Tracker Alignment: Introduction

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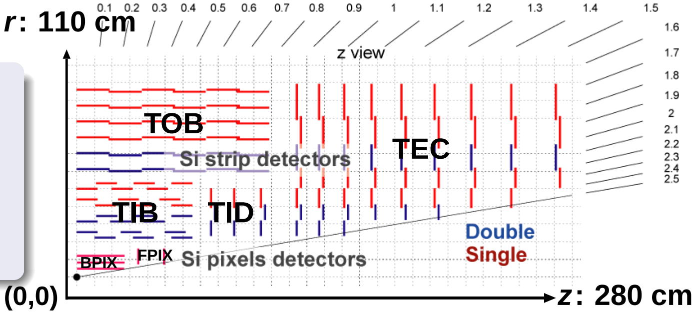
CMS Hamburg Meeting
June 3rd, 2009

Outline

- The CMS Tracker
- Track-Based Alignment Principle
- Alignment within CMS Alignment/Calibration Workflows
- Hamburg Involvement



Strips:

- TOB, TEC
- TIB, TID

Pixel:

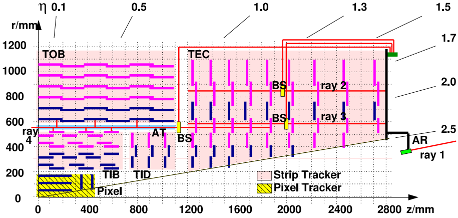
- BPIX, FPIX

- 15148 silicon strip moduls: $\sigma \approx 23 - 60\ \mu m\ (r\phi)$
  - 2D measurements by stereo moduls ($\angle = 100\ mrad$)
- 1440 silicon pixel moduls: $\sigma \approx 9 \times 10 - 35\ \mu m\ (r\phi \times z)$

Alignment Challenge:

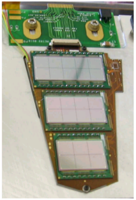
- Precision $<$ resolution σ: μm on distances $\mathcal{O}(m)$.
- $16588 \times 6 \approx 100\,000$ rigid body parameter.

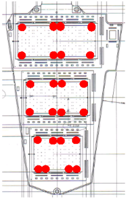
Input to Alignment

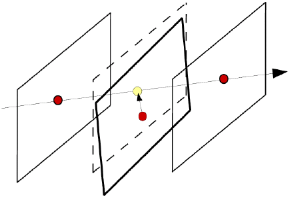


- Survey Measurements
- Laser Alignment System (LAS)
- Track Based Alignment

Combination desirable!

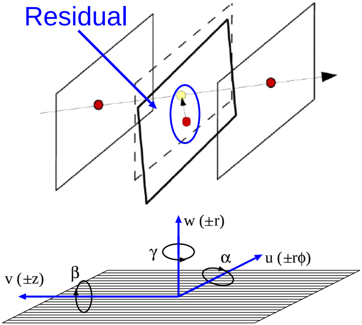






- Millepede (global)
- HIP (iterative)
- Kalman (sequential/global)

Track-Based Alignment with Millepede II



- Mis-positioned detector modules increase residual track ⇔ hit.
- Minimise **simultaneously** residuals of many tracks:

$$\chi^2(\boldsymbol{\tau},\boldsymbol{p}) = \sum_{j=1}^{N^{tracks}} \sum_{i=1}^{N_j^{hits}} \left(\frac{m_{ij} - f_{ij}(\boldsymbol{\tau}_j,\boldsymbol{p})}{\sigma_{ij}}\right)^2$$

- $\boldsymbol{\tau_j}$: Parameters of track j
  - $\Rightarrow$ appear only for hits of track $j \Rightarrow$ local parameters
- $\boldsymbol{p}$: Alignment parameters p
  - e.g. six rigid-body parameters of a silicon module
  - $\Rightarrow$ can appear in all data $\Rightarrow$ global parameters
- Linearising $f_{ij}(\boldsymbol{\tau}_j,\boldsymbol{p}) \Rightarrow$ redefine $\boldsymbol{\tau}_j/\boldsymbol{p}$ as small corrections to $\boldsymbol{\tau}_j^*/\boldsymbol{p}^*$.

Millepede: Combined Fit of Local/Global Parameters

Normal Equations

$$\sum_j \frac{1}{\sigma_j}(\boldsymbol{d}_j \cdot \boldsymbol{d}_j^T) \cdot \boldsymbol{a} = \sum_j \frac{1}{\sigma_j} m_j \boldsymbol{d}_j$$

- $\boldsymbol{a} = (\boldsymbol{p}, \boldsymbol{\tau}_1, \ldots, \boldsymbol{\tau}_n)^T$
  - alignment (“global”) parameters $\boldsymbol{p}$
  - track (“local”) parameters $\boldsymbol{\tau}_i$ of all n tracks

- Coefficients (i.e. derivatives): $\boldsymbol{d}_j = (\boldsymbol{d}_j^p, \underbrace{\boldsymbol{d}_j^{\tau_1}}_{=\boldsymbol{0}}, \ldots, \underbrace{\boldsymbol{d}_j^{\tau_j}}_{\neq \boldsymbol{0}}, \ldots, \underbrace{\boldsymbol{d}_j^{\tau_n}}_{=\boldsymbol{0}})^T$

$$\left(\begin{array}{c||c|c|c} \sum_k \boldsymbol{C}_k^{\text{global}} & \cdots & \boldsymbol{H}_k^{\text{global-local}} & \cdots \\ \hline\hline \vdots & \ddots & 0 & 0 \\ \hline (\boldsymbol{H}_k^{\text{global-local}})^T & 0 & \boldsymbol{C}_k^{\text{local}} & 0 \\ \hline \vdots & 0 & 0 & \ddots \end{array}\right) \times \left(\begin{array}{c} \boldsymbol{p} \\ \hline\hline \vdots \\ \hline \boldsymbol{\tau}_k \\ \hline \vdots \end{array}\right) = \left(\begin{array}{c} \sum_k \boldsymbol{b}_k^{\text{global}} \\ \hline\hline \vdots \\ \hline \boldsymbol{b}_k^{\text{local}} \\ \hline \vdots \end{array}\right)$$

- We are not interested in full $\boldsymbol{a} = (\boldsymbol{p}, \boldsymbol{\tau}_1, \ldots, \boldsymbol{\tau}_n)^T$:
  $\Rightarrow$ We want global parameters $\boldsymbol{p}$ only!
- Matrix algebra (inversion by partitioning) helps:

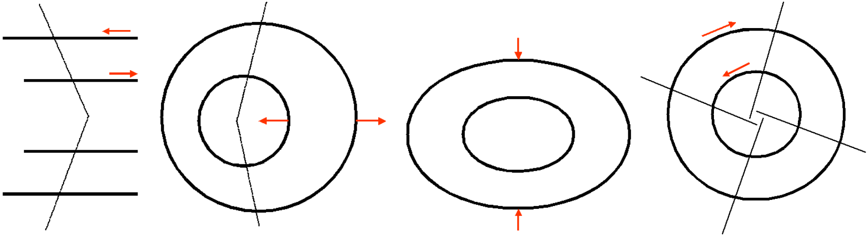
Reduced Matrix

$$\boldsymbol{C'p} = \boldsymbol{b'}$$

$$\begin{aligned}
\boldsymbol{C'} &= \sum_j \boldsymbol{C}_j^{global} - \sum_j \left(\boldsymbol{H}_j (\boldsymbol{C}_j^{local})^{-1} \boldsymbol{H}_j^T \right) \\
\boldsymbol{b'} &= \sum_j \boldsymbol{b}_j^{global} - \sum_j \boldsymbol{H}_j \underbrace{(\boldsymbol{C}_j^{local})^{-1} \boldsymbol{\tau_j}}_{\text{local solution}}
\end{aligned}$$

- Sums built while running over tracks k.
- Inversion of small matrices $\boldsymbol{C}_k^{local}$ only.
- $\boldsymbol{C'}$ is “small” $n \times n$ matrix for n global (alignment) parameters.

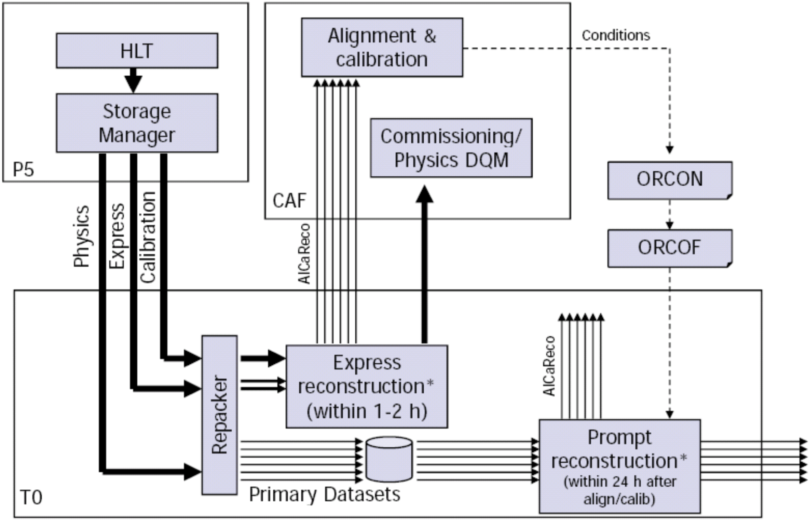
Minimising residuals can be insensitive to certain global distortions.



(There are more less obvious modes!)

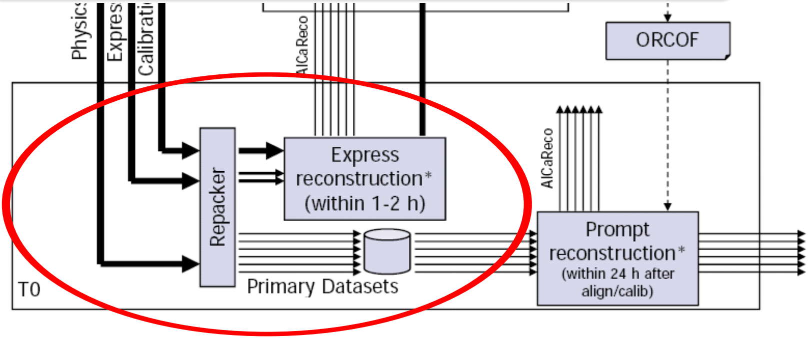
- Intrinsic to problem, independent of method.
- Biases measurements.
- Dependent on data fed into matrix.

$\Rightarrow$ Combine different sources of information.

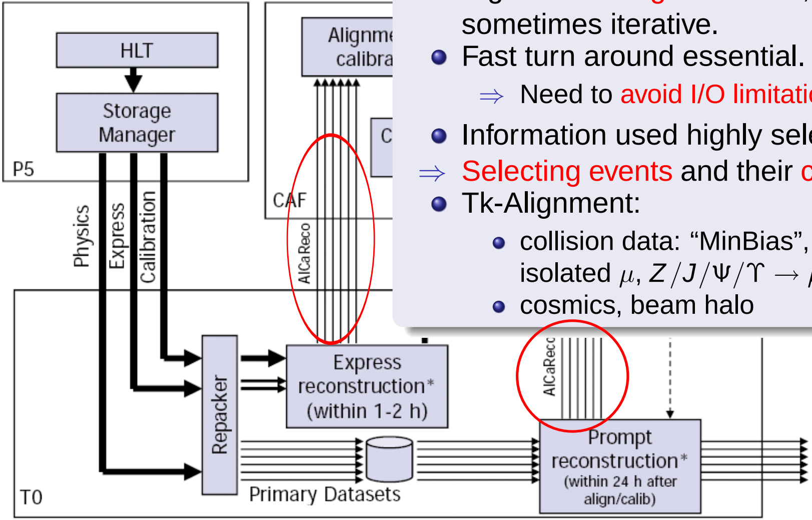

HLT
Storage Manager
P5
Alignment & calibration
Conditions
Commissioning/ Physics DQM
CAF
ORCON
ORCOF
Physics
Express
Calibration
AlCaReco
Repacker
Express reconstruction* (within 1-2 h)
AlCaReco
Prompt reconstruction* (within 24 h after align/calib)
Primary Datasets
T0

Tier-0 (T0): Offline Production at CERN (Meyrin)

- Repack into "Event Data Model" format: Datasets according to HLT.
- Buffer bulk of data on disk.
- $\mathcal{O}$(10-20%) Express Reconstruction.
  - ⇒ Alignment and Calibration Skims (AlCaReco) for Monitoring and Short Latency Calibration.



Prompt Alignment/Calibration Workflow: AlCaReco



AlCaReco Skims

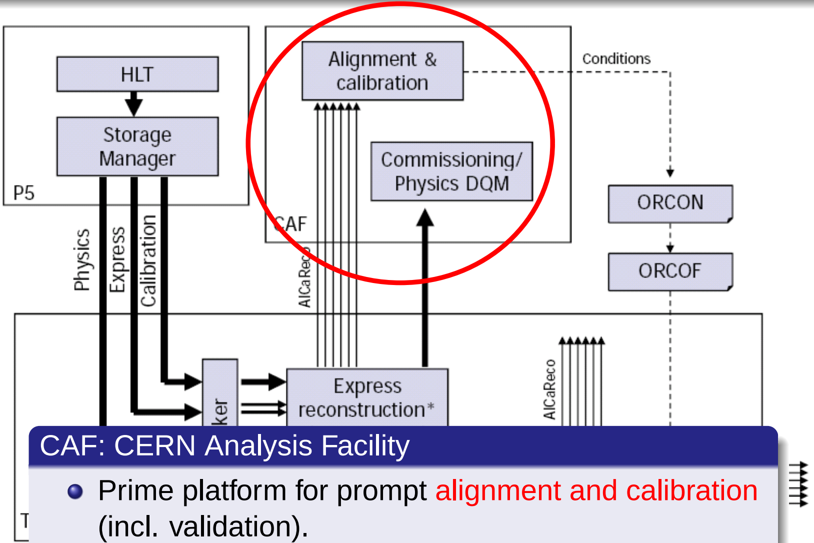
Small dedicated data skims

- Algorithms: large statistics, sometimes iterative.
- Fast turn around essential.
  - $\Rightarrow$ Need to avoid I/O limitations!
- Information used highly selective.

$\Rightarrow$ Selecting events and their content.

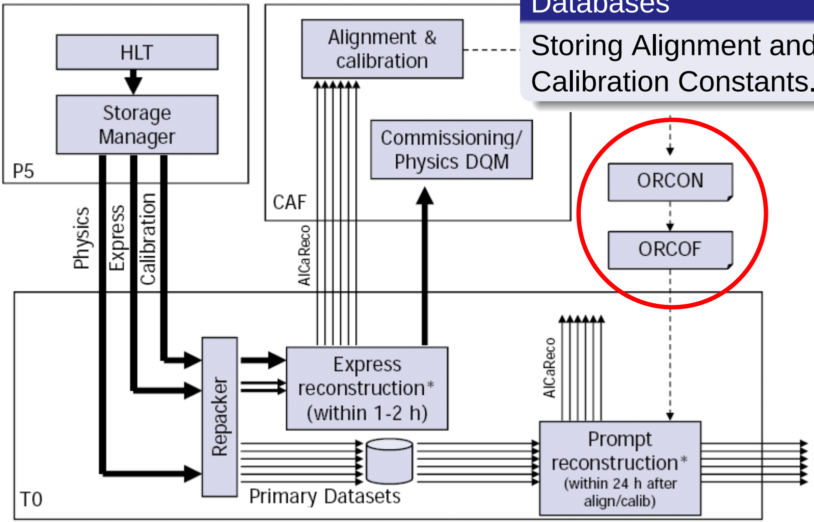
- Tk-Alignment:
  - collision data: “MinBias”, isolated μ, $Z/J/\Psi/\Upsilon \rightarrow \mu\mu$
  - cosmics, beam halo

Prompt Alignment/Calibration Workflow: CAF



CAF: CERN Analysis Facility

- Prime platform for prompt alignment and calibration (incl. validation).
- Batch farm (Millepede nodes with large memory).
- Fast access to data: Disk storage.



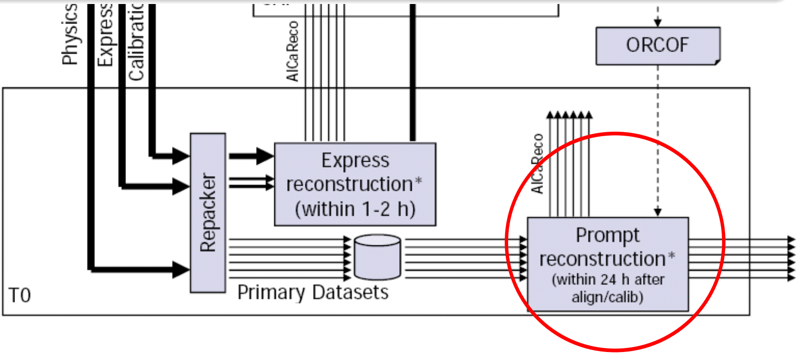
Databases

Storing Alignment and Calibration Constants.

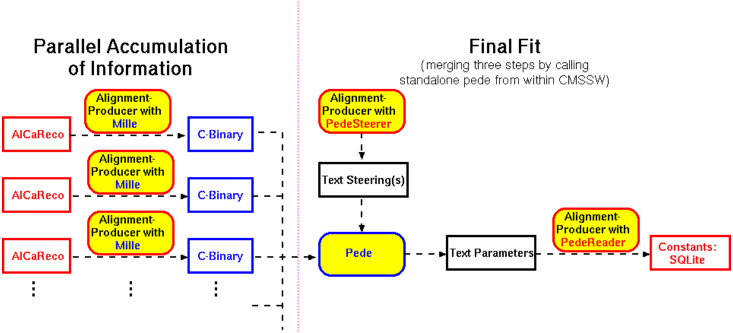
Prompt Alignment/Calibration Workflow: T0 (ctd.)

Tier-0 (T0): Offline Production at CERN (Meyrin)

- Prompt Reconstruction, $\mathcal{O}$(24/48 h) delay:
  - picking up updated constants,
  - sets time limit to achieve short term constants.
- Create Alignment and Calibration Skims (AlCaReco) for longer latency workflows.



Computational Layout of Millepede II Alignment



- Millepede II (by V. Blobel) experiment independent:
- Core is standalone **Pede** program (Fortran 77):
  - Text and binary input.
  - Text output.
  - $n = 50k$: 10 GB matrix $\Rightarrow$ sparse storage
- Trivial **Mille** accumulates experiment data:
  - local/global derivatives, residuals, uncertainties (non-trivial...),
  - Fortran or C++, integrated in experiment's software.

Alignment Input

- Cosmic muon tracks:
  - only real track data so far ($\Rightarrow$ talk by Jula Draeger).
- Beam halo tracks ($\Rightarrow$ talk by Andrea Parenti).
- LAS beams ($\Rightarrow$ talk by Kolja Kaschube)
- “MinBias” tracks at start-up (Justyna Tomaszewska starts)
  - beamspot constraint as started in 2008 by Silvia Miglioranzi
- Isolated muon tracks
  - mass and vertex constraint for resonances: Z, J/Ψ, Υ
- Survey measurements
  - pixel barrel survey implemented by Frank Meier (PSI), help from V. Blobel, G.F.

Hamburg Commitments (ctd.)

Validation

- Release validation of AlCaReco (Justyna T.)
- Alignment validation with residuals (Erik Butz, Jula D., Johannes Hauk)
- Systematics checking $(E/p)_{+}/(E/p)_{-}$
  (Holger Enderle, talk in July?)

Miscellaneous

- Determine **A**lignment **P**osition **E**rror (Johannes H., talk July?).
- Improving track model fed to pede (Claus Kleinwort).
- "Millepede Production System" maintenance (Andrea P.).

"Management" Tasks

- Alignment Software Coordinator (G.F.)
- Aligment and Calibration Convenor (Rainer Mankel)

Hamburg Commitments (ctd.)

Millepede II development (V. Blobel)

- Increased number of parameters N_{par} in CRAFT analysis:
  - $\Rightarrow$ unrevealed indexing problems with $N_{par} > 46340$,
  - now fixed.
- Regularisation method to reduce weak modes.
- Solve convergence problems in case of many outliers.

$\Rightarrow$ New Millepede II version currently being tested.

Summary

- CMS Tracker Alignment:
  Determination of many parameters.
- Millepede II:
  A global fit approach capable of this challenge.
- Tracker Alignment integrated in CMS AlCa workflows.
- Hamburg group actively contributing in many areas.

$\Rightarrow$ Focus on combining all input
to provide best tracker alignment for CMS.