Precision Tests of the SM and Beyond from Quark-Flavour

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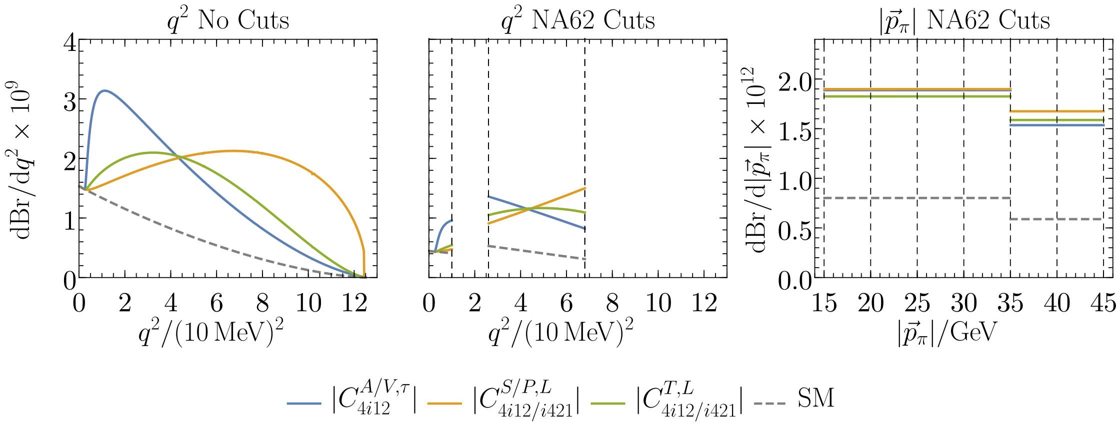
Low-energy observables below the electroweak (EW) scale across different flavour sectors provide high precision tests of the Standard Model (SM). A plethora of dedicated searches spanning B-, D-, K-, and nucleon-physics aim to find deviations from the precise predictions. With low-energy observables I investigate two kind of processes, flavour-changing-neutral-currents (FCNCs), and charged-currents (CCs) of the weak interaction.

The former are very rare processes, not allowed at tree-level within the SM and are hence highly suppressed. One of the FCNC processes I consider in my work is the charged golden kaon decay mode $K^+ \to \pi^+ \nu\bar{\nu}$ with a branching ratio of $\mathcal{O}(10^{-10})$. The smallness of the SM prediction combined with the very good understanding of the uncertainties in both experiment and theory, makes this process a promising probe for non-SM interactions including neutrinos. The aim of this work is to analyse the binned data published by the NA62 collaboration, with respect to the two physically different scenarios of Majorana and Dirac neutrinos. To this end, the theoretical setup includes two bases, one for the Majorana case and one for the Dirac case. In both scenarios we include (axial-)vector interactions, as well as (pseudo-)scalar and tensor interactions. For the case of Dirac neutrinos we add right-handed neutrinos, in order to generate the scalar and the tensor interaction, while still conserving lepton number. Furthermore, we include possible additional massive sterile neutrinos in both cases. With the calculated differential branching ratios we perform a maximum likelihood analysis including all available experimental and theoretical uncertainties.



In the above figure I show as an example the calculated the differential branching ratio for the case of an additional massive Majorana neutrino with a mass of $m_{\nu,4} = 50\,\mathrm{MeV}$, induced by different NP operators. Once without experimental cuts, as well as with the NA62 cuts applied. The rare kaon decay mode currently probes New Physics (NP) scales of up to $\mathcal{O}(100\text{TeV})$. As a follow-up project the general matching of our bases onto the Standard Model Effective Theory (SMEFT) is performed, in order to compare competitiveness of the rare kaon decay constraints, with correlated observables. To fully utilise the golden kaon modes, we further aim to also investigate the neutral kaon decay mode $K_L \to \pi^0 \nu\bar{\nu}$ in a combined study.

The other direction of my studies considers CC interactions, which are extensively used to pinpoint the quark-flavour-structure of the SM parameterised by the Cabibbo-Kobayashi-Maskawa (CKM) matrix. The unitarity of the CKM matrix provides a stringent tests for combinations of CKM matrix elements. Current results find deficiencies within the first-row unitarity test of up to 3σ. These tensions could be set on a more robust footing by improving the theory predictions required to extract the CKM matrix elements V_{ud} and V_{us}. In my work, I focus on higher-order determination of the SM prediction of the semi-leptonic operator inducing the $d/s \to u\nu_e e$ transition.