Halo structure involving core excitation in ^{15}C

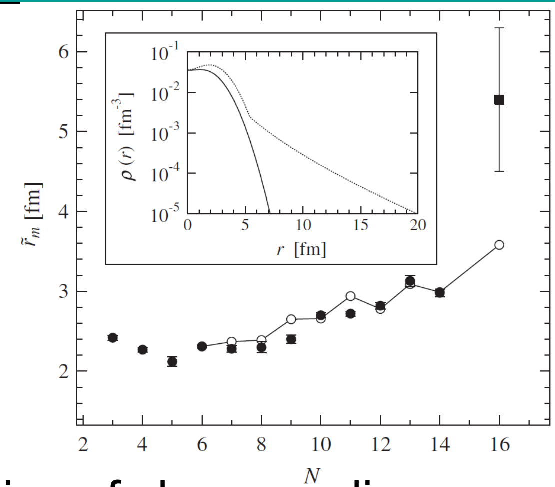
Meme Media Laboratory, Hokkaido Univ.
N. Furutachi

Introduction

- Investigation for halo nuclei in larger mass region
  - Rms matter radius of ^{22}C derived from reaction cross section measurement

    ^{22}C: 5.4±0.9 fm

    K. Tanaka et al. PRL104,062701 (2010)



Assumption of inert core is valid in heavier nuclei?

- Implication of core excitation in ^{11}Be from observation of charge radius
  - Approximately 0.1 fm larger than ^{10}Be
  - Development of 2α cluster core？ Recoil effect？

    W. Nörtershäuser et al. PRL102,062503 (2009)

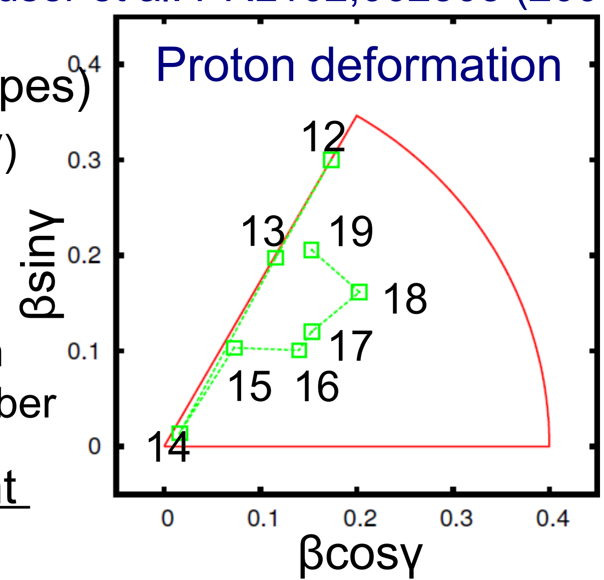
- Theoretical expectation (C isotopes)

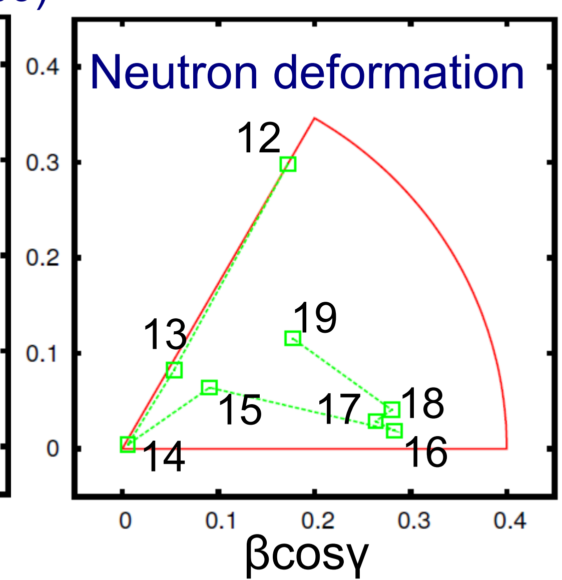
  MAMD: MV1+G3RS (V_{ls}=1800 MeV)

  ^{12}C is very soft against oblate deformation

  →Development of oblate deformation of proton change with neutron number

  <u>Core excitation can be important in halo nuclei</u>





Introduction

In this work,

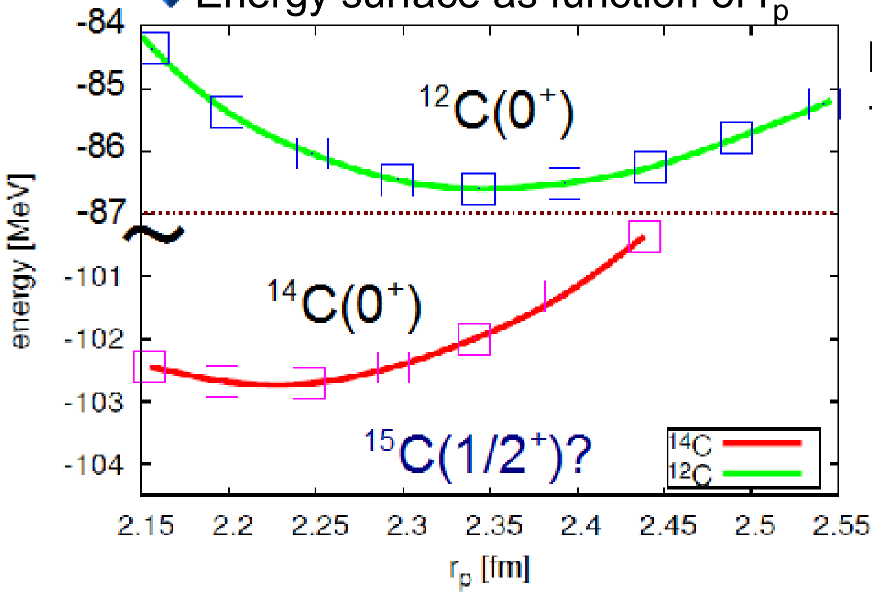
Structure of ^{15}C is investigated
to discuss importance of core excitation in halo nuclei

^{15}C:
- Small one neutron separation energy S_n=1.218 MeV
- Narrow longitudinal momentum distribution for $^{15}C \rightarrow ^{14}C$
- Large s-wave spectroscopic factor

- ^{15}C is One neutron halo nucleus？
- Inversion of $1/2^+$ state (ground state) and $5/2^+$ state(Ex 0.74 MeV)

- Importance of core excitation can be seen in energy surface as function of proton radius

- Energy surface as function of r_p



MAMD: Volkov No.2
+G3RS (V_{ls}=900 MeV)

- ^{12}C has flat energy surface in wide r_p range due to development of 3α cluster structure
- Development of 3α cluster structure suppressed in ^{14}C
- By adding one more neutron?

Extended framework of AMD

Framework

- Description of core excitation
  (development of 3α cluster structure is expected) → AMD
- Simultaneous description of
  halo structure and core excitation → Extended framework of AMD

AMD wave function

$$\Phi_{int} = \frac{1}{\sqrt{A!}} \det[\varphi_1, \varphi_2, \cdots, \varphi_A],$$

Improved nucleon wave function

$$\varphi_i(\mathbf{r}) = \phi_i(\mathbf{r}) \chi_i \tau_i. \qquad \phi_i(\mathbf{r}) = \exp\left[-\nu\left(\mathbf{r} - \frac{\mathbf{Z}_i}{\sqrt{\nu}}\right)^2\right]$$

↓

$$\varphi_i(\mathbf{r}) = \sum_\alpha C_i^\alpha \phi_i^\alpha(\mathbf{r}) \chi_i^\alpha \tau_i \qquad \phi_i^\alpha(\mathbf{r}) = \exp\left[-\nu_i^\alpha\left(\mathbf{r} - \frac{\mathbf{Z}_i^\alpha}{\sqrt{\nu_i^\alpha}}\right)^2\right]$$

The same type of nucleon wave function is used in FMD

- α=2 for |N-Z| neutron wave function
  α=1 for N=Z nucleon wave function (i=1-12:α=1, i=13-15:α=2)

Framework

- Variational function

$$\Phi^{\pm} = P^{\pm}\Phi_{int} = \frac{(1 \pm P_x)}{2}\Phi_{int}$$

- Hamiltonian

$$\hat{H} = \hat{T} + \hat{V}_{nucl} + \hat{V}_c - \hat{T}_g$$

$\hat{V}_{nucl}$; Volkov No.2 +G3RS force (V_0=900 MeV)

- Energy variation

$$E^{\pm} = \frac{\langle \Phi^{\pm} | \hat{H} | \Phi^{\pm} \rangle}{\langle \Phi^{\pm} | \Phi^{\pm} \rangle}$$

- GCM
  - Generator coordinate; proton and neutron radii
    - Proton radius: Description of core excitation
    - Neutron radius: Description of halo

$$\Psi_n^{J\pm} = \sum_i c_i^n \Phi_{MK_i}^{J\pm}(r_i^p, r_i^n) \qquad \Phi_{MK}^{J\pm}(r^p, r^n) = \hat{P}_{MK}^J \Phi^{\pm}(r^p, r^n)$$

- r^p=2.15～2.45 fm (intervals of 0.05 fm)
- r^n=r^p+0.15～r^p+0.95 (intervals of 0.1 fm)

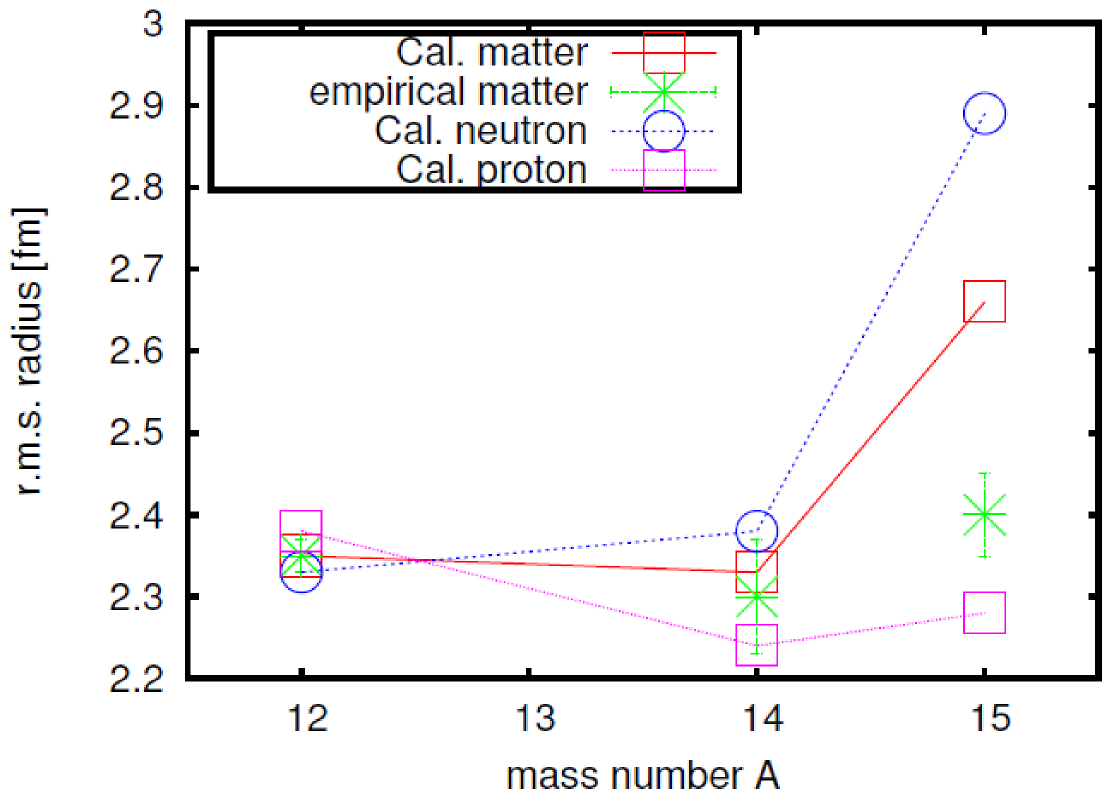
Binding energy and radius

Results

- Binding energy

	Cal. (MeV)	Exp.(MeV)
$^{14}C(0^+)$:	-105.6	-105.28
^{15}C $1/2^+$:	-106.7	-106.50
Ex. $5/2^+$:	2.0	0.74

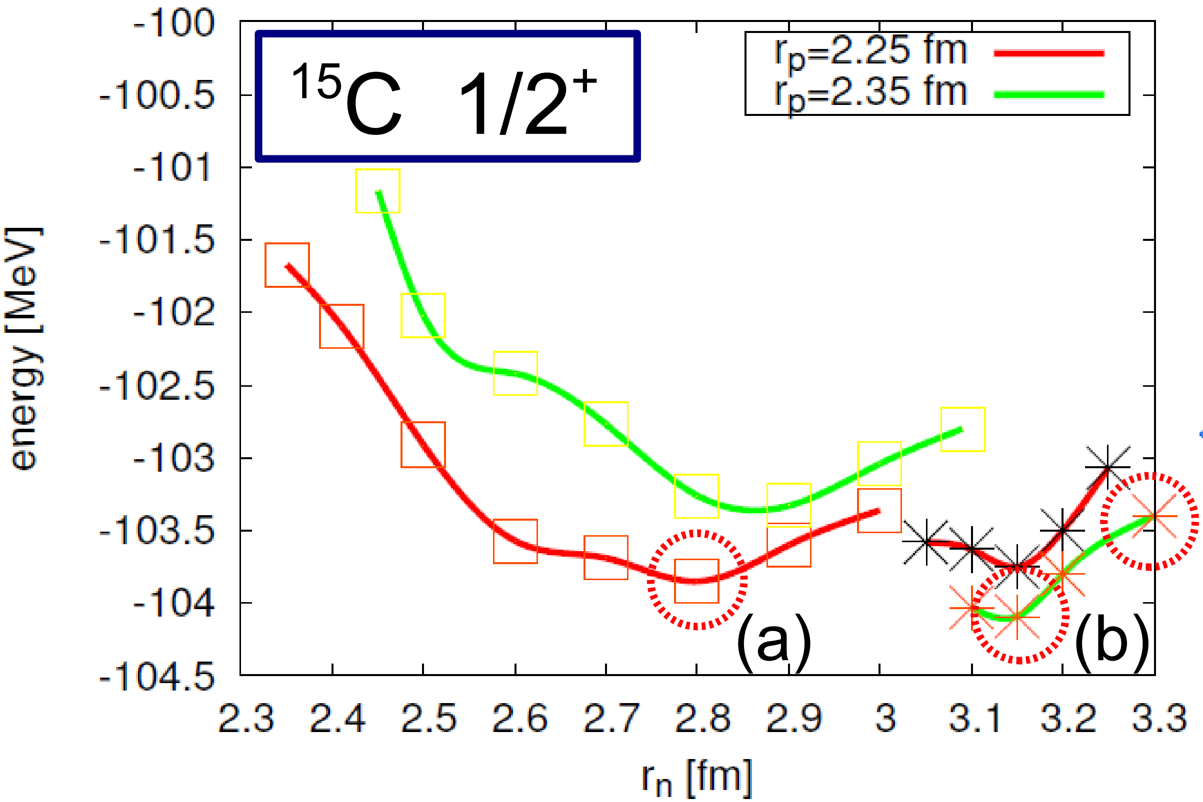
- Radius



- Ground state spin-parity and binding energies are reproduced
- Large neutron radius
  →Development of halo structure
- ^{15}C has larger proton radius than ^{14}C
  →core excitation?

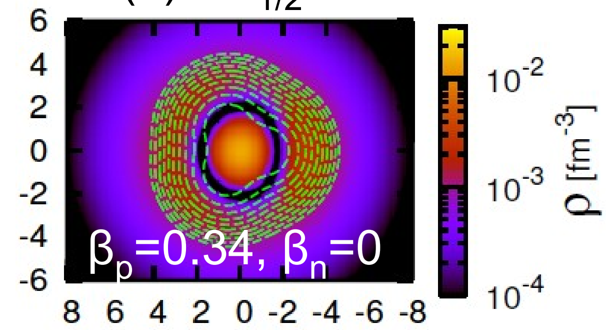
Energy surface of 1/2$^+$ state

Color plot:
Density distribution of the most weakly-bound neutron
Contour line:
Density distribution of ^{14}C

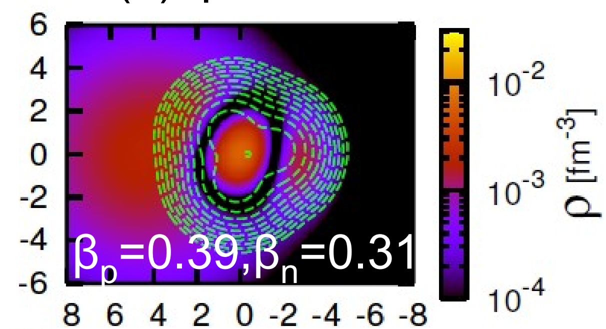


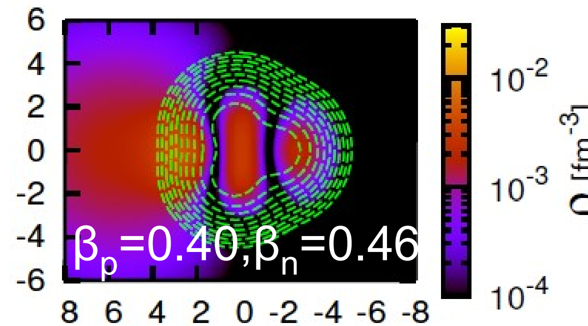
Neutron r.m.s radius

- Conf. (a): $1s_{1/2}$ orbit



- Conf. (b): prolate deformation

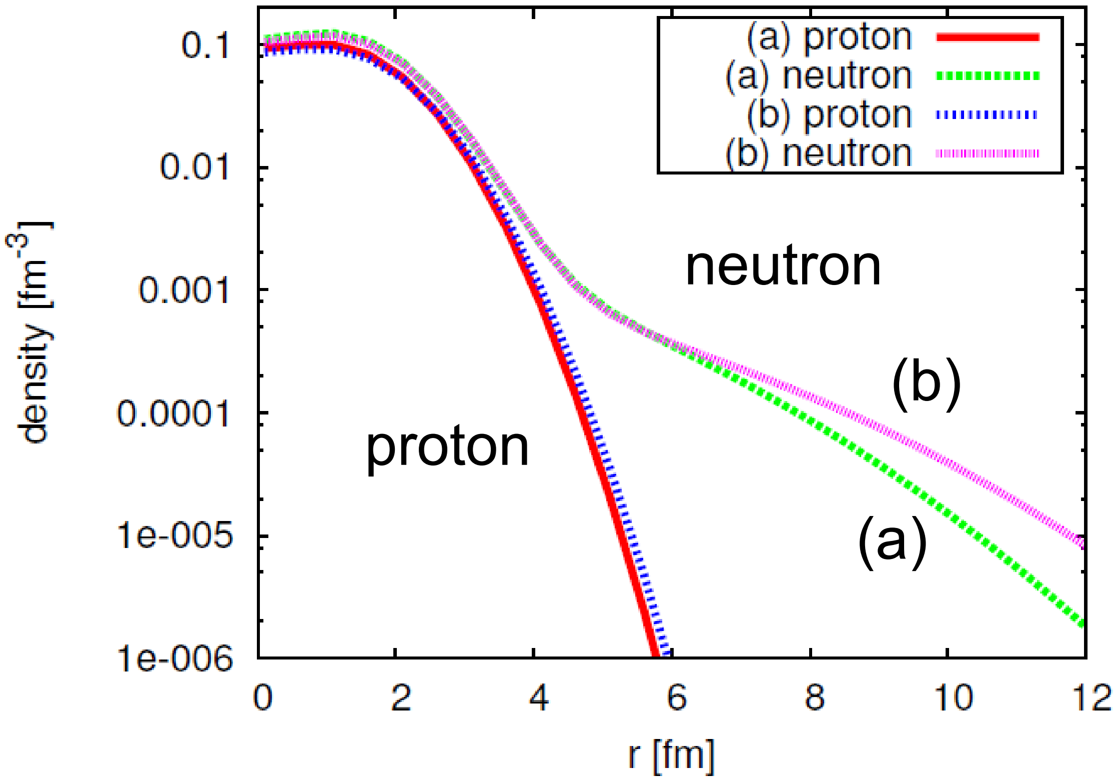




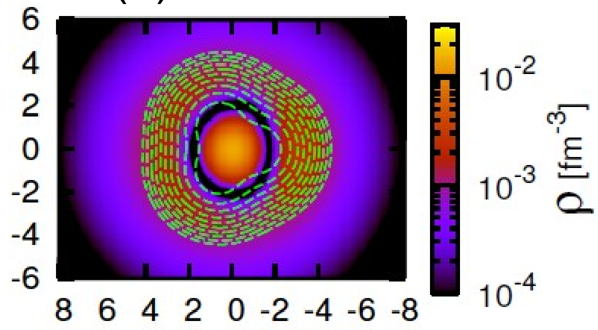
- Structure change around 3.0 fm → Conf. (a) and (b)
- Conf. (b) has deeper energy than Conf. (a) at r_p=2.35 fm

Radial density distribution of $1/2^+$ state

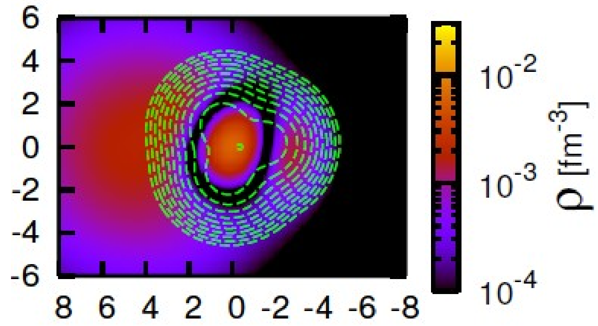
$^{15}C \ \ 1/2^+$



- Conf. (a): 1s1/2 orbit



- Conf. (b): prolate deformation

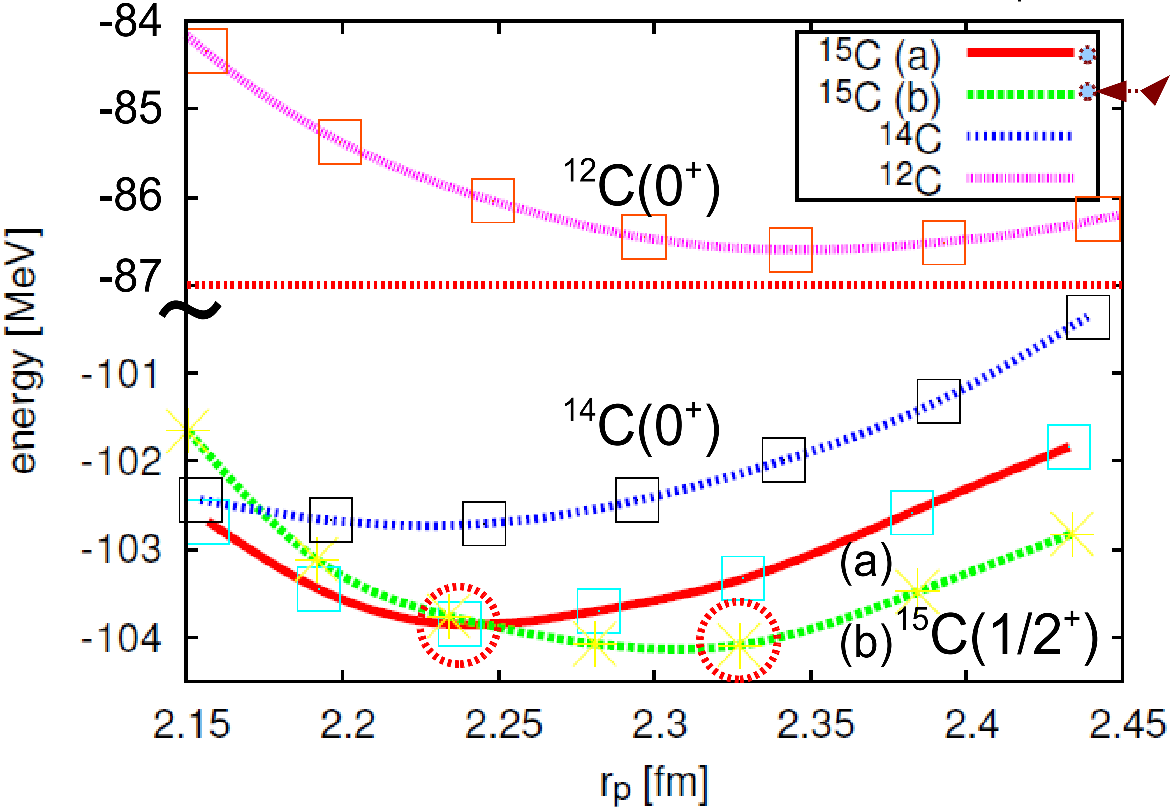


- Both Conf. (a) and Conf. (b) have halo like spatial extension of neutron density distribution

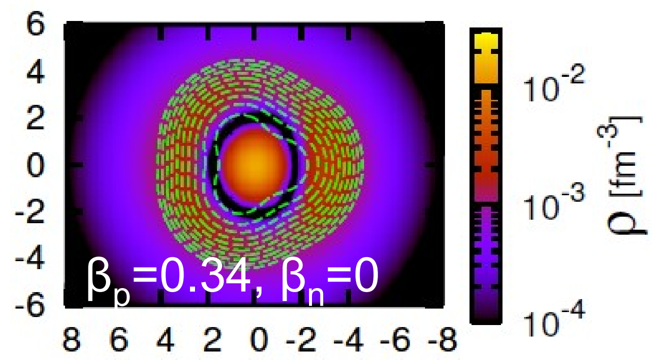
Energy surface of 1/2$^+$ state

Horizontal axis: proton r.m.s radius r_p

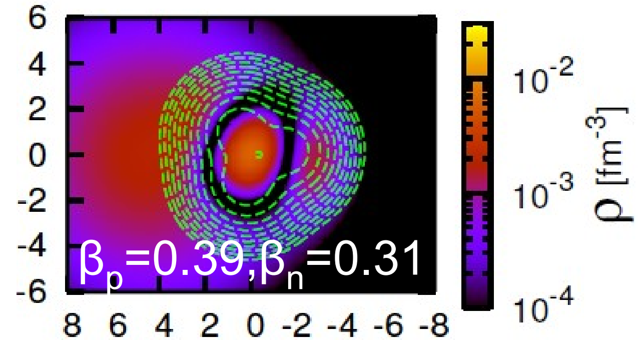
Optimal r_n values are chosen for each r_p



- Conf. (a): $1s_{1/2}$ orbit

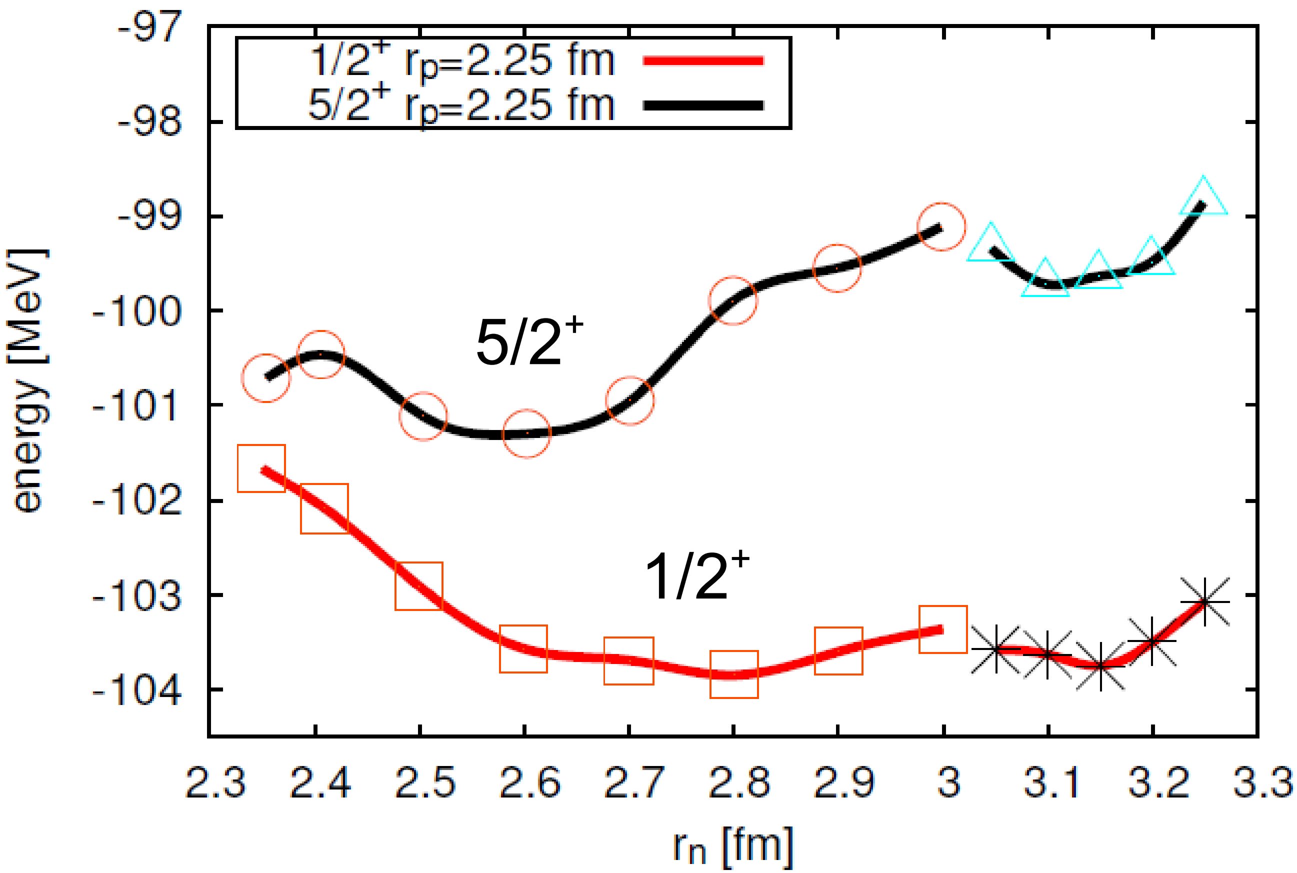


- Conf. (b): prolate deformation



- Different rp dependence of Conf. (a) and (b)
  - Conf. (a):Similar r_p dependence with ^{14}C→no core excitation
  - Conf. (b):Different r_p dependence from ^{14}C→core excitation
    →Increase of r_p is due to development of 3α cluster structure

Energy surface of 5/2$^+$ state



Neutron r.m.s radius

Summary

- Structure of ^{15}C has been investigated focusing on halo structure and core excitation
  ー Extended framework of AMD was used.

  - Ground state binding energies of ^{14}C and ^{15}C,
    and ground state spin-parity of ^{15}C ($1/2^+$) are reproduced.

  - Large neutron radius and spatial extension of neutron density distribution
    →development of one neutron halo structure
    $1/2^+$ state has larger proton radius than ^{14}C.
    →Implication of core excitation

  - Two configurations are important for ground $1/2^+$ state.
    (a) Inert ^{14}C core with valence neutron which occupy $1s_{1/2}$ orbit
    (b) Excited ^{14}C core with development of 3α cluster structure
    ー Energy surface as function of r_p is similar to that of ground state of ^{12}C.

- Future plan: ^{22}C

  - ^{22}C is a two neutron halo nucleus?
  - Core excitation?