Outline

- The CMS experiment at the LHC at CERN
- Alignment & calibration goals & challenges
- Global alignment & calibration workflow
- Alignment methodology
- CSA08 challenge
- Cosmics challenges (CRAFT)
- Summary & Outlook

Concrete examples will focus on alignment
The CMS Detector

- Pixels
- Tracker
- ECAL
- HCAL
- MUON Dets.
- Superconducting Solenoid

Total weight: 12500 t
Overall diameter: 15 m
Overall length: 21.6 m
Magnetic field: 4 Tesla

http://cms.cern.ch
The CMS Detector (cont’d)

- Super-conducting solenoid
  - large dimensions: length 13m, diameter 6m
  - central tracking and calorimetry inside the magnet
  - strong field (4T, working point at 3.8T)
  - stored energy at full field 1.6 GJ

- Tracker
  - Si-Pixel Detector with 66M pixels (100 *150 $\mu$m$^2$)
    - 3 barrel layers
    - 2*2 Endcap wheels
    - 4.7 < $r$ < 10.2 cm
  - Si-Strip Detector with 10M strips in 10 layers and > 200 m$^2$ of silicon
    - 20 < $r$ < 116 cm
    - 80–184 $\mu$m pitch
  - largest Si tracker ever built
CMS Tracker
The CMS Detector (cont’d)

- Muon System
  - precision measurements inside an instrumented iron yoke
    - Barrel Drift Tubes (DT): 4 Stations of 32 $r\phi + 12$ $z$ measurements
    - End cap Cathode Strip Chambers (CSC): 24 layers in 4 stations
    - interleaved RPC trigger layers (6 in the barrel, 3 in the end caps)
  - independent momentum measurement
  - optical alignment system
The CMS Detector (cont’d)

- **Electromagnetic Calorimeter**
  - high granularity with \( \sim 83000 \text{ Pb WO}_4 \) crystals
  - 25 \( X_0 \) for perp. passage

- **Hermetic Hadronic Calorimeter**
  - with barrel, endcap and forward sections (Brass-Scintillator)

Electromagnetic Calorimeters
Hadron Calorimeters
Inside the coil
Coverage up to \(|\eta| = 5\)

19-Jan-2009
Alignment & Calibration Goals & Challenges
Alignment & Calibration Goals & Challenges

- Ambitious goals in terms of detector resolution → essential for obtaining maximum in terms of physics in the LHC environment
- Resolution is determined by quality of alignment & calibration
  - calibration of a large number of detector channels
  - alignment of $O(20000)$ detector objects
  → rely on state-of-the-art methods
- For fast analysis of the data, already the first processing of a data sample should have constants as much up-to-date as possible
  → prompt alignment & calibration
  → need fast turnaround for algorithms
  → this is also a computational challenge
- Large data rate
  → need robust framework to handle alignment & calibration
DESY + Uni HH in CMS
Alignment / Calibration

- Alignment & calibration conveners: R. M. + David Futyan (IC)
- Alignment software coordinator: Gero Flucke

- Tracker alignment:
  - Erik Butz, Jula Draeger, Holger Enderle, G.F., Johannes Hauk, Kolja Kaschube, Claus Kleinwort, Andrea Parenti, Justyna Tomaszewa

- Calorimeter Calibration Group
CMS Alignment & Calibration Strategy
Alignment & Calibration Strategy

- Generally classify workflows by their latency
  1. Detector-near calibrations (pedestals, gains etc)
     - usually determined online
  2. Prompt calibrations → constants determined offline in prompt calibration workflow
     - constants are determined synchronously with data-taking within “prompt calibration loop”, and used in first full reconstruction of data sample
  3. Long-range calibrations
     - constants are determined using a data sample accumulated over a longer range of time
       - results in more subtle corrections
       - example: Z→μμ events for alignment
- applied in re-reconstruction campaigns
CMS Computing Infrastructure for Alignment & Calibration

- At the detector (point 5):
  - DAQ & HLT
  - event buffering
  - creation of streams
- At Tier-0:
  - creation of Primary Datasets
  - express & prompt reconstruction, creation of AlCaReco skims (more details in the following)
- At CAF (CERN Analysis Facility):
  - perform alignment & calibration workflows
  - constants validation

see Matthias Kasemann’s presentation from last week for more details on Computing Model
CMS Prompt Calibration Loop

- **Storage Manager**
- **Alignment & calibration**
- **Commissioning/Physics DQM**
- **ORCON**
- **ORCOF**

**Processes:**
- **Prompt reconstruction** (within 24 h after align/calib)
- **Express reconstruction** (within 1-2 h)

**Stages:**
- **HLT**
- **CAF**
- **Primary Datasets**
- **Repacker**

**Notations:**
- **P5**
- **T0**

*including AlCaReco skims
The Prompt Calibration Loop

- In addition to the physics main stream, the storage manager at P5 produces the calibration & the express stream
  - these contain specially selected subset of events (in total ~20%, initially more) of the total data bandwidth, chosen according to trigger bits, for alignment & calibration, detector & trigger commissioning, fast physics validation
- While the main data stream events are buffered at T0, express & calibration streams are passed through an express reconstruction within ~1 hour. Reconstructed data and AlCaReco skims (see later) are transferred to the CAF
- Prompt alignment & calibration workflows produce constants from the express & calibration stream data. These constants are validated and uploaded to the database.
- When prompt alignment & calibration are completed (target latency: ~24h), the full data sample is passed through prompt reconstruction with the updated constants, and generally made available for analysis
The AlCaReco Streams

- For fast turnaround of alignment & calibration workflows, CPU power must be used efficiently, and I/O limitations are to be avoided at all cost.
- Solution: AlCaReco format = reduced form of reconstructed data, containing precisely the minimal information required as input to a given calibration/alignment algorithm.
  - partly simply skims of RECO data (both event selection and event content selection)
  - partly with additional collections produced
  - can entirely rely on disk storage.
- As a result, calibration/alignment algorithms can run over very large datasets (millions of events), in some cases with many iterations, in a short time.
- AlCaReco datasets are produced centrally at T0 from the RECO data.
  - currently a total of 14 AlCaReco streams defined for collision data (a subset will be run for a given PD), plus 4 for cosmic data and 3 for beam halo data.
- Special case: AlCaRaw streams (“slimmed events”, already created at HLT).
Databases
The Conditions Database

**OMDS**

Oracle Relational DB
Serves L1 trigger

Transformation (020) from oracle to Pool-ORA (CMSSW) objects

**ORCON**

Pool-ORA DB
Serves HLT

Automatic streaming - synchronize online and offline DBs

**ORCOF**

Pool-ORA DB
Serves Offline Applications

Point 5

Tier 0 – Meyrin site

Read only

**POOL-ORA (Object Relational Access)**: provides mapping from relational DB to a C++ objects.

Pure online applications

HLT

POPCON application (database writing)

Offline CMSSW application

19-Jan-2009

R. Mankel, CMS Alignment & Calibration
For reading, ORCON and ORCOF are accessed via an **intermediate caching layer** called Frontier.

- Each database query is cached on the Frontier squids (http based proxy servers) to avoid the database itself being overloaded with repeated requests to access the same tables.
- T0 has 4 squids, FNAL has 2, all other T1, T2 sites have a single squid.
Managing Constants Validity

- Each set of calibration/alignment constants has an associated Interval of Validity (IOV)
  - finest granularity: luminosity section (93s)
- When constants are accessed in an offline CMSSW application, the EventSetup provides the set of conditions with IOV corresponding to the run and event number
- Overall set of constants is bundled into a “Global Tag”
  - co-existence of various constants scenarios possible
A Brief Look at Alignment & Calibration Algorithms

(can only scratch the surface)
CMS Alignment Framework

- CMS has a powerful software framework managing alignment constants of objects at different geometrical hierarchy levels.
- Depending on the problem at hand, parameters at module level or a higher hierarchical level can be used.
- Hierarchy constraints connect the different levels.
- This framework is shared by the various alignment algorithms.
Methodology of Track-Based Alignment

- Generally, track-based alignment is based on differences between
  - the expected hit position judging from the fitted trajectory
  - the real hit position → “residual”
- All alignment algorithms aim to adjust geometry parameters such that all residual distributions are centered, and their width is minimized (=reflecting only stochastic uncertainties)
  - general method: least squares fitting
  - complication: changing geometry parameters of one detector object changes also the fitted trajectory, and thus modifies the residuals observed in other detector objects
  - in reality, all track fits and all alignment parameters are coupled together
Methodology of Alignment (cont’d)

Three main approaches are addressing this challenge:

- **HIP algorithm** (“Hit Impact Point”)
  - fit alignment parameters locally for each object
    - few degrees of freedom per fit \(\rightarrow\) well manageable
    - further couplings are taken into account by many cycles of iteration
    - all tracks must be refitted once per iteration
    - can use the standard track fit

- **Global fit** (implementation: MillePede algorithm)
  - global fit of all track & alignment parameters
  - complex mathematical algorithms
  - MillePede-II has been shown to fit \(O(50000)\) alignment parameters simultaneously

- In addition, a **Kalman filter-based method** has been used
  - very elegant, but computationally extremely demanding
The HIP Algorithm

- Consider residual of hit k within a tracker element i as a function of its alignment parameters $p_i$:
  \[ r_k = u_k^{hit} - f(p_i, q) \]
  (where $f(\ldots)$ is the predicted hit coordinate based on track parameters $q$)

- Compute “local” $\chi^2$ using covariance matrix of residual by summing over all hits in this tracker element in the sample
  \[ \chi^2 = \sum_{k}^{hits} r_k^T (p, q) V_k^{-1} r_k (p, q) \]

- Obtain alignment parameters $p_i$ by minimizing this (mathematically simple). Do this for all alignable objects
  - only up to 6 parameters per fit → mathematically simple

- Downside: change of alignment parameters of various “alignables” will also change the track parameters ($q = q(p_1\ldots p_n)$)
  - iteration required, each with refit of all tracks.
  - Computationally intensive! Typically 50-80 iterations used.
The Global Fit Algorithm (MillePede-II)

- Find a **global minimization** of the overall $\chi^2$ as a function of all track parameters & all alignment parameters
  - fit all track and alignment parameters simultaneously $\rightarrow$ “MillePede” approach (by V. Blobel)
  - mathematically very demanding
    - $O(50k)$ alignment parameters
    - an upgraded version (MillePede-II) by has been shown to be capable of handling this degree of complexity $\rightarrow$ Markus Stoye, PhD thesis 2007

- **Advantage:** correlations of alignment & track parameters are handled correctly
  - track fit must be accurately modelled within MillePede procedure
The Global Fit Algorithm (MillePede-II, cont’d)

- O(50k) alignment parameters lead to a very large matrix representing the problem
- While MillePede-II uses very sophisticated techniques to reduce memory consumption, the workflow is still very demanding in terms of memory
- At CMS, we use dedicated CAF servers to handle the MillePede main optimization step
Alignment of the Muon System

- Typical muon leaves 24-44 hits in the muon system
- Polarity of magnetic field changes. Independent momentum measurement
Beyond 200 GeV, the muon system can contribute significantly to the overall momentum resolution

Precise alignment essential
Track-Based Alignment in the Muon System

- Several differences with respect to tracker
  - huge multiple scattering effects between stations
    - deflections & displacements → treat outliers from strong scatters
  - inhomogeneous magnetic field
- Method I: HIP algorithm
  - based on “global muons”, extrapolated from tracker
    - global alignment as side product
- Method II: MillePede algorithm
  - based on segments determined within each chamber
- Method III: Overlaps algorithm
  - exploits chamber overlaps within the rings of the CSC (end cap)
    - used with beam halo particles
Optical Alignment Systems
Hardware-Based Alignment

- CMS features four different hardware alignment systems:
  - tracker laser alignment
  - barrel muon system alignment (MAB)
  - end cap muon alignment system
  - link system (=used to connect the above three)
Tracker Laser Alignment

- End caps: 2x16 laser beams ($\lambda=1075$ nm), covering all disks, 288 modules
  - $x, y, \varphi_z$ for each module
- Alignment tube beams: eight-fold distributed along phi, interconnect TEC+ $\rightarrow$ TIB $\rightarrow$ TOB $\rightarrow$ TEC-
- Laser beams are measured in the actual tracking sensors. Absolute resolution $\sim$100 $\mu$m ($\sim$10 $\mu$m relative movements)
  - laser hits $\rightarrow$ laser tracks (straight line) $\rightarrow$ can be combined with regular tracks in alignment
  - operation: in stand-alone runs or within orbit gap (100 Hz)
  - one measurement (2000 shots) processed in 1-2 minutes

19-Jan-2009 R. Mankel, CMS Alignment & Calibration
Muon Barrel Optical Alignment System

- Cameras placed at 36 rigid reference structures ("MABs") attached to the wheels observe reference points in the DTs
- Relative chamber positions computed by triangulation
- 9000 measurements to determine 6 degrees of freedom for each of the 250 DT chambers

MAB = Modules for Alignment of Barrel
Muon End Caps Alignment System

- Laser lines traversing CCD sensors (DCOPS)
  - six axial transfer lines measure transverse positions of stations relative to end caps
  - three straight transverse lines (SLM)
  - covers 1/6 of the CSCs
- Proximity sensors → radial distances between inner & outer rings

DCOPS = Digital CCD Optical Position Sensors
SLM = Straight Line Monitor
The Link System

- Connect optical alignment systems of "muon barrel & end cap" with tracker
  - with direct monitoring of ME1 chambers
- Laser lines crossing transparent photosensors (ASPD)
  - in three rz alignment planes
- Connect to "Alignment Ring" mounted at tracker end plates

ASPD = Amorphous Silicon Position Detectors
The Computing, Software & Analysis Challenge 2008
Exercising Alignment & Calibration in Computing, Software & Analysis Challenge

- CSA08 was (for the first time), a full-scale challenge with large statistics under conditions similar to LHC startup
  - prompt reconstruction at T0
  - alignment & calibration “in real time” at CAF
  - re-reconstruction at T1
  - analysis
- Initial mis-alignments & -calibrations as expected
  - before collisions
  - after 1 pb\(^{-1}\) of data
  - event signatures & rates typical for low luminosity, with 43 and 156 bunches
  - full complexity of almost 20 concurrent alignment & calibration end-to-end workflows (with interdependencies)
  - realistic analyses based on derived constants
The CSA08 Scenarios

- Two scenarios as they are expected to appear during the beam commissioning of the LHC

<table>
<thead>
<tr>
<th>Name</th>
<th>Bunch schema</th>
<th>Luminosity</th>
<th>Duration [effective]</th>
<th>Integrated luminosity</th>
<th>HLT Output Rate</th>
<th>#Events</th>
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</thead>
<tbody>
<tr>
<td>S43</td>
<td>43x43</td>
<td>$2 \cdot 10^{30} \text{ cm}^{-2}\text{s}^{-1}$</td>
<td>6 days</td>
<td>1 pb$^{-1}$</td>
<td>300 Hz</td>
<td>150 M</td>
</tr>
<tr>
<td>S156</td>
<td>156x156</td>
<td>$2 \cdot 10^{31} \text{ cm}^{-2}\text{s}^{-1}$</td>
<td>6 days</td>
<td>10 pb$^{-1}$</td>
<td>300 Hz</td>
<td>150 M</td>
</tr>
</tbody>
</table>

- Consequently, the data are governed by low luminosity
  - dominated by minimum bias, jet triggers
  - small rate of high pt leptons & Z decays
## CSA08/CCRC08 Schedule

<table>
<thead>
<tr>
<th>Week 18</th>
<th>Week 19</th>
<th>Week 20</th>
<th>Week 21</th>
<th>Week 23</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tier-0</td>
<td>PreProduction</td>
<td>S43 Prompt Reco and dataset transfer to CERN</td>
<td>$156$ Prompt Rec</td>
<td>CCRC08 end-to-end tests</td>
</tr>
<tr>
<td>CAF</td>
<td>DataSets arrive</td>
<td>S43 alignment and calib</td>
<td>$156$ alignment and calib</td>
<td>$156$ User Analysis</td>
</tr>
<tr>
<td>Tier-1</td>
<td>PreProduction</td>
<td>S43 User Analysis</td>
<td>S43 ReReco</td>
<td>S156 ReReco</td>
</tr>
<tr>
<td>Tier-2</td>
<td>Phase 0 - Prep</td>
<td>Phase 1 - Centrally Organized Activities</td>
<td>Phase 2 - Chaotic analysis</td>
<td>Phase 3 - Final phase</td>
</tr>
</tbody>
</table>

### May 08

- **General philosophy:**
  - do not wait for items that are not ready in time
  - as the real LHC will also not wait for us
  - “if it is not ready, de-scope it” (“sink-or-swim”)
CSA08 Milestones

- The essential cornerstones of the CSA08 schedule have been kept
  - ~150 M simulated events have been pre-produced ✓
    - on average 8000 concurrent jobs, at all levels within WLCG
  - S43 sample:
    - prompt reconstruction started on 4-May at T0 ✓
    - alignment & calibration started on 12-May at CAF ✓
      - constants signed off & published 19-May ✓
    - re-reconstruction started 19-May at T1 ✓
  - S156 sample:
    - prompt reconstruction started on 16-May at T0 ✓
    - alignment & calibration started on 19-May at CAF ✓
      - constants signed off & published 26-May ✓
    - re-reconstruction started 27-May, ended 2-Jun ✓
### Alignment & Calibration Workflows (CSA08)

<table>
<thead>
<tr>
<th></th>
<th>1 pb⁻¹</th>
<th>10 pb⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ECAL calibration</strong></td>
<td>Phi symmetry</td>
<td>Phi symmetry</td>
</tr>
<tr>
<td></td>
<td>π° calibration</td>
<td>π° calibration</td>
</tr>
<tr>
<td><strong>HCAL calibration</strong></td>
<td>Phi symmetry with noise subtraction</td>
<td>Phi symmetry with noise subtraction</td>
</tr>
<tr>
<td></td>
<td>Isolated track calibration</td>
<td>Isolated track calibration</td>
</tr>
<tr>
<td></td>
<td>Di-jet balancing</td>
<td>Di-jet balancing</td>
</tr>
<tr>
<td></td>
<td>HO (muon-part only)</td>
<td>HO (muon-part only)</td>
</tr>
<tr>
<td><strong>Muon calibration</strong></td>
<td>TZero calibration</td>
<td>TZero calibration</td>
</tr>
<tr>
<td></td>
<td>vDrift calibration</td>
<td>vDrift calibration</td>
</tr>
<tr>
<td><strong>Tracker calibration</strong></td>
<td>Strip dE/dx calibration</td>
<td>Strip dE/dx calibration</td>
</tr>
<tr>
<td></td>
<td>Strip Lorentz angle calibration</td>
<td>Strip Lorentz angle calibration</td>
</tr>
<tr>
<td></td>
<td>Pixel Lorentz angle calibration</td>
<td>Pixel Lorentz angle calibration</td>
</tr>
<tr>
<td><strong>Tracker alignment</strong></td>
<td>TrackerMillePede alignment (minBias, MuonPT5)</td>
<td>Tracker alignment MillePede (minBias, MuonPT5 + cosmics + MuonPT11 + dimuons)</td>
</tr>
<tr>
<td></td>
<td>Tracker HIP alignment (minBias)</td>
<td>Tracker HIP alignment (MuonPT5 + cosmics + MuonPT11 + dimuons)</td>
</tr>
<tr>
<td></td>
<td>Tracker Kalman alignment</td>
<td>Tracker Kalman alignment</td>
</tr>
<tr>
<td><strong>Muon system alignment</strong></td>
<td>Muon HIP alignment (MuonPT5)</td>
<td>Muon HIP alignment (MuonPT5 + MuonPT11)</td>
</tr>
<tr>
<td></td>
<td>Muon S/A (MuonPT5)</td>
<td>Muon S/A (MuonPT5 + MuonPT11)</td>
</tr>
</tbody>
</table>
Workflow Interdependence

- There are several dependencies between individual alignment & calibration constants
- these were honored in the S156 alignment & calibration
Tracker Alignment

- Three methods used:
  - HIP
  - MillePede
  - Kalman filter
- $\chi^2$ from track fit (after alignment) indicator of alignment quality
- MillePede found to give best results
  - for S43, only minimum bias (6.6M) and muon ($p_T>5$ GeV) events were used
  - for S156, cosmics and more high-$p_T$ muons were added

- Computing effort (CPU):
  - 50 jobs a 30 min (preparation)
  - 1 job of 5h (final fit)

Data-driven validation: $\chi^2 / n_{\text{DOF}}$
Tracker Alignment: Precision

- Precision is defined relative to true geometry, after undoing apparent global shifts & rotations
  - in this sense, the accuracies given for parts of the tracker show the internal alignment of these structures

<table>
<thead>
<tr>
<th>System</th>
<th>$r\phi$ precision [$\mu$m] from MillePede</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Build</td>
</tr>
<tr>
<td>BPix</td>
<td>105</td>
</tr>
<tr>
<td>TIB</td>
<td>482</td>
</tr>
<tr>
<td>TOB</td>
<td>106</td>
</tr>
<tr>
<td>FPix</td>
<td>120</td>
</tr>
<tr>
<td>TID</td>
<td>445</td>
</tr>
<tr>
<td>TEC</td>
<td>92</td>
</tr>
</tbody>
</table>

- Overall $r\phi$ precision: **35 $\mu$m** (MillePede, S156)
- Pixel tracker: down to **3 $\mu$m**!
Tracker Alignment (cont’d)

- $p_T$ resolution at high momentum is very sensitive to coordinate resolution & thus to alignment
  - also systematic effects (e.g. due to weak modes) can show here

- Visible improvement (Gaussian fits):

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>MillePede S43</td>
<td>3.0%</td>
</tr>
<tr>
<td>MillePede S156</td>
<td>2.2%</td>
</tr>
<tr>
<td>Ideal</td>
<td>1.7 %</td>
</tr>
</tbody>
</table>
Alignment & Calibration in CRAFT

(Cosmics Run at Four* Tesla)

* B=3.8 T
The CRAFT Run

- CMS ran for 4 weeks continuously
  - 19 days with full magnetic field (3.8 T)
  - 370 M cosmics events collected in total
  - 290 M with B=3.8 T, and strip tracker + DT R/O
  - 194 M with all components in
- Instrumental & exceedingly powerful for alignment & calibration
  - for the first time, “real” data with magnetic field on
    - momentum cuts
    - rigorous multiple scattering treatment
  - first opportunity for serious pixel tracker alignment
  - hardware alignment/calibration systems
- We have successfully commissioned & performed a large range of our alignment & calibration workflows
  - exercised regular constants validation & sign-off procedures
  - towards the optimal “STARTUP” alignment/calibration in preparation of collisions
Cosmic Muon Event Display from CRAFT
Cosmic Muons Traversing Pixel Tracker

- ECAL in magenta, HCAL in blue, tracker and muon hits in green

19-Jan-2009  R. Mankel, CMS Alignment & Calibration
### Alignment & Calibration Skims in CRAFT (AlCaReco Datasets)

The AlCaReco datasets are designed to help with various alignment and calibration tasks in the CMS experiment. Here’s a list of datasets and their purposes:

<table>
<thead>
<tr>
<th>Dataset Name</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>TkAlCosmicsHLT [4.3 M]</td>
<td>Tracker alignment (with/without HLT selection, different cuts)</td>
</tr>
<tr>
<td>TkAlCosmics0T [4.9M]</td>
<td>Muon system S/A alignment</td>
</tr>
<tr>
<td>MuAlStandaloneCosmics [288 M]</td>
<td>Endcap chamber alignment</td>
</tr>
<tr>
<td>MuAlGlobalCosmics [5.5 M]</td>
<td>Muon system alignment wrt tracker</td>
</tr>
<tr>
<td>HcalCalHOCosmics [313 M]</td>
<td>HCAL HO calibration</td>
</tr>
<tr>
<td>HcalCalDijets [67 M]</td>
<td>HCAL calibration [comm.]</td>
</tr>
<tr>
<td>MuAlisolatedMu [51.8 M]</td>
<td>Muon system alignment [comm.], DT calibration</td>
</tr>
<tr>
<td>RpcCalHLT [241 M]</td>
<td>DT calibration, RPC monitoring</td>
</tr>
</tbody>
</table>

#### CRAFT Primary Datasets:

<table>
<thead>
<tr>
<th>/Cosmics, /MinimumBias, /Calo</th>
<th>/Reco AlCaReco</th>
<th>/Reco+ AlCaReco</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TkAlCosmicsHLT [4.3 M]</td>
<td>MuAlStandaloneCosmics [288 M]</td>
</tr>
<tr>
<td></td>
<td>TkAlCosmics0T [4.9M]</td>
<td>MuAlGlobalCosmics [5.5 M]</td>
</tr>
<tr>
<td></td>
<td>MuAlBeamHaloOverlaps [3.3 M]</td>
<td>HcalCalHOCosmics [313 M]</td>
</tr>
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<td></td>
<td>MuAlGlobalCosmics [5.5 M]</td>
<td>HcalCalDijets [67 M]</td>
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<td></td>
<td>MuAlisolatedMu [51.8 M]</td>
<td>RrpcCalHLT [241 M]</td>
</tr>
</tbody>
</table>

**Purpose:**

- Tracker alignment (with/without HLT selection, different cuts)
- Muon system S/A alignment
- Endcap chamber alignment
- Muon system alignment wrt tracker
- HCAL HO calibration
- HCAL calibration [comm.]
- Muon system alignment [comm.], DT calibration
- DT calibration, RPC monitoring

**Date:** 19-Jan-2009

**Author:** R. Mankel, CMS Alignment & Calibration
Constants Updates in CRAFT for 1st Reprocessing

- Constants for first reprocessing available a few days after end of running
  - Tracker alignment + alignment errors
  - Strip tracker gains, bad strips, bad fibers
  - Pixel tracker gains & pedestals
  - Muon DT & CSC alignment
  - Muon DT t0, noise, tTrig
  - ECAL gains & pedestals
  - HCAL gains & pedestals
Tracker Alignment in CRAFT

- For first time tracker tracks in real data with $B=3.8T$
- Based on 4 M tracks
- Two different algorithms used
  - HIP and Millepede
  - similar results in terms of track quality
- First serious track-based alignment of the pixel tracker
  - CRUZET allowed only rudimentary alignment of the pixel tracker
- Significant improvement of overall track $\chi^2$ wrt CRUZET geometry
Comparisons of Tracker CRUZET4 & CRAFT Alignment

- Standard validation: mean values of residual distributions for alignable modules
- Centering of residual distributions improves significantly compared to CRUZET
- CRUZET geometry validated on CRAFT data: double peak structure in TOB?
  - traced back to a problem in Lorentz angle calibration
  - will disappear in next reprocessing

19-Jan-2009
R. Mankel, CMS Alignment & Calibration
Muon System Alignment: Endcap Deformation at 3.8 T

3 Straight Line Monitor (SLM) Laser Lines per Muon Endcap Station
10 optical CCD sensors per SLM
Muon System Alignment

- CSC chamber alignment constants obtained from optical alignment system ($\Delta z_{\text{global}}, \phi_{x_{\text{local}}}$)
- Especially important for inner chambers, which are difficult to access with cosmic muons
- Besides shifts towards interaction point, typical tilts of $O(4 \text{ mrad})$ observed
Summary

- In the LHC regime, alignment & calibration are highly demanding tasks, also from the computing perspective.
- CMS has designed & implemented a powerful alignment & calibration strategy.
- This strategy has been commissioned & proven extensively both in Monte Carlo challenges & with real data (cosmics & beam).
- Looking forward to the first LHC collisions later this year.
(Pre-) Announcement

- The next LHC Alignment Workshop will take place
  
  16-17 June 2009 (tbc)

- Main topics:
  - alignment with cosmics & first beam
  - software frameworks & statistical methods
  - alignment for upgrade detectors