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Photon Reconstruction in CMS

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Abstract

If the mass of the Higgs boson is less than $150 \text{ GeV}/c^2$, the $H \rightarrow \gamma\gamma$ channel will provide a clear signature at the LHC. An overview of the general design of photon reconstruction in the CMS experiment is given. The handling of converted photons and rejection of neutral pions pose an additional challenge to triggering and measuring. Topics related to photon reconstruction are presented, such as an algorithm for track building of the electron and the positron coming from the photon conversion.

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1 Introduction

The Compact Muon Solenoid (CMS) experiment [1] is one of the two general purpose experiments of the future Large Hadron Collider (LHC). The LHC is a proton proton collider with a collision energy of 14 TeV. The nominal luminosity of the machine is $10^{34} \text{ cm}^{-2}\text{s}^{-1}$ (“high luminosity”), and at startup $2 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$ (“low luminosity”). Proton bunch crossings will take place every 25 ns and each crossing will result in on the average about 20 proton proton interactions at high luminosity.

The Higgs boson decaying into two photons is a promising signal if $m_H < 150 \text{ GeV}/c^2$. The channel has a large reducible background of π^0 s from jets and an irreducible background from prompt photons. To find the signal, a good mass resolution is required i.e. an excellent energy resolution for photons and the knowledge of the z position of the primary vertex are needed.

In this note, the photon reconstruction in CMS is described. In Section 2, the electromagnetic calorimeter and the tracker are briefly introduced. In Section 3, an overview of online selection is given. Photon conversions are discussed in Section 4. The last sections provide details of offline reconstruction of photons, including energy reconstruction, track building and primary vertex finding in Section 5.

2 Tracker and electromagnetic calorimeter

The detector elements used for photon reconstruction in CMS are the silicon tracker [3] and the crystal electromagnetic calorimeter (ECAL) [2]. The ECAL barrel is located at a radius of $r=130 \text{ cm}$ from the beam axis and it covers the area $|\eta| < 1.48$. The ECAL endcaps cover the area $1.48 < |\eta| < 3.0$. The lateral size of the lead tungstate crystals of the ECAL is 22 mm in the barrel and 25 mm in the endcaps.

The silicon strip tracker consists of the central part ($|\eta| < 0.8$) with ten layers, which cover radii from 20 cm to 105 cm, and of the forward part with nine vertical disks in each outer end cap. The silicon strip detectors of the tracker give a good hit position resolution in ϕ but not in the z direction unless the layer is a double sided layer. The double sided layers are at $r=20, 30, 60$ and 70 cm .

The innermost part of the tracker consists of three layers of silicon pixel detectors at $r=4, 7$ and 11 cm from the beam axis.

3 Online event selection: Level-1 and High-Level Trigger

The task for the trigger is to select signal events from large background. The trigger has a hierarchical structure. The Level-1 trigger is implemented in hardware, while the High-Level Trigger (HLT) [4] is run on a farm of commercial processor units. The Level-1 Trigger is required to bring the event rate down from 40 MHz to 100 kHz. The HLT reduces this further to 100 Hz, which is then written to permanent storage.

The HLT for electrons and photons uses energy thresholds for energies measured in the ECAL. The electron stream is separated from that of photons by finding compatible hits in the pixel detectors. For the photon candidates a higher transverse energy threshold is imposed and isolation cuts are applied [4]. The electron and photon HLT rates for the initial low luminosity are shown in Table 1 [4]. The signal and background rates are shown for the single and double objects of electrons and photons. The transverse energy thresholds applied to the double photon stream are 35 GeV for the more energetic and 20 GeV for the less energetic photon.

Table 1: Electron and photon High-Level Trigger rates for low luminosity [4].

$2 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$	Signal	Background	Total
Single e	$W \rightarrow e\nu$: 10Hz	$\pi^\pm/\pi^0$ overlap: 5 Hz π^0 conversions: 10 Hz $b/c \rightarrow e\nu$: 8 Hz	33 Hz
Double e	$Z \rightarrow ee$: 1 Hz	$\sim 0 \text{ Hz}$	1 Hz
Single γ	2 Hz	2 Hz	4 Hz
Double γ	$\sim 0 \text{ Hz}$	5 Hz	5 Hz
			43 Hz

4 Photon conversions

Because of the large amount of material in the tracker, photons have a large probability of converting into e^+e^- pairs. The e^+ and e^- tracks bend in the 4T magnetic field and thus the energy deposit at the ECAL is spread in ϕ . This results in a degradation of the energy resolution. The conversion probability for photons is 27% in the centre of barrel ($\eta = 0$), 50% at the junction of the tracker barrel and forward region ($\eta = 0.9$) and 62% at the end of the ECAL barrel ($\eta = 1.4$). In 70% of the $H \rightarrow \gamma\gamma$ events at least one of the photons converts.

5 Offline photon reconstruction

The important aspects of the offline photon reconstruction are the measurement of the photon energy and the position of the primary vertex of the event, which allows the momentum to be determined. Furthermore the π^0 s have to be rejected and the converted photons treated appropriately.

5.1 Photon energy reconstruction

The energy of the photon is measured in the ECAL by one of the three clustering algorithms. Unconverted photons are measured by a fixed window algorithm, which measures the energy deposit of the photon in the ECAL by collecting the signal in a 5×5 mesh of crystals around the crystal with the largest energy deposit. The other two algorithms, the hybrid and the island algorithms [5] collect clusters of clusters. They are therefore applicable to the reconstruction of electrons and converted photons, where the energy deposit is spread in a larger area on the ECAL.

Converted photons are generally measured with a poorer energy resolution than unconverted photons. The degradation of resolution can be reduced by using different algorithms for energy reconstruction depending on the conversion pattern. In Fig. 1, the energy resolution is shown for unconverted and converted photons. Different algorithms have been chosen depending on the separation of the e^+e^- pair measured on the ECAL front face. Events in which the separation is too large ($\Delta\phi \geq 0.045$) were not considered in this study. The photons energy distributions displayed in Fig. 1 have a resolution of 0.86% for unconverted photons and 1.15% for converted photons [2].

Figure 1: Distribution of the ratio of the reconstructed to the incident photon energy for a) unconverted and b) converted photons.

The separation of the e^+e^- pair in the ECAL is correlated with the conversion radius. This information can be obtained by the reconstruction of the e^+ and e^- tracks of the conversion, which is possible if the conversion takes place before the three outermost layers of the tracker before the ECAL.

5.2 Track building for converted photons

The tracks of the e^+e^- pair are reconstructed using a Kalman filter [6] which is the simplest method for reconstructing tracks in CMS.

The track is built inward in the tracker. The initial guess for the track parameters is formed using the ECAL cluster and the hits on the outermost tracker layer. The reconstructed tracks provide the conversion position, the z coordinate of the primary vertex and, possibly, the means to do π^0 rejection.

5.2.1 The primary vertex from conversion tracks

In this work the z coordinate of the primary vertex was measured by an extrapolation of the tracks to the beam axis in the (r, z) plane. The data used in this study were simulated photons with $p_T = 35$ GeV/ c and without pileup. The study was restricted to the tracker barrel region and is therefore very preliminary. The obtained resolution of the z coordinate of the primary vertex is shown in Figs. 2 to 4.

In Fig. 2, the resolution on the z coordinate of the primary vertex is shown for the tracks that have their innermost hit in the range $65 \text{ cm} \leq r_{\text{hit}} \leq 90 \text{ cm}$. The z coordinate resolution is poor, because the tracks have at most one hit in a stereo layer for which the z position can be measured accurately. In Fig. 3, the z coordinate resolution for the tracks that have their innermost hit in the range $20 \text{ cm} \leq r_{\text{hit}} < 65 \text{ cm}$ is shown. The effect of the stereo layers can be seen in the improved resolution compared to the resolution in Fig. 2. For the tracks that have been reconstructed all the way to the tracker pixel detectors, with $4 \text{ cm} \leq r_{\text{hit}} < 11 \text{ cm}$, the resolution of the primary vertex z coordinate is shown in Fig. 4. The resolution of the z coordinate of the primary vertex is the better the longer the tracks are. Indeed, the number of hits on stereo layers in the track is the crucial parameter for the resolution of the primary z vertex coordinate.

Figure 2: The resolution of the z coordinate of the primary vertex for conversions with the position of the innermost hit of the reconstructed track further than 65 cm from the beam axis.

5.2.2 The primary vertex from the underlying event

The primary vertex can also be determined by reconstructing all the charged particle tracks in the event and all vertices from these tracks. The Higgs boson production vertex is chosen using the fact that the total transverse momentum of the underlying event charged particles is larger than that of the pile up events.

At high luminosity finding the right vertex is difficult: it is found with a 70% success rate. Determination of the z coordinate of the primary vertex from the tracks of a converted photon may help to choose the right vertex, since

Figure 3: The resolution of the z coordinate of the primary vertex for conversions with the position of the innermost hit of the reconstructed track between 20 and 65 cm from the beam axis.

Figure 4: The resolution of the z coordinate of the primary vertex for conversions with the position of the innermost hit of the reconstructed track less than 20 cm from the beam axis.(Note the change of scale)

the conversion photon comes from the Higgs boson production vertex.

6 Summary

In CMS photons are selected by the HLT. Once selected, photons are reconstructed offline. Reconstructing converted photons requires appropriate algorithms. If at least one of the photons in $H \rightarrow \gamma\gamma$ converts, conversion tracking can be used to help to find the primary vertex of the event.

References

- [1] CMS Technical Proposal CERN/LHVV 94-38 (1994).
- [2] The Electromagnetic Calorimeter Project Technical Design Report CERN/LHCC 97-33 CMS TDR 4, 15 December 1997.
- [3] The Tracker Project Technical Design Report CERN/LHCC 98-6 CMS TDR 5, 15 April 1998
- [4] The TriDAS Project Technical Design Report, volume 2. Data Acquisition and High-Level Trigger CERN/LHCC 02-26 CMS TDR 6, 15 December 2002.
- [5] E.Meschi, T.Monteiro, C.Seez, P. Vikas, CMS Note 2001/034.
- [6] R.Frühwirth, Nucl. Instrum. and Methods A 262 (1987) 444