Performances of the small-strip Thin Gap Chambers (sTGC's) in the New Small Wheels of ATLAS

Sonia Kabana (University of Tarapaca, Chile) on behalf of the ATLAS Muon Spectrometer System collaboration

ICNFP 2023 10 July - 23 July 2023

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Outline

The New Small Wheels detector of ATLAS

sTGC performances

Conclusions and outlook

The ATLAS New Small Wheel-A in the ATLAS pit (2021)

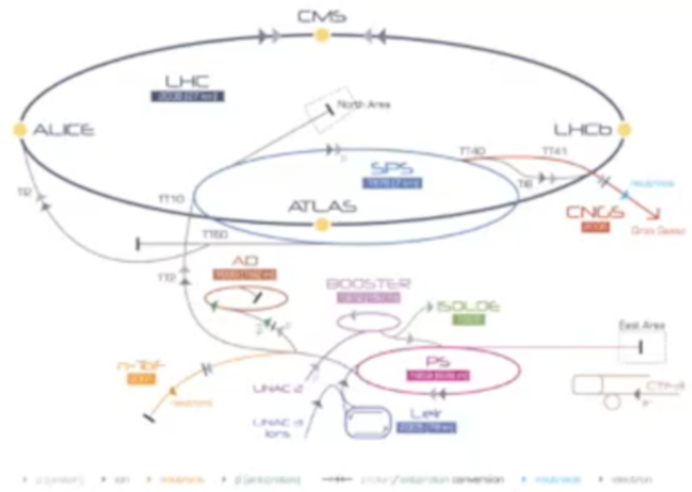
Other talks about the NSW of the Muon spectrometer of ATLAS shown in this conference :

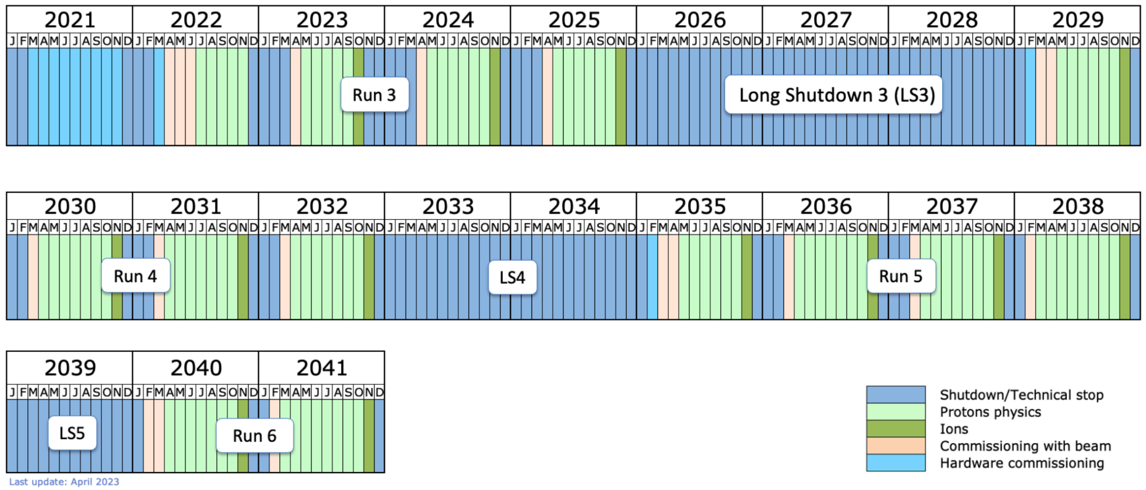
Performance studies of Micromegas detectors in ATLAS with Run3 data, Paolo Massarotti

Data quality and position reconstruction of the small-strip Thin Gap Chambers of the ATLAS NSW, Michael Schernau (extended day)

The New Small Wheels detector of ATLAS

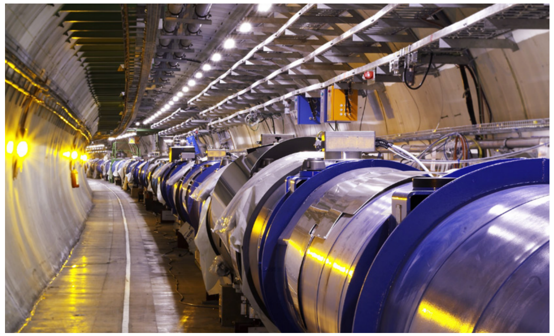
Large Hadron Collider





LHC design parameters for p+p collisions:

Design center of Mass energy = 14 TeV
Design instantaneous luminosity L ~ 10ˆ34 cm-2 sec-1
Design bunch spacing 25 nsec, 2800 bunches per beam
with 10ˆ11 protons per bunch at the start of a nominal fill



Run3 (2022-2025):

Instantaneous luminosity L: ca. 2 *10ˆ34 cm-2 sec-1
This corresponds to about 55 p+p interactions per bunch crossing.
Center of Mass energy for p+p collisions = 13.6 TeV, and is expected to reach design value of 14 TeV for the first time

Run4 or High Luminosity LHC (HL-LHC) (2029-2032):

Instantaneous luminosity L will raise to (5 to 7.5) *10ˆ34 cm-2 sec-1
This corresponds to about 140-200 p+p interactions per bunch crossing

The New Small Wheels detectors have been designed to cope with the high luminosity of HL-LHC. The NSW is a phase I upgrade foreseen to function for HL-LHC as well.

ATLAS Muon Spectrometer

ATLAS Muon Spectrometer prior to 2021 (from [1,2])

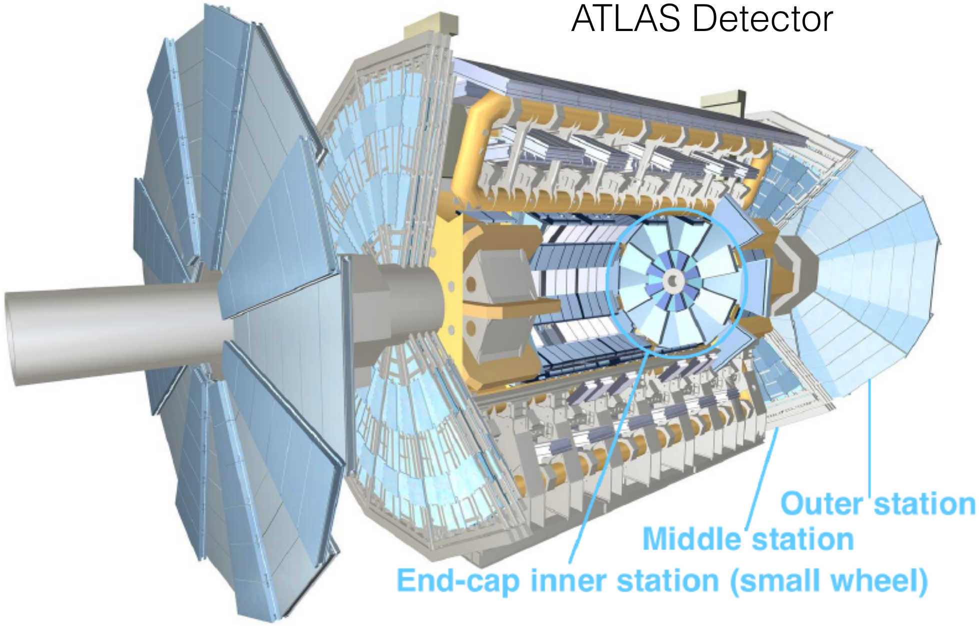
4 gaseous detector technologies have been used till now:

Cathode Strip Chambers (CSC)
Resistive Plate Chambers (RPC)
Monitored Drift Tube Chambers (MDT)
Thin Gap Chambers (TGC)

Spatial resolution better than 100 micron (MDT, CSC) resulting in a pT relative resolution of about 10% , at pT=1 TeV.
Muon reconstruction efficiency > 98%

Barrel: |eta|<1
End-Cap: 1<|eta|<2.7

ATLAS Detector



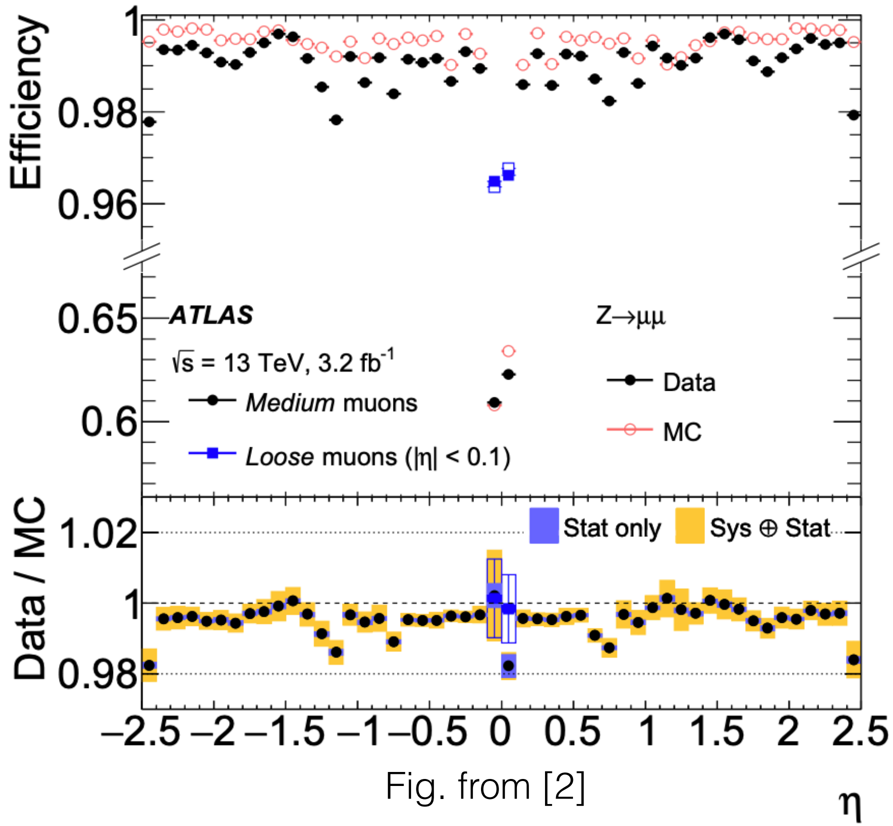
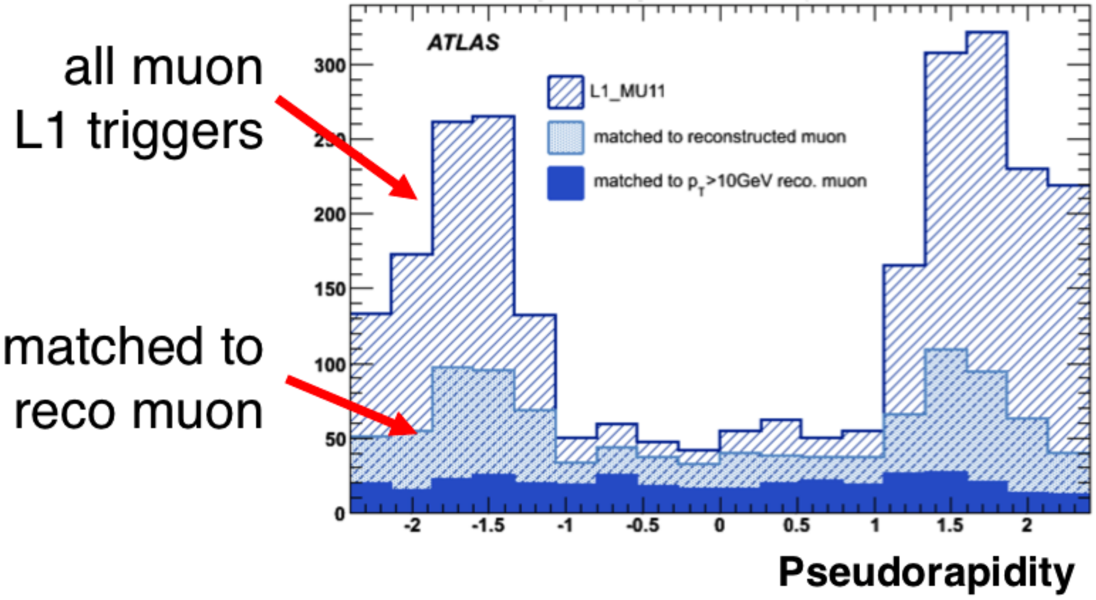


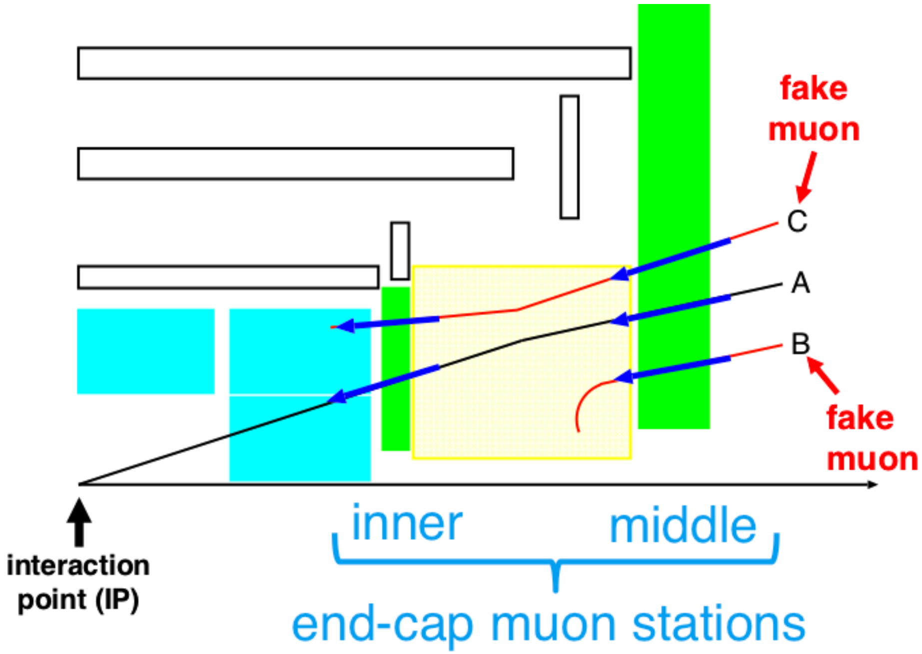
Fig. from [2]

[1] ATLAS Muon Spetrometer TDR,
[2] Muon reconstruction performance of the ATLAS detector in p+p collisions at sqrt(s)=13 TeV, G. Aad et al (ATLAS Collaboration) Eur. Phys. J. C 76 (2016) 292

ATLAS Muon Spectrometer expected performance at HL LHC

The Muon detector with the Old Small Wheels of ATLAS at HL LHC would be dominated by fake triggers





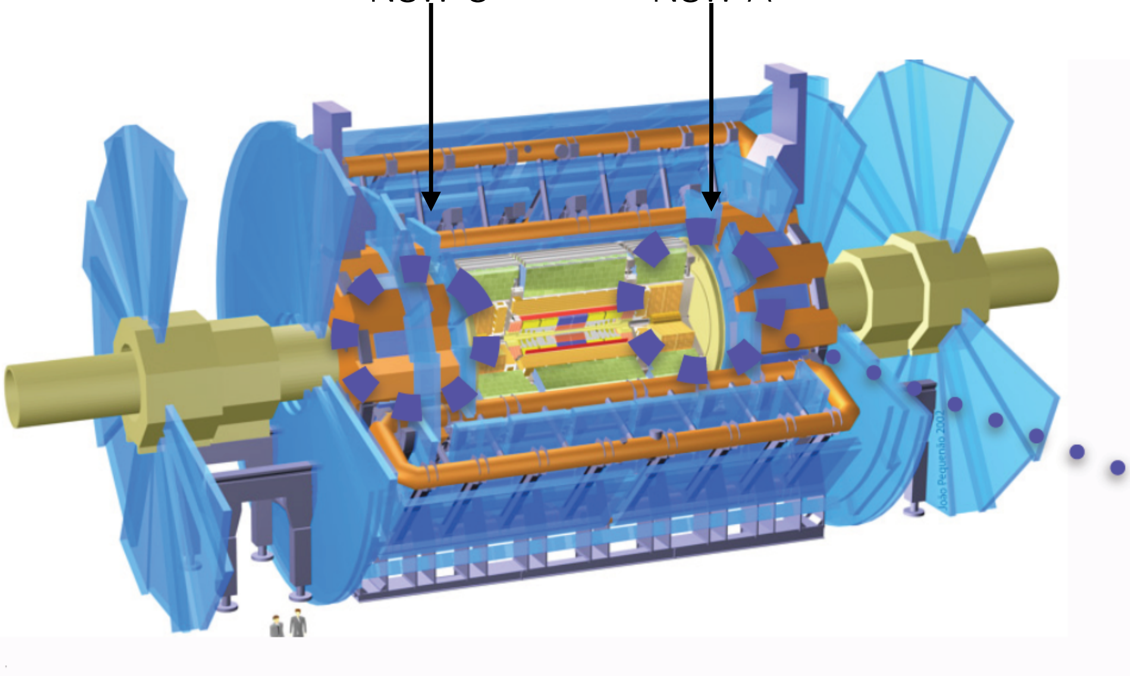
The new end-caps inner stations (the two New Small Wheels) have been designed to enhance tracking precision so that the fake muon triggers are reduced by a factor of 7
As a consequence it will allow to maintain the same trigger thresholds without increase in trigger rate

Resolution requirements for the NSW's :

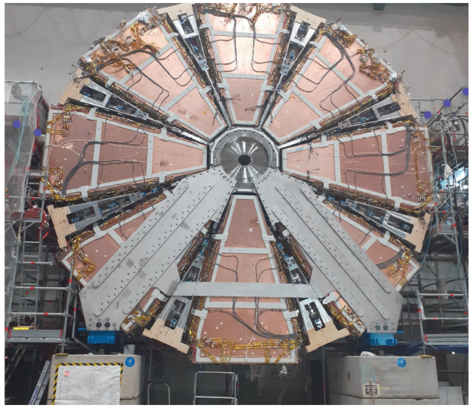
- Spatial resolution of the order of 100 mikrometer per layer is needed for precision tracking
- Angular resolution of about 1 mrad is needed to be able to reject tracks not coming from the primary interaction point with the Level-1 NSW Trigger
- It is designed to operate efficiently in run3 and beyond

[1] ATLAS TDR NSW

ATLAS New Small Wheel upgrade of the Muon Spectrometer



NSW-A

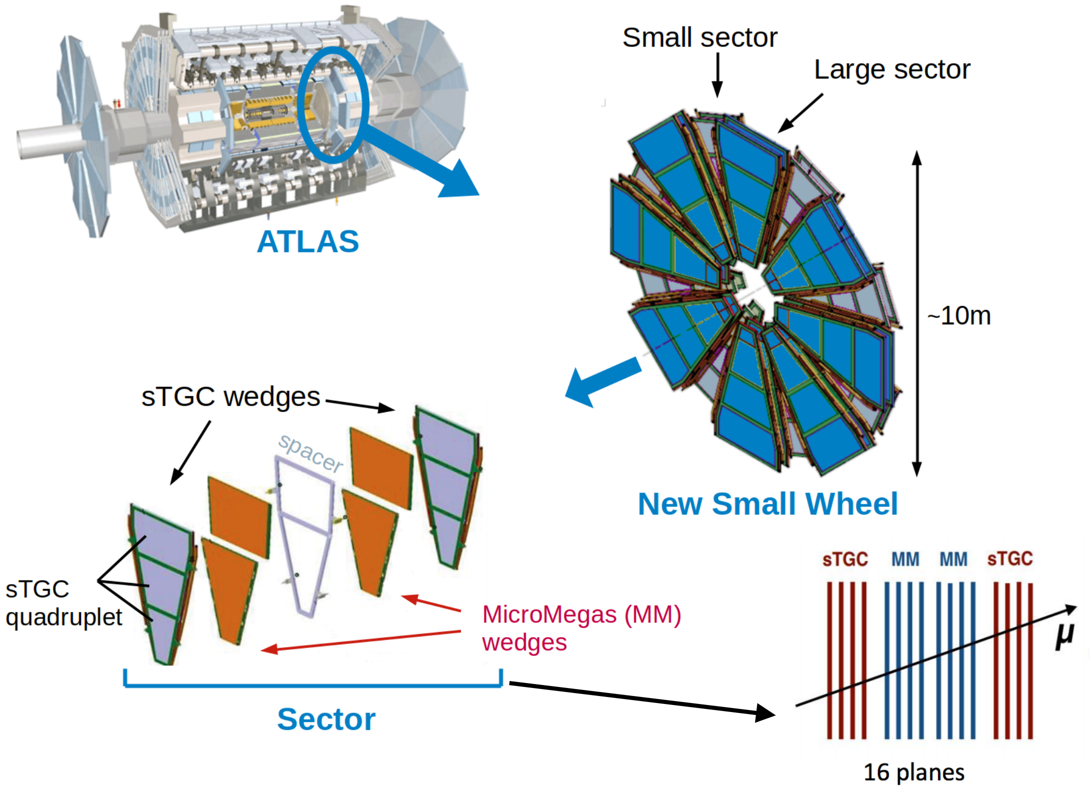


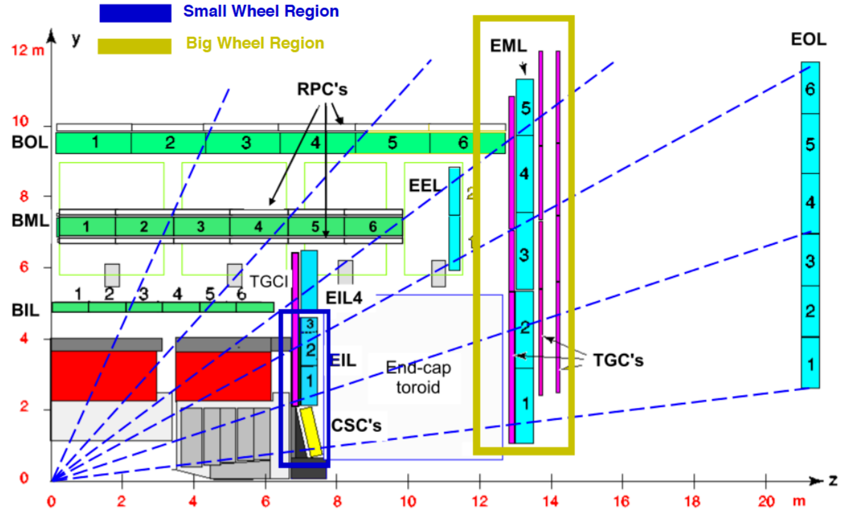
The New Small Wheels of ATLAS have 2 detector technologies:

- The small-strip Thin Gap Chambers (sTGC), primarily devoted to the Level-1 Trigger function and
- The MicroMegas detectors(MM) primarily devoted to precision tracking.

- The New Small Wheels cover a pseudorapidity region of 1.3 - eta - 2.7
-

The NSW structure





A z-y view of 1/4 of ATLAS detector (with the Old Small Wheel). From [1]

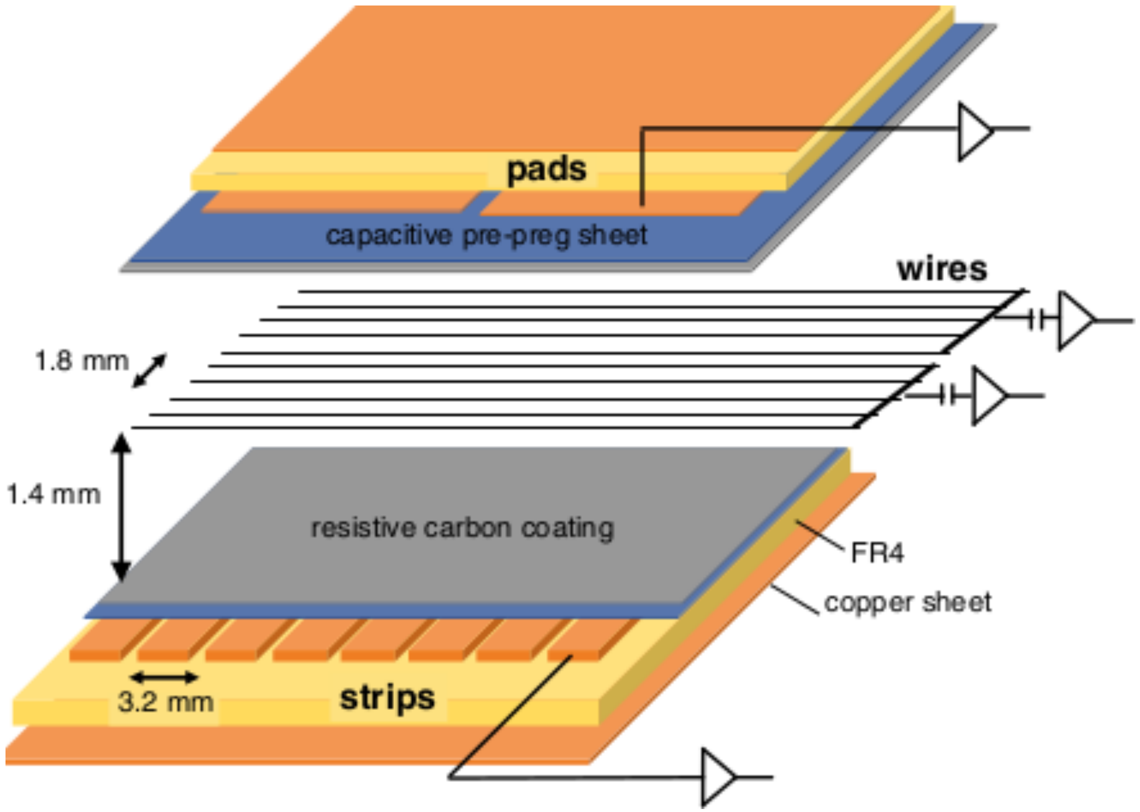
There are two New Small Wheels: A and C. Every Wheel has a diameter of 10 meters and a weight of about 100 tons and consists of 16 sectors (8 Large and 8 Small Sectors).
A Large and a Small sector are mounted in the Wheel alternatively.
2.4 million electronic channels

Every Sector consists of 4 wedges: an inner and an outer sTGC wedge and between them are placed 2 MicroMega wedges.
Every wedge has 4 layers, making in total 16 layers per sector.

Every sTGC wedge is made from 3 quadruplet modules Q1,Q2,Q3 (each made of 4 layers).

[1] TDR NSW

The sTGC inner structure

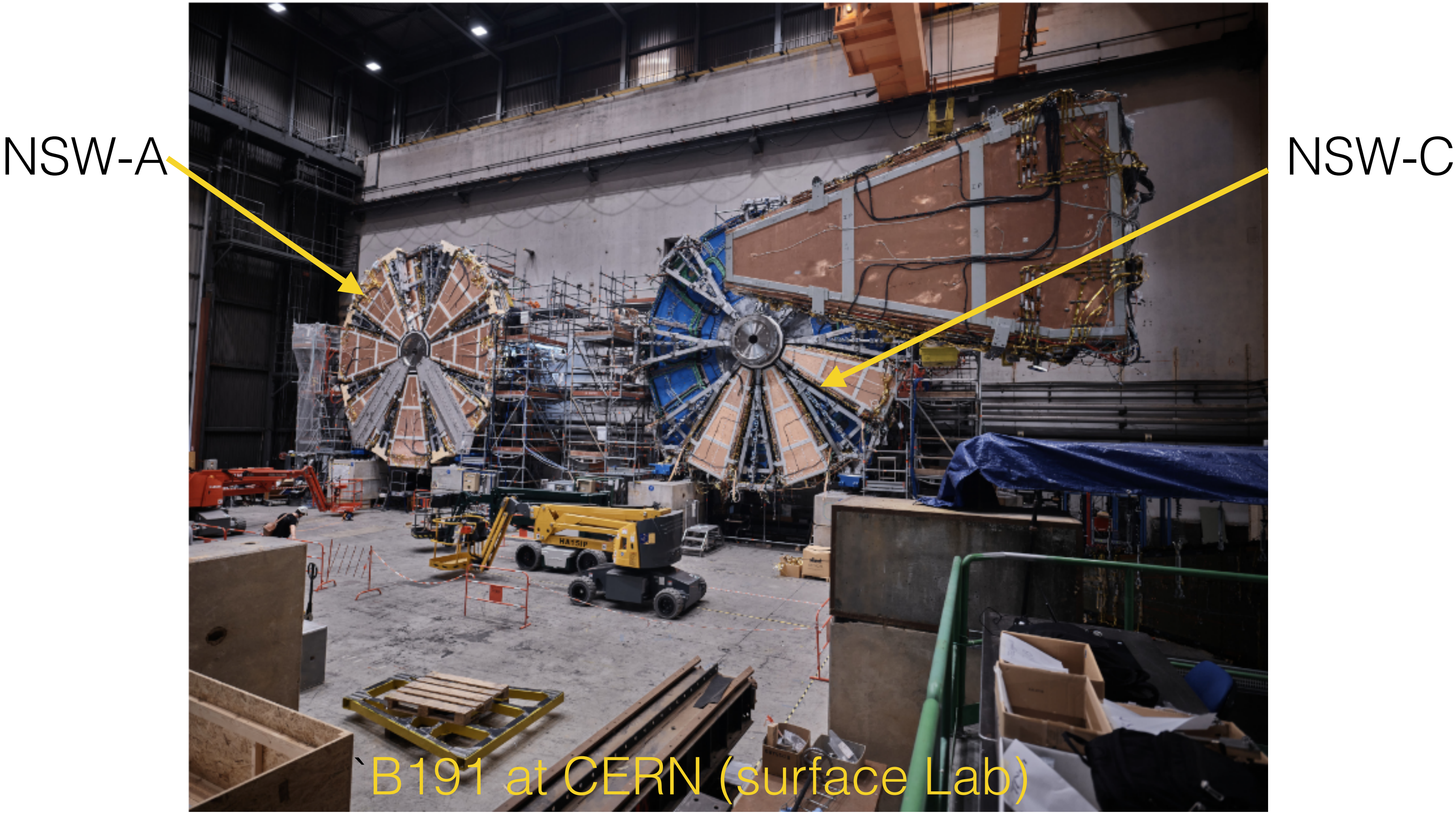


Small-strip Thin Gap Chambers are multiwire ionization chambers which consists of a grid of gold-plated tungsten wires sandwiched between two resistive cathode planes at a small distance from the wire plane. The precision cathode plane has strips with a 3.2 mm pitch for precision readout and the cathode plane on the other side has pads for triggering.

The sTGC are operated at a voltage of 2.8 kV and are filled wih a 55:45 gas mixture of CO2 and n-pentane.

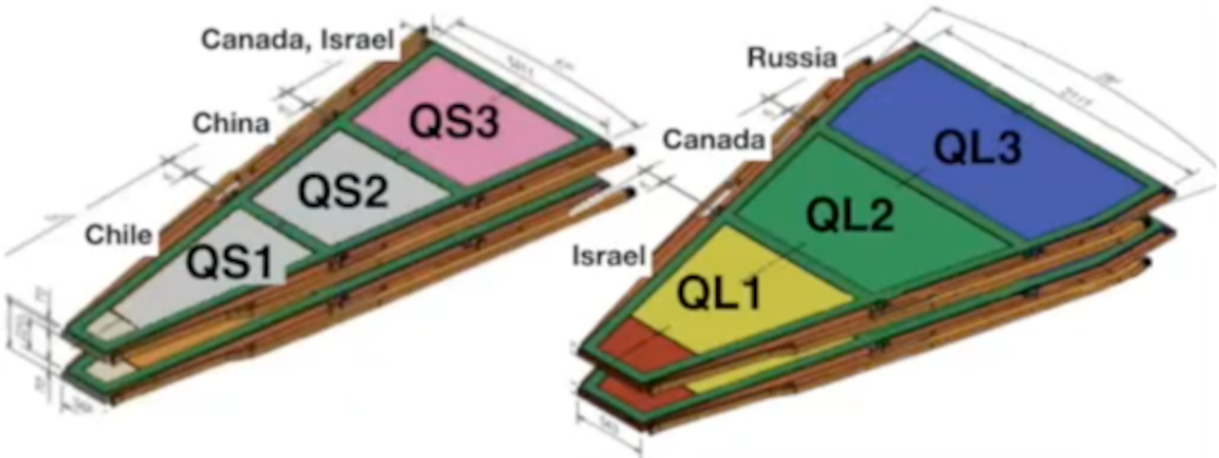
Has a smal strip pitch of 3.2 mm (this explains the prefix small strip Thin Gas Chamber: sTGC) that improves spatial resolution.

Fast signals (arrive within 25 nsec) due to small gas gap, strong electric field and coating with lower resisitivity (graphite)



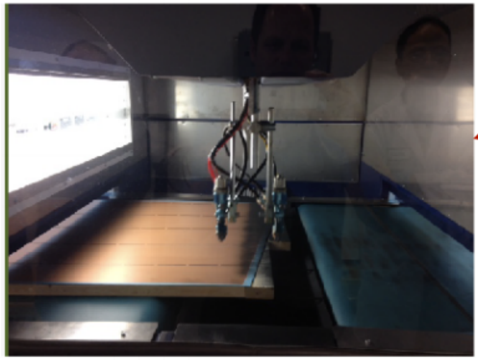
Both NSW's in B191 during integration of the wedges in the wheels in the past

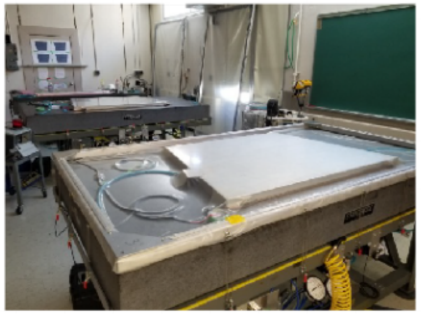
The sTGC detectors have been produced and tested with cosmic rays in Labs in Canada, Chile, China, Israel and Russia. They were sent to CERN to be mounted on the Wheels.

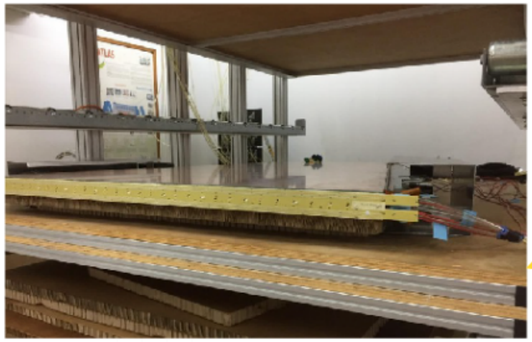


Canada	TRIUMF, Carleton University, McGill University	1/2QS3 QL2
China	Shandong University	QS2
Chile	Pontifical Catholic University of Chile, Federico Santa Maria Technical University	QS1
Israel	Weizmann Institute of Science, Tel Aviv University	1/2QS3 QL1
Russia	NRC Kurchatov Institute PNPI, Petersburg Nuclear Physics Institute	QL3

The sTGC construction







Graphite spraying
↓
Half-gap production
↓
Wire winding of cathode boards
↓
Gap closing and testing
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Doublet assembling and testing
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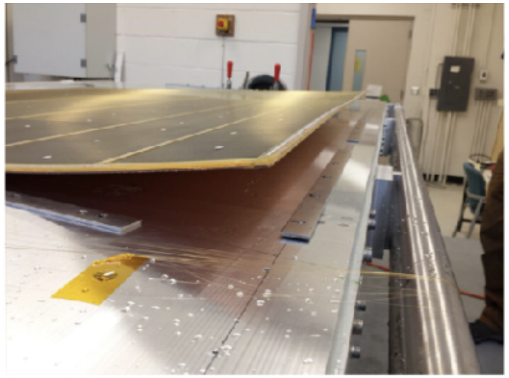
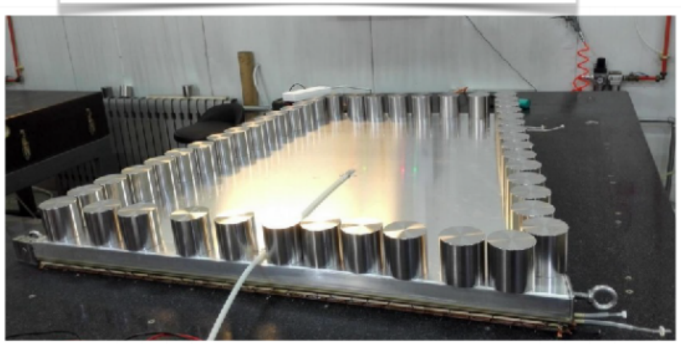
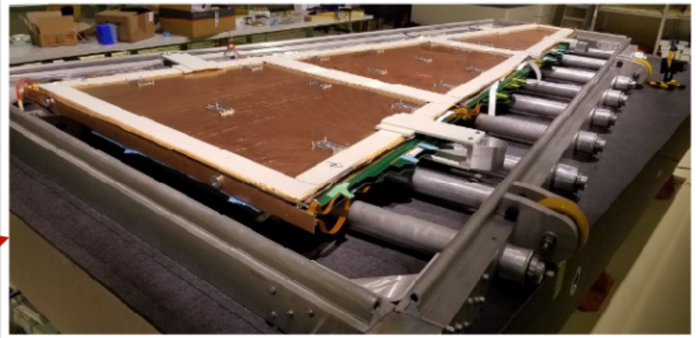
Quadruplet assembling
↓
Cosmic-ray testing
↓
Wedge assembly

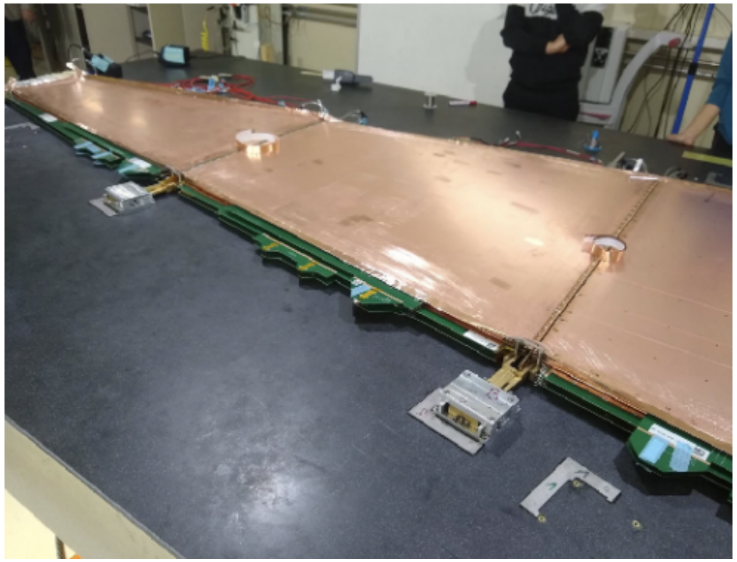






The sTGC Wedge Assembly and Integration at CERN

Quadruplets are assembled into wedges



Electronics and Sector integration

Integrate MM and sTGC into wedges and assembly them in the NSW support structure

The NSW-A has been completed in summer 2021

B191

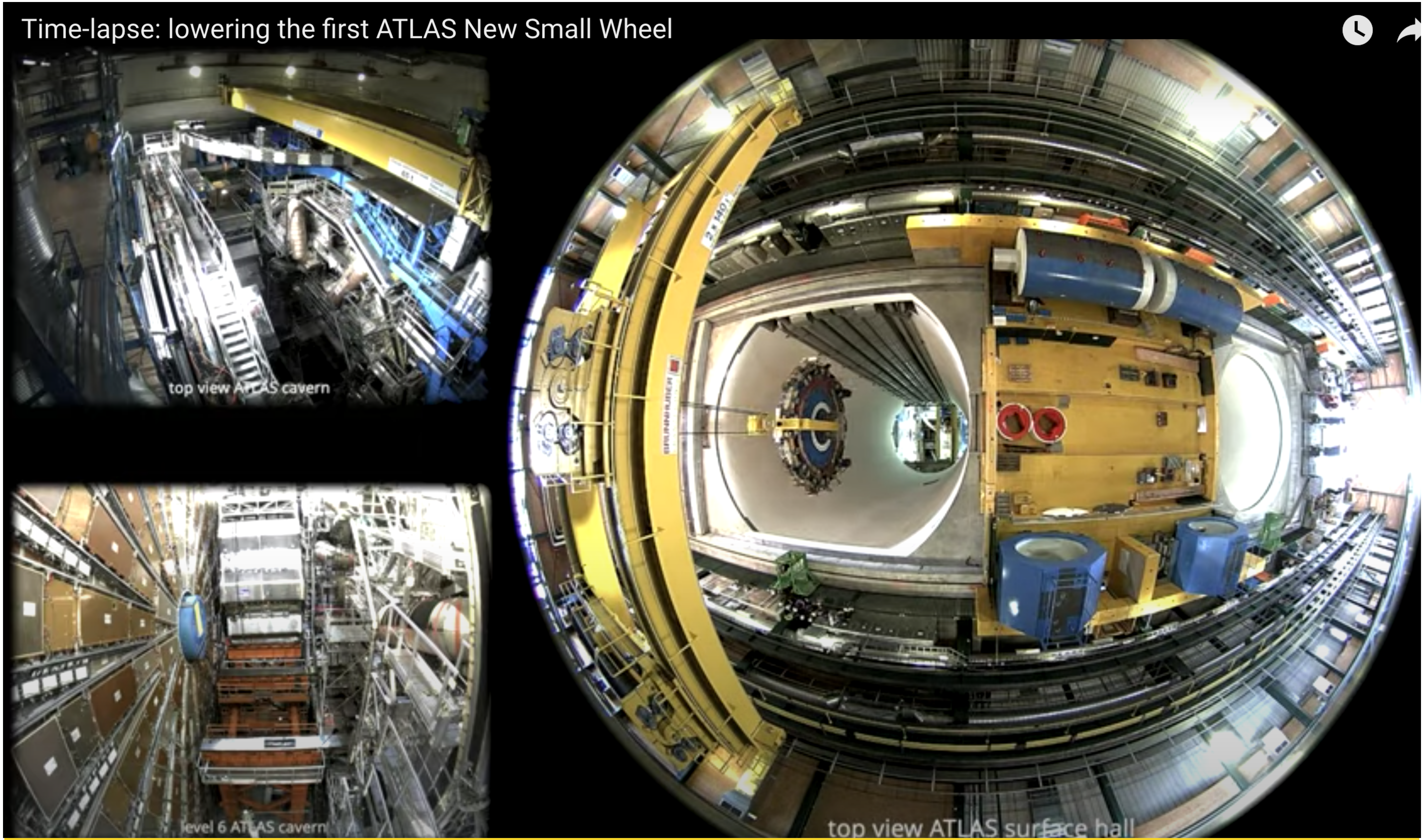
The NSW-A and NSW-C have been integrated in the ATLAS detector in 2021 (NSW-A: july 2021, NSW-C: October 2021) and took first data in the LHC p+p run-3 that started in 2022

Transport of the NSW-A to the ATLAS P1 in July 2021

https://www.youtube.com/watch?v=T9hgntb63hE

Lowering the ATLAS New Small Wheel-A into the ATLAS pit

NSW: an approx. 100 Ton Detector with 10m Diameter
ATLAS Detector: approx. 7000 tons
Depth of ATLAS cavern: 100 m



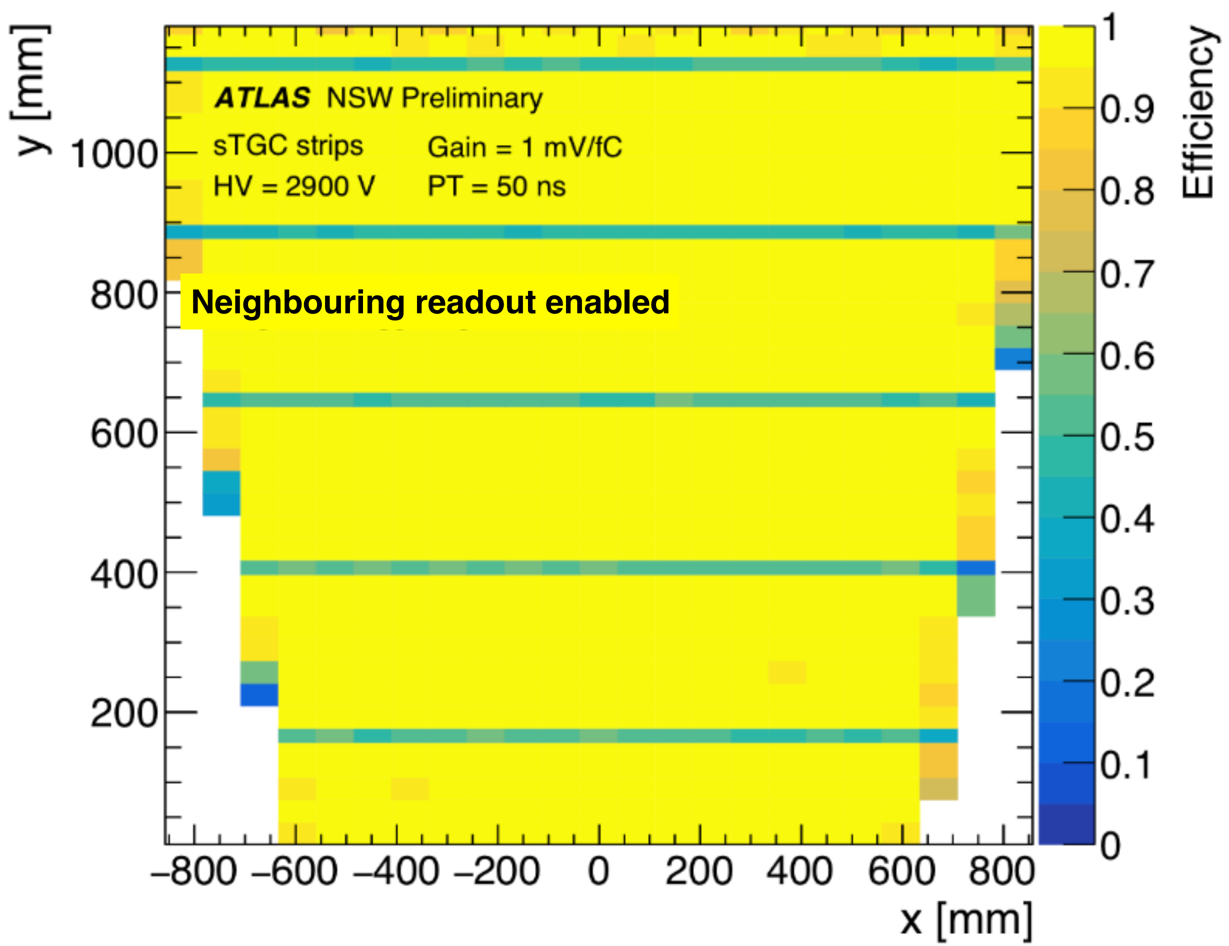
Transfer of the ATLAS New Small Wheel-C into the ATLAS pit

NSW “C” enters the ATLAS surface hall, located just above the experiment, on 14 October 2021. (Image: CERN)

The New Small Wheel-C goes ino the ATLAS pit (October 2021)

sTGC performances

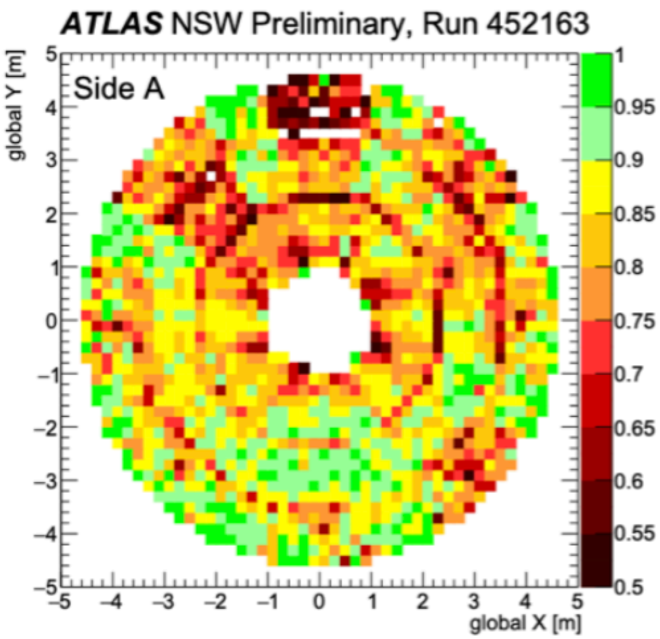
The sTGC efficiency measured with cosmic rays



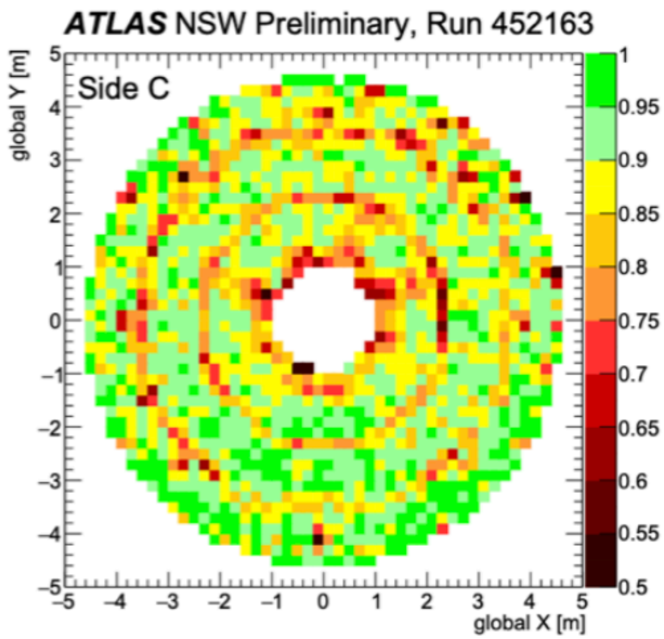
Efficiency is > 95%

NSW 4/8 layers efficiency, sTGC

NSW-A



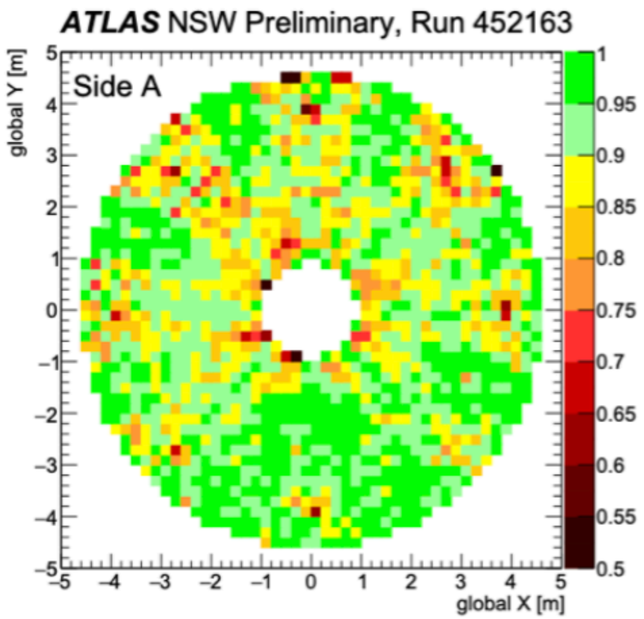
NSW-C



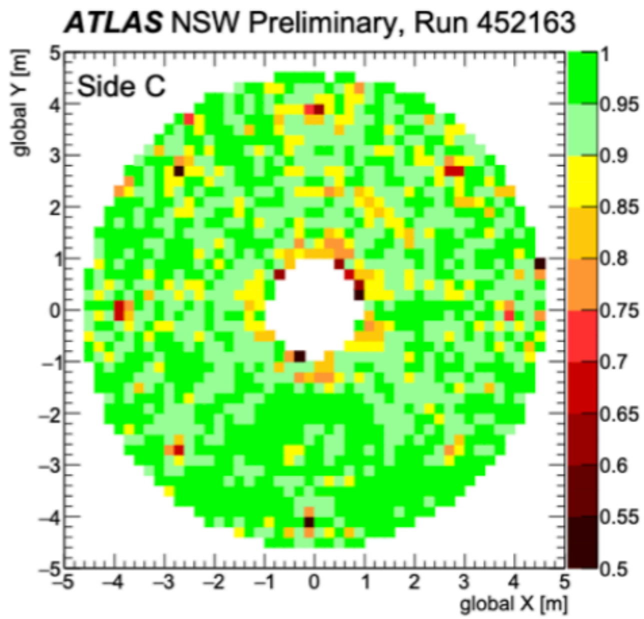
Efficiency of sTGC for having at least four out of eight layers of sTGC strip associated with a muon track with reconstructed pT greater than 15 GeV. The data was taken with pp collisions at √s=13.6 TeV in 2023.

NSW 4/8 layers efficiency, sTGC or MM

NSW-A



NSW-C

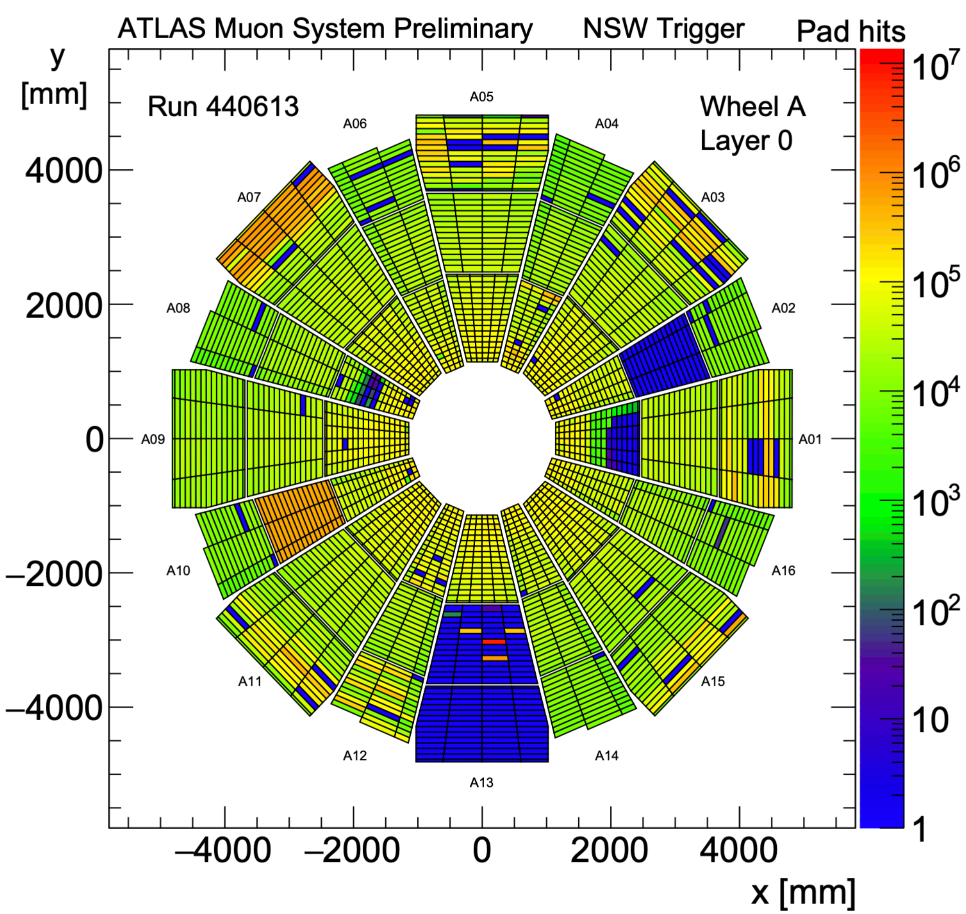


Efficiency of NSW for having at least four out of eight layers of either sTGC or Micromegas strip associated to a muon track with reconstructed pT greater than 15 GeV. The data was taken with pp collisions at $\sqrt{s}$=13.6 TeV in 2023.

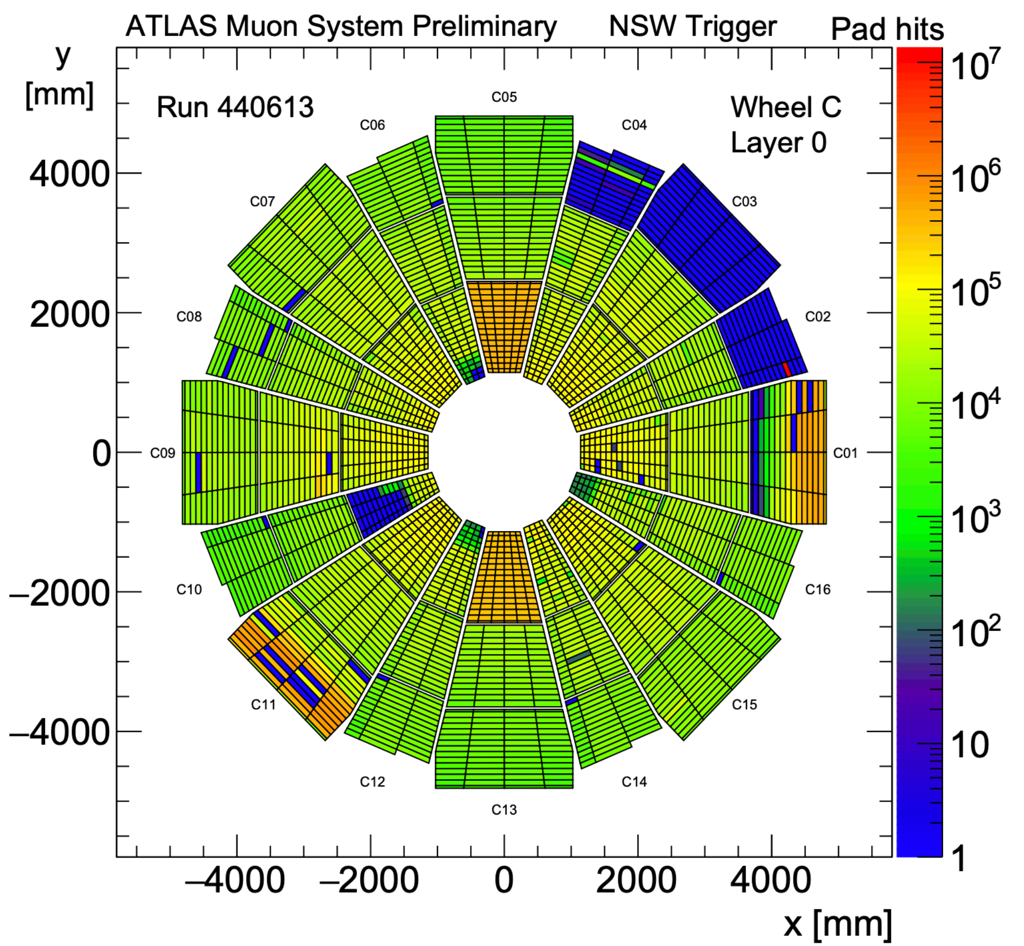
sTGC pad occupancy measured in p+p collisions at 13.6 TeV

First layer

NSW-A

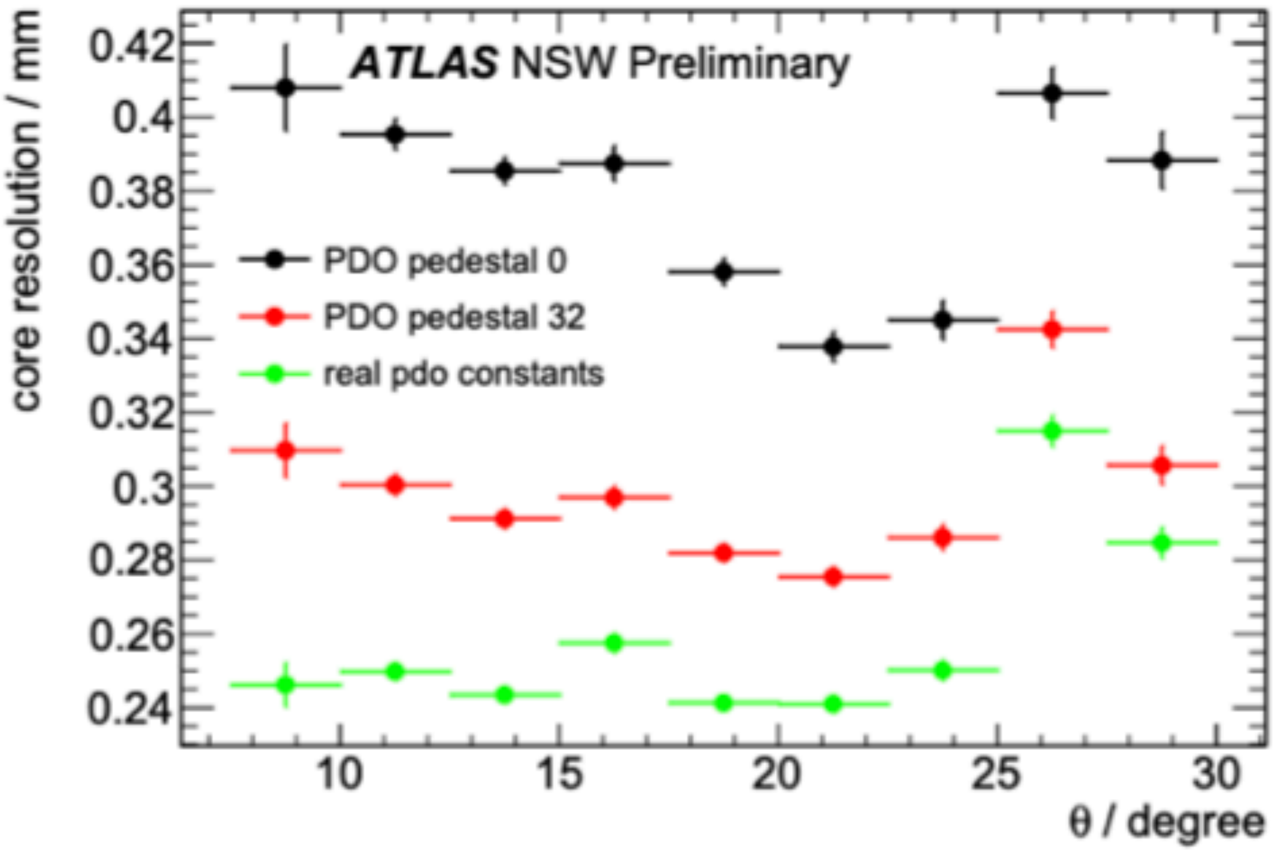


NSW-C



sTGC pad occupancy during the last run of proton proton collisions in 2022, as recorded by the pad trigger boards. Events are required to have at least one muon track of transverse momentum greater than 5 GeV and pseudorapidity greater than 1.2. The occupancy reflects all pad hits and not only pad hits associated to the muon tracks.
(The detector elements are moved slightly away frrom the beamline for visualization purposes).

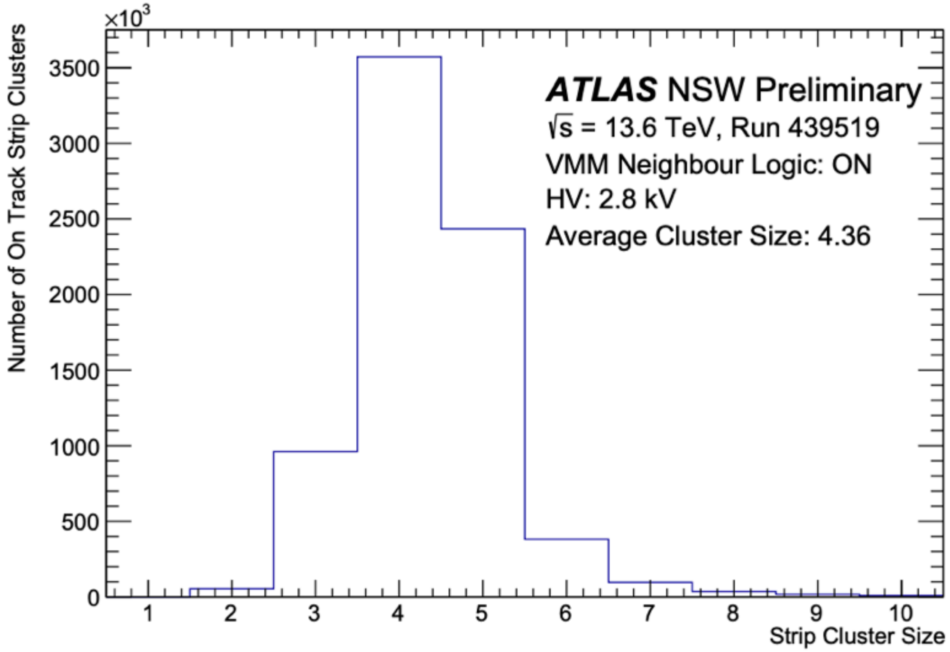
sTGC resolution measured in p+p collisions at 13.6 TeV



sTGC resolution as a function of angle theta, for muon tracks with a reconstructed pT greater than 15 GeV. The data was taken with p+p collisions at sqrt(s) =13.6 TeV. It is shown cases where 1) no pedestal was subtracted (black points) 2) a pedestal of 32 ADC counts was subtracted from each channel (red points) and 3) the pedestal was individually calibrated for each channel and subtracted in the reconstruction software (green points).

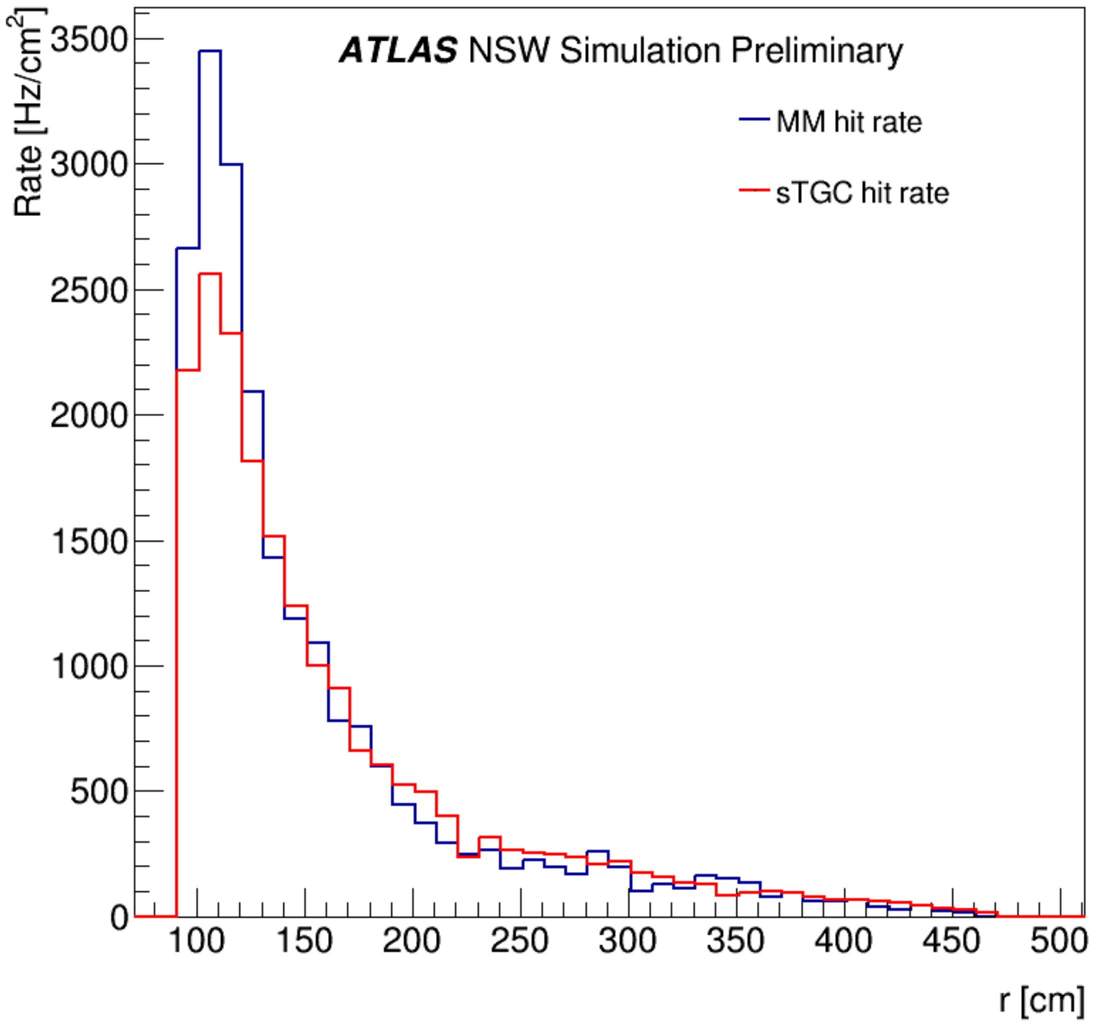
sTGC Strip Cluster Size measured in p+p collisions at 13.6 TeV

sTGC Strip Cluster Size



sTGC strip cluster size for clusters belonging to a muon track with reconstructed pT greater than 15 GeV, from p+p collisions at sqrt(s)=13.6 TeV.

Simulation of sTGC and MM hit rates



-Simulated hit rate in the NSW including contributions from in and out of time pileup in the form of minbias and cavern background.
-During the simulation, the bunch spacing is set to 25 ns, the average number of interactions per bunch crossing to 40 and the luminosity to 1.74 * 10^{34} cm^{-2} sec^{-1}.

Conclusions and outlook

Conclusions and outlook

The New Small Wheel-A and New-Small-Wheel-C of the ATLAS Muon Spectrometer has been completed and have been lowered in the ATLAS cavern in 2021.

The NSW's took first data from p+p collisions in the begin of Run3 in 2022.

The efficiency of the NSW for having 4 out of 8 layers of sTGC or Micromegas for muons with pT greater than 15 GeV in p+p collisions at 13.6 TeV is mostly higher than 95% (preliminary)

Preliminary studies show a resolution of sTGC with individual pedestal subtraction around 240 to 290 micrometers depending on the angle.

The NSW L1 pad trigger has been incorporated in the L1 muon trigger in 2023, leading to a significant reduction of the trigger rate in agreement with expectations.

Thank you very much

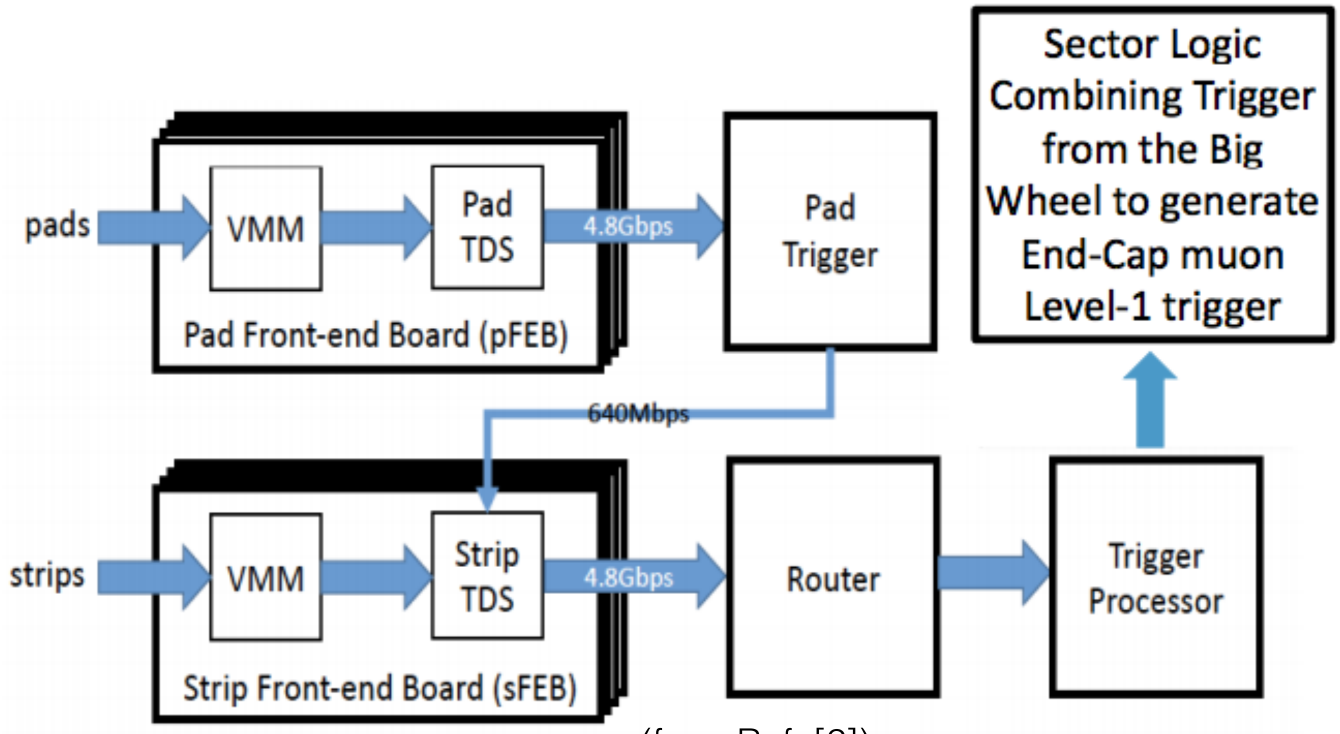
Backup Slides

The sTGC trigger and Data acquisition data flow

Trigger and DAQ chain flow:

The main goal of the NSW trigger is to provide additional information to the muon Level-1 trigger in order to dramatically reduce fake triggers arising from particles that are not high-pT muons originating in the interaction point (IP).

Trigger Data Serializer: (TDS)



(from Ref. [2])

- **Coincidences in pads in 8 layers that point to the interaction point define up to 4 "pad towers".**
- **The charges for a band of 14 strips under each tower in each layer are sent from the strip Trigger Data Serializer (TDS) to the Trigger Processor**
- **The Trigger Processor calculates track segments from the centroids of the strip charges**
- **Segments that don't point back to the interaction point are discarded.**
- **The sTGC Trigger Processor merges its segments with those from the Micromegas Trigger Processor**
- **If the Sector Logic finds that a Big Wheel coincidence is confirmed by a NSW segment, an End Cap Muon trigger is generated.**

2.4 Million readout electronics in total

Ref. [2] P. Gkountoumis, JINST12, no.01, C01088(2017)

The sTGC trigger and Data acquisition data flow

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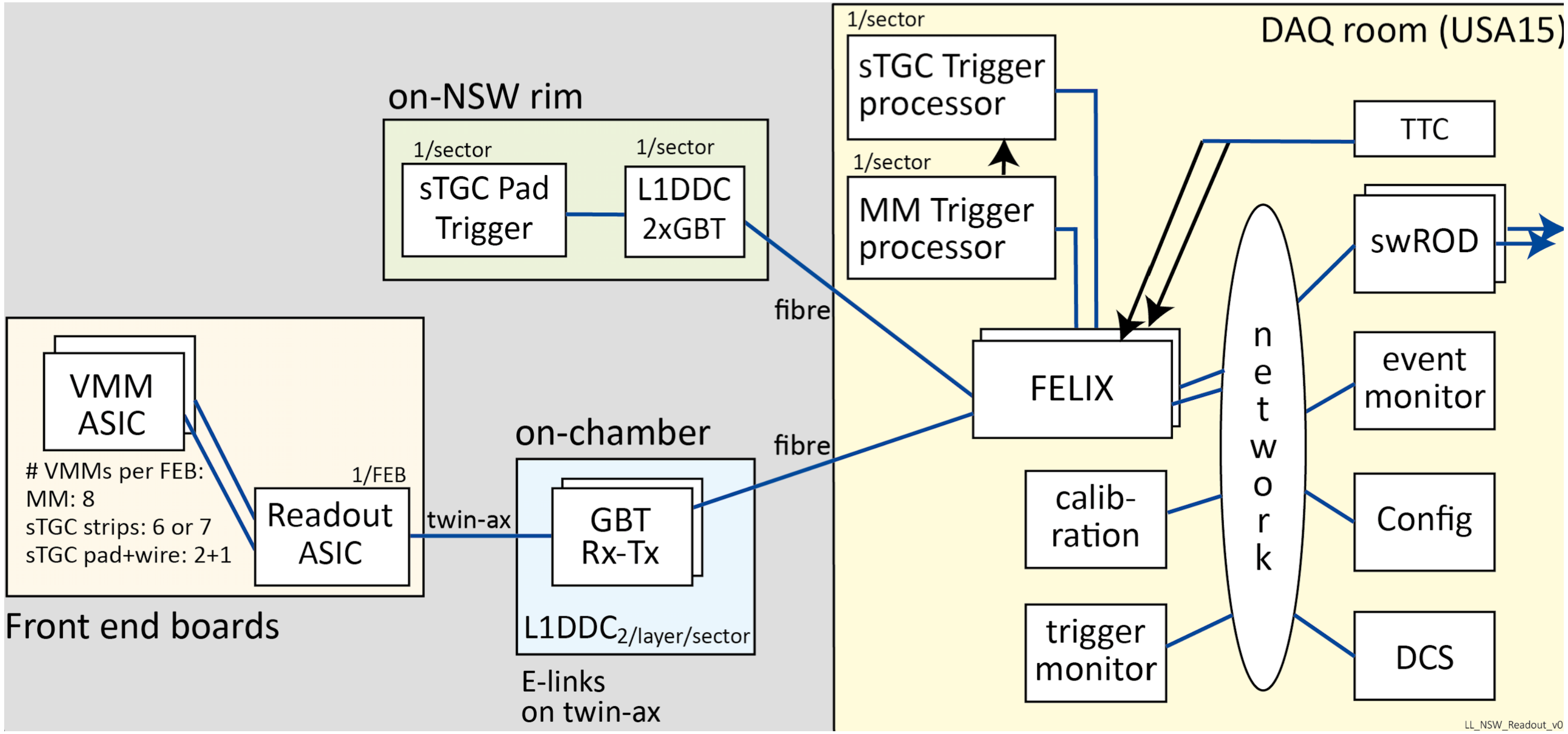

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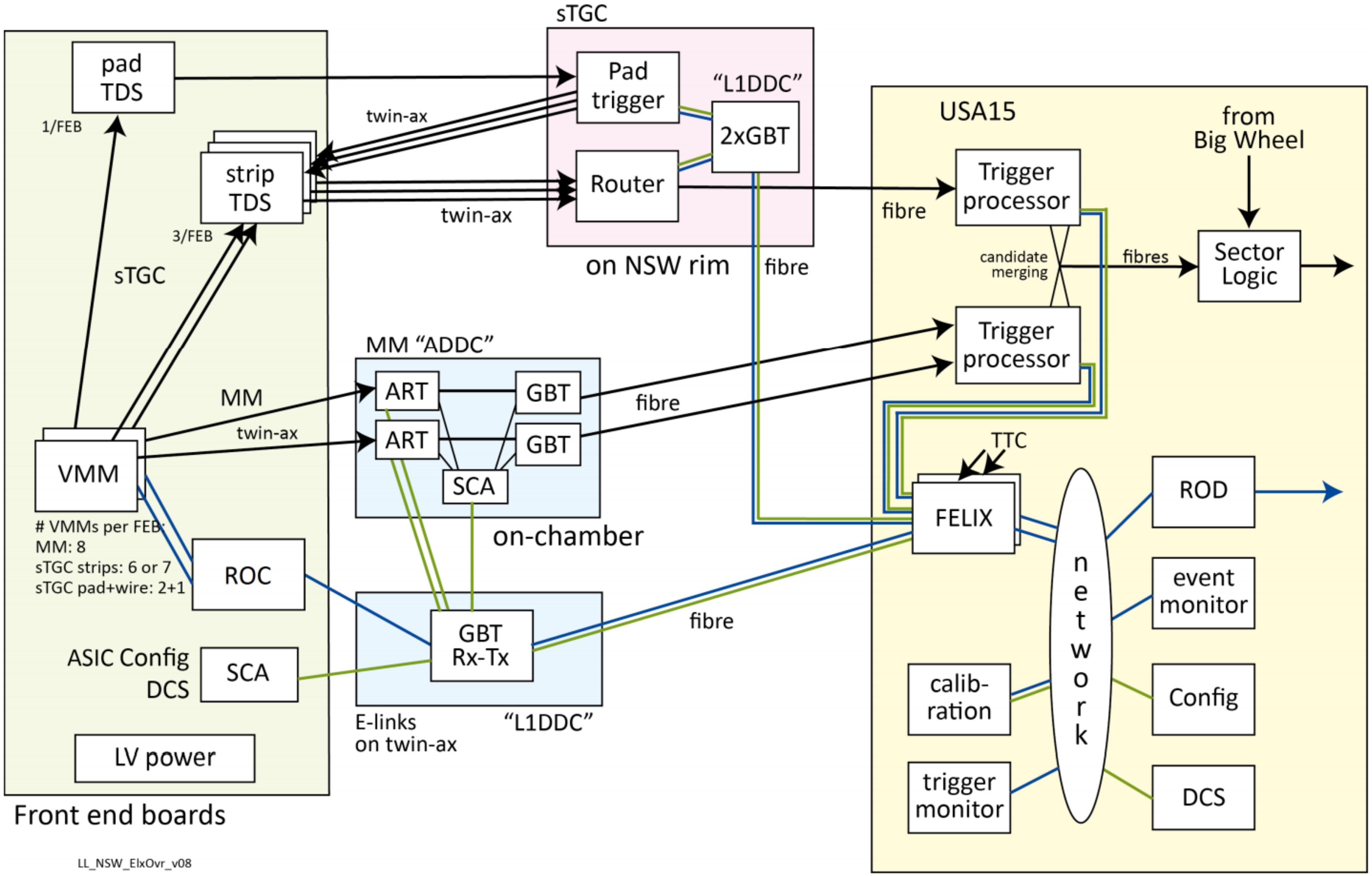
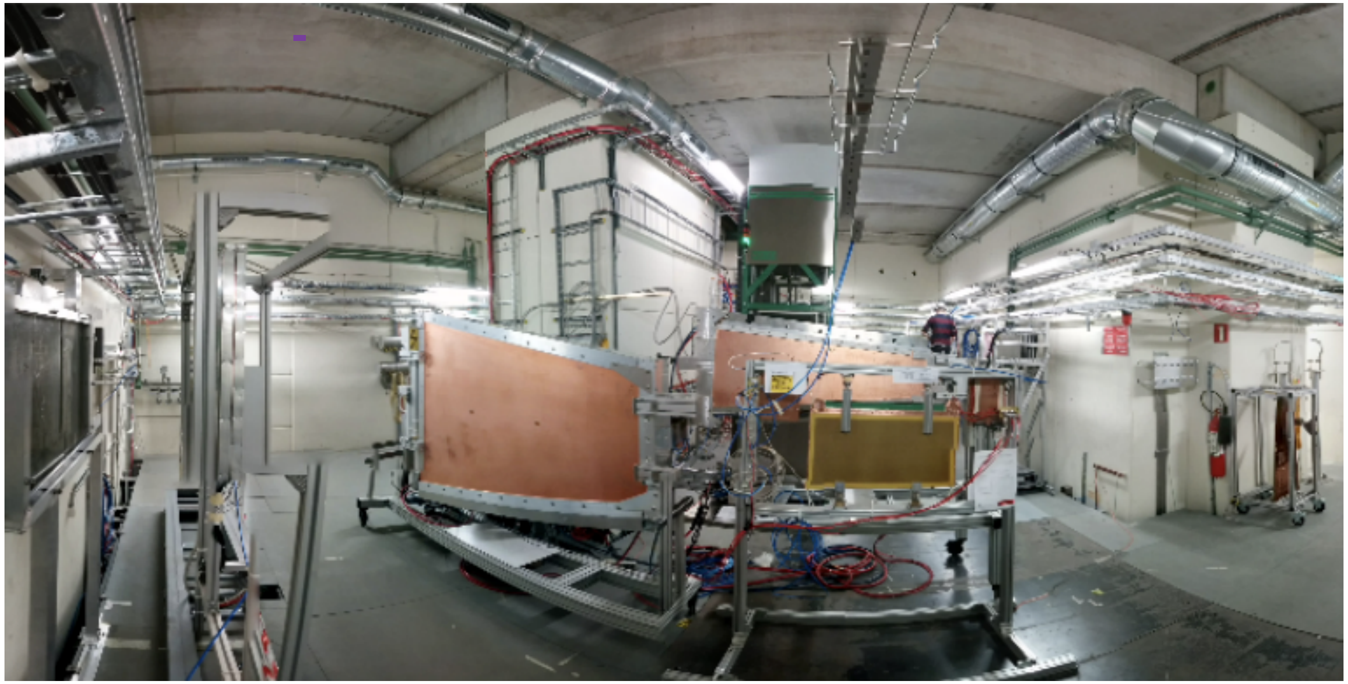


NSW quality controls at CERN

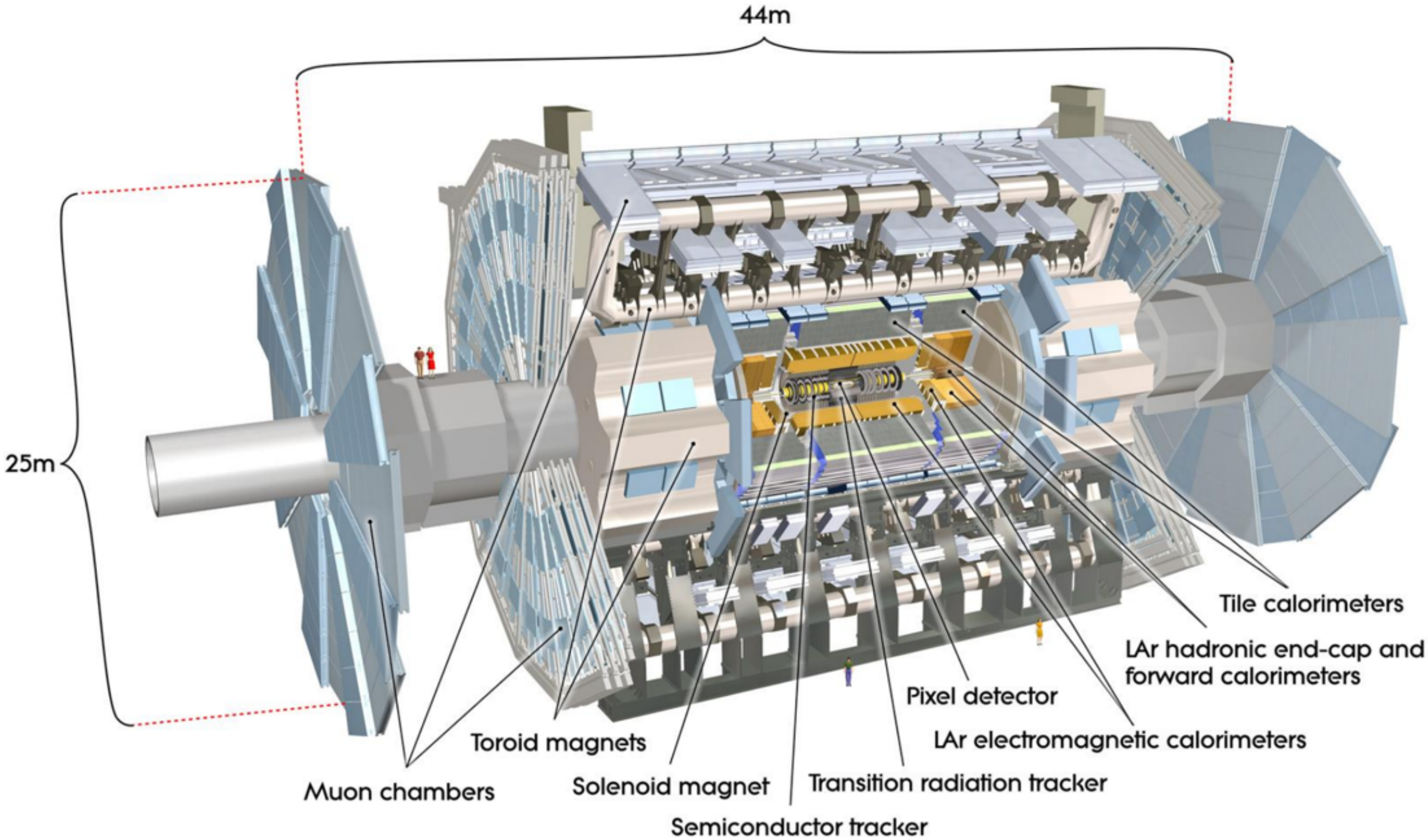
- Readout connectivity test
- Stability test under high radiation with 20 kHz/cmˆ2 (as expected in the HL LHC) using GIF++ facility at CERN
- Noise measurements with integrated electronics
- HV tests
- Measurement of misalignement using x-rays

- GIF++ facility at CERN



GIF++ operates with 137Cs source of 14 TBq that radiates gamma rays and can reach the rate we expect at HL LHC

The ATLAS Detector



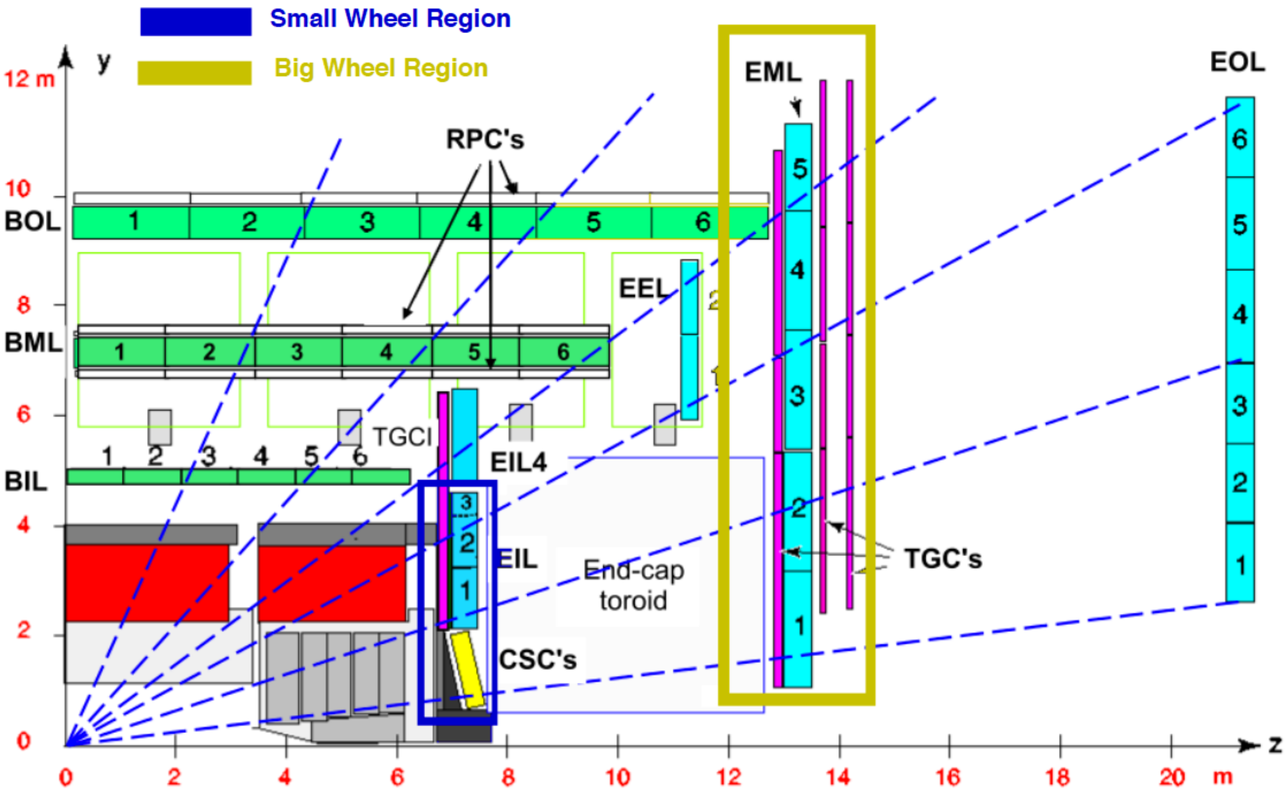


Figure 1.2: A z-y view of 1/4 of the ATLAS detector. The blue boxes indicate the end-cap Monitored Drift Tube chambers (MDT) and the yellow box in the Small Wheel area the Cathode Strip Chambers (CSC). The green boxes are barrel MDT chambers. The trigger chambers, Resistive Plate chambers (RPC) and Thin Gap Chambers (TGC), are indicated by the outlined white and the magenta boxes. This is a cut-out on the muon spectrometer at the large sectors, hence the names 'End-cap Inner Large' (EIL), 'End-cap Middle Large' (EML) and 'End-cap Outer Large' (EOL). The detector regions of the Small Wheel and Big Wheel are also outlined.

Expected Level-1 rate (based on 2011 data at 7 TeV) for luminosity $3 \times 10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$, $\sqrt{s} =$ 14 GeV and 25 ns bunch spacing for different p_{T} threshold with and without the NSW upgrade. The extrapolation uncertainty to 14 TeV is also shown.

L1MU threshold (GeV)	Level-1 rate (kHz)
$p_{\mathrm{T}} > 20$	60 ± 11
$p_{\mathrm{T}} > 40$	29 ± 5
$p_{\mathrm{T}} > 20$ barrel only	7 ± 1
$p_{\mathrm{T}} > 20$ with NSW	22 ± 3
$p_{\mathrm{T}} > 20$ with NSW and EIL4	17 ± 2

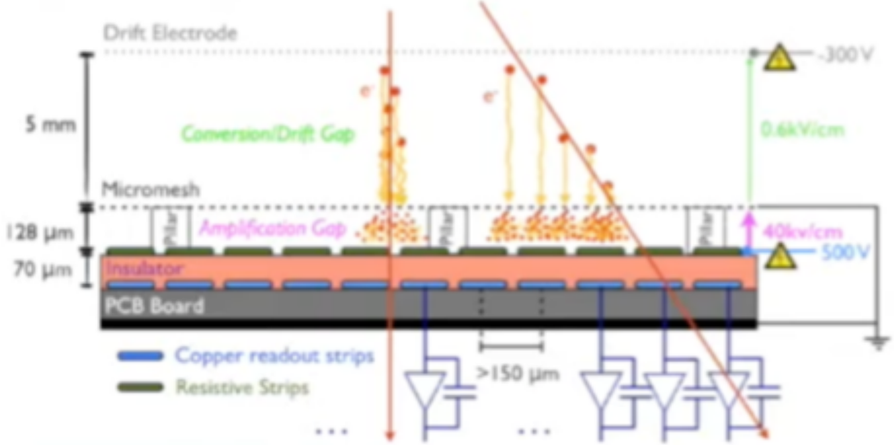
From [1]

[1] ATLAS TDR NSW

MicroMegas detector | sTGC detector

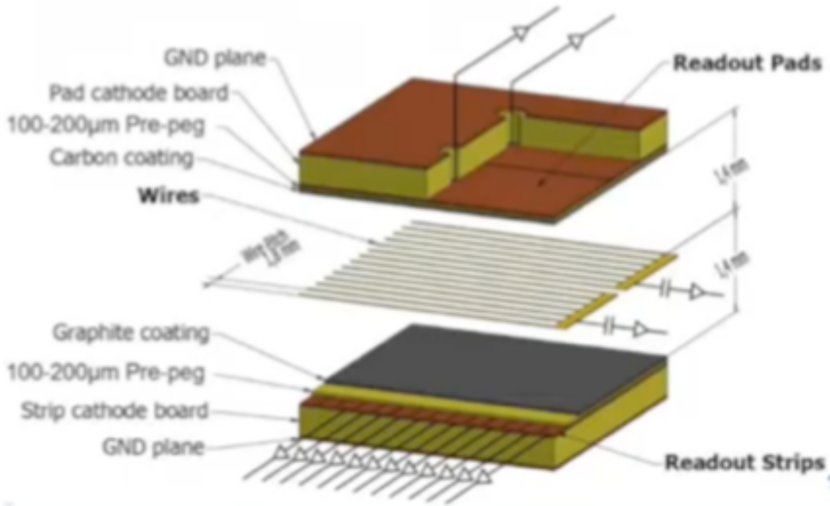
MM

- **Novel detector technology based on MPGD, first time used in such a large scale and at high-rate environment**
  - Asymmetric drift and amplification regions
    - Fast ion evacuation and high amplification achieved with reasonable voltages
  - An additional layer of resistive strips makes the detector tolerable to discharges (high-rate capable)
- **Excellent spatial resolution (0.1mm) due to the very fine strip pitch**

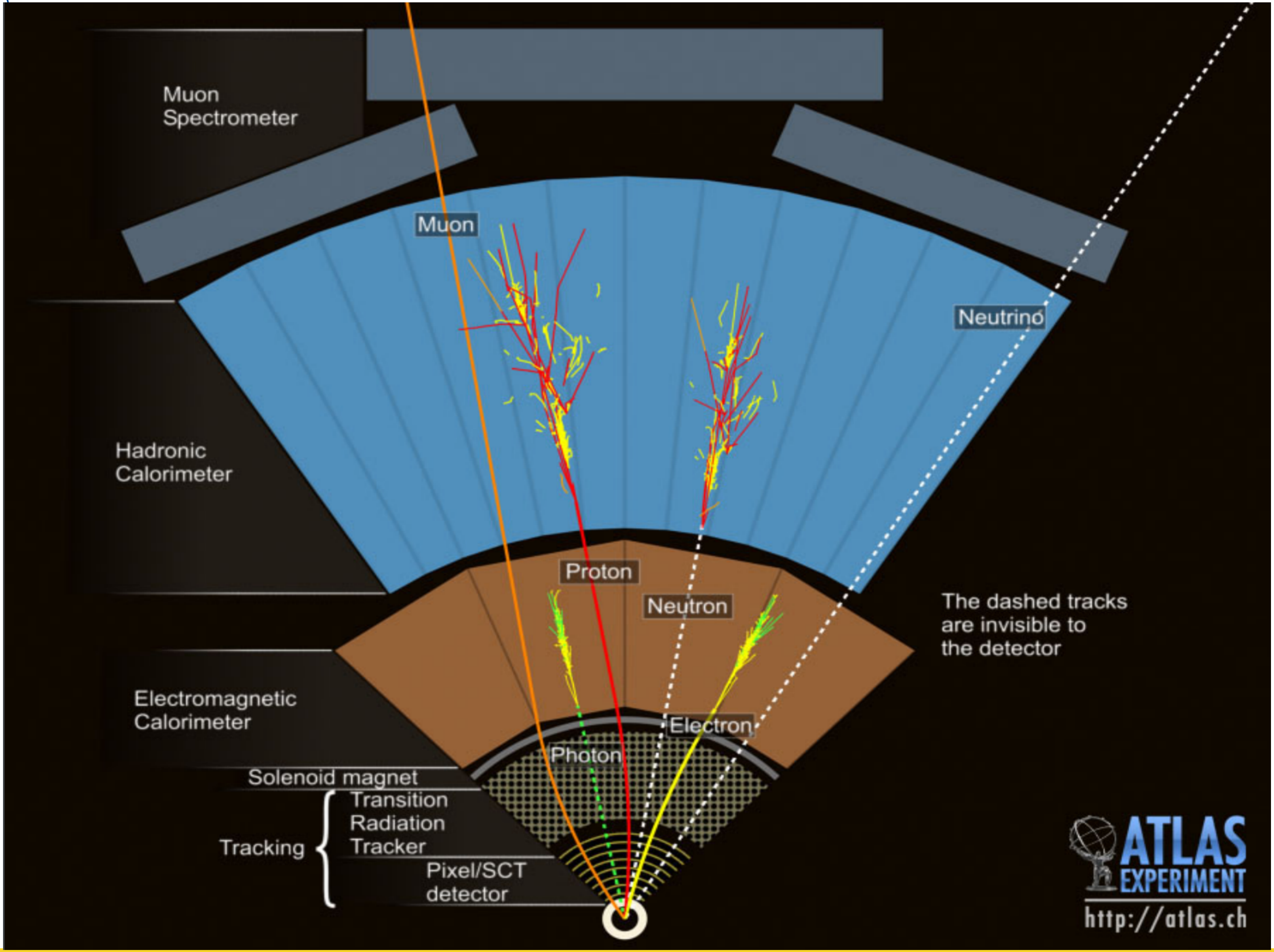


sTGC

- **Based on the well-proven legacy TGC system of the ATLAS detector**
  - Finer strip pitch of 3.2mm (improved resolution)
  - Resistive coating with lower resistivity (improved rate capability)
- **Excellent timing properties (fast signals) due to small gas gap and strong electric field (all signals arriving with 25ns)**

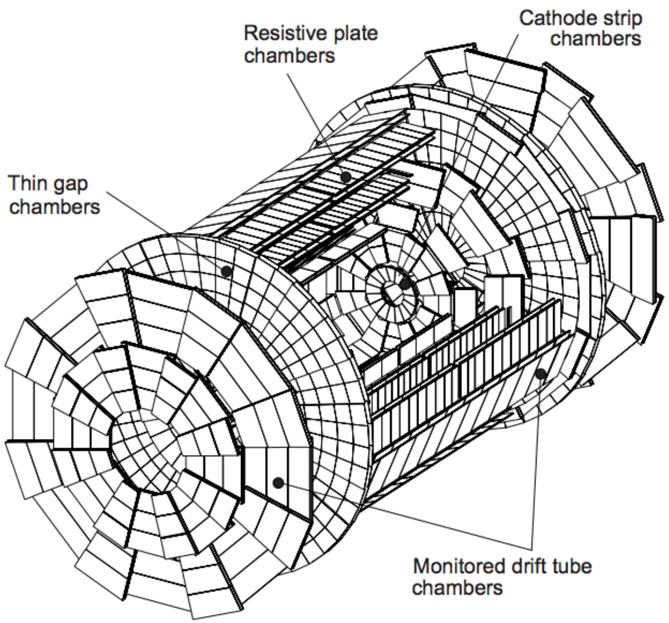


The ATLAS Detector - example



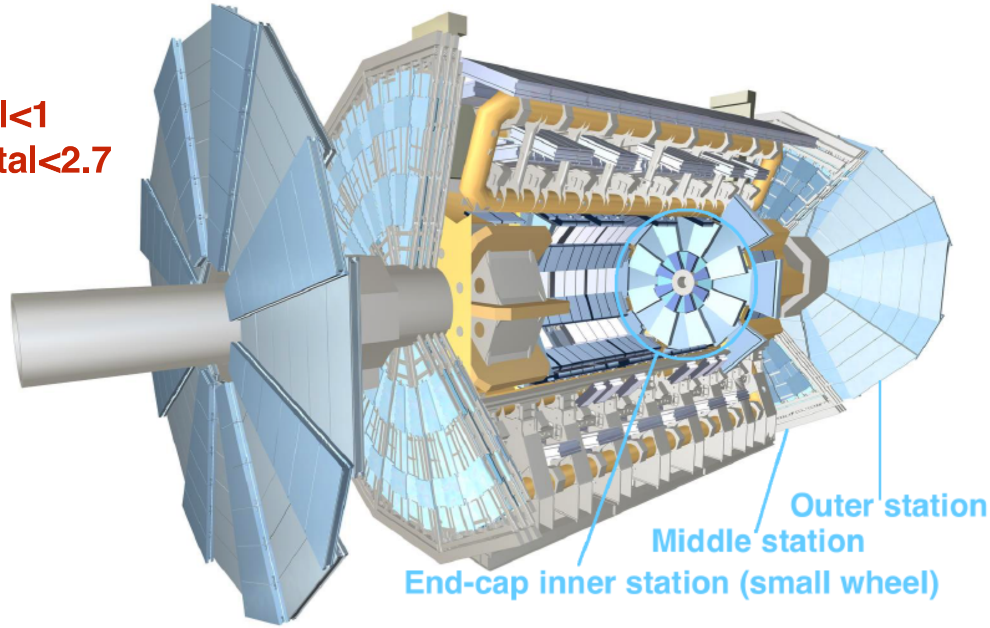
ATLAS Muon Spectrometer

ATLAS Muon Spectrometer prior to 2021 (from [2])



ATLAS Detector picture

Barrel: |eta|<1
End-Cap: 1<|eta|<2.7



4 gaseous technologies have been used till now:
Cathode Strip Chambers (CSC)
Resistive Plate Chambers (RPC)
Monitored Drift Tube Chambers (MDT)
Thin Gap Chambers (TGC)

Spatial resolution better than 100 micron (MDT, CSC) resulting in a pT relative resolution of about 10% , at pT=1 TeV.
Muon reconstuction efficiency > 98%

The Muon detector used in run1 and run2 is not able to take data efficiently in the HL LHC because:

The trigger rate would exceed the readout bandwidth of the ATLAS data acquisition system.
With the old muon detector configuration, most of the muon Level-1 triggers (90% [1]) would be bakground hits from particles created in the material between the inner and middle stations.
Radiation hardness for the max Instantaneous Luminosity of 7*10ˆ34 cm-2 sec-1

The new end-caps inner stations (the two New Small Wheels) have been designed to resolve these problems

[1] ATLAS TDR NSW [2] ATLAS Muon Spetrometer TDR