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Rare Charm decays at LHCb

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Rare decays are particularly sensitive to contributions from beyond the Standard Model. Here the focus is on rare charm decays where the latest results from the LHCb collaboration on branching fractions and on *CP* and angular asymmetries are reported.

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1. Introduction

Rare decays of charm hadrons are highly suppressed in the Standard Model (SM) making them ideal probes of physics beyond the SM. For instance, flavor changing neutral current (FCNC) decays proceeding through loops in the SM and they are further suppress from a strong GIM mechanism that takes place in the case of charm decays in addition to a CKM suppression of b quark loops. The importance of these decays is also given by the complementarity to the beauty and strange sector being the charm quark an up-type quark we can access beyond the SM couplings to the up sector. On the other hand, predictions in the charm sector are difficult due to dominant long-distance contributions. However, a lot of effort has been put into the development of new observables and techniques to reduce these uncertainties. This proceedings reports the last measurements of the LHCb experiment regarding rare charm decays.

2. The richness of $D^0 \to h^+h^-\mu^+\mu^-$

$D^0 \to h^+h^-\mu^+\mu^-$ decays, where h stands for kaon or pion, have overwhelming contributions from long-distance amplitudes proceeding through intermediate vector resonances in the $\mu^+\mu^-$ spectrum. However, the rich and diverse dynamics of a four-body decay compensate such penalty allowing us to measure observables accessing the short-term amplitudes [1, 2].

A search for this decays has been performed using $2\,\mathrm{fb}^{-1}$ of pp collision data from the Run 1 of the LHC [3]. D^0 mesons are reconstructed in $D^{*+} \to D^0\pi^+$ decays to suppress combinatorial background. The relative branching fraction with respect to the $D^0 \to K^-\pi^+[\mu^+\mu^-]_{\rho/\omega}$ is measured in bins of the dimuon invariant-mass $m(\mu^+\mu^-)$, as shown in Fig. 1. Integrating over dimuon mass the total branching fractions are measured to be

$$\begin{aligned} B(D^0 \to \pi^+\pi^-\mu^+\mu^-) &= (9.64 \pm 0.48 \pm 0.51 \pm 0.97) \times 10^{-7}, \\ B(D^0 \to K^+K^-\mu^+\mu^-) &= (1.54 \pm 0.27 \pm 0.09 \pm 0.16) \times 10^{-7}, \end{aligned} \tag{2.1}$$

where the uncertainties are statistical, systematic, and due to the limited knowledge of the normalization branching fraction $D^0 \to K^-\pi^+[\mu^+\mu^-]_{\rho/\omega}$. These are the rarest charm decays ever observed and are in agreement with the SM. Branching fractions are mainly dominated by long-term contributions even outside the resonances regions. Thus, to access the short-distance physics the following angular and CP asymmetries are measured:

$$\begin{aligned} A_{CP} &= \frac{\Gamma(D^0 \to h^+h^-\mu^+\mu^-) - \Gamma(\bar{D}^0 \to h^+h^-\mu^+\mu^-)}{\Gamma(D^0 \to h^+h^-\mu^+\mu^-) + \Gamma(\bar{D}^0 \to h^+h^-\mu^+\mu^-)}, \\ A_{FB} &= \frac{\Gamma(\cos\theta_\mu > 0) - \Gamma(\cos\theta_\mu < 0)}{\Gamma(\cos\theta_\mu > 0) + \Gamma(\cos\theta_\mu < 0)}, \\ A_{2\phi} &= \frac{\Gamma(\sin 2\phi > 0) - \Gamma(\sin 2\phi < 0)}{\Gamma(\sin 2\phi > 0) + \Gamma(\sin 2\phi < 0)}, \end{aligned} \tag{2.2}$$

where the angle θ_μ is the angle of the positive muon in the dimuon decay plane and ϕ is the angle between the decay plan of the dimuon and the decay plane of the two hadrons. These asymmetries are predicted to be negligible small in the Standard Model but could be as large as $\mathscr{O}(1\%)$ in scenarios of physics beyond the Standard Model [1, 2]. The measurement of A_{CP}, A_{FB}, and $A_{2\phi}$

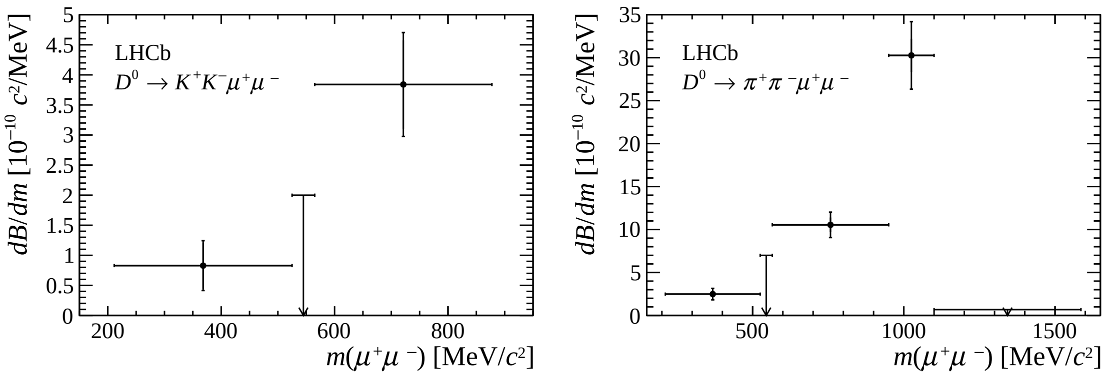

Figure 1: Differential branching fraction as a function of the dimuon mass for (left) $D^0 \to K^+K^-\mu^+\mu^-$ and (right) $D^0 \to \pi^+\pi^-\mu^+\mu^-$ decays.

is performed with the *pp* collision data collected with the LHCb experiment at center-of-mass energies of 7, 8, and 13 TeV between 2011 and 2016 [4]. The whole data sample corresponds to an integrated luminosity of about $5\,\mathrm{fb}^{-1}$. The integrated yields in the full dimuon spectrum are estimated to be about 1083 and 110 for $D^0 \to \pi^+\pi^-\mu^+\mu^-$ and $D^0 \to K^+K^-\mu^+\mu^-$ decays, respectively. The measured values of the asymmetries are

$$\begin{aligned} A_{CP}(\pi^+\pi^-\mu^+\mu^-) &= (\;\;4.9 \pm 3.8 \pm 0.7)\%, & A_{CP}(K^+K^-\mu^+\mu^-) &= (0 \pm 11 \pm 2)\%, \\ A_{FB}(\pi^+\pi^-\mu^+\mu^-) &= (\;\;3.3 \pm 3.7 \pm 0.6)\%, & A_{FB}(K^+K^-\mu^+\mu^-) &= (9 \pm 11 \pm 1)\%, \\ A_{2\phi}(\pi^+\pi^-\mu^+\mu^-) &= (-0.6 \pm 3.7 \pm 0.6)\%, & A_{2\phi}(K^+K^-\mu^+\mu^-) &= (0 \pm 11 \pm 2)\%. \end{aligned} \tag{2.3}$$

These measurements, as well as the asymmetries in each dimuon mass region, are compatible with zero within the current sensitivities. Thus, they are compatible with the Standard Model expectations.

3. Search for $\Lambda_c^+ \to p\mu^+\mu^-$

The LHCb experiments has collected a large amount of charmed baryons decays in addition to the charmed mesons. Thus, we can extend our searches for flavour changing neutral current to these decays. In particular, a search for $\Lambda_c^+ \to p\mu^+\mu^-$ decay has been performed using the *pp* collision data from the Run I of the LHC corresponding to an integrated luminosity of $3\,\mathrm{fb}^{-1}$ [5].

The sample is split into three independent subsamples by its dimuon invariant-mass (see Fig. 2) as follows: i) a region around the know ω mass, $[759, 805]\,\mathrm{MeV}/c^2$, in order to isolate the $\Lambda_c^+ \to p\omega$ decay mode, ii) a region around the known ϕ mass, $[985, 1055]\,\mathrm{MeV}/c^2$, used as a normalization channel, iii) a nonresonant region for $\Lambda_c^+ \to p\mu^+\mu^-$ which excludes the two regions defined above. About 100 events are reconstructed for the normalization mode, and an accumulation of about 13 candidates are observed in the ω region corresponding to a statistical significance of 5.0σ. Thus, the first observation of $\Lambda_c^+ \to p[\mu^+\mu^-]_\omega$ in the ω region is reported with a branching fraction of $B(\Lambda_c^+ \to p[\mu^+\mu^-]_\omega) = (9.4 \pm 3.2 \pm 1.0 \pm) \times 10^{-4}$. Instead, no significant signal is observed in the nonresonant region. Thus, a upper limit is determined corresponding to $B(\Lambda_c^+ \to p\mu^+\mu^-) < 7.7(9.6) \times 10^{-8}$ @ 90% (95%) *CL*.

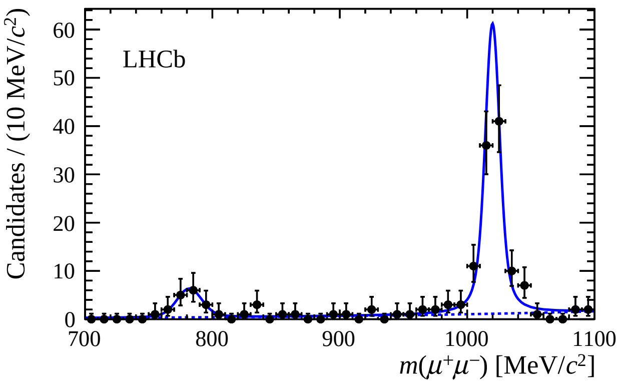

Figure 2: Dimuon invariant-mass distribution for $\Lambda_c^+ \to \mu^+\mu^-$ candidates with mass $\pm 25\,\mathrm{MeV}/c^2$ around the known Λ_c^+ mass.

4. Conclusion

Rare decays at LHCb are not just *beauty*-ful but they are also *charm*-ing. Thanks to the huge dataset of charm decays, LHCb is providing the most precise measurements in several charged decays. These will be improved with the addition of the total statistics accumulated in the full Run II corresponding to an integrated luminosity of about $6\,\mathrm{fb}^{-1}$.

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