CMS Trigger Improvements towards Run II

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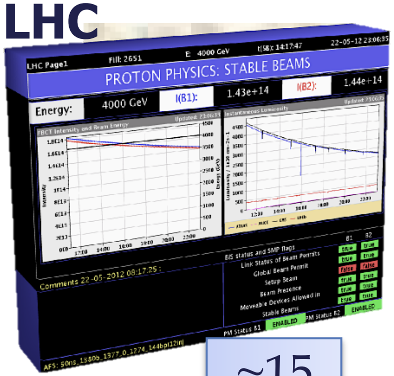
On behalf of the CMS collaboration

The CMS Triggering System

In 2012

LHC



~15 MHz

Level 1: FPGA, custom ASICs

~100k Hz

HLT : Software ~ 13000 commercial CPUs

~400 Hz

1. Level 1 :
   - FPGA implemented algorithms
   - 4 μs latency
   - Reduces the rate down to 100kHz
   - L1-Accept triggers read-out of the detector

2. High Level Trigger
   - Software selection (>400 algorithms for maximum physics reach)
   - Decision taken in < 200ms
   - Reduces the rate to 400Hz
   - HLT-accept triggers write-out of the event,

The Challenges of Run II

8TeV ⟶ 13 TeV

- Expect a factor 2 in cross section from the increased energy
- >2 for multiple objects triggers due to combinations

We face a rate x 4 at least

50 ns ⟶ 25 ns bunch spacing

- Factor 2 in rate
- Increased out-of-time pile-up

Pile Up

- 2012 <PU> ~ 25
- 2015 <PU> 20 to 50

- Level 1 constraints :
  - we need to keep the output rate down to 100kHz
- HLT constraints:
  - Increase the computing power to be able to cope with increased PU

Level 1 Trigger

L1 Trigger in 2012

Calorimetric L1 Objects from Global Calorimetric Trigger

- Ecal deposits:
  - e/γ objects: (w/ or w/o calorimetric isolation)
- Ecal+Hcal deposits :
  - Jets : up to 4 central, 4 forward, and 4 tau candidates
  - global quantities: MET, HT

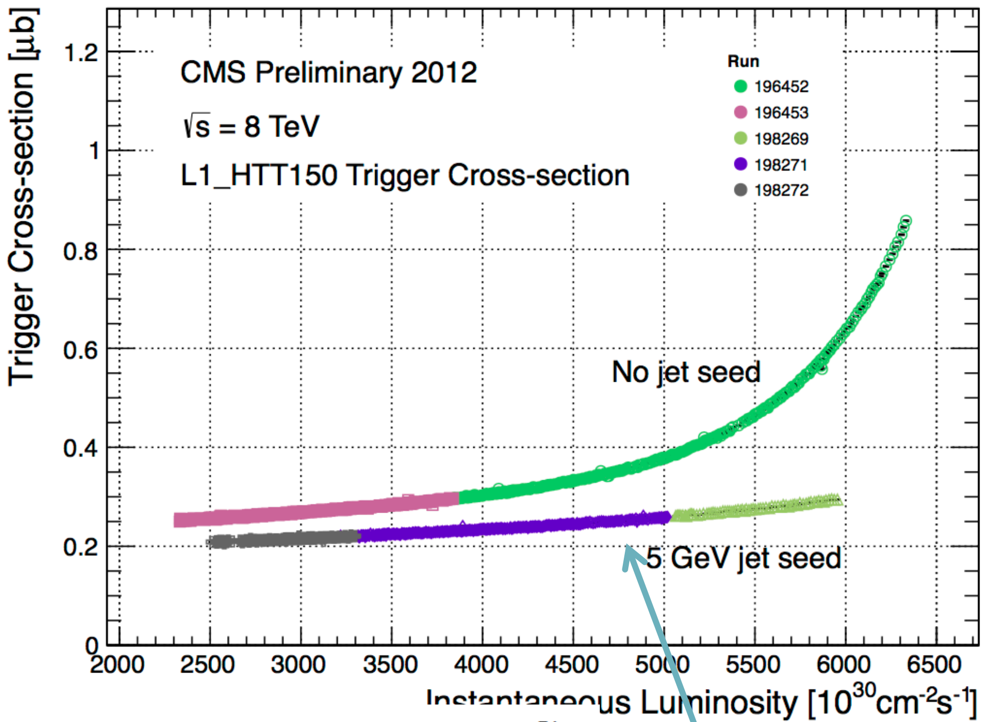
Muon L1 Objects from the Global Muon Trigger

- muon candidates
  - up to 4 candidates from the hits in the muon detectors

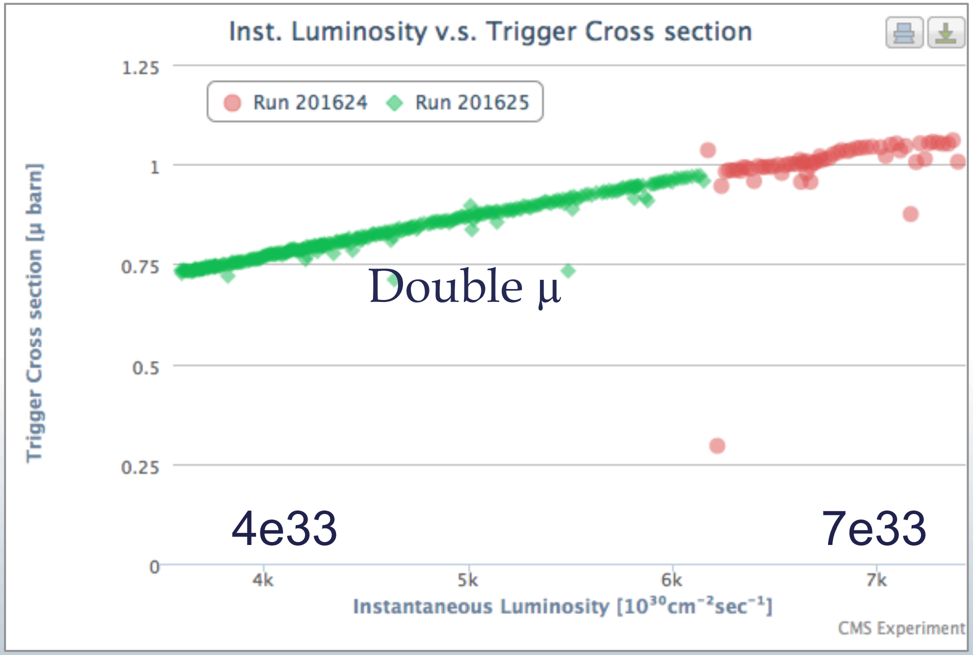
128 algorithms (bits) based on
- the candidates
- their quality
- their combinations

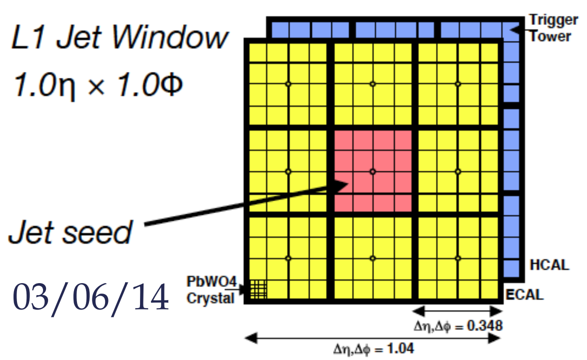
PU dependence of L1 triggers

Some triggers tend to increase non-linearly with PU, e.g.: ΣE_T (jet) for E_T>threshold



Multiple object triggers : Combinatorial effects





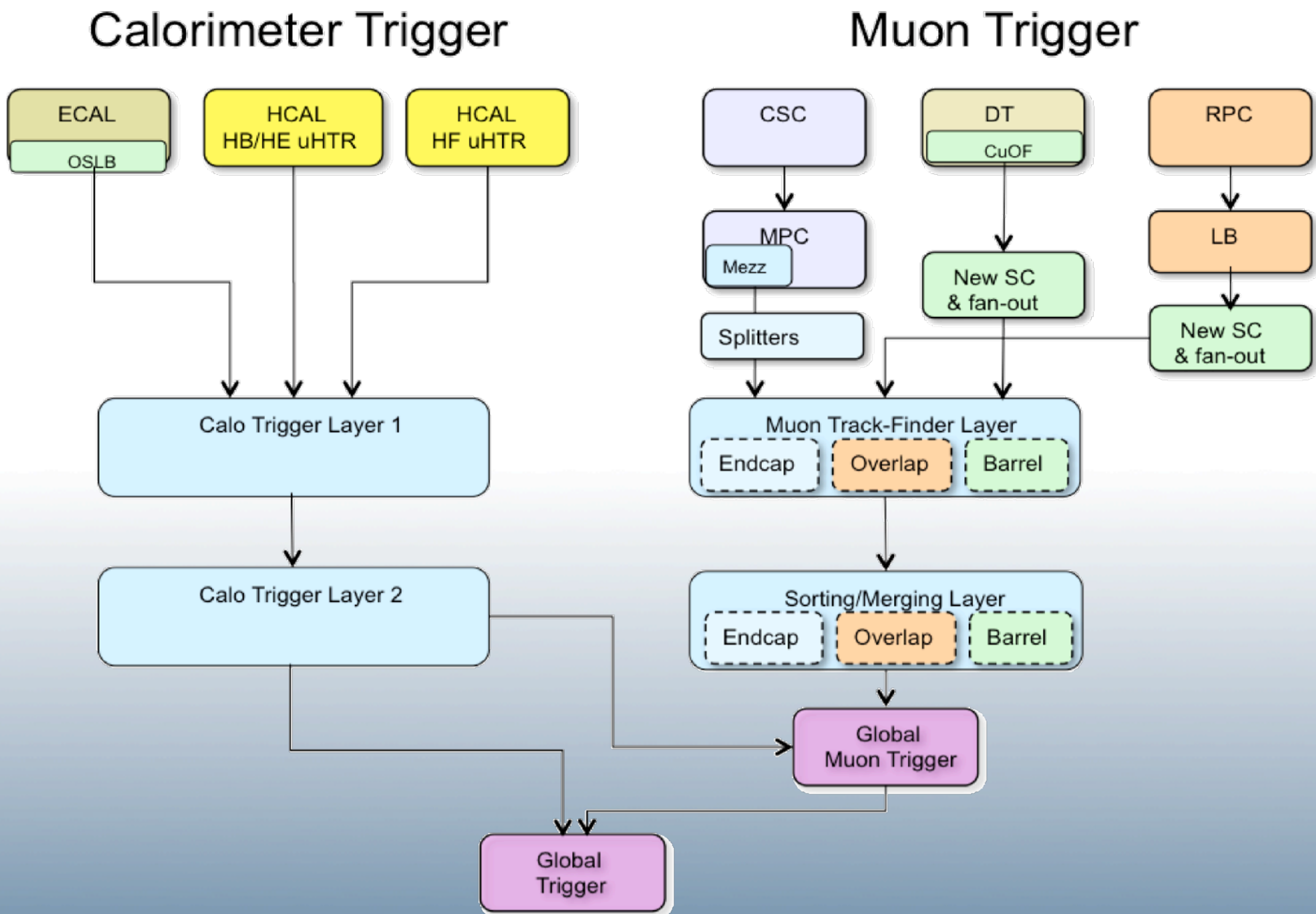
Solution in 2012

L1 Trigger upgrade for Run II

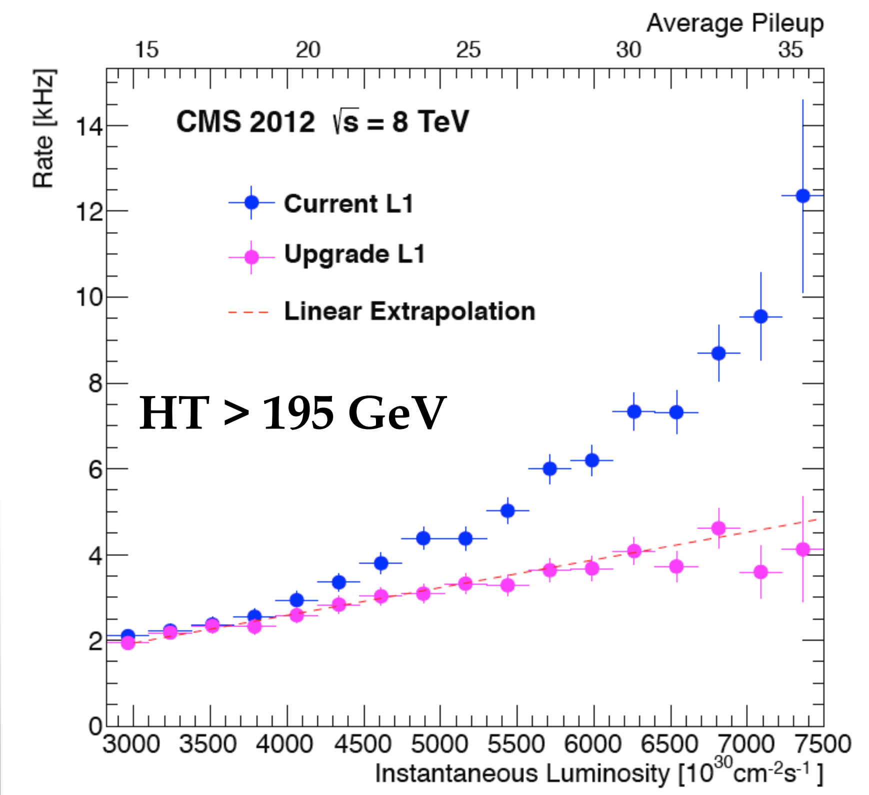
Replace the calorimeter, muon, and global trigger

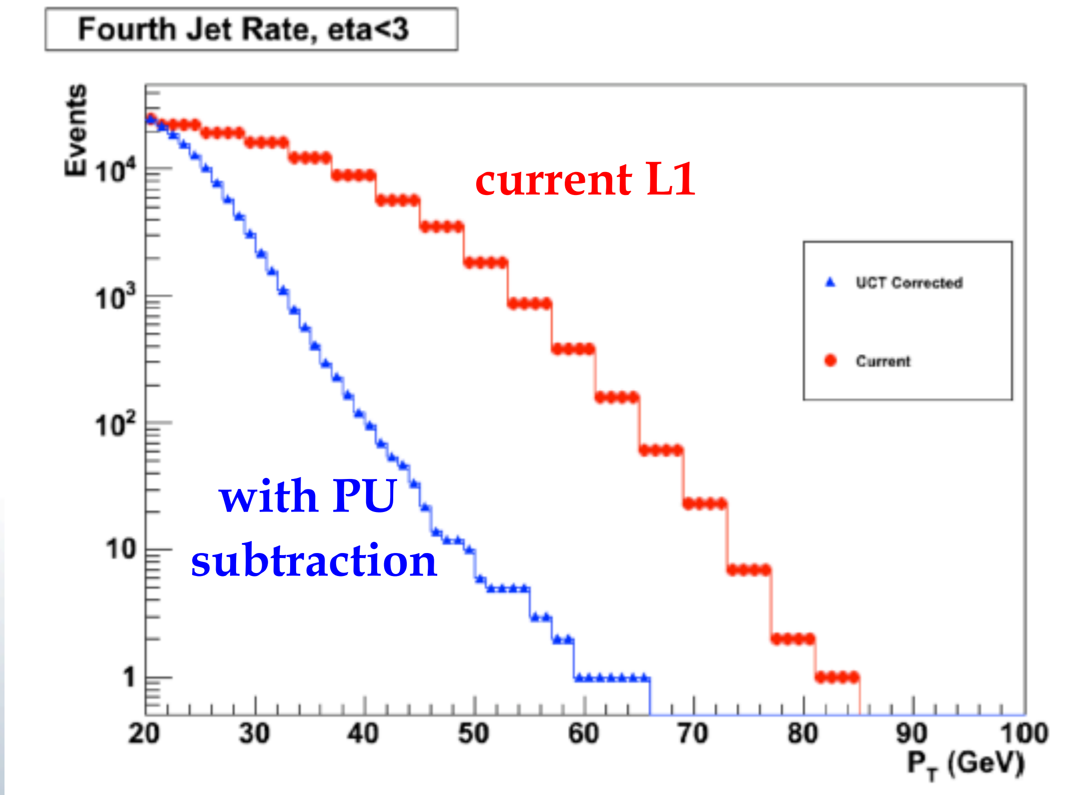
- Stage 1 : 2015
  - pile-up subtraction for jets, energy sums, e/γ isolation
  - dedicated τ trigger candidates (4x4 - 4x8 towers)
  - New muon chambers
  - Increased granularity in CSC readout
- 2016 - Stage 2
  - new muon trigger
    - Single track finder for DT, CSC & RPC systems ⟶ improved tracking
    - muon isolation using calorimetric information
  - new calorimetric trigger
    - increased granularity (%4 in η & ϕ) ⟶ tower-based isolation
  - new Global Trigger
    - increased number of candidates (at least x 2)
    - more powerful logic, improved resolution
    - support for more complex topologies (soft muon b-tagging, VBF jets, …)

L1 Trigger upgrade for Run II



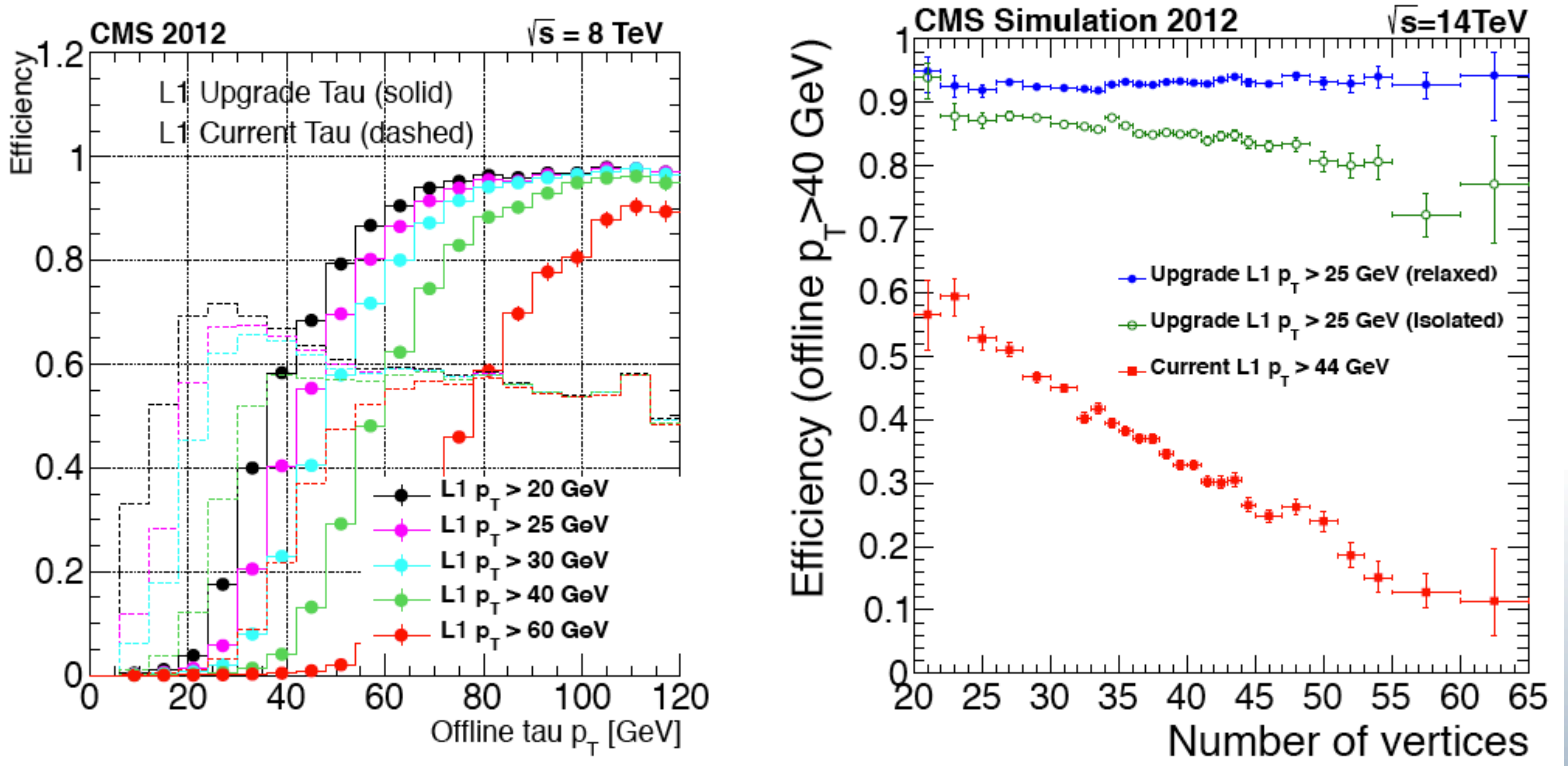
PU subtraction at L1





effect of pile-up subtraction on energy sums and multi-jet trigger

Tau L1 Trigger



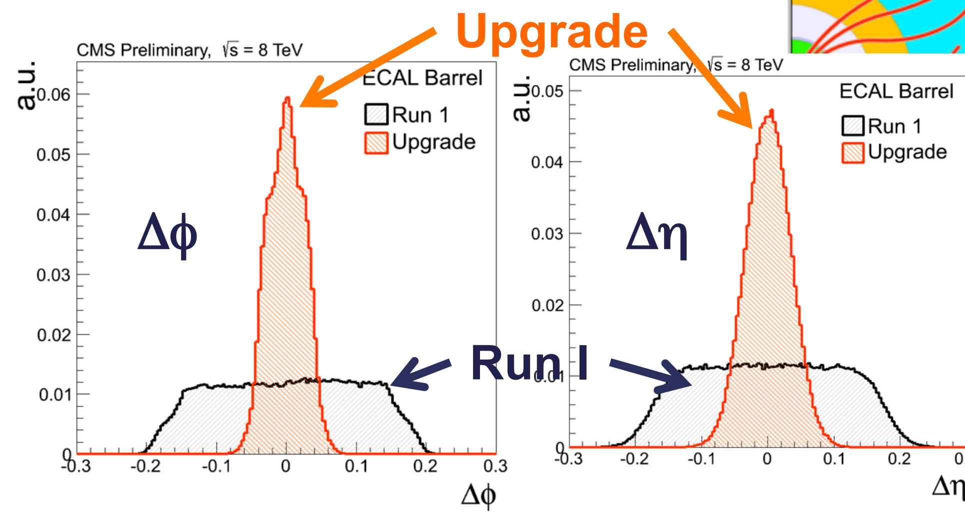
performance of upgraded L1 tau trigger

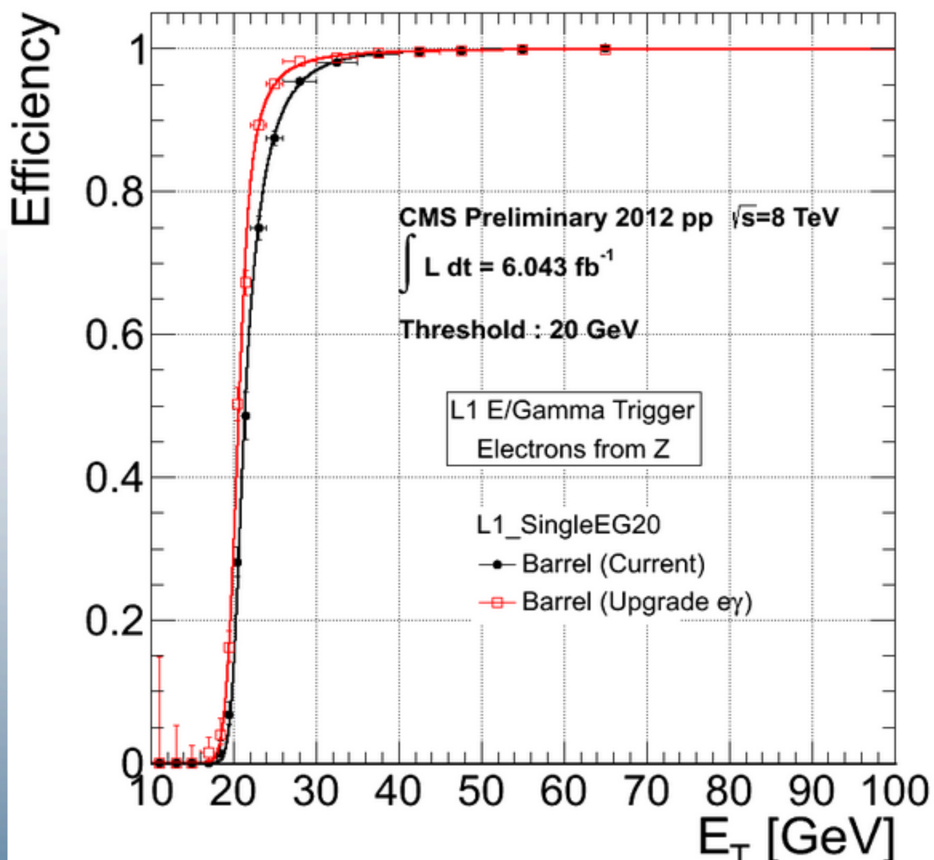
- improved efficiency at high p_t
- improved robustness vs. pile-up

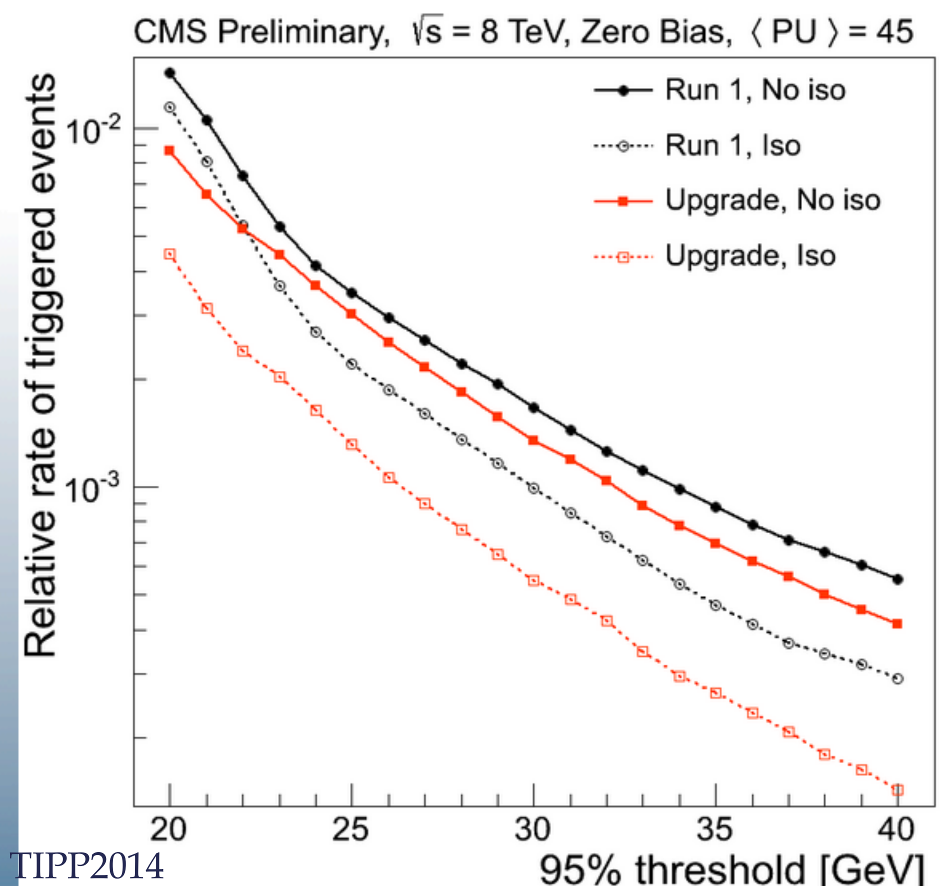
L1 E/γ trigger

New tower-based clustering :

- sharper turn-on
- better position resolution, η dependent calibration

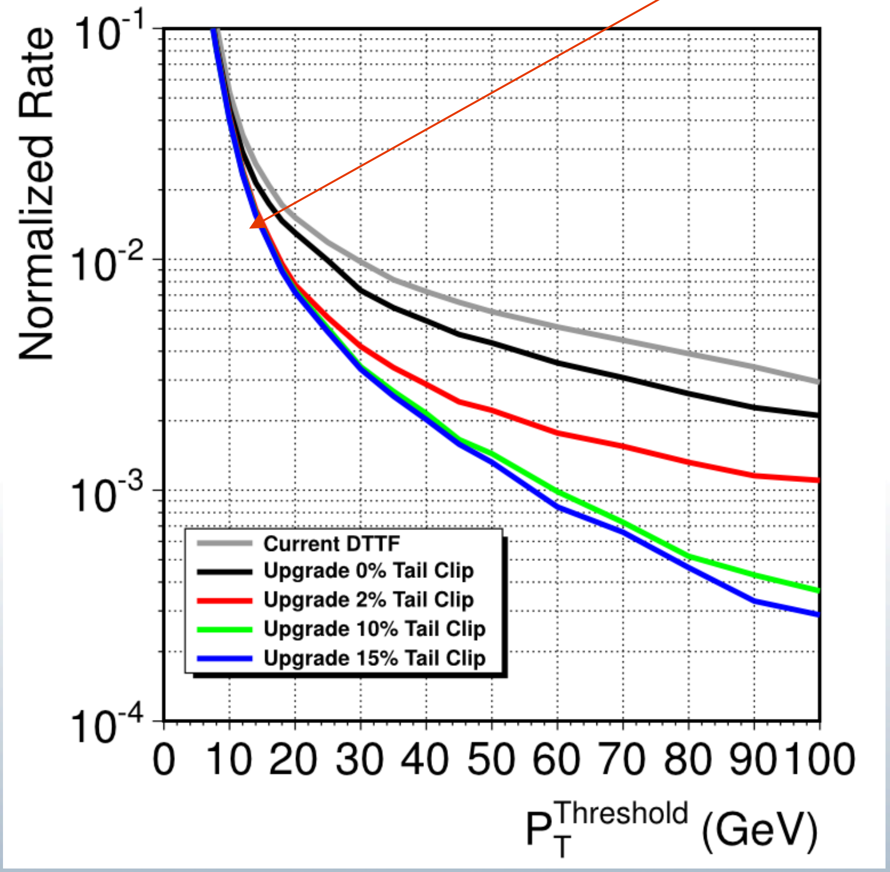


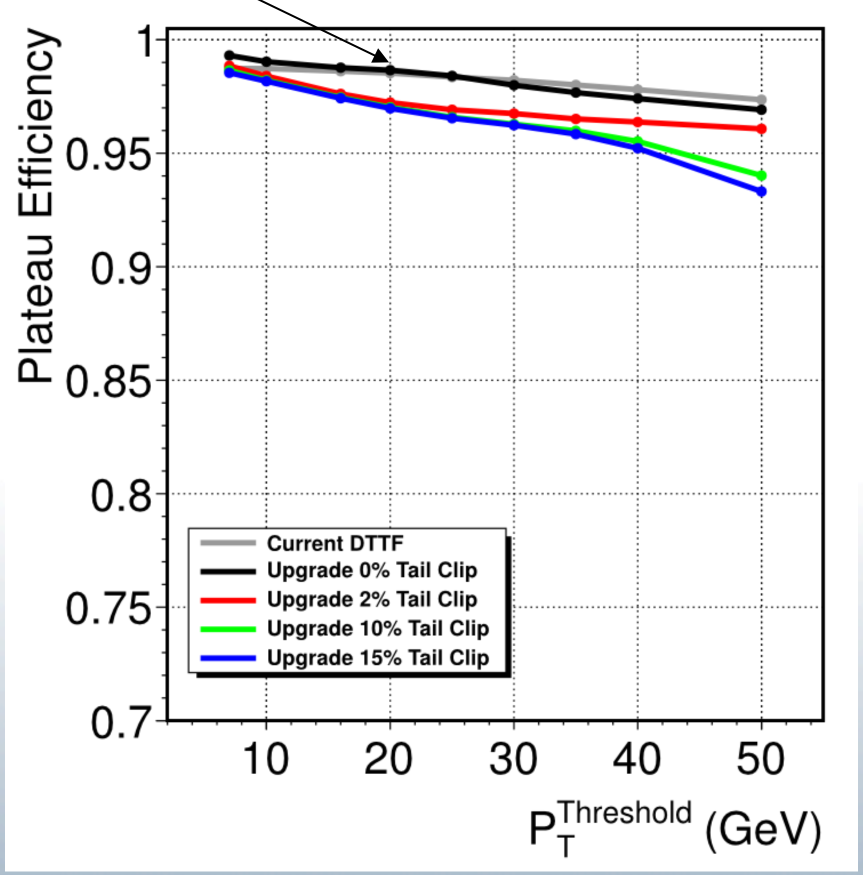




Muon L1 Trigger

rate reduction by a **factor 2 ~ 3**, with a **similar** efficiency

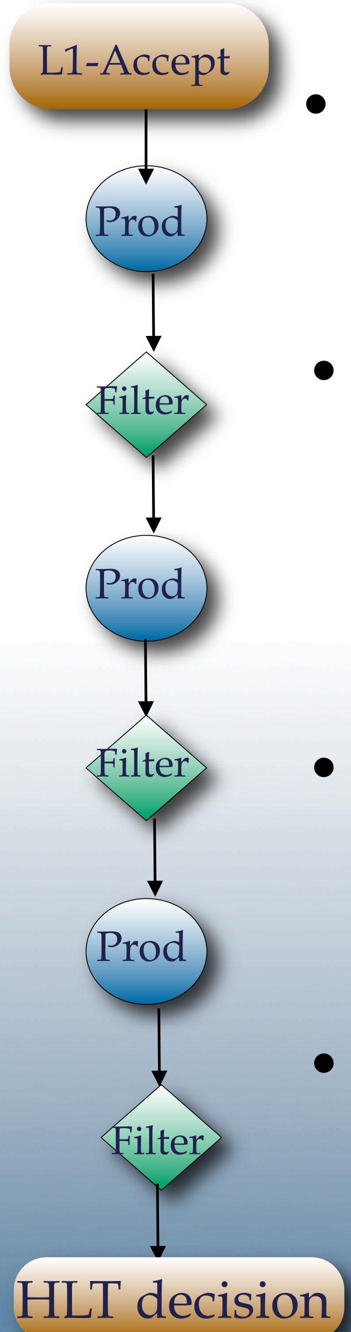




new muon pT assignment (bigger LUTs, post-processing)

High Level Trigger

HLT online reconstruction



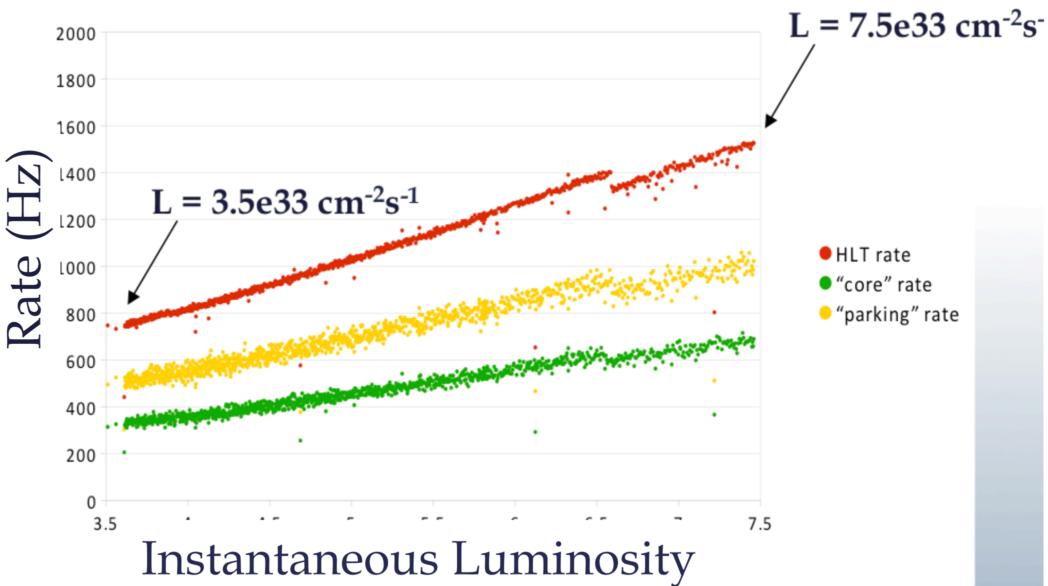
- the HLT is a “sped up” version of the offline reconstruction software. To keep **average** processing time per event low.
- modular approach:
  - reconstruct the **fastest object first**
    - L1 μ → L2 spectrometer μ→ L3 tracker+spectrometer μ
    - L1 jet → “calo” jet → tracking and particle flow jet
  - **reject an event as soon as possible**
- only look around candidates from a previous step
  - **regional “unpacking” and reconstruction**
    - read the detector data around L1 objects
    - reconstruct tracks inside jets, or around leptons
- keep combinatorics under control
  - **reject pile-up**, limit the number of candidates being evaluated

Over 400 algorithms in 2012

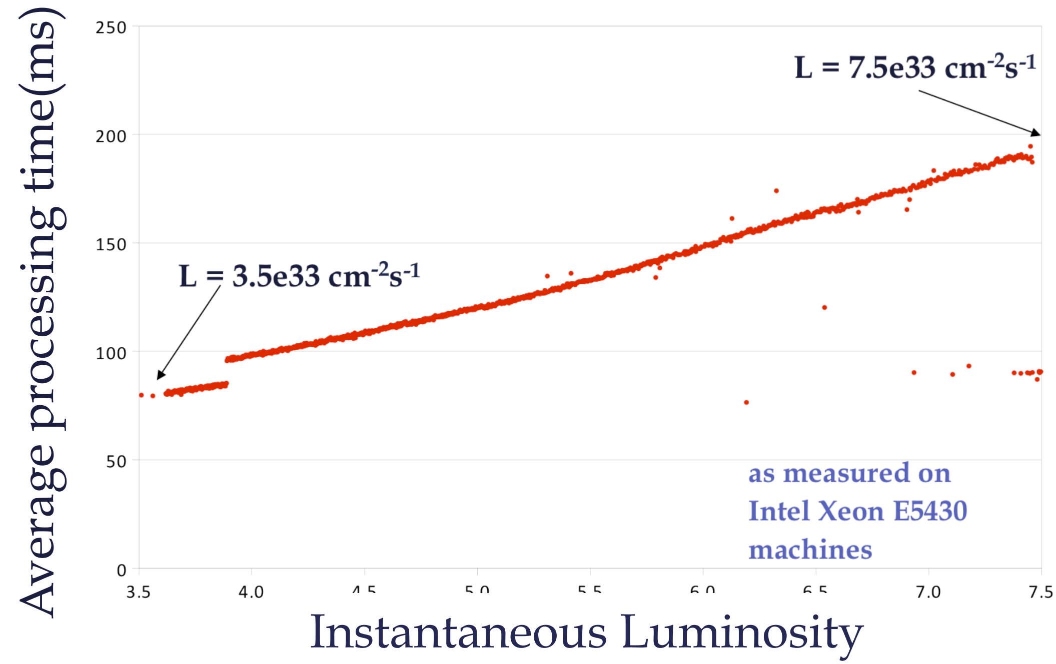
- $\mu^{\pm}$
  - "L2" μ-spectrometer muons
  - "L3" tracker+μ-spec muons
  - tracker-based isolation
- γ
  - based on ECAL superclusters
  - calorimeter-based id and isolation, tracker-based isolation
- $e^{\pm}$
  - match ECAL superclusters, pixel tracks, and full tracking
  - calorimeter-based id and isolation, tracker-based id and isolation
- $\tau^{\pm}$
  - particle flow reconstruction
- jets, MET, HT
  - particle flow-based jets and MET
- b-tagging
  - jets, full tracking
  - secondary vertex reconstruction
- and more…
  - dE/dx, …

Rates & timing vs Luminosity

HLT rates vs. Luminosity



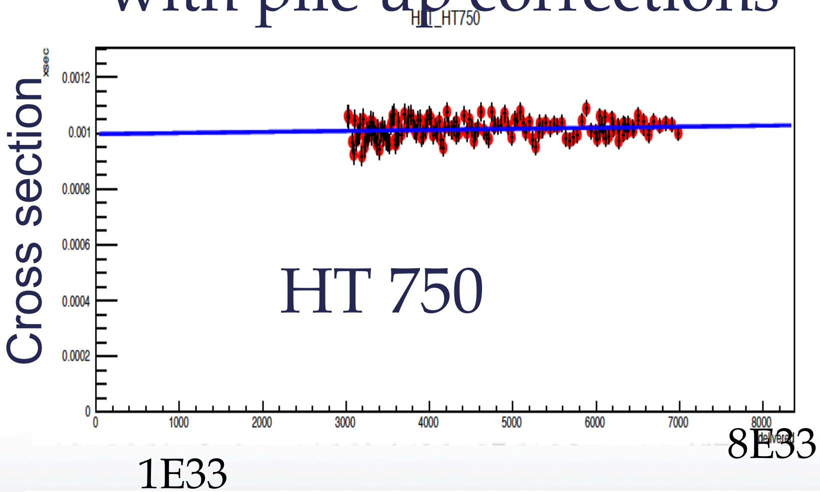
HLT timing vs. Luminosity

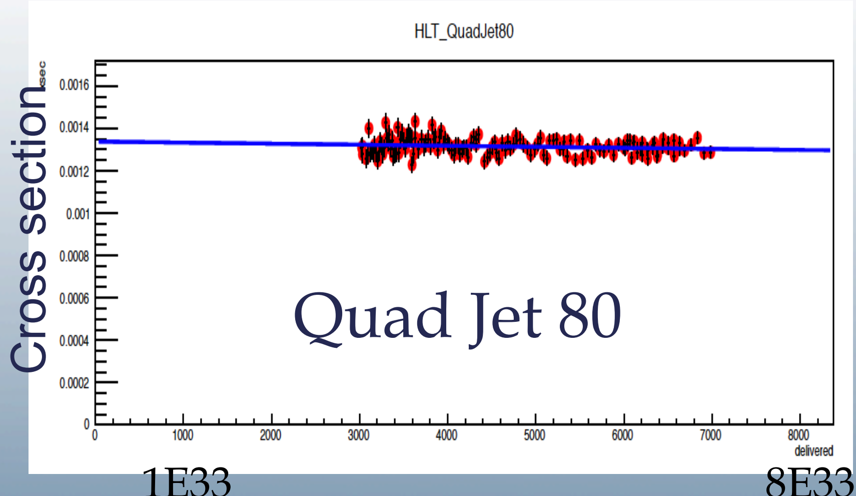


Ideal behaviour = linear increase

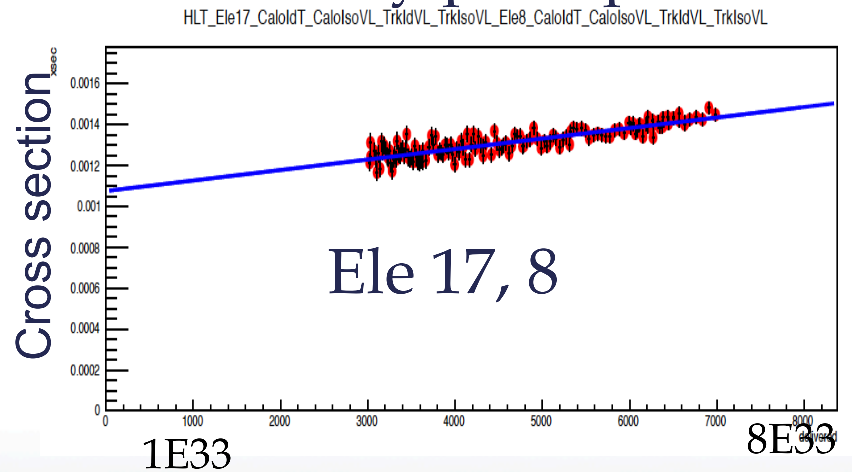
Effect of PU on composite triggers

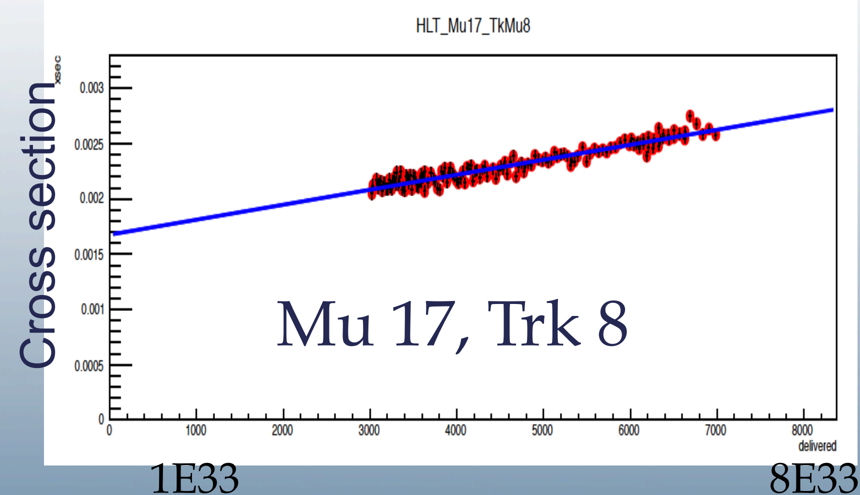
multi object triggers
with pile up corrections



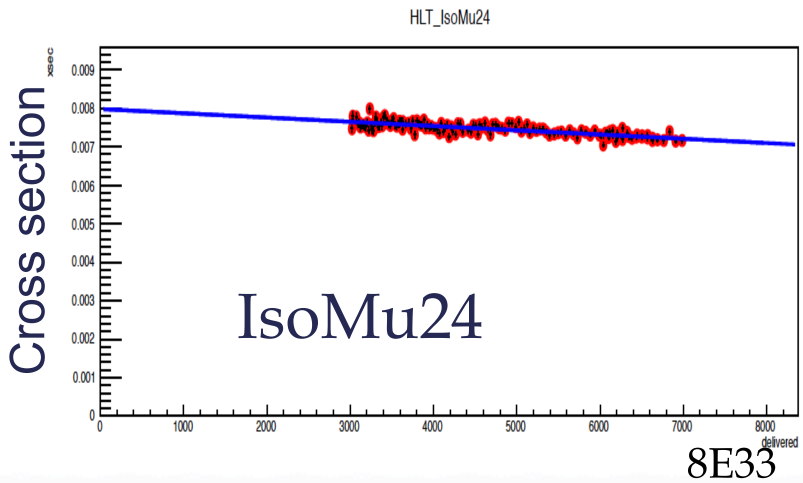


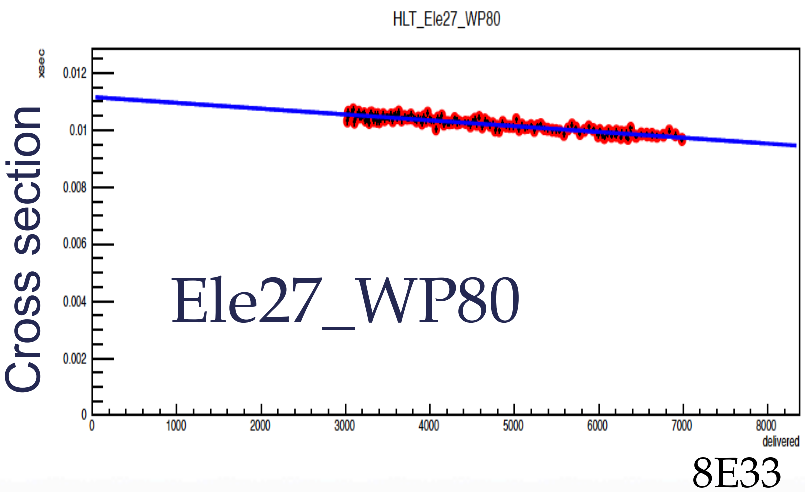
multi object triggers
affected by pile up

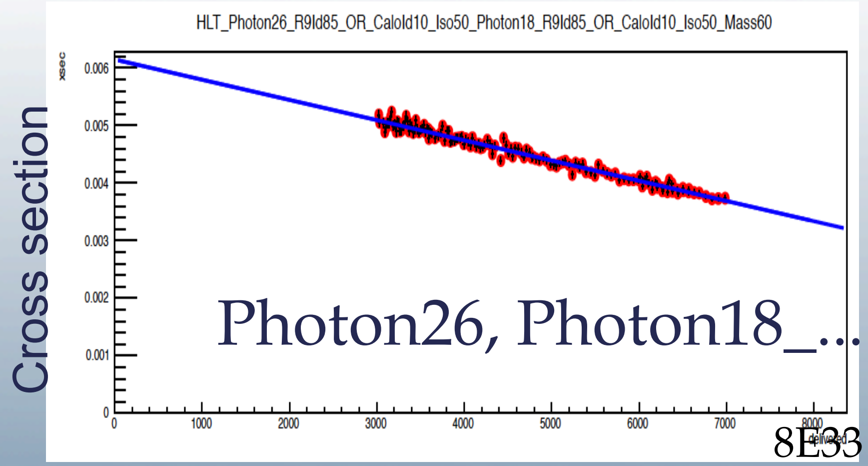




Effect of pile-up on isolation cuts





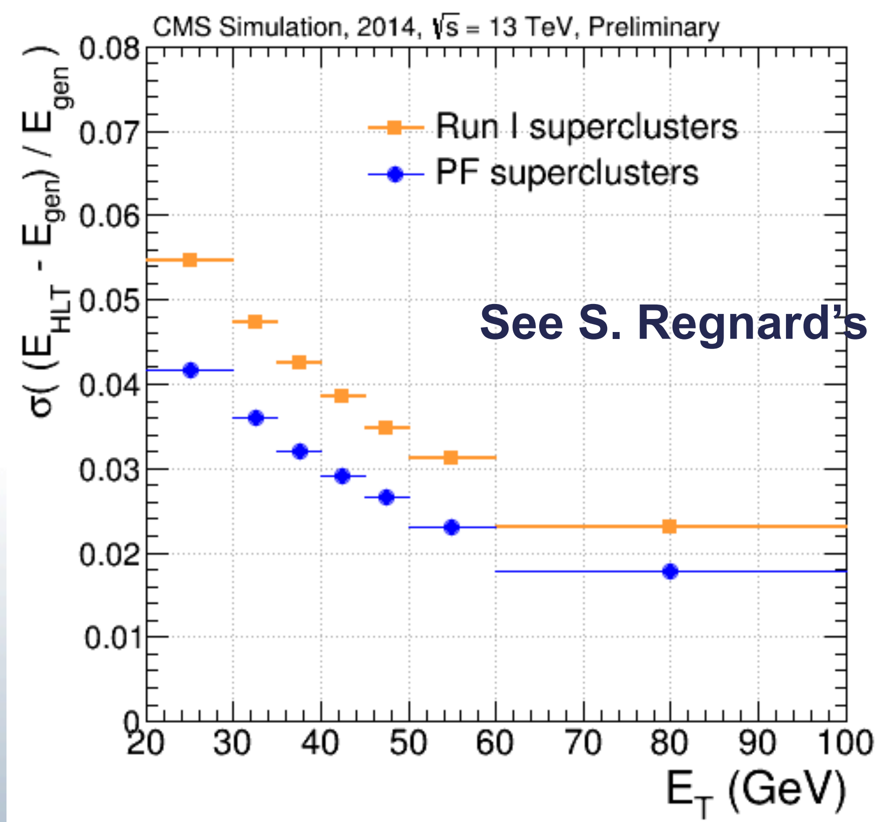


High Level Trigger for 2015

- **double** the HLT rate
  - thanks to the increase in offline storage and processing
  - but we still need an effective **reduction by a factor ~2**
- reduce effective rate by a factor 2, keeping the same physics acceptance
  - make better use of the available bandwidth
    - tighten triggers for signal samples, use dedicated triggers for background samples
  - improve **online reconstruction** and calibrations **to match** even better the **offline** and analysis objects
    - make a wider use of tracking and particle-flow based techniques
    - reduce the difference between online and analysis selection cuts
- increase the available computing power of the HLT farm

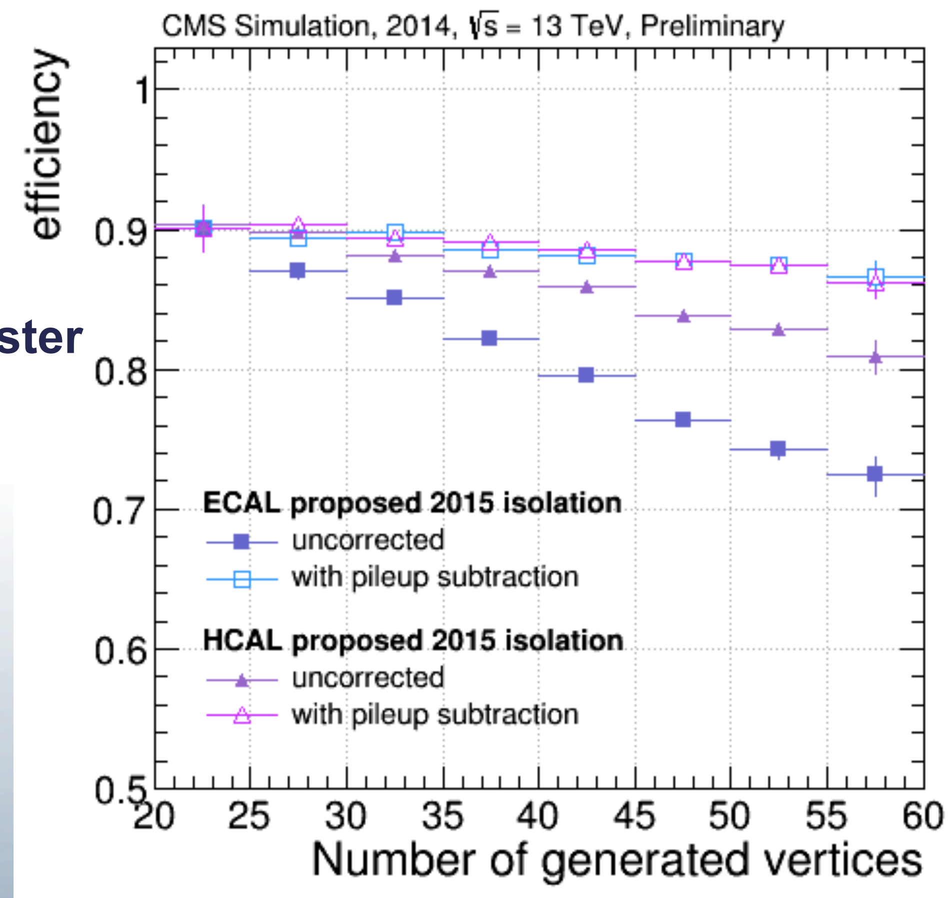
Electron reconstruction for 2015

Using Particle Flow clustering



See S. Regnard's poster

Using Particle Flow Isolation

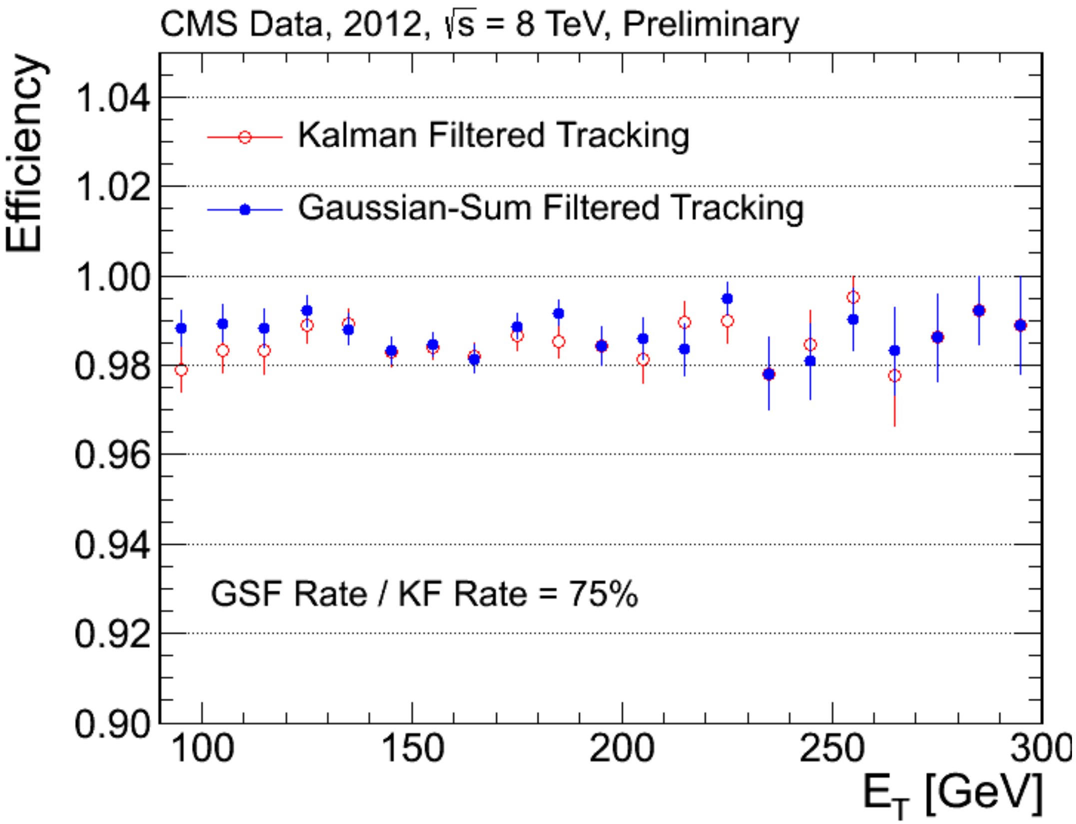


New η dependent calibration, improved resolution, will yield sharper turn-on curves

More efficient isolation allows tighter cuts, and improved background rejection

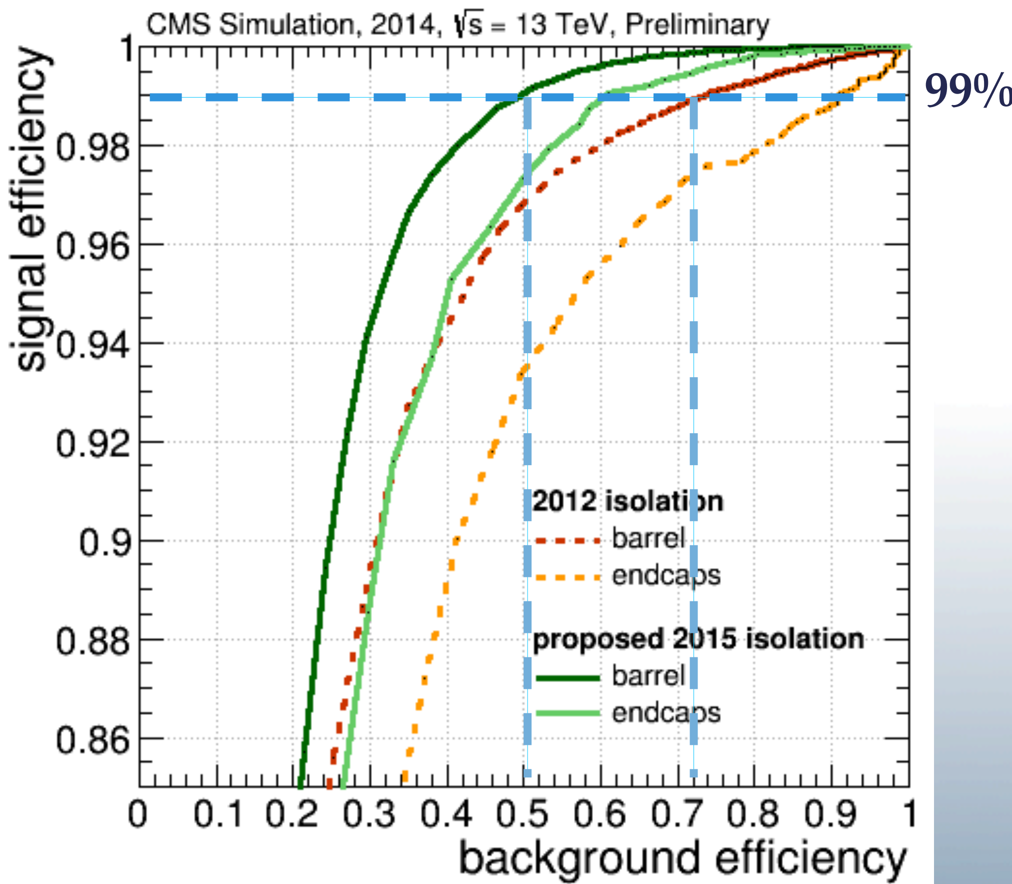
Electron reconstruction for 2015

Tracking : Gaussian Sum Filter



GSF vs KF : 25% rate reduction for same efficiency, non gaussian electron energy loss

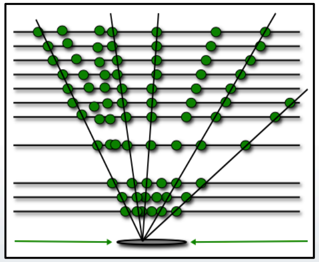
Using Particle Flow Isolation

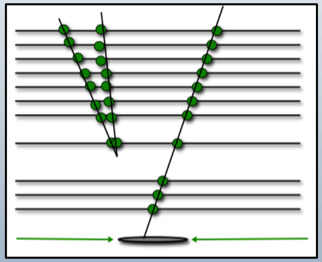


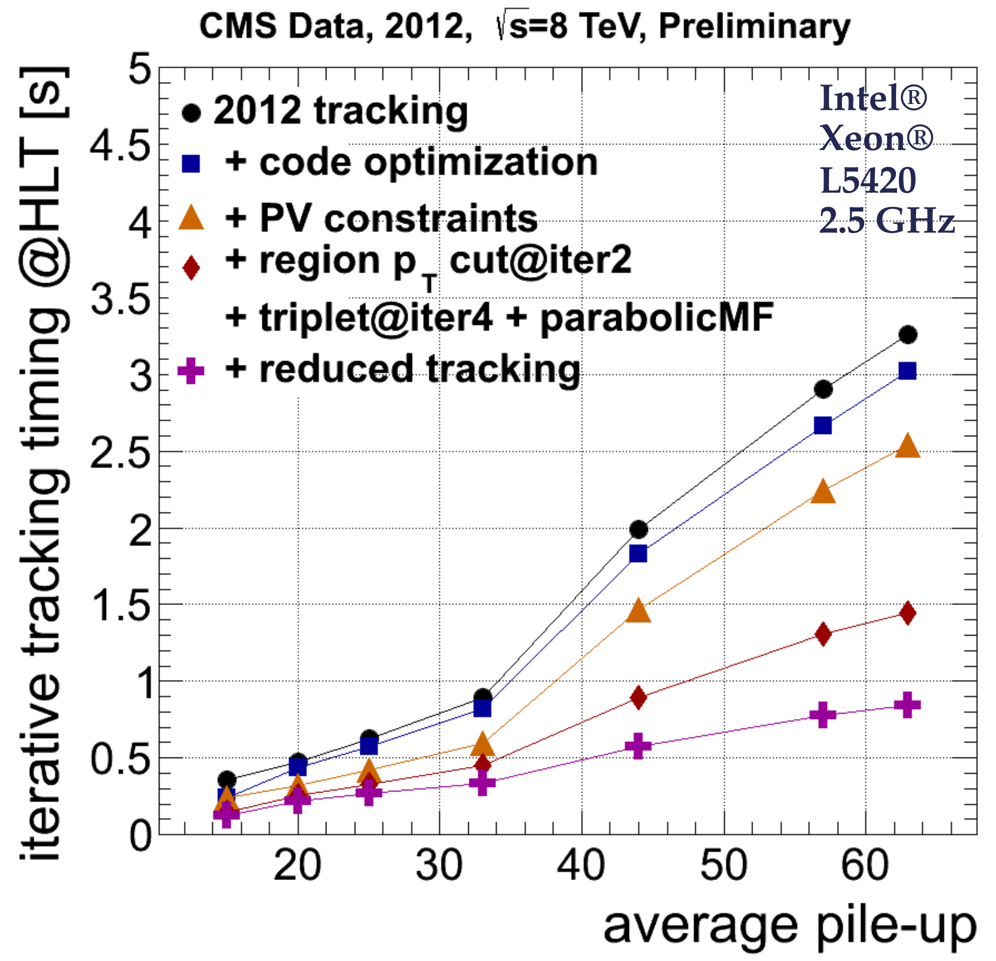
PF isolation : rejection improved by ~30% in barrel for same 99% signal efficiency

Tracking improvements

- **iter0**: prompt tracks <u>high</u> p_T [78%]
- **iter1:** prompt tracks <u>low</u> p_T [15%]
- **iter2:** recover prompt tracks high p_T [5%]







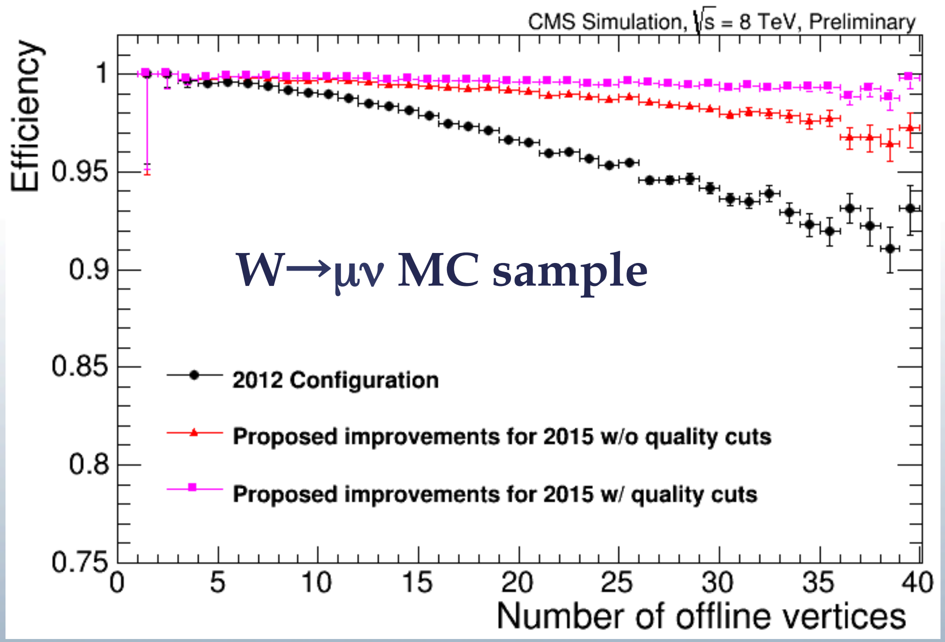
- Only around region of interest
- Primary vertex constraint

tracking : time -75% @PU44

See Mia Tosi's talk in tracking session

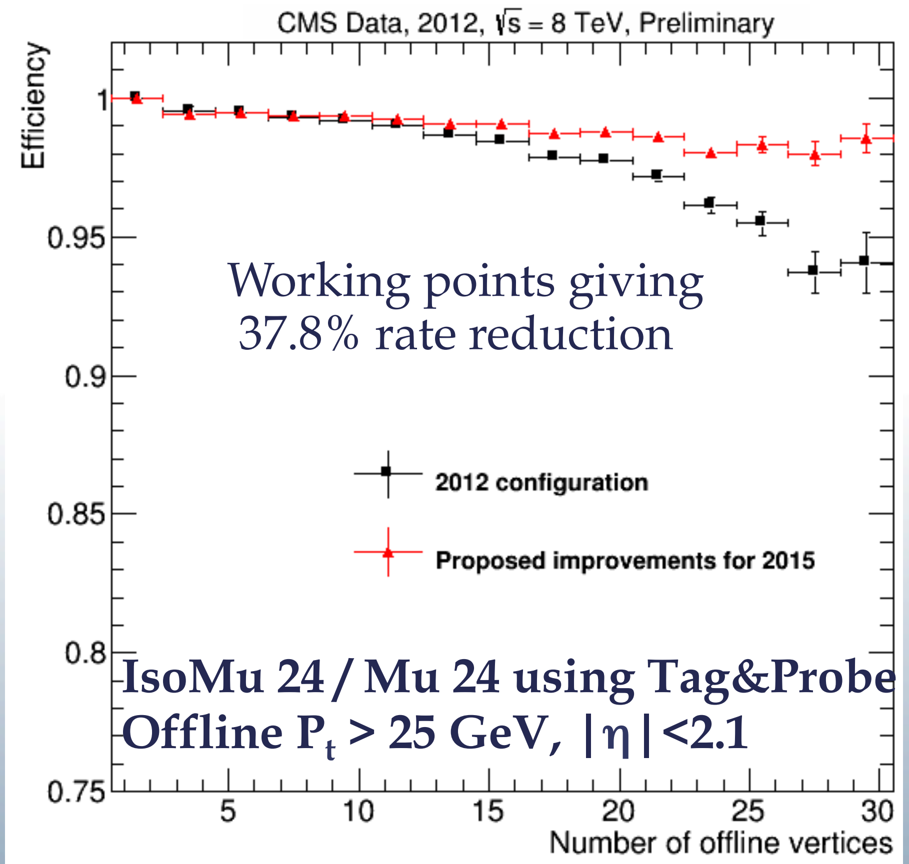
Muon reconstruction for 2015

Muon tracking:
- recovering tracks including outer tracker hit
- Additional recovery using inside-out tracking



Quality cuts:
- Distance to primary vertex
- χ^2/ndof

Muon Isolation:
- Tuned PU subtraction
- Iterative-tracking usage



Processing Time of HLT isolated muon p_t>24GeV/c path: 60% of path 2012 time

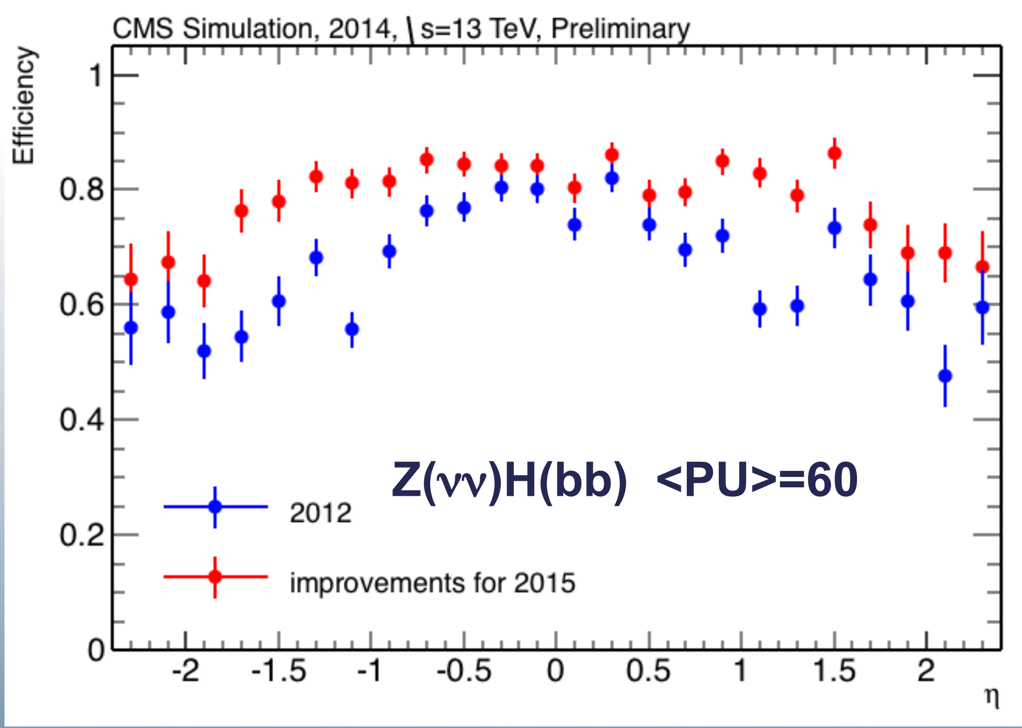
B-tagging Improvements

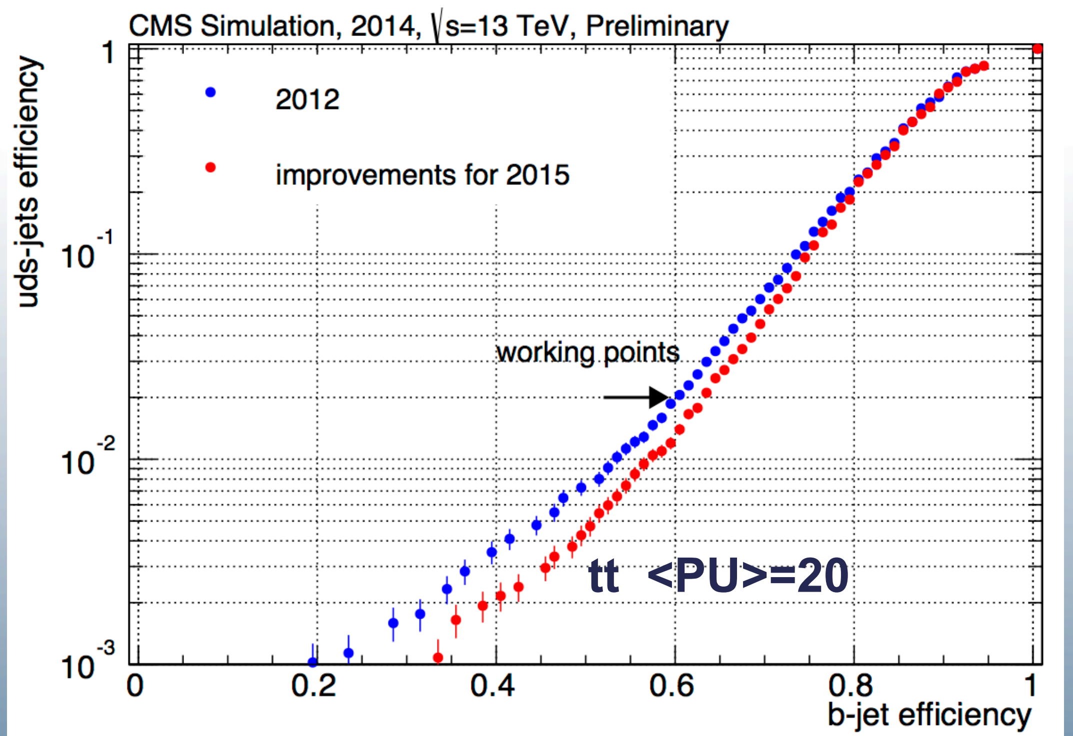
Improved Fast Primary Vertex :

- Regional reconstruction of pixel tracks with η compatible high pt jets
- Efficiency 84→90%
- Time -30%

Improved tracking:

- Iterative tracking using FPV input
- Deterministic annealing PV
- Time : 15% faster
- Increased b-tag efficiency for same light quark rejection





Conclusions

Conclusions

- Trigger issues for physics at high luminosity LHC
  - high instantaneous luminosity means **high rates** and **high pileup**
- L1 trigger
  - **more advanced algorithms**
    - more advanced electronics
    - higher granularity
- High Level Trigger
  - **increase computing power**
    - more advanced offline algorithms used online
    - **take advantage of new developments in processors**
  - higher output rate
- **We are on the right track to meet the challenge !**