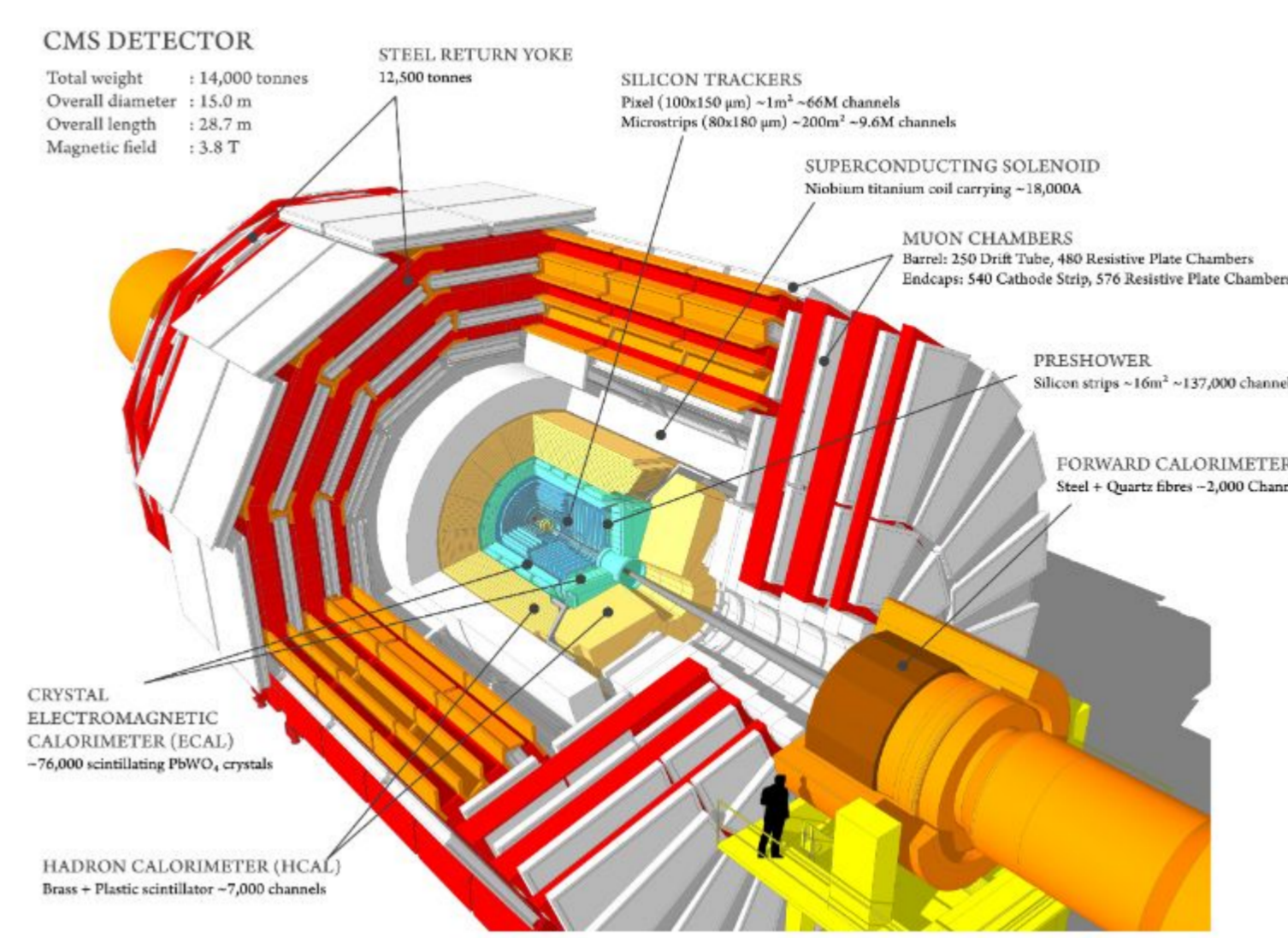
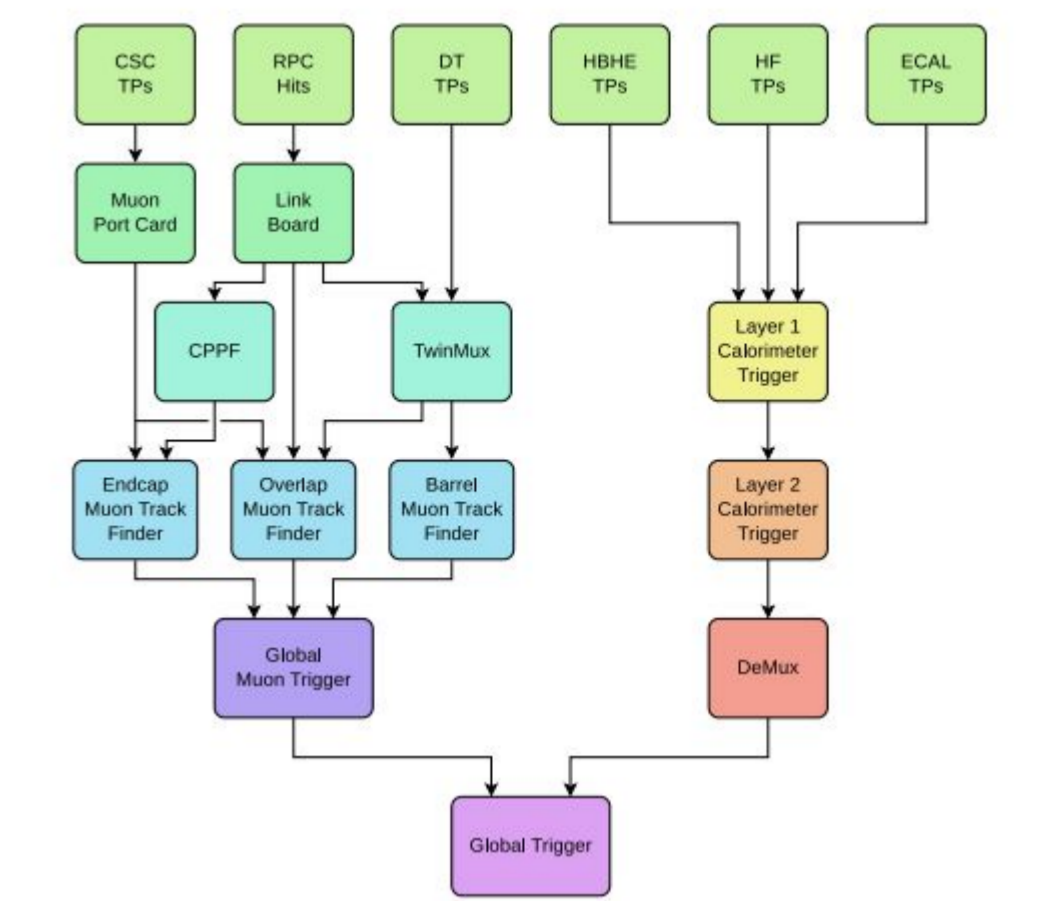


Introduction

- The Compact Muon Solenoid (CMS): general-purpose detector at the LHC.
 - Investigates a wide range of physics phenomena e.g. Higgs boson, Dark Matter etc.
 - Enables detection and analysis of particles produced in high-energy particle collisions.
- Robust trigger system filters out significant fraction of physics events in real time.
- The Level-1 Trigger (L1T) is a custom-designed electronics system – the first line of defense
 - Receives data with coarse granularity from Calorimeter and Muon systems.
 - Processes an event and makes the decision in less than 4 μ s.
 - Reduces the collision event rate from 40 MHz to about 115 kHz.
 - Makes data manageable for further processing by the High Level Trigger (HLT).



Schematic of CMS Detector



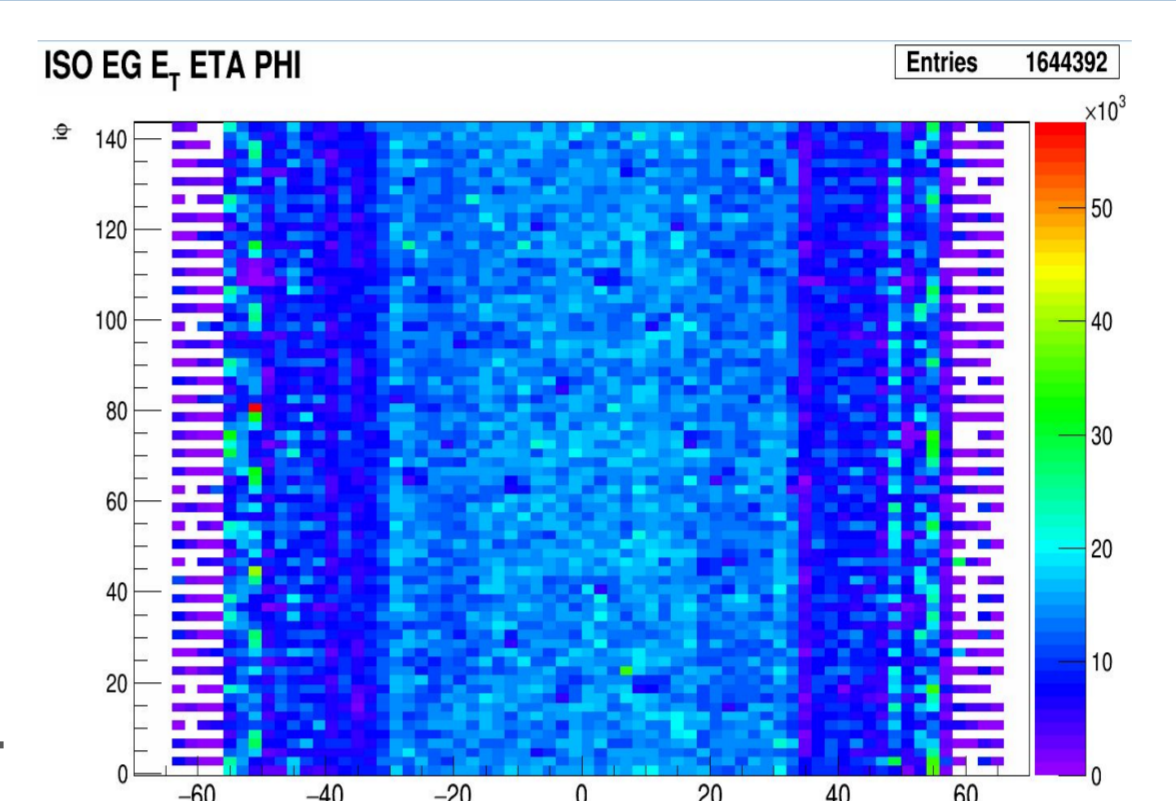
Overview of Level-1 Trigger at CMS

Optimal performance of the L1T requires effective monitoring of all its subsystems

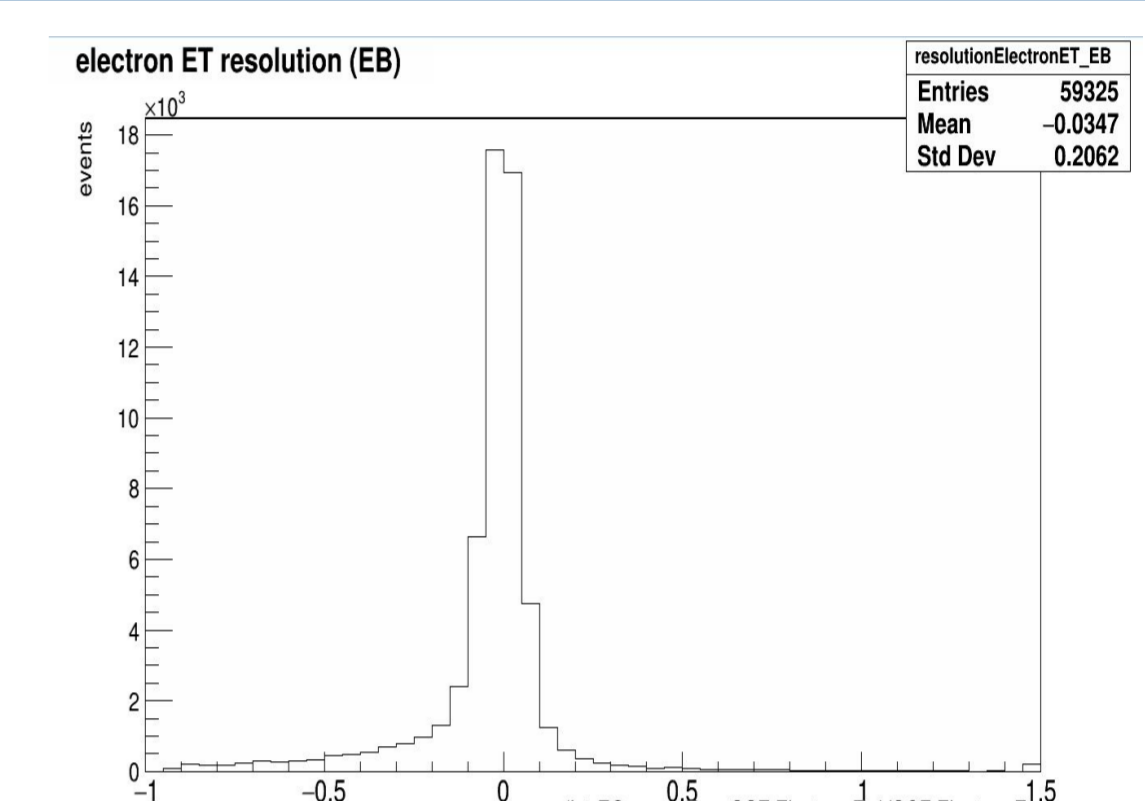
Overview of L1T Monitoring System and Workflows

Two-Step Data Certification:

- Online:
 - Performed while data is being collected to identify any anomalous behavior.
- Offline:
 - Compares performance of Level-1 objects with reconstructed offline quantities.
 - Performed per luminosity section (interval of 23.31 seconds) to provide high quality data with minimum loss.



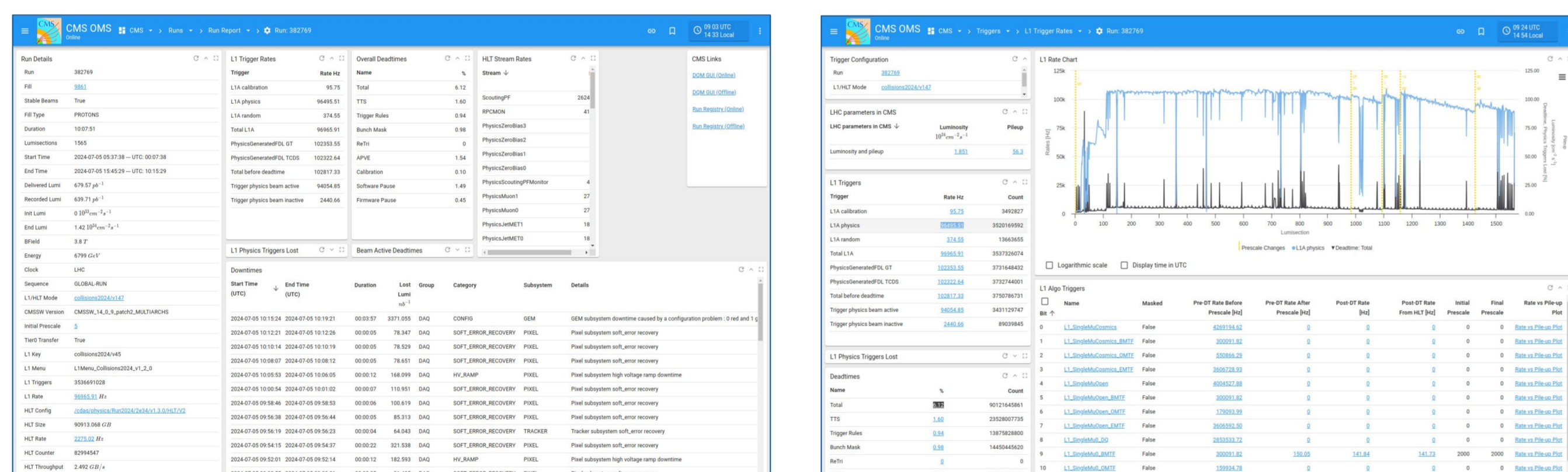
Online Monitoring: Iso Electron E_T η - ϕ Occupancy



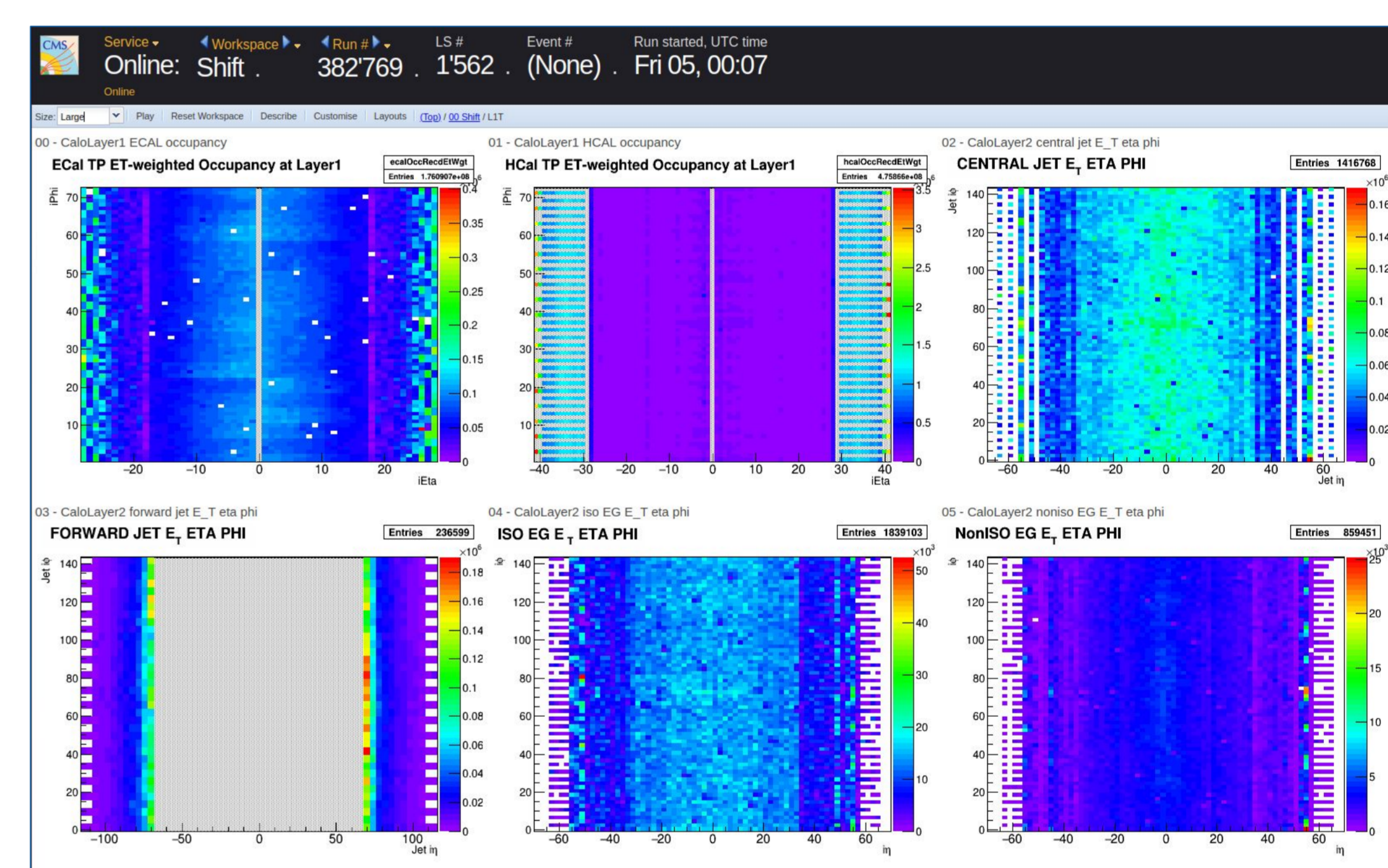
Offline Monitoring: Offline Electron E_T resolution

Monitoring Tools

- Two dedicated web-based GUI systems for Online and Offline Data Quality Monitoring (DQM).
 - Provide efficiencies, resolution, and occupancy maps of physics objects, as well as trigger object timings.
- The CMS Online Monitoring System web tool provides various information:
 - Trigger rates, deadtime, and time stamps for periods when the detector is collecting physics data.
 - Summary of delivered and recorded data, along with data quality checks performed by CMS subsystem experts.



CMS OMS Web Tool: Summary of Recorded data, Trigger Rate, Deadtime



Online DQM GUI: L1T Monitoring Plots

New Developments for Run-3

Auto-DQM tool

- Compares monitoring plots with reference.
- Performs statistical tests to flag anomalous behaviour.

New DQM GUI: An alternative to the current offline DQM, developed using Plotly/Streamlit.

- Significantly faster load times.
- Offers interactive plots, dedicated panel for shifter instructions, adaptive screen layouts.
- Recording Option - Handy to communicate any issue with experts.

Nano Workflow:

- Processes data in **user-friendly** plain Ntuple format.
- Produces performance check plots of various physics objects.
- Fast** in processing large data.
- Easy to use and train new developers.
- Allows for **easy addition of new functionalities** and quick performance checks.

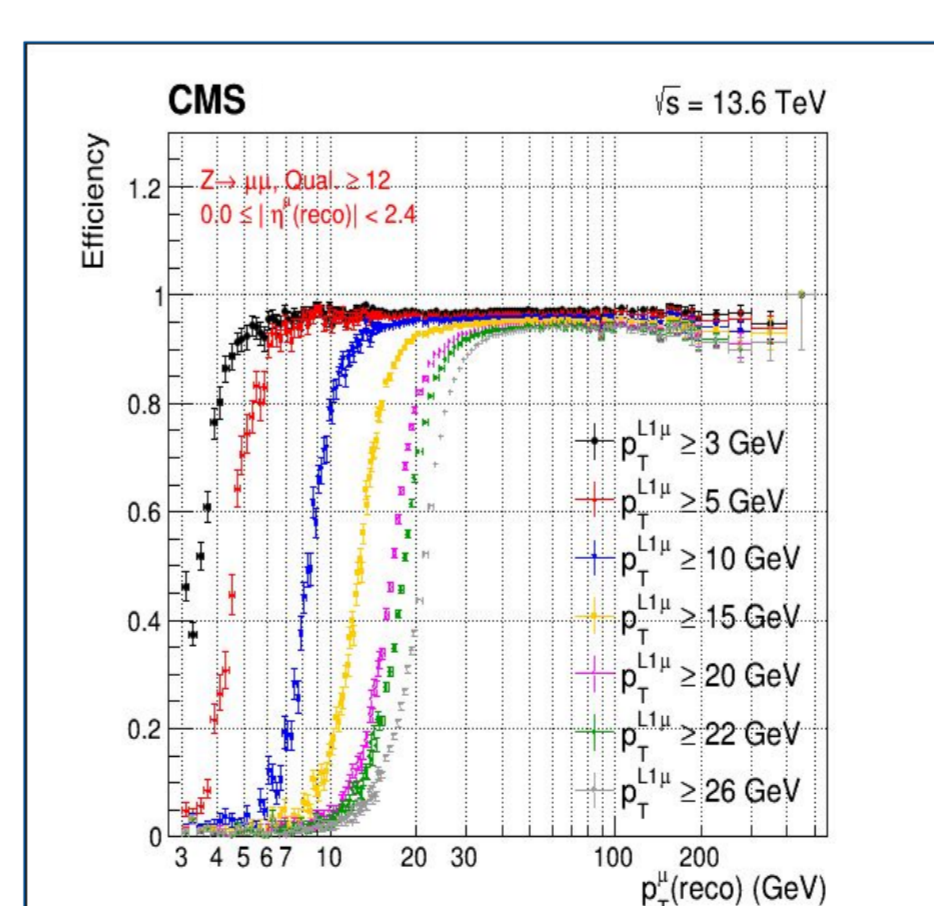
Prefiring Monitoring:

- Event passing an L1 seed for previous bunch crossing gets masked
- Need to monitor prefiring for preventing efficiency loss.

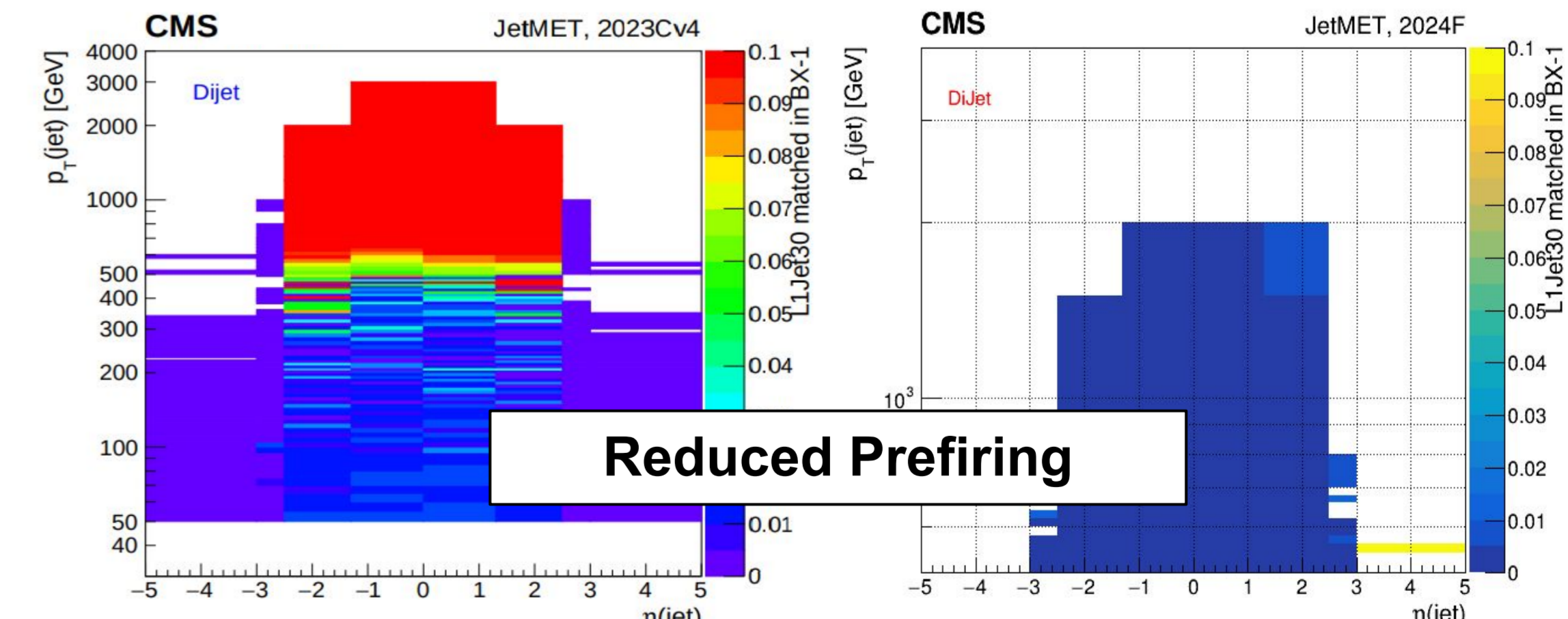
Auto DQM: Reference Comparison



New DQM GUI Dashboard



Performance of offline reconstructed muons



Comparison of prefiring monitoring plot across eras.

Conclusions

- The L1T data monitoring workflow ensures the integrity and quality of CMS trigger decisions.
- New tools like the NanoAOD data tier based workflow and Plotly/Streamlit based DQM GUI improve the monitoring efficiency significantly.
- Continuous improvements crucial to prepare CMS experiment for High Luminosity LHC era.

References

- CMS Collaboration, Performance of the CMS Level-1 trigger in proton-proton collisions at $\sqrt{s}=13$ TeV, JINST 15 (2020) P10017.
- Plotly - Data apps for production, <https://plotly.com>
- Streamlit - Shareable data apps, <https://streamlit.io>