CMS event reconstruction in LHC Run 2

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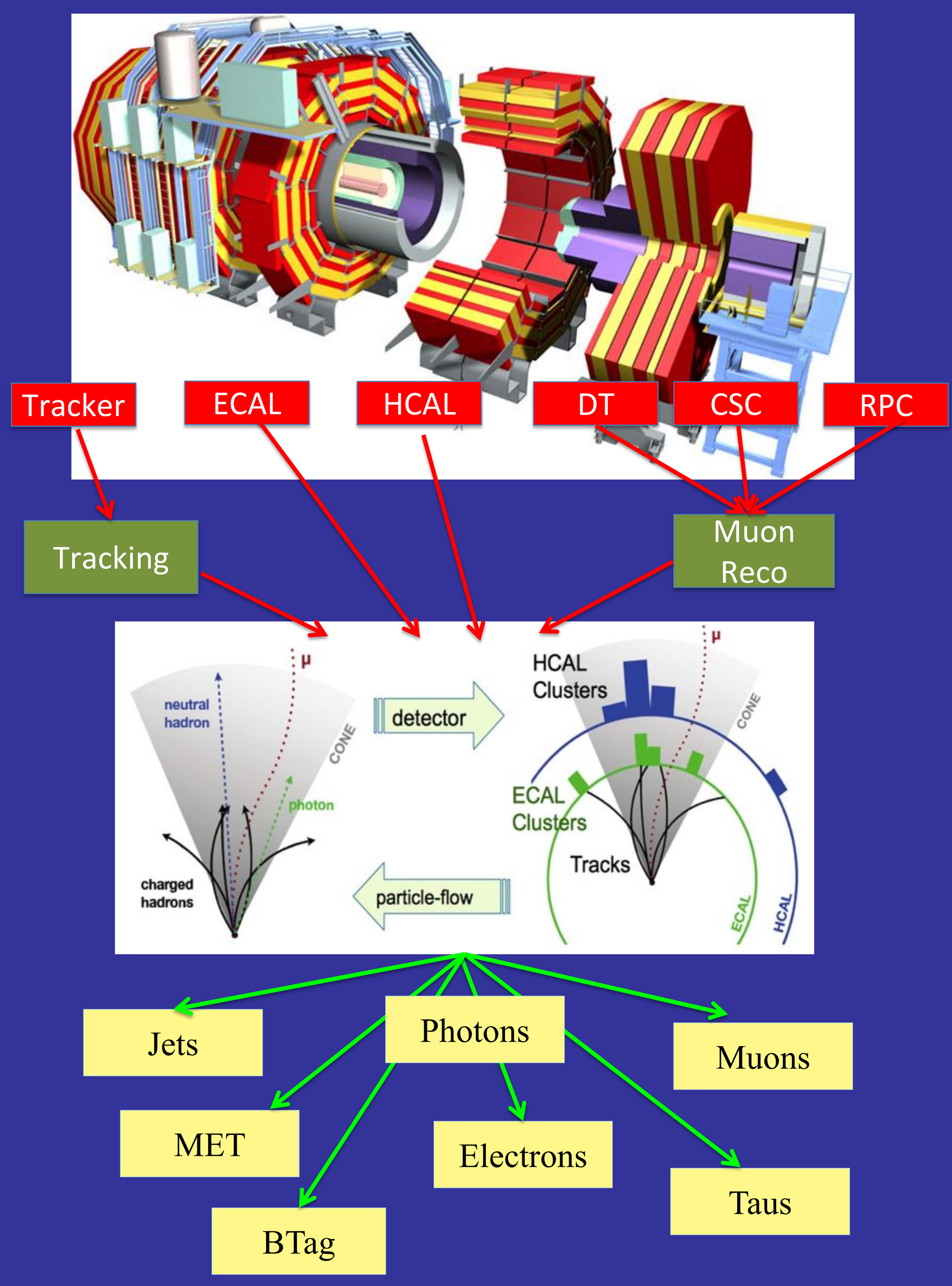
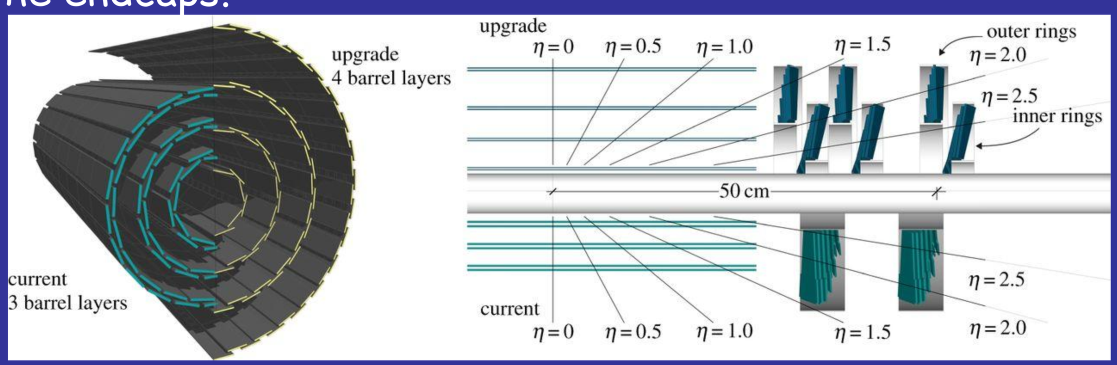
LHC Run2 began in April 2015 with the restart of the collisions in the CERN Large Hadron Collider. In the perspective of the offline event reconstruction, the most relevant detector updates appeared in 2017: they were the upgrading of the pixel detector, with the insertion of an additional layer closer to the beams, and the improved photodetectors and readout chips for the endcap hadron calorimeter, which allow a finer longitudinal segmentation. The long shutdown between Run1 and Run2 was instrumental in the optimization of the reconstruction code and for the introduction of new algorithms to mitigate sensitivity to increased pileup, especially to out-of-time contribution with advent of 25 ns separation between collisions compared to 50 ns in Run1. Such an optimization continued in the following years, when the reconstruction code of CMS evolved together with the improving of the performance of the LHC. We describe here the current status of the reconstruction software of the CMS experiment, with emphasis on some of the recently integrated developments.

CMS RECO IS PARTICLE FLOW DRIVEN



TRACKING

The precise determination of the trajectory parameters of charged particles is fundamental for the characterization of the Particle Flow objects, and the full event reconstruction.
CMS upgraded is Pixel detector in 2017: an additional layer improves track impact parameter resolution and vertexing performance. Also: improved material budget in the endcaps.

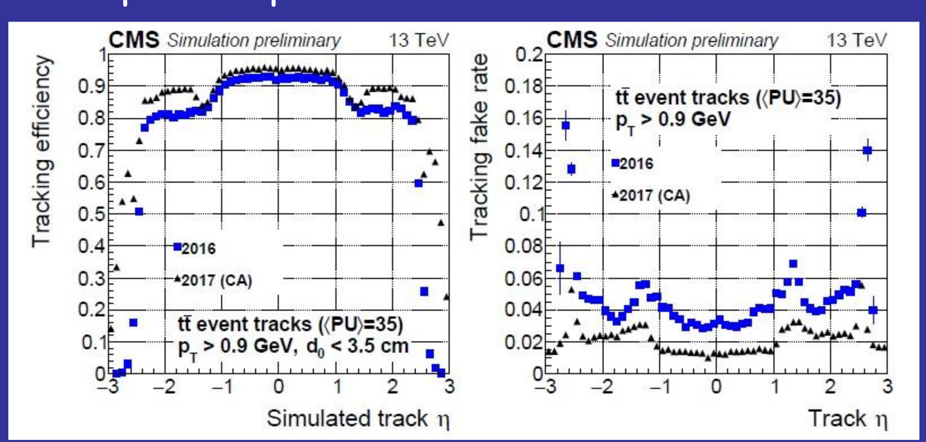


Iterative tracking is adopted in CMS to deal with the large combinatorial:

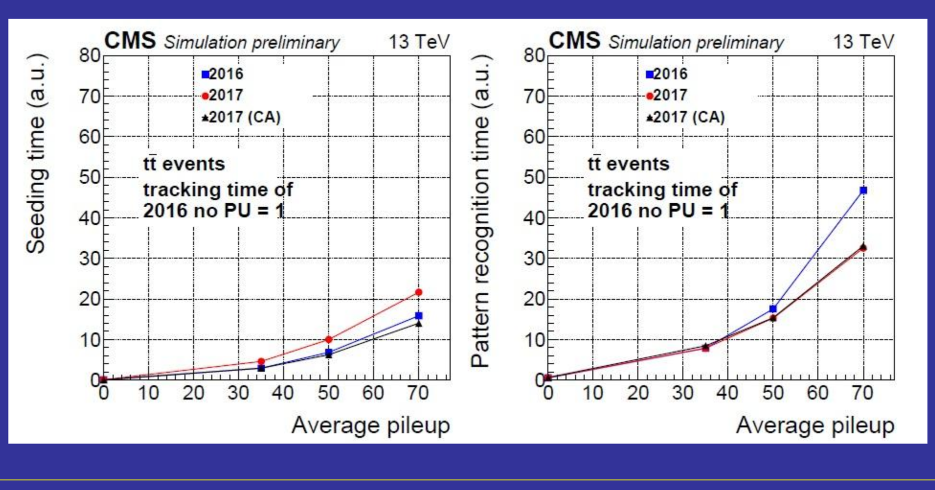
- Start with very tight criteria for track seeds and reconstruct tracks with all available hits
- Clear the detector of already used hits
- Loosen the seed criteria and repeat

Algorithm improvements that profit from the new pixel detector include:

- 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 seeding formed from compatible pairs



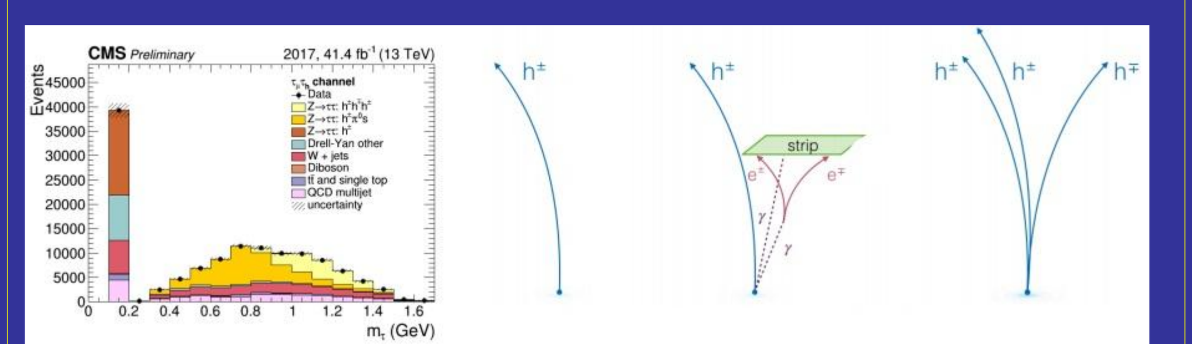
Timing performance improves wrt the 2016 tracking algorithm thanks to the use of the Cellular Automaton seeding; a smaller fake rate also reduces the time spent in pattern recognition.

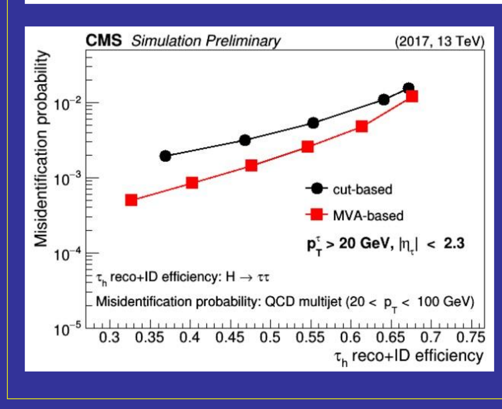


TAU RECONSTRUCTION AND ID

The "hadrons-plus-strips" (HPS) algorithm is used to reconstruct and identify the hadronic decay products of tau leptons in various decay modes :

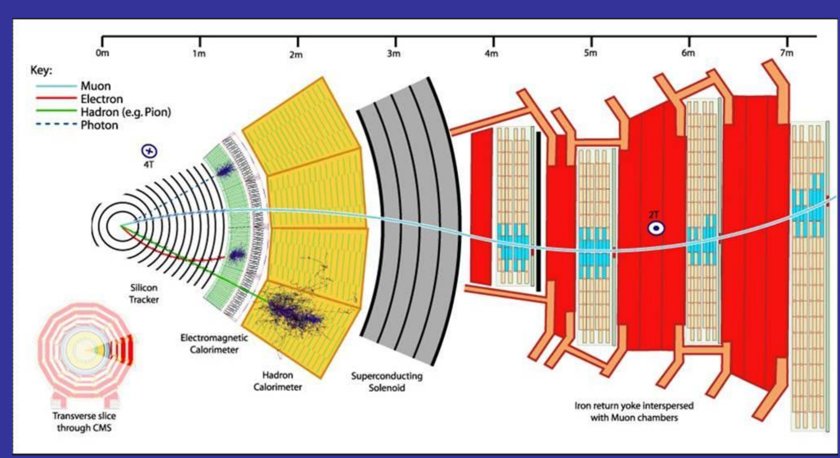
• extract PF constituents (electrons, photons, muons, hadrons) from the reconstructed jets
• reconstruct π^0 (as "Strips)
• test all possible decay modes and assign the one with highest p_T and charge/strip multiplicity that pass the mass cut-window





Probability for hadronic jets to be mistagged as tau jets is reduced by the use of isolation discriminators:
• cut based discriminator
•MVA based discriminator

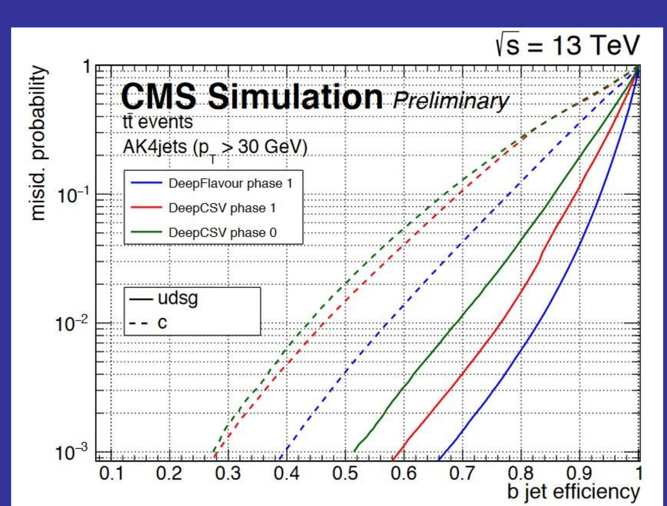
MUONS



Segments are reconstructed from local hits in the CMS muon detecters (DT, CSC, RPC), and combined to build **StandAlone** (SA) muon tracks. Inner tracks are also reconstructed in the silicon tracker. **Global Muons** are then obtained by merging SA and inner tracks (combined fit performed, p_T re-evaluated "outside-in").
Tracker Muons are identified "inside-out" by matching inner tracks with CSC/DT segments.
Ad-hoc algos specialized for high-pT muons exist, with dedicated muon-ID and momentum refits.
Isolation quantities around muons are computed (both based on detector quantities and particle flow ones).

B-TAGGING

The algorithms currently used for b-tag in CMS are:
CSVv2 (Combined Secondary Vertex) uses an artificial neural network (NN) to combine track and vertex infos.
DeepCSV feeds a deep NN with the same variables as used in CSV, but with more tracks included.
DeepFlavour: a deep NN algorithm based on 16 properties of up to 25 charged and 6 properties of 25 neutral particle-flow jet constituents, as well as 17 properties from up to 4 secondary vertices associated with the jet.
Double-b tagger: a dedicated algorithm for the identification of the decay of a boosted object to a b quark pair

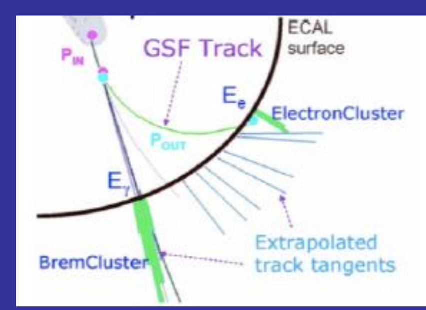


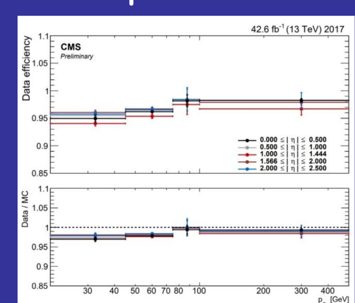
The new Pixel detector and the implementation of the DeepCSV and DeepFlavour methods allow a major breakthrough in the b-tagging performance in CMS

ELECTRONS AND PHOTONS

ECAL driven algorithm for electron and photon reconstruction:

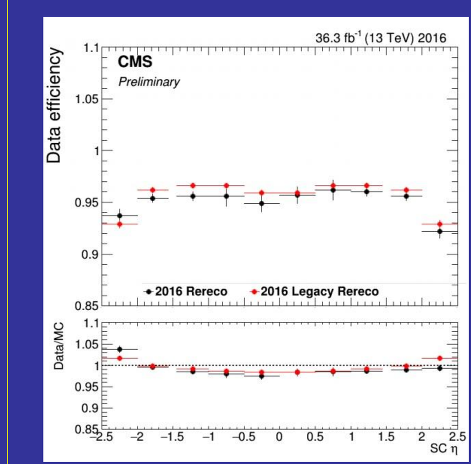
- Start from ECAL superclusters (group of one or more clusters of energy deposits in the ECAL)
- For electrons: use superclusters to seed silicon tracker tracks; the Gaussian Sum Filter (GSF) tracking algorithm takes into account the momentum loss due to bremsstrahlung
- Shower shape variables help separating single-core e/γ objects from multi-core π^0/η ones
- Cut based or MVA based IDs implemented



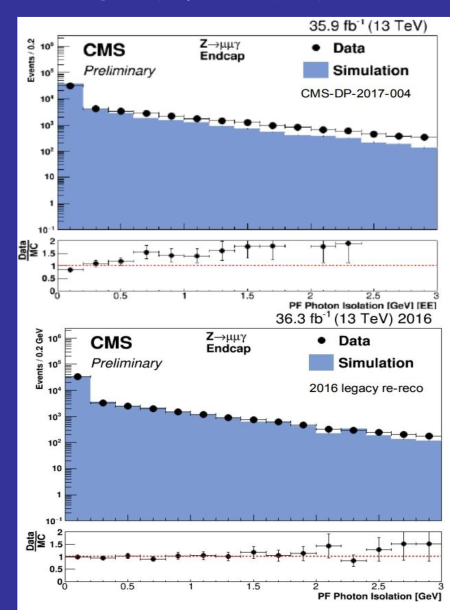


GSF tracking efficiency

Improvements from the new reconstruction and identification algorithm and the refined conditions are visible already in the re-reco of the 2016 CMS data

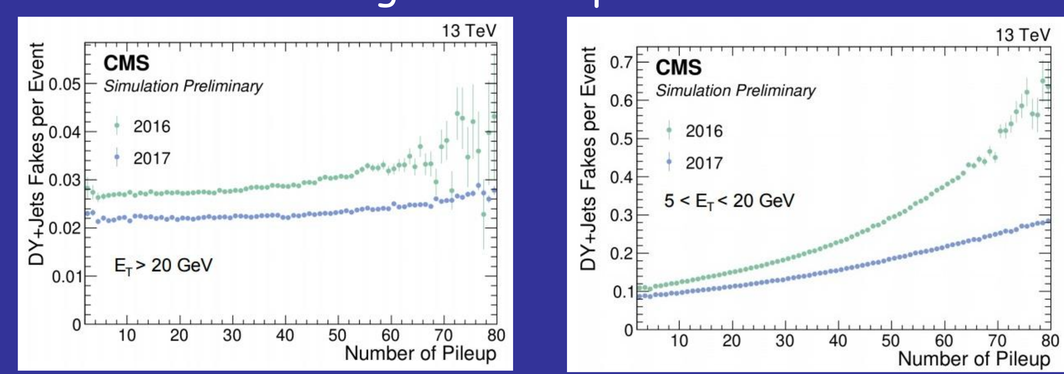


GSF efficiency: former 2016 and 2016 re-reco



Photon isolation: former 2016, and 2016 re-reco (includes recalibration)

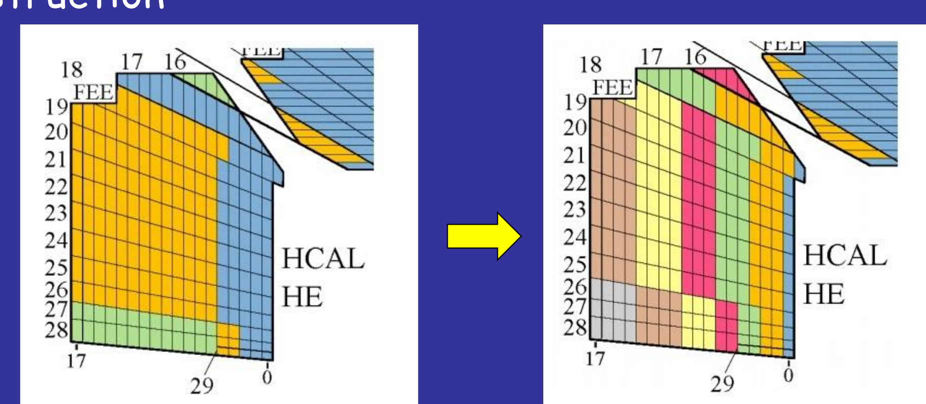
Electron/photon reconstruction and identification since 2017 take also advantage of the fourth layer and the reduced material budget of the pixel detector



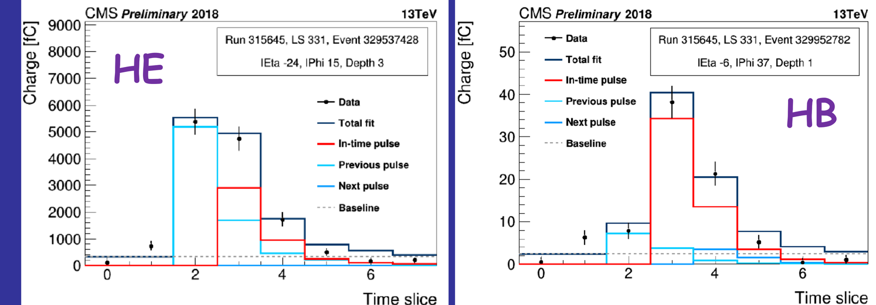
Big effort has been put on following the evolving data taking and detector status and conditions

HCAL

In early 2017, the readout electronics for one 20° wedge of the HCAL endcap was upgraded with silicon photomultipliers (SiPMs) and QIE11 digitizer. Based on the excellent experience, in 2018 the whole HE detector (36 wedges) has been upgraded. Besides the operational advantages of SiPMs wrt HPDs (noise, gain stability) a finer longitudinal segmentation is now available for local reconstruction



HB/HE out-of-time pileup mitigation in the HCAL local reconstruction is achieved by fits of up to three pulses in the bunch crossing of interest, the previous and following ones, and a flat baseline component. A non-negative least square algorithm is used for optimization.



Difference in charge scale due to differences in photo-detection efficiency and amplification

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