ATLAS NSW Micromegas GIF++ studies

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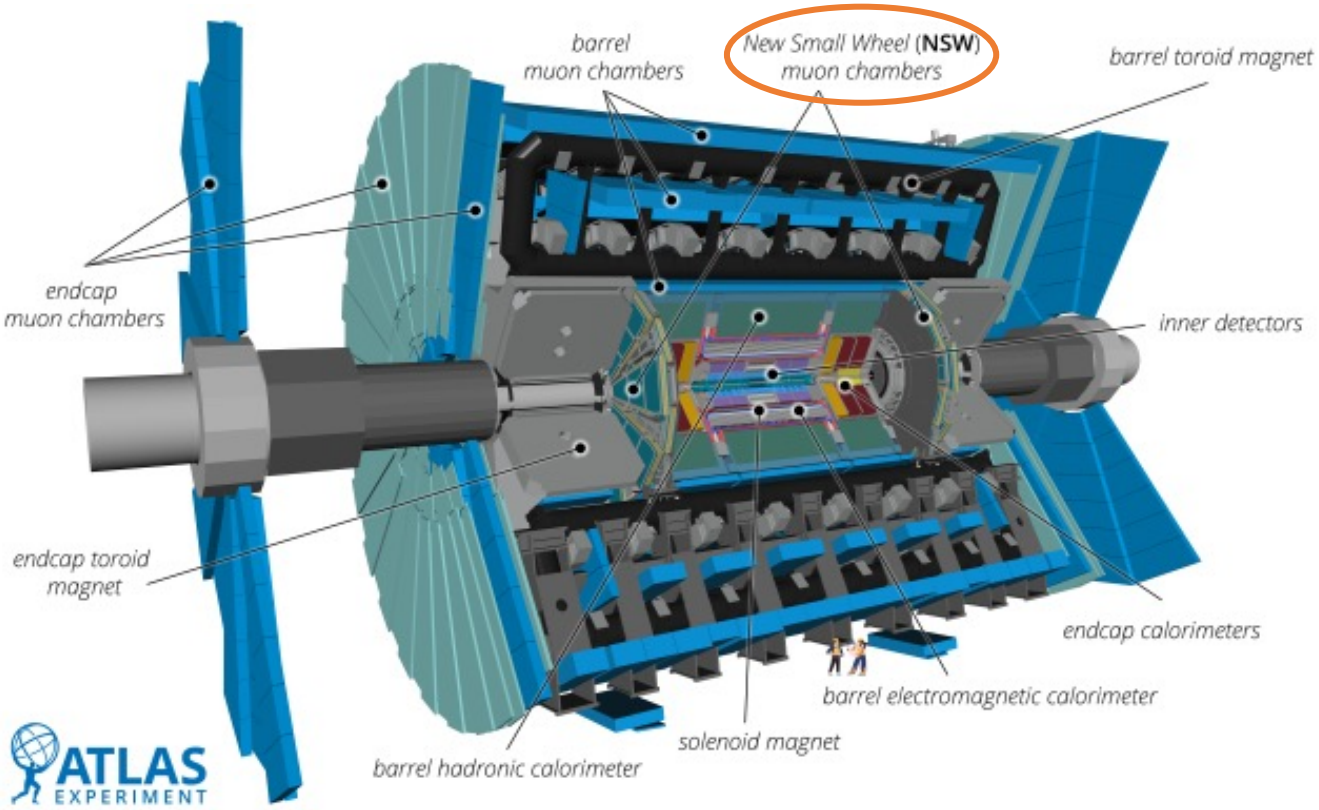
on behalf of the ATLAS Micromegas Team

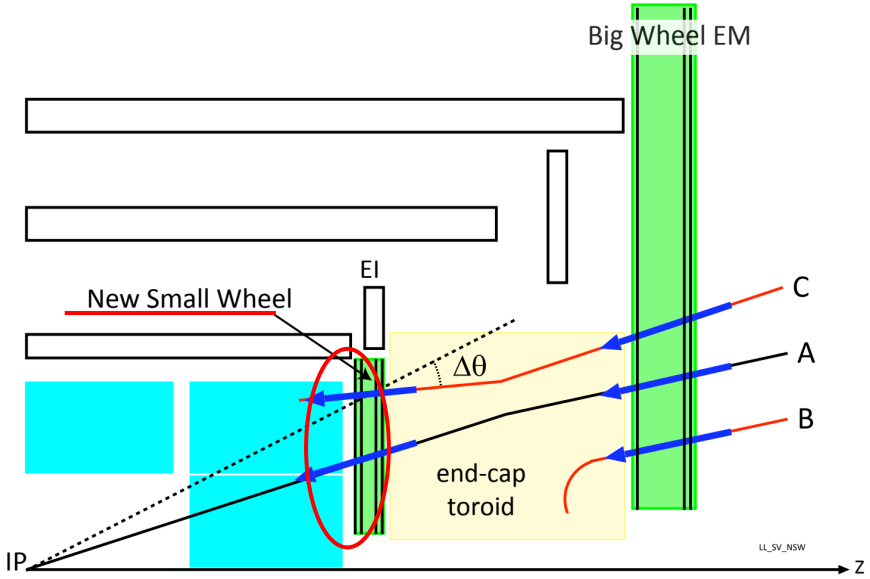
GIF++ Annual Users Meeting
03/12/2024

ATLAS New Small Wheel

- HL-LHC expected luminosity of $\mathbf{5-7\times10^{34}\ cm^{-2}s^{-1}}$, > 5 times the nominal!
  → Huge increase of particle rates, up to 35 kHz/cm^2 in the End-Cap
  → decrease of muon tracking performances

- Background hits originate mostly from low energy **photons** and **neutrons** generated by proton collisions

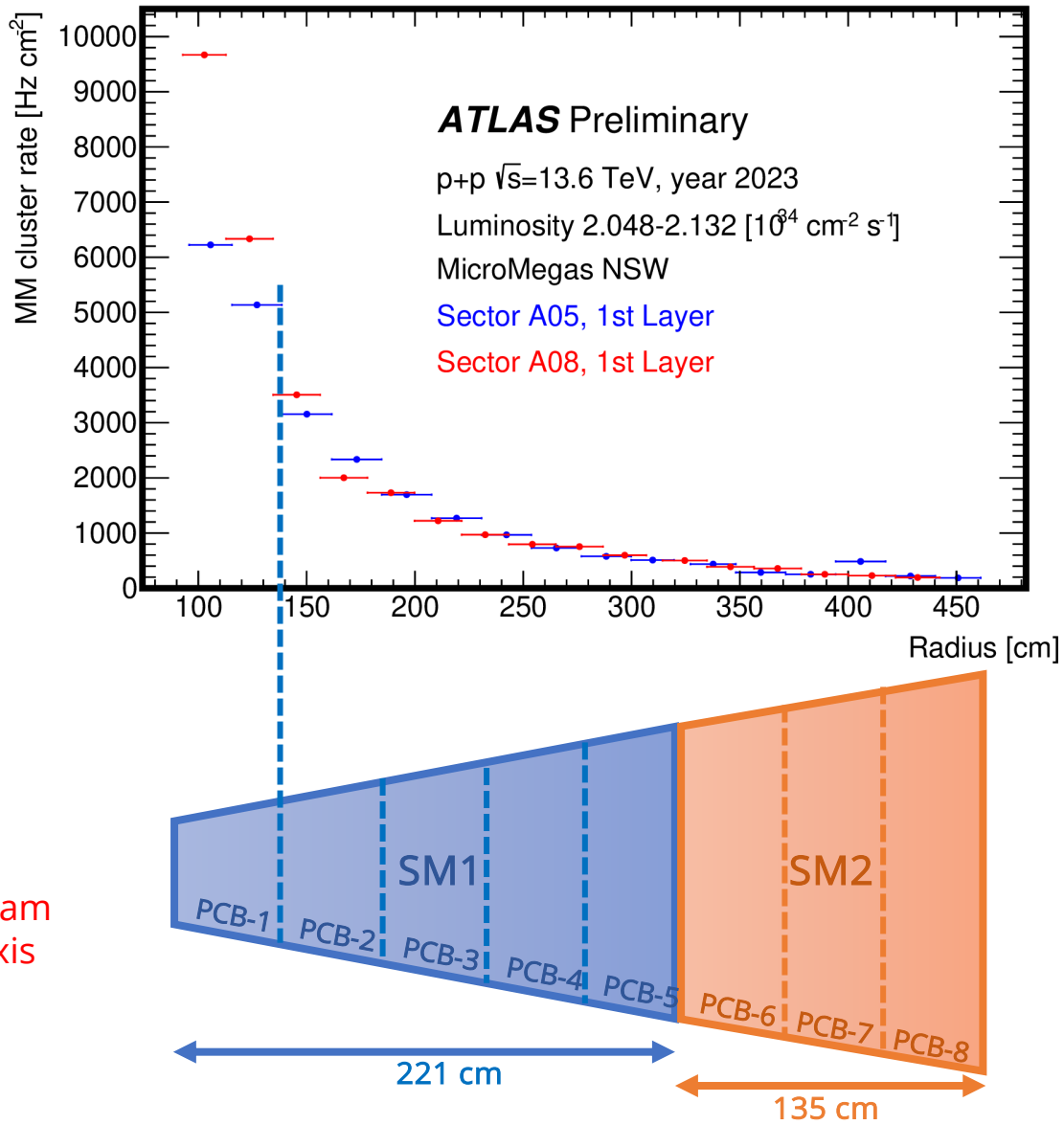




- New Small Wheels (NSW) operating in ATLAS Run3
  → sTGC and Micromegas (MM) for trigger and reconstruction
  → Redundancy with multiple detector layers:
  8 Micromegas and 8 sTGC

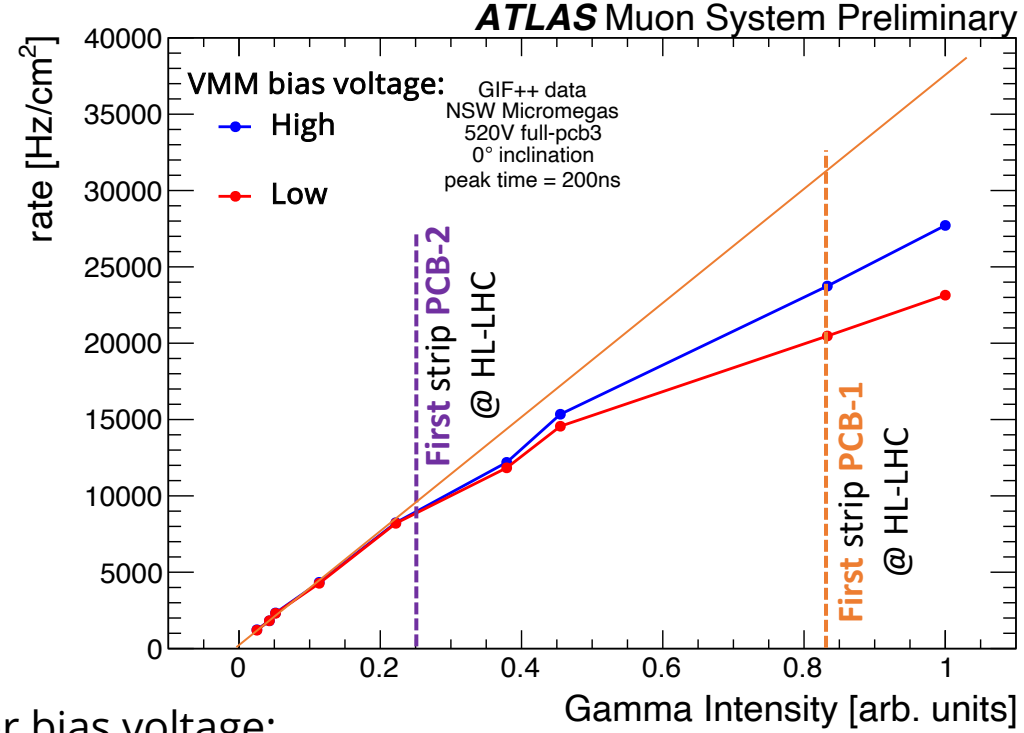
- Designed to provide an important reduction of the trigger rate and of the fake-track reconstruction in the $1.3 < |\eta| < 2.7$ region of ATLAS:
  - **$\sim$100 μm spatial resolution required by design**

Expected rates for HL-LHC



Rate values obtained scaling the measurements in ATLAS on Micromegas chambers to the luminosity expected at HL-LHC

- Highest rate only on the first strips of PCB-1:
  → up to $32\ kHz/cm^2$
- PCB-2 already a factor ~3 less in rate!!



Larger bias voltage:
→ faster restoration of the baseline
→ recovering partially hit occupancy

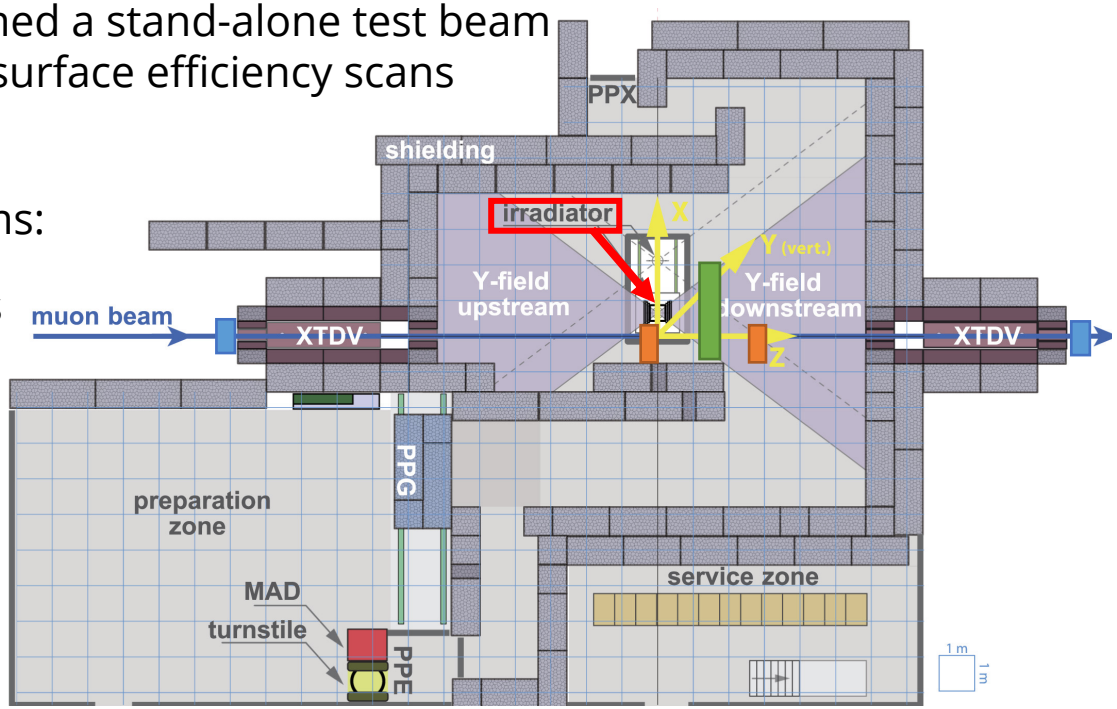
GIF++ facility and setup

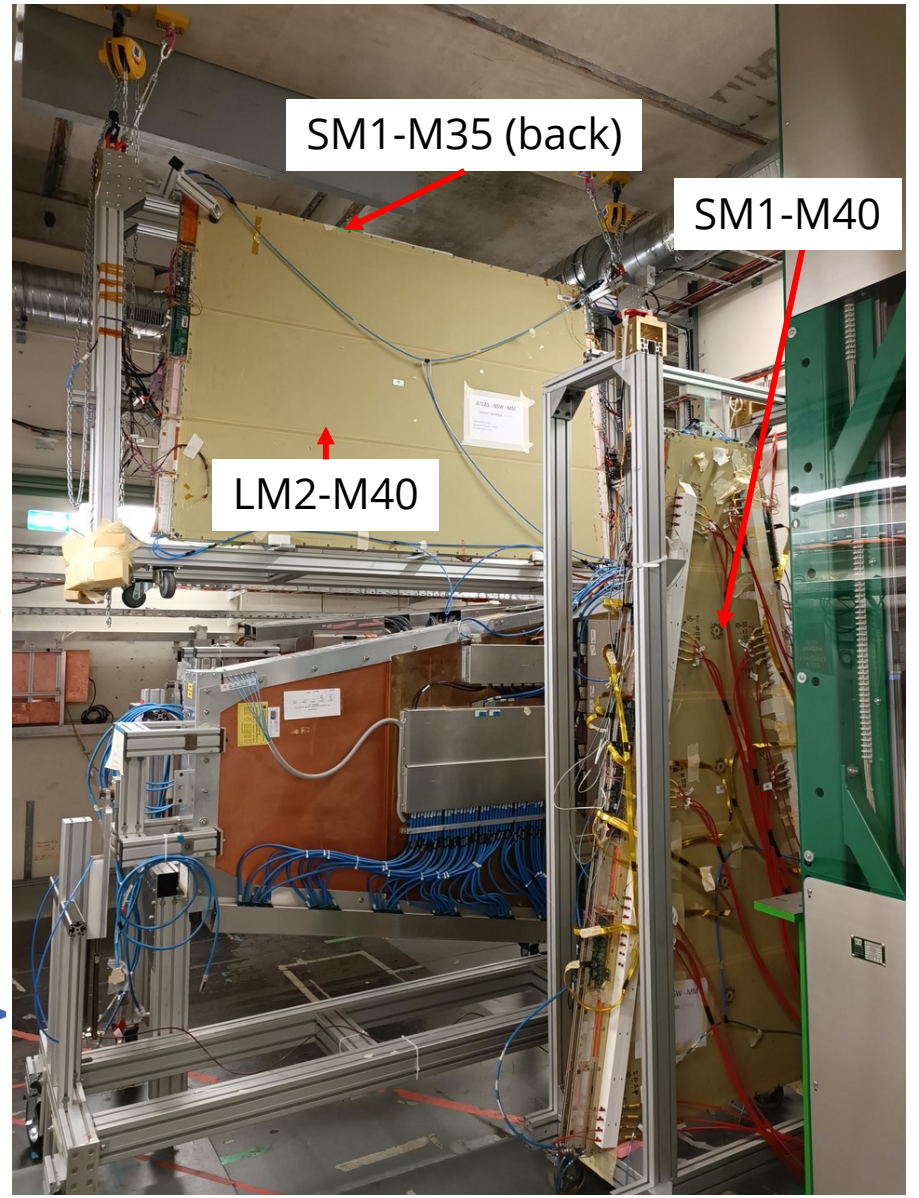
- 3 chambers constantly in GIF++ bunker in downstream area
- 1 standing in front of the source, and 2 on the hanging trolley
- Operating with $Ar:CO_2:iC_4H_{10}$ 93:5:2 vol% and $Ar:CO_2$ 93:7 vol% from premixed bottles
- In 2024 not participated in any GIF++ test beam, but planning to do it in 2025
- In June 2024 performed a stand-alone test beam in H8 with pions for surface efficiency scans

During GIF++ test-beams:

- Trigger from facility's scintillators outside the bunker
- 4 small $40\times40\ \mathrm{cm}^2$ tracking chambers

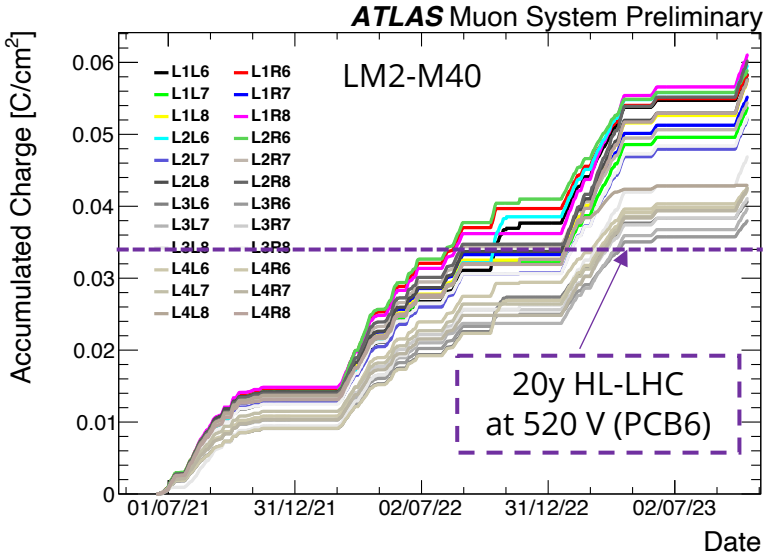
MM chamber
Tracking chamber
Scintillator

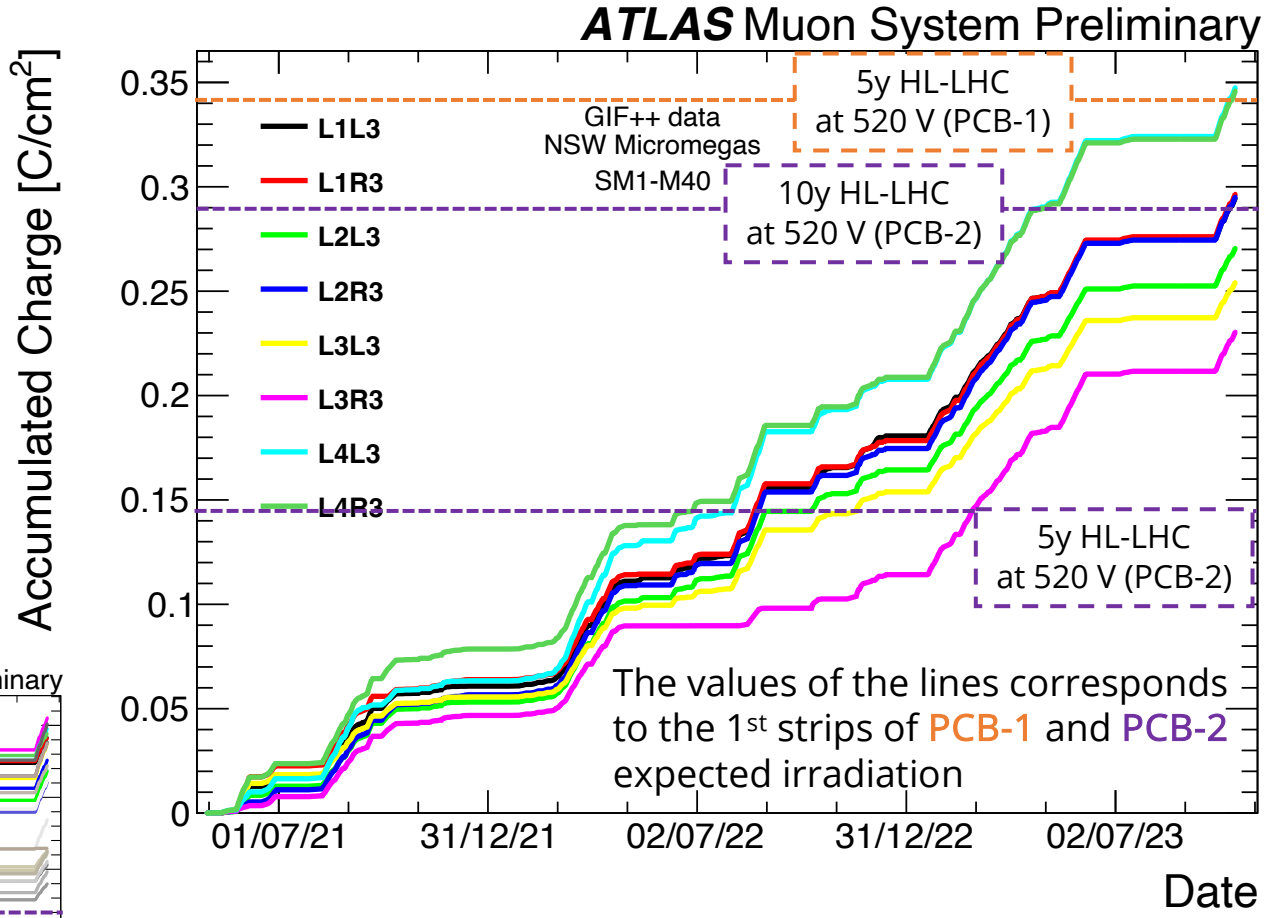




Irradiation of Micromegas detector

- Irradiation started in 2021 and measured in terms of charge accumulated by the detector
- Values scaled to the areas of the interesting PCBs
- Large difference of expected irradiation between the 1st strip of PCB-1 and PCB-2 :
  - Almost a factor 3 less for PCB-2 being 43 cm further from the beam axis
- Several years of HL-LHC equivalent have been accumulated so far on the detectors
- No general decrease of performance observed in periodic H4/GIF/H8 test beams

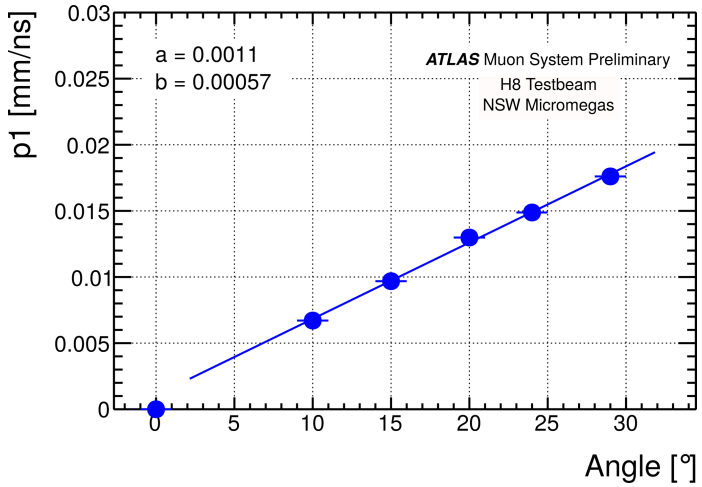


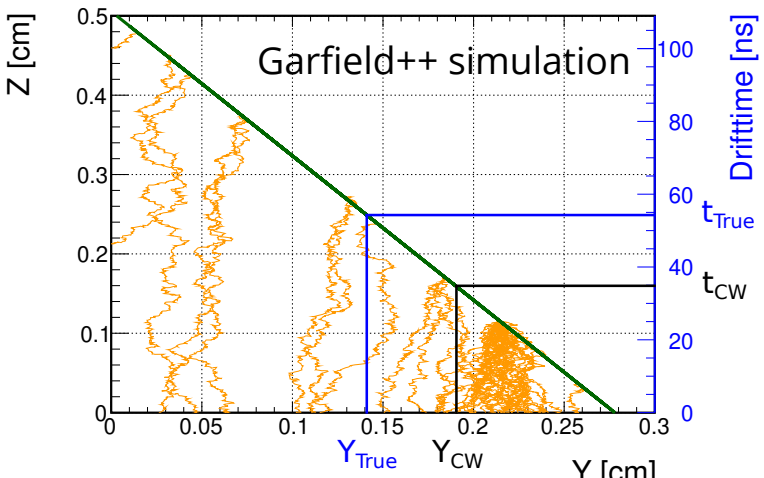


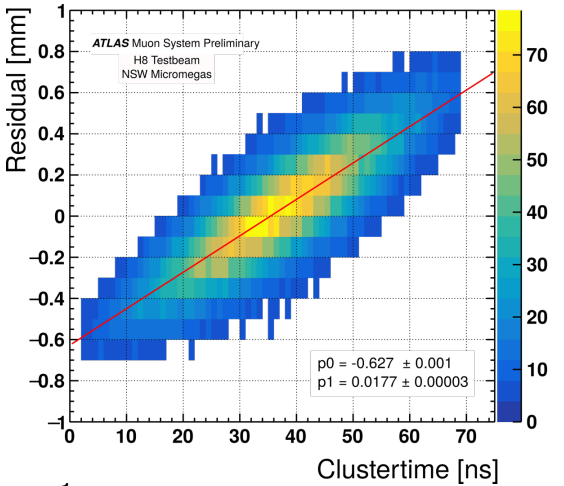
Validated the Ar+5%CO_2+2%iC_4H_{10} gas mixture against ageing for ATLAS Micromegas detectors!

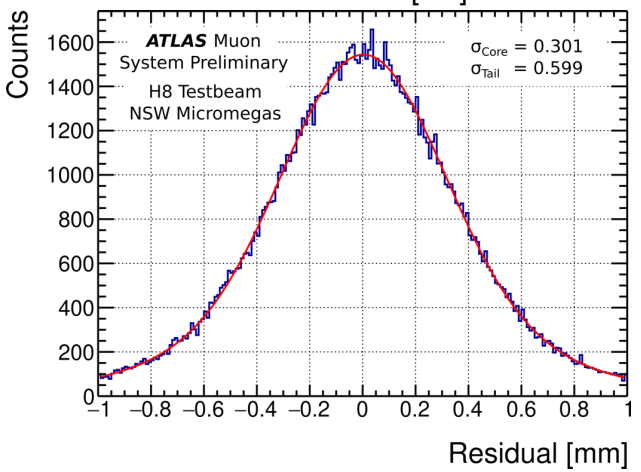
Spatial resolution inclined tracks

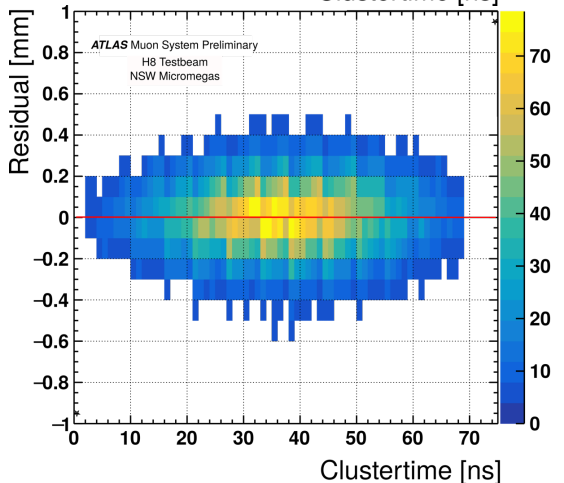
- Landau-shaped energy loss of MIPs in thin gaseous detectors shifts the charge deposit, biasing the charge centroid position
- With inclined tracks, a correlation arises between position residuals and cluster time: $t_{cluster} = \frac{\sum_i t_i \cdot q_i}{\sum_i q_i}$
- Residuals can be corrected fitting the 2D correlation plot, as for alignment corrections → Linear fit: $a + b \cdot t_{cluster}$
- Correlation parameter a scales linearly with angle → Extrapolatable!
- Constant parameter b is only a shift of the residual → Correctable!

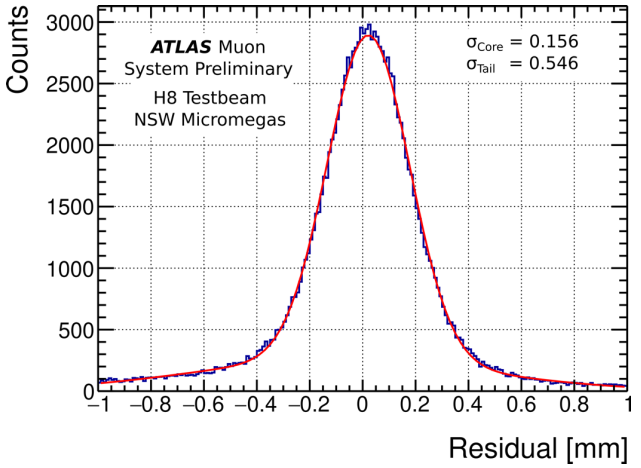






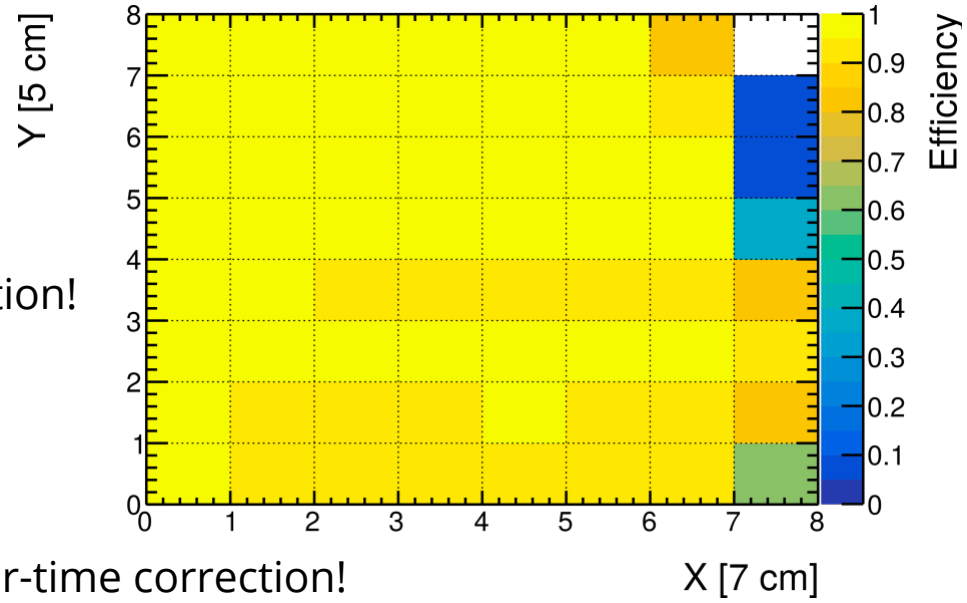


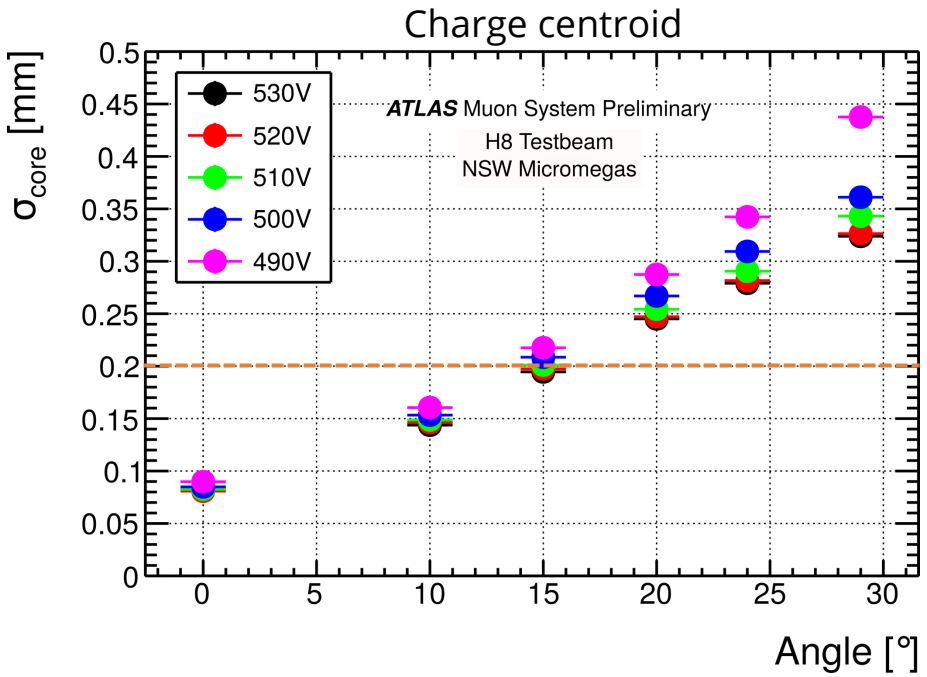


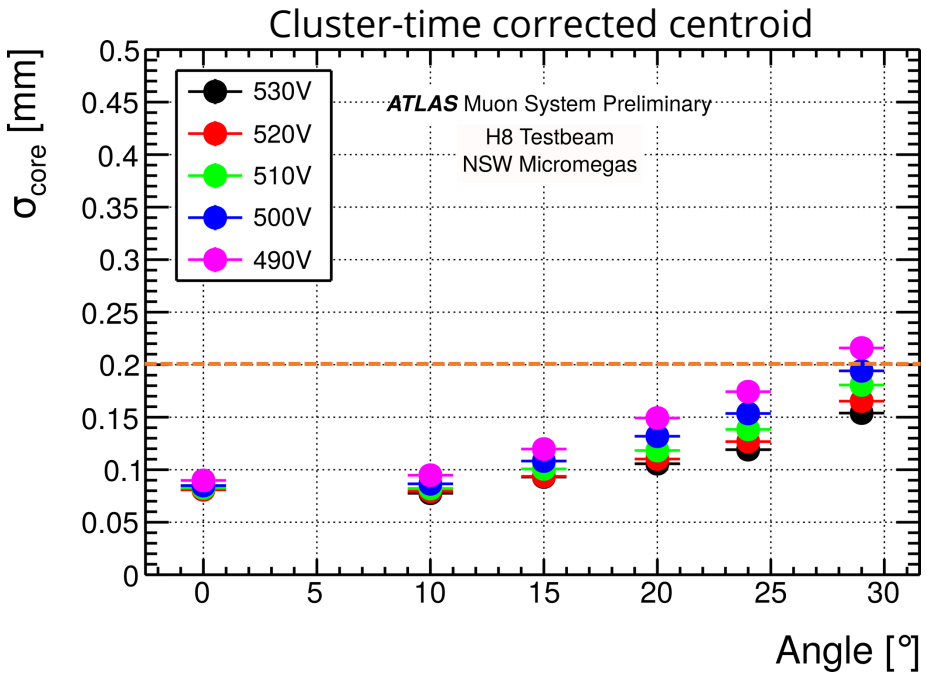


H8 beam time results

- Efficiency > 90% across the detector surface, no degradation after irradiation!
- Decrease only on inactive PCB edge, as expected
- spatial resolution: 80 μm (490 V) – 60 μm (530V) achievable for all 4 layers
- Huge improvement in spatial resolution obtainable by applying the cluster-time correction!
- Reaching 150 um resolution for 29° inclined tracks at high amplification gain







Summary and plans for 2025

- Smooth operations in GIF++ as always! Thanks to Giuseppe, Paolo and all the teams!
- **Reached several years of HL-LHC equivalents** and continuing irradiation program at GIF++
- **No decrease of performance seen on irradiated chamber, with very good HV stability!**
- **Very high efficiency and spatial resolution for perpendicular tracks**, verified on the surface of one PCB with H8 pions
- Confirmed improvement of inclined track reconstruction with cluster-time corrected centroid position, reaching ~150 μm at 30°

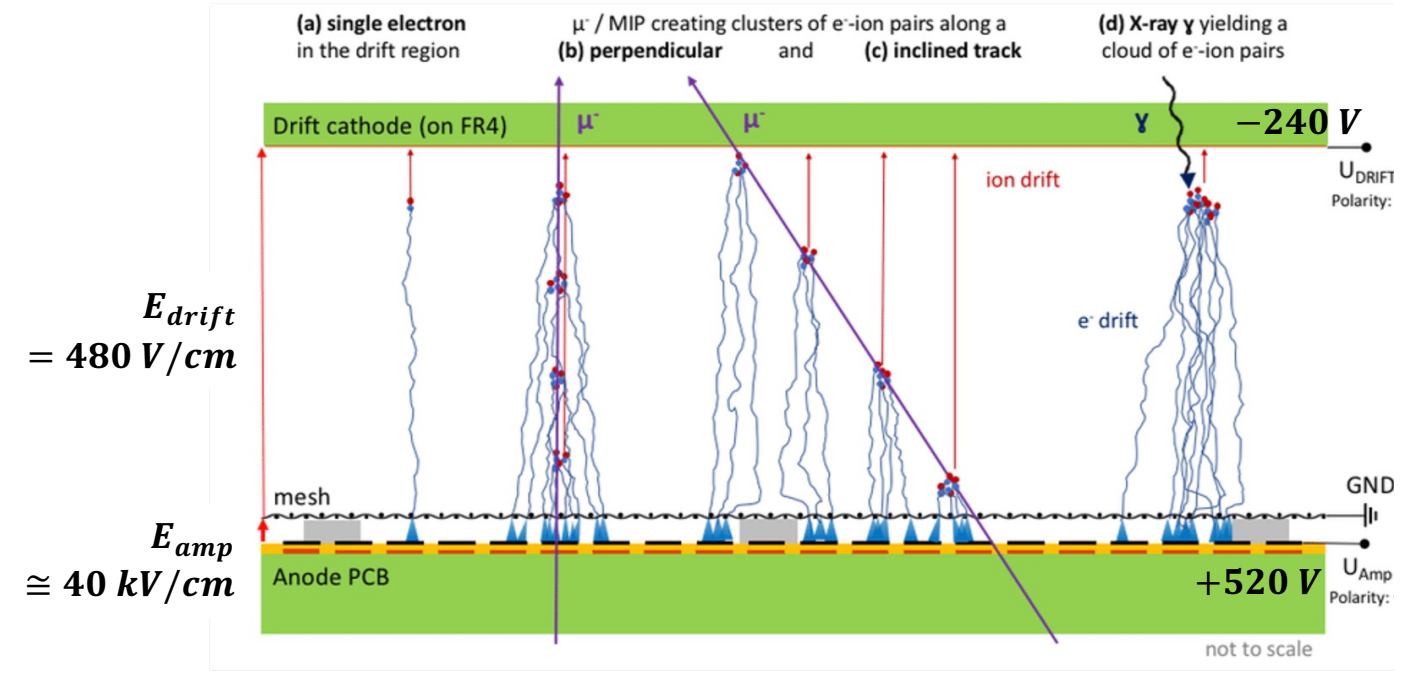
Plans for 2025:

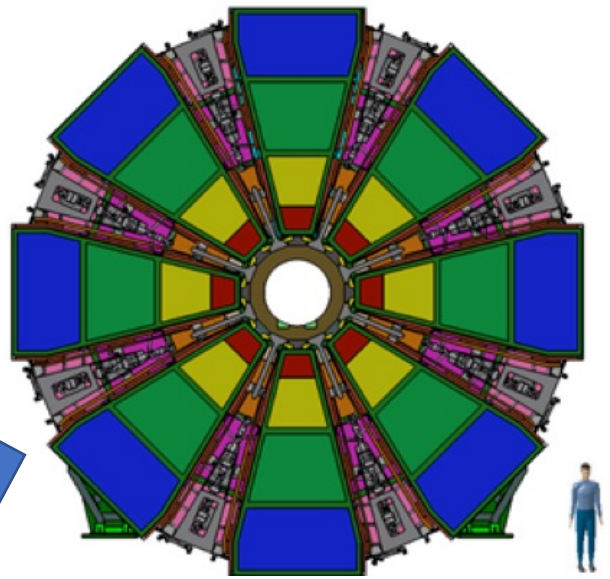
- Aging studies continuing with the 2 usual setups to increase the accumulated charge
- Plan to join beam times in GIF++ in 2025 **testing a new gas mixture Ar:+10%CF_4:+2%iC_4H_{10}** to study possible improvements in timing resolution with faster drift velocity

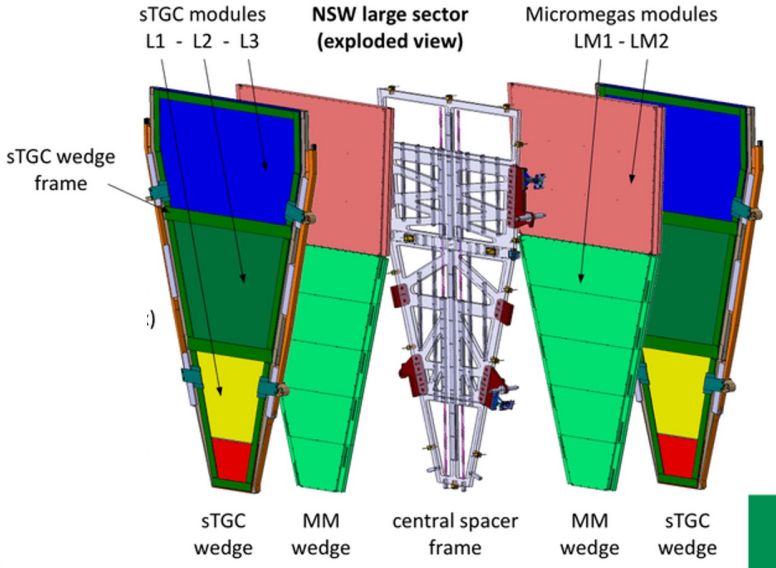
Backup

Micromegas detector

- Micro-pattern gaseous detector operating in proportional regime using $\boldsymbol{Ar: CO_2: iC_4H_{10}}$ $\boldsymbol{(93:5:2\ vol\%)}$ gas mixture
- Grounded metallic mesh separating drift and amplification regions
- Gas gain of $5000 - 1000$ in the amplification region
- Fast evacuation of positive ions
- Resistive strip readout to protect from occurring discharges
- Capacitive coupling between resistive and readout strip, which sends out the induced signal to the front-end electronics (VMM)



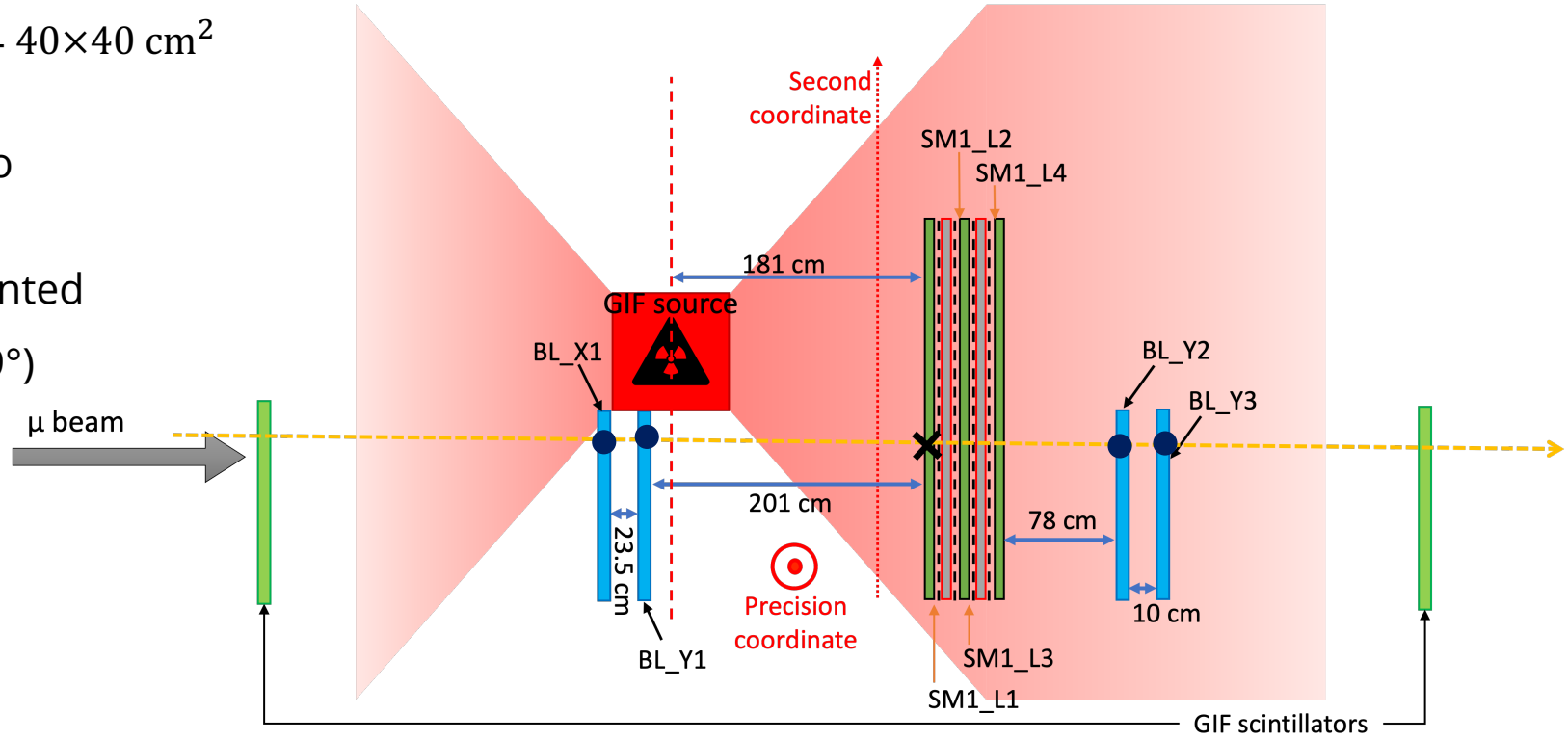




Large area $(2 - 3\ m^2)$ trapezoidal shaped 4-layer Micromegas detectors employed in the ATLAS New Small Wheel

GIF++ test beam operations

- Precision reference tracking made with 4 $40\times40\ \mathrm{cm}^2$ Micromegas chambers
- Linear fit of the track and interpolation to the plane of the layer to analyse
- Only PCB3 of the SM1 detector instrumented
- Collected data in vertical and inclined (29°) configuration of the chamber



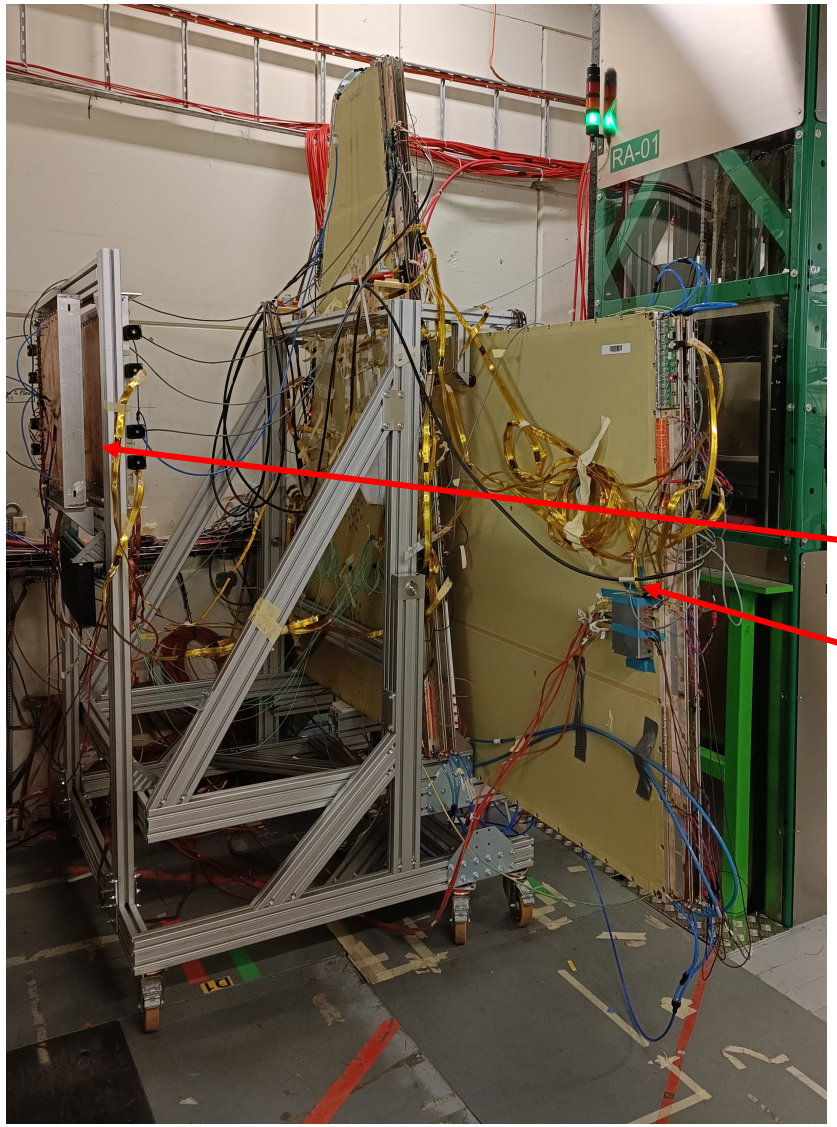
Cluster position reconstruction methods:

- **Charge centroid method** (standard):

$$x_{centroid} = \frac{\sum_{i=1}^{N} q_i x_i}{\sum_{i=1}^{N} q_i}$$, with N strips in the cluster

- **Cluster-time projection method** for inclined tracks:
  - Charge centroid corrected exploiting correlation with cluster time
  - Fitting 2D correlation plot and using the fit parameters to correct the centroid position

GIF++ beam time setup configuration



Several trolley setups have been used during the year, improving every time the stability and safety of the structure, and adding features for optimizing the beam time

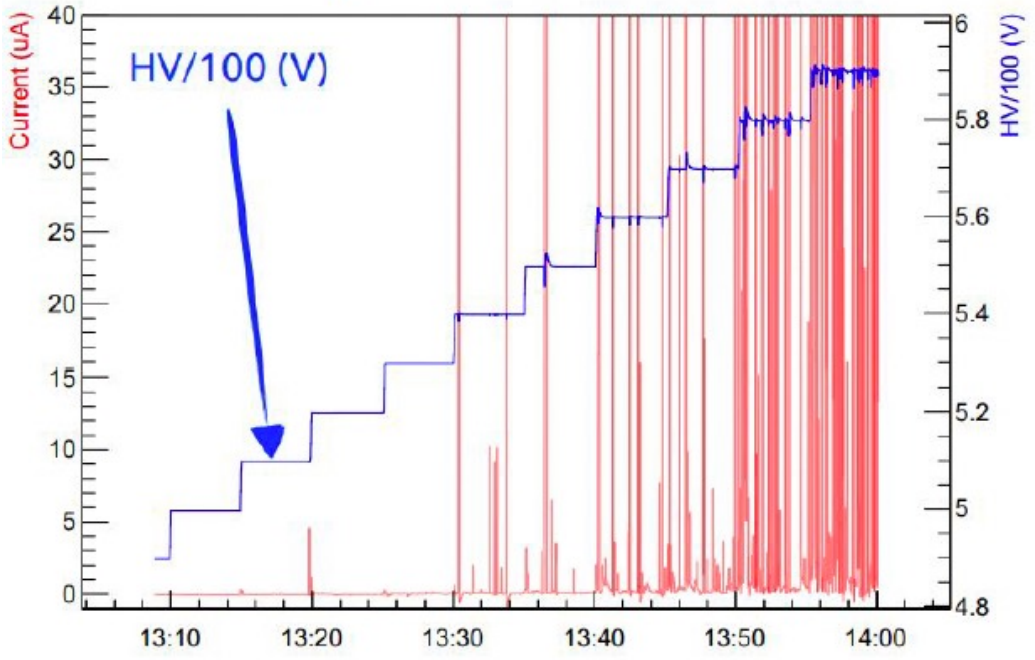
Tracking chambers upstream in the shade of the GIF++ source

Tracking chambers downstream in the far from the GIF++ source

SM1-M40 and LM2-M40 irradiated by the source and aligned with the beam
Possibility of tilting the two large MMG chambers up to 30°

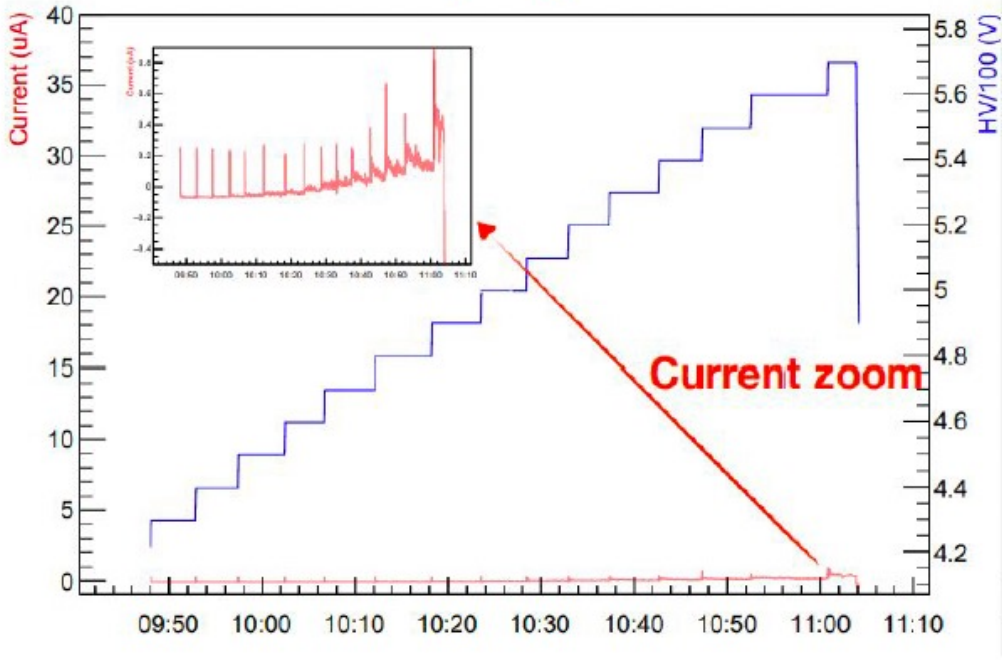
Isobutane gas mixture

- Long term stability studies in GIF++ of ATLAS Micromegas (MMG) chambers with the $Ar: CO_2: iC_4H_{10}$ 93: 5: 2 gas mixture, providing better HV stability



$Ar: CO_2$ 93: 7

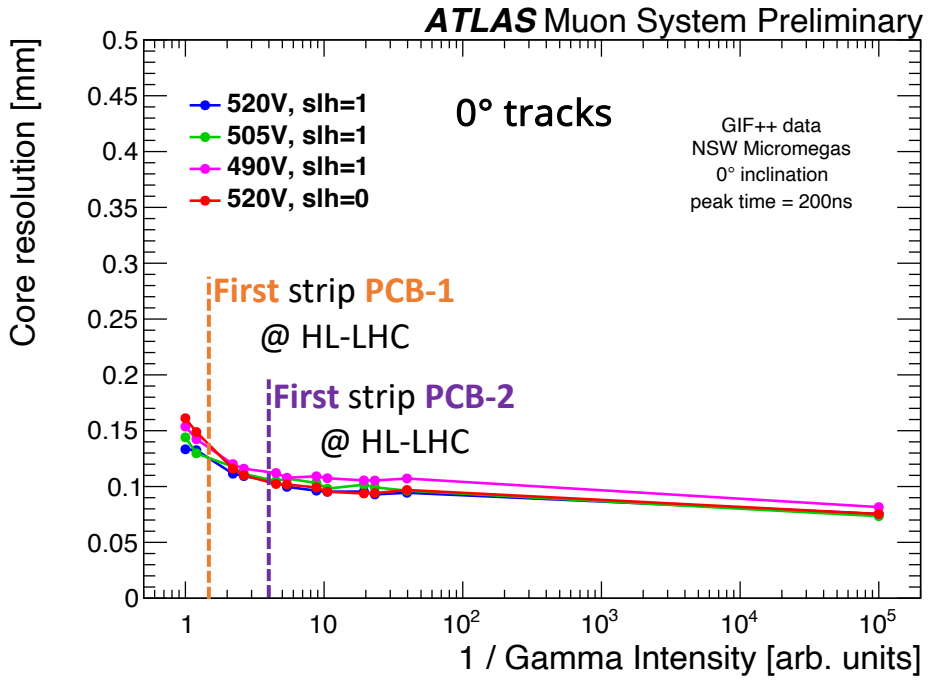
Improved
HV stability

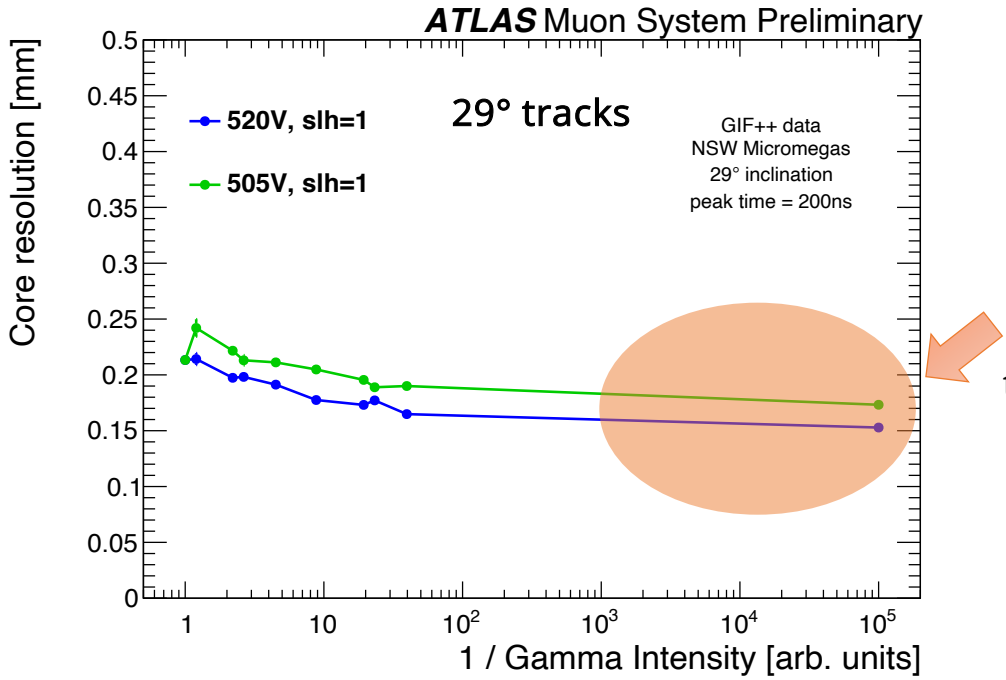


$Ar: CO_2: iC_4H_{10}$ 93: 5: 2

Performance with irradiation (2023)

- Spatial resolution < 100 μm achieved on irradiated chamber for perpendicular tracks
- 150 um resolution for 29° inclined tracks at ATLAS expected particle rate
- No degradation of performances visible after 2 years of irradiation
- Slightly worse resolution at very high rates but under control

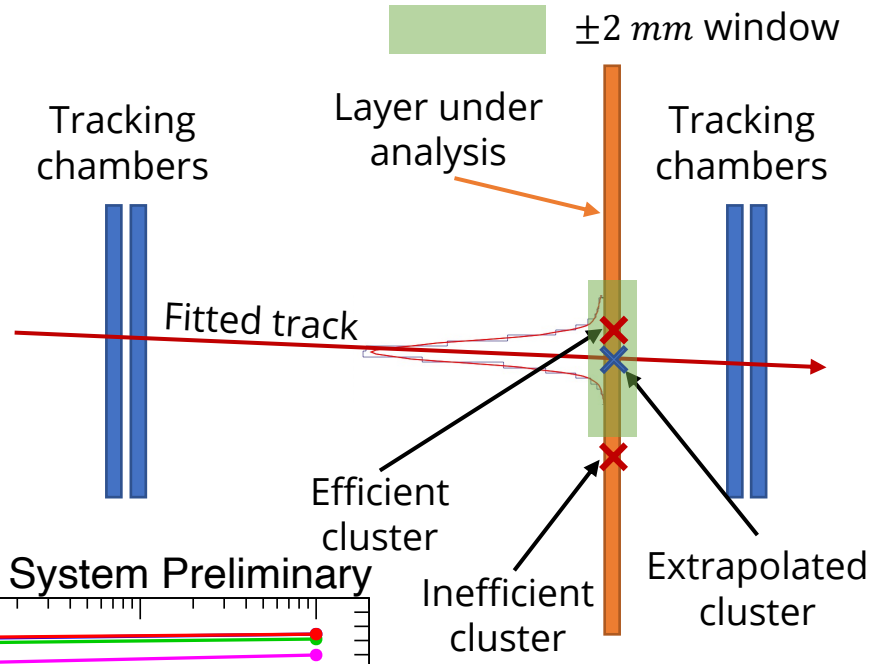


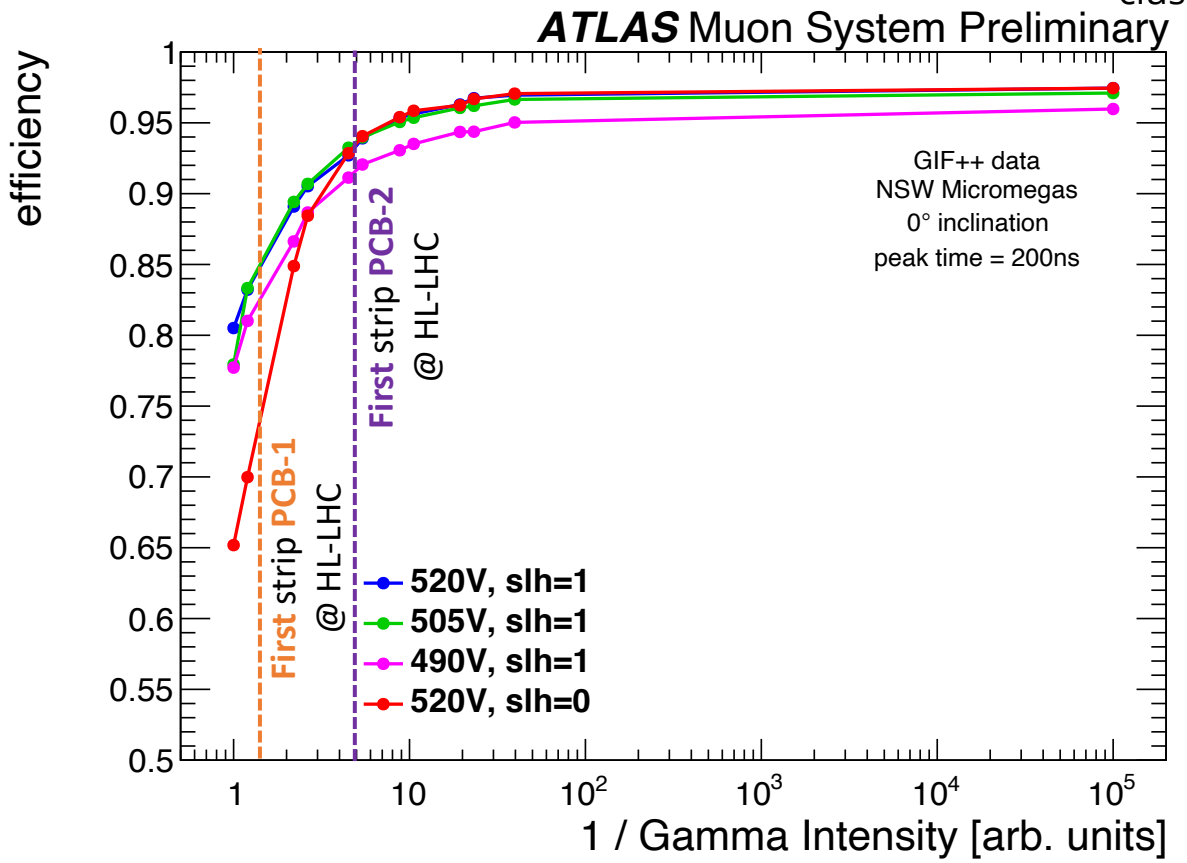


Range for >20° inclined muon tracks in ATLAS $\cong 150\ \mu m$

Efficiency with irradiation (2023)

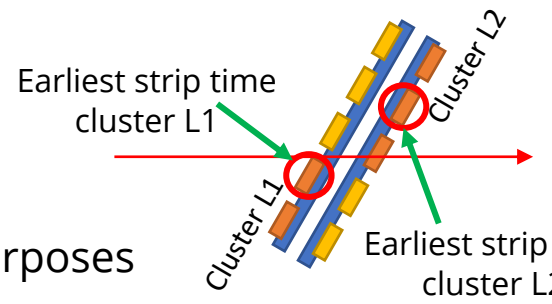
- VMM saturation effect impacting efficiency of PCB-1
- 1st strip of PCB-1 at ~85% efficiency
- Factor ~3 less background rate for 1st strip of PCB-2
  → reaching already >90% efficiency
- Other PCBs wit lower rates at HL-LHC
  → $> 95\%$ efficiency
- Overall good performances of ATLAS Micromegas detectors expected in HL-LHC conditions
- Redundancy of the several detector layers can be exploited to recover the tracking efficiency

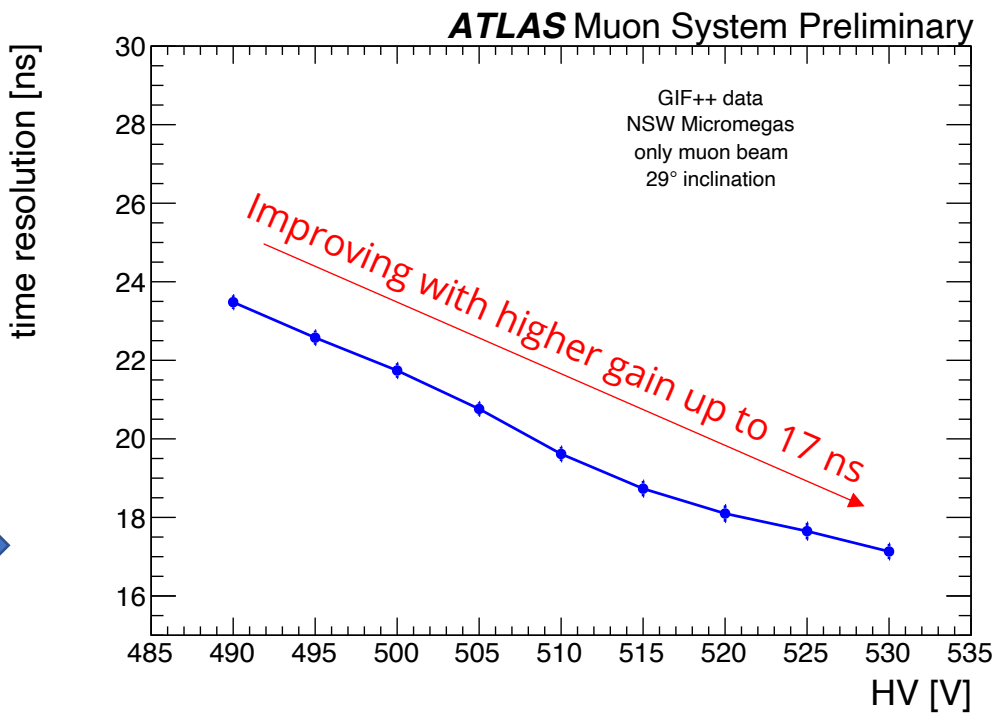


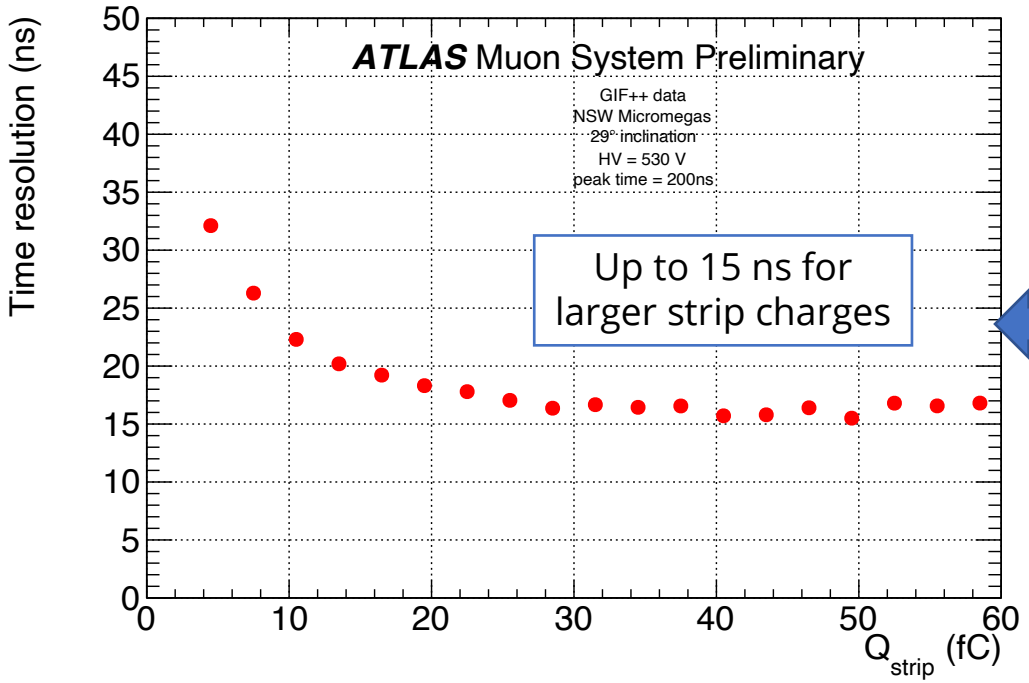


Time resolution

- Time resolution important for trigger purposes
- Time residuals of the earliest strips in back-to-back clusters, fitted with double-Gaussian → weighted resolution reported (divided by $\sqrt{2}$)
- First two layers of the detector used: $\Delta t = t_{L1}^{first} - t_{L2}^{first}$







Evaluated the time resolution also using the expected time:

- From the firing strip position, extrapolate the position in the gap using the track angle
- Expected hit time computed as $\boldsymbol{t_{exp} = \Delta z / v_{drift}}$
- $\boldsymbol{\Delta t = t_{strip} - t_{exp}}$ → fitted with Gaussian

Good time resolution obtained on a long-term irradiated chamber, confirming no degradation of performances!