Measurement of the W Boson Cross Section in pp Collisions using ATLAS OpenData

Dominic Williamson (ID 9846595) – experiment in collaboration with *James Cummins*.

Proton-proton collision data from the ATLAS detector at the LHC was used to investigate the $W^{\pm} \rightarrow l^{\pm}\nu$ decay channels (where $l^{\pm} = e^{\pm}, \mu^{\pm}$). Selection cuts were made to the data to isolate the pure signal from any background processes. The results for the W boson cross section are $\sigma_{(W \rightarrow l\nu)}$ = 21371 ± 12 (stat.) ± 696 (syst.) ± 296 (lumi.) pb. W boson charge asymmetry was also investigated using the individual $W^{\pm} \rightarrow \mu^{\pm}\nu$ cross sections, with the ratio σ_{W+}/σ_{W-} = 1.171 ± 0.099 (stat.) ± 0.021 (syst.) agreeing with theoretical predictions.

1. Introduction

In 2008, the construction of the LHC was completed and the detectors placed around its circumference began observing proton-proton (pp) collisions [1]. The collisions available in the ATLAS OpenData dataset were recorded at the ATLAS detector in 2012, when the energy of the colliding protons was 8 TeV [1].

This collision data will be used to determine the cross section of the decay channels $W^{\pm} \rightarrow l^{\pm}\nu$ decay channels (where $l^{\pm} = e^{\pm}, \mu^{\pm}$). This quantity is proportional to the probability of the decay process occurring within the detector. Additionally, the individual W^{+} and W^{-} cross sections will be used to investigate the charge asymmetry in pp collisions.

2. Theory

The cross section is defined as

$$\sigma = \frac{N_{signal}}{\varepsilon\,\mathcal{L}}$$

where N_{signal} is an estimate of the number of detected events corresponding to the desired decay channels, ε is the efficiency of selecting signal events, determined by comparing the "pure" Monte Carlo (MC) simulation data to N_{signal}, and $\mathcal{L}$ is the integrated luminosity – a measure of the number of pp collisions observed in the detector, with units of inverse picobarns (pb^{-1}) [2].

ATLAS itself consists of concentric layers of different detectors. The two significant to this experiment are the electromagnetic (EM) calorimeters and muon detectors. The EM calorimeters measure the kinematics of electrons as they interact with matter – for example as Bremsstrahlung radiation [2]. Muons are much more massive than electrons and do not deposit sufficient energy to be detected within the inner layers. As a result, a muon's momentum is found by tracking its path through multiple specialised detector layers filled with a magnetic field [2]. Neutrinos have negligible mass and therefore are invisible to ATLAS. Their kinematic properties instead have to be found indirectly, such as from the other decay products.

The detectors are able to measure certain parameters associated with the leptons which are useful in determining the signal data from the background. Important examples of these are the transverse momentum p_T, the transverse momentum cone p_T^{cone}, and the transverse mass m_T [3]. p_T is the total momentum of the lepton in the plane transverse to the beam direction. p_T^{cone} is the sum of the p_T of the background particles detected in a cone around the lepton in question. Lastly, m_T is the invariant mass of the system in the plane tangential to the beam direction. m_T is a useful quantity when analysing decays involving neutrinos since they are undetectable and so the total invariant mass of the system may not be easily found [3].

3. Experimental Methods

The ATLAS OpenData dataset contains raw pp collision data from the detector. It was therefore necessary to differentiate between the leptons produced directly by $W \rightarrow l\nu$ decays and those from other decay channels, called background processes.

In order to reduce the amount of background in the data, selection cuts were used. These are restrictions made to event parameters, such as those listed above, to isolate detections from the decay in question. These must be considered carefully as any cut will also remove some amount of signal data. The MC results were plotted with the ATLAS data for each parameter; when the MC data became negligible in comparison to the ATLAS data, the cut was made to remove a significant proportion of background relative to the remaining signal data. Each selection cut was assigned an uncertainty to take into account the values that they could reasonably take.

However, selection cuts cannot remove all background data. A secondary consideration is hadronic, or QCD (quantum chromodynamics), background processes, which cannot be simulated using MC methods due to their large cross sections. As a result of this background, we have

$$N_{signal} = N_{selected} - N_{background}$$

where $N_{selected}$ is the number of events passing the selection cuts and $N_{background}$ is the estimate of the number of remaining background events. To estimate this background, data-oriented methods

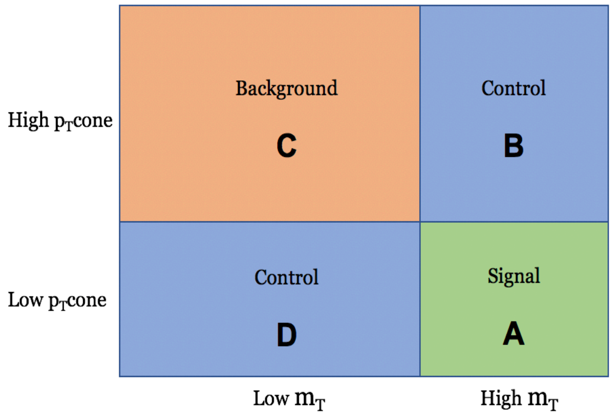

Figure 1: Division of phase space into four regions according to selection cuts in m_T and p_T^{cone}. We assume that region A is wholly composed of signal and QCD background while regions B, C, and D contain background events only.

are used in place of MC simulations, specifically the ABCD method and the fit method.

The ABCD method divides phase space into four sections, as shown in Figure 1. Assuming that the QCD background is equal in each section, we can make the estimate that

$$\mathcal{N}_A = \frac{\mathcal{N}_B \mathcal{N}_D}{\mathcal{N}_C}$$

where $\mathcal{N}_{A,B,C,D}$ denotes the number of QCD background events in each region [4].

The fit method includes plotting several graphs, as shown in Figure 2. We are interested in the shapes, rather than the magnitudes, of the 'template' of the QCD background and the MC data. A linear combination of the two curves was used to fit the ATLAS data. Figure 2 also shows the superimposed fit together with the ATLAS data. Multiplying the scale factor used for the QCD template with the number of events represented by the original template curve provides an estimate for the true QCD background in the ATLAS data.

4. Analysis & Results

Finding σ from the above methods comprises of the same process. $N_{selected}$ is determined by evaluating the total number of events passing the selection cuts, and $N_{background}$ from the estimates calculated above. The efficiency ε is found by dividing the number of simulated events in the MC data by $N_{selected}$. $\mathcal{L}$, meanwhile, was given to be 1000 pb^{-1} for this dataset. Out of the two methods, the value for σ obtained from the fit method was determined to be the most reliable given that it involves fewer assumptions.

The offset method – using the difference in σ between the fit and ABCD method – was used to find a systematic uncertainty on the value of σ [4].

To determine the statistical uncertainty of σ, the selection cut uncertainties were used to find bounds for $N_{selected}$. Maximum and minimum values for σ were then calculated and the difference between

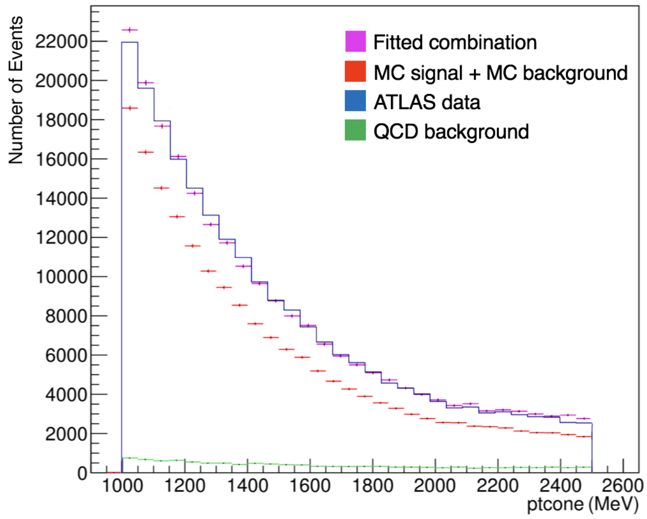

Figure 2: The QCD background curve is composed of the ATLAS data which did not pass the m_T selection cut subtracted by the MC background data.

these and the central σ were used as the statistical uncertainty. The luminosity uncertainty was found in an analogous way: the fractional uncertainty in $\mathcal{L}$ of 2% (given in the lab script) was used to establish upper and lower bounds, from which an uncertainty in σ could be found.

The final result for the combined W boson cross section is $\sigma_{(W \to l\nu)}$ = 21371 ± 12 (stat.) ± 696 (syst.) ± 296 (lumi.) pb. Taking the ratio of the W^+ and W^- cross sections, we obtain a charge asymmetry ratio of σ_{W+}/σ_{W-} = 1.171 ± 0.099 (stat.) ± 0.021 (syst.).

5. Conclusion

Comparing $\sigma_{(W \to l\nu)}$ to a similar study [5], our result is 0.99 standard deviations away from the study's value of 20620 pb. Similarly comparing σ_{W+}/σ_{W-} we find our value is 1.23 standard deviations from the study's result. These differences will be somewhat due to the different collision energies (8 TeV in our dataset, 13 TeV in their dataset). Furthermore, since the colliding protons are composed of two up quarks ($+^2/_3\,e$) and a down quark ($-^1/_3\,e$), the asymmetry in favour of W^+ production at the LHC agrees with intuition.

References

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