Track Selection Performance of the CMS
Cathode Strip Chamber Track Finder and Level 1 Trigger

Kristin Beck, University of Rochester
University of Michigan CERN REU

Introduction

The Compact Muon Solenoid (CMS) is a general purpose detector for particle physics that has been constructed in Cessy, France on CERN's Large Hadron Collider (LHC) beam line. It has been designed to record the particle debris that will result from 14 TeV proton-proton collisions. The identified particle tracks will then be used to reconstruct the collisions, the resulting particles and their decays. The eventual aim is to understand the physics that occurs at these higher center-of-mass energies. In particular, searches will go on to test the standard model of particle physics, looking for the predicted Higgs boson and for physics beyond the standard model as predicted by astrophysical data.

The Cathode Strip Chambers (CSCs) are one of CMS's three dedicated muon detector systems. The CSCs are located in the barrel endcaps of CMS in four stations (Figure 1). These stations are geometrically placed to observe muons coming from the interaction point (IP) with pseudorapidity η in the range $0.9 \leqslant \eta \leqslant 2.5$ [1]. The CSCs consist of six planes of conducting wires and strips arranged in a grid pattern. These planes are separated by gas chambers filled with a mixture of Ar, CO_2, and CF_4. When a muon passes through a chamber, it ionizes the gas. The ions induce charges on the wires and strips. Comparisons of the signals from these induced charges pinpoint the location of the deposited ions. When signals from wires and strips line up across a CSC, a Local Charged Track (LCT) is produced which includes location information for the deposited ions. LCTs are used by the CSC Track Finder/Level 1 Trigger (CSCTF/L1T) to create muon tracks.

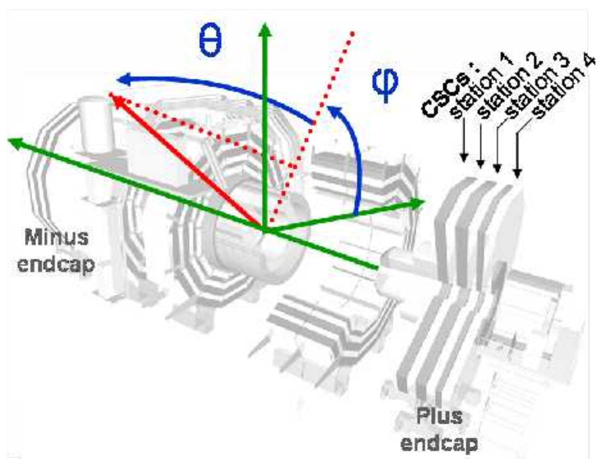

Figure 1: CMS detector coordinate axes and CSC locations. There are four stations of CSCs in each of CMS's two endcaps, labeled 1-4, with the first station nearest the interaction point. Station labels are shown here for the plus endcap.

The expected data rate from CMS (40MHz) is higher than what can be stored by the data farms (~200Hz). CMS cuts down this data rate by using a two-tiered triggering system that selects data to be stored. The Level 1 triggering system is a hardware based system that performs coarse, fast analysis to reduce the data rate to approximately 100kHz. The High Level Trigger (HLT) then performs a finer analysis and reduces the data rate down to a manageable rate for data storage.

---

1 Here, we have defined $\eta = -\ln[\tan(\theta/2)]$, where θ is the angle between the beam and the particle's velocity vector (Figure 1). η approximates the relativistic rapidity, y .

The CSCTF/L1T is part of the CMS Level 1 Trigger system. It is responsible for choosing up to four tracks (or muon candidates) per bunch crossing (25ns) to pass up the triggering chain. A track consists of two or more LCTs that fulfill a selection rule. For example, a selection rule could be that a pair of LCTs from stations 1 and 2 (mode 6) or stations 2 and 3 (mode 8) have a specified maximum value of $|\Delta\eta|$. Identified tracks are assigned a *track mode*, a number that encodes the LCTs and selection criteria that lead to the creation of that track. The track modes is used for subsequent analysis and/or troubleshooting.

Research

In order to prepare for the use of the CMS detector when first beam arrives from the LHC this fall, the CSCTF/L1T must be checked to ensure that it is working as expected. These checks are going on now that the CSCs and lower level electronics that feed into the CSCTF/L1T have been commissioned. The functionality of the system as a whole can be checked with events coming from cosmic muons.

This summer, I was responsible for performing some of these checks for CSCTF/L1T. After familiarizing myself with the computing environment at CERN and, specifically, the C++ code related to CSCTF/L1T within the CMS SoftWare (CMSSW) repository, I examined the basic functionality of the CSCs. I examined variables like η, ϕ, timing, track mode and the sector of the detector where the tracks were recorded. After confirming that I was able to reproduce basic plots with track-level information, I studied the LCTs that were used to make up these tracks. I made plots of $\Delta\eta$ and $\Delta\phi$ between the LCTs in a given track. A nice result was a plot of $\Delta\eta$ for two different runs from cosmic runs taken in June (CRUZET2) (Figure 2). For ease of performing this check, these two runs had been taken with the same selection rules on $\Delta\eta$ independent of track mode. In run 46788, there was no cut imposed on $\Delta\eta$, which is reflected by the data's large distribution. In run 46794, a hard cut on the maximum value of $|\Delta\eta|$ was set at a machine value of 0x5 (which, scaled to the true units of pseudorapidity, is approximately $|\Delta\eta|<0.0625$). This cut is visible in the data; however, there are a small percentage (less than 1%) of data points that fall outside of this data range.

After attempting to examine $\Delta\eta$ for a recently commissioned track mode for the detection of beam halo muons, muons that are produced by beam-pipe and beam-gas interactions, I realized that some of the tracks did not contain the LCTs that we expected them to contain based on their mode number. I studied the agreement of the reported mode with the LCTs that comprise the track through plots and subsequent unpacking of raw data in tracks where the expected LCT content of a track differed from the expected LCT content based on the assigned track mode. At first, I found many tracks that were in error (Figure 3). However, many of these errors were traced to a firmware update that was had not yet been fully reflected in the data unpacking software (it is now), undocumented special cases of mode assignment rules, and unrecorded “out of time” LCTs. Currently, only a handful of analyzed tracks have unexpected discrepancies between their mode and their LCT content.

Combining this mode-based analysis with the original $\Delta\eta$ study that motivated checking the for errors in mode assignment, I again looked at $\Delta\eta$ for run 46794, this time examining $\Delta\eta$ on a mode-by-mode basis with the working hypothesis that the 1% of tracks with $|\Delta\eta|>0\text{x}5$ were in tracks with more than two LCTs. In tracks with more than two LCTs, the value of $\Delta\eta$ that used to select a track in the CSCTF/L1T is not always the value of $\Delta\eta$ between the two outermost LCTs. However, this hypothesis was not supported by the data: the tracks with $|\Delta\eta|>0\text{x}5$ were in modes 6 and 8, modes that contain only two LCTs.

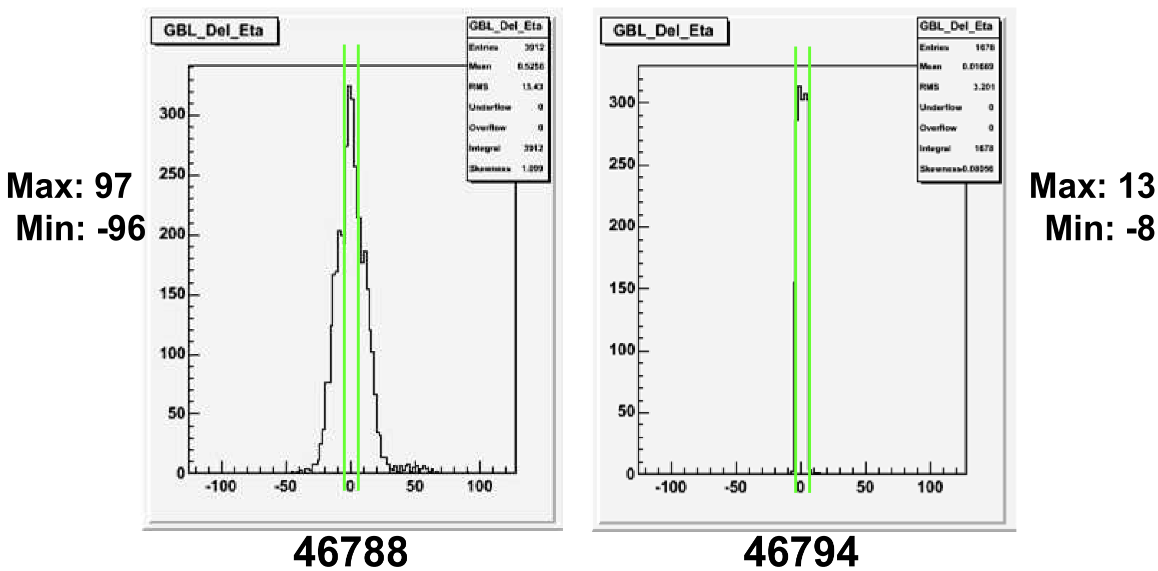

Figure 2: $\Delta\eta$ calculated between the LCTs from the two outermost stations of each track for one data file's worth of data from runs 46788 (no requirement on $\Delta\eta$) and 46794 ($|\Delta\eta| \leq 0x5$) taken during the CRUZET2 cosmic muon exercise in mid-June, 2008. The green lines in each plot mark the boundaries $|\Delta\eta| = 0x5$. The *x*-axis is $\Delta\eta$ in machine units and the *y*-axis is the number of tracks in each bin. While the two distribution agree to first order with the expected distributions, there are a few tracks (less than 1% of tracks observed) in run 46794 that do not seem to match the expected distribution.

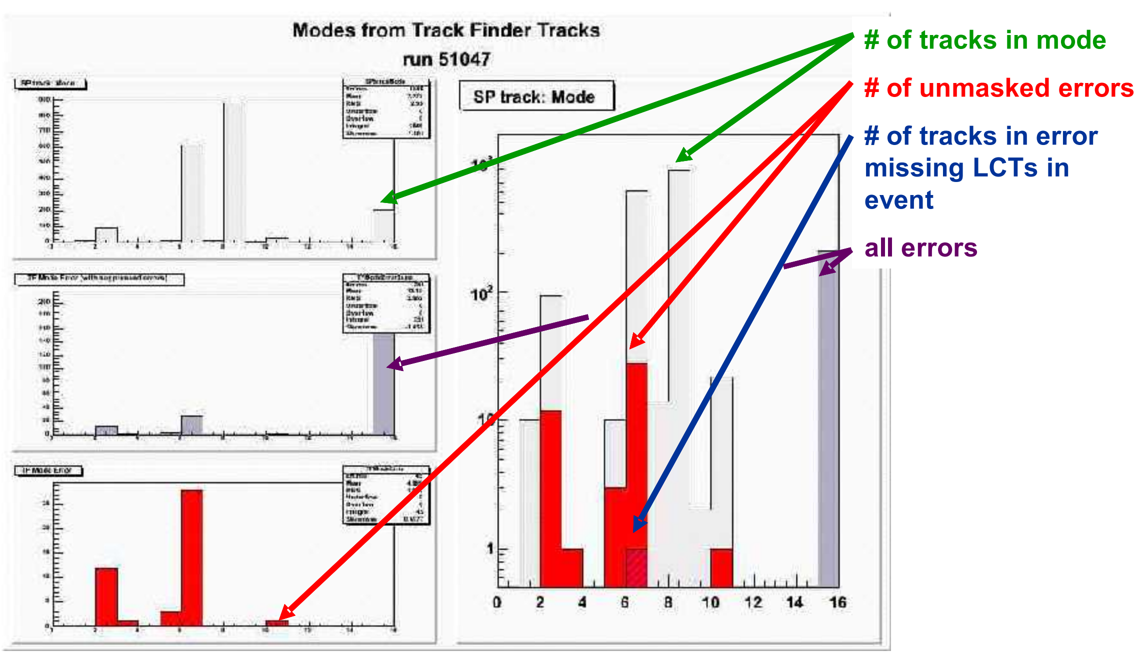

Figure 3: This graph displays mode occupation (gray) and tracks in which the LCTs in the track do not agree with the expected LCT content based on the reported mode type (red and purple). The *x*-axis is the assigned mode number (0-15) and the *y*-axis is the number of tracks. *N.B.* This is a historical graph. The mode errors depicted here were observed before understanding special cases of mode assignments and obtaining the proper data unpacking software.

Deliverables

I have produced analysis code that includes the two primary track analyses I developed this summer: (1) comparing the mode assignment and LCT content of tracks and (2) computing cuts made on quantities Δη and Δφ on a mode-by-mode basis. This code, along with complete documetation, has been packaged for installation. This code performs analysis in three stages. The first analysis runs within CMSSW to extract information of interest from the recorded tracks and store it in a manageably-sized ROOT tree. A separate program then runs over this ROOT tree to do the analysis calculations, computing $\Delta\eta$ and $\Delta\phi$ and comparing the LCT content of tracks with the expected LCT content based on the mode number. This program outputs a ROOT file with histograms as well as a text file of error messages and statistics that can be used to identify the specific tracks whose expected and actual LCT content differ. A third file, a ROOT script, is used to display the histograms produced in the second stage of analysis and optionally store these histograms as image files.

The analysis code I produced will be used to do the checks I have been performing this summer on new data from CMS to confirm that the hardware and unpacking software are performing as expected for cuts on $\Delta\eta$ and $\Delta\phi$ as well as the track mode assignment.

In addition to producing this package, I spent a few days this summer time participated in a few shifts for the CSCs during cosmic runs in July (CRUZET 3). These shifts gave me insight into the day-to-day operations of CMS as they will be once the LHC turns on in a few months.

Links

Source code and documentation for my analysis code (*CSCTF Mode and Basic Cut Track Analysis Pack*): http://cern.ch/csctf/studies/studies.html

Technical Presentation on this analysis code: http://indico.cern.ch/conferenceDisplay.py?confId=39150