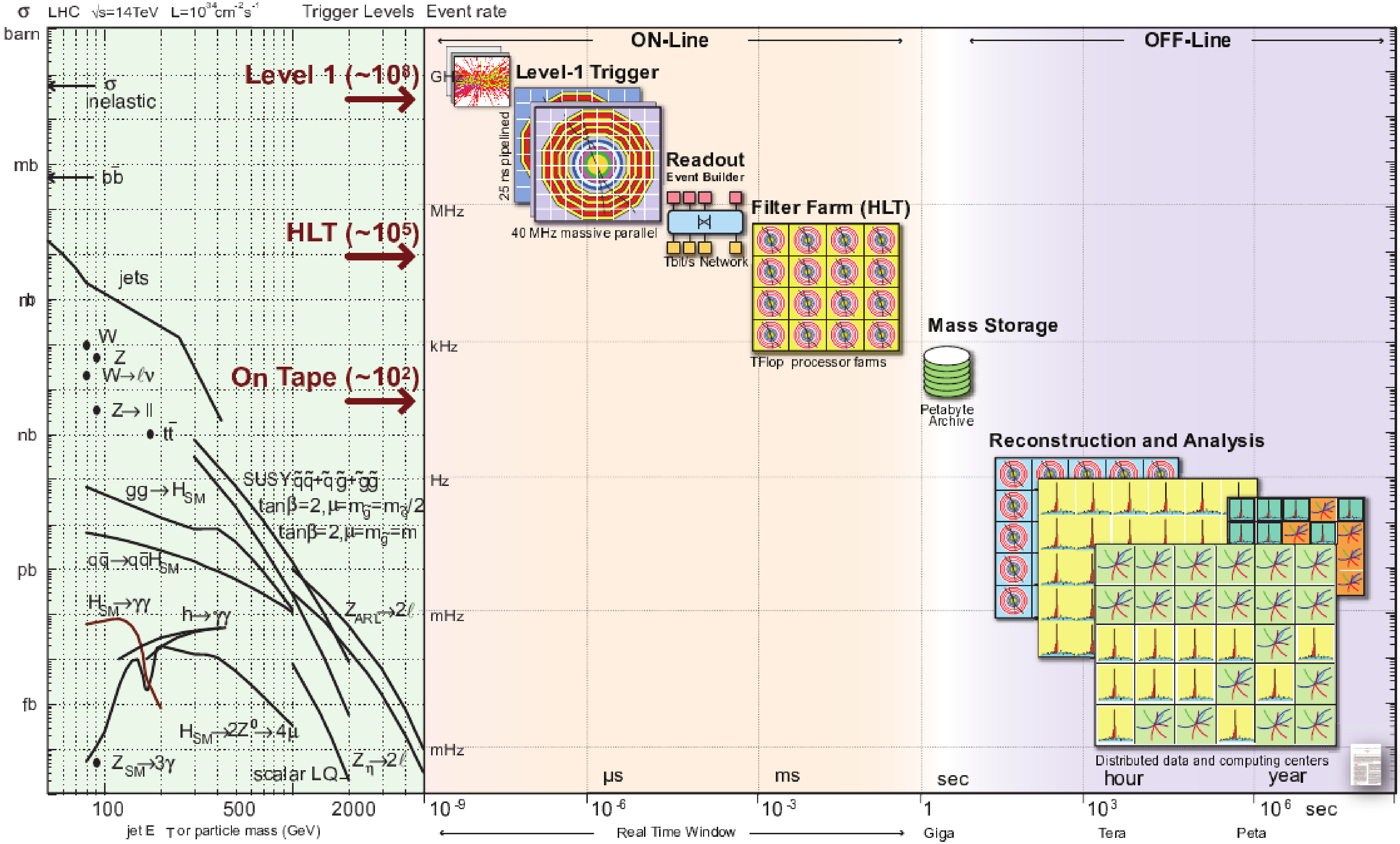
Introduction to CMS:
Data acquisition and trigger

Andrea Bocci

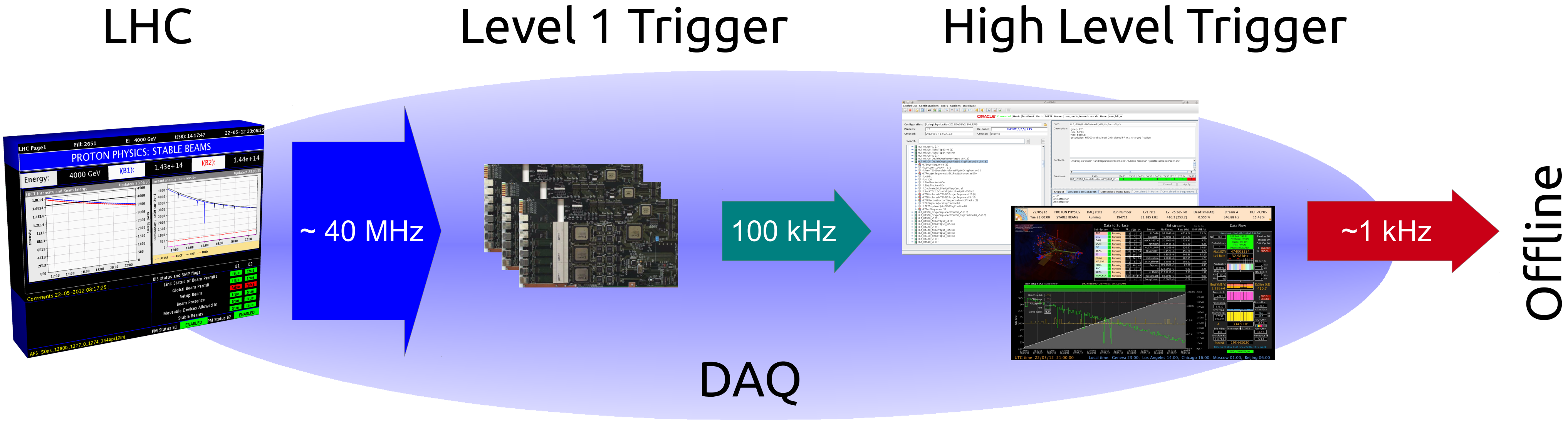
Triggering – why ?



CMS trigger system

- the role of the trigger is to
  - reduce the event rate from the LHC collision rate (**~ 40 MHz**) to what can be stored and analysed offline (**~ 1 kHz**)
  - while keeping the **physics reach** of the experiment

- CMS has been designed with a 2-level trigger system



LHC

Level 1 Trigger

High Level Trigger

~ 40 MHz

100 kHz

~1 kHz

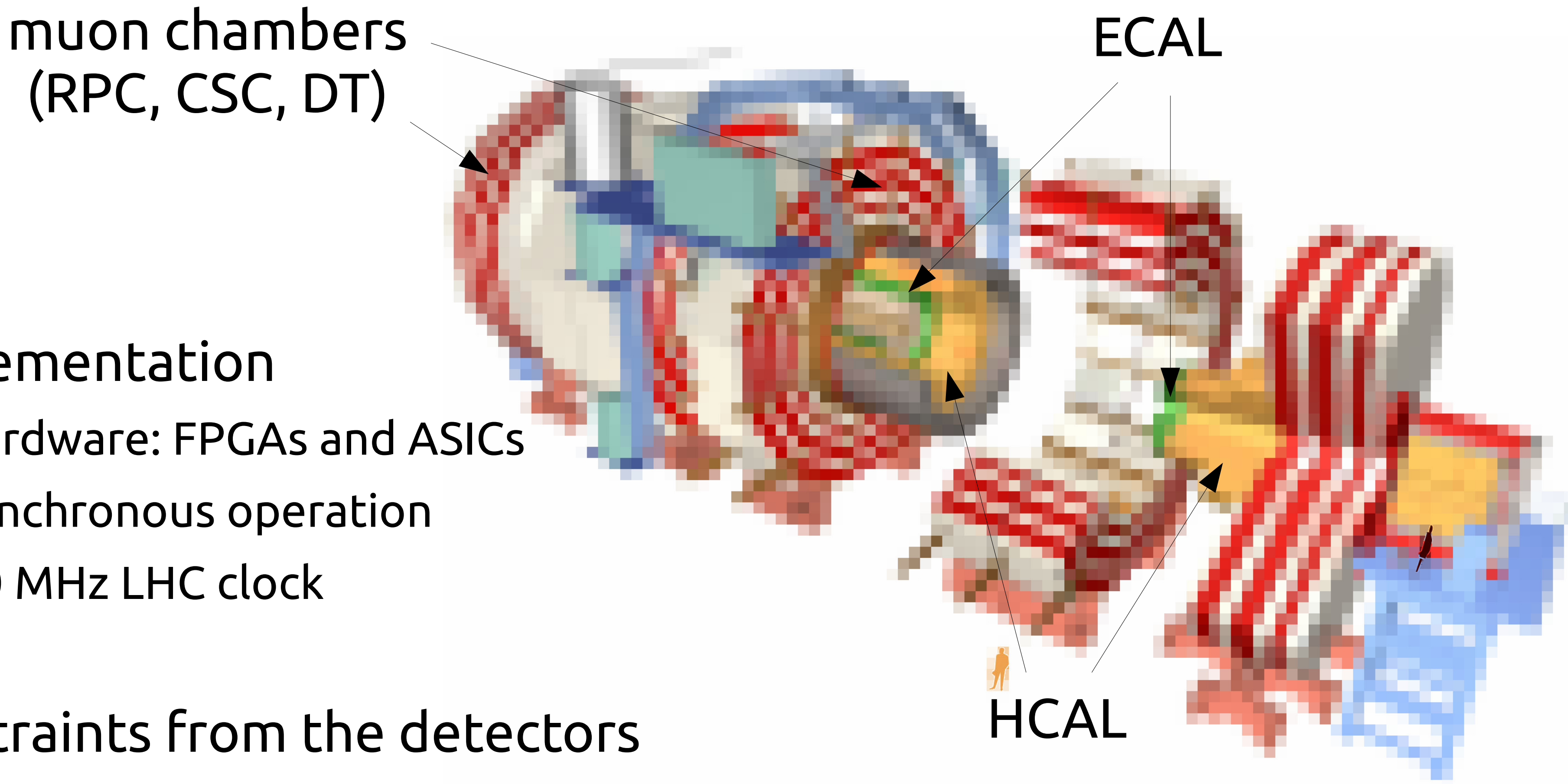
Offline

DAQ

Level 1 Trigger

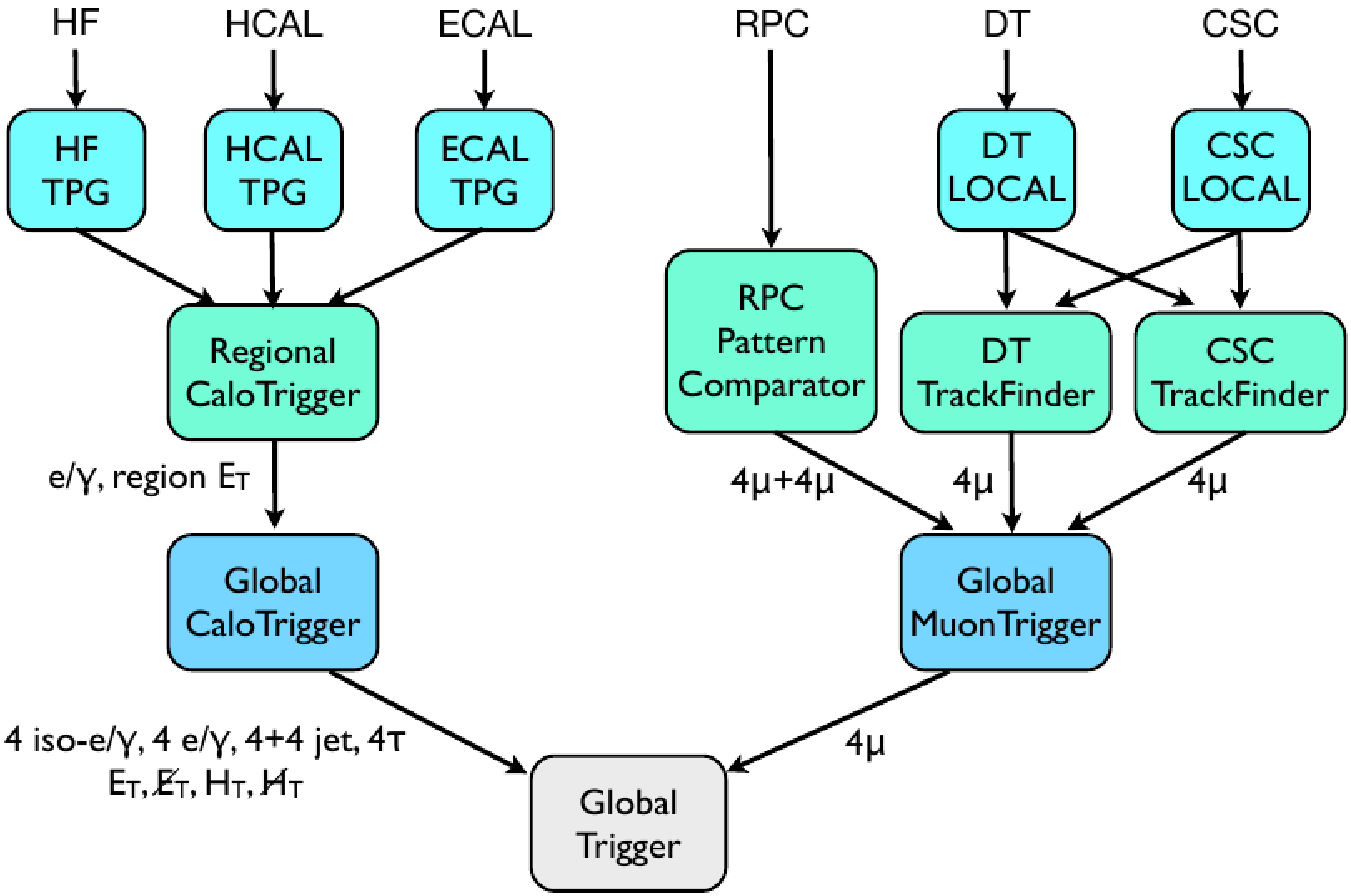
Level 1 Trigger

- fast readout of the detector, with a limited granularity

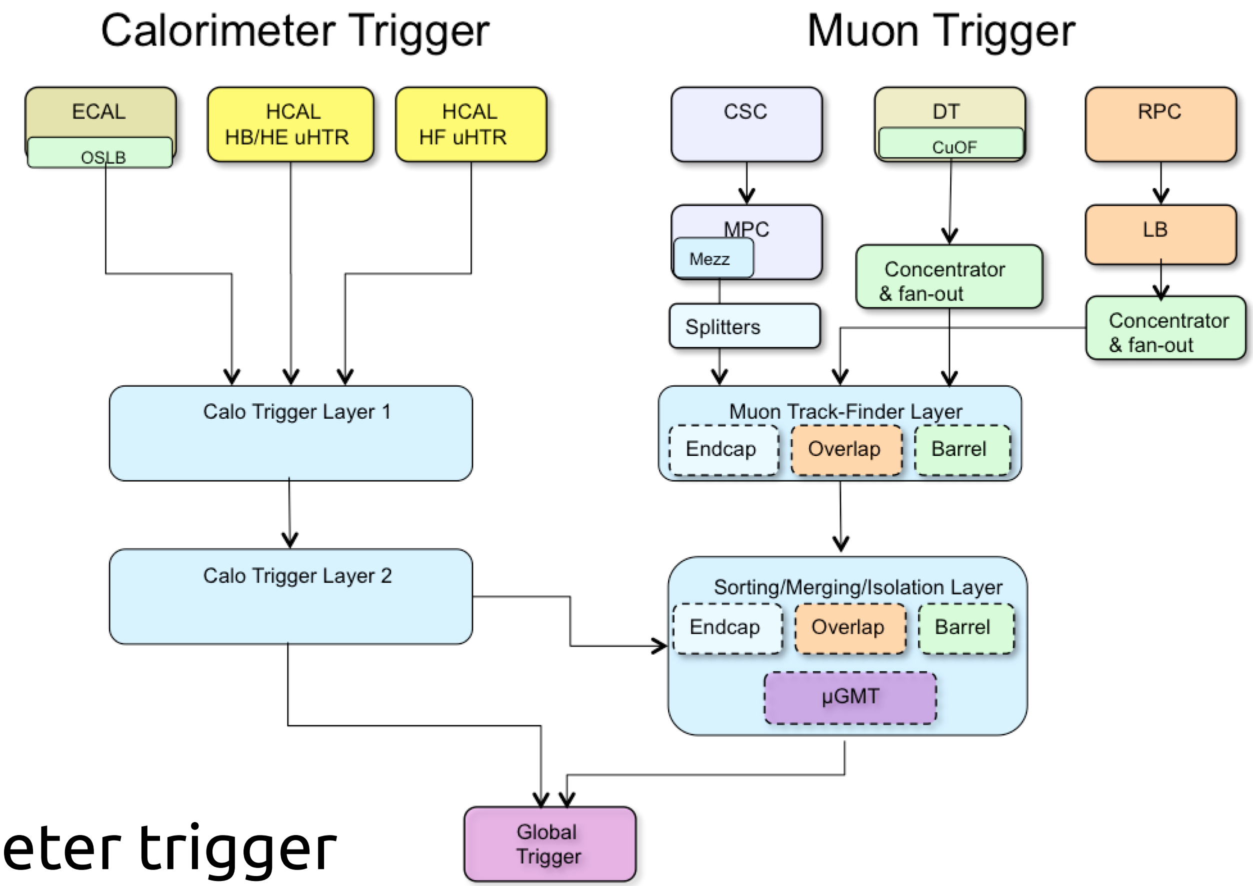


- implementation
  - hardware: FPGAs and ASICs
  - synchronous operation
  - 40 MHz LHC clock
- constraints from the detectors
  - pipeline: ~4 µs to take a decision
  - readout: 100 kHz maximum output rate

Level 1 Trigger in 2012



Level 1 Trigger in 2016



- Two-layer calorimeter trigger
  - with calorimeter tower-level precision and pile-up subtraction
- Muon trigger combining all 3 muon systems
  - integrated track-finding with more sophisticated p_T measurement

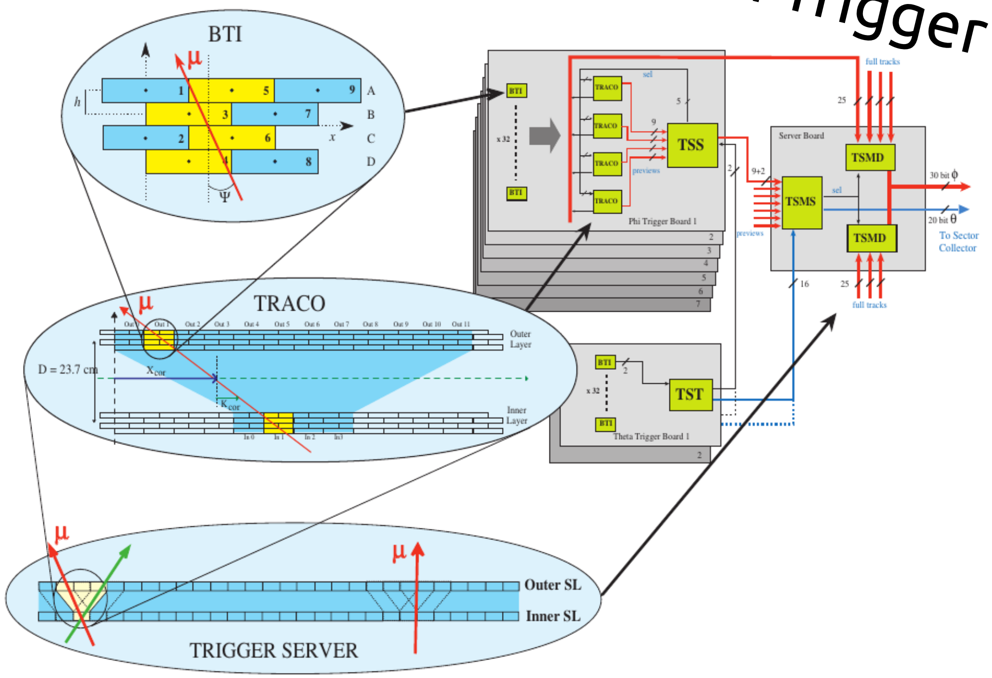
Stage 1: Level 1 Trigger in 2015

- replace the L1 GCT with a a prototype of the “Layer 2”
  - improved calorimetric trigger
    - pile-up subtraction for jets and energy sums
    - dedicated taus trigger candidates
- minor improvements to the muon trigger
  - make use of new muon chambers
  - increased granularity of the CSC readout
  - improve the LUTs used for track building and matching

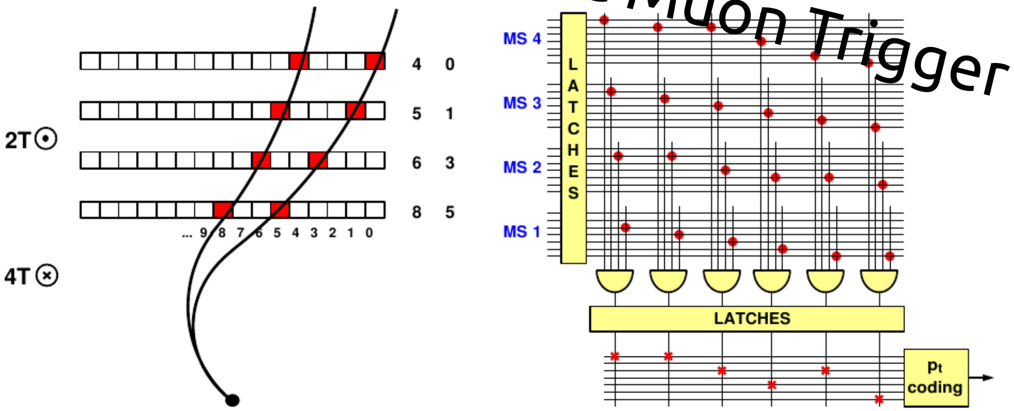
L1 Muon Trigger

- **DT and CSC**
  - track segments are identified in the detectors
  - track finders (DTTF and CSCTF) build muon candidates
  - each candidate is assigned η, φ, p_T and quality
  - **select 4 (DT) + 4 (CSC) candidates**
- **RPC**
  - hits are built into candidates
  - each candidate is assigned η, φ, p_T and quality
  - **select 4 (barrel) + 4 (endcap) candidates**
- **GMT – Global Muon Trigger**
  - combine candidates in the barrel (DT+RPC) and endcap (CSC+RPC)
  - merges or removes duplicates
  - each candidate is assigned η, φ, p_T and quality
  - select **4 leading muon candidates**
    - high quality candidates ued for single muon triggers
    - low quality candidates are used for di-muon and cross-triggers

DT Muon Trigger

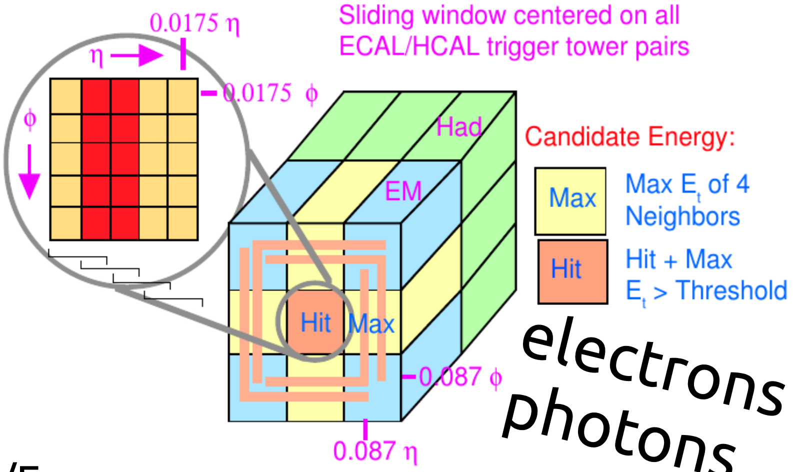


RPC Muon Trigger



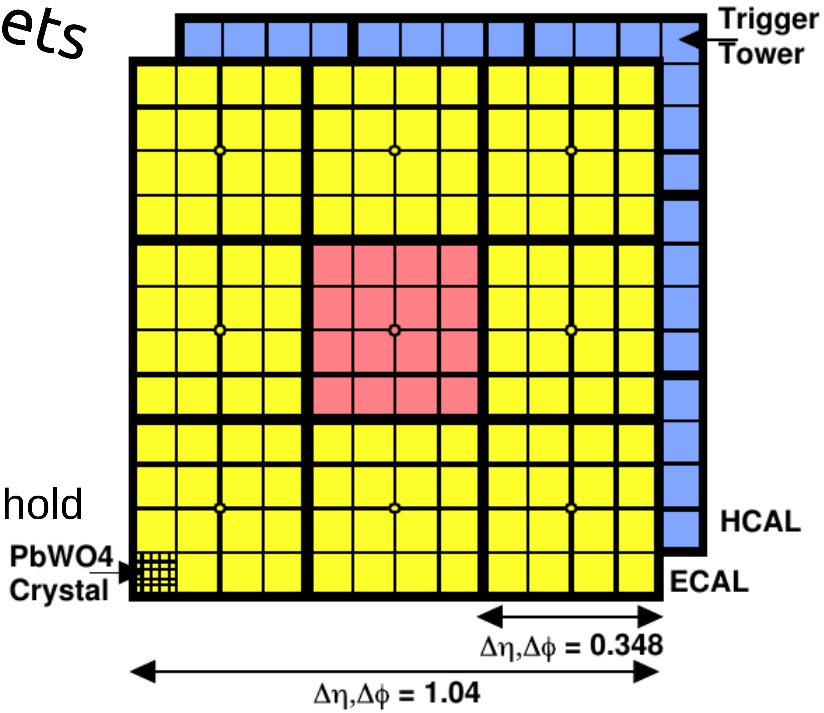
L1 Calo Trigger

- **ECAL trigger primitives**
  - trigger tower: 5x5 crystals
  - ET in each tower
  - reject “spikes”, apply “transparency corrections”
- **HCAL primitives**
  - ET in each tower
- **e/gamma candidates**
  - id based on shower shape, isolation from ECAL and H/E
  - **4 isolated** and **4 non-isolated** e/gamma candidates
- **jet candidates**
  - calorimeter regions (4x4 towers)
  - sum ET of 3x3 regions
  - **4 central jets** (|η| < 3) and **4 forward jets** (|η| > 3)
  - **4 tau jets** (|η| < 3)
- **energy sums**
  - **ETT, MET** computed from all trigger towers above threshold
  - **HT, MHT** computed from all regions above threshold



electrons
photons

jets



L1 Trigger Objects

- the L1 Trigger reconstructs

Global Muon Trigger

  - “stand alone” muon candidates
    - up to 4 candidates from the hits in the muon detectors

  - e/gamma objects: photons or electrons
    - from ECAL deposits
    - including the possibility for a loose calorimetric isolation
  - jets
    - up to 4 central, 4 forward, and 4 tau candidates
    - from the calorimetric deposits
  - global quantities: MET, HT
    - from the calorimetric deposits

Global Calo Trigger

L1 Global Trigger

- L1 Global Trigger
  - reads the candidates from the Muon and Calo triggers
  - define up to 128 algorithms
    - based on the candidates' energy and kinematics
    - their quality flags
    - and their combinations
  - including simple correlations between the candidates:
    - delta eta, delta phi, opposite sign, …
  - some random examples from 2012:
    - L1_SingleMu16
    - L1_IsoEG12er_ETM36
    - L1_TripleJet_68_48_32_VBF

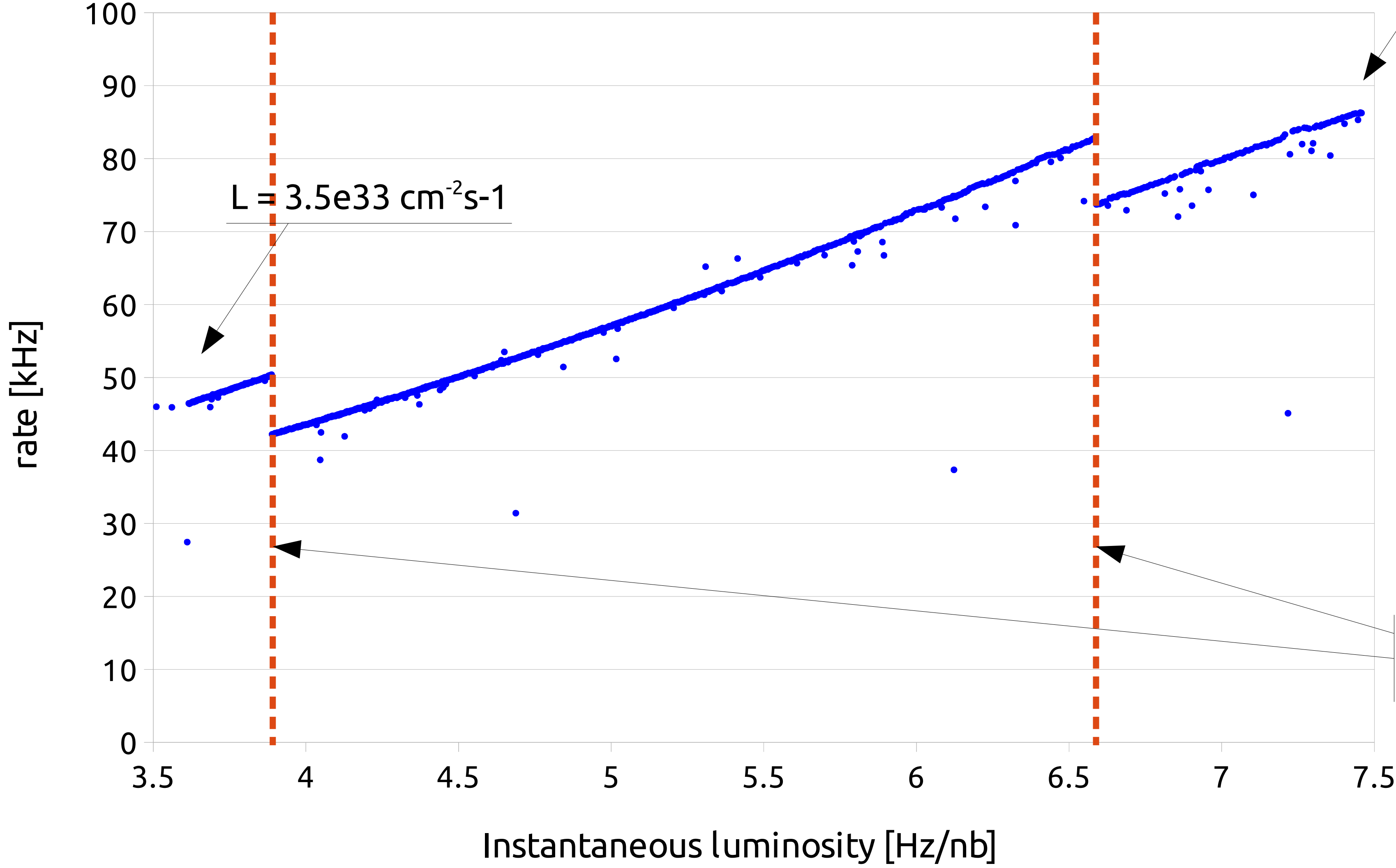
one (or more) muon(s), with pT above 16 GeV

one loosely isolated ECAL deposit, within |η| < 2.1 together with a missing ET above 36 GeV

3 jets above different thresholds, in a VBF-like topology

- In 2012: 4 iterations of the L1 menu
    - with minimal changes, remove unused triggers, add cross-triggers, …

L1 Trigger rate vs. Luminosity

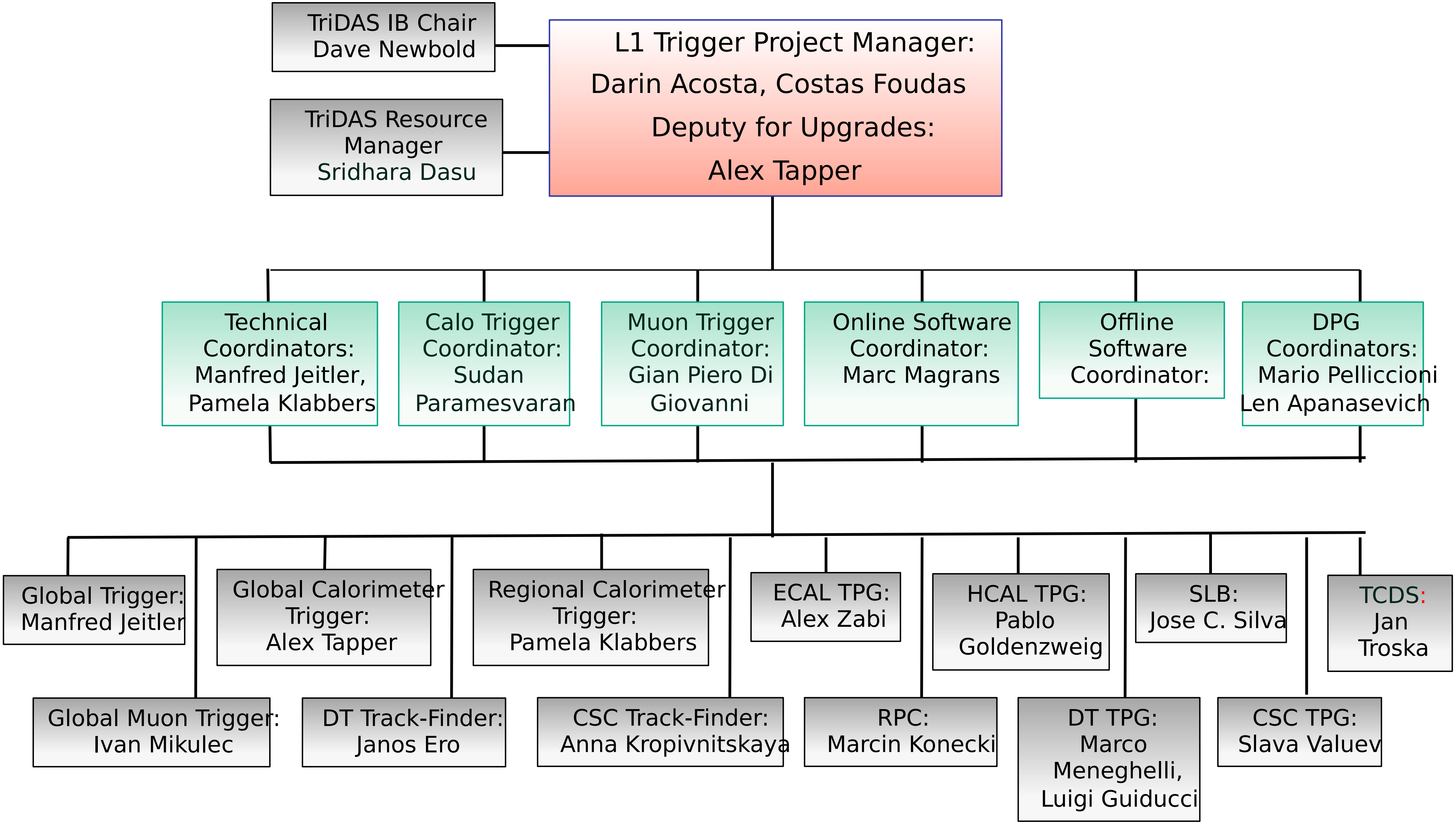


L = 7.5e33 cm^{-2}s-1

L = 3.5e33 cm^{-2}s-1

change of *prescales*

L1 Project (old, sorry)



TriDAS IB Chair
Dave Newbold

TriDAS Resource Manager
Sridhara Dasu

L1 Trigger Project Manager:
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Deputy for Upgrades:
Alex Tapper

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Muon Trigger Coordinator:
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Online Software Coordinator:
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Offline Software Coordinator:

DPG Coordinators:
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Global Calorimeter Trigger:
Alex Tapper

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ECAL TPG:
Alex Zabi

HCAL TPG:
Pablo Goldenzweig

SLB:
Jose C. Silva

TCDS:
Jan Troska

Global Muon Trigger:
Ivan Mikulec

DT Track-Finder:
Janos Ero

CSC Track-Finder:
Anna Kropivnitskaya

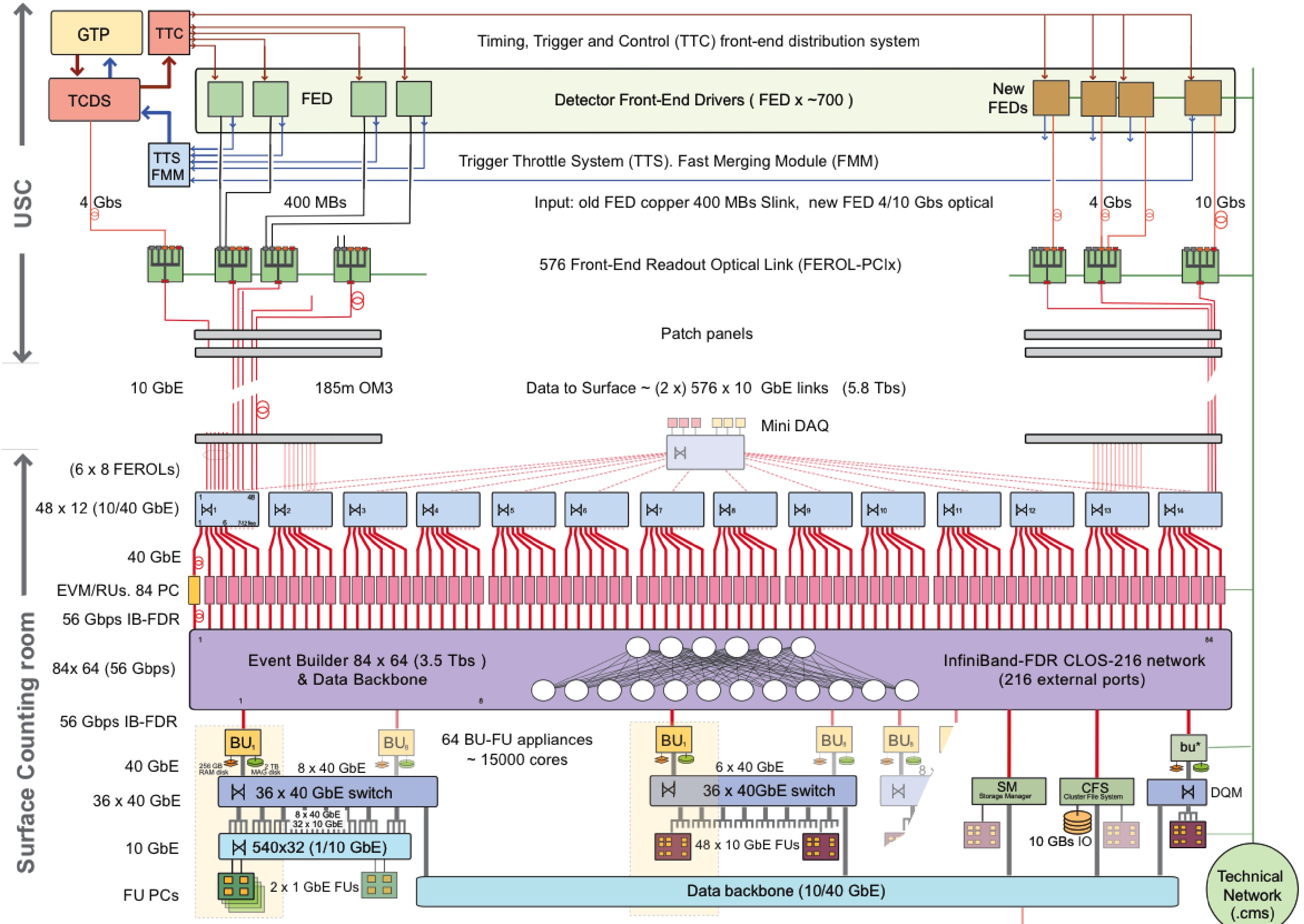
RPC:
Marcin Konecki

DT TPG:
Marco Meneghelli,
Luigi Guiducci

CSC TPG:
Slava Valuev

Data Acquisition (DAQ)

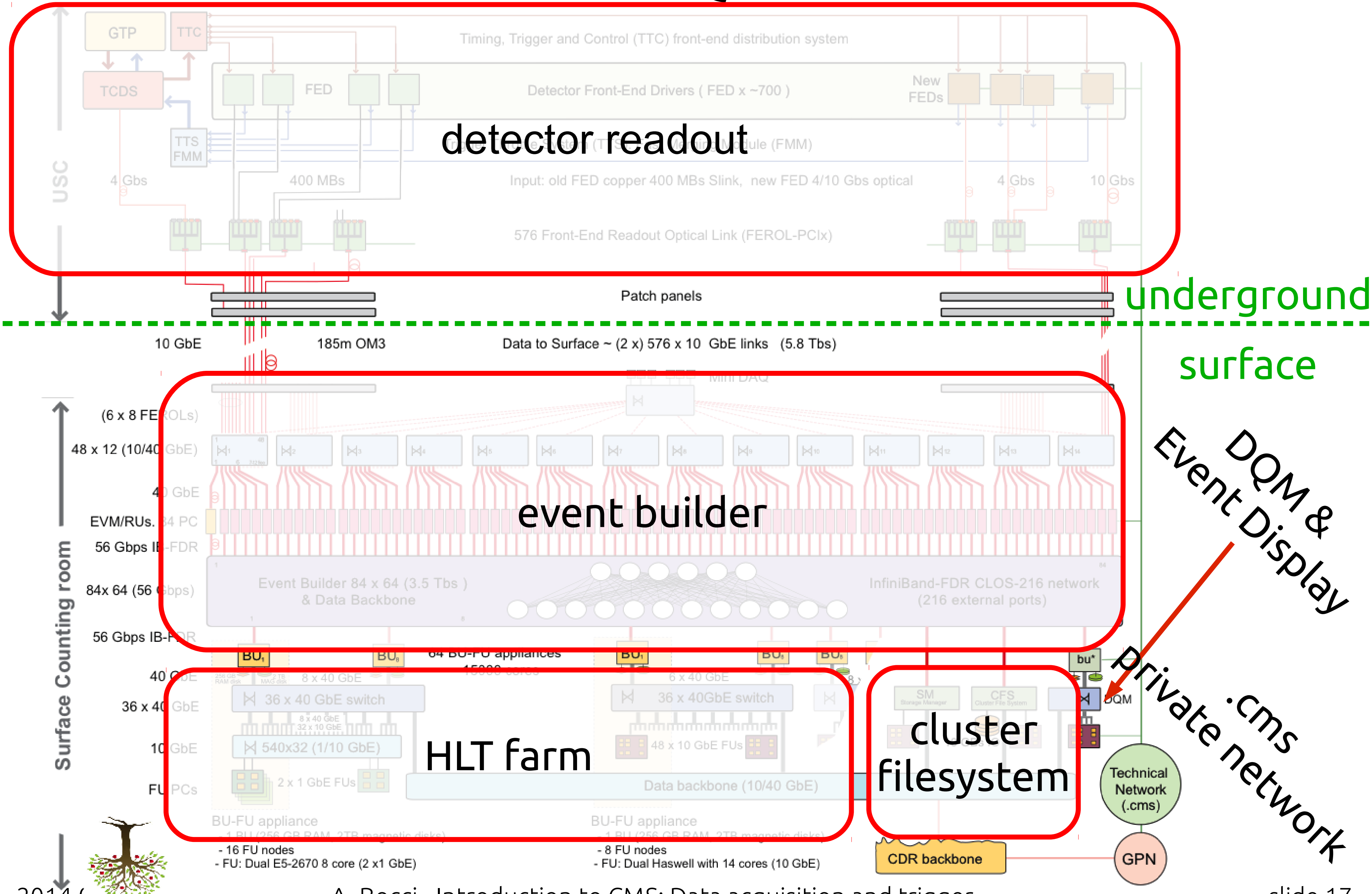
DAQ 2



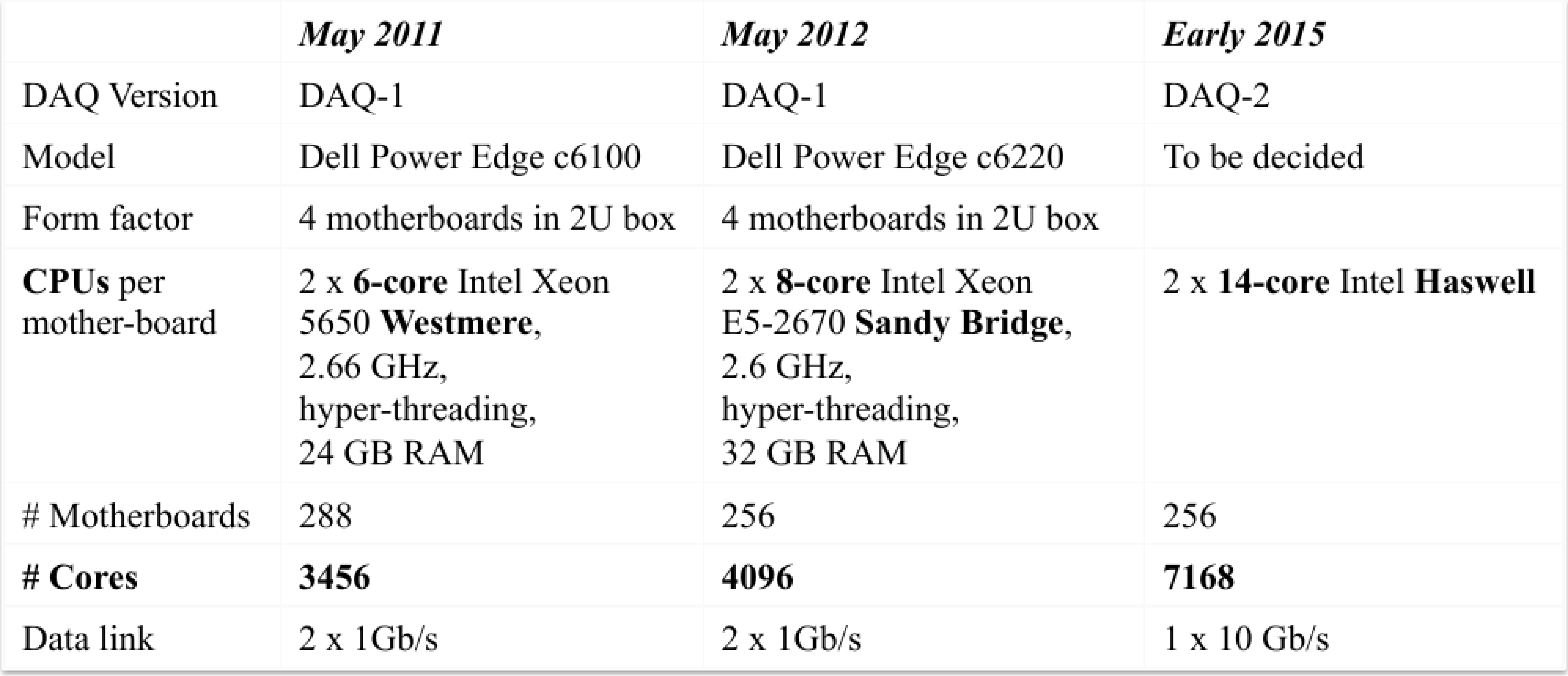
BU-FU appliance
- 1 BU (256 GB RAM, 2TB magnetic disks)
- 16 FU nodes
- FU: Dual E5-2670 8 core (2 x1 GbE)

BU-FU appliance
- 1 BU (256 GB RAM, 2TB magnetic disks)
- 8 FU nodes
- FU: Dual Haswell with 14 cores (10 GbE)

DAQ 2


detector readout
GTP
TTC
TCDS
TTS FMM
USC
Timing, Trigger and Control (TTC) front-end distribution system
FED
Detector Front-End Drivers (FED x ~700)
New FEDs
Trigger Throttle System Fast Merging Module (FMM)
4 Gbs
400 MBs
Input: old FED copper 400 MBs Slink, new FED 4/10 Gbs optical
4 Gbs
10 Gbs
576 Front-End Readout Optical Link (FEROL-PCIx)
Patch panels
underground
surface
10 GbE
185m OM3
Data to Surface ~ (2 x) 576 x 10 GbE links (5.8 Tbs)
Mini DAQ
(6 x 8 FEROLs)
48 x 12 (10/40 GbE)
40 GbE
EVM/RUs. 84 PC
56 Gbps IB-FDR
84x 64 (56 Gbps)
56 Gbps IB-FDR
40 GbE
36 x 40 GbE
10 GbE
FU PCs
Surface Counting room
event builder
Event Builder 84 x 64 (3.5 Tbs) & Data Backbone
InfiniBand-FDR CLOS-216 network (216 external ports)
BU
64 BU-FU appliances
15000 cores
8 x 40 GbE
6 x 40 GbE
36 x 40 GbE switch
36 x 40GbE switch
8 x 40 GbE
32 x 10 GbE
540x32 (1/10 GbE)
48 x 10 GbE FUs
2 x 1 GbE FUs
HLT farm
Data backbone (10/40 GbE)
BU-FU appliance
- 1 BU (256 GB RAM, 2TB magnetic disks)
- 16 FU nodes
- FU: Dual E5-2670 8 core (2 x1 GbE)
BU-FU appliance
- 1 BU (256 GB RAM, 2TB magnetic disks)
- 8 FU nodes
- FU: Dual Haswell with 14 cores (10 GbE)
SM Storage Manager
CFS Cluster File System
cluster filesystem
bu*
DQM
DQM & Event Display
.cms Private network
Technical Network (.cms)
GPN
CDR backbone

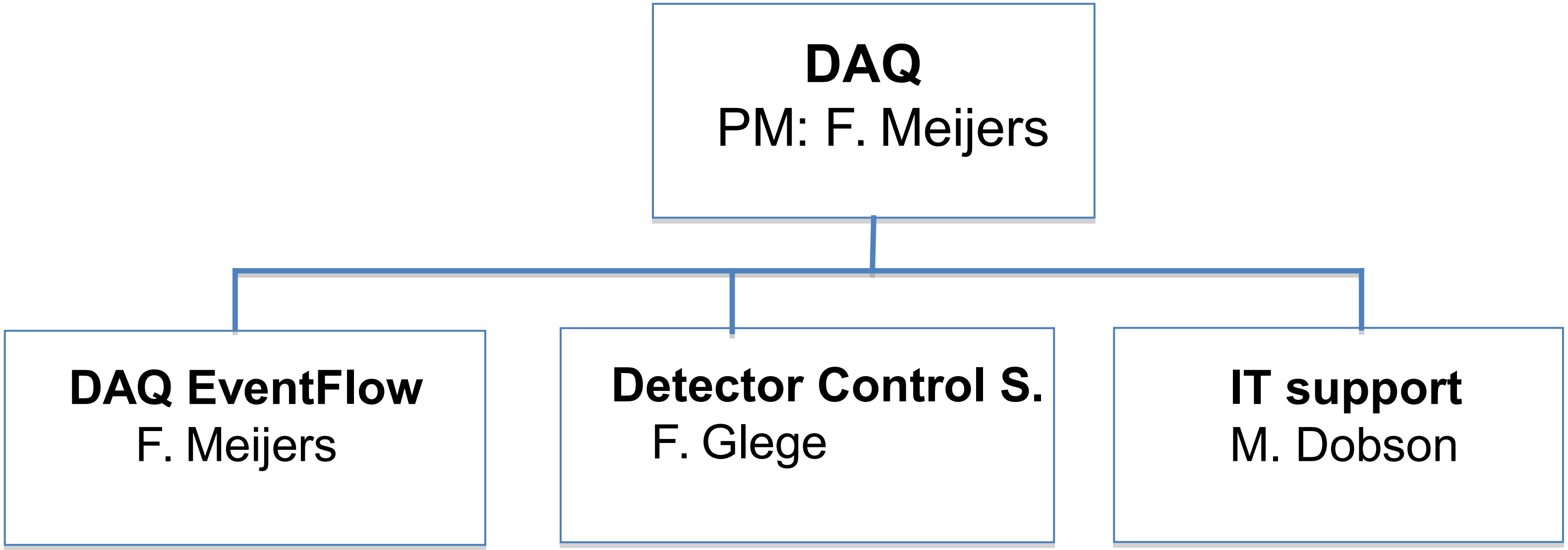
HLT farm



	May 2011	*May 2012*	*Early 2015*
DAQ Version	DAQ-1	DAQ-1	DAQ-2
Model	Dell Power Edge c6100	Dell Power Edge c6220	To be decided
Form factor	4 motherboards in 2U box	4 motherboards in 2U box	
CPUs per mother-board	2 x **6-core** Intel Xeon 5650 **Westmere**, 2.66 GHz, hyper-threading, 24 GB RAM	2 x **8-core** Intel Xeon E5-2670 **Sandy Bridge**, 2.6 GHz, hyper-threading, 32 GB RAM	2 x **14-core** Intel **Haswell**
# Motherboards	288	256	256
# Cores	**3456**	**4096**	**7168**
Data link	2 x 1Gb/s	2 x 1Gb/s	1 x 10 Gb/s

~15k cores (**~30k processes** or threads) ← **50% more processing power** than in 2012

DAQ Project (2014)



DAQ
PM: F. Meijers

DAQ EventFlow
F. Meijers

Detector Control S.
F. Glege

IT support
M. Dobson

DAQ Office

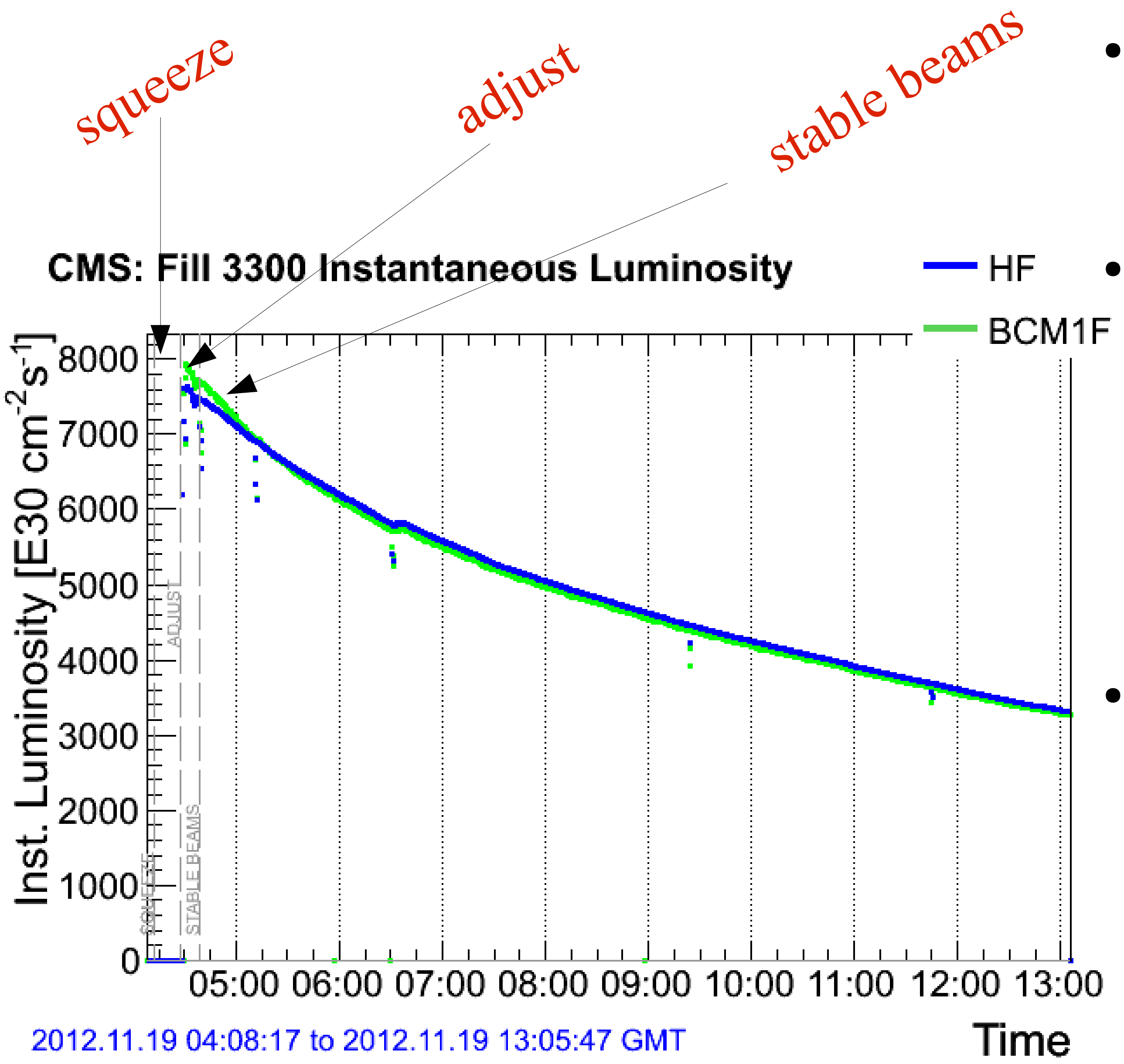
Resource Planning: F. Meijers
Operation: V. O'Dell, N.N.
Technical Coordination: A. Racz

CMS Upgrade Online Coordinator:
C. Schwick
CMS DAQ Upgrade: A. Racz

TriDAS SEB Chair: S. Erhan
TriDAS Conf. Committee: V. O'Dell

Interlude: a note about operations

LHC fill



squeeze

adjust

stable beams

CMS: Fill 3300 Instantaneous Luminosity

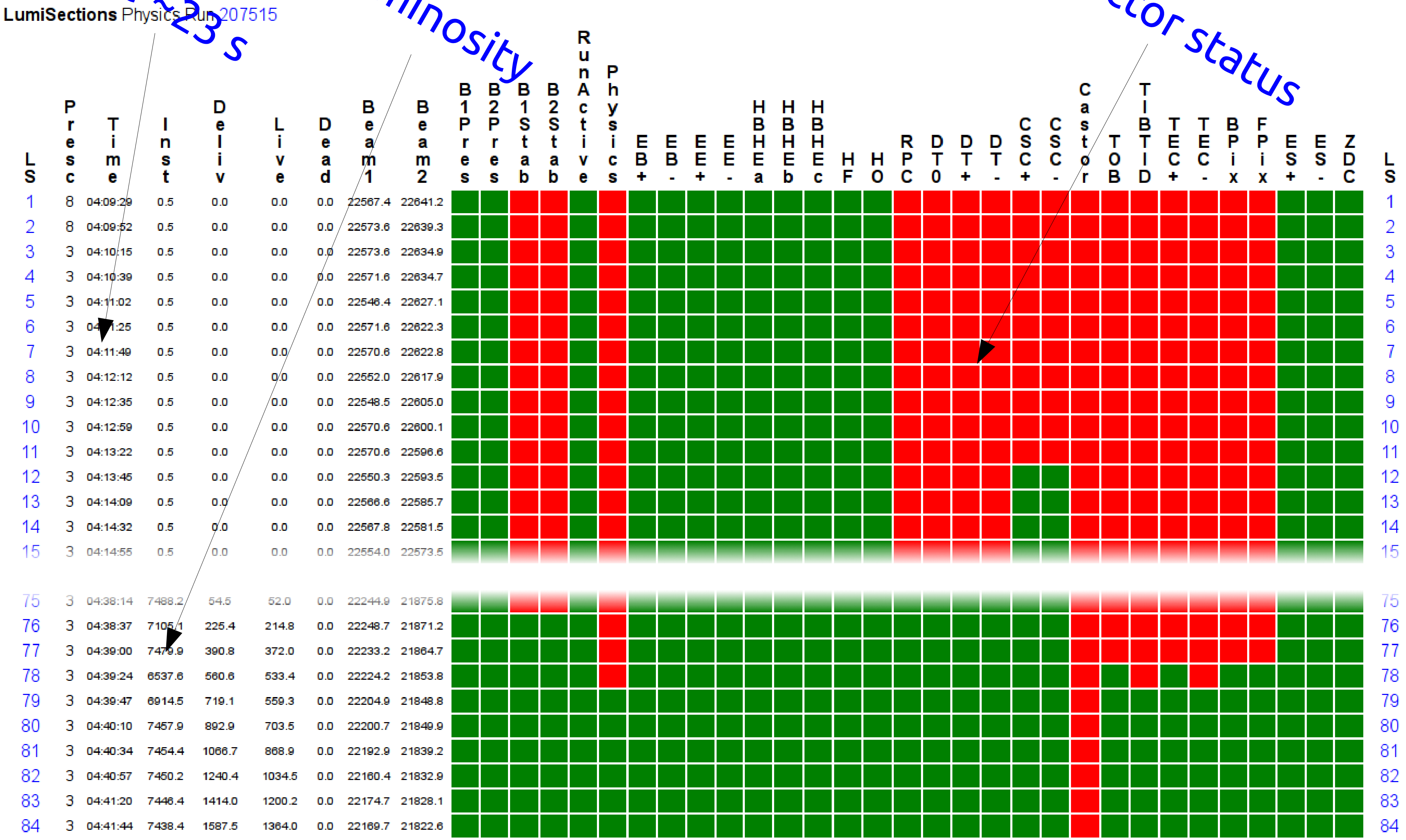
2012.11.19 04:08:17 to 2012.11.19 13:05:47 GMT

- an LHC fill usually lasts various hours
- after injection and acceleration to 8 TeV, the beams are
  - “squeezed” (focused)
  - brought into collisions
- declare “stable beams”

Luminosity Section

- in CMS, a run is split into “luminosity sections” (lumisection, or LS)
  - arbitrary definition: 2^{18} LHC orbits
  - corresponding to ~23.31 s
- large enough to …
  - measure the average instantaneous luminosity
  - monitor the status of the subdetctors
- small enough to
  - be used as the atomic amount of data
  - certification, data processing, bookkeeping, monitoring, etc. are all done on a lumisection by lumisection basis

Luminosity Section – online monitoring



time ~23 s

luminosity

detector status

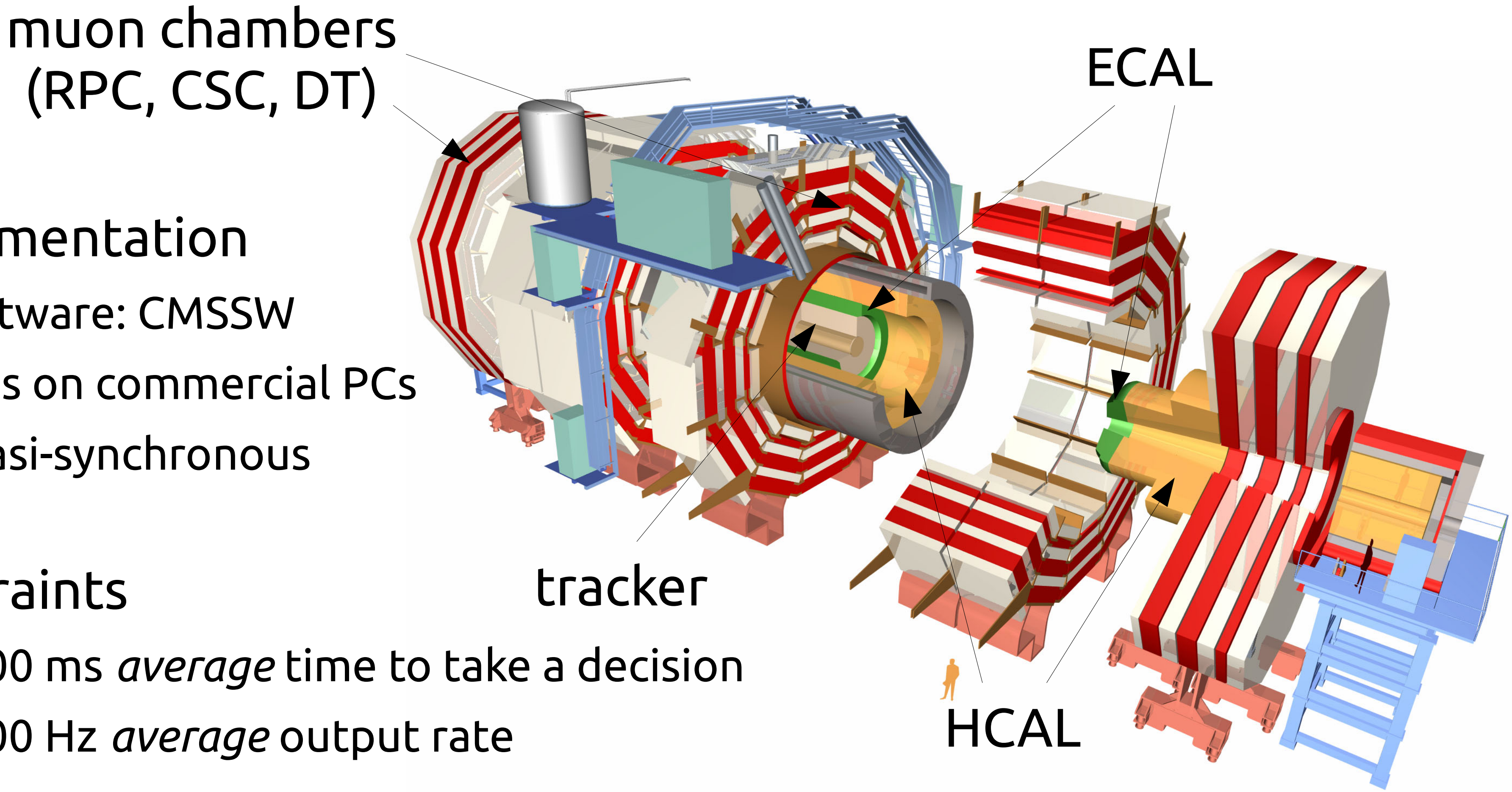
LumiSections Physics Run 207515

LS	Presc	Time	Inst	Deliv	Live	Dead	Beam1	Beam2	B1Pres	B2Pres	B1Stab	B2Stab	RunActive	Physics	EB+	EB-	EE+	EE-	HBHEa	HBHEb	HBHEc	HF	HO	RPC	DT0	DT+	DT-	CSC+	CSC-	Castor	TOB	TIBTID	TEC+	TEC-	BPix	FPix	ES+	ES-	ZDC	LS
1	8	04:09:29	0.5	0.0	0.0	0.0	22567.4	22641.2	🟩	🟩	🟥	🟥	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	1
2	8	04:09:52	0.5	0.0	0.0	0.0	22573.6	22639.3	🟩	🟩	🟥	🟥	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	2
3	3	04:10:15	0.5	0.0	0.0	0.0	22573.6	22634.9	🟩	🟩	🟥	🟥	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	3
4	3	04:10:39	0.5	0.0	0.0	0.0	22571.6	22634.7	🟩	🟩	🟥	🟥	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	4
5	3	04:11:02	0.5	0.0	0.0	0.0	22546.4	22627.1	🟩	🟩	🟥	🟥	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	5
6	3	04:11:25	0.5	0.0	0.0	0.0	22571.6	22622.3	🟩	🟩	🟥	🟥	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	6
7	3	04:11:49	0.5	0.0	0.0	0.0	22570.6	22622.8	🟩	🟩	🟥	🟥	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	7
8	3	04:12:12	0.5	0.0	0.0	0.0	22552.0	22617.9	🟩	🟩	🟥	🟥	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	8
9	3	04:12:35	0.5	0.0	0.0	0.0	22548.5	22605.0	🟩	🟩	🟥	🟥	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	9
10	3	04:12:59	0.5	0.0	0.0	0.0	22570.6	22600.1	🟩	🟩	🟥	🟥	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	10
11	3	04:13:22	0.5	0.0	0.0	0.0	22570.6	22596.6	🟩	🟩	🟥	🟥	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	11
12	3	04:13:45	0.5	0.0	0.0	0.0	22550.3	22593.5	🟩	🟩	🟥	🟥	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	12
13	3	04:14:09	0.5	0.0	0.0	0.0	22566.6	22585.7	🟩	🟩	🟥	🟥	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	13
14	3	04:14:32	0.5	0.0	0.0	0.0	22567.8	22581.5	🟩	🟩	🟥	🟥	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	14
15	3	04:14:55	0.5	0.0	0.0	0.0	22554.0	22573.5	🟩	🟩	🟥	🟥	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	15
75	3	04:38:14	7488.2	54.5	52.0	0.0	22244.9	21875.8	🟩	🟩	🟥	🟥	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	75
76	3	04:38:37	7105.1	225.4	214.8	0.0	22248.7	21871.2	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	76
77	3	04:39:00	7479.9	390.8	372.0	0.0	22233.2	21864.7	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	77
78	3	04:39:24	6537.6	560.6	533.4	0.0	22224.2	21853.8	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟥	🟩	🟥	🟩	🟩	🟩	🟩	🟩	78
79	3	04:39:47	6914.5	719.1	559.3	0.0	22204.9	21848.8	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	79
80	3	04:40:10	7457.9	892.9	703.5	0.0	22200.7	21849.9	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	80
81	3	04:40:34	7454.4	1066.7	868.9	0.0	22192.9	21839.2	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	81
82	3	04:40:57	7450.2	1240.4	1034.5	0.0	22160.4	21832.9	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	82
83	3	04:41:20	7446.4	1414.0	1200.2	0.0	22174.7	21828.1	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	83
84	3	04:41:44	7438.4	1587.5	1364.0	0.0	22169.7	21822.6	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	84

High Level Trigger

High Level Trigger

- full readout of the detector at 100 kHz



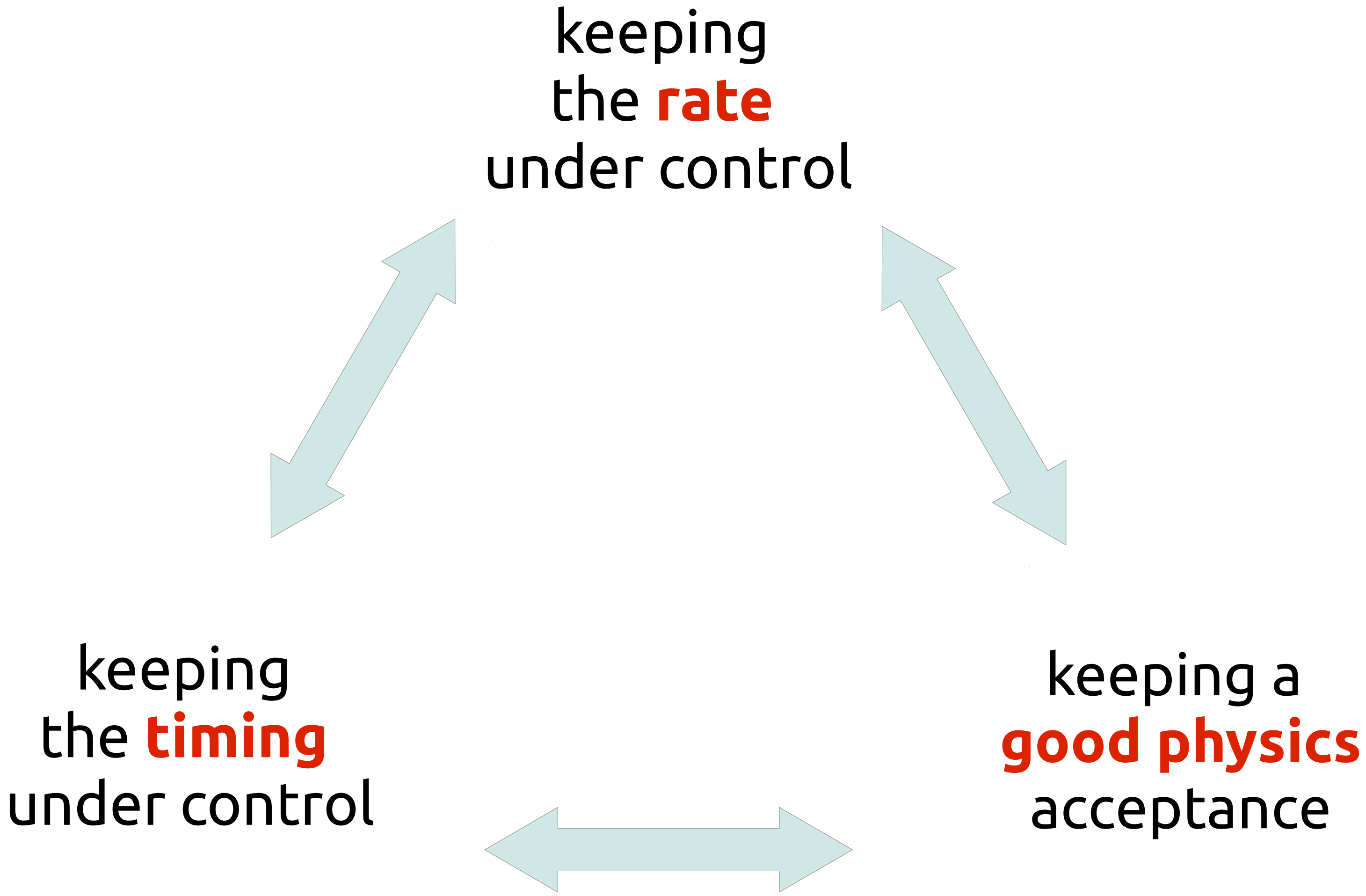
- implementation
  - software: CMSSW
  - runs on commercial PCs
  - quasi-synchronous
- constraints
  - ~200 ms *average* time to take a decision
  - ~400 Hz *average* output rate

High Level Trigger

- The High Level Trigger
  - is implemented in software (CMSSW)
    - running the same code used for offline reconstruction and analysis
    - but a very optimised configuration: O(~100) faster than offline
  - running on a farm of commercial computers
    - Intel Xeon, from different generations (2008-2012)
    - O(13'000) cpu cores, O(20'000) processes
  - over the full detector information
    - take advantage of regions of interests to speed up the reconstruction
    - reject events as early as possible

the challenge

- find a compromise between …



keeping
the **rate**
under control

keeping
the **timing**
under control

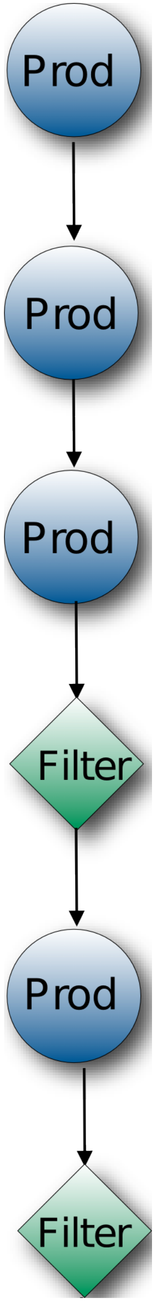
keeping a
good physics
acceptance

online reconstruction

- muons
  - “L2” stand alone muons
  - “L3” global and “tracker” muons
  - tracker-based isolation
- photons
  - based on ECAL superclusters
  - calorimeter-based id and isolation, tracker-based isolation
- electrons
  - match ECAL superclusters, pixel tracks, and full tracking
  - calorimeter-based id and isolation, tracker-based id and isolation

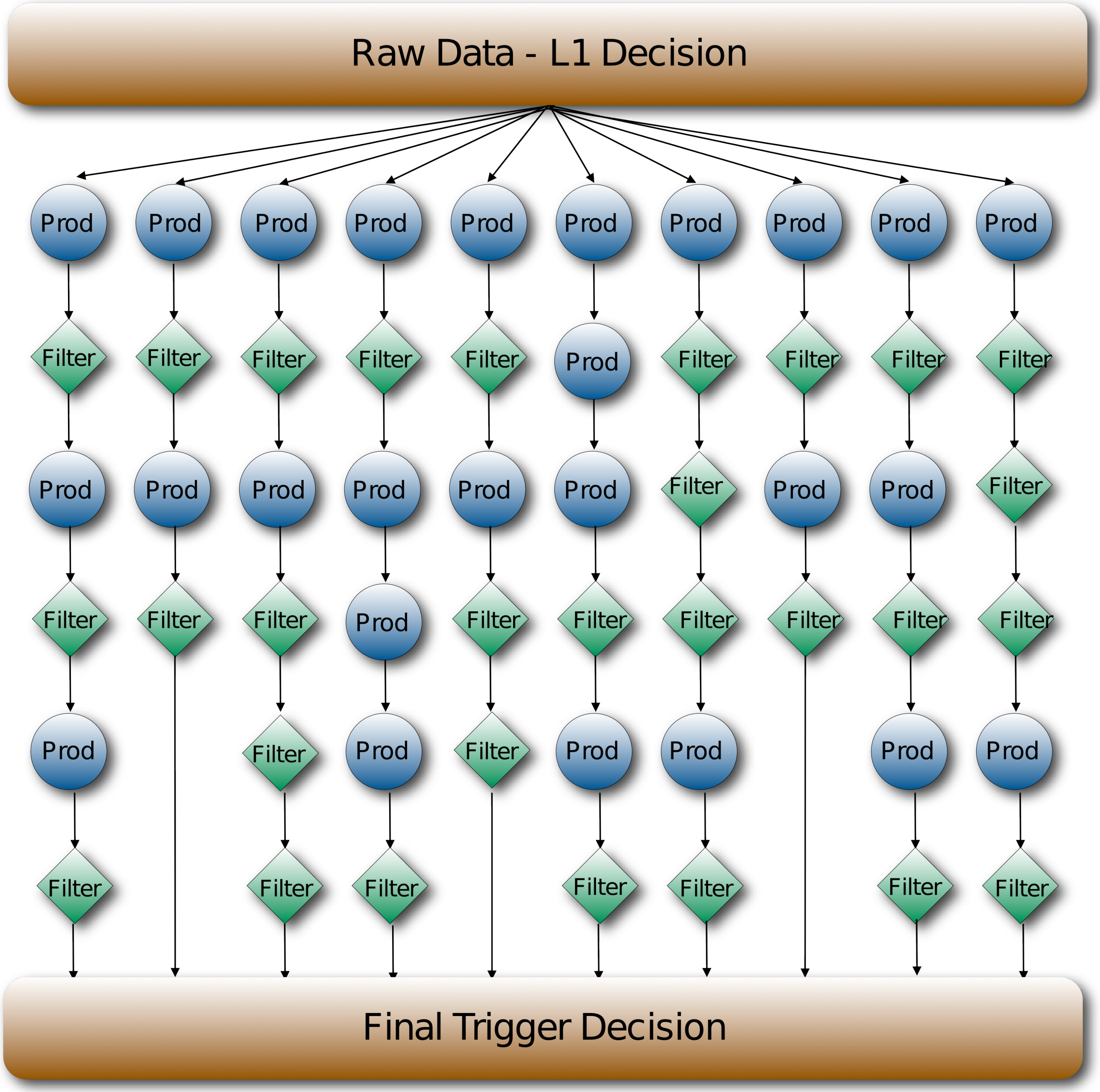
- taus
  - particle flow reconstruction
- jets, MET, HT
  - calorimteric jets and MET
  - particle flow-based jets and MET
- b-tagging
  - jets, full tracking
  - secondary vertex reconstruction
- but also
  - razor, α_T, dE/dx, …
  - jet substructure, …

online reconstruction



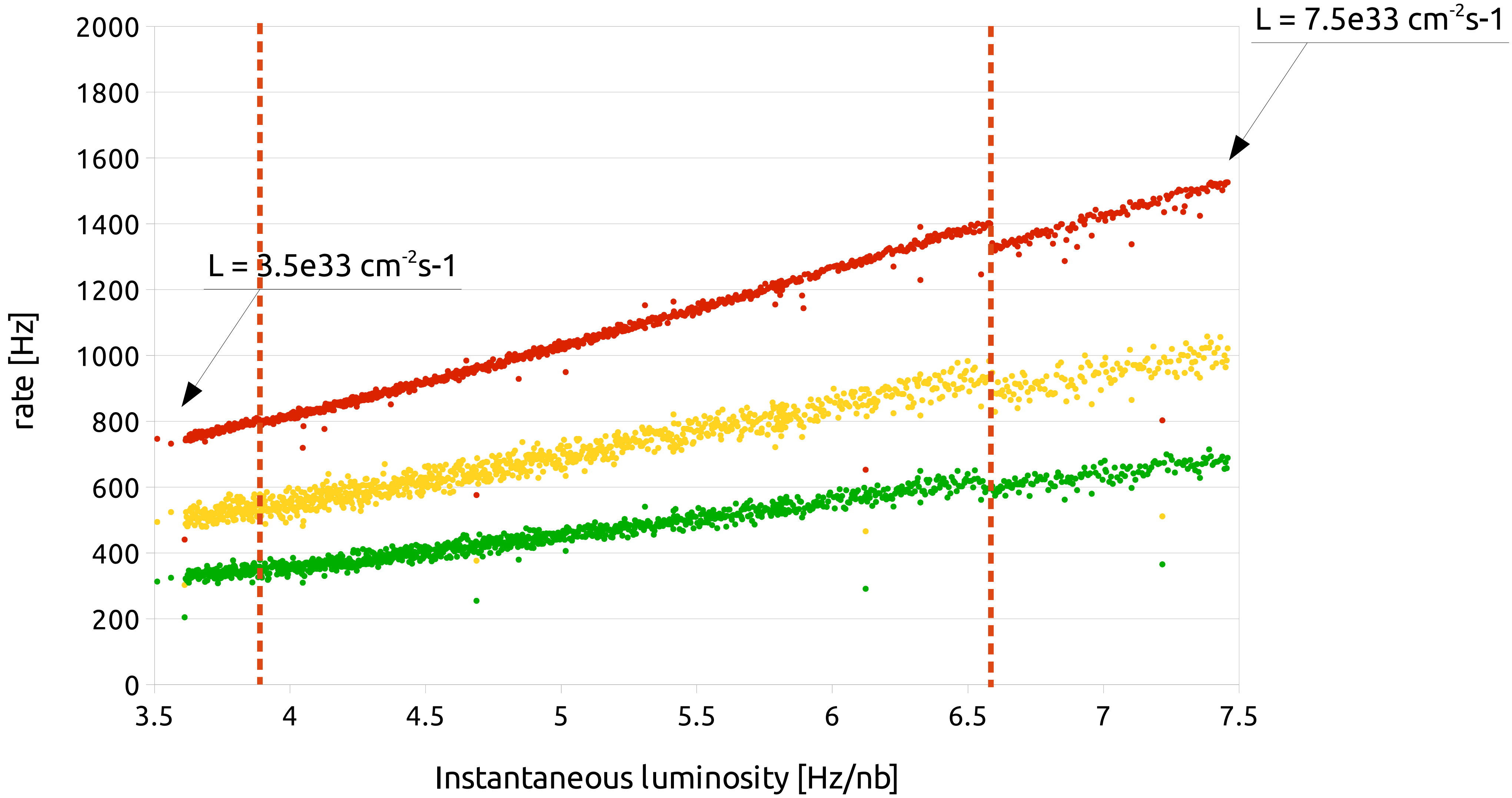
- the HLT uses many “tricks” to speed up the online reconstruction
  - remember – the limit is the **average** processing time per event
  - modular approach to reconstruction and filtering
    - reconstruct the **fastest object first**
      - L1 muon → L2 muon → L3 muon
      - L1 jet → “calo” jet → tracking and particle flow jet
    - **reject an event as soon as possible**
  - only look at what is really needed
    - **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

HLT menu

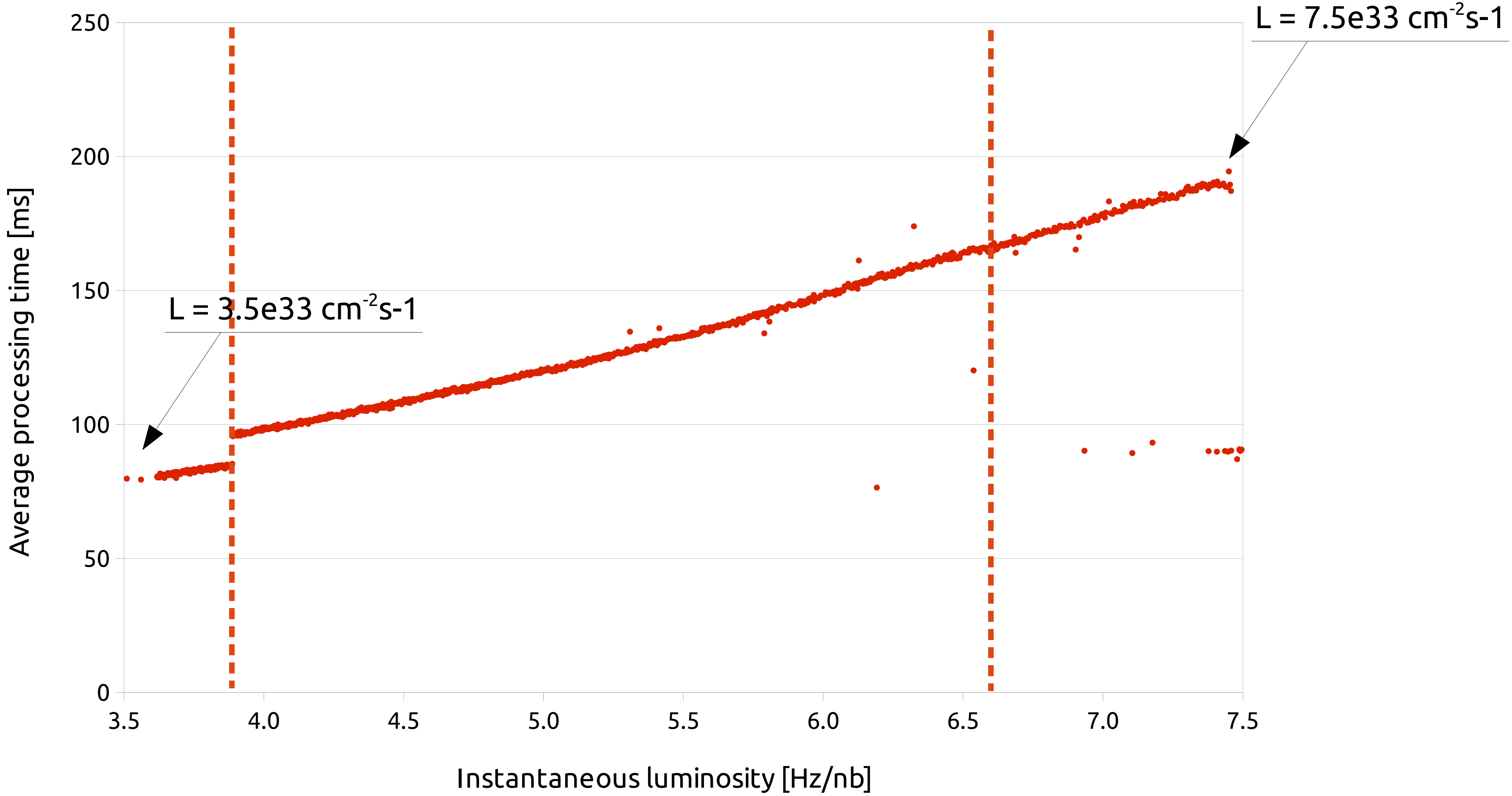


- many algorithms running in parallel
  - logically independent
- determine
  - the trigger decision
  - how to split the events, online and offline

HLT rates vs. Luminosity



HLT timing vs. Luminosity



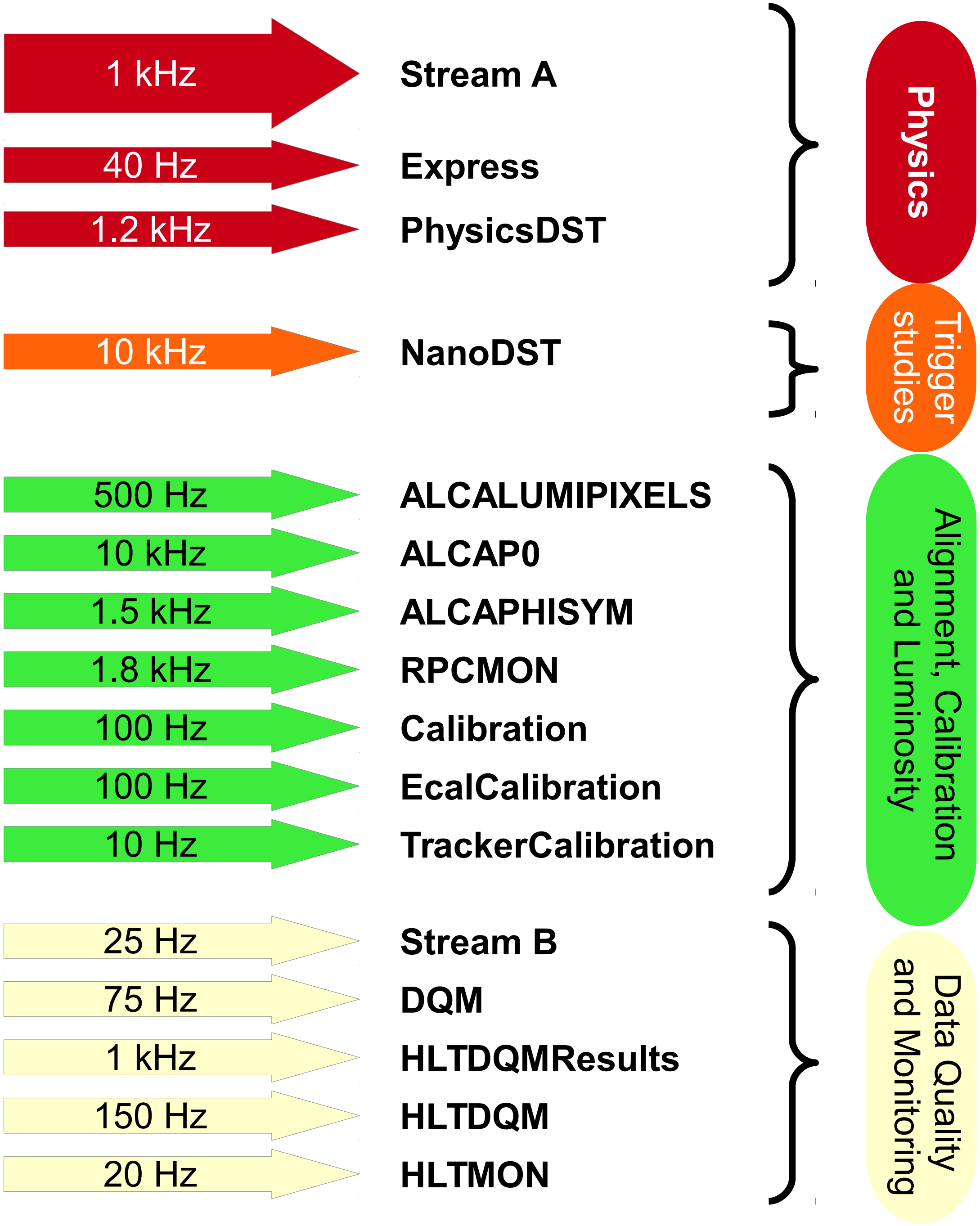
L = 3.5e33 cm^{-2}s-1

L = 7.5e33 cm^{-2}s-1

Streams

- the High Level Trigger is responsible also for splitting the data in different streams
  - different purposes
  - different event content
  - different rates

- physics, calibrations, monitoring, etc.

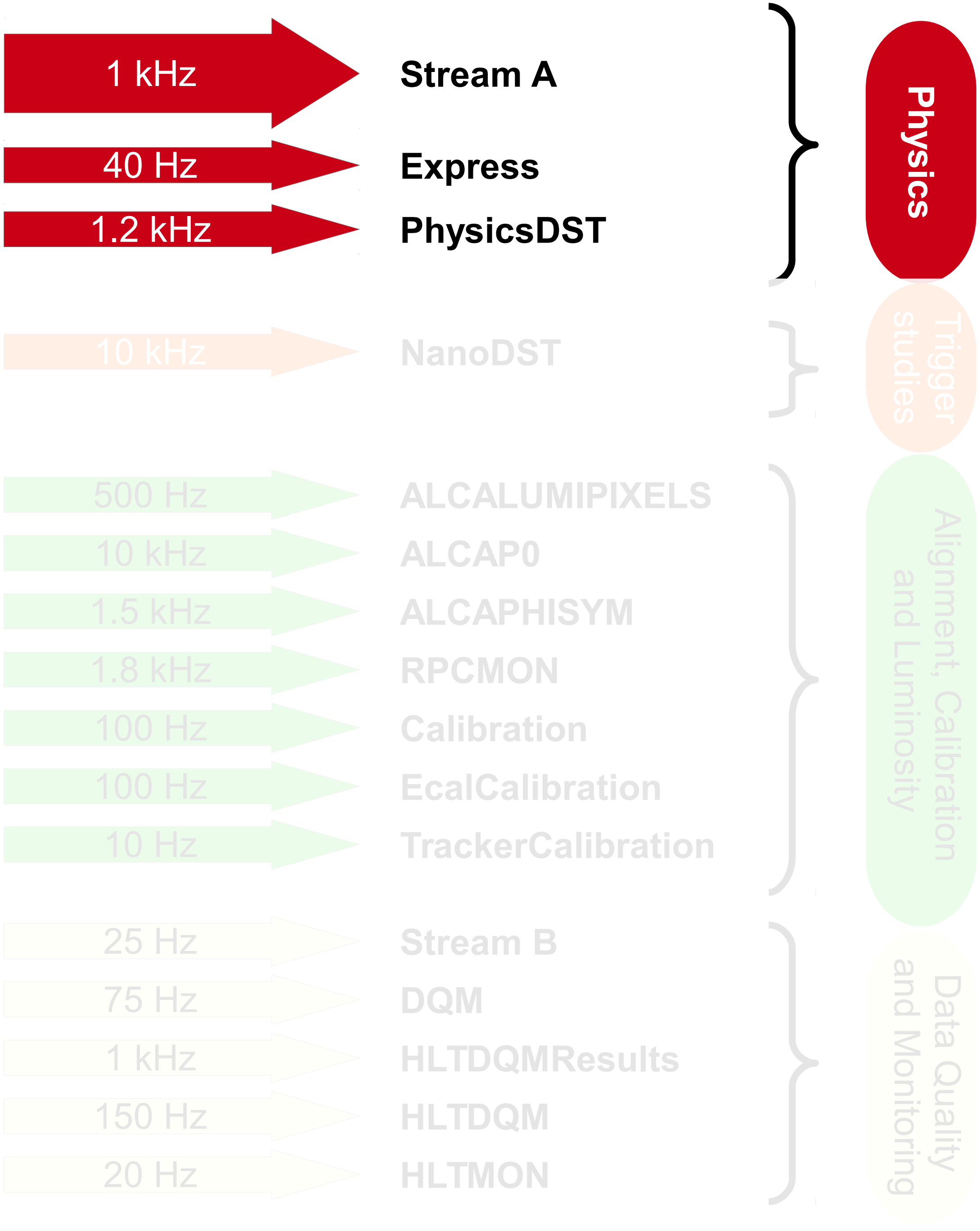


1 kHz	Stream A	Physics
40 Hz	Express	
1.2 kHz	PhysicsDST	
10 kHz	NanoDST	Trigger studies
500 Hz	ALCALUMIPIXELS	Alignment, Calibration and Luminosity
10 kHz	ALCAP0	
1.5 kHz	ALCAPHISYM	
1.8 kHz	RPCMON	
100 Hz	Calibration	
100 Hz	EcalCalibration	
10 Hz	TrackerCalibration	
25 Hz	Stream B	Data Quality and Monitoring
75 Hz	DQM	
1 kHz	HLTDQMResults	
150 Hz	HLTDQM	
20 Hz	HLTMON	

Streams

- **Stream A** collects all the events for physics analysis
  - average: ~ 400 Hz
- including ***parked data***
  - collected in 2012, but reconstructed and analysed only during 2013-14
  - average: ~ 600 Hz

- **PhysicsDST "scouting" stream**
  - analysis performed directly on HLT objects
  - no offline reconstruction



1 kHz	Stream A	Physics
40 Hz	Express	
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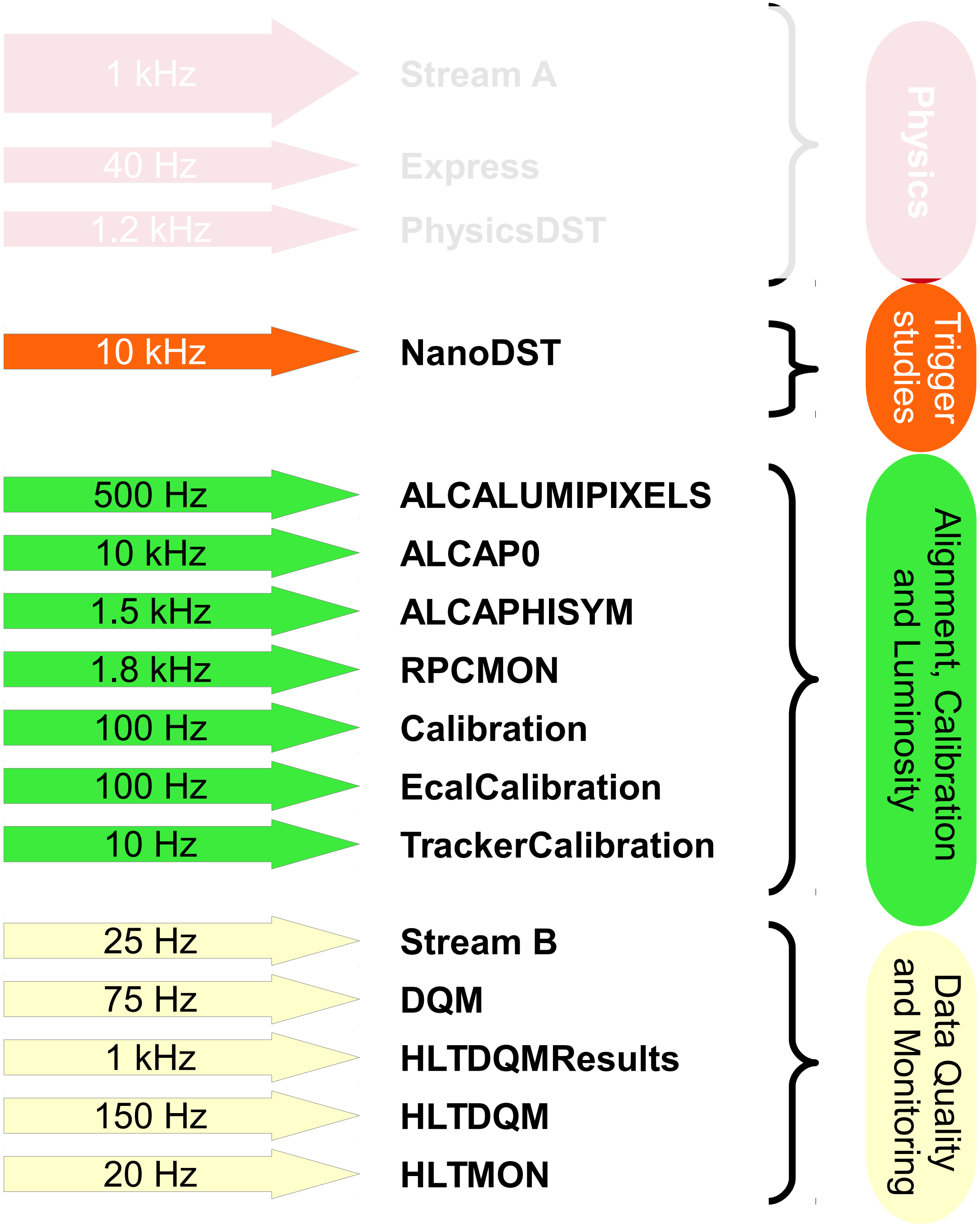
100 Hz	EcalCalibration	
10 Hz	TrackerCalibration	
25 Hz	Stream B	Data Quality and Monitoring
75 Hz	DQM	
1 kHz	HLTDQMResults	
150 Hz	HLTDQM	
20 Hz	HLTMON	

Streams

- **NanoDST stream**
  - Saves trigger information for 10% of all L1-accepted events
  - Useful for trigger studies
- **AlCa streams** collect events for dedicated calibration workflows
  - Only a fraction of the detector is read: small event size, high rate
- **Stream B** and **multiple DQM streams**
  - Monitor different aspects of data taking (online, offline, parking)



1 kHz	Stream A	Physics
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10 Hz	**TrackerCalibration**	
25 Hz	**Stream B**	Data Quality and Monitoring
75 Hz	**DQM**	
1 kHz	**HLTDQMResults**	
150 Hz	**HLTDQM**	
20 Hz	**HLTMON**	

Evolution of the Trigger constraints

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

fixed by 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, introduced data parking pre-LS1

- Run 2: 2015-2018
  - ?

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

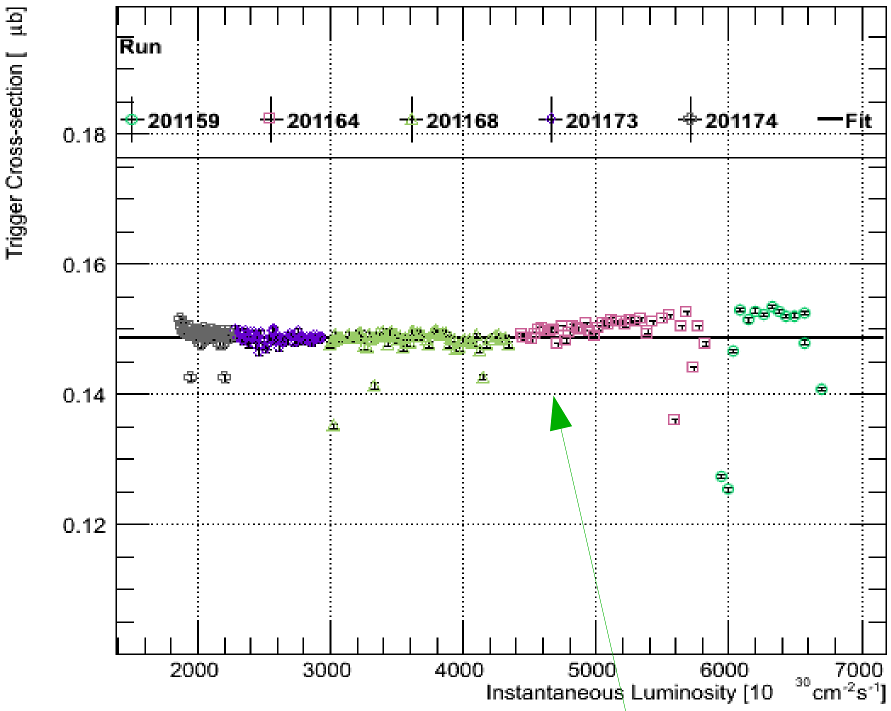
High Level Trigger for 2015

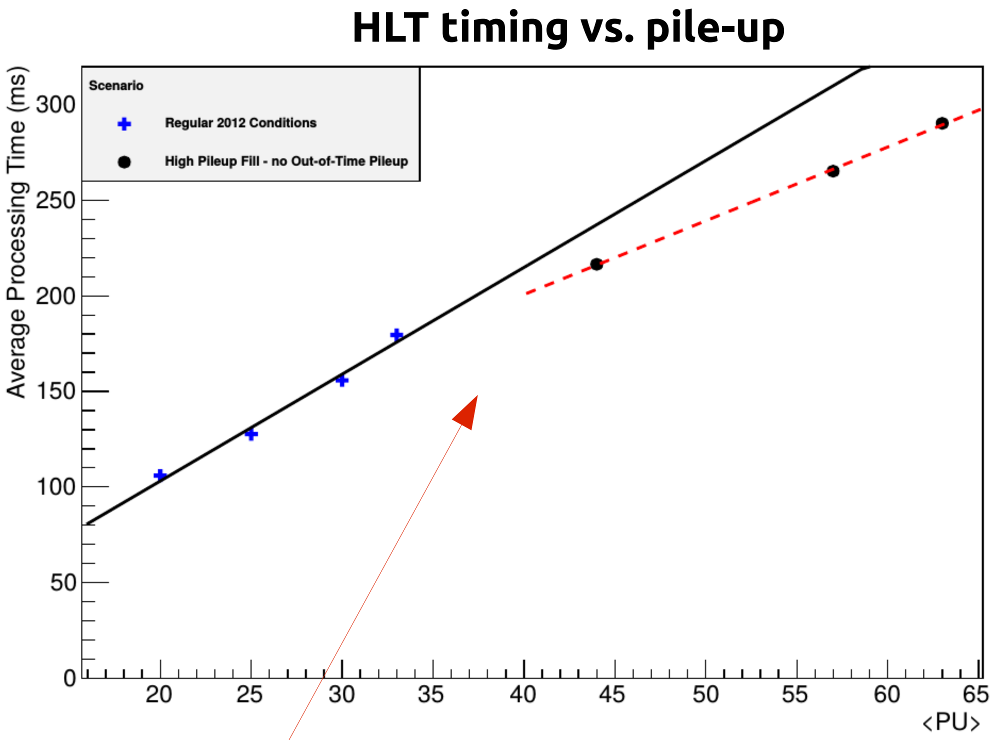
- run at 13 TeV
  - the higher collision energy leads to a higher cross-section
  - comparing 8 TeV and 13 TeV MC simulation we observe
    - a factor 1.5 ~ 2 for leptons
    - a factor > 4 for jets !
  - assume an average increase by **a factor ~ 2**

- higher luminosity: ~ 1.4e34 $cm^{-2}s^{-1}$
  - **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




HLT timing vs. pile-up

- and higher 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
    - by roughly **+50%**
    - to cope with **higher pile-up** and **more complex reconstruction** code

Trigger Coordination

Trigger Coordinator
Roberto Carlin
(Tulika Bose)
Deputies
Andrea Bocci, Simone Gennai

STEAM - Strategy for the Trigger Evaluation And Monitoring

Roberta Arcidiacono
Muriel Vander Donckt

STORM - Software Tools, Online Releases, and Menus

Martin Grunewald
Andrea Perrotta

FOG - Field Operations Group

Aram Avetisyan
Marina Passaseo

Trigger Coordination: L3's

POG Trigger conveners

Taus
Michal Bluj
Isobel Ojalvo

EGamma
Sam Harper
Matteo Sani

Jets/MET
Michele De Gruttola
Kostas Kousouris

B-Tagging
Anne-Catherine Le Bihan
Silvio Donato

Tracking
Mia Tosi
Marco Trovato

Muons POG
Carlo Battilana
Hugues Brun

PAG Trigger conveners

Exotica
Juliette Alimena
Zeynep Demiragli
Thiago Tomei Fernandez

TOP
Stephanie Beauceron
Javier Fernandez Mendez

Forward and Small-x QCD
Tomasz Froboes
Roberta Arcidiacono

Standard Model
Tristan du Pree
Dominik Olivito

B2G
Dylan Rankin

Higgs
Maria Cepeda
Pascal Vanlaer

B and Quarkonia
Valentin Knunz
Luca Martini

SUSY
Pablo Martinez
Frank Golf

HIN
Krisztian Krajczar

L1 Trigger conveners

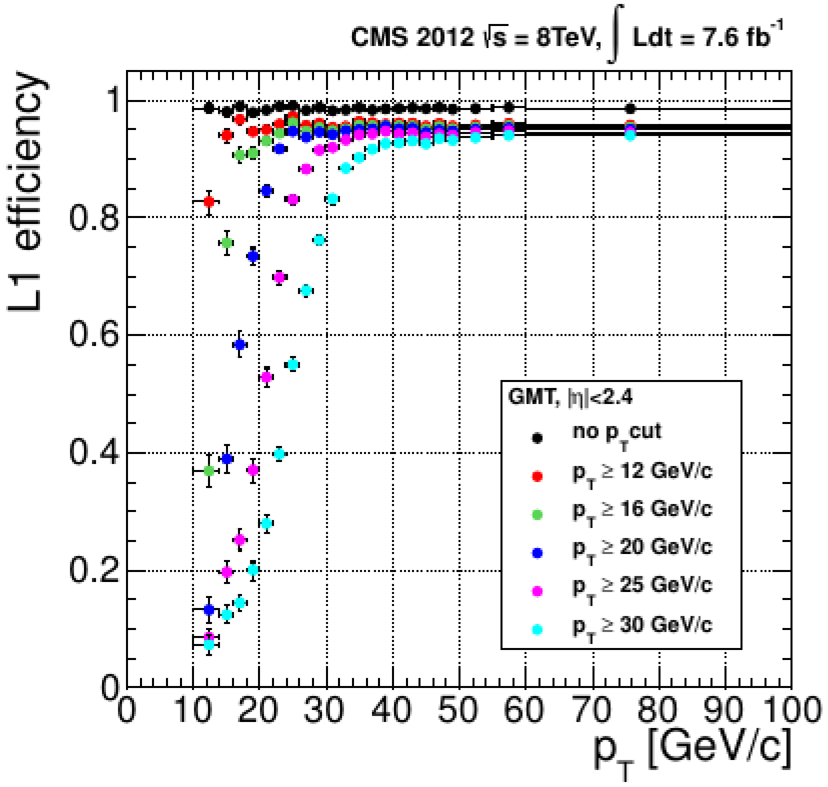
L1T
M. Pellicсioni
L. Apanasevich

Backup slides

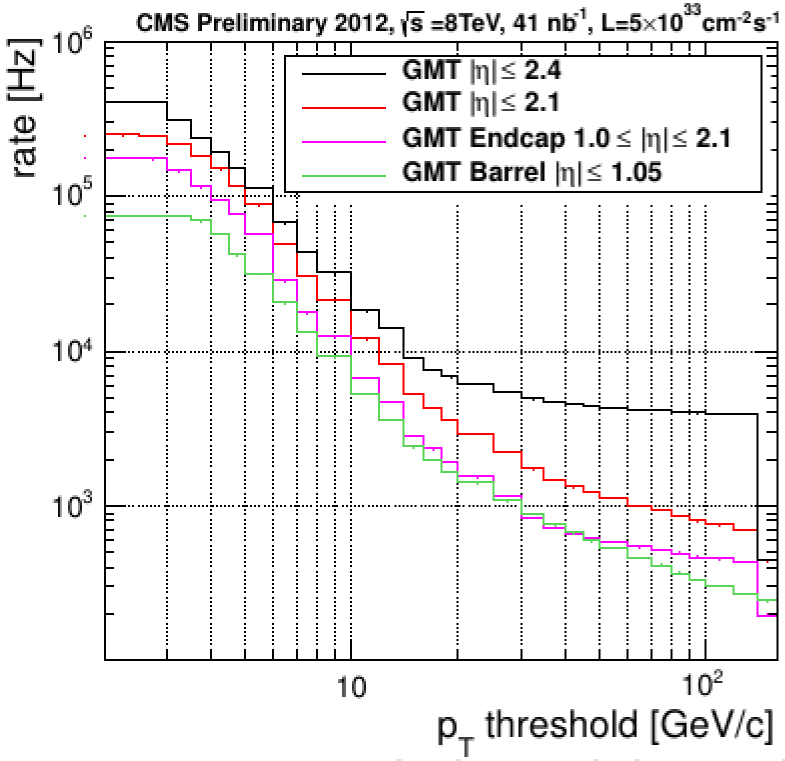
(some) L1 thresholds used in 2012

(Unprescaled) Object	Trigger Threshold (GeV)	Physics
Single muon	16 (14 central)	Searches
Double muon	(10, 0) or (10, 3.5)	Standard Model / Higgs
Double muon, tight	(0, 0) or (3, 0)	Quarkonia / B Physics
Single e/gamma	20 or 22	Standard Model / Searches
Single Isolated e/gamma	18 or 20	Standard Model / Searches
Double e/gamma	(13, 7)	Standard Model / Higgs
Muon + Ele x-trigger	(3.5, 12), (12, 7), (5, 6, 6)	Standard Model / Higgs
Single Jet	128	Standard Model
QuadJet	40	Standard Model /Searches
Six Jet	(6 x 45), (4 x 60, 2 x 20)	Searches
MET	40	Searches
HT	150 or 175	Searches

L1 Muon Trigger (2012)

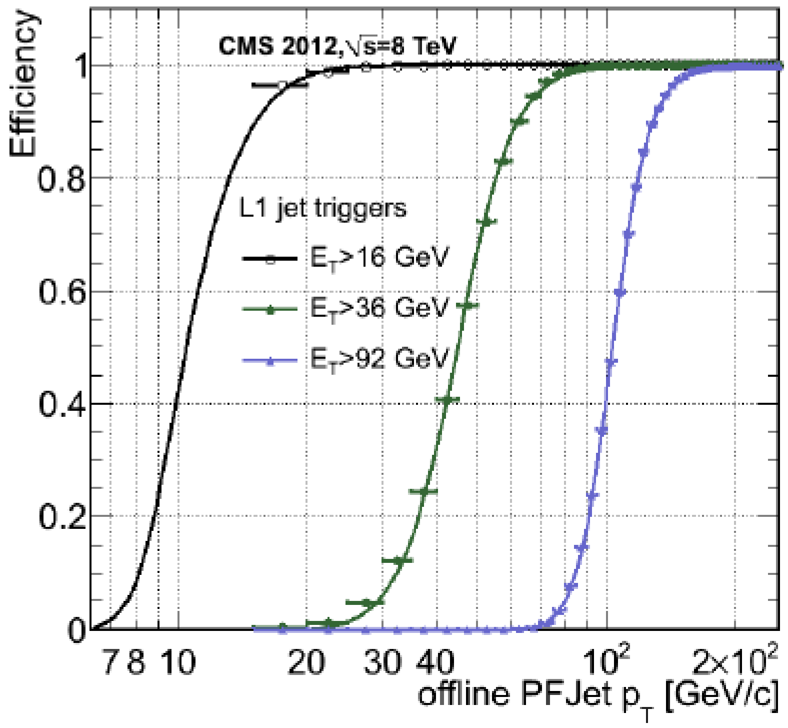


L1 muon efficiency vs.
offline transverse momentum

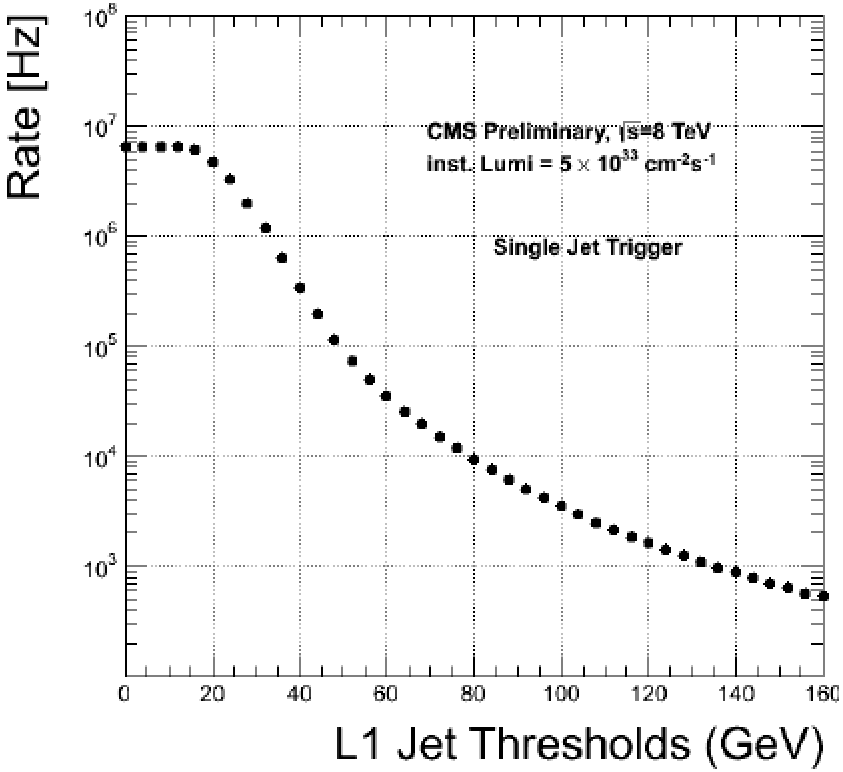


L1 muon rate vs. pT cut

L1 jets (2012)

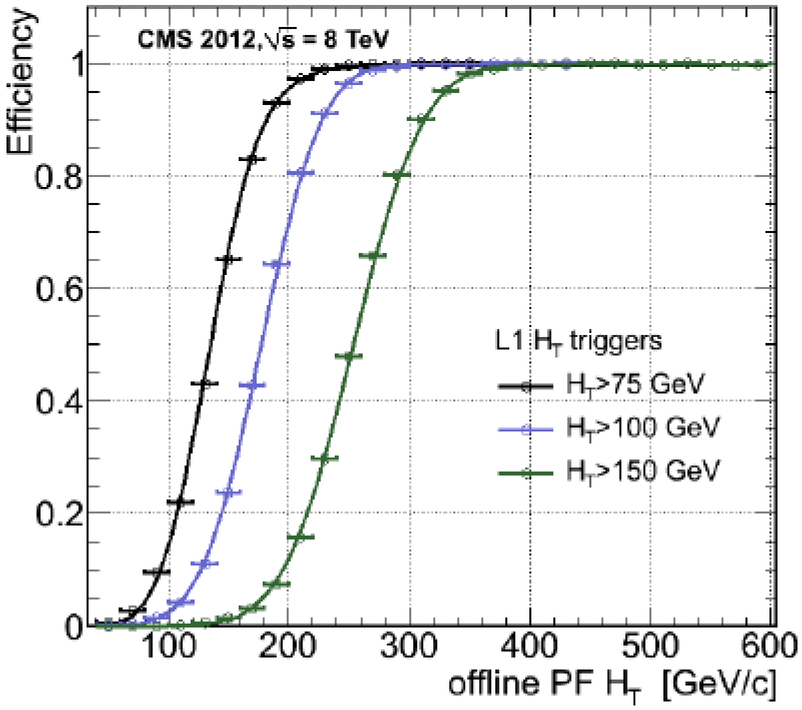


L1 jet efficiency vs.
offline transverse momentum

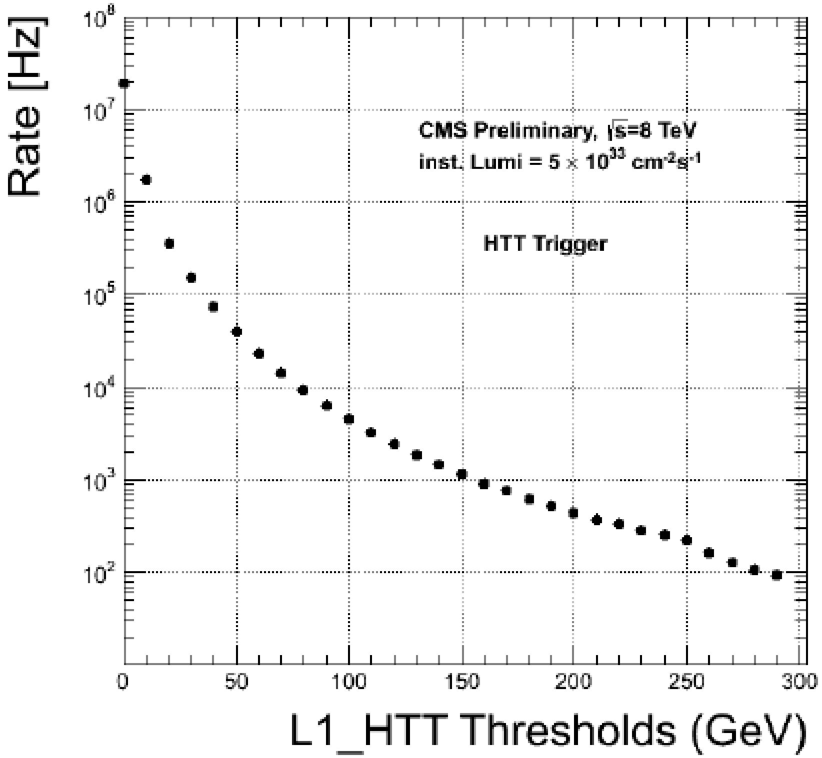


L1 jet rate vs. ET cut

L1 energy sums (2012)



L1 HT efficiency vs. offline HT

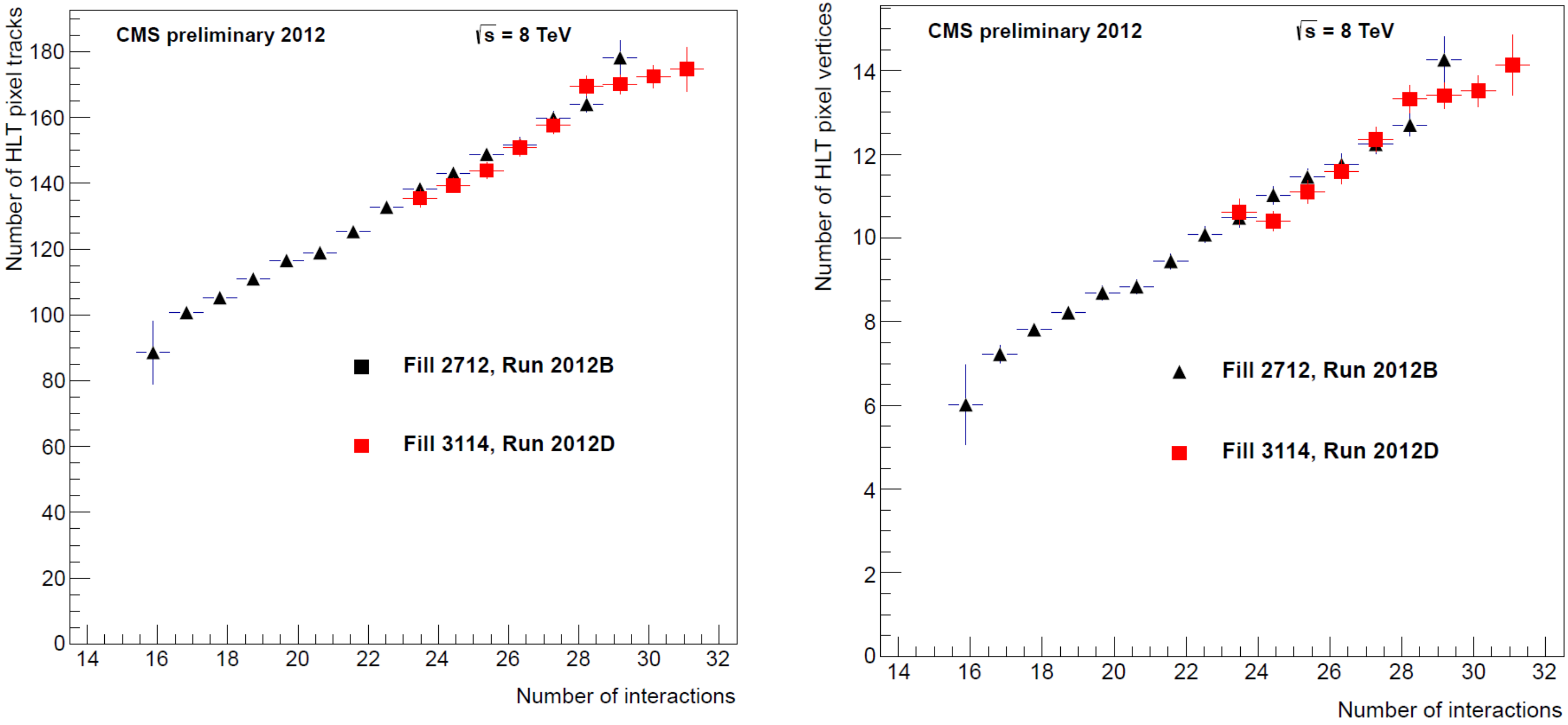


L1 HT rate vs. cut

(some) HLT thresholds used in 2012

(Unprescaled) Object	Trigger Threshold (GeV)	Physics
Single Muon	40	Searches
Single Isolated muon	24	Standard Model
Double muon	(17, 8) [13, 8 for parked data]	Standard Model / Higgs
Single Electron	80	Searches
Single Isolated Electron	27	Standard Model
Double Electron	(17, 8)	Standard Model / Higgs
Single Photon	150	Searches
Double Photon	(36, 22)	Higgs
Muon + Ele x-trigger	(17, 8), (5, 5, 8), (8, 8, 8)	Standard Model / Higgs
Single PFJet	320	Standard Model
QuadJet	80 [45 for parked data]	Standard Model / Searches
Six Jet	(6 x 45), (4 x 60, 2 x 20)	Searches
MET	120 [80 for parked data]	Searches
HT	750	Searches

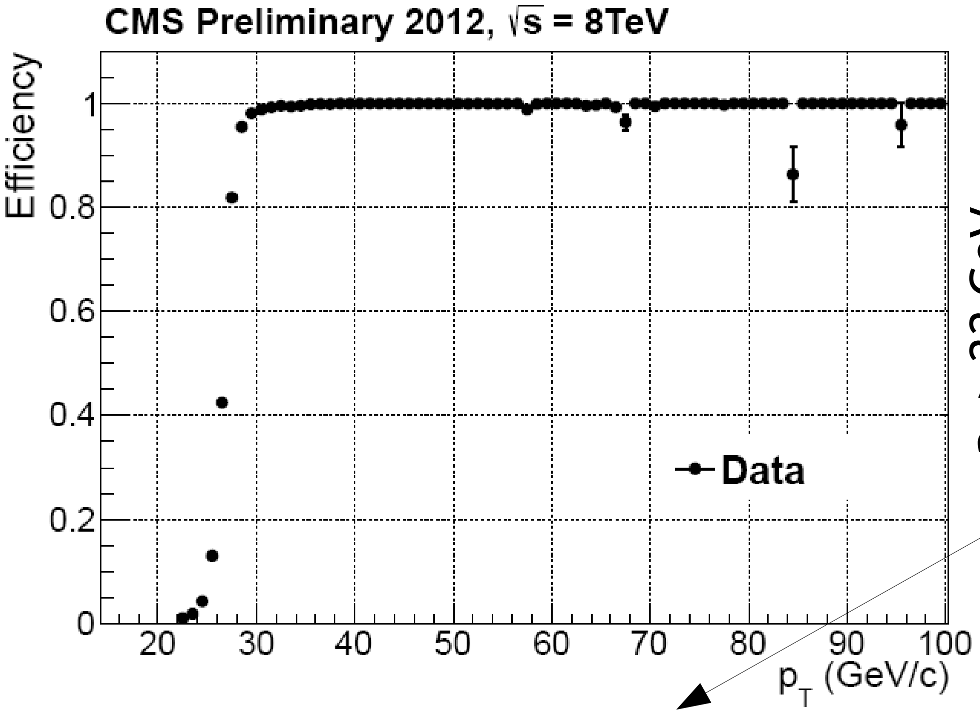
HLT tracking (2012)



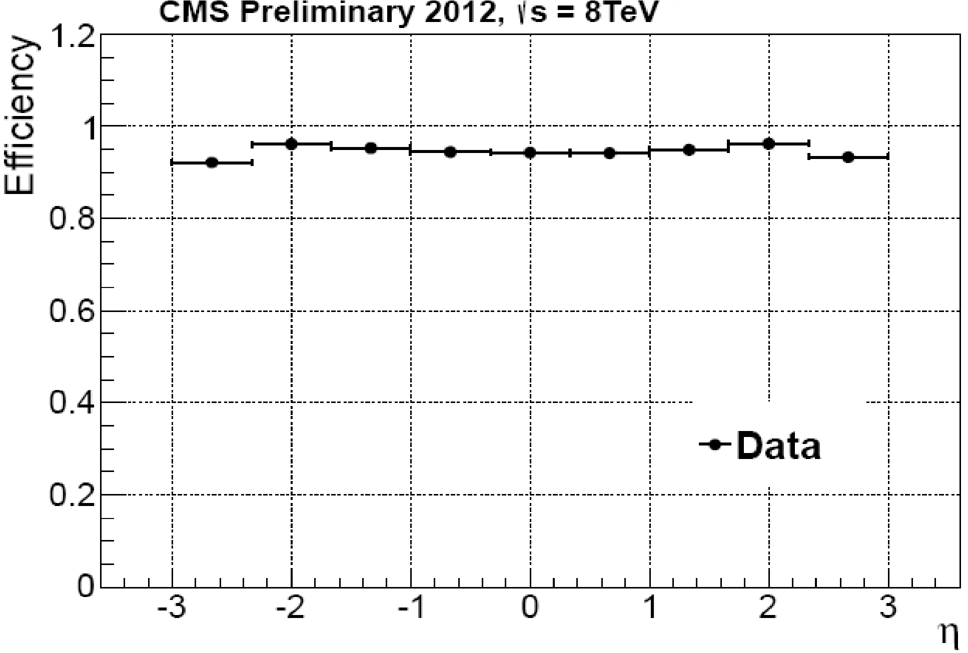
linearity of the HLT tracking performance vs. pileup, measured by
the number of reconstructed (pixel) tracks and vertices vs. the number of interactions

HLT photons and electrons (2012)

HLT photon reconstruction efficiency
vs. offline p_T and η

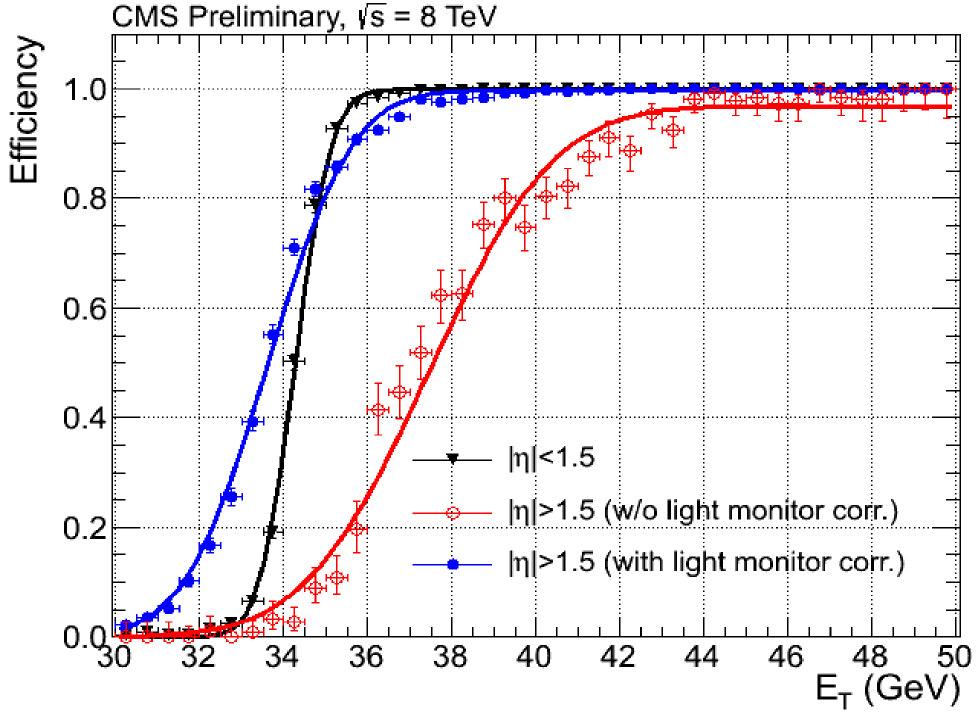


$p_T > 22$ GeV



$p_T > 22$ GeV

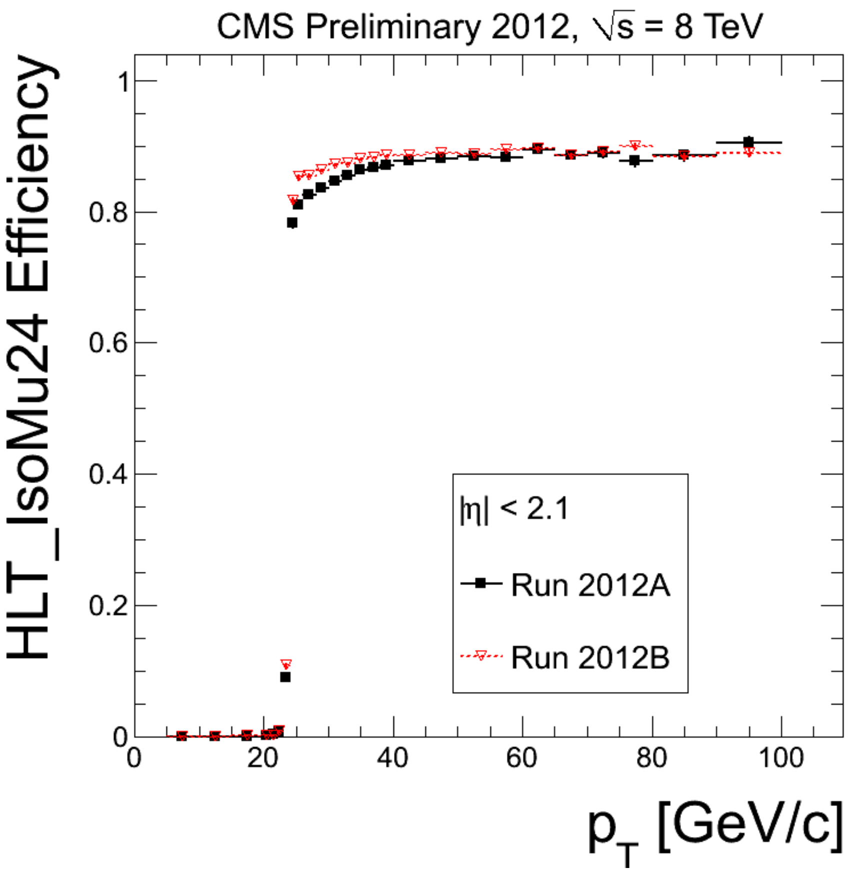
HLT electron efficiency vs. offline p_T
in the **barrel** and **endcap**

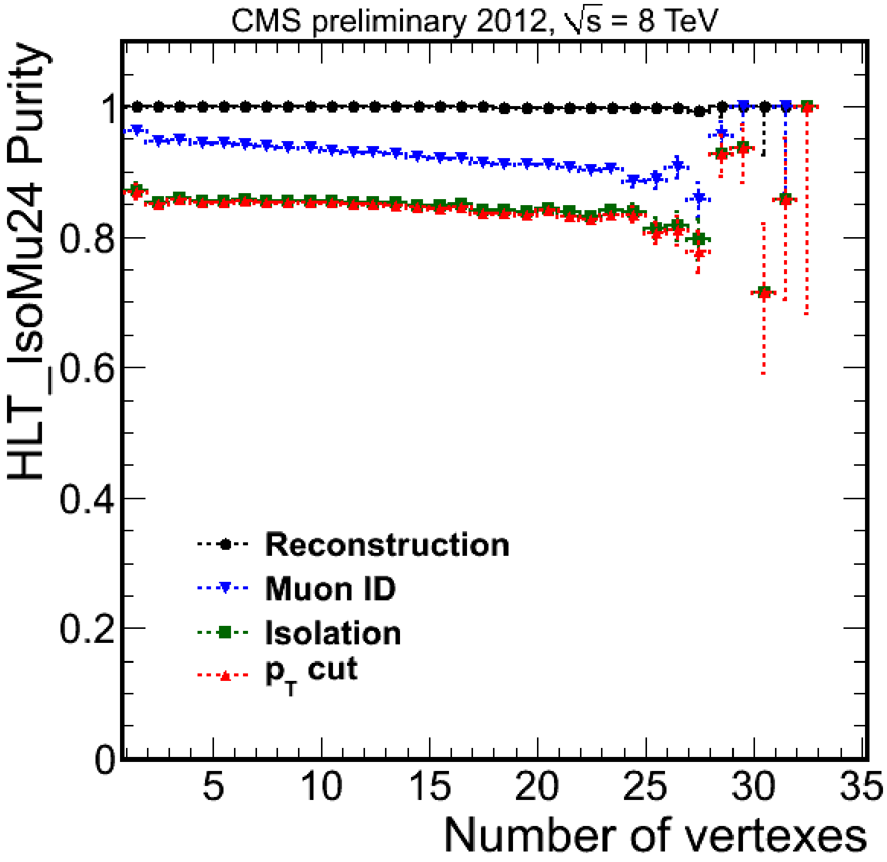


$p_T > 33$ GeV

HLT muons (2012)

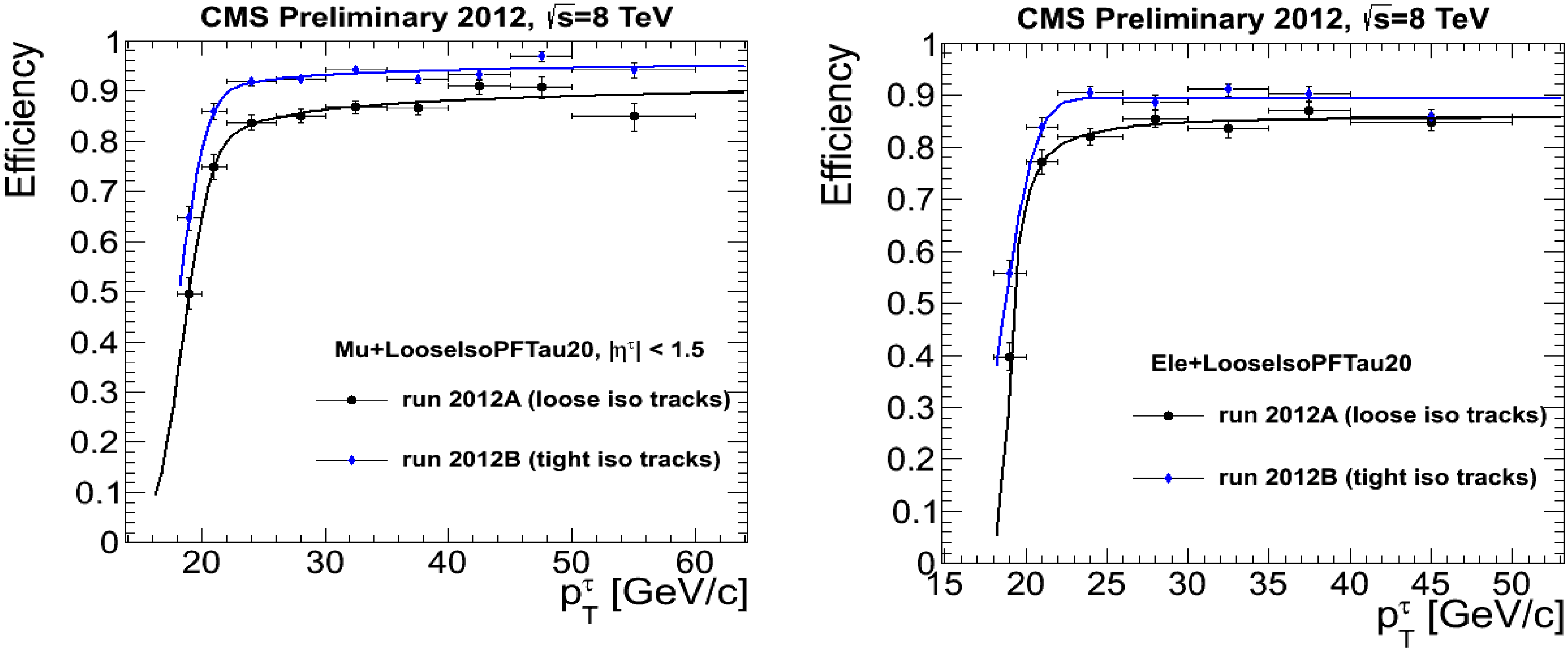
HLT isolated muon efficiency vs.offline p_T





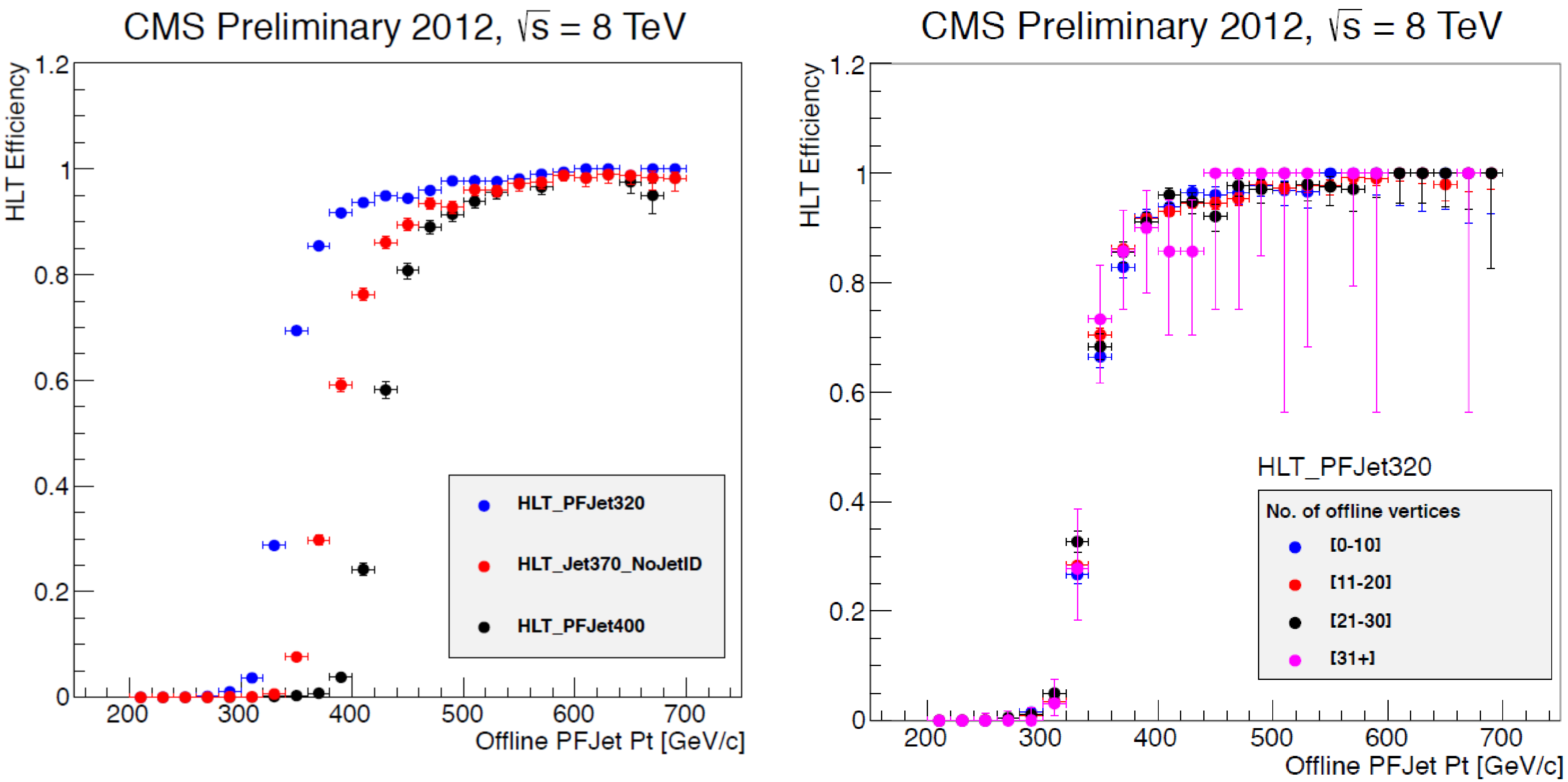
HLT isolated muon purity vs.pile-up (number of reconstructed vertices)

HLT taus (2012)



HLT tau reconstruction efficiency vs.offline p_T
measured in $Z \to \tau\tau, \tau \to \mu$ and $Z \to \tau\tau, \tau \to e$ events

HLT jets (2012)

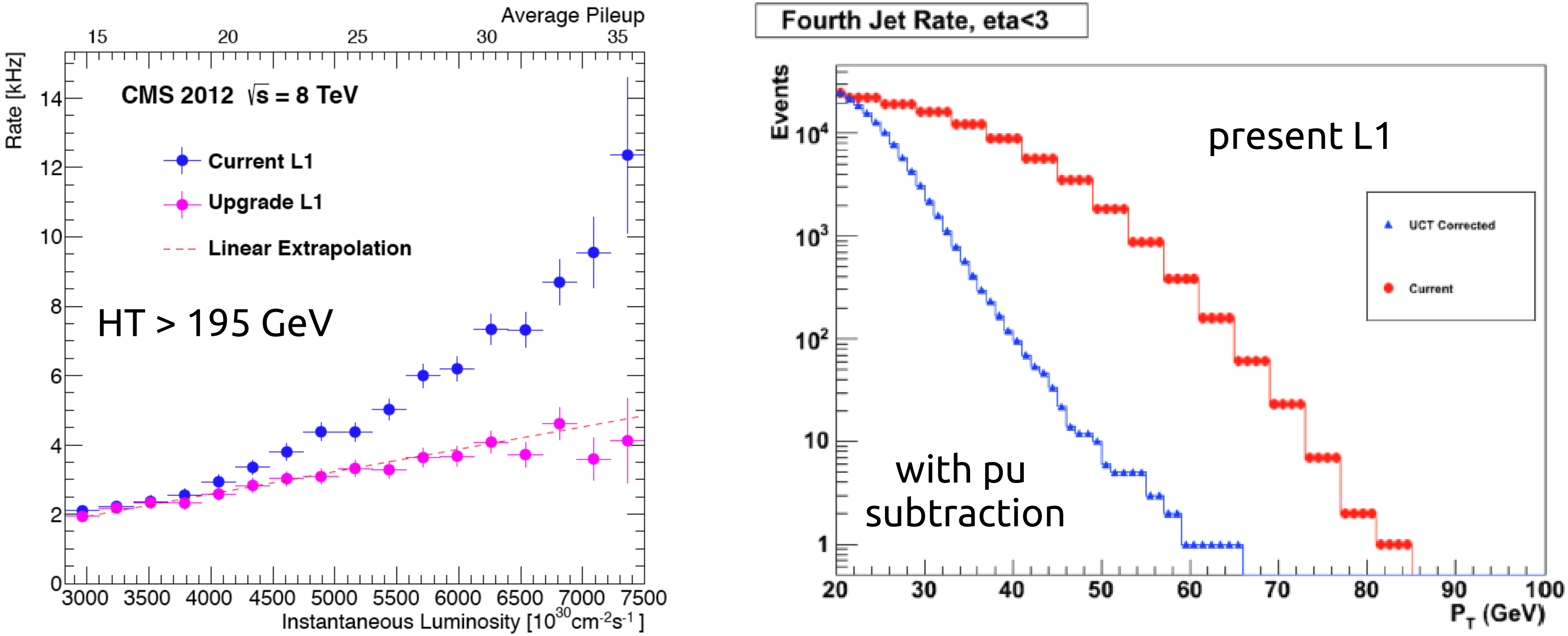


HLT jet efficiency vs. offline p_T , for different jet algorithms and different pile-up conditions

L1 Trigger upgrade for 2015

- 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
    - improve the LUTs used for track building and matching

PU subtraction at L1 (2015)



HT > 195 GeV

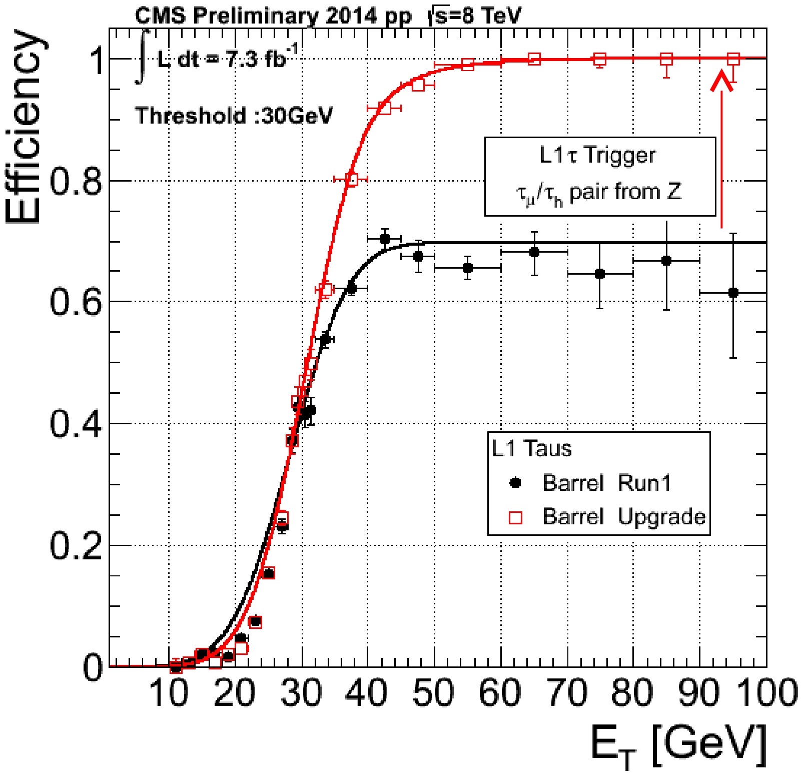
present L1

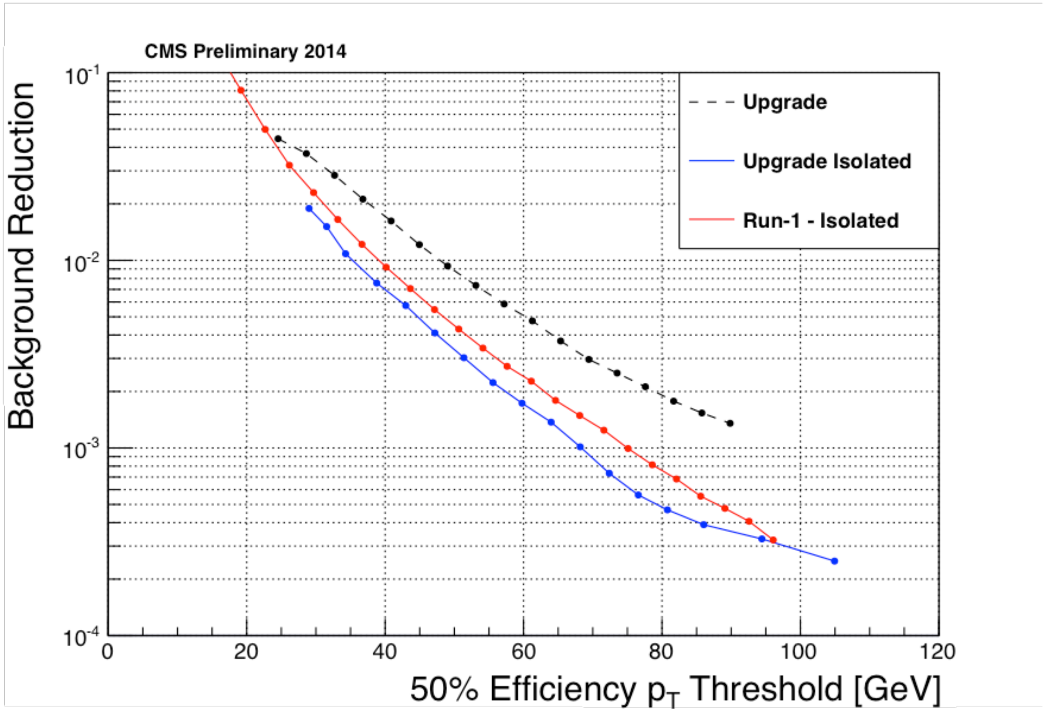
with pu subtraction

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

Tau L1 Trigger (2015)

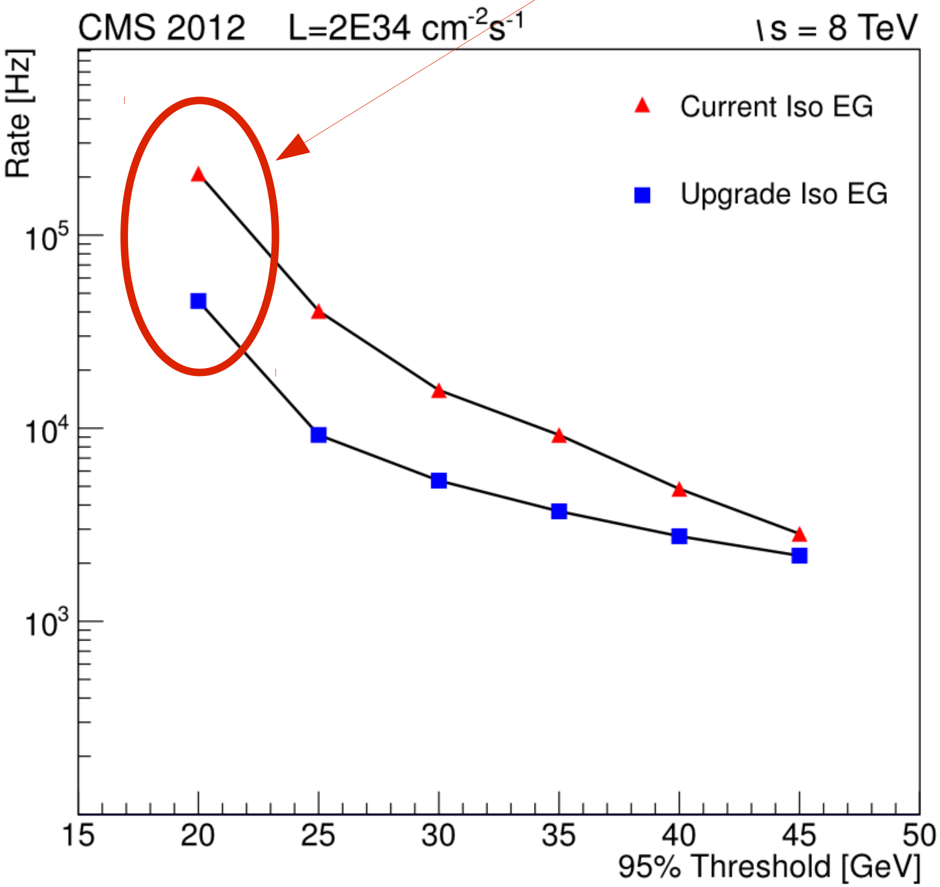
- Hadronic tau trigger with tower level granularity
  - Efficiency significantly improved over Run 1
- μ+τ trigger
  - 30% rate reduction and higher efficiency

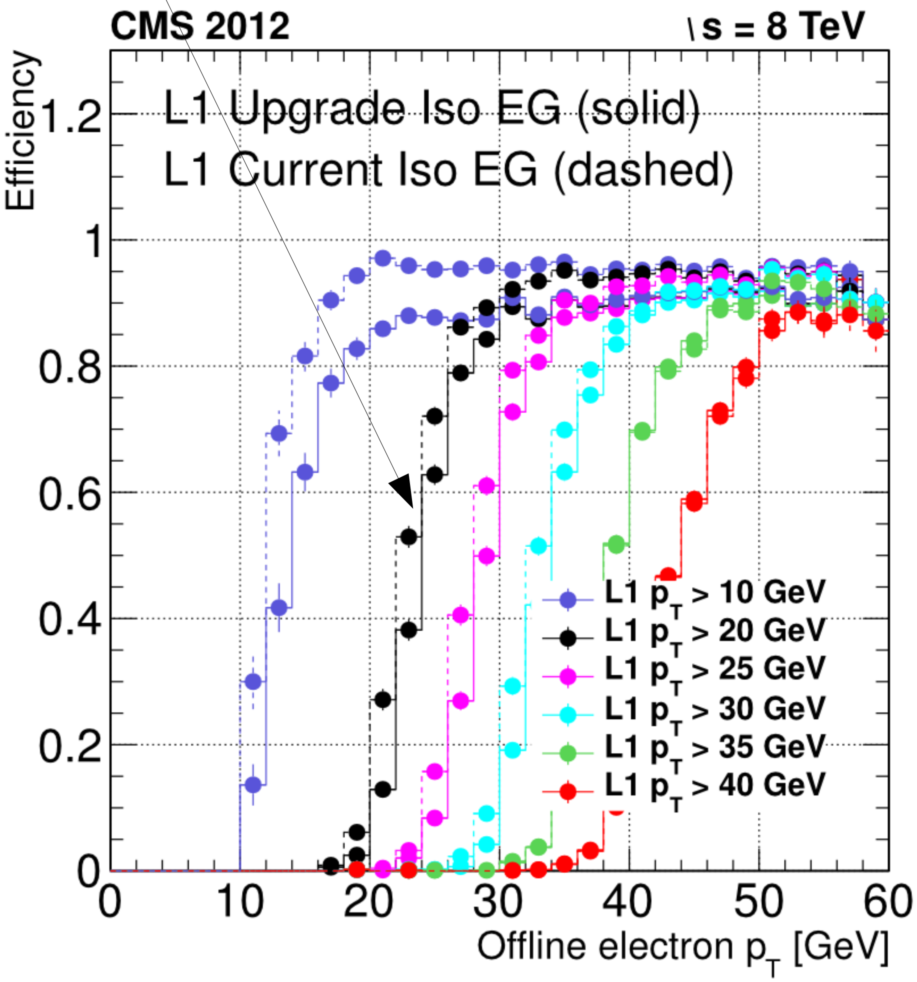




E/gamma L1 Trigger (2015)

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



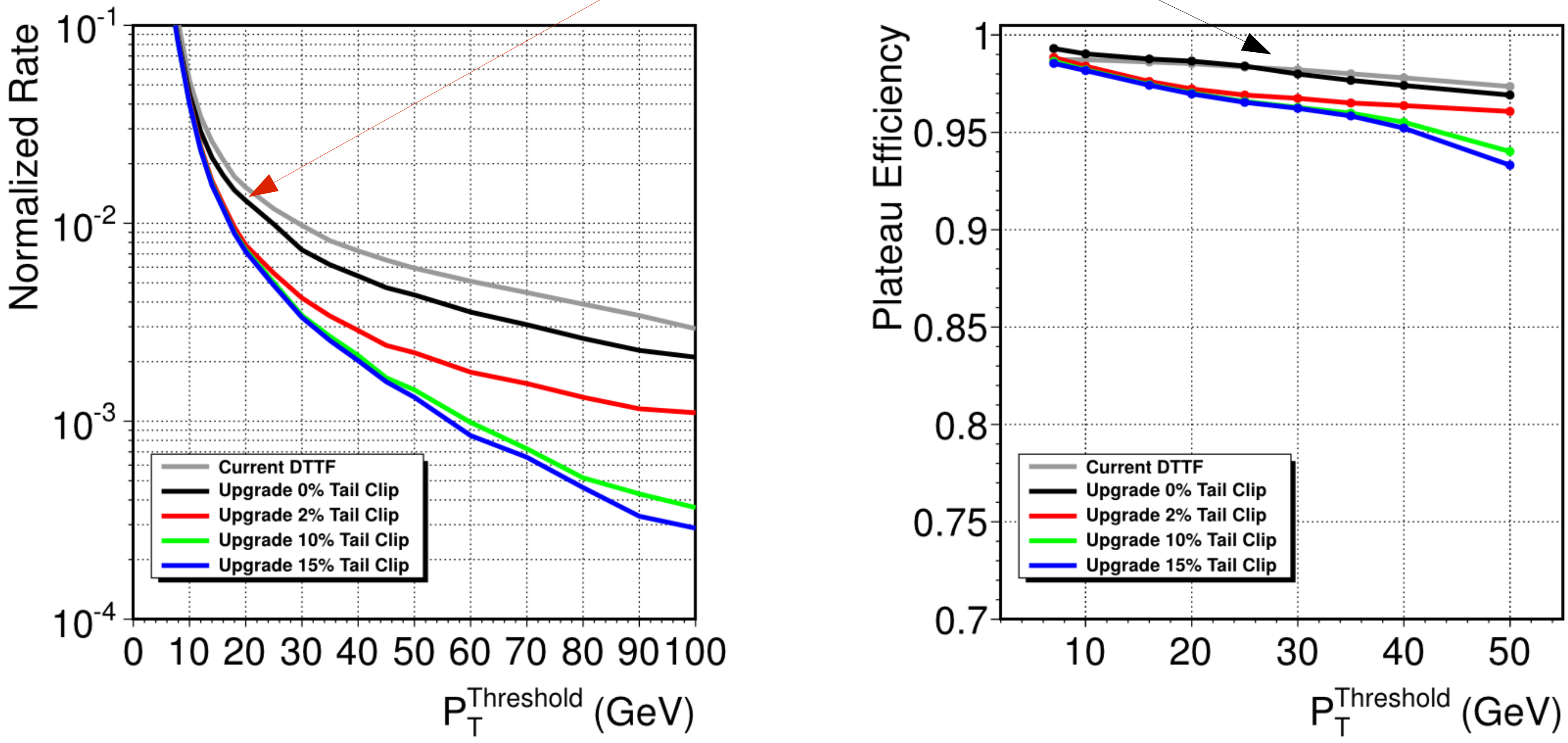


L1 Trigger upgrade for 2016

- 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 (2016)

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



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

Trigger upgrade for HL-LHC

- scenario for 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 2015-2020 **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

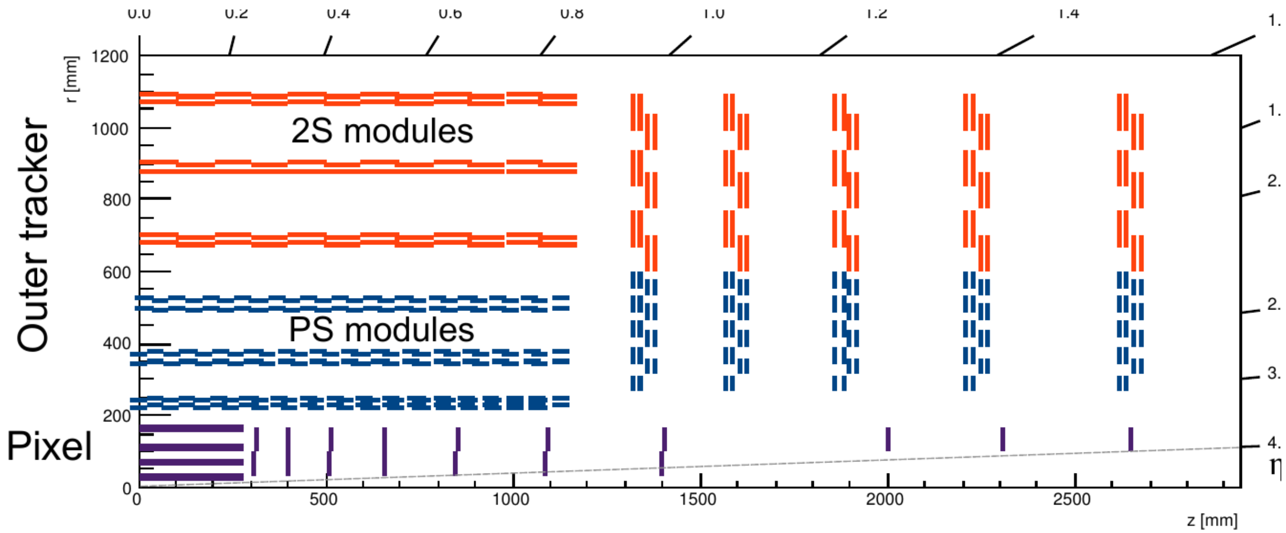
L1 Trigger upgrade for HL-LHC

- 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 thresholds
    - 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 …

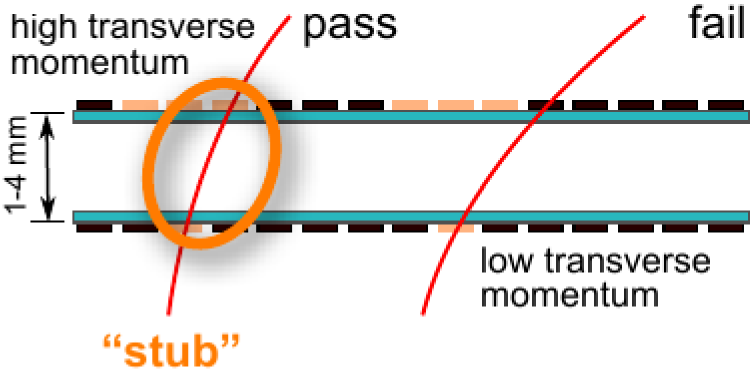


- … able to distinguish **high p_T** and **low p_T** and tracks

high p_T track (> 2 GeV)

small bending arm

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



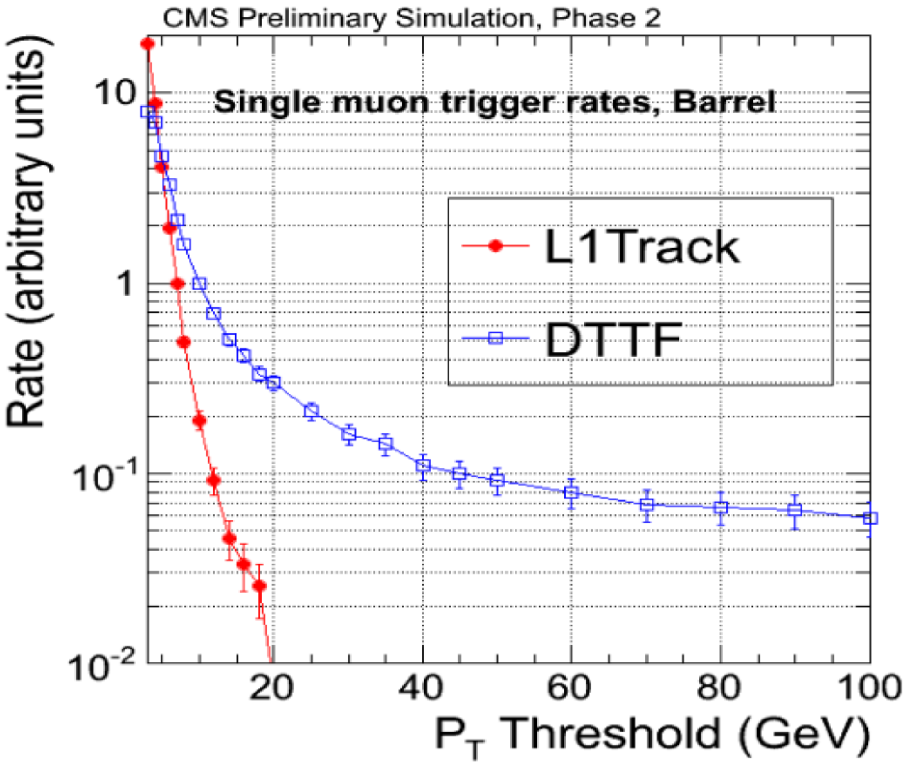
low p_T track (< 2 GeV)

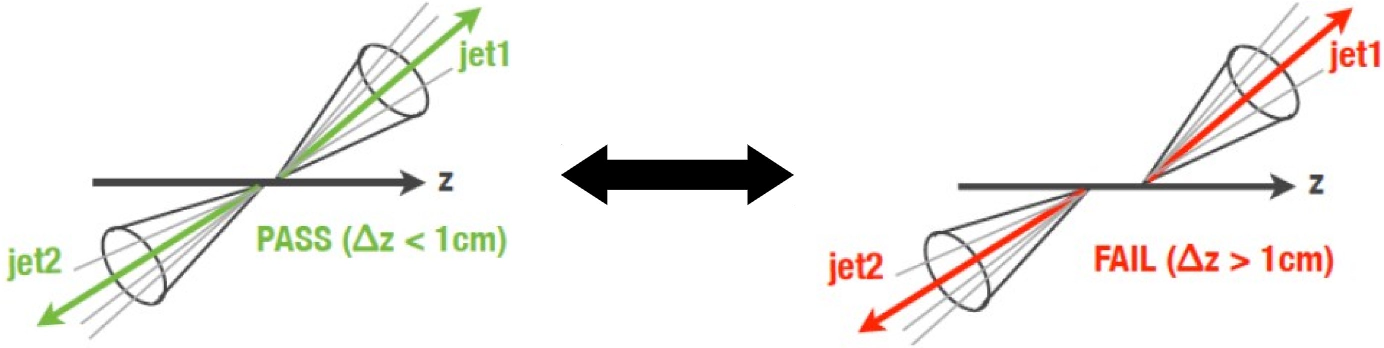
large bending arm

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





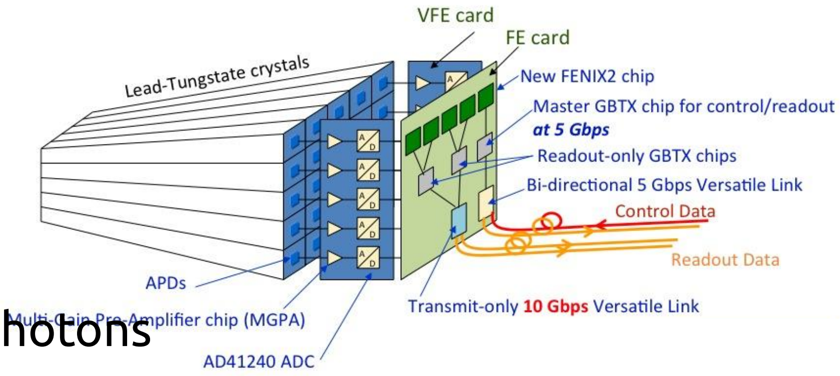
Tracking Trigger

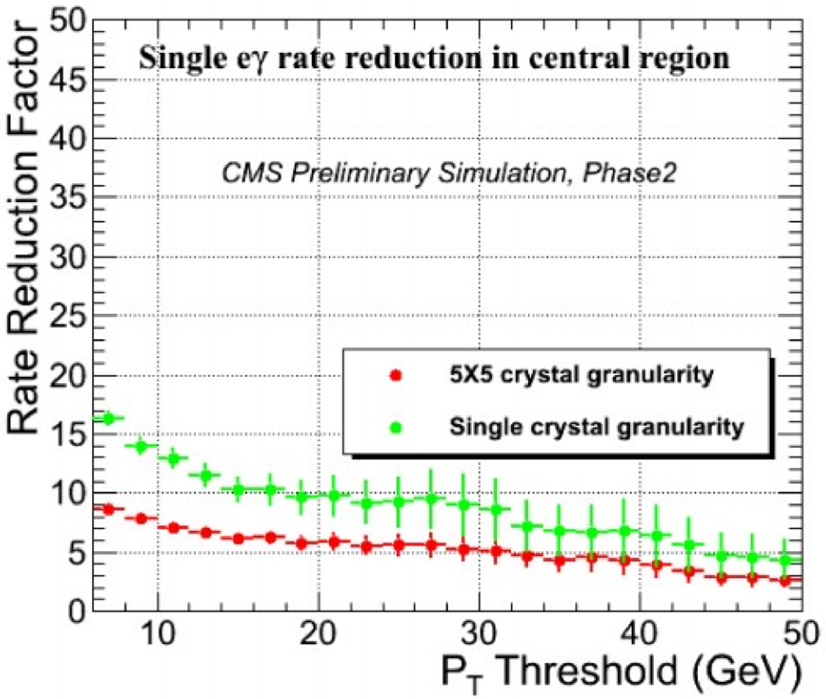
- first studies on the impact of a tracking trigger:

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) (| η | < 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