High-Precision Branching Ratio Measurement for the Superallowed Fermi β Emitter $^{22}\text{Mg}$

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Superallowed Fermi Beta Emitters

Precision measurements of the $ft$ values for superallowed $0^+ \rightarrow 0^+$ Fermi $\beta$ decays between isobaric analogue states provide demanding tests of the Standard Model description of electroweak interactions.

From Fermi’s Golden Rule:

$$ft = \frac{K}{g^2 |M_{fi}|^2}$$
Impacts of studying $T=1$ superallowed Fermi $\beta$ Emitters

Test of conserved vector current (CVC) hypothesis confirmed to better than 12 parts in $10^5$

Most precise determination of $V_{ud}$

$|V_{ud}| = 0.97420(21)$

Tests of CKM unitarity

$1 - |V_{ud}|^2 - |V_{us}|^2 - |V_{ub}|^2 = 0.00038(49)$

World survey consists of some 220 individual measurements

Search for physics beyond the Standard Model

Fundamental or induced scalar currents in Weak interaction
$ft$ values for superallowed transitions

$$ft = \frac{2\pi^3 \hbar^7 \ln 2}{2G^2_m c^4} = \text{constant}$$

experimentally measured $Q$ value, parent half-life ($T_{1/2}$), and branching ratio ($BR$) to superallowed state constant to within 1.5%
Superallowed Fermi Beta Emitters

\[ \mathcal{F} t = ft (1 + \delta'_R) (1 + \delta_{NS} - \delta_C) = \frac{K}{2G^2_V (1 + \Delta^V_R)} = \text{constant} \]

- Corrected \( ft \) value
- Calculated corrections (~1%) (nucleus dependent)
- Inner radiative correction (~2.4%) (nucleus independent)
- Experiment
- CVC Hypothesis

\[ \Delta^V_R = \text{nucleus independent inner radiative correction: } 2.361(38)\% \]
\[ \delta_R = \text{nucleus dependent radiative correction to order } Z^2 \alpha^3: \sim 1.4\% \]
  - \( \delta_R \) depends on electron’s energy and \( Z \) of nucleus
\[ \delta_{NS} = \text{nuclear structure dependent radiative correction: } -0.3\% – 0.03\% \]
\[ \delta_C = \text{nucleus dependent isospin-symmetry-breaking correction: } 0.2\% – 1.5\% \]
  - \( \delta_C \) strongly nuclear structure dependence
Isospin-symmetry breaking corrections

- Not all models have been equally constrained by experimental data (e.g. nuclear charge radii, separation energies, IMME)

- The Woods-Saxon and Hartree-Fock calculations have been favoured in the previous world surveys
Corrected $ft$ values

\[ \mathcal{F}t = \frac{K}{2G_V^2(1 + \Delta^V_R)} \]

Confirmation of CVC

Estimate theoretical model-dependent uncertainty with difference of values
Corrected $f_t$ values

\[ f_t(WS)_{ave} = 3072.26(60)_{stat}^{(34)}_{\delta R} s, \chi^2/\nu = 0.51 \]

\[ f_t(HF)_{ave} = 3071.95(71)_{stat}^{(40)}_{\delta R} s, \chi^2/\nu = 1.28 \]
Corrected $f_t$ values

Keeping only transitions where $f_t$ is determined to $\pm 0.15\%$ or better, “constancy” argument fails.
**Experiment**

Status of $^{22}\text{Mg}$ $f_t$ value:

Q-value recently measured @ TITAN – M.P. Reiter, K.G. Leach et al., PRC 96 052501 (2017)

Half-life recently measured @ ISAC – M.R. Dunlop et al., PRC 96 045502 (2017)

Branching Ratio has only been measured once to high-precision – J.C. Hardy et al., PRL 082501 (2003)

**Goal:** To improve the $^{22}\text{Mg}$ branching ratio measurement to the $\pm 0.15\%$ level
Measuring the $^{22}\text{Mg}$ Branching Ratio

Second-forbidden decay to ground state → all $\beta$ decays are accompanied by $\gamma$-rays

To measure the BR to ±0.15%, we need to measure $\varepsilon_\gamma$ to ±0.1%

*This is particularly challenging at 74 keV*
GRiffin Efficiency

$\varepsilon_\gamma$ changes quickly at low energies, so a well-calibrated efficiency curve is crucial.
IGLIS instrumental in suppressing long-lived $^{22}$Na ($T_{1/2} = 2.6$ y) contaminant by $10^7$
Novel $\gamma$-Coincidence Method

The 74 and 583 keV cascade are in 1:1 following the emission of a 1280 keV $\gamma$

Can measure $\varepsilon_{583}/\varepsilon_{74}$ in situ via coincidence with 1280 keV

The 583 keV excited state has a lifetime of ~250 ns.

Requires large event-build and coincidence gate
Summary of Data

In coincidence with 1280 keV (for ratio of efficiencies):
74 keV: $5.2 \times 10^6$ counts
583 keV: $2.2 \times 10^6$ counts

In singles:
74 keV: $5.8 \times 10^8$ counts
583 keV: $4.2 \times 10^8$ counts
1280 keV: $1.4 \times 10^7$ counts
1937 keV: $6 \times 10^4$ counts

Statistical precision <0.1%
Where does this leave us?

- All 3 experimental quantities required to calculate $ft$ (Q-value, half-life, and branching ratio) for $^{22}$Mg have been recently performed at TRIUMF.
- Branching ratio analysis is still ongoing.
- As in all precision measurements, a dedicated systematics investigation is being completed to ensure no biases are introduced.
- Any conclusions that affect the central value or uncertainty of the world-average $ft$ value will have implications for both the CVC and CKM unitarity.
Thank you for your attention

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