CMS tracking performance in Run-2 Legacy data using the tag-and-probe technique.

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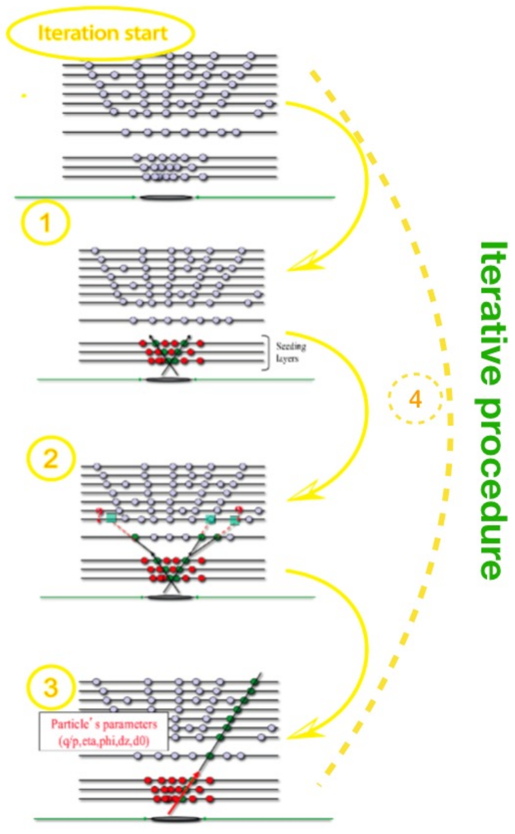
1. Introduction

During the second phase of data taking at the LHC Run 2, the accelerator has delivered pp collisions with a center-of-mass energy of 13 TeV, a bunch time separation of 25 ns, and an average of more than 25 inelastic collisions superimposed on the event of interest. In such a highly populated environment, accurate reconstruction of charged particle trajectories and measurement of their parameters (tracking) was one of the major challenges of the CMS experiment. In this work, we present the tracking performance measured in data where the tag and-probe technique was applied to $Z \rightarrow \mu^+\mu^-$ resonances using the legacy reprocessing of Run 2 CMS data, corresponding to an integrated luminosity of 137 fb^{-1} at $\sqrt{s}$ = 13 TeV.

2. Track reconstruction

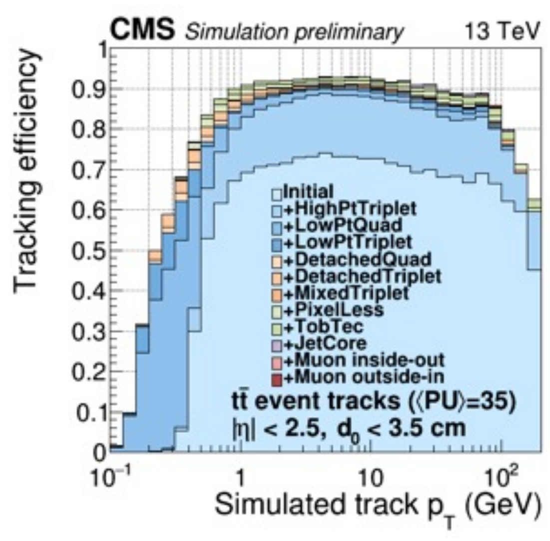
1. **Seeding:**
   provides an initial track candidate and trajectory parameters.
2. **Pattern recognition: (track finding)**
   - extrapolate current trajectory parameters to the next layer and find compatible hits and update with Kalman filter.
   - continue until there are no more layers or there is more than one missing hit.
3. **Final fit:**
   provides the best estimate of the parameters of each smooth trajectory after combining all associated hits [outlier hits are rejected]
4. **Selection:**
   the track selection sets quality flags based on a set of cuts sensitive to fake tracks, on the track normalized χ^2, and on its compatibility with interaction region.



3. Iterative Tracking in CMS

- Track reconstruction is an **iterative procedure**[1], where each step is meant for reconstructing a specific subset of tracks (prompt, low/high p_T, displaced, ...)

- Removing hits of found tracks reduce the combinatorial problem so that problematic tracks can be reconstructed within the CPU time budget.



Iterative tracking efficiency in MC as a function of track p_T

4. The Tag and Probe method

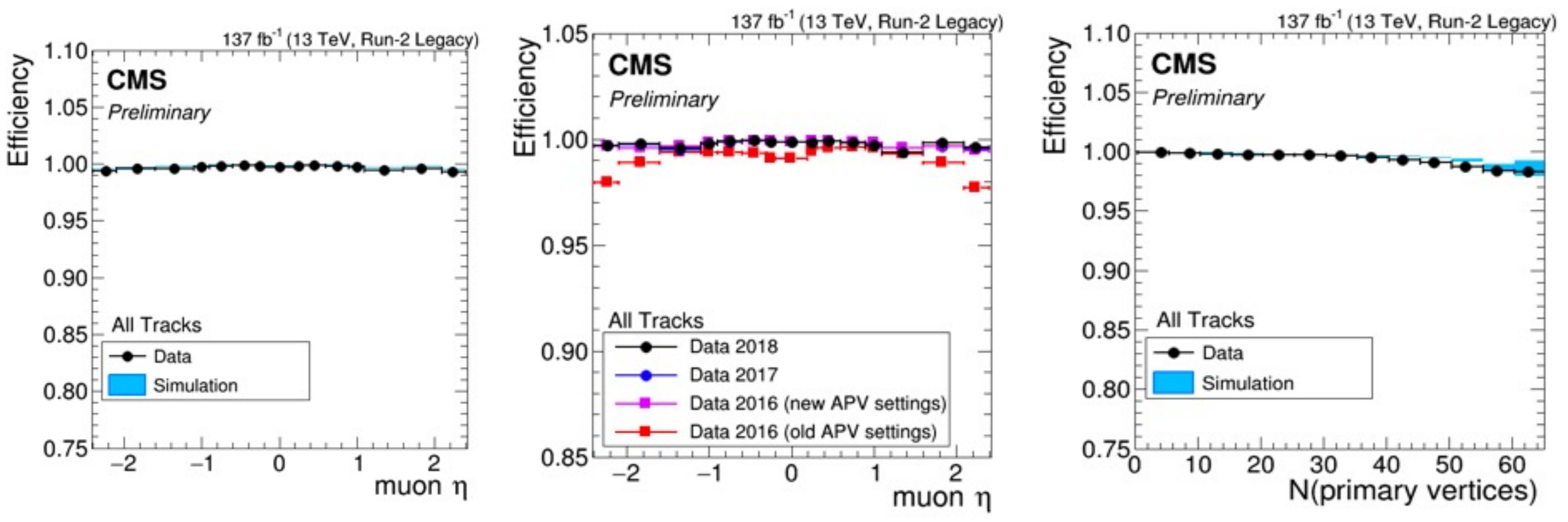
- The tag and probe method (T&P) is a data-driven technique used to measure the efficiencies from data. It is based on the reconstruction of well-known resonances, such as J/ψ or Z.
  - **Tag:** a global muon (i.e. reconstructed using both the muon chambers and the tracker) with transverse momentum $p_T \geq 27$, associated to one leg of the resonance and with a single muon trigger.
  - **Probe:** any standalone muon (i.e. reconstructed using only hits from the muon system) with at least one valid hit in the muon system (i.e. good track-hit χ^2).
  - **passing probe:** The standalone muon is matched with tracks that fulfill minimum quality requirements in (Δ R < 0.3). The matching is defined by comparing the directions at the point of the closest approach to the beamline of the two tracks.
- The (tag + passing probe) and (tag + failing probe) lineshapes are fit separately with a signal + background model.
- The efficiency is computed as the ratio between the "passing probes" and the total number of probes in the sample.

5. The probability of spurious matches

- The probability of spurious matches can be measured directly on data: before matching probes and tracker tracks, one can remove those tracks that combined with the tag give an invariant mass near the Z peak. Under these circumstances, the tracking efficiency measured estimates the probability of fake matches.
- The measured efficiencies have been corrected using the estimate of the probability of fake matches [3].

6. Tracking efficiency for All-Tracks

- In general, high tracking efficiency in Run-2 Legacy data ~ 99.9% for all reconstructed muon trajectories (**All-tracks**), thanks to significant improvements, which were made during both the LS1 and Run2:
  new iterations, new tuning, PU mitigation, code re-engineering, new seeding framework, Cellular Automaton(CA) seeding, mitigation strategy, etc..
- Good agreement of the tracking efficiency is observed for (2018, 2017, 2016 new APV settings). In the earlier part of 2016, in which Run1 APV settings had been used[4], a loss in efficiency up to ~ 2 % is found.

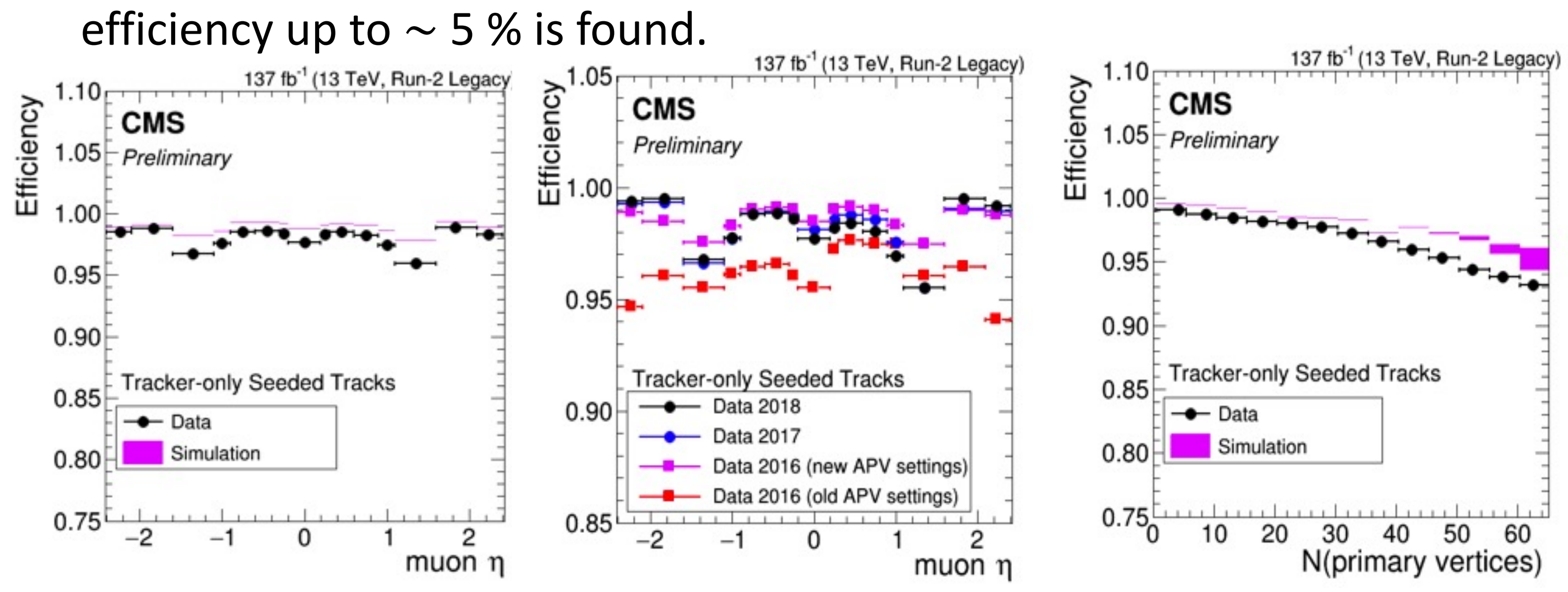


Muon tracking efficiency calculated from Z→μ+μ- events using Tag-and-Probe technique for all reconstructed muon trajectories (**All-tracks**).

(*) old APV settings: pre-amplifier of the APV25 readout chip is saturated (20 fb-1 of 2016 data).
new APV settings: APV setting changed for fast recovery (16 fb-1 of 2016 data).

7. Tracking efficiency for Tracker-only seeded tracks

- The tracking efficiency for **tracker-only seeded tracks** (the subset of trajectories in which the CMS Tracker is used to seed the measurement) in Run-2 Legacy data is ~ 98%.
- The efficiency is similar for 2018, 2017, 2016 new APV settings. In the earlier part of 2016, in which Run1 APV settings had been used, a loss in efficiency up to ~ 5 % is found.



Muon tracking efficiency calculated from Z→μ+μ- events using Tag-and-Probe technique for the subset of trajectories in which the CMS Tracker is used to seed the measurement (**Tracker-only seeded tracks**).

(*) old APV settings: pre-amplifier of the APV25 readout chip is saturated (20 fb-1 of 2016 data).
new APV settings: APV setting changed for fast recovery (16 fb-1 of 2016 data).

8. Conclusions

- Tracking efficiency measurements based on data-driven techniques have been shown.
- Despite challenging conditions at the LHC in Run-2, the CMS Tracker has robust performance in a challenging environment ⇨ "high tracking and vertexing performance".
- Performances show a dependence of the detector as well as the algorithms used in the event reconstruction.
- The Phase-1 pixel upgrade has helped to cope with higher LHC delivered luminosity and the increased number of PU events.

9. References

[1] The CMS Collaboration. "Description and performance of track and primary-vertex reconstruction with the CMS tracker". JINST, 9(10):P10009, oct 2014. URL https://doi.org/ 10.1088/1748-0221/9/10/p10009.
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