The role of the CMS electron and photon trigger in the study of the Higgs boson and high mass searches

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On behalf of the CMS collaboration

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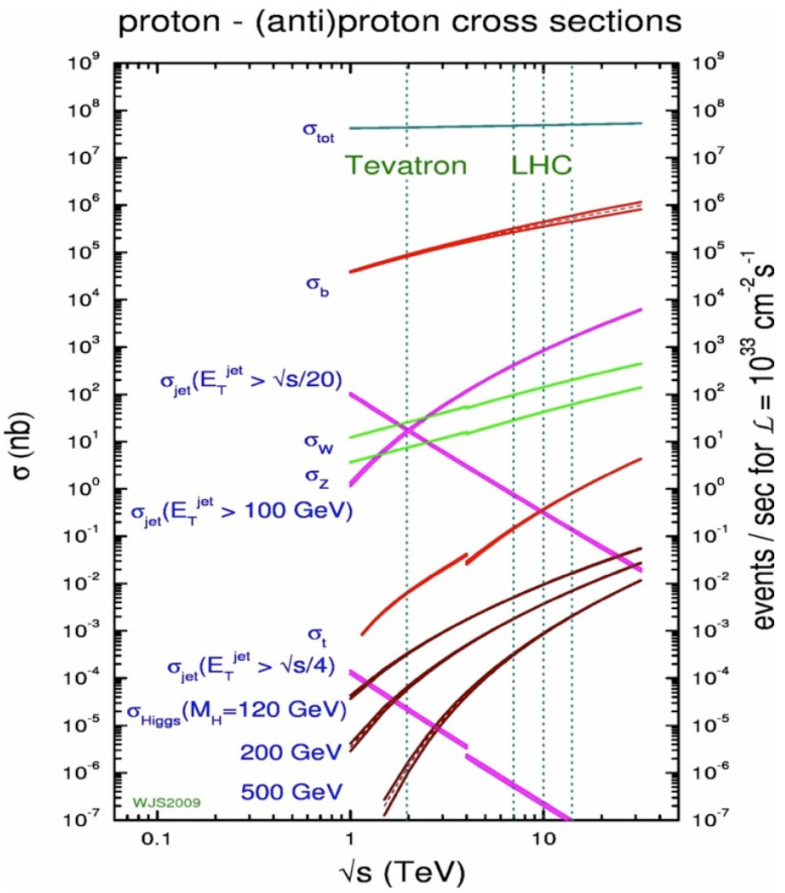
on Calorimetry in Particle Physics

Outline

- Introduction
- The Level-1 EG trigger in CMS
- The High Level Trigger selection for electrons and photons
- Impact of the electron and photon trigger on physics analyses

Introduction

The CMS trigger system

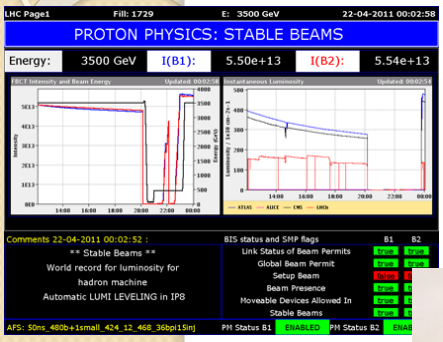


- **Very high collision rate required to observe very rare physics processes (Higgs production, new resonances…) but not technically possible to record every event**
- **Trigger system required to select events on the fly**
- **Must:**
  - be quick, to sustain a 40 MHz collision rate
  - reduce the rate by discarding uninteresting events
  - be efficient to keep as many interesting physics events as possible

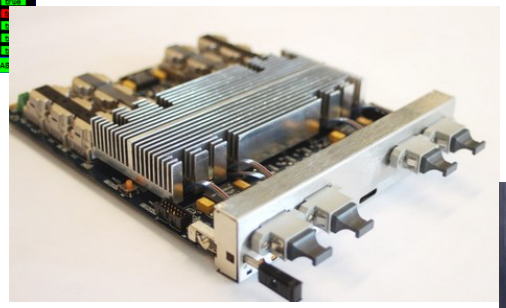
- **Due to high hadronic activity, leptons and photons provide ideal candidates to trigger on**

The CMS trigger system

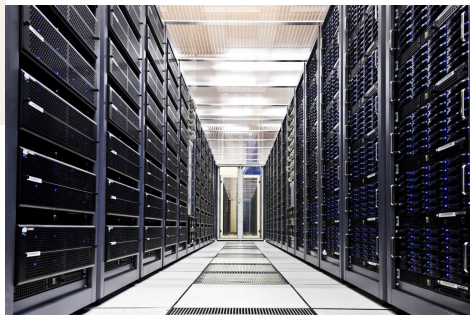
- **Two-layer implementation:**



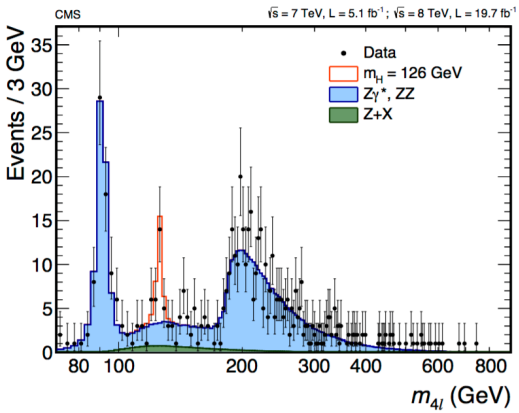
- The **Level-1 trigger** bases its decision directly on coarse granularity detector readout
- Hardware implementation (FPGA), synchronous operation



- ~4 μs to take a decision, 100 kHz max. L1 accept rate



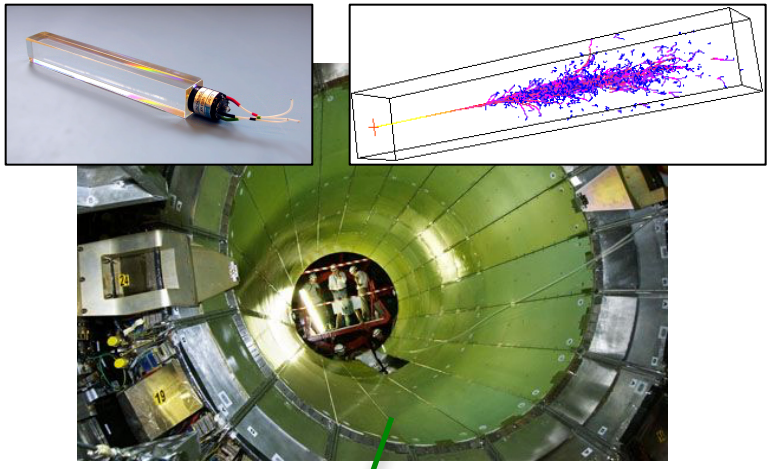
- **High-level trigger** benefits from full detector readout and full granularity
- Software implementation, close to offline reconstruction
- ~200 ms on average to take a decision, 1kHz average output rate

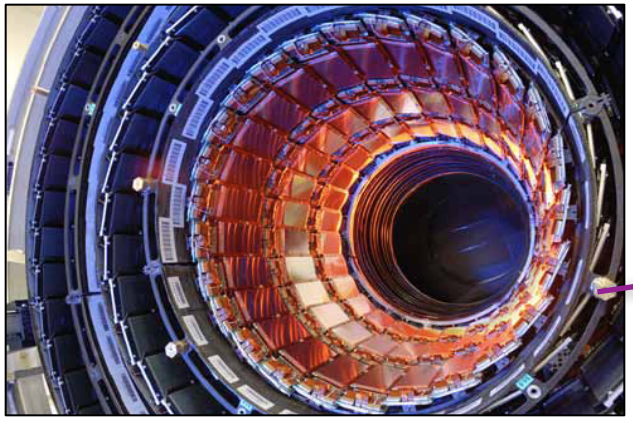


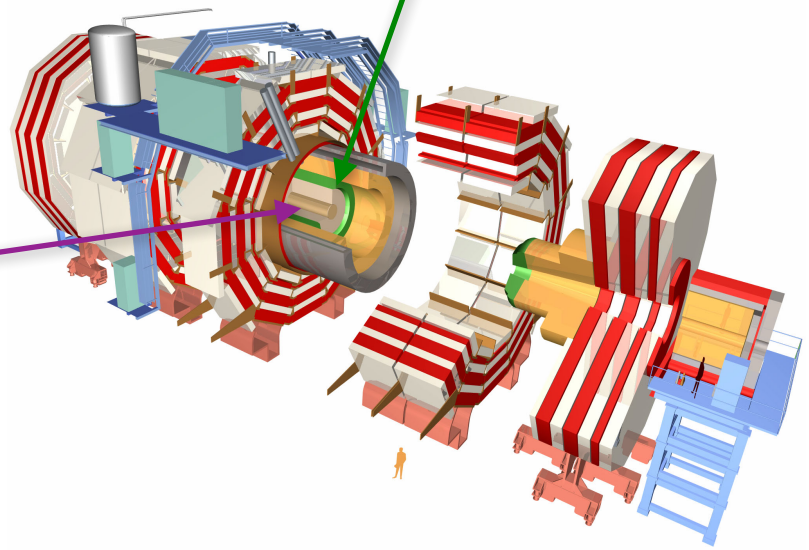
The CMS detector

- **For what regards the electron and photon reconstruction, CMS relies on information from tracker and ECAL**

- **ECAL made of 75'848 lead tungstate crystals, arranged between barrel and two endcaps:**
  - Dense material: 80% of e/γ energy in single crystal
  - fast scintillation: 80% light emitted in 25ns





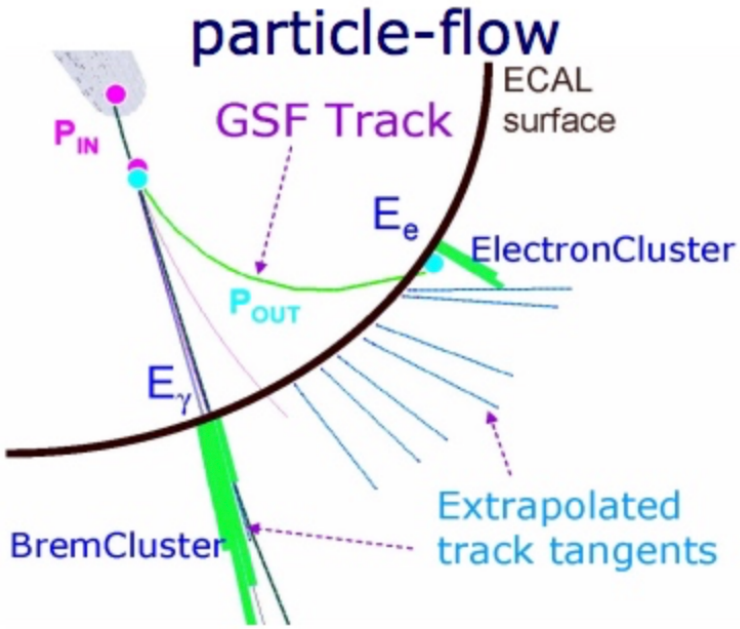


- **Tracker made of silicon pixels and strips**

Offline electron and photon reconstruction

- **For Run II, e/γ reconstruction fully integrated within CMS Global Event Description (also called Particle-Flow)**

- **Gaussian Sum Filter (GSF) tracking used for electrons: accounts possible Bremsstrahlung photon emission**



- **e/γ candidates seeded by:**
  - tracker driven GSF tracks
  - calo driven GSF tracks
  - EM superclusters

- **Different blocks linked together to reconstruct individual particles and leads to final unique event interpretation**

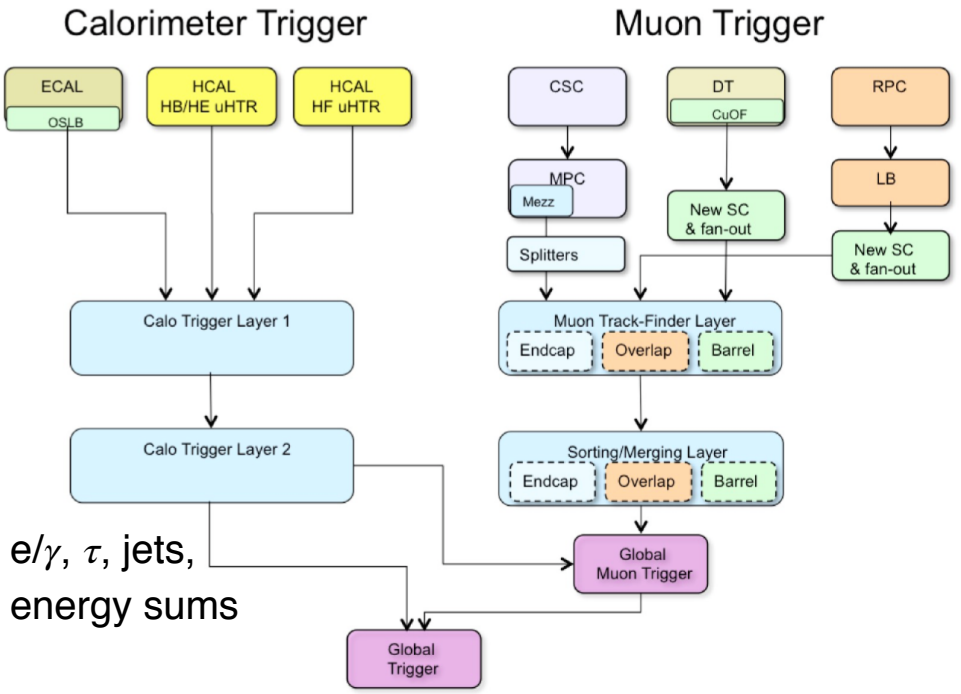
- **However not possible to run full reconstruction online as too time-consuming**

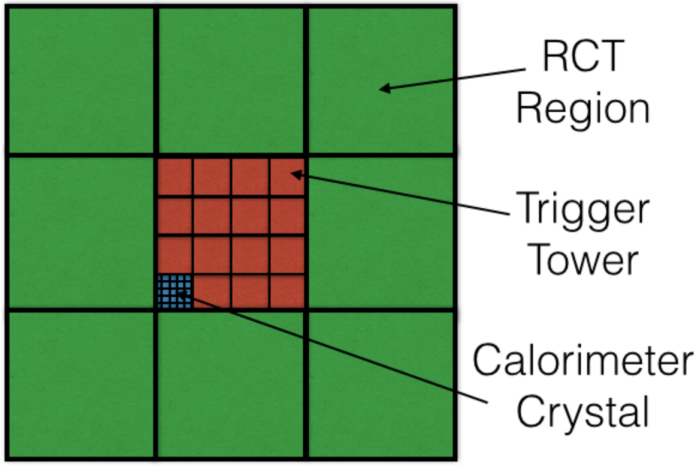
The Level-1 EG trigger in CMS

New Level-1 trigger system

- **2016 data-taking represents real challenge for trigger:**
  increase in luminosity (up to 1.6e34cm^{-2}s^{-1}) and in pile-up (up to 50)

- **To meet that challenge, the CMS Level-1 trigger underwent a major change of architecture**

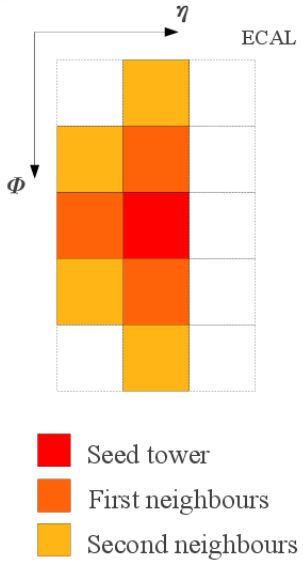


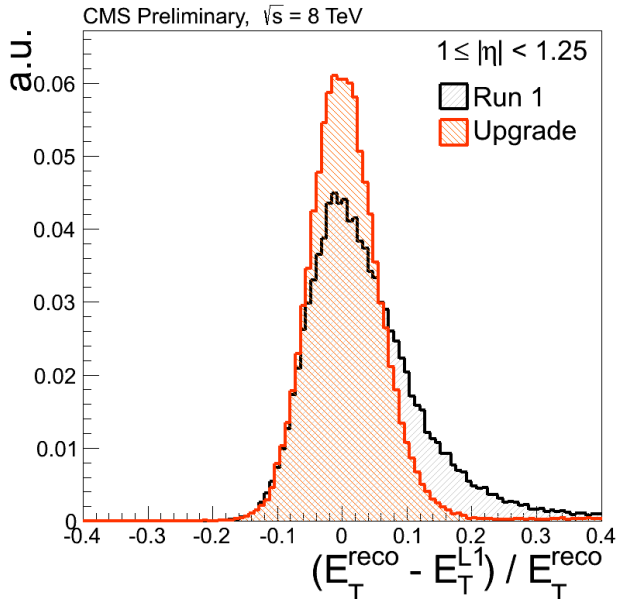


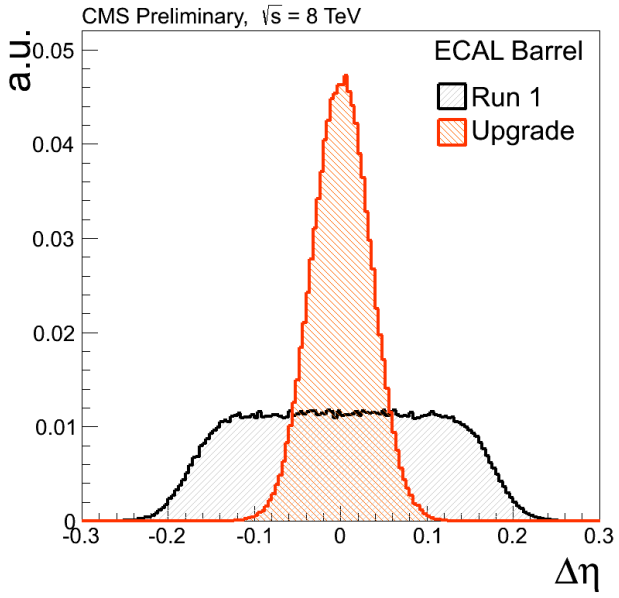
- **In Calorimeter Trigger, evolution from a regionalized approach to a global event-level approach: new system uses trigger tower granularity** (see A. Bundock's talk)

Improvements of the EG algorithm

- At Level-1, only access to calorimeter information to reconstruct e/γ candidates, built from cluster of calorimeter trigger towers
- New clustering allows now for extended shapes to better collect potential Bremsstrahlung radiation
- Large improvement in position resolution, thanks to better granularity
- Can be exploited in invariant mass trigger already at Level-1



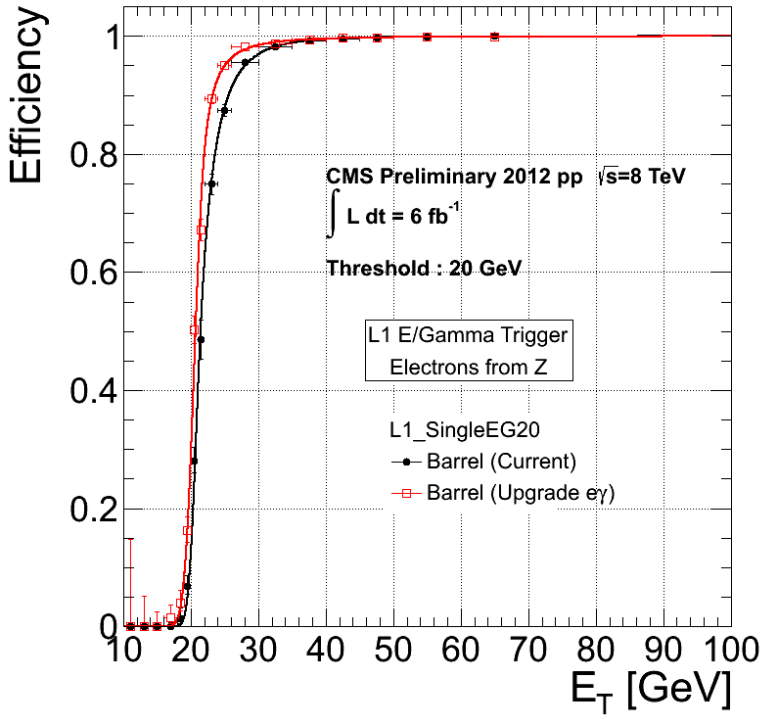


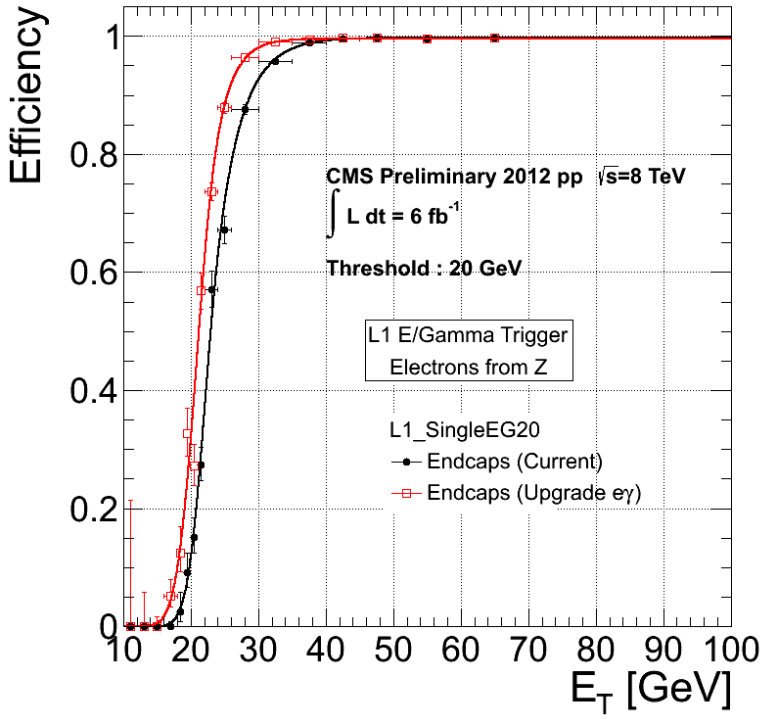


Improvements of the EG algorithm

- **Efficiency measured in data using Tag&Probe method:**
  - pair of opposite-sign electrons reconstructed offline with an invariant mass compatible with the Z boson
  - one of the two is used to trigger the event
  - other can be used to measure unbiased efficiency

- **Thanks to better energy resolution, it is possible to improve the trigger efficiency in the turn-on region in all parts of the calorimeter**

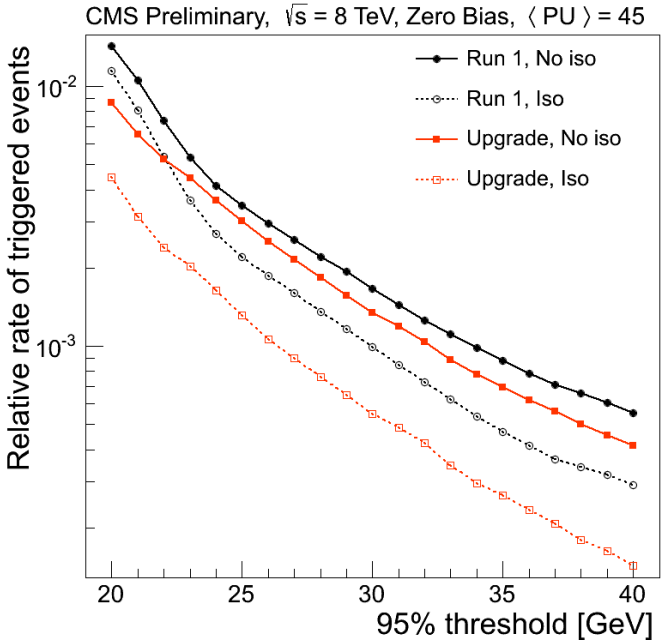


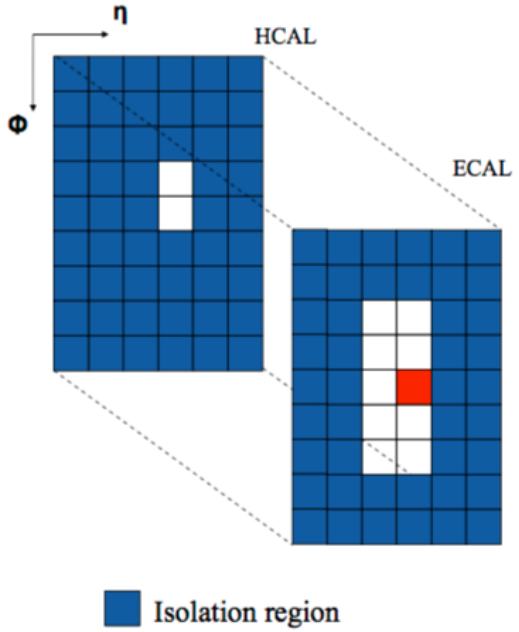


Improvements of the EG algorithm

- **Background reduction achieved thanks to several configurable features:**
  - fine-grain (energy distribution within a trigger tower)
  - H/E veto
  - shape trimming + veto

- **Possible isolation requirement: evaluated as a function of PU, to keep a constant efficiency**



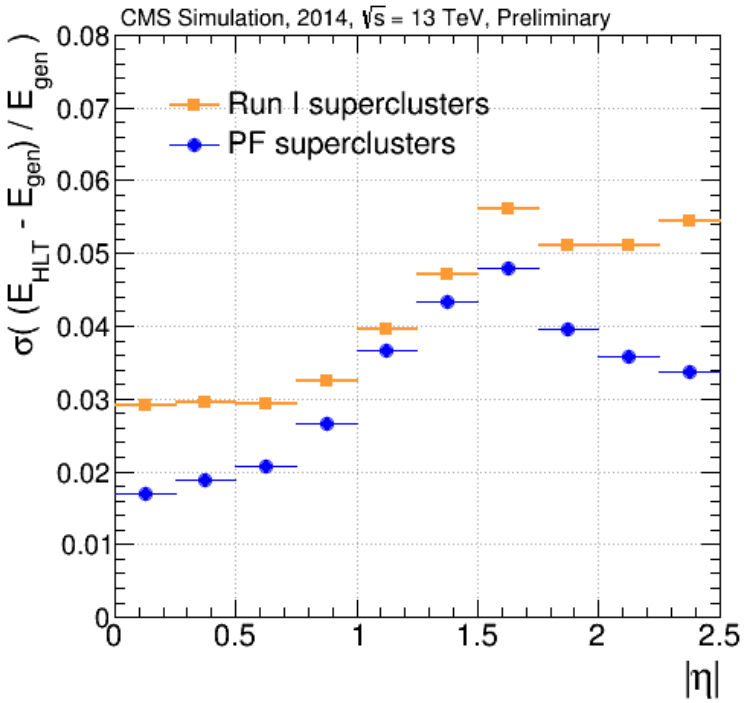


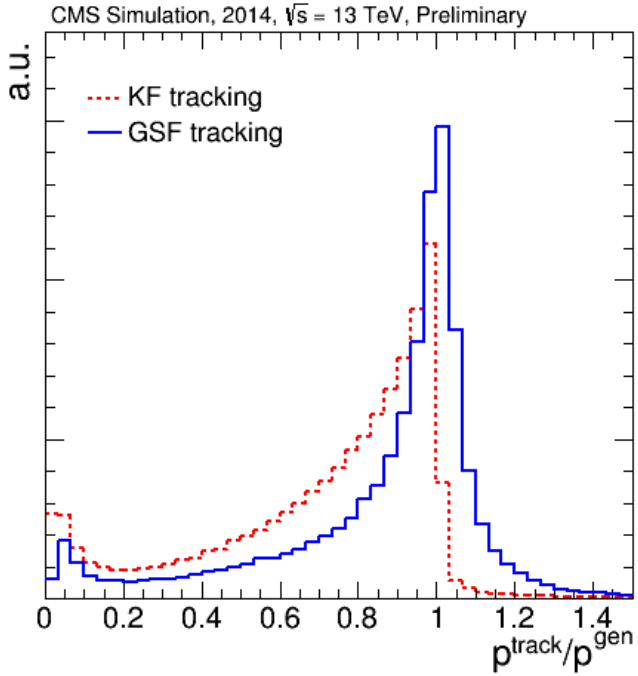
- **Large improvement in rate reduction achieved with new system with respect to Run I algorithm**

The High Level Trigger selection for electrons and photons

Electron and photon reconstruction at HLT

- For Run II, e/γ reconstruction at HLT really close to offline Particle-Flow reconstruction
- Start from L1 seeds to reduce computing time
- New superclustering algorithm + regression-based energy corrections significantly improves the energy resolution at HLT

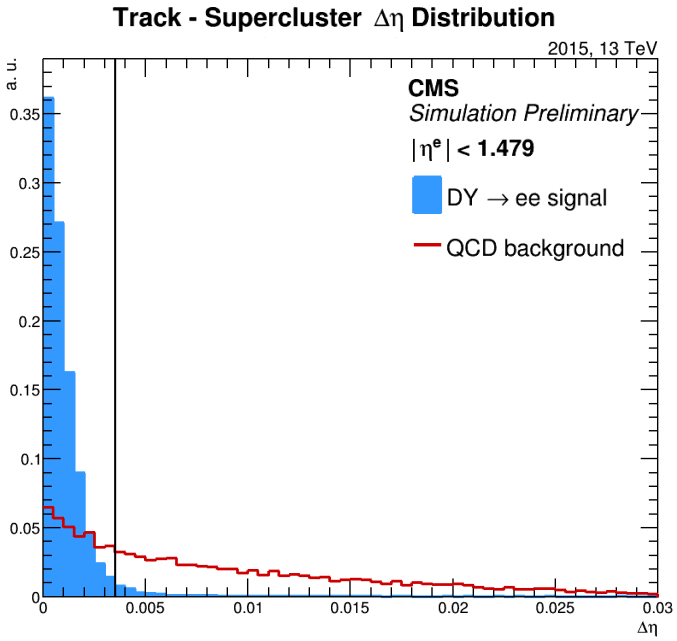


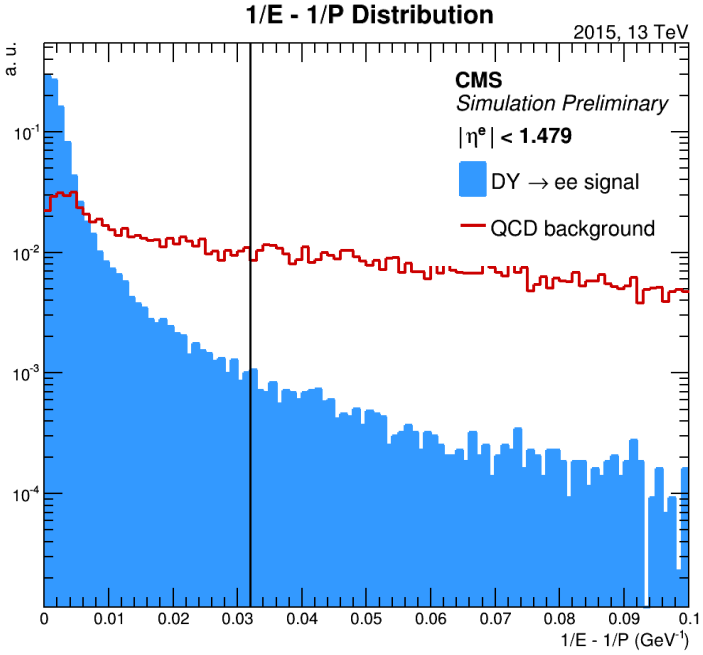


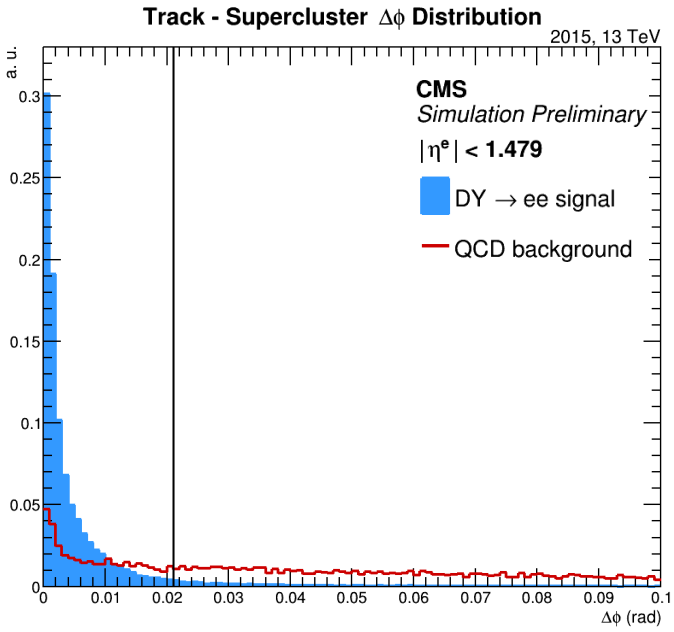
- Gaussian Sum Filter has replaced Run I Kalman Filter for electron track reconstruction, to better accommodate deviations due to Bremsstrahlung radiation

Electron identification

- **Tracks provide new parameters to identify electrons**
- **In combination with calorimeter information, possible to define selections to reduce background contamination**

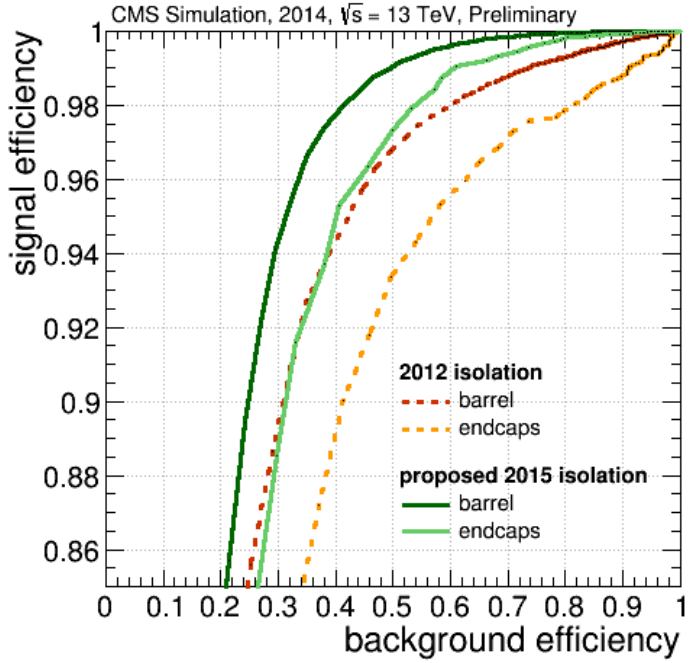


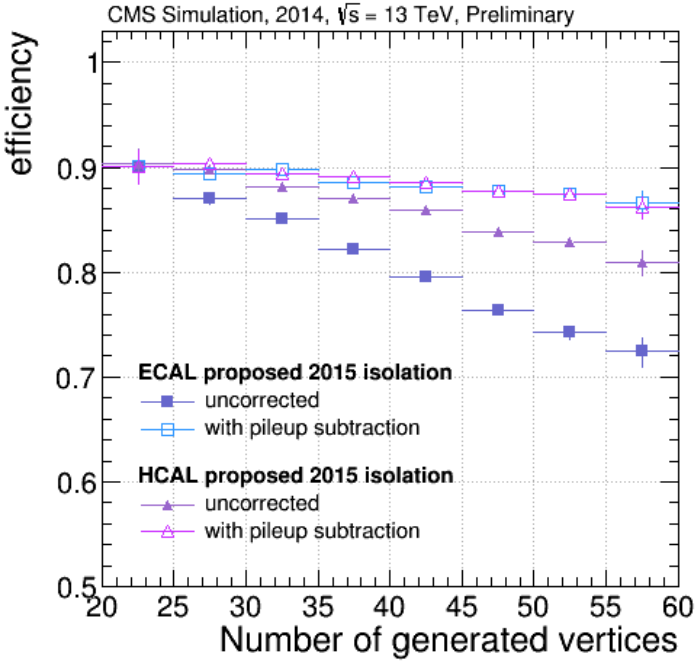




Isolation

- To further discriminate e/γ from hadronic processes, isolation can also be used
- Detector isolation used in Run I replaced by a Particle-Flow like isolation: uses PF calorimeter clusters + tracks in a 2nd step
- Also includes pileup subtraction based on average energy density in the event

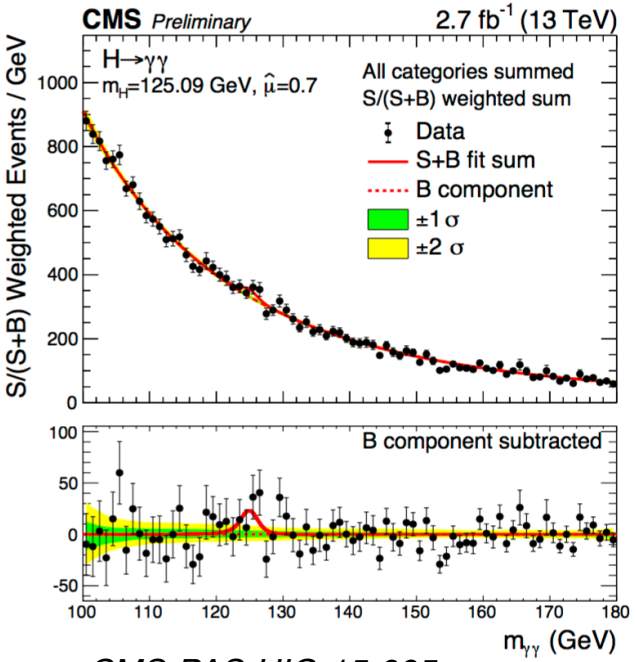




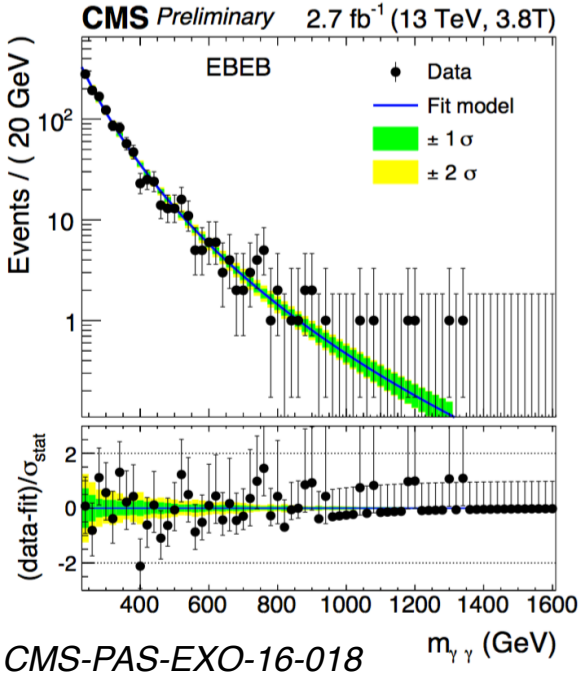
Impact of the electron and photon triggers on physics analyses

Diphoton analyses

- For H->$\gamma\gamma$ analysis at 13 TeV, SingleEG + DoubleEG seeds used at Level-1
- At HLT, two photons with p_T>30 (18) GeV + m($\gamma\gamma$)>95 GeV
- Region of interest m($\gamma\gamma$)>100 GeV, offline selections p_T>m($\gamma\gamma$)/3(4): not directly limited by the trigger thresholds



CMS-PAS-HIG-15-005

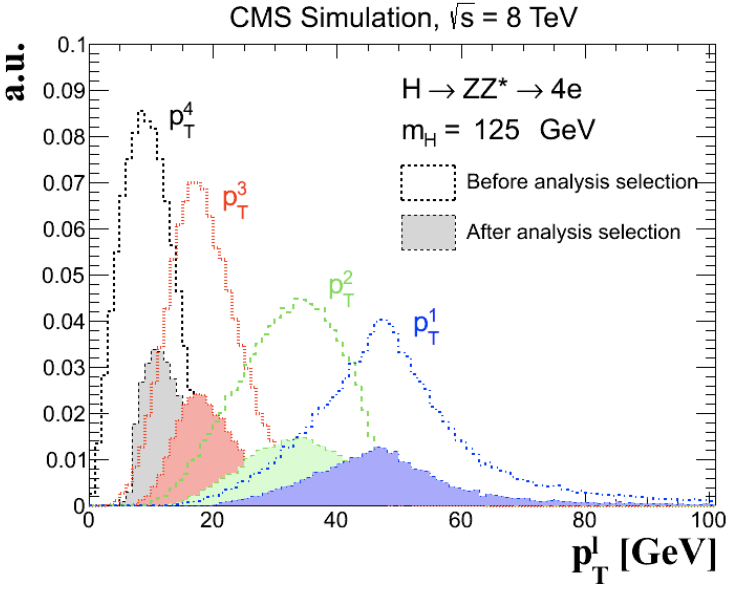


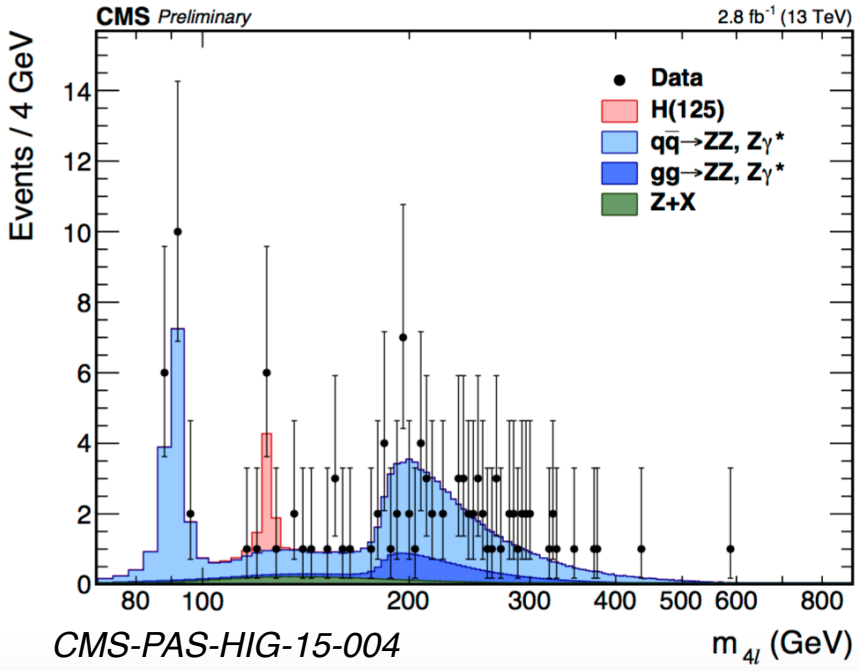
CMS-PAS-EXO-16-018

- Even more true for high mass searches: uses HLT_DoublePhoton_60 + offline selections p_T>75 GeV
- For those analyses, essential for EG trigger to avoid any inefficiency at high p_T

Higgs to four leptons studies

- **H->ZZ*->4l provides a clean signature in pp environment but low expected number of events**
- **Moreover p_T of trailing lepton can be quite low due to off-shell Z boson: offline electrons requirement p_T>20 / 10 / 7 / 7 GeV**





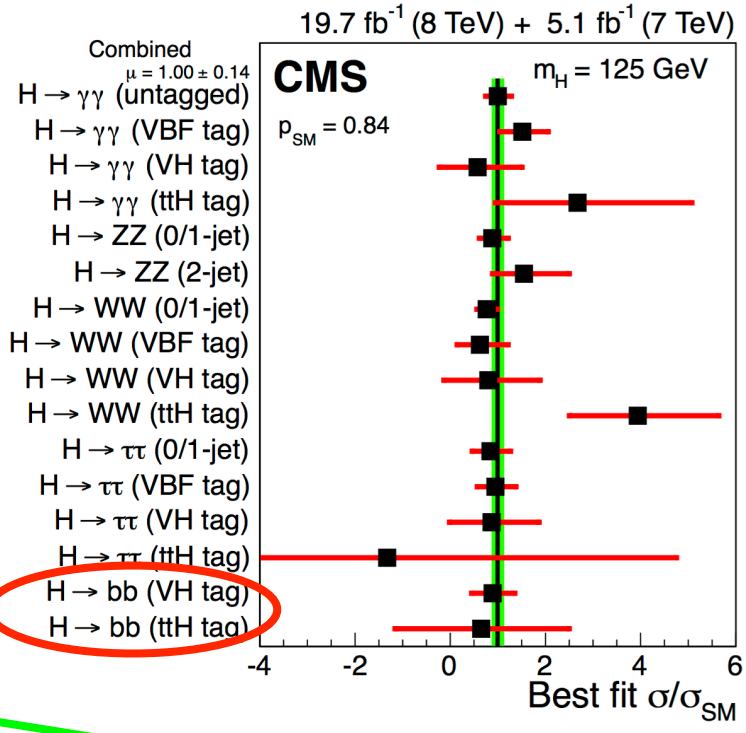
CMS-PAS-HIG-15-004

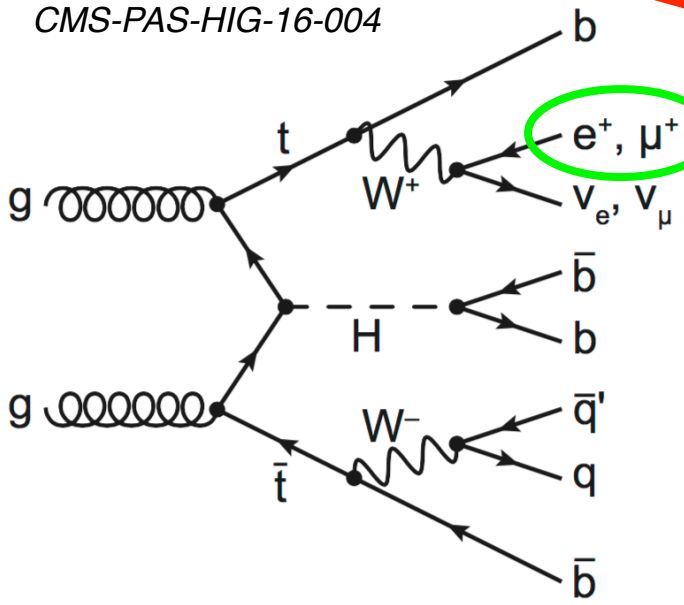
- **Triggering on low p_T leptons quite challenging because of the high rate**
- **To keep a high acceptance, combination of different SingleEG + DoubleEG + TripleEG (+ muon) trigger paths: enables to keep a trigger efficiency > 99%**

Associated production of Higgs boson

- **EG trigger not only used to target Higgs decay modes with e/γ in the final state but also H->bb**
- **Because of large QCD background, sensitivity only for associated production mode, mainly VH + ttH**

CMS-PAS-HIG-13-012
CMS-PAS-HIG-16-004





- **Benefits from lepton in the final state to trigger as hadronic triggers have higher thresholds**
- **Has still to rely on SingleEG triggers with threshold > 25 GeV at 13 TeV but targets anyway electrons produced in top or boosted W decays**

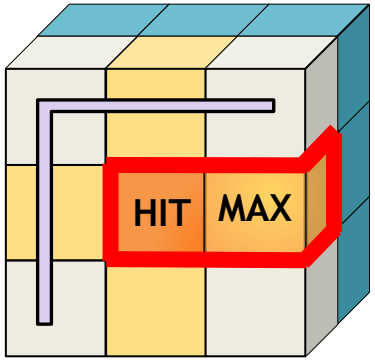
Conclusion

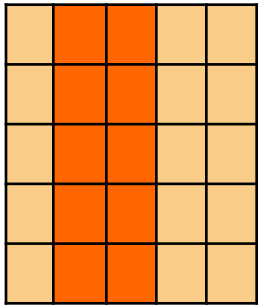
- **Triggering on electrons and photons is a real challenge for Run II due to luminosity increase and higher pile-up conditions**
- **Level-1 EG algorithm largely benefits from new Level-1 trigger system used in CMS from this year**
- **High-Level Trigger also improved thanks to techniques closer and closer to offline reconstruction**
- **Maintaining a highly efficient triggering on electrons and photons is critical for the Higgs properties studies and resonance searches**
- **Done successfully thanks to continuous improvements of the e/γ trigger, which contributes to a large number of physics analyses in CMS**

Back-up

Level-1 EG algorithm in Run I

- **L1EG candidates built from at most two trigger towers (= 5x5 crystals)**



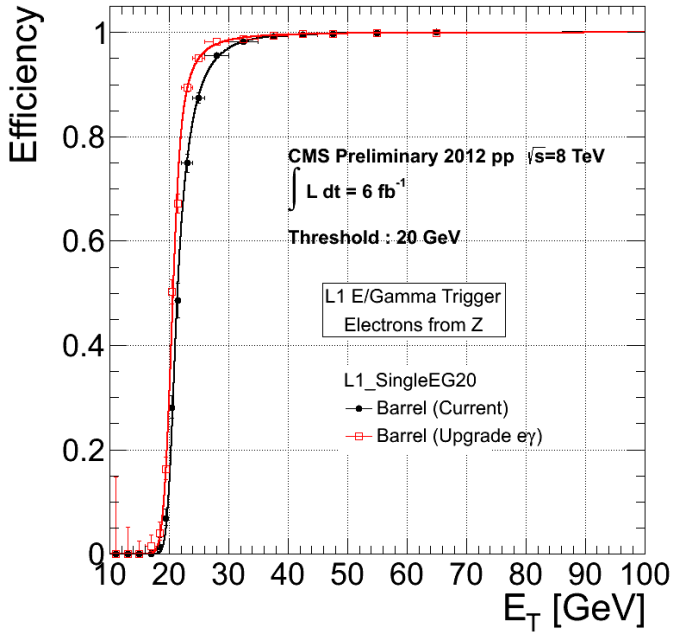


- **Apply vetoes based on:**
  - fine grain: 90% tower E_T within 2 adjacent strips
  - H/E: ratio of E_T in ECAL and HCAL towers < 5%

  (still used in Run II algorithm)

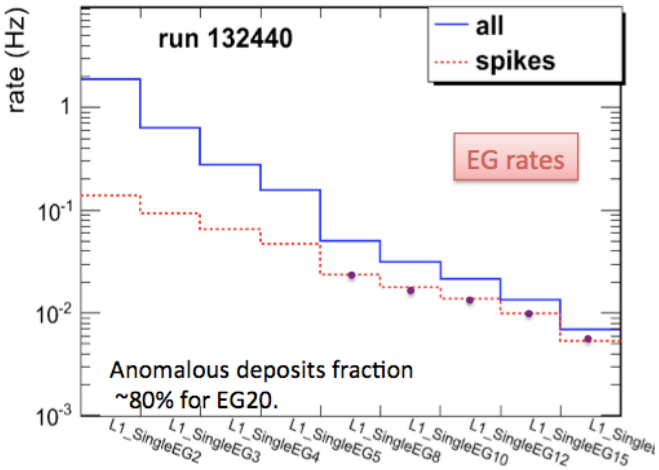
- **Isolation criteria:**
  - at least one "quiet corner" = ∑(5 adjacent towers)<3.5 GeV
  - 8 neighbour towers must pass FG and H/E selections

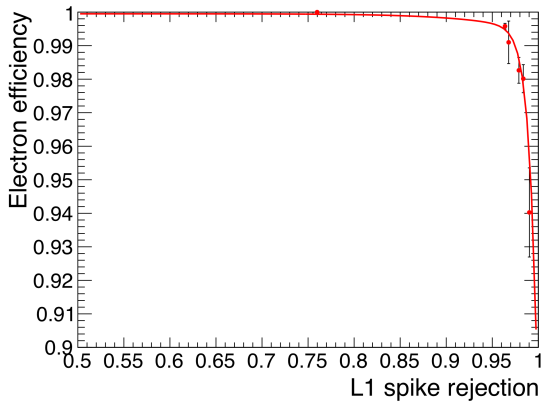
- **No PU dependence accounted for: changed in Run II algorithm**



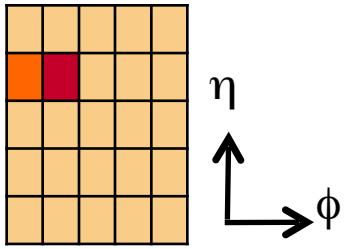
Anomalous ECAL signals

- **ECAL spikes: anomalous isolated high energy deposits measured in ECAL crystals**
- **Due to secondary particles directly ionizing the silicon of the photo-detector**





- **Dominate L1 bandwidth at high luminosity for thresholds above 5 GeV**
- **Spike removal algorithm designed for Run I based on energy distribution within a tower**



Real EM shower
if 2 crystals in a strip > T_1
(EM shower ⇒ ϕ spread)

Spike
E_T(tower) > T_2
⇒ tower set to 0

Diphoton analyses

- **Diphoton paths used in CMS-PAS-HIG-15-005 (H->$\gamma\gamma$):**
  - HLT_Diphoton30_18_R9Id_OR_IsoCaloId_AND_HE_R9Id_Mass95
  - HLT_Diphoton30PV_18PV_R9Id_AND_IsoCaloId_AND_HE_R9Id_DoublePixelVeto_Mass55
  - HLT_Diphoton30EB_18EB_R9Id_OR_IsoCaloId_AND_HE_R9Id_DoublePixelVeto_Mass55

- **Diphoton paths used in CMS-EXO-16-018 (high-mass diphoton searches):**
  - HLT_DoublePhoton_60 @ 3.8T
  - HLT_DoublePhoton_40 @ 0T

- **Uses:**

  - $E_T(\gamma)$, m($\gamma\gamma$), H/E

  - R_9 variable: energy sum of 3x3 crystals centered on the most energetic crystal in the candidate EM cluster / energy of the candidate
  - Calorimetric ID variables + tracker isolation
  - Veto on pixel seed

Higgs to four leptons studies

- **Trigger paths used in CMS-HIG-15-004 (H->ZZ*->4l):**

Seeded by L1 Single+Double+Triple EG

- HLT_Ele17_Ele12_CaloIdL_TrackIdL_IsoVL_DZ
- HLT_Ele16_Ele12_Ele8_CaloIdL_TrackIdL
- HLT_Ele23_WPLoose_Gsf

Seeded by L1 EG+Mu

- HLT_Mu8_TrkIsoVVL_Ele17_CaloIdL_TrackIdL_IsoVL
- HLT_Mu17_TrkIsoVVL_Ele12_CaloIdL_TrackIdL_IsoVL
- HLT_Mu8_DiEle12_CaloIdL_TrackIdL
- HLT_DiMu9_Ele9_CaloIdL_TrackIdL

Seeded by L1 Double+Triple Mu

- HLT_Mu17_TrkIsoVVL_Mu8_TrkIsoVVL_DZ
- HLT_Mu17_TrkIsoVVL_TkMu8_TrkIsoVVL_DZ
- HLT_TripleMu_12_10_5

Associated production of Higgs boson

- **Electron trigger paths used in CMS-HIG-13-012 (VH, H->bb @ 7+8 TeV):**
  - W(ev)H: HLT_Ele27 WP80
  - Z(ee)H: HLT_Ele17_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL_
    Ele8_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL

- **Electron trigger paths used in CMS-HIG-16-004 (ttH, H->bb @ 13 TeV):**

Lepton+jets categories
- HLT_Ele27_eta2p1_WPLoose_Gsf

Dilepton categories
- HLT_Ele17_Ele12_CaloIdL_TrackIdL_IsoVL
- HLT_Mu17_TrkIsoVVL_Ele12_CaloIdL_TrackIdL_IsoVL
- HLT_Mu8_TrkIsoVVL_Ele17_CaloIdL_TrackIdL_IsoVL