# Triggering on Electrons and Photons with the CMS experiment at the LHC

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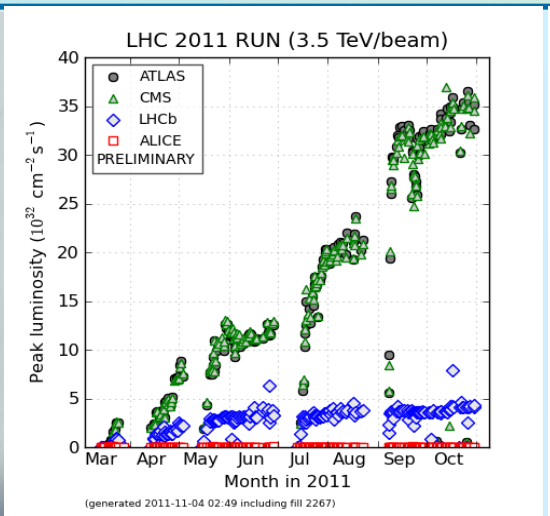
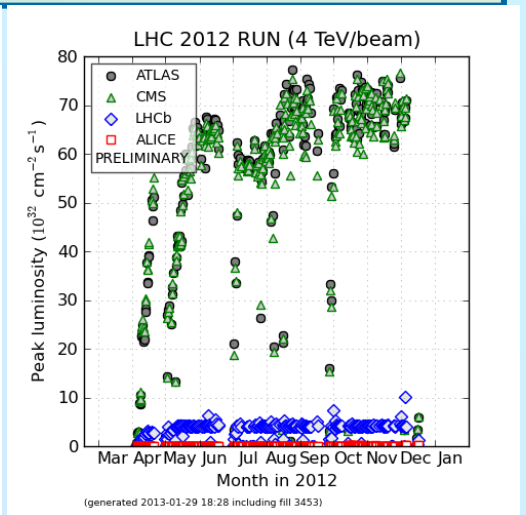
On behalf of the CMS collaboration

# OUTLINE

**Tremendous performance of the LHC throughout Run 1 (2010-2012): instantaneous luminosity constantly rising. Real challenge to keep best achievable trigger performance to guarantee our physics program.**

- *Presentation of the CMS Level-1 electron /photon trigger and its operation*
- *Effect of the ECAL anomalous signal on the rate and its removal 2010-2011*
- *Electron triggering efficiency performance 2011-2012*
- *Optimization for higher luminosity/pile-up 2012*

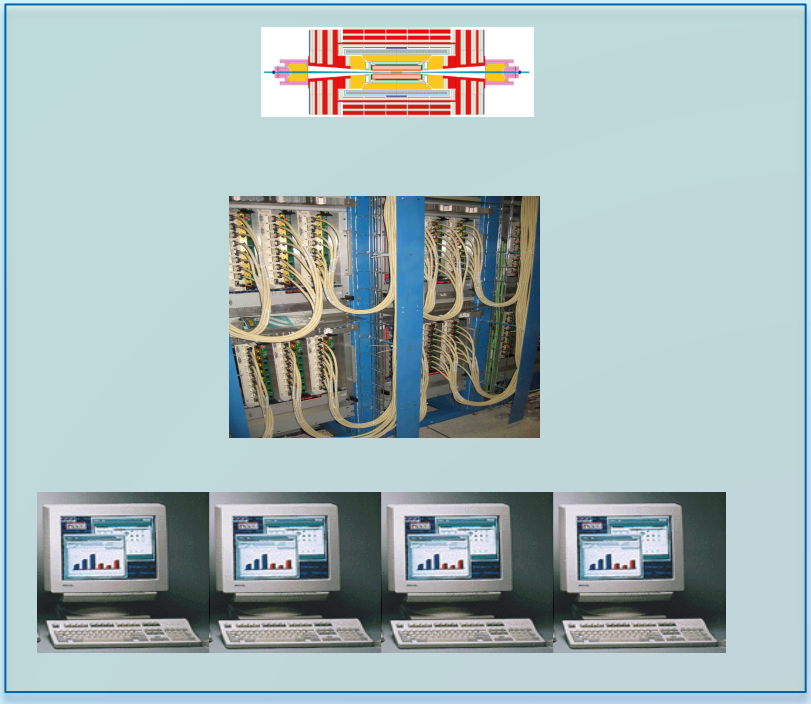




**2011 performance:**
**Record: $3.7 \times 10^{33}$ cm$^{-2}$ s$^{-1}$**
**Data recorded: 6 fb$^{-1}$**

**2012 performance:**
**Record: $7.7 \times 10^{33}$ cm$^{-2}$ s$^{-1}$**
**Data recorded: 23 fb$^{-1}$**

# CMS Event Selection

**The CMS trigger system is organized in 2 stages to achieve an input data rate reduction of the order of $4.10^5$. The L1 trigger decision is based on coarsely segmented data from the calorimeters and muon systems. Custom made hardware is implemented at L1 while the second stage (HLT) reconstructs partially the event with full sub-detector readout using a farm of computers.**



**Clock frequency: 40 MHz**

**L1 Trigger : max output 100kHz**

**High Level Trigger : average output 300Hz**

# Level-1 e/gamma trigger path

**Per regional RCT crate:**
- **4 highest isolated E.M objects**
- **4 highest non-iso E.M objects**
- **4 highest central, forward, τ jets**

**Regional Calo Trigger**

HCAL Trigger Primitives

- **4 isolated E.M objects**
- **4 non-iso E.M objects**
- **4 central, forward, τ jets**

**Global Calo Trigger**

**Global Trigger**

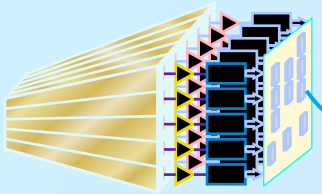
**E.M objects : based on the sum of 2 Trigger Towers**

Copper links = 10 m

**ECAL Trigger Primitives for each BXs :**
- **Trigger tower $E_T$ (8b)**
- **Compact bit (ECAL fine grain)**

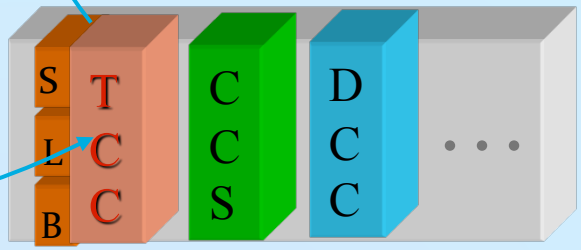
L1 accept signal !!!

**ECAL Trigger tower**



Pre-Trigger primitives @ 40 MHz, 800 Mb/s

Optical fibers ≈ 70 m




**VME 9U ECAL Off-Detector crates : service cavern**

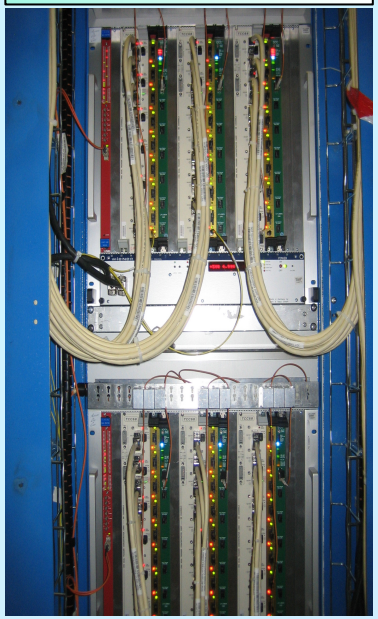
**Front End**
**On-Detector : experimental cavern**

**Trigger Concentrator Card**
**Synchro Link Board**

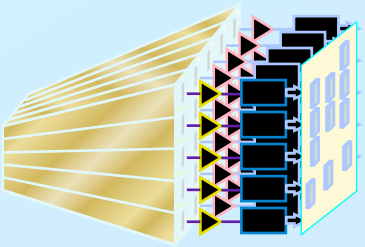
**Trigger Primitive (EB) = $\Sigma_{25}$ crystals + Fine Grain Veto Bit + BCID**

# Level-1 e/gamma trigger path

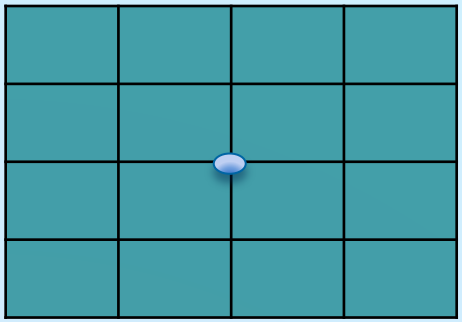
**ECAL TPG**
**T**rigger
**P**rimitive
**G**eneration



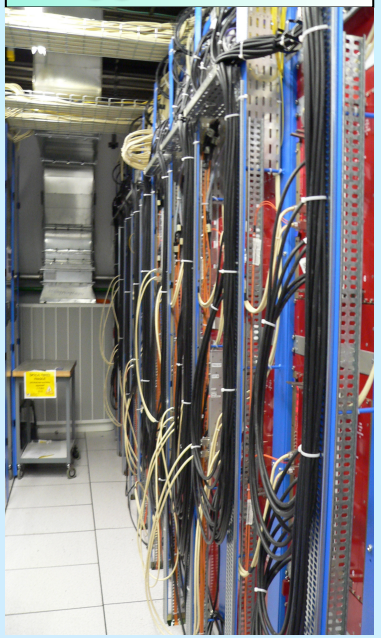
ECAL trigger tower (TT): 5x5 crystal matrix



Region of Interest: 4x4 TT



**RCT**
**R**egional
**C**alorimeter
**T**rigger

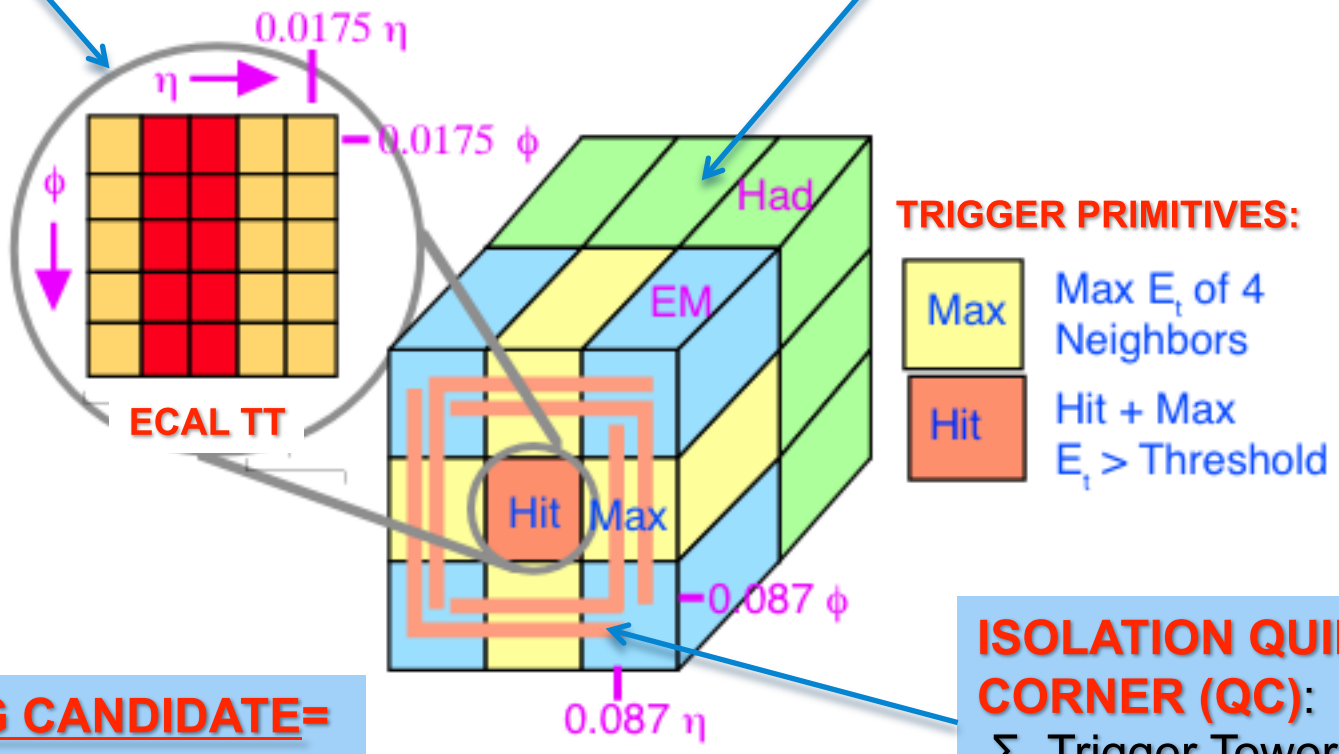


Definitions: L1_SingleEG15 = Single E/Gamma deposit above 15 GeV of $E_T$
Note: regions of interest are used to seed HLT (cluster/track reco)

# Level-1 e/gamma Algorithm

**VETO FINE GRAIN (FG)**:
Computed on Trigger Tower.
**FG > 90% for EM showers**

**HADRONIC VETO (H/E)**:
Ratio HCAL/ECAL $E_T$.
**H/E < 5% for EM showers**




**LEVEL1 EG CANDIDATE=**
**$\Sigma_2$ ECAL Trigger Tower $E_T$**
**Algo: 3x3 sliding window**

**ISOLATION QUIET CORNER (QC)**:
$\Sigma_5$ Trigger Tower ET
**QC< 3.5 GeV isolated**

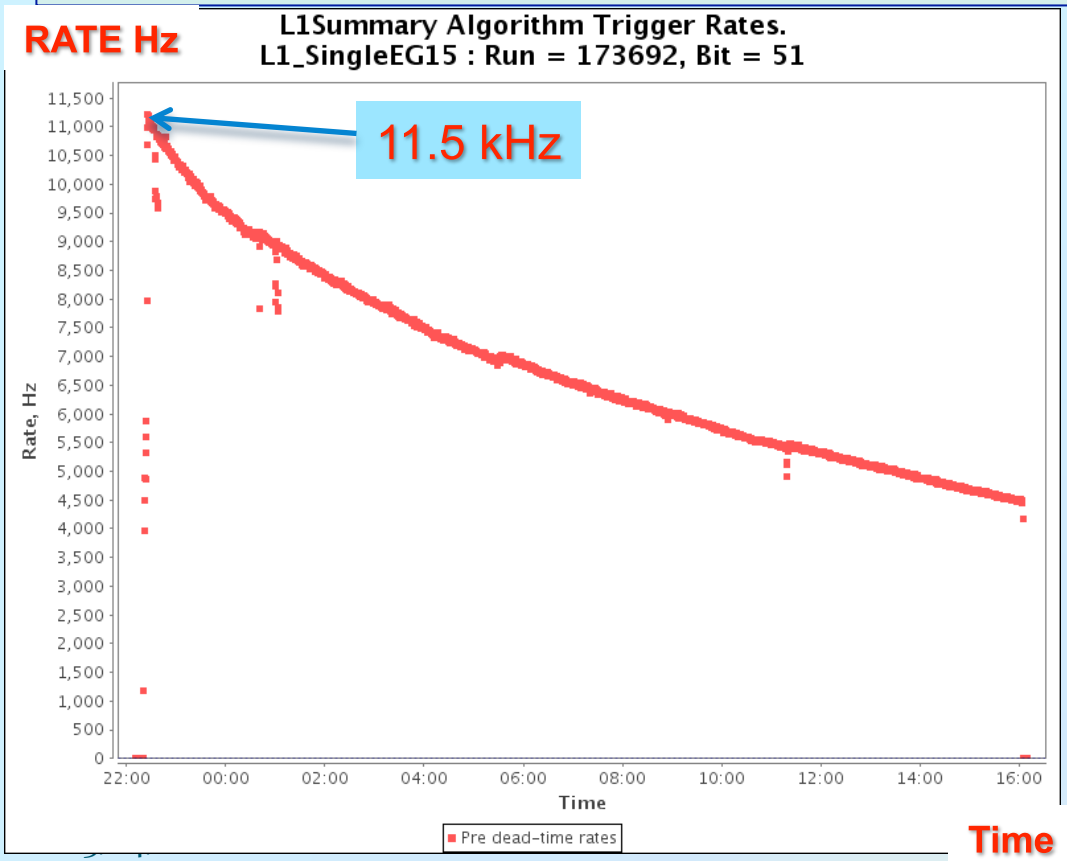
# Operating the L1 EG trigger

**CMS Level-1 trigger implements 128 algorithms: 23% of the total bandwidth (100 kHz) is dedicated to EG triggers.**

**Lowest EG trigger threshold:** EG2 (2010) and EG5 since 2011

**Lowest unprescaled single EG trigger:** EG12; EG15 (09/2011); EG20 (2012)

*Implementing important trigger for Higgs: DoubleEG_12_5 (H4l, γγ) **13_7** in 2012*




Time

**Example: single run for 18 h!**

**Trigger rate under control**

Instantaneous luminosity:

$2.1 \times 10^{33}$ cm$^{-2}$ s$^{-1}$

L1 total rate = 53 kHz

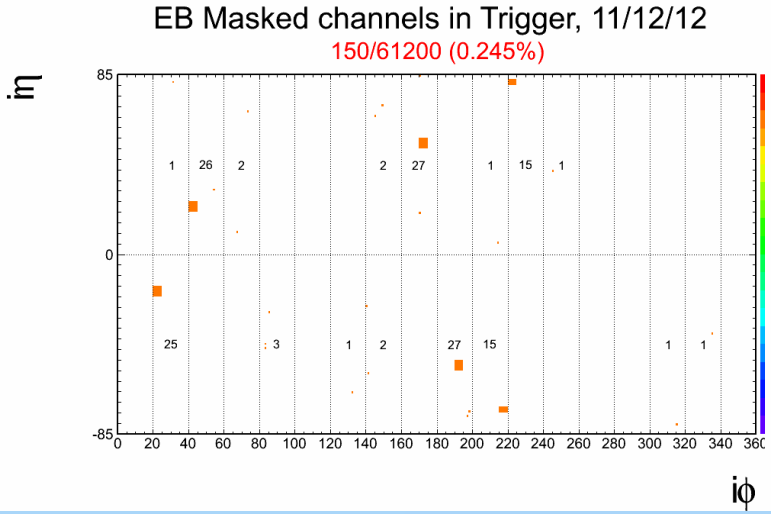
Total lumi: 83 pb$^{-1}$ (Fill 2040)

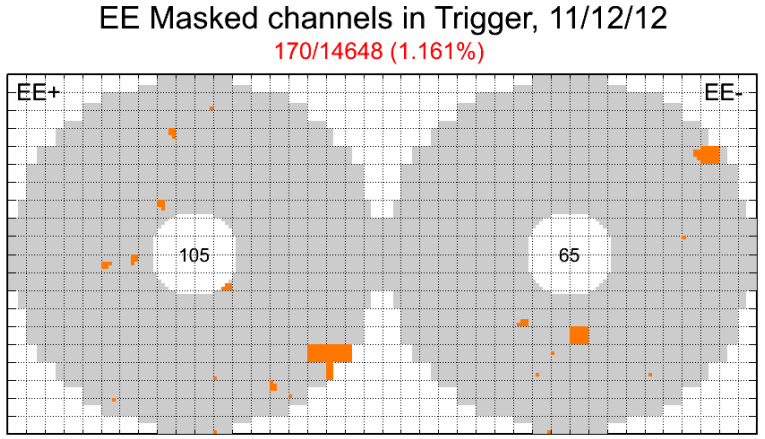
# Level-1 Active Channels

*CMS ECAL and RCT have the ability to mask problematic channels contributing to the level-1 trigger rate. ECAL Masks can be applied on single crystals, strips (5 crystals in EE) and full trigger towers (25 crystals in EB, 5-25 crystals in EE). DAQ and TRIGGER masking independent. RCT masks are applied on regions.*

***Masking level*** : **2010: 0.4% (EB) 2.1% (EE); 2011: 0.21%,1.3%; 2012:0.25%,1.16%**

2011: Channel recovered after front-end optimization and less impact of the noise due to increase of higher EG threshold.




**Active ECAL trigger primitive channels: 99.8 % in EB and 98.8% in EE**

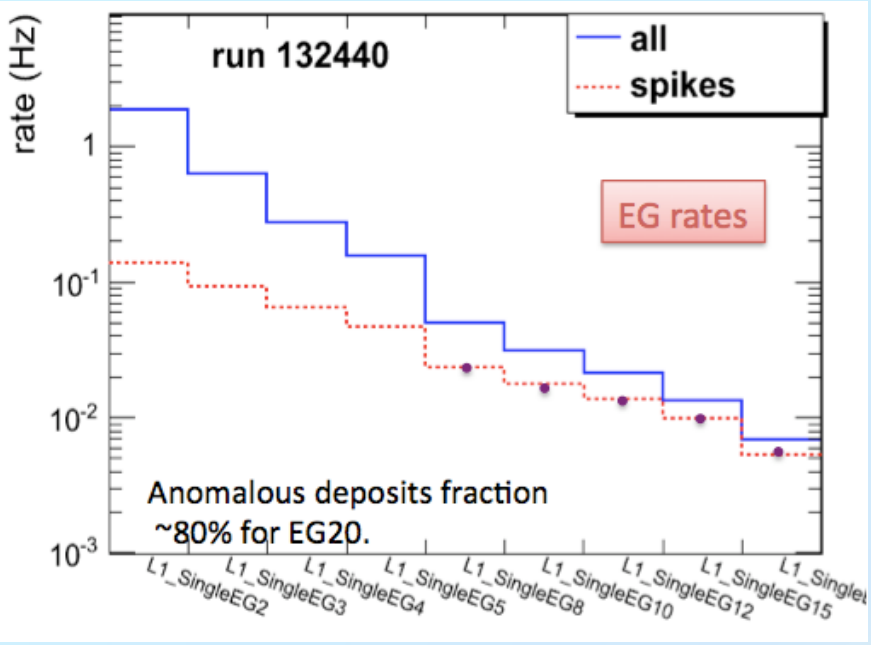
**Active Regional Calorimeter Trigger regions: 100 %**

**Optimum acceptance of the electron/photon trigger**

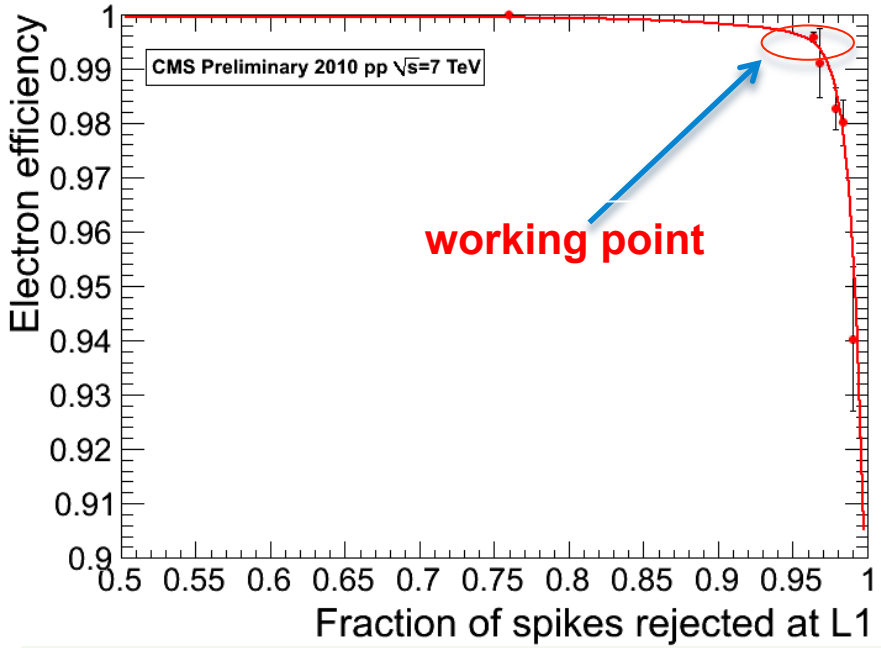
# ECAL anomalous signal

**Anomalous signals: particles passing through Barrel APDs can cause direct ionization resulting in the generation of a large anomalous signal in a single crystal, so called "spike"**

**Consequence on the level-1 trigger rate:**
Rate of all EG trigger threshold increased by important factors




Spike removal optimization




**L1 spike rejection: reject 96% of spikes & electron triggering efficiency >99% (99.6% for pT > 20 GeV)**

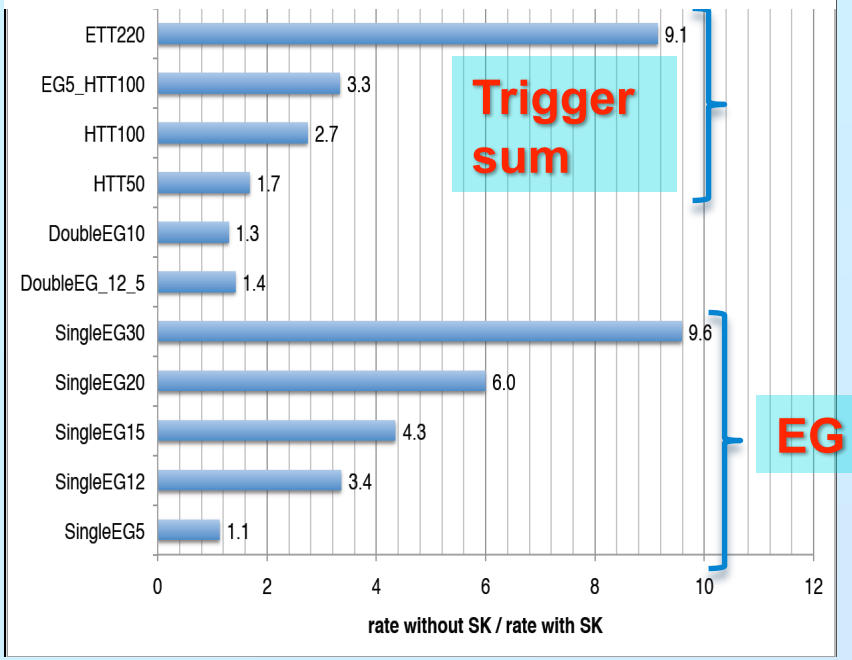
# L1 bandwidth optimized

Online test performed in march 2011 during commissioning period

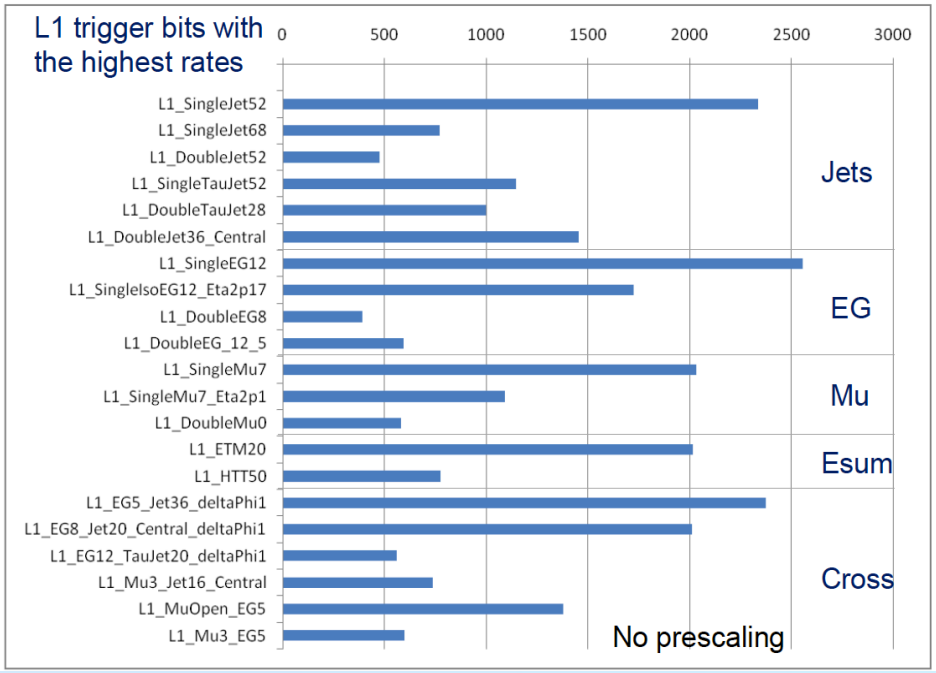
*Run without spike killer (161217) and with spike killer (161311)*

*Large rate reduction achieved on EG triggers and ET sum triggers*

## Rate reduction factors




**Run 161311 Average lumi 2E32 Total L1 rate 19 kHz**




**Level-1 total rate optimized : 19 kHz @ $2\times10^{32}$ $cm^{-2}$ $s^{-1}$ while 70 kHz in 2010 with comparable luminosity.**

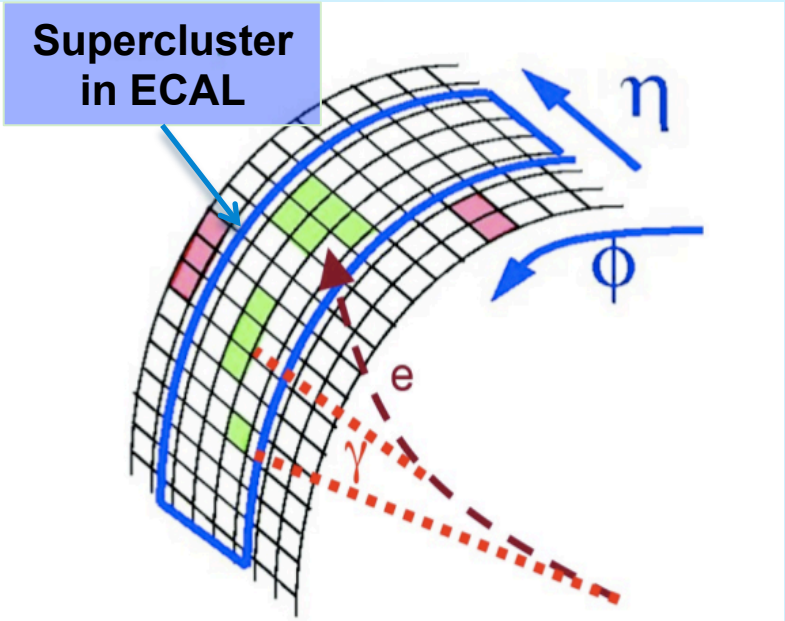
# Level-1 EG performance

**Measuring the electron trigger efficiency using 2011 (5 $fb^{-1}$) and 2012 (12 $fb^{-1}$ out of the 21 $fb^{-1}$ available) data recorded at CMS.**

**Electron reconstruction**: Electrons are reconstructed using the ECAL and the Tracker. Only ECAL information is used at the L1 trigger. As an electron can spread its energy due to bremsshtralung, the cluster is extended in ϕ (supercluster)

**Measuring trigger efficiency**:
Tag&Probe on Zee selected events:
Tag: ElectronID&Isolation cuts + L1trigger
Probe: ElectronID&Isolation cuts
Mass: 60 GeV < Mee < 120 GeV
➔Pure electron sample (negligible background)
*Selected pairs*: 778720 (EB-EB), 893324 (EB-EE), 33651 (EE-EE)

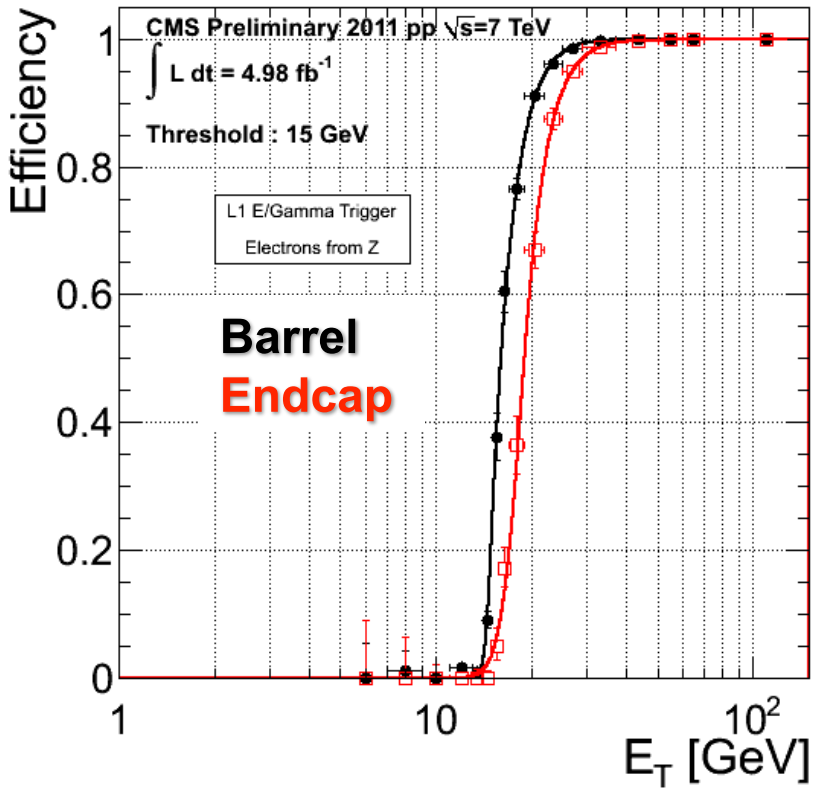
**Matching electron-L1candidate:**
Looking for the highest TT $E_T$ in the supercluster then find RCT region of L1 EG



**Electron reconstruction in CMS**

# Level-1 EG performance

## LEVEL1 EG15




**Excellent triggering efficiency performance in 2011**

| EG15 | EB | EE |
|---|---|---|
| **50%** | $16.0^{+0.01}_{-0.01}$ GeV | $19.1^{+0.05}_{-0.06}$ GeV |
| **95%** | $22.5^{+0.04}_{-0.05}$ GeV | $27.1^{+0.6}_{-0.4}$ GeV |
| **99%** | $28.0^{+0.1}_{-0.1}$ GeV | $34.6^{+1.5}_{-1.1}$ GeV |
| **100 GeV** | $99.9^{+0.01}_{-0.9}$ % | $99.8^{+0.1}_{-0.3}$ % |

**Shape and turn-on point:**

-Electrons spread their energy over many TT while L1 candidate only gathers 2 TT.

-EE turn-on point displaced due to preshower energy not included in the trigger decision.

**Sources of inefficiency**

-Masking of Trigger Primitive at ECAL level 0.2% in EB; 1.3% in EE

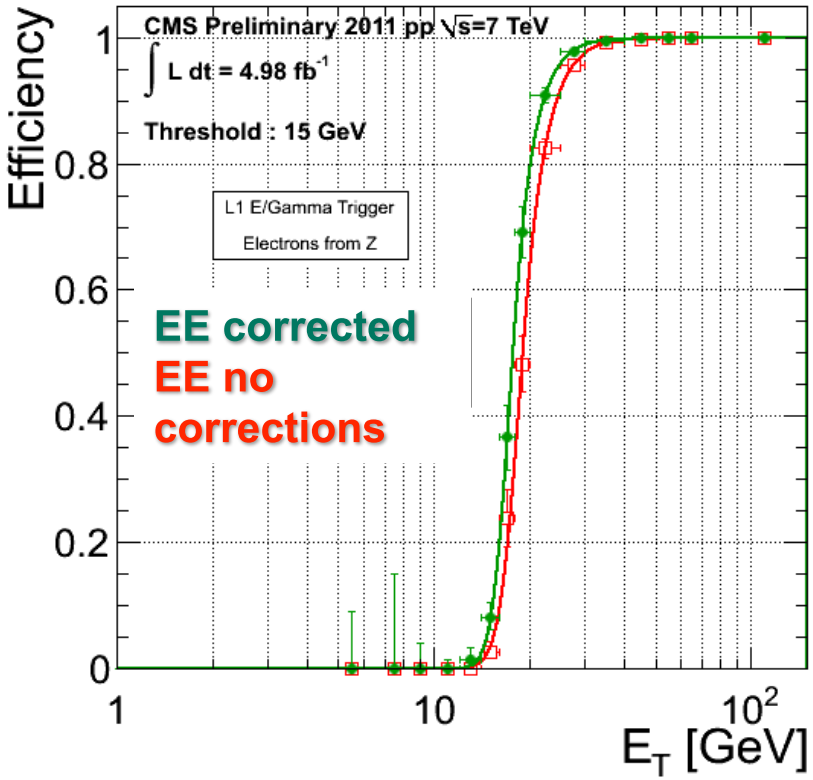
-pre/post firing < 0.1 %

-Response change (mostly in EE) described in next slides.

# Level-1 EG improvements

**Implementing corrections for ECAL response change in EE: 10 % average (40% inner rings) (see Margherita Obertino's talk)**

**EE online, EE corrected (EG15)**




| EG15 | EE data | EE corrected |
|---|---|---|
| 50% | $19.1^{+0.03}_{-0.06}$ GeV | $17.8^{+0.03}_{-0.06}$ GeV |
| 95% | $27.1^{+0.01}_{-0.01}$ GeV | $24.5^{+0.1}_{-0.2}$ GeV |
| 99% | $34.4^{+0.01}_{-0.01}$ GeV | $30.8^{+0.2}_{-0.5}$ GeV |
| 100 GeV | $99.8^{+0.06}_{-0.60}$ % | $99.9^{+0.01}_{-0.7}$ % |

**ECAL transparency corrections:**

Corrections are implemented at the trigger ECAL primitive level (EndCap only)

*2012 operations*: Transparency change is monitored and corrections were updated throughout the year (weekly corrections).

**Efficiency greatly improved in EE**
**USED THROUGHOUT 2012**

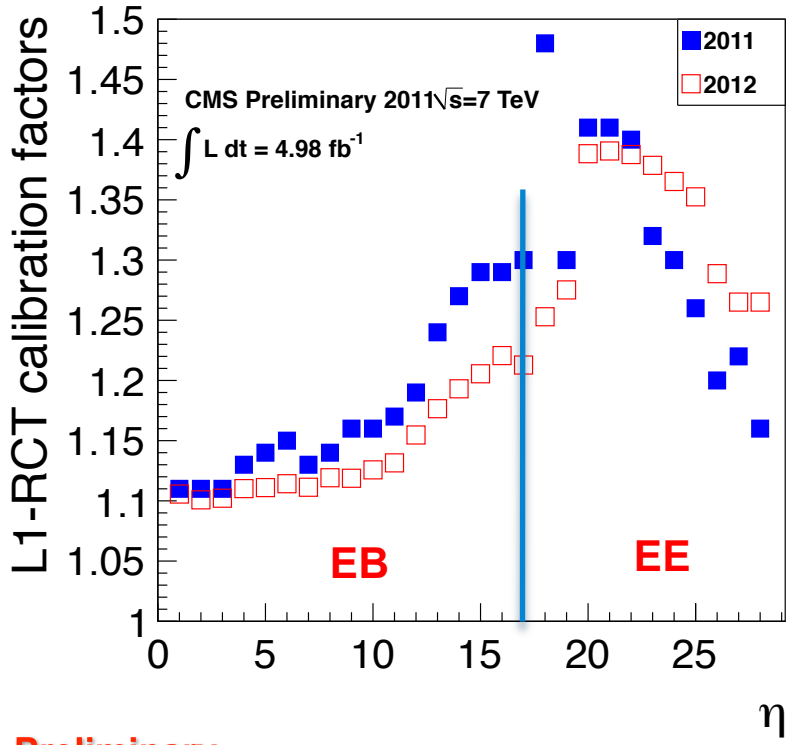
# Level-1 EG improvements

**Implementing Level-1 $E_T$ calibration at RCT level**

***Level-1 EG candidate $E_T$ can be calibrated at the RCT level*: input trigger primitives are corrected by a calibration factor before being summed to form Level-1 candidate. Correcting mainly for material budget in the detector and missing preshower info at trigger level.**

***2011 calibration based on 2010 MC Zee***
***2012 calibration based on 2011 dataset (~5 $fb^{-1}$) derived after ECAL transparency corrections applied.***

**EE turn-on point improved as preshower missing energy is corrected for.**
**USED THROUGHOUT 2012**

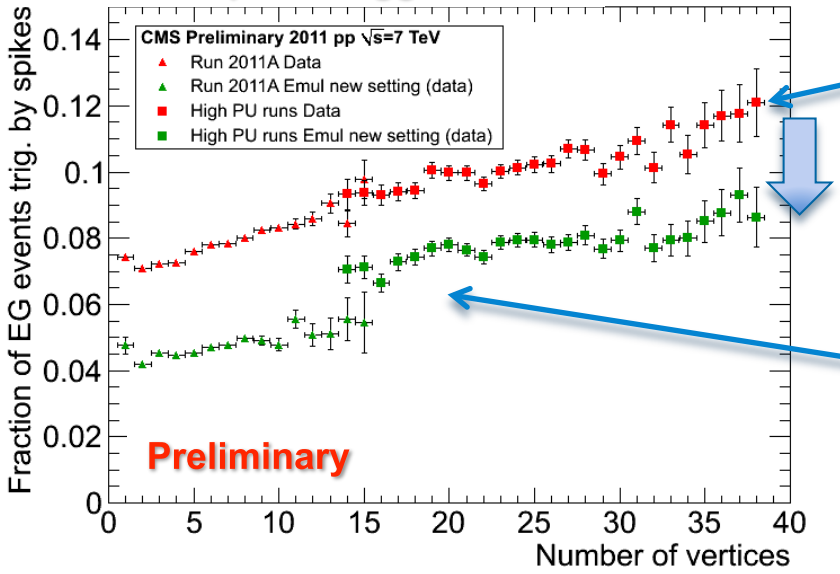


# Level-1 EG improvements

**Mitigation of the pile-up effect on the spike killer removal algorithm at L1**

The effect of pile-up has been studied with 2011 data: looking at fraction of offline identified spikes triggering EG trigger as function of the number of reconstructed verticies.

**Fraction of spikes trigger EG15**




Dedicated high pile-up run (Oct 2011)

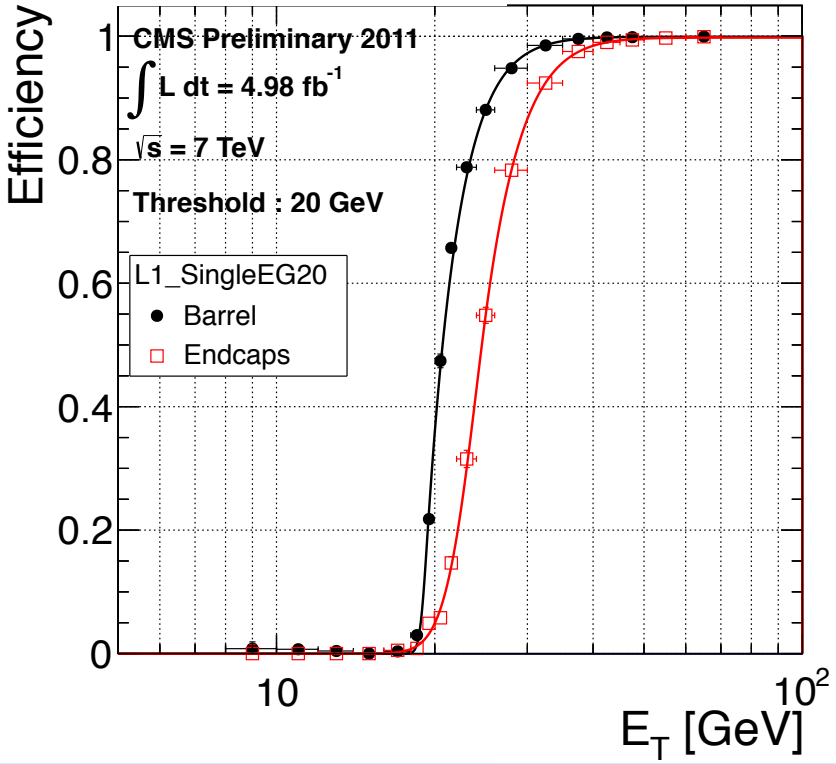
***New working point: keep electron trigger efficiency > 99%***
***Spike killer > 96%*** *(slightly improved but more robust in PU conditions)*

**Best achievable performance maintained with new spike killer setting**
**USED THROUGHOUT 2012**

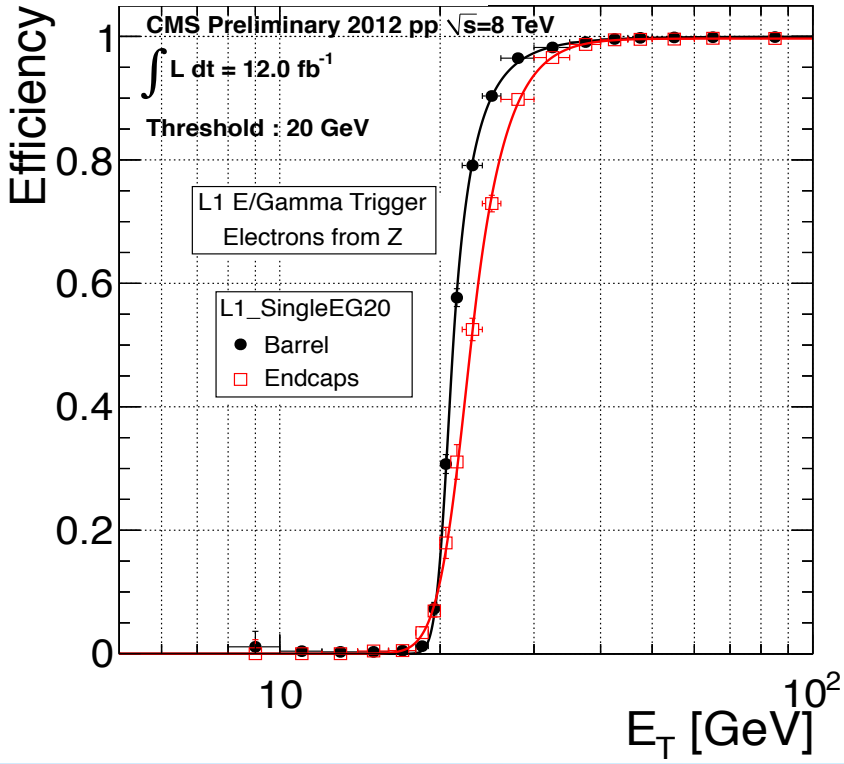
# Performance in 2012

**After implementation of all these changes: performance on EG20**

**EG20 2011**




**EG20 2012**




**Overall performance maintained in EB and improved for EE**
**EB and EE triggering efficiency more comparable**

# SUMMARY

CMS level-1 electron and photon trigger has shown excellent performance:

- Maintaining the highest possible electron trigger efficiency at high luminosity and high pile-up conditions was major challenge.
- A reprogramming of the front-end electronics and ECAL TCC has allowed the implementation and optimization of a spike killer at L1 which demonstrates the flexibility of this system.

*From the analysis of the recorded data, major improvements were made:*

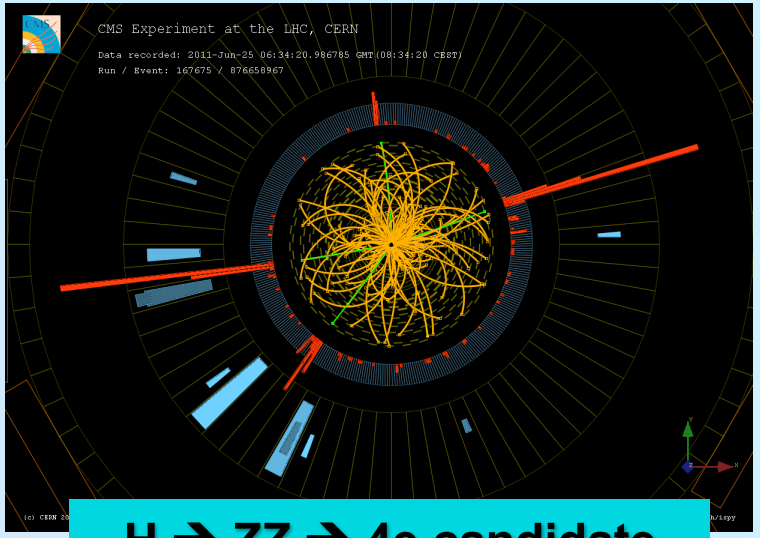
*-Mitigation of the effect of the pile-up on spike removal.*

*-Improved L1 EG calibration*

*-Mitigation of the effect of the ECAL response change.*

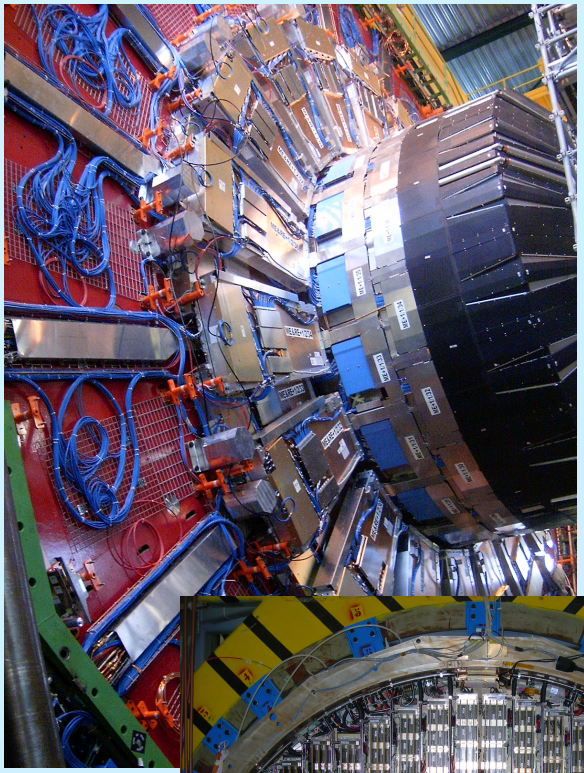
***All these are already implemented in 2012 to guarantee the best physics performance.***

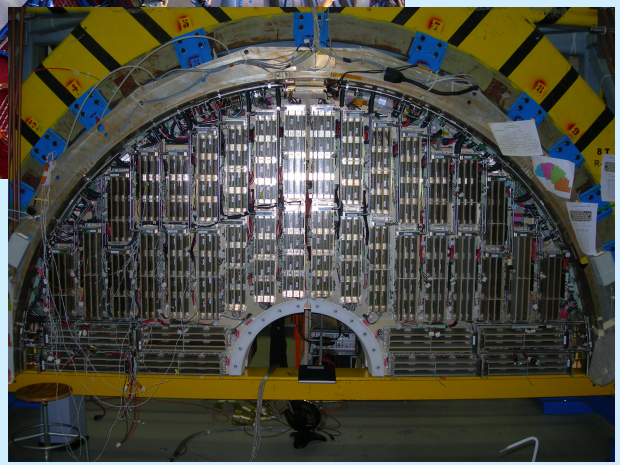
*During the long shutdown (2013-2014), the L1 trigger will be optimized further (based on new electronics).*



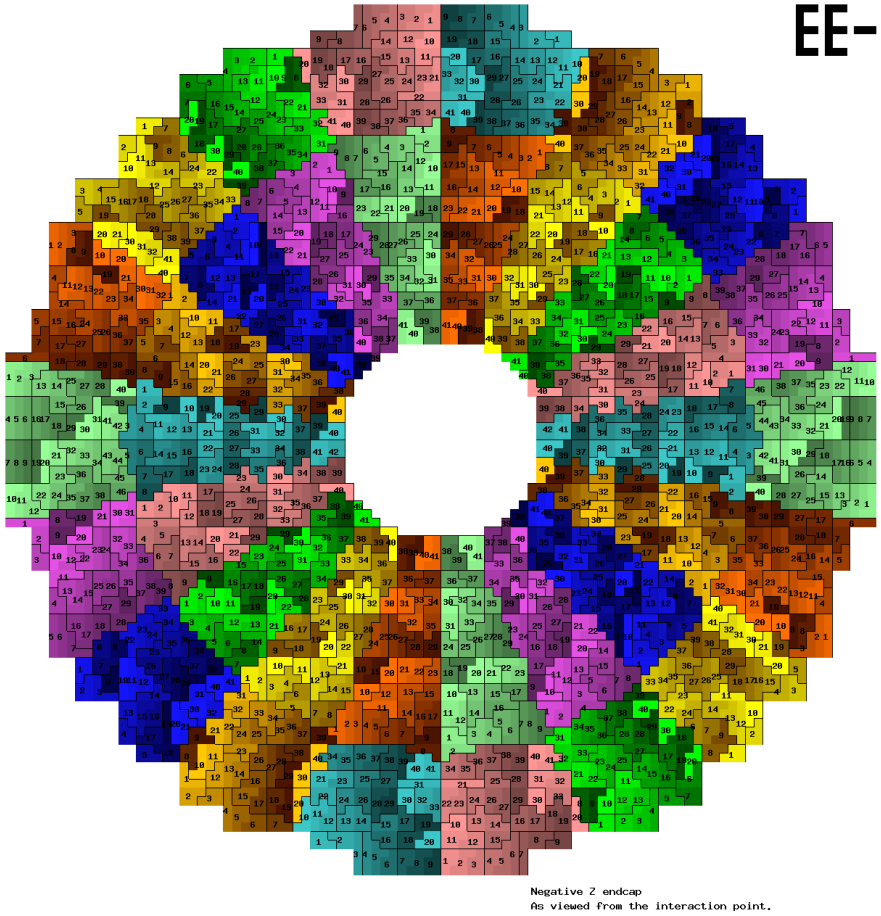

**H → ZZ → 4e candidate**

# BACKUP: L1 TPG EE





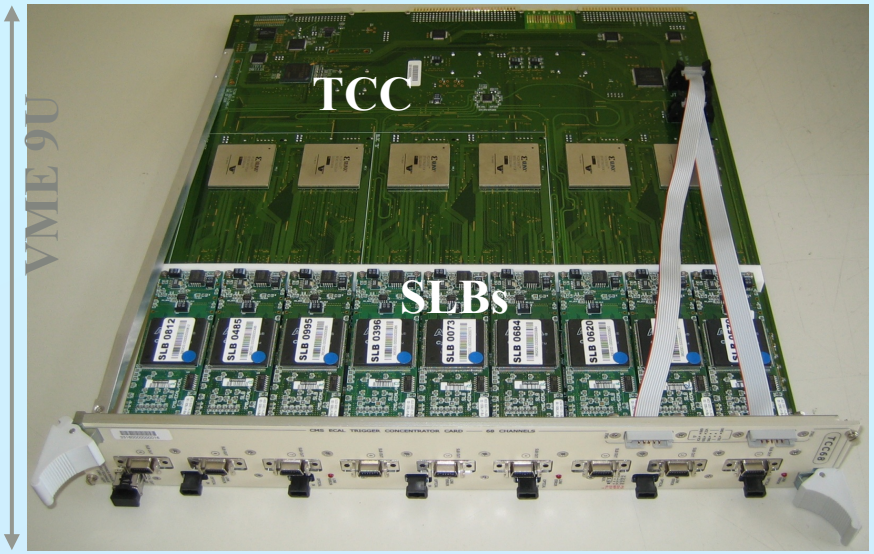
**ECAL EE trigger primitive map**



# BACKUP: ECAL TCC

## TCC-EB + SLB

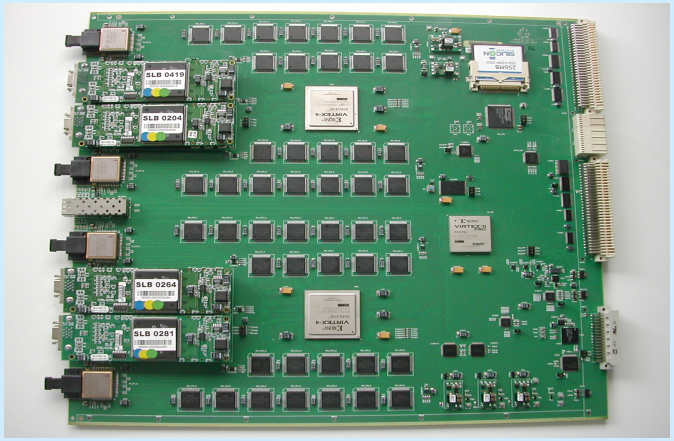
- 2448 FE boards
- 36 TCC cards
- 324 SLB cards




- Inputs: 68 Trigger towers (12×6 fibres)
- Outputs: 68 trigger towers (8×9 cables) after compression etc

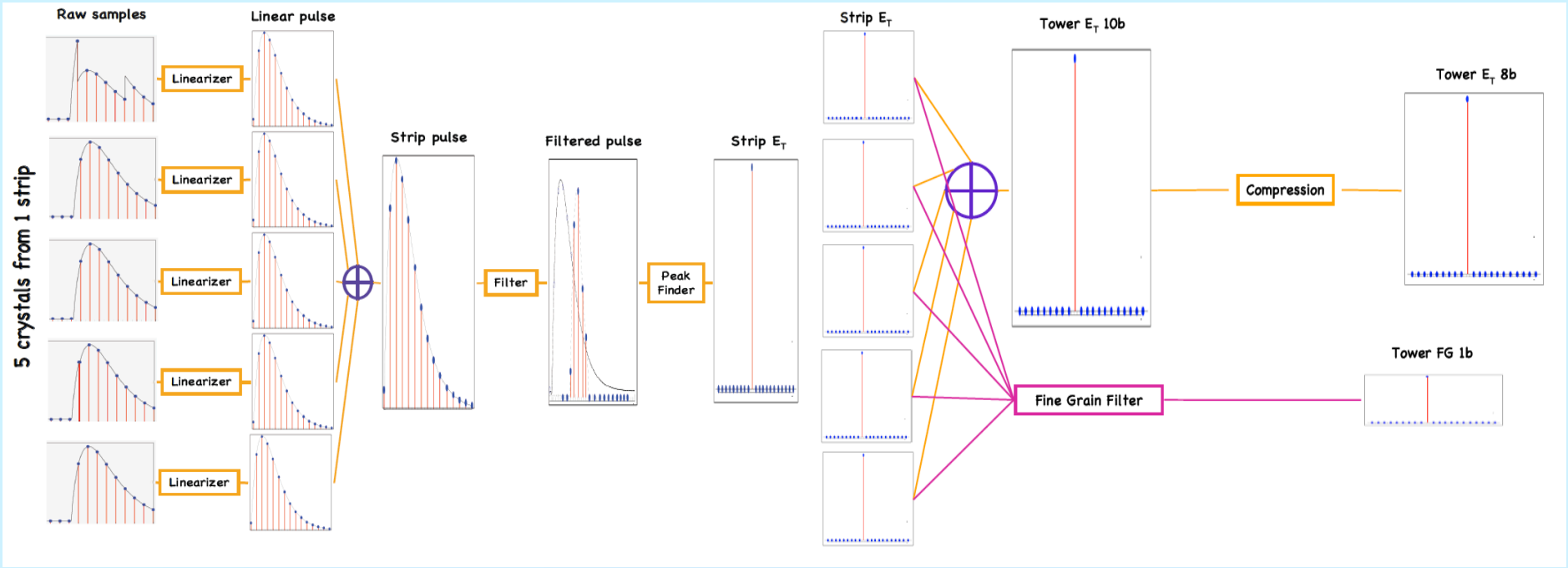
## TCC-EE + SLB:

- 72 TCC cards
- 252 SLB cards

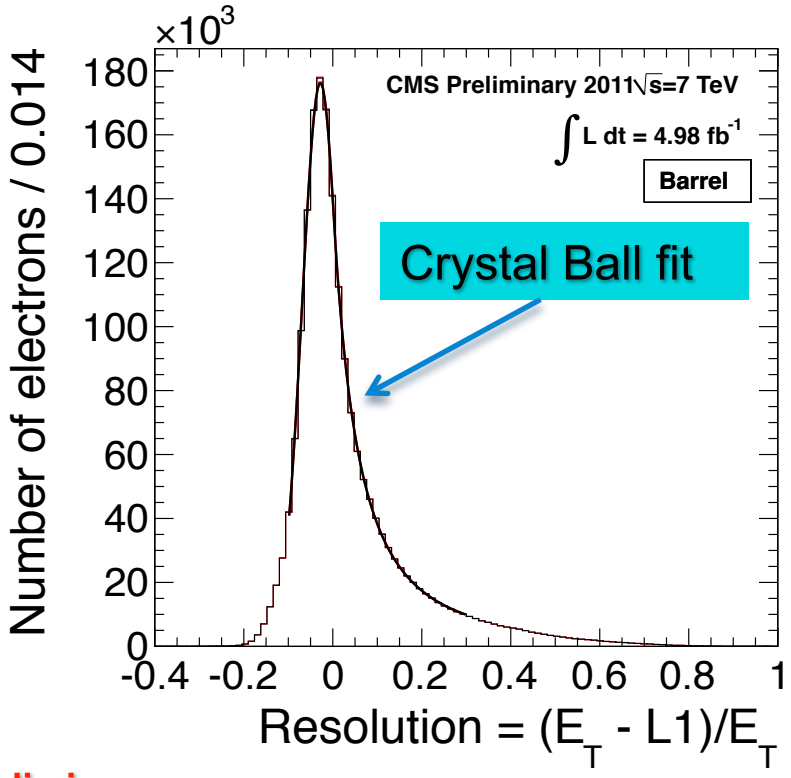


- Inputs: up to 48 strips (12×4 fibres)
- Outputs: 16 (outer) / 28 (inner) trigger towers (8×3 or 8×4 cables)

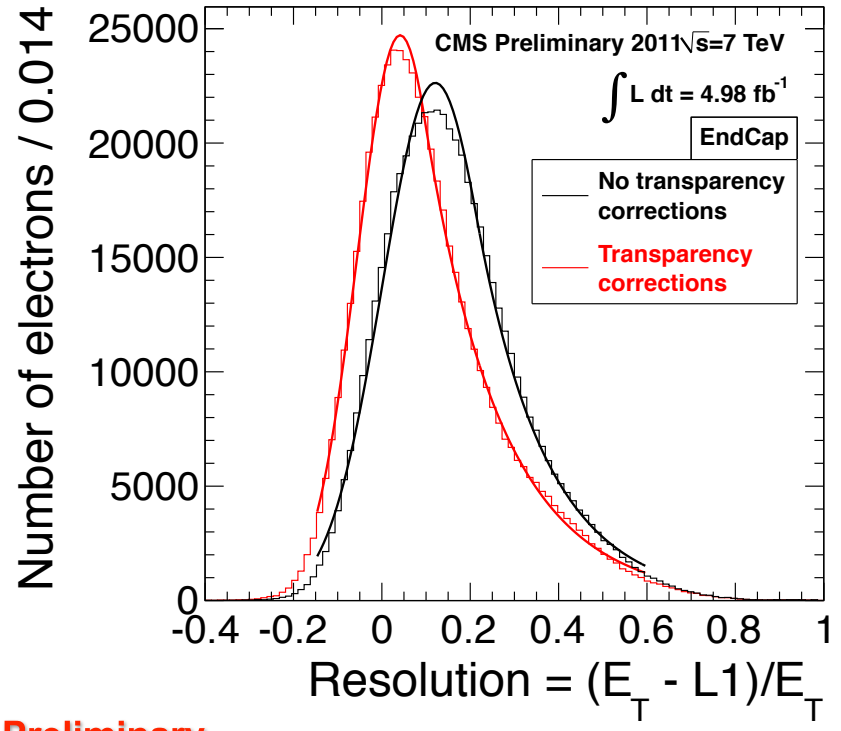
# BACKUP TPG CALCULATION



# BACKUP: L1 RESOLUTION




Preliminary

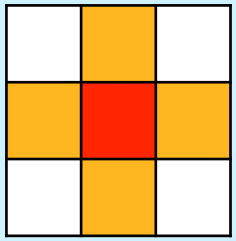



Preliminary

# ECAL anomalous signal definition

## OFFLINE IDENTIFICATION

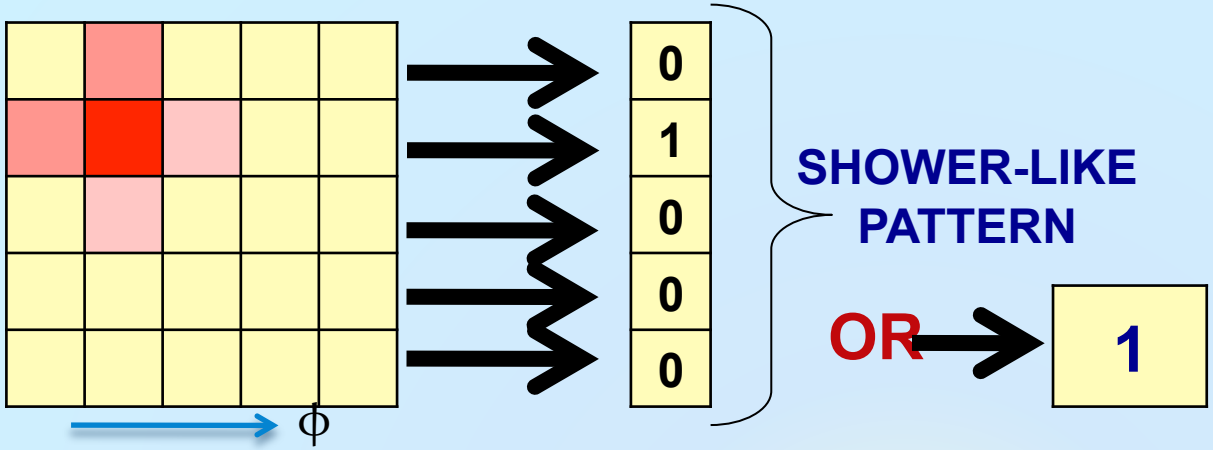
« **SwissCross** » : **(1 - $E_4$ / $E_1$)**
→ EM shower energy : ~80% in 1 xtal
→ Spike : single crystal



## ONLINE IDENTIFICATION

**« Strip Fine Grain Veto Bit » (sFGVB)**

**ECAL trigger tower**




**Trigger Primitive (TP) null for spike:**
**$E_T$ (TP)>killing thresh. & sFGVB(TP)=0**

# BACKUP: transparency

**2012 operation: Transparency change is corrected on a weekly average**