Z Boson Production at LHC with First Data

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Abstract. The study of the Z Boson at the ATLAS and CMS experiment provides several interesting aspects already in the starting phase of the LHC. The measurements of cross section and transverse momentum spectrum ($p_Z^t$) 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 analyses and must be understood very well. The achievable precision of the overall cross section $\sigma(pp \to Z/\gamma \to \mu^+\mu^-)$ measurement with first collisions of LHC recorded by the ATLAS and CMS detector is discussed.

1. Introduction

The ATLAS [1] and CMS [2] detectors, currently in their final installation phase at CERN, are designed to provide precise measurements of 14 TeV proton-proton collisions at the Large Hadron Collider. The Z boson at LHC is produced via Drell-Yan process and its theoretical cross-section is calculated at next-to-next-to-leading order. A total cross-section of $1.972 \pm 0.019 \text{ nb}$ of $pp \to Z\gamma^* \to \mu^+\mu^-$ is theoretically expected.

The study of the Z boson production and its properties provides not only a test of the standard model. A detailed study can constrain the parton density functions and is even sensitive to various exotic physics models. The large production cross-section and the detailed knowledge of the mass resonance curve of the Z-Boson from LEP experiments makes the decay of the Z boson to a standard physics process for the calibration of the ATLAS and CMS detector especially in the initial phase of LHC. In this study first results on the achievable precision of the total cross section measurement

$$\sigma(pp \to Z/\gamma \to \mu^+\mu^-) = \frac{N_{\text{Cand}} - N_{\text{Background}}}{\epsilon_{\text{total}} \int \mathcal{L} dt}$$

from the first 100 pb$^{-1}$ of LHC data with the ATLAS and CMS detector are discussed.

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. A significant contribution of QCD-background is expected 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 $Z \to \tau\tau$ were studied as possible backgrounds in this analysis. A further background source at LHC are $t\bar{t}$-events which decay leptonically. The expected invariant dimuon mass spectrum without any applied cuts is shown in Figure 1. It was generated with the full simulation of the ATLAS detector.

For the selection at least two high energetic reconstructed tracks in the inner detector and the muon system with opposite charge are required for the ATLAS detector. CMS requires only one matched reconstructed track in the muon system. The pseudorapidity range was chosen to be $|\eta| < 2.5$ for the ATLAS detector and $|\eta| < 2.0$ for the CMS detector. A more detailed overview of the selection cuts is shown in Table 1.

| Selection                      | ATLAS                  | CMS                  |
|--------------------------------|------------------------|----------------------|
| Invariant mass $M_{\mu\mu}$   | $|91.2 \text{ GeV} - M_{\mu\mu}| < 30 \text{ GeV}$ | $|91.2 \text{ GeV} - M_{\mu\mu}| < 7.5 \text{ GeV}$ |
| Pseudo-rapidity range          | $|\eta| < 2.5$          | $|\eta| < 2.0$        |
| Muon transverse momentum       | $p_T^1 > 25 \text{ GeV}$, $p_T^2 > 15 \text{ GeV}$ | $p_{T}^{1,2} > 20 \text{ GeV}$ |
| Muon Isolation                 | $\sqrt{\ }$           | $\sqrt{\ }$         |

In total, these cuts lead to an expected purity of $\rho = 99\%$ (Figure 2). The largest background contribution after the signal selection is expected to result from events with top-quark pairs. Several methods have been studied to determine the background contribution due to QCD processes and W decays using measured data only. It is expected that the background contribution can be estimated with an uncertainty of 0.25%.
3. In-Situ Determination of Detector Response

The 'tag and probe' method can be used to determine the muon trigger and reconstruction efficiencies of ATLAS and CMS. This method is based on the independent track measurement by the inner detector and the muon system. Two reconstructed tracks in the inner detector which have an invariant mass close to the Z boson mass are selected. Hard isolation cuts are applied on both tracks to minimize background contributions. It is further required that one track is matched to an independently reconstructed track in the muon system, which is called tag muon. The other track (probe muon) can then be used to test a specific property, e.g. the reconstruction efficiency of the muon system. This procedure can be also applied for the determination of the single muon trigger efficiency and the behaviour of the isolation cut requirement, mentioned in section 2. It is expected that the muon reconstruction and trigger efficiency can be determined to better than 0.5% with first data.

The Z boson resonance can be also used to determine the momentum scale and resolution of the muon systems of ATLAS and CMS. The basic idea here is to reproduce the measured invariant dimuon mass spectrum in Monte Carlo simulations by smearing the Monte Carlo predicted transverse momenta of muons resulting from a Z boson. The smearing is described by resolution function $f_R$ which accounts for various detector resolution effects. It is expected that the momentum scale can be determined to a few per mill and the momentum resolution to a few percent within the first data.

4. Further Systematic Uncertainties

![Figure 3. Pseudorapidity distribution for muons resulting from a Z boson decay for two different PDF-sets (Taken from [3]).](image)

![Figure 4. Transverse momentum distribution for muons resulting from a Z boson decay for leading order and next-to-leading order calculations (Taken from [3]).](image)

Experimental systematic uncertainties in the initial phase of both experiments, such as initial misalignments of the muon system, limited knowledge of the magnetic field, collision point uncertainty, pile-up effects and underlying events, have been investigated. It is expected that their uncertainty contribution to the cross-section measurement is smaller than 0.35%.

Theoretical systematic uncertainties are due to the choice of the parton density functions, the initial state radiation and higher order corrections. These effects have an impact on the pseudo rapidity distribution (Figure 3) and the momentum distribution (Figure 4) of the decaying muons and hence imply an uncertainty on the acceptance of the selection cuts. As a conservative estimation a theoretical uncertainty of 2% is assumed, which is likely to be reduced in the near future.
5. Conclusion

Combining all uncertainties, it is expected that the cross-section in the muon decay channel can then be measured up to a precision of

$$\frac{\Delta \sigma}{\sigma} \approx 0.4\% (\text{stat}) \pm 1.0\% (\text{ex.sys}) \pm 2.0\% (\text{th.sys}) \pm 10\% (\text{luminosity})$$

for an integrated luminosity of 100 pb$^{-1}$ independently by the ATLAS and the CMS detector. A complementary measurement of the Z boson production cross-section can also be performed in the electron decay channel, which depends on different experimental systematic uncertainties. It should be noted that the presented results are based on the assumption of fully operating detectors in the initial phase of LHC. A more detailed discussion can be found in [3], [4] and [5].

References

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