Run 2 data taking: Challenges for tau triggers

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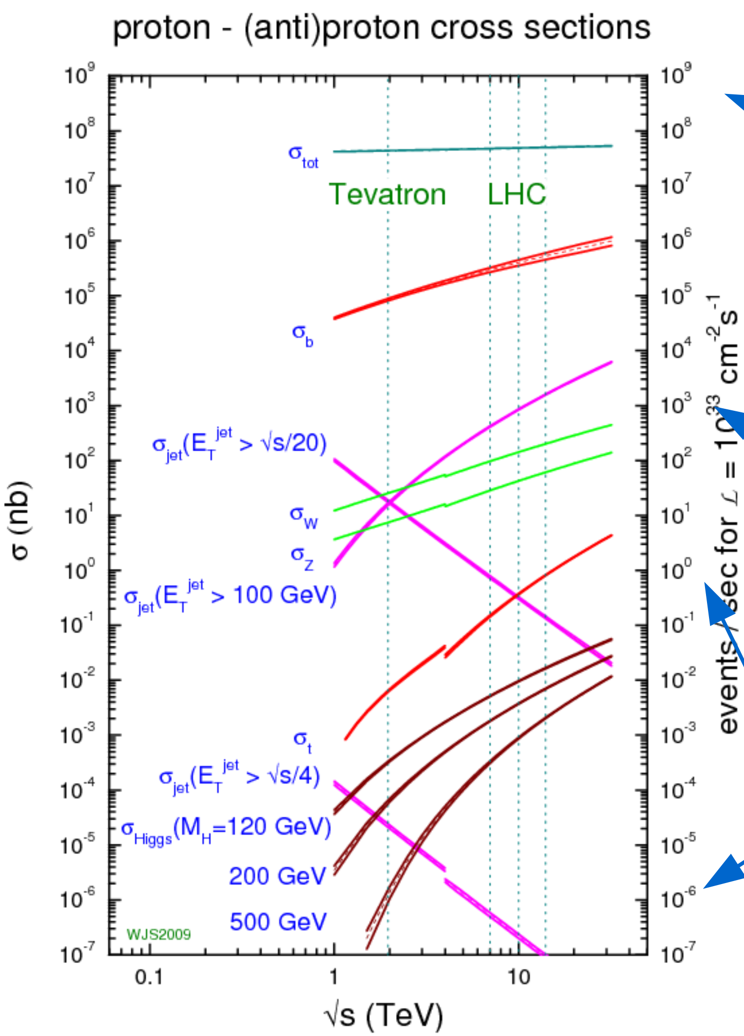
Preface: trigger of CMS

- Why trigger?
  - Reduce collision rate to manageable level keeping interesting events

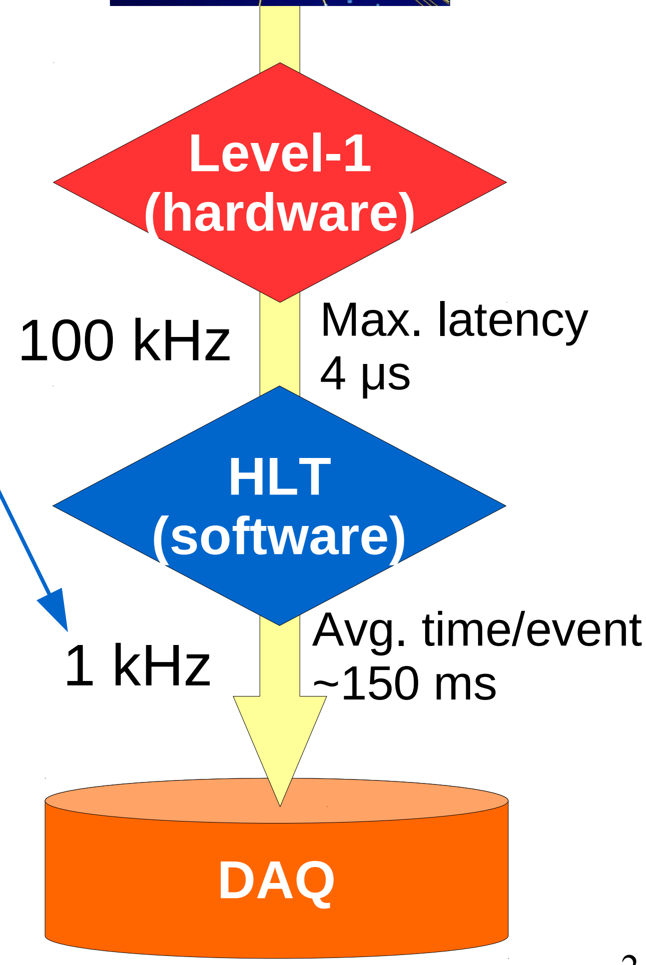


LHC rate:
40 MHz (at 25ns)

Maximal rate acceptable by data acquisition system (DAQ) and storage:
O(1) kHz (~0.5 kHz for prompt reconstruction)

Typical rate of interesting physics processes:
<10 Hz

The CMS way



Preface: trigger of CMS

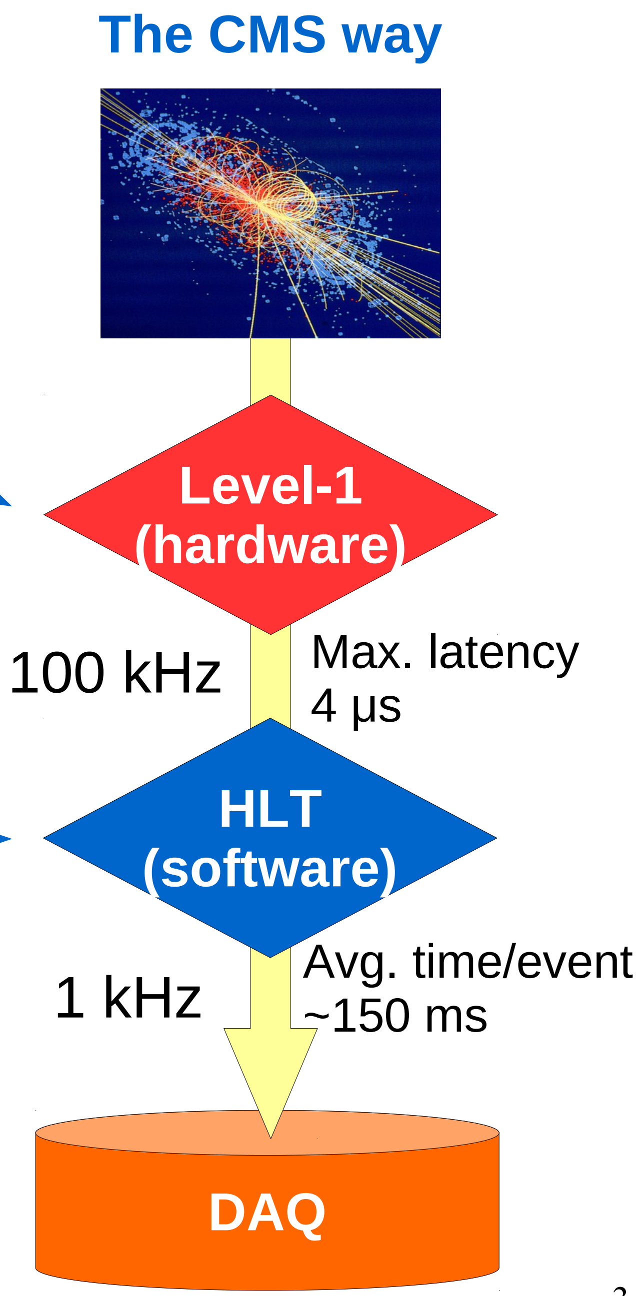
Level-1 trigger (L1)
Fast readout of detector with reduced granularity
- Muon system:
  - Standalone muons
- Calorimetry (HCal & Ecal):
  - Electron/gammas (EG's), jets, taus, MET, HT

 + combinations of above
Based on hardware (FPGA's, ASIC's)
Constraints (detector readout)
- Max. latency ~4 μs
- Max. output rate 100 kHz (~3 kHz for tau triggers)

High level trigger (HLT)
Full detector readout
- Muon system, calorimetry and **tracker**

Based on software at commercial CPU's (PC's)
- Same framework as for offline reconstruction
  => sharing of algorithms (Particle-flow)

Constraints
- Max. avg. time to take decision (timing) ~150 ms
- Max. output rate O(1) kHz



The challenges of LHC Run 2

- Compared to LHC Run 1

8 → 13 TeV
Factor of ~2 in cross-section from the increase of energy;
Can be >2 for multi-objects triggers because of combinatorial

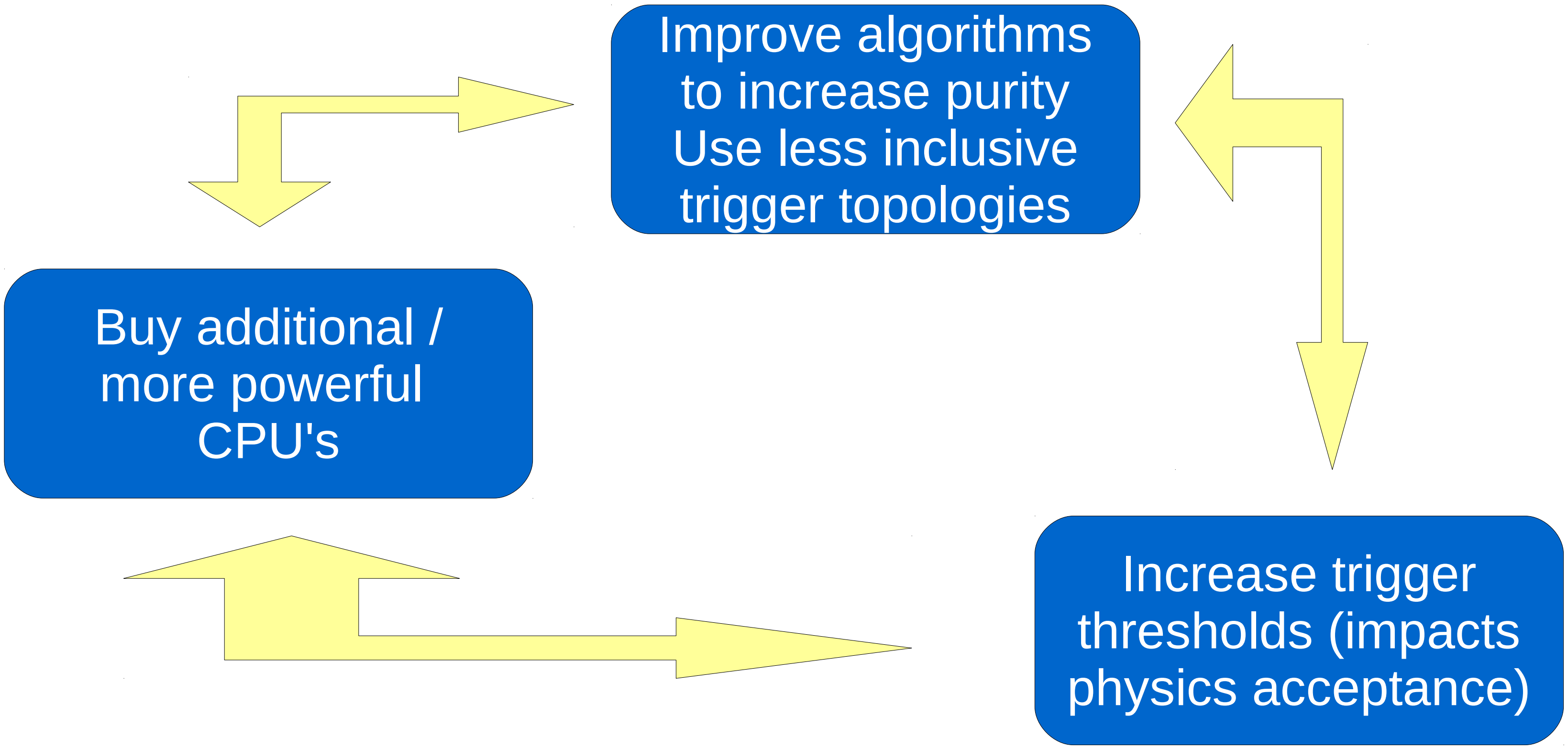
Luminosity
Peak luminosity
7e33 → 1.4e34 $cm^{-2}s^{-1}$
=> Factor of 2 in rate

Bunch spacing
50 → 25 ns
Increase of out-of-time pileup (PU)

Rate at least x4
In-time <PU>~25 → <PU> ~40
Impact of out-of-time pileup larger than during Run-1

- The challenge:
  - Keep **rate** under control
  - Keep **timing** (execution time of trigger system) under control
  - Keep **good physics acceptance**

Ways to react



- Use combination of all above strategies
  - Try to keep thresholds as low as possible
  - Upgrade L1 hardware (stage-1 in 2015 and stage-2 in 2016) keeping 100 kHz of output rate (limited by detector readout)
  - Increase of size of HLT and T0 (prompt reco) computer farms
    - Prompt reco rate avg. ~1 kHz (400 Hz in 2012)

Tau triggers

- Four different final states covered by triggers with taus (tau=τ_h)
  - double-tau
  - e+tau, mu+tau
  - tau+MEt

  with different purities and handles to control background (rate)

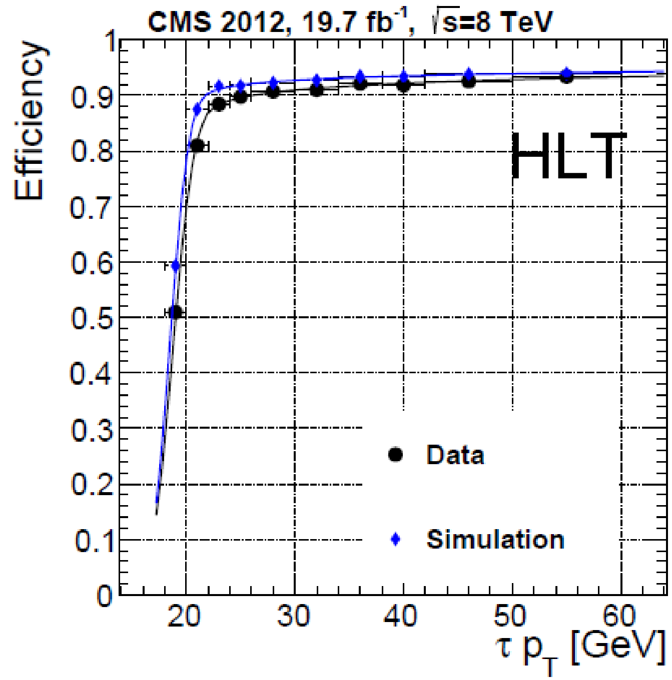
- Strategy: Use triggers as inclusive as possible => small number of (different) objects defining a trigger
  - Can be used by wide spectrum of analyzes => more bandwidth allocated per trigger
  - Easier to control => smaller systematics, smaller number of control triggers

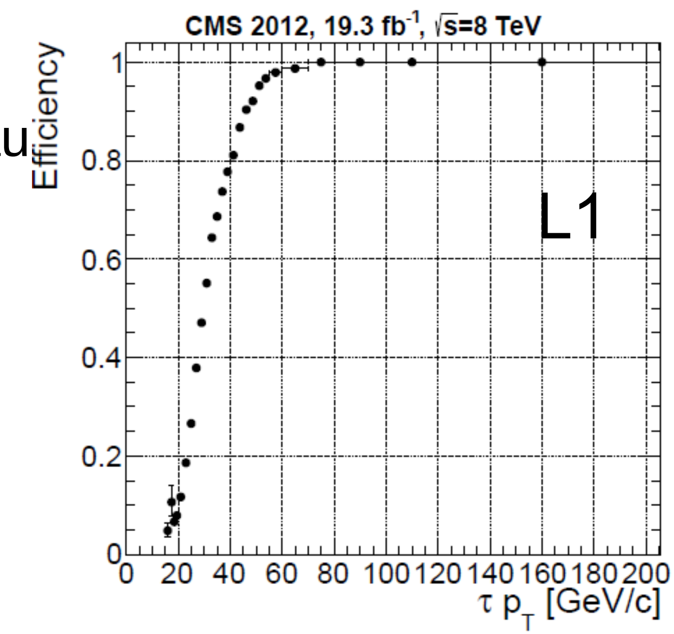
- **Disclaimer**: Double-(light)lepton final states, e+mu, 2mu, 2e, are not covered in this talk. They are however less difficult for triggering thanks to good purity.

Reference: tau triggers at Run 1

- **Muon+Tau:**
  Isolated muon **p_T> 17 GeV** + Loosely isolate Tau **p_T> 20 GeV**
  - Single muon at Level-1 => sharp turn-on of Tau
- **Electron+Tau**
  Isolated electron **p_T> 22 GeV** + Loosely isolate Tau **p_T> 20 GeV**
  - Single IsoEG at Level-1 => sharp turn-on of Tau
- **Double-Tau**
  Double-Tau **p_T> 35 GeV** + jet p_T> 30 GeV
  Double-Tau **p_T> 40 GeV** (parking)
  - Level-1: Double-Tau **p_T> 30 GeV*** => HLT/offline tau at L1 turn-on
- **Tau+MET:**
  Tau p_T> 35 GeV + MET > 70 GeV

=> Goal for Run 2: keep Run 1 acceptance (or even improve it)



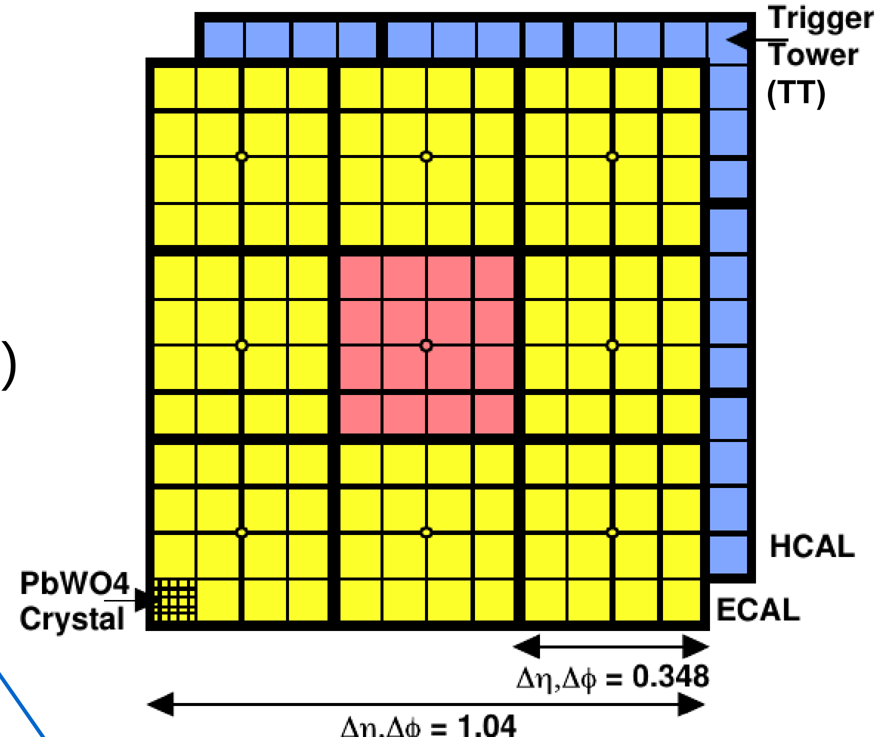


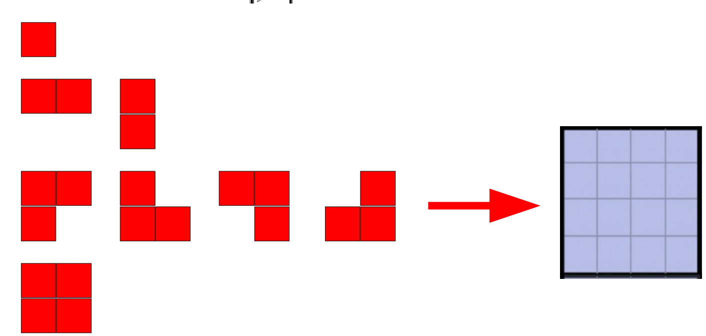
* Rescaled to offline scale, nominal value is 44

Level-1 taus

- Calorimetry only based
- Improvements: explore granularity of detector

- Run 1 algorithm
  - Built with 4x4 TT region (0.35x0.35 in η-φ)
  - **E_T** computed from 12x12 TT region with ES shared with jets (~30% too high),
  - **Isolation:** 7 from 8 non-central 4x4 TT regions with E_T< 2 GeV (w/o PU subtraction) => inefficiency at high E_T compensated by adding jet (high rate) and PU dependence,
  - **Tau veto:** energy contained with 2x2 region with E_T(TT) > 4 GeV
  - Unique tau collection (with up to 4 tau)





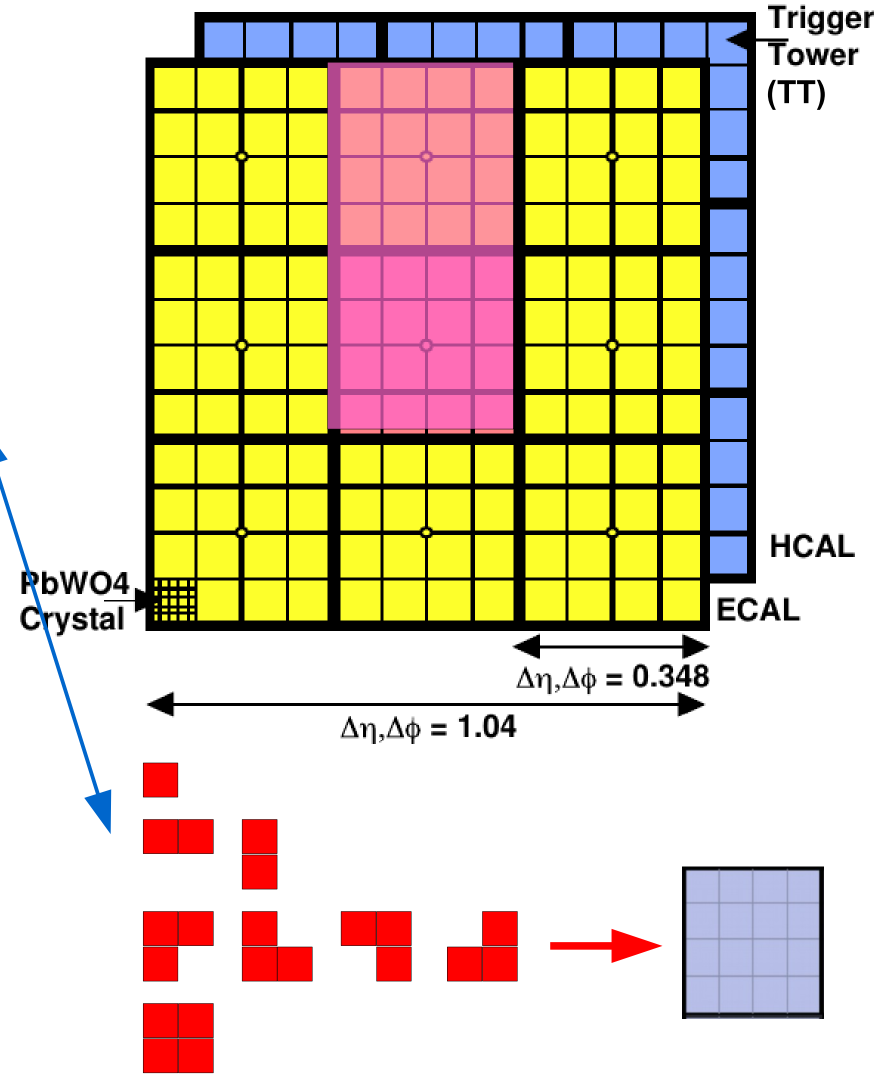
Level-1 taus

- Calorimetry only based
- Improvements: explore granularity of detector

- Run 2, stage-1 upgrade algorithm (2015)
  - Built with 4x4 TT region (0.35x0.35 in η-φ)
  - E_T computed from two neighbor 4x4 TT region with specific tau ES corrections,
  - **Isolation:** $E_T(12x12)/E_T(tau)-1<0.1$, where $E_T(12x12)$ (jet) with PU subtraction
  - **Tau veto:** in each 4x4 TT regions
  - **Two collections** (with up to 4 taus each):
    - Relaxed taus w/o isolation and tau veto
    - Tight w/ isolation and tau veto

  => Double-Tau L1T with E_T> 40 GeV (at 1.4e34) with tight WP

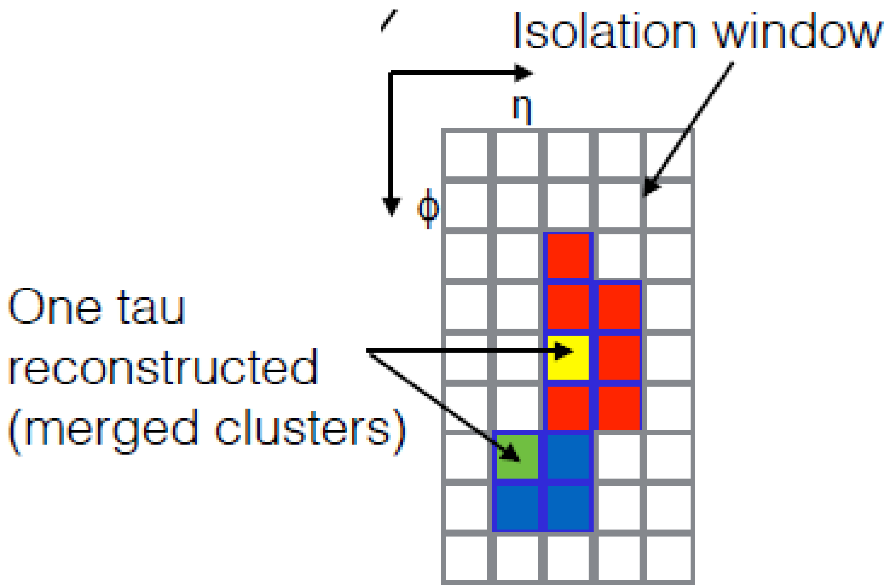
  => IsoEG/Mu+Tau with E_T(Mu/IsoEG) > 16/22 GeV and E_T(tau)>20 GeV



Level-1 taus

- Calorimetry only based
- Improvements: explore granularity of detector

- Run 2, stage-2 upgrade algorithm (2016+)
  - Built with TT (0.09x0.09 in η-φ)
  - **E_T** from dynamic clusters build around seeding TT, neighbor clusters can be merged => smaller rate thanks to reduced active area with preserved resolution
  - **Isolation:** $E_T(5x9)-E_T(tau)<X(E_T,\eta,PU)$
  - **Tau veto:** more shapes defined
  - **Many WP allowed** (up to ~6)
  - Single-tau trigger with sensible threshold (~100 GeV) should be affordable
  - Still requires final definition and tuning => work ongoing

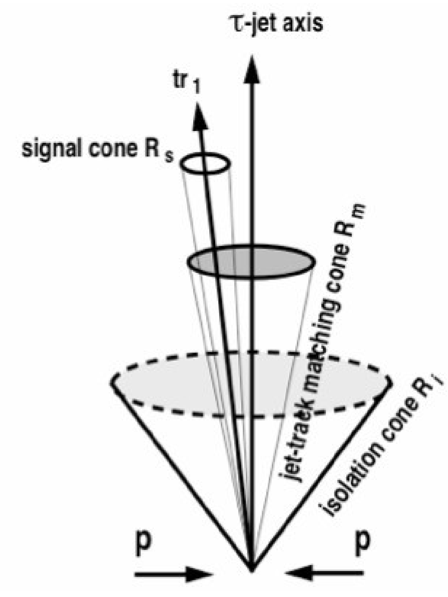


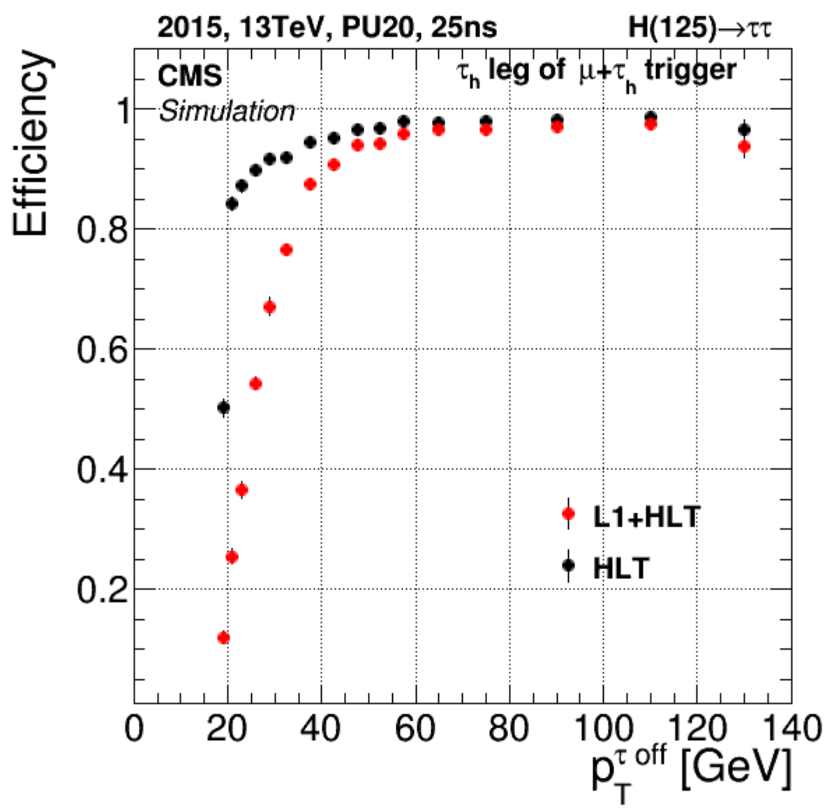
HLT Taus

- Simplified offline Tau-Id
  - Particle Flow based (online version)

- Reconstruction in steps
  - Leading track finding (close to jet axis)
    - 3 highest Pt tracks and EM strips in signal cone around leading track (0.08 < R=3.6/Pt < 0.12) define tau momentum
  - Track isolation in a cone around leading track (R=0.4)
    - Sum(Pt) < 3(2) GeV for Loose (Medium) WP

=> Simple, fast and robust algorithm
  - Resolution similar to offline one
  - Efficiency >90% (~100% at plateau)
  - Jet → tau fake rate 5-10%

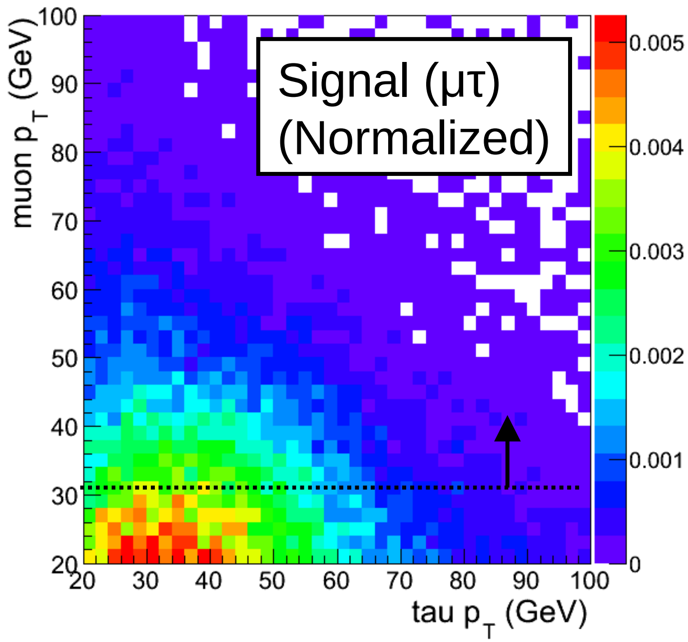


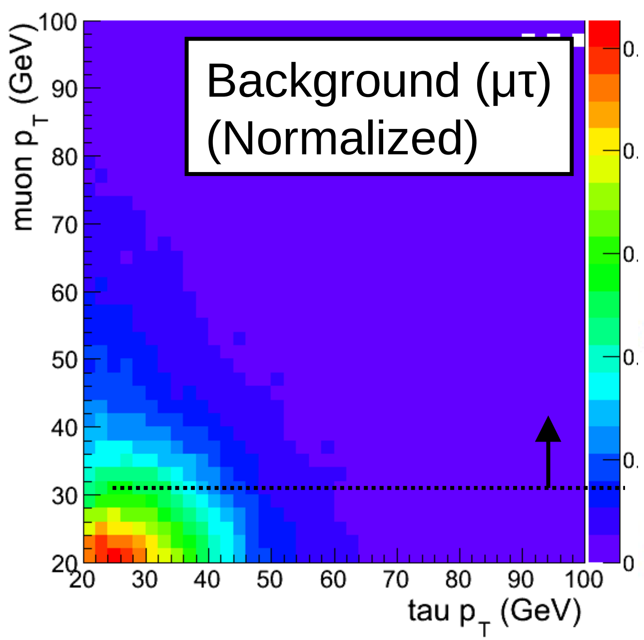


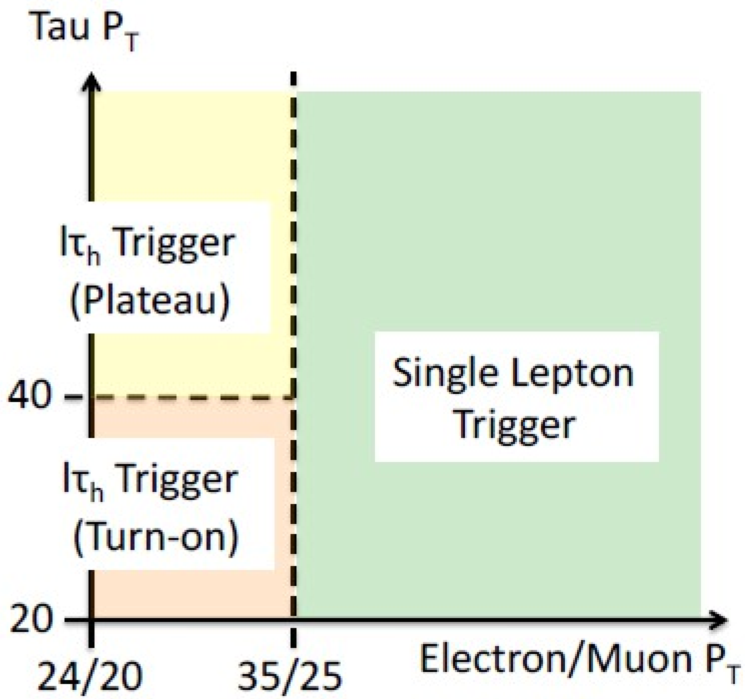
Strategy for Lepton+Tau

- High lepton Pt>30-35GeV will result sensitivity loss and different background composition
  - Threshold guided by Level-1 lepton rate
  - Z→ττ standard candle suppressed
- Cross-trigger (at Level-1) allows to save events with lepton Pt~20GeV with the cost of additional turn-on of L1 Tau

  => Combination of the two preserves Run 1 sensitivity
  - Affected region with smallest S/B ratio

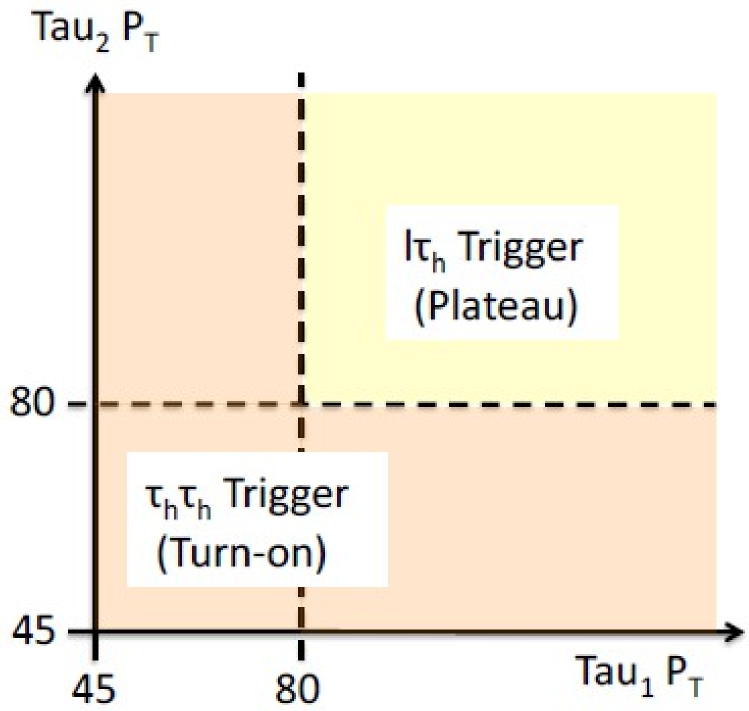






Strategy for Double-Tau

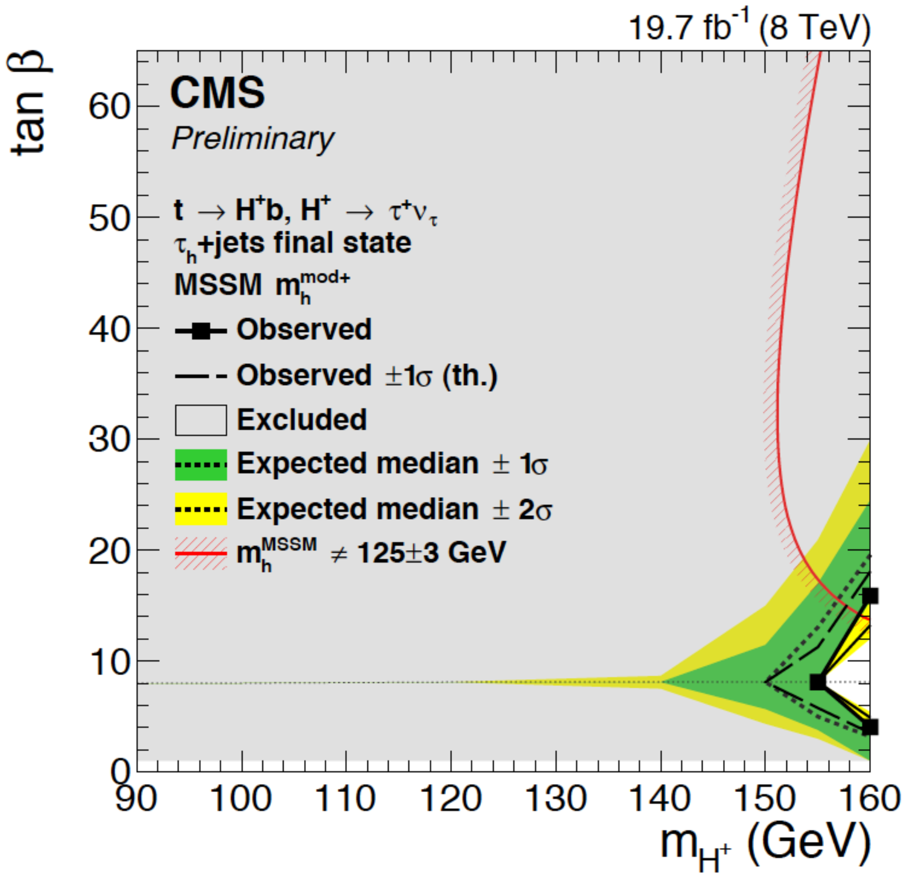
- Covered by double-tau trigger similar to Run 1, but with tighter isolation and higher threshold at Level-1
  - Overall efficiency for SM H125 will be 20-30% lower than during Run 1
  - Most of signal within turn-on region => need control turn-n very well!
- Efficiency at high-Pt (for high-mass H) can be improved with single-tau trigger – should be affordable with stage-2 upgrade algorithm



Strategy for Tau+MET

- Thresholds increase significantly in order to maintain rate
  - **Level-1**
    MET > 36 → 70 GeV
  - **HLT**
    Tau Pt > 35 → 50 GeV
    MET > 70 → 120 GeV

- However, increase of thresholds does not affect physics as focus for Run 2 are high mass $H^{\pm}$ / W' → τυ
  - low mass already excluded thanks to Run 1 data

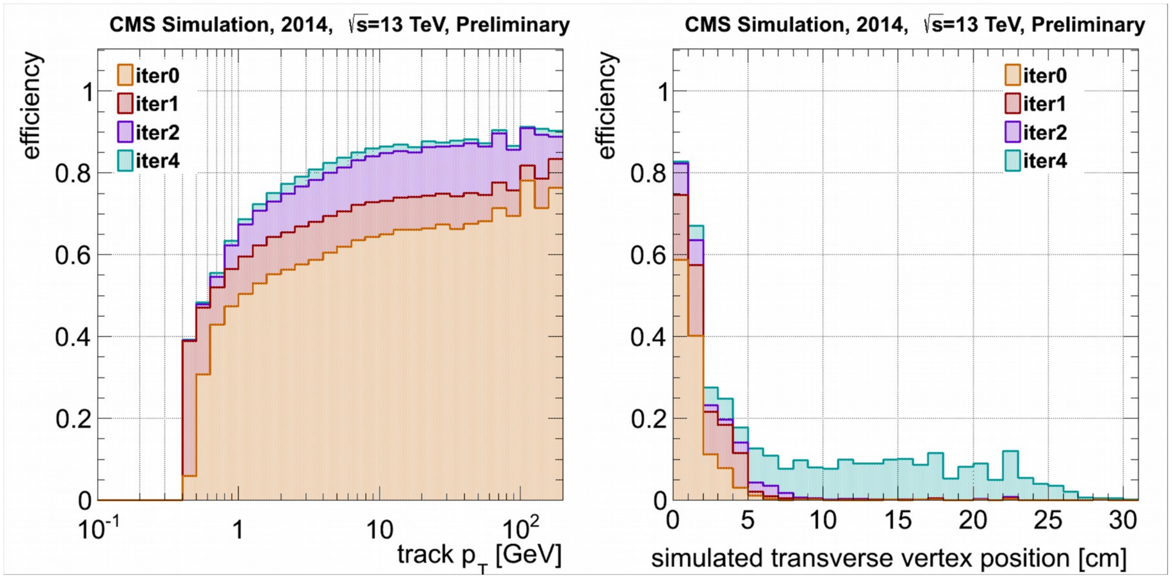


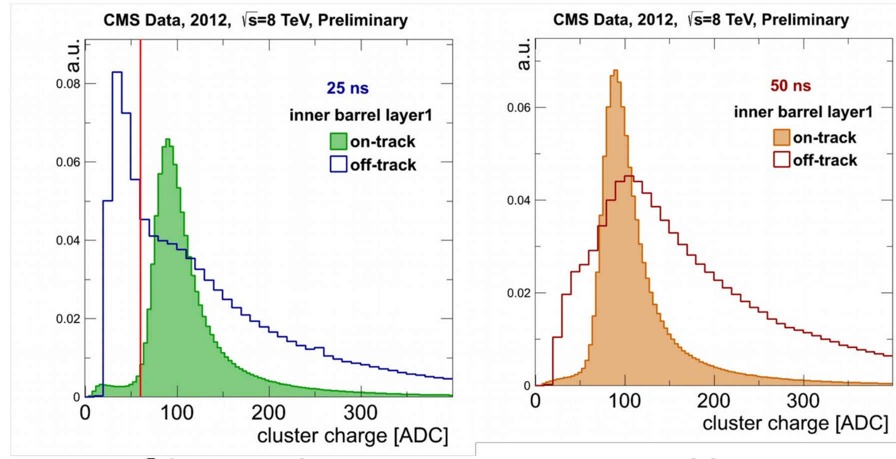
Summary

- Challenges of tau triggering with LHC Run 2 conditions was discussed
- Ways to preserve signal acceptance was discussed
  - Upgrade of Level-1 trigger hardware to better explore detector resolution
  - Increase of HLT performance thanks to both better algorithm and more powerful resources
- Acceptance in lepton+tau channels preserved thanks to combination of lepton+tau and single lepton triggers
- Double-tau efficiency will be reduced by 20-30%
- Waiting for data taking with inst. luminosity of 1.4e34 $cm^{-2}s^{-1}$:)

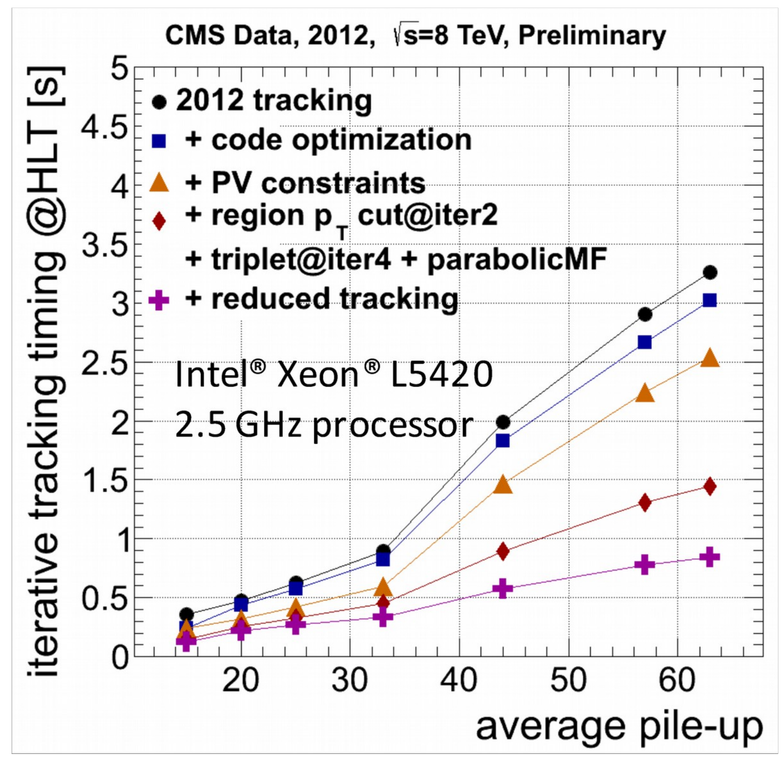
Additional material

HLT tracking





Cluster charge cut, meant to mitigate the effect of spurious clusters in 25ns runs



Iterative Tracking at HLT:

iter0: prompt tracks high pT w/ pixel tracks

iter1: prompt tracks low pT w/ pixel triplets

iter2: recover prompt tracks high pT w/ pixel pairs

iter4: displaced tracks w/ strip triplets (in 2015 it will be run only in a sub set of trigger paths where displaced tracks are needed)