Performances of ATLAS Micromegas detectors in high background environment and after long term irradiation at the Gamma Irradiation Facility at CERN

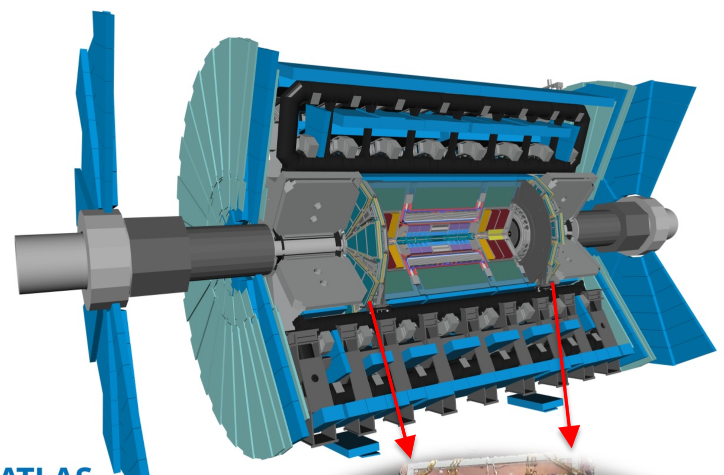
Valerio D'Amico (Ludwig-Maximilians-Universität München) on behalf of the ATLAS Muon System

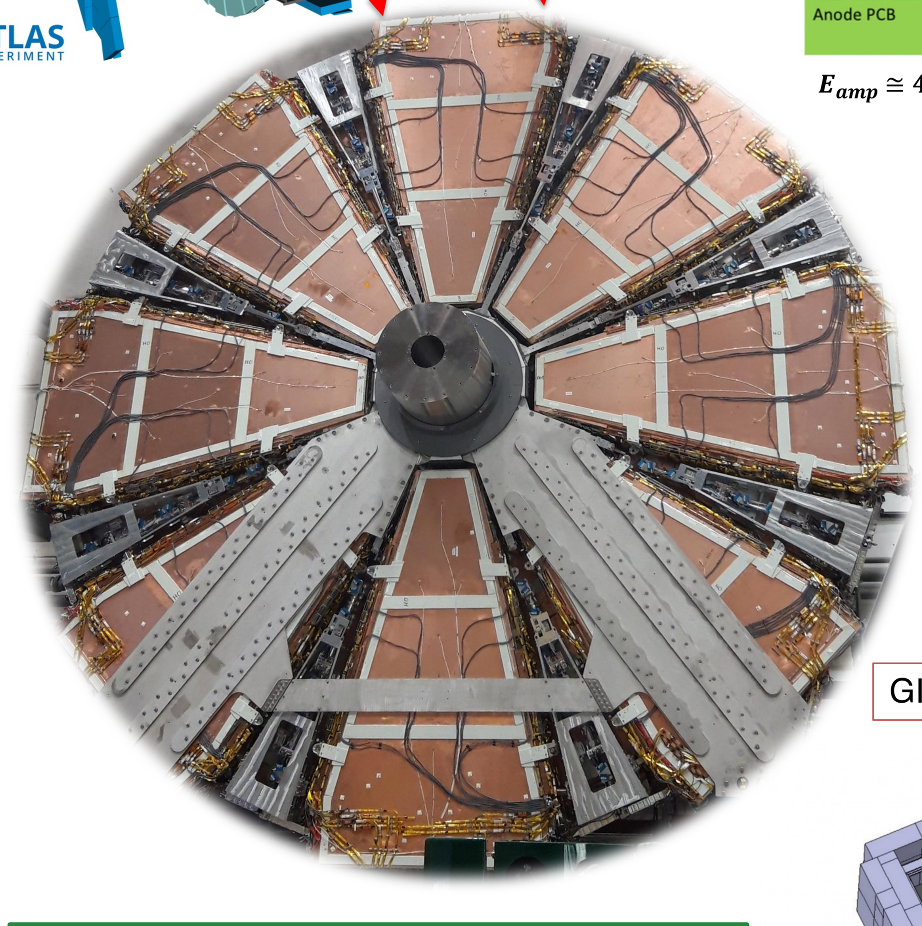
16° Pisa Meetings on Advanced Detectors 2024 - La Biodola, Isola d'Elba

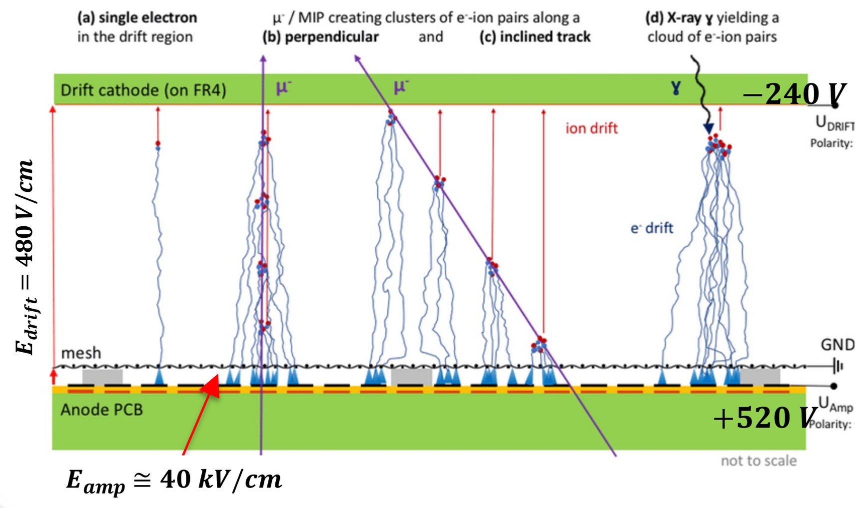
Introduction

Increase of luminosity provided by LHC:

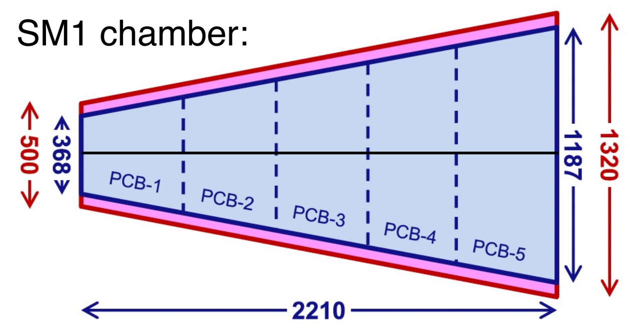
- High Luminosity LHC (2029–2040): $\mathcal{L} = 7.5 \times 10^{34}\ cm^{-2}\ s^{-1}$ up to more than 7 times design luminosity
- Huge increase of particle rates, mainly in forward regions
- New Small Wheels installed in 2021 in ATLAS
  - Substituting old wire detectors that would suffer of aging
  - Novel detector technologies to cope with the increase of particle rate → sTGC and Micromegas for trigger and position measurement
  - Redundancy by using multiple detector layers: 8 for Micromegas and 8 for sTGC in each sector of the wheel
- Need to evaluate the long-term stability and the performance in high background environment







SM1 chamber:



The Micromegas detector

Resistive Micro-Mesh Gaseous Structures (MM):

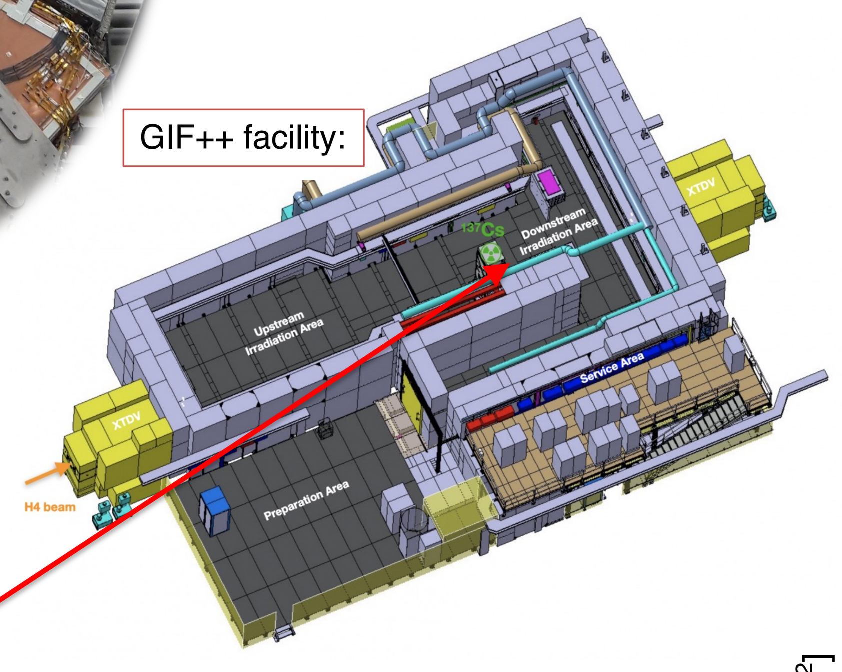
- **Ar + 5%CO_2 + 2%iC_4H_{10}** gas mixture → provides large gain and high-voltage stability
- Micro-mesh, grounded, transparent to electrons, divides drift and amplification regions
- Drift field ~480 V/cm
- Amplification field ~40 kV/cm
- Fast evacuation of positive ions: ~ 100 ns
- Strip (pitch = 0.45 mm) readouts stereo strips for 2[nd] coordinate
- Spark protection thanks to a layer of resistive strips coupled capacitively to readout strips

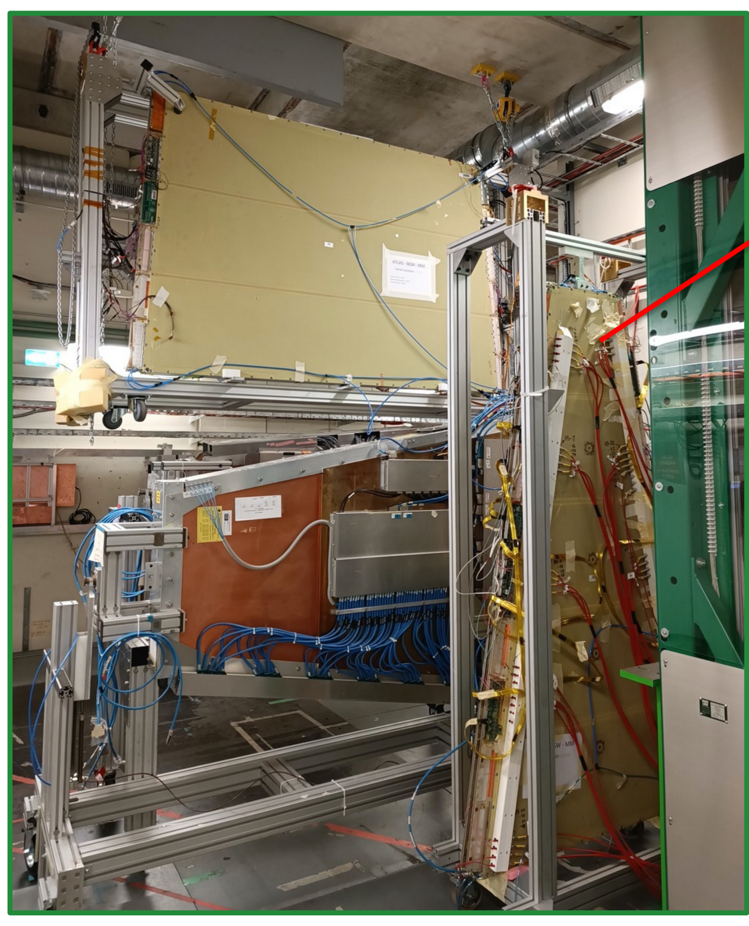
Irradiation at GIF++ facility

Irradiation of Micromegas detectors with a gamma-ray source in GIF++ facility at CERN:

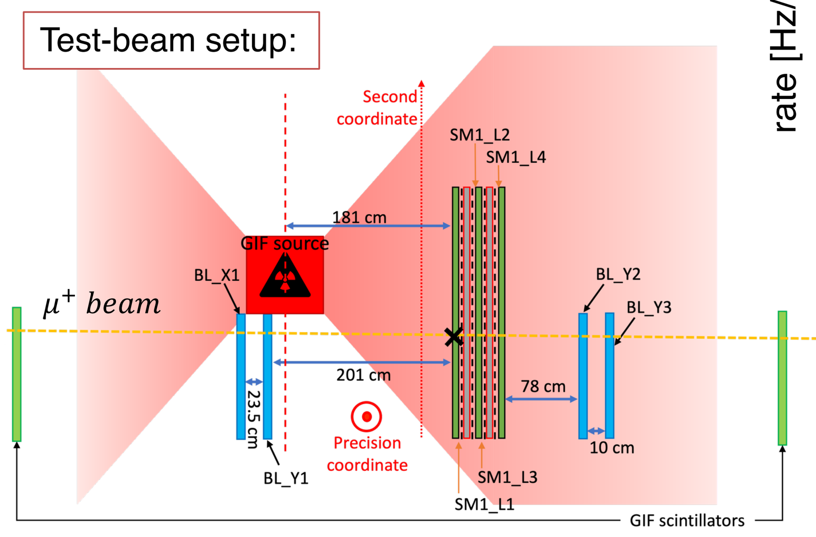
- Radioactive source: ^{137}Cs 662 keV Gammas ~11.6 TBq
- Possible to tune the irradiation intensity using 3 filters: → 24 combinations from Attenuation Factor=1 to 46000
- Irradiation measured in terms of charge accumulated by the detector and values scaled to the areas of the PCBs
- Large difference of expected irradiation at LHC between the 1st strip of PCB-1 and PCB-2 : → A factor ~3 less for PCB-2 being 43cm further from the beam axis
- Several years of HL-LHC equivalent have been accumulated so far

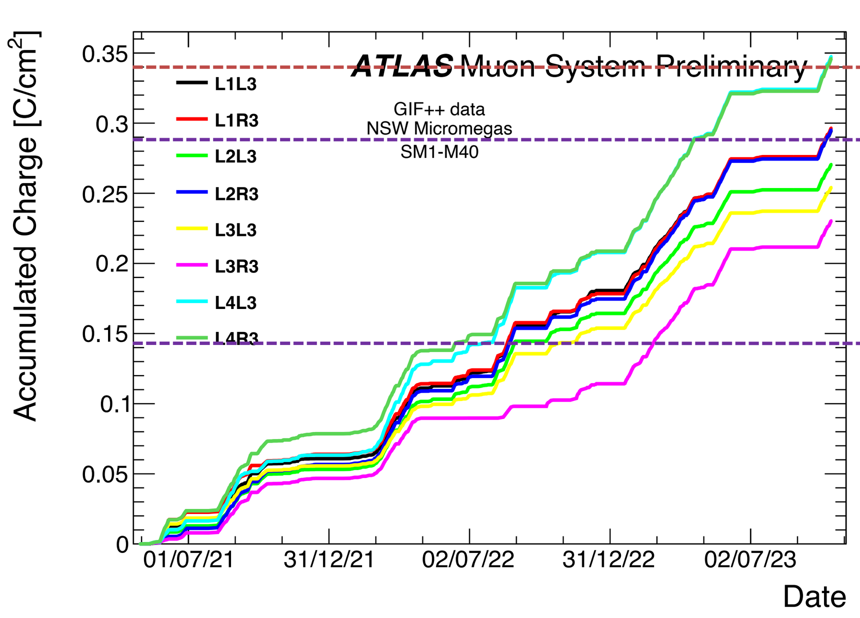
GIF++ facility:





Test-beam setup:

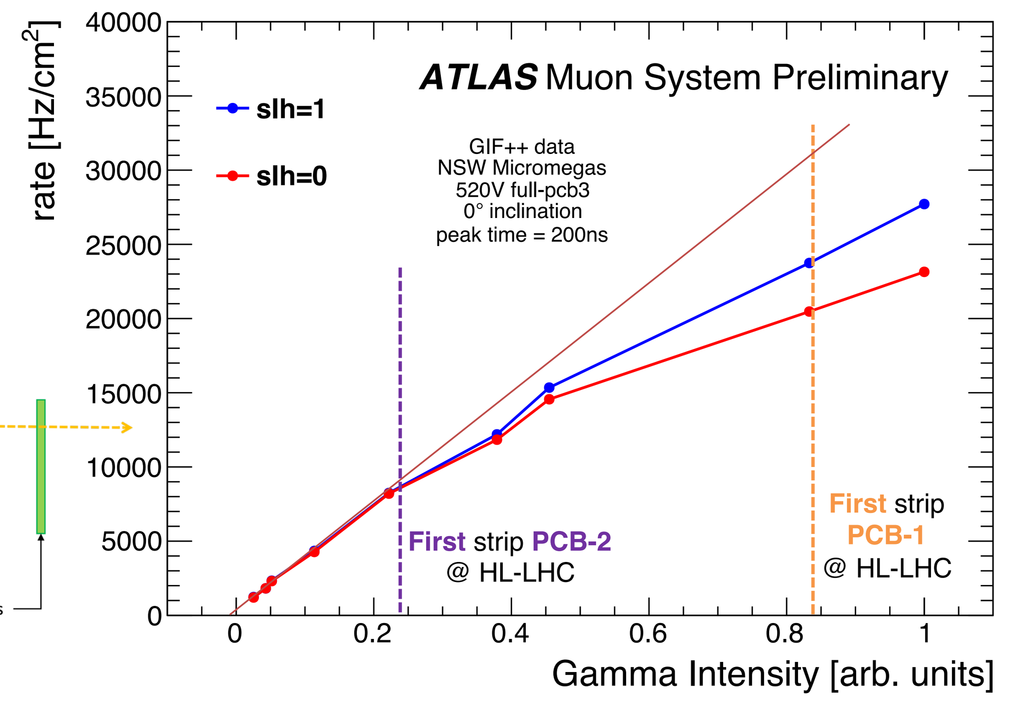




The values of the lines corresponds to the 1st strips of PCB-1 and PCB-2 expected irradiation

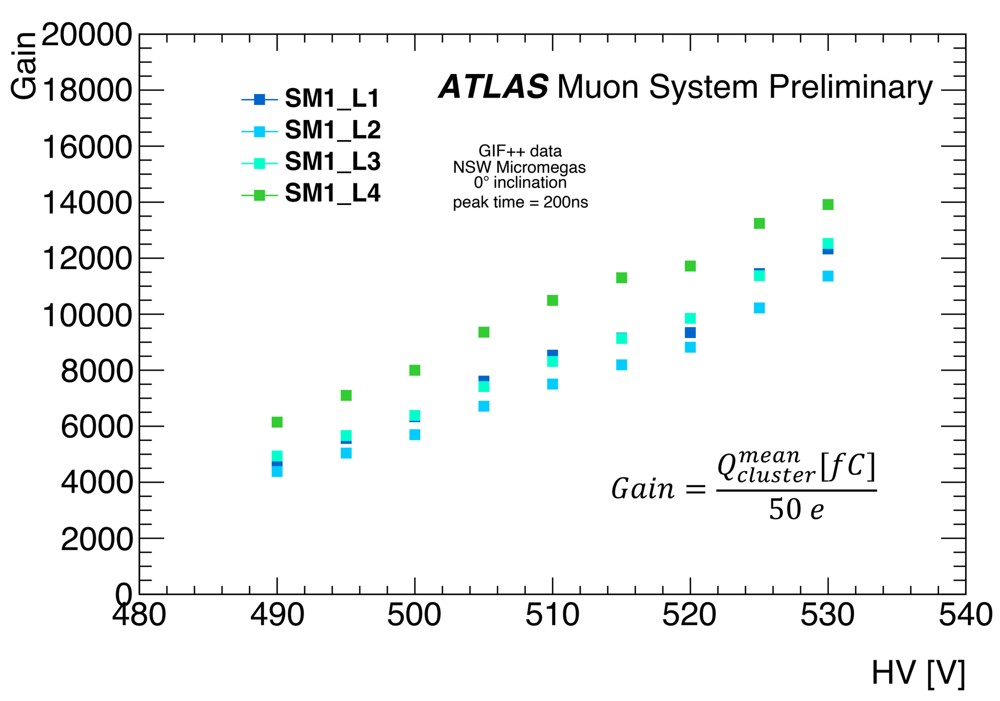
Rates studies

- Rate values obtained scaling the measurements in ATLAS on Micromegas chambers [1] 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 expecting at LHC a factor ~3 less in rate!!
- VMM channel saturation appearing at larger gamma intensities. Partial solution:
  - Larger bias voltage applied on VMM asic [2] channels (*slh* parameter setting): → faster restoration of the baseline → recovering partially hit occupancy



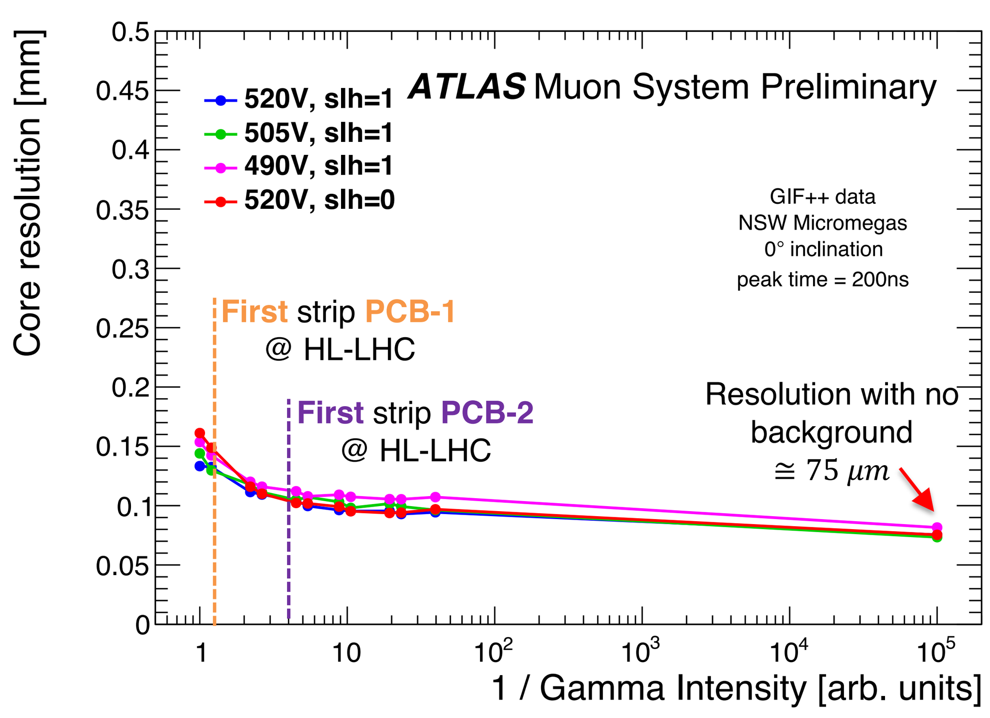
Performance after 2 years of irradiation

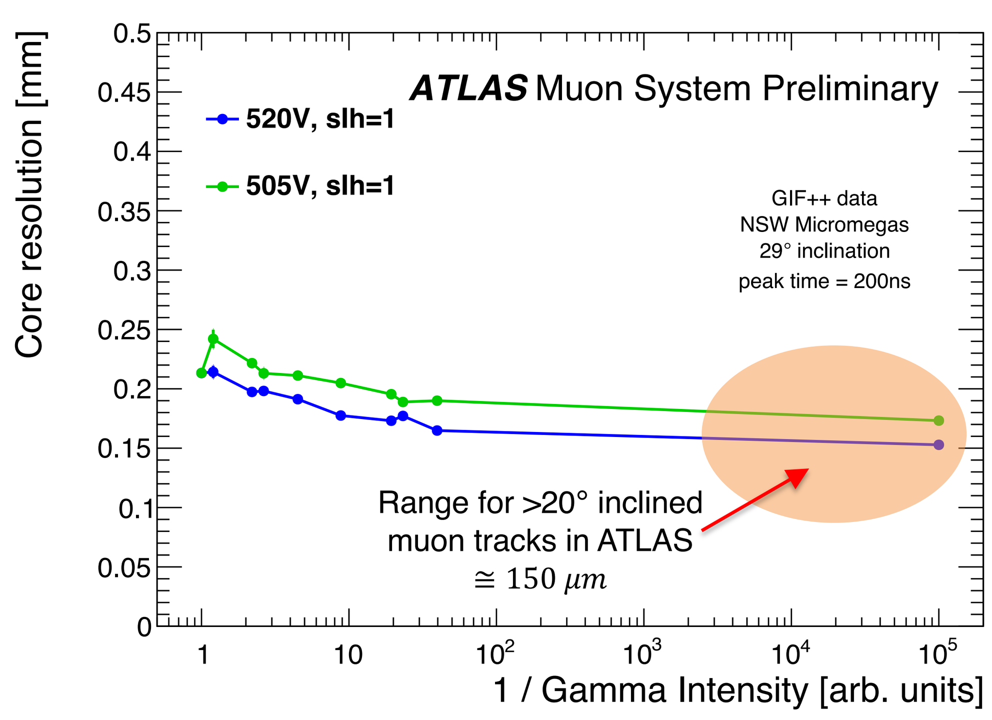
- Detector performances evaluated after 2 years of irradiation:
- No decrease of amplification gain: → greater than 8000 at 520 V
- Spatial resolution at 0° < 100 µm achieved on irradiated chamber
  → charge-centroid method used
  → performance matching ATLAS design requirements
  → showing no degradation of performances after irradiation
- Spatial resolution at 29° of 150 µm achieved on irradiated chamber
  → cluster-time projection method [3] used
  → best result obtained so far for inclined tracks
  → time calibration of the readout channels fundamental
- Good resolution maintained also in presence of irradiation

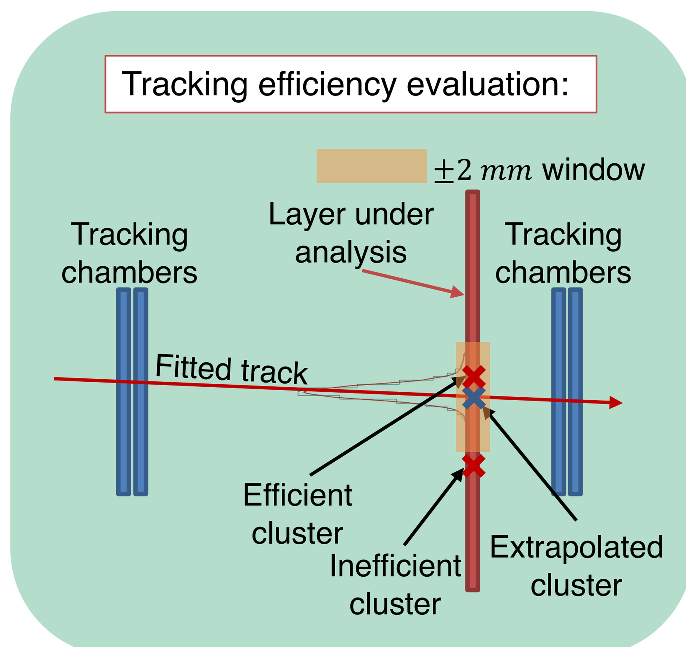


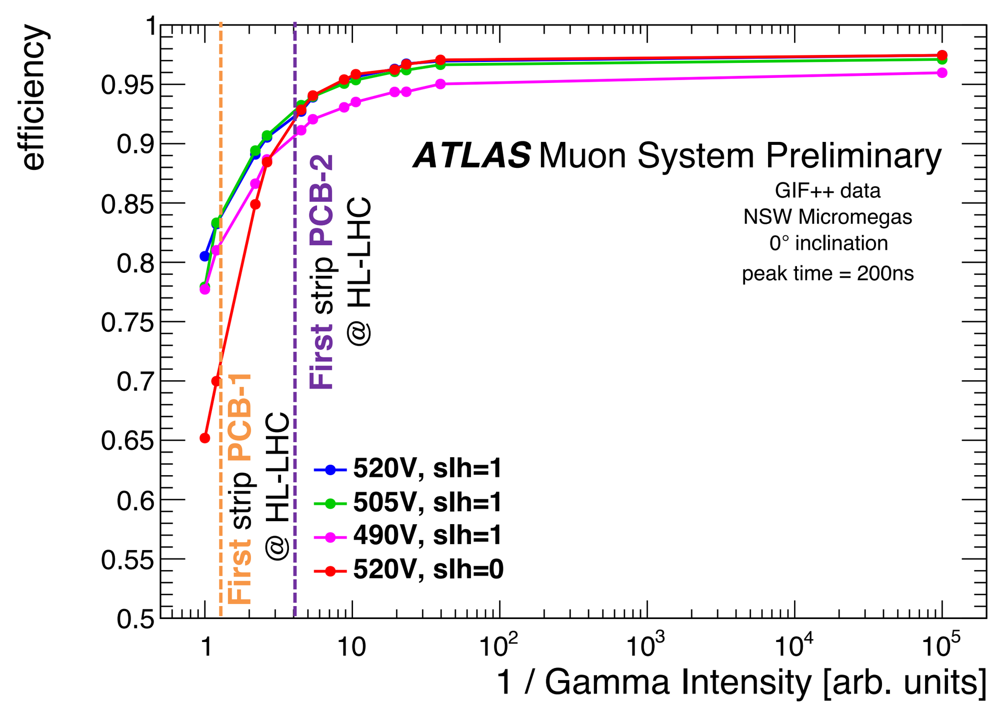
Tracking efficiency studies

- VMM channel saturation effect impacting efficiency of PCB-1 → First strips 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 MM detectors expected in HL-LHC conditions
- Redundancy of the several detector layers is exploited to recover the tracking efficiency







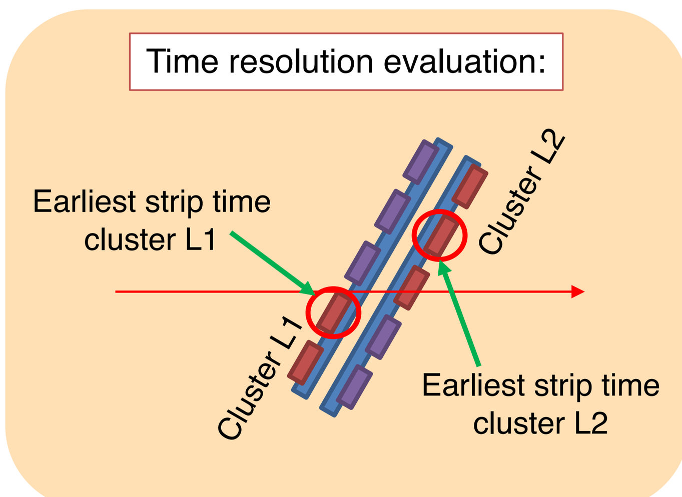


Timing studies

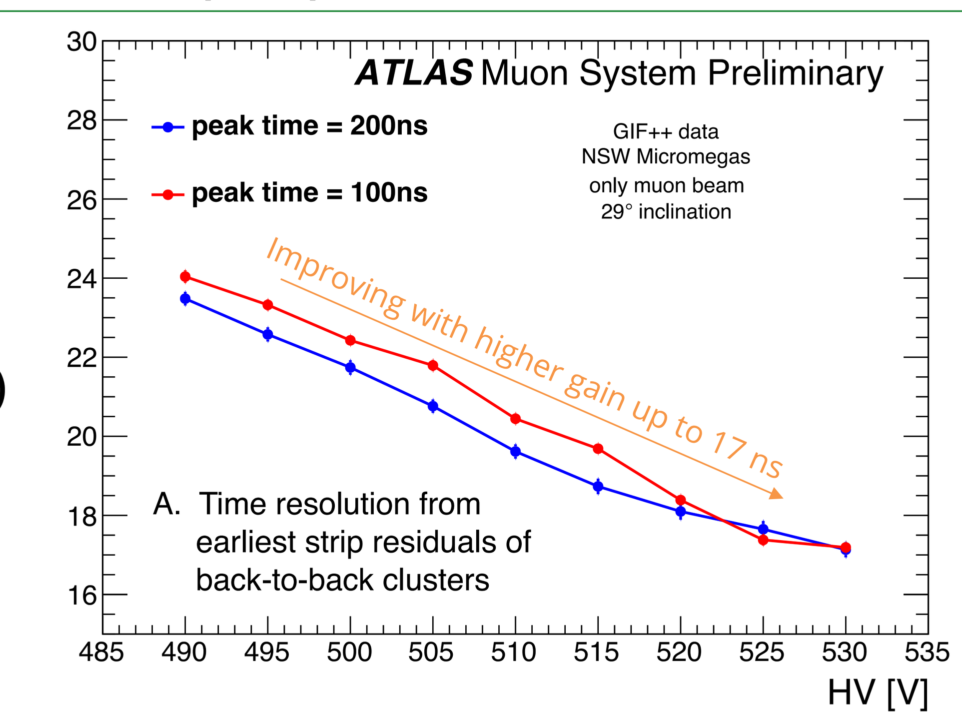
Time resolution important for trigger purposes

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

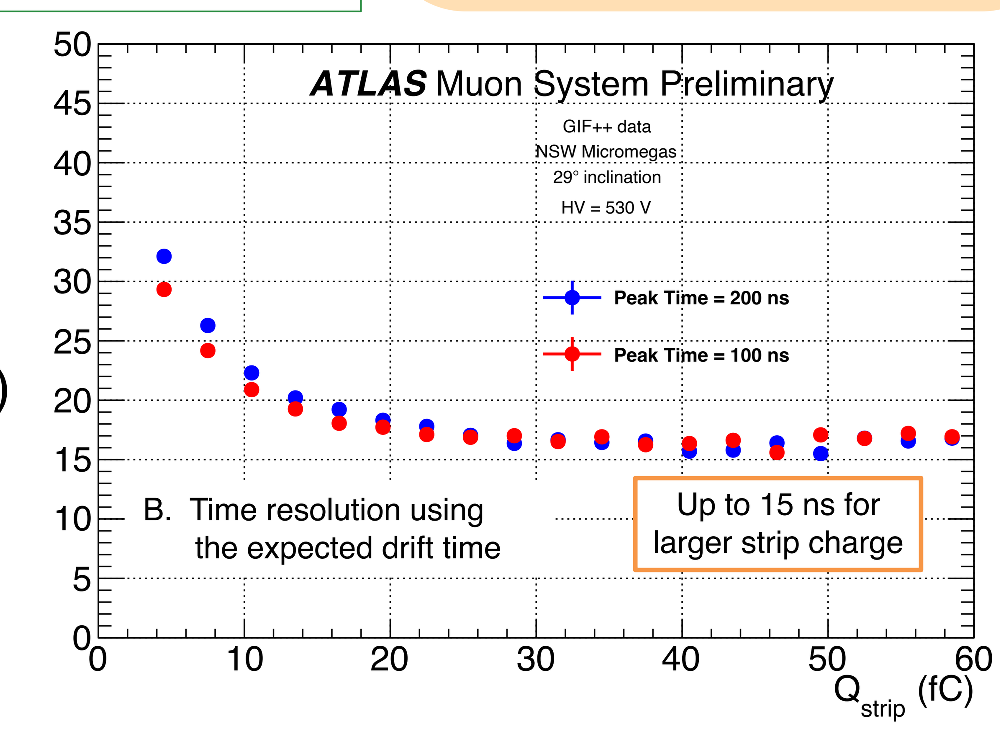
B. Evaluated the time resolution also using the expected time:
→ From the firing strip position, extrapolate the position in the gap using the track angle
→ Expected hit time computed as $t_{exp} = \Delta z / v_{drift}$
→ $\Delta t = t_{strip} - t_{exp}$ → fitted with Gaussian



(A)



(B)



Conclusions

- ATLAS Micromegas chambers fundamental for end-cap muon reconstruction during HL-LHC operations
- Irradiation studies useful to understand detector stability and performances after long-term irradiation and with HL-LHC expected particle rates!
- Already 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 nominal resolution for perpendicular tracks, maintained also with high gamma intensity
- Some efficiency drop affecting only the PCB-1 at the HL-LHC expected rates, but average of 90% efficiency → due to VMM channel saturation
- Evaluated best results in inclined track position resolution up to **150 µm** at higher gain
- Time resolution improving with higher gain, reaching 17 ns at 530 V, and 15 ns for larger strip charges
- Overall performances not suffering the irradiation accumulated so far, showing still nominal performances!

References:
1. ATLAS collaboration, *NSW MicroMegas Cluster Rates*, 2024, MDET-2024-01
2. G. de Geronimo et al, *The VMM3a ASIC*, 2022, IEEE Trans.Nucl.Sci. 69 (2022) 4, 976-985
3. B. Flierl, *Particle Tracking with Micro-Pattern Gaseous Detectors*, 2018, PhD Thesis.