Final Report on HELEN Short-Term Training (STT) at Università degli Studi di Padova and Sezione dell' INFN – Padova - Italy

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I - Introduction

The main goal of my training program at the *Università degli Studi di Padova "Il Bo"* in Italy was to acquire competence in many experimental aspects involved in the running of such a complex system as the CMS Muon System, and in the analysis of data aiming to optimize the performance of the apparatus.

The training consisted in learning how to work with the "new" framework of CMS, called CMSSW (version 0_6) and perform analysis on cosmic data using the tool ROOT.

During my period in Padova I participated of internal meetings and seminars of the local CMS group.

II - CMS and CMS Barrel Muon System

The Compact Muon Solenoid (CMS) experiment (see fig. 1) is one of four detector built on the Large Hadron Collider (LHC) at CERN in Switzerland, and was

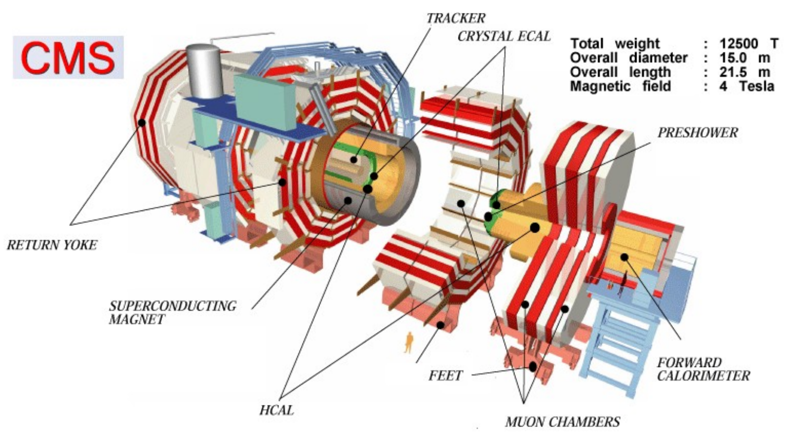


Figure 1: Overview of the CMS detector.

designed as a general purpose detector for proton-proton collision at centre-of-mass of 14 TeV and Pb-Pb collisions at centre-of-mass of 5.5 TeV/nucleon.

The main goals of CMS is the discovery of the Higgs boson, explore physics at TeV scale, to look for evidence of supersymmetry and to study aspects of heavy ion collisions.

The CMS detector is divided in 4 major subsystem plus a superconducting solenoid, as know:

- **Tracker** – to allows the reconstruction of charged particle track and precise measure of momenta ;
- **Electromagnetic Calorimeter** (ECAL) – is used to measure energy of particles that can interact electromagnetically. Consisted of around 80000 lead-tungstate crystals. When photons and electrons interact with material, the crystals to scintillate and the produced light is picked up by photodetectors and used to reconstruct the energy of incident particle;
- **Hadronic Calorimeter** (HCAL) – is used to measure energy of hadrons. Consisted, basically, of plates of brass and steel and plastic scintillators between the plates. In conjunction with ECAL form a complete calorimeter system for the measurement of jets and missing E_T.
- **Magnet** – a solenoid provide a powerful 4 T magnetic field that allows the charge/mass ratio of particles to be determined from the curved track that they follow in the magnetic field;
- **Muon System** – uses three different technologies to detect muons and measure their momenta. Is used drift chambers (DT) in the barrel region, cathode strip chambers (CSC) in the endcap region and resistive plate chambers (RPC) as a dedicated trigger detectors in the both barrel and endcap (see fig 2).

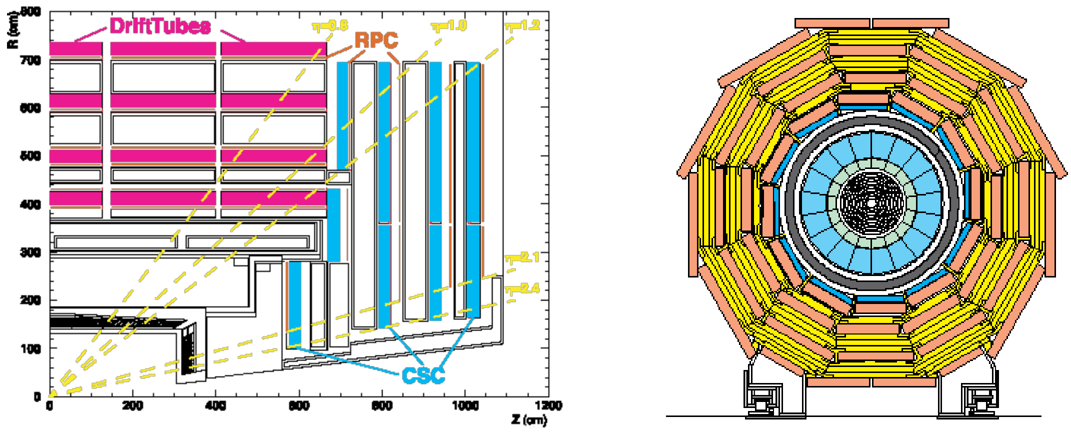


Figure 2: DT, RPC and CSC location in Rz view (left). Transversal view of CMS (right).

The barrel muon system consists of four stations interleaved with iron return yoke plates of the magnet. Twelve planes of drift tubes present in every chamber are organized in three independent sub-units called Super Layer (SL) made up four planes with parallel wires. Two SLs measure the coordinate in the bending plane (ϕ SL), the third measures the track coordinate along the beam (θ SL). In the outermost station, MB4, each DT chamber has only the 2 SLs that measure the r-ϕ coordinate.

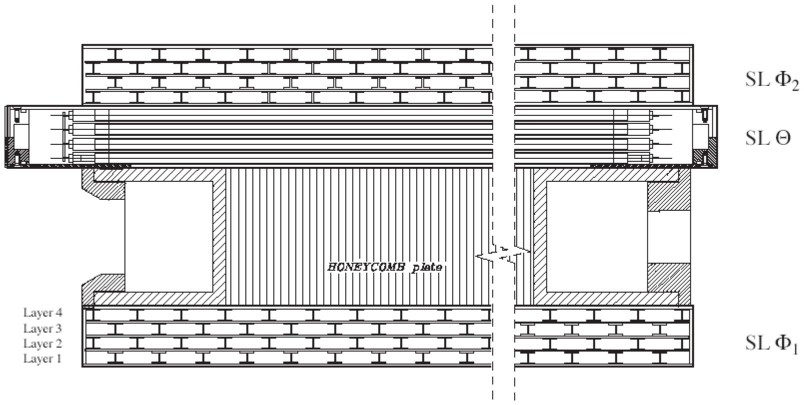


Figure 3: Layout of a DT chamber inside a muon barrel station.

Within a SL, the four layers are staggered by half a cell (see fig. 3), making it possible to use the correlation of the drift times in the different planes to compute the coordinate and the angle of crossing without any external time tag.

III - Activities

The period of my training program at Università degli Studi di Padova "Il Bo" started on April 15th and finished on July 15th. During the first week I contacted my advisor and prepared all the formalities to stay in Italy (Permesso di Soggiorno at the Questura, documents for the hostel and for the contract with the University of Padova).

In the second week I started my training, learning the CMS Software (CMSSW) version 0_6. This is the analysis code used in offline data analysis in CMS replacing ORCA/OSCAR (the old software), which provides the complete simulation-generation-digitization chain for Monte Carlo event generation, and is also to be used for physics analysis tasks. I did several tutorials and exercises about generation and digitization. It is important to note that all the tutorials were done in a local machine in Padova. This fact was problematic, as the tutorials were prepared for running under the lxplus machines at CERN and I did not have direct access to the required files, in order to do the tutorials. The problem was solved by my advisor using his CERN account to copy all these files to a local machine in Padova.

I started my training using an old version of CMSSW, but after two weeks using the version 0_6, my advisor decided to interrupt the training and wait for the new version. The release was late and I was only able to use some new features in the end of my last week in Padova.

The second part of the training consisted in performing some analysis to obtain information about the Muon System of CMS. For this, I used a rootuple containing the data of the cosmic challenge, taken on December 13th. This data was taken without magnetic field, and muon track reconstruction and identification were done using the Muon System standalone. The analysis was done using only the first sector of the central wheel, i.e., without superposition of the sectors (see fig. 4).

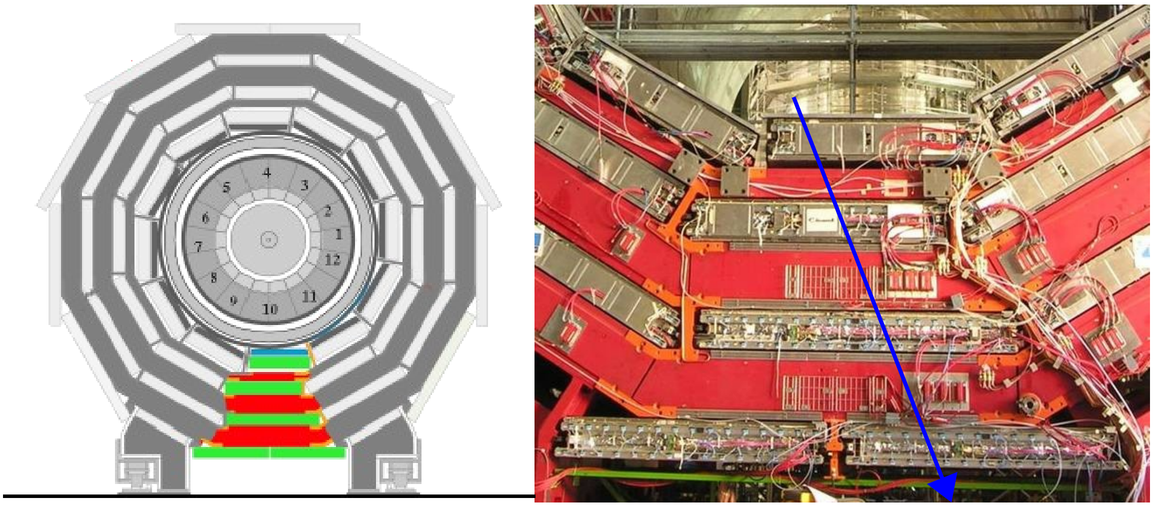
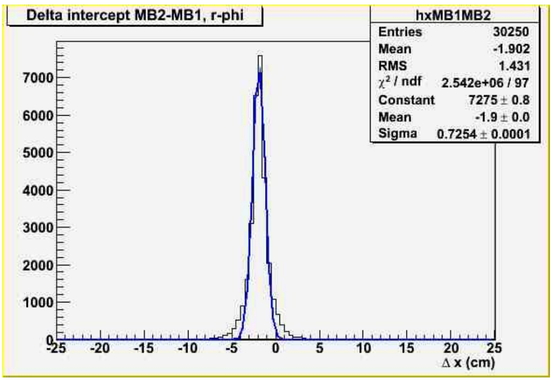
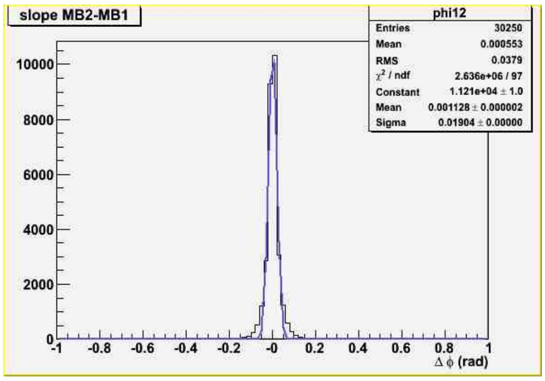


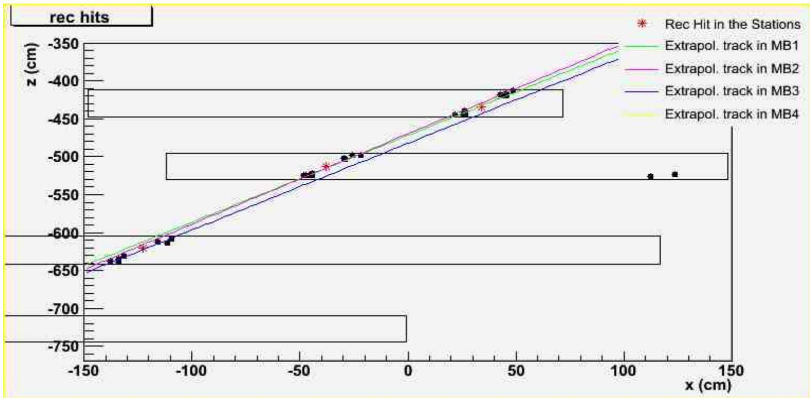
Figure 4: Transversal view of the barrel muon system (left) (credit by K. Hoepfner) and real photo of the region marked (right).

The first part of the training with the cosmic data of the Muon System consisted in check the reconstructed position and slope in each station. Following I check the difference between the slope measured in two different chambers in the Rϕ and Rz planes. This difference was used to do a naive estimative of the angular resolutions in ϕ and θ, respectively. After that, I repeated the procedure for the position in both planes, in order to check the resolution in x and in z. In the plots below (see fig 5), I show some of the results obtained for the x and ϕ resolutions.





I also implemented a script in C, running under ROOT, to study the extrapolation of the trajectories reconstructed in each muon station, in the Rϕ plane for one wheel, with more than 6 hits in the super-layers. The results of this study are shown in the following plot (see fig. 6):



I proceeded then to develop code to improve the analysis, in order to obtain a better result for the spatial and angular resolutions and the efficiency (in the x direction) of the muon reconstruction. The main improvements applied was:

- a geometrical cut in each station to prevent border's effects and to improve the reconstruction of the track;
- require more than 5 hits in each station in Rϕ plane and 4 hits in Rz plane;
- check if the extrapolated trajectory from MB3 was compatible with the position measured in MB2 using the resolution obtained previously.

The final results that were obtained for the standalone measurements taken in the Cosmic Challenge are shown below (see fig 7):

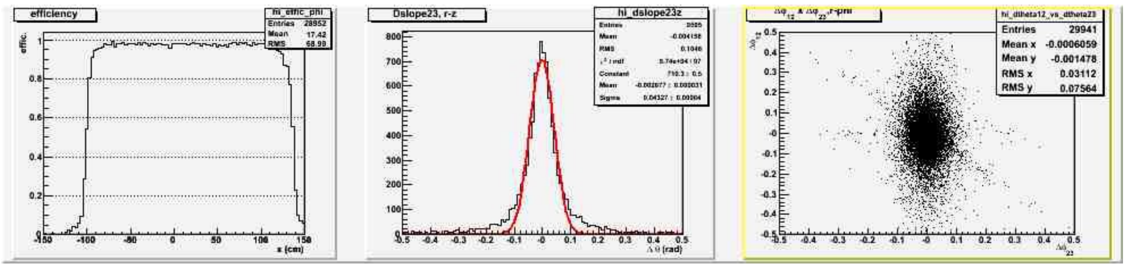


Figure 7: Efficiency of reconstruction in R-phi view (left), difference in theta measured in MB3 (trigger) and MB2 in R-z view (centre) and correlation between difference of phi measured in MB1 and MB2 and MB2 and MB3(right).

Due to a delay of the release of the latest version of CMSSW, it was only possible to use an old version (v.0_6). All the analysis was done using the software ROOT in a rootuple prepared by Dr. P. Ronchese. With the knowledge acquired during my stay in Padova, I will be able to implement in Rio de Janeiro the recent versions of the CMS Software and, eventually, repeat this analysis in the CMS framework.

The HELEN program gave me the chance to interact with my future research partners in High Energy Physics and was my first contact with CMS Software and analysis of CMS data.

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