IL NUOVO CIMENTO **43 C** (2020) 81
DOI 10.1393/ncc/i2020-20081-8

Colloquia: IFAE 2019

# Branching ratios and form factors in $B_s^0 \to D_s^{(*)-} \mu^+ \nu_\nu$ decays

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received 8 June 2020

**Summary.** — As a necessary step towards the test of lepton flavor universality provided by the observable $R(D_s^{(*)}) = \mathcal{B}(B_s^0 \to D_s^{(*)-} \tau^+ \nu_\tau)/\mathcal{B}(B_s^0 \to D_s^{(*)-} \mu^+ \nu_\mu)$, the exlusive branching ratios and form factor of its denominator are going to be measured for the first time at an hadron collider.

## 1. – Motivations

Semileptonic $B^0$ mesons have been abundantly studied at the $B$-factories and by LHCb, providing important precision tests of the SM and yielding puzzling results on the ratios of branching fractions: $R(D^{(*)}) \equiv \mathcal{B}(B^0 \to D^{(*)-} \tau^+ \nu_\tau)/\mathcal{B}(B^0 \to D^{(*)-} \mu^+ \nu_\mu)$, which is in tension with the lepton flavor universality hypothesis at approximately 3.7 $\sigma$ [1]. Therefore, it is essential to expand the measurement programme to other dynamical systems, which are subject to potentially different systematic uncertainties. Studies of a similar ratio: $R(D_s^{(*)}) \equiv \mathcal{B}(B_s^0 \to D_s^{(*)-} \tau^+ \nu_\tau)/\mathcal{B}(B_s^0 \to D_s^{(*)-} \mu^+ \nu_\mu)$ can be performed with $B_s^0$ mesons, which are copiously produced at the LHC. However, the knowledge of the $B_s^0$ semileptonic sector is fairly poor. In particular, only measurements of the semi-inclusive branching ratios were performed, and with a relatively modest precision [2]. In this paper a measurement of the branching ratios and form factors (FF) of $B_s^0 \to D_s^{(*)-} \mu^+ \nu_\mu$ decays will be presented.

## 2. – Data sample

The data sample used in this measurement corresponds to an integrated luminosity of $3\,\mathrm{fb}^{-1}$ of $pp$ collisions at a center-of-mass energy of 7 and 8 TeV collected by the LHCb experiment during 2011 and 2012. The chosen signal (normalization) channels are $B_s^0 \to D_s^- (\to K^+ K^- \pi^-) \mu^+ \nu_\mu$, $B_s^0 \to D_s^{*-} (\to D_s^- (\to K^+ K^- \pi^-) X) \mu^+ \nu_\mu$ ($B^0 \to D^- (\to K^+ K^- \pi^-) \mu^+ \nu_\mu$, $B^0 \to D^{*-} (\to D^- (\to K^+ K^- \pi^-) X) \mu^+ \nu_\mu$). Signal and normalization samples can be distinguished thanks to the good resolution on momentum of the final-state particles as well as the excellent particle identification of the LHCb experiment.

This results in $3 \times 10^5$ candidates in the signal sample and $1 \times 10^5$ in the normalization sample. The offline selection also permits to drastically reduce the background due to the wrong association of charged-particle tracks (combinatorial background). The remaining physical background is expected to be mainly composed by $B_{(s)} \to D^{(*,**)}\mu\nu X$, $B_s \to D_s K \mu X$, $\Lambda_b \to \Lambda_c D_s X$ and $B_{(s)} \to D_s D X$ decays, when one or more tracks are not correctly identified.

## 3. – Analysis strategy

Let $N_s$, $N_s^*$ be the yields of the two signal modes in the signal sample and $\epsilon_s$, $\epsilon_s^*$ their efficiencies. If we use similar definitions ($N_d$, $N_d^*$, $\epsilon_d$, $\epsilon_d^*$) for the analogous quantities of the normalization channels, the relevant branching ratios can be written as

$$\mathcal{B}(B_s^0 \to D_s^- \mu^+ \nu_\mu) = \frac{N_s}{N_d}\frac{\epsilon_d}{\epsilon_s} \cdot K \frac{f_d}{f_s}, \tag{1a}$$

$$\mathcal{B}(B_s^0 \to D_s^{*-} \mu^+ \nu_\mu) = \frac{N_s^*}{N_d^*}\frac{\epsilon_d^*}{\epsilon_s^*} \cdot K^* \frac{\mathcal{B}(D^{*-} \to D^- X)}{\mathcal{B}(D_s^{*-} \to D_s^- X)}\frac{f_d}{f_s}, \tag{1b}$$

where $K^{(*)} \equiv \mathcal{B}(B^0 \to D^{(*)-}\mu^+\nu_\mu)\mathcal{B}(D^- \to K^+K^-\pi^-)/\mathcal{B}(D_s^- \to K^+K^-\pi^-)$ and $f_s$ ($f_d$) is the hadronization fraction of $b$ quarks with $s$ ($d$) quarks. $N_{s,d}^{(*)}$ and $\epsilon_{s,d}^{(*)}$ are measured in this analysis while all the other quantities are external inputs. The ratio between quantities related to the same reconstructed final state is important to reduce many systematic uncertainties.

The FF describe how strong interactions modify the underlying weak decay. They are functions of the transfer four-momentum $q^2$ and also depend on parameters which need to be experimentally determined [3]. However, the $q^2$ distribution is not directly accessible in our case, due to the presence of an undetectable neutrino in the final state. In ref. [4] it was proofed that at LHCb it is possible to extract $N_{s,d}^{(*)}$ using the observable $m_{corr} = \sqrt{m^2 + p_\perp^2} + p_\perp$, where $m$ is the invariant mass of the visible final state and $p_\perp$ is the momentum of this system transverse to the $B_{(s)}^0$ flight direction. The $p_\perp$ of the system is strongly correlated with $q^2$ and together with $m_{corr}$ carries enough information to determine $N_{s,d}^{(*)}$ and FF parameters simultaneously. In particular, a two-dimensional fit in $m_{corr}$ and $p_\perp$ is executed, both for signal and normalization channels. The shapes of the various contribution are taken from templates, built using simulations. During the fit procedure not only the relative fraction, but also the shape of each template is free to vary, according to the variation of the FF parameters.

The efficiencies $\epsilon_{s,d}^{(*)}$ are estimated using simulated events after opportune data-driven corrections.

## 4. – Prospects

The analysis is in very advanced status and the strategy used to determine systematic uncertainties is already defined. It will represent the first measurement of the branching ratio of the exclusive $B_s^0 \to D_s^{*-}\mu^+\nu_\nu$ decays and the first determination of their form factors at an hadron collider. The uncertainty on the branching ratio measurement is expected to be dominated by external inputs, while the form factor determination is still statistically dominated. Further studies are testing the possibility to extend this analysis to reach the first determination of the magnitude of the Cabibbbo-Kobayashi-Maskawa matrix element $|V_{cb}|$ at an hadron collider.

## REFERENCES

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