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QCD Effects in Lepton-Number-Violating Meson and Tau Decays

Lepton-number-violating (LNV) meson and tau decays provide complementary probes of new physics that violate lepton number by two units. Below the electroweak scale, short-range contributions mediated by heavy particles can be described by a dimension-9 low-energy effective Lagrangian. While operators involving first-generation fermions are strongly constrained by neutrinoless double beta decay, operators with more general flavor structures can be tested through processes such as $M_1^- \rightarrow M_2^+ \ell_1^- \ell_2^-$ and $\tau^- \rightarrow \ell^+ M_1^- M_2^-$.

In this talk, I will discuss two complementary QCD aspects required for a complete interpretation of these decays. First, I will present the one-loop QCD renormalization-group evolution of the dimension-9 operator basis. The general flavor structure induces mixing not only among different Lorentz structures, but also among operators with different quark-flavor configurations. This evolution leads to new constraints on previously unbounded operators and can significantly modify the limits on individual Wilson coefficients.

Second, I will address the non-perturbative hadronic matrix elements entering LNV meson decays. Standard estimates commonly rely on the vacuum-insertion approximation and neglect connected contractions between the two quark currents. We evaluate these connected contributions using the $1/N_c$ expansion and show that they can provide significant corrections to the factorized result. Since they constitute leading contributions in the large- N_c expansion of the non-perturbative QCD effects, they provide a systematic first approximation toward a complete lattice-QCD determination of the relevant matrix elements. Together, these results improve the connection between experimental searches for LNV decays and constraints on the underlying effective operators.

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