Spatial properties of pairing and quarteting correlations in nuclear systems

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Outline

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1. Pairing Correlations
   - Pairing Tensor
   - Pairing Coherence Length
   - Results, Conclusions
2. Quarteting Correlations
   - Quartet and α tensors
   - Quartet and α Coherence Lengths
   - More Results, More Conclusions

- This presentation is largely based on [Delion & Baran 2015].

Outline

Pairing

The hypothesis of correlated pairs and superfluidity in nuclei is supported by a wealth of arguments [Ring & Schuck 1980, Pillet *et. al.* 2010]:

- $\exists$ energy gap;
- th.-exp. discrepancy in level density and moments of inertia;
- odd-even staggering;
- sudden onset of deformation away from shell closure;
- *large cross section of two-particle transfer*.

Pairing Tensor

Note:

- **pair transfer amplitude** $\approx$ **pairing tensor** [Pillet *et. al.* 2010];
- The pairing tensor κ captures the nontrivial correlations.

Paired systems present two types of densities [Ring & Schuck 1980]:

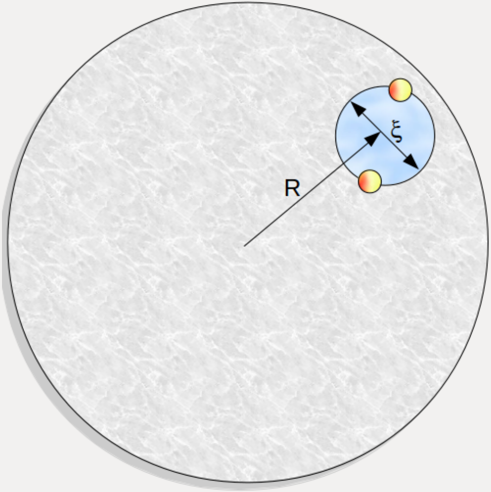
- normal: $\rho_{ab} = \langle c_a^\dagger c_b \rangle$
- abnormal: $\kappa_{ab} = \langle c_a c_b \rangle$

Pairing tensor [Pillet *et. al.* 2007, Pillet *et. al.* 2010]:

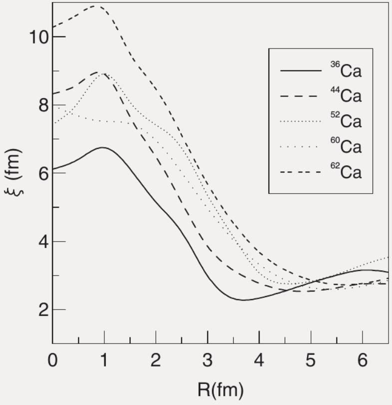
$$\kappa(\vec{r}_1, \vec{r}_2) = \langle BCS| \ \hat{\psi}(\vec{r}_1) \ \hat{\psi}(\vec{r}_2) \ |BCS\rangle$$

Nonlocal part of κ: The Coherence Length

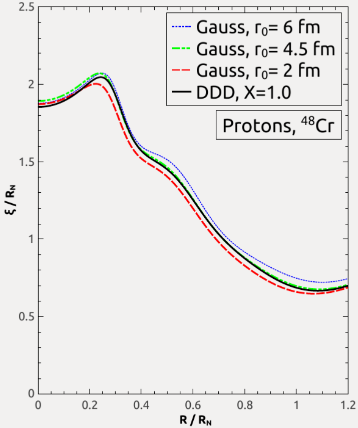
$$\xi(R) = \sqrt{\langle r^2 \rangle_{\kappa(r,R)}}$$



The Coherence Length: $\xi_{HFB} \sim \xi_{BCS}$

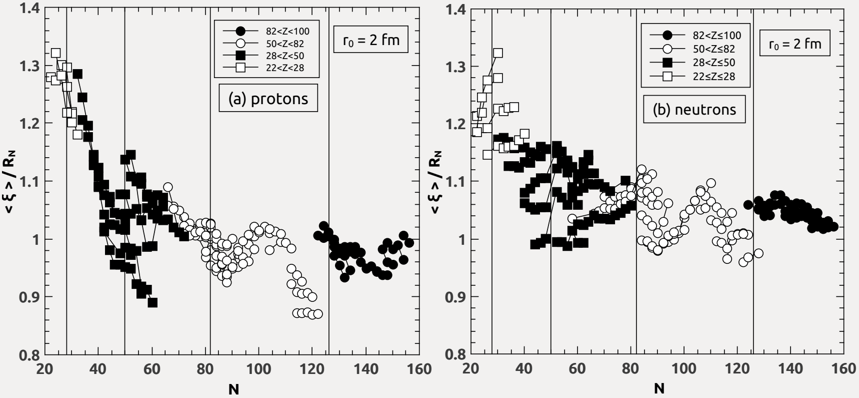


Pillet *et. al.* 2007: HFB, D1S Gogny force

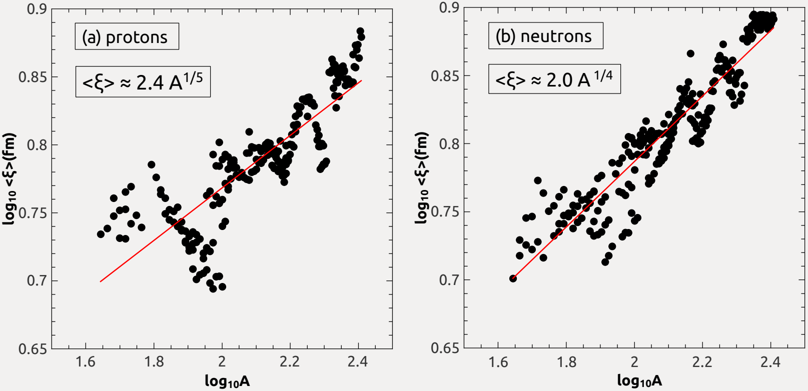


HF+BCS

Coherence Length Systematics



Coherence Length Scaling



Temperature dependence of ξ

What we expect:

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T increases

$\downarrow$

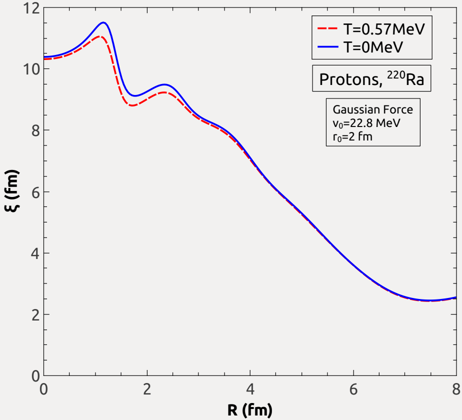
pairing correlations fade

$\downarrow$

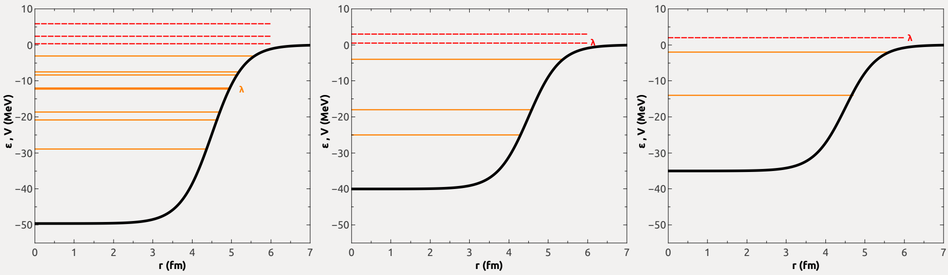
ξ should vary significantly

Temperature dependence of ξ

- **Almost no variation!**
- Mostly affected by the mixing between its parts κ_{odd} and κ_{even} [Pillet *et. al.* 2010].

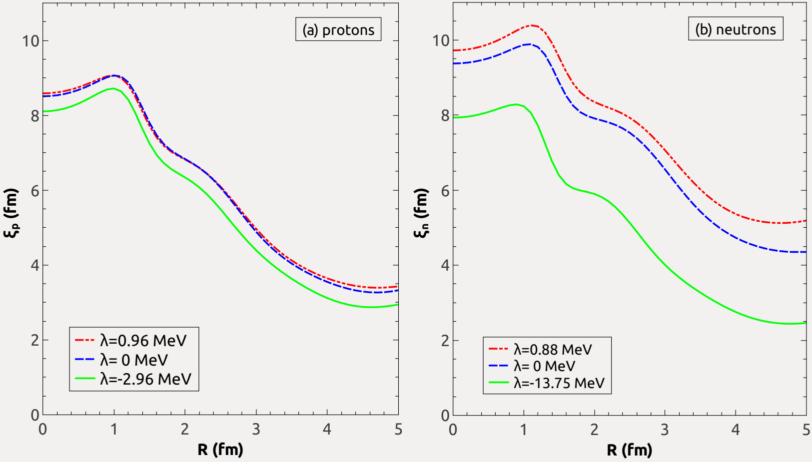


The Coherence Length vs λ



Keep N constant!

The Coherence Length vs λ



Conclusions - 1^{st} part

As far as pairing effects are concerned:

- ξ has similar properties for all considered interactions.
- $\xi_{HFB} \sim \xi_{BCS}$.
- Nice scaling behavior of $\langle \xi \rangle$, with some shell effects.
- ξ insensitive to variations of the intensity of pairing correlations due to thermal pair breaking.

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Quartet Correlations Density

Simplest way to build a quartet: proton and neutron pairs independent from each other [Mang 1960, Sandulescu 1962].

This allows us to define the quarteting density as:

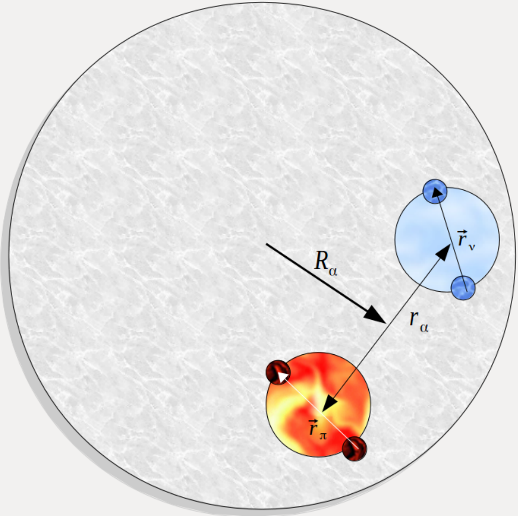
$$\kappa_q(\mathbf{R}_\pi, \mathbf{R}_\nu) = \langle \phi_{00}^{(\beta_\alpha/2)}(r_\pi) | \kappa_\pi(\mathbf{r_1}, \mathbf{r_2}) \rangle \cdot \langle \phi_{00}^{(\beta_\alpha/2)}(r_\nu) | \kappa_\nu(\mathbf{r_3}, \mathbf{r_4}) \rangle$$

α-particle internal wavefunction

$$\psi_\alpha = \phi_{00}^{(\beta_\alpha/2)}(r_\pi) \cdot \phi_{00}^{(\beta_\alpha/2)}(r_\nu) \cdot \phi_{00}^{(\beta_\alpha)}(r_\alpha)$$

Quartet Coherence Length

$$\xi_q(R_\alpha) = \sqrt{\langle r_\alpha^2 \rangle_{\kappa_q}}$$



Alpha Correlations Density

p-n correlations are described by the term $\phi_{00}^{(\beta_\alpha)}(r_\alpha)$ of ψ_α.

The α tensor

$$\kappa_\alpha(r_\alpha, R_\alpha) = \kappa_q(r_\alpha, R_\alpha) \cdot \phi_{00}^{(\beta_\alpha)}(r_\alpha)$$

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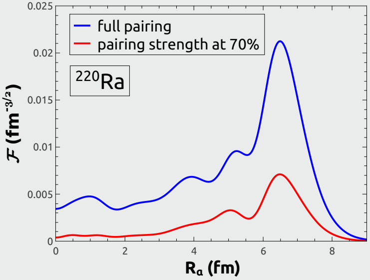
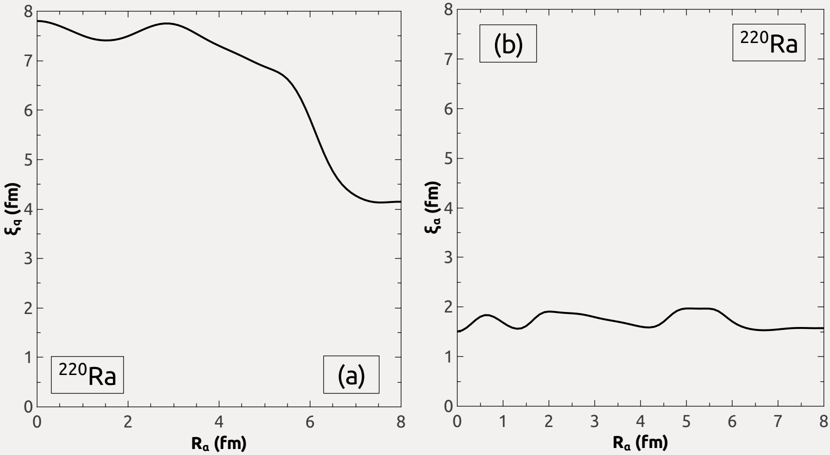
Formation Amplitude

The amplitude $\langle\psi_\alpha|\text{quartet}\rangle$ is [Mang 1960]:

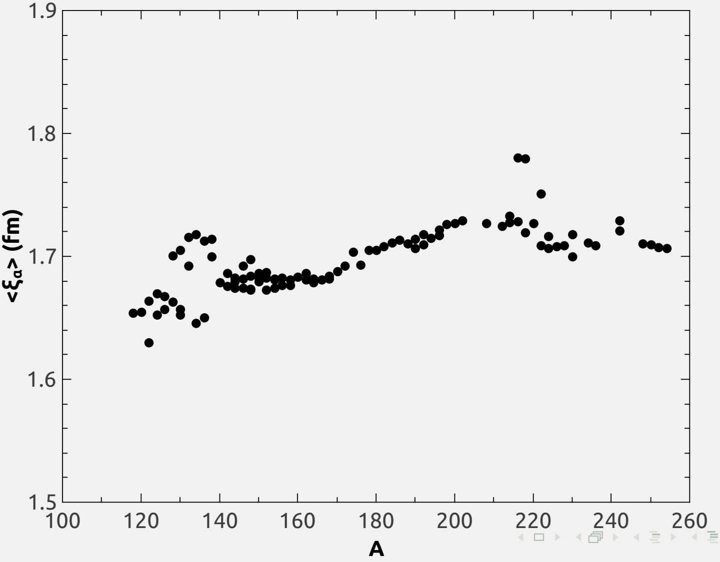
$$\mathcal{F}(R_\alpha) = \int_0^\infty \kappa_\alpha(r_\alpha, R_\alpha) r_\alpha^2 \mathrm{d}r_\alpha$$



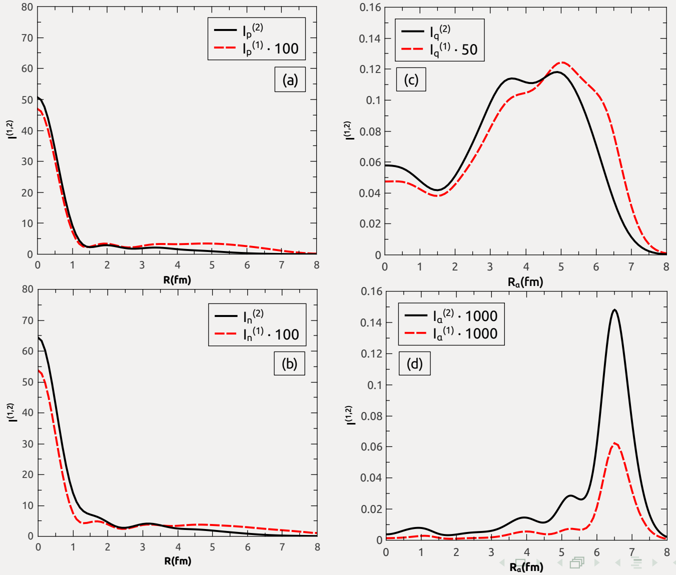
Quartet and α Coherence Lengths



α Coherence Length



$$\xi(R)^2 = \frac{\int r^2 \mathrm{d}r \;\; r^2 \;\; \kappa(r,R)^2}{\int r^2 \mathrm{d}r \;\; \kappa(r,R)^2} = \frac{I^{(2)}}{I^{(1)}}$$

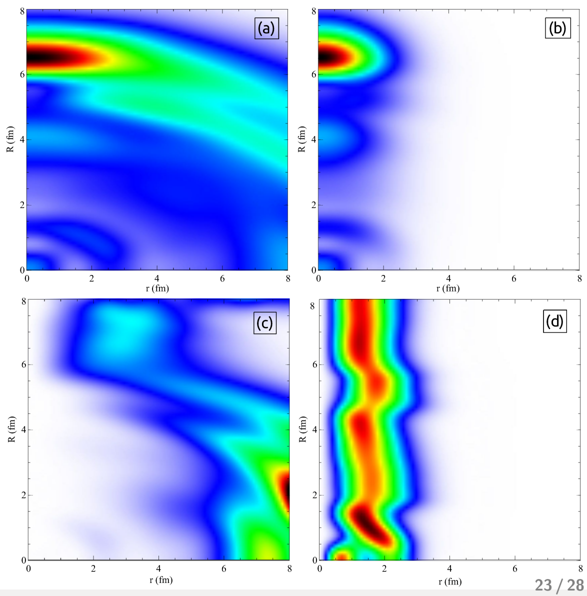


α Coherence Length

For ^{220}Ra:

- (a) $\kappa_q(r_\alpha, R_\alpha)^2$
- (b) $\kappa_\alpha(r_\alpha, R_\alpha)^2$
- (c) $w_q(r_\alpha, R_\alpha)$
- (d) $w_\alpha(r_\alpha, R_\alpha)$

where
$\xi(R)^2 = \int \mathrm{d}r\ r^2\ w(r, R)$



Conclusions - 2^{nd} part

- Our simple treatment evidences the surface nature of α condensation: the formation amplitude $\mathcal{F}(R_N)$=max.
- The quartet CL is somewhat similar to the pairing CL, but with larger values on the nuclear surface.
- The p-n correlations play an important role, as the α-CL has a quasiconstant value $\xi_\alpha \sim 1.7$fm$\leq r_\alpha = 1.9$fm.

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Thank you!

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