The Compact Muon Solenoid Experiment

Conference Report

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Alignment of the CMS Preshower Detector

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Abstract

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The alignment is based on the extrapolation of tracks from the Tracker to the Preshower and gives an alignment precision of a few millimeters for translation and a few milliradians for rotation. The method for Preshower alignment is discussed and the results of the alignment with respect to the Tracker, using LHC collision data collected by CMS in 2011, are given.

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Key words: LHC; CMS; Preshower; ES; alignment; silicon;

1. Introduction

The Preshower (ES) is designed to identify π^0 in the endcaps within a fiducial region $1.653 < |\eta| < 2.6$. It also improves the Endcap ECAL (EE) position determination of electrons and photons with its fine granularity. ES is formed from two orthogonal planes in each endcap, mounted with 4288 silicon sensors in total [1]. The planes are known as ES+F, ES+R, ES-F, and ES-R reflecting the nomenclature of the endcaps (+ or -) and whether the plane is Front (closest to the interaction point) or Rear [2]. In front of each plane of sensors is a sheet of lead, to initiate electromagnetic showers: $2X_0$ in the front plane and $1X_0$ in the rear plane. The active area of each sensor is $61 \times 61 \text{ mm}^2$, segmented into 32 strips [1].

Figure 1: Photo of the Preshower "micromodule" containing the $61 \times 61 \text{ mm}^2$ silicon sensor (32 strips at 1.9 mm pitch) bonded to the front-end electronics.

For minimum ionizing particles the intrinsic spatial precision is 1.76 cm parallel to the strips and 550 μm perpendicular to the strips.

For optimum performance the ES needs to be aligned with respect to the Tracker within the expected spatial precision. The alignment framework uses LHC collision data taken with CMS in 2011.

2. Algorithm

The ES alignment relies on the minimization of the residuals of the differences between the positions of charged tracks measured in the ES and those predicted by the Tracker.

The alignment procedure begins by selecting high quality tracks reconstructed in the Tracker: at least 10 hits (including 1 in the outermost Tracker layer) and $p_T > 1.5 \text{ GeV}/c$. The selection was refined by taking only tracks pointing to a restricted fiducial region in the endcaps, $1.7 < |\eta| < 2.3$ and not pointing to dead ES areas [2].

The track trajectories are propagated to the ES (roughly 3m from the collision point) using the *Stepping Helix propagator* [3], which provides extrapolation by using finite helix length with the magnetic field and material effects at each step. The extrapolation error is less than 1 cm. A search window with radius 30 mm is then opened, for matching the measured ES hits and the predicted point.

Figure 2: Extrapolation of a track from the Tracker to the Preshower plane (green curve) to give a predicted point, and the corresponding hit in a wafer (view expanded) showing the residual vector between the predicted and preshower measured point, ϵ .

With the residual vector pointing from a measured hit to a predicted point in the local coordinate on the ES plane, the χ^2 is defined below.

$$\chi^2/N = \frac{1}{N} \sum_i^{Tracks} (\epsilon_i^T)_{1 \times 2} (V_i^{-1})_{2 \times 2} (\epsilon_i)_{2 \times 1} \quad (1)$$

$$V_i = \begin{bmatrix} \sigma_{x'x'} & \sigma_{x'y'} \\ \sigma_{x'y'} & \sigma_{y'y'} \end{bmatrix}_{trackErr} + \begin{bmatrix} \sigma_x^2 & 0 \\ 0 & \sigma_y^2 \end{bmatrix}_{preshower} \quad (2)$$

where ϵ_i is the residual vector pointing from the measured ES hit to the predicted point, in the local coordinate system for track i , and V is the covariance matrix from the extrapolation uncertainty and the ES spatial precision. N is the number of selected tracks.

For calculating the 3 translational and 3 rotational alignment parameters, a least-squares method is used and a minimization is performed by adjusting the alignment vector $P_{(6 \times 1)}$ iteratively, where $P' = P - \delta P_{iter1} - \delta P_{iter2} - \dots$ with iteration values $\delta P = [\sum_i J_i V_i^{-1} J_i^T]_{(6 \times 6)}^{-1} [\sum_i J_i V_i^{-1} \epsilon_i]_{(6 \times 1)}$ [4], where J_i is a Jacobian matrix, and $J_{i,6 \times 2}$ is reduced to a function of position and momentum at the predicted point. The angular terms of $J_{i,6 \times 2}$ are reduced with the assumption of straight line trajectories over small rotational angles. The local origin of ES is moved iteratively from

the ideal position in the global coordinate system by using the vector P' . Then, P' becomes stable at the order of millimeters or milliradians as χ^2/N approaches its minimum.

3. Results

Figure 3 shows the translational residuals between the ES hit positions and the Tracker predictions, before and after the alignment has been performed, for all four planes. They show that there is a relative vertical mis-alignment between the Tracker and ES endcaps of about 9 mm (shown by the ES+R plane) and 7 mm (ES-R). There is also a horizontal mis-alignment, but only between the ES+ and the Tracker, of about 5 mm. After software alignment the ES is aligned (translationally) to the Tracker to better than 0.15 mm, well within the intrinsic spatial precision of the ES.

Figure 4 represents the amount of rotational mis-alignment for the two planes of ES+, corresponding to rotations with respect to the nominal of 1 or 2 milliradians.

Figure 3: The residual plots for the four ES planes before and after alignment using charged tracks with $p_T > 1.5$ GeV/c. The resulting alignment is better than 0.15 mm.

With the aligned ES geometry, we have measured the precision of the ES position measurement with high energy tracks ($p_T > 20$ GeV/c), where the extrapolation error from the Tracker and the effects of multiple scattering are minimized. The calculated ES precision $\sigma_{\text{preshower}}$ is given by:

$$\sigma_{\text{preshower}} = \sqrt{\sigma_{\text{total}}^2 - \sigma_{\text{track}}^2} \quad (3)$$

where σ_{total} are the fitted Gaussian widths from the residual plots in Figure 5 and σ_{track} is the average trajectory prediction error from the Tracker to ES. The expected precision for minimum ionizing particles is about $1.9 \text{ mm} / \sqrt{12} = 550 \mu\text{m}$. For the four ES planes the average tracker error is $500 \mu\text{m}$, and the total width is $800 \mu\text{m}$, which is the fitted Gaussian width weighted by the number of selected tracks in the ES planes, leading to a measured preshower precision of around $600 \mu\text{m}$, in good agreement with prediction.

Figure 4: The residual vectors along x-axis (ϵ_x) on ES+Front plane (left) and along the y-axis (ϵ_y) on ES+Rear plane (right). The blue arrows represent the direction of the residual vectors.

4. Summary

A systematic procedure for aligning the Preshower with respect to the Tracker has been developed and applied. After alignment, the spatial precision for minimum ionizing particles in the Preshower is as expected, around $600 \mu\text{m}$.

References

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- [3] CMS Collaboration, Muon Reconstruction in the CMS Detector, CMS AN-2008/097 (2008)
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Figure 5: Residual plots showing the position accuracy of charged tracks with $p_T > 20$ GeV/c incident on the Preshower, after alignment.