HEPCAT

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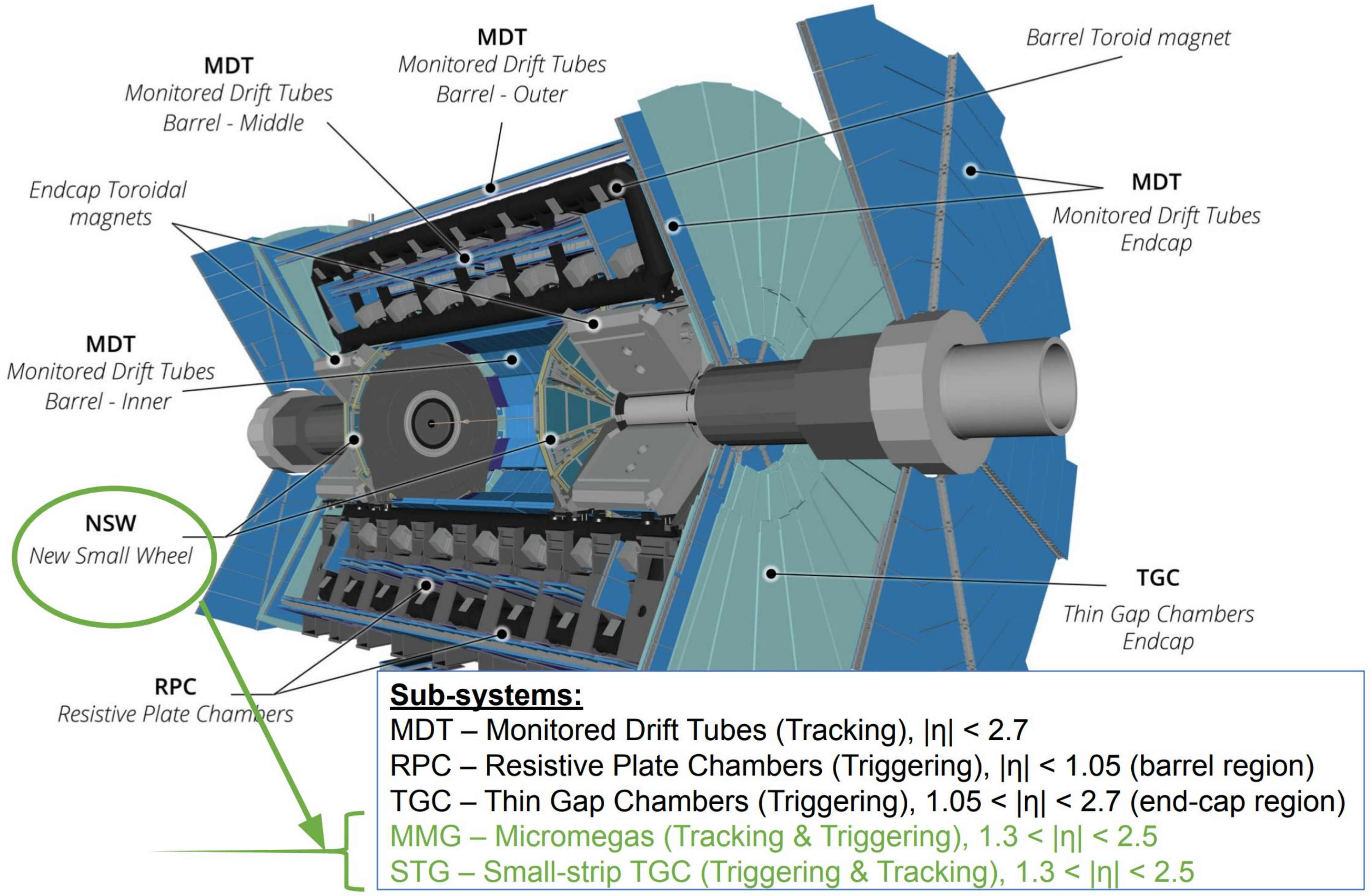
11/2/2024

ATLAS Detector

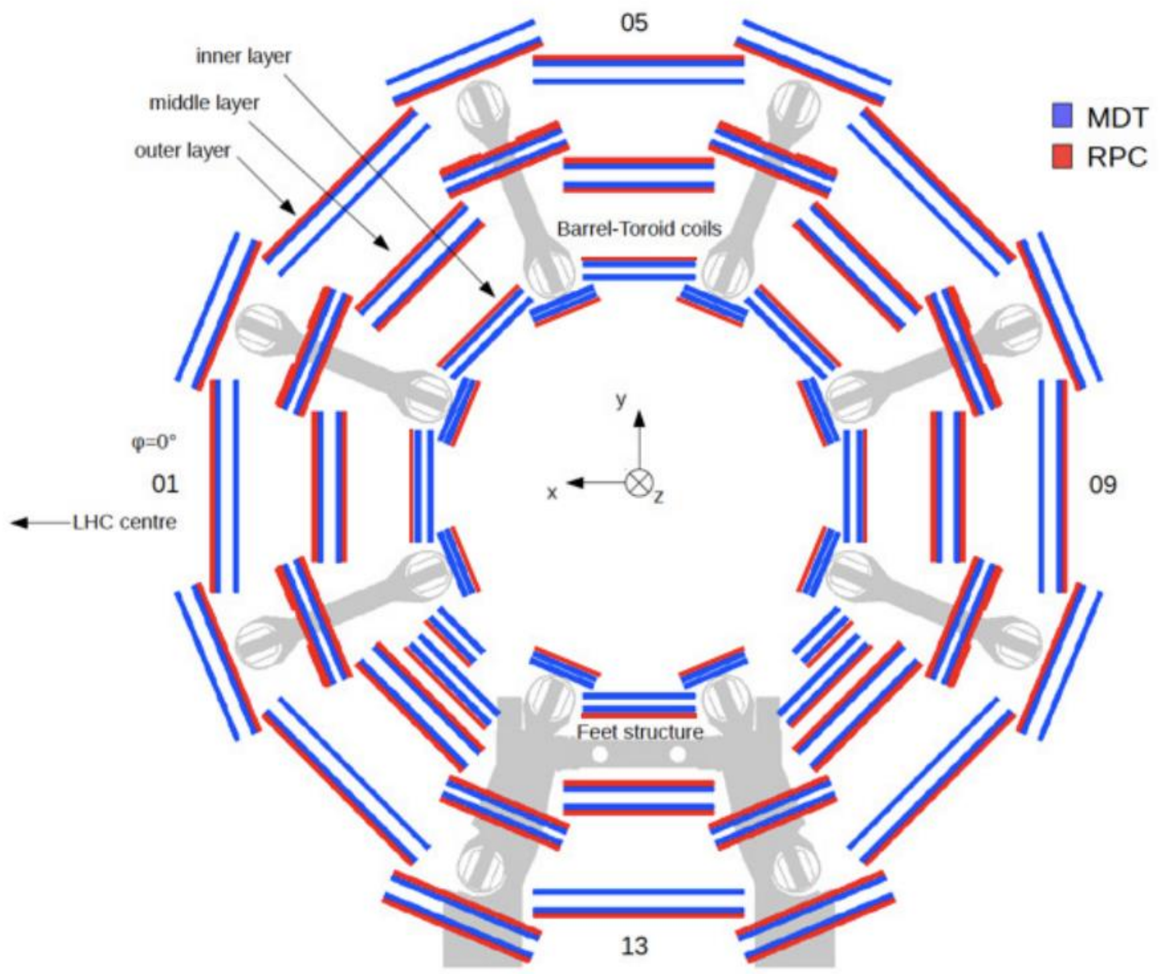
- The High-Luminosity (HL) LHC plans to deliver a substantial dataset (3000 fb-1) and consequently that increases pileup in this new environment

- Requires **improvements** to the Level-0 trigger system

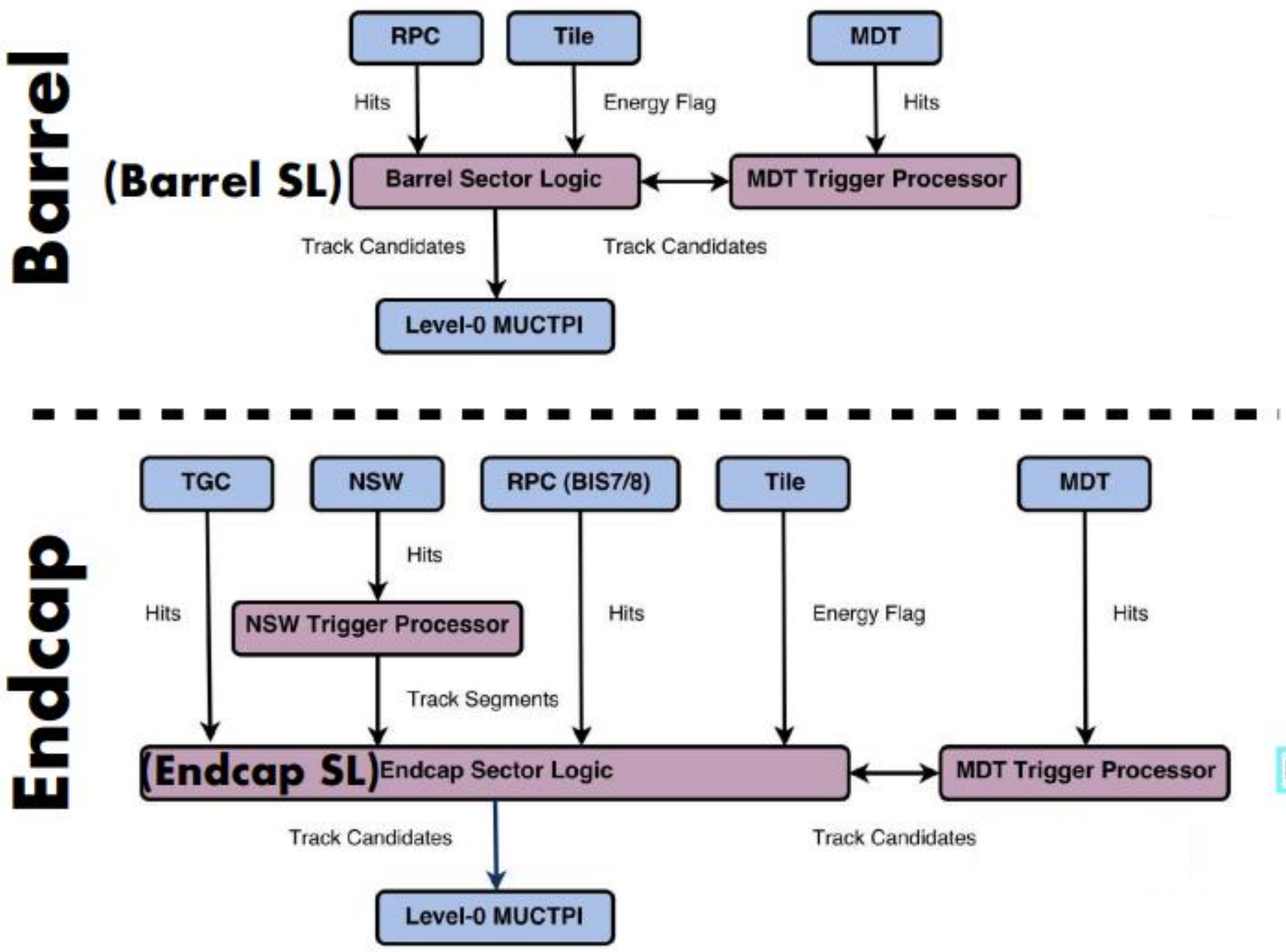
- A novel MDT-based low-level trigger; Level-0 Monitored Drift Tubes (L0MDT)

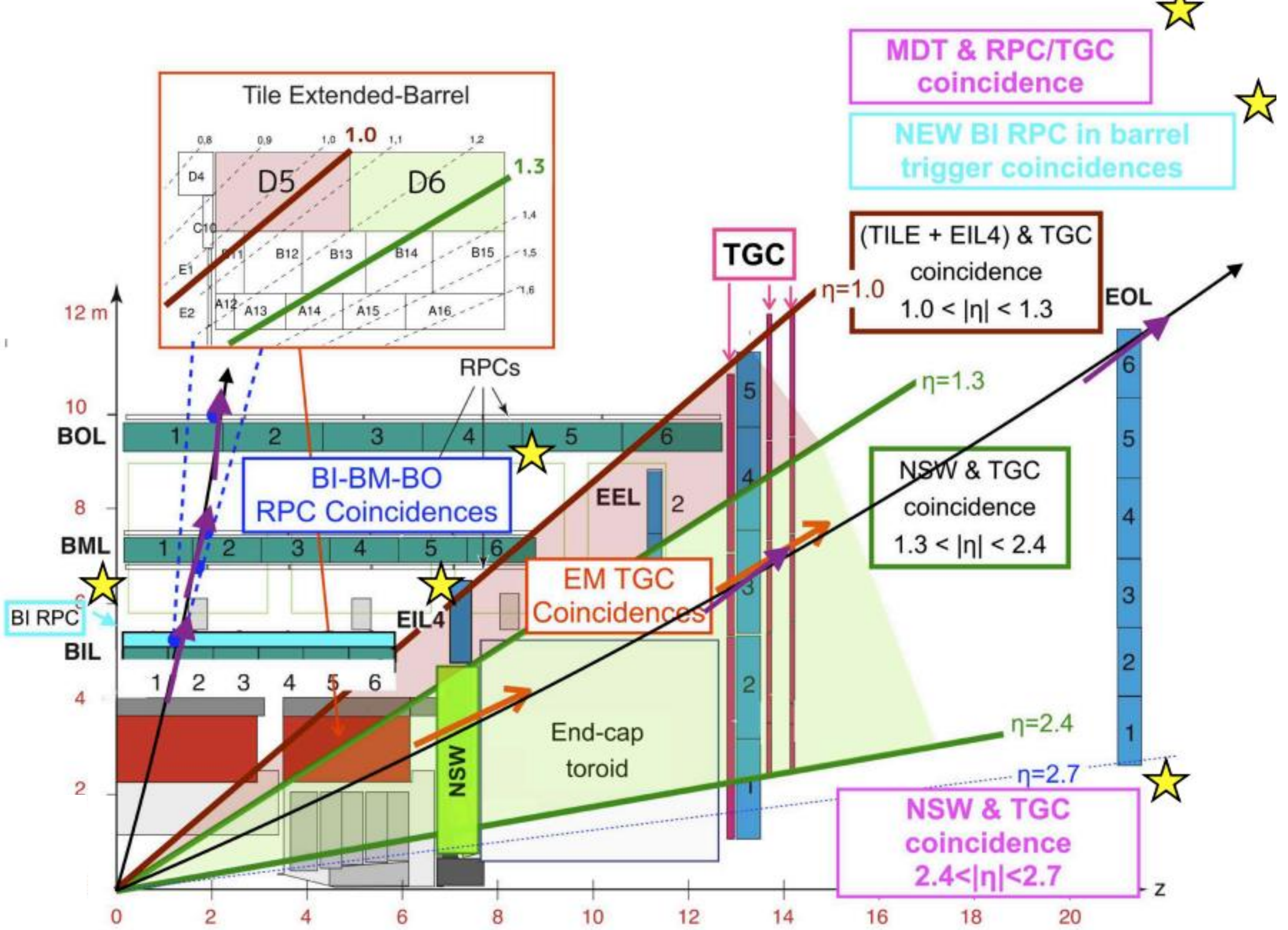


- Benefits
  - Improving the spatial resolution improves the transverse momentum (Pt) measurement
  - Due to this it reduces the muon level-0 trigger rates



Phase-2 Muon Trigger Architecture



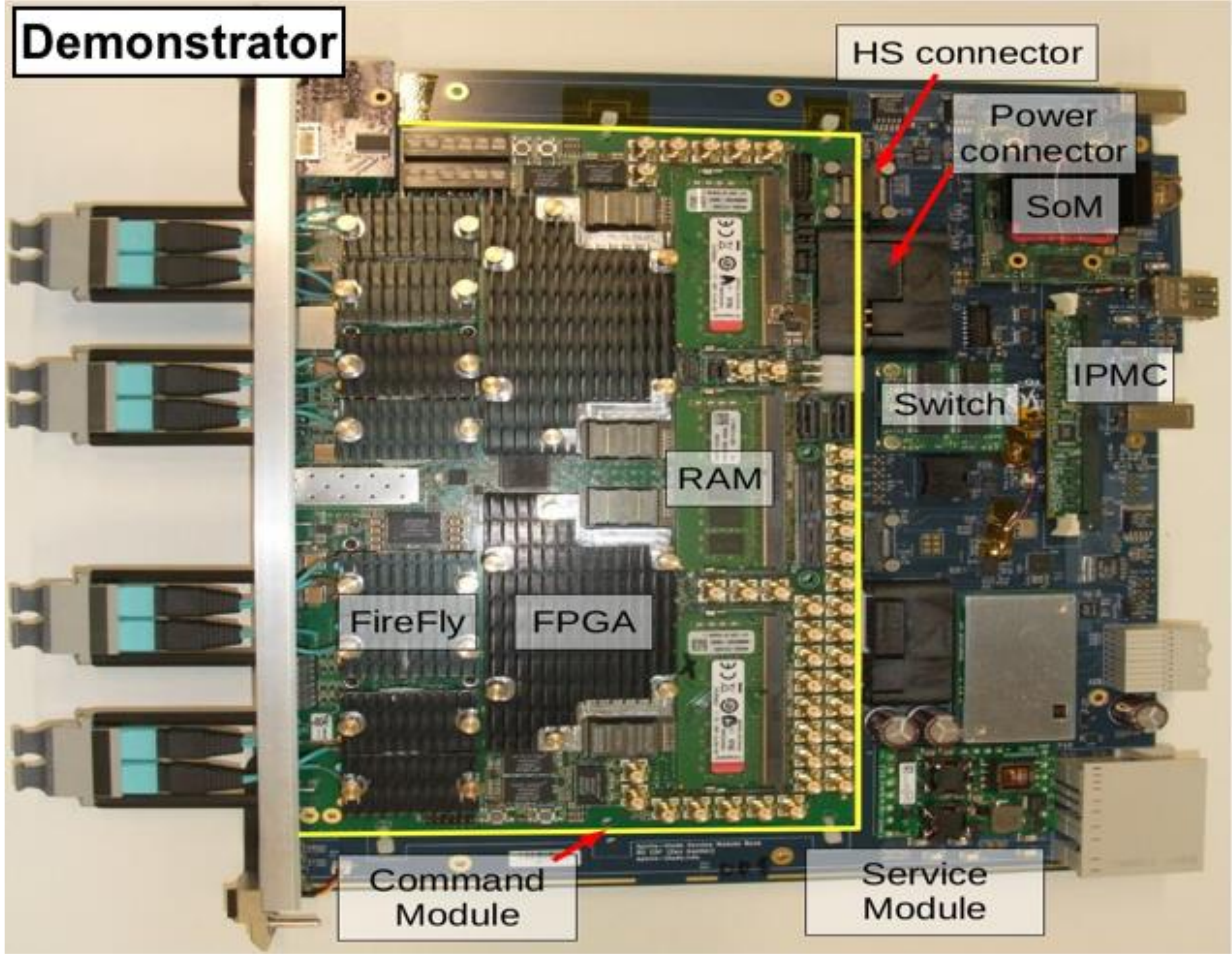


L0MDT System Architecture

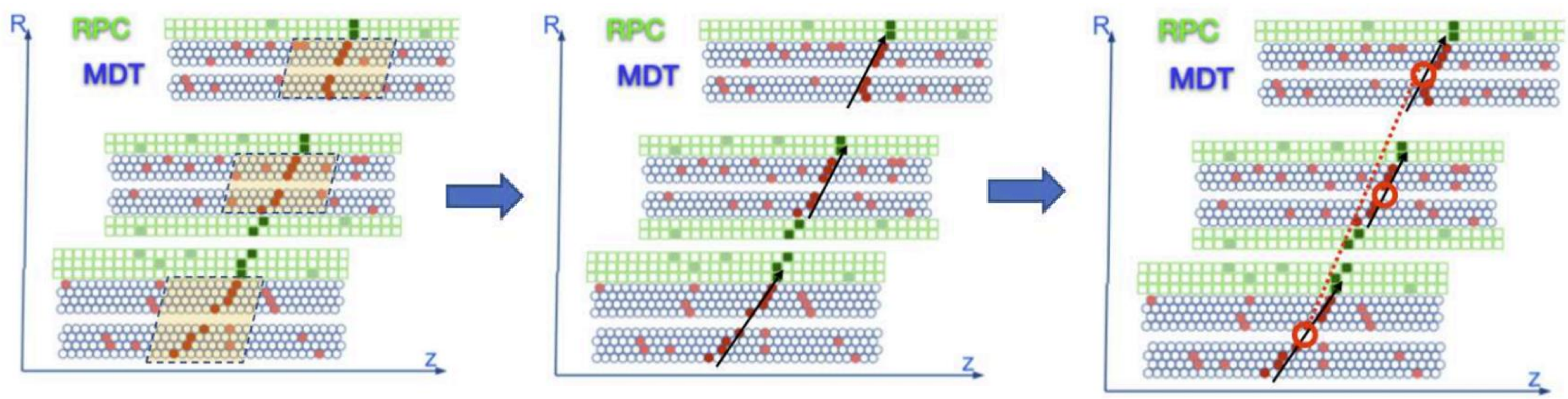
- Each sector(64) in the detector is equipped with a L0MDT blade

- The blades perform two functions:
  - **Data acquisition**, the board receives and processes the signals generated by the MDT chambers
  - **Muon Pt Refinement**, measurement of muon candidates Pt

- Monitored Drift Tubes Trigger Processors (MDTTP)s have two Field-Programmable Gate Arrays (FPGA)s
  - 1 in the Command Module (CM) used for the trigger/DAQ algorithms (read out of MDT chambers)
  - 1 in Zynq SOC on the Service Module (SM) used for configuration, monitoring and interfaces with the other ATLAS subsystems



Trigger Path (L0MDT Muon Tracking)



Hit Extraction

- SL information is used to define a Region of Interest (RoI), hits from the MDT tubes matching the RoI are extracted

Segment Finding

- Receive matched and calibrated MDT hits and SL vector from Hit Extraction
- Reconstruct segments in each MDT station

Pt Estimation

- Calculate the muon candidate Pt and q by measuring the deviation from straight track due to the B-field using reconstructed segments

OUTLINE

STUDIES ON THE PARAMETRIZATION OF THE PT

WEB INTERFACE FOR MDTTP DEBUGGING AND TESTS

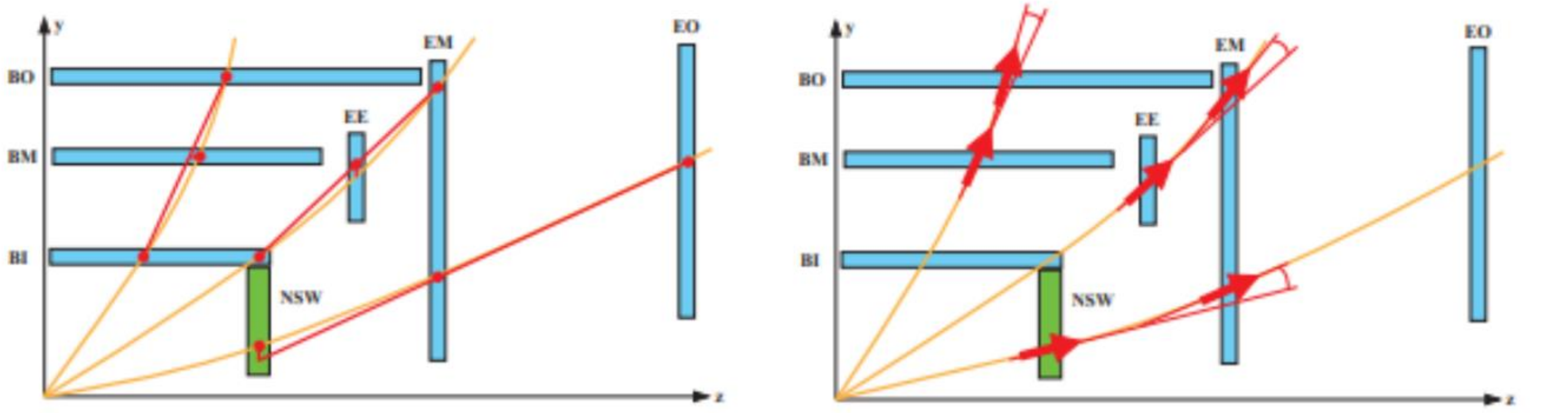
STUDIES ON THE PARAMETRIZATION OF THE PT

Measuring Pt

- Two methods for estimating the Pt using the MDT segments reconstructed at each station

- 3-Station Method:
  - **Sagitta**, is dependent on the reconstructed segment position

- 2-Station Method:
  - **Deflection angle**: the difference in polar angle between the track segments



(a) 3-station (b) 2-station

Parametrization for Calculating Pt

- Goal: Develop an algorithm to calculate the muon trigger candidate's Pt quickly so that it can be implemented in an FPGA

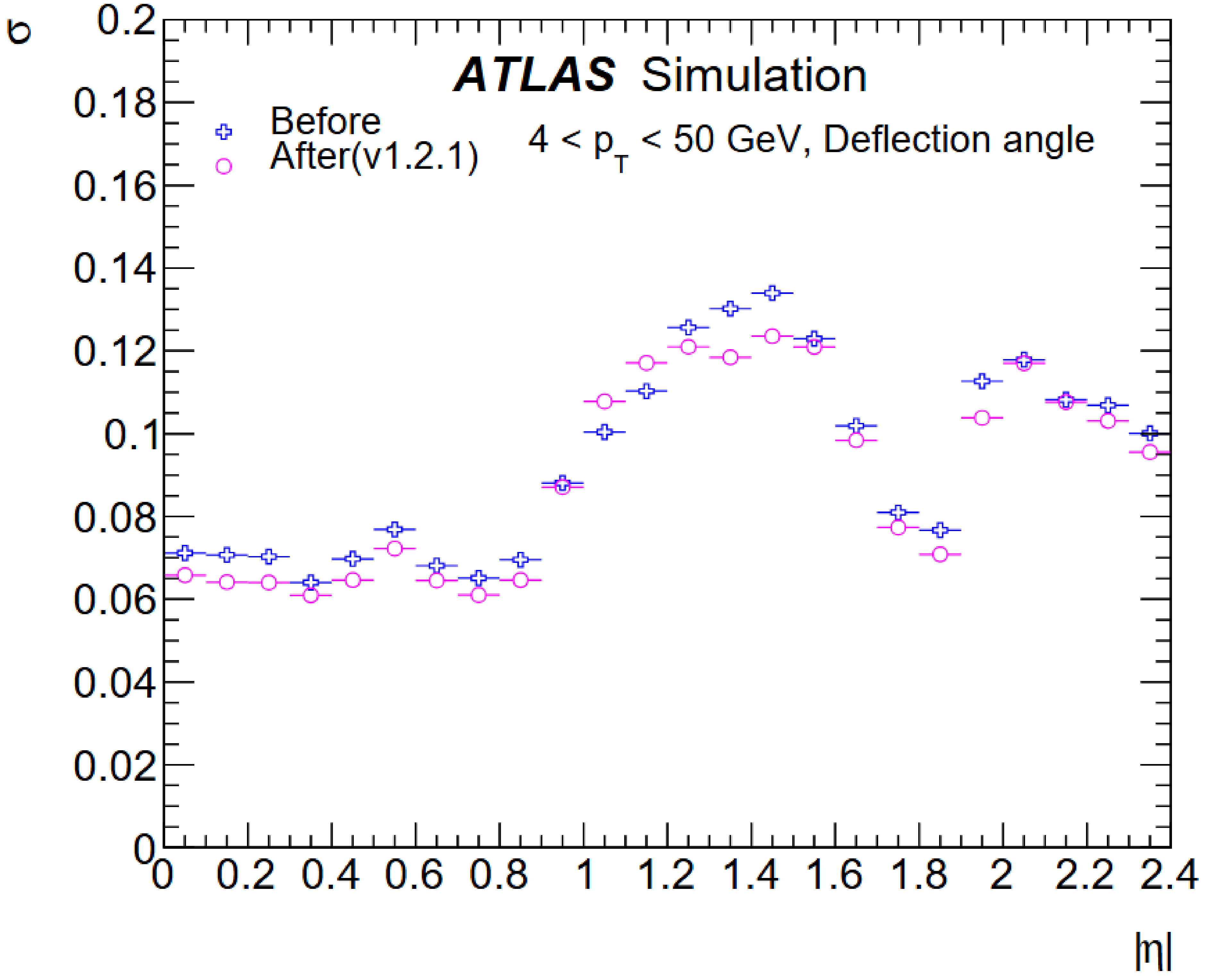
$$p_T \approx \frac{\left(\frac{1}{s} - a_0\right)}{a_1} + \sum_{i=0}^{2} p_i \phi_{mod}^i + \sum_{i=0}^{1} e_i |\eta^i|$$

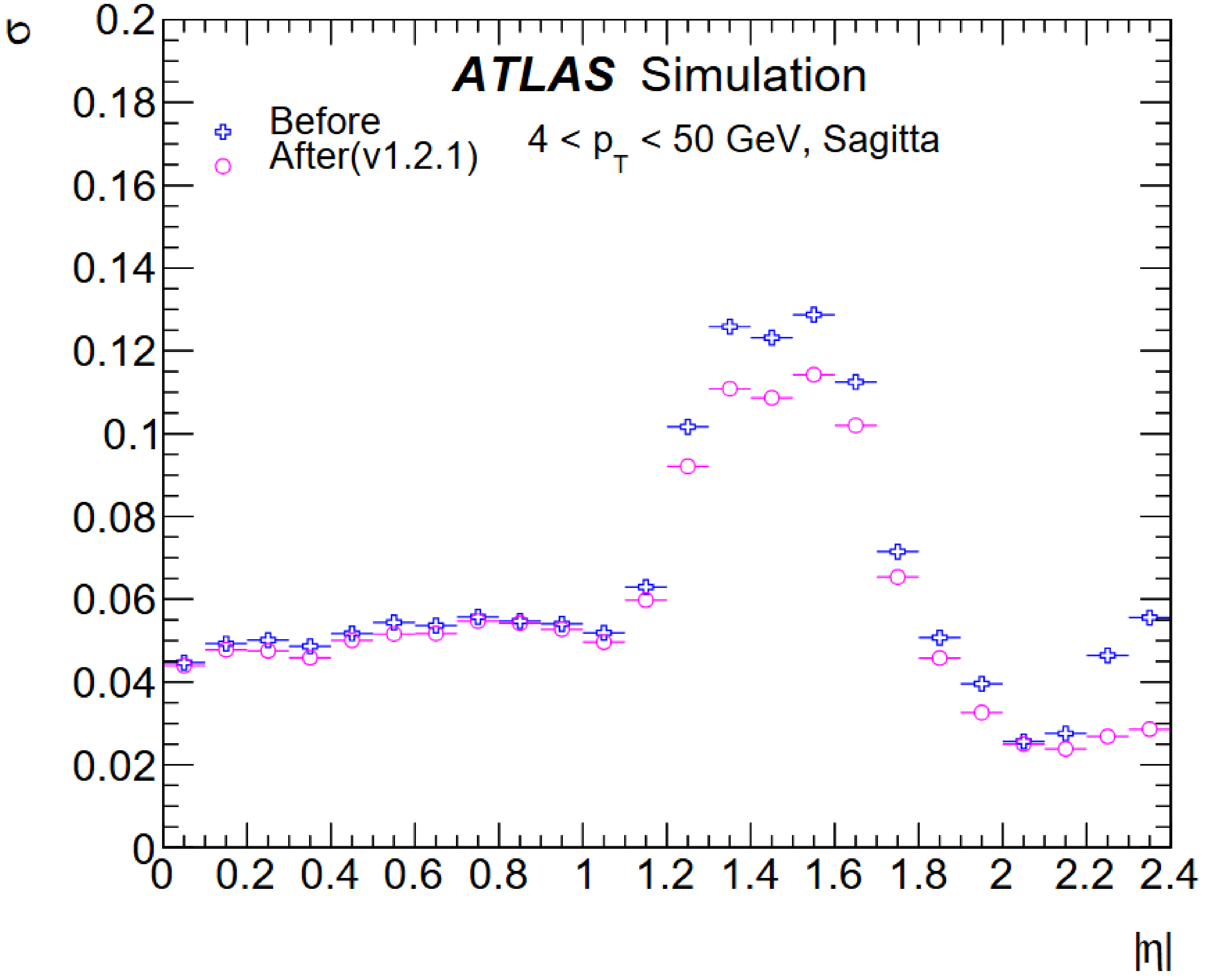
  - Algorithm starts by identifying segments in MDT station and uses those to compute either sagitta or deflection angle (s), Which is linearly dependent on Pt
  - Due to the **magnetic field non-uniformity** it is necessary to apply corrections
  - These involve adjustments for both the relative azimuthal angle (Φmod=Φ−Φregion center) and pseudorapidity (η)
  - Use a quadratic fits to extract parameters (p_i and e_i), then P_T^{ON} can be calculated
  - Every region (ComboName), over 650, uses the precise determination of up to 7 parameters
  - To determine the performance of the calculation, resolution is used

$$\sigma = \frac{p_T^{On} - p_T^{Off}}{p_T^{Off}}$$

  - P_T^{OFF}=offline Pt; P_T^{ON}=online Pt
    - Online reconstruction runs on FPGA, while offline full system reconstruction to ensure high accuracy
  - **The improvements were achieved by adjusting the code and refining the fit procedures to** extract the parameters to calculate P_T^{ON}

RESULT

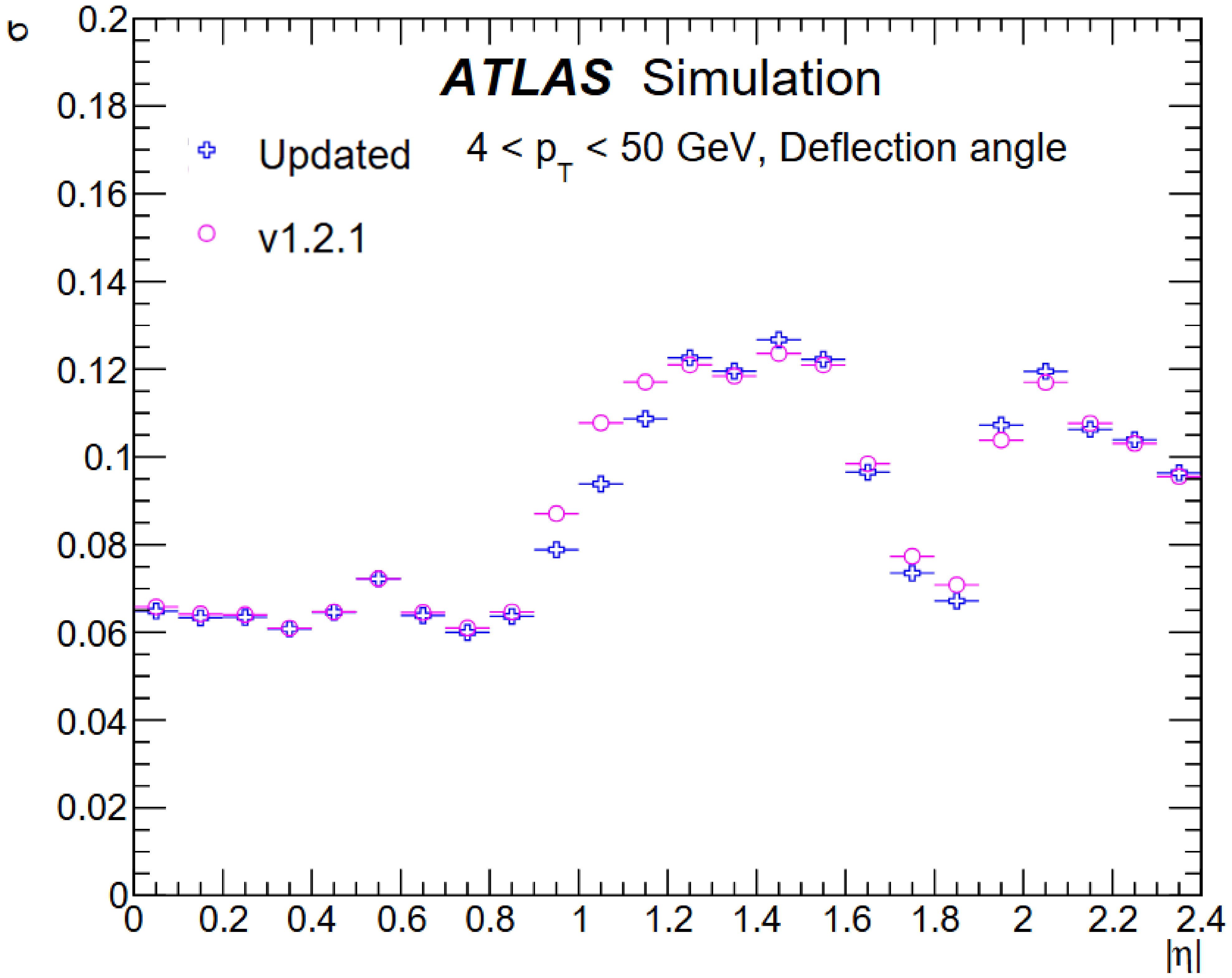


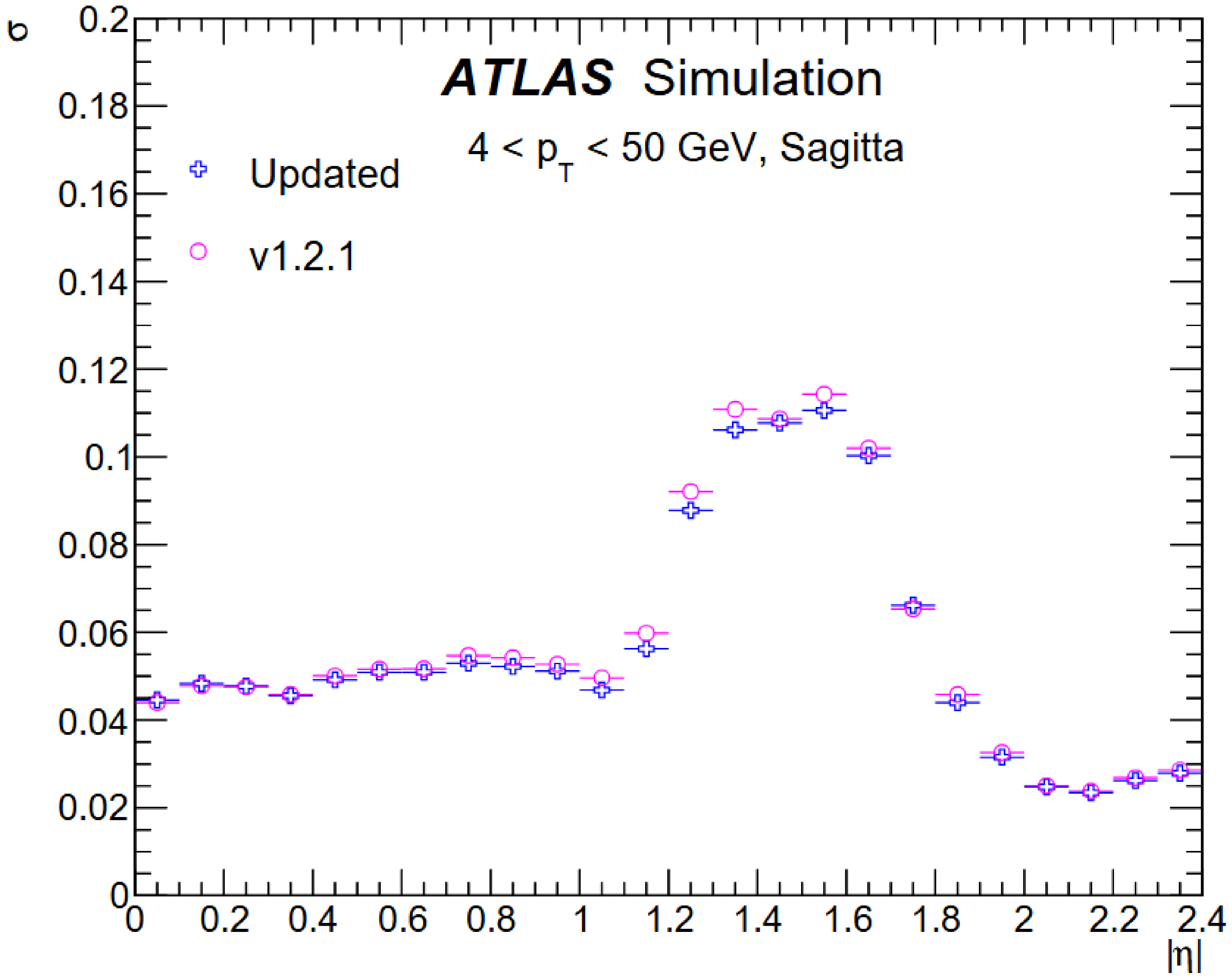


- Blue (Before) refers to the resolution prior to any work I did
- Pink (v1.2.1) Was the progress I showed for the HEPCAT report (March 31, 2024)

RESULT

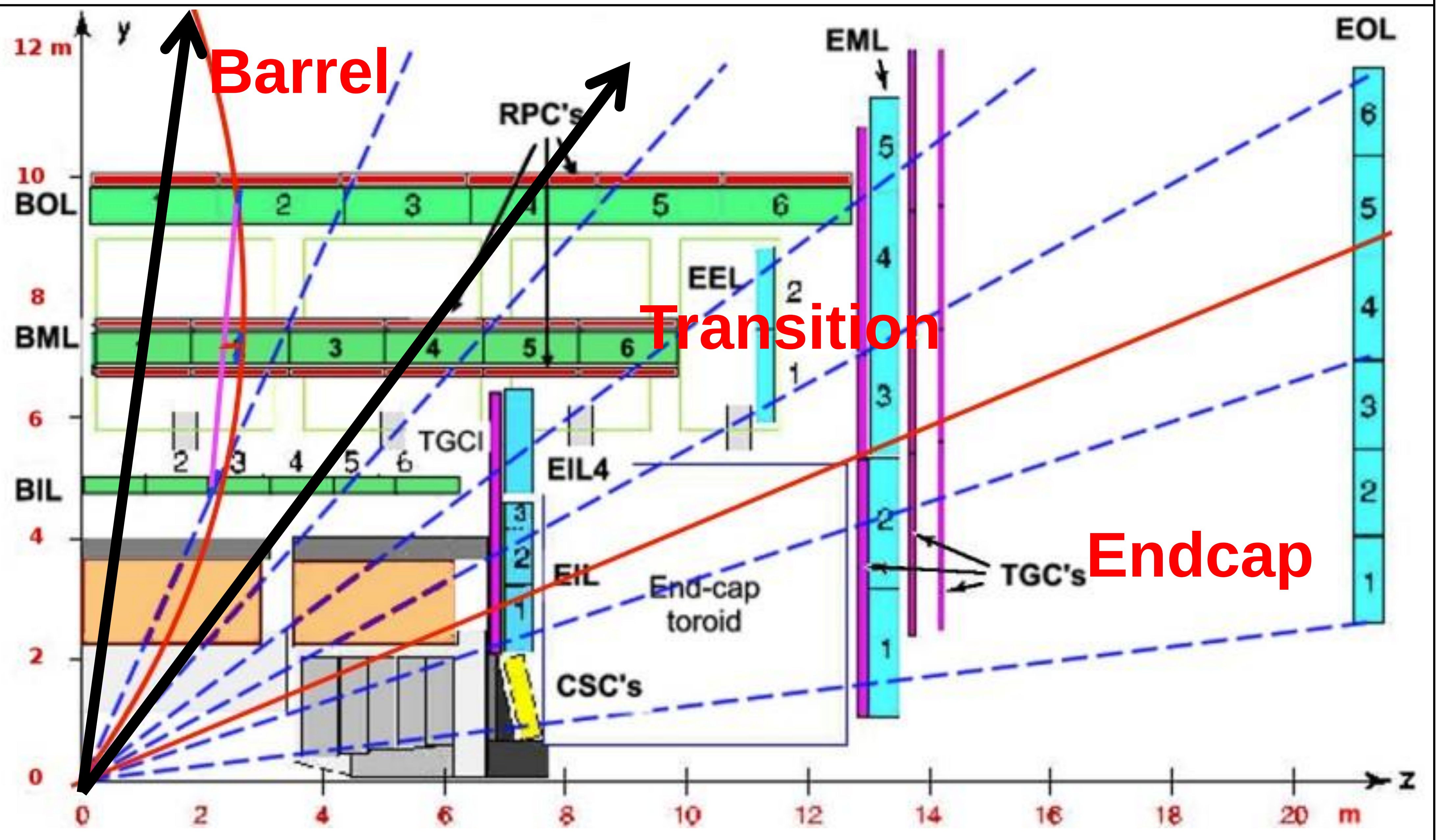
- Blue (Updated) refers to most recent resolution that I have made
- Pink (v1.2.1)





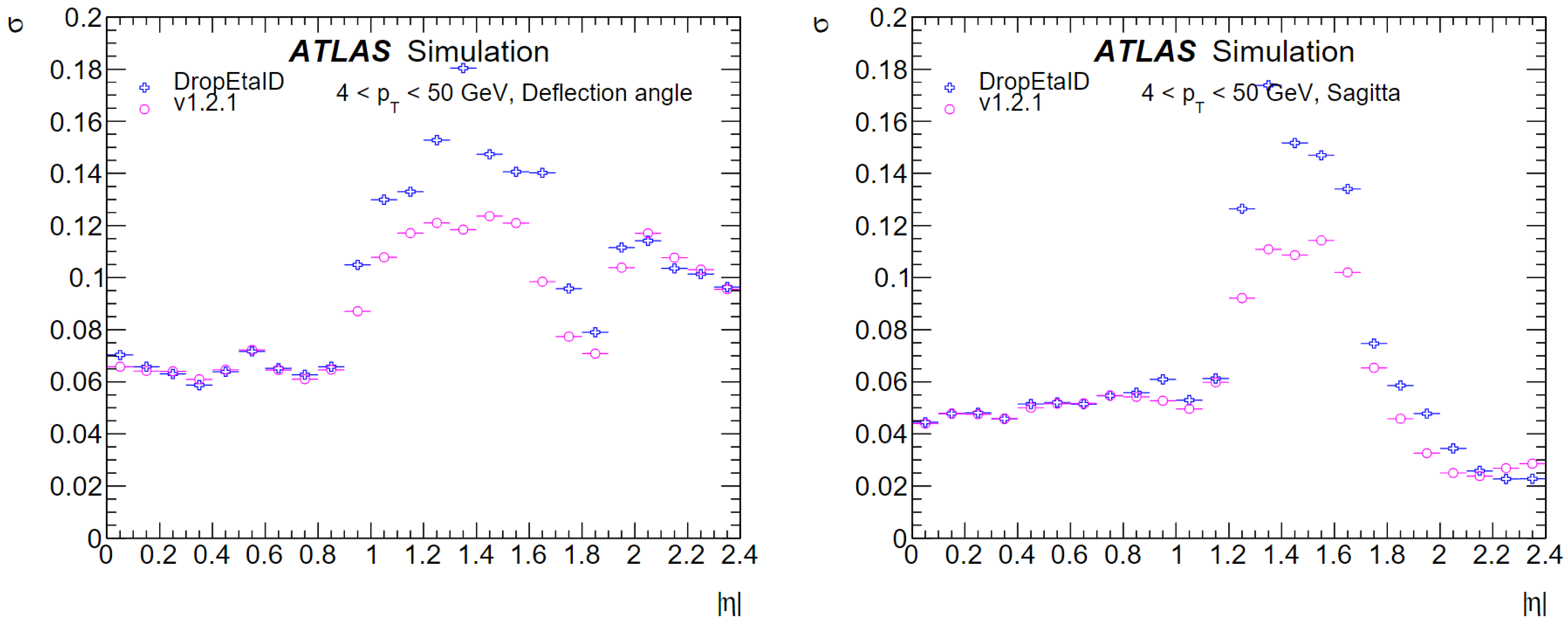
Drop Eta Chamber ID

- There are 1948 parameters that the Look-Up Tables (LUT) must store, thus raising a concern regarding the memory footprint in the FPGA
  - Created a function to reduce regional segmentation in the fit procedure, by a factor of **6**
  - **Reduced total number of parameters to 327**
  - More statistical data per region for fitting
  - Ability to observe local structures that might be missed in a full-range analysis.
  - **Challenge**: Different regions may have varying behaviors, complicating the fit procedure



- Ex (2 Black arrows). would be BIL1_BML1_BOL1 and BIL4_BML4_BOL4
- After dropping the eta chamber ID the 2 comboNames would both become BIL_BML_BOL and the total parameters would **drop from 14 to 7**

RESULTS



- Blue (Drop eta chamber ID resolution)
- Pink (v1.2.1)

Conclusion

- Except for $|\eta| = 2.05$, the resolution comparing, Before to Updated (Slides 10-11), has shown significant improvement
- Dropping the Eta Chamber ID approximately reduces the number of bits that the LUT occupy in the FPGA by 350%
- Dropping of the Eta Chamber ID does save space in the FPGA, however the resolution in the transition region would currently be better changed back to to the original
  - 114 ComboNames Regions in Transition, dropping the Eta Chamber ID reduces is down to 18
- In the future if more time is spent, it could be competitive with the version maintaining the Eta Chamber ID

WEB INTERFACE FOR MDTTP DEBUGGING AND TESTS

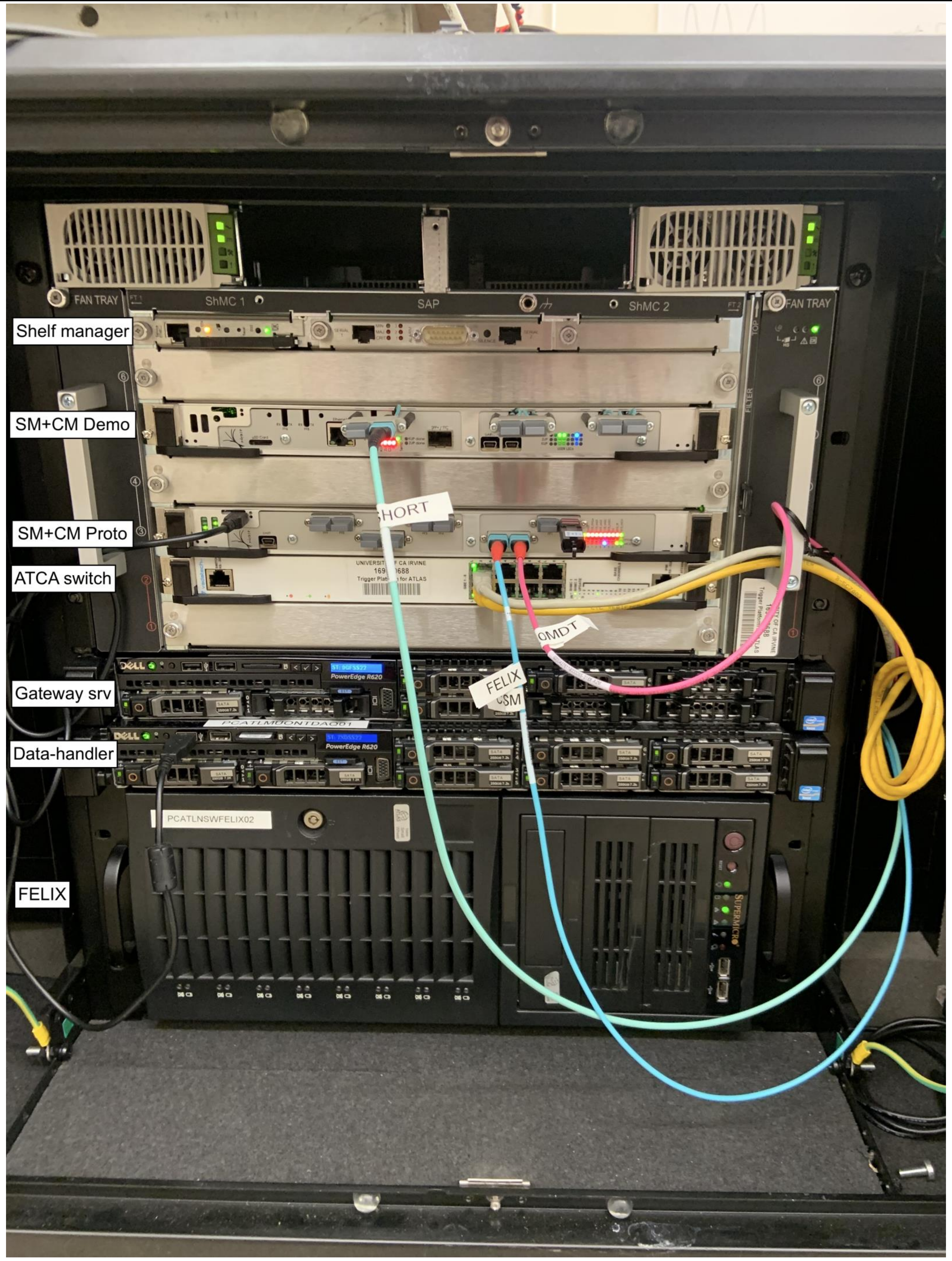
WebGUI

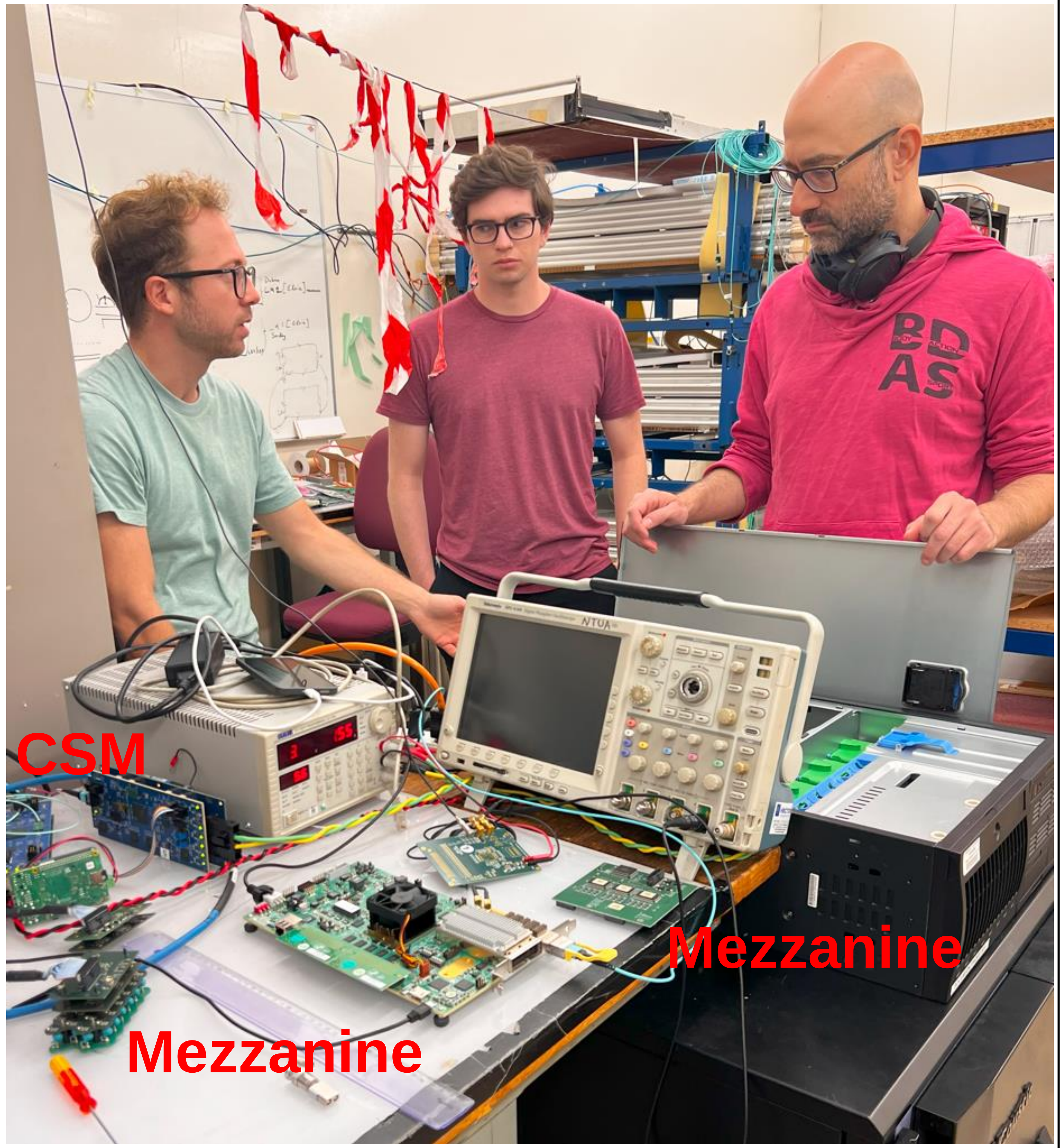
- Web-based graphic interface, user-friendly front-end application, **simplifies interaction with L0MDT hardware**
- Due to the complexities of the boards and external interfaces a WebGUI this tool would make performing **testing/validation** of L0MDT hardware across various test benches easier
- Functions to **help debug** issues during the long-term operation of the L0MDT system

OVERVIEW

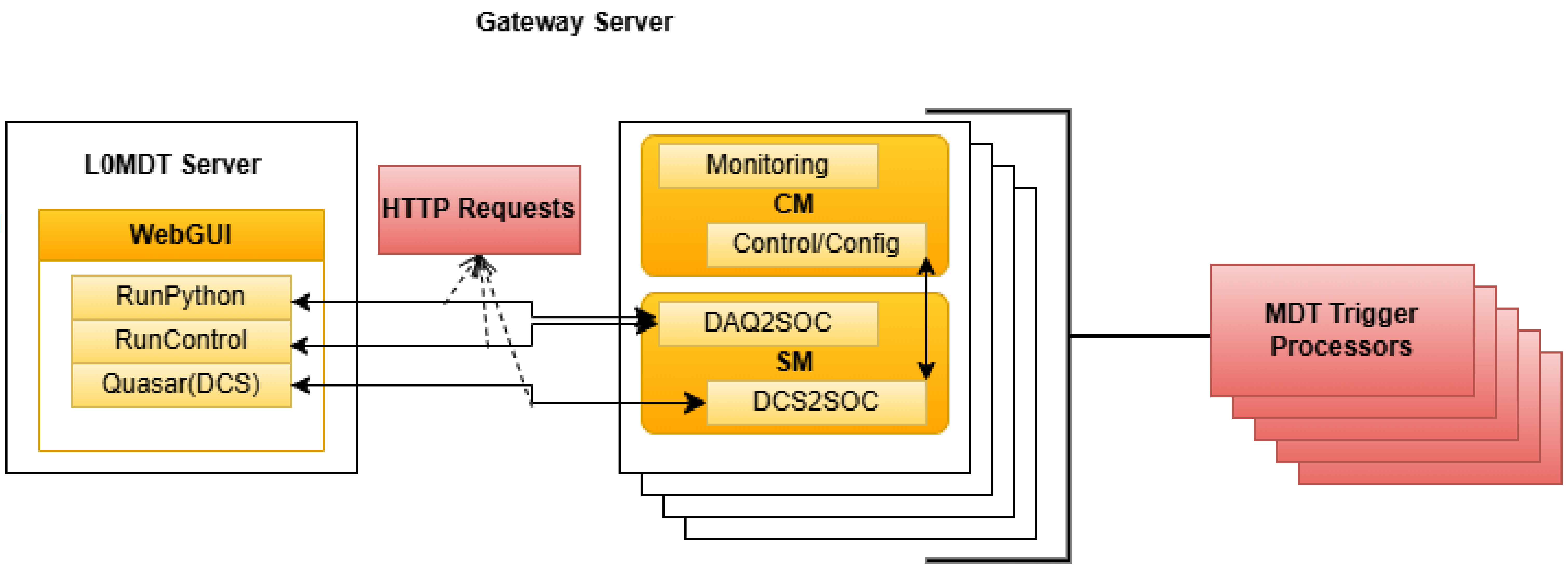
- WebGUI can access parts of the MDTTP ATCA blade hardware SM, CM, MDT on-detector electronics, Chamber Service Modules (CSM), and Mezzanine cards

- This allows for an easy way to view and control all components additionally, can run code on the SM, give basic commands (such as check status or program/reprogram) to the CM, interact with external interfaces MDT Front-End, and the Back-End FELIX





OVERVIEW

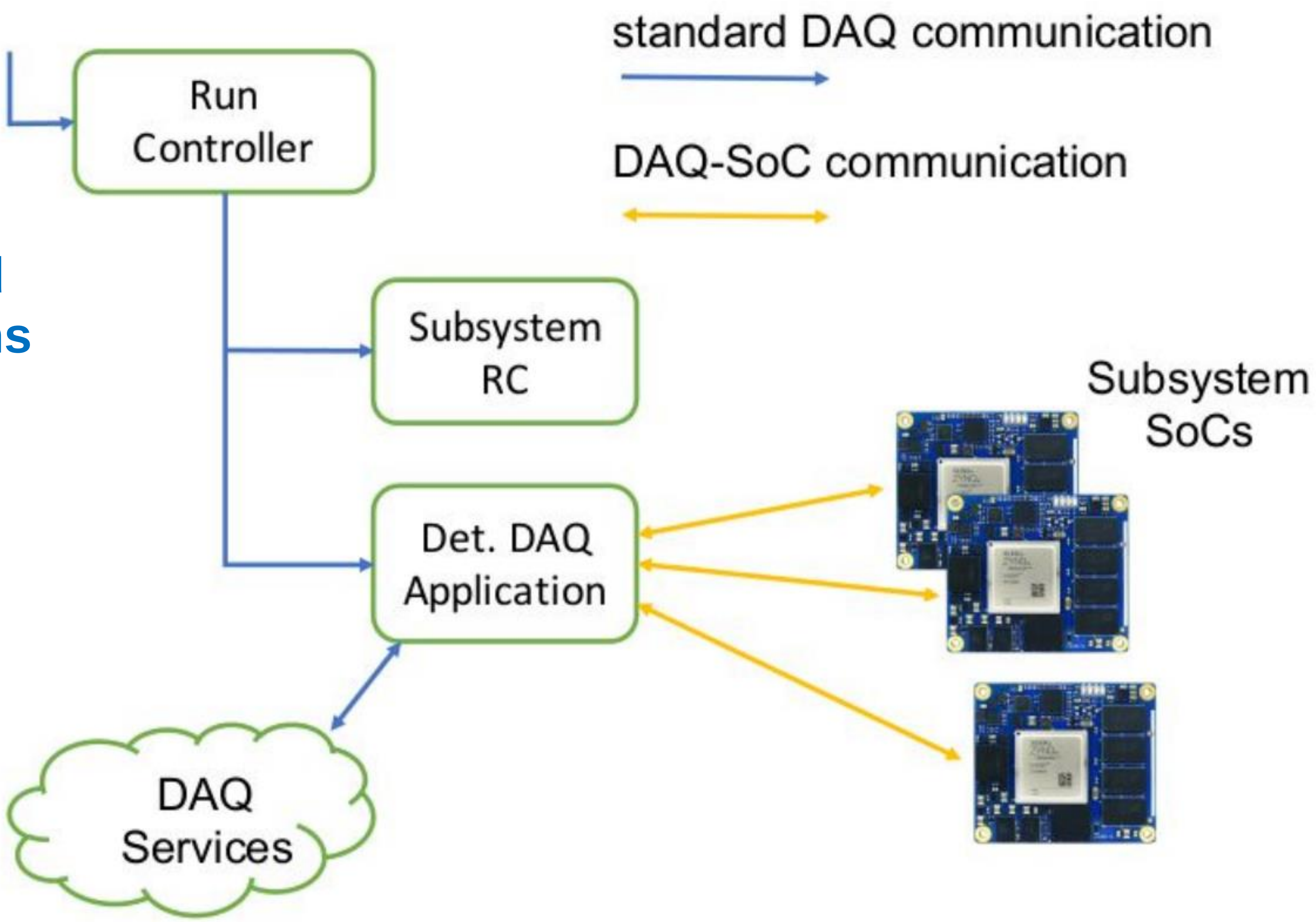


- The WebGUI connects to the various pieces of hardware through 2 ways
  - Data Acquisition (DAQ) to System on Chip (SOC) | Detector Control System (DCS) to SOC
  - Allow users to control the board
  - Will be part of final product in the control room

- Comprehensive **control over board status**
  - **Bring the system up from power down mode**
  - Programing the FPGA
  - Configuring the L0MDT firmware
  - Configure the MDT Front-End electronics
  - Testing and debugging firmware execution (Plots and Logs)
  - Monitoring MDTTP, CSM, Mezzanine hardware
  - Can **run any of the above in parallel on multiple boards and receive real-time outputs**

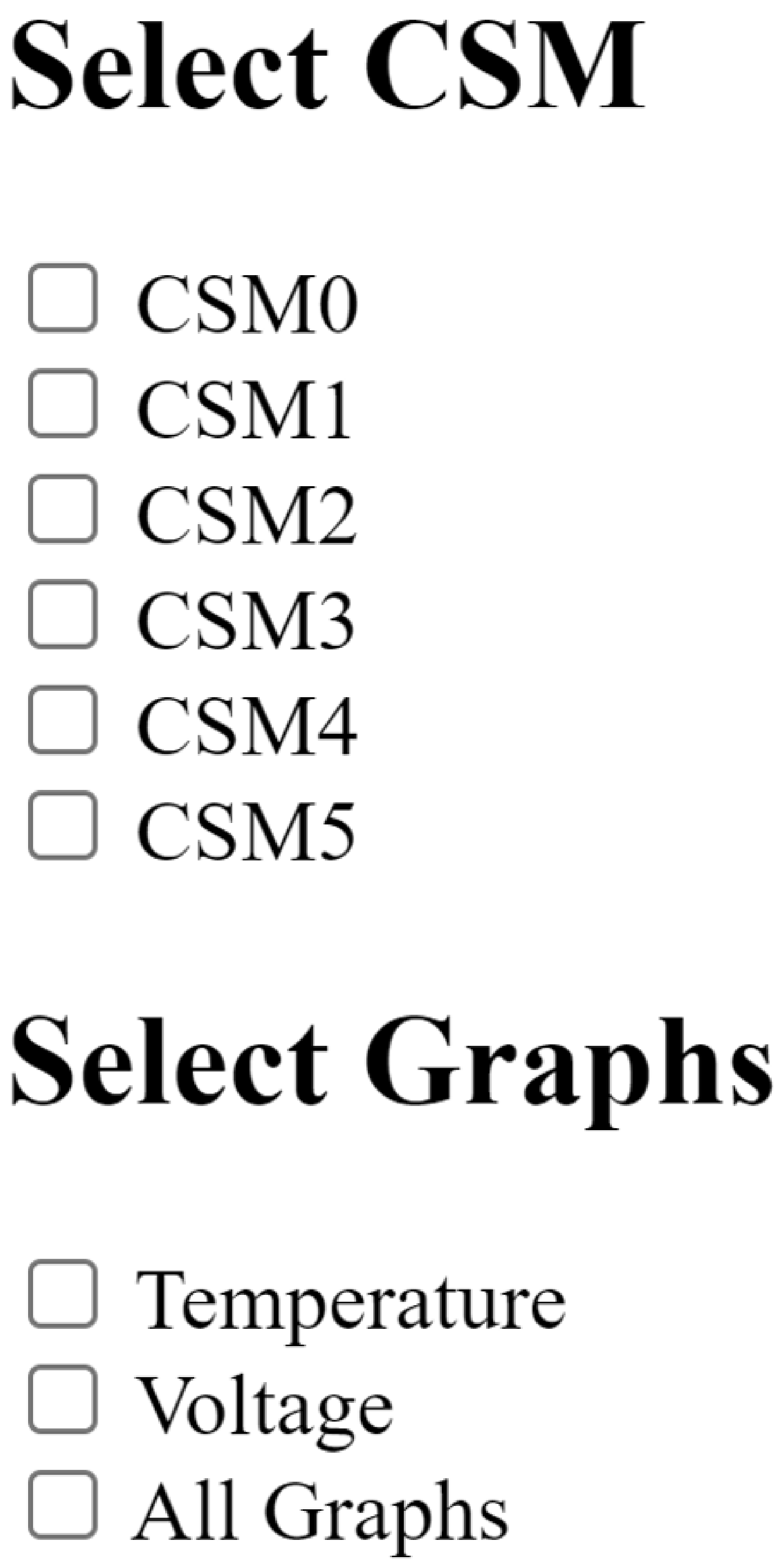
- Purpose:
  - Communication layer allowing **passing commands and data between standard DAQ Run Control applications and applications running on SOC**
  - Leverage on HTTP protocol, open to all variety of **client and server** implementations

- Benefits of DAQ2SOC for Service Modules:
  - **Manage/Monitor** multiple SM from a single server
  - **Easily scale infrastructure** management across numerous modules
  - Seamlessly interface with the DCS for improved control



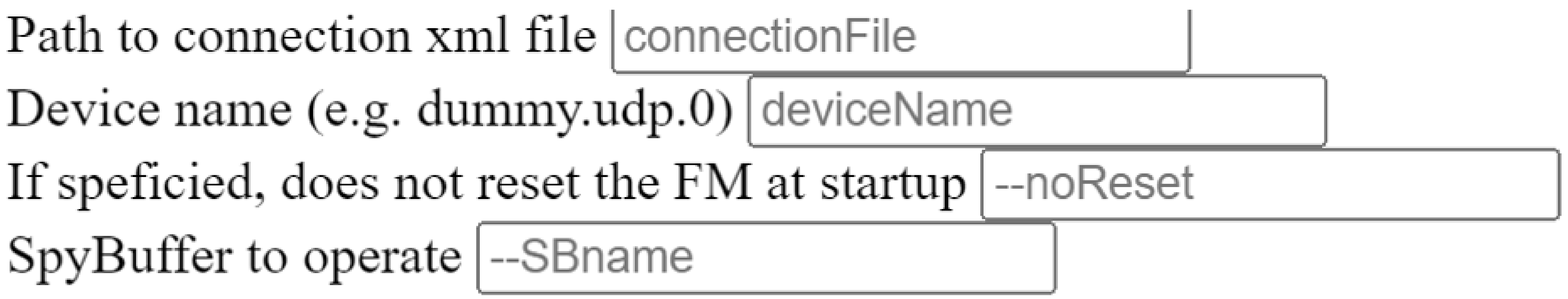
DCS2SOC

- Detector Control System (DCS) monitors and controls the detector's operational environment, ensuring the detector functions correctly and safely.
  - Configures the http publishing endpoints using the .xml description files
  - Implements a software interface to **read/write FPGA registers**
  - Instantiates the hardware objects monitored for each SM
- There is a server-client service with different endpoints that the WebGUI makes use of
- DCS can monitor temperature sensors in the detector, shutting down components if thresholds are breached to protect sensitive equipment



WEBGUI FUNCTIONS

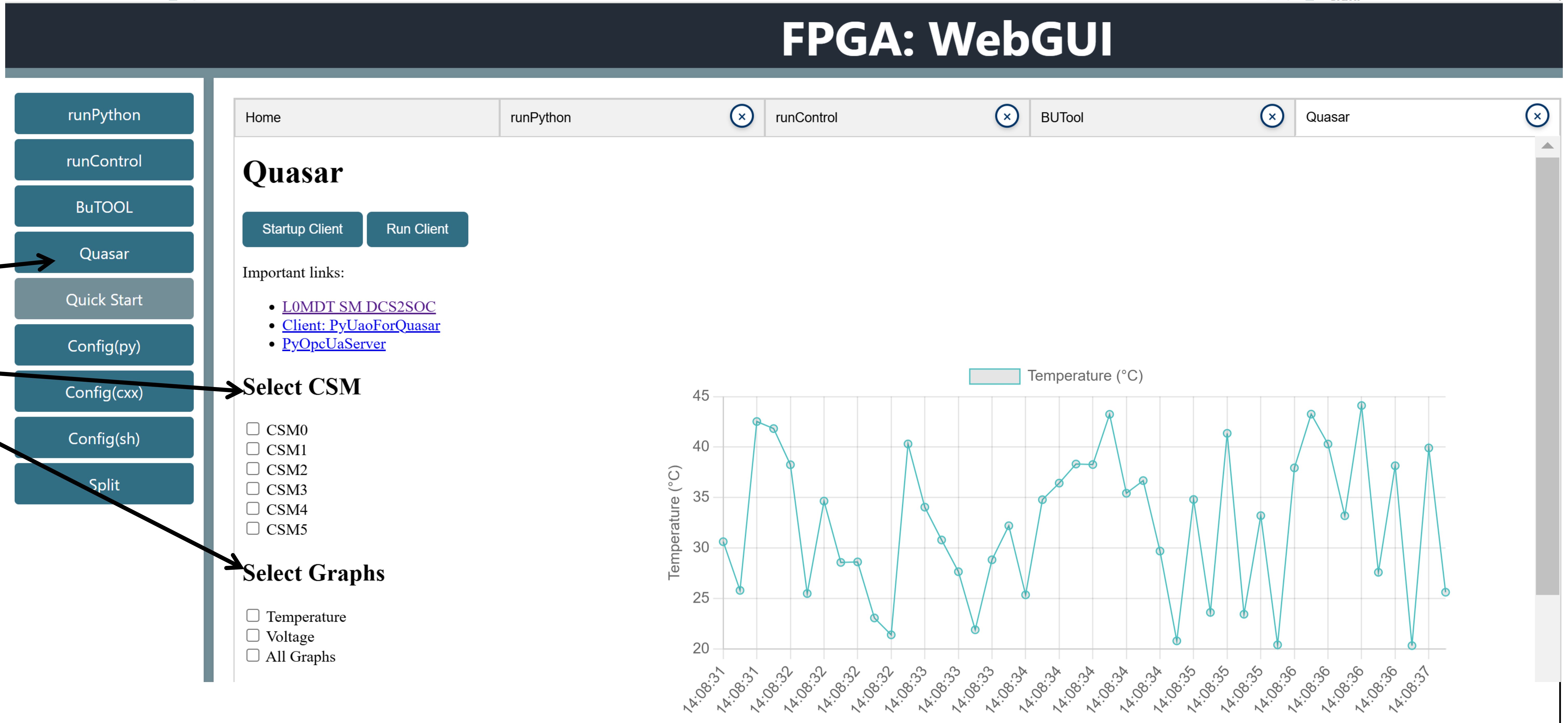
- Each of the buttons on the left open a tab in the WebGUI
  - runPython opens this tab
- Probe: Runs on load and checks if connection with any SM is possible
- Show Arguments: Goes through the DAQ2SOC to the SM and returns the script parameters



WebGUI Functions

- If runControl is clicked an additional mini tabs opens
- Allow users to initialize and configure the CM and the on-detector electronics

- If Quasar is clicked
- Users can monitor the values published by DCS2SOC



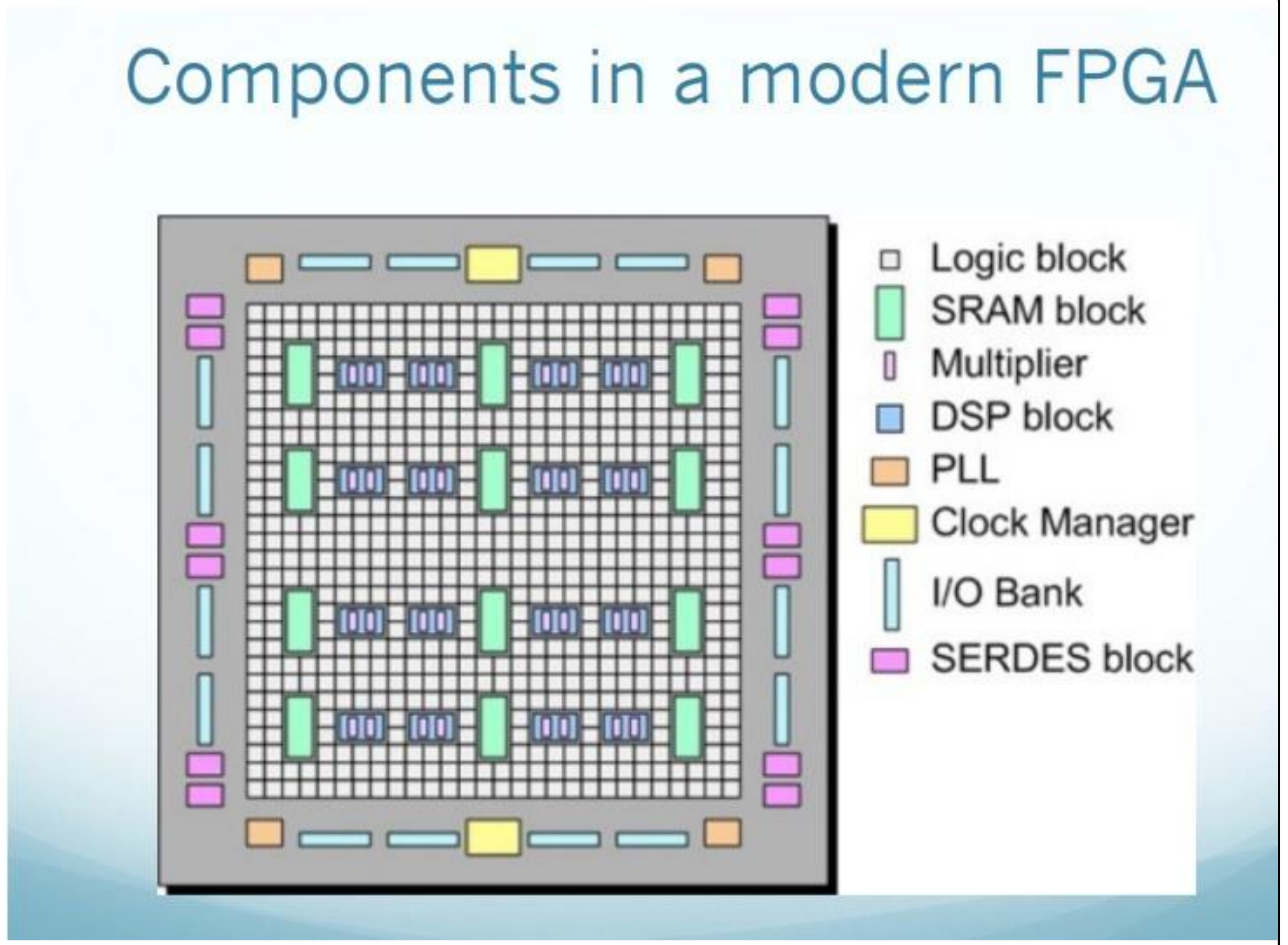
Conclusion

- WebGUI is planned to be used for testing the production of SM and CM boards during the early commissioning of the L0MDT system in the ATLAS cavern and long-term operation
- WebGUI code infrastructure is in place to start populating it with various tests
- Next goal will is to monitor MDT front end (multiple CSM and mezzanine to read 3 chambers) then add a plotting feature of the Drift time from the MDT

Backup

FPGA

- Offer high logic density and reconfigurability making them essential in modern data acquisition and control systems.
- Allow researchers to design and implement custom hardware accelerators tailored to the specific algorithms and computations needed for data processing, enabling efficient and high-speed execution.
- Facilitates rapid design, testing, and modification of hardware configurations and algorithms

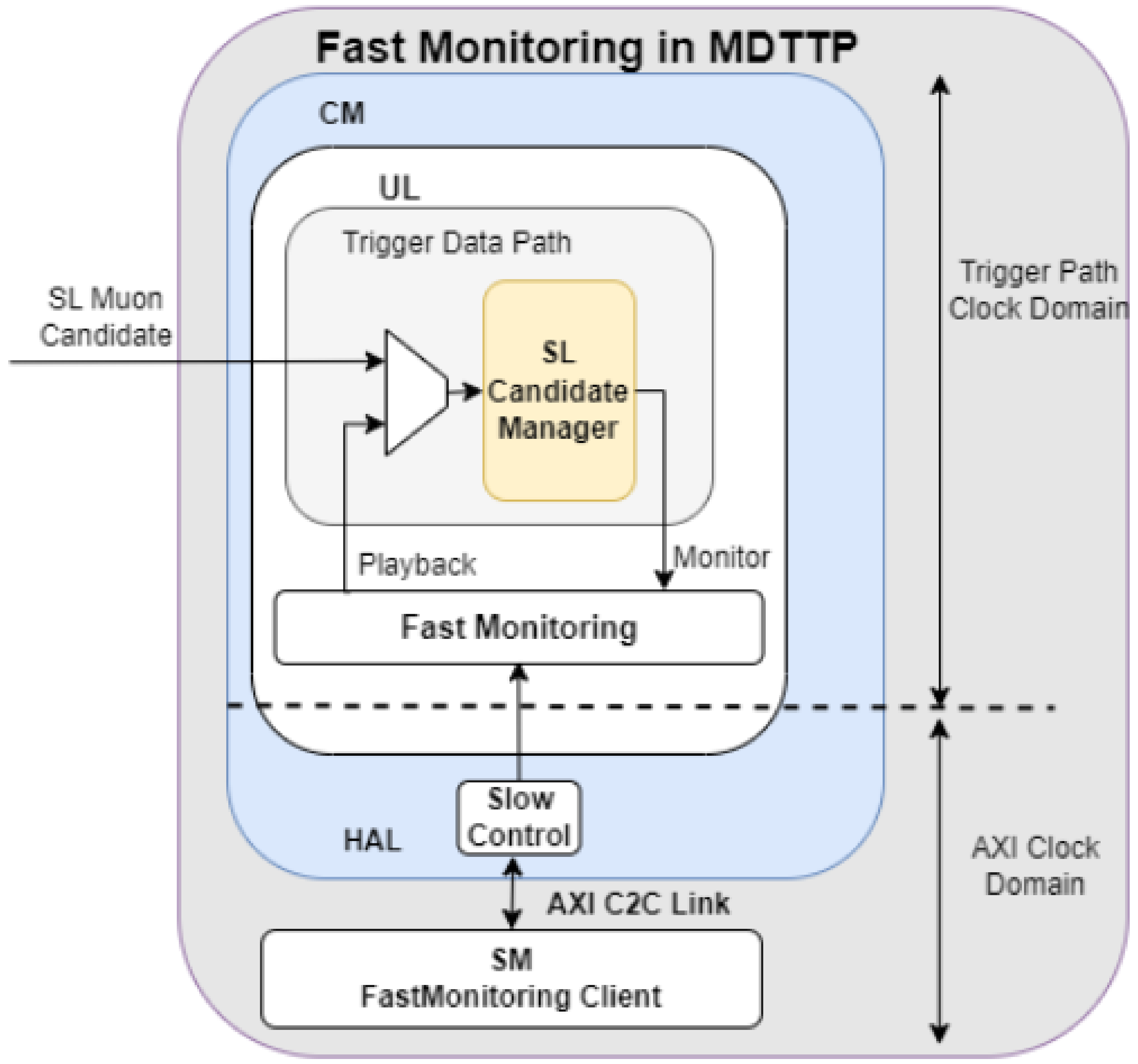


- Empowers effective exploration of various design alternatives
- Excels at parallel processing

Service Module (SM)

- The SM handles the blade infrastructure, monitoring and interface to the Detector Control System.

- The main components in this board include power management, the Intelligent Platform Management Controller (IPMC), ethernet interface and the Xilinx Zynq, which an System-On-Chip and a Field-Programmable Gate Array (FPGA)



Command Module (CM)

- The CM is application-specific and implements trigger and readout logic.
- It uses a single FPGA (VU13P).
- Software running on the Zynq SM programs the CM FPGA, communicates to the microcontroller to setup CM clocks and does hardware monitoring.
- Additional software services on the board perform slow control and fast monitoring of the CM firmware via the AXI C2C link

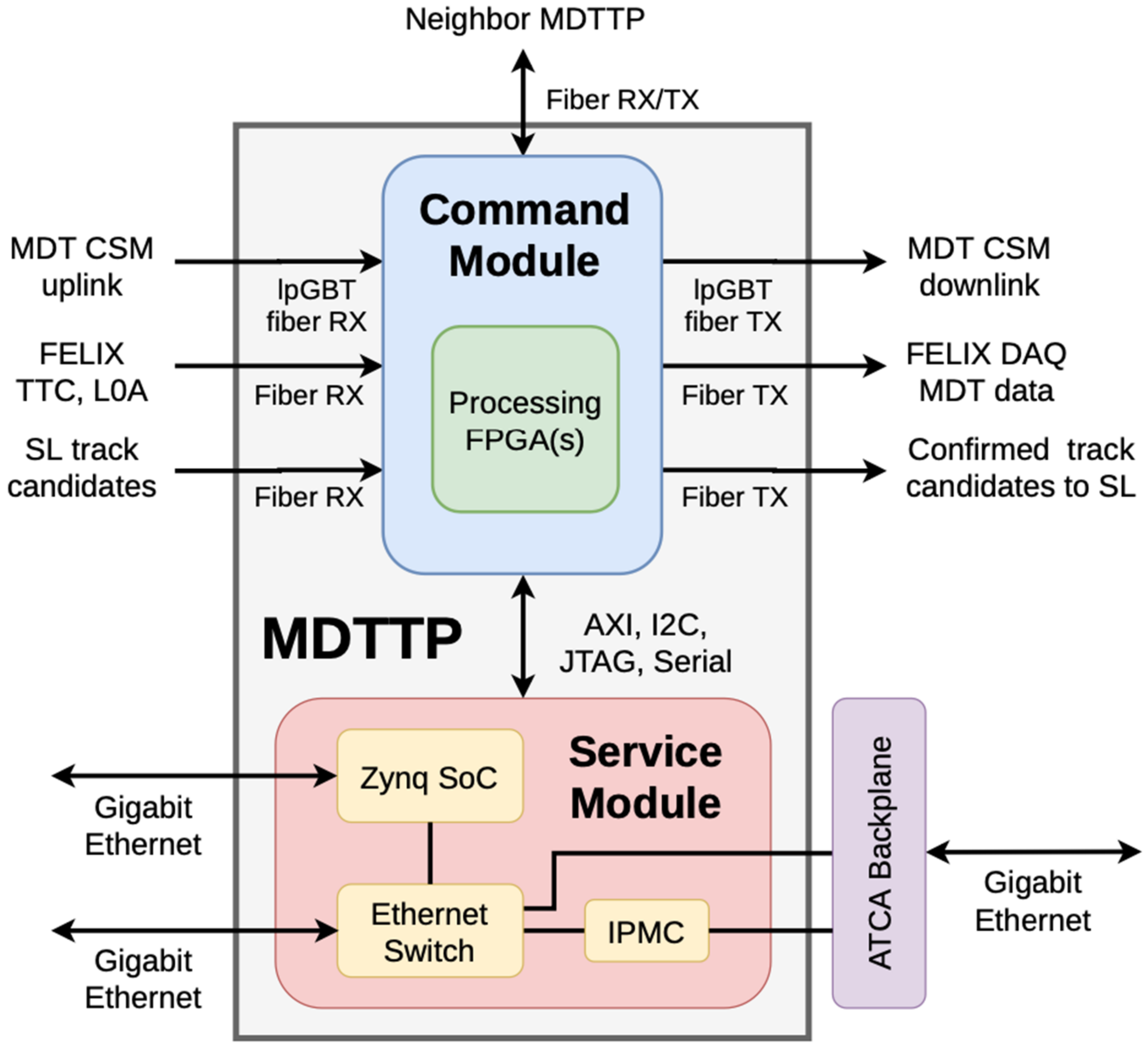
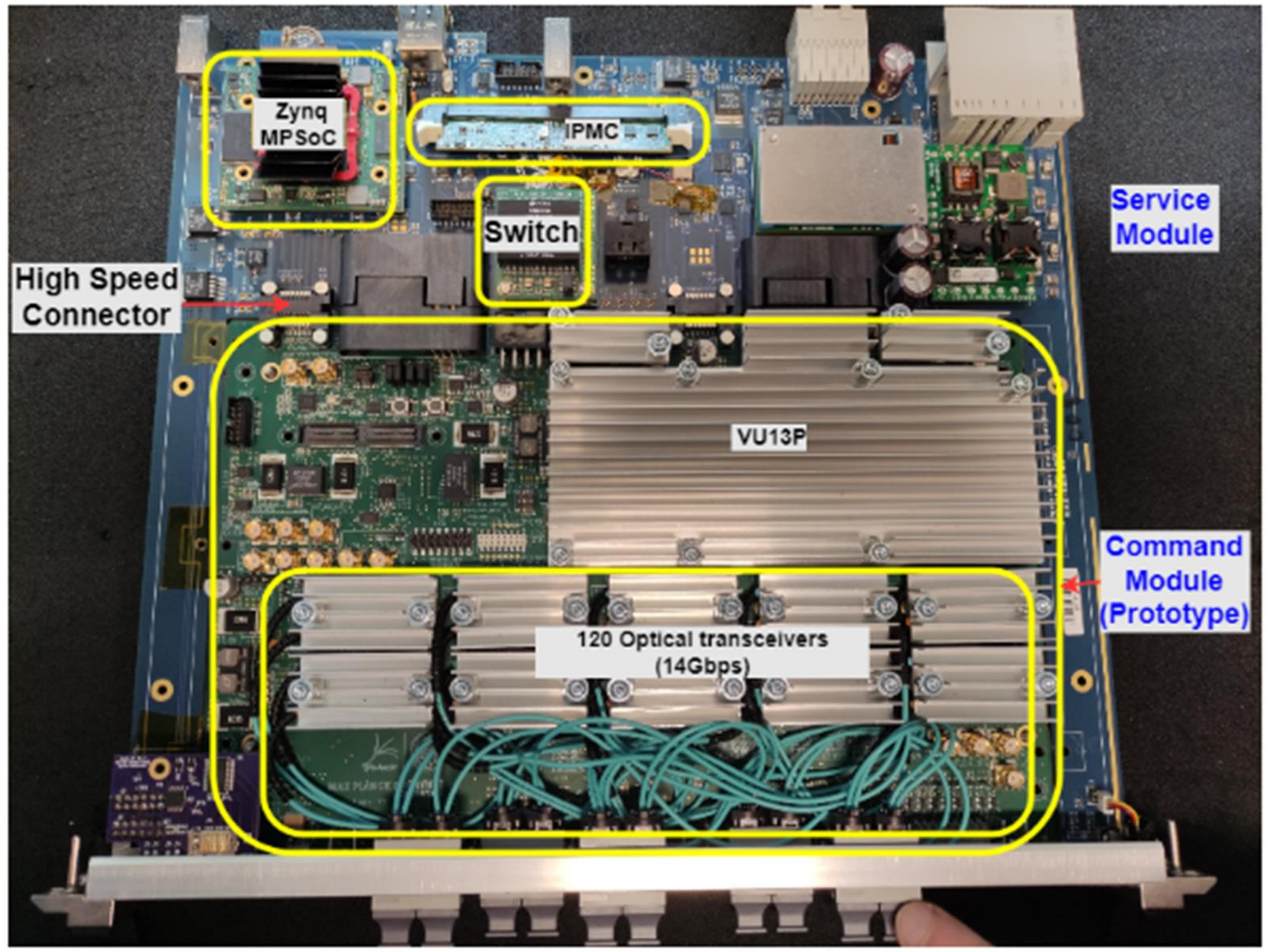


Figure 2.2: Block diagram for the MDTTP blade showing external and internal connectivity.

MDTTP ATCA Blade

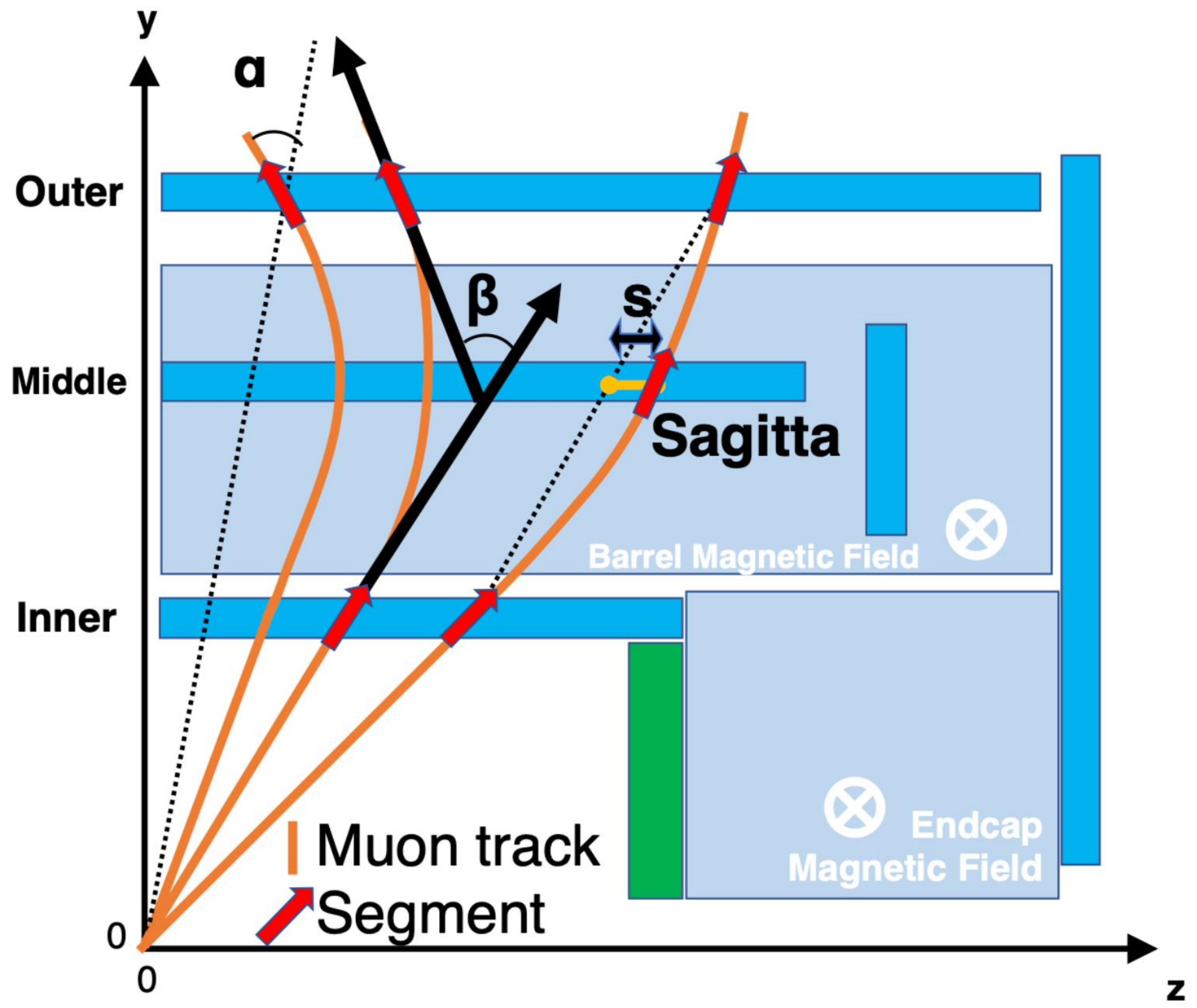


- The MDTTP ATCA blade uses the Apollo platform, divided into a Service Module (SM) and a Command Module (CM).
- The MDTTP board manages trigger and data acquisition (DAQ) for muon triggers.
- It interfaces with the Chamber Service Module (CSM) for MDT hit reception and front-end configuration
- DAQ matches buffered MDT hits to the relevant bunch crossing (BCID) on Level-0 Accept (L0A).

PTPARAM INFO

- RPC (Resistive Plate Chambers):
  - Provides fast timing information and helps in the initial triggering of muons. Works by detecting charged particles through the ionization of gas in the chamber.
- TGC (Thin Gap Chambers):
  - Offers high spatial resolution and fast response times. Helps to confirm the trajectory of muons in the trigger process.
- NSW (New Small Wheel):
  - A modern muon detection system with enhanced precision. Contributes additional tracking information from the inner regions of the muon spectrometer.
- Tile Information:
  - From the Tile Calorimeter, providing energy measurements that assist in distinguishing muons from other particles.

Sagitta



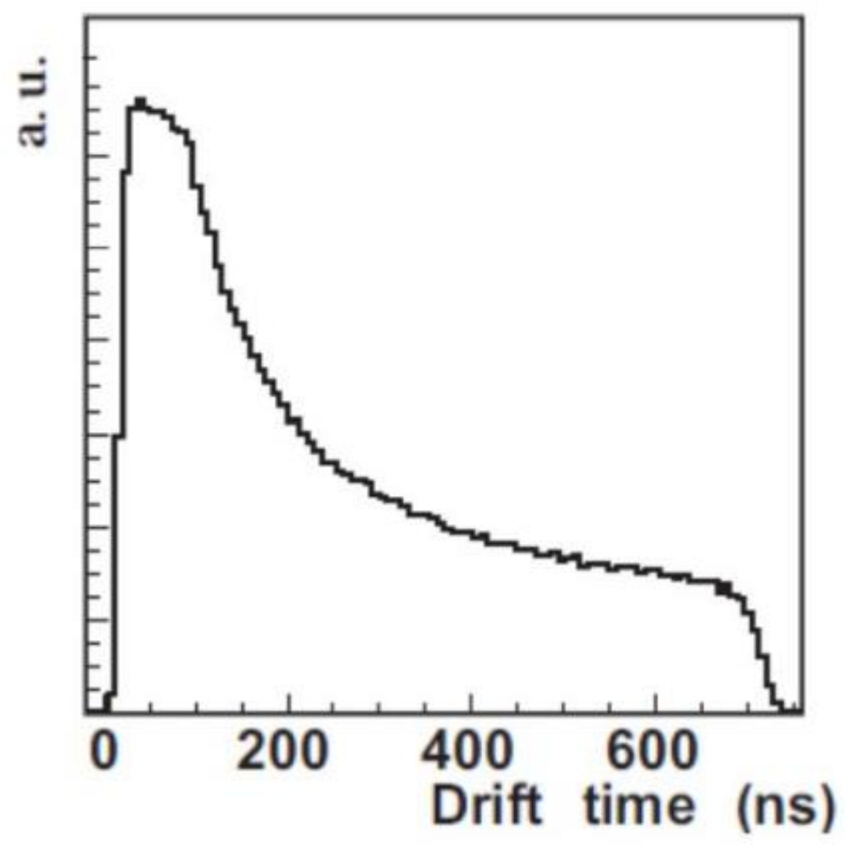
DAQ2SOC

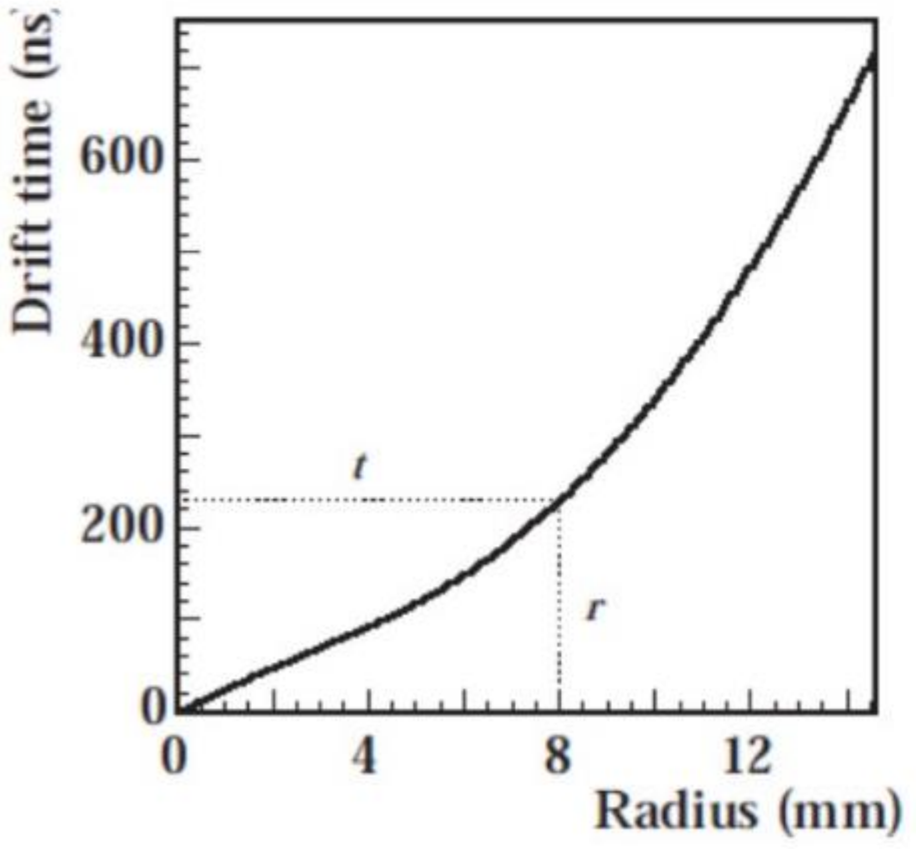
- DAQ (Data Acquisition): designed to handle the enormous amounts of data generated by particle collisions in the Large Hadron Collider (LHC). It captures data from the detectors, processes it in real-time to identify interesting events, and stores it for further analysis.

- SOC (System-On-Chip): technology integrates all components of a computer or other electronic system into a single chip. SOCs can be used to enhance data processing capabilities and improve the efficiency of the DAQ system.

MDT

- Main Purpose: Precision measurement of Eta coordinate
- Drift Time: 700 ns (slow)
- Covers
  - Barrel, |eta| < 1.05 and End-caps 1.05 < |eta| < 2.7





Resistive Plate Chambers (RPC)

- Main Purpose: Precision measurement of phi coordinate

- RPC/TGC (fast response with BCID capability) are used in the muon trigger decision
- Covers
  - |eta| < 1.05

Thin Gap Chambers (TGC)

- Main Purpose: triggering and φ-coordinate measurement in the end-cap region

- RPC/TGC (fast response with BCID capability) are used in the muon trigger decision
- Covers
  - |eta| < 1.05 < |eta| < 2.7