MEASUREMENT OF THE pp$\rightarrow$ Z$\rightarrow$ $\mu\mu + X$ CROSS SECTION AT LHC

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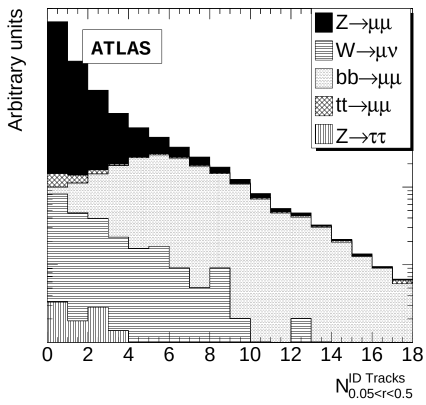
One of the first measurements in the ATLAS experiment at the Large Hadron Collider will be the Z boson cross section in proton proton collisions, due to its high production rate. The different decay channels of the Z boson will also be used in the initial data taking period as benchmark processes for the calibration of the detectors and performance measurements. In this paper we discuss the measurement of the cross section of pp$\rightarrow$Z$\rightarrow$ $\mu^+\mu^- + X$ process with first data in ATLAS experiment.

1 Introduction

In the first stage of data taking at the Large Hadron Collider (LHC), Standard Model processes will have a crucial role in the physics programme of the ATLAS [?] experiment, in particular for understanding and calibration of the subdetectors. In fact, starting from a few pb^{-1}, various Standard Model processes can be studied, in particular the heavy quark resonances like J/ψ or Υ that will be well visible over the background in the low mass region of the dilepton invariant mass distribution. Due to large production rates, the physics of W and Z bosons is also accessible in the early data taking phase at the LHC and will be used as *standard candles* for many measurements. In particular, their lepton channel decays can be used, depending on integrated luminosity, for the commissioning of detectors and analysis tools or the improvement in measurement of electroweak variables. Before any *new-physics* discovery, LHC will offer the possibility to check the consistency of the Standard Model at its high energies.
One of the first measurement that will be possible with the ATLAS experiment is the production cross section of the Z boson

$$\sigma_Z = \frac{N - B}{A \times \varepsilon \times \int Ldt} \tag{1}$$

where N is the number of selected candidate events, B refers to the number of background events, A is the detector acceptance computed from MC studies, L is the luminosity and ε includes the reconstruction and trigger efficiency and the signal selection cut efficiency. In the following sections, the measurement of $\sigma\,(pp \rightarrow Z) \times BR\,(Z \rightarrow \mu\mu)$ is discussed, starting with event selection (section **??**) and describing also techniques for the determination of the detector performance from data, like the measurement of muon reconstruction and trigger efficiency (section **??**) and the muon momentum scale and resolution (section **??**).



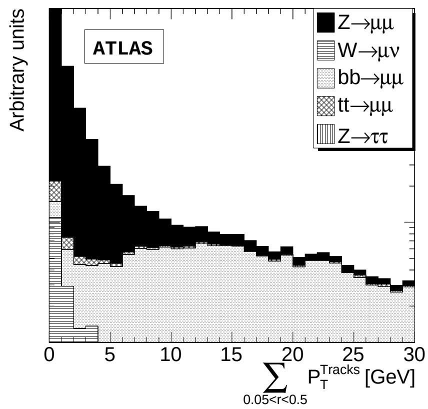


Figure 1: Isolation variables for signal and backgrounds after all selection cuts. Left: Distribution of the track multiplicity within $\Delta R = 0.5$ around the muon. Right: total transverse momentum of tracks within the same cone around the selected muon.

2 Event Selection

In order to select the $Z \to \mu^+\mu^-$ signal, at least a muon track candidate that passes the 10 GeV single muon trigger at the end of the ATLAS trigger chain is required. The events are further selected by requiring that they contain at least two reconstructed muon tracks. These tracks also have to satisfy a cut on the transverse momentum $p_T > 20$ GeV and $|\eta| < 2.5$. The selected candidate muons must have an opposite charge, and the invariant mass of the muon pair $M_{\mu\mu}$ should fulfill $|91.2\text{GeV} - M_{\mu\mu}| < 20$ GeV. An isolation cut is also applied to exclude non-isolated muons coming from jet events that are often produced in association with a shower cascade. In particular, the number of the tracks N^{ID} in the Inner Detector within a cone around the candidate muon with a size $\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2} < 0.5$ must satisfy the relation $N^{ID} \leq 5$ and the sum of the transverse momentum of the tracks inside the same cone must not exceed 5 GeV. The muon track itself is excluded from the isolation calculation. Figure **??** shows the distribution of the isolation variables, normalized to respective cross sections, for signal and backgrounds after all the other cuts.
The cuts discussed above are able to select about $(2.57 \pm 0.02(stat)) \times 10^4$ signal events for an integrated luminosity of 50 pb^{-1}, considering collisions at $\sqrt{s} = 14$ TeV. This corresponds to about the 70% of the $Z \to \mu^+\mu^-$ events generated in the ATLAS detector acceptance.
The background of this Z boson decay channel originates from

- $t\bar{t}$ events where muons come from the $t/\bar{t}$ quaks decay in $t \to Wb$ with $W \to \mu\nu$;
- $W \to \mu\nu$, where one muon come from W decay and the other one is a fake muon;
- $Z \to \tau\tau$ due to possibility to have muons from τ decays;
- jet background (in particular muons coming from b-hadron decay).

After all cuts discussed above, the residual background fraction is 0.004 ± 0.001. The dominant

Table 1: Expected results for the overall cross-section measurement with an integrated luminosity of 50 pb^{-1} at $\sqrt{s} = 14$TeV.

	N ($\times 10^4$)	B ($\times 10^4$)	$A \times \epsilon$	$\delta A/A$	$\delta\epsilon/\epsilon$	σ(pb) $\pm (stat) \pm (sys)$
$Z \to \mu\mu$	2.57 ± 0.02	0.010 ± 0.002	0.254	0.023	0.03	$2016 \pm 16 \pm 76$

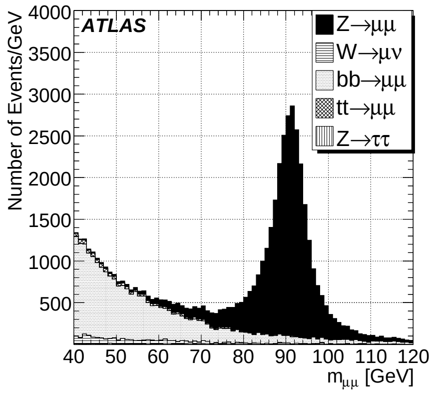


Figure 2: Di-muon invariant mass distribution in the $Z \to \mu^+\mu^-$ channel, for signal and background, for 50 pb^-1, after all cuts, except the isolation and $\mathrm{M}_{\mu\mu}$ cuts.

component comes form $t\bar{t}$ with a theoretical uncertainty of about 20% on the rate. The jet background is expected to have a smaller impact, but it's teoretycally not well known, so an uncertainty of 100% on the rate of this kind of events is assumed.
In Table **??** the expected precision on the $\sigma\,(pp \to Z) \times BR\,(Z \to \mu\mu)$ measurement for an integrated luminosity of 50 pb^{-1} at $\sqrt{s} = 14$ TeV is shown. The overall measurement uncertainty gets contribution from different terms as follows

$$\frac{\delta\sigma}{\sigma} = \frac{\delta N \oplus \delta B}{N - B} \oplus \frac{\delta\mathscr{L}}{\mathscr{L}} \oplus \frac{\delta A}{A} \oplus \frac{\delta\epsilon}{\epsilon} \tag{2}$$

The term δN has a pure statistic origin and the relative error will decrease with increasing integrated luminosity $\mathscr{L}$, following the relation $\delta N/N \sim 1/\sqrt{\mathscr{L}}$. The other terms δB, δA, $\delta\epsilon$ are systematic uncertainties in the cross section measurement but they can be constrained with auxiliary measurements. They combine effects due to background contribution, limited detector response knowledge and theoretical uncertainties on the acceptance. In particular, the impact on the acceptance of theoretical uncertainties related to PDFs, the parton shower model and the initial state radiation (ISR) have been studied. An overall luminosity uncertainty of $\delta\mathscr{L}/\mathscr{L} = 10\%$ should be taken into account for the measurement with $\sim 50\mathrm{pb}^{-1}$, but it is expected to decrease in time thanks to improved understanding of the LHC beam parameters and of the ATLAS luminosity detector response.

3 Muon Trigger and Reconstruction Efficiency

One of the ways chosen by the ATLAS experiment to evaluate the trigger and reconstruction efficiency for muons is the data driven method called *tag and probe* which exploit the two independent traking systems (Inner Detector and Muon Spectrometer) to cross-check their performances. The *tag and probe* method is based on the definition of an object (probe) that is used to make the performance measurement over a certain sample of events properly chosen (tagged). In particular, the $Z \to \mu^+\mu^-$ decay provides two muons with an high p_T that can give two tracks in the Muon Spectrometer and in the Inner Detector and two combined objects. To apply this method in the $Z \to \mu^+\mu^-$ decay, two reconstructed tracks in the Inner detector are required together with at least one associated track in the muon spectrometer. The invariant mass of the two inner-detector tracks have to be close to the mass of the Z boson, in order to ensure that the tracks are the ones associated to the decay muons of the Z boson. The efficiency estimation with this method is exact in the limit of a zero-background sample which can be

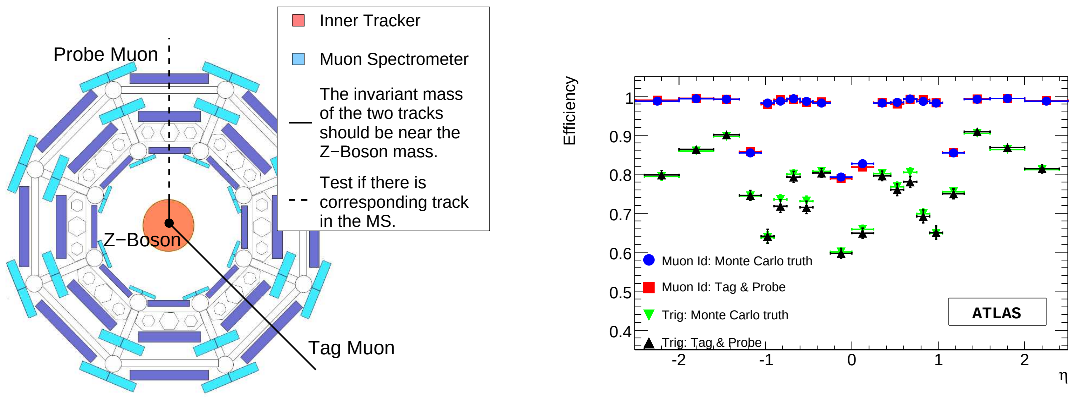


Figure 3: Left: Schematic illustration of the tag and probe method. Right: Muon detection efficiency vs. η, as measured from the tag-and-probe method and compared to the truth, for 50 pb$^-1$. The 20 GeV single muon trigger efficiency and the combined muon reconstruction efficiency are represented.

obtained using a tight trigger and quality cut for the tag. Figure **??** illustrate the 20 GeV single muon trigger efficiency and combined muon reconstruction efficiency using the tag and probe method compared to the MC truth.

4 Muon Momentum Scale and Resolution

In order to determine the p_T scale and resolution one can study the Z resonance shape. In fact the p_T scale has a direct impact on the measured mean value, while the p_T resolution has a direct impact on the measured Z width. To extract the value of muon resolution and momentum scale, the p_T resolution function predicted by Monte Carlo simulations is iteratively adjusted in its width and scale and the corresponding Z boson mass distribution is calculated. The procedure stops if the resulting distribution agrees within its statistical error to the distribution measured from data. We expect to determine the momentum scale for muons with a precision better than 1%, while the uncertainty on the resolution is smaller than 10%, for an integrated luminosity of $50\,\mathrm{pb}^{-1}$.

5 Conclusion

The signal and background acceptance uncertainties contribute to the cross section measurement error at the level of 2.3% with 50 pb^{-1} of data, neglecting the uncertainty on the integrated luminosity. All uncertainties are expected to scale with statistics, except the acceptance contribution which is theoretically limited.
Further studies of the differential $Z \to \mu^+\mu^-$ cross section will also be useful to improve the theoretical understanding, thus allowing to measure the cross-section with a precision better than 2% that can be obtained with the studies described above. However, they will require higher statistics. A detailed description of these studies can be found in ref. [?].

References

1. The ATLAS Collaboration, The ATLAS Experiment at the CERN Large Hadron Collider, 2008 JINST 3 S08003
2. ATLAS Collaboration, Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics, CERN-OPEN-2008-020, Geneva, 2008.