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Higgs searches in the forward region of pp collisions

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Summary. — The LHCb experiment offers a complementary phase space with respect to ATLAS and CMS to study the $H \to b\bar{b}$ and $H \to c\bar{c}$ decays, thanks to the forward acceptance and the large bandwidth of the trigger allowing low energy thresholds. In this contribution the latest study on $b\bar{b}$ resonances and the searches for $H \to b\bar{b}$ and $H \to c\bar{c}$ performed by the LHCb Collaboration are presented.

1. – Introduction

LHCb is a forward spectrometer, initially designed for b and c quarks physics [1]. Within the LHC experiments, LHCb alone provides precision coverage in the forward region of pp collisions corresponding to the $2 \leq \eta \leq 5$ pseudo-rapidity range. In both LHC Run I and Run II LHCb demonstrated its capability in electroweak and jet physics, qualifying it as a general purpose forward detector. About 5% of $H \to b\bar{b}$ produced in pp collisions are expected to be in the LHCb acceptance. Moreover, in the case of the Higgs associated production with a vector boson, if the two b-jets from the Higgs are in the acceptance, then there is a high probability (60%) that also the lepton from W/Z decay is in acceptance. In this contribution the LHCb capability on reconstructing $b\bar{b}$ resonances is discussed, and the measured upper limits on the $V + H(\to b\bar{b})$ and $V + H(\to c\bar{c})$ production in the forward region are presented.

2. – Measurement of the $Z \to b\bar{b}$ production in the forward region

The decay $Z \to b\bar{b}$ has been reconstructed by LHCb in pp collision data at a centre-of-mass energy of $\sqrt{s} = 8$, corresponding to $2\,\text{fb}^{-1}$ of integrated luminosity, and the corresponding production cross-section has been measured [2]. The fiducial region of the measurement is defined by b-jets with $2.2 < \eta < 4.2$, $p_T > 20\,\text{GeV}/c$ and with a di-jet invariant mass in the range $45 < m_{jj} < 165\,\text{GeV}/c^2$. The algorithm described in [3] 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 jets, the background originating from light partons is reduced.

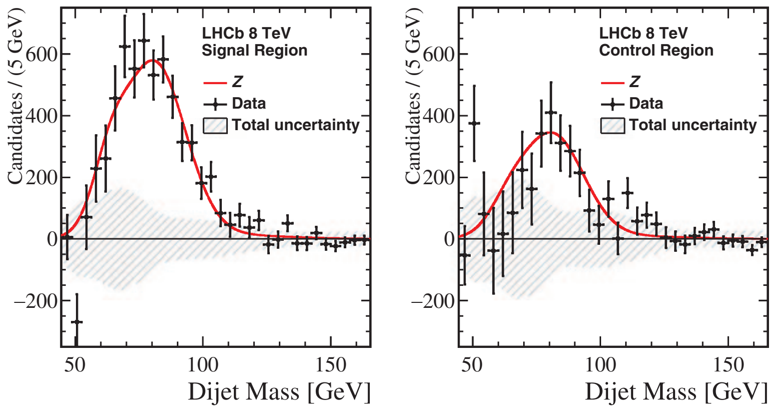

Fig. 1. – Background subtracted di-jet invariant mass distributions in the signal region (left) and in the control region (right). The uncertainty band in the background only hypothesis is also shown.

An additional jet recoiling to the Z boson candidate is also selected, to achieve extra discrimination between the signal and the QCD multi-jet events, which constitute the main source of background. A multivariate discriminator is trained to obtain such separation, employing observables related to the Z+jet kinematics. The classifier output is used to define a signal region, with enhanced $Z \to b\bar{b}$ contribution, and a control region, enriched with QCD events. The di-jet invariant mass distributions in the signal and control regions are simultaneously fitted to determine the $Z \to b\bar{b}$ and QCD yields. The background subtracted di-jet invariant mass distributions in signal and control regions are shown in fig. 1.

A production cross-section times branching fraction of $332 \pm 46 \pm 59\,\mathrm{pb}$ is obtained, where the first uncertainty is statistical and the second systematic. The systematic uncertainty is dominated by the knowledge of the b identification efficiency and the measurement is in agreement with the theoretical prediction calculated at next-to-leading order plus parton shower, which is $272^{+10}_{-13}\,\mathrm{pb}$.

3. – Measurements of the $W + b\bar{b}$ and $W + c\bar{c}$ production in the forward region

LHCb performed the observation of the $W + b\bar{b}$ production and the first measurement of the $W + c\bar{c}$ process in pp collisions, with a significance very close to 5σ, using a sample of $2\,\mathrm{fb}^{-1}$ of integrated luminosity collected at $\sqrt{s} = 8\,\mathrm{TeV}$ [4]. Using the same sample, the $t\bar{t}$ cross-section in the forward region has been also measured. These measurements are important not only because they can be used to probe the Parton Distribution Functions but also because they are the main background processes in the $V + H(\to b\bar{b})$ search.

The W boson is reconstructed in the muon (electron) final state, with $p_{\mathrm{T}} > 20\,\mathrm{GeV/c}$ and $2.0 < \eta < 4.5$ (4.25), jets are reconstructed as in the W+jet measurement, but with $p_{\mathrm{T}} > 12.5\,\mathrm{GeV/c}$. The b-jets are reconstructed and identified as in the $Z \to b\bar{b}$ cross-section measurement.

The number of $W^+ + b\bar{b}$, $W^- + b\bar{b}$, $W^+ + c\bar{c}$, $W^- + c\bar{c}$ and $t\bar{t}$ events is extracted by simultaneously fitting the distribution of the di-jet invariant mass, the distribution of two multivariate discriminators, one for each selected jet, which exploit the properties of the jets and the SVs to separate b from c, and the distribution of one multivariate

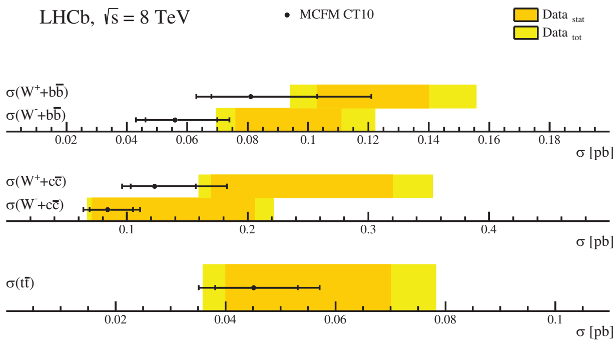

Fig. 2. – Measured $W+b\bar{b}$, $W+c\bar{c}$ and $t\bar{t}$ cross-sections together with the theoretical predictions.

discriminator that separates the $W+b\bar{b}$ process from the $t\bar{t}$ process. The measurements together with the theoretical predictions are shown in fig. 2. The uncertainties are dominated by the knowledge of the b identification efficiency. The measured cross-sections are in agreement with the theory within the uncertainties.

4. – Upper limits on the $V+H(\to b\bar{b})$ and $V+H(\to c\bar{c})$ production in the forward region

Since the measured cross-sections of $W+b\bar{b}$, $W+c\bar{c}$ and $t\bar{t}$ are compatible with the Standard Model prediction and no enhanced Higgs production is expected, upper limits are set on the $V+H(\to b\bar{b})$ and $V+H(\to c\bar{c})$ productions. The limits are calculated assuming a Higgs with a mass of 125 GeV and with Standard Model properties. The search for $V+H(\to b\bar{b})$ is performed using the dataset selected as described in the previous section. To search for $V+H(\to c\bar{c})$, an additional requirement on the SV-tagger algorithm variable that separates b jets from c jets is applied for both jets. This requirement removes about 90% of $V+H(\to b\bar{b})$ events while retaining 62% of $V+H(\to c\bar{c})$ events.

The upper limits on the production cross-section of the Higgs boson are set using the CL_s method. The expected upper limit on the $V+H(\to b\bar{b})$ production at 95 (90)% CL is 84 (69) times the Standard Model expectation, while the observed upper limit is 50 (40) times the Standard Model expectation. Therefore, the observed limit on $\sigma(pp \to W/Z+H)BR(H\to b\bar{b})$ in the LHCb acceptance (two b quarks from Higgs and one lepton from W/Z with $2<\eta<5$), is

$$\sigma(pp\to W/Z+H)BR(H\to b\bar{b}) < 1.6\ (1.3)\ \mathrm{pb}, \quad \text{at 95 (90)\% CL and at 8 TeV.}$$

The expected upper limit on the $V+H(\to c\bar{c})$ production at 95% (90%) CL is 7900 (6200) times the Standard Model expectation, while the observed upper limit is 6400 (4900) times the Standard Model expectation. Therefore, the observed limit on $\sigma(pp\to W/Z+H)BR(H\to b\bar{b})$ in the LHCb acceptance (two c quarks from Higgs and one lepton from W/Z with $2<\eta<5$) is

$$\sigma(pp\to W/Z+H)BR(H\to c\bar{c}) < 9.4\ (7.2)\ \mathrm{pb}, \quad \text{at 95 (90)\% CL and at 8 TeV.}$$

5. – Conclusions

During the Run I LHCb demonstrated its capability in b-dijet physics by measuring the $Z \to b\bar{b}$ cross-section and the $W + b\bar{b}$, $W + c\bar{c}$ and $t\bar{t}$ cross-sections in the forward region of pp collisions. Moreover LHCb set experimental upper limits on the $V+H(\to b\bar{b})$ and $V + H(\to c\bar{c})$ [5]. Neglecting any improvements in the analysis or detector, the extrapolation of the limit obtained at 8 TeV to 300 fb^{-1} at 14 TeV is $\sim 50 \times BR$ (SM) for $H(c\bar{c})$ production in the forward region. Detector improvements are expected in future upgrades, in particular in the impact parameter resolution which directly affects the c-tagging efficiency. A further improvement is expected from the electron reconstruction that will benefit from upgraded versions of the electromagnetic calorimeter. Electrons are used in the identification of the vector bosons associated with the Higgs. Therefore, with these improvements, the expected limit can be pushed down to 5–10 $\times$ BR (SM). In terms of Yukawa coupling this correspond to the limit of 2–3 times the Standard Model prediction.

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