Il trigger di alto livello di ATLAS

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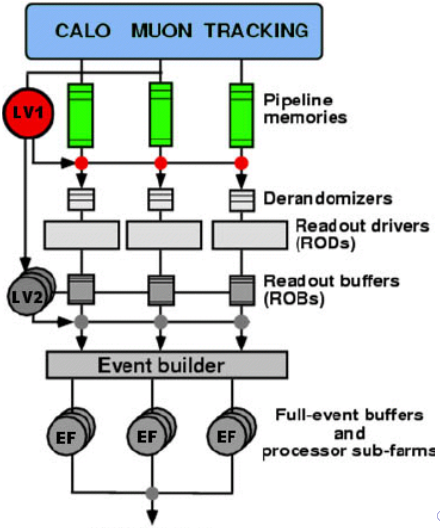
HLT in ATLAS

L1:

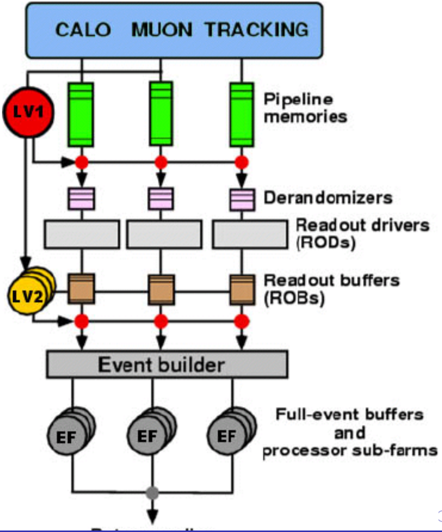
- hardware implemented
- latency 2.5 μs
- rate reduction: 40 MHz to 75 KHz
- defines Region of Interest (RoI)



HLT in ATLAS

L2:

- software implemented
- latency 10 *ms*
- rate reduction: 75 *MHz* to 1 *KHz*
- uses L1 RoI
- reconstruction based on custom offline algorithms

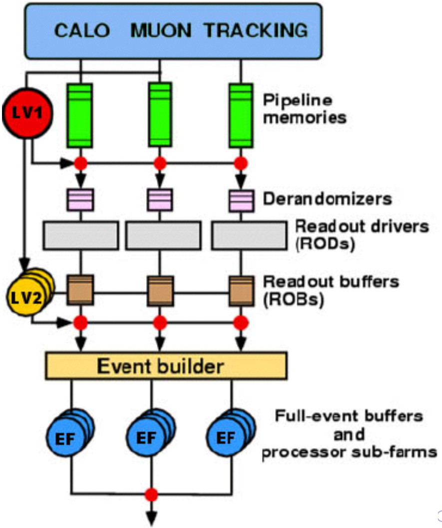


HLT in ATLAS

EF:

- software implemented
- latency $\sim$ 1 s
- rate reduction: 1 KHz to 100 Hz
- can access the full detector information (seeded mode performs reconstruction on the RoI found at L1/L2)
- reconstruction based on adapted offline algorithms

HLT = L2+EF



Trigger menus

Standard menu for $\mathcal{L} = 2 \cdot 10^{33} cm^{-2} s^{-1}$

Object	Physics coverage	$L = 2\times10^{33} cm^{-2}s^{-1}$	Rate (Hz)
Electrons	Higgs, new gauge bosons, extra dimensions, SUSY, W, top	e25i, 2e15i	~ 40
Photons	Higgs, extra dimensions, SUSY	γ60, 2γ20i	~ 40
Muons	Higgs, new gauge bosons, extra dimensions, SUSY, W, top	μ20i, 2μ10	~ 40
	Rare b-decays (*e.g.*, $B \to \mu\mu X$, $B \to J\Psi(\Psi')X$)	2μ6 + mass cuts	~ 25
Jets	SUSY, compositeness, resonances	j400, 3j165, 4j110	~ 20
Jet+missing E_T	SUSY, leptoquarks	j70 + xE70	~ 5
Tau+missing E_T	Extended Higgs models (*e.g.*, MSSM), SUSY	τ35i + xE45	~ 10
Others	Pre-scaled, calibration, monitoring		~ 20
Total HLT Output Rate			~ 200

Trigger menus

Recently working on:

Trigger menu for $\mathcal{L} = 10^{31} cm^{-2} s^{-1}$

- Detector studies on calibration and alignment
- Trigger studies for efficiency/thresholds/rate
- Physics studies

Trigger configuration for the proton-proton collisions at $\sqrt{s} = 900\ GeV$

($\mathcal{L} = 10^{29} cm^{-2} s^{-1}$) (based on prescaled minimum-bias + muon and calorimeters L1 triggers with very low p_T threholds)

Ingredients Needed to Operate a Full Trigger Slice

Reconstruction Algorithms	Hypothesis Algorithms	HLT Steering	Online Integration	Physics Selections	Tests with Real Data

Testing a "Trigger Slice" means carrying out performance studies spanning the full chain for a particular set of trigger signatures.

Examples:

- selections based on electrons and photons: e/γ slice;
- selections based on muons: μ slice;
- selections based on jets, τs and E_T: jet/τ/xE_T slice.

Ingredients Needed to Operate a Full Trigger Slice

Reconstruction Algorithms	Hypothesis Algorithms	HLT Steering	Online Integration	Physics Selections	Tests with Real Data

Reconstruction Algorithms

- seeded by L1;
- meant to reconstruct features contained in the events: tracks, calorimeter clusters, etc..;
- strong constraints on timing:
  - L2 average decision time: 10 ms;
  - EF average decision time: 1 s.

Hypothesis Algorithms

- they implement trigger selections;
- hystorically developed with standalone code; now integrated in the HLT framework

HLT Steering

- the Steering handles and drives HLT reconstruction and decision for the active trigger signatures.

Ingredients Needed to Operate a Full Trigger Slice

Reconstruction Algorithms	Hypothesis Algorithms	HLT Steering	Online Integration	Physics Selections	Tests with Real Data

Online Integration

- performance depends on all subsystems:
  - detectors;
  - online/offline software components;
  - computing infrastructure.
- crucial to test integration in the online framework, to check selection and system performance at the same time.

Physics Selections

- the physics impact of selections must be constantly monitored;
- basic trigger information must be used by trigger-aware analyses, to check trigger impact and provide feedback.

Tests with Real Data

- tests against operation on real data;
- first tests have been performed at the Combined Test Beam; results are available now from the first cosmic muons runs; preparing to commission the system with first beam.

HLT Reconstruction Algorithms

HLT reconstruction algorithms have been developed for each detector slice.

Calorimeter algorithms

Muon algorithms

ID tracking

HLT Reconstruction Algorithms

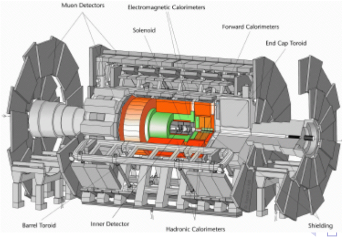
HLT reconstruction algorithms have been developed for each detector slice.

Calorimeter algorithms

- L2 and EF algorithms ready for e/γ;
- τ implementation ready at L2;
- offline tool adapted to the EF is ready for JetCone.

Muon algorithms

ID tracking



HLT Reconstruction Algorithms

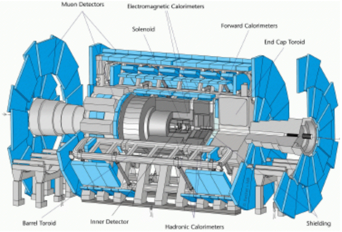
HLT reconstruction algorithms have been developed for each detector slice.

Calorimeter algorithms

Muon algorithms

- L2 and EF algorithms are available for the barrel region; work has started on extending the L2 algorithm to the endcap;
- ID to muon track matching tools are available at L2 and EF;
- muon isolation studies using calorimeters are being performed.

ID tracking



HLT Reconstruction Algorithms

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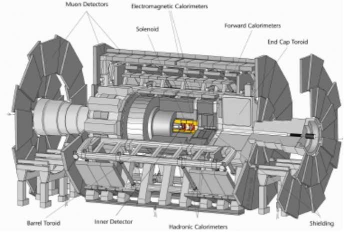
Calorimeter algorithms

Muon algorithms

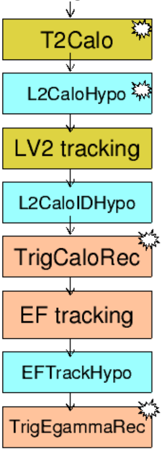
ID tracking

- tracking with Si data ready at L2 and EF; more approaches studied in parallel (IDSCAN projective approach, SiTrack combinatorial approach);
- tools available for both track extension to the TRT and stand-alone TRT reconstruction; emphasis on providing a robust tool for commissioning and early running.



Trigger Selections: e/γ

Electrons signatures: $e10$, $e25i$, $2e15i$, $e60$.
Photon signatures:$\gamma 10$, $2\gamma 20i$, $\gamma 60$



Photon sequence: 

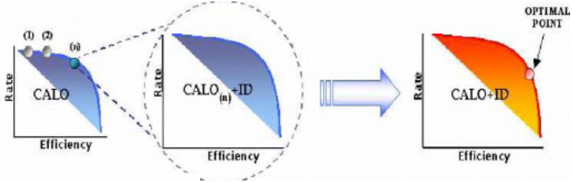
Electron sequence:
calo reconstruction + ID track matching

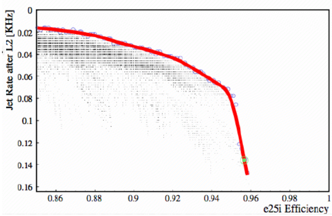
Trigger Selections: e/γ

Electrons signatures: $e10$, $e25i$, $2e15i$, $e60$

e25i

Results provided also as efficiency vs. rejection curves, to provide a continuous set of working points: essential for trigger bandwidth optimization.





	Tr. Eff (%)	Jet Rate (KHz)
L1	97.1 ± 0.4	6.5 ± 0.1
L2CALO	96.5 ± 0.4	1.31 ± 0.05
L2CALO+ID	92.9 ± 0.6	0.135 ± 0.016

Trigger Selections: e/γ

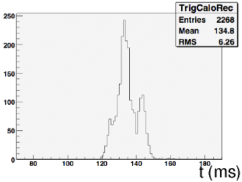
Electrons signatures: $e10$, $e25i$, $2e15i$, $e60$

e25i

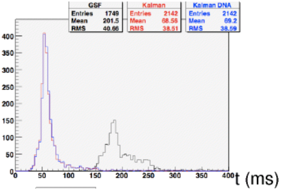
Selection performance must be always optimized together with the algorithm timing for the full trigger chain, to maximize the physics performance within the constraints of available computing power (online and offline).

Example: EF selection

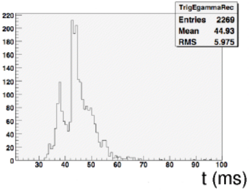
TrigCaloRec



EF Tracking



TrigEgammaRec



Clusterization takes 70% of the TrigCaloRec time (data preparation is dominating the time consumption at L2), three different fitting algorithms investigated in EFID. Continuous efforts put to improve performance in this field, in close collaboration with offline and detector software groups.

Trigger Selections: e/γ

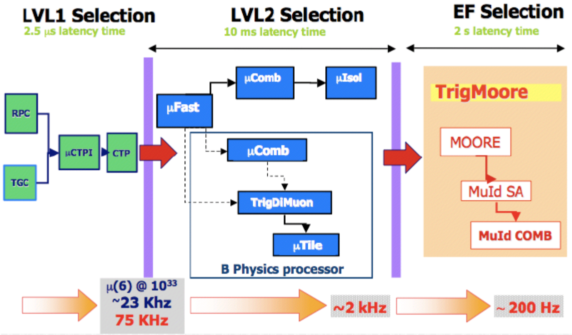
Electrons signatures: $e10$, $e25i$, $2e15i$, $e60$

e25i

25 GeV electrons (signal) and 17 GeV dijet events (background)

	Eff %	Rate
L1	96.5	6.5 KHz
L2 Calo	94.7	1.0 KHz
L2 ID	90.2	430 Hz
L2 Match	89.4	90 Hz
EF Calo	88.4	58±10 Hz
EF ID	81.8	49±9 Hz
EF Match	81.0	41±9 Hz

Trigger Selections: μ



- μFast fast pattern recognition (sagitta $\rightarrow p_T$ from LUT)
- μComb combines L2 μ with μ ID track
- MOORE refined EF pattern recognition

Trigger Selections: μ

Studies on single muon selections have been performed for two scenarios: 6 GeV threshold at $10^{33} cm^{-2} s^{-1}$ luminosity and 20 GeV at $10^{34} cm^{-2} s^{-1}$.
Cuts are defined so that a 95% efficiency is achieved at the threshold values.

Trigger Selections: μ

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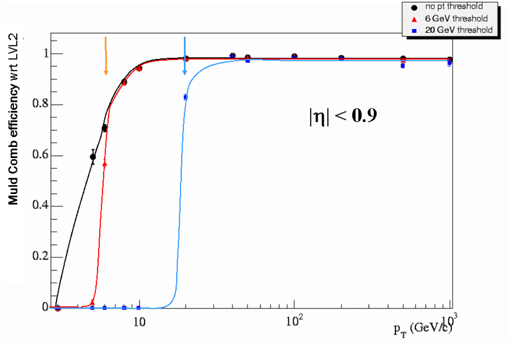
EF efficiency curves (w.r.t. L1) for $\mu 6$ and $\mu 20$.
Only a cut on p_T is applied; no further kinematic cuts, e.g. ID matching.



Trigger Selections: μ

Studies on single muon selections have been performed for two scenarios: 6 GeV threshold at $10^{33} cm^{-2} s^{-1}$ luminosity and 20 GeV at $10^{34} cm^{-2} s^{-1}$. Cuts are defined so that a 95% efficiency is achieved at the threshold values.

Rates for μ20 at $10^{34} cm^{-2} s^{-1}$.
Convolving the μ20 efficiency curve in the barrel for the full chain with background cross-section, the corresponding rates are evaluated. Only a cut on p_T is applied; no ID matching.

Muon sources	μ20 rate
π/K	56 Hz
b	77 Hz
c	30 Hz
W	22 Hz
Total	183 Hz

These rates are being re-evaluted using matching with ID in the full trigger chain and with the L2 algorithm extended to the end-cap.
Additional studies will be then performed using muon isolation.

Trigger Selections: jet/τ/xE_T

Very active trigger slice, just one year ago only small part of the selections were available.

Jets:

- Algorithms for L2/EF reconstruction and hypothesis in place
- Tools have been developed for trigger aware analysis

Tau:

- Algorithms for L2/EF reconstruction and hypothesis in place
- L2 sequence under optimization (first calo reconstruction or first tracking reconstruction)

ETmiss:

- Performance studies of ETmiss at L1 and EF.

More details in the specific talk by Francesca Sarri.

Trigger Selections: B physics

Di-muon trigger:

- core part of the trigger menu for ATLAS B-physics programme;
- active at all luminosity conditions;
- based on di-muon selections (L1 and HLT);
- used to select B decays with two muon final states: e.g. $B \to \mu\mu(X)$, $B \to J/\Psi(\mu\mu)X$.

EM and Jet RoI trigger:

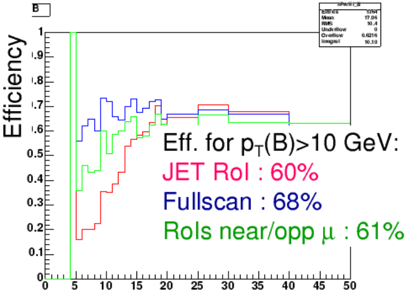
- used to enhance ATLAS B-physics programme;
- used for initial and lower luminosity running: around $10^{33} cm^{-2} s^{-1}$ and below;
- based on single L1 muon, reconstructing additional L1 EM and Jet RoIs
  - Jet RoI for hadronic final states (e.g. $B_s \to D_s(\phi\pi)$)
  - Em RoI for $e\gamma$ final state (e.g. $J/\psi \to e^+e^-$, $K^\star$)
  - Muon RoI to recover di-muon final-states in which second muon was missed at L1

Full reconstruction inside ID (for initial running)

Trigger Selections: B physics

L2 selection for $B_s \rightarrow D_s(\phi\pi)$

- Reconstruct tracks within a Jet RoI ($\Delta\phi \times \Delta\eta = 1.5 \times 1.5$) in RoI based approach of in full scan mode
- Combine pairs of tracks with K^+K^- mass hypothesis to form candidates. Add third track with mass hypothesis to form D_s candidates.



	Efficiency	Time
RoI	60%	44 ms
FullScan	68%	160 ms

(most of the time is spent in data preparation) and TRT extrapolation.

Background from $b\bar{b} \rightarrow \mu X \sim 3.5\%$ ($\sim 175 Hz$ at $10^{33} cm^{-2} s^{-1}$)

Trigger selections: *b*-tagging

The *b*-tagging selection is an element of flexibility in the ATLAS HLT.
It might help to increase acceptance for events with multi *b*-jets (SUSY or SM) or to select calibration samples.

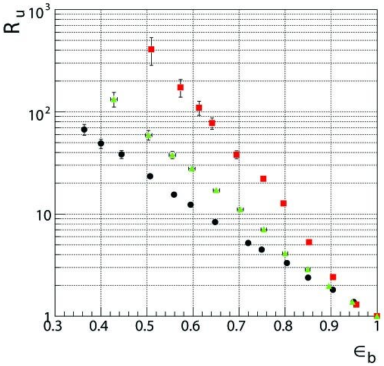
Example:

- $b\bar{b}A/H \rightarrow b\bar{b}$: not selected by the standard jet trigger; efficiency might be recovered by relaxing L1 thresholds and applying *b*-tagging at L2 to reduce the rate;

Trigger selections: *b*-tagging

b-tagging hypothesis algorithm: likelihood ratio method based on trasverse and longitudinal parameters (secondary vertex based methods studied standalone but not yet included in the slices).

Performance caracterized, per jet, as rejection (inverse of the light jet efficiency) as a function of *b*-jet efficiency (samples $WH \rightarrow b\bar{b}(u\bar{u})$):



Offline
EF
L2

Trigger selections: *b*-tagging

Study of the *b*-tagging strategies given HLT (and L1) constraints.

Assuming 20 Hz for the HLT output on multi-jet trigger how can we gain in E_t acceptance by applying HLT *b*-tagging ?

L1	KHz	HLT	Hz
3J90	0.2	3j165	10
4J65	0.2	4j110	10

Standard trigger menu

Trigger selections: *b*-tagging

Study of the *b*-tagging strategies given HLT (and L1) constraints.

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L1	KHz	HLT	Hz
3J90	0.2	3j165	10
		3b90	10
4J65	0.2	4j110	10
		4b65	10

very loose btagging ($\epsilon_b \sim 90\%$) at L2 or EF

Trigger selections: *b*-tagging

Study of the *b*-tagging strategies given HLT (and L1) constraints.

Assuming 20 Hz for the HLT output on multi-jet trigger how can we gain in E_t acceptance by applying HLT *b*-tagging ?

L1	KHz	HLT	
3J90	0.2	3j165	10
3J80	0.5	3b80	10
4J65	0.2	4j110	10
4J55	0.5	4b55	10

btagging: L2 ($\epsilon_b \sim 90\%$) EF ($\epsilon_b \sim 80\%$).
$\times 2$ L1 rate

Trigger selections: *b*-tagging

Study of the *b*-tagging strategies given HLT (and L1) constraints.

Assuming 20 Hz for the HLT output on multi-jet trigger how can we gain in E_t acceptance by applying HLT *b*-tagging ?

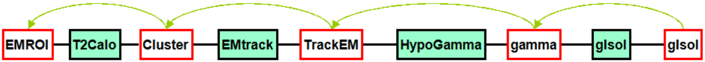
L1	KHz	HLT	
3J90	0.2	3j165	10
3J65	2	3b65	10
4J65	0.2	4j110	10
4J45	2	4b45	10

btagging: L2 ($\epsilon_b \sim 85\%$) EF ($\epsilon_b \sim 75\%$).
$\times$20 L1 rate

The multi-jet L1 rate ($3J + 4J$) is still a fraction of the total L1 rate (20 KHz) and well below the maximum allowed L1 rate ($\sim$ 75 KHz).
Anyway the final choice will be driven by the impact on physics channel sensitivity (and on their relevance).

HLT Steering

The steering has been used for a long time in the trigger slices.
First tests of scalability and timing were recently performed, moving from simple sequences to more complex scenarios; these triggered a significant timing optimization.
From this ...



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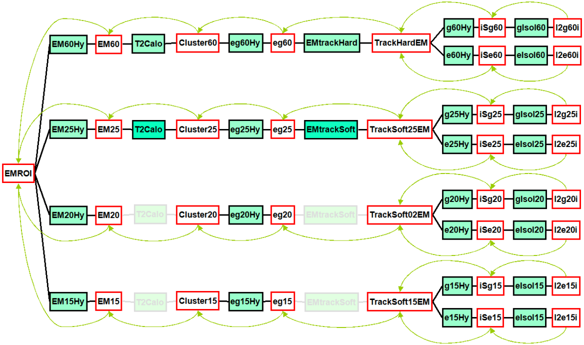
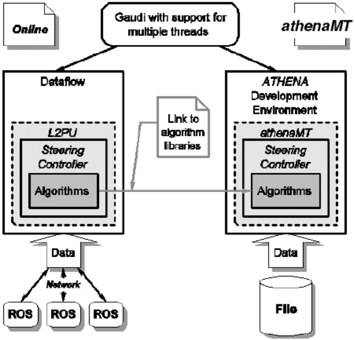


First measurements show that the Steering consumes a small fraction of L2 decision time.

Online Integration

HLT software development and first stage of testing in offline environment
Prior to deployment, certification on prototype multi-node data-flow systems using an emulated Read Out System (test bed)



Strategy

- slice integration
- combine slices to a single job
- test slices and combined job on online test beds and on pre-series (validation of a fully functional, small scale, versione of the complete HLT/DAQ)

Examples of physics applications: e/γ and Higgs

Results on single and double e/γ menus were used to evaluate the HLT efficiency for Z and W bosons and for Higgs candidates in the decay $H(120 \text{ GeV}) \rightarrow 2\gamma$.

To evaluate efficiency w.r.t. to the sample, geometrical and kinematical cuts on MC truth were taken into account.

Results for $H(120 \text{ GeV}) \rightarrow 2\gamma$

Trigger	L1 Eff	L2 Eff	EF Eff
$2\gamma20i$	94 %	84 %	78 %
$\gamma60$	85 %	81 %	69 %
$\gamma60$ or $2\gamma20i$	98 %	94 %	89 %

Geometrical and kinematical requirements applied on MC truth:

- one photon with $E_T > 40 \text{ GeV}$;
- one additional photon with $E_T > 25 \text{ GeV}$;
- both photons within $|\eta| < 2.4$, excluding barrel/endcap crack.

First tests with real data: *e* at the CTB

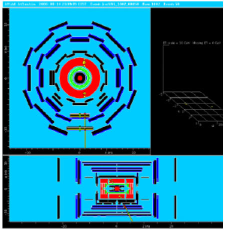
ID tracking algorithms were tested at the CTB, with no *ad hoc* modifications:

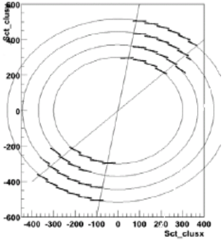
- tracking efficiency: 95% for 20 GeV positrons, 99% for 150 GeV muons;
- extrapolation from Si-detectors to TRT and Calorimeters put in place;
- particle identification with TRT tested.

CTB data was used to evaluate the electron efficiency and π fake rate obtained with selections based on modified L2 calorimeter algorithms.

	Electron eff. (%)	Fake π rate (Hz)
20 GeV sample	95.3 ± 0.4	1.6 ± 0.2
50 GeV sample	94.9 ± 0.3	0.7 ± 0.2

First tests with real data: cosmic runs





Offline reconstruction of muon tracks.
Integration of L2 with installed μ system.

Cosmic μ runs useful to understand timing information in the trigger (L2 & EF) for cosmic muons that don't come from interaction point and at random timing.

SCT only.
Offline reconstruction using IDSCAN and SiTrack, efficiency with respect to the offline track

	IdScan	SiTrack
crossed layers		
all(=4)	78.7%	90.6%
3	69.9%	84.3%

Preparing for tests with real data

Tests with realistic detector conditions.

Even before moving to real data studies, the trigger performance must be validated, using simulated data, against realistic detector simulations including:

- misalignments;
- miscalibrations;
- detector inefficiencies.

Commissioning with first collisions.

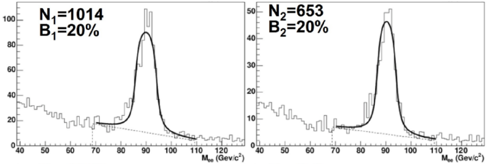
Study operation with "as installed" detectors.
Set-up a realistic trigger menu, emphasizing studies on pre-scales.
Single electron efficiency evaluation using $Z \to ee$ (see following slide).
Single muon efficiency evaluation using $Z \to \mu\mu$.
Hadronic and EM energy calibrations.
b-tagging tuning on $t\bar{t}$ samples.

Preparing for tests with real data: *e* trigger efficiency

Methods are being developed to extract efficiencies using physics events.

Operation scheme:

- run the HLT single *e*25*i* and double 2*e*25*i* selections and store events offline;
- determine the number of *Z*s in the two cases by a fitting procedure;
- compare the two samples to obtain single electron efficiency.



	$Z \to ee$ method	e/γ analysis framework
Method used	$Z \to ee$	MC truth
Eff. after L2 (%)	87.0 ± 0.2	87.0 ± 0.6

A 3% uncertainty on the evaluated efficiency should be achieved after 30 minutes of data acquisition at $10^{33} cm^{-2} s^{-1}$.

Conclusions

The ATLAS HLT Trigger system has strong links with all the other development areas in the experiment: detectors, online and offline software, physics performance, networking, computing, etc...

Trigger operation is a very challenging subject from the technical point of view; the system performance must be constantly monitored as the software components evolve and considerable optimisation will be required to fit within the resources available.

Trigger slices reached a mature stage, so next steps will be to study their integration in the online framework and to test the implementation of realistic menus.

From the physics performance point of view, this means having a collaboration with physics and combined performance working groups. These have the role of testing the quality of the trigger selections, providing an important feedback for their tuning.

Lots of progress is being achieved in all these areas and in the study of their interactions, starting to form an overall picture of the problems that still have to be attacked and solved.