MEASUREMENT OF $pp \to Z \to \mu\mu$ CROSS-SECTION AT THE ATLAS EXPERIMENT WITH THE FIRST 10 pb^{-1} AT $\sqrt{s}$ =14 TeV*

Matthias Schott

Ludwig-Maximilians-Universität Munich
Geschwister-Scholl-Platz 1, 80539 Munich, Germany

(Received November 15, 2006)

The study of the Z boson at the ATLAS experiment provides several interesting aspects. The measurements of cross-section and transverse momentum spectrum ($p_{\rm t}$) of the Z boson at ATLAS provide additional tests of the standard model and may be sensitive to exotic physics processes. Z boson production is also a common background process for many other physics analysis and must be understood very well. The achievable precision of the cross-section $\sigma(pp \to Z/\gamma \to \mu^+\mu^-)$ with first data of LHC at the ATLAS detector are discussed.

PACS numbers: 13.38.Dg, 14.70.Hp

1. Introduction

The ATLAS detector [1], currently being installed at CERN, is designed to provide precise measurements of 14 TeV proton–proton collisions at LHC. One of the major detector components is the Muon Spectrometer (MS) which consists out of more than 1,200 single drift-tube chambers. The MS provides an independent high precision measurement of the transverse momentum $p_{\rm T}$ of muons.

The mass spectrum of the Z boson is known to very high precision from LEP experiments and therefore can be used as a physics process for various calibration tasks.

In this study first results on the achievable precision of the cross-section measurement

$$\sigma(pp \to Z/\gamma \to \mu^+\mu^-) = \frac{N_{\rm Cand} - N_{\rm Background}}{\varepsilon_{\rm total} \int L dt}\,, \qquad (1)$$

* Presented at the "Physics at LHC" Conference, Kraków, Poland, July 3–8, 2006.

with the first 10 pb^{-1} of LHC data with the ATLAS detector are discussed. In a first step a cut based signal selection is presented and a method for background estimation $N_{\mathrm{Background}}$ based on real data is discussed. The efficiency factor $\varepsilon_{\mathrm{total}}$ in Eq. 1 includes all contributions from the trigger system, the muon spectrometer and the applied cuts. In a second step of this study we explore the possibility to use the Z boson resonance and its decay into two muons to determine some of these efficiencies namely the MS reconstruction efficiencies $\varepsilon_{\mathrm{ID}}$ and momentum resolution within data which is indispensable for the a cross-section measurement.

2. Signal selection

The decay of the Z boson into two muons has a very characteristic signature: two high energetic and isolated muons in the final state are produced. We expect a significant contribution of QCD-background due to the overwhelming cross-section of QCD-processes. It is assumed that QCD-processes which result in two high energetic muons are dominated by the decay of $b\bar{b}$-pairs into two muons. Moreover, the decay of a $W^{\pm}$ boson into one high energetic muon and a neutrino plus an additional muon from a QCD-jet and the process $Z \to \tau\tau \to \mu\nu\mu\nu$ were studied as possible backgrounds in this analysis. The expected invariant dimuon mass spectrum without any applied cuts is shown in Fig. 1 and it was generated with the full simulation of the ATLAS Detector.

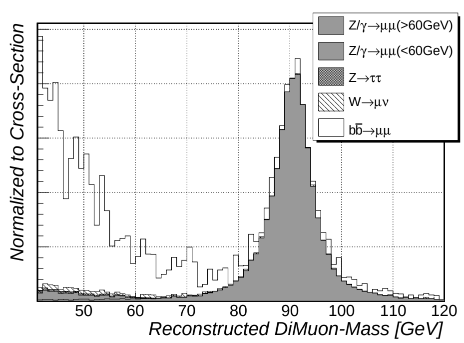

Fig. 1. Reconstructed DiMuon Mass for the signal and various background processes.

For the selection we require at least two reconstructed tracks with opposite charge in the pseudorapidity (η) range between -2.6 and 2.6 in the Muon Spectrometer. These tracks are considered to be muons. The invariant mass of the two muons $M_{\mu\mu}$ must be larger than 60 GeV[1]. The minimal transverse momentum $p_{\mathrm{T}}^{\mathrm{min}}$ has to be larger than 10 GeV, while the maximal transverse momentum $p_{\mathrm{T}}^{\mathrm{min}}$ of the two muons must be larger 15 GeV. The difference of the azimuthal angle ϕ of the two muon tracks is required to be greater than 2 rad.

Muons which result from QCD-processes tend to be not isolated as indicated in Fig. 2.

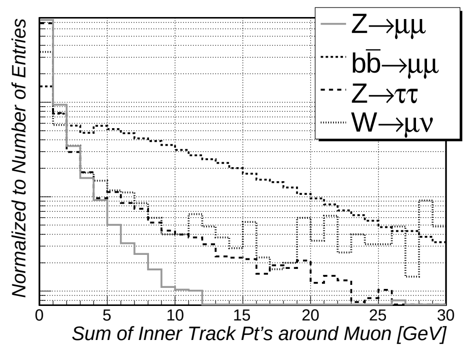

Fig. 2. Sum of inner Tracks around muons within a cone-radius of 0.5 for signal and various background processes.

This leads to the following requirements: The number of reconstructed tracks in the inner detector within a cone radius of 0.5 around each muon (N_{IT}) must be smaller than 7, while the sum of the transverse momenta of these tracks must fulfill $\sum_{N_{\mathrm{I}}} p_{\mathrm{T}} < 8$ GeV. The cone-distance is defined as

$$c = \sqrt{(\phi_\mu - \phi_{\mathrm{IT}})^2 + (\eta_\mu - \eta_{\mathrm{IT}})^2}\,.$$

The last cut requires that the reconstructed jet energy within a cone radius of 0.5 around each muon $\sum_{\mathrm{Jets}} E_{\mathrm{T}}$ is smaller than 20 GeV. A muon is called *isolated* if these three requirements are fulfilled.

In total, these cuts lead to an expected purity of $\rho = 99.75\%$ and an efficiency normalized to a single muon trigger above 6 GeV of 44.68%.

3. Background estimation

The QCD-background is estimated from the number of events $N_{\text{Non Isolated}}$ where the two muon tracks pass all cuts presented in Section 2 except the isolation cuts, hence are not isolated. According to Monte Carlo

[1] In the very rare case in which more than 2 reconstructed tracks pass all applied cuts, the muon pair with the invariant mass closer to the Z boson mass is considered.

studies more than 90% of these selected events are due to $b\bar{b}$ decays (Fig. 3). The ratio r_{QCD} of the number of events which have two isolated muons to events which have no isolated muons, is expected to be described sufficiently well by the full ATLAS simulation.

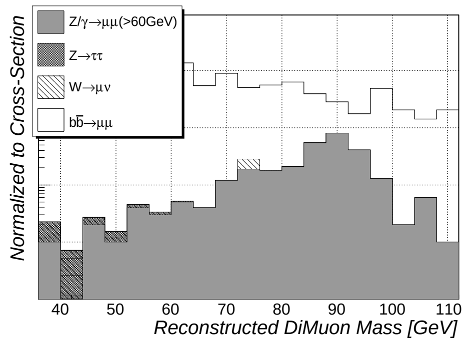

Fig. 3. Reconstructed DiMuon Mass requiring two non isolated muons with opposite charge.

The number of QCD-events which pass all selection cuts can then be estimated by

$$N_{\mathrm{QCD-Background}} = r_{\mathrm{QCD}} \times N_{\mathrm{Non\ Isolated}}\,. \tag{2}$$

On similar grounds the background contribution due to $W \to \mu\nu$ can be estimated. The advantage of this method is the independence of any Monte Carlo cross-section prediction. Only the ratio of r_{QCD} depends on Monte Carlo simulations. We assume that these ratios have an uncertainty of 100% as a very conservative estimation. This leads to an expected overall background contribution of

$$\frac{N_{\mathrm{Background}}}{N_{Z\to\mu\mu}} = 0.25\% \pm 0.20\%\,. \tag{3}$$

4. Measurement of detector properties with data

The tag and probe method (see Fig. 4) can be used to determine the reconstruction efficiency of the ATLAS Muon Spectrometer $\varepsilon_{\mathrm{MS}}$ and the efficiency of isolation cuts $\varepsilon_{\mathrm{Iso}}$ presented in Section 2. This method uses two tracks which have an invariant mass close to the Z boson mass. Hard cuts are applied on one candidate muon (*e.g.* isolation cuts) which is called *tag muon* and the other muon is used (*probe muon*) to test a specific property.

Two reconstructed tracks in the Inner Detector of ATLAS of which one can be associated with a track in the Muon Spectrometer (tag muon) are required to determine the reconstruction efficiency of the ATLAS Muon

Spectrometer. It is tested in a second step, if a corresponding track for the probe muon also exists in the MS. On this grounds the reconstruction efficiency of the MS can be calculated if this efficiency is assumed to be independent.

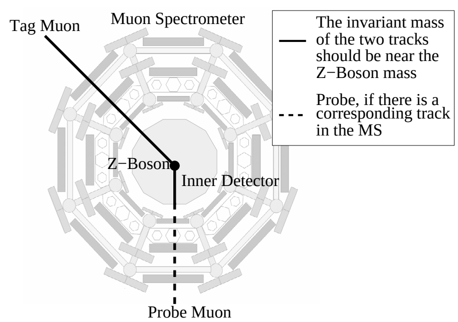

Fig. 4. Sketch of the Tag and Probe method.

The comparison between $\varepsilon_{\mathrm{MS}}$ determined by Monte Carlo Truth and $\varepsilon_{\mathrm{MS}}$ determined with Tag and Probe is shown in Fig. 5, which indicates an agreement within the statistical uncertainties.

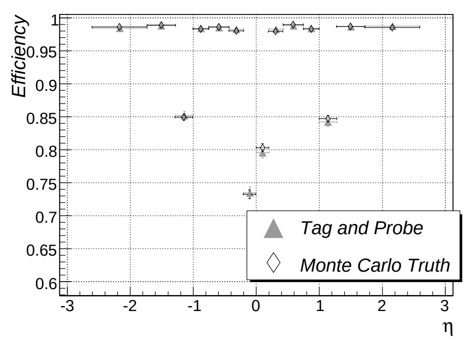

Fig. 5. Muon Reconstruction Efficiency determined with the tag and probe approach in comparison with Monte Carlo Truth information.

The following cuts are applied on both — tag and probe muon — to reduce the background:

- $|91\ \mathrm{GeV} - M_{\mu\mu}| < 10\ \mathrm{GeV}$
- $p_{\mathrm{T}}^{\mathrm{tag}} > 20\mathrm{GeV}$, $p_{\mathrm{T}}^{\mathrm{probe}} > 20\ \mathrm{GeV}$
- both tracks are required to be isolated.

The main background in this sample is due to the process $W \to \mu\nu$+jets, where one tag muon comes directly from the W-decay, while the probe muon results from QCD-process which leaves a track in the Inner Detector.

For an integrated luminosity of 10 pb^{-1} the overall MS reconstruction efficiency can be determined in this way up to a precision of

$$\Delta\varepsilon_{\mathrm{MS}} \approx \pm 0.21 \text{ (stat) } + 0.29 \text{ (sys)}\,, \tag{4}$$

where 0.21 is the statistical part and 0.29 the systematic part due to the background contribution. It is expected that it will be difficult to correct for the estimated background contribution within the first data. On this grounds the background contribution is treated as further systematic uncertainty.

This procedure can also be applied to determine $\varepsilon_{\mathrm{Iso}}$. In this case we require two reconstructed tracks in the MS with an invariant mass $|91\text{ GeV} - M_{\mu\mu}| < 10$ GeV. The tag muon is required to be isolated, the probe muon is used to test the isolation cut. This leads to

$$\Delta\varepsilon_{\mathrm{Iso}} \approx \pm 0.19 \text{ (stat) } \pm 0.36 \text{ (sys)}\,, \tag{5}$$

where again, 0.19 is the statistical part and 0.36 the systematic part due to the background contribution.

It is also possible to determine the p_{T}-resolution of the MS via the Z boson resonance. The p_{T}-resolution of the MS is defined with Monte Carlo Truth information as

$$\sigma = \frac{1/p_{\mathrm{T}}^{\text{MC Truth}} - 1/p_{\mathrm{T}}^{\text{MC Reconstruction}}}{1/p_{\mathrm{T}}^{\text{MC Truth}}}\,. \tag{6}$$

The expected σ-distributions for an ideal and for a misaligned MS geometry are shown in Fig. 6. These distribution can be parametrized by

$$f_{\mathrm{s}}(x, x_{\mathrm{m}}, \Sigma) = 0.61 e^{-\frac{(x-x_{\mathrm{m}})^2}{\Sigma}} + 0.27 e^{-\frac{(x-x_{\mathrm{m}})^2}{3.0*\Sigma}} + 0.005\,. \tag{7}$$

Both distributions are well described by f_{s} with different values of x_{m} and Σ. The values of x_{m} and Σ are determined from data by comparing the measured mean and width of the Z boson resonance to a Monte Carlo simulation using f_{s} as a smearing function for the transverse momentum of generated muons. For an integrated luminosity of 10 pb^{-1} both variables can be determined up to a precision of $x_{\mathrm{m}} = 0.0018 \pm 0.00077$, $\Sigma = 0.0277 \pm 0.00067$ for a perfect aligned ATLAS MS. This leads to an uncertainty on the efficiency $\Delta\varepsilon_{p_{\mathrm{T}}} \approx 0.07\%$, which is due to the p_{T}-cuts. This method was also validated for misaligned Muon Spectrometer layout simulations.

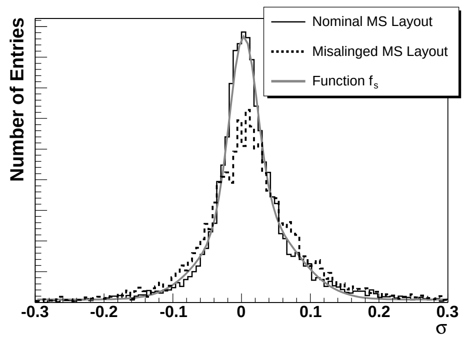

Fig. 6. Effect of a misaligned Muon Spectrometer on the $p_{\rm T}$-resolution of the Muon Spectrometer.

The uncertainty on the acceptance of the MS near the η-cuts $\varepsilon_{\rm acc}$ can be estimated by assuming that the η measurement is dominated by the measurement of the outermost MDT-chambers, which positions are assumed to be known to a precision of 5 mm in the beginning. This conservative estimations lead to an uncertainty of $\Delta\varepsilon_{\rm acc} \approx 0.07\%$.

The trigger efficiency $\varepsilon_{\rm trigger}$ can be also determined with tag and probe method. We estimate that the overall trigger efficiency $\varepsilon_{\rm trigger}$ can be determined up to a precision of $\approx 0.5\%$ from simple statistical considerations without a full Monte Carlo study.

5. Conclusion

Different contributions to the uncertainty of $\varepsilon_{\rm total}$ have been estimated and result in an overall uncertainty of

$$\Delta\varepsilon_{\rm total} \approx 1.3\%\,, \tag{8}$$

where the single contributions have been added quadratically. The cross-section can then be measured up to an precision of

$$\frac{\Delta\sigma}{\sigma} \approx 1.8\%\,, \tag{9}$$

assuming $N_{\rm Cand} = 7.500$ and $N_{\rm Background} = 20$ for an integrated luminosity of 10 pb^{-1}. Uncertainties on the particle density functions and on the measurement of the integrated luminosity have been neglected in this study. A detailed description of this study including those effects is available in [2].

REFERENCES

[1] The ATLAS Collaboration, ATLAS — Technical Design Report, CERN/LHCC 97-22, Geneva 1997.

[2] In preparation: Measurement of the W and Z production cross-section, ATLAS-CSC-Note, CERN, Geneva 2007.