Fermi Hypernetted chain description of doubly closed shell nuclei

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- Quasi-hole wave functions and spectroscopic factors.
- Conclusions.

Introduction

$$H = -\sum_{i=1}^{A} \frac{\hbar^2}{2m}\nabla_i^2 + \sum_{j>i=1}^{A} V_{ij} + \sum_{k>j>i=1}^{A} V_{ijk} \ .$$

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$$V_{ij} = \sum_{p=1}^{8} v^p(r_{ij}) O_{ij}^p$$

$$O_{ij}^{p=1,8} = [1, \boldsymbol{\sigma}_i \cdot \boldsymbol{\sigma}_j, S_{ij}, (\mathbf{L}\cdot\mathbf{S})_{ij}] \otimes [1, \boldsymbol{\tau}_i \cdot \boldsymbol{\tau}_j]$$

Interaction used: A8’+UIX

Variational principle

$$\delta E[\Psi] = \delta \frac{< \Psi|H|\Psi >}{< \Psi|\Psi >} = 0.$$

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Trial wave function

$$\Psi(1, ..., A) = \mathcal{F}(1, ..., A)\Phi(1, ..., A)$$

Φ Slater det. with Woods-Saxon pot.

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$$\mathcal{F}(1, ..., A) = \mathcal{S}\Big(\prod_{j>i=1}^{A}\sum_{p=1}^{6} f_p(r_{ij})O_{ij}^{p}\Big)$$

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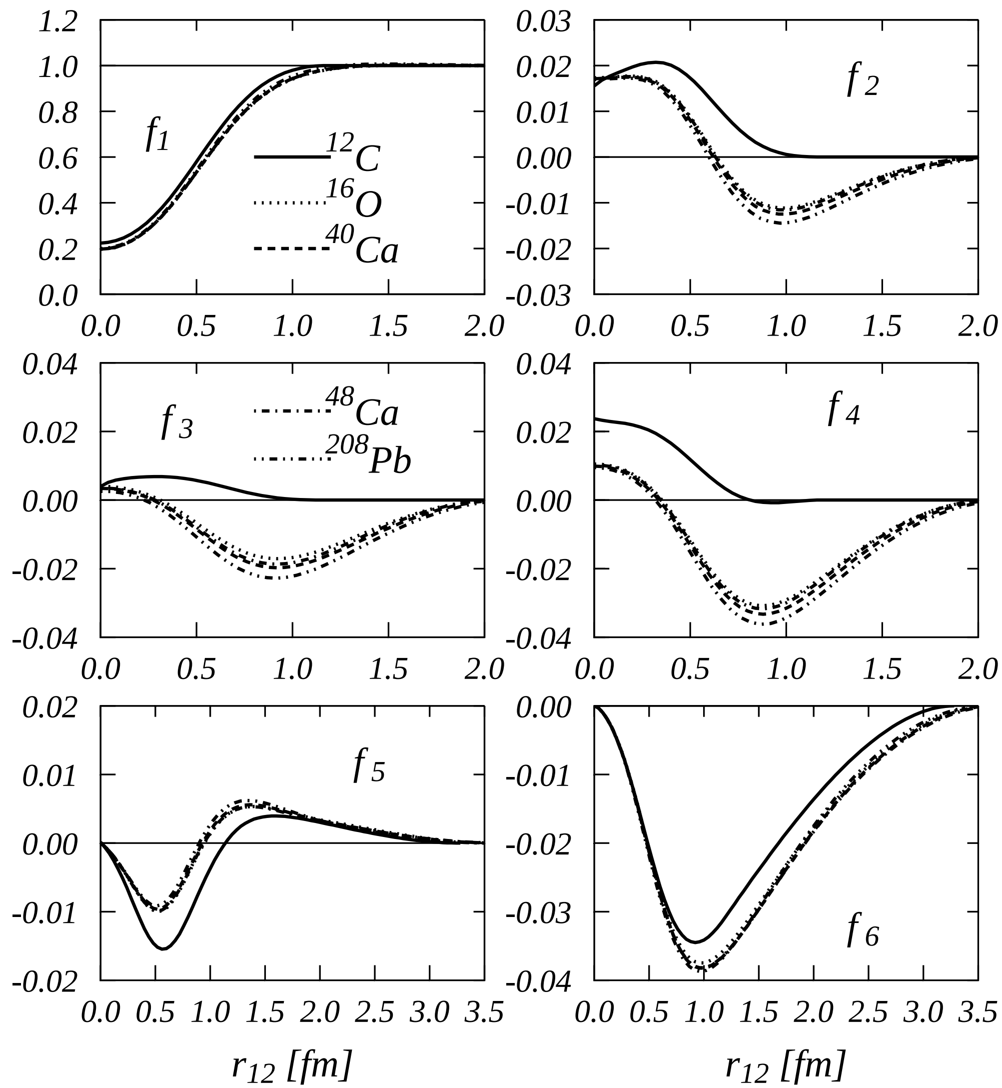
Φ Slater det. with Woods-Saxon pot.

$$\mathcal{F}(1, ..., A) = \left(\prod_{j>i=1}^{A} f_1(r_{ij}) \right) \mathcal{S} \left(\prod_{j>i=1}^{A} \left(1 + \sum_{p=2}^{6} \frac{f_p(r_{ij})}{f_1(r_{ij})} O_{ij}^p \right) \right)$$

f_p obtained with Euler procedure.

Euler correlations



Ground-state energies

AV8'+UIX	^{12}C	^{16}O	^{40}Ca	^{48}Ca	^{208}Pb
T	27.13	32.33	41.06	39.64	39.56
V_{2-body}	-29.38	-38.63	-49.36	-46.95	-48.88
V_{Coul}	0.67	0.86	1.97	1.57	3.97
$T+V_2$	-1.58	-5.34	-6.34	-5.74	-5.35
V_{3-body}	0.67	0.86	1.76	1.61	1.91
E	-0.91	-4.48	-4.58	-4.14	-3.43
E_{exp}	-7.68	-7.97	-8.55	-8.66	-7.86

Estimation of the rest of the channels in the interaction using nuclear matter calculations.

	^{12}C	^{16}O	^{40}Ca	^{48}Ca	^{208}Pb
$< k_F >$	1.09	1.09	1.19	1.19	1.21
E	-0.91	-4.48	-4.58	-4.14	-3.43
ΔE	-0.93	-0.93	-1.37	-1.37	-1.48
E+ΔE	-1.84	-5.41	-5.95	-5.51	-4.91

OBDF and TBDF

$$\rho^{t_1}(\mathbf{r}_1) = \frac{\mathcal{N}_{t_1}}{< \Psi|\Psi >} \int dx_2 \dots dx_A$$

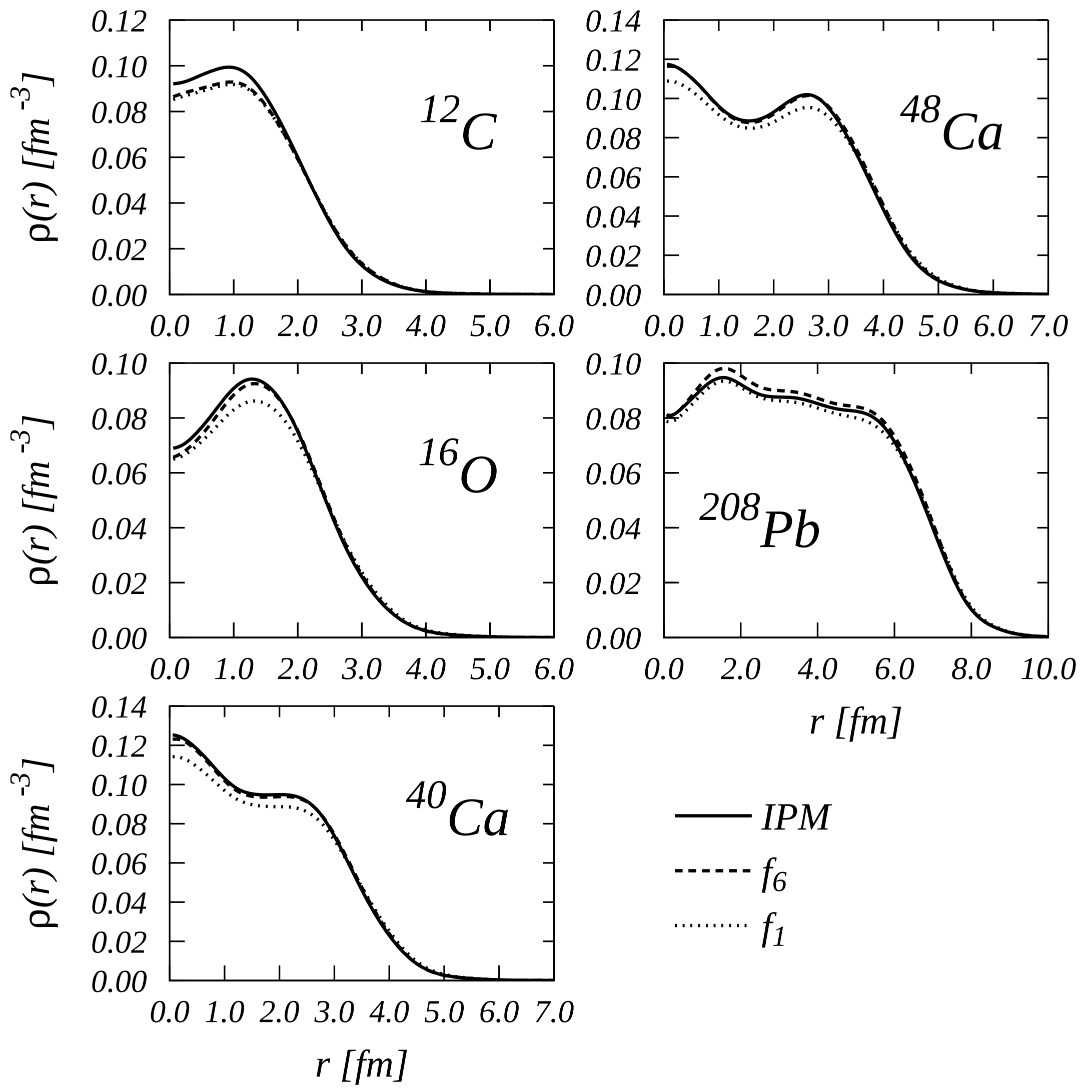
$$\times \quad \Psi^*(x_1, \dots, x_A)\, P_1^{t_1}\, \Psi(x_1, \dots, x_A) \quad ,$$

$$\rho_2^{q,t_1t_2}(\mathbf{r}_1, \mathbf{r}_2) = \frac{\mathcal{N}_{t_1}(\mathcal{N}_{t_2} - \delta_{t_1t_2})}{< \Psi|\Psi >} \int dx_3 \dots dx_A$$

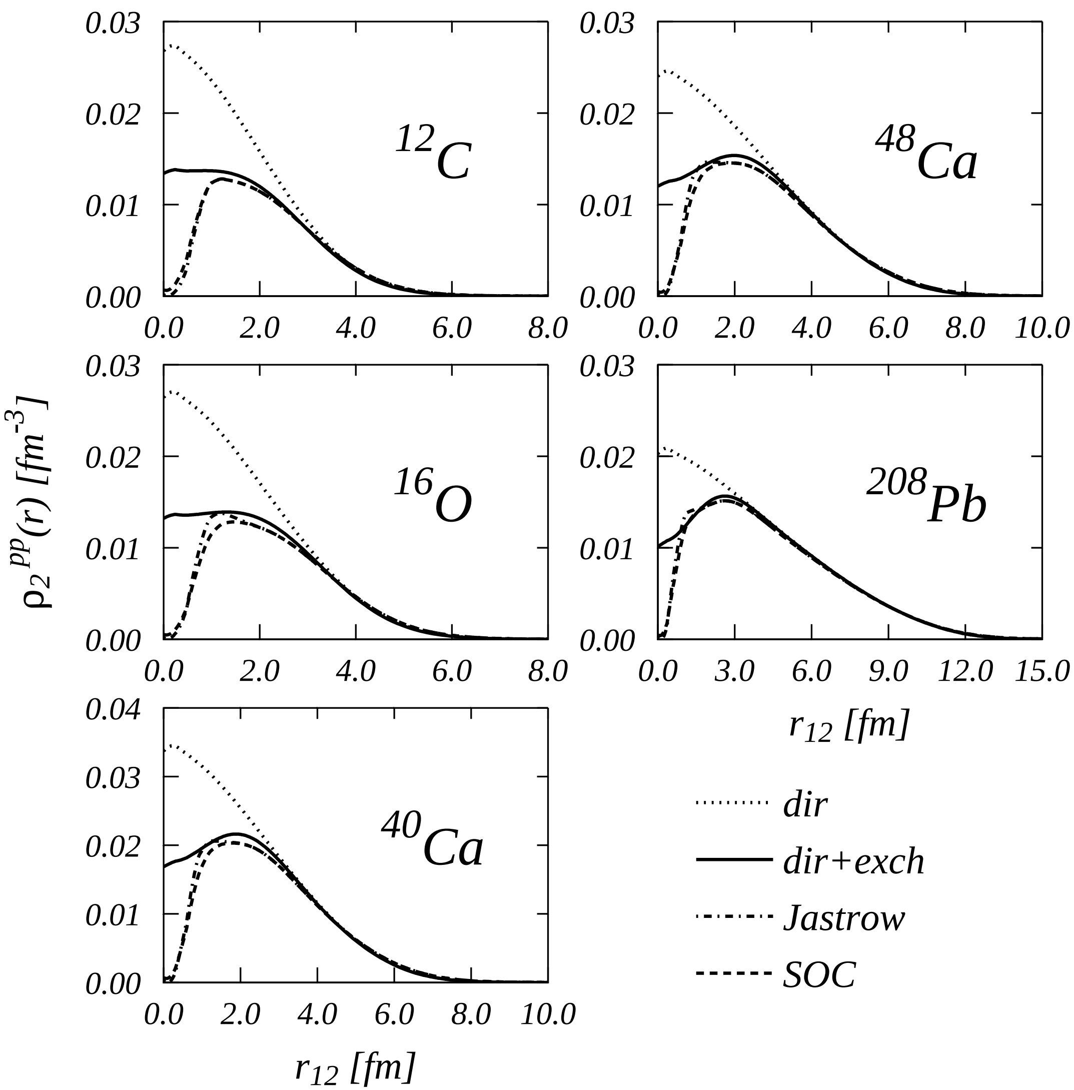
$$\times \quad \Psi^*(x_1, \dots, x_A) P_1^{t_1} O_{12}^q P_2^{t_2} \Psi(x_1, \dots, x_A)$$

$\mathcal{N}_p = Z$ and $\mathcal{N}_n = N$

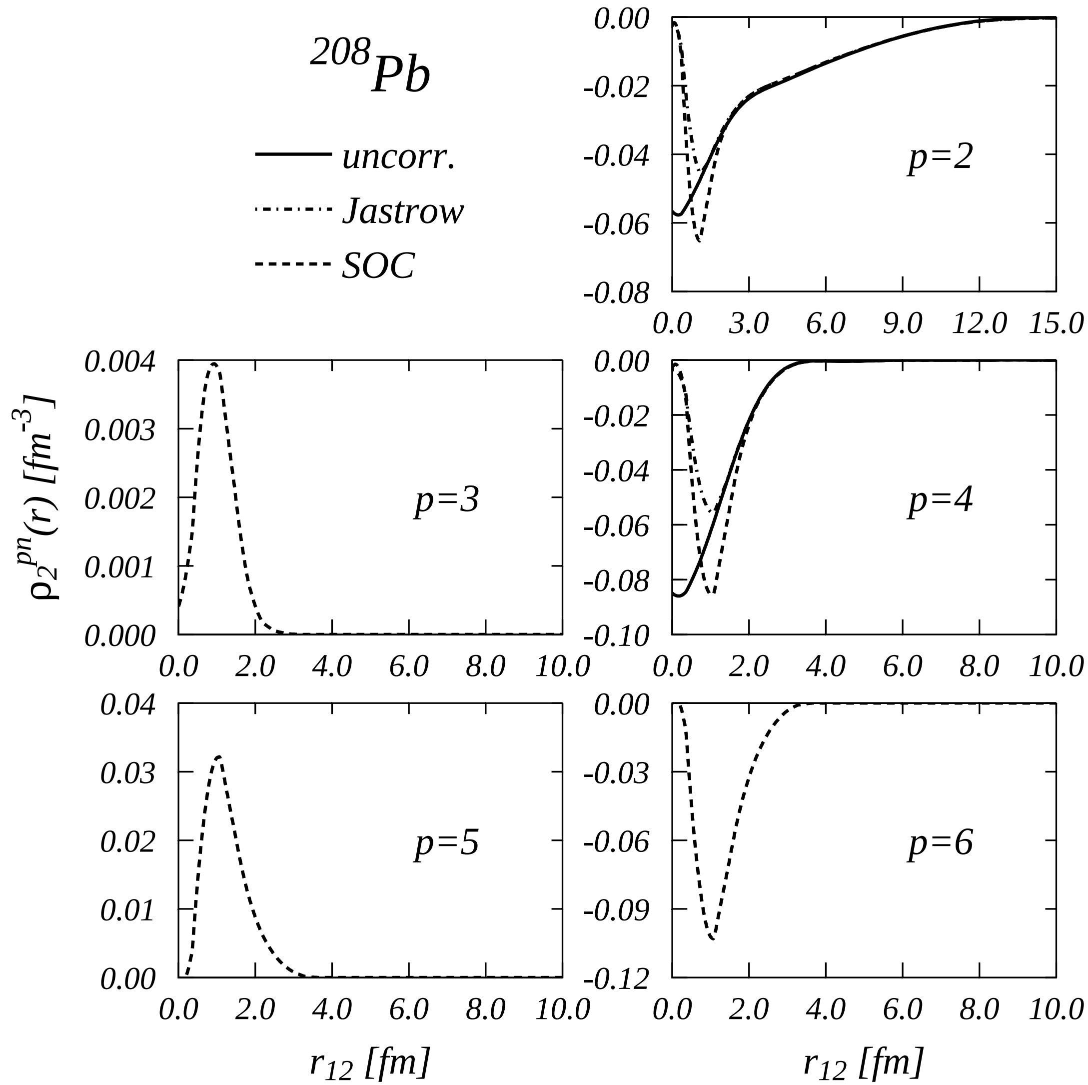
Neutron density functions



$\rho_2^{1,pp}(r_{12})$



0.03
0.02
0.01
0.00
0.0
2.0
4.0
6.0
8.0
^{12}C
^{48}Ca
10.0
^{16}O
^{208}Pb
3.0
9.0
12.0
15.0
0.04
^{40}Ca
$\rho_2^{pp}(r)$ [fm^{-3}]
r_{12} [fm]
dir
dir+exch
Jastrow
SOC



208Pb
uncorr.
Jastrow
SOC
p=2
p=3
p=4
p=5
p=6
ρ2pn(r) [fm-3]
r12 [fm]
r12 [fm]

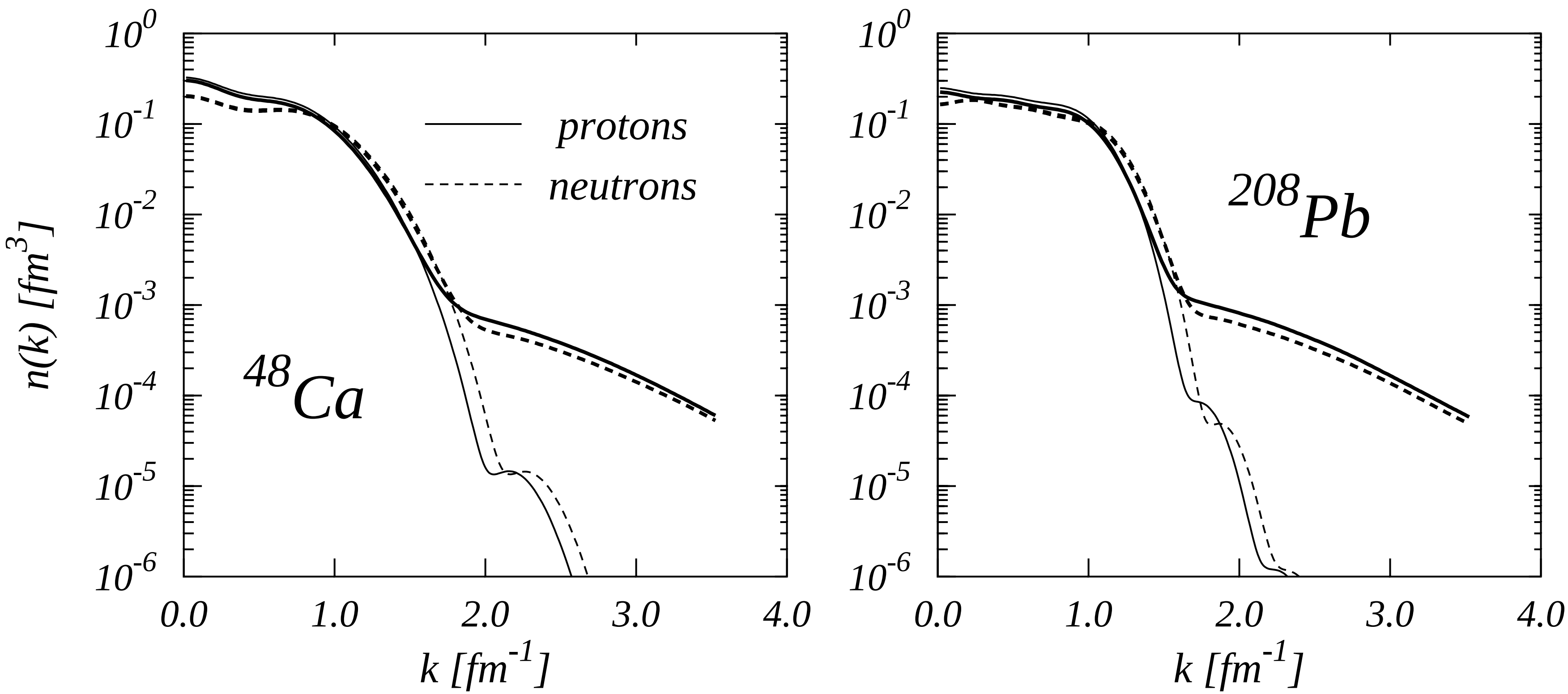
Momentum distribution

$$\rho(x_1, x_1') = \sum_{s,s',t} \rho^{s,s';t}(\mathbf{r}_1, \mathbf{r}_1') \chi_s^+(1) \chi_t^+(1) \chi_{s'}(1') \chi_t(1')$$

$$= \frac{A}{< \Psi | \Psi >} \int dx_2 \ldots dx_A \; \Psi^\dagger(x_1, \ldots, x_A) \, \Psi(x_1', \ldots, x_A)$$

$$\rho^t(\mathbf{r}_1, \mathbf{r}_1') = \sum_{s=\pm 1/2} \left[\rho^{s,s;t}(\mathbf{r}_1, \mathbf{r}_1') + \rho^{s,-s;t}(\mathbf{r}_1, \mathbf{r}_1') \right] \; ,$$

$$n^t(k) = \frac{1}{(2\pi)^3} \frac{1}{\mathcal{N}_t} \int d\mathbf{r}_1 d\mathbf{r}_1' \, e^{i\mathbf{k}\cdot(\mathbf{r}_1 - \mathbf{r}_1')} \rho^t(\mathbf{r}_1, \mathbf{r}_1') \; ,$$

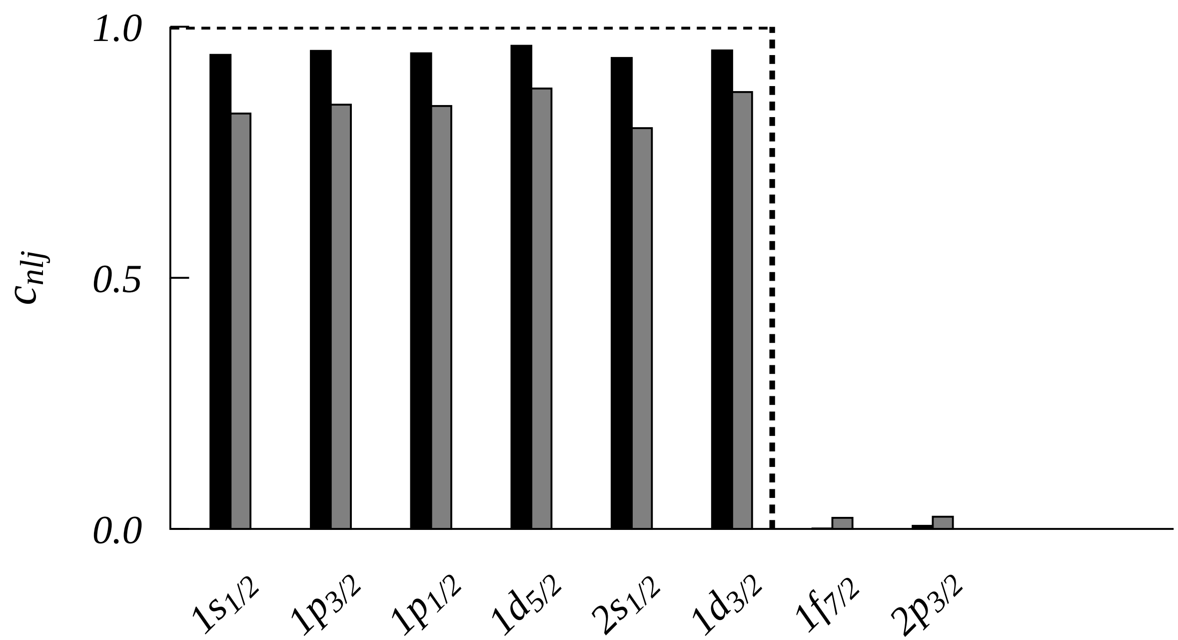


10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
$n(k)$ $[fm^3]$
protons
neutrons
^{48}Ca
0.0
1.0
2.0
3.0
4.0
k $[fm^{-1}]$
^{208}Pb

Natural orbits

$$\rho^t(\mathbf{r}_1, \mathbf{r}'_1) = \sum_{nlj} c^t_{nlj} \phi^{*\,t,NO}_{nlj}(\mathbf{r}_1) \phi^{t,NO}_{nlj}(\mathbf{r}'_1)$$

Occupation numbers of protons for ^{48}Ca.



Quasi hole wave functions

$$\psi^t_{nljm}(x) = \frac{\sqrt{A} < \Psi^t_{nljm}(1,...,A-1)|\delta(x-x_A)P^t_A|\Psi(1,...,A) >}{< \Psi^t_{nljm}|\Psi^t_{nljm} >^{1/2} < \Psi|\Psi >^{1/2}}$$

$$\Psi^t_{nljm}(1,...,A-1) = \mathcal{F}(1,...,A-1)\Phi^t_{nljm}(1,...,A-1)$$

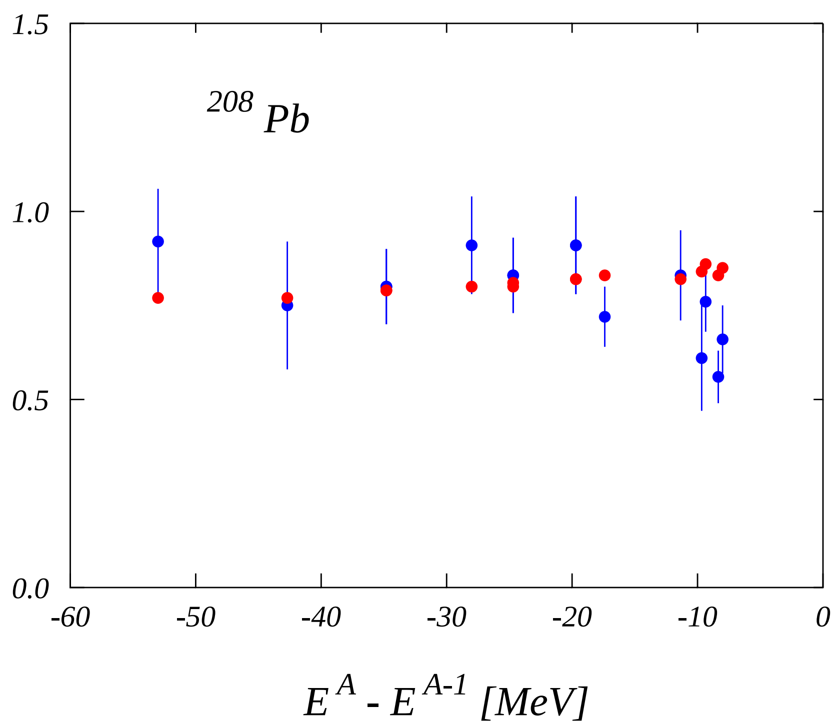
Interested in its radial part:

$$\psi^t_{nlj}(r) = \frac{1}{2j+1}\sum_m \int d\Omega\, \mathbf{Y}^{*m}_{lj}(\Omega)\, \psi^t_{nljm}(x)$$

Spectroscopic factors

$$S^t_{nlj} = \int dr\, r^2\, |\psi^t_{nlj}(r)|^2$$

Proton spectroscopic factors for ^{208}Pb.



Conclusions

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- Short-range correlations are important to describe nuclei.