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Electroweak Physics in the forward region and measurement of the electroweak mixing angle at the LHCb experiment

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Summary. — The LHCb experiment offers a complementary phase space region to ATLAS and CMS to study electroweak processes, thanks to the unique acceptance and the large bandwidth trigger at low energy threshold. Here, the latest measurements performed during the LHC Run I and Run II data taking are presented. In particular the determination of the effective electroweak mixing angle, obtained by studying the forward-backward asymmetry in the $Z \to \mu^+\mu^-$ decay, is discussed.

1. – Motivation

Precision measurements of W and Z cross-sections ($\sigma_{W(Z)}$) in pp collisions are important tests of perturbative QCD and electroweak theory, within the Standard Model (SM). Moreover, they can be used to probe Parton Distribution Functions (PDFs).

LHCb is a forward spectrometer, mostly dedicated to b and c quarks physics [1]. While ATLAS and CMS are limited to a pseudorapidity of $\eta \leq 2.5$, LHCb detects W and Z daughters in the $2 \leq \eta \leq 5$ range. At LHCb two different regions are available in the x-Q^2 phase space, where x is the momentum fraction of the parton and Q^2 is the transferred momentum: one well understood (high x and high Q^2), the other unexplored (low x and high Q^2) (fig. 1).

2. – Measurement of forward W production at $\sqrt{s} = 7,\ 8\,\text{TeV}$

The measurement of the inclusive $W \to \mu\nu$ production cross-section has been performed by LHCb using data from pp collisions at a centre-of-mass energy of 7 and 8 TeV, corresponding to 1.0 fb^{-1} and $2.0\,\text{fb}^{-1}$ of integrated luminosity [2].

The signature of $W \to \mu\nu$ consists of a high transverse momentum (p_T) muon, with a p_T greater than $20\,\text{GeV}/c$ and a pseudo-rapidity in the range $2.0 < \eta < 4.5$. The muon isolation, defined as the scalar sum of the p_T of charged particles in a cone of radius $R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.5$ around the selected muon, has to be less than $2\,\text{GeV}/c$. To reduce the muons from τ decays or from heavy flavour semileptonic decays, the impact parameter with respect to the pp interaction vertex is required to be less than $40\,\mu\text{m}$.

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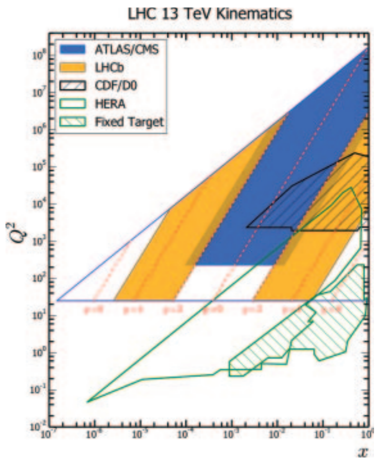

Fig. 1. – LHCb acceptance in x-Q^2 phase space, in comparison with other experiments.

The signal yield is determined by simultaneously fitting the p_T spectra of positively and negatively charged muons in data [2]. The measured W^+ and W^- cross sections as a function of the muon pseudo-rapidity at 8 TeV are presented in fig. 2. The results are compared to predictions at NNLO in QCD with different PDFs parametrizations. Generally there is a good agreement within the errors, that are dominated by the luminosity uncertainty.

3. – Measurement of forward Z production at $\sqrt{s} =$ 7, 8, 13 TeV

The cross sections of $Z \to \mu^+\mu^-$ in the forward region at 7, 8 and 13 TeV in the centre-of-mass energy are based on data samples of respectively 1.0 fb^{-1}, 2.0 fb^{-1} and 294 pb^{-1} of integrated luminosity [2-4].

The muons must have a pseudo-rapidity in the range $2 < \eta < 4.5$ and $p_T > 20\,\mathrm{GeV}/c$. The selected samples have high purity, greater than 99%. The low background contam-

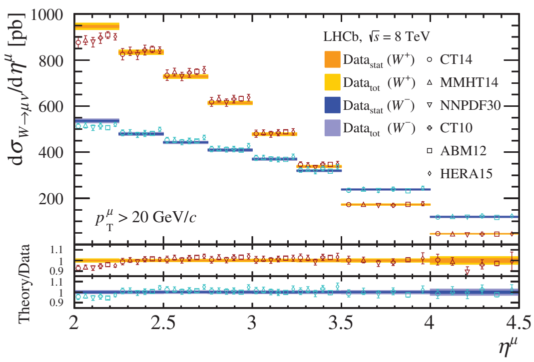

Fig. 2. – Measured W^+ and W^- differential cross sections as a function of the muon pseudo-rapidity at 8 TeV, compared with different predictions, obtained using different PDFs parametrizations [2].

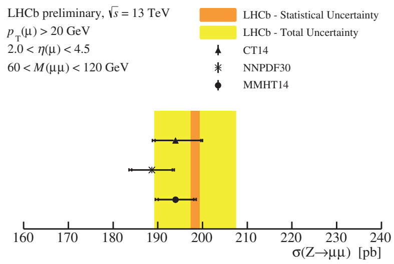

Fig. 3. – Comparison of the measured Z cross section at 13 TeV with different predictions, obtained using different PDFs parametrizations [3].

ination is evaluated using simulation and data-driven techniques. The measured cross-section at 13 TeV is presented in fig. 3, compared with theoretical predictions: these are in good agreement with data.

4. – Measurement of the $W + b/c$/light-jet cross-section at $\sqrt{s} = 7$, 8 TeV

The measurement of the cross-section for the production of a W boson in association with a jet has been performed by LHCb using 1 fb^{-1} and 2 fb^{-1} of integrated luminosity of pp collisions, respectively, at a centre-of-mass energy of 7 TeV and 8 TeV [5]. The W bosons are reconstructed in the $W \to \mu^+\nu^-$ decay, where the muons have a p_T greater than 20 GeV/c and a pseudo-rapidity in the range $2.0 < \eta < 4.5$. The jet must have a p_T greater than 10 GeV/c and must be in the range $2.2 < \eta < 4.2$.

In the jets reconstruction, charged and neutral particles are clustered using the anti-k_T algorithm with a distance parameter $R = 0.5$. Jets have to be isolated from W muons, requiring $\Delta R(jet, \mu) > 0.4$.

The algorithm described in [6] is used for the identification of secondary vertices (SVs) consistent with the decay of a beauty or charm hadron, using tracks that belong to the jets. By requiring SVs inside the jet, the background originated from light partons is reduced. The number of b/c and light jets is extracted by fitting the output of two multivariate discriminators, that have in input observables related to the SVs and that are trained respectively for heavy/light jets and b/c jets separation . The measured $W+b$ and $W+c$ cross sections normalized to the W+jet cross section are presented in table I, as well as the W charge asymmetry. These results are in agreement with theoretical predictions within the errors.

TABLE I. – *Measured $W + b$ and $W + c$ cross sections normalized to the W+jet cross section and W charge asymmetry, compared to the Standard Model expectation.*

	7 TeV	8 TeV	7 TeV (exp.)	8 TeV (exp.)
$\frac{\sigma(Wb)}{\sigma(Wj)} \times 10^2$	$0.66 \pm 0.13 \pm 0.13$	$0.78 \pm 0.08 \pm 0.16$	$0.74^{+0.17}_{-0.13}$	$0.77^{+0.18}_{-0.13}$
$\frac{\sigma(Wc)}{\sigma(Wj)} \times 10^2$	$5.80 \pm 0.44 \pm 0.75$	$5.62 \pm 0.28 \pm 0.73$	$5.02^{+0.80}_{-0.69}$	$5.31^{+0.87}_{-0.52}$
$\mathcal{A}(Wb)$	$0.51 \pm 0.20 \pm 0.09$	$0.27 \pm 0.13 \pm 0.09$	$0.27^{+0.03}_{-0.03}$	$0.28^{+0.03}_{-0.03}$
$\mathcal{A}(Wc)$	$-0.09 \pm 0.08 \pm 0.04$	$-0.01 \pm 0.05 \pm 0.04$	$-0.15^{+0.02}_{-0.04}$	$-0.14^{+0.02}_{-0.03}$

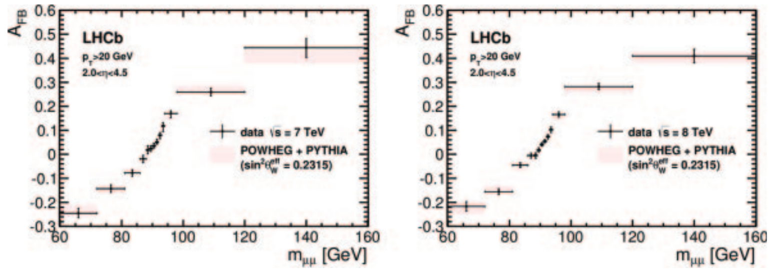

Fig. 4. – Measured asymmetry and theoretical prediction in bins of dimuon invariant mass, for the 7 TeV and the 8 TeV dataset.

5. – Determination of the effective electroweak mixing angle

The electroweak mixing angle θ_W is a fundamental parameter of the Standard Model electroweak Lagrangian: it quantifies the relative strength between the electromagnetic and the weak forces. The determination of the effective electroweak mixing angle by LHCb has been performed by measuring the forward-backward asymmetry (A_{FB}) in the decay $Z/\gamma^* \to \mu^+\mu^-$. The asymmetry is measured in the Collins-Soper frame [7]: an unfolding bayesian technique is applied to obtain the true asymmetry from the raw asymmetry [8]. The measured asymmetry, obtained in bins of dimuon invariant mass, is presented in fig. 4 for the 7 TeV and 8 TeV data sample. A χ^2 comparison is made between simulation samples generated with different value of $\sin^2\theta_W^{\mathrm{eff}}$, and the measured A_{FB} as a function of the dimuon mass. The χ^2 minimum sets the favoured value of $\sin^2\theta_W^{\mathrm{eff}}$:

$$\sin^2\theta_W^{\mathrm{eff}} = 0.23142 \pm 0.00073(stat.) \pm 0.00052(syst.) \pm 0.00056(th.) \tag{1}$$

The experimental uncertainty is dominated by momentum biases originated from remaining detector misalignment; the theoretical error is dominated by the PDFs uncertainties.

6. – Conclusions

The latest measurements performed by LHCb in the electroweak sector have been presented: they are competitive and complementary with the corresponding measurements of the other LHC experiments. The measured Z and W cross sections set a reference for future searches. Thanks to the LHCb forward acceptance the experiment performed the most precise measurement at LHC of the effective electroweak mixing angle.

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