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The ATLAS Muon Trigger

Experience and Performance
in the first 3 years of LHC pp runs

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ATLAS (A Toroidal LHC ApparatuS)

General purpose experiment at CERN (Geneve) for Standard Model high-precision measurements and for New Physics discoveries.

Muon Trigger System

Barrel ($|\eta| < 1.05$) instrumented with **Resistive Plate Chambers**.

Endcaps ($1.05 < |\eta| < 2.4$) instrumented with **Thin Gap Chambers**.

ATLAS data taking in 2010-2012

Thanks to the excellent LHC performance, ATLAS has collected an integrated luminosity of $\sim 27 \text{ fb}^{-1}$ **pp** collisions in the last three years

Year	Center of mass energy $\sqrt{s}$	Integrated Luminosity L
2010	7 TeV	$\sim 45 \text{ pb}^{-1}$
2011	7 TeV	$\sim 5 \text{ fb}^{-1}$
2012	8 TeV	$\sim 21 \text{ fb}^{-1}$

ATLAS Trigger System

A three-level structure implemented with sequential steps of increasing accuracy and complexity

• Level 1

- Hardware based
- Coarse granularity calorimeter and muon systems only

• High-Level Trigger (HLT)

- Software based
- Mostly commodity hardware
- **Level 2**
 - ✓ Special fast algorithms
 - ✓ Full detector granularity in RoIs identified by Level 1
- **Event Filter (EF)**
 - ✓ Seeded by Level 2
 - ✓ Access to full event
 - ✓ Full detector granularity
 - ✓ Based on offline algorithms with both **outside-in** and **in-outside** approaches

Main trigger signature rates

Muons represent a relevant fraction of the acquired rate by ATLAS Trigger/DAQ system. Table refers to 2012: there is significant overlap between groups.

Signature	Peak L1 (Hz)	Peak L2 (Hz)	Average EF (Hz)
b-jets	5000	900	45
B-physics	7000	50	20
e/gamma	30000	2000	140
Jets	3000	1000	35
Missing E_T	4000	800	30
Muons	14000	1200	100
Tau	24000	800	35
Total	65000	5500	400

Up to 6 transverse momentum (p_T) thresholds can be defined at **Level 1** based on fast sector logic board. Typical thresholds are:

6 GeV, 8 GeV, 10 GeV and **11 GeV, 15 GeV, 20 GeV** .

2-station coincidences

(low p_T)

3-station coincidences

(high p_T)

Level 1 efficiencies

The muon trigger efficiencies at Level 1 with respect to the offline muon reconstruction have been measured by selecting offline muons using the *Tag & Probe* method (both $J/\Psi \rightarrow \mu\mu$ and $Z \rightarrow \mu\mu$ events). Most of inefficiency is due to the geometrical coverage, which is $\sim 80\%$ for **RPC** and $\sim 99\%$ for **TGC** detectors. Plots on the right refer to 2010 run, with the corresponding thresholds implemented in barrel and endcaps.

Efficiencies vs. muon p_T for the Level 1 thresholds defined in 2010 for barrel (top) and endcaps (down)

Level 2 isolation

After standalone and combined algorithms, further rate reduction at Level 2 is performed by applying **isolation** on both **calorimetric** and **tracking** variables.

Level 2 isolation variable vs.
number of vertices in the event

Rejection of Level 2 isolation vs.
efficiency (EF_mu18i_medium)

Efficiency on real data and simulations (1/2)

Measurements with respect to offline muon reconstruction in $Z \rightarrow \mu^+ \mu^-$ events (Tag&Probe). Good agreement found for primary triggers (EF_mu18_medium in 2011, EF_mu24i_tight in 2012), for both *inside-out* and *outside-in* EF algorithms.

Efficiency on real data and simulations (2/2)

Scale factors are obtained as efficiency ratios (data/MC) vs. p_T , η and ϕ : they are generally very close to 1 although there are some variations which need to be properly taken into account in all physics analyses with muons in the final state.

Scale Factors for **EF_mu24_tight** computed vs. η and ϕ .

For events with two or more muons, scale factors are evaluated as:

$$SF = \frac{1 - \prod_{n=1}^N (1 - \epsilon_{\text{Data},n})}{1 - \prod_{n=1}^N (1 - \epsilon_{\text{MC},n})}$$

Efficiency as function of pile-up

Primary triggers show stable performance with no significant pile-up dependency

Efficiency of single isolated muon trigger at EF in endcap regions vs. # of interactions per bunch crossing

Efficiency of EF isolation requirement vs. # of interactions per bunch crossing.

Resolution studies

Both standalone and combined Muon HLT algorithms have competitive resolution performance.

EF algorithms show resolution on p_T , η and ϕ comparable with the corresponding offline algorithms.

Processing times

Average execution times per RoI due to extrapolation (65%), combination (29%), data decoding and unpacking (~5%). Intel R CoreTM2 Duo CPU E8400 @ 3.00 GHz.

High- p_T muons in relevant ATLAS events since LHC start

2009: collision event with two muon candidates

High- p_T muons in relevant ATLAS events since LHC start

2010: $Z \rightarrow \mu\mu$ candidate event in 7 TeV collisions

High- p_T muons in relevant ATLAS events since LHC start

2011: possible candidate of $WZ \rightarrow \mu\mu\nu\mu$ event

High- p_T muons in relevant ATLAS events since LHC start

2012: candidate of Standard Model Higgs in 4 muons

Higgs boson searches

The optimization and the performance studies of the ATLAS muon trigger have given a contribution to the discovery of the 'Higgs-like' boson announced at CERN on July 4, 2012.