Comparison of track properties between Data and MC at CMS using early Run-3 data

QR code to poster

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Public results twiki: https://twiki.cern.ch/twiki/bin/view/CMSPublic/CMSEarlyRun3DataMCComparisons (note in preparation)

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Introduction

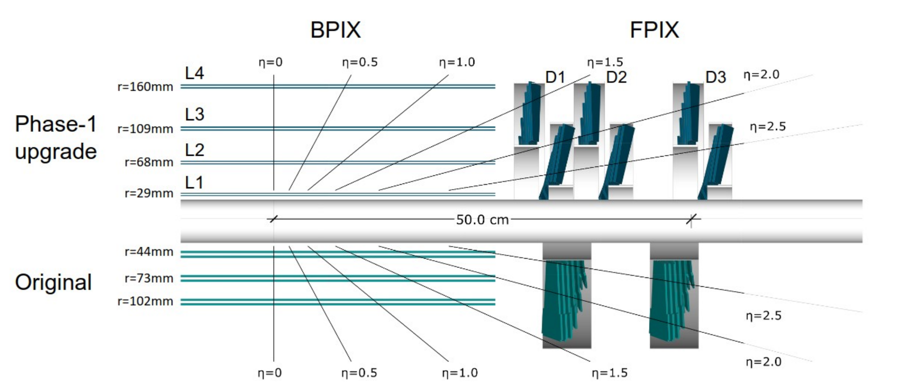
- Properties of reconstructed tracks are compared using CMS data from first Run 3 pp collision at 13.6 TeV.
- This work is essential for understanding the level of agreement between data and MC, and supporting the tuning of the different ingredients which enter in data and in the simulations - like tuning of MC generators, debugging of tracker conditions (alignment, bad components, etc.), and software commissioning.
- Preliminary data and MC datasets are used in the comparisons.
- Data used in this studies are from July 19th, 2022 to October 17th, 2022, with the exception of the period from August 23rd to September 27th.
- Two different kinds of events are used, to probe two different p_T ranges:
  - **ZeroBias**, triggered using information on the beam-beam coincidences.
  - **Z→ μμ**.
- Some figures are shown for different data-taking time periods as a function of the integrated luminosity delivered since the installation of the new BPix layer 1 [6].

Event selection

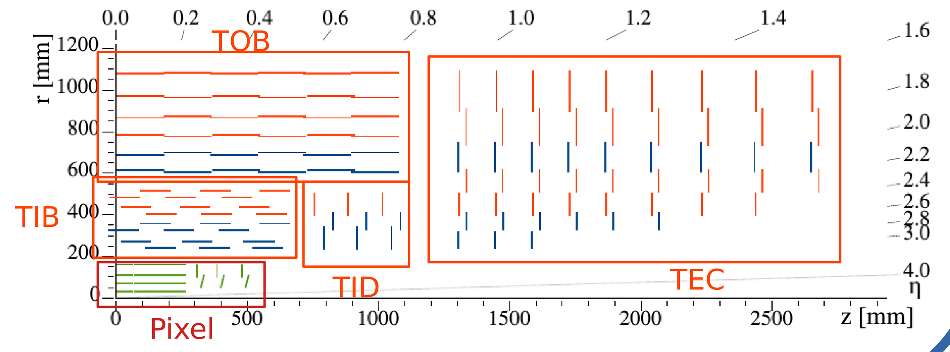
- **ZeroBias**: triggered using only the information on the beam-beam coincidence. The trigger which is used collects only a fraction of delivered events. The corresponding integrated luminosity is **11.5 nb⁻¹**. Tracks which pass the **highPurity** selection [1], with p_T > 1GeV, are considered for this study.
- **Z→μμ**: selected by a High Level Trigger having at least one isolated muon with p_T > 24 GeV. The corresponding integrated luminosity is **14.5 fb⁻¹**. Tracks are selected with the following requirements:
  - **global Particle Flow muons** [5]
  - **$|\eta|$ < 2.4, p_T > 5 GeV**
  - **Normχ^2 < 10, $|d_{xy,BS}|$ < 0.02 cm, $|d_{z,BS}|$ < 20 cm**
  - Has at least **one pixel hit**, at least **8 strip hits**, at least **hits in 2 muon stations**
  - **Relative isolation within a cone of radius ΔR=0.4 less than 0.3** [5]
  - The two highest p_T tracks must have **60 GeV < $m_{\mu\mu}$ < 120 GeV**
- MC events are weighted to match the distribution of number of vertices in data.

CMS Tracker Detector [1], [2]

- Immersed in 3.8 T solenoidal magnetic field
- Pixel detector:
  - Closer to the interaction point
  - CMS Phase-1 pixel detector (since 2017):
    - 124M pixels in total (size 100x150 μm²)
    - BPIX: 4 layers
    - FPIX: 3 disks on each side

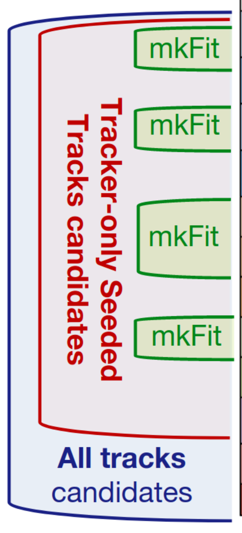


- Silicon strip detector:
  - 9.6M strips in total (pitch 80-180 μm)
  - TIB: 4 layers (2 stereo)
  - TID: 3 disks (2 stereo) on each side
  - TOB: 6 layers (2 stereo)
  - TEC: 9 disks (3 stereo) on each side



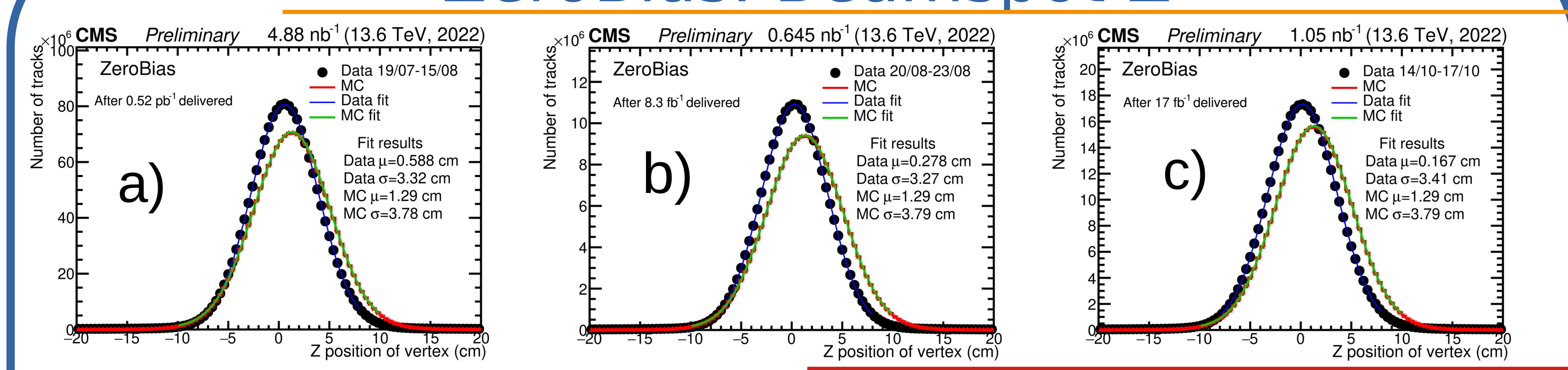
Tracking at CMS

- Iterative tracking:
  - Multiple iterations of the same Kalman Filter algorithm [1] are run, first looking for easily identifiable track and removing their hits. The algorithm then runs again with progressively looser settings. New mkFit [3], [4] algorithm is under development for Run 3 and is already implemented in some of the iterations.
- Each iteration has four steps:
  - **Seed generation**: seeds are built using a few hits using from specific layers and a rough estimate of the parameters is provided.
  - **Pattern recognition**: extrapolation of the seed track parameters to next layers looking for compatible hits, taking into account the magnetic field and material effects.
  - **Fitting**: both inside-out and outside in.
  - **Quality flagging**.



Iteration	Seeding	Target track
Initial	pixel quadruplets	prompt, high p_T
LowPtQuad	pixel quadruplets	prompt, low p_T
HighPtTriplet	pixel triplets	prompt, high p_T recovery
LowPtTriplet	pixel triplets	prompt, low p_T recovery
DetachedQuad	pixel quadruplets	displaced--
DetachedTriplet	pixel triplets	displaced-- recovery
MixedTriplet	pixel+strip triplets	displaced-
PixelLess	inner strip triplets	displaced+
TobTec	outer strip triplets	displaced++
JetCore	pixel pairs in jets	high-p_T jets
Muon inside-out	muon-tagged tracks	muon
Muon outside-in	standalone muon	muon

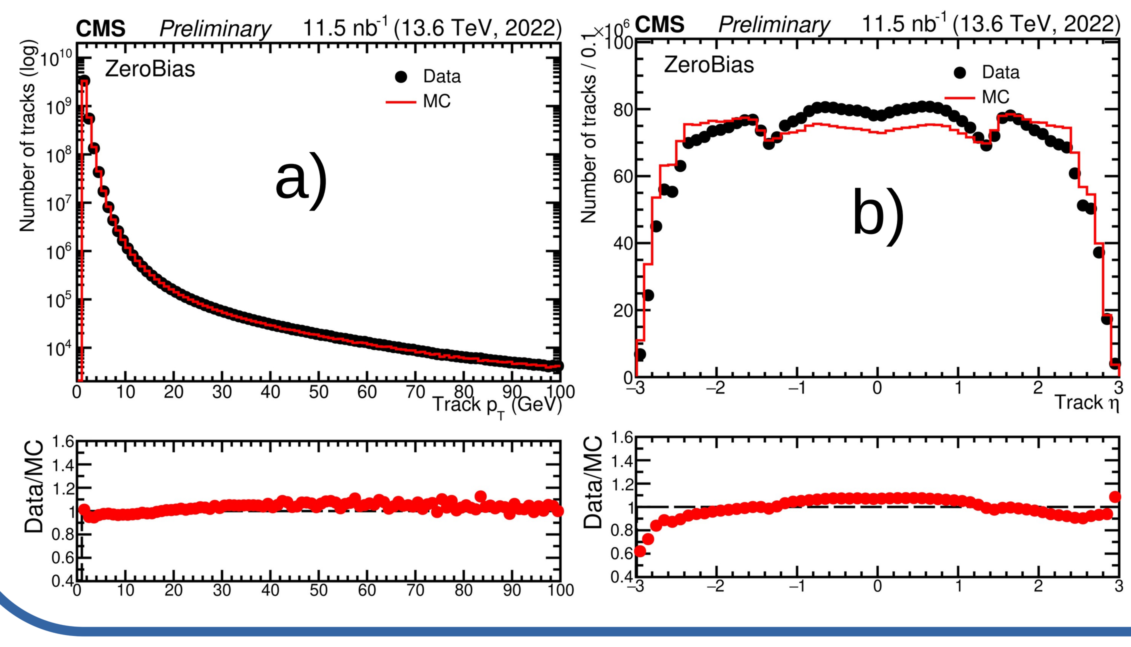
ZeroBias: Beamspot Z



- Fits using a Gaussian distribution plus a constant are superimposed on data and MC.
- Distributions in data corrected to account for pixel detector position. This is done since the MC sample is simulated with pixel detector in (0,0,0) and the beam is displaced, while in data both pixel detector center and luminous region centroid are free floating parameters.
- Distributions in data are narrower and the peak tends to move towards 0 with time.

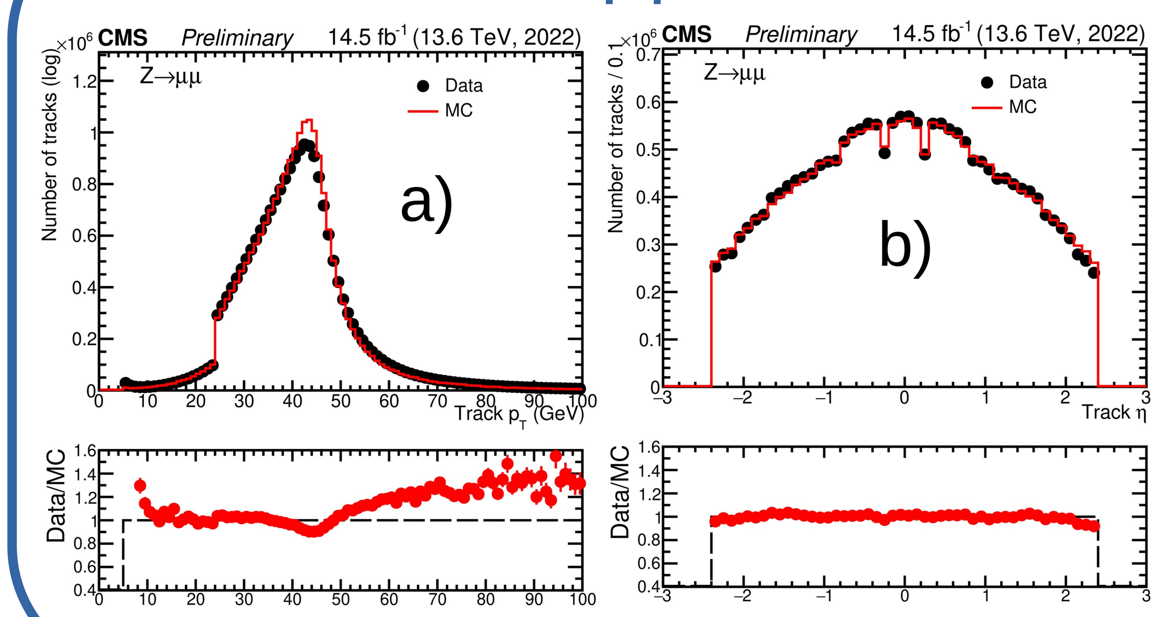
[1]: Description and performance of track and primary-vertex reconstruction with the CMS tracker, CMS Collaboration, JINST 9 (2014) P10009
[2]: The CMS Phase-1 Pixel Detector Upgrade, CMS Tracker Group of the CMS Collaboration, JINST 16 (2021) P02027
[3]: Speeding up Particle Track Reconstruction using a Parallel Kalman Filter Algorithm, S. Lantz et al., arXiv:2006.00071v2 [physics.ins-det] 10 Jul 2020
[4]: Performance of Run 3 track reconstruction with the mkFit algorithm, CMS Collaboration, CERN-CMS-DP-2022-018
[5]: Performance of the CMS muon detector and muon reconstruction with proton-proton collisions at √s = 13 TeV, CMS Collaboration, JINST 13 (2018) P06015
[6]: CMS Phase-1 pixel detector refurbishment during LS2 and readiness towards the LHC Run 3, CMS Collaboration, CMS-CR-2021-255 (2021)

ZeroBias: track kinematics



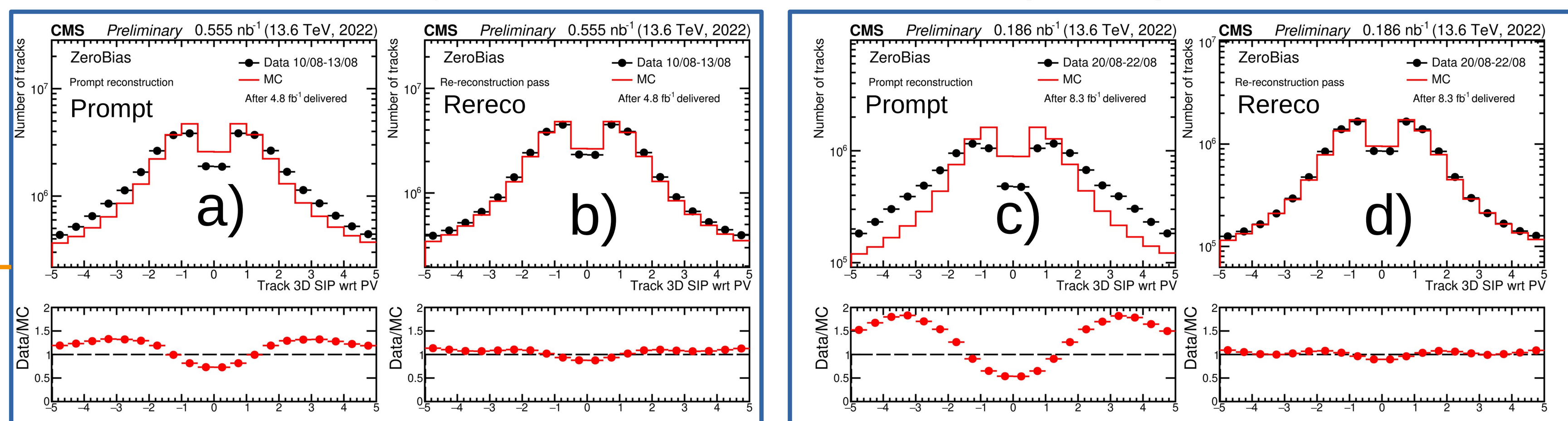
- Agreement in the p_T distribution (figure a) is found within 10%.
- The η distribution (figure b) in MC is wider than in data:
  - Possibly due to the tuning of the MC generator used
  - Also asymmetry in absolute value, due to beamspot Z.

Z→μμ: track kinematics



- Disagreement in p_T (figure a) between data and MC, due to improper modelling of Z boson production mechanism.
  - Sharp increase at 24 GeV due to trigger threshold.
- η distribution (figure b): agreement is good, except at high values.
- Muons reconstructed in the muon system are used → structures of the muon spectrometer can be seen, |η| acceptance is reduced to 2.4

ZeroBias: significance of the 3D impact parameter

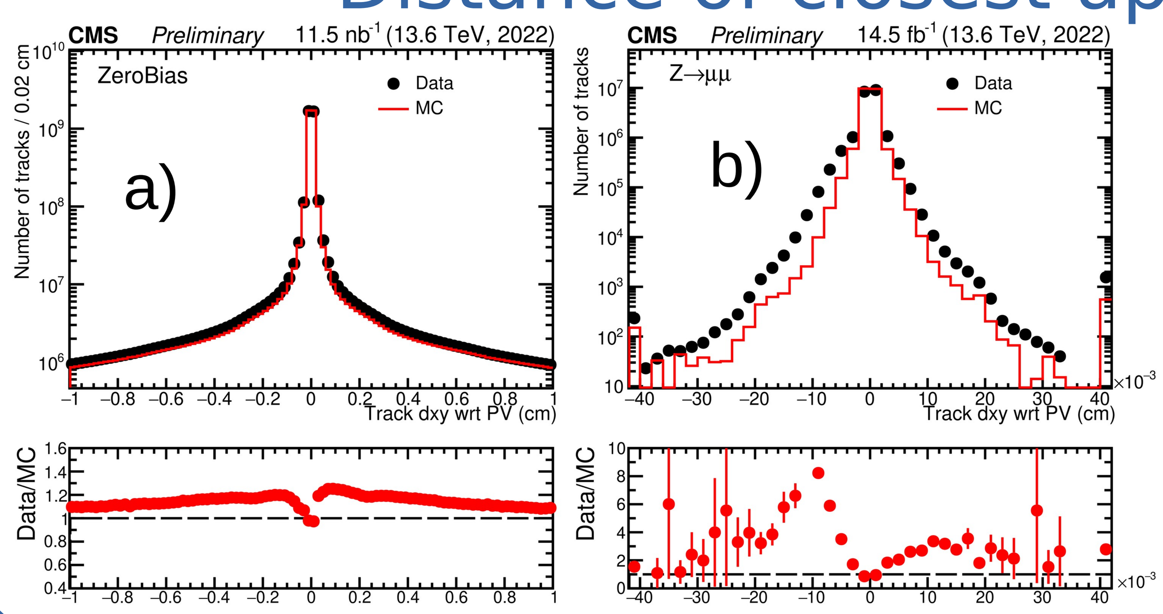


Subset of events in a) in BeamSpot Z block, right reprocessed with latest updates

Subset of events in b) in BeamSpot Z block, right reprocessed with latest updates

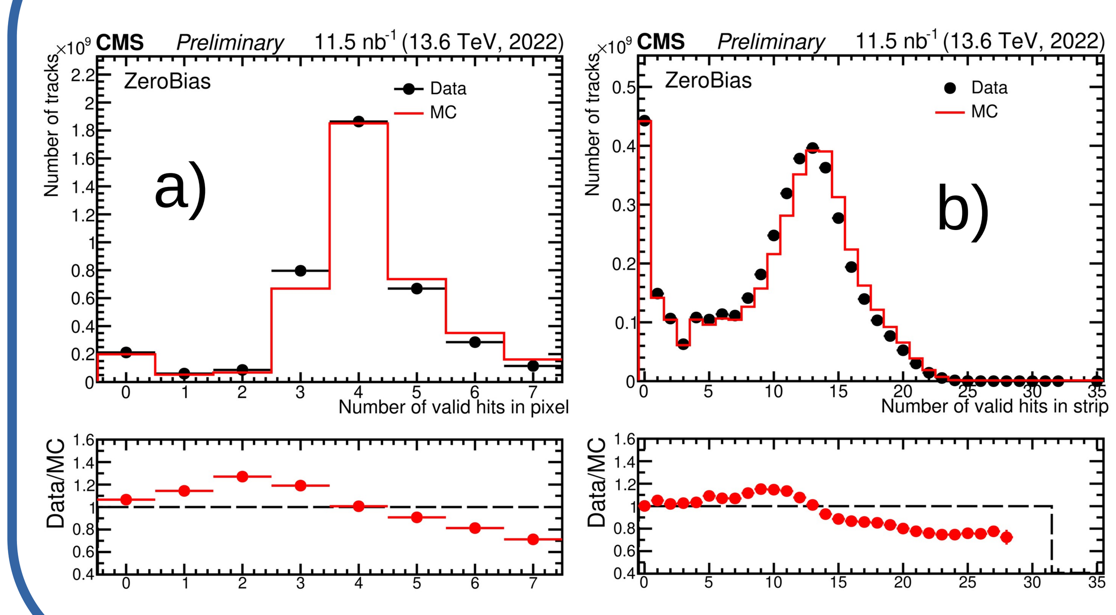
- Comparing figure a) to c): the agreement between data and MC gets worse over time, indicating aging of BPix layer 1.
- Comparing a) to b) and c) to d): the agreement in the re-reconstructed data is much better and the effect from irradiation is reduced.
- Residual disagreement might indicate better quality of alignment in MC.

Distance of closest approach



- Figure a): ZeroBias events. Figure b): Z→μμ events.
- Distribution wider in data than in MC, shifted.
- The MC distribution is narrower than that in data, indicating a better quality of alignment in MC.

ZeroBias: number of valid hits



- Pixel detector (figure a): trend with number of hits (nHits=4 good).
- Strip detector (figure b): number of hits overestimated in MC, agreement at the 20% level.
- Sensitive to the bad components of the tracker.
- The number of bad components in simulation set to correspond to the period from August 20th, 2022 to August 23rd, 2022.

Conclusions

- Track kinematic properties with early Run 3 data compares well with simulation.
- Differences in data/MC due to improper modelling of production mechanism and/or missing reconstruction corrections, differences in alignment, especially for muons.
- The distributions of the distance closest approach and the significance of the 3D impact parameter seem to indicate that the quality of alignment in MC is superior to that in data.
- Effects related to the aging of BPix layer 1 can be observed in the significance of the 3D impact parameter distributions. Updates have been implemented in the reprocessing of data which make the agreement better (similar updates are being implemented in the reconstruction of new events).
- Number of valid hits in general overestimated in MC. Might be due to some dependence on kinematics or perhaps the different quality of alignment