Triggers, Data Acquisition and Data Processing: Part 1

HCPSS 2014

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Yale University

Definitions

Trigger

Data Acquisition

Data Preparation

A Note On Pedagogy…

apple	a_pl_
friend	frie_d
cranky	c_anky
yellow	ye_lo_
breath	brea_h

Definitions

Trigger

Selects (filters) wanted events

Data Acquisition

Delivers and stores wanted events

Data Preparation

Prepares data for analysis

Documentation

ALICE

Technical Design Report https://edms.cern.ch/document/456354/2

ATLAS

ATLAS HLT, DAQ and DCS Technical Design Report
http://atlas-proj-hltdaqdcs-tdr.web.cern.ch/atlas-proj-hltdaqdcs-tdr/

Overall ATLAS Technical Design Report
http://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/TDR/access.html

CMS

Trigger System Technical Design Report
https://cds.cern.ch/record/706847/files/cer-002248791.pdf

Software and Detector Technical Design Report
https://cds.cern.ch/record/922757/files/lhcc-2006-001.pdf

LHCb

Trigger System Technical Design Report
http://cds.cern.ch/record/630828/files/lhcc-2003-031.pdf

Technical Design Report
http://cds.cern.ch/record/630827/files/lhcc-2003-030.pdf

Really? All that documentation?

These TDRs represent just a fraction of the information available.

Beware the differences between design and implementation – always best to find performance documents.

Some of the text may be juicier than you expect…

At CERN, the most appealing new methods and formalisms that appeared over the years have been tried out but, in practice, all the Software Engineering methods introduced so far in our environment have not delivered the expected benefits. Of course, people who have invested money, effort, and good will have had some reticence in admitting the truth. In most of the cases, the simple fact that a software-engineering method had been used for part of a project was considered as a proof of success in itself, no matter how marginal the real contribution to the software of an experiment has been.

Designing a Trigger/DAQ System

<u>The Incomplete Standard List of Questions</u>

Physics: What measurements do I want to do with the detector?

Accelerator Conditions: How much time between collisions? How many overlapping interactions? Radiation doses to electronics?

Detector: Number of channels? Length of time for readout of each sub-detector?

Hardware capabilities: How many menu items? What algorithms are fast enough?

Software Constraints: How long do the algorithms take to run? How much information do they need for reasonable performance?

Political and budget constraints: Which group/country builds what? How much will it cost?

<u>The specific:</u>

"Constraints of floor space and cooling capacity, in particular in the underground experimental cavern and adjoining service rooms, limit the number of racks available to the HLT/DAQ system."

ATLAS DAQ TDR

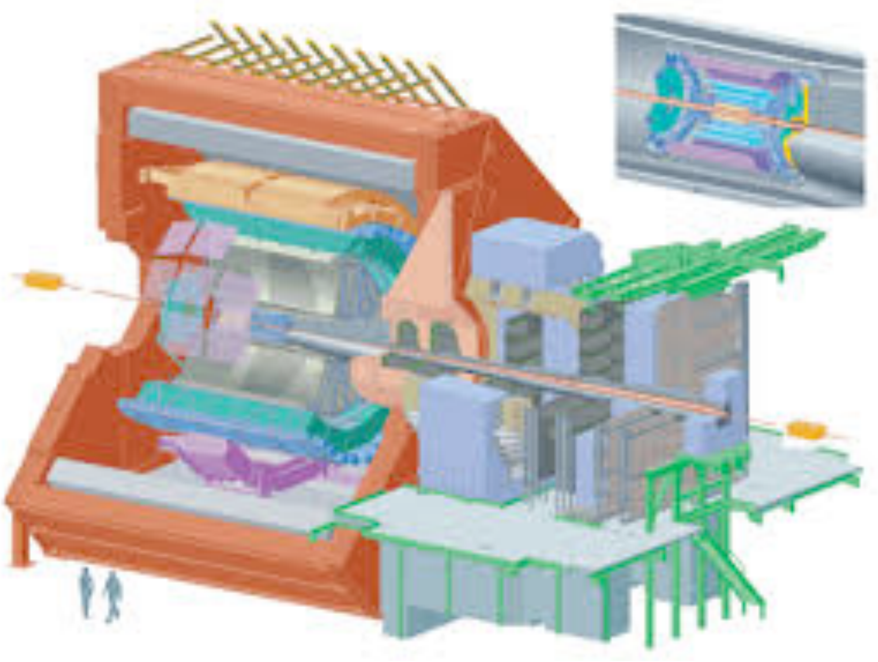
A Staged-Approach

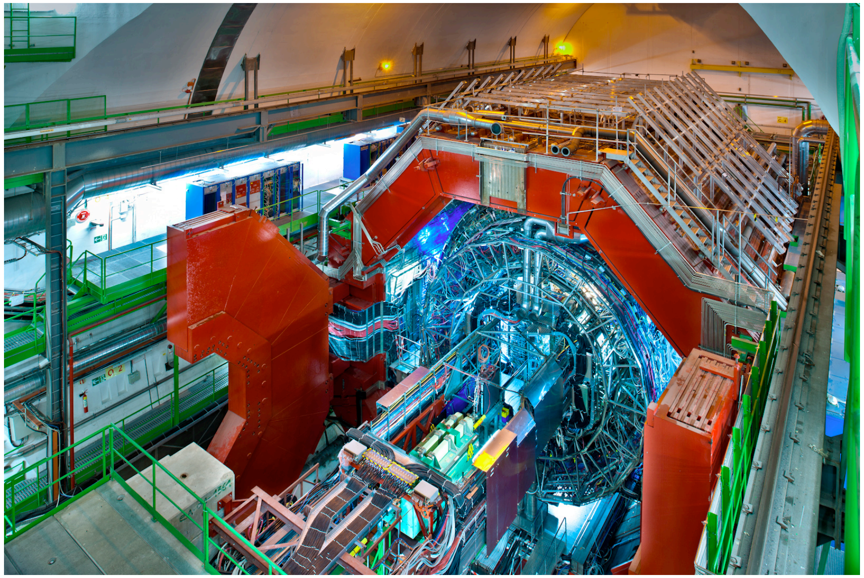
Successive layers of triggers, with more complete information and more time

Hardware Triggers
with local information → Software Triggers
with more time and
more information

**Reject early
and
reject often!**

ALICE





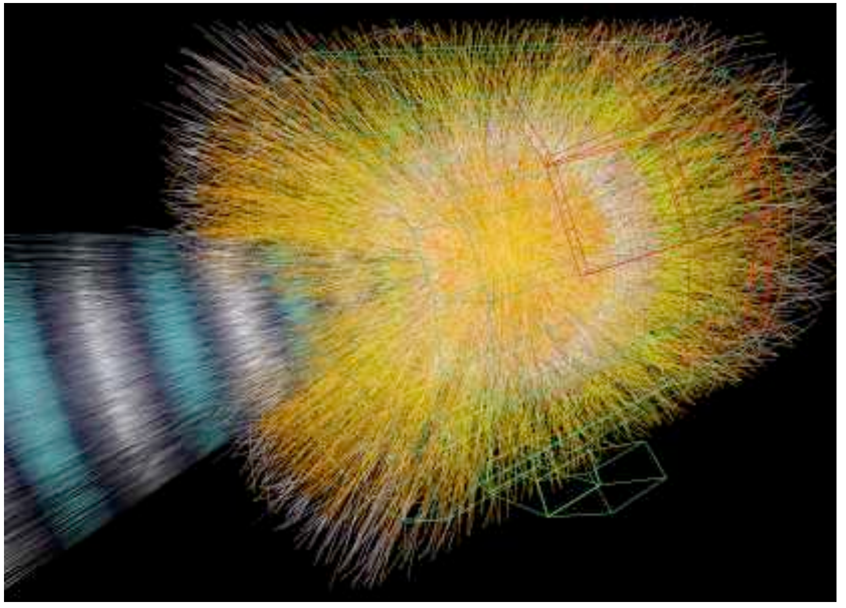
ALICE Trigger/DAQ Design

Expected Event Size from Different Running Modes

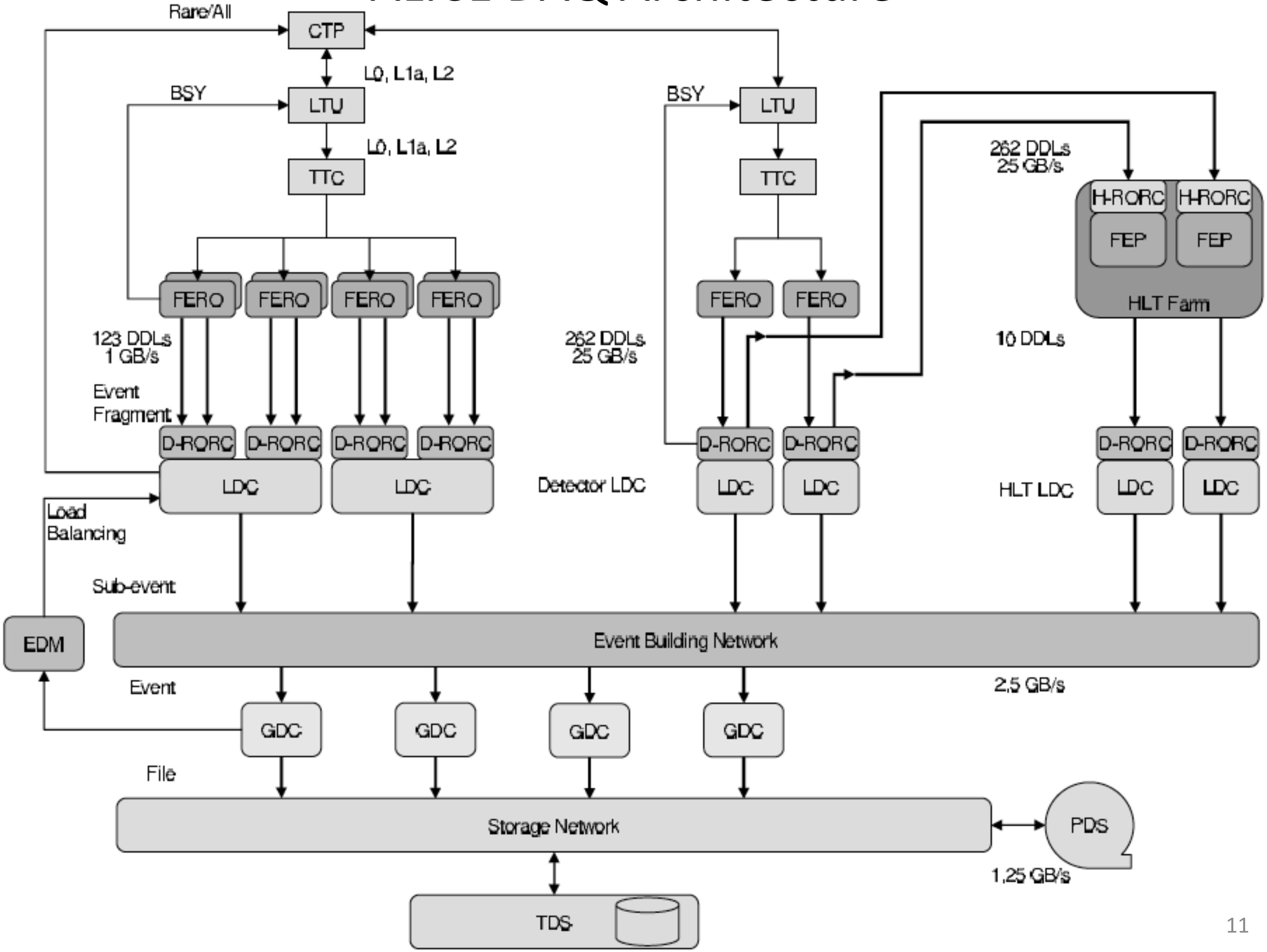
Detector	pp (kB)	Pb–Pb (MB)
ITS Pixel		0.140
ITS Drift	1.8	1.500
ITS Strips		0.160
TPC	2450.0	75.900
TRD	11.1	8.000
TOF		0.180
PHOS		0.020
HMPID		0.120
MUON		0.150
PMD		0.120
Trigger		0.120
Total	2500	86.500

Goal: Be able to run in three modes

- DAQ-only
- DAQ + HLT Active
- DAQ + HLT Enabled



ALICE DAQ Architecture



Field Guide: Reading the flow Diagrams

Define the acronyms.

Follow the event fragments in DAQ and in the trigger.

Are data fragments pushed or pulled through the system?

At what stage are events assembled (built)?

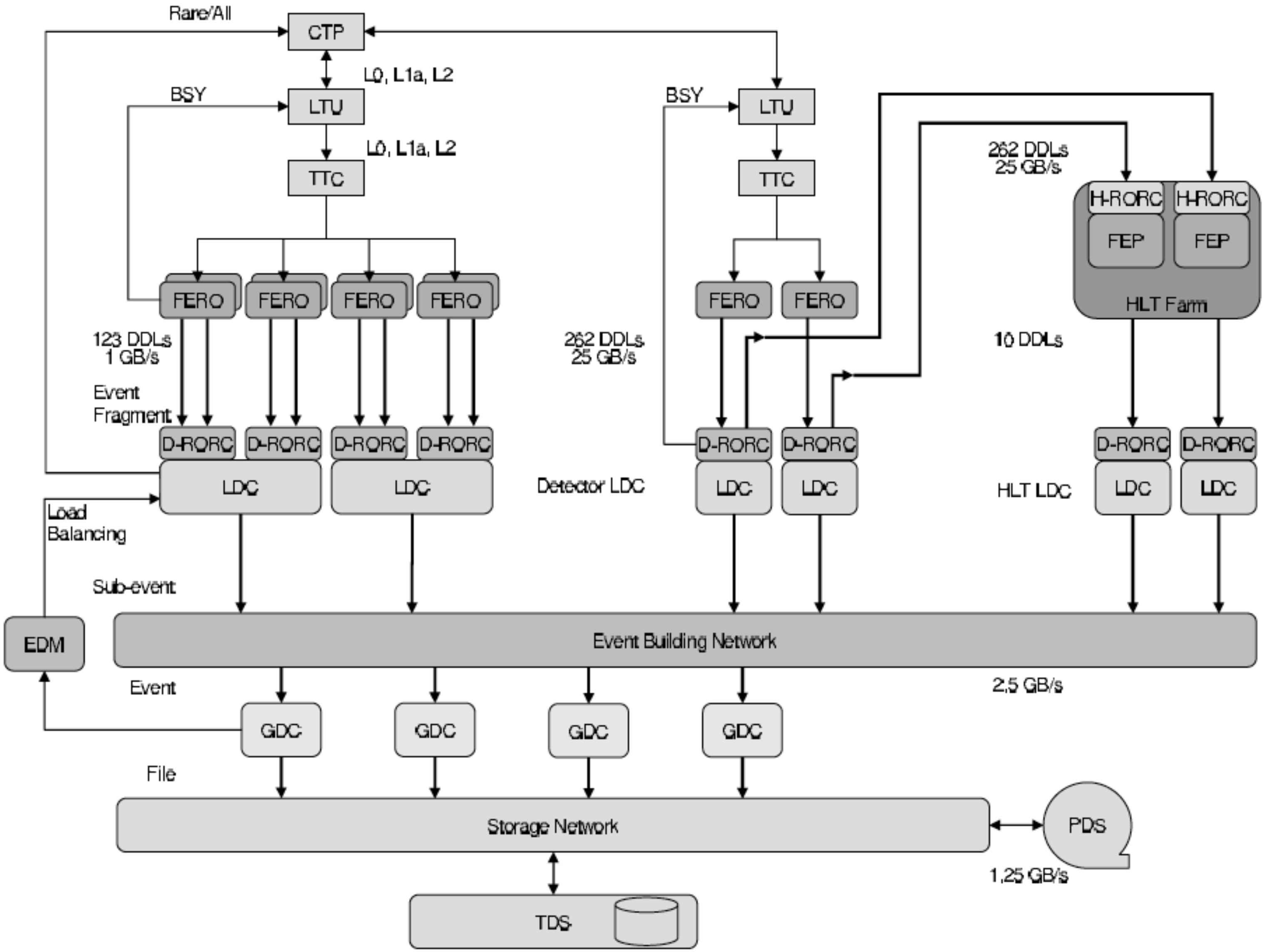
Where is the brain of the trigger?

What are the bandwidth limitations?

What are the timing requirements?

What rejection factor is required at each level?

ALICE DAQ Architecture



CTP: Central Trigger Processor

LTU: Local Trigger Unit

TTC: Timing, Trigger and Control

FERO: Front-end readout

DDL: Detector data links

D-RORC: DAQ Readout Card

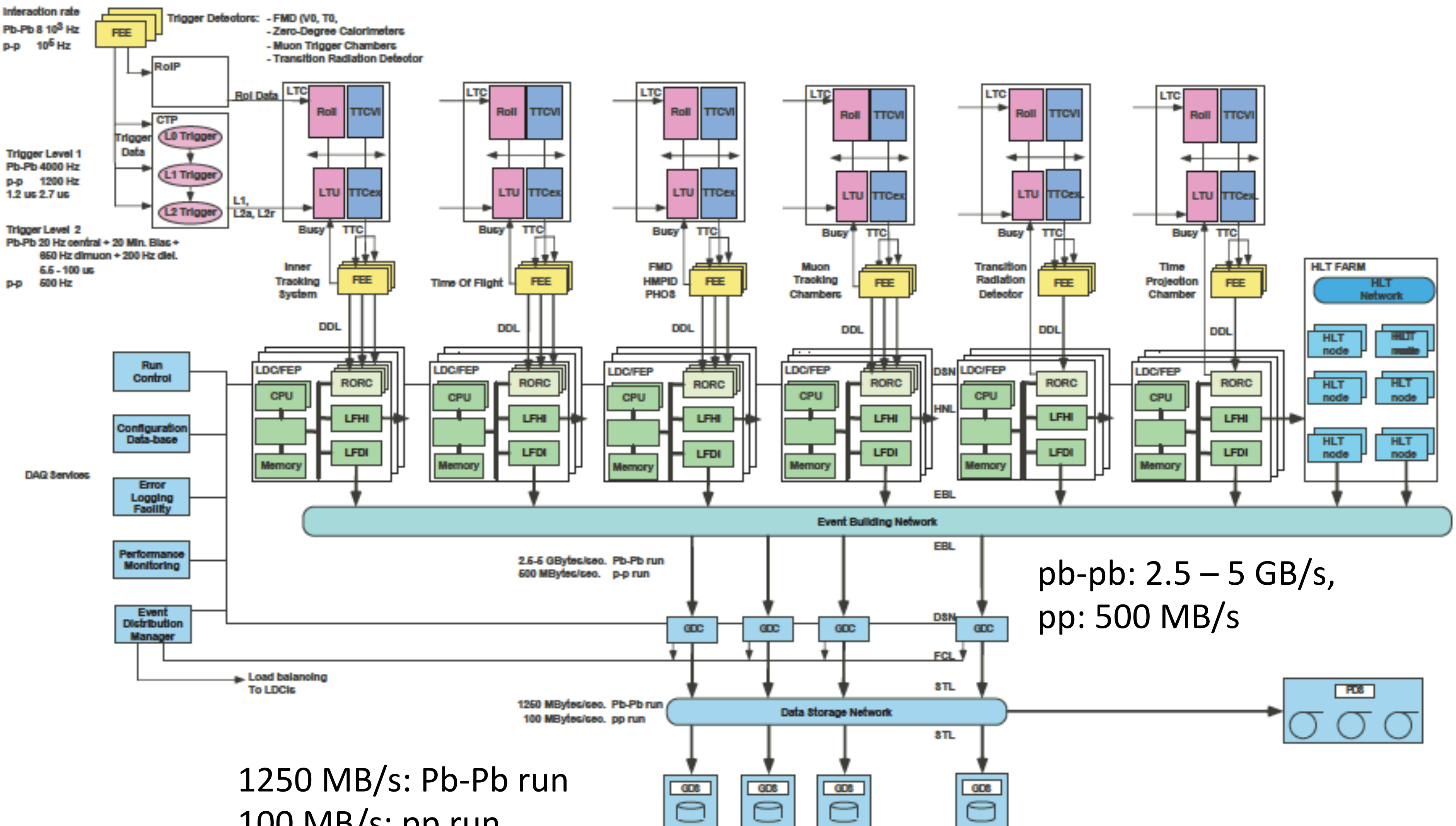
LDC: Local Data Concentrators (PCs)

GDC: Global Data Concentrators

EDM: Event Destination Manager

PDS: Permanent Data Storage

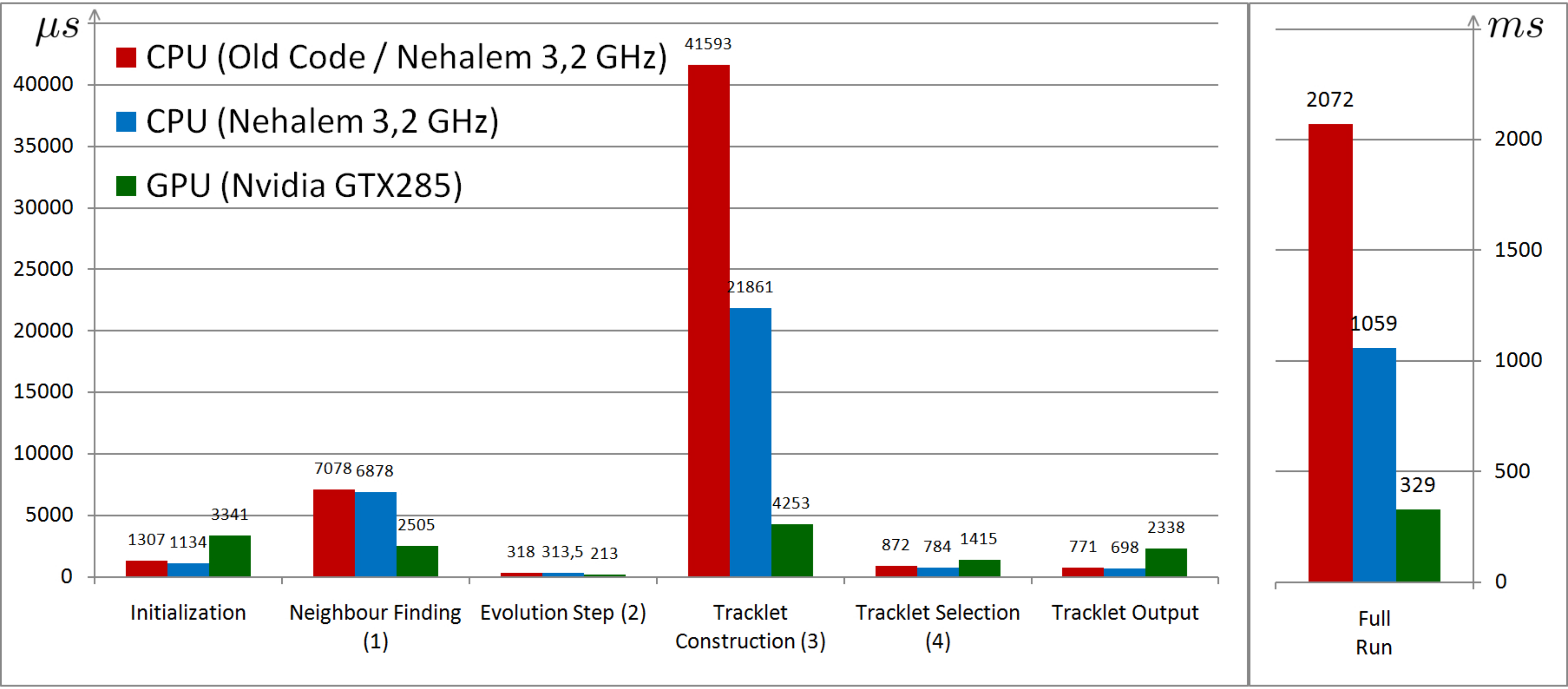
pb-pb: Interaction Rate of 1 X 10^3 Hz, L1 Accept of 4000 Hz
pp: Interaction Rate of 1 X 10^6 Hz, L1 Accept 1000 Hz



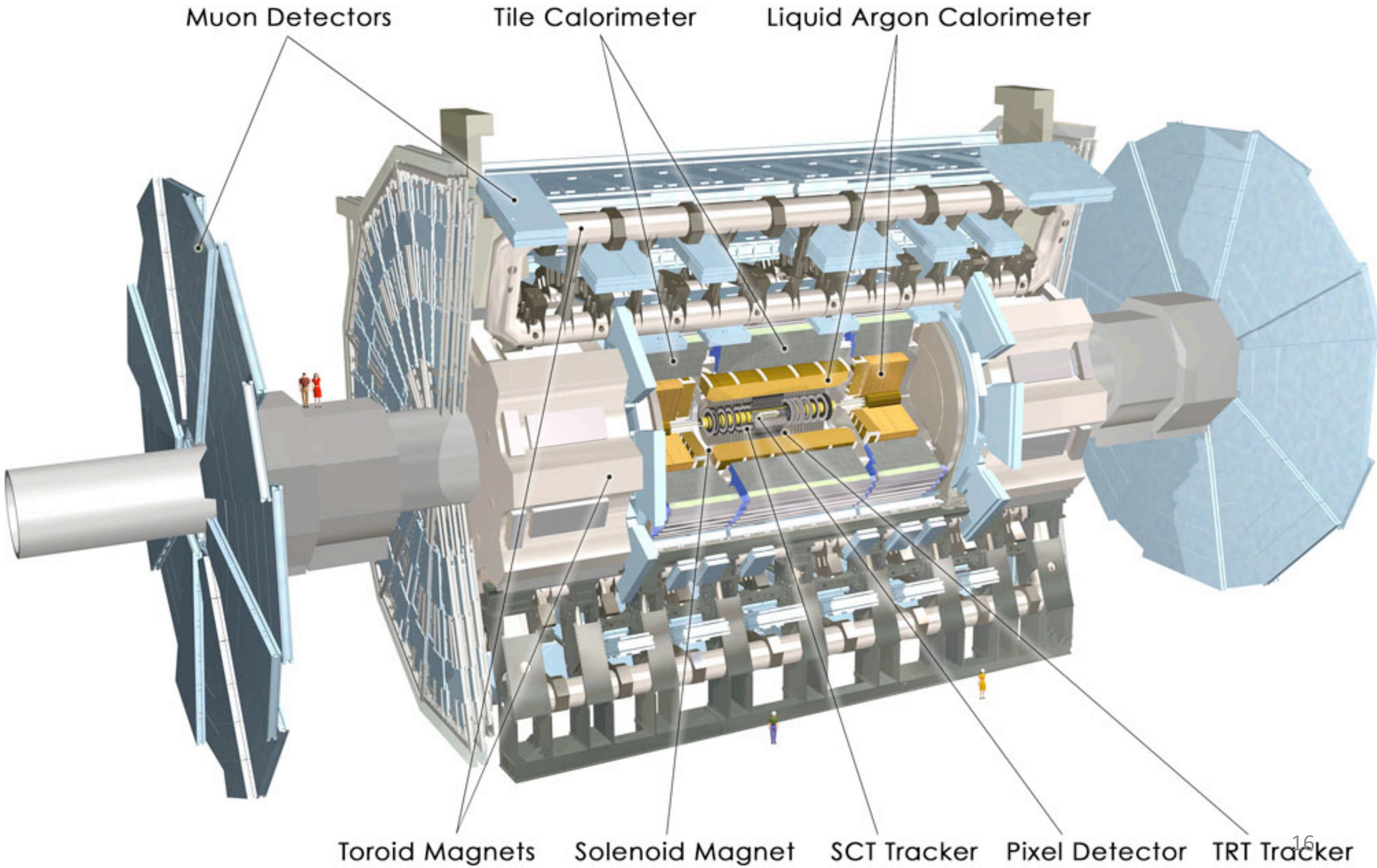
pb-pb: 2.5 – 5 GB/s,
pp: 500 MB/s

1250 MB/s: Pb-Pb run
100 MB/s: pp run

ALICE Tracking on GPUs (Graphics Processing Unit)



ATLAS


Muon Detectors
Tile Calorimeter
Liquid Argon Calorimeter
Toroid Magnets
Solenoid Magnet
SCT Tracker
Pixel Detector
TRT Tracker

ATLAS 3-Level Trigger System

Level 1
Hardware Trigger
Latency: < 2.5 μs
Rate Reduction: 20 MHz -> 75 kHz

Level 1 passes along not just the thumbs up (something you've defined interesting has happened!) but also the RoI - where that event of interest occurred in the detector.

Level 2
Software Trigger
Time per event: 75 ms
Rate Reduction: 75 kHz -> 6.5 kHz

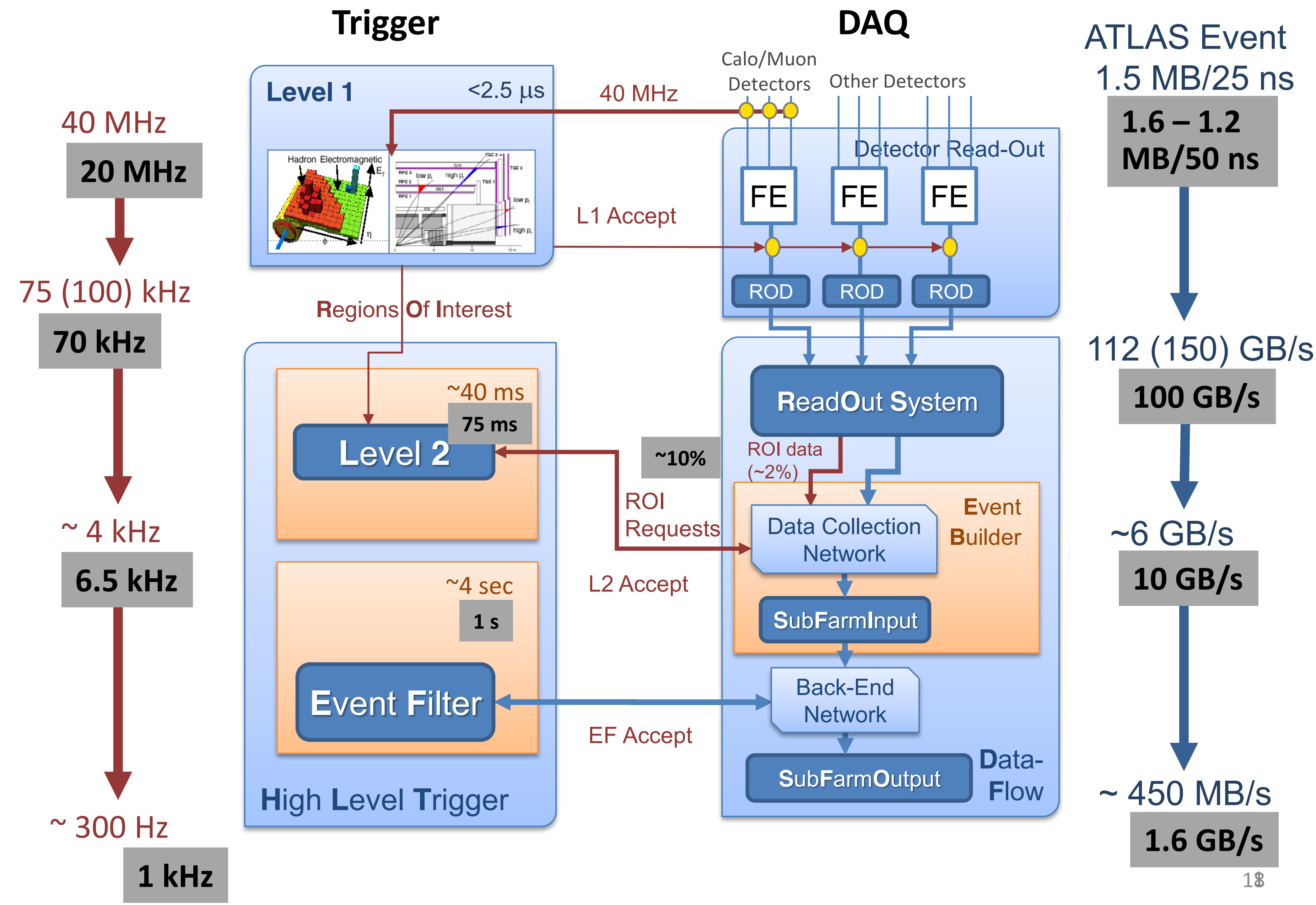
The entire event is assembled and available at the stage of the final trigger level.

Event Filter
Software Trigger
Time per event: 4 s
Rate Reduction: 6.5 kHz -> 1 kHz

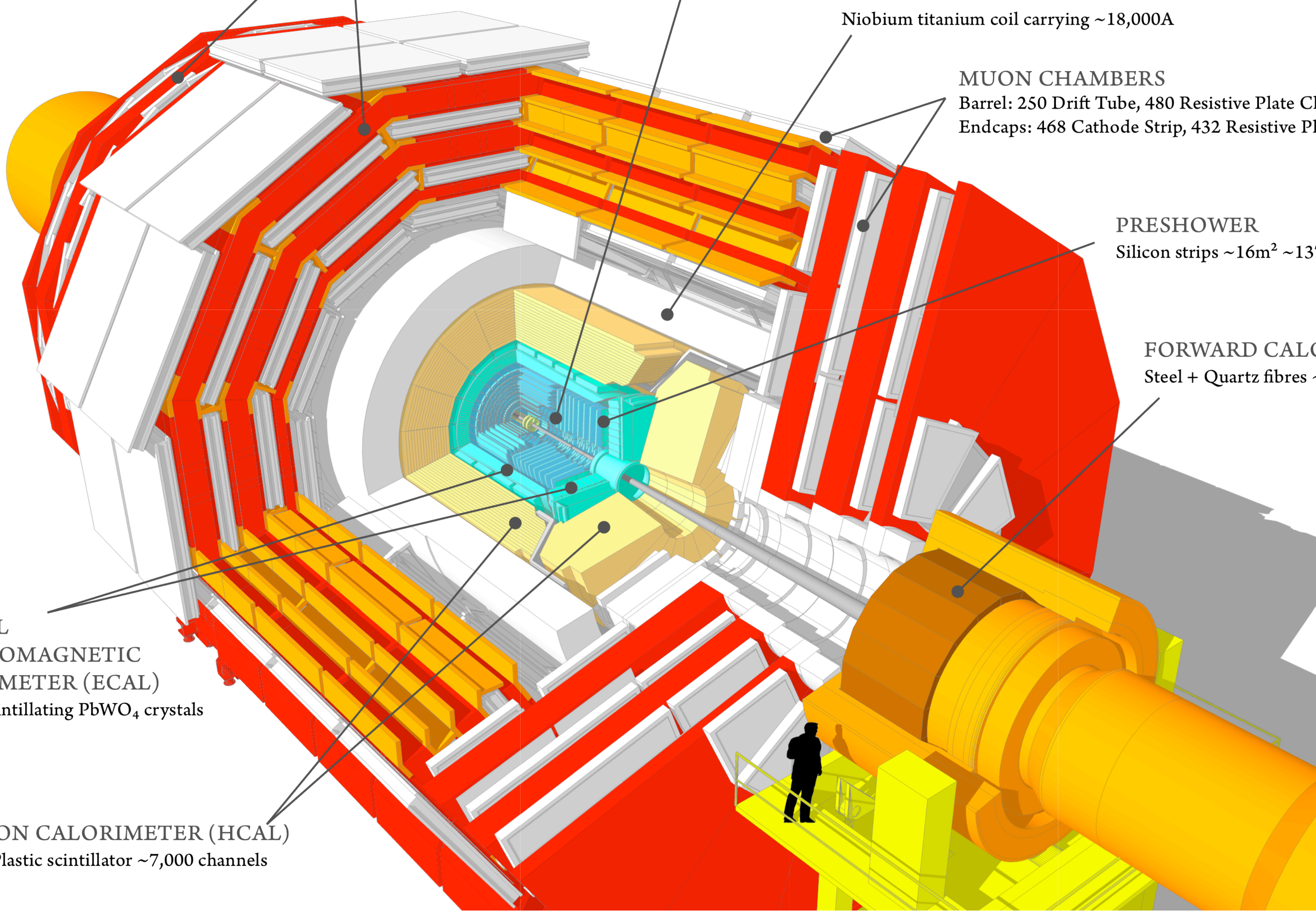
2012

ATLAS TDAQ in 2012

ATLAS Data
Trigger Info

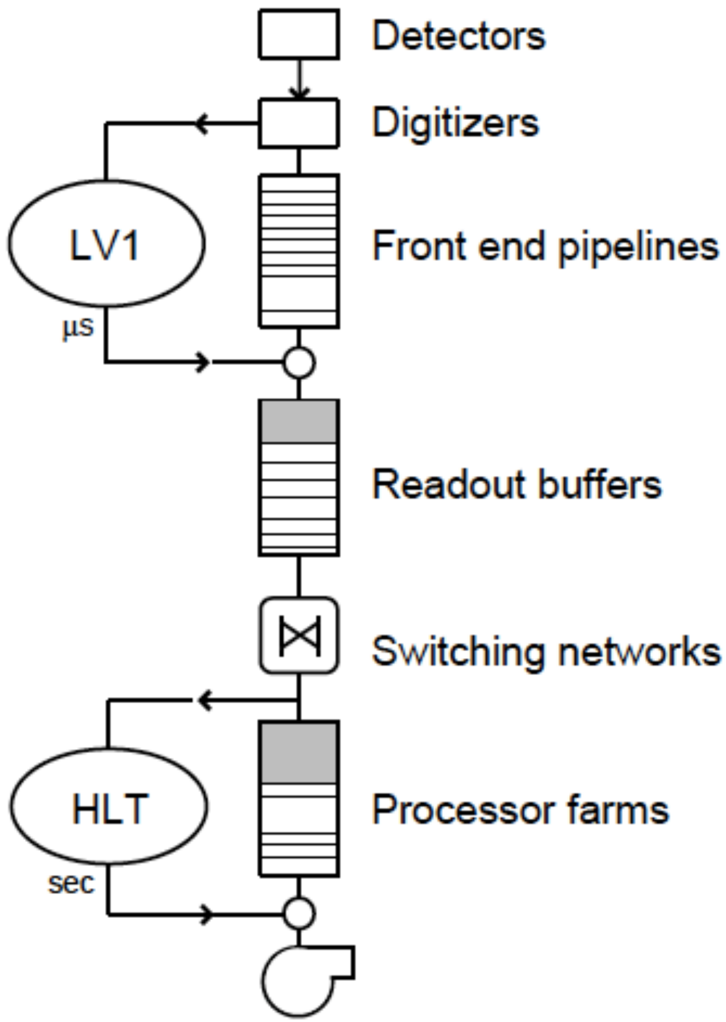


CMS DETECTOR

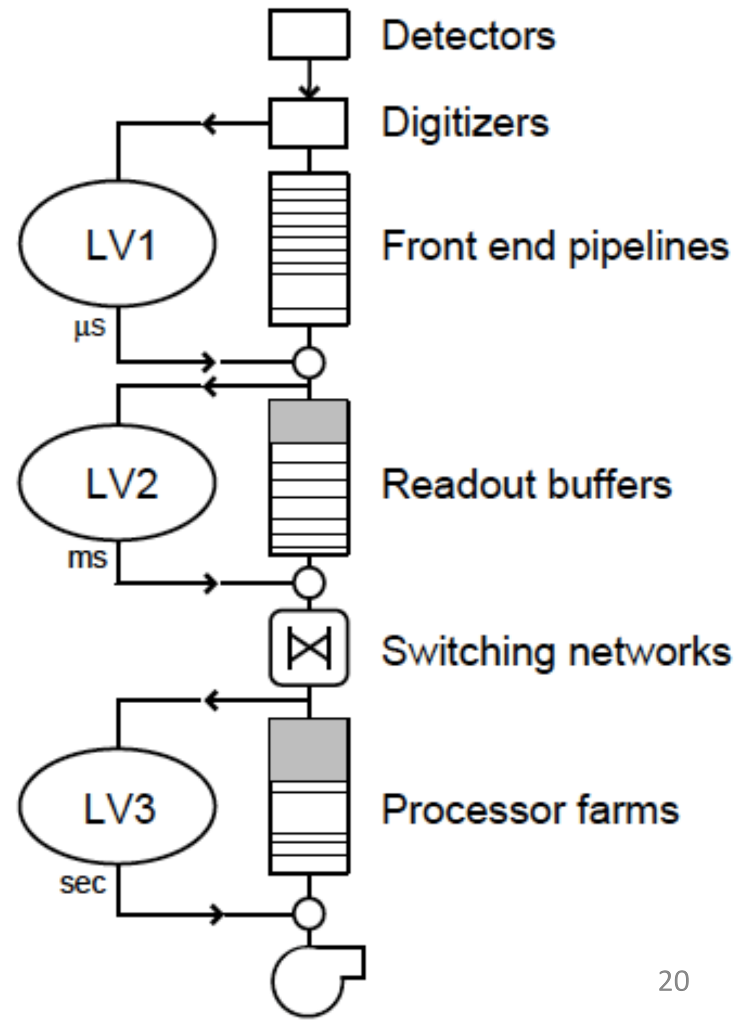


CMS: The Two-Level Trigger

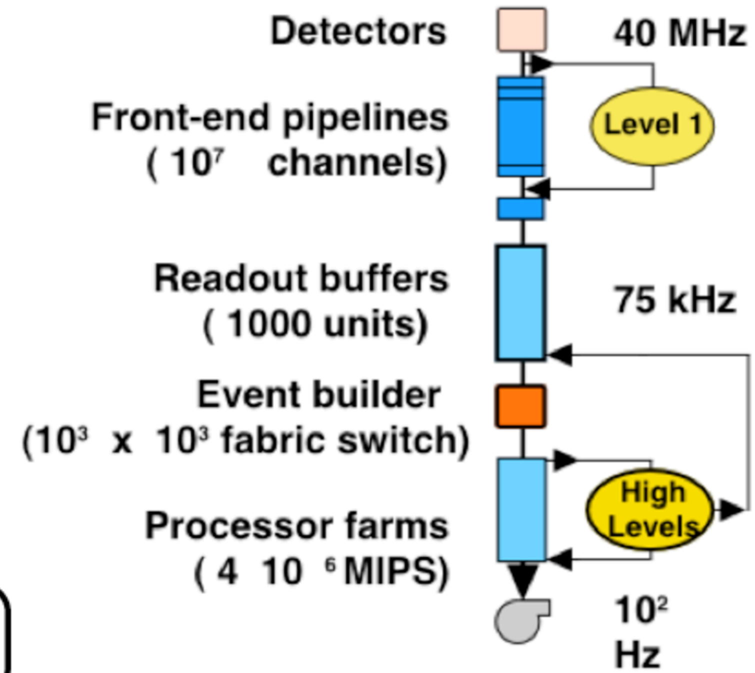
CMS Design

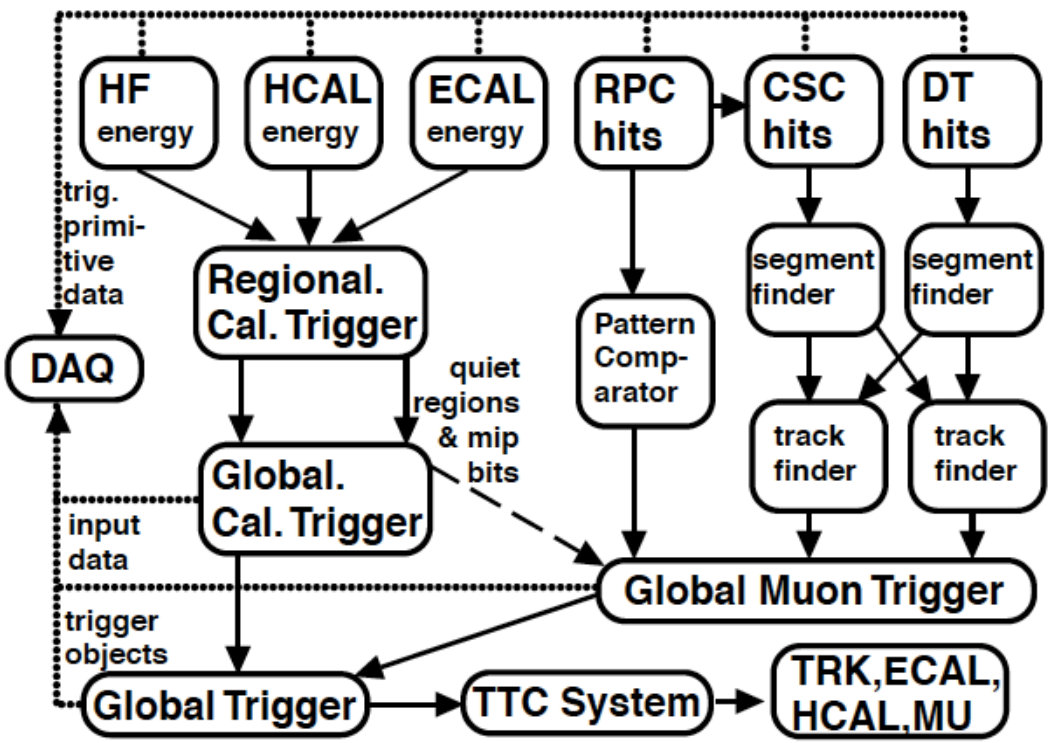


Three-Level Trigger



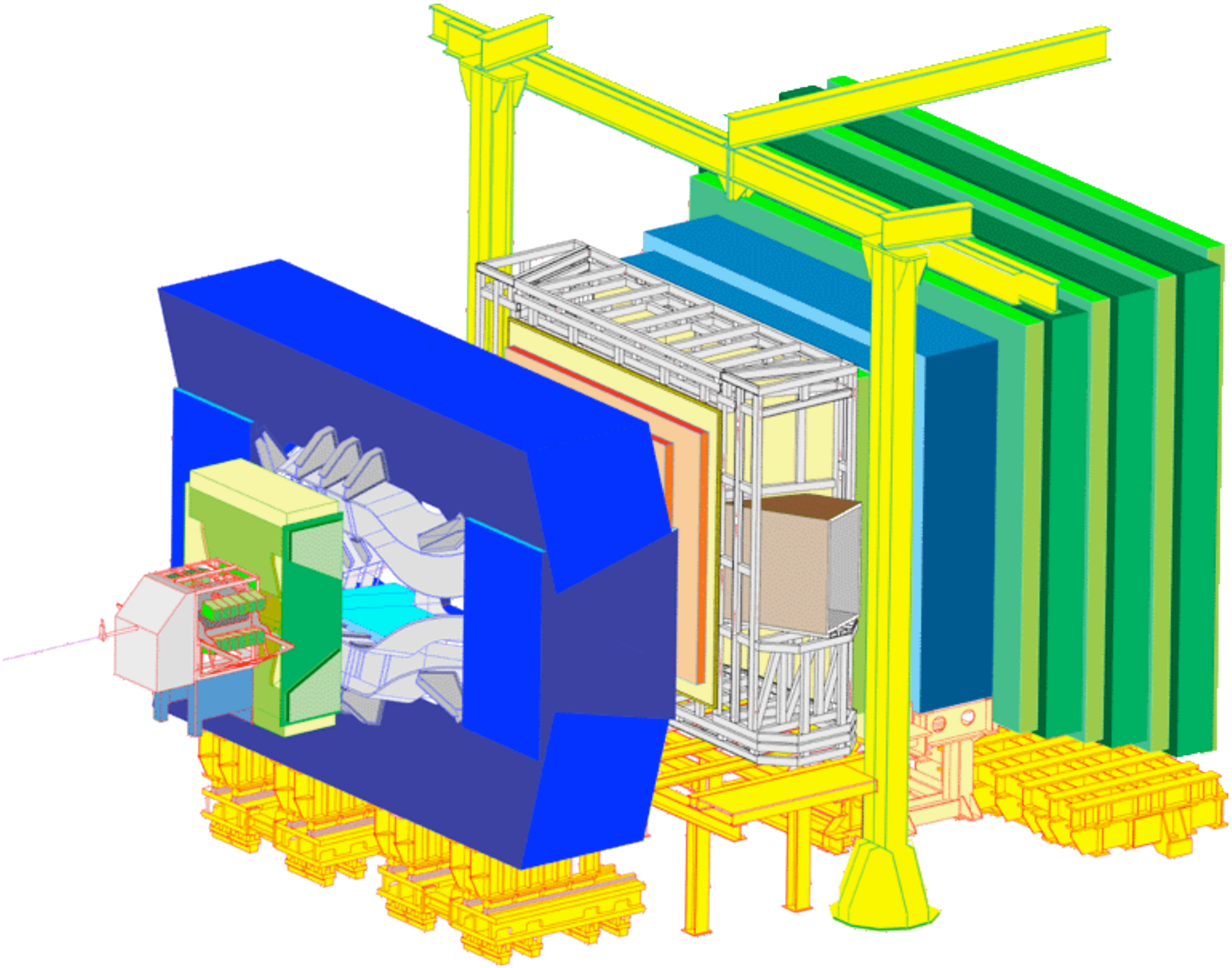
CMS DAQ Architecture



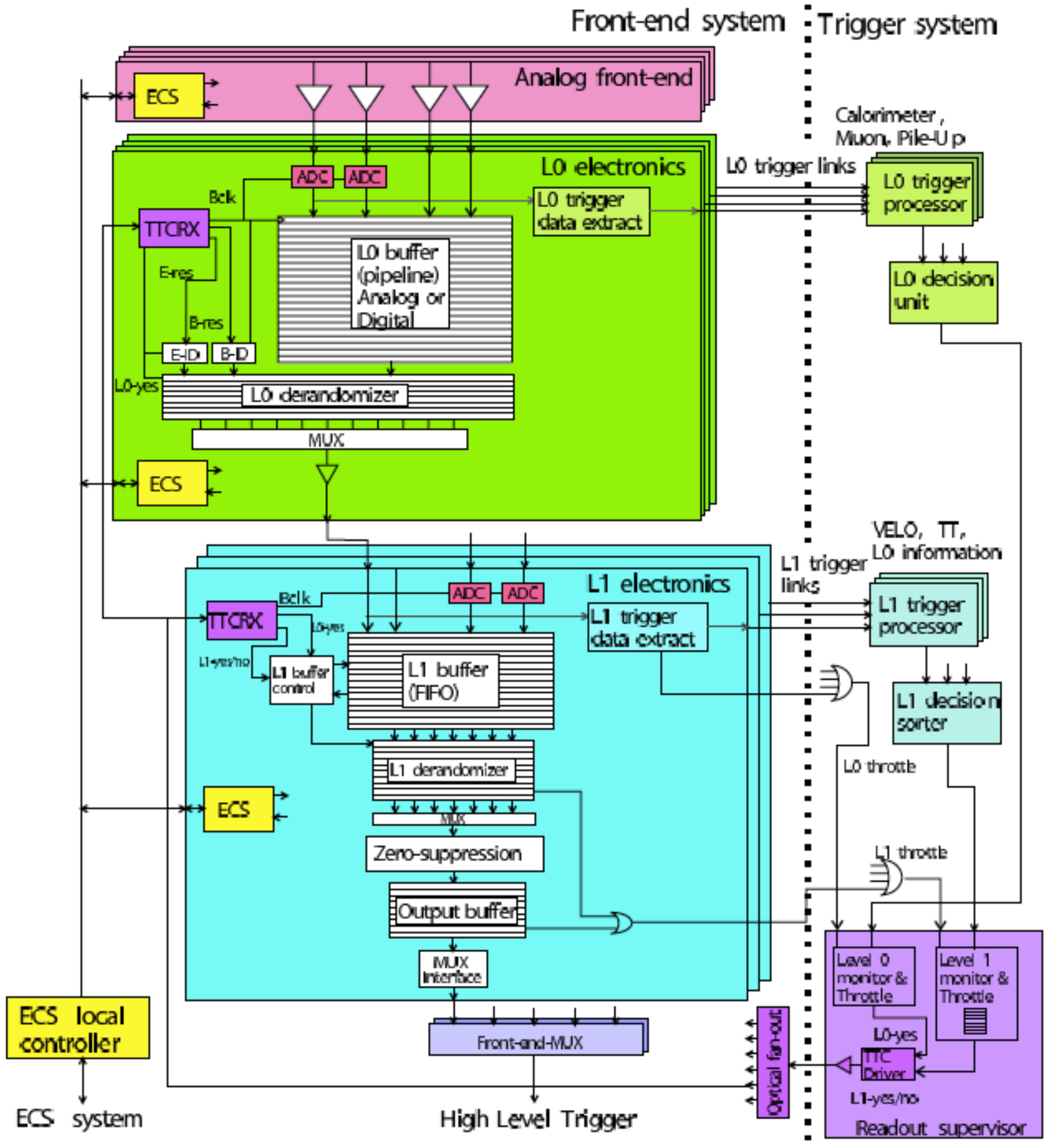


L1 Trigger

LHCb



LHCb



Front-end system
Trigger system
Analog front-end
ECS
L0 electronics
ADC
ADC
Bclk
TTCRX
L0 trigger data extract
L0 buffer (pipeline) Analog or Digital
E-res
B-res
E-ID
B-ID
L0-yes
L0 derandomizer
MUX
ECS
Calorimeter, Muon, Pile-Up
L0 trigger links
L0 trigger processor
L0 decision unit
VELO, TT, L0 information
L1 trigger links
L1 electronics
ADC
ADC
Bclk
TTCRX
L0-yes
L1-yes/no
L1 buffer control
L1 buffer (FIFO)
L1 trigger data extract
L1 trigger processor
L1 decision sorter
L0 throttle
L1 derandomizer
ECS
MUX
Zero-suppression
L1 throttle
Output buffer
MUX Interface
Front-end-MUX
ECS local controller
Level 0 monitor & Throttle
Level 1 monitor & Throttle
L0-yes
TTC Driver
L1-yes/no
Optical fan-out
Readout supervisor
ECS system
High Level Trigger

Trigger Selection:
Object- vs. Event- Based

Objects
e
μ
γ
τ
b-jets
jets

Correlations
Angular distributions
Mass

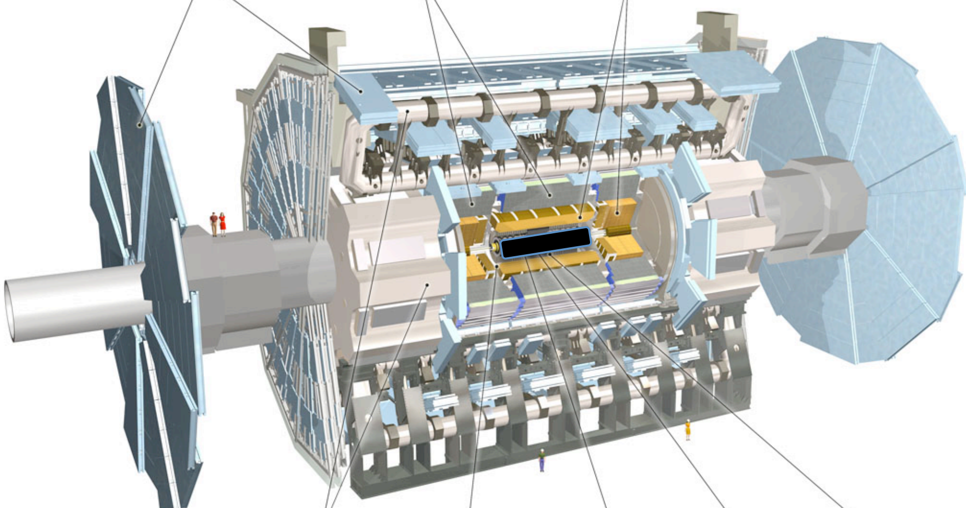
Event Info
MET
SUM ET
Tracks
Centrality

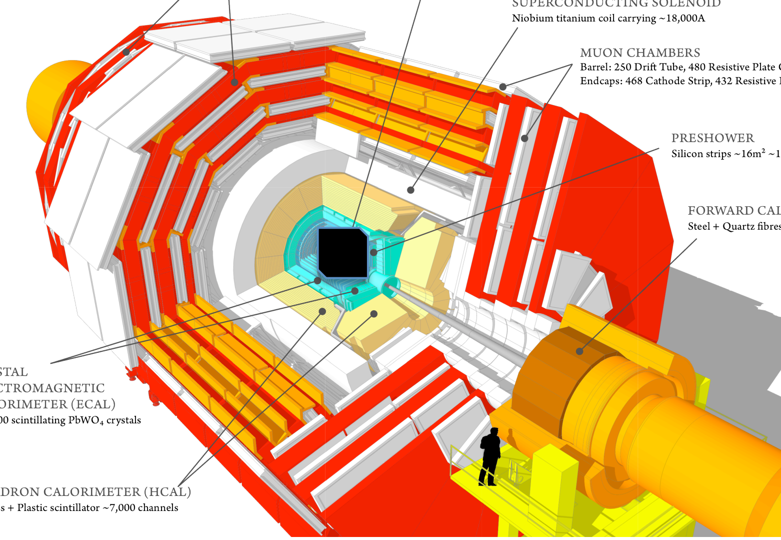
Monitoring and Support Triggers
Zero Bias
Minimum Bias
Empty Bunches
…

Objects
- e
- μ
- γ
- τ
- b-jets
- jets

Level 1 Triggering:
Et tu, inner detectors?!

Event Info
- MET
- SUM ET
- # Tracks
- Centrality



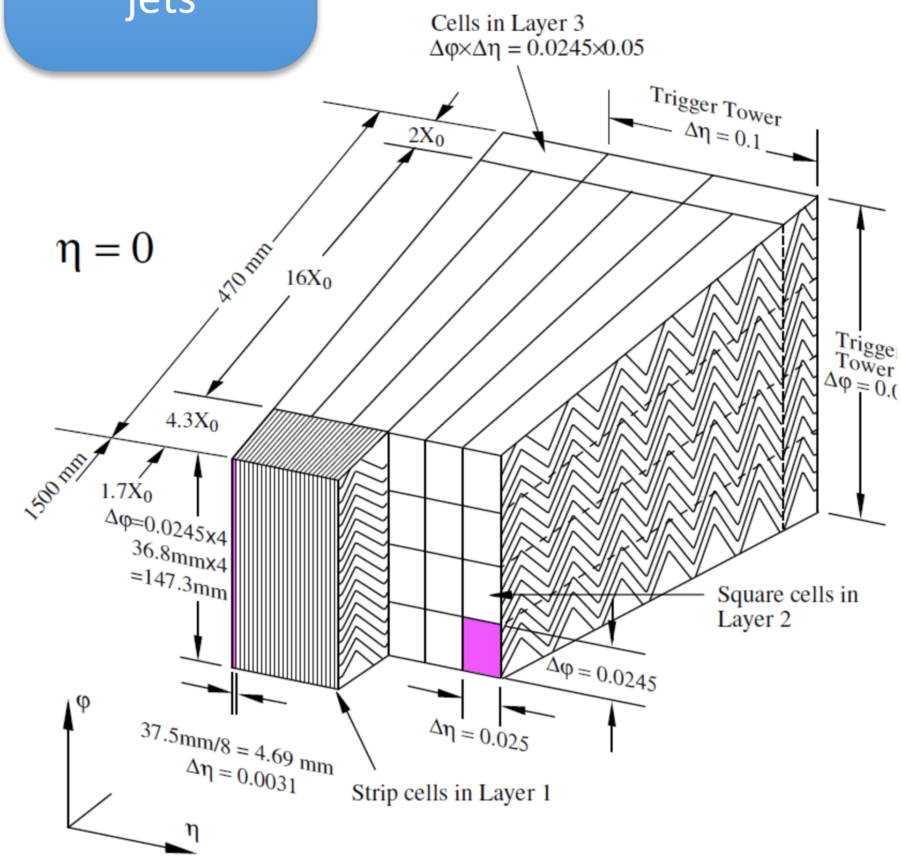


Level 1 Triggering: Calorimeter Granularity

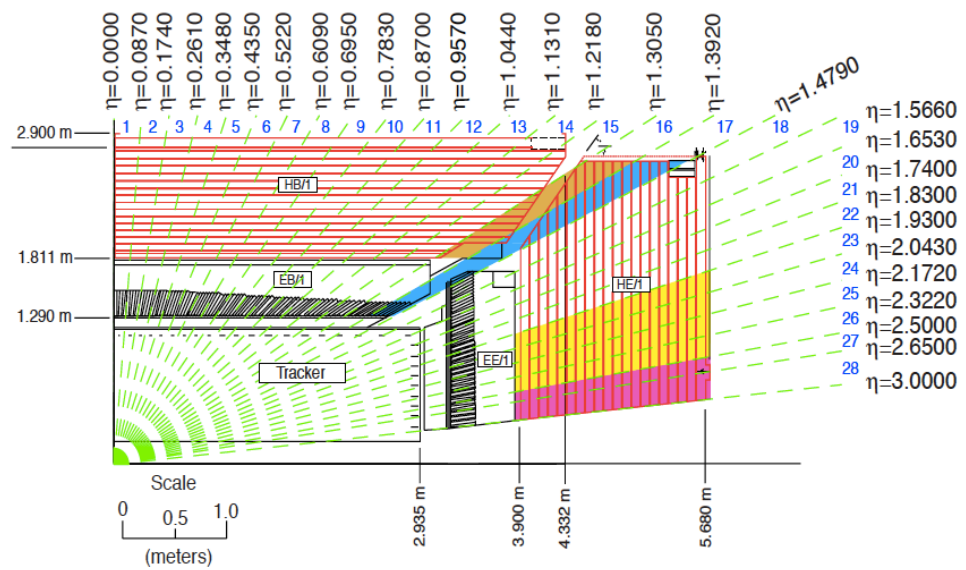
Objects
e
μ
γ
τ
b-jets
jets

Event Info
MET
SUM ET
Tracks
Centrality

ATLAS



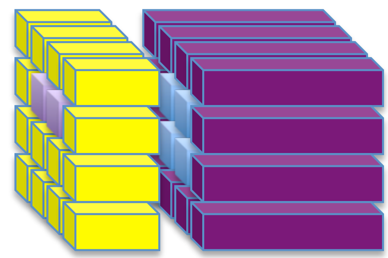
CMS



Level 1 Triggering: Imposing Calorimeter Isolation

Separating objects like electrons, photons and taus from the jet backgrounds is helped by imposing isolation requirements

EM Trigger Towers

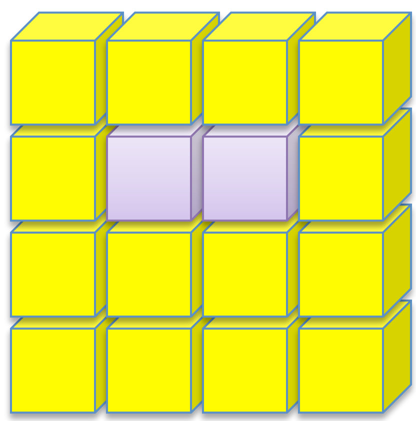


HAD Trigger Towers

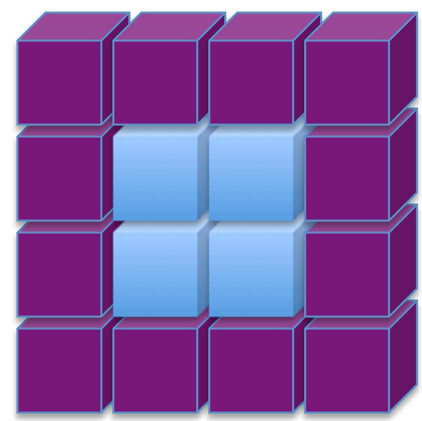
Example:

The ATLAS L1 Tau Trigger

Threshold Calculation =



2 Adjacent EM Trigger Towers

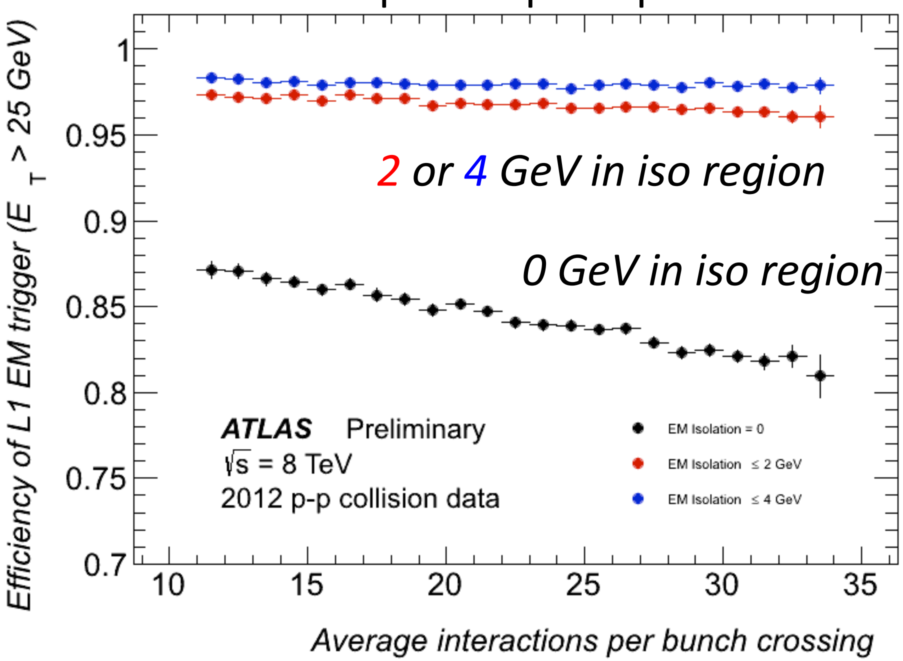


2x2 HAD Towers behind them

Level 1 Triggering: Imposing Calorimeter Isolation

Separating objects like electrons, photons and taus from the jet backgrounds is helped by imposing isolation requirements

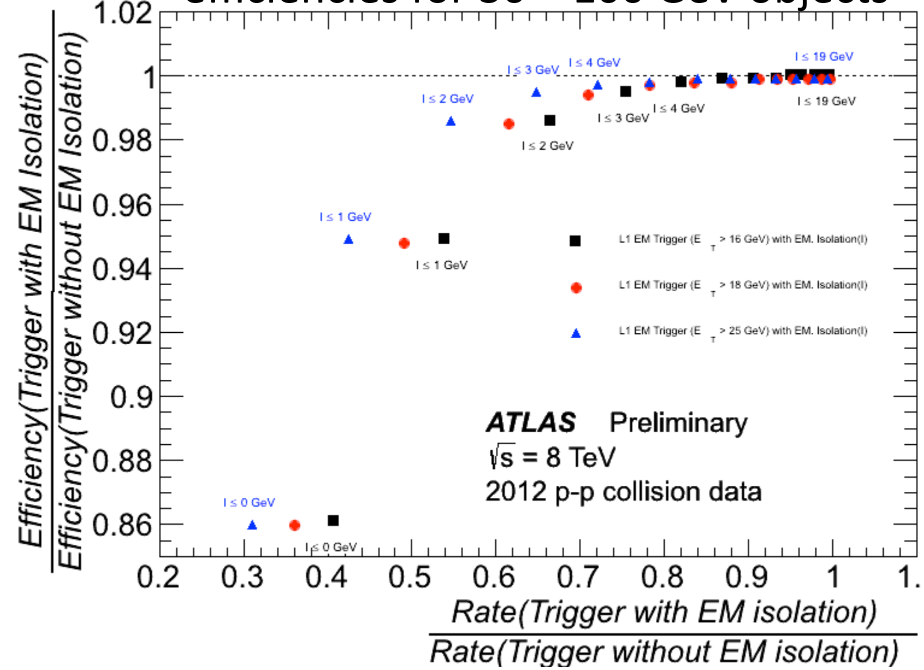
Impact of pile-up?



Rate Reduction?

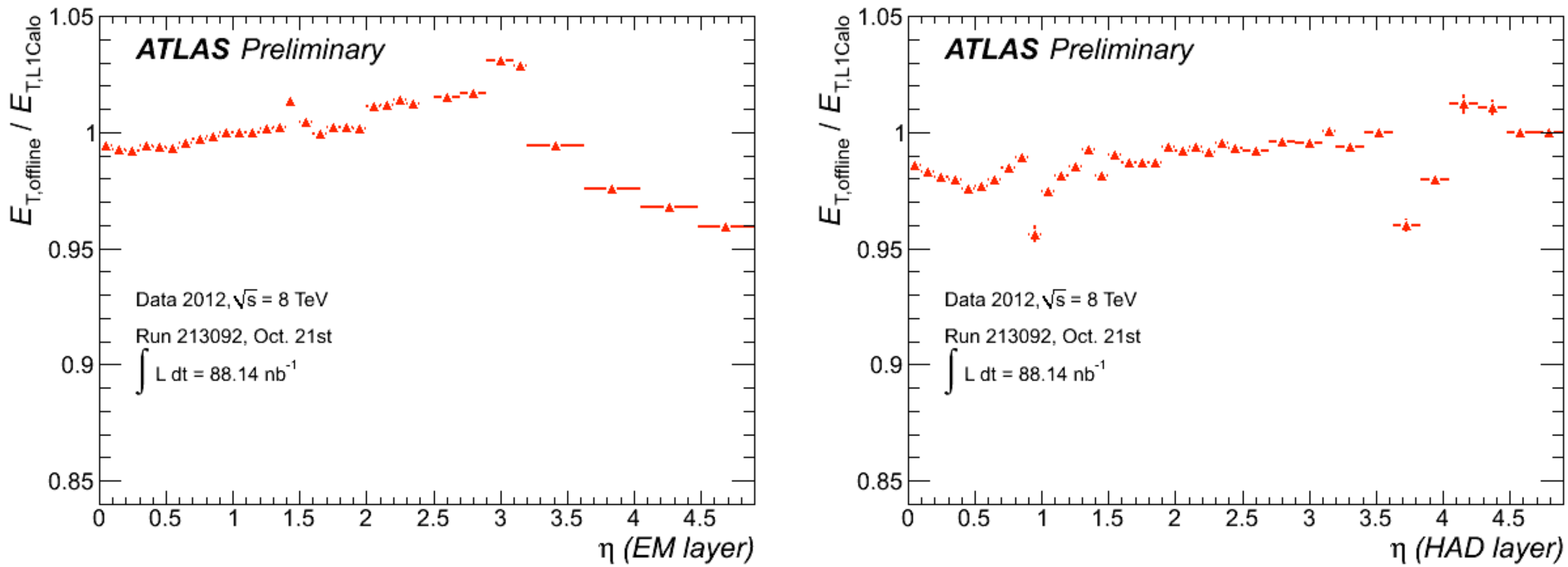
16, 18, 25 GeV thresholds,

efficiencies for 30 – 100 GeV objects

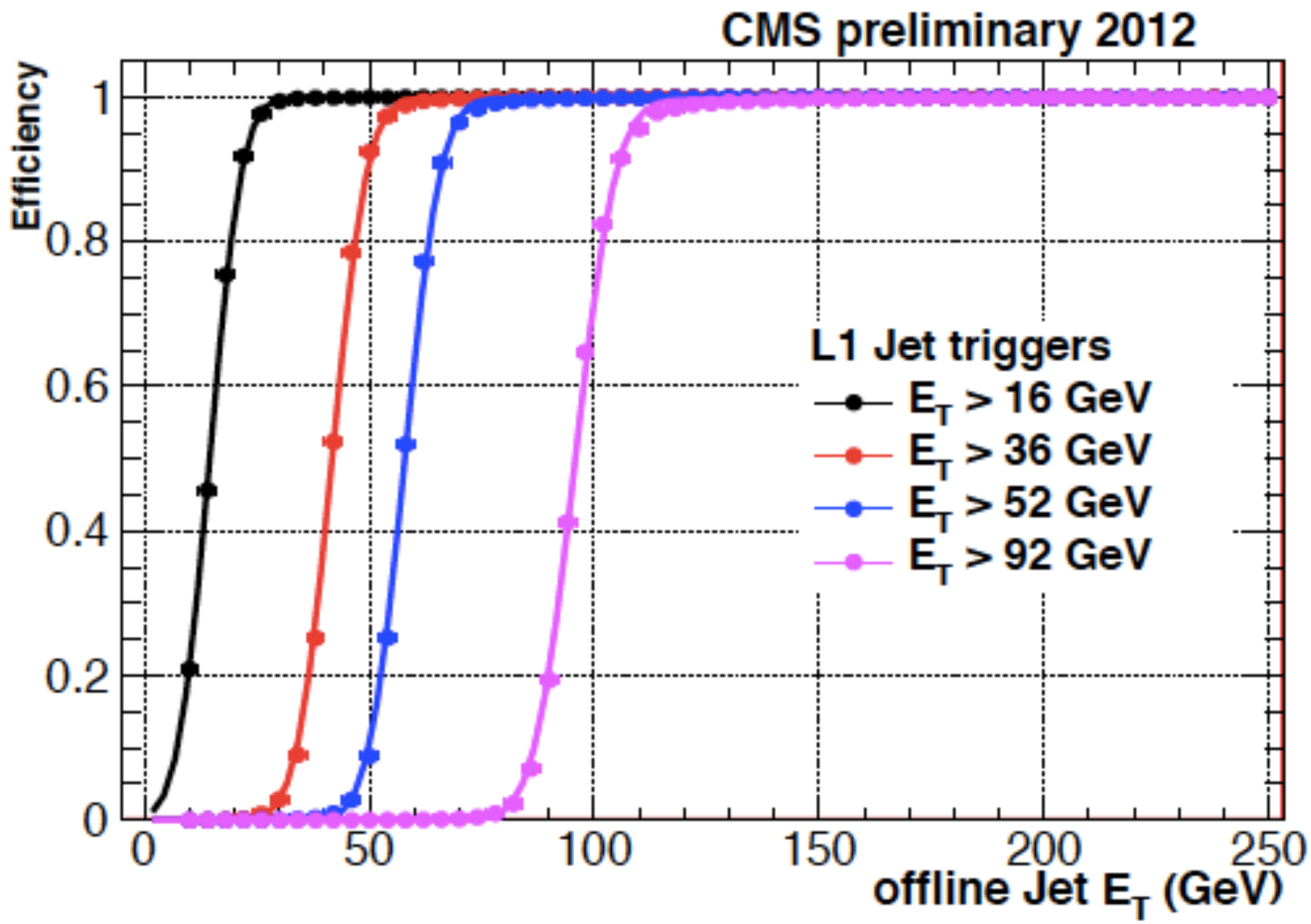


Level 1 Triggering: E_T Calculation

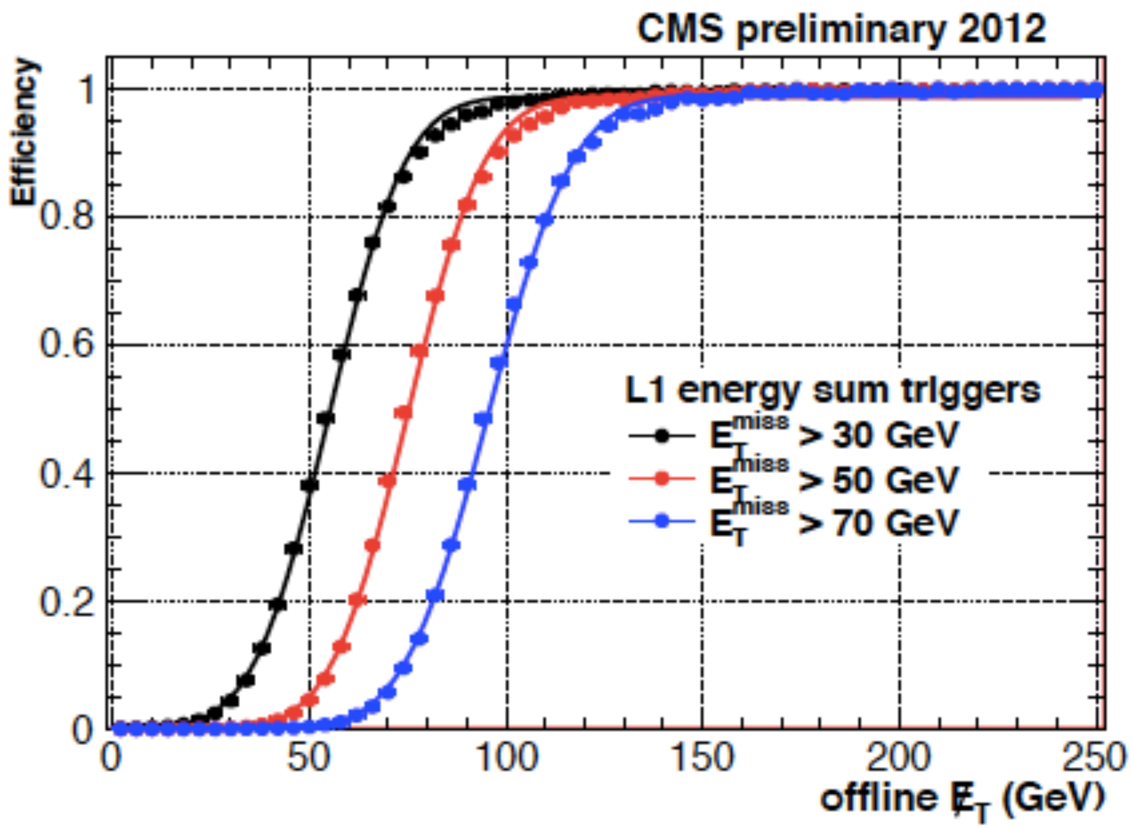
Differences with the offline in different eta slices



Level 1 Triggering
Jets

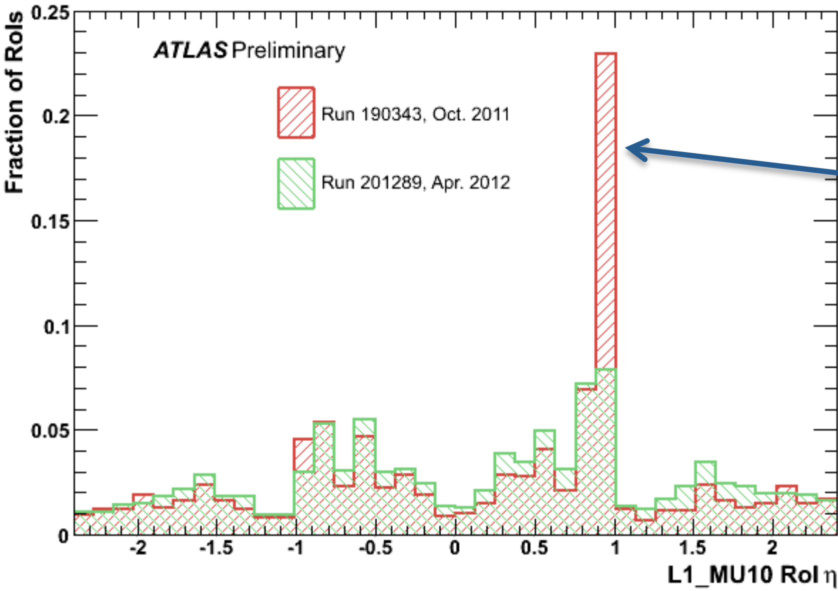


L1 Missing ET

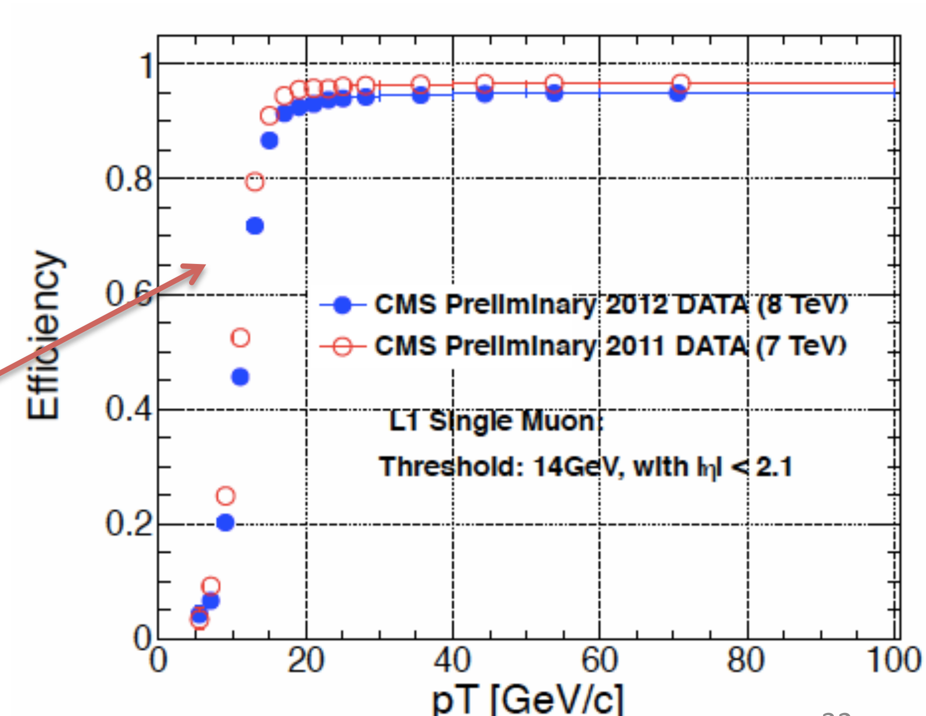


Missing Corrections for muons, energy scale of clusters (physics objects), pile-up, …

L1 Muon Trigger



ATLAS had an area without sufficient shielding – shielding added before 2012 run

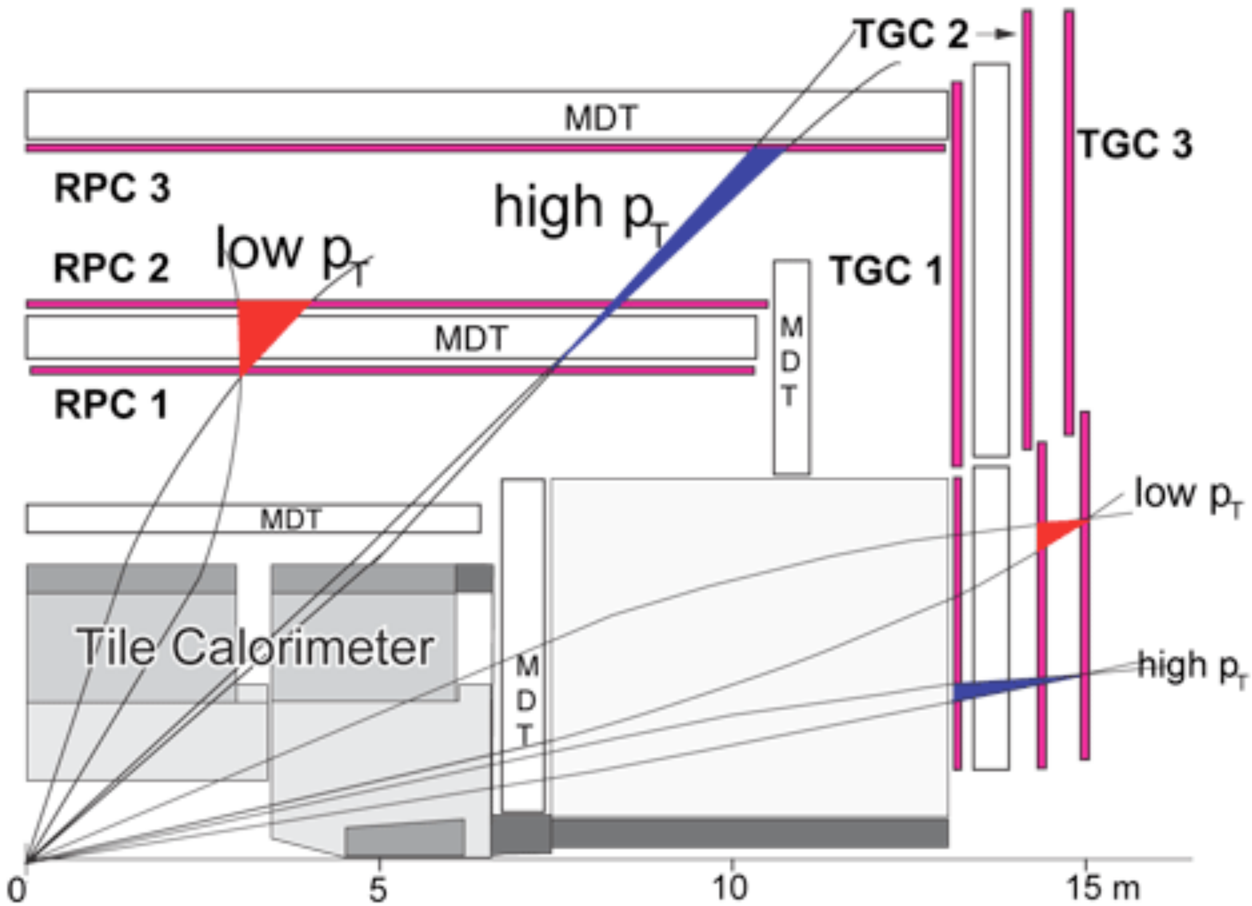


CMS improved assignment of muon p_T for 2012

L1 Muon Trigger: ATLAS

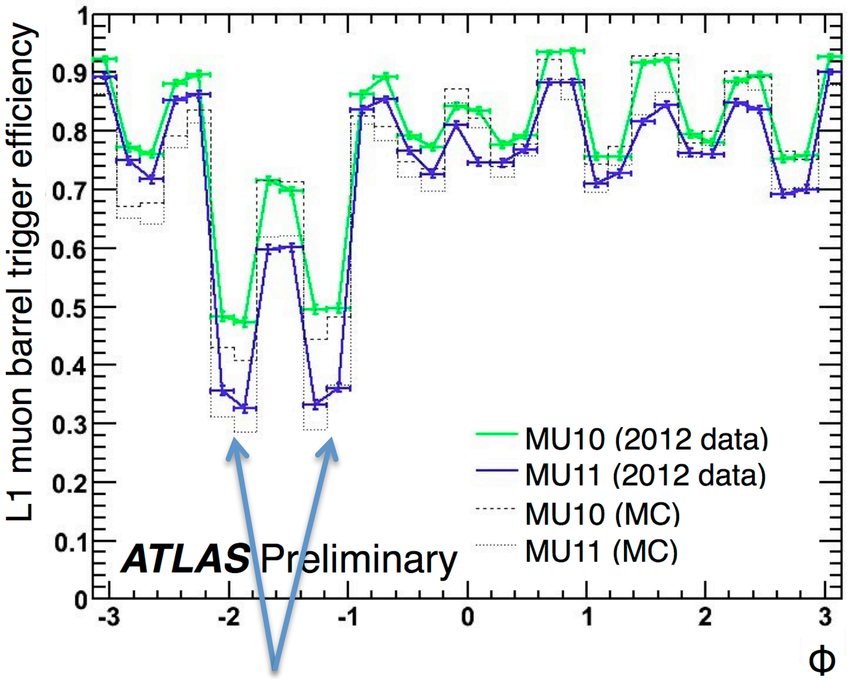
RPC: Resistive Plate Chambers

TGC: Thin Gap Chambers

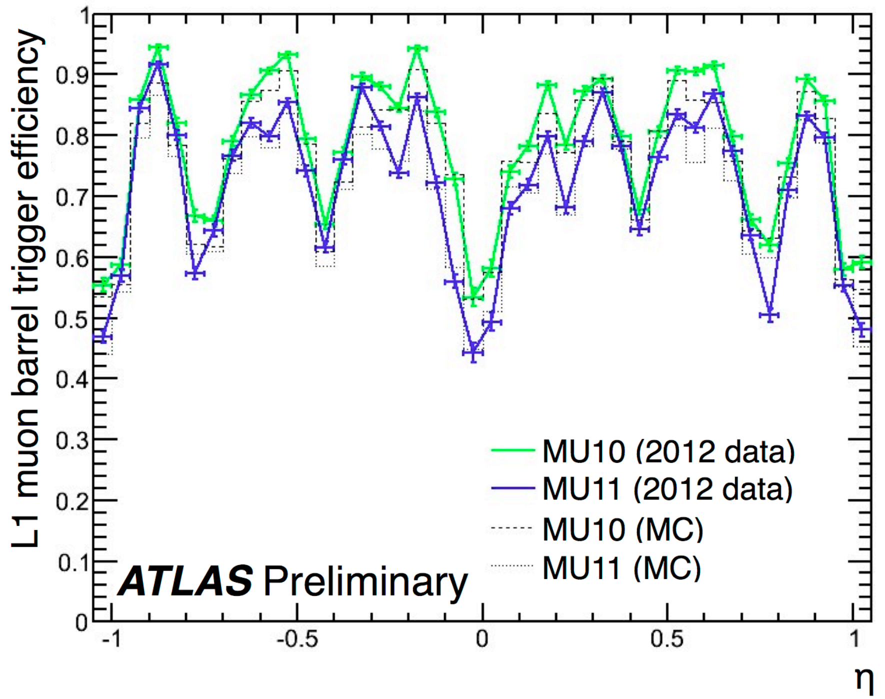


L1 Muon Trigger: ATLAS

Expect physics to be symmetric in phi (just gravity breaking symmetry)



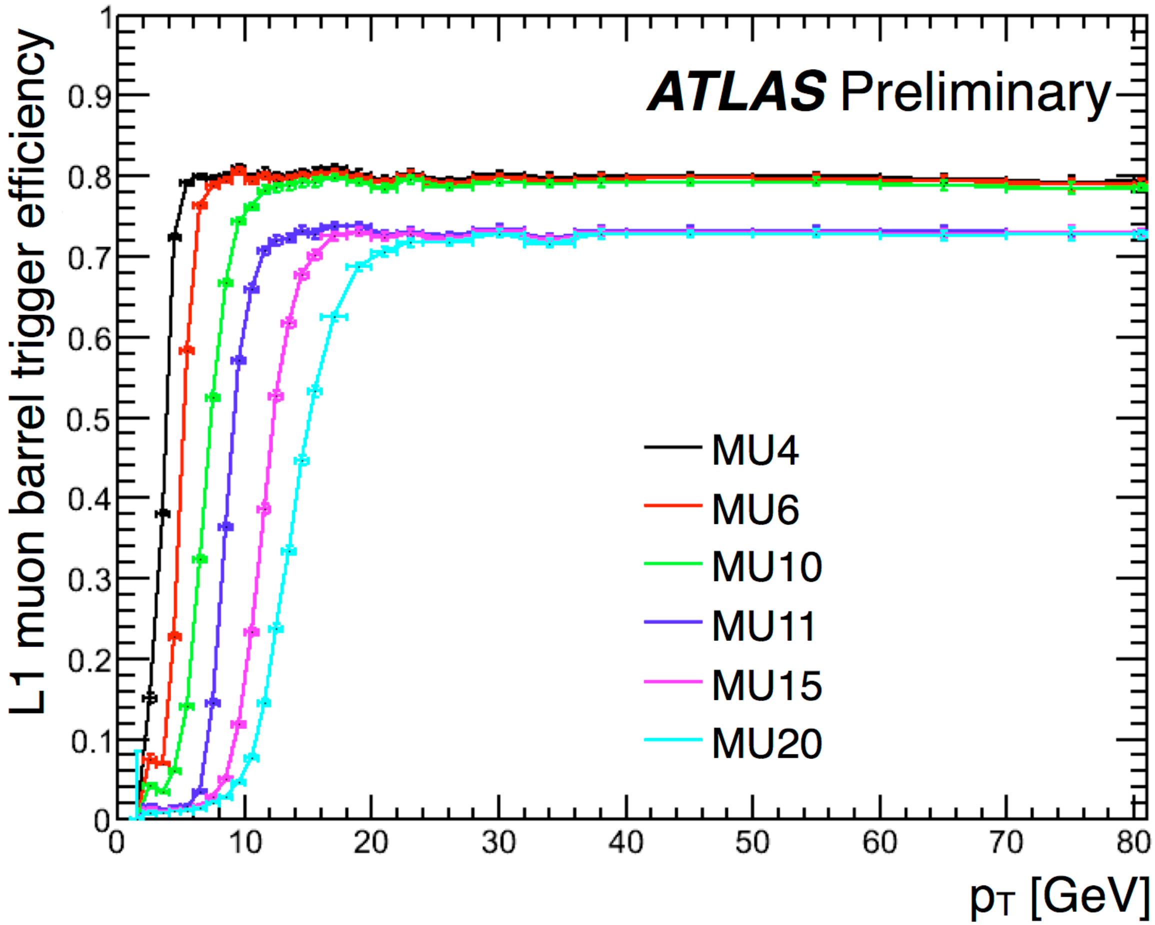
"Feet": ATLAS Mechanical Supports



Again, losses due to mechanical supports – areas where we do not have muon trigger instrumentation

Efficiencies for > 15 GeV muons

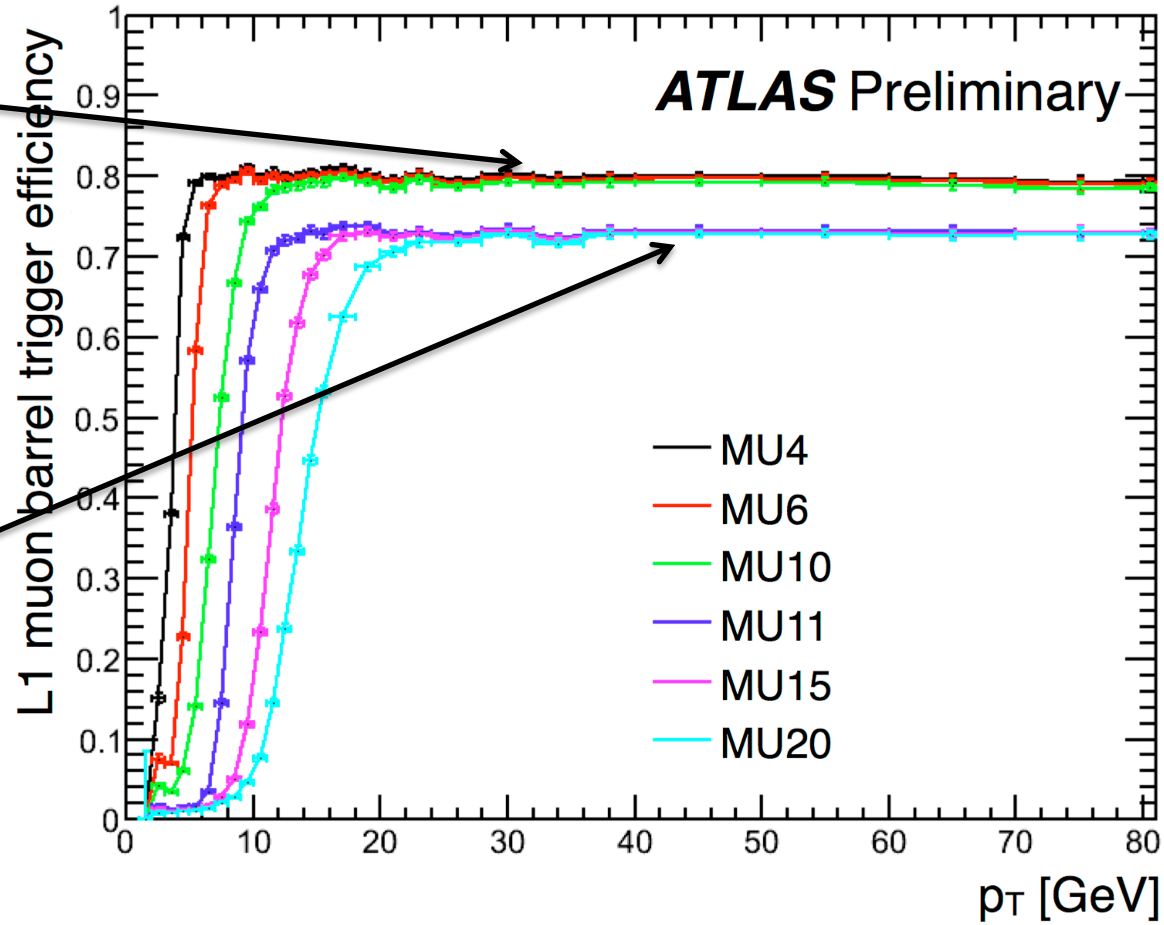
L1 Muon Trigger: ATLAS



L1 Muon Trigger: ATLAS

Lower p_T thresholds require coincidences in two RPC chambers

Higher p_T thresholds require coincidences in three RPC chambers

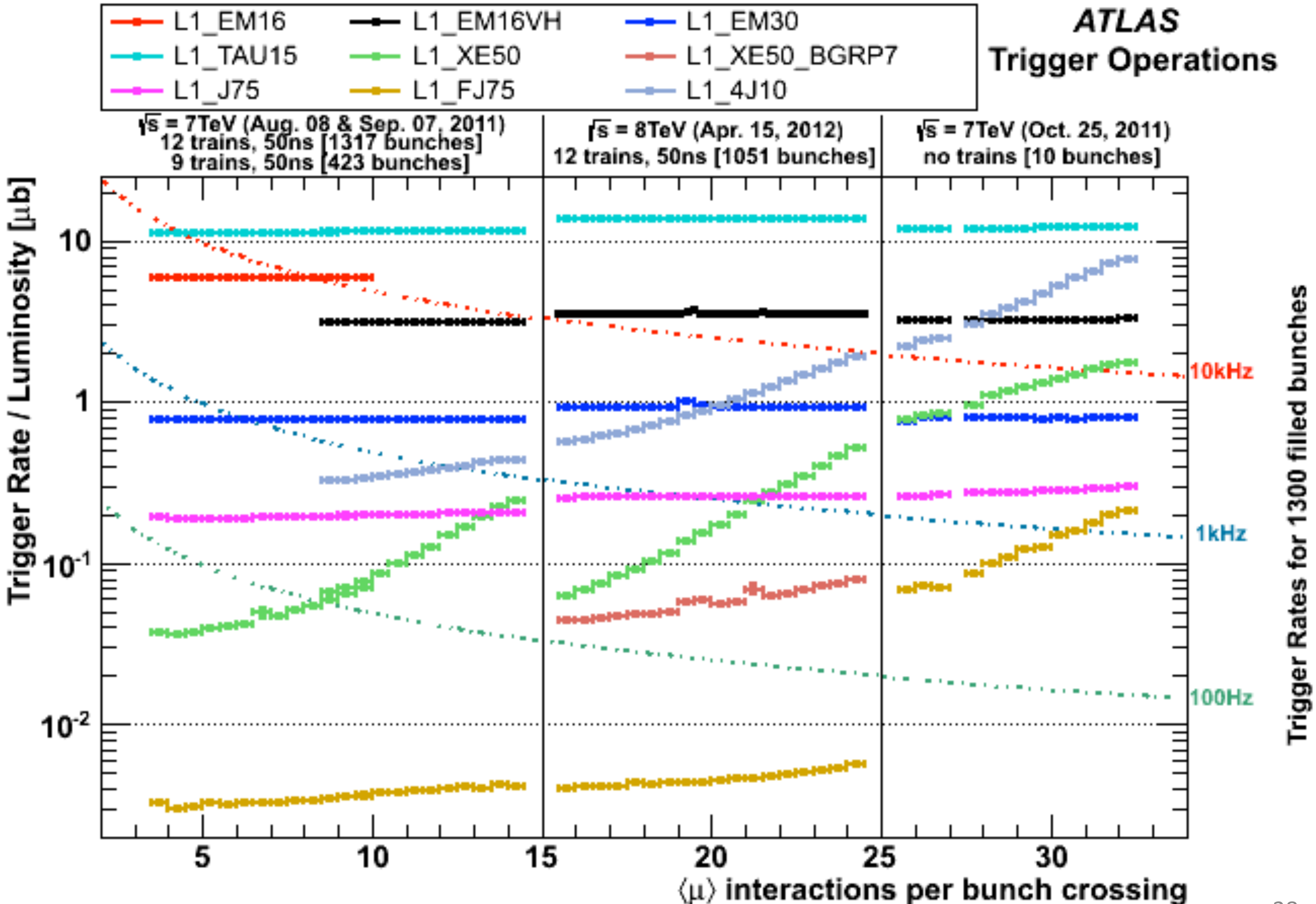


L1 Triggering
Menus and Rates

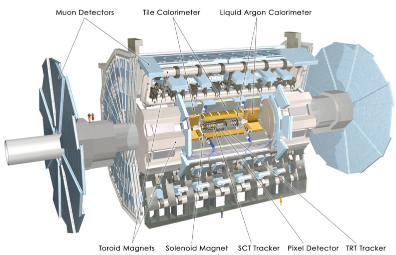
CMS 2012: $L = 6.6 \times 10^{33} \text{cm}^2 \text{s}^{-1}$

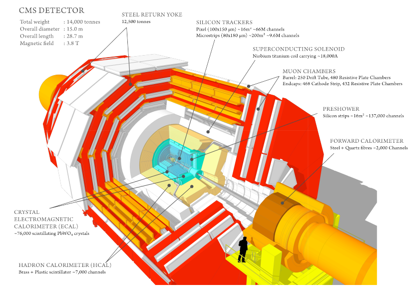
Trigger	Threshold (GeV)	Rate (kHz)
Single μ ($\eta < 2.1$)	14	7
Double μ ($\eta < 2.4$)	10, 0	6
Single e/γ	20	13
Double e/γ	13, 7	8
e/$\gamma + \mu$	12, 3.5	3
μ + e/γ	12, 7	1.5
Single jet	128	1.5
Quad jet	36	5
H_T	150	5
E_T^{miss}	40	8

ATLAS Performance



High Level Trigger: Software Reconstruction





Region of Interest Information available at L2
Full Event available at Event Filter (L3)

Full event available

ATLAS CPU Farm

What information does the High Level Trigger need to begin data-taking?

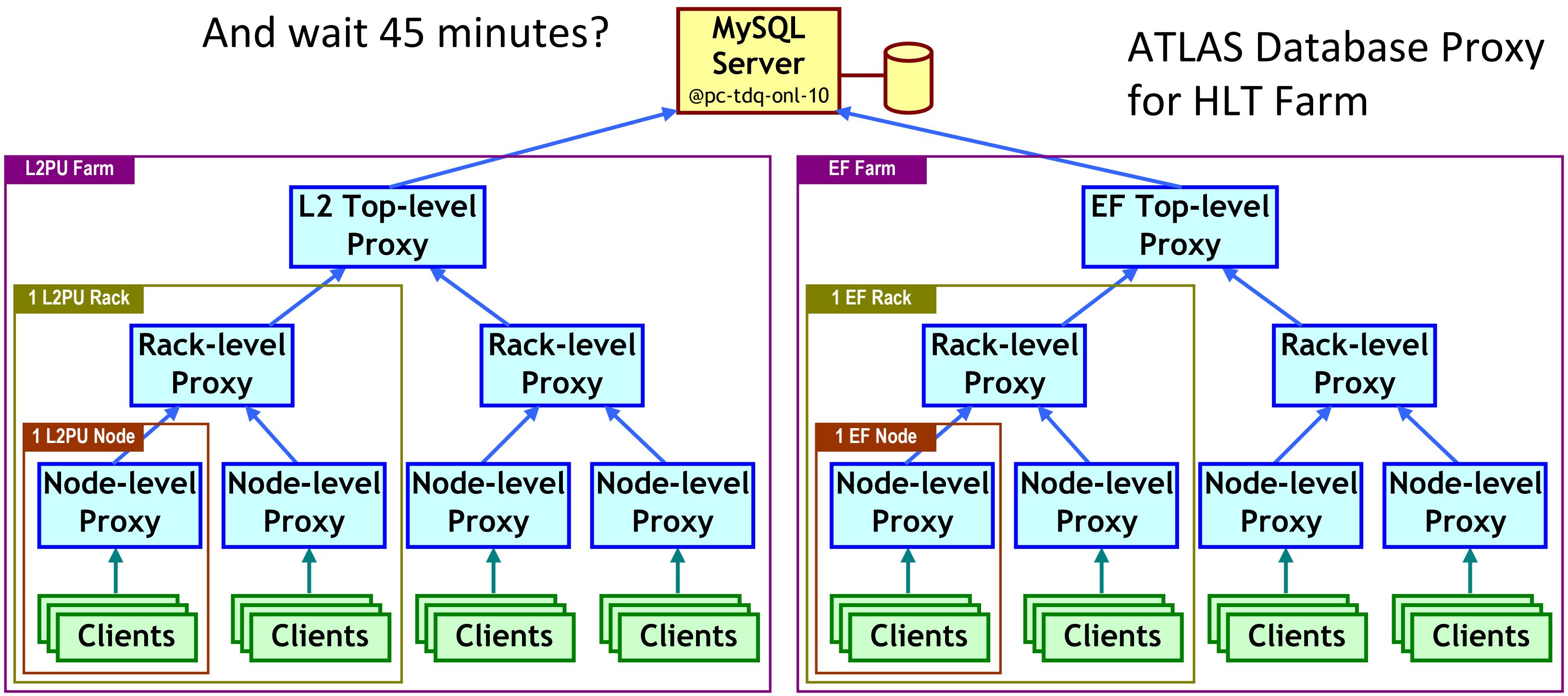
Getting Configuration Info to FARM

The LHC is delivering stable collisions, you have chosen the trigger menu that you want to use, your CPU farm is eagerly awaiting your instructions, you hit RUN.

. . .

And wait 45 minutes?

ATLAS Database Proxy for HLT Farm

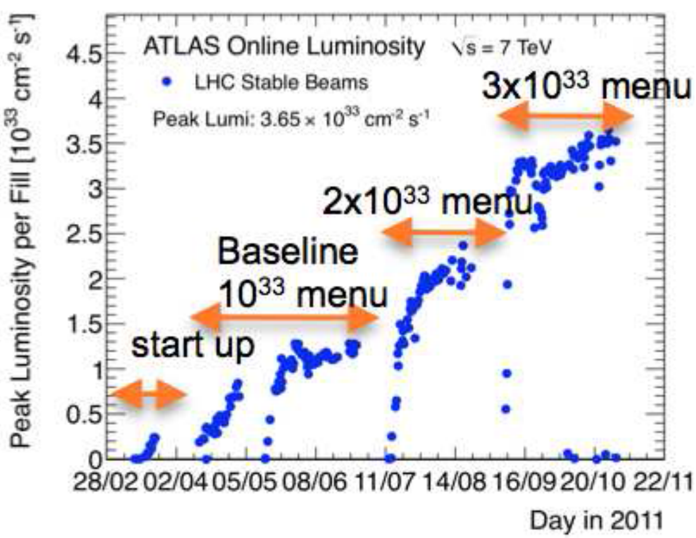


Prescales

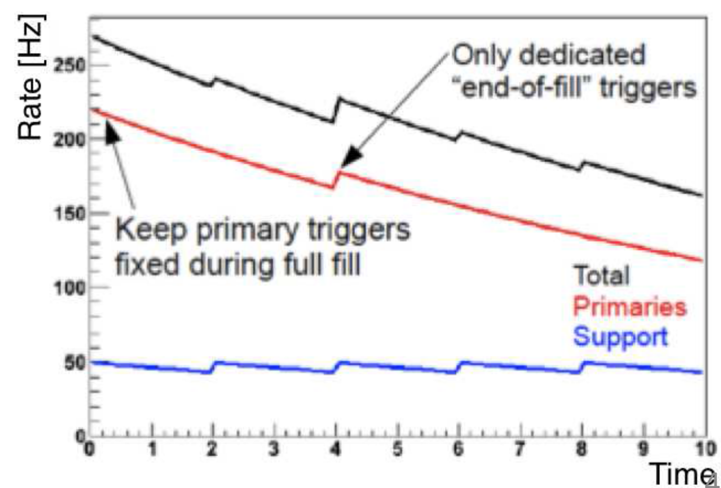
poor man's rate reduction
or
providing back-up triggers for analysis

Luminosity Profile

Over the course of a year…



Over the course of a run…



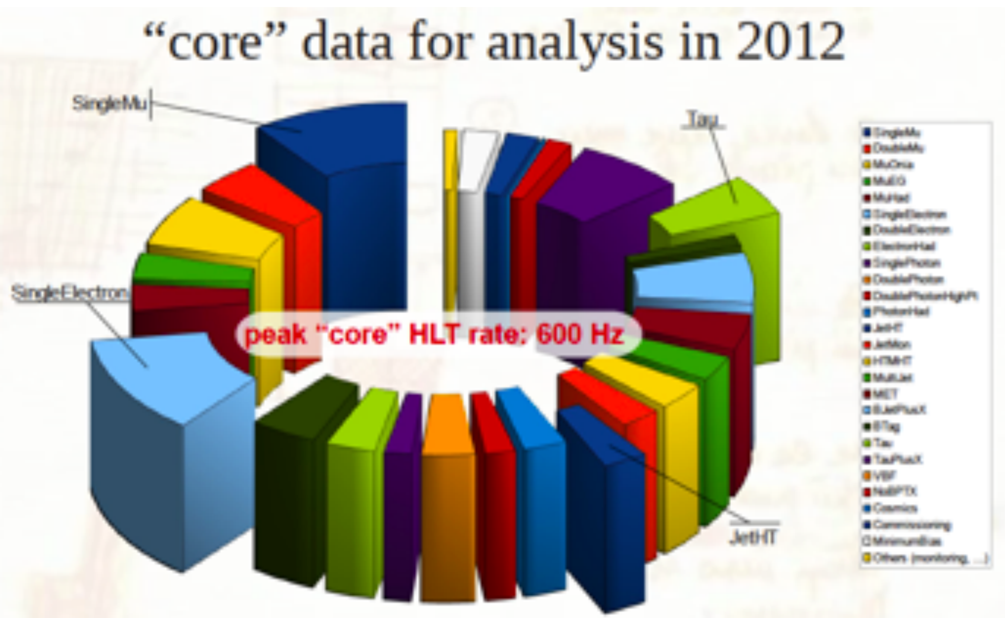
Building a Trigger Menu

Level 1 has hardware limitations

96 items for ATLAS – results in some compromises!

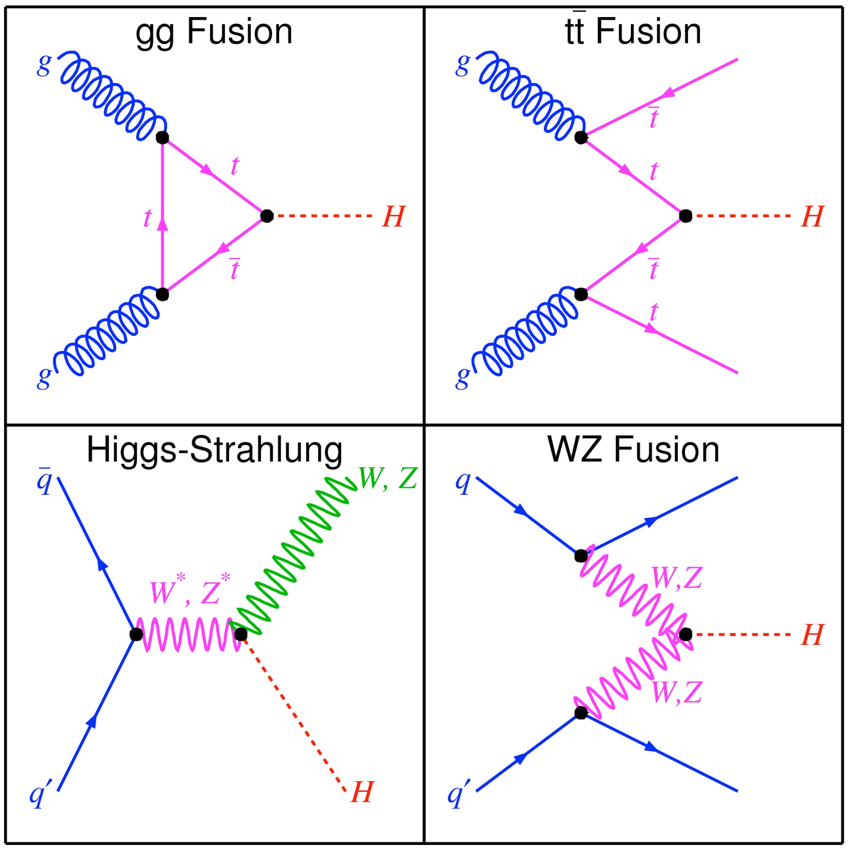
In 2011 running, ATLAS had 300 trigger chains.
In 2012 there were 700.

CMS rate allocation

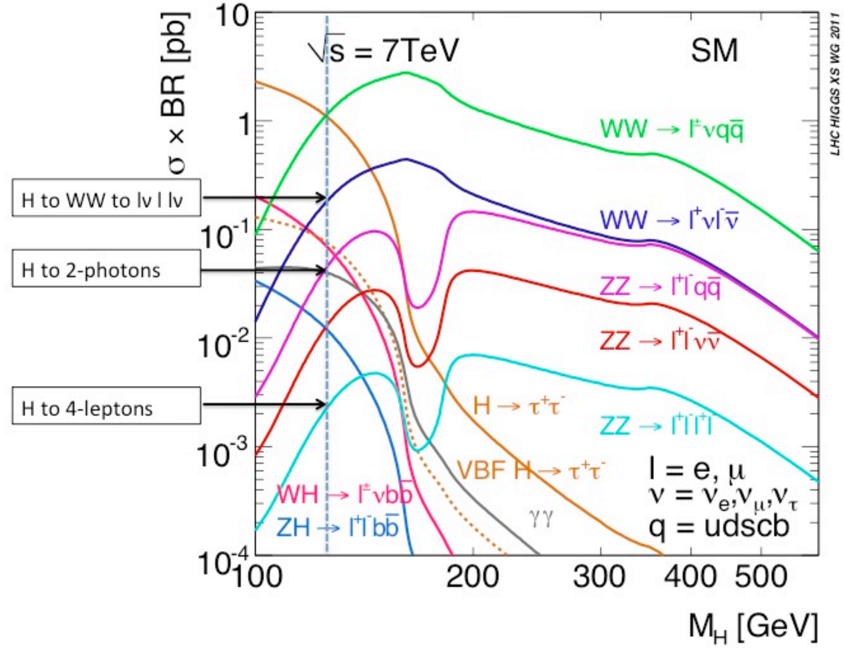


Case Study: Triggering on the Higgs

Higgs Production

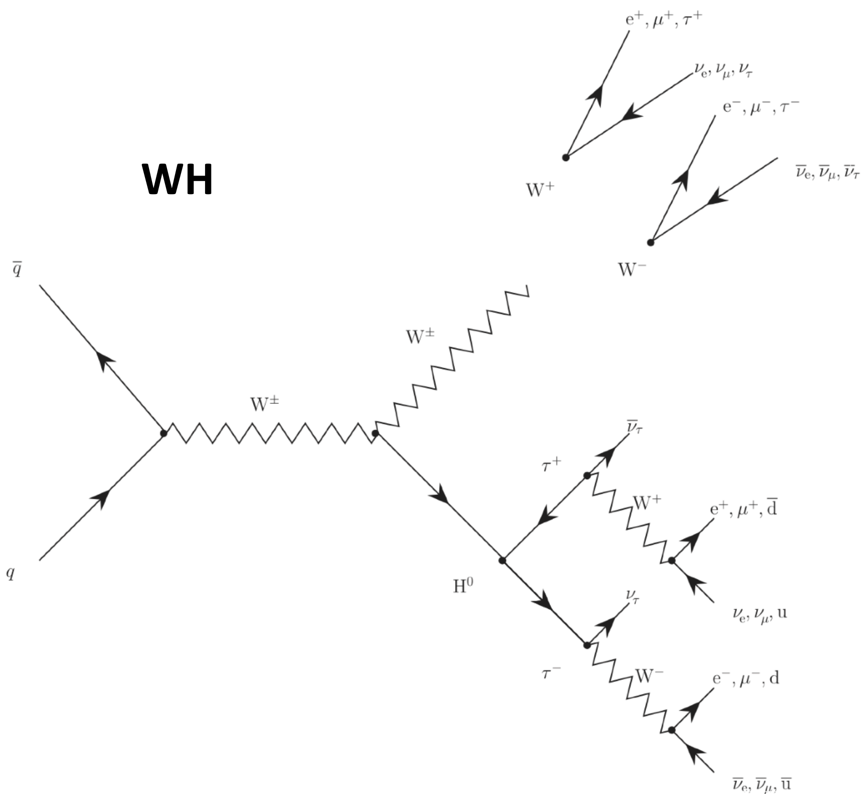


Higgs Decay

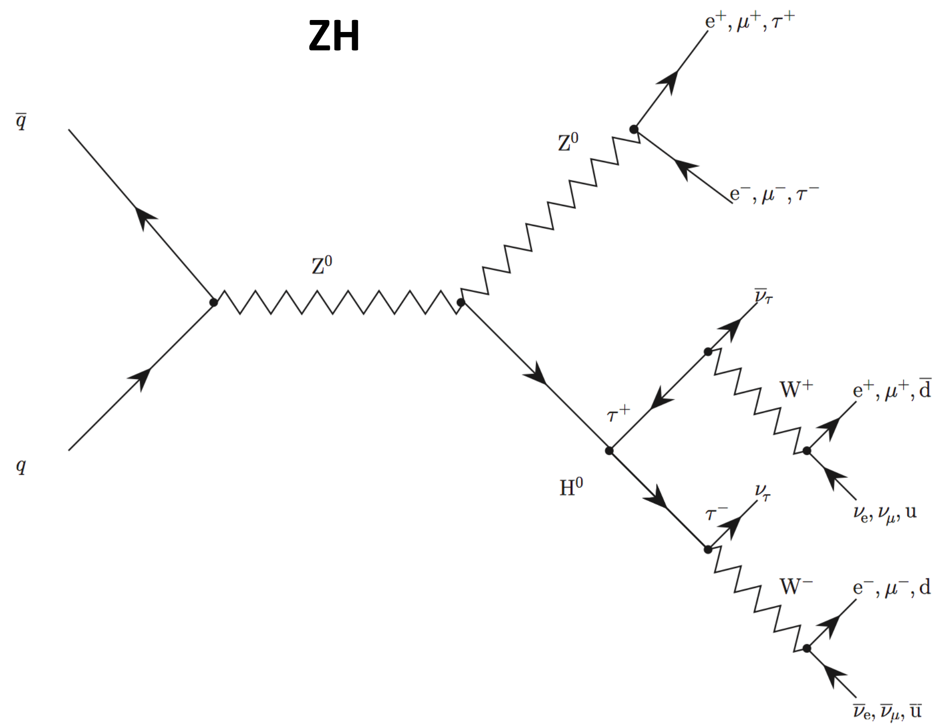


Pick one production mode (VH) and one decay mode (tau pairs)

WH



ZH



Thanks to Eran Rea for Diagrams!

and add in possible cascade decays…

A selection (far from complete!) of SUSY models with cascade Higgs decay

- ϟ $H \to 4b, 4\tau$ in NMSSM, Dermisek,Gunion [hep-ph/0502105,hep-ph/0611142]
- ϟ $H \to 6j$ in R-parity violating MSSM Carpenter,Kaplan,Rhee [hep-ph/0607204]
- ϟ $H \to 4g$ (Buried Higgs) in SUSY Little Higgs Bellazzini,Csaki,AA,Weiler [0906.3026]
- ϟ $H \to 4c$ (Charming Higgs) in SUSY Little Higgs Bellazzini,Csaki,AA,Weiler [0910.0345]
- ϟ $H \to$ lepton jets in MSSM+light hidden sector AA,Ruderman,Volansky,Zupan [1002.2952]

Examples from Adam Falkowski's slides

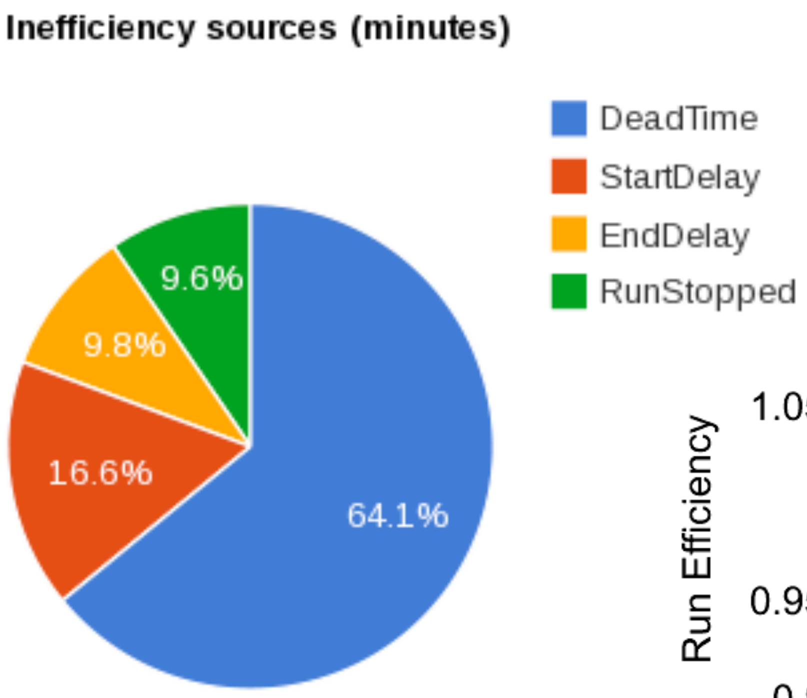
Evaluating Performance

Operations
- Deadtime, busy, run start/stop

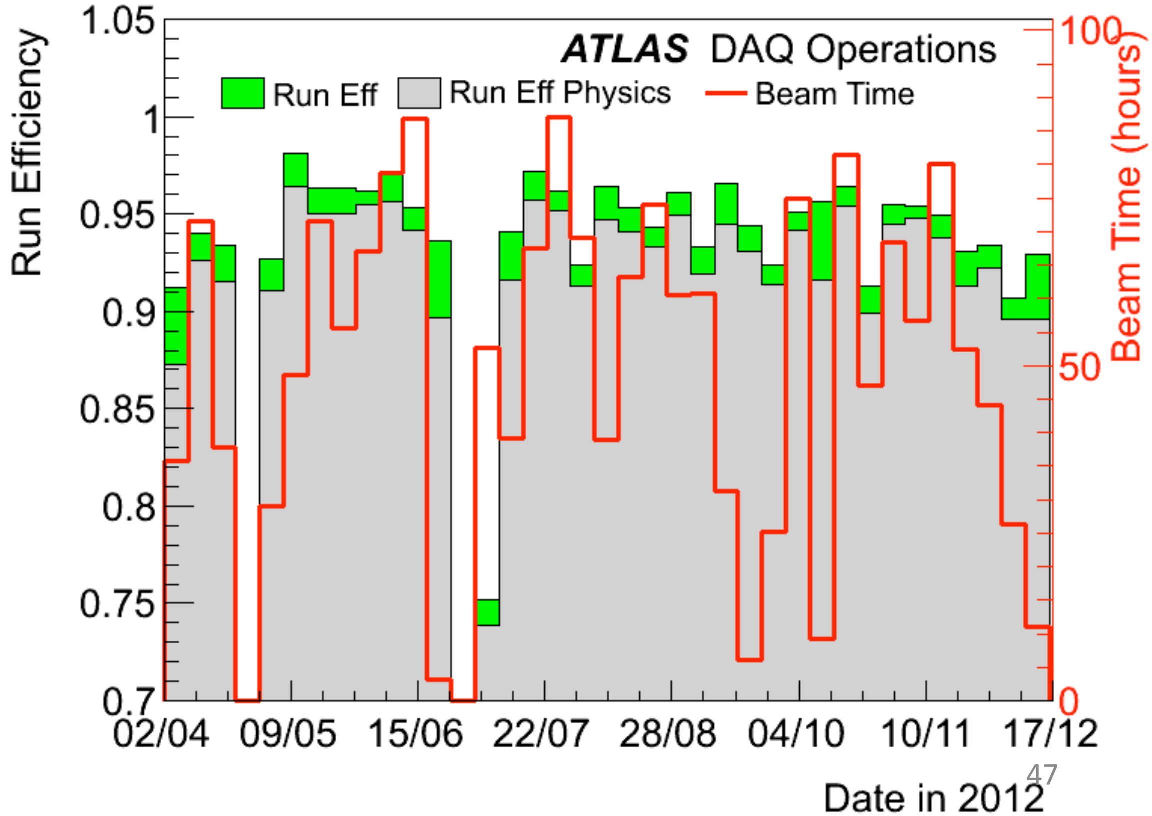
Algorithms
- Timing
- Efficiency
- Purity
- Response to Instantaneous Luminosity
- Response to pile-up

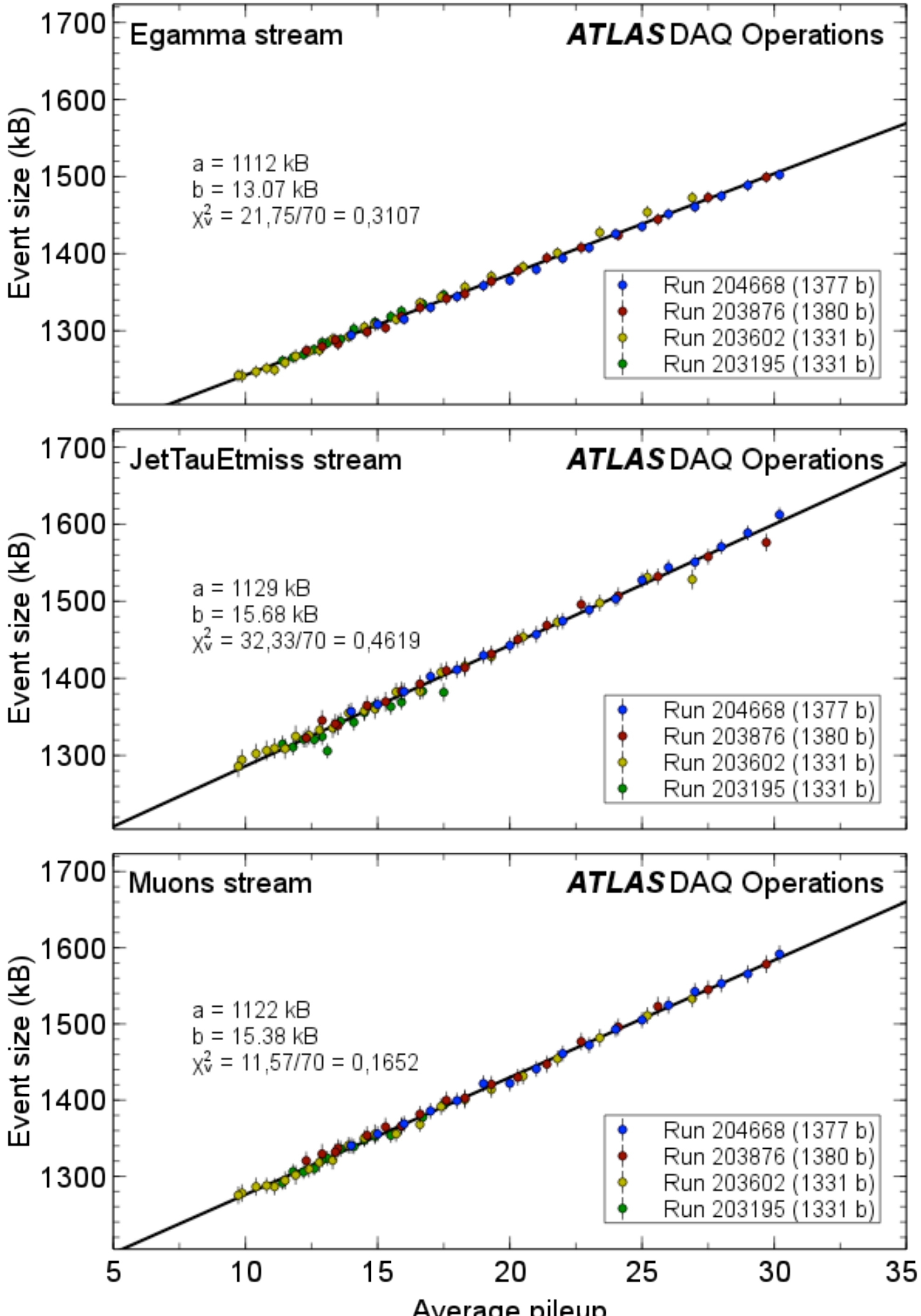
Physics
- Were the triggers used in analyses?

2012 ATLAS Performance



Running and not busy: 94.4 %

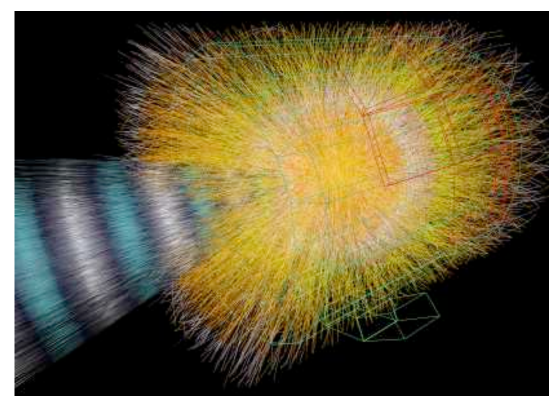




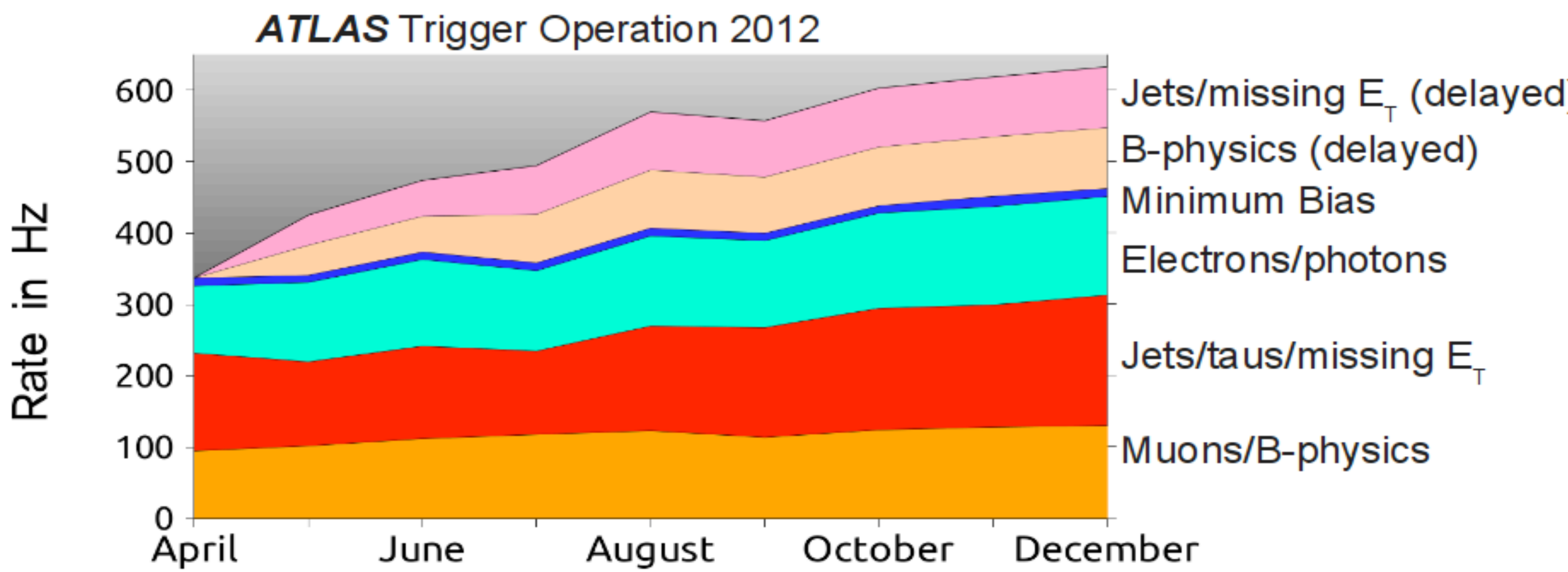
2012 ATLAS Performance

(Sobering) event size coming out of SFO (HLT/DAQ) as a function of pile-up

Still, much less than the O(100) MB at ALICE pb-pb

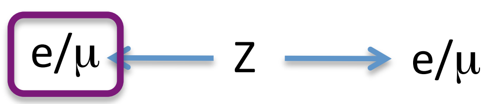


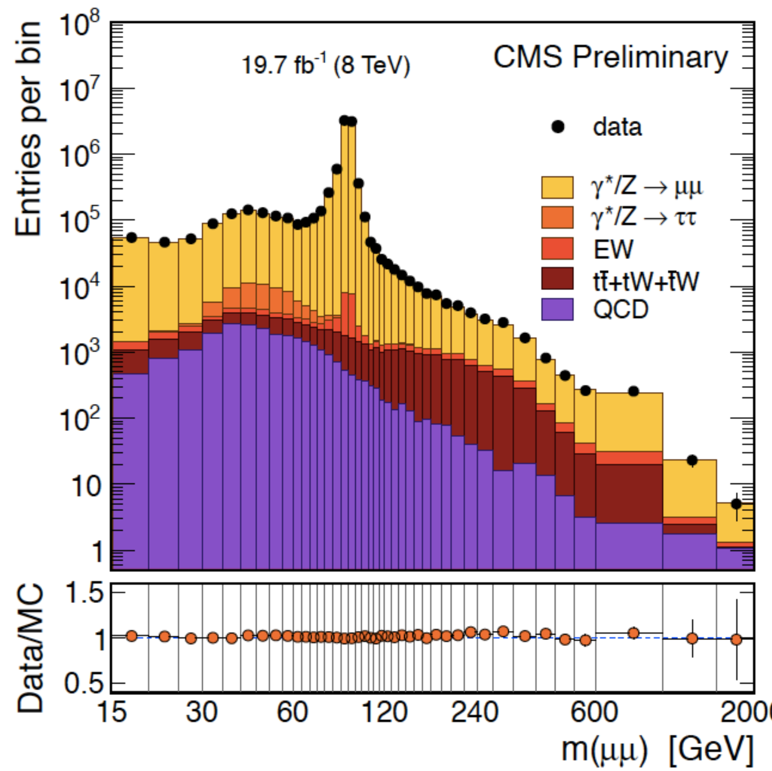
Performance (ATLAS)



Measuring Algorithm Performance: Tag and Probe

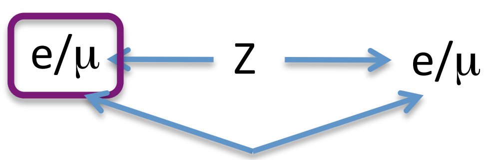
Tag: passes trigger tight identification cuts



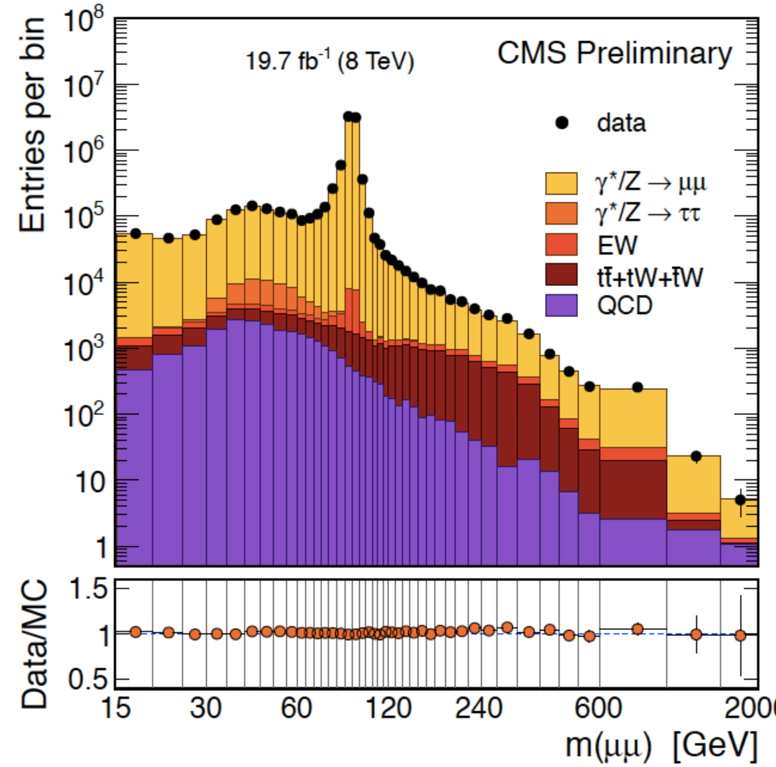


Measuring Performance: Tag and Probe

Tag: passes trigger tight identification cuts



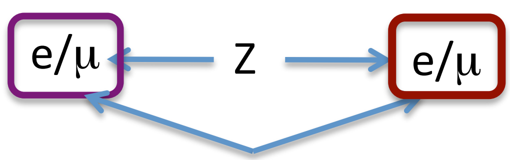
Require ee / μμ pair to
- have opposite charge
- give Z mass



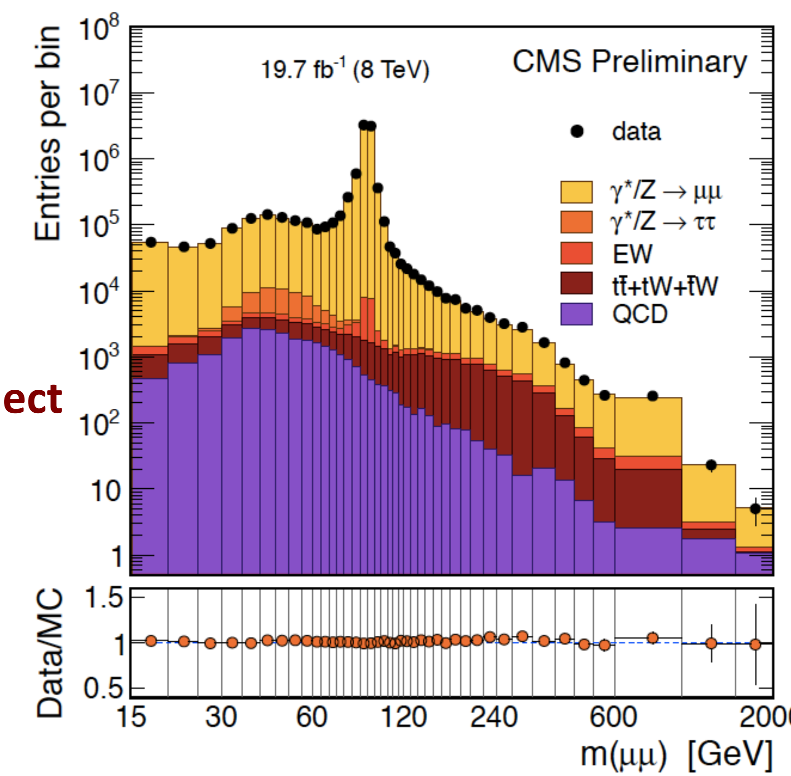
Measuring Performance: Tag and Probe

Tag: passes trigger tight identification cuts

Probe: unbiased object with known ID



Require ee / μμ pair to
- have opposite charge
- give Z mass



Can even do this for hadronic tau decays!
What about high pT objects?

Tomorrow…

Data Preparation and analysis

What keeps trigger people up at night?

Trigger/DAQ upgrades