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Recent results on rare charm decays at LHCb

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Summary. — Rare decays of charmed hadrons are a powerful tool to search New Physics in the up-quark sector, complementary to searches in the strange and bottom hadron systems. In particular, anomalies in the $c \to u$ transitions, highly suppressed in the Standard Model, can be investigated in the decays with leptons of opposite charge in the final state. Given the high forward charm-anticharm production cross-section, LHCb is the ideal experiment for this type of studies. Two recent results on the semileptonic decays of the D^0 meson and the Λ_c^+ baryon are presented.

1. – Introduction

Rare charm decays offer a unique possibility to probe New Physics (NP) in the up-type quarks sector, given the deeply different dynamics compared to the first and third generations and the possibly different couplings with respect to down-type quarks.

In particular, leptonic and semileptonic decays proceeding via the short-distance (SD) $c \to ul^+l^-$ transition are flavour changing neutral current decays (FCNC), highly suppressed in the Standard Model (SM) since only possible at loop level and subject to a more effective GIM suppression compared to the B mesons [1], with branching fractions (BFs) less than $\mathcal{O}(10^{-9})$ [2].

The SD-dominated BF can be enhanced up to $\mathcal{O}(10^{-6})$ in various NP models [3], due to new high-mass particles contributing inside the loops or generating new tree-level couplings. However, long-distance (LD) tree-level contributions involving intermediate resonances dominate the decay rate, with BF up to $\mathcal{O}(10^{-6})$ [2-5].

Sensitivity to NP effects are therefore greatest in the low and high di-lepton invariant mass regions and far from intermediate resonances [4], which though populate the entire dilepton mass spectrum due to their long tails.

Two recent analysis performed by the LHCb Collaboration are discussed: the search for the FCNC decay $\Lambda_c^+ \to p\mu^+\mu^-$ and the first observation of the decays $D^0 \to h^+h^-\mu^+\mu^-$ $(h = K, \pi)$ with the BF measurements. The latter offer also the opportunity to investigate angular and CP asymmetries, for which several NP models predict enhancements up to $\mathcal{O}(1\%)$ [5].

2. – Search for the FCNC decay $\Lambda_c^+ \to p\mu^+\mu^-$

A search for the FCNC decay $\Lambda_c^+ \to p\mu^+\mu^-$ has been recently published by LHCb [6] using a data set collected in 2011 and 2012, corresponding to an integrated luminosity of $3.0\,\mathrm{fb}^{-1}$ of proton-proton collisions. The measurements are perfomed in regions of dimuon mass, $m_{\mu\mu}$, according to the main resonances: ϕ mass region (985–1055 MeV/c^2), $\omega(782)$ (759–805 MeV/c^2) and the two non-resonant regions at low and high $m_{\mu\mu}$, outside the resonant-dominated regions. The decay $\Lambda_c^+ \to p(\phi(1020) \to \mu^+\mu^-)$ is used as normalization channel, so that many systematic effects cancel. After the reconstruction, trigger selection and preselection, consisting of vertex and tracks good-quality requirements, a boosted decision tree (BDT) is trained to further reduce the combinatorial background, while two particle identification (PID) variables, applied to the reconstructed proton and muons, are used to reduce background sources from misidentified final-state particles in hadronic D^+, D_s^+ and Λ_c^+ decays.

A maximum-likelihood fit to Λ_c^+ mass distribution in each dimuon mass region is performed to extract the signal yields. An excess is seen at the known ϕ mass and, for the first time, at the ω mass with a statistical significance of five standard deviations, which allowed to measure the BF:

$$\mathcal{B}(\Lambda_c^+ \to p[\mu^+\mu^-]_{\omega\text{-region}}) = (9.4 \pm 3.2 \pm 1.0 \pm 2.0) \cdot 10^{-4}, \tag{1}$$

where the first uncertainty is statistical, the second systematic and the third is due to the limited knowledge of the normalization BF. No evidence for non-resonant $\Lambda_c^+ \to p\mu^+\mu^-$ is found, so an upper limit on the BF is determined using the CL$_s$ method [7]:

$$\mathcal{B}(\Lambda_c^+ \to p\mu^+\mu^-) < 7.7(9.6) \cdot 10^{-8} \quad \text{at } 90\%\ (95\%)\ \text{C.L.} \tag{2}$$

This upper limit corresponds to an improvement by two orders of magnitude with respect to the previous measurement by the BaBar Collaboration [8].

3. – First observation of $D^0 \to h^+h^-\mu^+\mu^-$ ($h = K, \pi$)

The LHCb experiment has recently performed the first observation of the decays $D^0 \to \pi^+\pi^-\mu^+\mu^-$ and $D^0 \to K^+K^-\mu^+\mu^-$ [9], up to now the rarest charm decays observed, using data collected in 2012, corresponding to $2\,\mathrm{fb}^{-1}$ at center-of-mass energy of 8 TeV. The BFs are measured splitting data into regions of dimuon mass, $m_{\mu\mu}$, taking into account the main resonances: low-mass region ($m_{\mu\mu} < 525$ MeV/c^2), η (525–565 MeV/c^2), ρ^0/ω (565–950 MeV/c^2), ϕ (950–1100 MeV/c^2) and high-mass region ($m_{\mu\mu} > 1100$ MeV/c^2).

The low- and high-$m_{\mu\mu}$ regions are the most sensitive to NP effects, however, significant pollution from tails of the resonances in other regions is present. In this analysis no attempt is done to distinguish SD and LD effects.

The Cabibbo-favoured $D^0 \to K^-\pi^+\mu^+\mu^-$ is used as normalization channel, first observed by the LHCb experiment in the ρ^0-ω region [10], having the same topology and similiar kinematics.

The D^0 mesons are selected from the $D^{*+} \to D^0\pi^+$ decay, with a restriction of the mass difference between the D^{*+} and D^0 to 144.5–146.5 MeV/c^2, in order to reduce the combinatorial background with high efficiency, which is further rejected training a BDT.

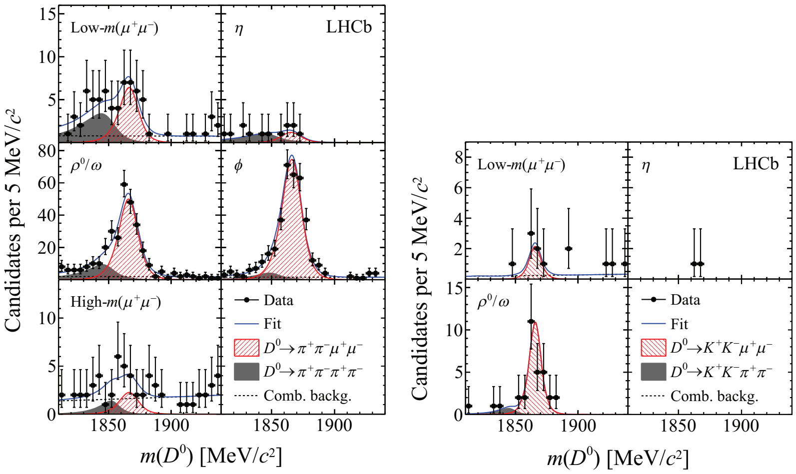

Fig. 1. – Distributions of $m(D^0)$ in different dimuon mass regions for the $D^0 \to \pi^+\pi^-\mu^+\mu^-$ candidates (left) and $D^0 \to K^+K^-\mu^+\mu^-$ (right), with the fit projections overlaid. No fit is performed in the η region of the $D^0 \to K^+K^-\mu^+\mu^-$ decay.

The peaking background of the $D^0 \to h^+h^-\pi^+\pi^-$ decay, where two pions are misidentified as muons, is reduced applying PID selection to the reconstructed muons. The final selection is determined optimizing simultaneously the BDT and PID requirements.

Finally, the signal yields in each dimuon mass regions are obtained through an unbinned maximum-likelihood fit to D^0 mass distributions, as shown in fig. 1, with the signal and misidientified background shapes studied from simulation. An excess of candidates with a significance greater than three standard deviations with respect to the background-only hypothesis is observed in all the dimuon mass regions, except in both the η regions and in the high-mass region of the $D^0 \to \pi^+\pi^-\mu^+\mu^-$, for which an upper limit on the BF is determined.

The dimuon mass integrated BFs measured are

$$\mathcal{B}(D^0 \to \pi^+\pi^-\mu^+\mu^-) = (9.64 \pm 0.48 \pm 0.51 \pm 0.97) \cdot 10^{-7}, \tag{3}$$

$$\mathcal{B}(D^0 \to K^+K^-\mu^+\mu^-) = (1.54 \pm 0.27 \pm 0.09 \pm 0.16) \cdot 10^{-7}, \tag{4}$$

where the first uncertainty is statistical, the second systematic and the third is the uncertainty on the BF of normalization decay. These results are in agreement with theoretical predictions [4].

4. – Conclusions

The LHCb experiment is leading the field of charm rare decays, determining world's best measurements or upper limits on BFs and making first observations. Significant improvements are expected from the inclusion of Run II data and in the upcoming LHCb upgrade, where improvements of one order of magnitude in the yields are expected.

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