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ENSAR2

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^{15}C STRUCTURE AND DYNAMICS: COUPLING HALO EFT TO REACTION MODELS FOR TRANSFER, BREAKUP AND RADIATIVE-CAPTURE

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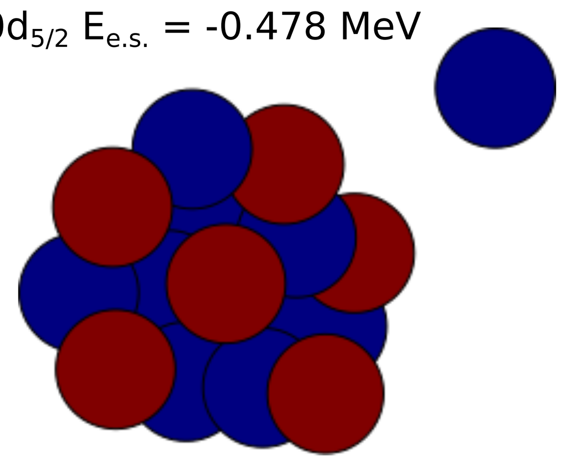
DESCRIPTION OF ^{15}C STRUCTURE WITHIN HALO EFT

$^{15}C = {}^{14}C(0^+) + n$

^{15}C is a one-neutron halo nucleus modeled as a compact ^{14}C core with one loosely bound neutron

> $1s_{1/2}$ $E_{g.s.}$ = -1.218 MeV

> $0d_{5/2}$ $E_{e.s.}$ = -0.478 MeV



Effective 1-body Hamiltonian

$$H_0 = -\frac{\hbar^2}{2\mu_{^{14}Cn}}\Delta + V_{^{14}Cn}(\mathbf{r})$$

V_{cn} effective potential simulating core-neutron interaction

Eigenvalue problem

$$H_0\varphi_{n'lj}(E,\mathbf{r}) = E\varphi_{n'lj}(E,\mathbf{r})$$

Bound states wavefunctions radial behaviour

$$u_{n'lj}(r) \underset{r\to\infty}{\longrightarrow} \mathcal{C}_{n'lj}\, e^{-k_{n'lj}r}$$

$C_{n'lj}$ is the ANC, associated to the WF tail strength

V_{cn} IN HALO EFT

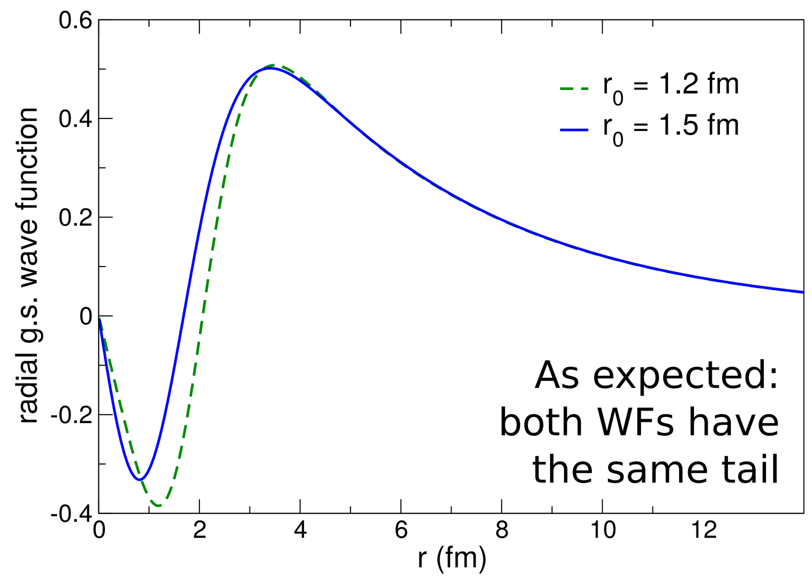
Hammer, Ji, Phillips JPG 44, 103002 (2017)

$$@NLO\;\; V_{^{14}Cn}(r) = V_0 e^{-\frac{r^2}{2r_0^2}} + V_2 r^2 e^{-\frac{r^2}{2r_0^2}}$$

V2 and V0 adjusted to fit
> in s wave:
binding energy (known experimentally)
ANCs (extracted from peripheral transfer reaction, see below)
> in p wave: δ_p (assumed nil)
V_{cn} = 0 for l >1

r0 to evaluate sensitivity to short range physics

We consider:
> two ^{14}C+n potentials at NLO with r_0 = 1.2 and 1.5 fm
> two potentials for the excited state to see if we have to go beyond NLO



ANC EXTRACTION FROM TRANSFER REACTION

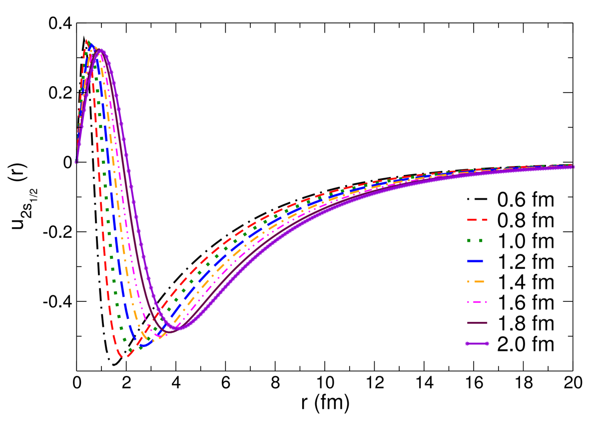
Yang and Capel PRC98,054602(2018)

1. Determination of different potentials V_{Cn} @LO

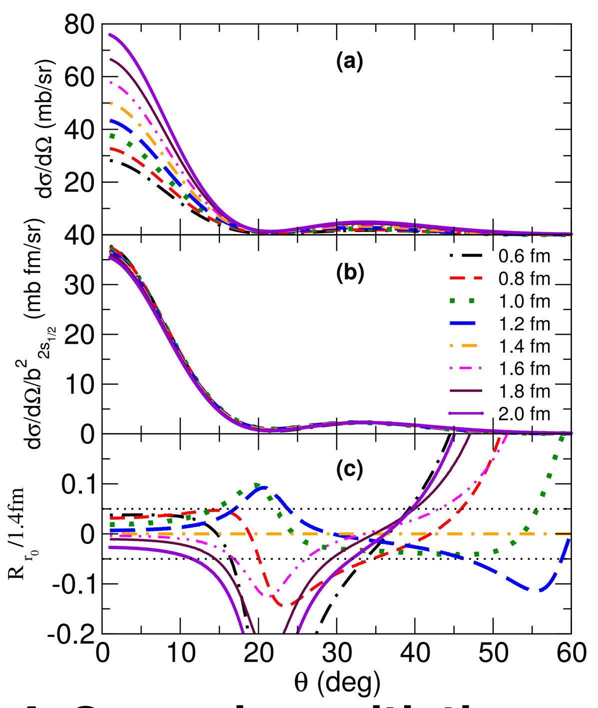
$$V_{^{14}Cn}(r) = V_0 e^{-\frac{r^2}{2r_0^2}}$$

with different r_0 ⇒ V_0 adjusted neutron binding energy

2. Generation of different wave functions $\varphi_{n'lj}$ with different ANCs



3. Computation of corresponding $d\sigma_{th}/d\Omega$ for the transfer to ^{15}C g.s. at E_d = 17 MeV



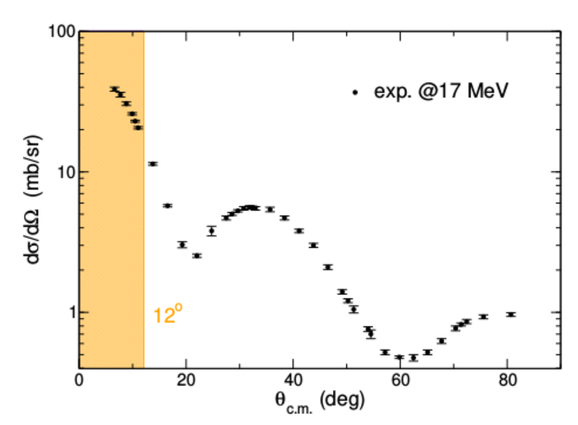
(a) FR-ADWA calculation Johnson and Tandy NPA235, 56 (1974)

(b) spread reduced at forward angle scaling by ANC^2

(c) $\mathcal{R}_{r_0/1.4fm}(\theta) = \left(\frac{ANC^{(1.4fm)}}{ANC^{(r_0)}}\right)^2 \frac{d\sigma_{th}^{(r_0)}/d\Omega}{d\sigma_{th}^{(1.4fm)}/d\Omega} - 1$

reaction assumed peripheral if spread lower than 5% ⇒ θ < 12°

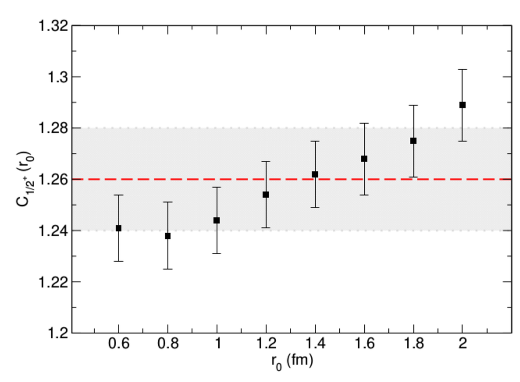
4. Comparison with the experimental cross section



Experiment: Mukhamedzhanov et al. PRC84, 024616 (2011)

We infer an ANC for each potential from a χ^2 analysis in the peripheral region

5. Extracted ^{15}C ANC



We obtain a final ANC for g.s.

$C_{1/2^+}$ = 1.26 ± 0.02 fm$^{-1/2}$

Analogously for the e.s.

$C_{5/2^+}$ = 0.056 ± 0.001 fm$^{-1/2}$

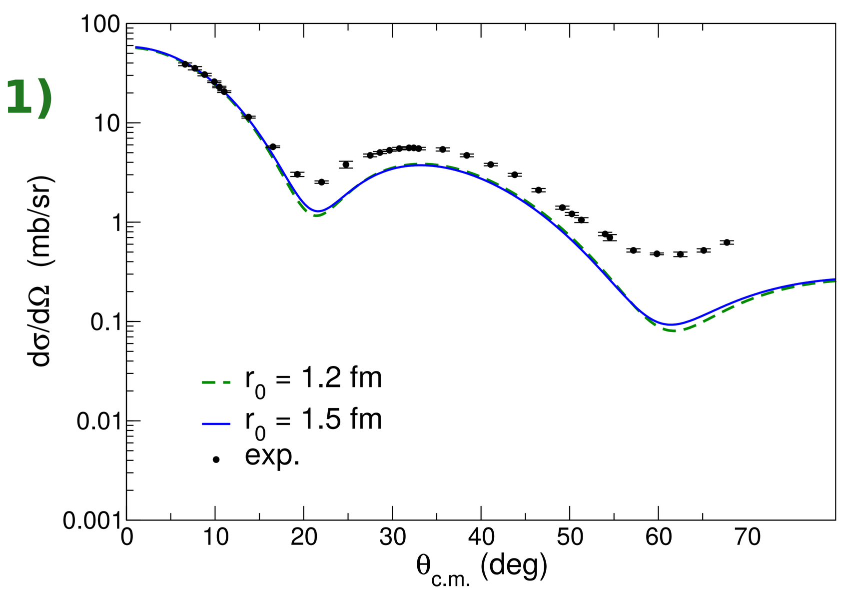
TRANSFER ^{14}C(d,p)^{15}C

Experiment: Mukhamedzhanov et al. PRC84, 024616 (2011)

FR-ADWA calculation
Johnson and Tandy NPA235, 56 (1974)

Results

- Good agreement with data for θ < 12°
- The reaction does not depend on WF inner part r_0 = 1.2 fm ~ r_0 = 1.5 fm for θ < 12°
- For θ > 12° short range physics shows up



COULOMB BREAKUP OF ^{15}C ON Pb

Three-body reaction model applied to ^{11}Be to solve GSI and RIKEN dB(E1)/dE discrepacy Moschini and Capel arXiv:1807.07537

Experiments: > GSI E_{LAB} = 605 AMeV Datta Pramanik et al., PLB551 (2003) 63
> RIKEN E_{LAB} = 68 AMeV Nakamura et al., PRC79 (2009) 035805

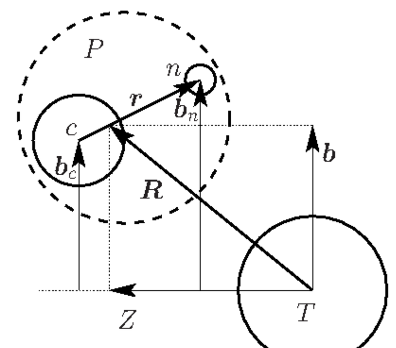
The relativistic Eikonal model

Klein-Gordon equation in the T-P CM frame $\left[(\hbar c)^2\nabla^2 + (\hbar ck)^2 - 2EV_{PT}\right]\Psi = 0$ Satchler, Nucl. Phys. A 540 (1992) 533

Adiabatic and eikonal approximations neglecting core excitations, to obtain the eikonal expression

$$\hat{\Psi}(\mathbf{b},z,\mathbf{r}) = e^{i\chi(\mathbf{b},\mathbf{s})}\Phi_{l_0j_0m_0}(E_0,\mathbf{r}) \quad \text{where} \quad \chi(\mathbf{b},\mathbf{s}) = \chi^N(\mathbf{b},\mathbf{s}) + \chi^C(\mathbf{b},\mathbf{s}) + \chi^C_{PT}(b)$$

Nuclear phase: optical limit approximation Horiuchi, Suzuki, Capel and Baye, PRC 81 (2010)
Coulomb phase: correction to avoid divergence Margueron, Bonaccorso and Brink, Nucl. Phys. A720 (2003)

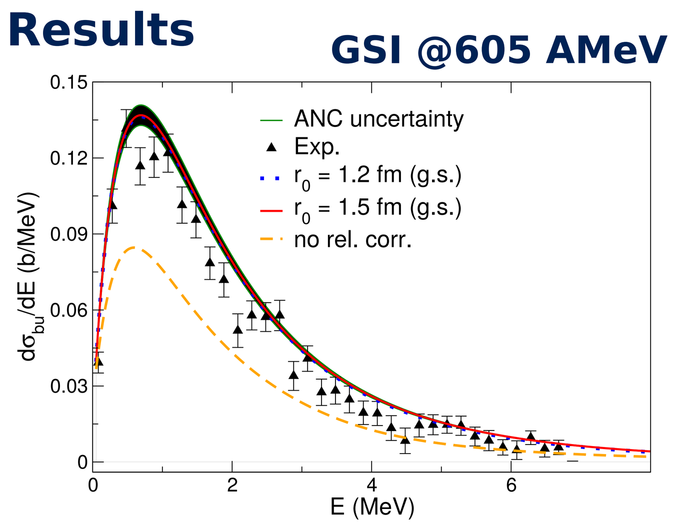


Lorentz boost **V_{PT} (b,z,r) → γV_{PT} (b,γz,r)** to express breakup cross section in P rest frame
Winther and Alder, Nucl. Phys. A 319 (1979)

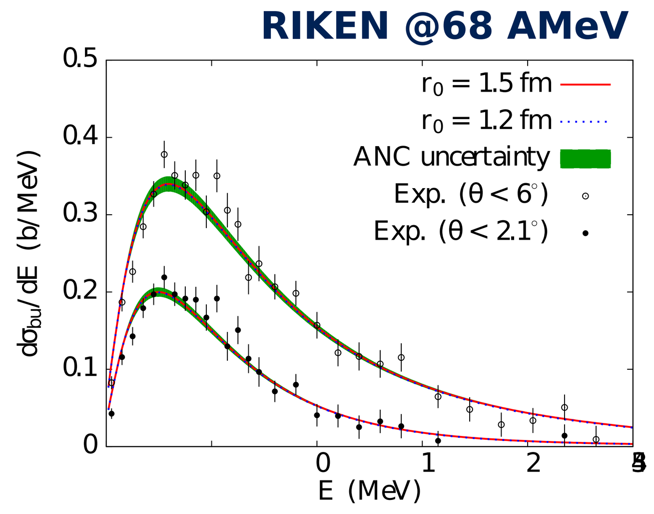
$$\frac{d\sigma_{bu}}{dE} = \frac{4\mu_{cf}}{\hbar^2 K}\frac{1}{2j_0+1}\sum_{m_0}\sum_{ljm}\int_0^\infty bdb|S^{m_0}_{kljm}(b)|^2 \quad \text{where} \quad S^{m_0}_{kljm}(b) \sim \langle\varphi_{ljm}(E)|e^{i\chi^N}(e^{i\chi^C} - i\chi^C + i\chi^{FO})e^{i\chi^C_{PT}}|\varphi_{l_0j_0m_0}(E_0)\rangle$$

Results

GSI @605 AMeV



RIKEN @68 AMeV



- Relativity is important in the high energy case
- Excellent agreement with data
- Band shows ANC uncertainty
- The reaction does not depend on WF inner part r_0 = 1.2 fm ~ r_0 = 1.5 fm
- No effect for the e.s. inclusion
⇒ for Coulomb breakup the Halo EFT expansion works fine at NLO

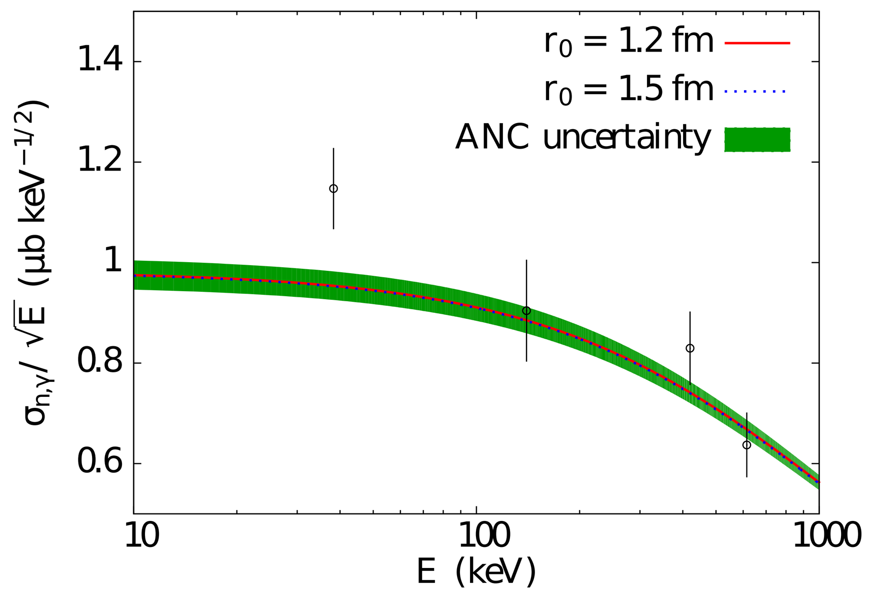
RADIATIVE CAPTURE MODEL ^{14}C(n,γ)^{15}C

Experiment: Reifarth et al., PRC77 (2008) 015804

^{14}C and n merge to form ^{15}C by emitting a photon from ^{15}C continuum (E) to one of its bound states (E_{nl})

Results

- Good agreement with data for E>100 keV
- Band related to ANC uncertainty
- Cross section independent on internal wave function
- Problem at low energy ⇒ more research on this point is needed!



CONCLUSIONS

Using one single Halo-EFT description of ^{15}C adjusted on
> binding energy → known from experiment
> ANC → extracted analysing transfer reaction
We reproduce data for different reactions: transfer, breakup (at intermediate and high energy) and radiative capture

In particular:
- Halo-EFT description works well @NLO
- using the r_0 parameter we can test short-range physics (important only in transfer processes at large angles)