No-Core Shell Model with the Continuum (NCSMC)

Simone Baroni

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A new ab-initio theory: NCSMC

Simone Baroni, Petr Navrátil, Sofia Quaglioni

An ab-initio theory for low-energy nuclear reactions:

cross sections, bound states, resonances, EM transitions

i.e., $p + {}^{7}Be \rightarrow {}^{8}B$; $n + {}^{10}Be \rightarrow {}^{11}Be$; $n + {}^{8}Li \rightarrow {}^{9}Li$;

$d + {}^{4}He \rightarrow {}^{6}Li$; ${}^{3}He + {}^{4}He \rightarrow {}^{7}Be$

The NCSMC in one line:

it merges the NCSM with the NCSM/RGM technique

The goal

increased predictive power
extended area of applicability

Outline

- The idea behind the NCSMC

- Ab initio ad spectra: proof of principle

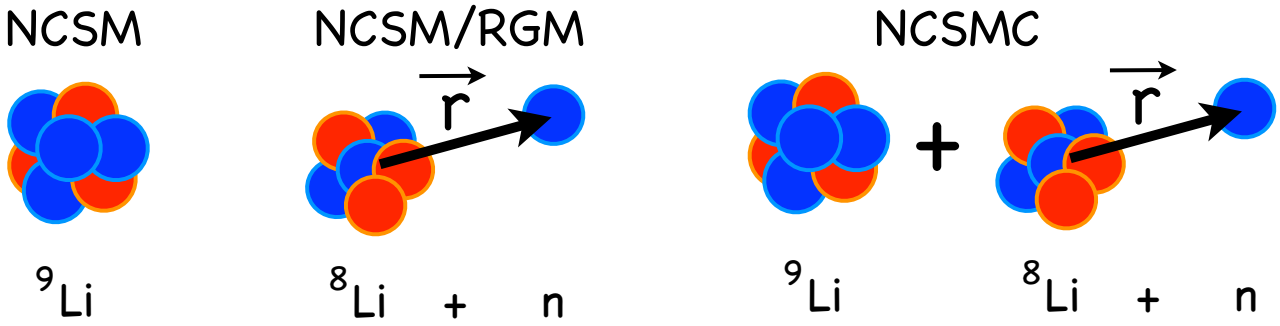
  $n + {}^{8}\mathrm{Li} \rightarrow {}^{9}\mathrm{Li}$

- Ab spectra ad calculum

  $n + {}^{10}\mathrm{Be} \rightarrow {}^{11}\mathrm{Be}$

The idea behind the NCSMC

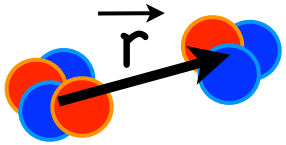
example: n + ^{8}Li --> ^{9}Li



bound-state energies	✓	○	✓
A-body correlations	✓	○	✓
broad resonances	○	✓	✓
asymptotics	✗	✓	✓
phase shifts	✗	✓	✓
cross sections	✗	✓	✓

The idea behind the NCSMC

NCSM/RGM



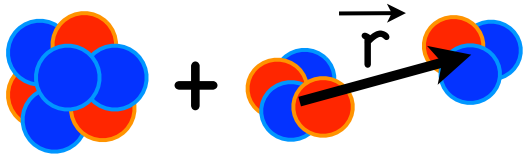
$$|\Psi_A^{J^\pi T}\rangle = \sum_\nu \int d\vec{r}\chi_\nu(\vec{r})\hat{A}\Phi_{\nu\vec{r}}^{J^\pi T(A-a,a)}$$

$$\mathcal{H}\chi = E\mathcal{N}\chi$$

$$\bar{\chi} = \mathcal{N}^{+\frac{1}{2}}\chi$$

$$\boxed{(\mathcal{N}^{-\frac{1}{2}}\mathcal{H}\mathcal{N}^{-\frac{1}{2}})\bar{\chi} = E\bar{\chi}}$$

NCSMC



$$|\Psi_A^{J^\pi T}\rangle = \sum_\lambda c_\lambda |A\lambda J^\pi T\rangle + \sum_\nu \int d\vec{r}\left(\sum_{\nu'}\int d\vec{r}\,'\mathcal{N}^{-\frac{1}{2}}_{\nu\nu'}(\vec{r},\vec{r}\,')\bar{\chi}_{\nu'}(\vec{r}\,')\right)\hat{A}\Phi_{\nu\vec{r}}^{J^\pi T(A-a,a)}$$

$$\boxed{\begin{pmatrix} H_{NCSM} & \bar{h} \\ \bar{h} & \mathcal{N}^{-\frac{1}{2}}\mathcal{H}\mathcal{N}^{-\frac{1}{2}} \end{pmatrix}\begin{pmatrix} c \\ \bar{\chi} \end{pmatrix} = E\begin{pmatrix} 1 & \bar{g} \\ \bar{g} & 1 \end{pmatrix}\begin{pmatrix} c \\ \bar{\chi} \end{pmatrix}}$$

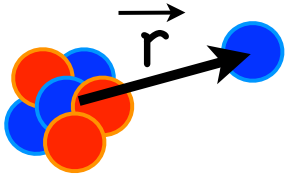
Ab initio ad spectra: proof of principle

example: n + ^{8}Li --> ^{9}Li bound states

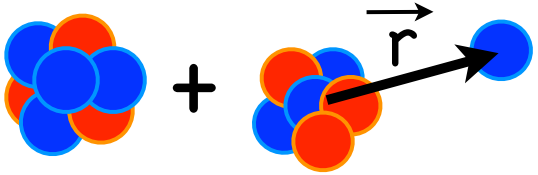
Nmax=6, Λ_{SRG} = 1.9 fm^{-1}

NCSM

NCSM/RGM



NCSMC



with 1 ^{8}Li state	expt.	^{9}Li	^{8}Li + n	^{9}Li ^{8}Li + n
^{9}Li, 3/2^{-}(g.s.)	-45.34 MeV	-43.03 MeV	-41.03 MeV	-43.28 MeV
^{9}Li, 1/2^{-}	-42.65 MeV	-41.90 MeV	-39.15 MeV	-42.13 MeV

Ab initio ad spectra: proof of principle

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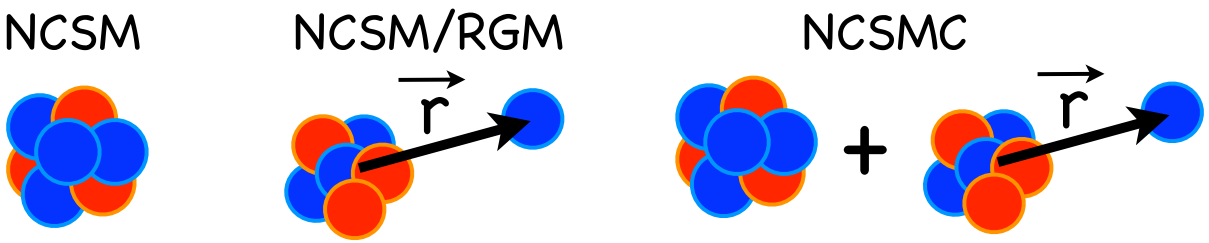

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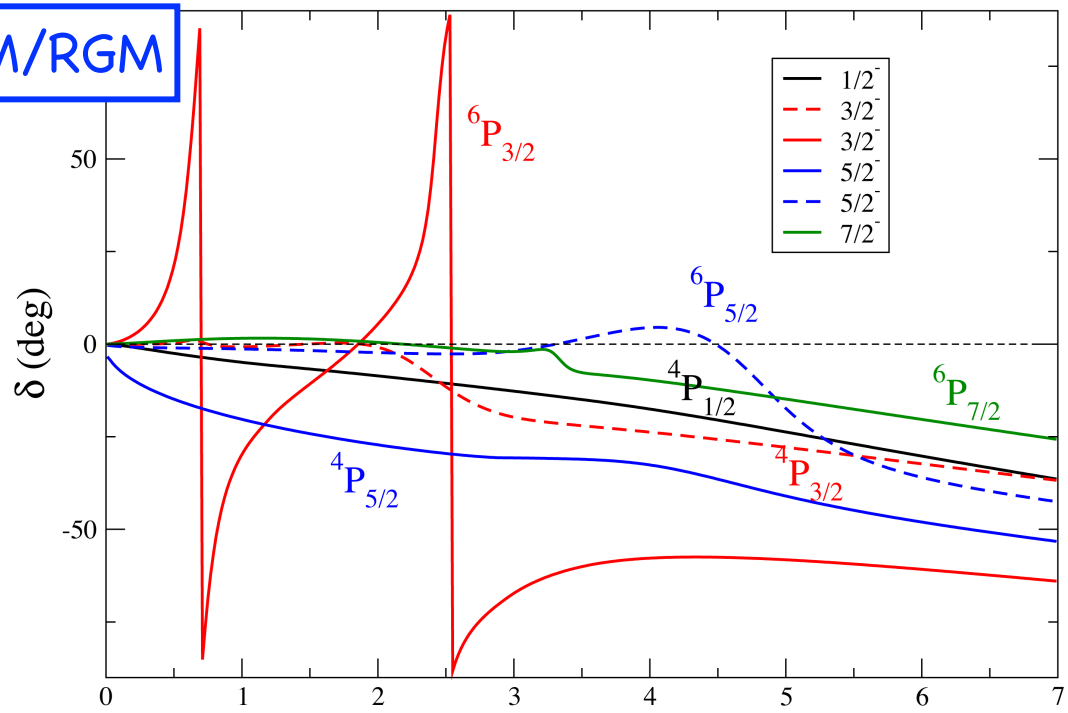
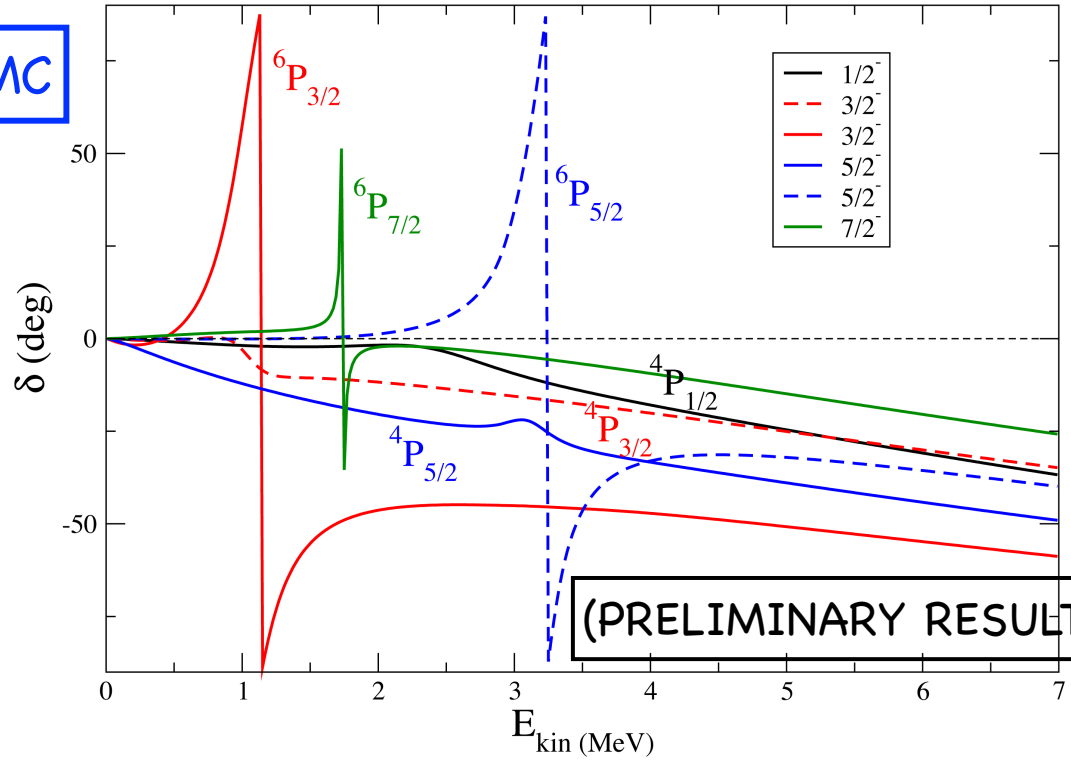
NCSM/RGM needs more target states

with 4 ^{8}Li states	expt.			
^{9}Li, 3/2^{-}(g.s.)	-45.34 MeV	-43.03 MeV	-42.36 MeV	-43.51 MeV
^{9}Li, 1/2^{-}	-42.65 MeV	-41.90 MeV	-40.68 MeV	-42.24 MeV

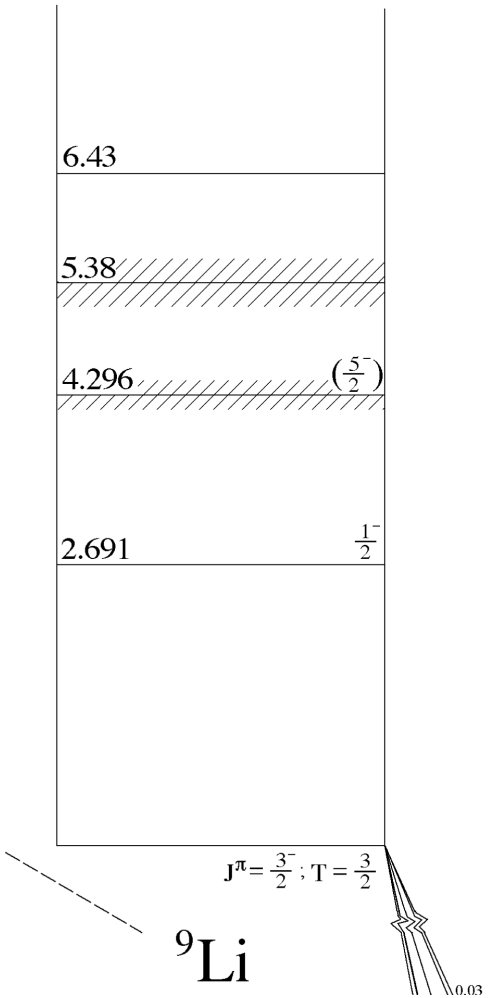
NCSM/RGM



NCSMC

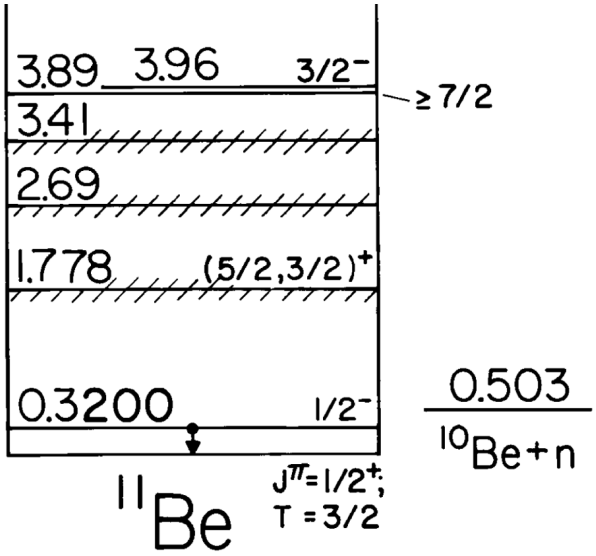


(PRELIMINARY RESULTS)



Ab spectra ad calculum

example: n + ^{10}Be --> ^{11}Be



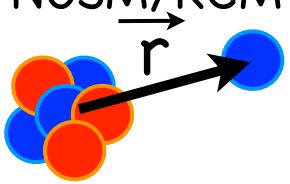
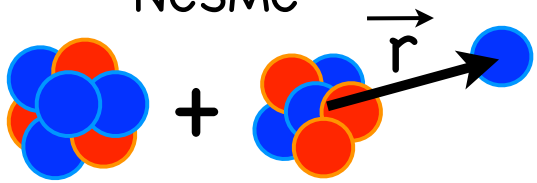
Past experiments:

$B(E1;1/2^- \rightarrow 1/2^+)$ = 0.105±0.007 (e^2fm^2)

0.116±0.012 (e^2fm^2)

Oncoming TRIUMF experiment (S1247):

^{11}Be + ^{186}W w/ TIGRESS/BAMBINO

	NCSM	NCSM/RGM	NCSMC
			
$B(E1;1/2^- \rightarrow 1/2^+)$ (e^2fm^2)	0.0065		
$1/2^-$ excited state	unbound (+2.5 MeV)	slightly bound with ^{10}Be(0^+,2^+,2^+) and SRG	

it needs more states,
but then it cannot go to large Nmax

Conclusions and outlook

- A new ab-initio theory: NCSMC, No-Core Shell Model with the Continuum

- Good description of both bound states and scattering properties

- Theory as a predictive tool
  Nuclear structure and nuclear reactions from underlying nucleonic interactions.

- Wide range of applicability