Superallowed $0^+ \rightarrow 0^+$ nuclear β decays: 2014 critical survey, with precise results for V_{ud} and CKM unitarity

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Beta decay between nuclear analog states of spin-parity, $J^\pi = 0^+$, and isospin, T = 1, has been a subject of continuous and often intense study for five decades. The strengths, or ft values, of such transitions are nearly independent of nuclear-structure ambiguities and depend uniquely on the vector part of the weak interaction. Thus, their measurement has given nuclear physicists access to clean tests of some of the fundamental precepts of weak-interaction theory and, over the years, this strong motivation has led to very high precision being achieved in both the experiments and the theory required to interpret them.

As befits such an important issue, we have undertaken periodic surveys of the relevant world data (see, for example, refs [1-6]). Since our last survey closed in September 2008, a large amount of significant new data has appeared, so that survey was already out of date. We have now published a thorough new overview [7], in which we critically survey all relevant measurements formally published before September 2014.

Compared with our last review, we have added results from 24 new publications and eliminated 9 references, the results from which having been superseded by much more precise modern data. We obtained world-average ft-values for each of the eighteen transitions that have a complete set of data, then applied radiative and isospin-symmetry-breaking corrections to extract "corrected" $\mathcal{F}t$ values. Fourteen of these $\mathcal{F}t$ values now have a precision of order 0.1% or better. In the process of obtaining these results we carefully evaluated the available calculations of the isospin-symmetry-breaking corrections by testing the extent to which they lead to $\mathcal{F}t$ values consistent with conservation of the vector current (CVC). Only one set of calculations satisfactorily meets this condition. As shown in Fig. 1, the results for the $\mathcal{F}t$ values are impressively constant.

The resultant average $\mathcal{F}t$ value, when combined with the muon lifetime, yields the up-down quark-mixing element of the Cabibbo-Kobayashi-Maskawa (CKM) matrix, V_{ud} = 0.97417 (21), a result that is consistent with, but more precise than, values we have obtained in previous analyses of superallowed β decay. To emphasize the consistency and steady improvement that has characterized the value of V_{ud} as derived from nuclear β decay, in Fig. 2 we plot our new result together with V_{ud} values published at various times over the past two-and-a-half decades.

The unitarity test on the top row of the matrix becomes $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.99978$ (55) if the Particle Data Group recommended value for V_{us} is used. However, recent lattice QCD calculations, not included yet in the PDG evaluation, have introduced some inconsistency into kaon-decay measurements of V_{us} and V_{us}/V_{ud} . In ref. [7], we have examined the impact of these new results on the unitarity test and conclude that there is no evidence of any statistically significant violation of unitarity. Finally, from the $\mathcal{F}t$-value data we also set limits on the possible existence of scalar interactions.
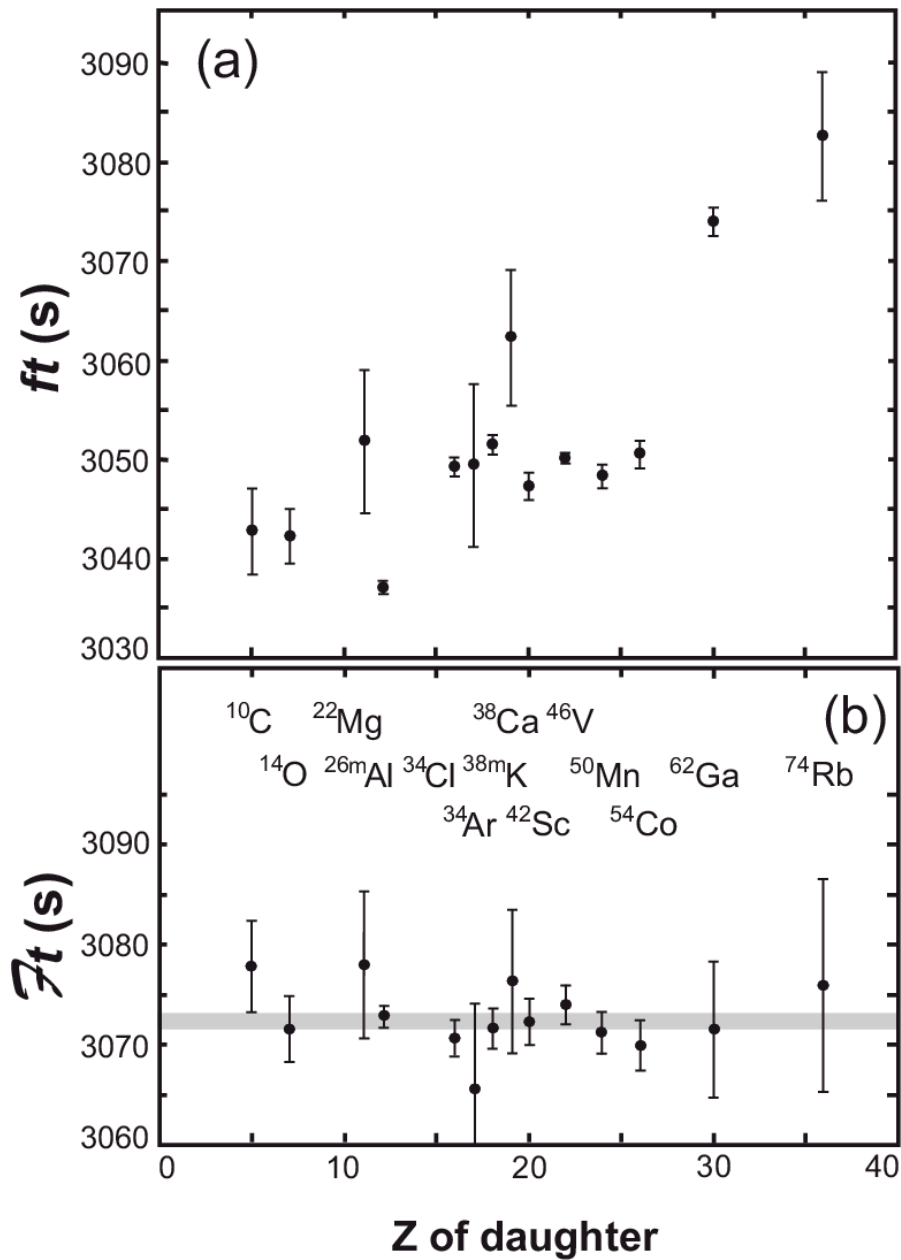
FIG. 1. In the top panel are plotted the uncorrected experimental *ft* values as a function of the charge on the daughter nucleus. In the bottom panel, the corresponding $\mathcal{F}t$-values are given; they differ from the top panel simply by the inclusion of the correction terms δ'_R, δ_{NS} and δ_C. The horizontal grey band in the bottom panel indicates the average $\mathcal{F}t$-value with its uncertainty.
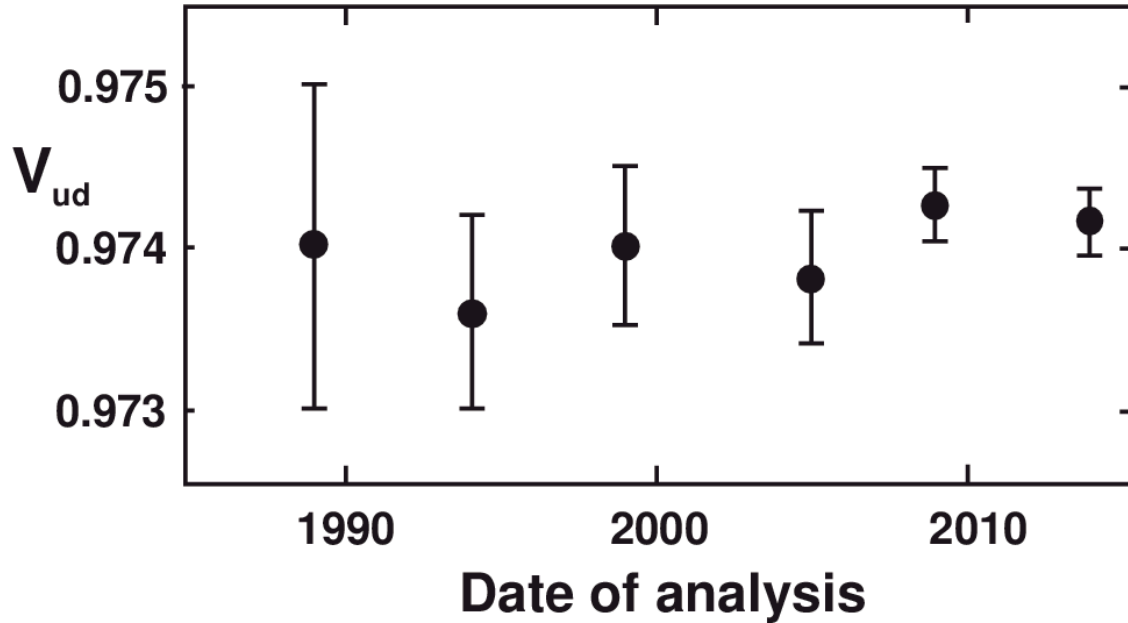
FIG. 2. Values of V_{ud} as determined from superallowed $0^+ \rightarrow 0^+$ β decays plotted as a function of analysis date, spanning the past two-and-a-half decades.

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