The ATLAS Trigger: Operation and Optimisation

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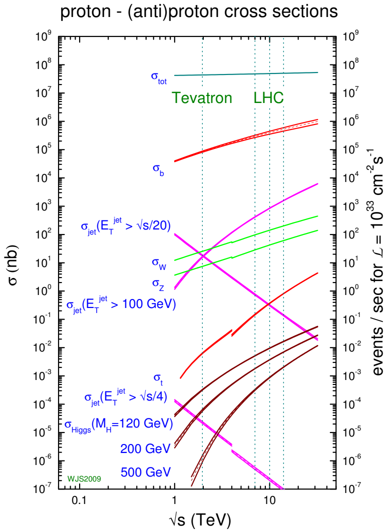
Triggering Discoveries
in High Energy Physics
Jammu, India

Introduction

Introduction



Extensive and ambitious physics programme pursued by ATLAS

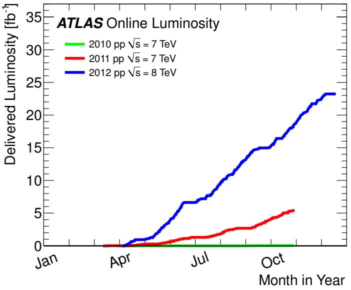
- Majority of processes of interest have cross sections many orders of magnitude below total
- Operating in a challenging environment!
- Processes of interest have a wide range of physics signatures

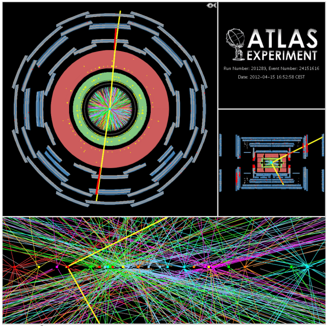
LHC collides protons at 20 MHz

- In practice can only record around 400 Hz for physics

Introduction

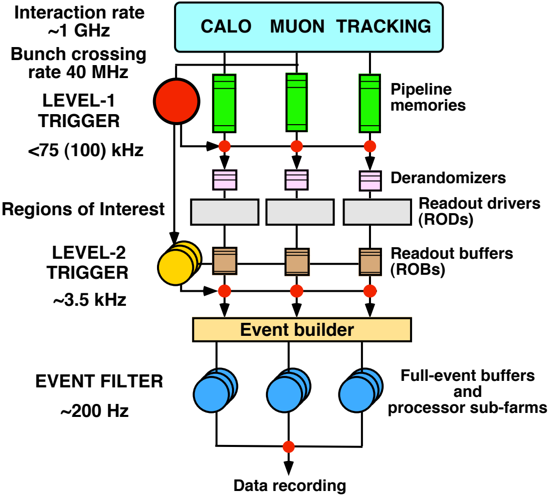
- Highly successful operation of LHC during run I
- Significant ramp up in Luminosity





- Consequence of this is a high pileup environment
- Challenge to mantain trigger performance with a high number of collisions per event

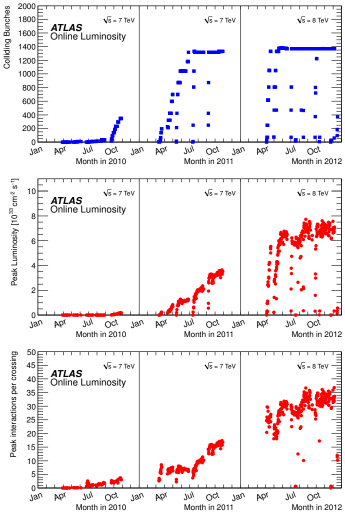
ATLAS Trigger



See talk from Benedict Allbrooke

Trigger menu and rates

Luminosity Evolution

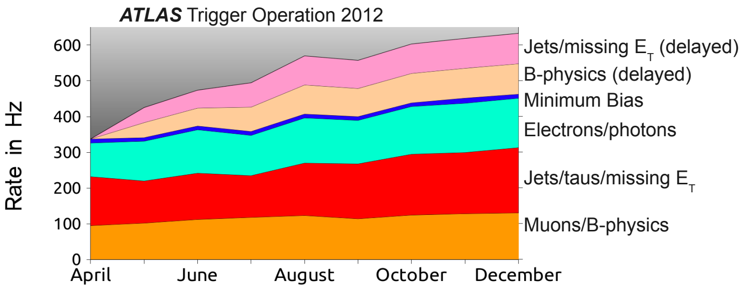


- Significant increase in luminosity during run I
- Menu correspondingly evolved
- 3 $p - p$ trigger menus used for physics in 2011 and 2012
- Note that for heavy ion physics a different, specifically designed menu is used

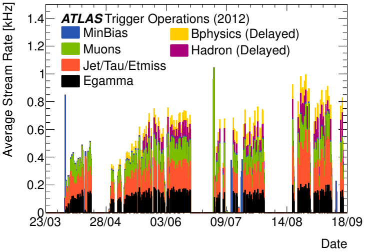
Some Nomenclature

- A *trigger chain* is a sequence of algorithms (L1 $\rightarrow$ L2 $\rightarrow$ EF) used to select a signal
- Similar trigger chains are collectively known as *trigger signature groups*
  - e.g. chains relating to muons referred to as muon trigger signature group
- Accepted events are recorded into different datasets - *streams*
  - Streams are designed such that overlap is minimised
- The full collection of trigger chains is known as the *trigger* menu
- In 2012, ATLAS ran with a *delayed stream* where events passing certain trigger chains were stored for later reconstruction
  - e.g. triggers for B-Physics

Streams



- Output rates predominantly from jet/τ/MET stream, e/γ and muon streams
- Primary triggers enabled throughout run
- As run progresses $\rightarrow$ luminosity drops $\rightarrow$ calibration/background chains enabled



Trigger Menu

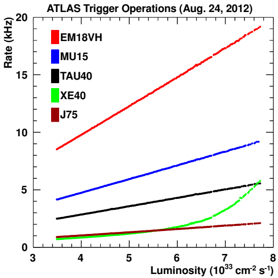
Distribution of trigger rates for $7 \times 10^{33} cm^{-2} s^{-1}$:

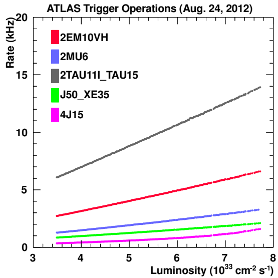
Signature Group	Peak L1 Rate (Hz)	Peak L2 Rate (Hz)	Average EF rate (Hz)
μ	14000	1200	100
e/γ	30000	2000	140
τ	24000	800	35
Jets	3000	1000	35
MET	4000	800	30
B-jets	5000	900	45
B-physics	7000	50	20
Total	65000	5500	400

- Bandwidth distribution based on physics priorities
- Note that rates do not include delayed stream and totals take overlap into account

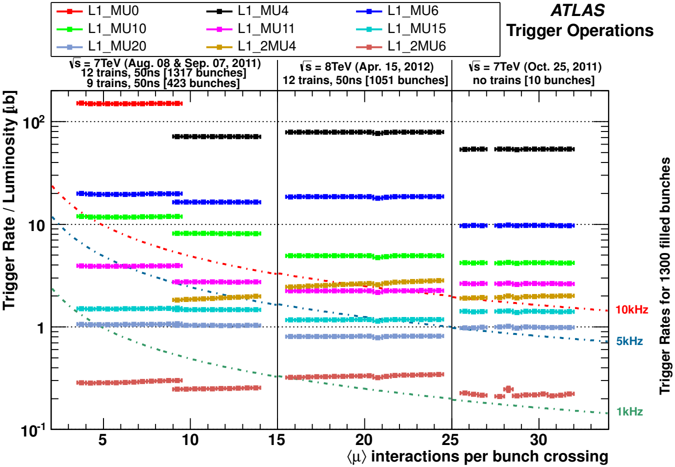
Trigger Rates at L1

- Rates of RoI based triggers in general proportional to luminosity
- Non-linear effects with pileup for global triggers
  - e.g missing E_T, multi-jet triggers
  - Pileup also affects forward jet triggers

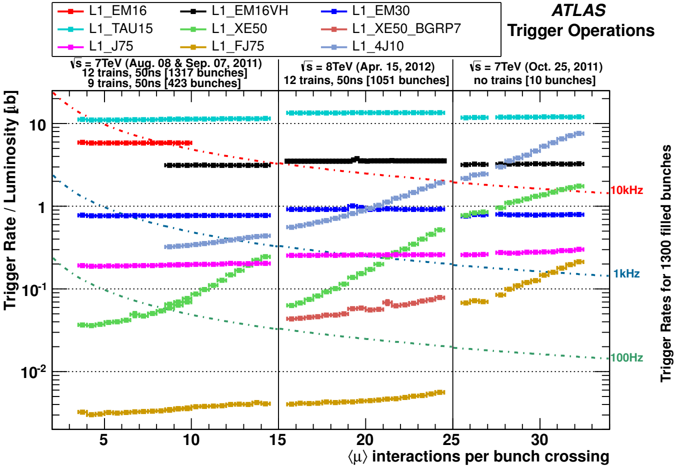




Trigger Rates at L1



Trigger Rates at L1



Trigger Monitoring

Trigger Monitoring

- A thorough and comprehensive monitoring infrastructure essential for the successful operation of the ATLAS detector
  - A swift response to any problems particularly important for the trigger
- Trigger monitoring strategy on two fronts:
  - Online monitoring
    - Performed by shifter in control room
  - Offline monioring
    - Performed by trigger experts

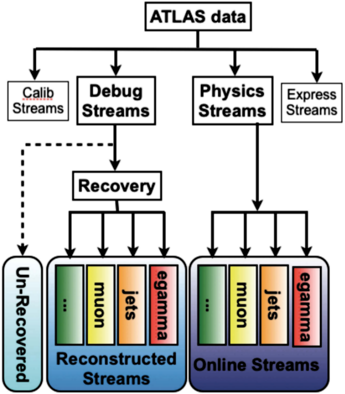
Trigger Monitoring: Online

Several tools specifically designed to monitor performance of trigger menu and algorithms

- Data quality monitoring display:
  - Automatic comparison of real-time data with reference histograms using comparison algorithms (e.g. Kolmogorov test)
  - Flagging of bad histograms
- Online Histogram Presenter:
  - Configurable, interactive histograms displayed for various distributions for each signature group
- Trigger Rate Presenter:
  - Real time rates vs predictions

Trigger Monitoring: Offline

- A subset of the data is recorded immediately after running - *express stream* - to assess data quality
  - Comparison of trigger and offline quantities
  - Basic efficiency plots, kinematic distributions



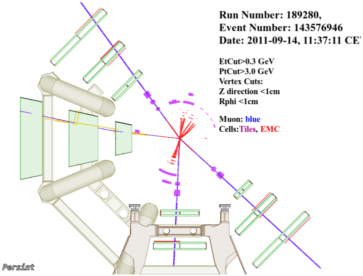
- Events where trigger unable to decision recorded to *debug stream*
  - Most events have many RoIs or high track multiplicity so a timeout occurs
  - Events recovered and integrated into physics streams

- *Reprocessed data* used to validate changes to trigger menu and software

Trigger Performance

Muons

- Chatacterised by presence of track in MS and track in ID
  - Specific detectors devoted to triggering muons
- At L1, RoI information from RPCs and TGCs
- At L2 MDT information used, then MS track combined with ID
- Two complementary reconstruction algorithms at EF
  - *InsideOut*
  - *OutsideIn*



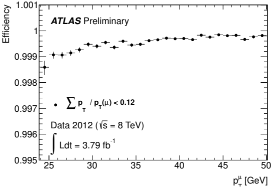
A H $\rightarrow 4\mu$ *candidate event*

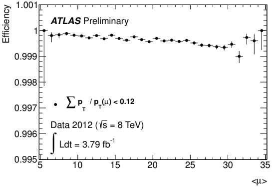
- L1 rates scale linearly with the instantaneous luminosity, pile-up robust
- Efficiencies measured in Z$\rightarrow \mu\mu$ to $< 1\%$

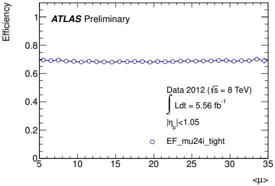
Muons

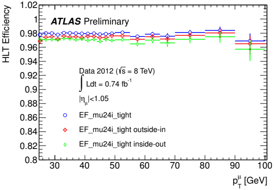
For 2012:

- Additional shielding installed
- Single muon trigger $\rightarrow p_T > 24$ GeV
- Di-muon trigger $\rightarrow (p_T > 24 \text{ GeV}) \times 2$
- Require track and calorimeter isolation
  - Robust against pileup
  - See right



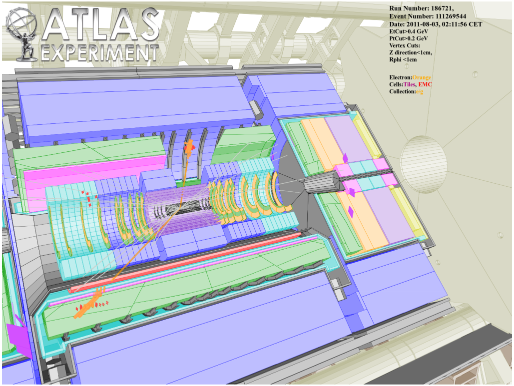






Electrons

- Single (25 GeV) and Di-electron (2×15 GeV) triggers used
- L1 algorithm uses hadronic veto (introduced during 2011 run)
- HLT selection similar to offline

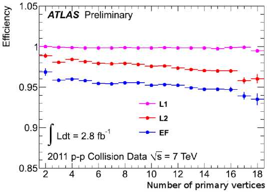


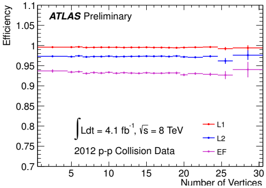
A high mass dielectron event

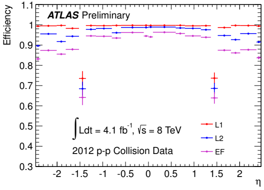
Electrons

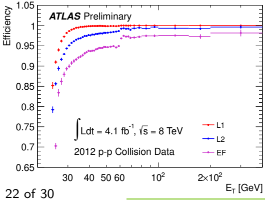
For 2012:

- Raised L1 threshold 16 GeV → 18 GeV
- Optimise electron identification at HLT for high pileup
- Require track and calorimeter isolation
- Improved performance with pileup in 2012







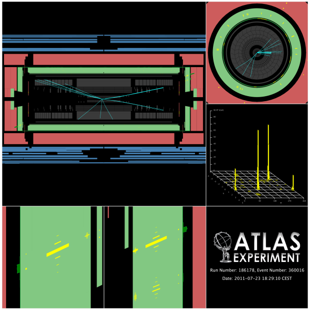


Photons

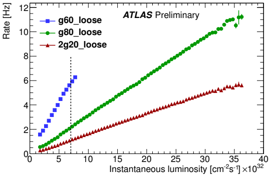
- Primary triggers require two photons
- $>$ 99% efficiency for H$\rightarrow \gamma\gamma$
- Stable for 2011, some optimisation for 2012

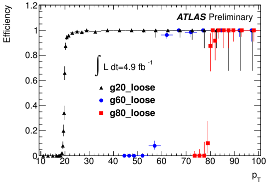
For 2012:

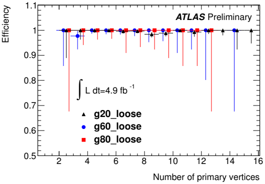
- Raise di-photon p_T thresholds
- Tighten photon identification at HLT
- Introduce 3-photon tiggers



A high mass diphoton event

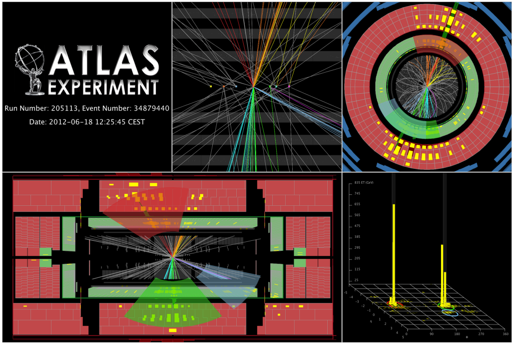






Jets

- Triggers use a range of jet sizes
- Pileup and noise suppression (introduced in 2011)
- Acceptance up to $|\eta| < 4.9$: forward jet triggers
- Also use b-tagging for b-jet triggers

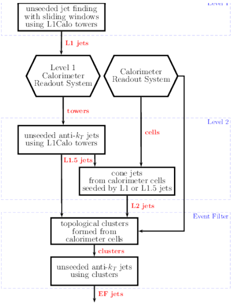


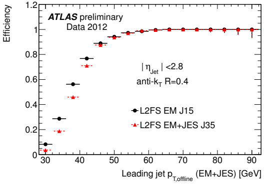
A high mass dijet event

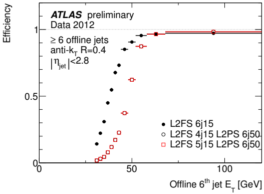
Jets

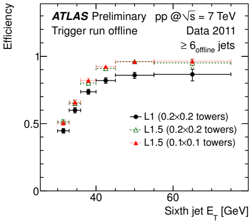
For 2012:

- Significant changes to L2
  - Full scan allows full detector coverage using trigger towers
  - Availability of anti-k_T algorithm due to FastJet software
- Hadronic calibration at EF
- Pileup and noise suppression (introduced during 2011 run)
- σp_T and multi-jet triggers
  - Previous strategy gave degraded performance for multi-jet events



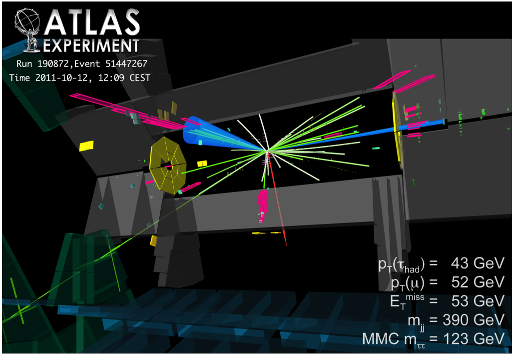






Taus

- τ triggers identify hadronic τ decays
- Exploit differences between τ and QCD jets
  - Narrow and isolated
  - Low track multiplicity
- Triggers optimised for $H \rightarrow \tau\tau$ and $H^+ \rightarrow \tau\nu$
- Used mostly in combination:
  - e.g. di-τ, $\tau + MET$

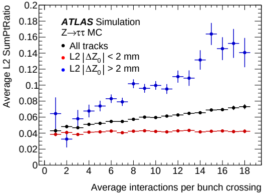


A H$\rightarrow \tau\tau$ candidate event

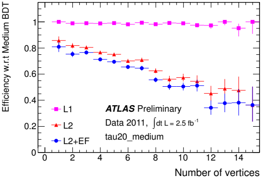
Taus

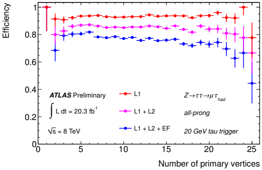
For 2012:

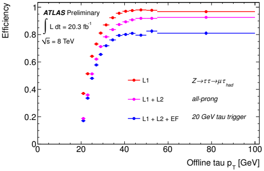
- L2 uses E_T and shape variables in Calorimeter and ID track information
  - For 2012, cone used to compute these optimised to be pileup robust



- Introduce impact parameter requirements on ID tracks
- Use isolation at L1
- At EF, BDT used for τ identification
  - Significant improvement in rejection power

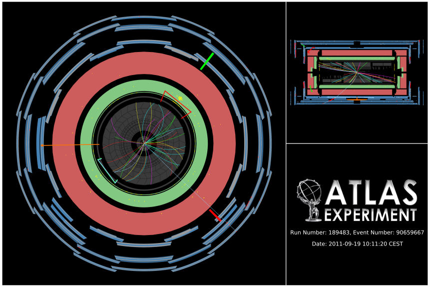






Missing Transverse Energy (MET)

- The MET trigger designed to select events including neutrinos or other particles which escape detector without interacting
- Trigger sums over calorimeter cells
- Potential large sensitivity to pileup
  - In 2011, trigger rate dominated by out-of-time pileup noise from forward calorimeter (FCAL)

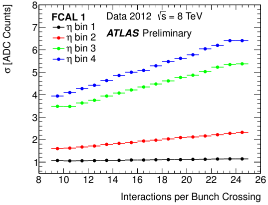


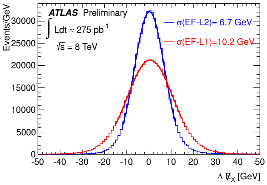
A $H \to WW \to l\nu l\nu$ candidate event

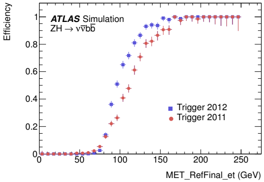
MET

For 2012:

- L1: Raised FCAL noise cut thresholds
  - Little impact on efficiency, rates significantly reduced
- L2: access to cell level information (as opposed to trigger tower information in 2011)
  - Significant improvement in rejection
  - Significant improvement in resolution
- EF: Cluster level calibration (common with jets)







Conclusion

- Successful data taking in LHC run I for ATLAS experiment
  - Underpinned by successful trigger operation
- Trigger operations have benefitted from throrough and careful trigger menu design and strategy
- Operation of trigger supported by a comprehensive monitoring infrastructure
- High selection efficiency across a broad range of physics signatures
- Adapted to changing conditions in a challenging, high pileup environment