ATLAS Trigger System, performance and strategy for Physics

Valeria Perez Reale (CERN)
On behalf of the ATLAS Collaboration

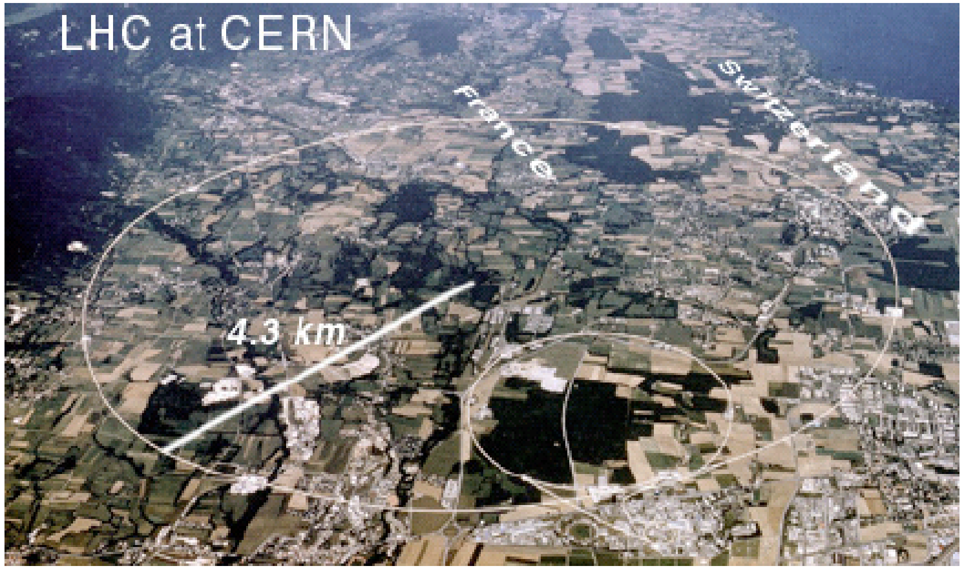
HEP 2008, Valparaiso, January 7, 2007

OUTLINE

- **Physics Motivation**
- **ATLAS Trigger System:**
  - **Requirements and main ideas**
- **Trigger Strategy for Physics:**
  - **Baseline for Early running**
  - **Strategy for higher luminosities**
- **Trigger Performance:**
  - **Optimization & system performance**
  - **Trigger Efficiency determination from data**
- **Trigger Performance on Physics**
  - **electrons, photons, taus, muons, jets, Bphysics triggers…**
- **Summary**

Large Hadron Collider

- pp collisions at $\sqrt{s}$=14 TeV
- Bunch crossing every 25 ns
- Interaction rate R=40 MHz
- Low Luminosity **$L = 10^{33}$ cm^{-2} s^{-1}**
  ($\mathcal{L}$=10fb^{-1}/year)
- High Luminosity **$L = 10^{34}$ cm^{-2} s^{-1}**
  ($\mathcal{L}$=100fb^{-1}/year)



Process	Events for 10fb^{-1}
Beauty	**10^{13}**
W→eν	**10^{8}**
Z→ee, Top	**10^{7}**
Black holes (m>3 TeV)	**10^{3}**
Higgs M_H=130 GeV	**10^{5}**

⇨ Large statistics: small statistical error

Production cross section and dynamics largely controlled by QCD

Mass reach up to ~ 5 TeV

Test QCD predictions and perform precision measurements

ATLAS Detector

Centre of mass energy = 14 TeV

BX rate = 40 MHz

pp-collision rate = 1 GHz

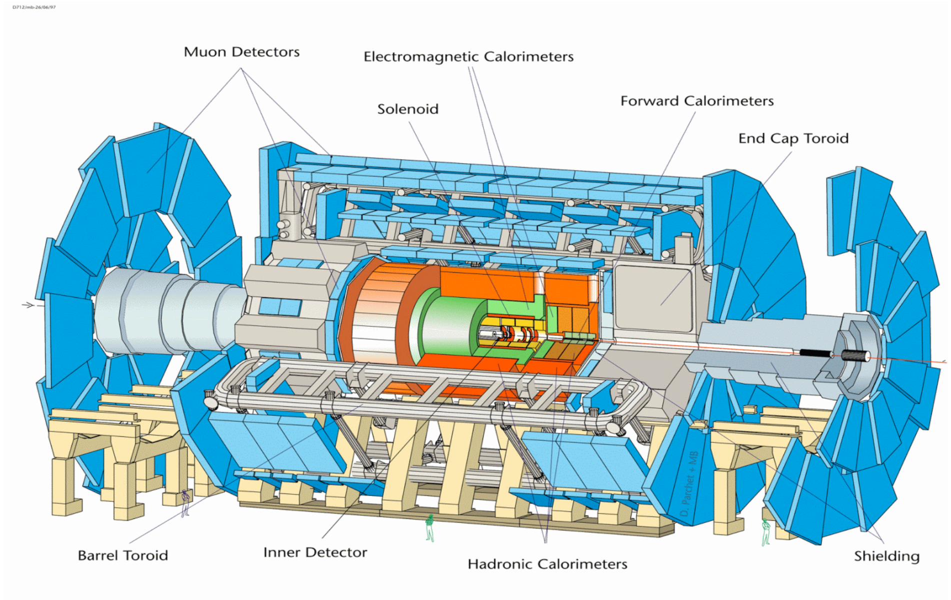
Luminosity :

initial: $10^{31} cm^{-2} s^{-1}$

design: $10^{34} cm^{-2} s^{-1}$

7000 Ton Detector,

22m Diameter, 46m Long



Inner Detector (tracker): *Si pixel & strip detectors + TRT; 2 T magnetic field; $|\eta| < 2.5$*

***Calorimetry**: highly granular LAr EM calorimeter ($|\eta| < 3.2$); hadron calorimeter – scintillator tile; $|\eta| < 4.9$*

***Muon Spectrometer**: air-core toroid system; $|\eta| < 2.7$*

ATLAS detector is a general purpose spectrometer: broad physics program with an emphasis on high-p_T physics (p_T~10 GeV)

- See **ATLAS Overview talk by P. Jenni** - Fri 11th
- See **ATLAS SM Physics talk by M. Wielers** Fri 11th
- See **ATLAS beyond SM Physics talk by H.P. Beck** from today's morning session

Trigger Requirements: Rates

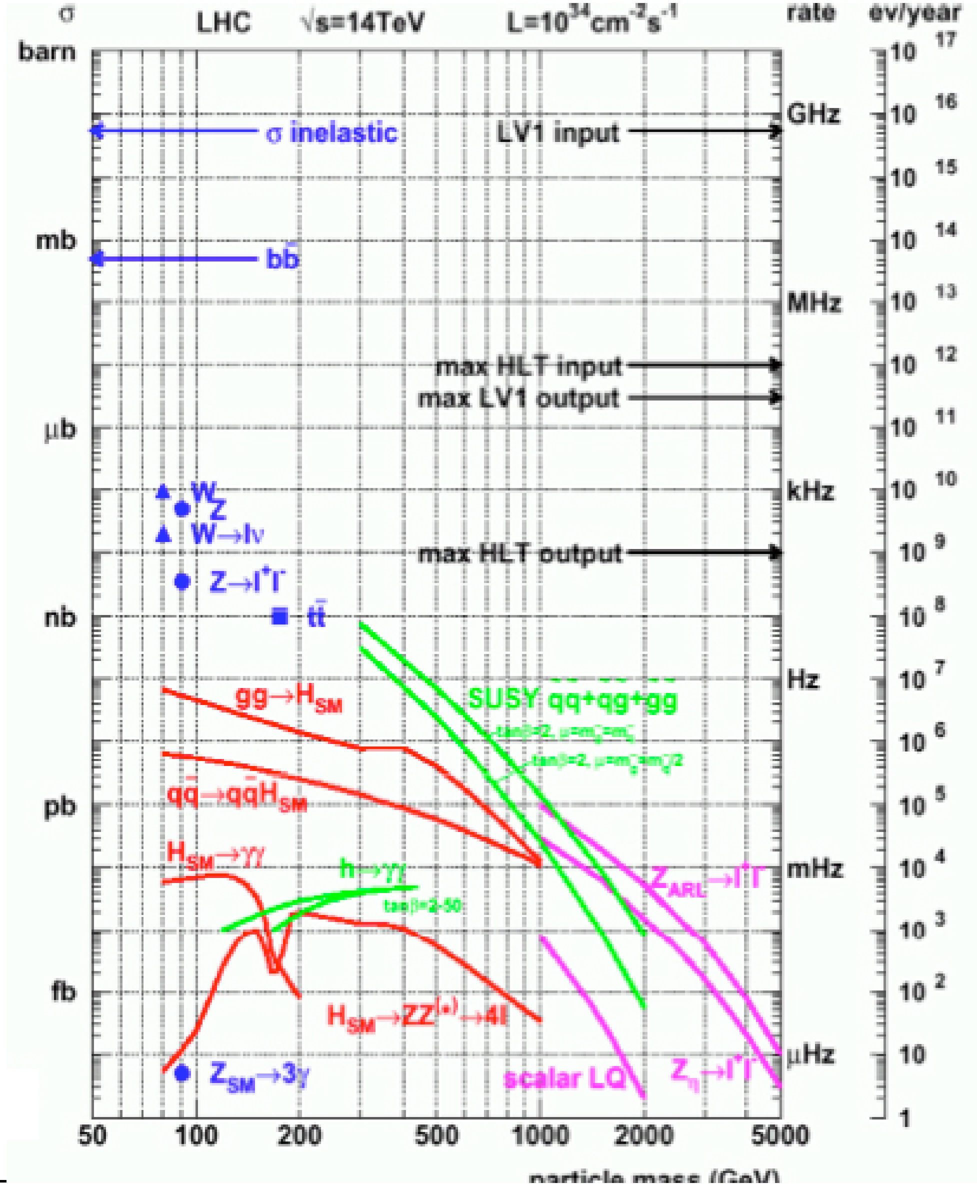
Interaction Rate
$R = L \times \sigma_{inelastic}$ (pp)
$R = 10^{34}\ cm^{-2}\ s^{-1} \times 70\ mb$
$R = 10^{9}$ Hz
Bunch crossing rate $\Delta t = 25$ ns

Physics Cross Sections:

- Inelastic: 10^{9}Hz
- $W \rightarrow l\nu$ 10^{2}Hz
- t t production: 10 Hz
- Higgs (100 GeV/c2): 0.1 Hz
- Higgs (600 GeV/c2): 10^{-2}Hz
- 250 GeV E_T Jets - 1kHz

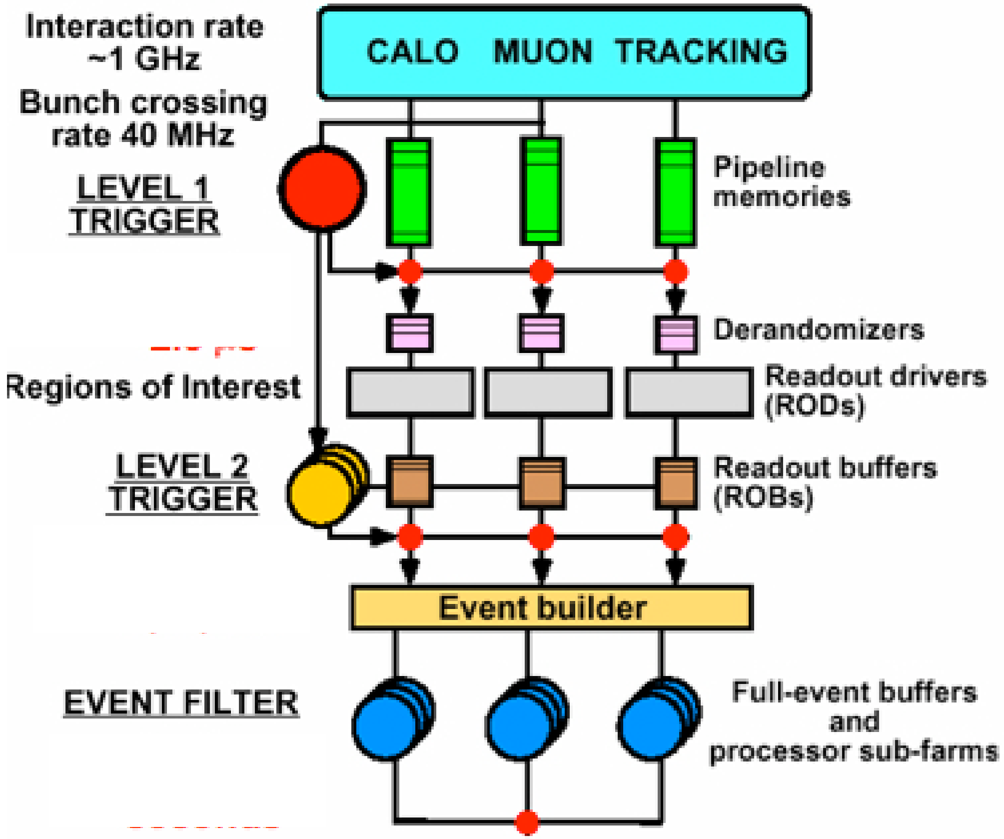
Rejection power 10^{10-11}

Trigger must reduce rate: 40 MHz → ~ 200 Hz



ATLAS: 3 Level Trigger

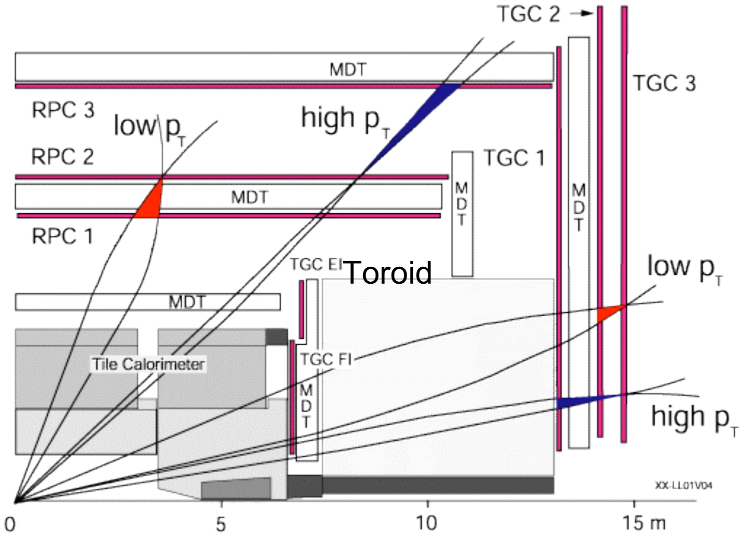
- **L1**
  - **Custom electronics & ASICS, FPGAs**
  - **Latency: 2.5 μs**
  - **Use of Calorimeter and Muon detector data**
  - **Reduce interaction rate to 75 kHz**
- **L2**
  - **Software trigger based on linux PC farm (~500 dual CPUs)**
  - **Mean processing time ~40 ms**
  - **Uses selected data from all detectors (Regions of Interest indicated by LVL1)**
  - **Reduces LVL1 rate to ~2 kHz**
- **Event Filter (L3)**
  - **Software trigger based on linux PC farm (~1600 dual CPUs)**
  - **Mean processing time ~4s**
  - **Full event & calibration data available**
  - **Reduces LVL2 rate to ~200Hz**
  - **Note – large fraction of HLT processor cost deferred to initial running with reduced computing capacity**



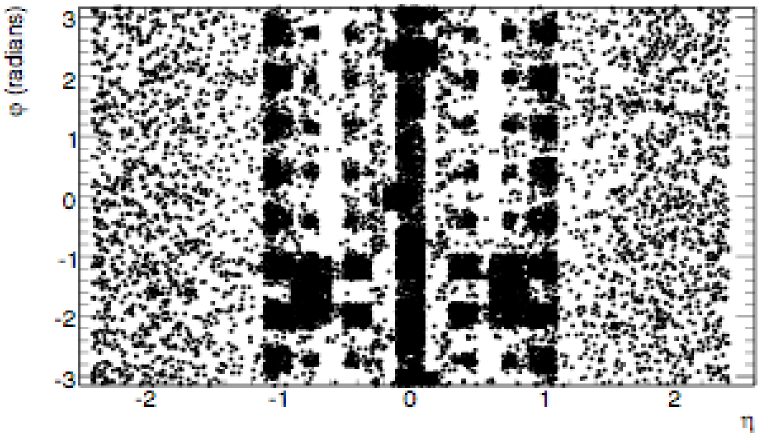
High Level Trigger:

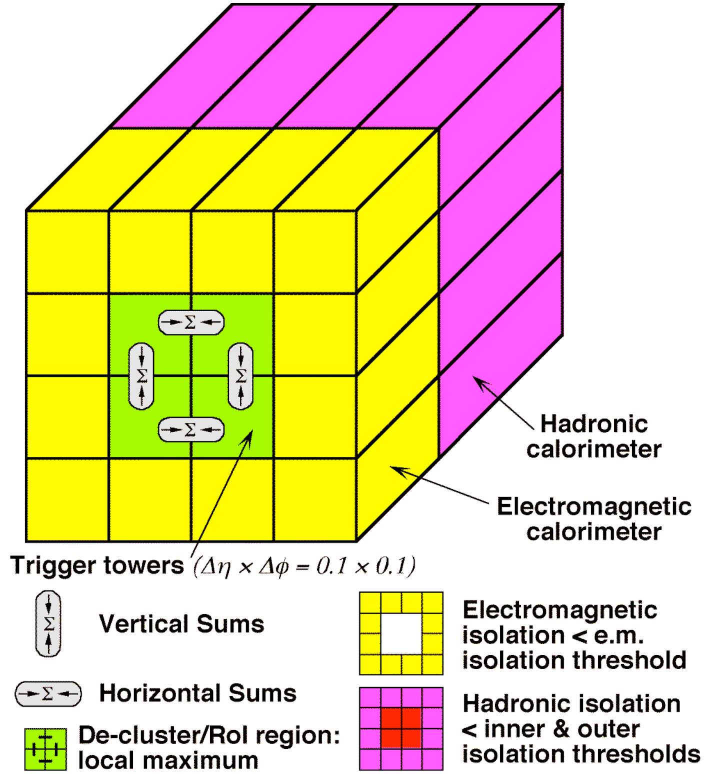
LVL2 + Event Filter

L1: Muons & Calorimetry



Muon Trigger looking for coincidences in muon trigger chambers





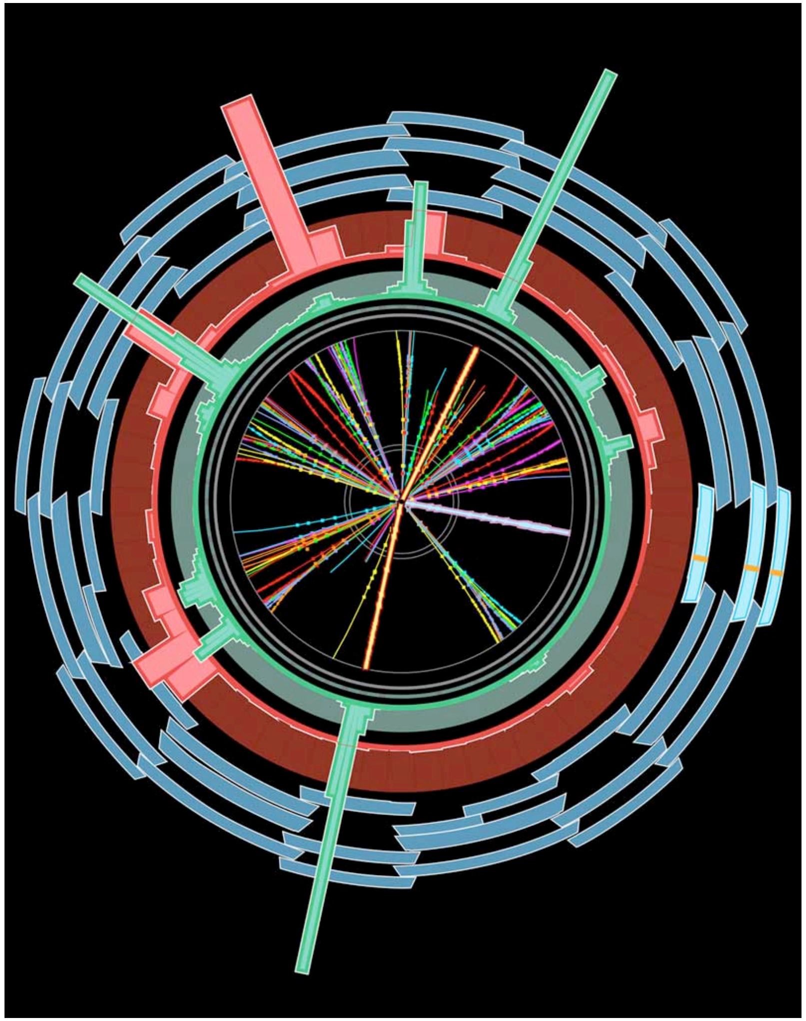
Calorimetry Trigger looking for e/γ/τ+ jets+ETmiss/sumET

- **Various combinations of cluster sums and isolation criteria**

HLT Event Selection

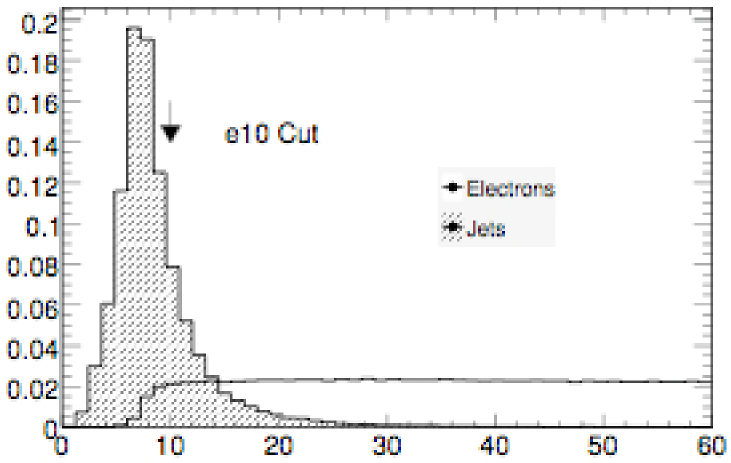
- **Regions of Interest**
  - Reduce data bandwidth at LVL2
  - Reconstruction in regions of interest **RoI in $\Delta\eta$ x $\Delta\varphi$** (~2% of the detector)

- **Early rejection**
  - Three level trigger
  - **Steps** within LVL2 and EF
  - Alternate steps of feauture extraction with hypothesis testing
  - Events can be rejected at any step if the required criteria is not fulfilled (signature)

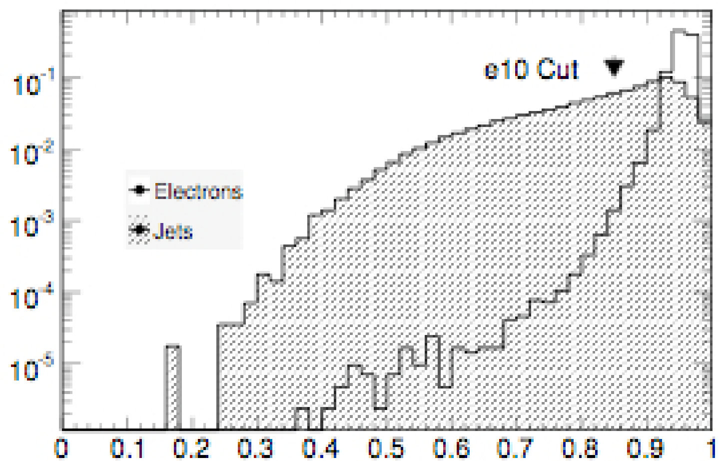


Goal: Reduce decision latency and network traffic

Example: e/γ-ID at the L2 trigger



ET (GeV)



E3x7/E7x7

T2CaloEgamma:

- Performs calorimeter cluster reconstrunction.
- Full detector granularity
- Shower shape variables to discriminate electron/photon of jets

IDSCAN:

- zFinder: Reconstruction of the z-position of the primary pp collision
- hitFilter & groupCleaner: The main pattern recognition step
- trackFitter: final track fit and removal of outliers

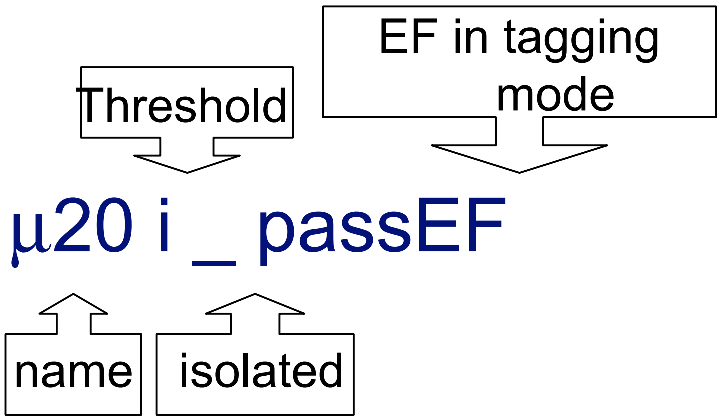
SiTrack:

- Space point sorting
- Track seeds formation
- Primary vertex reconstruction
- Track extension

Trigger Selection

- Trigger must efficiently cover ATLAS physics programme for SM precision measurements and for new physics searches
- **inclusive online selection approach to the "unknown", safe overlap with Tevatron reach, avoid biases from exclusive selections, margin for offline optimization and QCD uncertainties**
- enough bandwidth for commissioning, calibration, monitoring triggers (especially at beginning !)
- Single and di-object high p_T triggers (p_T~10 GeV) : electrons, photons, muons, taus, jets, missing ET

Trigger Item:



Rate Constraints:

Rate	Design	Early Running
L1	75 kHz	45 kHz
L2	2 kHz	1 kHz
EF	200 Hz	200 Hz

Early running and Start-up

The expected start-up luminosity at the LHC **$L=10^{31}$ $cm^{-2}s^{-1}$** provides convenient conditions for commissioning of the trigger and detectors, validate trigger and offline algorithms and ensure basic SM signatures can be observed

- Start-up menu with L1 items only non prescaled and HLT items in “flag” mode
- HLT selection added once L1 understood
- Triggers are as simple as possible: no isolation or complex criteria

Signature	Examples of physics coverage	L= 1* 10^{31} $cm^{-2}s^{-1}$	Rates (Hz)
Minimum bias	Prescaled trigger item		10
e10, 2e5	b,c→e, W, Z, Drell-Yan,tt, J/ψ,ϒ	electrons	~27
γ20, 2γ15	Direct photon, photon pairs, γ-jet balance	photons	~7
μ10, 2μ4	W,Z,tt, B-Physics, Drell-Yan, J/ψ,ϒ	muons	~22
j120, 4j23	QCD, high pT final states,multi-jet final states	jets	~13
τ20i+e10, τ20i+μ6	Z→ττ	taus	4
τ20i+xE30	W,tt	Tau+missingET	~10
	Prescaled, calibration, monitoring triggers		~17
Total HLT rate			~100

Example: W→eν and jet triggers

- Trigger items for W→eνphysics process

Signature	LVL1 item	EF selection	Pre-scale	Rate [Hz]	Motivation
e20	EM18	loose	1	4.3 ± 0.2	main physics trigger
g20	EM18	loose	1	5.4 ± 0.2	redundancy, check of tracking eff. and performance
e20_xe15	EM18_XE15	loose	1	1.6 ± 0.1	backup if rate is too high
g20_xe15	EM18_XE15	loose	1	1.9 ± 0.2	backup if rate is too high, check tracking eff and performance
e15_xe20	EM13_XE20	loose	1	1.0 ± 0.4	access to lower p_T-range
e10_xe30	EM7_XE30	medium	1	0.3 ± 0.3	access to lower p_T-range
e20i	EM18I	loose	1	2.8 ± 0.1	backup if rate too high
e25i	EM23I	loose	1	1.4 ± 0.1	backup if rate too high

- Single and mutli-jet L1 jet trigger items: for different luminosities strategy is to modify prescale factors

Trigger item	j10	j18	j23	j35	j42	j70	j120	3j10	3j18	4j10	4j18	4j23
Pre-scale factor at L1	42000	6000	2000	500	100	15	1	150	1	30	1	1
L1 rate (Hz)	4	1	1	1	4	4	9	40	140	40	20	8
EF rate (Hz)	4	1	1	1	4	4	9	0.05	1	0.04	0.1	5

Towards Higher Luminosities

• Towards a higher luminosity at the LHC **$L=10^{33}$ $cm^{-2}s^{-1}$** the trigger and detector will be better understood, the full ATLAS physics programme should be covered by the trigger
• Due to higher rates triggers L1 isolation must be added or more complex criteria or increase of E_T thresholds or prescale must be added/increased

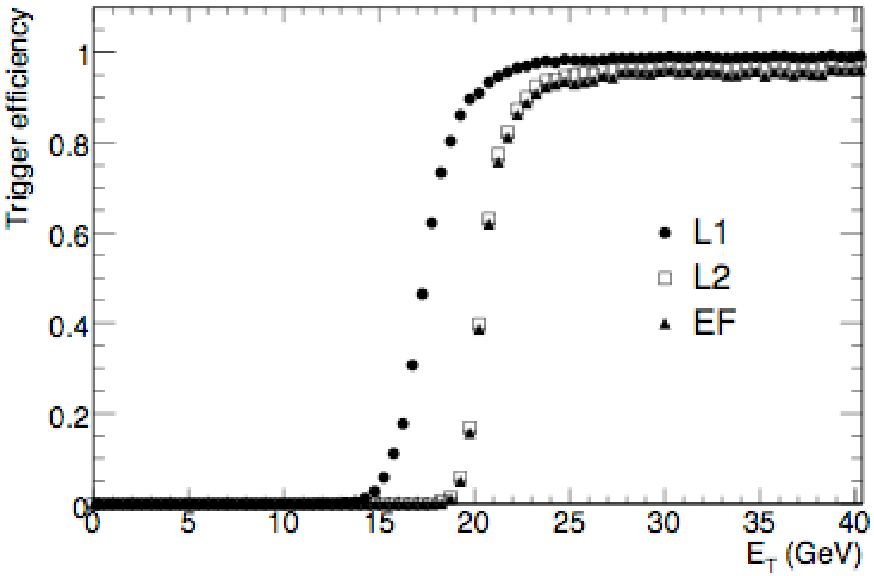
Signature	Examples of physics coverage	L= 1* 10^{33} $cm^{-2}s^{-1}$	Rates (Hz)
e22i, 2e12i	Higgs (SM, MSSM), new gauge bosons, extra dimensions, SUSY, W, top	electrons	~40
2γ17i, γ55	Higgs (SM, MSSM), extra dimensions, SUSY	photons	~27
μ20i, 2μ10	Higgs (SM, MSSM), new gauge bosons, extra dimensions, SUSY, W, top,	muons	~50
2μ6 for Bphysics	Rare b-decays (B→μμX, B→JΨ(Ψ')X	Bphysics	~10
J370, 4j90	SUSY, compositeness, resonances	jets	20
j65+xE70	SUSY, leptoquarks	Jet+MissingET	~5
τ35i+xE45	Extended Higgs models (e.g. MSSM), SUSY	Tau+MissingET	~10
Total HLT rate			~200

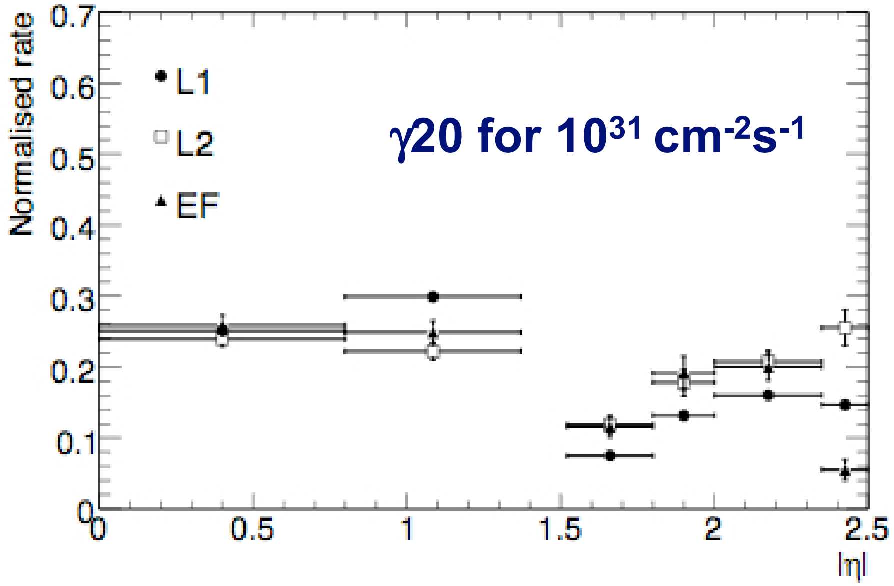
Trigger menus will evolve continuously with time to reflect our best knowledge of the physics and the detector

Trigger Optimization

The trigger performance optimization of a trigger item is a compromise between several factors:

1) **trigger efficiency for signal**
2) **QCD background rate (constrained by total allowed HLT bandwidth)**
3) **constrains of the average execution time at each trigger level**





- Efficiency after the last trigger selection step (EF) with respect to offline as high as possible: e.g. for photons 80% a factor 1000 of rejection

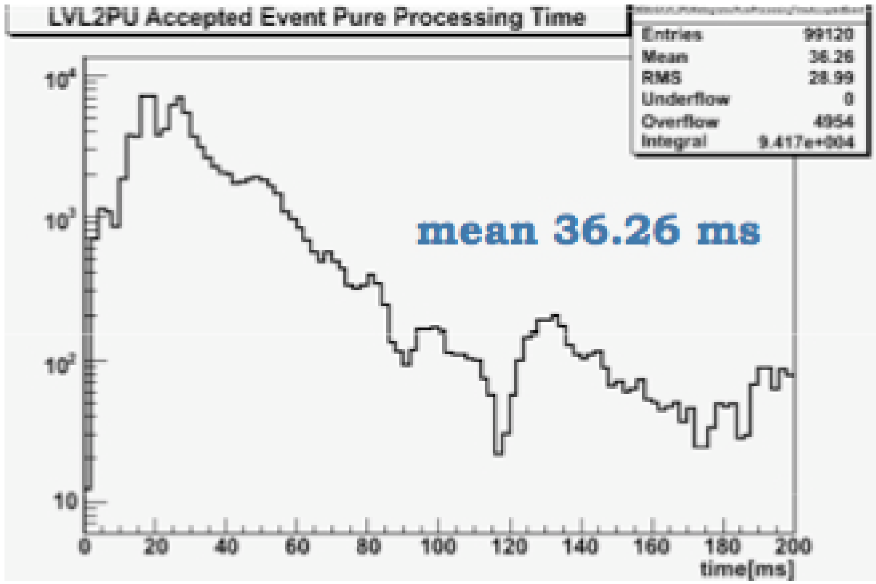
System Performance

• The High Level Trigger algorithms have been tested **“online”** in different Technical runs in which simulated raw data are preloaded in to the readout systems and played back through the HLT/DAQ system

• ~10% of TDAQ final system tested with real network switches

• Simulated Monte Carlo ttbar events (mixture of events)

• **More than 200 trigger items tested online!!**



LVL2 processing time

• The HLT acceptance/rejection is the same for online-offline running

• **LVL2 processing time measured online is compatible with the designed 40 ms/event**

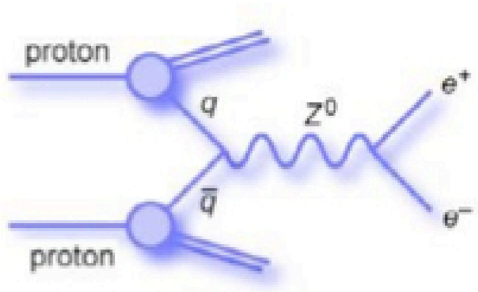
Measurement of Trigger Efficiency (I)

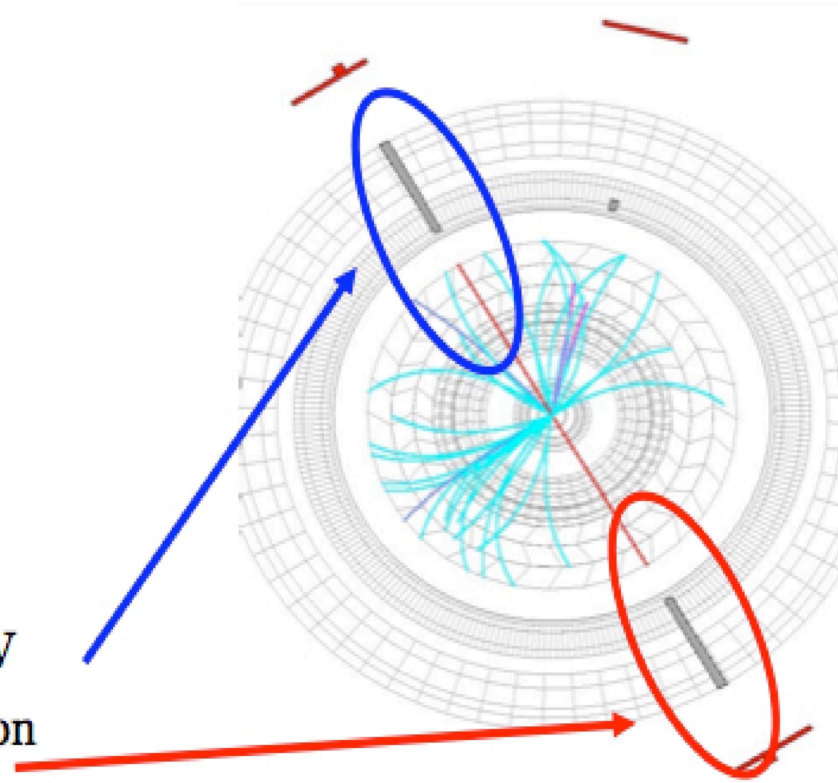
Two independent methods to estimate the trigger efficiency from data have been studied in ATLAS (independent of Monte Carlo methods):

• **Tag and probe:** triggering events with the electron in Z→ee decays and measuring the efficiency to trigger on the positron in addition

• **Boot-strap:** method using minimum bias events to measure the efficiency to trigger on low pT jets, then triggering on low pT jets and using them to measure the efficiency to trigger on the higher pT jets, etc.

- One method: Tag&Probe:





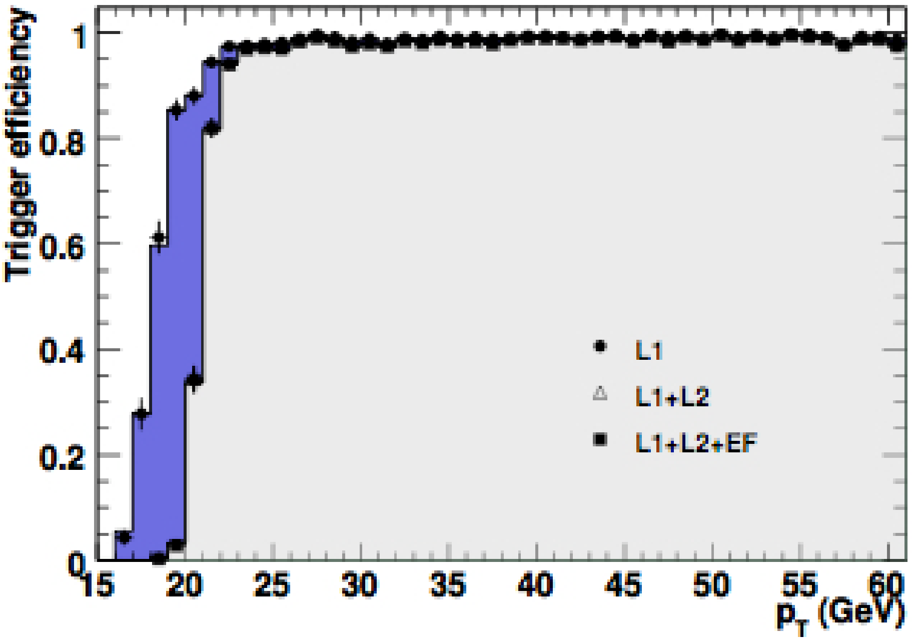
In offline analysis require:

- Two reconstructed electrons with $M_{inv} = M_Z$ +/- 20GeV
- Require that event has been triggered by "Tag" electron
- Determine trigger efficiency with "Probe" electron

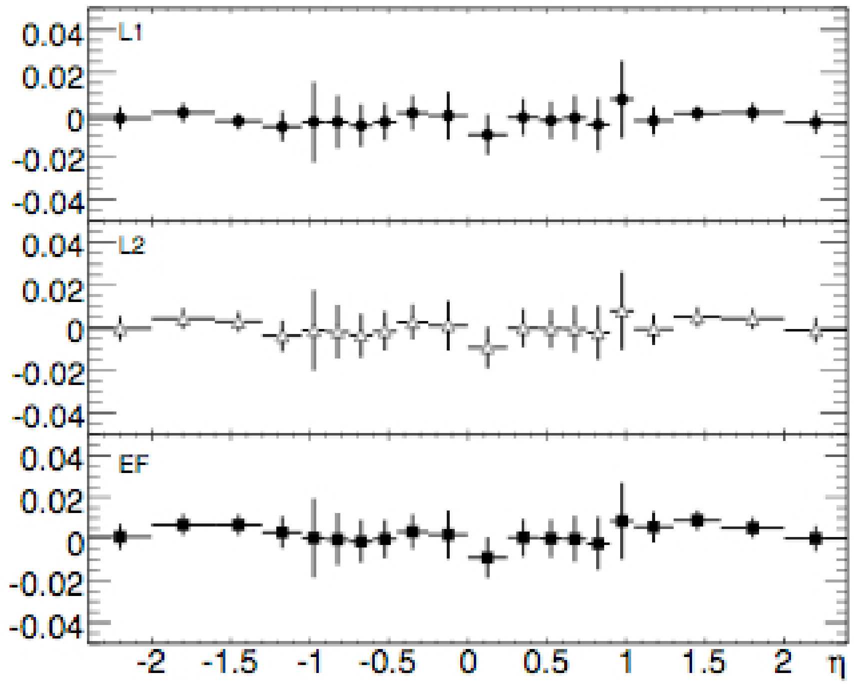
Measurement of Trigger Efficiency (II)

The tag and probe method single electron (from Z→ee events) and single muon trigger efficiency (from $Z \rightarrow \mu\mu$) has been evaluated for an integrated luminosity of 100 pb^{-1}:

- values agrees with MC thruth trigger efficiency better than 1%



e20 trigger item: Z→ee decays for 100 pb^{-1}



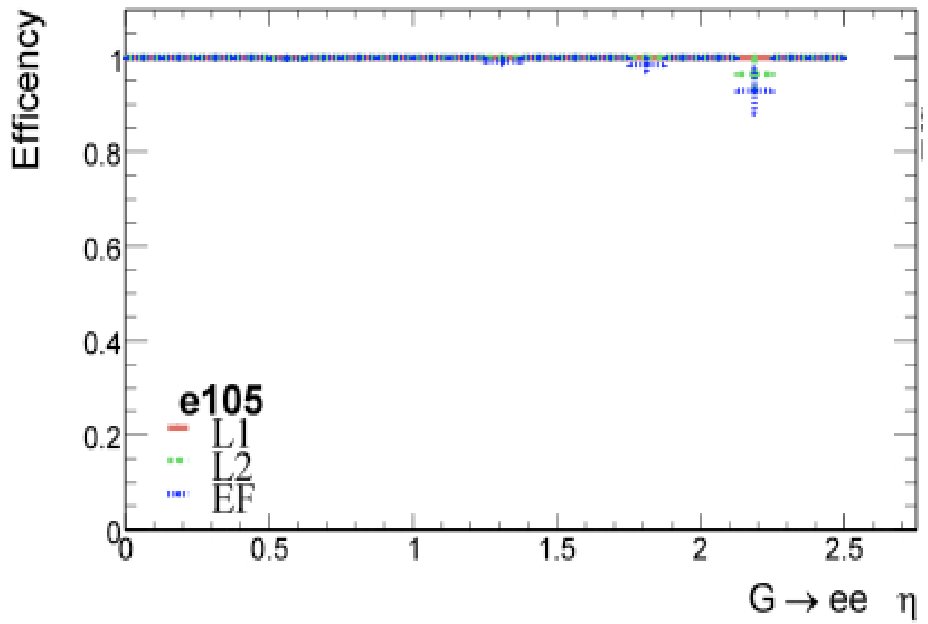
Difference in trigger efficiency tag and probe and MC truth: $Z \rightarrow \mu\mu$ decays for 100 pb^{-1}

Electrons: very high pT

Trigger performance studies have covered the high pT range of electrons from heavy objects (M~1 TeV): Extra dimensional Gravitons and heavy gauge bosons Z'

- early running **10^{31} cm^{-2} s^{-1}** : only L1 selection p_T>100 GeV (100% efficient)
- to low luminosity **10^{33} cm^{-2} s^{-1}** : add HLT selection to keep rate <1 Hz

e105	G→ee (500 GeV)	Z'→ee (1TeV)
L1	100 ± 0.1	99.9 ± 0.1



- Very good trigger performance wrt to offline of high p_T electron trigger menus for initial running

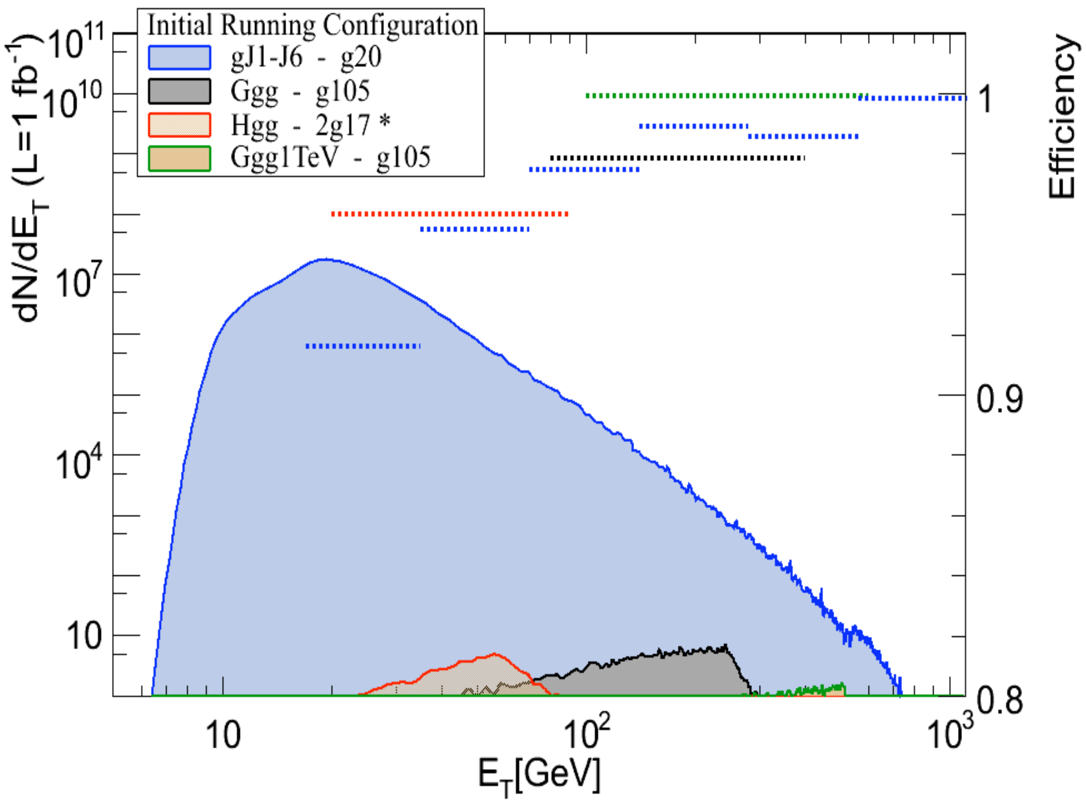
Photons

Trigger performance studies have covered the a wide pT range of photons spectrum from 10 GeV to 1 TeV addressing trigger efficiency strategy, optimization and rate evaluation for:

- early running **10^{31} cm^{-2} s^{-1}** : direct photon production, Exotics
- to low luminosity **10^{33} cm^{-2} s^{-1}** : SM Higgs $H \to \gamma\gamma$

- Trigger for SM $H \to \gamma\gamma$ at low luminosity 10^{33} cm^{-2} s^{-1} 2γ17i is efficient wrt offline with affordable QCD jet rate of few Hz

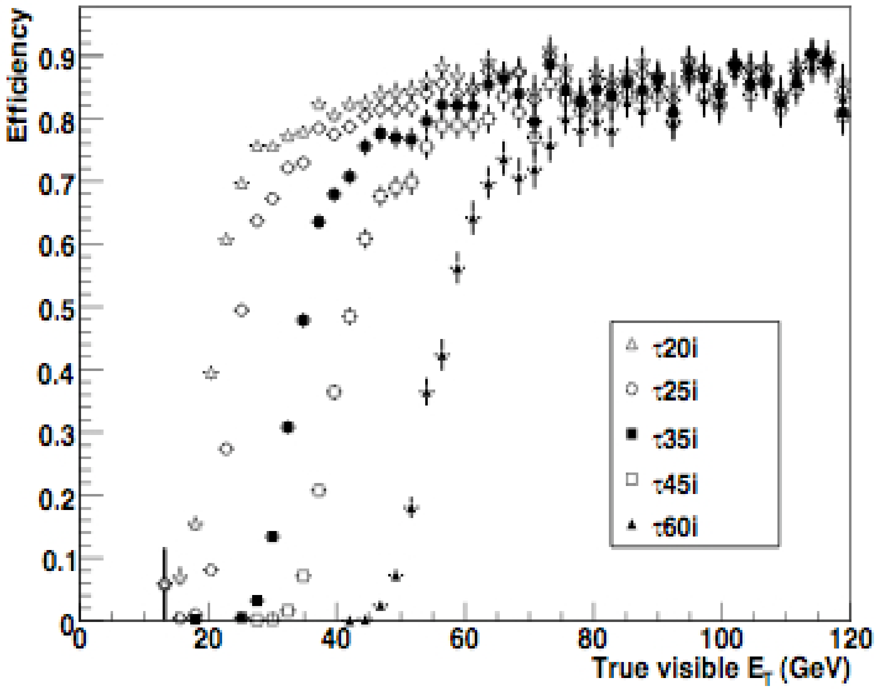
2γ17i	$H \to \gamma\gamma$ (120 GeV)
L1	95.9 ± 0.3
L2	94.6 ± 0.3
EF	93.0 ± 0.4



Tau-leptons & ETmiss

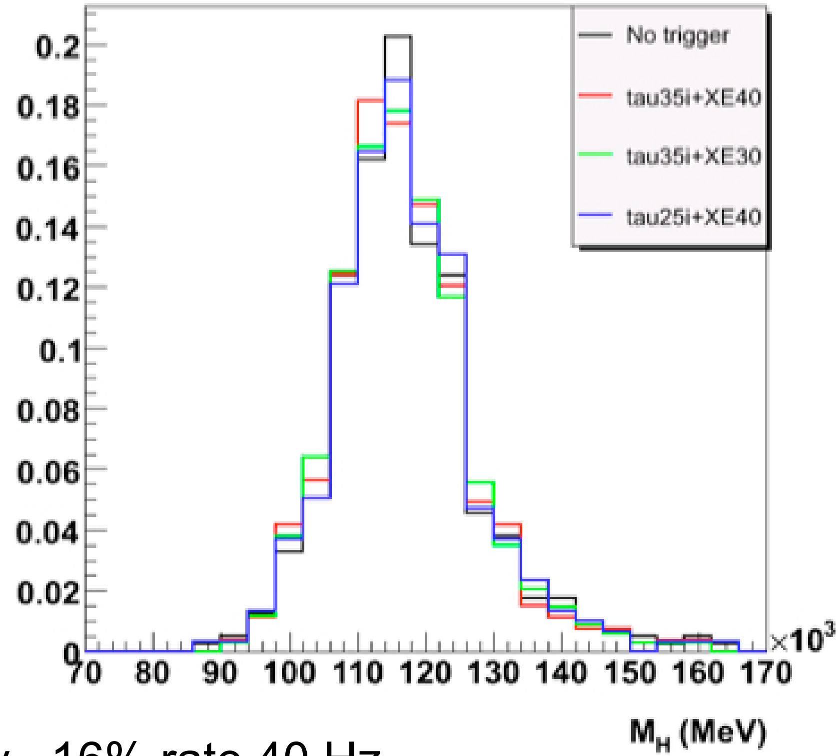
Tau trigger menus for early running from hadronic decays $Z \rightarrow \tau\tau$ $W \rightarrow \tau\nu$

- **85% τ trigger efficiency**
- lots of work in improving performance wrt offline selection



Example Trigger strategy for **VBF H→ττ** at low luminosity 10^{33} cm^{-2} s^{-1} :

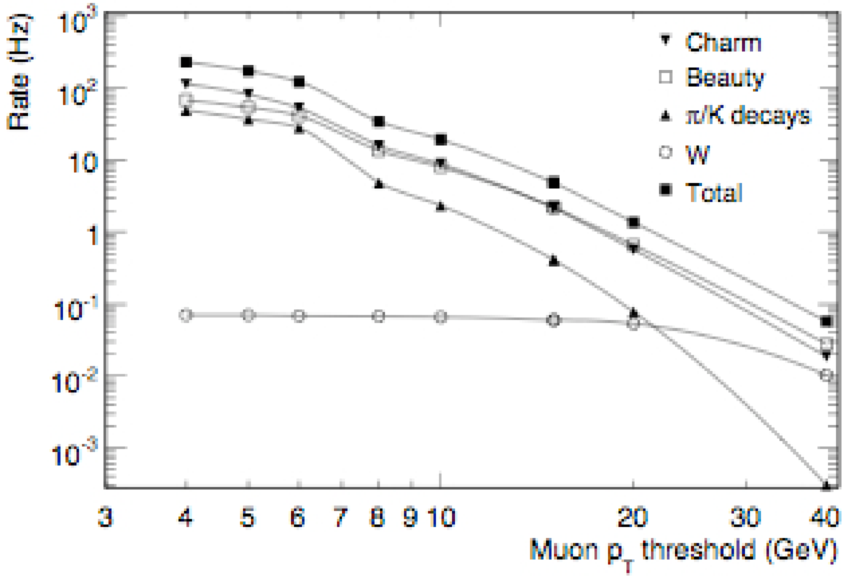
- for ll,lh channels: combined single e or muon+tau or e+muon
- for hh channels: best trigger is tau+tau (visible mass req) or tau+ETmiss



τ35i+xe40 Trigger: overall efficiency ~16% rate 40 Hz

Muons

•Within the fiducial acceptance of the muon trigger detector, the L1 trigger efficiency for muons with pT larger than selection thresholds exceeds 99%

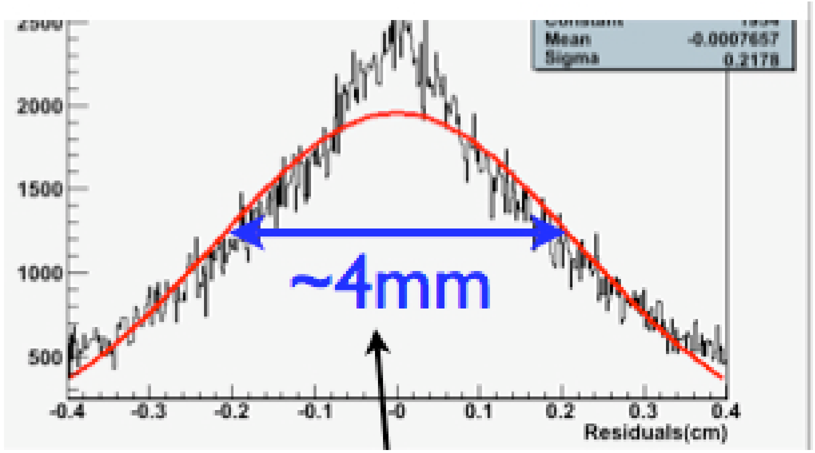


• Estimated EF output rate of single muon vs. pT for L= 10^{31} cm^{-2} s^{-1} : largest contribution from charm, beauty and inflight decays of π/K (4 GeV< p_T < 6 GeV)

• Rate can be further reduced by adding isolation criteria

• The full muon trigger chain has been commissioned with **Cosmic Rays**:

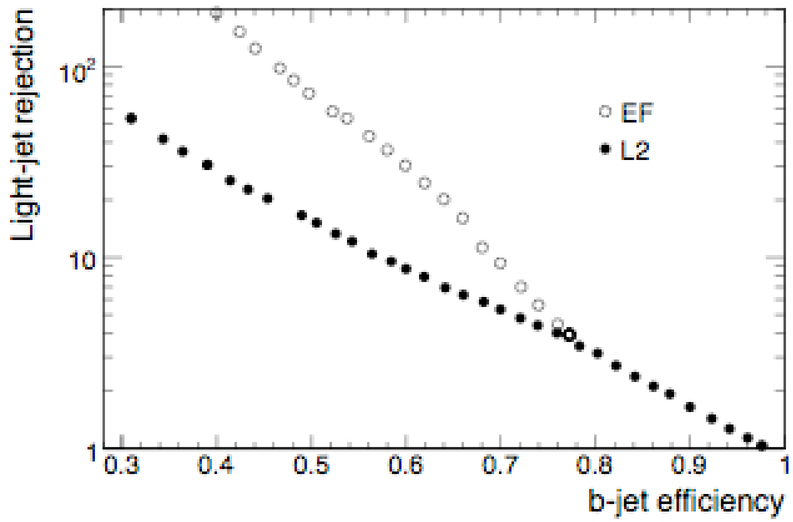
• from the LVL1 muon chambers (RPC, MDT, TGC) to event building after a LVL2 and EF accept signal including RoI mechanism



L2 hits residual

Jets & b-tagging

B-tagging trigger performance



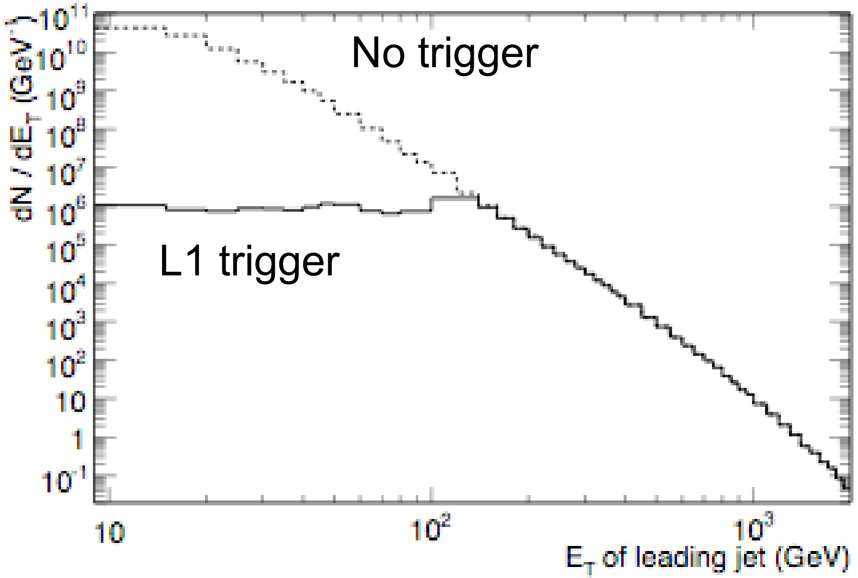
▶ signal: $WH \to b\bar{b}$

▶ background: $WH \to u\bar{u}$

with $m_H = 120$ GeV/c^2.

- Online working point for **ε_b=70%** (R_u=1/ ε_u)
- **B-tagging using likehood methods based on impact parameters is robust**

Jet trigger performance

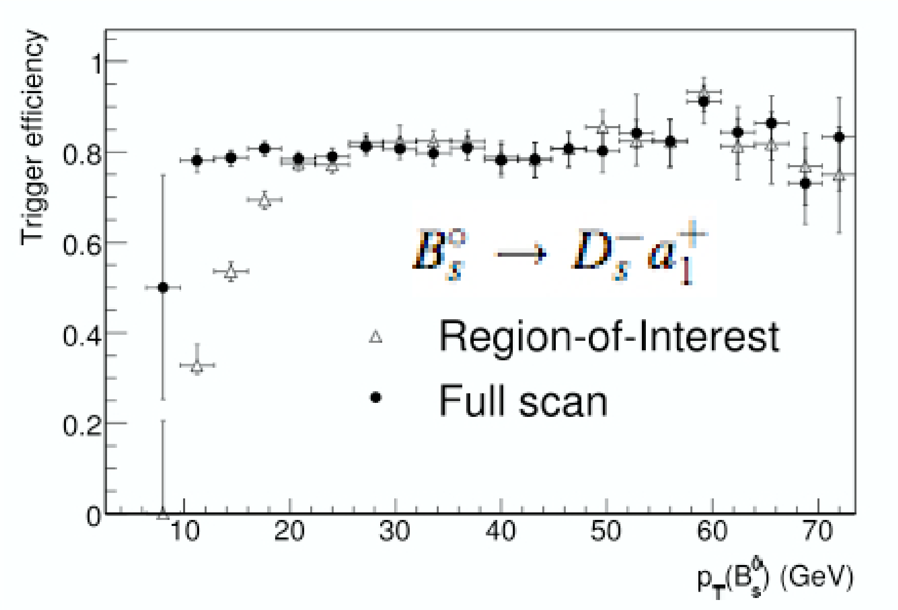


- Inclusive jet triggers give uniform rate across the jet spectrum

$\rightarrow$ 10^8 leading jets with 10 < E_T <100 GeV for 100 pb^{-1}

Bphysics Trigger Strategy

- **High luminosity (>2x10^{33} cm^{-2}s^{-1})** use di-muon trigger (p_T > 6 GeV)
  - B → J/ψ(mm) X
  - Rare decays with di-muon , e.g. B→K^{0*}mm
- **Low luminosity (<2x10^{33} cm^{-2}s^{-1})** use single or dimuon trigger (p_T > 4 GeV) with additional JET/EM RoI information from LVL1. At LVL2 have 2 possible approaches:
  - *Full reconstruction inside inner detector (time costly)*
  - *Use LVL1 Regions of Interest (RoI) to seed LVL2 reconstruction:*
    - Jet RoI for hadronic final states
    - EM RoI for e/g final states
    - Muon RoI to recover di-muon final-states in which second muon was missed at LVL1.



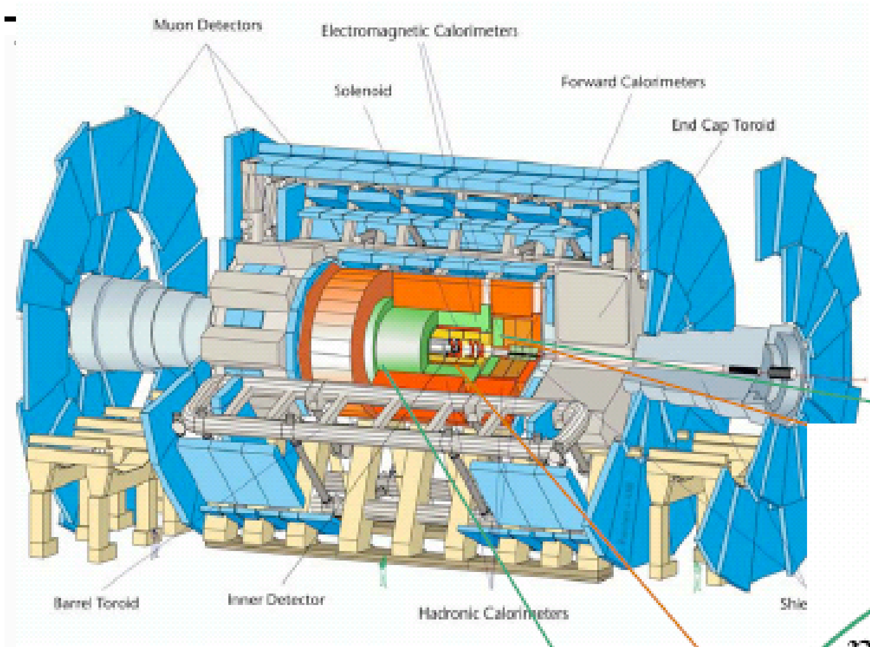
The most performing HLT scenario is the full scan of the Inner detector for low luminosity

CONCLUSIONS

- The ATLAS TDAQ system has a three-level trigger hierarchy, making use of the Region-of-Interest mechanism
  - important reduction of data movement
- A complete physics strategy to cover the complete ATLAS physics programme has been developed for early running and is ongoing for higher luminosities:
  - Monte Carlo simulation studies based on final trigger algorithms and realistic raw-data input yield expected trigger and physics performance
  - Preparation for online running is being assessed: for example methods to determine trigger efficiency from data are available
- The Trigger selection has already been run “online” in ATLAS detector commissioning: Cosmic Rays and Technical Runs:
  - Proof of trigger event selection mechanism: trigger algorithms target processing times are realistic
- Plenty more work remains to be done in testing and commissioning the Trigger system in preparation for data-taking: Cosmics and first collisions

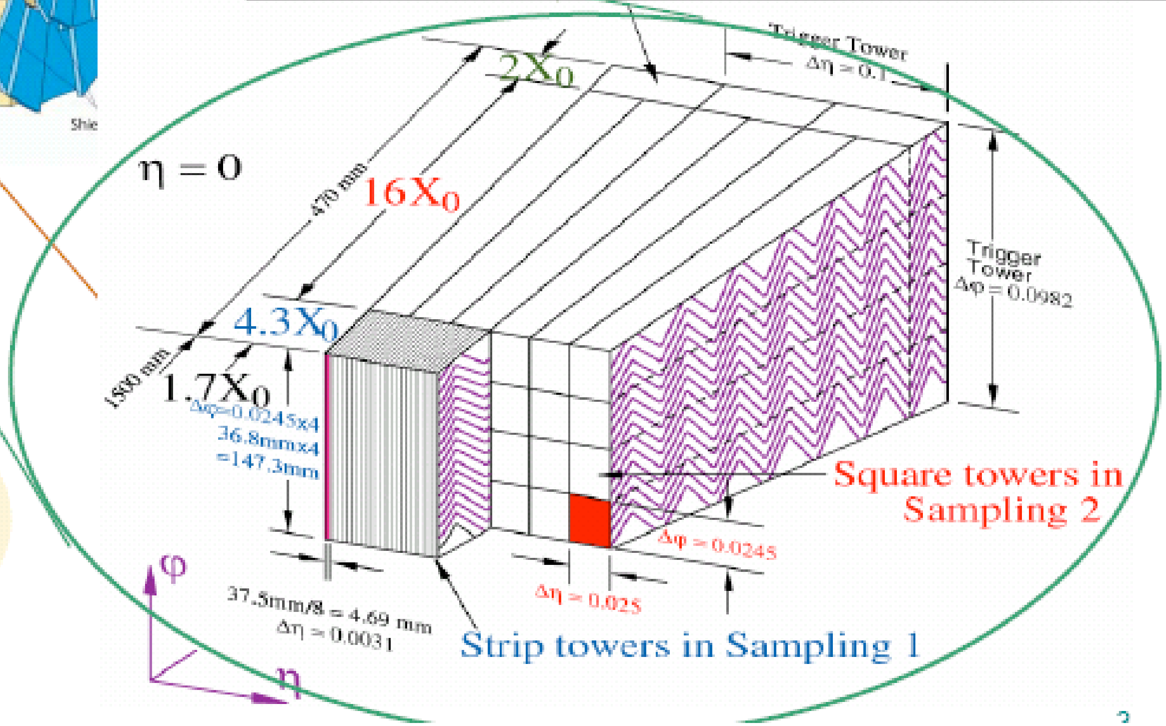
BACK-UP SLIDES

ATLAS Calorimeter System



General requirements for the LArEM:

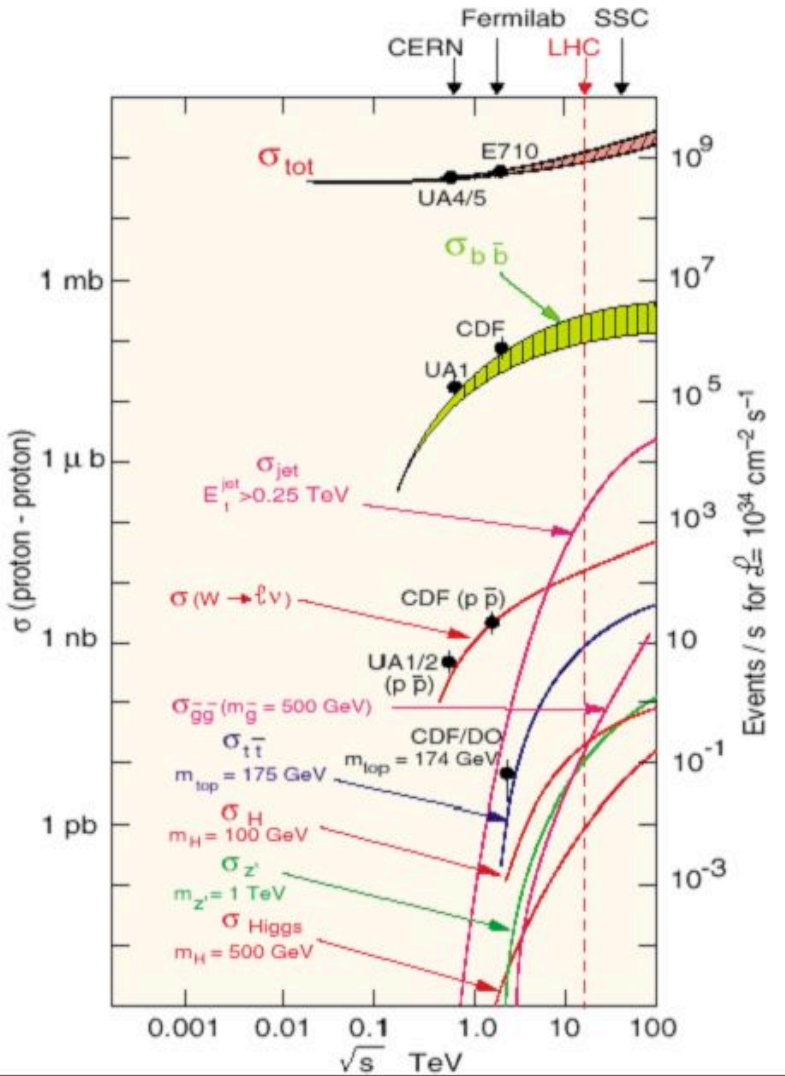
- $\sigma_E/E = 10\%/\sqrt{E} \oplus 24.5\%/E \oplus 0.7\%$
- linearity better than 0.5% up to 300 GeV
- shower direction with σ_θ ~50 mrad / $\sqrt{E}$
- fine granularity of 1st compartment
- shower shape measurement



Layer	Granularity (Δη x Δφ)
Pre-sampler	0.025 x 0.1
Front	0.003 x 0.1
Middle	0.025 x 0.025
Back	0.05 x 0.025

Trigger Requirements

N = L x $s_{inelastic}$ (pp) » 10^{34} cm^{-2} s^{-1} x 70 mb = 10^{9} interactions/s



- Highly hermetic and granular detectors ⊕ large particle multiplicity → **huge data volume!** Average event size 1.5 MB
- 25 ns bunch spacing → **high event rates!**

Data throughput

At detectors (40 MHz)	(equivalent to)	PB/s
--> LVL1 Accepts		100 GB/s
--> Mass storage		**300 MB/s**

- Number of overlapping events per bunch crossing: 23 (1 · 10^{34} cm^{-2}s^{-1}): **pile-up**
- High Energy (14 TeV) → **Huge QCD backgrounds**
- Low cross sections for discovery physics (e.g., Higgs production) →

Rejection power 10^{13} (H->γγ 120 GeV)

•Trigger must reduce rate from 40 MHz (interaction rate) to ~ 200 Hz (affordable rate to storage)

ARCHITECTURE: Functional elements