Hardware-based CMS Alignment

Iván Vila on Behalf of CMS alignment group
Instituto de Física de Cantabria [CSIC-UC]
Outline

- **Introduction**
  - Tracking at CMS
  - The alignment task
  - Steps toward a Hardware alignment.

- **Alignment subsystems overview**
  - Inner tracker
  - Global alignment: Link system
  - Muon spectrometer: Barrel, Endcap

- **Initial Magnet Test and Cosmic Challenge “lessons”**

- **Summary and conclusions**

Thanks to Bruno, Martin, Pablo, Vladimir and Zoltan for their help and plots
Introduction – CMS Tracking

- 4 Teslas
- Gradients up to 600 Gauss/cm
- Complex field map

Range of expected Motions:
- ~1-3 cm from B on/off
- < 500 T and humidity

- Hard radiation environment
- Photons, neutrons, charged hadrons

- Dose: 1 - 100 x 10^3 Gy (10 years)
- Fluence 5 x 10^{10} - 2 x 10^{14} n/cm^2 (10 years)

- Magnetic Field
- ~100 μm
- ~20 μm
- ~75-150 μm
Introduction – Alignment Overview

- Hardware alignment (position monitoring) tasks:
  - Silicon tracker internal alignment
  - Muon spectrometer internal alignment:
    - Barril zone
    - EndCap zone
  - Global alignment: Relative positioning of TK wrt Muon spectrometer
    - Link system.

- Different geometries, tracking technologies, requirements ⇒ 4 systems based on different technologies.
Intro. Common road map to Hw align.

System Design
- Selection/calibration of components/devices
- Assembly/mounting/fiducialization of components on “rigid” supporting structures
- Installation and adjust of the system in the detector

Design modification

Geodesy grids, photogrametry and other metrology technologies are a must

Thanks to CERN TS-SU Survey Group
TK local Alignment – LAS system

BS: Beam Splitter  AT: Alignment tube  AR: Alignment ring

TID and Pixel not in LAS!
Main advantages:

- Particle tracks and laser beam share the same sensors removing the need of any mechanical transfer.
- Minimum interference with Silicon support structures.
- No precise positioning of the aiming of the collimators. The number of measurements has to be redundant enough.
LAS – Optical treatment of sensors

- 10 mm hole in aluminum backside coating
- All sensors with anti-reflective coating
  Transmission measured to be
  14-20% (R4) and 13-18% (R6)
  (at $\lambda$=1075 nm)
- Reflectivity $\leq 6\%$
LAS – Collimators/splitters

Colinearity of laser beams meas. at 50μRad
LAS – Performance @ TEC integration

RMS of Residuals in first Sector: <70 μm

Reproduceability: 10 μm
Global Alignment – Link System
Laser-based Multipoint monitor
Links MAB – AR & TK-ME1

Beam Laser

Distance tube

MAB X 6

ME1/2 Zone

ME1/1 Transfer

YN1 Zone

η =3 Zone

Tracker Zone

Laser source

Link Disk

MAB Zone

Zona ME1/1
CF pillar attached directly to Disk 10 (outside the cold mass and tension-free support design)
3D relative position of AR wrt silicon supports of disc 10 are measured in Aachen
Link – Semitransparent ASPD sensors

- At lot of R&D on amorphous silicon semitransparent sensors
  - Improved version based on previous “ALMY” sensors for Atlas muon alignment

Deflex ~Tens of μRads  
Deflex ~few μRads

Used as a tool at the geodesic grid for calibration too!
Link Calibration geodesic network

Calibration bench 1:1 scale
Muon Barrel Local Alignment

Highly redundant triangulation measurement.

LED sources installed in the muons chambers monitored by Video cameras located in rigid CF structures (MAB)
Muon Barrel – Calibration challenge

- ALL muon chambers are instrumented and monitored
  - Thousands of components are to be installed and “calibrated” before installation...
Muon barrel second challenge

- Recognition of real vs. reflected LED spots

This is a real image taken on forks installed on a chamber. Larger dots belong to the closer fork, while smaller dots are spots of the farther fork. Inside the red markers the real spots can be seen. All the other spots are reflections.
Barrel – First “results”

- Event before starting... wire layer “SL3” nominal location from calibration.

Distribution of the Y translation

Distribution of the X translation

Bias > 2mm
Muon EndCap Local Alignment

- Straight line monitors + potentiometers network
Muon Endcap – “Transparent” sensors

- Crosshair laser beam + CCD window frame
Muon Endcap – Hardrad CCD?

Fig 1. Dark current spectra for irradiated CCDs, taken with the new COPS prototype. The number next to each spectrum is the corresponding radiation dose, in neutrons/cm². The lowest line corresponds to a non-irradiated CCD.

Fig 3. Raw spectra of two of the irradiated CCDs, showing the peaks produced by the laser lines.
Magnet Test and Cosmic Challenge a.k.a MTCC

Very significant fraction of all the muon alignment system commissioned.

Let’s switch the magnet on and see how things move:

Aims:
- System Commissioning (Hard & Control)
- Check Detector Assembly Tolerances & field effects vs system dynamic range
- Monitor Iron deformation (endcap disks)
- Extract initial CMS geometry from $B = 0$ T (Optical & Cosmic)
- Compare Cosmic data vs optical alignment (@ $B$: 0 and max field)
MTCC aftermath (very, very preliminary)

- What we have learn ?
  - How (some)things move (next)
  - How (not) to install/adjust some of the components.
  - The actual help (accuracy) we can expect from survey at field B=0.
  - Installation tolerances far from promised in some cases.

- What we have encounter?
  - “Anticipated” issues (not all of them solved).
    - Crashes when closing the yokes.
    - Difficult adjustments of components.
  - Non anticipated issues (sensitivity to B of electronics.)
MTCC – First results/observations

- Real time monitoring of Iron yoke movements vs. magnetic field.
- Track vs. Muon chamber Survey (Sector 10)
Summary

- Hardware alignment systems extremely complex (thousands of r/o channels)

- Large collaborative effort (Atomki, CERN, Ciemat, Fermilab, Florida, Cantabria, RWTH, University of Debrecen...)

- Many ad-hoc solutions & innovative developments.

- This is just a very coarse overview...*precision* is in the details.

- First performances under real fire (MTCC) tell as that we are in the right track toward a “Fast” alignment, BUT there is still a long way to go...
Local TK alignment:
- Gaussian profile laser lines monitored with optically treated microstrips detectors.

Local alignment of $\mu$-spectrometer (Barril):
- LED placed on chambers and monitored by video cameras on very rigid FC structures

Local alignment of $\mu$-spectrometer (EndCap):
- Cross-hair laser profiles monitored by ccd frames on top of the chamber covers.

Global alignment:
- Gaussian profile laser lines monitored by custom made semitransparent PSD sensors on top of rigid FC structures.
Alignment systems - The challenges

- Barril Muon spectrometer:
  - 240 chambers to be monitored directly with a few hundred microns precision

- End Cap Muon spectrometer:
  - Precision better than a few hundreds of micron.

- Global alignment: Link system
  - Linking the TK and $\mu$-spectrometer reference frames with a few hundred microns and tens of microRads.