Application of the Kalman Alignment Algorithm to the CMS Tracker

Edmund Widl, Rudolf Frühwirth
Institute of High Energy Physics, Vienna, Austria

ÖAW Austrian Academy of Sciences

HEPHY Institut für Hochenergiephysik

The Kalman Alignment Algorithm

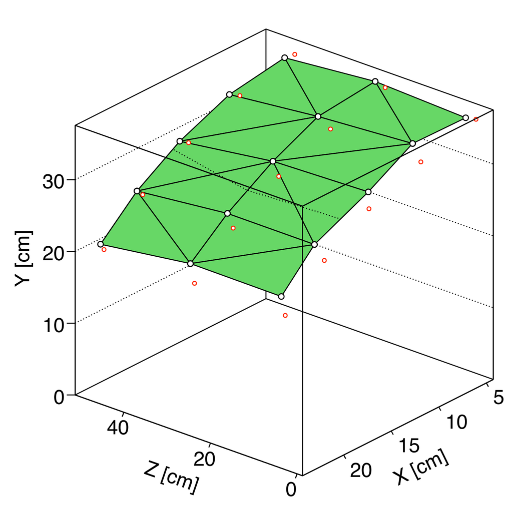
- The **Kalman Alignment Algorithm** [1, 2] extracts the information from particle trajectories to obtain a set of alignment constants by utilizing the Kalman filter technique.
- The tracks are processed consecutively one-by-one, updating the knowledge on the alignment parameters at every step.
- The method accounts for the geometrical/statistical correlations between all involved detector modules. Therefore the updates are not restricted to detector modules that were hit by the current track, but in principle have to include all other detector modules at every step.
- For a system as big as the CMS Tracker this can become impractical. However, the number of detector modules per update can be restricted to a fair amount, requiring only some additional bookkeeping.
- The full statistical interdependencies between all hits of a trajectory due to material effects are included.
- The geometrical correlations between the individual detector modules have to be stored, requiring a potentially vast amount of virtual memory.
- Reading and writing the alignment parameters at every step causes a non negligible IO overhead

Results from the Tracker Integration Facility

The final assembly of the CMS Silicon Strip Tracker has been carried out at a dedicated facility, referred to as the **Tracker Integration Facility** (TIF) [3].

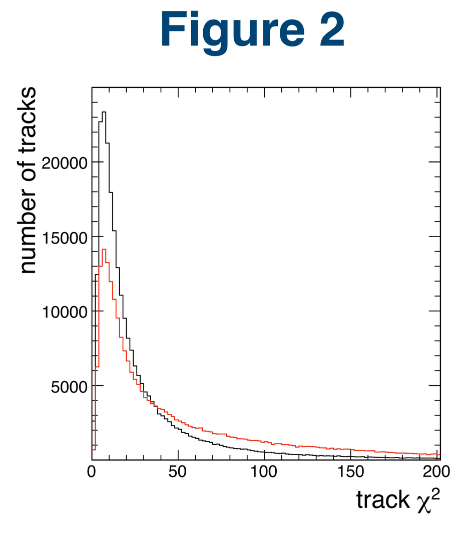
The Tracker was partially operated at different coolant temper-atures. Up to 15% of all detector modules were powered and read-out simultaneously.

Figure 1



The recorded data was analyzed with all three track-based alignment algorithms implemented for the CMS Tracker, providing alignment information on the level of individual detector modules.

Figure 2

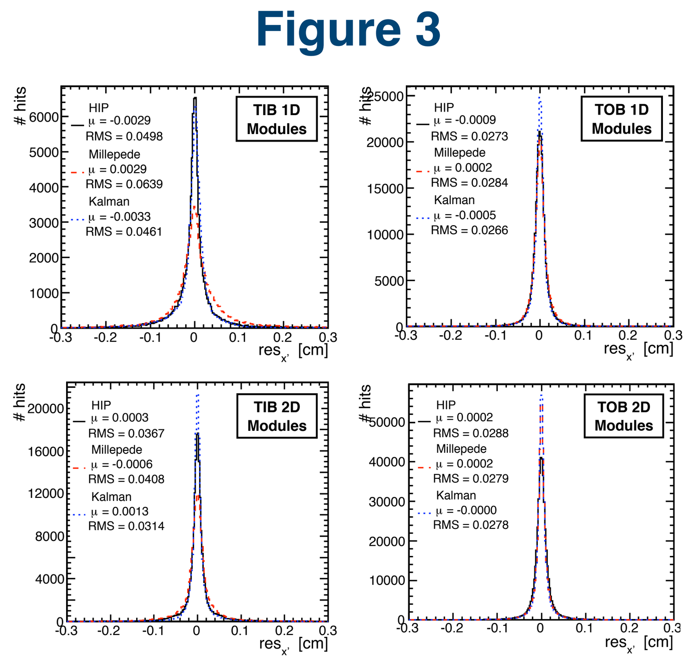


The corrections to the nominal geometry were partly larger than previously expected, especially in the innermost barrel regions. These large deviations turned out to be correlated, stemming from deformations of the barrel layers.

Figure 1 visualizes such a distorted surface. The circles show the nominal positions of the center of the modules (in red) and as computed with the KAA (in black). The misalignment has been scaled by a factor 10 for visibility, the green surfaces are merely a guide for the eye.

Systematical validation of the results is possible only by examining track properties: Figure 2 shows the track-χ^2 before (red) and after (black) alignment. Figure 3 compares the resulting tracking residuals for the three different applied algorithms.

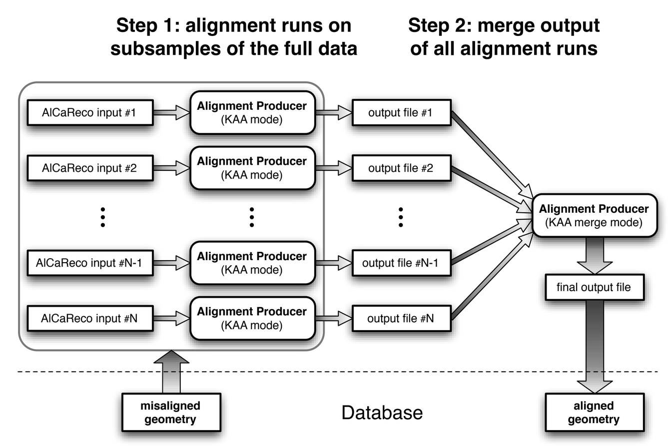
Figure 3



Results from Detailed Simulation Studies

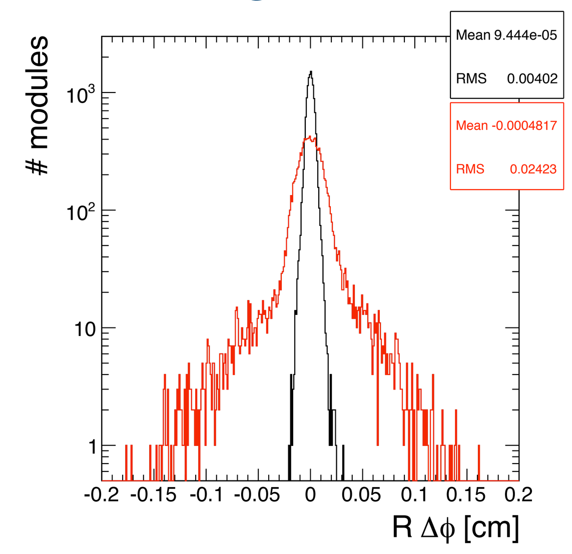
Realistic start-up scenarios have been simulated in the course of the **Computing and Software Analysis Challenge 2008**, which tried to test the full scope of offline data handling and analysis activities which will be needed for the first months of real data-taking.

Figure 4



All computations have been done at the **CERN Analysis Facility** (CAF) [4], a computing farm which will also be used in the future for the alignment runs with real data.

Figure 5



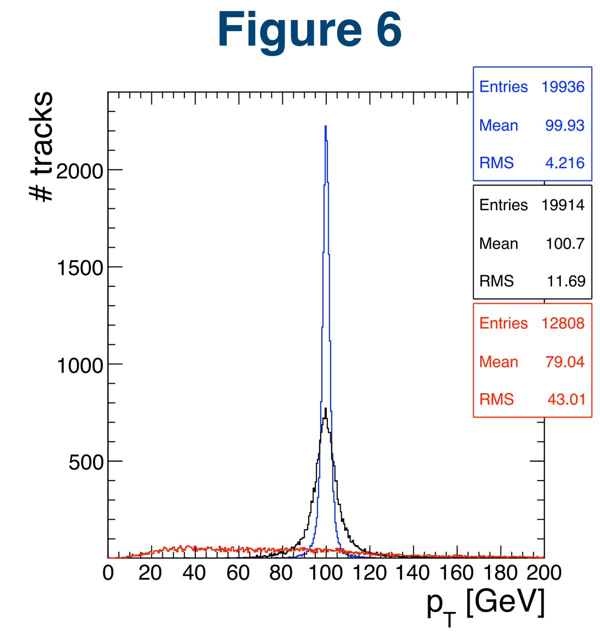
The Tracker was aligned in three steps, starting with the outermost silicon micro-strip regions, contin-uing with the inner silicon micro-strip regions and finishing with the silicon pixel detector.

All of these consecutive steps have been carried out utilizing the scheme for a single alignment run as shown in Figure 4 repeatedly.

The results of this alignment exercise were very satisfying, showing that the algorithm itself as well as the alignment strategy and the computational concept are performing as expected. Figure 5 shows the initial (red) and remaining (black) overall misalignment in the precise coordinates of the detector modules.

Figure 6

The importance of alignment: Figure 6 shows the reconstructed transverse momenta for a sample of simulated muons with p_T = 100 GeV for the case of full misalignment (red), the aligned geometry (black) and the ideal geometry (blue).



Conclusion and Outlook

- The Kalman Alignment Algorithm is a functional and well understood method.
- It is one of three track-based alignment algorithms that will be used for the CMS Tracker and, in fact, has been specifically developed for this purpose.
- Results from detailed simulation studies demonstrate that the Kalman Alignment Algorithm is able to align the CMS Tracker under the conditions expected during the LHC start-up phase.
- The associated computational effort can be kept at a reasonable level by deploying the available CMS computing resources to process the data in parallel.
- For production, a dedicated production system is available.
- An analysis of the first experimental data from cosmic particle tracks, recorded at the Tracker Integration Facility (TIF), shows that the Kalman Alignment Algorithm is at least competitive to existing algorithms when applied to real data.

[1] E. Widl, R. Frühwirth, W. Adam. *A Kalman Filter for Track-based Alignment.* CMS NOTE-2006/022 (2006)

[2] E. Widl. *Global Alignment of the CMS Tracker.* Ph.D. thesis, CMS TS-2008/026 (2008)

[3] The CMS Tracker Collaboration. *CMS Tracker Alignment at the Integration Facility.* CMS NOTE-2009/002 (2009)

[4] CMS T0 Requirements and Technical Assessment Group. *A T0 Architecture for the CMS experiment.* CMS NOTE-2006/095 (2006)