W mass measurement in the ATLAS experiment

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A precise measurement of the mass of the W boson will be essential to provide improved indirect constraints, e.g. on the Higgs boson mass. Using new methods developed for this challenging measurement, the performance expected is presented, evaluating various sources of systematic uncertainties, both of experimental and theoretical nature. The focus of this contribution will be on the expectation for the initial data taking and results will be shown for an integrated luminosity of 15 pb^{-1}. Prospects on the total uncertainties which may be obtained with an integrated luminosity of 10 fb^{-1} will be given.

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1. Introduction

The W boson mass is a crucial ingredient of the Standard Model global fit: a precise measurement allows consistency checks of the model, insights at new physics and constraints of the Higgs boson mass. In the context of TeVatron experiments providing more and more precise results (the world average is now 80.399 ± 0.025 GeV [1]), the ATLAS experiment [2] can contribute thanks to the high cross section of W and Z productions, Z events being used to calibrate the detector and constrain the systematics uncertainties. The LHC will produce around 20×10^6 W bosons and 2×10^6 Z bosons per leptonic decay channel and per fb^{-1} at a center of mass energy of 14 TeV, thus statistical uncertainties will become negligible very fast and the real challenge will be to control the systematic uncertainties.

2. General description of the analysis method

Only $W \rightarrow \ell\nu$ final states are used, with $\ell = e, \mu$. Because of the neutrino other observables than M_W have to be used: p_T^ℓ, the transverse mass defined as $m_T = \sqrt{p_T^\ell p_T^\nu (1 - \cos(\phi^\ell - \phi^\nu))}$ and p_T^ν. The following will be restricted to the case of the p_T^ℓ distribution in $W \rightarrow e\nu$ final states.

Template method The reconstructed distribution is tested, with a χ^2 test, against a set of template distributions, characterized by a mass scale α_M. The minimum of the parabola χ^2 *vs* α_M gives M_W. This relies crucially on the control of any effect distorting the test distribution, which come from different sources: experimental (lepton energy scale, linearity and resolution, E^ℓ non-Gaussian tails, efficiencies, missing transverse energy (MET) scale and resolution), theoretical (initial and final state radiation, boson width, parton density functions (PDF)) and environmental (backgrounds, underlying event, pile-up). Most of them can be strongly constrained with Z measurements.

Detector response modelisation To create the templates, generated leptons from $W \rightarrow \ell\nu$ are smeared according to a model of detector response. In bins of p_T, η and ϕ of the leptons, the distributions of the reconstructed energy divided by the true energy are fitted by "Crystal-ball" functions [3] characterized by a Gaussian core and power-low tails. To validate the model, the parameters (describing the scale, resolution and tails) are first taken from Monte-carlo events then from *in situ* calibration on Z events.

Systematic uncertainties estimation To estimate the impact of an effect, templates are produced with varying effect sizes and the deviation of the results in terms of M_W is given as a function of the effect size.

Selection It requires one high p_T (>20 GeV) isolated electron and MET>20 GeV. Geometrical cuts are made to exclude the calorimeter region where the resolution is degraded. The selection efficiency times the acceptance is of the order of 22 % and reduces the background to the level of 2.2 % (mainly $W \rightarrow \tau\nu$ events).

3. Analysis example with 15 pb^{-1}

In this case we expect to select 65000 $W \rightarrow \ell\nu$ and 6500 $Z \rightarrow \ell\ell$, per leptonic channel.

Calibration with $Z \rightarrow ee$ events Here the energy scale α_E and resolution σ_E can only be estimated averaged over the electron (η,ϕ,p_T) phase space. A template method is used with the di-electron invariant mass to extract simultaneously α_E and σ_E with a precision of 0.1 % and 6 % respectively. Templates to the W mass are then produced using the obtained values. The transportation of the calibration from Z to W events is validated by the fit result: 80.466 ± 0.11 GeV to be compared to the generated mass, 80.405 GeV.

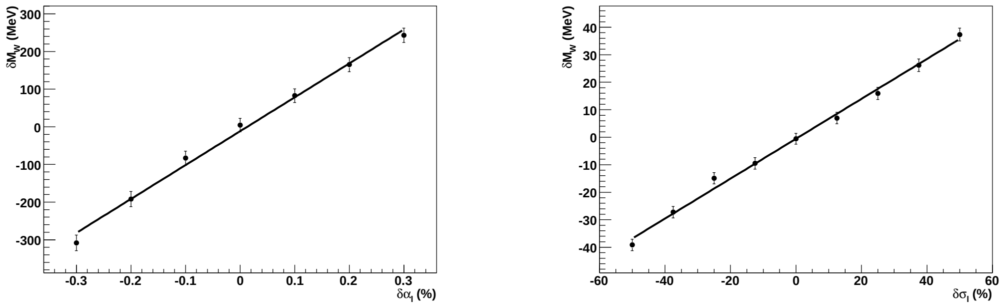

Figure 1: Bias induced on the fitted M_W versus the relative bias tested on α_E (left) and σ_E (right) [4].

Systematic uncertainties estimation Examples of this analysis step are illustrated on Fig. 1 which gives the bias induced on the fitted M_W as a function of the relative bias tested on α_E (left) and σ_E (right). The dependances are linear: $\partial M_W/\partial\alpha_E = 800$ MeV/%, $\partial M_W/\partial\sigma_E = 0.8$ MeV/%.

Results The result is $\delta M_W = 120(\text{stat.}) \oplus 114(\text{experimental}) \oplus 25(\text{PDFs})$ MeV for the electron channel and the p_T^e analysis [5]. The experimental uncertainty (which sources are listed in the description of the template method) is dominated by the 110 MeV contribution from the electron energy scale. Note that this error analysis does not include contributions from underlying theoretical uncertainties such as the $p_T(W)$ distribution. With the limited Z statistics available in this sample, these contributions would be expected to increase the overall systematic error. Note also that this analysis implies a center of mass energy of 14 TeV. With a center of mass energy of 7 TeV, it corresponds to roughly 30 pb^{-1}.

4. Analysis example with 10 fb^{-1}

With this luminosity, 45 millions of W bosons and 4.5 millions of Z bosons are expected to be selected per leptonic channel. It is then possible to perform extensive systematic studies. This analysis has been reported in [4].

Systematic uncertainty studies Example 1: the electron energy dependant scale and resolution are extracted with the same template method as before but in bins of E^e, as illustrated on Fig. 2. Whereas an hypothesis was made on the shape of the resolution energy dependance to create the templates, the true shape is recovered. The impact on M_W is determined through a set of M_W exercises where the parameters are randomly drawn within their uncertainties. The RMS of the distribution of the fitted M_W gives the expected uncertainties: $\delta M_W(\alpha_E) = 4$ MeV and

$\delta M_W(\sigma_E) = 1$ MeV. Example 2: the impact of the PDFs uncertainty on the rapidity distributions of the bosons. The study is based on CTEQ6.1 [6] which provides a global best fit and 40 PDFS sets corresponding to the variation of $\pm 1\sigma$ of each of the 20 parameters. The global uncertainty induced on M_W is $\sim$25 MeV. Since, at the LHC, W and Z are mainly produced through interactions of sea quarks which are nearly equally represented, a strong correlation is expected between the rapidity distributions of W and Z bosons, y_W and y_Z as confirmed by Fig. 3 (left). With 10 fb^{-1}, an improvement by a factor 30 is expected on the y_Z distribution as shown on Fig. 3 (right). This translates, *via* the correlation, into a factor 23 on the y_W distribution leading to $\delta M_W(y_W) = 1$ MeV.

Results The systematic uncertainties are expected to be reduced to around 7 MeV per channel and per study [4]. The different observables (p_T^ℓ, m_T and p_T^ν) show different behaviour with respect to the different sources of uncertainty, so a combination will prove usefull.

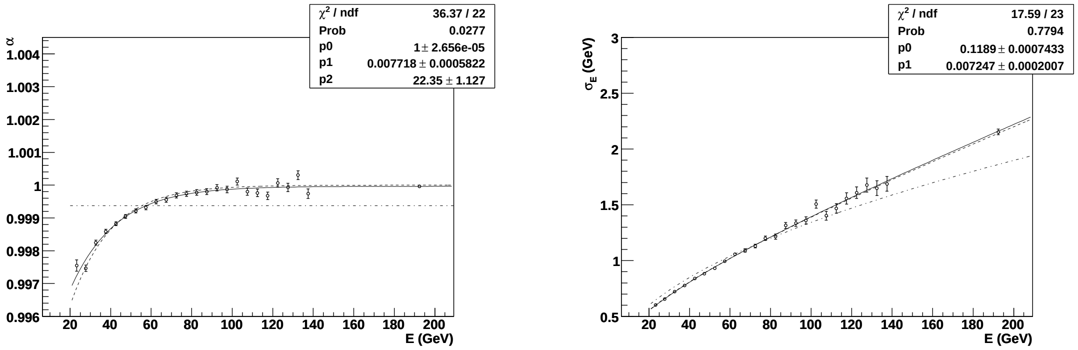

Figure 2: Left: reconstructed α_E *vs* E^e (points). Full line: injected function, dashed line: empirical function fitted through the points, dot-dashed line: result of an energy independant analysis. Right: reconstructed σ_E *vs* E^e (points). Full line: true resolution function ($\sigma(E)/E = a/\sqrt{E} + b$), dashed line: fitted function, dot-dashed line: assuming no constant term ($b = 0$) [4].

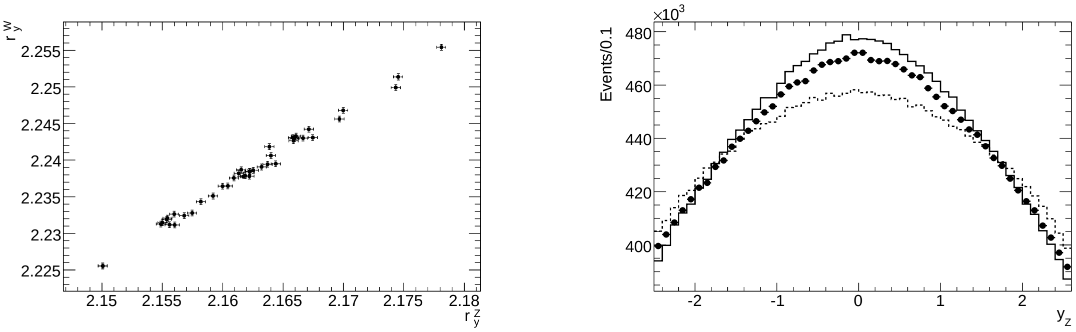

Figure 3: Left: correlation between the RMS of the W and Z rapidity distributions, varying the CTEQ6.1 PDF sets. Right: the line histograms represent 2 extreme prediction for y_Z as given by the CTEQ6.1 PDF sets. The points correpond to the central set [4].

5. Conclusion

The W mass determination at the LHC is a long term project. In the first years, systematic uncertainties of both experimental and theoretical origin will dominate the measurement, but it was shown using two examples that the LHC has the power to constrain these uncertainties and provide a competitive measurement on the long term.

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