Longevity test of ATLAS Micromegas detectors at the CERN GIF++ facility

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on behalf of the ATLAS Muon System

ATLAS EXPERIMENT

3rd International Conference on Detector Stability and Aging Phenomena in Gaseous Detectors

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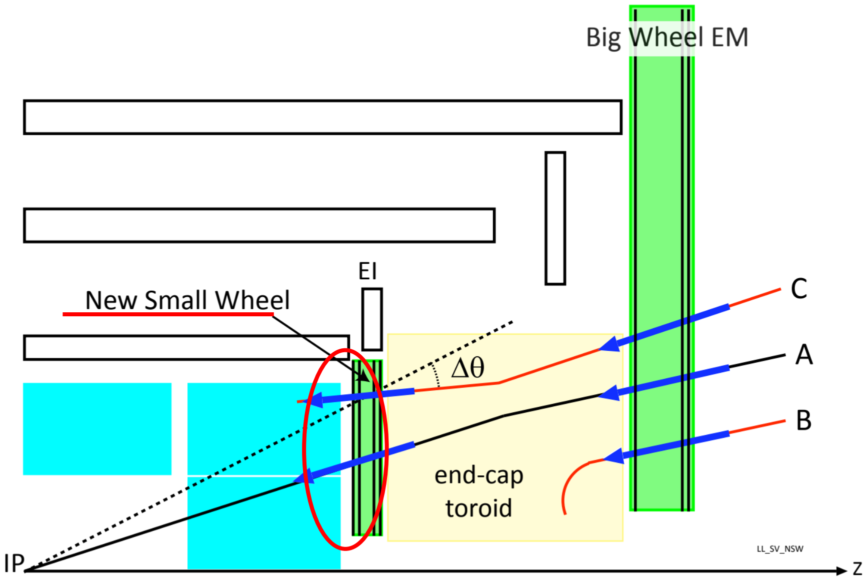
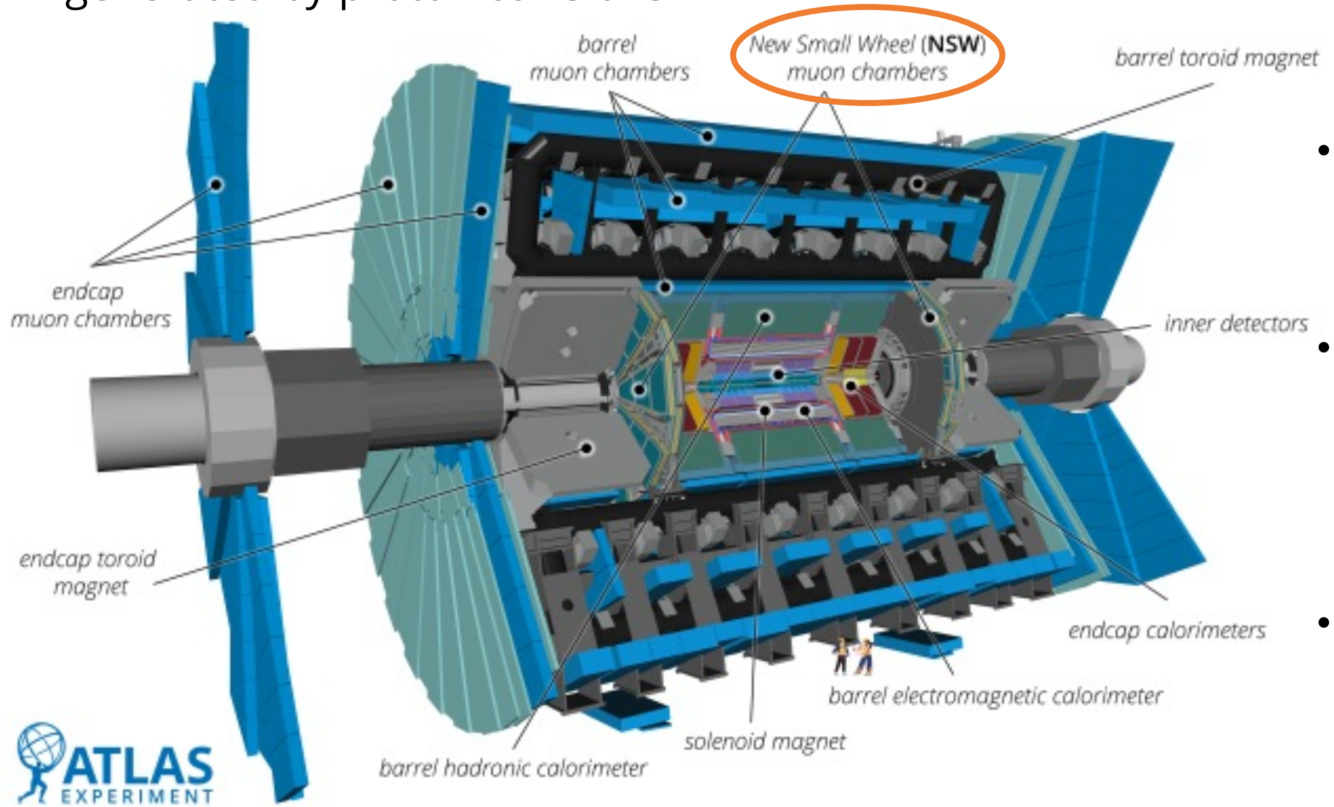
LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

ATLAS New Small Wheel



- HL-LHC expected luminosity of $\mathbf{7.5 \times 10^{34}\ cm^{-2}s^{-1}}$, 7.5 times the nominal!
  → increase of the expected background rate, in particular in the forward region
  → decrease of muon tracking performances
  → old detectors in the first end-cap station not designed for these rates
- Background hits originate mostly from low energy photons and neutrons generated by proton collisions

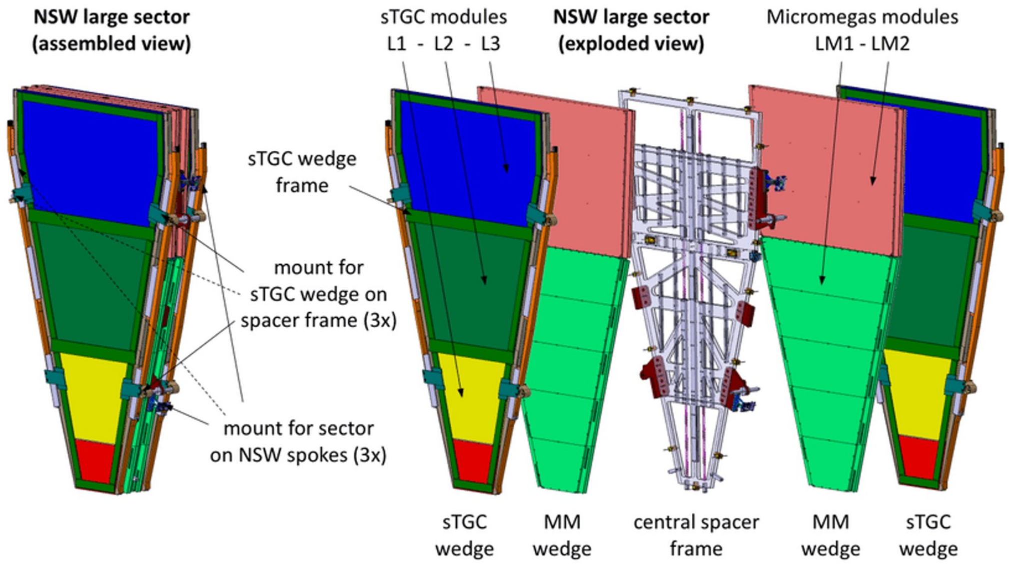


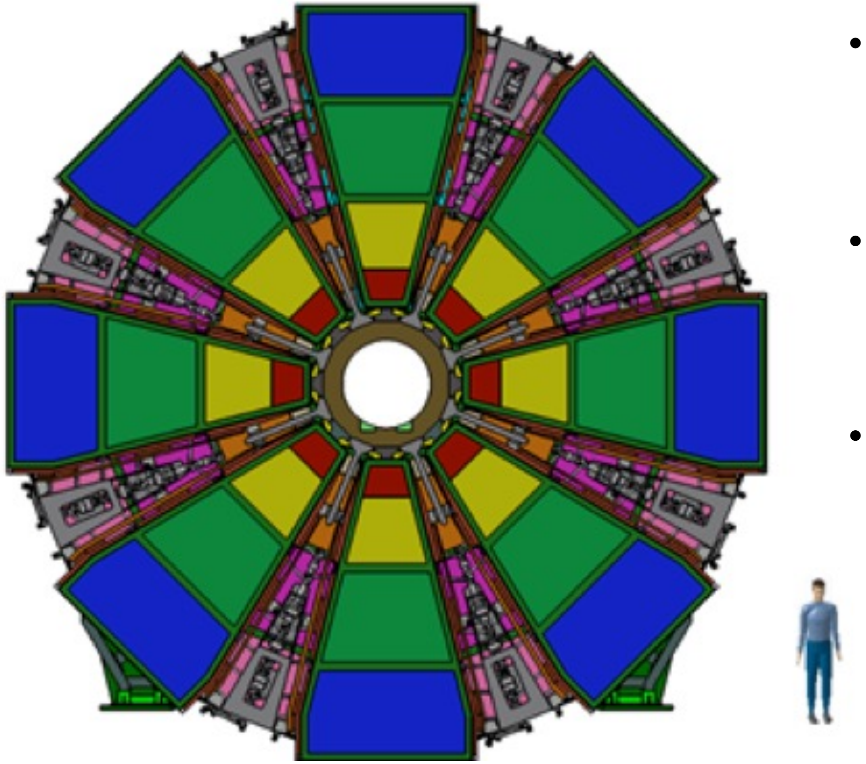
ATLAS EXPERIMENT

- The New Small Wheels (NSW) is the new first end-cap station of the ATLAS muon spectrometer, installed in 2021 in view of the HL-LHC upgrade
- 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:
  - **$100\ \mu m$ spatial resolution required by design**
- Efficient detector in front of the end-cap toroid is fundamental to reduce the fakes-rate below ATLAS limits

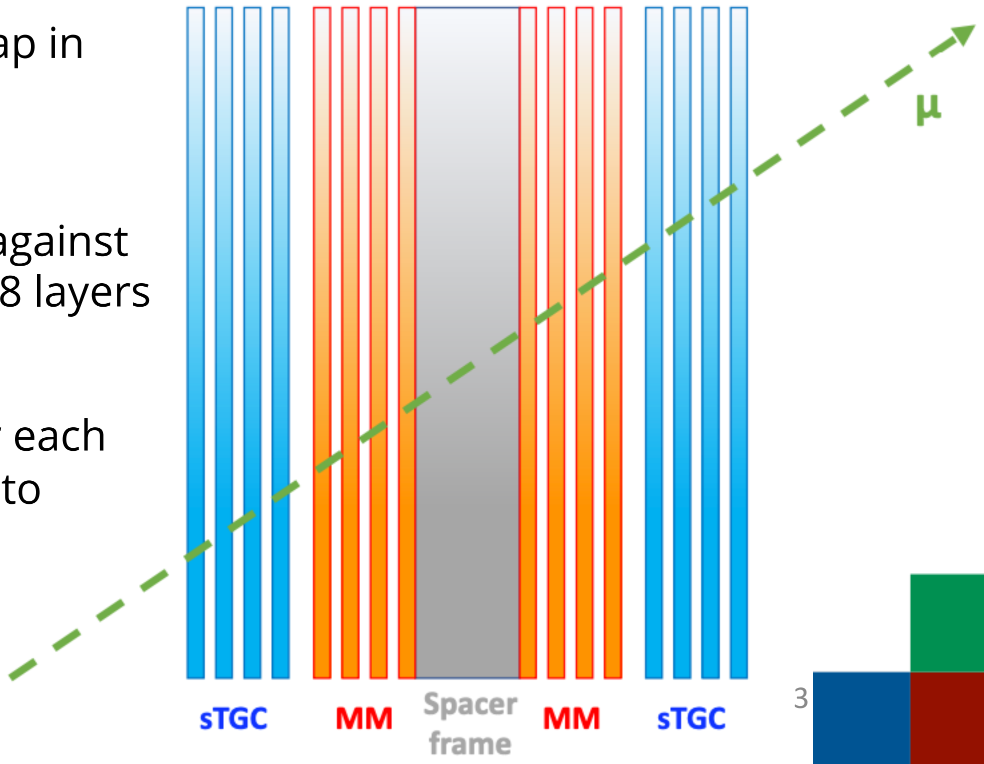
New Small Wheel structure

- Each wheel is made of 16 sectors (8 small and 8 large), covering the $1.3 < |\eta| < 2.7$ end-cap region
- Every sector is composed by 16 layers of 2 detector technologies:
  - Small Thin Gap Chambers (sTGC), primarily for trigger purposes
  - Micromegas (MM), primarily for tracking purposes



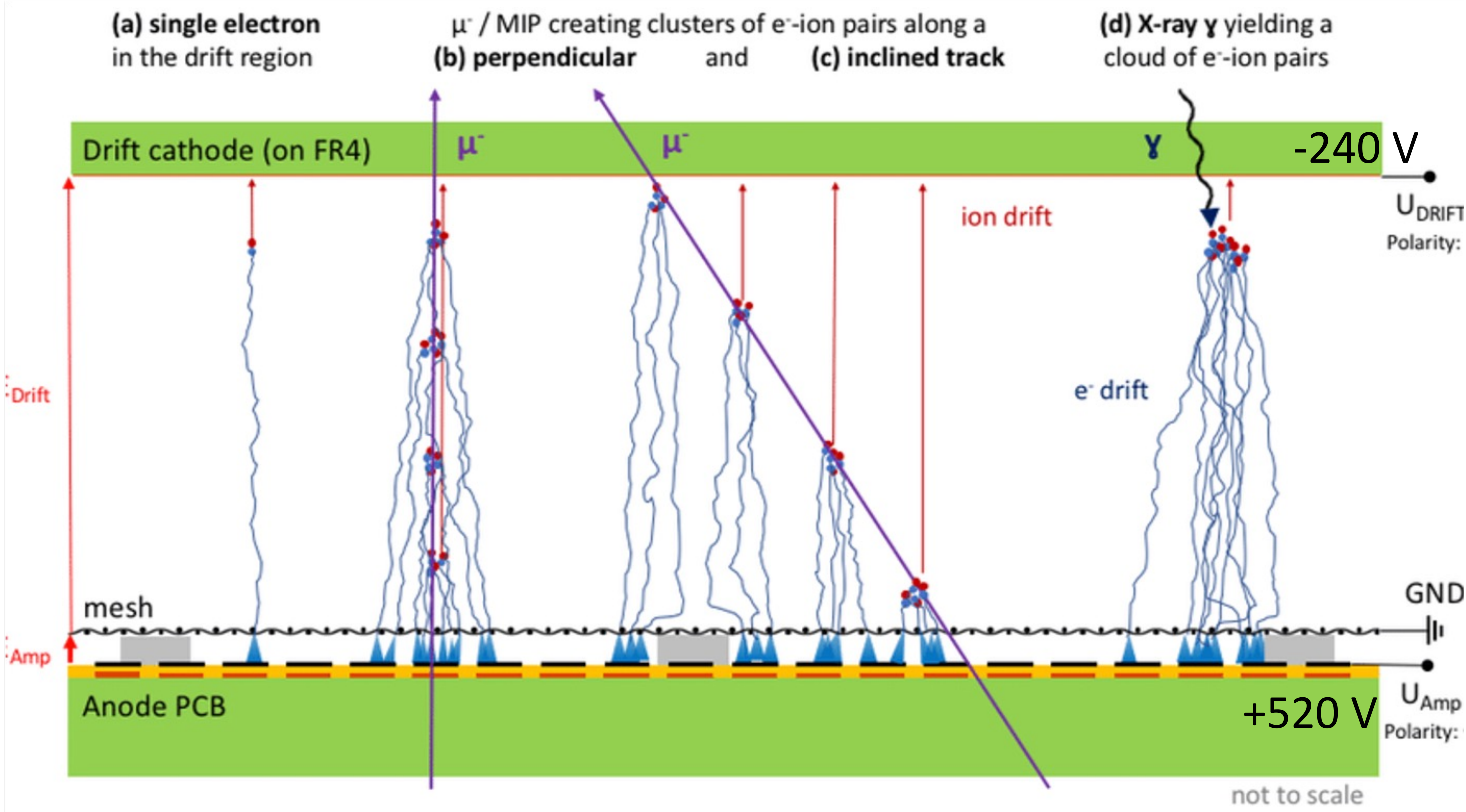


- Large and Small sectors overlap in order to cover the holes of acceptance between sectors
- **Redundancy** and **robustness** against inefficiencies provided by the 8 layers → 4/8 coincidence possible
- For MM detectors, 2 layers for each quadruplet are tilted by $\pm 1.5°$ to provide second coordinate position of the track → **stereo** layers



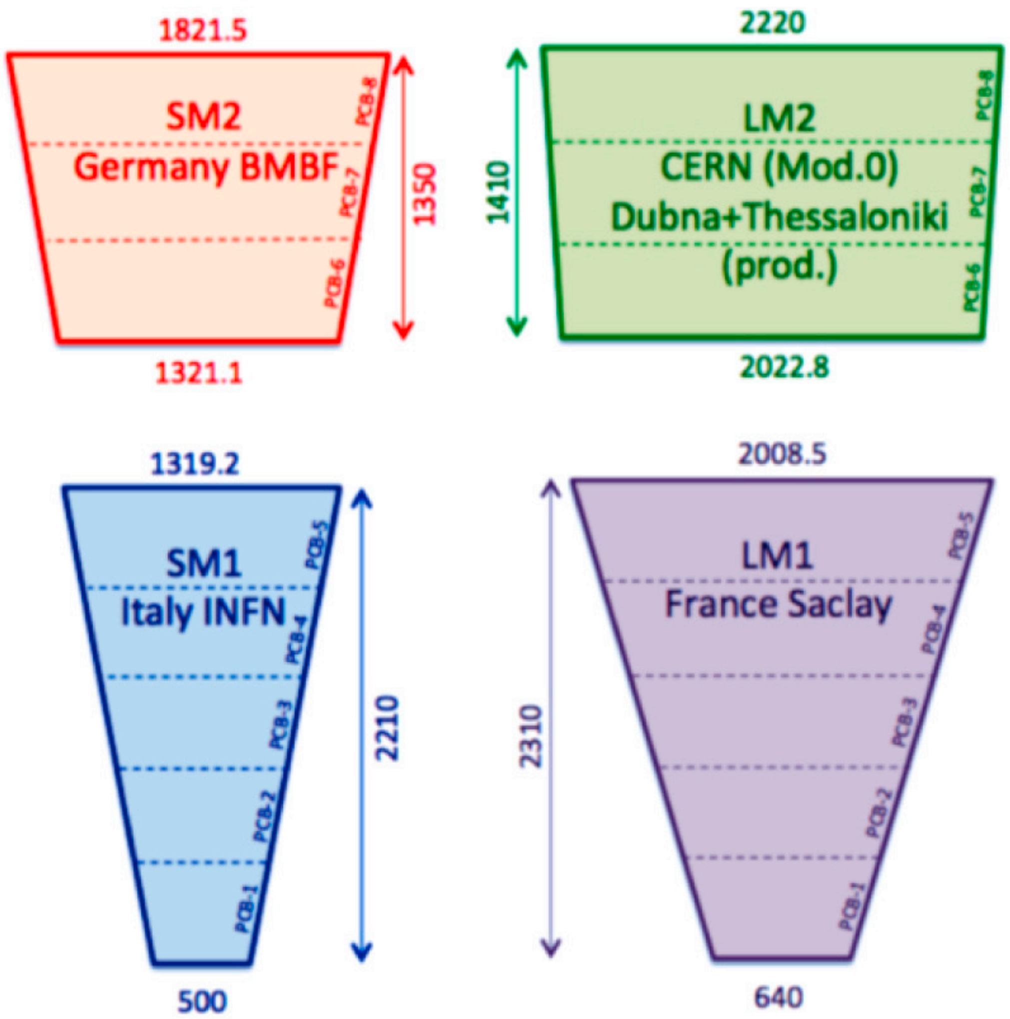
Micromegas detector

- Micro-pattern gaseous detector operating in proportional regime using $\boldsymbol{Ar{:}\,CO_2{:}\,iC_4H_{10}}$ $(\mathbf{93{:}\,5{:}\,2\ vol\%})$ gas mixture
- Grounded metallic mesh separating drift and amplification regions:
  - Drift gap $(5\ \mathrm{mm})$ with $E = 480\ \mathrm{V/cm}$
  - Amplification gap $(128\ \mu\mathrm{m})$ with $E \cong 40\ \mathrm{kV/cm}$
- Gas gain of $\sim 10^4$ obtained in the amplification region
- Short dead time provided by the separation of the two regions and the 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)



The ternary $\boldsymbol{Ar{:}\,CO_2{:}\,iC_4H_{10}}$ $(\mathbf{93{:}\,5{:}\,2\ vol\%})$ gas mixture has demonstrated to provide a better high voltage stability and a larger pulse height, useful for inclined track reconstruction, with respect to the previous used $Ar{:}\,CO_2$ $(93{:}\,7\ \mathrm{vol\%})$

Expected rates in NSW for HL-LHC



< 1 kHz/cm^2

< 1 kHz/cm^2

< 1 kHz/cm^2

1.2 kHz/cm^2

2 kHz/cm^2

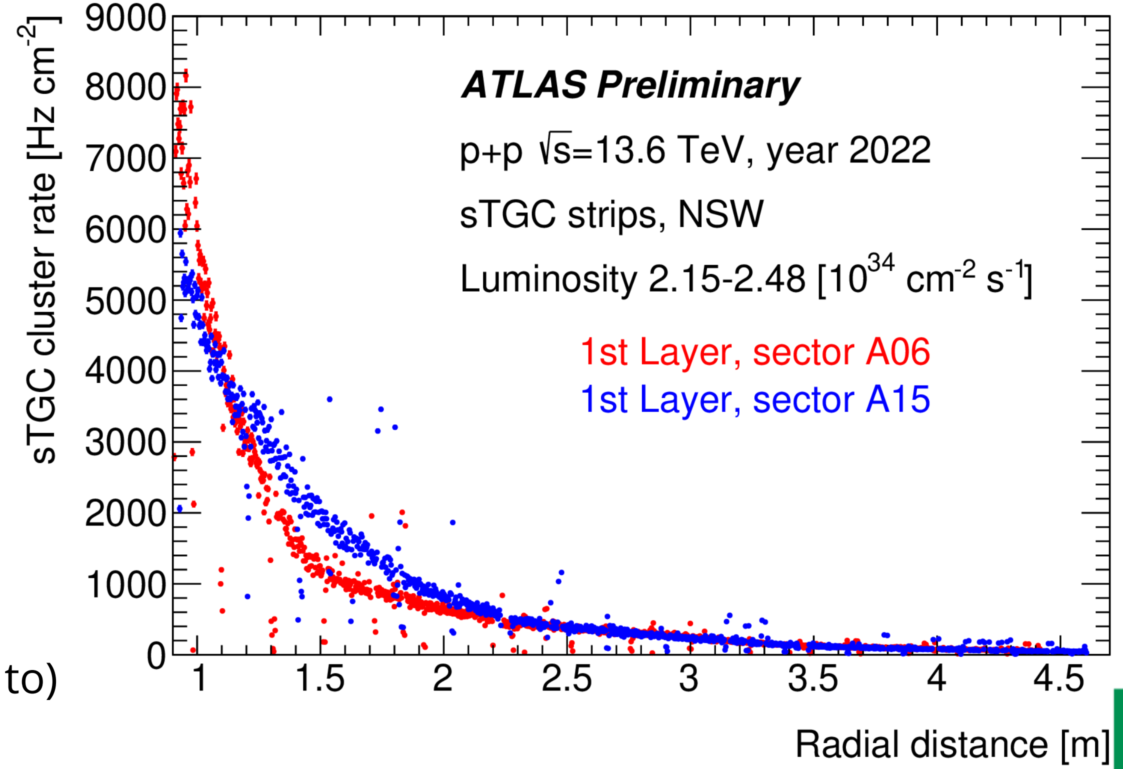
3.5 kHz/cm^2

7.5 kHz/cm^2

25 kHz/cm^2 (up to)

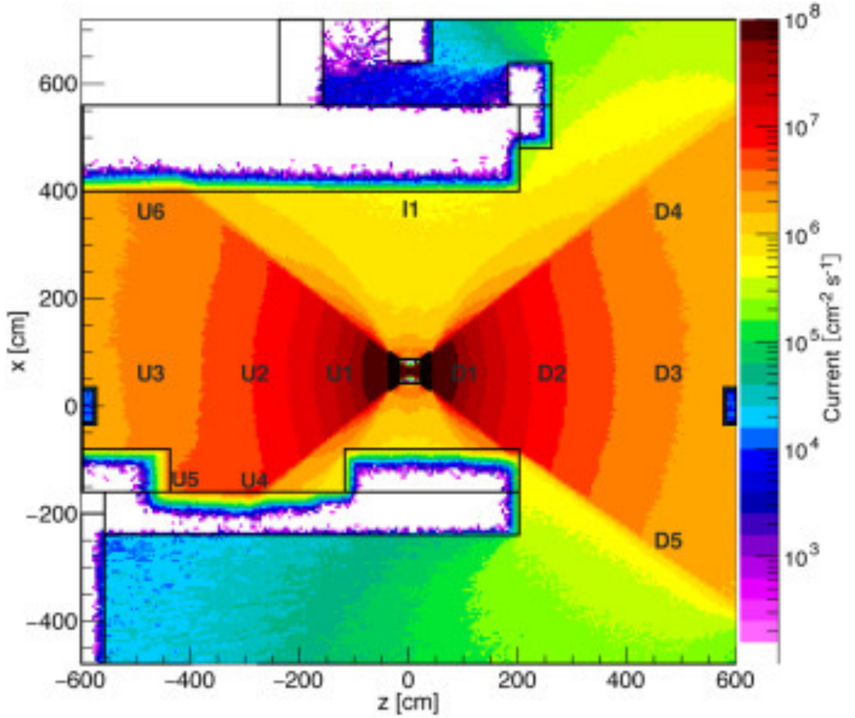
Values obtained scaling the rates measured in ATLAS in 2022 on sTGC chambers (similar values also for MM)

Highest rate only on the first strips of PCB-1
PCB-2 already a factor ~4 less in rate!!



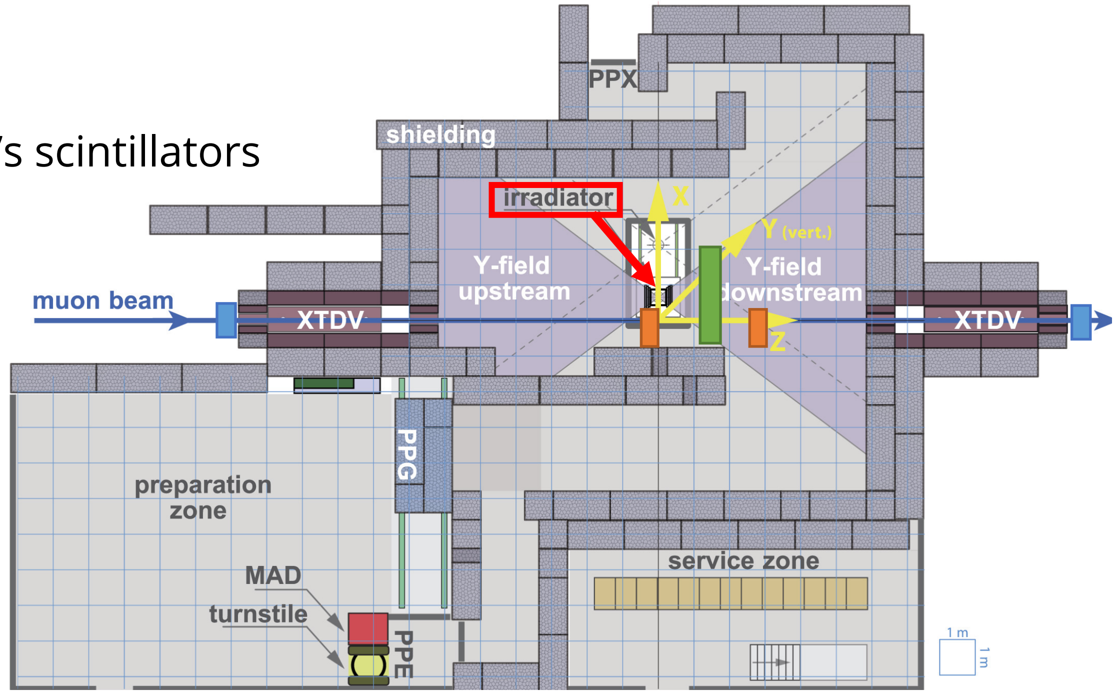
GIF++ facility and setup

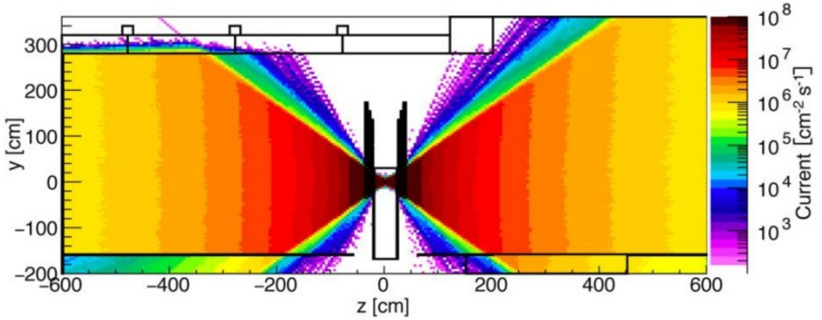
- Irradiation and performance studies of MM detectors with irradiation from a gamma-ray source in GIF++ facility at CERN
- Radioactive source: ^{137}Cs $662\ \mathrm{keV}$ Gammas $\sim 11.6\ \mathrm{TBq}$
- Possible to tune the irradiation intensity by selecting a set of 3 filters in front of the source (24 combinations from Attenuation Factor=1 to AF=46k)



During test-beams:

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





MM chamber
Tracking chamber
Scintillator

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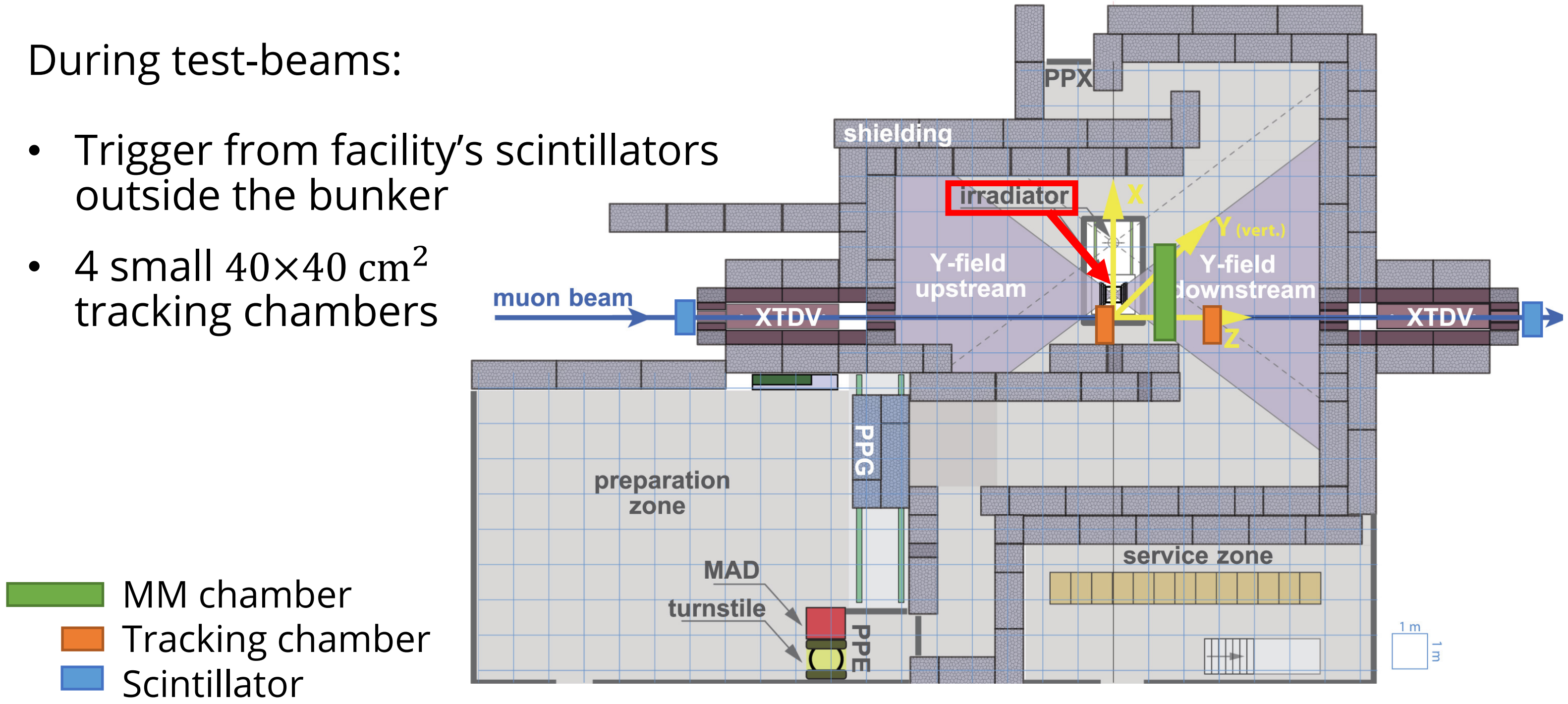
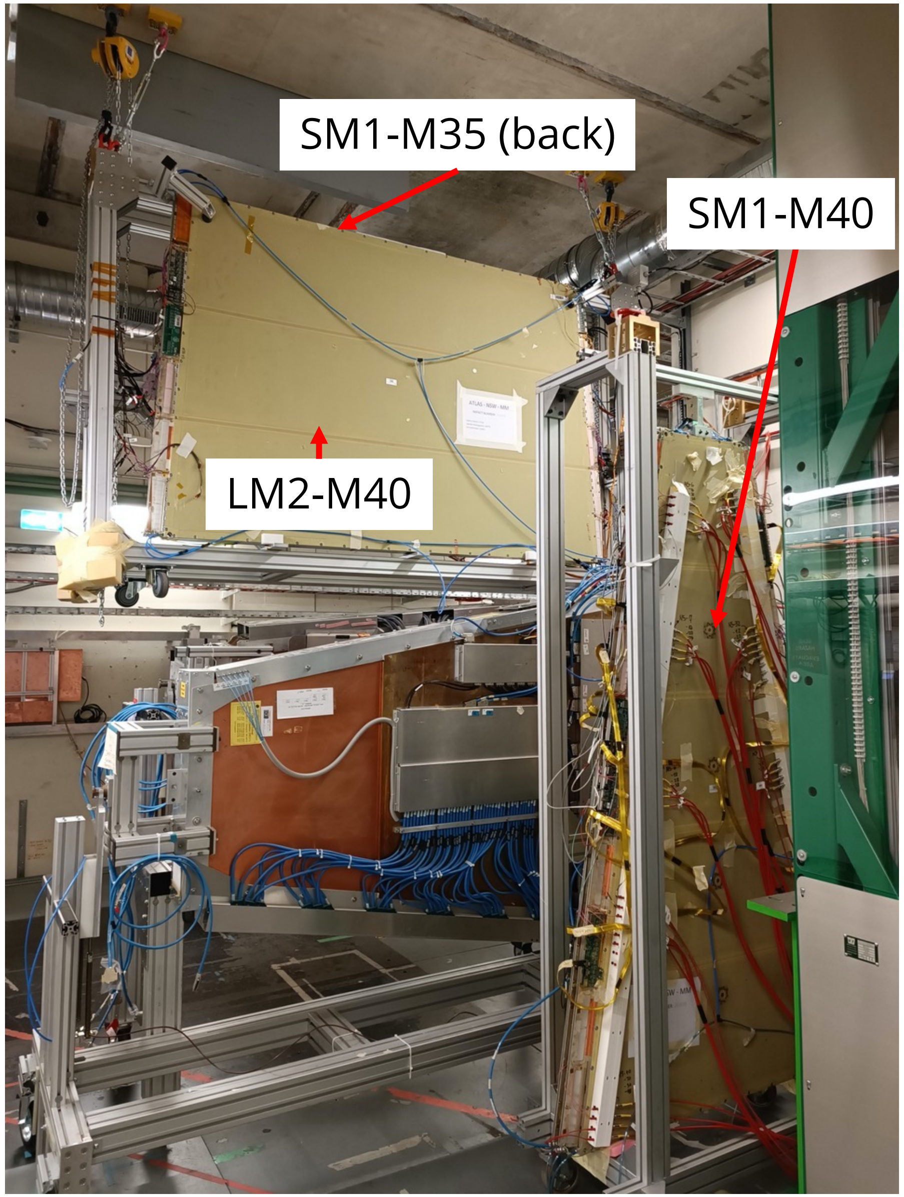
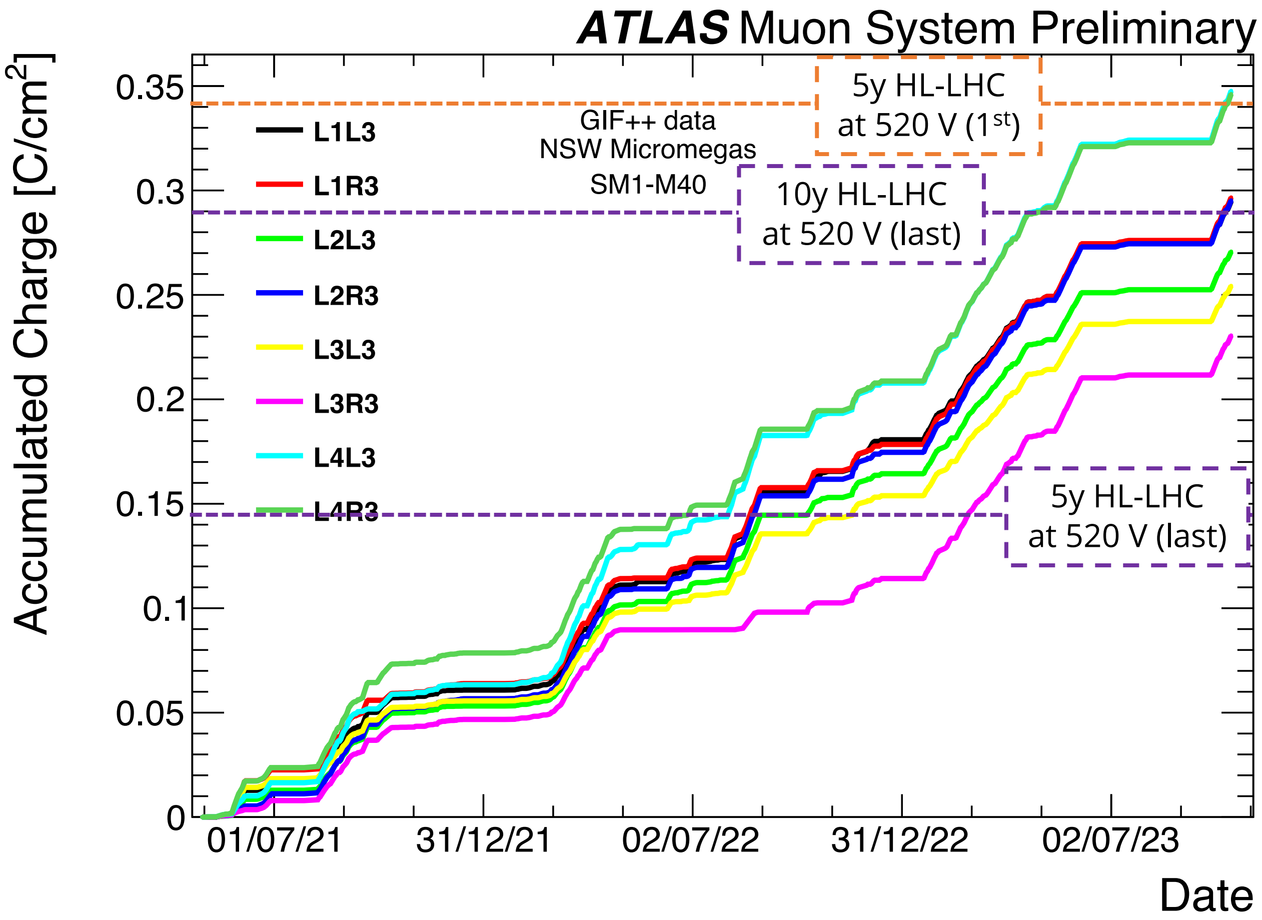




Irradiation of Micromegas detector

- Long term irradiation studies started in 2021 using MM production detectors (spares): SM1 and LM2 type
- Different distance from the source of SM1 and LM2 chambers resulting in different accumulated charge
- Focusing on SM1 chamber having a larger expected irradiation in HL-LHC conditions
- Large difference of expected irradiation between the 1st and the last strip of the PCB1:
  - Almost a factor 2 less being 43 cm further from the beam axis
- **Several years of HL-LHC equivalent have been accumulated so far, with no general decrease in performance observed!**
- Test beams performed during irradiation campaign to validate and track the performances of the irradiated detectors
- All results shown in the slides are evaluated after more than 2 years of irradiation!

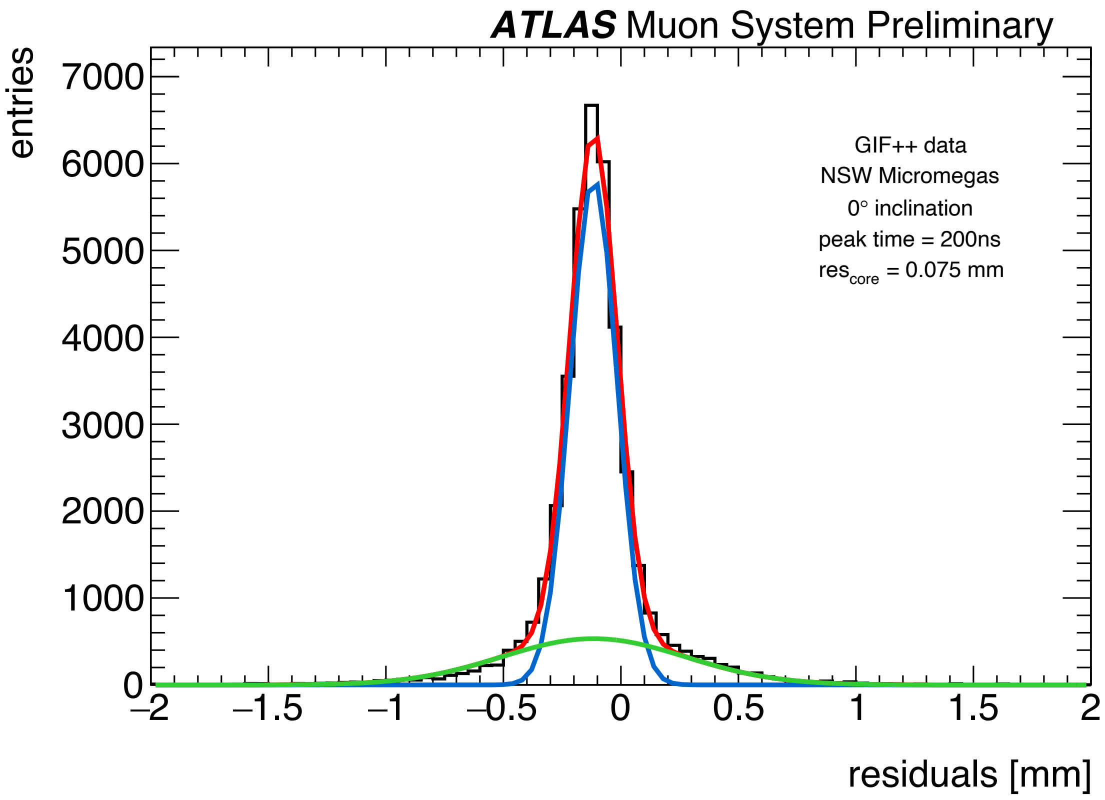


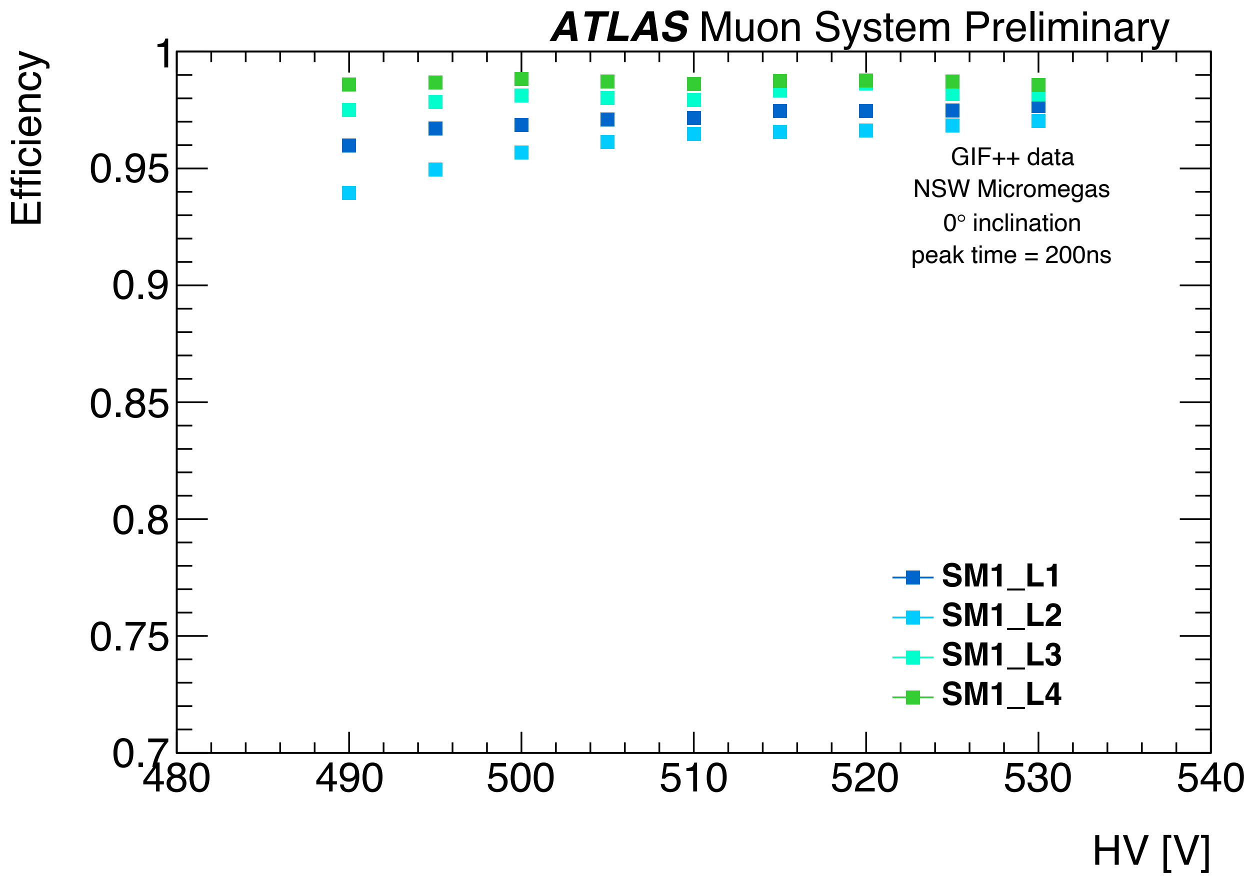
The values of the lines corresponds to the first and last strips of PCB1 expected irradiation

Performance after 2 years of irradiation

Detector performances evaluated after 2 years of irradiation:

- Perfect efficiency for several values of applied high voltage
- Spatial resolution $< 100\ \mu m$ achieved on irradiated chamber



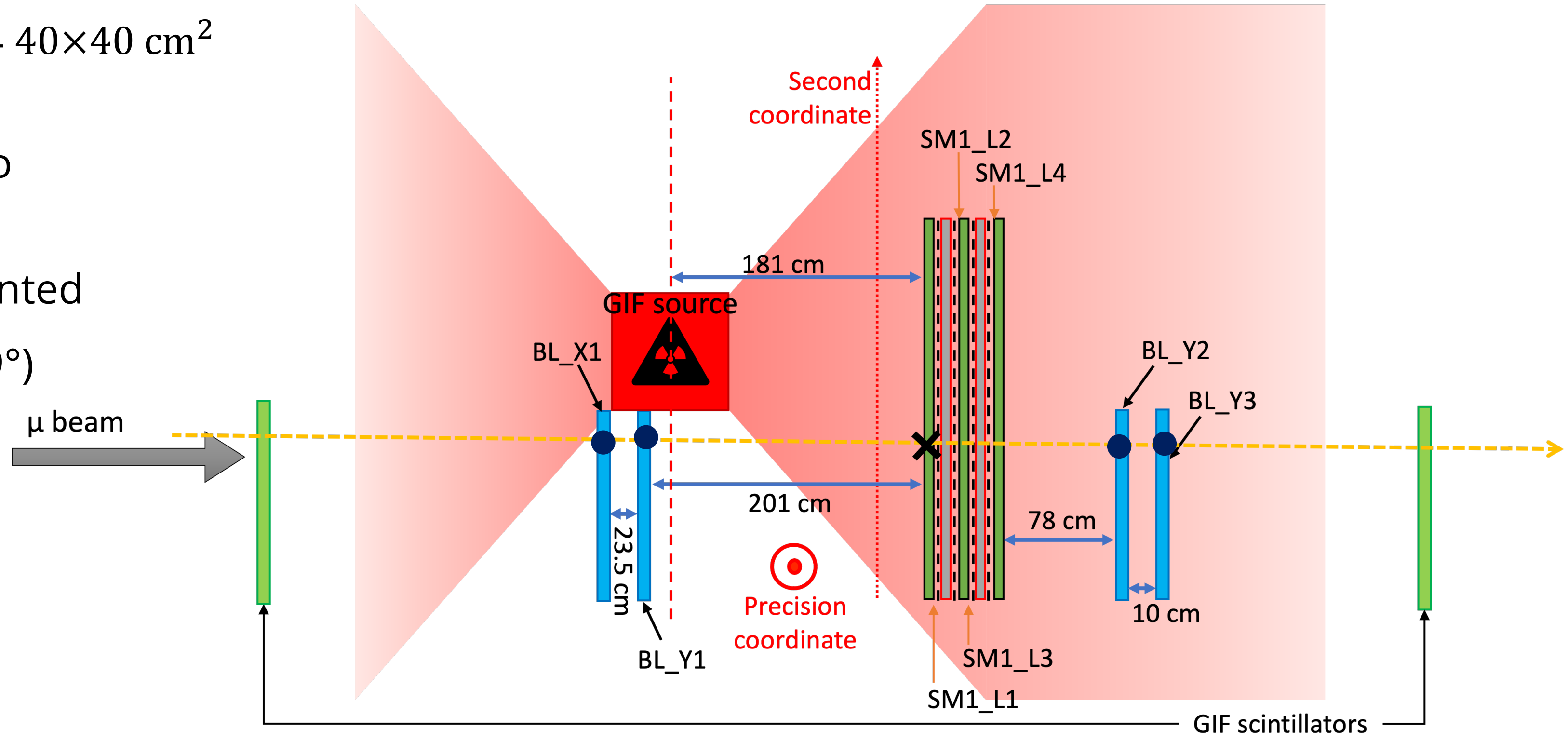


→ performances matching ATLAS design requirements

→ showing no degradation of performances after irradiation

Test beam strategy

- 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:

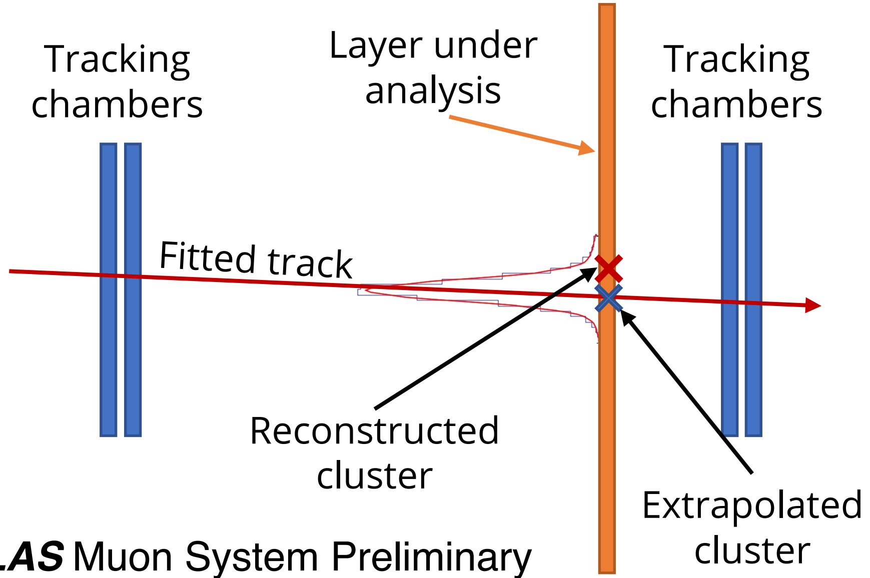
- **Charge centroid method** (standard):

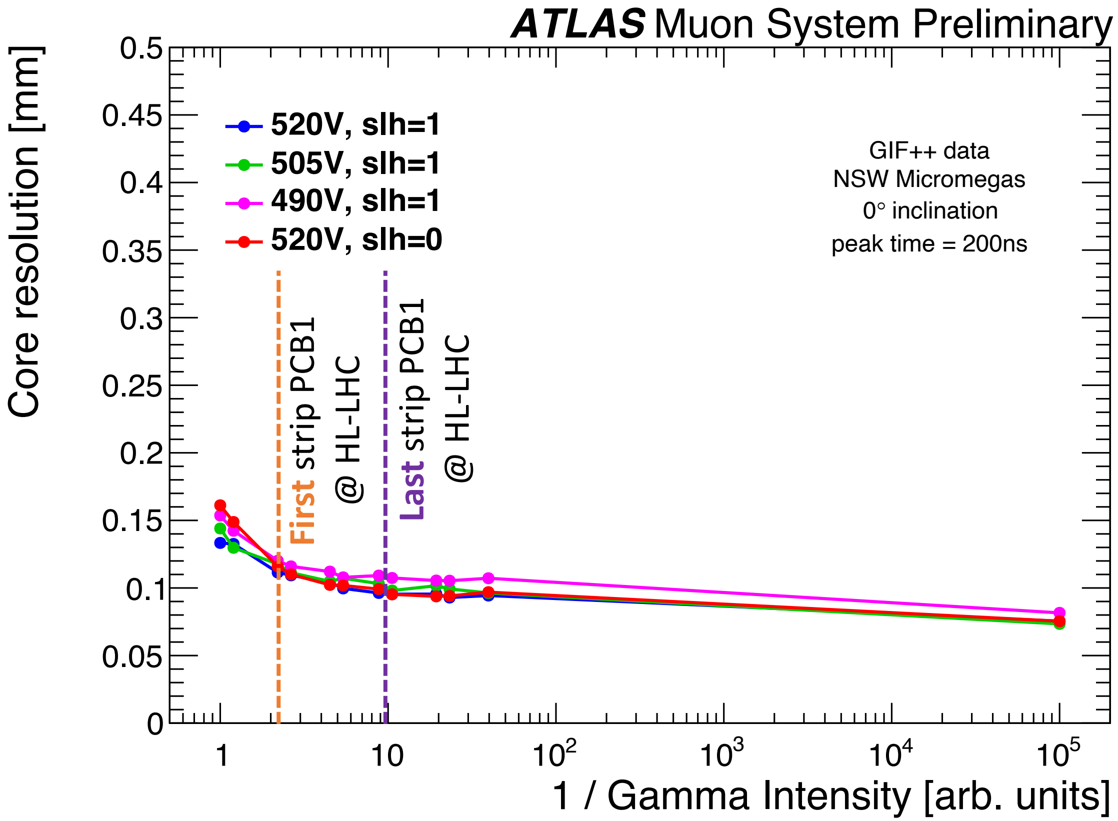
$$x_{centroid} = \frac{\sum_{i=1}^{N} q_i x_i}{\sum_{i=1}^{N} q_i}$$, with N strips in the cluster

- **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

Spatial resolution

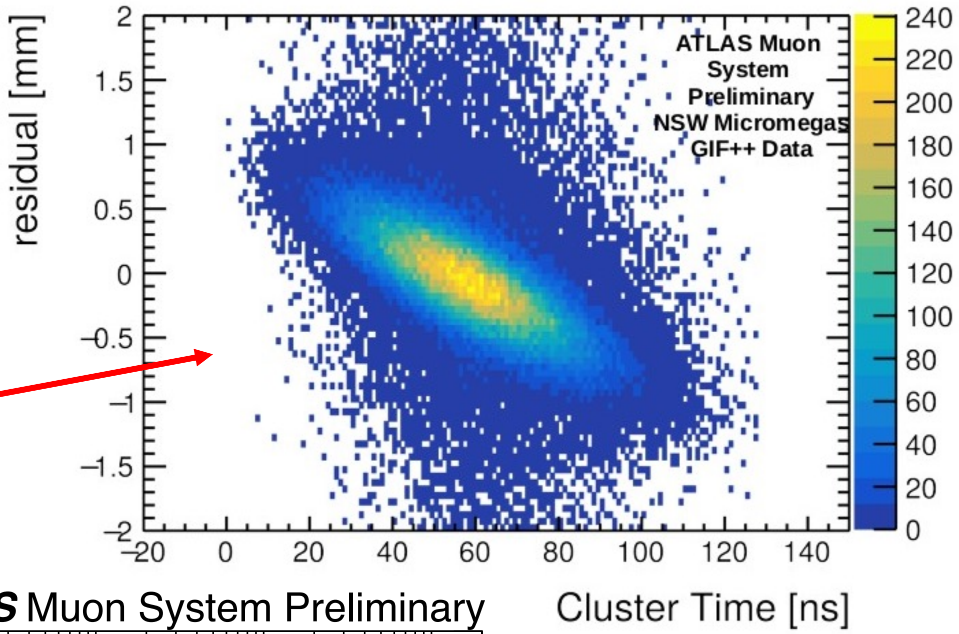
- Spatial resolution is evaluated by a bi-Gaussian fit performed on the residuals between the cluster position and the track extrapolated position on the analysed layer
- All alignment corrections are applied accounting for offsets and rotations
- Flat spatial resolution vs HV, and below $100\ \mu m$, slightly degradation at $490\ V$ having lower gain and less strips over threshold
- Slightly degradation of resolution at larger background rate, but still below $140\ \mu m$ at $520\ V$, due to larger tails from background hits
- **Confirmation of good performances at high rates and after long irradiation of the chamber!**



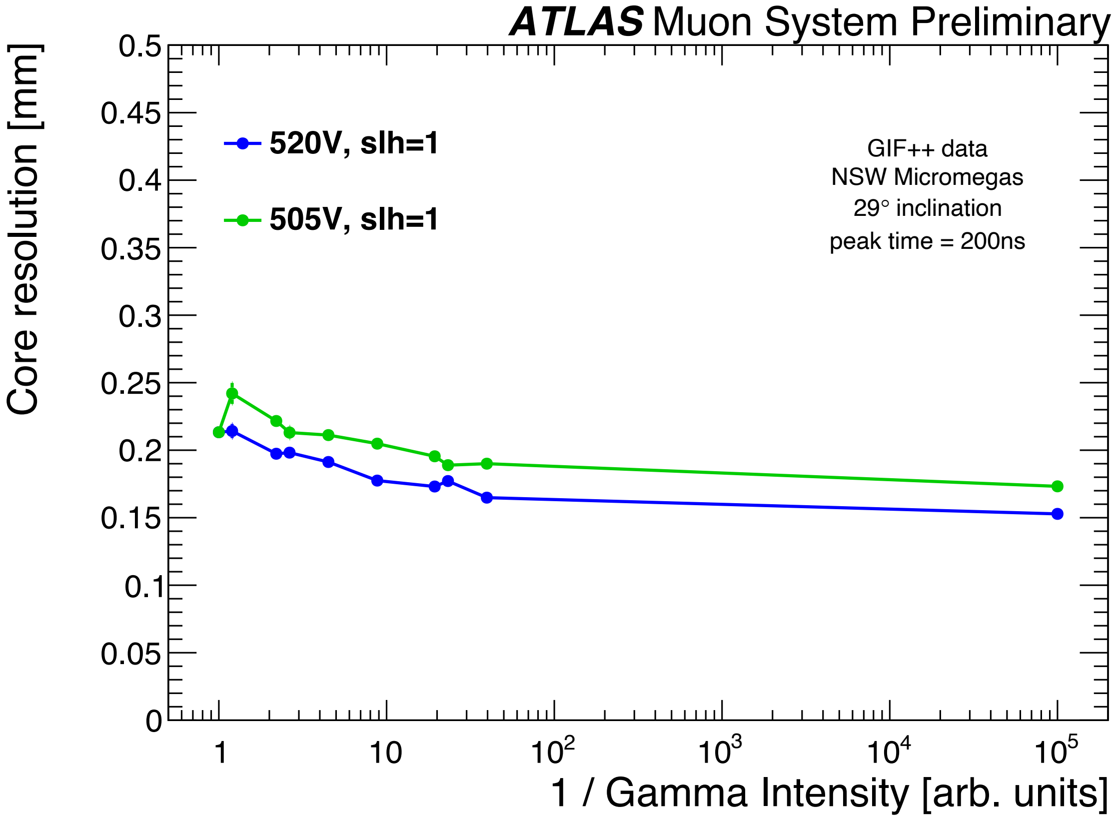


Spatial resolution inclined tracks

- Cluster position for inclined tracks is reconstructed using the **cluster-time projection method:**
  - Correlation between residuals and time of the cluster is exploited to narrow the residuals distribution and achieve better spatial resolution!



- Reaching 150 μm with no background radiation at 520 V
- Slightly worse resolution decreasing HV having lower gain and less strips over threshold, specially for inclined tracks
- Degradation of resolution at larger background rate due to larger tails from background hits, but still below 250 μm
- **Best results obtained so far for inclined tracks reconstruction for ATLAS Micromegas detectors!!**

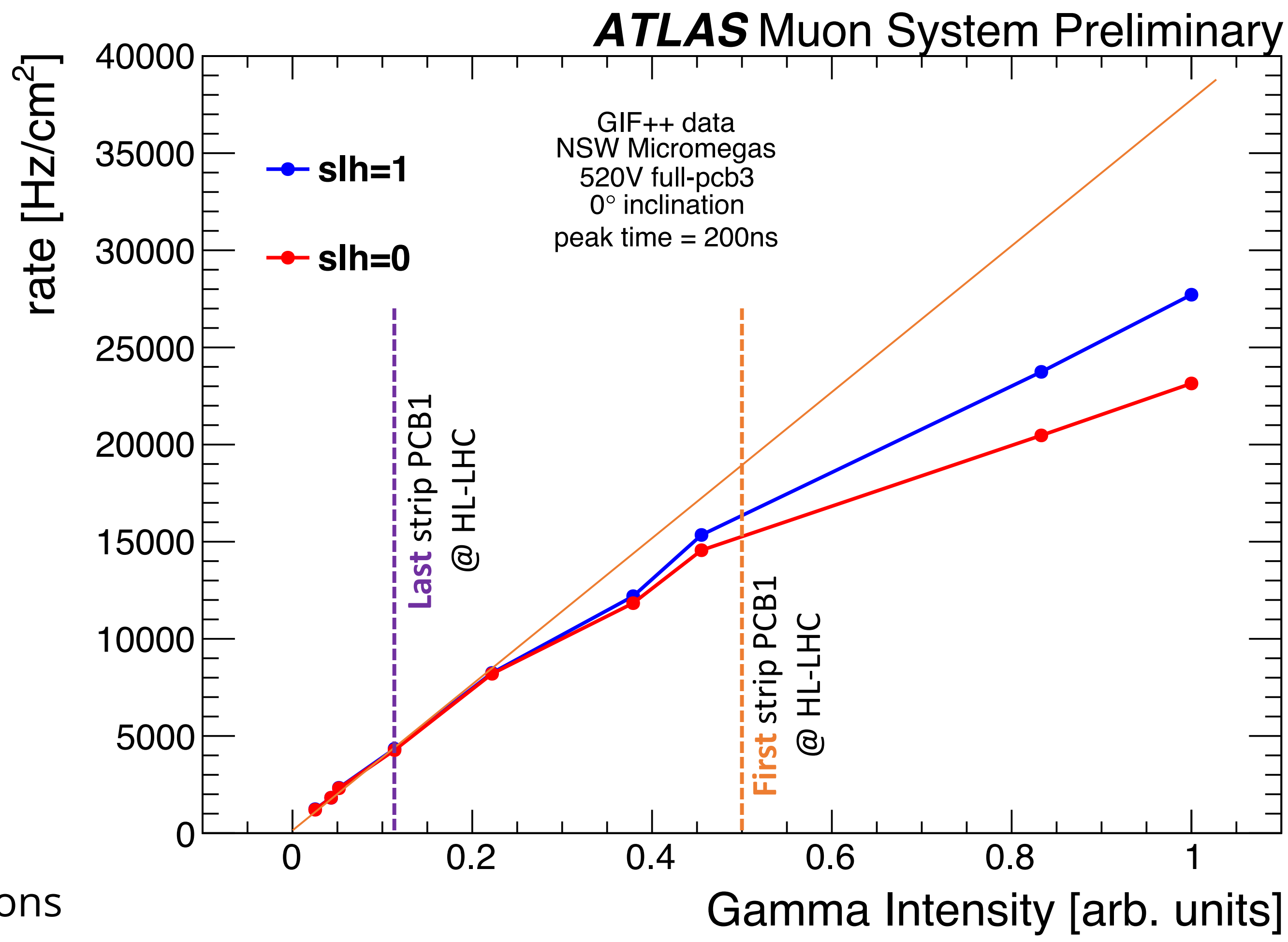


Rates

- Rates important to understand their correspondence to the gamma source intensity

$$rate = \frac{mean\ number\ of\ clusters}{time\ window \times area}$$

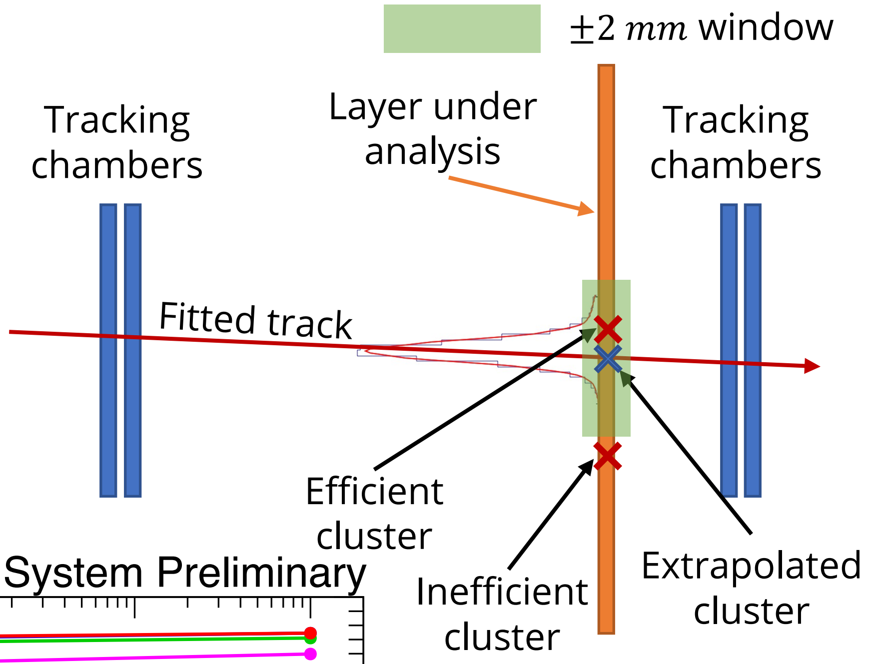
- Cluster (≥ 1 strip) rates evaluated with vertical setup
- The two lines corresponds to the different setting of the slh parameter of the VMM electronics, corresponding to an higher ($slh = 1$) or lower ($slh = 0$) bias voltage at the input of the electronic channels
- Larger bias voltage provide a faster restoration of the baseline, recovering partially hit occupancy and slightly larger rate detection at higher gamma intensity
- Saturation effect visible only partially in HL-LHC conditions and only limited to the PCB1
- Other PCBs should not see such high rates, causing this saturation issue

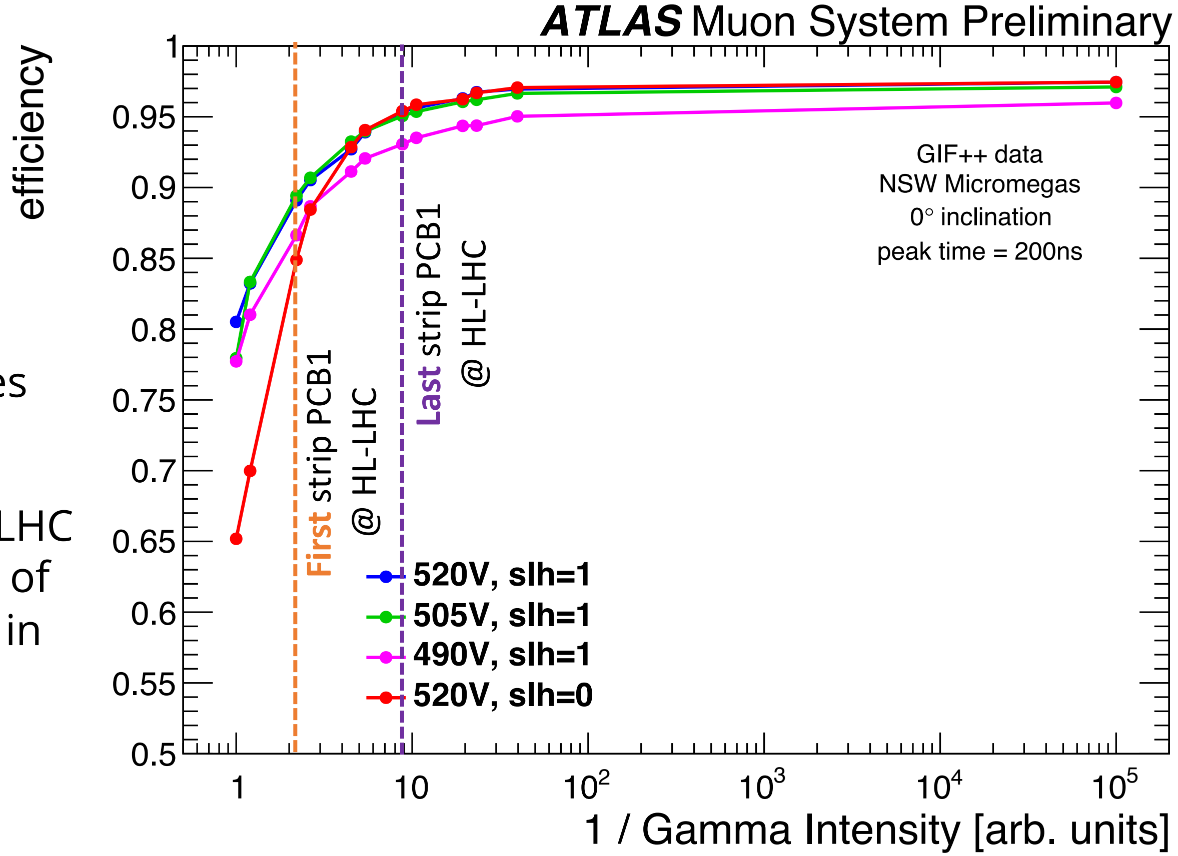


From currents measurements in ATLAS and at GIF++, the value gamma intensity~0.5 is the equivalent to the expected irradiation of the first strip of pcb1 during HL-LHC operations

Efficiencies

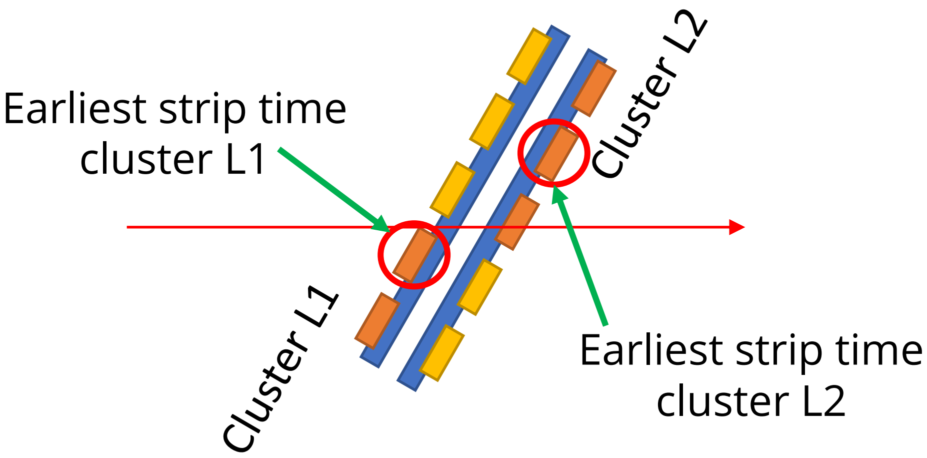
- Effect of slh VMM parameter shows partial recovery of efficiency at larger background rates
- Decrease of efficiency expected to be limited to the PCB1
- 1st strip of PCB1 at ~90% efficiency
- Factor ~4 less background rate for last strip of PCB1 → reaching already >95% efficiency
- Other PCBs should not see such high rates and should have >95% efficiency at the expected HL-LHC conditions rates
- Overall good performances of ATLAS Micromegas detectors expected in HL-LHC conditions, specially when redundancy of the several detector layers is exploited in muon reconstruction with 4/8 layer coincidence

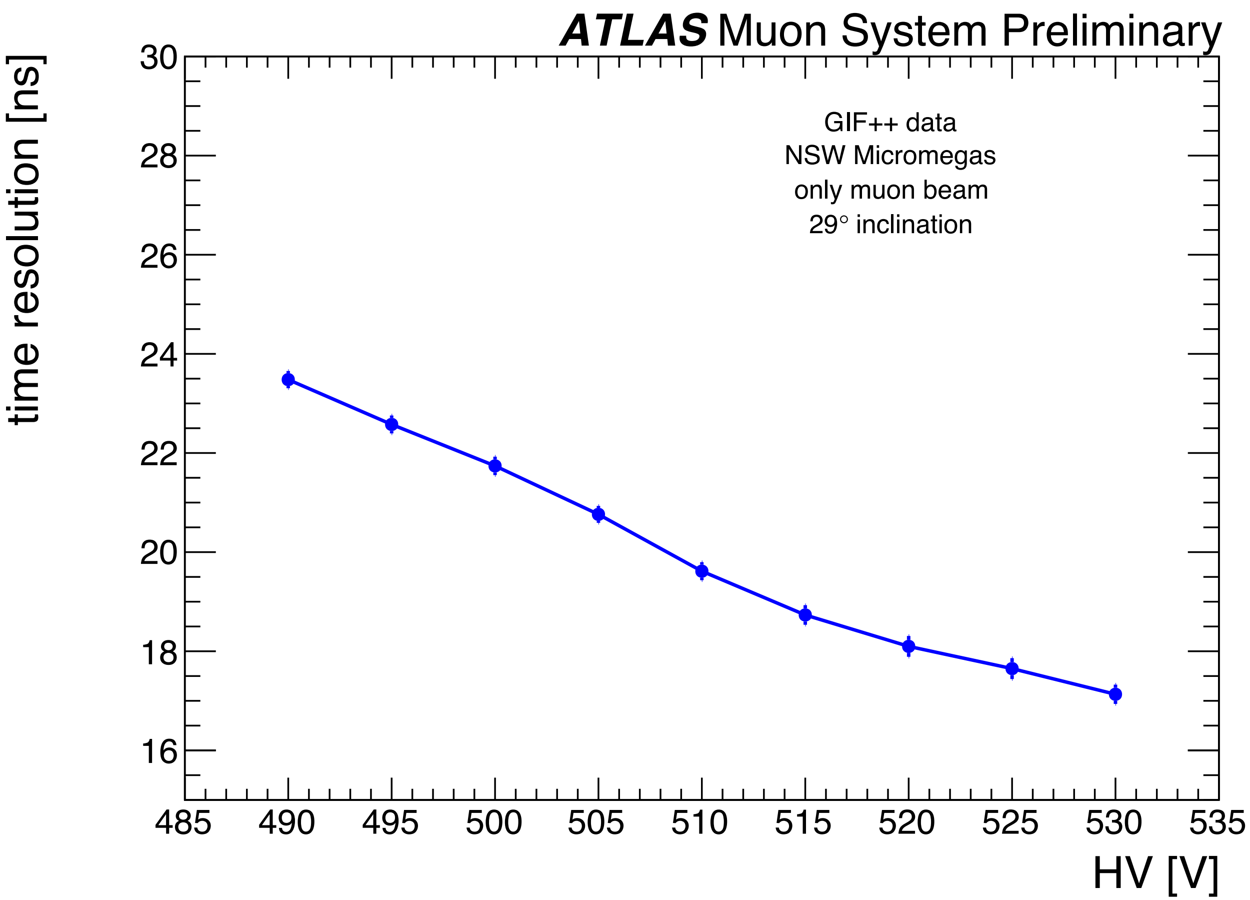




Time resolution

- Time resolution also measured on irradiated chamber to determine timing performances for trigger purposes
- Time residuals of the earliest strips in back-to-back clusters, fitted with double-Gaussian
  → weighted resolution reported
- First two layers of the detector used





- Values improve with higher gain!
  From $505\ \mathrm{V}$ to $530\ \mathrm{V}$ we go from $\sim 21\ \mathrm{ns}$ to $\sim 17\ \mathrm{ns}$ of time resolution, improving reconstruction performances and trigger time spread
- **$17\ \mathrm{ns}$ time resolution reached on a long-term irradiated chamber, confirming no degradation of performances!**

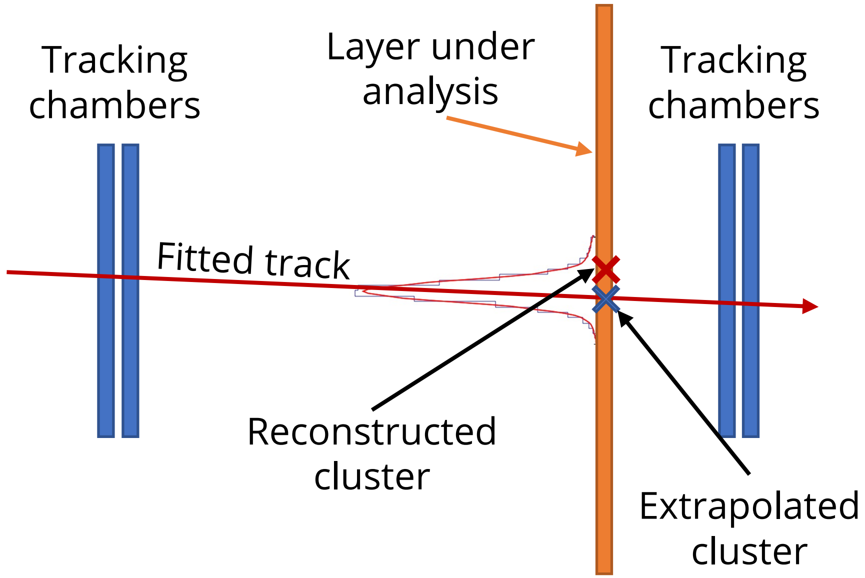
Summary

- 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!
- New bias voltage of the VMM channels ($slh = 1$) exploited to cope with the large signals and high rates at the larger gamma intensity provided by the GIF++ source
- Very high efficiency and nominal resolution for perpendicular tracks, maintained also with high gamma intensity
- Evaluated best results in inclined track position resolution up to $\mathbf{150\ \mu m}$ at higher gain WP
- Time resolution improving with higher gain, reaching $17\ \mathrm{ns}$ at $530\ \mathrm{V}$
- Overall performances not suffering the irradiation accumulated so far, showing still nominal performances!

Thanks for your attention!

Backup

Cluster building parameters



Cuts are applied on strips and in the cluster building:

STRIPS :

- Charge min: 58 PDO counts (~3 fC)
- Charge max: no limits

CLUSTERS:

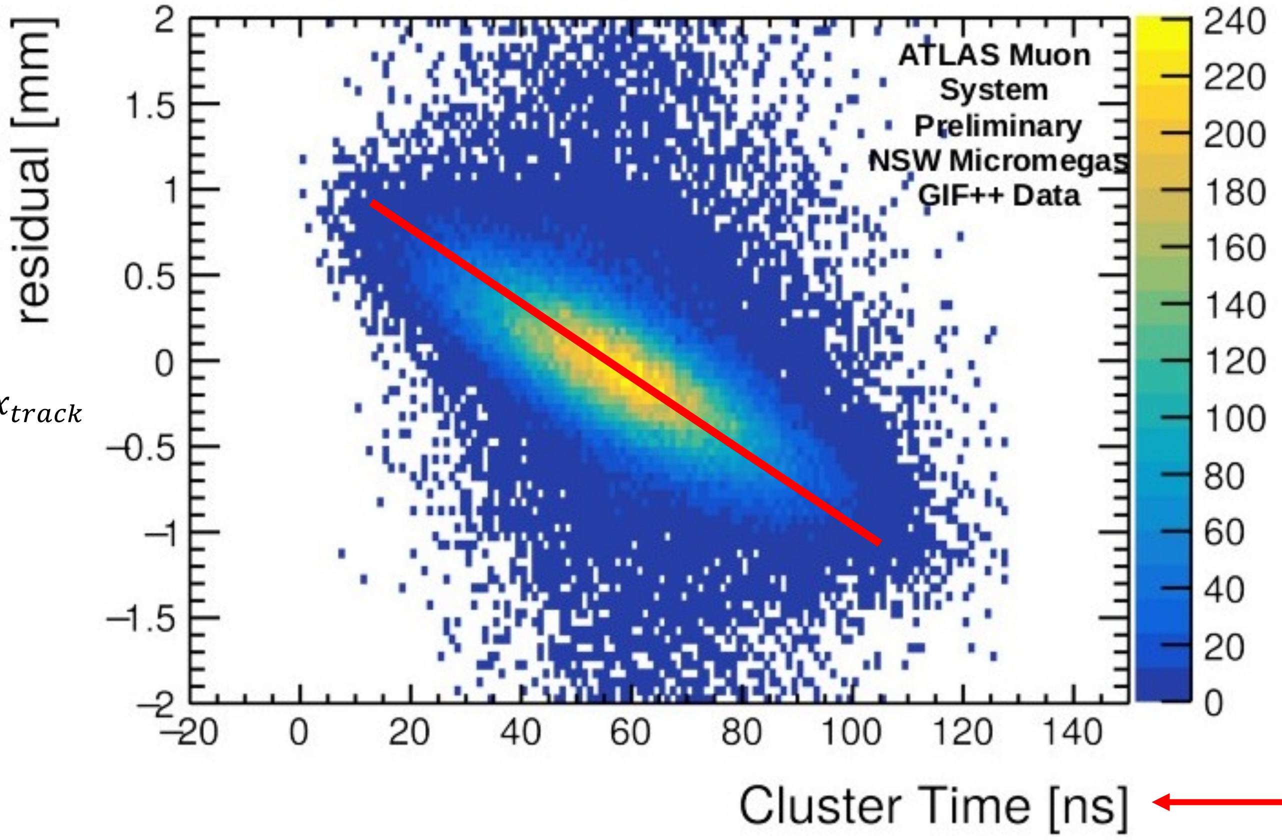
- Charge min: 100 PDO counts (~5.2 fC)
- Charge max: no limits
- N strip min: 1
- N strip max: 50
- N max holes: 2
- N max consecutive holes: 1

- Alignment done with Beam only runs (source OFF)
- Tracking made with the 4 BL chambers 1 providing 2nd coordinate
- Coincidence of single cluster on Y1 and X1 + back-to-back clusters on Y2-Y3
- Linear fit of the track and interpolation to the plane of the layer to analyse
- Bi-Gaussian fit is performed on the residuals between the cluster position and the extrapolated position on the analysed layer

Cluster-time projection

- Cluster-time projection method for the correction of the centroid reconstructed position
- Time of the cluster from charge weighted average of the strip's time: $t_{cluster} = \frac{\sum_i^N t_i \cdot q_i}{\sum_i^N q_i}$
- Correlation fitted with linear function and correction applied to the centroid position
- Elliptical shape coming from the inhomogeneous energy loss of the muon in its path inside the drift gap

$$x_{centroid} - x_{track} = \frac{\sum_{i=1}^N q_i x_i}{\sum_{i=1}^N q_i} - x_{track}$$



$$t_{cluster} = \frac{\sum_i^N t_i \cdot q_i}{\sum_i^N q_i}$$

Spatial resolution results 2022

- In 2022 observed good performance during intermediate test-beam during the irradiation campaign
- Up to $\mathbf{80\ \mu m}$ core resolution (depending on the tuning of the alignment of the layer) using centroid method
- Values compatible with the ones measured in 2023 after several months of additional irradiation, confirming stability of the detector performances!