Functional approach for pairing with good Particle number

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Coll: G. Hupin,
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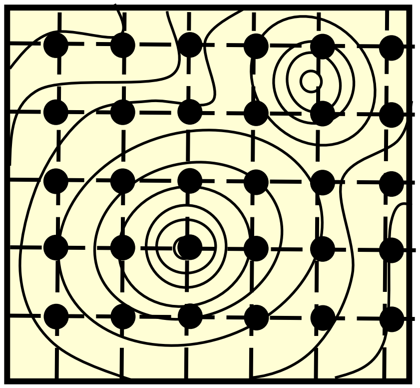
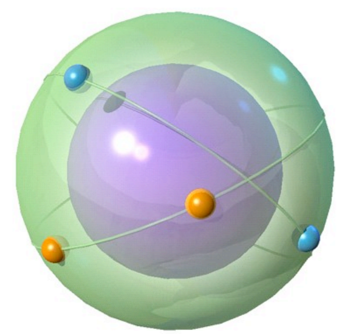
Outline of my talk

Multi- Ref. (MR)-GCM



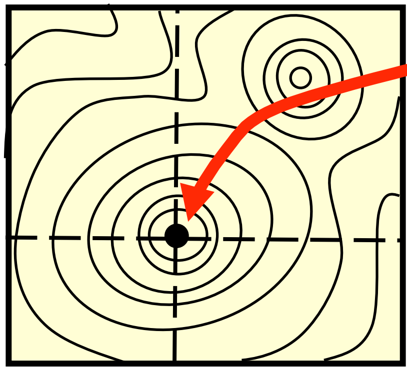
- Some recent discussion on symmetry breaking and Restoration in Energy Density Functional theory
  - ⇨ Hamiltonian vs EDF
  - ⇨ Self-interaction problem
  - ⇨ Density dependence of effective interaction ?
  - ⇨ Can we interpret the MR-EDF as a functional theory?
- Proposition of a different strategy to break and restore symmetry in EDF : The Symmetry-Conserving EDF concept
  - ⇨ Application to Particle number Restoration
  - ⇨ Examples of application of Projection before or After variation to light and medium mass nuclei



- DFT for small superconductors

Configuration Mixing within Energy Density Functional

Single Reference (SR)-Mean-Field



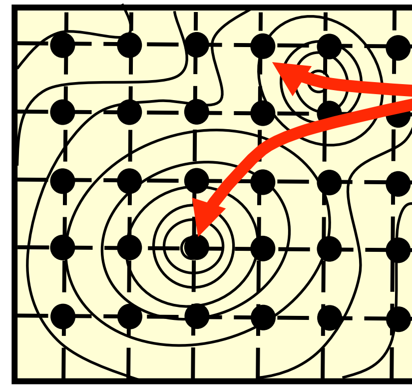
$$|\Phi\rangle = \Pi \alpha_k |0\rangle$$

(Skyrme, Gogny)

$$\langle \Phi(Q) | \hat{H} | \Phi(Q) \rangle$$

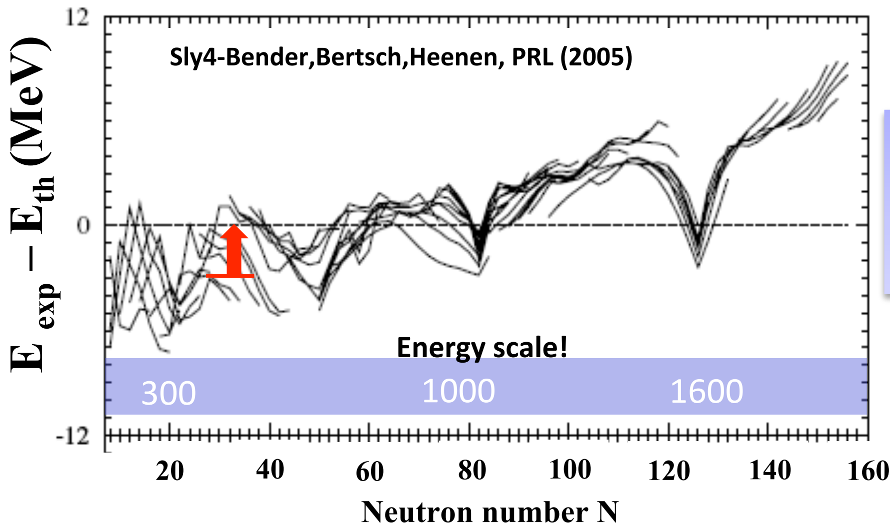
Multi- Ref. (MR)-GCM

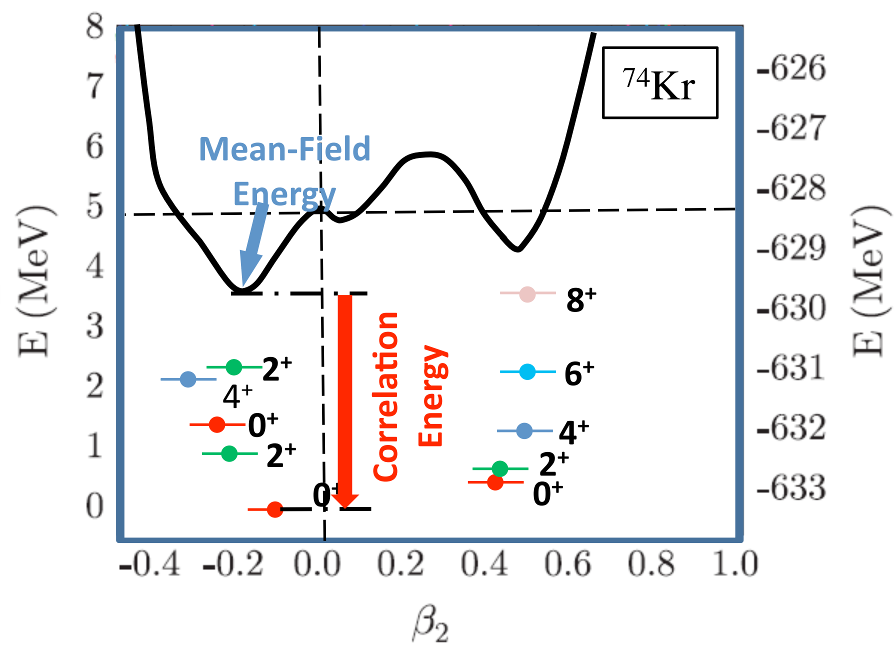
$$|\Psi\rangle = \int dQ f(Q) |\Phi(Q)\rangle$$



$$|\Phi(Q_i)\rangle$$

$$\langle \Psi | \hat{H} | \Psi \rangle$$



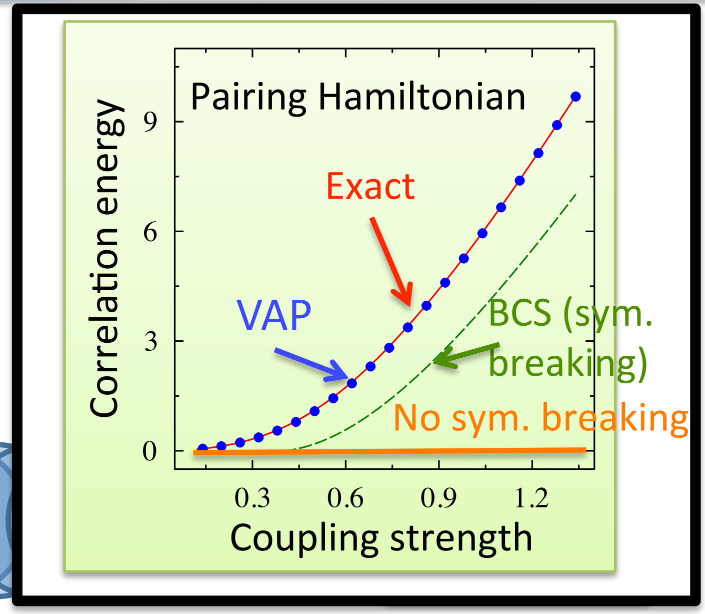


Bender et al, PRC74 (2006)

Breaking and restoring symmetries

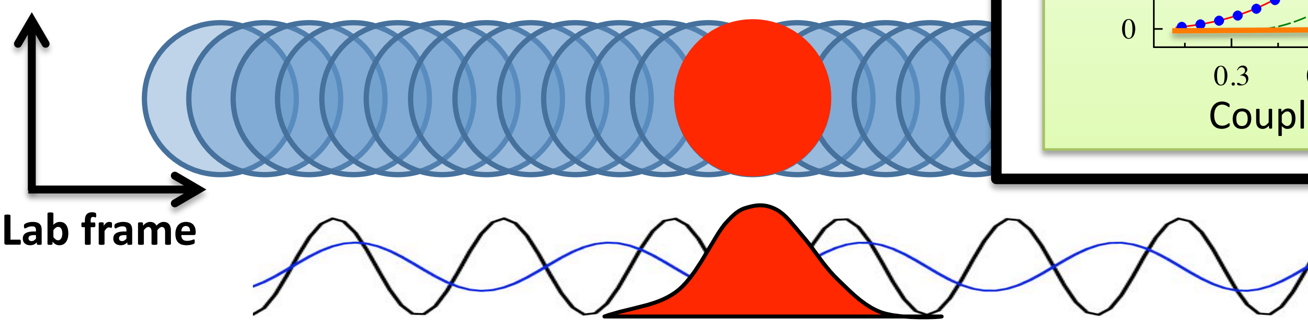
Inclusion of correlation through symmetry breaking:

EDF breaks as much as possible symmetries
to incorporate correlations

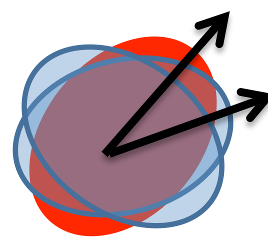


Few examples

- translational invariance $\Longrightarrow$ $[\hat{H}, \hat{P}_{\rm cm}] \neq 0$

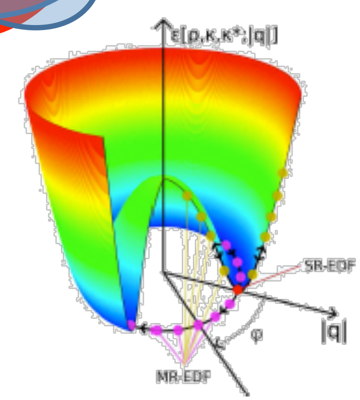


- Rotational invariance $\Longrightarrow$ $[\hat{H}, \hat{J}] \neq 0$



Quadrupole Correlation - Rotational Bands

- U(1) symmetry $\Longrightarrow$ $[\hat{H}, \hat{N}] \neq 0$

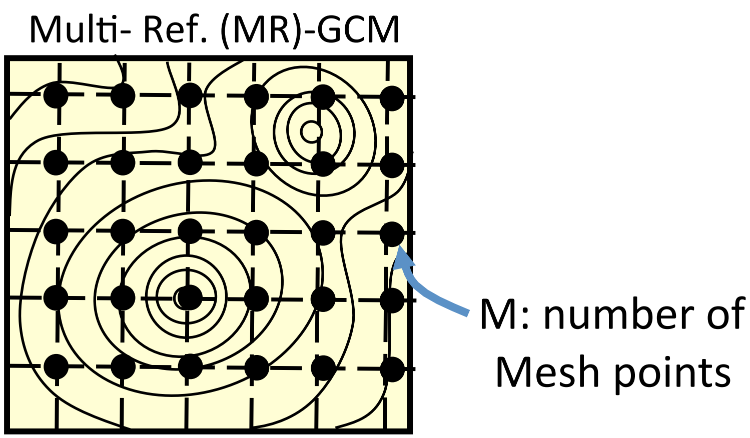


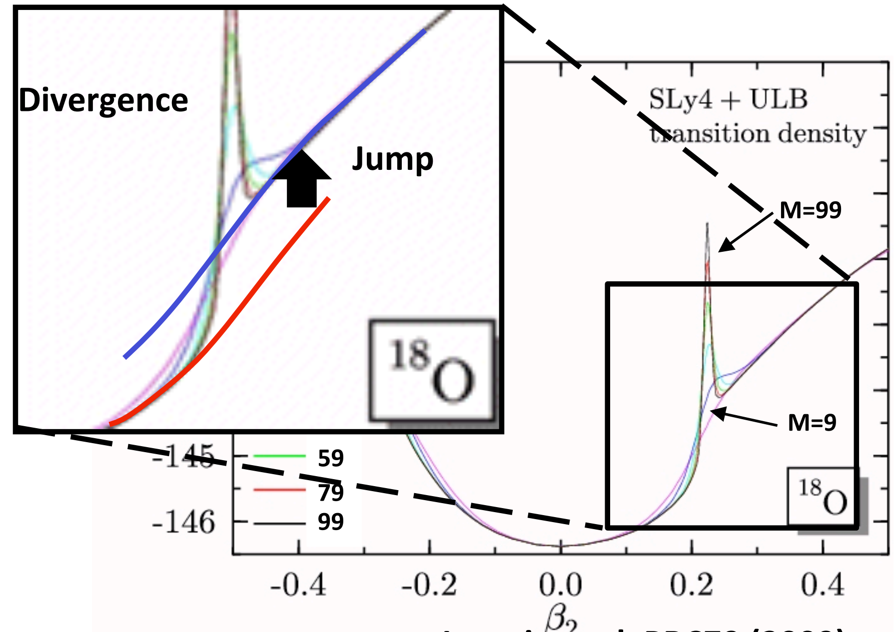
Pairing Correlations - Odd-even effects

In all cases: $$|\Psi\rangle = \int dQ f(Q) \, |\Phi(Q)\rangle$$

Ring and Schuck book (1980)

Application of conf. mixing in EDF
Needs to be regularized

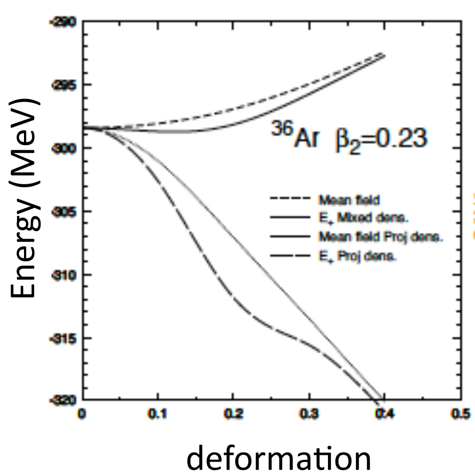




Only functional of ρ, ρ^2, ρ^3, ρ^4, ρ^5 could be used, not ρ^α !!

Lacroix et al, PRC79 (2009), Bender et al, PRC79 (2009), Duguet et al, PRC79 (2009)

What should be the density to be used in the effective interaction ?



Taken from
L. M. Robledo, J. Phys. G 37 (2010)

The very notion of symmetry restoration in EDF needs to be clarified

T. Duguet and J. Sadoudi, J. Phys. G 37 (2010)

Configuration mixing as a functional theory

The two-body Hamiltonian case: what is a functional of what?

$$H = \sum_{ij} t_{ij}\, a_i^\dagger\, a_j + \frac{1}{4} \sum_{ijkl} \bar{v}_{ijkl}\, a_i^\dagger\, a_j^\dagger\, a_l\, a_k$$

Mean-Field (with Pairing)

$$|\Phi_0\rangle = \Pi \beta_\alpha^\dagger |-\rangle$$

$$\langle H \rangle = \sum_i t_{ii}\rho_{ii} + \frac{1}{2}\sum_{i,j} \bar{v}_{ijij}\rho_{ii}\rho_{jj} + \frac{1}{4}\sum_{i,j} \bar{v}_{i\bar{i}j\bar{j}}\kappa^*_{i\bar{i}}\kappa_{j\bar{j}}$$
$$= E_{SR}\left[\rho, \kappa, \kappa^*\right]$$

$$\Phi_0 \rightarrow \{\rho, \kappa\} \rightarrow E_{SR}$$

Projection

$$|\Psi_\Omega\rangle = P^\Omega |\Phi_0\rangle$$
$$= \int dQ f(Q) |\Phi(Q)\rangle$$

$$E_{MR} = \iint dQ dQ' \mathcal{N}(Q, Q') E_{SR}(\rho^{QQ'}, \kappa^{QQ'}, \kappa^{*QQ'})$$

$$\Phi_0 \rightarrow \{\rho^{QQ'}, \kappa^{QQ'}, \kappa^{*QQ'}\} \rightarrow E_{MR}$$

Alternative formulation

$$|\Psi_\Omega\rangle = P^\Omega |\Phi_0\rangle$$

$$E_{MR} = \sum t_{ij}\, \langle a_i^\dagger\, a_j \rangle_\Omega + \frac{1}{4}\sum \bar{v}_{ijkl} \langle a_i^\dagger\, a_j^\dagger\, a_l\, a_k \rangle_\Omega$$

$$E_{MR} = \sum_{ij} t_{ij}\, \rho_{ij}^\Omega + \frac{1}{4}\sum_{ijkl} \bar{v}_{ijkl} R^\Omega_{kl,ij}$$

$$\Phi_0 \rightarrow \Psi_\Omega \rightarrow \{\rho^\Omega, R^\Omega\} \rightarrow E_{MR}$$

What about the EDF theory?

The particle number restoration case

$$|\Psi_N\rangle = P^N |\Phi_0\rangle$$

$$P^N = \frac{1}{2\pi}\int_0^{2\pi} d\varphi \;\; e^{i\varphi(\hat{N}-N)}$$

Alternative formulation ?

Mean-Field (with Pairing)

For non-density dependent effective int.

$$|\Phi_0\rangle = \Pi \beta^\dagger_\alpha |-\rangle$$

$$\mathcal{E}_{SR}\left[\rho,\kappa,\kappa^*\right] = \sum t_{ii}\rho_{ii} + \frac{1}{2}\sum \overline{v}^{\rho\rho}_{ijij}\rho_{ii}\rho_{jj} + \frac{1}{4}\sum \overline{v}^{\kappa\kappa}_{i\bar{i}j\bar{j}}\kappa^*_{i\bar{i}}\kappa_{j\bar{j}}$$

$$\Phi_0 \rightarrow \{\rho,\kappa\} \rightarrow \mathcal{E}_{SR}$$

$$\begin{aligned}
\mathcal{E}_N[\Psi_N] &= \boxed{\sum_i t_{ii} n^N_i + \frac{1}{2}\sum_{i,j,j\neq\bar{i}} \overline{v}^{\rho\rho}_{ijij} R^N_{ijij} + \frac{1}{4}\sum_{i\neq j, i\neq\bar{j}} \overline{v}^{\kappa\kappa}_{i\bar{i}j\bar{j}} R^N_{j\bar{j}i\bar{i}}} \quad \textbf{OK} \\
&+ \frac{1}{2}\sum_i \overline{v}^{\rho\rho}_{i\bar{i}i\bar{i}} \int_0^{2\pi} d\varphi \;\; n^{0\varphi}_i \;\; n^{0\varphi}_i \mathcal{N}_N(0,\varphi) \\
&+ \frac{1}{2}\sum_i \overline{v}^{\kappa\kappa}_{i\bar{i}i\bar{i}} \int_0^{2\pi} d\varphi \kappa^{\varphi 0\star}_{i\bar{i}} \;\; \kappa^{0\varphi}_{i\bar{i}} \mathcal{N}_N(0,\varphi)\,,
\end{aligned}$$

?

Projection

$$\mathcal{E}_N[\Psi_N] \equiv \int_0^{2\pi} d\varphi \, \mathcal{E}_{SR}\left[\rho^{0\varphi},\kappa^{0\varphi},\kappa^{\varphi 0\star}\right] \mathcal{N}_N(0,\varphi)$$

$$\Phi_0 \rightarrow \{\rho^{0\varphi},\kappa^{0\varphi},\kappa^{*0\varphi}\} \rightarrow \mathcal{E}_N$$

The particle number restoration case

$$|\Psi_N\rangle = P^N|\Phi_0\rangle$$

$$P^N = \frac{1}{2\pi}\int_0^{2\pi} d\varphi \;\; e^{i\varphi(\hat{N}-N)}$$

Mean-Field (with Pairing)

$$|\Phi_0\rangle = \Pi\beta^\dagger_\alpha|-\rangle$$

$$\mathcal{E}_{SR}\left[\rho,\kappa,\kappa^*\right] = \sum t_{ii}\rho_{ii} + \frac{1}{2}\sum \overline{v}^{\rho\rho}_{ijij}\rho_{ii}\rho_{jj} + \frac{1}{4}\sum \overline{v}^{\kappa\kappa}_{i\bar{i}j\bar{j}}\kappa^*_{i\bar{i}}\kappa_{j\bar{j}}$$

$$\Phi_0 \rightarrow \{\rho,\kappa\} \rightarrow \mathcal{E}_{SR}$$

Projection

$$\mathcal{E}_N[\Psi_N] \equiv \int_0^{2\pi} d\varphi\, \mathcal{E}_{SR}\left[\rho^{0\varphi},\kappa^{0\varphi},\kappa^{\varphi 0\star}\right]\mathcal{N}_N(0,\varphi)$$

$$\Phi_0 \rightarrow \{\rho^{0\varphi},\kappa^{0\varphi},\kappa^{*0\varphi}\} \rightarrow \mathcal{E}_N$$

Alternative formulation ?

For non-density dependent effective int.

After regularization proposed in

Lacroix, Duguet, Bender, PRC79 (2009)

$$\begin{aligned}\mathcal{E}_N[\Psi_N] = {} & \sum_i t_{ii}n_i^N \\ & + \frac{1}{2}\sum_{i,j,j\neq\bar{i}} \overline{v}^{\rho\rho}_{ijij}R^N_{ijij} \\ & + \frac{1}{4}\sum_{i\neq j,j\neq\bar{i}} \overline{v}^{\kappa\kappa}_{i\bar{i}j\bar{j}}R^N_{j\bar{j}i\bar{i}} \\ & + \frac{1}{2}\sum_i \overline{v}^{\rho\rho}_{i\bar{i}i\bar{i}}(n_i^N n_i^N - \delta n_i\delta n_i) \\ & + \frac{1}{2}\sum_i \overline{v}^{\kappa\kappa}_{i\bar{i}i\bar{i}}\left[n_i^N(1-n_i^N) + \delta n_i\delta n_i\right] ,\end{aligned}$$

OK

$$\delta n_i = n_i^N - n_i^0$$

Ψ_N $\quad$ Φ_0

The particle number restoration case

$$|\Psi_N\rangle = P^N|\Phi_0\rangle$$

$$P^N = \frac{1}{2\pi}\int_0^{2\pi} d\varphi \; e^{i\varphi(\hat{N}-N)}$$

Mean-Field (with Pair

$$|\Phi_0\rangle = \Pi\beta^\dagger_\alpha|-\rangle$$

$$\mathcal{E}_{SR}\left[\rho,\kappa,\kappa^*\right] = \sum t_{ii}\rho_{ii}$$

$$+\frac{1}{2}\sum \bar{v}^{\rho\rho}_{ijij}$$

$$\Phi_0 \rightarrow \{\rho,\kappa\} \rightarrow$$

Projection

$$\mathcal{E}_N[\Psi_N] \equiv \int_0^{2\pi} d\varphi \, \mathcal{E}_{SR}\left[\rho^{0\varphi},\kappa^{0\varphi},\kappa^{\varphi 0\star}\right]\mathcal{N}_N(0,\varphi)$$

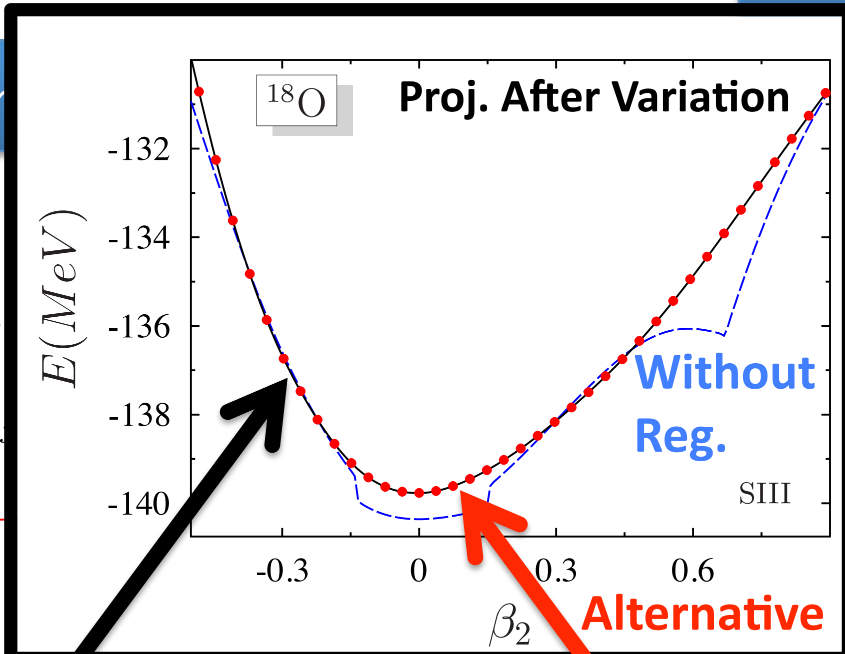
$$\Phi_0 \rightarrow \{\rho^{0\varphi},\kappa^{0\varphi},\kappa^{*0\varphi}\} \rightarrow \mathcal{E}_N$$

Alternative formulation ?

sity dependent effective int.

rization proposed in

Lacroix, Duguet, Bender, PRC7 (2009)



MR-EDF+reg

$$t_{ii}n_i^N$$

$$\sum_{,j,j\neq\bar{\imath}} \bar{v}^{\rho\rho}_{ijij}R^N_{ijij}$$

$$\sum_{\neq j,j\neq\bar{\imath}} \bar{v}^{\kappa\kappa}_{i\bar{\imath}j\bar{j}}R^N_{j\bar{j}i\bar{\imath}}$$

$$+\frac{1}{2}\sum_i \bar{v}^{\rho\rho}_{i\bar{\imath}i\bar{\imath}}(n_i^N n_i^N - \delta n_i\delta n_i)$$

$$+\frac{1}{2}\sum_i \bar{v}^{\kappa\kappa}_{i\bar{\imath}i\bar{\imath}}\left[n_i^N(1-n_i^N)+\delta n_i\delta n_i\right],$$

OK

$$\delta n_i = n_i^N - n_i^0$$

Ψ_N Φ_0

Discussion

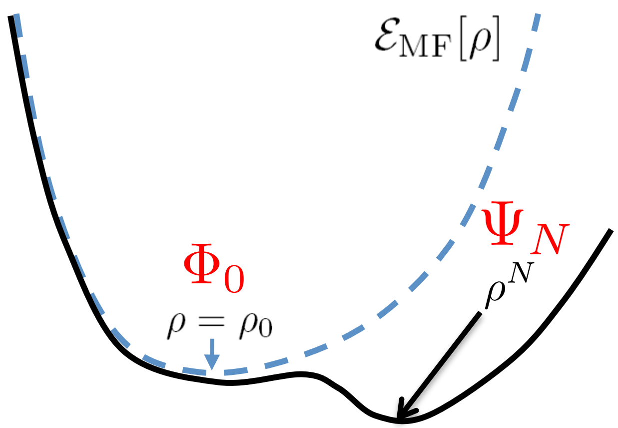
The Symmetry Conserving EDF

Direct formulation:

$$\Psi_N \rightarrow \{\rho^N, R^N\} \rightarrow \mathcal{E}_{SC}(\rho^N, R^N)$$

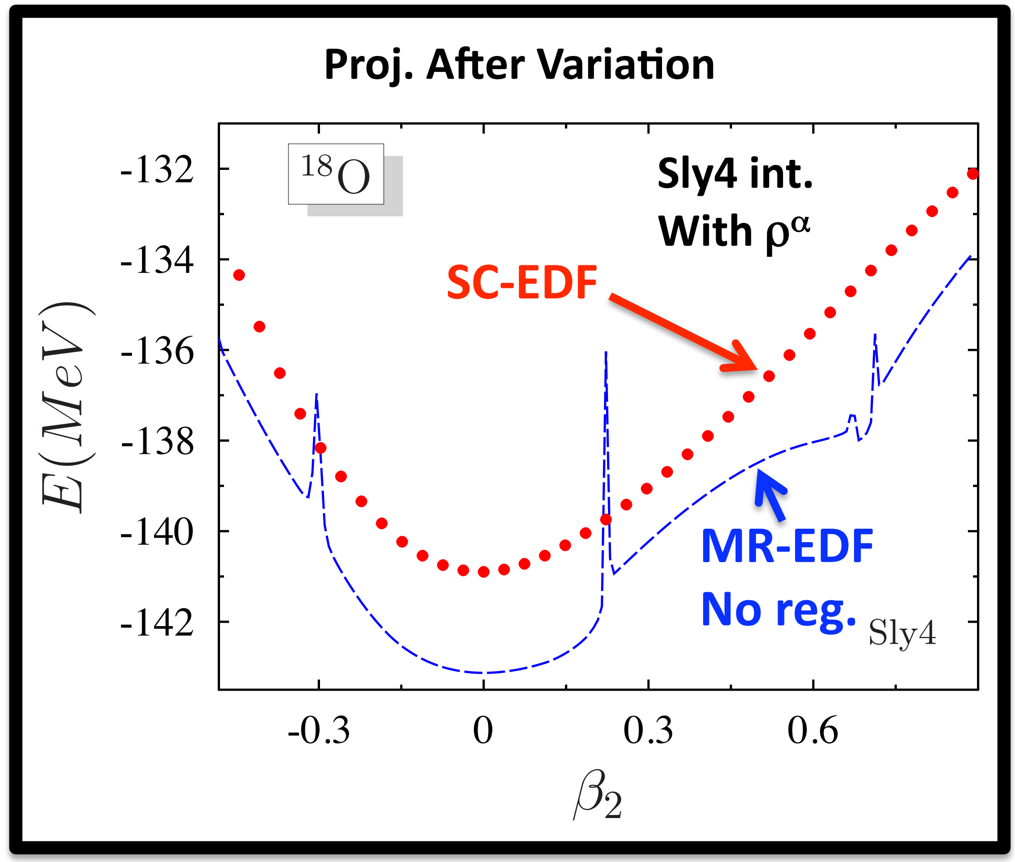
Advantages

- the functional is automatically symmetry conserving.
- It is equivalent to MR-EDF for non density dependent term
- It is a natural extension of SR-EDF



- It is free of jumps/divergence

Hupin, Lacroix, Bender, (2011) arXiv 1105.4084



- It could be extended to dens. dependent interaction

$$\overline{v}^{\rho\rho}[\rho] \Longrightarrow \overline{v}^{\rho\rho}[\rho^N], \ \overline{v}^{\kappa\kappa}[\rho] \Longrightarrow \overline{v}^{\kappa\kappa}[\rho^N]$$

Variation After Projection: the projected BCS case

$$\Psi_N \to \{\rho^N, R^N\} \to \mathcal{E}_{SC}(\rho^N, R^N)$$

Functional:

$$\mathcal{E}_N[\Psi_N] = \sum_i t_{ii} n_i^N + \frac{1}{2} \sum_{i,j,j\neq\bar{\imath}} \bar{v}^{\rho\rho}_{ijij} R^N_{ijij} + \frac{1}{4} \sum_{i\neq j, j\neq\bar{\imath}} \bar{v}^{\kappa\kappa}_{i\bar{\imath}j\bar{j}} R^N_{j\bar{j}i\bar{\imath}} + \frac{1}{2} \sum_i \bar{v}^{\rho\rho}_{i\bar{\imath}i\bar{\imath}} n_i^N n_i^N + \frac{1}{2} \sum_i \bar{v}^{\kappa\kappa}_{i\bar{\imath}i\bar{\imath}} n_i^N (1 - n_i^N)$$

Trial state:

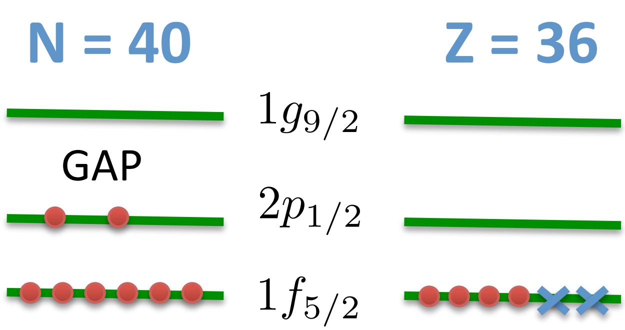
$$|\Psi_N\rangle = P^N \Pi(u_i + v_i a_i^\dagger a_{\bar{i}}^\dagger)|-\rangle$$

Minimization:

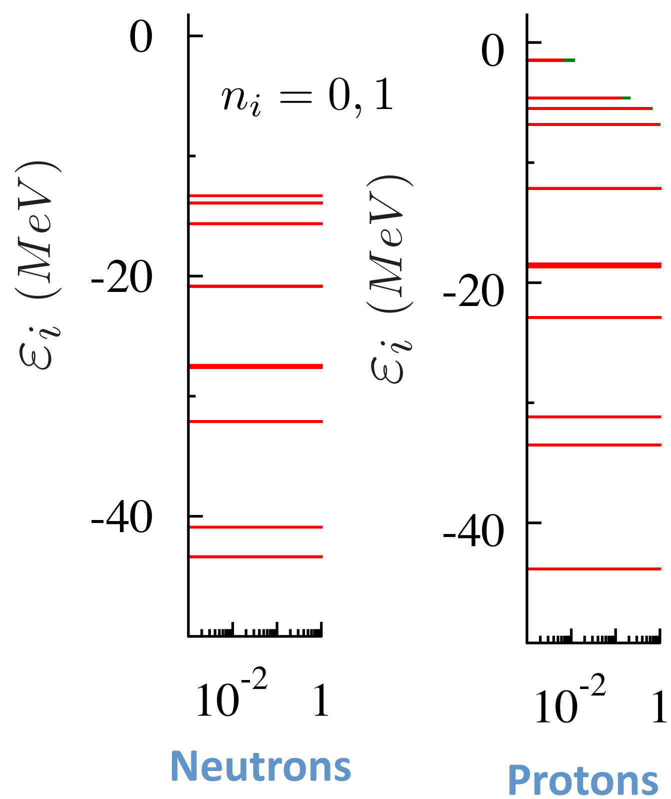
$$\frac{\partial \mathcal{E}_N}{\partial v_i^2} = 0 \qquad \frac{\partial \mathcal{E}_N}{\partial \varphi_i^*(r)} = 0$$

Sheik, Ring, NPA665 (2000),
Dietrich et al, PRB135 (1964)

Application: ^{76}Kr

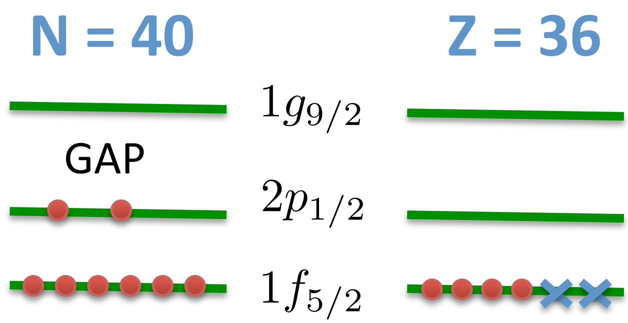


Occupation Probability (BCS case)-ev8 code

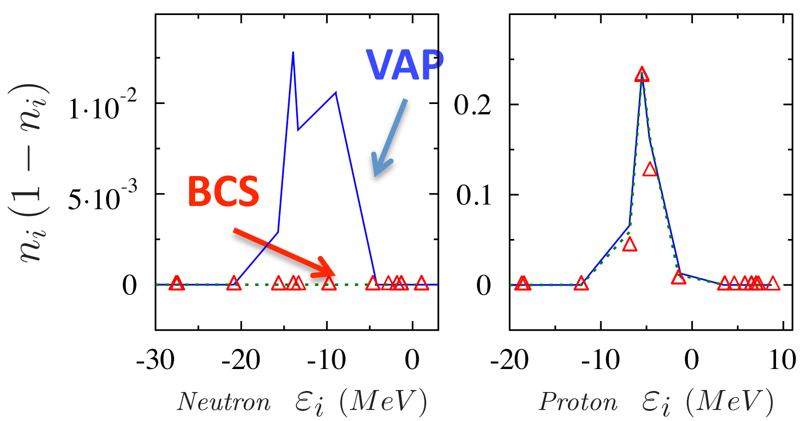


Variation After Projection: the projected BCS case

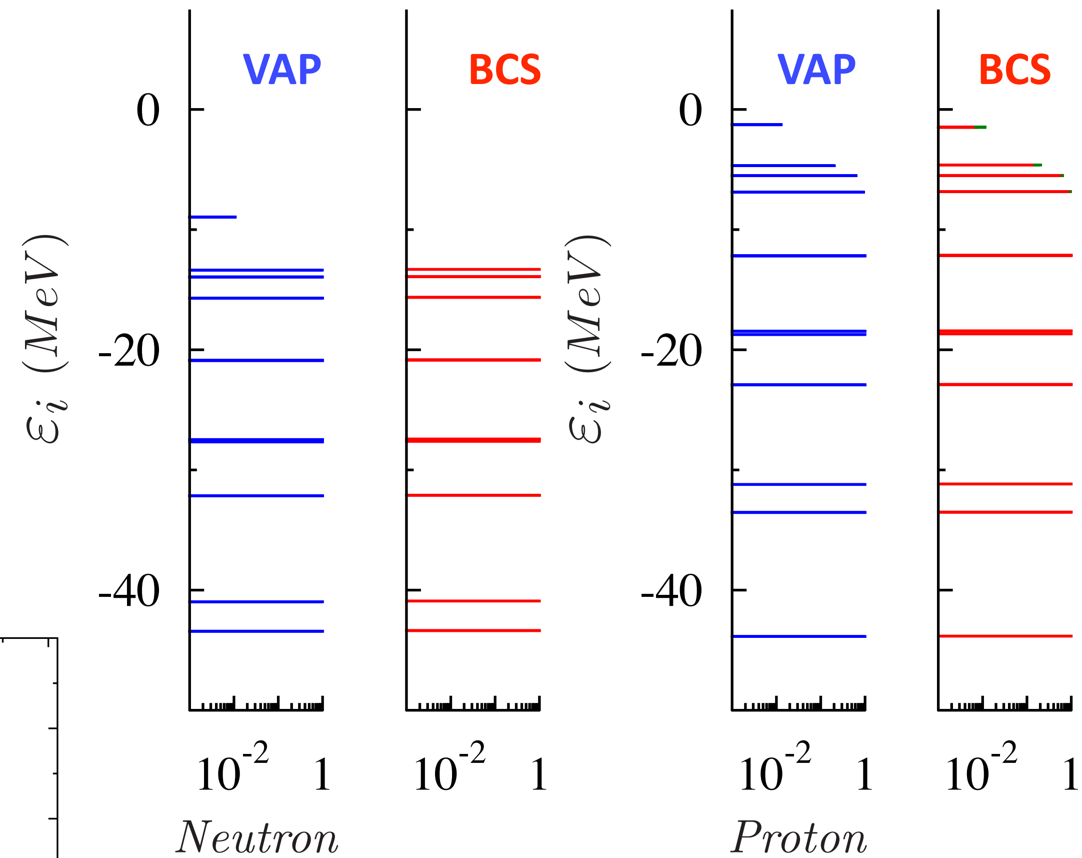
Application: ^{76}Kr



Pairing correlations



Occupation Probability



Hupin, Lacroix, *in preparation*

Energy (in MeV)

	BCS	PAV	VAP
Pairing	-2.56	-2.67	-4.07
Total	-652.45	-653.02	-653.44

1MeV gain

Starting point

$$H = \sum_{ij} \langle i|T|j\rangle a_i^+ a_j + \frac{1}{2}\sum_{ijkl} \langle ij|v_{12}|lk\rangle a_i^+ a_j^+ a_l a_k$$

Exact solution

Variational parameters

$$E_{\text{Exact}} = \langle \Psi|H|\Psi\rangle = \underline{E_{\text{MF}}[\rho] + E_{\text{Corr}}[C_{12}]}$$

$$\rho = \sum |\varphi_i\rangle n_i \langle\varphi_i| \qquad \{\varphi_i, n_i, C_{ij;kl}\}$$

$$C_{12} = R_{12} - \rho_1\rho_2(1 - P_{12})$$

Mean-Field (EDF)

$$E_{\text{Exact}} \simeq \mathcal{E}_{\text{MF}}[\rho] \qquad \rho = \sum |\varphi_i\rangle\langle\varphi_i| \qquad \{\varphi_i\}_{i=1,A}$$

Mean-Field
+ Pairing

$$E_{\text{Exact}} \simeq \overline{\mathcal{E}_{\text{MF}}[\rho] + \mathcal{E}_{\text{Pair}}[\kappa]}$$

$$\rho = \sum |\varphi_i\rangle n_i \langle\varphi_i|$$

$$C_{\bar{i}i,j\bar{j}} \simeq \sqrt{n_i(1-n_i)}\sqrt{n_j(1-n_j)} \qquad \{\varphi_i, n_i\}_{i=1,\infty}$$

MF + Pairing
+Conf. Mixing

or

$$\Psi_N \to \{\rho^N, R^N\} \to \mathcal{E}_{SC}(\rho^N, R^N)$$

$$\rho^N = \sum |\varphi_i\rangle n_i^N \langle\varphi_i|$$

If $R^N = \mathcal{F}(n_i^N, \varphi_i) \Rightarrow \mathcal{E}_{SC} = \mathcal{E}_{SC}(n_i^N, \varphi_i)$

Density Matrix Functional Theory

Occupation-number based energy functionals

Lieb (1983), Papenbrock, Bhattacharyya, PRC75 (2007) ; Bertolli, Papenbrock, PRC78 (2008) ; Lacroix, PRC79 (2009)

$$F(\{n_j\}) = \boxed{E} - \sum_{k=1}^{\Omega} n_k \varepsilon_k \quad \text{with} \quad n_k \equiv \frac{\partial E}{\partial \varepsilon_k}$$

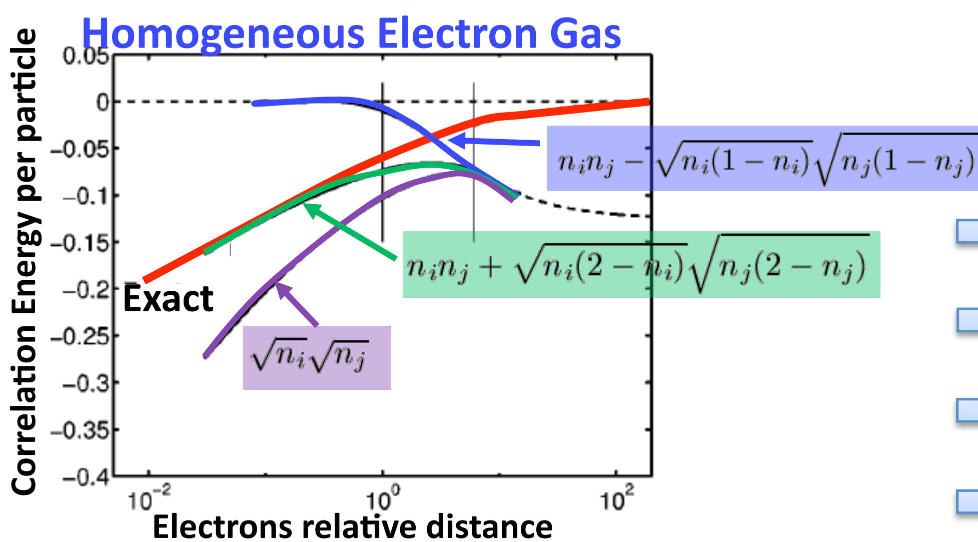
BCS, RPA, NLO…

- Richardson model
- 2- and 3-level Lipkin
- Some motivation for the Duflo-Zuker mass formula

Density Matrix Functional Theory (DMFT) for electronic systems

Gilbert (1975). Klooster, http://theochem.chem.rug.nl/publications/Abstracts.html#587.

$$\mathcal{F}[\{\varphi_i\},\{n_i\}] = \mathcal{E}[\{\varphi_i\},\{n_i\}] - \mu\{Tr(\rho) - N\} - \sum_{ij} \lambda_{ij}(\langle \varphi_i | \varphi_j \rangle - \delta_{ij})$$



From Csanyi et al, PRA65 (2002)

- DMFT for self-bound systems ?
- DMFT with symmetry breaking?
- DMFT for excited states?
- More than ground state : dynamics ?

Functional Theory for Pairing with particle number conservation

BCS *vs* Projected BCS state

Test on a model case : Pairing Hamiltonian

$$E \to \mathcal{E}(n_i, C_{ij}) = \sum_i \varepsilon_i n_i + -\frac{g}{2}\sum_{i,j} C_{ij} \quad \text{with} \quad n_i = \frac{\langle\Phi|a_i^\dagger a_i|\Phi\rangle}{\langle\Phi|\Phi\rangle}, \quad C_{ij} = \frac{\langle\Phi|a_i^\dagger a_{\bar{i}}^\dagger a_{\bar{j}} a_j|\Phi\rangle}{\langle\Phi|\Phi\rangle}$$

BCS

$$|BCS\rangle \propto \prod_i (1 + x_i a_i^\dagger a_{\bar{i}}^\dagger)|-\rangle$$

$$x_i = (v_i/u_i)$$

$$n_i = \frac{|x_i|^2}{(|x_i|^2+1)}$$

$$C_{ij} = \frac{x_i^* x_j}{(|x_i|^2+1)(|x_j|^2+1)}$$

PBCS

$$|N\rangle = \left(\sum_i x_i a_i^\dagger a_{\bar{i}}^\dagger\right)^N |-\rangle$$

$$n_i = N|x_i|^2 \frac{\sum^{\neq}_{(i_1,\cdots i_{N-1})\neq(i)} |x_{i_1}|^2 \cdots |x_{i_{N-1}}|^2}{\sum^{\neq}_{(i_1,\cdots i_N)} |x_{i_1}|^2 \cdots |x_{i_N}|^2}$$

$$C_{ij} = N x_i^* x_j \frac{\sum^{\neq}_{(i_1,\cdots i_K)\neq(i,j)} |x_{i_1}|^2 \cdots |x_{i_K}|^2}{\sum^{\neq}_{(i_1,\cdots i_N)} |x_{i_1}|^2 \cdots |x_{i_N}|^2}$$

$$\mathcal{E}(\{x_i\})$$

Sandulescu and Bertsch, PRC 78 (2008)

Functional Theory for Pairing with particle number conservation

BCS *vs* Projected BCS state

Illustration: Richardson Hamiltonian

$$E \rightarrow \mathcal{E}(n_i, C_{ij}) = \sum_i \varepsilon_i n_i + -\frac{g}{2} \sum_{i,j} C_{ij} \quad \text{with} \quad n_i = \frac{\langle \Phi | a_i^\dagger a_i | \Phi \rangle}{\langle \Phi | \Phi \rangle}, \quad C_{ij} = \frac{\langle \Phi | a_i^\dagger a_{\bar{i}}^\dagger a_{\bar{j}} a_j | \Phi \rangle}{\langle \Phi | \Phi \rangle}$$

BCS

$$|BCS\rangle \propto \prod_i (1 + x_i a_i^\dagger a_{\bar{i}}^\dagger) |-\rangle$$

$$x_i = (v_i / u_i)$$

$$\begin{aligned} n_i &= \frac{|x_i|^2}{(|x_i|^2 + 1)} \\ C_{ij} &= \frac{x_i^* x_j}{(|x_i|^2 + 1)(|x_j|^2 + 1)} \end{aligned}$$

$$|x_i|^2 = \frac{n_i}{(1 - n_i)}$$

$$\mathcal{E}(\{x_i\})$$

$$\mathcal{E}(\{n_i\})$$

PBCS

$$|N\rangle = \left(\sum_i x_i a_i^\dagger a_{\bar{i}}^\dagger \right)^N |-\rangle$$

$$\begin{aligned} n_i &= N |x_i|^2 \frac{\sum^{\neq}_{(i_1, \cdots i_{N-1}) \neq (i)} |x_{i_1}|^2 \cdots |x_{i_{N-1}}|^2}{\sum^{\neq}_{(i_1, \cdots i_N)} |x_{i_1}|^2 \cdots |x_{i_N}|^2} \\ C_{ij} &= N x_i^* x_j \frac{\sum^{\neq}_{(i_1, \cdots i_K) \neq (i,j)} |x_{i_1}|^2 \cdots |x_{i_K}|^2}{\sum^{\neq}_{(i_1, \cdots i_N)} |x_{i_1}|^2 \cdots |x_{i_N}|^2} \end{aligned}$$

?

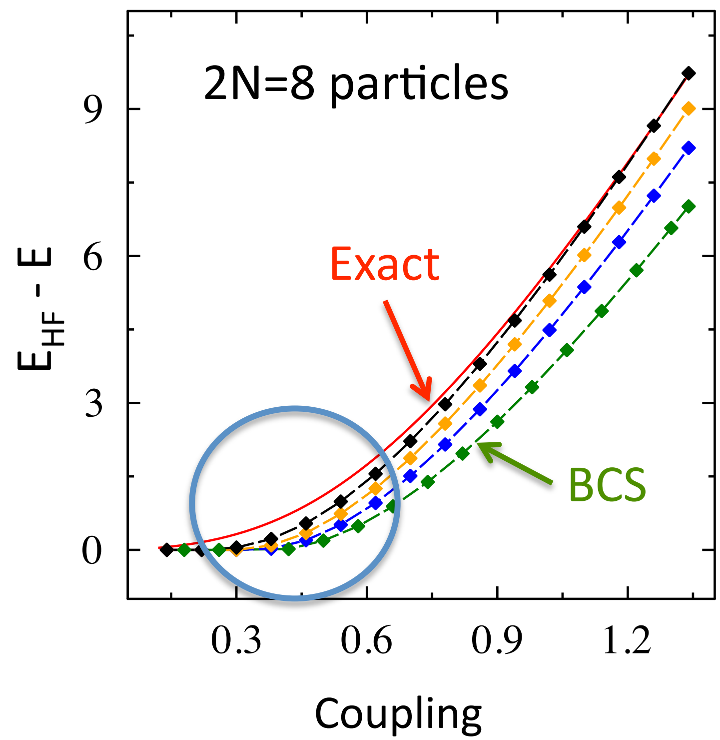
Explicit Functional of occupation numbers for Pairing

$$n_i = N|x_i|^2 \frac{\sum^{\neq}_{(i_1,\cdots i_{N-1})\neq(i)} |x_{i_1}|^2 \cdots |x_{i_{N-1}}|^2}{\sum^{\neq}_{(i_1,\cdots i_N)} |x_{i_1}|^2 \cdots |x_{i_N}|^2} \quad \Longrightarrow \quad x_i = \mathcal{F}(n_i) \ ?$$

A new systematic 1/N expansion beyond BCS:

$$\begin{aligned} |x_i|^2 \simeq & \left(\frac{n_i}{1-n_i}\right)\Big\{1 \\ - & \frac{1}{N} n_i \\ + & \frac{1}{N(N-1)} \sum_{j\neq i} n_j^2 [1-(n_i+n_j)] \\ + & \frac{1}{N(N-1)(N-2)} \sum^{\neq}_{k,j} n_j^2 n_k^2 \left[2-(n_i+n_j+n_k)\right] \\ + & \cdots \Big\} \end{aligned}$$

BCS



Lacroix and Hupin, PRB82 (2011).

Explicit Functional of occupation numbers for Pairing

All contributions can be approximately summed to give:

$$\boxed{|x_i|^2 = \underbrace{\left(\frac{n_i}{1-n_i}\right)}_{\text{BCS}} \left[a_0 + a_1 n_i + \cdots\right]}$$

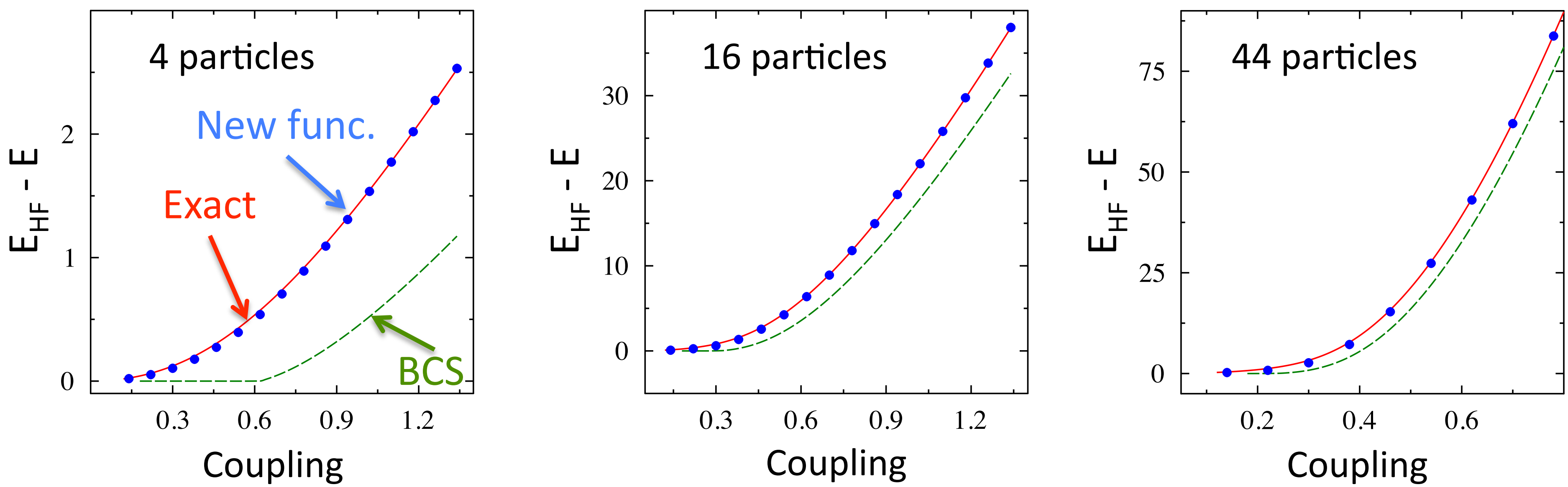
$$a_1 = -\frac{1}{N}\frac{1-s_2^N}{1-s_2}$$

with

$$a_0 = 1 - (s_2 - s_3)\frac{\partial a_1}{\partial s_2}$$

$$s_2 = \frac{1}{N}\sum_i n_i^2 \qquad s_3 = \frac{1}{N}\sum_i n_i^3$$

Application **Lacroix and Hupin, PRB82 (2010), Hupin, Lacroix, PRC83 (2011)**



Summary

- Analysis of configuration mixing within EDF
- In some cases, the MR-EDF can be interpreted as a functional
  Of the one- and two-body density of the projected state

$$\Psi_N \rightarrow \{\rho^N, R^N\} \rightarrow \mathcal{E}_{SC}(\rho^N, R^N)$$

- This provides a different way to perform projection in EDF
  - No pathologies
  - Consistent with SR-EDF
  - Directly applicable (PAV and VAP)
- We further simplify the problem using DMFT

$$\Psi_N \rightarrow \{n_i^N, \varphi_i\} \rightarrow \mathcal{E}_{MR}$$

Outlooks

- Systematic Nuclear Structure study with Variation After projection
- Time-Dependent EDF with pairing
- Thermodynamics of systems with pairing

Explicit Functional of occupation numbers for Pairing

Standard treatment of Pairing: BCS → Projection

$$\underbrace{\mathcal{E}_{PBCS}(n_i^{BCS}) \qquad \mathcal{E}^N}_{\mathcal{E}(n_i)}$$

New functional theory: $\mathcal{E}(n_i)$

Here the n_i should be interpreted as the physical occupation numbers

Example of occupation number :