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OPTICAL POSITION MONITORING SYSTEM FOR THE CENTRAL MUON DETECTOR OF THE CMS EXPERIMENT AT CERN

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Abstract − The CMS experiment (Compact Muon Solenoid) [1,2] is one of the experiments on the future Large Hadron Collider at CERN (European Organization for Particle Physics). To achieve the best performance in the reconstruction of the particle tracks the knowledge of the positions of the tracking detectors is required. In this paper the optical position monitoring system of the Central Muon part of the CMS Detector is described.

Keywords: Position Monitoring, geometrical network.

1. INTRODUCTION

The CMS is one of the two general-purpose experiments being built at the LHC proton-proton collider at CERN (European Organization for Particle Physics, Geneva, Switzerland). The CMS detector, constructed by an international collaboration of 153 laboratories from 33 countries will allow us to study the fundamental questions of physics: search for the Higgs boson up to a mass of *1* TeV, detect the presence of a new particles, carry out a wide research program in both quantum electrodynamics and cromodynamics at energies never reached before. The CMS detector is shown in Fig.1. It can schematically described as a series of different particle detectors of cylindrical shape around the interaction point closed by disk-shaped detectors of the same kind housed in a *4* Tesla solenoid magnet. The most inner subdetector, the Central Tracking System made up with silicon detectors and measures the tracks of charged particles. This subdetector is surrounded by the electromagnetic and hadronic calorimeters. The muon system, composed of four radial layers of individual muon chambers is fixed to the return yoke of the magnet. It is organized in a barrel geometry at big polar angles from the detector axis, this part of the Muon system is called the Central Muon Detector. At low polar angles the Muon Detector is organized in disks, this is the Endcap Detector. The overall dimensions of the CMS detector are as follows: diameter: *15* m, length: *20* m, total weight: *14000* t.

One of the design concepts of the CMS detector is that the event selection is based on the muon detection and reconstruction. From this aspect the Central Tracking and the System together with the magnet can be considered behaves as a compact muon spectrometer. The initial accuracy of the localization of a muon as measured by a muon chamber is in the order of $100x10^{-6}$ m . The trajectory of the muon is bent in the magnetic field created by the *4* T solenoid in such a way that the measurement of its sagita allows for the measurement of its momentum. The final precision in the measurement of the momentum will be given by the precision in the measurements carried out by the Central Tracker, those of the muon chambers in the Muon Detector, and the accuracy of the knowledge of the positions of the Muon chambers.

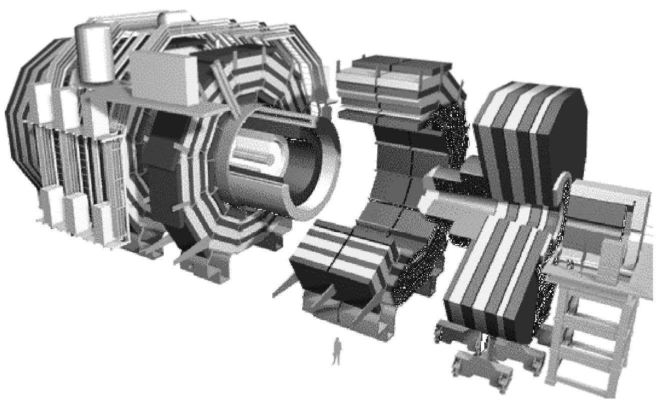


Fig.1. Three-dimensional view of the CMS experiment. The detectors are mounted on the *4* T solenoidal magnet. The muon detectors are mounted around the magnet in 4 layers interleaved with the three layers of the iron yoke for the return magnetic field. The Inner Tracker detector and the calorimeters are inside the coil of the magnet. The CMS experiment consists of an assembly of 5 central wheels and 2 Endcaps (3 disks each). These units can be separated during shutdown (as shown in the picture).

The accuracy of the determination of the positions of the muon chambers with traditional geodesy methods and the stability of their positions during the CMS operation cannot be guaranteed within $100x10^{-6}$ m. Three factors must be taken into consideration:

1. Accuracy of the positioning of the detector elements during the installation and after maintenance. According to the engineering calculations and test measurements the precision of positioning-repositioning can be guaranteed within few mm.

2. Deformations due to the effect of the magnetic forces on the return yoke. The expected longitudinal movements will range from several mm to *2* cm.

3. Position change of the detectors due to thermal effects. After studying the gradients across the muon detectors and their effects on the muon chambers and the structures that support them, these displacements will be in mm range.

Therefore a monitoring system (called also as alignment system) is required to continuously measure the positions of the chambers. The information provided by this monitoring system will later be used in the off-line analysis in order to introduce the corrections that will improve the track reconstruction performance of the system. As the best information in the muon momentum is obtained by combining the measurements on a given trajectory of the different subdetectors involved, the monitoring system has to provide information on the positions of the different components of the Central Tracker and the positions of the muon chambers in both the Central Muon Detector and the End-caps with respect to each other. To carry out these functions the full position monitoring system of the CMS detector has a modular organization:

1. The internal monitoring system of the Central Tracker. This measures the positions of the different parts of this subdetector.

2. The Central Muon Detector Position Monitor measures the positions of the muon chambers of the Central Muon Detector with respect to each other and with respect to some points called link points.

3. The Endcap Muon Detector Position Monitor measures the positions of the muon chambers of the Endcap Muon Detector with respect to each other and with respect to the link points.

4. The link system, which is the responsible to relate the measurements of all the three subsystems by transferring the positions of the link points to the Central Tracker system.

Due to the different geometry and the number of elements to be monitored the four subsystems have different solutions. The Central tracker, the Endcap and the link system is based on lasers. The Central Muon Detector Position Monitor is based on a different approach as described in the next chapter. But the common feature of all the four subsystems is that they provide an absolute measurement of the positions of all the monitored elements at any time, and the fact of switching them off an on will not affect the precision of the system.

The full alignment system is divided into three active planes separated by 60^0 according to the azimuthal distribution of the CMS Detector. The tracking subdetectors of CMS, namely the Central Tracker, the Central Muon Detector and the End-cap muon detectors are connected to these planes. We show the muon alignment scheme for an active plane on Fig.2. The Central Tracker information provides the common reference for all the independent active planes.

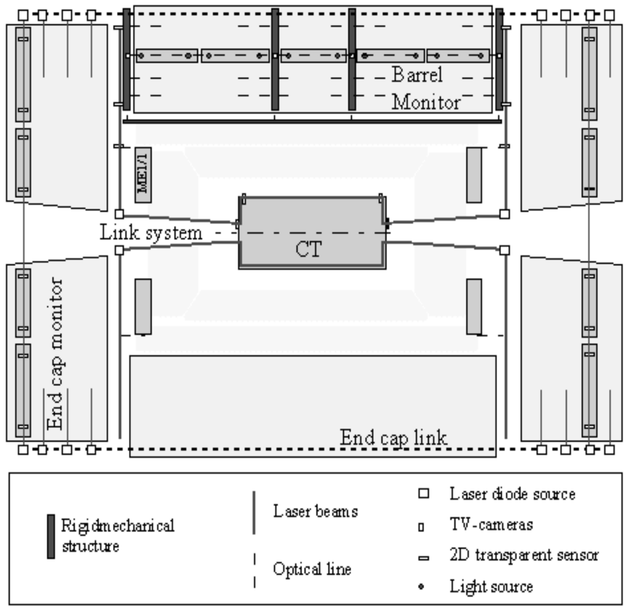


Fig.2. The full optical monitoring system of CMS is represented in the picture. It comprises 4 modules. The Central tracker (CT) has an internal monitoring system. The Muon Detector made up with 2 modules: the Central Detector and the End-caps. The module called "link system" makes the connections between the 3 other modules.

2. THE CENTRAL MUON DETECTOR POSITION MONITOR

In this paper the Optical Position Monitoring System for the Central Muon Detector is presented.

The schematic view of the Central Muon Detector with the monitoring system is shown in Fig.3. The chambers (Fig.4) to be monitored are mounted on the five *2.5*m wide barrel rings of the return yoke with a gap of about *15*cm between them. In each ring they are arranged in four radial layers at approximate radii of 4, 5, 6 and 7m respectively with dimensions between $2\times2.5\times0.3$ m^3 to $4\times2.5\times0.3$ m^3 (depending on the radius). The total number of chambers to be monitored is 250. The chambers are practically hidden in the iron yoke.

The required monitoring accuracy is determined by the requirements to the muon momentum resolution. In order to stay within the acceptable 20% degradation in the momentum definition, the knowledge of the chamber positions better than $150\text{-}350x10^{-6}$ m (depending on the radius) in the cylindrical coordinate around the detector axis, $0,5x10^{-3}$ m in the radial direction and 10^{-3} m in the detector axis is required [3].

There are additional technical problems linked to the particular conditions in which the system has to operate. The CMS detector is located in an underground cavern reachable only during the yearly maintenance stops. Also, the high beam energy and the huge beam flux of the LHC create a hostile radiation environment. At the central muon detectors the expected neutron fluence can reach 10^{11} neutrons/cm^2 during the planned ten years of operation. Therefore the system must be reliable and radiation-hard. For the same reasons the control of the system is carried out remotely from a control room located at *120* m from the CMS detector.

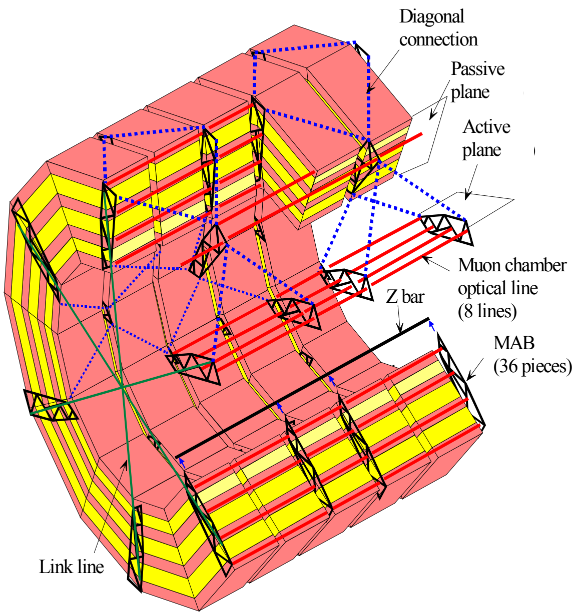


Fig.3. The schematic view of the central muon position monitoring system embedded in the Central Muon Detector system (muon barrel chambers in red, and among them the magnet return yoke in yellow). The system is based on a network of rigid mechanical structures, 36 MABs and 6 Z-bars, the optical connections between them and the optical connections between MABs and the barrel muon chambers. The position of the Barrel Muon system with respect to the Central Tracker is determined by means of the link lines indicated in the figure.

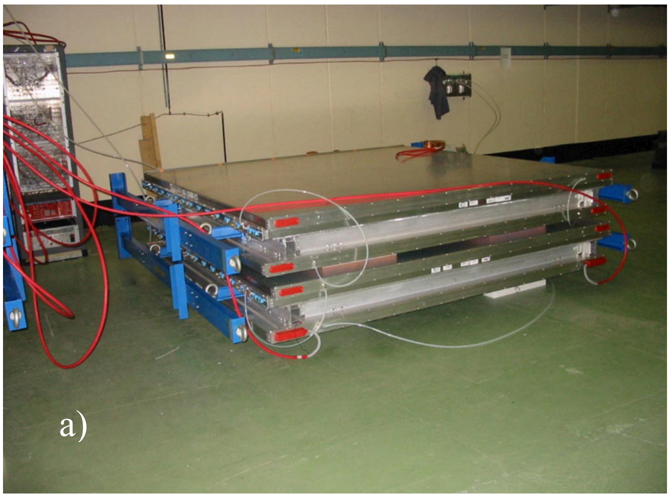
2.1 The system structure and its principle

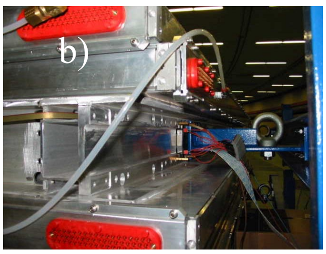
The working principle is based on a geometrical network of 36 rigid mechanical structures called MABs (Module for Alignment of Barrel) fixed to the rings of the return yoke. The chambers are equipped with light sources on their sides close to their corners. Each MAB contains video cameras, which observe the light sources mounted on the chambers. The light sources on the chambers are sending light in both directions parallel to the detector axis, so they can be observed from both sides. This establishes a connection between the MABs. The MABs are arranged in 12 sectors along the angular coordinate of the detector containing 4 or two MABs in an alternate way. Sectors with four MABs (called "active planes") are connected to sectors with two MABs (called "passive planes") via diagonal connections composed of light sources (mounted on the MABs of the active planes) and video-cameras (mounted on the MABs of the active planes. The last element of the system is the Z-bar under active planes (six altogether). The Z-bars contain light sources that are observed by video cameras mounted on the MABs of the active planes and oriented towards the Z-bar.

The rigid structures (MABs, Z-bars and the muon chambers themselves) and the optical connections (light sources observed by video-cameras) form a redundant geometrical network. The redundancy is achieved by setting a maximum number of interconnections between measured points and measurement points. The measurement of an object is carried out more than once from different positions within the network. This design strategy results also in the higher tolerance to faults of its elements.

2.2 The elements of the system

The light sources are bright red (670nm) LEDs (Stanley FH1011) housed in aluminium support. The total number of the LEDs in the system is about 10000. The MABs (and the Z-bars) are light structures composed of carbon-fiber tubes and plates to guarantee the mechanical stability within $50x10^{-6}$ m. The video-cameras are CMOS analog sensors sitting in an aluminium house. The house is the structural part of the MAB therefore the mechanical stability is guaranteed. The lens in front of the sensor is a f=$30x10^{-3}$ m ($80x10^{-3}$ mm for the diagonal connections) singlet with $3x10^{-3}$ m aperture placed at the focal distance. In this geometry the incoming light from the LED sources located at different distances (between *500* and $7000x10^{-3}$ m) from the video camera is forming a spot with circular symmetry, easy to process. The total number of the video cameras is 600 (about 16-17 per MAB in average).





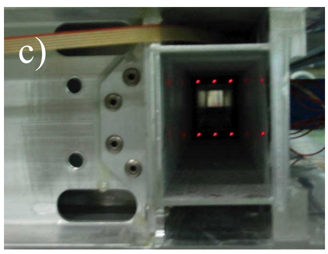


Fig.4. a) Two piled barrel muon chambers at CERN at the quality control facility. b) The chamber corner with the optical channel. c) The LEDs seen in the optical channel.

The MABs with the video cameras and the diagonal LEDs, the Z-bars with the LEDs and the muon chambers with the LEDs are preliminarily calibrated in geometrically known laboratory setups. The precision that can be achieved during the calibration is less than $50x10^{-6}$ m and $50x10^{-6}$ rad for the camera position (defined by the center of the lens) and the camera orientation (defined by the line between the center of the sensor and the lens) in the MAB coordinates. The positions of the LEDs mounted on the chambers are known with less than $70x10^{-6}$ m precision in the chamber coordinates. The LEDs on the MABs and Z-bars are determined by less than $50x10^{-6}$ m accuracy.

The video-images from each MAB are digitized and preprocessed in-place by local board-PCs built in PC104 standard. During the preprocessing of the image the centroid of the light spot corresponding to the observed LED is determined. The coordinates of the centroid are sent to the control room via local Ethernet connecting the 36 board-PCs and the main control computer. It is also the task of the main computer and the board-PCs to guarantee the synchronization of the LED and camera operations.

2.3 The geometry reconstruction

As the number of elements and the connections between them is enormous and the degree is redundancy is high the reconstruction is based on a program called COCOA [4] developed for this type of tasks. This is a universal program in which opto-geometrical systems consisting of mechanical structures, light sources, lasers, detectors, tilt-meters, etc can be described and analyzed. The first task is to build the COCOA model of the monitoring system containing all the elements and the results of the calibrations. Once the model exists, using the results of the measurements (the centroid coordinates) as input data the full geometry is calculated.

3. THE STATUS OF THE PROJECT

The full system will be operational at the start of the CMS experiment in 2007. Presently the R&D phase of the elements of the system including the radiation hardness tests is mainly finished and the construction of the calibration set-ups is in progress. The first test run of a partial system consisting of 10 MABs forming two neighbouring active planes and the passive plane between them is planned to be tested in 2005.

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4. KEY STATEMENTS

The System uses video cameras to observe light sources in order to measure the position of the chambers they are on. It monitors a very big number of parameters inside a very big volume, precisely and with demanding space constraints. It needs to be redundant in order to achieve the highest accuracy with the constraints to face. It needs to be radiation resistant. It also has to be simple, as the number of variables to handle is already big in itself. Finally, it has to be robust to operate in a potentially non-gentle scenario. The singularity of the project is given up to some extent by the challenge of its size, complexity and extraordinary conditions in which it will operate.

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