A Systematic Study of the Theoretical Calorimetric Electron Capture Spectrum

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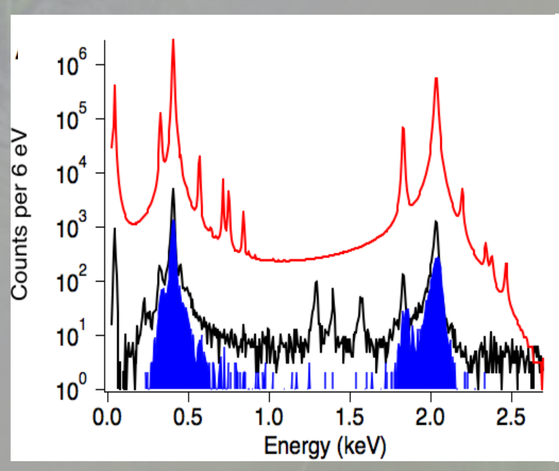
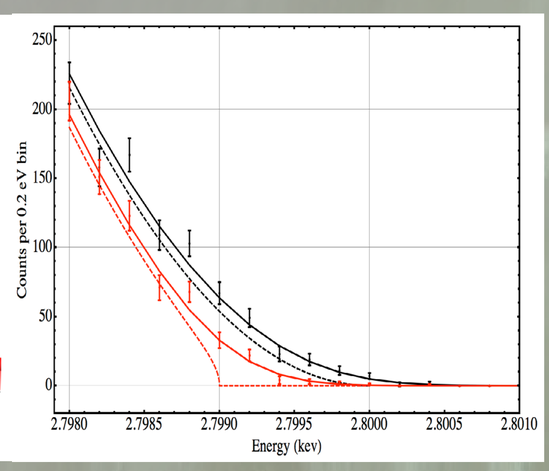
Context

Calorimetric Electron Capture for Neutrino Mass Measurements

Spectral end point shape gives neutrino mass
Spectral shape dependent on theoretical description





Choices made while constructing spectrum:

1. How to create orbital wavefunctions?
2. Which atomic excitations to include?
3. Order of terms kept in fully antisymmetrized expansion?
4. How to evaluate the atomic orbital overlap with the nucleus?
5. How to perform orbital overlap calculations with "digitized" wavefunctions?

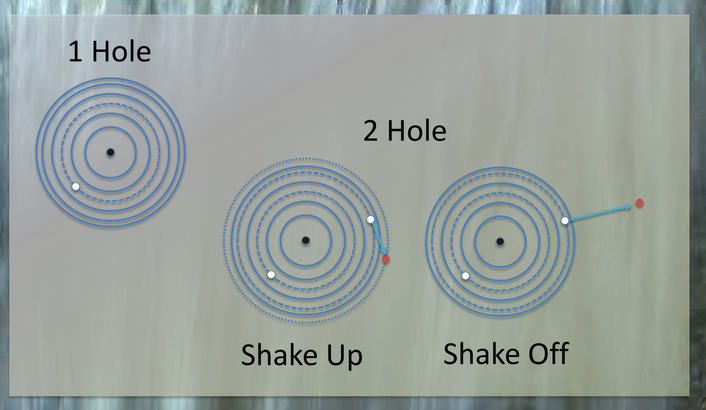
These choices can change the shape of the calculated spectrum!

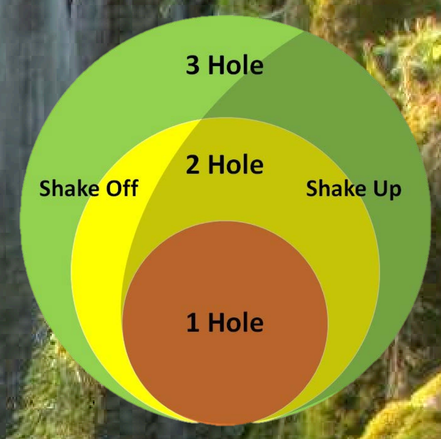
Building a Theoretical Spectrum: Choose Your Own Adventure

1. Create Wave Functions

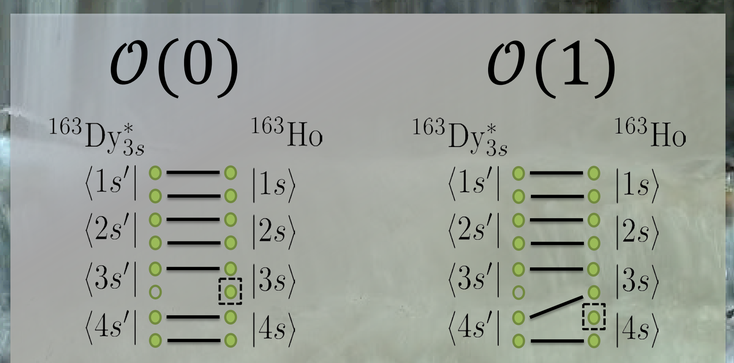
Non-relativistic — Semi-relativistic — Fully-relativistic

2. Choose Excitations



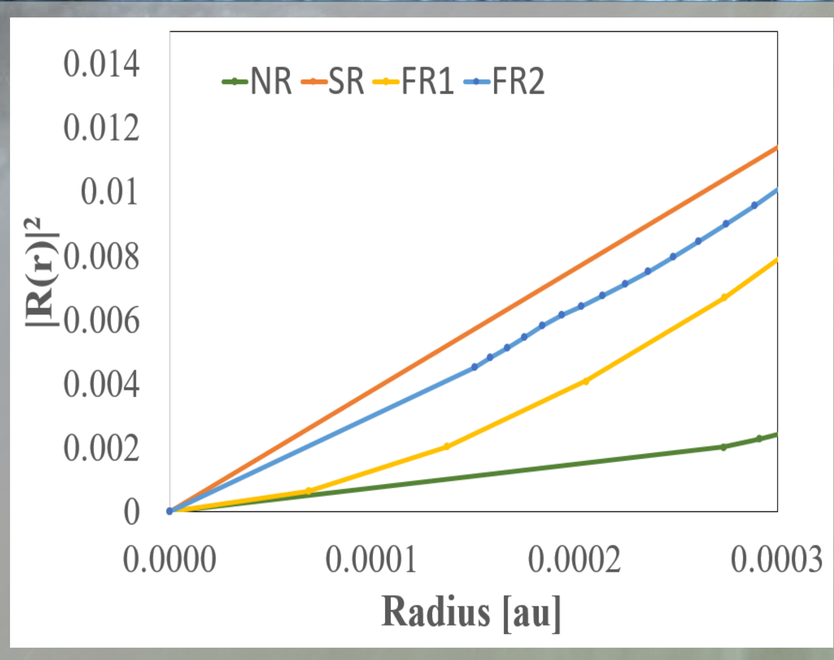


3. Pick Order of Terms to Keep



$\mathcal{O}(0)$ $\mathcal{O}(1)$ $\mathcal{O}(2)$ $\mathcal{O}(N)$

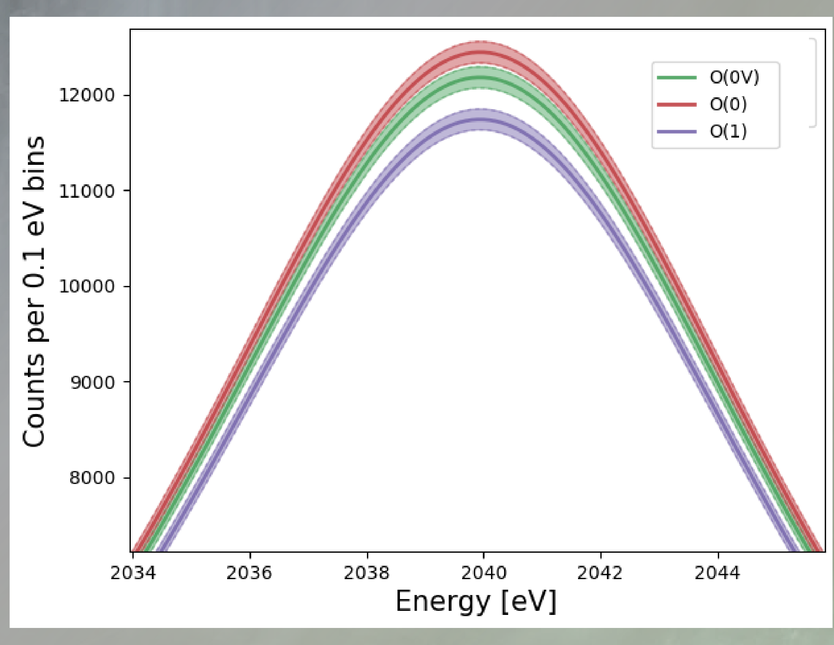
Your Choices Have Consequences



Radial wavefunctions for the 3s orbital in a Dy atom with a hole at 3s. The M1 peak in the electron capture spectrum is scaled by $|\Psi(R)|^2$, which is affected by the choice of R and the code used to generate the wavefunction.

4. Evaluate Atomic Overlap with Nucleus

$\Psi(0)$ $\Psi(R)$ $\sqrt{\frac{\int_0^R \Psi^*(r)\Psi(r)r^2dr}{\int_0^R r^2dr}}$



M1 peak from ^{163}Ho showing the effect of increasing the number of terms kept in the atomic overlap. The 1-hole spectra (10^7 counts) are created with FR wavefunctions. The orbital wavefunction of the hole is evaluated at the nuclear radius, R=6.828 fm.

5. Calculate Orbital Overlaps

Multiply and Integrate on a Mesh

- Parent
- Daughter
- Union
- Linear
- Other

Make a Vatai approximation

6. Sum Weighted Lorentzians for Final Spectrum

$$\frac{d\Gamma}{dE_c} \propto (Q - E_c)\sqrt{(Q-E_c)^2 - m_\nu^2} \sum_{f=f'} \left|\langle {}^{163}\mathrm{Dy}^*_{f'} | {}^{163}\mathrm{Ho}\rangle\right|^2 \frac{\Gamma_{f'}}{2\pi} \frac{1}{\left(E_c - E_{f'}\right)^2 + \frac{\Gamma_{f'}^2}{4}}$$