HIT RECONSTRUCTION IMPROVEMENTS IN THE CATHODE STRIP CHAMBERS OF THE CMS EXPERIMENT

N. Voytishin[1]

on behalf of the CMS Collaboration

[1] *Joint Institute for Nuclear Research, 6 Joliot-Curie St, Dubna, Russia 141980*

E-mail: nvoytish@jinr.ru

The reconstruction of charged particle trajectories in the CMS endcap muon system is based on hits detected by the Cathode Strip Chambers. The reconstruction procedure for these multilayer detectors can be divided into two main parts: the reconstruction of hits on each layer, and the assembly of track segments within the chambers from the reconstructed hits. At the HL-LHC the increased luminosity implies higher muon and background rates which, without improvement of the existing hit reconstruction algorithm, may deteriorate the present performance of the Cathode Strip Chambers system. On one hand, the increasing hit rates will require a better precision in the identification of two or more particles that pass very close to each other. On the other, upgraded readout electronics for the Cathode Strip Chambers provides options for improved reconstruction, which have not yet been fully exploited in offline software. Some proposed solutions for these issues, together with figures comparing the standard and improved reconstruction algorithms, are presented here.

Keywords: CMS, cathode strip chambers, reconstruction algorithms

Nikolay Voytishin

1. Introduction

The Cathode Strip Chambers (CSCs) are the main detectors of the endcap muon system of the CMS experiment [1]. Each CSC consists of six layers. When a charged particle passes through a layer of CSC (fig. 1), it knocks electrons out of the gas molecules and they flock to anode wires, meanwhile positively charged ions move towards cathode strips inducing a charge on them.

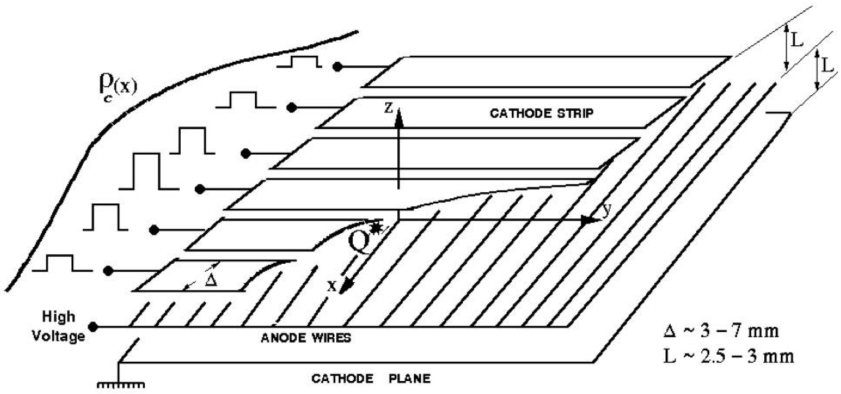

Figure 1. Principle of work of one CSC layer

The signal from wires, along with the charge distribution from strips, gives us a 2D coordinate of the passing particle on the layer. If we have such coordinates on at least 3 layers, it is possible to assemble them into segments and reconstruct the entire trajectory of the charged particle in the particular chamber. Information from several CSCs, along with information from other detectors, is gathered together in order to reconstruct the entire trajectory of the passing particle, starting from the interaction point and up to the limits where it exits the frame of the CMS detector.

2. Overlapping signals recognition

While developing a new segment building algorithm for CSCs [2], it was noticed that in some cases the segment builder struggled to add hits on the segment due to the fact that they have a poor reconstruction accuracy in terms of the strip coordinate. The strip coordinate is estimated by fitting the strip charge distribution with the Gatti function [3]. If the Gatti function cannot be applied, the strip coordinate is reconstructed with a poor accuracy of about 30-60% of the strip width, while 2-5% is the accuracy for good cases. In these cases there is a high multiplicity of consecutive fired strips. For clusters that are formed out of overlapping signals a simple Center of Gravity (CoG) approach is used for coordinate reconstruction.

The development of a new wavelet-based reconstruction algorithm for the strip coordinate was initiated in order to improve the strip coordinate reconstruction for overlapping signals. The g2-WTS (Wavelet-TranSform method based on the use of second degree wavelets (g_2)) [4] was chosen by us for overlapping signals recognition.

The main function in the wavelet analysis is the following double Gaussian function

$$\mathrm{G}(\mathrm{x}; \mathrm{A}, \mathrm{x}_1, \sigma_1; \mathrm{B}, \mathrm{x}_2, \sigma_2) = \mathrm{A}\exp(-\frac{(\mathrm{x}-\mathrm{x}_1)^2}{2\sigma_1^2}) + \mathrm{B}\exp(-\frac{(\mathrm{x}-\mathrm{x}_2)^2}{2\sigma_2^2}) \quad (1)$$

We build 2, 3 or 4 Gaussians on the chosen interval of strips with a constant step as a first approximation. For the case of three overlapping signals the formula (1) looks as follows:

$$G(x; A_1, x_1, \sigma_1; A_2, x_2, \sigma_2; A_3, x_3, \sigma_3) = A_1 e^{-\frac{(x-x_1)^2}{2\sigma_1^2}} + A_2 e^{-\frac{(x-x_2)^2}{2\sigma_2^2}} + A_3 e^{-\frac{(x-x_3)^2}{2\sigma_3^2}} \quad (2)$$

The parameters $A_1, x_1, A_2, x_2, A_3, x_3, \sigma_1, \sigma_2, \sigma_3$ of the overlapping signals are obtained by fitting the data distribution to the sum of these three Gaussians in each coordinate x.

An example of two overlapping signals recognition is shown in Figure 2. The green line that corresponds to the simulated muon coordinate coincides exactly with one of the signals recognized by the proposed algorithm (red lines), while the standard approach (blue line) misses by almost half of a strip width.

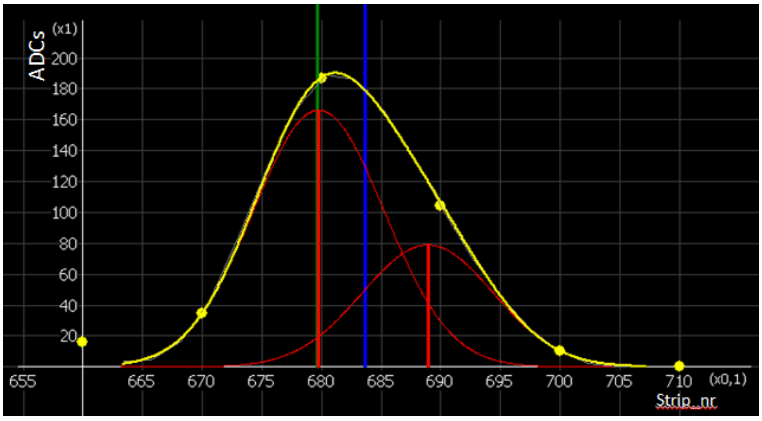

Figure 2. Recognition of two overlapping signals. The yellow line is the initial strip charge distribution; the green line is the simulated muon coordinate; red lines are coordinates found by the wavelet analysis; the blue line is the coordinate found by the standard approach (CoG like)

Overall the new approach shows better results than the standard approach (fig. 3). But the time consumption in the framework of the CMS software is still unknown because at the moment it is a standalone tool adjustable for any input data. This may be crucial, because the wavelet approach is an iterative method and there are strict limits for the time spent for the reconstruction of the CMS event, especially within the trigger.

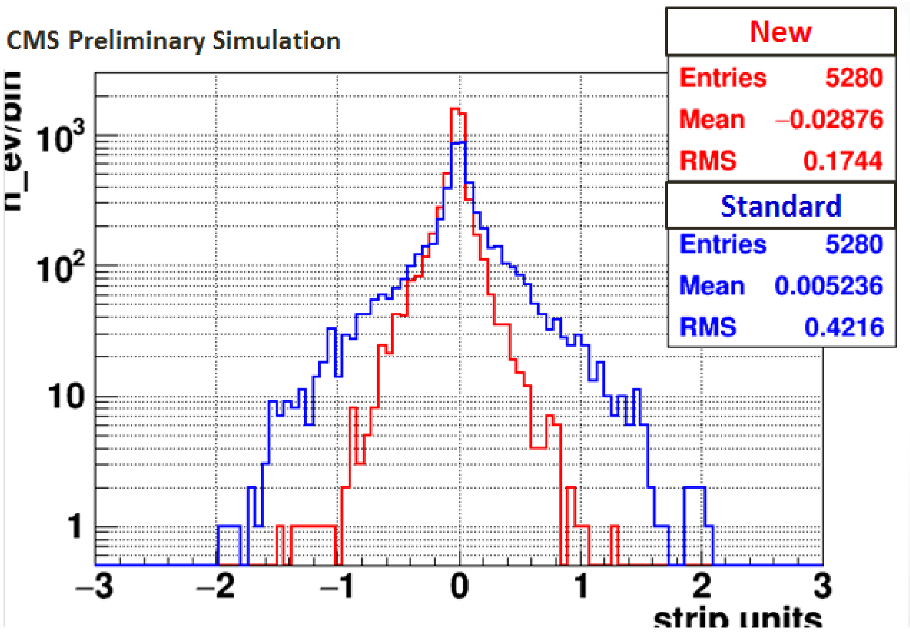

Figure 3. Difference between the simulated and reconstructed strip coordinates. The results for the new approach are shown in red and for the standard one in blue. They were obtained using simulated single muons with pT = 1000 GeV

A much simpler approach for two overlapping signals recognition was also developed. The shape of the strip charge distribution coming from two overlapping signals can be easily detected. It usually comprises 5 or 6 strips that have charges above the pedestal level. They contain one maximum, and the shape of the distribution is not regular. We treat such cases as two signals overlapping, where one maximum is clearly noticeable and the second one is hidden at one strip distance from the main maxima. If such a distribution is found, it is divided into two simple and regular distributions by sharing the charge from the common strip between two maxima proportionally to their charges (fig. 4).

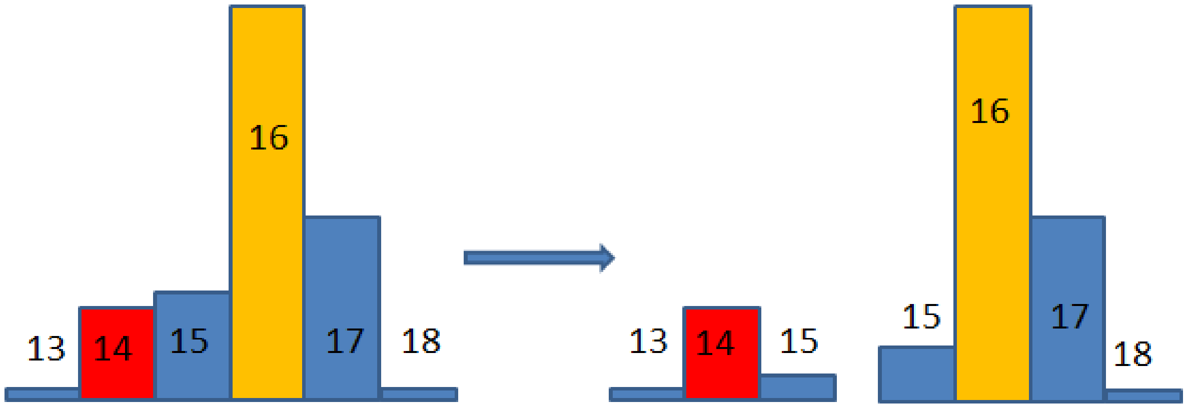

Figure 4. The abnormal strip charge distribution is divided into two regular strip distributions around two maxima at the strip number 14 and 16. The charge of the strip number 15 is proportionally divided between two maxima

As a result the overall number of reconstructed segments increases, and their χ^2 / ndf becomes smaller (fig. 5). It means that the application of the proposed approach gives us the opportunity to reconstruct more segments and their overall quality improves.

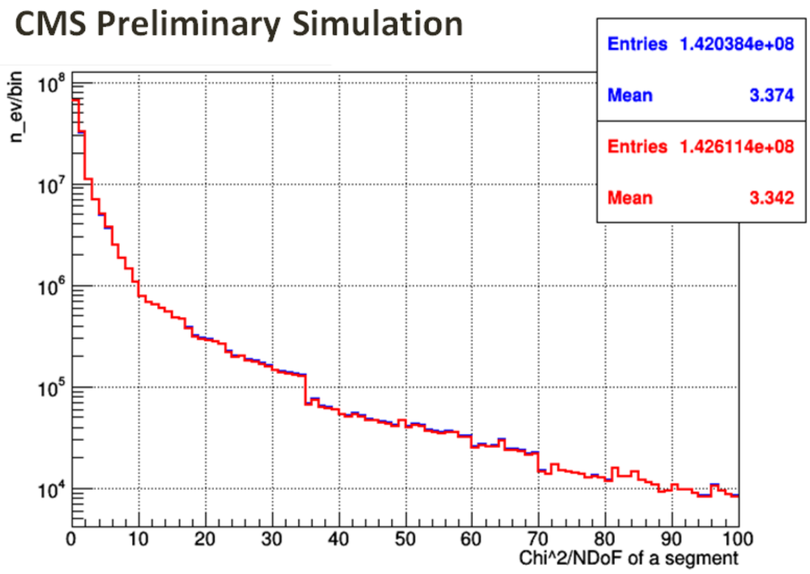

Figure 5. χ^2 / ndf of the segment. The results for the new approach are pictured in red and for the standard (CoG) one in blue

3. Other improvements in hit and segment reconstruction

Aspects of the detector geometry have led to inefficiencies in specific regions of the CSC muon detectors. The ME11 chambers are the closest CSC chambers to the interaction point. In order to be able to reconstruct trajectories of passing particles at high rates, a special geometric design was implemented in these chambers [5]. The wires in these chambers are not perpendicular to the strips and the chambers are divided into two radial regions for reading out the cathode strips. In the reconstruction it was necessary to apply geometric selection isolating hits and segments to specific radial regions. Recent hardware improvements have enabled the removal of this selection allowing better reconstruction in the boundary region. Comparisons of the improved reconstruction algorithms to the original performance for hits and segments are shown in Figure 6.

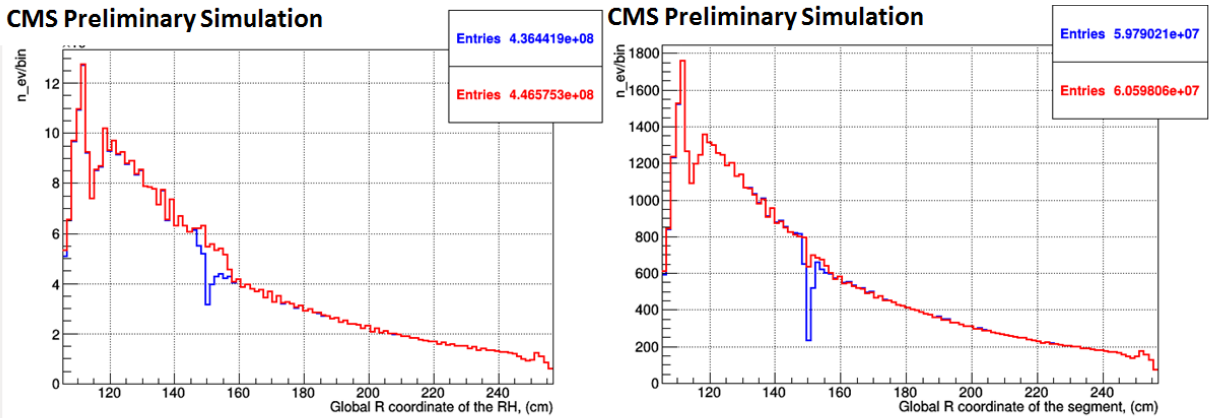

Figure 6. (Left) hit reconstruction frequency; (Right) segment reconstruction frequency in the ME11 chambers depending on the R-coordinate (distance to the beam axis) for the standard signal reconstruction algorithm (blue line) and the modified algorithm taking into account the ME11 hardware upgrade (red line)

4. Conclusions

The application of the wavelet analysis gives us the possibility of reconstructing the strip coordinate ~2.5 times closer to the simulated muon in comparison with the standard approach, although the iterative method most likely will be too time-consuming. A simpler way to divide overlapping signals is also proposed. It is limited to two overlapping signals delimitation and the comparison in performance with the wavelet approach is ongoing.

The hardware upgrade in particular chambers made it possible to improve hit reconstruction. The regions that were suffering from the lack of reconstructed hits can now be fully used for hit and segment reconstruction.

There are multiple places for improvements in terms of hit and segment reconstruction in CSCs. Different approaches can be used for solving the same problem. The main objective is to get as much and as accurate information as possible for further steps of particle trajectory reconstruction.

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