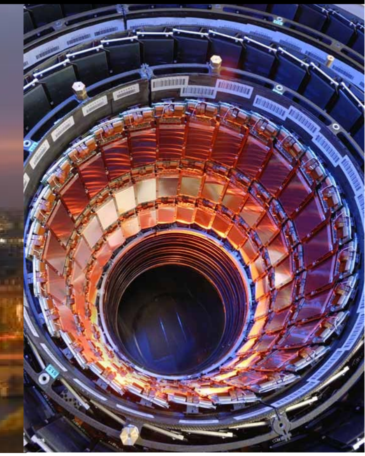

BOSTON UNIVERSITY

CMS

Performance of the CMS High-Level Trigger

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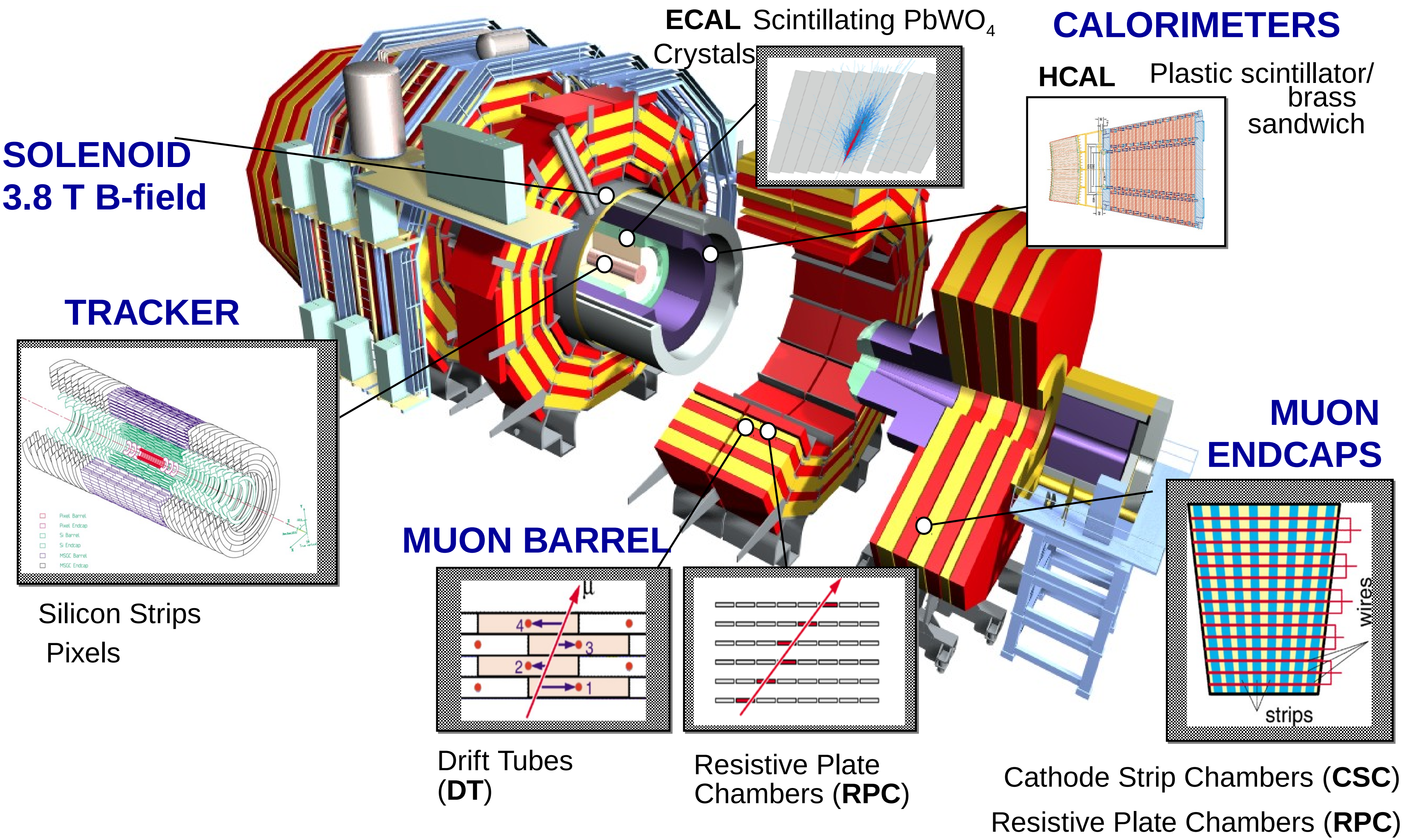
for the CMS Collaboration

Overview

- Introduction
- Commissioning Triggers
  (referenced to other ICHEP contributions)
- Physics Triggers Performance:
  - Electrons
  - Muons
  - Jets
  - Missing Transverse Energy (MET) objects
- Rates and CPU Performance
- Conclusions

The CMS Detector

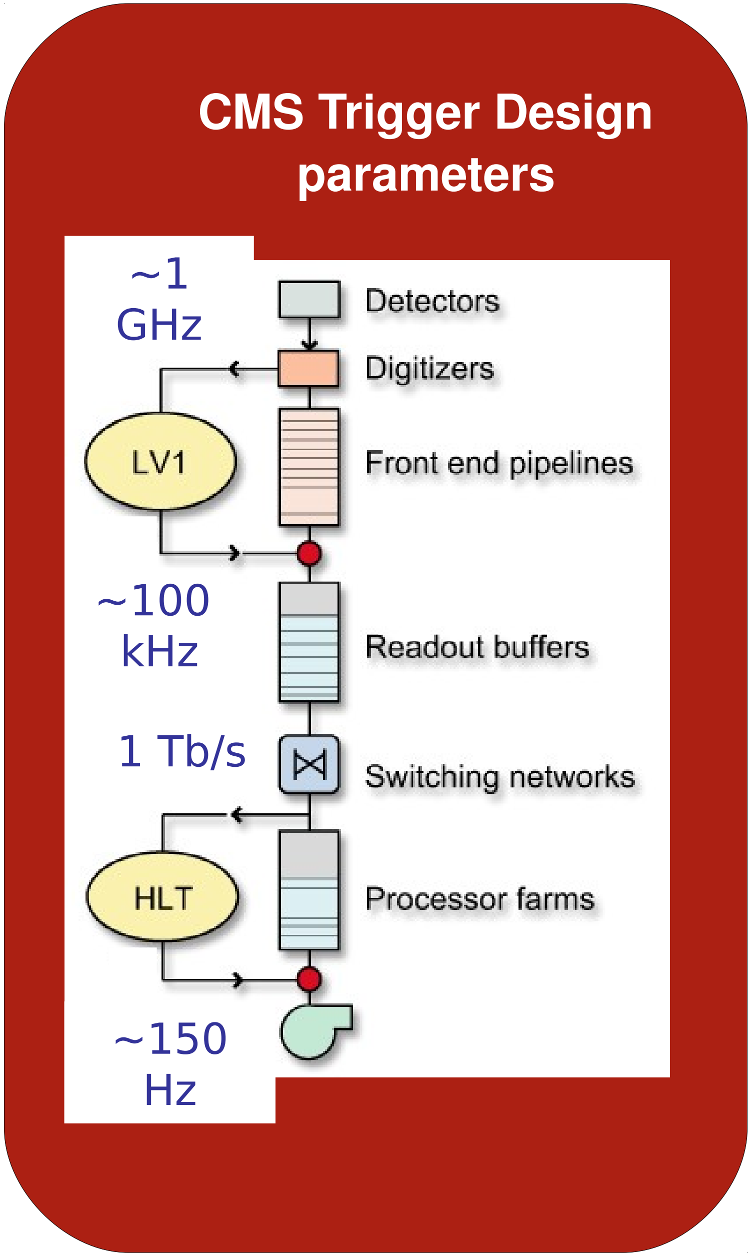


Azimuthal angle: ϕ

Polar angle: θ

Pseudorapitidy: $\eta = -\ln \tan(\theta/2)$

The CMS High Level Trigger (HLT) System



- Full CMS event rate reduced in two steps, Level-1 (L1) Trigger and HLT.
- L1: uses custom-designed, programmable electronics
- The HLT:
  - receives input directly from L1.
  - Software based; offline-quality algorithms running in real time on a ~5K processor filter farm.
  - Combines the traditional Level-2 and Level-3 steps into a single step and uses full granularity data.
  - Internally, it works in several stages: First stage: only calorimeters and muon system information; second stage: selection including reconstruction of full tracks in the tracker; intermediate stage: use of partial tracker information

The CMS High Level Trigger (HLT) System

- Currently, the HLT trigger menu consists of about 150 triggers, which include physics and commissioning

- Smooth running and excellent performance of the HLT system during the first months of LHC operations at $\sqrt{s}$ = 7 TeV.

  - Background and L1 rate optimally brought down.
  - Quality data successfully delivered for analysis.

- In the following slides:
  Plots of HLT performance in Spring 2010 proton-proton collision data taken at $\sqrt{s}$ = 7 TeV (L1 max rate 50 KHz)

Commissioning Triggers

- A fraction of the bandwidth (close to 30% at start-up) is reserved for calibration triggers to ensure complete understanding of the detector performance.

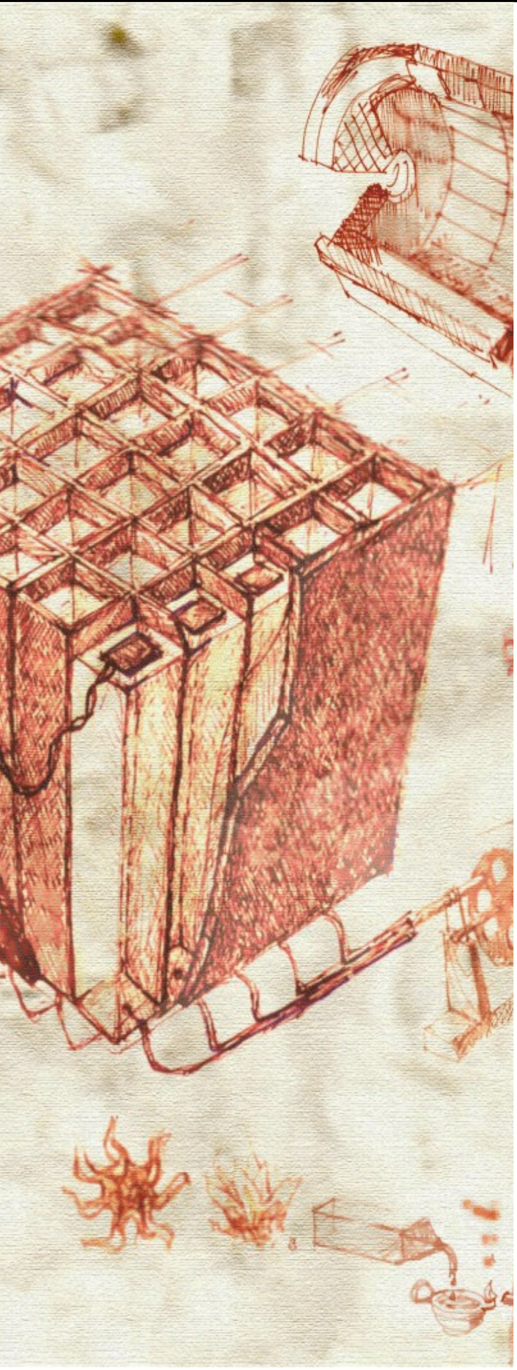
- Data collected by these triggers are used for providing new calibration and alignment constants for use by offline reconstruction algorithms.

MORE on Commissioning/Alignment/Calibration triggers

- Parallel talk "**Operation of the CMS detector with first collisions at 7 TeV at the LHC**", Salle 252A, 24 July 2010, Advances in Instrumentation and Computing for HEP:
http://indico.cern.ch/contributionDisplay.py?sessionId=58&contribId=1196&confId=73513

- Poster: "**Commissioning, Performance, and Calibration of the Electromagnetic Calorimeter of CMS**"

Photon and Electron Triggers

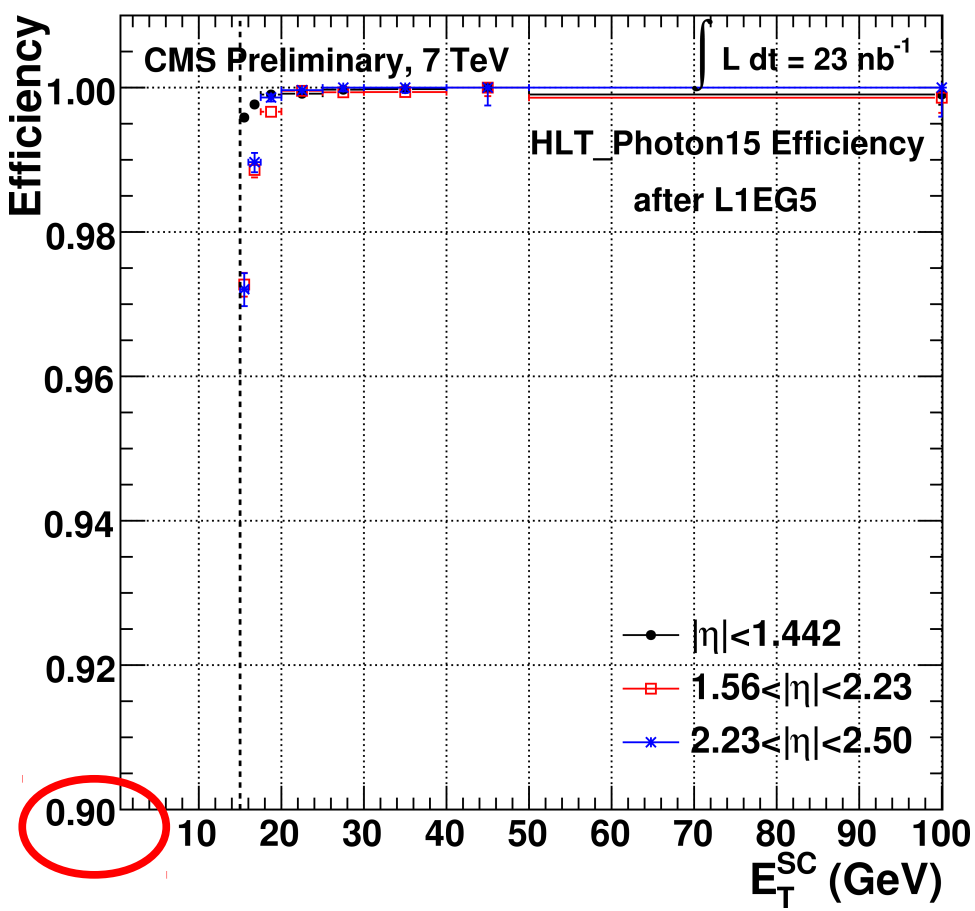


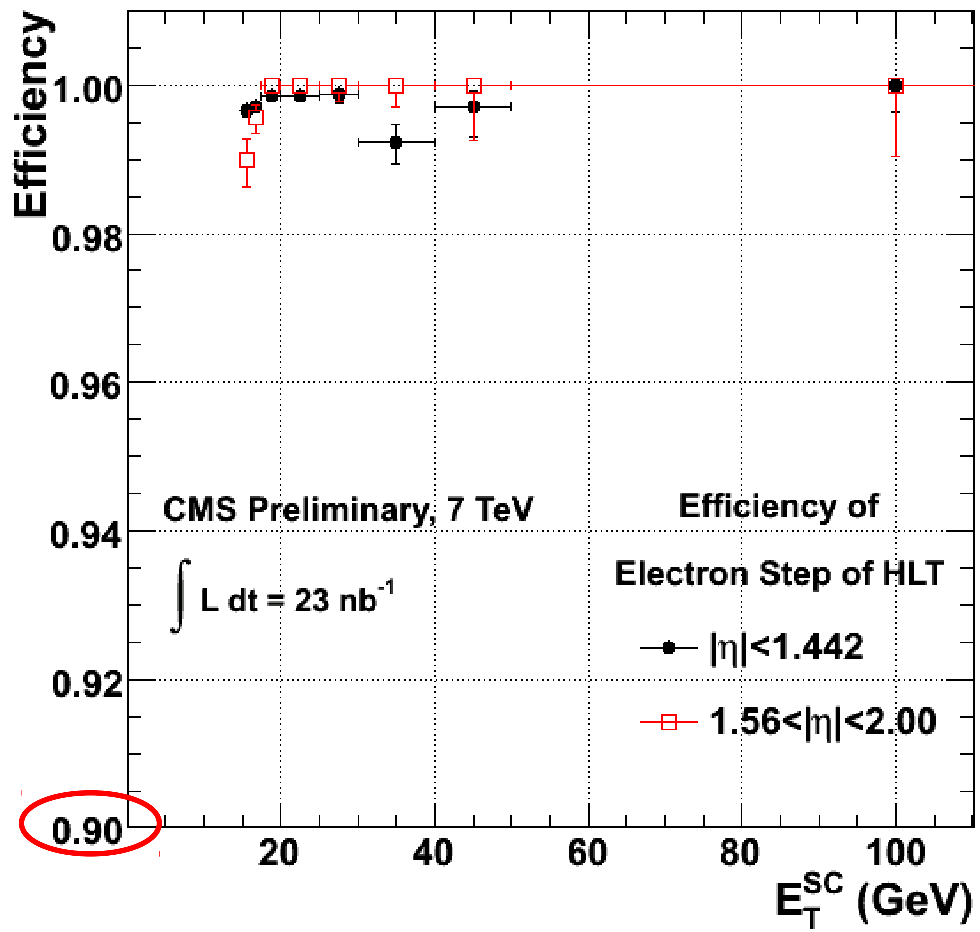
- Common stage for Photons and Electrons:
  - Angular matching of energy deposits (clusters) in the Electromagnetic Calorimeter (ECAL) with e/γ candidates at L1.
  - Form super-clusters (group of clusters; bremsstrahlung/conversions recovery)
  - E_T cut applied
  - ECAL super-cluster shape consistent with an electromagnetic object
  - Calorimetric (ECAL+HCAL) isolation
- Photons
  - Tight track isolation in a solid cone
- Electrons:
  - Matching with hit pairs in pixel detectors
  - Electron track reconstruction
  - Angular matching of ECAL cluster and full track
  - Loose track isolation in a hollow cone

Performance of Photon and Electron Triggers

Trigger efficiency for selected offline superclusters matched to L1 objects to pass a photon trigger with a threshold of $E_T > 15$ GeV, plotted vs. the supercluster E_T.

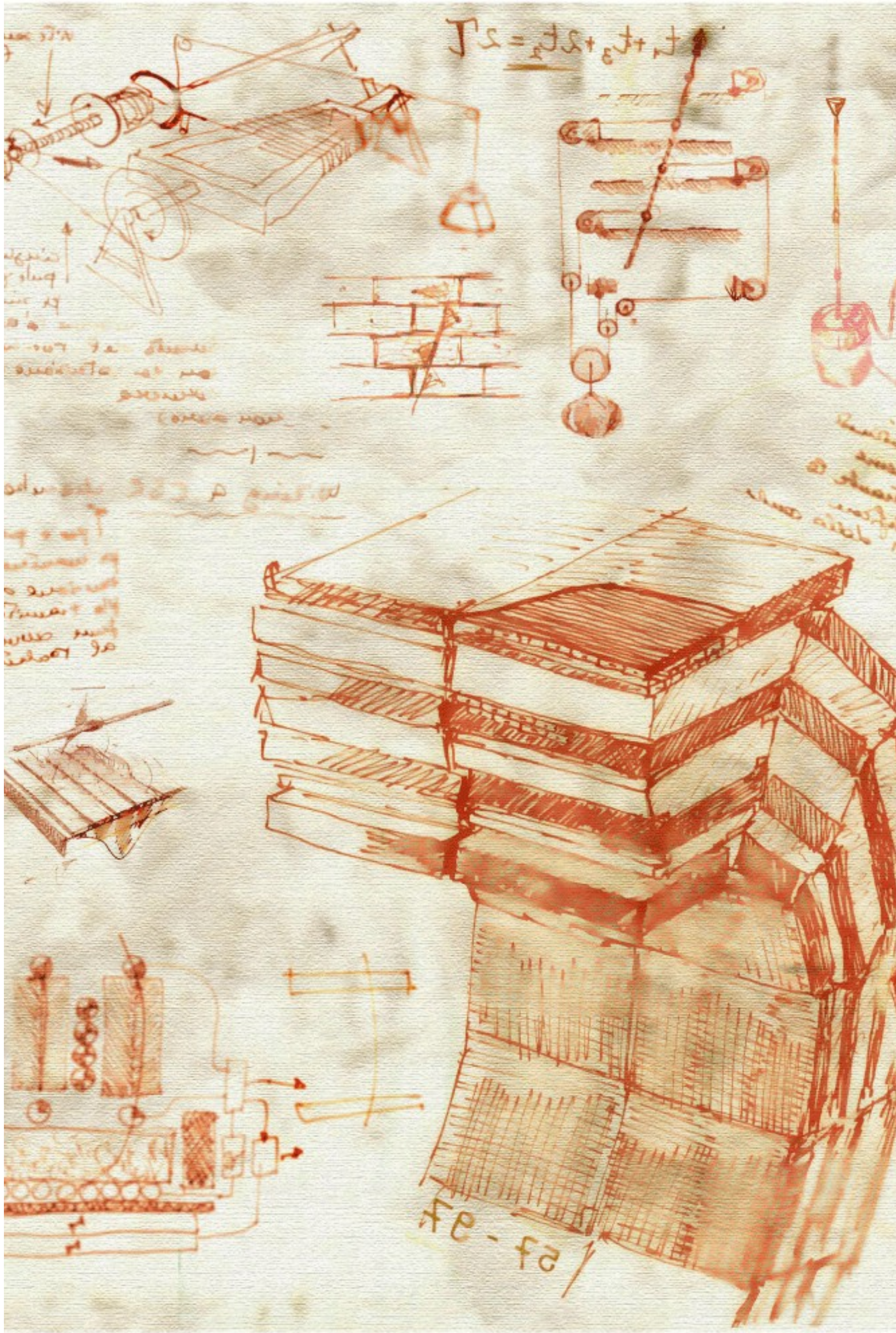
Efficiency for offline reconstructed electrons, which have passed a photon trigger with a threshold of E_T > 15 GeV, to pass an electron trigger with similar E_T threshold.





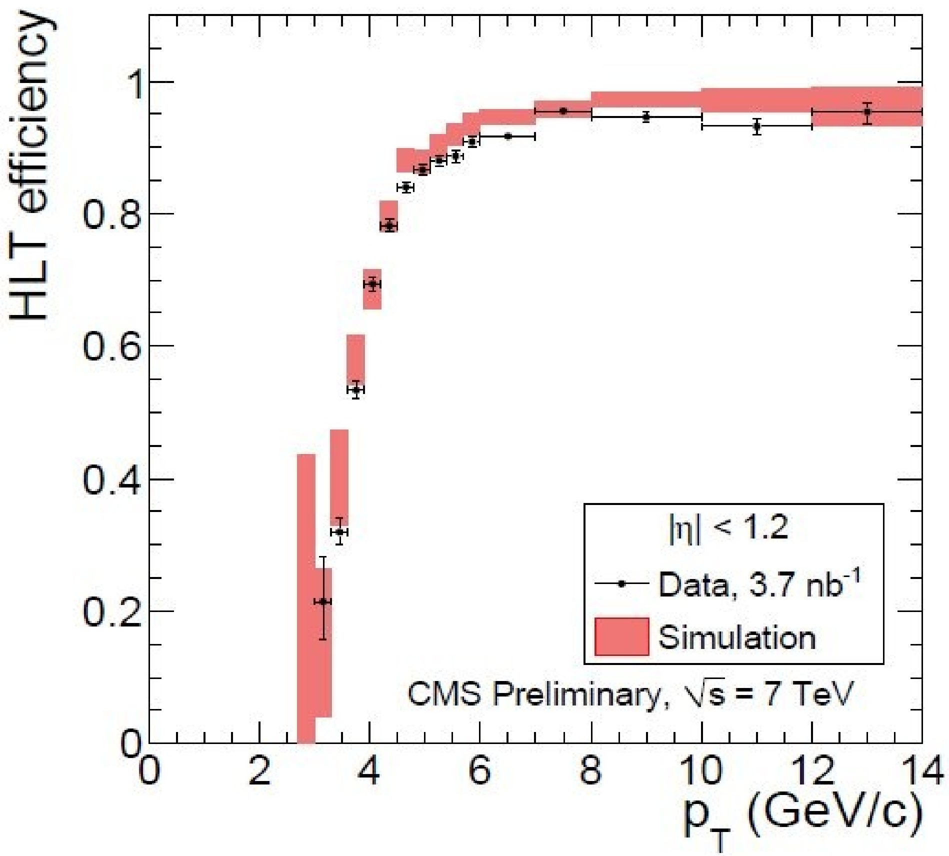
Muon Triggers

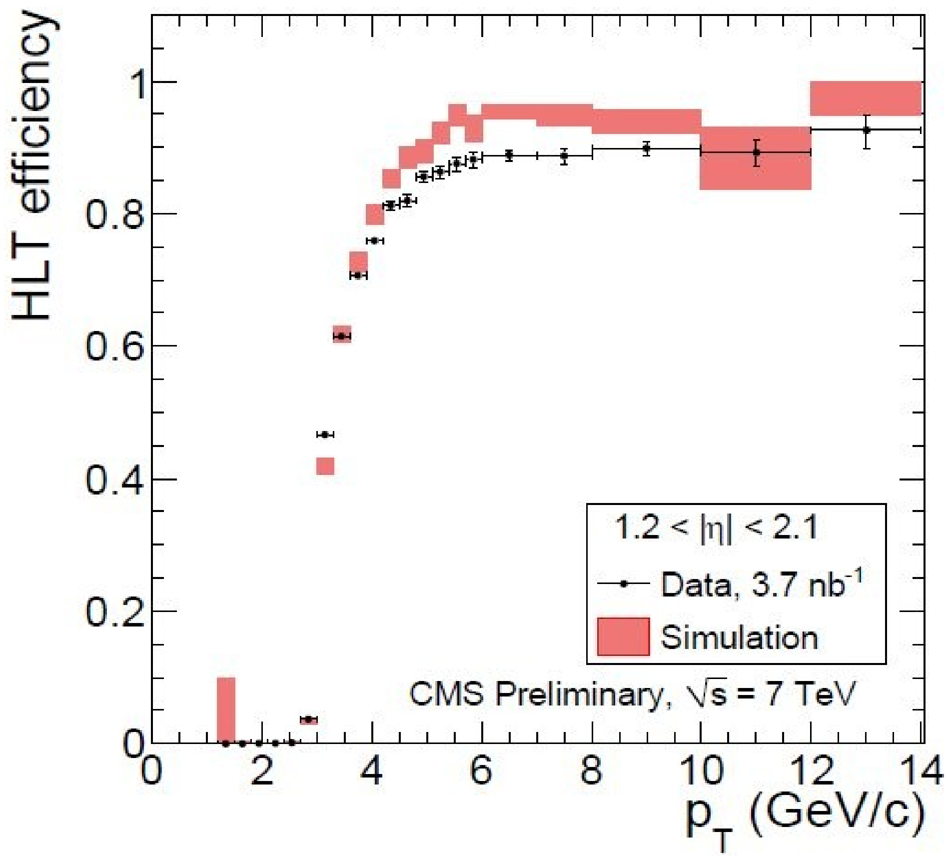
- First Stage:
  - Confirm L1 “seeds”: refit hits in the muon chambers with full granularity
  - Reconstruction in L1 regions of interest
  - Kalman filter iterative technique
- Second Stage:
  - Inclusion of tracker hits
  - Regional tracker reconstruction
  - Combine 1st-stage objects to charged particle tracks in the tracker.
  - p_T resolution much better compared to 1st stage
- Optional: Isolation in calorimeters (at 1st Stage) and tracker (at 2nd Stage)



Performance of Muon Triggers

- Efficiency for a high-quality offline reconstructed muon matched to L1 object to pass the HLT single muon trigger with a threshold of $p_T > 3$ GeV, plotted as a function of p_T
- Events collected with the minimum bias trigger
- Lower than expected efficiency due to time calibration at start-up





Jet-MET Triggers

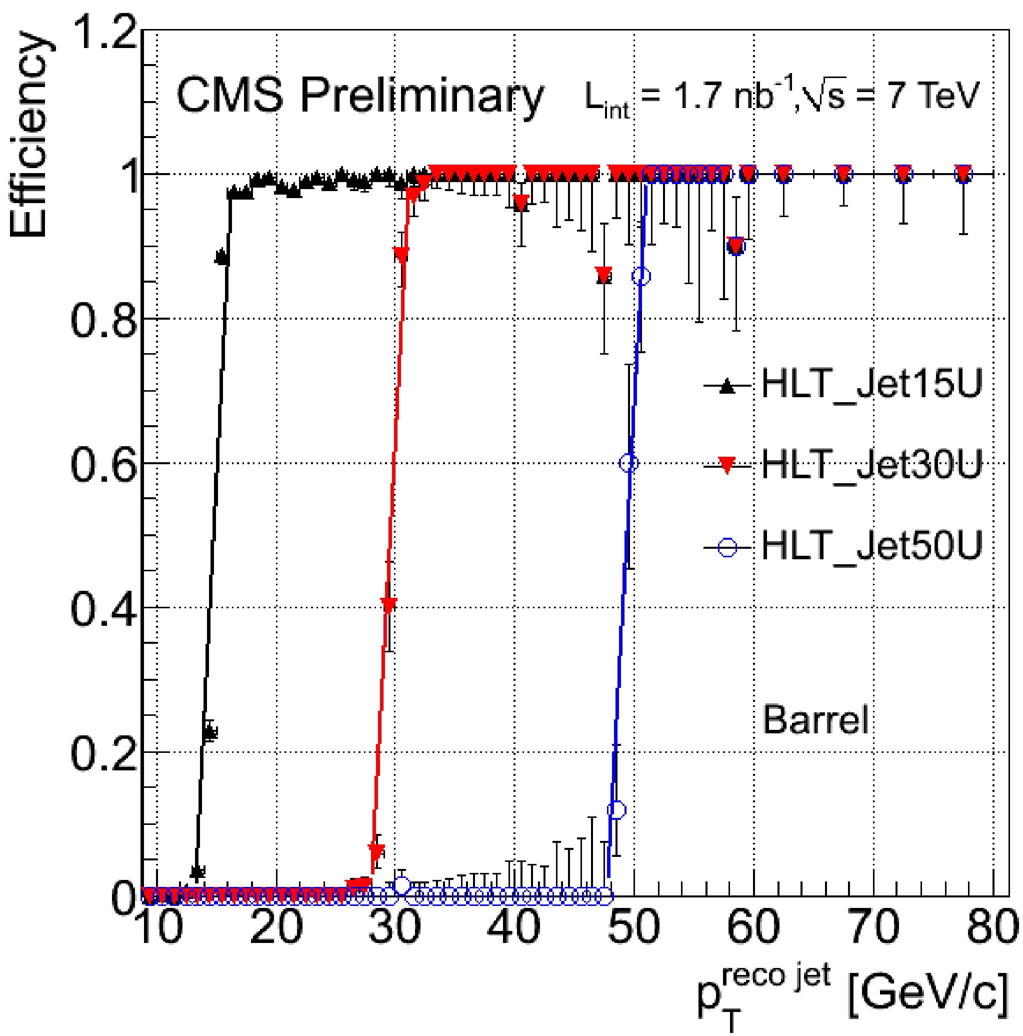
- **Jet Triggers:**
  - Use calorimeter "towers" (HCAL + projection on ECAL)
  - Energy deposits above certain threshold
  - Use an "iterative cone algorithm" with a cone of radius:

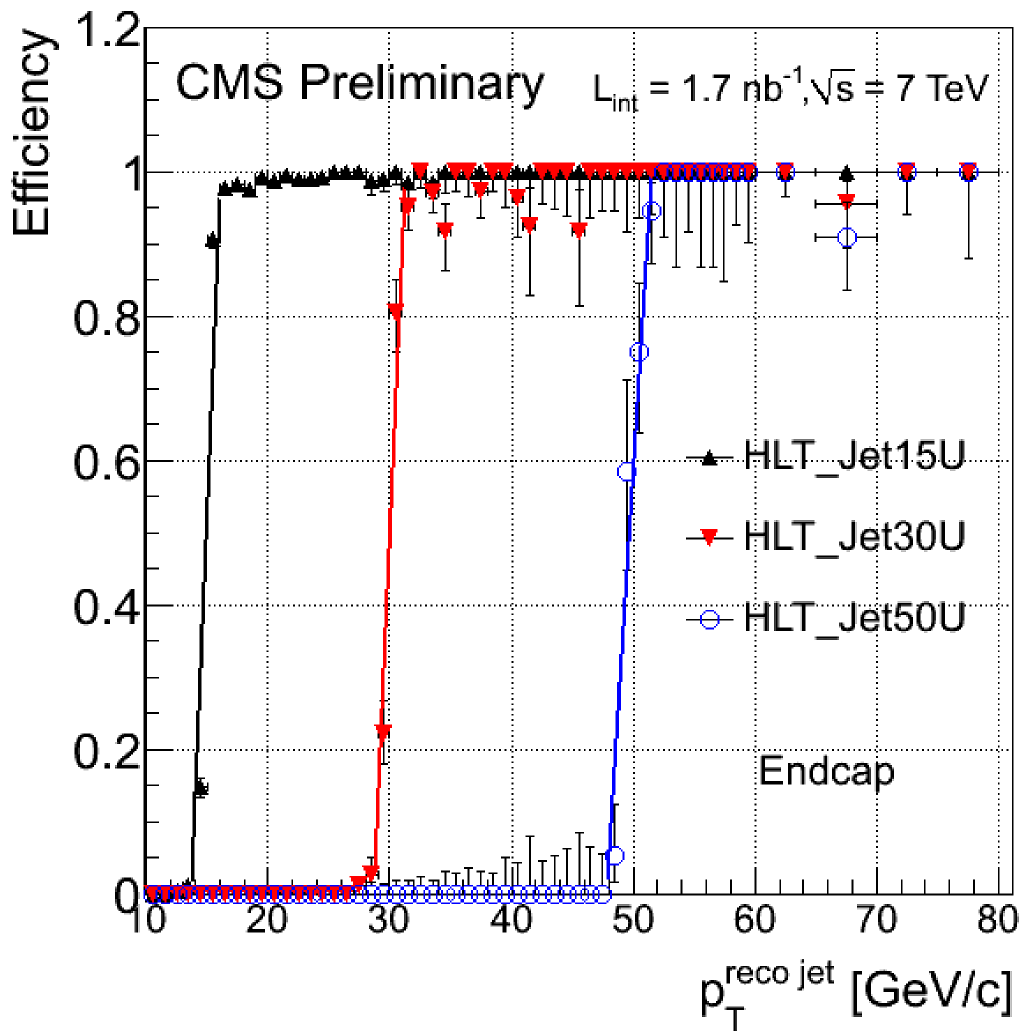
$$R=\sqrt{(\Delta\phi)^2+(\Delta\eta)^2}=0.5$$

- **MET Trigger:**
  - Algebraic sum of transverse energies of calorimeter objects plus muons
  - Can be used in combination with one or more jet requirement.

Performance of Jet Triggers

Efficiency for offline reconstructed jets to pass HLT jet triggers of different p_T thresholds, namely 15, 30, and 50 GeV, plotted versus p_T

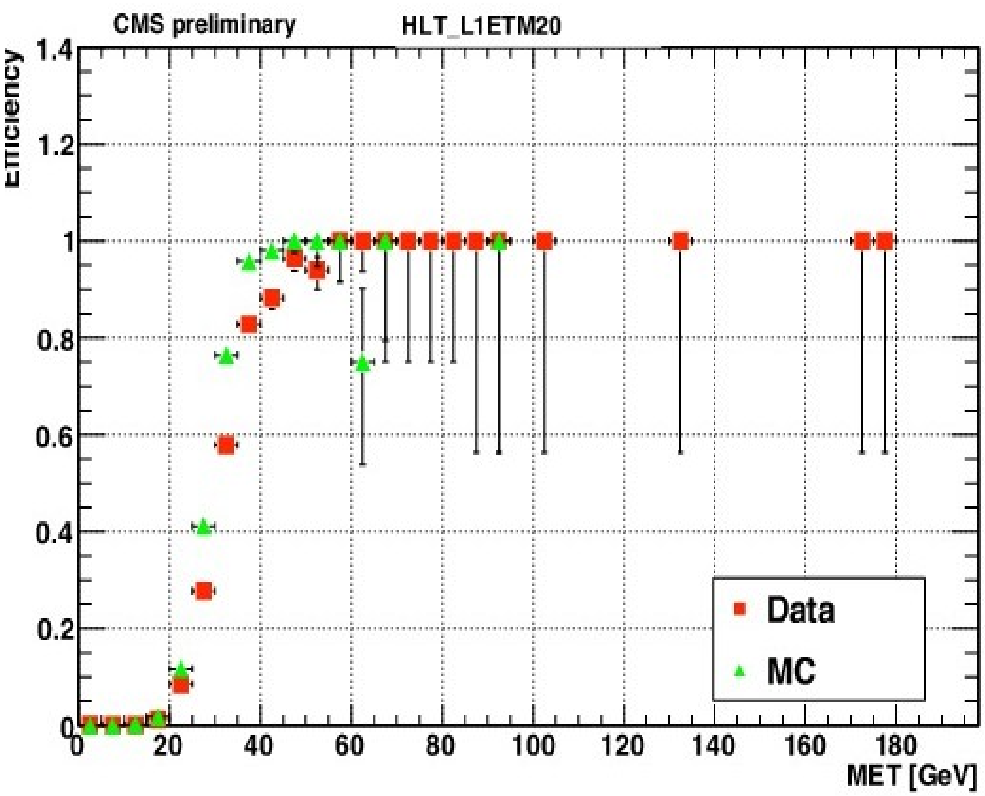


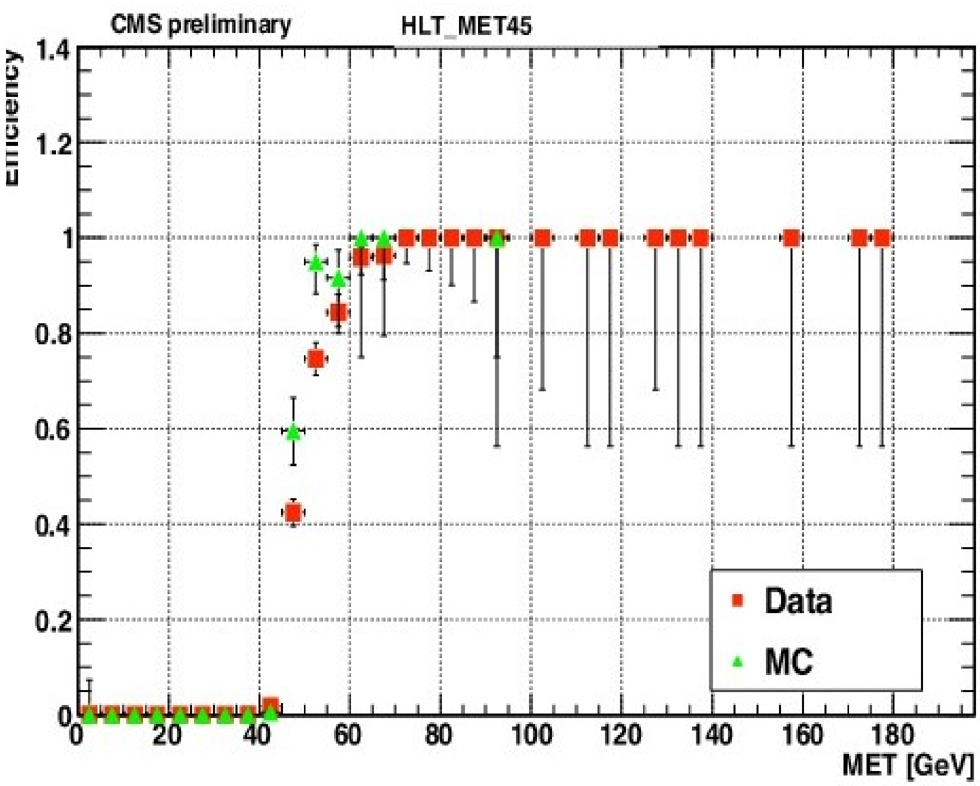


Performance of MET Triggers

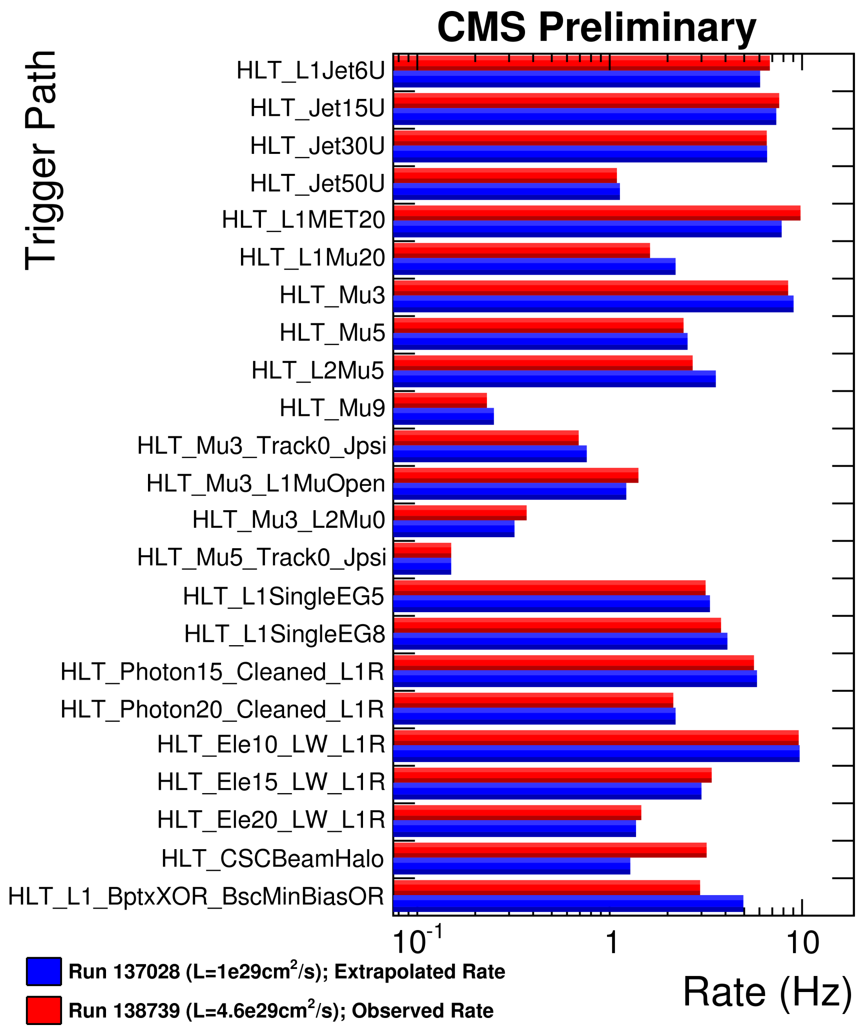
Efficiency for events recorded with a jet trigger of threshold p_T > 6 GeV to pass a trigger with a threshold of MET > 20 GeV

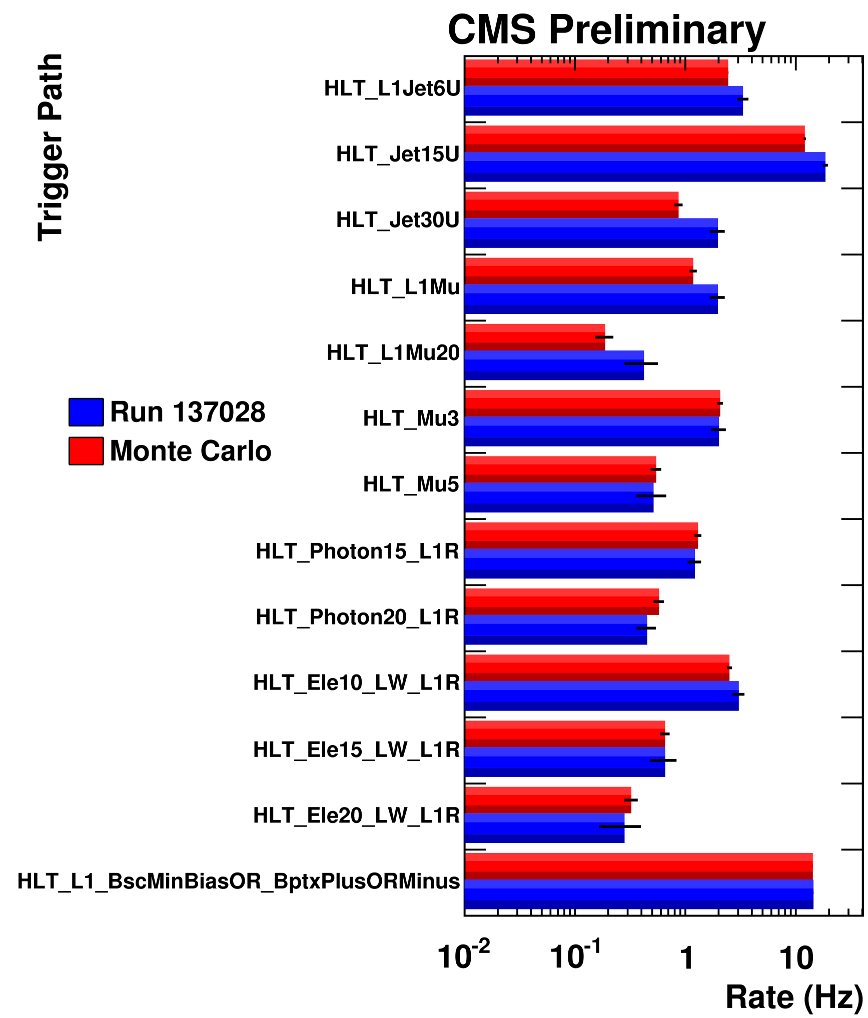
Efficiency for events passing an L1 trigger of threshold MET > 20 GeV to pass an HLT trigger with a threshold of MET > 45 GeV





HLT Rate Extrapolations and Predictions

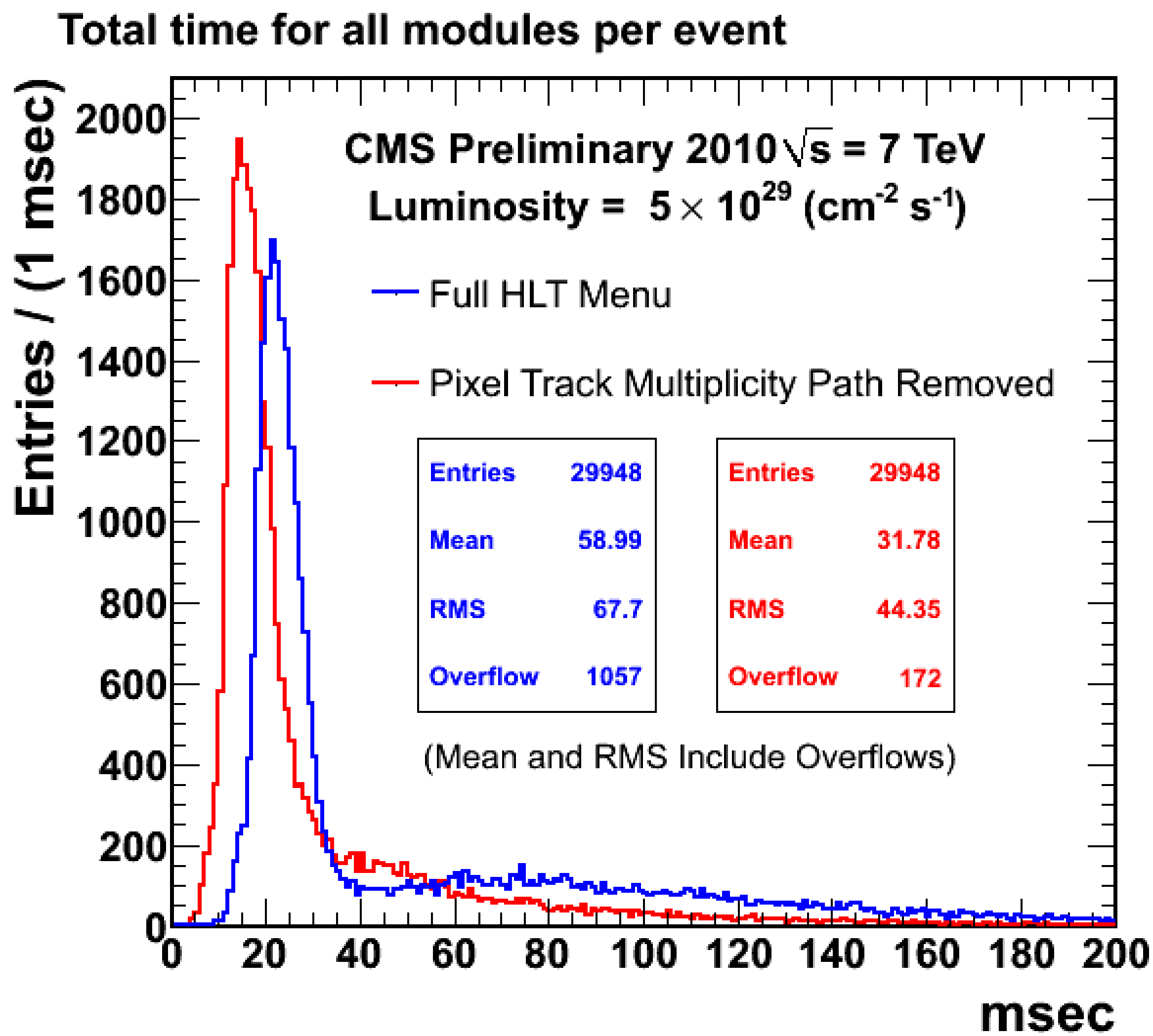




- Extrapolations accurate within 20% for most triggers (used for HLT development)
- Monte Carlo predictions, using a Minimum Bias sample, match the observed rates except for those triggers susceptible to detector noise or significant cosmic muons component (e.g. HLT L1-pass-through muon triggers)

HLT CPU Performance

- Study performed on a Minimum Bias sample of collected data (average pile up ~ 1.5 event/xing).
- Filter farm machine specs:
  - Processors: 2 Quad Core Intel ® Xeon ® 5430
  - 2.66 GHz nominal frequency
  - 16 GB of memory
- Average CPU time budget at 100KHz (50KHz) of input rate is 50 ms (100 ms)
- Blue curve corresponds to full pixel detector unpacking for tracking.



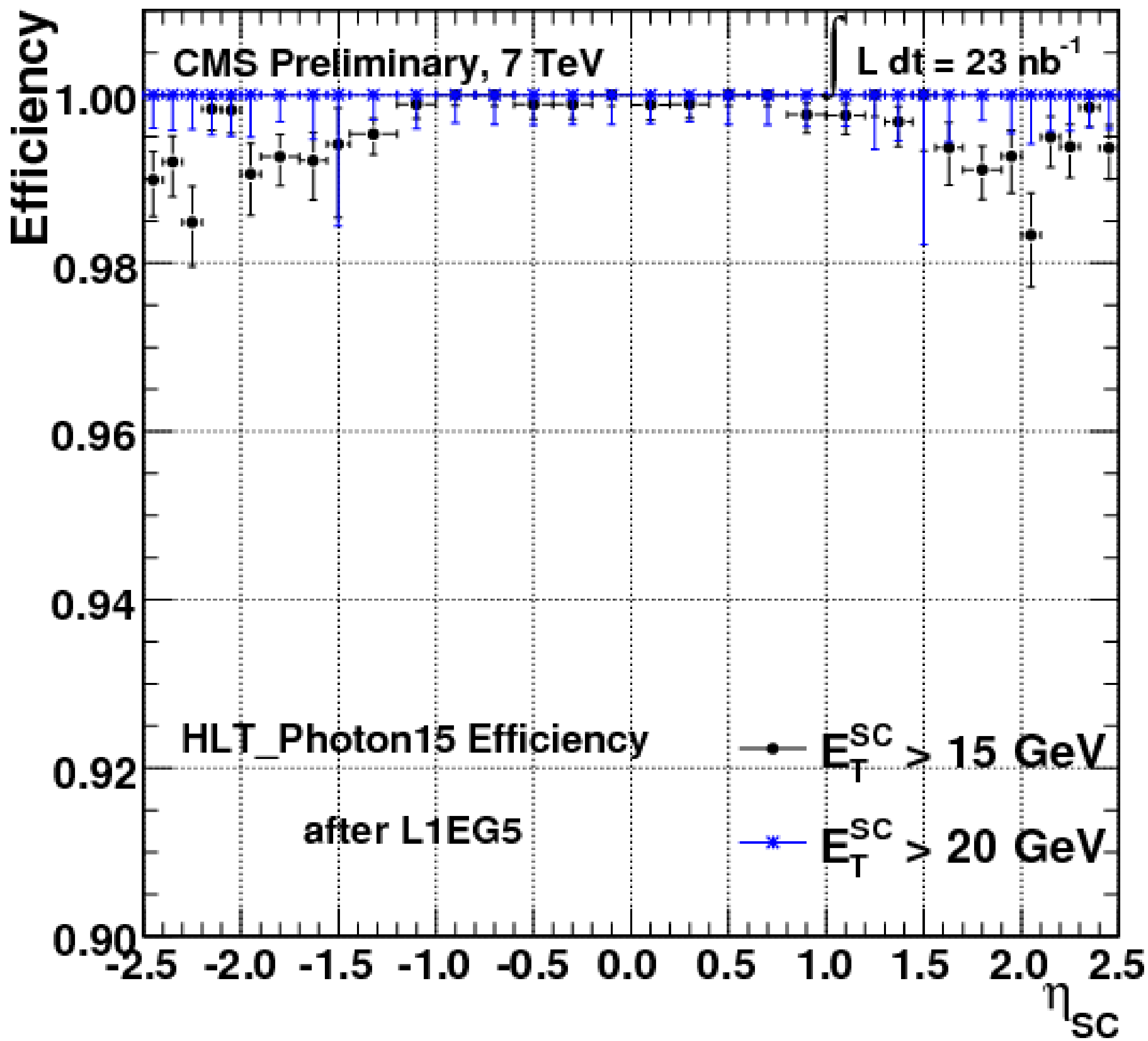
Conclusions

- Full understanding of the evolution of trigger rates and CPU timing with instantaneous luminosities allowed optimal operation of the HLT.

- Performance of Electron/Photon, Muon, and Jet/Met triggers were studied extensively.
  - In general, efficiency curves in very good shape at start-up.
  - There is mostly agreement with expectations from simulation.
  - Discrepancies with simulation understood.

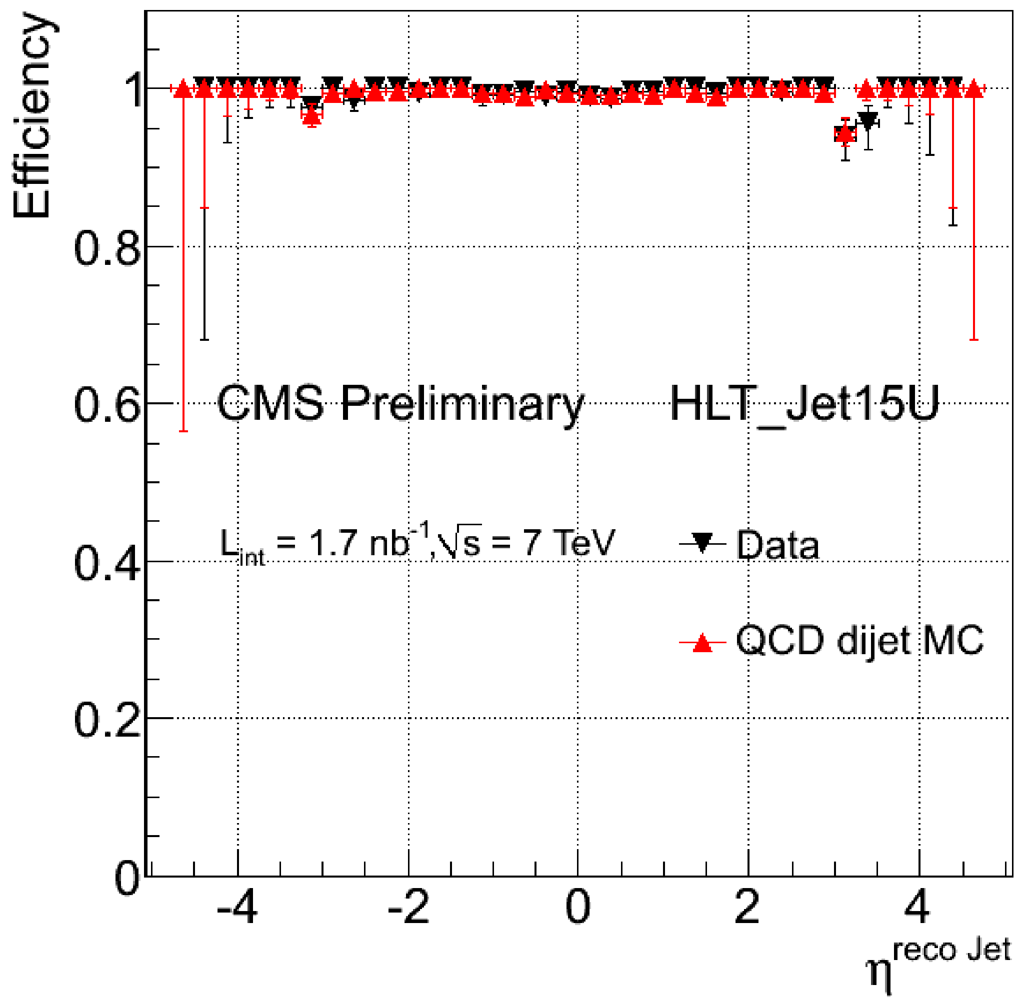
- Outlook: the LHC machine constantly making progress towards higher instantaneous luminosities, the CMS HLT will keep adjusting quickly and optimally to these changes.

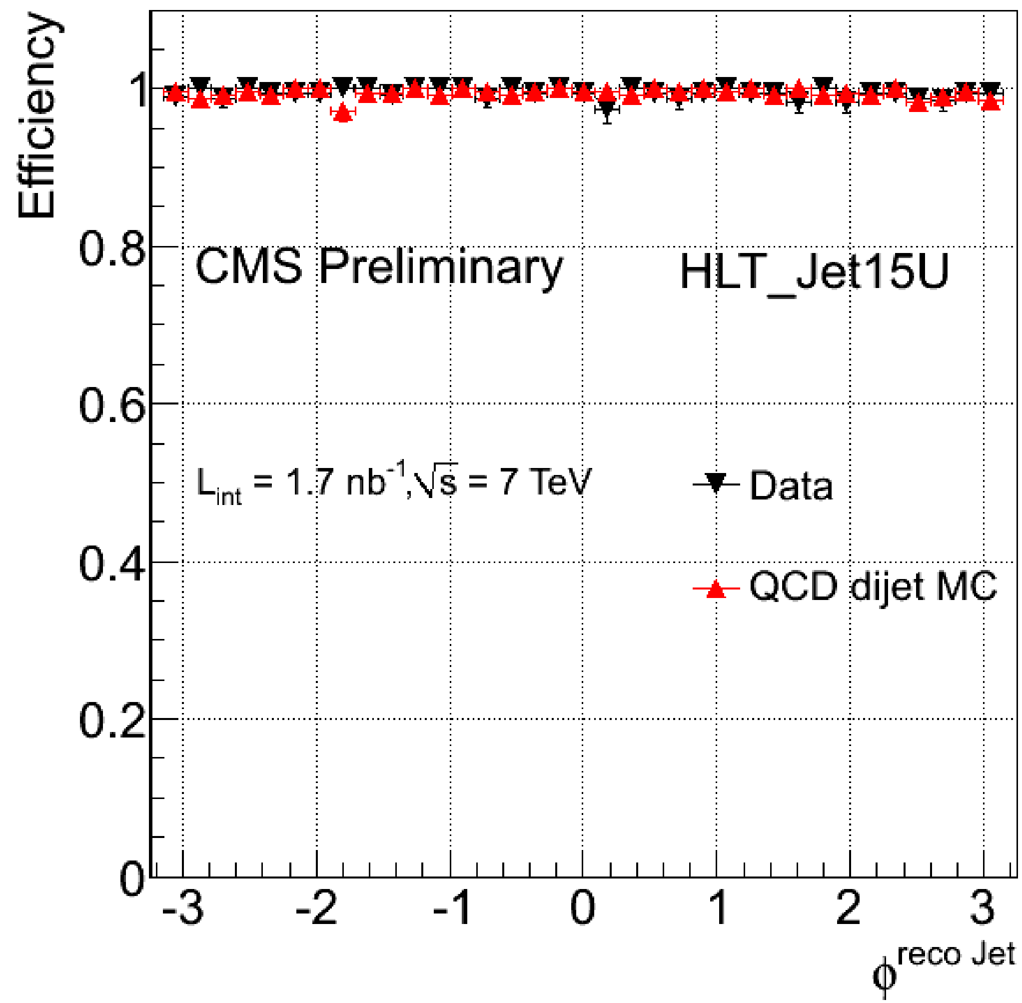
Backup: Trigger Efficiency for Photon Trigger



Backup: Monte Carlo Comparison for Jet Triggers

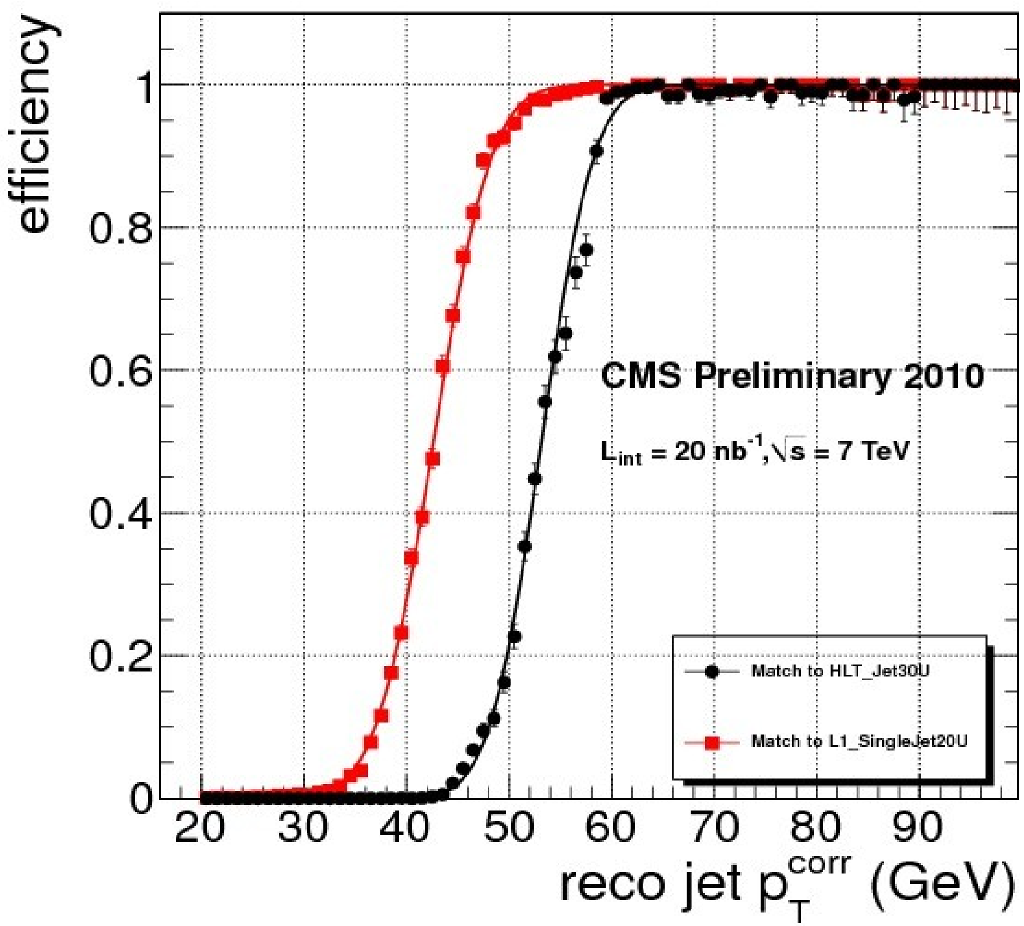
Efficiency for an offline reconstructed jet to pass an HLT trigger with a threshold of p_T > 15 GeV, for both data and simulation, as a function of angular variables.

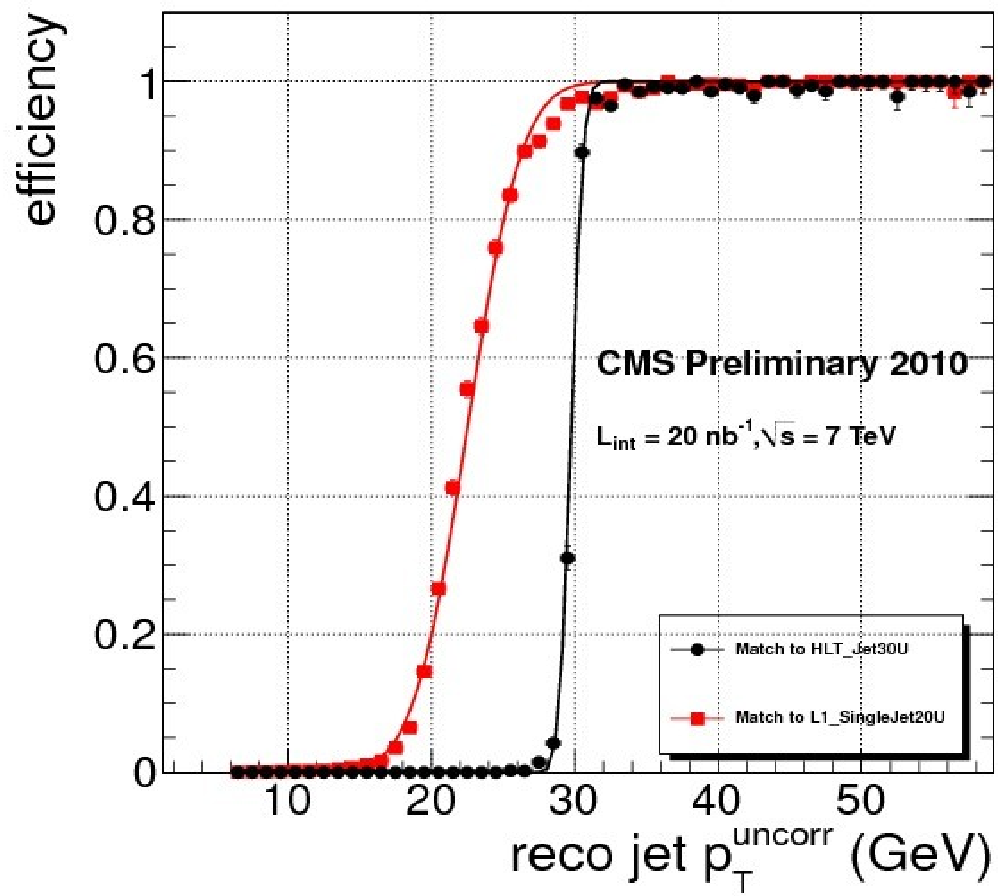




Backup: Efficiency of Jet Triggers

Efficiency for an offline reconstructed jet to pass an HLT trigger with a threshold of p_T > 15 GeV and its corresponding L1 seed as a function of corrected and uncorrected p_T





Backup: Efficiency of Jet Triggers using muon dataset