Structure of *sd*- and *pf*-shell nuclei with microscopic effective interactions

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Importance of the microscopic study with the bare nuclear force in free space

- The most fundamental problem in the quantum mechanical system
- To confirm the validity of assumptions (adjustments) in the actual calculation using nuclear models
- To investigate new properties which cannot be described by nuclear models

However, ⋯

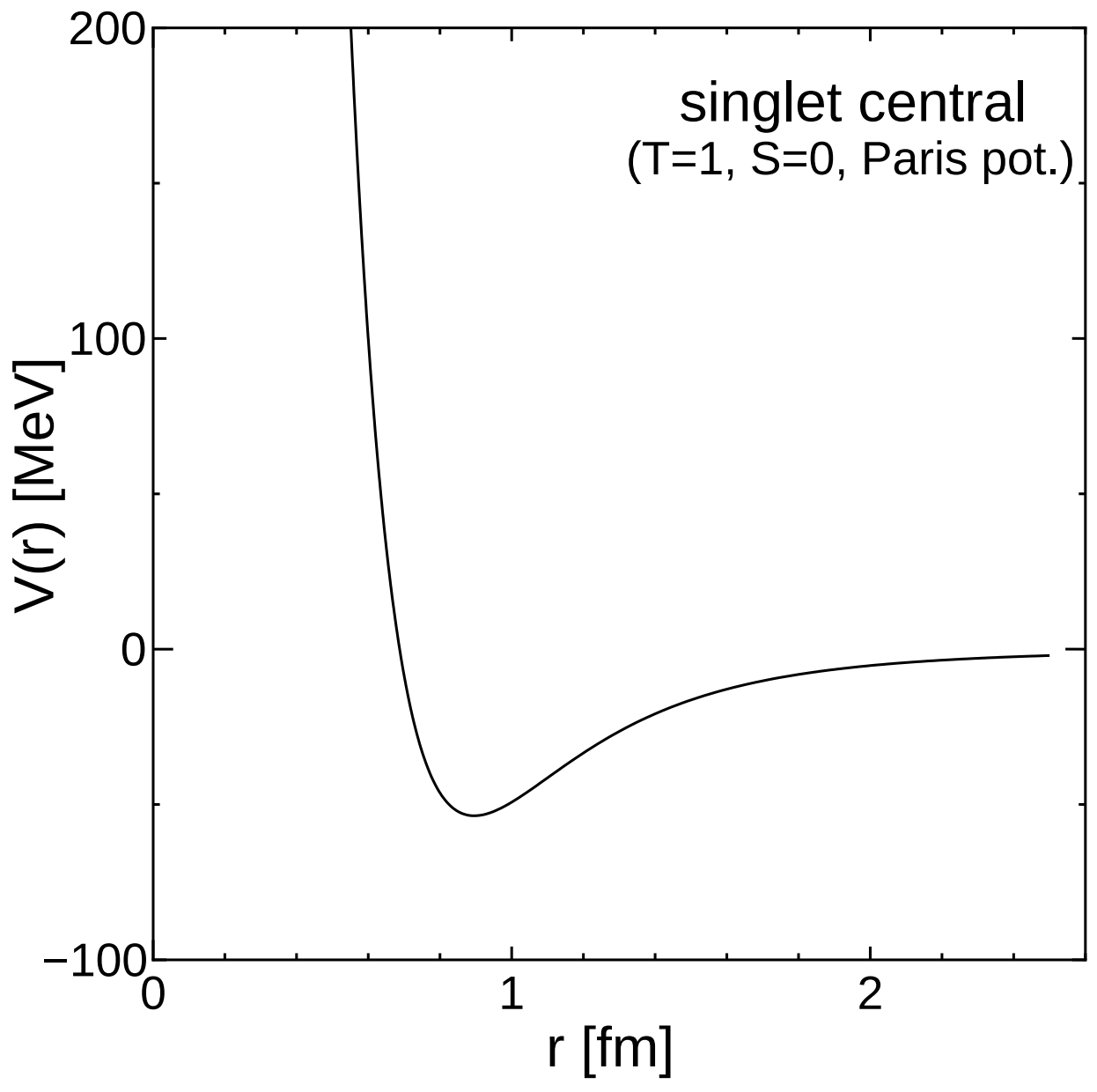
If we employ the bare NN force directly ⋯

Extremely large-scale calculations are needed

(300 $\hbar\Omega$ space with h.o. basis states for deutron!)

Necessity of deriving the microscopic effective interaction

- Similarity / Unitary transformation


singlet central
(T=1, S=0, Paris pot.)
V(r) [MeV]
r [fm]
200
100
0
−100
0
1
2

Coupled-cluster theory

Our ongoing study:

Unitary-model-operator approach (UMOA)

- **Closed-shell nuclei, single-particle (-hole) states in nuclei up to the *pf*-shell region**

No-core shell model

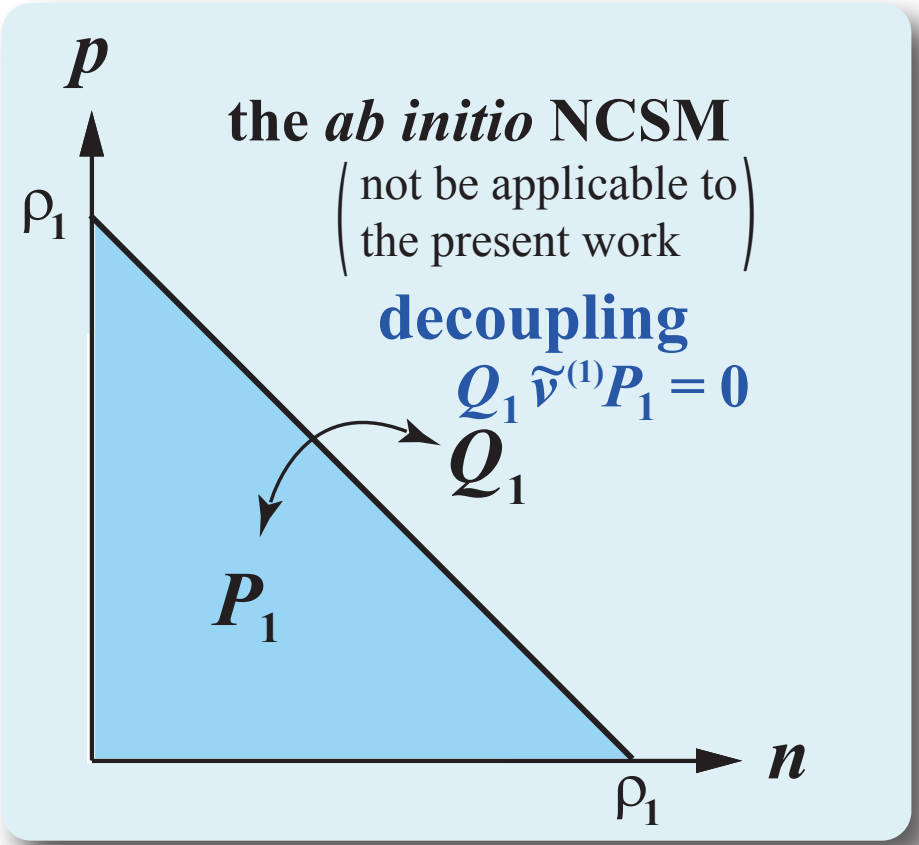
Our ongoing study:

Hybrid method combining a no-core type of shell model with single-particle information obtained by the UMOA

- **Neutron-rich carbon isotopes, oxygen isotopes**

Derivation of effective interaction

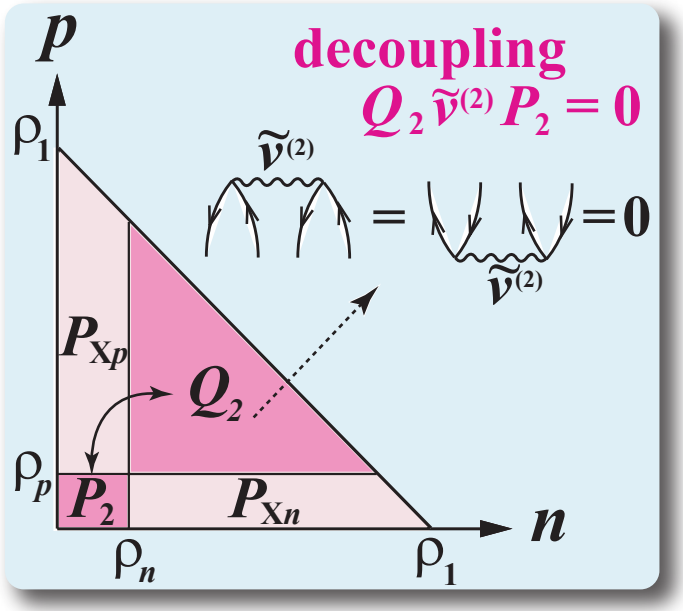
Eff. int. in a huge model space



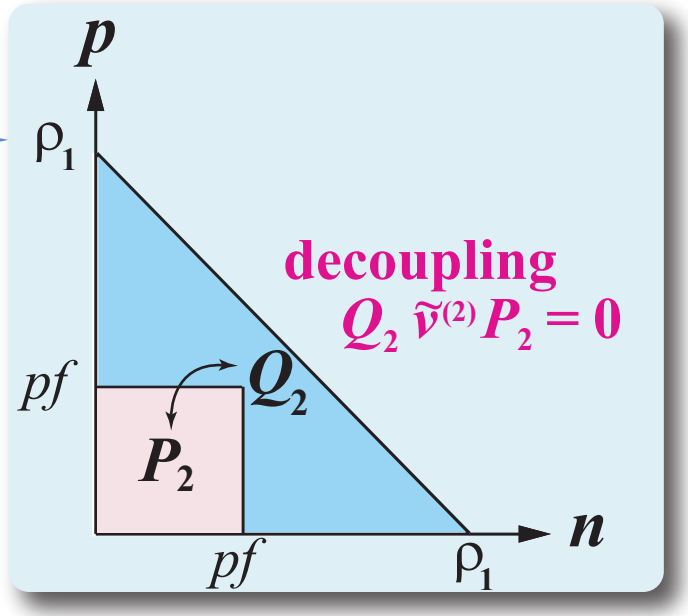
$\rho_1 = 2n_a + l_a + 2n_b + l_b$ ($\{n_a, l_a\}$ and $\{n_b, l_b\}$: sets of h.o. quantum numbers of the two-body states)

(For details,
- S. F., T. Mizusaki, T. Otsuka, T. Sebe, and A. Arima, Phys. Lett. **B650**, 9 (2007).
- S. F., R. Okamoto, and K. Suzuki, Phys. Rev. C **69**, 034328 (2004).)

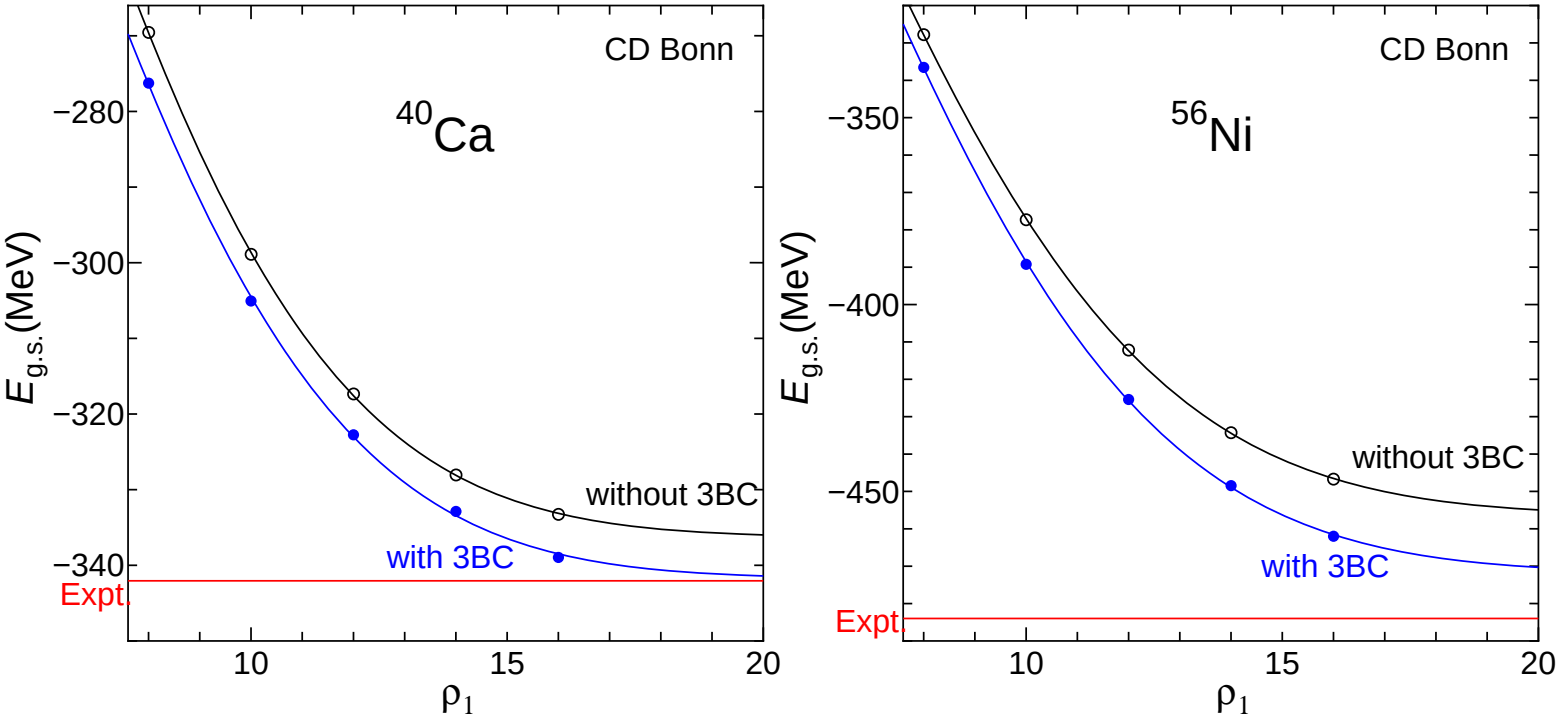
Eff. int. for the UMOA



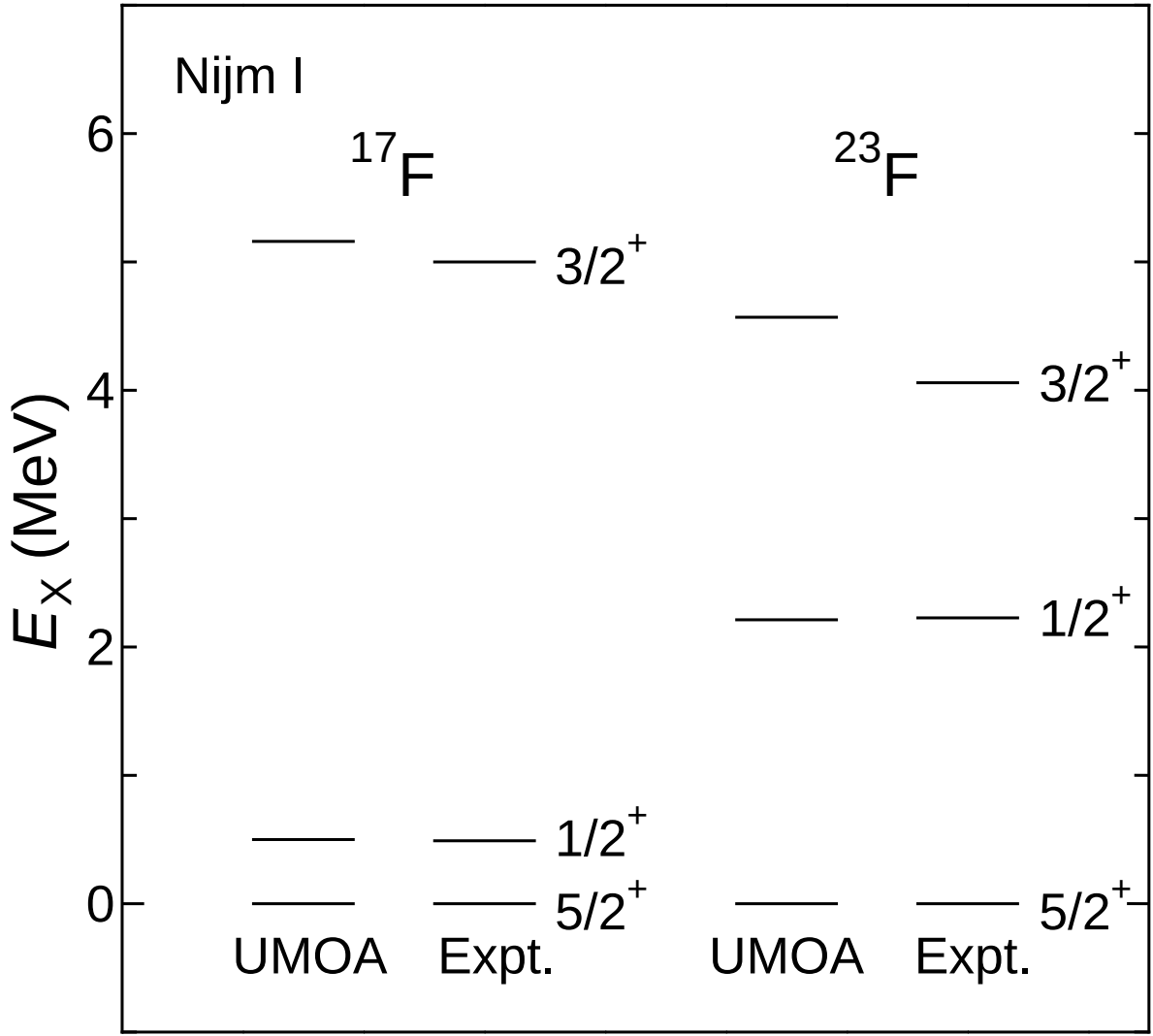
Eff. int. for the $0s-1p0f$ shell model



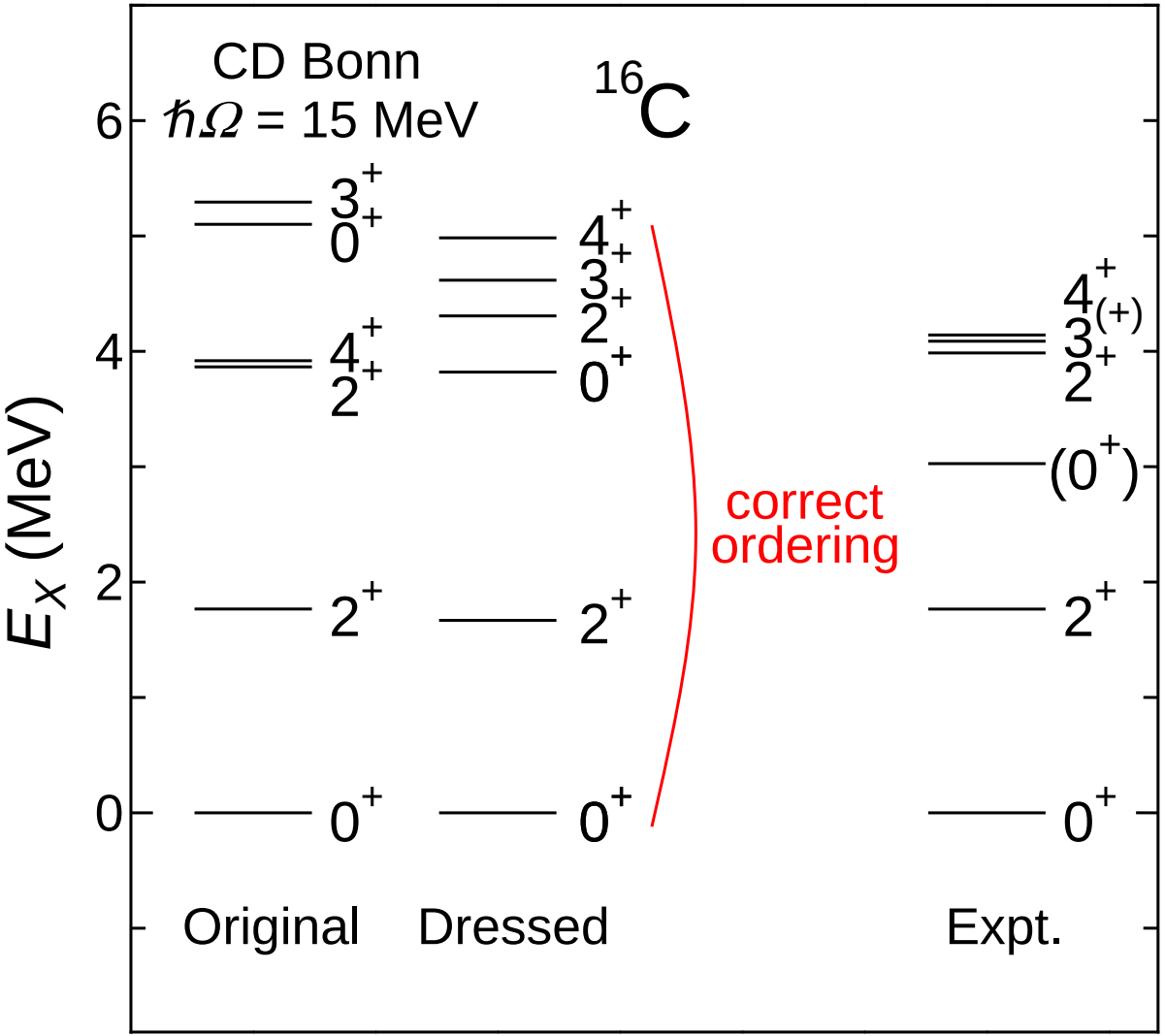
The ρ_1 dependence of the calculated ground−state energies of ^{40}Ca and ^{56}Ni

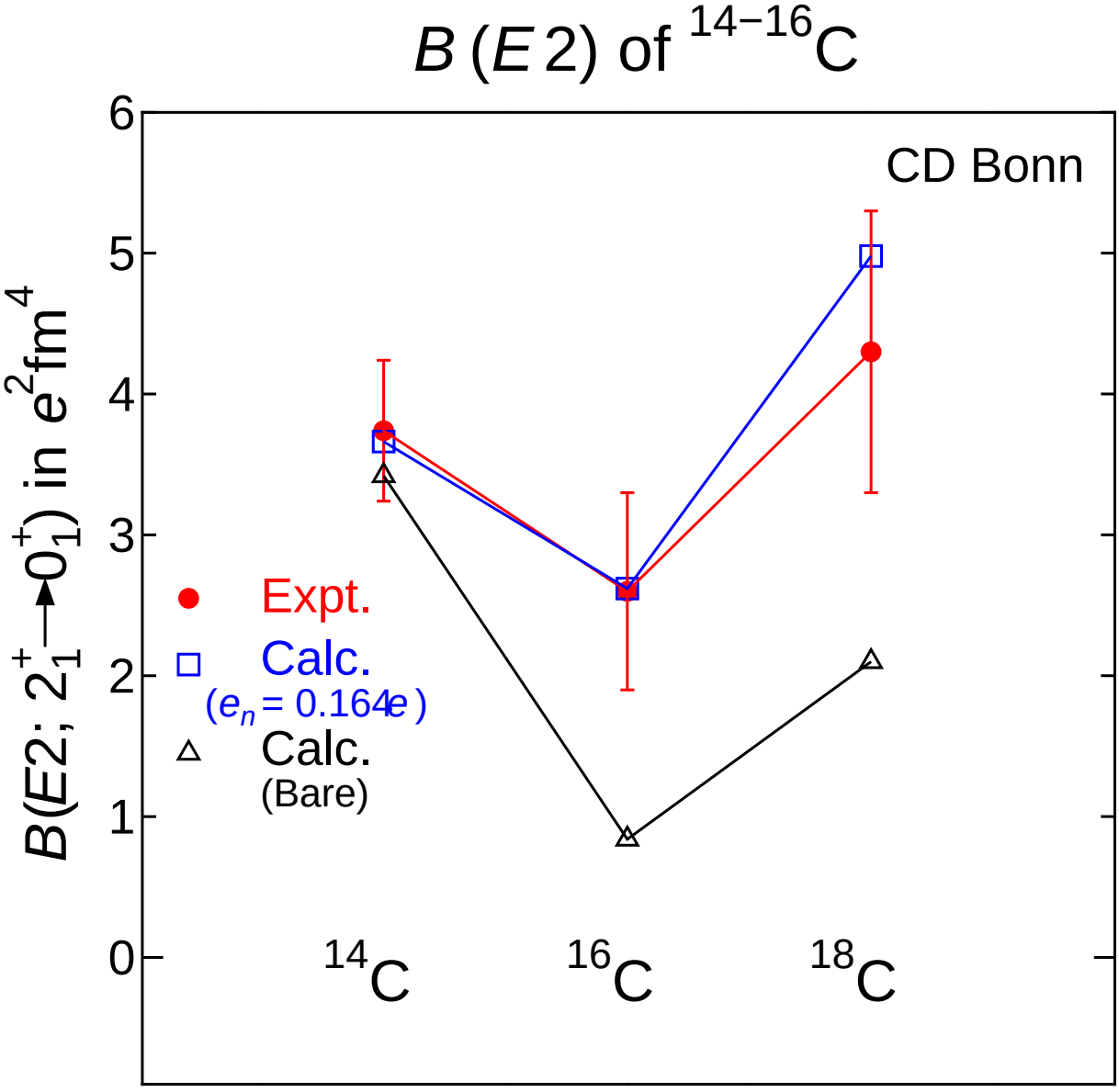


Single−particle levels in ^{17}F and ^{23}F

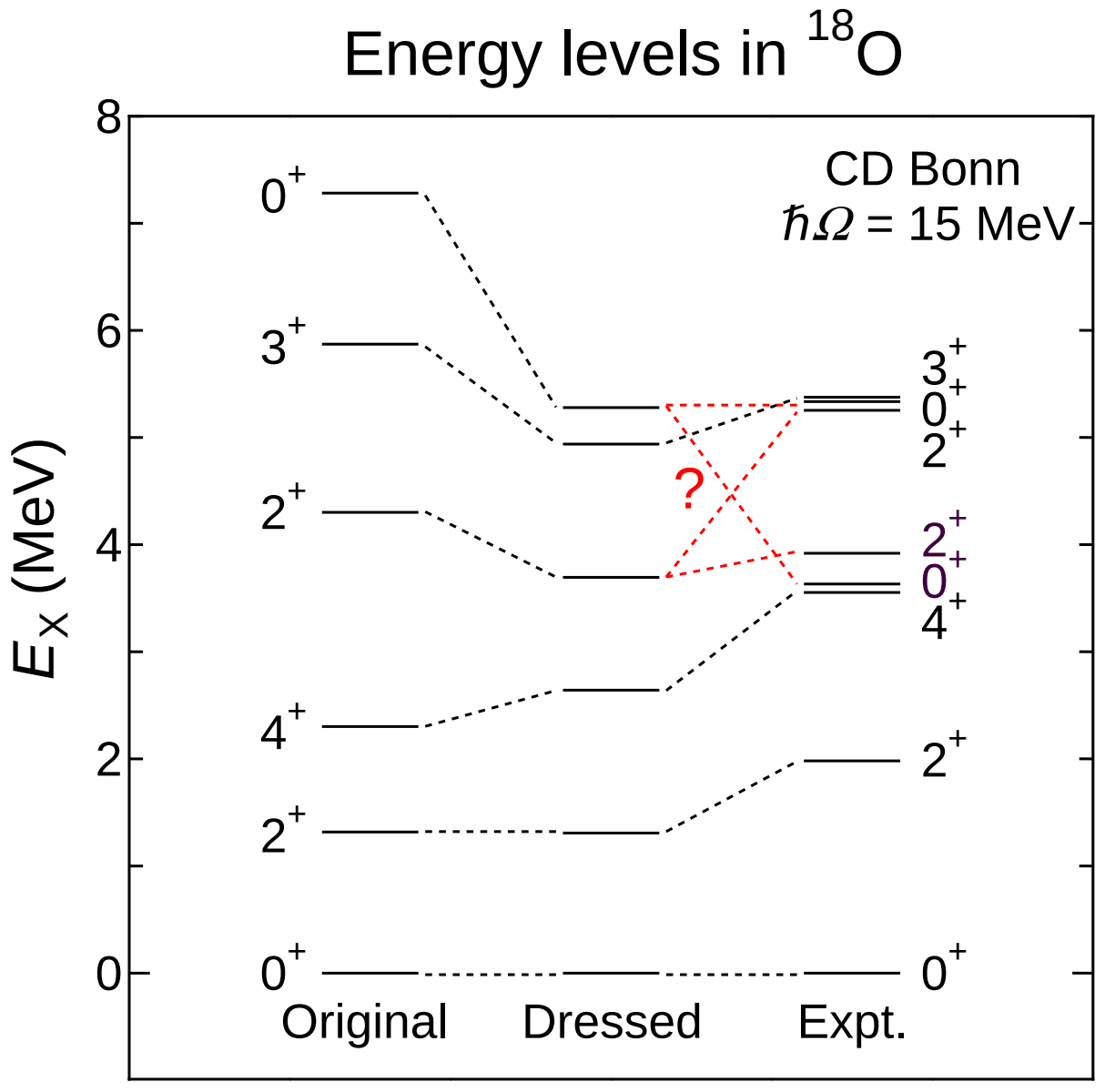


Low−lying energy levels in ^{16}C





Expt. data for ^{16}C and ^{18}C:
H. J. Ong *et al.* , arXiv:0711.4062 [nucl−ex]


Energy levels in ^{18}O
CD Bonn
$\hbar\Omega$ = 15 MeV
E_X (MeV)
8
6
4
2
0
0^+
3^+
2^+
4^+
2^+
0^+
?
3^+
0^+
2^+
2^+
0^+
4^+
2^+
0^+
Original
Dressed
Expt.

Summary

- We have developed two methods for the microscopic description of nuclei beyond *p* shell with a realistic NN force in free space.
  - Unitary-model-operator approach (UMOA)
  - "No-core" shell model in a restricted model space
- In both methods, the microscopic effective interaction derived through a unitary transformation is a key ingredient.
- The microscopic effective interaction will be very helpful to reduce the model-space size in large-scale structure calculations even if we have a peta-flops computer.

  - Derivation of the effective operator
  - Inclusion of the genuine three-body force
  - Diminishing approximations (or truncations) with the development of the computer performance

Collaborators

UMOA

- Ryoji Okamoto (Kyushu Inst. of Tech.)
- Kenji Suzuki (Kyushu Inst. of Tech.)

“No-core” shell model

- Takahiro Mizusaki (Senshu Univ.)
- Takaharu Otsuka (Univ. of Tokyo)
- Takashi Sebe (Hosei Univ.)
- Akito Arima (Japan Science Foundation)

Application of the “No-core” shell model to ^{18}O

- Bruce R. Barrett (Univ. of Arizona)