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The Preshower Detector of CMS at LHC

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Abstract

A preshower detector aimed at neutral pion identification will be installed in the endcaps of CMS in front of the crystal calorimeter. The physics and the radiation environment impose strong requirements on this detector. Simulations and beam test results show good performance of the preshower used in association with the crystal calorimeter.

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Figure 1: Processes contributing to the background in the search of Higgs decaying to two photons

1 Introduction

The LHC will provide proton-proton collisions at a centre of mass energy $\sqrt{s} = 14$ TeV. The principle goal of both ATLAS and CMS at LHC is the discovery (or not) of the Higgs boson. The most promising channel for a intermediate mass Higgs search at LHC is $H \rightarrow \gamma\gamma$. This channel requires very good energy resolution and good π^0/γ separation in order to reduce the background. This latter requirement justifies the need for a preshower in CMS as will be explained in section 2. The characteristics of the preshower will be given in section 3 and its performance in section 4.

2 Why a preshower for CMS?

The precision electroweak measurements at LEP and SLC point to a relatively light Higgs: $M_H < 215$ GeV(95% C.L.) [1]. The minimal supersymmetric model predicts that the lightest Higgs boson has a mass lower than 145 GeV. In this *intermediate mass* region the two-photon decay of the Higgs is rare but easy to identify. This is the most promising channel at LHC for a Higgs mass ranging between 100 and 150 GeV. For this mass range the Higgs width is smaller than 100 MeV, therefore the resolution on its mass will be entirely dominated by the detector resolution, necessitating a high resolution calorimeter.

The predicted rate of Higgs to two photons is low and has some large backgrounds. The most important backgrounds are shown in Fig. 1. Cuts on the photon isolation with respect to jets are applied in order to reduce the bremsstrahlung and the jet backgrounds. The dangerous jet background which has large uncertainties needs to be further reduced by a factor of about 3 so that it does not dominate the irreducible background. This is achieved by π^0 identification. For a Higgs mass of 120 GeV, the π^0 s have a transverse energy of the order of 60 GeV leading to a separation between the 2 photons arising from the π^0 decay of about 0.8 cm in the barrel region while it is only few millimeters in the endcaps. The CMS electromagnetic calorimeter is made of PbWO_4 crystals with a front face of about $2.2 \times 2.2 \text{ cm}^2$ in the barrel and $2.9 \times 2.9 \text{ cm}^2$ in the endcap. The π^0 rejection can be performed with the crystal calorimeter in the barrel, whereas in the endcap the crystals cannot resolve the 2 photons from π^0 decays: a fine-grain photon sensitive detector (preshower) is needed in this region.

3 Characteristics of the preshower

A global view of the electromagnetic calorimeter is shown in Fig 2. Details of the CMS crystal calorimeter can be found in other contributions to this conference [2, 3]; only the preshower characteristics and performance will be discussed here.

In the preshower the absorber must be sufficiently thick in order to initiate photon showers but a too thick absorber would degrade the excellent energy resolution of the crystal calorimeter. The optimum is found for a total absorber thickness of $2.8X_0$ at normal incidence.

A transverse view of the preshower is shown in Fig 3. It is formed with two orthogonal planes of silicon detectors each divided into 32 strips with a pitch of 1.9 mm. Each plane is preceded by a thin absorber of $1.9 X_0$ and $0.9 X_0$ respectively. A total of 4304 detectors are needed, leading to 137728 channels.

The main goal of the preshower is π^0/γ separation but it also gives complementary information for $e^\pm/\pi^\pm$ separation, improves the isolation, reduces the longitudinal leakage from energetic showers and helps for the photon

Figure 2: Schematic view of the electromagnetic calorimeter.

Figure 3: Schematic view of the preshower.

direction measurement.

Few percent of the total electromagnetic energy is deposited in the preshower. It is measured and added to the energy deposited in the crystals as will be explained in section 4.2

Silicon detectors

Each silicon detector is a square of $63 \times 63 \text{ mm}^2$ divided into 32 strips of $60 \times 1.9 \text{ mm}^2$. Fig 4 shows a silicon detector with its very front-end electronics. The silicon detectors are $300 \mu\text{m}$ thick leading to a capacitance of 50 pF per strip.

These detectors have to resist the high radiation environment of LHC. At $\eta = 2.6$, the integrated radiation after 10 years LHC running will be equivalent to 2×10^{14} neutrons per cm^2 and 6 Mrad. Because of the radiation the silicon detectors will undergo type inversion. The implications are the following:

- After type inversion the bias needed to reach the full depletion increases; moreover an over-depletion is needed because of charge trapping, therefore the detectors must withstand up to 500 V.
- The leakage current also increases with radiation and the detectors have to be maintained at -5°C to keep the current below $20 \mu\text{A}$ per strip.
- The charge loss (reaching about 10% at the end of LHC) due to radiation will be taken into account with calibration.

Figure 4: A silicon detector used for the preshower.

Very front end electronics

The very front end electronics PACE (Preshower Analog CMS Electronics) have been described in another talk of this conference [4]. It is based on voltage sampling (at 40 MHz frequency). Three samples will be used for charge measurement. The requirements for these electronics are the following:

- Since only a few percent of the total charge is deposited in the preshower, it only needs to be measured with a precision of about 5%.
- A large dynamic range is needed in order to measure large signals (up to 400 Mips) and also single Mips which will be used for calibration. This justifies the use of a switchable 2-gain system. Low noise (1/5 of a Mip) is needed in order to measure single Mips.
- Since the preshower is not in the first level trigger, an analog memory of $4 \mu\text{s}$ is needed for each channel.
- The detector is DC coupled, requiring a leakage current compensation circuit.
- It has to be radiation hard and will be built in the DMILL technology.

4 Performance of the preshower

4.1 π^0 rejection

For the purposes of π^0 rejection the crystals are used to predict the position of the shower in the preshower in each plane. Then the shower shape is analysed with a neural net using 11 strips centered on these positions [5]. A

rejection factor of about 3 is obtained for the energy range of interest for the $H \rightarrow \gamma\gamma$ search, keeping a photon efficiency of 91%. Fig 5 shows the reducible jet background after isolation and after π^0 rejection as a fraction of the irreducible $\gamma\gamma$ background. After these cuts the jet background is less than 15% of the irreducible $\gamma\gamma$ background.

Figure 5: Reducible jet background after isolation and after π^0 rejection expressed as a fraction of the irreducible $\gamma\gamma$ background

4.2 Test beam results

The energy and position resolutions of the crystal calorimeter with the preshower in front were measured in the H4 beam at CERN in 1999 and compared to a simulation based on GEANT 3.21. The results of this beam test are described in [6].

The setup consists of:

- a prototype preshower made of 2 planes of absorber, each equipped with an array of 2x2 full-sized silicon detectors,
- a 5x5 matrix of full size endcap crystals

The total radiation length in the preshower prototype seen by an incident particle is $3.24 X_0$. The simulation includes all the materials present in this prototype with the same geometry.

An energy scan was performed with electrons at energies ranging from 15 to 180 GeV.

The total energy deposited in the system is given by:

$$E_{tot} = E_9 + E_{presh} \quad (1)$$

with

$$E_{presh} = \gamma(E_1 + \alpha E_2) \quad (2)$$

where E_9 is the energy in the crystals summed on a 3x3 array centered on the most energetic, E_1 and E_2 , expressed in Mips are the charge deposited in each plane of the preshower summed on 5 strips centered on the strip with the highest energy. The coefficient α defines the relative weight of each plane and is adjusted in order to get the best energy resolution. It is constant with energy and the results are very stable for variations of α of the order of 10%. Therefore the same value, $\alpha = 0.7$ is used in all cases. The value of γ is obtained from the distribution of E_9 versus $(E_1 + \alpha E_2)$ as shown in Fig. 6. It is also very stable with energy: $\gamma = 0.030$ GeV/Mip with less than 10% variation. Figure 7 shows the distribution of E_9 and E_{tot} for $E_{beam} = 180$ GeV in the data. The total noise on E_{tot} is 420 MeV. It is subtracted in the following. Figure 8 gives the energy resolution in data and in simulation, showing a very good agreement. The energy resolution obtained with the bare crystals is also shown.

The preshower prototype thickness will be reduced for beam tests in 2000 so that it corresponds to the CMS design. The accuracy of the simulation allows us to predict the effects of modifying the preshower geometry. Figure 9 shows the energy resolution for thicknesses of 2.8 and 3.0 X_0 compared with the 3.2 X_0 geometry for beam energies of 25, 50 and 120 GeV. Also shown is a curve representing the Technical Design Report [7] goal. The prototype will be placed in a 3T magnetic field in 2000. The effect on the energy resolution, from simulation,

Figure 6: E_9 versus $E_1 + \alpha E_2$ in the data for $E_{beam} = 80$ GeV

Figure 7: Distribution of E_9 and of E_{tot} for $E_{beam} = 180$ GeV

Figure 8: Energy resolution after noise subtraction.

Figure 9: Energy resolution for preshower thicknesses of $3.24 X_0$, $3.0 X_0$ and $2.8 X_0$.

is negligible.

The beam incidence position is determined with an energy-weighted centre-of-gravity using 3 strips centered on the one with the maximum energy deposit. The reference position was defined by wire chambers upstream of the preshower. The position measured in the preshower is corrected for the characteristic S-curve shape. Good agreement is found with the simulation and the precision is below $300\mu\text{m}$ in both planes for energies above 50 GeV.

5 Conclusion

The results of the 1999 beam test showed that the preshower performance is well within the requirements. A good energy resolution is obtained with the association of the preshower and the crystals. Simulation showed that the preshower can achieve a good π^0 rejection in the interesting energy range. These results lead to good performance for the difficult $H \rightarrow \gamma\gamma$ search.

Acknowledgments

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