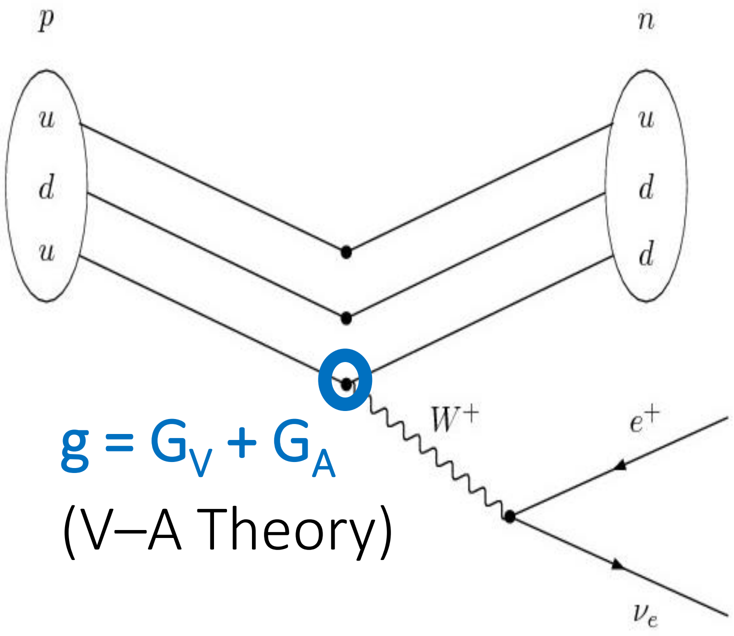
High-Precision Branching Ratio Measurement for the Superallowed Fermi β Emitter ^{22}Mg

A.T. Laffoley – University of Guelph

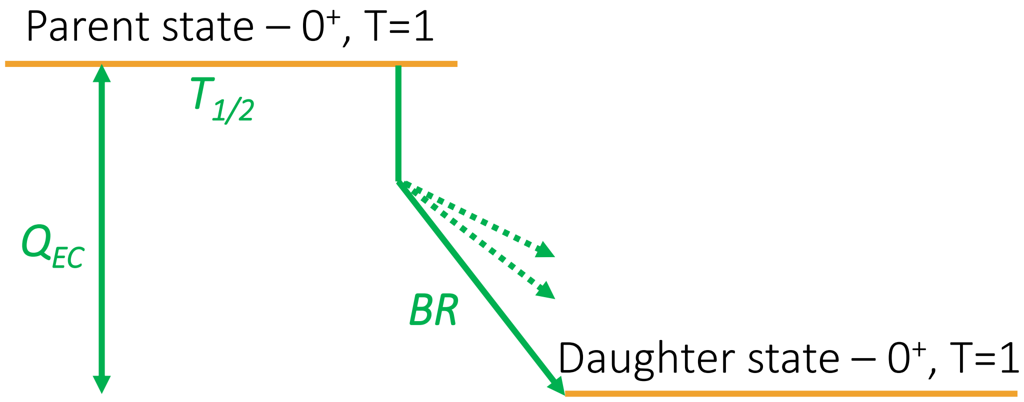
WNPPC, February 15th 2019

Beta Decay and *ft* Values



$g = G_V + G_A$

(V–A Theory)



From Fermi's Golden Rule:

$$ft = \frac{K}{g^2\,|M_{fi}|^2}$$

Experimentally determine:

- Q value
- Half-life ($T_{1/2}$)
- Branching Ratio (BR)

ft Values for Superallowed Transitions

In the special case of pure Fermi transitions between isobaric analogue states, we have that:

1. $g = G_V$ (constant from CVC)
2. $|M_{fi}|^2 = (T-T_Z)(T+T_Z+1) = 2$ (isospin ladder operator)

$$ft = \frac{2\pi^3\hbar^7 \ln 2}{2G_V^2 m_e^5 c^4} = \text{constant}$$

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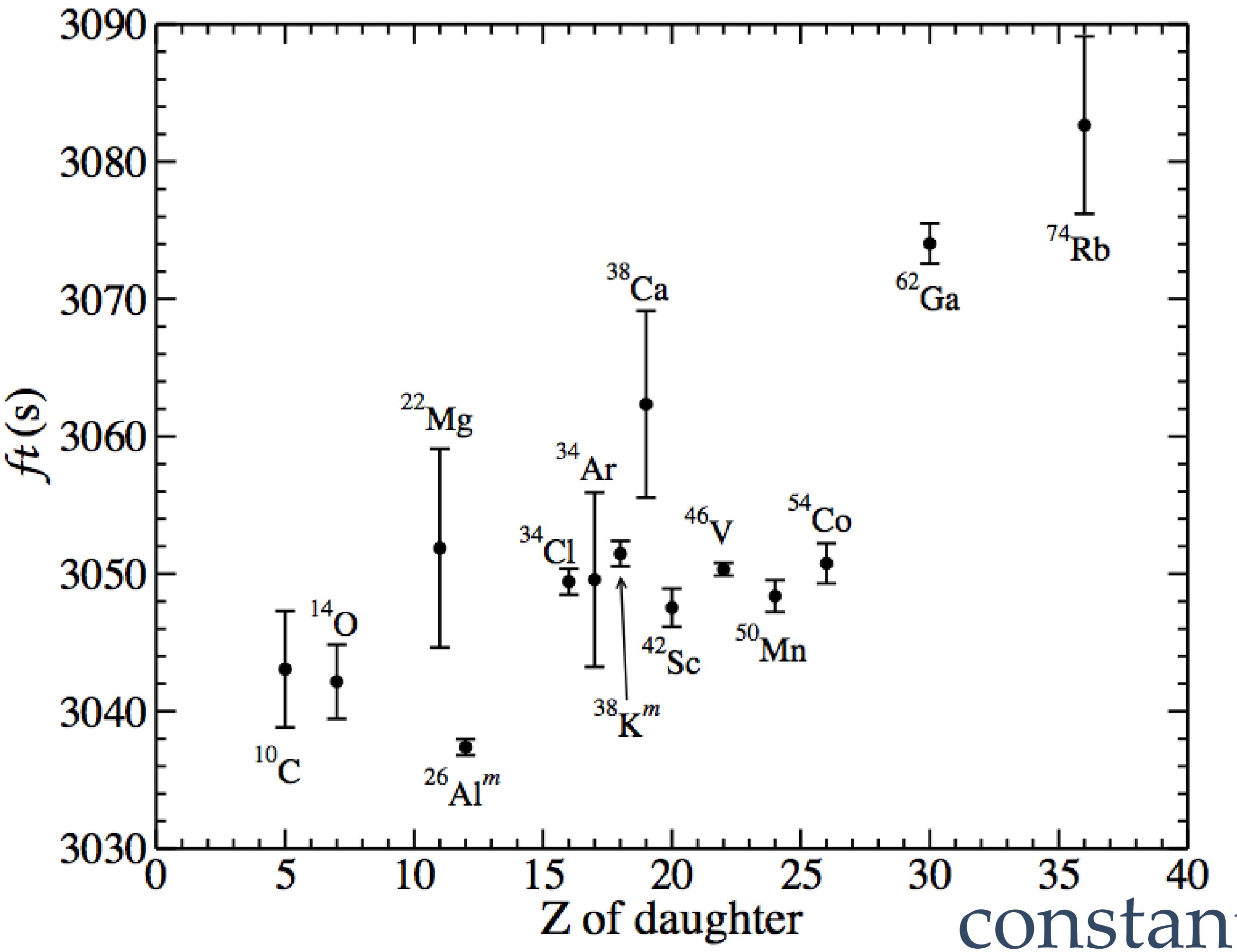


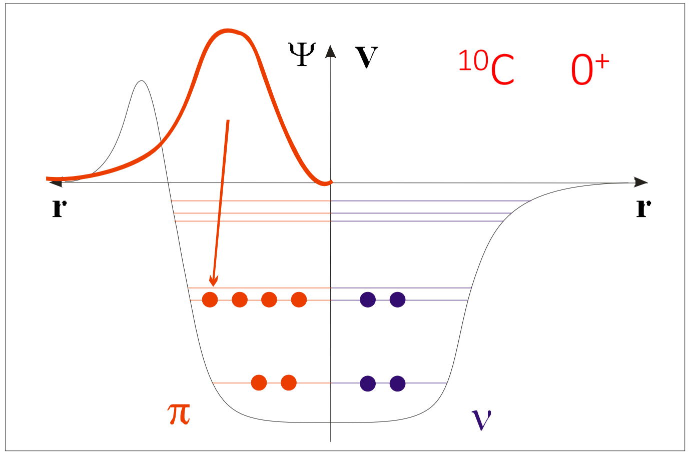
constant to within 1.5%

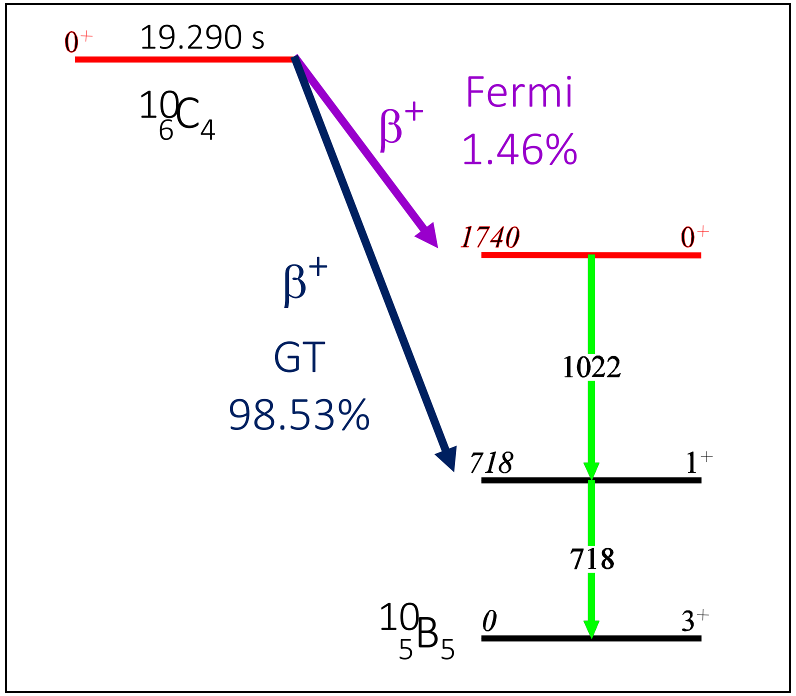
Isospin Symmetry Breaking

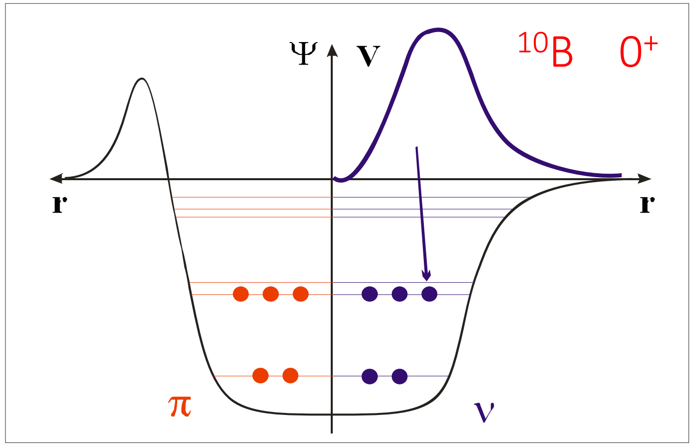
Superallowed Fermi β decays occur between nuclear isobaric analogue states.

A proton is converted into a neutron with an (almost) identical wavefunction, so that the transition matrix element is trivial: $< f|\mathcal{O}|i > = \sqrt{2}$ (for T = 1).

The exact symmetry between proton an neutron wavefunctions in the nucleus is broken by Coulomb and charge-dependent nuclear interactions.







Superallowed Fermi β Decay: Corrections

$$\mathcal{F}t = ft(1+\delta_R')(1+\delta_{NS}-\delta_C) = \frac{K}{2G_V^2(1+\Delta_R^V)} = \text{constant}$$

- $\mathcal{F}t$: Corrected *ft* value
- ft: Experiment
- δ_R', δ_{NS}, δ_C: Calculated corrections (~1%) (nucleus dependent)
- Δ_R^V: Inner radiative correction (~2.4%) (nucleus independent)
- constant: CVC Hypothesis

Δ_R^V = nucleus independent inner radiative correction: 2.361(38)%

δ_R' = nucleus dependent radiative correction to order $Z^2\alpha^3$: ~1.4%

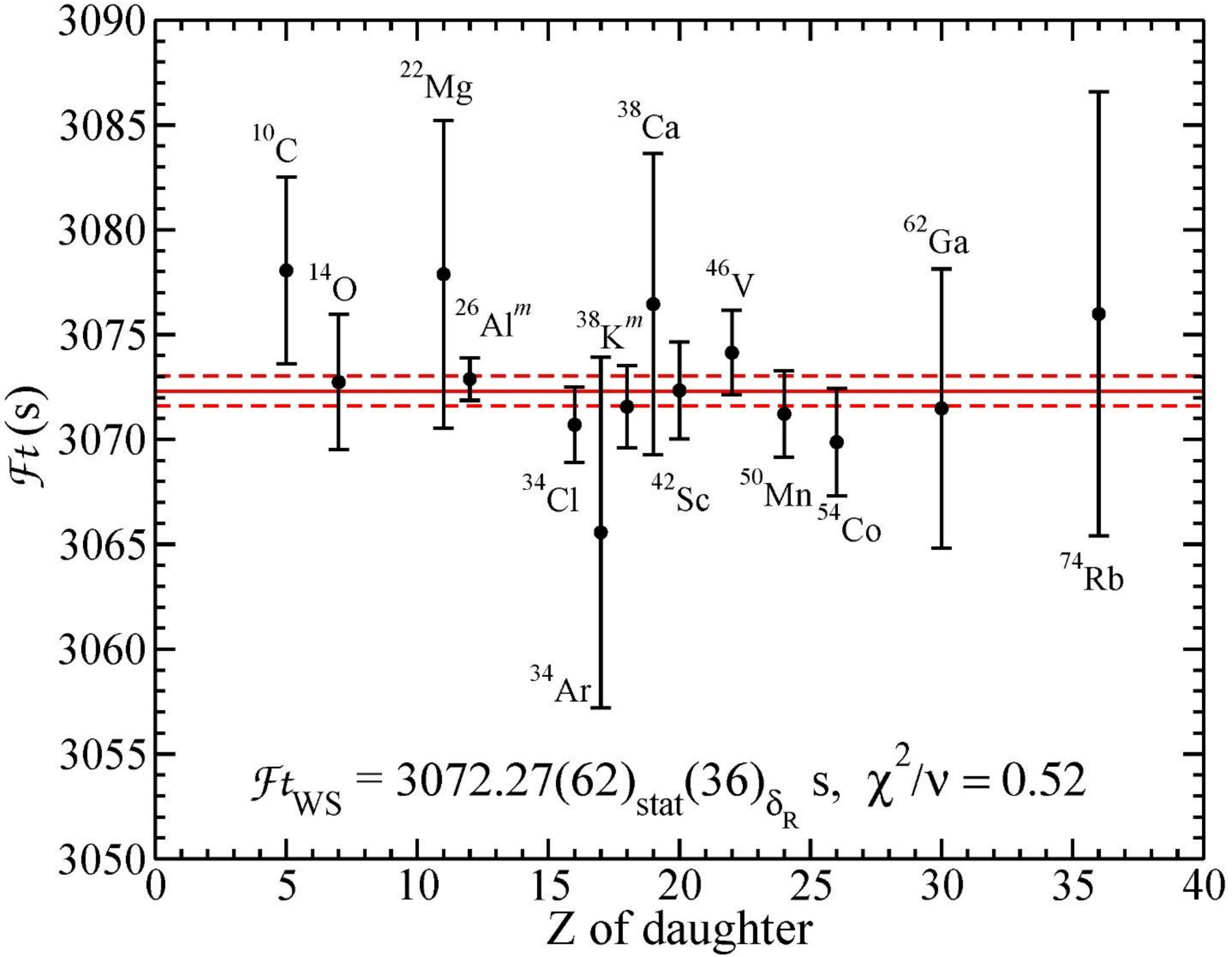
↳ depends on electron's energy and *Z* of nucleus

δ_{NS} = nuclear structure dependent radiative correction: -0.3% – 0.03%

δ_C = nucleus dependent isospin-symmetry-breaking correction: 0.2% – 1.5%

↳ strong nuclear structure dependence

Corrected Superallowed $\mathcal{F}t$ Values



Hardy and Towner, Phys. Rev. C 91, 025501 (2015)

$$\mathcal{F}t = \frac{K}{2\,G_V^{\;2}}$$

Confirmation of CVC!

and

$$|V_{ud}| = \frac{G_V}{G_F}$$

Fermi coupling constant
(from leptonic decays)

Impacts of studying T=1 superallowed Fermi β Emitters

Most precise determination of V_{ud}

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

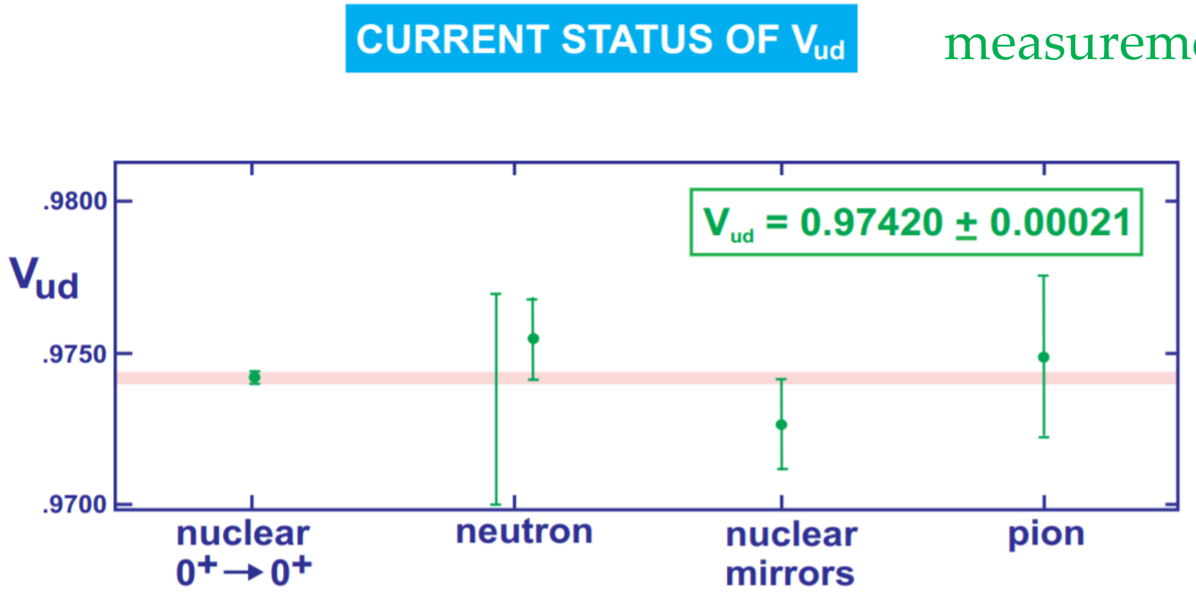
Test of conserved vector current (CVC) hypothesis

confirmed to better than 12 parts in 10^5

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

Corrected *ft* values & ^{22}Mg

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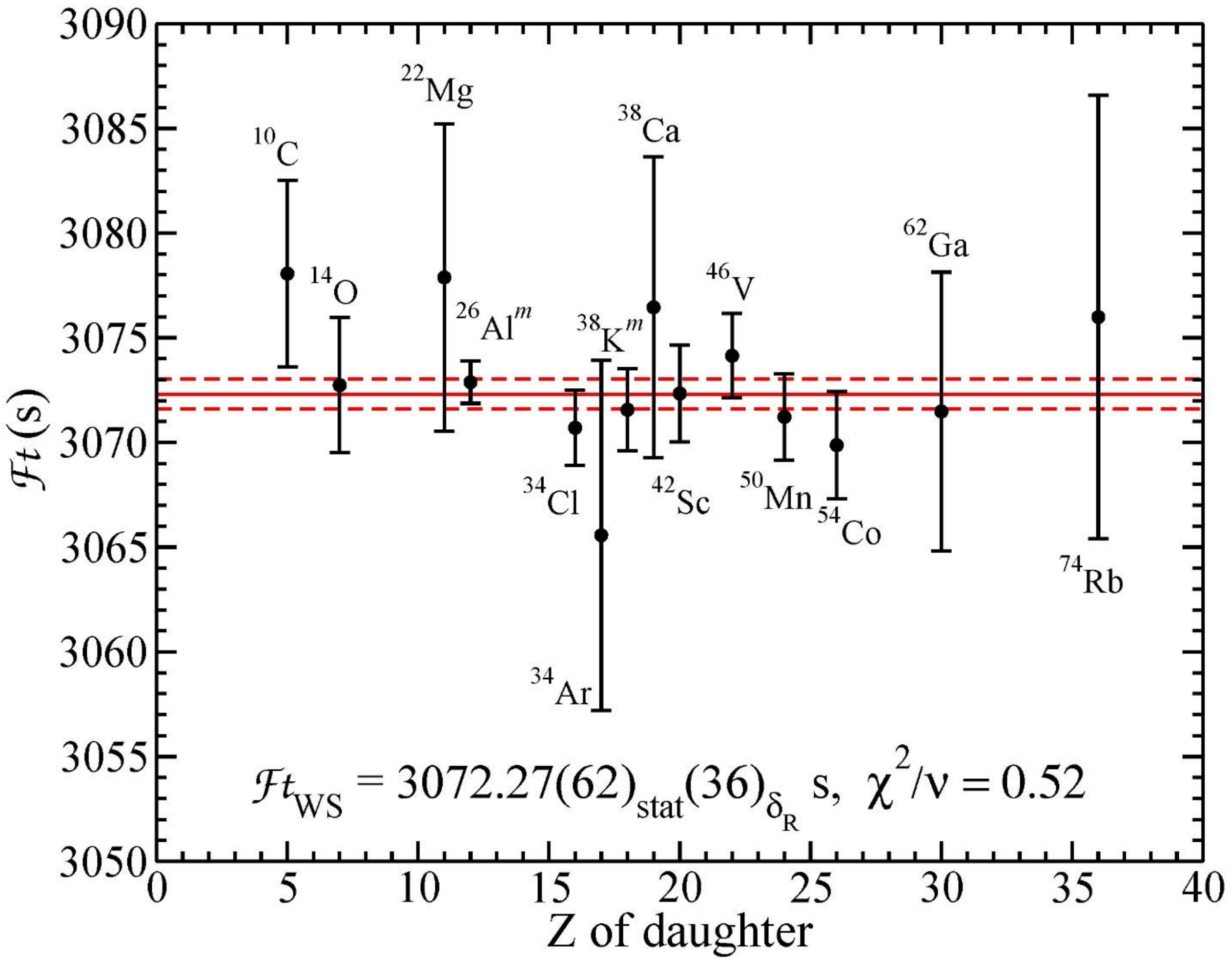

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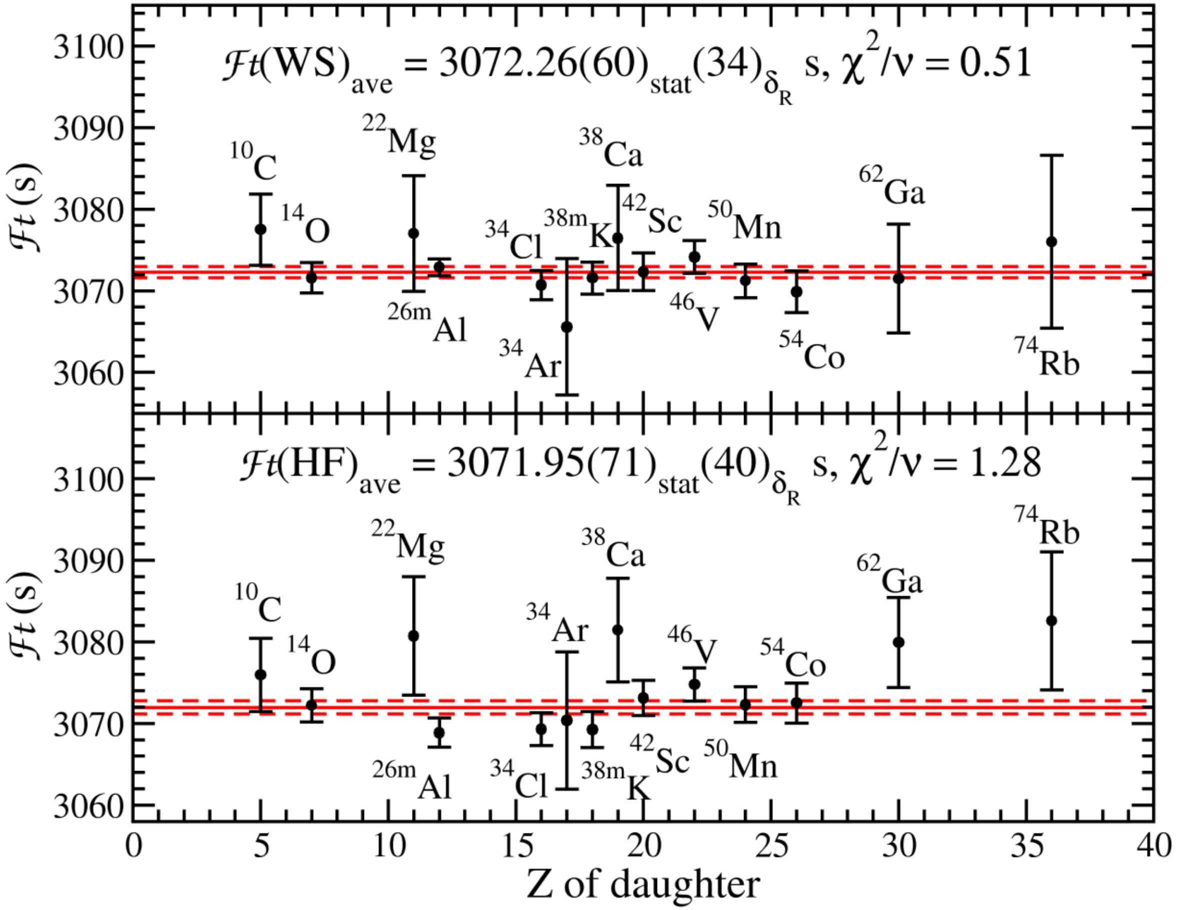

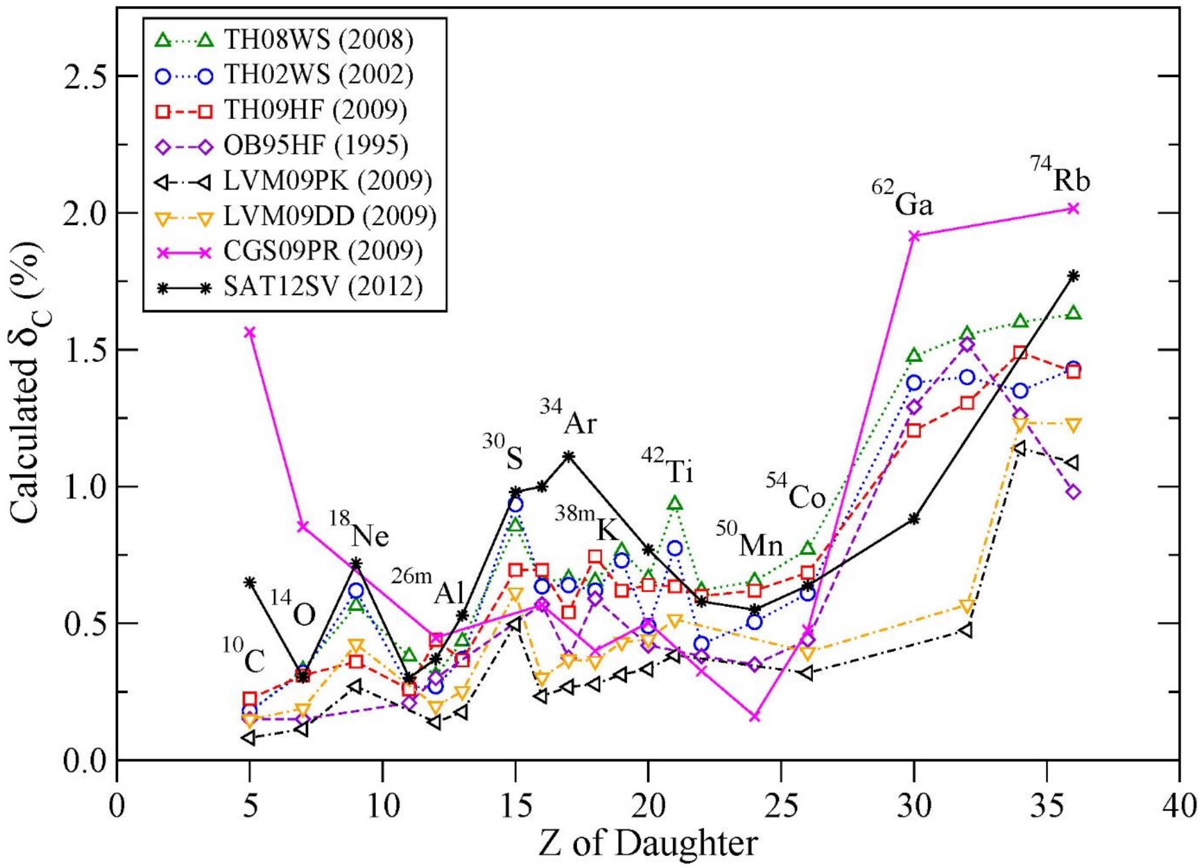

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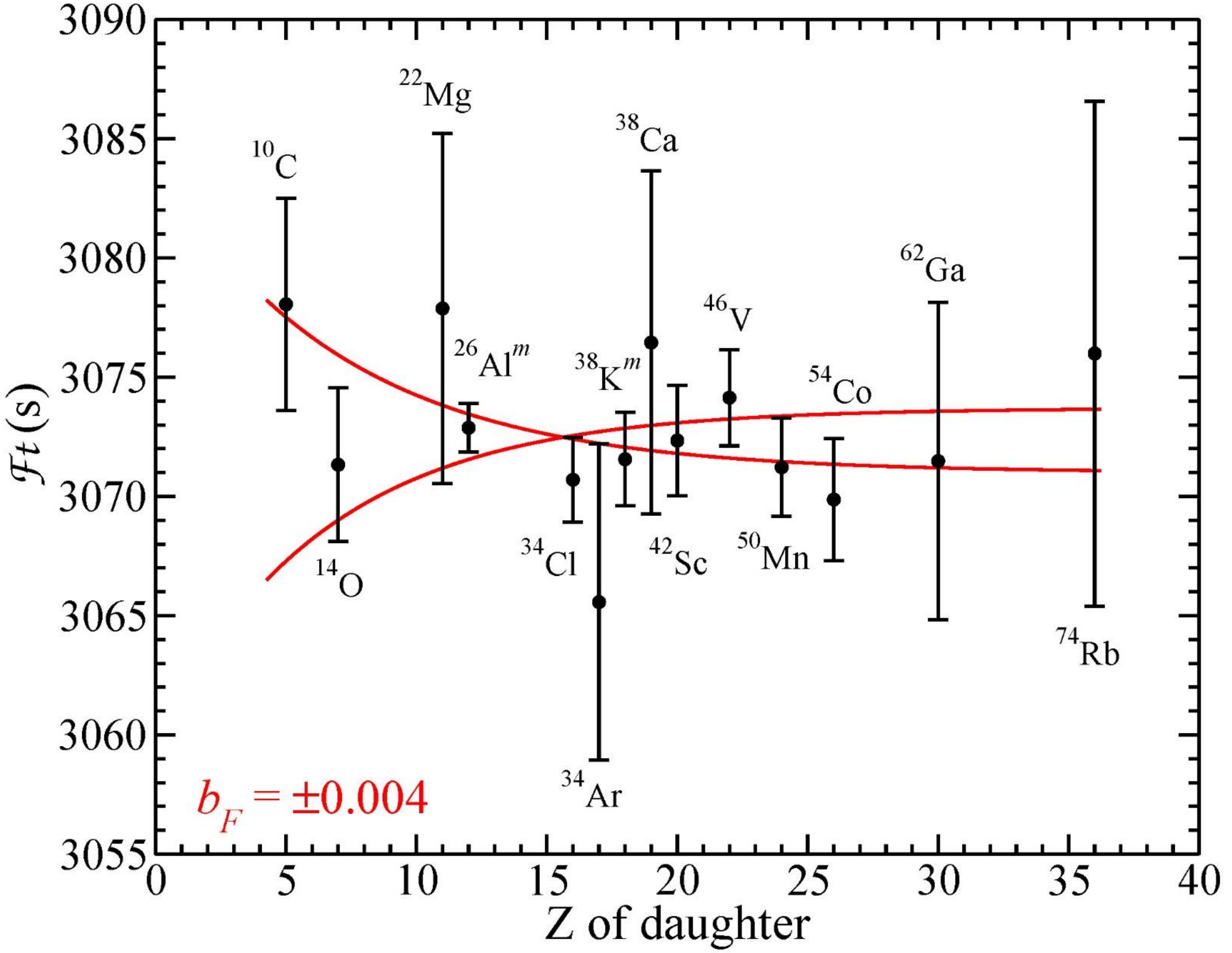
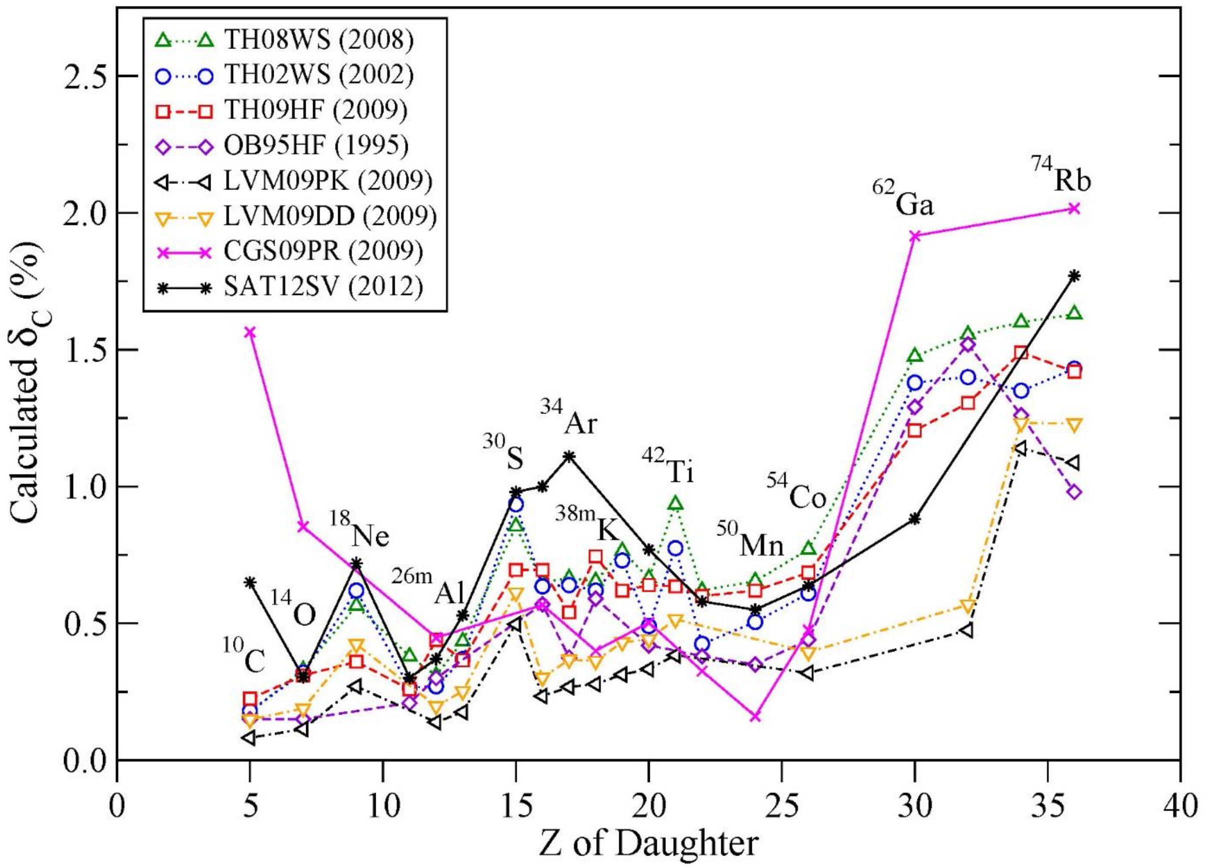
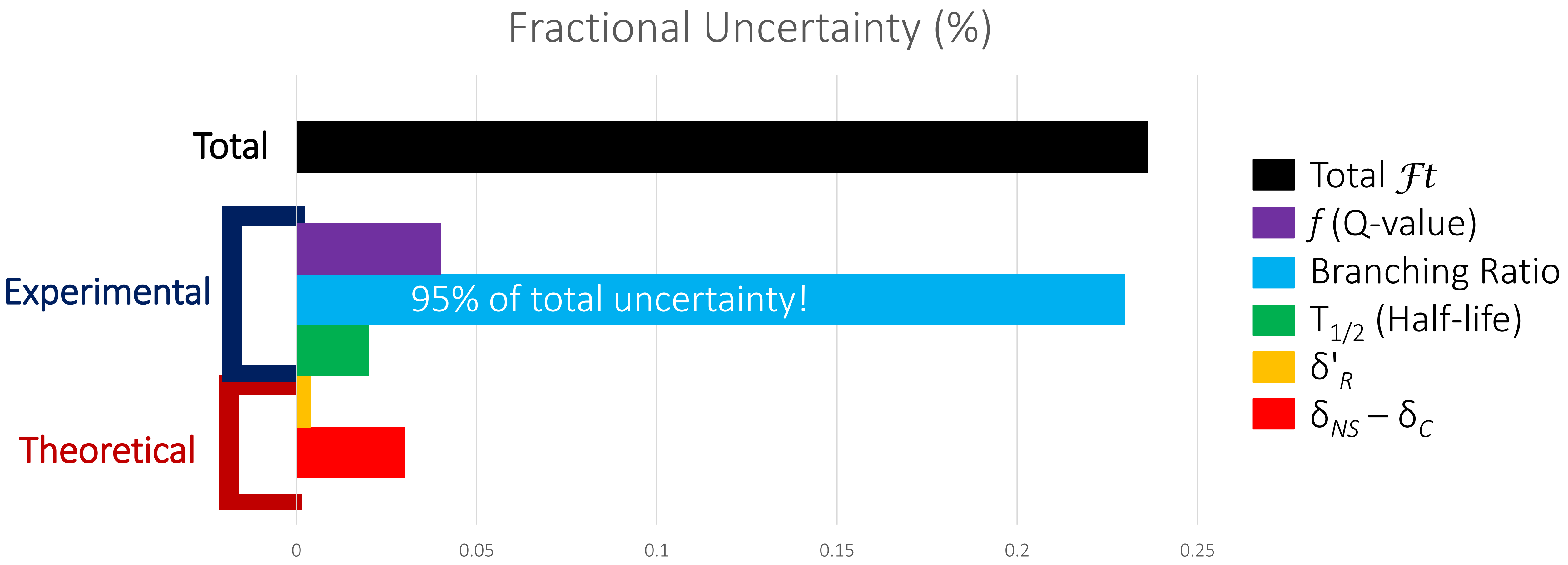




Status of ^{22}Mg *ft* Value



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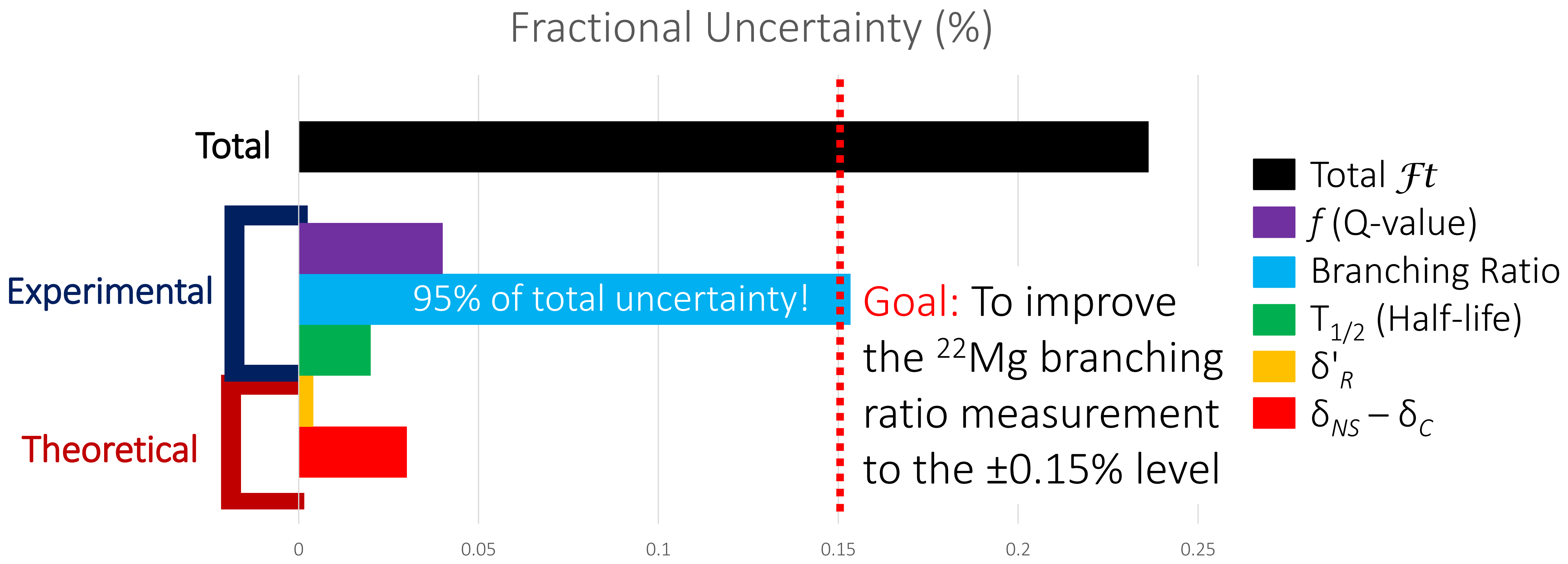


Goal: To improve the ^{22}Mg branching ratio measurement to the ±0.15% level

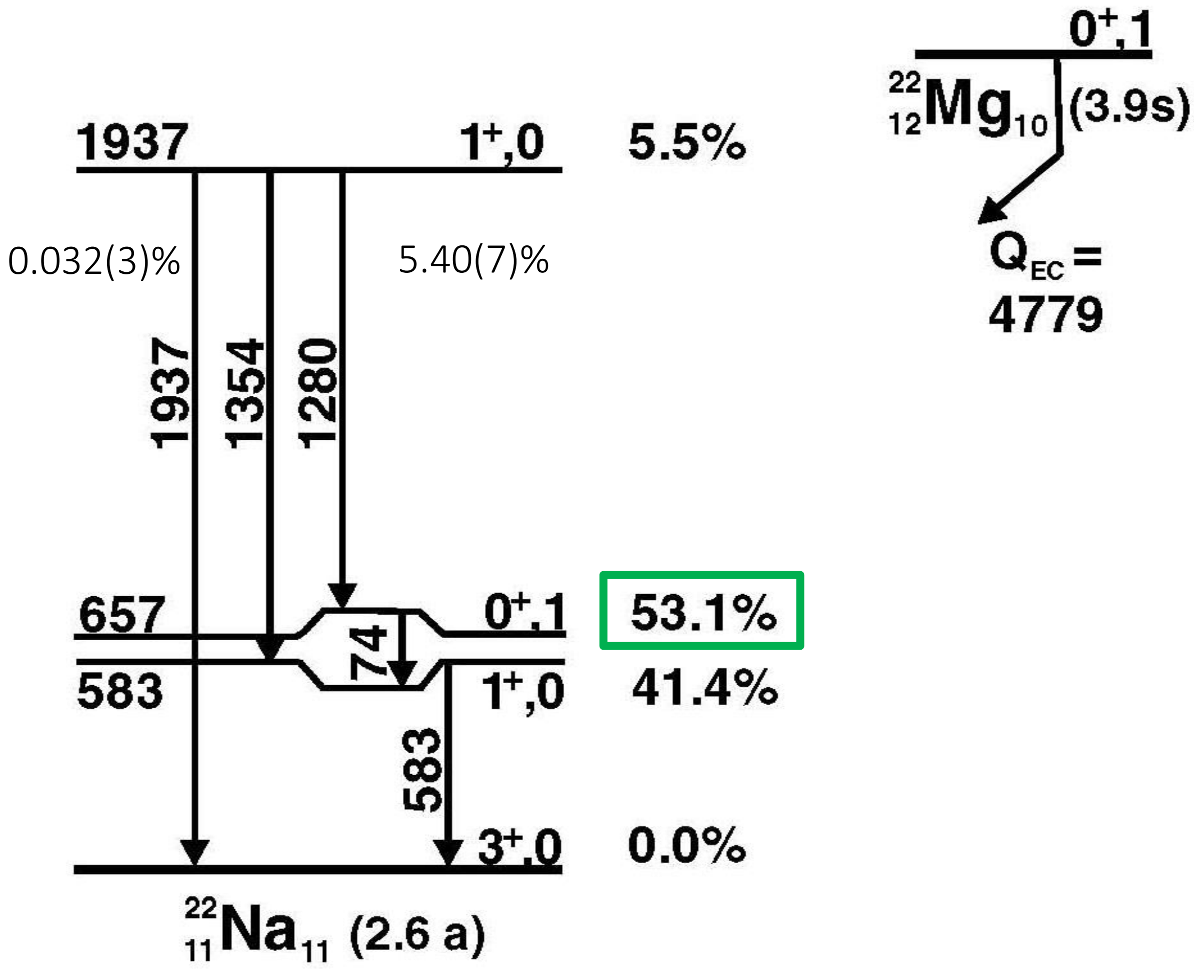
$$\mathcal{F}t = ft(1 + \delta'_R)(1 + \delta_{NS} - \delta_C)$$

^{22}Mg Superallowed Branching Ratio

As decay to the ground state is 2nd forbidden, the superallowed branching ratio can be determined through the measurement of *relative* γ ray intensities:

$$BR(sa) = \frac{I_\gamma(74)(1+\alpha) - I_\gamma(1280)}{I_\gamma(583) + I_\gamma(1937)}$$

with α(74) = 0.00357(5).



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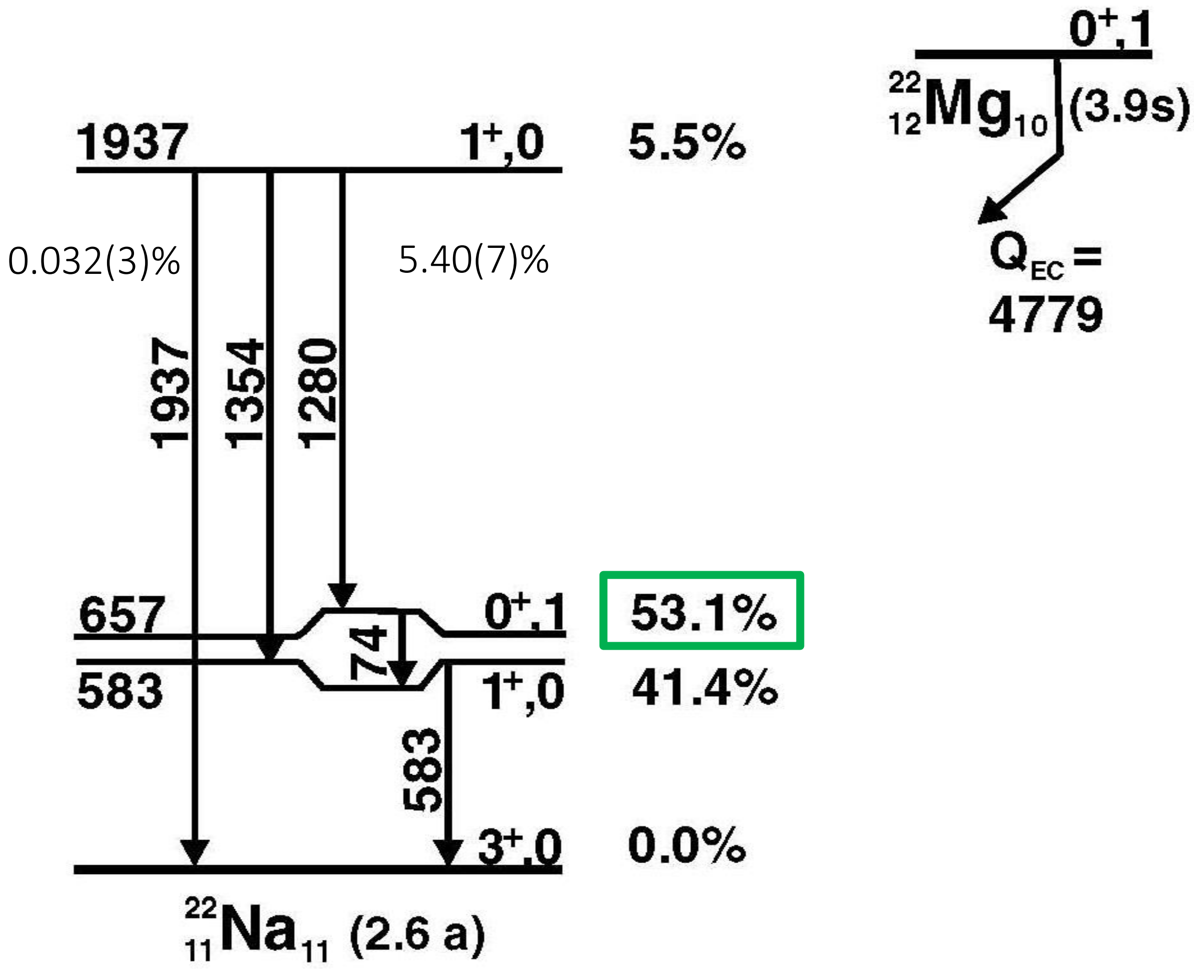
0.3% correction — 10% correction

$$BR(sa) = \frac{I_\gamma(74)(1+\alpha) - I_\gamma(1280)}{I_\gamma(583) + I_\gamma(1937)}$$

0.03% correction

I(gamma) = N(observed)/ε_γ

$$\approx \frac{N_\gamma(74)\varepsilon_\gamma(583)}{N_\gamma(583)\varepsilon_\gamma(74)} - \frac{N_\gamma(1280)\varepsilon_\gamma(583)}{N_\gamma(583)\varepsilon_\gamma(1280)}$$



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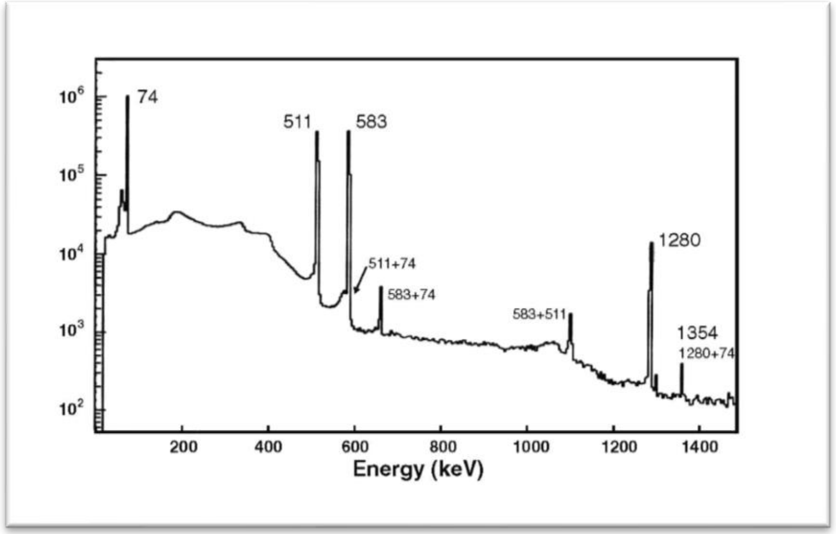
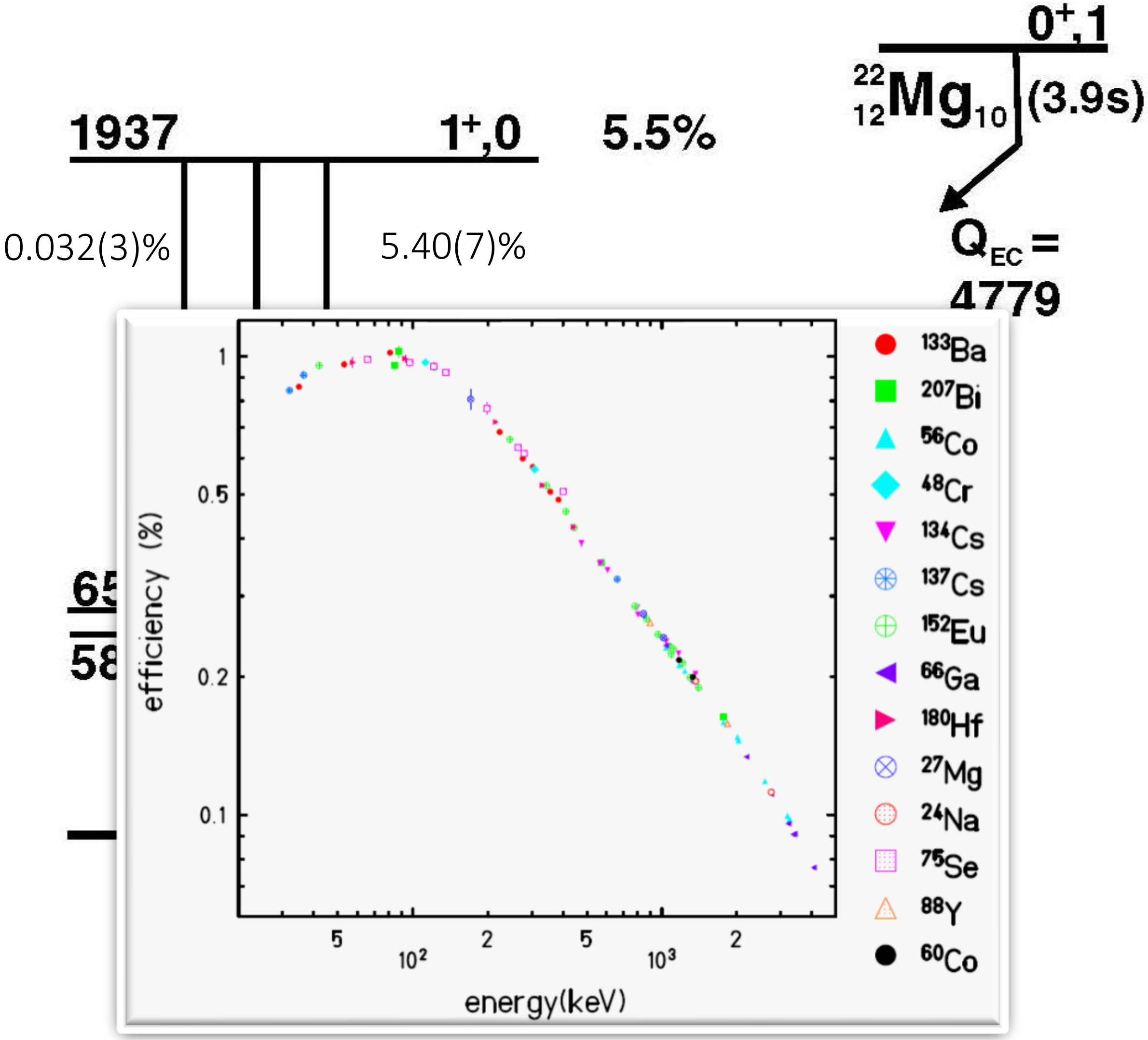
With a precisely calibrated HPGe detector, Hardy et al., PRL 91, 092501 (2003) obtained:
BR = 53.15(12) % (± 0.23 %)



J.C. Hardy et al., PRL 91, 082501 (2003)



B. Blank et al., NIM A 776, 34 (2015)

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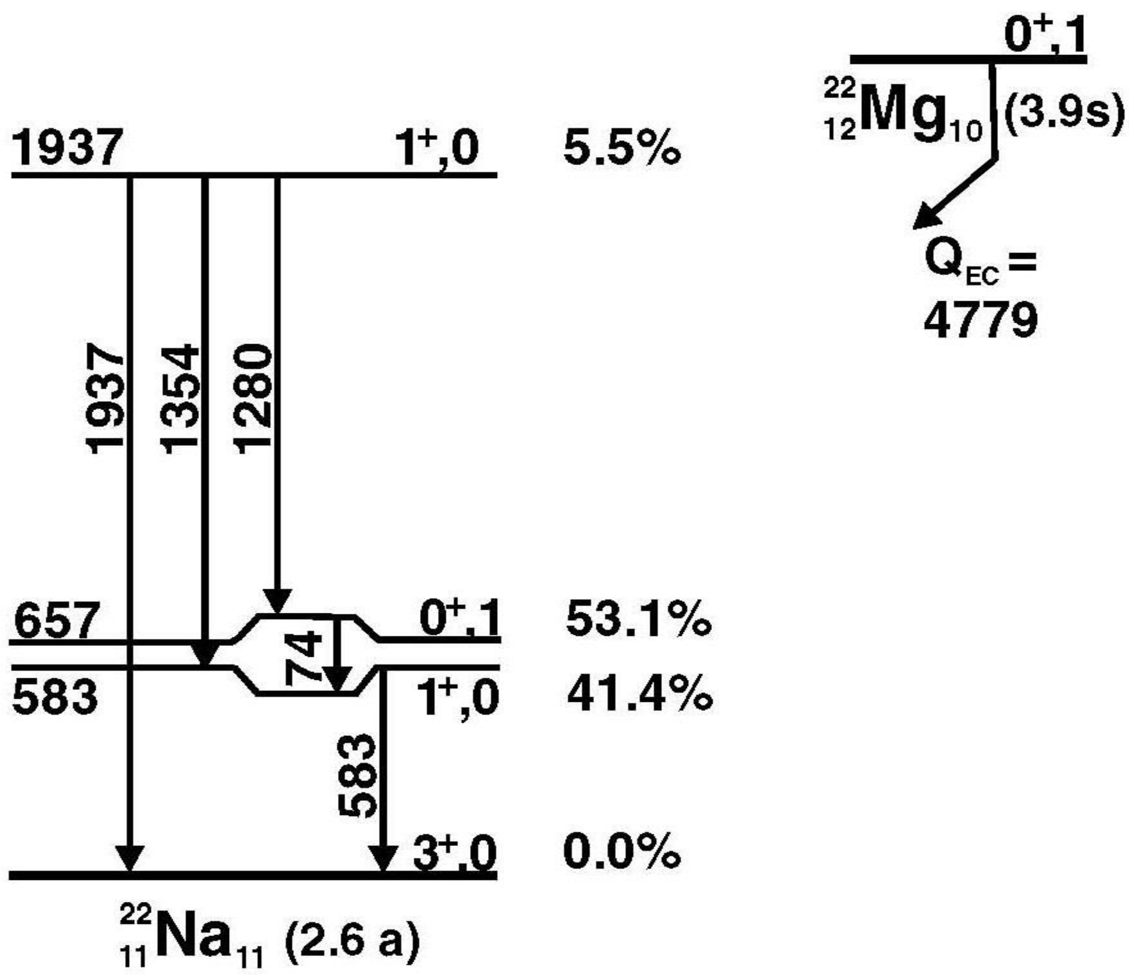
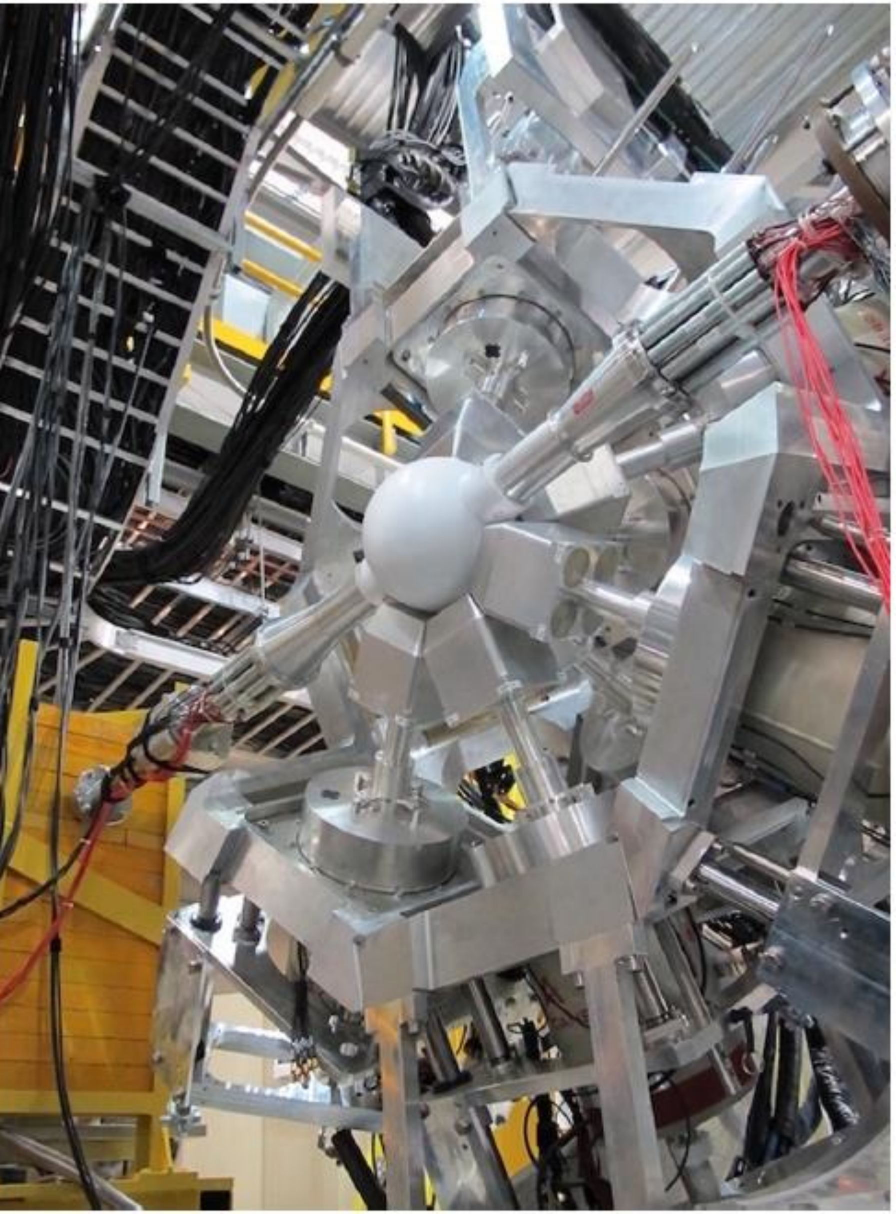
With a high γ–γ efficiency, one can establish the *relative* efficiency *between 74 and 583 keV* *in situ* by gating on the 1280 keV γ ray.

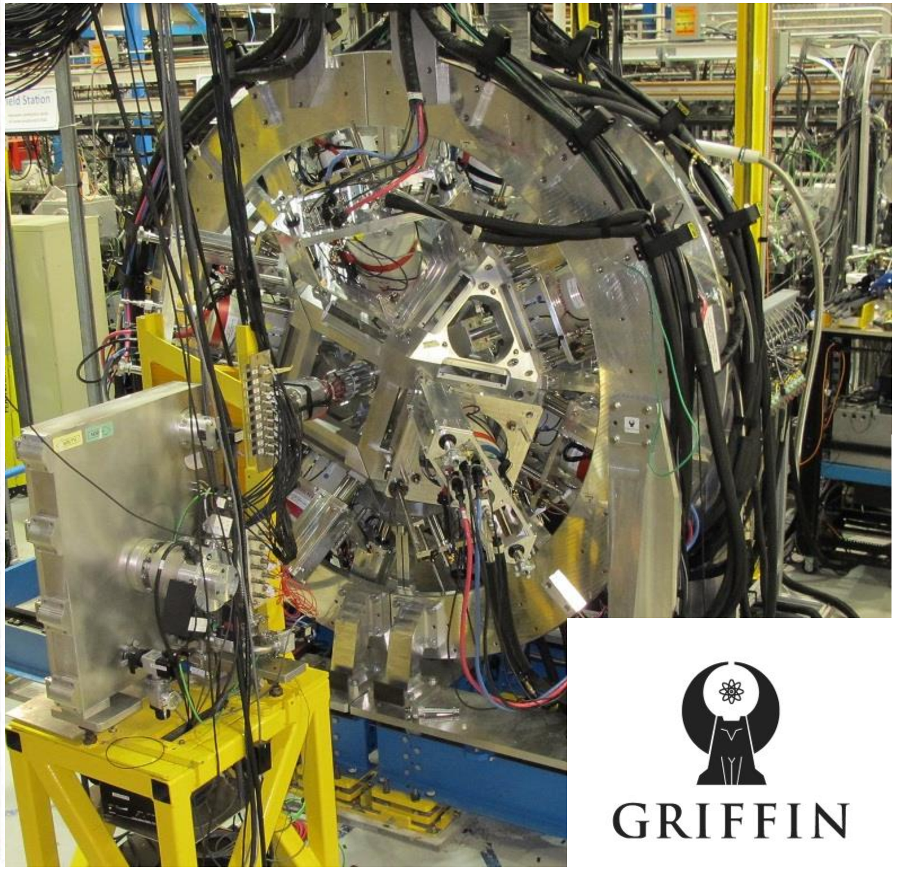
To measure the BR to ±0.15%, we need to measure ε_γ to ±0.1%.



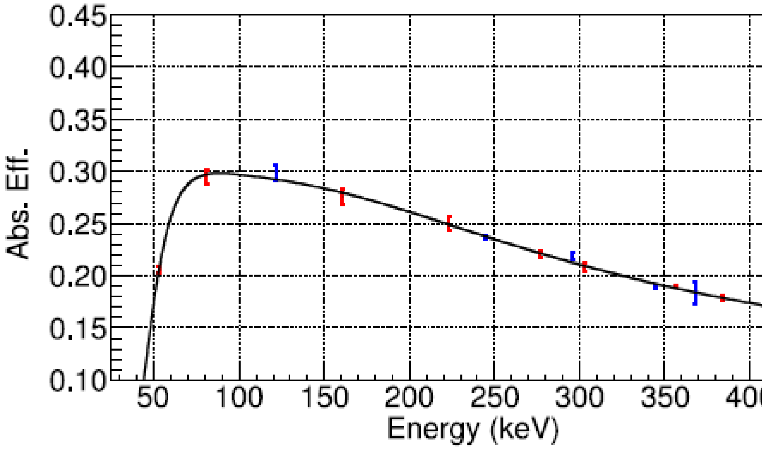
GRIFFIN @ ISAC



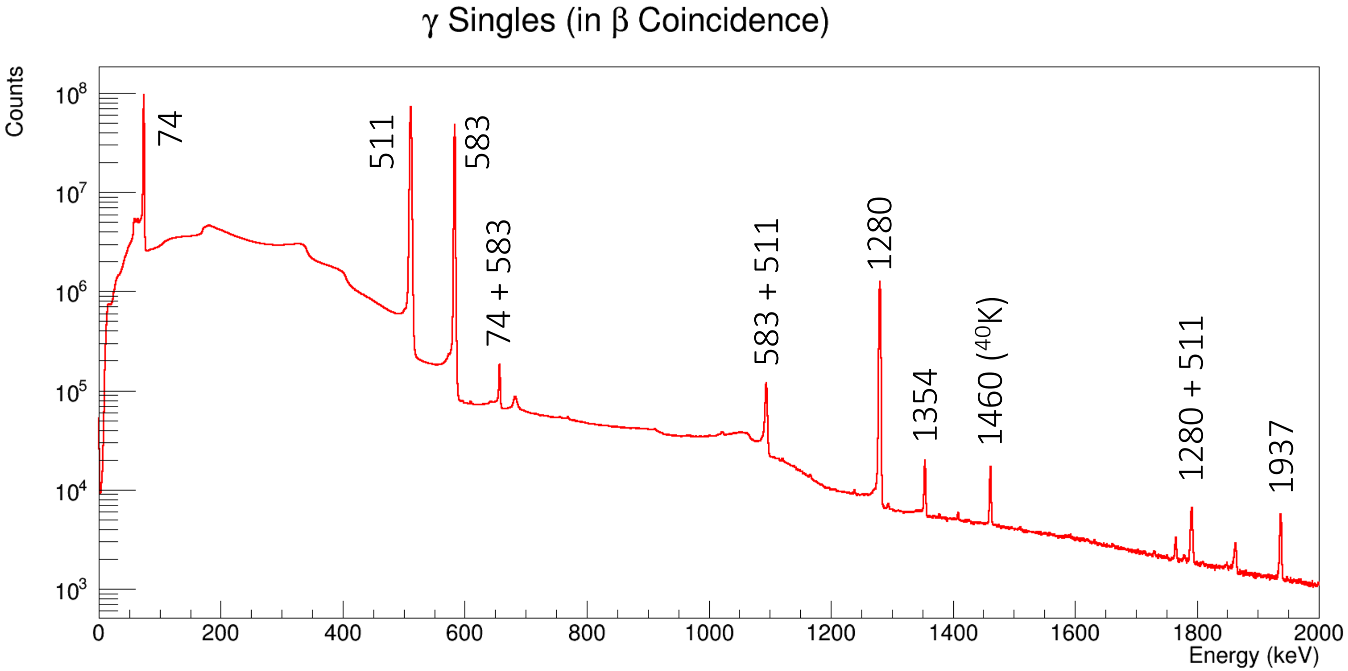
A new high-efficiency decay spectroscopy facility for ISAC-I

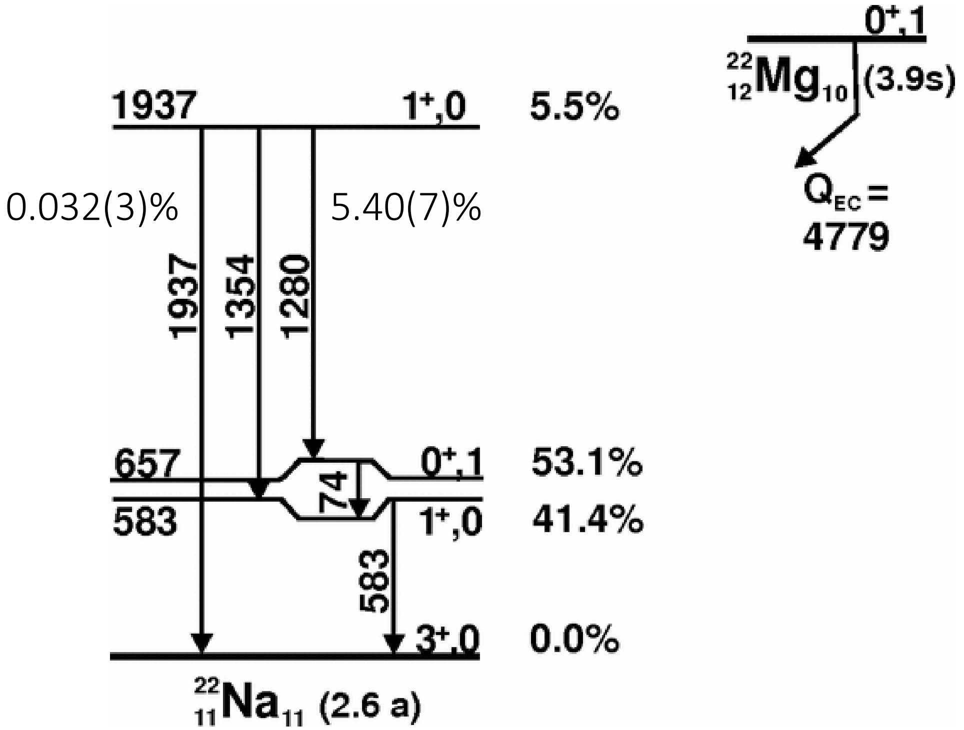


- Comprised of 16 large-volume clover-type HPGe
- Tape transport system
- Ancillary detectors for beta tagging (+ CE + $LaBr_3$ + neutrons)

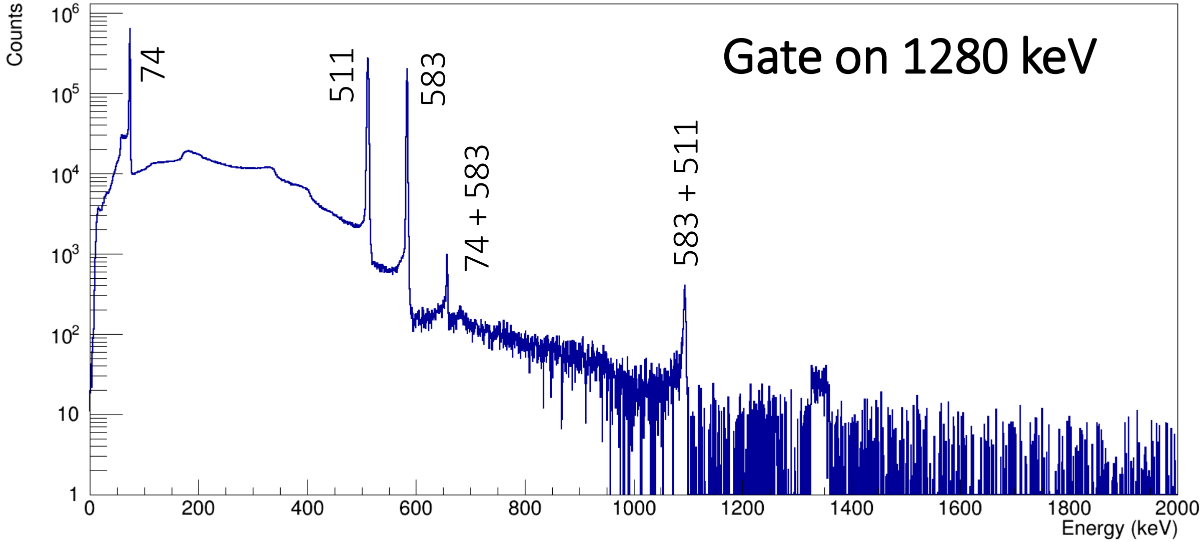


Experimental Results





- ^{22}Mg beam attenuated to 2.5 x 10^4/s to reduce pile-up
- >2x10^6 counts in 1280-coincident 74 and 583 peaks means statistical precision of ε_γ of 0.1% achieved
- Summing and pile-up corrections underway



Thank you for your attention

H. Bidaman; V. Bildstein; C. Burbadge; A. Diaz Varela; M. R. Dunlop; R. Dunlop; P. E. Garrett; B. Jigmeddorj; A. D. MacLean; C. E. Svensson; J. Turko; T. Zidar

C. Andreoiu

G. C. Ball; N. Bernier; M. Bowry; R. Caballero-Folch; A. B. Garnsworthy; G. Hackman; J. Measures; B. Olaizola; Y. Saito

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J. R. Leslie

J. K. Smith