MANYBODY, Roma unit

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Members

- Current Members
  - Omar Benhar
  - Angela Mecca (PhD student)
  - Noemi Rocco (PhD student)
- Past members
  - Artur M. Ankowski (now a research associate at Virginia Tech)
  - Riccardo Biondi (now a Ph.D. student at University of L'Aquila and LNGS)
  - Giulia De Rosi (now a Ph.D. student at University of Trento)

Topics

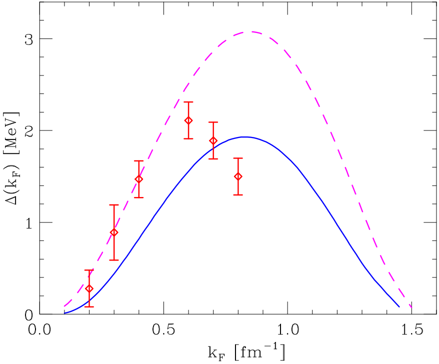
- ⋆ Equilibrium and non equilibrium properties of neutron star matter
  - Development of an effective interaction within the correlated basis function (CBF) formalism (A. Lovato, OB)
  - Calculation of the superfluid gap in neutron star matter (G. De Rosi, OB)
- ⋆ Application of the CBF effective interaction approach to the Fermi hardd sphere system (A. Mecca, OB)
- ⋆ Studies of the electroweak nuclear response
  - Systematic analysis of electron-carbon data (A. Ankowski, M. Sakuda, OB)
  - Effects of two-nucleon currents and extended factorization ansatz (N. Rocco, A. Lovato, OB)
  - Calculation of the charged current neutrino-nucleus cross section in the deep inelastic regime (E. Vagnoni, OB)
- ⋆ Correlation effects on the nuclear matrix elements of double β-decay (R. Biondi, E. Speranza, OB)

Neutron pairing in the $^1S_0$ channel (arXiv:1305.4659)

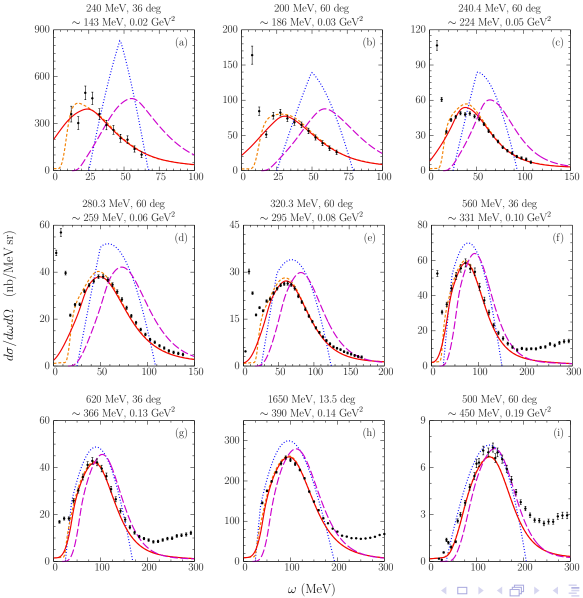
- Gap equation

$$\Delta(k) = -\frac{1}{\pi} \int k'^2 dk' \frac{\mathrm{v}(k,k')\Delta(k')}{[(e(k') - \mu)^2 + \Delta^2(k')]^{1/2}}$$

$$\mathrm{v}(k,k') = \int r^2 dr j_0(kr) \mathrm{v}_{\mathrm{eff}}(r) j_0(k'r)$$



Comparison to electron-carbon data (arXiv:1404.5687)



Correlations in $0\nu\beta\beta$ decay [PRC 90 065504 (2014)]

★ The results of existing studies of correlation effects on the NME of $0\nu\beta\beta$-decay show a striking model dependence

Nucleus	Bare	FNS	SRC		FNS + SRC	
			CCM	Miller-Spencer	CCM	Miller-Spencer
^{76}Ge $\rightarrow$ ^{76}Se	7.39	6.14	5.86	4.46	5.91	4.54
^{100}Mo $\rightarrow$ ^{100}Ru	6.15	4.75	4.40	2.87	4.46	2.96
^{130}Te $\rightarrow$ ^{130}Xe	5.62	4.49	4.22	2.97	4.27	3.04

▹ F. Šimkovic *et al*, PRC **79**, 055501 (2009)

SRC	$M_{\rm GT}^{0\nu}$	$M_F^{0\nu}$	$M_T^{0\nu}$	$M^{0\nu}$
None	0.556	−0.219	−0.015	0.711
Miller-Spencer	0.465	−0.141	−0.014	0.570
CD-Bonn	0.688	−0.222	−0.014	0.845
AV18	0.634	−0.204	−0.014	0.779

▹ M. Horoi and S, Stoica, PRC **81**, 024321 (2010)

	Bare	Jastrow	UCOM Bonn-A
$M_{\rm GT}^{(0\nu)}$	−6.755	−4.681	−6.265
$M_{\rm F}^{(0\nu)}$	2.474	1.778	2.310
Total	−8.328	−5.811	−7.734

▹ M. Kortelainen *et al*, PLB **647**, 128 (2007)

★ Factorisation of the two-nucleon matrix elements

$$M_\alpha = \sum_{j_1,j_2,j'_1,j'_2,J^\pi} TBTD\,(j_1,j_2,j'_1,j'_2;J^\pi)\langle j'_1 j'_2;\ J^\pi\ T|\,\tau_1^+\tau_2^+ O_{12}^\alpha(r)\,|j_1 j_2;\ J^\pi\ T\rangle_a\,.$$

- The coefficients $TBTD\,(j_1,j_2,j'_1,j'_2;J^\pi)$ describe how the spectator nucleons rearrange themselves as a result of the decay process. They are computed in a model space using an effective nucleon-nucleon interaction.
- the two-body matrix element is decomposed into products of reduced matrix elements of operators acting in spin and coordinate space
- The coordinate-space two-nucleon state is rewritten in terms of relative and center of mass coordinates using the Talmi-Moshinski transformation of the harmonic oscillator basis $\mathbf{r}_{12} = \mathbf{r}_1 - \mathbf{r}_2$ and $\mathbf{R}_{12} = (\mathbf{r}_1 + \mathbf{r}_2)/2$

$$\langle \mathbf{r}_1|k_1 l_1\rangle\langle \mathbf{r}_2|k_2 l_2\rangle = \sum_{k,l,K,L} \langle kl,\ KL|k_1 l_1,\ k_2 l_2\rangle_\Lambda \langle \mathbf{R}_{12}|KL\rangle\langle \mathbf{r}_{12}|kl\rangle\ ,$$

Correlations in the two-body $0\nu\beta\beta$-decay matrix element

- ⋆ Correlations are included modifying the two-nucleon states according to

$$|kl\rangle \to f_{12}|kl\rangle$$

- ⋆ The above prescription amounts to replacing the F and GT transition operators with effective operators defined as

$$\widetilde{O}^{\alpha}_{12} = f_{12} O^{\alpha}_{12} f_{12} \ .$$

- ⋆ Because for a neutron-neutron pair $(\boldsymbol{\tau}_1 \cdot \boldsymbol{\tau}_2) = 1$, neglecting non-central correlations

$$f_{12} = f(r_{12}) + g(r_{12})(\boldsymbol{\sigma}_1 \cdot \boldsymbol{\sigma}_2)$$

and

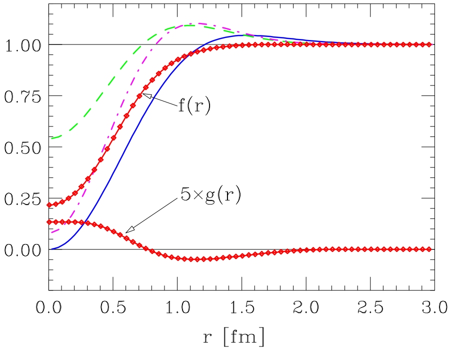
$$\widetilde{O}^{F}_{12} = [f^2(r_{12}) + 3g^2(r_{12})]O^{F}_{12} + 2g(r_{12})[f(r_{12}) - g(r_{12})]O^{GT}_{12} \ ,$$

$$\widetilde{O}^{GT}_{12} = [f^2(r_{12}) - 4f(r_{12})g(r_{12}) + 7g^2(r_{12})]O^{GT}_{12} + 6g(r_{12})[f(r_{12}) - g(r_{12})]O^{F}_{12} \ .$$

★ Numerical results: $\sim 20\%$ suppression

	$f(r_{12})$	$f(r_{12}) + g(r_{12})(\boldsymbol{\sigma}_1 \cdot \boldsymbol{\sigma}_2)$
M/M_{SM}	0.77	0.79

★ Comparison between different correlation functions, yielding different results



Alternative approach

★ Correlation effects can also be included through a renormalization of the shell model states

$$|k_i l_i j_i\rangle \rightarrow \sqrt{Z_{k_i l_i j_i}}\, |k_i l_i j_i\rangle$$

★ The spectroscopic factor $Z_{k_i l_i j_i}$ is the residue of the nucleon Green's function at the single particle pole.

★ It can be computed from the definition $(\alpha = p,\ n)$

$$Z^{\alpha}_{k_i l_i j_i} = \int d^3x |\phi^{\alpha}_{k_i l_i j_i}(x)|^2$$

$$\phi^{\alpha}_{k_i l_i j_i}(x_1) = \frac{\sqrt{A}}{N^{\alpha}_{k_i l_i j_i}} \langle \Psi^{\alpha}_{k_i l_i j_i}(x_2, \ldots, x_A) | \Psi_0(x_1, \ldots, x_A)\rangle \, .$$

$$N^{\alpha}_{k_i l_i j_i} = \langle \Psi^{\alpha}_{k_i l_i j_i} | \Psi^{\alpha}_{k_i l_i j_i}\rangle^{1/2} \langle \Psi_0 | \Psi_0\rangle^{1/2}$$

Including the spectroscopic factors in the NME

- In the case of ^{48}Ca $\to$ ^{48}Ti $0\nu\beta\beta$-decay we replace

$$M_\alpha \to \widetilde{M}_\alpha = Z^p_{1f_{7/2}}(^{48}\text{Ti}) Z^n_{1f_{7/2}}(^{48}\text{Ca})\, M_\alpha$$

- Under the further assumption (the validity of which is strongly supported by nuclear matter calculations)

$$Z^p_{1f_{7/2}}(^{48}\text{Ti}) \approx Z^n_{1f_{7/2}}(^{48}\text{Ca})$$

one finds

$$\widetilde{M}_\alpha = [Z^n_{1f_{7/2}}(^{48}\text{Ca})]^2 M_\alpha$$

- The spectroscopic factor of the $f_{7/2}$ state of ^{48}Ca calculated using nuclear wave functions, including correlations as well as surface and shell effects, can be used to obtain the NME

$$Z^n_{1f_{7/2}}(^{48}\text{Ca}) = 0.91 \Rightarrow M/M_{SM} = 0.83$$