Tests of *ab-initio* nuclear theory via the isobaric multiplet mass equation in $T = 1$ superallowed beta decay systems

Matthew S. Martin[1], K.G. Leach[1], J.D. Holt[2], S.R. Stroberg[3]

[1]Department of Physics, Colorado School of Mines
[2]Theory Division, TRIUMF, Canada
[3]Department of Physics, University of Washington

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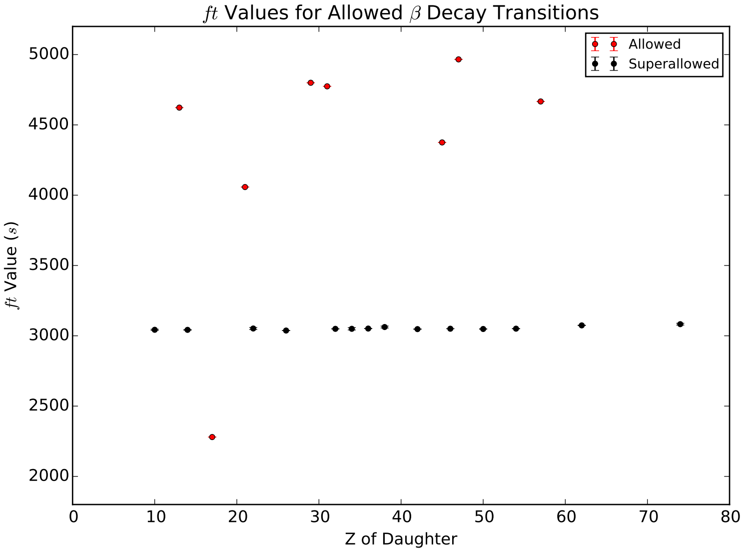
The CKM Matrix

- The mass eigenstates and weak-interaction eigenstates of the quarks are not equal
- In the Standard Model, the Cabbibo-Kobayashi-Maskawa (CKM) matrix provides a unitary transformation between these eigenstates

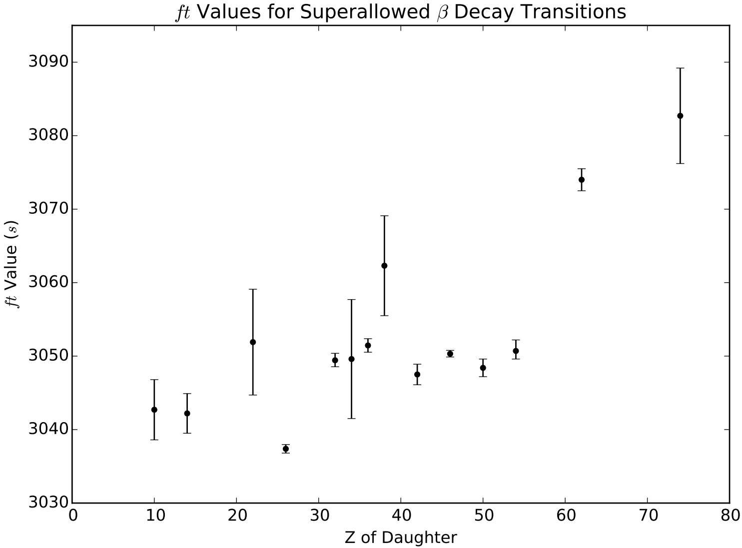
$$\begin{bmatrix} d' \\ s' \\ b' \end{bmatrix} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} \begin{bmatrix} d \\ s \\ b \end{bmatrix}$$

If CKM unitarity does not hold, it implies that there is physics outside the Standard Model

Experimental Allowed ft Value



Experimental Superallowed ft Value

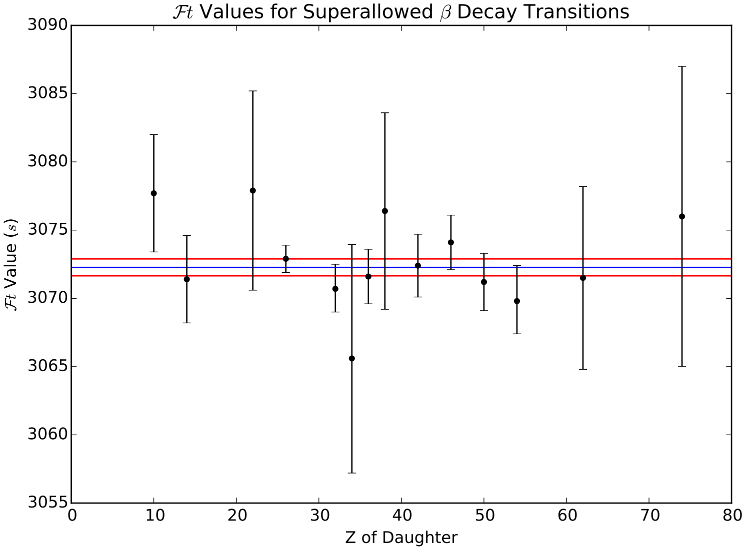


Experimental Superallowed $\mathcal{F}t$ Value

$$\mathcal{F}t = ft(1 - \delta_R)(1 - \delta_C) = \frac{K}{2G_V^2(1 + \Delta_R)}$$

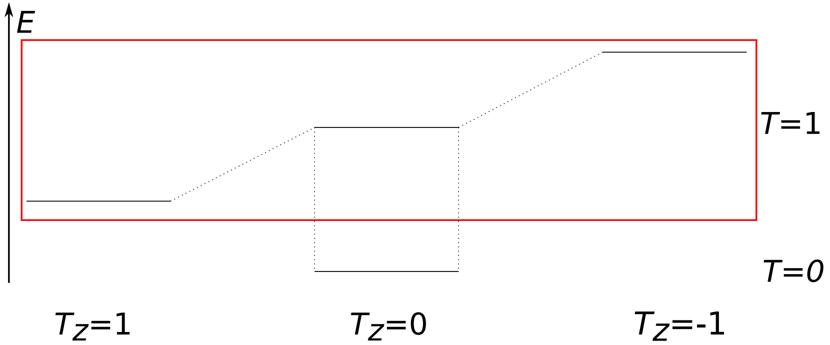
$$\begin{aligned}
\mathcal{F}t &= \text{corrected } ft \text{ value} \\
\delta_R &= \text{transition-dependent radiative correction} \\
\delta_C &= \text{isospin symmetry breaking correction} \\
K &= \text{constants} \\
G_V^2 &= \text{vector coupling constant} \\
\Delta_R &= \text{transition-independent correction}
\end{aligned}$$

Experimental Superallowed $\mathcal{F}t$ Value



Isobaric Analogue States

- Superallowed β decay chain is a $T = 1$ isobaric analogue triplet



Isobaric Multiplet Mass Equation

$$M = Nm_n + Zm_p - E_{bind} - A$$

- Testing the validity of theoretical methods for use in calculating isospin symmetry breaking corrections for superallowed decay
- Using the Isobaric Multiplet Mass Equation

$$M(T_z) = a + bT_z + cT_z^2$$

- IMME derived from first order perturbation of Coulomb potential[1,2]
- *b* and *c* coefficients very sensitive to isospin symmetry breaking

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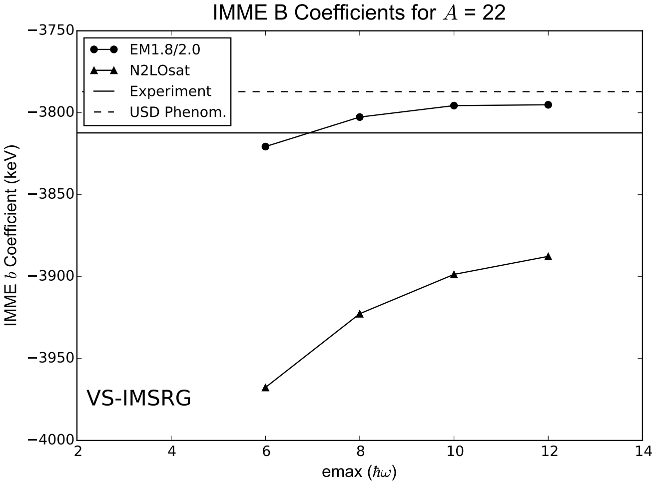
[1] J.M. Dong *et al.*, Physical Review C **99**, 014319 (2019)
[2] Bączyk *et al.*, J Phys G *Accepted Manuscript*

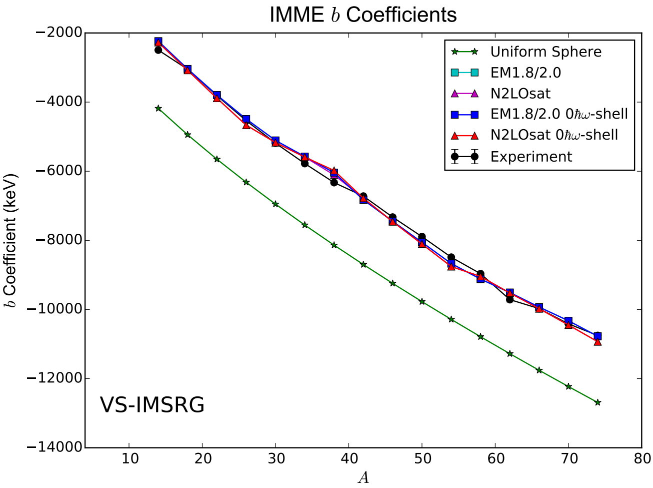
$M(T_z) = a + b\,T_z + cT_z^2$

- Seem to converge well
- Similar for all $A \in \{14 : 74\}$



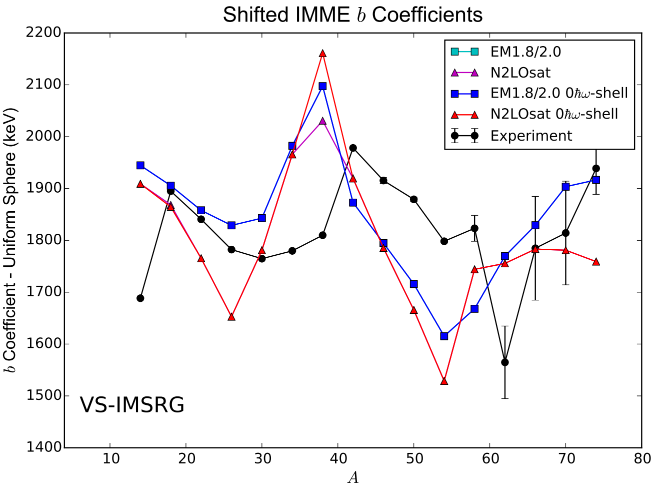
$M(T_z) = a + b T_z + c T_z^2$

- General trend of uniform sphere
- Slight peak at $A = 14, 38$

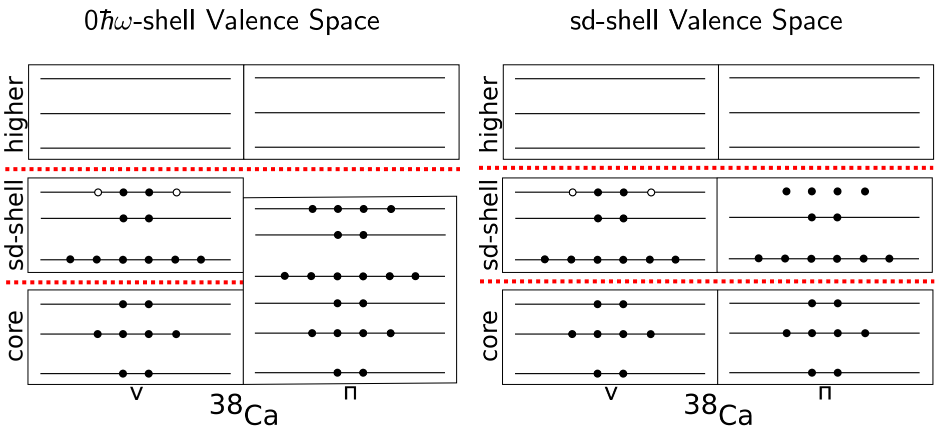


$M(T_z) = a + b\,T_z + cT_z^2$

- Same peaks can be seen
- *sd*-shell VS reduces error



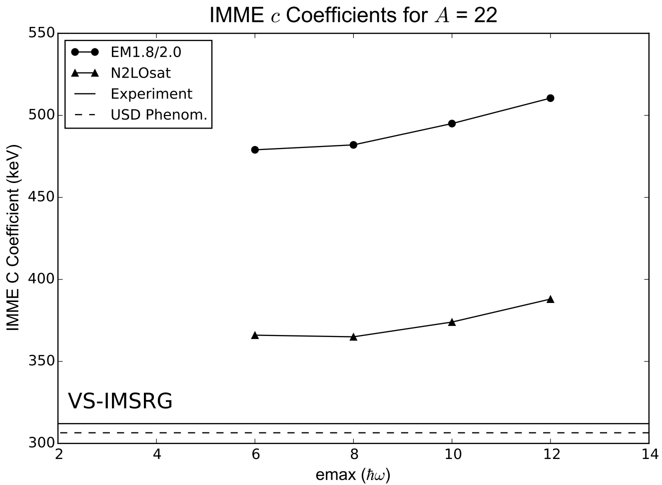
VS-IMSRG



$$\text{Induced Error} \propto \langle\Psi|\,\Delta H\,|\Psi\rangle$$

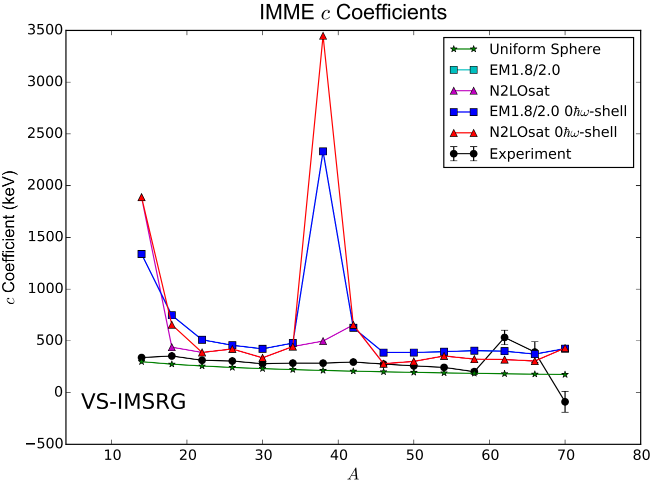
$M(T_z) = a + bT_z + c\,T_z^2$

- Converging?
- Similar for all $A \in \{14 : 70\}$

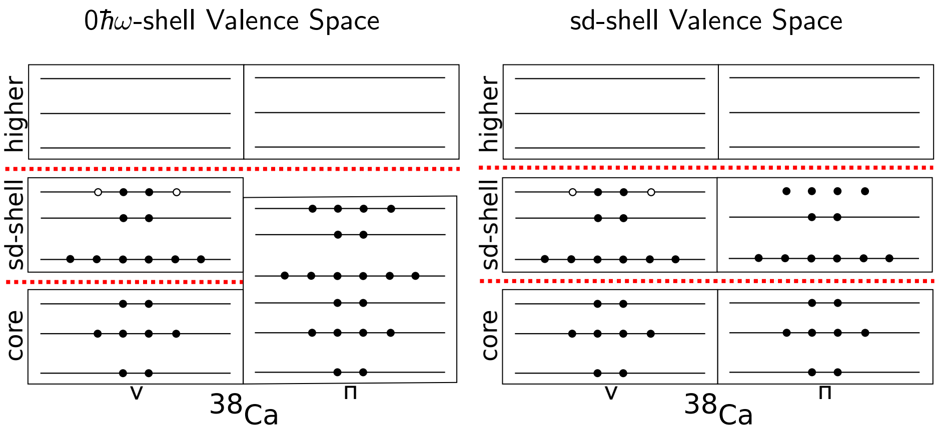


$M(T_z) = a + bT_z + c\,T_z^2$

- $A = 14, 38$ peaks larger
- Fixed by *sd*-shell VS



VS-IMSRG



$$\text{Induced Error} \propto \langle\Psi|\,\Delta H\,|\Psi\rangle$$

Summary

- IMME coefficients converge well with *emax*
    - *b* coefficients converging
    - *c* coefficients not changing much wtih *emax*
    - Need to check $emax = 14$ to see further
- Both coefficients follow trend predicted by uniform charged sphere
    - IMME seems to remove systematic theoretical and many-body errors
- Significant error/deviation at shell closures
    - Fixed by forcing valence space to be same in IAT
    - Currently running the rest of these cases
- Determine use of *ab initio* methods for *superallowed* decay