Crisis in Beta-Delayed Neutron Emission: Shell Model to the Rescue

(Integrating Nuclear Shell Model and Hauser-Feshbach Calculations for Fission Fragment Studies)

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Theory/Codes V
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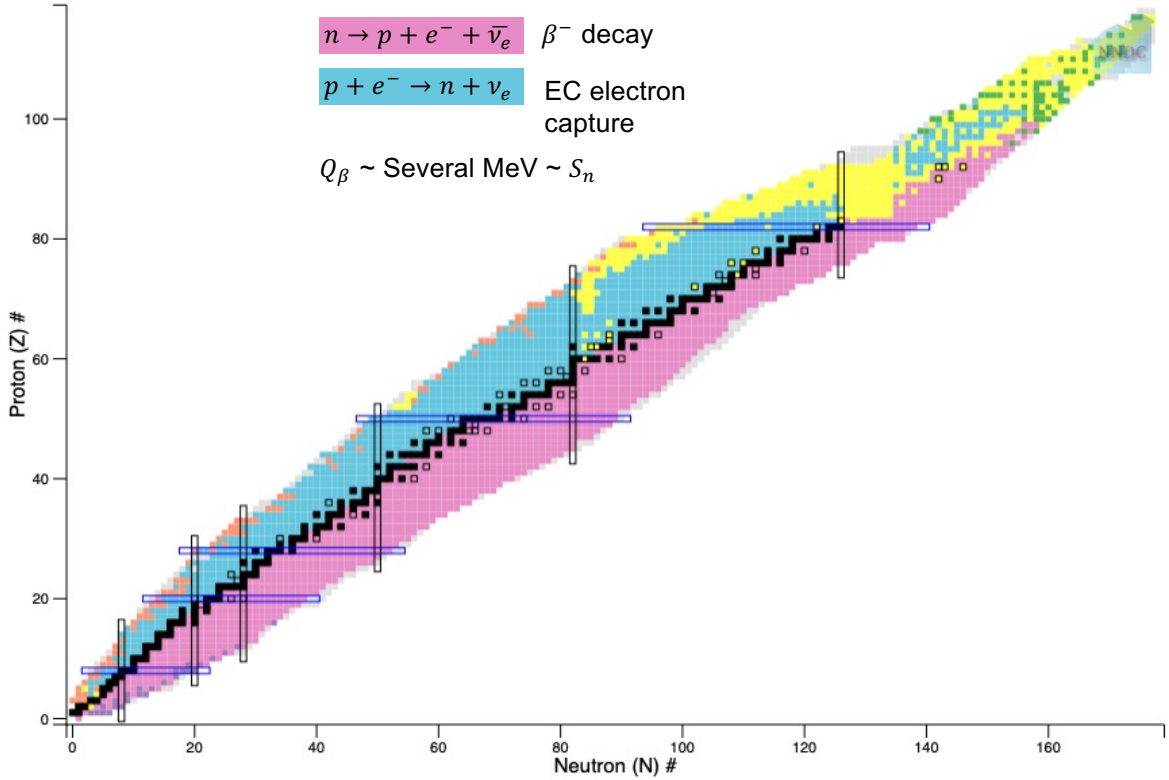
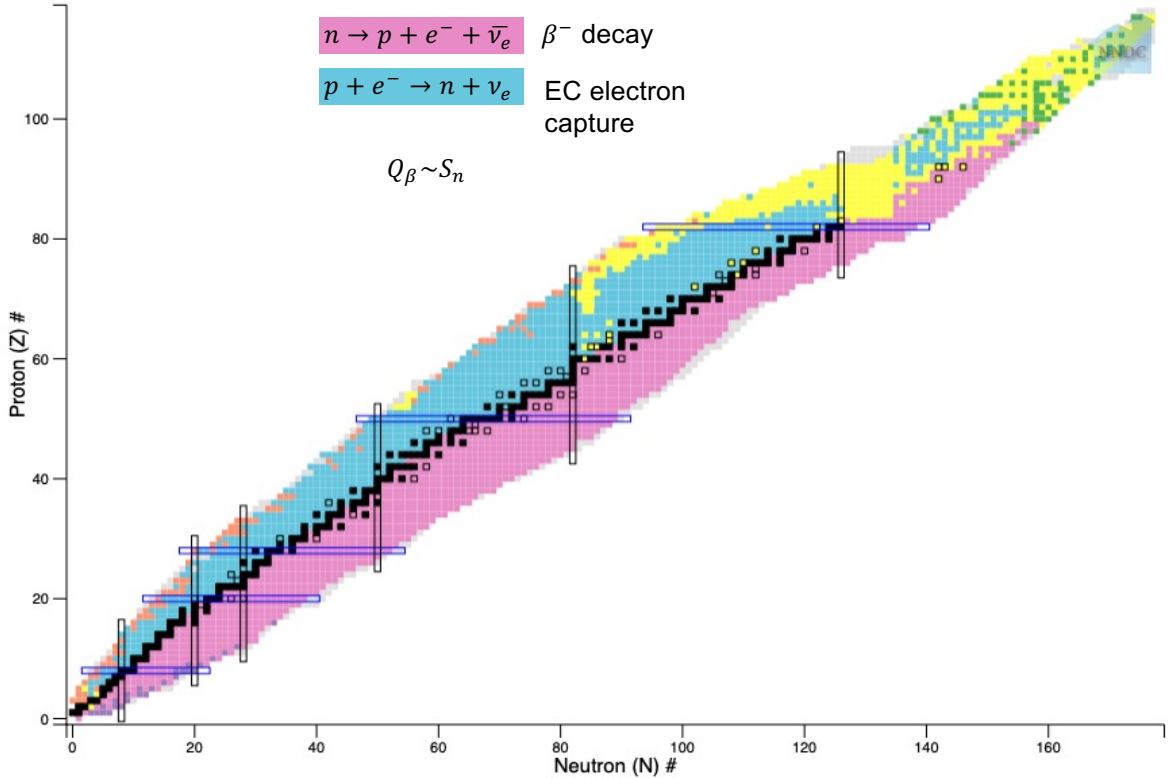
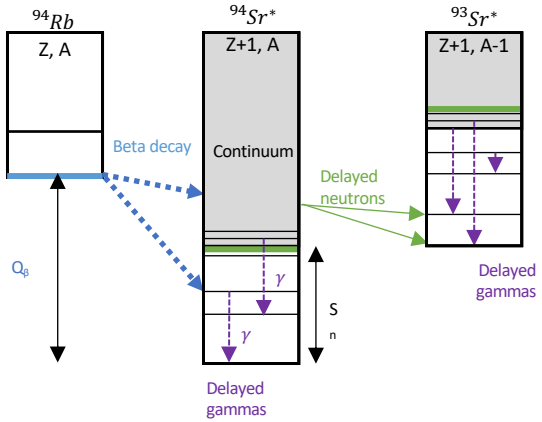
Beta decay is the most common radioactive decay mode!



NuDat 3.0 https://www.nndc.bnl.gov/nudat3/

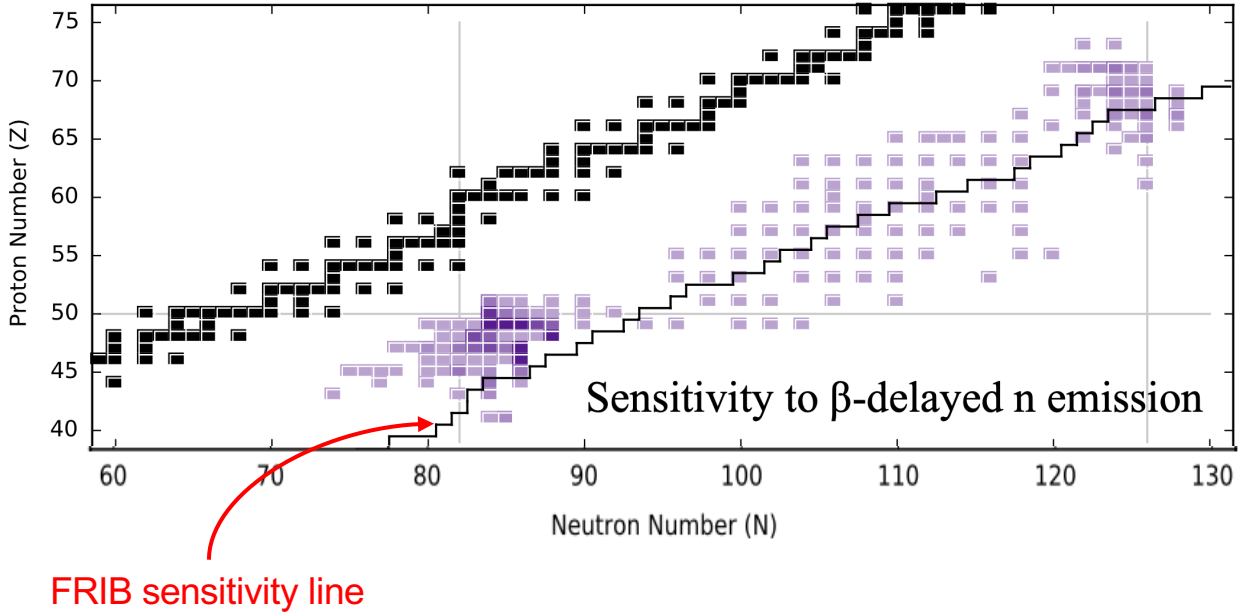
Beta decay is the most common radioactive decay mode!





- Beta-delayed neutrons
- Beta-delayed gammas/photons

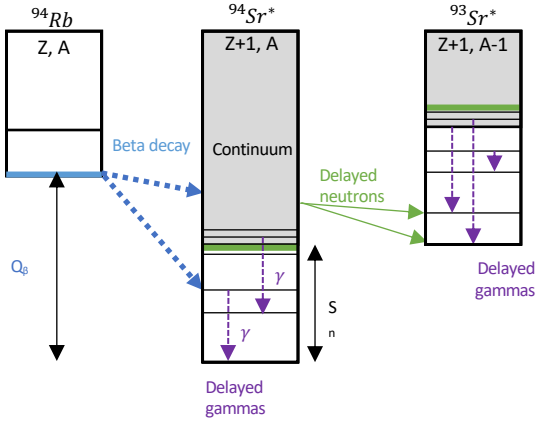
Beta-delayed neutron emission is important for astrophysical element synthesis

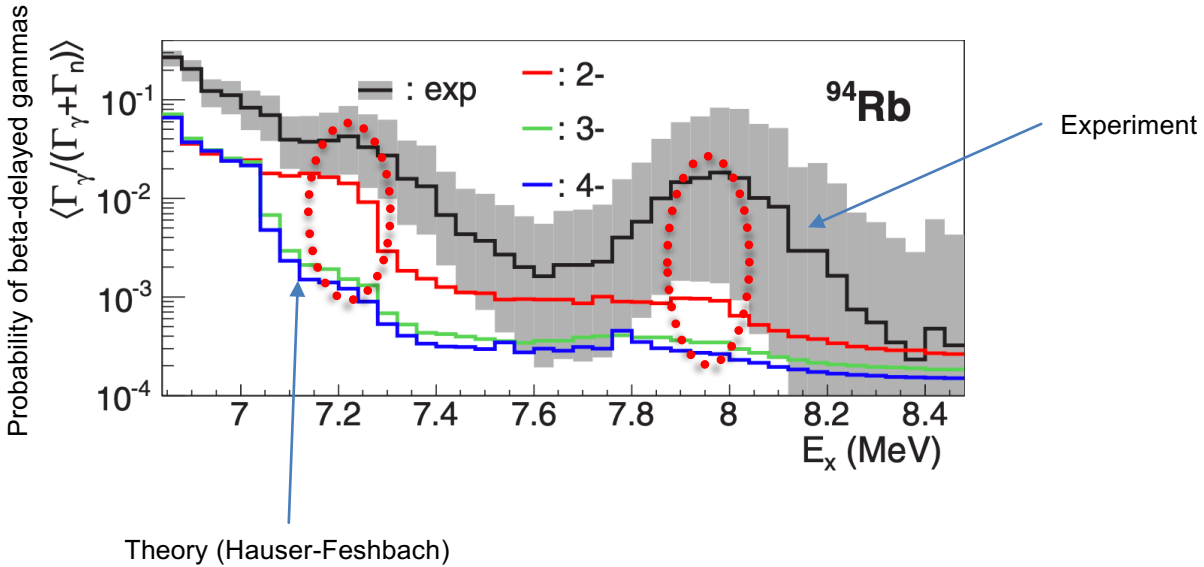


It's important to have a strong theoretical description of BDNE

Mumpower, et al., 2015 https://doi.org/10.1016/j.ppnp.2015.09.001

Crisis: Statistical models fall short of measured beta-delayed gamma emissions





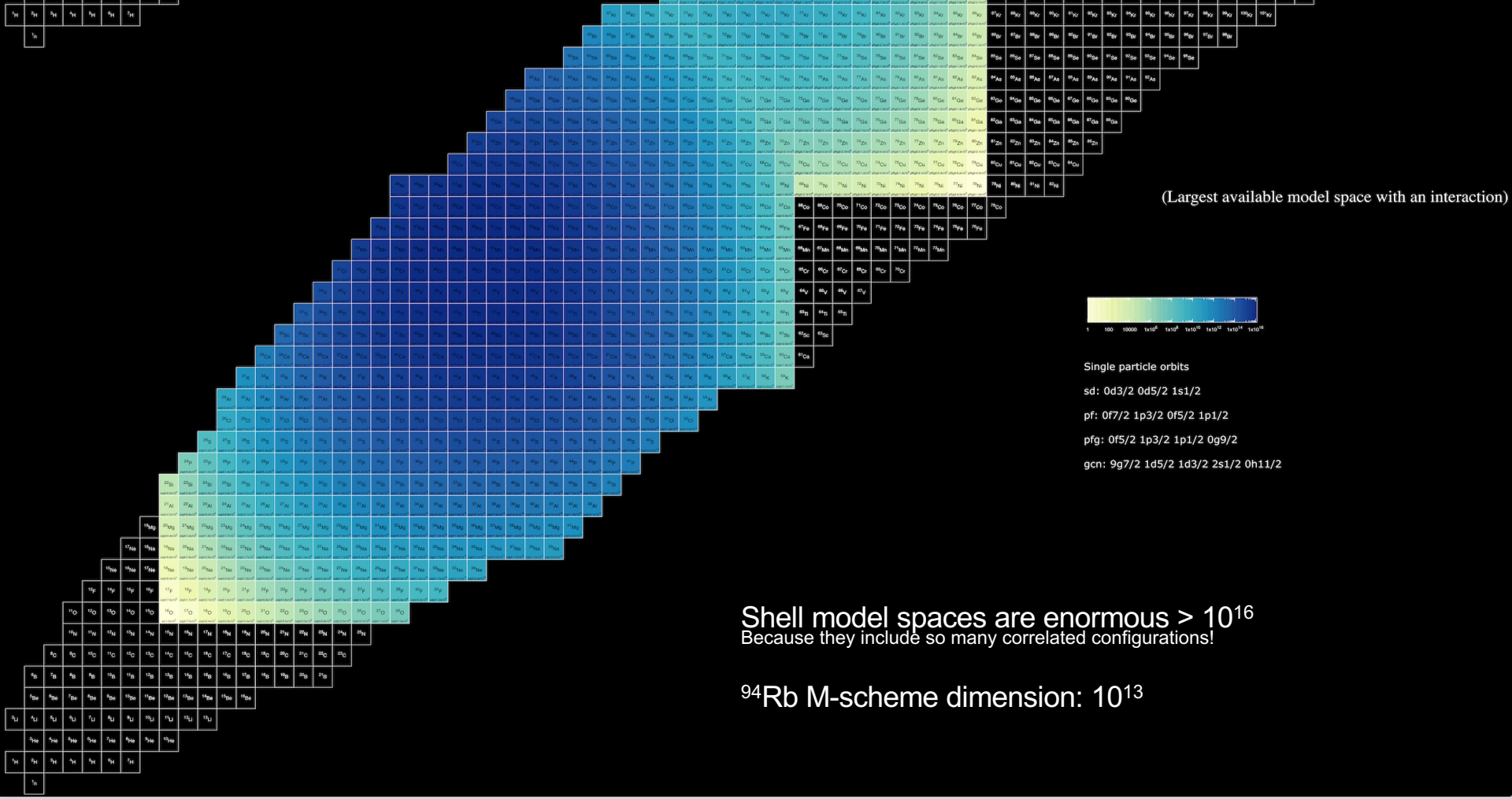
Valencia, et al., 2017 https://link.aps.org/doi/10.1103/PhysRevC.95.024320

Why are we getting this so wrong? New questions:

- Does beta decay create a well-equilibrated (statistical) nucleus? ✅ SM
- Does an unexpectantly large “forbidden” beta decay block neutron emission? ✅ SM
- Is the gamma-ray decay strength greatly enhanced? ✅ SM

The issue: Nuclear structure for short-lived nuclei is lacking

My quest: Use shell model (SM) calculations to supply them!

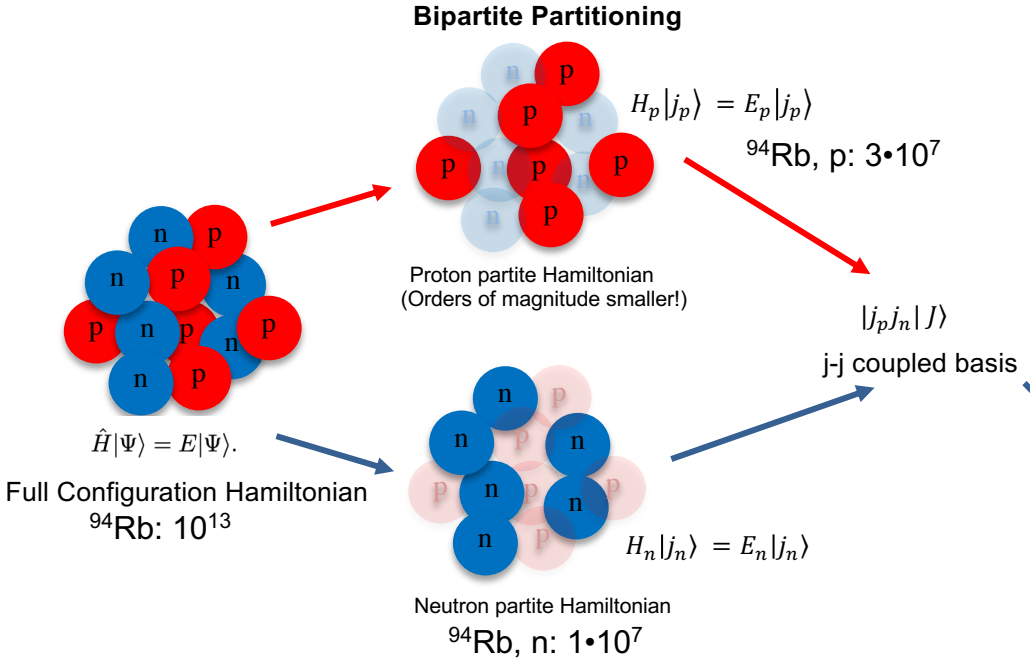


Shell model spaces are enormous > 10^{16}

Because they include so many correlated configurations!

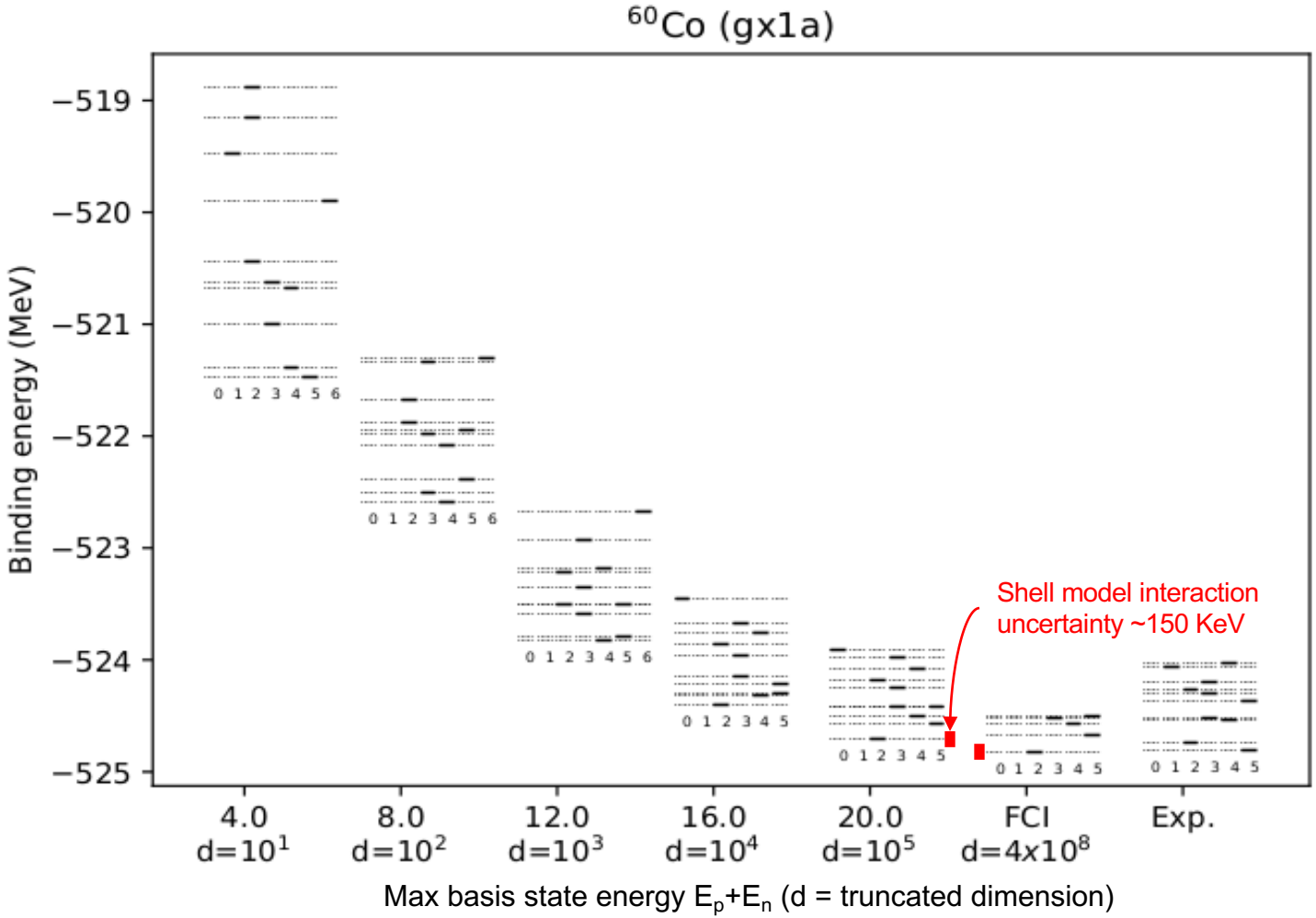
^{94}Rb M-scheme dimension: 10^{13}

Shell Model Importance-Truncation by Proton-Neutron Partitioning



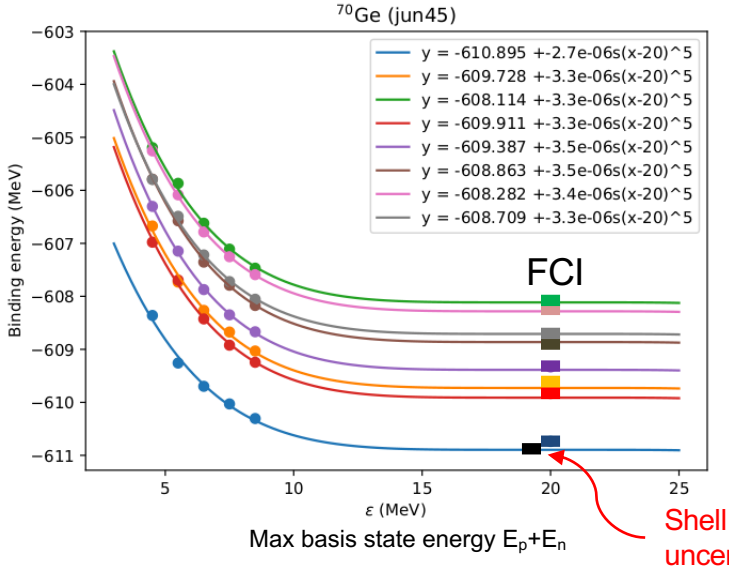
- "Poor-man's DMRG" – Steven White
- Solve for projection in each subspace as a basis for full solution
- Subspace solutions tell us which configurations are important

Different ways to select basis components:
- By excitation **energy** Ep+En of partition components
- By number **n** of partition components


^{60}Co (gx1a)
Binding energy (MeV)
−519
−520
−521
−522
−523
−524
−525
0 1 2 3 4 5 6
0 1 2 3 4 5 6
0 1 2 3 4 5 6
0 1 2 3 4 5
0 1 2 3 4 5
0 1 2 3 4 5
Shell model interaction uncertainty ~150 KeV
4.0 d=10^1
8.0 d=10^2
12.0 d=10^3
16.0 d=10^4
20.0 d=10^5
FCI d=4x10^8
Exp.
Max basis state energy E_p+E_n (d = truncated dimension)

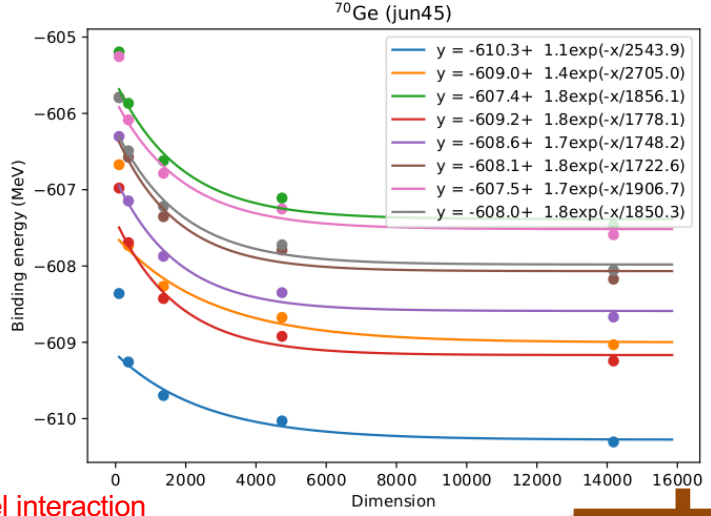
Convergence of spectra (preliminary)

Polynomial in basis energy



Max basis state energy E_p+E_n

Exponential in basis dimension

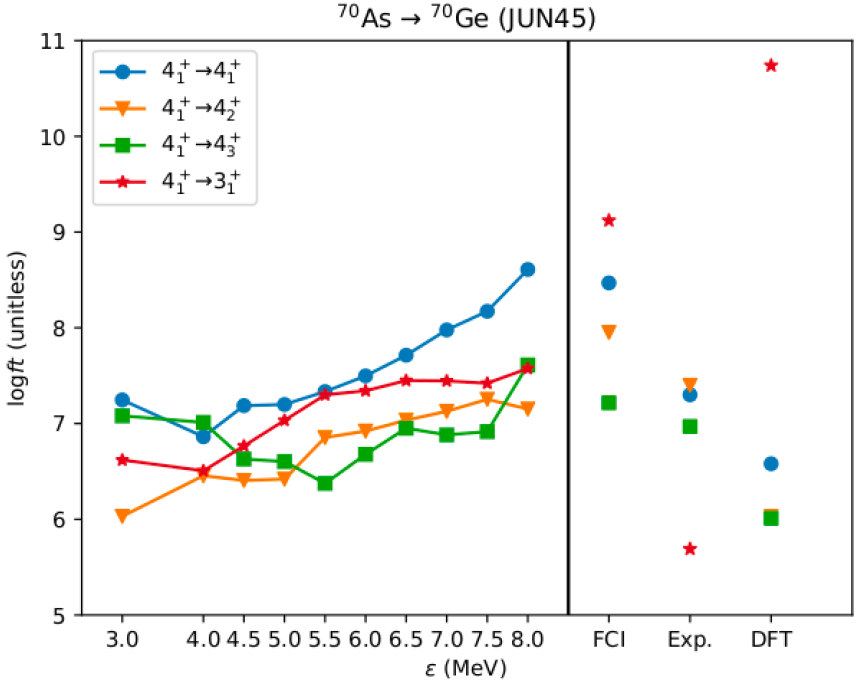


Shell model interaction uncertainty ~150 KeV

M-scheme 280 Million

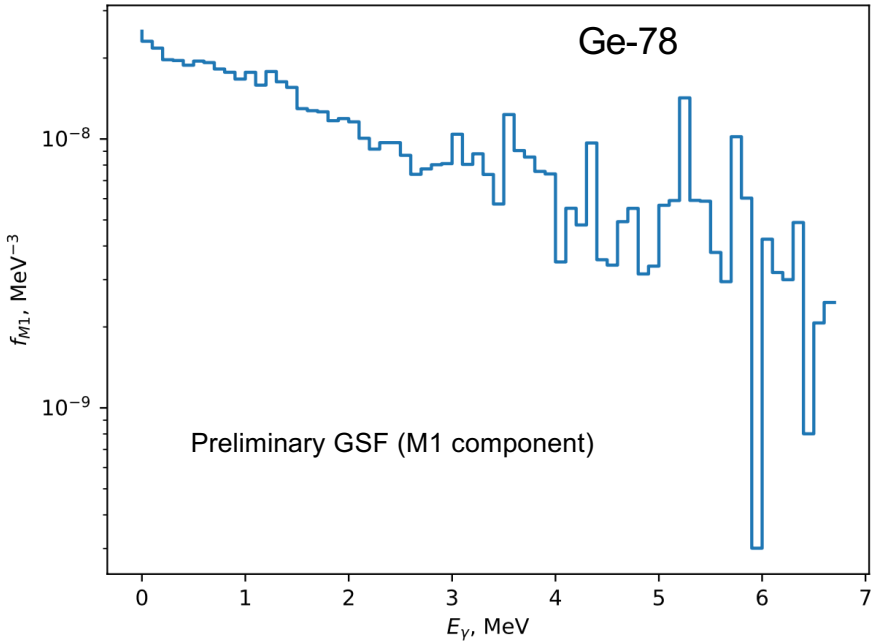
Ge70 is a complicated nucleus!

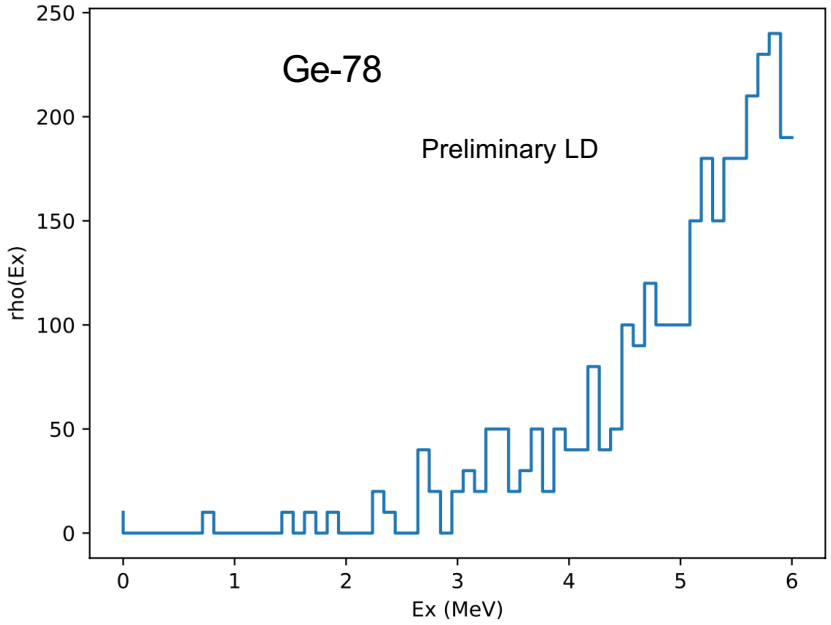
We can predict beta decay rates



- Large log*ft* values correspond to small transition probabilities
- Leads to small-number errors
- The distribution/ratio of these will matter for beta-delayed neutron emission

Soon we can calculate gamma strength functions (GSFs) as well as level densities (LDs)





With all these ingredients from the shell model, we expect new insights into beta delayed processes