IL NUOVO CIMENTO Vol. 32 C, N. 3-4 Maggio-Agosto 2009
DOI 10.1393/ncc/i2009-10485-5

Colloquia: IFAE 2009

Measurement of W/Z cross-sections in the ATLAS experiment

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(ricevuto il 19 Settembre 2009; pubblicato online il 27 Novembre 2009)

Summary. — The propects for the measurements of the production cross-section for W and Z bosons in the ATLAS experiment will be briefly presented here, together with a discussion on the strategy for controlling the main sytematic effects.

PACS `14.70.Fm` – W bosons.
PACS `14.70.Hp` – Z bosons.

1. – Introduction

The first benchmark for the ATLAS experiment [1] will be to achieve a complete and detailed understanding of known Standard Model physics at the LHC. The completely new detector and the unexplored energy range call for major efforts in order to fully understand the detection and reconstruction performance. In this context, the physics of the W and Z bosons plays a crucial role. First, the clean and fully reconstructed Z leptonic final states can be used to measure from data the detector performance (trigger efficiency, reconstruction efficiency, lepton energy scale). Second, the available high-precision cross-section calculation, including higher-order corrections, allows to use these measurements as a stringent test of QCD. Moreover, several electroweak parameters are accessible through these channels (M_W, $\sin^2\theta_w$, lepton universality). Last, but not least, these channels are important backgrounds to several new-physics studies.

This paper will give an overview of the measurement strategies to be used by the ATLAS experiment for W and Z cross-section measurements, with focus on the electron and muon final states. A complete treatment can be found in [2]. Results shown here refer to an integrated luminosity from 50 to 100 pb^{-1}, and a center-of-mass energy of 14 TeV.

2. – Contributions to the total error

For a given number of selected events N, with an estimated background contamination B, the error on the cross-section measurement can be written as shown in eq. (1):

$$\frac{\delta\sigma}{\sigma} = \frac{\delta N + \delta B}{N - B} \oplus \frac{\delta\varepsilon}{\varepsilon} \oplus \frac{\delta A}{A} \oplus \frac{\delta L}{L}\,, \tag{1}$$

where ε takes into account the trigger, reconstruction and selection efficiency, A is the acceptance as calculated via Monte Carlo (MC) studies, using the most up to date QCD and EW predictions, L is the integrated luminosity. All these terms need to be either measured from data or estimated from MC in order to provide a reliable measurement.

Luminosity. From the point of view of a physical process, the luminosity is the link between process rates and cross-sections. From the point of view of the accelerator, taking into account the beam parameters one could in principle calculate the luminosity exactly from "first principles", by knowing the bunch crossing frequency, the number of colliding protons per bunch crossing, and the transversal beam size. The latter gives, in this case, the larger contribution to the error. ATLAS will exploit a two-phases strategy for luminosity measurements. First, in special "low luminosity" runs, beam parameters will be used to measure the absolute luminosity with a precision of about 20%. In a second phase, elastic pp collisions will be observed by Roman Pot detectors, thus obtaining a more precise ($< 3\%$) measurement. During physics runs, relative luminosity will be measured by luminosity monitors. Moreover, well-known processes (such as muon pair production or W/Z production itself) can be used for luminosity measurement. The aim is to reach an accuracy of less than 5% during physics runs.

Acceptance. Of all the errors mentioned in eq. (1), acceptance is the one which is not expected to scale with statistics, since it comes from purely theoretical uncertainties. In particular, PDF uncertainties are known to be the dominant contributions to the error on Standard Model measurements at LHC. The low-x gluon uncertainty is dominant at the EW scale, while the high-x gluon contribution becomes important at the TeV scale. On the longer term, of course, LHC data itself will constraint the PDFs, probing new regions of x and Q^2. For example, direct photon production can be used to constrain the gluon distribution mid-to-high-x, while inclusive jet production will improve the high-x gluon PDF at the TeV scale. In addition, W and Z rapidity distributions can lead to reduction up to 40% of the uncertainty on gluon PDF in low-x region, and Z+b process can give insights on the b-PDF.

In order to estimate the error due to the acceptance, several Monte Carlo programs have been used, and different effects were tested (PDFs, electroweak corrections, initial state radiation, underlying event, etc.). The global $\delta A/A$ value has been estimated to be about 2.3%, the major contribution ($\sim 1\%$) coming, as expected, from PDF uncertainties.

Efficiencies. As far as muon performance is concerned, the main systematics are those related to the muon spectrometer, namely trigger/reconstruction performance and momentum scale. In order to reduce the dependence on simulation, a data-driven approach must be taken. The idea is to exploit the two independent tracking systems of the ATLAS detector (Inner Tracker and Muon Spectrometer) to cross check their performance using the so-called Tag and Probe method. A combined (Inner Tracker + Muon Spectrometer) track is chosen as a tag, and a track in the Inner Tracker is used as a probe. The invariant mass of the tag and the probe must be close to the Z mass. The response of the Muon Spectrometer to the probe is checked, thus allowing to measure its performance. A similar approach is used also for electron performance determination, in this case stydying $Z \rightarrow ee$ decays, while semileptonic $Z \rightarrow \tau\tau$ events allow to measure the missing transverse energy (MET) performance. The width and position of the Z peak are also used to determine lepton energy scales and resolutions.

3. – Event selections

Muon final states. Single muon trigger is the preferred one for these final states, the threshold for $W \rightarrow \mu\nu$ (20 GeV) being however harder than the one used for $Z \rightarrow \mu\mu$ (10 GeV). A very clean $Z \rightarrow \mu\mu$ sample, with a residual background fraction of $\sim 0.4\%$ is selected by requiring the existence of two isolated and high-p_t ($> 20\,\mathrm{GeV}$) muons, whose invariant mass is within 20 GeV from the true M_Z.

The topology of $W \rightarrow \mu\nu$ events is selected by requiring a high-p_t ($> 25\,\mathrm{GeV}$), isolated muon, and a significant amount of MET ($> 25\,\mathrm{GeV}$). The transverse mass of the muon and the MET must be greater than 40 GeV. Jet background is not an issue in this channel, while the isolation, p_t and impact parameter cuts significantly reduce the contributions from heavy flavours. Residual contamination from $Z \rightarrow \mu\mu$ events is $\sim 3\%$, and is the dominant background source for this channel.

Electron final states. Signal selection follows the same lines of the muon final states: single electron trigger (10 GeV for $Z \rightarrow ee$, 20 GeV for $W \rightarrow e\nu$), electron p_t cut (15 GeV for $Z \rightarrow ee$, 20 GeV for $W \rightarrow e\nu$), electron quality cut. As opposed to the muon channels, however, residual background contamination in this case is dominated by the jet background. Being jet production and fragmentation at LHC affected by a large theoretical uncertainty, it is crucial to estimate this background with data-driven techniques. For $Z \rightarrow ee$, an almost pure background sample can be extracted from data by releasing the electron ID and quality cuts (signal contribution is negligible in these conditions). A simultaneous fit of signal and background after all cuts yields a background fraction of $(8.5 \pm 1.5)\%$, with residual uncertainty coming mainly from the shape modelization. In the case of $W \rightarrow e\nu$, an essentially pure sample of di-jet events can be selected using cuts similar to the ones for the Z searches, but requiring photon trigger and ID (track veto) instead of electron. The MET shape obtained in these conditions is identical to the one from QCD jets background in W searches, where it is used for background subtraction before the MET cut. This leads to a jet background fraction of $0^{+4}_{-0}\%$.

4. – Cross-section results

The results for cross-section measurements at two different integrated luminosities (50 and $100\,\mathrm{pb}/^{-1}$) are shown in tables I and II. The overall luminosity uncertainty, discussed above, is not included in the tables. The systematic error (last numbers on the last columns) is the dominant source of uncertainties already at this very early stage of data taking.

In particular, the W channels are dominated by the uncertainty on the backgrounds, while Z channels are "easier", as far as the background is concerned, thanks to their fully reconstructed leptonic final states. For the same reasons, however, they suffer from a larger contribution from efficiency uncertainty.

Table I. – *Cross-section measurements with an integrated luminosity of* 50 pb^{-1}, *for the channels discussed above.*

Process	$N(\times 10^4)$	$B(\times 10^4)$	$A \times \varepsilon$	$\delta A/A$	$\delta\varepsilon/\varepsilon$	σ (pb)
$Z \to \mu\mu$	2.57±0.02	0.010±0.002	0.254	0.023	0.03	2016±16±76
$W \to \mu\nu$	30.04±0.05	2.01±0.12	0.273	0.023	0.02	20530±40±630
$Z \to ee$	2.71±0.02	0.23±0.04	0.246	0.023	0.03	2016±16±83
$W \to e\nu$	22.67±0.04	0.61±0.92	0.215	0.023	0.02	20520±40±1060

Table II. – *Cross-section measurements with an integrated luminosity of* 100 pb^{-1}, *for the channels discussed above.*

Process	$N(\times 10^5)$	$B(\times 10^5)$	$A \times \varepsilon$	$\delta A/A$	$\delta\varepsilon/\varepsilon$	σ (pb)
$Z \to \mu\mu$	5.14±0.01	0.02±0.001	0.254	0.023	0.007	2016±4±49
$W \to \mu\nu$	60.08±0.02	4.02±0.05	0.273	0.023	0.004	20535±7±480
$Z \to ee$	5.42±0.01	0.46±0.02	0.246	0.023	0.007	2016±4±49
$W \to e\nu$	45.34±0.02	1.22±0.41	0.215	0.023	0.004	20520±9±516

Systematic uncertainties from the backgrounds and detector efficiency are in general expected to scale with statistics (hence, they are smaller in table II). On the other hand, acceptance contribution does not change (unless new input is given to the theory), and dominates the result at higher luminosities.

5. – Conclusions

Standard Model physics, and in particular W/Z bosons, will be an important benchmark for the ATLAS detector in the early phase of data taking. Z purely leptonic final states are crucial to measure from data the performance of electron and muon trigger/reconstruction/identification, while W final states and the semi-leptonic $Z \to \tau\tau$ decay will allow to tune MET measurements. In addition, W/Z cross-sections can also be used to monitor beam luminosity, once other major systematics are kept under control. The main areas of acivities in the ATLAS Collaboration are now focused on preparation for first data, including optimizing analyses for early beam conditions (10 TeV), *in situ* detector calibration and data-driven background estimation.

REFERENCES

[1] The ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, *JINST*, **3** (2008) S08003.

[2] The ATLAS Collaboration, *Expected Performance of the ATLAS Experiment: Detector, Trigger and Physics*, *CERN-OPEN-2008-020* (2008).