Shell-model description of ^{16}C with modern NN forces

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Anomalously Hindered $E2$ Strength $B(E2; 2_1^+ \rightarrow 0^+)$ in ^{16}C

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The electric quadrupole transition from the first 2^+ state to the ground 0^+ state in ^{16}C is studied through measurement of the lifetime by a recoil shadow method applied to inelastically scattered radioactive ^{16}C nuclei. The measured mean lifetime is 77 + 14(stat) + 19(syst) ps. The central value of mean lifetime corresponds to a $B(E2; 2_1^+ \rightarrow 0^+)$ value of $0.63 e^2$ fm^4, or 0.26 Weisskopf units. The transition strength is found to be anomalously small compared to the empirically predicted value.

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Experiment

Theoretical studies

- **Shell model**
  - **Eff. int.**
    - **for the 0*p*1*s*0*d* shells**
  - **Eff. charge**
- **AMD**
  - **Eff. int.**
    - **MV1(central) + G3RS (spin-orbit)**
  - **Bare charge**

Both methods can reproduce the systematic decrease of the experimental $B(E2; 2_1^+ \rightarrow 0_1^+)$ values in the neutron-rich C isotopes with increasing the mass number up to $A = 16$. However, the absolute values are considerably larger than the experiments.

New approach to neutron-rich C isotopes

- **Large-scale shell model**

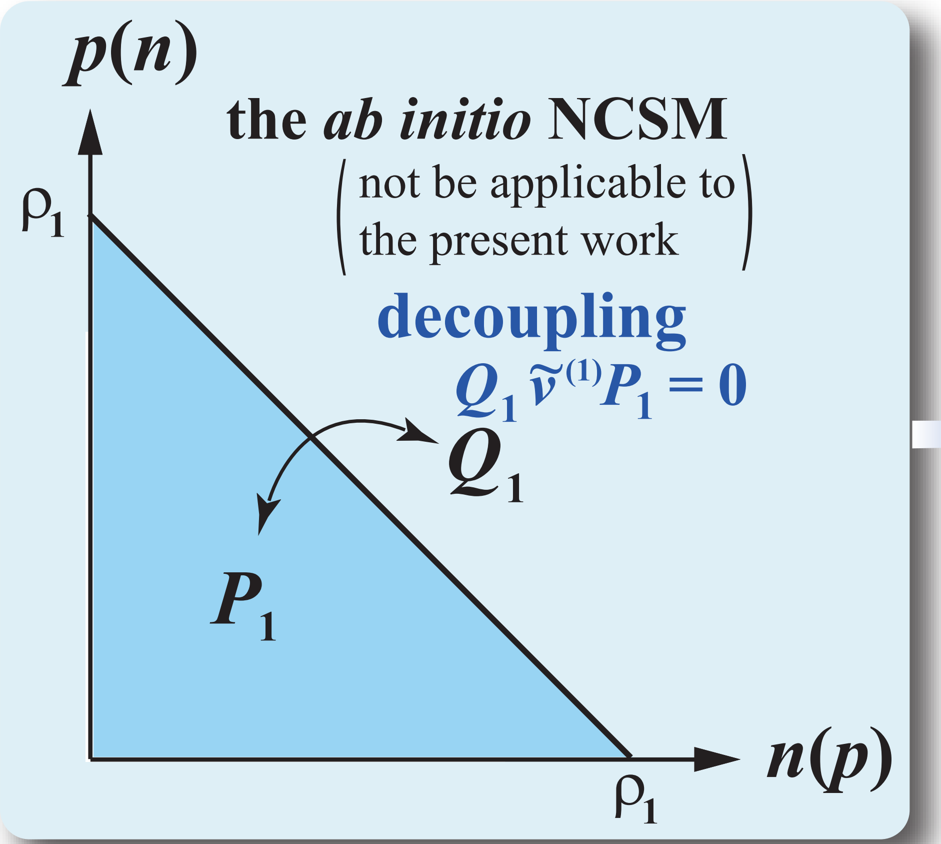
  - Code: newly developed version of MSHELL
  - Model space: the 0*s*—1*p*0*f* shells
  - Nucleon excitation: up to 2 nucleons from the occupied shells for ^{14}C
up to 2 nucleons to the 1*p*0*f* shells
  - Bare charge

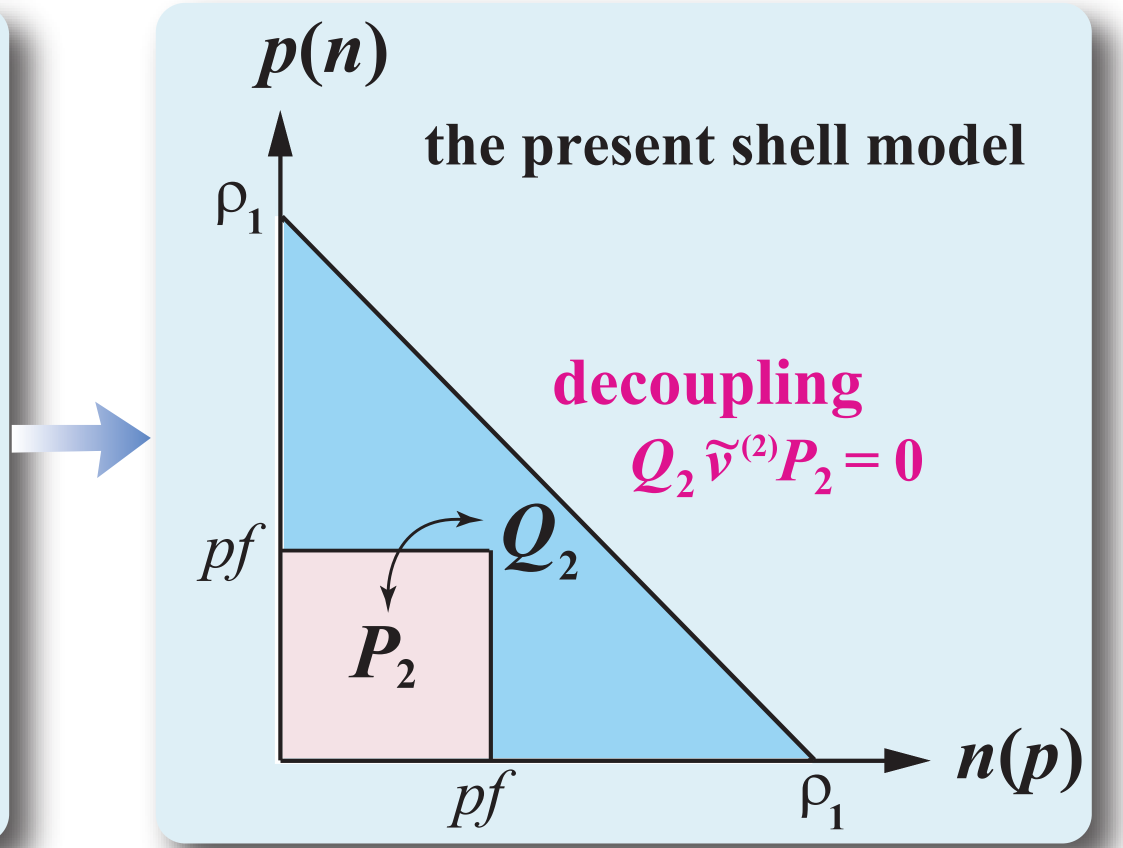
- **Microscopic effective interaction**

  Derived from a high-precision NN interaction (CD Bonn, ···) and the Coulomb force in the neutron-proton formalism for the given model space through a unitary-transformation theory

Derivation of effective interaction

- **Eff. int. in a huge model space**
- **Eff. int. in the 0*s*－1*p*0*f* shells**

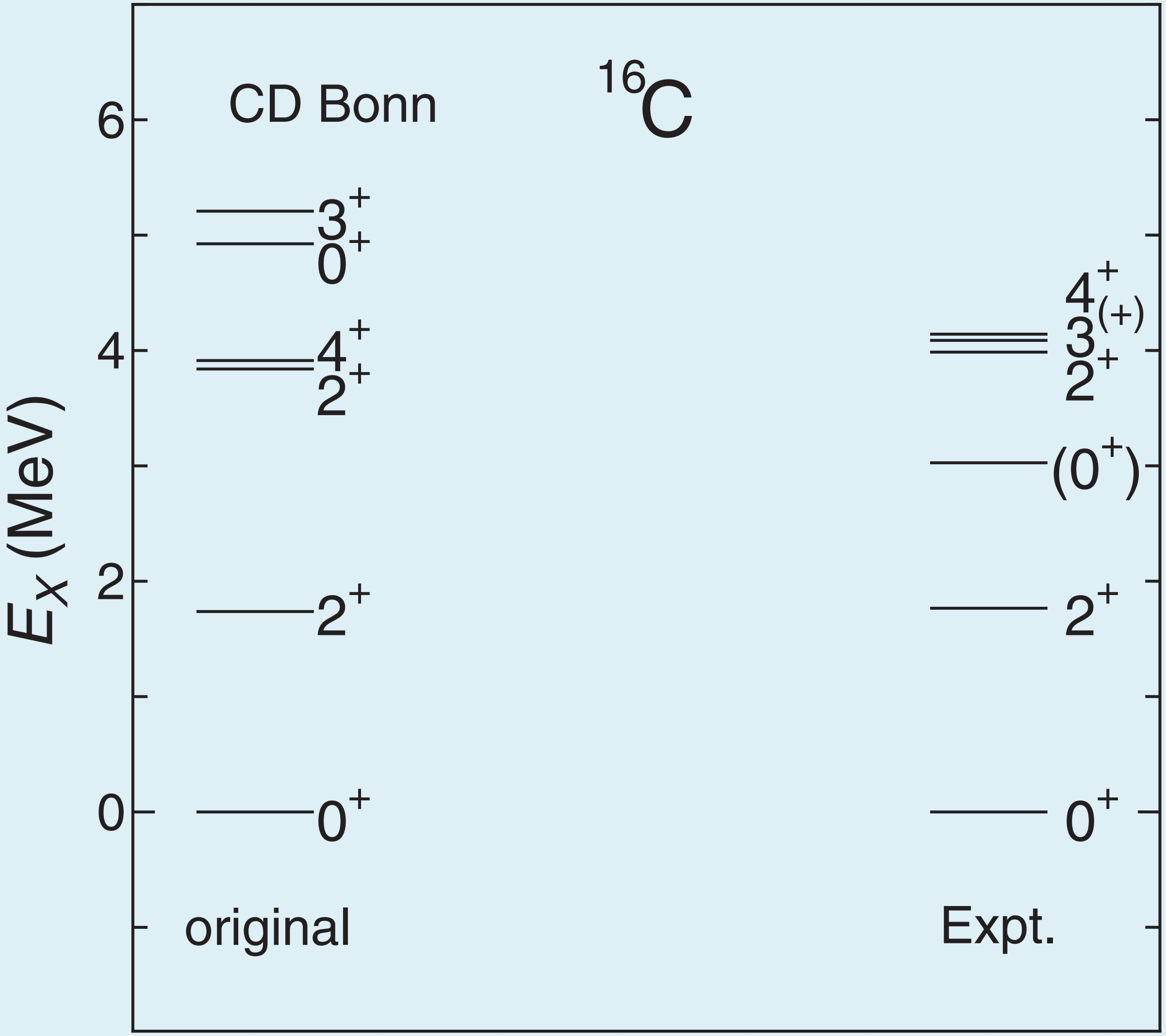




$\rho_1 = 2n_a + l_a + 2n_b + l_b$ ($\{n_a, l_a\}$ and $\{n_b, l_b\}$: sets of h.o. quantum numbers of two-body states)

(Unitary transformation
- S. Okubo, Prog. Theor. Phys. **12**, 603 (1954)
- S. F., R. Okamoto, and K. Suzuki, Phys. Rev. **C** 69, 034328 (2004))

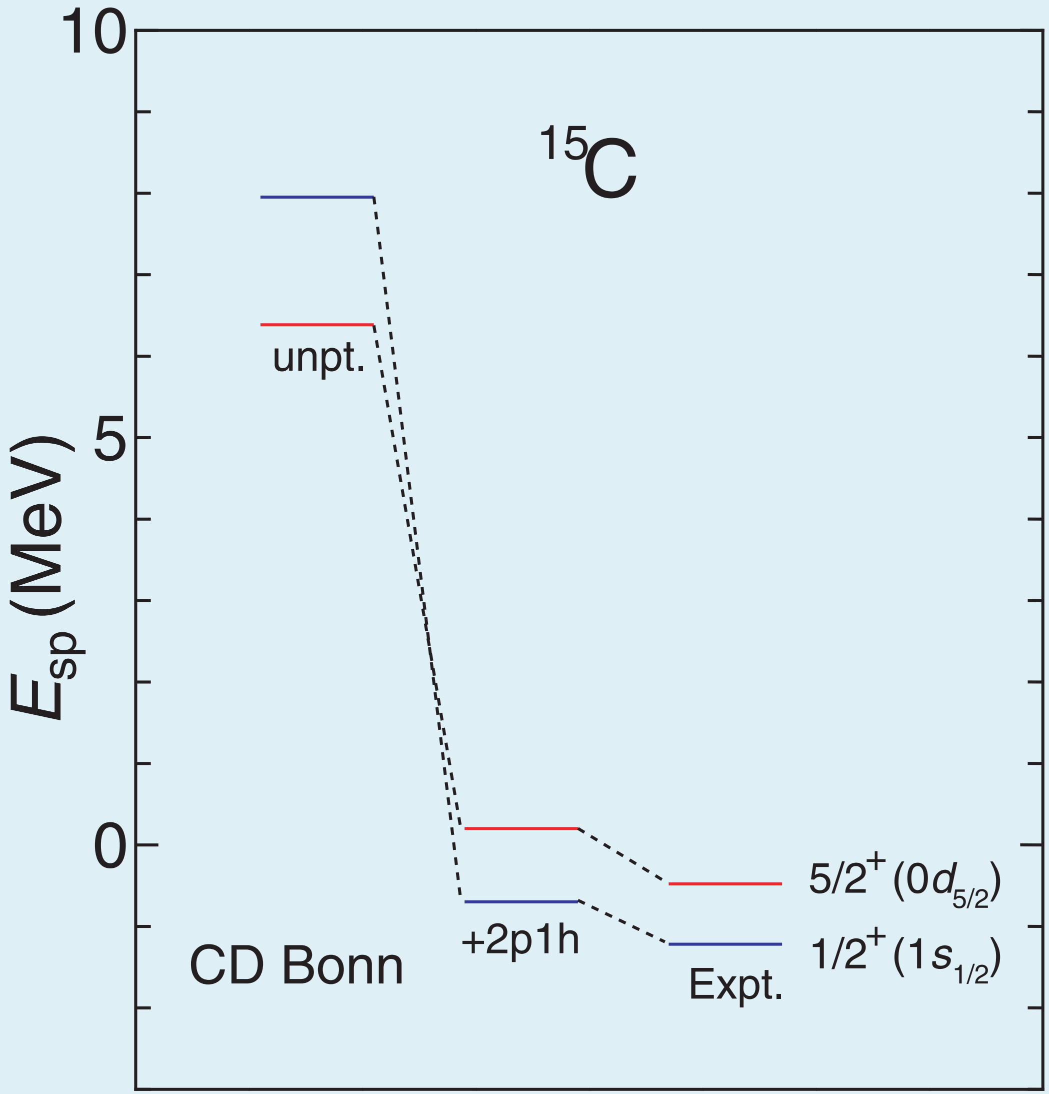
Low-lying energy levels in ^{16}C



$B(E2; 2_1^+ \rightarrow 0_1^+)$ in $e^2\text{fm}^4$

original	Expt.
1.27	$0.63 \pm 0.11\text{(stat)} \pm 0.16\text{(syst)}$

Single-particle energies in ^{15}C



Calculated results by the unitary-model-oparator approach (UMOA)

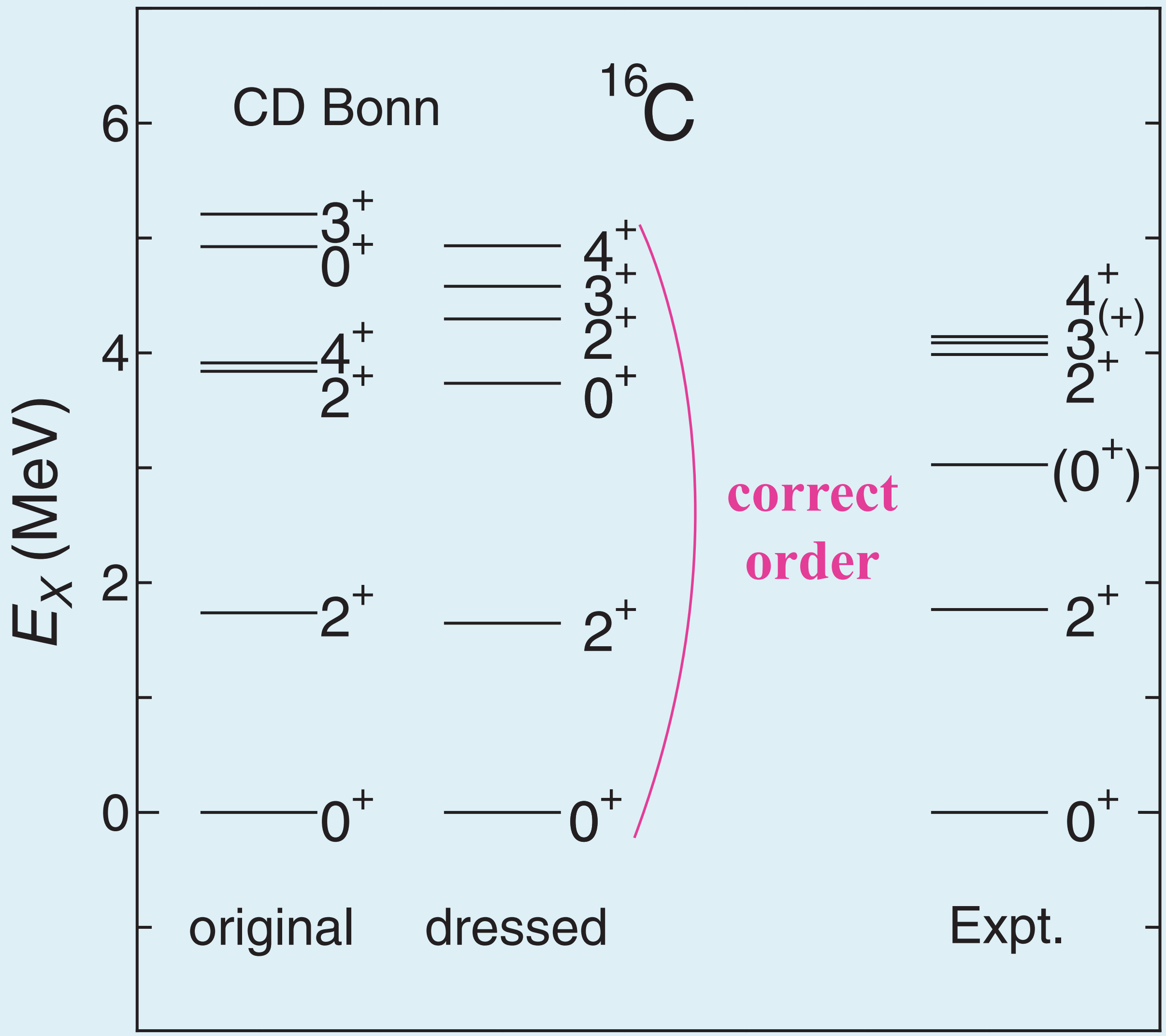
In the present shell model without any adjustable parameters
→ wrong order for the $1/2^+$ and $5/2^+$ states in ^{15}C due to the *small* model-space size

To remedy the wrong order and reproduce the binding energies for the $1/2^+$ and $5/2^+$ states of the UMOA results
→ introduce a minimal refinement on the one-body energies for the $0d_{5/2}$ and $1s_{1/2}$ orbits of the neutron

The calculated results are denoted by

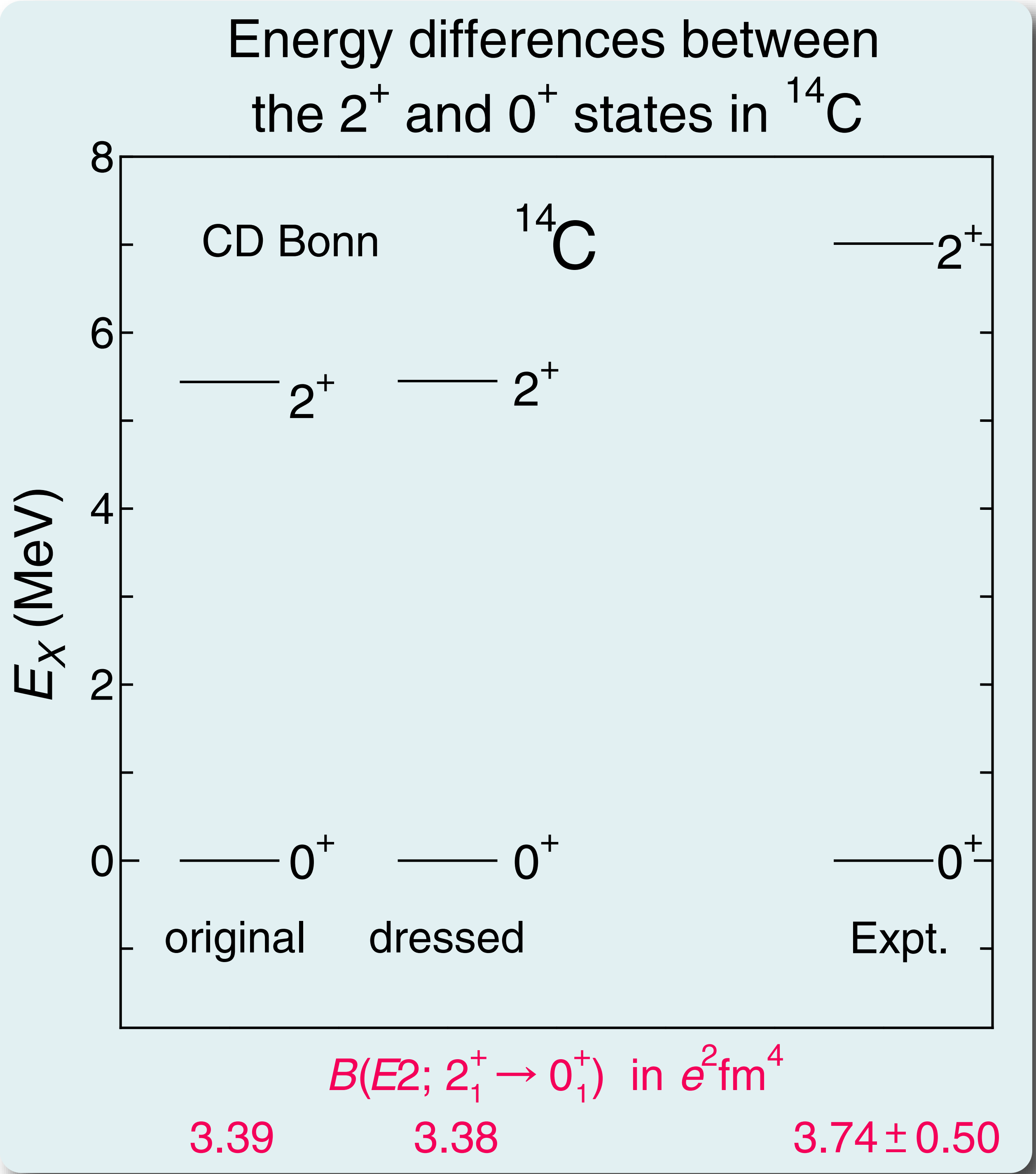
"dressed"

Low-lying energy levels in ^{16}C



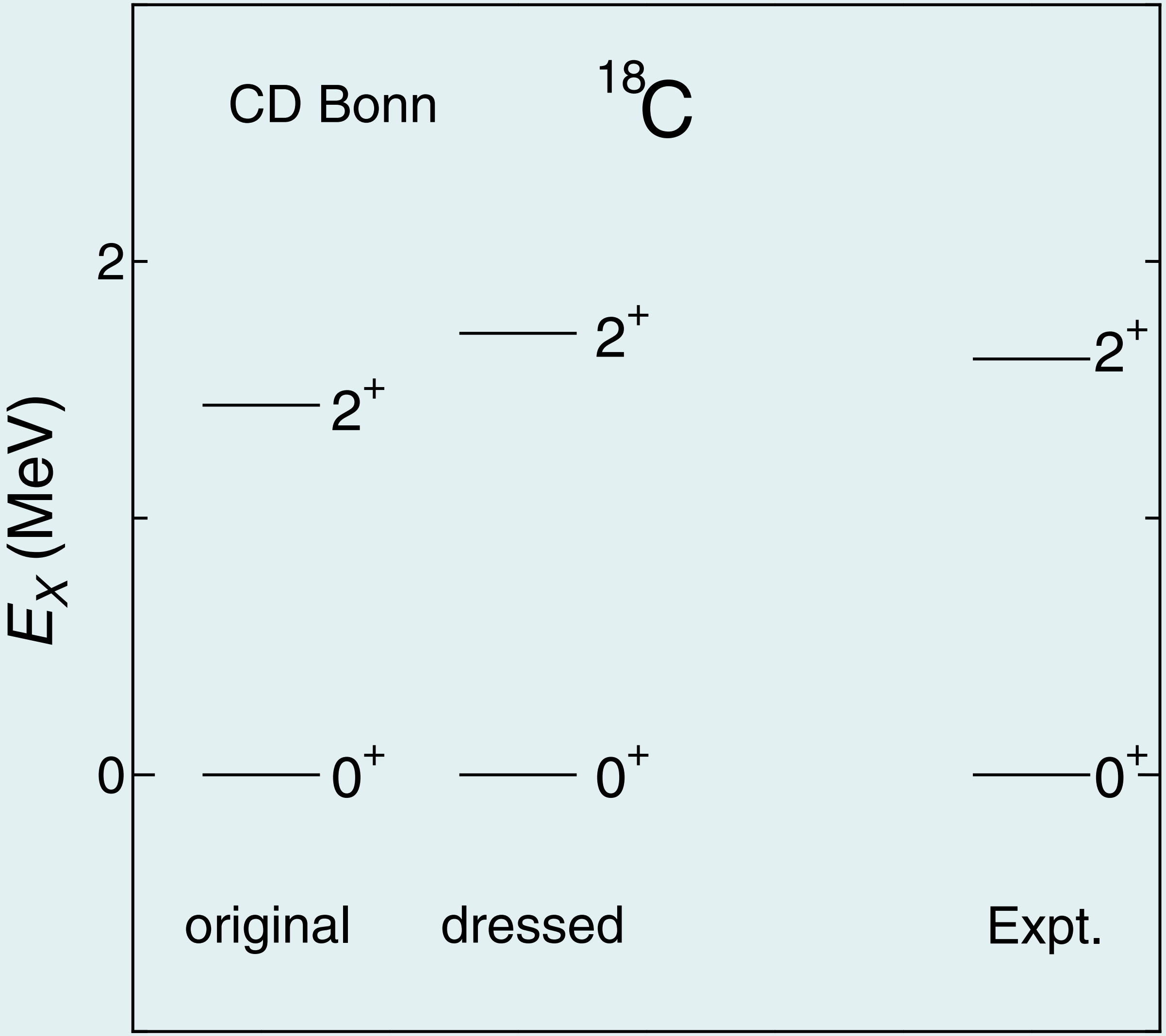
$B(E2; 2^+ \rightarrow 0^+)$ in $e^2 fm^4$

original	dressed	Expt.
1.27	0.85	$0.63^{\pm 0.11(stat)}_{\pm 0.16(syst)}$



Energy differences between
the 2^+ and 0^+ states in ^{14}C
8
6
4
2
0
E_X (MeV)
CD Bonn
^{14}C
2^+
2^+
2^+
0^+
0^+
0^+
original
dressed
Expt.
$B(E2; 2_1^+ \rightarrow 0_1^+)$ in e^2fm^4
3.39
3.38
3.74 ± 0.50

Energy differences between the 2^+ and 0^+ states in ^{18}C



$B(E2; 2_1^+ \rightarrow 0_1^+)$ in $e^2 fm^4$

original	dressed	Expt.
1.18	2.03	?

Occupation numbers in ^{14}C and ^{16}C

for "dressed"

	J^{π}	*p* or *n*	$0p_{3/2}$	$0p_{1/2}$	$1s_{1/2}$	$0d_{5/2}$
^{14}C	0^+_1	*p*	3.58	0.27	0.10	0.02
		n	3.87	1.94	0.08	0.02
	2^+_1	*p*	2.82	1.02	0.09	0.02
		n	3.87	1.94	0.08	0.03
^{16}C	0^+_1	*p*	3.40	0.42	0.12	0.02
		n	3.87	1.94	0.95	1.03
	2^+_1	*p*	3.39	0.44	0.12	0.02
		n	3.88	1.94	0.80	1.19

Summary

- **Developed a new shell-model framework to microscopically investigate neutron- or proton-rich exotic nuclei**
  - **Large-scale shell-model code**
    new MSHELL
  - **Microscopic effective interaction**
    derived from the CD-Bonn potential through a unitary-transformation theory
- **Experimental low-lying energy levels and *B*(*E*2) in ^{16}C**
  → well reproduced by the calculation
- **Including the genuine three-body force and diminishing the approximations in the calculation**