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CMS silicon strip tracker calibration workflow and tools

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Abstract. The silicon strip tracker of CMS is by far the biggest detector of its kind ever operated. Its 15 000 detector modules and 9 million readout channels are individually calibrated in order to achieve the optimal data quality for the experiment. Software tools were designed to automate the operations and reduce the need for maintenance as much as possible, taking care to use pre-existing software frameworks, when possible. The calibration software implements a dedicated scheme of event building, on-line distributed analysis, storage management, data analysis and configuration archival. Dedicated user interfaces and web-applications were developed to ease the operations, speed-up the calibration process, monitor its quality, and track the problems. A complete set of monitoring analyses are also performed online during data taking to validate the data acquired. The calibration parameters are measured continuously, and the values are fed back to the calibration database in order to refine the on-line event reconstruction. A review of the software tools and calibration processes is given here and the obtained results are discussed.

1. Introduction

The silicon strip tracker of the CMS experiment is by far the biggest detector of its kind ever operated. It consists of 15 148 silicon strip modules covering an area of about 200 m^2 within the tracker volume of 24.4 m^2 [1]. When the first high energy collisions were produced at the LHC in 2010, the tracker was already well prepared and tested with experience from several periods of data taking with cosmic rays [2]. For the silicon strip tracker, these preparations included for instance individual calibrations for all 9 million readout channels.

To validate the data and its processing, a large number of tools and dedicated workflows have been established. This paper gives an overview of the workflows and tools related to the silicon strip tracker, and presents some selected results.

2. Data Streams and Monitoring

The offline reconstruction scheme for the CMS tracker is depicted in Fig. 1. Event reconstruction obtains the necessary calibration information from the offline conditions database, for example, the status of the readout channels, hit efficiency, Lorentz angle and gain calibration.

Figure 2 illustrates the data streams from CMS. Beside the physics data stream, the express and calibration data streams are reconstructed within 1–2 hours for the purposes of data quality monitoring (DQM), alignment and calibration. With these data, the offline conditions database, which is used to store and provide condition data needed for trigger, DQM and offline

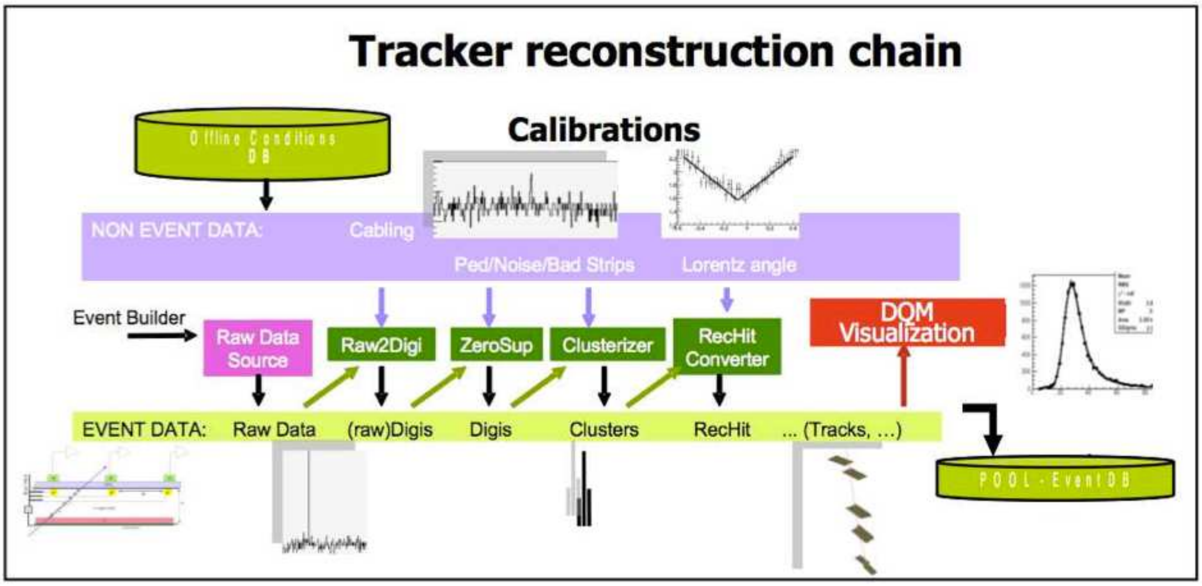

Figure 1. CMS tracker reconstruction chain.

reconstruction [3], can be updated so that the actual physics data stream from the detector can be reconstructed after a short, intentional delay with up-to-date conditions.

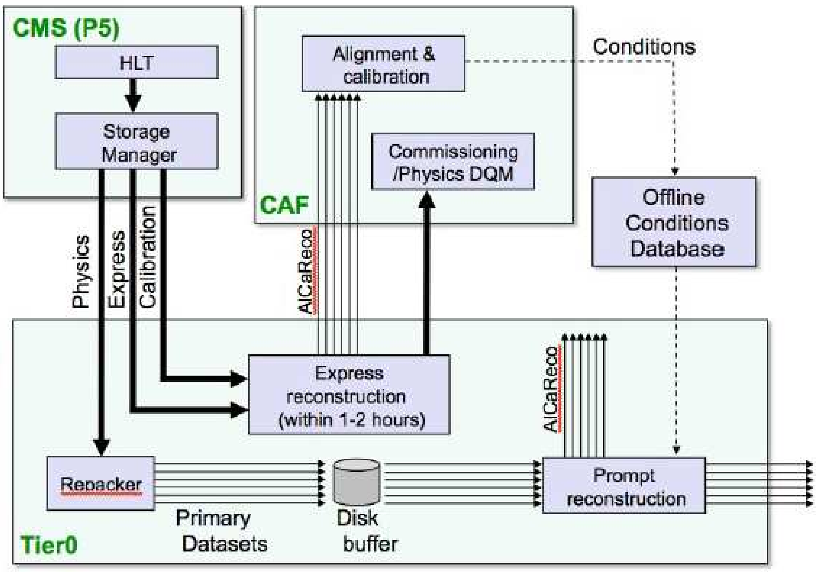

Figure 2. Offline processing data streams between CMS, the CAF (CMS CERN Analysis Facility, a local computing facility designed to host a large variety of latency-critical workflows) and Tier-0 [4].

However, during the 2010 LHC operation, this *prompt calibration loop* was not routinely utilized since the data sample was still small enough to allow for frequent reprocessing. [5]

Towards the end of the 2010 proton-proton run period, CMS introduced a 48-hour delay to the prompt reconstruction process and operated the prompt calibration loop for one week. Deployment of further prompt calibration workflows is planned for the silicon strip tracker, including calibration of the readout channel status.

The DQM, explained in more detail in [6], is divided into two parts: online and offline. The online DQM provides prompt feedback with a subset of data, whereas in the offline DQM all data is analyzed and certified. To monitor the 9.3 million readout channels of the CMS silicon strip tracker as well as each stage of the full reconstruction chain for the tracker, a total of 300 000 histograms are generated, and an overview is provided in the form of summary histograms and diagrams of the tracker.

The DQM tools monitor detector and reconstruction performance for quick feedback. Streams of minimum bias events, which are normally discarded by physics triggers, are used. The online calibration consists of, for example, beamspot position measurements (every 23 s for each luminosity section), detection of problematic channels, and alignment of large structures. Monitoring is integrated to central CMS DQM.

These constants are saved to the offline conditions database, from which they are read during event reconstruction.

Another feature in the offline monitoring is the spy channel, in which raw unprocessed data for a complete event is read during normal data taking. This allows, among other things, validation of FED zero-suppression firmware algorithms [7].

More details of calibration streams in CMS can be found in [8], and more details of alignment and calibration are presented in [5, 9].

3. Calibration Results

3.1. Cosmic rays

CMS recorded hundreds of millions of cosmic rays during several periods in 2008–2010 [2, 10]. These data were used to carefully calibrate the strip tracker, allowing the following procedures to be completed:

- adjust detector timing,
- comparison of data recorded in peak and deconvolution modes [11] to ensure correct operation in each mode,
- measure hit efficiencies,
- align the tracker as well as possible with cosmic rays,
- measure Lorentz angle, and
- test the tracking algorithms.

As a result, the strip tracker was already well calibrated and aligned prior to collisions, and the workflows and tools had already been tested. Naturally, collision data recorded at 900 GeV, 2.36 TeV and 7 TeV provided additional insight for calibration and alignment and were used for further improvement.

3.2. Collision data

With collision data, the sampling time of individual modules (with respect to the bunch crossing timing) was optimized to correctly retrieve the charge collected by the detector. The sampling time was scanned in steps of 2 ns over a window of ± 25 ns in April 2010. The result of this fine delay scan is presented in Fig. 3. As a result, the signal-to-noise ratio (S/N) of the sensors improved by about 4%. The S/N distributions of sensors belonging to the barrel part of the silicon strip tracker are shown in Figs. 4 and Fig. 5.

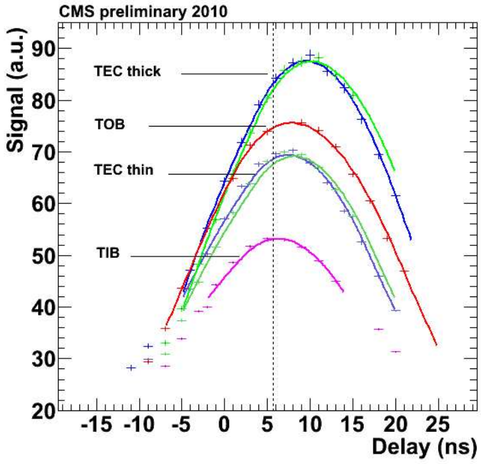

Figure 3. Results of the fine delay scan. Sensors of tracker inner barrel (TIB) and tracker outer barrel (TOB) are shown in respective datasets. Sensors of the tracker end cap (TEC) are classified depending on which side of CMS they are, and also according to their thickness (320 or 500 μm).

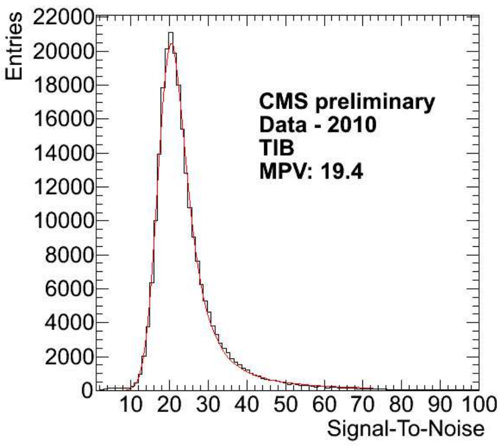

Figure 4. S/N distribution for sensors of tracker inner barrel (TIB), 7 TeV data in 2010.

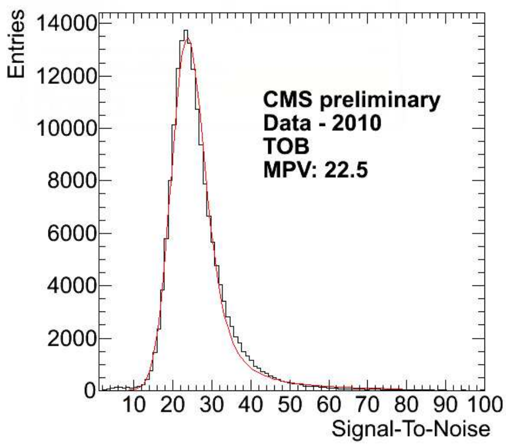

Figure 5. S/N distribution for sensors of tracker outer barrel (TOB), 7 TeV data in 2010.

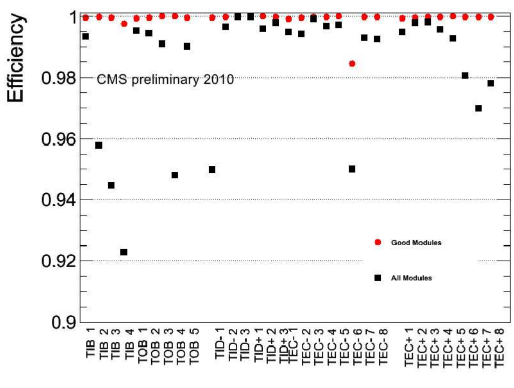

Figure 6. Module efficiency for each layer or disk of the strip tracker using 7 TeV collision data. Red circles correspond to functional modules, while black squares correspond to all modules.

The fraction of operational channels in the silicon strip tracker was 98.1% in 2010. The module efficiency for layers or disks is illustrated in Fig. 6. Efficiencies of the functional modules are high enough to allow robust and reliable track reconstruction.

Fig. 7 depicts the ionization energy loss dE/dx measured for Si strip sensors versus p of

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the track in 7 TeV collision events. The relation between particle mass, dE/dx and p can be fitted to proton data (line shown in red). The fitted constants can be applied also to kaon and deuteron, allowing to draw the corresponding lines, as described in [12]. The particle mass distribution, obtained from dE/dx and p, is shown in Fig. 8, as well as the distribution obtained from simulated events. Good agreement indicates proper calibration of the charge response of Si strip sensors.

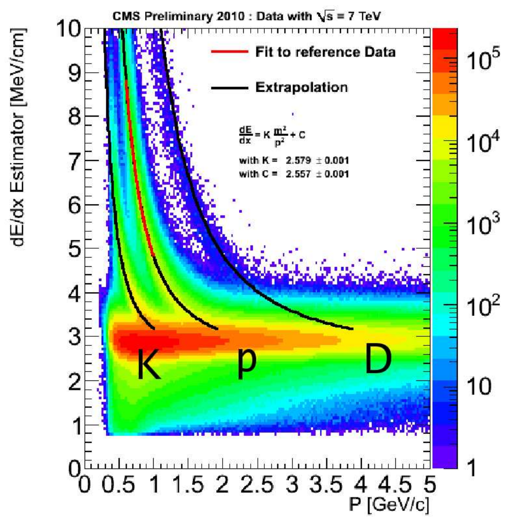

Figure 7. Ionization energy loss dE/dx vs. p for Si strip sensors. dE/dx depends on p and particle mass, and is used for particle identification. Lines for kaon, proton and deuteron are shown.

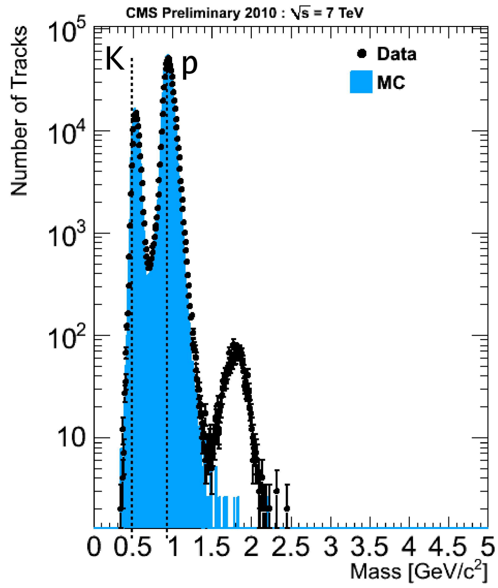

Figure 8. Distribution of particle mass reconstructed from dE/dx and p, both in 7 TeV collisions and in simulated events. The known values of the kaon and proton masses are indicated as vertical dotted lines. Deuterons are suppressed in simulation (Pythia and Geant4), which explains the discrepancy at high masses.

In addition to efficiency, the most important characteristic of a position-sensitive silicon sensor is the accuracy to measure the position of the crossing particle, the hit resolution. The hit resolutions for barrel sensors of the silicon strip tracker are shown in Fig. 9 for 7 TeV collision data. These results are as expected.

Good calibration results as well as fast and well-established workflows have ensured delivery of calibration constants in a timely manner, allowing CMS to maintain the high quality of its physics results.

In future, additional workflows benefiting from the increasing instantaneous luminosity will be introduced.

4. Summary

Alignment and calibration experiences obtained with cosmic rays have proved to be very useful for the operation of the CMS silicon strip tracker during high energy collision runs. Powerful calibration workflows and tools have been established and all necessary calibrations have been performed. As a result, excellent track efficiency, tracking resolution and particle identification have been achieved.

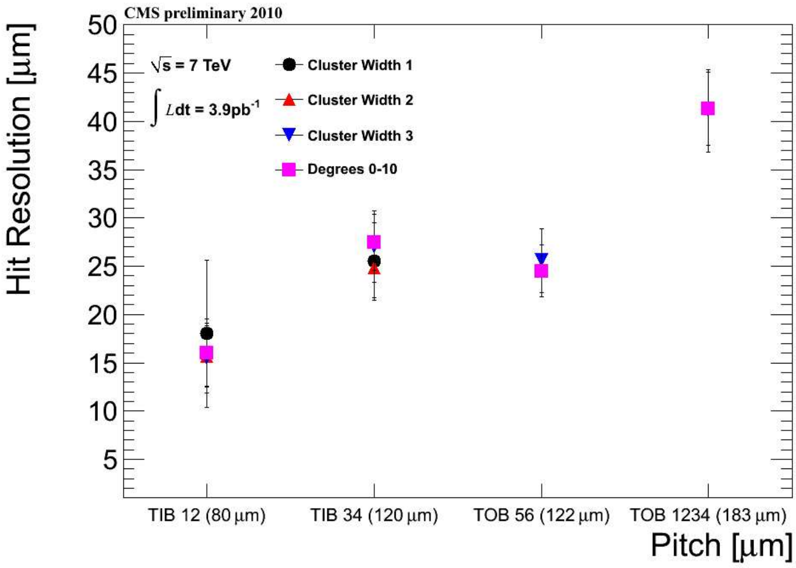

Figure 9. Hit resolution for sensors of the barrel of silicon strip tracker. Sensors are classified according to their strip pitch, which varies for different layers, and cluster width (the number of strips on which additional charge is detected). Separately shown are hits corresponding to a particle crossing the sensor nearly perpendicularly (angle with the normal of the sensor smaller than 10 degrees), which best reveal the intrinsic sensor resolution.

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