Scattering Applications with the Time-dependent Basis Function Approach

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Collaborators

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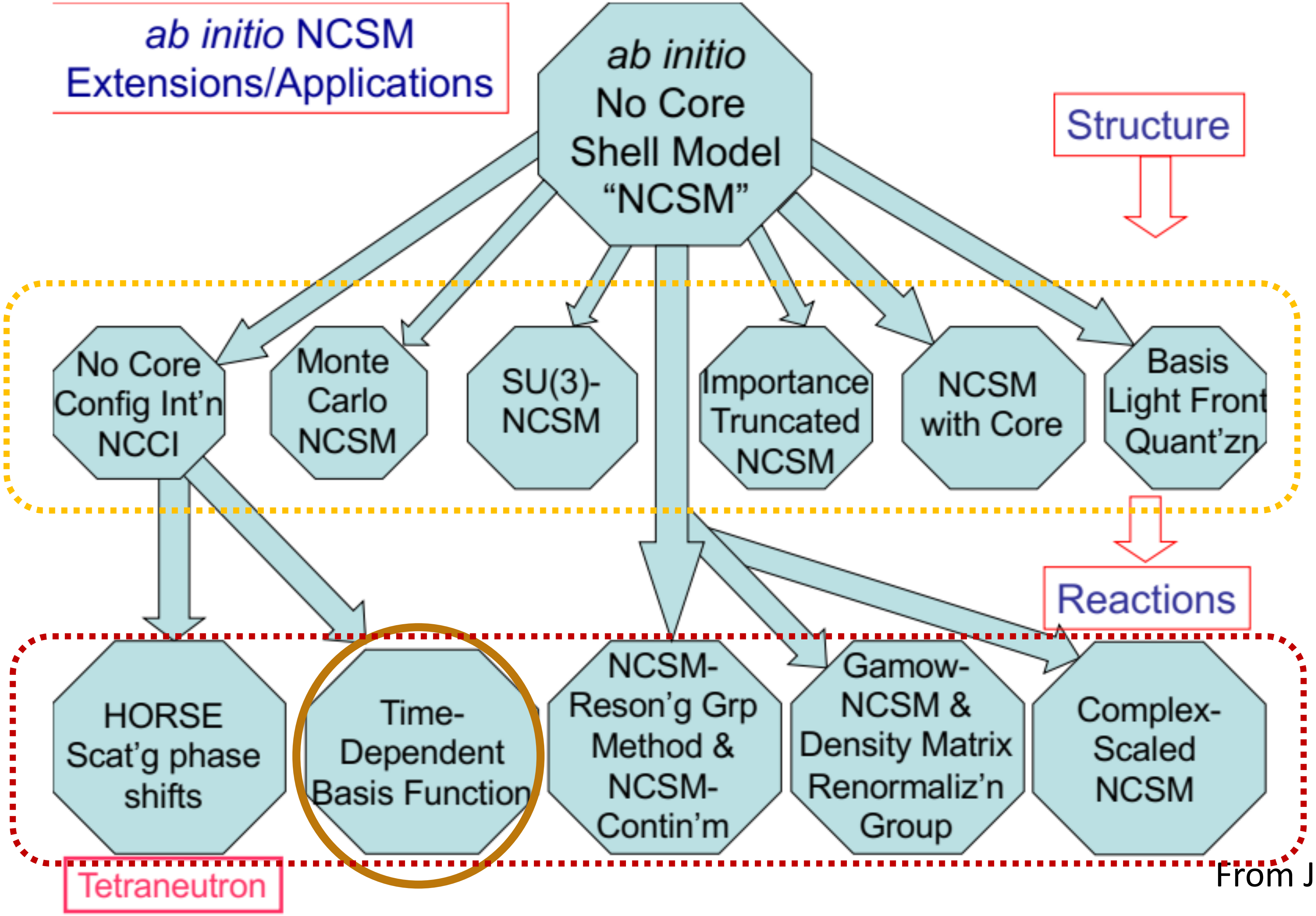
Motivations for time-dependent basis function (tBF) approach

- Develop nuclear reaction theory based on *ab initio* nuclear structure calculations,   e.g., no-core shell model (NCSM)

- Full quantal coherence and non-perturbative couplings among all possible elastic and inelastic processes

- This could enable promising avenues of research to:
  - ❖ Probe *ab initio* nuclear structure results [e.g., B(*E1*)] with external time-dependent Coulomb+nuclear forces
  - ❖ Investigate "forbidden" transitions resulting from non-perturbative processes.
  - ❖ Compare with experimental cross section data



From James P. Vary

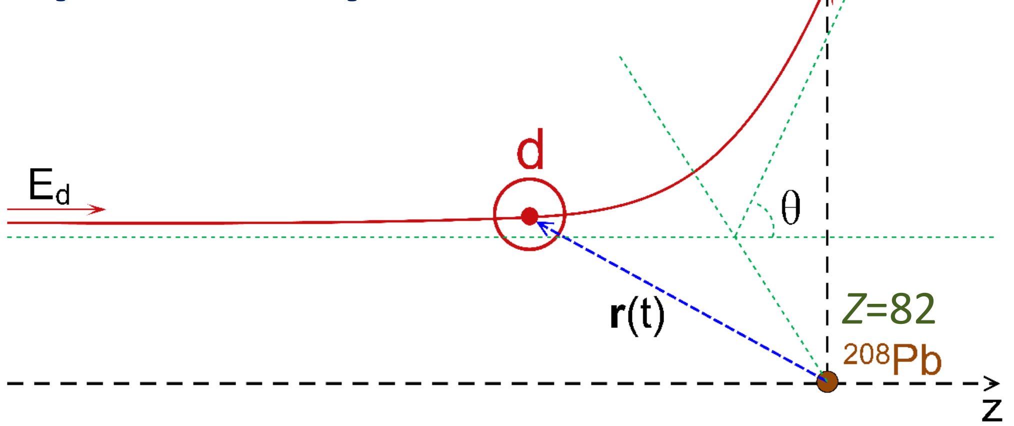
d+^{208}Pb scatterings below Coulomb barrier (11 MeV)

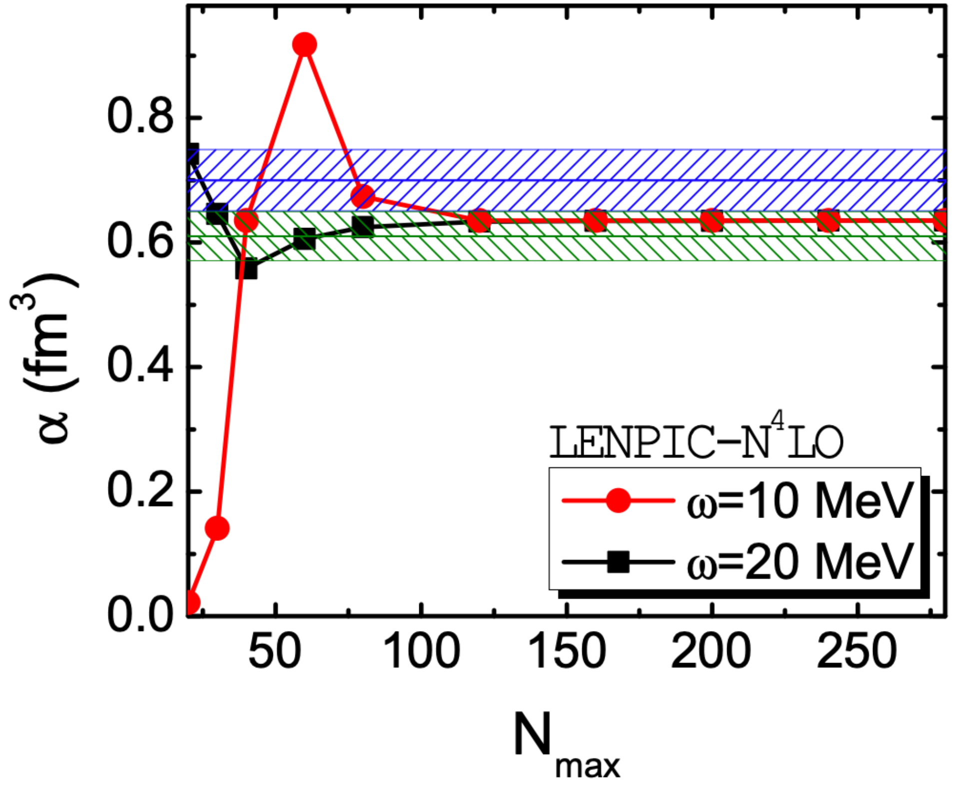
Solving EOM for CM motion of deuteron in external field:

$V = V_{coul} + V_{pol}$

$$V_{pol} = -\frac{1}{2}\alpha Z^2 e^2 \frac{1}{r^4}$$

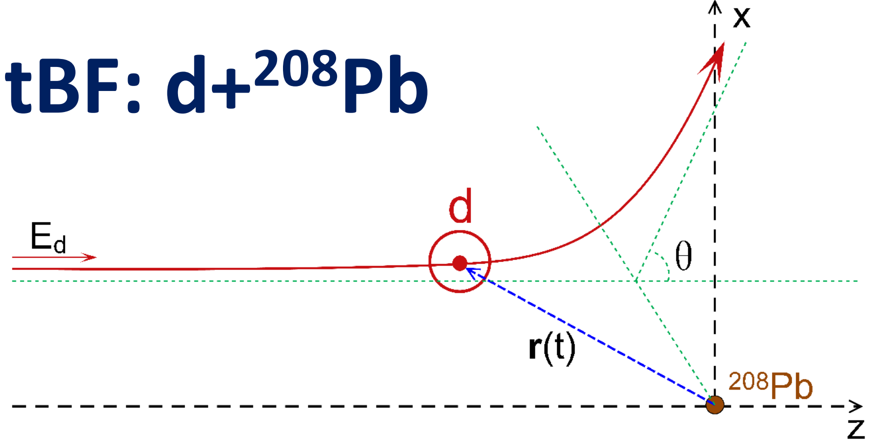
$$\alpha = \frac{8\pi}{9}\sum_{n\neq 0}\frac{B(E1; 0 \to n)}{(E_n - E_0)}$$





- Harmonic oscillator (HO) basis;
- Parameters of HO basis:
  N_{max} and ω, $(2n + l \leq N_{max})$;
- α is converged with respect to N_{max} and ω;
- LENPIC interactions:
  regulator R=1.0 fm.

tBF: d+^{208}Pb



Time-independent:

$$H_0 = T_{rel} + V_{np}$$

$$H_0|\beta_i\rangle = E_i|\beta_i\rangle$$

Basis set $\{|\beta_j\rangle\}$

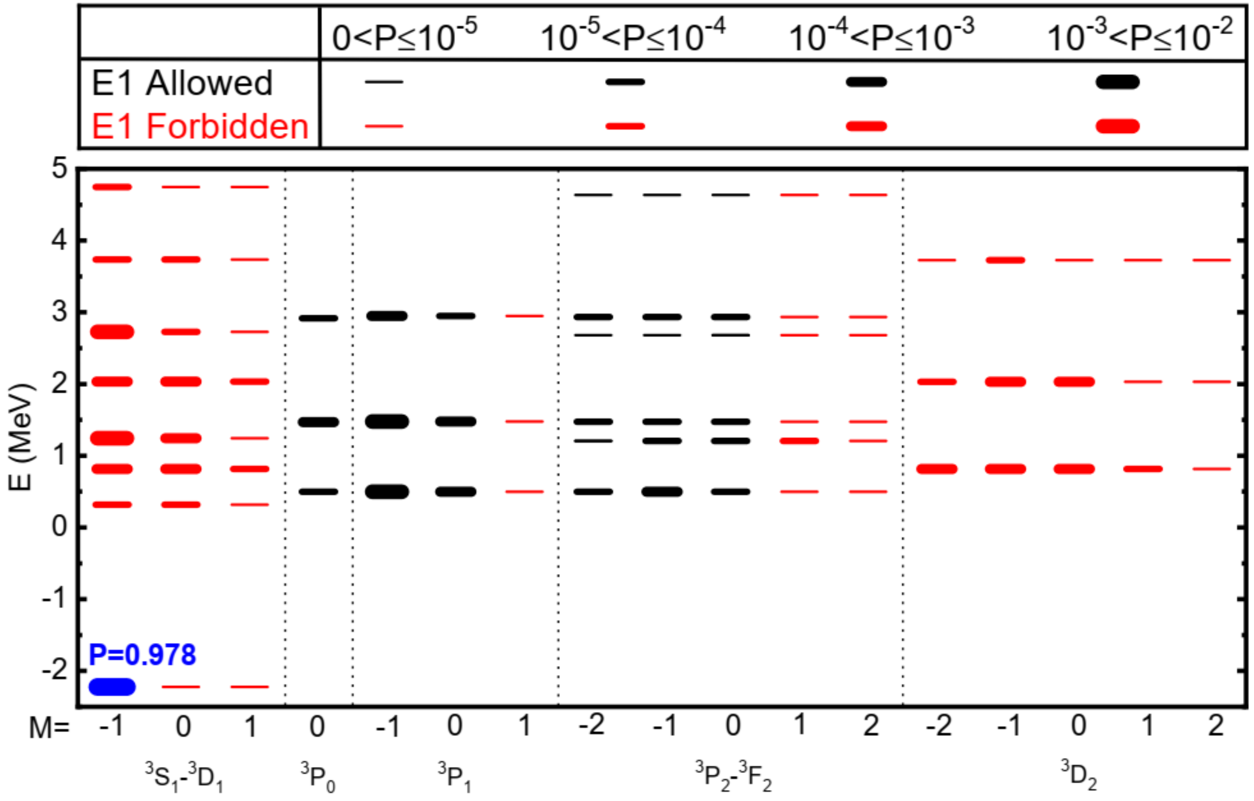
$$H(t) = H_0 + V(t)$$

E1 is dominant

Time-dependent:

$$i\frac{\partial}{\partial t}|\psi(t)\rangle_I = V_I(t)|\psi(t)\rangle_I$$

$$|\psi(t)\rangle_I = \sum_{j=1}^{n} A_j^I(t)|\beta_j\rangle$$



[Peng Yin *et al.,* in preparation]

- *NN* interaction: LENPIC-N^{4}LO
- HO basis: N_{max}, $\omega = 20$ MeV
- S=1, J_{max}=2

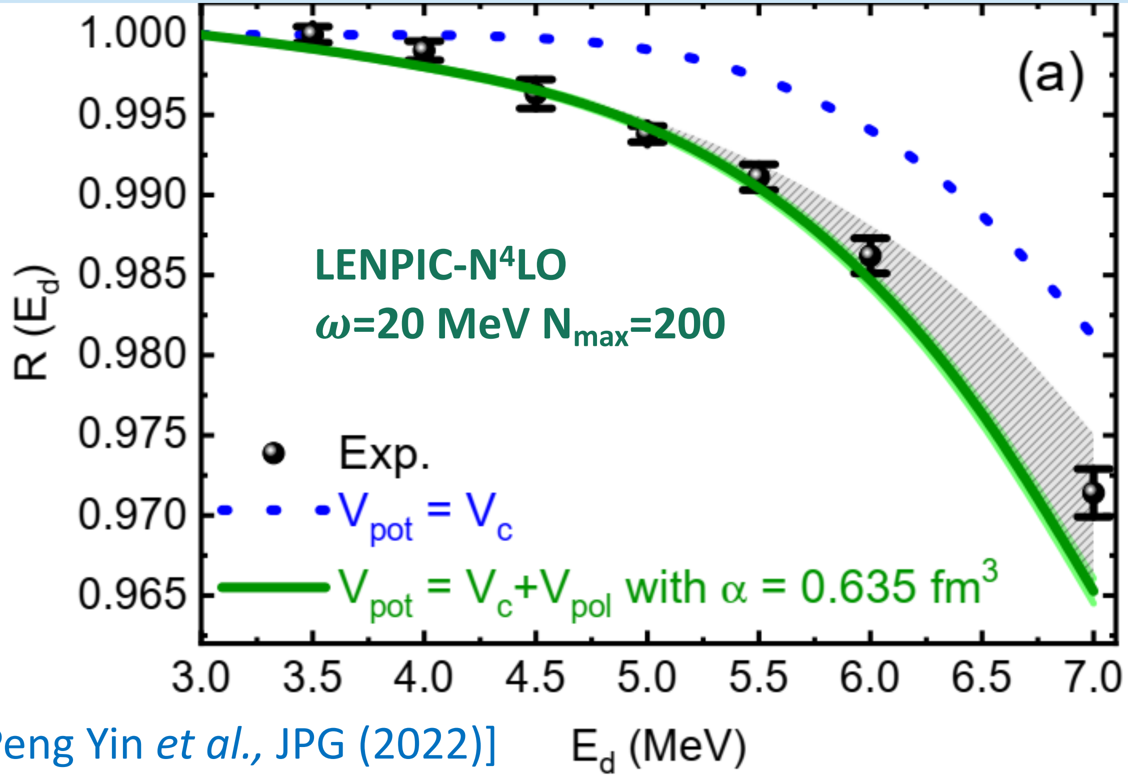
- Weijie Du, Peng Yin, Yang Li, Guangyao Chen, Wei Zuo, Xingbo Zhao, and James P. Vary, *Phys. Rev. C* **97**, 064620 (2018);
- Weijie Du, Peng Yin, Guangyao Chen, Xingbo Zhao, and James P. Vary, *in Proceedings of the International Conference "Nuclear Theory in the Supercomputing Era–2016" (NTSE-2016), Khabarovsk, Russia, September 19–23,* 2016;
- Peng Yin, Weijie Du, Wei Zuo, Xingbo Zhao and James P. Vary, J. Phys. G (2022)

Observables for d+^{208}Pb scattering

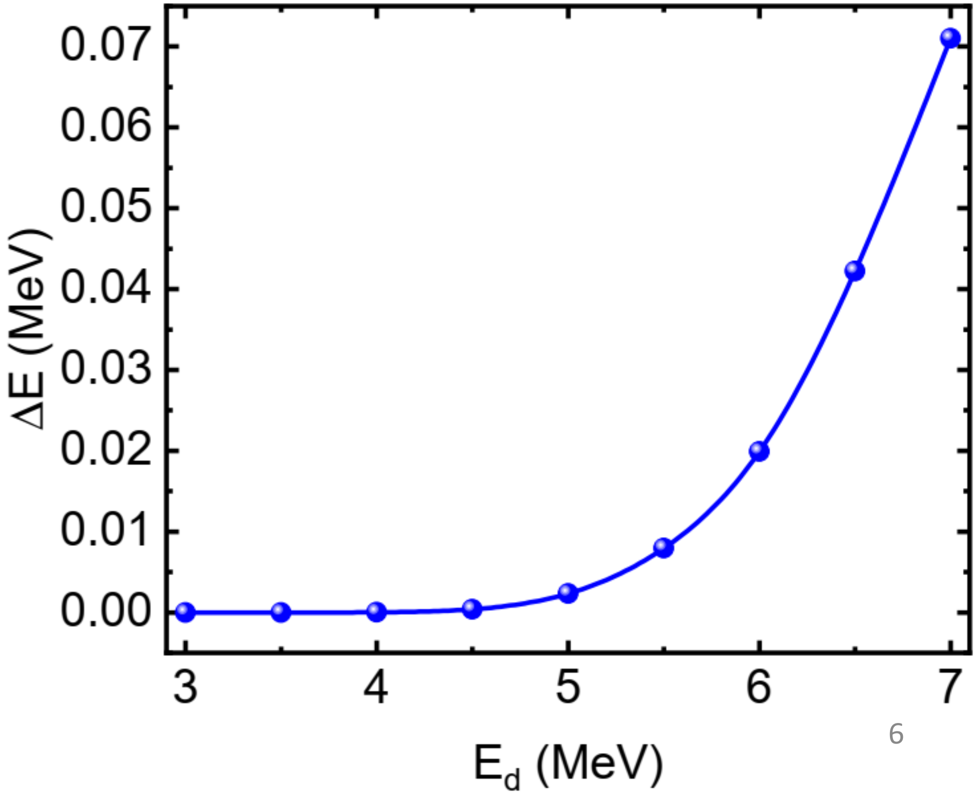
$$R(E_d) = \frac{\sigma(E_d = 3\text{ MeV}, \theta_1 = 60^\circ)}{\sigma(E_d = 3\text{ MeV}, \theta_2 = 150^\circ)} \frac{\sigma(E_d, \theta_2 = 150^\circ)}{\sigma(E_d, \theta_1 = 60^\circ)}$$

- Exp: N. L. Rodning, L. D. Knutson, W. G. Lynch and M. B. Tsang, Phys. Rev. Lett. 49, 909 (1982)
- No adjustable parameter
- No optical potential
- Energy loss correction

$$V_{pol} = -\frac{1}{2}\alpha Z^2 e^2 \frac{1}{r^4}$$



[Peng Yin *et al.*, JPG (2022)]



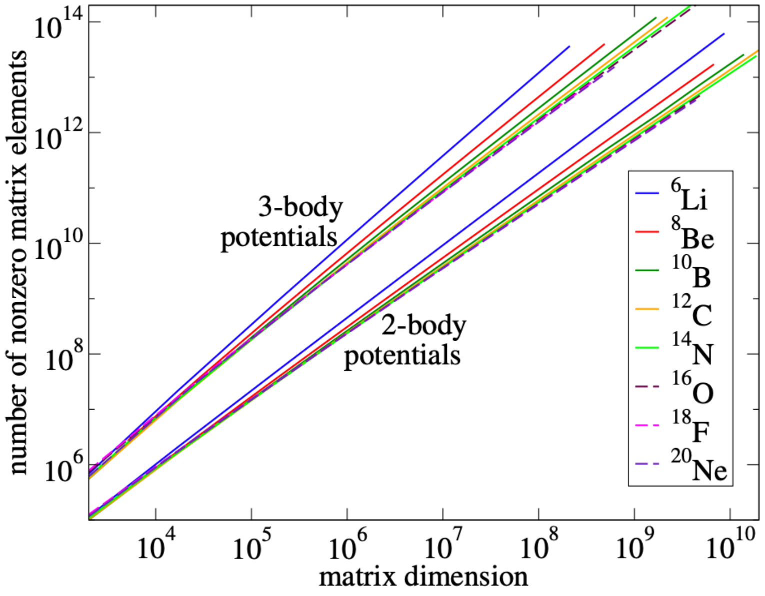
A>2 projectile

- NCSM in HO basis with N_{max} truncation; CoM motion;

  Pieter Maris (ISU), James P. Vary (ISU)

  Cori, Perlmutter, Sugon
- Calculate E1&M1 transition matrix elements
- One body density matrix elements (mixed parities, two independent runs)
- Postprocessor (manipulate wavefunctions),

  Patrick Fasano (UND) and Pieter Maris (ISU)
- Two-body operator (E1&M1) from LENPIC chiral EFT
- Application to tBF
- Photodisintegration of light nuclei



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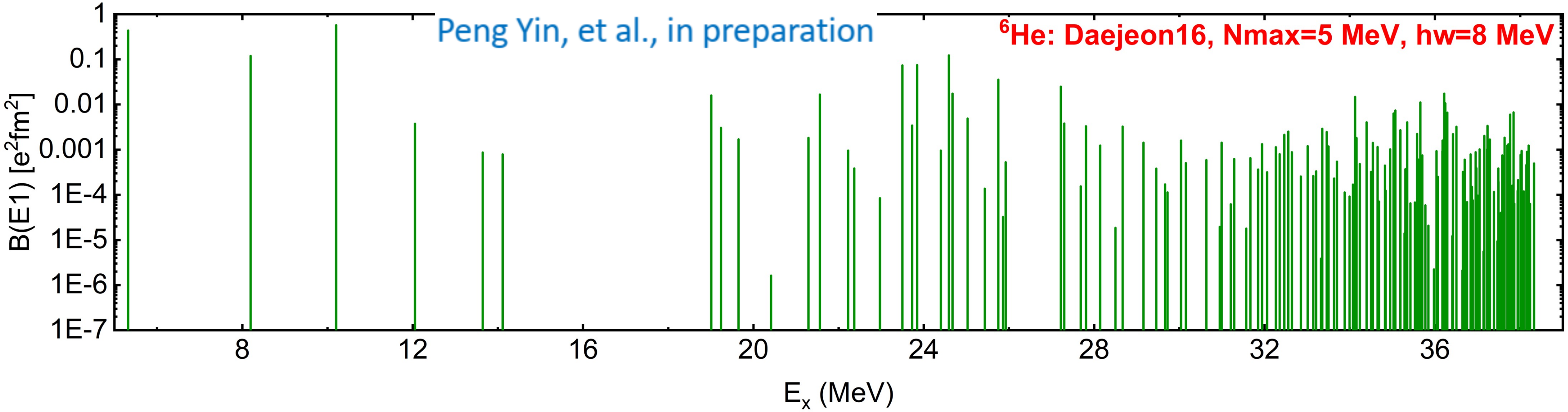

Conclusions/Perspectives

- Non-perturbative time-dependent basis function approach
- Application to d+^{208}Pb scattering
- Extension of the tBF method to heavier projectiles, e.g., rare isotopes,… using wavefunctions from NCSM
- Extension to higher incident energies: adding strong interaction between scattering nuclei
- Two-body electromagnetic operators from chiral effective field theory
- Quantum consideration of center of mass motion of the projectile