Data analysis at Level-1 Trigger level

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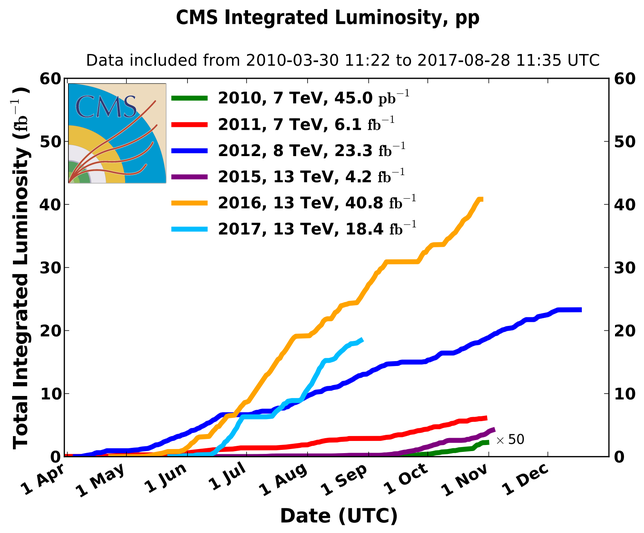
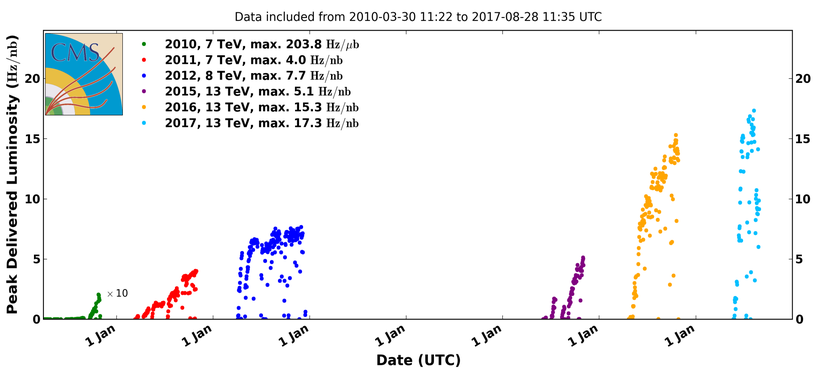
New challenges for the Level-1 Trigger

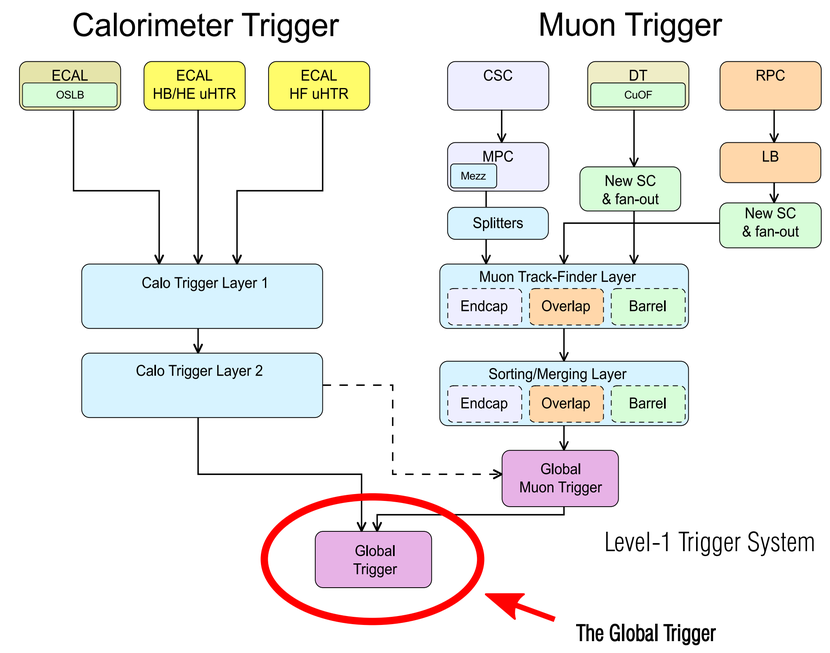
- The Level-1 Trigger of the CMS experiment is facing new challenges because of the impressive performance of the LHC. This leads to a luminosity of more than 1.7x10^{34}cm^{-2}s^{-1} and a pile-up (proton collisions during one bunch crossing) of more than 45 superimposed events.
- New techniques and algorithms need to be developed to get better online data reduction. A transfer of "data analysis" methods to the Level-1 Trigger can help to achieve this goal.



Cumulative luminosity versus day delivered to CMS during stable beams and for p-p collisions



The Peak luminosity versus day delivered to CMS during stable beams and for p-p collisions

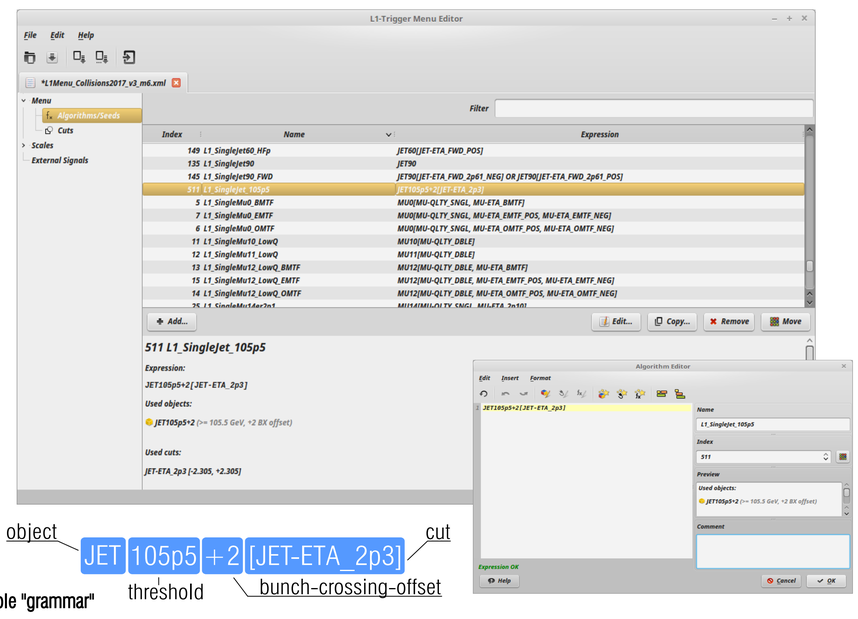


Level-1 Trigger System

The Global Trigger

The CMS Global Trigger and its features

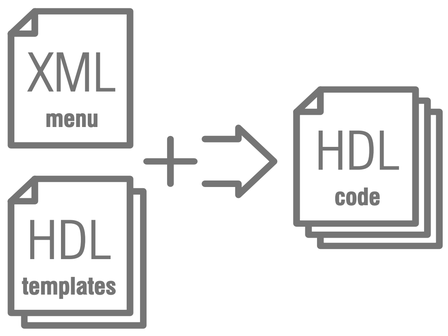
- Six MP7 modules using powerful XILINX Virtex-7 FPGAs[1] are running in parallel to provide enough logic resources needed by the Global Trigger physics algorithms.



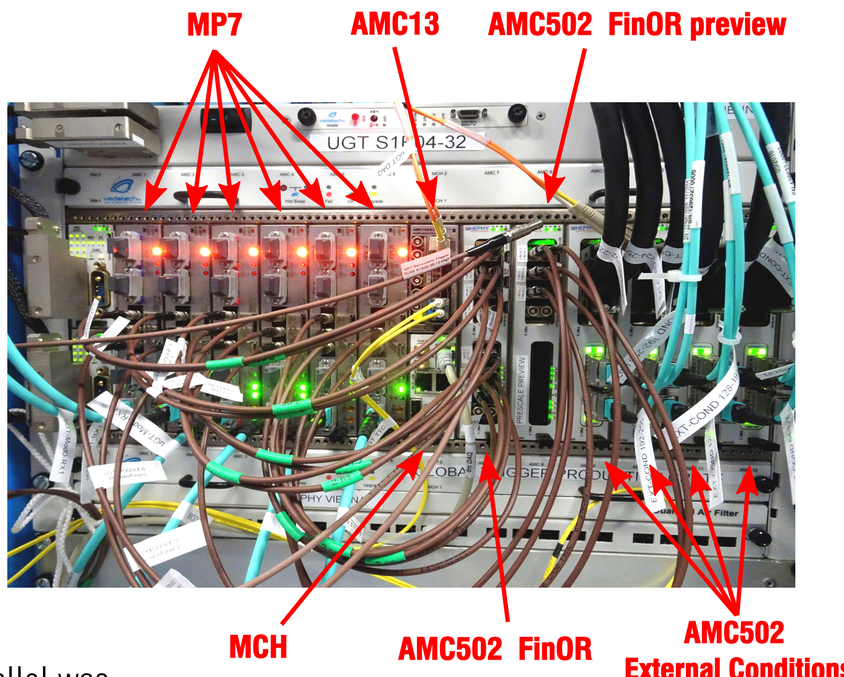
object: JET | threshold: 105p5 | bunch-crossing-offset: +2 | cut: [JET-ETA_2p3]

Flexible "grammar"

The Trigger Menu Editor and its grammar



Flexible VHDL code generation using a template engine



The fully equipped Global Trigger crate

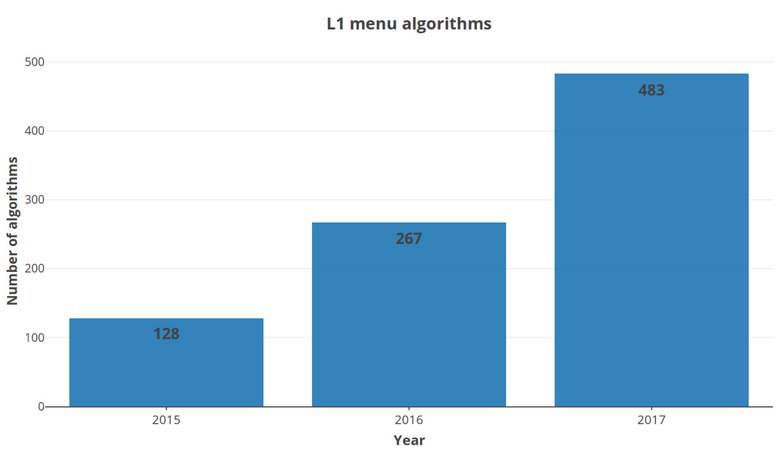
- The number of trigger algorithms computed in parallel was limited to 128 in the past and has now been increased to 512[2].
- A new, dedicated AMC502 FinOR preview module facilitates selecting the correct prescale values. A second set of prescales can be applied during data taking and the expected rates are calculated.
- The Trigger Menu Editor and its specially designed, flexible grammar assists the collaboration in composing new sets of physics algorithms for the Global Trigger, so-called menus.
- Combining the trigger menus with predefined, static VHDL templates guarantees a fast and reliable generation of Global Trigger firmware[3].

MU25p5+2 AND JET10[ETA_2p2] OR comb{TAU10, TAU20}

Easy-to-learn expression language for composing complex algorithms

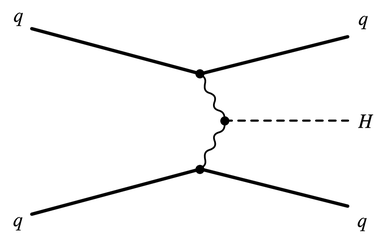
New Global Trigger Algorithms

- Several new types of algorithms are migrating complex selection algorithms from offline analysis and High-Level Trigger to the trigger electronics.
- The number of parallel computed trigger algorithms has steadily increased over the last 3 years.



Maximum number of algorithms used in the L1 Menu from 2015-2017

- In addition to the invariant-mass algorithms, new transverse-mass triggers for objects without eta information have been introduced.
- The Vector Boson Fusion is an important channel in the H → $\tau\tau$ analysis. The jets from the surviving quarks can be efficiently selected by applying an invariant-mass cut. To calculate it, this formula is used: $M_{inv} \approx \sqrt{2\, p_{T1}\, p_{T2}\, [\cosh(\eta_1 - \eta_2) - \cos(\varphi_1 - \varphi_2)]}$
- Mass triggers now have an optional "two body pt" cut, which is the transverse momentum calculated for the hypothetical mother particle of the two objects whose mass is being calculated.
- Avoid double counting of calorimeter objects (e.g. the same particle is seen as jet and as tau) by introducing a function called "Overlap Remover".
- A new feature gives the opportunity to add constraints on the number of objects used by an algorithm. The index of objects in a collection can be confined to take, e.g., just the leading jet of an event. This is also a feasible way to save FPGA ressources.



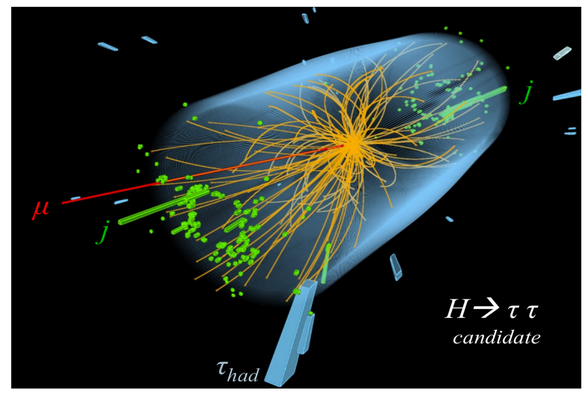
Feynman diagram showing Higgs production through vector boson fusion

muon | conjunction | invariant mass

MU10[MU-QLTY_SNG] AND mass_inv{JET30, JET30}[MASS_MIN_400]

VBF algorithm in the Global Trigger "grammar"

Recorded event at CMS with a H → $\tau\tau$ candidate



References:
[1] A. Rose et al.: The MP7 and CTP-6: multi-hundred Gbps processing boards for calorimeter trigger upgrades at CMS, Journal of Instrumentation Volume 7, C12024, 2012.
[2] J. Wittmann et al.: Design and performance of the phase I upgrade of the CMS Global Trigger, Journal of Instrumentation Volume 12, C01046, 2017.
[3] T. Matsushita: Software for implementing trigger algorithms on the upgraded CMS Global Trigger System, CMS Note (CMS-CR-2015-083), 2015.

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