Small-Strip Thin Gap Chambers and Electronics Performance for the Muon Spectrometer Upgrade of the ATLAS Experiment

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Introduction

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**.
- 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

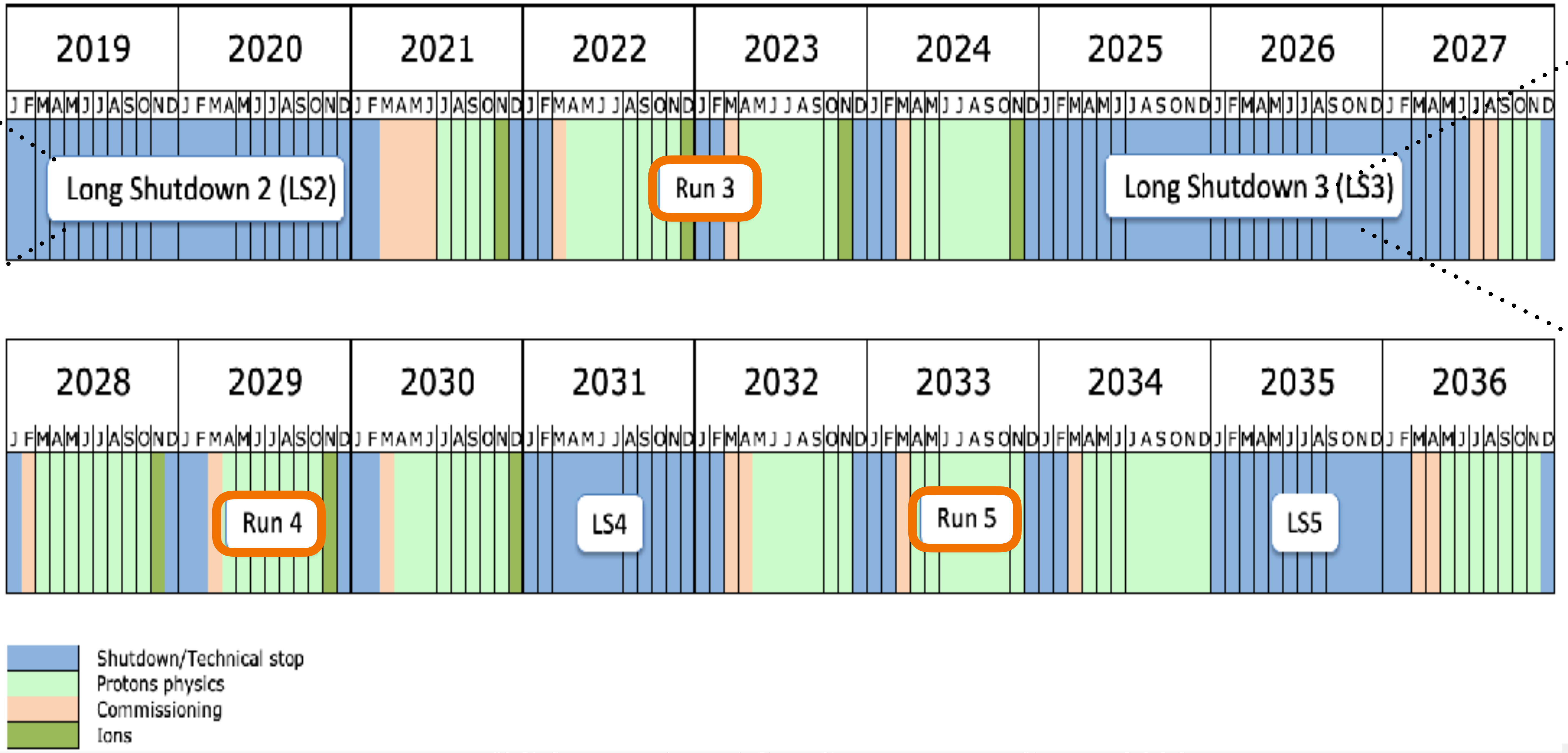
ATLAS Upgrade projects(LS3)

Muon System

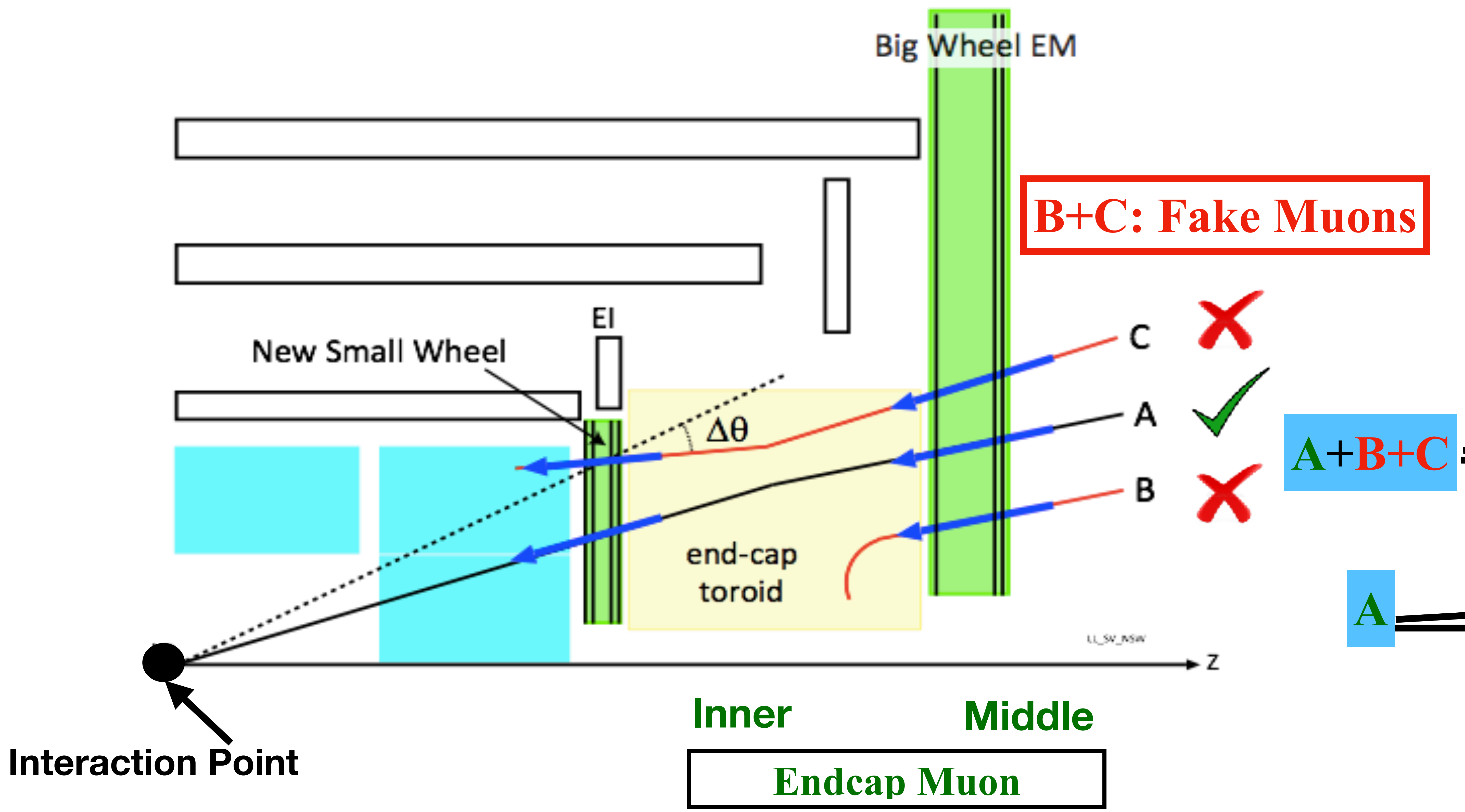
Inner tracker

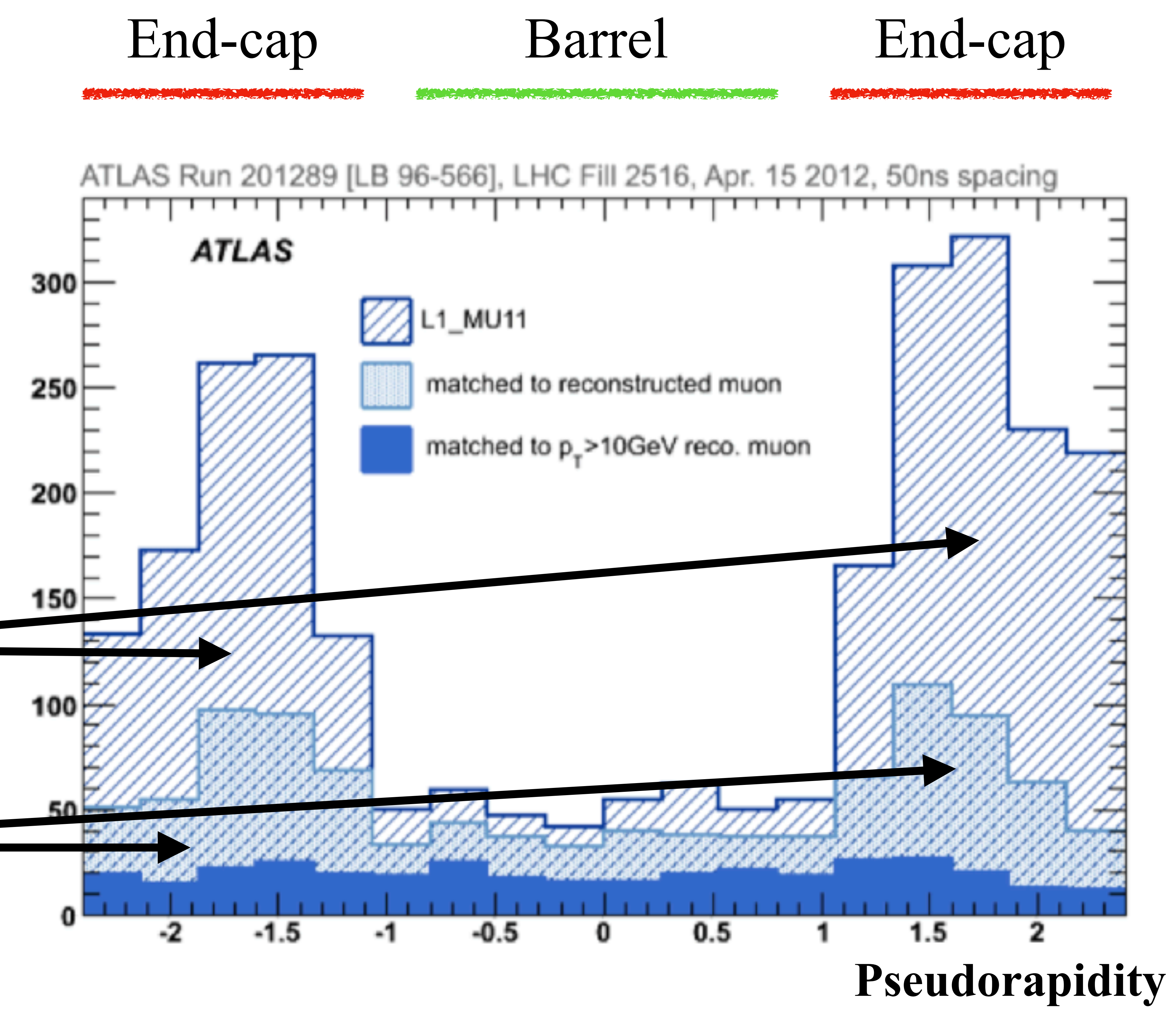
LAr and Tile calorimeters

DAQ and trigger systems



Trigger Rate & Identification Limitations





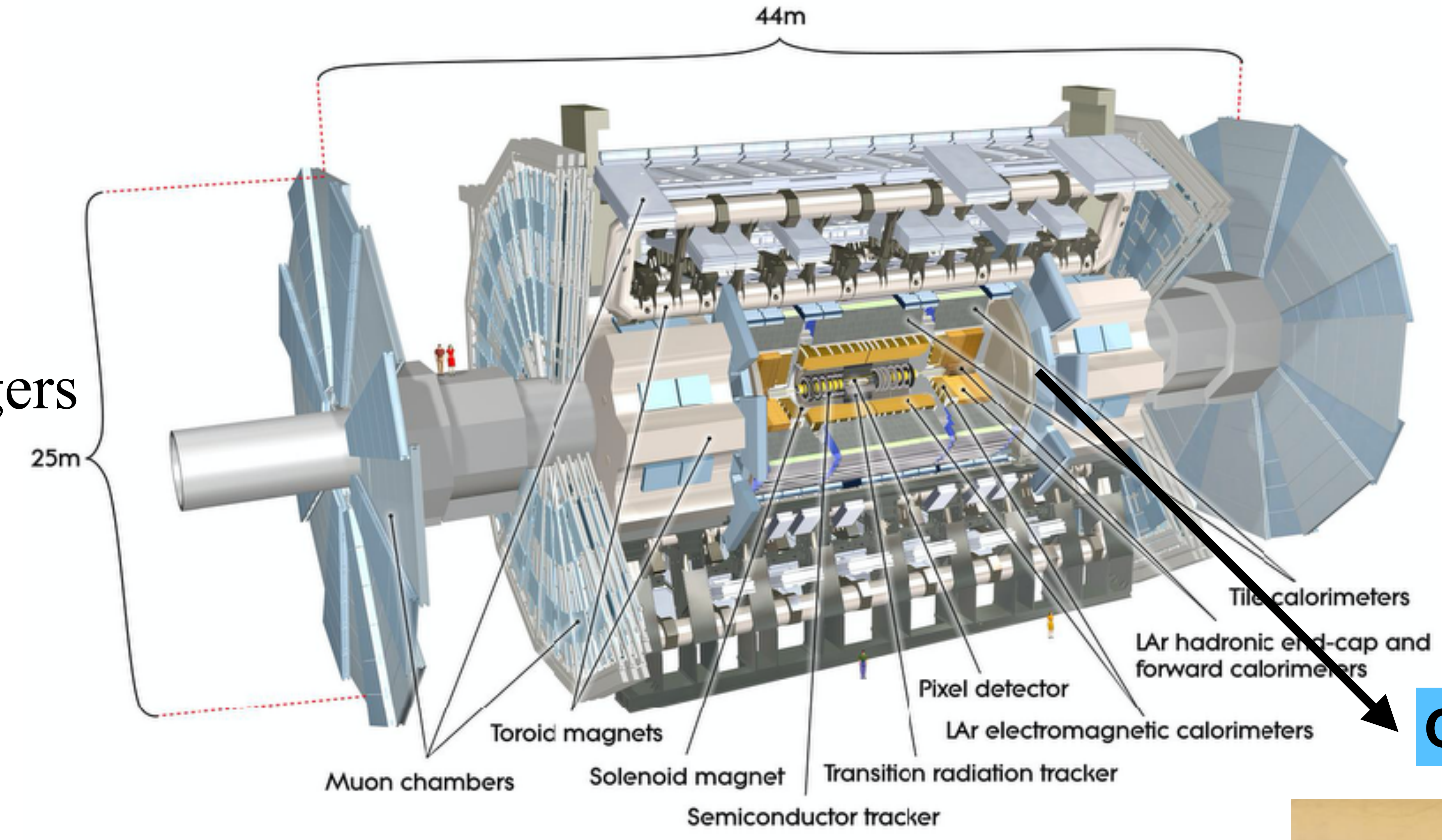
Online Muon Identification: Current Wheel Chambers will lose efficiency at high hit rates due to higher instantaneous luminosity.

- Current Muon system only uses middle wheel for triggering; it 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

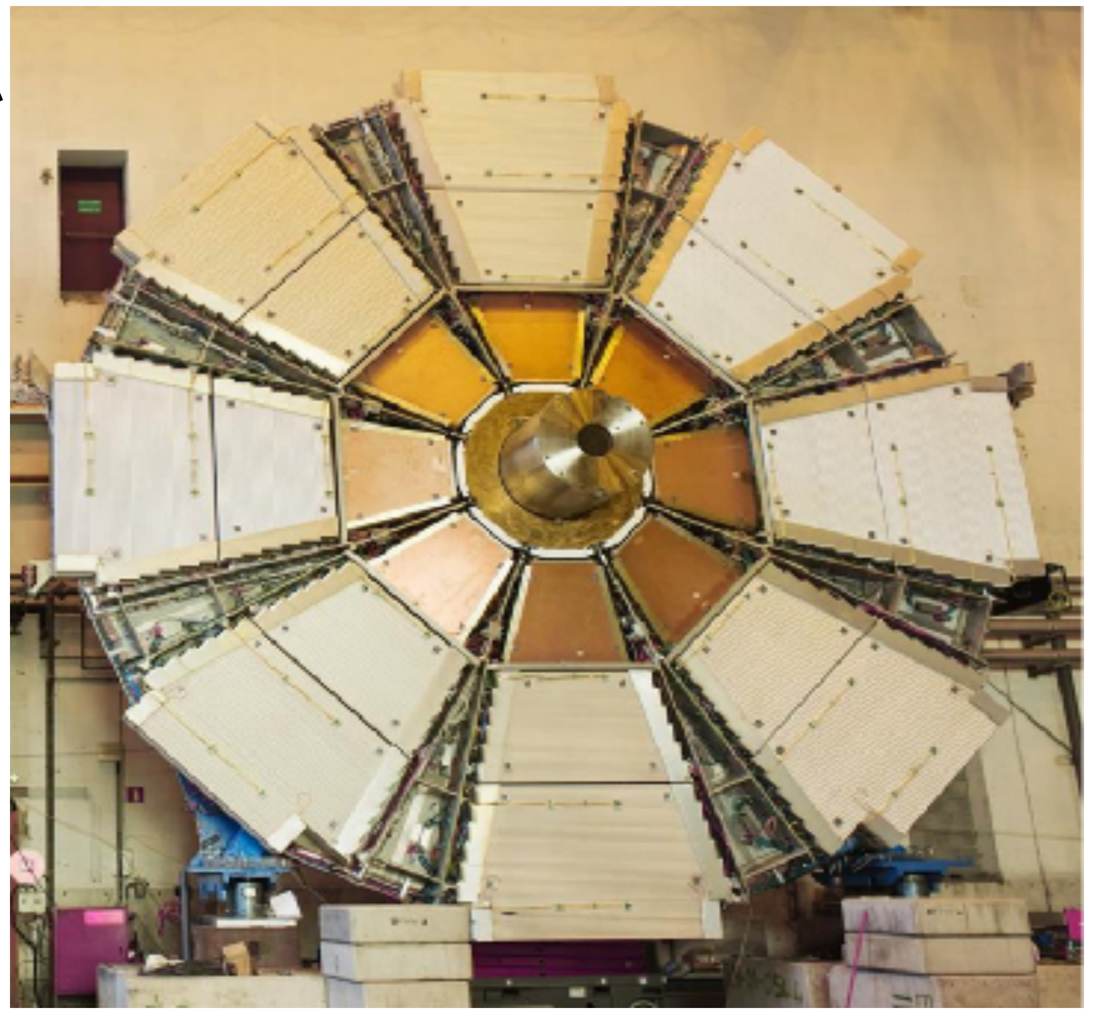
Solution: The New Small Wheel(NSW) upgrade will replace the current Small Wheel of the ATLAS Muon Spectrometer to handle tracking and triggering problems.



It is designed to:

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

Current Small Wheel



New Small Wheel

Strict Requirements for the new small wheel:

- Excellent online angular spatial resolution; less than 1 mrad
- Operate efficiently at Run-3 and beyond it

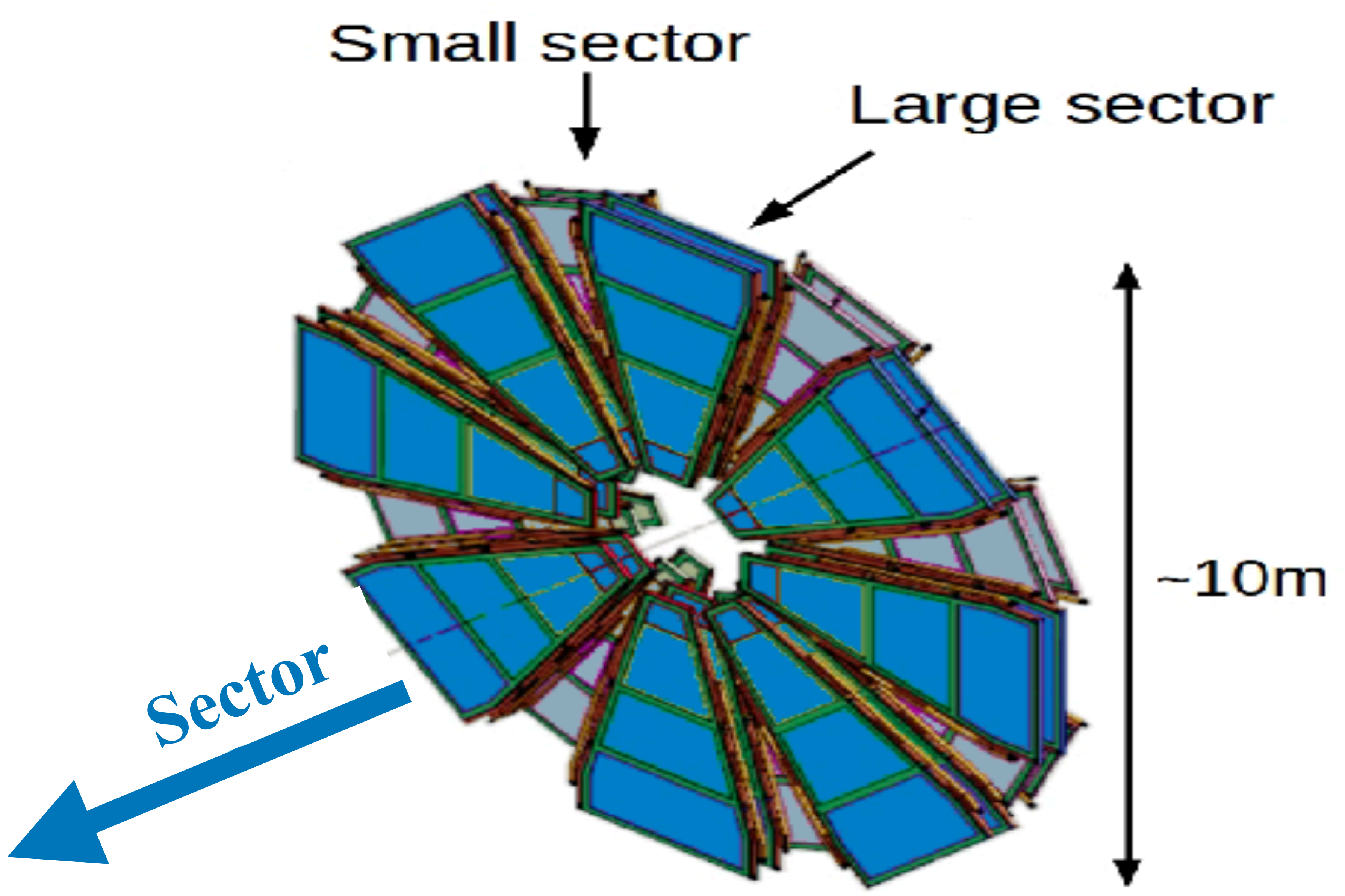
New Small Wheel Upgrade

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

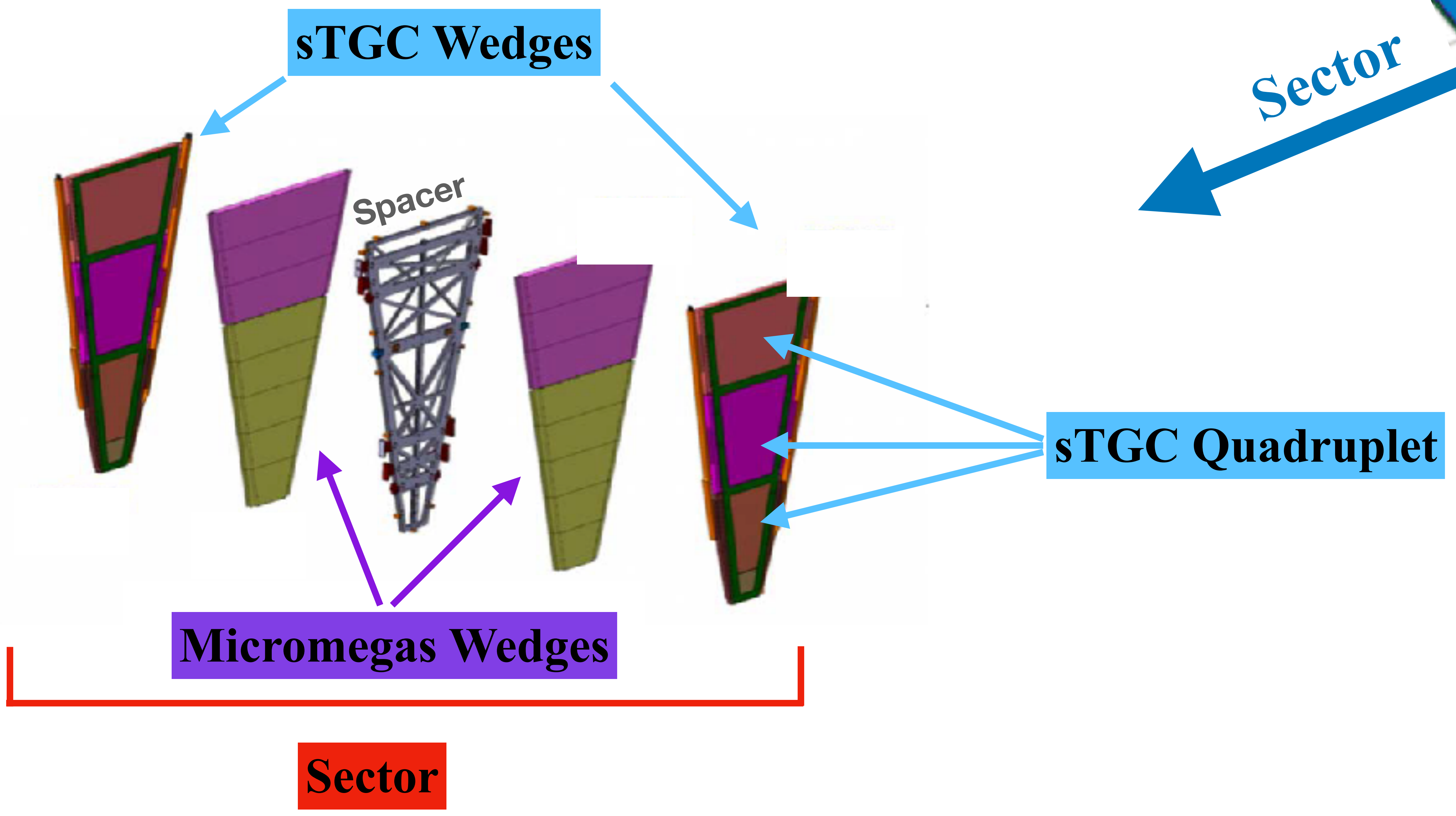
- The Micromegas (MM) designed for precision tracking
- The small-strip Thin Gap Chambers (sTGC) optimized for triggering

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

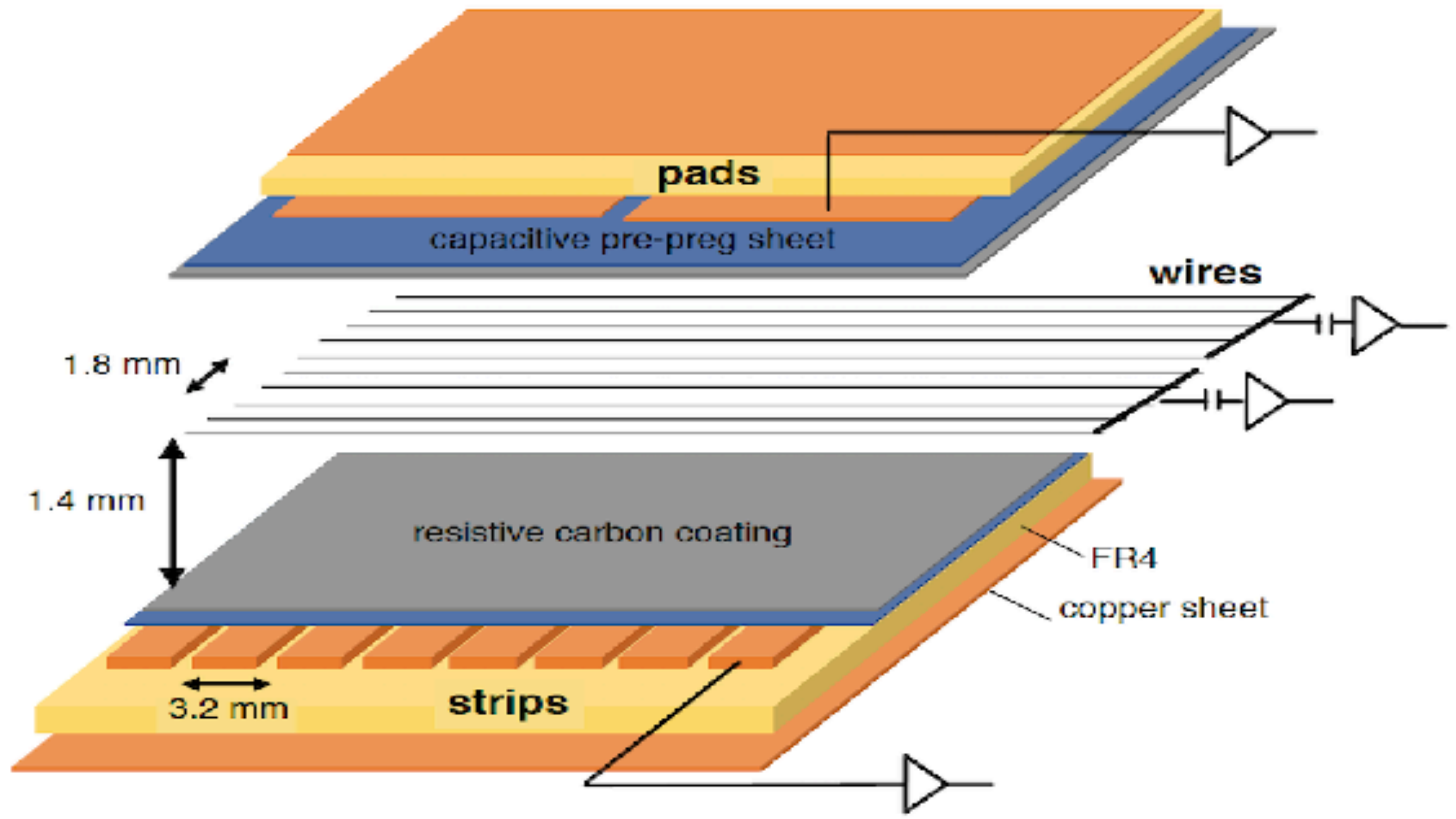


New Small Wheel

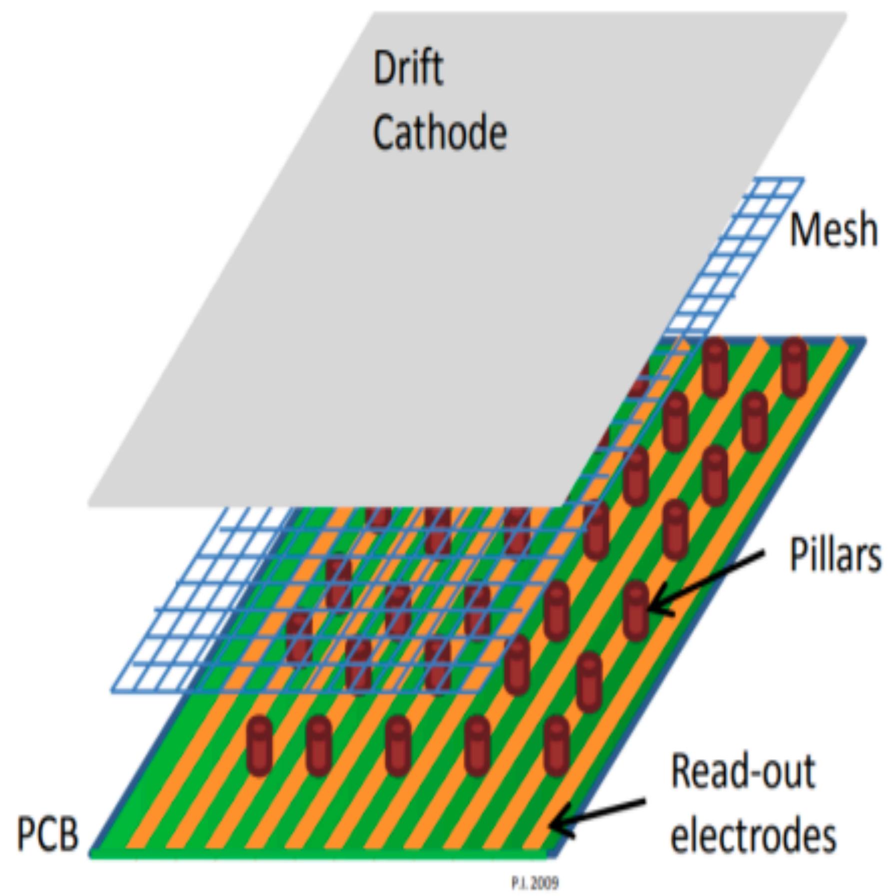


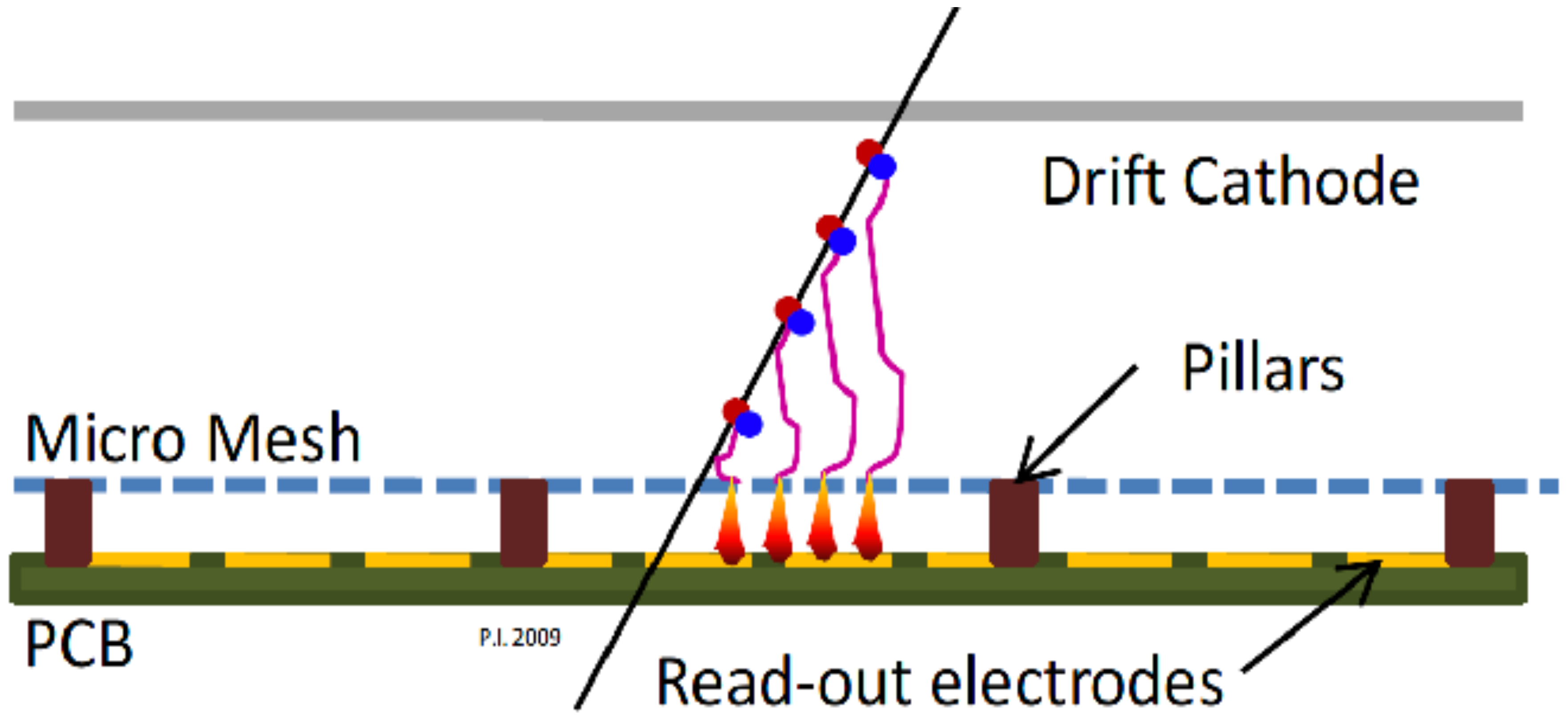
Carleton UNIVERSITY ATLAS EXPERIMENT

sTGC detector



Micromegas detector





Mainly for triggering, also for good tracking

- Good timing resolution with short drift time for electrons
- 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.

Mainly for precise tracking, also for triggering

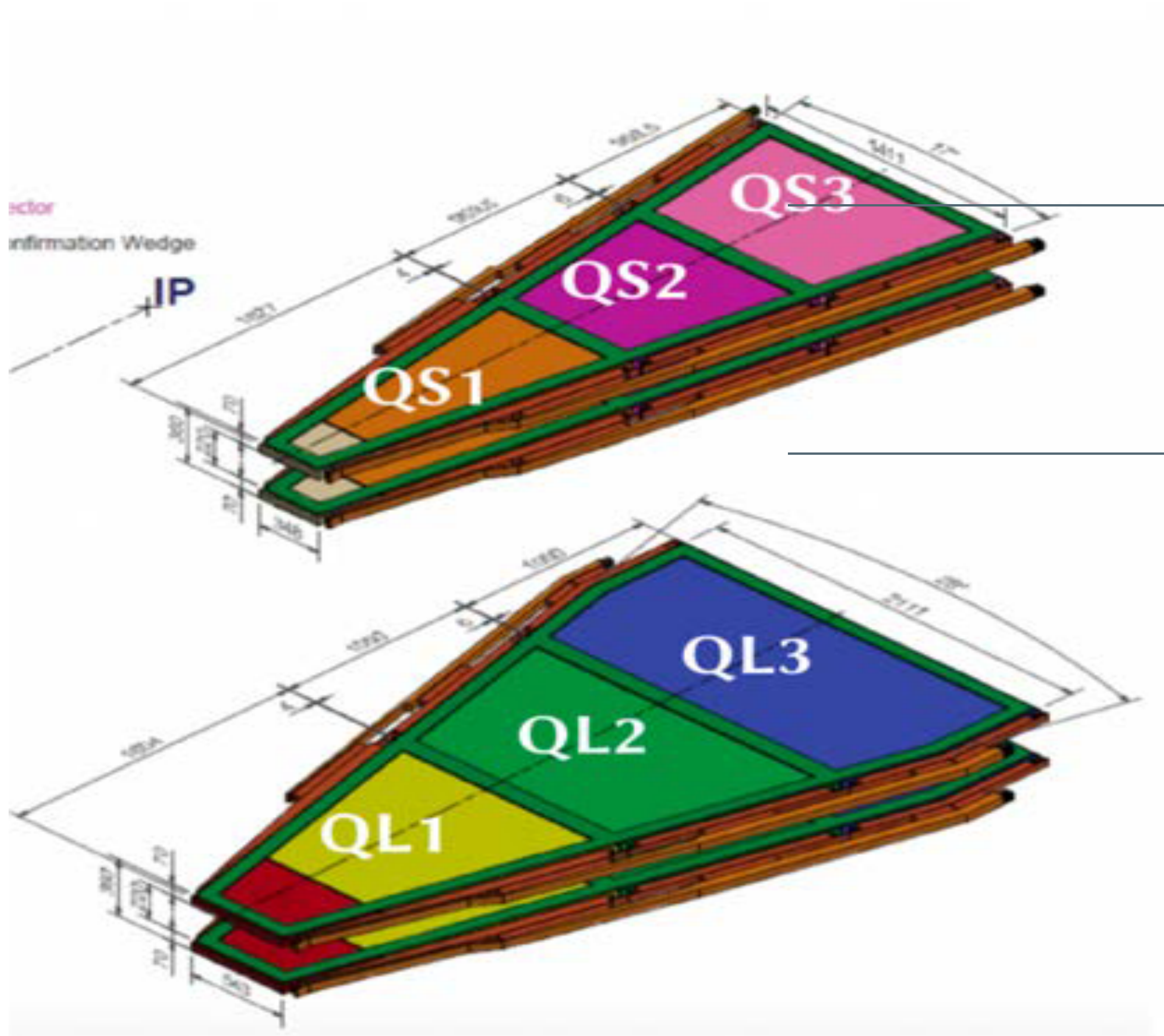
- Small strip pitch (~0.4 mm)
- Fast drift time (~100 ns)

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



sTGC Modules

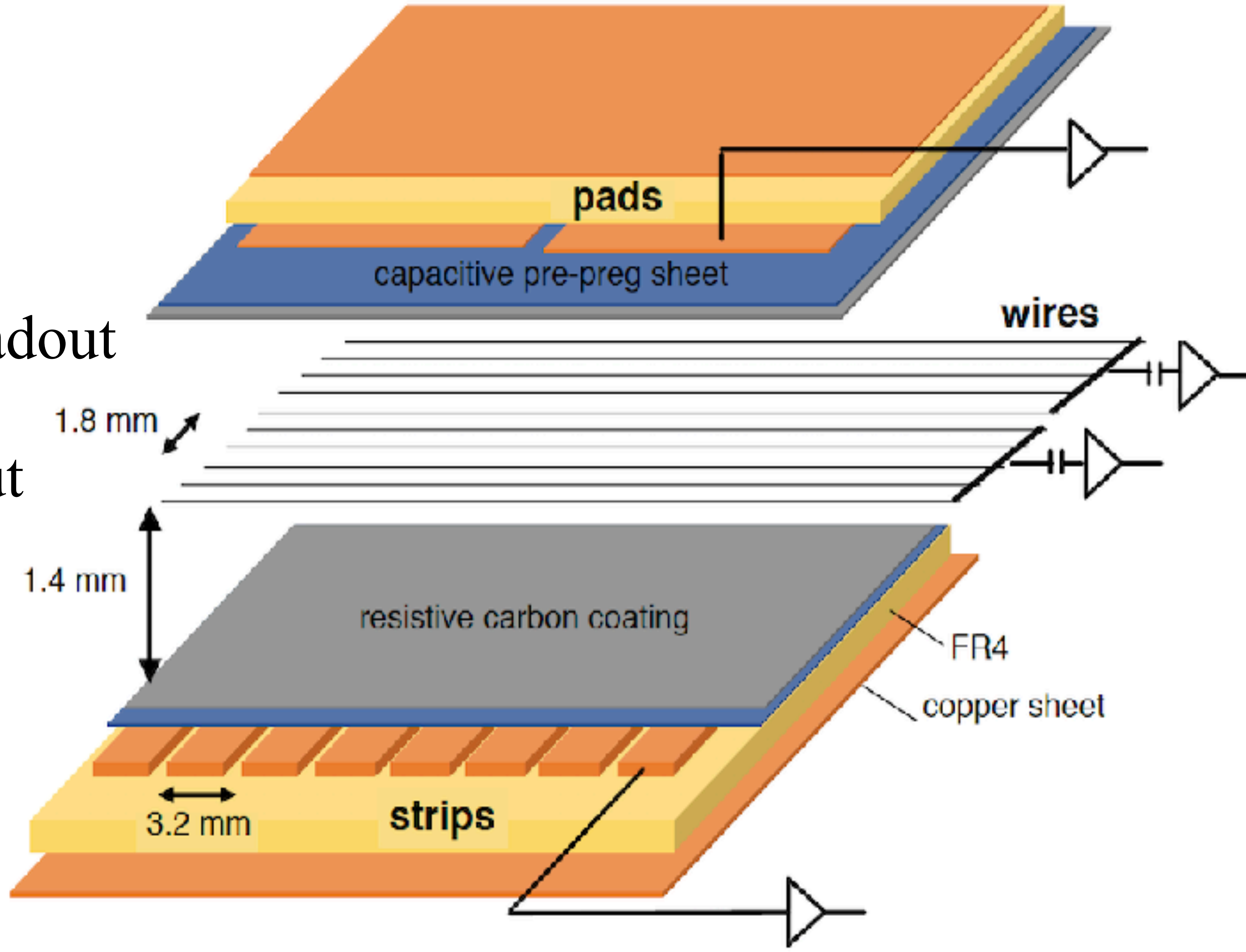
A Small-Strip Thin Gap Chamber (sTGC) is a multiwire proportional chamber operated in quasi-saturated mode. It is made up of 2 segmented cathodes and one plane of anode wires.

The sTGC chambers are operated with a gas mixture of CO2 and npentane vapour and at a voltage of 2.8 kV. Ionization products induce current on wires, pads and strips as **three readout channels:**

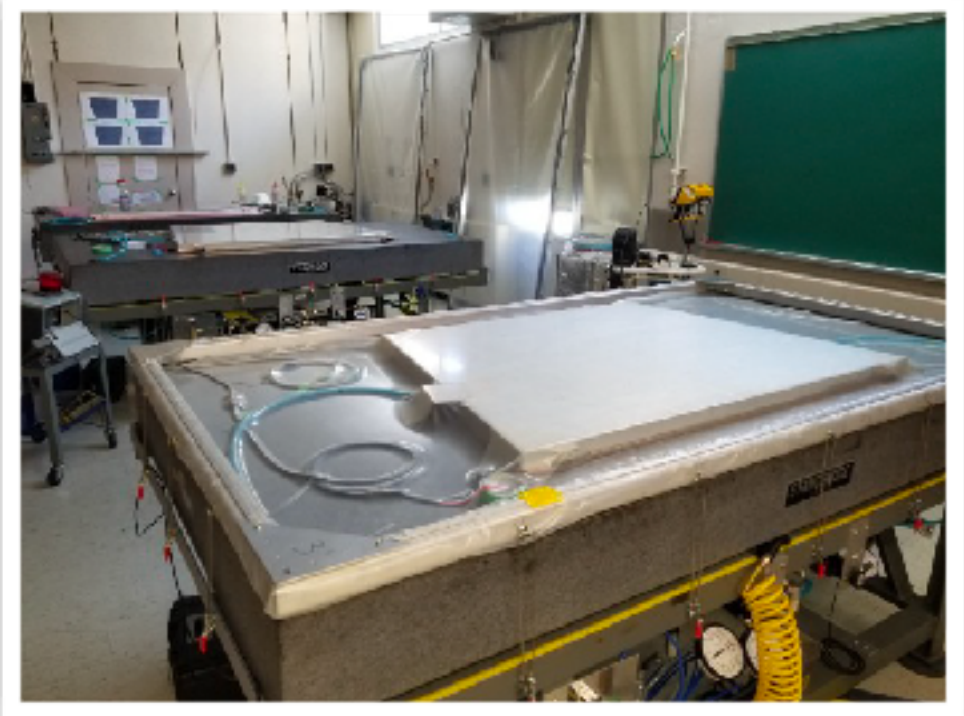
Wires: Coarse azimuthal muon coordinate

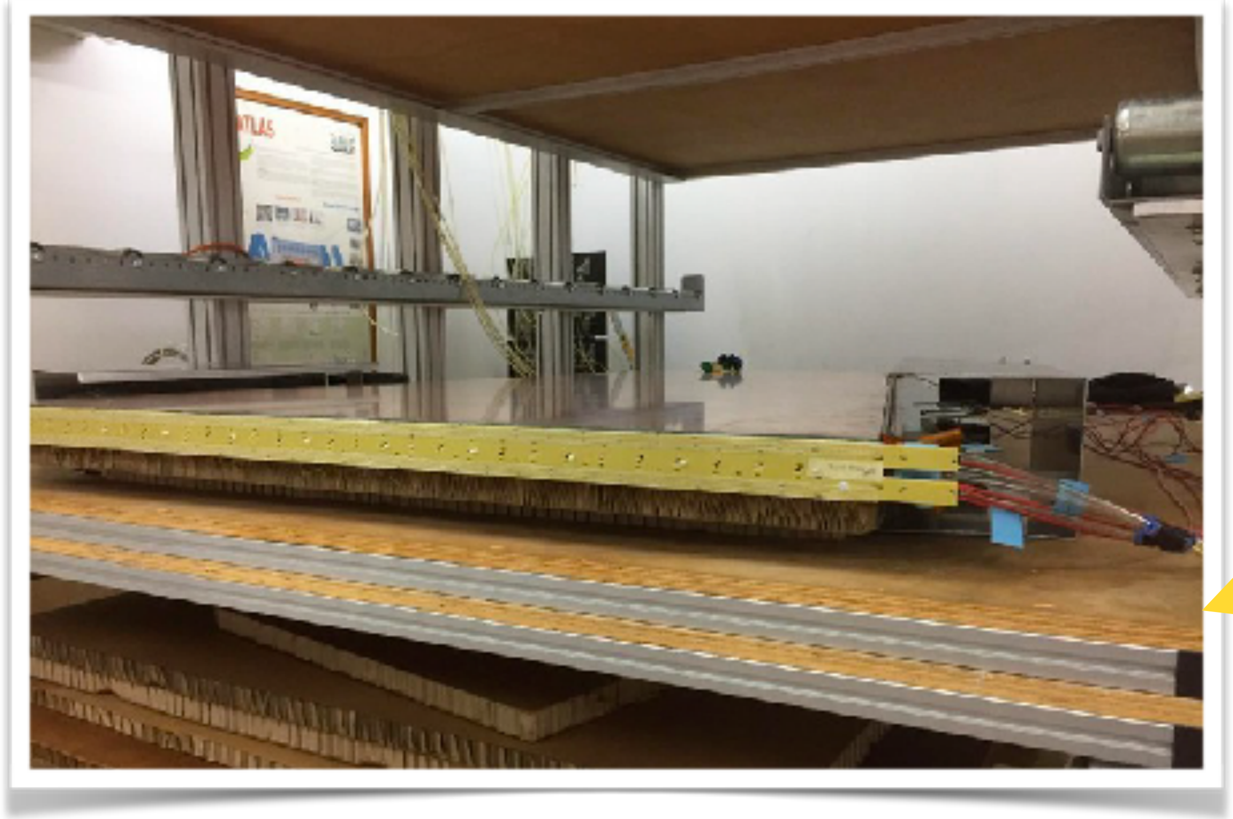
Strips: Precision muon track reconstruction and 1mrad angular resolution; analog readout

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

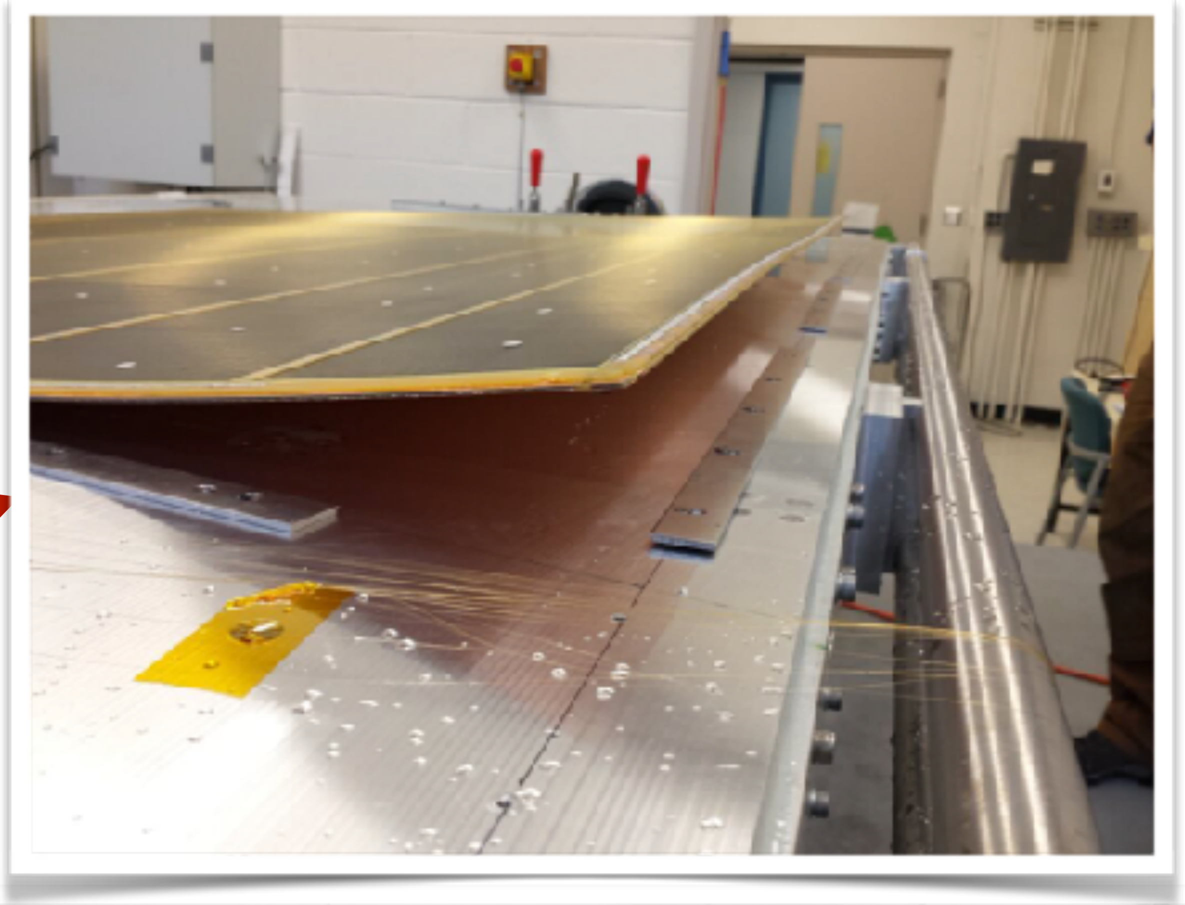


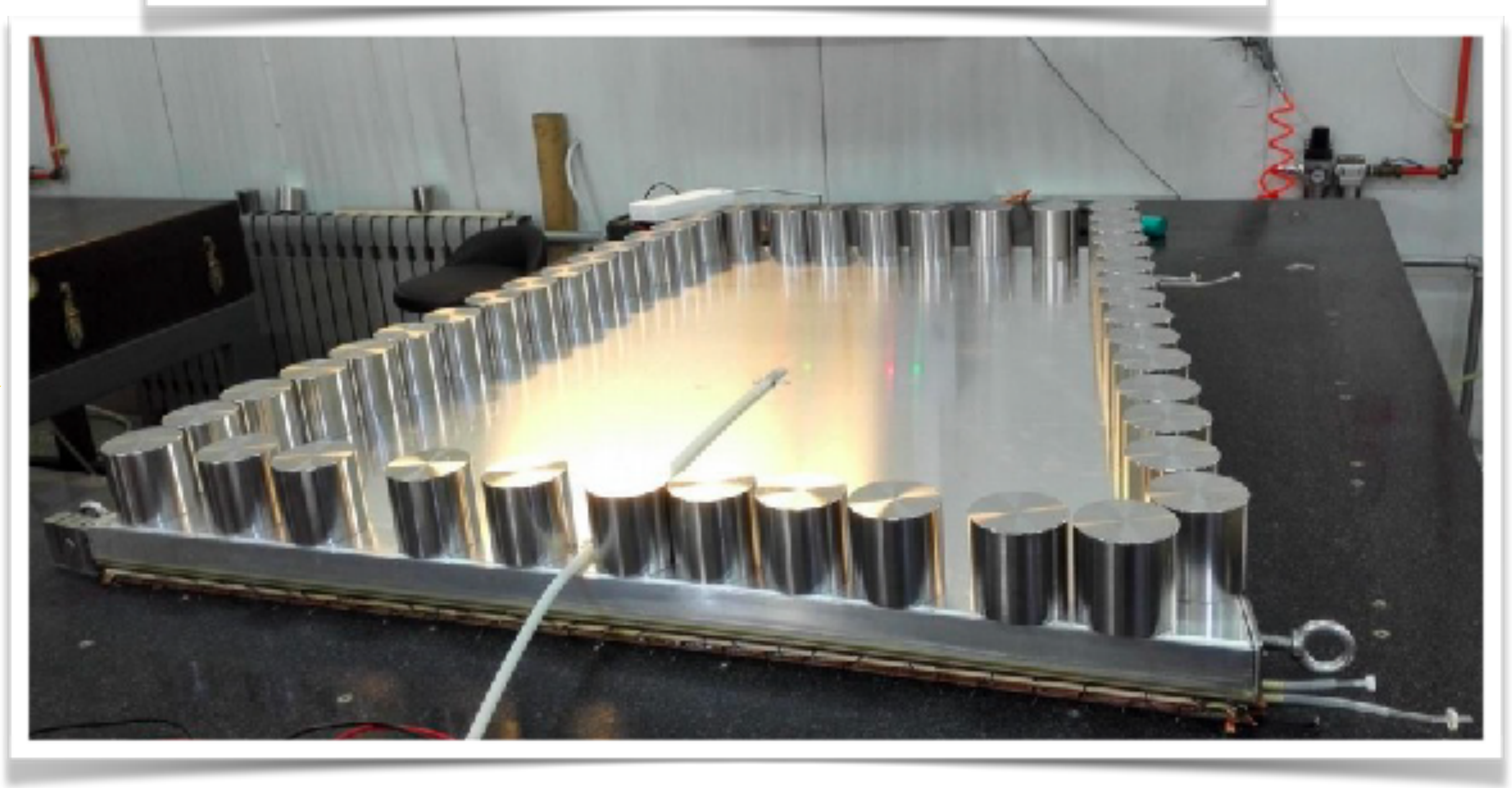
sTGC Construction





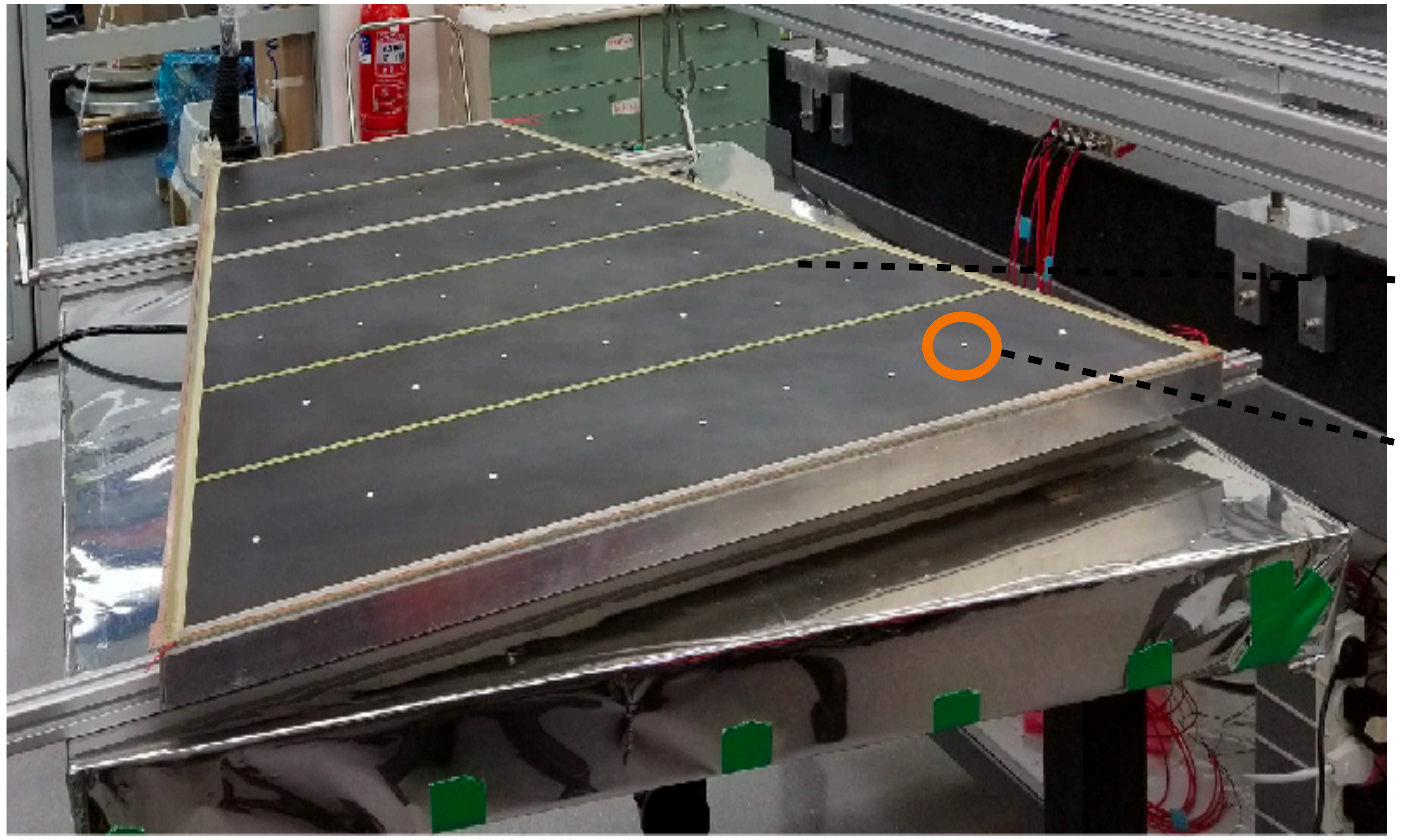
- Graphite spraying
- Half-gap production
- Wire winding of cathode boards
- Gap closing and testing
- Doublet assembling and testing
- Quadruplet assembling
- Cosmic-ray testing
- Wedge assembly

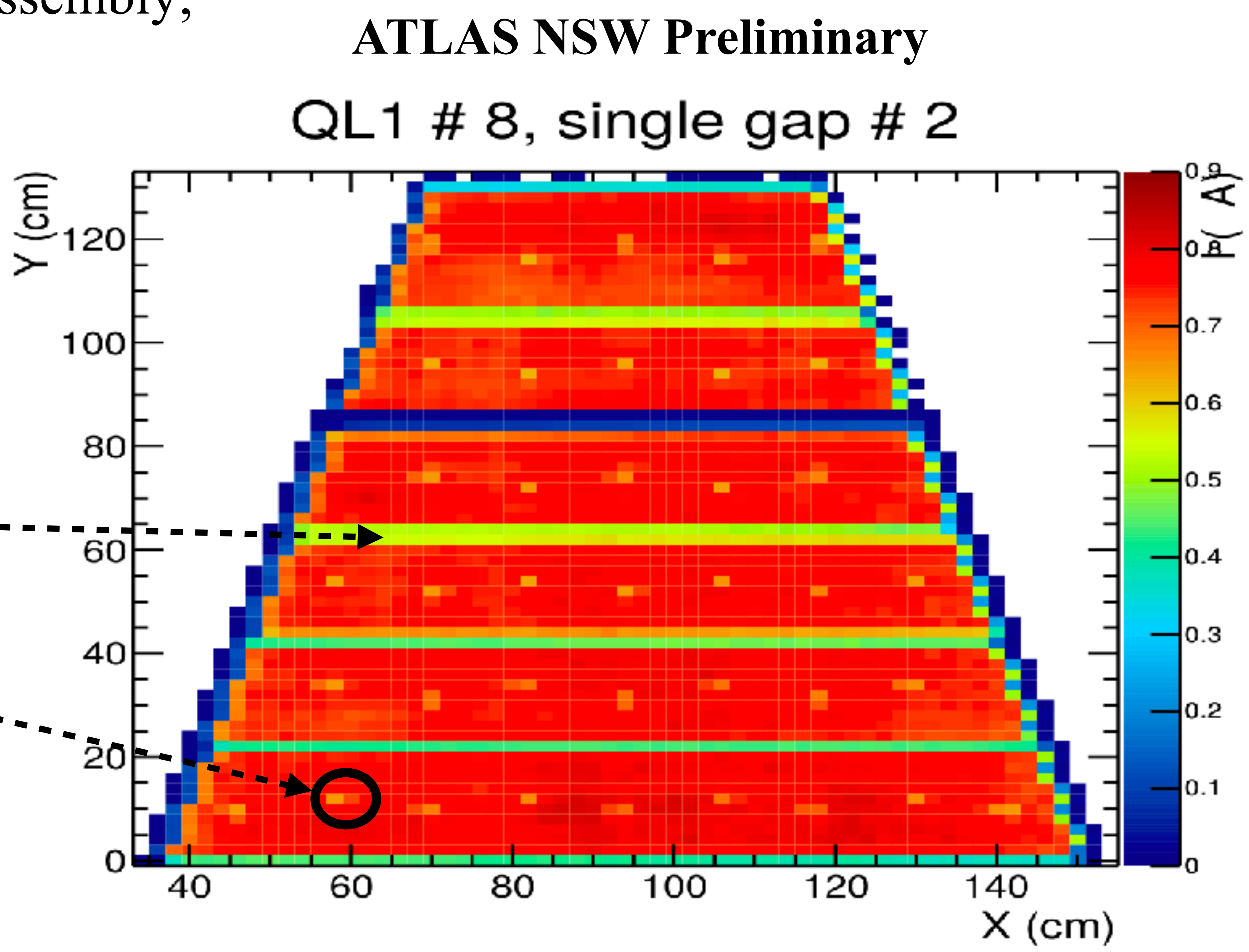




sTGC Quality Tests @ Construction Sites

- 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;



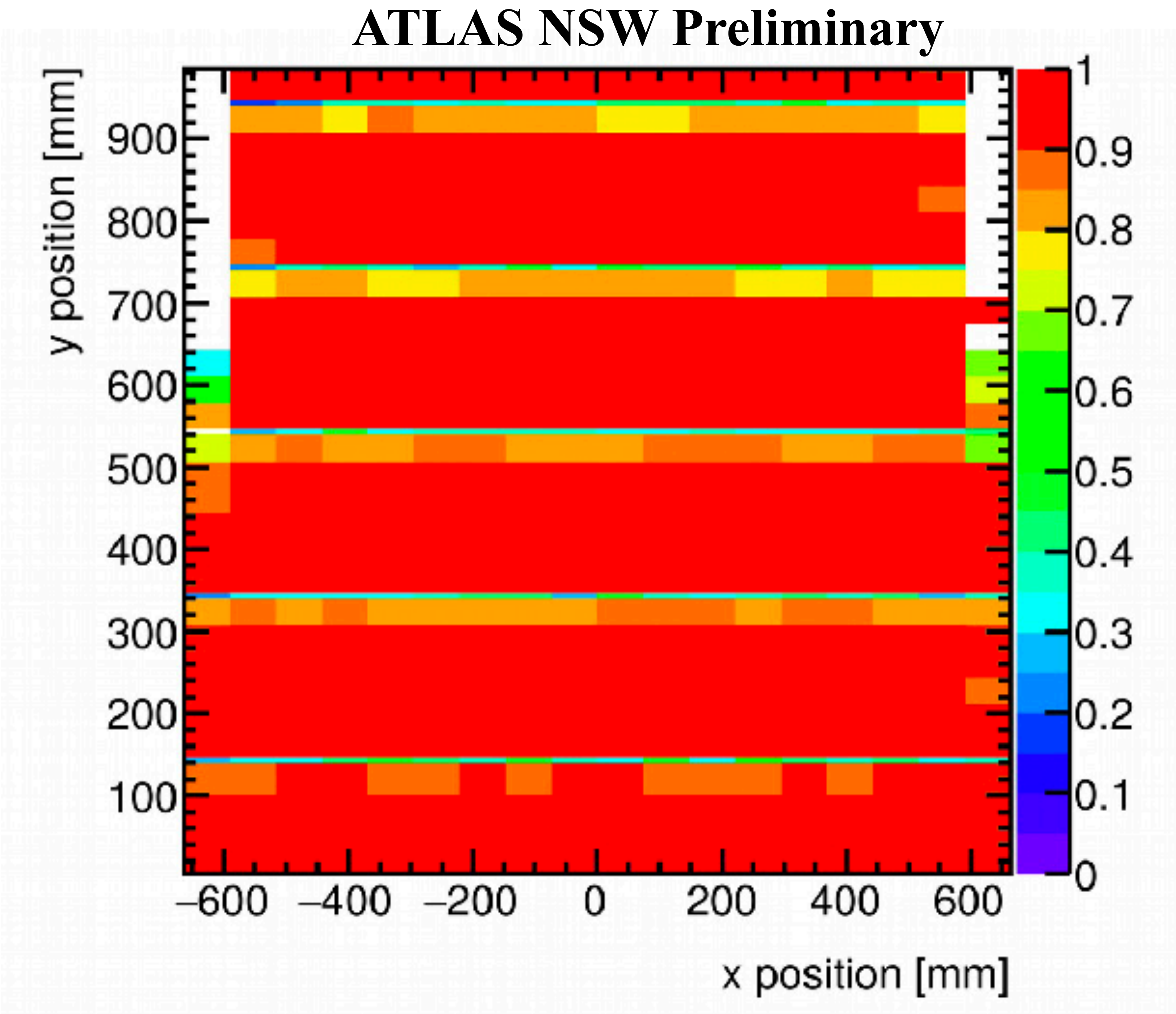


sTGC Cosmic Tests

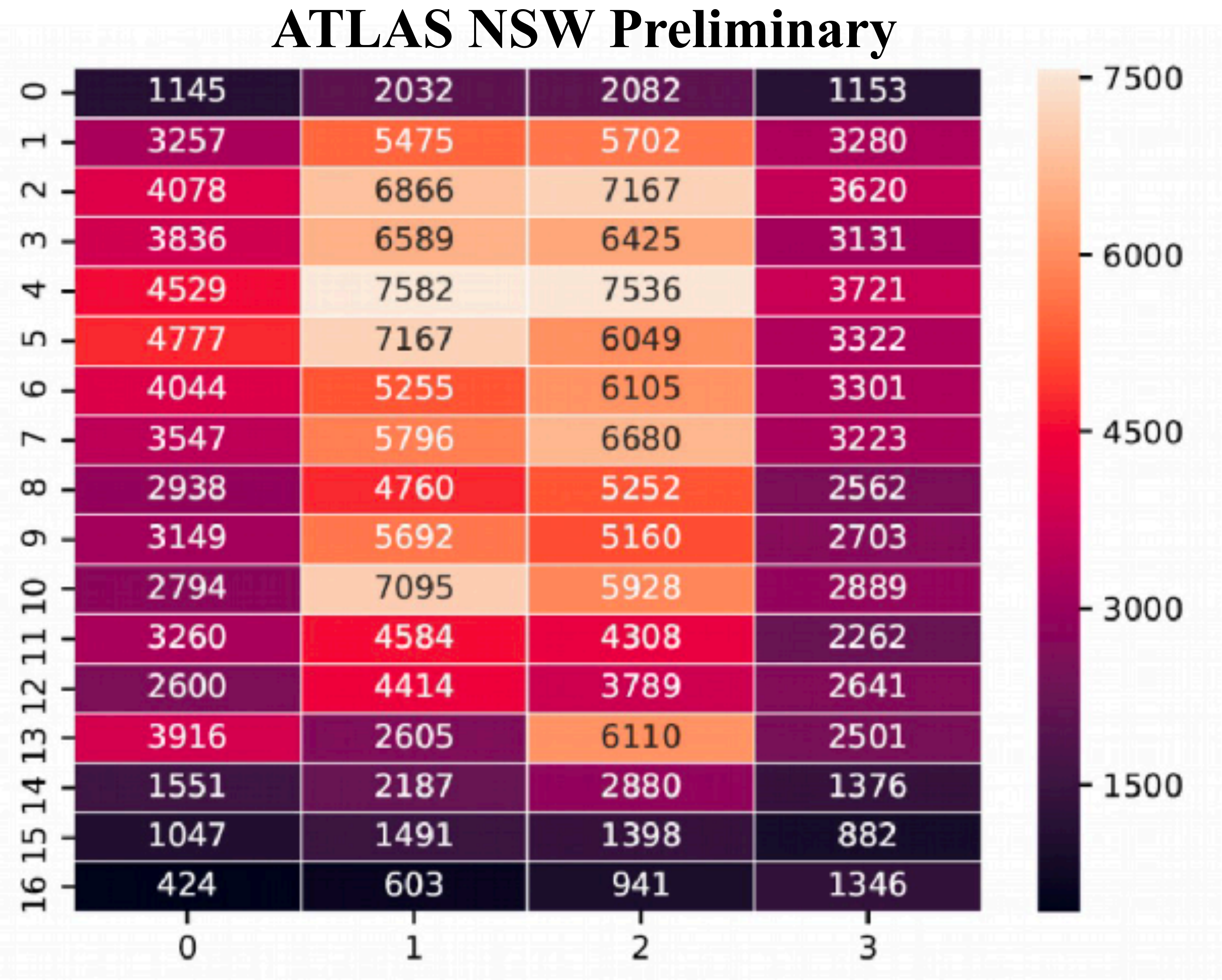
Carleton University ATLAS Experiment

Tests are conducted to check:

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



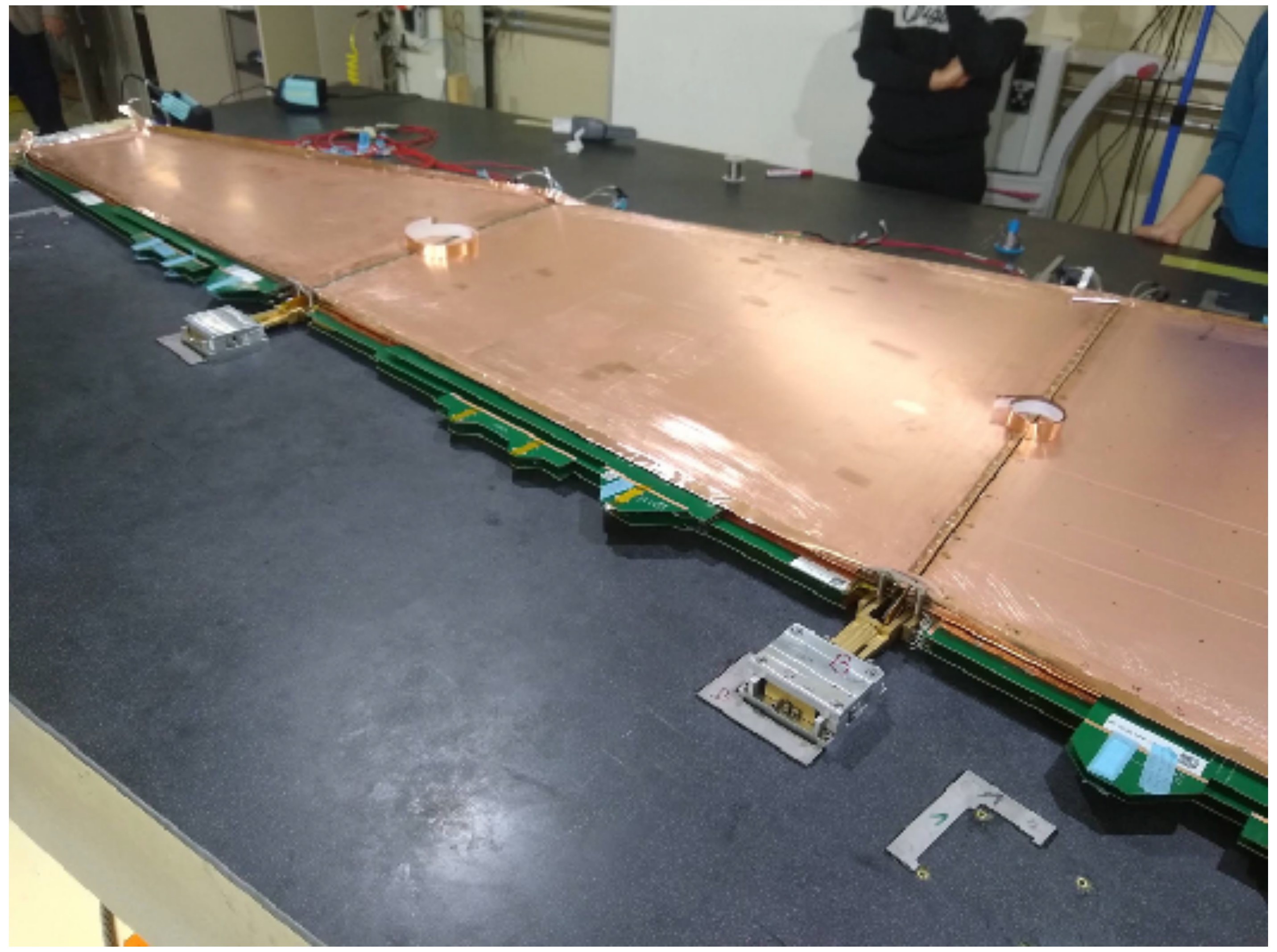
Preliminary 2D efficiency of strip channels of a QS3 gap



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

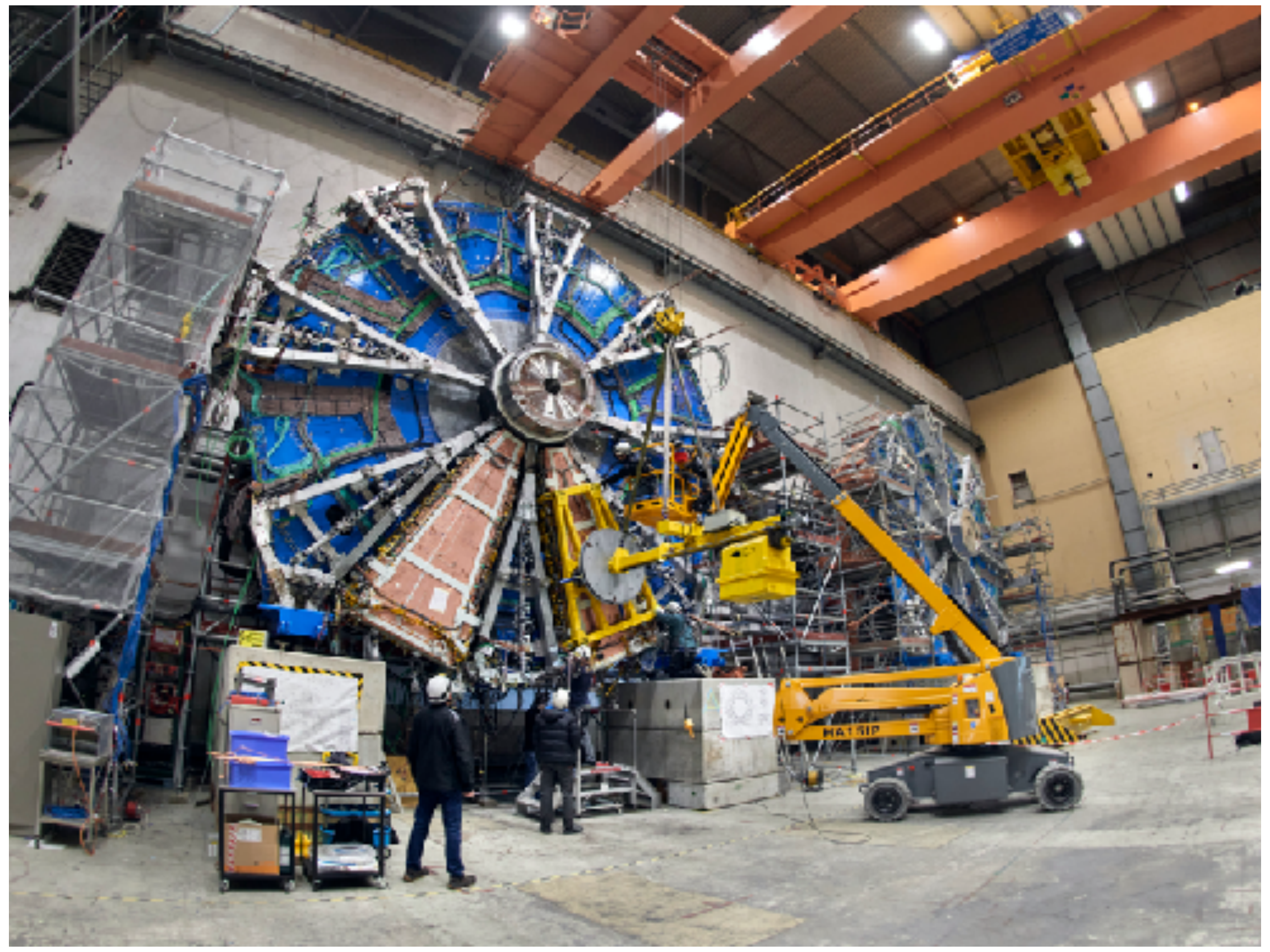
Wedge Assembly and Integration @ CERN

Gluing: 3 quads are assembled into wedges



Faraday cage assembly

Install the electronics and sector integration(sTGC and MM)

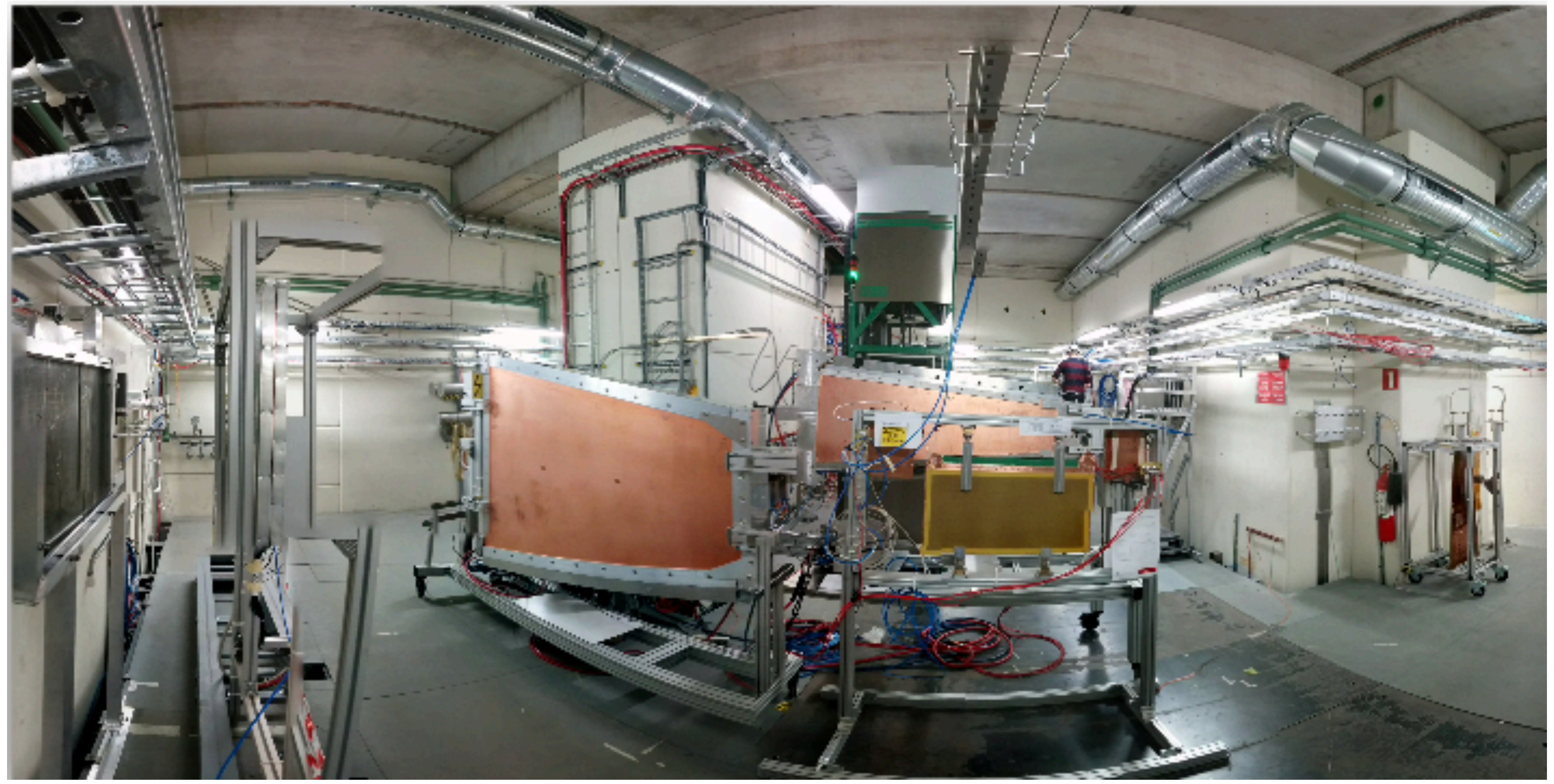


Integrate sTGC and MM into sectors and wheel assembly

Quality control carried out at every step of assembly:

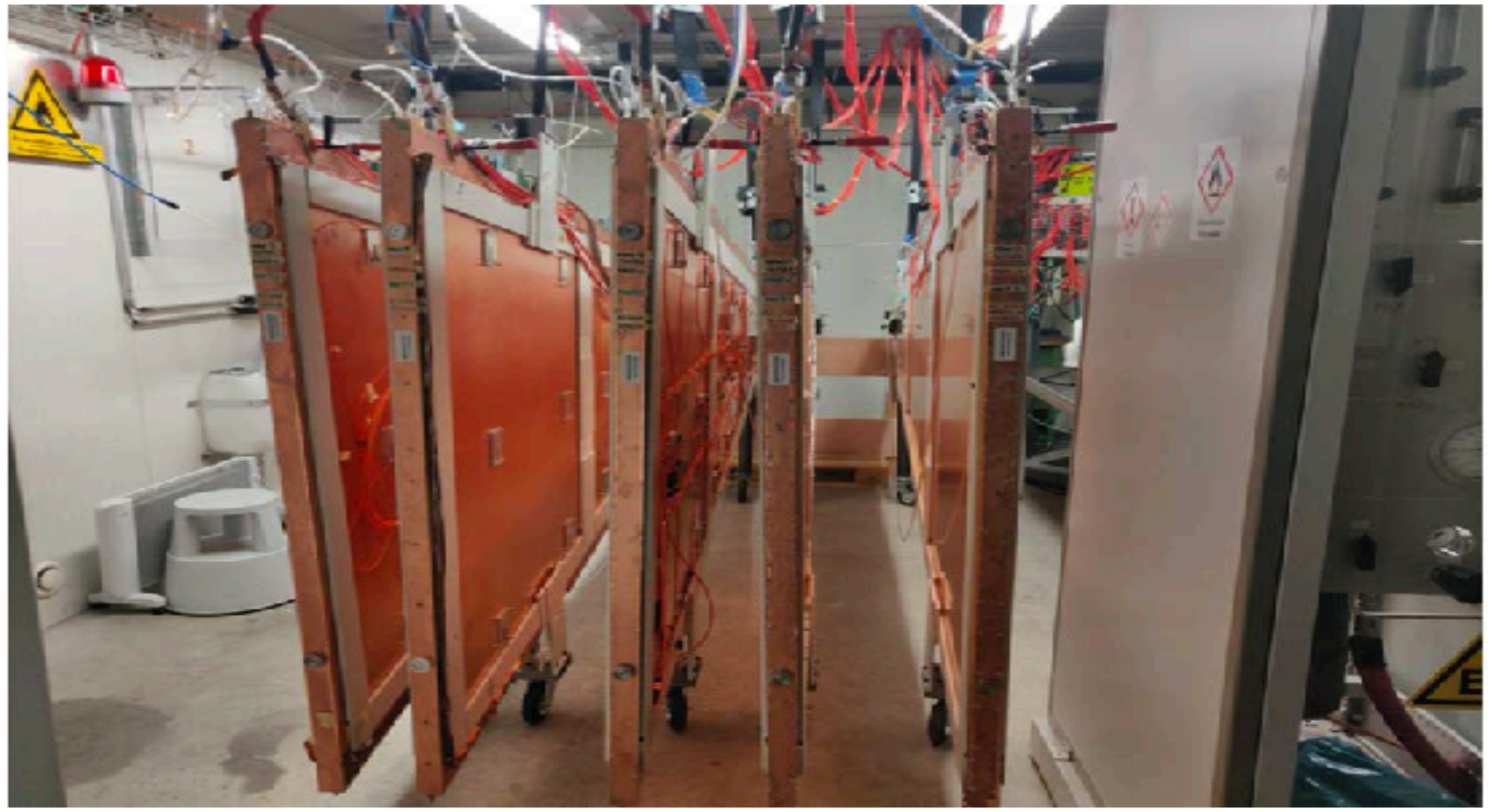
- Ensure no damage during shipment
- Readout connectivity test
- Stability test under high radiation with 20 kHz/cm^2 (at CERN; GIF++ facility)
- Noise measurements with integrated electronics(wedges)
- Long-term HV test(wedges)
- Measurement of misalignment using x-rays (wedges)

CERN GIF++ facility

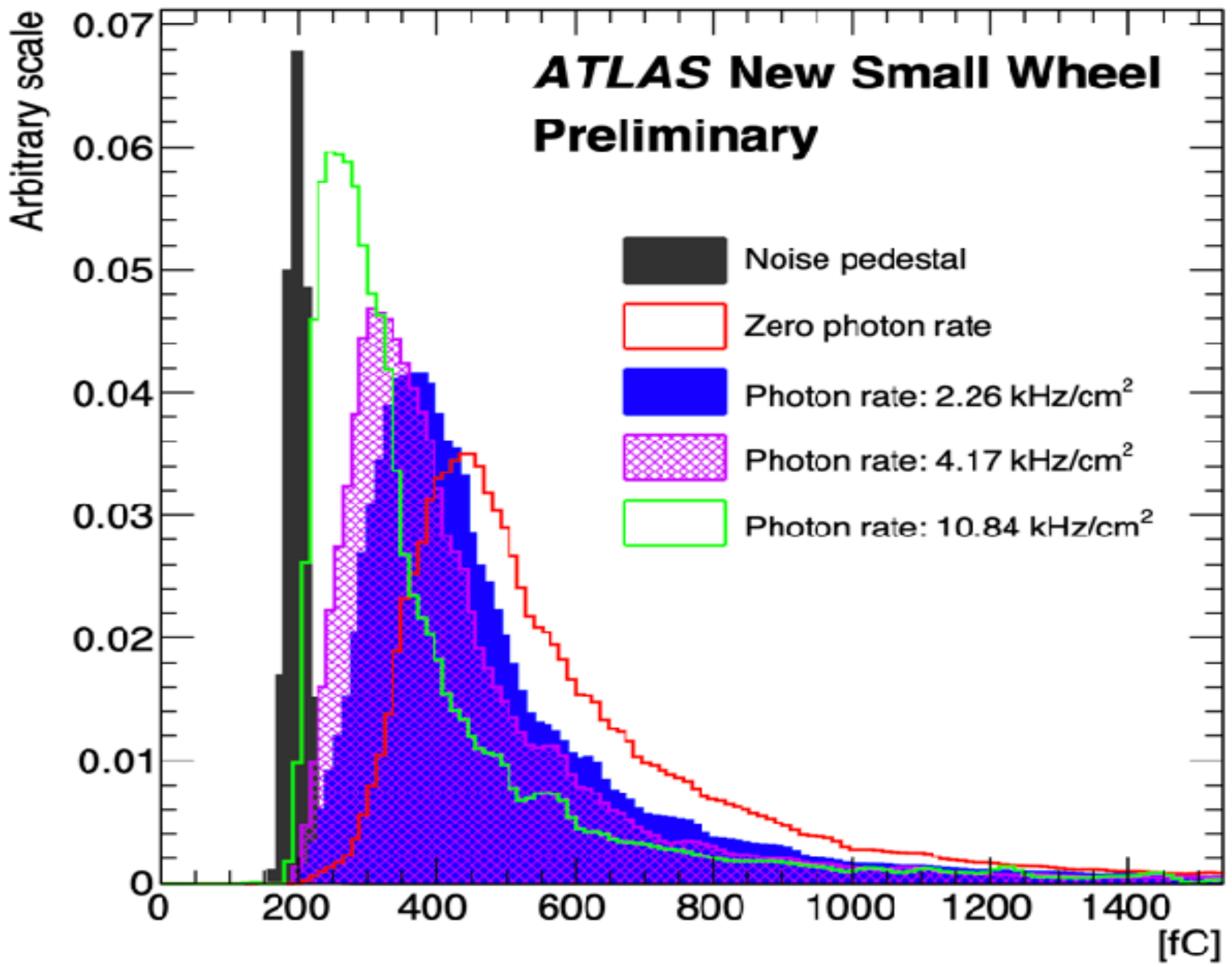


GIF++ operates with 137Cs source of 14 TBq that radiates gamma rays.

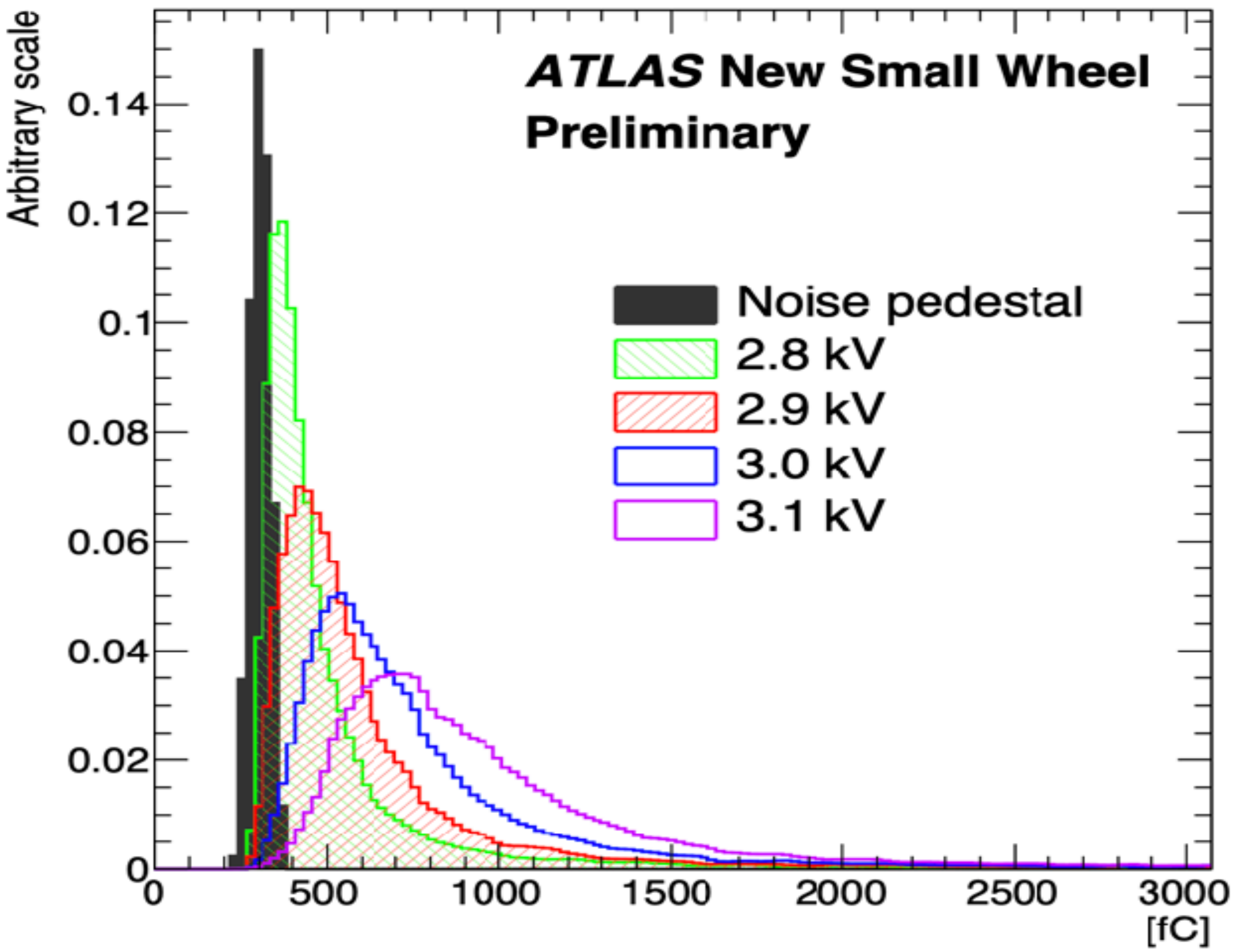
HV test @ CERN



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

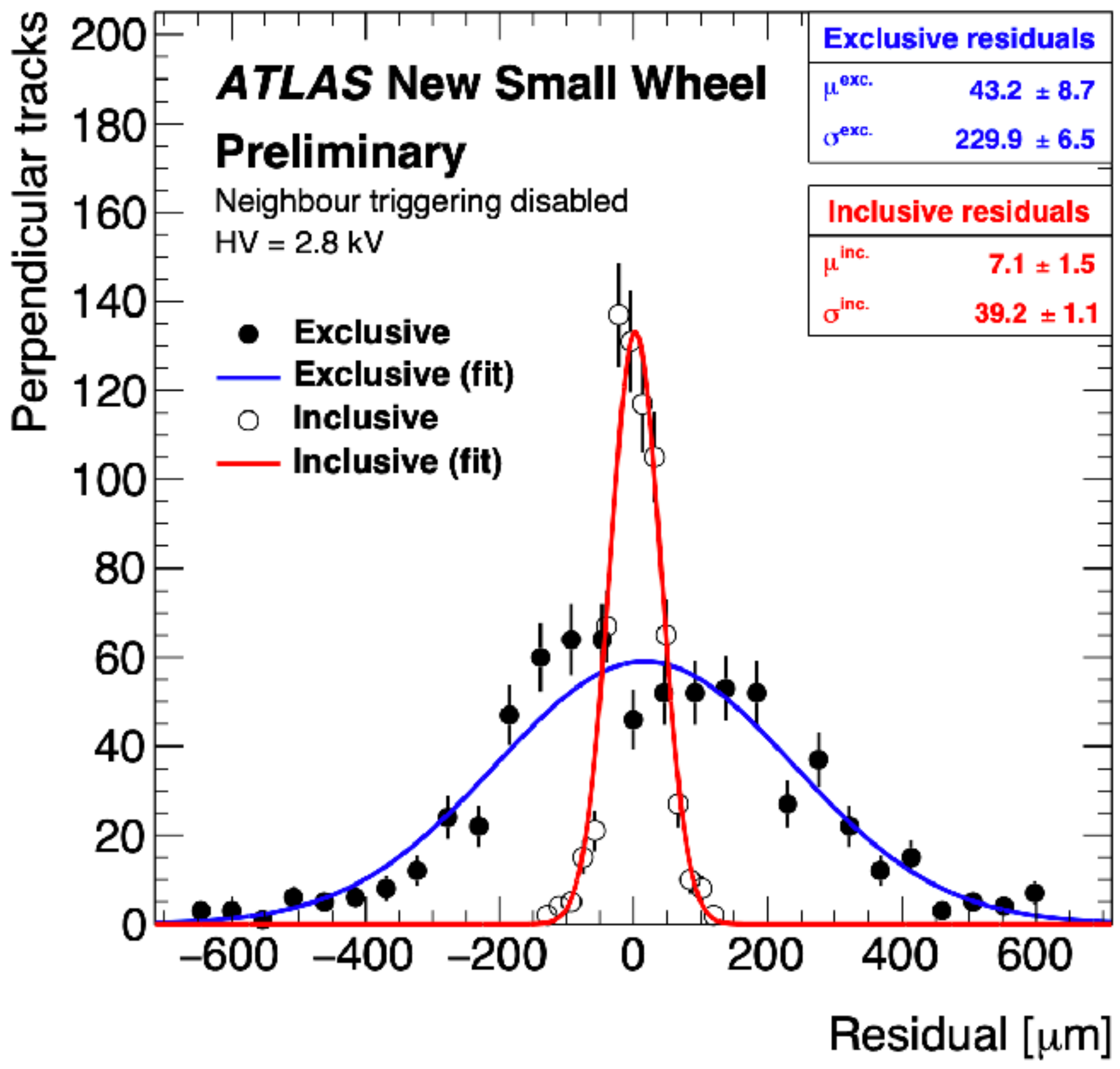


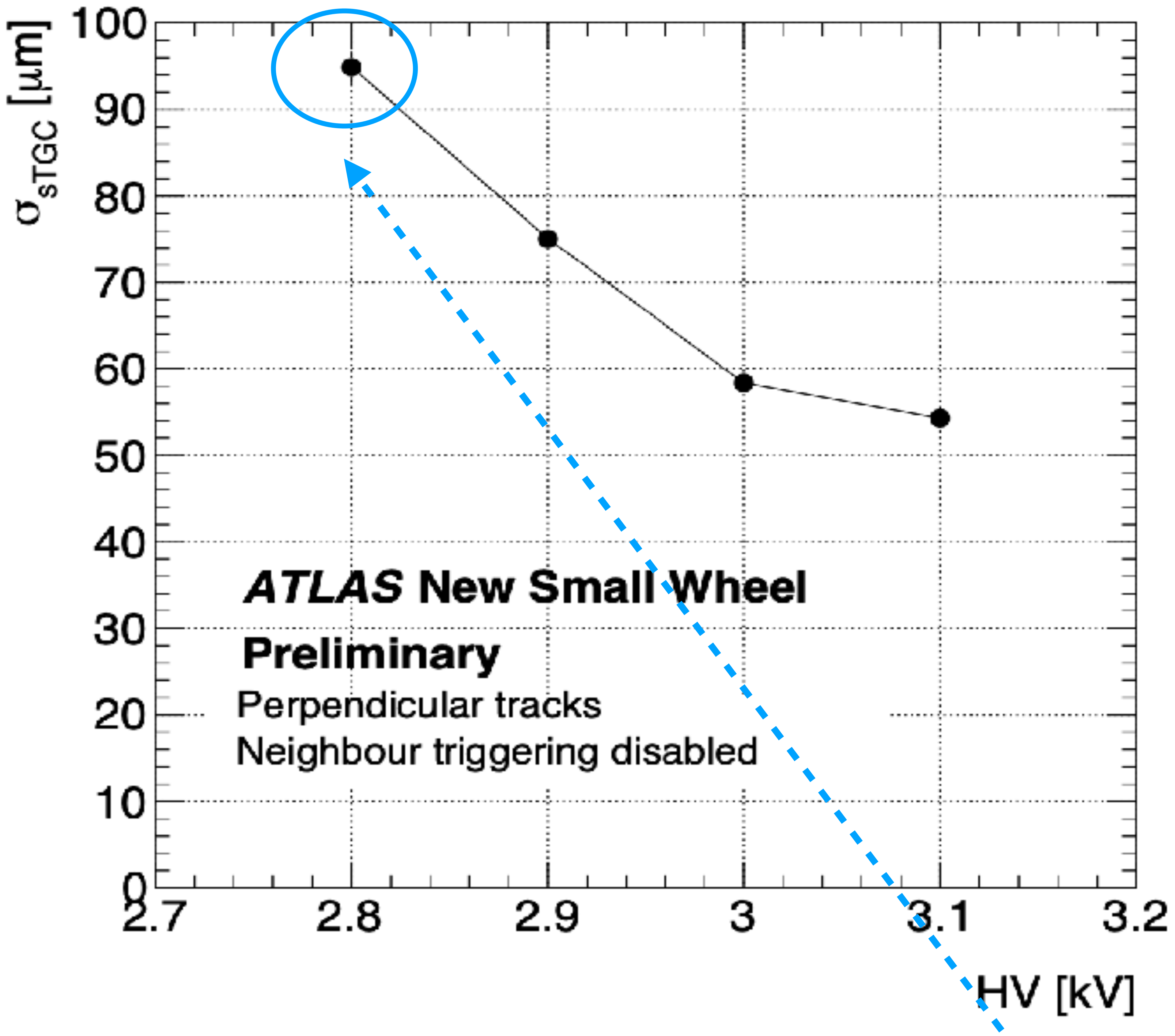
Test with muon beam
CERN H8 beam line with QS3



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

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





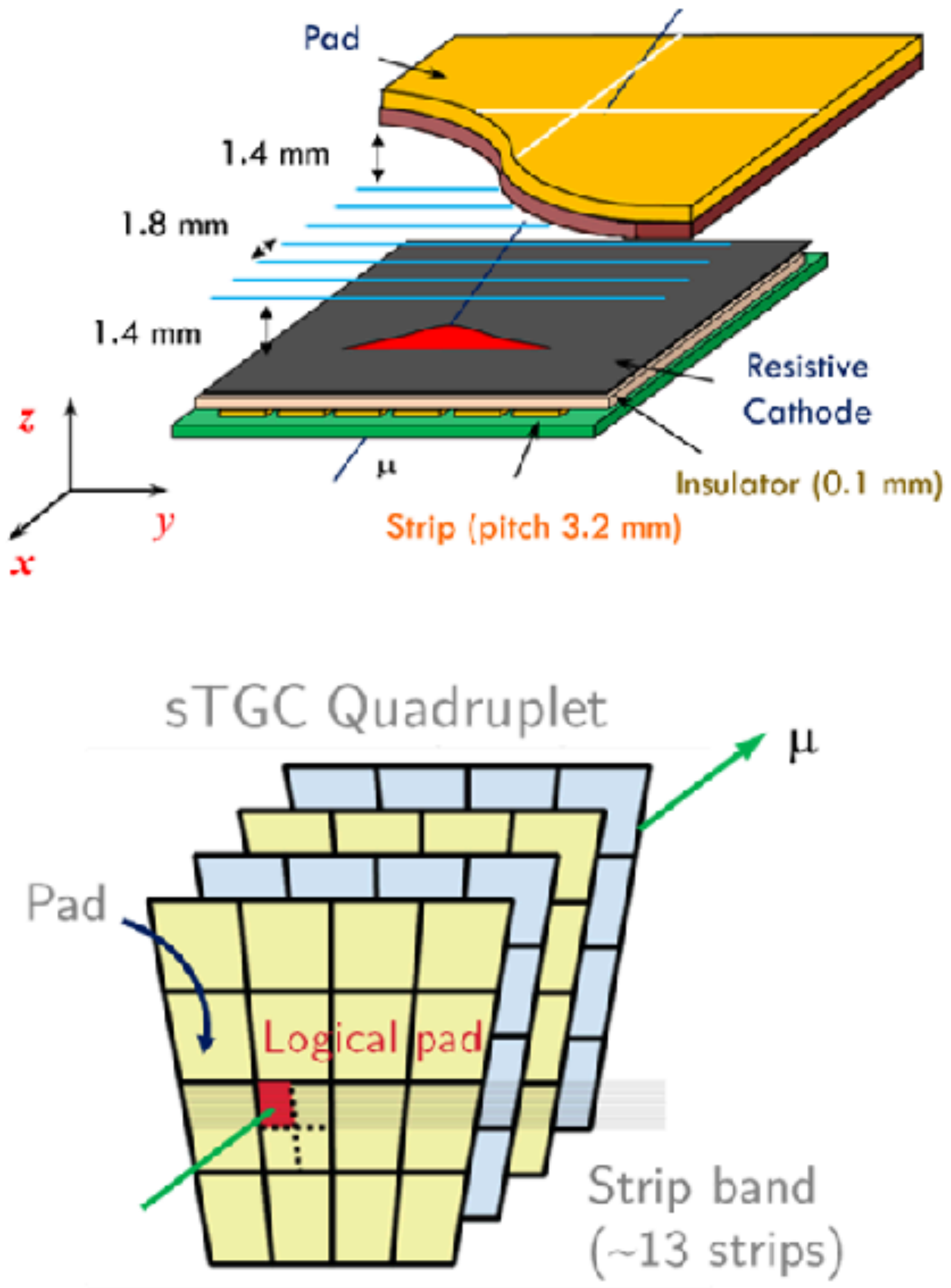
The strip spatial resolution is obtained from the distributions of the exclusive and inclusive residuals of the reconstructed tracks.

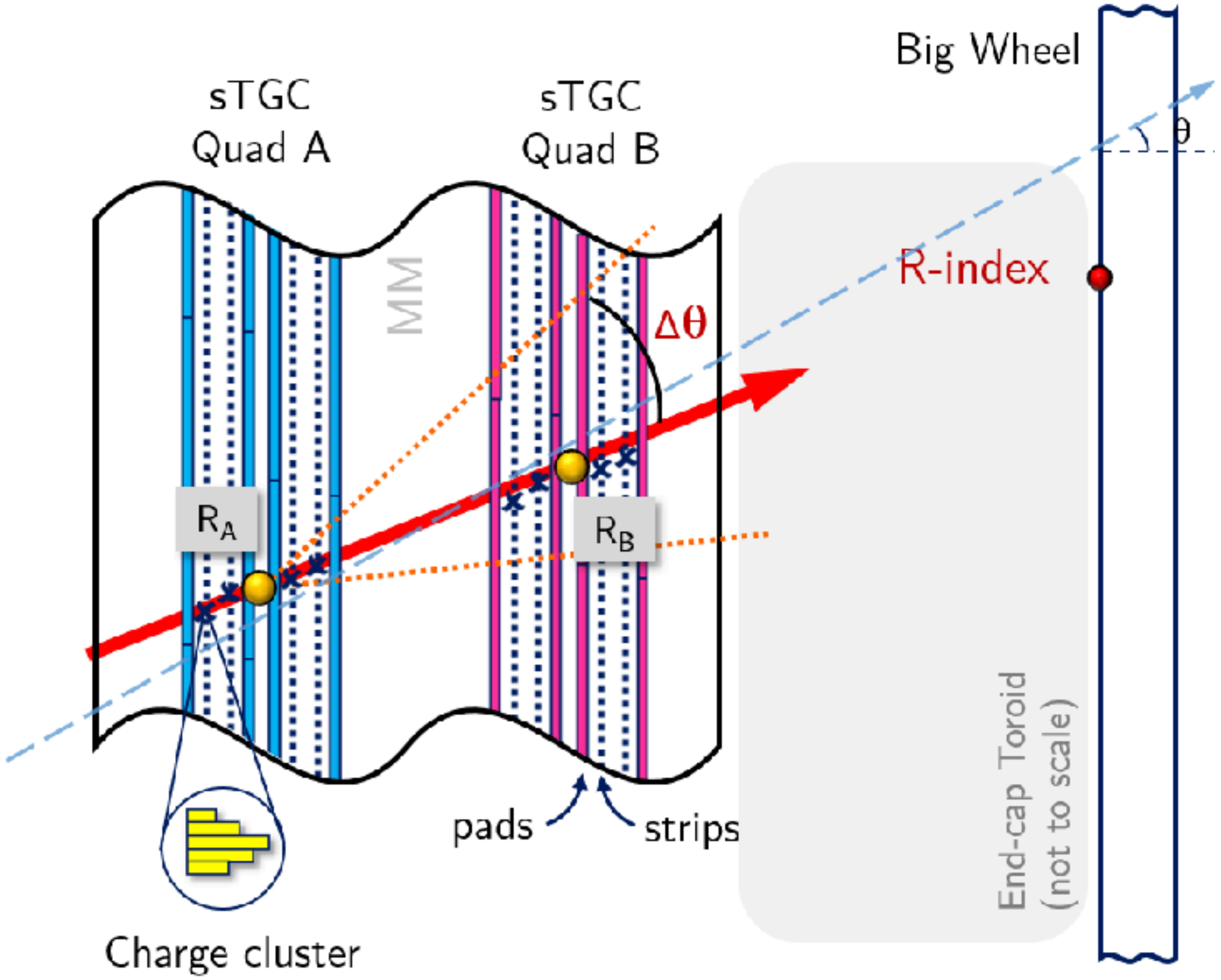
$$\sigma_{sTGC} = \sqrt{\sigma^{inc.} \times \sigma^{exc.}} = 95\mu m$$

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

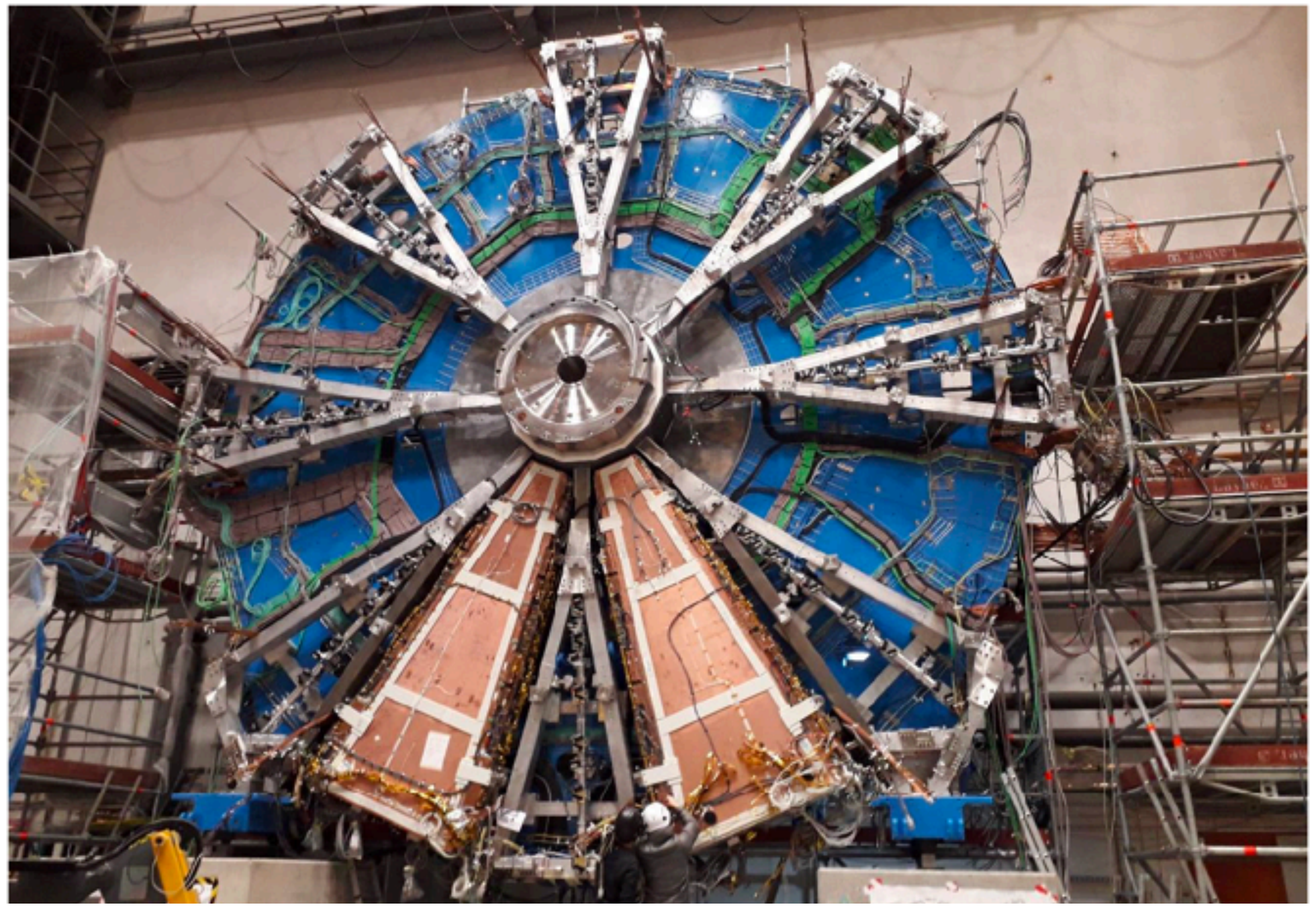
- Pad layers staggered to make “logical’ pad towers
- Muon trajectories define pad trigger towers
- 3 out of 4 layers with a hit required for single wedge trigger
- Final decision based on geometrical matching between the two wedge triggers
- Strips from both sTGC wedges and MM hits used for online track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





Summary

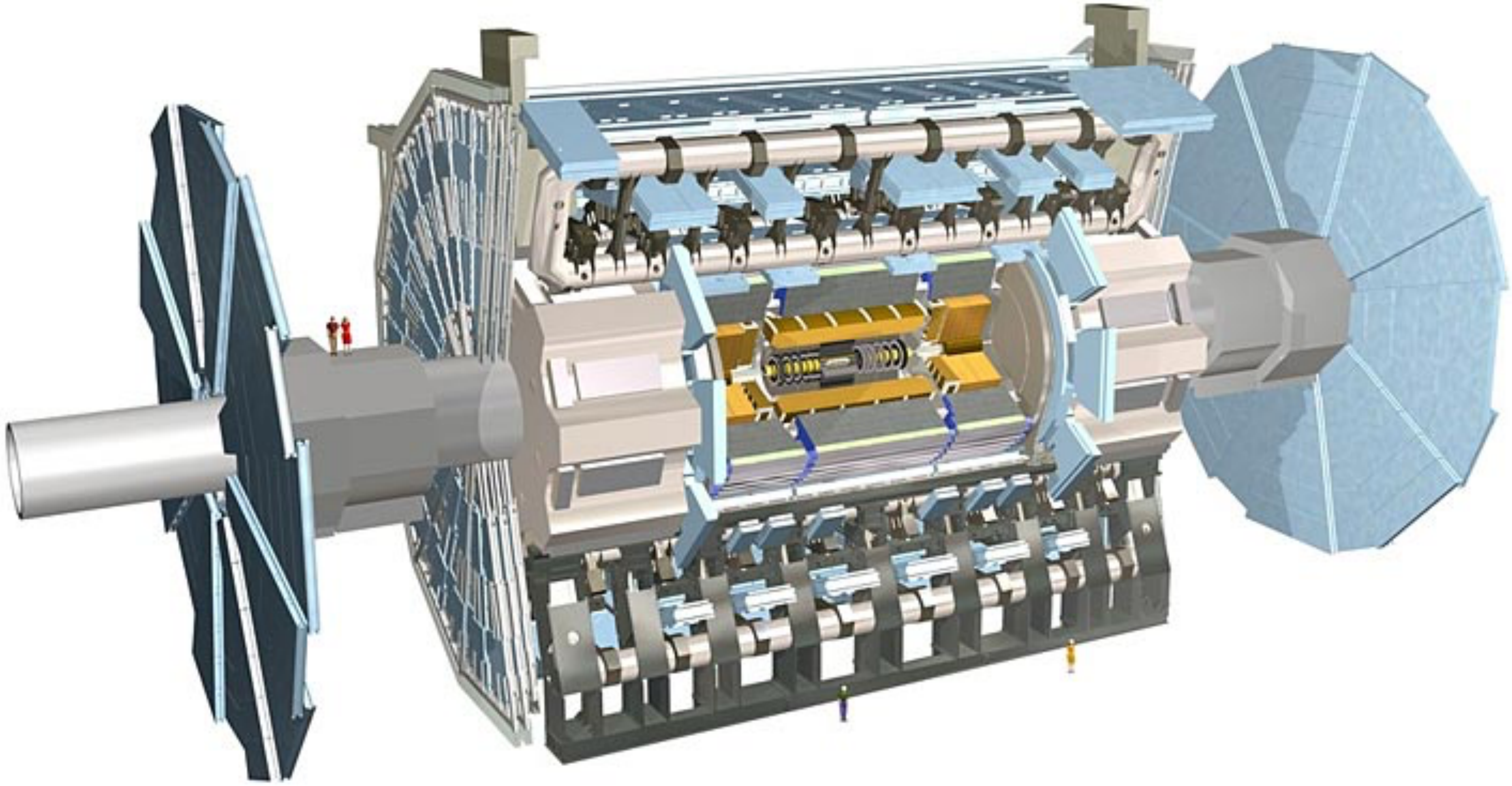
- The NSW is essential for ATLAS to maintain high trigger efficiency and momentum resolution in the high pile-up and high radiation environment expected during high luminosity phase of the HL-LHC.
- The installation of front-end electronics on the wedges is going well.
- Test beam and irradiation tests are done for the NSW electronics.
- Electronics performance is in really good shape.
- sTGC quadruplet production is underway at all construction sites.
  - It is complete for side A and well under way for side C.
- Integration at CERN is progressing with chambers and electronics:
  - 4 small sTGC wedges completed with electronics.
  - Sector 12 and 14 installed.
  - NSW-A small sector installation has resumed in July.
  - All NSW-A large wedges have to be ready to install in sectors by end of January 2021.
  - NSW-C has to be complete by October 1, 2021.



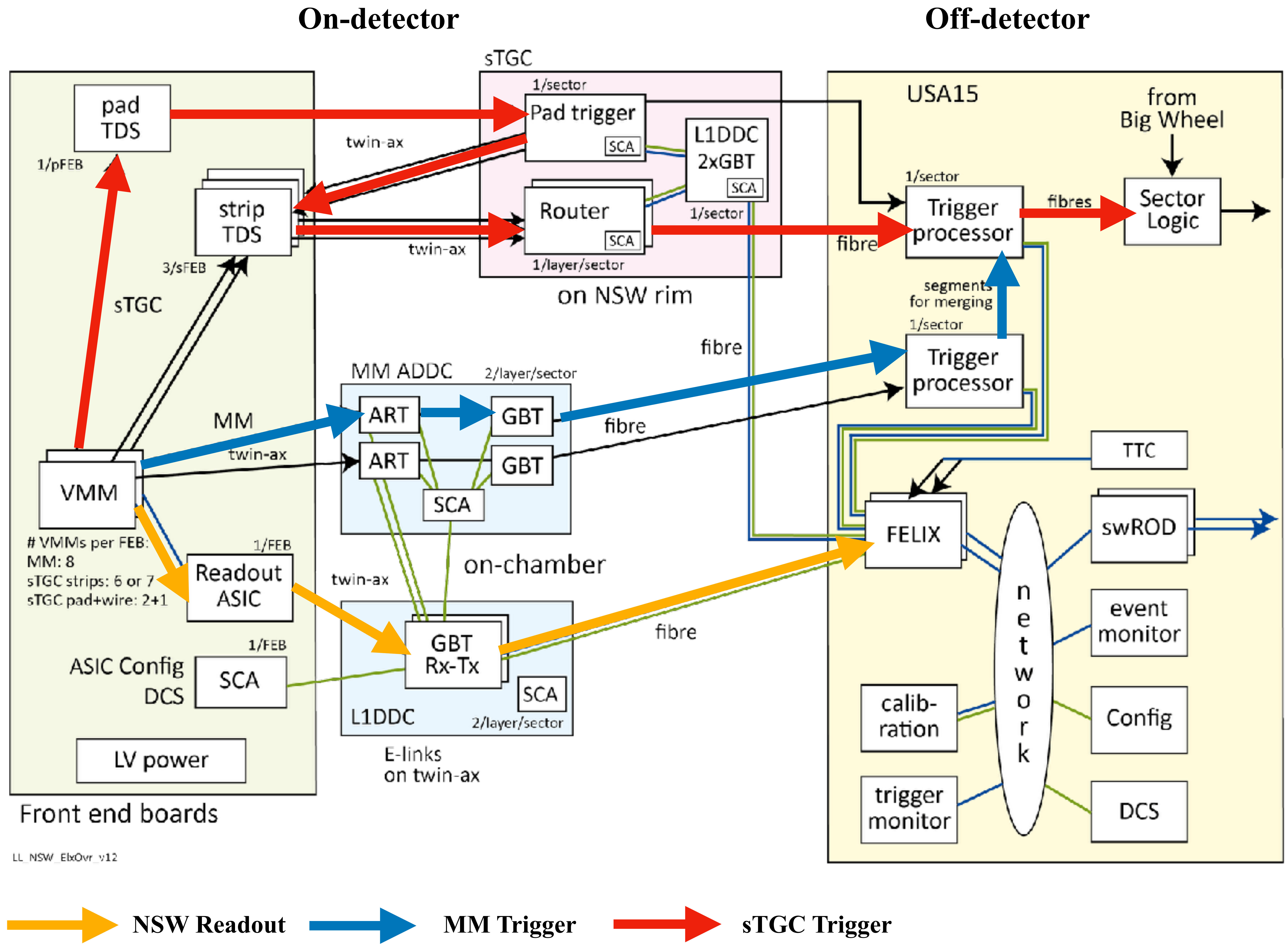
NSW-A with 2 small sectors installed


Thank you for listening!

Back-up Slides



NSW Electronics & DAQ Data Flow



Latency from IP to SL limited to 1075 ns

PCBs:
pFEB/sFEB(sTGCpad/strip front-end board)
MMFE8(Micromegasfront-end board)
L1DDC(Level-1 Data Drive Card)
Pad Trigger
Router
ADDC
FELIX(Front-End LInkeXchange)
Trigger Processor

Radiation tolerant ASICs:
VMM (amplifier, shaper, digitizer)
Readout ASIC
Trigger Data Serialiser(TDS)
Address Real Time (ART)
Slow Control Adapter (SCA)
GigaBitTransceiver (GBTX)

sTGC Performance