Andrea Perrotta – INFN Bologna
(on behalf of the CMS Collaboration)

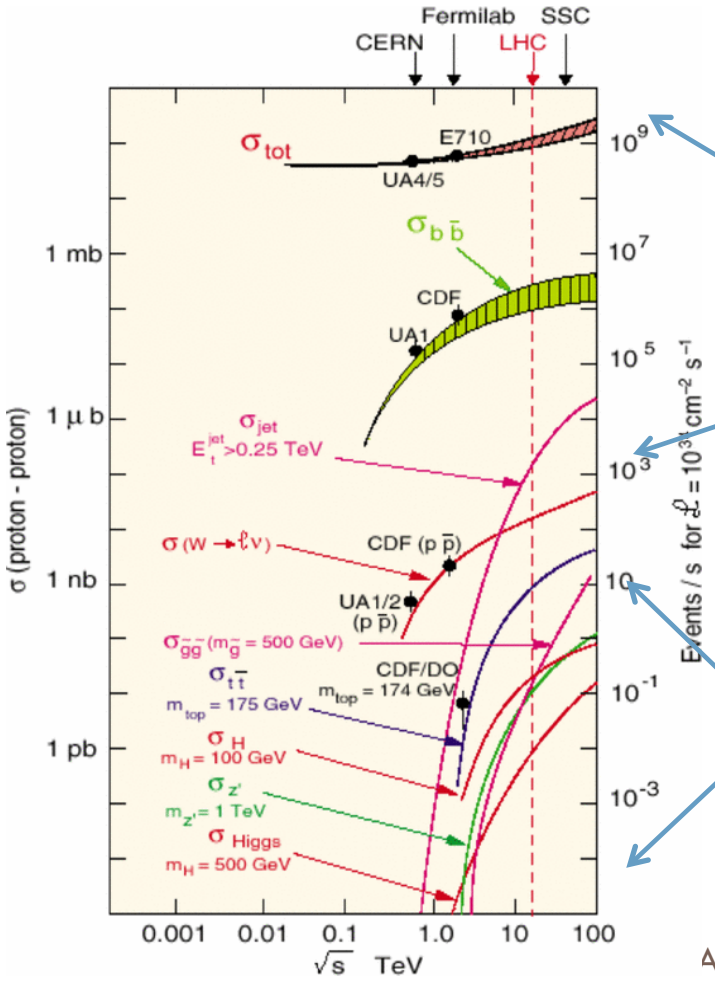
PERFORMANCE OF THE CMS HIGH LEVEL TRIGGER

How the HLT of CMS will deal with LHC Run-2 conditions

21st International Conference on Computing in High Energy Physics – CHEP 2015

Why do we need a trigger

- Reduce collision rate down to a manageable level

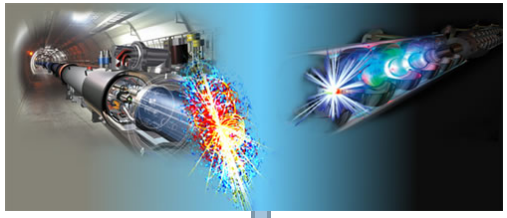


LHC rate = 40 MHz (@ 25 ns)

Max acceptable rate for the Data Acquisition System and storage = O(1 kHz)

Typical rate for the interesting physics processes is O(10 Hz) or below

The CMS way:



L1 Trigger (hardware)

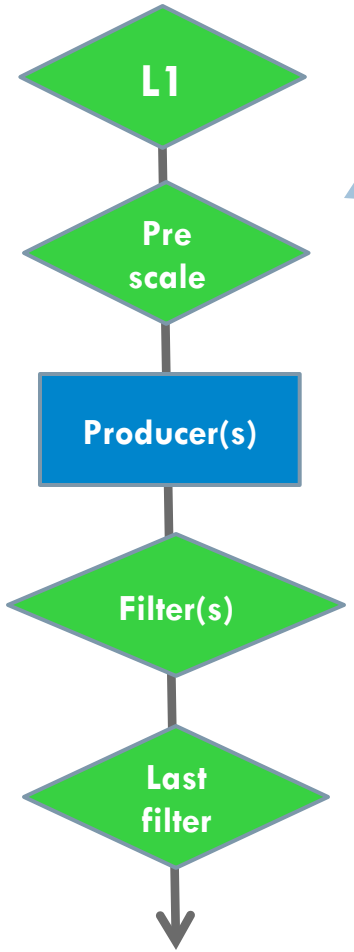
100 kHz

High Level Trigger (software)

1 kHz

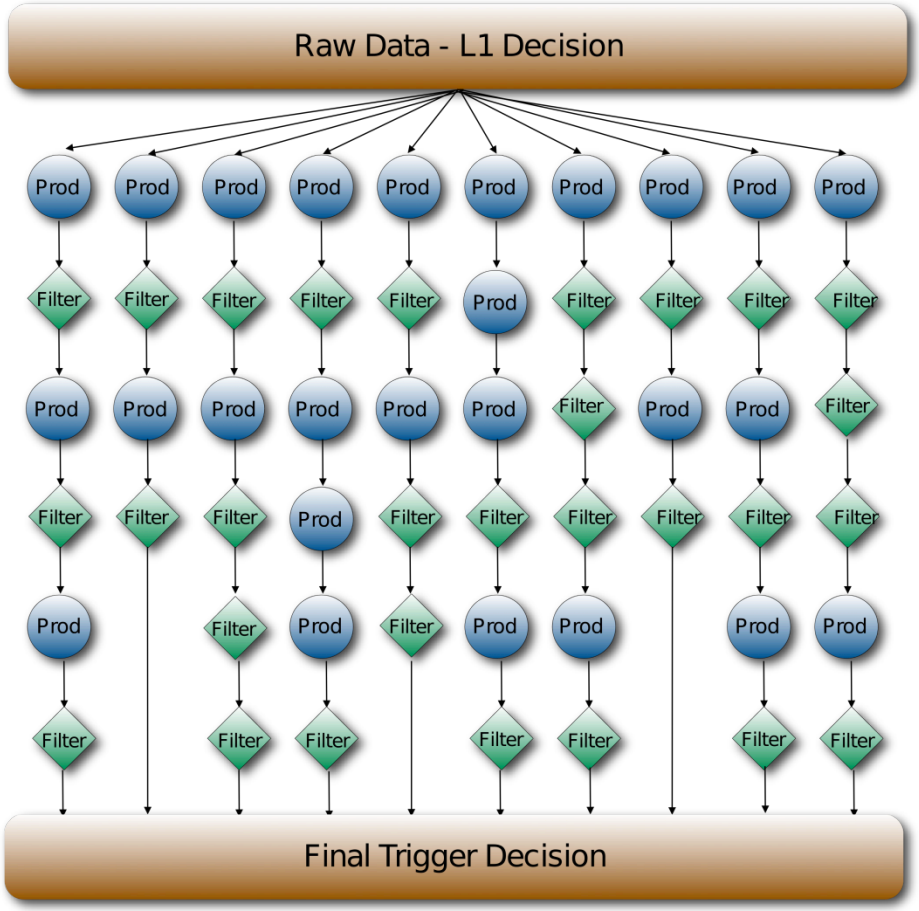
DAS

The High Level Trigger in CMS



One HLT path

The HLT menu: a collection of paths (plus streams, output modules, etc.)



The challenges of LHC Run2

8 TeV → 13 TeV

Factor ~2 in cross-section from the increased energy
Factor > 2 for multiple object triggers (due to combinatorials)

50 ns → 25 ns bunch spacing

Increased level of out of time pileup

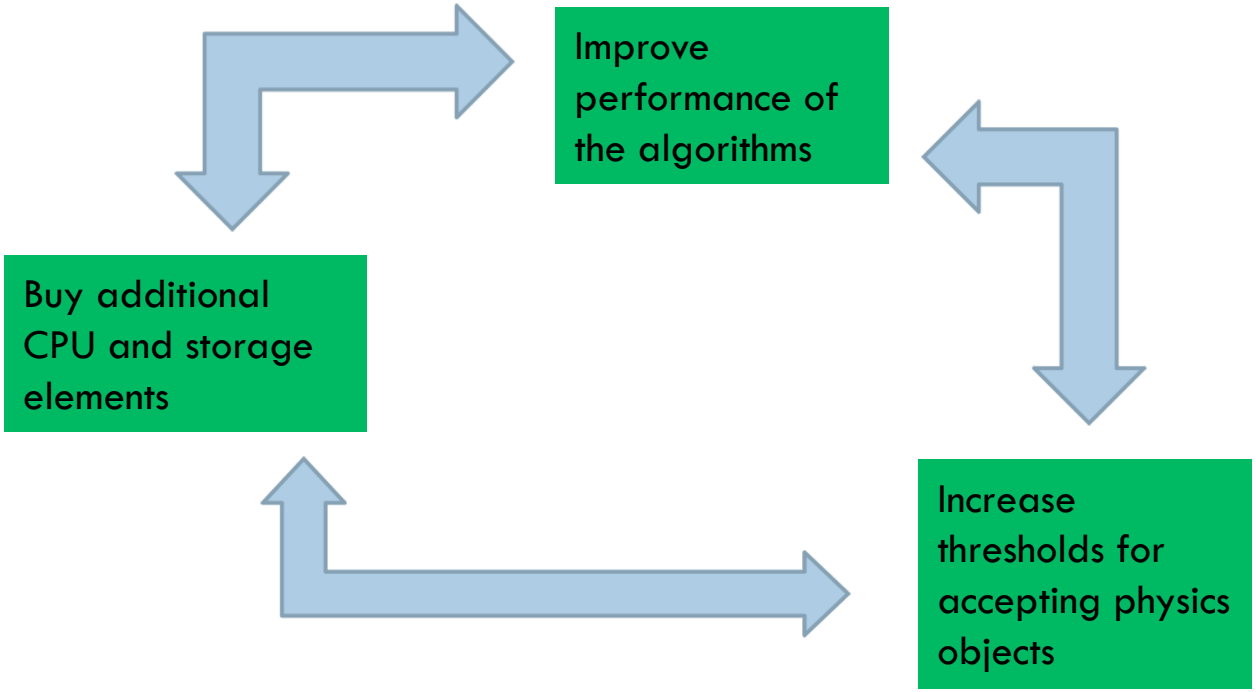
Peak luminosity from ~7e33 $cm^{-2}s^{-1}$ to 1.4e34 $cm^{-2}s^{-1}$

Factor 2 in rate

Rate x 4 (at least)

In time pileup from <PU> ~ 25 (Run1) up to <PU> ~ 40 (Run2)
Out of time pileup has a much lager impact than at Run1

How to react?



Expected input L1 rate: ~100 kHz

Planned budget for Run2: **1.35 kHz peak HLT rate** for **1 kHz average offline rate**

Trigger scenarios for 2015 runs

Targeting three main scenarios, corresponding to LHC running periods:

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

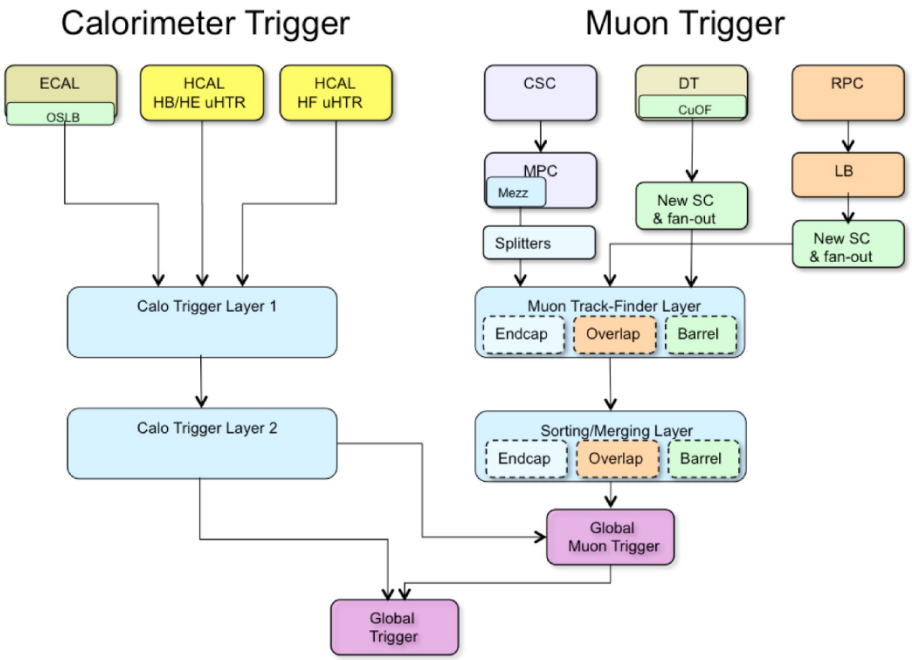
Plus additional dedicated trigger menus for:

- Low PU runs (PU = 0.01, 0.4)
- Heavy Ion runs
- Commisioning

more details in poster "Software for implementing trigger algorithms on the upgraded CMS Global Trigger System", by T. Matsushita

L1 updates for 2015

- Pileup subtraction for jets, energy sums, e/gamma isolation
- Dedicated tau trigger candidates (4x4 or 4x8 calo towers)
- Additional muon chambers in the endcaps
- Increased granularity of the CSC (endcap muon) readout



(Full L1 upgrade will be commissioned during 2015, and made available for 2016 runs)

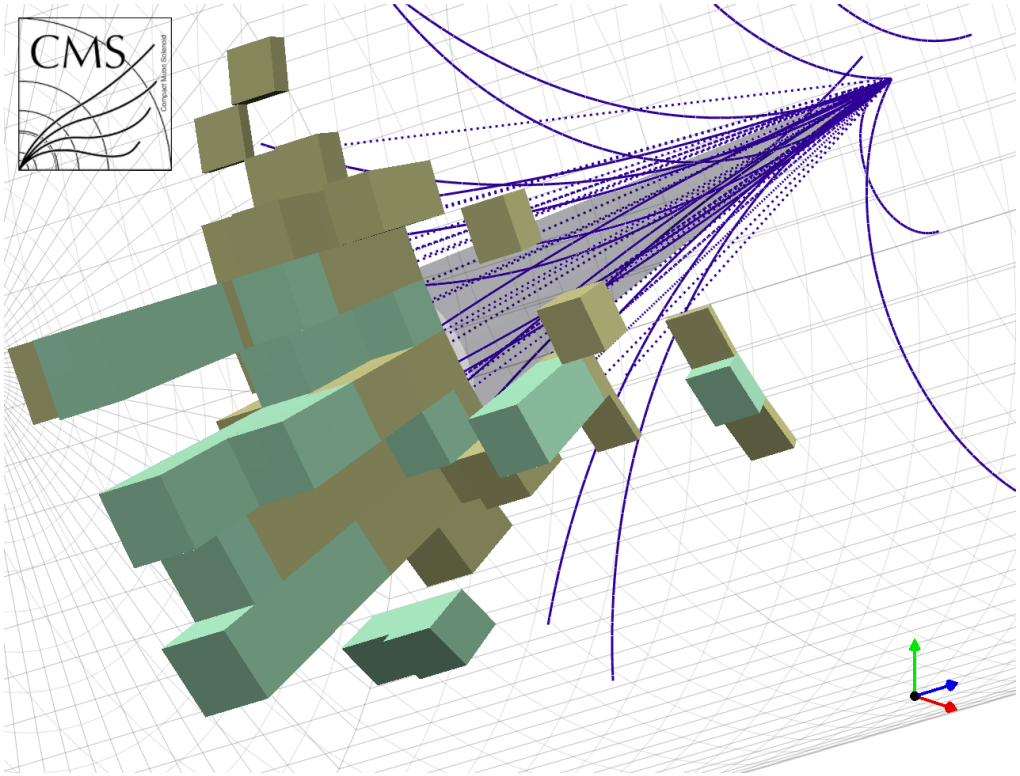
(A few) L1 thresholds

(*) "er" = "eta restricted" (restrict to objects at large angles wrt beam)

(Unprescaled) object	PT threshold 2012 (final lumi), GeV	PT threshold 2015 (50ns, L=5e33), GeV	PT threshold 2015 (25ns, L=14e33), GeV
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	22er(*)	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(*)

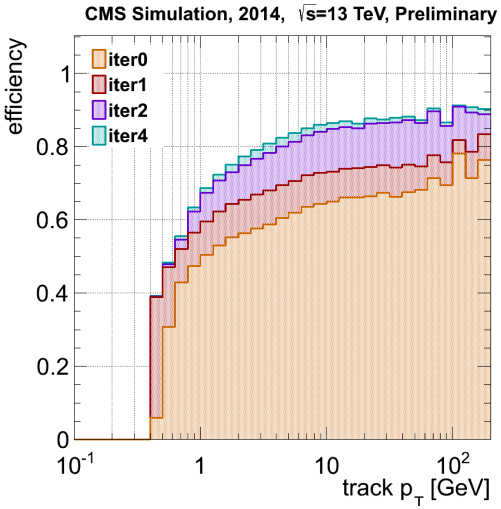
Move HLT to Particle Flow

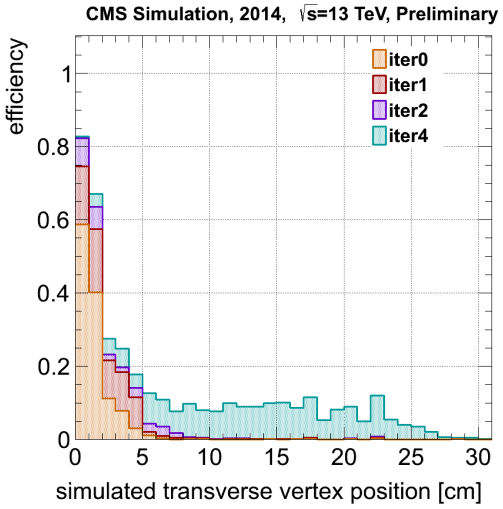
- Main improvement towards Run2: move basically all HLT in CMS to Particle Flow based methods and event reconstruction
  - Improved overall event reconstruction
  - Closer look to offline reco objects and selections



more details in poster "Performance of Tracking, b-tagging and Jet/MET reco at the CMS High Level Trigger", by M. Tosi

HLT Tracking





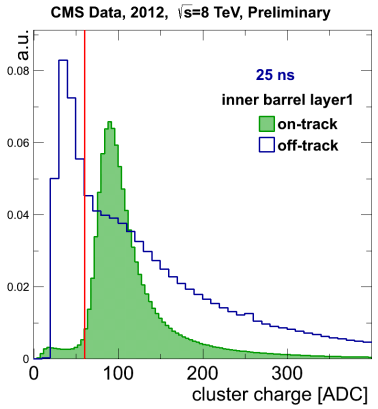
Iterative Tracking at HLT:

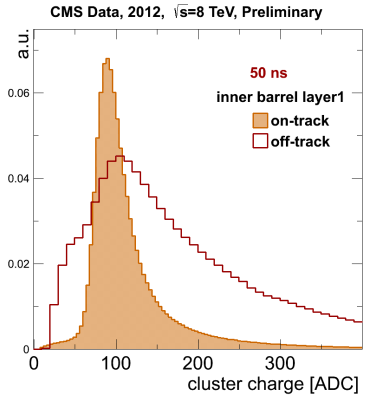
iter0: prompt tracks high pT w/ pixel tracks

iter1: prompt tracks low pT w/ pixel triplets

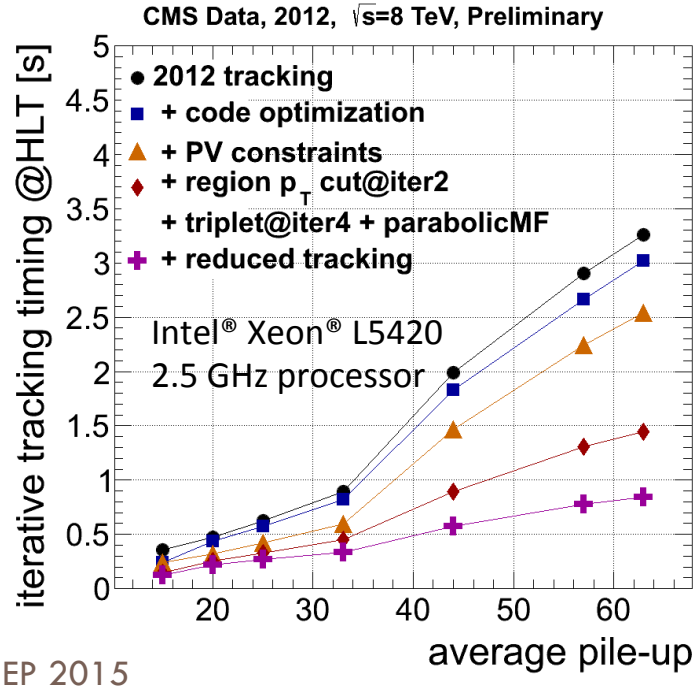
iter2: recover prompt tracks high pT w/ pixel pairs

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)



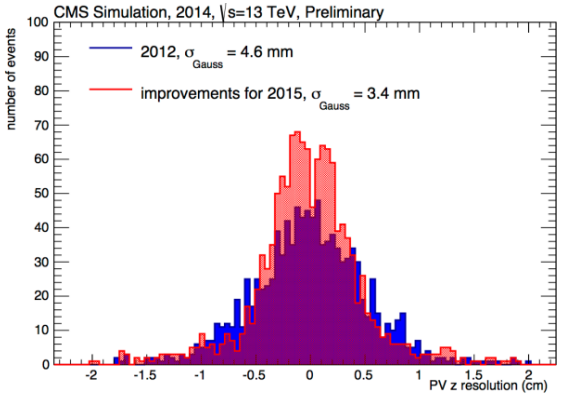


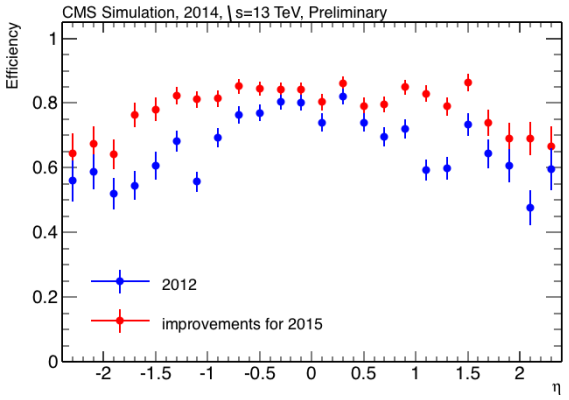
Cluster charge cut, meant to mitigate the effect of spurious clusters in 25ns runs



more details in poster "Performance of Tracking, b-tagging and Jet/MET reco at the CMS High Level Trigger", by M. Tosi

b-Tagging



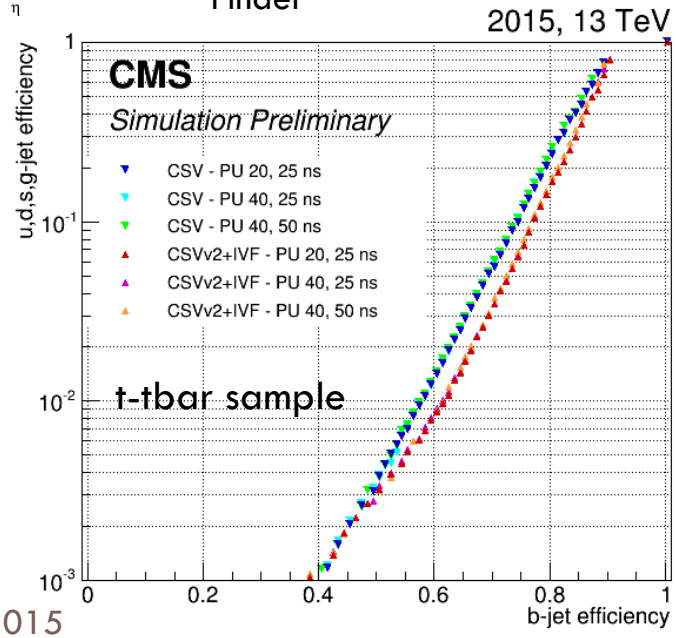


Improved b-tagging performance due to:

- Tracks reconstructed with Iterative Tracking
- Deterministic annealing in the primary vertex reconstruction
- New b-tagging algorithm
- Inclusive secondary Vertex Finder

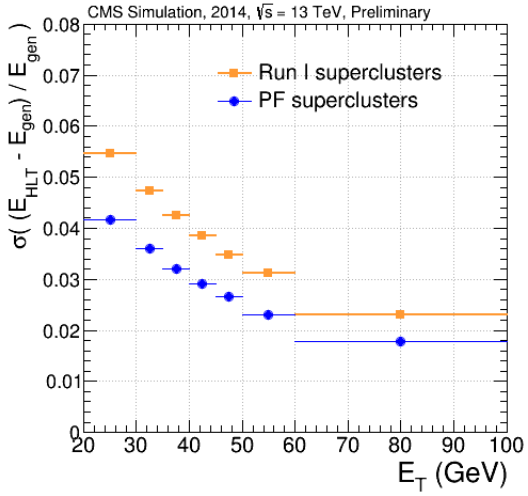
Improvements in the reconstruction of **Fast Primary Vertices:**

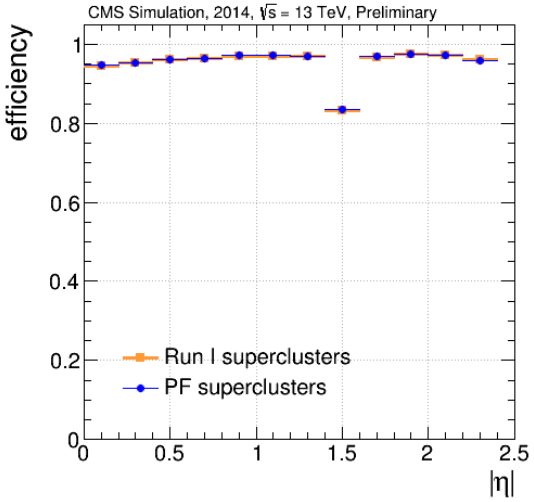
- Improved primary vertex finding thanks to weighted clusters, extended jet acceptance to |eta|<2.4, exploiting clusters from pixel end-caps
- Improved primary vertex reconstruction using regional pixel tracking around the jets

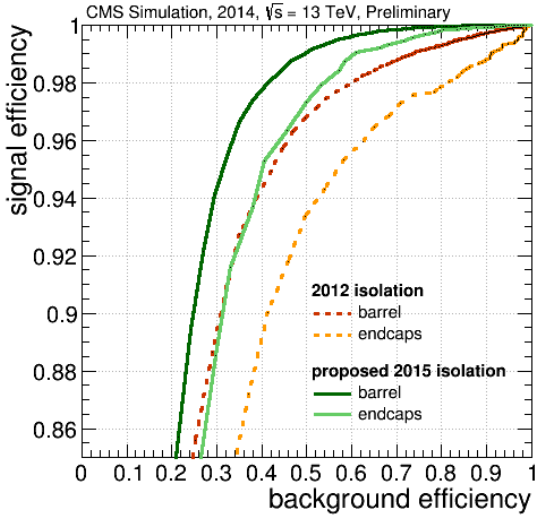


more details in poster "Electrons and photons at High Level Trigger in CMS for Run II", by A. Aizuddin Bin Anuar

Electrons



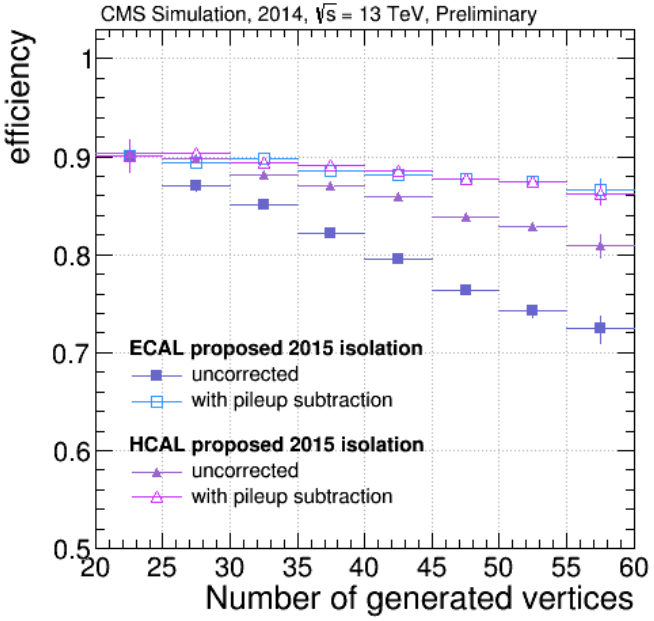




Energy resolution and **efficiency** of electron superclusters at HLT, built with and without Particle Flow methods

Signal vs background efficiency: comparison of the "Particle Flow cluster-based" isolation algorithm meant for 2015 runs with the calorimeter based one used at Run1

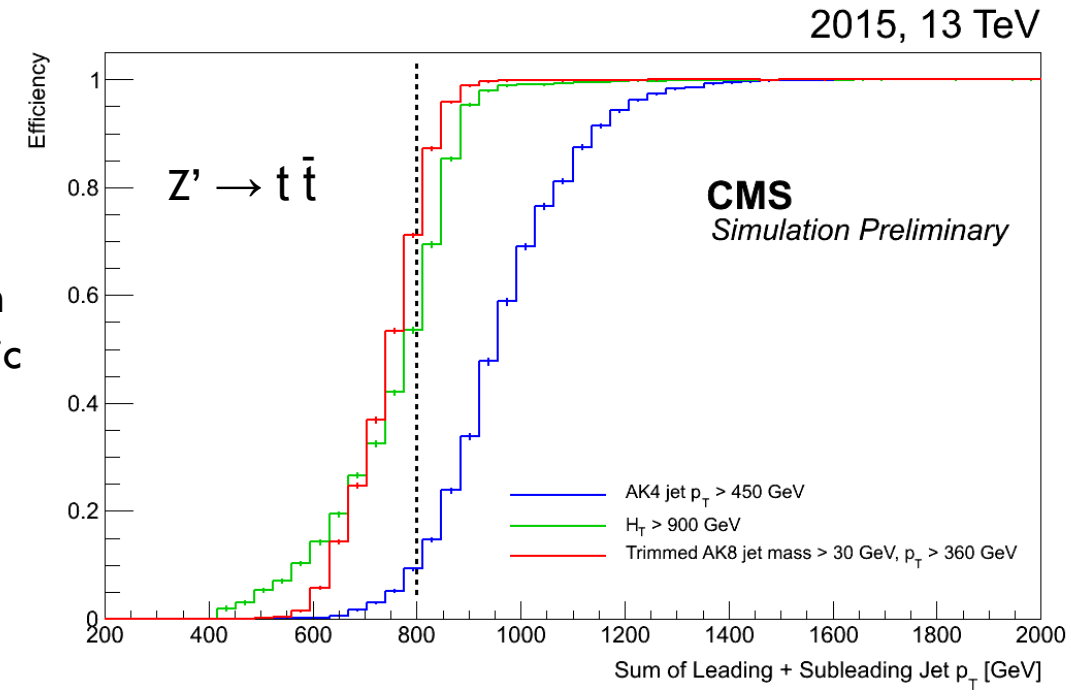
Effect of **pileup subtraction** on the 2015 "PF cluster based" isolation, and comparison of performance with the one used at Run1



Jets

Advances in triggering on **jets with substructures** (for boosted hadronic topologies):

- "Fat" jets reconstructed with the AK8 algorithm
- Trimmed jet mass cut



more details in poster "Performance of muon-based triggers at the CMS High Level Trigger", by B. Radburn-Smith

Muon reconstruction at HLT

L1 Muon → **L2 Muon** (use only the muon spectrometers) → **L3 Muon** (include tracker info)

For **L3**, a sequence of three algorithms is tried in cascade (from the fastest to the most CPU consuming one):

OIState
1. Seed Generation
2. Trajectory Building
3. TrackerTrack Creation
4. Filter on Quality Cuts*
5. TrackerTrack-L2Muon Matching

→ No L3 Track → **OIHit**

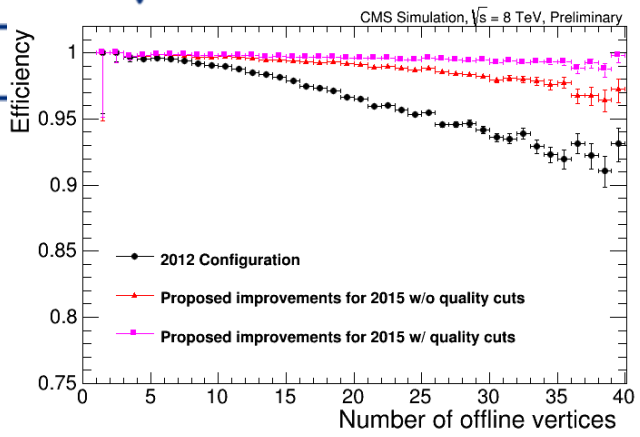
1. Seed Generation
2. Trajectory Building
3. TrackerTrack Creation
4. Filter on Quality Cuts*
5. TrackerTrack-L2Muon Matching

→ No L3 Track → **IOHit**

1. Seed Generation
2. Trajectory Building
3. TrackerTrack Creation
4. Filter on Quality Cuts*
5. TrackerTrack-L2Muon Matching

Has L3 Track (OIState) | Has L3 Track (OIHit) | Has L3 Track (IOHit)

→ Collection Merging & L3 Muon Filter



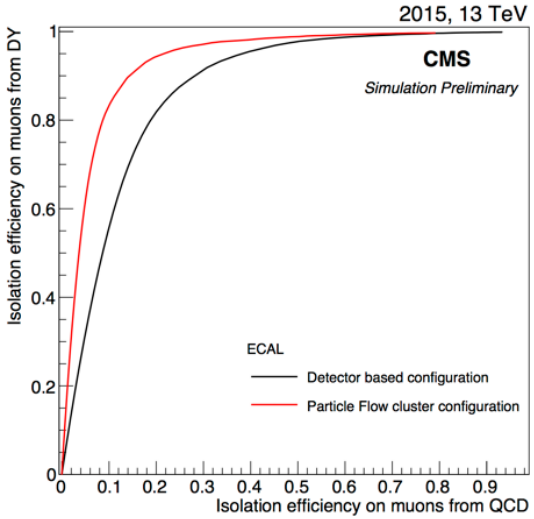
Main updates to the L3 algorithm for Run2:

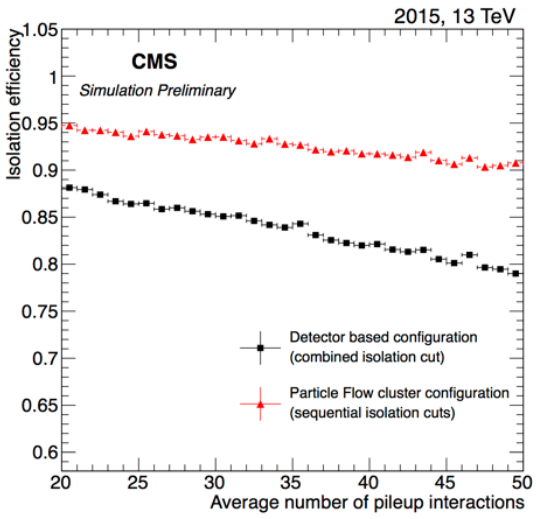
- Use χ^2 measurement to assign hits to tracker tracks
- Quality filters on tracker tacks become part of the L3 reconstruction

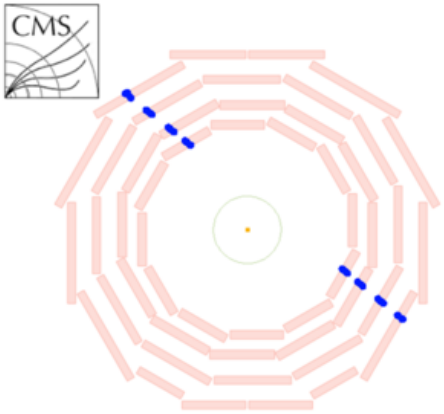
more details in poster "Performance of muon-based triggers at the CMS High Level Trigger", by B. Radburn-Smith

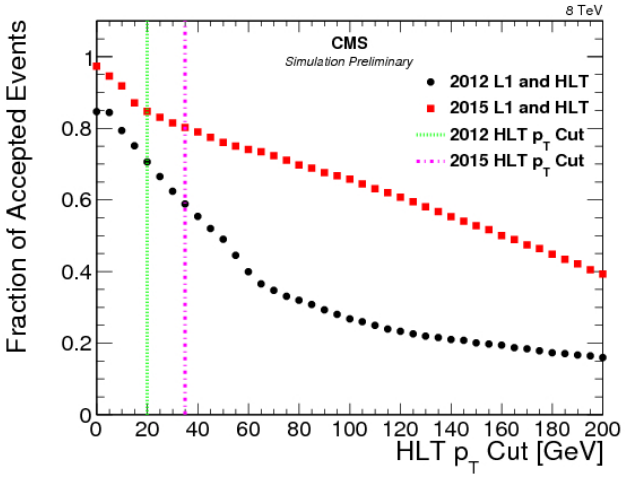
Muons

Particle Flow vs detector based muon isolation









Better p_T resolution (mean-timer technique and cosmic-like muon seeding) increases efficiency for topologies with **highly displaced muons**

HLT thresholds on simple objects (work in progress to further fine tune them)

(*) "er" = "eta restricted" (restrict to objects at large angles wrt beam)

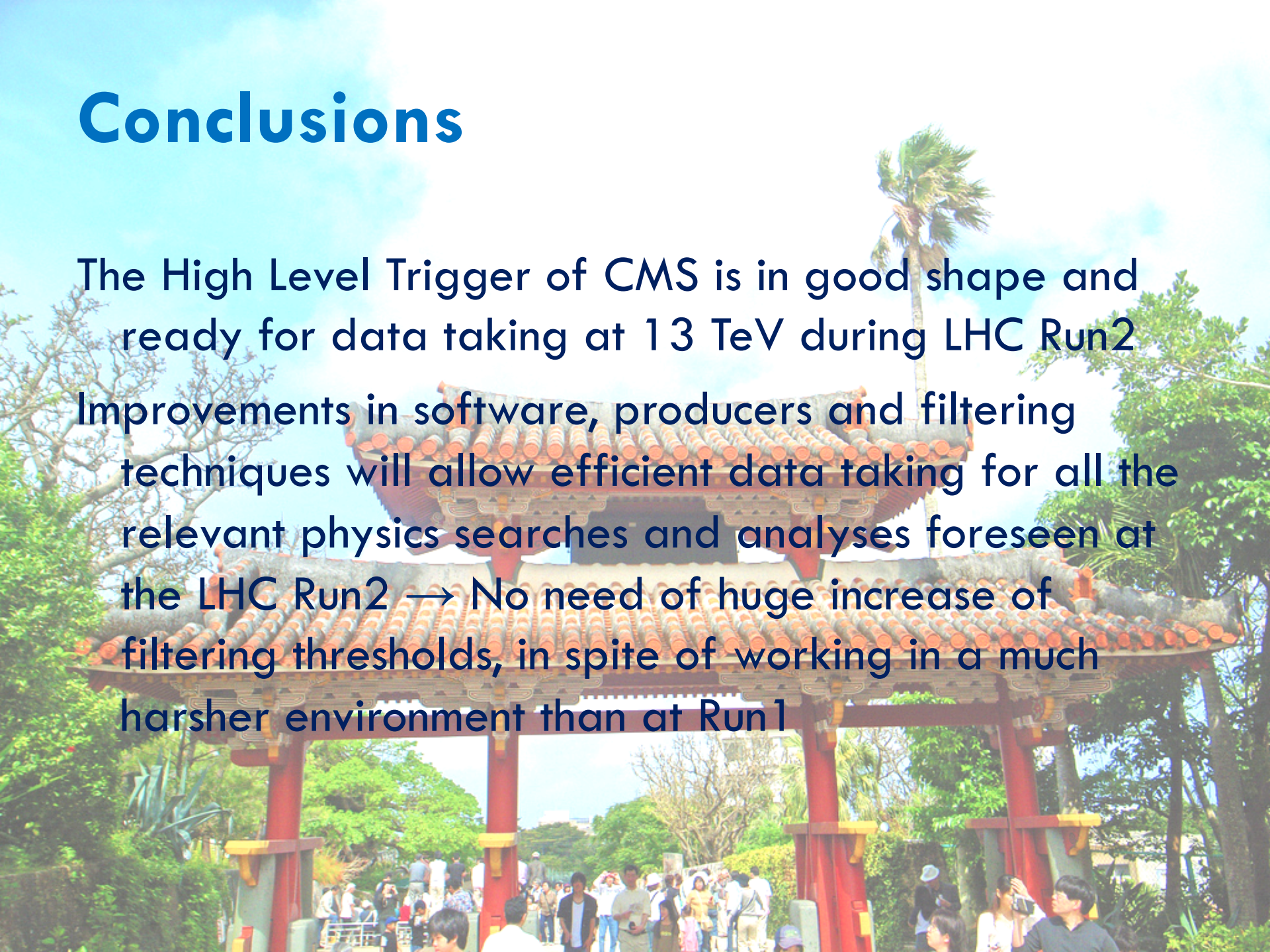
(Unprescaled) object	PT threshold 2012 (final lumi), GeV	PT threshold 2015 (50ns, L=5e33), GeV	PT threshold 2015 (25ns, L=14e33), GeV
Single Muon	40	50 / 45er(*)	50 / 45er(*)
Single Iso Muon	24	20	27 / 24er(*)
Single Iso Electron	27	27	32
Single Photon	150	170	170
Single PF Jet	320	450	450
(PF) MET	120 (80 parked)	170	170
(PF) HT	750	900	900

… just a tiny subset of the O(400) HLT paths foreseen for the Run2 HLT menus at 50ns and 25ns

Conclusions

The High Level Trigger of CMS is in good shape and ready for data taking at 13 TeV during LHC Run2

Improvements in software, producers and filtering techniques will allow efficient data taking for all the relevant physics searches and analyses foreseen at the LHC Run2 → No need of huge increase of filtering thresholds, in spite of working in a much harsher environment than at Run1



Backup

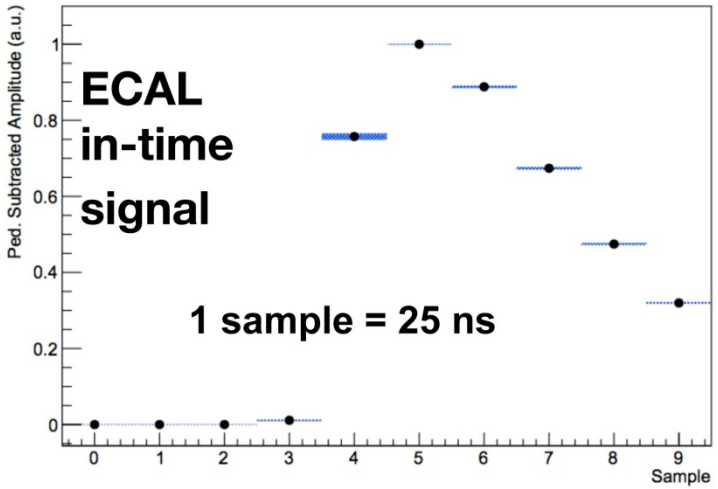
Calo local reconstructions @ 25ns

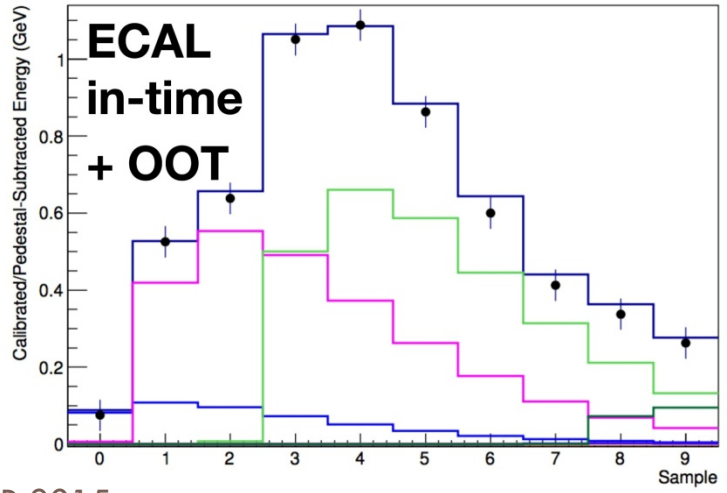
LHC runs with 25ns bunch spacing will inject significant out-of-time pileup in the data

Offline RECO adjustments: ECAL and HCAL will use different kind of fit of the superimposed shapes of charge deposits in the central BX and in the ones nearby

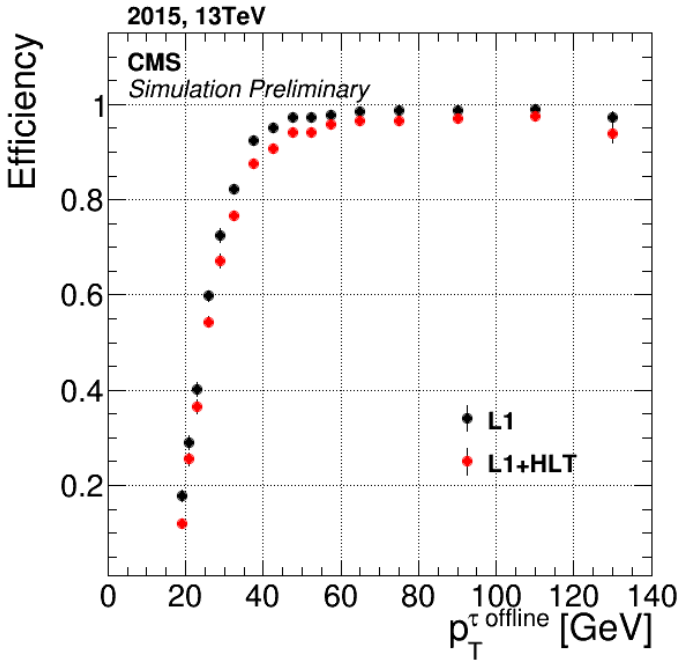
Faster version of these were needed by **HLT**:

- **Fast ECAL fit of superimposed multiple pulses** (*first try to fit a single pulse, keep result if* χ^2 *below some threshold, otherwise do full multifit*)
- **Deterministic fit in HCAL** (*solve system of equations for pulse amplitude, using energy in each time slice and assuming pulse shape and time slew*)

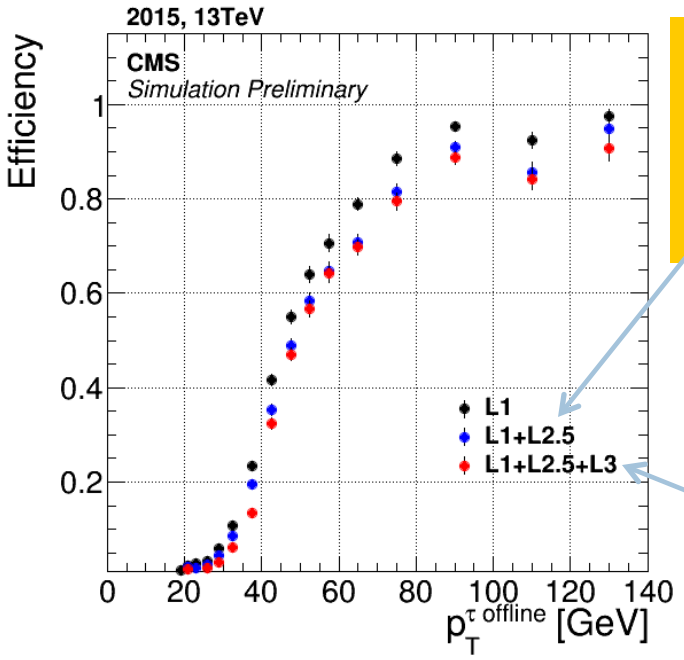




Taus



LooseIsoPFTau20: efficiency of the tau leg in a mu+tau trigger with respect to offline loosely isolated taus, estimated on H(125) → ττ events at 13 TeV with <PU>=20 and 25ns bunch spacing



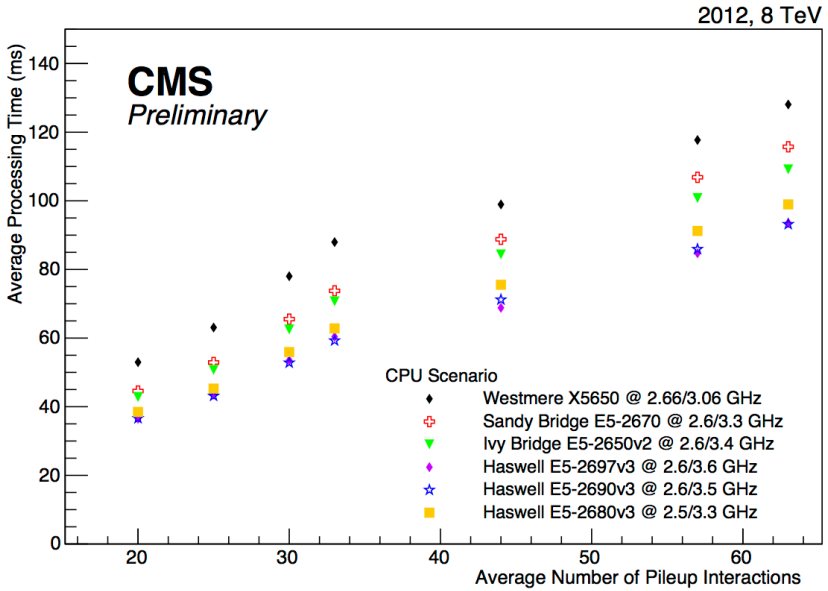
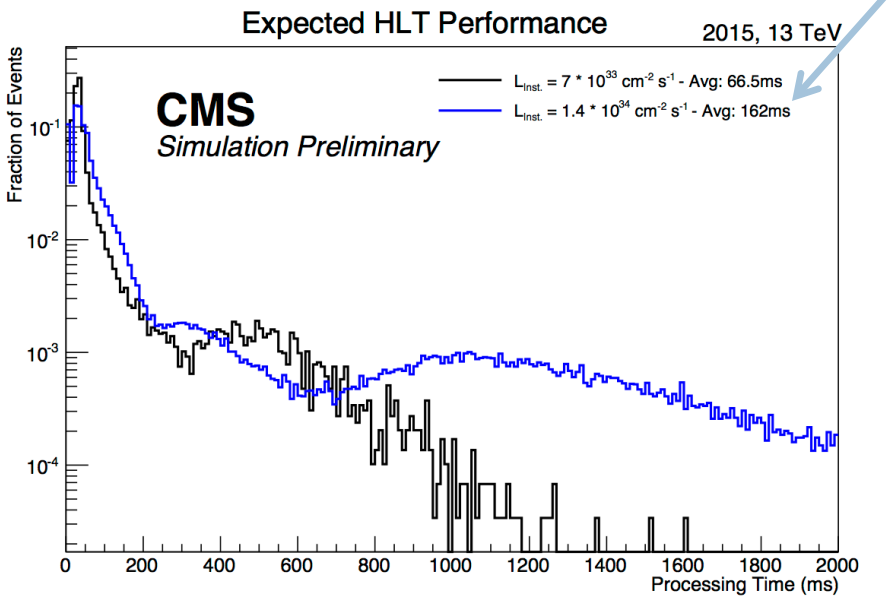
L2.5: tau reconstructed at HLT with calorimeters and isolated with Si-pixel tracks

L3: tau reconstructed at HLT with Particle Flow particles based on silicon and pixel tracks

MediumIsoPFTau40: efficiency of the tau leg in a mu+tau trigger with respect to offline medium isolated taus, estimated on H(125) → ττ events at 13 TeV with <PU>=20 and 25ns bunch spacing

more details in poster "CMS High Level Trigger Timing Measurements", by C. A. Richardson

Timing estimates at high Lumi



Target average CPU budget per event: **160ms**
Already very close to it, even at the largest luminosities expected for Run2 !