ATLAS
TRIGGER AND DAQ: CAPABILITIES AND COMMISSIONING

- Introduction
- DataFlow
- Trigger and Menu
- Conclusions

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CERN
on behalf of the
ATLAS TDAQ Collaboration
LHC (Large Hadron Collider)
- proton-proton collisions at 14 TeV (design)
- 25 ns bunch-crossing interval, 40 MHz bunch-crossing rate
- Design luminosity $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ (~23 interactions per crossing)
- Start-up luminosity $10^{31} \text{ cm}^{-2} \text{ s}^{-1}$

ATLAS (A Toroidal LHC ApparatuS)
- A general purpose experiment
- If all data would be recorded:
  - data rate equivalent to 50 billion phone calls at the same time
- Storage:
  - event rate ~200 Hz, event size ~1.5 MB, bandwidth ~300 MB/s

Trigger (event selection) performance is connected to the Dataflow (data conveyance) performance
- No data to analyze if trigger and/or dataflow fails!
ATLAS

- ATLAS is one of the 4 major experiments installed at LHC (CERN)
  - Largest volume particle detector ever constructed

**SIZE**
- Length 44 m
- Diameter 25 m
- Weight 7000 t

~2500 scientists
169 institutes
37 countries
3-levels selection schema

**Level 1 (LVL1)**
- Custom electronics
- Reduced granularity (calorimeter, muon)
- Latency 2.5 µs
- Select rate 75 kHz

**Level 2 (LVL2)**
- Software based, specialized algorithms
- Full granularity
- Region Of Interest (2% of data transferred)
- Event processing time: ~40 ms

**Event Filter (EF)**
- Software based, offline algorithms
- Full event available
- Seeded by LVL2
- Event processing time: ~4s
DataFlow components

Responsible for the collection and the conveyance of event data from the detector front-end electronics to the mass storage, and provision of data to LVL2 and EF

RoIB
- RoI info assembled into a unique data structure and sent to LVL2

LVL2
- Guided by RoI info, data fragments are requested from the ReadOut System for analysis
- Decision sent to DataFlow Manager

DFM
- receives LVL2 decision
- assigns accepted events to Event Building
- for rejected and built events notifies ROS to expunge event data

EB
- collects data from ROSs, i.e. builds the full event
- notifies DFM when events are built
- built events are sent to Event Filter

EF
- selects and classifies the events
- selected events are sent to SFO

SFO
- Received events are stored locally

Push-pull architecture
DataFlow Performance

- Regular TDAQ tests are performed to assess the system performance
- Current system size allows for the evaluation of scalability & performance
- Connection between the EB and EF is organized in sub-farms
  - Each sub-farms contains a subset of the EB and EF nodes
  - Such a configuration allows for flexibility and redundancy in the usage of the available resources

- Standalone EB performance
  - scales linearly with the number of SFIs
  - an SFI contributes ~90 MB/s to the aggregate bandwidth

- The full system runs successfully at a
  - LVL1 trigger rate of 70 kHz,
    - depending on test conditions, can be limited by the ROS processing power
  - LVL2 trigger rate of 3.5 kHz
During detector commissioning and combined running the SFO farm has been regularly used at the design working point and even beyond.

- The farm is able to sustain an aggregated I/O rate of 550 MB/s (design value is 300 MB/s)

- Roughly 1 PB of data, distributed over 650 thousand files, has been handled by the farm during the ATLAS cosmic data-taking.
# HLT (LVL2+EF) Farms: Status

## Current System
- 27 racks (XPU)
  - X = LVL2 or EF
  - 850 PC (850x8 core)
- 35% of the final system
  - Sufficient for $10^{31} \text{cm}^{-2} \text{s}^{-1}$

## Final System
- 17 LVL2 racks (~500 PC)
- 62 EF racks (~1800 PC)
  - 28 configurable as LVL2 or EF (XPU)

<table>
<thead>
<tr>
<th>1 rack</th>
<th>31 PC</th>
<th>2 quad-core</th>
<th>RAM: 16 GB (2GB/core)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Local File Server</td>
<td>2 (2.5 GHz)</td>
<td>16 GB (2GB/core)</td>
<td></td>
</tr>
</tbody>
</table>

### Diagram
- UPS for CFS
- CFS nodes
- SDX1 2nd floor
- Rows 3 & 2

**Source:** Diana Scannicchio  
**Date:** 27 May 2009
ATLAS
Trigger
Trigger: Introduction

- Large rejection against QCD processes is needed while maintaining high efficiency for low cross-section physics processes (e.g. new physics)

- Start-up luminosity (up to $10^{31}$ cm$^{-2}$ s$^{-1}$)
  - Standard Model processes
  - Trigger and detector commissioning
  - Selection strategy focused on
    - Low thresholds
    - Loose selection criteria
    - HLT algorithms in pass-through mode (only at the very beginning)

- Design luminosity ($10^{34}$ cm$^{-2}$ s$^{-1}$)
  - reduce background rates while achieving selection of interesting physics with high efficiency
    - Higher thresholds
    - Isolation criteria
    - Tighter selections
Level 1

- Rate to be reduced from 40 MHz to ~40 kHz
  - 75 kHz at nominal luminosity
- Latency 2.5 µs
- Data from calorimeter and muon detectors
  - reduced granularity of precision measurements
- Identifies physics objects: EM, τ, jet, μ, Σ Eₜ, Eₜmiss
- Identifies the regions of the detector that contains the object, i.e. RoIs

<table>
<thead>
<tr>
<th>Object</th>
<th>Thresholds #</th>
</tr>
</thead>
<tbody>
<tr>
<td>EM</td>
<td>8-16</td>
</tr>
<tr>
<td>τ</td>
<td>0-8</td>
</tr>
<tr>
<td>Jets</td>
<td>8</td>
</tr>
<tr>
<td>For. jets</td>
<td>4+4</td>
</tr>
<tr>
<td>Eₜmiss</td>
<td>8</td>
</tr>
<tr>
<td>Σ Eₜ</td>
<td>4</td>
</tr>
<tr>
<td>Σ Eₜ(jets)</td>
<td>4</td>
</tr>
<tr>
<td>μ ≤ 10 GeV</td>
<td>3</td>
</tr>
<tr>
<td>μ &gt;10 GeV</td>
<td>3</td>
</tr>
</tbody>
</table>

- Total number of LVL1 trigger items up to 256
  - Each item is a combination of one or more of the configured thresholds
  - For each item a pre-scale value can be specified

LVL1 pre-scale value can be adjusted to keep the output bandwidth filled without stopping and restarting a run
Level 2

- Rate to be reduced from 40 kHz to 3.5 kHz
- Average event processing time is 40 ms
- The selection is performed by specialized algorithms running on a farm of PCs
- The LVL2 processing is seeded by the RoI
  - selectively accesses and analyzes data from limited regions of the detector (i.e. the RoIs)
  - reduces processing time and required network bandwidth
- Refined analysis of the LVL1 object based on
  - full granularity detector data
  - up-to-date calibration constants
  - ability to access all detector data such as tracking
    - primarily within the RoI
  - topological selection criteria that can be applied
Event Filter

- EF performs the final online selection
  - the complete built event is available
  - algorithms are seeded by LVL2
- Rate to be reduced from 3.5 kHz to ~200 Hz (corresponding to ~300 MB/s) at both start-up and nominal luminosity
  - the output rate is limited by the offline computing budget and storage capacity
- The average event processing time is 4 s
- Seeded by the result of the LVL2 processing
  - although it has direct access to the complete data for a given event
- EF mostly uses offline algorithms running on a farm of PCs
  - more sophisticated and time consuming selection algorithms
  - Up-to-date calibrations constants are used to improve the selection
- Event classification is performed
- Based on classification, events are written by SFO to different data streams for storage
**Data Streams**

- Inclusive streaming model has been adopted
- Events will be streamed to one or more files based on the EF classification
  - 4 data streams: electrons or photons, jetTauEtmiss, muons and minbias
    - foreseen for physics running
  - express stream: it contains a subset of triggers and can be used to provide a feedback on the quality of data
    - intended for monitoring (not for physics analysis)
  - calibration stream: it includes triggers that provide data needed for detector alignment and energy scale operations
    - partial event building is available
- Each stream contains events that pass one or more signatures

<table>
<thead>
<tr>
<th>Stream</th>
<th>Total rate (Hz)</th>
<th>Unique rate (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>egamma</td>
<td>55</td>
<td>48</td>
</tr>
<tr>
<td>jetTauEtmiss</td>
<td>104</td>
<td>89</td>
</tr>
<tr>
<td>muon</td>
<td>35</td>
<td>29</td>
</tr>
<tr>
<td>minbias</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>express</td>
<td>18</td>
<td>0</td>
</tr>
<tr>
<td>calibration</td>
<td>15</td>
<td>13</td>
</tr>
</tbody>
</table>

- Unique rate reflects the number of events written only to the specified stream
  - difference between the total rate and the unique rate is the rate of replicated events in each stream

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Diana Scannicchio
27 May 2009
ATLAS
Trigger Menu
**Trigger Menu**

- Table of trigger signatures, each specifying the thresholds and selection criteria to be used at each trigger level
  - A criteria is based on one or more objects
- It provides a recipe for triggering on various physics processes

- Each signature is considered carefully:
  - its physics goals
    - or commissioning or calibration goals
  - efficiency and background rejection it provides to meet these goals
  - bandwidth consumed
- Start-up phase will be an extend period of time (more than 6 months)
- Different menus are being prepared with increasing complexity to match different running conditions

<table>
<thead>
<tr>
<th>Objects</th>
<th>Examples of signatures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrons</td>
<td>e3, e7</td>
</tr>
<tr>
<td>Photons</td>
<td>γ60i, 2γ20i</td>
</tr>
<tr>
<td>Muons</td>
<td>μ4, μ6</td>
</tr>
<tr>
<td>Jets</td>
<td>j5, j10, j70, 3j10</td>
</tr>
<tr>
<td>Jet + $E_T^{\text{miss}}$</td>
<td>j70 + xE70</td>
</tr>
<tr>
<td>Tau + $E_T^{\text{miss}}$</td>
<td>τ35 + xE45</td>
</tr>
</tbody>
</table>
Initial physics is almost all about
- understanding the detector
- object triggering
- identification performance (background, efficiency)

High priorities in the first data:
- Understanding simpler object triggering, reconstruction, identification, background, efficiency
  - e, γ, μ, jets
- At the same time, start commissioning more complex signatures
  - τ, $E_T^{\text{miss}}$, flavour tagging

A trigger menu for the start-up phase has been developed
- ~150 items at LVL1
- ~200 items at HLT

Trigger menus also include additional signatures for trigger validation, monitoring, calibration and measuring the performance of the physics trigger signatures
## Physics motivations: examples

<table>
<thead>
<tr>
<th>Signature</th>
<th>Motivation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e$ (10 GeV)</td>
<td>$e^+, e^-$ from $b, c$ decays, $E/p$ studies, $Z \to \tau \tau \to eX$</td>
</tr>
<tr>
<td>$2e$ (5 GeV)</td>
<td>$J/\psi \to ee$, $\Upsilon \to ee$, Drell-Yan</td>
</tr>
<tr>
<td>$e$ (20 GeV)</td>
<td>$Z \to ee$, $W \to e\nu$, top, main physics, efficiency estimation for tau trigger, high-$p_T$ physics</td>
</tr>
<tr>
<td>$\gamma$ (20 GeV)</td>
<td>direct photon, jet calibration using $\gamma$ -jet events, high $p_T$ physics</td>
</tr>
<tr>
<td>$\mu$ (10 GeV)</td>
<td>Bphysics, $W, Z$, top to muons, $Z \to \tau \tau$</td>
</tr>
<tr>
<td>$2\mu$ (4 GeV)</td>
<td>Bphysics, Drell-Yan, $J/\psi$, $\Upsilon$</td>
</tr>
<tr>
<td>$\mu$ (4 GeV), $J/\psi \to \mu\mu$ (full scan)</td>
<td>$J/\psi \to \mu\mu$ cross section and polarization, B-cross section measurement</td>
</tr>
<tr>
<td>$\mu$ (4 GeV), $J/\psi \to e$ (5 GeV) $e$ (3 GeV) (full scan)</td>
<td>$J/\psi \to ee$ channels</td>
</tr>
<tr>
<td>$\tau$ (16 GeV) &amp; EF $E_T^{miss}$ (30 GeV)</td>
<td>$W \to \tau \nu$, $W \to e\nu$, $X \to \tau \tau$ (X=Z, SM $h$, Heavy Higgs, Z, SUSY di $\tau$)</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>
Combining objects provides at LVL1 another mechanism to control the rates preserving many physics requirements

- single-object triggers may suffice for low luminosity running
- multi-objects triggers need to be deployed at low luminosity to
  - validate them
  - ensure their reliability at high luminosity

- Unique rate is the number of events that fulfill one trigger signature
- Overlap rate includes events that fulfill more than one trigger signature

LVL1 Unique Rates

<table>
<thead>
<tr>
<th>Trigger chain</th>
<th>Rate (Hz)</th>
<th>Unique Rate (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1_2EM3</td>
<td>3300</td>
<td>1490</td>
</tr>
<tr>
<td>L1_EM7</td>
<td>2600</td>
<td>1200</td>
</tr>
<tr>
<td>L1_2EM3_TAU6</td>
<td>1770</td>
<td>0</td>
</tr>
<tr>
<td>L1_MU4</td>
<td>1060</td>
<td>236</td>
</tr>
<tr>
<td>L1_2EM3_EM7</td>
<td>1030</td>
<td>0</td>
</tr>
<tr>
<td>L1_MU6</td>
<td>755</td>
<td>0</td>
</tr>
<tr>
<td>L1_MU10</td>
<td>610</td>
<td>0</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>
**HLT Trigger Menu at $10^{31} \text{ cm}^{-2} \text{ s}^{-1}$**

Most of the LVL2 and EF triggers are used in pass-through mode or with loose selections and low un-prescaled thresholds.

<table>
<thead>
<tr>
<th>Trigger chain</th>
<th>Rate (Hz)</th>
<th>Unique rate (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egamma_L2</td>
<td>186.0</td>
<td>165.0</td>
</tr>
<tr>
<td>Express_L2</td>
<td>79.6</td>
<td>6.71</td>
</tr>
<tr>
<td>jetTauETmiss_L2</td>
<td>160.0</td>
<td>138.0</td>
</tr>
<tr>
<td>Minbias_L2</td>
<td>0.17</td>
<td>0.17</td>
</tr>
<tr>
<td>Muon_L2</td>
<td>104.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Egamma_EF</td>
<td>41.80</td>
<td>30.30</td>
</tr>
<tr>
<td>Express_EF</td>
<td>14.50</td>
<td>3.65</td>
</tr>
<tr>
<td>jetTauETmiss_EF</td>
<td>29.40</td>
<td>27.90</td>
</tr>
<tr>
<td>Minbias_EF</td>
<td>0.17</td>
<td>0.17</td>
</tr>
<tr>
<td>Muon_EF</td>
<td>16.90</td>
<td>16.20</td>
</tr>
</tbody>
</table>

- This allows validation of many trigger algorithms during the start-up phase
- Higher threshold trigger signatures required during high luminosity running are also deployed to validated them early on

Well within the design bandwidth:

Rates estimated using a sample of simulated minimum-bias events: large uncertainties in simulation.

<table>
<thead>
<tr>
<th>Level</th>
<th>Rate at $L = 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>LVL1</td>
<td>6470.0 Hz</td>
</tr>
<tr>
<td>LVL2</td>
<td>427.0 Hz</td>
</tr>
<tr>
<td>EF</td>
<td>94.2 Hz</td>
</tr>
</tbody>
</table>
10 September 2008
ATLAS was ready
10 September 2008: firsts beams

- Muon system with reduced HV
- TRT on, SCT reduced HV, Pixel off
- BCM, LUCID, MinBias Scint. (MBTS), Beam Pickups (BPTX)
- L1 trigger processor, DAQ up and running, HLT available (but used only for streaming)
- Trigger Menu: single beam

ATLAS ready: beam operation mode

LHC startup scenario

- Machine strategy:
  ★ Stopping beam on collimators
  ★ Re-aligning with centre
  ★ Opening collimator
  ★ Circulating beam (up to 30 minutes)
- Splash from collimators for each beam shot
- Radio Frequency turned on
At Trigger desk...
... and on the projector ...
Conclusions

- **ATLAS** is (was on September 10th, 2008) ready to take data
  - Successfully operated with first beams
- **Large fraction of the Trigger and Data Acquisition system** has been installed and commissioned
  - Functionality are all there, 65% of the HLT farm to be added (CPUs)
    - imply a lot more processes to configure and control the system
  - Tests performed show that both the architecture and the hardware deployed meet ATLAS requirements
- **A trigger menu** has been developed for the LHC start-up phase
  - Low thresholds and loose selections allow for rapid commissioning and preparation for high luminosity
  - Trigger items and their performance have been studied in detail with MC at both low and high luminosity
  - Detector commissioning needs feedback on its performance
- **Trigger rate estimates** are within the TDAQ design specifications
- **Trigger and Data Acquisition system** was (and is being) used successfully in data taking for commissioning runs (cosmic rays)
Backup slides
LHC: schema of the 2 beams and sites
7025 applications
- Maximum tried 9000

1535 computer
- TDAQ
  - 25 online nodes
  - 31 monitoring nodes
  - 154 ROS
  - 63 SFI
  - 5 SFO
  - 11 DFM
  - 2 L2SV
  - 789 XPU
- Detector nodes

Log file (Run 87764)
- 115 k messages archived into database (Oracle)

DAQ Configuration
- Described in a database (OKS) di 47 MB
- 49 schema files, 483 classes
- 771 data file, 114 k “objects”

Data Quality
- 100 k histograms saved
- 10 k histograms checked per minute
Trigger and DAQ overview

Event data pulled:

LVL2: partial events @ 75 kHz,
Event Builder: full events @ ~ 3 kHz

Event data pushed @ ≤ 100 kHz, 1600 fragments of ~ 1 kByte each
Cosmic rays
TDAQ block diagram
Rates: view of 10 TeV at $10^{31}\text{cm}^{-2}\text{s}^{-1}$

Rates estimated using a sample of simulated minimum-bias events

<table>
<thead>
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<td>EF</td>
<td>94.2 Hz</td>
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</table>

Well within the foreseen bandwidth