ATLAS Operation and Upgrade

Davide Cieri (MPP) on behalf of the MPP ATLAS Group

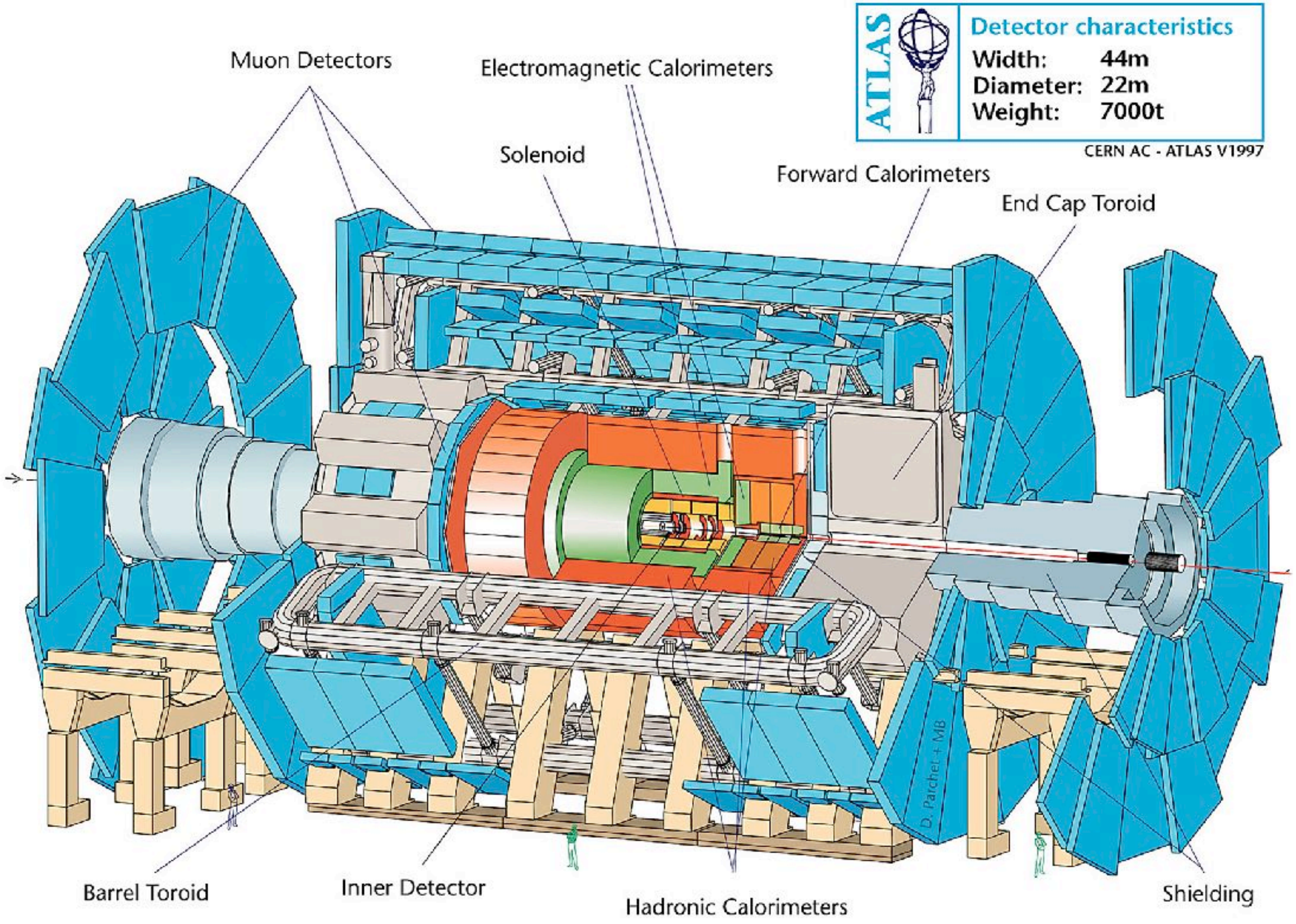
14. December 2020 - MPP Project Review

ATLAS EXPERIMENT

MAX-PLANCK-INSTITUT FÜR PHYSIK

ATLAS: A Toroidal LHC ApparatuS

- Largest general-purpose particle physics detector
- ~3000 scientists from 181 institutions around the world
- MPP plays a major role in the operation and HL-LHC upgrade of the experiment
  - Radiation backgrounds
  - Inner tracker (ITk)
  - Liquid argon calorimeters (LAr)
  - Muon Detectors
  - Computing



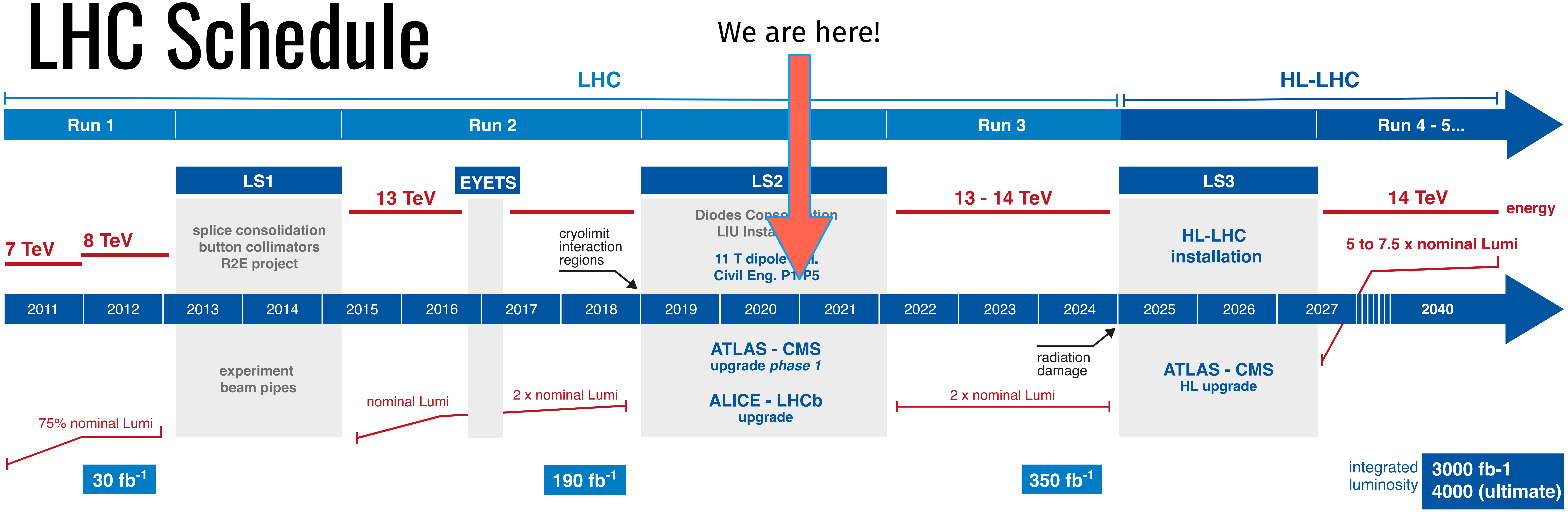
MPP ATLAS Group and contributing technical department

- Siggi Bethke (Director)
- Teresa Barillari (Deputy Team Leader)
- Muon Spectrometer:
  - Seniors:
    - Oliver Kortner
    - Sandra Kortner (independent PL)
    - Hubert Kroha (PL)
    - Robert Richter
  - Post-docs:
    - Davide Cieri
    - Dominik Duda
    - Michael Holzbock
    - Johannes Junggeburth
    - Patrick Rieck
    - Elena Voevodina
    - Verena Walbrecht
  - PhD students
    - Philipp Gadow
    - Andreas Hoenle
    - Marian Rendel
    - Stefan Maschek
    - Korbinian Schmidt-Sommerfeld
  - Master students
    - Simon Grewe, Gregor Eberwein, Daniel Prelipcean (CERN)
  - Bachelor students:
    - Thomas Baier, Chiara Brandenstein, Patrick Bongratz, Andreas Grasser, Inken Gruener, Philipp Haas, Lisa Hofbauer, Aeneas Leingaertner-Goth, Daniel Ortmann, Timur Turkovic, Christian Ventura
  - Engineers
    - Sergey Abovyan, Varuzhan Danielyan, Daniel Soyk, Joerg Zimmermann
  - Technicians:
    - Lea Schafroth, 3 technicians from IHEP Protvino
  - Work student:
    - Simeon Simeonov
- Calorimeters:
  - Seniors:
    - Sven Menke (PL)
    - Teresa Barillari
    - Andrey Kiryunin
    - Peter Schacht
  - Post-docs:
    - Tom McCarthy
    - Margherita Spalla
  - PhD students:
    - Nina Wenke
  - Engineers:
    - Ulrich Leis
- Inner Tracker:
  - Seniors:
    - Richard Nisius (PL)
  - Post-docs:
    - Francesco Guescini
    - Javier Jiménez Peña
    - Merve Şahinsoy Karacasu
  - Phd students
    - Šejla Hadžić
  - Work students:
    - Nicolas Barón Pérez
    - Abishek Chikkaballi Ramalingegowda
- Computing:
  - Seniors:
    - Stefan Kluth (PL)
    - Stefan Stonjek
    - Cesare Delle Fratte
    - Sergio Tafula
    - Andrii Verbytskyi
  - Post-docs:
    - Daniel Britzger
  - PhD students
    - Fabian Klimpel (CERN)
  - Master students:
    - Johannes Hessler
- Technical Department:
  - Engineers:
    - Markus Fras, Jörg Habring, Thomas Haubold, Sergey Podkladkin, Markus Stadler, Sven Vogt, Yazhou Zhao
  - Mechanical Department:
    - Thomas Brunner, Quirin Fischl, Annika Lange, Markus Lippert (CERN), Martin Nonnemann, Carina Schlammer, Enrico Töpper, Paul Vanoni, Marco Wehrmeister, Alexander Wimmer
  - Electrical Department:
    - Alexander Fischer, Vincent Grueninger, Jannis

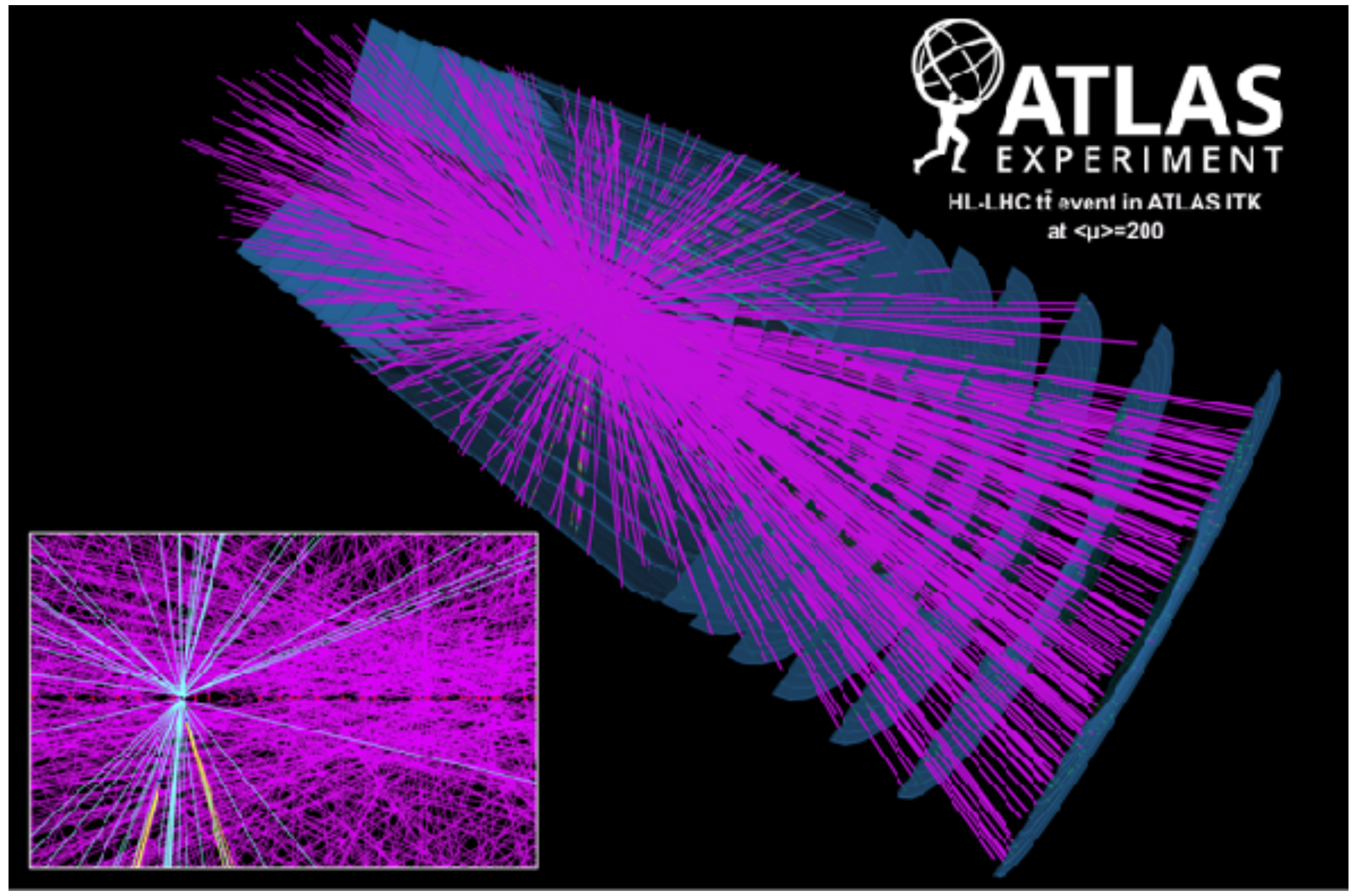
MPP ATLAS Operations and Coordination Tasks

- Muons:
  - Muon Phase-II Upgrade Steering Group Member:
    - Hubert Kroha
  - sMDT Upgrade Coordinator:
    - H. Kroha
  - RPC Mechanical Engineering Coordinator:
    - D. Soyk
  - ASD Chip Coordinator:
    - R.Richter
  - MDT Frontend Board Coordinator:
    - O. Kortner
  - MDT Trigger Co-coordinator:
    - O. Kortner
  - MDT Trigger firmware coordinator:
    - D. Cieri
  - TDAQ HDL-On-Git (HOG) maintainer
    - D. Cieri
  - Coordination of searches for diboson resonances
    - D. Duda
  - Coordination of searches for dark matter in hadronic final states
    - P. Rieck
  - Coordination of the global ATLAS EFT fit
    - S. Kortner
  - Muon Efficiency Measurement Coordinator (Institute Commitment):
    - J. Junggeburth, D. Cieri
  - Central software reviewer
    - J. Junggeburth
- Calorimeter:
  - ATLAS POTS (Panel for Operation Task Sharing) member
    - T. Barillari
  - Monitoring of HEC cold pre-amps
  - Monitoring and maintenance of 8 HEC LVPS
    - T. Barillari, U. Leis, J. Habring, A. Fischer
  - Development of new HEC LVPS for Phase-II
    - T. Barillari, S. Menke, J. Habring, A. Fischer, P. Schacht
  - LAr Steering group and Management member
    - S. Menke
  - LAr Phase-II Electronics Upgrade Project Leader
    - S. Menke
  - LAr Phase-II Upgrade Steering member
    - T. Barillari
  - Calorimeter HiLum Project Leader
    - P. Schacht
  - Simulations for Hi-Lum setup
    - A. Kiryunin
  - Simulation of FCal degradation
    - S. Menke
  - Calorimeter SW Topological Clustering
    - S. Menke, M. Spalla, T. McCarthy
  - Calorimeter SW Local Hadron Calibration
    - S. Menke, T. Barillari
  - LAr Monitoring SW
    - M. Spalla
  - Jet Reconstruction SW PileUp-suppression with calorimeter cell timing
    - M. Spalla, T. McCarthy
  - Jet Reconstruction SW Pflow calibration for high energies
    - N. Wenke
  - Radiation Effects Task Force Member
    - S. Menke
- Inner Detector:
  - Inner Detector Alignment coordinator:
    - J. Jimenez Peña
  - ITk Pixel test-beam coordinator:
    - F. Guescini
  - CO_2 cooling design:
    - S. Vogt
- Computing:
  - Operation of Tier-2 Facility at MPCDF
  - Central software reviewers
    - S. Stonjek

LHC Schedule



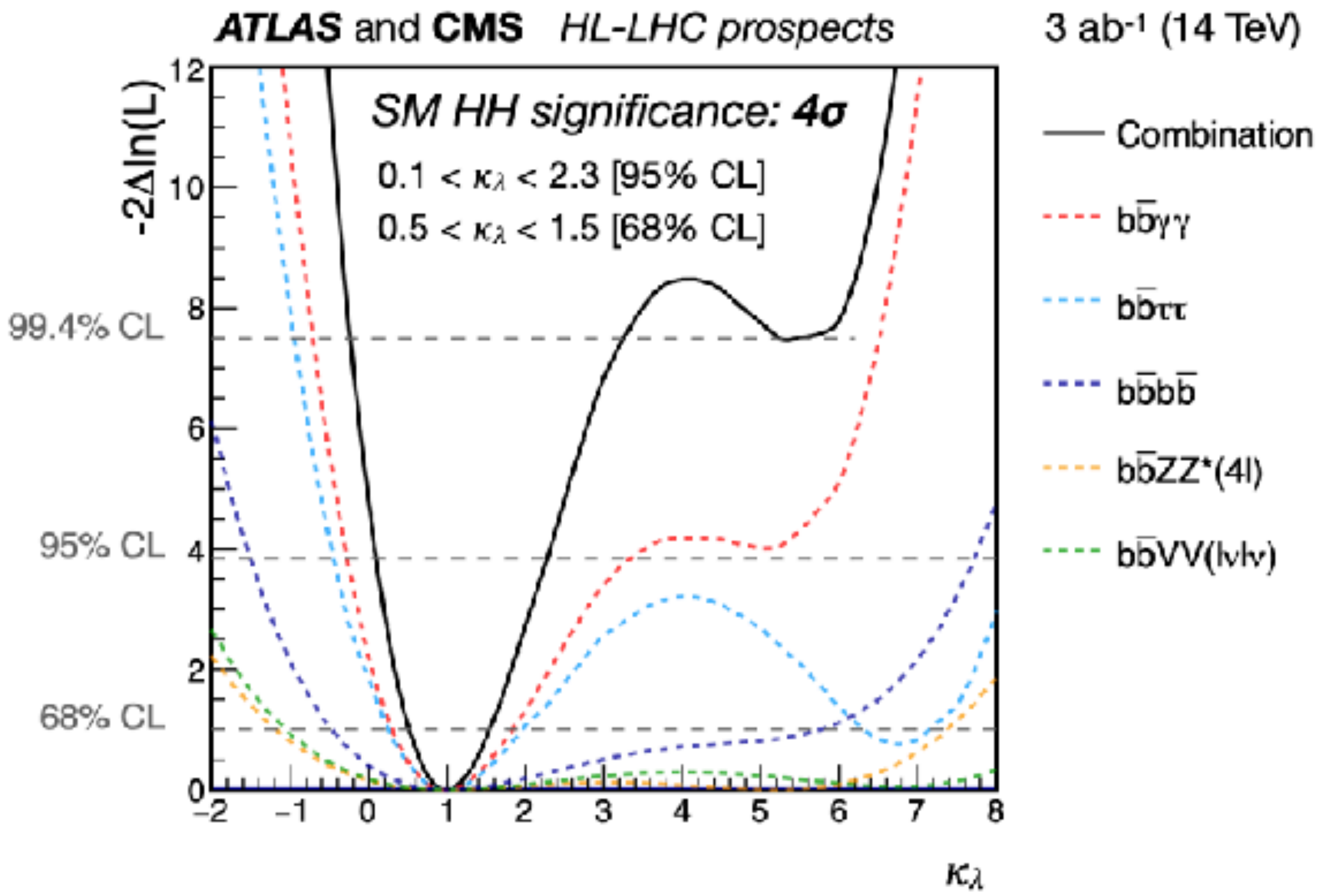
- ATLAS currently undergoing phase I upgrade
- HL upgrades (Phase II) planned for 2025, data taking starting in 2027
- Increased instantaneous luminosity: ~7.5×10^{34} cm^{-2} s^{-1}
  - 4000 fb^{-1} integrated luminosity over more 10 years data taking
- Increased pile-up: ~200 interactions/bunch crossing
- Increased radiation damage
- ATLAS upgrade goal is to maintain its high-performance



Physics Motivation for the upgrades

- Up to 30 times more data then now ensures a rich physics programme for the next two decades
- Physics reach:
  - O(%) precision on Higgs couplings, differential and CP properties, limits on Higgs self-coupling
  - Electroweak precision fits, multi-boson probes of the electroweak symmetry-breaking, rare processes (e.g. tttt)
  - Precision measurements in top-quark physics
  - Direct searches for particles beyond the Standard Model
    - Dark Matter search complementing non-LHC experiments
    - New resonances with masses up to O(10) TeV
    - Sensitivity to long-lived particles up to 3.5 TeV
    - Covering Challenging unexplored corners of Supersymmetry

Run 2	2015 - 2018	150 fb^{-1}	13 TeV
Run 3	2022 - 2024	350 fb^{-1}	13-14 TeV
HL-LHC	2027 -	4000 fb^{-1}	14 TeV

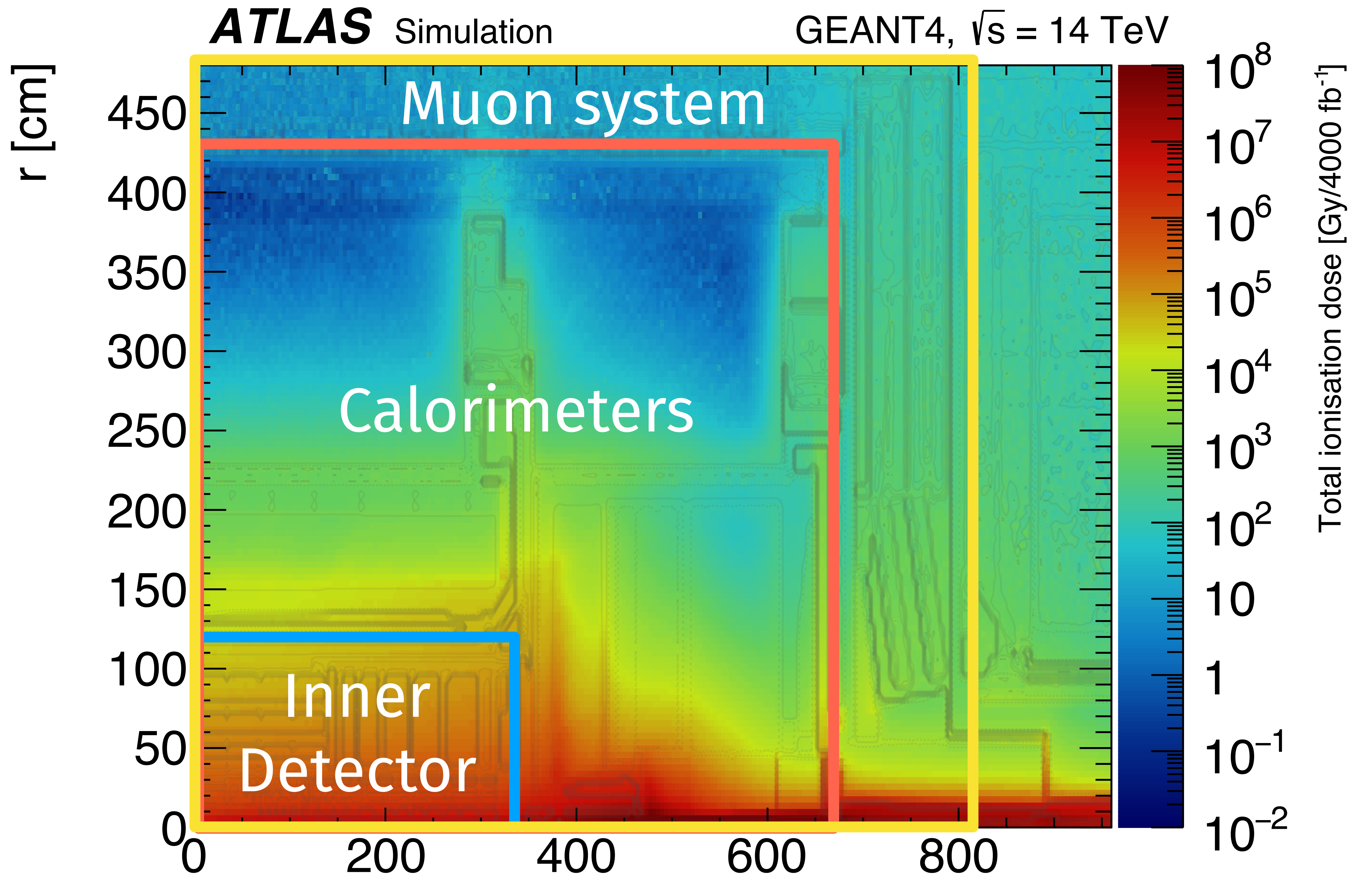


Expected κ_λ measurement precision:

HL-LHC	50 %
ILC (500 GeV)	27 %
FCC-ee (365 GeV)	36 %
FCC-hh (100 TeV)	5 %

Radiation Background @ HL-LHC

- Knowledge of the radiation background with high precision is fundamental for the upgrade of the detector and the electronics
- ATLAS uses Geant4 predictions made by MPP-group for radiation estimates
  - Public interactive page: [WebRadMaps Full R2 public.html; ATLAS-SOFT-PUB-2020-003]



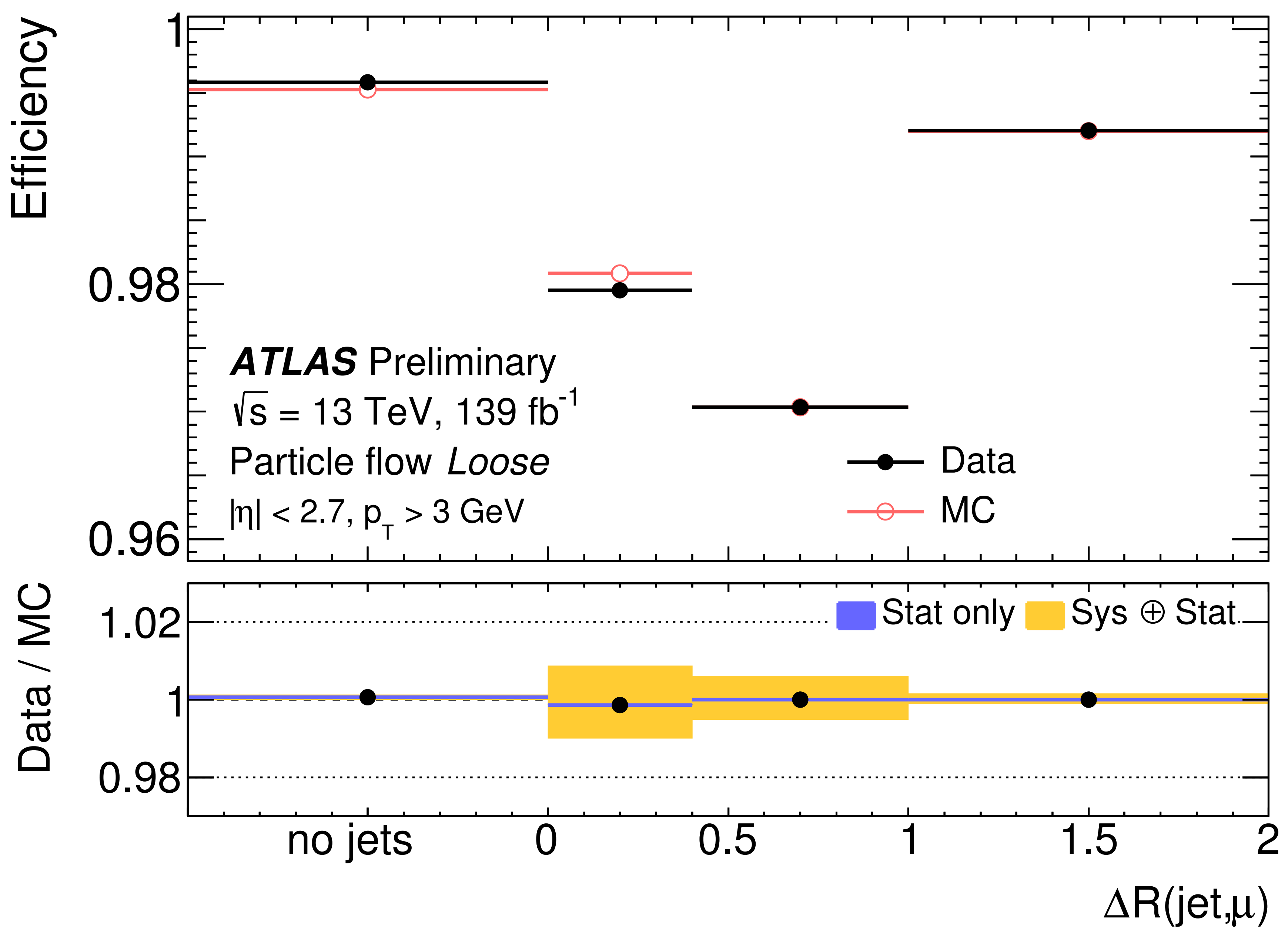
TID > charge traps

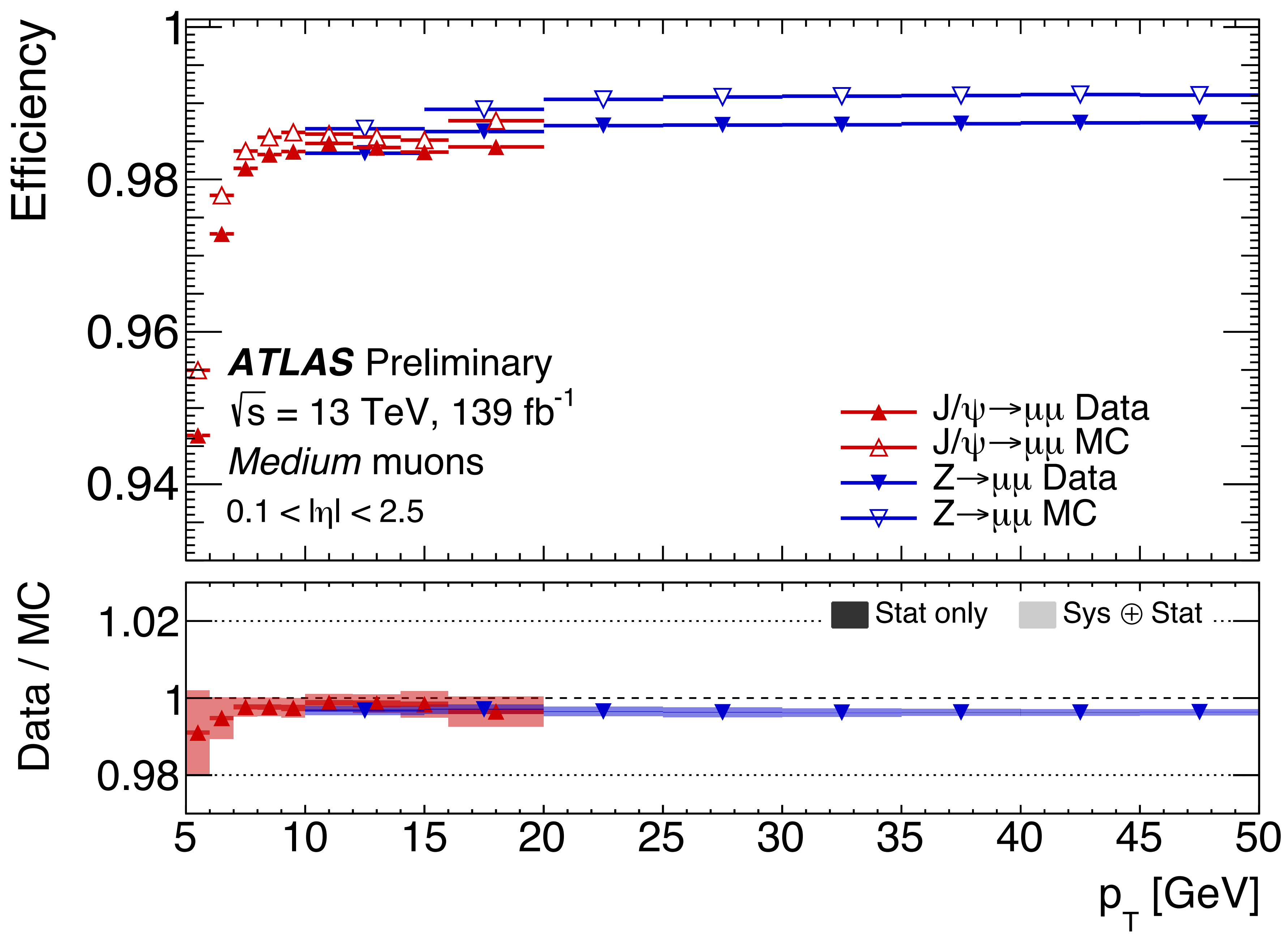
- In the plot: Expected Total Ionising Dose after 4000 fb^{-1}
  - Beam line along *z*, Interaction point (IP) at (0,0)
  - Subsystems before magnet

ATLAS Muon System

Muon Operation: reconstruction and identification performance

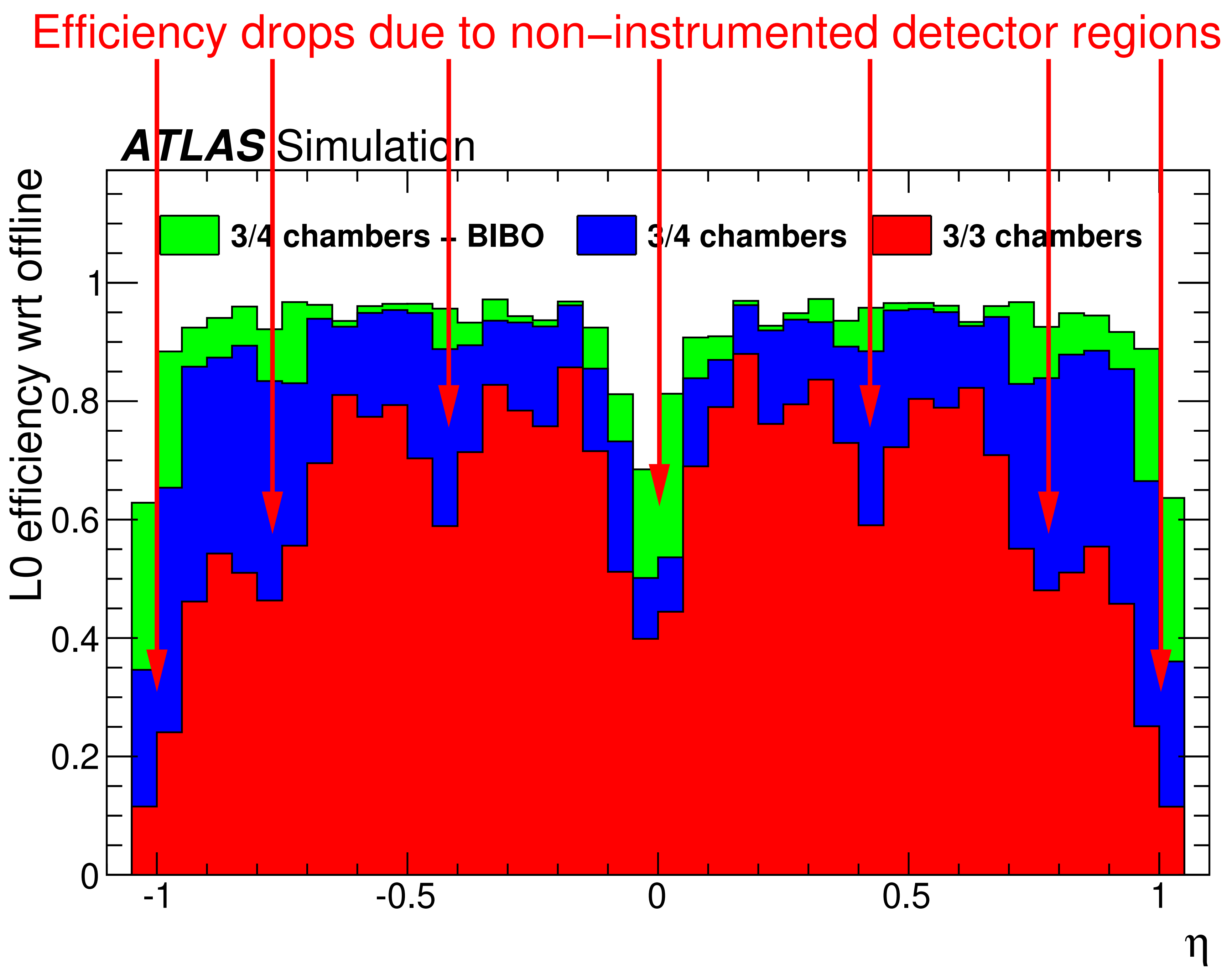
- MPP is part of the Muon Combined Performance (MCP) group, which defines a set of requirements (WP: Working Points) for different muon types to be used in physics analyses
- MCP measures, for each WP, the muon reconstruction, isolation and track-to-vertex association efficiencies, in real and simulated data
- The ratio between efficiencies in real and simulated data (Scale Factors) are used in physics analyses to improve the data-simulation agreement and to minimise the uncertainties

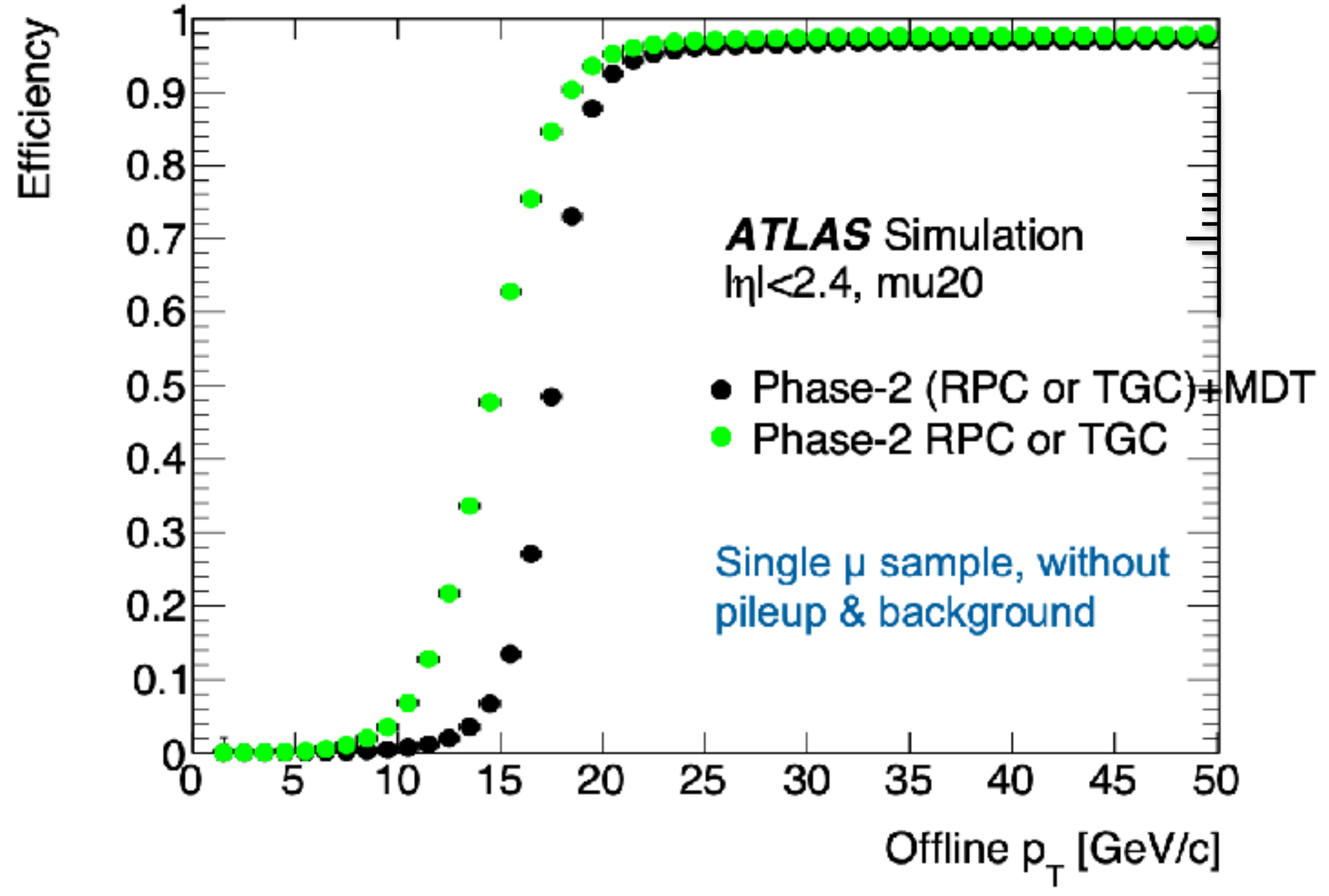




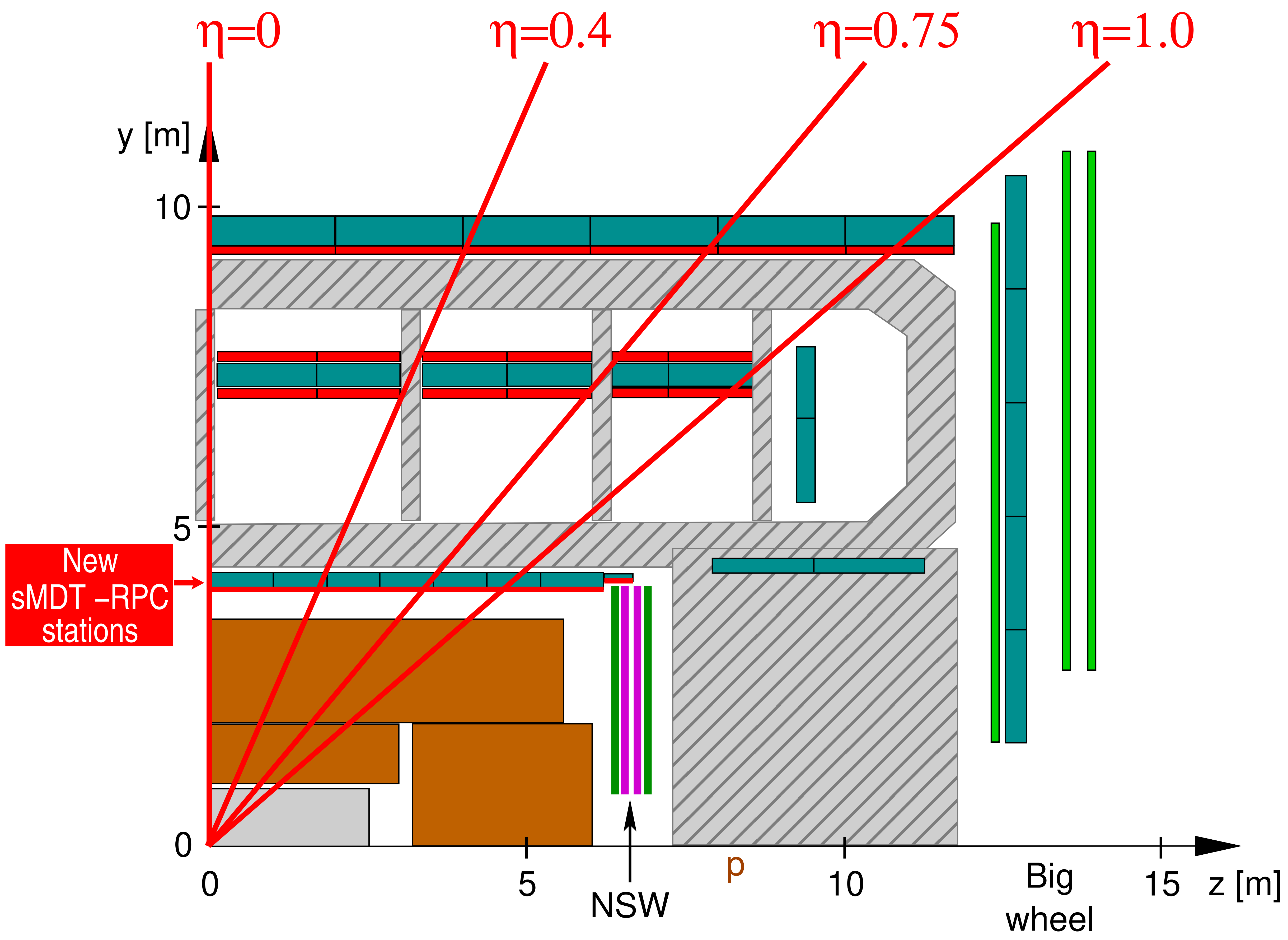
ATLAS Muon System Upgrade

- Muon Spectrometer upgrade is a muon trigger upgrade
- Maximise the muon trigger acceptance
  - New Thin-gap Resistive Plate Chambers (RPCs) + small Monitored Drift Tubes (sMDT) stations in Barrel Inner layer (BIS)
- Increase the selectivity of the muon trigger by an order of magnitude to suppress low-momentum muon background
  - Use MDT data at first-level trigger (Level-0) to improve muon momentum resolution





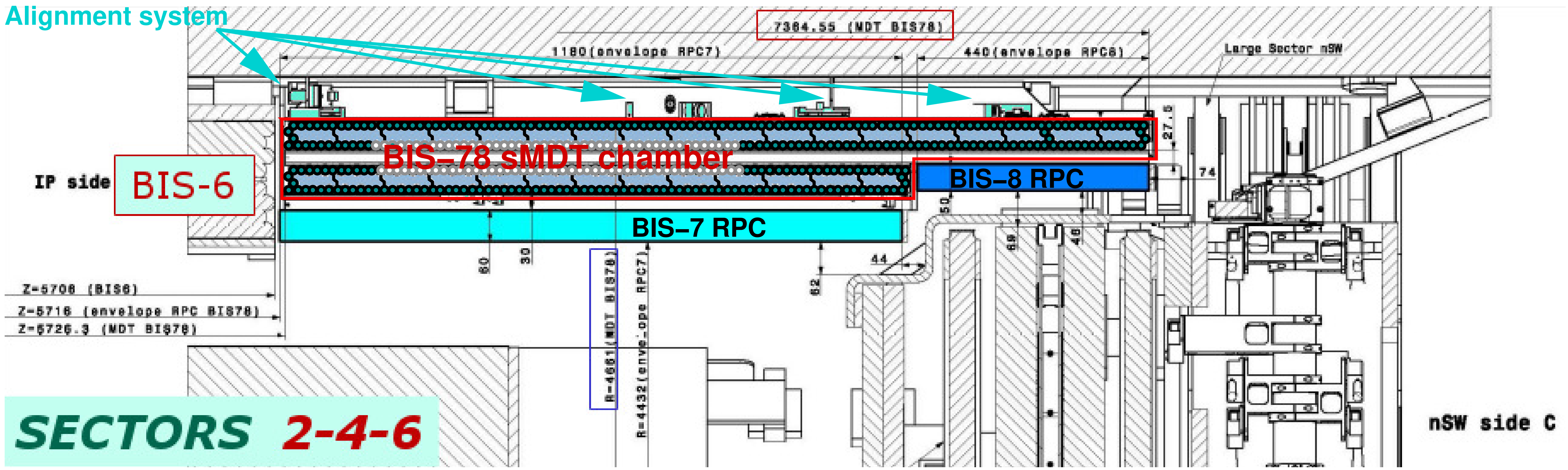
Muon: New chambers with high-rate capabilities

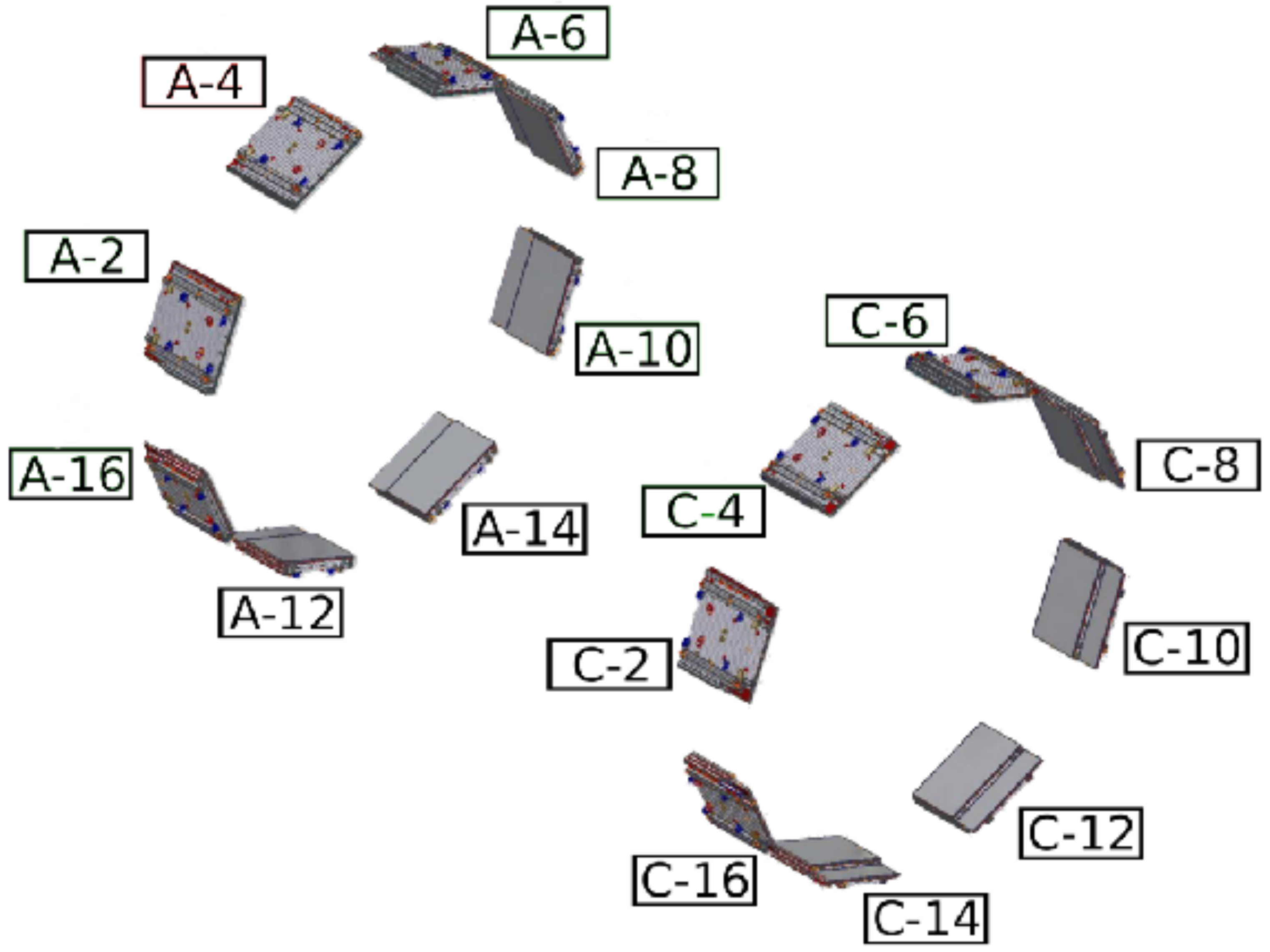


- In the plot: a quadrant of the Phase-II ATLAS muon spectrometer
  - Beam along z, IP at (0,0)

- Close acceptance gaps by installing new stations of sMDT chambers and thin-gap RPCs
- The muon chambers are operated in a large background of γ rays
- 10 times larger background rates at the HL-LHC than at the LHC
- New sMDTs and thin-gap RPCs provide an order of magnitude higher rate capability than present muon detectors

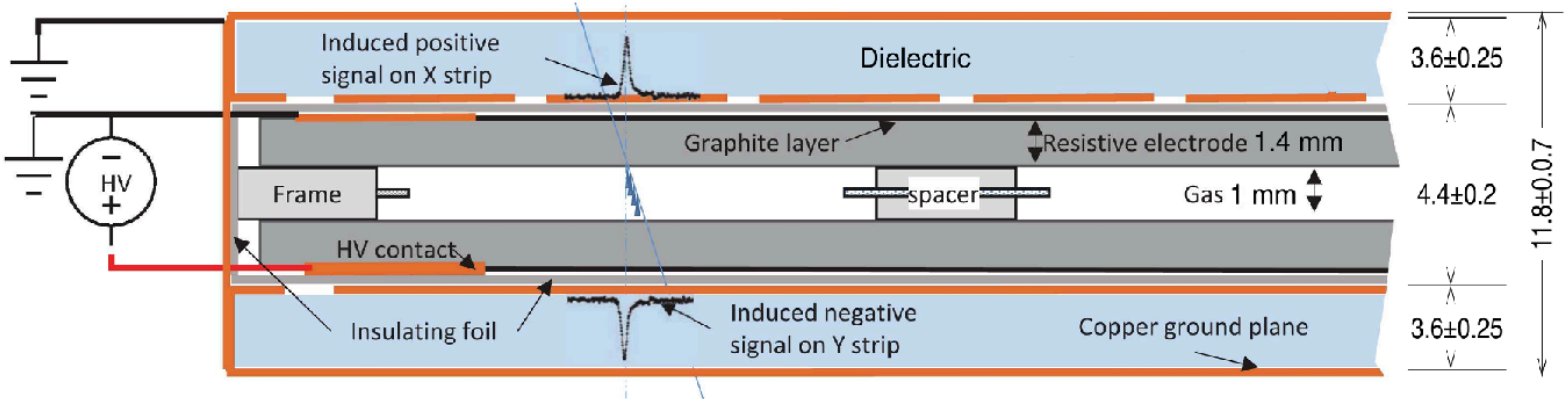
Muon: the BIS-78 Pilot project

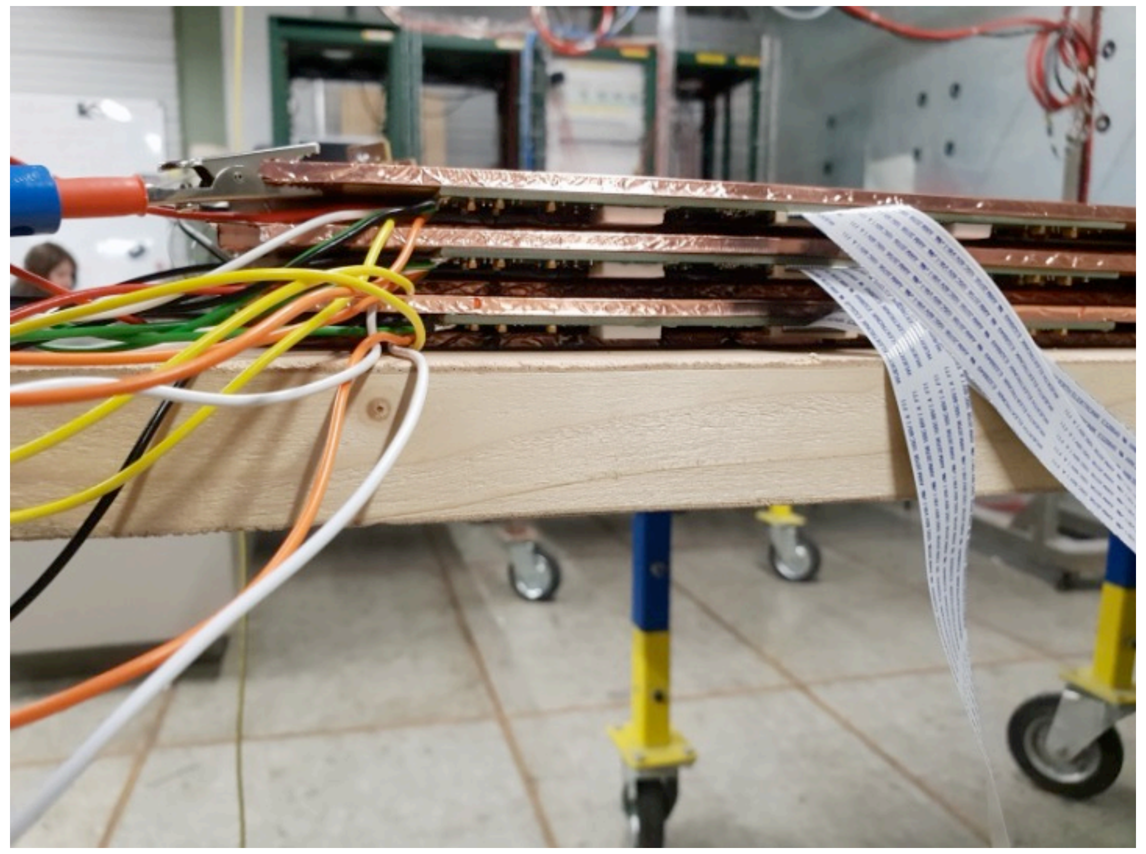




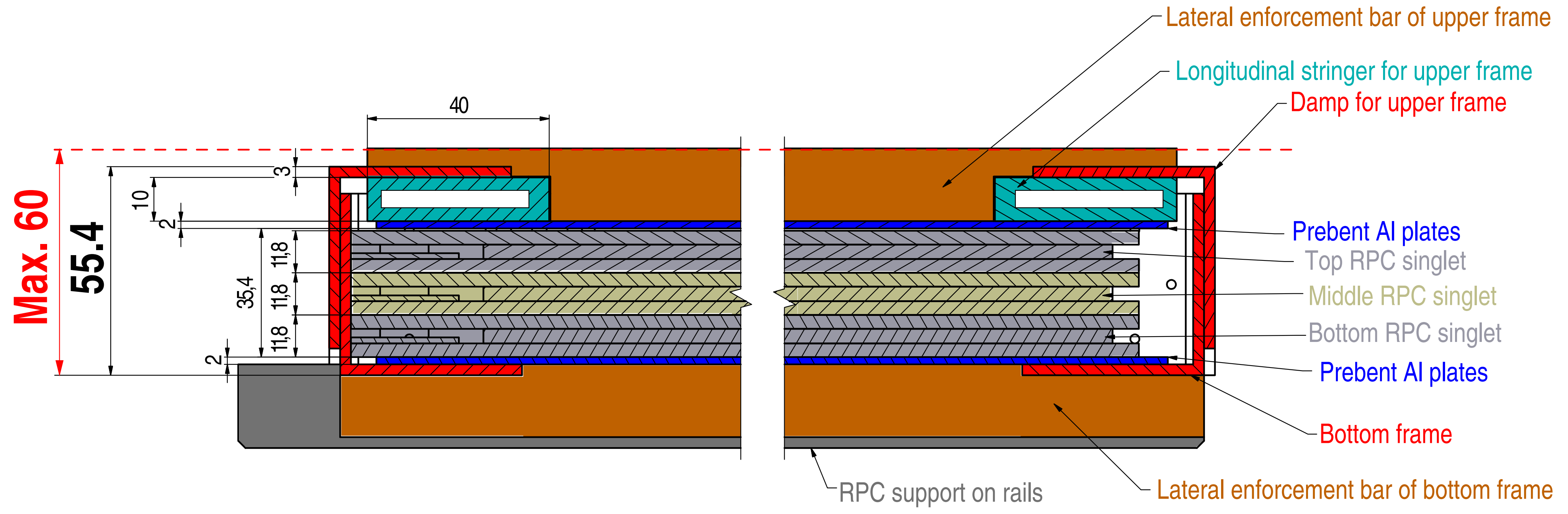
- Installation of 16 sMDT-RPC stations in the inner layer of the barrel/end-cap transition region
  - Chamber ID 7 and 8
- Very difficult and tight space constraints
- sMDT chamber designed by MPP
- Production of 16 sMDT chambers completed at MPP in December 2019

Muon: New Thin-Gap RPCs

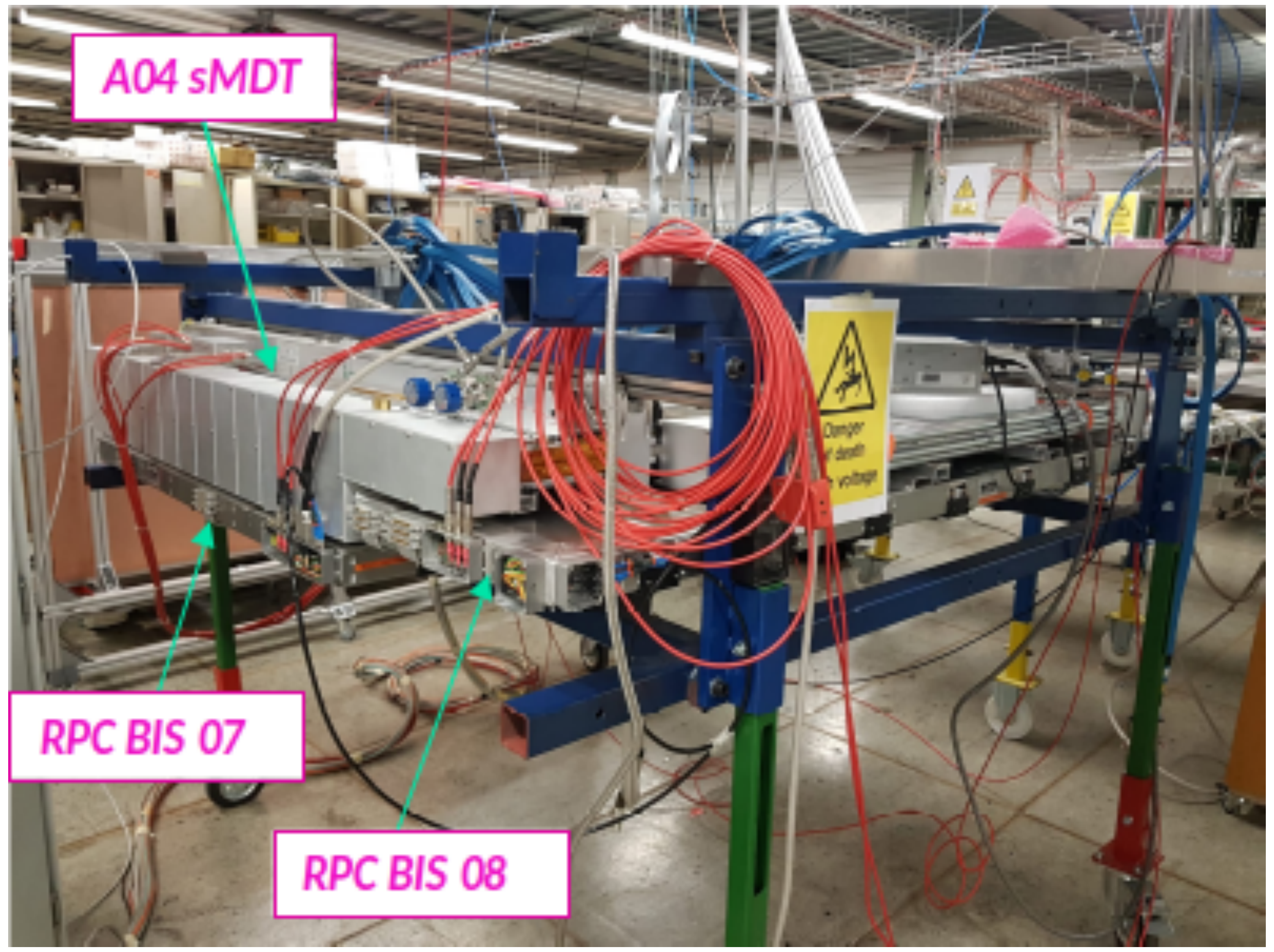




- Thin gas gap: 1 mm instead of 2 mm -> triplets
- More sensitive read-out electronics
  - Reduced operating voltage (5.6 kV) leading to smaller gas gain and significantly less accumulated charge than currently
  - An order of magnitude higher rate capability
- High demand on mechanical precision and reliability in RPC production
- MPP responsibility
  - Complete mechanical design of the integrated sMDT + RPC upgrade
  - Industrialisation of the RPC gas gap production



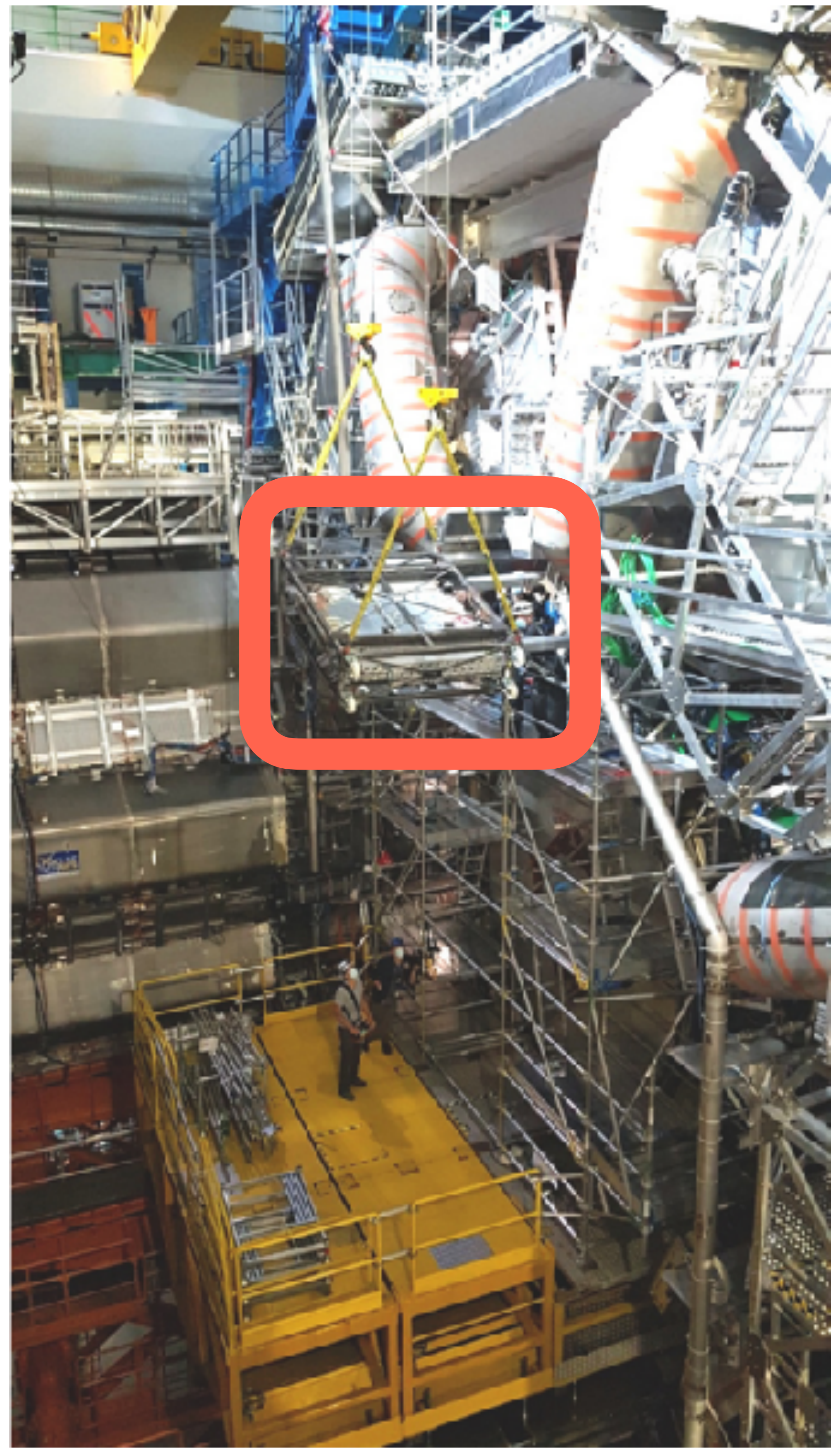
Muon: Integration of BIS-78 RPC and sMDT chambers



- Integration for all chambers between March and December 2020.
- Final cosmic-ray certification of the integrated chambers before installation.

Muon: Installation of BIS-78 chambers

Chamber ready to be installed

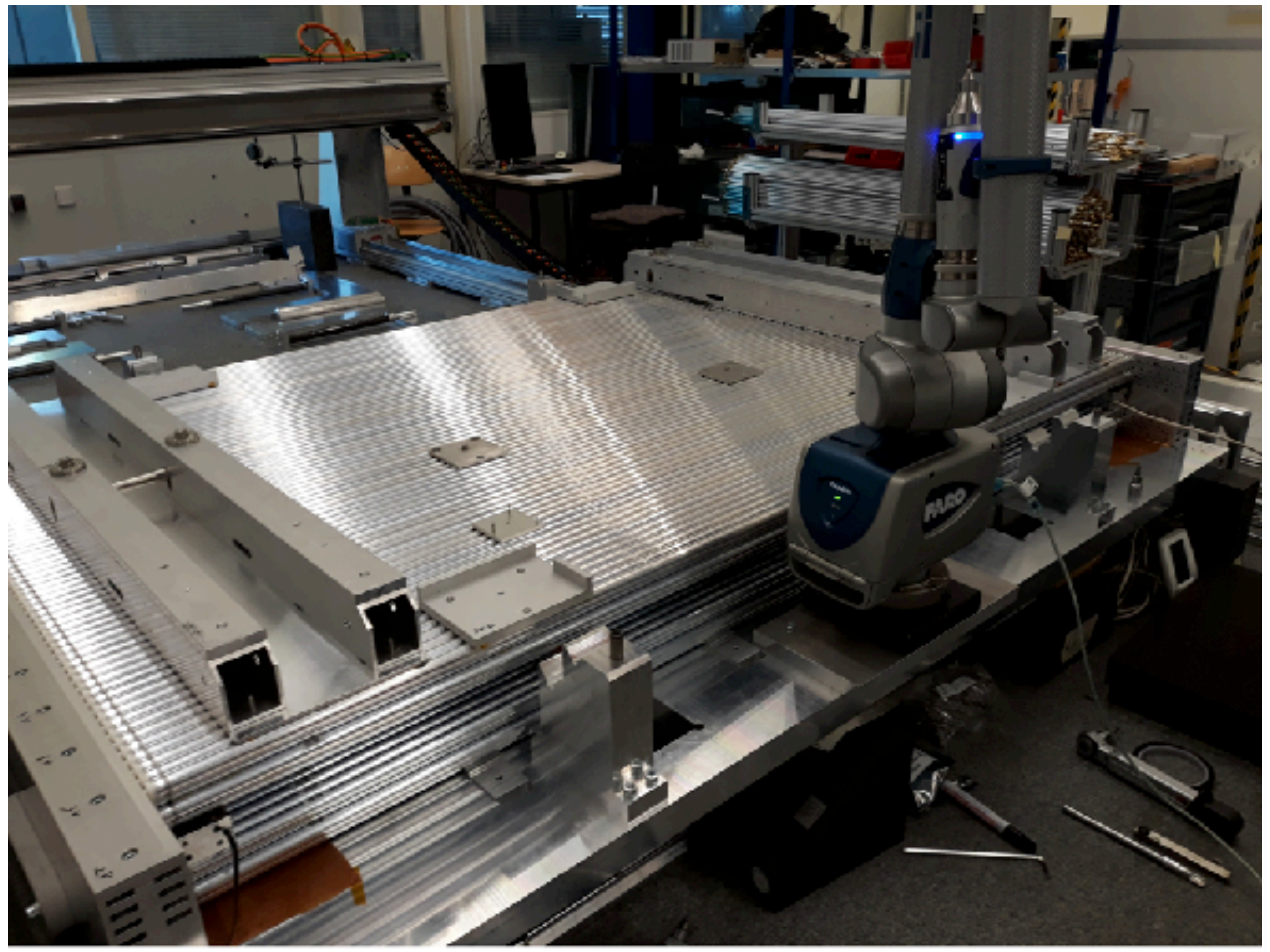


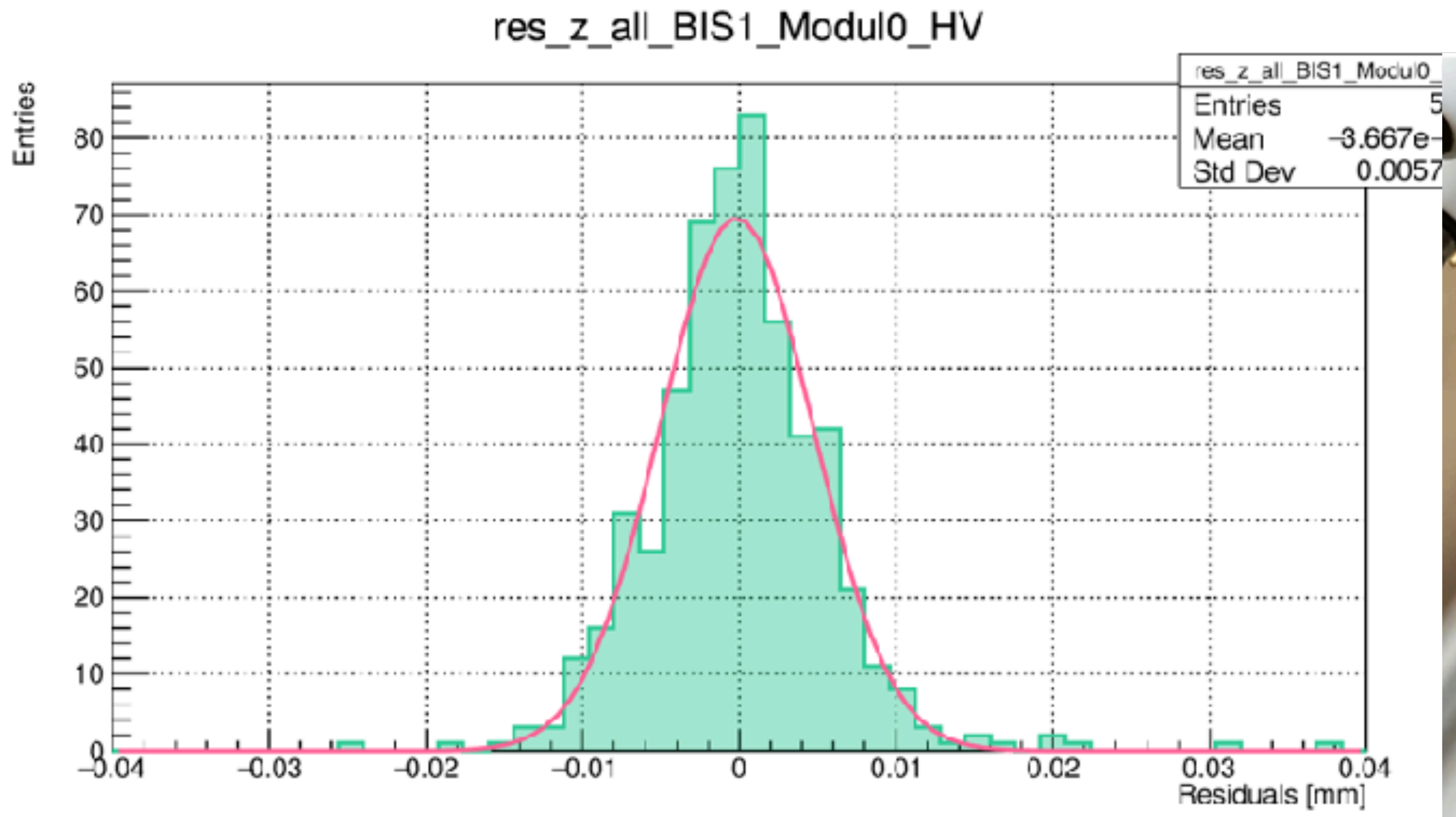
Lowering the chamber

Chamber installed in sector A04

- First chamber installed successfully for A04 sector on 17. September 2020
- Chamber installation completed in December 2020

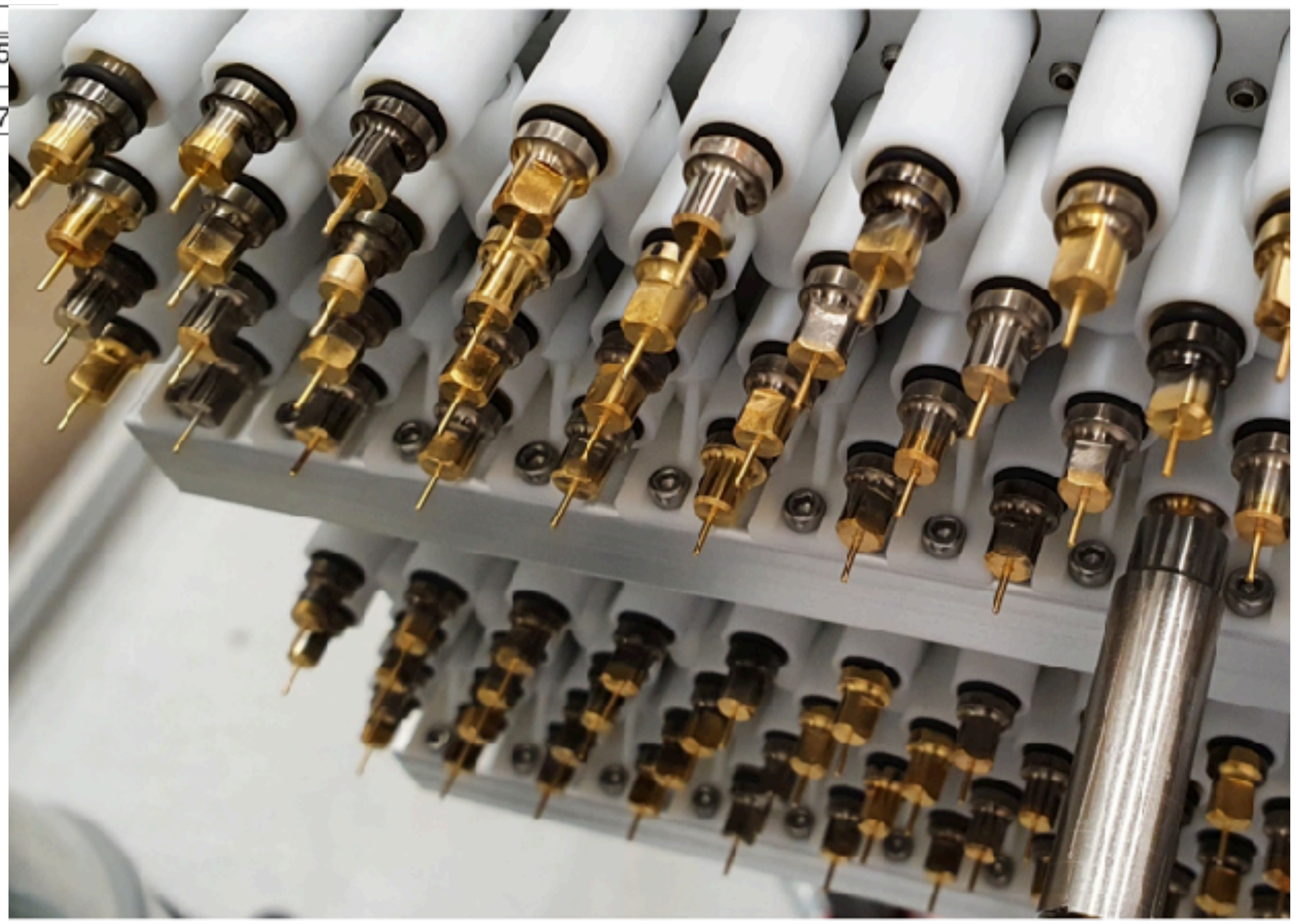
Muon: BIS 1-6 project





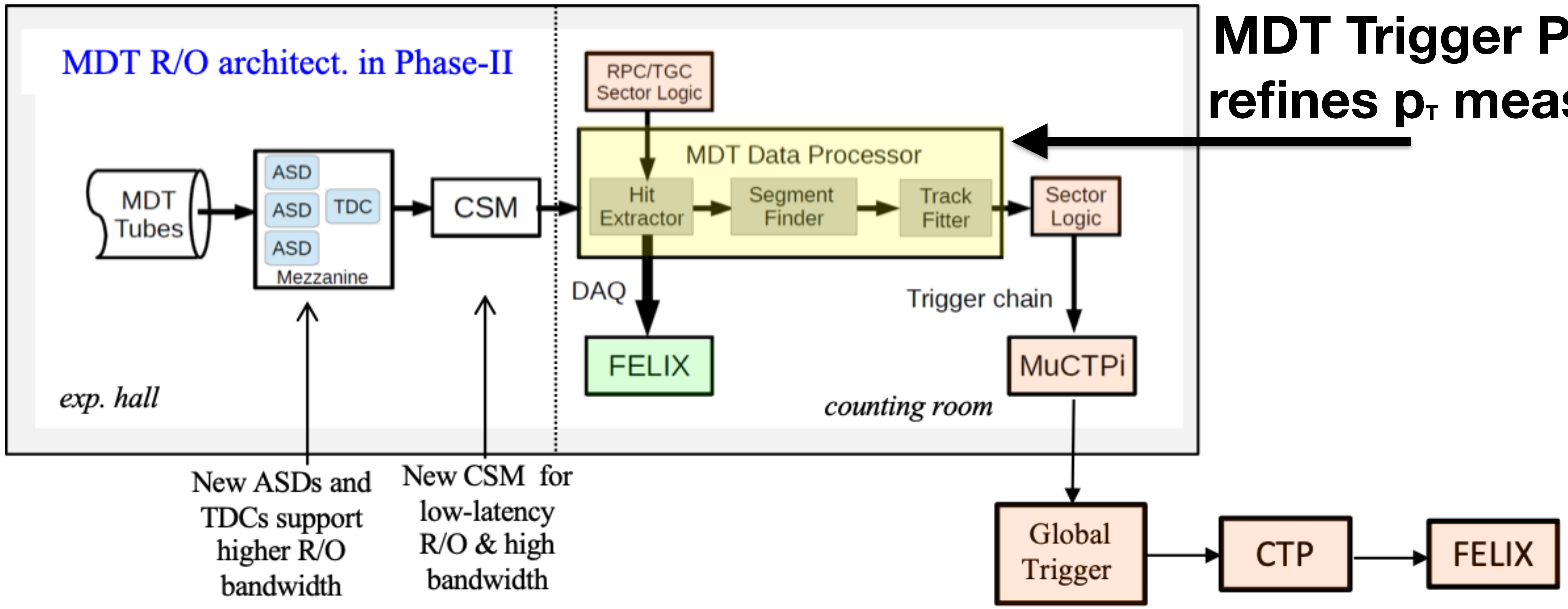
Achieved accuracy: 6 µm

Required accuracy: 20 µm

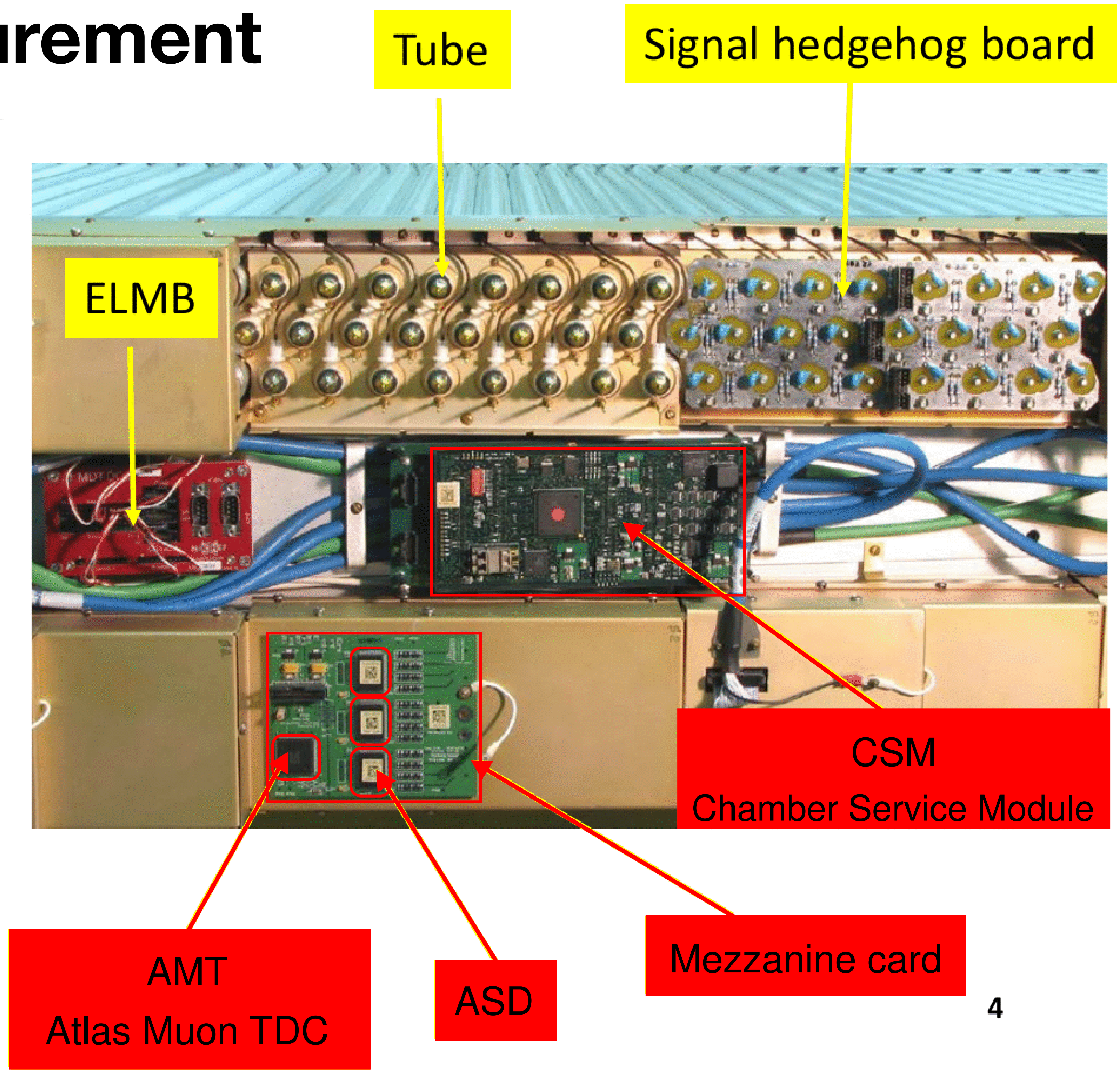


- Successful construction and test of a module 0 sMDT chamber in September 2020
- Start of series production in October 2020
- Two modules produced since the start of the production

Muon: MDT Upgraded read-out electronics



MDT Trigger Processor refines p_T measurement



- Trigger requirements at the HL-LHC
  - 1st level trigger rate will be increased from the present 100 kHz to 1-4 MHz.
    - Present TDCs and CSMs incompatible with trigger rates >200 kHz.
    - New on-chamber electronics
    - MPP responsible for new ASD, TDC, mezzanine card and new BIS Hedgehog card (Front-end) and new MDT Trigger Processor (Back-end)

ASD: Amplifier-Shaper-Discriminator

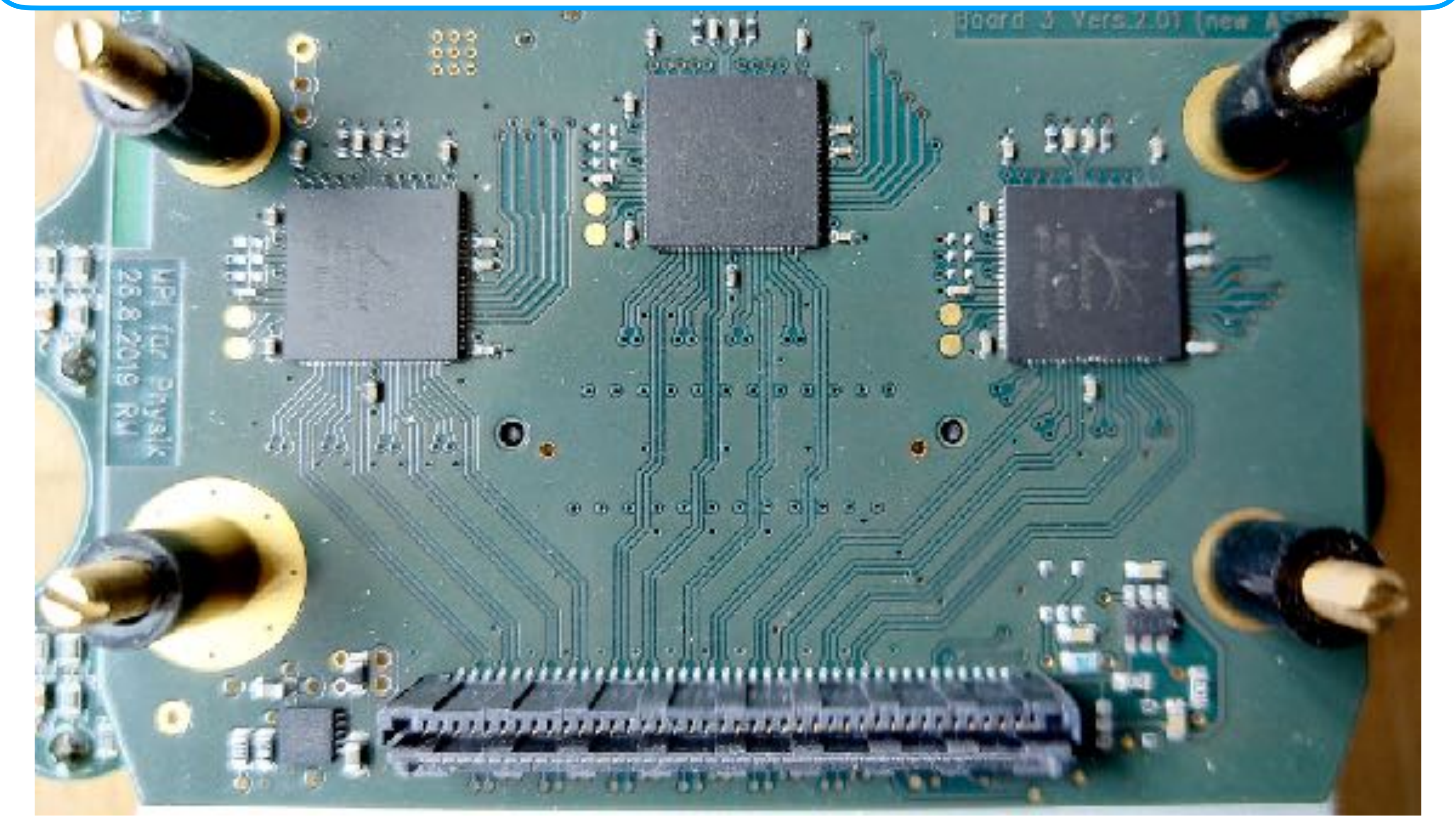
TDC: Time-to-Digital Converter

CSM: Chamber Service Module

Muon: Front-end MDT electronics @ MPP

- Design of new ASD chips
  - Design completed in 2018
  - Preproduction of 7500 ASD chips in 2019
  - Certification of the preproduction chips in spring 2020 (>90% yield achieved)
  - Production of 80k ASD chips in fall 2020
- Design of a new TDC chip
  - Design of a new TDC chip in collaboration with the University of Michigan
  - Production of the prototype chip in 2020. First tests promising
  - Final design in Q2 of 2021
- Design of read-out cards

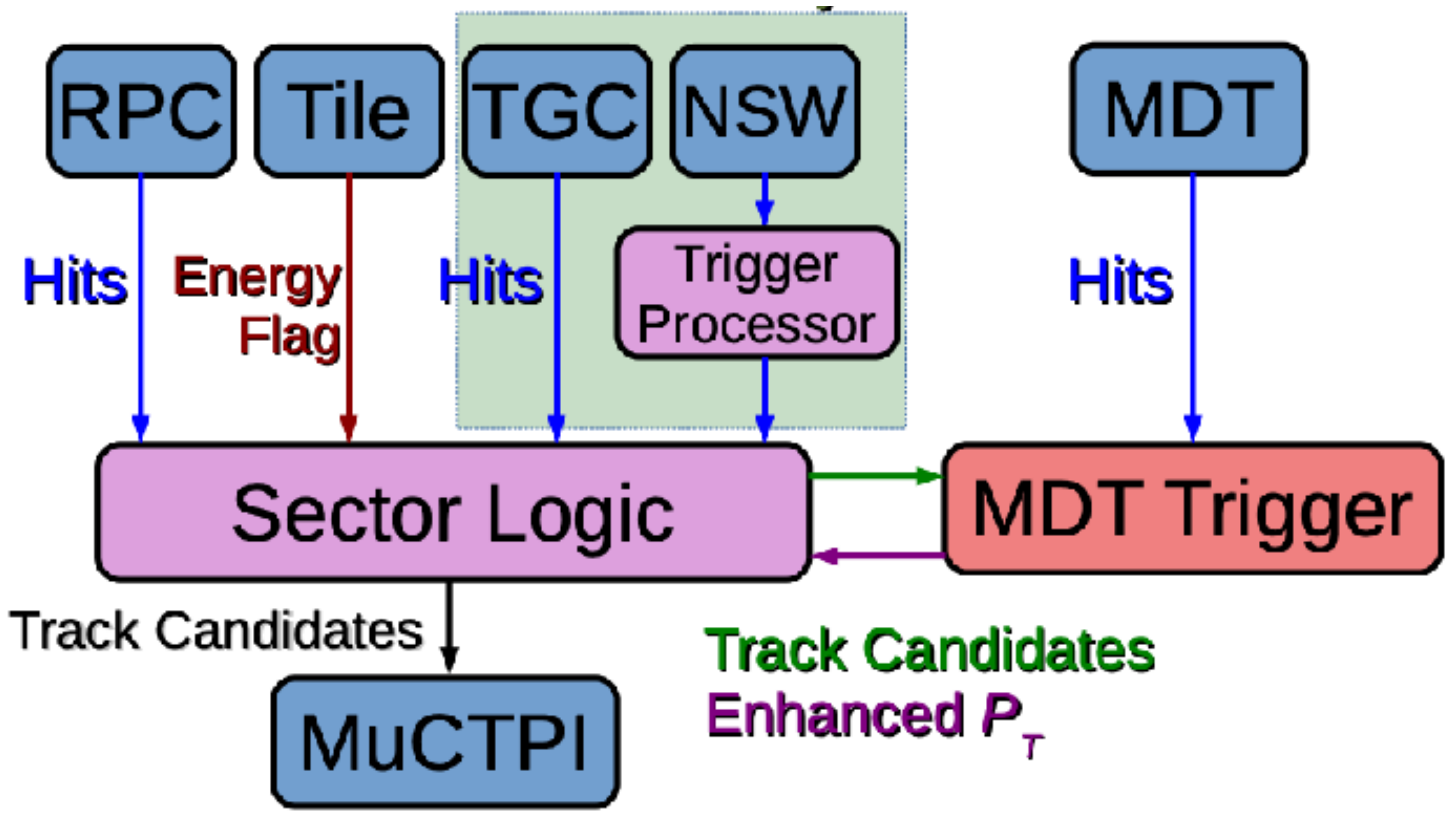
ASD board with 3 new ASD chips

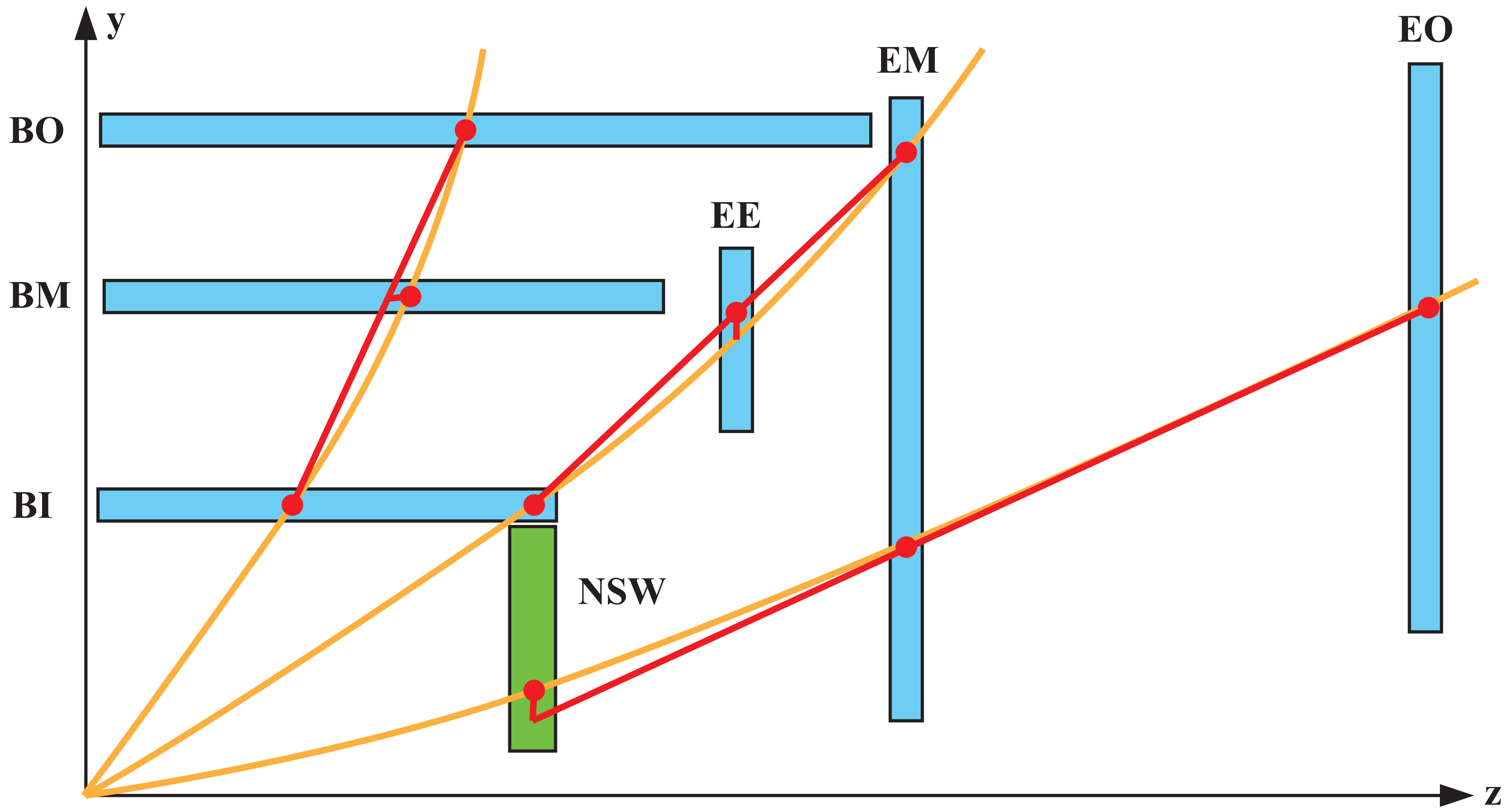


TDC board with new TDC chip

Muon: First-level MDT trigger

- Requirements for 1st level muon trigger:
  - Reduce Trigger Rate from ~200 kHz to ~50 kHz
  - 6% p_T resolution for 20 GeV muons
  - 1 µs processing time
- Concept developed by MPP
- Development of new trigger processor (MDT Trigger Processor) necessary
- 64 processor boards will be used in ATLAS
  - Input from Sector Logic trigger boards and MDT CSMs

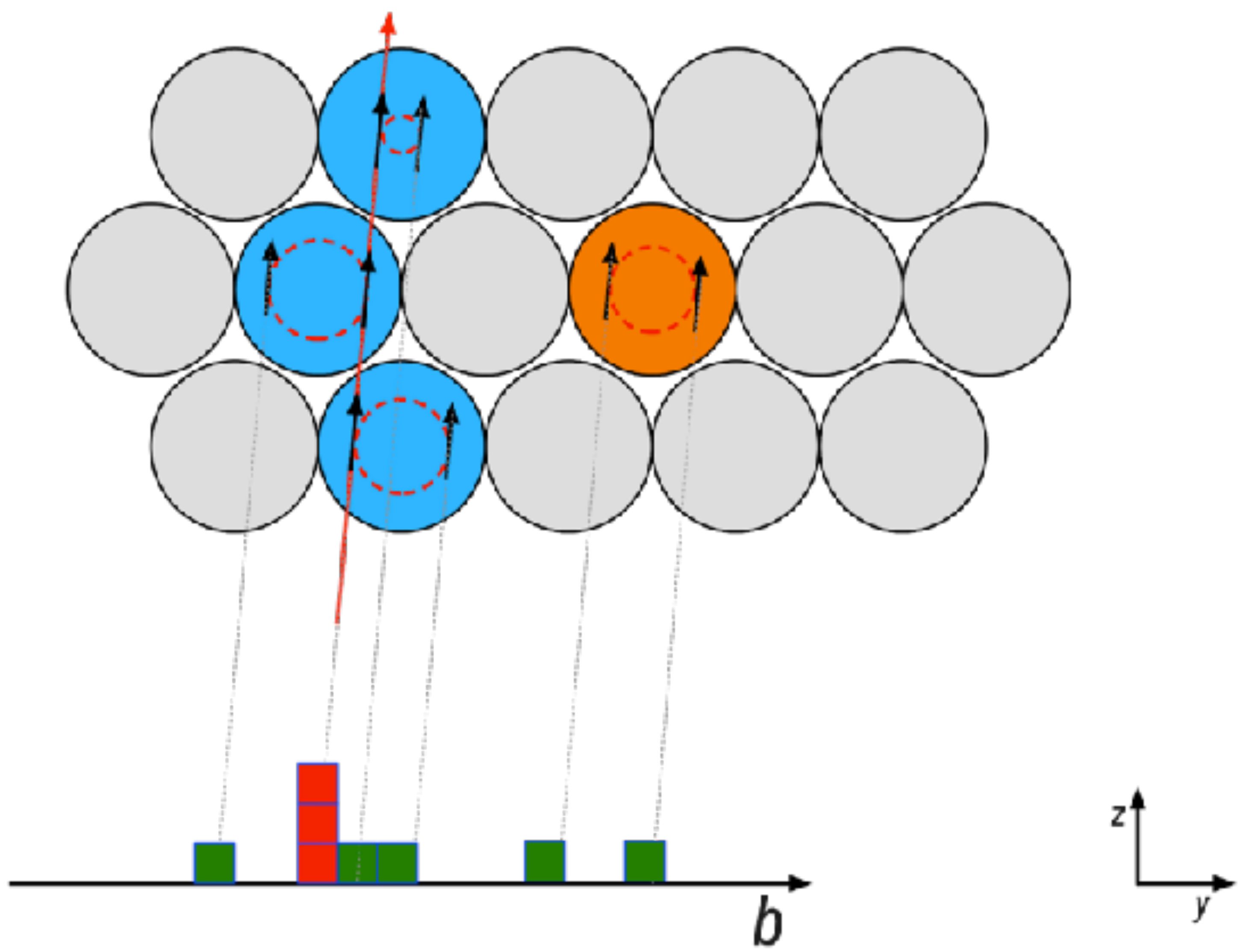


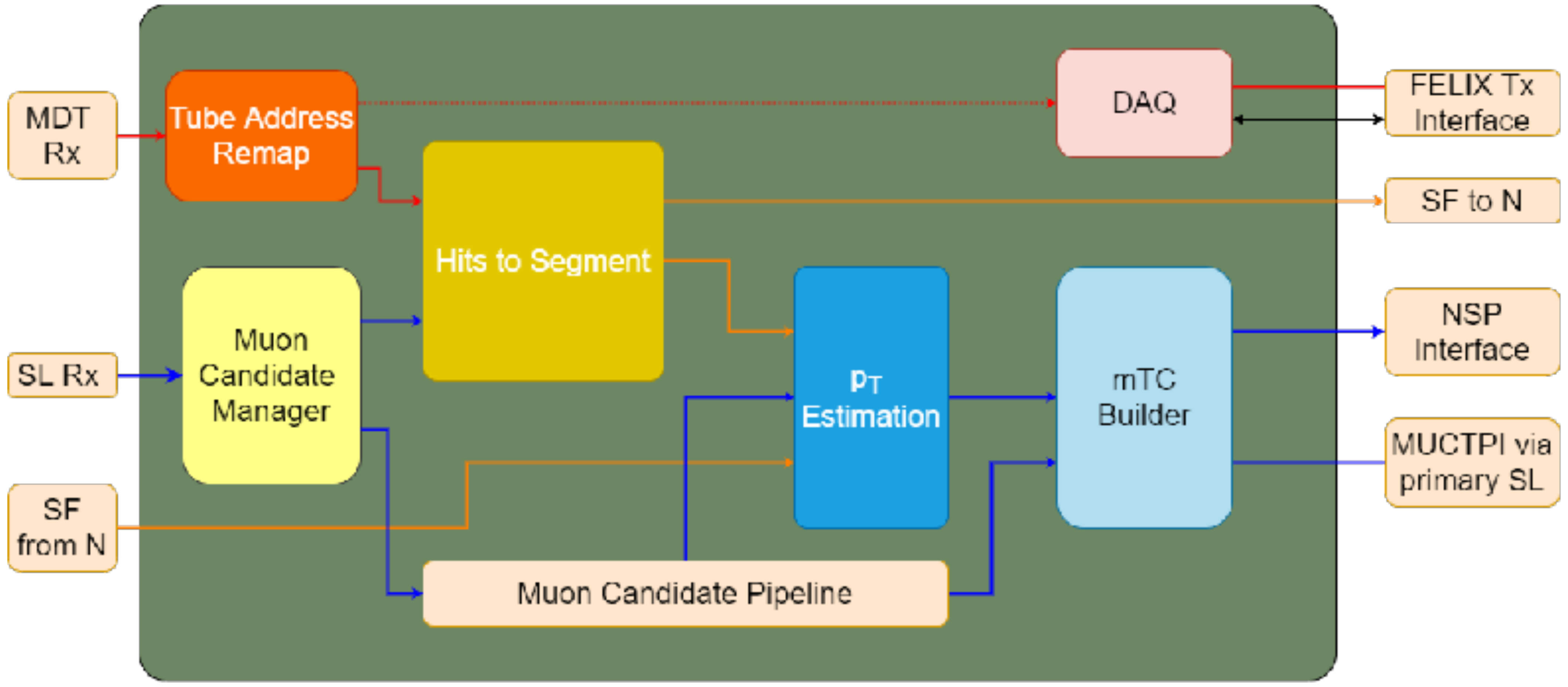


Muon: L0MDT trigger algorithm

FPGA: Field-Programmable Gate Array
Reprogrammable integrated circuit

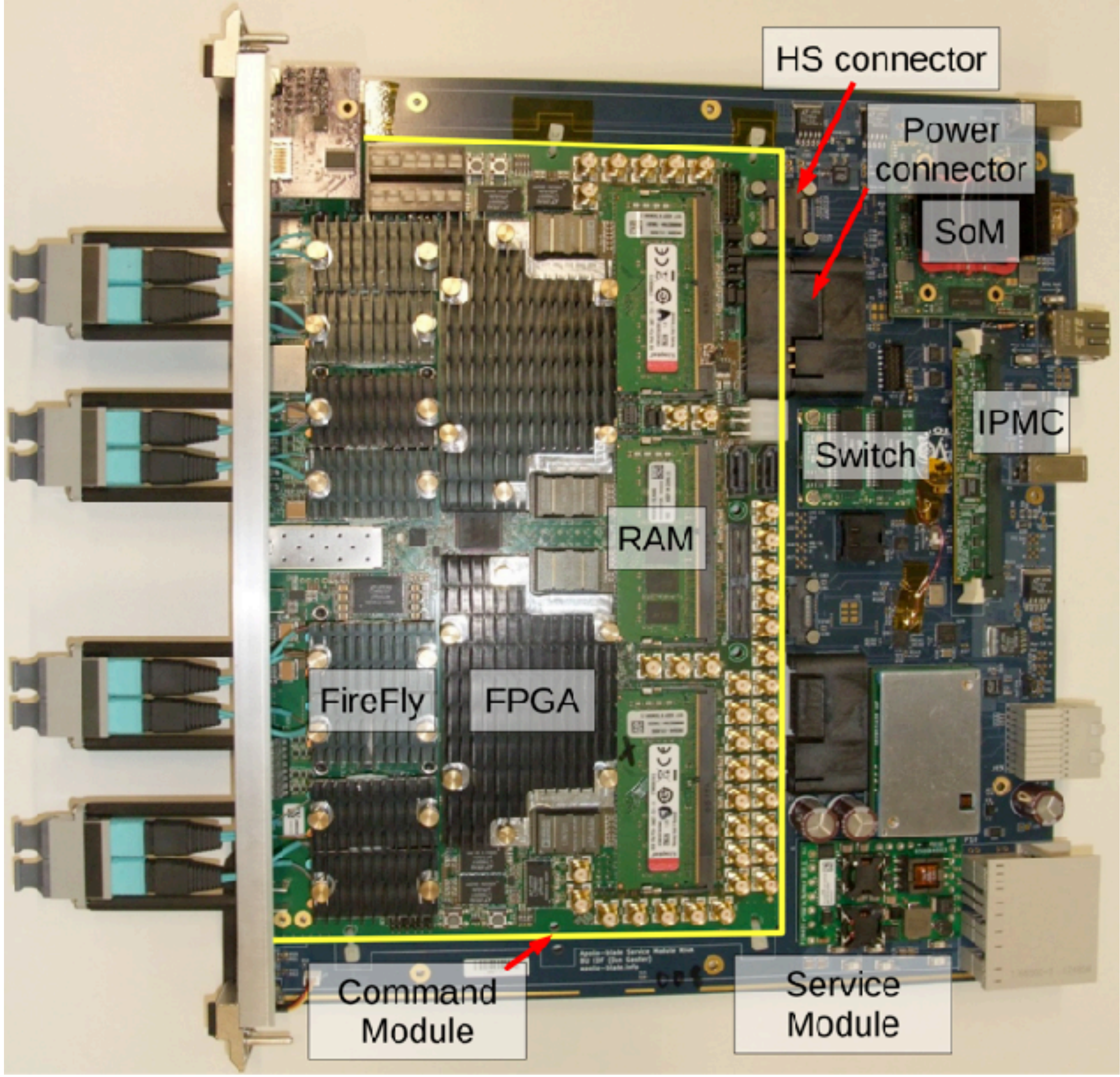
- MDT-based trigger algorithm (MPP)
  - [Compact Segment finder]
  - 1D histogram using trigger chambers as seed
  - Find muon segments in each MDT station
  - Calculate p_T out of segment position/angle
- Firmware implementation
  - Algorithm implemented on FPGA and validated against official ATLAS simulation
  - Design satisfies muon trigger requirements
  - Requires powerful FPGA with large number of high-speed links





Muon: L0MDT hardware

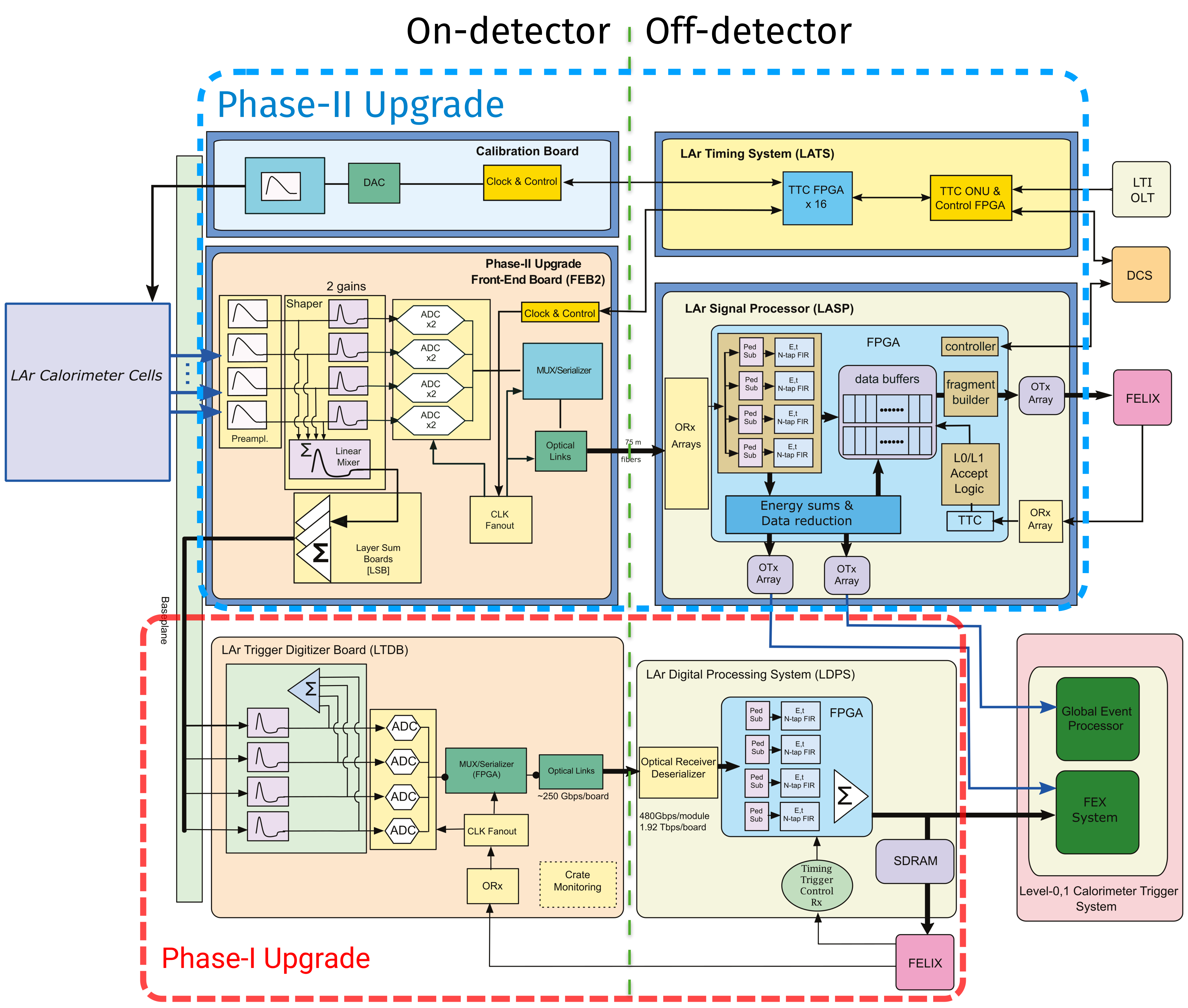
- Challenging hardware design due to large number of high-speed links
- Hardware demonstrator (MPP)
  - Two-FPGA-based ATCA board designed in collaboration with proDesign as industrial partner
  - First two boards received in Summer
  - Second revision under production (December 2020)
- Single-FPGA ATLAS prototype (2021 - 2022)
- Series production (2023 - 2025)



ATLAS Liquid Argon Calorimeter

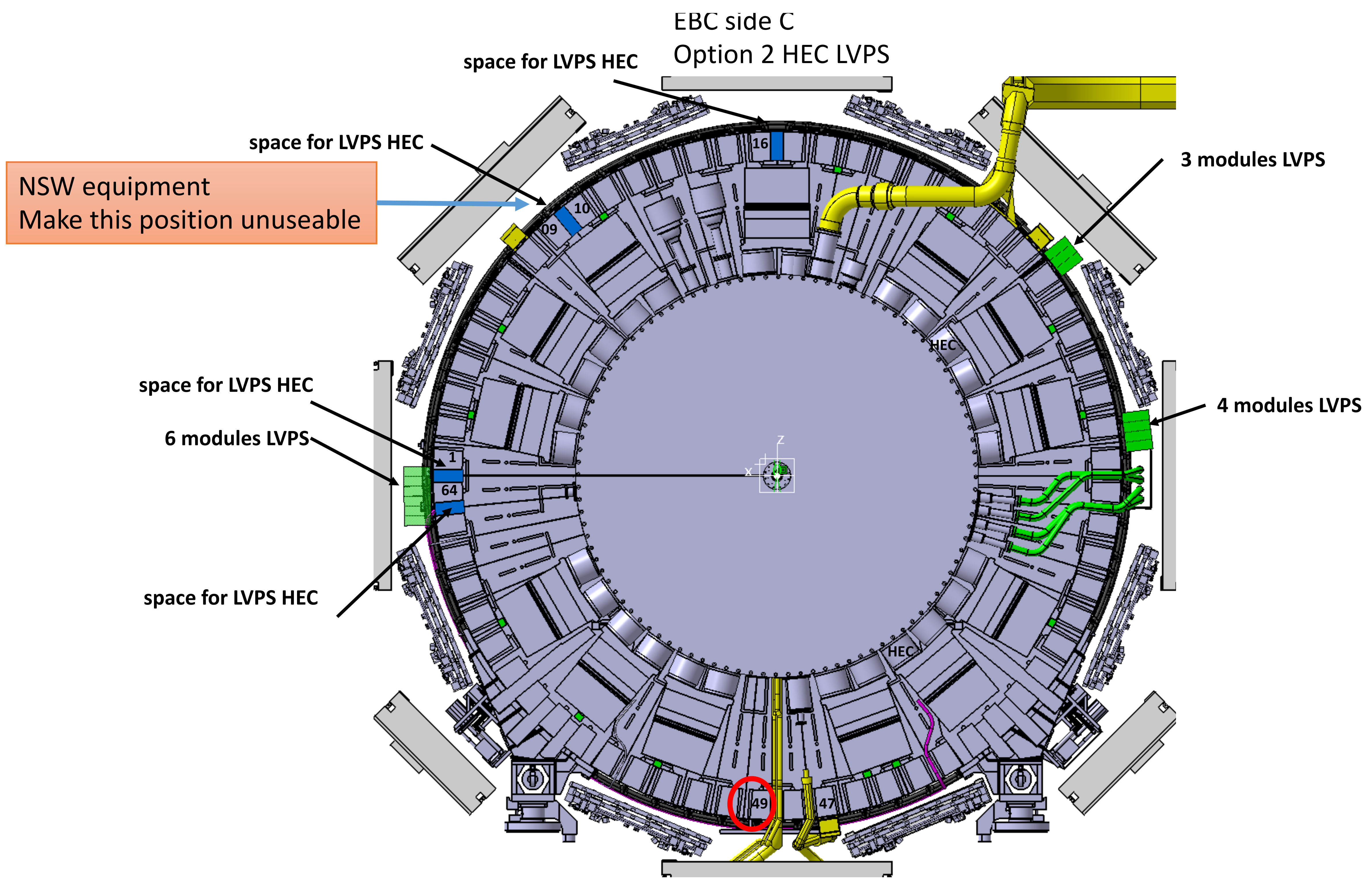
LAr: Upgrades

- Calorimeter hardware remains unchanged
  - LAr sampling calorimeters are inherently radiation hard
  - FCal studies performed by MPI
- Readout and trigger electronics changes
  - Phase-I upgrade (2019-2021) for trigger
  - Phase-II upgrade (2025-2027) for readout electronics
    - To meet requirements of new trigger and data-acquisition scheme
    - Radiation tolerance and long ageing
    - MPP provides new HEC low voltage power supplies
- Requirements
  - 10 µs Level-0 trigger latency
  - 1-4 MHz Level-0 trigger rate
    - 40 MHz digital readout with 2 gains for all 180k cells



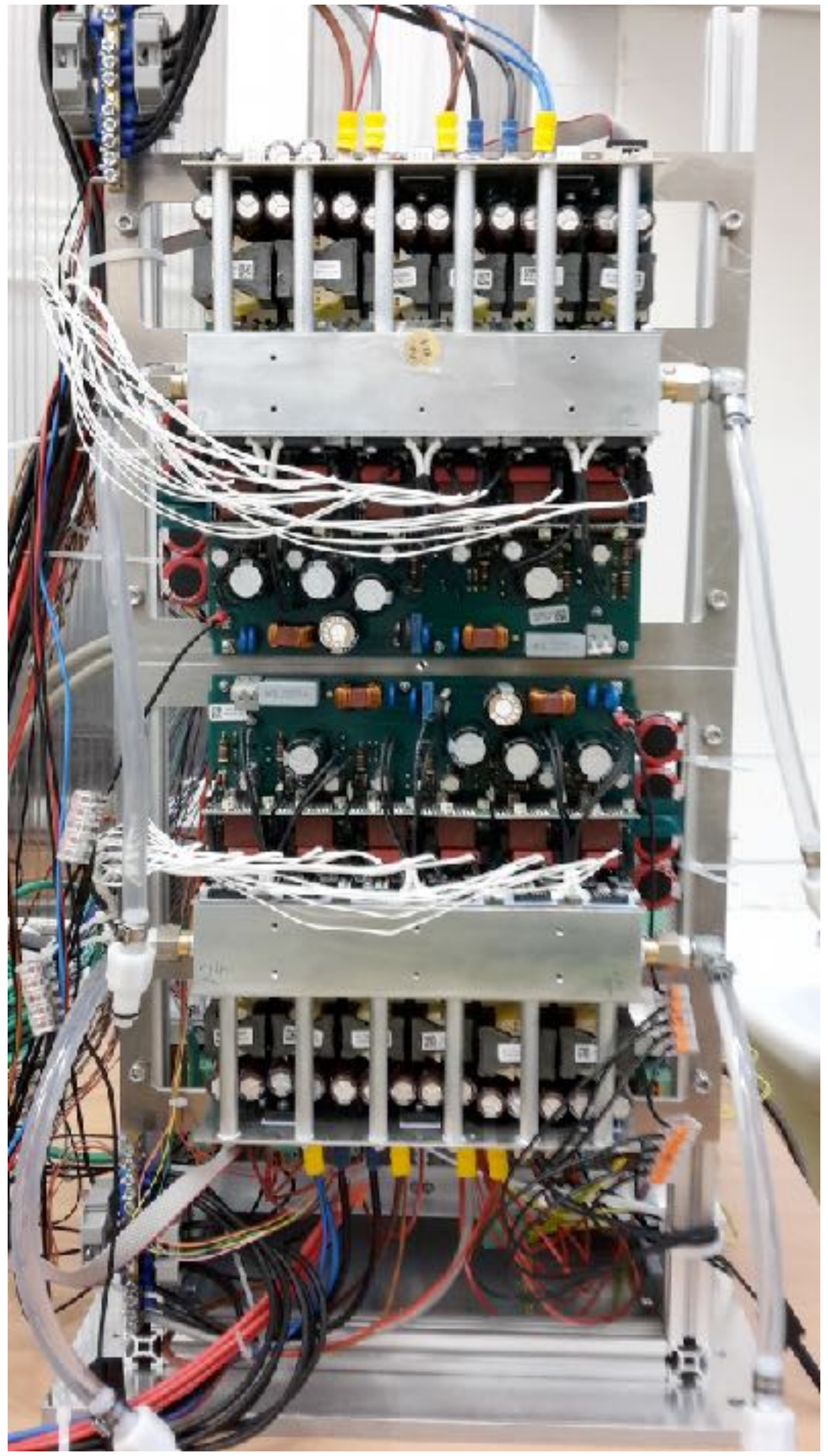
LAr: HEC low voltage power supplies

- MPP responsible for the production of 16 (8 + 8 spares) new radiation-hard Low Voltage Power Boxes for the HEC
- To be installed in 4 new positions per side in ATLAS (blue tiles)
  - Need up to 16m longer warm cables
  - Electrical tests o.k.
  - Need still in-situ noise test in ATLAS to confirm
  - Mechanical design allows extraction of the boxes in closed detector position (maintenance/repairs)



LAr: HEC low voltage power supplies

- Power board pre-prototypes tested
  - Using radiation hard MOSFET technology
  - Neutron Fluence (NIEL) and Total Ionising Dose (TID) tests of full pre-prototypes boards done
- Electronics
  - radiation-hard voltage regulators already secured in sufficient quantities
  - radiation-hard component chosen for monitoring
  - FPGA for Low-Voltage Boxes selected after successful radiation tests (picture on bottom right)

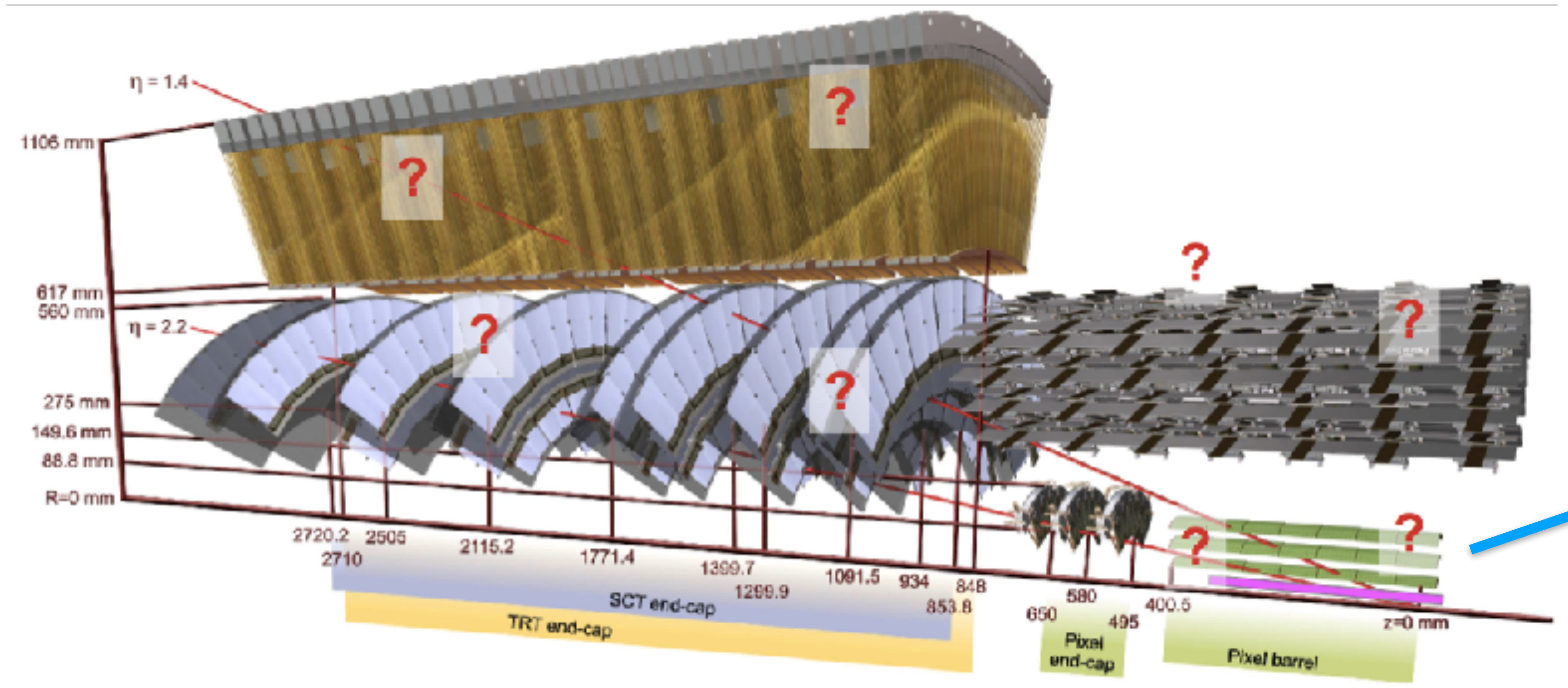


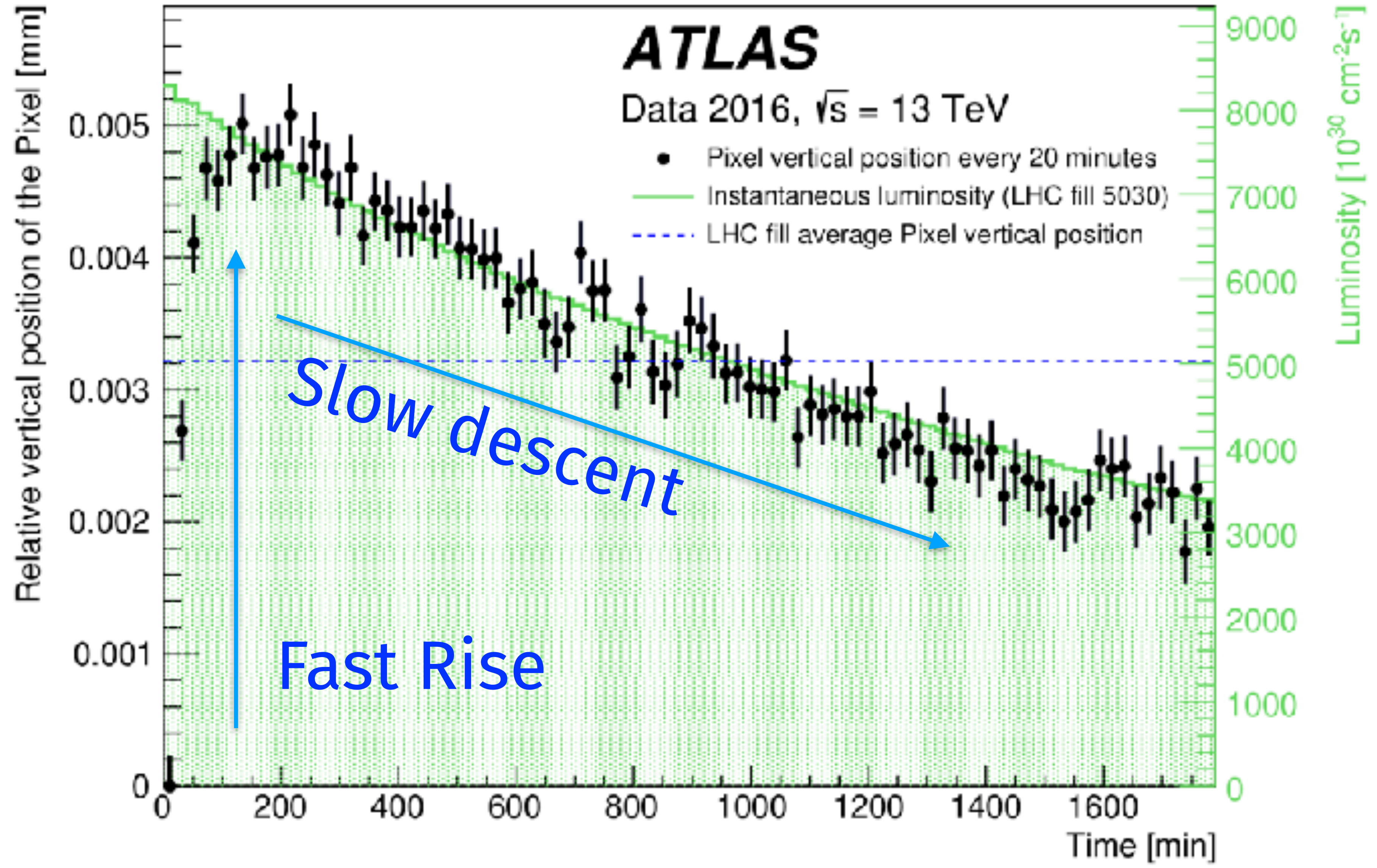
ATLAS Inner Tracker

Inner Detector Operation: Alignment

[Further Info here!]

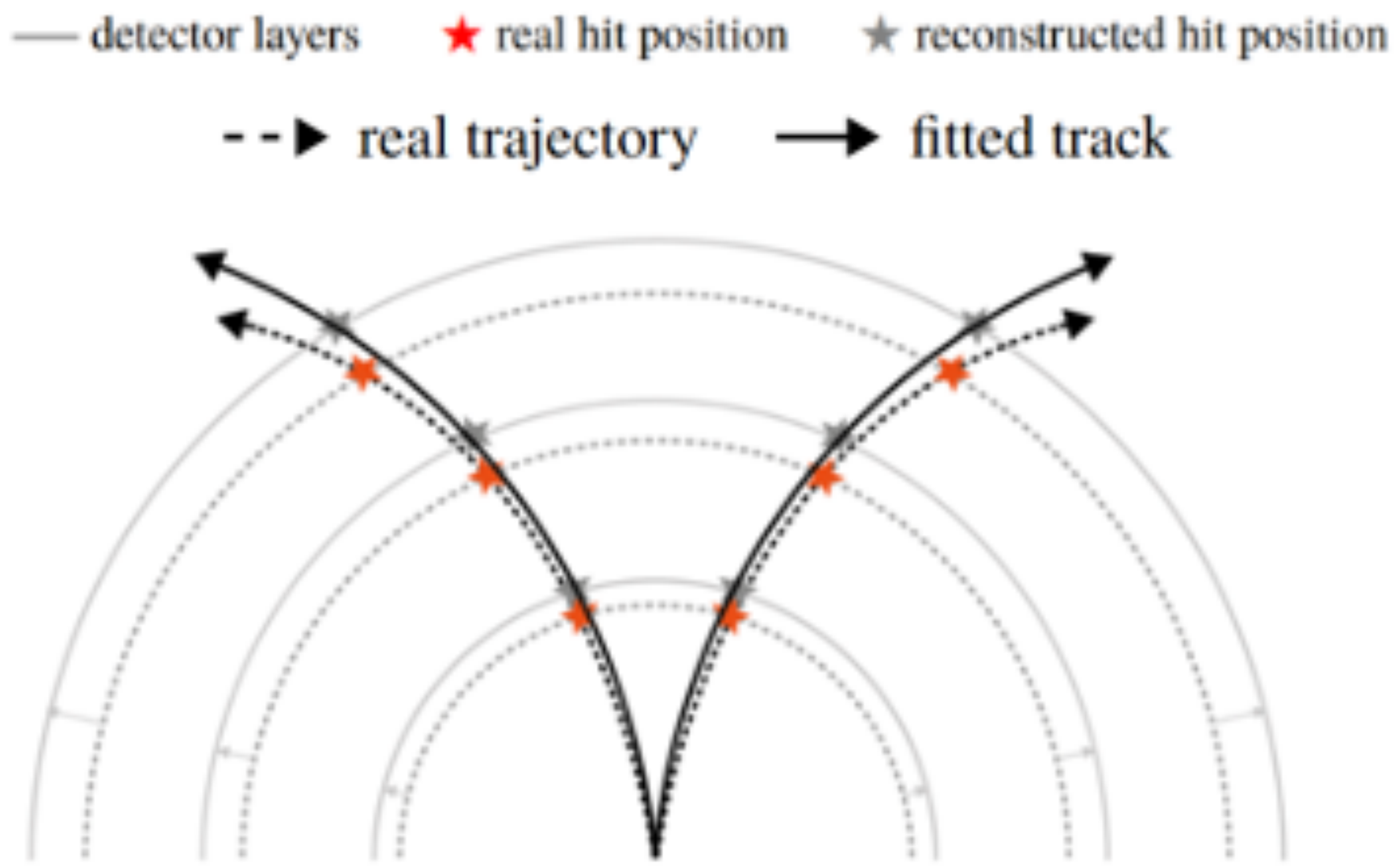
- For an accurate reconstruction, a precise knowledge of the position and orientation of each tracking component is needed.
  - This is achieved by the track-based alignment
  - Short Timescale movements during operation
- E.g. vertical displacement of the pixel sub-detector (See plot)
  - New alignment constants derived during data-taking



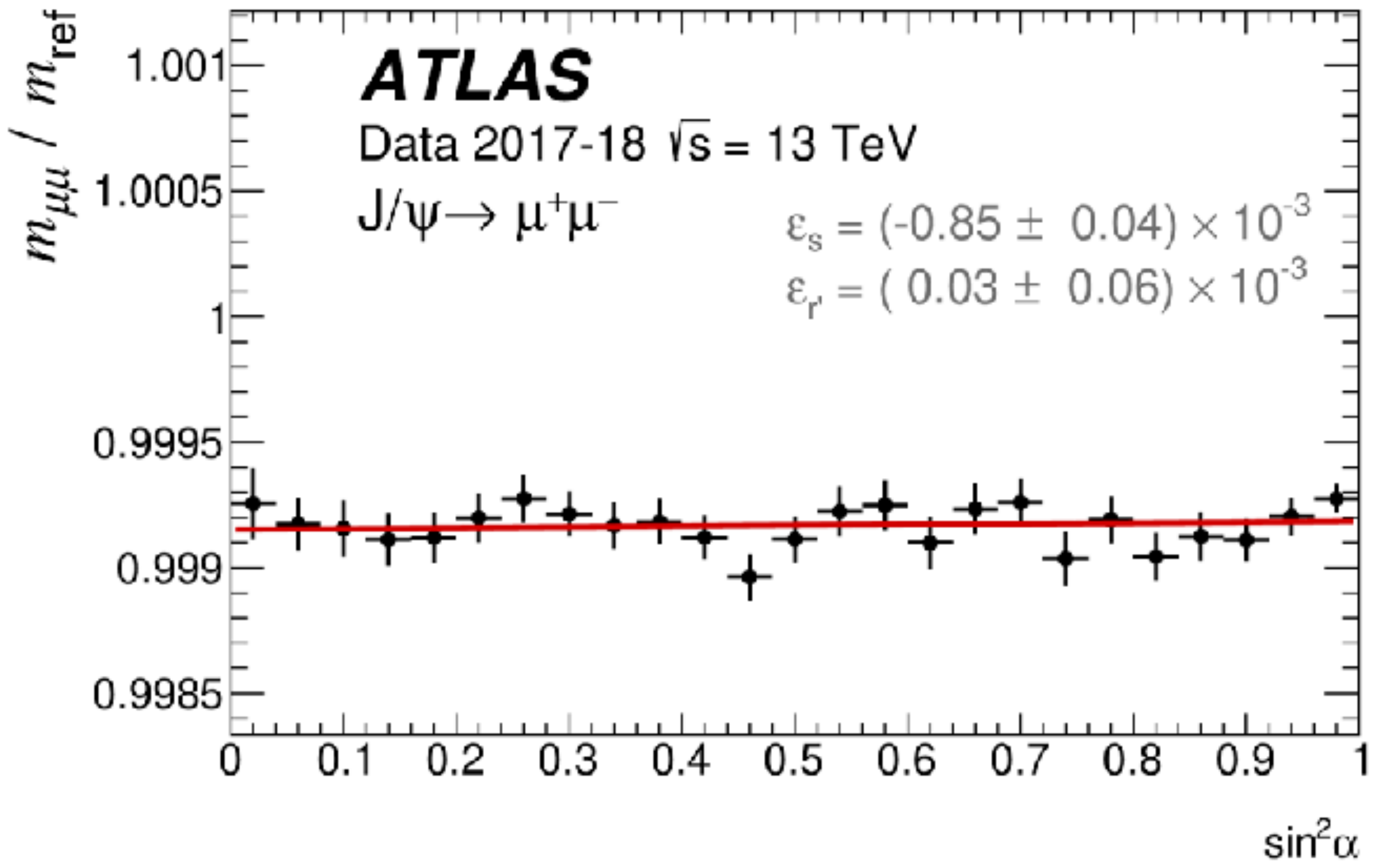


ID Alignment: Removing bias on track parameters

- Well-known particles as Z-bosons or J/Psi-mesons are exploited to measure and minimise possible biases of the tracks
- Both of these particles decay to pairs of oppositely-charged muons, whose measured energy and direction would be impacted by length-scale biases
- Using such decays, it has been proven that the Inner Detector is free of global momentum scale biases at the level of 1 per mille



Radial expansion of the detector



News › News › Topic: Experiments

Voir en français

Keeping the ATLAS Inner Detector in perfect alignment

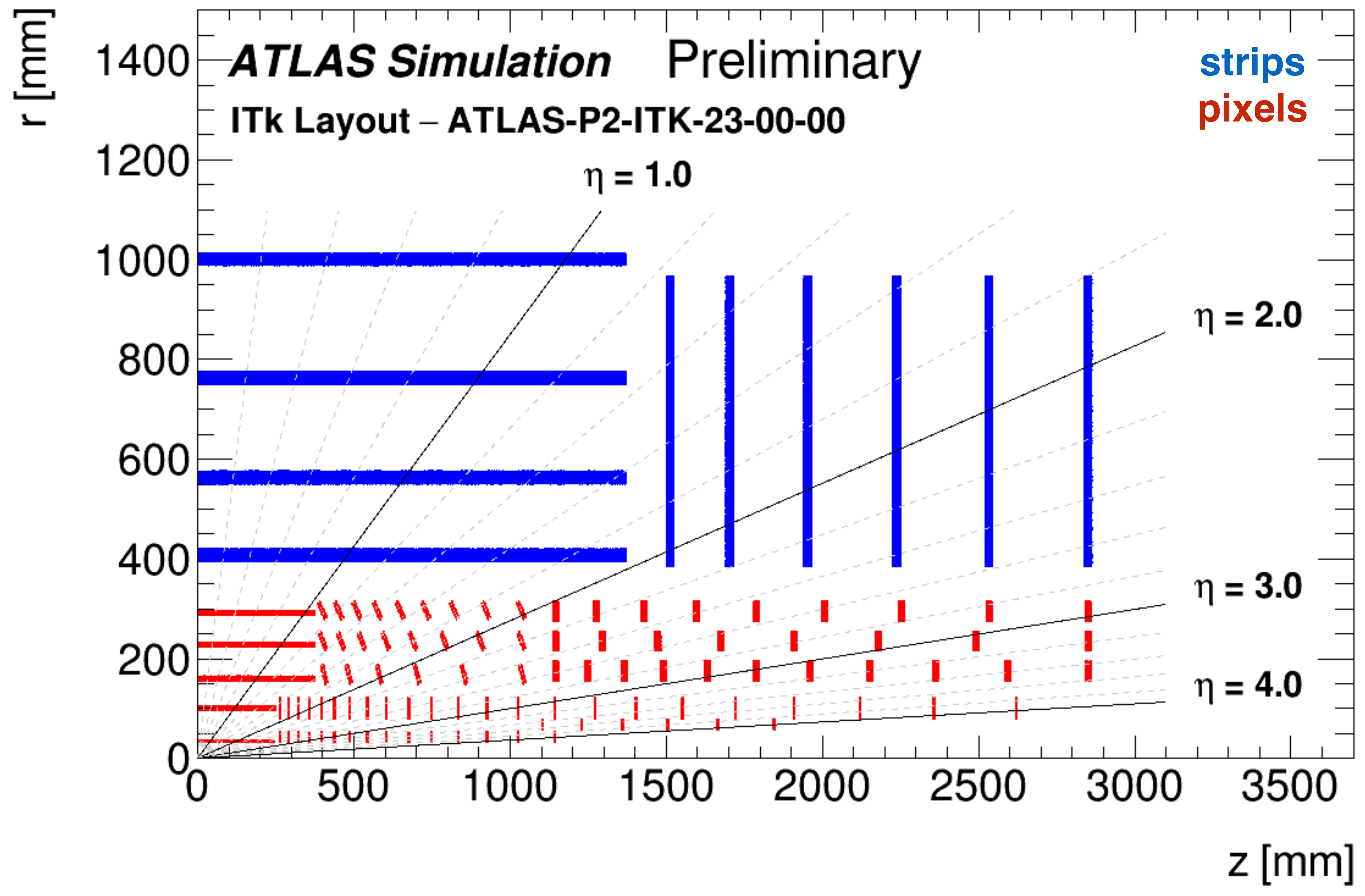
The ATLAS Inner Detector can measure the position of charged particles that pass through it to better than a 100th of a millimetre! To reach that precision, the detector must be aligned to equal or better accuracy

30 SEPTEMBER, 2020 | By ATLAS

Further information can be found in a pair of outreach articles:
ATLAS briefing
CERN news

ITk: Phase-II Upgrade

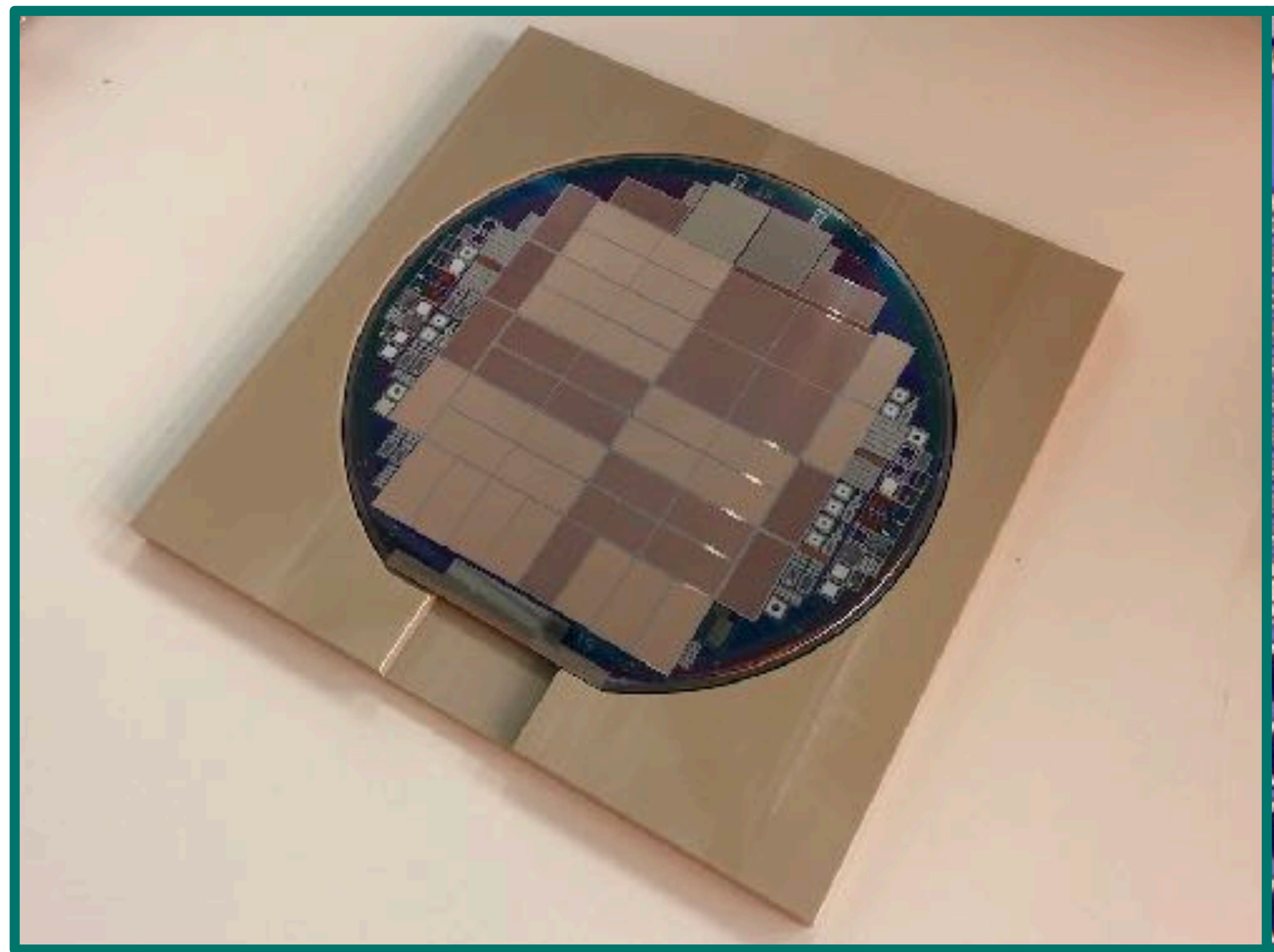
- Phase II Upgrade:
  - replace current ATLAS Inner Detector
- ATLAS Inner Tracker: all-silicon tracking detector
  - strips: 4 barrel layers, 6×2 end-cap discs
  - pixels: 5 layers, |η| ≤ 4.0
    - MPP contributing to Layer 1 sensor and module production and CO_2 cooling

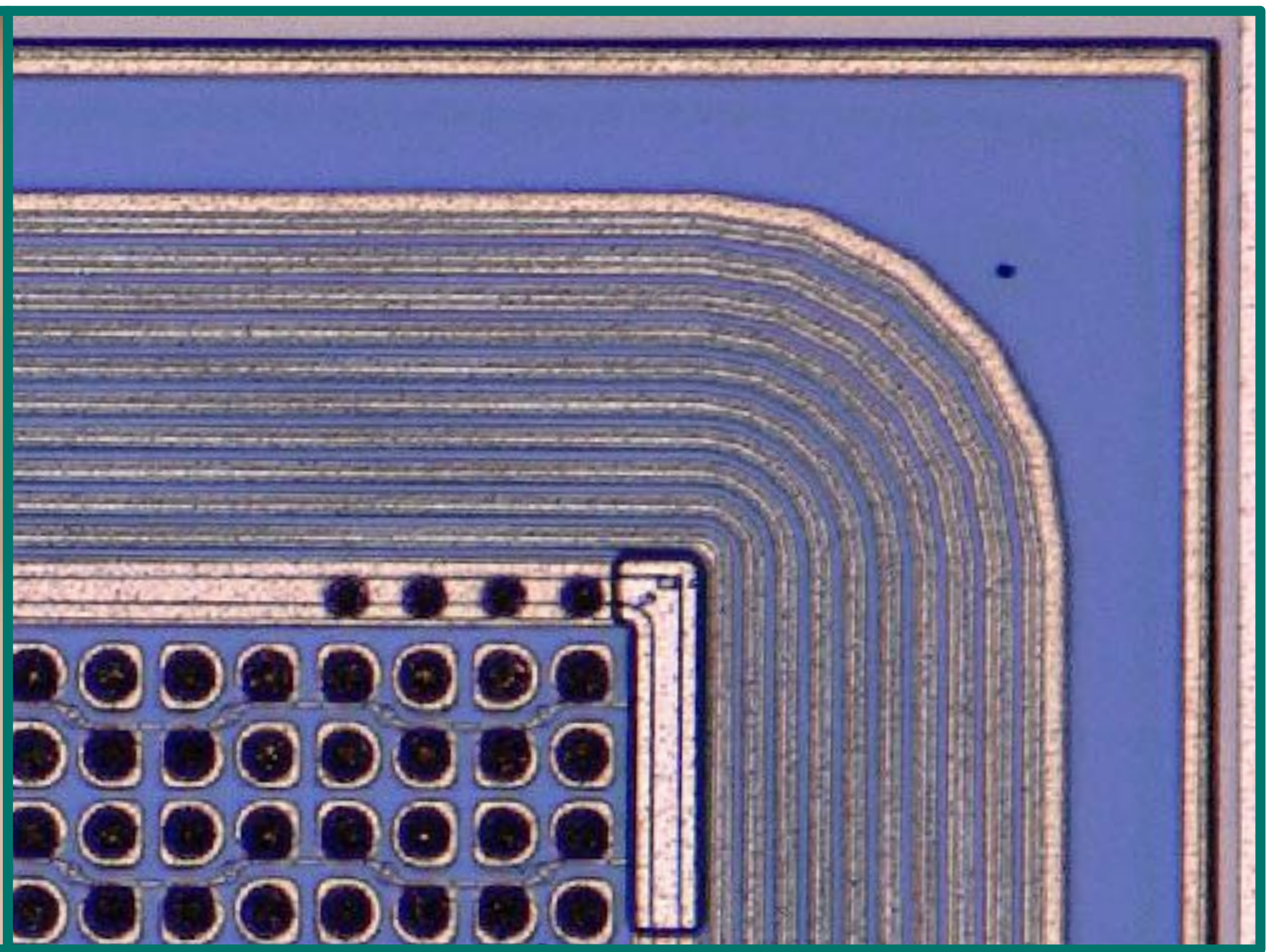


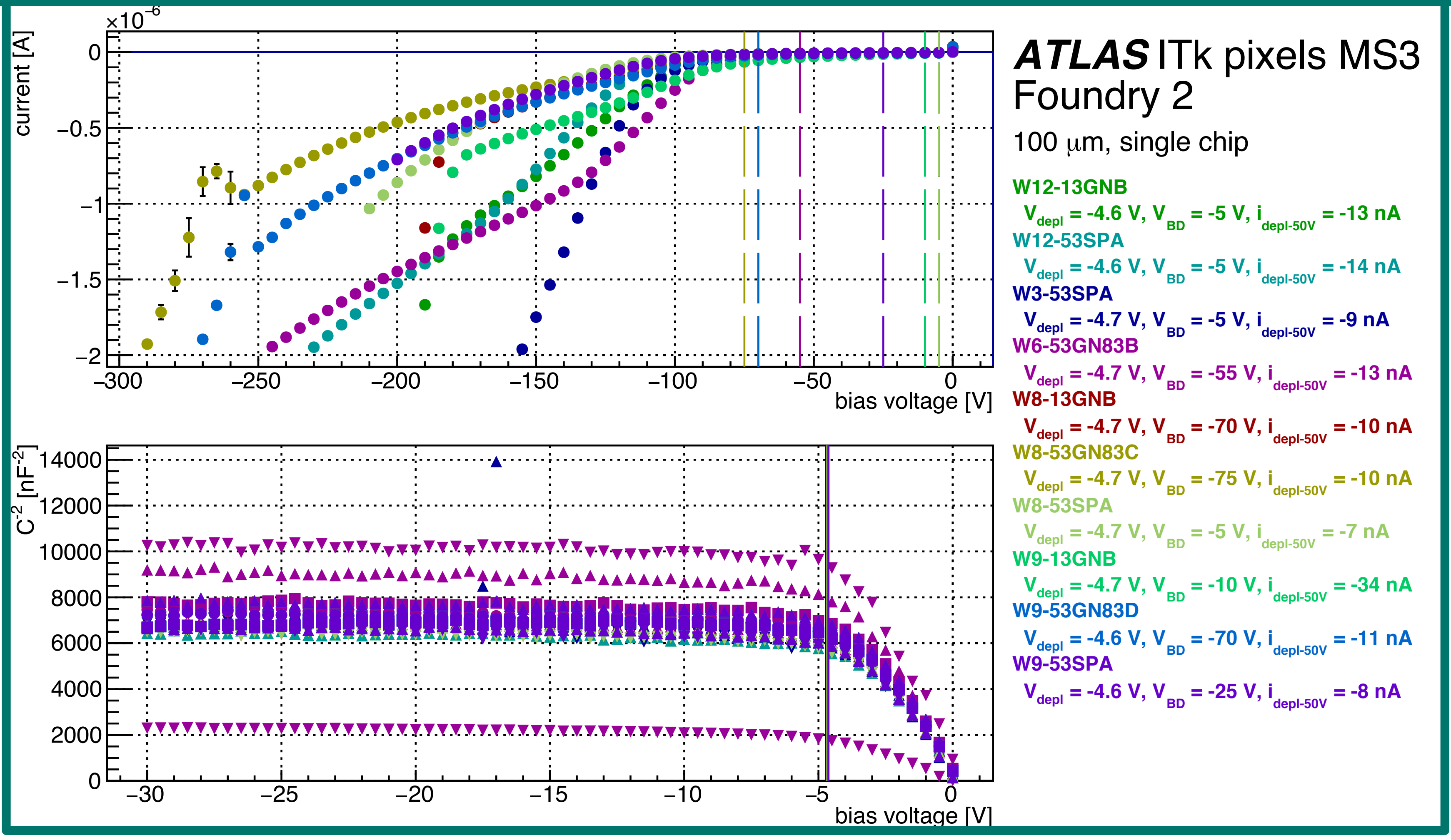
ITK-2020-002

ITk: HLL sensors

- MPG Halbleiterlabor (HLL) participating as a planar pixel sensor manufacturer
- vendor market survey about to be completed:
  - HLL qualified for 100 µm (L1) thin and 150 µm (L2-4) thick sensors
    - focus on 100 µm sensors (L1)
- R&D currently in progress to refine and verify sensor production process
  - scheduled for around 01.2021
- pre-production
  - 10% of the total (8-10 wafers)
  - scheduled for spring 2021
- production
  - 20.6% of total L1 quad sensors
    - 420 quad sensors
  - scheduled for late 2021 to end of 2022

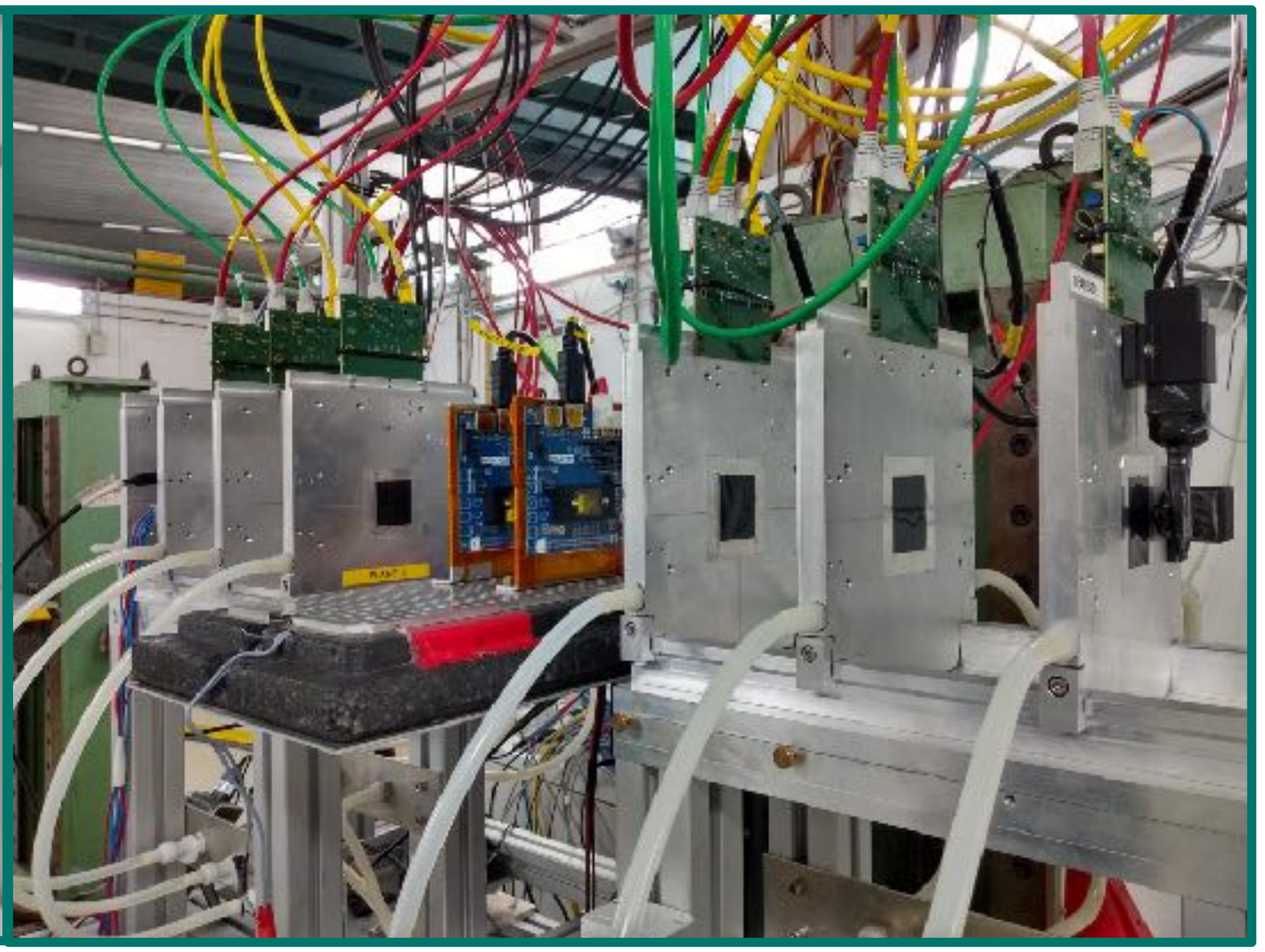


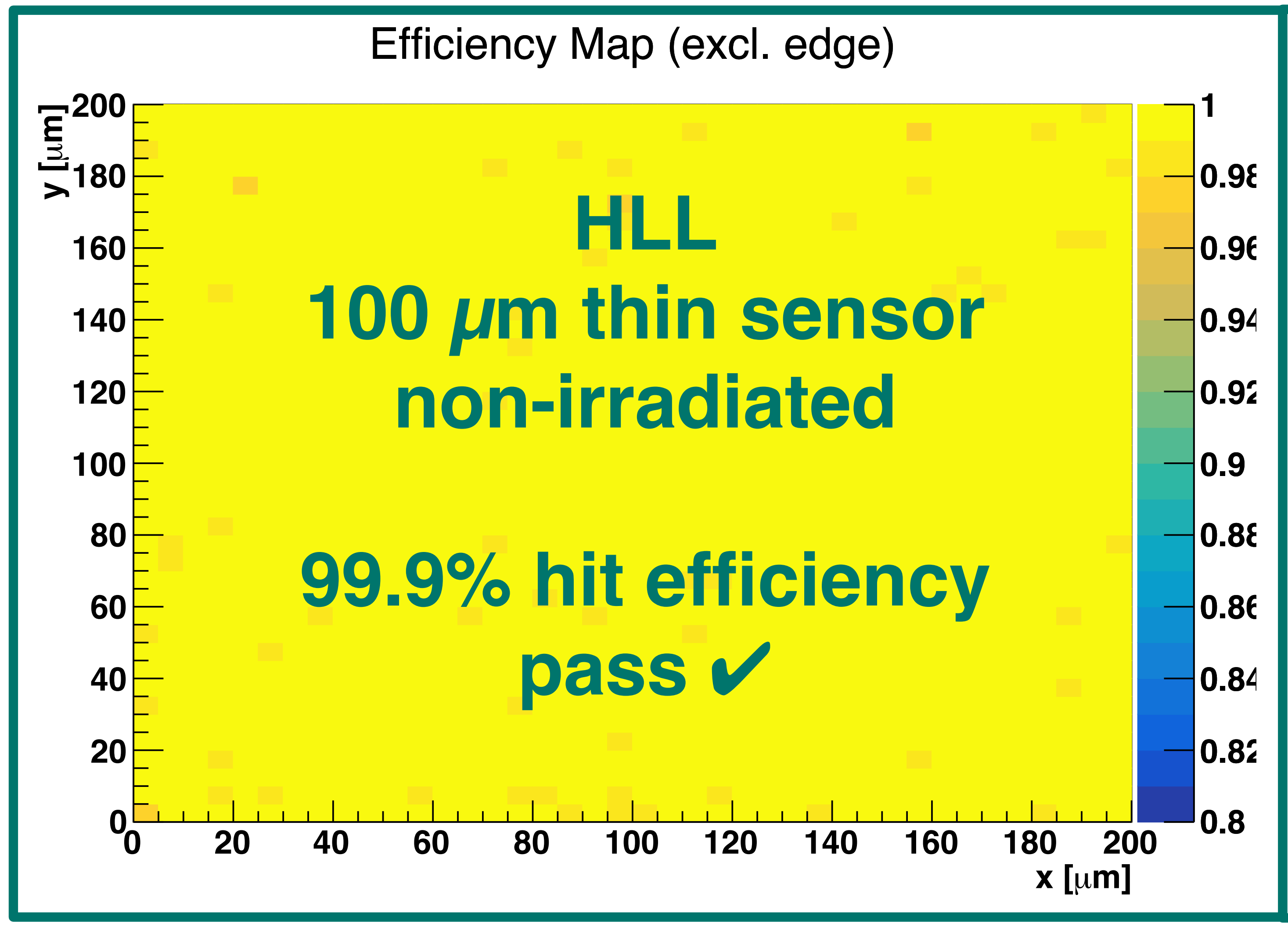


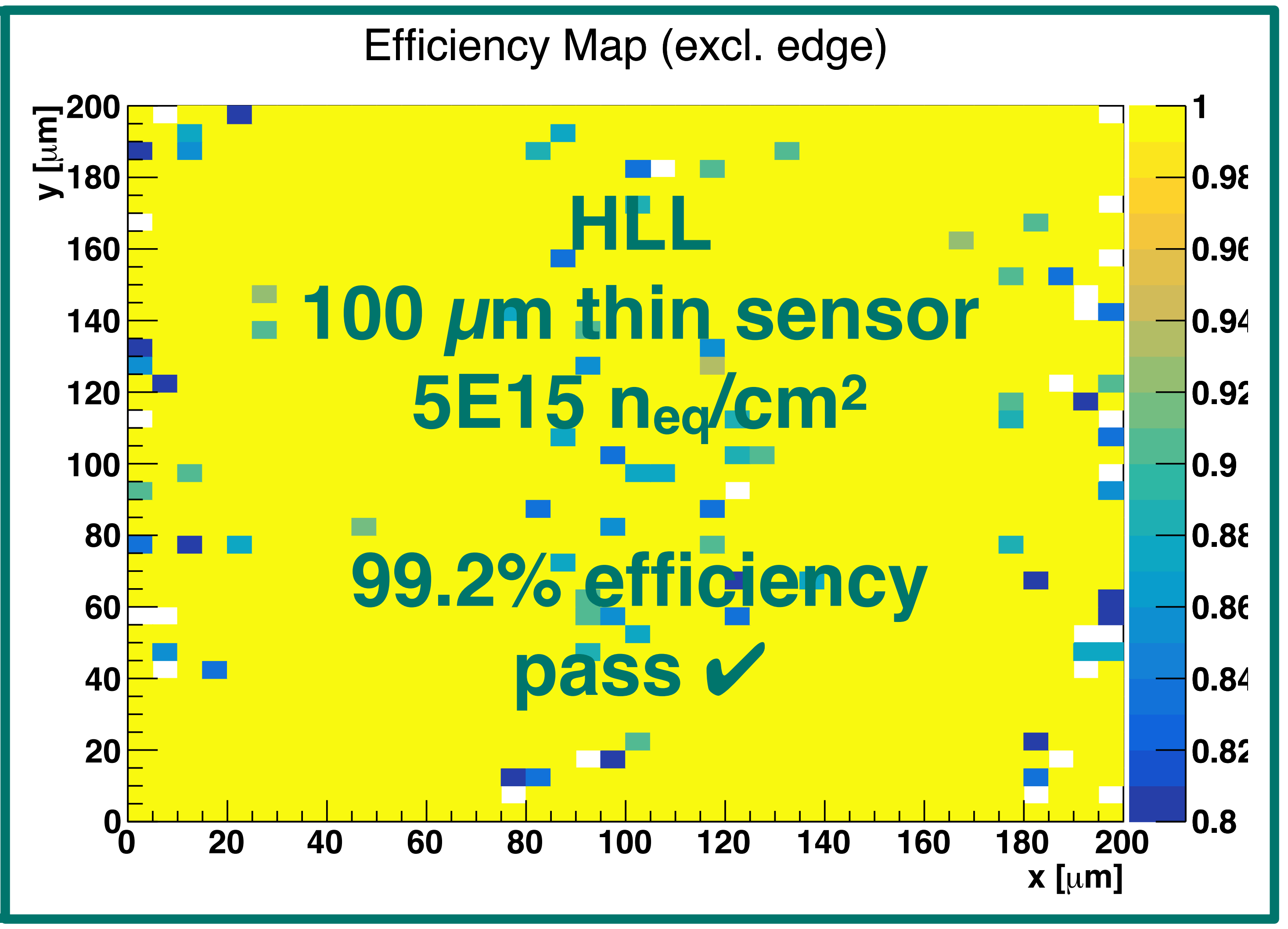


ITk: test-beam measurements

- sensor qualification through test-beam measurements
- sensors from participating vendors measured in a series of test-beam campaigns at DESY in 2019 and 2020
  - 5 GeV electron beam
- hit efficiency requirements
  - >98.5% before irradiation
  - >97% after irradiation
    - 2x10^{15} and 5x10^{15} N_{eq}/cm^2
- test-beam activities to continue in 2021 to measure pre-production modules

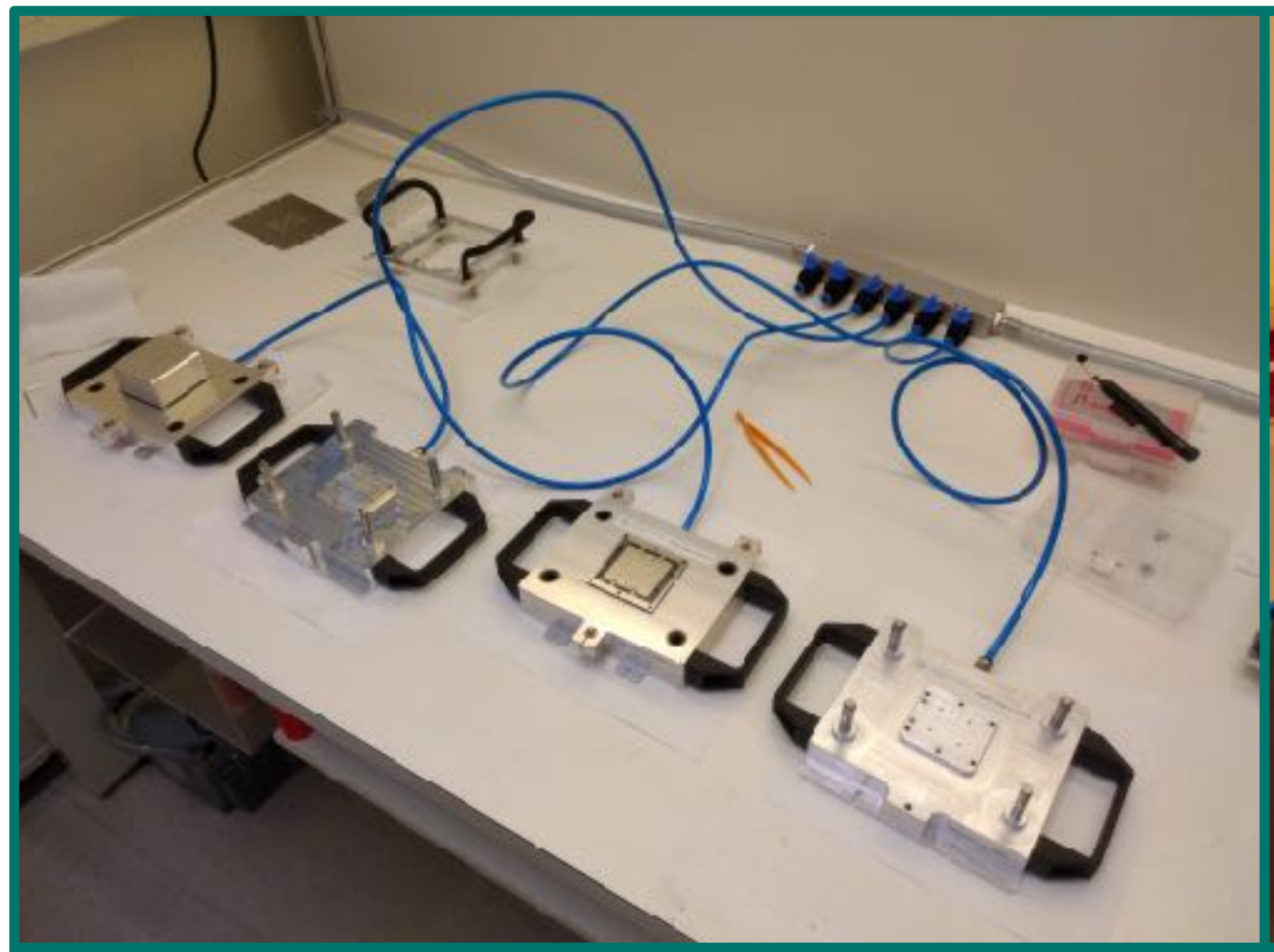


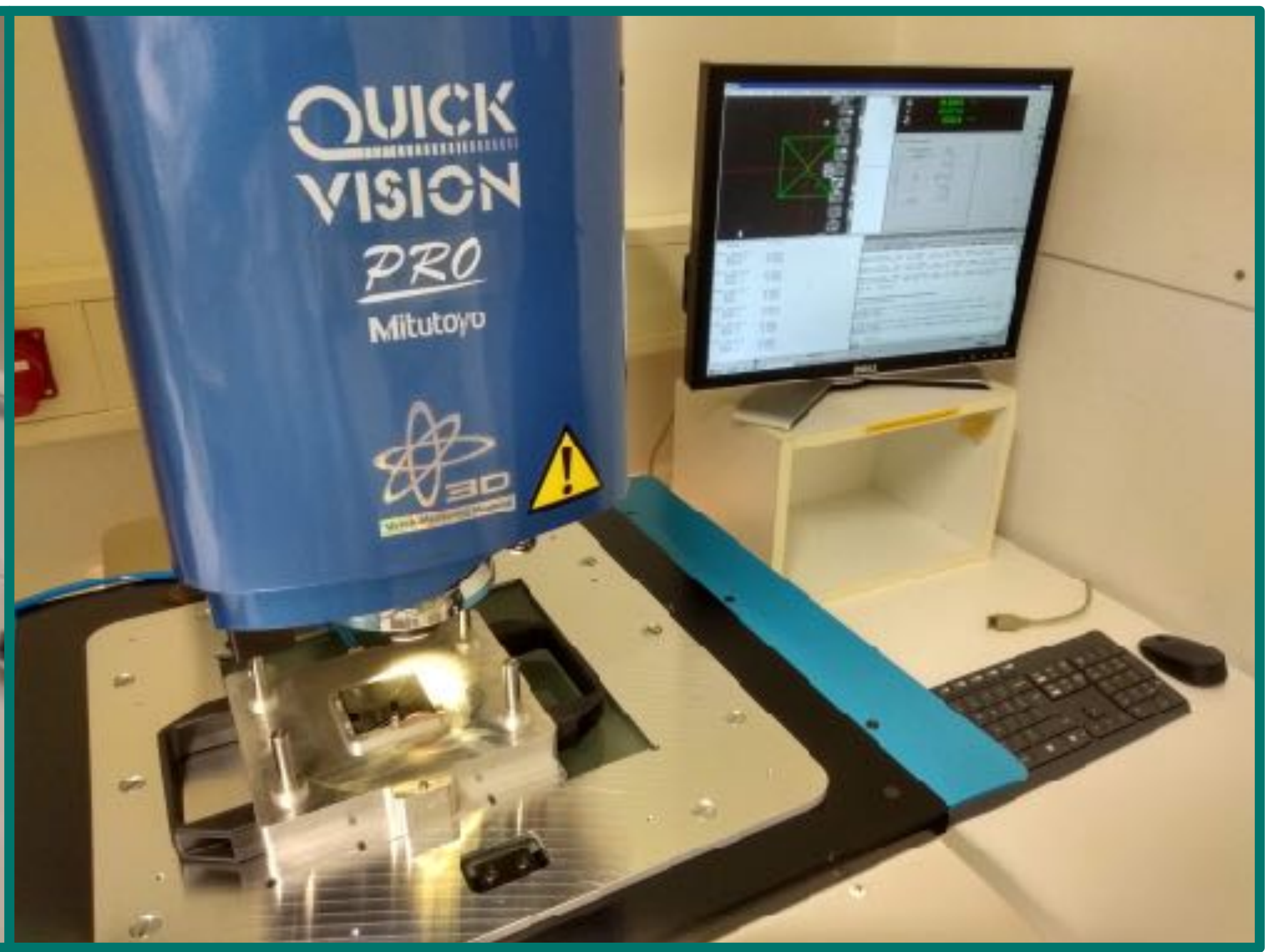


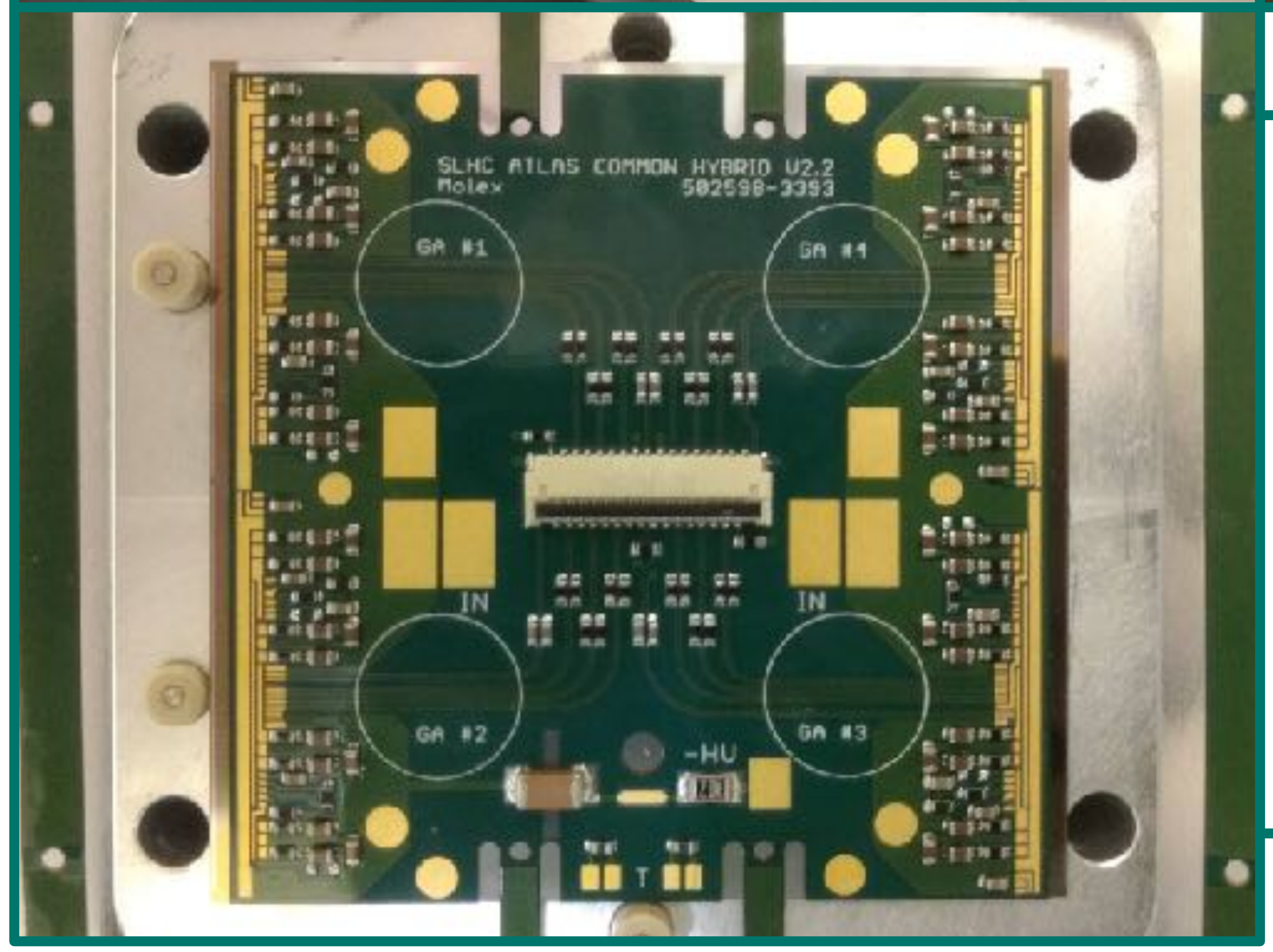


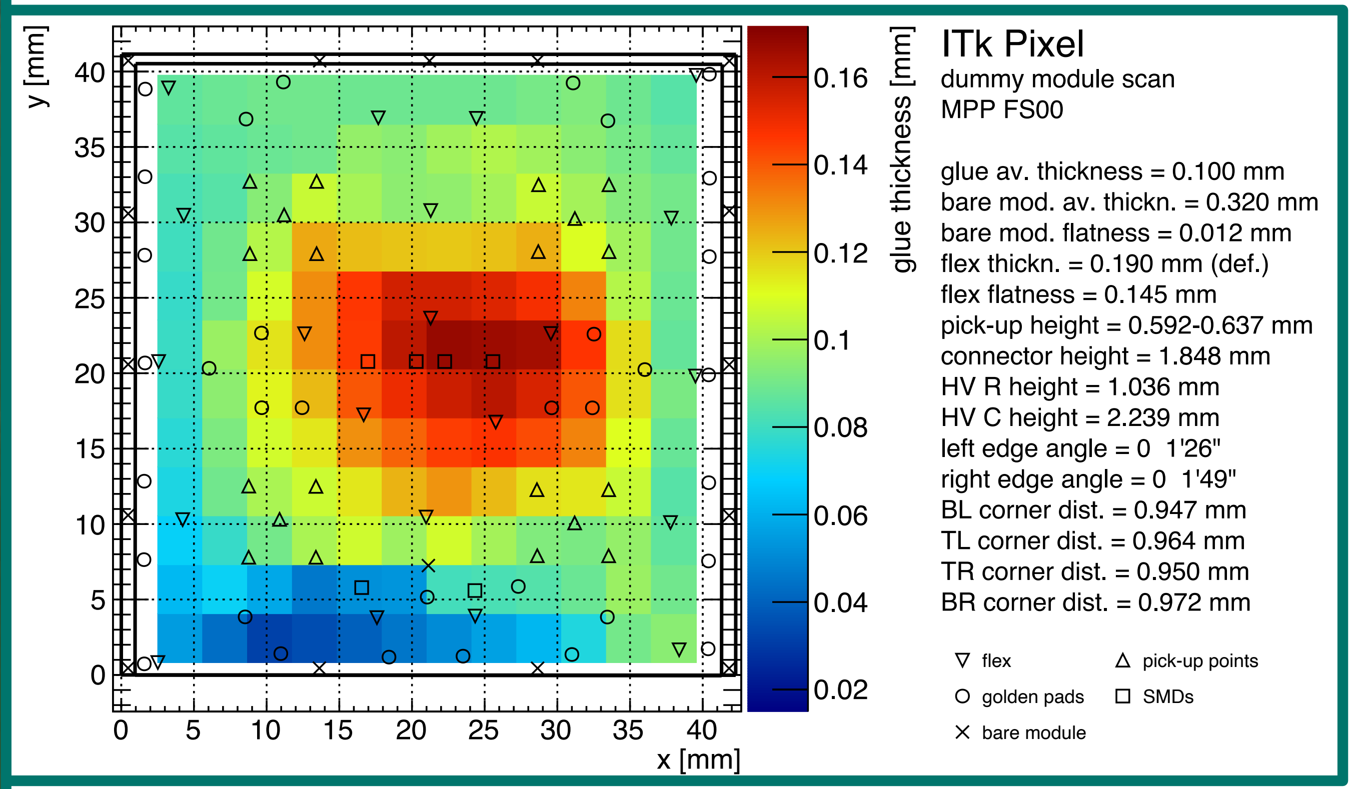
ITk: module assembly

- preparing for MPP qualification as module assembly+test site
- tooling built in-house at MPP
  - calibrated using optical survey measurements
- module building practice ongoing
  - building mechanical modules from dummy components: steel, glass, silicon and dummy flex
- built first silicon+flexible PCB mechanical modules for qualification
  - wire bonding in progress
- upgrading DAQ system for testing 4-chip modules (quads)
  - testing first digital quad module



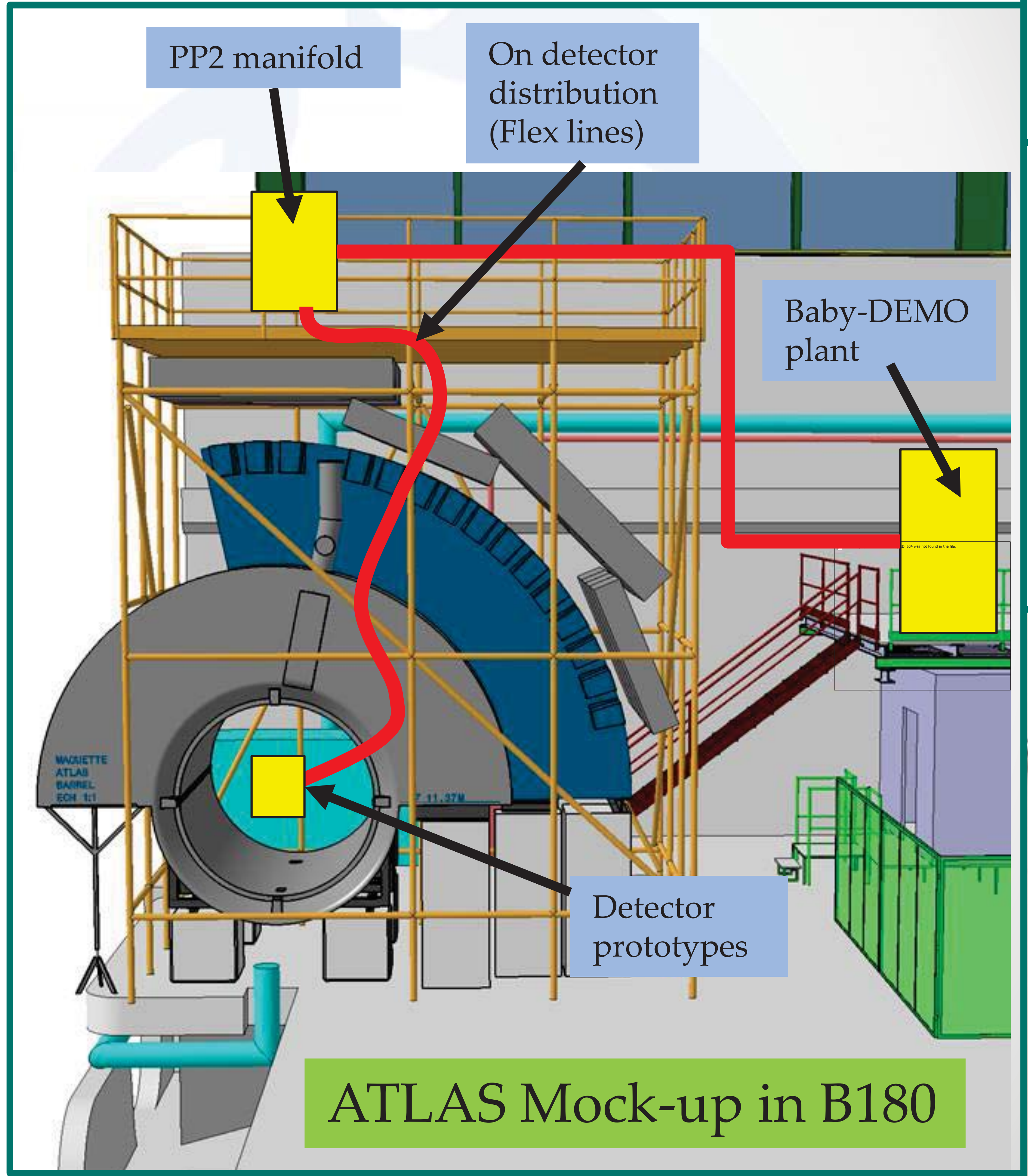


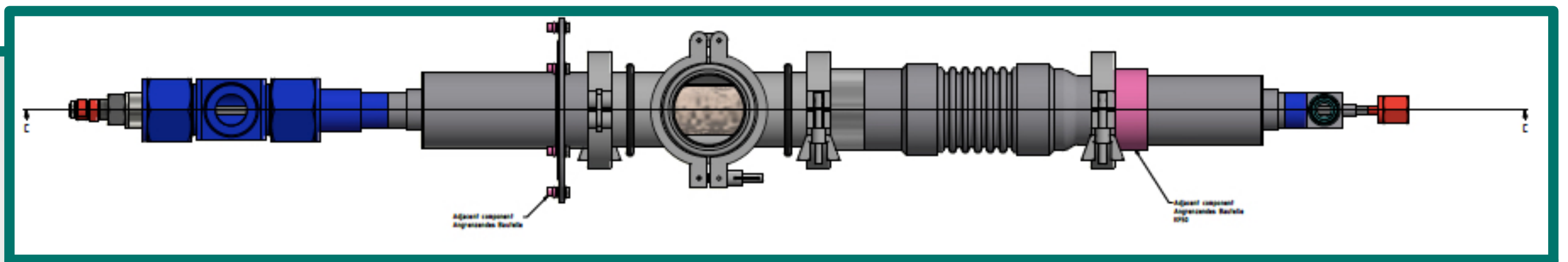


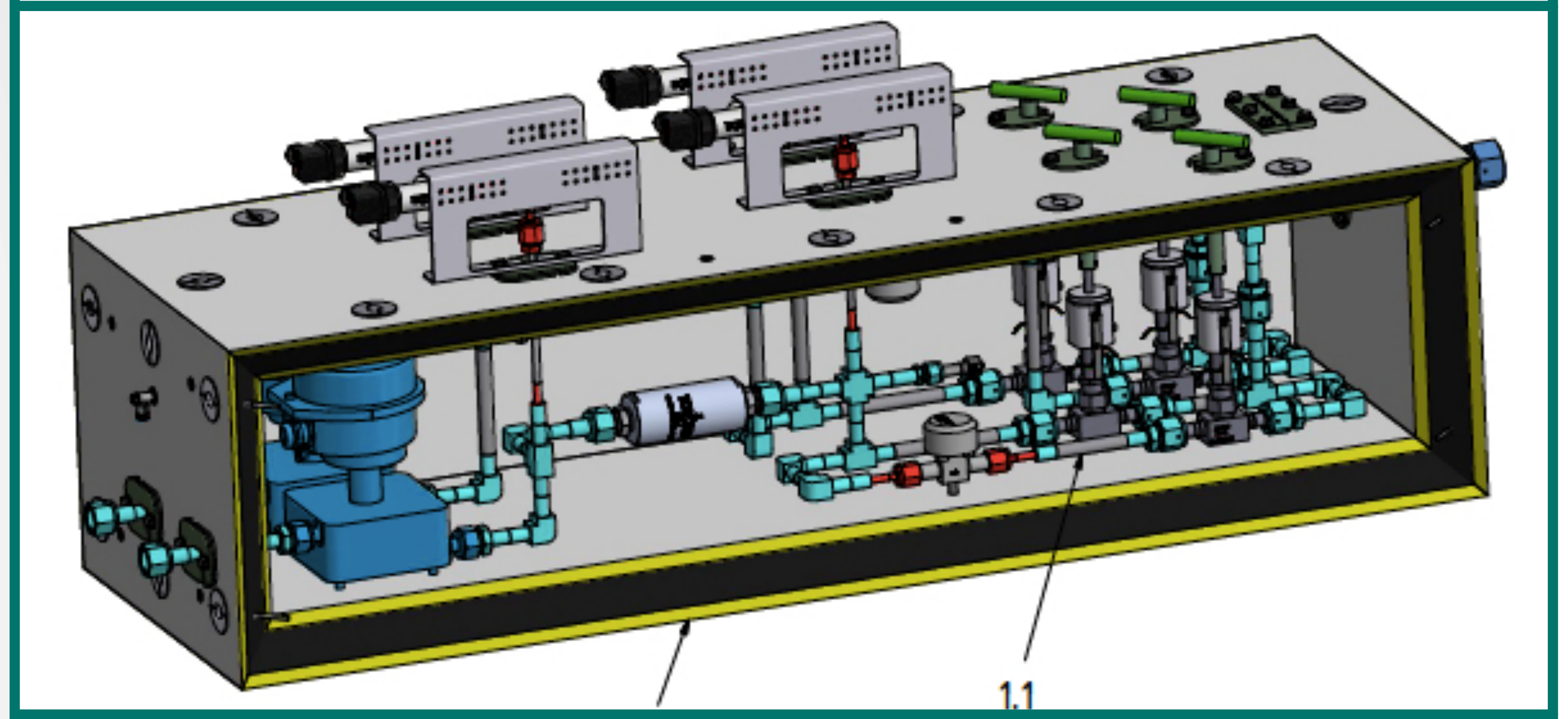


ITk: CO_2 cooling

- MPP contributing to the design of flexible cooling lines and distribution boxes of the ITk CO_2 cooling
- design validated using the Baby Demonstrator setup
  - built around the ATLAS mock-up
  - same geometry as in ATLAS to replicate pressure drops along the cooling path
  - 2.5 kW cooling power plant
  - successfully operated at -40°C needed to cope with ITk L1 power dissipation







Upgrade Timeline

		2021	2022	2023	2024	2025	2026	2027
Muons	sMDT	Production		Commissioning		Integration and Installation		
	RPC	Design	Prototype	Production				
	ASD	Production						
	TDC	Final Design	Production					
	FE cards	Final Design	Production			Installation and Commissioning		
	Trigger	Design	Prototype	Production			Commissioning	
LAr	LVPS	Design		Production		Commissioning		
ITk	Planar sensors	Pre-production	Production					
	Pixel modules	Pre-production	Production					
	CO_2 cooling	Design		Production				

Summary and Conclusions

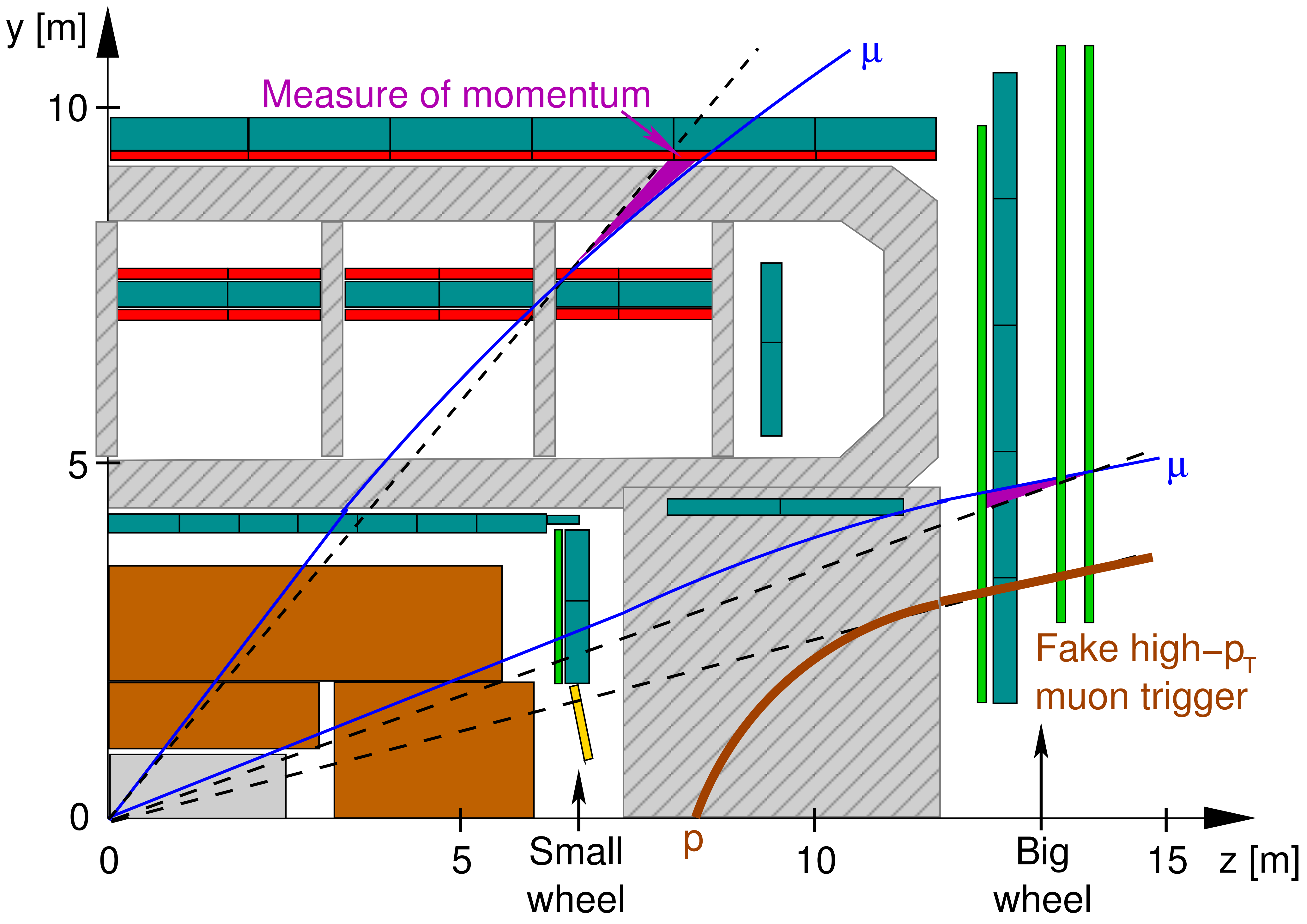
- ATLAS will still collect more than 95% of the planned integrated luminosity (best still to come)
- Huge upgrade program undergoing to cope with challenging conditions of HL-LHC
- MPP plays a fundamental role in the upgrade of the Muon system for the High Luminosity LHC
- MPP provides also major contribution to the operation and upgrades of the Inner Detector and Liquid Argon calorimeter
- Thanks to the technical department for the unique support (especially under Covid)

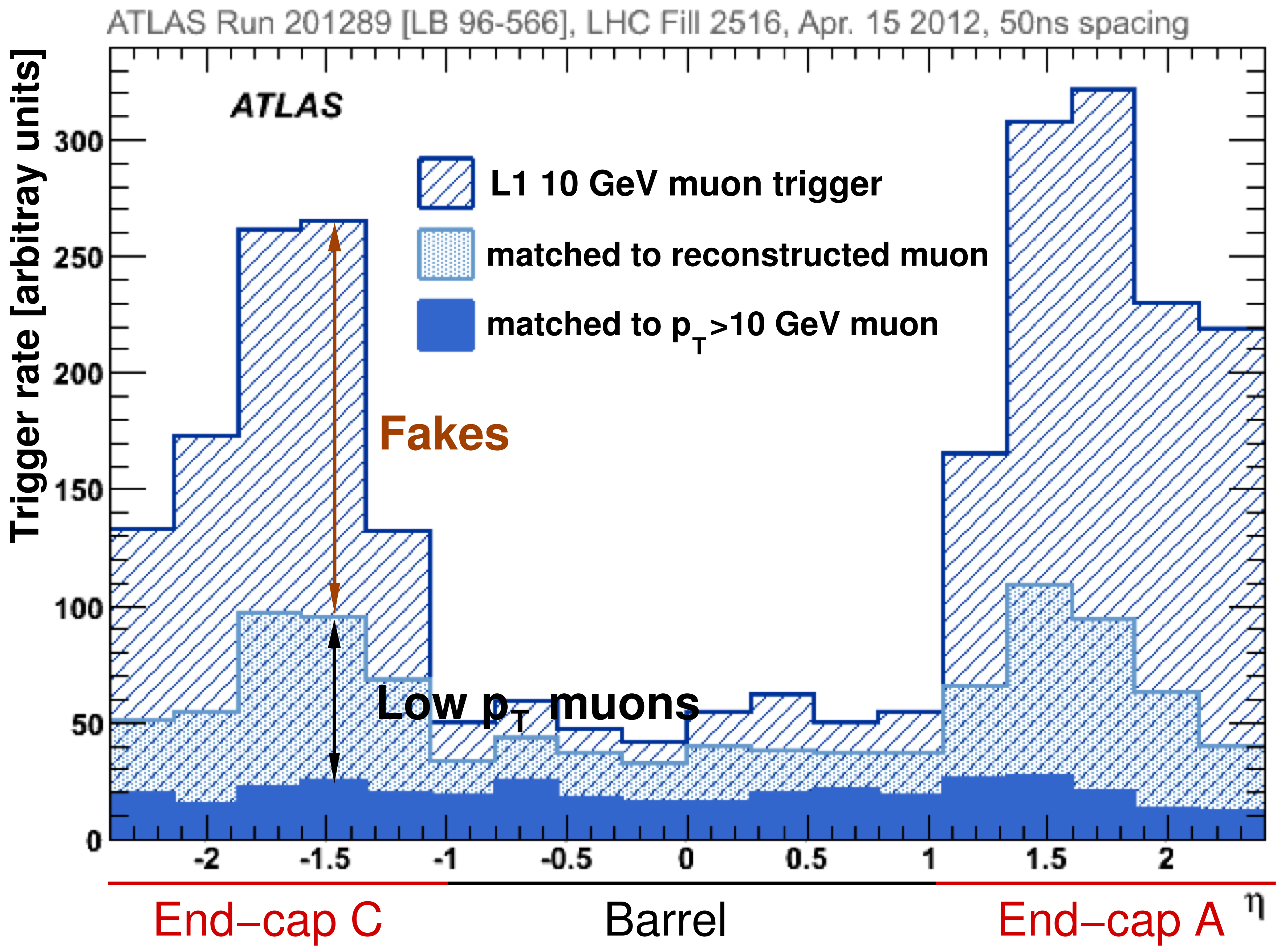
Thank you for listening, any questions?

Davide Cieri (MPP Munich) - davide.cieri@cern.ch

ATLAS Muon System Upgrade

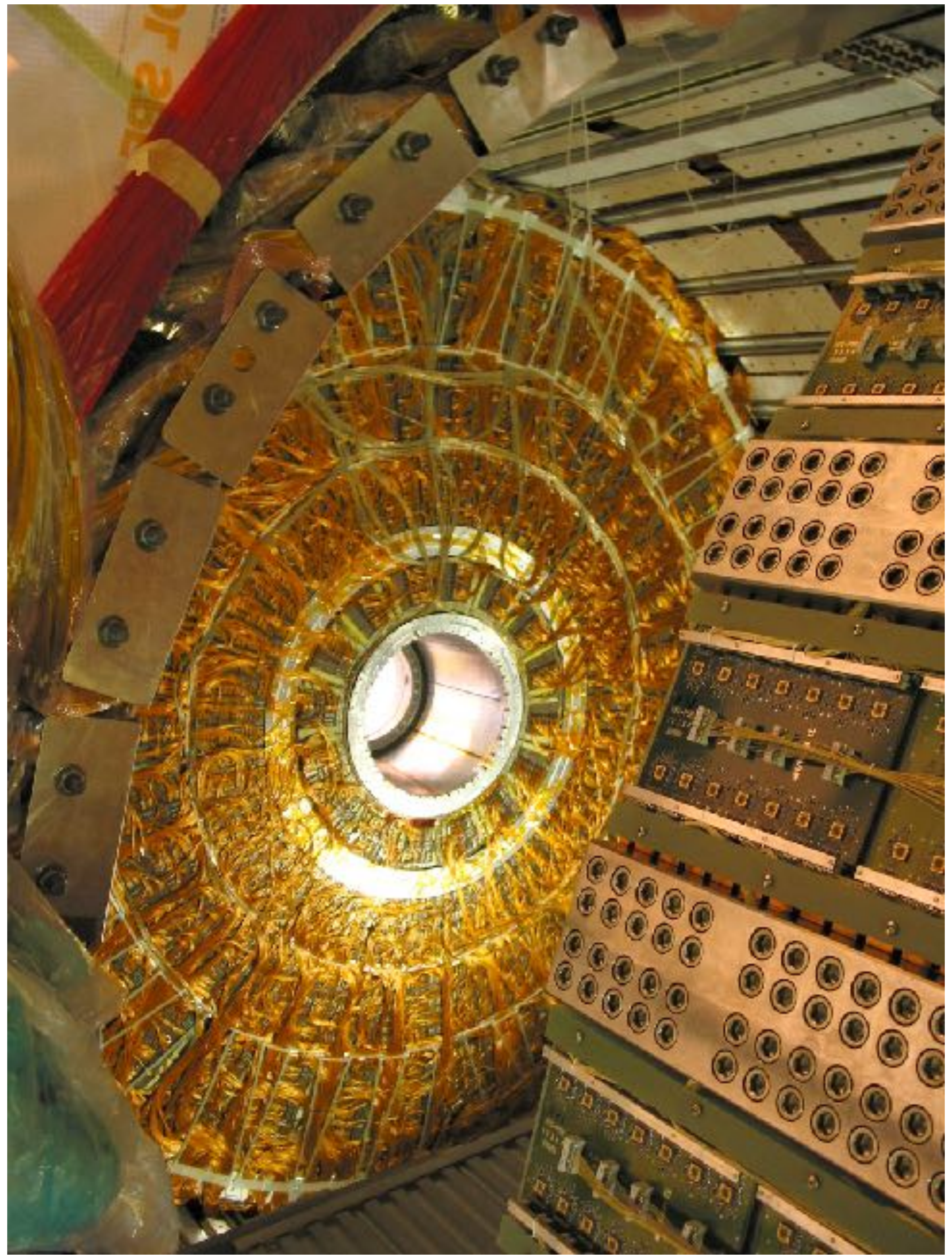
- Muon Spectrometer upgrade is a muon trigger upgrade
- Current level-1 high p_T muon trigger uses coincidences of three RPCs in the Barrel or three TGCs in the big end-cap wheel
- Muon momentum estimate from the size of the deviation of hits from an infinite momentum track from the interaction point
- Trigger rate dominated by fake triggers in the end-caps caused by charged particles not emerging from interaction point
- High rate of under-threshold muons, because of moderate spatial resolution of the trigger chambers

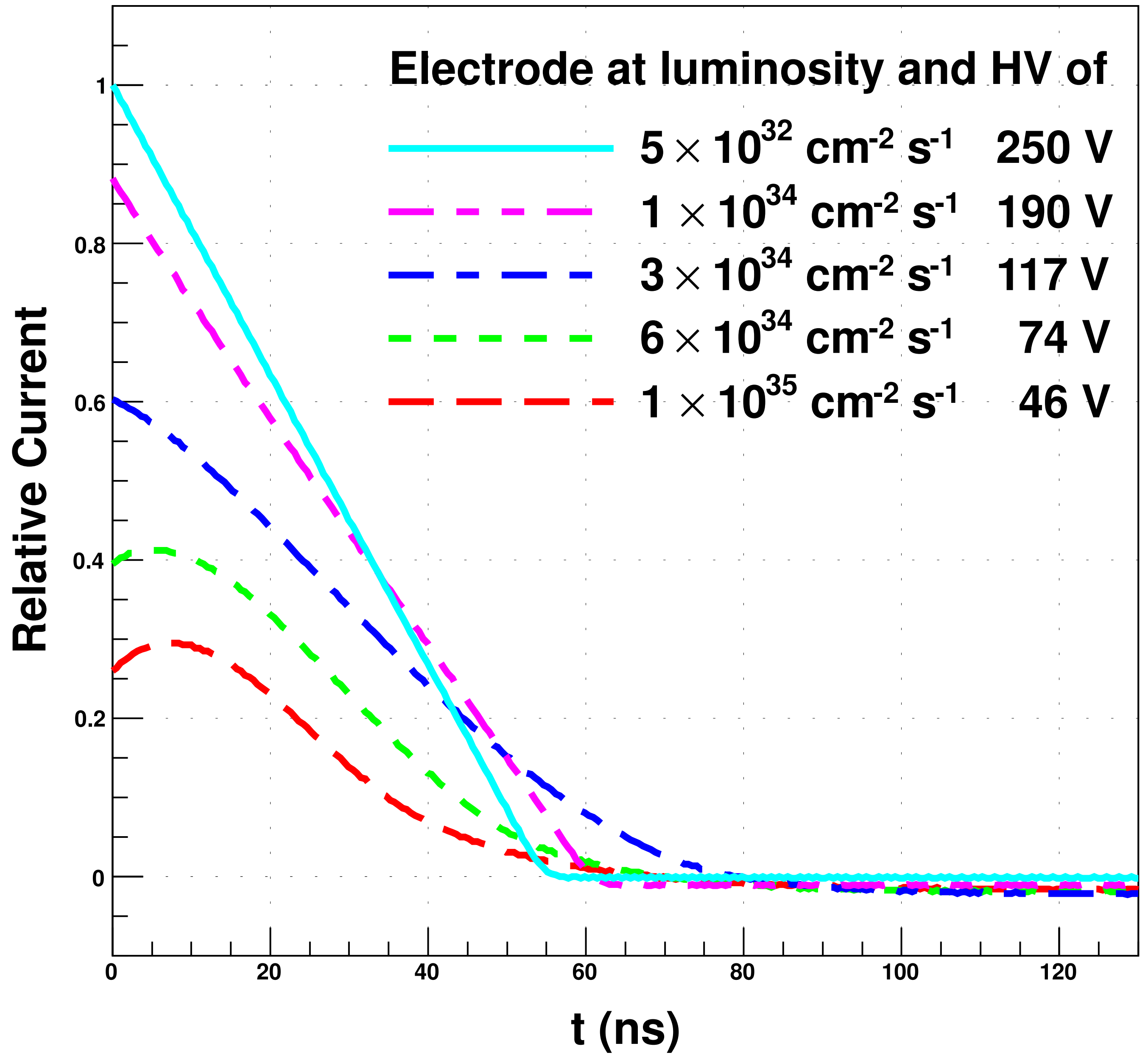




LAr: MPP contributions

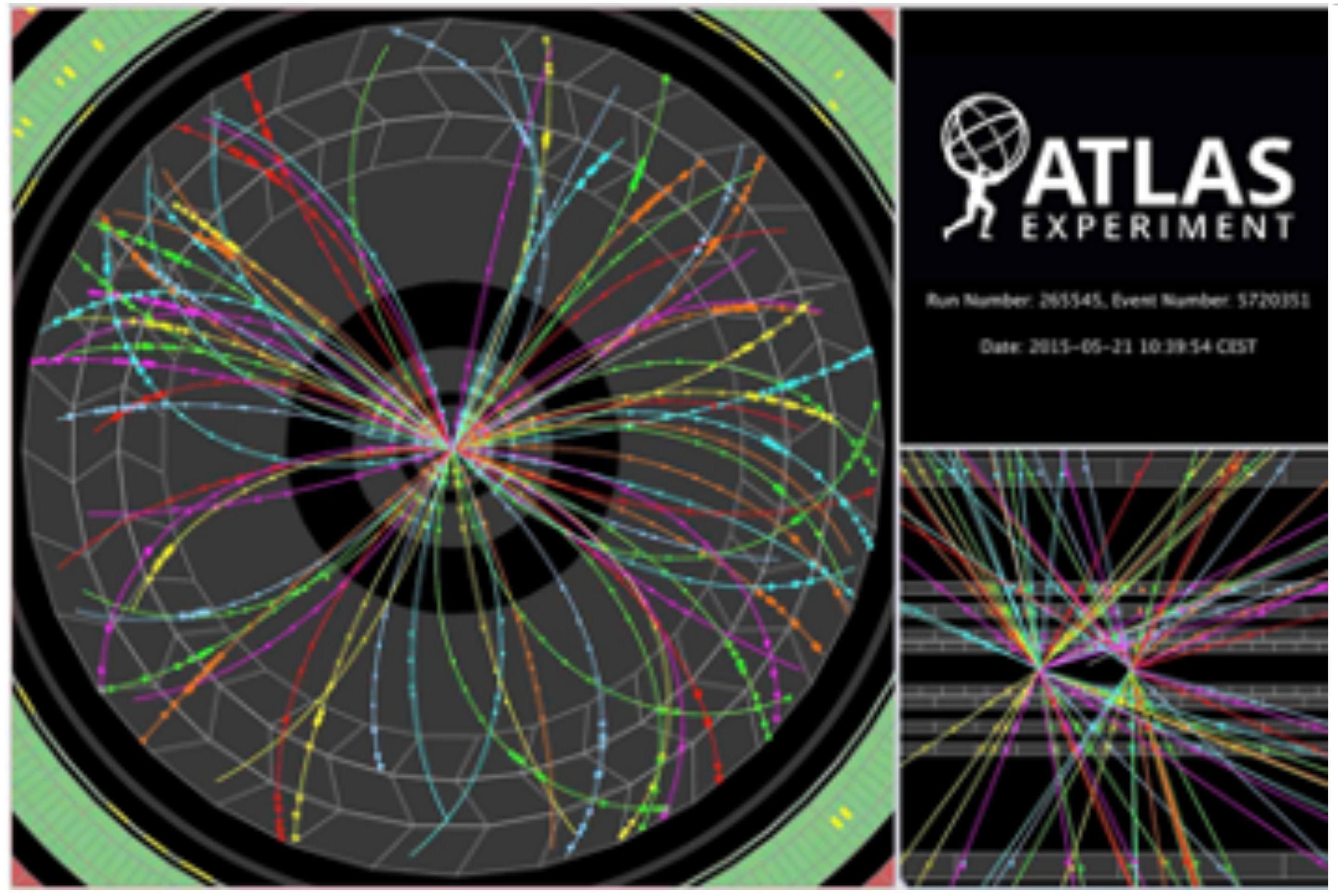
- HEC Readout electronics
  - GaAs based ASICs stay in cold since we tested them as rad-hard enough
  - need special front-end ASIC since polarity, gain and timing differ from rest of LAr
  - need more radiation-hard new low-voltage power supplies
- FCal studies
  - signals in FCal will be degraded at HL-LHC (plot to the right) due to large HV currents through protection resistors lowering the HV over the LAr gaps
  - potential build-up of positive argon ions in the gaps destroying the electric field

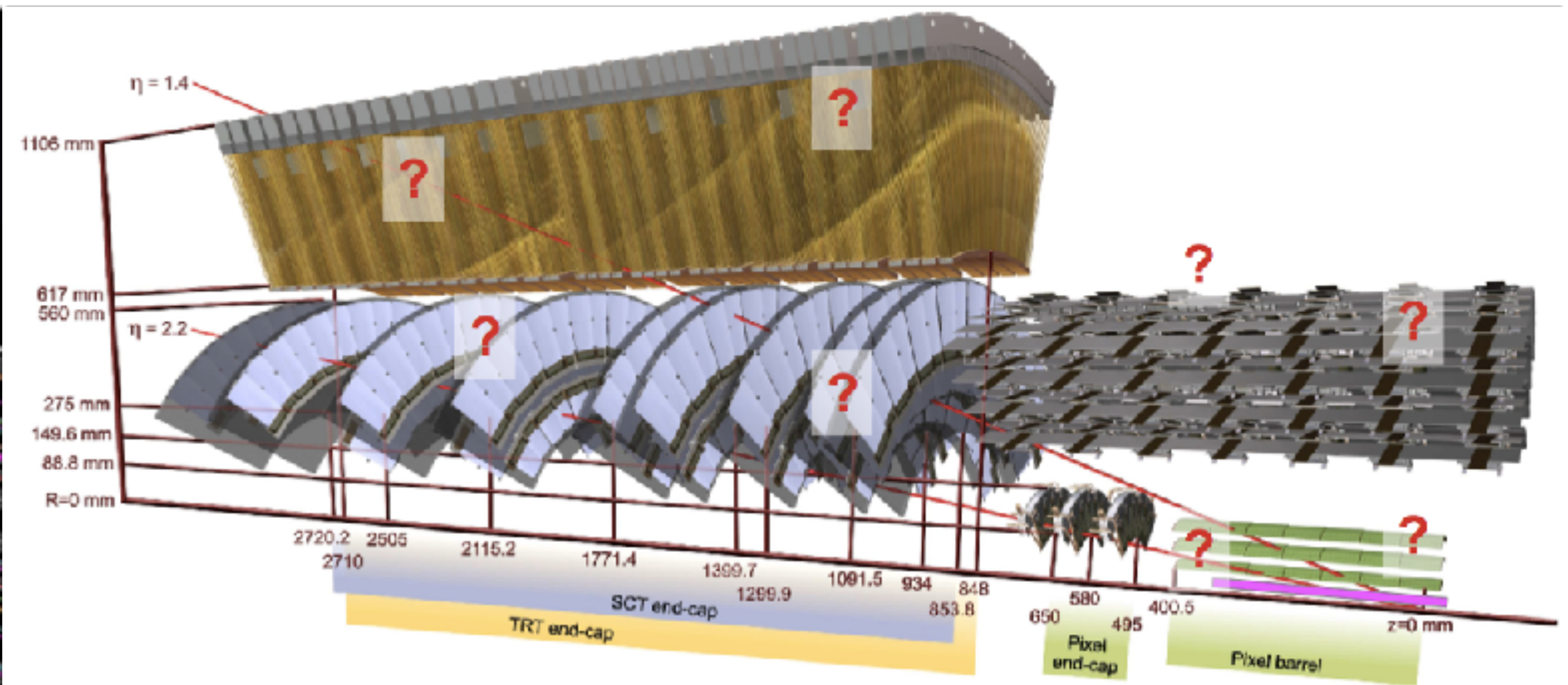




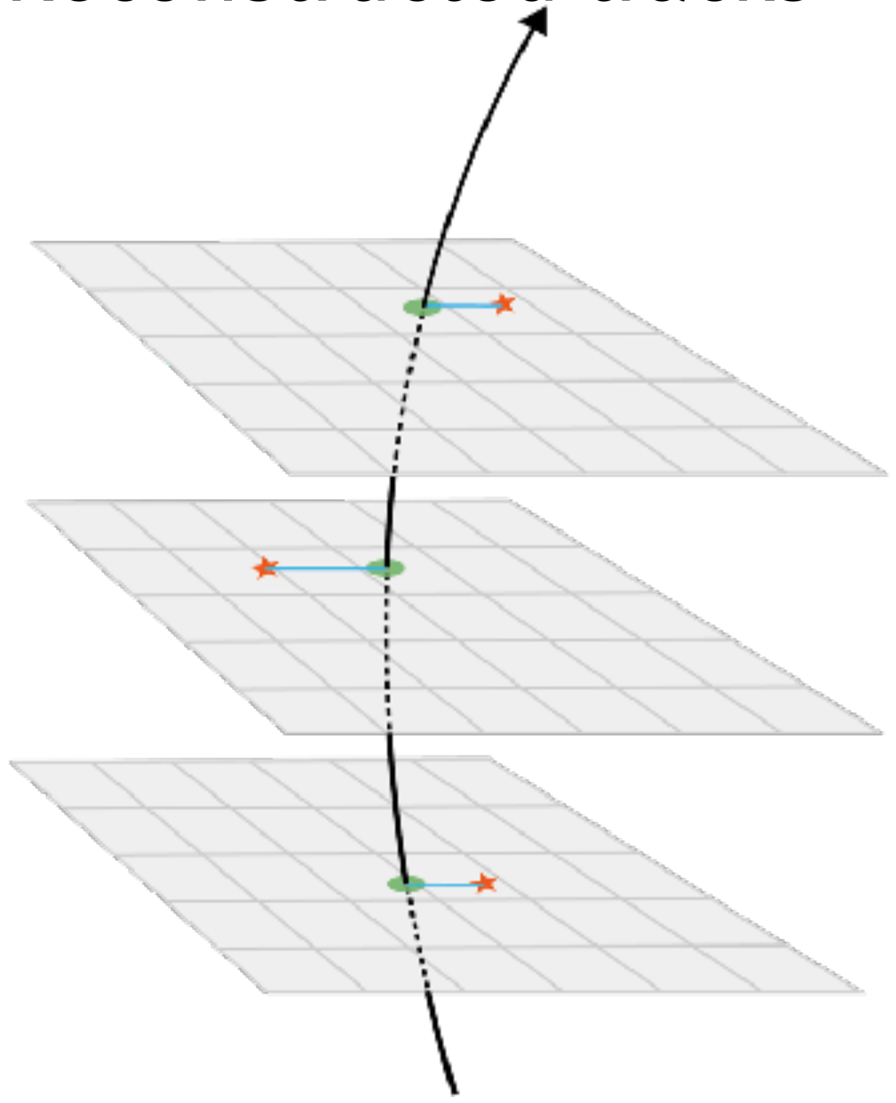
ITk: ATLAS Inner Detector Alignement

- The ATLAS ID reconstructs the trajectories of the charged particles created in the LHC collisions.
- For an accurate reconstruction, a precise knowledge of the position and orientation of each component is needed.
- This knowledge is called alignment, but the ID is not accessible while the LHC is in operation and the detector geometry is measured indirectly.
- The measured tracks are used to infer the detector geometry: This process is known as alignment.
- The ID is composed by more than 6k silicon detectors and 350k TRT straws, which makes the task quite complex.



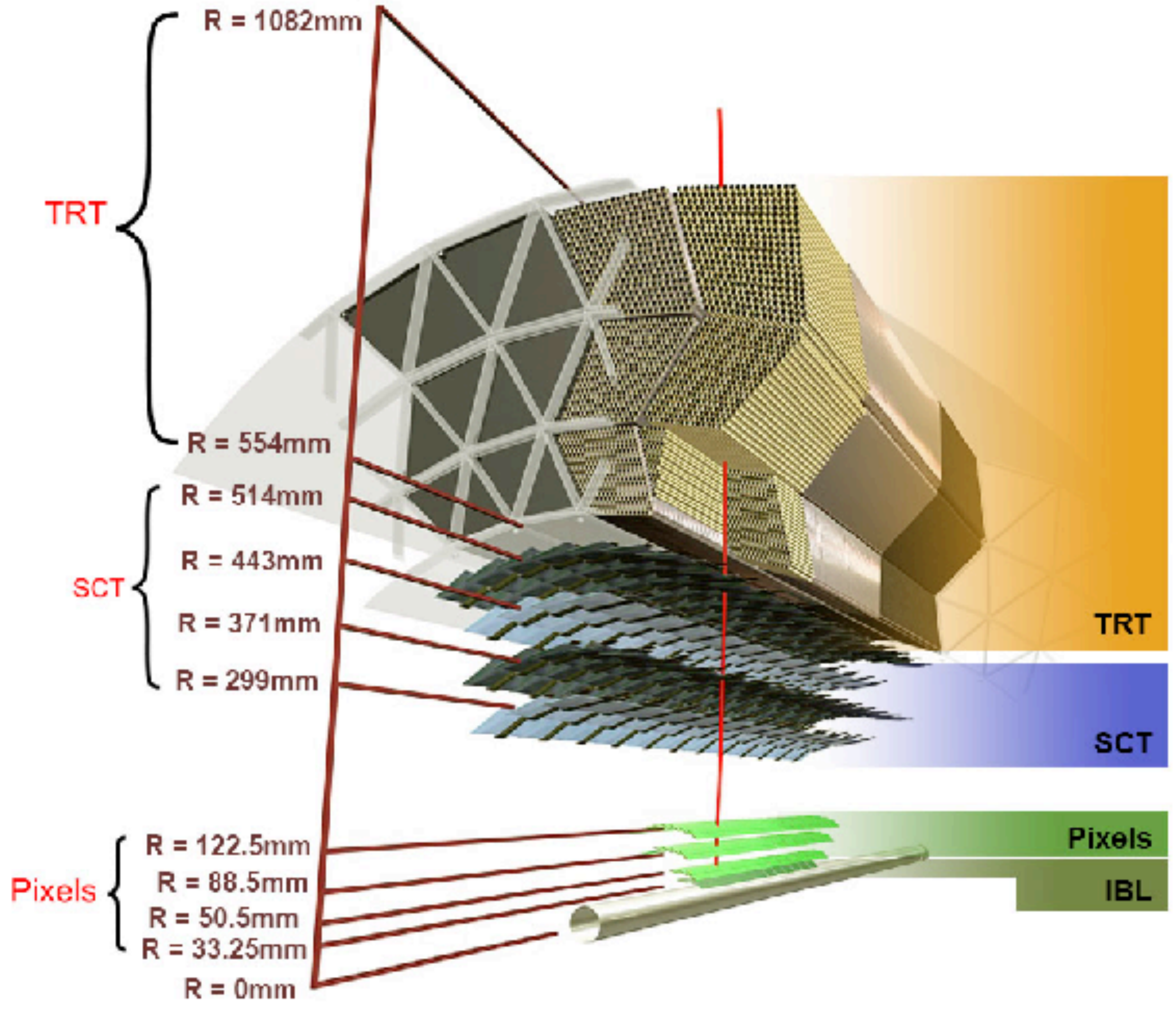


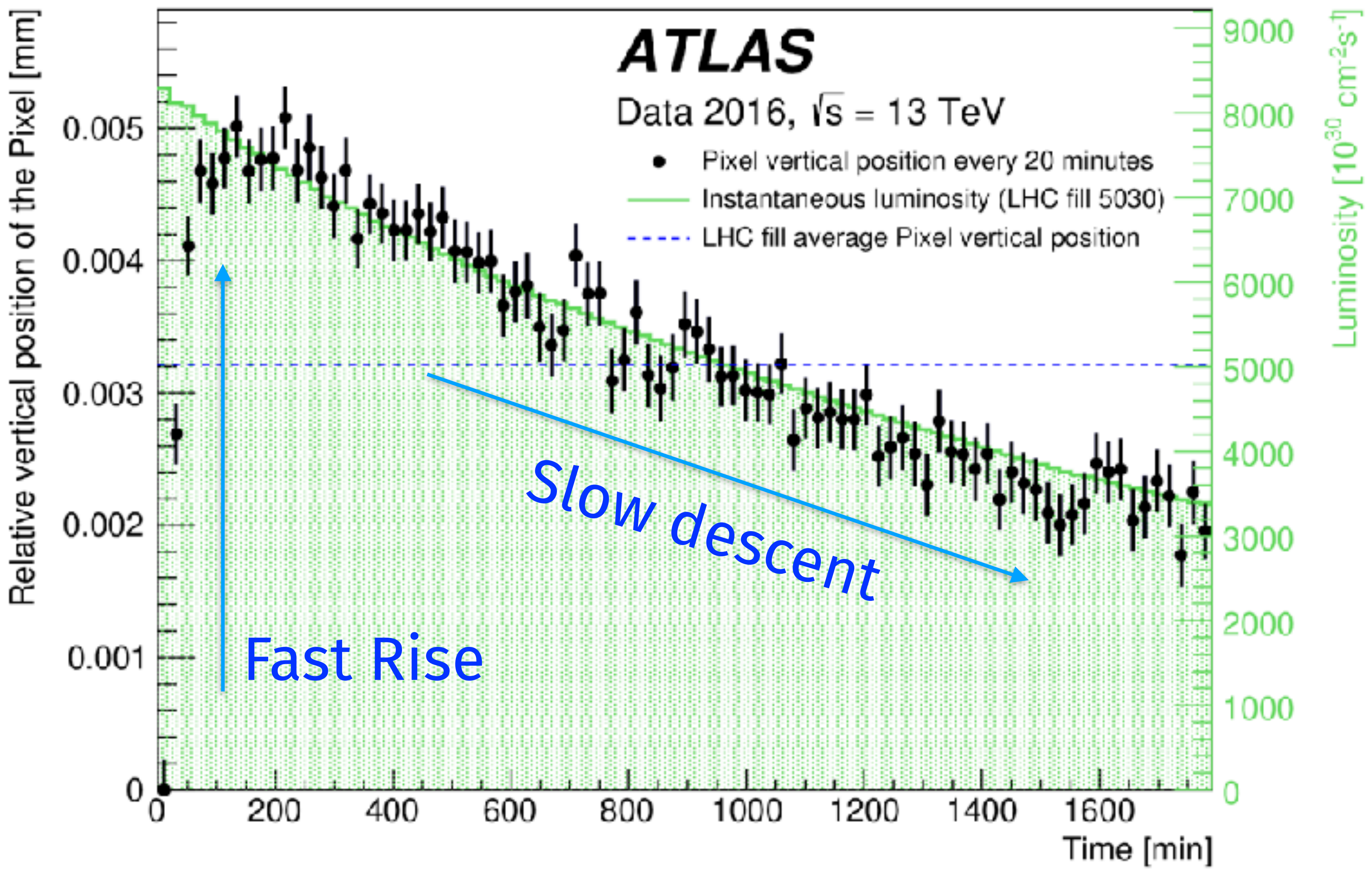
Reconstructed tracks



ITk: ID short-timescale movements

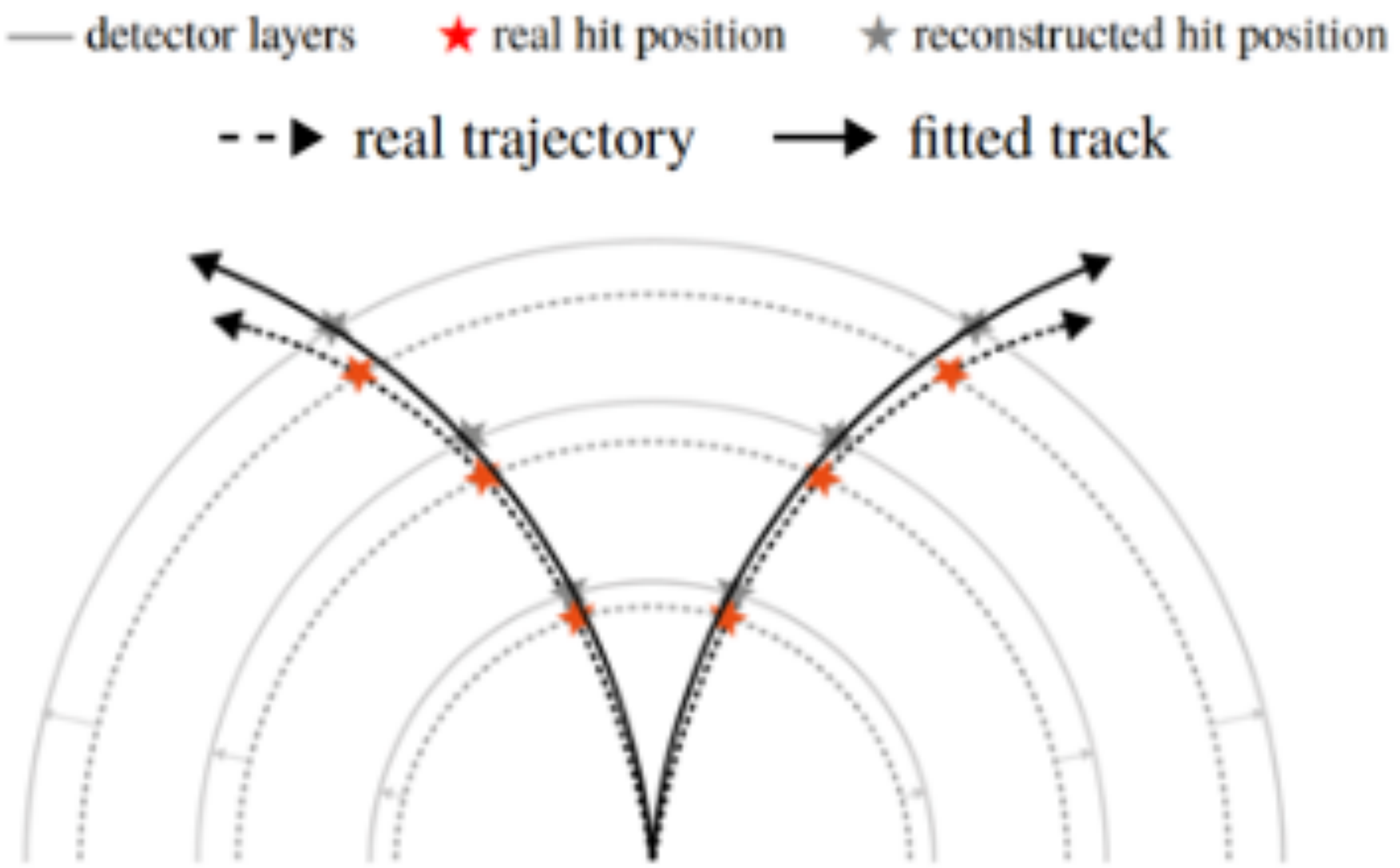
- Parts of the ID showed indications of short-timescale movements while recording data in run 2
- E.g. vertical displacement of the Pixel sub-detector
  - Caused by a change in the weight of the cooling liquid inside the Pixel volume during collisions
  - Consists of a fast rise of the Pixel of up to 10 microns at the run start, followed by slow descend
  - Need correction, to avoid biases in the tracks.
  - New alignment constants derived every 20 minutes during the first hour of data-taking and every 100 minutes for the rest of the fill.



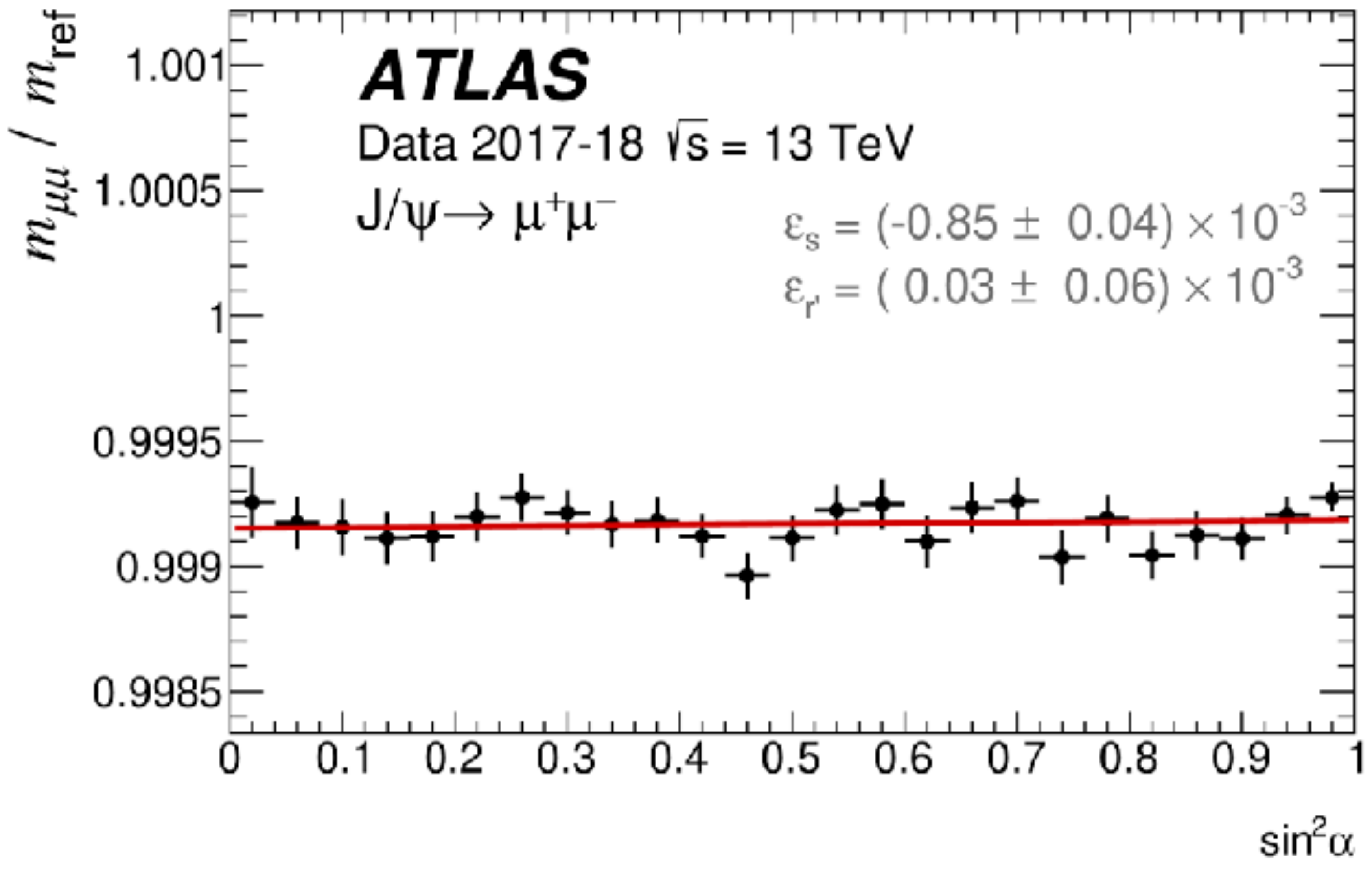


ITk: Removing bias on track parameters

- Well-known particles as Z-bosons or J/Psi-mesons are exploited to measure and minimise possible biases of the tracks.
- Both of these particles decay to pairs of oppositely-charged muons, whose measured energy and direction would be impacted by length-scale biases.
- For example, it has been proven that the Inner Detector is free of global momentum scale biases at the level of 1 per mille.



Radial expansion of the detector



News › News › Topic: Experiments

Voir en français

Keeping the ATLAS Inner Detector in perfect alignment

The ATLAS Inner Detector can measure the position of charged particles that pass through it to better than a 100th of a millimetre! To reach that precision, the detector must be aligned to equal or better accuracy

30 SEPTEMBER, 2020 | By ATLAS

Further information can be found in a pair of outreach articles:
ATLAS briefing
CERN news