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Electroweak Physics in the forward region and $b\bar{b}$ resonances search at the LHCb experiment

L. Sestini(*)
INFN, Sezione di Padova and Dipartimento di Fisica, Università di Padova
Padova, Italy

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Summary. — The LHCb experiment offers a complementary phase space region with respect 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 data taking are presented, setting the scene for the future. Possible developments in this sector are discussed, in particular the search for $b\bar{b}$ resonances, considered preferred channels in the observation of new exotic states and New Physics.

1. – Motivation

Precision measurement of $\sigma_{W(Z)}$ are important tests of perturbative QCD and electroweak theory, within the Standard Model (SM). The factorization theorem gives the $pp \to X$ cross section, σ, in terms of the partonic cross section, $\hat{\sigma}$, as

$$\sigma_{pp\to X} = \sum_{a,b} \int \mathrm{d}x_a \mathrm{d}x_b f_a(x_a, Q^2) f_b(x_b, Q^2) \hat{\sigma}_{pp\to X}(Q^2), \tag{1}$$

where f_i are parton distribution functions (PDFs) evaluated at the parton momentum fraction x (Bjorken-x) and transferred momentum squared Q^2.

$\hat{\sigma}_{W(Z)}$ is known at NNLO in QCD and NLO in electroweak theory with an accuracy better than 1%, since these measurements act as “standard candles” to probe other processes. It is important to perform them at high precision.

LHCb is a forward spectrometer, mostly dedicated to b and c quarks Physics [1]. While ATLAS and CMS are limited to a pseudorapidity of $\eta \leq 2.5$ (with Bjorken-x in the range of $10^{-3} \leq x \leq 0.1$), LHCb detects W and Z daughters in the $2 \leq \eta \leq 5$ range.

(*) E-mail: lorenzo.sestini@pd.infn.it

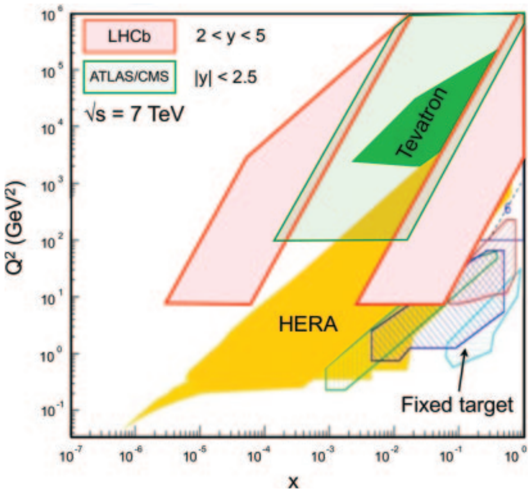

Fig. 1. – LHCb acceptance in x-Q^2 phase space, in comparison with other experiments.

At LHCb two different regions are available in the x-Q^2 phase space: 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 $\sqrt{s} = 7\,\text{TeV}$

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 TeV, corresponding to $1.0\,\text{fb}^{-1}$ of integrated luminosity [2].

The theoretical predictions rely on the PDFs parametrization, and the forward acceptance of the LHCb experiment allow to access the region of low Bjorken-x values, where PDFs uncertainties are larger, and provide unique constraints.

The signature of $W \to \mu\nu$ consists of an isolated high transverse momentum (p_T) muon, greater than 20 GeV/c and a pseudorapidity in the range $2.0 < \eta < 4.5$. The 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 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 $40\,\mu$m.

The signal yield is determined by simultaneously fitting the p_T spectra of positively and negatively charged muons in data [2]. The integrated cross sections, obtained by taking into account the acceptance, the efficiencies and the final state radiation correction, for $P_T(\mu) > 20\,\text{GeV/c}$ and $2 < \eta(\mu) < 5$ are

$$\sigma_{W^+\to\mu^+\nu} = 861.0 \pm 2.0(\text{stat}) \pm 11.2(\text{syst}) \pm 14.7(\text{lumi})\,\text{pb}, \tag{2a}$$

$$\sigma_{W^-\to\mu^-\bar{\nu}} = 675.8 \pm 1.9(\text{stat}) \pm 8.8(\text{syst}) \pm 11.6(\text{lumi})\,\text{pb}, \tag{2b}$$

where the first error is statistical, the second systematic and the third is due to luminosity determination. The results are compared to predictions at NNLO in QCD with different PDFs parametrizations. Generally there is a good agreement within the errors as shown in fig. 2.

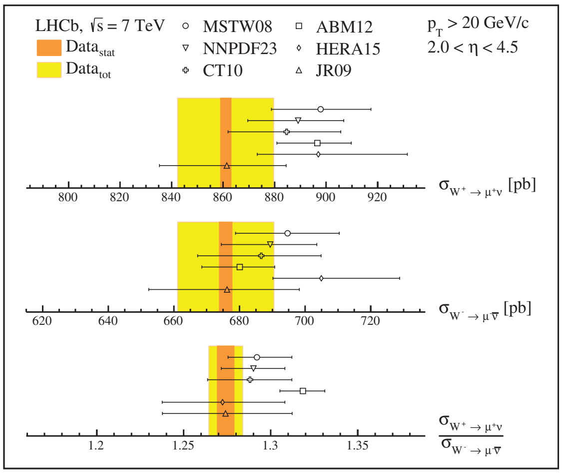

Fig. 2. – Comparison of the measured W cross sections with different predictions, obtained using different PDFs parametrizations [2].

3. – Measurement of forward $Z \to e^+e^-$ production at $\sqrt{s} = 8$ TeV

The cross section for $Z \to e^+e^-$ in the forward region at 8 TeV in the centre-of-mass energy is based on a data sample of $2.0\,\text{fb}^{-1}$ of integrated luminosity [3]. As for the W cross section, this measurement can directly access PDFs at low Bjorken-x.

The reconstructed electron and positron must have a pseudorapidity in the range $2 < \eta < 4.5$ and $p_T > 20\,\text{GeV/c}$. Their measured momentum has to have a fractional uncertainties less then 10% and the e^+e^- invariant mass must be greater than $40\,\text{GeV/c}^2$. In order to identify particles as electron or positron candidates a significative amount of energy in the electromagnetic and hadronic calorimeters is required, $E_{ECAL}/pc > 0.1$ and $E_{HCAL}/pc < 0.05$, respectively.

The cross-section is determined using the following expression:

$$\sigma = \frac{N(e^+e^-) - N(e^\pm e^\pm) - N_{bg}}{\epsilon \int L dt} f_{MZ}, \tag{3}$$

where $N(e^+e^-)$ is the number of the selected events, $N(e^\pm e^\pm)$ is the number of same-sign candidates, N_{bg} is the expected background dominated by $Z \to \tau^+\tau^-$ and determined with Monte Carlo simulation, ϵ is the detection efficiency, and $\int L dt$ is the integrated luminosity. f_{MZ} is a factor that corrects for candidates that pass the event selection whilst the true mass lies outside the range $60 < M(e^+e^-) < 120\,\text{GeV/c}^2$. The measured cross-section, for $2 < \eta(e^\pm) < 4.5$, $p_T(e^\pm) > 20\,\text{GeV/c}$ and $60 < M(e^+e^-) < 120\,\text{GeV/c}^2$, is

$$\sigma_{pp \to Z \to e^+e^-} = 93.81 \pm 0.41(\text{stat}) \pm 1.48(\text{syst}) \pm 1.14(\text{lumi})\,\text{pb}. \tag{4}$$

The measurement is compared to NNLO QCD predictions, with different PDFs parametrizations. Predictions are in good agreement with data (fig. 3 left).

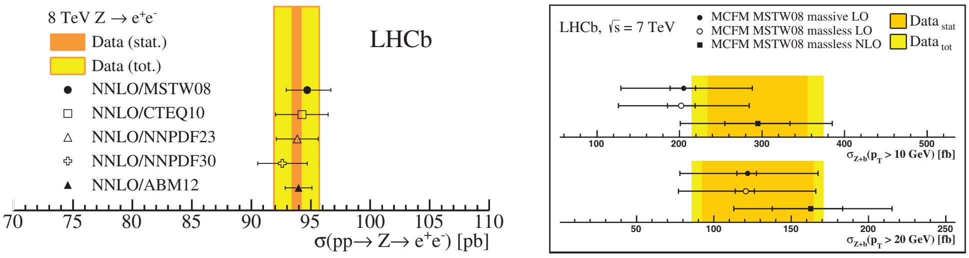

Fig. 3. – $Z \to e^+e^-$ (on the left) and Z + b-jet (on the right) measured cross sections compared to different SM predictions [3, 4].

4. – Measurement of the Z+b-jet cross-section at $\sqrt{s} = 7\,\text{TeV}$

The cross-section measurement of the Z boson in association with a bottom quark has been performed by LHCb using $1\,\text{fb}^{-1}$ of integrated luminosity of pp collisions at a centre-of-mass energy of 7 TeV [4]. The Z bosons are reconstructed in the $Z \to \mu^+\mu^-$ decay, where the muons have a p_T greater than 20 GeV/c. Two different p_T thresholds are considered for jets, 10 GeV/c and 20 GeV/c, and both jets and muons are reconstructed in the range $2.0 < \eta < 4.5$ of pseudorapidity. The dimuon candidate mass is required to be in the 60–120 GeV/c^2 range.

In the jets reconstruction, charged and neutral particles are clustered using the anti-k_T algorithm with a distance parameter $R = 0.5$ [5]. Jets have to be isolated from Z muons, requiring $\Delta R(jet, \mu) > 0.4$.

An algorithm similar to that described in [6], is used for the identification of secondary vertices consistent with the decay of a beauty hadron, using tracks that belong to the jets. By requiring secondary vertices inside the jet, the background originated from light partons and charm quarks is reduced. The number of b-jets is extracted by fitting the corrected mass of the topological vertex, $M_{corr} = \sqrt{M^2 + p^2 \sin^2\theta} + p \sin\theta$, where M is the vertex invariant mass, p is the vertex momentum and θ is the angle between the p direction and the flight direction inferred from the position of primary and secondary vertices [4]. The measured cross-sections are obtained by correcting the number of fitted candidates for b-tagging efficiency:

$$\sigma(Z(\to \mu^+\mu^-) + b\text{-jet}) = 295 \pm 60(\text{stat}) \pm 51(\text{syst}) \pm 10(\text{lumi})\,\text{fb} \tag{5}$$

for $p_T(jet) > 10\,\text{GeV/c}$ and

$$\sigma(Z(\to \mu^+\mu^-) + b\text{-jet}) = 128 \pm 36(\text{stat}) \pm 22(\text{syst}) \pm 5(\text{lumi})\,\text{fb} \tag{6}$$

for $p_T(jet) > 20\,\text{GeV/c}$.

These results are in agreement with theoretical predictions within the errors (fig. 3 right) that will be improved in the next data taking to better constrain the theory.

5. – Future developments: search for $b\bar{b}$ resonances

With the $Z + b$-jets cross-section measurement the capability of identify b-jets at LHCb has been demonstrated. In addition, the excellent performances in b-, c- and light-jets tagging by using reconstructed displaced vertices are presented in [7]. The possibility to search for $b\bar{b}$ resonances at LHCb is currently under study: $b\bar{b}$ resonances are considered favoured channels in the search for New Physics, and LHCb has several specific features that can allow the experiment to perform complementary measurements respect to ATLAS and CMS. The most important are: the forward acceptance ($2 < \eta < 5$), the cleanest LHC events, with a mean pile-up around 2, and a very large bandwidth trigger for events with b-jets at very low p_T. LHCb can aim to observe New Physics if it produces events with low p_T jets.

In addition to New Physics searches several measurements in the electroweak sector will be possible. For example the Higgs decay in two b-jets has not yet been clearly observed at ATLAS and CMS. It can be searched in associated production with a vector boson to reduce the combinatorial background. Several background studies for this search are currently ongoing ($Wb\bar{b}$, $Zb\bar{b}$, $t\bar{t}$ and QCD combinatorial).

It may be possible to attempt $H \to b\bar{b}$ reconstruction using topological cuts to reduce the $b\bar{b}$ background. To this purpose it is important to study the $Z \to b\bar{b}$ decay. $Z \to b\bar{b}$ is a well-known resonance: it would be possible to confirm the correctness of all tools, test the background model and validate the jet energy scale. Furthermore any $b\bar{b}$ resonance cross section can be normalized to that one.

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 capability to reconstruct and identify b-jets several SM measurements and New Physics searches will be possible in the near future.

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