VIII International Conference on
Hypernuclear & Strange Particle Physics
Jefferson Lab, Newport News, Virginia
October 14-18, 2003

Density-dependent Hartree-Fock Calculations in Hypernuclei

Toru Harada

Osaka Electro-Communication University
Neyagawa 572-8530, Osaka, Japan
harada@isc.osakac.ac.jp

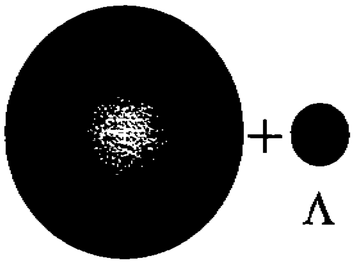
In this talk,

We perform density-dependent Hartree-Fock (DDHF) calculations in hypernuclei by using the effective NN, YN interaction with a finite range.

Contents

1. **Motivation and Purpose**
2. **DDHF framework**
3. **Results: $^{5}_{\Lambda}$He ($_{\Lambda\Lambda}^{6}$He), $^{17}_{\Lambda}$O**
4. **Summary and Future investigation**

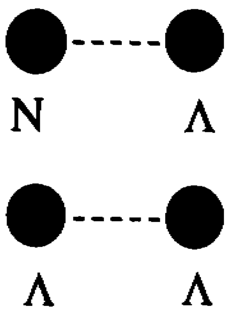
Core polarization effects



- Hartree-Fock calculations M. Rayet, Ann.Phys.102(1976)226S.
- Skyrme-density-dependent HF D.E.Lanskoy, PRC58(1998)3351.
- Relativistic mean-field approach S. Marcos et al.,PRC57(1998)1178.
- Few-body variational calculation A.R.Bodmer et al.,NPA609(1996)326
- Cluster-model calculation E. Hiyama, et al.,PRC59(1999)2351

→ The Λ as an "impurity" in nuclei to probe nuclear aspects.

To understand properties of YN, YY interactions



- OBE models Th.A. Rijken, et al, PRC59(1999)21; PRC59(1999)3009

NHC-D,-F / NSC89 —(improve, spin-spin)→ NSC97a-f —(improve)→ ESC

- (3q)-(3q) RGM+EMEP Y. Fujiwara et al., PRC64(2001)054001

RGM-F —(upgrade, +all PS)→ FSS —(upgrade !, +V-meson)→ fss2

Observation of a ${}_{\Lambda\Lambda}^{6}\mathrm{He}$ Double Hypernucleus

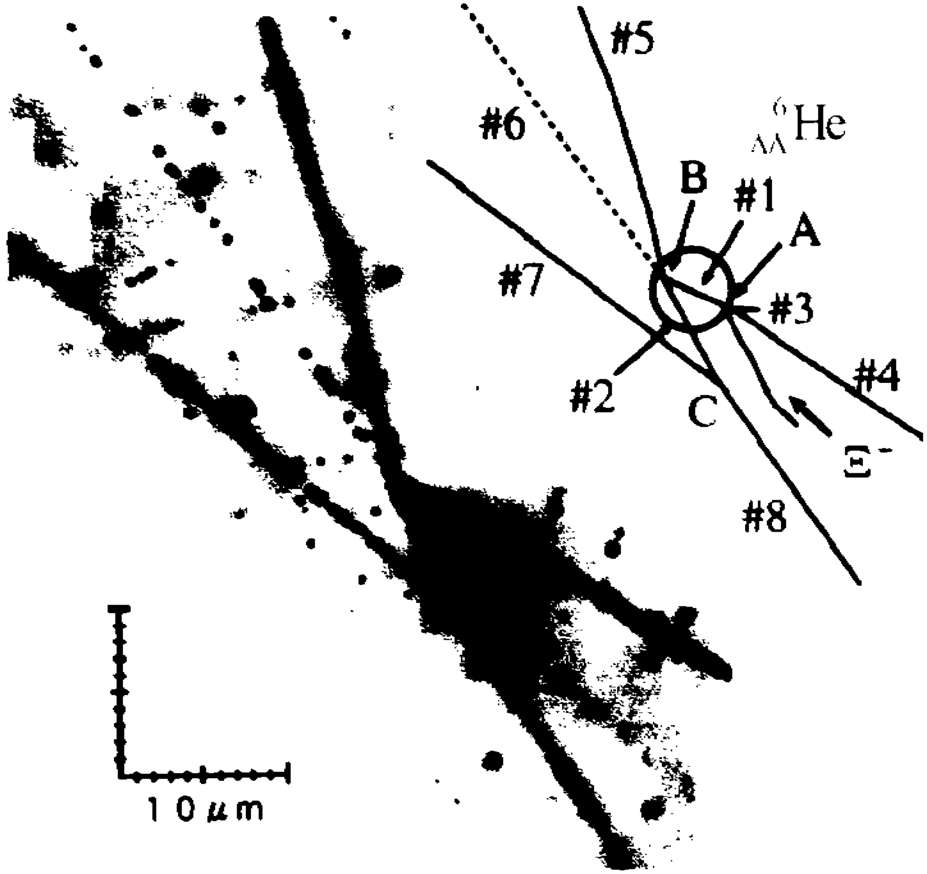
NAGARA event

KEK-E373

H.Takahashi et al., PRL87(2001)212502

$$^{12}\mathrm{C}+\Xi^- \to {}_{\Lambda\Lambda}^{6}\mathrm{He}+{}^{4}\mathrm{He}+t$$

$$\hookrightarrow {}_{\Lambda}^{5}\mathrm{He}+p+\pi^-$$



${}_{\Lambda\Lambda}^{6}\mathrm{He}$

$$B_{\Lambda\Lambda} = 7.25 \pm 0.19^{+0.18}_{-0.11}\,\mathrm{MeV}$$

$$\Delta B_{\Lambda\Lambda} = 1.01 \pm 0.20^{+0.18}_{-0.11}\,\mathrm{MeV}$$

$$\Delta B_{\Lambda\Lambda}({}_{\Lambda\Lambda}^{6}\mathrm{He}) = B_{\Lambda\Lambda}({}_{\Lambda\Lambda}^{6}\mathrm{He}) - 2B_{\Lambda}({}_{\Lambda}^{5}\mathrm{He})$$

-3.12±0.02

$\Delta B_{\Lambda\Lambda}({}_{\Lambda\Lambda}^{6}\mathrm{He}) \approx 4.7$ MeV D.J. Prowse, PRL17(1966)783

$\Delta B_{\Lambda\Lambda}({}_{\Lambda\Lambda}^{10}\mathrm{Be}) \approx 4.5$ MeV M. Danysz et al., NP49(1963)121

≈ 1.3 MeV $({}_{\Lambda\Lambda}^{10}\mathrm{Be} \to {}_{\Lambda}^{9}\mathrm{Be}^*(3.1\mathrm{MeV})+p+\pi^-)$

$\Delta B_{\Lambda\Lambda}({}_{\Lambda\Lambda}^{13}\mathrm{Be}) \approx 4.8$ MeV S. Aoki et al., PTP85(1991)1287

⇨ **There is rather a weak attraction in the ΛΛ interaction !?**

Rearrangement effects on the core-nucleus ^{4}He

Ab initio calculation with realistic potentials

H. Nemura, Y. Akaishi, T. Suzuki, PRL89(2002)142504

NNNNY NSC97e(S)

$^5_\Lambda$He

$$\Delta E_C({}^5_\Lambda\mathrm{He}) = \left[\langle T_C\rangle + \langle V_{NN}\rangle\right]_{{}^5_\Lambda\mathrm{He}} - \left[\langle T_C\rangle + \langle V_{NN}\rangle\right]_{{}^4\mathrm{He}} \approx 4.7\,\mathrm{MeV}$$

$$\left[\langle V_{NN}(\mathrm{tensor})\rangle\right]_{{}^5_\Lambda\mathrm{He}} - \left[\langle V_{NN}(\mathrm{tensor})\rangle\right]_{{}^4\mathrm{He}} \approx 2.9\,\mathrm{MeV}$$

reduction

⇨ **Due to the tensor forces of NN, NΛ-ΣN coupling channels.**

Brueckner rearrangement effects

M. Kohno, Y. Fujiwara, Y. Akaishi, PRC(2003)

$^5_\Lambda$He

$$\Delta PE \simeq -\frac{\kappa_{NN}}{1+\kappa_{NN}}\left[e_\Lambda({}^5_\Lambda\mathrm{He}) - \langle t_\Lambda\rangle - \Delta T_{\mathrm{CM}}\right] = 2.5 \sim 2.9\ \mathrm{MeV}$$

wound integral $\kappa_{NN} \simeq -\sum_{hh'}\langle hh'|\frac{\partial G_{\Lambda\Lambda}}{\partial\omega}|hh'\rangle_{\mathrm{AS}}$ ~ 0.2

$^6_{\Lambda\Lambda}$He

$$\Delta B_{\Lambda\Lambda}({}_{\Lambda\Lambda}^{6}\mathrm{He}) \approx -\langle V_{\Lambda\Lambda}\rangle - 2D + \Delta T_{\Lambda\Lambda}$$

$$\Delta B^{\mathrm{exp.}}_{\Lambda\Lambda} \approx 1\ \mathrm{MeV} \xrightarrow[\text{Rearrangement} \sim 1\ \text{MeV}]{} \langle V_{\Lambda\Lambda}\rangle \approx -2\ \mathrm{MeV}$$

⇨ **Due to the starting-energy (ω) dependence of the effective interactions.**

Our Purpose.

We investigate theoretically the structure of hypernuclei within local-density approximation (LDA) based on the effective NN, YN interactions.

- **Density-dependent Hartree-Fock (DDHF) calculation**

  with density (k_F)- and starting-energy (ω)-dependent effective interactions,
  which are obtained by using Breuckner's g-matrix theory

Tensor force effects

⇓

We discuss the nuclear rearrangement (core-polarization) effects in ${}^{5}_{\Lambda}$He and ${}^{17}_{\Lambda}$O.

Densty-dependent Hartree-Fock (DDHF) calculations

J.W. Negle, PRC4(1970)1969.
X. Campi, D.W.L.Sprung, NPA194(1972)401.
M. Kohno et al., PTP.Suppl.65(1979)200.

Total energy

kinetic energy

$$E = \sum_{\alpha}^{\text{occ.}} \langle \alpha | \hat{t} - \hat{T}_{\text{c.m.}} | \alpha \rangle + \frac{1}{2} \sum_{\alpha,\beta}^{\text{occ.}} \langle \alpha\beta | \hat{V} | \alpha\beta \rangle_{\text{AS}}$$

C.M. kinetic energy

2-body effective pot.

$$\hat{V} = \hat{V}(k_F, \omega) + \hat{V}_{\text{Coul}} + \hat{V}_{\text{LS}}$$

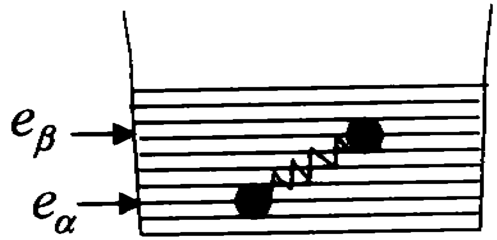
Spin-Orbit

Coulomb

Fermi momentum (k_F)

Starting energy

$$\omega = e_\alpha + e_\beta$$



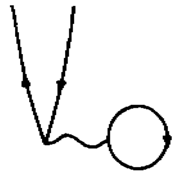
Brueckner's sigle-particle energy

$$e_\alpha = \langle \alpha | \hat{t} | \alpha \rangle + \sum_{\beta}^{\text{occ.}} \langle \alpha\beta | \hat{V} - \hat{V}_{\text{Coul}} | \alpha\beta \rangle_{\text{AS}}$$

DDHF Equations

Hartree-Fock equation with k_F- and ω-dependence

Hartee-Fock



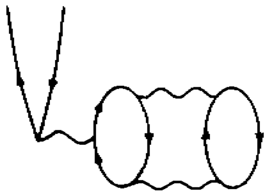
$$(1+S_\alpha)t|\alpha\rangle + \sum_{\beta}^{\text{occ.}}(1+S_\alpha+S_\beta)\langle\ldots\beta|\hat{V}|\alpha\beta\rangle_{\text{AS}}$$

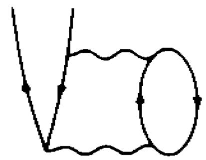
Occupation prob.

s.p. energy

$$+\frac{1}{2}\sum_{\beta,\gamma}^{\text{occ.}}(1+S_\alpha+S_\beta)\langle\beta\gamma|\frac{\partial V}{\partial\rho}\frac{\partial\rho}{\partial\langle\alpha|}|\beta\gamma\rangle_{\text{AS}} = \varepsilon_\alpha|\alpha\rangle$$

$$S_\alpha \equiv \sum_{\beta,\gamma}^{\text{occ.}}\langle\beta\gamma|\frac{\partial V}{\partial\omega}|\alpha\beta\rangle_{\text{AS}}A^{-1}_{\beta\alpha}$$





Starting-energy-rearrangement

Pauli-rearrangement

Gaussian-basis treatment

H.Nakada, M.Sato, NPA699(2002)511; NPA714(2003)696(E)

$$\langle\vec{q}_i|\alpha\rangle = \sum_{p}^{\text{N}} C_{\alpha p}N_a^p r_i^\ell e^{\frac{r_i^2}{b_p^2}}\left[Y_\ell(\hat{\mathbf{r}}_i)\otimes\chi_{\frac{1}{2}}(\sigma_i)\right]_{jm}\chi_{\tau m_\tau}(\tau_i) \qquad N_a^p = \left[\frac{2^{\ell+\frac{5}{2}}}{\Gamma(\ell+\frac{3}{2})b_p^{2(\ell+\frac{3}{2})}}\right]^{1/2}$$

Effective NN Interactions

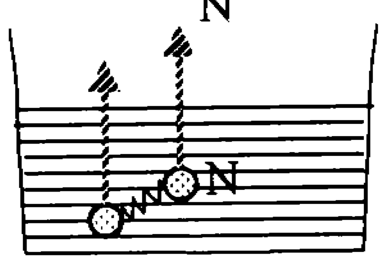
Brueckner's G-matrix in nuclear matter

Pauli-operator

$$g_{B'B}(k_F,\omega)=v_{B'B}+v_{B'B''}\frac{Q_N}{\omega-QTQ}g_{B''B}(k_F,\omega)$$

G-matrix

$k_F = 1.35\,\mathrm{fm}^{-1}$



k_F: Fermi momentum (densitiy) dependent

$\omega = e_\alpha + e_\beta$: Starting-energy dependent

+ Three-body force

N. Yamaguchi et al., PTP62 (1979)1018.

$$g^{ST}(r:k_F,\omega)=\sum_{i=1}^{3}\left(a_i^{ST}+b_i^{ST}k_F+c_i^{ST}k_F^2\right)\cdot h_i^{ST}(\omega_i)\exp(-(r/\lambda_i)^2)$$

k_F-dep. ω-dep.

$$h_i^{ST}(\omega)=(\beta_i\omega-\gamma_i)/(\omega+\alpha_i)$$

M. Kohno et al., PTP.Suppl.65(1979)200.

Modified W2 (MW2) potential

$$\hat{V}(k_F,\omega)+\hat{V}_{LS}$$

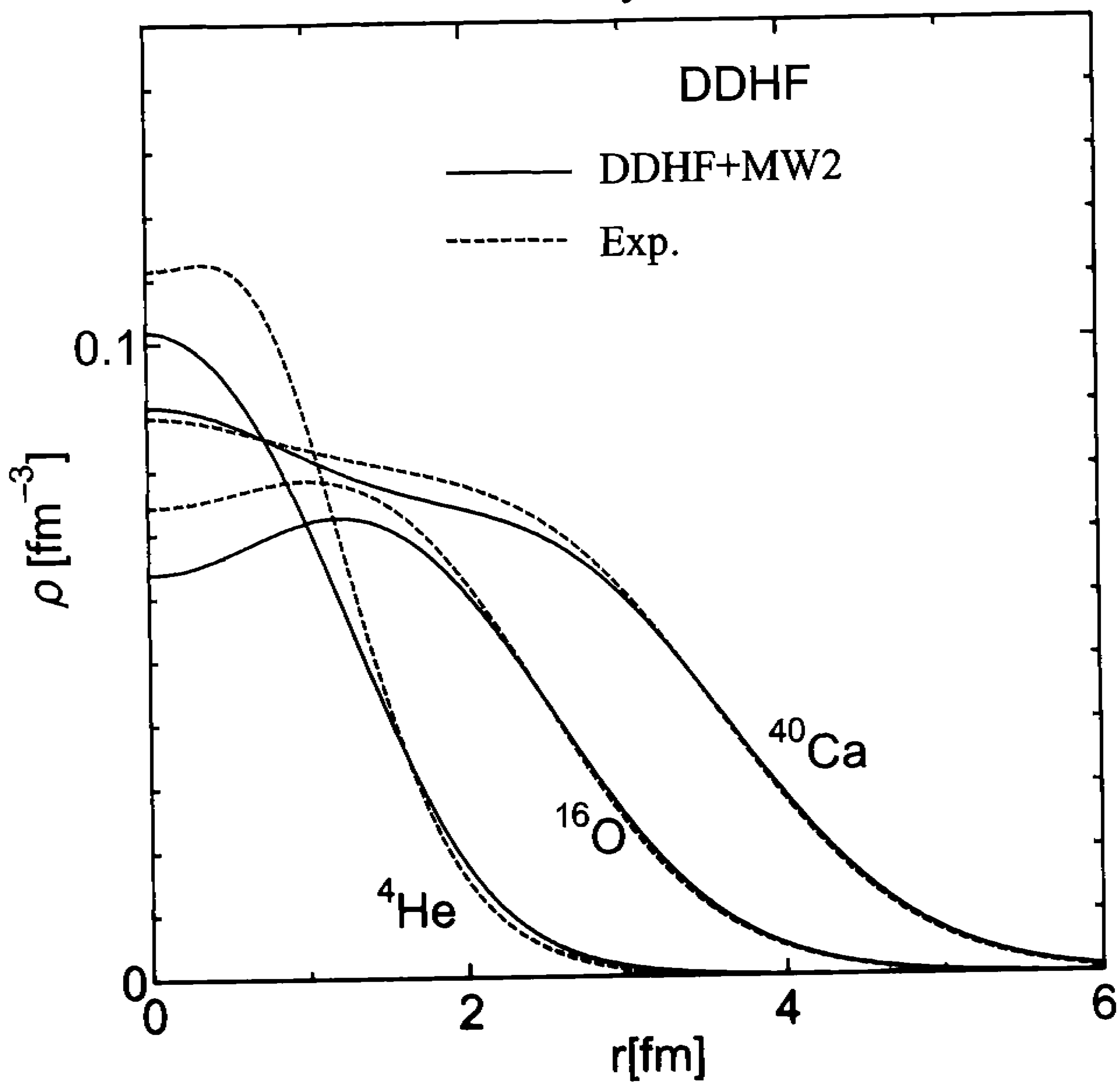
Zero-range spin-orbit force

$$\hat{V}_{LS}=iB(\boldsymbol{\sigma}_1+\boldsymbol{\sigma}_1)\cdot(\overleftarrow{\nabla}_{\mathbf{r}}\times\delta(\mathbf{r}_1-\mathbf{r}_2)\vec{\nabla}_{\mathbf{r}})$$

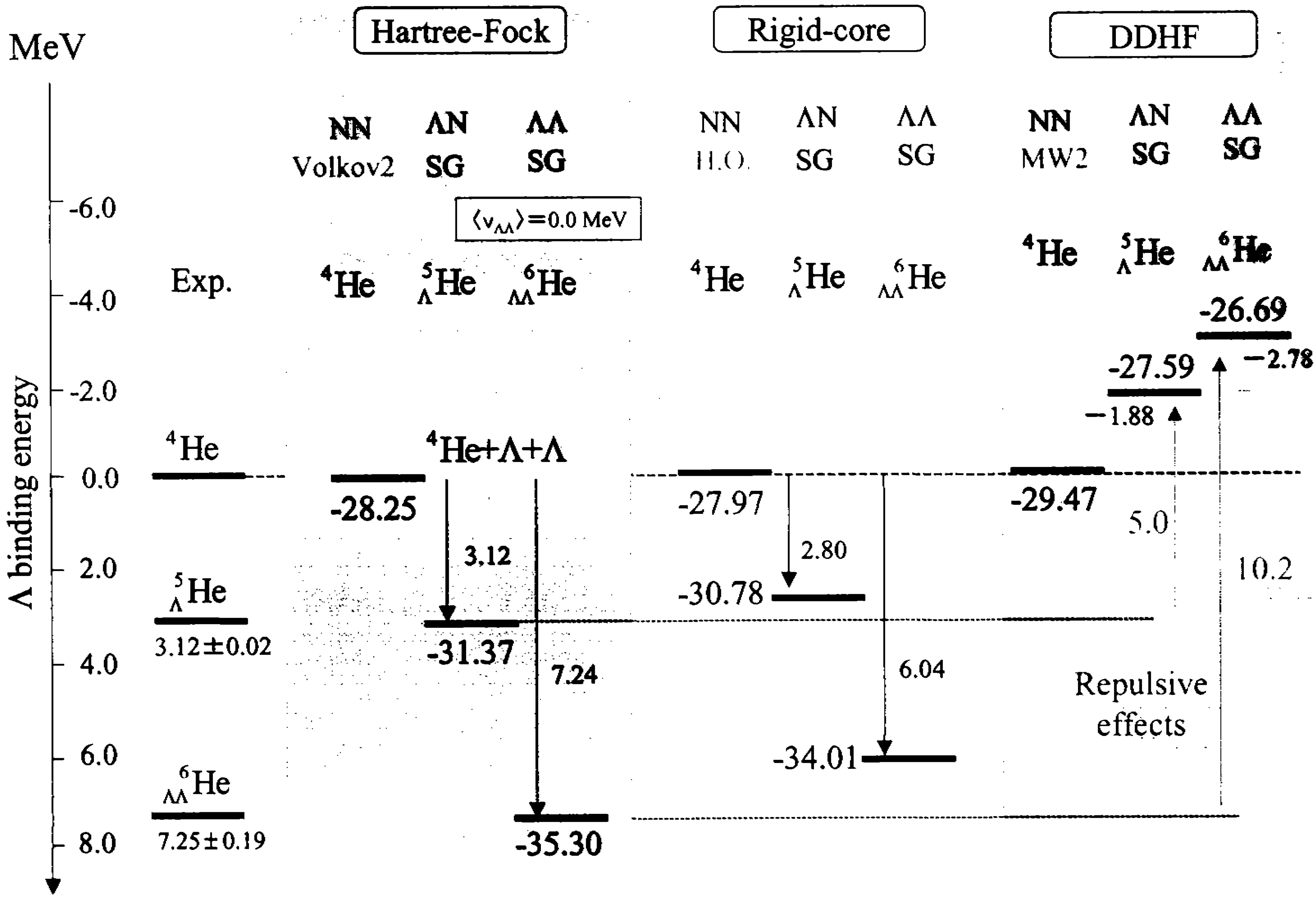
130 MeV fm^5

Charge density distributions: ^{4}He, ^{16}O and ^{40}Ca

By DDHF with MW2 pot.

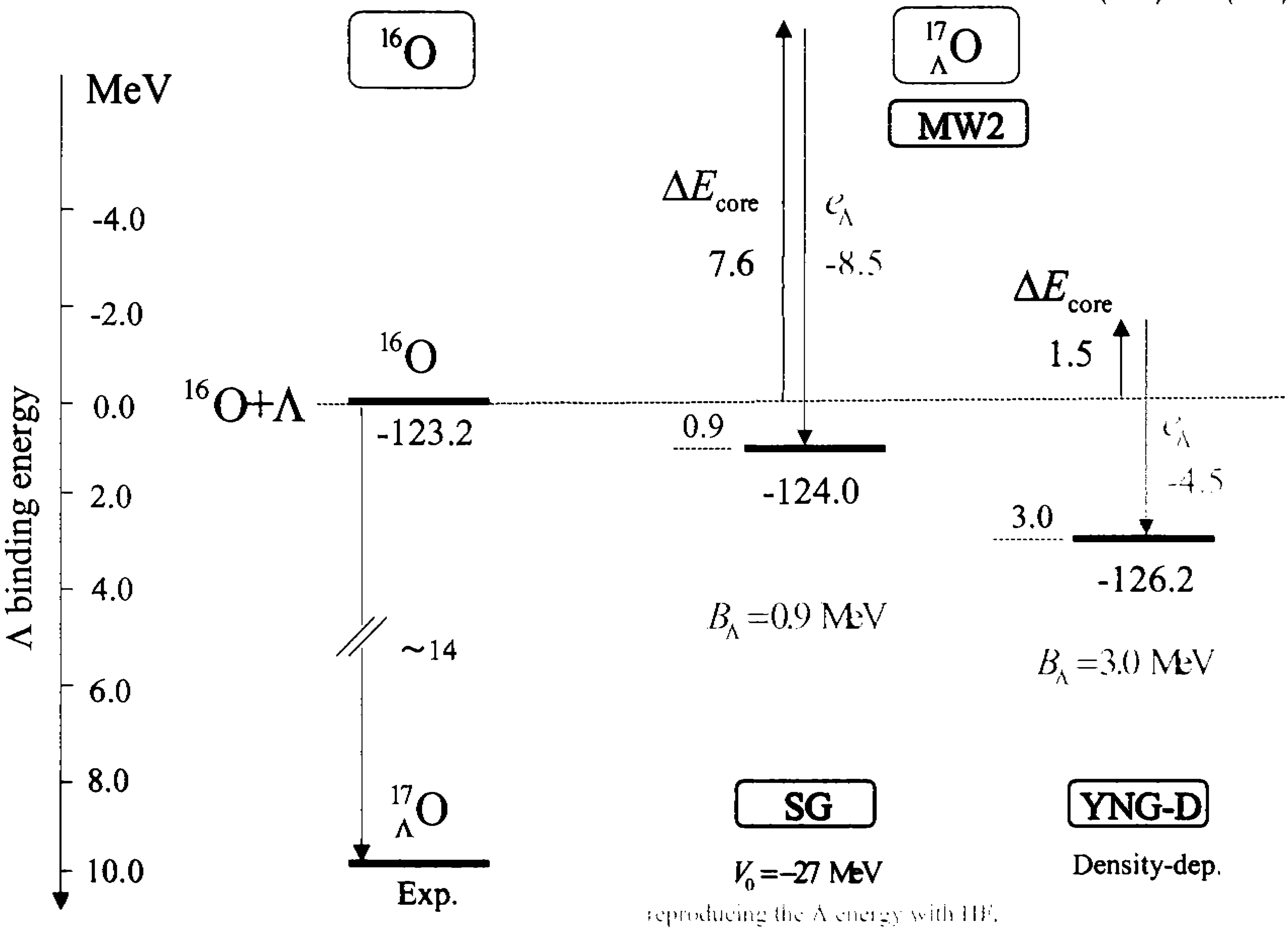


Rearrangement effects on $_{\Lambda}^{5}He$ and $_{\Lambda\Lambda}^{6}He$



Rearrangement effects on $^{17}_{\Lambda}\mathrm{O}$

$$B_{\Lambda}\left({}^{17}_{\Lambda}\mathrm{O}\right)=E\left({}^{16}\mathrm{O}\right)-E\left({}^{17}_{\Lambda}\mathrm{O}\right)$$



The core-polarization energy depends on the effective ΛN interaction.

Summary

•We perform DDHF calculations in $^{5}_{\Lambda}$He ($^{6}_{\Lambda\Lambda}$He) and $^{17}_{\Lambda}$O by using the effective NN, YN interactions.

Volkov No.2 / MW2 — Phenomenological SG / YNG-D

•We discuss nuclear rearrangement effects; the energy of the core-nucleus is reduced, (when the s.p. energy becomes deeper by the addition of Λ) but it depends on the ΛN effective interactions employed.

$\Delta E_{CORE}(^{16}O)$ ~7.6 MeV for SG, ~1.5 MeV for YNG-D

•It is important to investigate the structure of hypernuclei by considering the density- (k_F-dep.) and starting energy- (ω-dep.) dependence through the effective interactions.