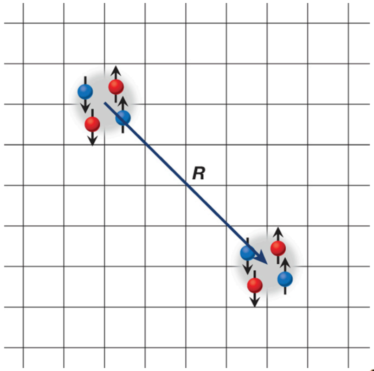
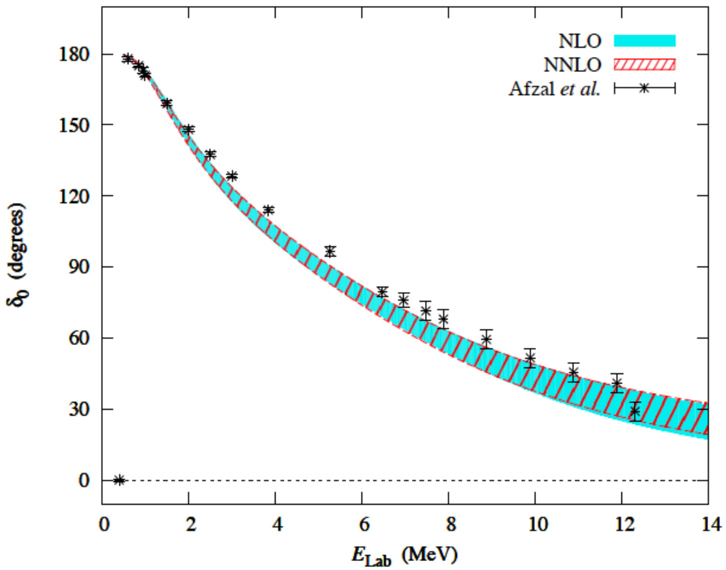
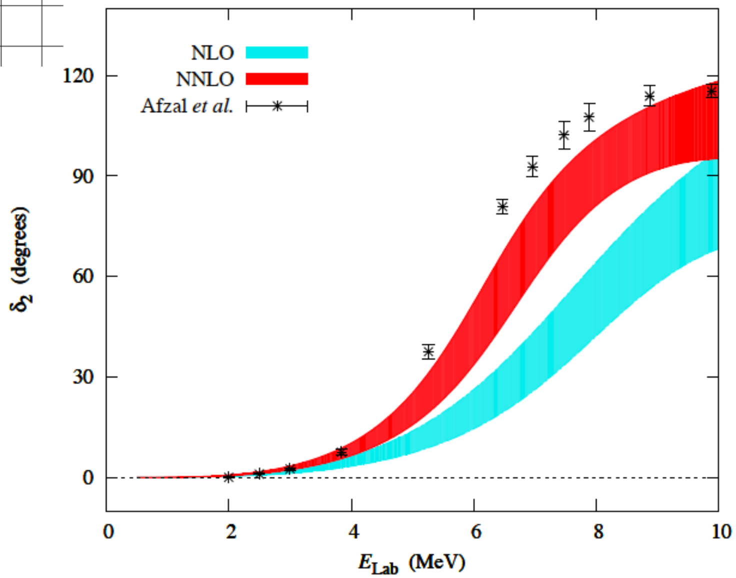
ab-initio alpha-alpha scattering







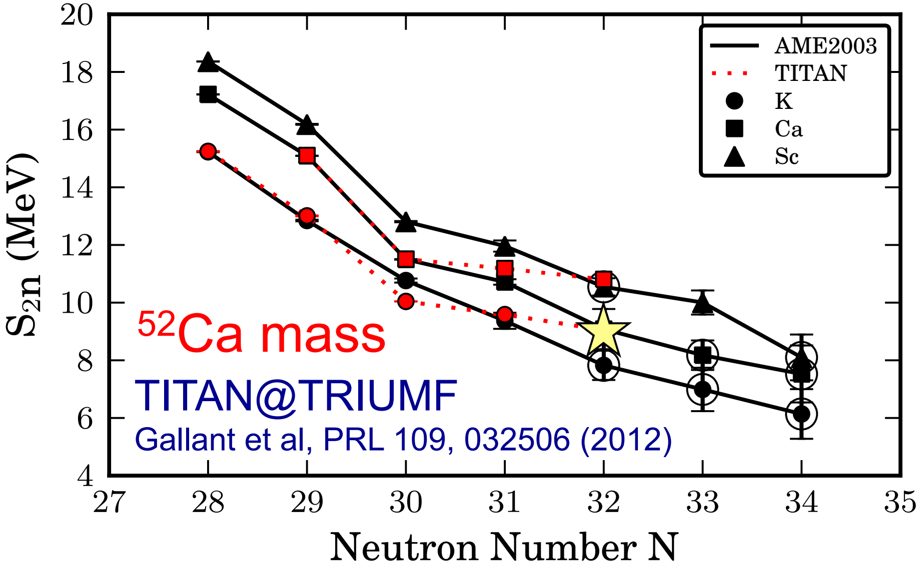
Elhatisari et al., Nature 528, 111 (2015)

http://www.nature.com/nature/journal/v528/n7580/full/nature16067.html
http://www.nature.com/nature/journal/v528/n7580/abs/528042a.html

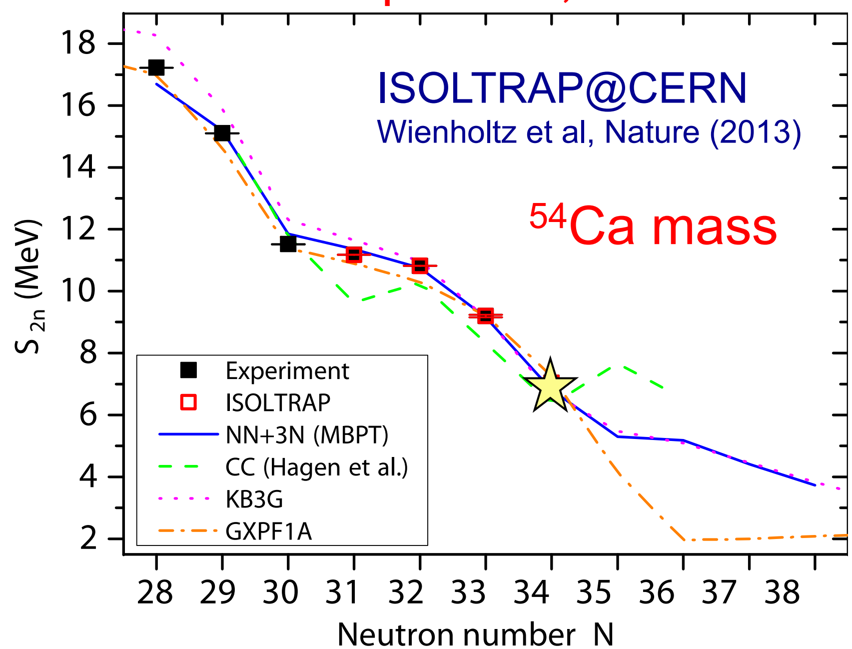
http://phys.org/news/2015-12-insights-creation-heavy-elements-simulate.html

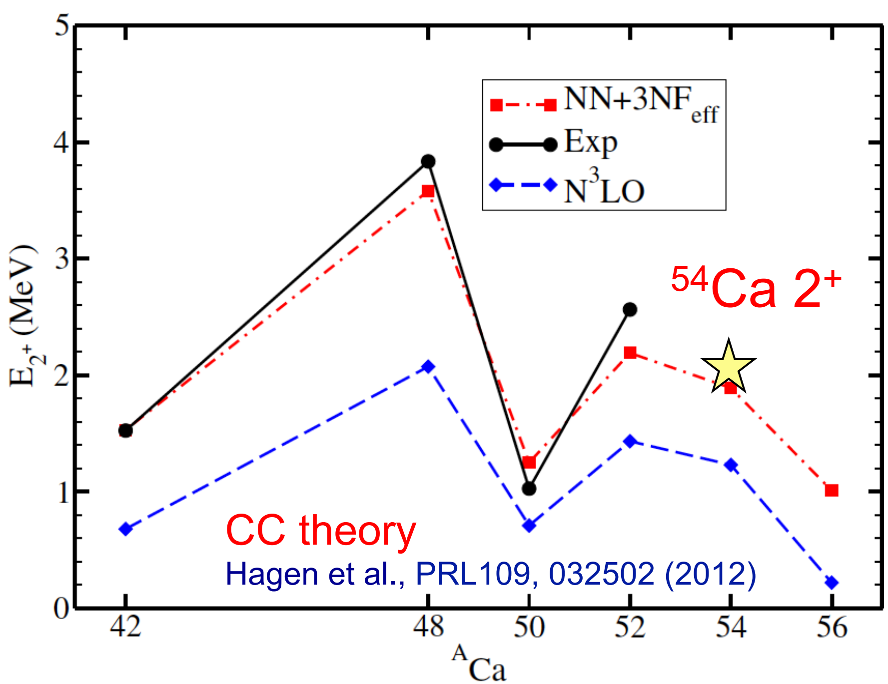
The frontier: neutron-rich calcium isotopes

probing nuclear forces and shell structure in a neutron-rich medium



^{54}Ca: 20 protons, 34 neutrons

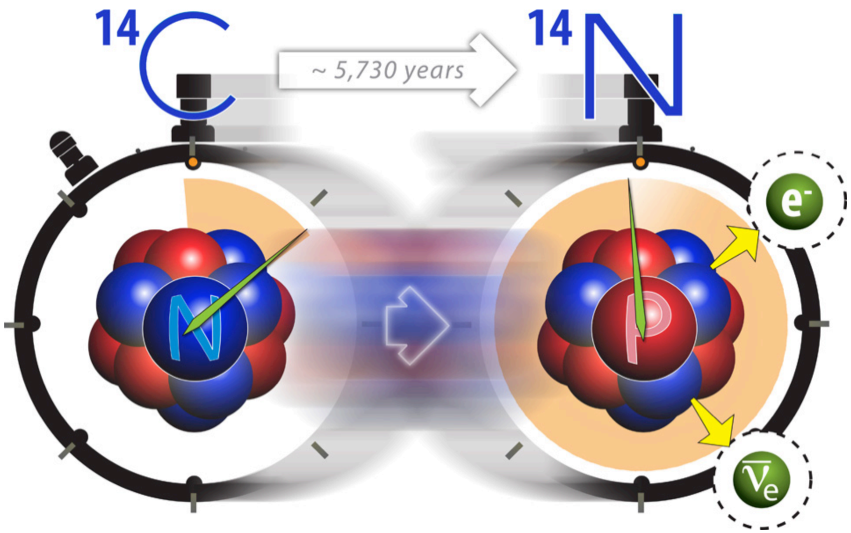


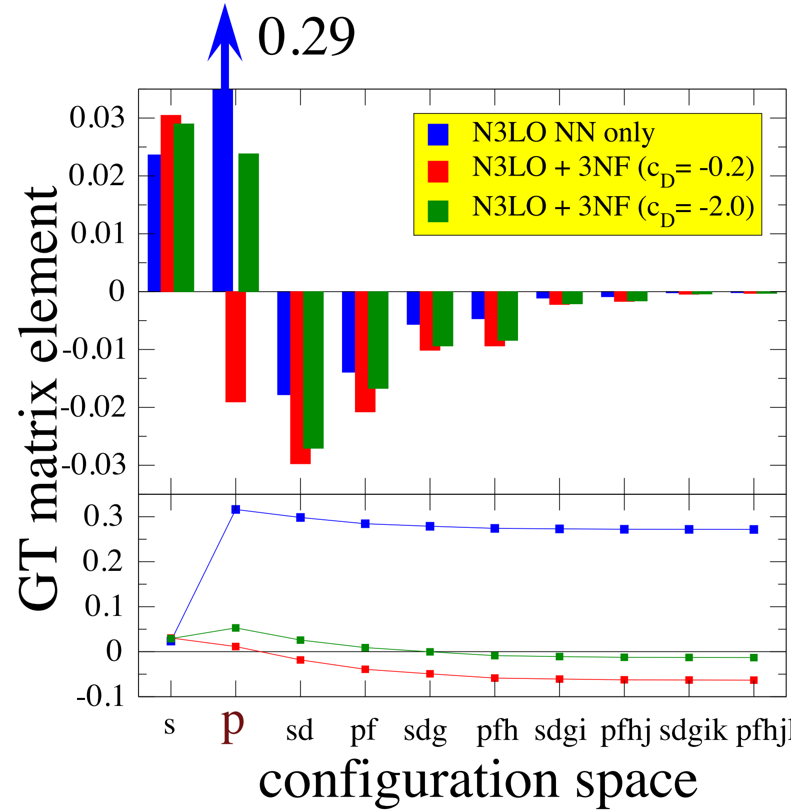


RIBF@RIKEN
Steppenbeck et al
Nature (2013)

Anomalous Long Lifetime of ^{14}C

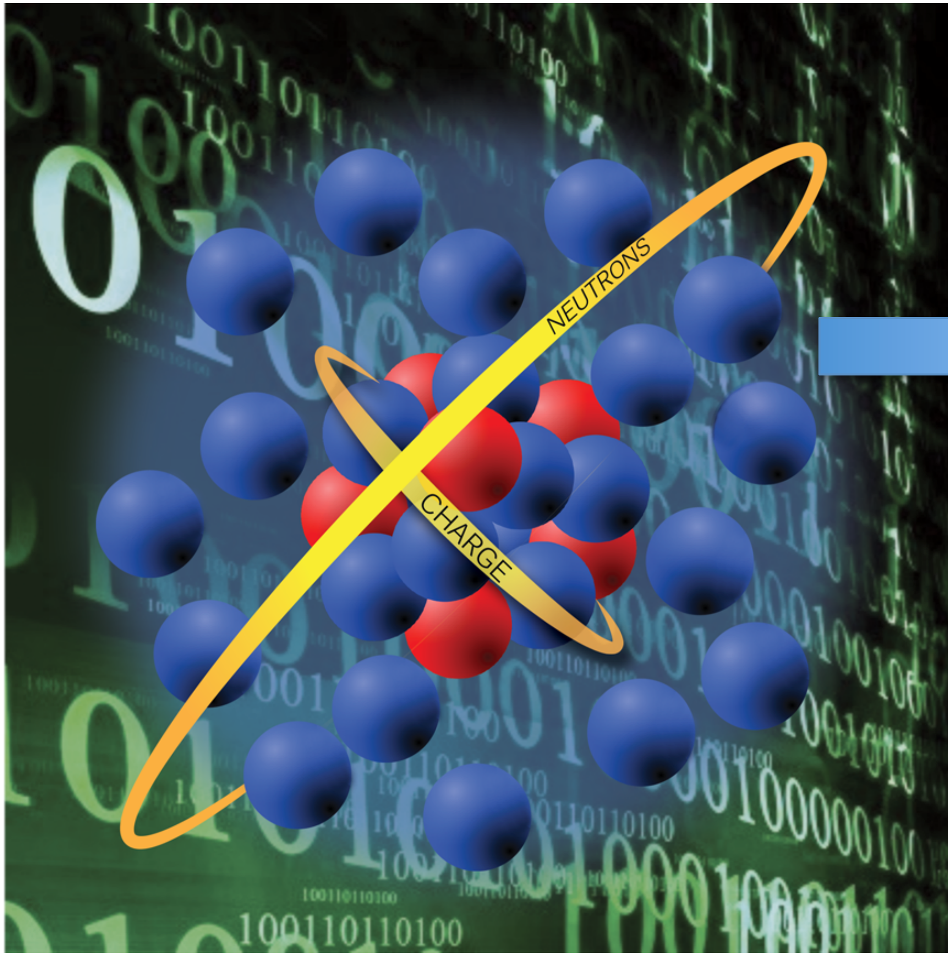
Determine the microscopic origin of the suppressed β-decay rate: 3N force

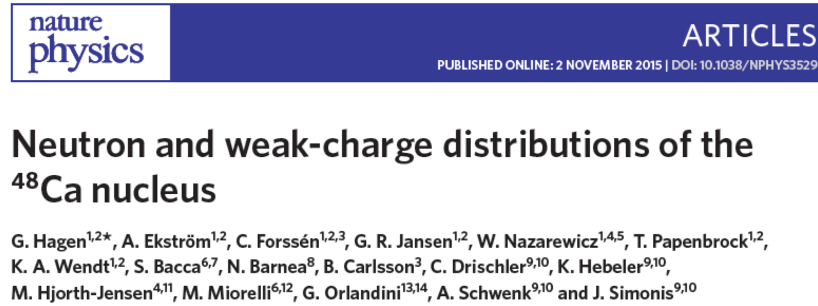




Maris et al., PRL 106, 202502 (2011)

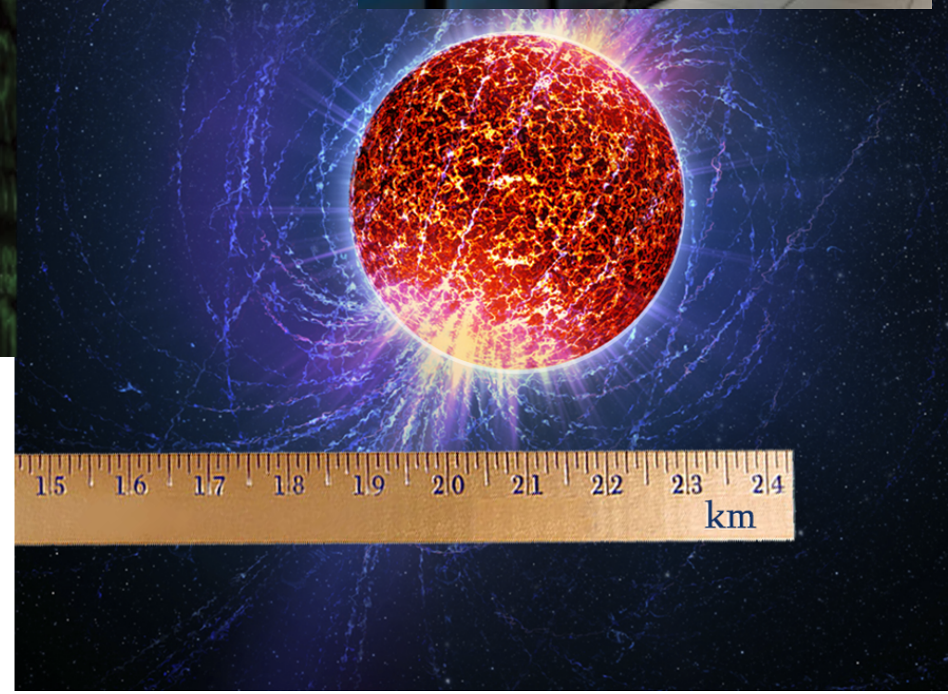
Dimension of matrix solved for 8 lowest states ~ 10^9
Solution took ~ 6 hours on 215,000 cores on Cray XT5 Jaguar at ORNL




nature physics
ARTICLES
PUBLISHED ONLINE: 2 NOVEMBER 2015 | DOI: 10.1038/NPHYS3529

Neutron and weak-charge distributions of the ^{48}Ca nucleus

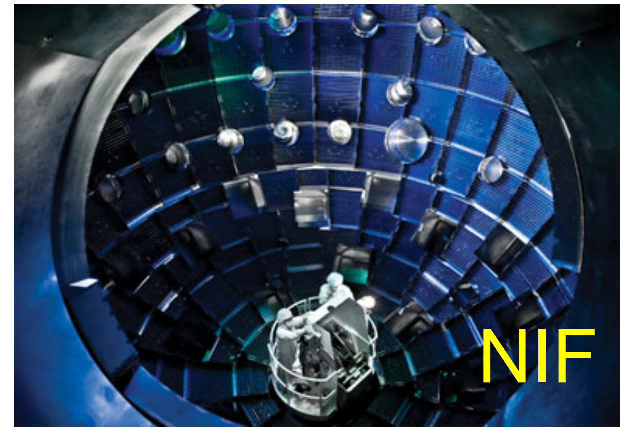
G. Hagen[1,2*], A. Ekström[1,2], C. Forssén[1,2,3], G. R. Jansen[1,2], W. Nazarewicz[1,4,5], T. Papenbrock[1,2], K. A. Wendt[1,2], S. Bacca[6,7], N. Barnea[8], B. Carlsson[3], C. Drischler[9,10], K. Hebeler[9,10], M. Hjorth-Jensen[4,11], M. Miorelli[6,12], G. Orlandini[13,14], A. Schwenk[9,10] and J. Simonis[9,10]



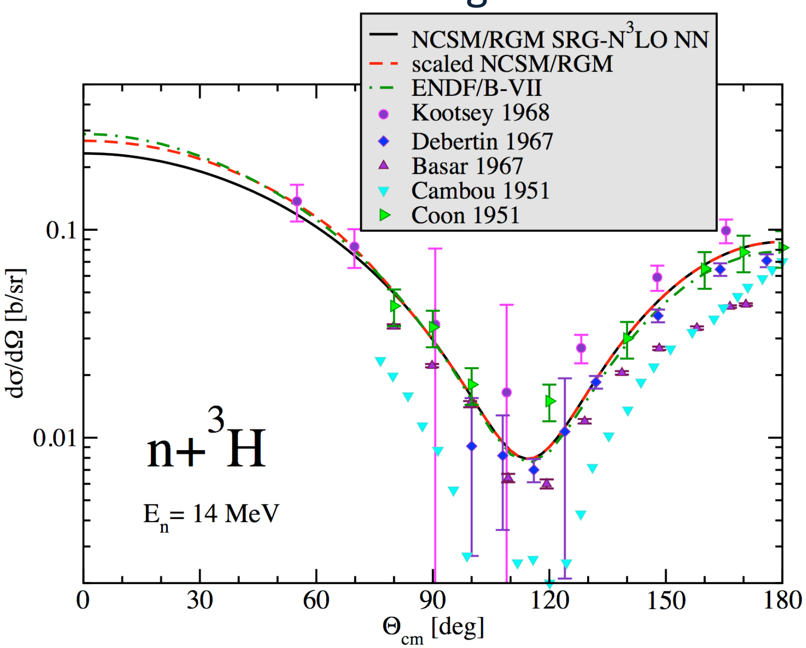
ORNL, University of Tennessee, Michigan State University, Chalmers University of Technology, TRIUMF, Hebrew University, Technical University Darmstadt, University of Oslo, University of Trento

Fusion of Light Nuclei

Computational nuclear physics enables us to reach into regimes where <u>experiments and analytic theory are not possible</u>, such as the cores of fission reactors or hot and dense evolving environments such as those found in inertial confinement fusion environment.



Ab initio theory reduces uncertainty due to conflicting data

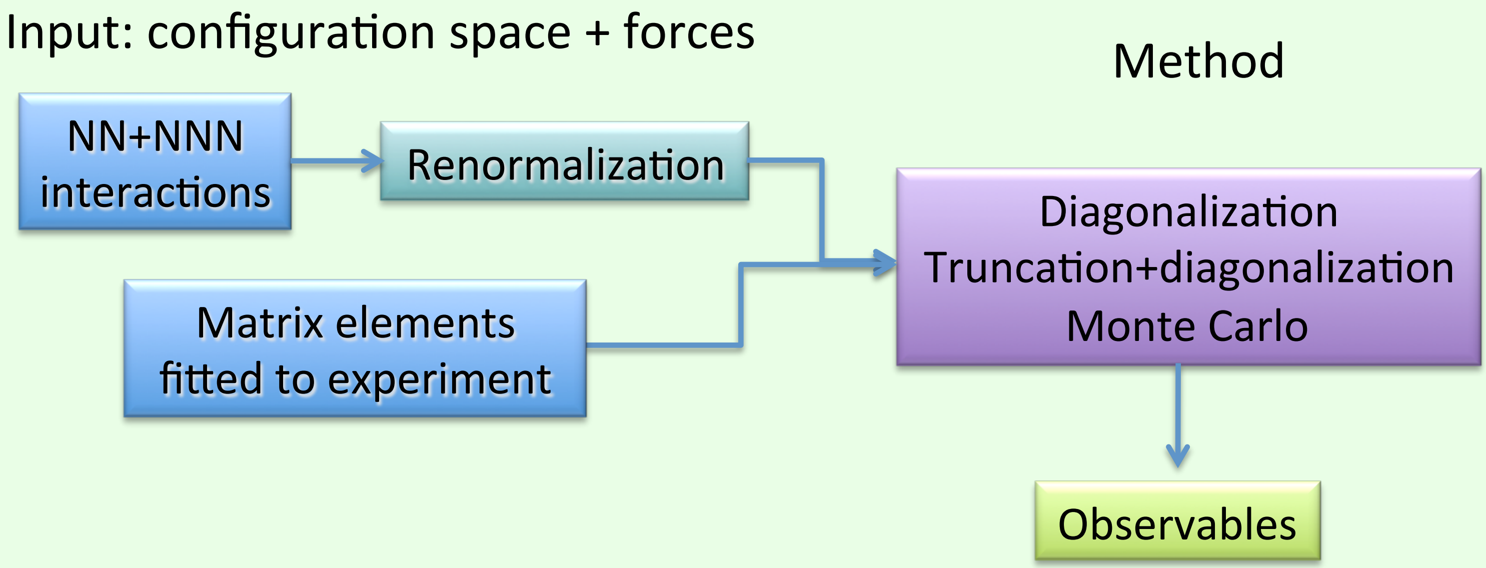


- The n-^{3}H elastic cross section for 14 MeV neutrons, important for NIF, was not known precisely enough.
- Delivered evaluated data with required 5% uncertainty and successfully compared to measurements using an Inertial Confinement Facility
- "First measurements of the differential cross sections for the elastic n-^{2}H and n-^{3}H scattering at 14.1 MeV using an Inertial Confinement Facility", by J.A. Frenje *et al.,* Phys. Rev. Lett. **107,** 122502 (2011)

http://physics.aps.org/synopsis-for/10.1103/PhysRevLett.107.122502

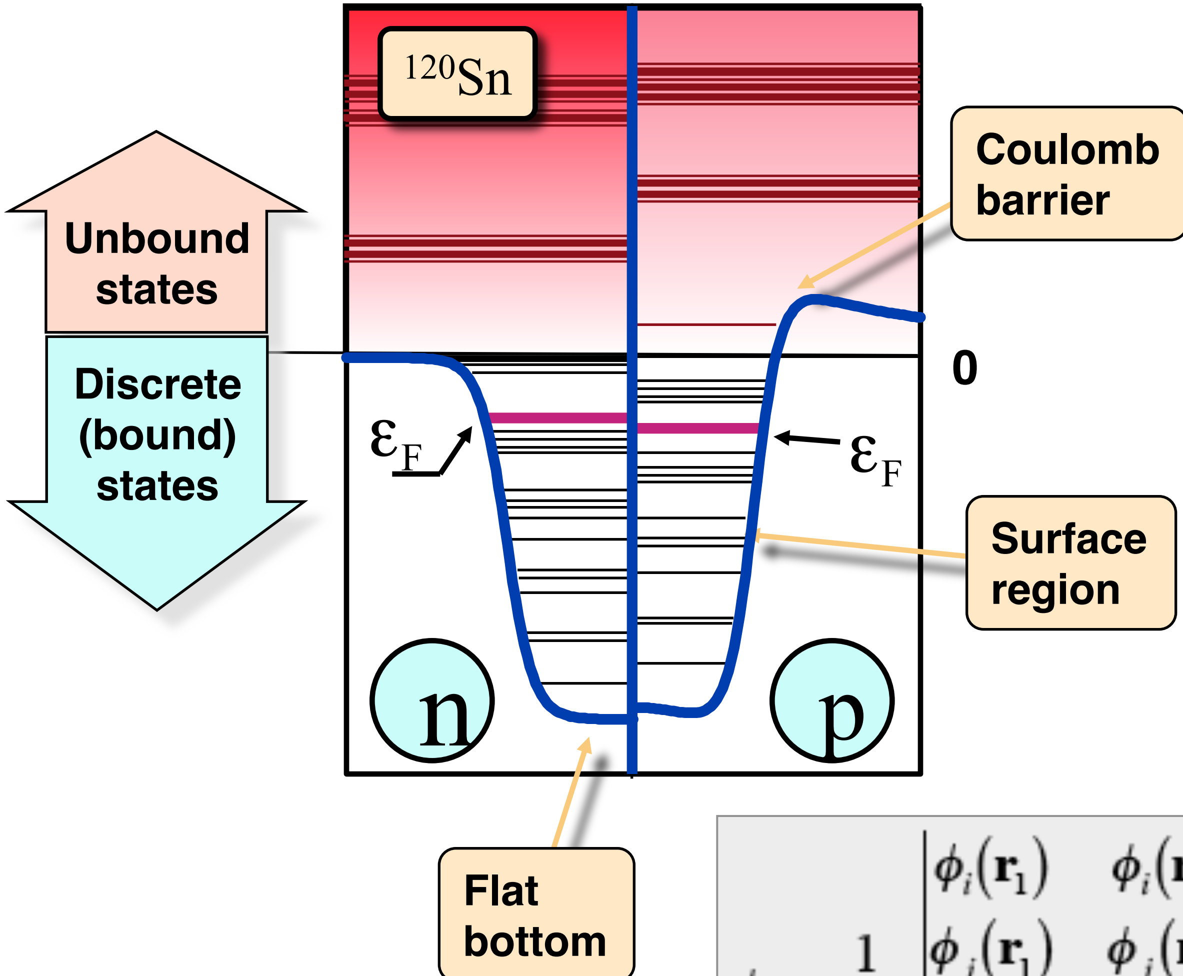
Configuration interaction techniques

- light and heavy nuclei
- detailed spectroscopy
- quantum correlations (lab-system description)



- Direct comparison with experiment
- Pseudo-data to inform reaction theory and DFT

Average one-body Hamiltonian



$$\hat{H}_0 = \sum_{i=1}^{A} h_i, \quad h_i = -\frac{\hbar^2}{2M}\nabla_i^2 + V_i$$

$$h_i \phi_k(i) = \varepsilon_k \phi_k(i)$$

$$\phi = \frac{1}{\sqrt{A!}} \begin{vmatrix} \phi_i(\mathbf{r}_1) & \phi_i(\mathbf{r}_2) & \dots & \phi_i(\mathbf{r}_A) \\ \phi_j(\mathbf{r}_1) & \phi_j(\mathbf{r}_2) & & \phi_j(\mathbf{r}_A) \\ & \vdots & \ddots & \vdots \\ \phi_l(\mathbf{r}_1) & \phi_l(\mathbf{r}_2) & \dots & \phi_l(\mathbf{r}_A) \end{vmatrix}$$

$$= a_l^+ \dots a_j^+ a_i^+ |0\rangle$$

Nuclear shell model

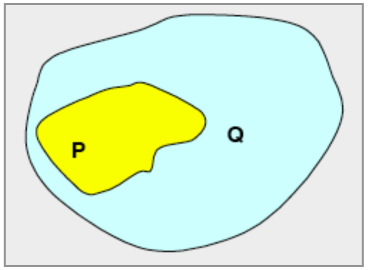
$$\hat{H} = \sum_i t_i + \frac{1}{2}\sum_{\substack{i,j \\ i\neq j}} v_{ij} = \sum_i (t_i + V_i) \quad + \quad \left[\frac{1}{2}\sum_{\substack{i,j \\ i\neq j}} v_{ij} - \sum_i V_i \right]$$

One-body Hamiltonian

Residual interactioni

- Construct basis states with good (J_z, T_z) or (J,T)
- Compute the Hamiltonian matrix
- Diagonalize Hamiltonian matrix for lowest eigenstates
- Number of states increases dramatically with particle number

$$P + Q = 1$$

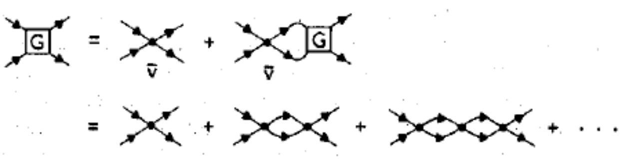


Full fp shell for ^{60}Zn : $\approx 2\times 10^9$ J_z states

5,053,594 $\quad J=0, T=0$ states

81,804,784 $\quad J=6, T=1$ states

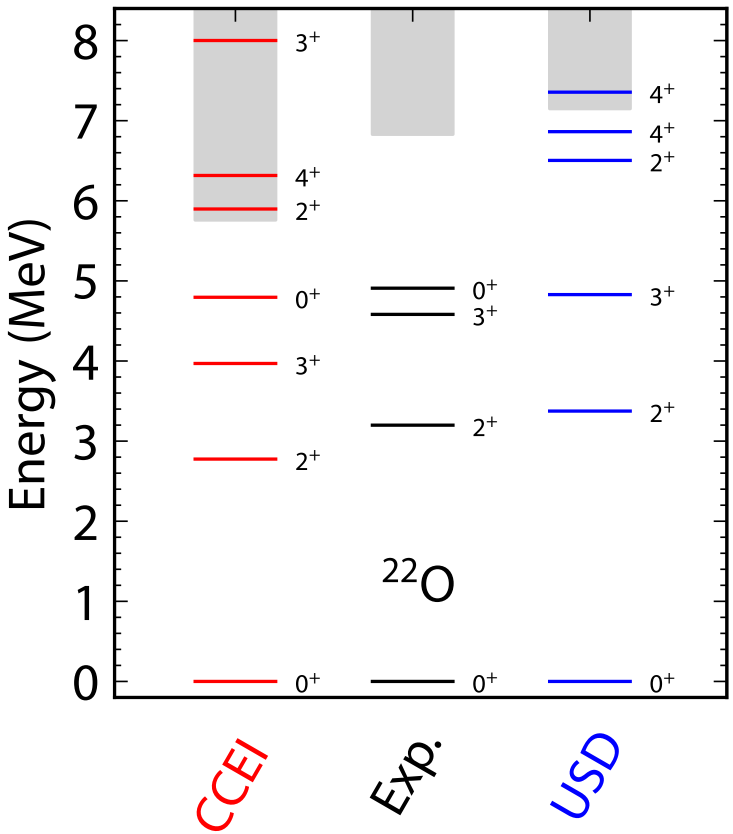
- Can we get around this problem? Effective interactions in truncated spaces (P-included, finite; Q-excluded, infinite)
- Residual interaction (G-matrix) depends on the configuration space. Effective charges
- Breaks down around particle drip lines



G-matrix, obtained from the Bethe-Goldstone equation (scattering within a nuclear medium)

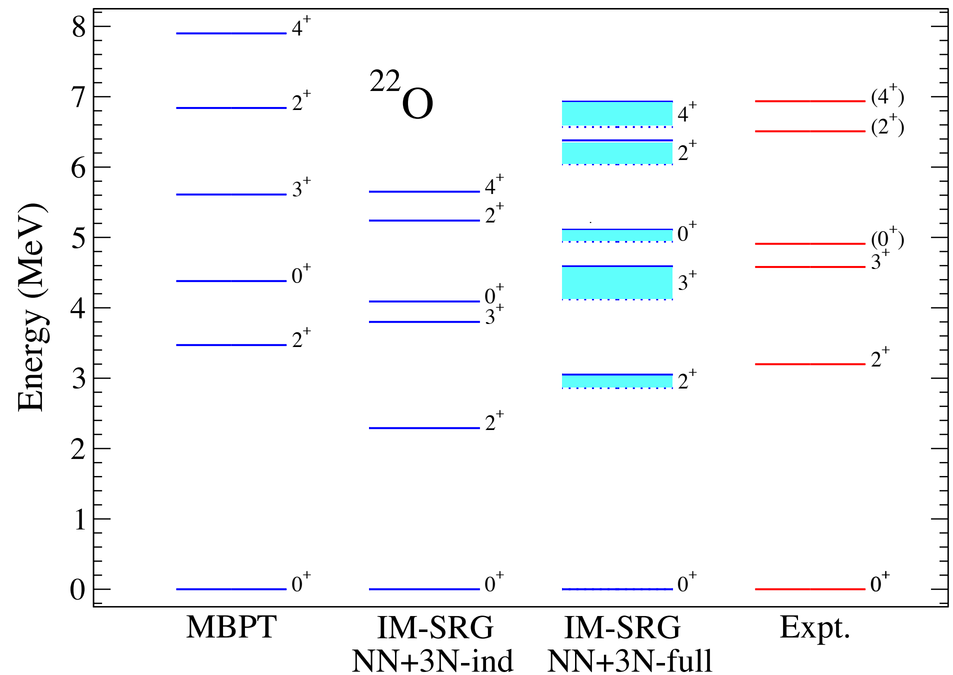
Microscopic valence-space Shell Model Hamiltonian

Coupled Cluster Effective Interaction (valence cluster expansion)



G.R. Jansen et al., Phys. Rev. Lett. **113**, 142502 (2014)

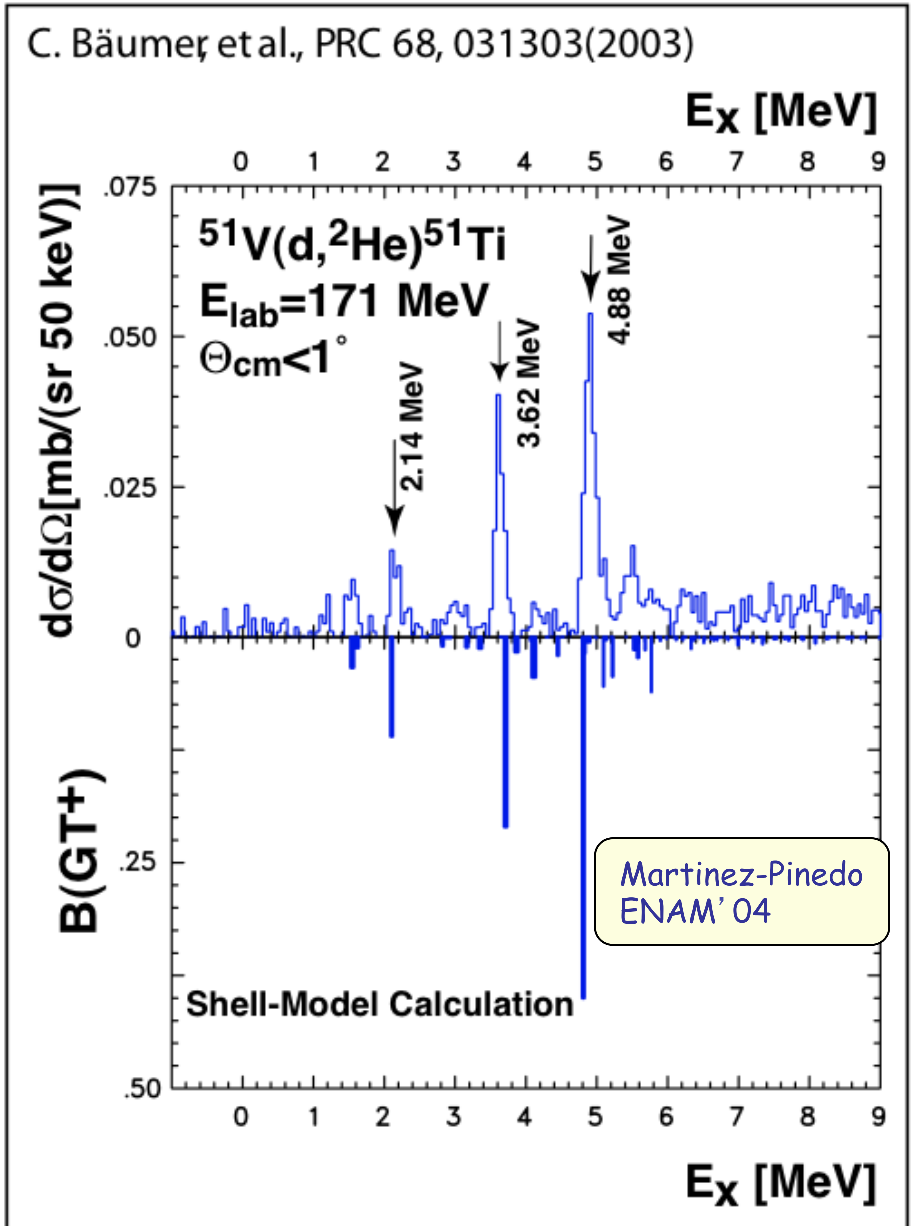
In-medium SRG Effective Interaction



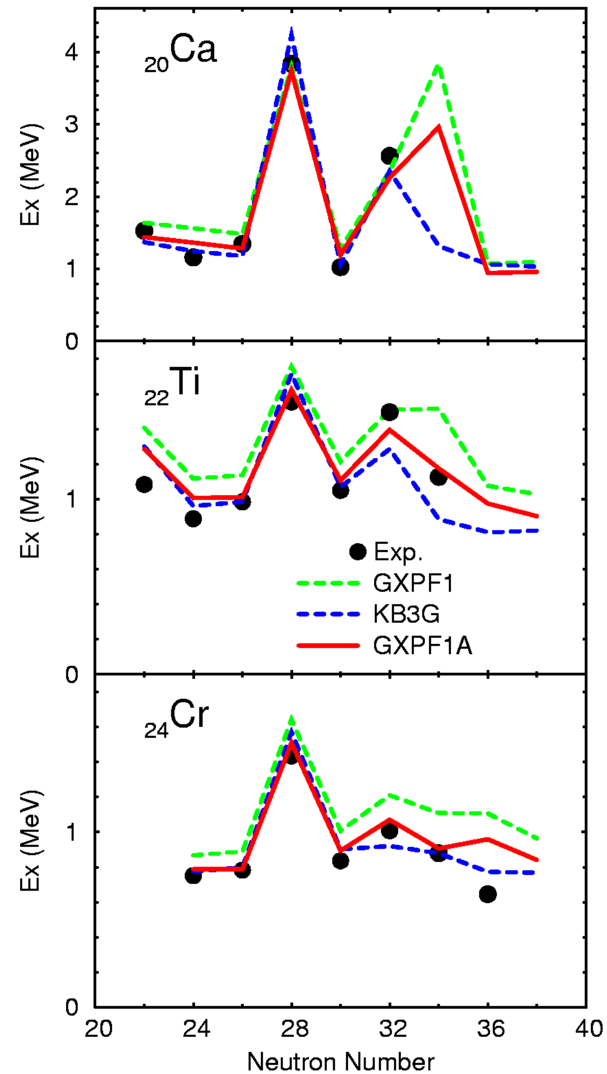
S.K. Bogner et al., Phys. Rev. Lett. **113**, 142501 (2014)

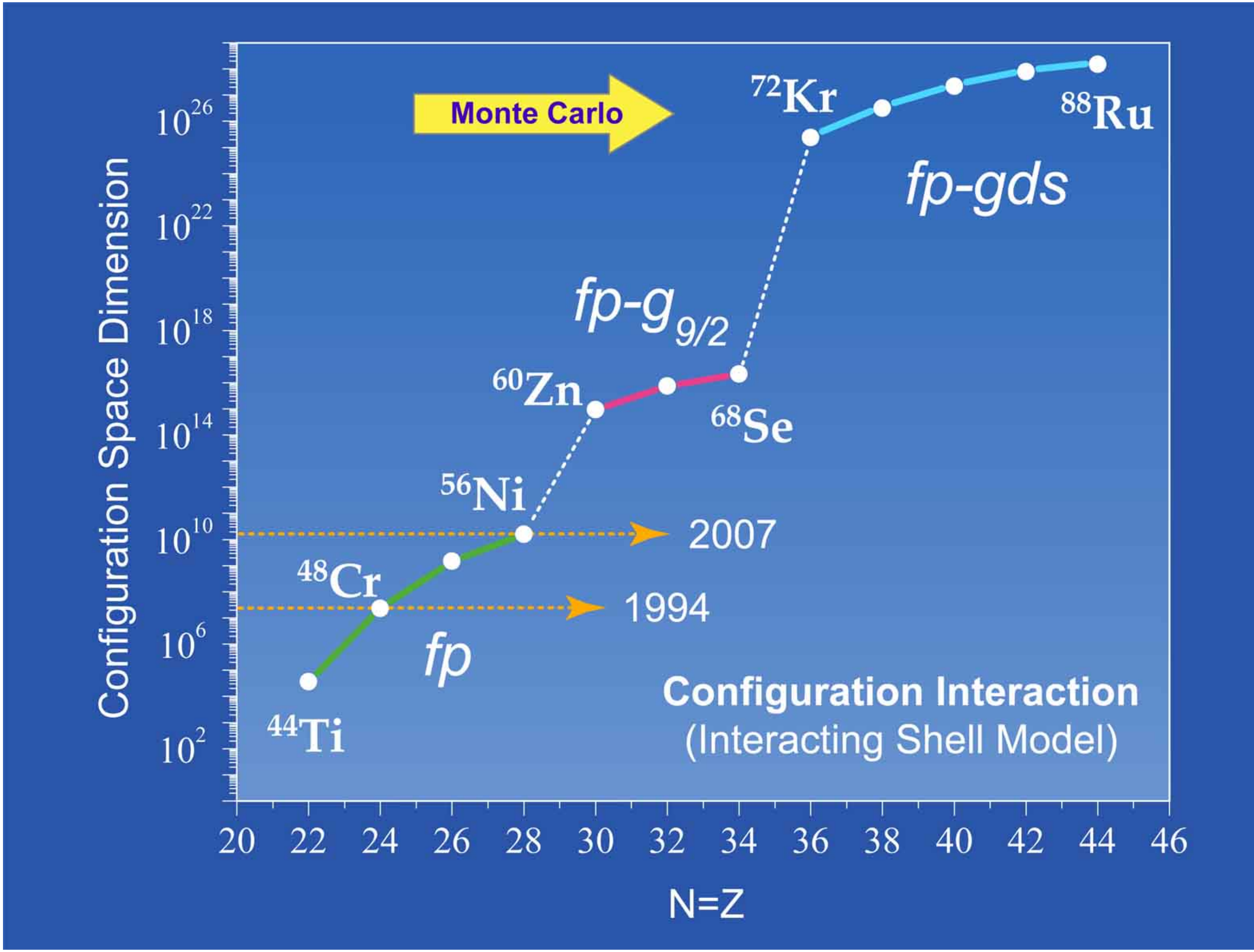
Diagonalization Shell Model

(medium-mass nuclei reached;dimensions 10^9!)



Honma, Otsuka et al., PRC69, 034335 (2004)





Monte Carlo
Configuration Space Dimension
10^{2}
10^{6}
10^{10}
10^{14}
10^{18}
10^{22}
10^{26}
^{44}Ti
^{48}Cr
^{56}Ni
^{60}Zn
^{68}Se
^{72}Kr
^{88}Ru
fp
$fp\text{-}g_{9/2}$
fp-gds
2007
1994
Configuration Interaction
(Interacting Shell Model)
20 22 24 26 28 30 32 34 36 38 40 42 44 46
N=Z