PROCEEDINGS OF SCIENCE

Measuring WZ longitudinal polarization with the ATLAS detector

Eyal Brodet[*]
School of Physics and Astronomy
Tel-Aviv University
69978, Tel Aviv, Israel
Eyal.Brodet@cern.ch

The prospects are presented for measuring, in ATLAS, the spin density element, ρ_{00}, of the Z and W bosons in WZ production. The analysis considers events where both W and Z decay leptonically via electron or muon channels. This is done by reconstructing the decay angle of the leptons in the Z and W rest frames. The fraction of longitudinally polarized Z's and W's are extracted from the angular distributions. The errors presented correspond to an integrated luminosity of 100 fb^{-1}. The expected final error on the measurement includes the systematic error due to detector correction and also due to the choice of proton parton distribution function.

European Physical Society Europhysics Conference on High Energy Physics, EPS-HEP 2009,
July 16 - 22 2009
Krakow, Poland

[*]Speaker.

PoS(EPS-HEP 2009)348

1. Introduction

The production of WZ events is of interest since it is precisely predicted in the Standard Model (SM) through the interaction of quarks. These predictions concern not only the total cross section but also the polarization of the Z's and W's produced and their dependence on the centre of mass energy. The WZ process was first observed at the Tevatron[1] but could not be studied in detail due to poor statistics. In the LHC there is a unique opportunity to observe and study this process in much more detail and in particular to investigate the longitudinal polarization of the Z and W. The longitudinal polarization is of special interest since it can not be observed in single Z or single W production where there is only transverse polarization, whereas in di-boson processes there is also longitudinal polarization. Data and MC comparison of the WZ polarization states will be important for ensuring that this interaction is well understood in the SM.
This paper describes the feasibility of the WZ longitudinal measurement[2] and is organized as follows. Section 2 presents the theoretical framework. In section 3 event generation and software are discussed. Section 4 presents the event selection and the proposed measurement technique. The systematic uncertainties are discussed in section 5 and the results are presented in section 6.

2. Theoretical Framework

Assuming a W of spin one decaying into two spin half leptons, the expected angular distribution for massless leptons in the rest frame of the parent W is given in terms of the diagonal elements of the SDM[3] by,

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta_l} = \rho_{--}\frac{3}{8}(1+\cos\theta_l^*)^2 + \rho_{++}\frac{3}{8}(1-\cos\theta_l^*)^2 + \rho_{00}\frac{3}{4}\sin^2\theta_l^*. \tag{2.1}$$

where θ_l^* is the decay angle of the negatively charged lepton (positively charged anti-lepton) produced in the decay of the W^- (W^+), as seen in the W rest frame, with respect to the W direction in the WZ centre of mass frame.
In the case of the Z boson[4,5] the angular distribution of the leptons in the Z rest frame is given by:

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta_l} = \rho_{--}\frac{3}{8}(1+\cos\theta_l^{*2} + 2\cdot A\cdot\cos\theta_l^*) + \rho_{++}\frac{3}{8}(1+\cos\theta_l^{*2} - 2\cdot A\cdot\cos\theta_l^*) + \rho_{00}\frac{3}{4}\sin^2\theta_l^*. \tag{2.2}$$

where $A = \frac{2\cdot \mathrm{v}\cdot \mathrm{a}}{\mathrm{v}^2+\mathrm{a}^2}$ in terms of v and a the vector and axial vector couplings of the Z to leptons and θ_l^* is the decay angle of the negatively charged lepton in the Z rest frame with respect to the Z direction in the WZ centre of mass frame. The diagonal elements satisfy the condition: $\sum\rho_{\tau\tau} = 1$.

3. MC Data Samples

Samples of simulated data events of $q\overline{q}$ producing WZ's in the final state were generated using the MC@NLO[6] MC generator. CTEQ6M[7] parton distributions functions were used for this and other generators. In order to evaluate the contribution of possible background sources MC samples for $t\bar{t}$, W^+W^-, ZZ and Z+jet events were also produced using MC@NLO. Z+photon events were produced by PYTHIA[8]. The generated MC samples were processed by the full ATLAS simulation program and then reconstructed as for real data.

4. Measurement of the Spin States of the Z and W Bosons

4.1 Event selection

The process $WZ \to \ell\nu\ell^+\ell^-$, $\ell = e, \mu$, can potentially have some dangerous backgrounds. The main distinguishing feature of this process is three isolated leptons. The background sources considered are $t\bar{t}$, W^+W^-, ZZ, Z+jet and Z+photon events, all of which can contain three real or fake leptons in the final state. To enhance signal and suppress background we apply the following cuts:

- A minimum angle of 20° is required between the leptons and any jet so that the leptons are isolated.
- The leptons must have p_T over 25 GeV and rapidity below 2.5 (motivated by the detector acceptance[9]). These two cuts make sure that the event is well contained in the detector with full trigger efficiency.
- The next cut is the requirement that the missing transverse momentum in the events should be more than 25 GeV. This requirement takes account of the missing energy caused by the undetected momentum of the neutrino in the event.
- The invariant mass of the two leptons associated with the Z is required to be within 12 GeV of the Z mass.
- The next cut is the requirement that there should at most one jet in the events, and the transverse momentum of that jet must be below 30 GeV. This cut minimizes background from multi-jet events.
- Similarly to the cut on the invariant mass of the Z candidate, one would like to cut on the invariant mass of the W. However, the W cannot be reconstructed, as the longitudinal component of the invisible neutrino cannot be measured. We use instead the W transverse mass, M_T^W which is composed from the reconstructed transverse momenta of the charged lepton, p_T^l, and the neutrino $p_T^{\rm miss}$,

  $$M_T^W = \sqrt{(p_T^l + p_T^{\rm miss})^2 - (\overrightarrow{p_T^l} + \overrightarrow{p_T^{\rm miss}})^2}. \tag{4.1}$$

  The requirement here was to accept events with transverse mass between 50 and 90 GeV and was optimized to reject non-WZ events.
- The angle in the transverse plane between the missing transverse momentum and the nearest lepton is required to be larger than 40°. This cut rejects non-WZ events since in a real WZ event the neutrino direction (represented by the missing energy) and the direction of each of the leptons is not expected to overlap.

	W^-Z	W^+Z	$t\bar{t}$	W^+W^-	ZZ	Z+jet	$Z+\gamma$	all backg
3 Lep	8025	11100	87080	1596	591	10081	12372	111720
P_T and Rap	4239	5748	3724	192	266	735	6150	11067
Missing Energy	3387	4611	3108	156	65	54	432	3815
M_Z Constraint	3281	4451	672	6	43	51	330	1102
At most 1 jet	1764	2212	280	0	22	32	126	460
M_T^W and Isol Ang	1265	1608	4	0	5	11	8	28

Table 1: Expected number of events for signal and background after cuts for an integrated luminosity of 100 fb^{-1}.

The expected number of events passing each selection stage are presented in table 1. One can see that after all the cuts the level of background to WZ events is around a 1%. This is considered negligible.
The reconstruction of the leptons is described in Refs [10,11] and the jets in Ref. [12].

4.2 Measurement technique

The values of the different SDM elements, $\rho_{\tau\tau}$, depend on the true $\hat{s}$ and on the production angle of the Z or W. In a $q\bar{q}$ interaction from proton-proton collisions, the value of true $\hat{s}$ varies over a significant range. Therefore, there is a unique opportunity to study the dependence of the different $\rho_{\tau\tau}$ on true $\hat{s}$. According to the Standard Model, the dependence of the $\rho_{\tau\tau}$ on the Z and W production angle is expected to be quite weak and therefore was not studied in this analysis.
The events were divided into 3 bins in true $\sqrt{\hat{s}}$ such that there is a variation in the theoretical value for ρ_{00} and adequate statistics in each bin according to the MC. The Z, W^- and W^+ decay angle distribution changes considerably between the energy bins.
For real data there will be an experimental difficulty in reconstructing the lepton decay angle in the rest frame of the Z or W. This is due to the inability to measure the longitudinal momentum of the neutrino, p_z^ν and therefore to fully reconstruct the event. However, constraining the invariant mass of the lepton and neutrino system to the W mass, yields a quadratic equation with two solutions for p_z^ν, leading to two different reconstructions for each event. For each reconstruction, we calculate the corresponding cross section contribution, using the formalism of Ref. [13]. This allows us to construct a weight for each solution. The weighted average of the two p_z^ν values is then used for the final reconstruction of that event. This technique gives an estimate of the decay angles and $\sqrt{\hat{s}}$. The quality of this estimate is shown in figure 2(left) where the difference between the true and reconstructed $\sqrt{\hat{s}}$ is shown, and also in figure 2(right) where the difference between the true and reconstructed W^- decay angle is shown. The differences are centered at zero showing that there is no bias in this technique. The width of the distribution is a measure of the quality of the technique. We consider the resolution of this technique to be reasonable. The systematic uncertainties on our measurement from the use of this technique will be discussed in the next subsection. The main motivation for this technique is the reconstruction of the decay angle for the W^- and W^+. However this technique is also needed in the case of the Z since we do not know the boost of the system and therefore we can not correctly reconstruct the decay angle.

The polarization is measured by the means of an un-binned fit of equations [3] and [4] to the decay angle distribution. The values of the ρ^{++} and ρ^{--} can also be determind in the fit but are not the focus of the present study.

5. Systematics

In this analysis the MC is used to correct the $\cos\theta_l^*$ distribution of the decaying lepton in the Z and W rest frames for the effects of the angular reconstruction (in the case of the W's) and the cuts made for signal selection. It is necessary to consider systematic uncertainties on these corrections. The uncertainties considered are MC statistics, the choice of the proton parton distribution function(PDF) and the sensitivity to the event weight used in the reconstruction of the decay angle. In general the systematic uncertainties were found to be smaller than the statistical errors and they are presented in more details in[2].

6. Results and Conclusions

Table 2 shows the fraction of longitudinally polarized W's and Z's bosons measured for each $\sqrt{\hat{s}_{\mathrm{reco}}}$ bin using simulated data of 100 fb^{-1}. The values have been corrected for the detector effects as described in in detail in[2]. For comparison the true MC values are shown. The errors on the simulated data indicate the expected sensitivity of the measurement. In this analysis the measurements and the true MC values should agree since the correction factors are taken from MC. These results are shown in figure 2. Since according to MC the results for Z coming from W^-Z are consistent with the results for Z coming from W^+Z only the result for Z coming from W^-Z are shown.
In conclusion, it was shown that it would be possible to measure the SDM element ρ_{00} with luminosity of a 100 fb^{-1} in WZ events. This may be done in bins of $\sqrt{\hat{s}_{\mathrm{reco}}}$ which will be interesting for a detailed study of this process.

7. Acknowledgments

I would like to thank the Israel Science Foundation for supporting this research.

References

[1] CDF Collaboration, *Observation of WZ production*, arXiv:hepex/0702027.

[2] ATLAS Collaboration, *Measuring WZ longitudinal polarization with the ATLAS derector*, ATL-PHYS-PUB-2009-078.

[3] OPAL Collaboration, Phys.Lett.B585,223-236(2004).

[4] M.J. Duncan and M.H. Reno, arXiv:hep-ph/9409334v1

[5] R. Tenchini and C. Verzegnassi, *The Physics of the Z and W Bosons*, published by World Scientific (2008), page 74

[6] S. Frixione and B.R. Webber, JHEP 0206(2002)029 [hep-ph/0204244].

[7] J. Pumplin et al, JHEP **0207** (2002) 012.

	$\sqrt{\hat{s}_{\text{reco}}}$ GeV	ρ_{00} $\pm$ stat $\pm$ syst	true ρ_{00}
W^- in W^-Z	$170 < \sqrt{\hat{s}_{\text{reco}}} < 215$	$0.263 \pm 0.084 \pm 0.015$	0.284
	$215 < \sqrt{\hat{s}_{\text{reco}}} < 270$	$0.288 \pm 0.092 \pm 0.020$	0.20
	$\sqrt{\hat{s}_{\text{reco}}} > 270$	$0.166 \pm 0.084 \pm 0.018$	0.10
Z in W^-Z	$170 < \sqrt{\hat{s}_{\text{reco}}} < 215$	$0.172 \pm 0.074 \pm 0.011$	0.22
	$215 < \sqrt{\hat{s}_{\text{reco}}} < 270$	$0.274 \pm 0.073 \pm 0.017$	0.20
	$\sqrt{\hat{s}_{\text{reco}}} > 270$	$0.077 \pm 0.079 \pm 0.019$	0.14
W^+ in W^+Z	$170 < \sqrt{\hat{s}_{\text{reco}}} < 215$	$0.176 \pm 0.057 \pm 0.021$	0.27
	$215 < \sqrt{\hat{s}_{\text{reco}}} < 270$	$0.171 \pm 0.063 \pm 0.015$	0.21
	$\sqrt{\hat{s}_{\text{reco}}} > 270$	$0.096 \pm 0.061 \pm 0.012$	0.09
Z in W^+Z	$170 < \sqrt{\hat{s}_{\text{reco}}} < 215$	$0.103 \pm 0.056 \pm 0.012$	0.22
	$215 < \sqrt{\hat{s}_{\text{reco}}} < 270$	$0.134 \pm 0.055 \pm 0.019$	0.19
	$\sqrt{\hat{s}_{\text{reco}}} > 270$	$0.147 \pm 0.054 \pm 0.011$	0.12

Table 2: ρ_{00} values obtained for the different energy bins for 100fb^{-1} for W^-, W^+ and Z. The errors are split into their statistical and systematical components.

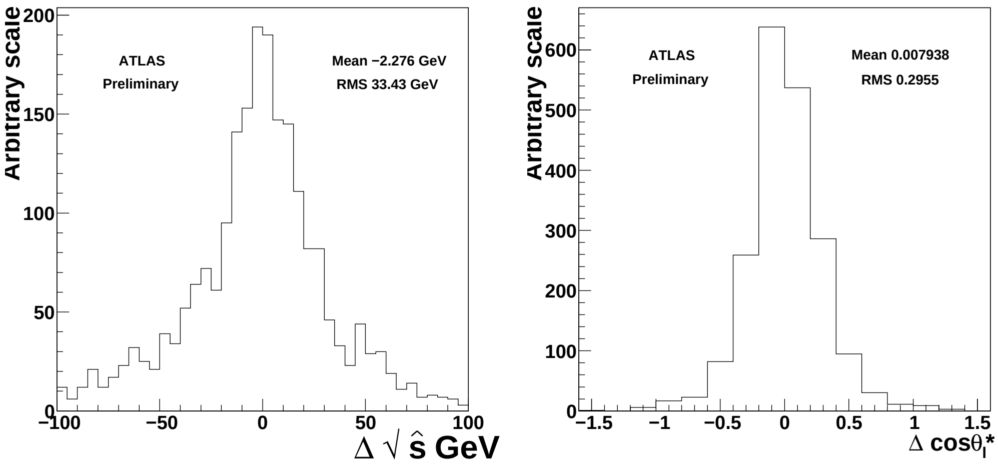

Figure 1: Distribution of the difference between the true centre of mass energy and the reconstructed one in W^-Z events(left). Distribution of the difference between the true and reconstructed $\cos\theta_l^*$ for the W^- decay in W^-Z events(right).

[8] T. Sjostrand, S Mrenna and P. Skands, JHEP 05 (2006) 026.

[9] ATLAS Collaboration, G. Aad et al. JINST 3(2008) S08003.

[10] ATLAS Collaboration, Electron chapter, pages 46-53, CERN-OPEN-2008-020

[11] ATLAS Collaboration, Muon chapter, pages 165-174, CERN-OPEN-2008-020

[12] ATLAS Collaboration, Jets chapter, pages 263-276, CERN-OPEN-2008-020

[13] G. Bella, *Weighting Di-Boson Monte Carlo Events in Hadron Colliders*, arXiv:0803.3307v1

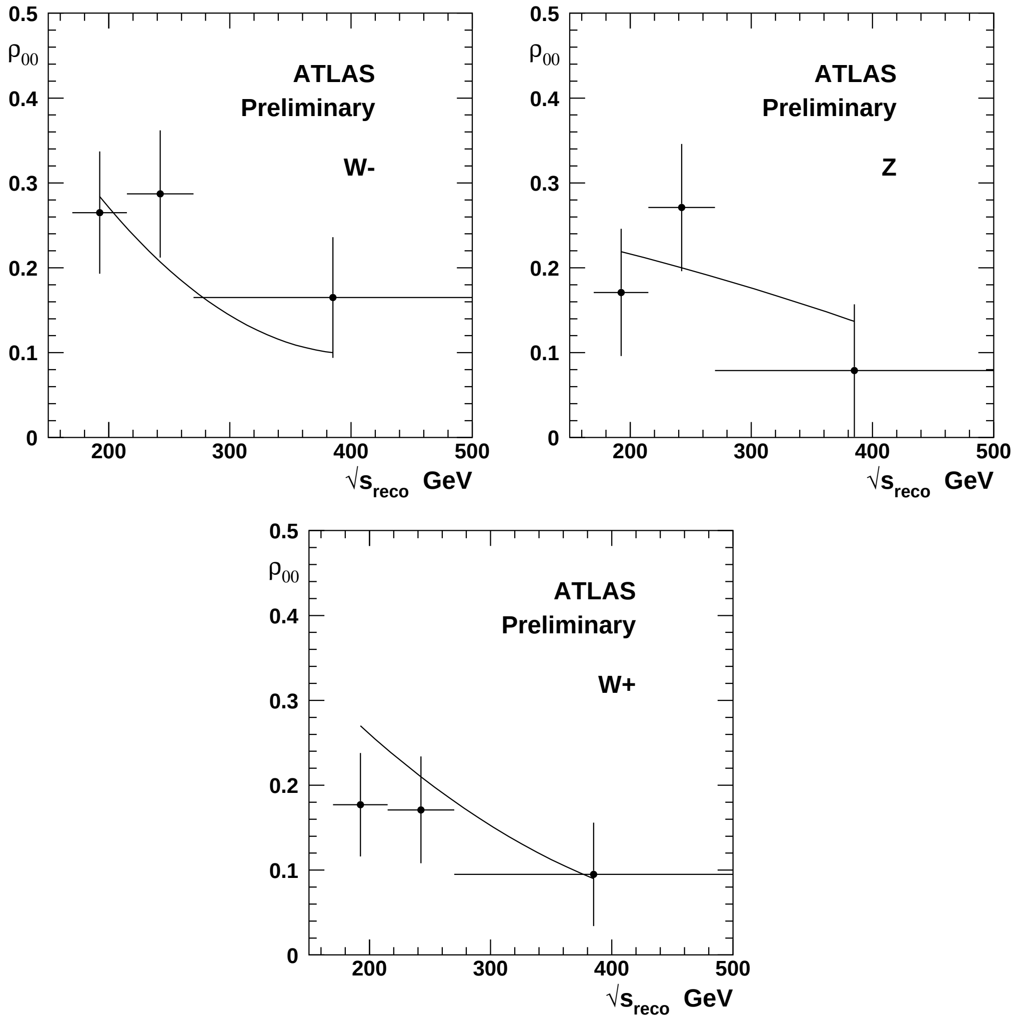

Figure 2: ρ_{00} as a function of the estimated centre of mass energy $\sqrt{\hat{s}_{\text{reco}}}$ for W^-(left), Z(right) and W^+(bottom). The errors include statistical and systematical uncertainties. The solid line represents the theoretical predictions according to the MC.