THE CMS LINK SYSTEM

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1. The CMS detector, muon momentum measurement and alignment.

The Compact Muon Solenoid (CMS) is a multi-purpose detector that is going to be installed in the future Large Hadron Collider (LHC) at CERN. Muons are one of the main physical signatures of the expected new physics. The muons are going to be detected by the Central Tracker (CT) (Si pixels, Si microstrips and microstrip gas chambers with a position resolution of a few tens of micron) and the Muon Spectrometer (MS) (drift chambers with a hundred microns position resolution) [1].

Both, the CT and MS can provide an independent muon momentum measurement, but for all η and momentum values the highest precision for muon momentum measurement is achieved when the muon tracks are reconstructed using both tracking detectors [2]. The calorimeters and the solenoid volumes separate about three meters the CT and the MS (see Figure 1). It has been shown that the alignment of the CT with respect to the MS can not be guaranteed by a software alignment in a reasonable time scale [3]. Therefore, an optomechanical system (the multipoint link system) have been designed to monitor, on-line, the relative position of both subdetectors providing a common reference frame for both of them [4].

If we allow a maximum degradation of the momentum resolution of 20% due to the misalignment, a precision of 100-150 μm is required to the system for all η and momentum values [5].

2. The multipoint system.

The local alignment of the muon barrel spectrometer determines the relative position of the muon chambers with respect to themselves and also with respect to a carbon fiber rigid structure called MAB (Module for the Alignment of the Barrel). There are a total of 36 MABs distributed in the boundary planes of each muon spectrometer sector. The planes with external MAB located between the barrel and end cap regions are called active planes. The total number of active planes is three, with 4 external MABs per plane [6] (see Figure 2).

The task of the multipoint monitor is to *determine the position of each external MAB with respect to the tracker, consequently* there is a total of 12 multipoint monitors. Since the position of each external MABs is know with respect to the local reference frame of the muon spectrometer, each monitor can *define the relative position between the tracker and the muon spectrometer* independently, increasing the robustness and redundancy of the system

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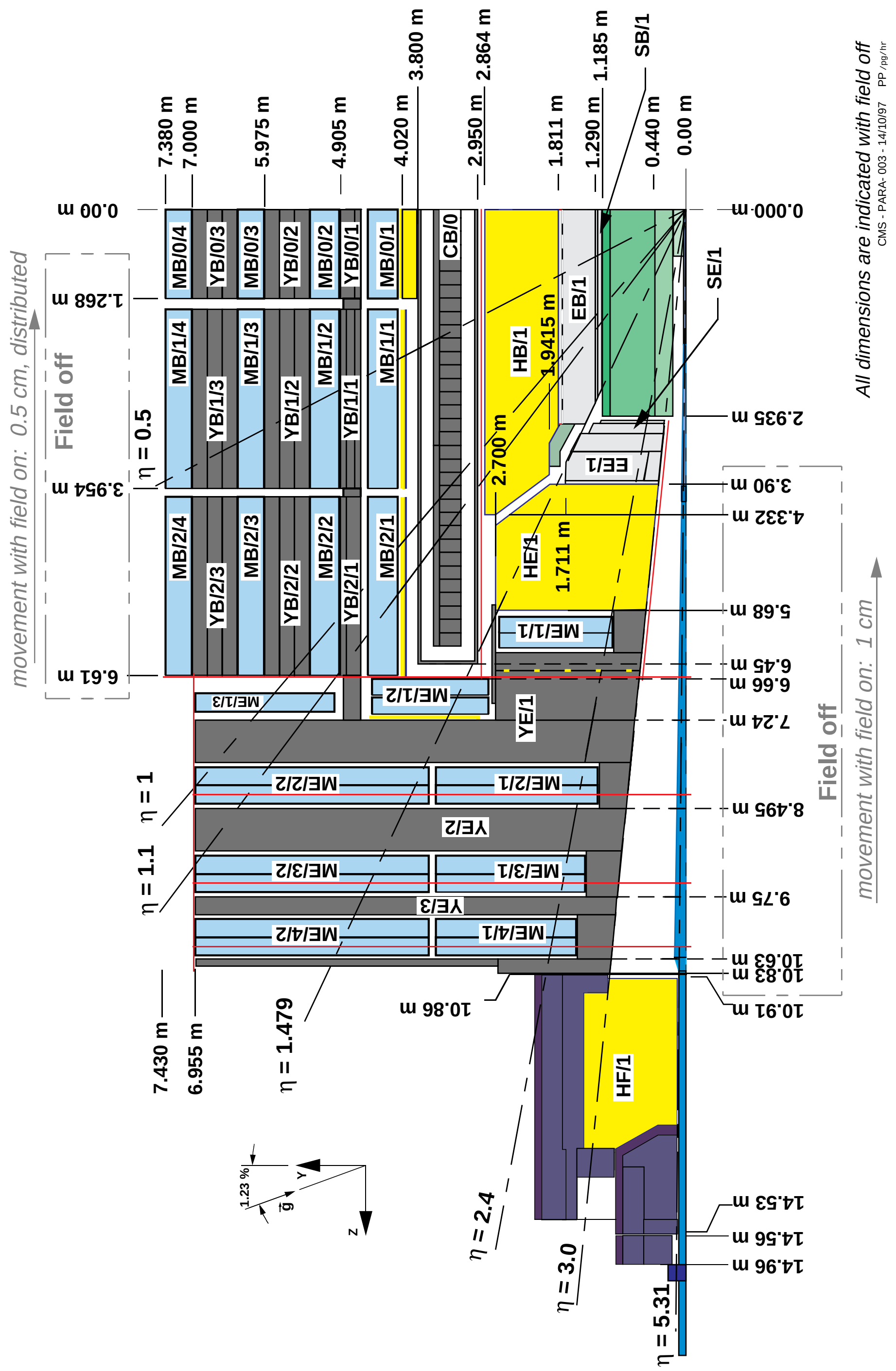

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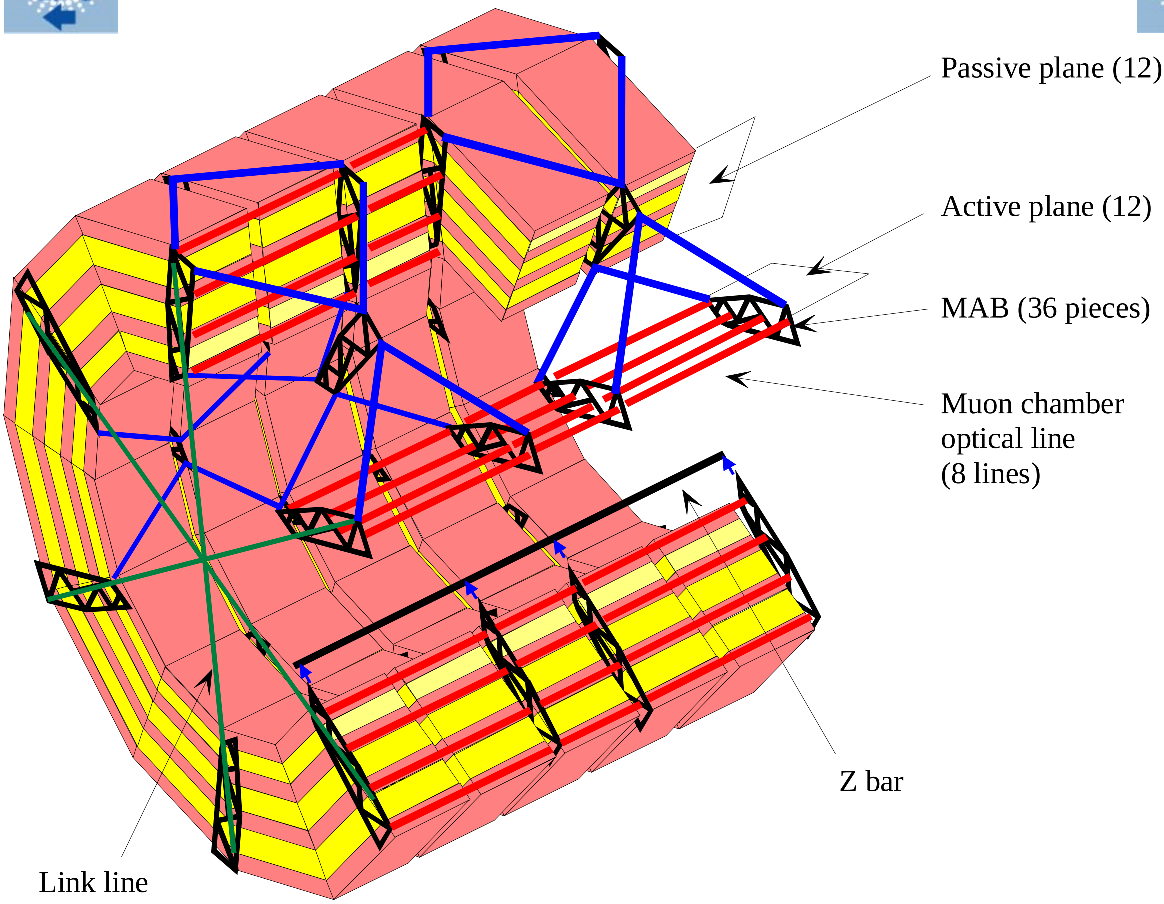
Figure 1 –CMS longitudinal view: On green the central tracker, on white and yellow the calorimeters and on blue the muon spectrometer



ructures, active planes

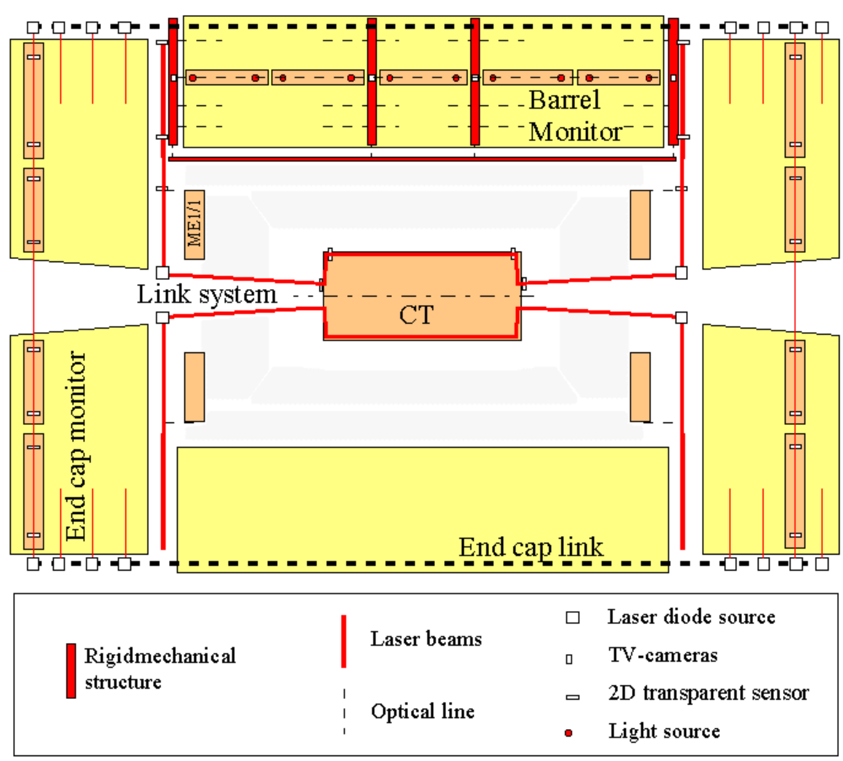


Figure 3 Longitudinal view of a active plane. The MS and CT volumes are shown with the alignment reference lines created by the different alignment subsystems.

2.1 Principle of measurement

The current design of the multipoint monitor combines the use of different techniques. To connect the tracker with the MAB, the systems uses two *multipoint straightness monitors* based on 2D DPSD semitransparent sensors and laser beam as reference. One of the laser reference lines goes to the MAB, intersecting the two transparent sensors there located. The other laser line goes to the CT, traversing a modified periscope (to bypass the tracker volume envelop, avoiding holes but keeping enough lever arm between sensors) and also being detected by the semitransparent sensors located at the Tracker. The two reference laser lines of each straightness monitor have a common origin, they are created by the same source, what is used as a constrain to transfer the tracker coordinates to the MAB.

To complete the measurement, two 1D measurements along the laser beam are done. These measurements are based on a distance monitor which consists on a carbon fiber tube coupled to a proximity sensor. Finally, the ϕ orientation (rotation around the longitudinal z axis) is defined by mean of two laser levels, one located on the MAB and the other one on the Tracker.

2.3 The laser source.

The laser source has to generate three reference laser beams, the third beam have been added for the direct alignment of the forward station ME1. The relative position between beams has to be precisely calibrated. A prototype has already been built and also some preliminary calibration has been performed. For the current design the laser light is generated by a laser diode module coupled to an optical monomode fiber. The light coming from the fiber is collimated and partially reflected by a free space beam splitter, creating two laser beam, finally the third laser beam is generated passing the transmitted beam trough a compensated rhomboidal prism, which generates two parallel optical beams. The radiation hardness of the optical parts seems to be guaranteed (for instance using fused silica). It is though an open issue to find a radiation resistant optical glue.

The calibration precision obtained during the first test with a prototype is better than 3μrad [7]. The remaining issue with the source is its motorization. The source is installed on the end cap iron, which is expected to move of the order of centimeters due to the magnetic field. A repositioning of the source is therefore needed to guarantee that the laser beams are always intersecting the transparent sensors. Conventional solution based on an electrical motor and magnetic shields are unfeasible because the elevated magnetic field of 4T, other possible solutions based on hydraulic mechanism are under study.

2.4 The semitransparent sensors.

The current proposal for the semitransparent 2D DPSD sensor is the ALMY. The ALMY sensors where initially designed by the Max Planck Institute of Munich for the alignment of the ALTLAS muon spectrometer [8]. The main advantages of the detector are the large active area,

good spatial resolution about 5 µm, radiation and magnetic field resistance. The main drawbacks are the aging and bad optical behavior of the transmitted beams. Our latest effort on the R&D of these detectors is summarized on [9] its current status can be find on [10]
Possible backup solutions based on a small optical bench including 2D DPSD and beam splitter has been studied [11].

2.5 The periscope.

As it has been already said, in order to bypass the central tracker envelope using the free passages of the detector, a “modified” periscope have to be used. The modified adjective is used because the incoming and the outcoming laser beam are not parallel, so the two mirrors are slightly tilted. The other modification resides in replacing the first mirror by a beam splitter and then the transmitted beam is detected on a semitransparent sensor. A first prototype has been recently built and a calibration procedure has been tested [12].

2.6 The laser levels.

The current prototype of laser level includes a tiltmeter [13] and a laser module. The tiltmeter give us the angle with respect to the gravity with a precision better than 5 µrad and its radiation resistance has been successful tested. The angle between the tiltmeter "horizontal" and the laser beam must be calibrated. Once the laser level is calibrated we can know the angle of the laser with respect to the gravity. A final resolution about 10 µrad is expected to be achievable.

2.7 The distance monitors.

There are two distance measurements per multipoint monitor along the directions defined by the laser beams. The current design is based on a carbon fiber tube coupled with a proximity sensor. The tube is used to simultaneously protect the laser beam and assure the rigidity in the direction of measurement against thermal gradients and humidity.

A prototype of a carbon fiber tube of 3.2 m has been already built and tested [14]. The prototype shows a 10 µm stability for a humidity variation of the 60%, and a thermal stability better than 6 µm/ºC. The proximity sensor is still an open issue, a prototype have been built [15] and also some commercial sensor have been tested. The resolution and range requirements can be fulfilled with a wide range of sensor, but the radiation resistance remains the key point.

2.8 The expected performances.

With the software Simulgeo++ [16] we have simulated the performances of the multipoint monitor, using as input for the simulation the expected resolutions and calibration precisions of the current components. The table 1 summarized the nominal values used for the simulation:

Table 1 – The nominal precisions used for the geometrical simulation

Sensor ALMY	5µm
Transfer. ALMY-CT	50µm
Transfer. ALMY-MAB	20µm
Periscope Angular position	100µrad
Periscope linear position	500µm
Angle between periscope beams	10µrad
Distance measurement	80µm
Tiltsensor	5µrad
Laser level calibration	10µrad
Calibration of the angle between source beams	10µrad
Calibration of the offset beween beams of the source	20µm

We have just simulated a quarter of an active plane. The simulation results for the nominal precisions, and also how its performance is affected when we modify the input value of some parameters are summarised on the Table 2. The critical figure for the momentum measurement is the resolution achieved for the transversal coordinate σx. We can see that the final result is within the 100-150 µm.

Table 2 – Geometrical simulation results.

	Precision	σx (µm)	σy (µm)	σz (µm)
	Nominal	104.8	128.5	143.0
Trans. ALMY-CT	20 µm	84.1	112.9	133.0
	100 µm	157.1	172.7	171.3
	150 µm	217.8	227.8	209.7
	200 µm	281.5	287.8	253.8
Angle Source	5 µrad	104.8	128.5	138.9
	20 µrad	104.8	128.5	158.4
Angle Periscope	5 µrad	93.4	111.1	117.4
	20 µrad	141.7	182.0	217.3
Angle Laser level	5 µrad	99.1	128.5	143.0
	20 µrad	125.0	128.5	143.0

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