Ab initio exploration of ^{12}C

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$$p + {}^{11}B \rightarrow \alpha + \alpha + \alpha$$

Outline

– No-core shell model (NCSM) ^{12}C

– NCSM with Resonating Group Method (NCSM/RGM) ^{11}B $+ p$

– NCSM with continuum (NCSMC) *preliminary results*

N4LO NN+3N, SRG 1.8

Ab initio calculation of ^{12}C

No-core shell model (NCSM):

- A-nucleon wavefunction expansion in the harmonic oscillator basis
- Short- and medium-range correlations
- Bound-states, narrow resonances

NCSM calculation of ^{12}C
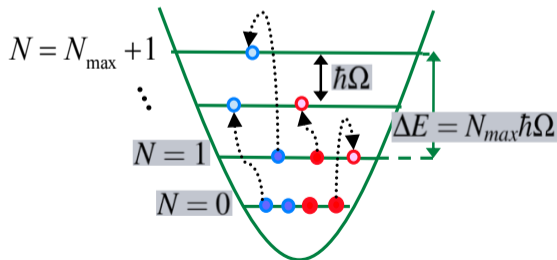
Ab initio calculation of ^{12}C

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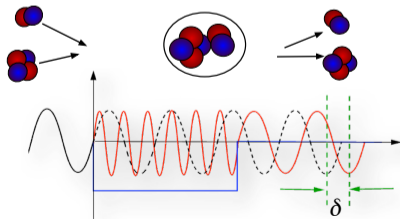- Bound-states, narrow resonances

NCSM with Resonating Group Method (NCSM/RGM):

- Cluster expansion where clusters are described by NCSM
- Proper asymptotic behavior
- Long-range correlations

$$\sum_\nu \int d\vec{r}\ \gamma_\nu(\vec{r})\ \hat{A}_\nu \left| \underset{(A-a)}{\overset{\vec{r}}{\bullet\!-\!\!-\!\!\bullet}}_{(a)}, \nu \right\rangle \quad ;$$

$$= \sum_\nu \int \frac{\gamma_\nu^{J^\pi T}(r)}{r} \hat{A}_\nu \left[\left(\left| A-a\ \alpha_1 I_1^{\pi_1} T_1 \right\rangle \left| a\ \alpha_2 I_2^{\pi_2} T_2 \right\rangle \right)^{(sT)} Y_\ell(\hat{r}_{A-a,a}) \right]^{(J^\pi T)} \frac{\delta(r-r_{A-a,a})}{r r_{A-a,a}}\ r^2 dr$$
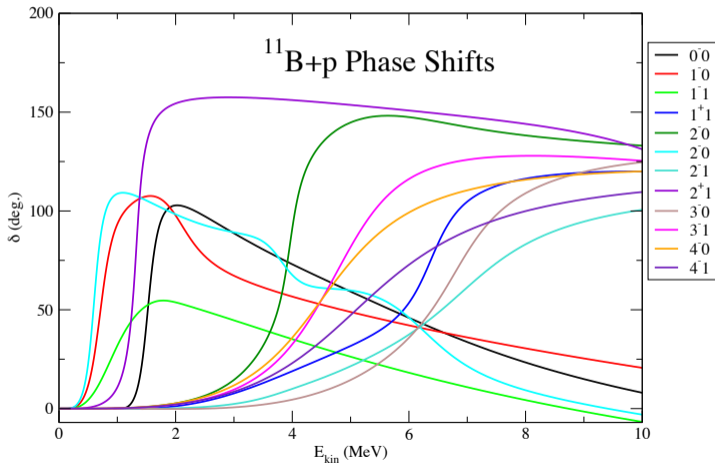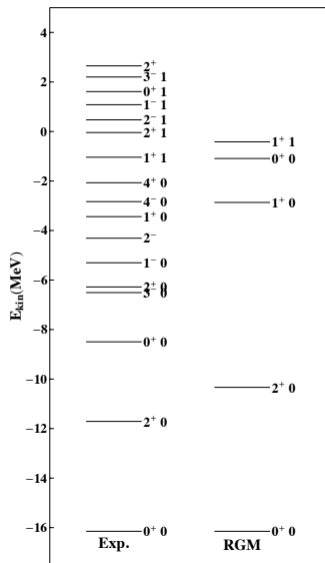
$$\sum_{\nu} \int d\vec{r} \; \gamma_{\nu}(\vec{r}) \; \hat{A}_{\nu} \left| \begin{array}{c} \overset{\vec{r}}{\underset{(A-a)}{\bullet}} \underset{(a)}{\bullet} \end{array}, \nu \right\rangle$$

$$= \quad \sum_{\nu} \int \frac{\gamma_{\nu}^{J^{\pi}T}(r)}{r} \hat{A}_{\nu} \left[\left(\left| A-a \; \alpha_{1} I_{1}^{\pi_{1}} T_{1} \right\rangle \left| a \; \alpha_{2} I_{2}^{\pi_{2}} T_{2} \right\rangle \right)^{(sT)} Y_{\ell}(\hat{r}_{A-a,a}) \right]^{(J^{\pi}T)} \frac{\delta(r - r_{A-a,a})}{r r_{A-a,a}} r^{2} dr$$
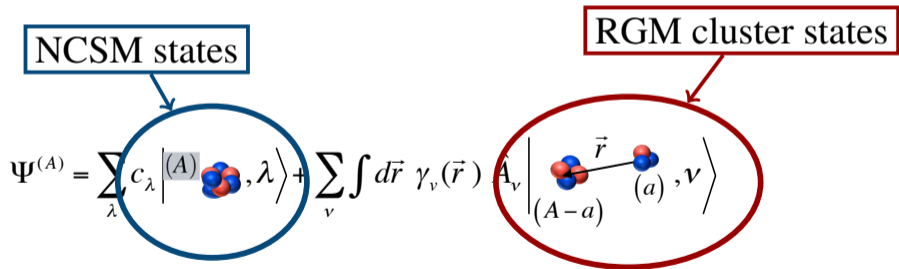
NCSM states

NCSM/RGM calculation of ^{12}C

^{11}B+p Phase Shifts

No-Core shell model with continuum (NCSMC)

Put scattering (RGM) and bound state (NCSM) problems on equal footing

NCSM states

RGM cluster states

$$\Psi^{(A)} = \sum_\lambda c_\lambda \left| (A), \lambda \right\rangle + \sum_\nu \int d\vec{r}\ \gamma_\nu(\vec{r})\ \hat{A}_\nu \left| (A-a) \xrightarrow{\vec{r}} (a), \nu \right\rangle$$

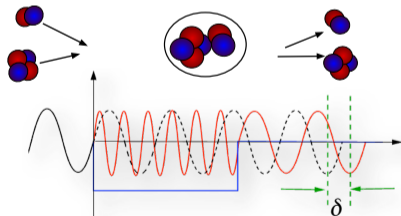# No-Core shell model with continuum (NCSMC)
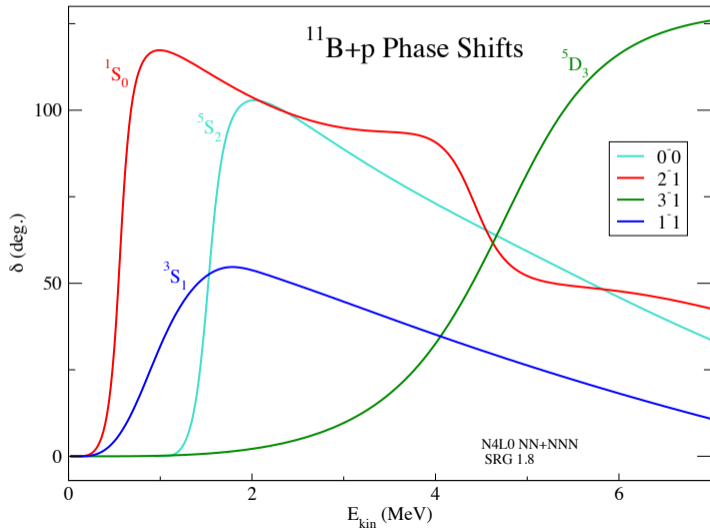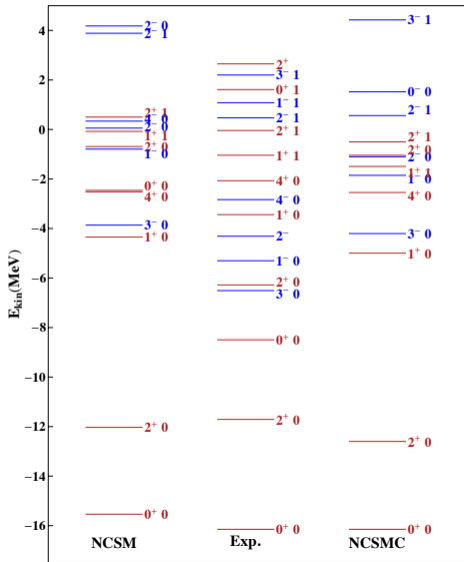
No-Core shell model with continuum (NCSMC)

– Solve using R-matrix method on Lagrange mesh

– Get both bound state energies and phase shifts from scattering matrix
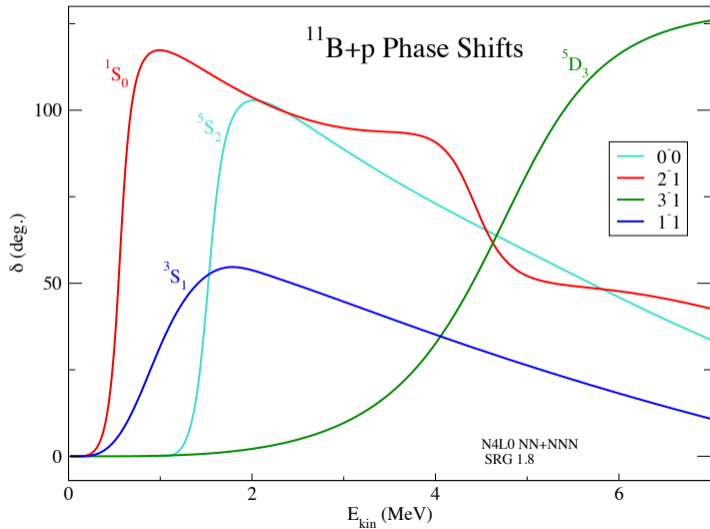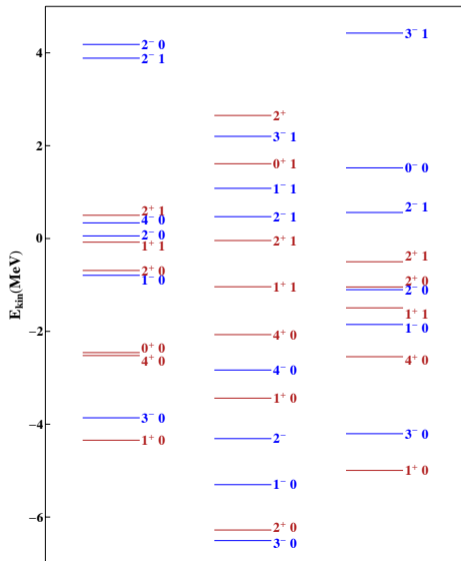
NCSMC calculation of ^{12}C

– NCSM: First 10 positive parity and first 6 negative parity states of ^{12}C *($N_{max} = 6/7$)*

– RGM: First 2 negative parity states of ^{11}B plus proton *($N_{max} = 6$)*
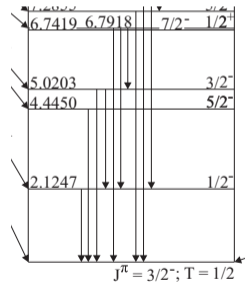
NCSMC calculation of ^{12}C

NCSMC calculation of ^{12}C

Summary

– Preliminary results for ^{12}C are promising

– Combining the ^{11}B + p cluster states with the ncsm basis improves the spectrum

– NCSMC calculation can be improved

  – Include the full 3N interaction

  – Include more of the NCSM states for both ^{11}B and ^{12}C

Thank you!

^{11}B

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Thank you!
Merci!

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