# Algorithm for Muon Reconstruction


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**Abstract**

In CMS detector, many particles are created and go through from inside of the detector to outside. We have to reconstruct their tracks as much as possible in order to determine their momentum and electric charge. With these information we can know what kind of particles are created and/or study their properties. Muon is one kind of particles created by *pp* collision in LHC and reconstructing its track plays very important role in CMS experiment. In this summer student programme, I improved muon reconstructing algorithm in DT and CSC detectors, which take muon detecting system in CMS. I tried choosing muon segments from all hits in CMS detector more efficiently than muons which are found by the conventional algorithm. And I also tried to improve algorithm to be able to use for various situation, for example, a muon which don't come from the beam axis or two muons which are very close to each other. The improvement in term of efficiency is given in the results section.


## 1 CMS detector[1]

### 1.1 Overview of CMS

The Compact Muon Solenoid (CMS) is a general purpose experiment operated at LHC. Figure.1 shows the overview of CMS detector. CMS detector is made of a lot of part and each part plays their special role. Figure.2 shows the way that each part works to detect particles.

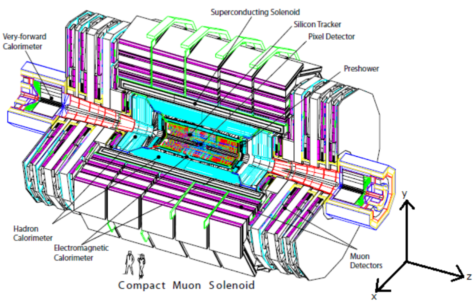


Figure 1: CMS detector

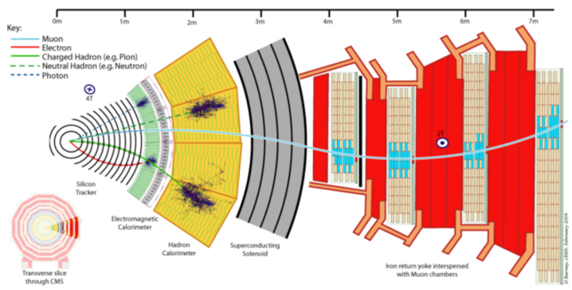


Figure 2: detect

### 1.2 CMS Coordinate System

In this report, I use the coordinate system of right-handed Cartesian frame, with the z axis coincident with the beam direction, y axis directed upwards and x axis horizontal to the ground. This is shown in Figure. 1.

### 1.3 The Muon System

Muon detecting system in CMS locate the outermost side of detector as usual detector. Both the barrel and the endcaps of the muon system are made up of four stations (see Figure. 3 and 4). The barrel muon system uses *drift tube chambers* (DTs), while the endcaps use *cathode strip chambers* (CSCs); in both regions, tracking detectors are complemented with the use of *resistive plate chambers* (RPCs).

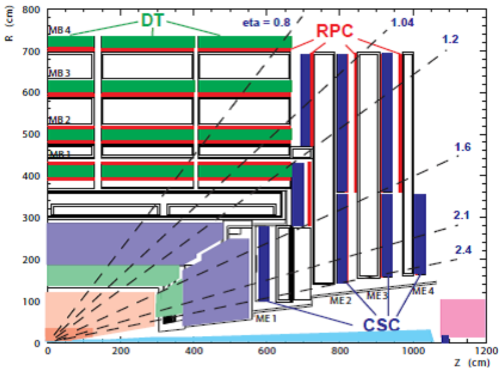


Figure 3: CMS detector

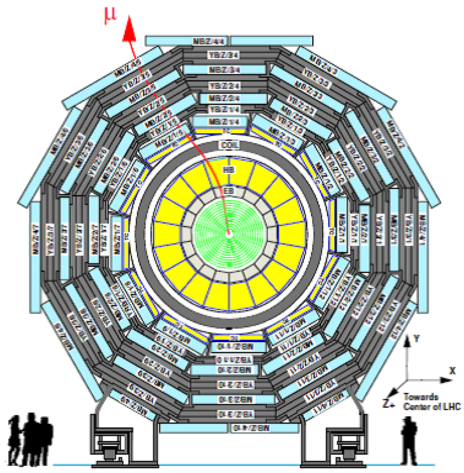


Figure 4: detect

### 1.4 Muon Reconstruction

Muon reconstruction is done with next 4 steps.
1) First, a local reconstruction is finding hits in CSC, RPC and DT. Hits are put together in segments in CSC and DT. We call these hits "segments".
2) Then from segments in DT and CSC, a seeding algorithm will try to find aligned segments, which are the signature of a muon.
3) From these seeds, the reconstruction algorithm will try to build muon tracks in the muon system: it then uses all the hits in CSC, DT and RPC (we call it a standalone muon in CMS)
4) Then, the muon reconstruction is trying to find a track in the tracker which is matching with the track in the muon system: if it is successful, then we have a muon (called in CMS the global muon).
In fact in CMS, many of the analysis are using the muon from the step4 because it is the tracker track reconstruction which permit to have the resolution needed for many analysis (as Higgs decaying in 4 leptons).
And I worked on the step 2, which was the improvement of the seeding of the muons.

## 2 Motivation

I want to find aligned segments which is are the signature of a muon with higher efficiency.This helps to reconstruct muon tracks with higher resolution. It is also important to reconstruct very close two muons which come from high transverse momentum $Z^0$ or $J/\psi$.

## 3 Method

### 3.1 Cone Search

The basically method to find aligned muon is like this. First, I sort segments according to station number they hit. Then from a segment in station[N], giving off cone shaped "search light" and trying to find some segments in station[N+1] (see Figure 5). If I can find some segments in the cone, giving off next "search light" from these segments as like Figure 6. As I say later, I determine cone angle $\theta$ using statistics. I set the angle separately by station. Not only cone shape search, I also use the angle between direction of two segments (Figure 7). I only pick up segments which have angle between them under the value of maximum $\phi$ which I set.

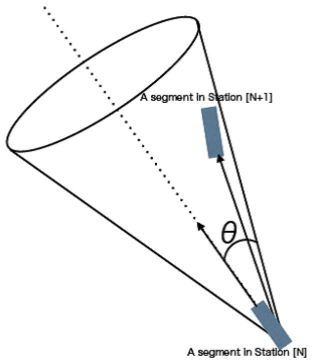


Figure 5: Cone Search

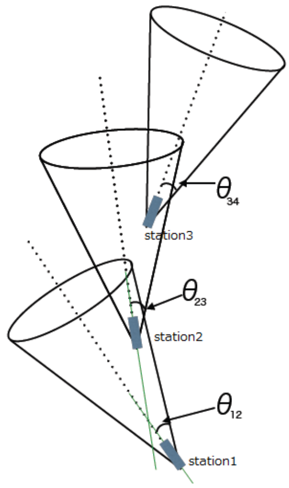


Figure 6: detect

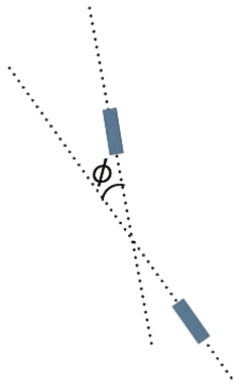


Figure 7: aaaa

I use this cone search in the order of (1) station 1→station 2→station 3→station 4, (2)station 1→station 2→station 4, (3)station 1→station 3→station 4, (4)station 2→station 3→station 4, (5)station 1→station 4, (6)station 2→station 4, (7)station 3→station 4 to be able to pick up all muon segments in any situation.

### 3.2 Determine the angle $\theta$ and $\phi$

In order to determine the angle $\theta$, angle of cone, and the angle $\phi$, angle of two segments' direction, I used already known muon events and made histograms of their $\theta$ and $\phi$. Then I determine each angles so that I can pick up more than 99% of segments. I show you one example of histograms in Figure 8, this is the histogram of cone angle from station 1 segments to search station 2 segments. The results of angles are shown in Table 1.

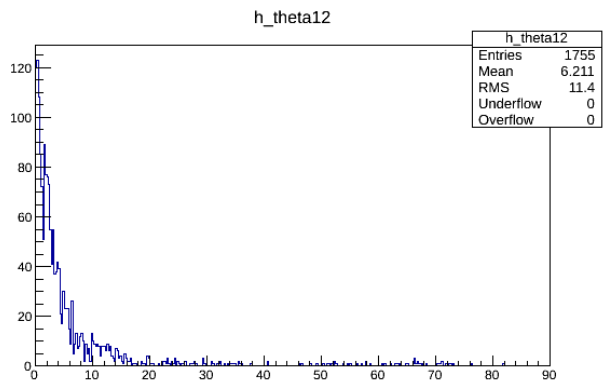


Figure 8: angle $\theta$ from station 1 to station 2. Integrating from 0° to 66.5°, I can pick up 1737 segments (98.97% segments)

| | $\theta$ | $\phi$ |
|---|---|---|
| sta 1→sta 2 | 66.5° | 45° |
| sta 2→sta 3 | 60° | 50° |
| sta 3→sta 4 | 60° | - |
| sta 1→sta 3 | 54° | 50° |
| sta 2→sta 4 | 55° | - |
| sta 1→sta 4 | 50° | - |

Table 1: angle

As shown in Table 1, I did not use the angle $\phi$ involving station 4 segments because they don't have information of $z$-axis direction.

# 4 Result

I used my algorithm to 2 types of simulation events, one is 5GeV, low transverse momentum muon events and the other is 100GeV but not coming from beam line events. I show one example 5GeV event in Figure 9. This is xy-plane histogram of simulation muon events, represented with black point and colored points represent muons found by my algorithm. It seems that I could reconstruct muon track well.

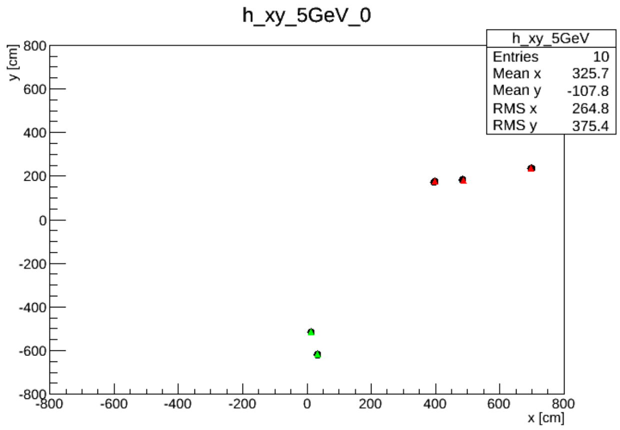


Figure 9: An example event : black point is muons created my simulation and colored triangle is muons found by my algorithm

- 5GeV event
  I used my algorithm to 393 events. And I find 2751 muon segments. When I use conventional algorithm, I can find 2515 muon segments, So I can say that it is better to use my algorithm.
- 100GeV and not coming from beam line event
  There are 346 events. Using my algorithm, I found 3119 muon segments and using conventional algorithm I found 2234 muon segments. So this time I also can say my algorithm can find more muon segments than conventional one.

So, I can conclude that initial aim, finding muons more efficiently, is achieved. But I have some more studies that have to be done (in this summer I have no time to do these) :

- Having a look on close-by muon to check that this reconstruction is performing well with them.
- Implementing it in the CMS software to understand how these new seeds are handled by the other steps of the muon reconstruction and then see how much is the improvement.
- Testing also in real data (not containing only muon events but also background) so check that the algorithm is not making too much fake seeds (even if we can rely on the other steps to remove this fake seeds).

# 5 Acknowledgment

Whole part of this work is supported by my supervisor Hugues Louis Brun. I would like to thank Hugues and CERN Summer Student staffs here for their great support.

## reference

[1] Muon Reconstruction and Momentum Scale Calibration and Their Application to Standard Model Higgs Searches with the CMS Experiment. Daniele Trocino 27th January 2011.