Measurements of $\mathcal{B}(B^0_s \rightarrow D^{(*)\mp}_s K^\pm)/\mathcal{B}(B^0_s \rightarrow D^{(*)}_s \pi^+)$ at LHCb

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Summary. — The $B_s \rightarrow D^{(*)\mp}_h K^\pm$ and $B_s \rightarrow D^{(*)}_h \pi^\pm$ decay amplitudes are of great interest, since, by means of a time-dependent analysis, they allow us to measure the weak phase $\gamma$. In this article, using an integrated luminosity of $3\text{ fb}^{-1}$ recorded by the LHCb experiment until 2012, a measurement of the branching fraction of $B^0_s \rightarrow D^{(*)}_s h^\pm$ with respect to $B^0_s \rightarrow D^{(*)}_s \pi^\pm$ is presented, where $D^{(*)}_s \rightarrow K^{\mp} K^{\pm} \pi^\mp$. Moreover, the first observation of the $B^0_s \rightarrow D^{(*)}_s K^\pm$ and the measurements of its branching fraction are reported, where $D^{(*)}_s$ are reconstructed through the decay chain $D^{(*)}_s \rightarrow D^{(*)}_s \rightarrow K^{\mp} K^{\pm} \pi^\mp$. These decays are experimentally challenging for a detector operating at an hadronic collider due to the low photons transverse energy. Both measurements resulted to be compatible with QCD expectations.

1. – Introduction

The weak phase $\gamma$, one of the least well-determined CKM parameters, can be measured using time-dependent $B$ meson decay rates, such as those of $B^0_s \rightarrow D^{(*)}_s h^\pm$ and $B^0_s \rightarrow D^{(*)}_s \pi^\pm$, where $h$ indicates a light meson [1]. The sensitivity to $\gamma$ is a consequence of interference between the amplitudes of the $b \rightarrow u$ and $b \rightarrow c$ transitions occurring through mixing. The decays $B^0_s \rightarrow D^{(*)}_s h^\pm$ occur predominantly through colour-allowed tree diagrams. This paper describes the experimental measurements of the ratios of branching fractions $\mathcal{B}(B^0_s \rightarrow D^{(*)}_s h^\pm)/\mathcal{B}(B^0_s \rightarrow D^{(*)}_s \pi^\pm)$, using $pp$ collision data corresponding to an integrated luminosity of $3\text{ fb}^{-1}$ recorded by the LHCb detector until 2012. The LHCb detector is a single-arm forward spectrometer designed for the studies of particles containing $b$ or $c$ quark [2]. Based on $SU(3)$ flavour symmetry and measurements at the $B$ factories, the theoretical expectations are predicted to be $\mathcal{R} = \mathcal{B}(B^0_s \rightarrow D^{(*)}_s K^\pm)/\mathcal{B}(B^0_s \rightarrow D^{(*)}_s \pi^\pm) = 0.086^{+0.069}_{-0.067}$ and $\mathcal{R}^* = \mathcal{B}(B^0_s \rightarrow D^{(*)}_s K^\pm)/\mathcal{B}(B^0_s \rightarrow D^{(*)}_s \pi^\pm) = 0.099^{+0.030}_{-0.036}$, where the uncertainty includes

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contributions from non-factorisable effects and from possible $SU(3)$-breaking effects [1].
The CDF and Belle Collaborations have pioneered the studies of $R$ [3, 4]; instead, the
presented $R^{\ast}$ measurement is the first one as a consequence of the first observation of
$B_s \rightarrow D_s^{(*)\pm} K^{\pm}$ decays at LHCb. The $B_s \rightarrow D_s^{(*)\pm} h^{\pm}$ decays are experimentally chal-
lenging for detectors operating at hadron colliders since they require the reconstruction
of a soft photon in the $D_s^{(*)\ast} \rightarrow D_s \gamma$ decays. The ratio of branching fractions $R$ and $R^{\ast}$
are evaluated according to

$$R^{(*)} \equiv \frac{B(B_s^0 \rightarrow D_s^{(*)\pm} K^{\pm})}{B(B_s^0 \rightarrow D_s^{(*)\mp} \pi^{\mp})} = \frac{n_{\text{obs}}(B_s^0 \rightarrow D_s^{(*)\pm} K^{\pm}) \epsilon(B_s^0 \rightarrow D_s^{(*)\mp} \pi^{\mp})}{n_{\text{obs}}(B_s^0 \rightarrow D_s^{(*)\mp} \pi^{\mp}) \epsilon(B_s^0 \rightarrow D_s^{(*)\pm} K^{\pm})},$$

where $n_{\text{obs}}$ and $\epsilon$ are the observed yields and the overall reconstruction efficiency, respectively.

2. $B_s^0 \rightarrow D_s^{\mp} h^{\pm}$ invariant mass fits

Candidate $B_s^0$ are reconstructed by combining a $D_s^{\pm}$ with an additional pion or kaon,
where $D_s^{(*)\pm} \rightarrow K^{\mp}K^{\pm}\pi^{\mp}$. Each of the final hadrons is required to have a good track
quality, high momentum and transverse momentum, and a large impact parameter with
respect to any primary vertex. Signal events are selected within the mass windows
$1940 < M(D_s^{(*)}) < 1990$ MeV/c$^2$ and $5000 < M(B_s^0) < 5800$ MeV/c$^2$. PID cuts are
enforced to identify kaons and a multivariate algorithm is applied to reduce the combi-
natorial background. Finally, a further veto on $\Lambda_b \rightarrow \Lambda_c(\rightarrow pK\pi)\pi$ is imposed to
reduce the background from decays where the proton is misidentified. An unbinned fit
to the candidate invariant mass distribution is performed (fig. 1). The signal shape is
parametrized by a double-sided Crystal Ball and the background contributions are fixed
using MC templates. The functional form for the combinatorial background, correspond-
ing to an exponential function, is obtained from a wrong sign sample [5].

3. $B_s^0 \rightarrow D_s^{*\mp} h^{\pm}$ invariant mass fits

Candidate $B_s^0$ are reconstructed by combining a $D_s^{*\mp}$ with an additional pion or kaon
of opposite charge. The $D_s^{*\mp}$ and a $D_s^{\mp}$ are reconstructed in the $D_s^{(*)\pm} \gamma$ and $K^{\pm}K^{\pm}\pi^{\mp}$
decay modes, respectively. Each of the $D_s$ daughters tracks is required to have good track
quality, momentum $p > 1000$ MeV/c, transverse momentum $p_T > 100$ MeV/c, and
any large impact parameter with respect to primary vertex. Photons are identified
using energy deposits in the electromagnetic calorimeter that are not associated with
any track in tracking system. Due to the small difference between the mass of $D_s^{(*)}$
and a $D_s$, $\Delta m$, the average transverse energy of photons is of a few hundred MeV/c$^2$, and
events are selected within the region $124 < \Delta m < 164$ MeV/c$^2$. PID requirements are
applied to all final-state hadron. Moreover, the maximum distance in the $\eta-\phi$ plane
between $D_s$ and the photon is required to be less than 1. Finally a multivariate approch
is used to reduce the combinatorial background. The signal yield are derived using
unbinned maximum likelihood fits to the invariant mass distribution (fig. 1). The signal
shape is parametrized by a double-sided Crystal Ball, instead to model the background
contributions non-parametric PDF, obtained from simulated samples, are used [6].
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![Graphs showing invariant mass fits for $B_0^s \to D_s^{(*)\mp} K^\pm$](image)

Fig. 1. – The $B_0^s \to D_s^{(*)\mp} K^\pm$ (left) and $B_0^s \to D_s^{(*)\mp} K^\pm$ (right) invariant mass fit, 2011+2012 data [5, 6].

4. – Conclusions

The ratios of branching fractions $\mathcal{R}$ and $\mathcal{R}^*$ measured by LHCb are

$$\mathcal{R} = \frac{B(B_0^s \to D_s^+ K^\mp)}{B(B_0^s \to D_s^- \pi^\mp)} = 0.0752 \pm 0.0015({\text{stat.}}) + 0.0019({\text{syst.}}), \text{ see ref. [5],}$$

$$\mathcal{R}^* = \frac{B(B_0^s \to D_s^{*+} K^\mp)}{B(B_0^s \to D_s^{*-} \pi^\mp)} = 0.068 \pm 0.005({\text{stat.}}) + 0.003({\text{syst.}}), \text{ see ref. [6].}$$

These measurements of $\mathcal{R}$ and $\mathcal{R}^*$ are the most accurate in the world.

REFERENCES

[5] LHCb Collaboration (Aaij R. et al.), Determination of branching fractions of $B_0^s \to D_s^{(*)\mp} K^\pm$ and $B \to D_s^{(*)\mp} K^-$, arXiv:1412.7654.