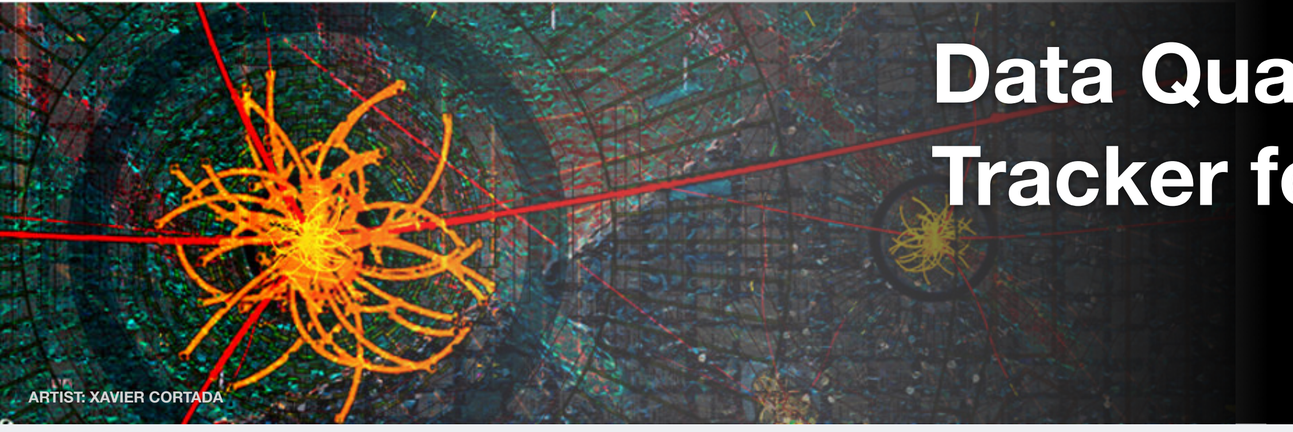

Data Quality Monitoring of CMS Outer Tracker for the HL-LHC Upgrade

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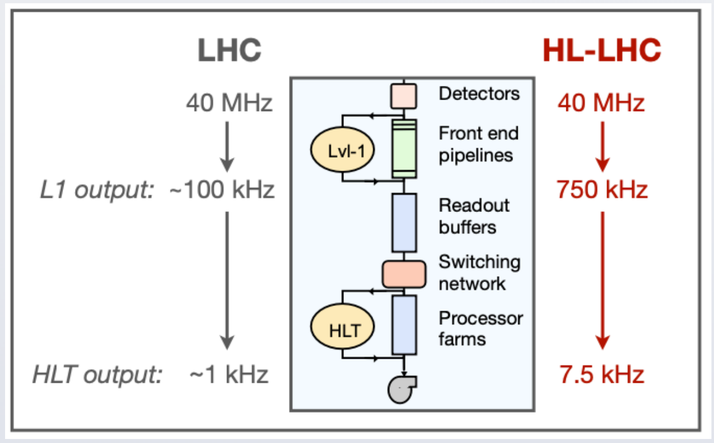
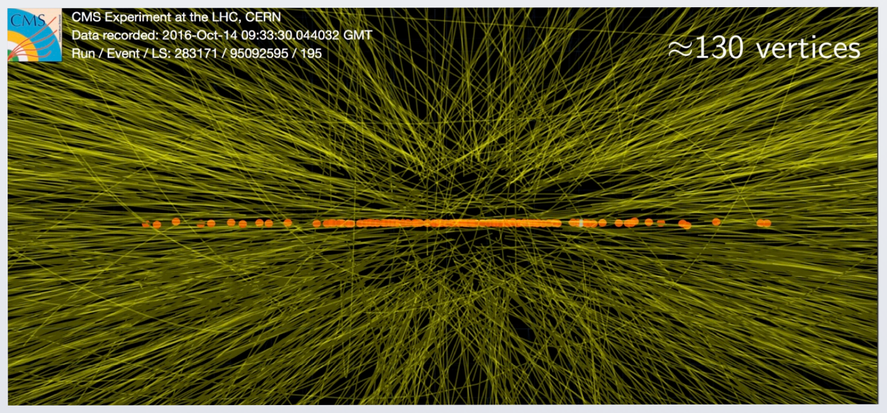
High Luminosity Large Hadron Collider (HL-LHC)



For the upgrade [1]:
- High pileup with 140 to 200 proton-proton collisions per bunch crossing on average
- Harsh radiation environment

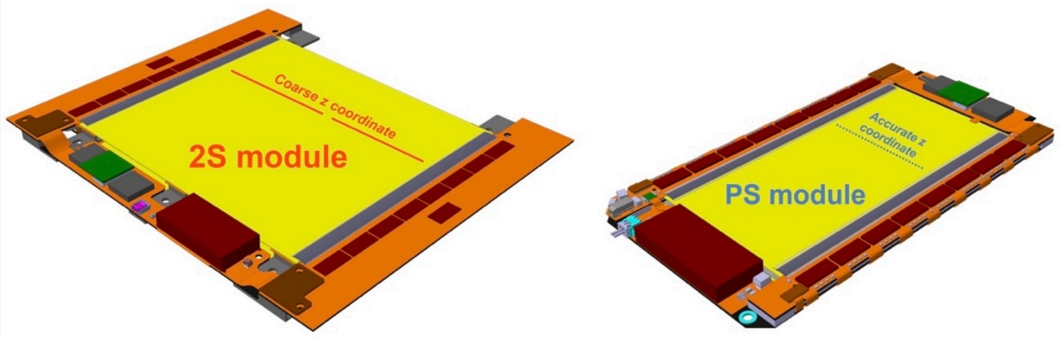
Level 1 (L1) Trigger:
- For the first time at the LHC, use tracker inputs in addition to calorimeter and muon information, improving the precision of event selection

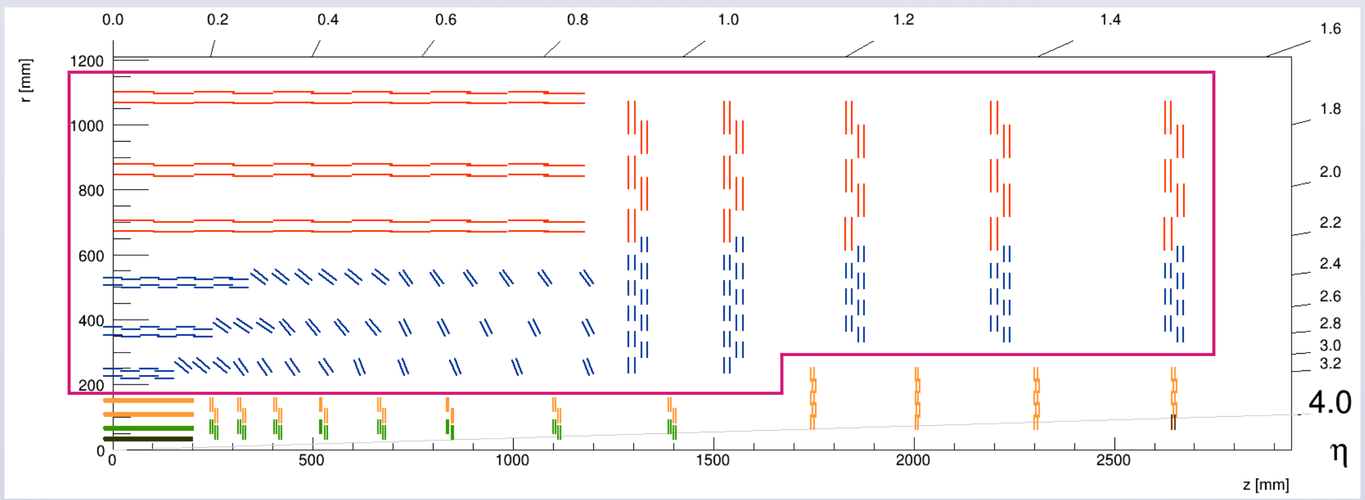


Real event with HL-LHC-like pileup from special run in 2016 with individual high intensity bunches. [2]

CMS Outer Tracker Upgrade

2S module	PS module
$\sim 2 \times 90$ cm^2 active area	$\sim 2 \times 45$ cm^2 active area
2×1016 strips: ~ 5 cm $\times$ 90 μm	2×960 strips: ~ 2.4 cm $\times$ 100 μm
2×1016 strips: ~ 5 cm $\times$ 90 μm	32×960 macro-pixels: ~ 1.5 mm $\times$ 100 μm

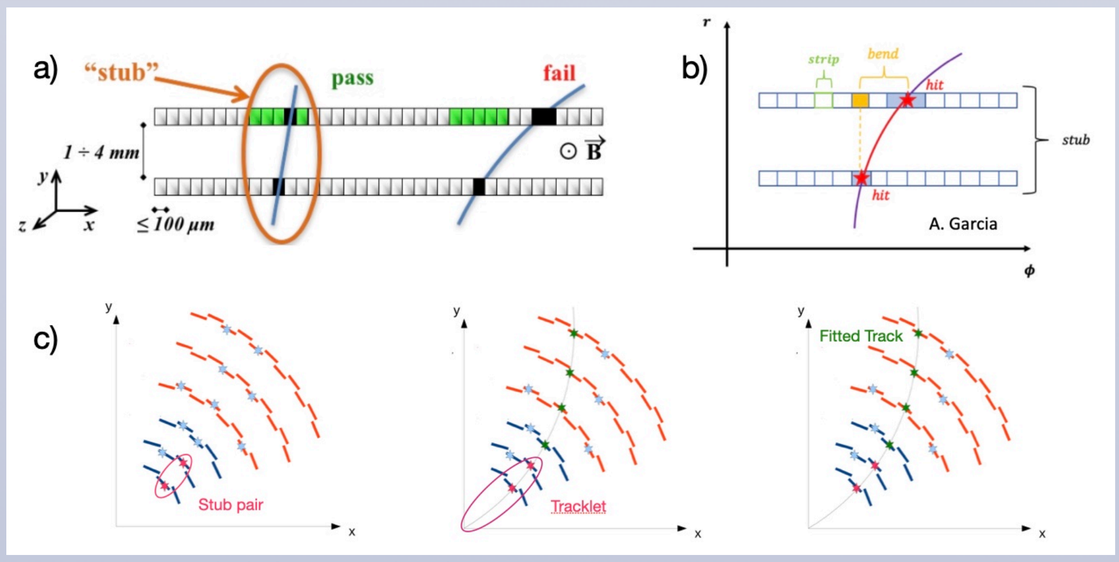




Two modules types each made up of two stacked sensors [4]:
- 2S (two strip sensors)
- PS (modules with a strip and a macro-pixel sensor)

- Outer tracker region (inside raspberry) has 6 layers in the barrel and 5 discs in the endcaps. [3]
- PS modules (blue): in the 1st 3 layers of the outer tracker, in the radial region 200-600 mm
- 2S modules (red): in the outermost 3 layers, in the radial region above 600 mm

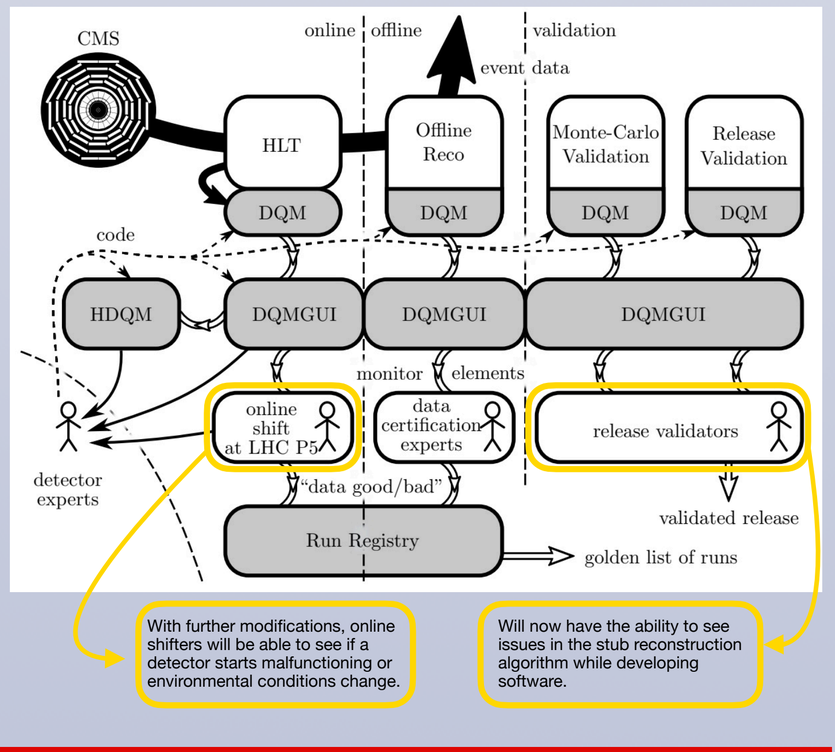
Stubs and Tracking Particles



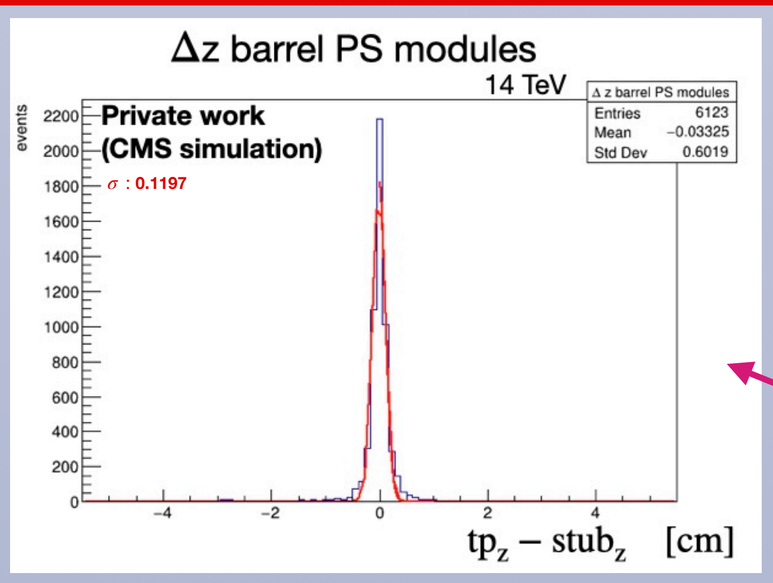
Tracking Particles (TP): Generated (truth) values representing the particle's true trajectory. [4]
Cluster: Shown in b), a cluster is a hit (depicted by a red star).
Stubs: Stubs are formed when a hit in the bottom sensor is matched with a hit in the top sensor, using common front-end electronics, within a programmable predefined window.
Genuine: Refers to clusters or stubs that are correctly matched to generated particles (TPs), where the majority of transverse momentum is contributed by a single particle.

Data Quality Monitoring (DQM)

DQM is essential for keeping an eye on data quality at all stages, from when we first gather data to the final analysis. Used in the following key environments [5]:
- Online: for real-time detector monitoring
- Offline: for prompt-offline-feedback and final fine grained data quality analysis and certification
- Validation: software and simulation



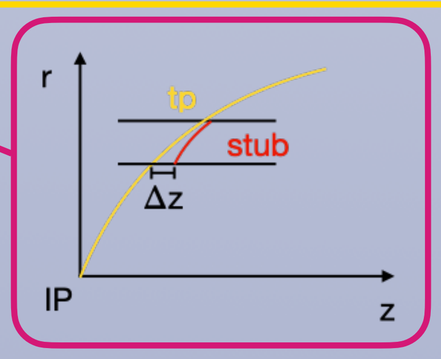
Results

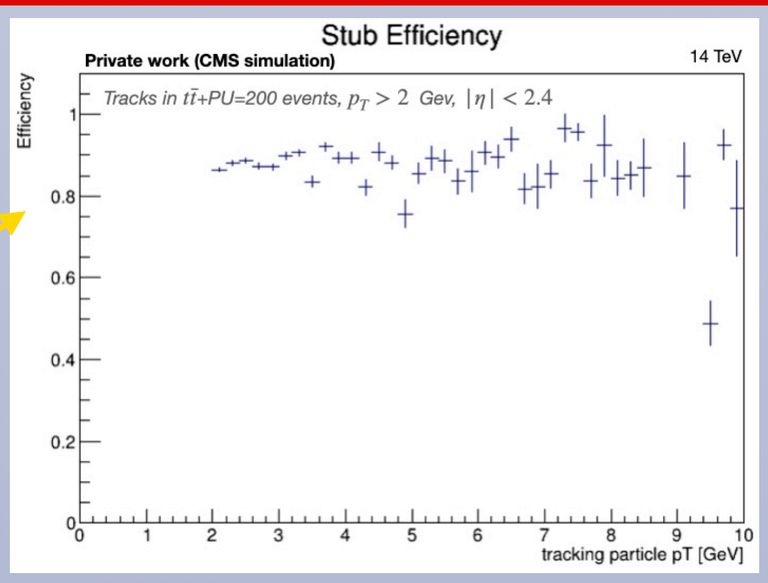


- This plot shows the difference in z-position (Δz) between the stub and the tracking particle (tp) at the sensor's radius.
- Monitoring this parameter ensures the accuracy of vertex identification and pileup rejection in the CMS Outer Tracker.

Develop methods and include histograms to evaluate the stub reconstruction performance
- Analyzed stub finding efficiency, position and bend resolution
- Introduced the ability to examine stub residuals for enhanced understanding of measurement precision

$$\text{Stub efficiency} = \frac{\text{Number of genuine clusters used in genuine stubs}}{\text{Number of genuine clusters}}$$





- This plot helps monitor changes in stub efficiency, enabling early detection of issues affecting overall tracking performance.
- Drop in tracking efficiency can be analyzed by investigating stub efficiency, crucial for debugging and maintaining system

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References
[1] CMS Collaboration. The TriDAS Project: Technical Design Report, Volume 2: Data Acquisition and High-Level Trigger. CERN-LHCC-2002-026, CMS-TDR-6, CERN, 2002.
[2] CMS Collaboration. Collisions recorded by the CMS detector during the high pile-up fill. CMS-PHO-EVENTS-2016-008, CERN, 11 November 2016.
[3] CMS Collaboration. The Phase 2 Upgrade of the CMS Data Acquisition and High Level Trigger. Technical Design Report CERN-LHCC-2021-007, CMS-TDR-022, CERN, 17 June 2021.
[4] CMS Collaboration. The Phase 2 Upgrade of the CMS Tracker. Technical Proposal CERN- LHCC-2017-009, CMS-TDR-014, CERN, 2017.
[5] CMS Collaboration. The Data Quality Monitoring Software for the CMS experiment at the LHC: past, present and future. EPJ Web of Conferences 214, 02003 (2019), CHEP 2018.