The ATLAS Trigger System

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ATLAS EXPERIMENT

NEW YORK UNIVERSITY

From Run 1 to Run 2

The ATLAS trigger system operated successfully in Run 1

- Selected events online at √s up to 8 TeV between 2009 and 2013 with high efficiencies for a wide range of physics processes in ATLAS

In Run 2, trigger rates are expected to increase by a factor of ~5

Period: year	Bunch-spacing	√s	Luminosity	Pileup μ_{peak}
Run-1: 2012	50 ns	8 TeV	~8e33	40 (8e33)
Run-2: 2015-2018	25 ns	13 TeV	1-2e34	25-50 (1e34)

- A factor of ~2 due to the energy increase (higher for high p_T jets)
- A factor of 2-3 due to the luminosity increase

→ Improvements to the trigger system and software are necessary to help reduce the trigger rates to acceptable levels while maintaining or even improving selection efficiencies in the challenging conditions

In the following slides, the upgrades of the ATLAS trigger system for Run 2 are briefly discussed as well as the way the trigger is online configured and run:

- The ATLAS Trigger System (L1 and HLT)
- LHC Bunch Structure and Bunch Groups
- L1 Items, HLT Physics Signatures & Streams
- Trigger Menu and Configuration

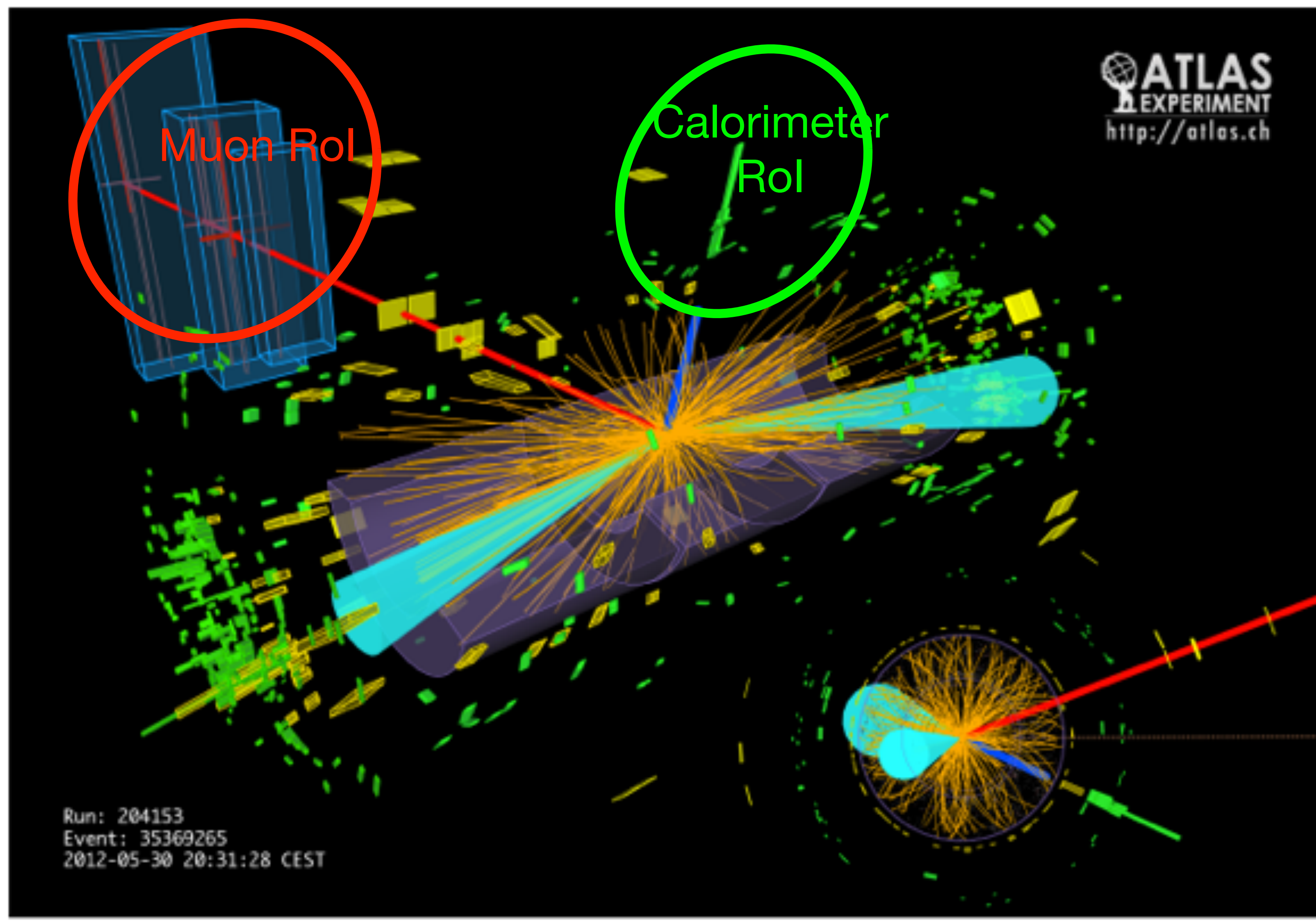
The ATLAS Trigger System (1)

Job: Selection of a few hundred events of interest/second for permanent storage

- In Run 2: 40 MHz → ~1kHz => rejection factor of 40 000

First level trigger (L1):

- Synchronous at 40 MHz with a fixed latency of 2.5 μs
- Identifies Region-of-Interest (RoI) in the muon spectrometer and/or in the calorimeter with coarse resolution



High Level Trigger (HLT):

- Handles complexity with custom fast software on commercial CPUs
- Accessing the full resolution of all the detectors

Once HLT is passed, the event is accepted and recorded.

Then, offline software is run to reconstruct the objects (muons/electrons/jets/etc.) in the event. Trigger matching can be used to match offline reconstructed object with trigger object found by trigger software.

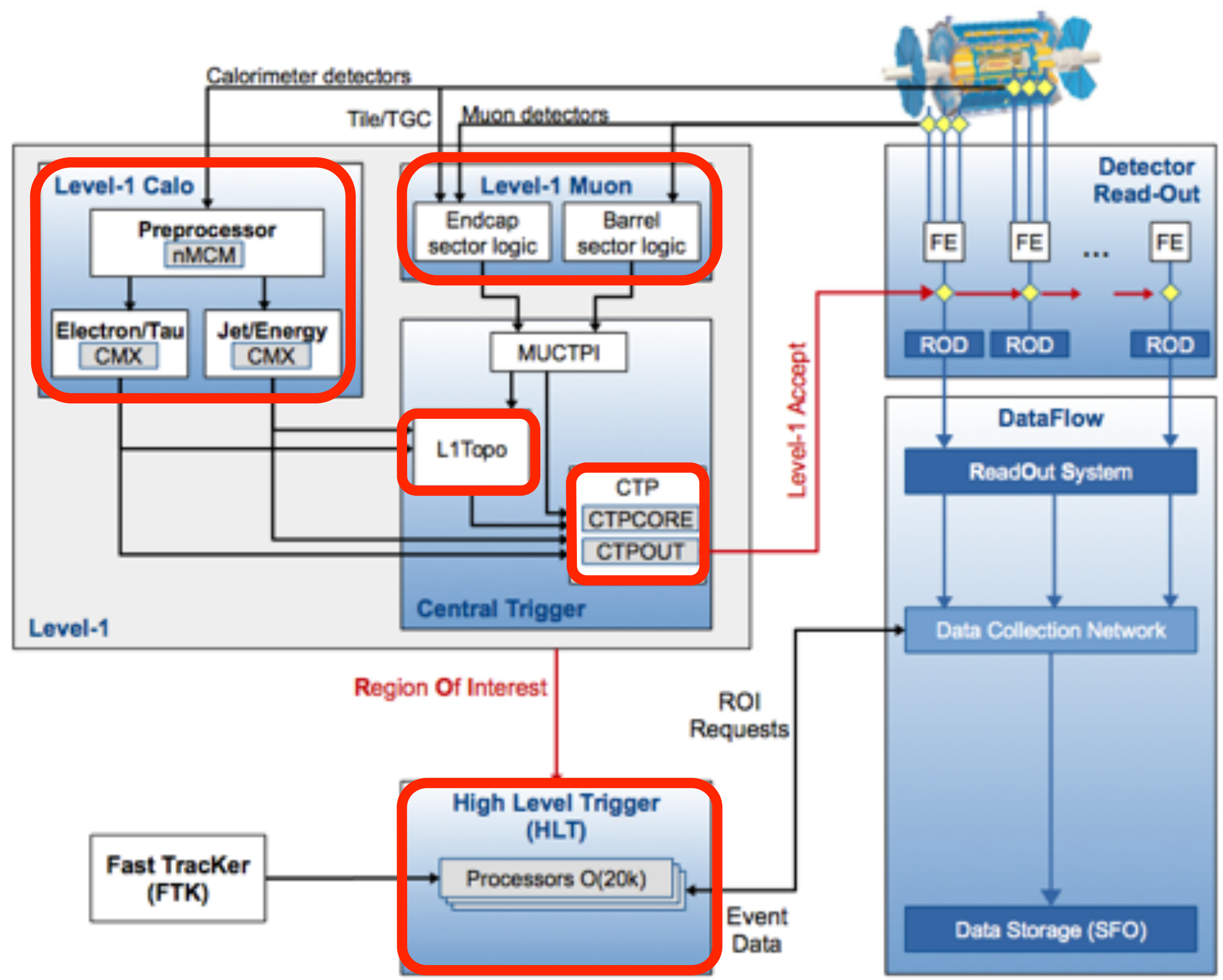
The ATLAS Trigger System (2)

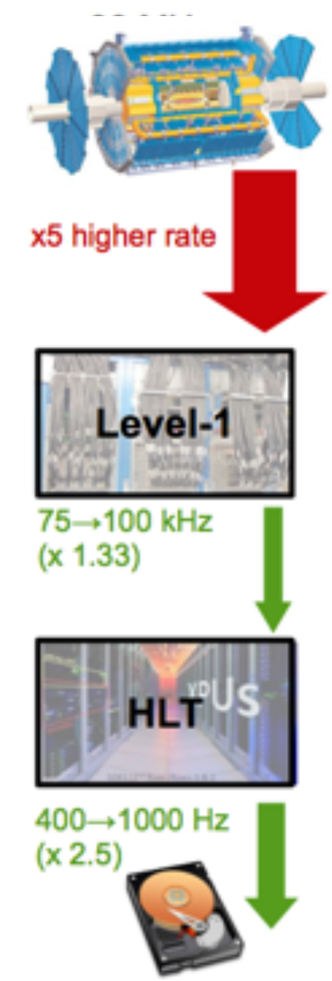
- Two staged trigger system (was three-staged in Run-1).

Stage	Functionalities	Components	Latency	Rate reduction
Level-1 (L1)	Fast custom-made electronics finds regions of interests using Calorimeter/ Muon data with coarse info	L1Calo, L1Muon, L1Topo, Central Trigger Processor	$< 2.5\ \mu s$	40 MHz → 100 kHz
High-Level Trigger (HLT)	Fast algorithms in RoI, or offline-like ones with full-event info on PC farm	(FTK,) HLT farm	~0.2 s (average)	→ 1 kHz (average)

FE: Front End
ROD: Read Out Device
HW: HardWare
DC: Data Collector
RoI: Region of Interest
BE: Back End
ROS: ReadOut System
EB: Event Builder
SFO: SubFarm Output
MUCTPI: Muon to Central Trigger Processor Interface
TTC: Timing, Trigger Control

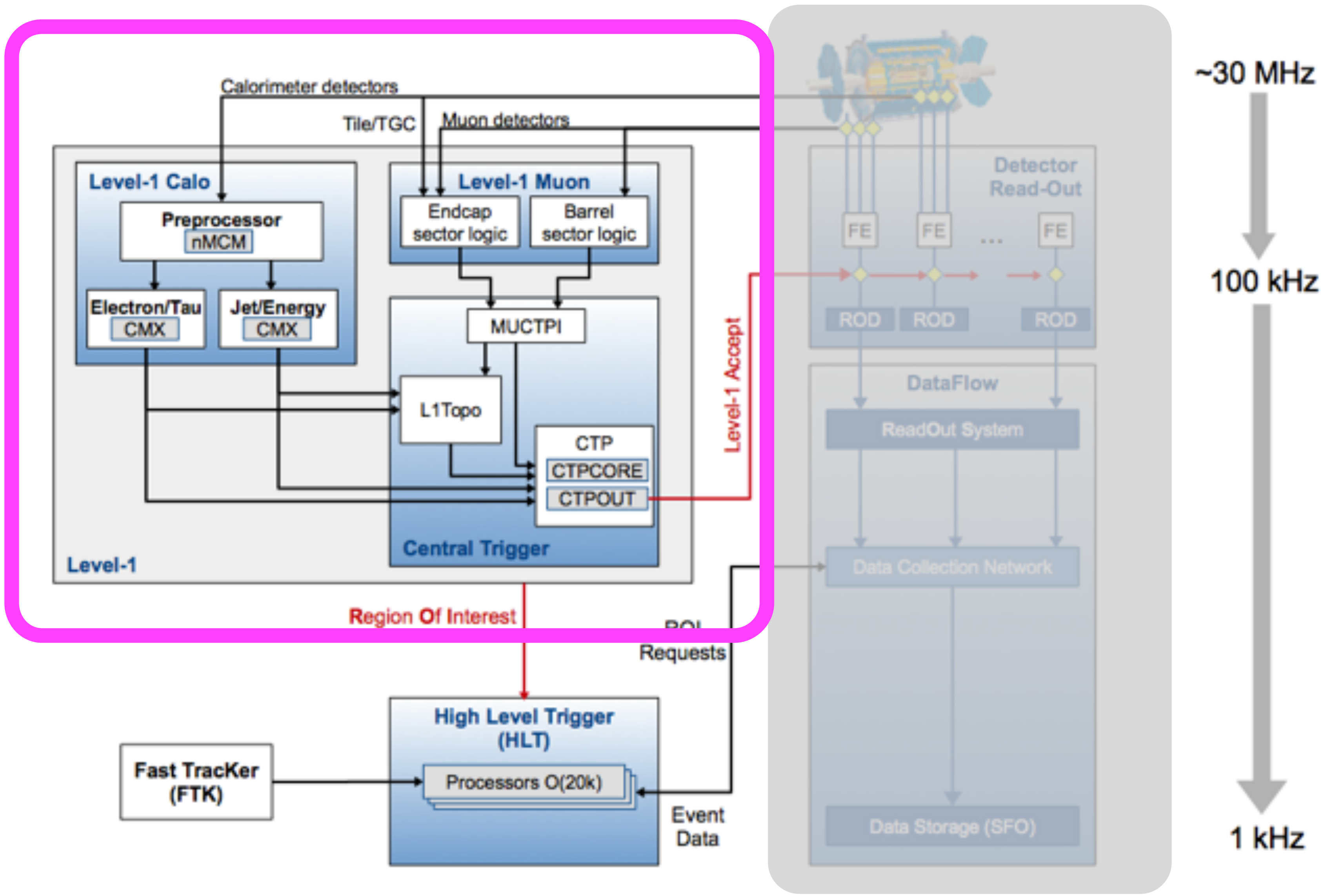
CPM: Cluster Processor Module
CMX: Common Merger eXtended Module
CTP: Central Trigger Processor
TP: Topological Processor
nMCM: new Multi Chip Module
PPM: Pre-Processor Module
JEM: Jet Energy sum Module
TCG: Thin Gap Chambers



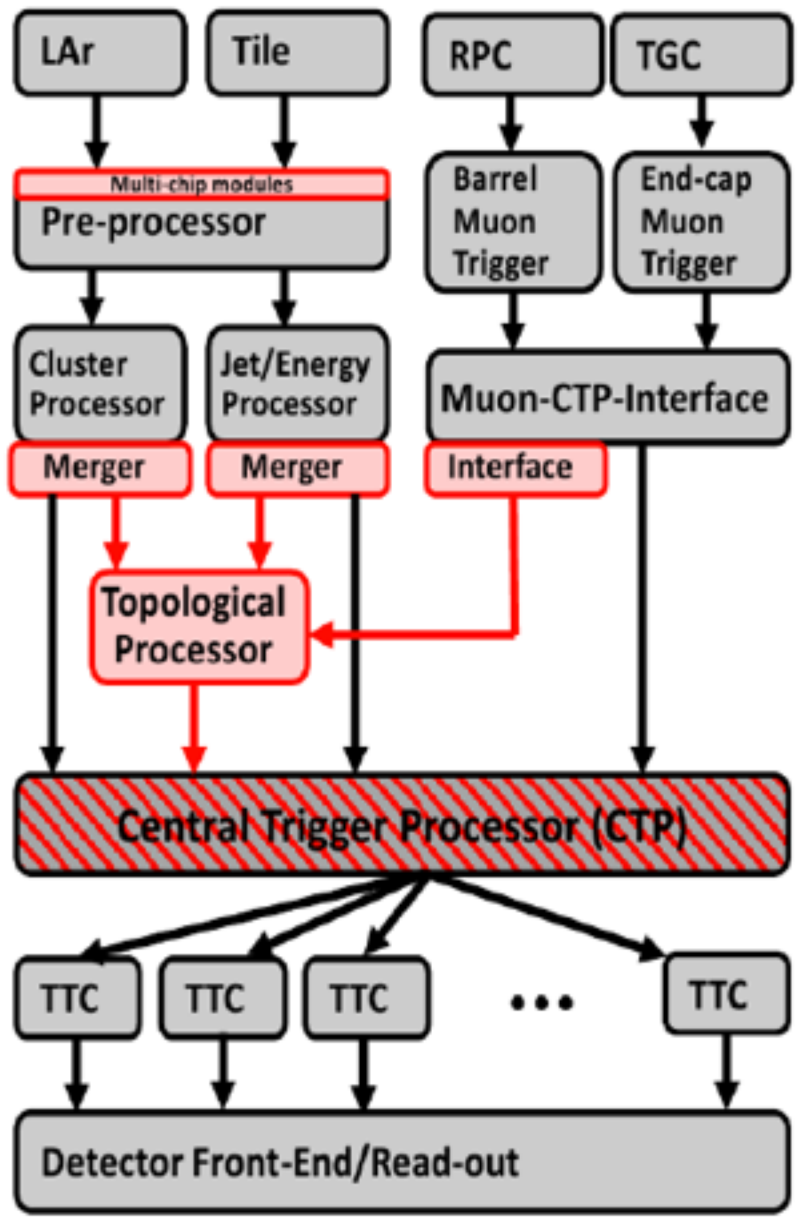


Catrin Bernius, NYU

The L1 Trigger System



Upgraded L1 System



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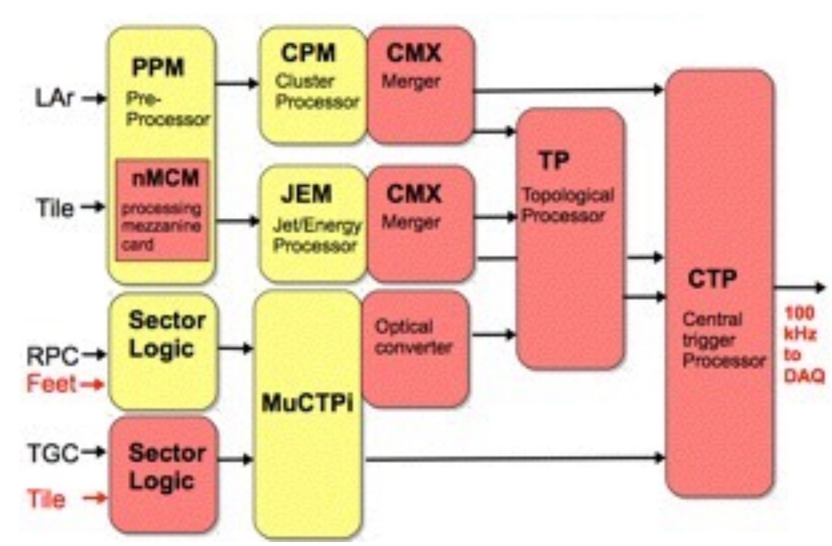
L1 upgrades



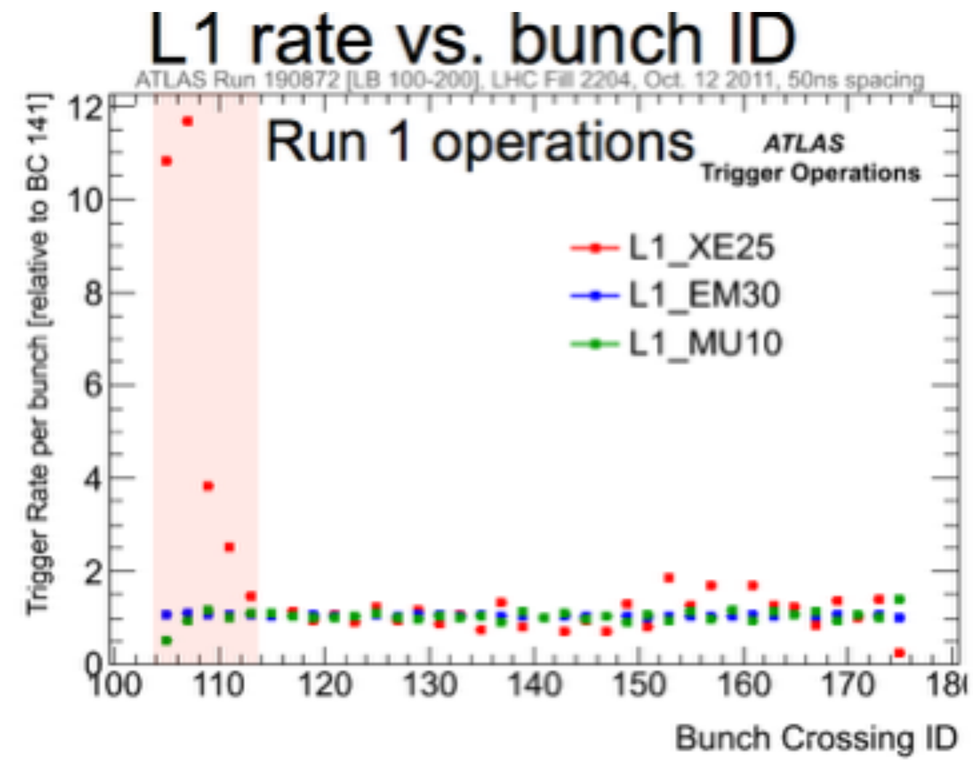
L1 Calorimeter Trigger

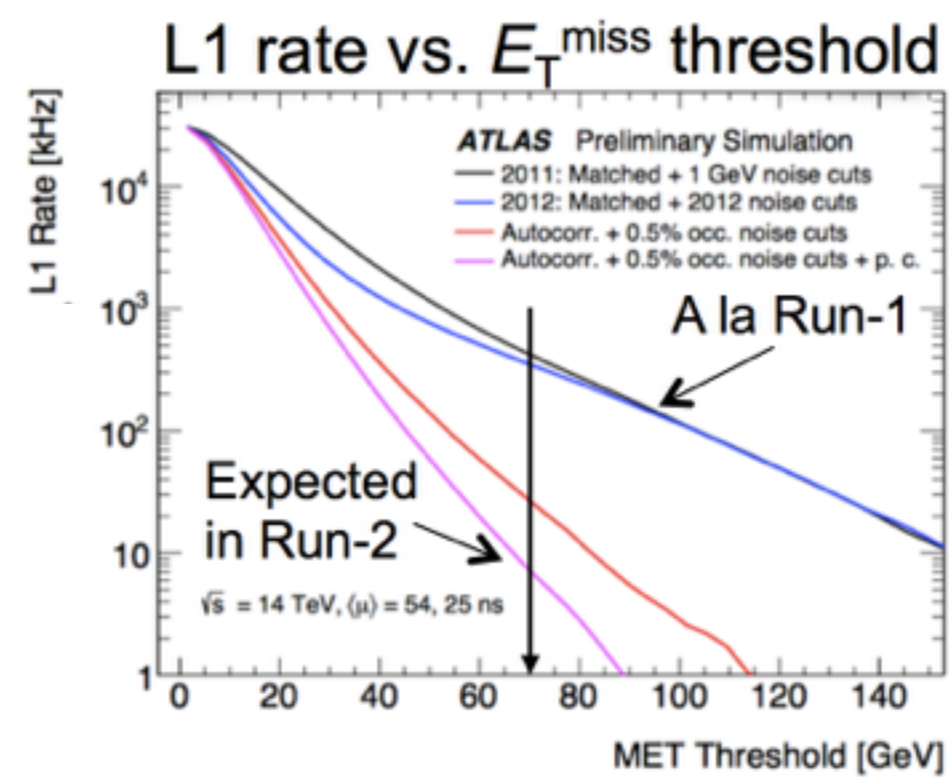
- In Run 1, L1 E_T^{miss} rates were severely affected by pile-up at the start of the bunch train
  - due to unbalanced overlapping of bipolar signal shapes in the EM calorimeter

- In Run 2, more flexible signal processing due to new Mulit-Chip Module (nMCM)
  - dynamic pedestal subtraction based on global cell occupancy and in-bunch train positions

  → Huge reduction of E_T^{miss} rates

- More thresholds can be defined for more varieties of L1 combined triggers
  - Jets & forward jets: 8+4 (Run 1) → 25 thresholds in Run 2
  - EM, TAU clusters: 8 (Run 1) → 16 thresholds each in Run 2

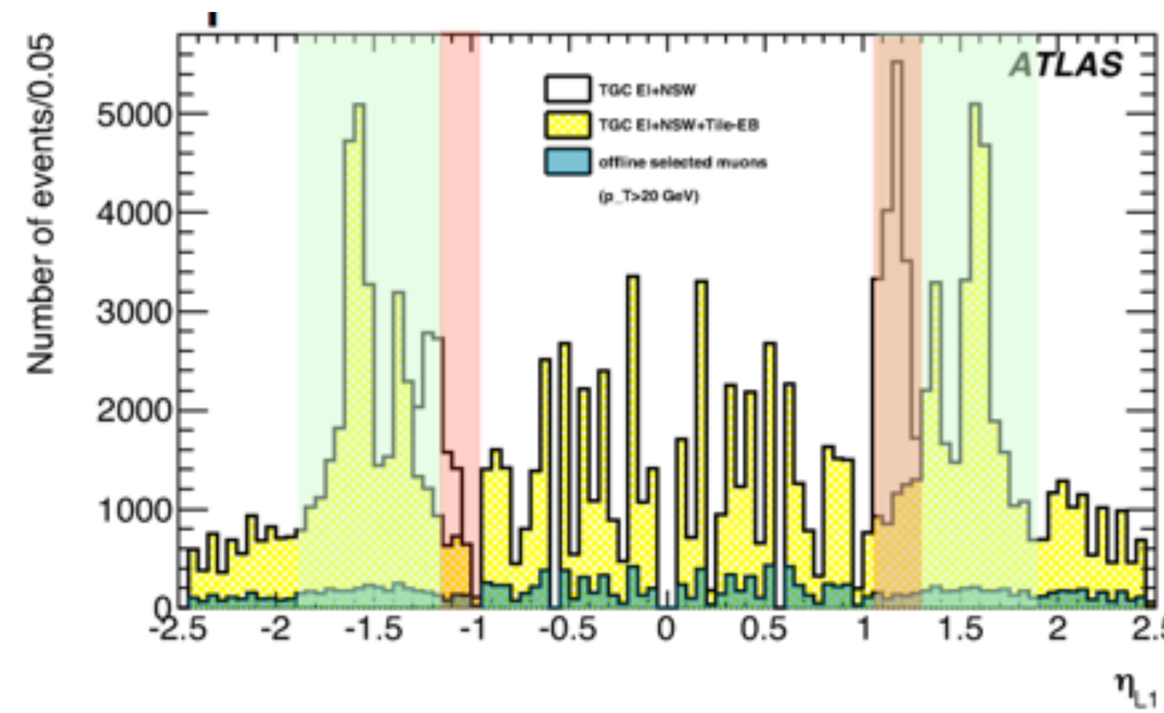


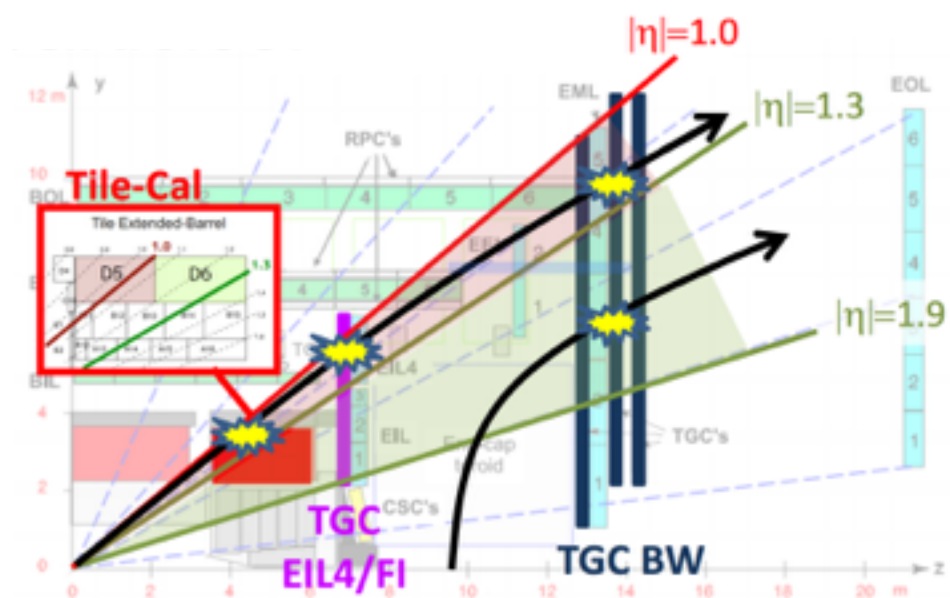


L1 Muon Trigger Improvements

- In Run 1, L1 muon rates in the forward region were polluted by low-p_T charged particles (protons) from out of the interaction point
  - this lead to a significant rate increase at 25 ns
- In Run 2, coincidences with inner detectors are used to clean up these charged particles
  - with the inner muon chambers placed before the toroid
  - with the extended barrel region of the tile calorimeter

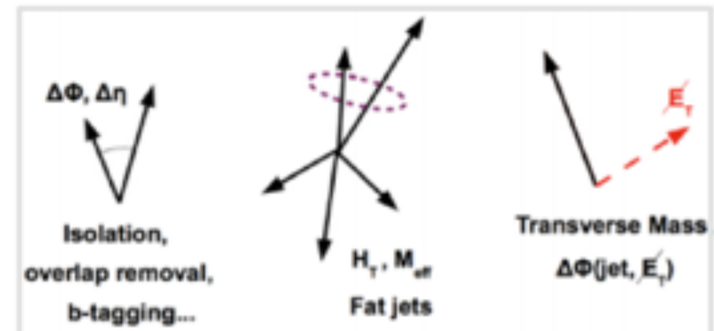
  → 50% rate reduction for L1 muons with $p_T < 20$ GeV, $1.0 < |\eta| < 1.9$ at 25 ns
- Additional trigger chambers in the feet of the barrel region
  - 4% larger acceptance for L1 muons





L1 Topological Trigger Module

- In Run 2, event topological selections between L1 objects are used to keep L1 thresholds low
  - decisions on FPGA within L1 latency
  - variety of algorithms: e.g. angular separation, invariant mass, global quantities like H_T (sum of jet E_T) etc



Angular Requirements

$\Delta\eta, \Delta\varphi, \Delta R^2, \Delta\eta+\Delta\varphi$

Mass Requirements

$M^2 = 2E_T^1 E_T^2(\cosh\Delta\eta - \cos\Delta\varphi)$

$M_T^2 = 2E_T^1 E_T^{miss}(1-\cos\Delta\varphi)$

$M_{CT}^2 = 2E_T^1 E_T^{miss}(1+\cos\Delta\varphi)$

Event Requirements

$H_T = \sum p_T(jets)$

$H_{CT} = \sum p_T(central\ jets)$

$M_{eff} = H_T + MET$

L1Topo MET

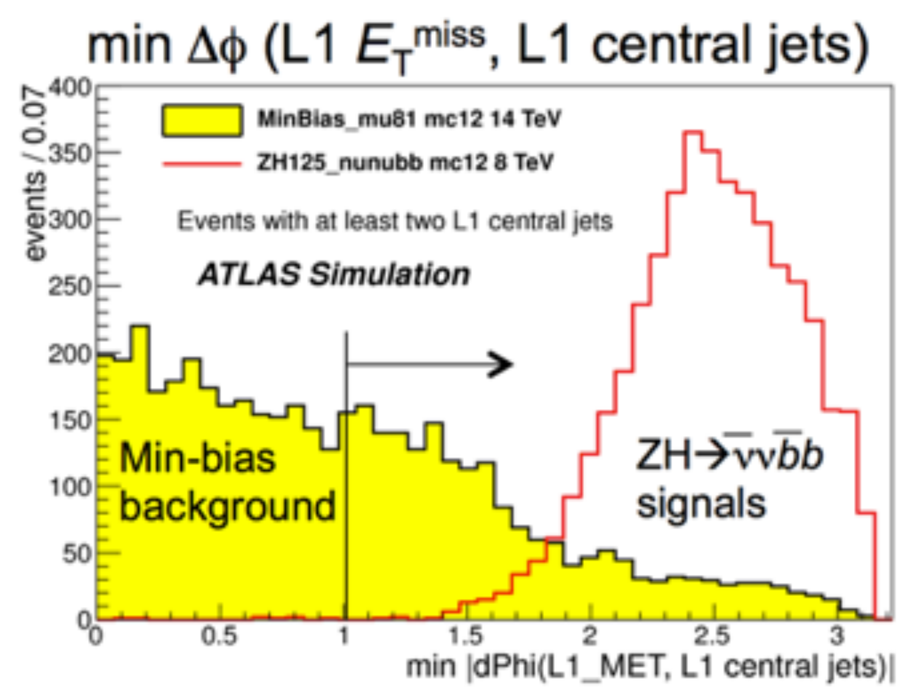
Dedicated Algorithms

Calorimeter Ratio

Delayed Particles

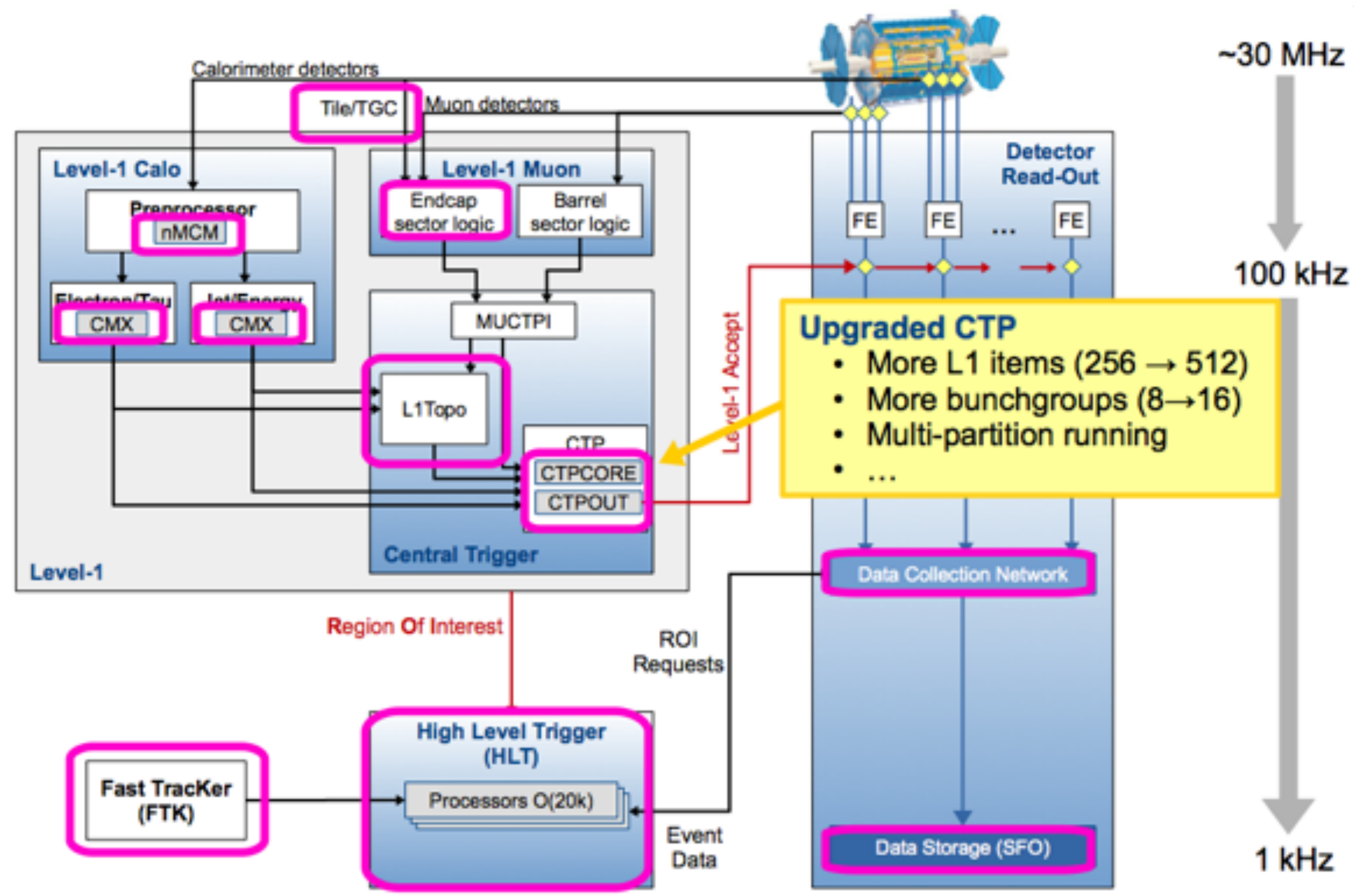
- Essential to final states with E_T^{miss}, jets and taus, e.g. SM Higgs ZH → υυbb and H → ττ

→ For ZH → υυbb, loose selection of the smallest ΔΦ (L1 E_T^{miss}, L1 central jets)
=> L1 E_T^{miss} threshold: 70 GeV → 50 GeV while keeping efficiencies



New/Improved L1 System - CTP

New/Improved

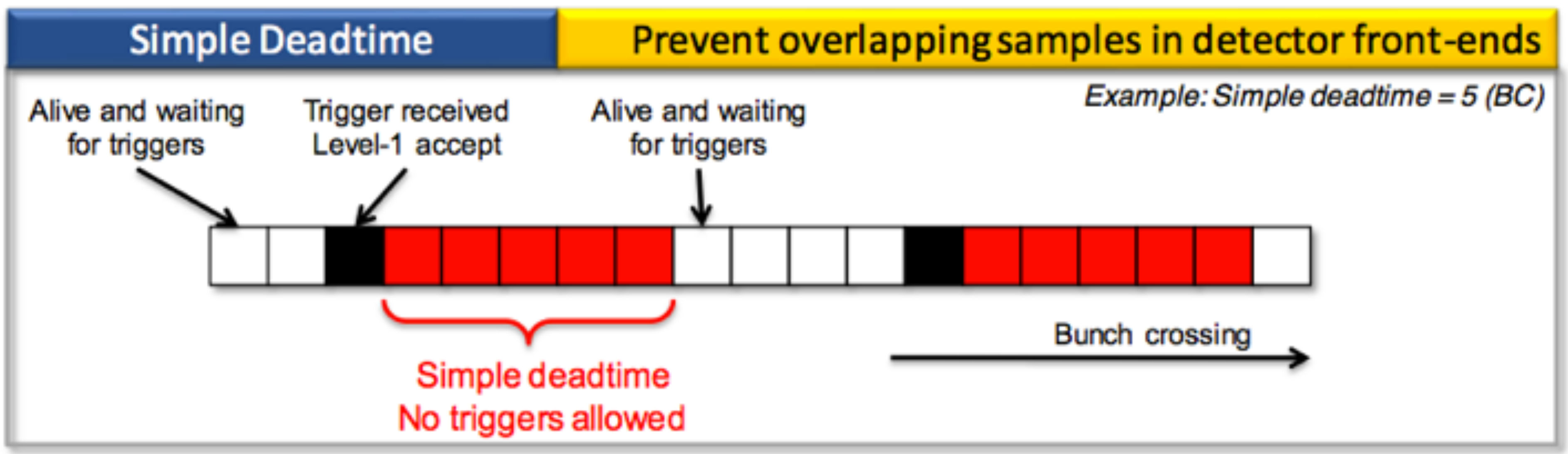


- More resources
  - 320 input bits on backplane (Run 1: 160)
  - **512 trigger items (Run 1: 256)**
  - More CTPOUT output cables
- **Increased number of bunch groups (8 → 16)**
- 192 direct input bits:
  - L1 topological processor adds latency to trigger path → save latency in CTP with direct input to CTPCORE
- Improved monitoring capabilities
- **Support for three logical sessions** (multi-partition running)
  - Enables parallel usage of trigger during commissioning and testing
  - L1 accept and timing signals duplicated

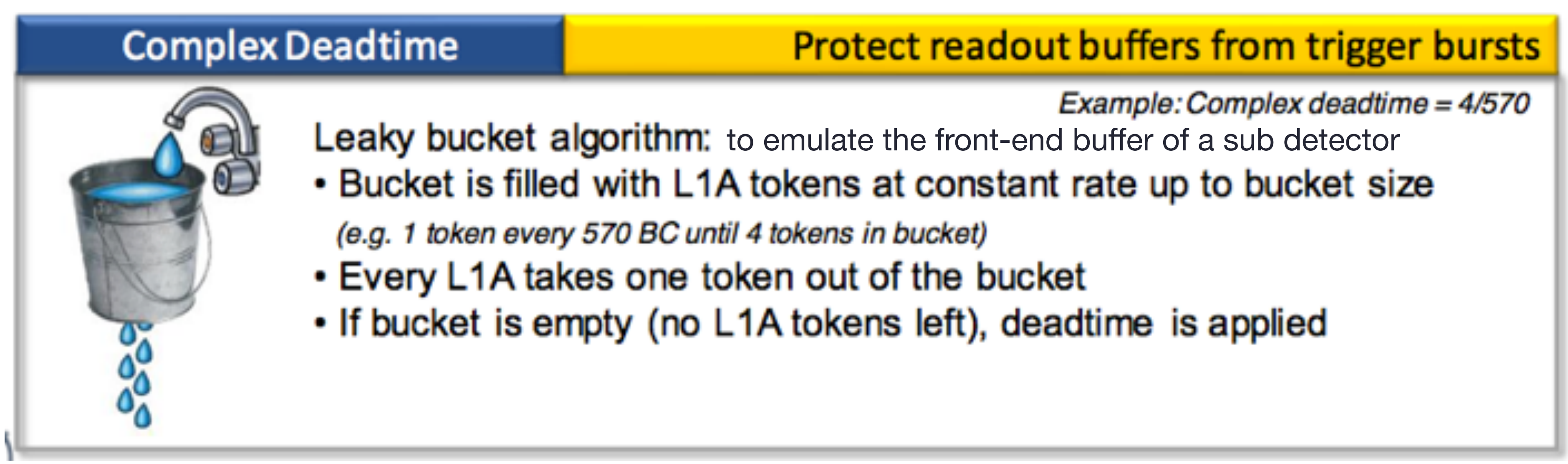
Simple & Complex Dead-time

http://cds.cern.ch/record/1300249/files/ATL-DAQ-PROC-2010-036.pdf

Preventive dead-time introduced by CTP to stop the front-end buffers from overflowing (processing time for a L1 accept), two different dead times: simple and complex dead-time

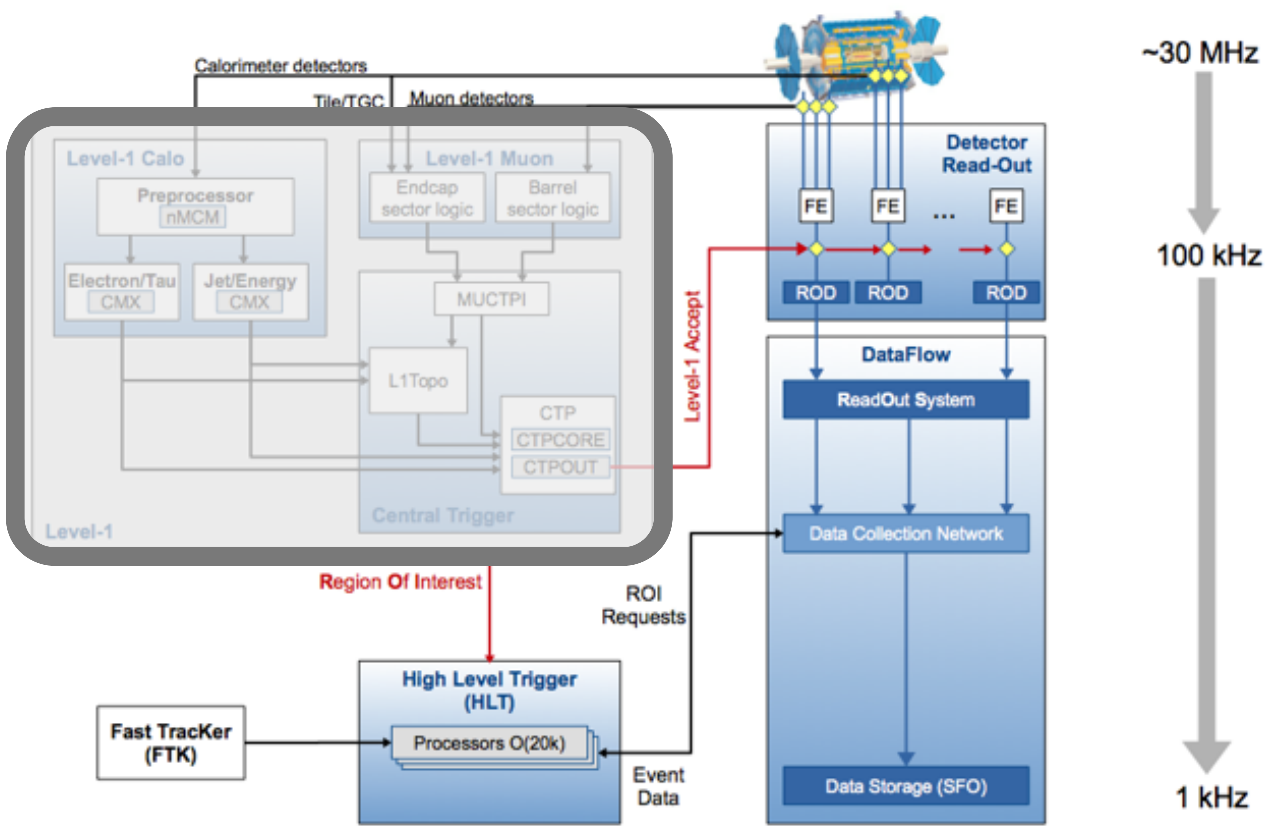


Simple dead-time: number of bunches the trigger will wait before a new L1 accept



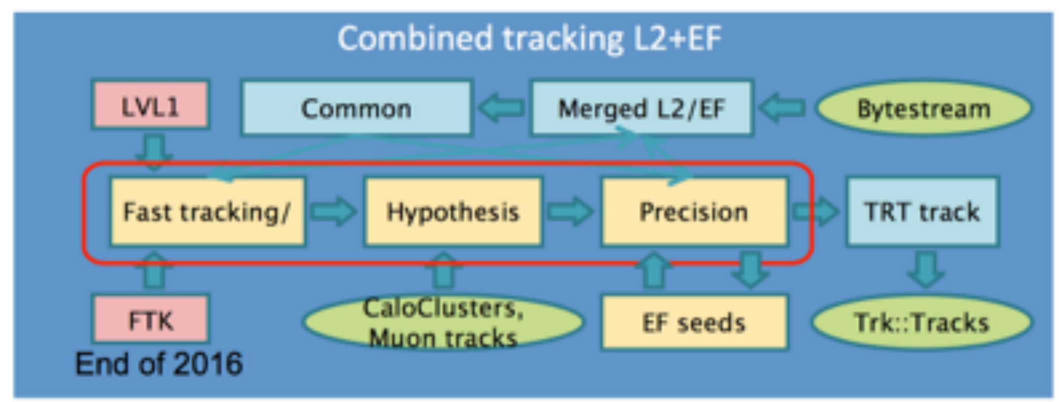
Complex Dead-time = restricts the number of L1 accepts in a given period of time (in bunch crossings)

HLT and Data Flow



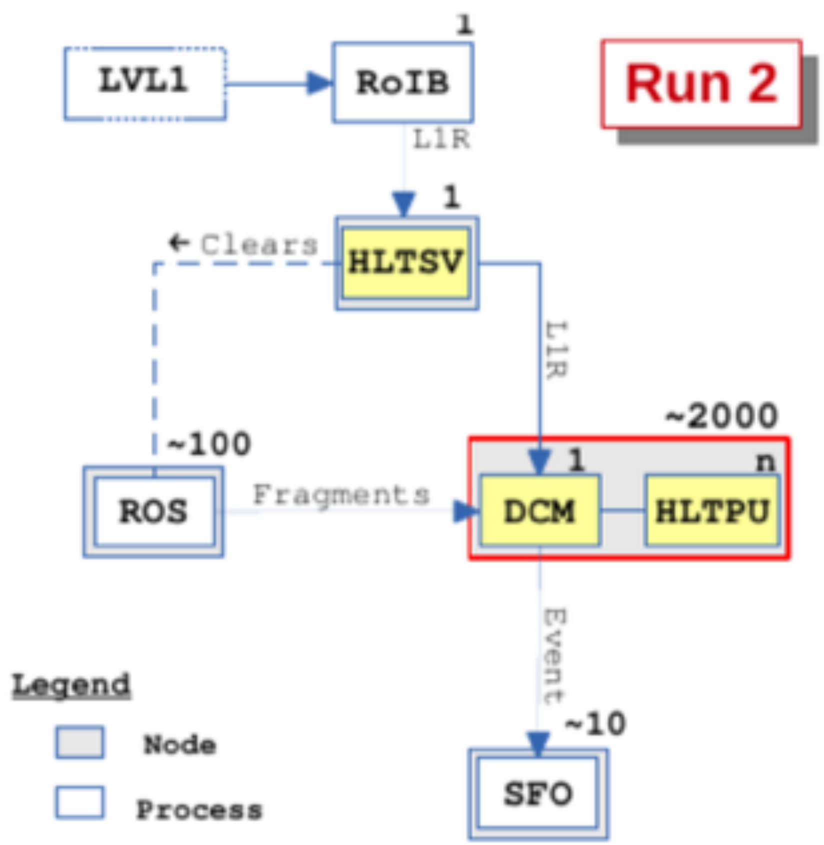
Improvements in the HLT System

- In Run 2, the L2, Event Builder & EF farms have been merged to a unique HLT farm for simplification and dynamic resource sharing
  - BW bottlenecks from network were replaced by in-memory transfer
  - Algorithms mainly reconstruct in regions of interest, but can now also do more unseeded reconstructions for specific detectors (Calo, Muon)
  - New fast HLT algorithms with full-data access, closer to offline
    → reduce rates at an early stage against high pile up, e.g. offline-like tracking and clustering run straight after L1



- Ready for increased bandwidth from the DAQ limits
  - L1 total rates: 70 kHz → 100 kHz
  - HLT output rates to storage: 600 Hz → 1-1.5 kHz (at peak luminosity)

Data Flow Architecture



Region of Interest Builder (RoIB)
- receives L1 trigger information and RoIs and combines the information for the HLT SuperVisor (HLTSV)

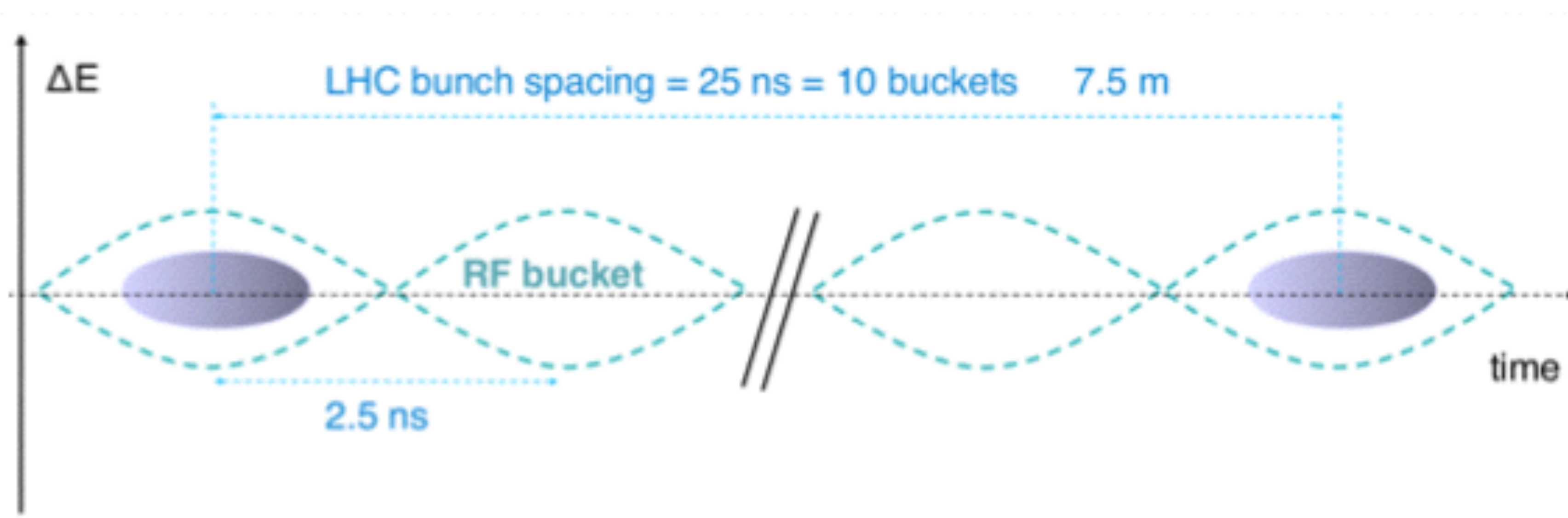
HLT SuperVisor (HLTSV)
- dispatches Regions of Interest (RoIs) to available HLT nodes
- handles eventual time-outs

Data Collection Manager (DCM)
- handles all input/output on the HLT nodes, including RoI requests from the HLT and full event building
- assign fragments from ReadOut System (ROS) to HLTPU (HLT Processing Units)
  - ROS: buffers front-end data from the detectors, provides standard interface to the DAQ
  - HLTPUs: execute HLT algorithms; HLT processing tasks are forked from a single mother process to maximise memory sharing
- sends accepted events to the Data Logger (SFO)
  - responsible to save accepted events to disk and send files to EOS

Important to understand the data flow since it might help to find out why the system is busy (see Run Control Shifter Training talk from this morning!)

LHC Bunch Structure & Bunch Groups

LHC Bunch Structure



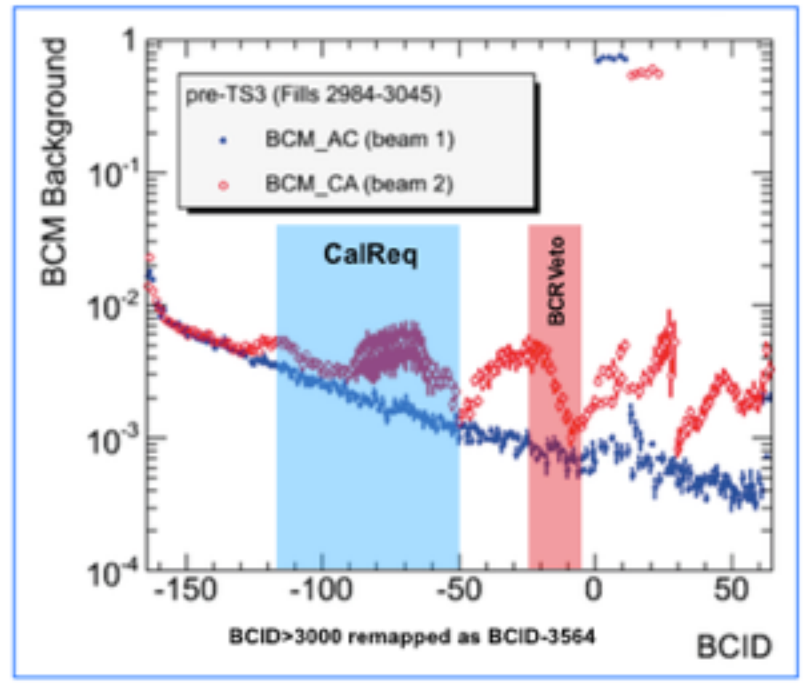
- LHC bunch spacing of 25ns corresponds to 10 buckets (7.5 m, 2.5 ns RF buckets)
- **3564** possible bunches in LHC identified by Bunch Crossing Identifier (BCID)
  → BCID = 0,…., 3563
- A bunch can be filled or empty
  - 2 crossing bunches can be
    - “paired”: both beams with protons
    - “unpaired”: only one beam with protons
    - “empty”: neither beam with protons
  - ATLAS defines additional crossings for special purposes
- A Bunch Group (BG) is a list of BCIDs
- Various bunch groups combined form a Bunch Group Set (BGS)

Bunch group definition

- In Run1, up to 8 bunch groups can be used
  - BGRP#7 was shared among a few purposes: veto first 3 BCs in a train (used for MET trigger), VdM, ALFA

- In Run2 with the new CTP, we can define up to 16 bunch groups
  - #0 – BCRVeto
  - #1 – Filled
  - #2 – Calib (BCID 3445-3514)
  - #3 – Empty
  - #4 – UnpairedIsolated
  - #5 – UnpairedNonisolated
  - #6 – EmptyAfterFilled
  - #7 – InTrain (veto first 3BCs in train)
  - #8 – AbortGapNotCalib (BCID 3515-3563)
  - #9 – VdM
  - #10 – ALFA

  - Same as in Run1 up to #7

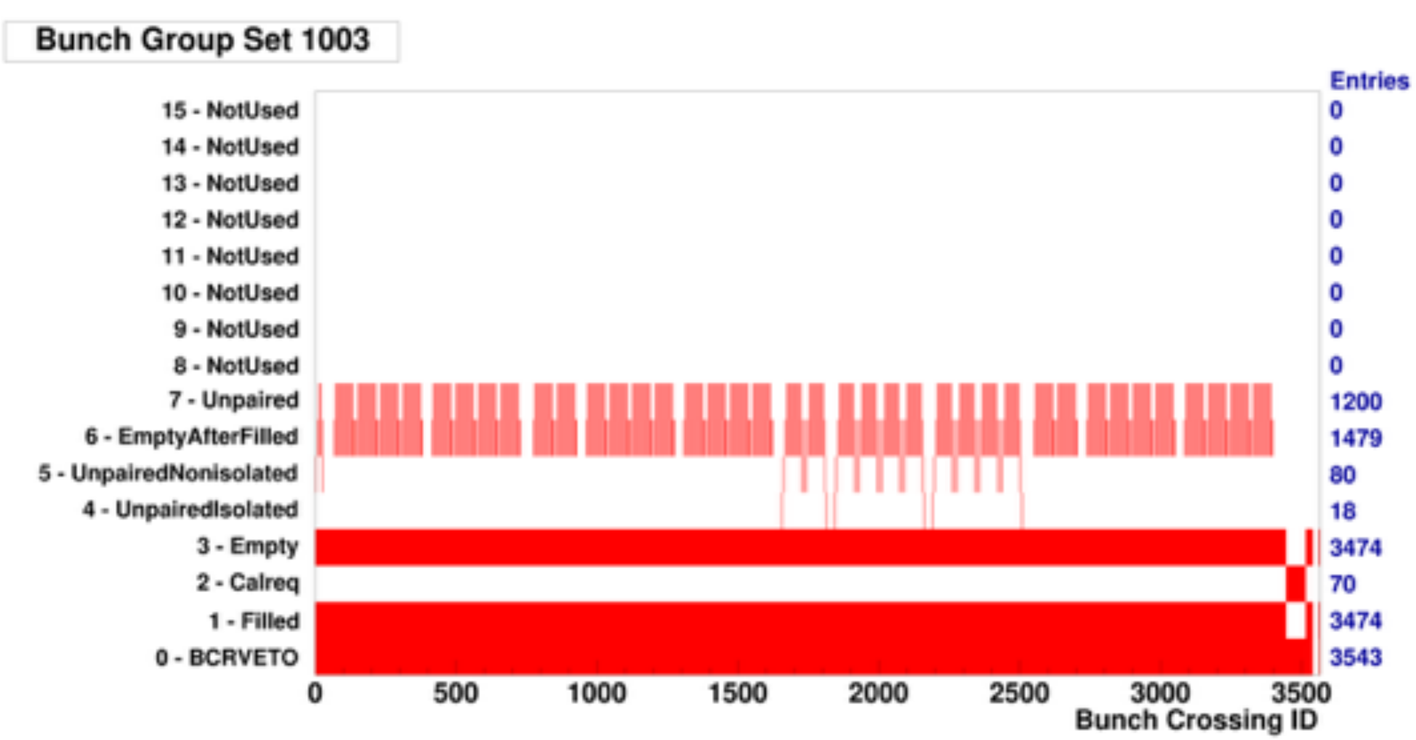


In 2012 BCM saw beam background in the abort gap !

- **Only seen in beam 2**
- **Very stable (position & magnitude) from fill to fill**
- **Appears between 4-7 Aug, coincident with changes in LHC chromaticity**
- **Almost certainly originating form momentum cleaning in IR3**

Bunch Groups & BGS

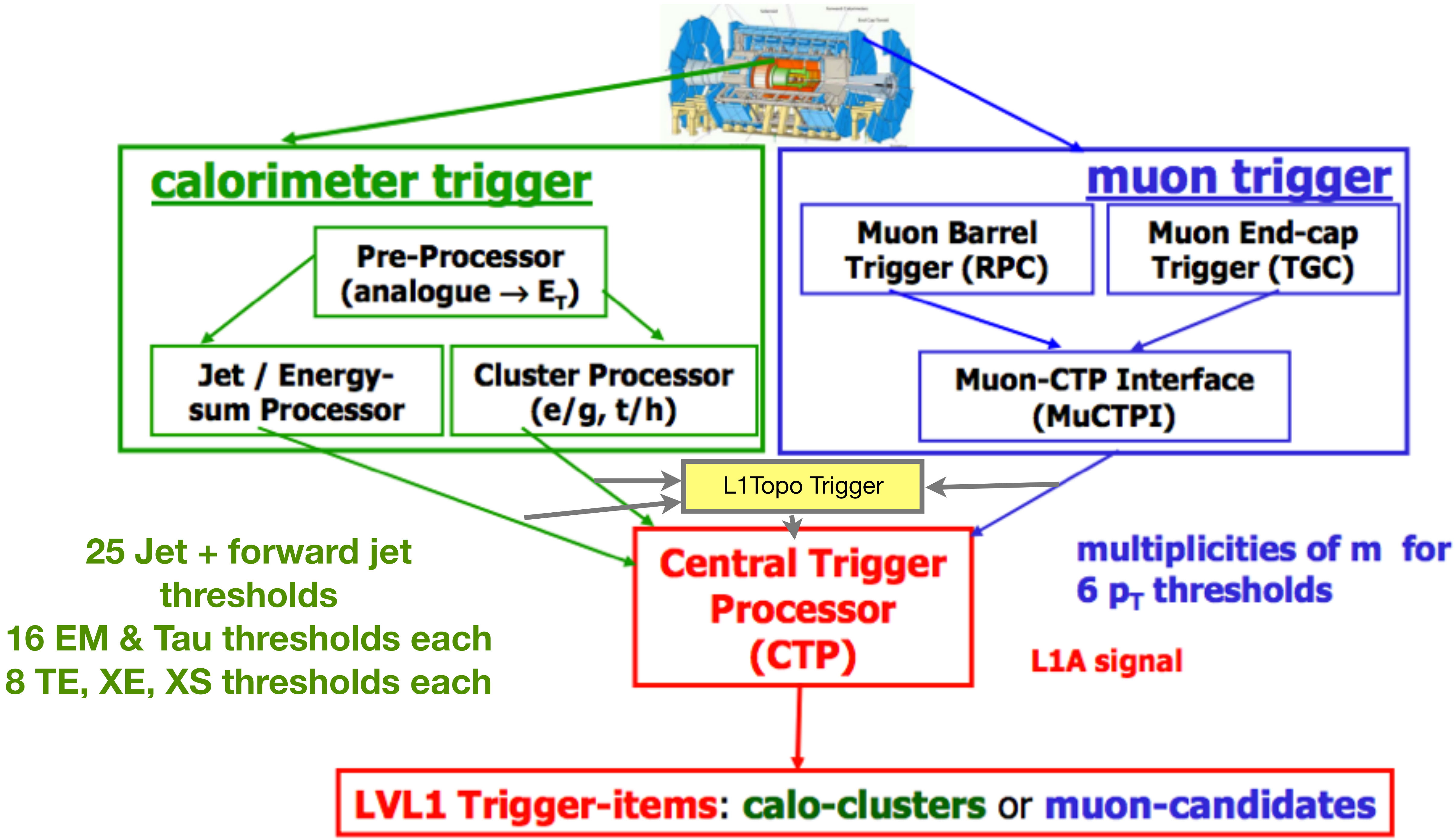
- A Bunch Group is a list of BCIDs, various bunch groups together form a Bunch Group Set:
  0) BCRVeto: Bunch Counter Reset (within abort gap), allows triggers everywhere but in a small region when the bunch counter reset is sent
  1) Paired/Filled: Colliding bunches in ATLAS
  2) Calreq: Calibration requests for TileCal (laser/charge injection) in the abort gap
  3) Empty: Two empty bunches crossing in ATLAS (for Cosmics, Noise)
  4) Unpaired Isolated: unpaired bunches separated by at least 3 BC from any bunch in the other beam
  5) Unpaired NonIsolated: unpaired bunches not in category 4)
  6) Empty after Filled: 3 empty bunches after paired bunch
  7) Unpaired: logical OR of 4) and 5)
- Look-up page for BGS: http://atlas-trigconf.cern.ch/bunchgroups?key=1003



0 - BCRVETO
0-3539, 3561-3563
1 - Filled
0-3444, 3515-3539, 3560-3563
2 - Calreq
3445-3514
3 - Empty
0-3444, 3515-3539, 3560-3563
4 - UnpairedIsolated
1654, 1656, 1658, 1812, 1814, 1816, 1841, 1843, 1845, 2159, 2161, 2163, 2188, 2190, 2192, 2506, 2508, 2510
5 - UnpairedNonisolated
0, 2, 4, 24, 26, 28, 1660, 1662, 1664, 1726, 1728, 1730, 1732, 1738, 1740, 1742, 1744, 1806, 1808, 1810, 1847, 1849, 1851, 1913, 1915, 1917, 1919, 1925, 1927, 1929, 1931, 1993, 1995, 1997, 1999, 2005, 2007, 2009, 2011, 2073, 2075, 2077, 2079, 2085, 2087, 2089, 2091, 2153, 2155, 2157, 2194, 2196, 2198, 2260, 2262, 2264, 2266, 2272, 2274, 2276, 2278, 2340, 2342, 2344, 2346, 2352, 2354, 2356, 2358, 2420, 2422, 2424, 2426, 2432, 2434, 2436, 2438, 2500, 2502, 2504
6 - EmptyAfterFilled
7, 9, 11, 13, 15, 17, 19, 21, 23, 25, 27, 66, 68, 70, 72, 74, 76, 78, 80, 82, 84, 86, 88, 90, 92, 94, 96, 98, 100, 102, 104, 106, 108, 110, 112, 114, 116, 118, 120, 122, 124, 126, 128, 130, 132, 134, 136-140, 146, 148, 150, 152, 154, 156, 158, 160, 162, 164, 166, 168, 170, 172, 174, 176, 178, 180, 182, 184, 186, 188, 190, 192, 194, 196, 198, 200, 202, 204, 206, 208, 210, 212, 214, 216-220, 226, 228, 230, 232, 234, 236, 238, 240, 242, 244, 246, 248, 250, 252, 254, 256, 258, 260, 262, 264, 266, 268, 270, 272, 274, 276, 278, 280, 282, 284, 286, 288, 290, 292, 294, 296-300, 306, 308, 310, 312, 314, 316, 318, 320, 322, 324, 326, 328, 330, 332, 334, 336, 338, 340, 342, 344, 346, 348, 350, 352, 354, 356, 358, 360, 362, 364, 366, 368, 370, 372, 374, 376-380, 413, 415, 417, 419, 421, 423, 425, 427, 429, 431, 433, 435, 437, 439, 441, 443, 445, 447, 449, 451, 453, 455, 457, 459, 461, 463, 465, 467, 469, 471, 473, 475, 477, 479, 481, 483-487, 493, 495, 497, 499, 501, 503, 505, 507, 509, 511,

L1 Items, HLT Signatures & Streams

L1 Trigger Items

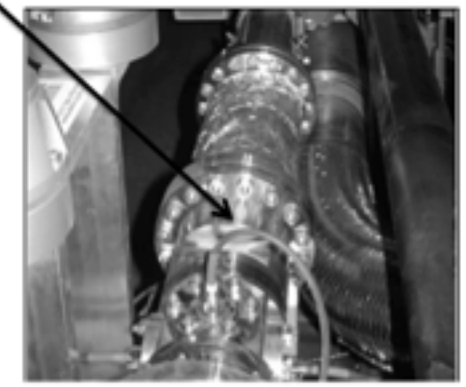


Additional L1 Items & Bunch Groups

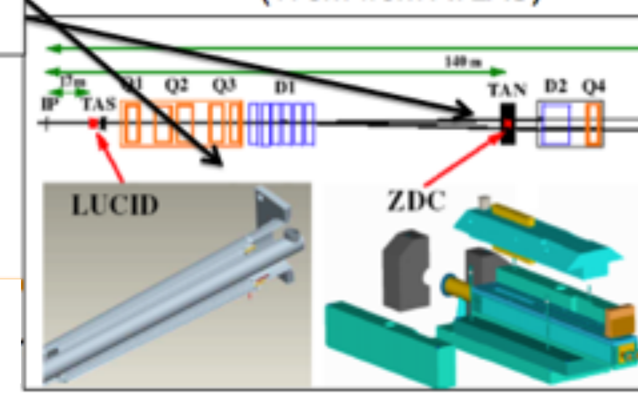
Other triggers you might see during early running:

- L1_MBTS: Minimum Bias Trigger Scintillators
- L1_BPTX: Beam Pickup Timing Experiment
- L1_BCM: Beam Condition Monitors
- L1_LUCID: Luminosity Measurement with Cherenkov Integrated Detector
- L1_ZDC: Zero Degree Calorimeter
- L1_TRT: Cosmic Track Trigger
- L1_CALREQ: Calo Calibration Triggers
- L1_RD0/L1_RD1

(between the end-cap calo & ID)



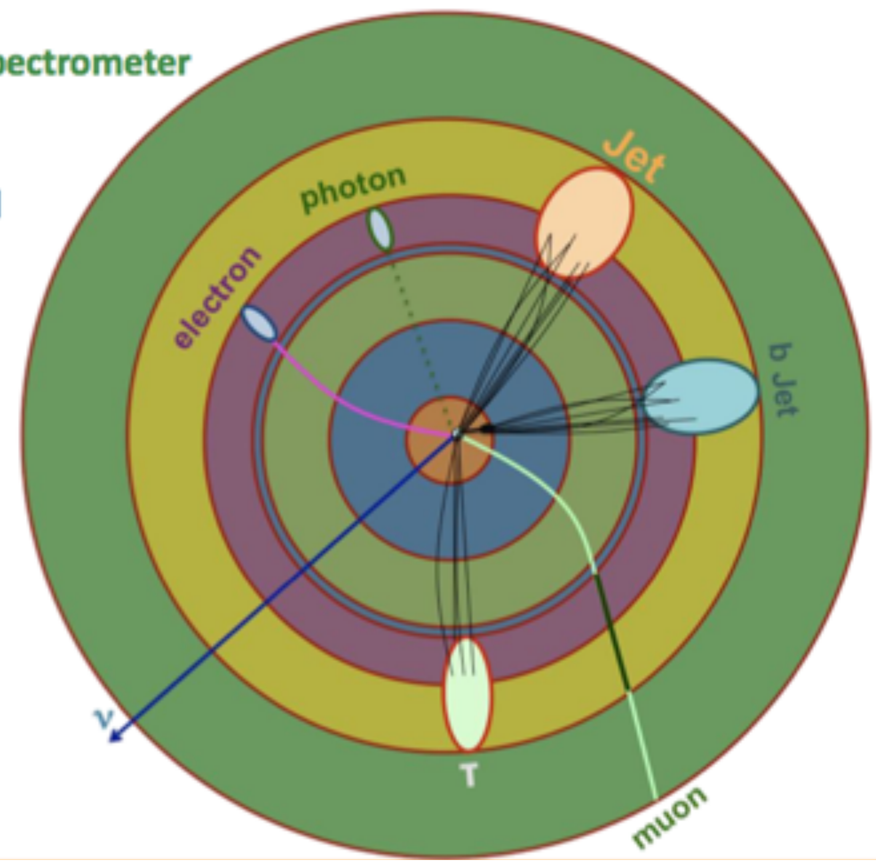
(175m from ATLAS)



- All L1 trigger items have one or more explicit or implicit bunch group requirement
  - all triggers are ANDed with BCRVeto
  - all physics triggers (e.g. L1_J100) ANDed with PAIRED
- If triggers are paired with other bunch groups, they carry the bunch group in their name:
  - e.g. L1_EM3_EMPTY, L1_TAU5_UNPAIRED
  - L1_RD0_FILLED, L1_RD0_EMPTY, L1_TRT_FILLED, L1_TRT_EMPTY, etc….

HLT Physics Signatures

Physics signature:
- Defined as a group of closely related trigger chains, e.g. Muons, B-physics, Jets…
- Each Signature has primary, backup, supporting and monitoring chains



The different trigger signatures define the trigger physics streams (and corresponding trigger signature groups):

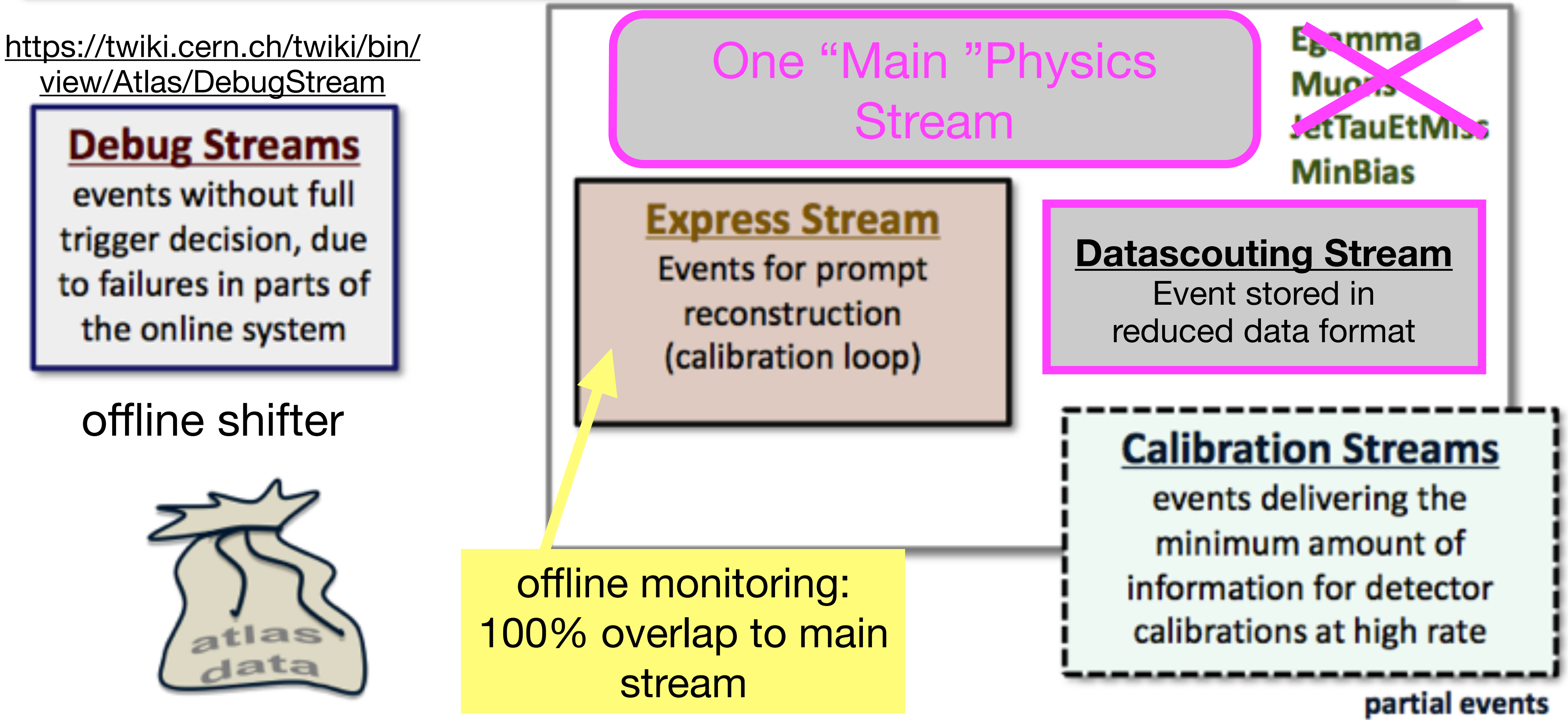
- **Electrons/photons**
- **Muons/B-physics,**
- **Jets/Met/taus**
- **Minimum Bias**

- **Chain**: one full L1 → HLT (Run 2) selection
  - starting with a L1 item as seed
  - each chain is organised in steps (Trigger Elements), at any step it can be rejected
  - each step: execution of a sequence of algorithms, typically Feature Extraction (FEX) and hypothesis testing algorithms (Hypo)
  - if surviving till the last step → event accepted

Data Streaming

Stream: Collection of events or event fragments in the same data set

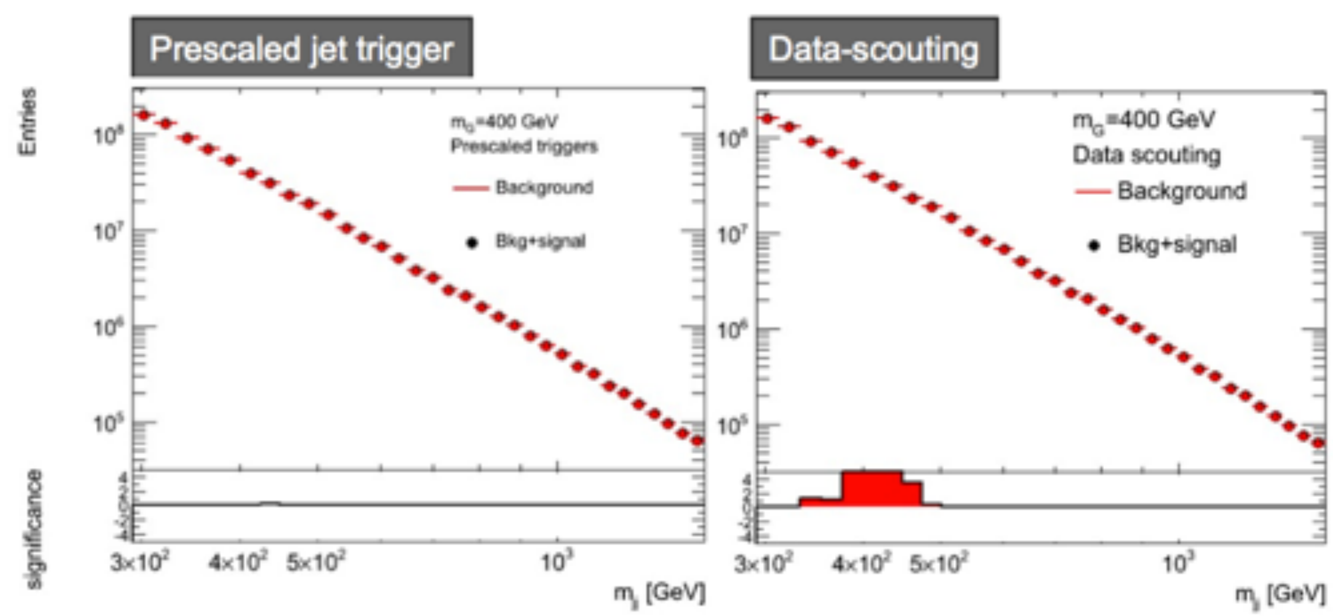
- Streaming is based on trigger decisions at the HLT
- Raw Data physics streams are generated at the SFO
- All streams are inclusive, except for the debug stream
- New in Run 2:
  - one main physics stream
    - merge of Egamma, Muon, JetTauEtMiss
    - saves ~10% in computing/storage
  - datascouting stream



Data Scouting

DataScouting: write out data with reduced event content (i.e. store calo jets reconstructed during HLT only)

- New HLT/DAQ functionality
  - Store only HLT reconstructed objects in RAW data (not detector data)
  - Signal statistics increased by orders of magnitude
- Use-case: Di-jet resonance search
  - In Run-1 low-mass resonance searches limited by statistics
  - Due to limited output rate, had to rely on prescaled triggers
  - Run-2: Run and store HLT jet reconstruction on all L1_J100 triggered events
- Challenges
  - No detector data in RAW



Trigger Menu & Configuration

Trigger Menu Terminology

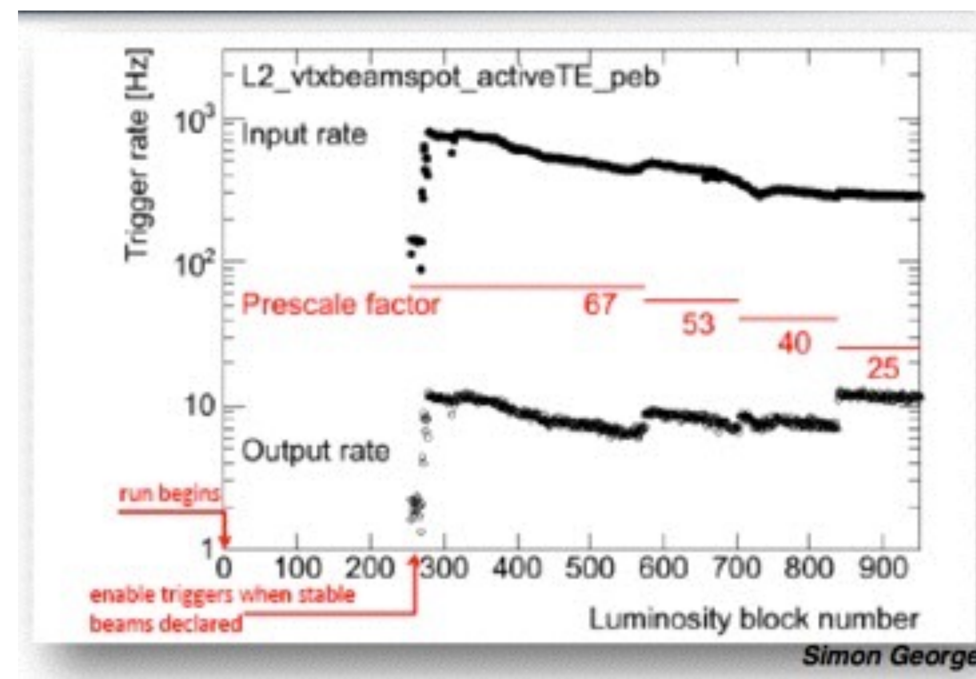
https://cds.cern.ch/record/1632445/files/ATL-DAQ-SLIDE-2013-893.pdf

- **Trigger Menu:** full set of chains and prescale factors
  - A typical menu contains several hundreds of chains (~500 in Run 1) to meet a large variety of physics goals at the LHC. Chains can be classified as:
    - **primary chains**: chains for physics signals in general, all events passing these chains are kept (unprescaled)
    - **backup chains:** higher thresholds, used in case of unexpected luminosity increase
    - **supporting chains:** used for maintaining or to support a physics analysis (e.g. to extract background in a data driven way)
    - **monitoring chains:** used to monitor the data qualities (e.g. to check the performance of tracking by the inner detectors)
  - Menus are designed for specific data-taking purpose and LHC beam conditions, e.g. LS1 menu, Physics menu, MC menu, HI menu, Cosmics/Standby menu
  - Prescale factor = reduction factor to issue a trigger (e.g. a prescale factor on chain X of 5 means that every 5th event that is accepted by the chain is recorded, all others are discarded)

Trigger Menu Configuration Keys

- To completely specify the trigger configuration for a run, three keys are required:
  - **SuperMaster Key (SMK)**: chooses one unique configuration (menu, configuration, etc.)
  - **L1 and HLT Prescale Set key (PSK)**: several L1 and HLT PSKs are usually associated to one SMK, can be changed (prescale, enable, disable triggers) during the run at the luminosity block boundaries

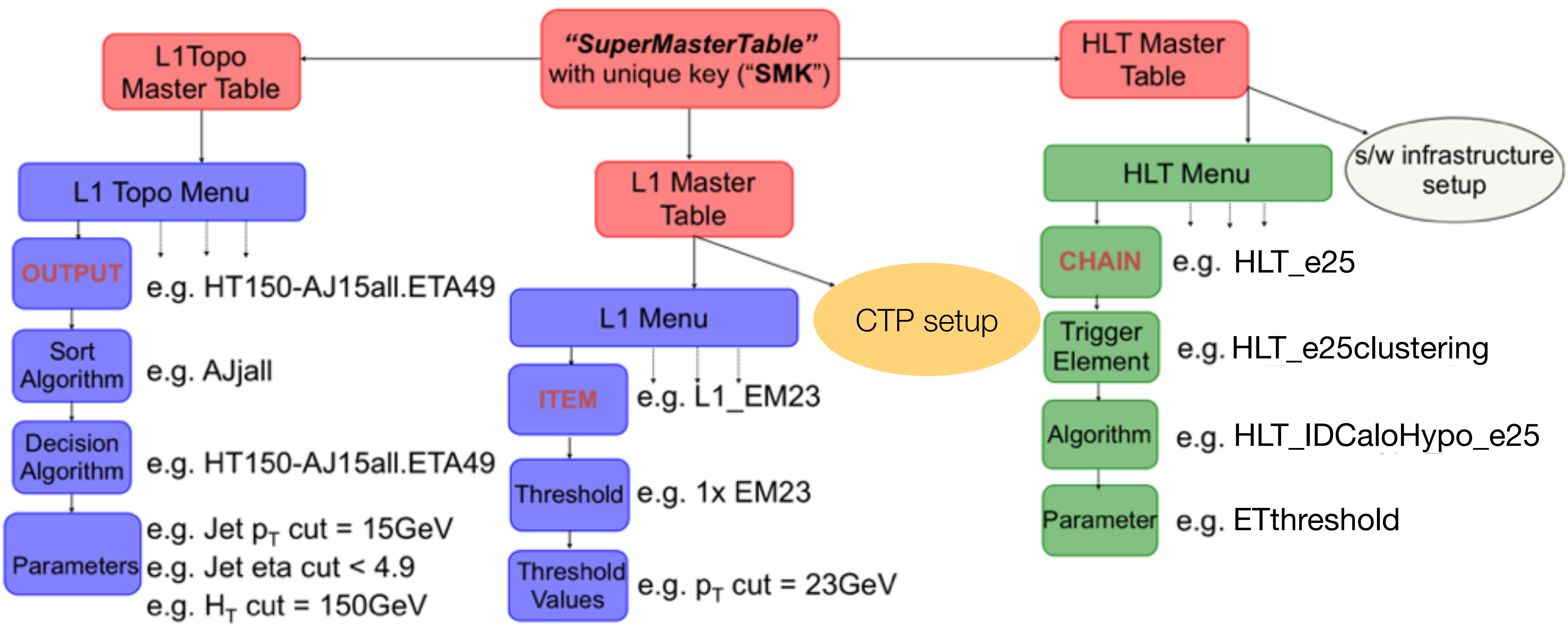
  - Cosmics Prescales: for cosmic data-taking
  - Standby Prescales:
    - No beam or un-stable beams (before warm start)
    - Detectors in SAFE mode, high voltage off (low) for inner detector and muon systems
    - Only a few L1 triggers needed for detectors to measure background levels
  - Physics Prescales:
    - Stable beams, all detectors in physics mode
    - Data for physics analysis, all triggers in, HLT rejection
    - Prescale sets for different luminosities
  - Special Prescales:
    - High Rate tests
    - Special sub-detector tests



- Additionally there is a L1 Bunch Group Set (BGS) key which defines the LHC fill pattern for the Central Trigger Processor (CTP):
  - in data-taking period generated during ramp
  - can create user specified BGS

Trigger Configuration

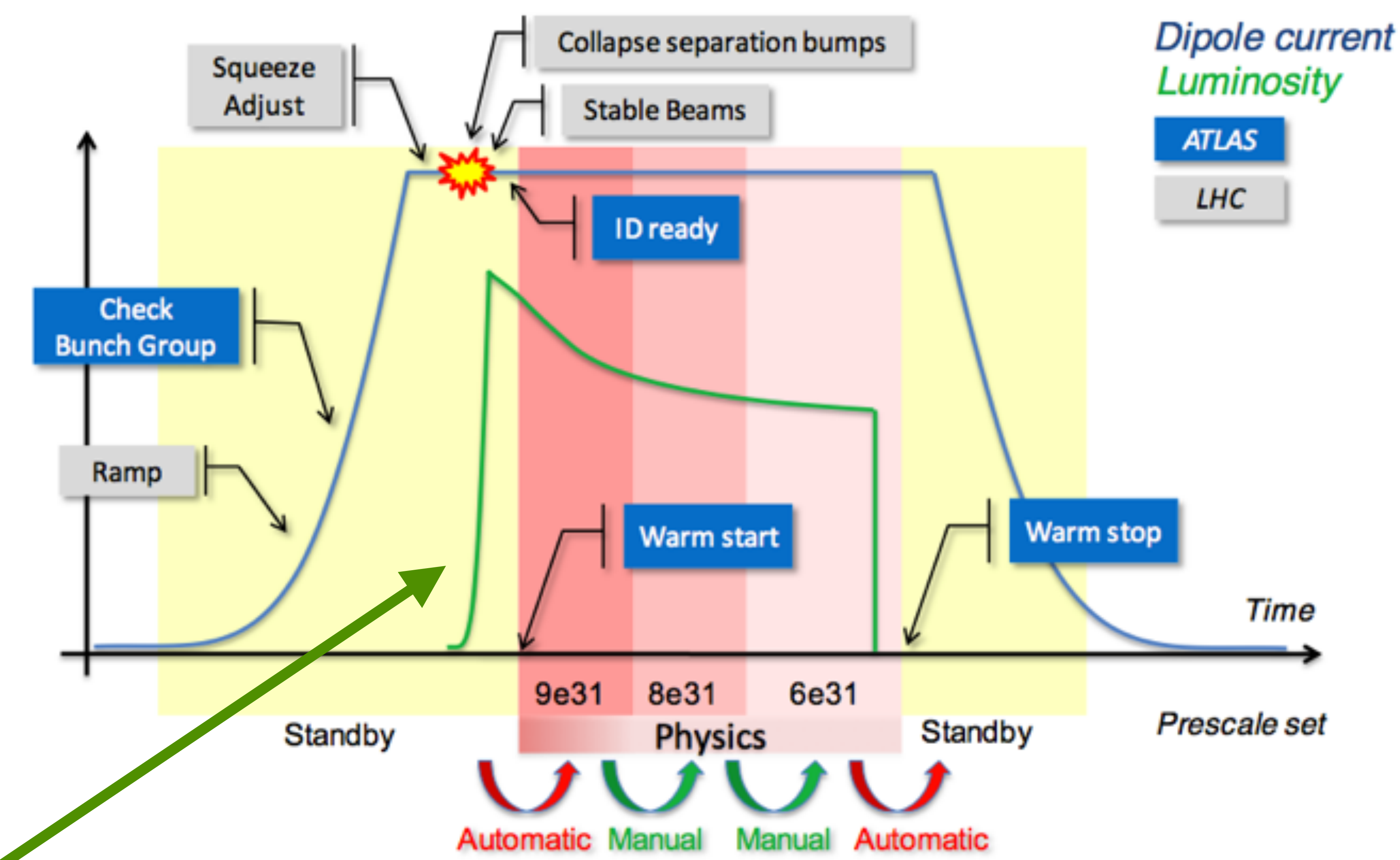
- The Trigger DB stores the L1 and HLT Menus and the setups (= configurations of L1 hardware and HLT software)
  → Configuration = trigger menu + setup
- The TriggerTool (TT) is the user interface to TriggerDB



Summary

Trigger during ATLAS running

- Run:
  - Period of data taking with a fixed trigger configuration (SMK) and detector setup
  - Usually corresponds to one LHC fill (many hours)
  - Make sure the correct information is displayed on the TriggerWhiteBoard
- Luminosity Block (LB):
  - Luminosity, conditions and data quality are considered to be approximately constant
  - Time interval of about ~2min within a run



- Drop of luminosity during a fill results in decreasing trigger rates
  - This is where prescale key changes come in which prescales on certain chains are released to maximise the selection of events of interest and to make use of the full bandwidth

The End…
….and some links….

Inputs to this talk:

- Trigger Expert Training (https://indico.cern.ch/event/333628/):
  - https://indico.cern.ch/event/333628/contribution/3/material/slides/1.pdf
  - https://indico.cern.ch/event/333628/contribution/0/material/slides/0.pdf
- Various talks:
  - https://cds.cern.ch/record/1712900/files/ATL-DAQ-SLIDE-2014-373.pdf
  - https://cds.cern.ch/record/1609564/files/ATL-DAQ-SLIDE-2013-831.pdf
  - https://cds.cern.ch/record/1609597/files/ATL-DAQ-SLIDE-2013-837.pdf
  - https://indico.cern.ch/event/323425/session/7/contribution/7/material/slides/0.pdf
  - https://cds.cern.ch/record/1670926/files/ATL-COM-DAQ-2014-013.pdf
  - https://www.masse-spektrum-symmetrie.de/events/blockcourse_10_11/23_2011-10_zurneddenmartin.pdf
  - ATL-COM-DAQ-2015-022
  - https://cds.cern.ch/record/2002014/files/ATL-COM-DAQ-2015-021.pdf
  - https://cds.cern.ch/record/2002339/files/ATL-COM-DAQ-2015-025.pdf
- ATLAS TDAQ glossary:
  - http://atlas.web.cern.ch/Atlas/GROUPS/DAQTRIG/glossary.html

ATLAS EXPERIMENT

NEW YORK UNIVERSITY

Simple & Complex Deadtime

Complex Dead-time

Complex dead-time:

- defined by the size of the bucket X (in units of L1A) and the time it takes to leave one L1A, R (in units of BC)
- trigger rate is limited to X triggers in a time period of X x R bunch crossings

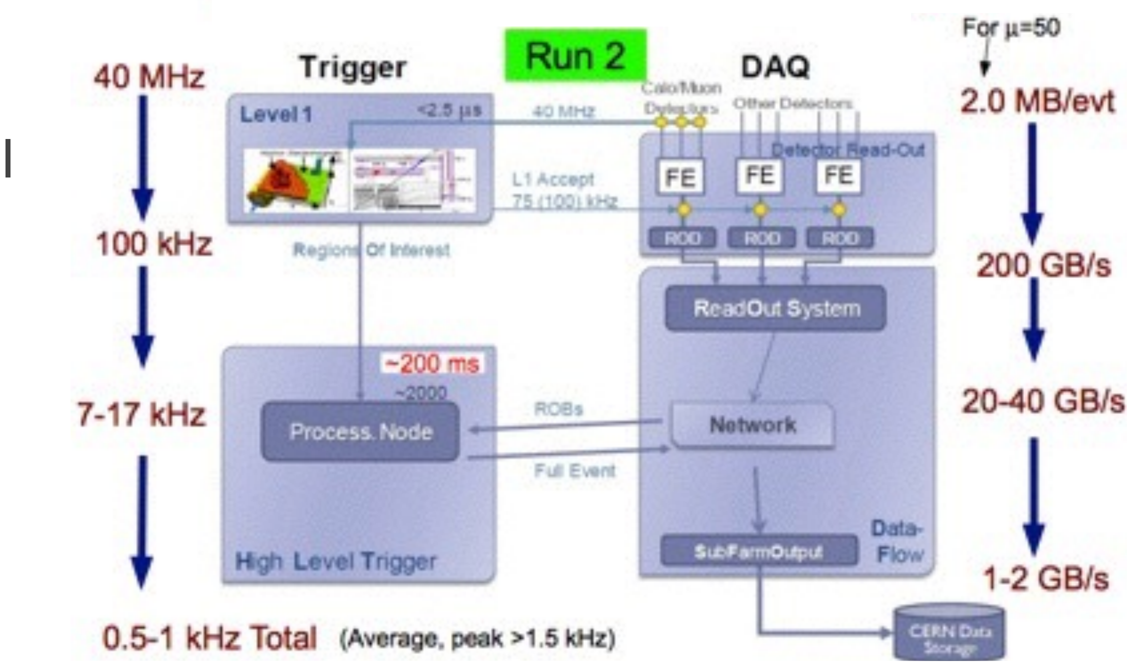
Backup

TDAQ System Upgrade

Changes in the TDAQ system to cope with Run 2 LHC conditions:

- Increase of output rate:
  - L1: from 75 kHz to 100 kHz
  - HLT: from ~200-400 Hz to ~ 500-1000 Hz on average per fill
    - limited by offline computing costs
- L1Calo and L1Muon upgrades
  - L1Calo: pile-up subtraction, more available thresholds
  - L1Muon: additional coincidences in endcap
  - Tile endcap trigger to reduce rate at 25ns
- Topological Trigger at L1
- Central Trigger Processor (CTP) upgrade:
  - more trigger items (256 → 512)) → more flexible menu
- Fast TracKer (FTK)
  - commissioning in 2015, full system available ~2016
  - offline-like tracks for all events passing L1
  - improvement of trigger performance in many areas, e.g. τ or b-jet triggers
- Merge of L2 and EF gives new opportunities for HLT
  - more flexibility in the order of selections and event building
  - even HLT farm loading (no fixed L2/EF allocation)
  - reduced ROS access (data retrieved only once)
    → 3rd gen. ROS would allow much more full-scan algorithms (but need to stay within CPU resources)

TDAQ System upgrades



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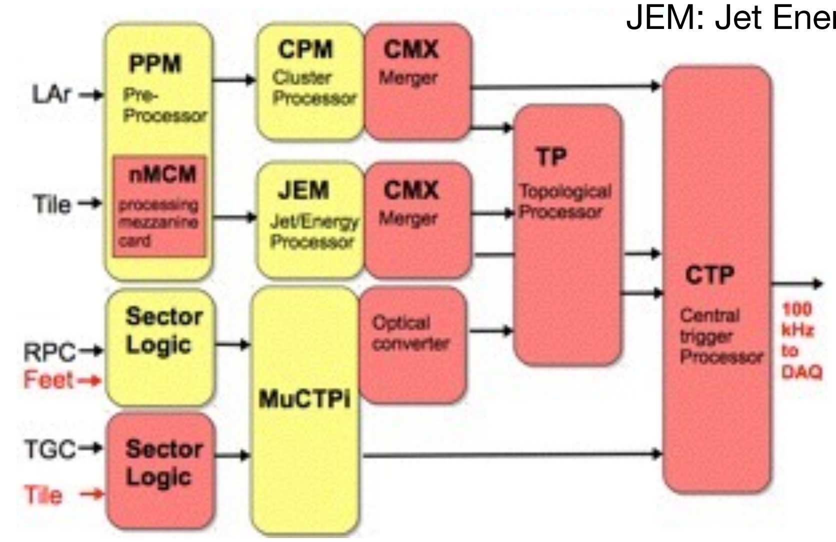
L1 upgrades



ATLAS TDAQ Glossary

http://atlas.web.cern.ch/Atlas/GROUPS/DAQTRIG/glossary.html

FE: Front End
ROD: Read Out Device
HW: HardWare
DC: Data Collector
RoI: Region of Interest
BE: Back End
ROS: ReadOut System
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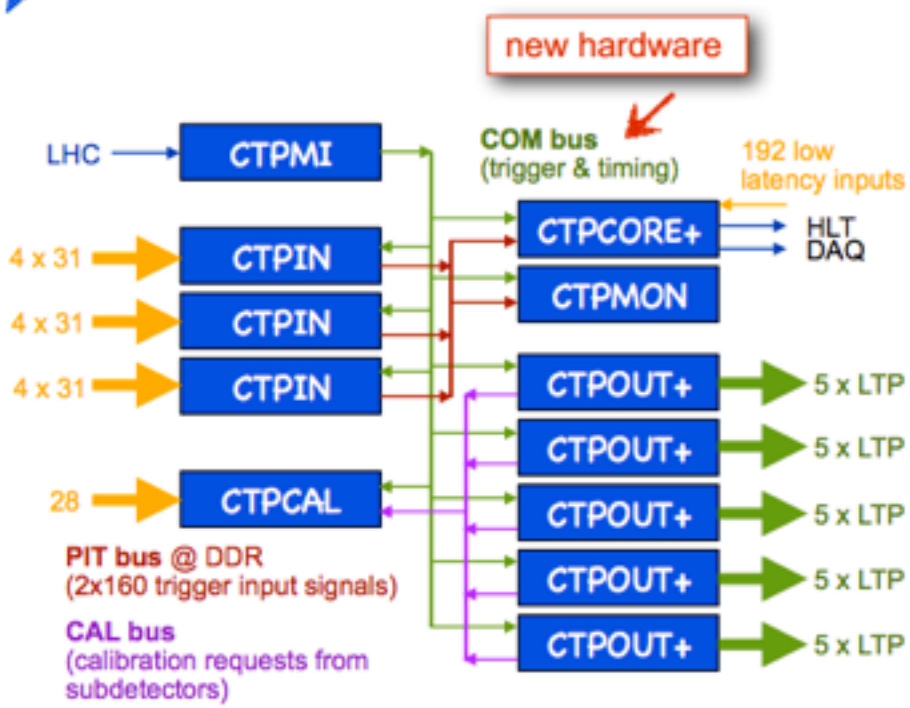
CTP Upgrade

https://cds.cern.ch/record/1756906/files/ATL-DAQ-SLIDE-2014-658.pdf

Central Trigger Processor (CTP)



Why the upgrade?

- more inputs: 160 → 512
- more outputs: 20 → 25
- more trigger items: 256 → 512

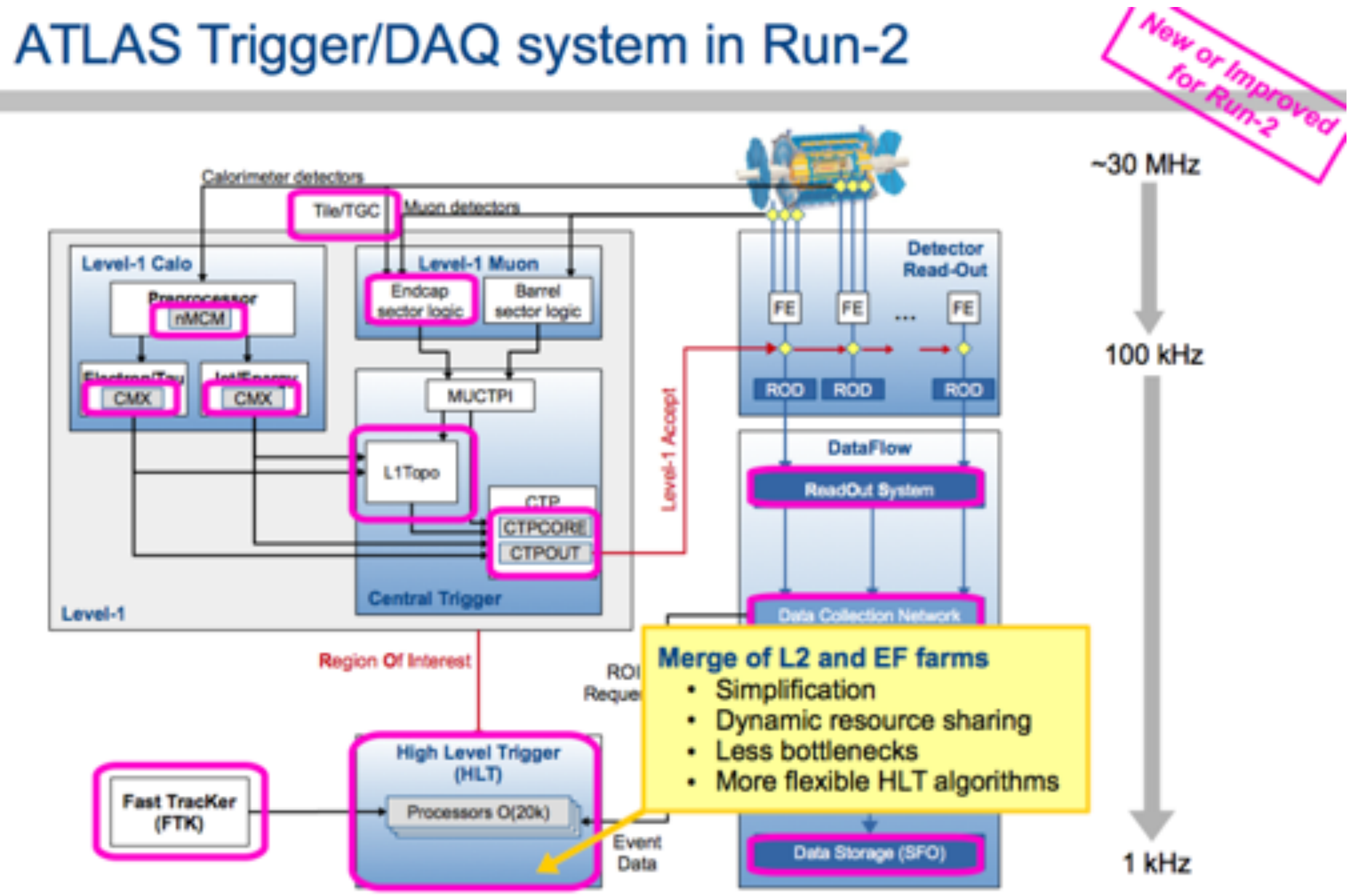
(logical combination of inputs)

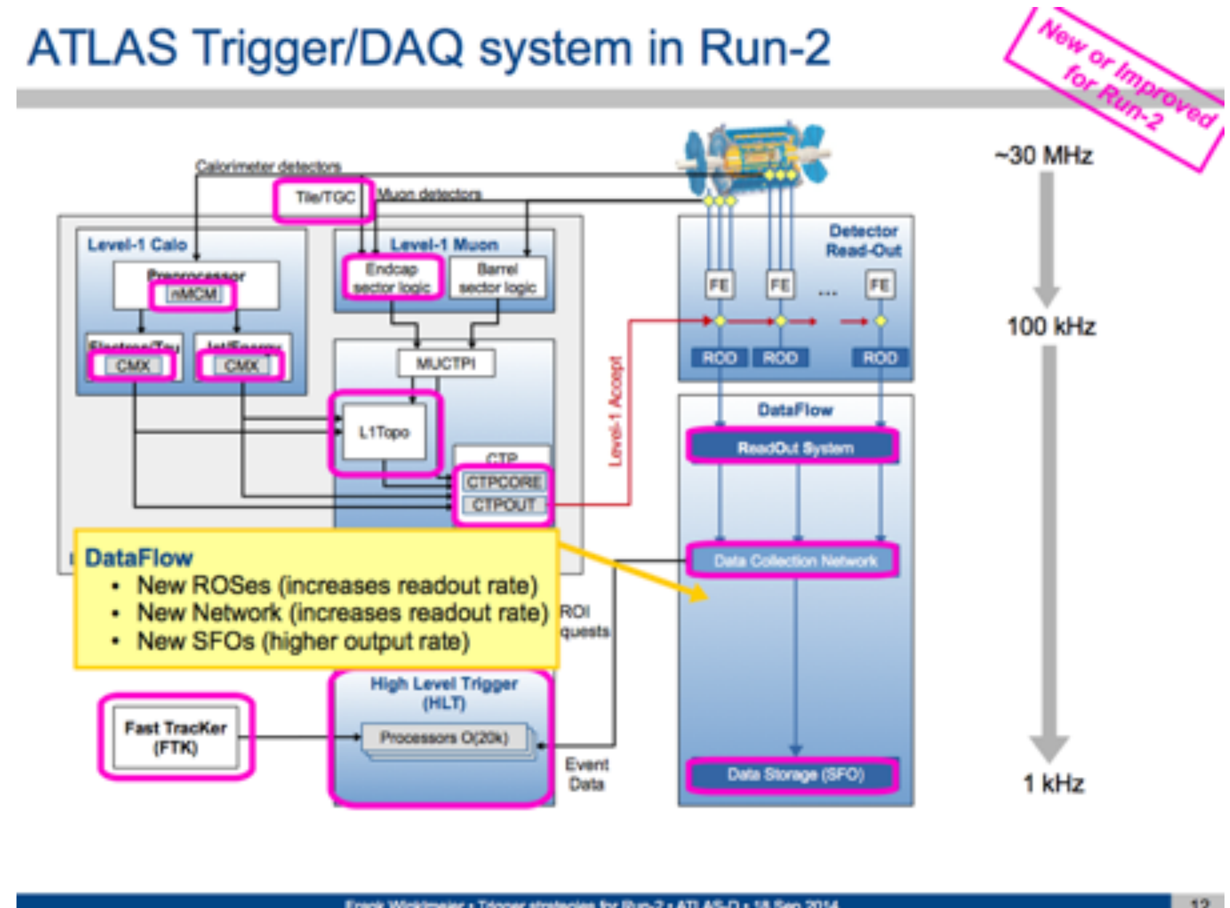
- better monitoring

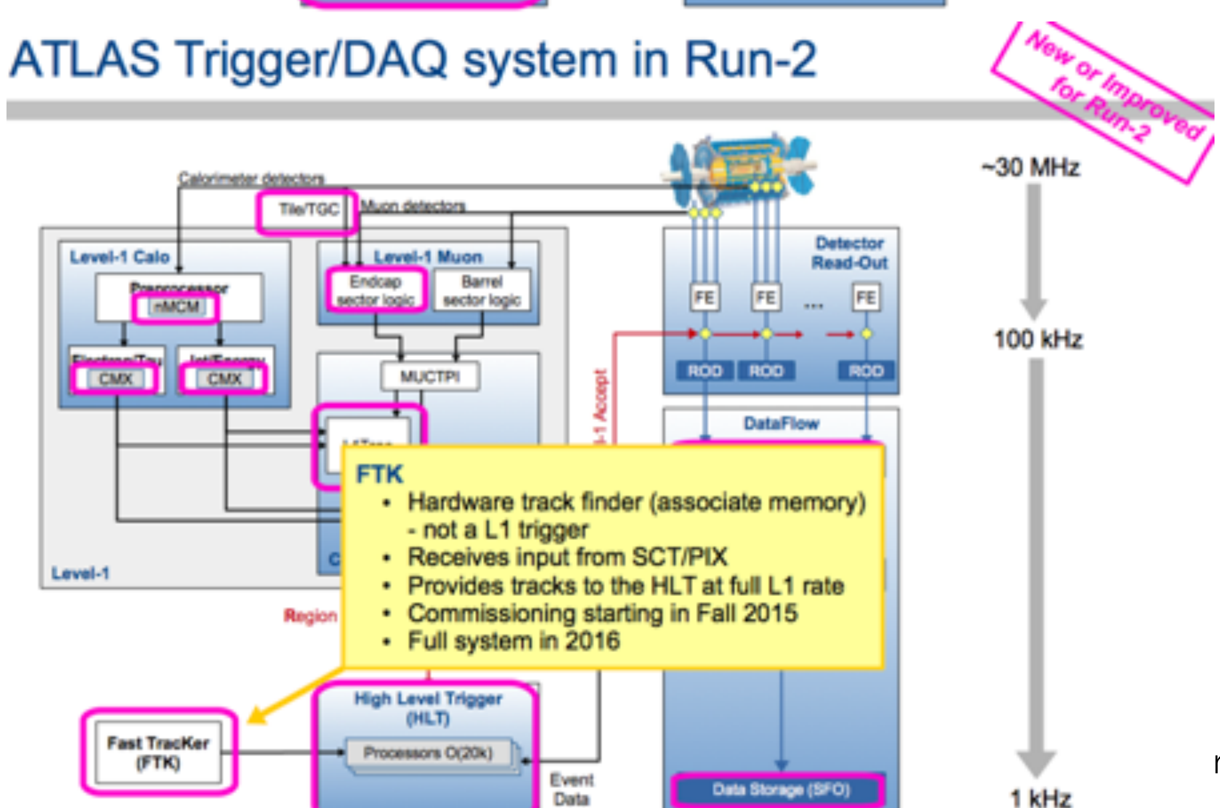
- CTPMI (machine interface)
  - receives timing signals from LHC
- CTPIN (input modules) — new firmware
  - trigger inputs from sub-detectors
  - synchronization / alignment / monitoring
- CTPCAL (calibration module)
- CTPCORE+ — new hardware
  - decision taking → L1 accepts (L1A)
  - dead time generation
  - generation of timing signals
  - summary information to HLT / DAQ
- CTPMON (monitoring module)
  - per bunch monitoring of trigger rates
- CTPOUT+ (output modules) — new hardware
  - distribute trigger & timing signals to sub-detectors
  - receives calibration requests

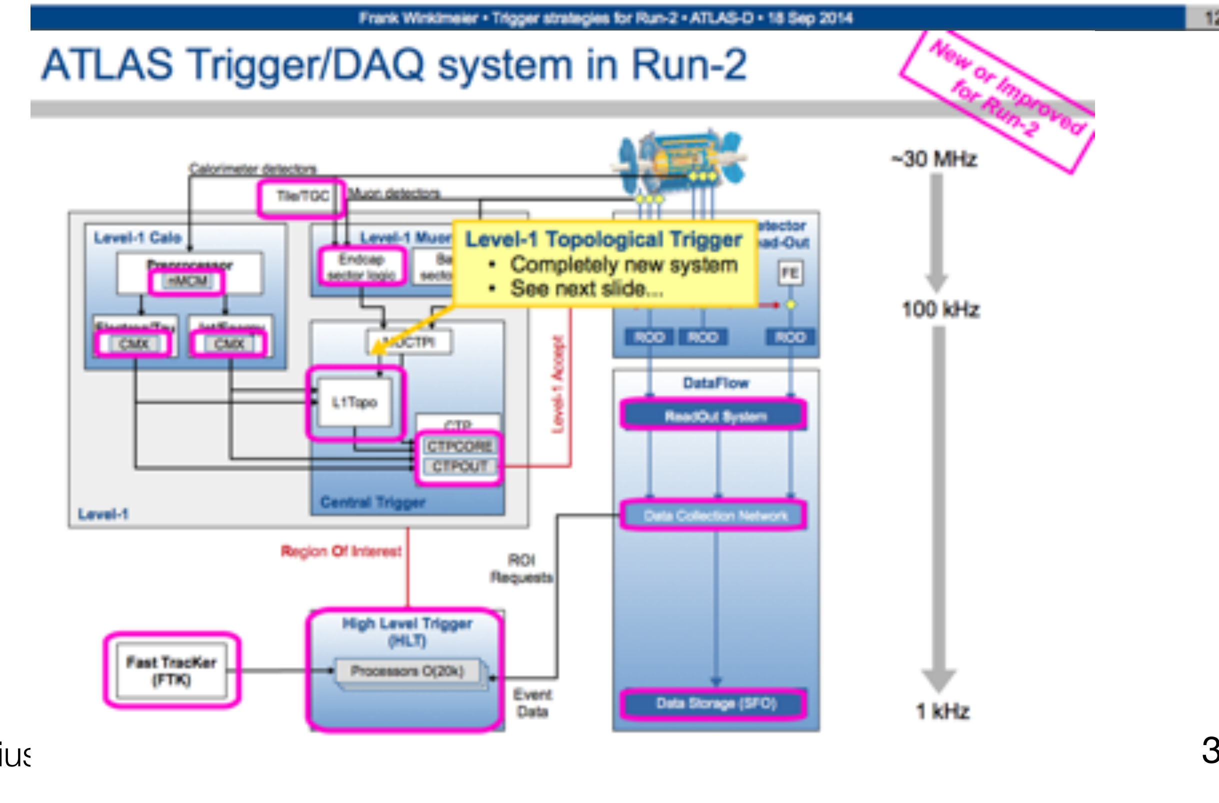
Kristof Schmieden TWEPP 2014 8

The ATLAS Trigger System









The ATLAS Trigger Configuration System

- The Trigger DB – central source of the trigger configuration
  - DB & tooling designed to never overwrite any setting – only reuse

So far ~1500 trigger configurations stored

- Content
  - L1 system configurations - essentially the hardware settings
  - Trigger chains definitions o ~1k
  - Algorithm properties o ~4k
  - Prescale values ~1k for HLT, 256 for L1
    The prescale values are organized in sets and are managed independently

About 10k prescale value sets for L1 and 8k for HLT were used so far

https://cds.cern.ch/record/1609597/files/ATL-DAQ-SLIDE-2013-837.pdf

New HLT Design

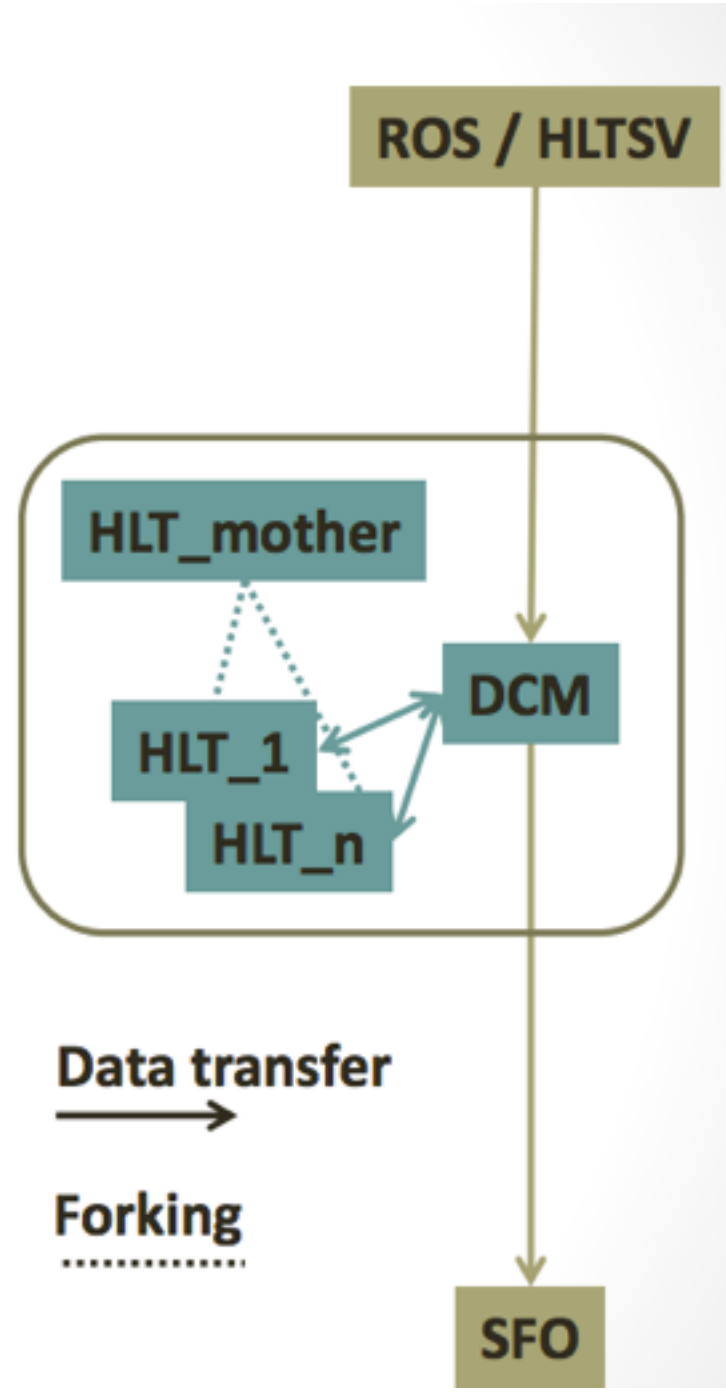
https://cds.cern.ch/record/1609564/files/ATL-DAQ-SLIDE-2013-831.pdf

Former L2 and EF algorithms ran in one process

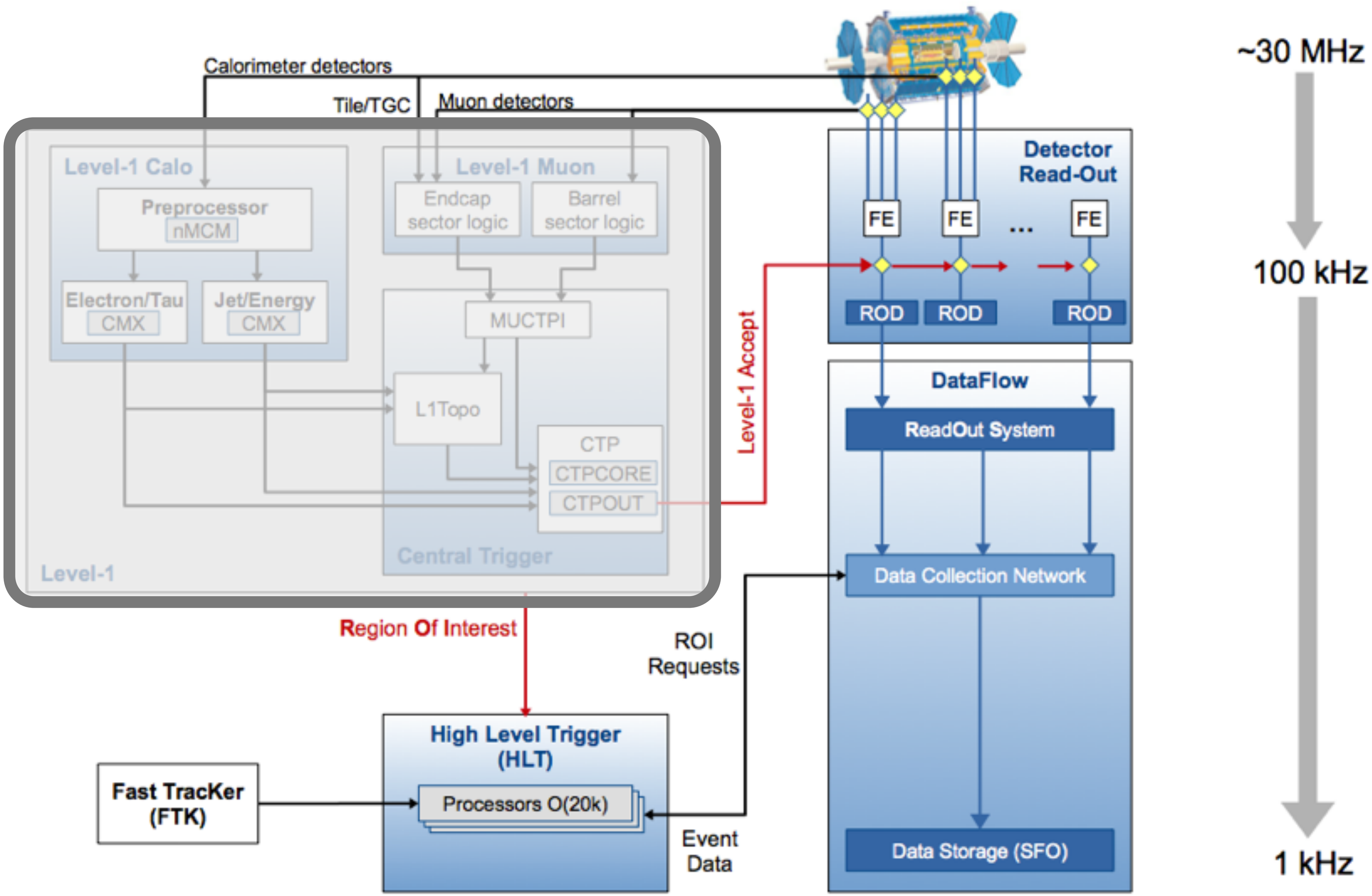
- Limited network transfer of data from L2 to EF algorithms replaced by unlimited in-memory transfer
- Data Collection optimization
- Flexible event building

Mother Process forks to exploit kernel's Copy on Write feature (CoW):

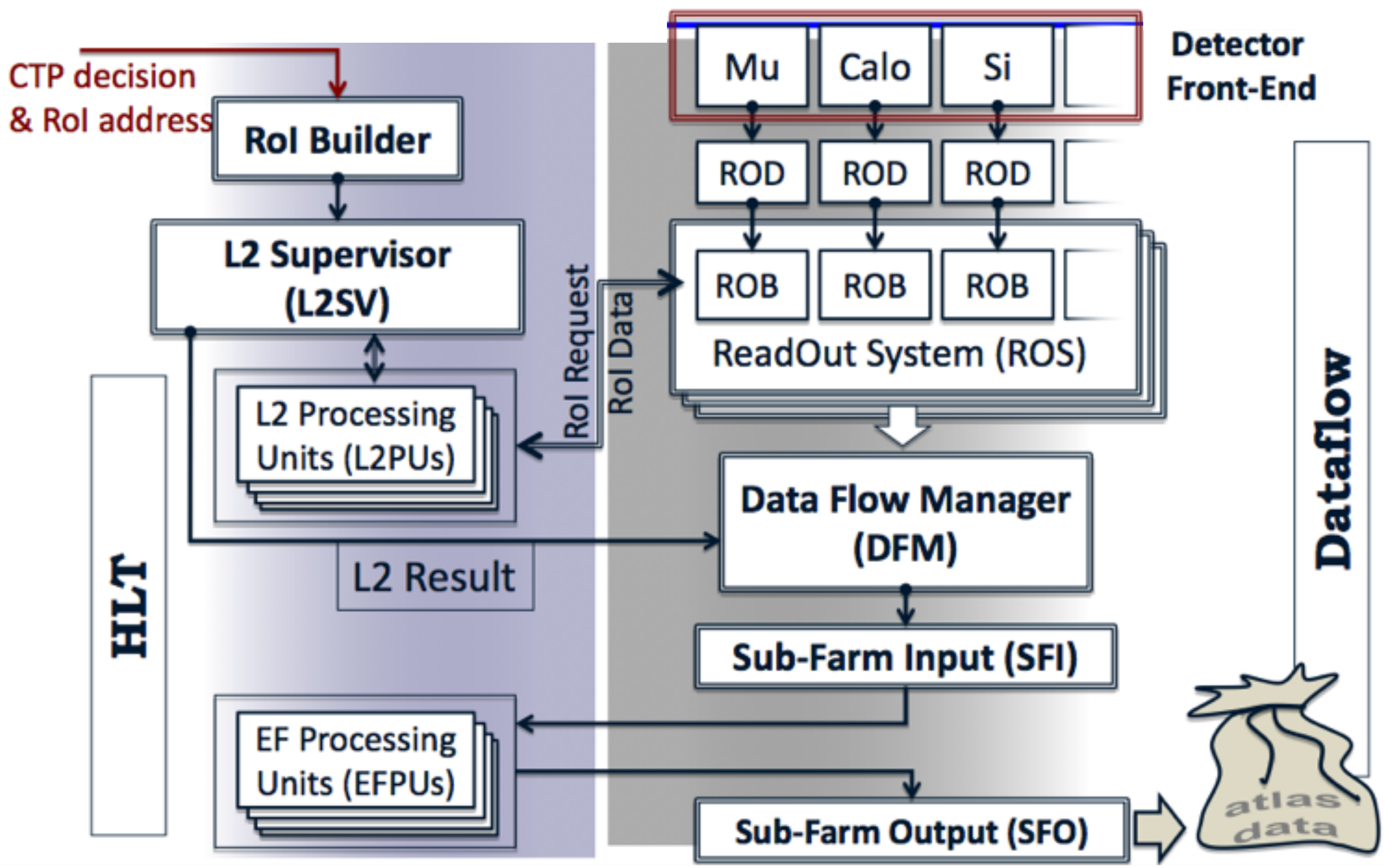
- HLT workers (multi-process HLT) created at start of data taking session
- Substantial amount of memory saving



Run 2 Data Flow



Run 1: HLT & Data Flow

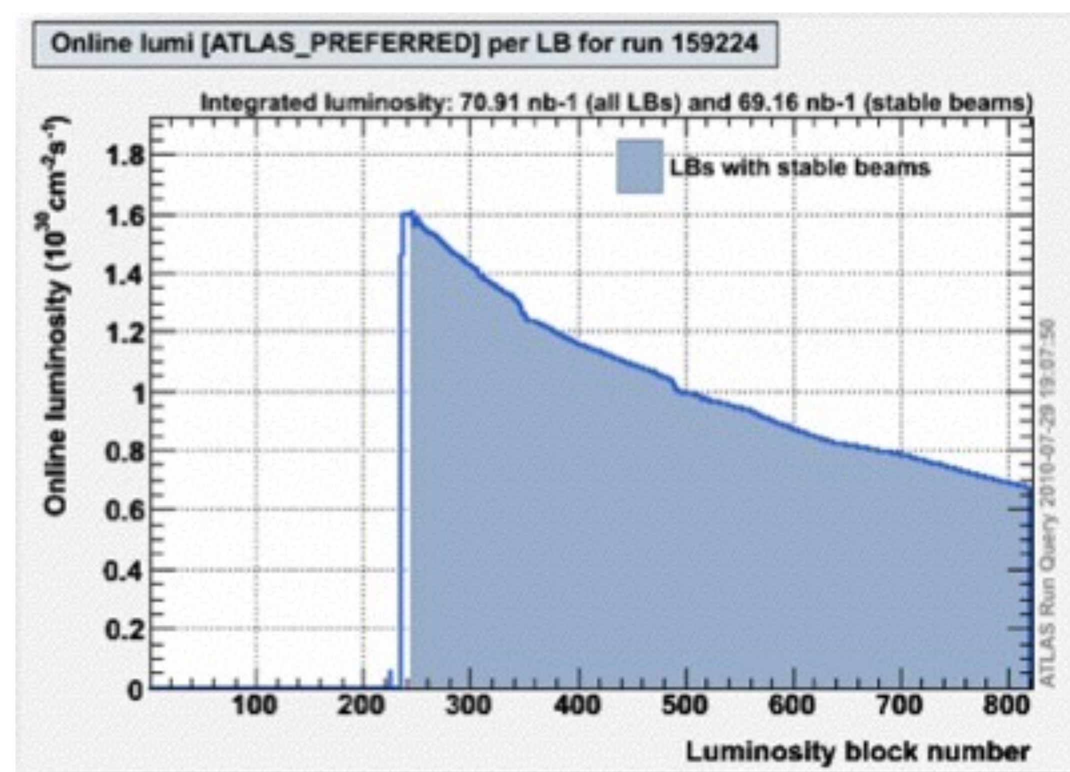


ATLAS Data Taking Strategy

- Run:
  - Period of data taking with a fixed trigger configuration (SMK) and detector setup
  - Usually corresponds to one LHC fill (many hours)
  - Make sure the correct information is displayed on the TriggerWhiteBoard

- Luminosity Block (LB):
  - Luminosity, conditions and data quality are considered to be approximately constant
  - Time interval of about ~2min within a run

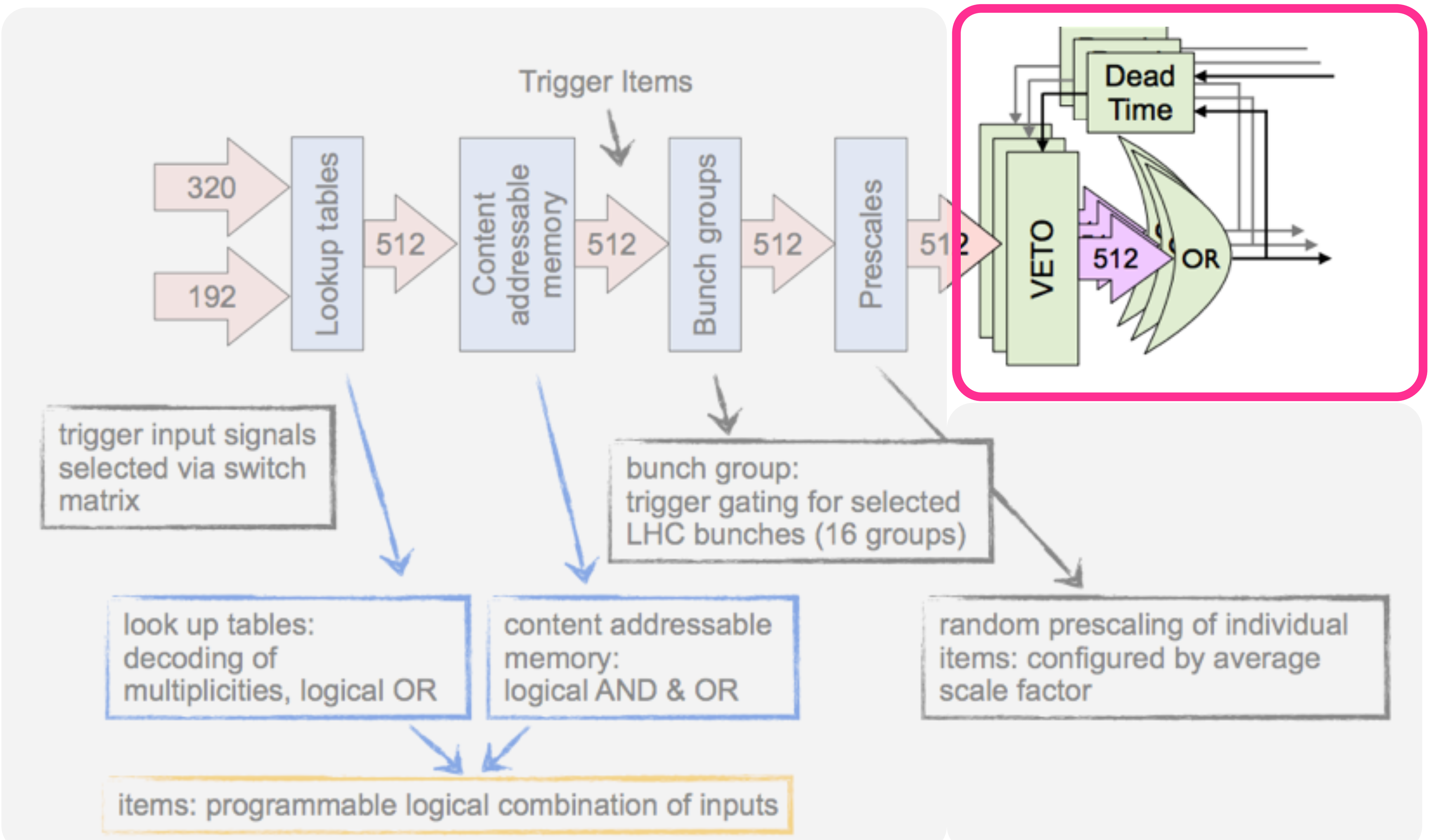
- Luminosity drops during a fill, meaning the trigger rates drop too. Ideally we'd like to take all data of interest and make use of the full bandwidth:
  - This is where prescale key changes come in which certain pre scales are released
  - Limitations imposed by detector and DAQ system (processing speed, buffer sizes, internal bandwidth), Tier0 and long-term storage capacities



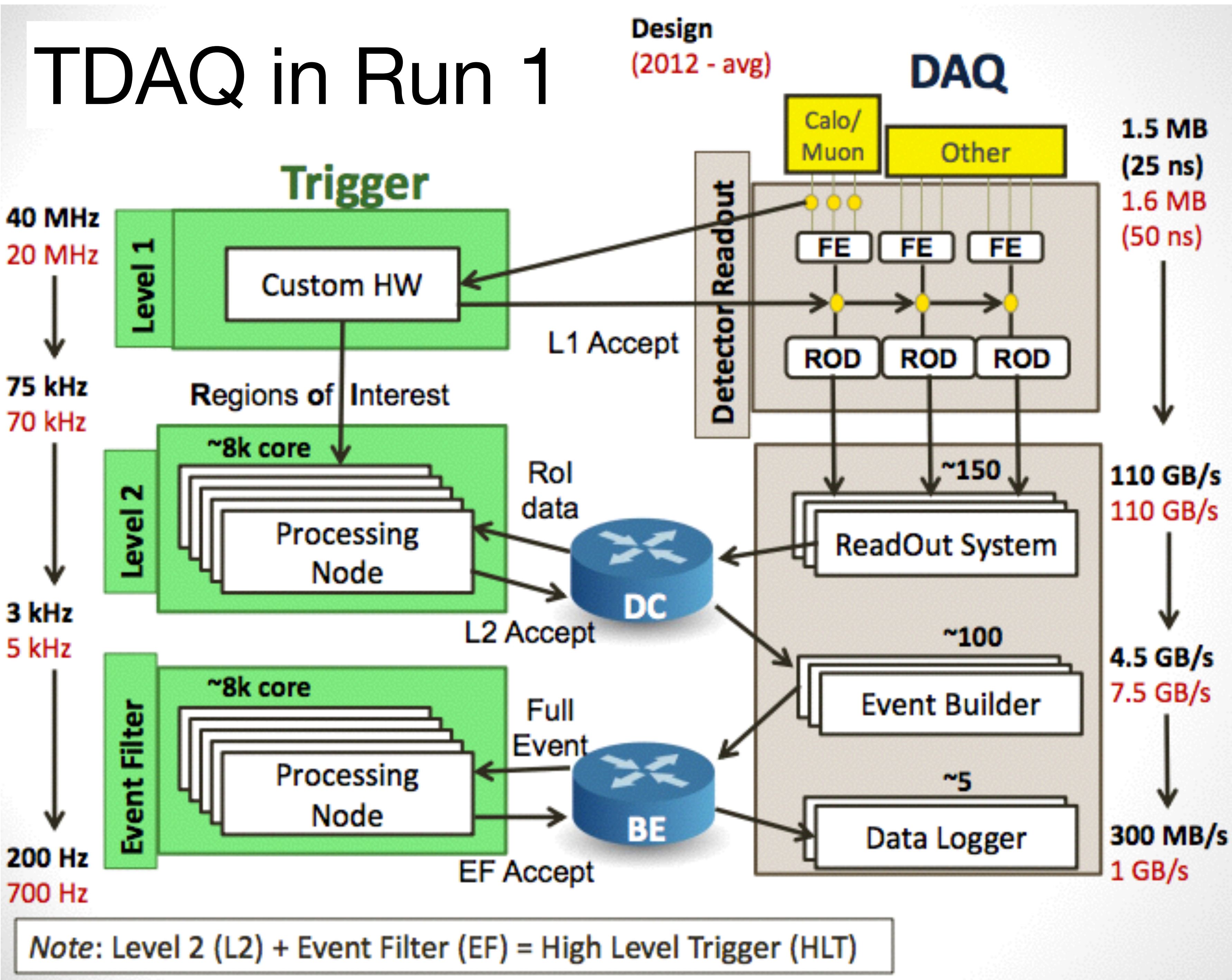
Trigger Path

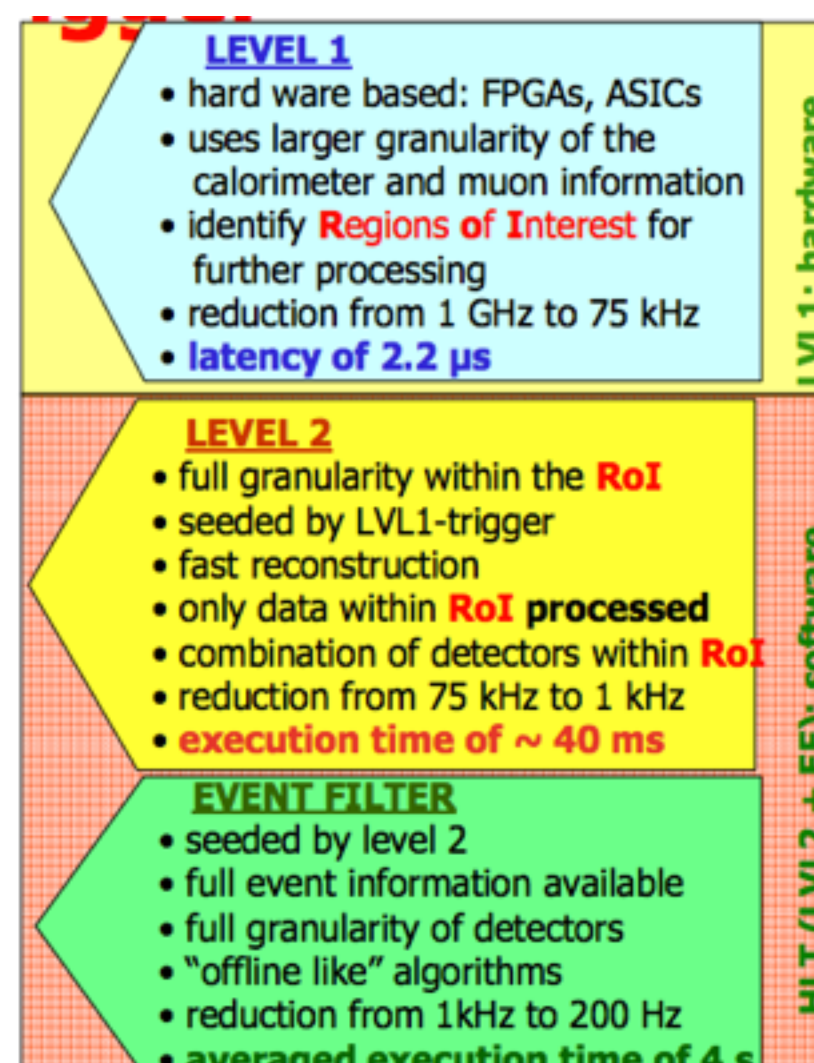
https://cds.cern.ch/record/1756906/files/ATL-DAQ-SLIDE-2014-658.pdf

- The way the deadtime is applies is shown in the following picture:



The ATLAS Trigger System in Run 1





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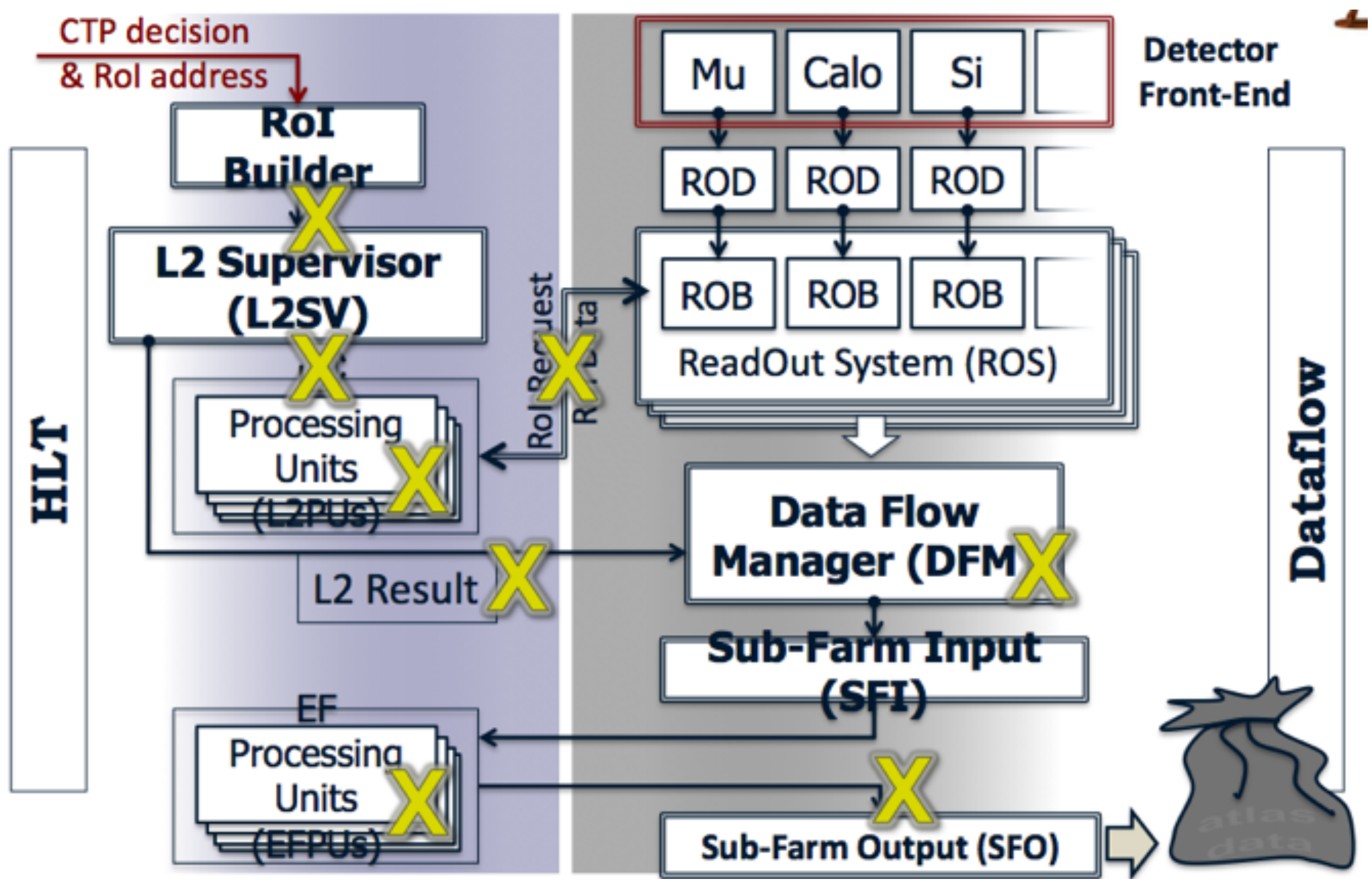
Debug Stream in Run 1

https://twiki.cern.ch/twiki/bin/view/Atlas/DebugStream

Debug stream:

- a way to spot problems and weaknesses of the online system without loosing events
- presence of events in a timeout debug stream does not necessarily imply a bug in the online system
- timeouts ensure the system robustness



Debug Stream in Run 2

Debug sub-streams used to differentiate failures in the online system seen by the HLT:

- `debug_DcmFetchRobsError`:
- `debug_DcmL1IdMismatchError`:
- `debug_HLTMissingData`: The event processing could not be started in the PU because some data was missing (very rare)
- `debug_HLTSVForceAccept`:
- `debug_HltError`: Severe algorithm errors which abort the event processing
- `debug_LateEvents`: Events that didn't make it to the SFO at the LB boundaries. The SFO has closed the "right" file, so it writes the late events to the debug_LateEvents stream.
- `debug_PUCrash`: PUCrash
- `debug_PUTimeout`: Event processing timeout where the steering was able to abort the event processing in time

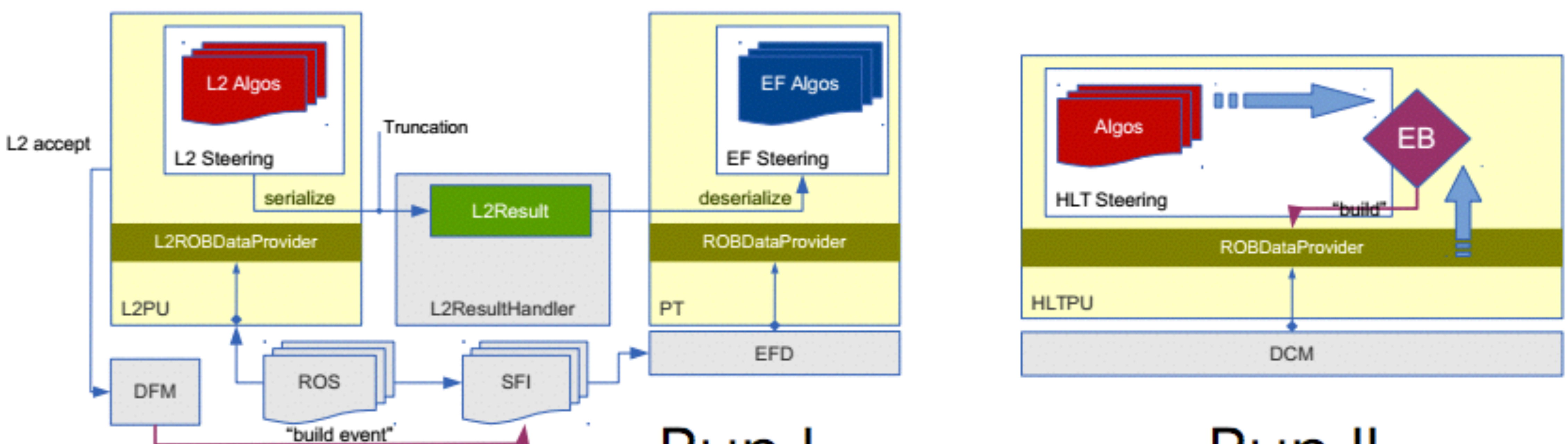
Other debug streams:

- `debug_LateEvents`: Events that didn't make it to the SFO at the LB boundaries. The SFO has closed the "right" file, so it writes the late events to the debug_LateEvents stream.
- `debug_duplicated`: *Possibly* duplicated events, due crashes/communication failures in the DF system. Duplication can take place in DFM, SFI and EFD.
- `debug_DISCARD`: This is the "default" stream of some chains, e.g. xe chains running on all L1 TEs, that should never be included int he run, but executed only in *rerun* mode. This stream should never be seen. If it is, there has been a mistake in the online trigger configuration.

https://twiki.cern.ch/twiki/bin/view/Atlas/DebugStream

Changes in HLT for Run 2

- Merged HLT Farm allows for flexible resource allocation in conjunction with combined network
- No need to read data from buffers multiple times, no network use for L2 → EF
  - No dedicated event building step → more flexibility
- Changes are accompanied by new software to exploit this merged design



Run I

Run II

Data Streaming - Run 1

Stream: Collection of events or event fragments of related signatures in the same data set, overlap between streams is designed to be minimal

- ✓ Streaming is based on trigger decisions at the HLT
- ✓ The Raw Data physics streams are generated at the SFO
- ✓ All streams are inclusive, except the debug stream

Debug Streams
events without full trigger decision, due to failures in parts of the online system

Physics Streams
data for physics analyses

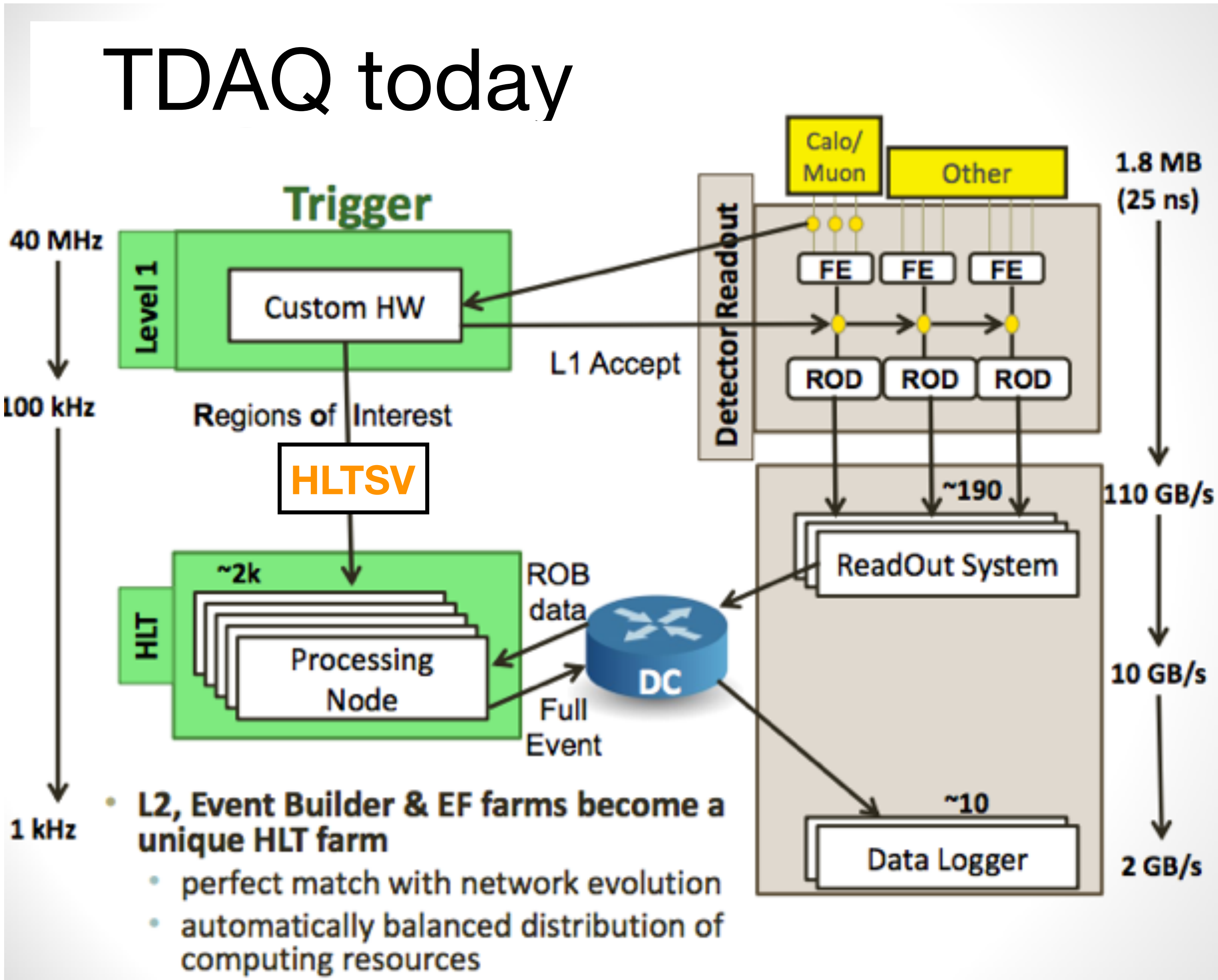
Egamma
Muons
JetTauEtMiss
MinBias
...

Express Stream
Events for prompt reconstruction (calibration loop)

Calibration Streams
events delivering the minimum amount of information for detector calibrations at high rate

partial events

Data Flow Architecture



Region of Interest Builder (RoIB)

- sends L1 result to HLT SuperVisor (HLTSV)

HLT SuperVisor (HLTSV)

- dispatches Regions of Interest (RoIs) to available HLT nodes

Data Collection Manager (DCM)

- data collection, caching, building
- assign fragments from ReadOut System (ROS) to HLTPU (HLT Processing Units)
  - HLTPUs: execute HLT algorithms
- sends accepted events to the Data Logger

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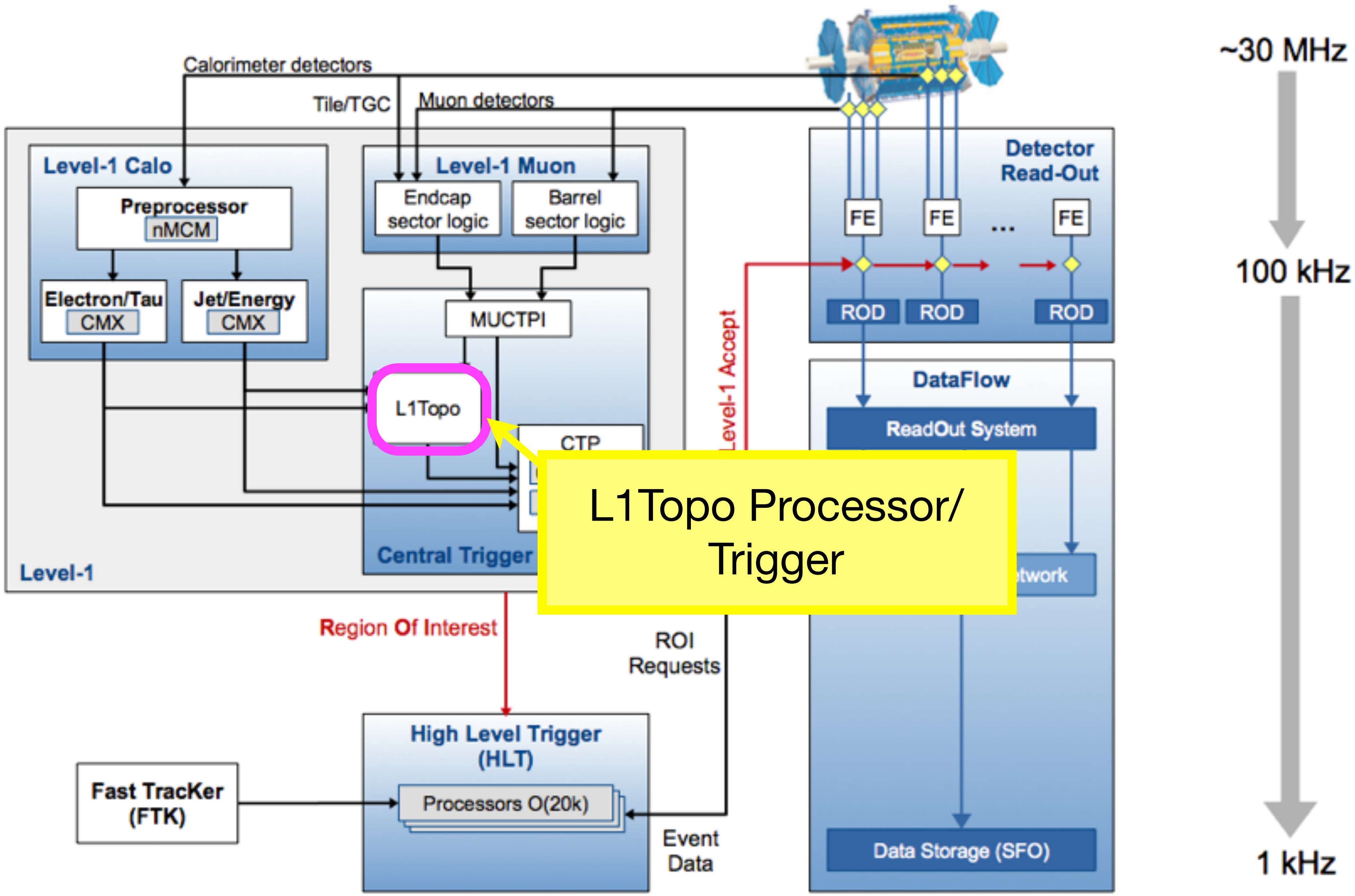
L1 Topological Processor/Trigger



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Debug Stream

Debug stream:

- a way to spot problems and weaknesses of the online system without loosing events
- presence of events in a timeout debug stream does not necessarily imply a bug in the online system
- timeouts ensure the system robustness

New/Improved L1 System - Tile TGC

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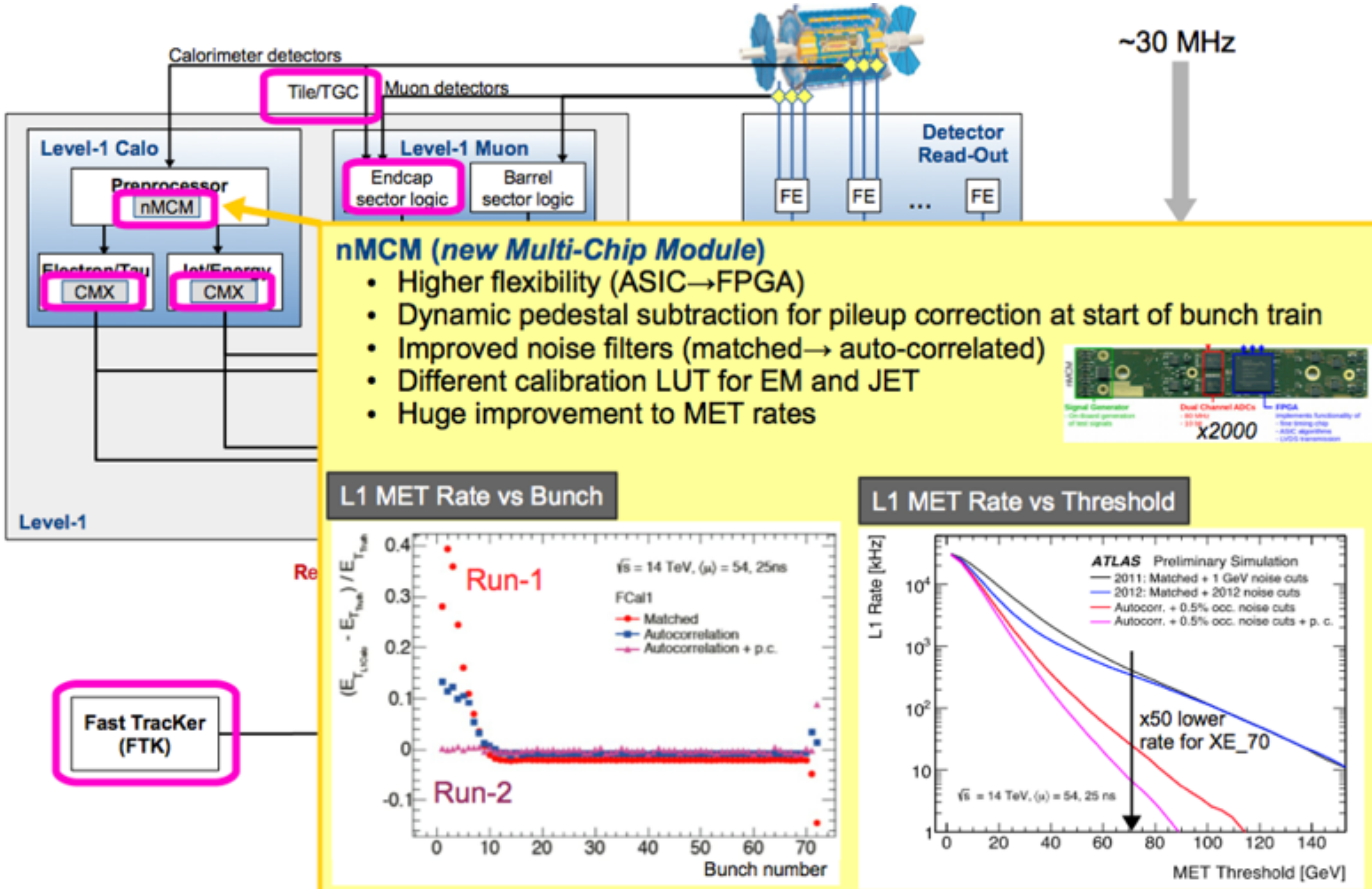
New/Improved L1 System



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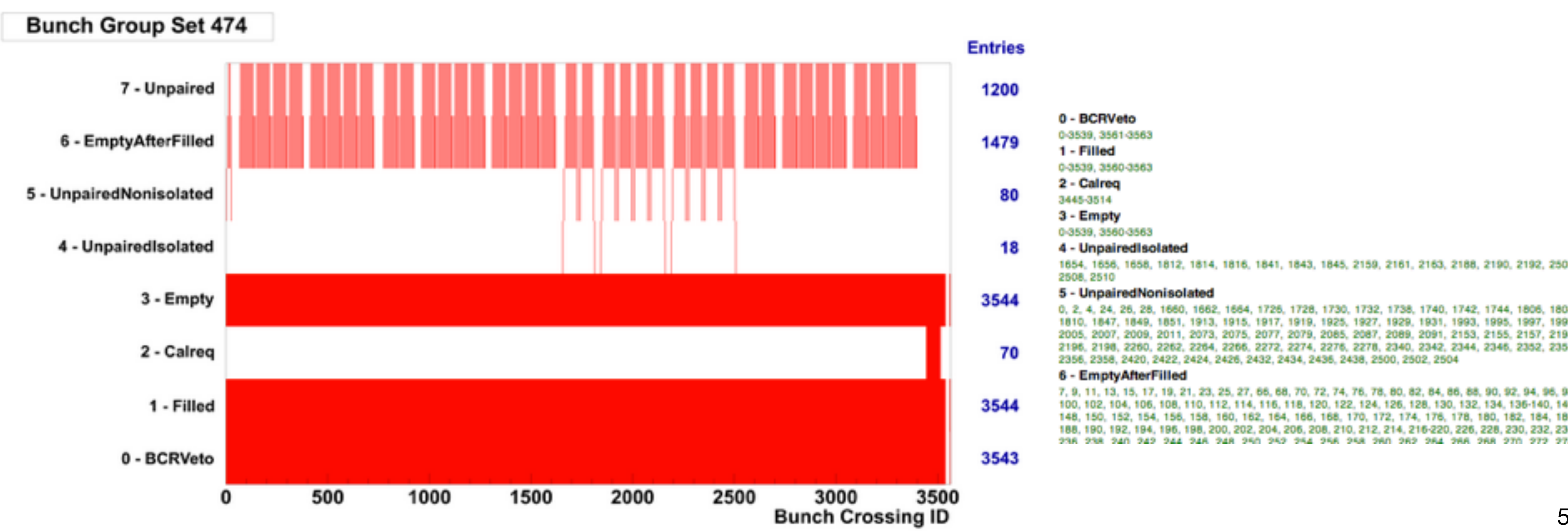
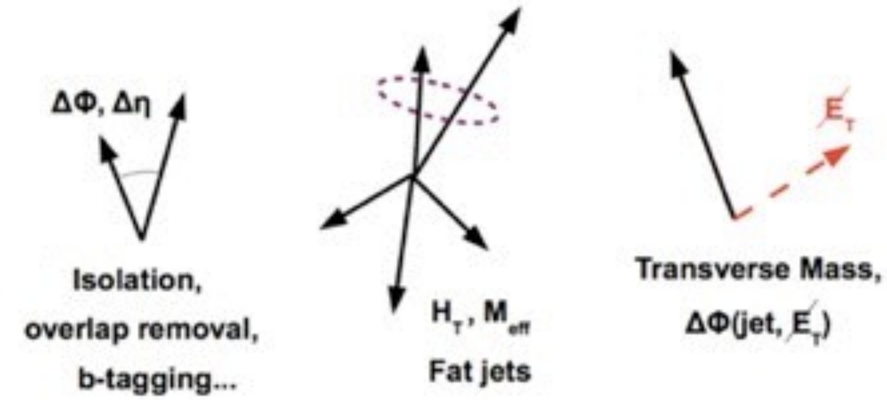
Run 1: Bunch Groups & BGS

- A Bunch Group is a list of BCIDs, all 8 bunch groups form a Bunch Group Set:
  0) BCRVeto: Bunch Counter Reset (within abort gap), allows triggers everywhere but in a small region when the bunch counter reset is sent
  1) Paired/Filled: Colliding bunches in ATLAS
  2) Calreq: Calibration requests for TileCal (laser/charge injection) in the abort gap
  3) Empty: Two empty bunches crossing in ATLAS (for Cosmics, Noise)
  4) Unpaired Isolated: unpaired bunches separated by at least 3 BC from any bunch in the other beam
  5) Unpaired NonIsolated: unpaired bunches not in category 4)
  6) Empty after Filled: 3 empty bunches after paired bunch
  7) Unpaired: logical OR of 4) and 5)
- Look-up page for BGS: http://atlas-trigconf.cern.ch/bunchgroups?key=474



L1 Topological Processor/Trigger

- Completely new piece of L1 hardware
  - Programmable trigger selections (FPGA = Field-Programmable Gate Array)
  - Receives input from L1Calo and L1Muon
  - Applies selection on trigger objects



- Possible selections:
  - Angular cuts (ΔR, ΔΦ, Δη)
  - Invariant mass cuts
  - Object refinements
  - etc.

Objects	All List*	Abbreviated (9)	Sorted (6)
Muons	32	MU4	
Electrons	120	EM10, EM8I	
Taus	120	TAU12	
Jets 8x8	64	J15.0ETA26 J25.0ETA49	
Jets 4x4	-	-	-
MET	1	n/a	n/a

Input to

Angular Requirements
$\Delta\eta, \Delta\varphi, \Delta R^2, \Delta\eta + \Delta\varphi$

Mass Requirements
$M^2 = 2E_T^1 E_T^2(\cosh\Delta\eta - \cos\Delta\varphi)$
$M_T^2 = 2E_T^1 E_T^{miss}(1 - \cos\Delta\varphi)$
$M_{CT}^2 = 2E_T^1 E_T^{miss}(1 + \cos\Delta\varphi)$

Event Requirements
$H_T = \sum p_T(jets)$
$H_{CT} = \sum p_T(central\ jets)$
$M_{eff} = H_T + MET$
L1Topo MET

Dedicated Algorithms
Calorimeter Ratio
Delayed Particles

- Constraints:
  - 128 L1Topo trigger items
  - Latency (algorithms) ≤ 3 BC (75 ns)
  - FPGA resources
  - Combinatorial constraints:
    most algorithms will be limited to work with top-N objects