Combining Symmetry Breaking and Restoration with Configuration Interaction

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Progress in Ab Initio Techniques in Nuclear Physics
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Purpose of this work

- Design novel many-body method for *ab initio* computations.
- For open-shell nuclei.
- Use symmetry breaking and restoration.
- Variational.
- Numerically effective.
- Access to ground-state and excited-states properties.
- Alternative to Gorkov SCGF, (symmetry-restored) BMBPT and BCC.

Nuclear Many-Body Problem

Vertical development of configurations

- Symmetry restricted methods, dominant *ab initio* approaches.
- Use SD reference state and particle/hole excitations.
- Efficiently grasp dynamical correlations.
- Ex: MBPT, CC, NCSM...

Horizontal development of configurations

- Symmetry unrestricted methods, dominant EDF approaches
- Use Bogoliubov vacua with different constrained parameters.
- Use symmetry breaking to grasp non-dynamical correlations:
  - $U(1)$ (particle number): nuclear superfluidity
  - $SU(2)$ (angular momentum): nuclear deformation

1. Consider a (constrained) Hartree-Fock-Bogoliubov state.
2. Make normal ordering of the Hamiltonian with respect to this state.
3. Build quasiparticle excitations on top of HFB state.
4. Restore symmetries by projecting those states.
5. Truncate the basis efficently (nQP and/or energy of configurations).
6. Apply the variational principle: leads to a Generalized EV Problem.
7. Optimize the reference state *in presence* of the configuration mixing.

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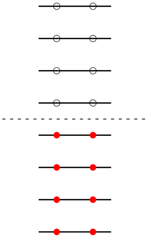
Application to the Pairing Hamiltonian

The Richardson Model

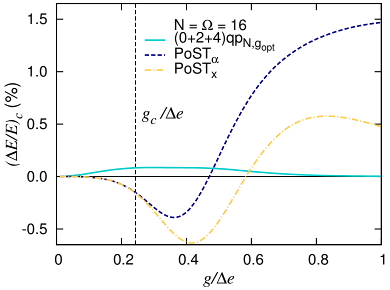
- Ω doubly degenerated and equidistant shells.
- Half-filling.
- Attractive pairing interaction:
  $H(g) \equiv \sum_{k=1}^{N} e_k(a_k^\dagger a_k + a_{\bar{k}}^\dagger a_{\bar{k}}) - g \sum_{k \neq l}^{N} a_k^\dagger a_{\bar{k}}^\dagger a_{\bar{l}} a_l$.
- $U(1)$ spontaneous symmetry breaking beyond g_c.
- Strongly interacting fermions.



$\Omega = N = 8$

Application to the Pairing Hamiltonian

- BCS solution of $H(g_{aux})$ along with 2QP and 4QP configurations.
- Reference state further optimized according to g_{aux}.



Error in correlation energy:

$$(\Delta E/E)_c = |E_c^{\text{exact}} - E_c^{\text{approx}}|/E_c^{\text{exact}}$$

J. Ripoche et al, PRC **95**, 014326 (2017)

- Lowest error in E_c (0.1%) for polynomialy scaling methods.
- Good reproduction of low-lying spectroscopy.
- Optimization correct appearance of "first order phase transition".
- Good motivation for *ab initio* application !