現代的核力から出発した大規模殻模型計算による^{16}Cの構造

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1. 最近の^{16}Cについての研究
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KEK原子核研究会「現代の原子核物理　ー多様化し進化する原子核の描像ー」
2006年8月1ー3日, KEK

VOLUME 92, NUMBER 6 PHYSICAL REVIEW LETTERS week ending 13 FEBRUARY 2004

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

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(Received 17 August 2003; published 12 February 2004)

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 $77 \pm 14(\text{stat}) \pm 19(\text{syst})$ ps. The central value of mean lifetime corresponds to a $B(E2; 2_1^+ \rightarrow 0^+)$ value of $0.63 e^2\,\text{fm}^4$, or 0.26 Weisskopf units. The transition strength is found to be anomalously small compared to the empirically predicted value.

DOI: 10.1103/PhysRevLett.92.062501 PACS numbers: 23.20.Js, 21.10.Tg, 27.20.+n, 29.30.Kv

Experiment

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Physics Letters B 586 (2004) 34–40
PHYSICS LETTERS B
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Decoupling of valence neutrons from the core in ^{16}C

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Received 4 December 2003; received in revised form 10 February 2004; accepted 11 February 2004

Editor: J.P. Schiffer

Abstract

The neutron and proton excitations in ^{16}C nucleus have been investigated by use of the Coulomb-nuclear interference method applied to the $^{208}Pb + ^{16}C$ inelastic scattering. Angular distribution of the ^{16}C nuclei in the inelastic channel populating the first 2^+ state has been measured. The neutron and proton transition matrix elements, M_n and M_p, have been determined from the "Coulomb" and "matter" deformation-length parameters obtained by distorted wave calculations. The M_p or its corresponding $B(E2; 2_1^+ \to 0^+)$ value was found to be extremely small: 0.28 ± 0.06 Weisskopf units consistent with a recent lifetime measurement. Furthermore, the extracted M_n/M_p ratio has an unexpectedly large value of 7.6 ± 1.7. These results suggest that the 2_1^+ state in ^{16}C is a nearly pure valence neutron excitation.

PACS: 25.70.De; 24.10.Eq; 29.30.Kv; 21.10.Gv; 27.20.+n

Keywords: Coulomb excitation of ^{16}C; Angular distribution; Distorted wave calculation; Neutron and proton transition matrix elements

Experiment

Shell-model calc. in the *psd* ($2\hbar\omega$) space

(R. Fujimoto, Ph. D. Thesis, Univ. of Tokyo, 2003)

$B(E2; 2_1^+ \rightarrow 0_1^+)$ in $e^2\mathrm{fm}^4$ ($e_p = 1.3e$, $e_n = 0.5e$)

	present	PSDMK2	PSDWBP	PSDWBT	Expt.
^{12}C	11.78	12.06	11.41	11.36	8.2 ± 1.0
^{14}C	8.18	8.69	8.11	8.18	3.74 ± 0.50
^{16}C	8.05	8.37	8.70	8.05	0.63 ± 0.11(stat) ± 0.16(syst)
^{18}C	10.26	13.18	12.81	12.33	?

New approach to neutron-rich C isotopes

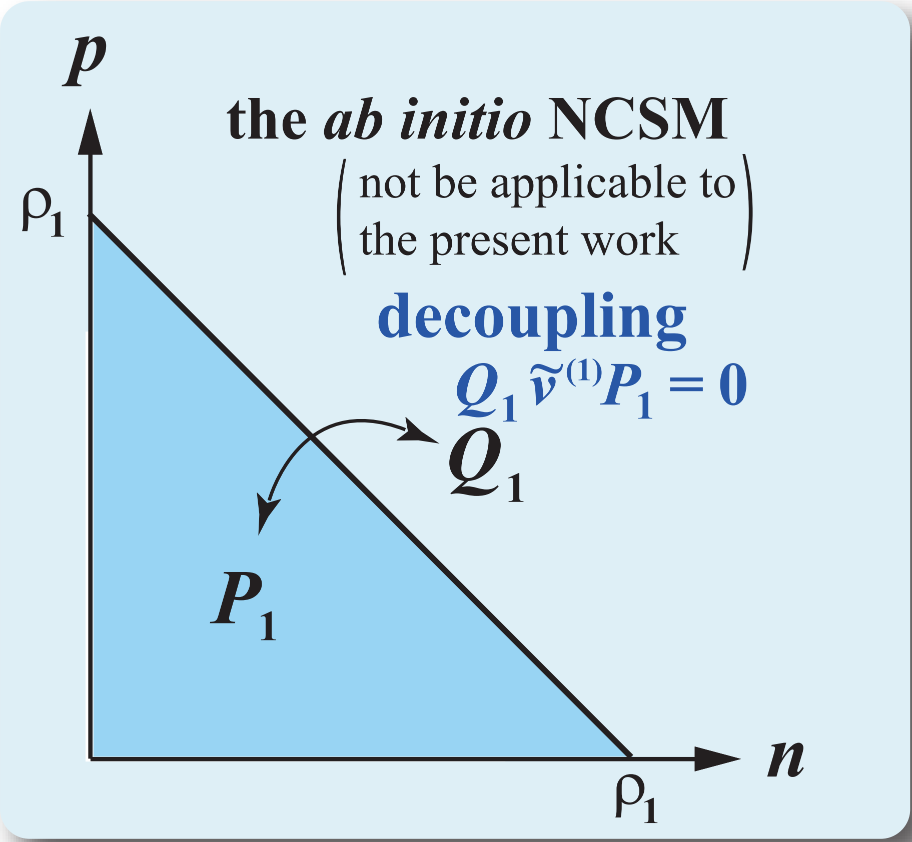
- **Large-scale shell model**
  - Code: newly developed version of MSHELL
  - Model space: the 0*s*－1*p*0*f* shells
  - Nucleon excitation: up to 2 nucleons from the occupied shells for ^{14}C
    up to 2 nucleons to the 1*p*0*f* shells
  - Bare charge

- **Microscopic effective interaction**

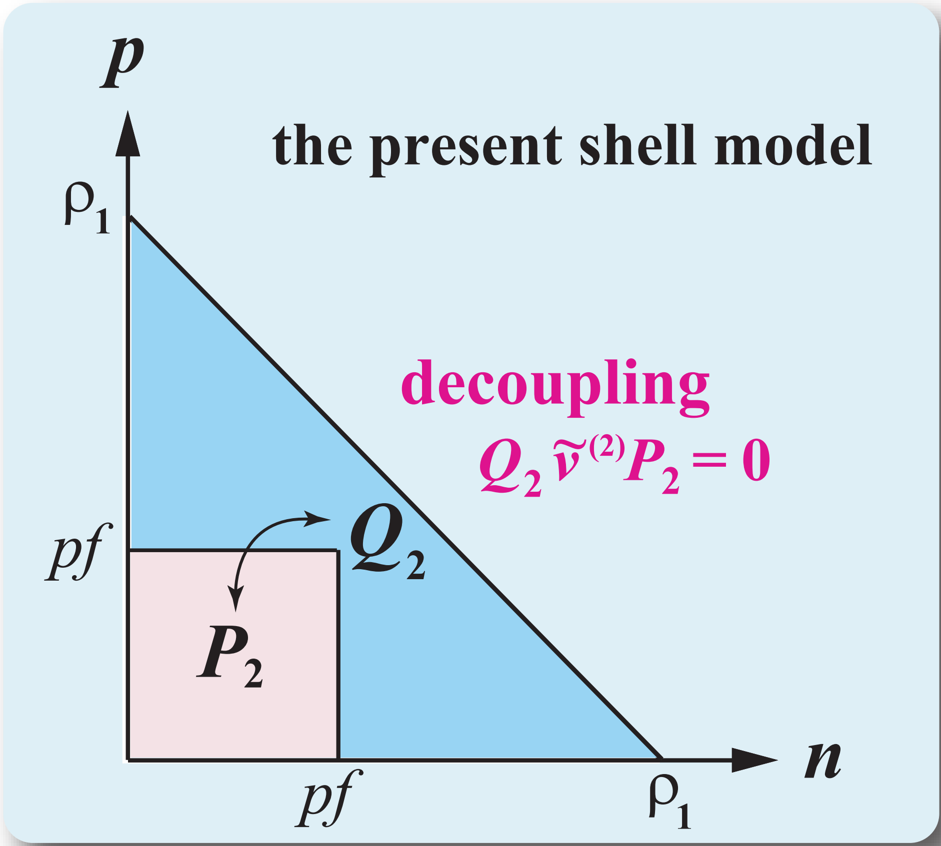
  Derived from a high-precision NN interaction (CD Bonn, ···) and the Coulomb force in the neutron-proton formalism for the given model space through a unitary-transformation theory

Derivation of effective interaction

- **Eff. int. in a huge model space**



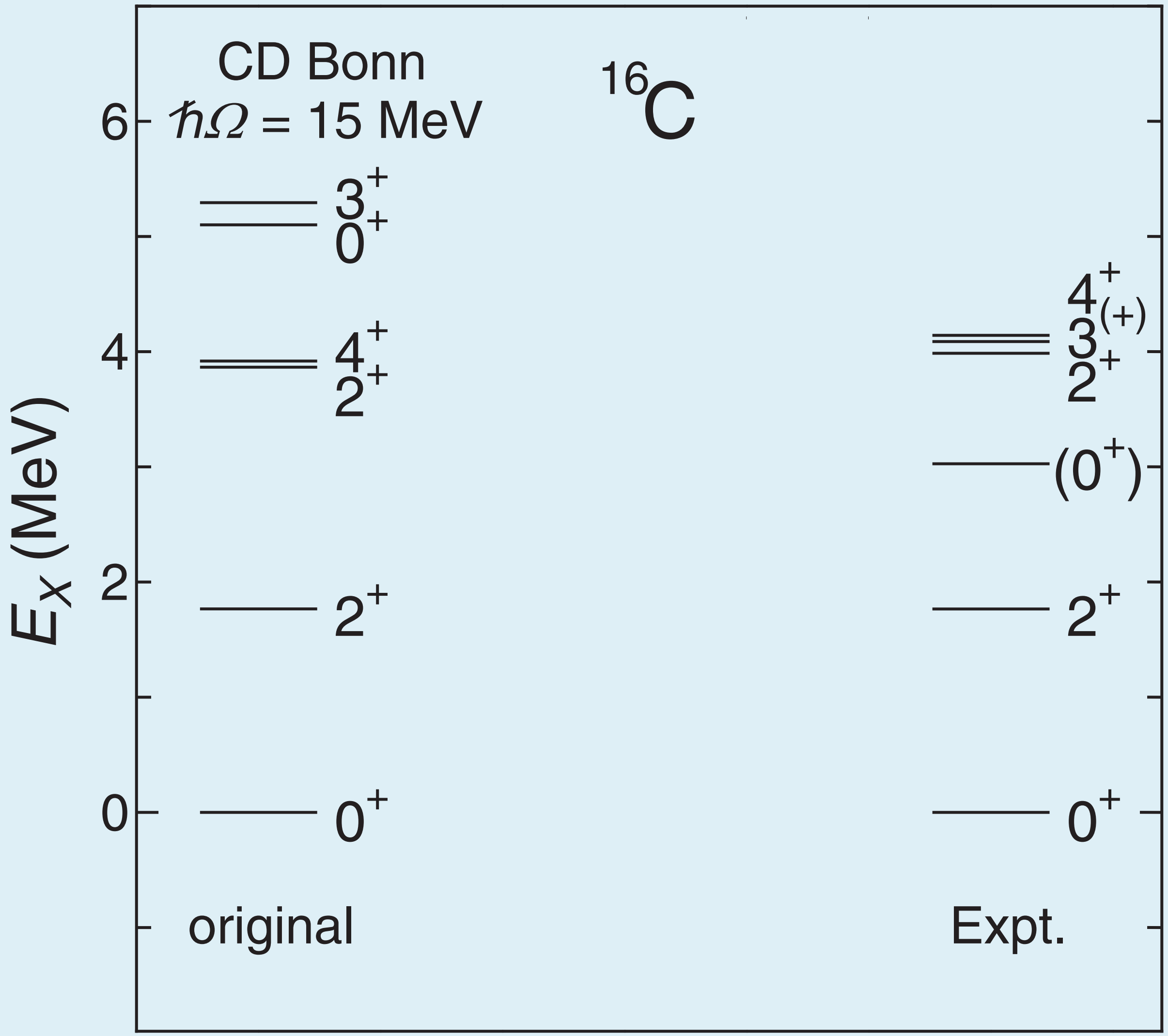
- **Eff. int. in the $0s-1p0f$ shells**



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

(For details,
・S. F., T. Mizusaki, T. Otsuka, T. Sebe, and A. Arima, nucl-th/0602002.
・S. F., R. Okamoto, and K. Suzuki, Phys. Rev. C **69**, 034328 (2004).)

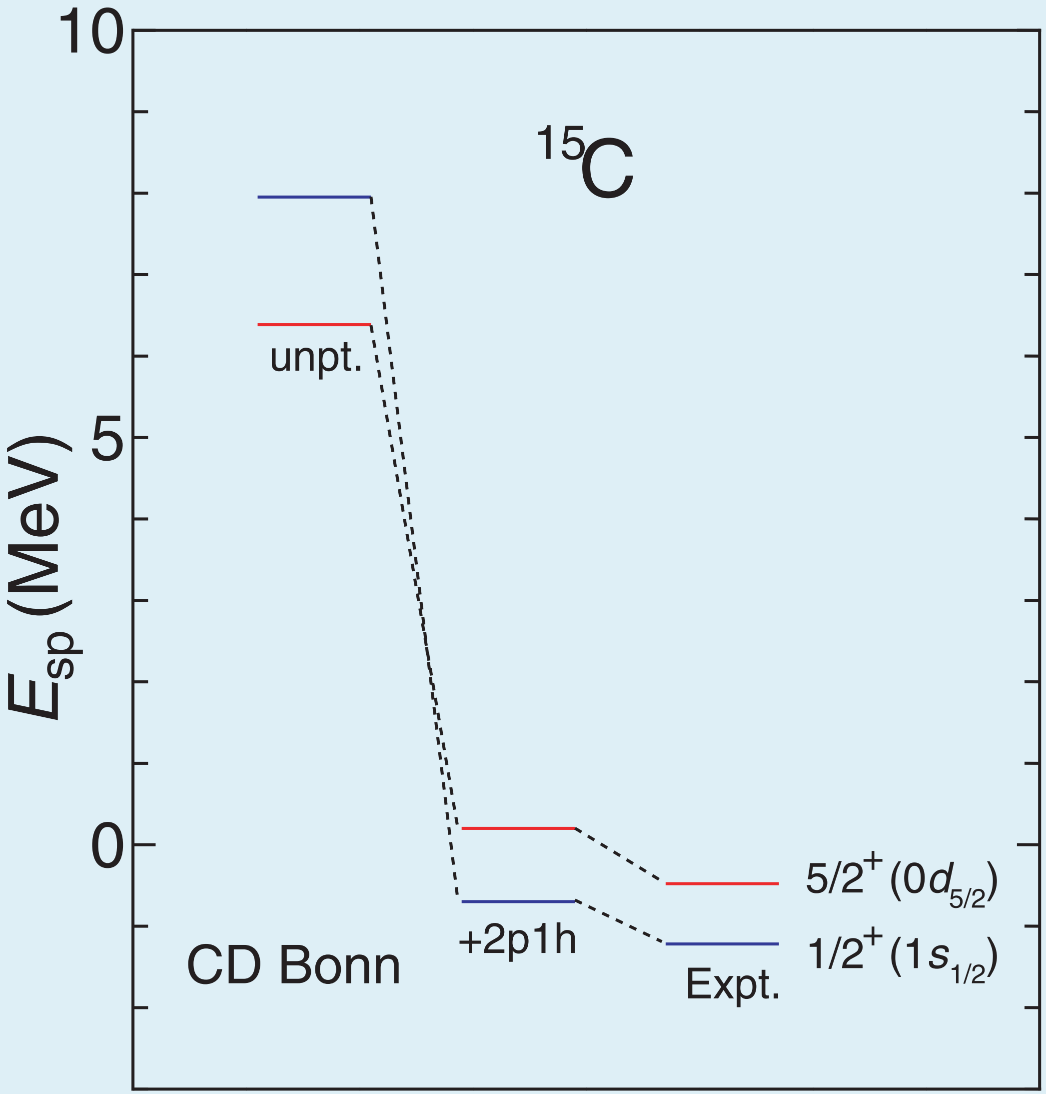
Low-lying energy levels in ^{16}C



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

1.30 $\quad$ $0.63^{\pm 0.11(stat)}_{\pm 0.16(syst)}$

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 ordering for the $1/2^+$ and $5/2^+$ states in ^{15}C due to the *small* model-space size

↓

To remedy the wrong ordering and re-produce the binding energies for the $1/2^+$ and $5/2^+$ states of the UMOA results

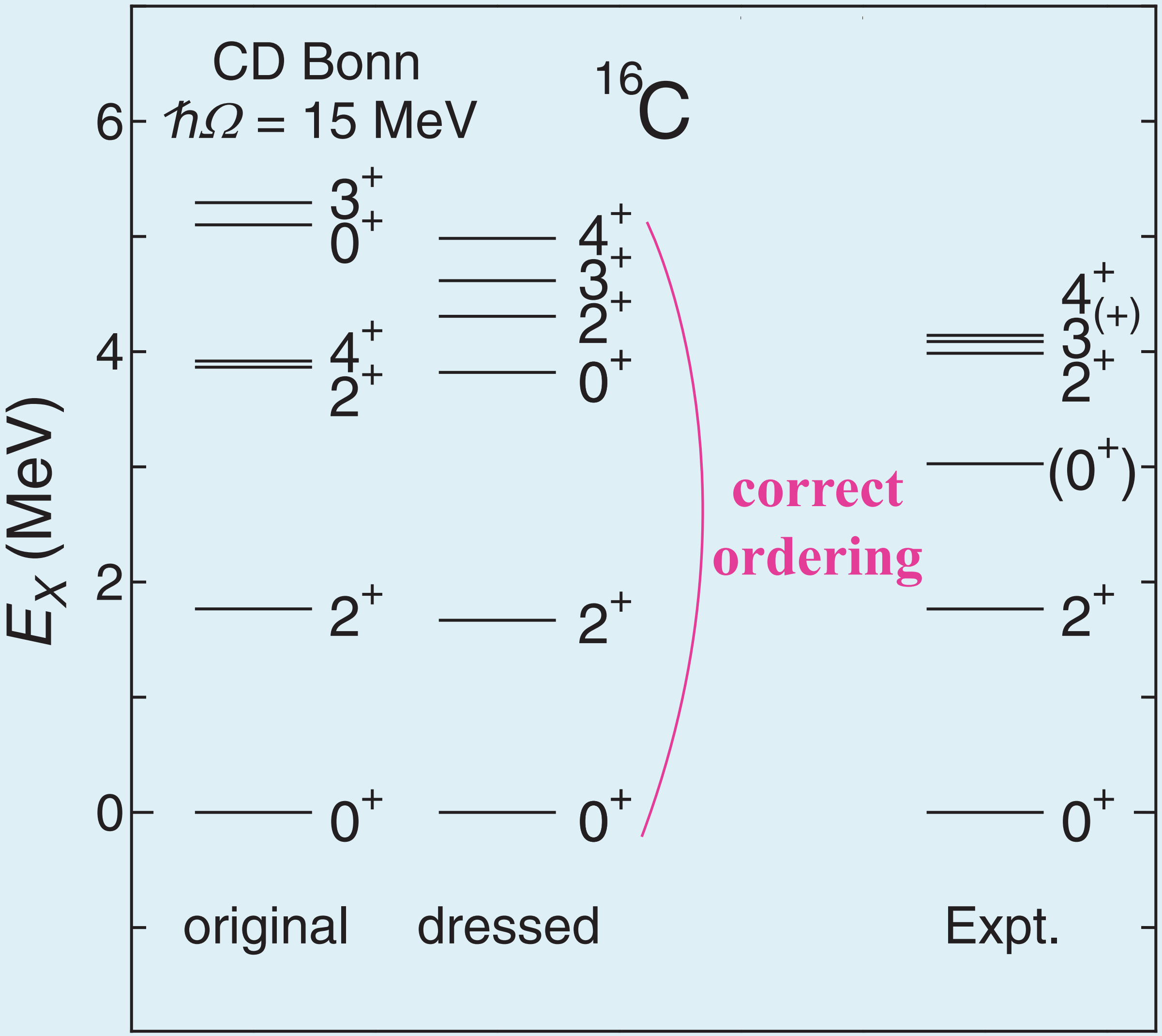
→ introduce a minimal refinement of the one-body energies for the $0d_{5/2}$ and $1s_{1/2}$ orbits of the neutron

↓

The calculated results are denoted by

"dressed"

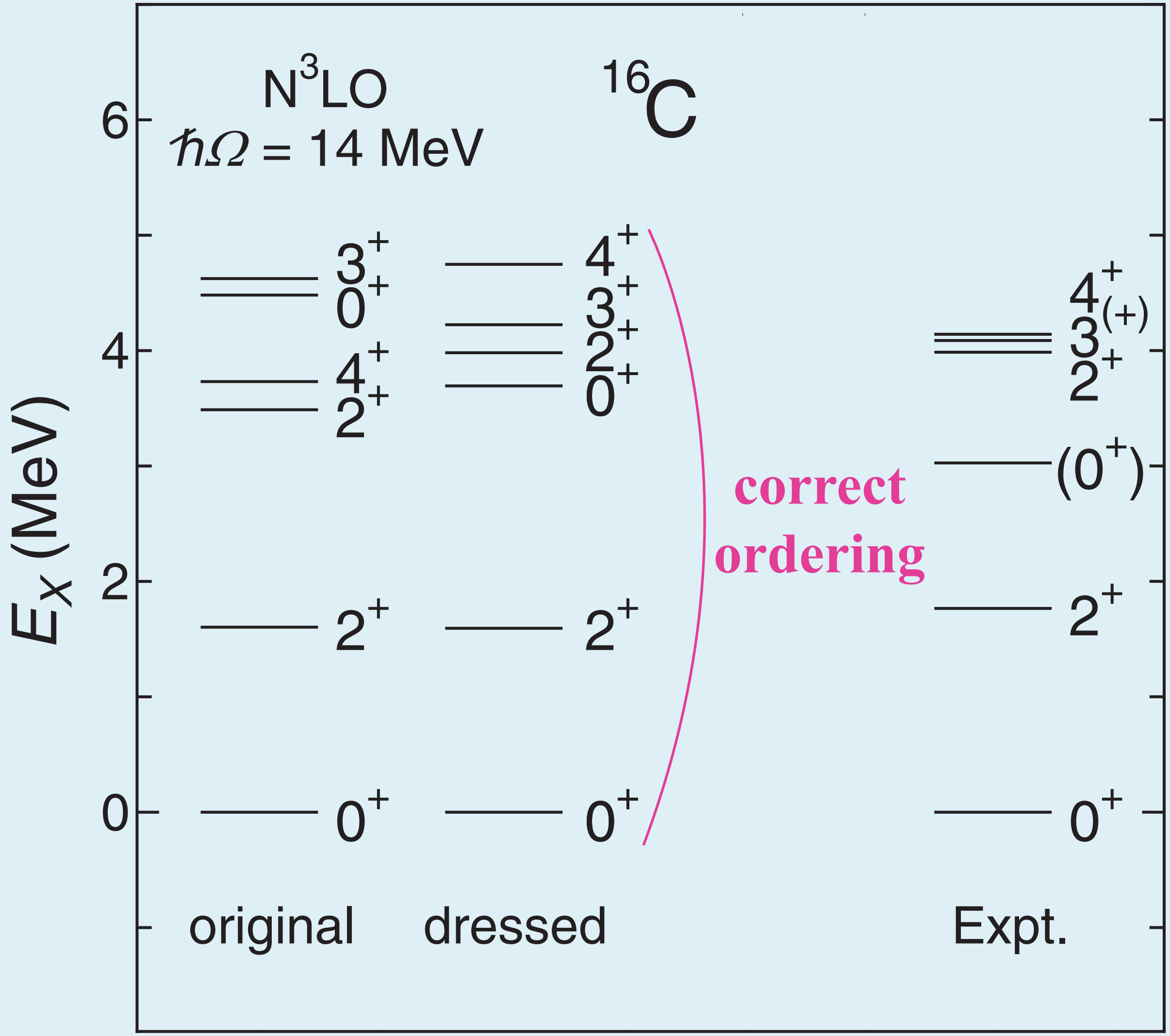
Low-lying energy levels in ^{16}C



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

1.30   0.84 $0.63^{\pm 0.11 (\mathrm{stat})}_{\pm 0.16 (\mathrm{syst})}$

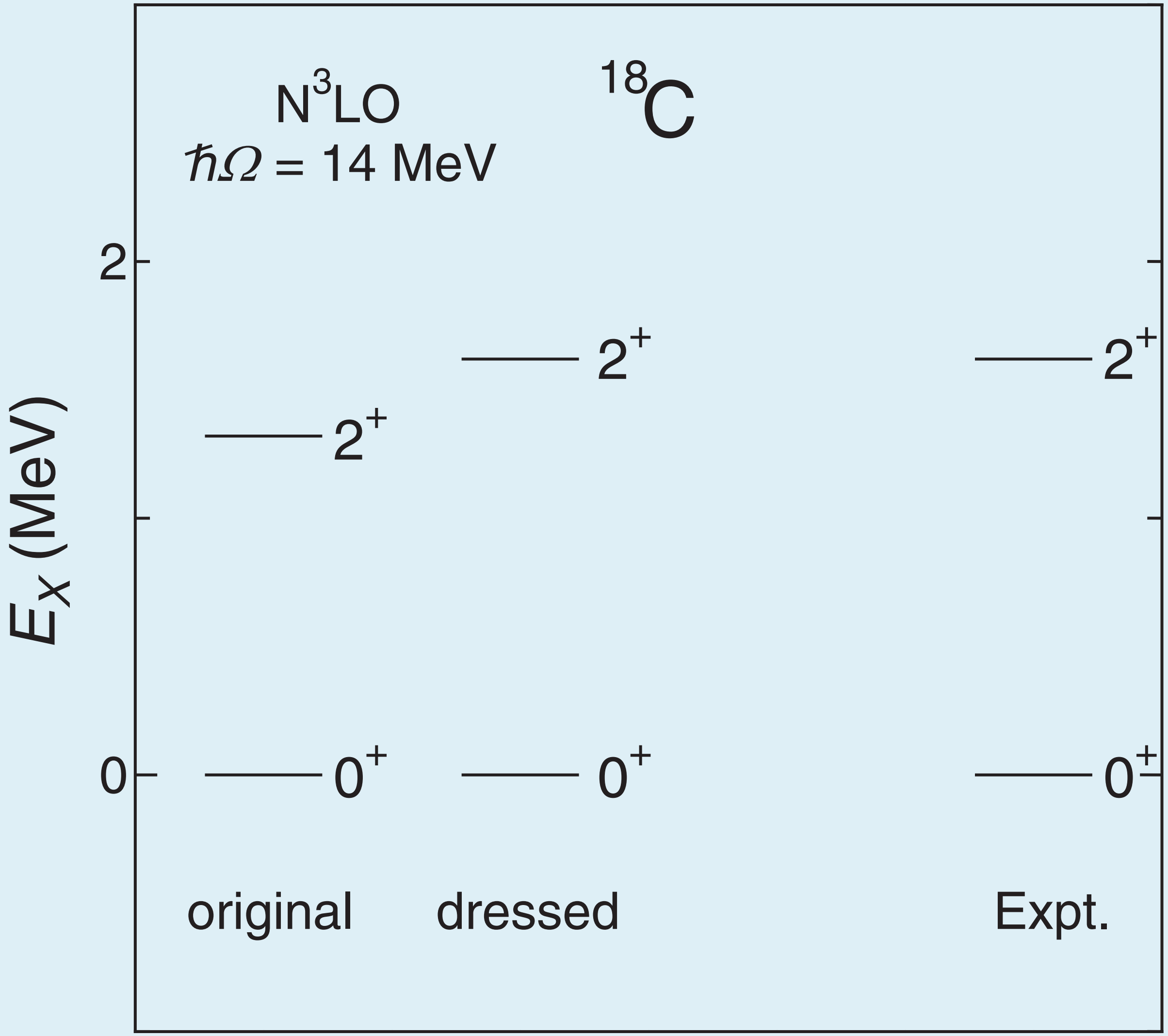
Low-lying energy levels in ^{16}C



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

original	dressed	Expt.
1.38	0.91	$0.63^{\pm 0.11(\mathrm{stat})}_{\pm 0.16(\mathrm{syst})}$

Energy differences between the 2_1^+ and 0_1^+ states in ^{18}C



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

original	dressed	Expt.
1.38	2.47	?

$B(E2;\, 2_1^+ \rightarrow 0_1^+)$ in $^{14,16,18}C$

for "dressed"

	CD Bonn	N^3LO	Expt.
^{14}C	3.42	4.11	3.74±0.50
^{16}C	0.84	0.91	0.63 $\pm$ 0.11(stat) $\pm$ 0.16(syst)
^{18}C	2.10	2.47	?

in e^2fm^4

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 modern NN interactions through a unitary-transformation theory

- **Experimental low-lying energy levels and $B(E2)$ in neutron-rich carbon isotopes including ^{16}C**
  → well reproduced by the calculation

- **Including the genuine three-body force and diminishing the approximations in the calculation**