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Goals of the Level-1 Trigger Upgrade for Run-II

- **Electron and Photon Triggers**
  - Better isolation for electron/photon triggers
  - Pile up subtraction
  - The new electron/photon algorithms is similar to offline

- **Jet triggers based on calorimeter towers (0.087x0.087)**
  - A factor of 16 better granularity and pile-up subtraction
  - Improvement of jet $\eta$ and $\phi$ resolutions

- **Tau Trigger**
  - Much improved efficiency and modest rata reduction
  - Capability of triggering at hadronic taus
  - Pile-up subtraction

- **Muon Triggers**
  - Improvement of the muon $P_T$-Resolution
  - Significant reduction of background rates at high $\eta$

- **Capability for introducing new triggers**
Level-1 Trigger Strategy

- Build a very flexible trigger to adapt to the physics needs of CMS from LS1 to LS3, and provide basis for further development and expansion for beyond LS3

- CMS must have a functional trigger, appropriate to LHC running conditions, at all times

- Build up in parallel ready for running in 2016 to safeguard CMS physics, decouple from LHC schedule

- Implement low-risk, modifications to the present trigger during LS1 to ensure improved performance at startup in 2015

TMT Design:
(1) Eliminates boundaries and can take data at full detector granularity
(2) Allows for more flexibility in algorithm design
(3) It can be upgraded in a ‘straight-forward’ way
(4) It brings the Lvl-1 capabilities closer to HLT
CMS L-1 Trigger Hardware Platforms in $\mu$TCA

- **MP7 (Calo Trigger Layer-2):**
  - 72 I/O Optical Links at 10 G, Virtex-7 690 FPGA
  - Also used for, Global Trigger, Global Muon Trigger and the Barrel Muon Track Finder

- **CTP7 (Calorimeter Trigger Layer-1):**
  - 67 Rx, 48 Rx Links at 10 G
  - Virtex-7 690 FPGA

- **MTF7 (EndCap, Overlap Muon Track Finder):**
  - Optimized for maximum input from muon detectors (84 Rx, 28 Tx @ 10 Gbps)
  - Dual card with large capacity RAM (~1GB) for $p_T$ assignment in track finding

- **Modular $\mu$TCA designs which allow for**
  - Different trigger architectures
  - Adding more processors as needed
  - Data exchange via the $\mu$TCA backplane (point-to-point)
• Search for seeds with $E_T > 2$ GeV threshold
• Form 3x3 calorimeter tower proto-clusters
  • Dynamical Trimming (Brem., Posit., $E_T$ resol.)
  • Towers with $E_T > 1$ GeV are clustered.
  • The side in $\eta$ with the maximum $E_T$ is kept.
  • Corners kept only if linked to the seed.
  • Extensions in $\phi$ are added if linked to the seed.
• Require Fine Grain Bit and H/E cut
  • The Fine Grain Bit requires that the energy deposition within a tower is consistent with that from an electron ($\phi$ band of crystals).
  • $H/E < 0.040$ in the EndCap and $H/E < 0.015$ in the Barrel
• Require a 9x5 tower isolation window
  • $E(5x9) - H(1x2) - E(2x5) < \text{Isol-cut (nTT, } \eta)$
• 9 Possible Impact points based on cluster shape
• Market improvement in $\eta$, $\phi$, and $E_T$ resolutions.
• Sharper threshold curves to reduce backgrounds.
• Non Iso-e rates by $\sim 2$ lower for $E_T < 20$ GeV and 10-20% lower for $E_T > 30$ GeV.
• Iso-e rates 30% lower than before.
• 1-prong or 1-Prong + $\pi^0$: Use e/gamma clusters with E+H and no H/E cut (2x3).
• 3-prong: Search for extra seed in the $\phi$ direction and if found combine clusters.
• Dynamically assign the tau footprint based on cluster shape (5x9, 3x5, 2x5).
• Isolation based on a 5x9 window.
• Dramatic improvement in efficiency; modest rate reduction; $E_T > 20$ GeV possible.
CMS Level-1 Jet Trigger Performance

- Use a 9x9 tower mask which $\sim R=0.4$
- Compare all trigger tower depositions in the mask with the seed.
  - Use $>$ for blue
  - Use $\geq$ for purple
- If the above statement is TRUE then veto the jet and move on to another seed.
- For Pile-up Subtraction two approaches:
  - Global jet based $\rho$ subtraction: Estimate energy to subtract off jet using the median of calorimeter energy deposits, see arXiv:0707.1378v2
  - Local subtraction: Estimate energy to subtract off jet using a region local to the jet, see arXiv:1010.1759
  - The local is currently implemented but the global will also be tried
The new muon trigger aims mainly in increasing the muon $P_T$ resolution. Hence to reduce the rate. It does this by using large LUTs (EndCap) and advanced pattern recognition (Overlap and Barrel).

Three Muon track finders have been installed: Overlap, EndCap and Barrel.

The first two consist of 12 MTF7 processors and the last of 12 MP7 processors.
- Modest loss of efficiency results to considerable reduction in rate.
- The efficiency loss in the Barrel (right) is minimal but it is larger in the EndCap.
- All three track finders are undergoing testing at P5 and parallel running with the legacy system is to commence during September/October.
- The new muon Trigger will be operational in February 2016.
• Use the one MP7 trigger processor but has been designed to be expandable by adding more MP7s. Firmware for the basic trigger menu has been tested.

• To be commissioned in September 2015
All trigger groups have installed electronics at P5 and testing has started.

- Calo. Trig., uGT, uGMT, EndCap Muon TF: Complete.
- Barrel and Overlap to be completed by Sep. 2015.
- **Parallel running with Legacy Trig. In the Fall 1025.**
CMS Level-1 Trigger Summary

• CMS is Looking forward to the High Luminosity LHC runs and is confident that will be able to exploit the full physics potential of the data.

• The new Level-1 trigger system will enable CMS to operate at high luminosity and high pile-up with a better selection efficiency.

• It is planned to start taking data with the new trigger early in 2016. However, a small scale upgrade of the calorimeter trigger has been commissioned and is ready to go in for the 25ns run. And this will give:
  • Improved isolation for electron triggers
  • Improved tau trigger
  • Pile-up subtraction

• We are getting ready for new discoveries starting in 2015.

• We feel confident that with the upgraded detector we will be able to measure the Higgs properties with increased precision.