CMS trigger in Run 2

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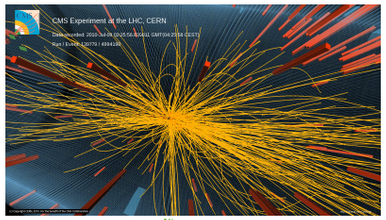
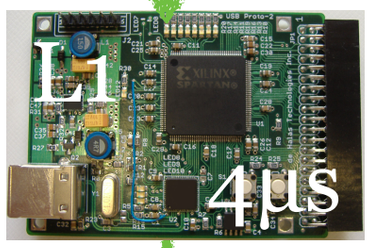
for the CMS collaboration

The Third Annual Conference on
Large Hadron Collider Physics

CMS trigger system:

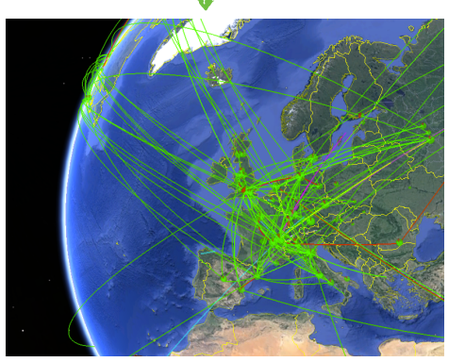


30 MHz



100 kHz

1 kHz



Level 1:

- Algorithms implemented on electronic cards (FPGA, ASICs)
- Reduce the rate to 100kHz
- Readout of the detector only for events passing the L1
- Latency of 4µs

HLT:

- Based on a simplified reconstruction
- Decision taken in ~150ms
- Reduce the rate to 1kHz
- Events passing the HLT will be stored for physics and detector calibration/ alignement

Run 2 beam conditions

collisions at 13TeV
⇒ cross section x 2
in average

peak instantaneous
luminosity at
$1.4 \times 10^{34} cm^{-2}s^{-1}$
⇒ x 2 respect to 2012

- increase of average pile-up from ~25 to ~40 interactions
- space between collisions from 50ns to 25ns

rate x 4 in average

decrease of the efficiency on the physic signals

improvements needed to keep high performance the trigger system

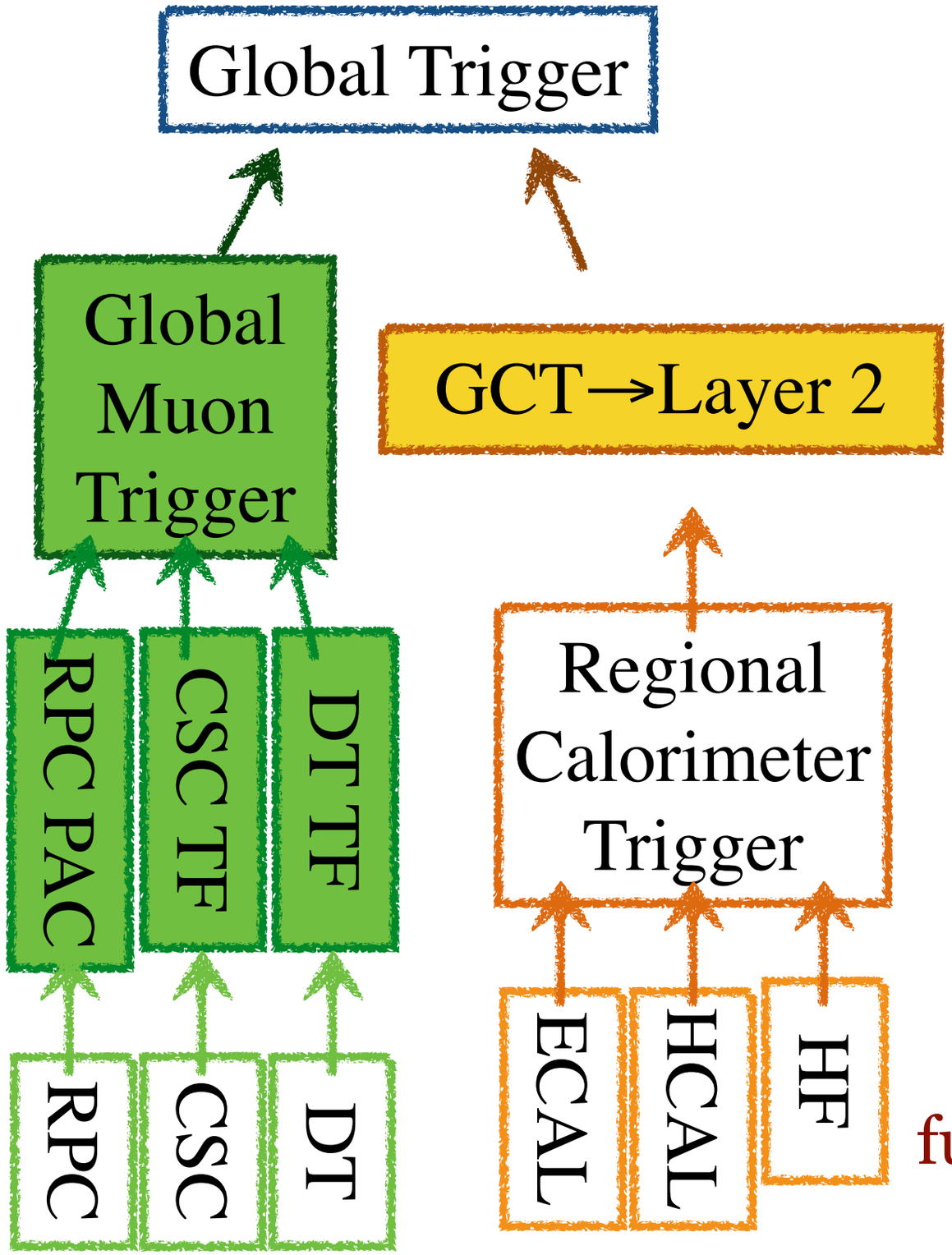
3 scenarios have been considered for run 2 preparation, targeting the main LHC running period:

- 50ns, peak lumi = 5×10^{33} $cm^{-2}s^{-1}$, (PU=30)
- 25ns, peak lumi = 7×10^{33} $cm^{-2}s^{-1}$, (PU=20)
- 25ns, peak lumi = 1.4×10^{34} $cm^{-2}s^{-1}$, (PU=40)

plus dedicated trigger menus for:

- Low PU runs
- Heavy Ion
- Commissioning

Improvements at L1



<u>GCT replaced by Layer 2</u>

- More efficient τ triggers (4x4 or 4x8 tau tower + possibility of τ isolation)
- pile-up soustraction for jets, energy sums and e/gamma candidates

<u>Muon trigger:</u>

- Muon system improvement:
  - Addition of chambers in the endcaps
  - Increase of the granularity of the CSC readout
- Re-optimisation of the Look-Up tables

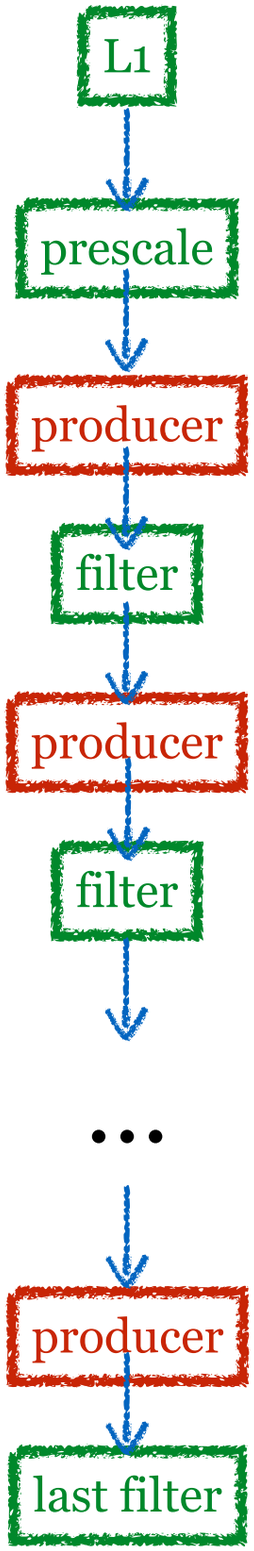
full L1 upgrade will be available in 2016

Summary of L1 thresholds

(*) er = eta restricted (restrict to object with large angle wrt beam)

Unprescaled object	pT threshold in 2012, GeV	pT threshold in 2015 GeV, (50ns, L=5e33)	pT threshold in 2015 GeV, (25ns, L=1.4e34)
Single Muon	16	16	20er(*)/25
Double Muon	10+3.5	10+3.5	12+5
Single EGamma	22	25	40
Single Iso EGamma	20	20er(*)	30er(*)
Double EGamma	13+7	15+10	22+10
Muon + EGamma	12+7/3.5+12	12+10/5+15	20+10/5+20
Single Jet	128	128	200
Quad Jet	40	40	60
MET	40	50	70
HTT	175	125	175
Double Iso Tau	-	36er(*)	40er(*)

Principle of reconstruction at HLT



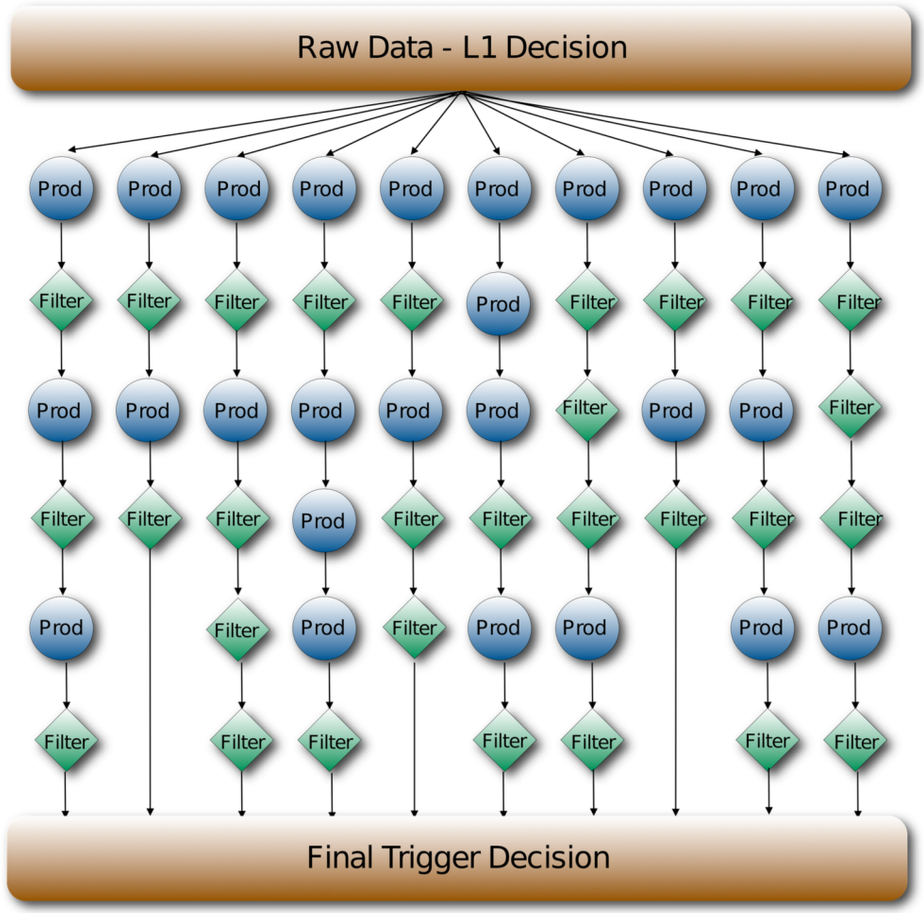
Several 'tricks' to speed up online reconstruction:

- Modular approach
  → faster comes first
- Only look what is needed
  → regional unpacking and reconstruction
- Keep combinatoric under control
  → reject pile up, limit the number of candidates

main constraint at HLT = **average** reprocessing time per event

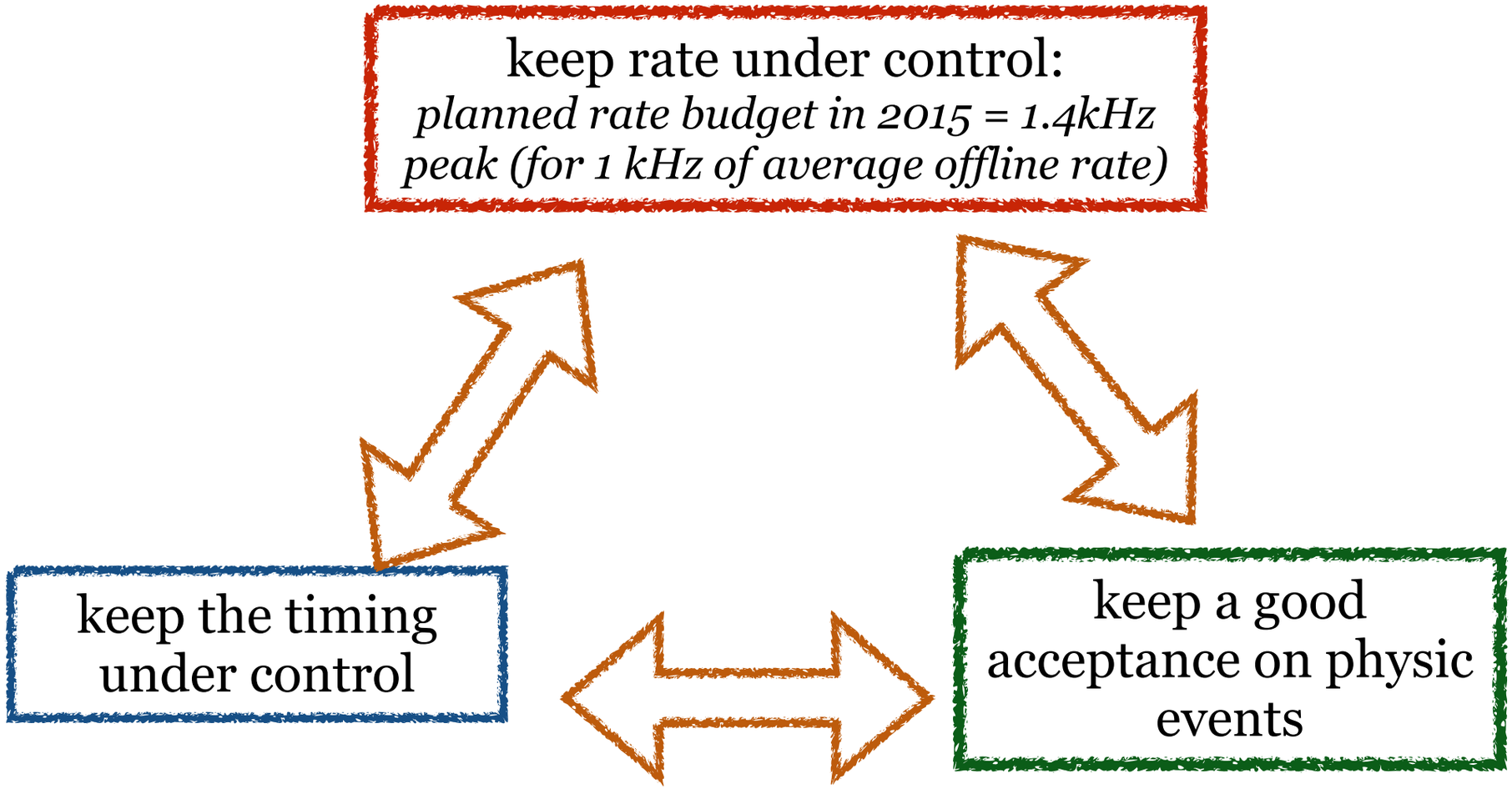
Many algorithms are run in parallel:

- Logically independent
- Result determine:
  → the trigger decision
  → how to split the events (online and offline)



Challenge of reconstruction at HLT

need to find a compromise between:



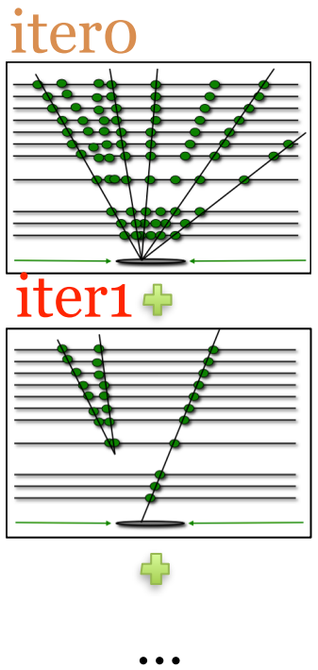
<u>To meet this challenge:</u>

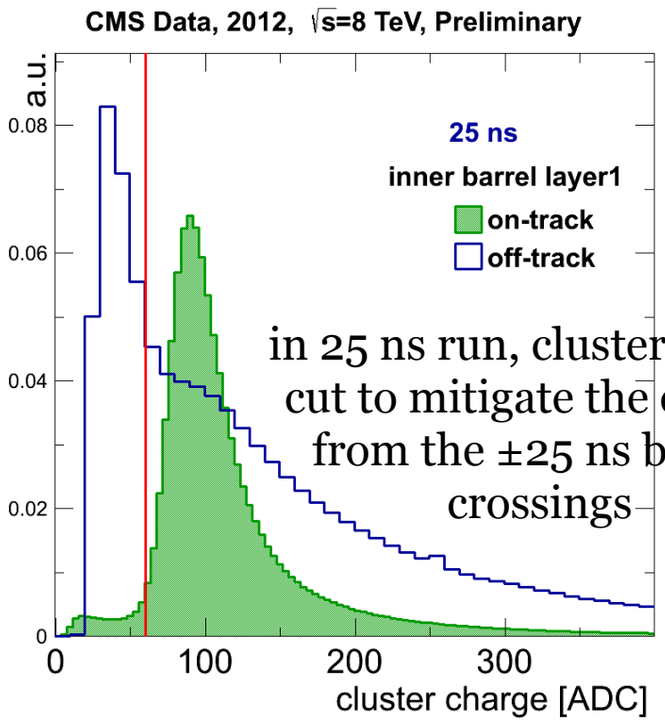
- used an improved tracking
- usage of Particule Flow (PF) at HLT → permit use some technics used offline

Tracking improvements at HLT

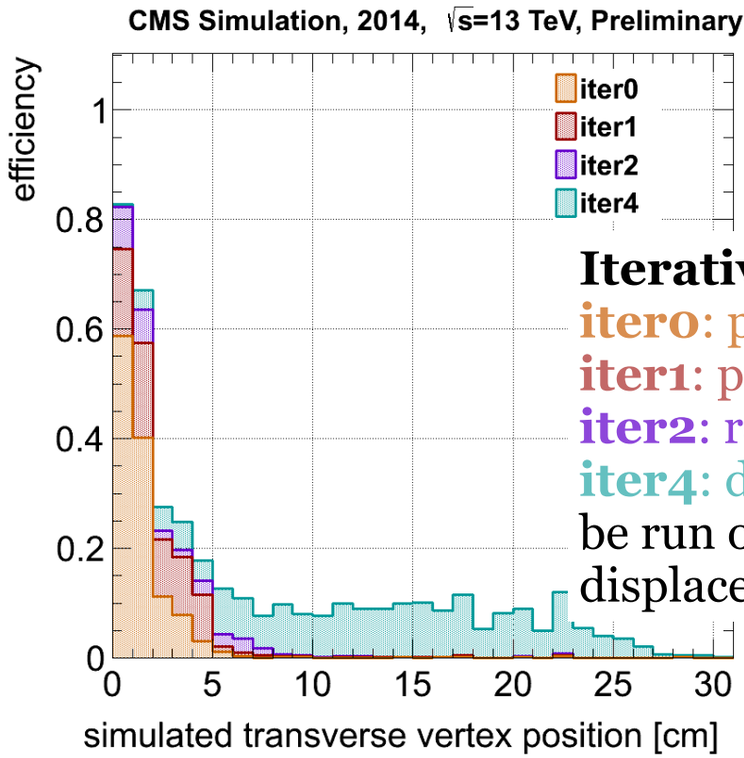
use of regional iterative tracking

- Iterative tracking:
  track reconstruction procedure done iteratively where each step is meant for reconstructing a specific subset of tracks
- Regional:
  unpacking of the tracker information done only in a region of interest



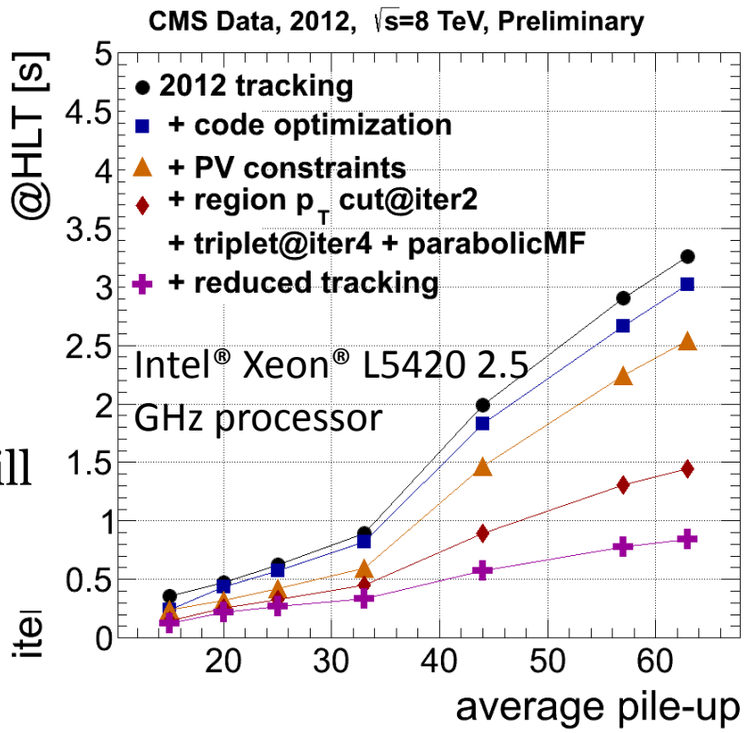


in 25 ns run, cluster charge cut to mitigate the cluster from the ±25 ns bunch crossings



Iterative Tracking at HLT:

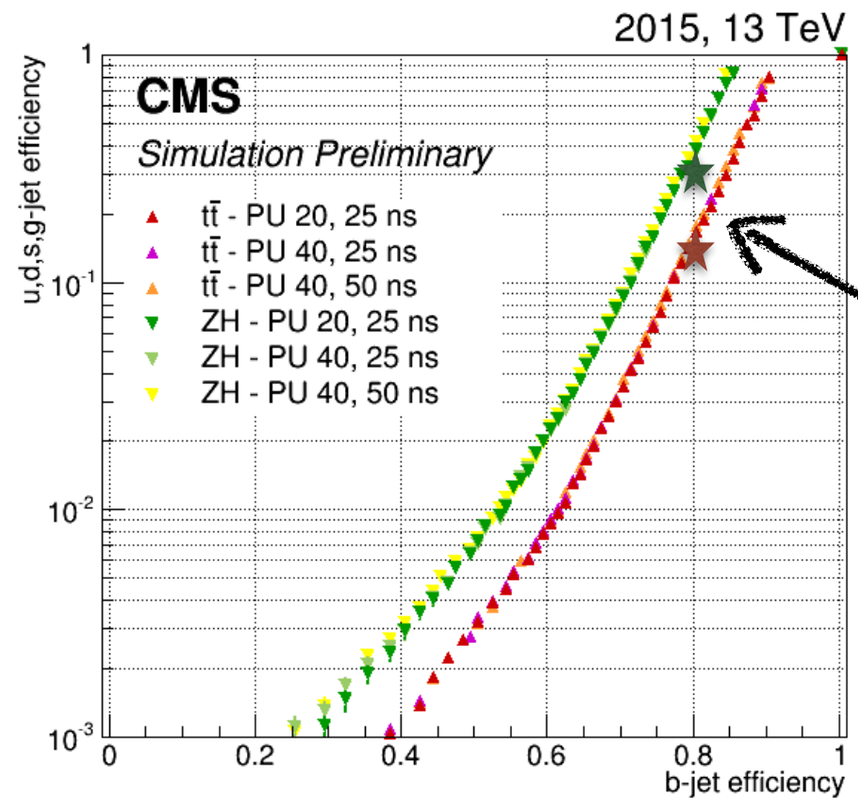
itero: prompt tracks high pT w/ pixel tracks
iter1: prompt tracks low pT w/ pixel triplets
iter2: recover prompt tracks high pT w/ pixel pairs
iter4: displaced tracks w/ strip triplets (in 2015 it will be run only in a sub set of trigger paths where displaced tracks are needed)



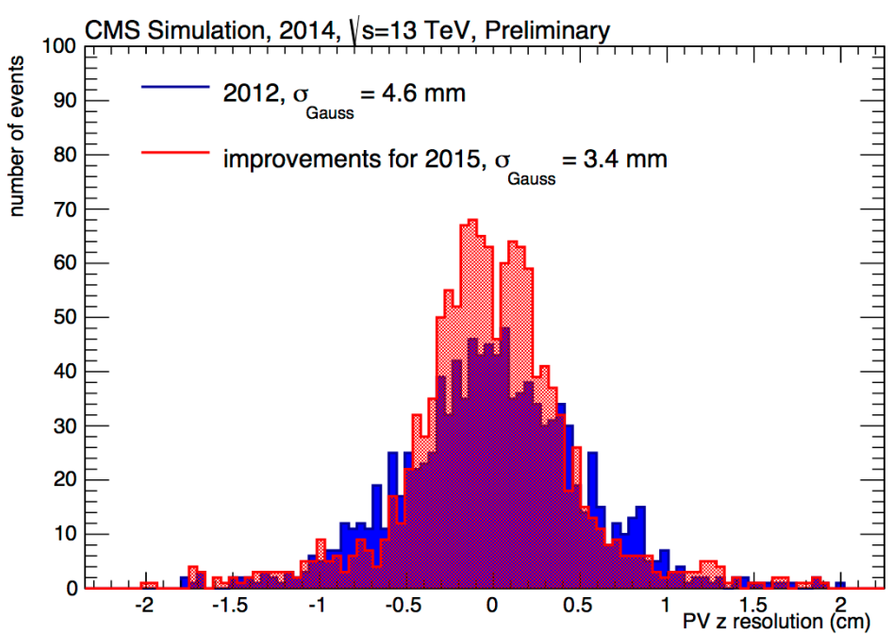
b-tagging

Improved b-tagging performances:

- Track reconstructed with iterative tracking
- Primary vertex found thanks to a deterministic annealing
- New algorithm (CSVv2 + Inclusive secondary Vertex Filter)



typical working points

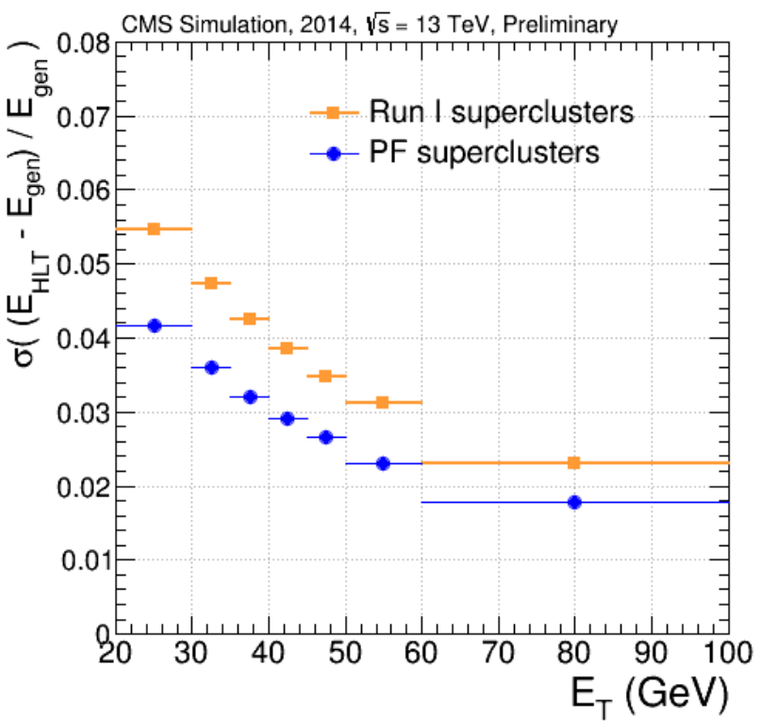


Fast Primary Vertex Algorithm:

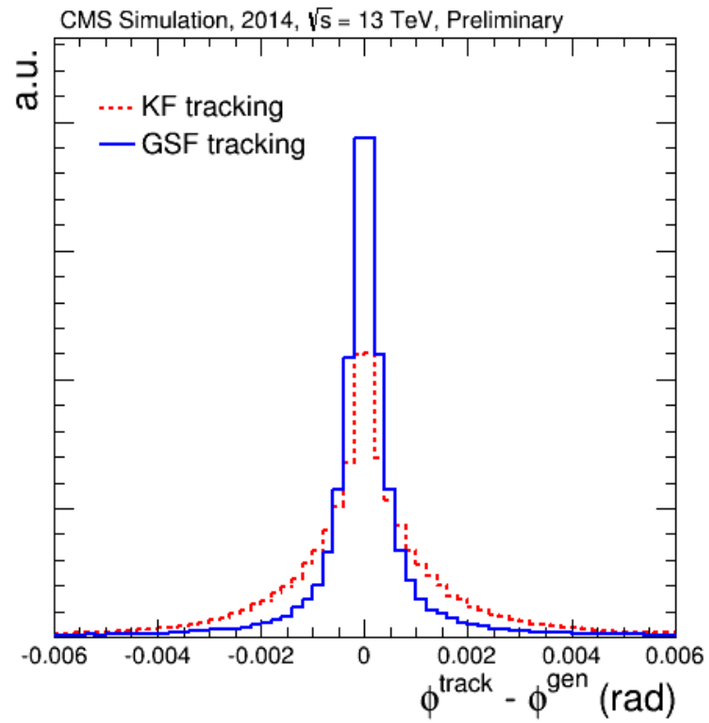
- Takes leading jet and projet pixel hit to beam line along jet direction
  → primary vertex = cluster of projected hits
- Useful for tagging pile-up jet for HT and MHT cleaning

Electrons

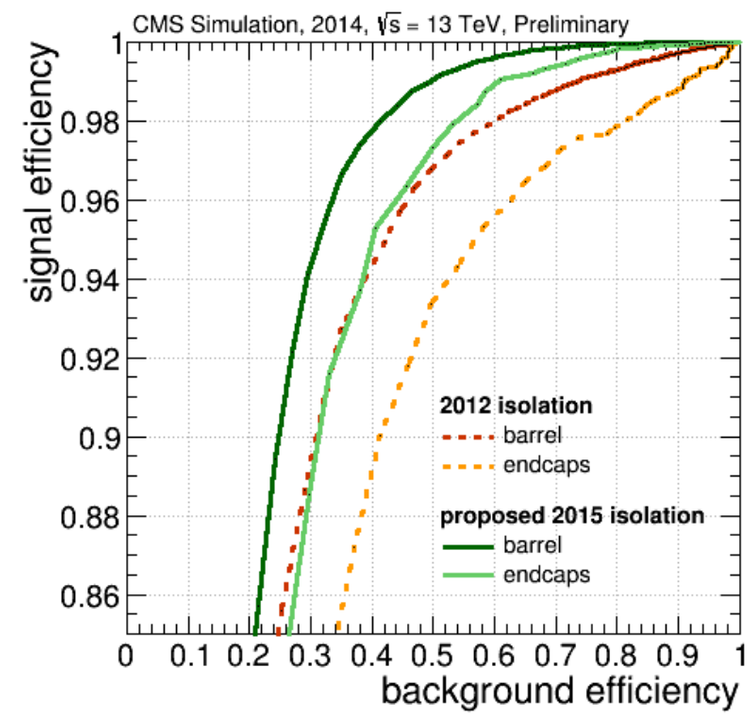
Improvements at every stage of the electrons reconstruction:



Energy resolution improved thanks to particle flow algorithms



GSF tracking ported at HLT



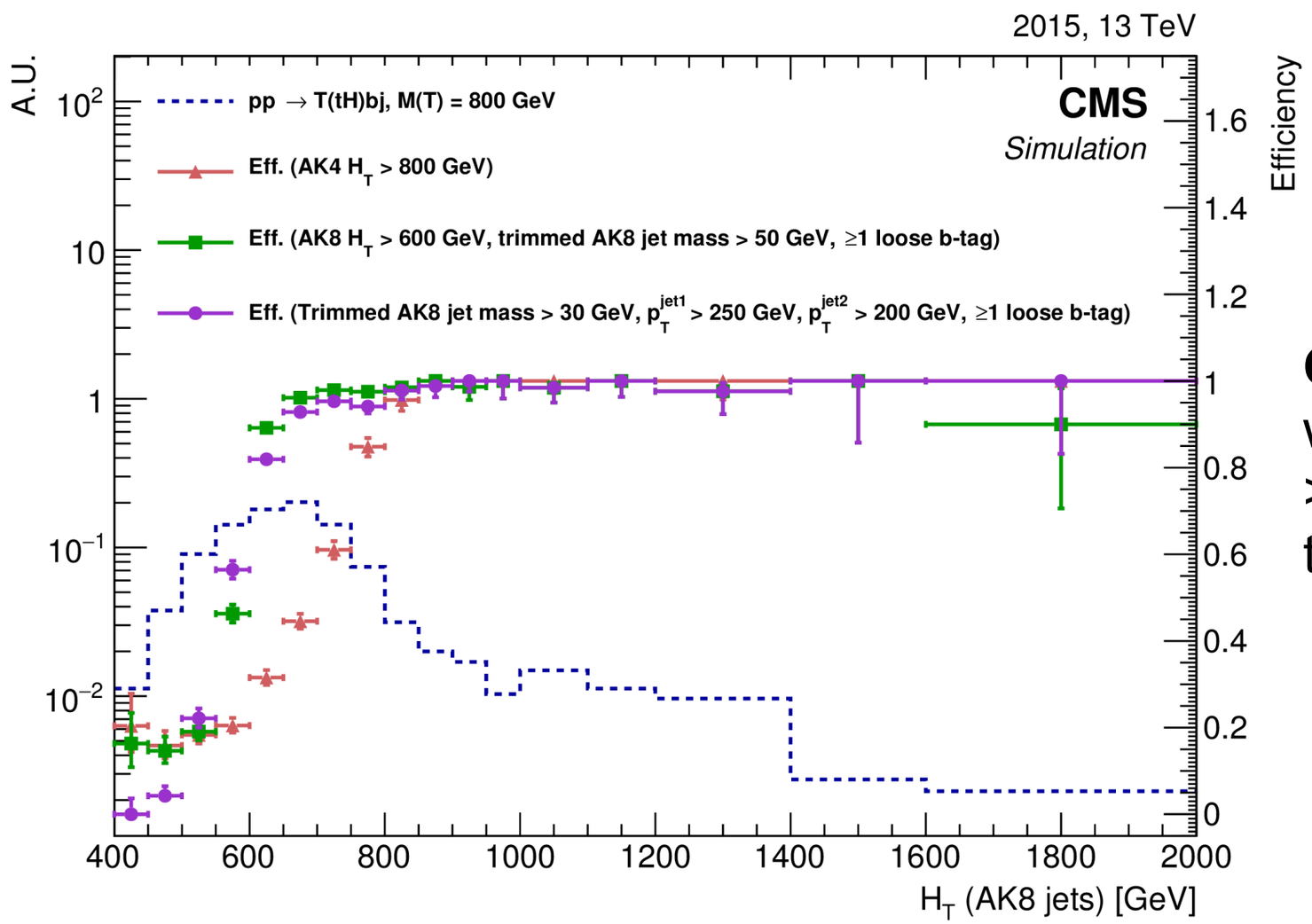
Usage of isolation based on PF clustering permits better discriminating power

Jets / boosted topologies:

Jet reconstruction at HLT makes large benefits of the usage of particle flow

→ particular advantage for boosted topologies:

- ‘Fat’ jets reconstructed with the AK8 algorithm
- Possibility to cut on trimmed mass

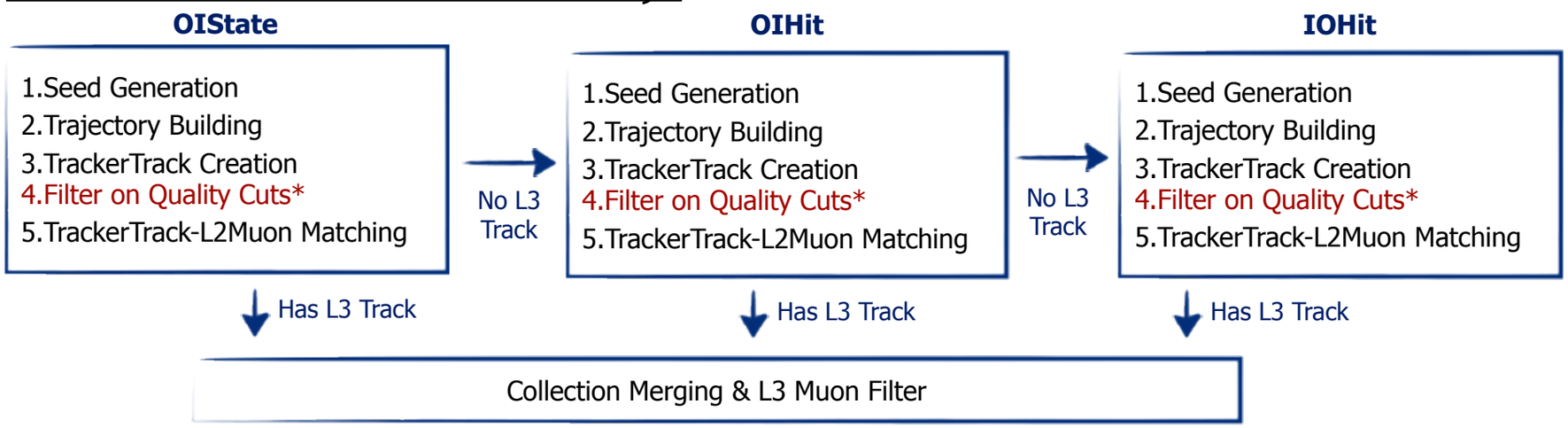


Offline selection: 2 AK8 jets with soft-drop mass > 50 GeV, pT > 300, 250 GeV, either 3 loose b-tags OR 1 medium b-tag

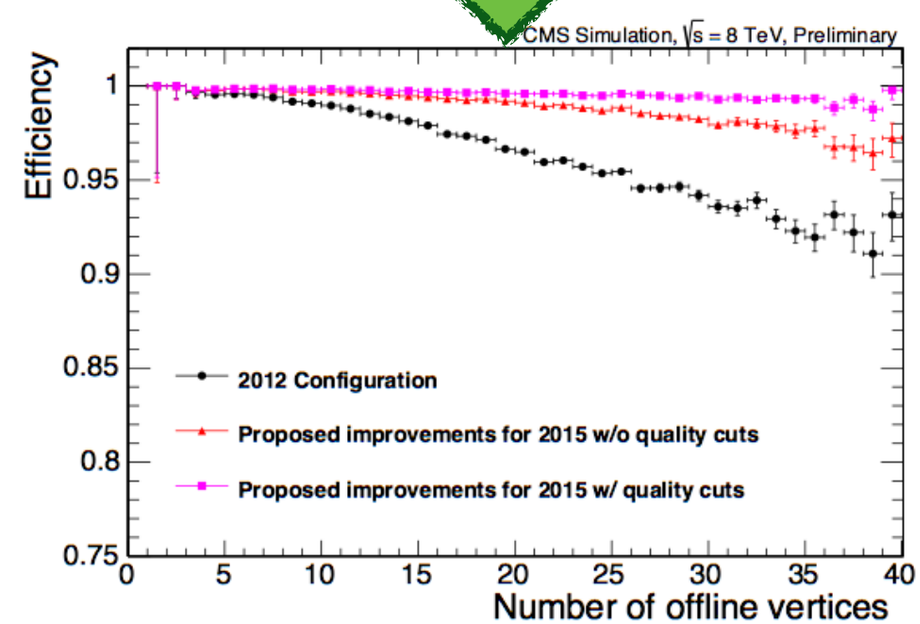
Muon reconstruction improvements

L1 muon → L2 muon (including only muon spectrometer) → L3 muon (add the tracker information)

For L3 tracking, a sequence of 3 algorithms is tried in cascade (from the faster to the most CPU intensive one):



- Use χ^2 measurement to assign hits to tracker tracks
- Update the logic of the cascade: addition of a quality filter between the steps



New tracker muon at HLT:

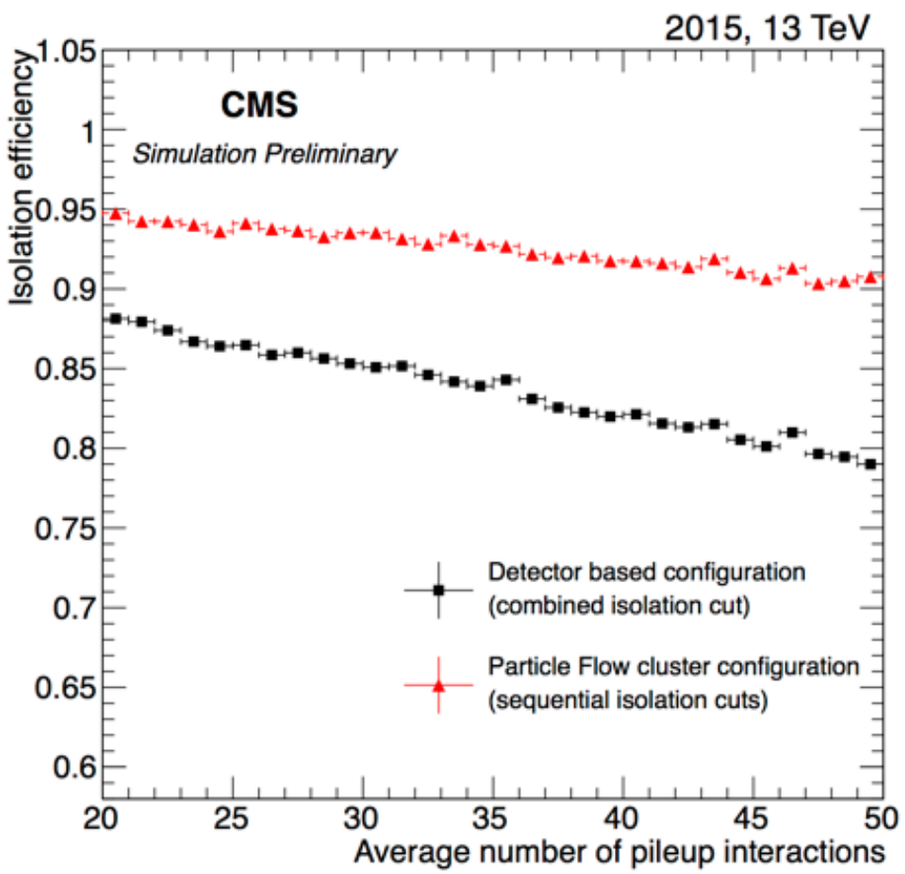
L1 muon → Tracker track: Iterative tracking in region around L1 candidate → Tracker Muon: Match tracker track with muon spectrometer hits/ segments

- permit to gain few additional % of efficiency
- interest of having 2 reconstructions poorly correlated

Muon isolation

For single muon paths:

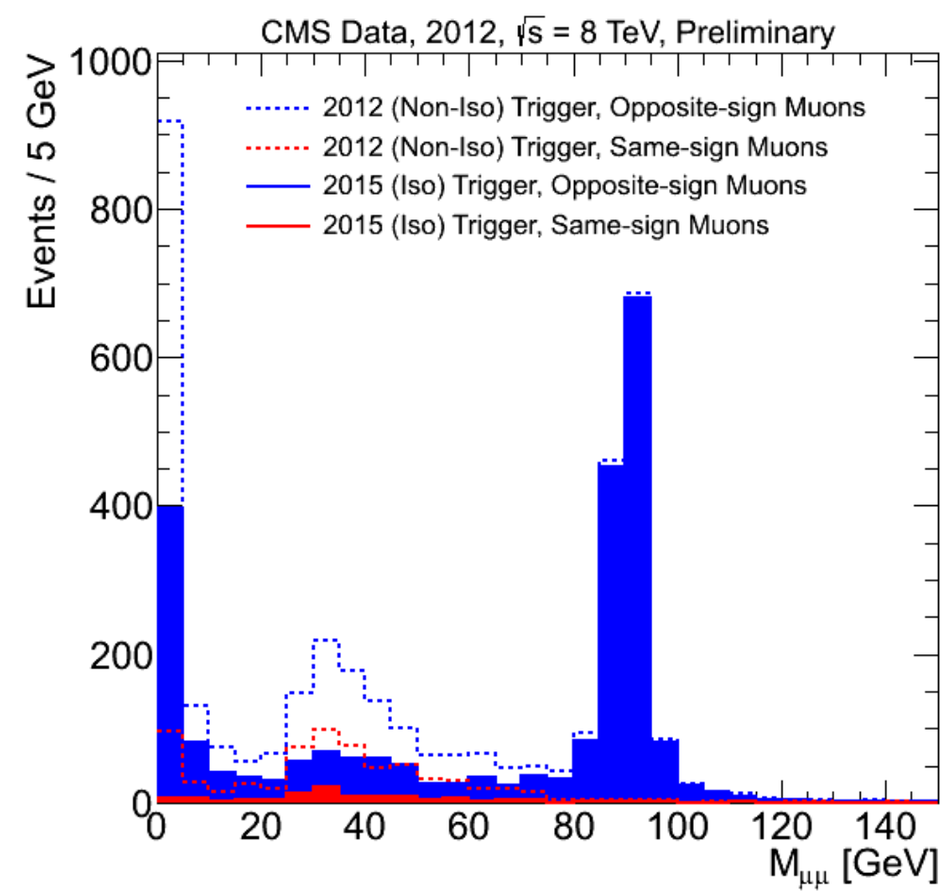
- Use PF cluster isolation
- Change the logic: from a combined isolation to sequential cuts on isolation components
- Pile-up subtraction based on rho correction



comparison between 2012 and 2015 isolation efficiencies for a working point giving the same rate reduction (used in 2015)

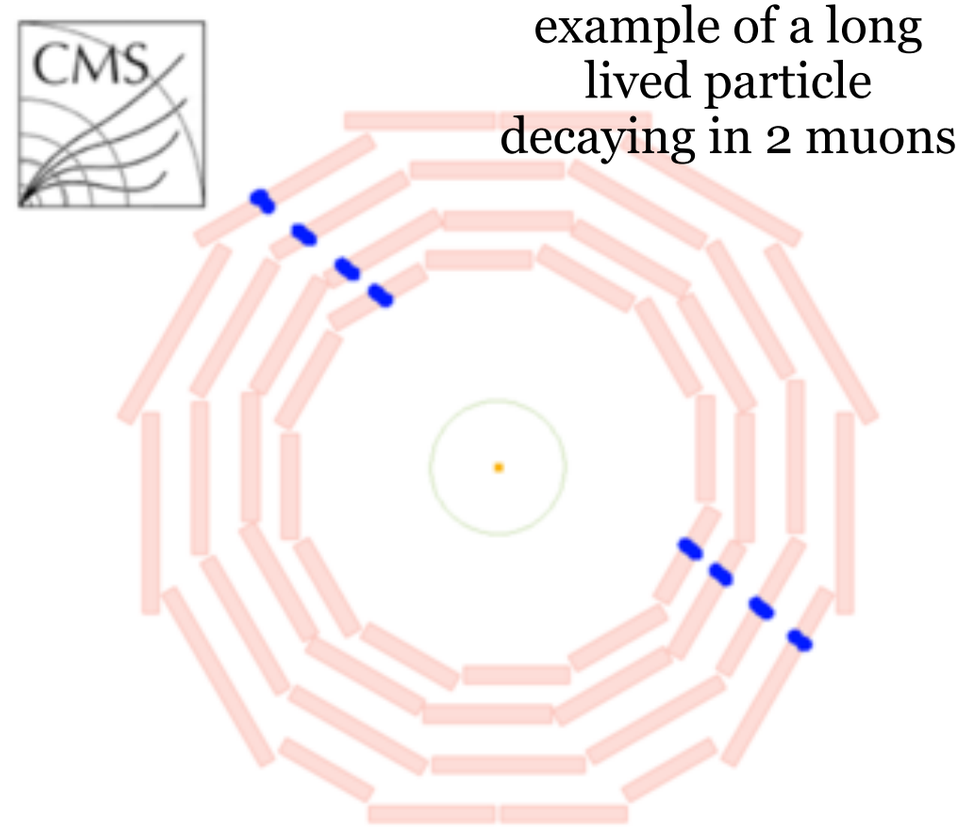
For double muon paths:

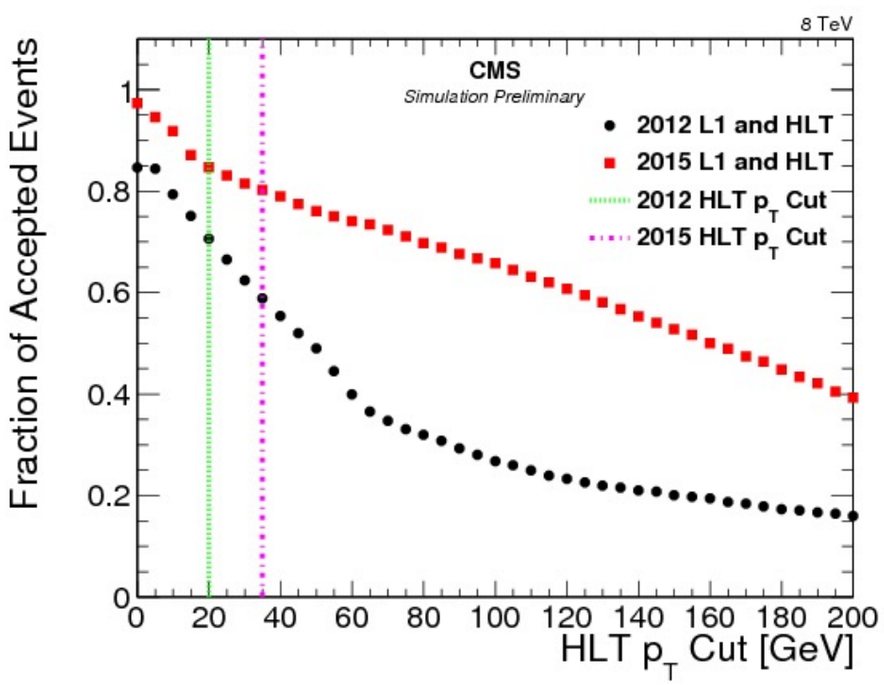
- Apply loose tracker isolation on both legs of double muon paths
- Permits to divide the rate by 2 for an efficiency cost ~ 1%
- Permit to keep thresholds the same as in 2012



Displaced muons

- Use of meantimer reconstruction in the barrel to build out of time segments
- Reconstruction using a cosmic seeding
- Collisions events vetoed at L1 to keep timing and rate under control





higher efficiency respect to 2012 despite the higher pT threshold, thanks to better pT resolution

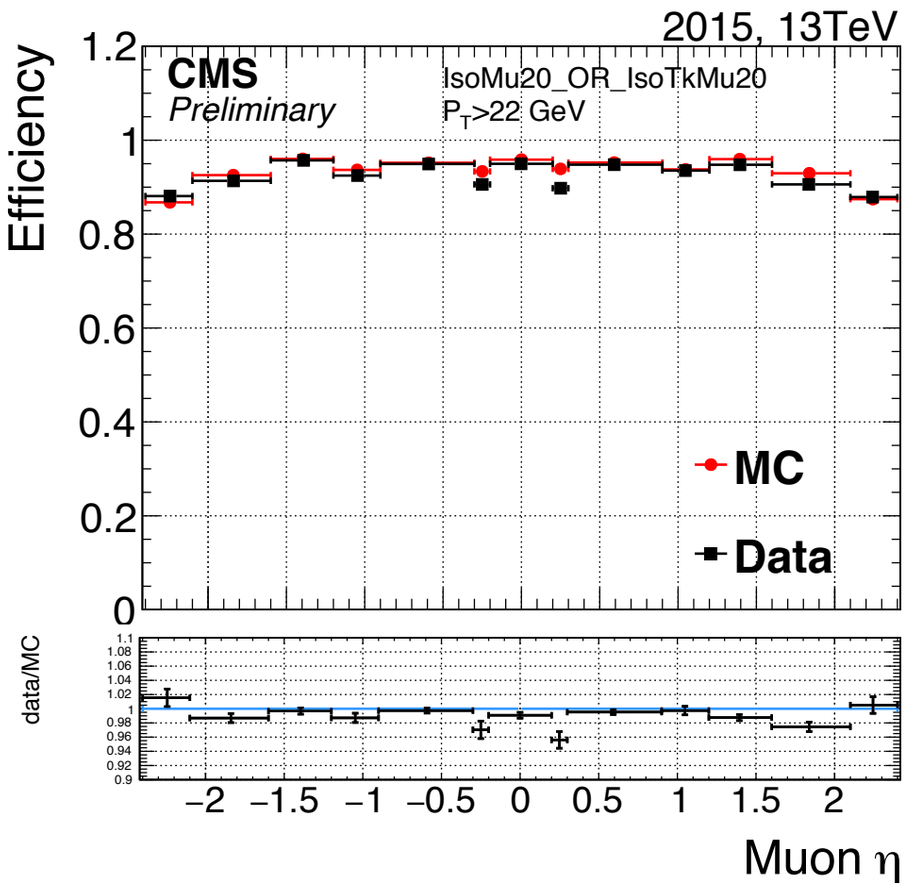
Some of the HLT thresholds

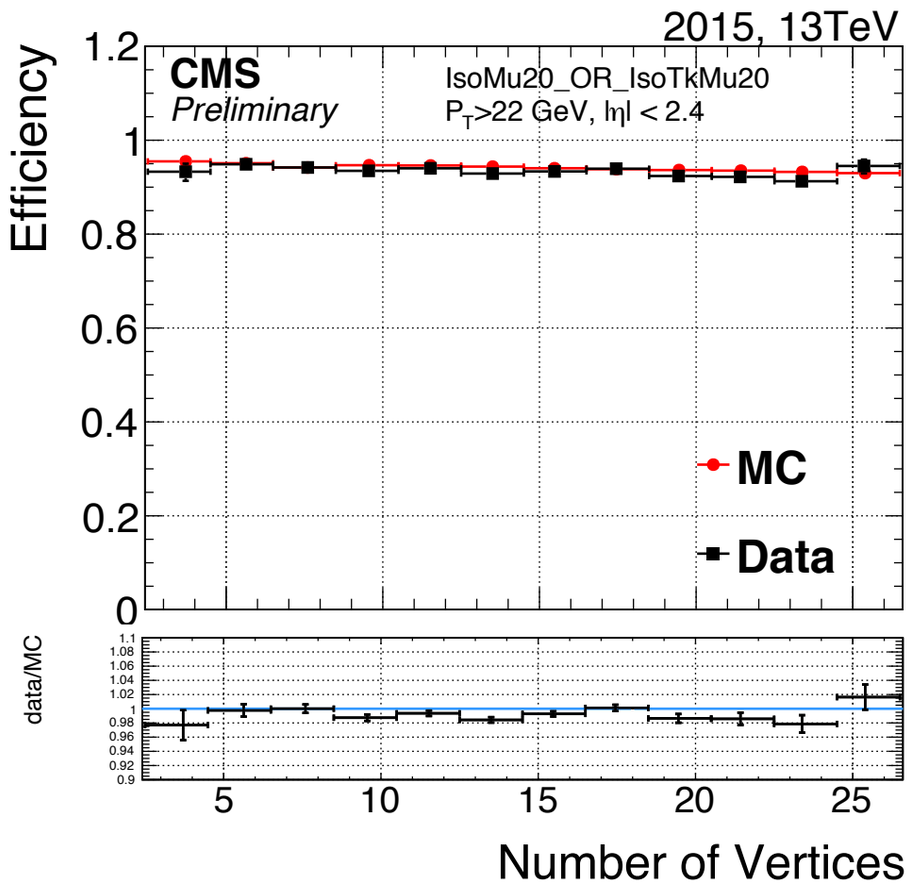
(*) er = eta restricted (restrict to object with large angle wrt beam)

Unprescaled object	pT threshold in 2012, GeV	pT threshold in 2015 GeV, (50ns, L=5e33)	pT threshold in 2015 GeV, (25ns, L=1.4e34)
Single Muon	40	50/45er(*)	50/45er(*)
Single Isolated Muon	24	20	24er
Double Muon	17+8	17+8	17+8
Single Isolated Electron	27	27	32
Single Photon	150	170	170
Single PF jet	320	450	450
PF MET	120 (80 parked)	170	170
PF HT	750	900	900

work in progress to fine tune some thresholds,
taking benefits of the first data

Single muon efficiency in first 2015 data





efficiency of the **OR of HLT_IsoMu20 and HLT_IsoTkMu20** on the top of offline muon identification and isolation in the 50 ns LHC data

Conclusion

- Thanks to improvements in trigger algorithms, no need of a huge increase of the filtering thresholds despite the higher luminosity and pile-up foreseen in run 2
  → Will keep a high efficiency for all the final states used in CMS searches and analyses

- Smooth operation and commissioning of the trigger in first LHC data
  → Performance studies of the trigger is ongoing with these data