Study of Halo Nature via Reaction and Neutron Removal Cross Sections

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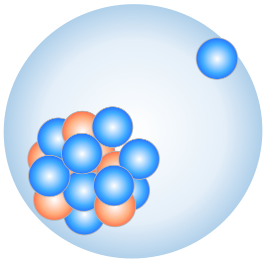
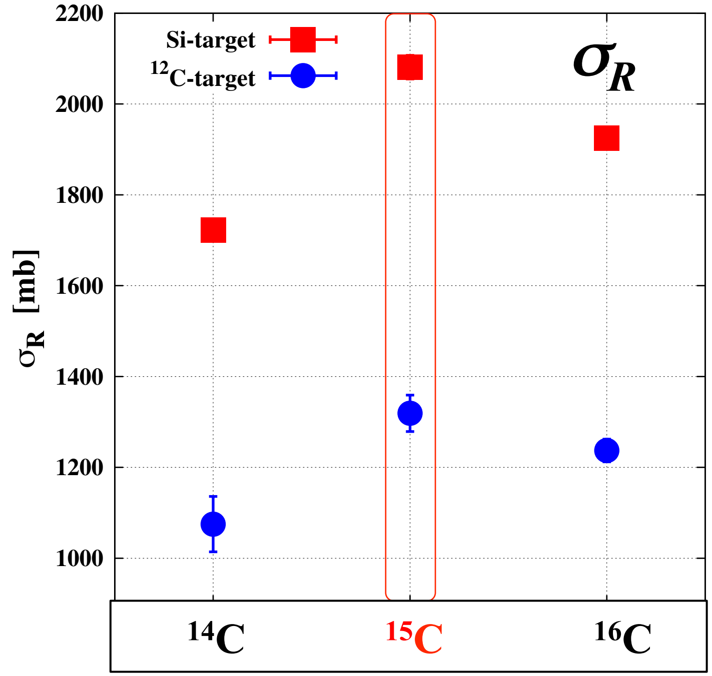
Introduction

- **Halo nuclei**
  - ✓ *Weakly bound neutron(s) in s- or p-wave orbit.*
  - ✓ *Large radius*

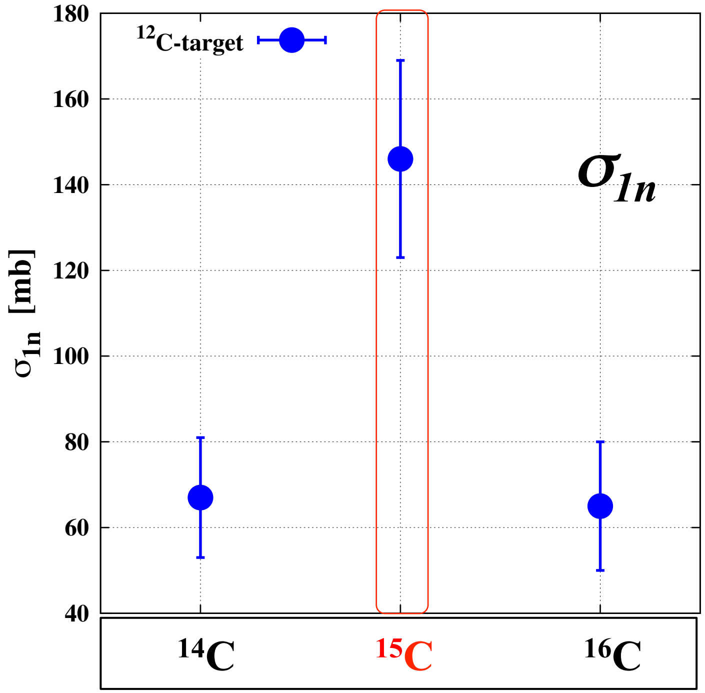


- **Reaction cross section**
  - ✓ *Enhancement of σ_R*



Villari et al., PLB268, 345, Fang et al., PRC69.034613.

- **Neutron removal cross section**
  - ✓ *Enhancement of σ_{1n}*



Yamaguchi et al., NPA724, 3, Zheng et al., NPA709, 103.

Analysis of ^{15}C and ^{16}C

- ***Properties of one neutron halo ^{15}C and neighboring nucleus ^{16}C are investigated via analyses of reaction and neutron removal cross sections.***

◆ **^{15}C: ^{14}C + n two-body model**

$$H_{^{15}C} = -\frac{\hbar^2}{2\mu_y}\nabla_y^2 + V_{nc}(y)$$

V_{nc} : central + LS + OCM [1]

$1s_{1/2+}$: -1.215 MeV

$0d_{5/2+}$: -0.478 MeV

◆ **^{16}C: ^{14}C + n + n three-body model**

$$H_{^{16}C} = -\frac{\hbar^2}{2\mu_r}\nabla_r^2 - \frac{\hbar^2}{2\mu_y}\nabla_y^2 + V_{nc}(y_1) + V_{nc}(y_2) + V_{nn}(y_3) + \boxed{V_{nnc}(r,y)}$$

V_{nn} : BonnA

V_{nnc}: Phenomenological 3BF

[1]*Hagino, and Sagawa., PRC75, 021301*

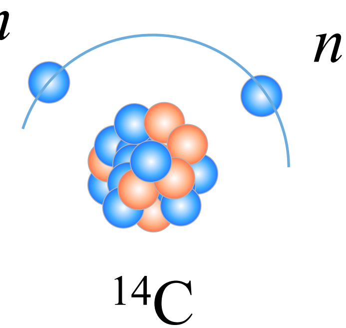
Structure of ^{16}C

^{15}C

$1s_{1/2+}$: -1.215 MeV

$0d_{5/2+}$: -0.478 MeV

Ground state wave function of ^{16}C



$$\Phi(^{16}C) = \alpha \left| \phi(^{14}C) \otimes \left(s_{1/2}\right)^2 \right\rangle + \beta \left| \phi(^{14}C) \otimes \left(d_{5/2}\right)^2 \right\rangle + \cdots$$

✓ ***Probability of each configuration can be optimized with V_{nnc}.***

Type I: $\alpha = 0.7, \beta = 0.6 \left(\alpha > \beta\right)$ ***s*-dominant structure**

Type II: $\alpha = 0.4, \beta = 0.8 \left(\alpha < \beta\right)$ ***d*-dominant structure**

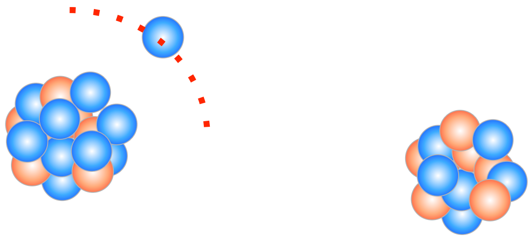
✓ ***From analyses of reaction, we discuss which is better structure.***

Three- and Four-Body Reactions

Breakup processes of ^{15}C and ^{16}C are treated by *CDCC*.

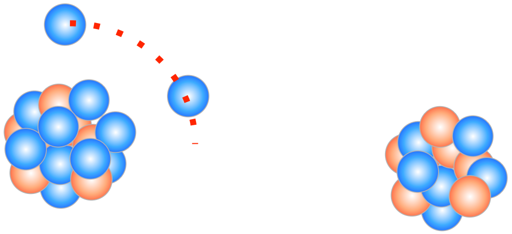
(Review)Yahiro, Ogata, TM, Minomo, PTEP01A206, (2012).

Three-body scattering system of ^{15}C



$$\left[-\frac{\hbar^2}{2\mu}\nabla^2 + H_{^{15}C} + U_n + U_c - E\right]\Psi = 0$$

Four-body scattering system of ^{16}C



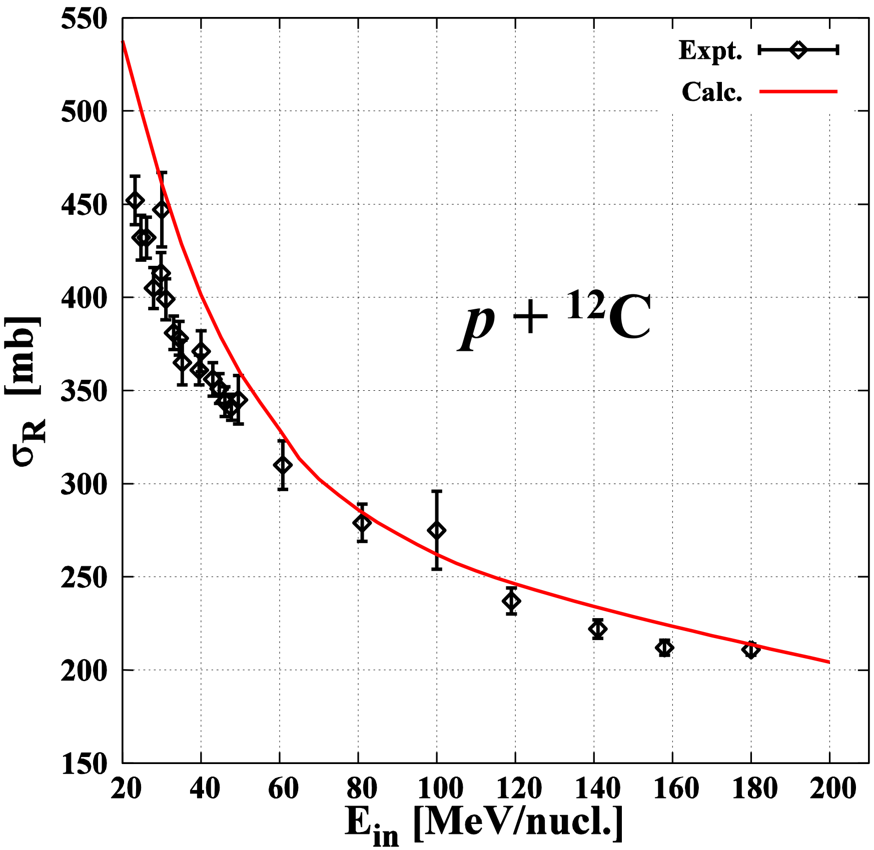
$$\left[-\frac{\hbar^2}{2\mu}\nabla^2 + H_{^{16}C} + U_n + U_n + U_c - E\right]\Psi = 0$$

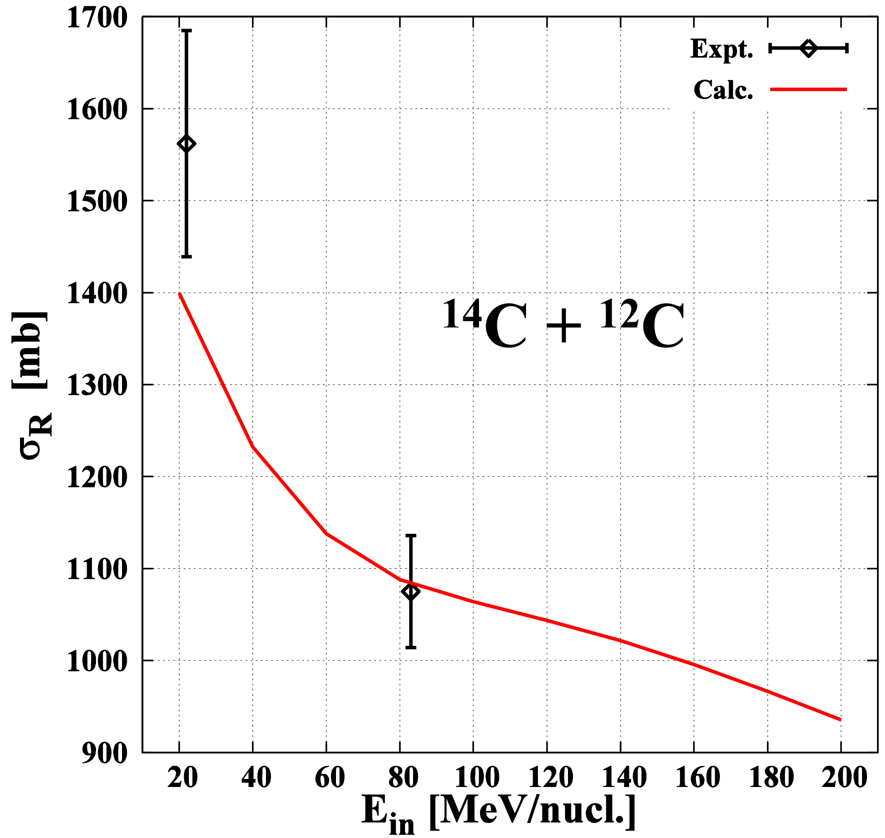
M. Toyokawa et al., PRC92, 024618 (2015)

Optical Potential

Optical potentials of *n*-T and ^{14}C-T are calculated by folding model with *g* matrix based on χ−EFT (N^{3}LO 2BF, N^{2}LO 3BF).

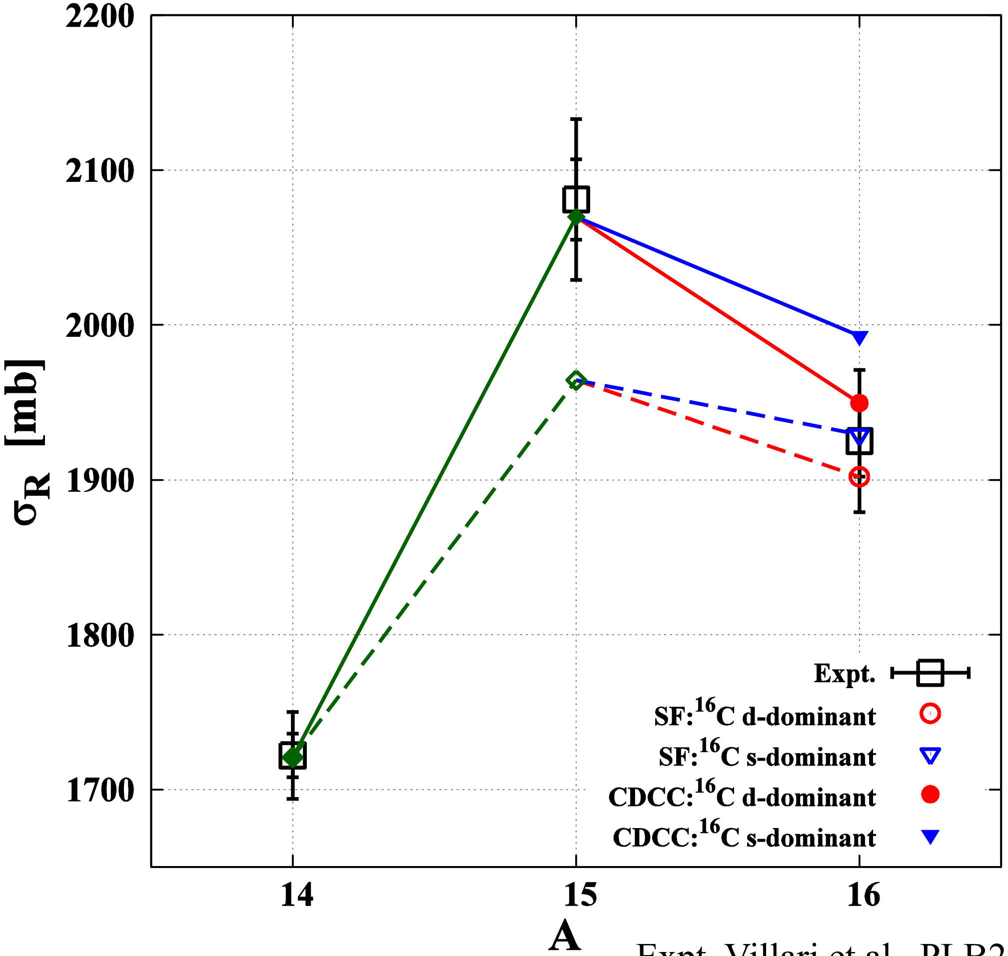
Toyokawa (Poster)





Reaction Cross Section on ^{28}Si

$^{14\text{-}16}$C + ^{28}Si @45-50 MeV/nucl

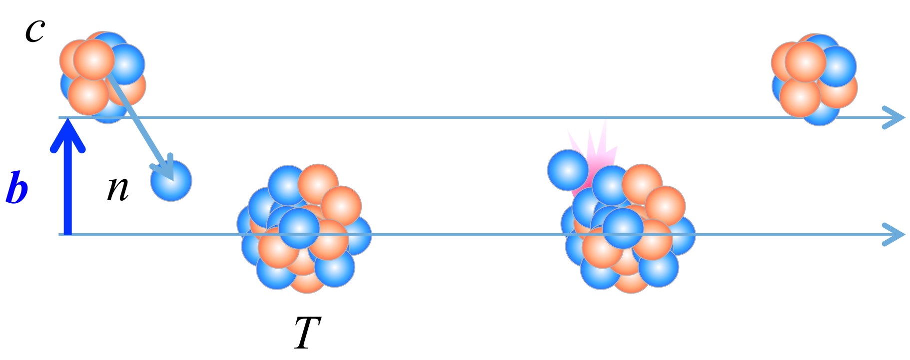


Expt. Villari et al., PLB268, 345.

- ✓ ***For ^{16}C, σ_R of s-dominant is larger than σ_R of d-dominant.***
- ✓ ***σ_R of d-dominant is well reproduce the odd-even deviation.***
- ✓ ***Main configuration of valence two neutrons of ^{16}C is $(0d_{5/2})^2$.***

M. Yahiro, K. Ogata, K. Minomo, PTP126, 167 (2011).

Eikonal Reaction Theory



- **S-matrix in eikonal approximation**

$$S = S_n S_c$$

- **Stripping cross section (one neutron)**

$$\sigma_n = \int db \langle \phi_0 | |S_c|^2 \left(1 - |S_n|^2\right) | \phi_0 \rangle$$

Hussein and McVoy NPA445, 124 (1985)

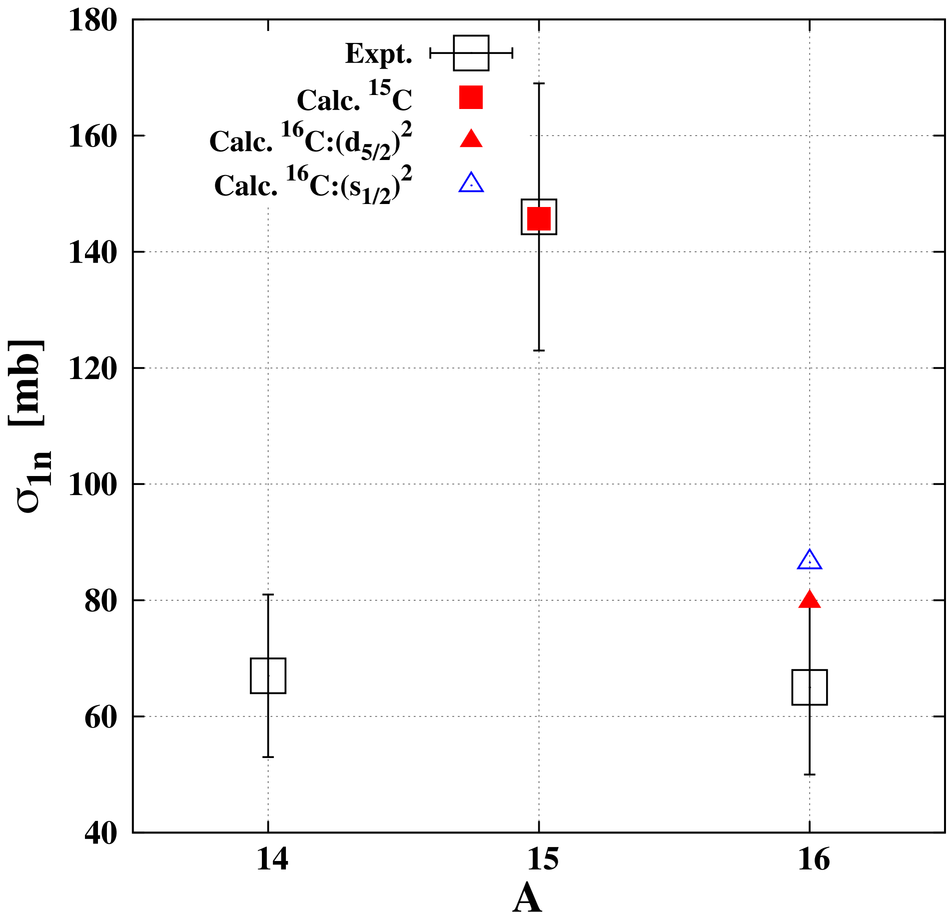
- **Eikonal Reaction Theory (ERT)**

  - ***S_c (S_n) is estimated by solving Eikonal-CDCC equation with only U_n (U_c).***

$$\left[-\frac{\hbar^2}{2\mu_R}\nabla_R^2 + h_r + U_n(r,R) - E \right] \Psi(r,R) = 0 \qquad \textit{for } S_n$$

$$\left[-\frac{\hbar^2}{2\mu_R}\nabla_R^2 + h_r + U_c(r,R) - E \right] \Psi(r,R) = 0 \qquad \textit{for } S_c$$

1-neutron Removal of ^{15}C & ^{16}C



ERT and CDCC well reproduce 1n removal cross sections of ^{15}C and ^{16}C

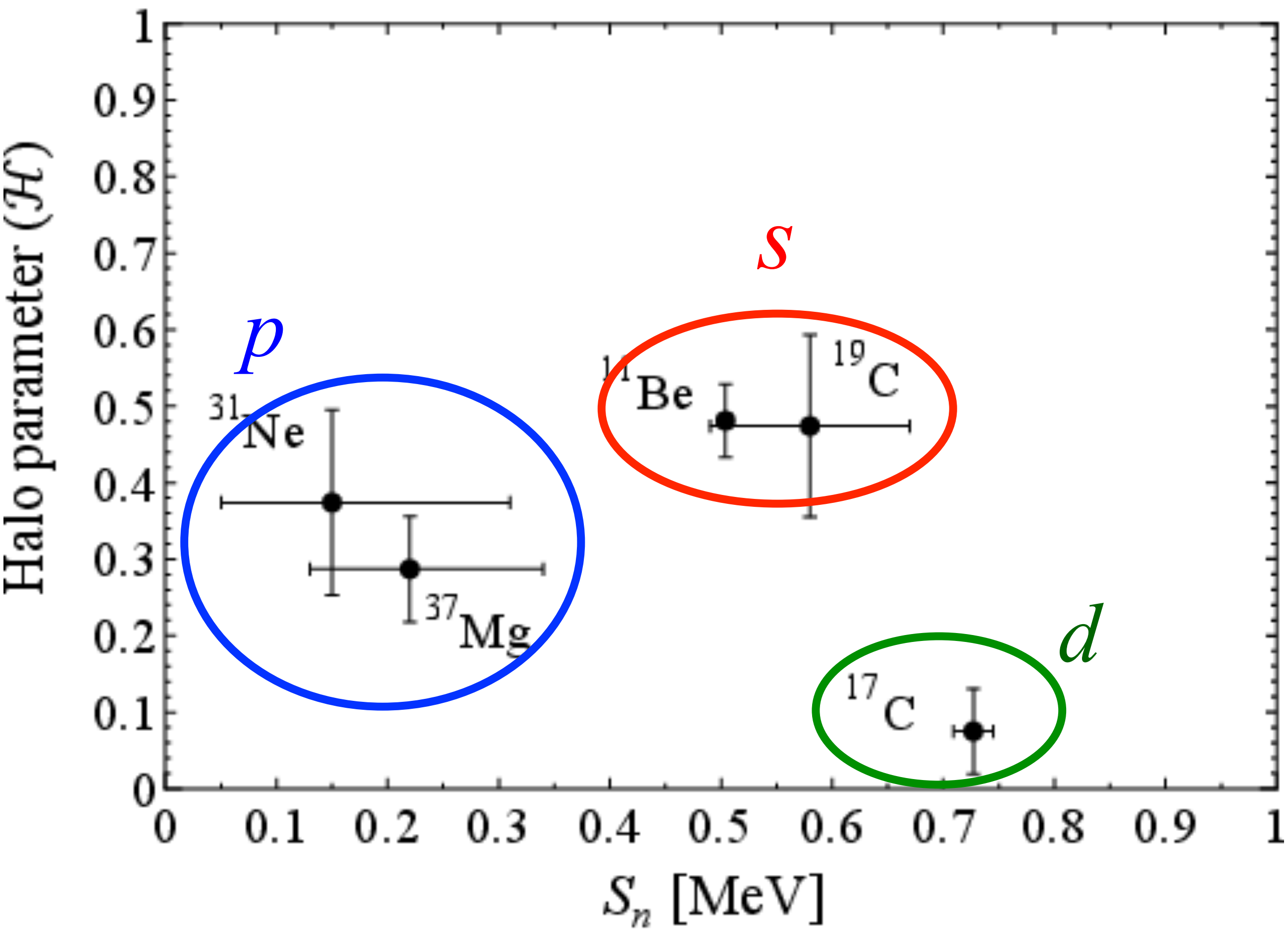
$(d_{5/2})^2$ configuration in ^{16}C is preferred.

Expt. Yamaguchi et al., NPA724, 3. Zheng et al., NPA709, 103.

Yahiro, Watanabe, Toyokawa, TM, PRC93, 064609 (2016)

Halo parameter $\mathcal{H}$

$$\mathcal{H} = \frac{\sigma_{abs}(c+n)-\sigma_{abs}(c)}{\sigma_{abs}(n)} \approx \frac{\sigma_R(c+n)-\sigma_R(c)}{\sigma_R(n)}$$



- ✓ *Extrapolation of $\mathcal{H}$ to S_n=0 with Glauber model.*

Yahiro, Watanabe, Toyokawa, TM, PRC93, 064609 (2016)

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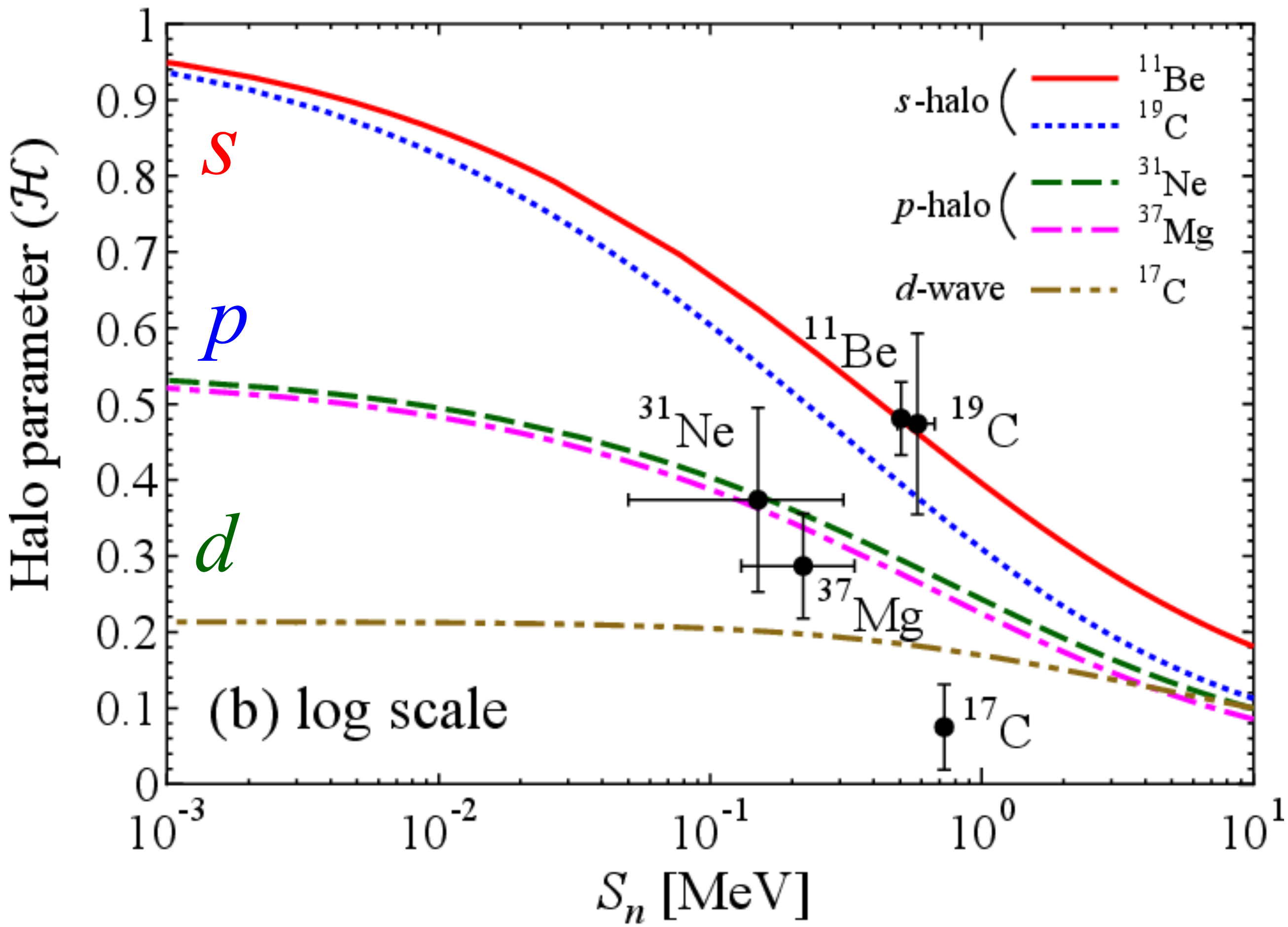
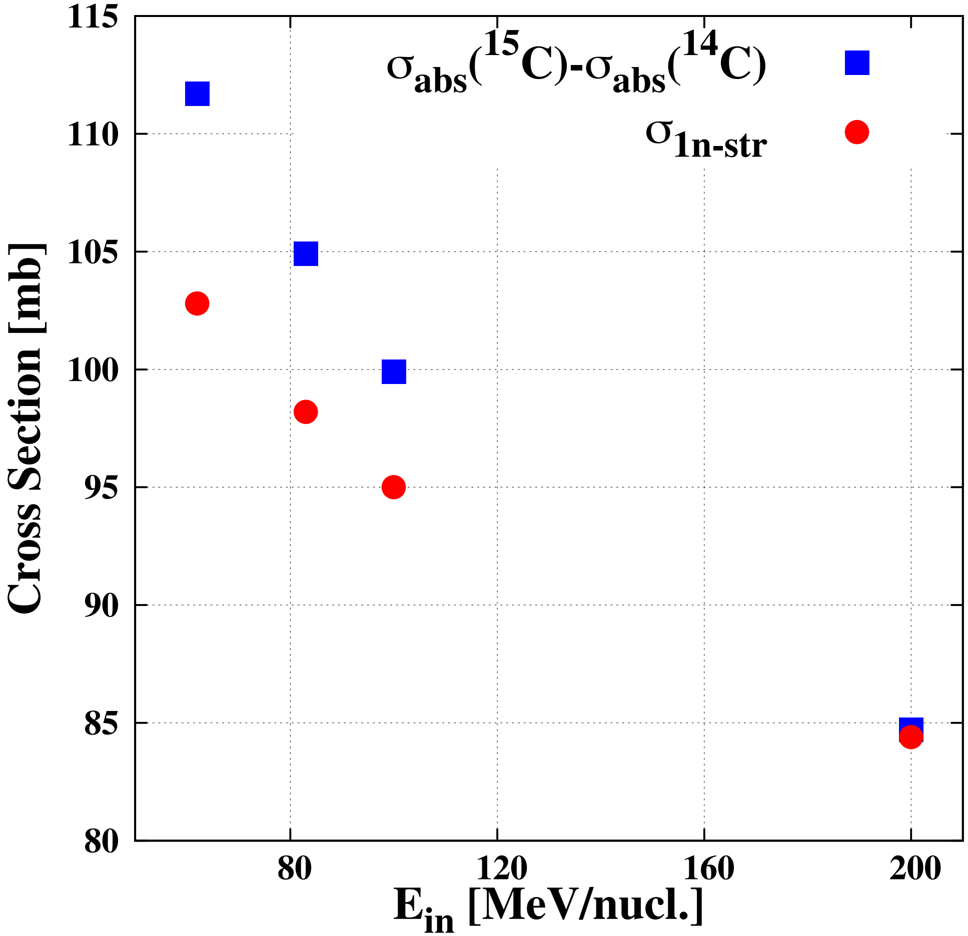


- ✓ *Extrapolation of $\mathcal{H}$ to S_n=0 with Glauber model.*
- ✓ *We can separate neutron orbit at S_n=0.*
- ✓ $\mathcal{H}$ of s-wave halo becomes 1 at S_n=0

$\mathcal{H}$ defined by $\sigma_{1n\text{-}str}$



✓ Glauber model approx.

$$\sigma_{1n-str} \approx \sigma_{abs}(^{15}C) - \sigma_{abs}(^{14}C)$$

New definition of $\mathcal{H}$ with $\sigma_{1n\text{-}str}$

$$\mathcal{H} \approx \frac{\sigma_{1n-str}}{\sigma_R(n)}$$

Summary

- ***We investigate halo (^{15}C) and neighboring nuclei (^{14}C,^{16}C) with core + neutron(s) model.***

- ***For analyses of σ_R and σ_{1n}, we found main configuration of the ground state of ^{16}C is $(d_{5/2})^2$.***

- ***ERT and CDCC calculations well reproduce one-neutron removal cross sections of ^{15}C and ^{16}C.***

- ***New definition of Halo parameter.***

- ***Future work***

✓ ***Calculation of two-neutron removal cross section***

✓ ***Other systems ($^{10-12}Be$, $^{18-20}C$, $^{30-32}Ne$)***