Triggers, Data Acquisition and Data Processing: Part 2

HCPSS 2014

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Yale University

Plan for Today

- Finish up last topics from yesterday (trigger performance)
- Respond to discussion session
  - ATLAS Trigger, Timing and Control (TTC) functionality
  - latency pipeline
- A few comments about Data Preparation
- What keeps trigger people up at night?
- Trigger/DAQ Upgrades

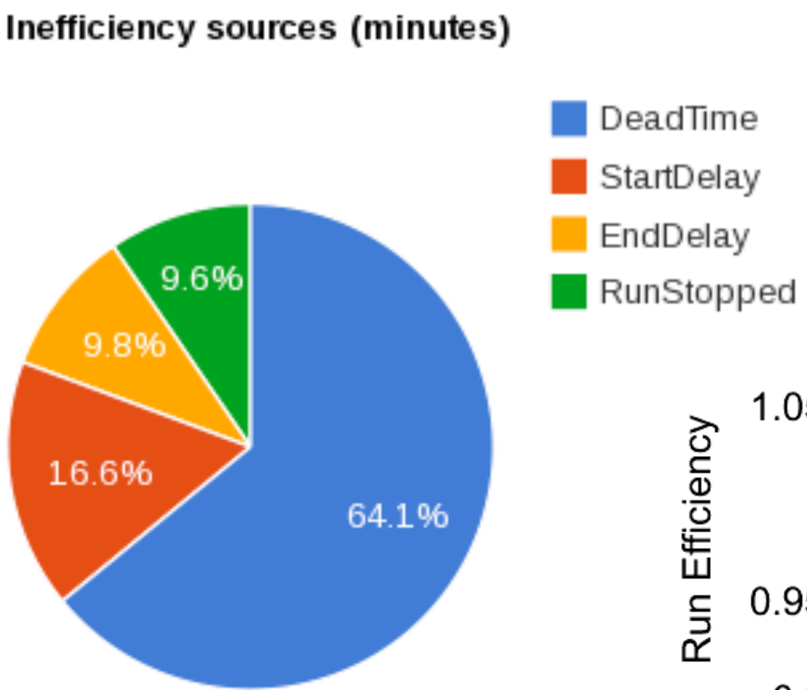
Evaluating Performance

Operations
- Deadtime, busy, run start/stop

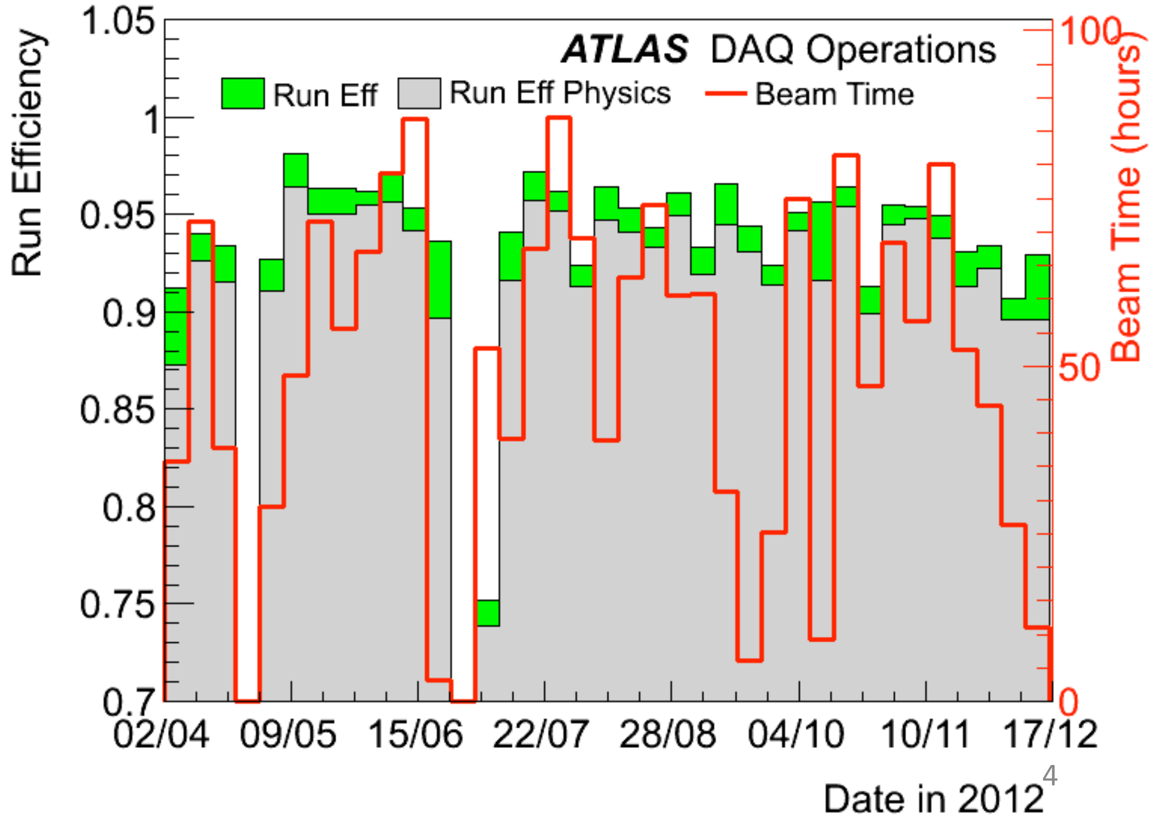
Algorithms
- Timing
- Efficiency
- Purity
- Response to Instantaneous Luminosity
- Response to pile-up

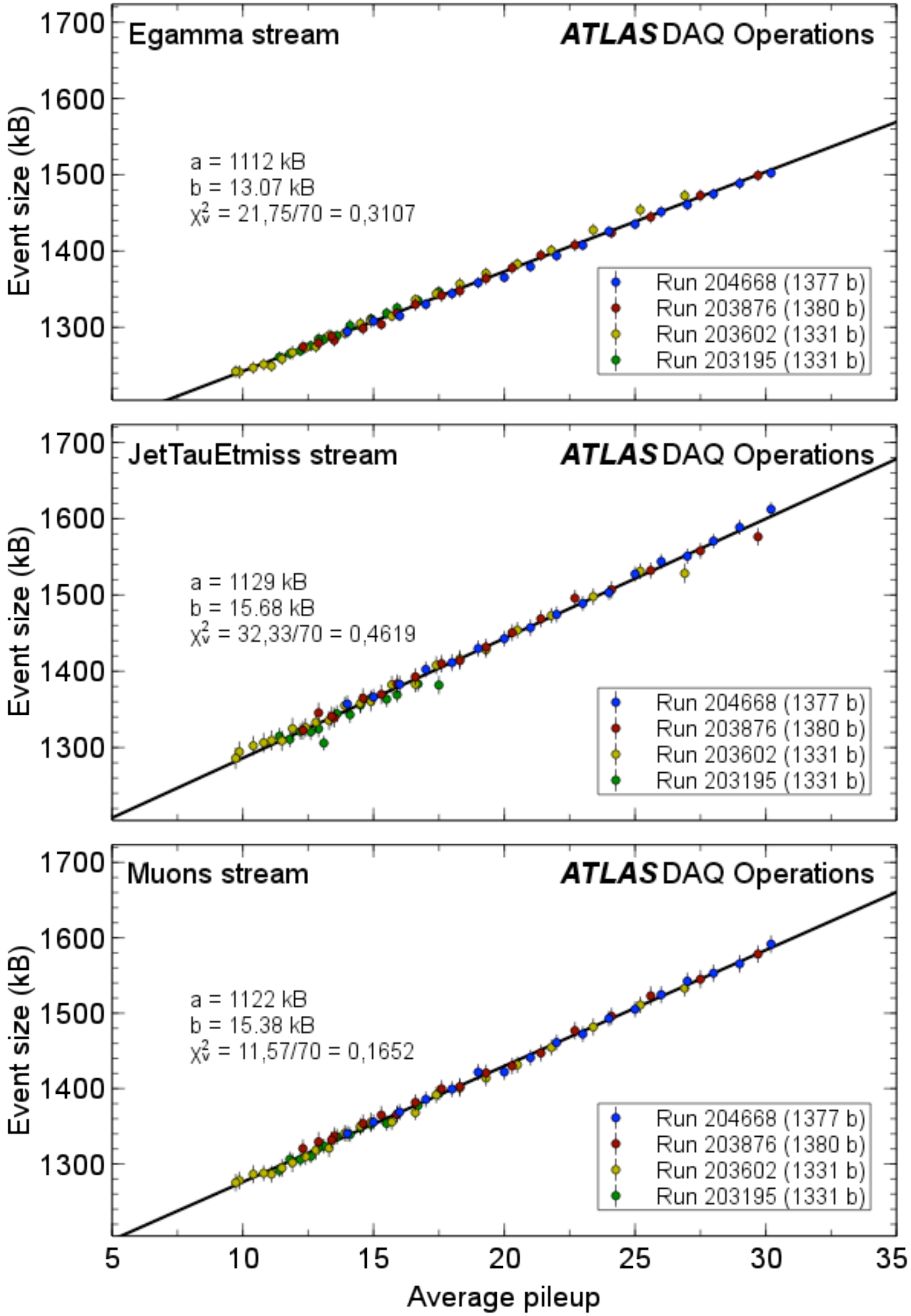
Physics
- Were the triggers used in analyses?

2012 ATLAS Performance



Running and not busy: 94.4 %

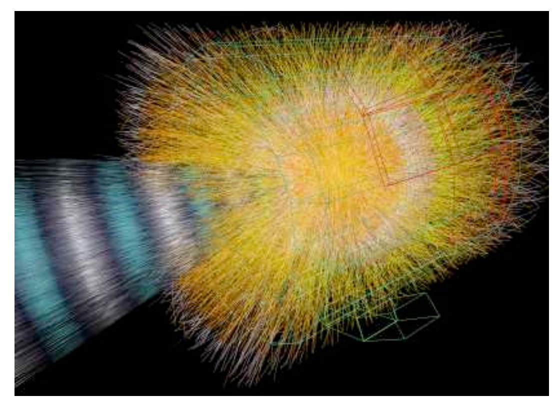




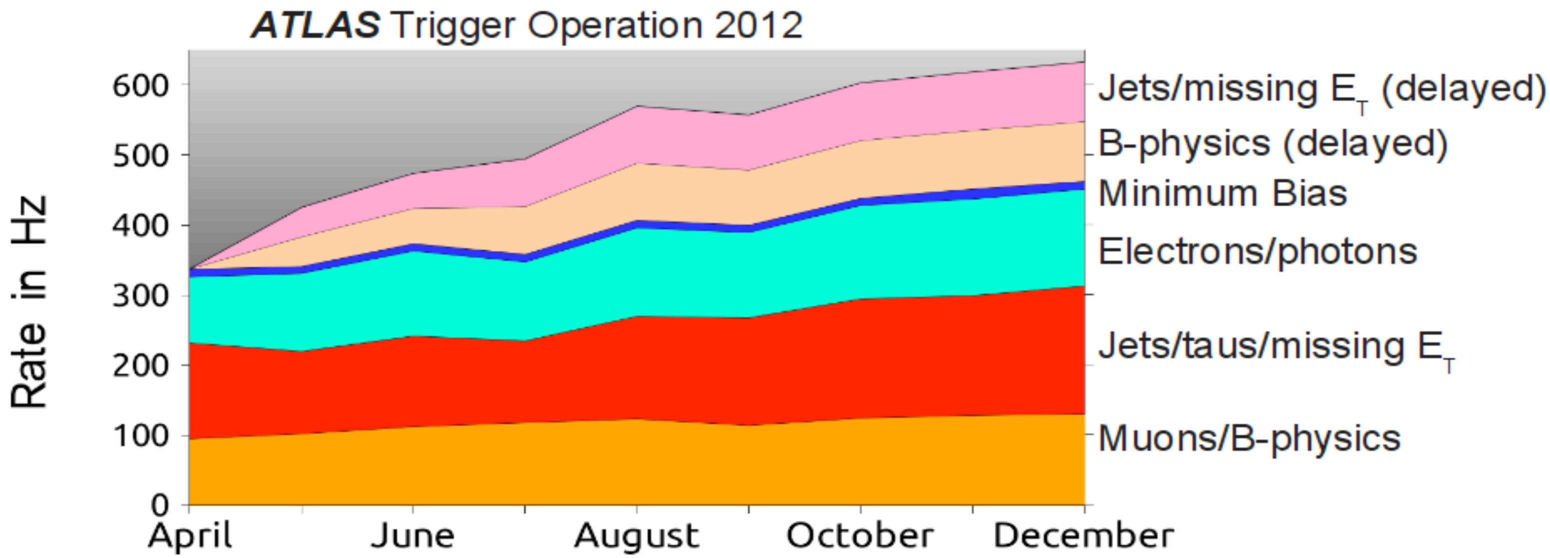
2012 ATLAS Performance

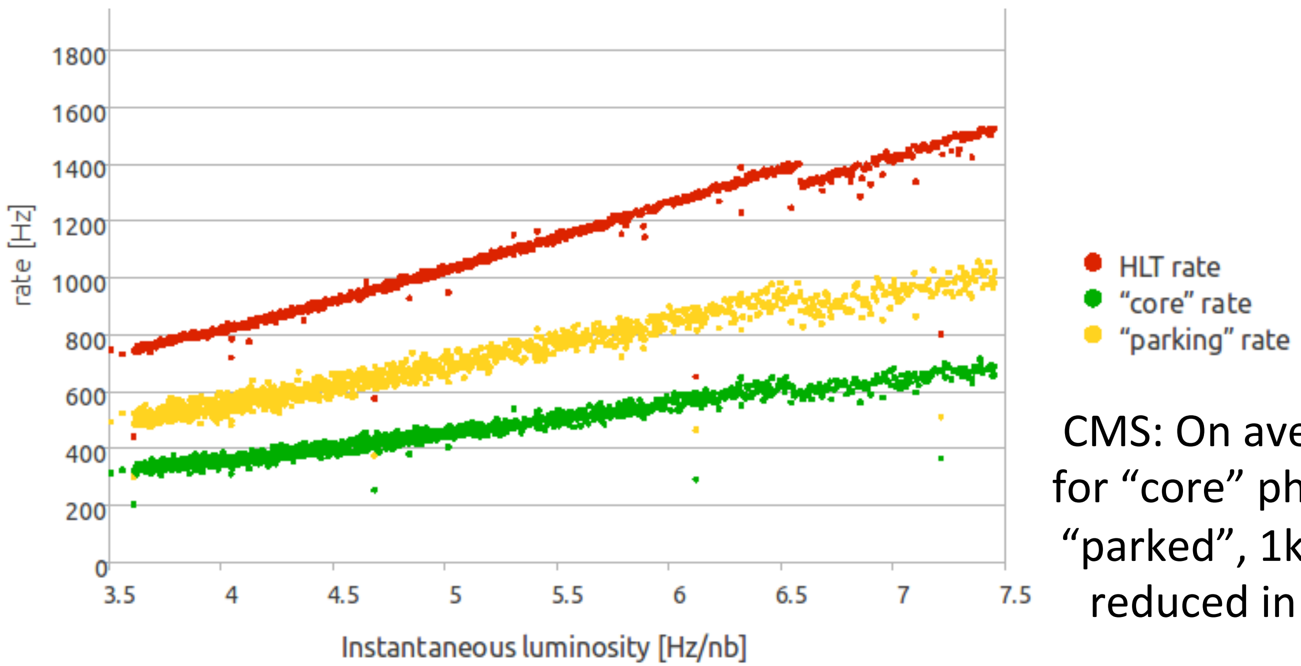
(Sobering) event size coming out of SFO (HLT/DAQ) as a function of pile-up

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



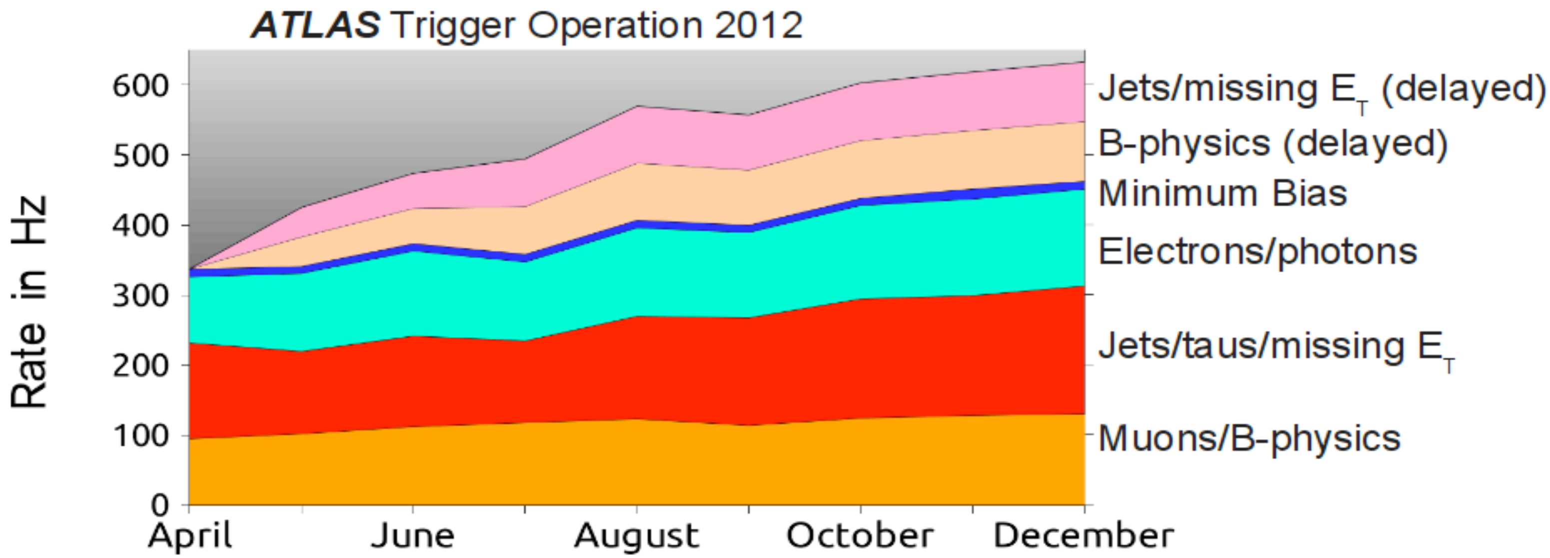
Performance: Use of bandwidth

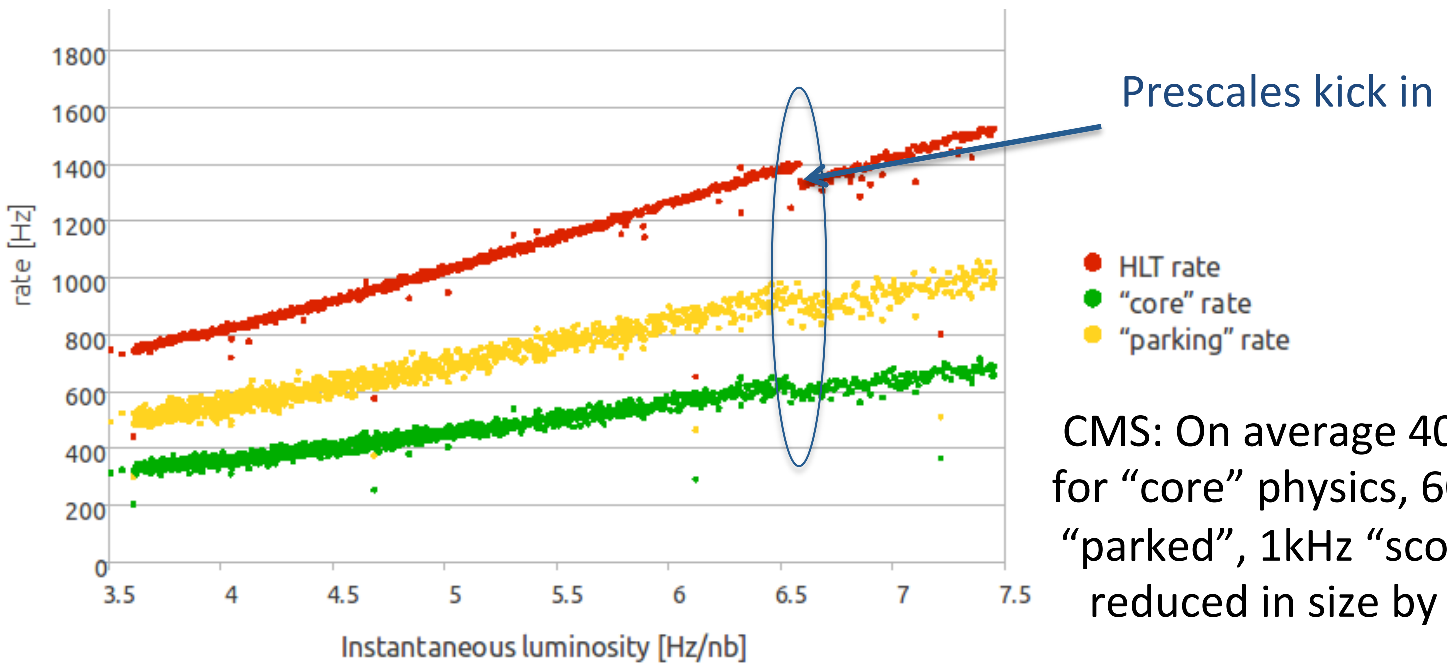




CMS: On average 400 Hz for “core” physics, 600 Hz “parked”, 1kHz “scout” – reduced in size by 10^3

Performance: Use of bandwidth





CMS: On average 400 Hz for "core" physics, 600 Hz "parked", 1kHz "scout" – reduced in size by 10^3

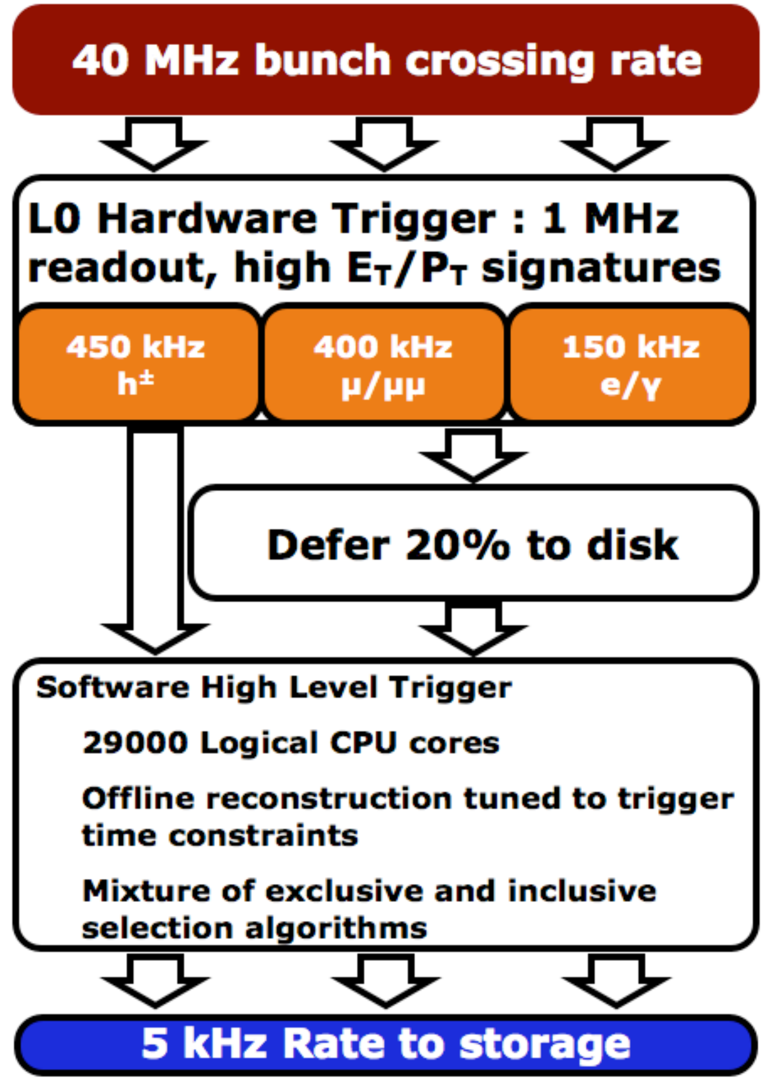
Performance: Use of bandwidth

In 2012, LHCb used a “deferred” trigger scheme, sending 20% of L0 rate directly to disk

Allowed for more inclusive tracking conditions, increasing efficiency for important signal processes

$$D^0 \to K_S^0 \pi^- \pi^+$$

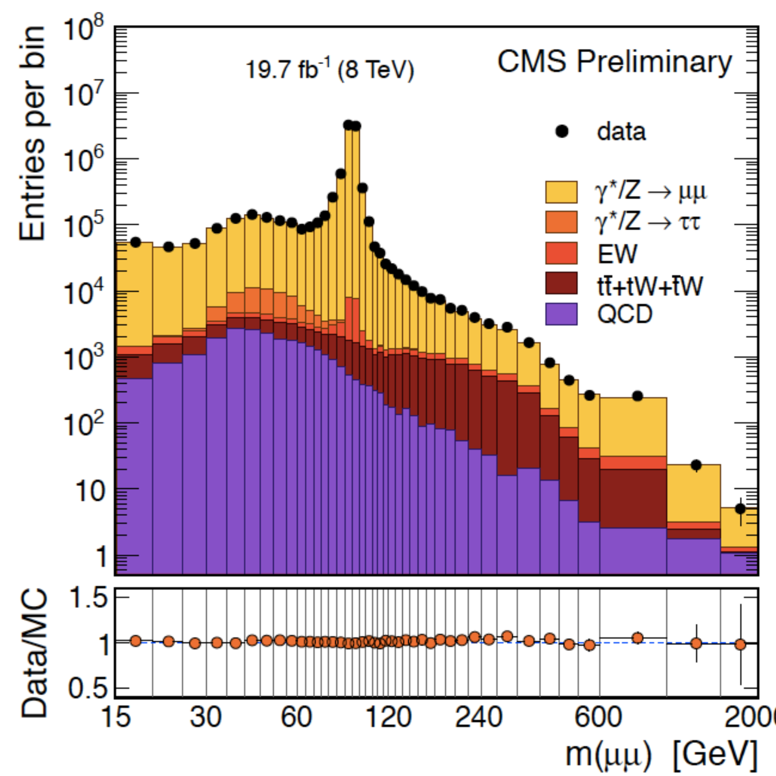
efficiency increased by factor of three



Measuring Algorithm Performance: Tag and Probe

Tag: passes trigger tight identification cuts

e/μ ← Z → e/μ



Measuring Performance: Tag and Probe

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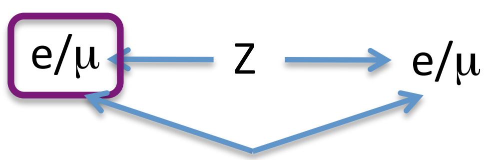
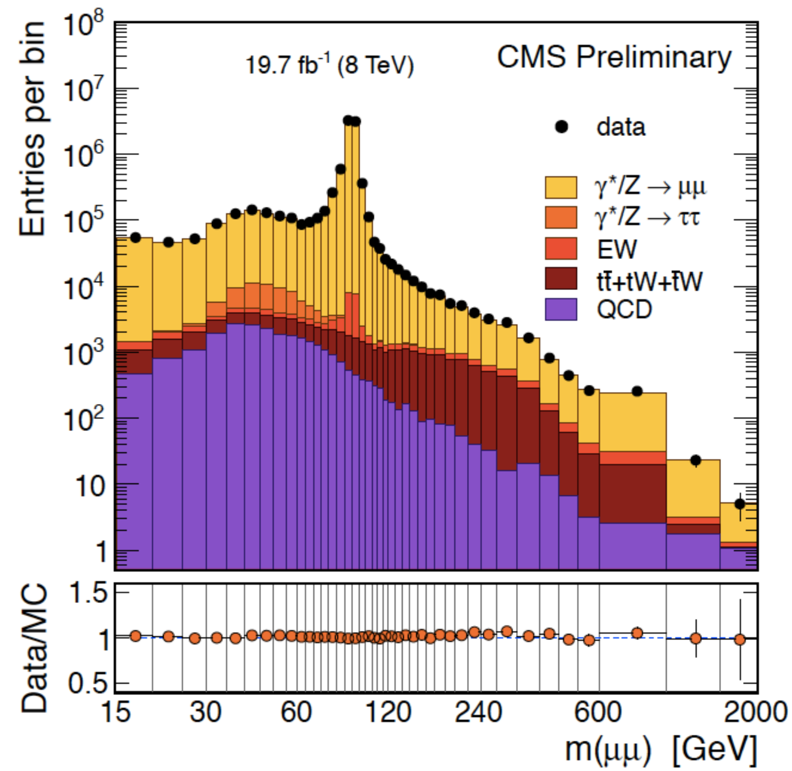
tight identification cuts



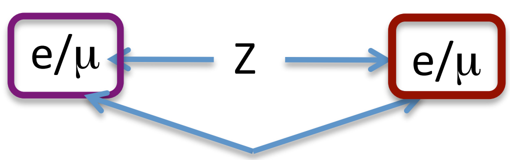
Require ee / μμ pair to
- have opposite charge
- give Z mass



Measuring Performance: Tag and Probe

Tag: passes trigger tight identification cuts

Probe: unbiased object with known ID



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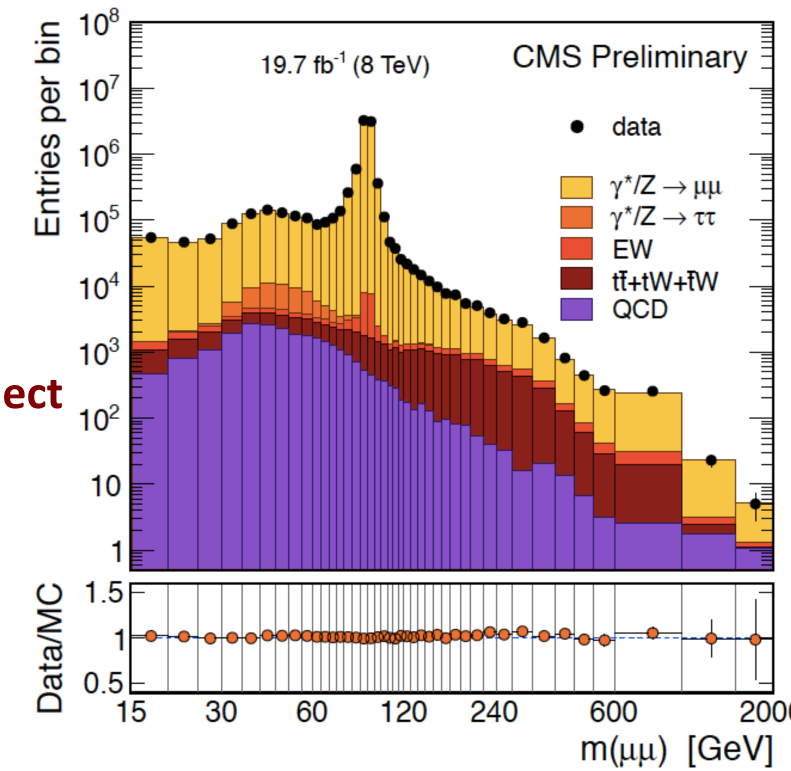


Can even do this for hadronic tau decays!
What about high pT objects?

Tomorrow…

Data Preparation and analysis

What keeps trigger people up at night?

Trigger/DAQ upgrades

Today…

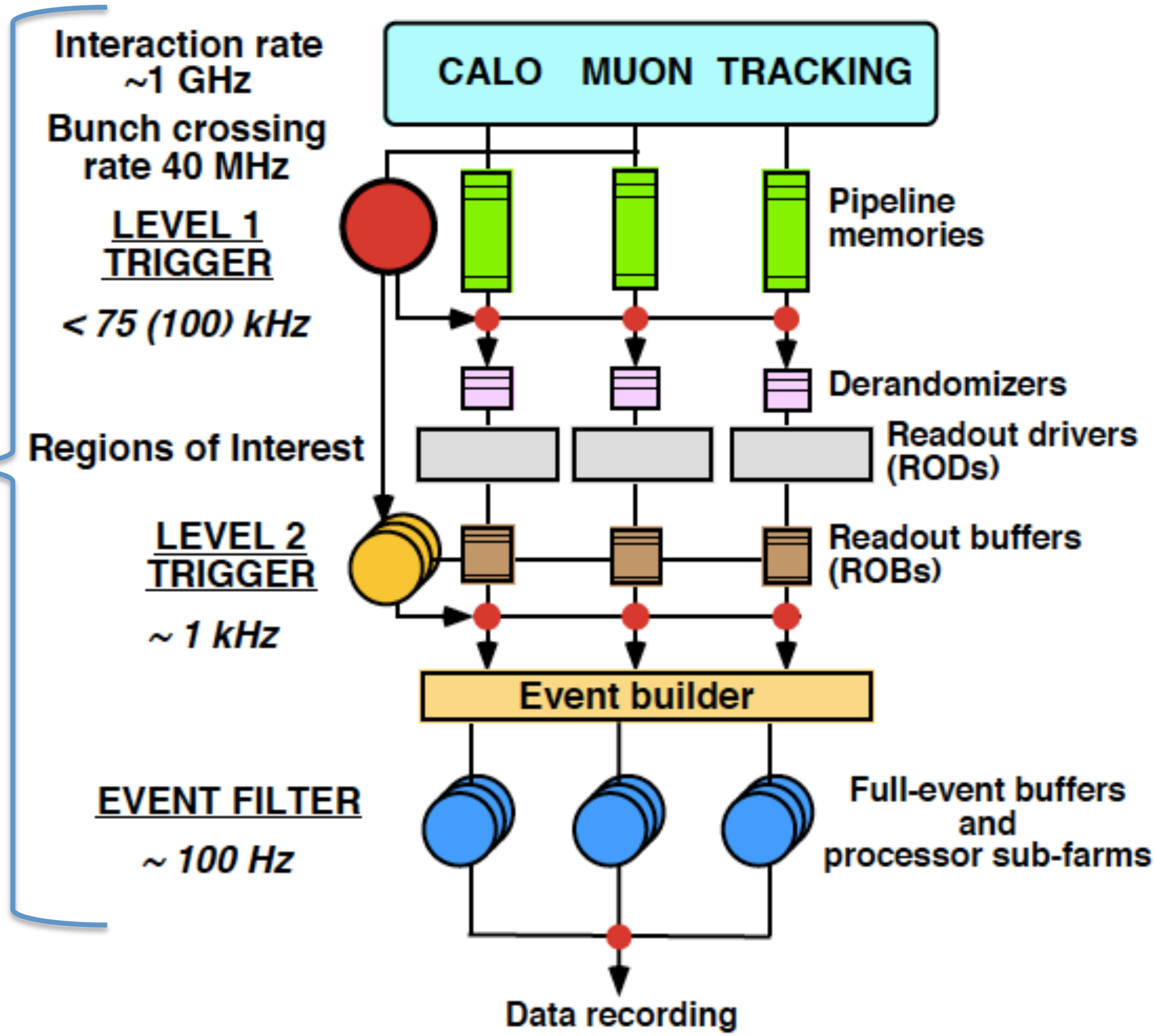
Data Preparation and analysis

What keeps trigger people up at night?

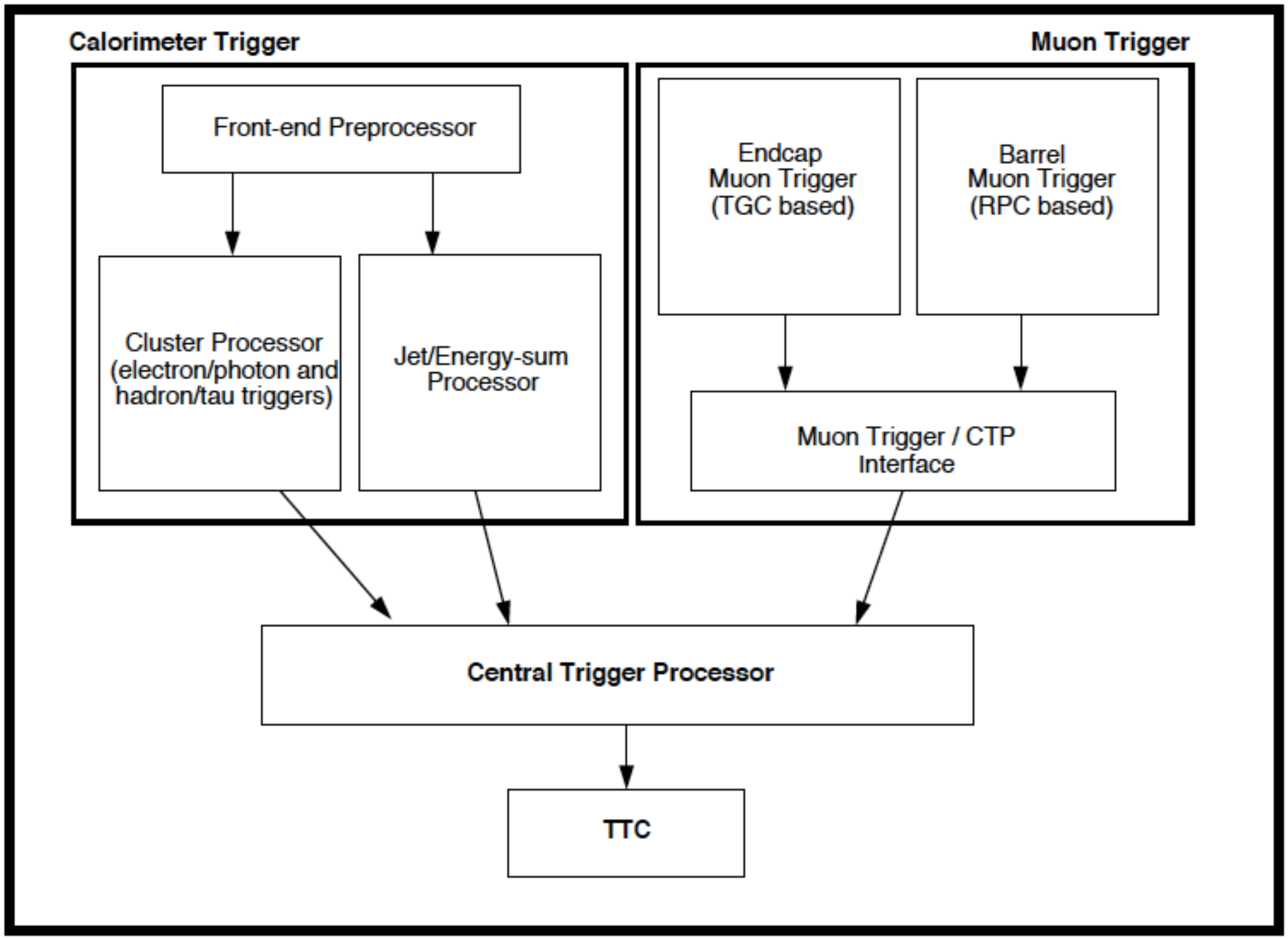
Trigger/DAQ upgrades, but first, some details about the TTC, and the latency pipeline.

ATLAS TTC: Trigger, Timing and Control (ATLAS L1 Technical Design Report: ATLAS TDR-12)

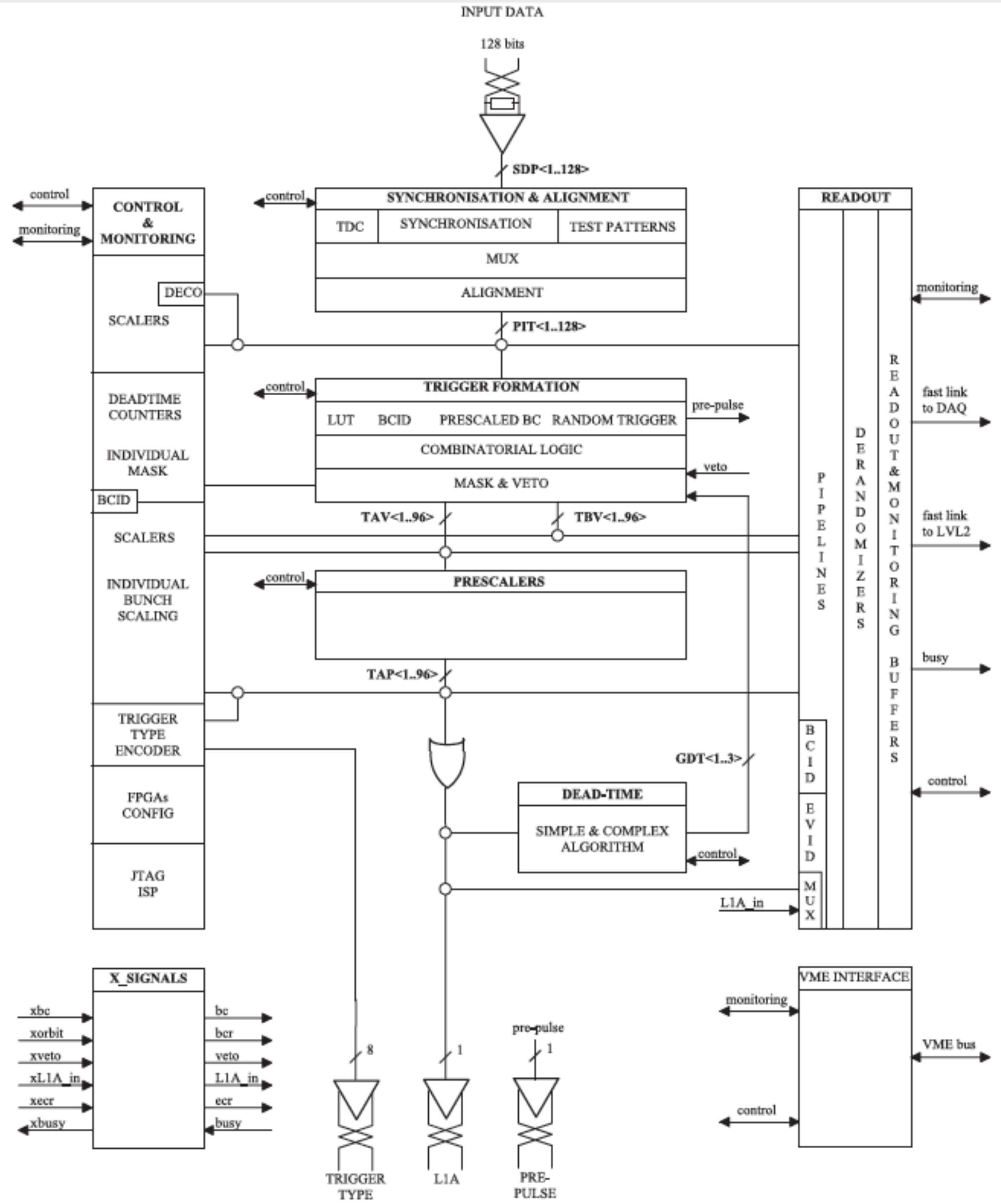
Design Numbers
<u>not</u>
Operations



ATLAS L1 Trigger



Central Trigger Processor

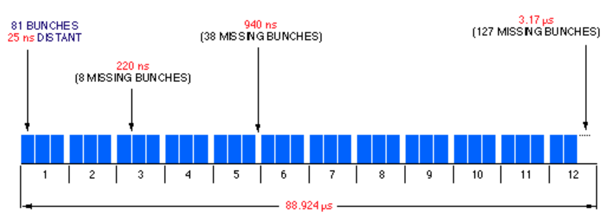


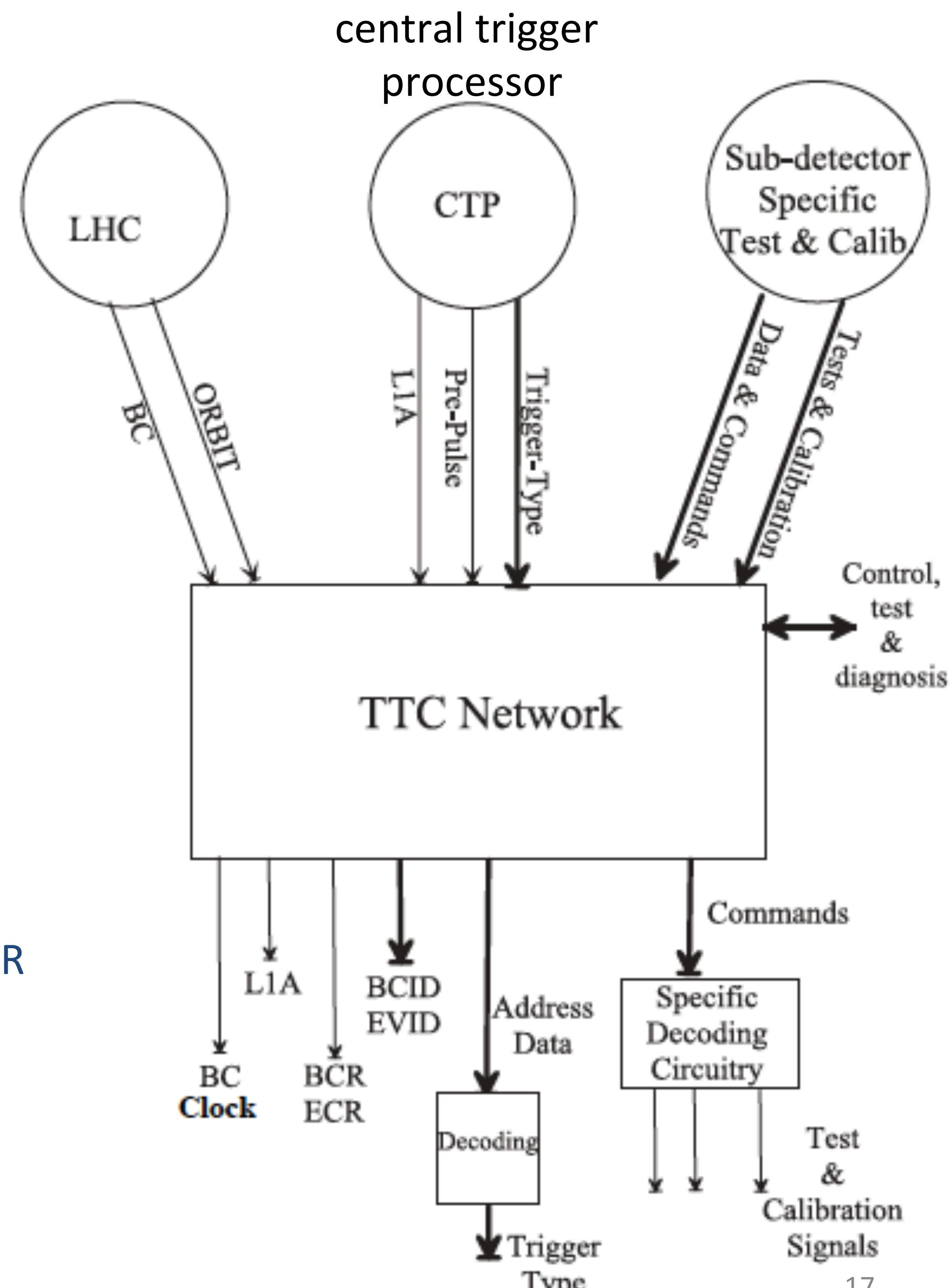
ATLAS TTC
Trigger, Timing and Control

From the LHC:
- bunch-crossing clock
- once per orbit, BC=0 signal

From CTP:
- type of trigger with each L1 Accept
- prepulse (for calibration triggers)

Out of TTC:
- clock from LHC (BC clock)
- L1 Accept with trigger type
- BCID: Bunch-crossing ID
- EVID: event identifier
- for reset/synchronization, BCR + ECR
- BCR: bunch counter re-set
- EVR: event counter re-set





ATLAS Latency

Item	Contribution to latency (BC)		Comment
Muon trigger	**54.0**		
RPC-specific part		36.0	Including worst-case 80 m fibres to USA15
TGC-specific part		46.0	Including worst-case 80 m fibres to USA15
Interface to CTP		8.0	
Calorimeter trigger	**56.1**		
Signal processing and cables up to input of trigger preprocessor		20.6	Including worst-case 60 m cables to USA15
Preprocessor (e/γ, τ/h)		15.0	
Preprocessor (jet, E_T)		17.0	
Electron/gamma finding		14.0	
Tau/hadron finding		14.0	
Jet finding		18.0	
Missing E_T		18.5	
Total scalar E_T		18.5	
CTP	**4.0**		
TTC	**3.1**		Includes cable from CTP
Fibres to FE electronics	**16.0**		Using worst-case 80 m fibres
TTC receiver (in FE electronics)	**3.0**		
TOTAL	**82.2**		

For Real This Time: ~~Tomorrow~~ Today

Data Preparation and analysis

What keeps trigger people up at night?

Trigger/DAQ upgrades

A Challenge: Open the “data fragment header” black box for your experiment

Advanced Challenge: understand data format for raw data

Common Data Fragment Header

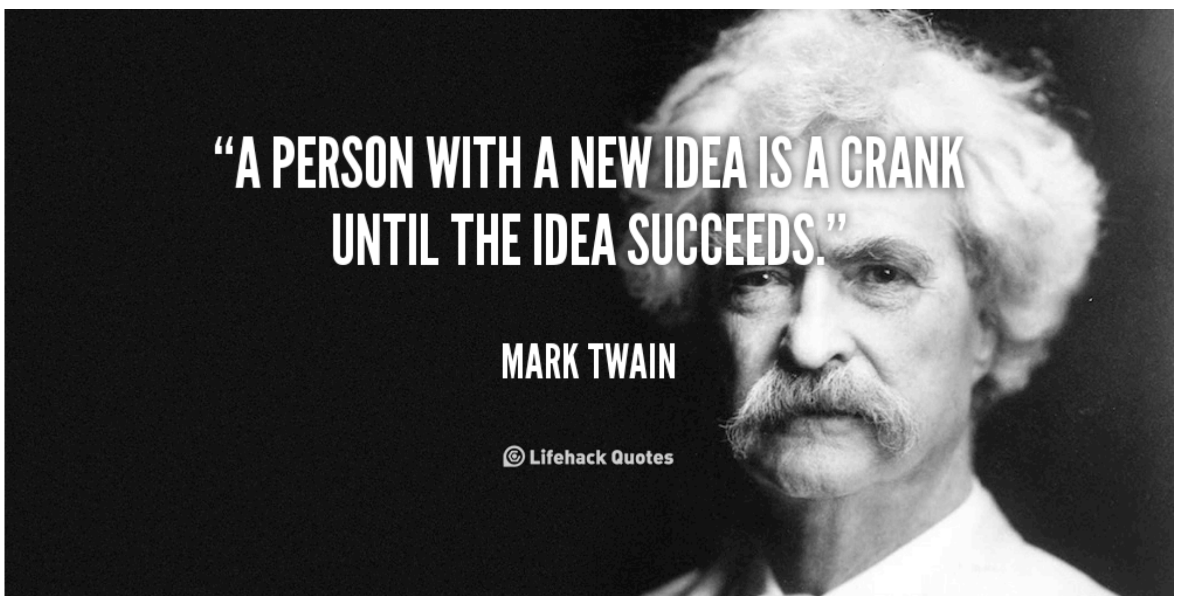
	31 … 24 … 16 … 8 … 0			
0	Block length [0-31]			
1	Format Version [24-31]	L1 Trigger Message [14-23]	MBZ [12-13]	Event ID 1 (Bunch crossing)[0-11]
2	MBZ [24-31]	Event ID 2 (Orbit Number) [0-23]		
3	Block Attributes [23-31]	Participating Sub-Detectors [0-23]		
4	MBZ [28-31]	Status & Error Bit [12-27]	Mini-Event ID (Bunch crossing)[0-11]	
5	Trigger classes Low [0-31]			
6	ROI Low [28-31]	MBZ [18-27]	Trigger classes High [0-17]	
7	ROI High [0-31]			

So, you want to introduce a new trigger?

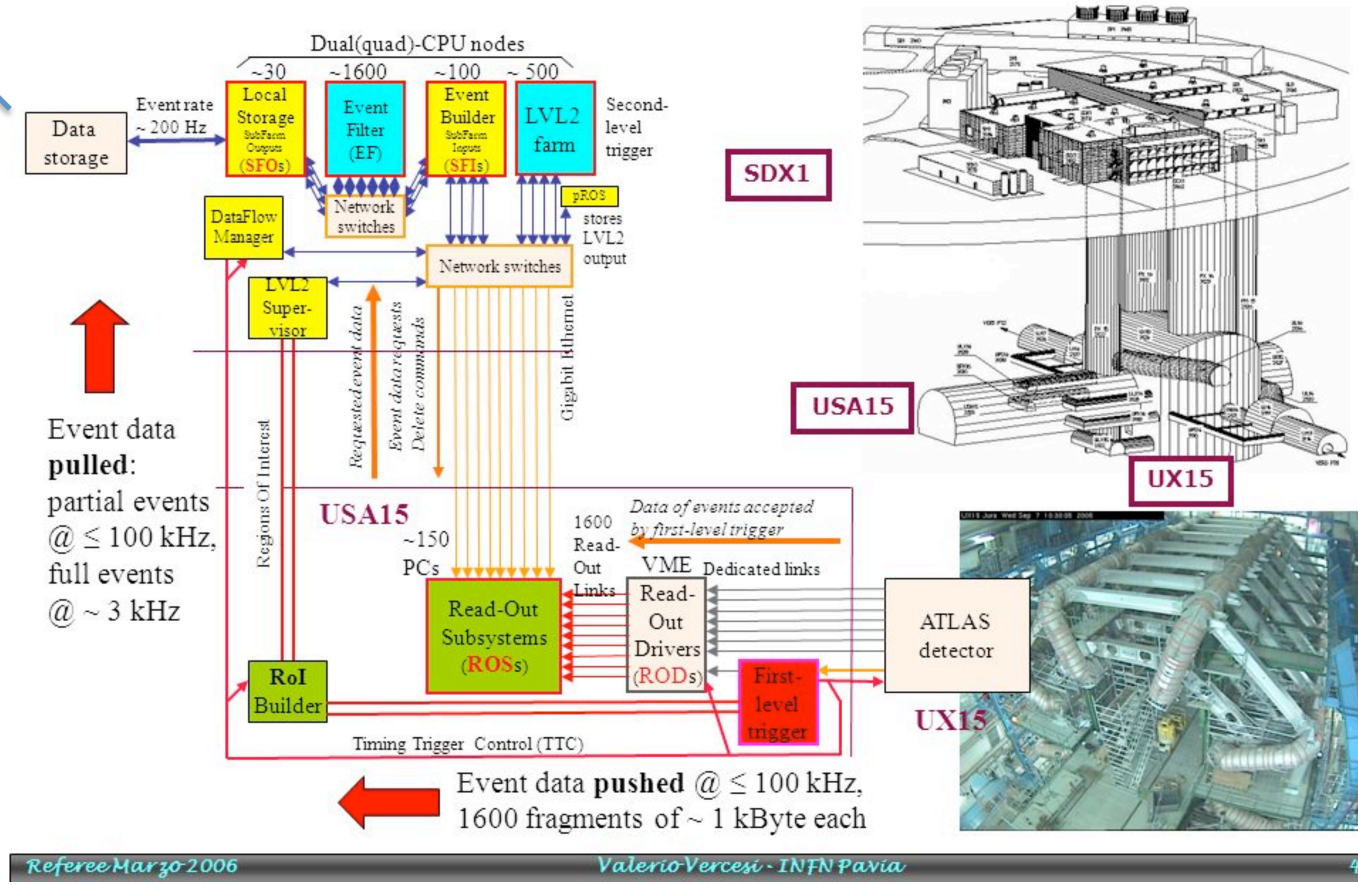
So you want to introduce a new trigger?

What is the rate of the trigger? Both TOTAL and UNIQUE Rate.

What fraction of that rate will you use in your analysis?
Optimize against your offline reconstruction objects, not truth objects!
How will you evaluate your trigger efficiency?



Data Preparation

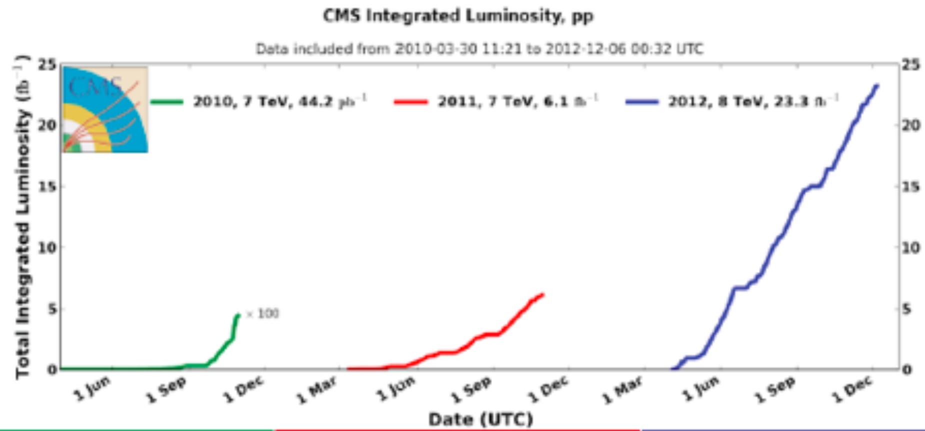


Data Preparation

Data Quality

Reprocessing

Example from CMS, *P. Azzi*



2010

- ~15 Re-reco passes
- 3 production releases (3.6, 3.8, and 3.9)
- No prompt calibration loop

2011

- ~3 Re-reco passes of MC and targeted reco)
- 3 releases (4.1 used briefly, 4.2, and 4.4 used mostly in 2012)
- PCL commissioned

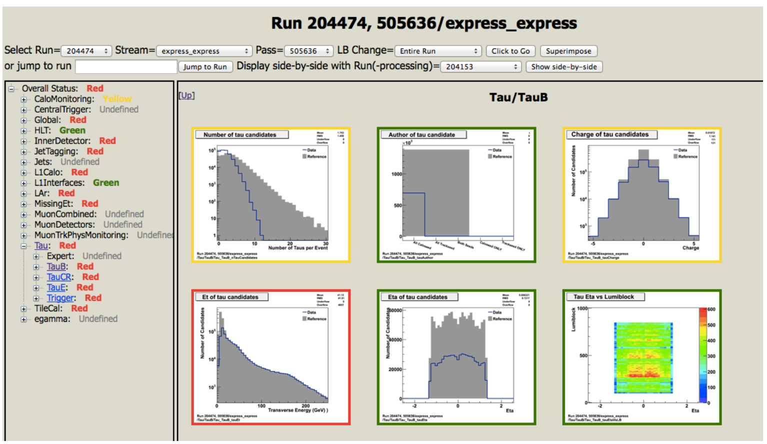
2012

- ~3 Re-reco passes and targeted reco)
- 5_2 and 5_3
- Good Management of calibration and validation

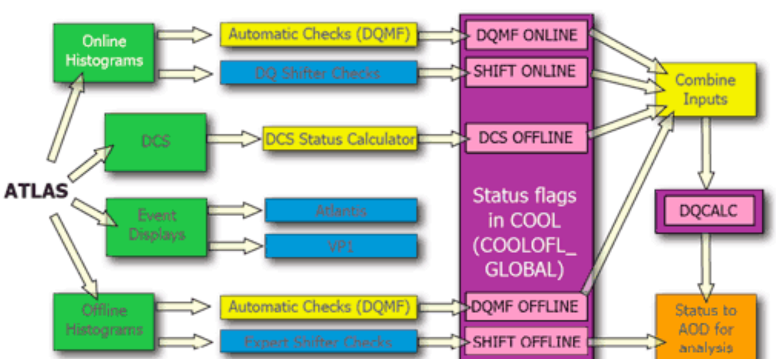
2

Data Preparation

Data Quality
Example from ATLAS



Data Quality Monitoring Framework



Reprocessing
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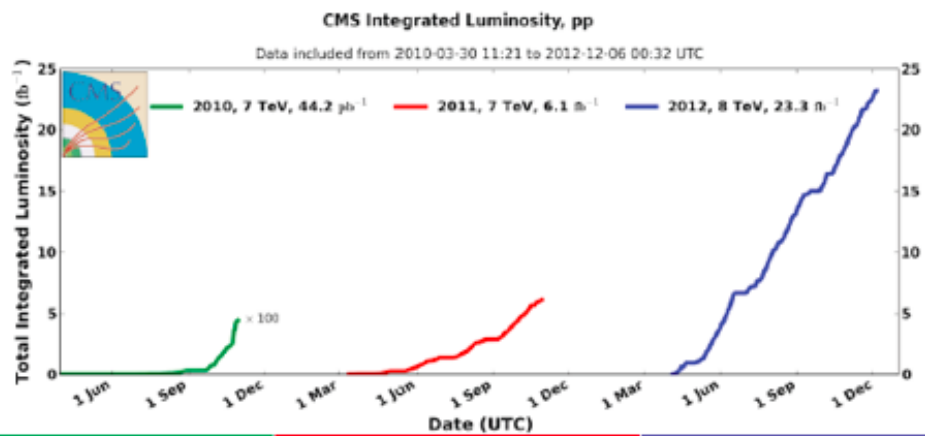

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2

What keeps the trigger group up at night?

Missing physics beyond the standard model because:

Triggers are too tightly tuned to specific scenarios and miss new physics that we didn't expect.

Slow-moving particles do not fire the trigger.
Long-lived particles do not fire the trigger.
Cascade decay products of new particles all have low energy and are therefore below trigger thresholds

Your nightmare scenario here…

Reminder of some challenges

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

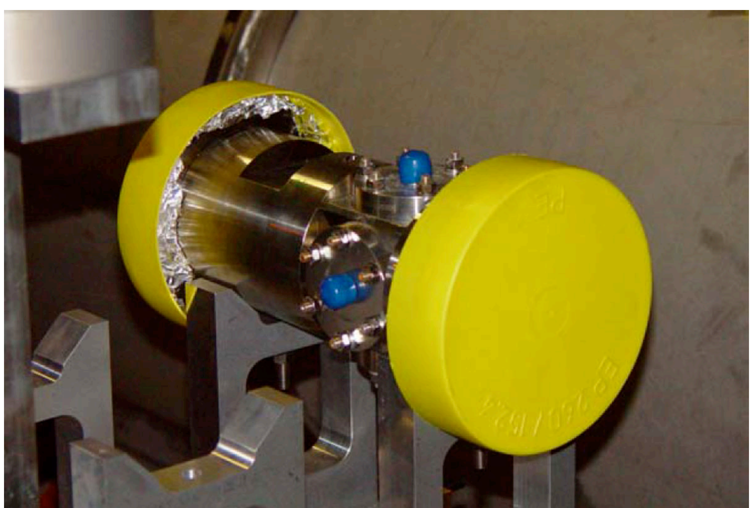
- ↯ $H \to 4b, 4\tau$ in NMSSM, Dermisek,Gunion [hep-ph/0502105,hep-ph/0611142]
- ↯ $H \to 6j$ in R-parity violating MSSM Carpenter,Kaplan,Rhee [hep-ph/0607204]
- ↯ $H \to 4g$ (Buried Higgs) in SUSY Little Higgs Bellazzini,Csaki,AA,Weiler [0906.3026]
- ↯ $H \to 4c$ (Charming Higgs) in SUSY Little Higgs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

Examples from Adam Falkowski's slides

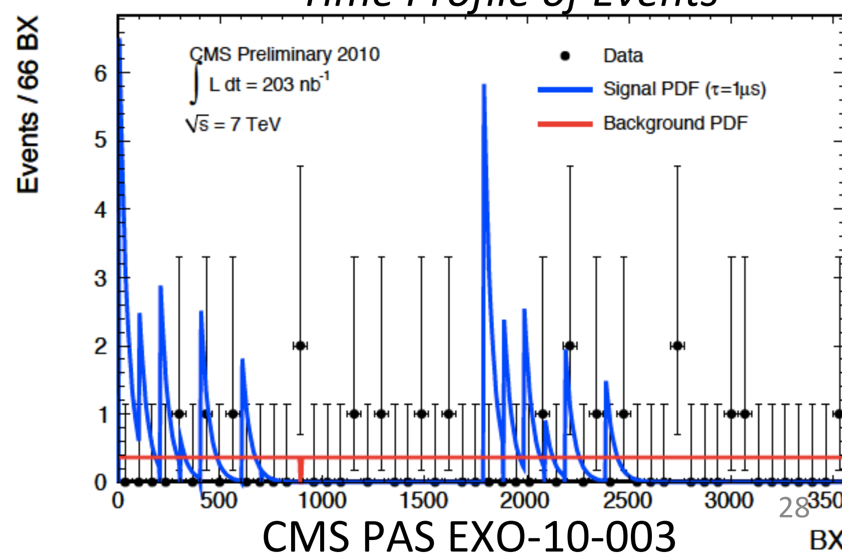
Dedicated Triggers: CMS Stopped Gluinos

Selection Criteria	Background Rate (Hz)
L1+HLT (HB+HE)	3.27
Calorimeter noise filters	1.12
BPTX/BX veto	1.11
muon veto	6.6×10^{-1}
$E_{jet} > 50$ GeV, $\lvert\eta_{jet}\rvert < 1.3$	7.6×10^{-2}
$n_{60} < 6$	7.6×10^{-2}
$n_{90} > 3$	3.1×10^{-3}
$n_{phi} < 5$	1.3×10^{-4}
$R_1 > 0.15$	1.1×10^{-4}
$0.1 < R_2 < 0.5$	8.5×10^{-5}
$0.4 < R_{peak} < 0.7$	7.9×10^{-5}
$R_{outer} < 0.1$	6.9×10^{-5}

BPTX Monitors 175 m from collision point



Time Profile of Events



CMS PAS EXO-10-003

Dedicated Triggers: CMS Stopped Gluinos

10 GeV (L1) and 20 GeV (HLT) trigger

Pulse shape consistent with energy deposit

veto on cosmic rays

veto jets too wide or narrow (consistent with noise) 60% of energy needs to require < 6 towers, 90% of energy needs to require > 3

single photodiode reads out 18 channels, all with the same phi

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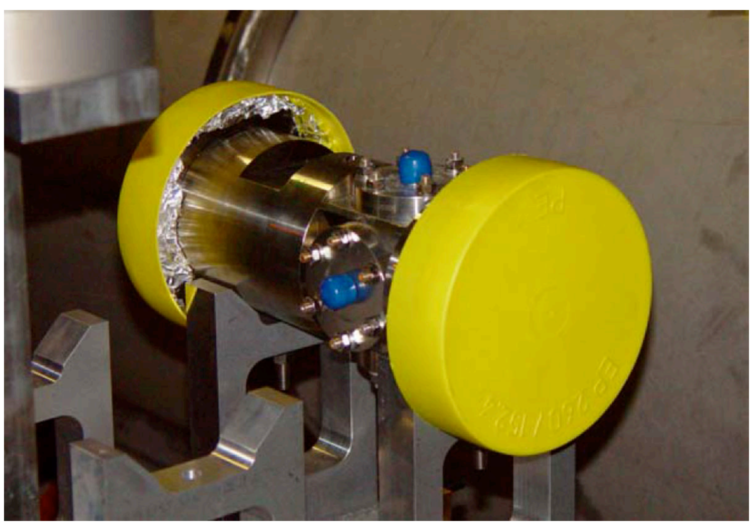

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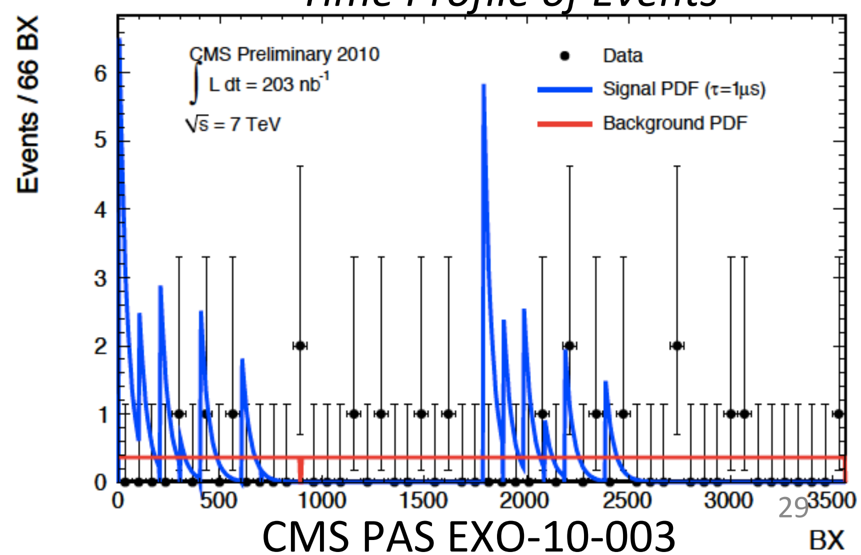


CMS PAS EXO-10-003

Looking Forward. Waaaaay forward.

Trigger/DAQ Upgrades

ALICE

Upgrade of the Readout and Trigger System

http://cds.cern.ch/record/1603472?ln=en

ATLAS

Phase-I Upgrade of TDAQ

http://cds.cern.ch/record/1602235?ln=en

Letter of Intent for Phase-II Upgrade

http://cds.cern.ch/record/1502664?ln=en

CMS

Level 1 Trigger Upgrade

http://cds.cern.ch/record/1556311?ln=en

LHCb

Trigger and Online Upgrade

https://cds.cern.ch/record/1701361/files/LHCB-TDR-016.pdf

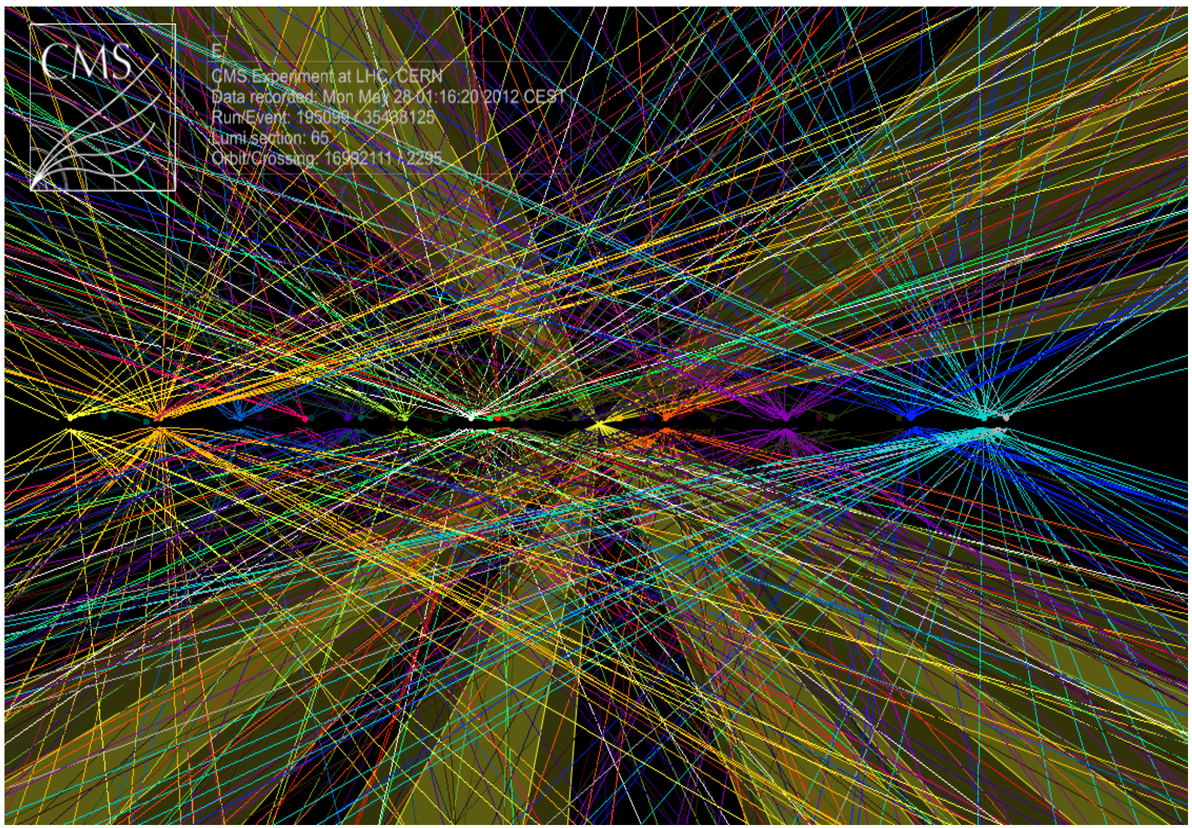
LS1: Ongoing, prepare for ~13 TeV, 1×10^{34} cm^{-2}s^{-2} <PU> 25 - 40

LS2: 2018, prepare for 2.5×10^{34} cm^{-2}s^{-2} <PU> ~60 PHASE-I Upgrades

LS3: 2022, prepare for 5×10^{34} cm^{-2}s^{-2} <PU> ~140 PHASE-II Upgrades

Upgrade

Going back to the mantra of being driven by physics, how would you define the performance needs of the upgrade?



Crossing with pile-up of 50 events

ALICE Upgrade

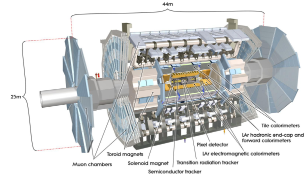
Broad Physics Goals

Precision measurements of quark-gluon plasma
heavy flavor transport, quarkonia, low mass di-leptons

Jet quenching and fragmentation

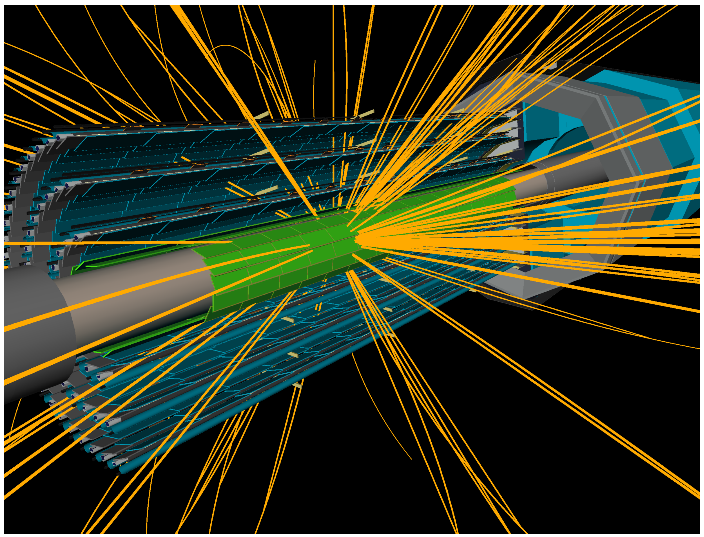
Exotic heavy nuclear states

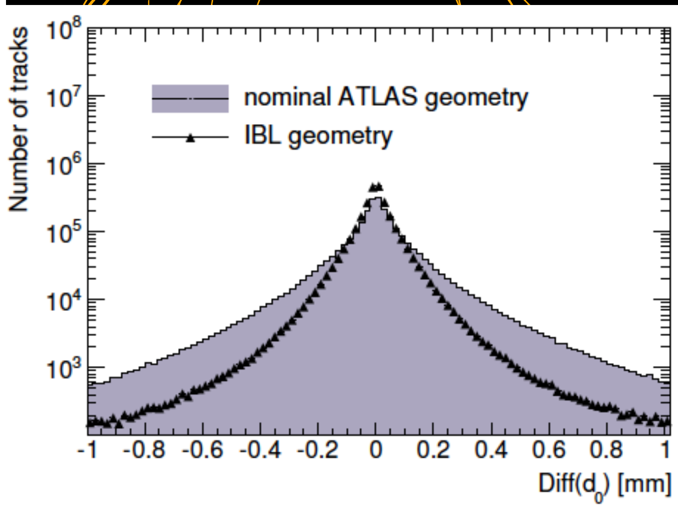
Maximum readout 500 Hz -> 50 kHz (pb-pb) and up to 200 kHz (p-p and p-pb)



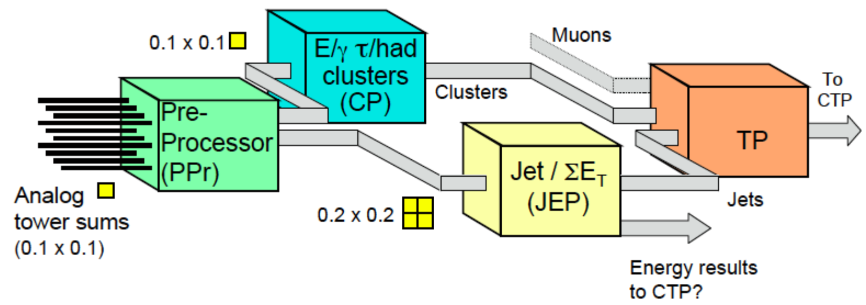
ATLAS Upgrade
Current Work Includes:

Insertable B-Layer



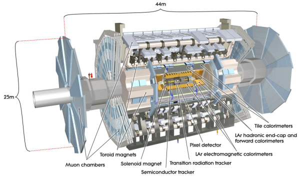


Topological Trigger



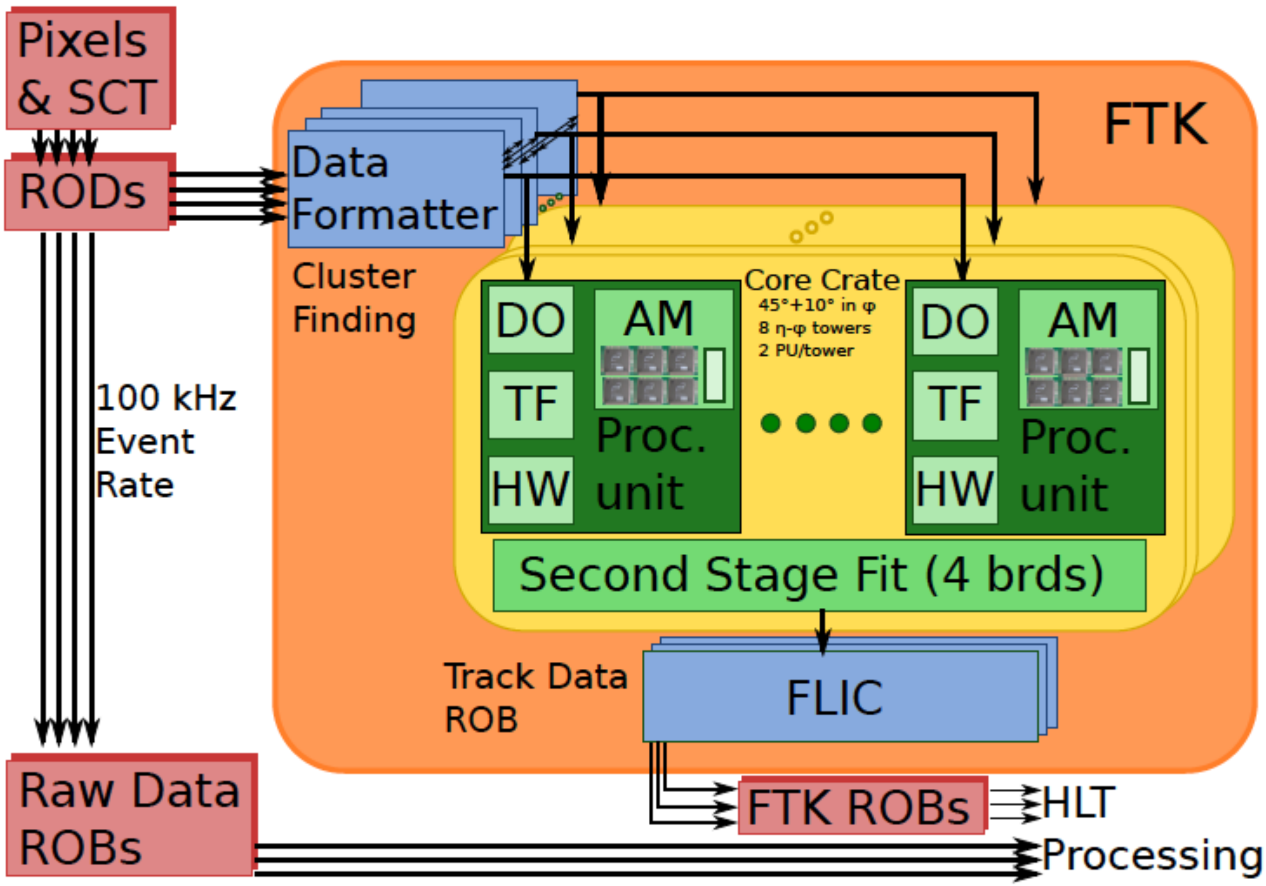
Combining muon and calorimeter objects – can make requirements on angular distributions, masses to select signal or reject BG

Fast TracKer (FTK)

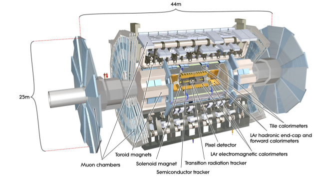


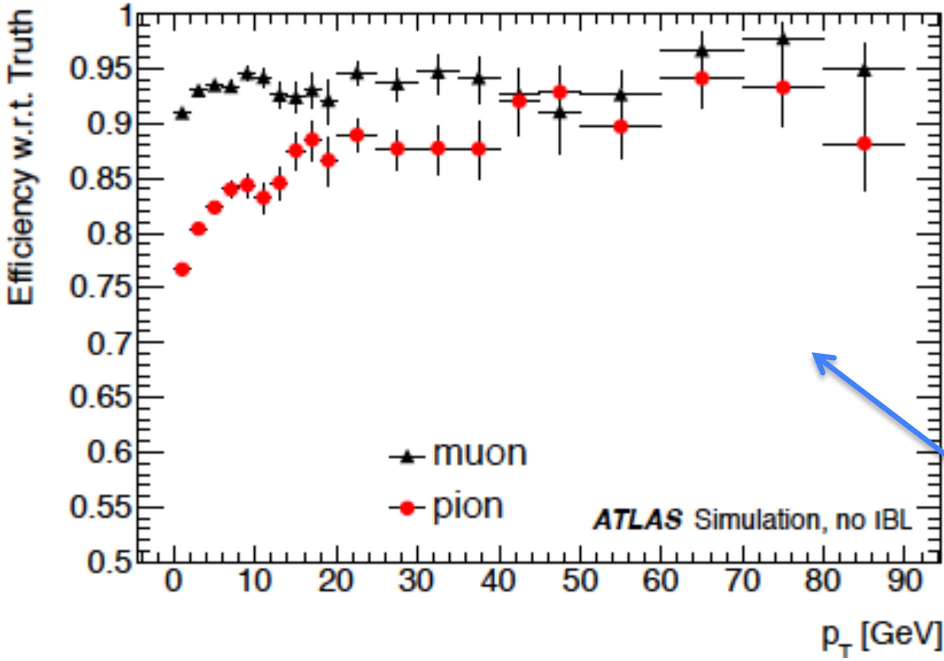
Electronics for global tracking on every L1 Trigger to provide early access to tracking information at Level 2.

Main motivation: b- and τ-tagging

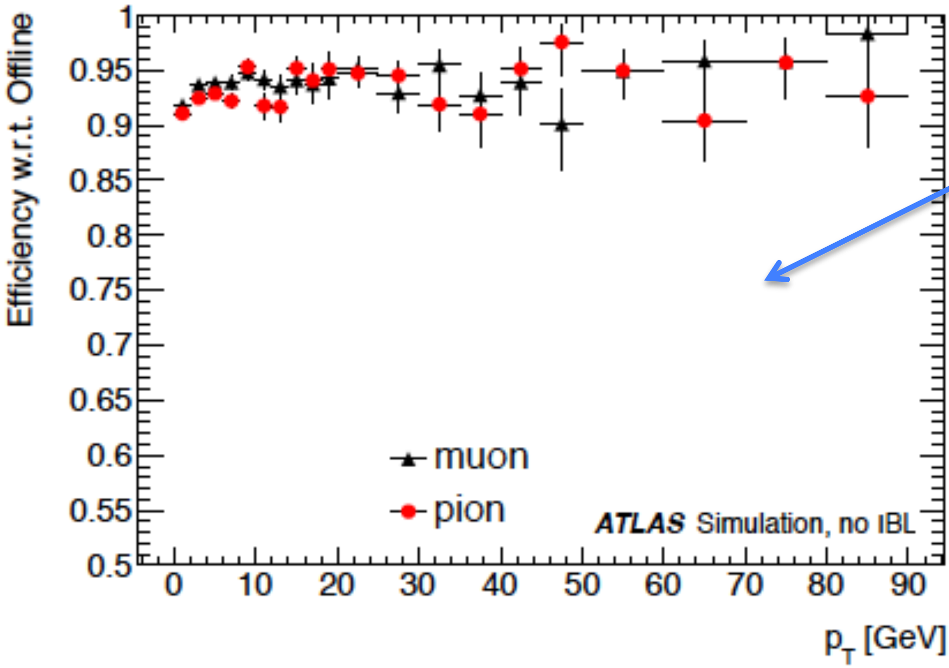


FTK

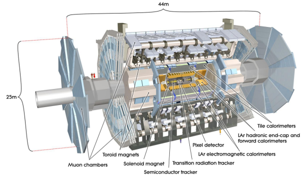




Efficiencies for muons and pions
with respect to
truth (simulation)
and
offline reconstruction



ATLAS-TDR-021-2013



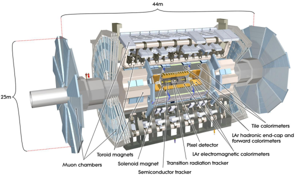
2018 – 2022   300 fb^{-1} 60 - 80 pile-up events

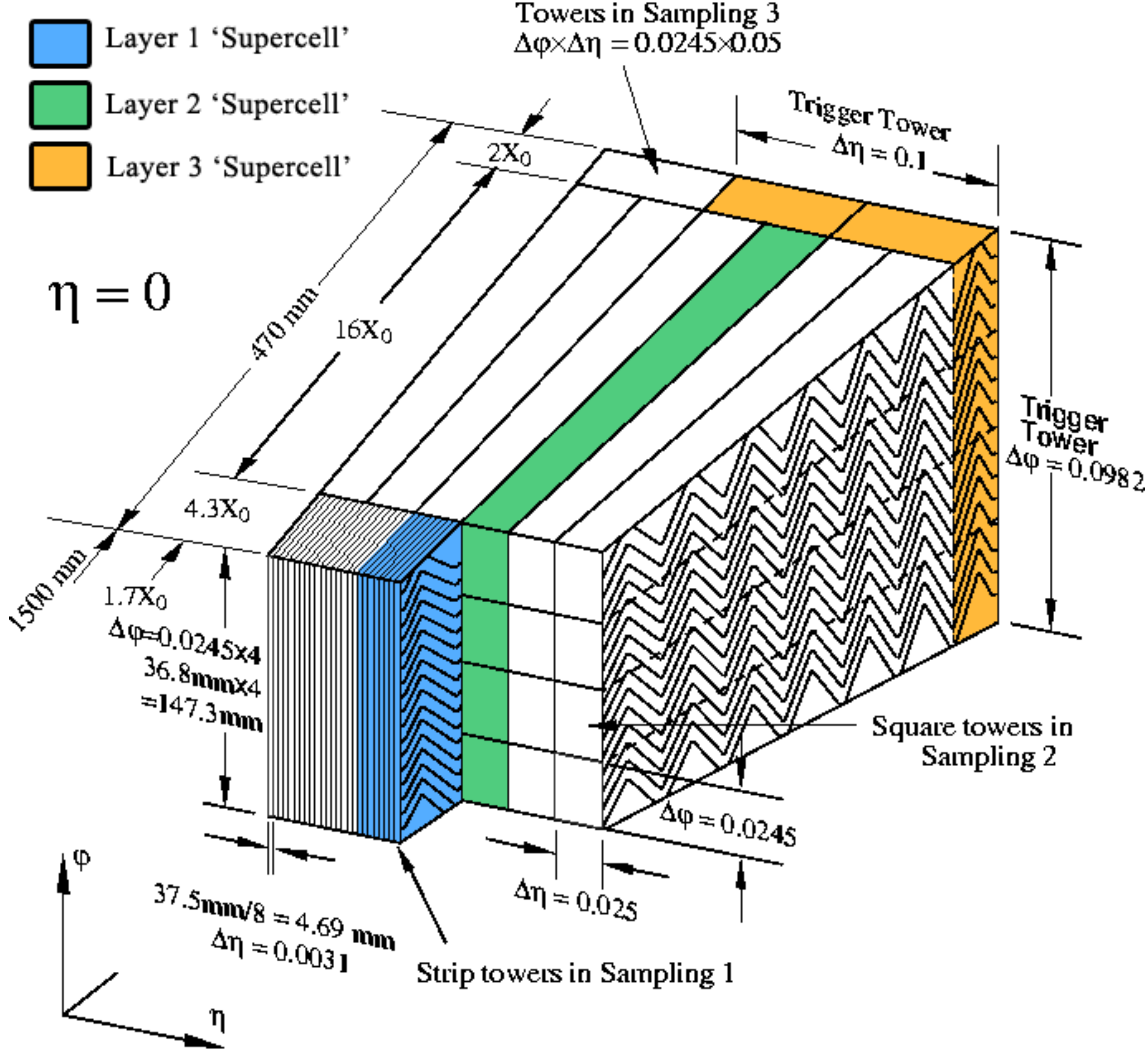
PHASE-I

Level1 Calorimeter Trigger/Readout

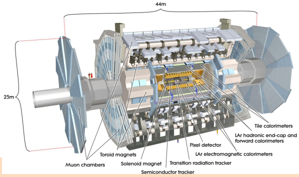
Muon New Small Wheel

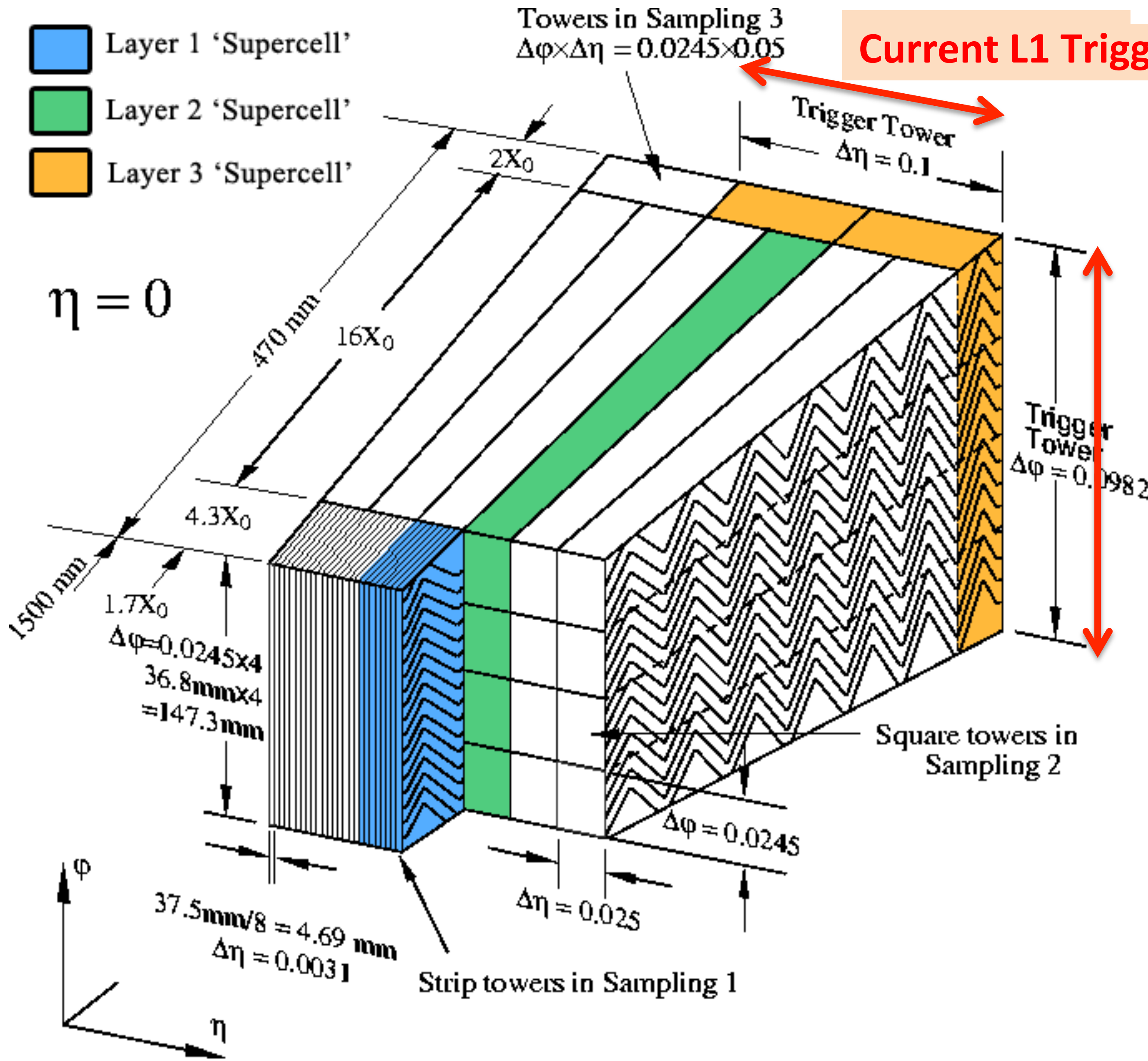
Level 1 Calorimeter Trigger: Increased Granularity



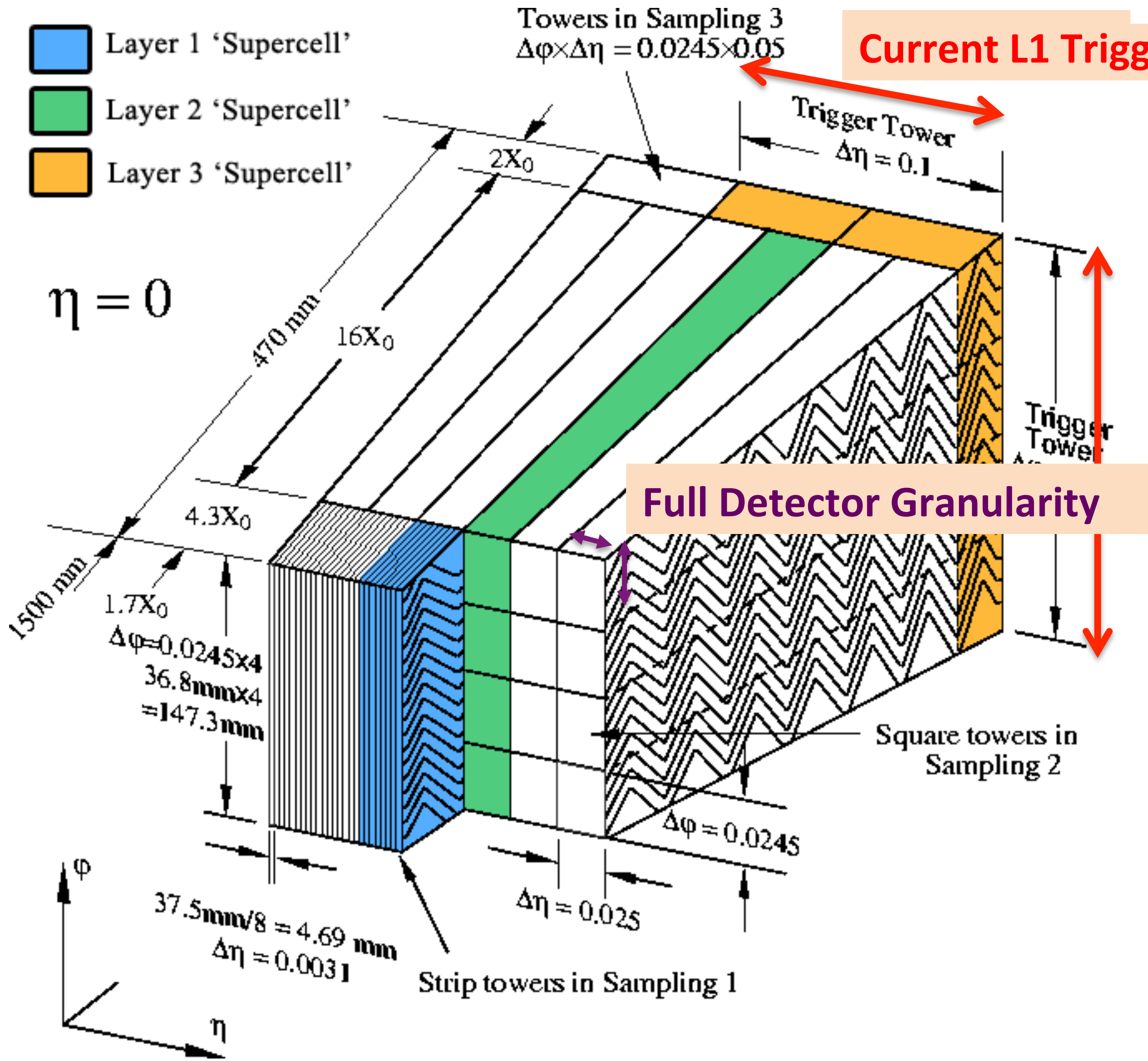


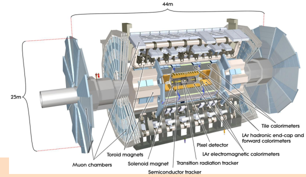
Level 1 Calorimeter Trigger: Increased Granularity



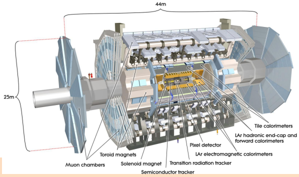


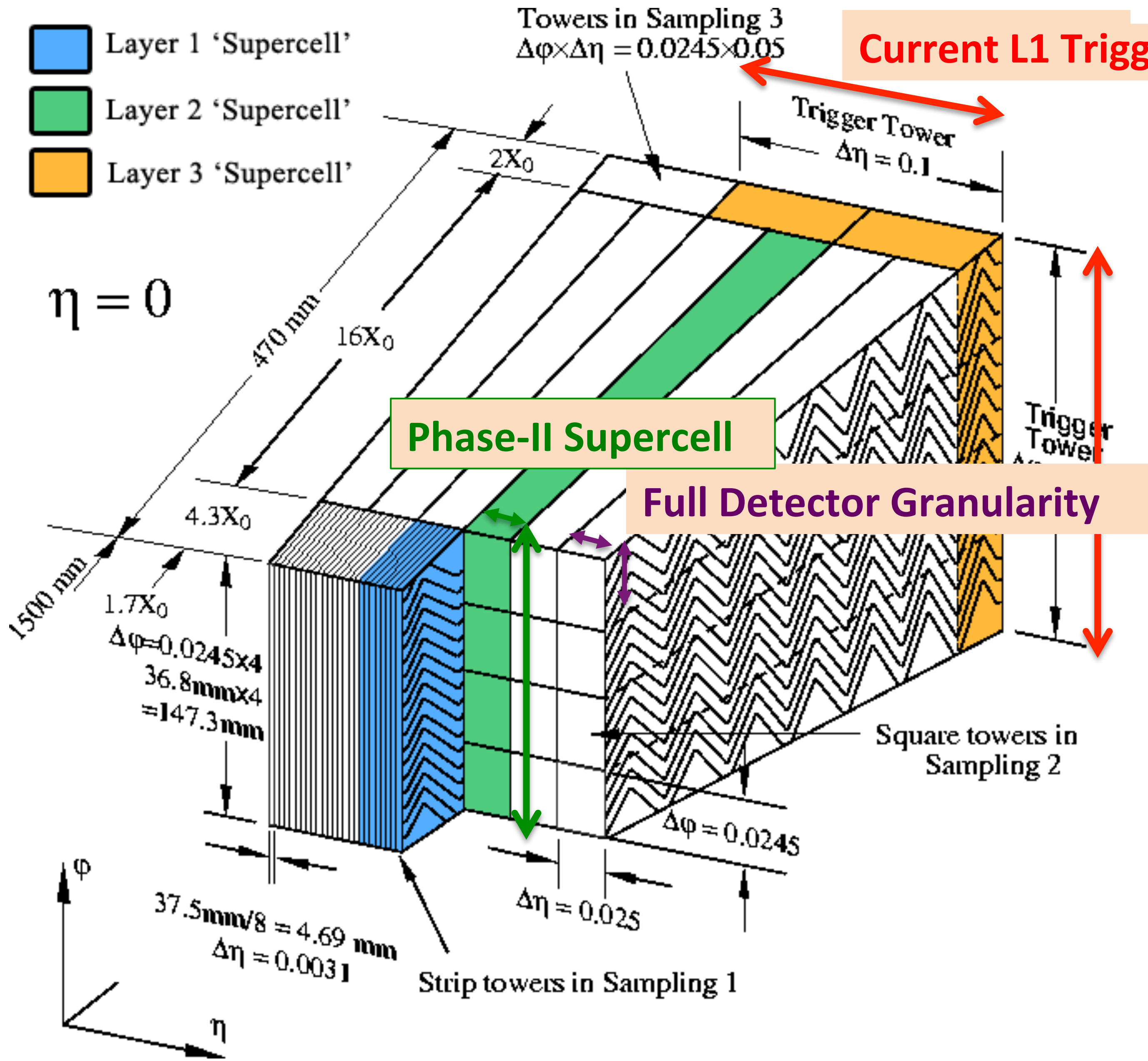
Level 1 Calorimeter Trigger: Increased Granularity

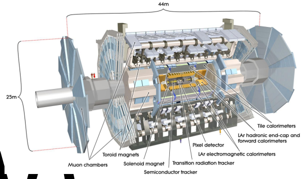




Level 1 Calorimeter Trigger: Increased Granularity

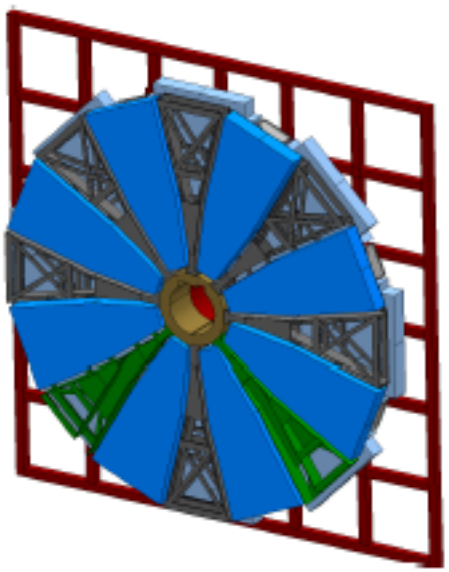






Muon New Small Wheel (NSW)

A set of precision tracking and trigger detectors that can work at high rates with excellent time and spatial resolution.

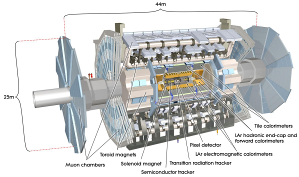


L1MU threshold (GeV)	Level-1 rate (kHz)
$p_{\mathrm{T}} > 20$	60 ± 11
$p_{\mathrm{T}} > 40$	29 ± 5
$p_{\mathrm{T}} > 20$ barrel only	7 ± 1
$p_{\mathrm{T}} > 20$ with NSW	22 ± 3

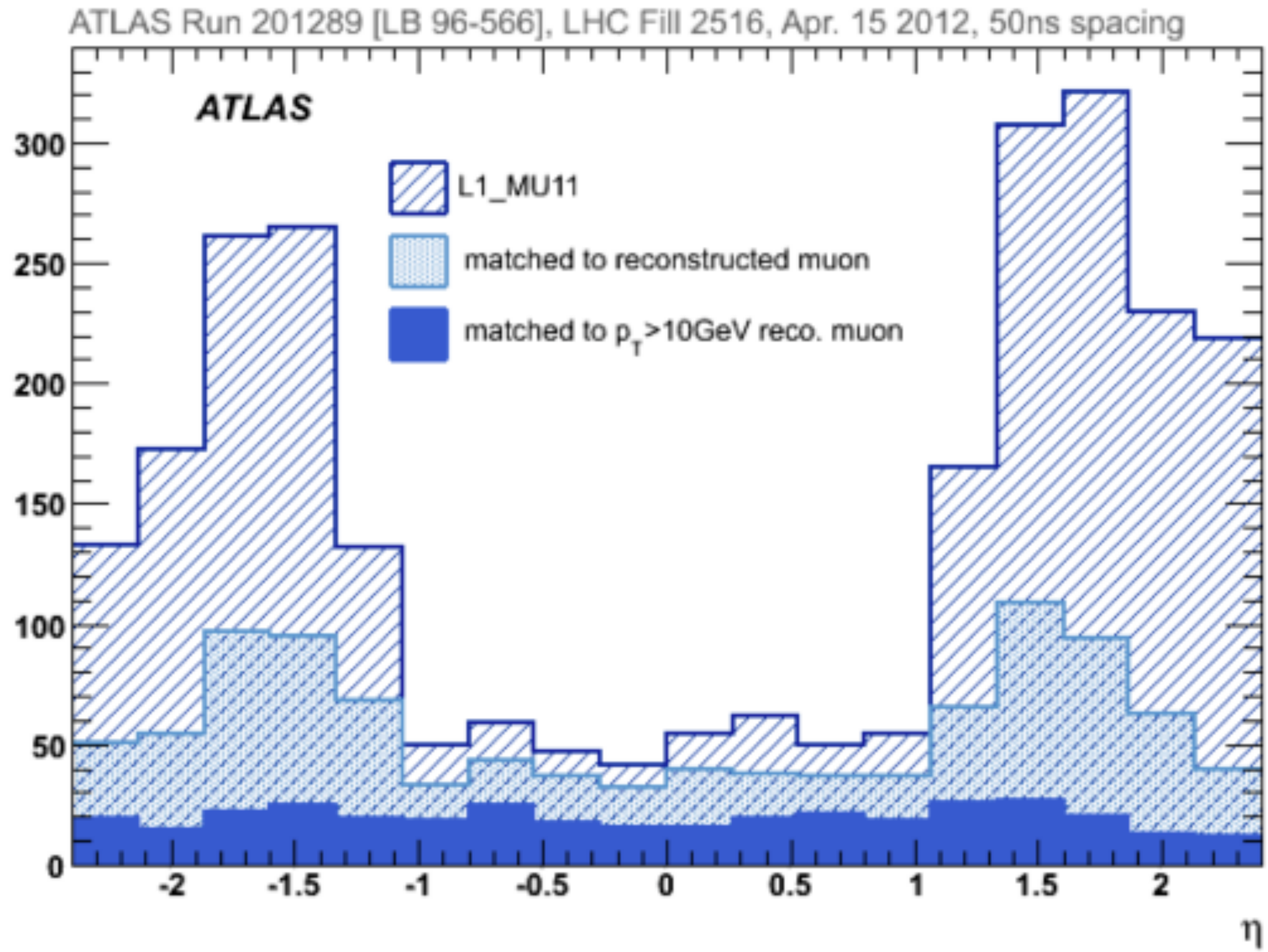
budget of L1 ~100 kHz

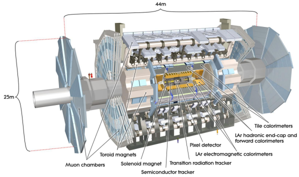
ATLAS-TDR-020-2013

Muon New Small Wheel



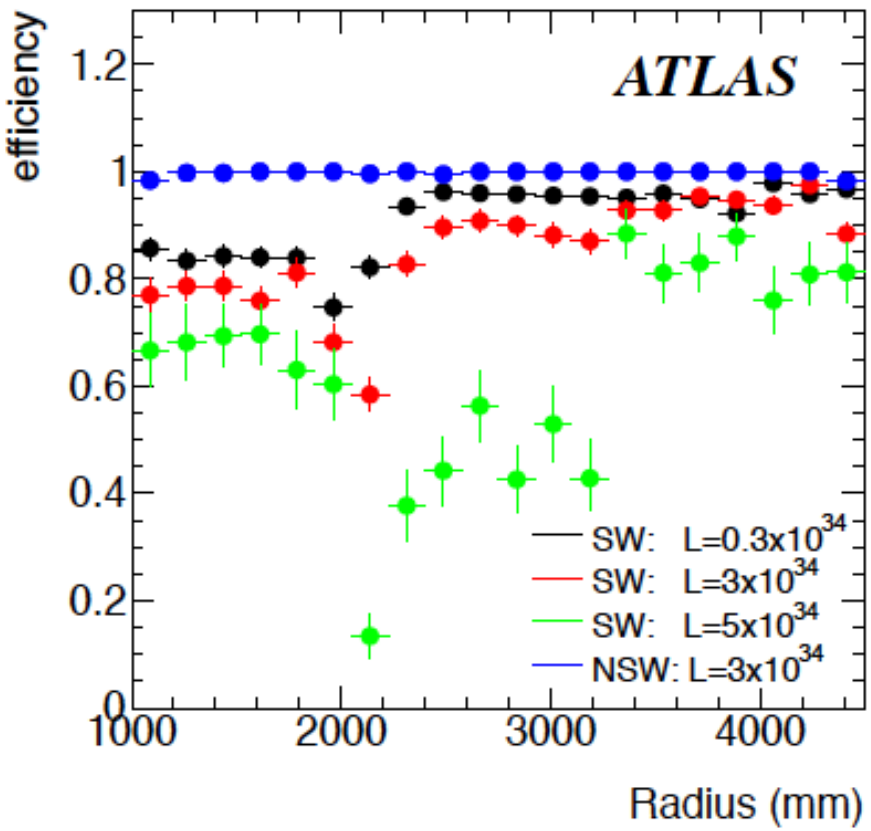
Low purity (currenty) in the end-cap region

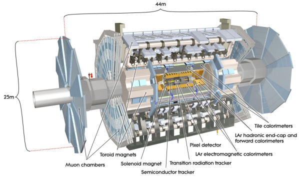




Muon New Small Wheel

Segment finding for a 2 TeV Z’ decaying to a pair of muons

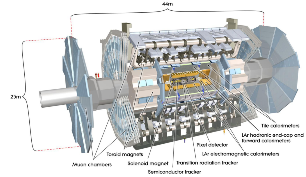




2024 – 203x 3000 fb^{-1} 140 – 200 pile-up events

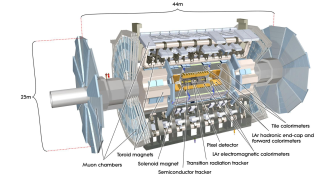
PHASE-II

Level 1
Track
Trigger

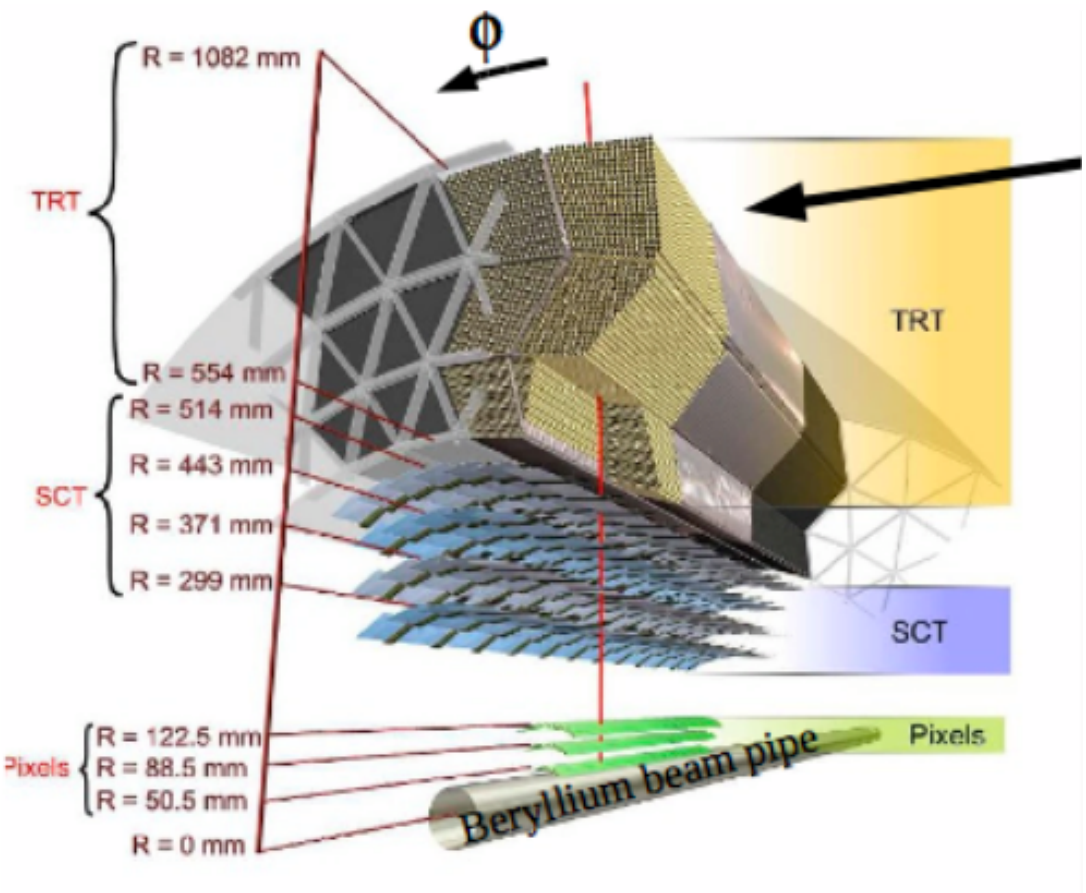


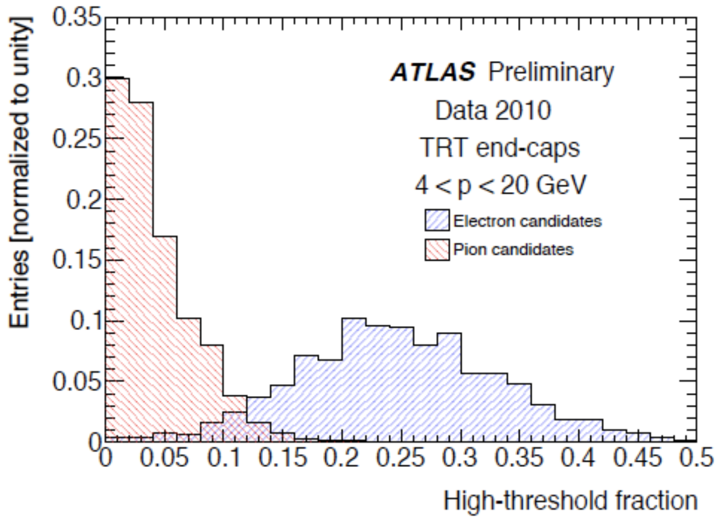
Motivation for the Track Trigger

Object(s)	Trigger	Estimated Rate	
		no L1Track	with L1Track
e	`EM20`	200 kHz	40 kHz
γ	`EM40`	20 kHz	10 kHz*
μ	`MU20`	> 40 kHz	10 kHz
τ	`TAU50`	50 kHz	20 kHz
ee	`2EM10`	40 kHz	< 1 kHz
$\gamma\gamma$	`2EM10`	as above	$\sim$5 kHz*
$e\mu$	`EM10_MU6`	30 kHz	< 1 kHz
$\mu\mu$	`2MU10`	4 kHz	< 1 kHz
$\tau\tau$	`2TAU15I`	40 kHz	2 kHz
Other	`JET + MET`	$\sim$ 100 kHz	$\sim$ 100 kHz
Total		$\sim$ 500 kHz	$\sim$ 200 kHz

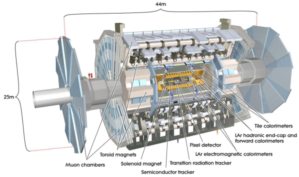


The ATLAS Tracking Chambers

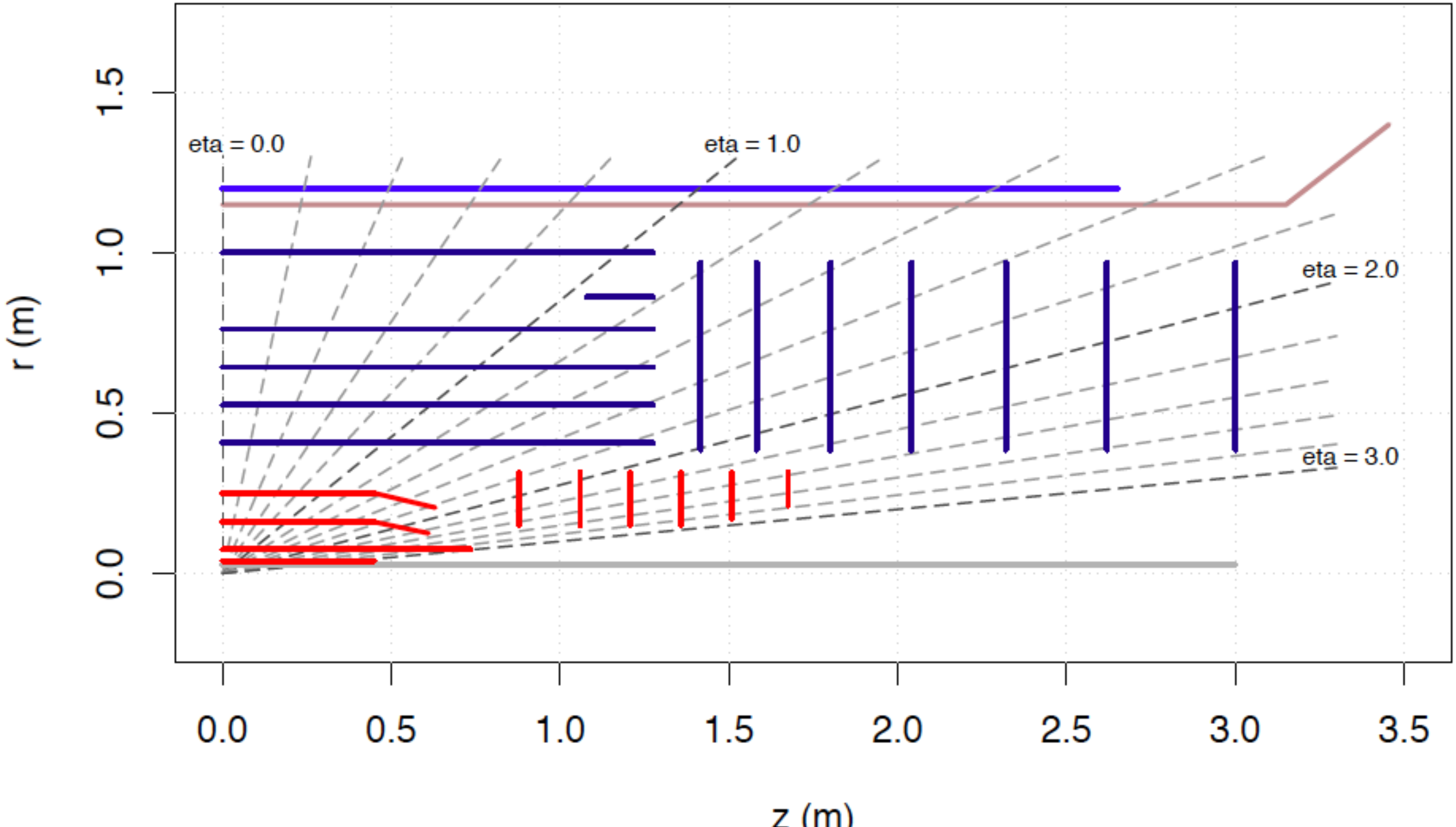




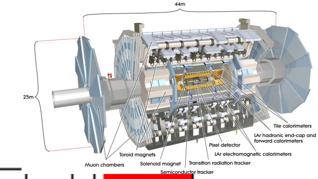
Detector	Max. Rate	Max. Latency
MDT	$\sim 200\,\text{kHz}$	$\sim 20\,\mu\text{s}$
LAr	any	any
TileCal	$> 300\,\text{kHz}$	any
ITK	$> 200\,\text{kHz}$	$< 500\,\mu\text{s}$

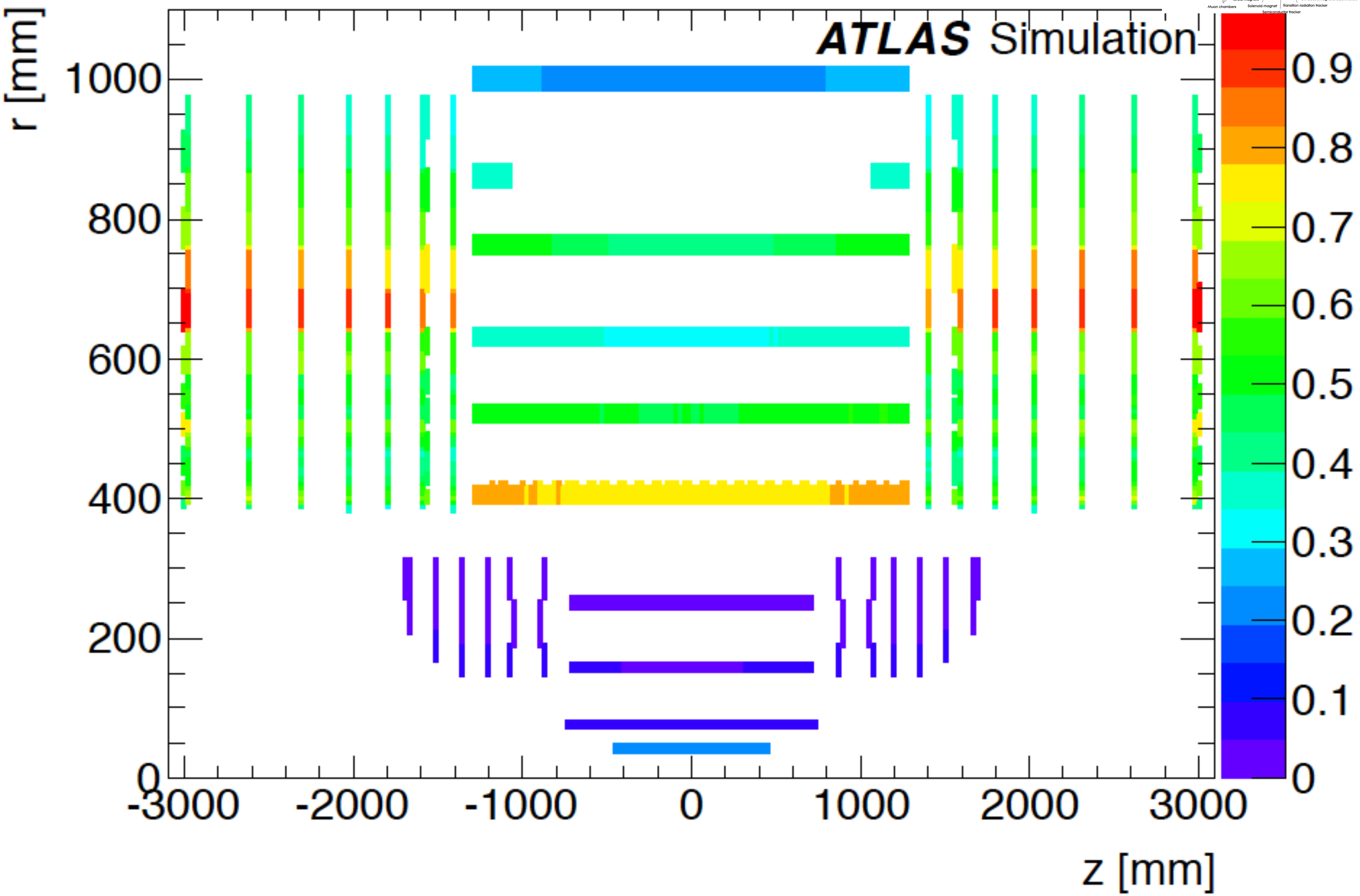


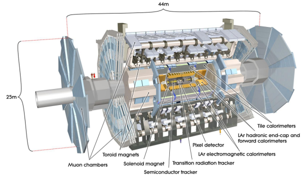
an example upgrade layout



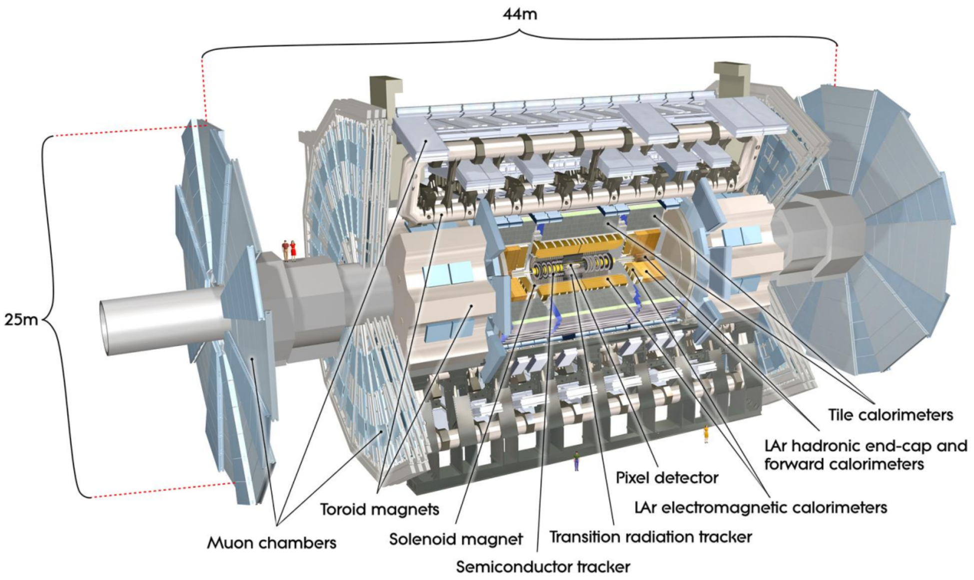
channel occupancy with 200 pile-up interactions





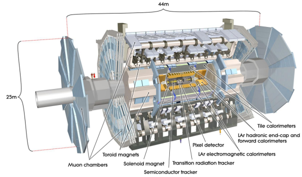


Constraints Include Access



Detector	Max. Rate	Max. Latency
MDT	$\sim 200\,\text{kHz}$	$\sim 20\,\mu s$
LAr	any	any
TileCal	$> 300\,\text{kHz}$	any
ITK	$> 200\,\text{kHz}$	$< 500\,\mu s$

From ATLAS Phase-II Letter of Intent



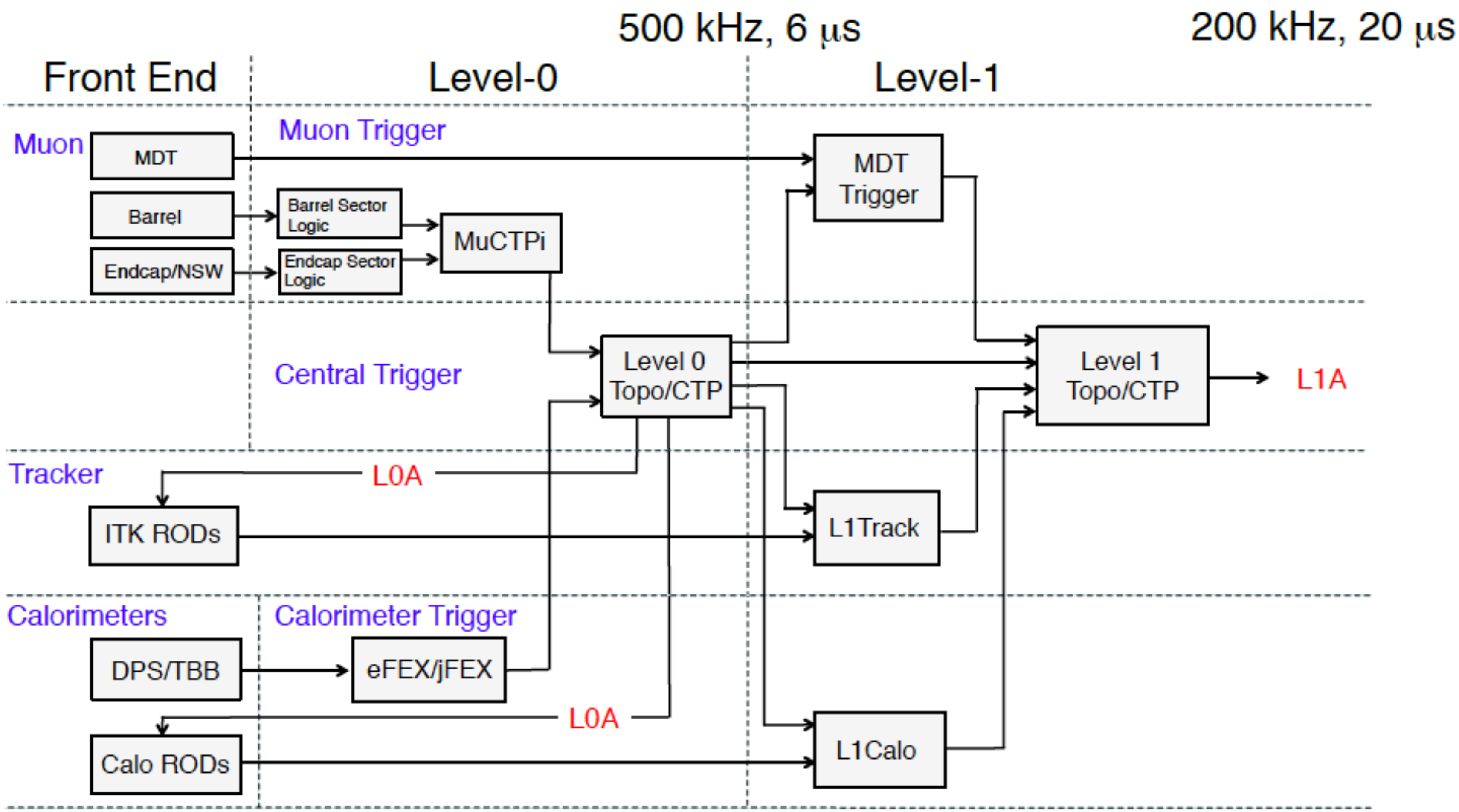
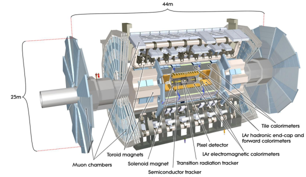


Figure 2.2: A block diagram of the architecture of the split Level-0/Level-1 hardware trigger proposed for the Phase-II upgrade. (The MDT trigger is shown as part of the Level-1 but may be used at Level-0).



Performance assumptions based on full simulation for an upgraded ATLAS detector at a High-Luminosity LHC

The ATLAS Collaboration

ATLAS-PUB-2013-009

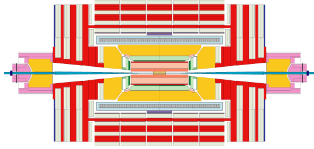
		8 TeV $10^{34}\ cm^{-2}s^{-1}$	14 TeV $7.10^{34}\ cm^{-2}s^{-1}$	
Object	L0/L1 threshold	L1 rate	L0 rate	L1 rate
Muons	MU20 + ID track	7 kHz	42 kHz	8 kHz
Electrons	EM18VH + ID track	23 kHz	130 kHz	25 kHz
Tau	TAU40 + ID track	7 kHz	110 kHz	14 kHz
Photon	EM30 + L1Calo	9 kHz	48 kHz	16 kHz
Missing Energy	XE150	-	$\approx$ 5 kHz	$\approx$ 5 kHz

offline cuts of

25 GeV for electrons and muons

60 GeV for photons and taus

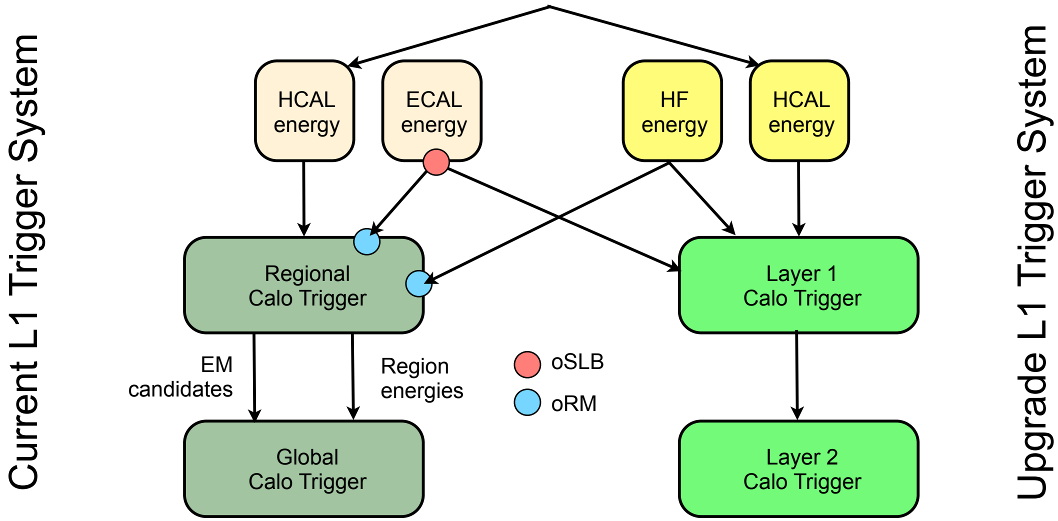
180 GeV for Missing E_T



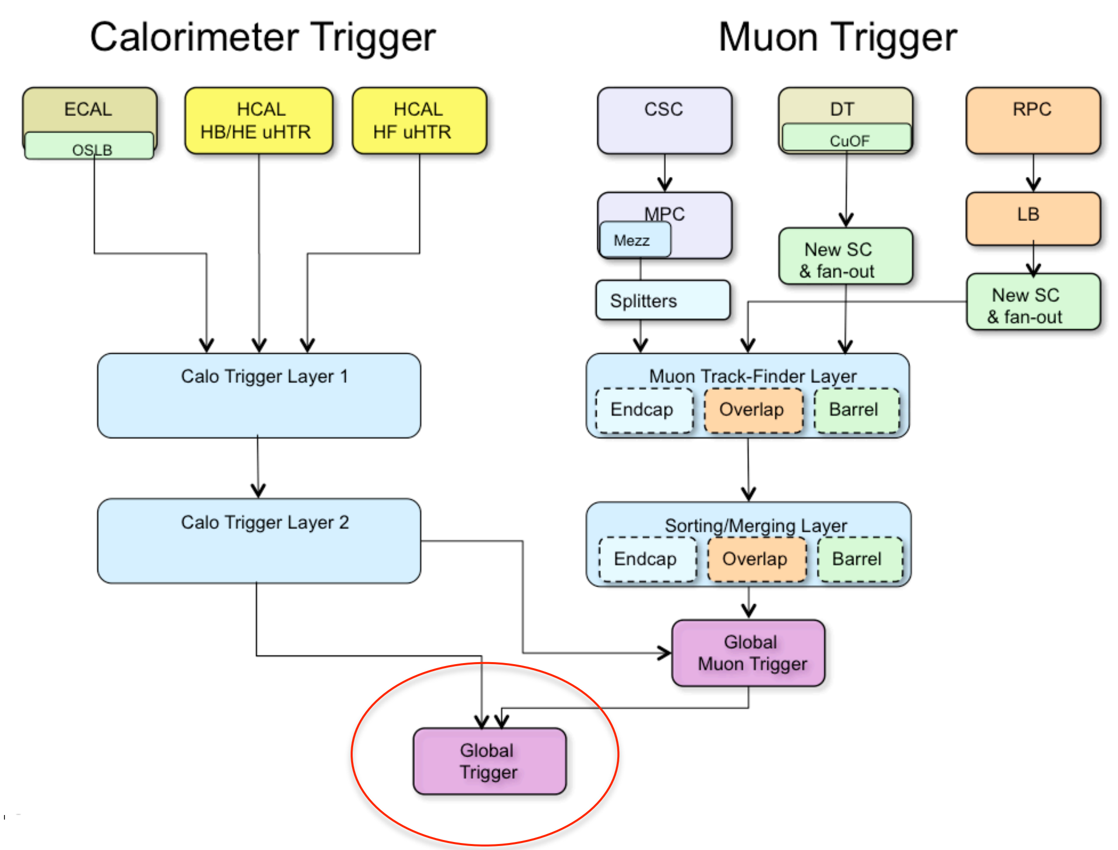
Thanks to slides from Jeff Spaulding

CMS TDAQ Upgrades

Currently ongoing – prep for phase-1 upgrade, splitting signals so that the upgraded trigger can be implemented in parallel.

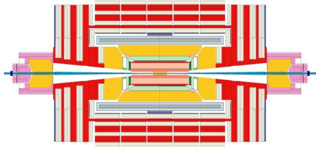


CMS: Expected for 2016 data-taking



Allow for access to objects from Calo and Muon systems together at L1

CMS: Phase-1



New L1 Global Trigger will be commissioned and running (2016)

New Pixel Detector

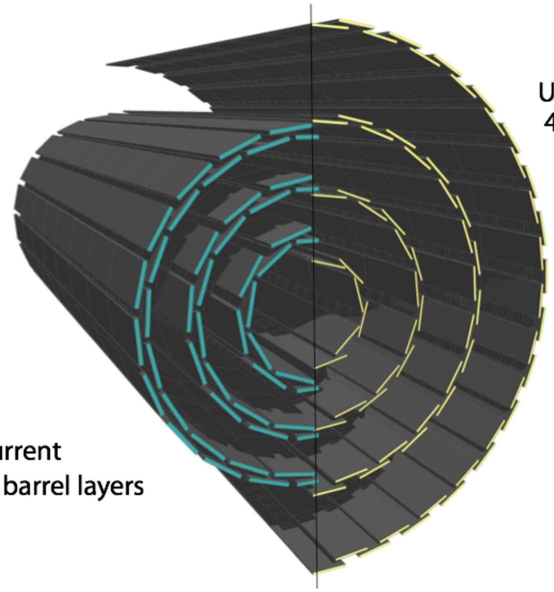
HCAL upgrade: photodetectors and electronics

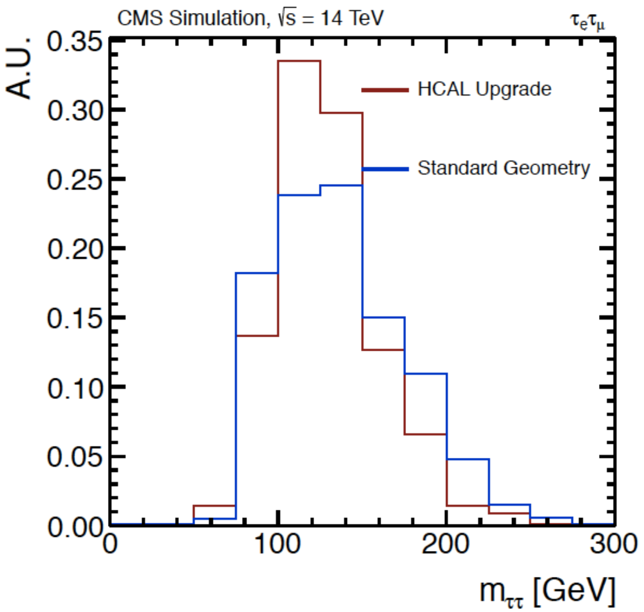
http://cds.cern.ch/record/1481837/files/CMS-TDR-010.pdf

hybrid photodiodes (HPDs) -> silicon photomultiplier (SiPM) devices

on- and off-detector electronics upgraded

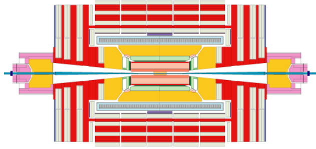
http://cds.cern.ch/record/1481838/files/CMS-TDR-011.pdf

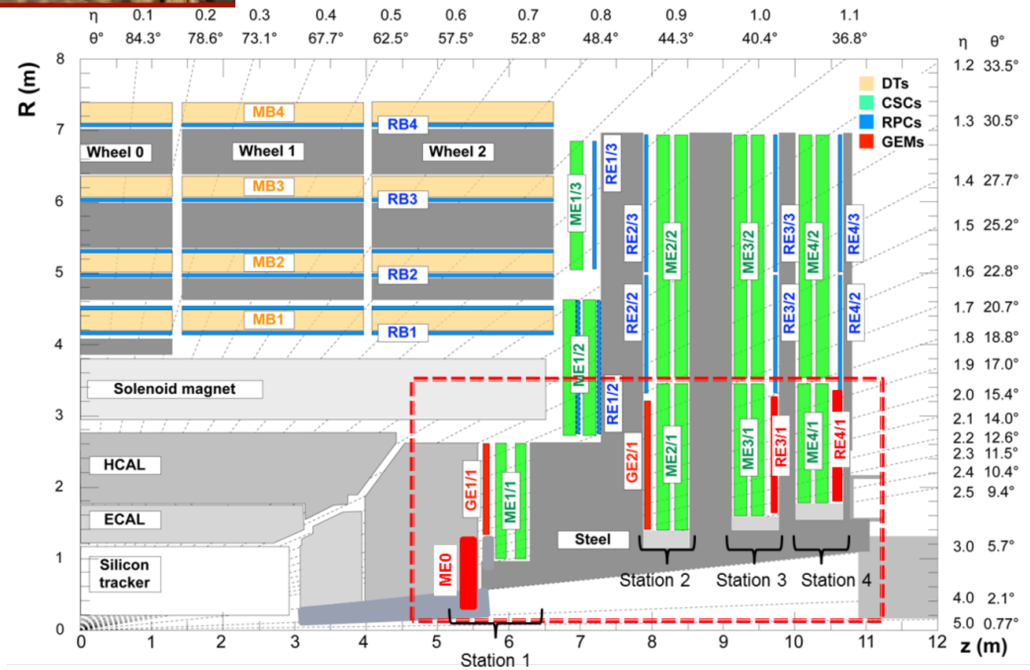




H->ττ (VBF)

CMS: Phase-2





Major upgrades, including the muon trigger and introducing a L1 track trigger

Goals

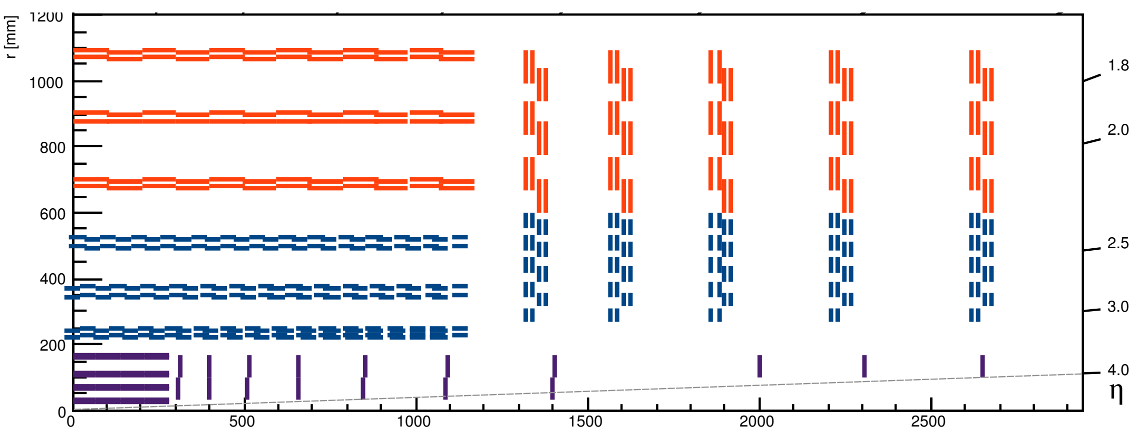
track info for all L1 triggers

increased EM Calo granularity

1 MHz into HLT

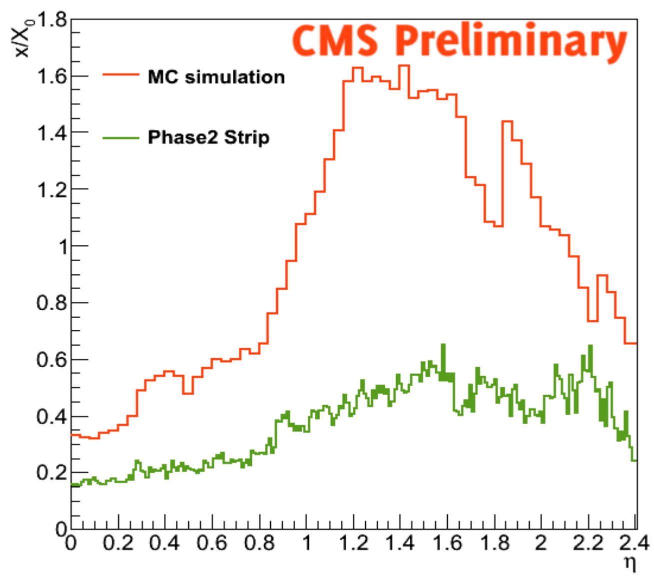
10 kHz output from HLT

“conceptual design” layout

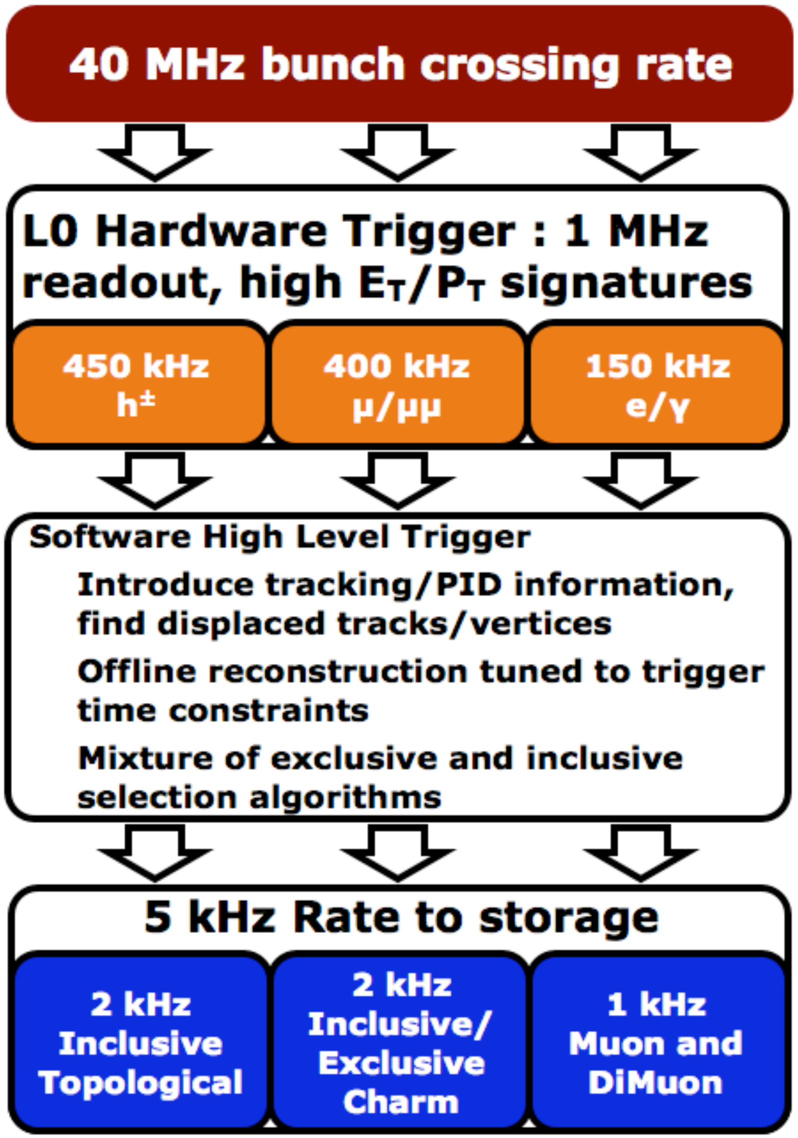


Outer tracker material

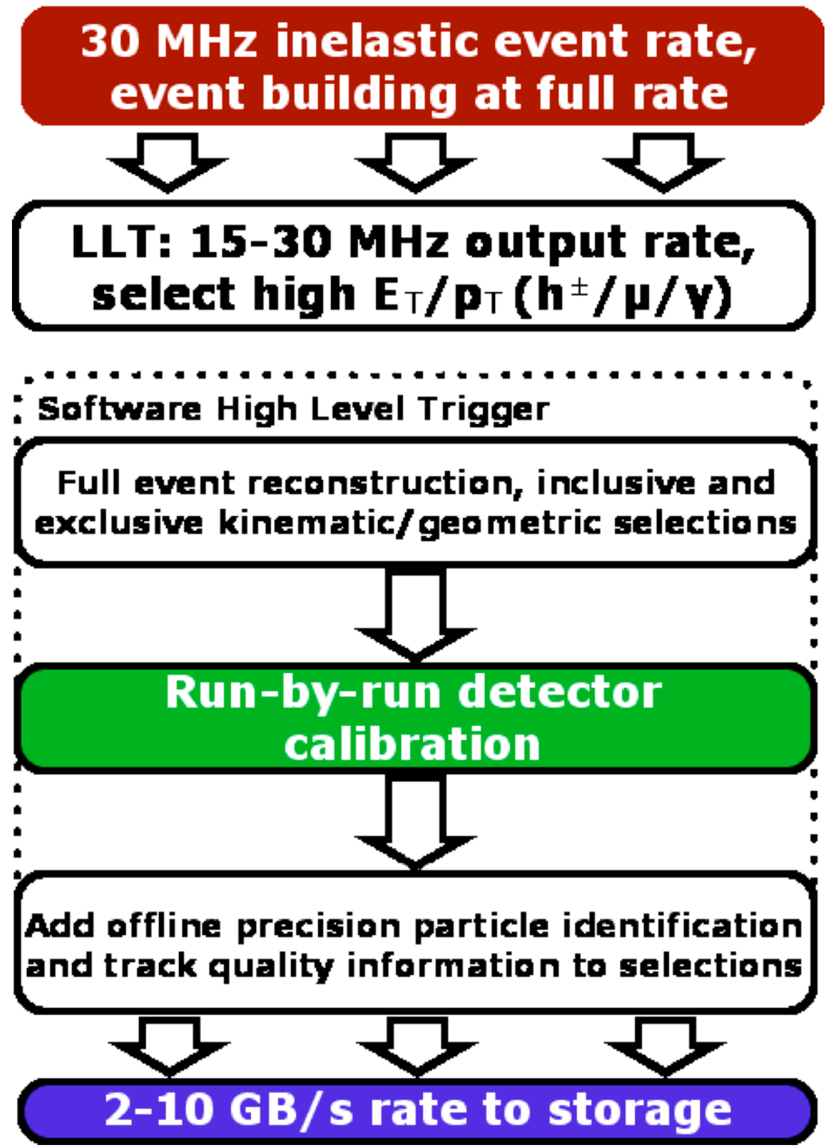
Phase 1 & Phase 2



LHCb Upgrade



LHCb Upgrade Trigger Diagram



Thanks to the school organizers for the opportunity to talk about triggers and data acquisition!

Thanks to many colleagues for writing such beautiful slides and documentation that preparing for this talk was a pleasure!

Thanks to you for your attention!

Enjoy the rest of your week!

FERMILAB-CERN
HADRON COLLIDER PHYSICS
Summer School 2014

I'm heading home to cheer up the pirates!