ATLAS Muon Thin Gap Chamber technology for a detector at the ILC

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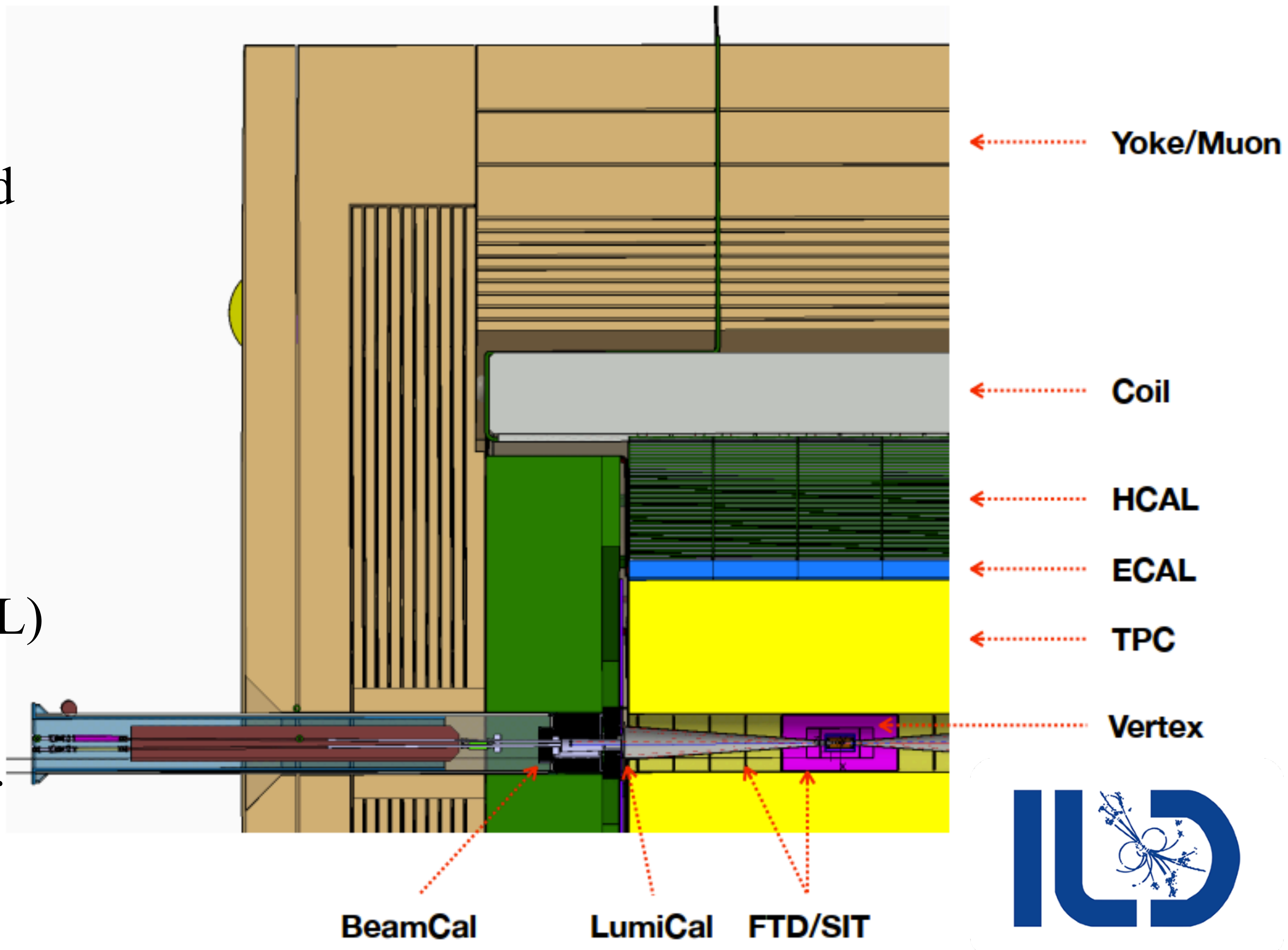
Muon Detectors at ILC

- There are many available technologies that can meet the needs of muon detection in the ILC environment.
- Muon detector requirements at ILC are similar than the one required at LEP and SLD.
- Muons are very penetrating so they are identified by placing large piece of iron absorber (λ = 16.7 cm in iron).
- For ILD, a large volume superconducting coil surrounds the calorimeters, creating an axial B-field of nominally 3.5 Tesla (IDR-L) or 4 Tesla (IDR-S). The iron yoke returns the magnetic flux of the solenoid, and serves as a muon filter, muon detector and tail catcher calorimeter.
- For SiD, iron acts as the flux return for the 5 Tesla magnetic field.



Iron yoke gaps instrumented with scintillator bars (default option), RPCs, and gas detectors like planar drift tubes chambers or Thin Gap Chambers can also be considered considered for muon tracking

TGC as Muon Detectors

- TGC's have been used for the OPAL detector at LEP. Muon spectrometers at LEP achieved spatial resolution of about 2 mm, with the probability of a pion reaching the muon chambers to be less than 0.1%.
- Thin gap wire chamber as a well known technology is relatively cheap and fast. In addition, there is an advantage to have a detector with timing <25ns to mitigate "on-time" beam noise.
  - **TGC's can be considered as a robust solution for a muon system at ILC.**
- **Interest from groups in ATLAS, in particular Canada, to port the ATLAS sTGC technology into an ILC detector.**
- Muon identification relies on track matching between hits in the muon system and hits in the tracking system.
- At ILC, the required muon tracking precision is less than 1 cm in azimuth and can be a few cm longitudinally.
- **R&D to optimize design / gas / geometry / HV for:**
  (i) hit timing & bunch matching, (ii) spatial resolution, iii) efficiency & fake rate, and (iv) cost

	ATLAS	ILC
timing requirement for bunch ID	25 nsec	366 nsec (lumi upgrade)
single hit resolution	~ 0.1 mm	**~ 1 mm**
wire pitch	1.8 mm	1.8 mm
gap size	2.8 mm	2.8 mm
strip pitch	3.2 mm	**~ 20 mm**

A sequence of LHC upgrades are scheduled during Long Shutdown (LS) periods.

- Instantaneous luminosity expected to increase up to 5 to 7 times higher than nominal following **LS3** in **2027**.
- After the LS2 (2019-2020), LHC will reach design energy 14 TeV and collision intensity $L=2x10^{34}cm^{-2}s^{-1}$.
- Expect to collect approximately **3000 fb^{-1}** of data by the end of LHC operations in **2037**.

ATLAS Upgrade projects(LS2)

New Small Wheel

LAr calorimeter

Fast tracker

ATLAS Upgrade projects(LS3)

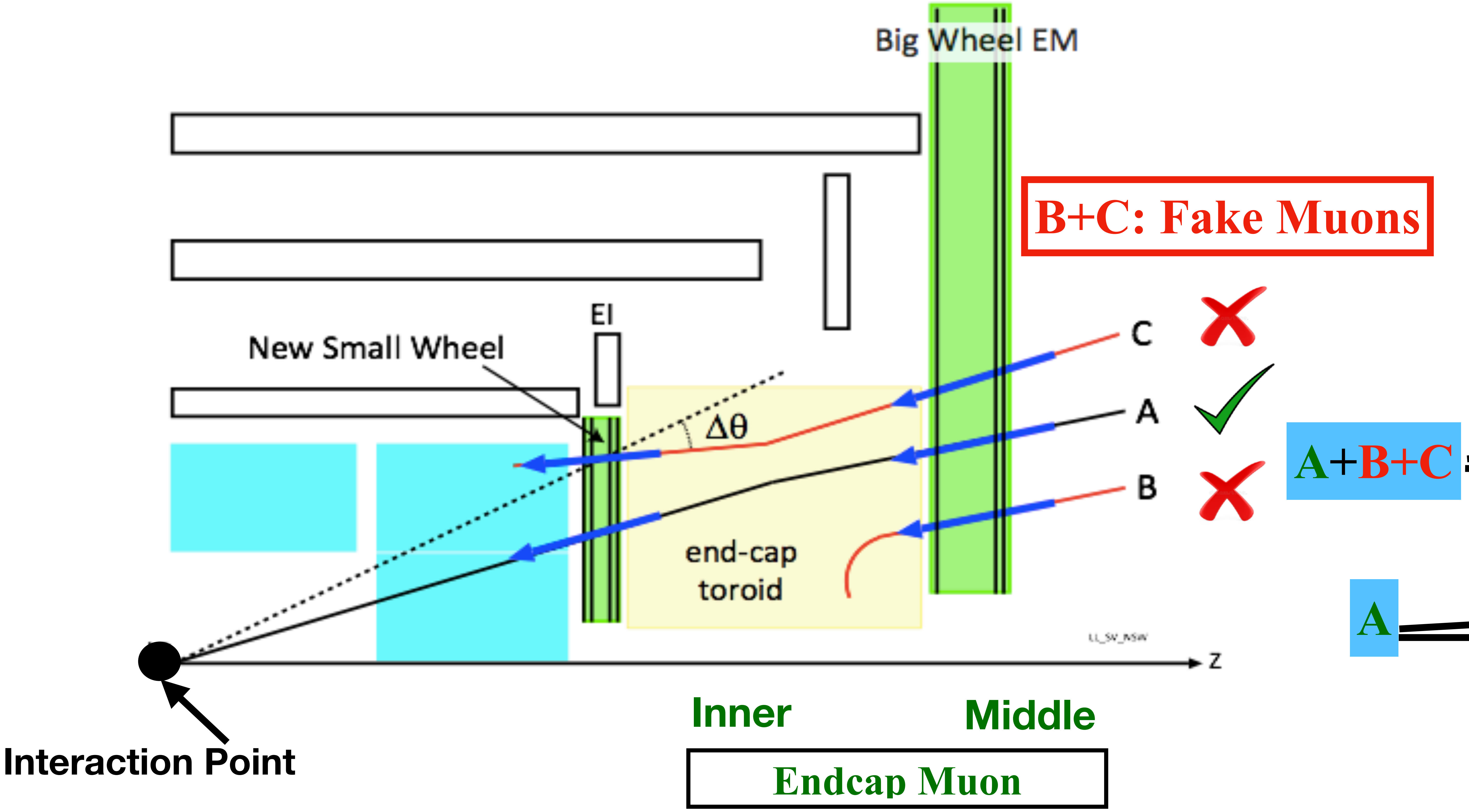
Muon System

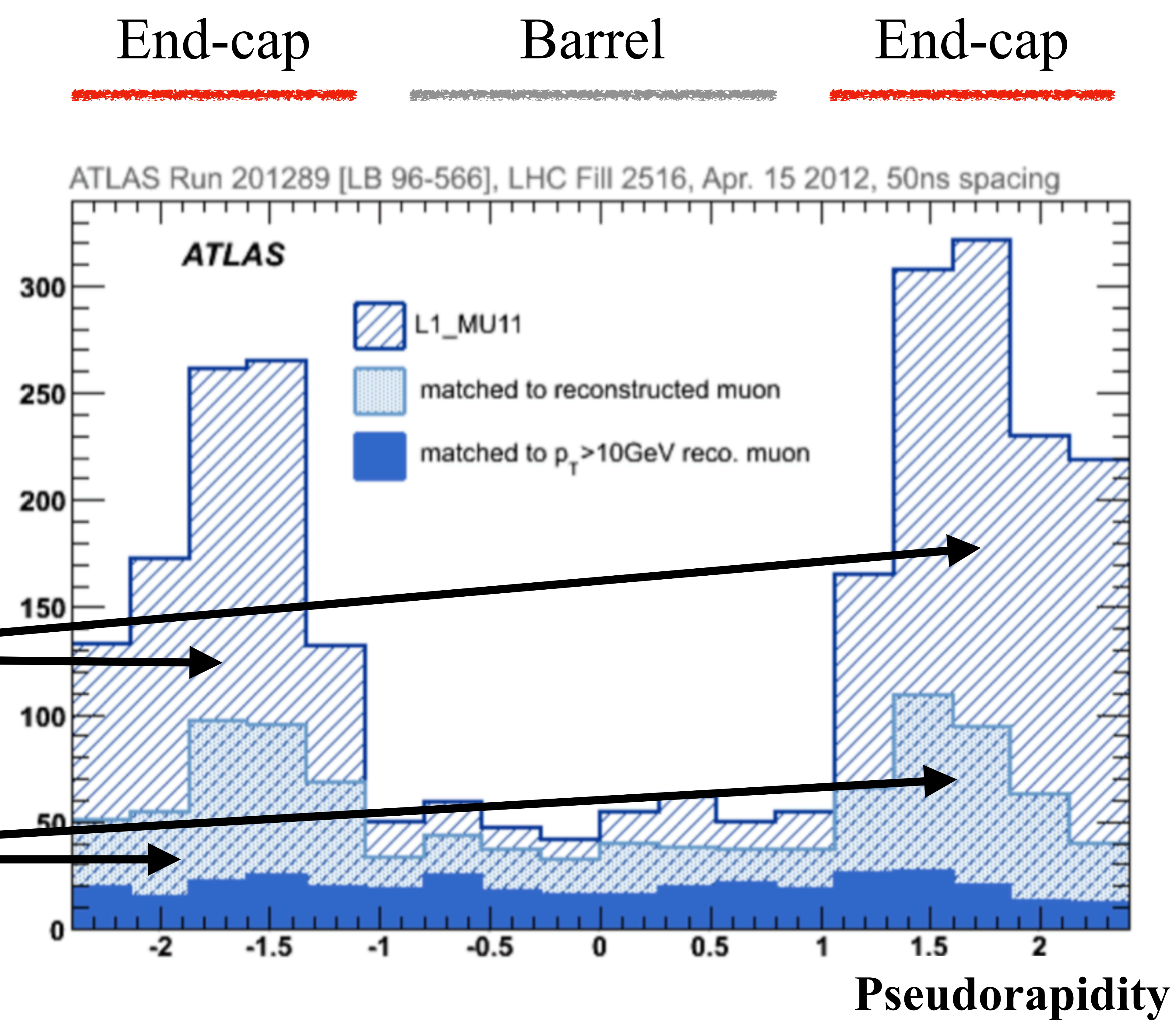
Inner tracker

LAr and Tile calorimeters

DAQ and trigger systems

Trigger Rate & Identification Limitations





Online Muon Identification: Current Wheel Chambers will lose efficiency at high hit rates due to higher instantaneous luminosity.

- Current Muon system would not be able to hold such rate.

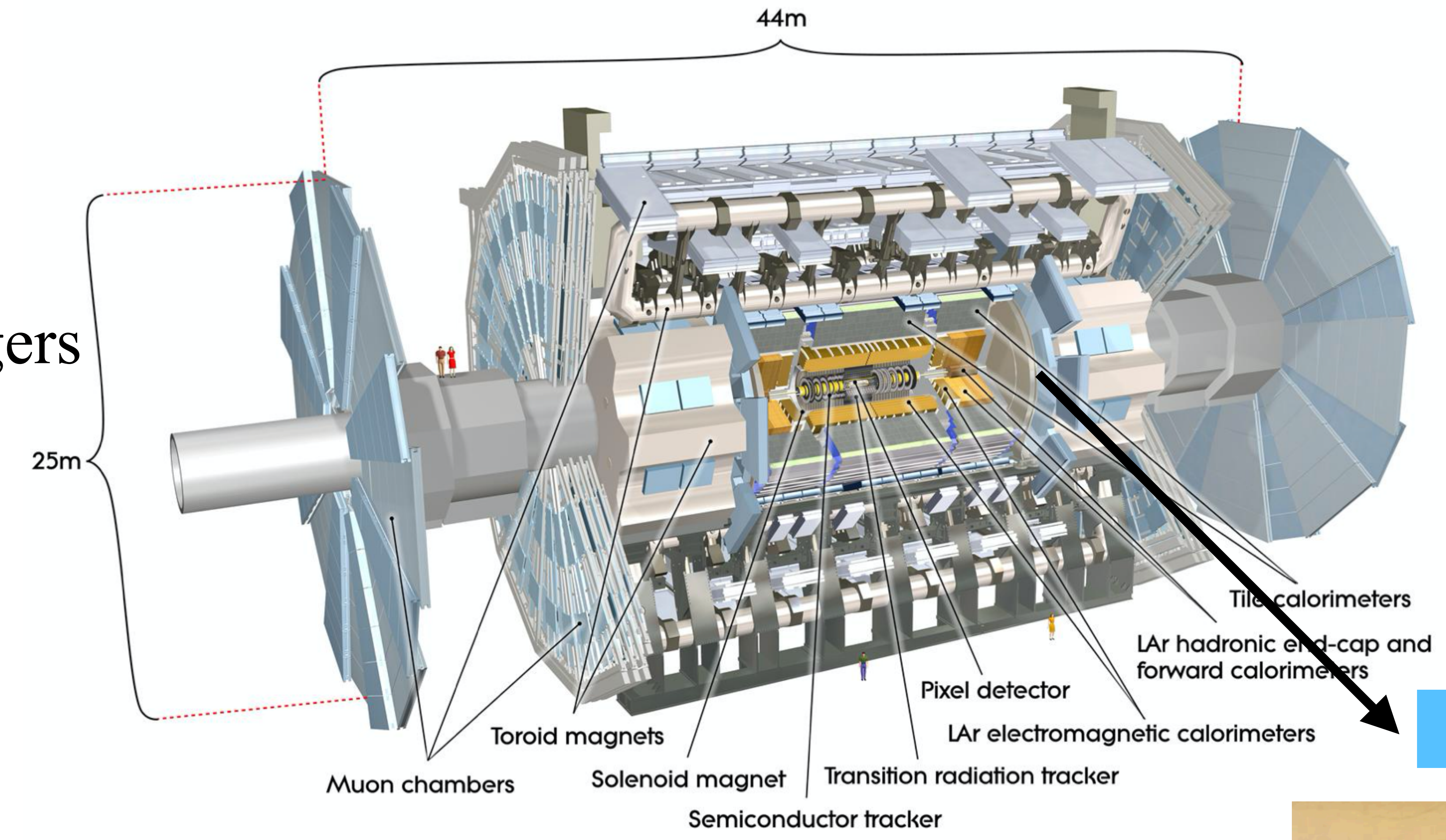
Trigger limitations: Lowest unprescaled muon trigger is dominated by fake muons (90%) in the endcap region which waste the bandwidth of the HLT.

ATLAS-Muon Spectrometer Upgrade

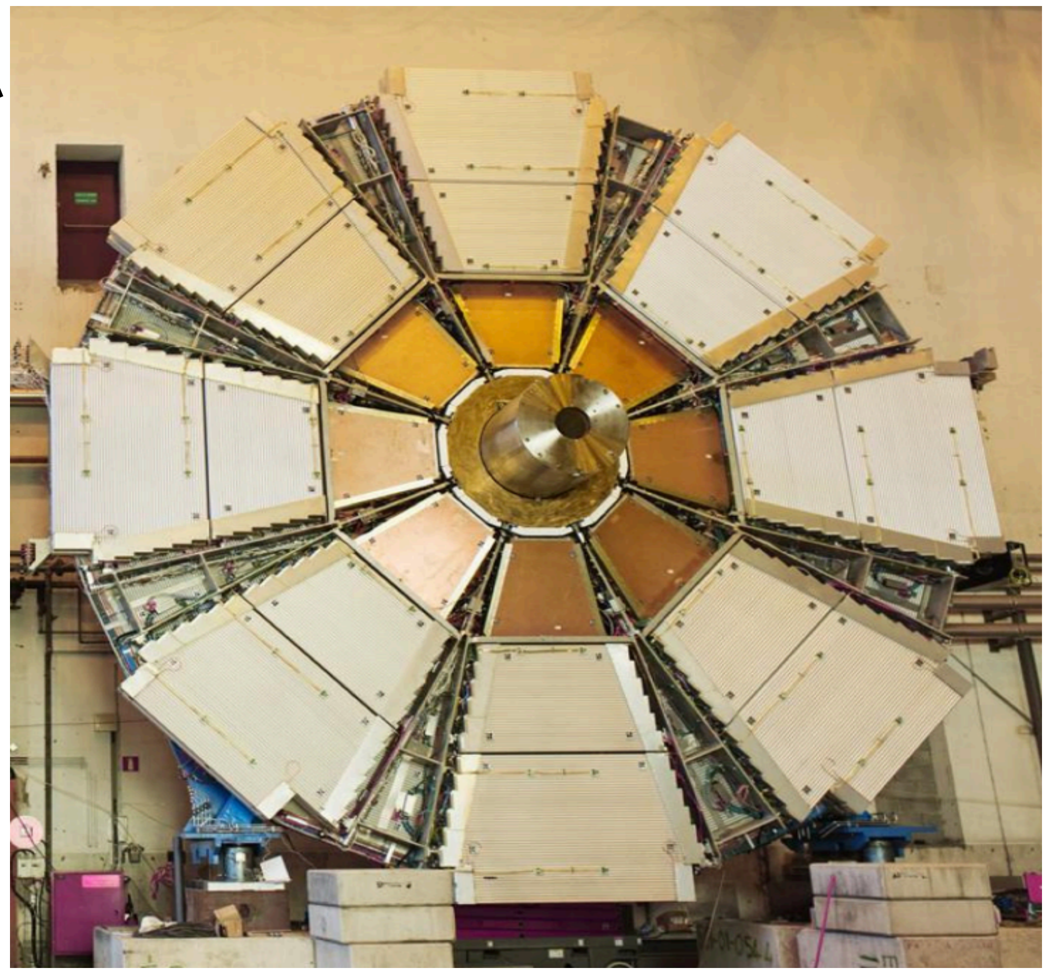
Solution: The New Small Wheel(NSW) upgrade will replace the current Small Wheel of the ATLAS Muon Spectrometer to handle tracking and triggering problems. The current muon chambers (CSC and MDT) will suffer for high inefficiencies at the rate of HL-LHC.

It is designed to:

- Significantly reduce the fake Level-1 muon triggers
- Precisely reconstruct muon tracks
  - 95% on-line track reconstruction efficiency



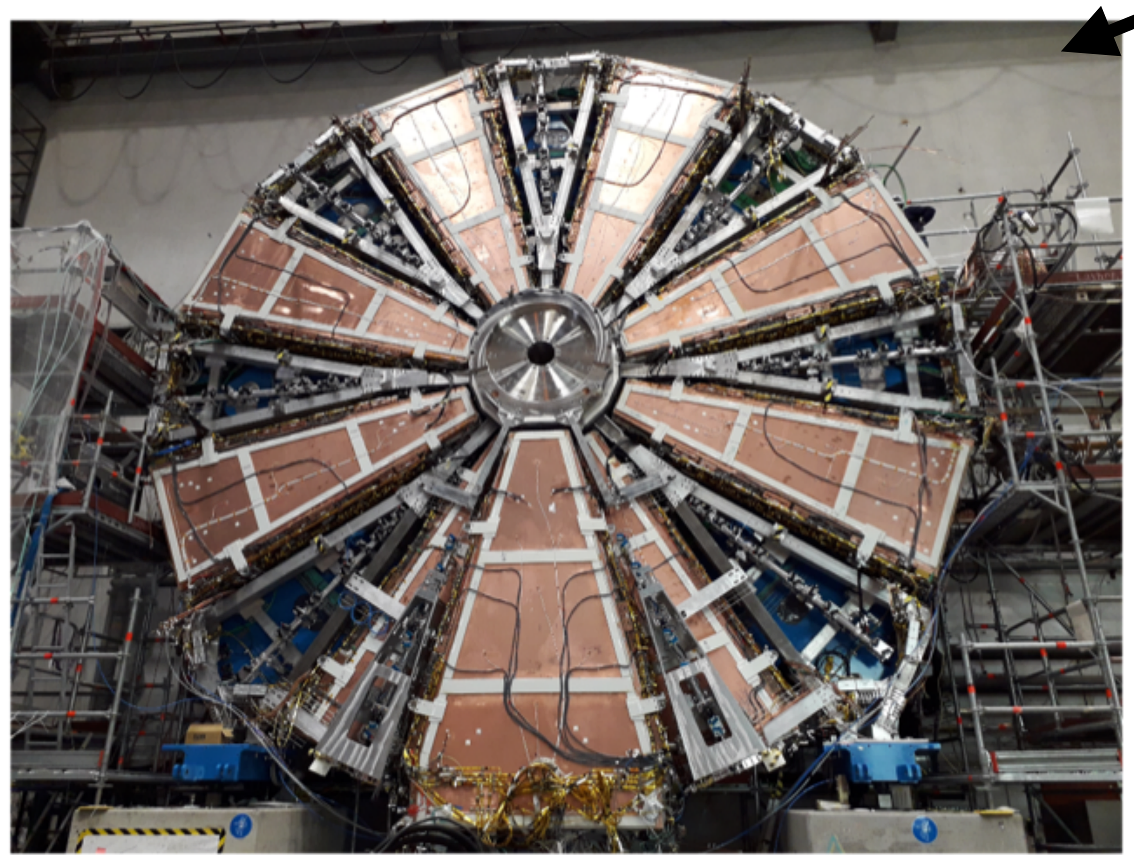
Current Small



Strict Requirements for the new small wheel:

- Excellent online angular spatial resolution; less than 1 mrad
- Operate efficiently at Run-3 and beyond it
  - Important for Run 3, vital for High Luminosity LHC (2028)

New Small

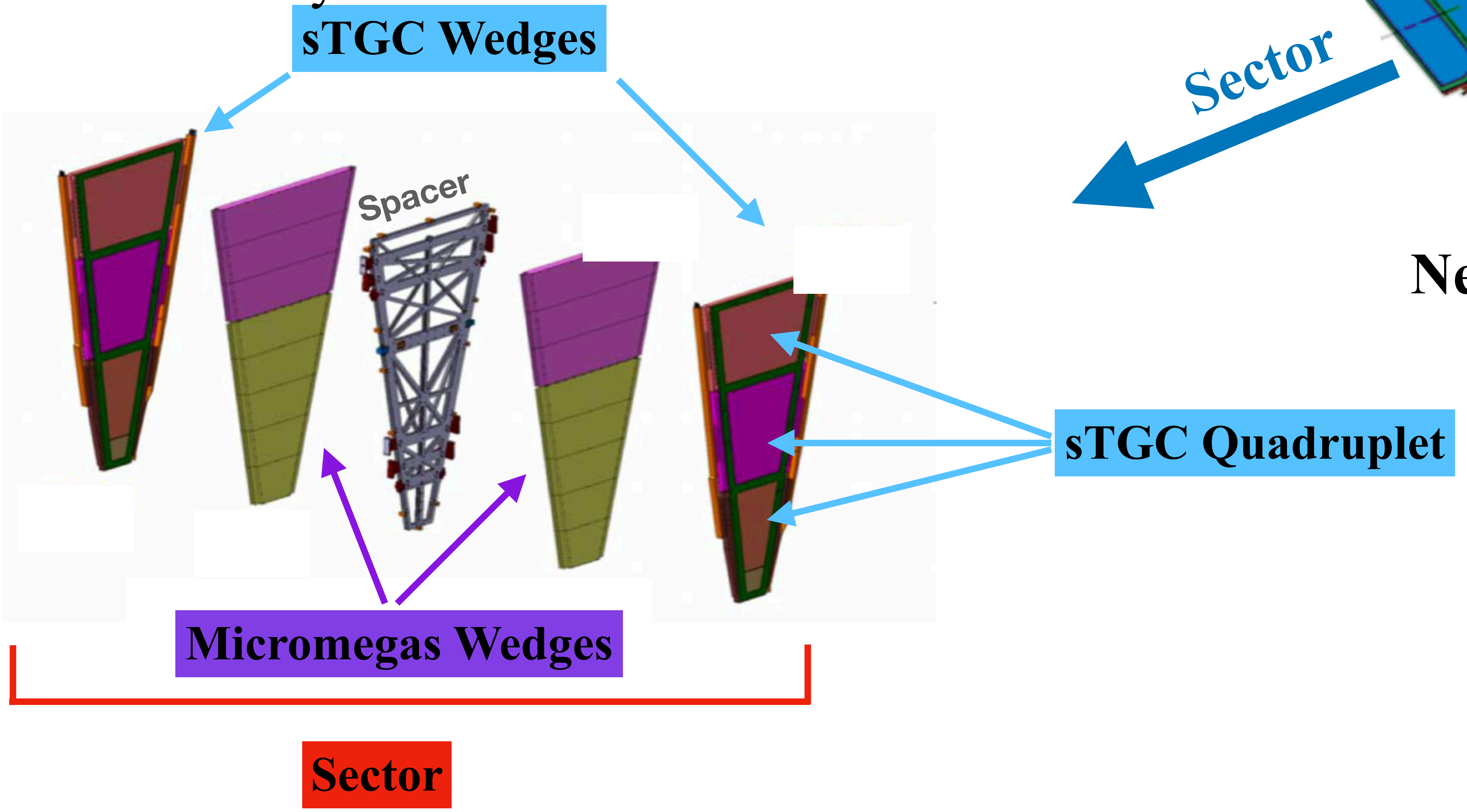


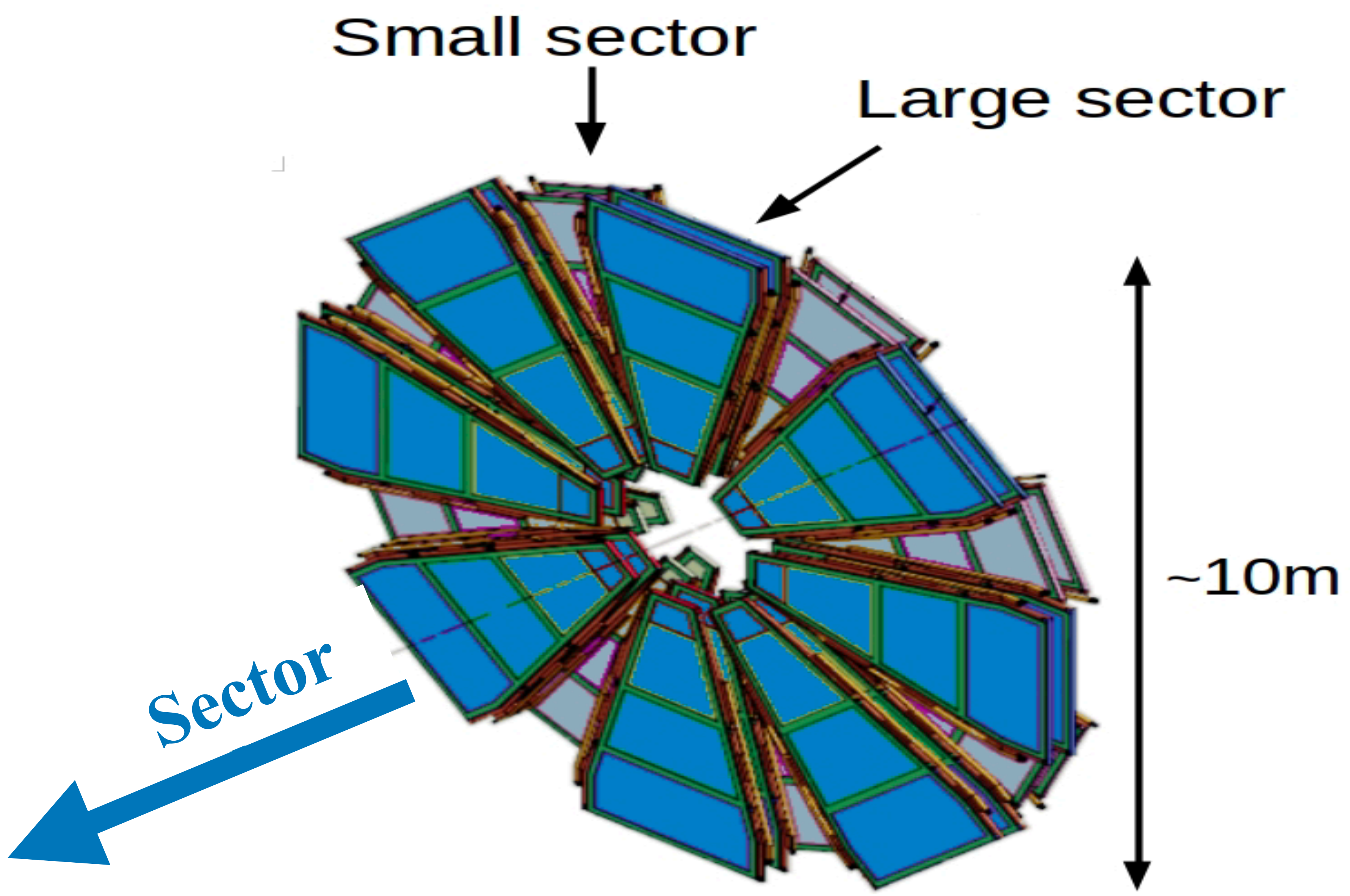
The NSW is composed of 16 trapezoid sectors, each sector being made of two detector technologies:

- The Micromegas (MM) optimized for precision tracking
- The small-strip Thin Gap Chambers (sTGC) optimized for triggering

Each sector is made of 2 sTGC wedges and 2 MM wedges.

- The sTGC wedges are made up of 3 quadruplets modules
- Each quadruplet is a multiplet with 4 sTGC layers



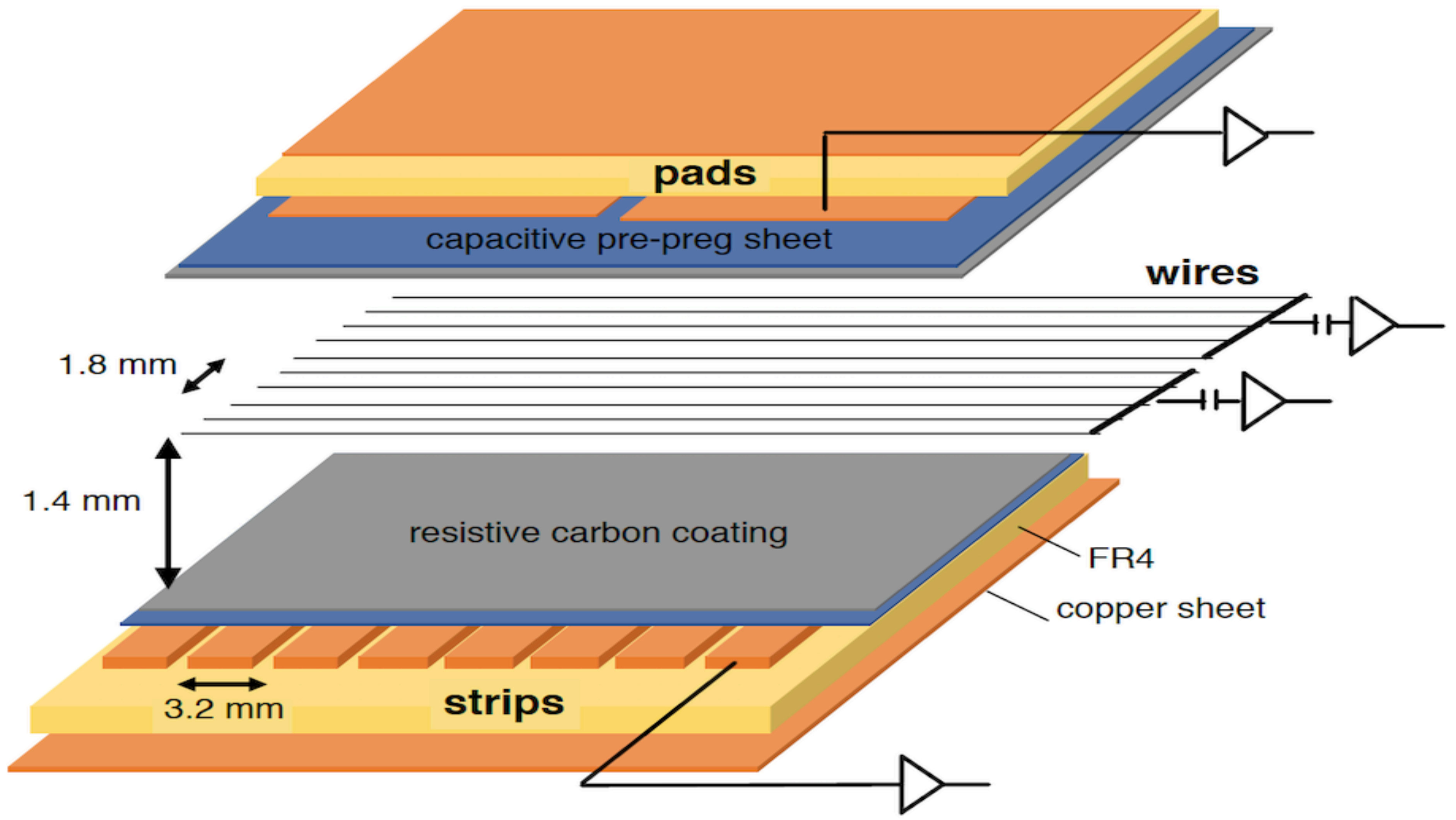


New Small Wheel

The whole NSW structure includes 128 detectors, in total to ~2.1 million readout channels.

NSW Structure

sTGC detector

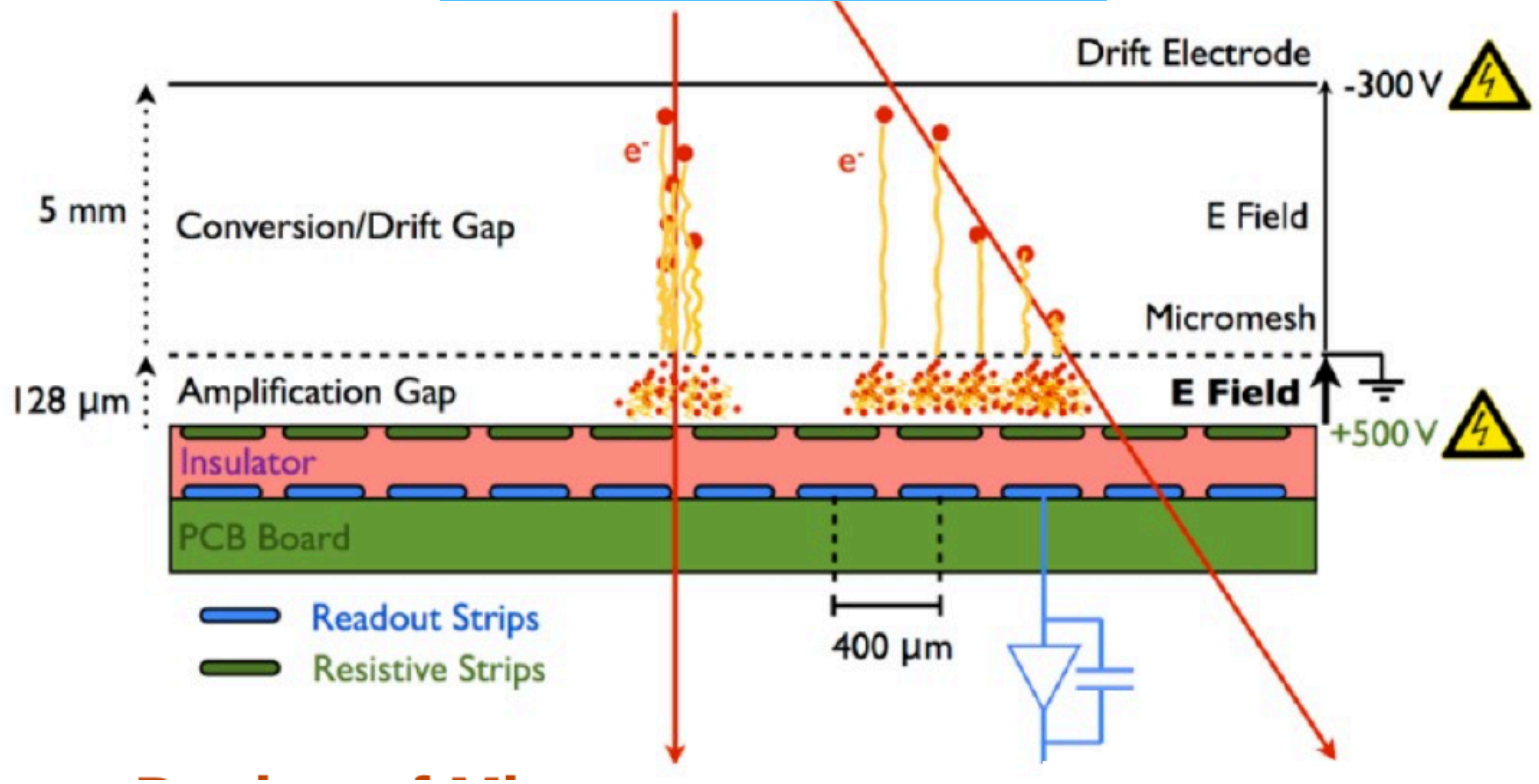


Mainly for triggering, also for good tracking

- Good timing resolution with short drift time for electrons
  - On average, the arrival time of more than 95% signals can be contained in a 25ns window.
- Small strip pitch (3.2 mm)
  - less than 1 mrad trigger track resolution

It will provide a ~ 7 fold increase in rejection rate for fake muon triggers.

Micromegas detector



Mainly for precise tracking, also for triggering

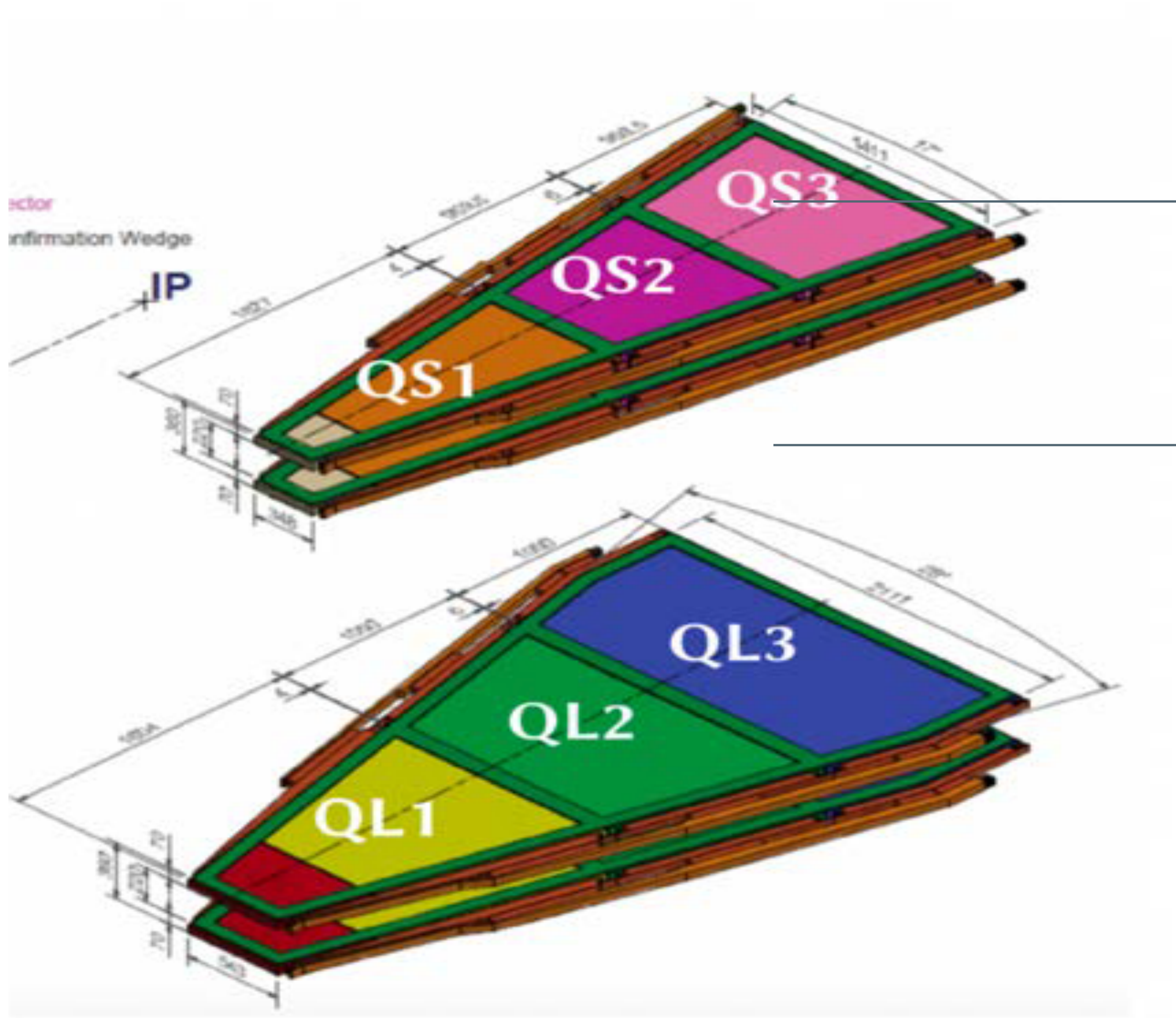
- Small strip pitch (~0.4 mm)
- Fast drift time (~100 ns)

It will reach space resolution < 100 µm independent of track incidence angle.

sTGC Construction Sites

sTGC quadruplets (each with 4 layers) are assembled at independent construction sites located in 5 countries.

sTGC Production Sites		
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



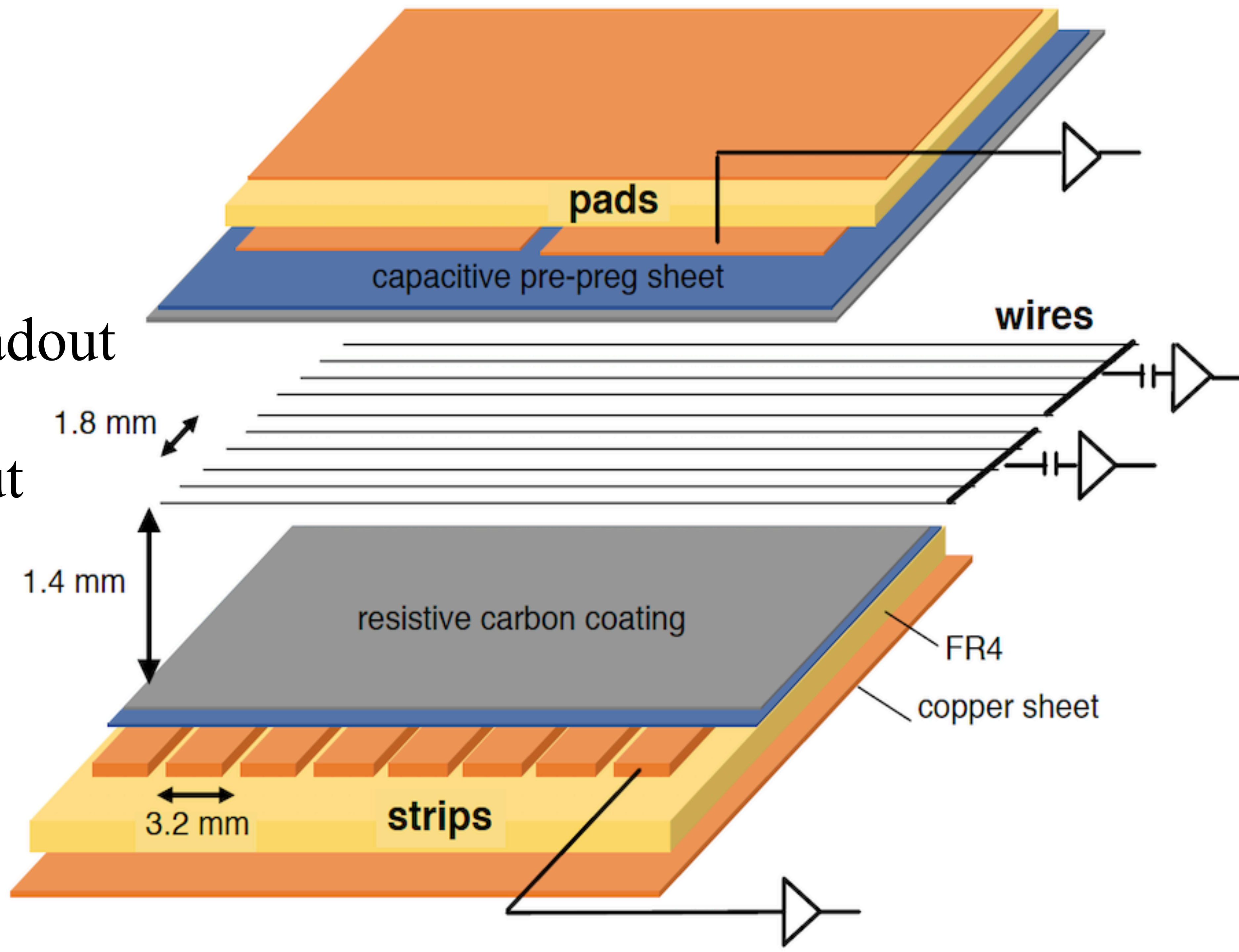
A Small-Strip Thin Gap Chamber (sTGC) is a multiwire proportional chamber operated in quasi-saturated mode. It is made up of 2 segmented cathodes and one plane of anode wires.

The sTGC chambers are operated with a gas mixture of CO_2 and npentane vapour and at a voltage of 2.8 kV. Ionization products induce current on wires, pads and strips as **three readout channels:**

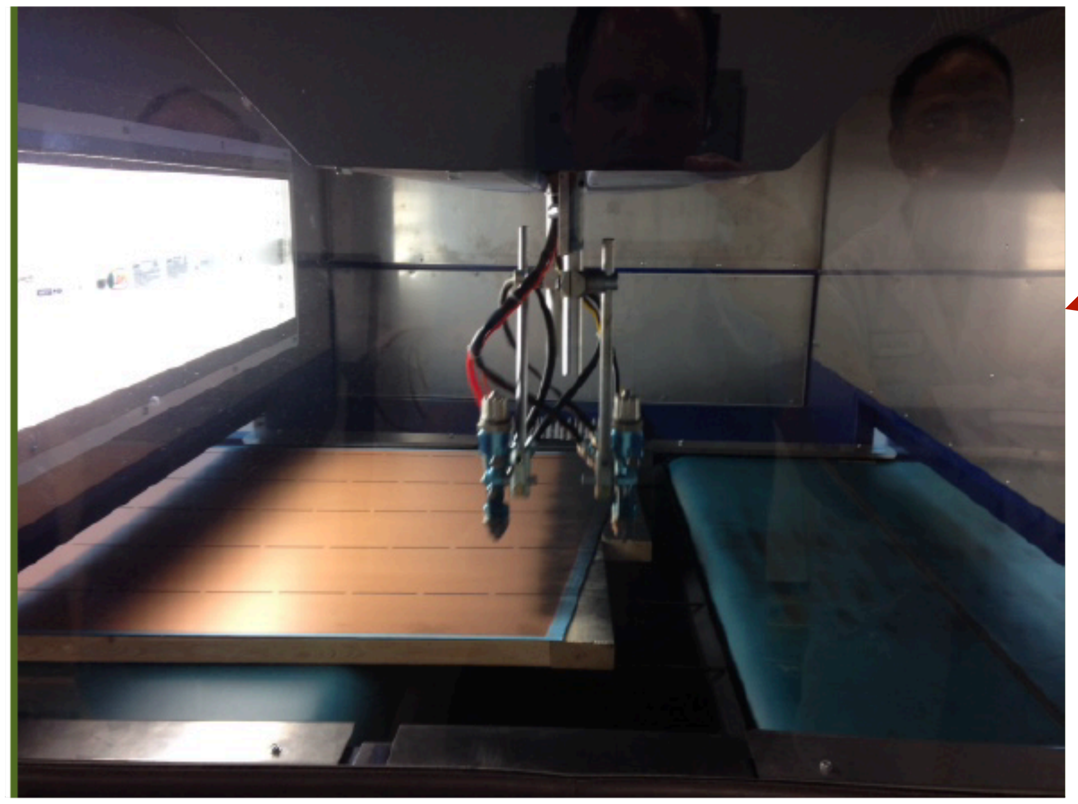
Wires: Coarse azimuthal muon coordinate

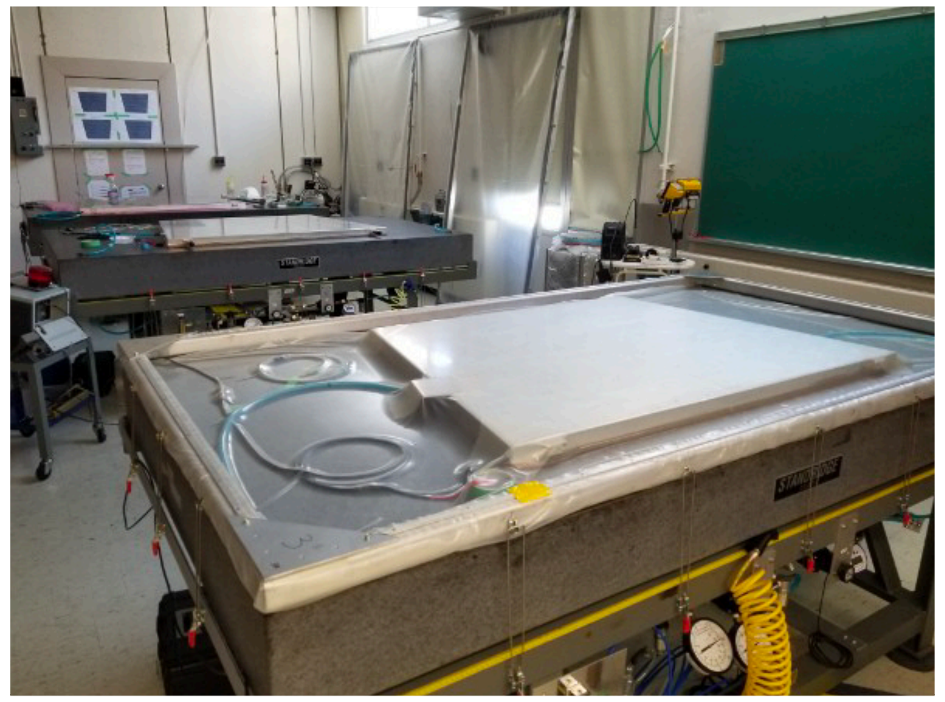
Strips: Precision muon track reconstruction and 1mrad angular resolution; analog readout

Pads: Define NSW trigger region of interest(ROI) and coarse tracking; digital readout



sTGC Construction





Graphite spraying

Half-gap production

Wire winding of cathode boards

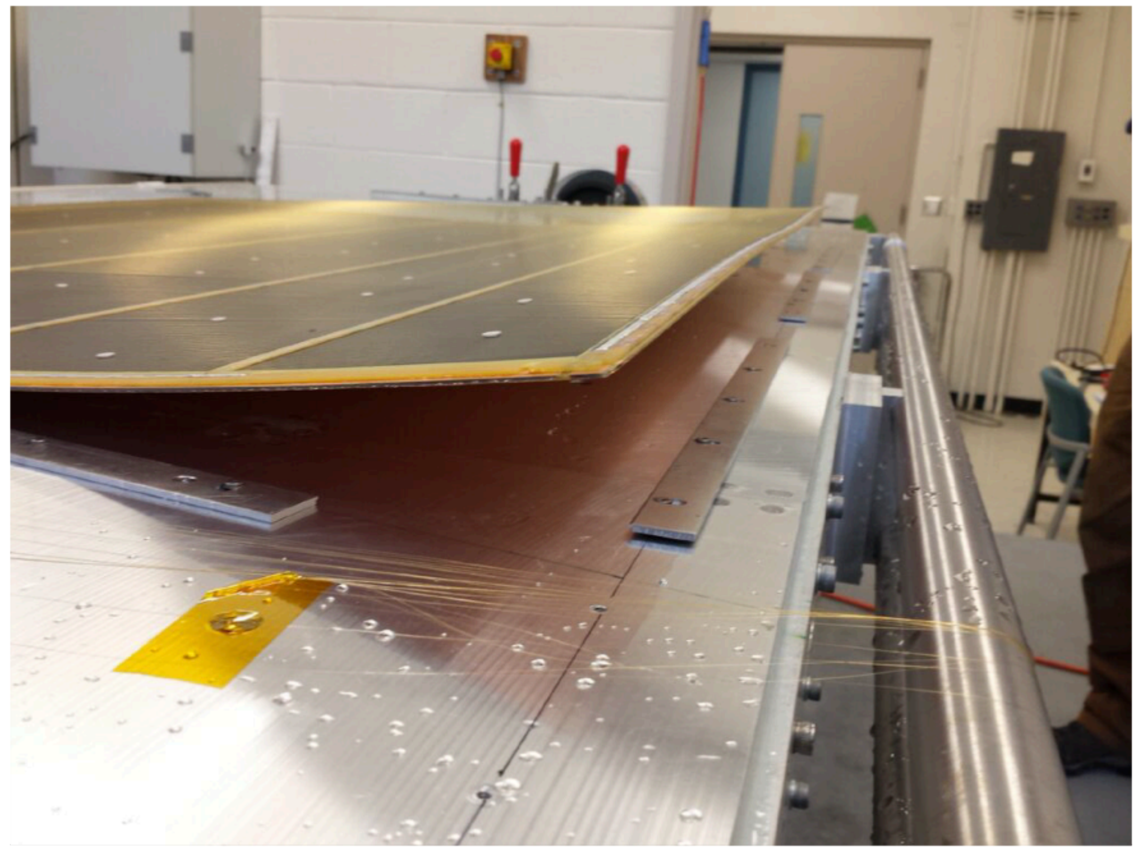
Gap closing and testing

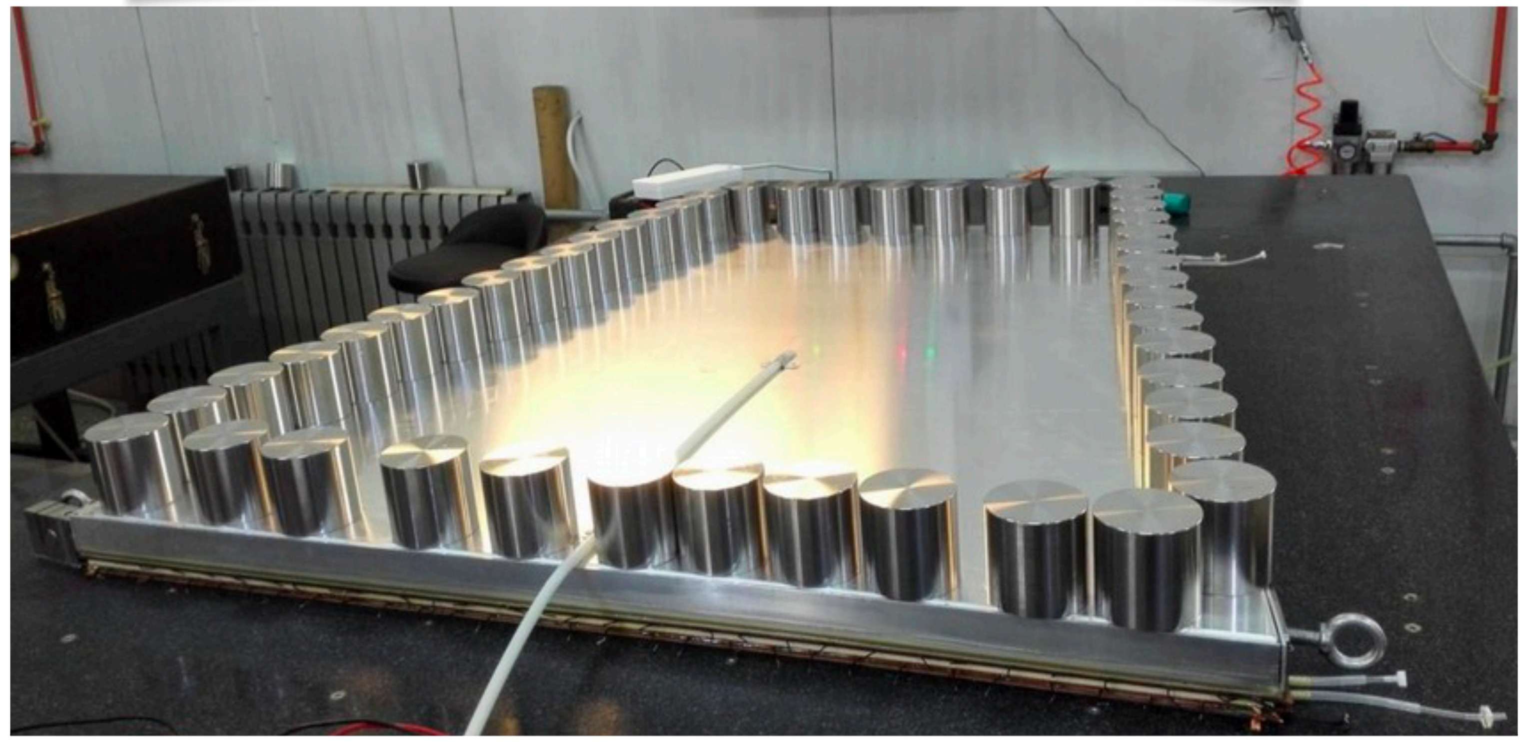
Doublet assembling and testing

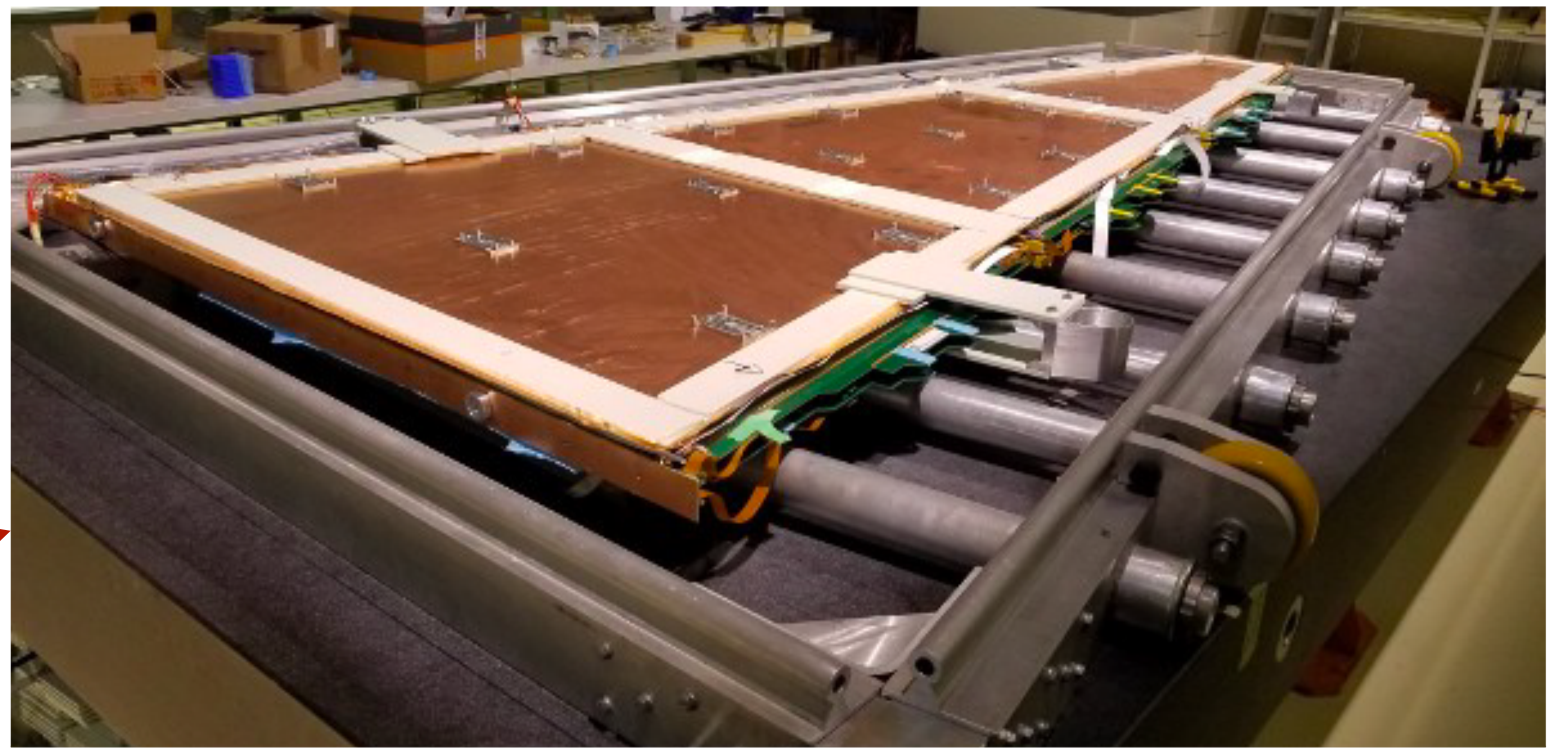
Quadruplet assembling

Cosmic-ray testing

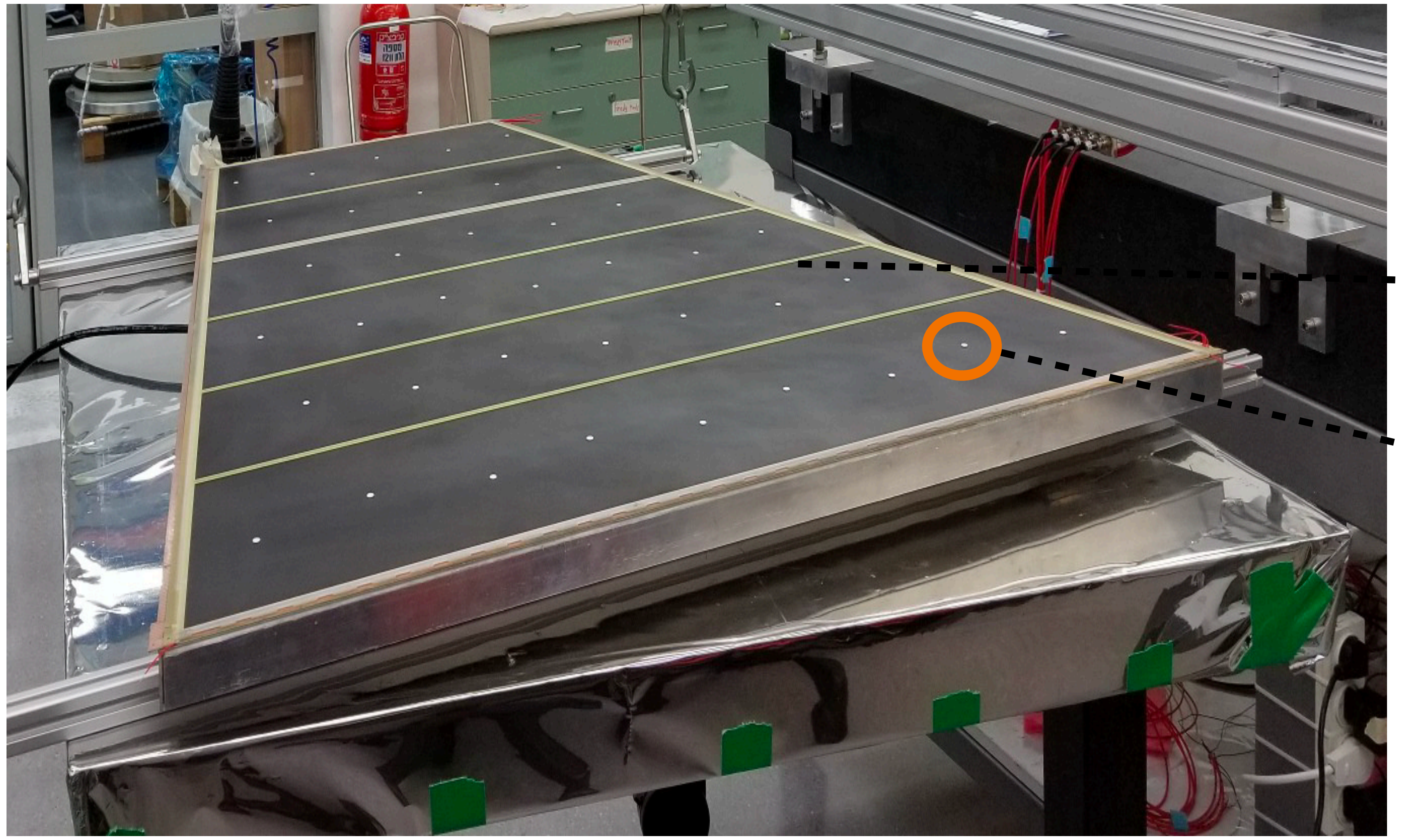
Wedge assembly

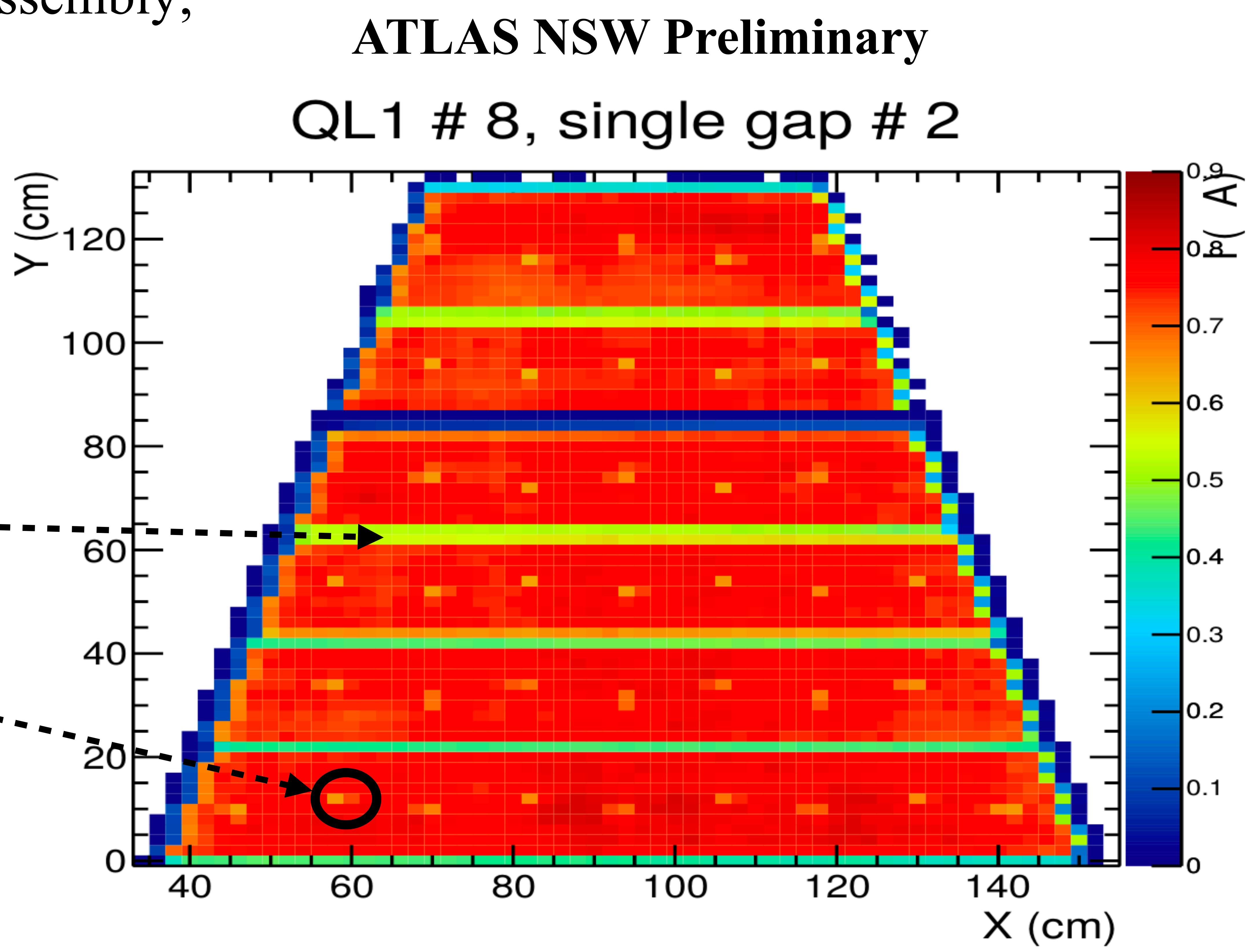






- HV tests at different stages (single gap, doublet, quad) to identify leakage currents, shorts, sparks;
- X-Ray scan of single gap to measure gain uniformity and probe internal structure of gaps;
- Electrical connectivity test of readout channels after adapter board assembly;

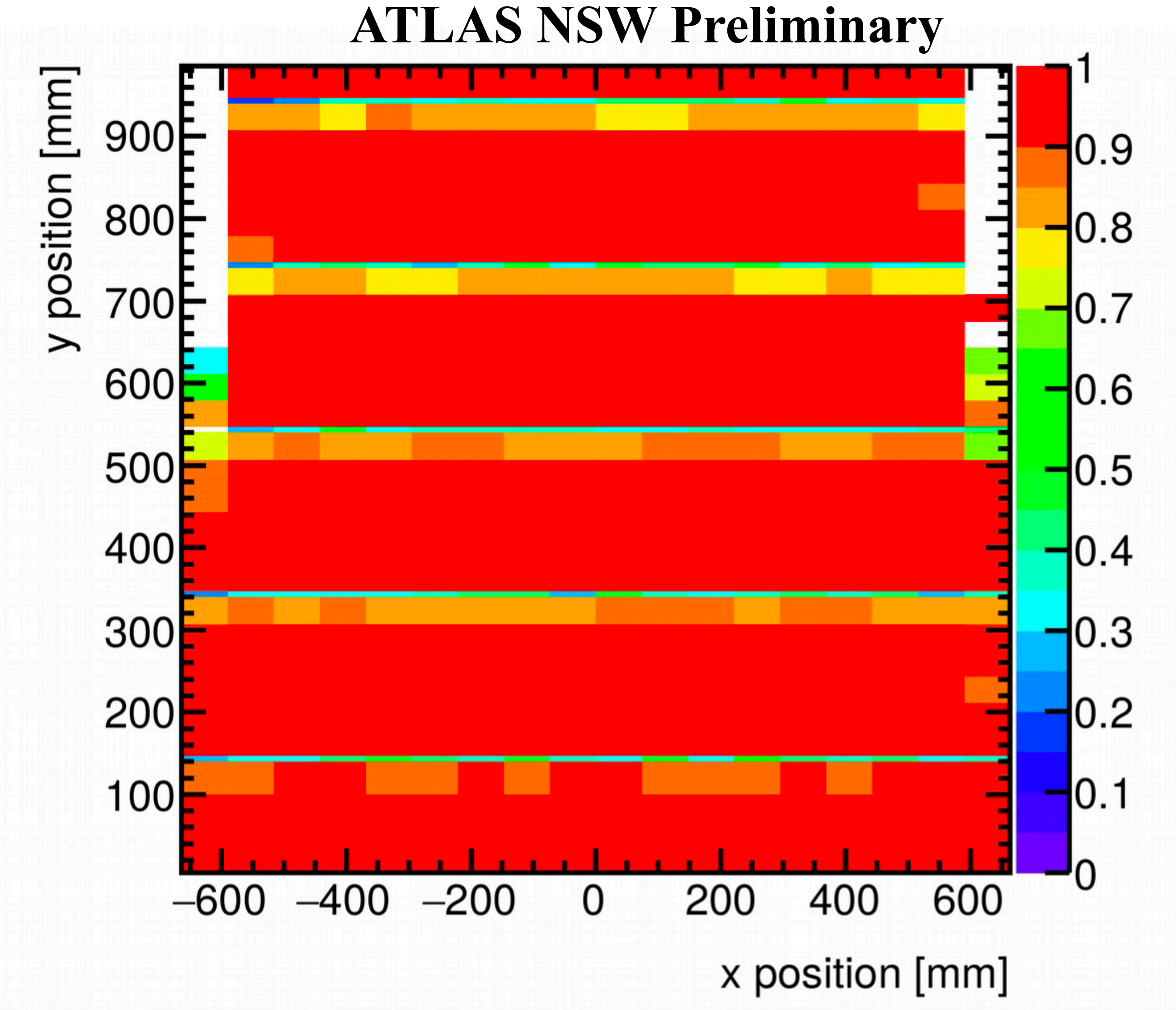




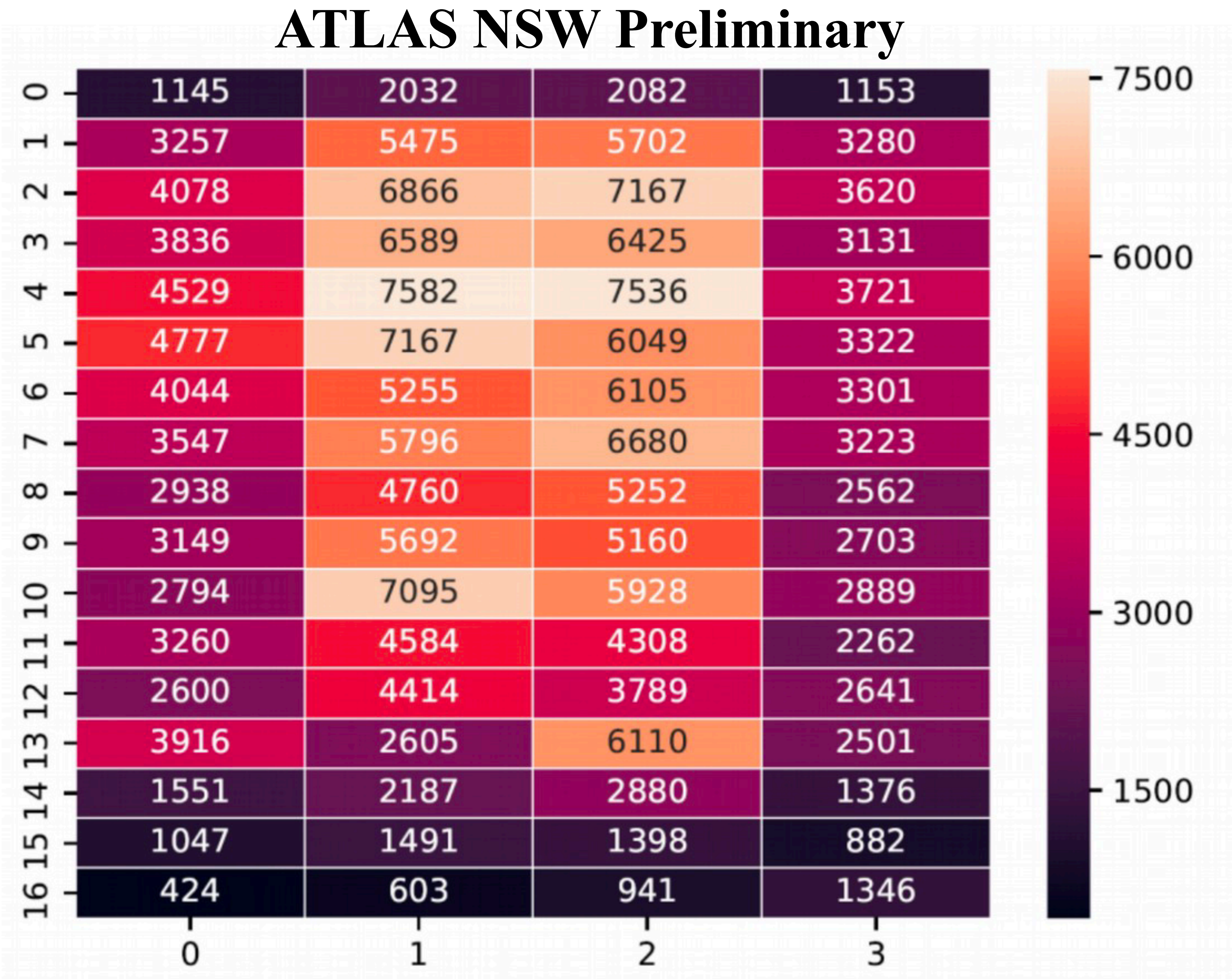
sTGC Cosmic Tests

Tests are conducted to check:

- Hit maps
- 2D efficiency maps
- Resolution and misalignment corrections
- Noise measurement



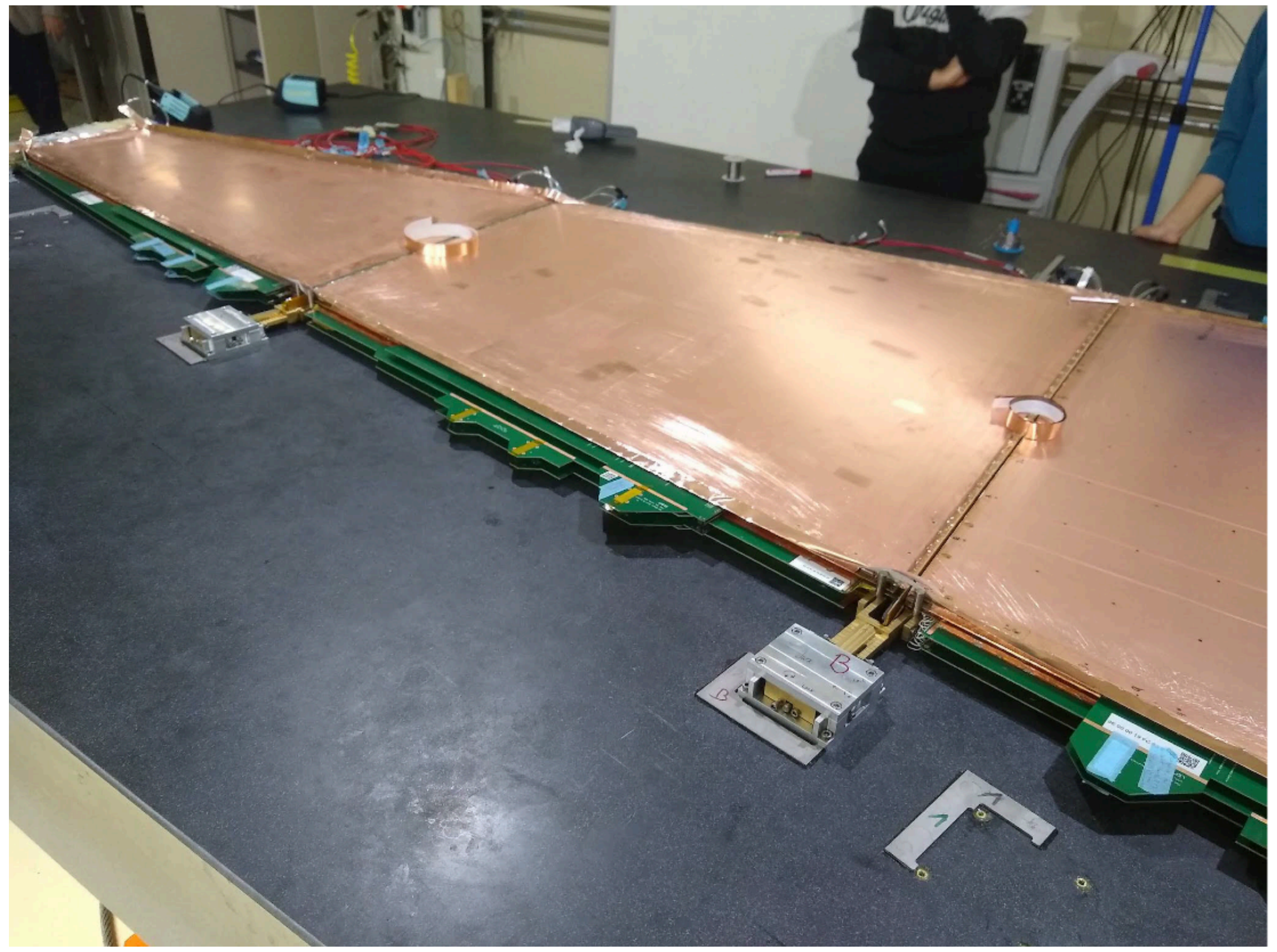
Preliminary 2D efficiency of strip channels of a QS3 gap



Number of cosmic muons counted in a QS1 gap during a period of approximately 13 hours.

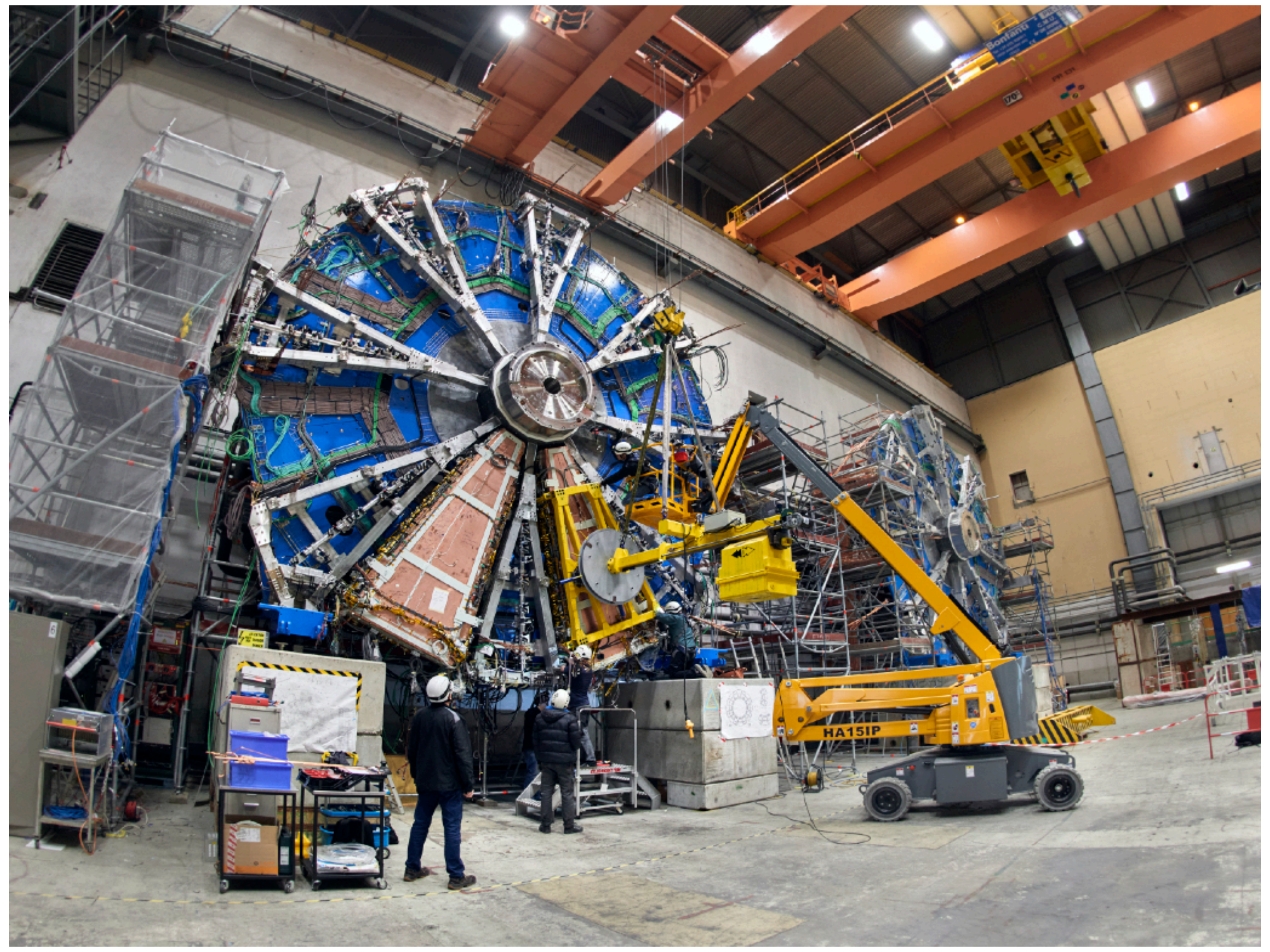
Wedge Assembly and Integration @ CERN

Gluing: 3 quads are assembled into wedges



Faraday cage assembly

Install the electronics and sector integration(sTGC and MM)



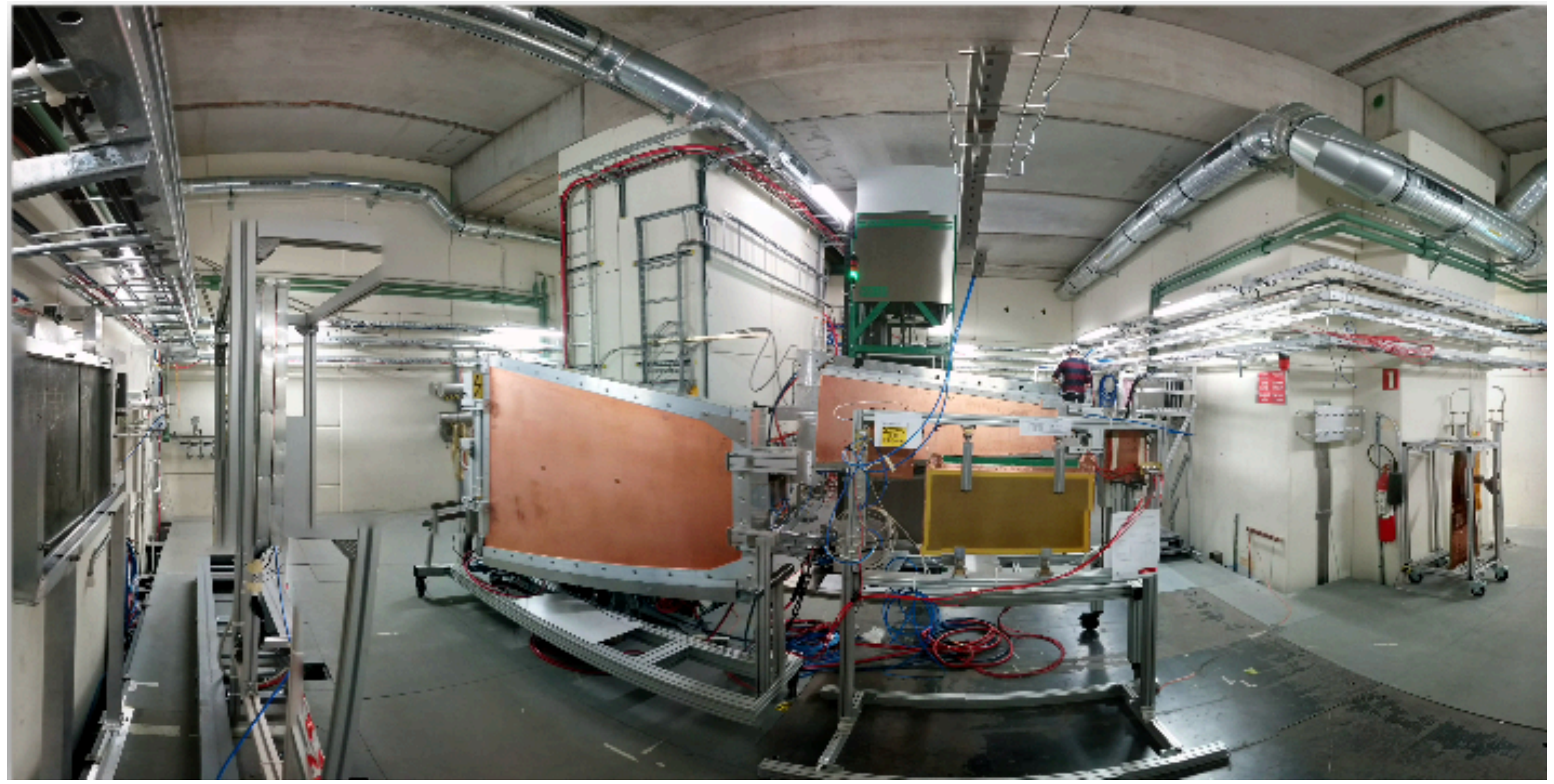
Integrate sTGC and MM into sectors and wheel assembly

Quality Controls @ CERN

Quality control carried out at every step of assembly:

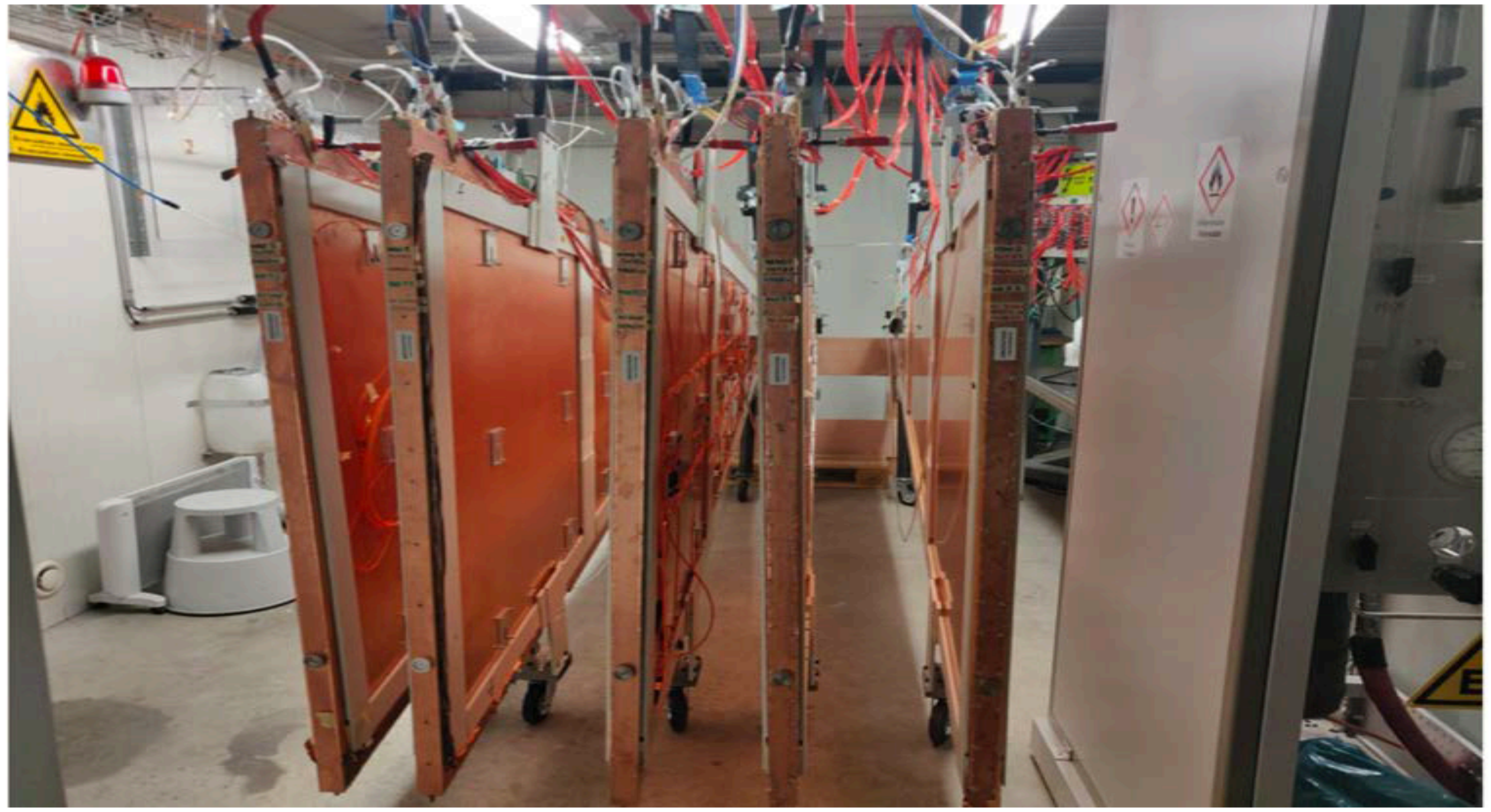
- Ensure no damage during shipment
- Readout connectivity test
- Stability test under high radiation with 20 kHz/cm^2 (at CERN; GIF++ facility)
- Noise measurements with integrated electronics(wedges)
- Long-term HV test(wedges)
- Measurement of misalignment using x-rays (wedges)

CERN GIF++ facility



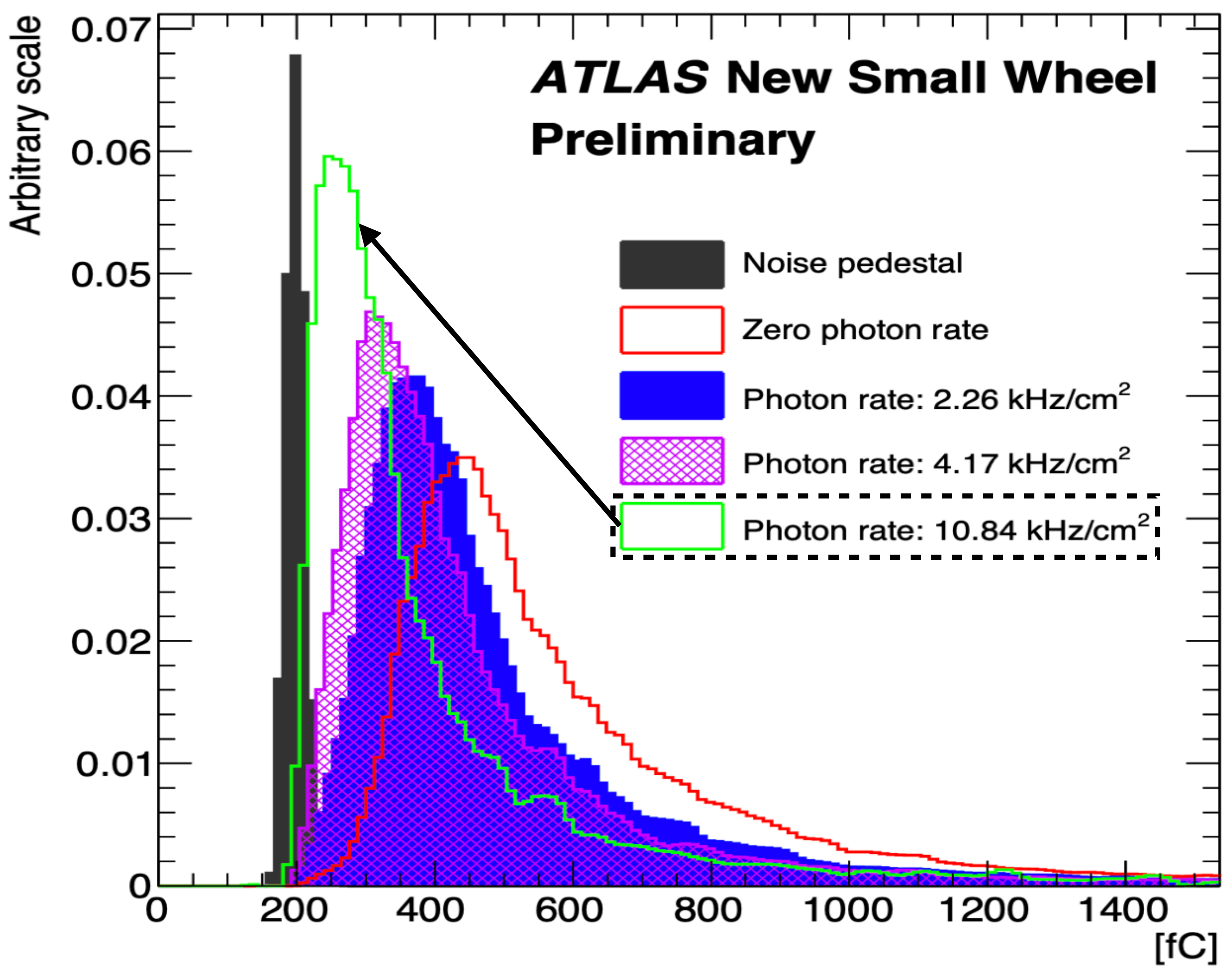
GIF++ operates with 137Cs source of 14 TBq that radiates gamma rays.

HV test @ CERN

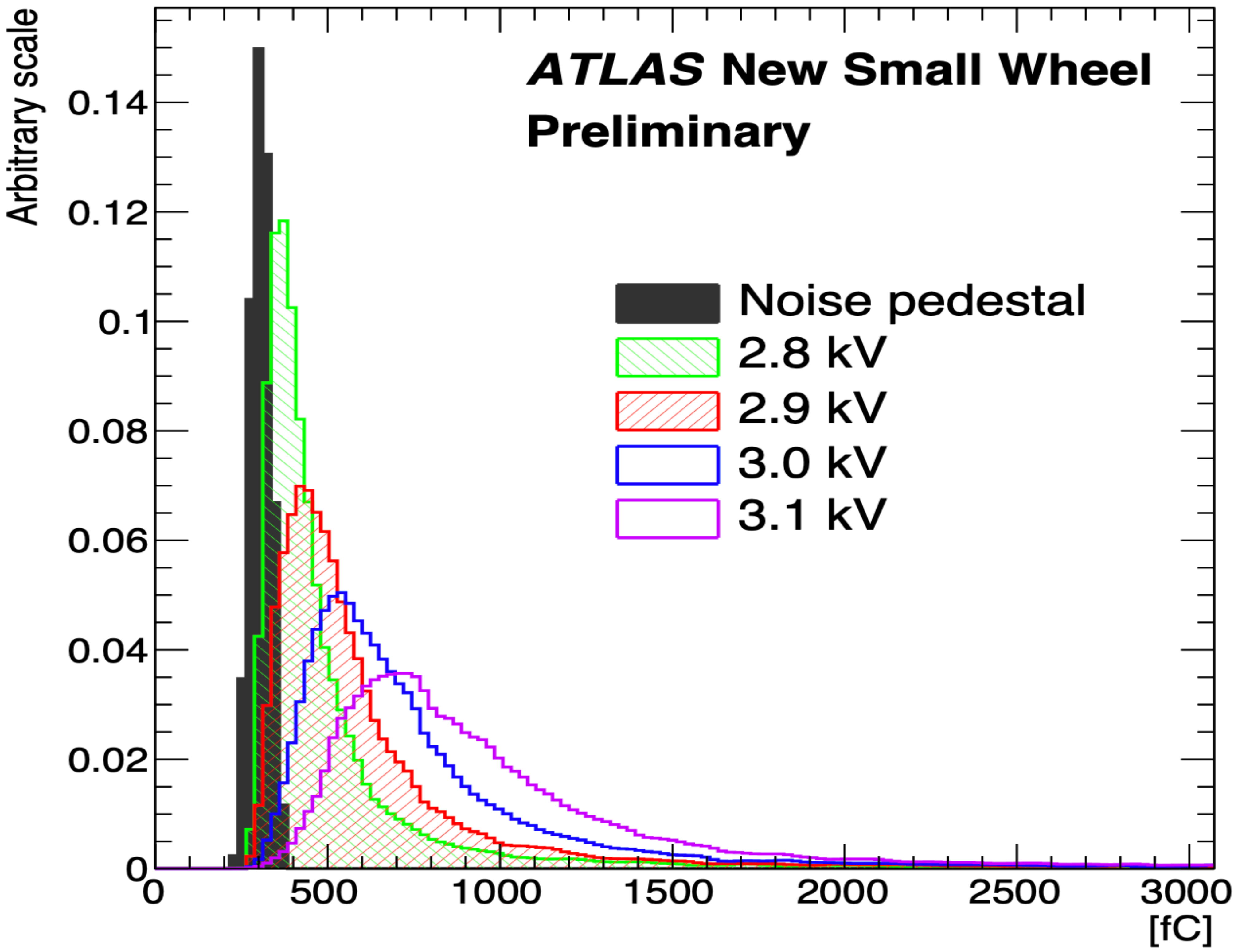


sTGC Performance in Muon Test Beam at CERN

Test with muon beam in the presence of high rate photon background;
CERN GIF++ facility with QL1



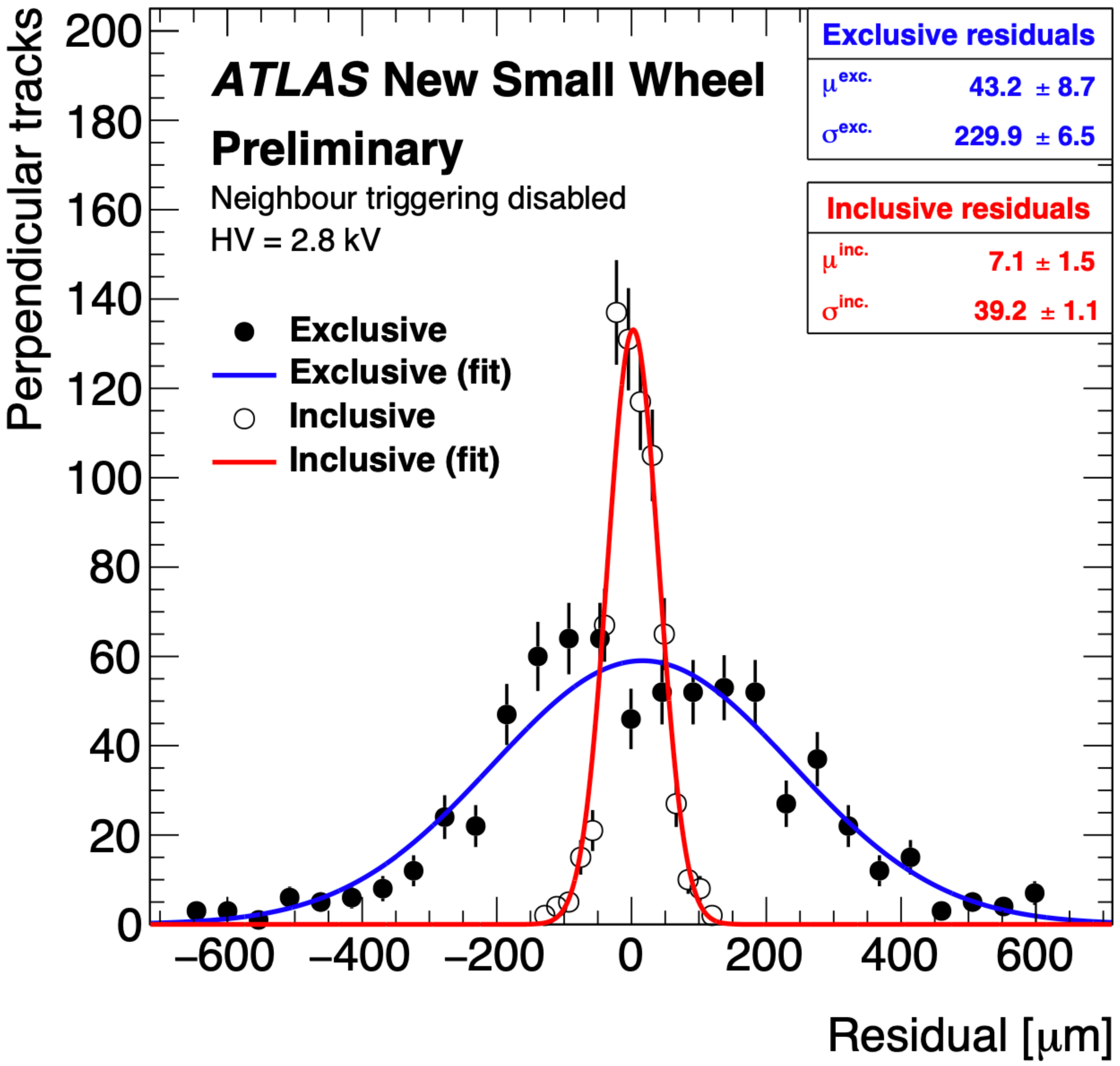
Test with muon beam
CERN H8 beam line with QS3

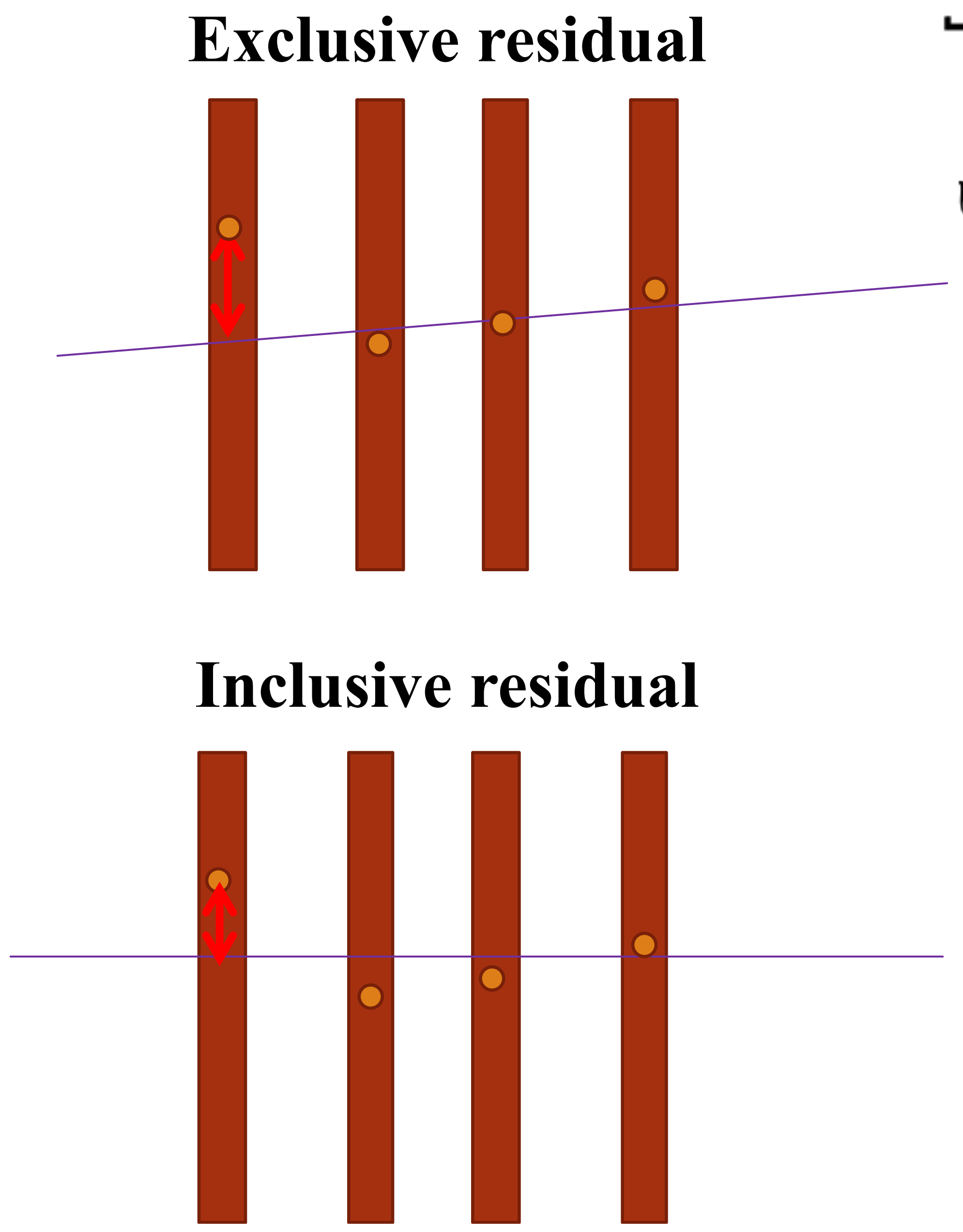


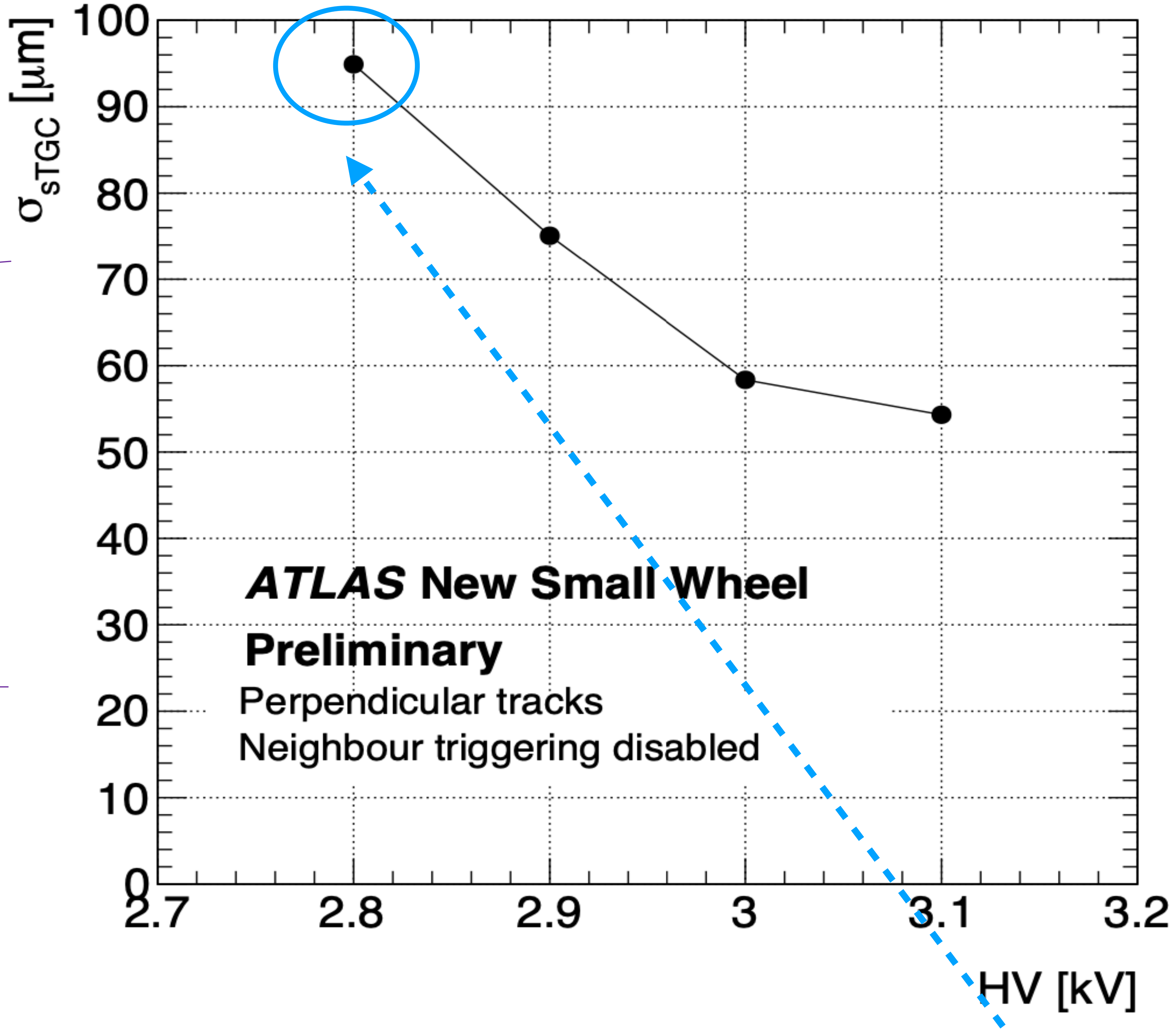
- NSW detectors read out using the VMM amplifier-shaper-discriminator ASIC
- VMM on custom front-end-boards (FEB) designed for sTGC readout

The sTGC chambers are operated with a gas mixture of CO2 and npentane vapour and at a voltage of 2.8-2.9 kV.

sTGC strip spatial resolution as a function of the applied high voltage; measured with final VMM prototype.







The strip spatial resolution is obtained from the distributions of the exclusive and inclusive residuals of the reconstructed tracks.

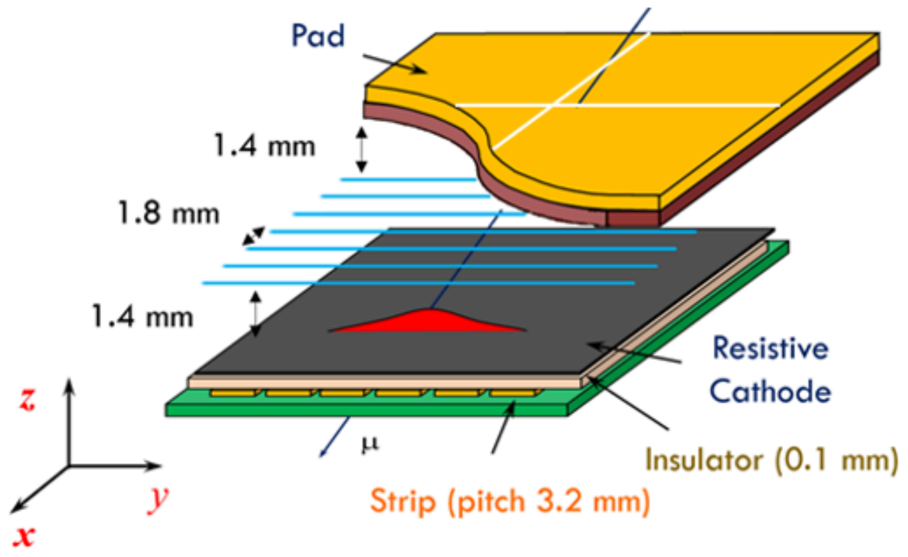
$$\sigma_{sTGC} = \sqrt{\sigma^{inc.} \times \sigma^{exc.}} = 95\mu m$$

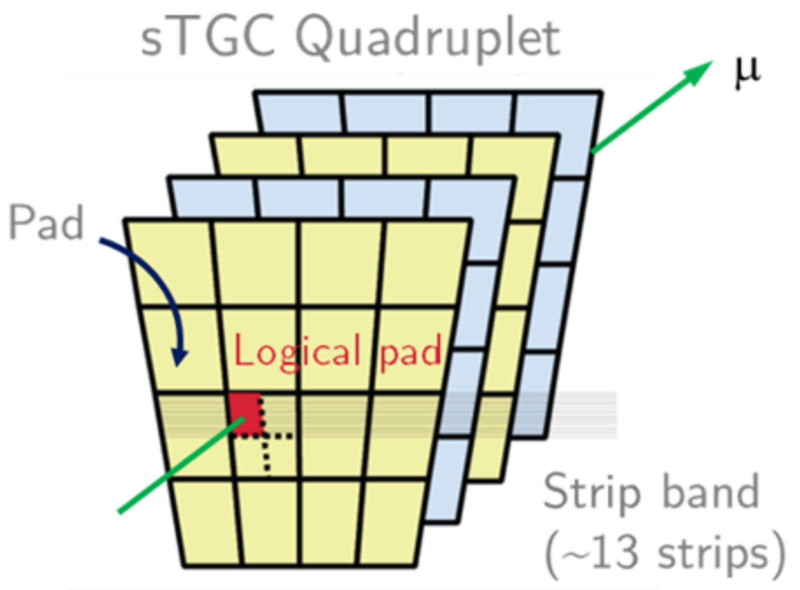
Inclusive residuals for a layer of interest are defined as the position difference between the layer space point and the position of a track reconstructed using the space points of all 3 layers. The **exclusive residuals** are obtained the same way but reconstructing the track without the space point of the layer of interest.

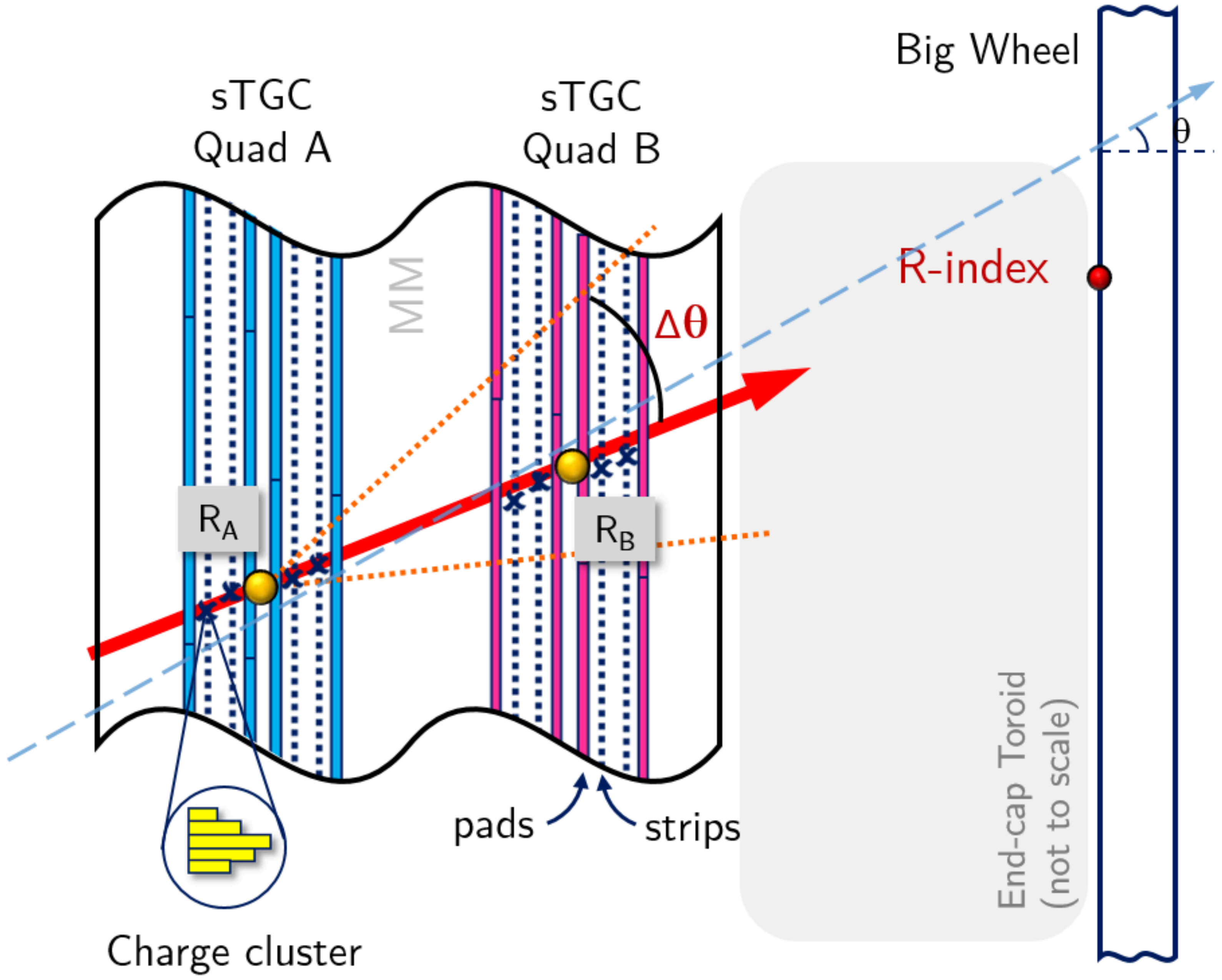
sTGC Trigger

The pads are used through a 3- out of 4 coincidence to identify muon tracks pointing back to the interaction point.

- Pad layers staggered to make “logical’ pad towers
  - Muon trajectories define pad trigger towers
  - 3 out of 4 layers with a hit required for single wedge trigger
  - Final decision based on geometrical matching between the two wedge triggers
- Strips from both sTGC wedges and MM hits used for online track angle measurement

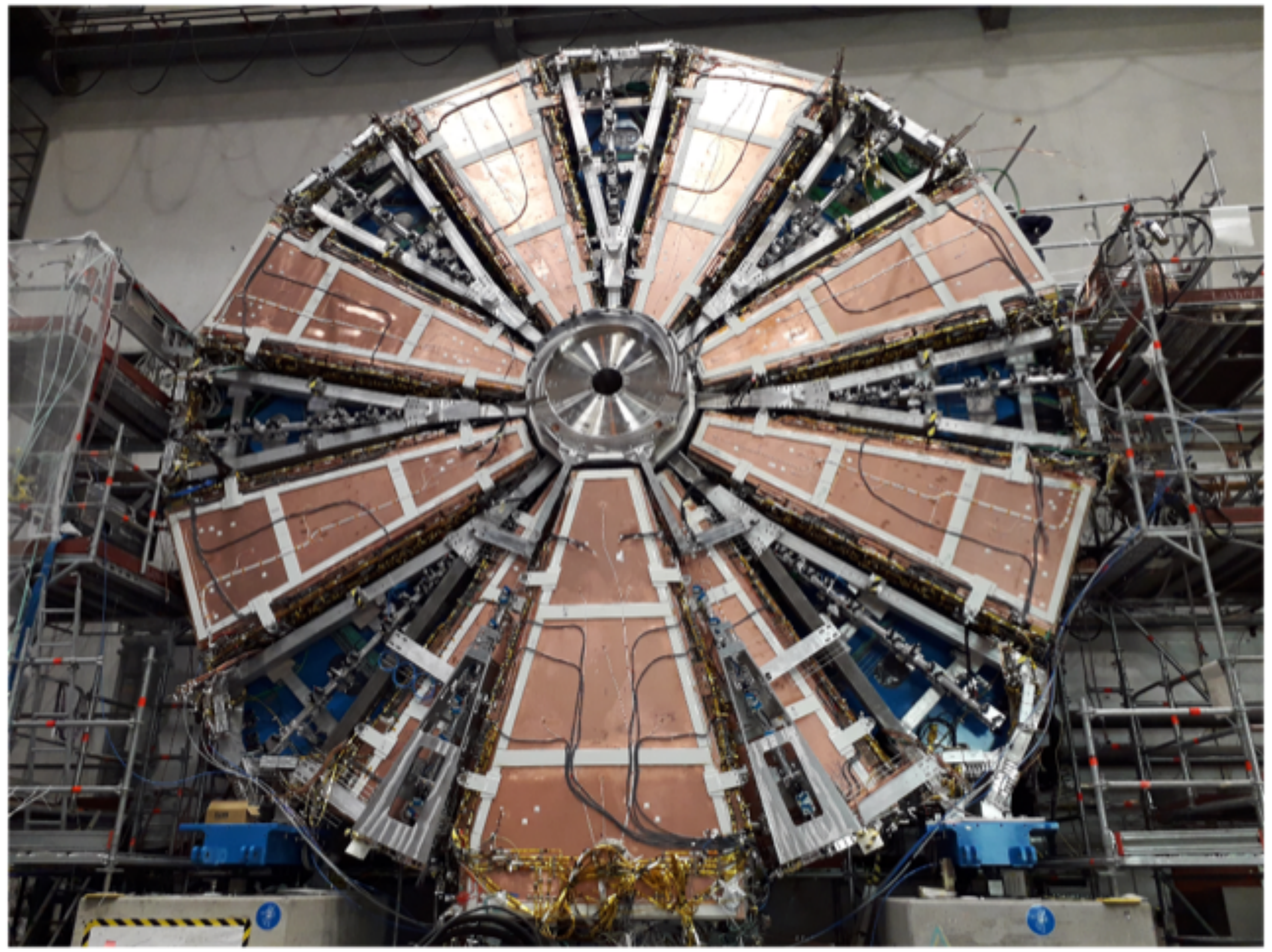






Summary

- The NSW is essential for ATLAS to maintain high trigger efficiency and momentum resolution in the high pile-up and high radiation environment expected during high luminosity phase of the HL-LHC.



- Many sTGC wedges already produced at CERN and the integration is progressing with chambers and electronics.

THANKS FOR THE ATTENTION

- There are some advantages to promote ATLAS Muon Thin Gap Chamber technology to be used at ILC.
  - It can be considered as a robust solution for a muon system at ILC.
- Interest from groups in ATLAS, in particular Canada, to port the ATLAS sTGC technology into an ILC detector.