CMS Conference Report

17 January 2005

High-Level Trigger for Electrons and Photons in CMS

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Abstract

The CMS experiment will take data at the LHC proton proton collider, running at a centre-of-mass energy of 14 TeV. The CMS electromagnetic calorimeter (ECAL) is made of about 76000 PbWO₄ crystals. The possibility to use the measured events for the physics studies relies on the robustness and efficiency of the triggering procedure. In this report the ElectronPhoton package of the ORCA framework (Object oriented Reconstruction for CMS Analysis) is presented and results from full simulation studies of the High-Level Trigger procedures to reconstruct and select electrons and photons are given.

1 Introduction

The CMS [1] detector is a multi-purpose apparatus that will take data at the LHC proton-proton collider, running at centre-of-mass energy of 14 TeV.

The CMS Electromagnetic Calorimeter ECAL [2] consists of about 76.000 PbWO₄ scintillating crystals, arranged in a barrel part (EB), which covers the central rapidity region $|\eta| < 1.48$ and two endcaps (EE), which extend the coverage up to $|\eta| < 3$. In the following the High-Level Trigger procedures to reconstruct and select electrons and photons in the EB are described.

2 The ECAL detector

The $21.8 \times 21.8 \times 230$ mm³ PbWO₄ crystals are assembled into EB with a modular structure. The biggest modular element is the *supermodule*. It contains 1700 crystals and covers a region of 20° in ϕ and 1.48 in η , so that 18 supermodules form half of the EB. The crystals are displaced in such a way to be off-pointing with respect to the mean position of the primary interaction vertex, with a 3° tilt both in ϕ and η . The scintillation light of each crystal is detected by two Avalanche Photo Diodes (APD), with a quantum efficiency of about 80 % around the PbWO₄ emission peak. Each crystal is coupled to two APDs, for a total area of 50 mm². Consequently 4000 photoelectrons are produced per GeV of deposited energy. The APDs are operated with a gain 50, to compensate the low light yield. On the external side of the barrel some space is left for the front-end electronics and its cooling, as well as for services in and out. Because the radiation length of PbWO₄ is small ($X_0 \simeq 0.89$ cm), the ECAL is very compact. As a consequence both the electromagnetic and the hadron calorimeters can be placed inside the coil. The latter generates the 4 T magnetic field needed for the tracking. Furthermore it can stand the high radiation doses of LHC, which at high luminosity varies between 0.15 Gy/h in the EB up to 15 Gy/h in the EE.

3 The physics goals of ECAL

The fast scintillation mechanism (80 % of the light is emitted within 25 ns) allows the crystals to match the LHC crossing rate of 40 MHz. The fine granularity of the detector is required to cope with the 20 events and the 1000 tracks produced on average per bunch crossing. The main motivation for the PbWO₄ choice was the excellent energy resolution, a key issue to fight against the background in the search for a low mass ($m_H < 150$ GeV/c²) Higgs boson, decaying in the channel $H \rightarrow \gamma\gamma$ (Fig. 1).

Figure 1: The $H \rightarrow \gamma\gamma$ signal for $m_H = 130$ GeV/c² with a luminosity of 100 fb⁻¹, before (a) and after (b) background subtraction.

The mass resolution depends linearly on the photon energy resolution achieved, which can be parametrized as $\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$. The target values for the ECAL are 2.7 % GeV^{1/2} for the stochastic term a , 200 MeV for the noise term b , and 0.5 % for the constant term c .

At high energies the most relevant contribution to the energy resolution comes from the constant term which is related to the longitudinal shower containment, the uniformity of the light collection in the crystals and the precision of the intercalibration. The challenging goal of keeping it very small can be reached only if the intercalibration between crystals is very precise and if instabilities and non-uniformities in the detector response are controlled at the level of few permil. This goal puts severe requirements on the control of the temperature stability (cooling system) and on the follow-up of the radiation damage (monitoring system).

4 Reconstruction of electrons and photons

The requirements for the computing at CMS, as well as the choice for object-oriented programming are extensively described in [4]. The simulation of the particle propagation inside the detector is performed by the OSCAR [5] package, an application of GEANT4 [6]. The reconstruction and analysis program ORCA [3] handles both the simulation of the detector response and all the reconstruction tasks.

A precision reconstruction of electrons and photons has to cope with the bremsstrahlung from the electrons and the conversion of the photons in the tracker material. Because of the tracker thickness, shown in Fig. 2, both effects are relevant.

Figure 2: Material budget of the tracker, in units of radiation lengths, as a function of the pseudorapidity η .

On average electrons with $p_T = 35$ GeV/c and $|\eta| < 1.5$ lose over 40 % of their energy inside the tracker, by emitting quasi-collinear low energy photons. About 24 % (35 %) of the photons coming from the $H \rightarrow \gamma\gamma$ decay convert before reaching the barrel (endcap) ECAL. In both cases, because of the high magnetic field, the energy is spread along the ϕ direction.

5 The Level-1 Trigger

The Level-1 Trigger [7] is performed by means of a partially programmable hardware. It performs a first selection over the events, in order to cope with the maximum total rate of 100 kHz the DAQ can handle. It relies on trigger primitives, i.e. the summary of the information sent by the calorimeters and the muon detectors.

The calorimetric part of the Level-1 Trigger is based on elements called trigger towers, composed by an HCAL tower and a matrix of 5×5 ECAL crystals. The criteria to select electron and photon candidates are based on the transverse energy E_T and on the ratio of the energies measured in the ECAL and the HCAL. The top four candidates pass the selection.

Table 1: The energy and position resolution of the ECAL barrel, obtained with electron samples simulated with different pileup conditions: σ is the fitted width of the Gaussian part of the distribution, while σ_{rm} is the half-width containing 68.3 % of the events [7].

		$\sigma(E)/E$	$\sigma_{rm}(E)/E$	$\sigma(\eta)$	$\sigma(\phi)$	$\sigma_{eff}(\phi)$
$p_T = 35$ GeV/c	no pileup	1.1 %	2.2 %	1.1×10^{-3}	1.7 mrad	2.5 mrad
$p_T = 35$ GeV/c	$L = 2 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$	1.2 %	2.3 %	1.1×10^{-3}	1.7 mrad	2.5 mrad
$p_T = 35$ GeV/c	$L = 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$	1.5 %	2.7 %	1.1×10^{-3}	1.9 mrad	2.7 mrad
$10 \text{ GeV/c} < p_T < 50 \text{ GeV/c}$	$L = 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$	1.5 %	3.4 %	1.2×10^{-3}	2.1 mrad	3.4 mrad

6 The High-Level Trigger

All events accepted by Level-1 Trigger are processed in a single filter farm, by the High-Level Trigger (HLT). The HLT reconstructs and selects physics objects in real-time, on the basis of reconstructed quantities in only limited regions of the detector. The HLT has the primary goal of reducing the rate down to $O(100 \text{ Hz})$, while keeping high efficiency for the interesting physical objects. The selection algorithms used by the HLT follow as closely as possible the offline frame and in particular the on-demand reconstruction philosophy which has been implemented in the ORCA software. For the calorimeter reconstruction, the transverse momentum cuts and thresholds for triggering are lower for electrons than for photons and therefore most of the effort has been dedicated to the detailed study of the electron reconstruction. For this purpose the key issue is to include, in the shower reconstruction, all the energy radiated in the tracker. From a logical point of view, the identification of electrons performed by the HLT can be divided in the following phases:

1. At Level 2: only the calorimeter information is used;
2. At Level 2.5: partial tracker information, coming from the pixels, is included;
3. At Level 3: the complete tracker information from the CPU consuming full charged particle track reconstruction is exploited.

The first step of the HLT (Level 2) is to reconstruct clusters of energy, starting from a seed crystal and gathering the closest ones. Because the energy radiated by electrons is spread mainly over the ϕ direction, clusters are gathered into super-clusters along a ϕ path. The improvement of the energy resolution is clearly visible in Fig. 3.

Figure 3: Reconstructed energy for $p_T = 30 \text{ GeV}/c$ electrons, with basic cluster and super-cluster algorithms.

The position measurement of the shower is obtained with weighted average of the mean positions of the crystals belonging to the cluster. The weights are proportional to the logarithm of the deposited energy to take into account that the shower transverse profile decreases exponentially. In Table 1, the energy and position resolutions obtained with electron samples simulated with different pileup conditions are reported. The super-clusters are required to have E_T above a threshold which gives 95 % efficiency for electrons. At low luminosity ($2 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$) these thresholds are evaluated to be 26 GeV for single trigger and 14.5 GeV for double trigger.

The second step of the HLT (Level 2.5) consists in the association of hits in the pixel detector with the super-cluster, along the direction of a track extrapolated back through the magnetic field. Matching hits are expected by mostly electrons and very few photons, because most of the tracker material lies after the pixel detector. The super-clusters are identified as electrons if at least two compatible hits are found and as photons otherwise. For an electron efficiency of 95 % a rejection factor 17 is estimated for dijets at low luminosity.

For each electron candidate the third step of the HLT (Level 3) consists in the full reconstruction of the track, using the pixels associated to the super-cluster as seeds, and in cuts that combine the information coming from the calorimeter and the tracker (E/p and $\Delta\eta$). For photon candidates higher thresholds on E_T are applied and other cuts on isolation and π^0 rejection are used to reduce the background. For unconverted photons the sum over a 5×5 matrix around the maximum energy is used, while for converted photons the same algorithms are applied as for electrons. A resolution on the Higgs boson mass of 0.86 % (1.15 %) is obtained for unconverted (converted) photons in the channel $H \rightarrow \gamma\gamma$.

7 Conclusions

An accurate reconstruction of electrons and photons has to cope with the bremsstrahlung from the electrons and the conversion of the photons in the tracker material. The position and energy resolution achieved by means of the super-clusters comply with the severe requirements put by the search for the Higgs boson or new physics. The results from full simulation studies of the High-Level Trigger procedures to reconstruct and select electrons and photons give results that fulfil the CMS physics requirements.

References

- [1] CMS Collaboration, “The CMS Technical Proposal”, CERN/LHCC 94-38, 1994.
- [2] CMS Collaboration, “The CMS Electromagnetic Calorimeter TDR”, CERN/LHCC 97-33, 1997.
- [3] <http://cmsdoc.cern.ch/orca>
- [4] CMS Collaboration, “The CMS Computing TDR”, CERN/LHCC 96-45, 1996.
- [5] <http://cmsdoc.cern.ch/oscar>
- [6] A. Agostinelli et al., Nucl.Instr.Meth.A 506(2003)250
- [7] CMS Collaboration, “The Data Acquisition and High-Level Trigger TDR”, CERN/LHCC 2002-26, 2002.