Tracking, alignment and b-tagging performance and prospects in CMS

Jan-Frederik Schulte
on behalf on the CMS Collaboration

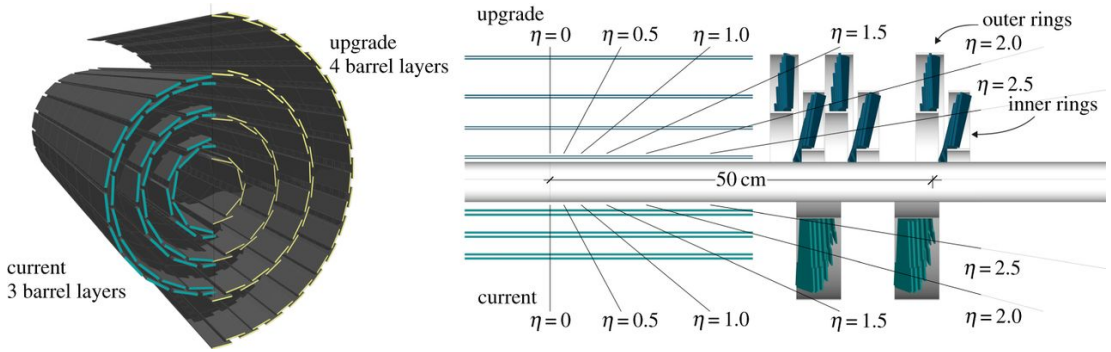
LHCP 2018 - Bologna

June 3, 2018

Introduction

- Reconstruction of charged particle trajectories is a key ingredient of reconstructing the full event
- High efficiency and precision are mandatory to ensure overall performance of the experiment
- Contingent on good performance and alignment of the tracking detectors
- Identification of b-quark jets is crucial for the CMS physics programme and depends on optimal tracking performance

- CMS upgraded its pixel detector in 2017
- Additional layer improves track impact parameter resolution and vertexing performance, helpful especially for b-tagging



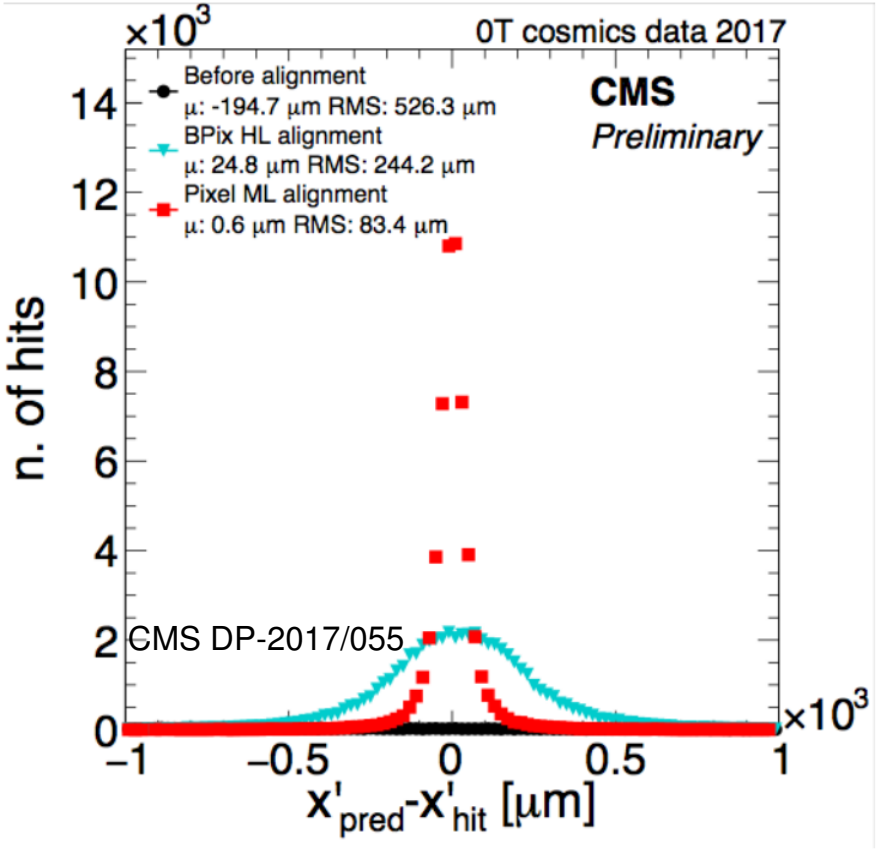
CMS Alignment Strategy

- Possible displacements and rotations of detector modules much larger than intrinsic hit position resolution on the sensor
- Corrected for by track-based tracker alignment in two complementary approaches
  - Simultaneously fit all track and alignment parameters in a global approach (MillePede II)
  - Local fits, handling the correlations iteratively (HipPy)
- Both are used to validate each other and best performing results is used in the event reconstruction

- Needed to align the new pixel detector quickly in 2017 to ensure good detector performance from the start
- Achieved using both cosmic ray data at 0 T and 3.8 T, as well as tracks from the first collision data

2017 Tracker Alignment Performance

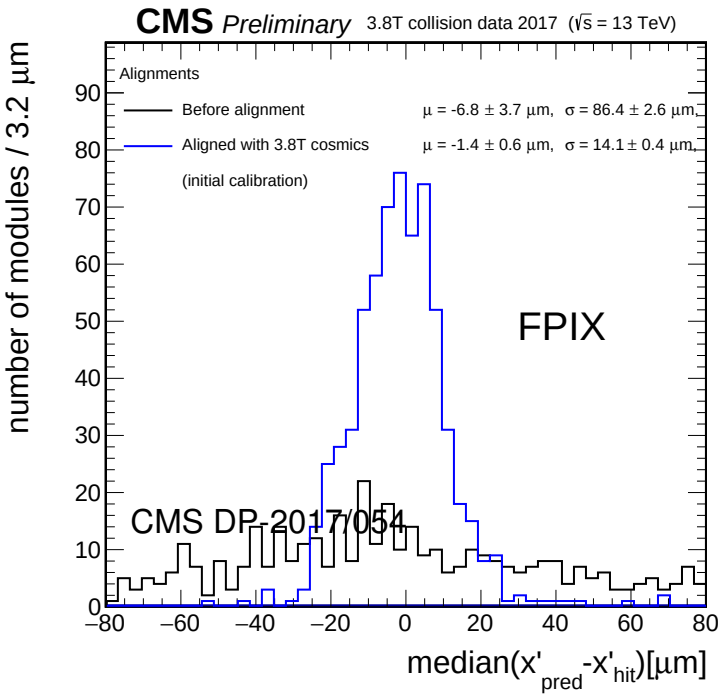
- 2017 startup alignment derived on 0 T cosmic ray data
- Performed in two steps:
  - 1.: only the high level (HL) structures of the new pixel are considered
  - 2.: alignment is performed on module level (ML)

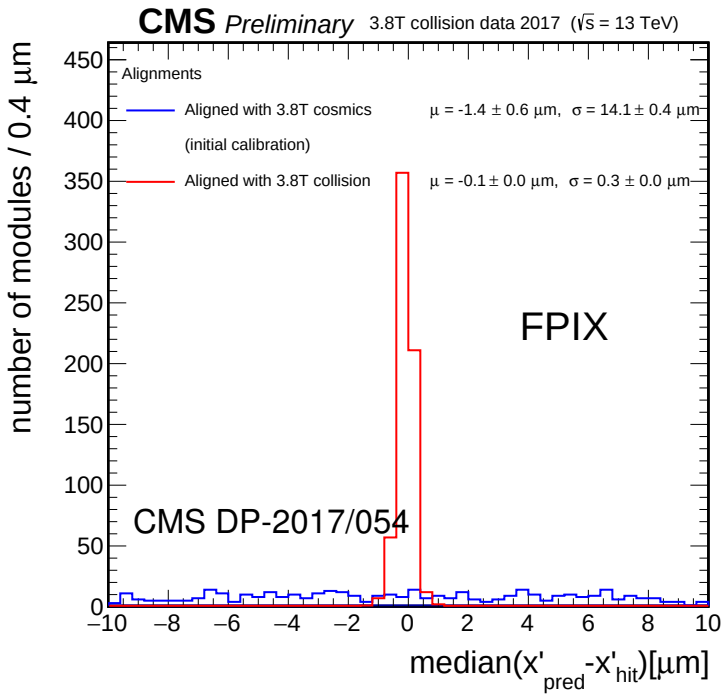


- Track hit residuals show significant improvement in performance, correcting the overall offset and improving the resolution

2017 Tracker Alignment Performance

- Alignment was updated with 3.8 T cosmic ray events
- Updated again with tracks from collision data
- Much larger track sample
- Helps especially in FPix which is not illuminated well by cosmic ray tracks

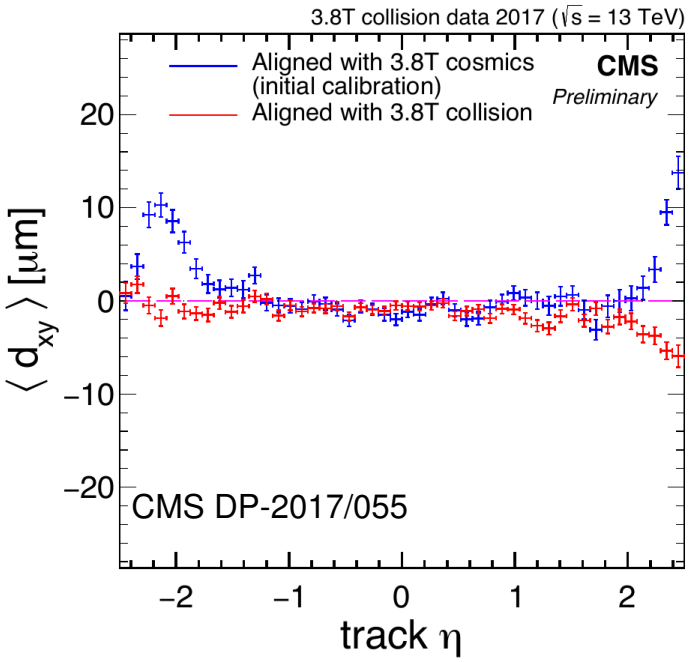


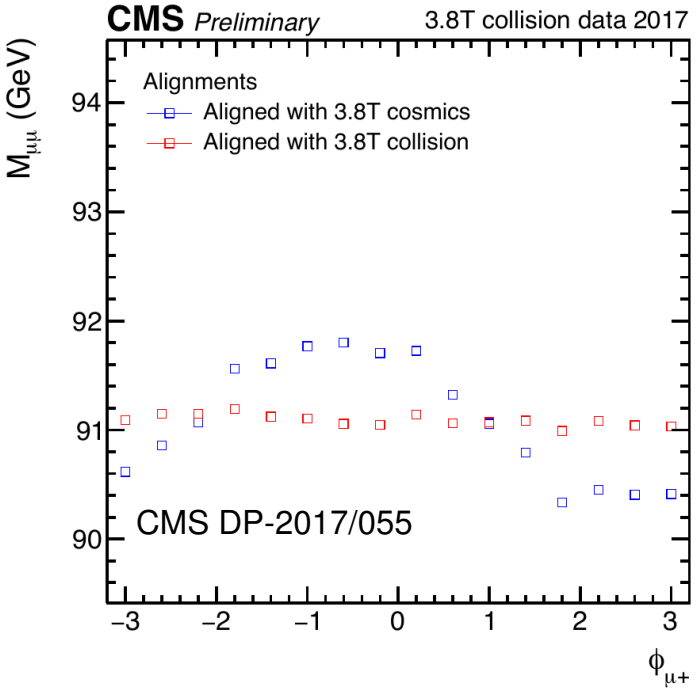


- With the final alignment the track hit residuals are significantly improved again, reaching a precision better than the intrinsic hit resolution of the detector

2017 Tracker Alignment Performance

- Alignment performance in monitored by studying higher level quantities
- Biases in the alignment are visible in the mean track impact parameter, mostly cured by the final alignment
- Using millions of Z boson events where the mass constrain can be used allows to control systematic deformation in the detector

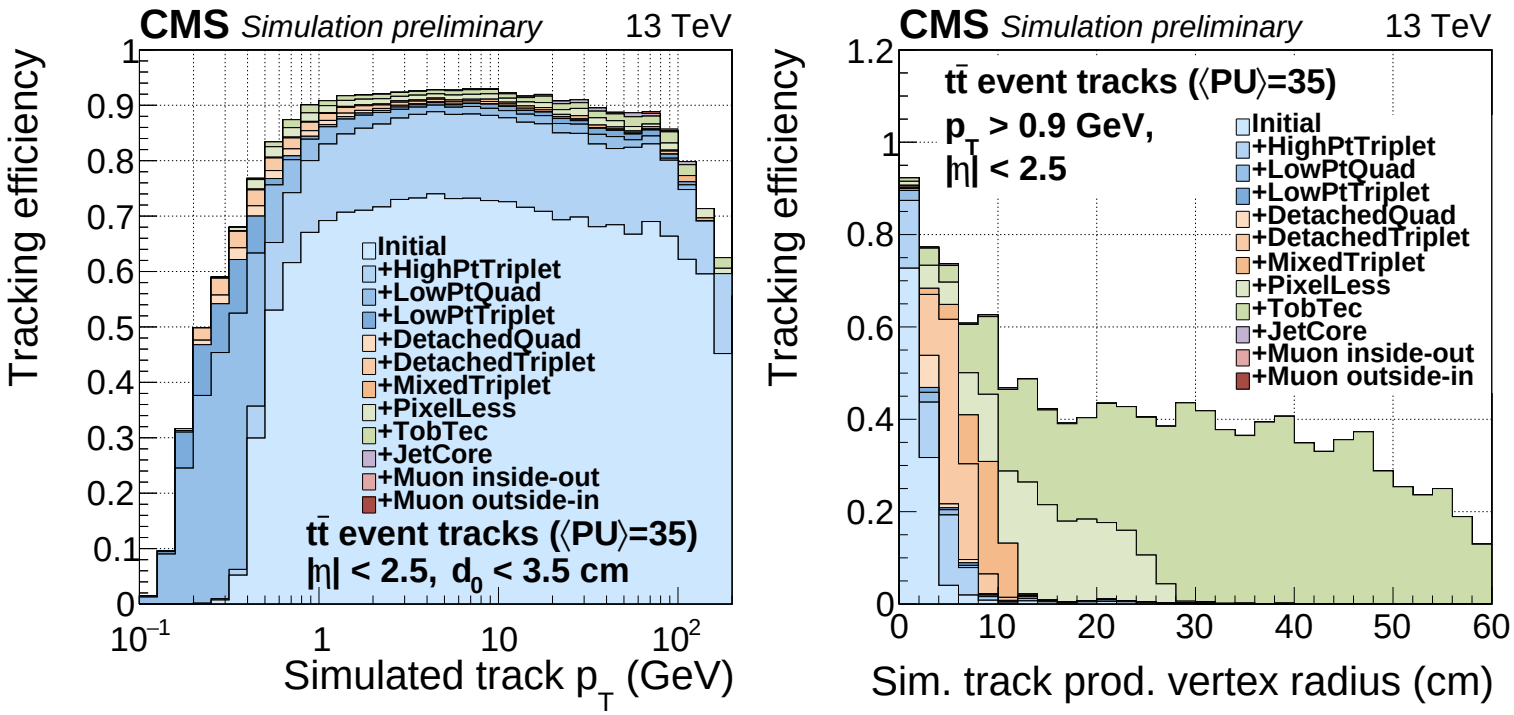




- With this alignment, very good performance was achieved
- The same procedure of subsequently improving alignments has been applied successfully in the 2018 data taking

Iterative Tracking in CMS

- Tracks are reconstructed iteratively to deal with the large combinatorical puzzle
  - Start with very tight criteria for track seeds and reconstruct tracks
  - Clear the detector of already used hits
  - Loosen the seed criteria and repeat

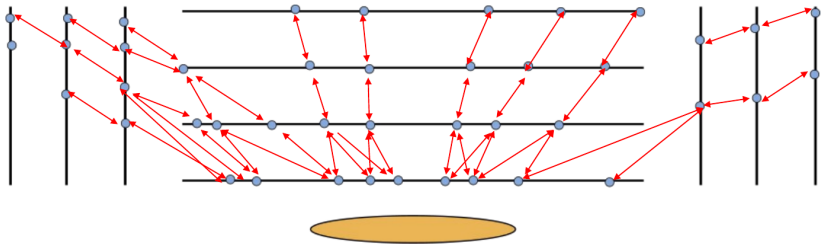


https://twiki.cern.ch/twiki/bin/view/CMSPublic/TrackingPOGPerformance2017MC

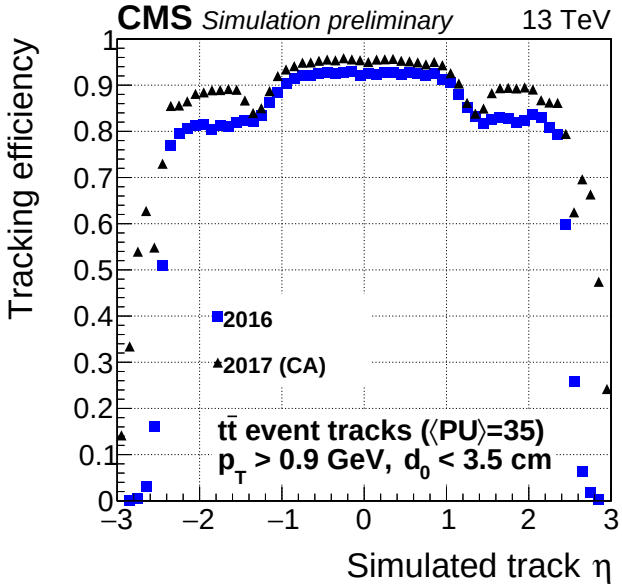
- Tracking efficiency $> 90\%$ for $p_T > 1$ GeV

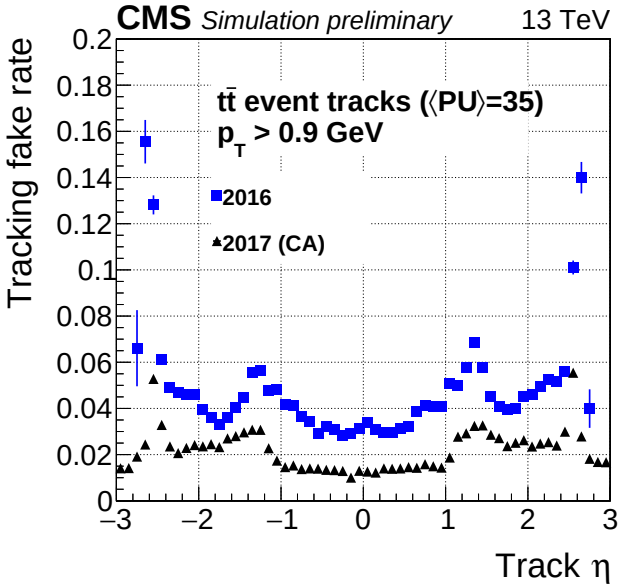
Improvements in 2017

- Tracking seeded mostly by pixel hits → Update needed with new pixel detector



- Pixel seeds found using Cellular Automaton technique
- Hit pairs are formed between detector layers
- Pair compatibility w.r.t. the interaction point is checked
- Hit triplets or quadruplets used for seeing formed from compatible pairs



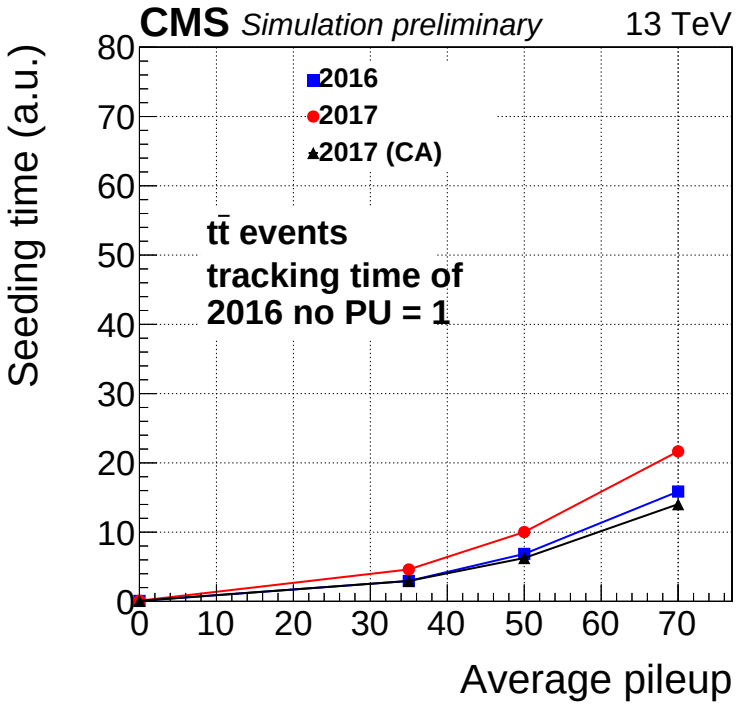


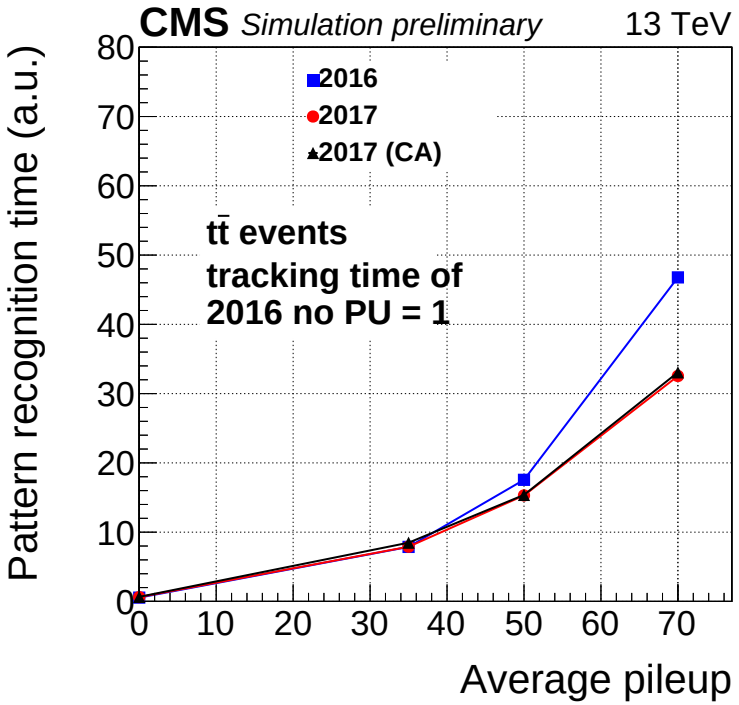
https://twiki.cern.ch/twiki/bin/view/CMSPublic/TrackingPOGPerformance2017MC

- Significantly improved efficiency and fake rate

Improvements in 2017 - Timing

- With the additional layers, conventional seed finding in the pixel detector would have significantly slowed down track seeding
- Use of CA reduces timing back to or below the 2016 performance
- Reduction in fake rate leads to reduction of time spent on pattern recognition, independent of seed algorithm

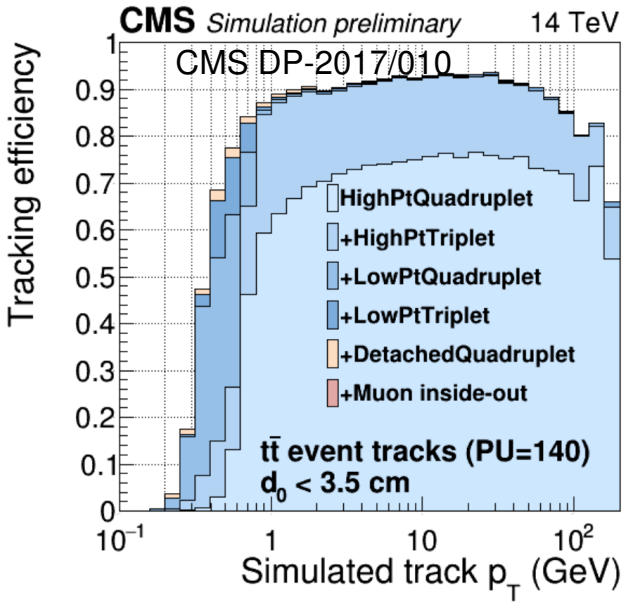




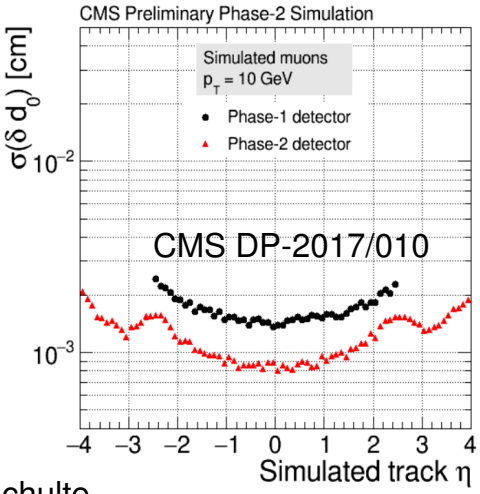
https://twiki.cern.ch/twiki/bin/view/CMSPublic/TrackingPOGPerformance2017MC

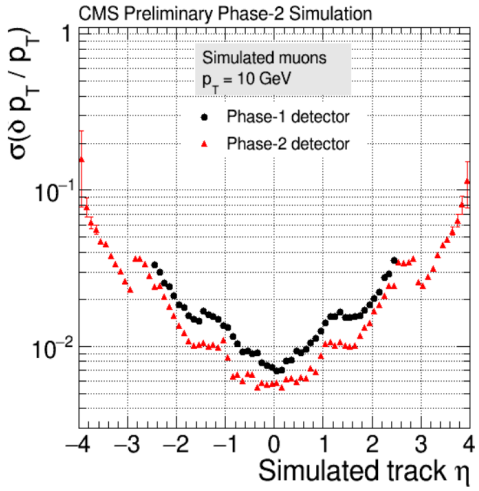
Future Tracking

- CMS will upgrade it's tracking detectors in LS 3
- Major improvements, such as extending coverage to $|\eta|$ of 4, track triggering at the Level 1 trigger



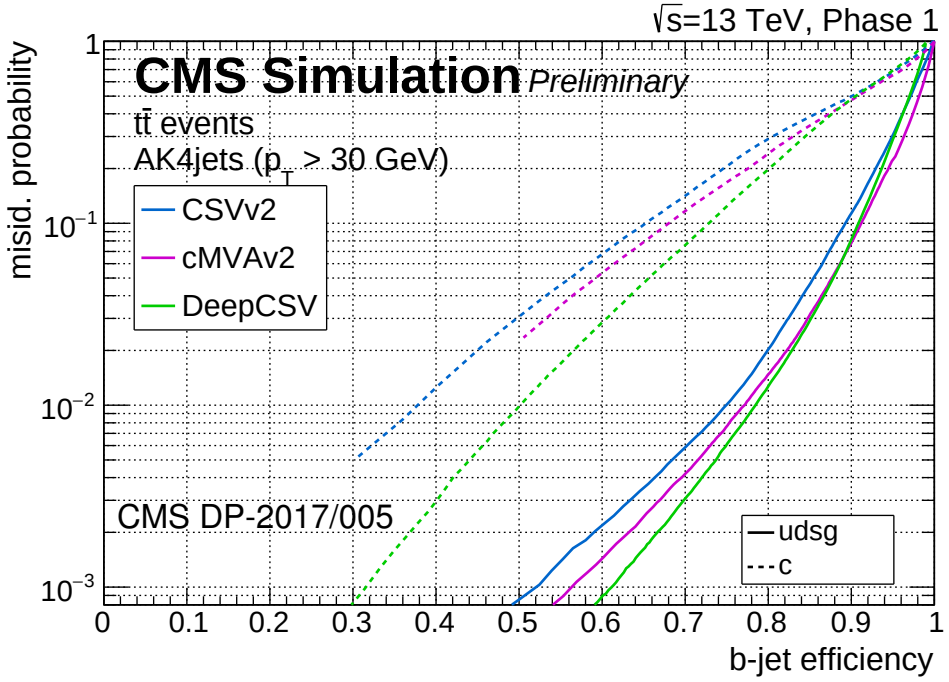
- Development of tracking algorithm for the upgrade are in full swing
- Many further algorithmic improvements planned, but estimated performance already very good
- Same efficiency at PU 140 as with PU 35 in current setup
- Significantly improved resolution for key track properties





B-Tagging in CMS

- Identification of jets originating from heavy flavor quarks is essential for the CMS physics programme
- CMS has developed several algorithms over the years, using more sophisticated techniques to improve performance
- Two algorithms currently used for analysis:
  - **CSVv2** uses an artificial neural network to combine track and vertex information
  - **DeepCSV** Uses the same variables as CSV, but uses more tracks and a deep neural network to increase performance

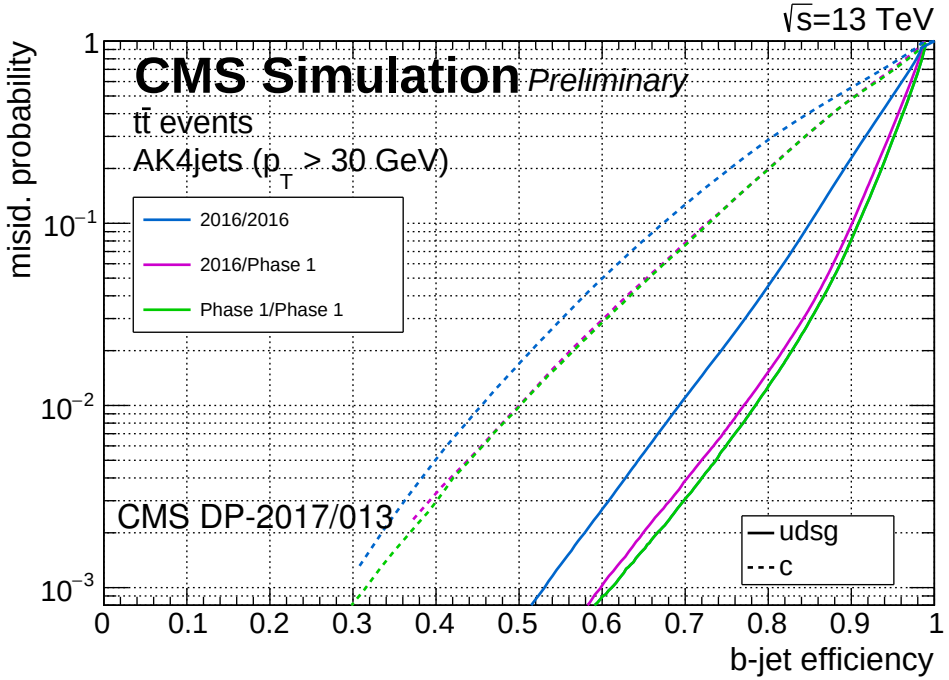


- DeepCSV currently gives 4% efficiency gain at 1% mis-tag rate

Impact of the Phase-I Pixel upgrade

- Upgrade of the pixel detector in 2017 improved track impact parameter resolution and vertexing
- Especially important for b-tagging performance

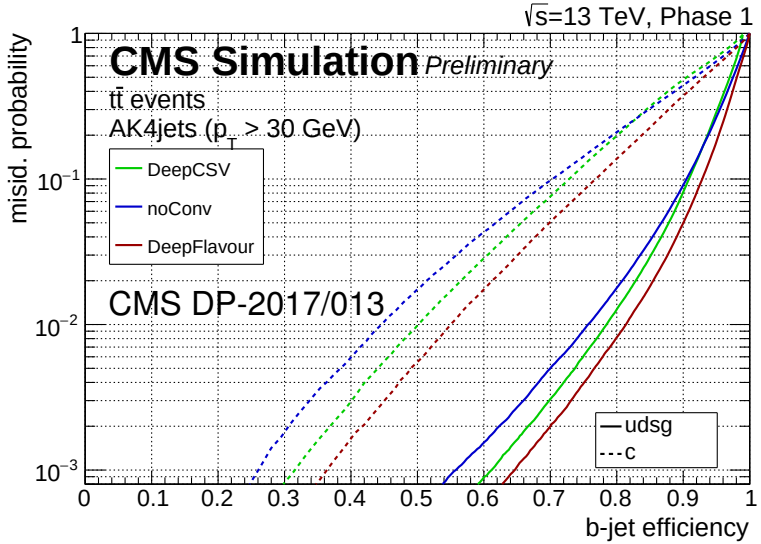
- Performance improvement illustrated for the example of DeepCSV
- Significant improvement out of the box
- Further small improvement with retraining of the neural network

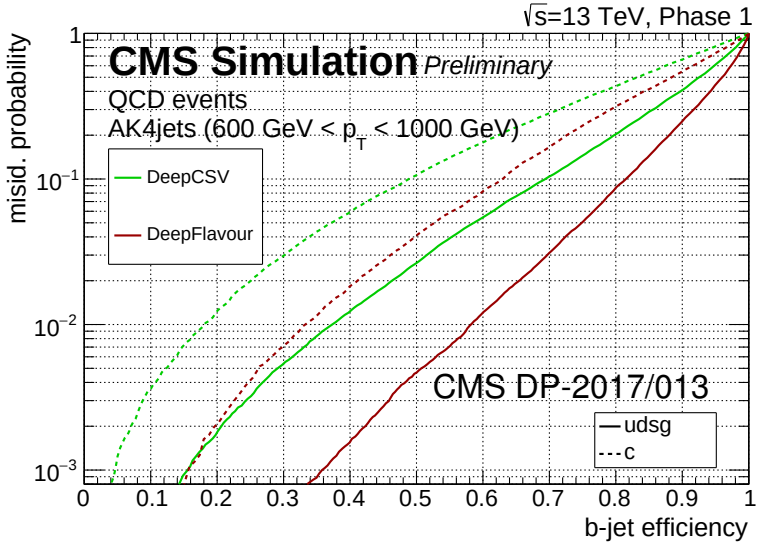


- 7-8% better efficiency at 1% mis-tag rate

Future b-tagging developments

- Further developments on improved b-taggers ongoing
- DeepFlavour algorithm currently being commissioned
  - Includes more information from more tracks, neutral particle candidates and vertices are used to train a more complex deep neural network
- Further improves performance compared to DeepCSV
- Especially prominent gains for high p_{T} jets





- 4% better efficiency at 1% mis-tag rate for low p_{T} jets, about 20% at very high p_{T}

Summary

- Tracks and track-derived quantities are essential for the success of the CMS physics programme
- Depends on the performance of the detector as well as the algorithms used in the event reconstruction

- Good performance of the CMS tracking detectors, aligned by well established methods
- Tracking in CMS profits significantly from the Phase-I pixel detector upgrade and shows very good performance
- Running basically unchanged in 2018, with some added protection for potential detector issues
- Developments to make use of the Phase-II tracking detector in a very high PU environment well under way

- CMS b-tagging performance steadily improving, profiting both from the new pixel detector as well as constant algorithmically improvements