The CMS Level-1 Electron and Photon Trigger

For RUN II of LHC

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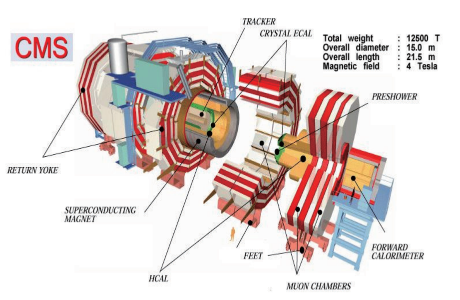
The CMS Detector

Trigger system and the Electromagnetic Calorimeter

The CMS Detector has a sophisticated ***two-level trigger system*** that reduces the input data rate by more than 10^5 - the Level 1 (L1) trigger is implemented using custom hardware and bases its decision directly on data from calorimeters and muon systems and the software-based High Level Trigger (HLT) runs on a massive computer farm and partially reconstructs the event using full sub-detector readout.



40 MHz

Bunch Crossing Input

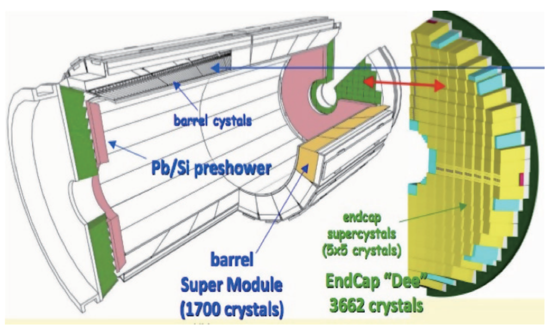
100 kHz

L1 Trigger Output

~ 1kHz

HLT Output

The ***CMS Electromagnetic calorimeter (ECAL)*** is a hermetic system designed for precisely measuring the energies of electrons and photons. The segmented and radiation hard ECAL is made of scintillating lead tungstate ($PbWO_4$) crystals and is equipped with fast electronics. The crystals are grouped in base blocks of 2 to 25 crystals called Trigger Towers. It also contains a preshower detector for discriminating photons from π^0 decays.



LHC RUN-II

Harsher conditions and L1 trigger upgrade

Harsher Conditions:

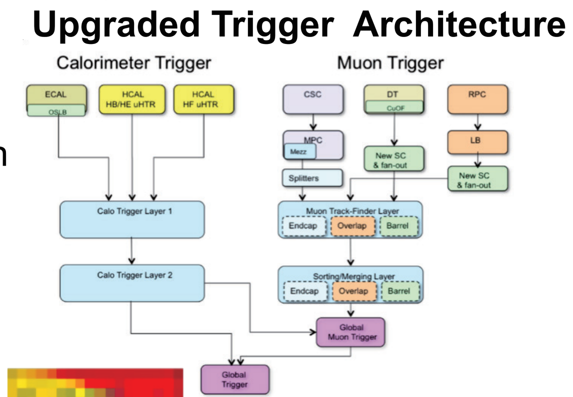
- Luminosities up to ~2 x 10^{34}, PileUp ~ <50>
- Reduced Bunch Spacing of 25 ns
- Higher Center of mass energy at 13 TeV

Increased event rates posed a big challenge for CMS requiring a significant upgrade of its L1 trigger systems in order to maintain low Physics thresholds.

Upgrade: A novel concept - *Time Multiplexed Trigger* introduced. Nine main processors receive all of the calorimeter data from an entire event provided by 18 preprocessors. This allows a global view and full granularity of calorimeters, as opposed to a regionalized approached used before.

e.g.- Single e/γ (18 GeV) gives a rate of 6kHz (Run I) compared to 40kHz (Run II without upgrade).

Upgraded Trigger Architecture



Resolution: After Upgrade **Before Upgrade**

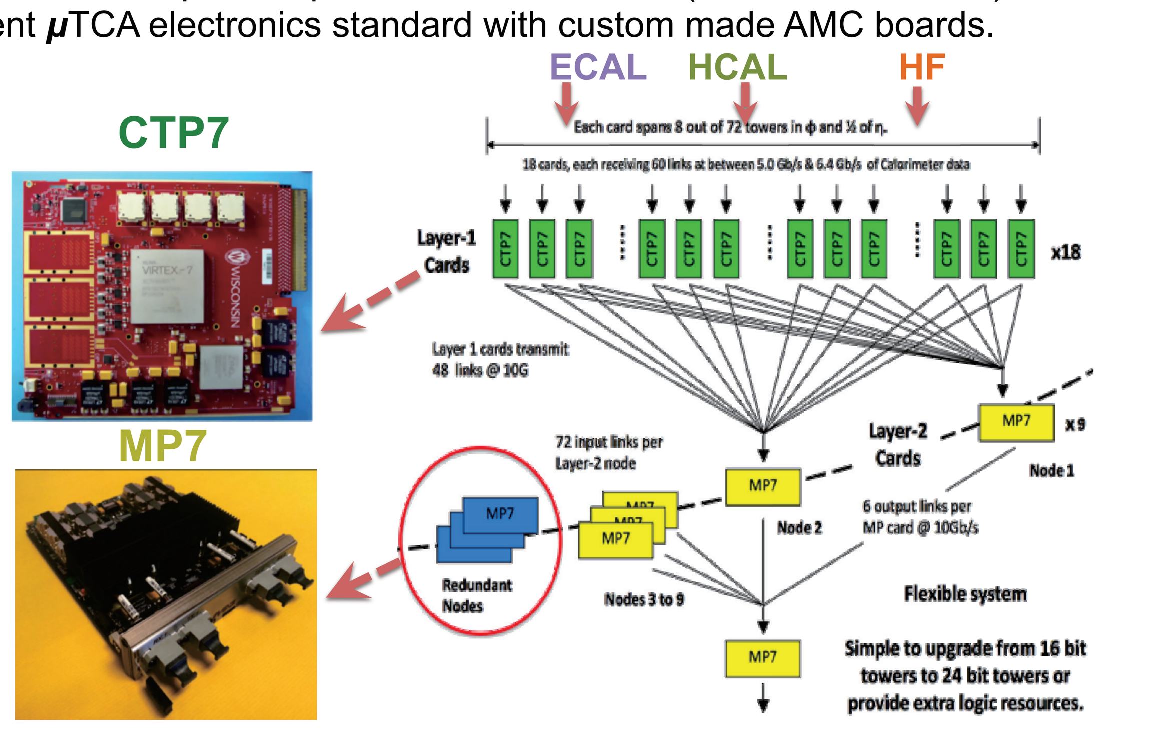
Improvements in Hardware

Benefits from technological developments

- New optical link boards installed with speeds up to 4.8 Gb/s for ECAL (6.4 Gb/s for HCAL)
- Architecture based on recent μTCA electronics standard with custom made AMC boards.

Layer-1 CTP7 boards:
Receives Trigger Primitives from ECAL and HCAL, formats and preprocess data

Layer-2 MP7 boards:
Reconstructs and identifies trigger objects

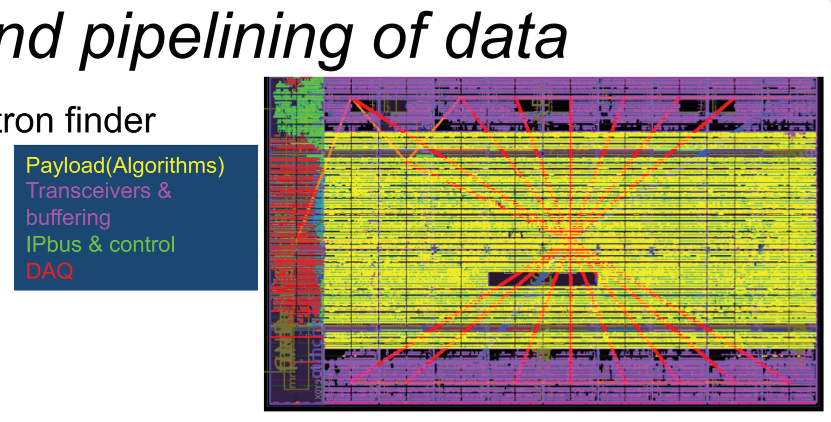


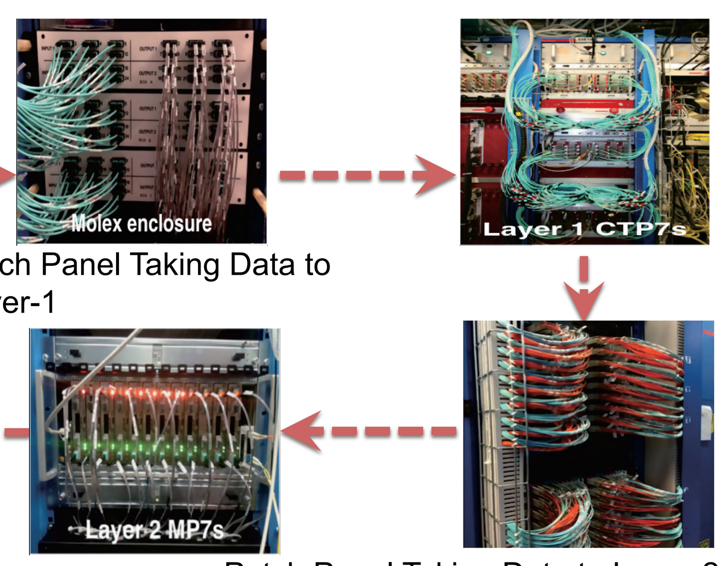
Data is sent by 36 Layer-1 cards alternatively at each bunch crossing to Layer-2. The 9 Layer-2 cards process the event and send data to the Global Trigger within a time window of 10 bunch crossings.

Firmware Implementation

Efficient processing and pipelining of data

Firmware Implementation a challenge as the electron finder along with the τ-lepton and jet finders must fit within a single Xilinx FPGA. The software interface is based on the IPBUS standard using libraries such as μHAL developed at CERN.





TMT architecture allows data coming from calorimeters to be rearranged in geometrical order. Fully pipelined algorithms process the data at the incoming rate starting on the reception of the first data word.

Upon reception, the Trigger Towers are combined to form basic blocks (base components of algorithms), potential cluster seeds are identified, pile-up level is estimated etc.

Fully pipelined firmware approach provides an efficient way to localize the processing, reduce the size and number of fan-outs, minimize routing delays and eliminates register duplication.

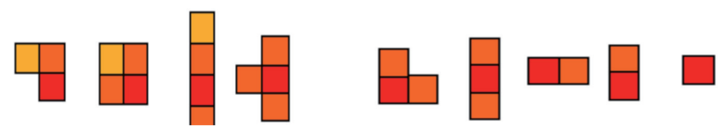
New Improved Algorithms

Dynamic Clustering and Background Reduction Techniques

Dynamic Clustering:

- Clusters of towers are built from a seed tower (local energy maximum) with neighbors dynamically clustered with it. Extended region in ϕ-direction for better energy containment.
- Starting from the center of seed, the position of the cluster is refined within the seed tower, based on the distribution of energy in the cluster leading to better position resolution .

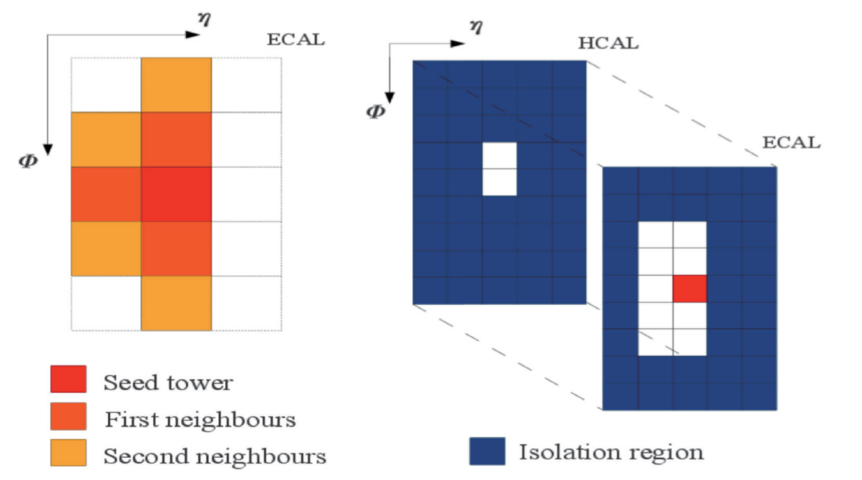
Clustering and isolation



Examples of Cluster Shapes

e/γ candidate isolation:

- Accounts for pile-up using the number of trigger towers in the central region of the calorimeter with a non-zero energy deposit.
- A candidate is considered isolated if it has energy in the isolation region (blue) below a threshold, which depends on pile-up and eta.



e/γ candidate identification:

- Ratio of energies deposited in ECAL & HCAL
- Energy distribution within crystals of seed tower
- Discriminating power from the difference in shapes of e/γ like clusters and jet-like clusters

Energy corrections are applied to the sum of Ecal transverse energies (E_T) of the seed and neighboring clustered towers in order to be close to E_T of the candidates reconstructed offline.

The corrections applied depend on:

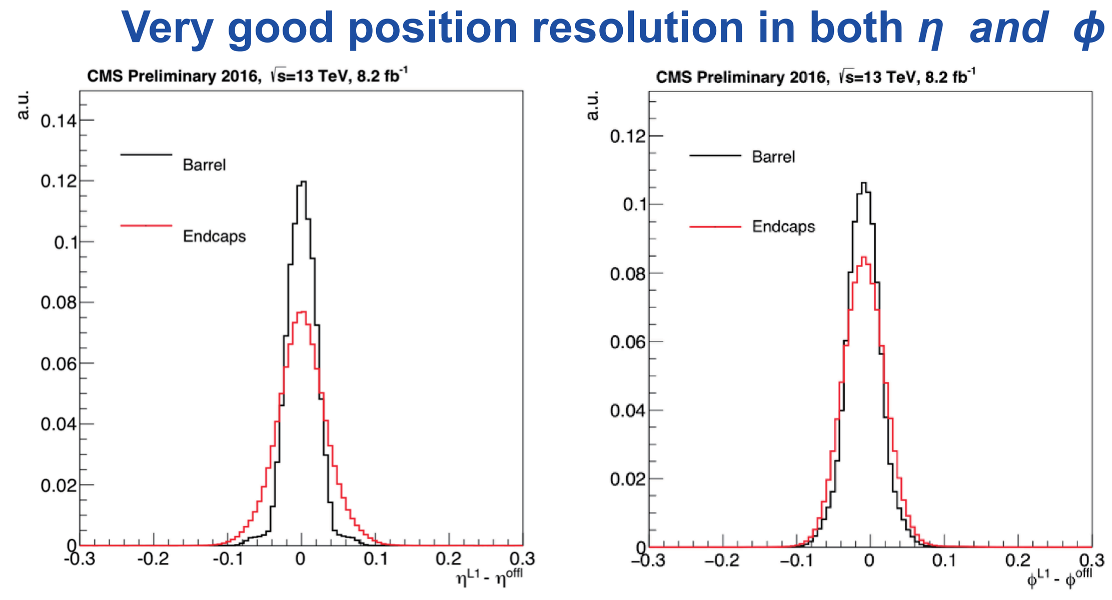
- η-position of the seed tower
- The shape of the cluster
- The energy of the cluster

The position resolution has improved by up to a factor of 4, and energy resolution has improved by up to 30% with respect to Run 1.
The efficiency is better with sharper turn-on curves and there is up to a factor of 2 rate reduction.

Performance in 2016

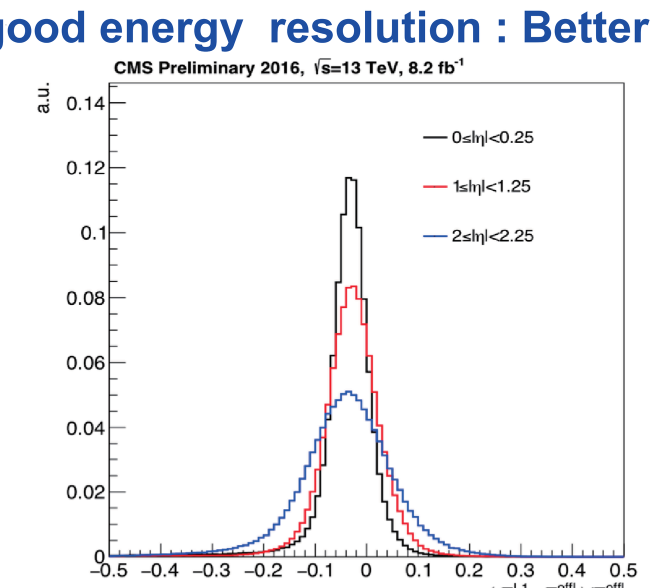
Very Good e/γ trigger performance delivered in 2016

Very good position resolution in both η and ϕ



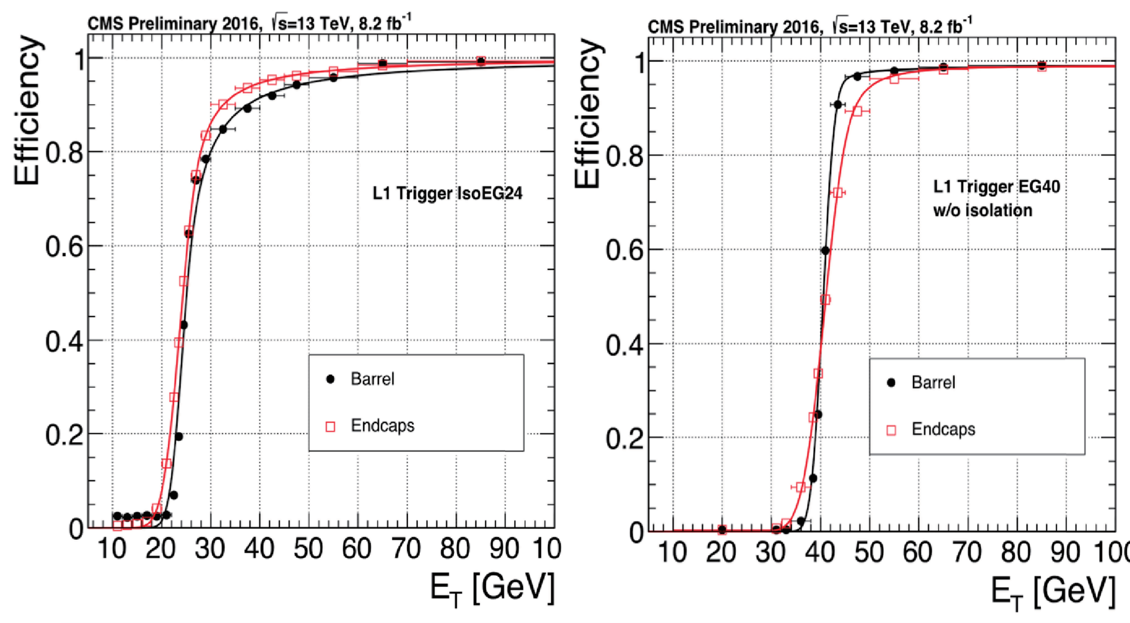
Differences in pseudo-rapidity η and azimuthal angle ϕ for L1 EG candidates with respect to the offline reconstructed electron supercluster, in the barrel ($|\eta|<1.479$, in black) and in the endcaps ($|\eta|>1.479$, in red).

Very good energy resolution : Better for lower η ranges



Relative difference in transverse energy for L1 EG candidates with respect to the offline reconstructed transverse energy, in the range $0\leq|\eta|<0.25$ (black), $1\leq|\eta|<1.25$ (red) and $2\leq|\eta|<2.25$ (blue).

Very Good efficiency with sharp turn-on curves



L1 trigger efficiency for an e/γ object as a function of the offline reconstructed supercluster transverse energy E_T for electrons in the barrel ($|\eta|<1.479$, in black) and in the endcaps ($|\eta|>1.479$, in red), for a threshold of 24 GeV with and for a threshold of 40 GeV without isolation requirement.

Current trigger scheme for physics:
EWK : Single Isolated e/γ 26 GeV (28 GeV), Single e/γ 40 GeV
Higgs :Double e/γ (18 & 16) GeV (20 & 10 GeV), Triple e/γ (14 & 10 & 8) GeV

- Isolation and calibration optimized on a regular basis to follow the LHC luminosity (currently ~ 1.4 x 10^{33})
- Possible to increase our trigger selectivity by introducing new invariant mass triggers for EWK.
- The new trigger architecture, being modular, provides the flexibility to add more processing nodes if needed.

It is very important for e/γ trigger to be able to trigger efficiently for possible new physics results. CMS was able to to trigger efficiently in challenging Run II conditions with high efficiency!

The new Level-1 electron and photon trigger has delivered very high performance in 2016, consistent with expectations and is expected to continue to do so through challenging conditions of LHC Run-II .

References:

- CMS collaboration, CMS technical design report for the Level-1 Trigger upgrade, CERN-LHCC-2013-011, CMS-TDR-12 (2013)
- CMS collaboration, L1 calorimeter trigger upgrade: electron and photon performance, CMS-DP-2015-003 (2015)13)
- CMS collaboration, J.B. Sauvan, Performance and upgrade of the CMS electron and photon trigger for Run 2, J. Phys. Conf. Ser. 587 (2015) 012021

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