Vol. 51 (2020) *Acta Physica Polonica B* No 6

EXOTIC SEARCHES AT LHCb*

Mateusz Goncerz

on behalf of the LHCb Collaboration

H. Niewodniczański Institute of Nuclear Physics Polish Academy of Sciences
Kraków, Poland

(Received April 14, 2020)

Jet physics offers a wonderful environment to study both the Standard and beyond the Standard Model physics. The most recent LHCb cross-section measurements of the top-quark pair production and the production of W boson with quark pairs at 8 TeV are presented. Results show a very good agreement with NLO predictions. Additionally, updated constraints on the Hidden Valley pion signal strength are shown, alongside with a new ongoing search for b' and Z' in the process of Z-boson production associated with two b jets at 13 TeV.

DOI:10.5506/APhysPolB.51.1357

1. Motivation

Jet physics provides a unique opportunity to search for the Beyond the Standard Model and prove the Standard Model physics. The cross-section measurements serve as a test of the perturbative Quantum Chromodynamics regime, allowing for fine tuning of the Parton Density Functions. However, due to the underlying production mechanisms, it is also highly sensitive to New Physics phenomena.

2. LHCb experiment

The LHCb detector is a single-arm forward spectrometer, fully instrumented in the pseudorapidity range of $2 < \eta < 5$, capable of searches in a phase-space region complementary to other General Purpose Detectors at the LHC. Its excellent capabilities, most notably tracking and particle identification, provide a wonderful environment for precision measurements.

* Presented at XXVI Cracow Epiphany Conference on LHC Physics: Standard Model and Beyond, Kraków, Poland, January 7–10, 2020.

As the W and Z bosons are produced in collisions of low and high x-Bjorken partons, the LHCb spectrometer may easily probe both scale regions. The low x-Bjorken region still remains mostly unexplored by other experiments. Assuming the missing energy to be negligible, the study of top-quark production is also possible via the partial final-state reconstruction.

3. Jet tagging

The standard approach for jet tagging at the LHCb is to use two Boosted Decision Trees (BDT), trained on the secondary vertex parameters [1]. One of them is constructed to distinguish between jets coming from light and heavy quarks, while the other distinguishes between those that originated from b and c quarks. Figure 1 shows the response of those classifiers to single-flavour simulated samples. The overlap leads to the identification efficiency of approximately 65% for b and 25% for c jets.

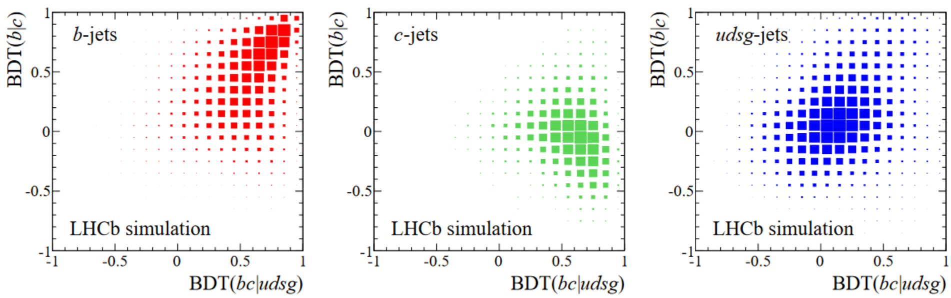

Fig. 1. The response of jet tagging classifiers to single-flavour simulated events [1].

4. $W + c\bar{c}$, $W + b\bar{b}$ and $t\bar{t}$ production at 8 TeV

The published $W + c\bar{c}$, $W + b\bar{b}$ and $t\bar{t}$ production cross-section measurements [2] have been conducted using 2 fb^{-1} of 8 TeV data. Signal Monte Carlo samples have been produced using ALPGEN and showered with PYTHIA 8, while the background samples of $W+$jets, $Z+$jets, single-top, WZ and ZZ were generated using PYTHIA 8.

Two heavy-flavoured jets were required with transverse momentum above 12.5 GeV and within the $2.2 < \eta < 4.2$ pseudorapidity window, alongside with a single electron or muon with transverse momentum above 20 GeV. The leptons were also constrained to be in the pseudorapidity range of $2 < \eta < 4.5$ for muons and $2 < \eta < 4.25$ for electrons, due to the electromagnetic calorimeter acceptance. An additional isolation condition, $\Delta R > 0.5$, has been imposed by requiring them to be separated from both of the jets in the ϕ–η plane, where $\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$.

The data was split into four sub-samples according to lepton flavour and charge. Each sample was then simultaneously fitted in four variables to determine the yield of all of the considered signal processes. These four variables were the invariant masses of both jets, a BDT response recognising jets from b and c quarks used to separate $W + b\bar{b}$ and $W + c\bar{c}$ events as well as a special classifier trained to distinguish between $W + b\bar{b}$ and $t\bar{t}$ samples. Figure 2 shows the fitted yields for a sample containing events with μ^+.

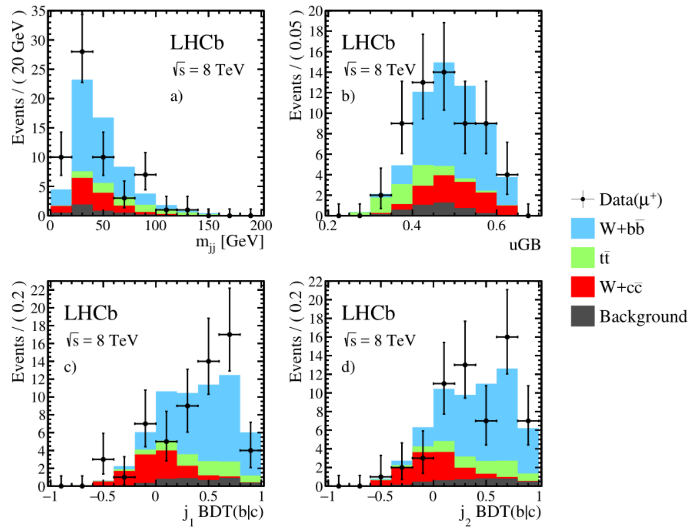

Fig. 2. The fitted yields in a μ^+ sample [2].

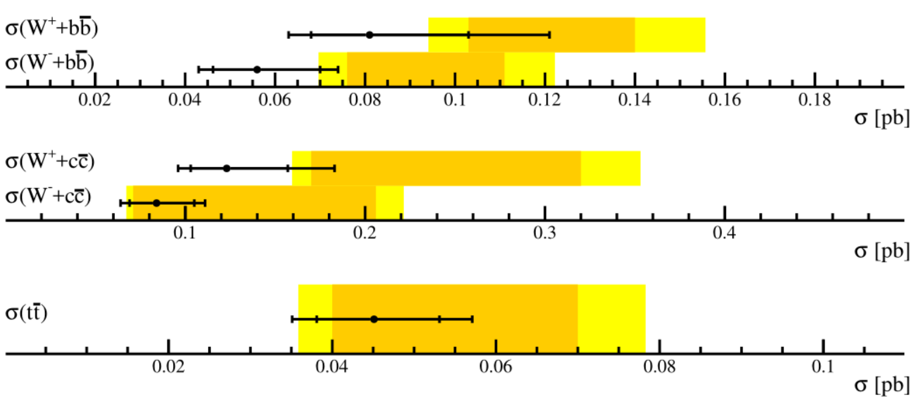

Fig. 3. (Colour on-line) Production cross-section measurement results. Black bars are the CT10 NLO predictions, grey/dark yellow show the statistical and light grey/bright yellow the total uncertainty [2].

Results have been found to be in a very good agreement with Next Leading Order (NLO) predictions calculated using MCFM NLO with CT10 PDF set [3]. Figure 3 shows the comparison of measured cross sections with the predictions and the significance levels for each sample.

5. Long-lived particles decaying to jet pairs at 7 and 8 TeV

Hidden Valley models propose the addition of a new confining gauge group to the Standard Model with a structure similar to that of the Standard Model itself [4]. This sector is unreachable directly at currently available energies due to the potential barrier. It may, however, be studied indirectly — either by its influence on the phenomenology of other Standard Model extensions or by the decays of unstable Hidden Valley particles into Standard Model final states via portal mechanisms.

An update of a search for such a process with Higgs boson decaying into a pair of Hidden Valley pions, which in turn decay into pairs of b quarks has been published [5]. Compared to the previous analysis [6], it introduces 8 TeV data, up to a total of 2 fb^{-1} of 7 and 8 TeV combined. The Monte Carlo samples used were generated with PYTHIA 8.

As usually, only one of the pions decays within the LHCb acceptance, a single displaced vertex was required. It had to, however, be associated with two heavy flavour jets forming a dijet aligned with the displacement vector. In order to suppress background from back-to-back events and reduce tails in the dijet invariant mass distribution, both jets were required to be reasonably close to each other in the ϕ–η plane with $\Delta R < 2.2$.

The data was split into sub-samples based on the Hidden Valley particle mass and lifetime. With an assumption that $\pi_v \to b\bar{b}$ channel dominates, more focus was placed on the $b\bar{b}$ final state. In that case, masses of 25, 35, 43 and 50 GeV and lifetimes of 10 and 100 picoseconds were considered. Only one mass and lifetime has been simulated for $\pi_v \to c\bar{c}$ and $\pi_v \to s\bar{s}$ channels, consisting of events with pions having a mass of 35 GeV and lifetime of 10 picoseconds. Since the background levels depend strongly on the distance of the displaced vertex from the beam axis (Fig. 4), each sample was further binned in this parameter and separate fit was performed in each of the bins. No significant excess of signal has been observed in the data, although new upper limits on the signal strength have been placed at 95% confidence level. They were also re-weighted for multiple lifetime hypothesis (Fig. 5). $\mathcal{B}_{q\bar{q}} = \mathcal{B}\left(\pi_v \to q\bar{q}\right)$ is assumed to be 100%, but limits scale as $1/\left(\mathcal{B}_{q\bar{q}}\left(2 - \mathcal{B}_{q\bar{q}}\right)\right)$.

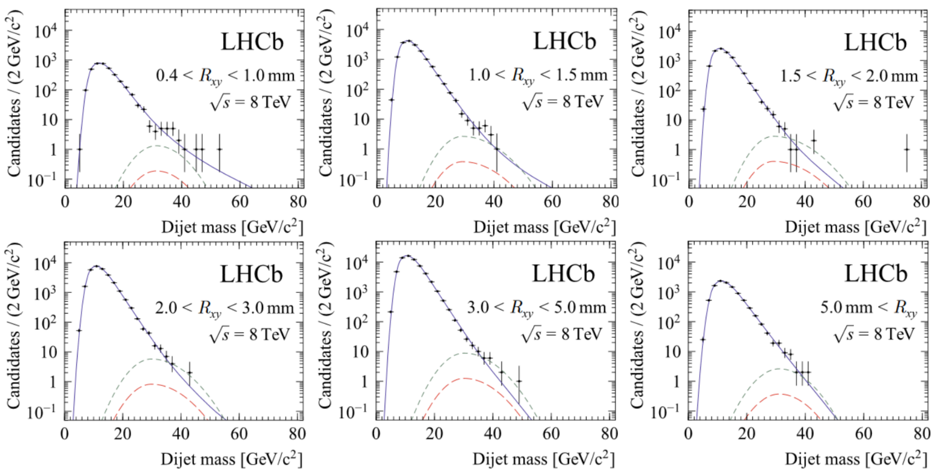

Fig. 4. (Colour on-line) Dependence of the background strength (top/blue line) on the distance of the displaced vertex from the beam axis R_{xy} in 8 TeV data. The middle/green line shows signal of strength 1 and bottom/red shows the best signal fit [5].

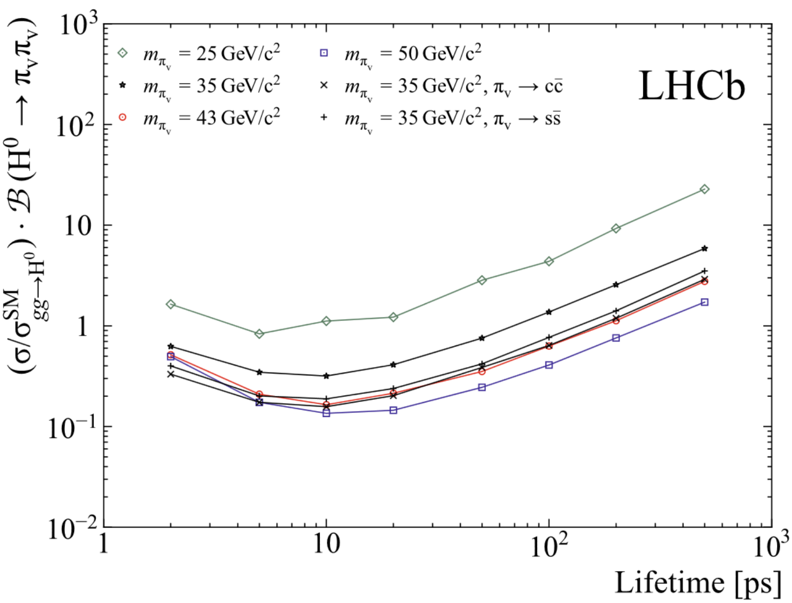

Fig. 5. Signal strength limits placed on the process for multiple mass and lifetime hypotheses. If not explicitly mentioned, the $b\bar{b}$ final state is assumed [5].

6. Z-boson production in association with two b-jets at 13 TeV

A new measurement of the Z-boson production associated with two b jets is underway, motivated by the process' sensitivity to the appearance of b' and Z' particles. It also shares the final-state signature with decay chains involving Higgs and additional vector boson, which are used extensively in the studies of the Higgs properties and is thus an important background source for them.

The measurement will use 2 fb^{-1} of 13 TeV data collected during Run 2 of the LHC and NLO Monte Carlo generated with Madgraph. At this stage, only the muon channel is considered, but electron channel will be added in the future. The main background sources have been determined to be $t\bar{t}$, WZ, ZZ, $W+b\bar{b}$, $Z+q\bar{q}$, single top and inclusive $b\bar{b}$. Their study is based on jet kinematics and the underlying event signature, which consists of the particles not assigned to any jet.

The preliminary study conducted with the main background source — $t\bar{t}$ — shows a very promising background separation.

7. Conclusions

Jet physics plays a crucial role in the study of both — Standard and beyond the Standard Model physics. The most recent measurements of top-pairs and W-boson production associated with jet pairs at 8 TeV show a very good agreement with NLO predictions. The search for Hidden Valley pions has been updated with 8 TeV data, although no significant signal has been observed. Additionally, a new search for b' and Z' in the process of Z-boson production associated with two b jets at 13 TeV is in an advanced stage and the preliminary results are very promising.

REFERENCES

[1] LHCb Collaboration, *JINST* **10**, P06013 (2015).
[2] LHCb Collaboration, *Phys. Lett. B* **767**, 110 (2017).
[3] Hung-Liang Lai *et al.*, *Phys. Rev. D* **82**, 074024 (2010).
[4] M.J. Strassler, K.M. Zurek, *Phys. Lett. B* **651**, 374 (2007).
[5] LHCb Collaboration, *Eur. Phys. J. C* **77**, 812 (2017).
[6] R. Aaij *et al.*, *Eur. Phys. J. C* **75**, 152 (2015).