The ATLAS Trigger Performance and Evolution

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Overview over the ATLAS Trigger System

3 Level Trigger System:

- Level 1
 - hardware based
 - coarse granularity
 - mainly muon chambers and calorimeters
- Level 2 (part of High Level Trigger)
 - software based
 - full granularity in regions of interest
 - all subdetectors
- Event Filter (part of High Level Trigger)
 - offline-like algorithms
 - events put into output streams based on physics content

ATLAS input rate: <40 Hz

Trigger Level	decision time	output rate
Level 1 (L1)	<2.5 μ s	<75kHz
Level 2 (L2)	~60ms	~5kHz
Event Filter (EF)	~1s	300Hz-1kHz

Data Taking Efficiency of Trigger System

2011:

L1			High Level Trigger (HLT)						
Muon	Calo	CTP	electron	photon	muon	tau	jet	b-jet	missing E_T
99.0	100	99.8	99.3	99.3	100	99.9	98.6	99.9	99.3

Luminosity weighted relative fraction of good trigger data quality delivery during 2011 stable beams in pp collisions at $\sqrt{s}=7$ TeV between 13 March and 30 October (in %).

- Trigger Signatures at L1: concerning the hardware components and the central trigger reprocessor (CTP)
- Trigger Signatures at the High Level Trigger: identifying physics objects corresponding to fundamental particles
- Minor issues due to gas leaks in RPC and one run in 2011 with an issue of the jet algorithm after a hardware recovery
- L1 and HLT rates are calculated independently
- Overall Data Quality very high in 2011 and 2012

Evolution of the luminosity

- 2011: 7 TeV centre of mass energy proton-proton collisions
 - 2012: 8 TeV centre of mass energy collisions
 - up to $7.7 \cdot 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ instantaneous luminosity
 - 50 ns bunch spacing
 - up to 38 mean collisions per beam crossing (pile-up)
 - 19.28 fb^{-1} recorded luminosity
 - November – December 2011: heavy ion (Pb) collisions
- almost linear increasing instantaneous luminosity of the LHC

Consequences on the Streaming

- main output rates from Muons, Jet/Tau/Etmiss and Egamma streams
- Jet/Tau/Etmiss trigger rates decreasing during run
- increasing rate of data stored during 2012
- due to increasing rate of data streams introduction of delayed streams in 2012 (data will be analysed during shutdown periods)
- Average event size of raw data 1.2MB
- Total number of events: $2 \cdot 10^9$ in 2012
- Total data stored for physics: about 2 Pb in 2012

Data Streams in 2011 - 2012

Data Streams in a typical run

No. of Interactions: 33 24 19 16 14 12 11

2012 Trigger Menu for $7 \cdot 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$

- optimal distribution of bandwidth is critical
- driven by physics requirements and priorities
- most bandwidth given to most generic triggers
- frequent trigger changes complicate physics analyses
 - in 2011 only 3 base menus for proton-proton collisions
- separate menu for heavy ion runs

Trigger Signature	Peak L1 Rate	Peak L2 Rate	Average EF Rate
Muon	14kHz	1200Hz	100Hz
Electron / Gamma	30kHz	2000Hz	140Hz
Tau	24kHz	800Hz	35Hz
Jets	3kHz	1000Hz	35Hz
Missing Energy	4kHz	800Hz	30Hz
B-jets	5kHz	900Hz	45Hz
B-physics	7kHz	50Hz	20Hz
Total	65kHz	5500Hz	400Hz

Group overlap accounted for in total

Consequences of luminosity increase on L1

- L1 trigger rates mainly independent of pileup
- non-linear behaviour of missing transverse energy trigger items, multi-jet and forward jet trigger items
 - use missing energy trigger items as an example to show improvements

L1MuX: L1 item of a muon candidate $p_t > X \text{ GeV}$
 L12MuX: L1 item of two muon candidates with a $p_t > X \text{ GeV}$
 L1EMX: L1 item of an electron/gamma candidate with $E > X \text{ GeV}$
 L1EMXVH: the same with high pileup optimisation
 L1TAUX: L1 item of tau candidate with $E > X \text{ GeV}$
 L1(F)JX: L1 item of a jet candidate with $E > X \text{ GeV}$
 L1_XEX: Missing Energy Item of missing energy of $E > X$

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V.Bartsch:
ATLAS Trigger Performance

Muon based Trigger Items

Calorimeter based Trigger Items

Missing Energy Triggers: advances in L1

bin 1: $\eta=3.1-3.2$
 bin 2: $\eta=3.2-3.5$
 bin 3: $\eta=3.5-4.2$
 bin 4: $\eta=4.2-4.9$

- out-of-time pileup noise from FCAL dominated Missing Energy Trigger rate
- raised noise cuts in FCAL region to suppress rate
- minimal impact on trigger efficiencies
- L1 thresholds lowered in 2012

Missing Energy Triggers: Out-of-Time Pileup

Out of time pileup issues:

- Calorimeter pulses last longer than the time between bunch crossings and go to negative values
- Unbalanced overlaying of signal shapes from neighbouring bunches causes spike in L1 Missing Energy trigger compared to muon and electron/gamma trigger

→ need to enable the Missing Energy Triggers only after this balance is reached

Trigger Rates for Missing Energy

Schematics of a LAr signal pulse

Missing Energy Trigger: advances in HLT

Advances in L2:

- In 2012: access to summed cell information rather than coarse L1 trigger towers
- resolution improves by about 50%
- rejection rate improved by a factor ~ 5
- trigger thresholds lowered

Advances in EF:

- In 2012: cluster based MET / hadronic calibration (shared with Jet triggers)
- 40% resolution improvement
- allows to lower the trigger plateau value for the same threshold by about 30%

Resolution of Ex for 2 different algorithms

Influence on turn-on curves

Tau Trigger

- Tau triggers mostly used in combination with 2nd tau (hadronic or leptonic) or Missing Energy trigger

Significant improvement for 2012:

- much improved pileup robustness due to smaller cone sizes and vertex track cuts
- Event Filter uses multi-variate selection to increase rejection power significantly

Physics with the ATLAS trigger

- Tau trigger enables high acceptance of tau events
- Jet trigger alone would not be sufficient due to high thresholds
- Next step: look at branching ratios and spin to confirm standard model Higgs

Conclusions

- ATLAS trigger operating successfully in 2011-2012
- Handling challenge of luminosity increases of LHC
- Significant improvements deployed for 2012:
 - Shown at the example of the missing energy signature and tau triggers
 - Retuned selection for high pileup conditions
 - More advance HLT selection algorithms
 - Trigger thresholds only raised minimally w.r.t. 2011

Backup slides

Muon Triggers

2011:

- Muon trigger at $p_T > 18 \text{ GeV}/c$
- Tightened L1 trigger due to out-of-time hits with 50ns beam spacing

2012:

- Additional shielding installed
- Raise to $p_T > 24 \text{ GeV}/c$
- Track isolation required (pileup robust)

Electron / Gamma triggers

Electrons

- 25GeV and 2x15GeV electron triggers

2011:

- Hadronic veto at L1
- Retuned HLT and offline electron ID

2012:

- Raised L1 threshold
- Retuned electron ID for high pileup
- Track isolation required

Gamma:

- Loosened pileup sensitive selection, but raised pt thresholds
- 2x20GeV trigger with somewhat tighter photon identification
- Added 3-photon trigger

Jet Triggers

2012:

- Evolution away from RoI based triggers
- Full scan reco of L1 towers for anti-kt jets
- Hadronic scale for HLT jets
- Noise threshold adjusted for higher pileup
- More advanced b-tagger (multi-variate, multi-jet vertex)