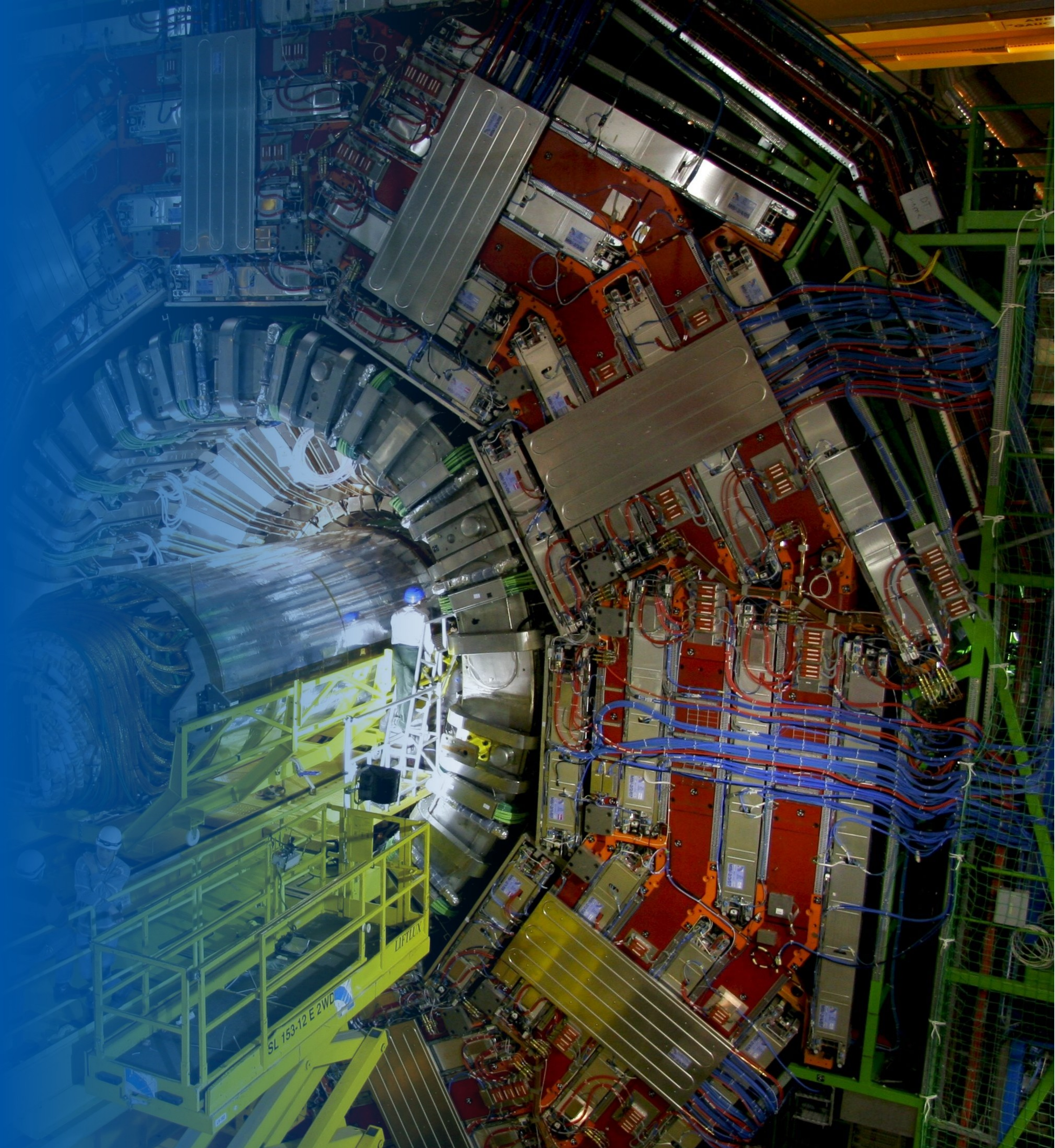


Trigger upgrade

Andrea Bocci - CERN

Evolution of the Trigger constraints

- Run 1: 2010-2012
  - L1T rate limited by detector readout
    - maximum rate: 100 kHz
    - maximum latency: 4 μs

"hard coded" in the readout electronics

  - HLT reconstruction time limited by online farm processing power
    - maximum average time per event:
      - 2010: 50 ms
      - 2011: 100 ms
      - 2012: 180~200 ms

farm extended in 2011 and 2012, improved configuration

  - HLT rate limited by offline resources
    - maximum average rate:
      - 2010-11: 300 Hz
      - 2012: 400 Hz "core" + 600 Hz "parking"

increased offline resources, introduce data parking pre-LS1

- post-LS1: 2015-2016
  - ?
- Phase 2
  - ?

how much do we have to **increase the limits** of the trigger system ?

What we can expect post-LS1

Data taking scenarios

- 2012
  - collision energy: 8 TeV
  - peak instantaneous luminosity: 7.5e33 $cm^{-2}s^{-1}$ @ 50 ns
- post-LS1
  - collision energy: 13 TeV
  - peak instantaneous luminosity: 1.6e34 $cm^{-2}s^{-1}$ @ 25 ns
    or 1e34 $cm^{-2}s^{-1}$ @ 50 ns
- Phase 2 - HL-LHC
  - collision energy: 14 TeV
  - peak instantaneous luminosity: 5e34 $cm^{-2}s^{-1}$ @ 25 ns

Data taking scenarios

- 2012
  - collision energy — 8 TeV
  - peak instantaneous luminosity — 7.5e33 $cm^{-2}s^{-1}$ @ 50 ns — **peak avg. PU ~ 35**
- post-LS1 — **cross-section increase by ~ factor 2**
  - collision energy — 13 TeV
  - peak instantaneous luminosity — 1.6e34 $cm^{-2}s^{-1}$ @ 25 ns — **peak avg. PU ~ 40**

    or — 1e34 $cm^{-2}s^{-1}$ @ 50 ns — **lumi-leveled ? peak avg. PU ~ 50**
- Phase 2 - HL-LHC
  - collision energy — 14 TeV
  - peak instantaneous luminosity — 5e34 $cm^{-2}s^{-1}$ @ 25 ns — **peak avg. PU 125~140**

Data taking scenarios

- 2012
  - collision energy — 8 TeV
  - peak instantaneous luminosity — 7.5e33 $cm^{-2}s^{-1}$ @ 50 ns
- post-LS1
  - collision energy — 13 TeV
  - peak instantaneous luminosity — 1.6e34 $cm^{-2}s^{-1}$ @ 25 ns

    or — 1e34 $cm^{-2}s^{-1}$ @ 50 ns

  expected **trigger rate** roughly **"2012" x4**
- Phase 2 - HL-LHC
  - collision energy — 14 TeV
  - peak instantaneous luminosity — 5e34 $cm^{-2}s^{-1}$ @ 25 ns

  expected **trigger rate** roughly **"2012" x12** *or more*

  –

  plus pile-up dependency

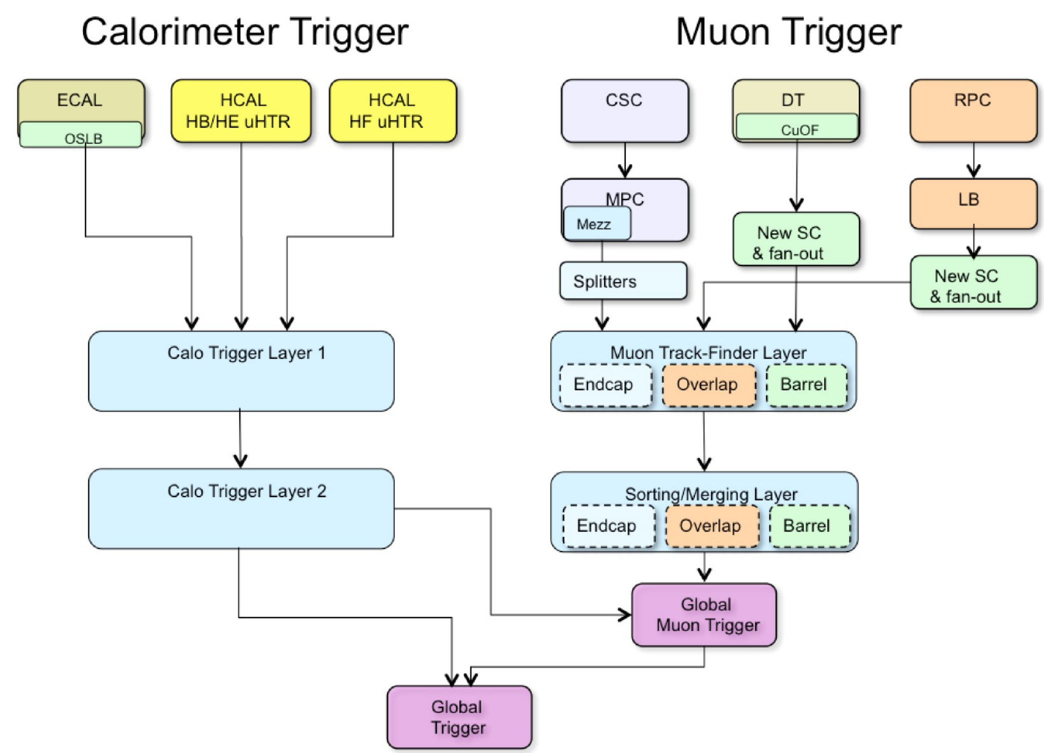
post-LS1

Trigger, post-LS1

- expect ~ **factor 4** in trigger rate increase
  - keeping the same physics acceptance
- **but**
  - L1 Trigger rate is limited by the detector readout
    - fixed at **100 kHz**
  - HLT rate is limited by the offline processing power
    - for 2015, expect to be able to cope with an average HLT rate of **1 kHz**
- how can we deal with it ?
  - improve the trigger selection
  - both for L1T and HLT

L1 Trigger upgrade for Phase 1

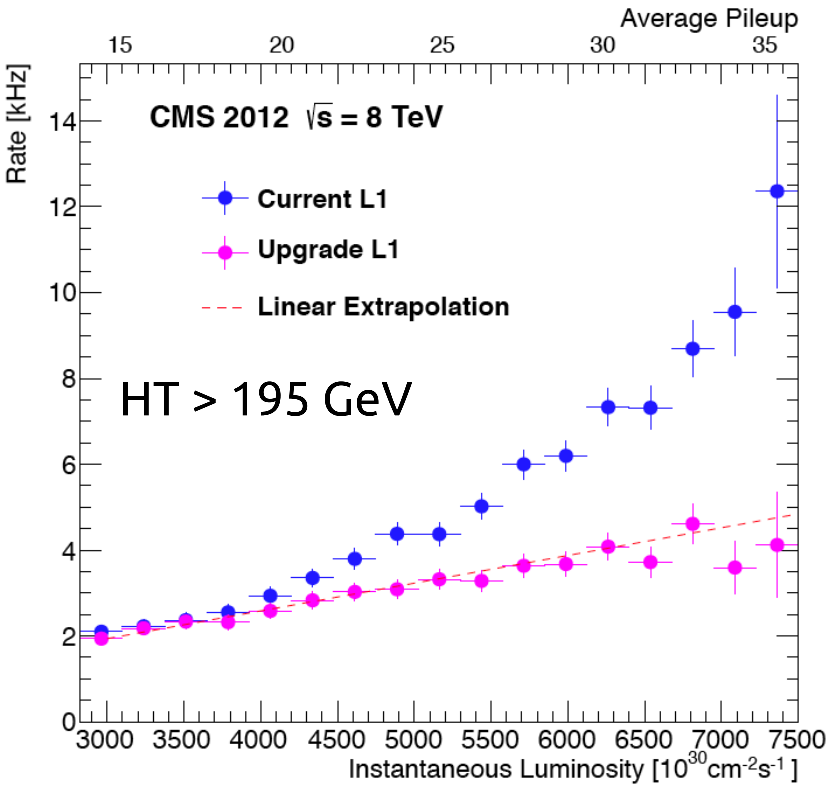
- replace the calorimeter, muon, and global trigger
- staged approach
  - first stage installed during LS1, and available in 2015
  - full upgrade commissioned during 2015, and available in 2016

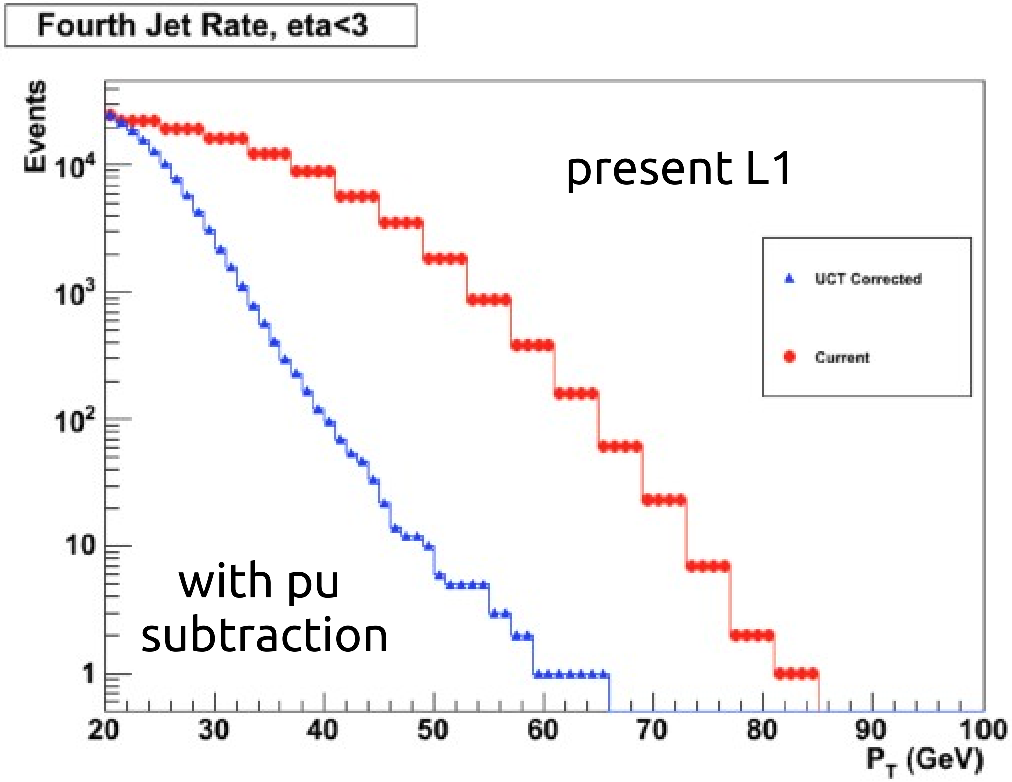


L1 Trigger upgrade for Phase 1

- 2015 - Stage 1
  - improved calorimetric trigger
    - pile-up subtraction
      - for jets, energy sums, e/gamma isolation
    - dedicated taus trigger candidates
      - from 2x1 EG object without E/H cut
  - minor improvements to the muon trigger
    - make use of new muon chambers
    - increased granularity of the CSC readout
    - possibility to improve the LUTs used for track building and matching

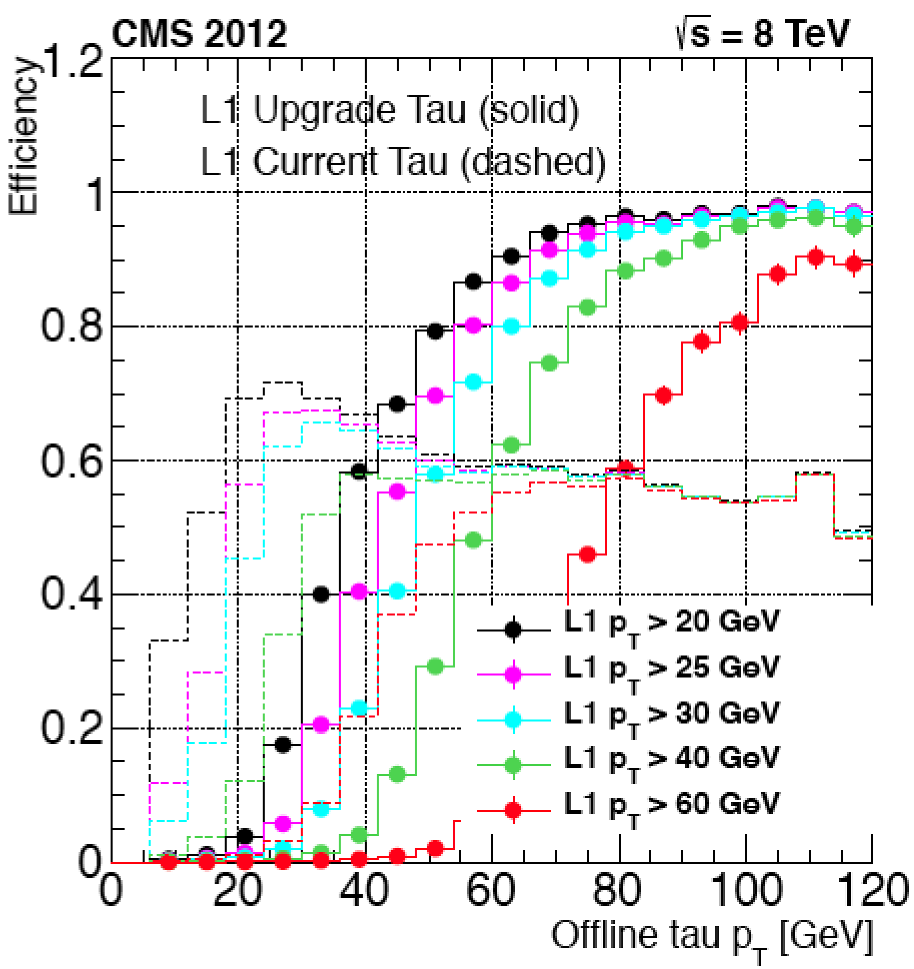
PU subtraction at L1

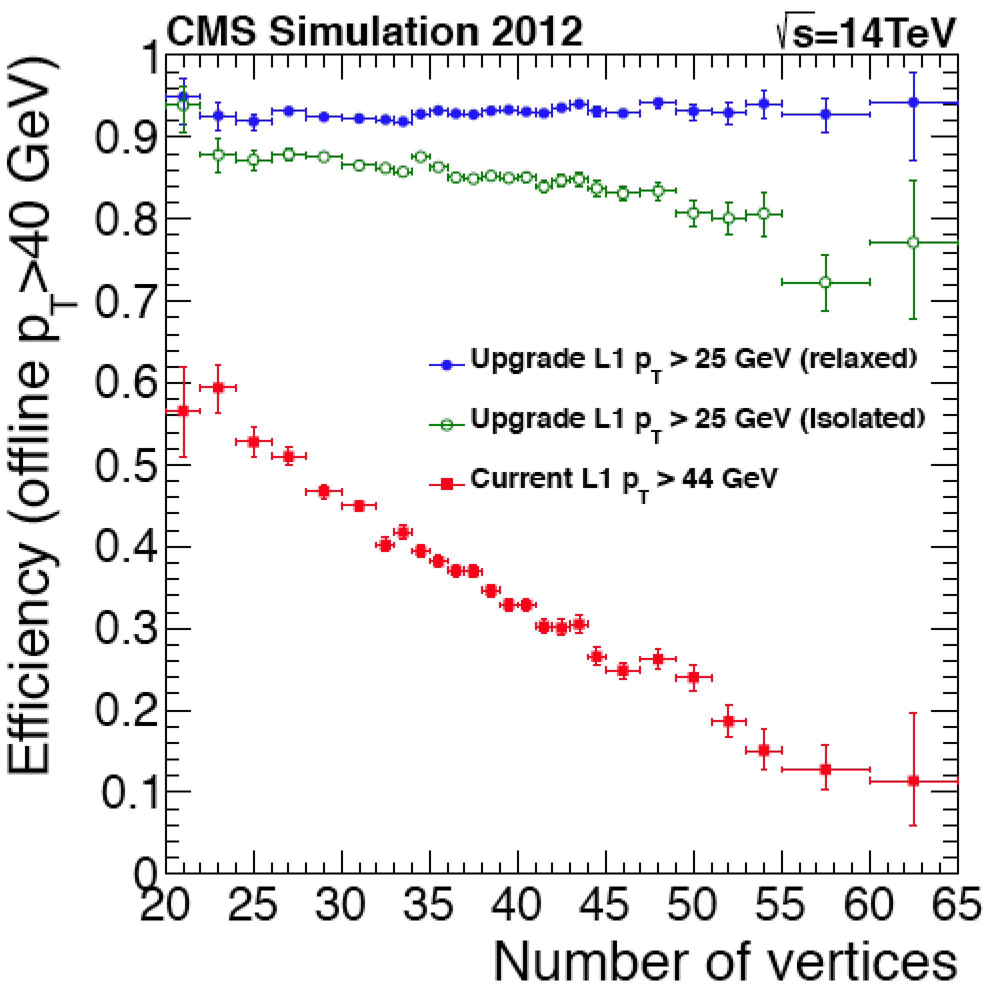




effect of pile-up subtraction on energy sums and multi-jet trigger

Tau L1 Trigger



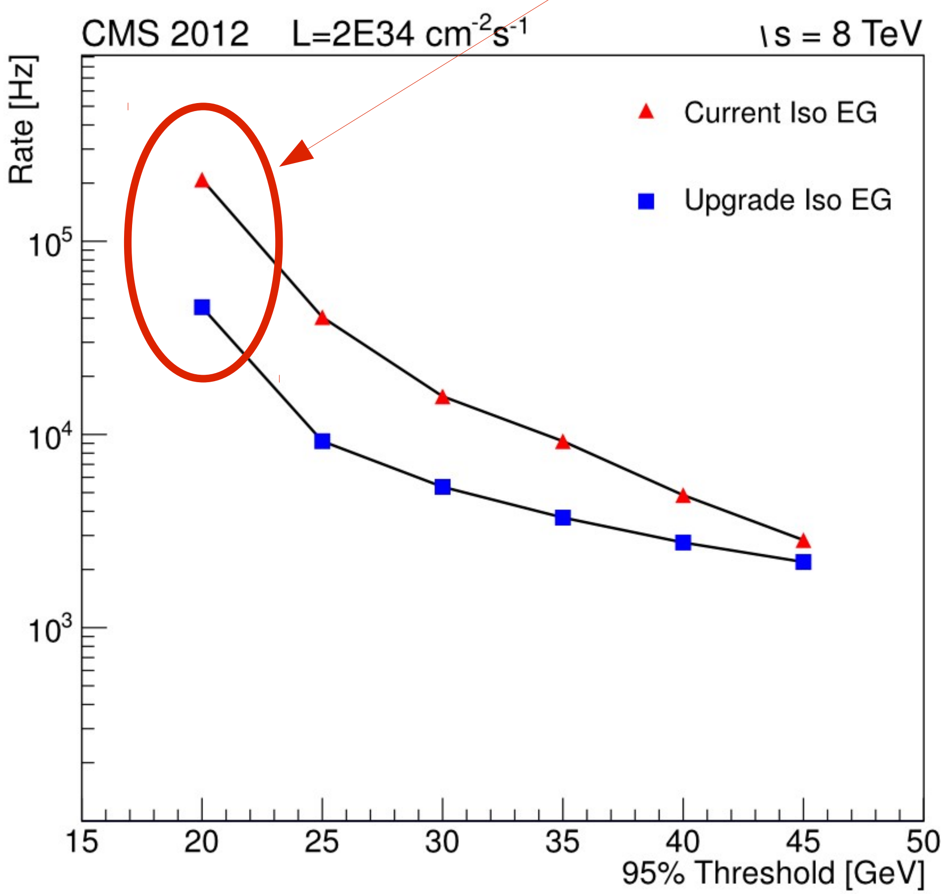


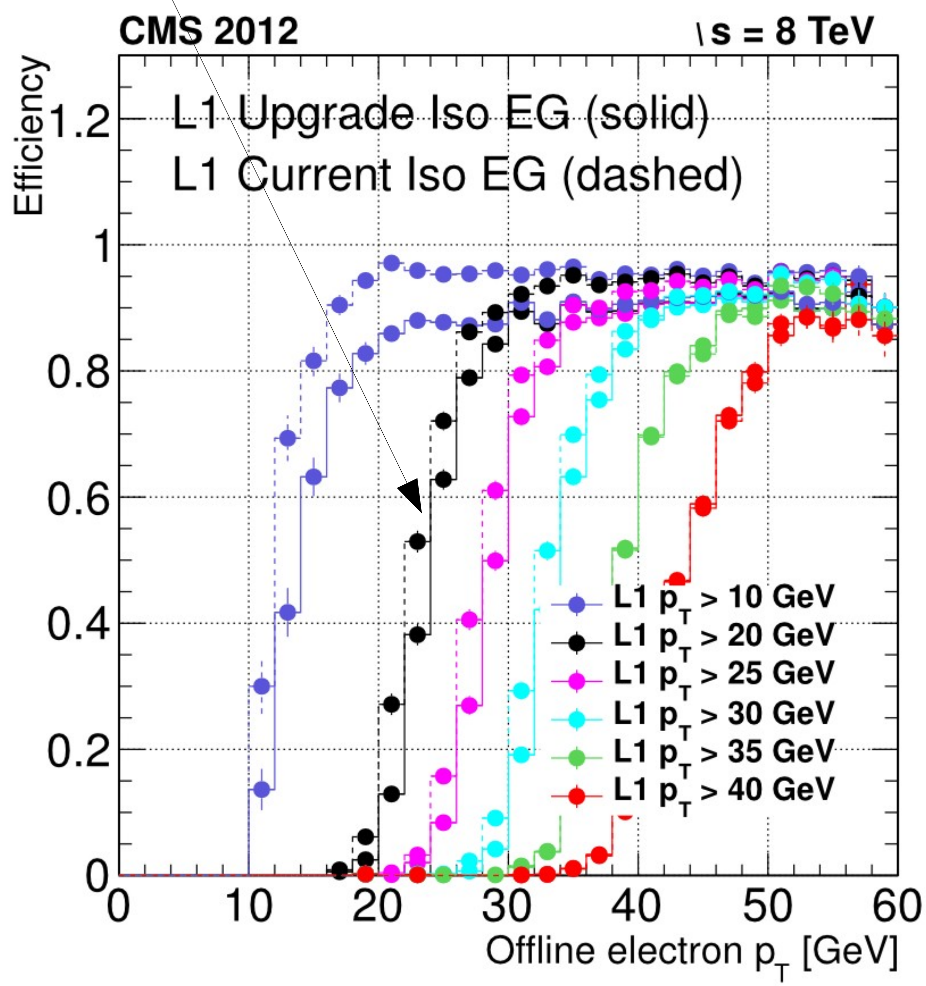
performance of upgraded L1 tau trigger

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

E/gamma L1 Trigger

rate reduction by a **factor 5**, with a **similar** efficiency



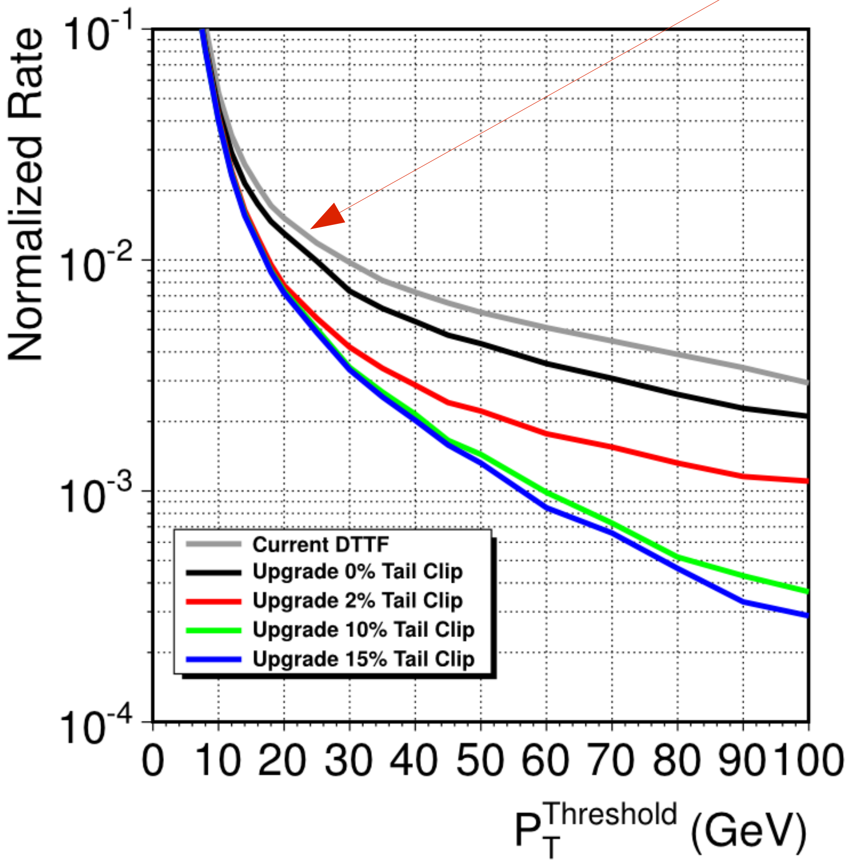


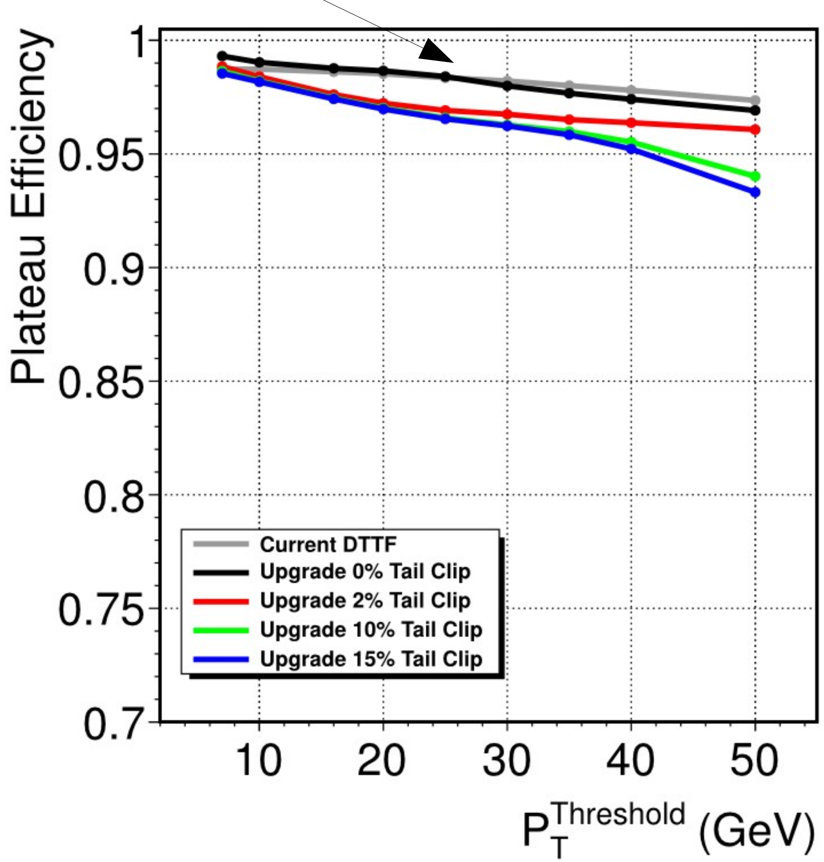
L1 Trigger upgrade for Phase 1

- 2016 - Stage 2
  - new muon trigger
    - unified track finder
      - replace DTTF, CSCTS, RPC pattern comparator
      - more powerful track reconstruction
    - muon isolation
  - new calorimetric trigger
    - increased granularity
      - tower-based isolation
  - new Global Trigger
    - increased number of candidates (at least twice as much as now)
    - more powerful logic, improved resolution
    - support for more complex topologies (soft muon b-tagging, VBF jets, …)

Muon L1 Trigger

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

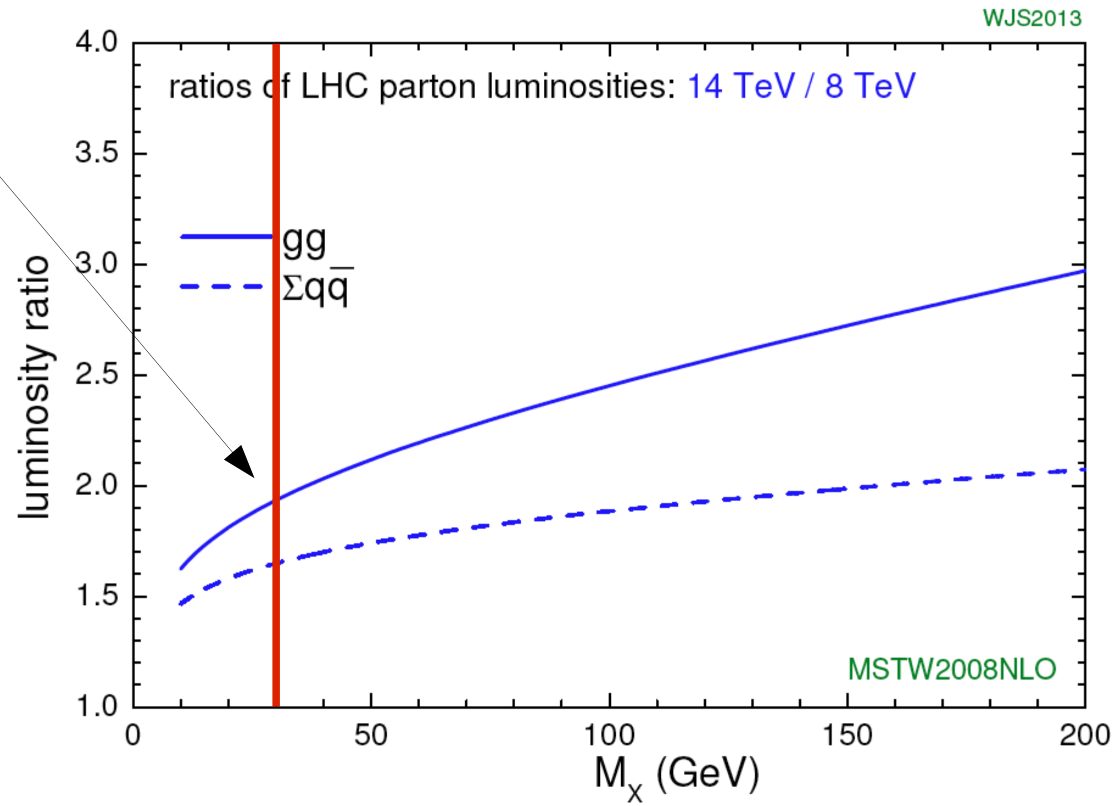




new muon pT assignment (bigger LUTs, post-processing)

High Level Trigger for 2015

- run at 13 TeV
  - the higher collision energy leads to a higher cross-section
  - for the average HLT-accepted events, we expect an increase by **a factor ~ 2**

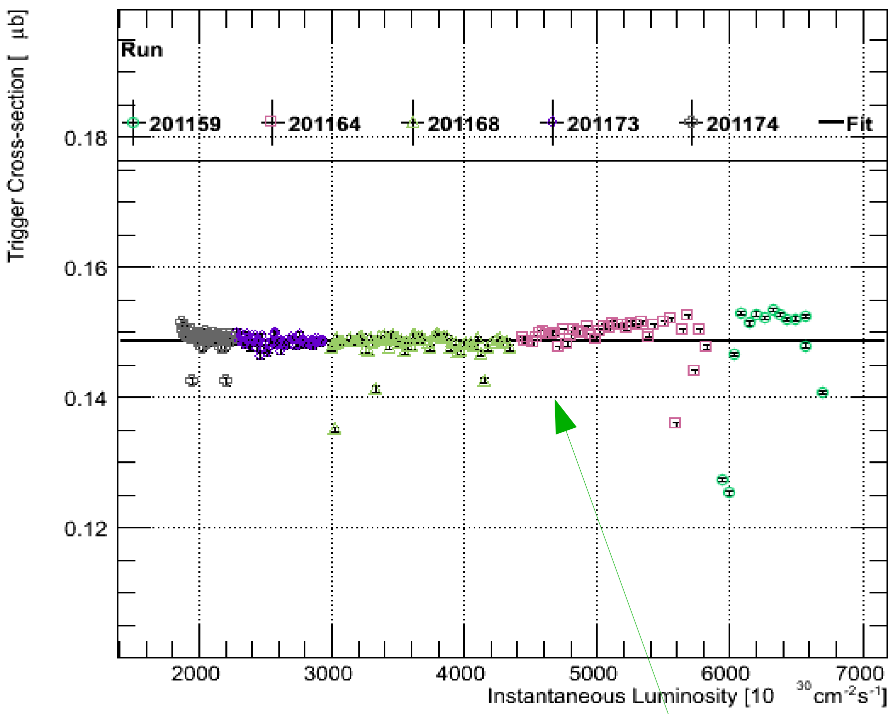


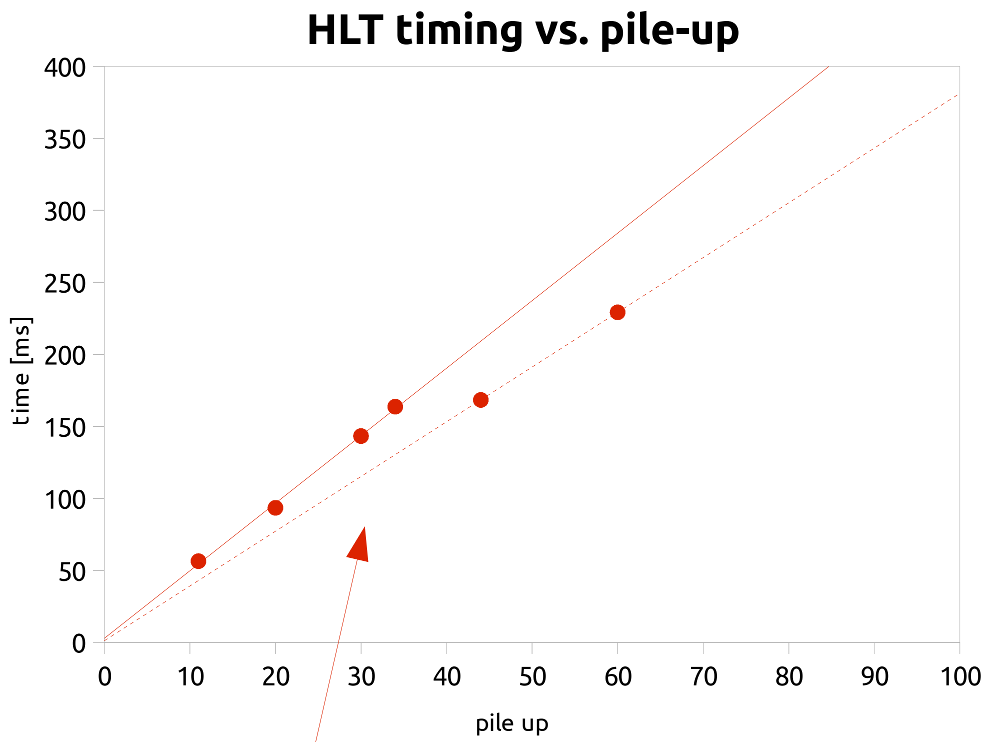
High Level Trigger for 2015

- run at 13 TeV
  - the higher collision energy leads to a higher cross-section
  - for the average HLT-accepted events, we expect an increase by **a factor ~ 2**

- higher luminosity: 1.6e34 $cm^{-2}s^{-1}$ …
  - **a factor ~2** higher than the peak luminosity in 2012
  - similar pile-up
  - overall, **a factor ~4** increase in the expected HLT rate

High Level Trigger for 2015





- … and pile-up
  - maximum average pu ~ 40, close to the 2012 value (~35)
  - overall HLT rate is **robust** against pile-up
  - but the HLT cpu usage increases **linearly** with pile-up

High Level Trigger for 2015

- plans
  - **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
    - between **+30%** and **+100%**
    - to cope with **higher pile-up** and **more complex reconstruction** code

Phase 2

Trigger upgrade for Phase 2

- scenario for Phase 2 (HL-LHC)
  - even higher luminosity (and pile-up)
    - instantaneous luminosity: 5e34 $cm^{-2}s^{-1}$
    - peak pile-up: 125 ~ 140 interactions / event
  - target: **keep the same physics acceptance as in 2012**

- the trigger system from Phase 1 **cannot cope** with such high luminosity

- upgrade L1 Trigger
  - **higher rate** and latency
  - tracking trigger
  - full calorimeter granularity

- upgrade High Level Trigger
  - **higher rate**
  - more processing power
  - alternative processors

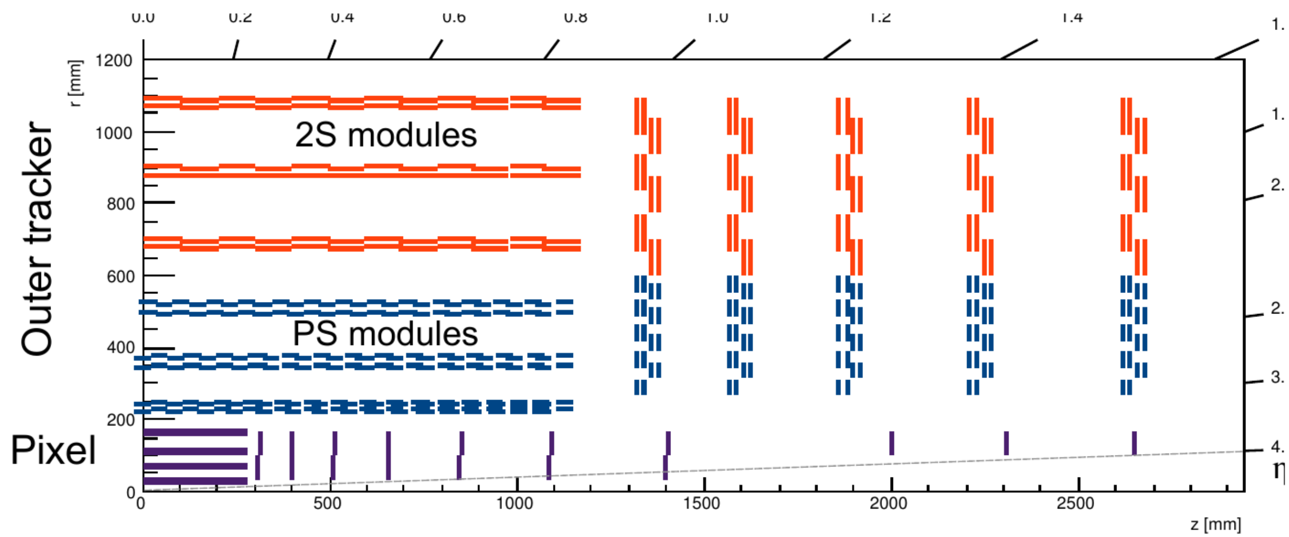
L1 Trigger upgrade for Phase 2

- higher rate and latency
  - the Level 1 Trigger rate and latency are limited by the front-end electronics of the detector
    - upgrade the electronics to support a higher rate and latency
  - increase the L1 Trigger rate from **100 kHz** to **500 kHz** … **1 MHz**
  - increase the L1 Trigger latency from **4 µs** to **10 µs**
    - requires replacing the ECAL barrel electronics
    - to go even higher, would need to replace the CSC electronics

- why ?
  - **rate** – increasing the readout rate, and thus the L1 trigger rate, is the easiest way to keep lower L1 thrsholds
    - especially for jets, tracking trigger (next slide) mostly helps for leptons
  - **latency** – higher latency gives the L1 more time to process the data
    - necessary for tracking trigger

Tracking Trigger

- the upgraded silicon strip tracker is being designed with triggering capabilities
- layers are composed by pair of modules …

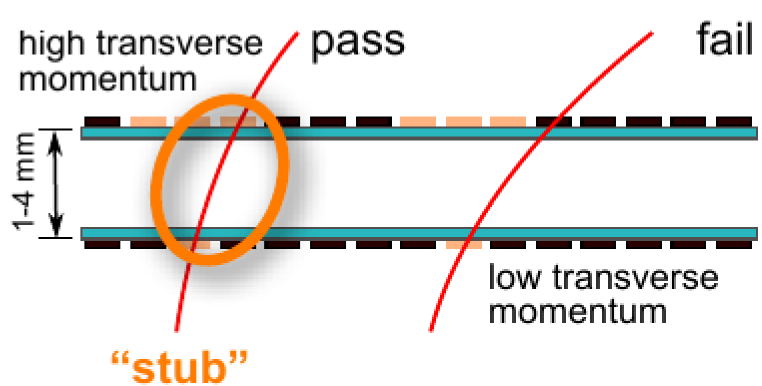


- … able to distinguish **high p_T** and **low p_T** and tracks

high p_T track (> 2 GeV)

small bending arm

the 2 hits are **inside** the coincidence window



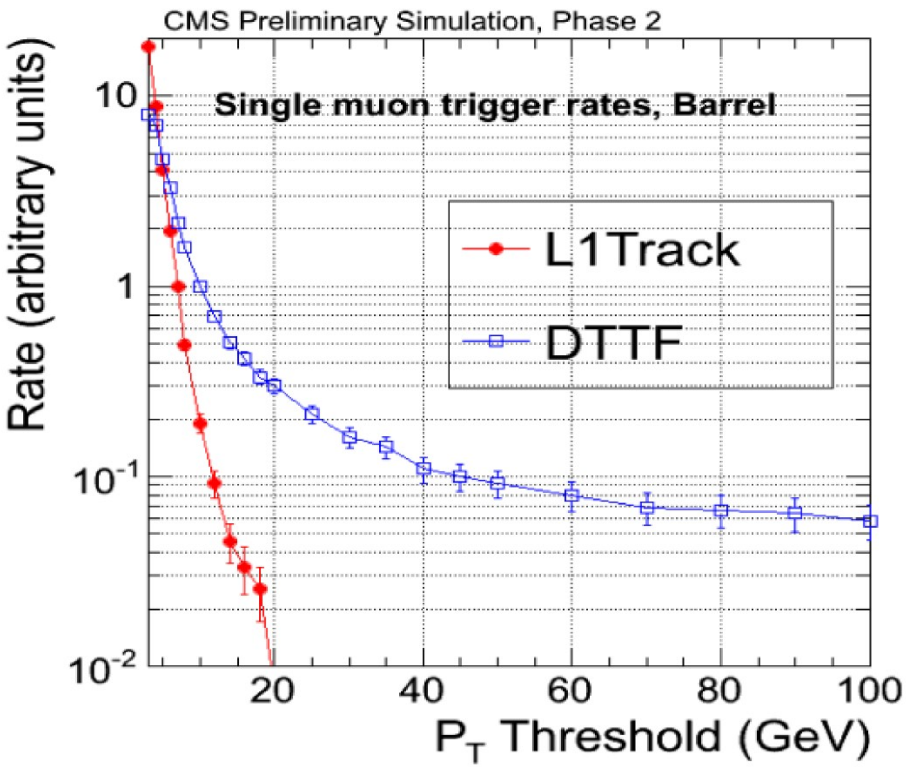
low p_T track (< 2 GeV)

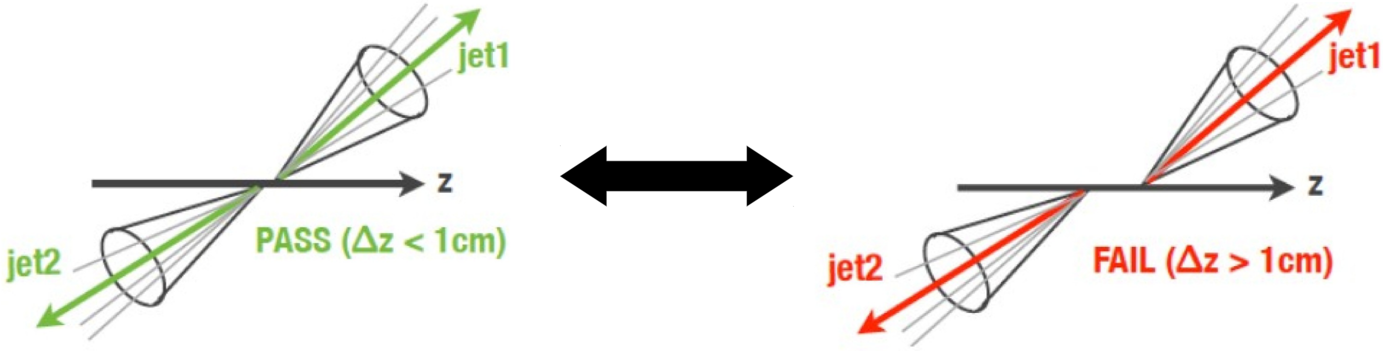
large bending arm

the 2 hits are **outside** the coincidence window

Tracking Trigger

- How is a tracking trigger useful ?
  - improve reconstruction at L1
    - combine tracks with standalone muons for a better pT resolution
    - recover rejection power at lower pT threshold
    - tracker-based isolation
    - combine tracks with e/gamma deposits → electrons
  - dZ vertex matching between objects
    - reject combinatorics due to pile-up





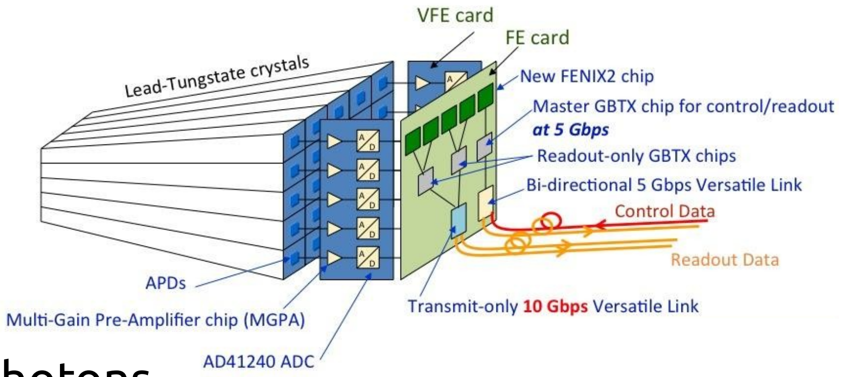
Tracking Trigger

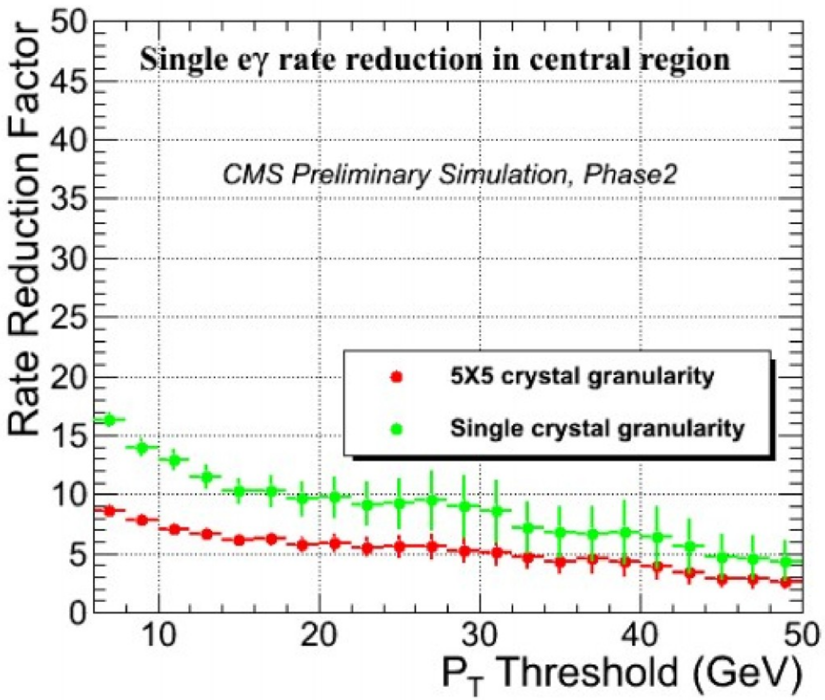
- first studies on the impact of a tracking trigger:

Trigger, Threshold	Algorithm	Rate reduction	Full eff. at the plateau	Comments
Single Muon, 20 GeV	Improved Pt, via track matching	~ 13 (central region)	~ 90 %	Tracker isolation may help further.
Single Electron, 20 GeV	Match with cluster	> 6 (current granularity) >10 (crystal granularity) ($\mid \eta \mid < 1$)	90 %	Tracker isolation can bring an additional factor of up to 2.
Single Tau, 40 GeV	CaloTau – track matching + tracker isolation	O(5)	O(50 %) (for 3-prong decays)	Very preliminary. Work in progress.
Single Photon, 20 GeV	Tracker isolation	40 %	90 %	Probably hard to do much better.
Multi-jets, HT	Require that jets come from the same vertex			Performances depend a lot on the trigger & threshold.

ECAL upgrade and L1 Trigger

- the present L1 Trigger reads the electromagnetic calorimeter with a **limited granularity**
  - trigger towers, made out of 5x5 crystals
- replace ECAL barrel electronics
  - read the ECAL with **full granularity**
  - improve spike rejection
  - improve spacial resolution for electrons and photons



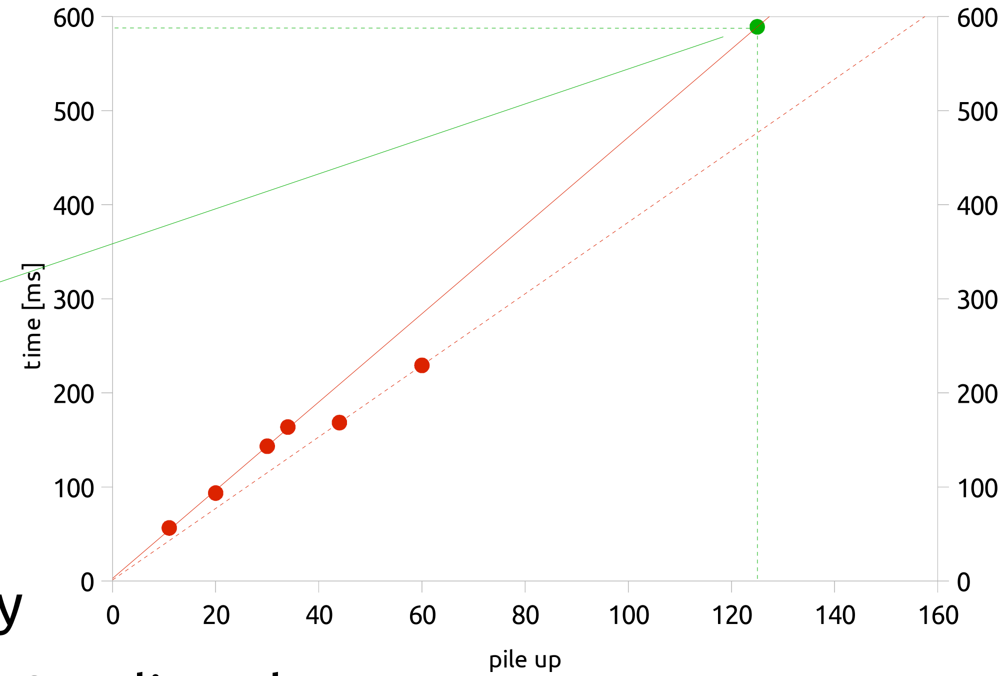


- combined with tracking trigger
  - reduce electron rate by O(10)
- new electronics needed for 10 us latency

High Level Trigger for Phase 2

- increase the output rate
  → **5 ~ 10 kHz** @ 5e34 $cm^{-2}s^{-1}$

- increase the cpu power
  - linear extrapolation
    → **600 ms/ev.** @ 5e34 $cm^{-2}s^{-1}$
  - **5~10x** increase in input rate
  - **1.5x** due to higher collision energy
    → factor ~ 50x with respect to 2012 online cluster



- "possible"
  - assuming **20% / year** increase in processing power
  - 10 years from now → **x6** increase

High Level Trigger for Phase 2

- can we take advantage of other improvements ?
  - L1 tracking trigger
    - access to L1 tracklets: can be used to seed the HLT tracking
    - no need to redo a similar step → substantial saving in cpu
  - parallel processors
    - GPUs, Xeon Phi, ARM, …
    - HLT relies on the same software used offline
      - if CMS develops its software for one of these architecture, the HLT farm could easily take advantage of it

Conclusions

Conclusions

- Phase 1
  - "*closer than you may think*"
    - this is no longer considered an "upgrade", it's simply the **next Run** !
  - upgrade and optimisations of the existing systems
    - L1 and HLT are under heavy development

- Phase 2
  - 10 years from now - 10 years of work ahead of us :-)
    - large changes to the trigger system
  - work has already started
    - **contributions are welcome** !