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# Motions of CMS detector structures due to the magnetic field forces as observed by the Link alignment system during the test of the 4 T magnet solenoid

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ABSTRACT

This document describes results obtained from the Link alignment system data recorded during the Compact Muon Solenoid (CMS) Magnet Test. A brief description of the system is followed by a discussion of the detected relative displacements (from micrometres to centimetres) between detector elements and rotations of detector structures (from microradians to milliradians). Observed displacements are studied as functions of the magnetic field intensity. In addition, the reconstructed positions of active element sensors are compared to their positions as measured by photogrammetry and the reconstructed motions due to the magnetic field strength are described.



## 1. Introduction

From the point of view of muon measurement, the Compact Muon Solenoid (CMS) Detector [1–3] is a muon spectrometer and the detection of these particles is favoured. Attending to the magnet field intensity, two different technologies are employed for their measurement. In the barrel region, surrounding the coil of the solenoid, four layers of drift chambers, interleaved with the return iron yoke, make a redundant measurement of the muon momenta. A muon chamber is made of three superlayers. Each superlayer is made of four layers of drift cells. The drift cell is the basic unit measuring the drift time of a muon, providing a spatial resolution of 250 μm. Each superlayer will contribute with the measurement of one coordinate. Two superlayers measure the $r\phi$ coordinate and one layer measures the $z$ coordinate. The mechanical design of a drift chamber is driven by the precision in the determination of a point of the muon track, 100 μm, which is obtained by a fit of the individual hits in each cell.

The muon drift chambers will be subject to variable residual magnetic fields, below 0.4 T for all the chambers except for the MB1 chambers near the endcaps. There, the magnetic field will rise up to 0.8 T. In the region of the ME1/1 chambers the field will be $B_z \approx 3$ T. For such magnetic field intensity the operation of the muon drift chambers is limited, since the drift cell escapes the linear regime. CMS uses, at the endcaps, other gaseous detectors called Cathode Strip Chambers (CSCs) that can operate in large and non-uniform magnetic fields without significant deterioration of performance. CSCs are multiwire proportional chambers in which one cathode plane is segmented into strips running across wires, both of them instrumented, giving 2D information of the particle passage. Due to the intense magnetic field, the muon trajectories bend more in the vicinity of the first endcap station where the higher precision is required (75 μm). For the rest of the chambers the precisions will be of about 150 μm.

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**Table 9**
Difference in position (in mm) and orientation (in mrad) between the fitted values at the quoted $B$ field and $B=0\,T$ at the end of Phase I using COCOA for the YB + 2 Disk (w.r.t. the tracker).

| YB + 2 Phase I | $\Delta_X$ | $\Delta_Y$ | $\Delta_Z$ | $\Delta_{AngX}$ | $\Delta_{AngY}$ | $\Delta_{AngZ}$ |
|---|---|---|---|---|---|---|
| $B=2\,T$ | 0.81±0.35 | −0.24±0.38 | −0.58±0.63 | −0.51±0.09 | 0.23±0.12 | 0.35±0.08 |
| $B=3\,T$ | 1.28±0.35 | 1.26±0.38 | −0.14±0.63 | −0.30±0.09 | 0.91±0.12 | −0.07±0.08 |
| $B=3.8\,T$ | 1.00±0.35 | 1.37±0.38 | −0.37±0.63 | −0.51±0.09 | 1.27±0.12 | −0.37±0.08 |
| $B=4.0\,T$ | 1.21±0.35 | 2.28±0.38 | −0.03±0.63 | −0.63±0.09 | 1.71±0.12 | −0.33± 0.08 |

**Table 10**
Difference in position (in mm) and orientation (in mrad) between the fitted values at $B=3.8\,T$ in Phase I using COCOA and $B=0\,T$ for ME1/1, ME1/2 and MAB structures.

| $B=3.8\,T$ Phase I | $\Delta_X$ | $\Delta_Y$ | $\Delta_Z$ | $\Delta_{AngX}$ | $\Delta_{AngY}$ | $\Delta_{AngZ}$ |
|---|---|---|---|---|---|---|
| ME11-75 | 1.60±0.34 | −0.09±0.27 | −2.36±0.39 | – | – | – |
| ME11-255 | 0.08±0.31 | 0.97±0.28 | −2.67±0.36 | – | – | – |
| ME11-315 | −0.36±0.28 | −0.51±0.29 | −1.22±0.35 | – | – | – |
| ME12-75 | 2.02±0.38 | −1.82±0.78 | 1.97±0.39 | – | −3.87±0.72 | −0.38±0.69 |
| ME12-255 | −0.84±0.34 | −2.00±0.64 | 1.45±0.36 | – | −3.91±0.72 | −0.35±0.69 |
| ME12-315 | 0.21±0.50 | −0.80±0.50 | 3.10±0.35 | – | – | – |
| MAB-75 | – | – | 1.49±0.76 | – | −0.44±0.08 | −0.32±0.08 |
| MAB-255 | 1.25±0.50 | −1.18±0.66 | −4.16±0.70 | – | 0.28±0.16 | −0.10±0.16 |
| MAB-315 | −0.13±0.67 | −0.27±0.64 | 2.67±0.73 | – | 0.32±0.19 | −0.12±0.19 |

– plain lines indicate degrees of freedom not measured in the fit.

**Table 11**
Difference in position (in mm) and orientation (in mrad) between the fitted values at the quoted $B$ field in Phase I and $B=0\,T$ using COCOA for the ME1/2 chamber placed at 255° (w.r.t. YE + 1).

| ME12-255 Phase I | $\Delta_X$ | $\Delta_Y$ | $\Delta_Z$ | $\Delta_{AngX}$ | $\Delta_{AngY}$ | $\Delta_{AngZ}$ |
|---|---|---|---|---|---|---|
| $B=2\,T$ | 1.10±0.34 | −2.15±0.64 | −0.31±0.36 | – | −1.68±0.07 | 0.23±0.07 |
| $B=3\,T$ | 0.10±0.34 | −1.68±0.64 | 0.21±0.36 | – | −2.71±0.07 | −0.14±0.07 |
| $B=3.8\,T$ | −0.84±0.34 | −2.00±0.64 | 1.45±0.36 | – | −3.91±0.07 | −0.35±0.07 |
| $B=4.0\,T$ | −0.75±0.34 | −1.73±0.64 | 1.06±0.36 | – | −4.01±0.07 | −0.35±0.07 |

**Table 12**
The difference in position (in mm) and orientation (in mrad) between the fitted values at the quoted $B$ field values in Phase II and $B=0\,T$ using COCOA for the YB + 2 Disk (w.r.t. YE + 1).

| YB + 2 Phase II | $\Delta_X$ | $\Delta_Y$ | $\Delta_Z$ | $\Delta_{AngX}$ | $\Delta_{AngY}$ | $\Delta_{AngZ}$ |
|---|---|---|---|---|---|---|
| $B=2\,T$ | 0.05±0.36 | −0.34±0.38 | 5.12±0.67 | −0.42±0.10 | −0.23±0.12 | −0.22±0.10 |
| $B=3\,T$ | 0.06±0.36 | −0.26±0.38 | 8.70±0.67 | −0.63±0.10 | −0.37±0.12 | −0.02±0.10 |
| $B=3.8\,T$ | −0.02±0.36 | −0.17±0.38 | 13.30±0.67 | −0.72±0.10 | −0.31±0.12 | 0.07±0.10 |
| $B=4\,T$ | −0.09±0.36 | −0.17±0.38 | 14.34±0.67 | −0.70±0.10 | −0.09±0.12 | −0.19±0.10 |

**Table 13**
Difference in position (in mm) and orientation (in mrad) between the fitted values at the quoted $B$ field in Phase II and $B=0\,T$ using COCOA for the ME12 chamber placed at 255° (w.r.t. YE + 1).

| ME12–255 Phase II | $\Delta_X$ | $\Delta_Y$ | $\Delta_Z$ | $\Delta_{AngX}$ | $\Delta_{AngY}$ | $\Delta_{AngZ}$ |
|---|---|---|---|---|---|---|
| $B=2\,T$ | −0.96±0.38 | −0.71±0.63 | 0.27±0.38 | – | −1.89±0.08 | −0.28±0.07 |
| $B=3\,T$ | −0.18±0.38 | −1.48±0.63 | 0.87±0.38 | – | −3.12±0.08 | 0.11±0.07 |
| $B=3.8\,T$ | −0.37±0.38 | −1.94±0.63 | 1.74±0.38 | – | −4.23±0.08 | 0.09±0.07 |
| $B=4.0\,T$ | −0.71±0.38 | −2.01±0.63 | 1.18±0.38 | – | −4.57±0.08 | −0.09±0.07 |

commissioning of the four-Tesla Magnet. The test (Magnet Test and Cosmic Challenge) took place in the SX5 CMS assembly Hall at CERN. About 5% of the muon detector was also commissioned with cosmic rays.

A quarter of the Link alignment system was installed and operated during the test. The readout electronics, DAQ and detector control systems, integrated into the DCS (Detector Control System) environment, were also successfully tested. The reconstruction procedure was established and for the first time applied to a sizable set of data recorded by the system. Calibrations of individual sensors and laser holder structures, 3D measurements of sensor mounts and associated mechanics, and survey and photogrammetry