Pairing in dilute matter and in exotic nuclei

Q0. Do we have good ab initio description of $\Delta$ in typical systems?
   - Dilute uniform matter, stable nuclei
   - BCS-BEC crossover, small Cooper pair

Di-neutron correlation in n-rich nuclei

Q1. In which situations does the di-neutron correlation become prominent?
   - Halo, skin, light/heavy, separation energy

Q2. What are theoretical measures of the di-neutron correlation?
   - Coherence length? Short distance prob.?

Q3. Relation to the BCS-BEC in dilute matter?

Q4. What are experimental observables of the di-neutron correlation?

Exotic pairing

Q5. T=0 np-pairing?

Q6. Its relation to quarteting & clusterization?
Q0. Do we have good ab initio description of $\Delta$ in simple systems?

**pairing gap in dilute neutron matter**

$$\Delta = (1 \sim 0.5) \Delta_{\text{mean-field}}$$ in recent calculations

Gezerlis & Carlson, PRC81 (2010)

Lombardo & Schulze 2001
Strong coupling pairing in dilute matter & BCS-BEC crossover

“Large” pair gap vs. Fermi energy $\Delta/e_F > 0.2$ at low-densities

Monte-Carlo calculation

$\rho/\rho_0 = 10^{-3} \sim 0.5 \times 10^{-1}$

Mean-field calculation (BCS approx.)

$\rho/\rho_0 = 10^{-4} \sim 2 \times 10^{-1}$

Large scattering length $a = -18\text{fm}$ for nn-attraction

Gezerlis & Carlson, PRC81,025803 (2010)

MM, PRC73,044309(2006)
Q3. How can we relate the di-neutron correlation to the BCS-BEC in dilute matter? How do we learn the pairing in dilute matter?

BCS calculation using A bare force (G3RS) Gogny force (D1)

Cooper pair wave function

Pair wave function has large amplitude at short relative distances $r \sim 2-3$ fm

Neutron pairing gap

Gogny D1 symm. matter

G3RS neutron matter

Relative distance $r$ (fm)

$\xi_{\text{rms}}$ ms

$\xi$ nm

Margueron et al, PRC77,054309(2008)

MM, PRC73,044309(2006)

Margueron et al, PRC77,054309(2008)
Q1. In which situations does the di-neutron correlation become prominent?
   Halo, skin, light/heavy, separation energy

1. 2n-halo nuclei e.g. $^{11}$Li

2. Heavy n-rich nuclei e.g. $^{84}$Ni
   Matsuo, Mizuyama, Serizawa
   PRC71,064326(2005)

3. Heavy stable nuclei
   e.g. $^{18}$O, $^{210}$Pb, (alpha in 212Pb)
   Ibarra et al. NPA288, 397 (1977)
   Janouch & Liotta PRC27,896 (1983)
   e.g. $^{120}$Sn
   Pillet, Sandulescu, Schuck, PRC76, 024310 (2007)

4. Slab, Semi-infinite matter
Q2. What are (theoretical) measures of the di-neutron correlation?

Rms radius of 'Cooper pair' as a function of $R$

\[ \xi = \langle r^2 \rangle = \frac{\int r^2 P_c(R,r)dr}{\int P_c(R,r)dr} \]

It is influenced by geometrical effect of finite volume and also by the surface spatial correlation (especially in halo).


Pair contact probability \( r < 2.6 \text{ fm} \)

Probability of pair at short relative distances within the interaction range

\[
p(R) = \int_{0}^{r_{\text{eff}}} P_c(R, r) dr
\]

Effective range 2.6fm

Volume pairing a-1

Single-j Cooper pair

\(^{142}\text{Sn}\)

DDDII a-18
Q4. What are (experimental) observables of the di-neutron correlation?

*Pair transfers in neutron-rich nuclei*

132Sn~140Sn  precursory $0^+_2$
142Sn~        enhanced $0^+_2$ transfer

**Pair removal**

**Pair addition**

Shimoyama’s presentation on Oct.24

**2n break-up through soft dipole excitation in nuclei near n-drip line**

2n correlation ??  

$^{11}$Li, $^6$He, etc.

Hagino et al., PRC80, 031301 (2009)
Kikuchi et al., PRC81, 044308 (2010)