Measurement of the inclusive muon differential cross section with the ATLAS detector at LHC

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Introduction

The inclusive muon p_T spectrum from pp interactions at $\sqrt{s}$ = 7 TeV is measured in the range $4<p_T<100$ GeV with the ATLAS detector at the Large Hadron Collider. The measured differential cross-section is defined by:

$$\frac{\Delta\sigma_i}{\Delta p_{T_i}} = \frac{N_{\mathrm{sig}_i}}{\Gamma_{\mathrm{bin}_i}\cdot\int\mathcal{L}dt}\cdot\frac{C_{\mathrm{migration}_i}}{\epsilon_{(\mathrm{reco+ID})_i}\cdot\epsilon_{\mathrm{trigger}_i}}$$

i : index of the bin;

$N_{\mathrm{sig}\ i}$: number of signal muons with reconstructed p_T in the bin i of width $\Gamma_{\mathrm{bin}\ i}$;

L: instantaneous luminosity;

$\epsilon_{\mathrm{trigger}\ i}$: trigger efficiency;

$\epsilon_{(\mathrm{reco+ID})\ i}$: combined reconstruction and identification efficiency;

$C_{\mathrm{migration}\ i}$: bin by bin unfolding correction factor.

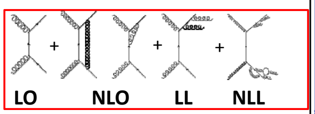
The inclusive muon cross section is dominated by the heavy flavour semileptonic decays after the subtraction of the theoretical prediction for $W/Z/\gamma^{(*)}$. The comparison to the QCD heavy quark production is obtained using the FONLL computation:

FONLL computation

[M. Cacciari, P. Greco, P. Nason JHEP 9805 (1998) 007]

$$\frac{d\sigma^l}{dp_T} = \frac{d\sigma^Q}{d\hat{p}_T}\otimes D^{Q\to H_Q}\otimes g^{H_Q\to l}$$

1) heavy quark (Q) production cross section evaluated at NLO+NLL;
2) fragmentation function evaluated at NLO+NLL accuracy from LEP data;
3) Heavy Quark decay modelisation extracted from B factories data.



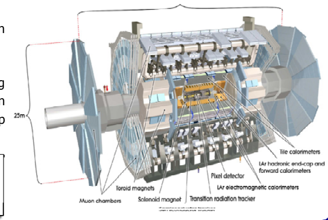
The ATLAS detector and the data sample

The ATLAS detector consists of three main components:

① The Inner Detector (ID) provides precise track reconstruction within $|\eta|$ < 2.5, employing pixel detectors, silicon microstrip detectors (SCT) and a Transition Radiation Tracker (TRT). It is immersed in a 2 T magnetic field.

② The Liquid-Argon Electromagnetic calorimeter (EM) and the steel/scintillating tile hadronic calorimeters.

③ The Muon Spectrometer (MS) constituted of three superconducting air-core toroids and a precise tracking system made with Monitored Drift Tubes (MDT) chambers, plus Cathode Strip Chambers in the forward regions; an independent trigger system is constituted of Resistive Plate Chambers (RPC) in the barrel and of Thin Gap Chambers (TGC) in the endcaps.



The analysis is based on a data sample collected at $\sqrt{s}$=7 TeV by the ATLAS detector during April-August 2010. Requirements were made on the beam, detector and data quality, yielding a total integrated luminosity of $1.42 \pm 0.05\ \mathrm{pb}^{-1}$.

Trigger requirements and efficiency

In order to use unprescaled triggers with the lowest possible thresholds, the data have been divided into two different sets according the chosen trigger:

★A low threshold trigger requiring at least three trigger hits in time coincidence with the collision (used in the analysis for muons with p_T <16 GeV);

★A 10 GeV threshold trigger requiring a trigger hit pattern compatible with a track with p_T>10 GeV (used for all muons with $16<p_T<100$ GeV)

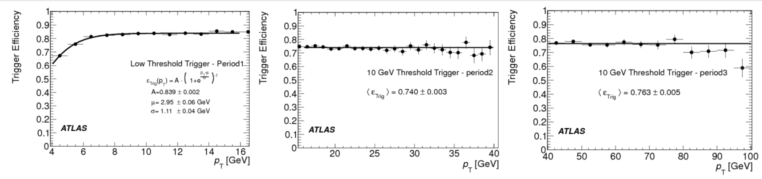
The trigger efficiency respect to offline (signal + background) reconstructed tracks is evaluated using events recorded by an independent trigger using only calorimeter information. Correction factors of 1.04 and 1.08 have been determined from the simulation to obtain the efficiency for signal muons for the low and the 10 GeV threshold triggers respectively.

Trigger efficiency in 3 homogeneous periods of data taking.

Period1 46 nb^{-1}

Period2 286 nb^{-1}

Period3 1.1 pb^{-1}



Reconstruction efficiency

Muon requirements

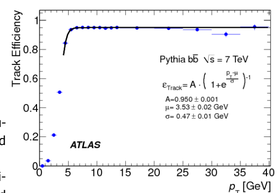
☑ Combined muons: muon reconstructed both in the ID and the MS;

☑ $|\eta|$ < 2.5;

☑ at least two MDT segments and hits in both projections of the trigger chambers;

☑ combined track parameters are computed by the statistical combination of MS and ID track parameters.

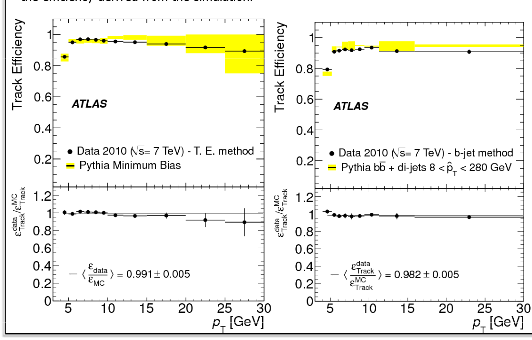
The combined muon reconstruction efficiency was determined from simulated samples of both heavy-flavour hadrons and $W/Z/\gamma^{(*)}$ decays (consistent results are obtained).



Track reconstruction efficiency according to the simulation.

DATA/MC effciency scale factor determination

Simulated track efficiency has been probed on data using two methods: the first method identifies muons using Inner Detector and hits information in the trigger chambers (Trigger Enhanced method); the second identifies muons using Inner Detector tracks and an analysis based on the identification of muons from b-jets, furthermore MIP-like deposits in the hadronic calorimeter are used to identify muons. The scale factor average is used to correct the efficiency derived from the simulation.



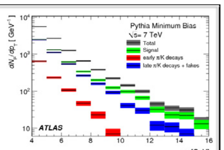
Signal extraction

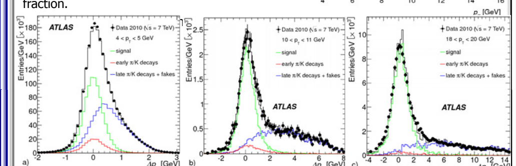
Combined muons include muons from charm and beauty hadron decays and $W/Z/\gamma^{(*)}$ decays plus a significant fraction of background muons from:

+ pion and kaon decays inside the inner detector ("early π/K");
+ late π/K decays and hadronic shower remnants wrongly matched to an ID track ("fakes").

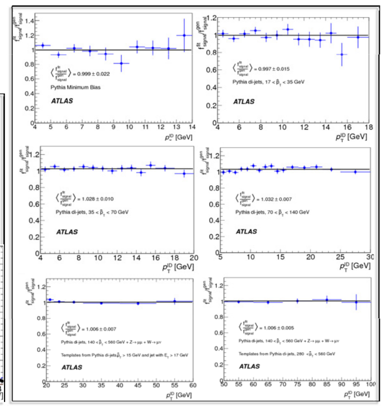
The background muon fraction is determined on data using the two independent p_T measurements in the ID and in the MS.

The variable $\Delta p_T = p^{ID}_T - p^{MS}_T$ is sensitive to the origin of the muons. The Δp_T distribution is fit in p_T bins over the whole range using templates from simulation to extract the signal fraction.

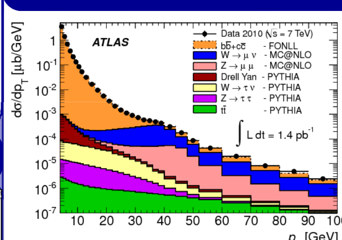




Closure test The method is applied on several MC samples. The maximum bias is 3%, taken as systematic error.



Inclusive muon differential cross section



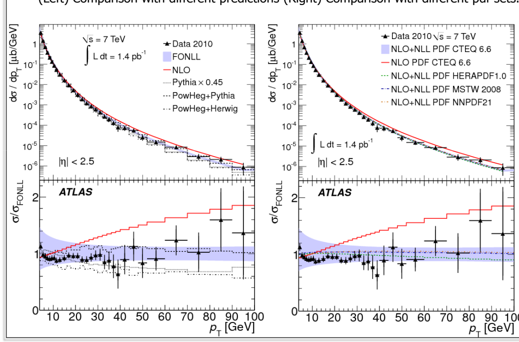
Inclusive muon differential cross section

Inclusive muon differential cross-section for $|\eta|$<2.5 as a function of p_T, compared to the overall theoretical expectation. The CTEQ6.6 set is used for bb and cc production (FONLL) and for W and Z (MC@NLO), the MRST LO* set is used for Pythia predictions. The integrated cross section is:.

$$\sigma_\mu = 6.55 \pm 0.01\ (\mathrm{stat.}) \pm 0.37\ (\mathrm{syst.}) \pm 0.22\ (\mathrm{lumi.})\ \mu b$$

Muon differential cross section after subtraction of the W,Z,γ^* contribution.

(Left) Comparison with different predictions (Right) Comparison with different pdf sets.



Results:

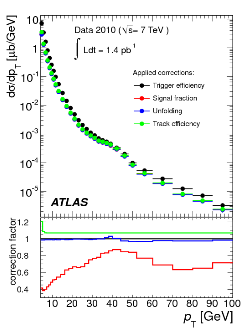
+ The FONLL (NLO+NLL) prediction is fully compatible with data within the overall uncertainty band dominated by the scale uncertainties (higher order contribution).

+ The NLO expectation, obtained from the FONLL program excluding the NLL resummation term in the calculation of the hard process, deviates from data in the high p_T region. **This is the first measurement at a hadron collider sensitive to the NLL resummation term in the pQCD calculation.**

+ The NLO predictions of the POWHEG program, interfaced to both PYTHIA and HERWIG for the showering, shows good agreement in the POWHEG+PYTHIA case while POWHEG+HERWIG predicts a significantly lower cross-section.

+ Pythia correctly predicts the spectrum shape with an overall normalisation factor of 0.45.

Corrections and systematics



The differential cross section is obtained from the p_T spectrum applying corrections for signal extraction, trigger and reconstruction efficiencies and unfolding the detector response with a bin-by-bin method.

The resolution matrix has been obtained from a smearing of the simulation prediction evaluated using $Z\to\mu^+\mu^-$ and $J/\psi\to\mu^+\mu^-$ events.

Source of systematic uncertainty	Cross-section uncertainty (%)
Possible bias in signal extraction	3
Early-π/K fraction	<2
Stat. uncertainty on signal extraction templates	1–8
Efficiency scale factor	1
Trigger efficiency control sample statistics	0.4–0.9
Trigger efficiency control sample bias	<2.3
Trigger efficiency background bias	0.2–0.7
Trigger efficiency mis-modelling of signal fraction	0.5–0.7
Unfolding procedure	0.1–1.2
Integrated luminosity	3.4
Total	5–8

References: https://twiki.cern.ch/twiki/bin/view/AtlasPublic