Tracker Performance in 2017 Legacy processing

CMS Collaboration

Abstract

During the LHC Long Shutdown 2, the CMS experiment started a collaboration-wide effort to re-calibrate the data and optimize the simulation, reconstruction and analysis software in order to reprocess the data collected during LHC Run 2 with uniform software and detector calibrations (Legacy processing). In this note are collected selected performance results obtained using the updated Legacy software and calibration concerning the pixel tracker simulation and the tracker detector alignment for the data collected by CMS during the year 2017, compared with the corresponding results at the time of the end of 2017 data-taking.
Tracker Performance in Run 2 Legacy processing

https://twiki.cern.ch/twiki/bin/view/CMSPublic/TrackerPerformanceRun2Legacy

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Distortions of the tracker geometry can lead to a bias in the reconstructed track curvature $k^\pm \propto \pm 1/p_T$.

These are investigated using the reconstructed mass of $Z^0 \rightarrow \mu^+\mu^-$ decays, as a function of the muon direction and separating $\mu^+$ and $\mu^-$ (since curvature bias has opposite effect on their $p_T$).

Invariant mass distribution is fitted to a Breit-Wigner convoluted with a Crystal ball function [1] (i.e. taking into account the finite track resolution and the radiative tail) for the signal plus an exponential background. The fit range is 75–105 GeV/$c^2$, $Z^0$ width fixed to PDG value of 2.495 GeV/$c^2$.

This does not show the CMS muon reconstruction and calibration performance!

- This is the tracker input to all object reconstruction. Physics analyses apply momentum calibration on top of this.
$Z\rightarrow\mu\mu$ mass bias vs $\phi_\mu$

- $Z^0$ peak mass as a function of the azimuthal angle of the positive and negative muons $\phi_\mu^\pm$ for all events at all pseudorapidities.
- Sensitive to distortions of the tracker in the transverse plane (e.g. the so-called "sagitta").
- The black points show the results with the alignment constants used in End-Of-Year (EOY) 2017 processing, the red points show the results with the alignment constants as obtained in the Legacy alignment procedure.
- Overall pattern in the Legacy processing is significantly reduced with respect to End-Of-Year reprocessing 2017 data.
Z\rightarrow\mu\mu mass bias vs \Delta\eta_\mu

- Z^0 peak mass as a function of the pseudorapidity difference $\Delta\eta_\mu = \eta_{\mu^+} - \eta_{\mu^-}$.
- The black points show the results with the alignment constants used in End-Of-Year (EOY) 2017 processing, the red points show the results with the alignment constants as obtained in the 2017 data Legacy alignment procedure.
- A twist distortion ($\Delta\phi \propto z$) would introduce a slope, as seen in the 2017 EOY alignment. This is fixed in the Legacy alignment thanks to the use of $Z\rightarrow\mu^+\mu^-$ mass constraint in the alignment fit [2].
2D $Z\rightarrow\mu\mu$ Mass bias vs $\eta_{\mu}$ and $\phi_{\mu}$

- $Z^0$ peak mass as a function of the pseudorapidity $\eta_{\mu^+}$ and the azimuthal angle of the positive muon $\phi_{\mu^+}$ for 2017 End-of-Year reprocessing CMS data. The z-axis range is centred at the peak value corresponding to the fitted mass for all events in the 2017 sample (91.08 GeV/c$^2$).
2017 Legacy processing  CMS Preliminary (13 TeV)

- $Z^0$ peak mass as a function of the pseudorapidity $\eta_{\mu^+}$ and the azimuthal angle of the positive muon $\phi_{\mu^+}$ for Legacy processing of 2017 data. The z-axis range is centred at the peak value corresponding to the fitted mass for all events in the 2017 sample (91.08 GeV/c$^2$). Overall pattern is significantly reduced with respect to End-Of-Year reprocessing 2017 data.
Alignment Validation with Primary vertices

- The resolution of the reconstructed vertex position is driven by the pixel detector since it is the closest detector to the interaction point and has the best hit resolution. The primary vertex residual method is based on the study of the distance between the track and the vertex, the latter reconstructed without the track under scrutiny (unbiased track-vertex residual) \[2\].

- Selection and reconstruction of the events is the following:
  - Events used in this analysis are selected online with zero bias triggers.
  - The fit of the vertex must have at least 4 degrees of freedom.
  - For each of the vertices, the impact parameters are measured for tracks with:
    - more than 6 hits in the tracker, of which at least two are in the pixel detector,
    - at least one hit in the first layer of the Barrel Pixel or the first disk of the Forward Pixel,
    - \(\chi^2/ndof\) of the track fit < 5.

- The vertex position is recalculated excluding the track under scrutiny.

- A deterministic annealing clustering algorithm \[3\] is used in order to make the method robust against pileup, as in the default reconstruction sequence.

- The distributions of the unbiased track-vertex residuals in the transverse plane, and in the longitudinal direction, are studied in bins of track azimuth and pseudo-rapidity. Random misalignments of the modules affect only the resolution of the unbiased track-vertex residual, increasing the width of the distributions, but without biasing their mean. Systematic movements of the modules will bias the distributions in a way that depends on the nature and size of the misalignment and of the selected tracks.
In order to present the overall impact parameter bias performance as a function of time throughout one year of data-taking, we plot as a function of luminosity collected in each CMS run the mean and the dispersion (RMS) of the transverse $d_{\text{xy}}$ and longitudinal $d_z$ impact parameter as a function of $\phi$ and $\eta$ of the track.
Mean of the average transverse impact parameter

- The mean of the average impact parameter in the transverse plane $d_{xy}$ versus track azimuth $\phi$, as a function of integrated luminosity.
- The vertical blue lines indicate changes in the calibration of the local hit reconstruction in the pixel tracker. The black points show the results with the alignment constants used during 2017 End-Of-Year reprocessing, the red points show the results with the alignment constants as obtained in the Run-2 Legacy alignment procedure.
- Aligning the tracker improves the mean of this distribution.
- Outliers in the trend are understood as degraded tracking performance caused by suboptimal pixel local reconstruction calibration input.
The RMS of the average impact parameter in the transverse plane $d_{xy}$ in bins of the track azimuth $\phi$, as a function of integrated luminosity.

The vertical blue lines indicate changes in the calibration of the local hit reconstruction in the pixel tracker. The black points show the results with the alignment constants used during 2017 End-Of-Year reprocessing, the red points show the results with the alignment constants as obtained in the Run-2 Legacy alignment procedure.

Aligning the tracker reduces the RMS.
Simulation of pixel detector ageing

- For non irradiated, fully depleted detector, the pixel charge profile (normalised average pixel charge as a function of the production depth) is expected to be flat as detector is fully efficient and all charge is collected, while for irradiated detector the losses are expected due to the trapping of carriers. The losses are larger for the charges released further from the readout plane.

- Due to the increased irradiation of the pixel detector in Run-2, in 2018 the radiation damage effects were incorporated in the CMS pixel detector simulation. The radiation damage effects in the pixel detector are simulated by reweighting the charge of each pixel using the cluster shapes for the non irradiated and irradiated detector obtained from the PIXELAV simulation tuned to the CMS data \([4,5]\).

- The normalised average pixel charge as a function of the production depth in the silicon substrate is shown for Layer 1 of the CMS pixel barrel detector after 30.1 fb\(^{-1}\) (black) and is compared to the profiles obtained using the CMS Pixel detector simulation with incorporated radiation damage effects (red). Apart from the bins close to the sensor edges, the agreement between data and MC is better the 4%.
References

[1] CMS Collaboration “Performance of CMS muon reconstruction in pp collision events at sqrt(s) = 7 TeV” JINST 7 (2012) P10002
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Tracker Performance in Run2 Legacy processing