Operation of the upgraded ATLAS Level-1 Central Trigger System during the LHC run II

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on behalf of the ATLAS collaboration

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Outline

- Introduction
  - Challenges for run II data taking
- The ATLAS trigger and data acquisition system
  - Overview of the trigger system
  - Upgrade of the L1 Central Trigger
- Operation of the L1 Central Trigger
  - Commissioning of the L1 Central Trigger
  - First beam splashes
  - First collisions

Introduction

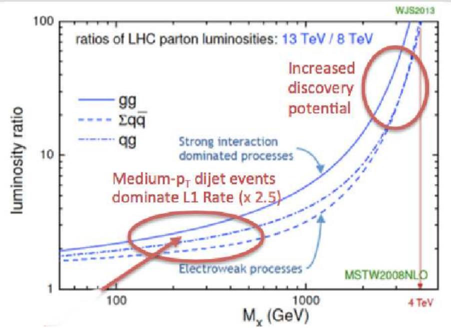
- Challenging increase of interaction rate in run II :

	energy [TeV]	bunch-spacing [ns]	$\mathcal{L}^{inst}$ [$cm^{-2}s^{-1}$]	average collisions / bunch-crossing
Run I (2012)	8	50	8×10^{33}	25-30
Run II	13	25	1.5×10^{34}	40-45

▸ expected rate × 2 - 2.5 from the higher center-of-mass energy

▸ expected rate × 2 from the higher instantaneous luminosity

$\Longrightarrow$ total rate increase up to a factor 5 to 6 in run II compared to run I

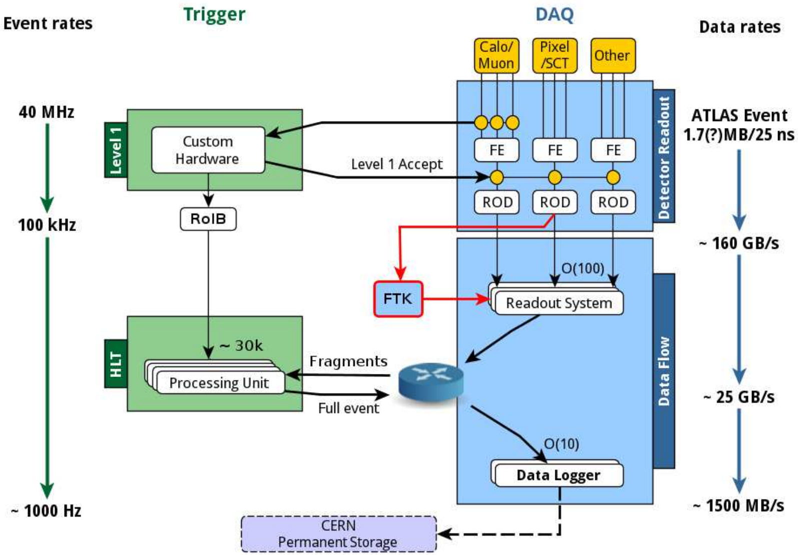


- Storage space and CPU available increase by a factor 2 only

▸ trigger upgrade needed to increase the trigger rate and improve event selection

Overview of the ATLAS trigger and data acquisition system (TDAQ)

The trigger selects collision events which are reconstructed and recorded for offline analyses



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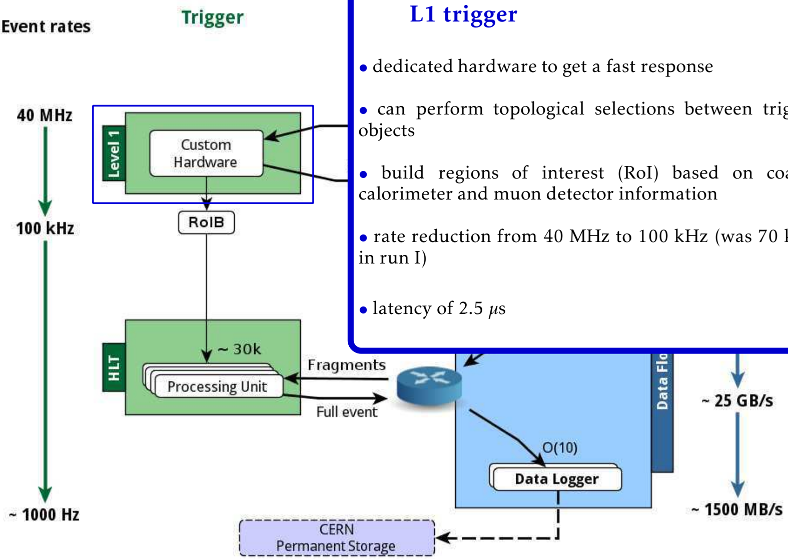
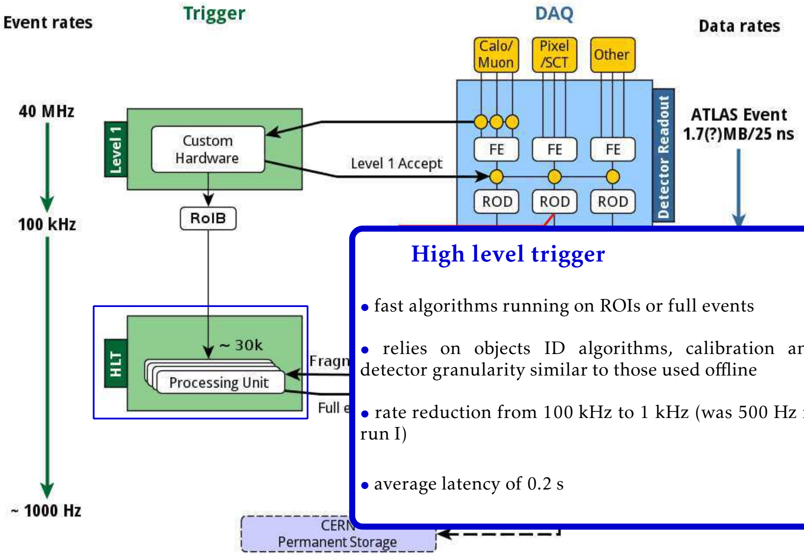


L1 trigger

- dedicated hardware to get a fast response
- can perform topological selections between trigger objects
- build regions of interest (RoI) based on coarse calorimeter and muon detector information
- rate reduction from 40 MHz to 100 kHz (was 70 kHz in run I)
- latency of 2.5 μs

Overview of the ATLAS trigger and data acquisition system (TDAQ)

The trigger selects collision events which are reconstructed and recorded for offline analyses



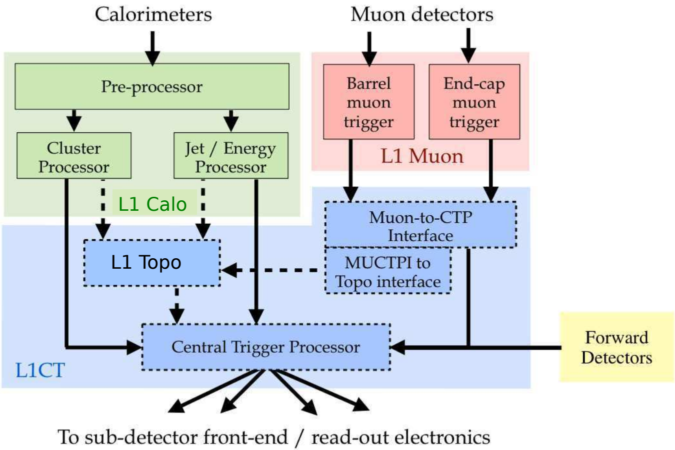
High level trigger

- fast algorithms running on ROIs or full events
- relies on objects ID algorithms, calibration and detector granularity similar to those used offline
- rate reduction from 100 kHz to 1 kHz (was 500 Hz in run I)
- average latency of 0.2 s

Overview of the L1 trigger system

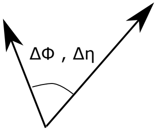
- The L1 trigger systems is composed of 4 main subsystems :
  - L1Calo : custom electronics to identify electrons, photons, jets and build $\not{E}_T$ and $\sum E_T$
  - L1Muon : dedicated muon chambers to identify muons in the barrel (RPC) and in the end-caps (TGC)
  - L1Topo : topological selections between trigger objects ($\Delta\phi$, $\Delta\eta$, H_T ...)
  - CTP + MUCTPI : receive the information from L1Topo, L1Calo and L1Muon to form the trigger decision

$\Longrightarrow$ This talk will focus on the upgrade of the L1 Central Trigger Processor (CTP)



Highlights of the trigger upgrade

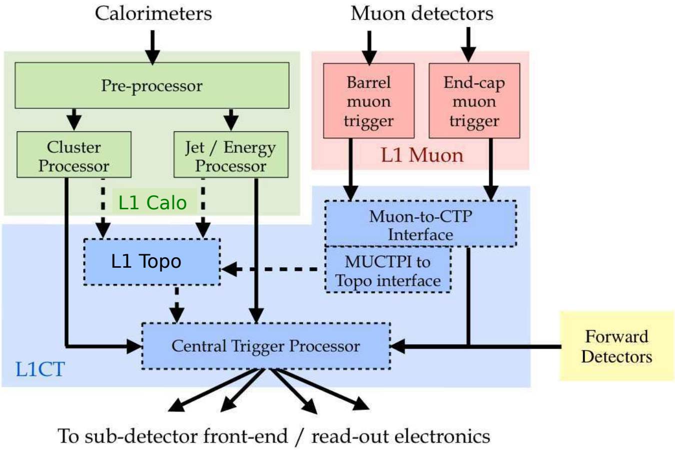
- L1Calo :
  - dynamic pedestal subtraction to reduce pileup dependence
  - noise autocorrelation filters to improve energy resolution
  - E_T dependent isolation
- L1Muon :
  - new RPC chambers to gain 2.8% trigger coverage in the detector feet region
  - require coincidence between TGC inner station and Tile D-layer to reduce the fake rate
- new L1Topo module :
  - perform topological selections between trigger objects ($\Delta\phi$, $\Delta\eta$, H_T ...)



- L1 CTP :
  - upgrade of the MUCTPI to work with the L1topo
  - increase the number of trigger inputs :160→512 and triggers 256→512
- HLT :
  - algo faster & closer to offline to scale better with increasing pileup and with better calibration
- Trigger rates :
  - increase the L1 rate from 70 kHz to 100 kHz (required upgrade of several sub-detectors)
  - increase the HLT rate from 500 Hz to 1 kHz

Upgrade of the L1 central trigger system

- Upgraded systems are shown with dashed lines / boxes :
  - new firmware in the Muon-to-CTP module (MIOCT) to provide muon η, ϕ, p_T information to L1Topo
  - new MuCTPiToTopo interface to convert electrical MIOCT output to optical L1Topo input
  - upgraded hardware/firmware/software of the CTP to increase the number of inputs and triggers



Muon interface modules upgrade

- The Muon to CTP Interface (MUCTPI) receives the trigger information from L1Muon, calculates the multiplicity of muon candidates for different momentum thresholds, and sends them to the CTP

- The new L1Topo module requires the additional (η, ϕ) information from the muon system to perform the topological cuts :

▶ MUCTPI firmware has been upgraded :

- the 16 octant modules (MIOCT) have 2 electrical outputs designed to operate at 40 MHz
- the design of the run I hardware is flexible enough to provide the topological information

  → **upgrade of the firmware only**
- the new firmware enables 8-fold overclocking in order to send 16 bits per MIOCT :

0	1	1	1	0	0	1	0	0	1	0	1	1	1	0	1
η			ϕ			p_T		η			ϕ			p_T	
Candidate 1								Candidate 2							

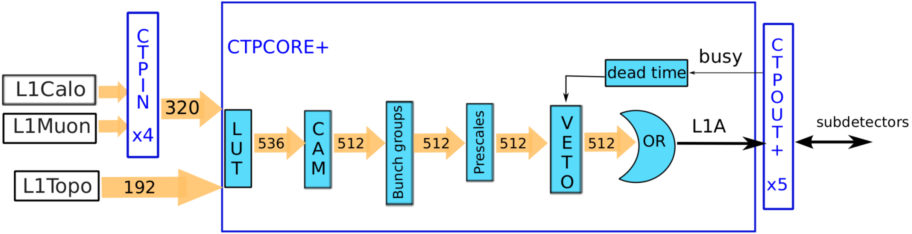
- $\eta = [1,1,1]$ means no muon
- $p_T = [1,1]$ means > 2 muons

- the position of the 2 leading muons is encoded in bins of $\Delta\eta \times \Delta\phi = 0.3 \times 0.1$

▶ new MuCTPiToTopo interface module :

- performs the conversion of electrical MIOCT output to optical L1Topo input

Forming the trigger decision path in the CTP



■ CTPIN : select, align and route the trigger inputs from L1Calo and L1Muon to the CTPCORE+

▶ firmware upgraded to allow double data rate at 80 MHz : 160 → 320 trigger inputs

■ CTPCORE+ : form the L1 trigger decision

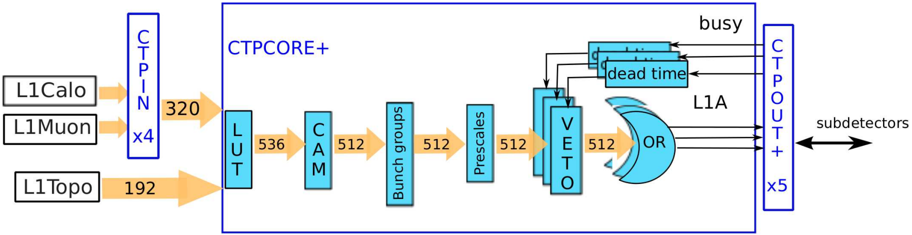
▶ hardware re-designed and re-built to support more trigger inputs (160→512) and provide more triggers (256→512) and better monitoring

- form the 512 triggers using LUT + CAM to decode the multiplicities and perform the logical OR & AND
- do the coincidence with the LHC bunch pattern (up to 16 configurable bunch patterns)
- perform random prescaling of each trigger to reduce the rate of low threshold triggers
- generate dead time after each L1 accept according the sub-detectors specifications
- monitor the dead time and the trigger rate of each trigger before prescale, after prescale and after veto (including per-bunch monitoring for timing)

■ CTPOUT+ : distribute trigger and timing signal to the sub-detectors, and receive BUSY signals

▶ hardware re-designed and re-built to improve diagnostics, test features, monitoring and support multiple-partitions

New functionality : concurrent running of up to 3 partitions



- useful to have simultaneous calibration / commissioning of different sub detectors
  - ▶ new hardware and software makes it possible to have 3 partitions using the CTP simultaneously
- All partitions are logically separated :
  - each trigger is assigned to only 1 partition
  - each partition can independently configure dead time
  - each partition can use different bunch-groups and prescales sets
- multiple-partitions already tested hardware-wise
- commissioning with the ATLAS detector foreseen during the next Winter shutdown

New random prescales

run 1 : deterministic prescales

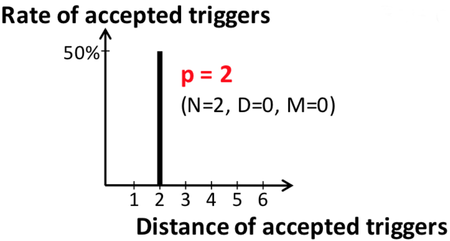
- prescale factor p = (N+1) * (M+D+1) / (M+1), with N= 24 bits, M= 4 bits and D = 4 bits
- keep events every p trigger (integer), or every p and p+1 triggers (fractional)

run 2 : random prescales

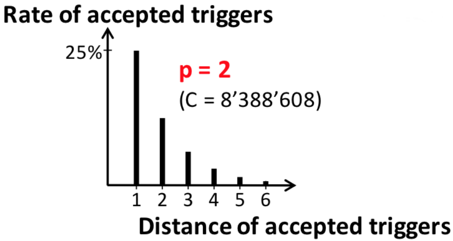
- define a comparison value C in the range $[0, 2^{24} - 1]$
- keep event if pseudo-random number $\geqslant C \Longrightarrow PS \sim 1 - \frac{C}{2^{24}-1}$

- less bias and less overlap between prescaled triggers yielding larger statistics available to analyses using an OR of prescaled triggers

deterministic prescales



random prescales



Software architecture

■ Completely new software architecture designed to be more stable, robust and to support multiple-partitions :

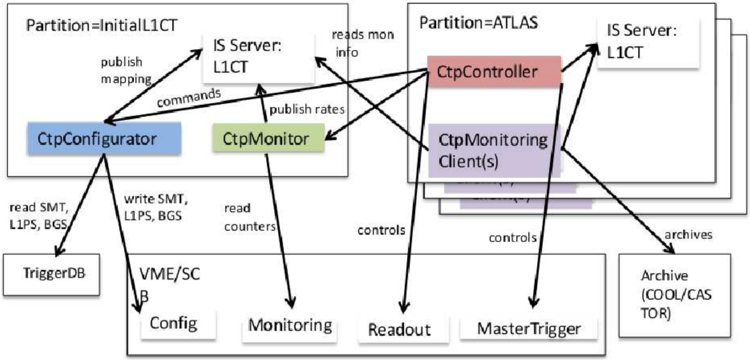
CtpConfigurator : perform the configuration of the hardware which is common to all partitions

CtpController : perform the tasks specific to each partition

CtpMonitoring : read all the monitoring information from the hardware (VME), and publish it on the IS server used to share information between applications in a distributed environment

CtpMonitoringClient(s) : read the information from IS, archive it and display it in a human readable way

▸ highly modular approach, separating functionality, communication through Information Service (IS) using clearly defined interfaces and objects



Auto-prescaler

- auto-prescaling needed to reduce the number of shifter interventions and the reaction time in case of rate increase to avoid potential problems

2 use cases :

- I → already for run I :

low threshold triggers are sensitive to noise and can produce large rate spikes (e.g. from single hot tower)

→ need to be prescaled to reduce the rate

- II → new for run II :

some background triggers need to be turned off when stable beams are reached

- requirements :
  - must be independent of the other CTP applications to be safely turned off if misbehaving
  - able to monitor the publication of trigger rates and beam status
  - must document all actions taken
  - must know for each trigger the maximum rate beyond which it should be prescaled
  → store the prescale rules of each trigger in a database
  - must be fast, robust and always return the expected response for a given situation

► This new auto-prescaler application has been used in a stable way for the 13 TeV collisions

Monitoring capabilities

- Several applications have been developed to provide the monitoring information needed to ensure smooth data taking :
  - rate and counts of trigger inputs (TIP)
  - rate and counts of the 512 triggers before prescale (TBP), after prescale (TAP) and after veto (TAV)
  - 3×64 per-bunch monitoring counters for TBP, TAP and TAV counters
    → useful for the timing of all sub-dectectors
  - Busy fraction from each sub-detector
  - full event monitoring which contains all trigger bits for a fraction of events
- One dedicated monitoring server extracts the counters from the hardware to minimize VME access, and publishes them via network to be easily accessible
- Client monitoring applications read and reformat these informations and publish them in a readable way :
  - web display (including mobile phone interface)
  - archiving
  - error detection notification by e-mail and sms

Example of monitoring web page : trigger rates

- all triggers + input rates easily readable on the web page
- trigger rates are shown before prescale, after prescale and after veto

Home | Busy | Browser | LHC | Triggers | CTPIN | BGPattern | ERS | Logs | Muctpi RDT | Muctpi Rates | CTP Status

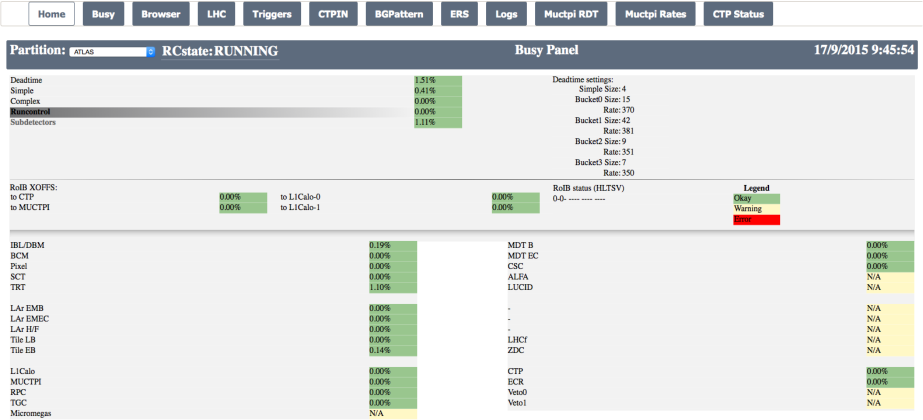
Partition: ATLAS — **Trigger Rates** — **17/9/2015 9:44:33**

Items PITs Enabled Search Trigger Keys: SMK: 2198, L1PSK: 3140, HLTPSK: 2305, BGK: 1312, AutoPrescaler L1PSK History: 3140,

Type	ID	Name	PITrate	PS	TBP	TAP	TAV	Enabled	Ratio TBP/TAP
Item	8	L1_EM18VH	-	1.00000	9200.70	9200.70	9071.56	True	1
Item	32	L1_2MU4	-	1.00000	8923.98	8923.98	8704.54	True	1
Item	59	L1_TAU20_2TAU12	-	1.00000	6758.76	6758.76	6668.47	True	1
Item	9	L1_EM20VH	-	1.00000	6537.39	6537.39	6445.15	True	1
Item	53	L1_TAU30	-	1.00000	6028.61	6028.61	5941.23	True	1
Item	10	L1_EM20VHI	-	1.00000	3875.05	3875.05	3818.74	True	1
Item	25	L1_2EM10VH	-	1.00000	3577.94	3577.94	3521.63	True	1
Item	58	L1_TAU20IM_2TAU12IM	-	1.00000	3048.77	3048.77	3011.88	True	1
Item	11	L1_EM22VHI	-	1.00000	2811.86	2811.86	2776.91	True	1
Item	39	L1_MU6_2MU4	-	1.00000	2740.01	2740.01	2671.08	True	1
Item	27	L1_2EM15	-	1.00000	2698.26	2698.26	2668.16	True	1
Item	17	L1_MU15	-	1.00000	2641.95	2641.95	2569.13	True	1
Item	54	L1_TAU40	-	1.00000	2523.49	2523.49	2484.65	True	1
Item	30	L1_EM12_2EM3	-	15.0000	36523.1	2458.44	2421.54	True	14.8562
Item	129	L1_3J15.0ETA25	-	1.00000	1704.98	1704.98	1685.56	True	1
Item	18	L1_MU20	-	1.00000	1704.98	1704.98	1657.41	True	1
Item	14	L1_MU4	-	171.001	278112	1534.10	1502.06	True	181.287
Item	126	L1_3J15	-	2.00000	2272.02	1107.85	1091.34	True	2.05083
Item	15	L1_MU6	-	38.0001	41195.3	1097.17	1073.87	True	37.5469
Item	29	L1_EM7_2EM3	-	120.000	132221	1088.43	1068.04	True	121.478
Item	31	L1_EM15VH_3EM7	-	1.00000	1067.07	1067.07	1056.39	True	1
Item	200	L1_RD0_FILLED	-	11459.8	1.15e+7	1026.29	1015.61	True	11187.5
Item	127	L1_3J20	-	1.00000	986.482	986.482	971.918	True	1
Item	26	L1_2EM13VH	-	1.00000	915.603	915.603	903.952	True	1
Item	98	L1_J75	-	1.00000	895.213	895.213	881.620	True	1
Item	42	L1_EM15I_MU4	-	1.00000	810.741	810.741	800.060	True	1
Item	70	L1_TAU20IM_2TAU12IM_J25_2J20_3J12	-	1.00000	772.874	772.874	766.077	True	1
Item	33	L1_2MU6	-	1.00000	754.426	754.426	737.920	True	1
Item	104	L1_J30.31ETA49	-	4.00000	2813.81	685.489	672.866	True	4.10482
Item	399	L1_EM8I_MU10	-	1.00000	678.692	678.692	667.041	True	1
Item	155	L1_EM15_XS30	-	12.0000	7825.83	672.866	662.186	True	11.6306
Item	23	L1_2EM3	-	852.025	571735	646.651	638.883	True	884.147
Item	55	L1_TAU60	-	1.00000	647.622	647.622	634.029	True	1
Item	62	L1_EM15HI_TAU40_2TAU15	-	1.00000	564.120	564.120	557.324	True	1
Item	36	L1_MU10_2MU6	-	1.00000	559.266	559.266	545.672	True	1
Item	28	L1_2EM15VH	-	1.00000	547.614	547.614	539.847	True	1
Item	154	L1_EM10_XS20	-	72.0003	40509.9	541.789	532.079	True	74.7706
Item	110	L1_J20.28ETA31	-	7.00000	3800.29	538.876	532.079	True	7.05225
Item	108	L1_J15.28ETA31	-	16.0000	8112.26	518.486	509.747	True	15.6461
Item	87	L1_MU4_J12	-	18.0000	8871.54	505.863	499.067	True	17.5374
Item	103	L1_J20.31ETA49	-	24.0000	11859.1	490.328	482.561	True	24.1861

Example of monitoring web page : busy fractions

- Busy signal from each sub-detector can be easily monitored from the web page
- Value of the dead-time setting and dead-time fractions are also displayed



Commissioning of the CTP

■ Latency : Overall latency for the upgraded CTP is slightly larger than during run I

▸ latency measured to be ∼ 6 BCs, well within the budget

■ Timing adjustment

▸ phase adjustment of timing signals done before first beams for all sub-detectors

▸ overall timing of each trigger w.r.t. the LHC clock done with beam-splashes and first collisions

■ Dead-time : bunch-crossing for which all triggers are vetoed

- simple dead-time : no trigger during *n* BCs following a L1 accept
- complex dead-time : leaky bucket algorithm to avoid overflow in sub-detector FE-derandomizers (as these can not provide a busy signal as feedback). 2 **parameters :**
  - **bucket size :** describes size of FE buffers → increase the counter at each L1A
  - **drip rate :** describes FE data handling speed → rate of bucket counter decreasing

  ⟹ L1A allowed only if bucket not full

the number of complex dead-time buckets has been increased from 1 to 4 in run II to better address sub-detector specific requirements in order to reach 100 kHz

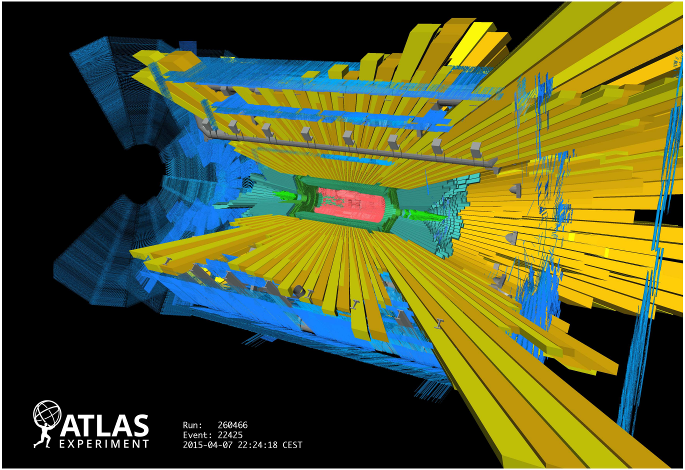
▸ all dead-time parameters have been tuned separately for each sub-detector to minimize total dead-time

■ L1 rate : from 75kHz in run I to 100 kHz in run II

▸ high rate tests with random triggers have demonstrated that the ATLAS data-acquisition chain can run successfully with 100 kHz L1 rate

Beam splashes

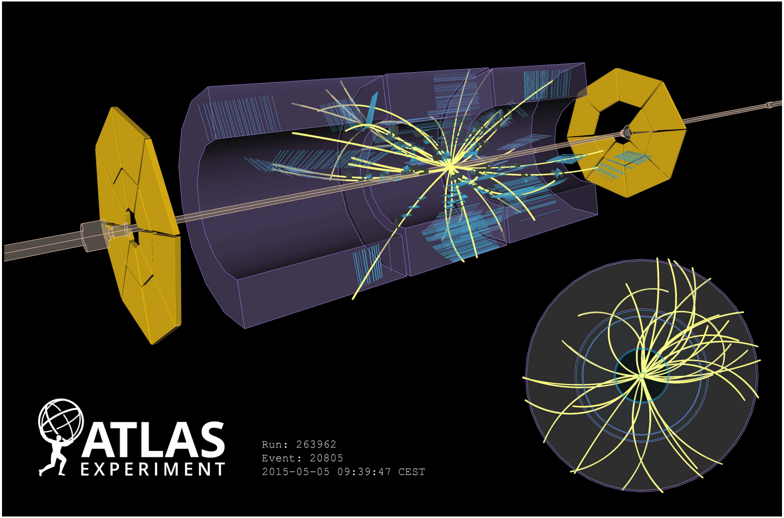
- first beam splashes on Easter sunday (April 5, 2015)
- we used a special trigger with well known timing for these events
- ▶ almost all beam splashes events were triggered, and then used for the timing of other triggers



beam splash event taken on April 7th. The length of the yellow bars indicates the amount of energy deposited in the ATLAS calorimeter.

Collisions

- first collisions at 900 GeV on May 5, 2015
  - first collision events correctly triggered by ATLAS



One of the first 900 GeV collision events. Tracks are reconstructed from hits in two of the tracking detectors (SCT and TRT).

Summary

- The ATLAS L1 Central Trigger has undergone a major upgrade for run II :
  - new hardware / firmware / software
  - More than 3 times the number of trigger inputs (160 → 512)
  - Improved diagnostics and monitoring features
  - Double the number of triggers (256 → 512)
  - up to 3 partitions running in parallel for calibration / commissioning

- Integration of the new CTP hardware + firmware + software successfully done before the first LHC beams

- Lots of effort to provide all the needed monitoring information in easily readable way

- Commissioning successfully done with the first beam splashes and first collisions at 900 GeV

- L1 trigger now working smoothly with 13 TeV collisions

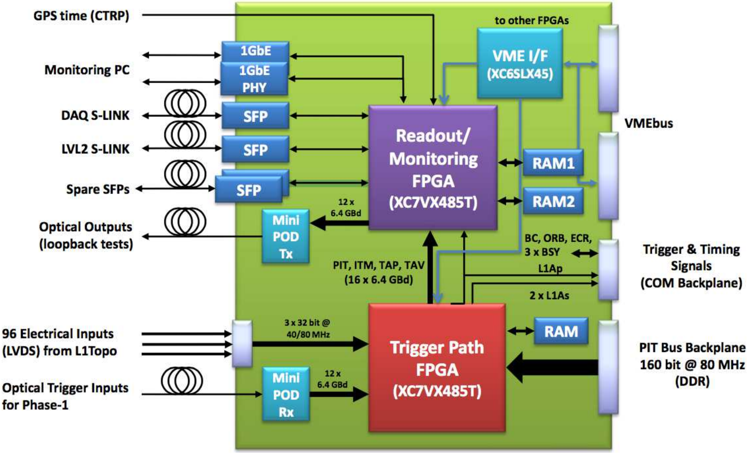
Other TDAQ ATLAS talks and posters at TWEPP 2015

- A new approach to front-end electronics interfacing in the ATLAS experiment
  Andrea Borga (Nikhef)
- Design of a Hardware Track Finder - Fast Tracker - for the ATLAS Trigger
  Viviana Cavaliere (UI Urbana)
- Operation of the enhanced ATLAS First Level Calorimeter Trigger at the start of Run-2
  Marek Palka (Jagiellonian)
- The Evolution of the Region of Interest Builder in the ATLAS Experiment at CERN
  Othmane Rifki (U. of Oklahoma) - poster
- The Phase-1 Upgrade of the ATLAS First Level Calorimeter Trigger
  Reinhard Schwienhorst (Michigan SU)

BACK-UP

Upgrade of the CTPCORE module

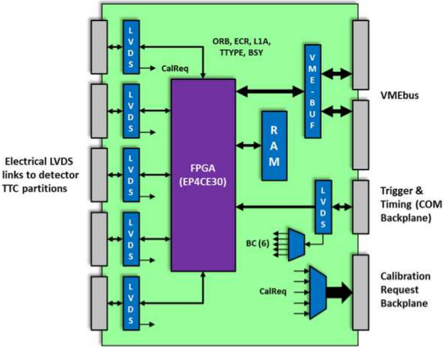
- backplane bus at double data rate : 160 → 320 inputs
- new 3 × 92 = 192 direct inputs
- hardware support for up to 12 optical trigger inputs for new or upgraded detectors
- 512 triggers instead of 256 in run I
- 256 per-bunch counters instead of 12 in run I
- support for up to 3 concurrent partitions (only 1 in run I)



Upgrade of the CTPOUT modules and COM backplane

■ Upgrade of the CTPOUT modules

- support for up to 3 concurrent partitions (only 1 in run I)
- improved monitoring of the busy signal from the sub-detectors (per-bunch monitoring now possible)
- programmable pattern generator for diagnonising issues with the trigger signal to the sub-detectors



■ Upgrade of the CTPOUT modules

- support for up to 3 concurrent partitions (only 1 in run I)

- support for up to five CTPOUT boards