large-area MM by changing the operating gas

Long-term Irradiation Tests (MM) Part 2

Spare modules irradiated under the ternary gas mixture $Ar:CO_2:iC_4H_{10}$

- 14 TBq ^{137}Cs at GIF++ (~10y HL-LHC; no safety factor; ongoing)
- 10 GBq Am-Be neutron source at LMU (2y of irradiation at 3x HL-LHC equivalent neutron fluxes)

GIF++ irradiation



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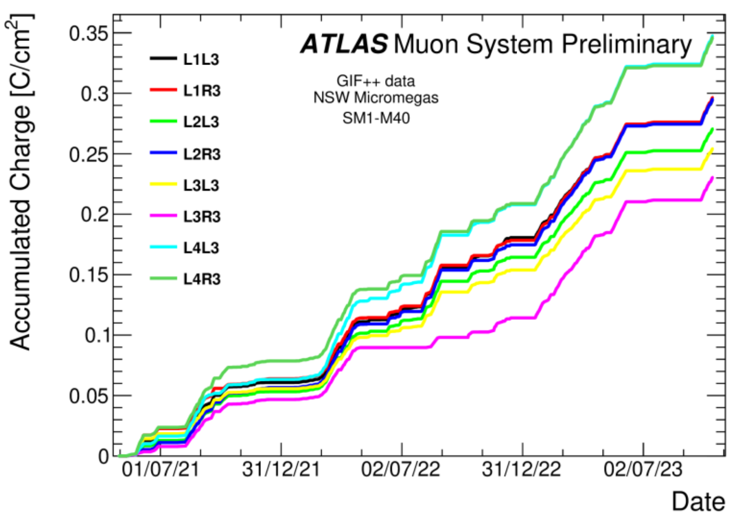
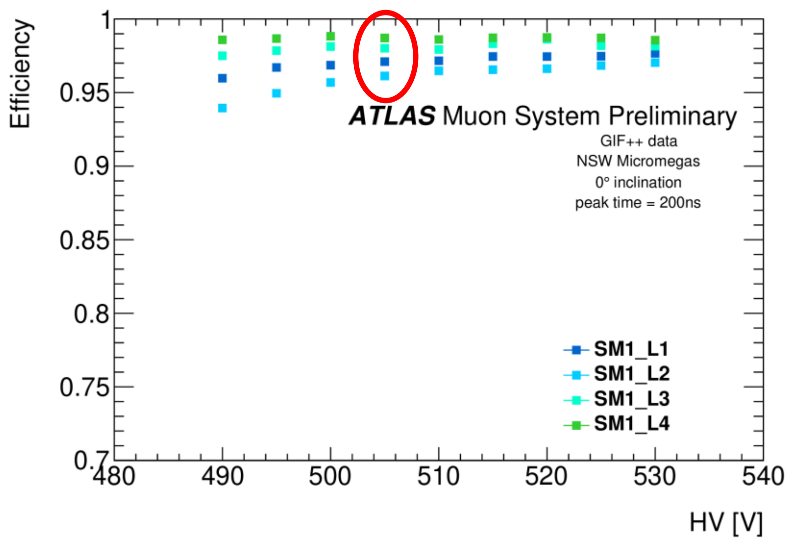


after irradiation



Excellent detection efficiency after 10y HL-LHC irradiation equivalent → no aging ✓

ATL-COM-MUON-2023-044

Conclusion

Performance at High-Luminosity (HL) LHC (factor 3.75 higher) as good as SW detectors at low luminosity:

- Trigger:
  - Trigger rate reduction to ~20kHz ✓
  - Online track segment reconstruction in full η ($1.3 < |\eta| < 2.7$) ✓

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  - Efficiency >97% for muons of $p_T > 10$GeV ✓

- General:
  - No detector aging (~1C/cm^2) ✓
  - High-background tolerance 20 kHz/cm^2 ✓
  - High precision manufacturing O(40 µm) ✓

Additional Material

Data Acquisition System

Prerequisites:

- 2.5 **million** readout channels
- precision readout and fast trigger
- High-background capable at HL-LHC (>20 kHz/cm^2)
- radiation tolerant
- operation in magnetic fields

Readout Technology:

VMM3a: a custom front-end ASIC designed for Micromegas and sTGCs
GBTx: GigaBit Tranceiver, fast interface (4.8 Gb/s) between detector and processing unit outside ATLAS
FELIX: Front End Link eXchange, data transporter
swROD: software Read Out Driver, detector specific data processor

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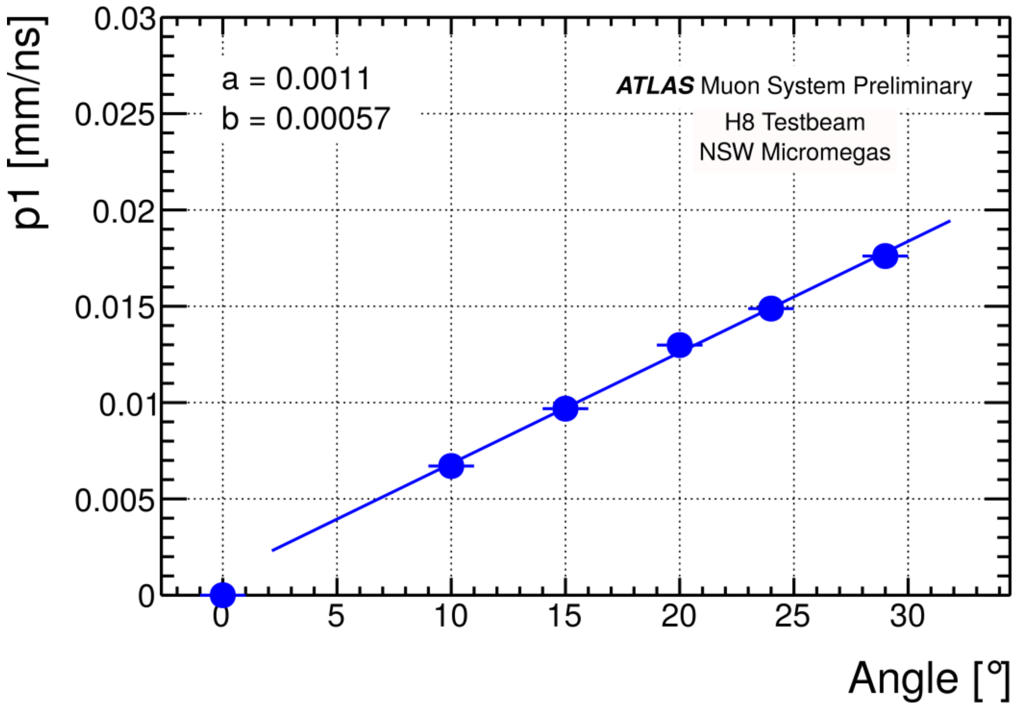
Time Corrected Centroid Correlation Parameter



Correlation parameter between Charge weighted Time and Charge weighted Position
→ Linearly dependent on the μ track angle

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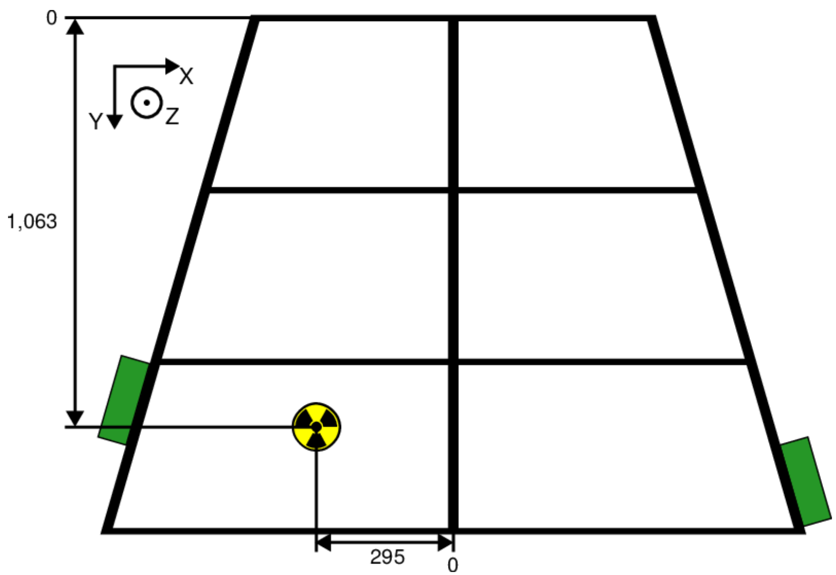
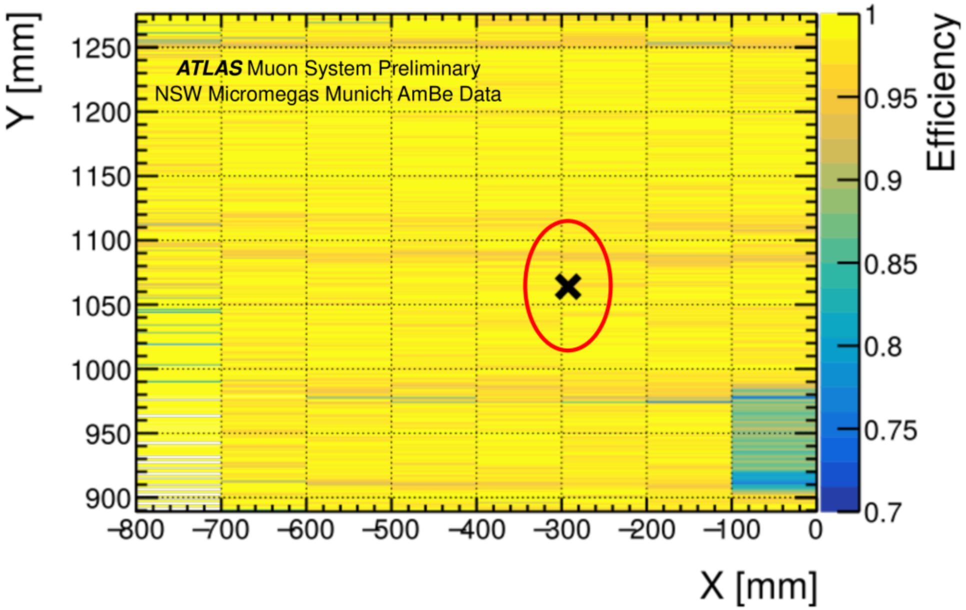
Neutron irradiation at LMU

Spare NSW MM module (locally) irradiated over 2 years with a 10 GBq Am-Be neutron source (neutron flux 3x HL-LHC)



cosmic muons after irradiation



No local efficiency deterioration observed ✓

PHD F. Vogel (LMU)

ATL-COM-MUON-2023-044