Effective field theory analysis of rare $|\Delta c| = |\Delta u| = 1$ charm decays

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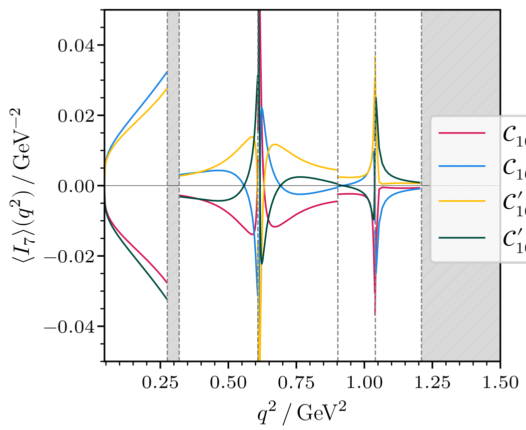
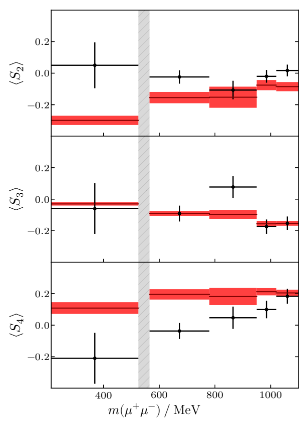
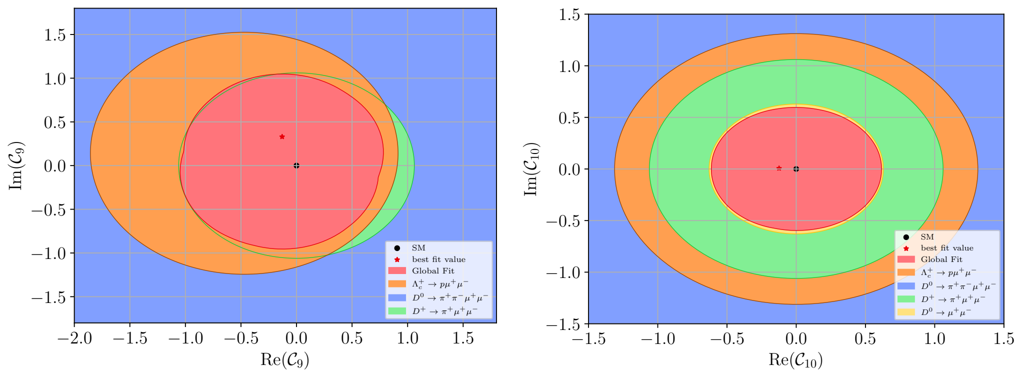
Rare charm decays present a unique opportunity to study New Physics (NP) in the up-sector. They are induced by Flavor-changing neutral currents which are strongly suppressed in the Standard Model (SM) through the GIM mechanism as an interplay between fermion masses and mixing parameters. We perform a global analysis of $|\Delta c| = |\Delta u| = 1$ decays, including $D^0 \to \mu^+\mu^-$, $D^+ \to \pi^+\mu^+\mu^-$, $\Lambda_c^+ \to p\mu^+\mu^-$ and $D^0 \to \pi^+\pi^-\mu^+\mu^-$, within the framework of Weak Effective Theory and Standard Model Effective Field Theory. We study NP contributions from the 4-fermion vector current operators $\mathcal{O}_9^{(\prime)}$, $\mathcal{O}_{10}^{(\prime)}$ and from the dipole operators $\mathcal{O}_7^{(\prime)}$. Upper limits on the branching fraction from low- and high-$m^2_{\mu^+\mu^-}$ have been measured in all those channels as well as the branching fraction of resonant contributions for the latter three. Additionally, various angular observables have been measured for $D^0 \to \pi^+\pi^-\mu^+\mu^-$ by LHCb. Although most of these charm decays are plagued by resonance contributions, there are null tests that remain. The forward-backward asymmetry of the lepton pair $\langle A_{\rm FB}\rangle$ in $\Lambda_c^+ \to p\mu^+\mu^-$ or the angular observables $\langle I_{5,6,7}\rangle$ in $D^0 \to \pi^+\pi^-\mu^+\mu^-$ are sensitiv to $\mathcal{O}_{10}$ and enhanced around the resonance poles. The experimental data allows us with additional input from Lattice QCD to fit remaining resonance parameters of a Breit-Wigner parametrization. Utilizing this we analyze all observables of the above charm decays with regards to NP, compare their sensitivities and present upper limits on the Wilson coefficients (WCs).





We place special emphasis on the decays $D^0 \to \pi^+\pi^-\mu^+\mu^-$ and $\Lambda_c^+ \to p\mu^+\mu^-$. For the former we try to improve on the modelling of the resonance contribution from previous works. We find in agreement with other works that the new LHCb data indicates both S- and P-wave resonances decaying to $\pi^+\pi^-$, but further improvements are required to utilize all bins and angular observables. As it stands the SM prediction appears to have short-coming for low-$m^2_{\mu^+\mu^-}$ and for certain resonance polluted angular observables like $\langle S_{2,4,9} \rangle$. We clarify how LHCb can improve the SM prediction in the future and which theoretical difficulties we face.

Nevertheless, the null tests remain and we work out conservative limits on WCs. The binned angular observables of the null tests have been measured by LHCb in bins suited to suppress cancellations as the NP contributions spike around $q^2 \simeq m^2_\rho, m^2_\phi$ and can change sign depending on the strong phases. The high-$m^2_{\mu^+\mu^-}$ region and the region of the η resonance have been excluded by the experiment. We find that the strong phases severely limits the upper limits on WCs and that they remain below those of the limits on the branching fraction in low- or high-q^2 for $D^0 \to \mu^+\mu^-$, $D^+ \to \pi^+\mu^+\mu^-$ and $\Lambda_c^+ \to p\mu^+\mu^-$.



Together with the added complexity and hadronic uncertainties in $D^0 \to \pi^+\pi^-\mu^+\mu^-$ we find that we should instead focus on the baryonic decays $\Lambda_c^+ \to p\mu^+\mu^-$. With their added complexity compared to $D^0 \to \mu^+\mu^-$ and $D^+ \to \pi^+\mu^+\mu^-$ they still posses $\langle A_{\rm FB} \rangle$ as a $\mathcal{O}_{10}$ null test while retaining a lower hadronic uncertainty through its preciser known form factors. We work out future projections for measurements of $\langle A_{\rm FB} \rangle$ and discuss the required binning to obtain the strongest bounds on NP.