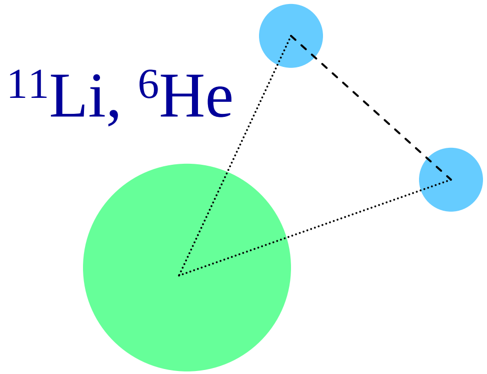
Di-neutron correlation in light neutron-rich nuclei



K. Hagino (Tohoku University)

in collaboration with
H. Sagawa (University of Aizu)

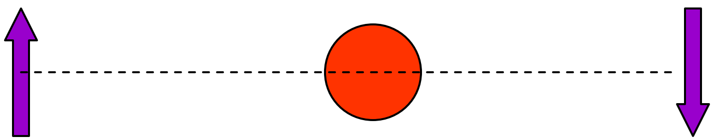
1. *Introduction: Pairing correlations in nuclei*
2. *Three-body model with density-dep. contact int.*
3. *E1 excitations and Geometry of Borromean nuclei*
4. *Coexistence of BCS- and BEC- like pair structures*
5. *Summary*

Introduction: Pairing correlations in nuclei

Spatial structure of a Cooper pair?

Coherence length of a Cooper pair:

$$\xi = \frac{\hbar^2 k_F}{m\Delta}$$



→ much larger than the nuclear size

(note)

$$k_F = 1.36 \quad \text{fm}^{-1}$$
$$\Delta = 12/\sqrt{140} = 1.01 \quad \text{MeV}$$

(for A=140)

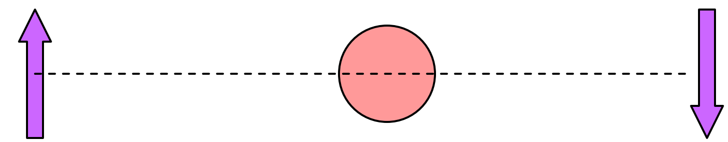
⇒ ξ = 55.6 fm

↕

R = 1.2 x 140$^{1/3}$ = 6.23 fm

Coherence length of a Cooper pair: $\xi = \dfrac{\hbar^2 k_F}{m\Delta}$

much larger than the nuclear size

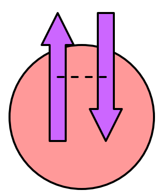


?

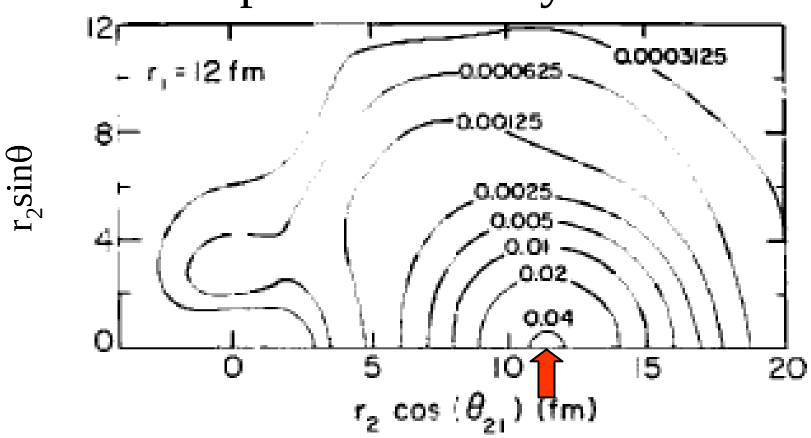
Di-neutron correlations in neutron-rich nuclei

cf. HFB calculations for $^{18\text{-}24}$O, $^{50\text{-}58}$Ca, $^{80\text{-}86}$Ni:

M. Matsuo, K. Mizuyama, Y. Serizawa, PRC71('05)064326

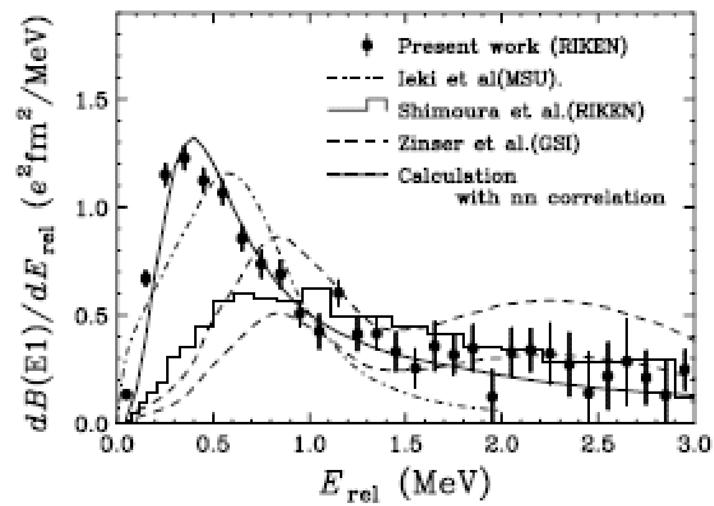


two particle density of ^{11}Li



G.F. Bertsch, H. Esbensen,
Ann. of Phys., 209('91)327

Coul. b.u. of ^{11}Li



T. Nakamura et al., PRL96('06)252502

Another motivation: Spatial correlation of valence neutrons?

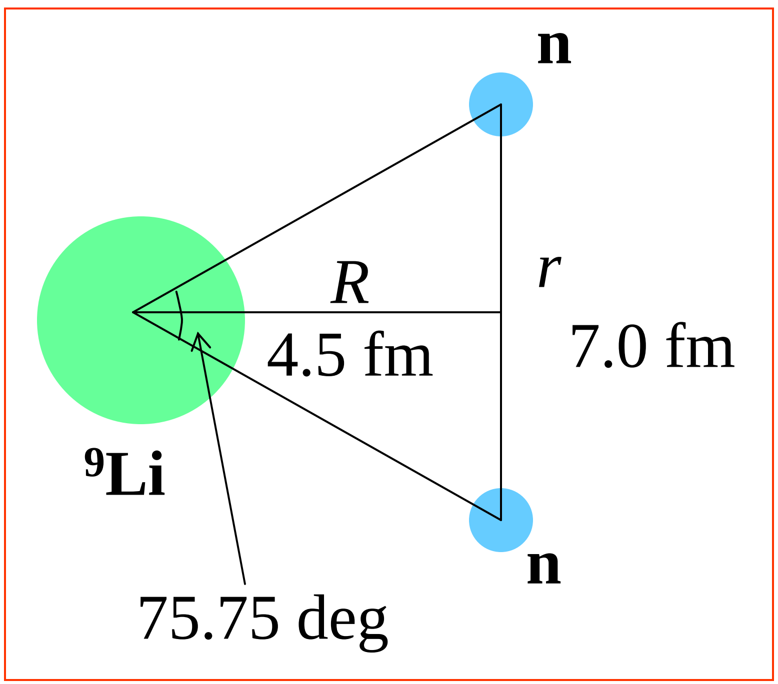
Analysis of Coul. Dissociation for ^{11}Li

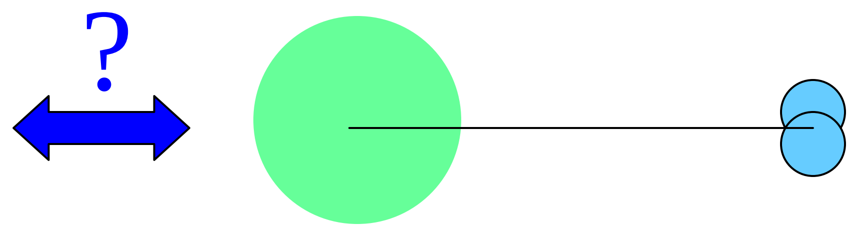
S. Shimoura et al., PLB348('95) 29

$$\Psi(\boldsymbol{R},\boldsymbol{r}) \sim \int d\boldsymbol{k}\, a(k)\psi_k(\boldsymbol{R})\phi_k(\boldsymbol{r})$$

$$\psi_k(\boldsymbol{R}) \sim \exp(-\eta(k)R)/R$$

$$\phi_k(\boldsymbol{r}) \sim \exp(i\boldsymbol{k}\cdot\boldsymbol{r})/r$$



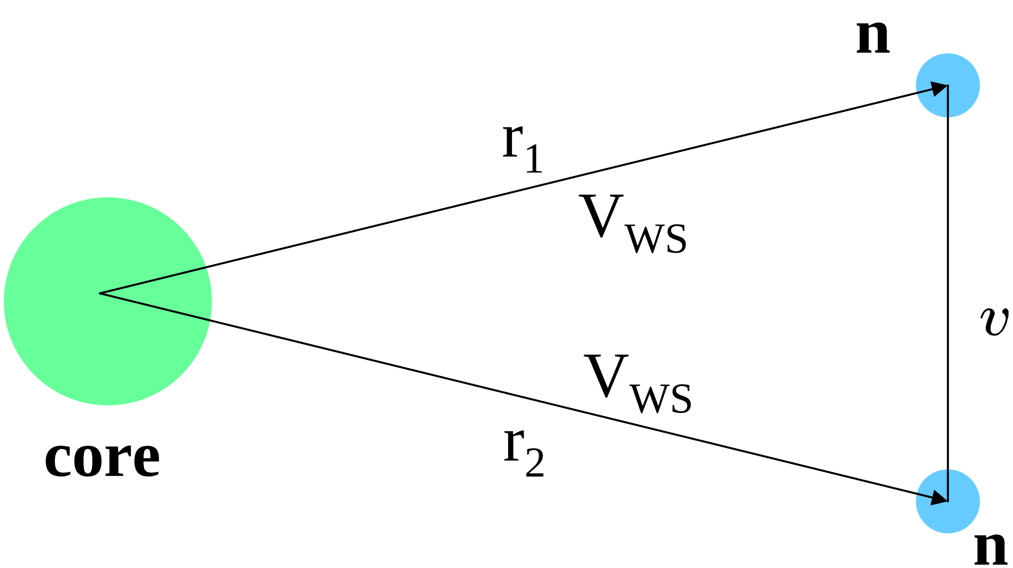


Di-neutron correlation

Detailed theoretical re-analysis of
- ➢Density distribution
- ➢Dipole excitations

Three-body model

G.F. Bertsch and H. Esbensen,
Ann. of Phys. 209('91)327
H. Esbensen, G.F. Bertsch, K. Hencken,
Phys. Rev. C56('99)3054



Density-dependent delta-force

$$v(\boldsymbol{r}_1,\boldsymbol{r}_2) = v_0(1+\alpha\rho(r)) \times\delta(\boldsymbol{r}_1-\boldsymbol{r}_2)$$

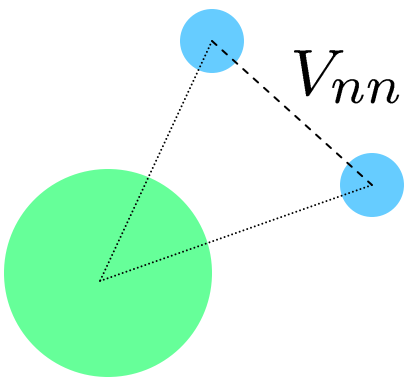
$$H = \frac{\boldsymbol{p}_1^2}{2m} + \frac{\boldsymbol{p}_2^2}{2m} + V_{nC}(r_1) + V_{nC}(r_2) + V_{nn} + \frac{(\boldsymbol{p}_1+\boldsymbol{p}_2)^2}{2A_c m}$$

(note) recoil kinetic energy of the core nucleus

Density-dependent delta interaction

H. Esbensen, G.F. Bertsch, K. Hencken, *Phys. Rev. C56('99)3054*

$$V_{nn}(\boldsymbol{r}_1, \boldsymbol{r}_2) = \delta(\boldsymbol{r}_1 - \boldsymbol{r}_2)\left(v_0 + \frac{v_\rho}{1 + \exp[(r_1 - R_\rho)/a_\rho]}\right)$$



➢Two neutron system in the vacuum:

$$V_{nn}^{(0)}(\boldsymbol{r}_1, \boldsymbol{r}_2) = v_0\,\delta(\boldsymbol{r}_1 - \boldsymbol{r}_2)$$

$$a_{nn} = \frac{\pi}{2} \cdot \frac{\alpha}{1 + \alpha k_c}$$

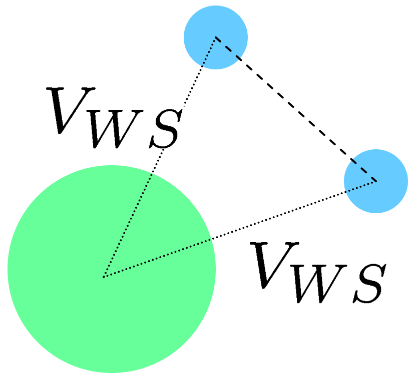
$$\alpha = \frac{v_0}{2\pi^2}\frac{m}{\hbar^2}, \qquad E_{\rm cut} = \frac{\hbar^2 k_c^2}{m}$$

$$v_0 = \frac{2\pi^2\hbar^2}{m} \cdot \frac{2a_{nn}}{\pi - 2k_c\,a_{nn}}$$

➢Two neutron system in the medium:

$v_\rho, \quad R_\rho, \quad a_\rho$: adjust so that S_{2n} can be reproduced

Two-particle wave functions (J=0 pairs)



$$\hat{h}\,\psi_{nljm}(\boldsymbol{r}) = \epsilon_{nlj}\,\psi_{nljm}(\boldsymbol{r})$$

$$\Psi^{(2)}_{nn'lj}(\boldsymbol{r},\boldsymbol{r}') = \sum_m \langle jmj-m|00\rangle \psi_{nljm}(\boldsymbol{r})\psi_{n'lj-m}(\boldsymbol{r}')$$

Hamiltonian diagonalization

$$\Psi_{gs}(\boldsymbol{r},\boldsymbol{r}') = \mathcal{A}\sum_{nn'lj}\alpha_{nn'lj}\,\Psi^{(2)}_{nn'lj}(\boldsymbol{r},\boldsymbol{r}')$$

- Continuum: box discretization
- Energy cut-off:

$$\epsilon_{nlj} + \epsilon_{n'lj} \leq \frac{A_c+1}{A_c}E_{\rm cut}$$

Application to ^{11}Li, ^{6}He

^{11}Li, ^{6}He: Typical Borromean nuclei

⬅ Esbensen et al.

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^{11}Li: $a_{nn} = -15$ fm, $E_{\rm cut} = 30$ MeV, $R_{\rm box} = 40$ fm

WS: adjusted to $p_{3/2}$ energy in ^{8}Li & n-^{9}Li elastic scattering

Parity-dependence ⟵ to increase the s-wave component

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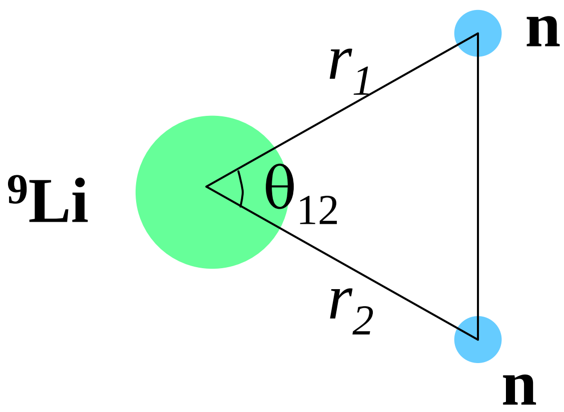
^{6}He: $a_{nn} = -15$ fm, $E_{\rm cut} = 40$ MeV, $R_{\rm box} = 30$ fm

WS: adjusted to n-α elastic scattering

Results for ground state properties

Nucleus	S_{2n} (MeV)	$\langle r^2_{nn} \rangle$ (fm^2)	$\langle r^2_{c-2n} \rangle$ (fm^2)	dominant config.	fraction (%)	$S=0$ (%)
^{6}He	0.975	21.3	13.2	$(p_{3/2})^2$	83.0	87.0
^{11}Li	0.295	41.4	26.3	$(p_{1/2})^2$	59.1	60.6

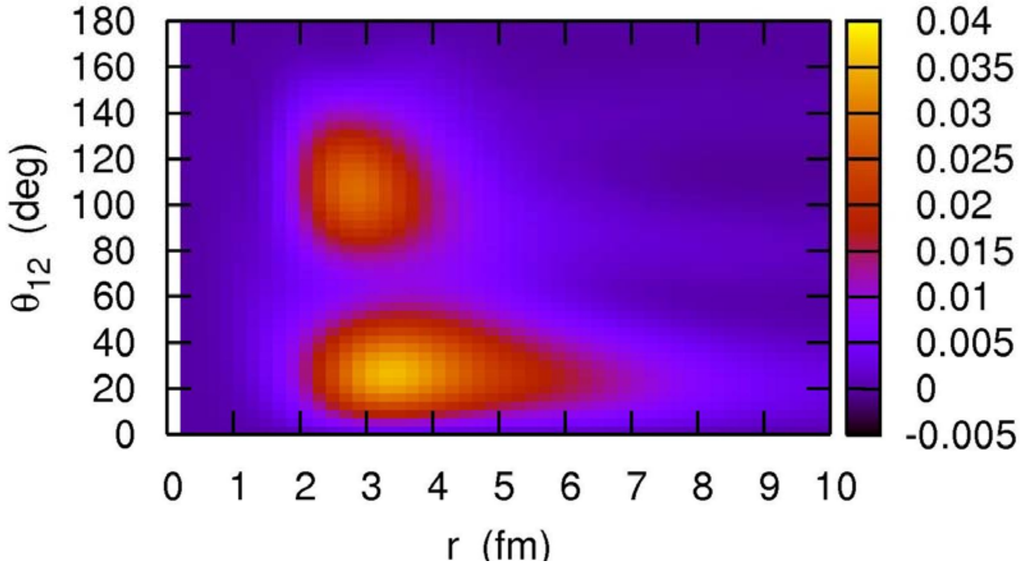
Two-particle density for ^{11}Li



$$\rho_2(r_1, r_2, \theta_{12})$$

Set $r_1 = r_2 = r$, and plot ρ_2 as a function of r and θ_{12}

$$4\pi r^2 \cdot 2\pi r^2 \sin\theta_{12} \times \rho_2(r, r, \theta_{12})$$

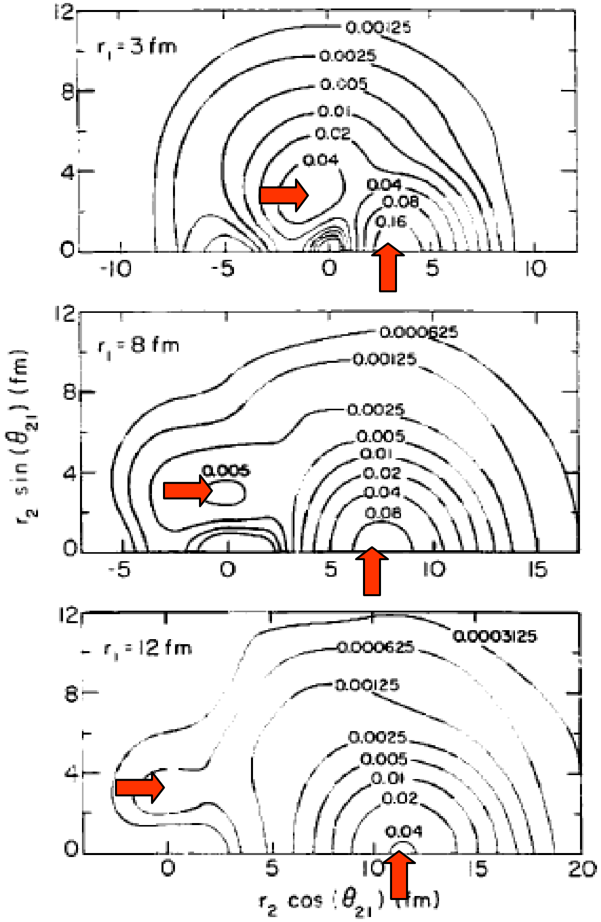


- two-peaked structure
- Long tail for "di-neutron"

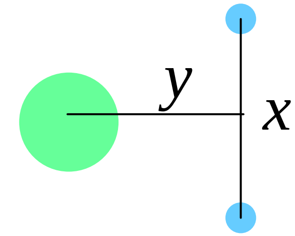
(note)

$$\int_0^\infty 4\pi r_1^2 dr_1 \int_0^\infty r_2^2 dr_2 \int_0^\pi 2\pi \sin\theta_{12} d\theta_{12}\, \rho_2(r_1, r_2, \theta_{12}) = 1$$

$\rho_2(r_1, r_2, \theta_{12})$ for ^{11}Li



G.F. Bertsch, H. Esbensen,
Ann. of Phys., 209('91)327



$x^2 y^2 \rho_2(x, y)$ for ^{6}He

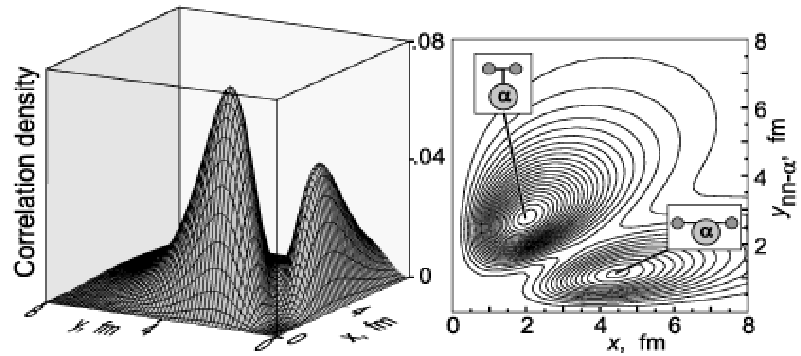


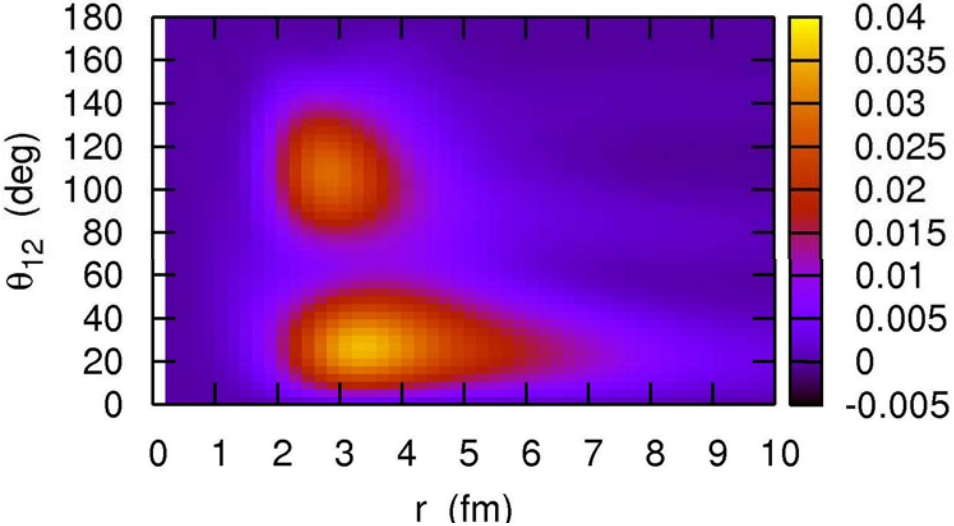
FIG. 1. Spatial correlation density plot for the 0^+ ground state of ^{6}He. Two components—di-neutron and cigarlike—are shown schematically.

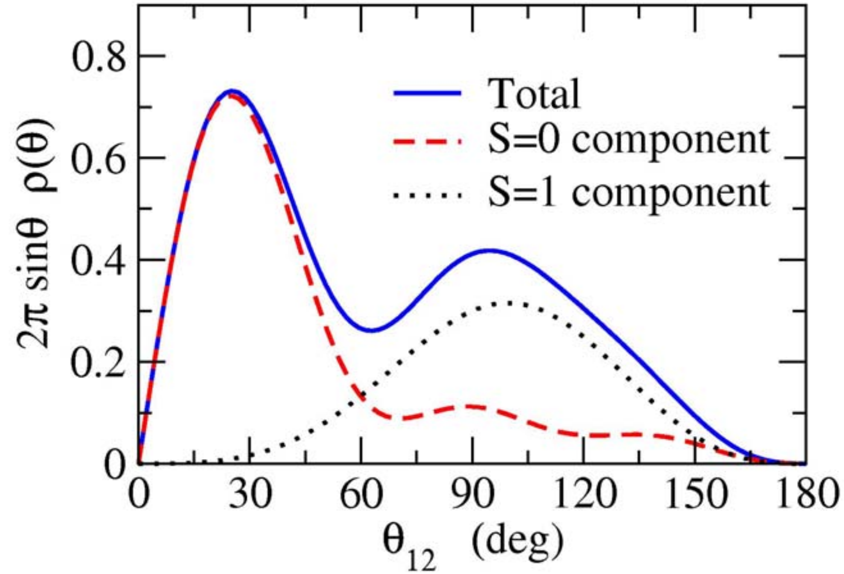
Yu.Ts. Oganessian, V.I. Zagrebaev,
and J.S. Vaagen, *PRL82('99)4996*
M.V. Zhukov et al., *Phys. Rep. 231('93)151*

"di-neutron" and *"cigar-like"* configurations

Two-particle density for ^{11}Li

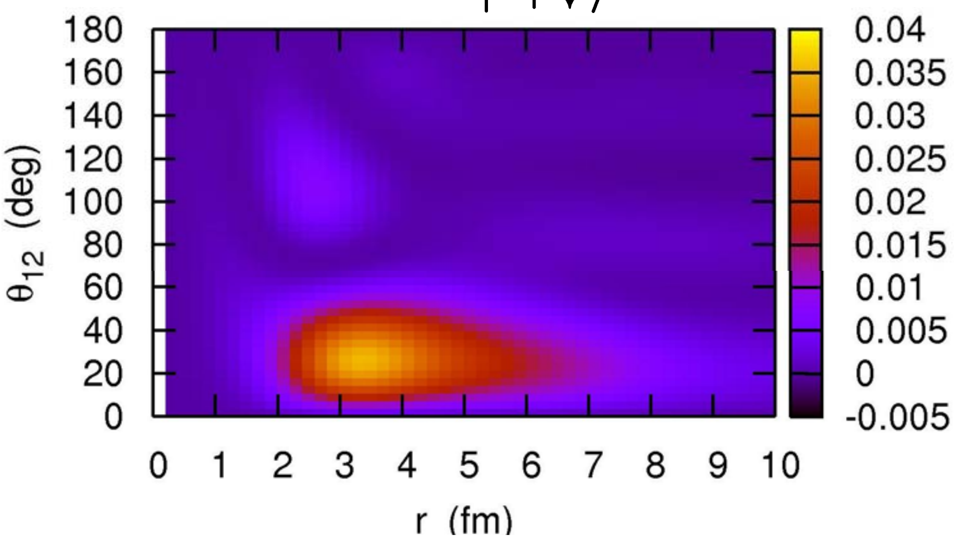
Total



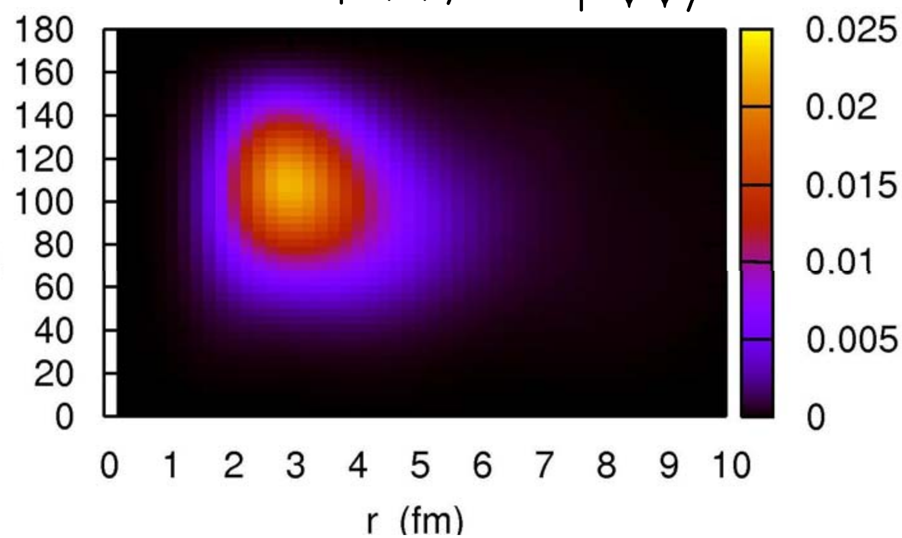


$\rightarrow \langle \theta_{12} \rangle = 65.29$ deg.

S=0 $|\uparrow\downarrow\rangle$

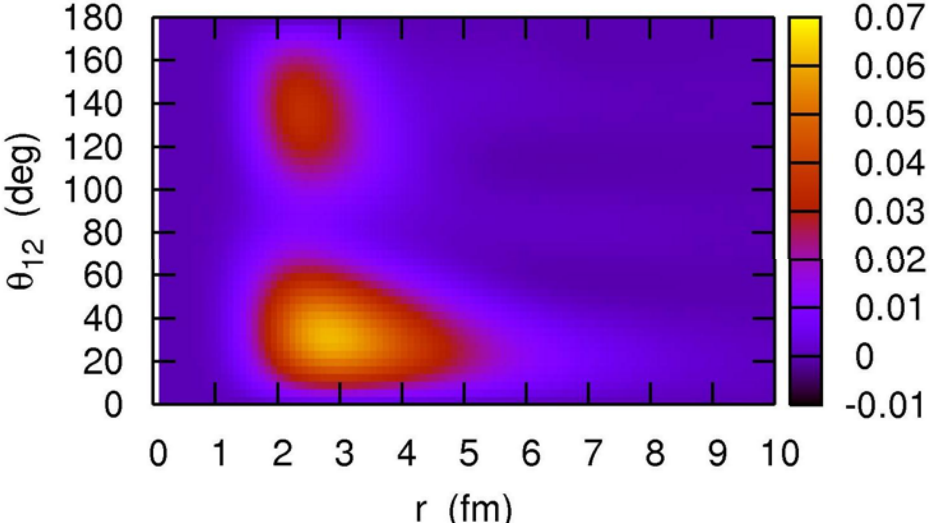


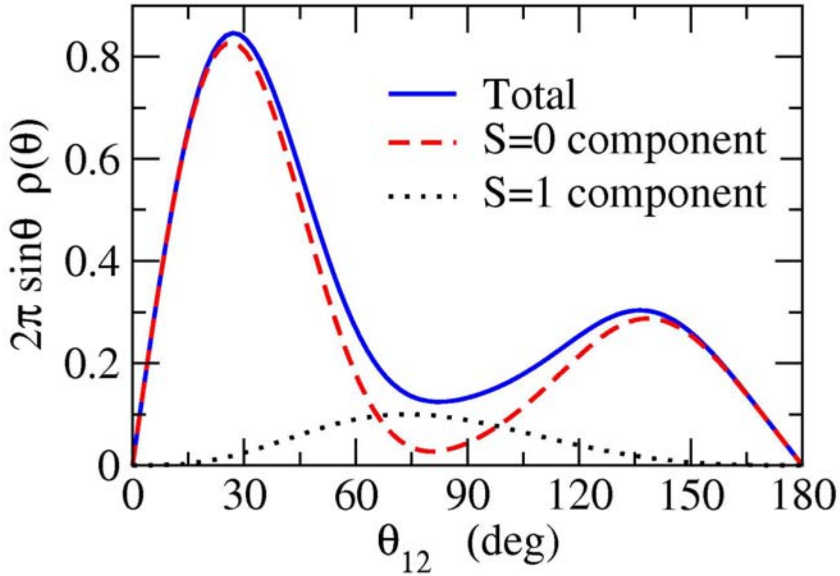
S=1 $|\uparrow\uparrow\rangle$ or $|\downarrow\downarrow\rangle$



Two-particle density for ^{6}He

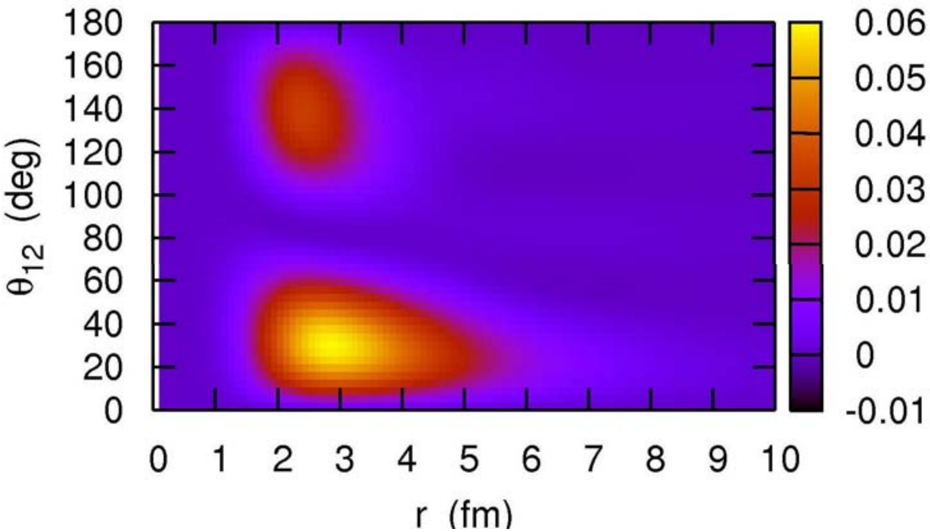
Total



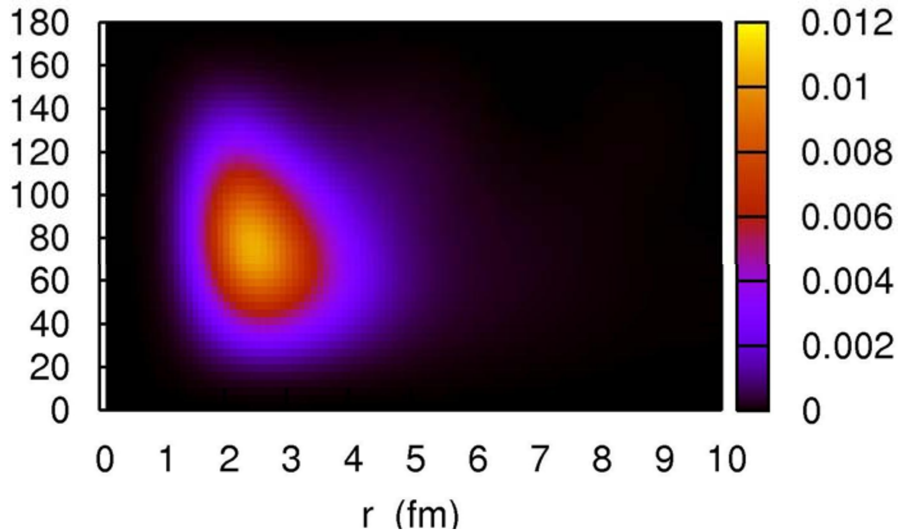


$$\rightarrow \langle \theta_{12} \rangle = 66.33 \text{ deg.}$$

S=0 $|\uparrow\downarrow\rangle$

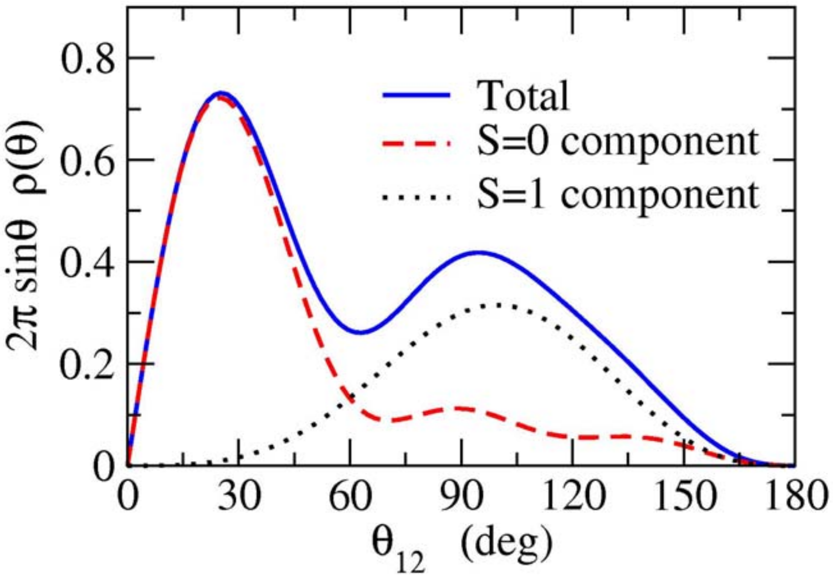


S=1 $|\uparrow\uparrow\rangle$ or $|\downarrow\downarrow\rangle$



Comparison between the two nuclei

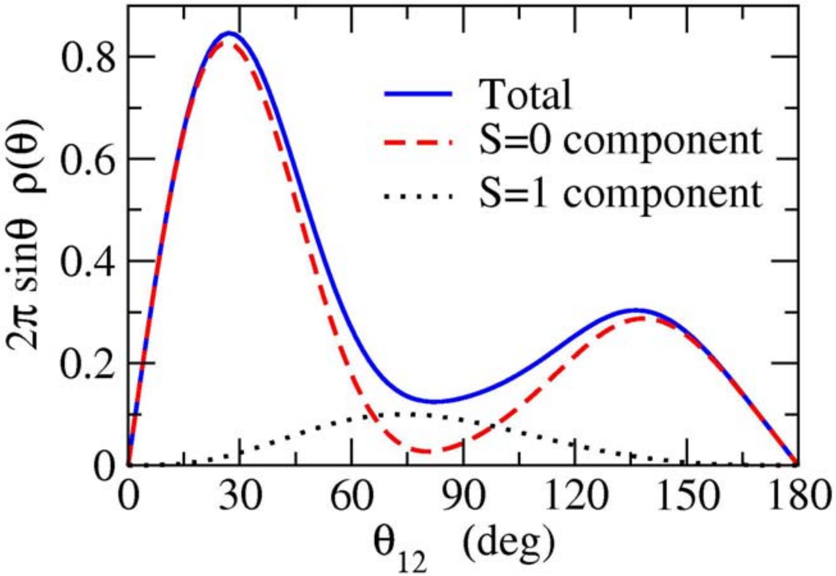
^{11}Li



$(p_{1/2})^2$:59.1%

$(s_{1/2})^2$:22.7% $(d_{5/2})^2$:11.5%

^{6}He



$(p_{3/2})^2$:83.0 %

$(d_{5/2})^2$:6.11 %,

$(p_{1/2})^2$:4.85 %

$(s_{1/2})^2$:3.04 %, $(d_{3/2})^2$:1.47 %

$$\rho^{S=0}(\theta) \propto \cos^2\theta$$
$$\rho^{S=1}(\theta) \propto \sin^2\theta$$

for $(p_{1/2})^2$ or $(p_{3/2})^2$

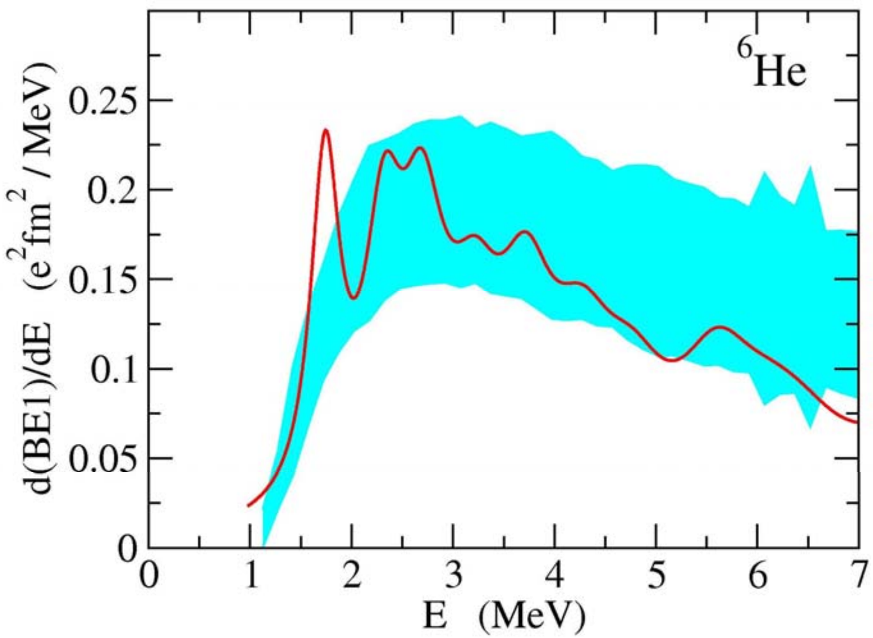
E1 excitations and geometry of Borromean nuclei

Dipole excitations

Response to the dipole field:

$$B_k(E1) = 3\,|\langle \Psi^k_{1^-}|\hat{D}_0|\Psi_{gs}\rangle|^2$$

$$\hat{D}_M = -\frac{Ze}{A}\sum_{i=1,2} r_i Y_{1M}(\hat{\boldsymbol{r}}_i)$$



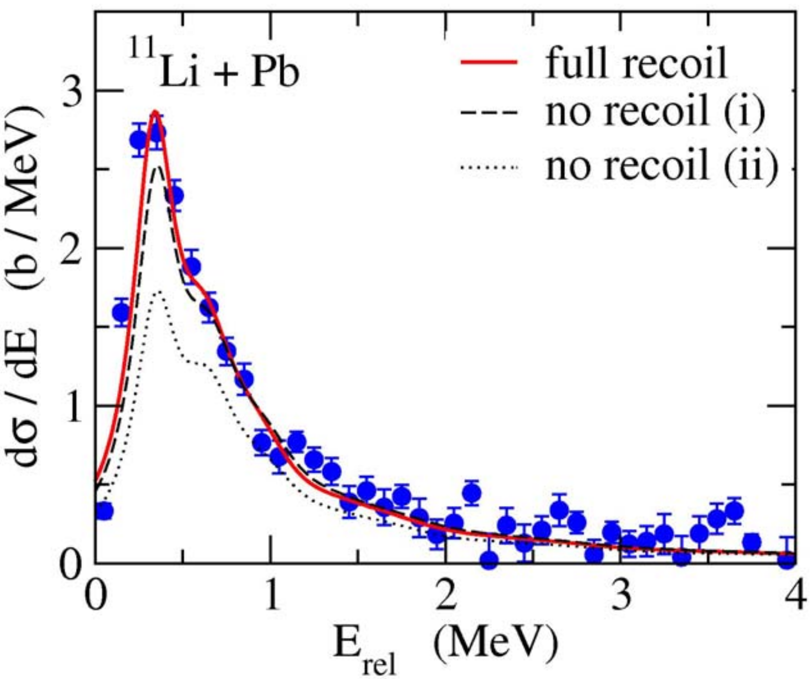
Smearing:

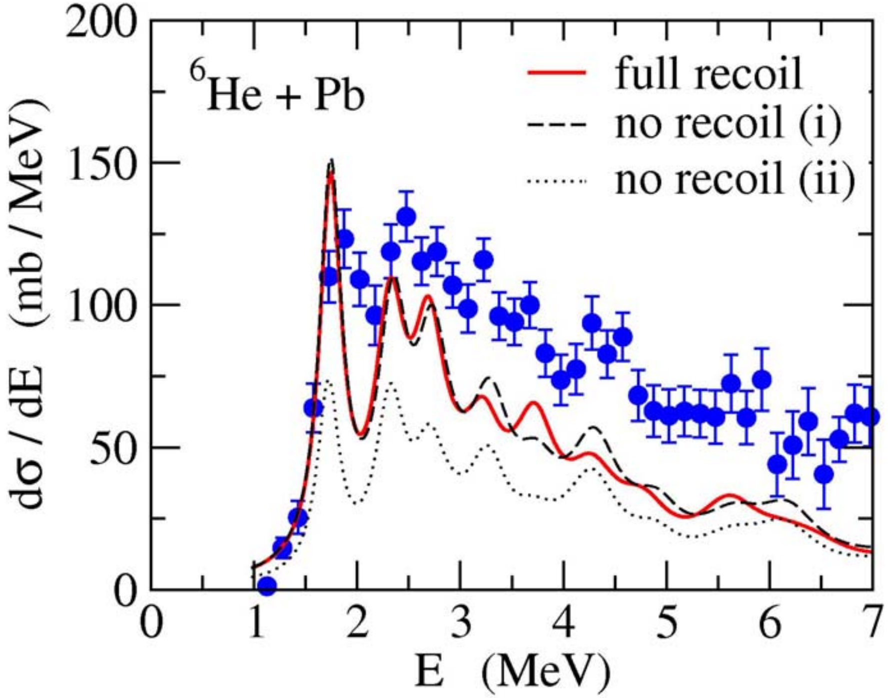
$$B(E1) = \sum_k \frac{\Gamma}{\pi}\frac{B_k(E1)}{(E-E_k)^2+\Gamma^2}$$

$$\Gamma = 0.2\cdot\sqrt{E-E_{\rm th}} \quad \text{(MeV)}$$

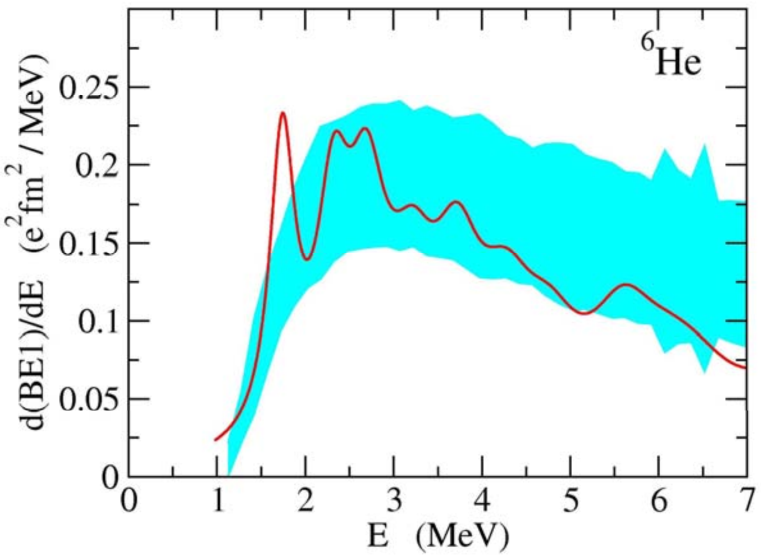
K.H. and H. Sagawa,PRC76('07)047302

Dipole excitations



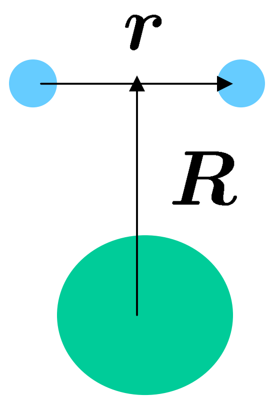


$$\Gamma = 0.25 \cdot \sqrt{E - E_{\rm th}} \quad \text{(MeV)}$$



K.H. and H. Sagawa, PRC76('07)047302

Geometry of Borromean nuclei



"experimental" mean opening angle

$$\sqrt{\langle R^2\rangle}$$

$$B(E1) = \sum_i B(E1; gs \to i) = \frac{3}{\pi}\left(\frac{Ze}{A}\right)^2 \langle R^2\rangle$$

(note) forbidden transition

$$\langle R^2\rangle_{\rm exp} = \frac{B(E1; E \le E_{\rm max})_{\rm exp}}{B(E1; E \le E_{\rm max})_{\rm cal}} \cdot \langle R^2\rangle_{\rm cal}$$

H. Esbensen, K.H., P. Mueller, and H. Sagawa, PRC76('07)924302

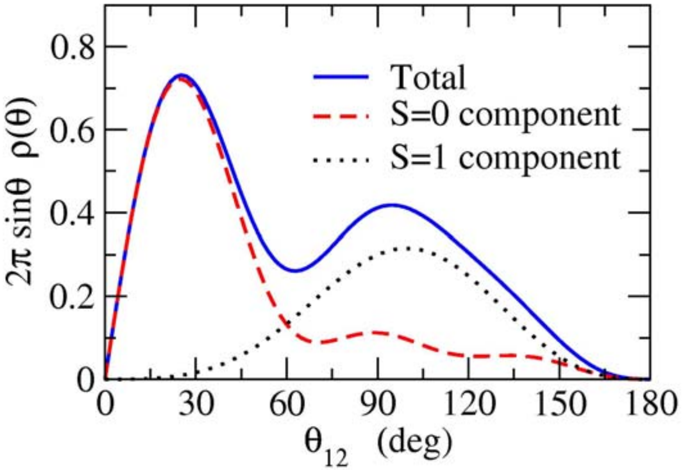
$$\sqrt{\langle r^2\rangle}$$

$$\langle r_m^2\rangle = \frac{A_c}{A}\langle r_m^2\rangle_{A_c} + \frac{2A_c}{A^2}\langle R^2\rangle + \frac{1}{2A}\langle r^2\rangle$$

or also from HBT-type 2n correlation study

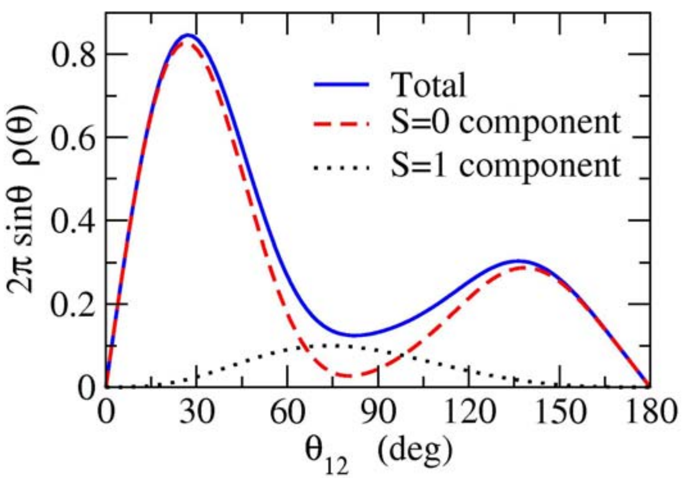
Geometry of Borromean nuclei

^{11}Li

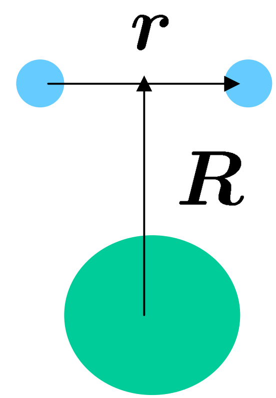


$$\langle \theta_{12} \rangle = 65.29 \quad \text{deg.}$$

^{6}He



$$\langle \theta_{12} \rangle = 66.33 \quad \text{deg.}$$



"experimental" mean opening angle

$\sqrt{\langle R^2 \rangle}$ ← B(E1)

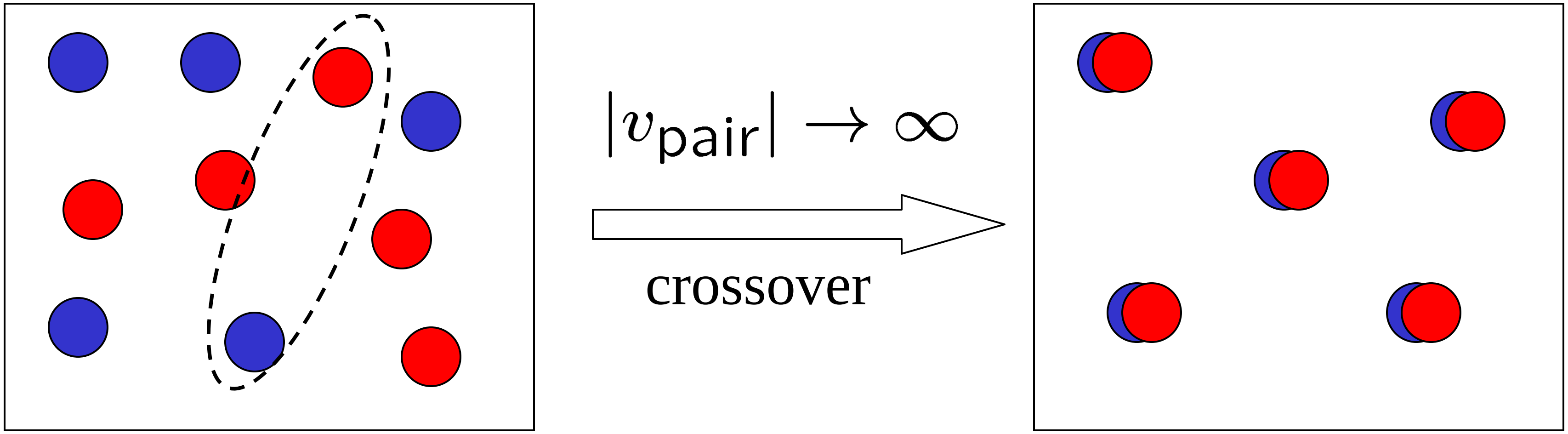
$\sqrt{\langle r^2 \rangle}$ ← matter radius or HBT

$$\langle \theta_{12} \rangle = 65.2^{+11.4}_{-13.0} \quad (^{11}\text{Li})$$
$$= 74.5^{+11.2}_{-13.1} \quad (^{6}\text{He})$$

K.H. and H. Sagawa,PRC76('07)047302

Nucleus	Method	$\sqrt{\langle r_{nn}^2 \rangle}$ (fm)	$\sqrt{\langle r_{c-2n}^2 \rangle}$ (fm)	$\langle \theta_{nn} \rangle$ (deg.)
^{6}He	Matter radii	3.75+/-0.93	3.88+/-0.32	$51.6^{+11.2}_{-12.4}$
	HBT	5.9+/-1.2		$74.5^{+11.2}_{-13.1}$
	3body calc.	4.65	3.63	66.33
^{11}Li	Matter radii	5.50+/-2.24	5.15+/-0.33	$56.2^{+17.8}_{-21.3}$
	HBT	6.6+/-1.5		$65.2^{+11.4}_{-13.0}$
	3body calc.	6.43	5.13	65.29

BCS-BEC crossover phenomenon

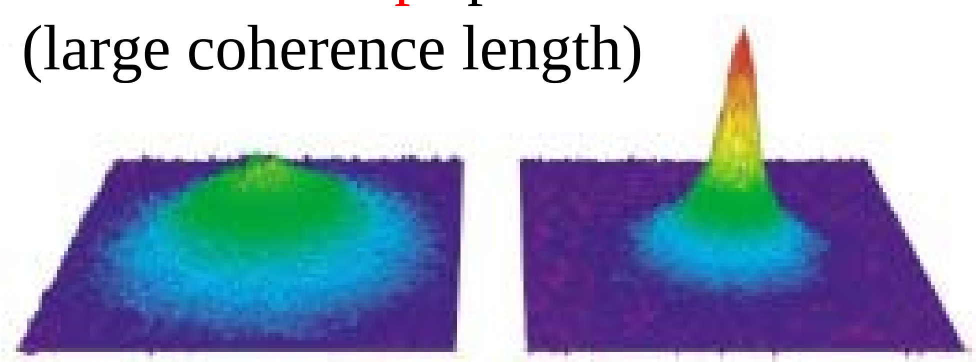


BCS (weak coupling)

- Weakly interacting fermions
- Correlation in p space (large coherence length)

BEC (strong coupling)

- Weakly interacting "diatomic molecules"
- Correlation in r space (small coherence length)

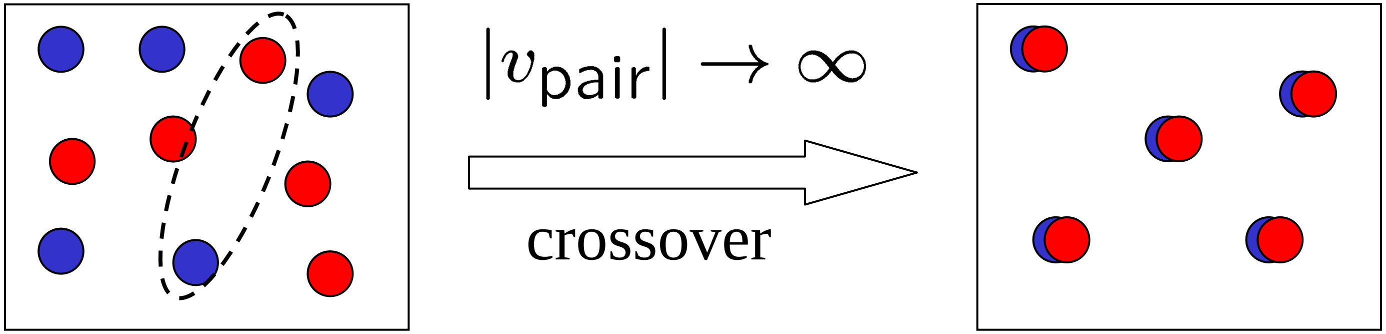


cf. BEC of ^{40}K molecules
M. Greiner et al., Nature 426('04)537

cf. BCS-BEC crossover in color superconductivity: Y. Nishida and H. Abuki, PRD72('05)096004

BCS-BEC crossover

Cooper pair wave function: $\Psi(\boldsymbol{r},\boldsymbol{r}') \sim \langle \Phi_0 | c^\dagger(\boldsymbol{r},\uparrow)\, c^\dagger(\boldsymbol{r}',\downarrow) | \Phi_0 \rangle$



BCS (weak coupling)

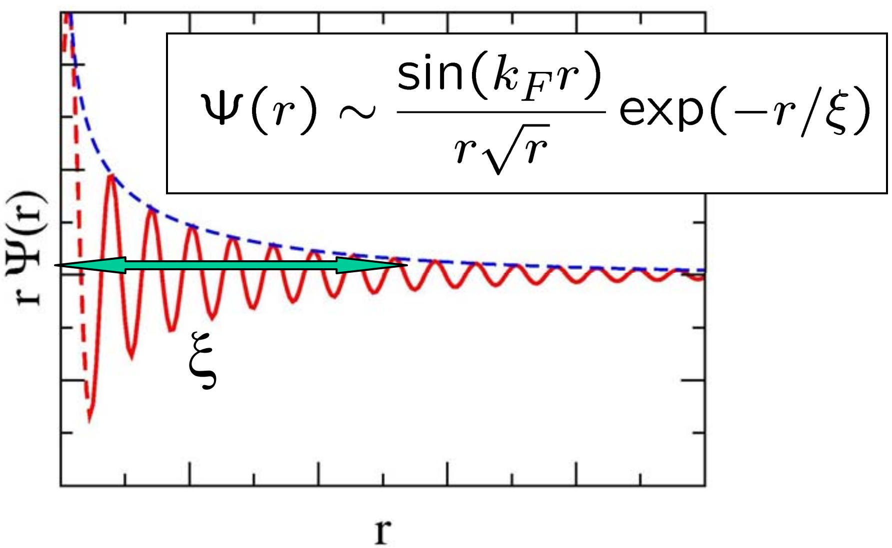
Correlation in p space

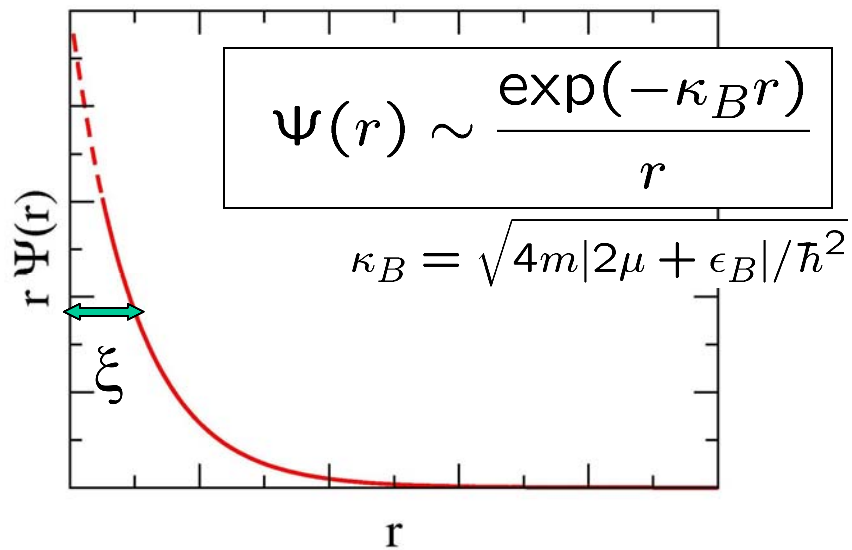
(large coherence length)

BEC (strong coupling)

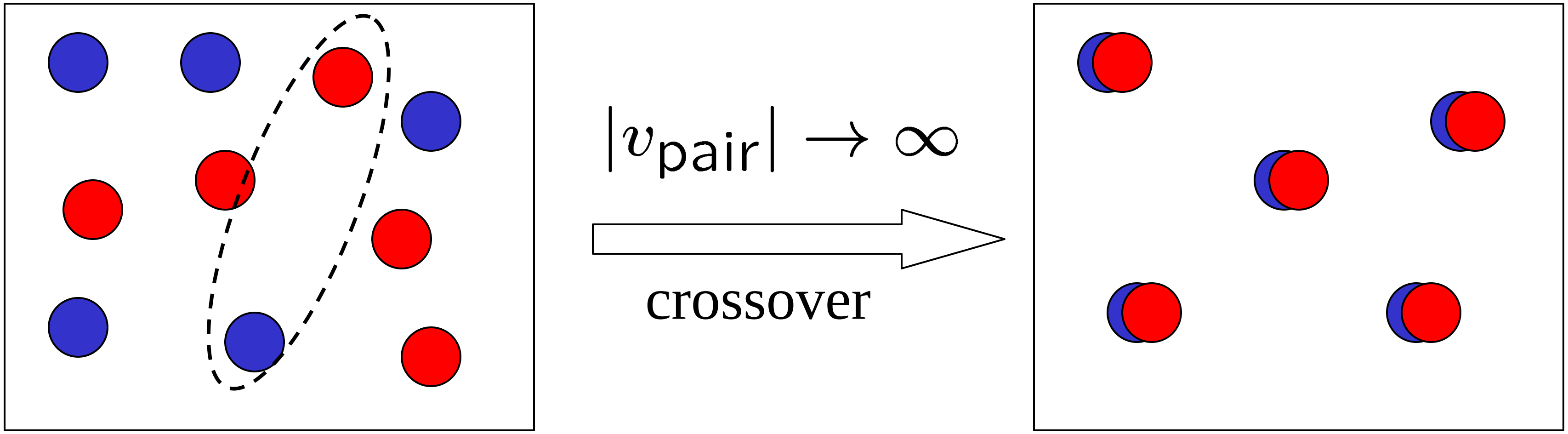
Correlation in r space

(small coherence length)





BCS-BEC crossover



BCS (weak coupling)

- Weakly interacting fermions
- Correlation in p space (large coherence length)

↕ ??

Pairing in stable nuclei

BEC (strong coupling)

- Weakly interacting "diatomic molecules"
- Correlation in r space (small coherence length)

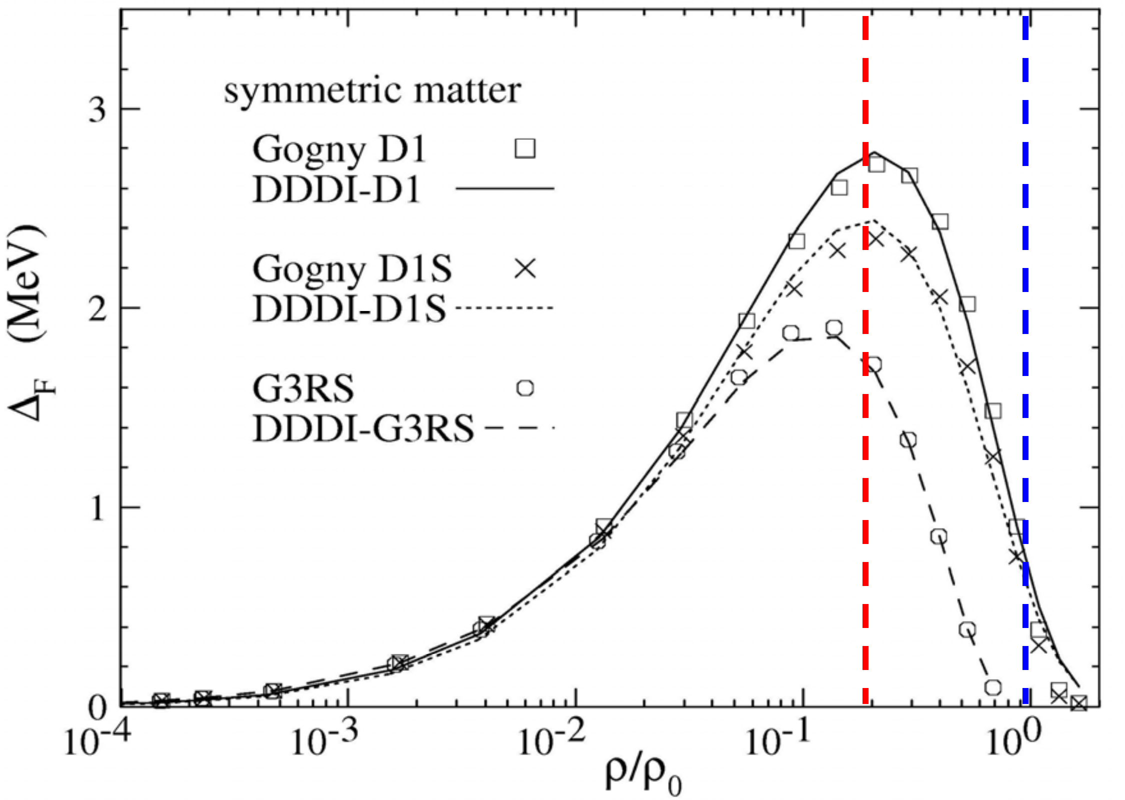
↕ ??

Di-neutron correlations in neutron-rich nuclei

BCS-BEC crossover behavior in infinite nuclear matter

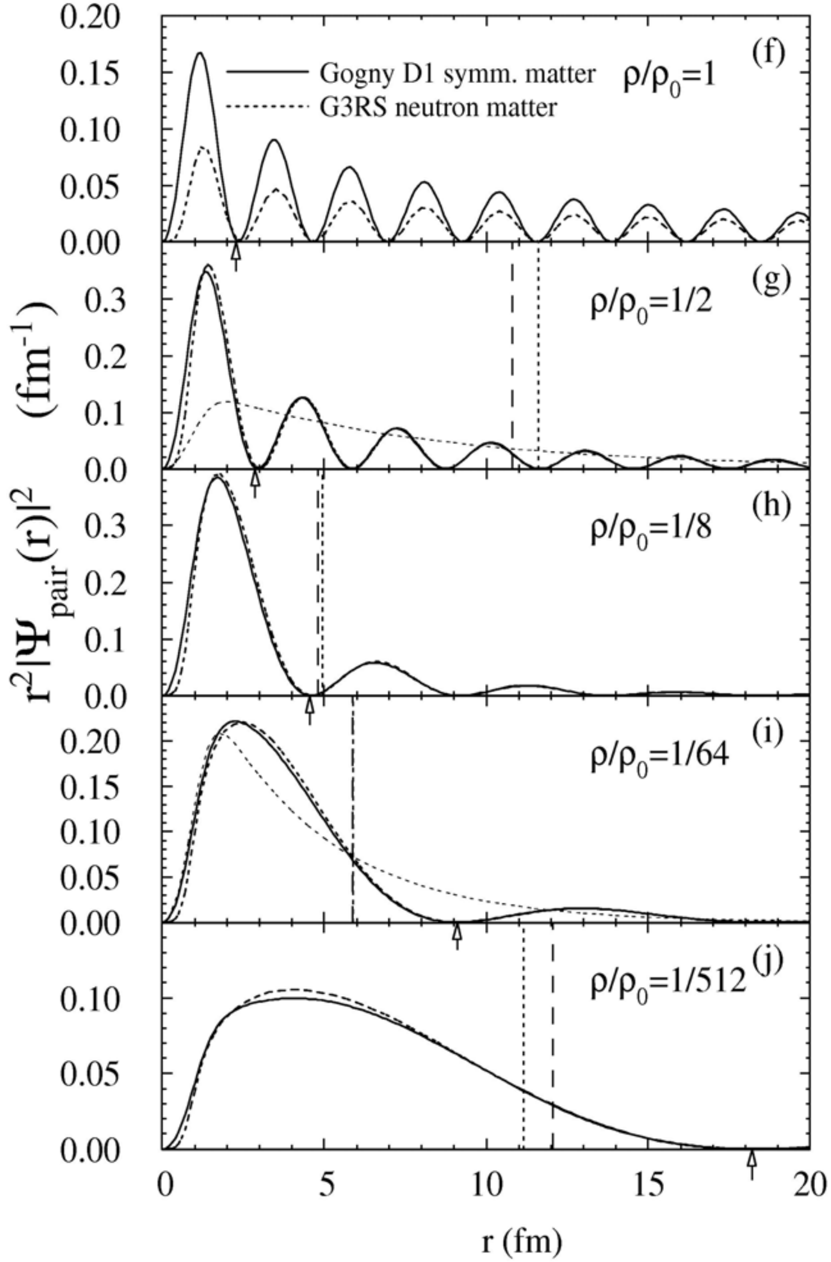
Neutron-rich nuclei ⟺
- ●Weakly bound levels
- ●Unsaturated density around surface (halo/skin)

pairing gap in infinite nuclear matter



M. Matsuo, PRC73('06)044309

Spatial structure of neutron Cooper pair in infinite matter

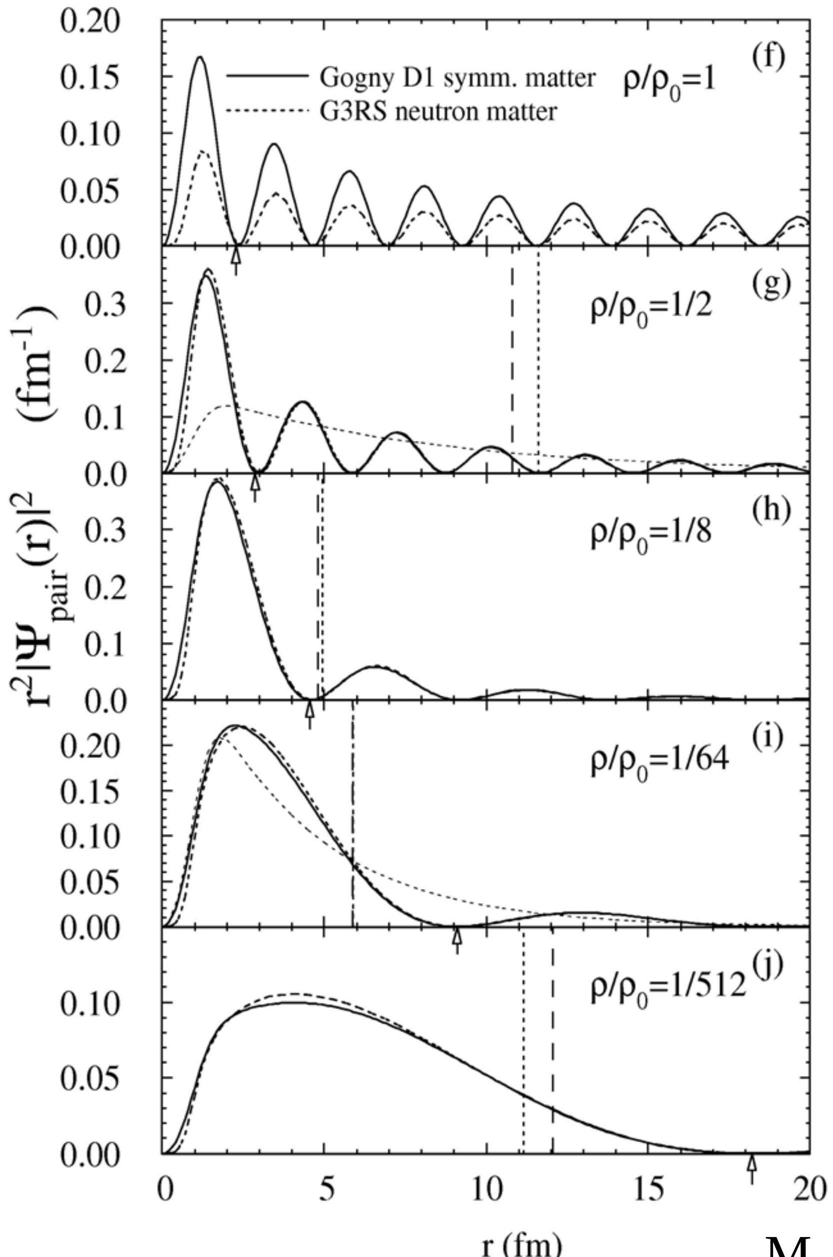


BCS

Crossover region

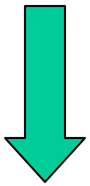
M. Matsuo, PRC73('06)044309

Spatial structure of neutron Cooper pair in infinite matter



Our Motivations

- How can this behavior be seen in *finite* nuclei?
- Relation to di-neutron correlation?

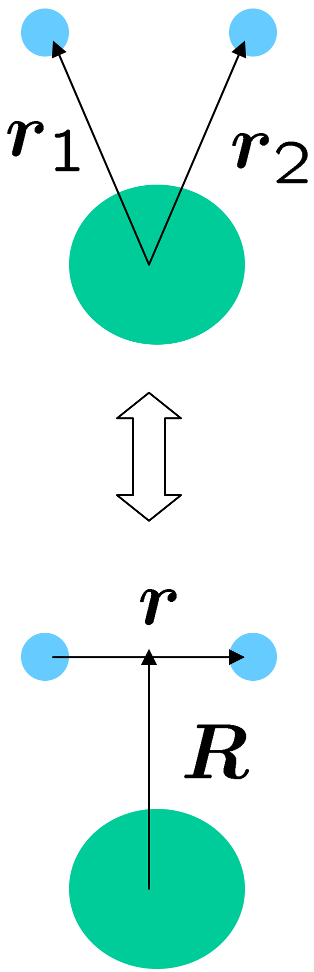


$^{11}Li = ^{9}Li + n + n$

M. Matsuo, PRC73('06)044309

Di-neutron wave function in Borromean nuclei

$$\Psi^{(S=0)}(\boldsymbol{r}_1,\boldsymbol{r}_2)=\sum_L f_L(r,R)[Y_L(\hat{\boldsymbol{r}})Y_L(\hat{\boldsymbol{R}})]^{(00)}$$



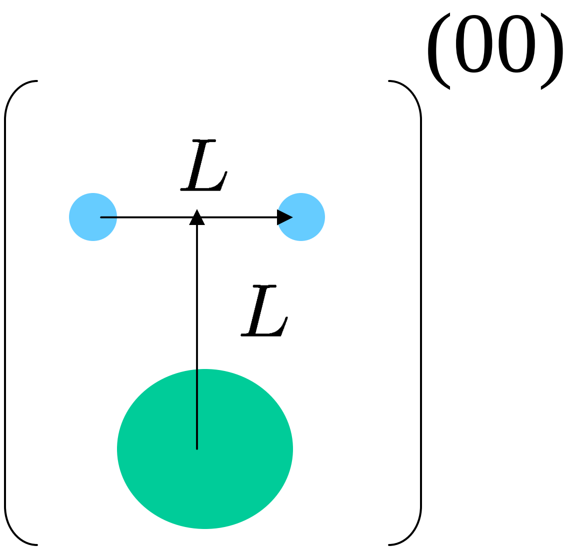
$$\begin{aligned}
f_L(r,R) &= \sum_{n'\leq n}\sum_{l,j}\alpha_{nn'lj}\,(-)^{l+L}\frac{\sqrt{2\pi(2j+1)}}{\sqrt{2(1+\delta_{n,n'})}}\\
&\times\int_0^\pi \sin\theta d\theta\, Y_{L0}(\theta)\,\sum_m(-)^m\frac{(l-m)!}{(l+m)!}\\
&\times P_l^m(\cos\theta_1)P_l^m(\cos\theta_2)\\
&\times\phi_{nlj}(r_1)\phi_{n'lj}(r_2)\\
r_1 &= \sqrt{R^2+r^2/4+Rr\cos\theta}\\
r_2 &= \sqrt{R^2+r^2/4-Rr\cos\theta}\\
\cos\theta_1 &= (R+r\cos\theta/2)/r_1\\
\cos\theta_2 &= (R-r\cos\theta/2)/r_2
\end{aligned}$$

B.F. Bayman and A. Kallio, Phys. Rev. 156('56)1121

Di-neutron wave function in Borromean nuclei

$$\Psi^{(S=0)}(\boldsymbol{r}_1,\boldsymbol{r}_2)=\sum_L f_L(r,R)[Y_L(\hat{\boldsymbol{r}})Y_L(\hat{\boldsymbol{R}})]^{(00)}$$

$$P_L=\int r^2dr\int R^2dR\,|f_L(r,R)|^2$$

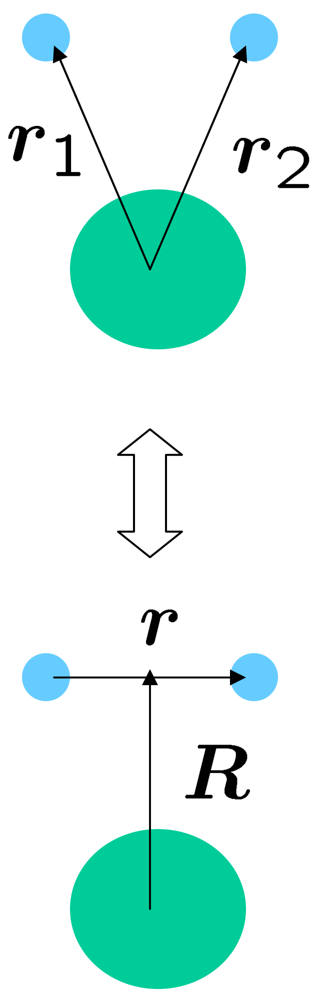


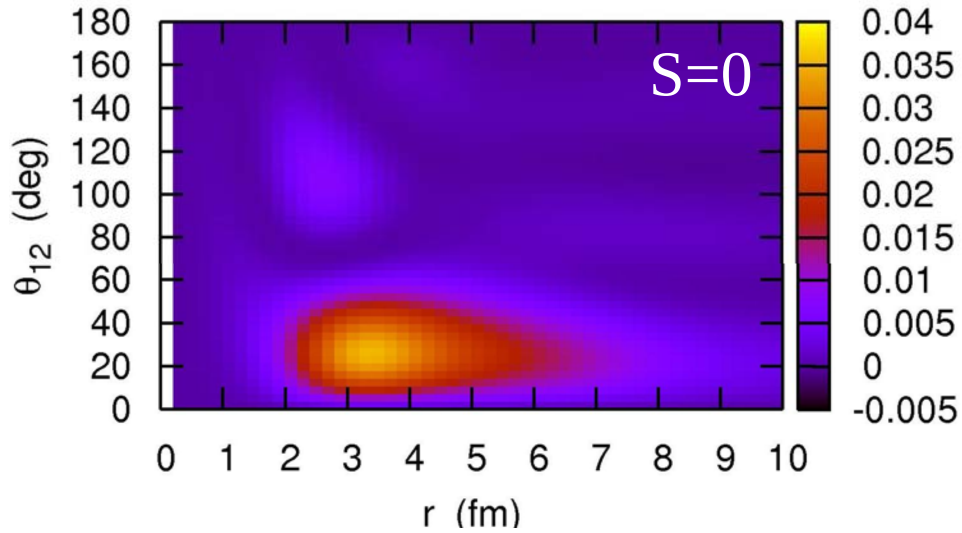
$$P_{L=0} = 0.578$$
$$P_{L=2} = 0.020$$
$$P_{L=4} = 0.00452$$

Sum = 0.603

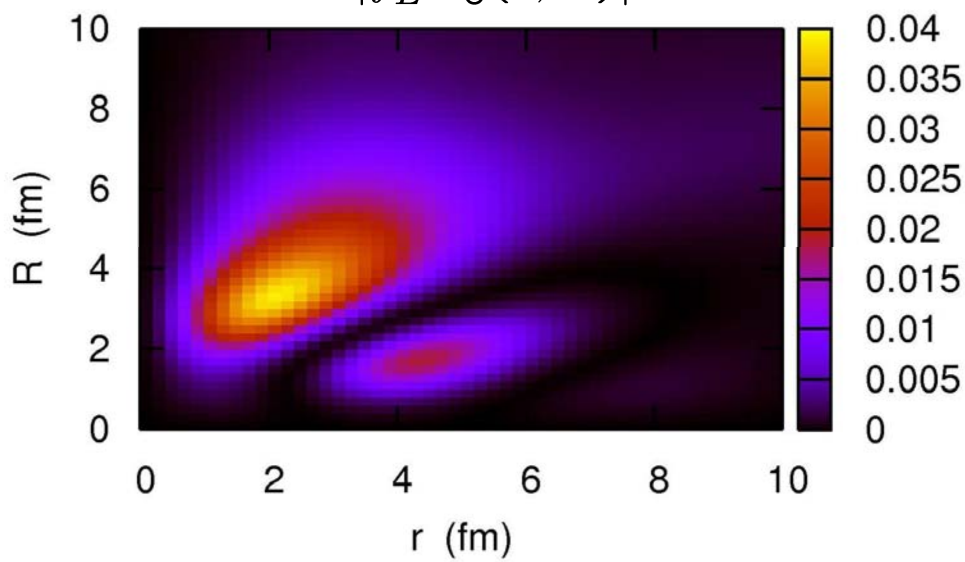
$\Longleftrightarrow$ $P_{S=0}$ = 0.606

$$\Psi^{(S=0)}(\boldsymbol{r}_1, \boldsymbol{r}_2) = \sum_L f_L(r, R)[Y_L(\hat{\boldsymbol{r}})Y_L(\hat{\boldsymbol{R}})]^{(00)}$$



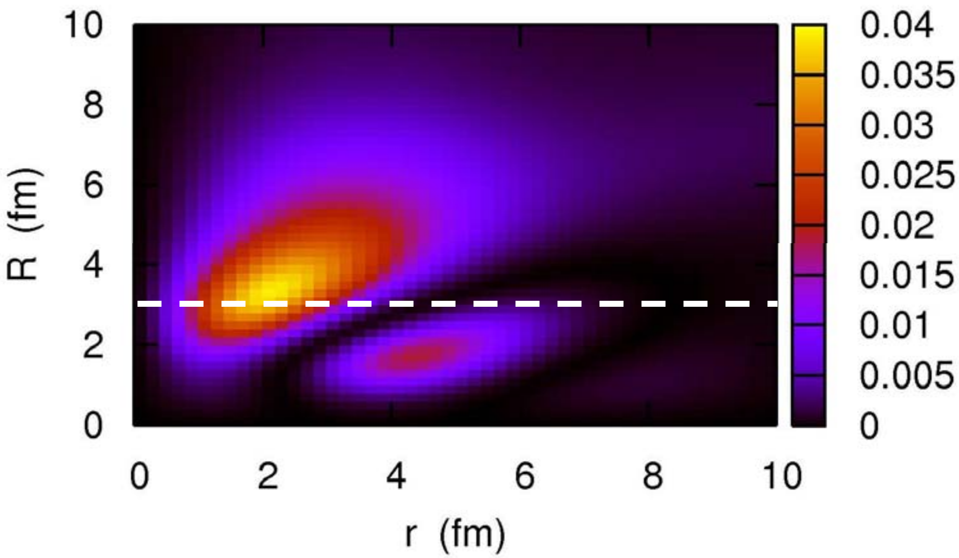


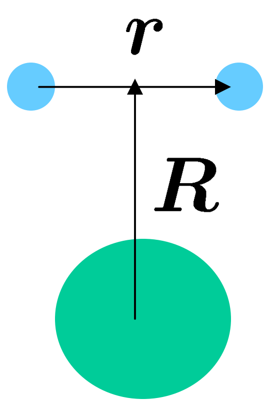
$r^2R^2|f_{L=0}(r,R)|^2$



Plot the wf at several values of *R*

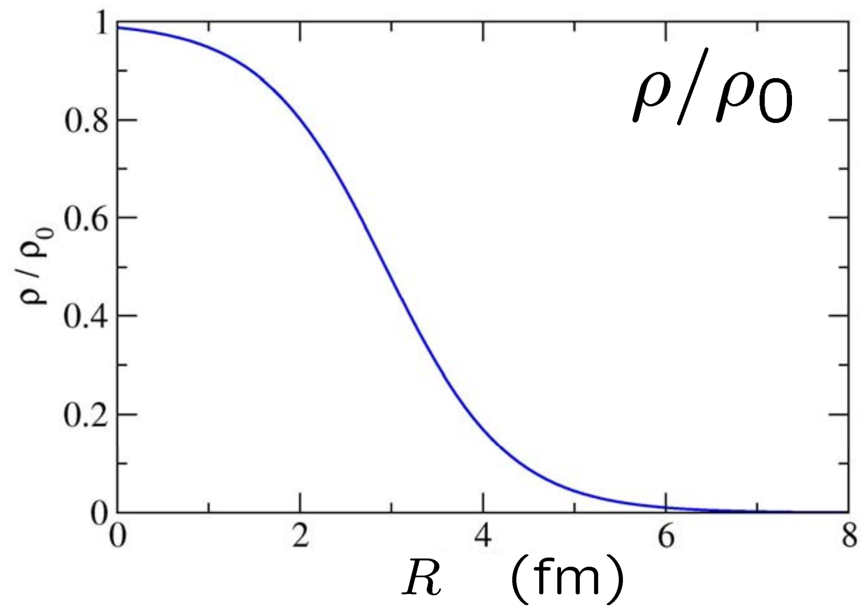
$$r^2 R^2 |f_{L=0}(r,R)|^2$$



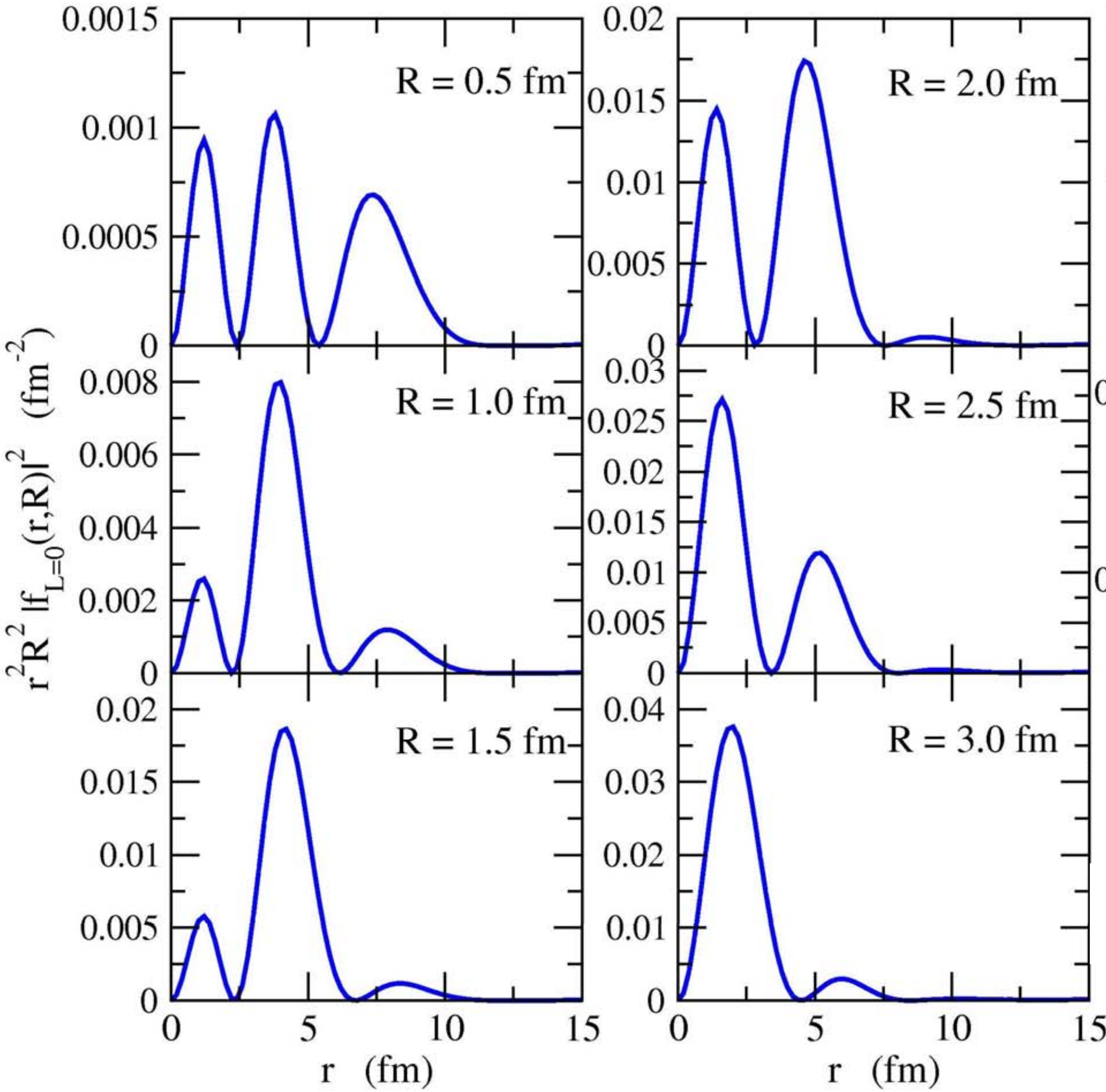


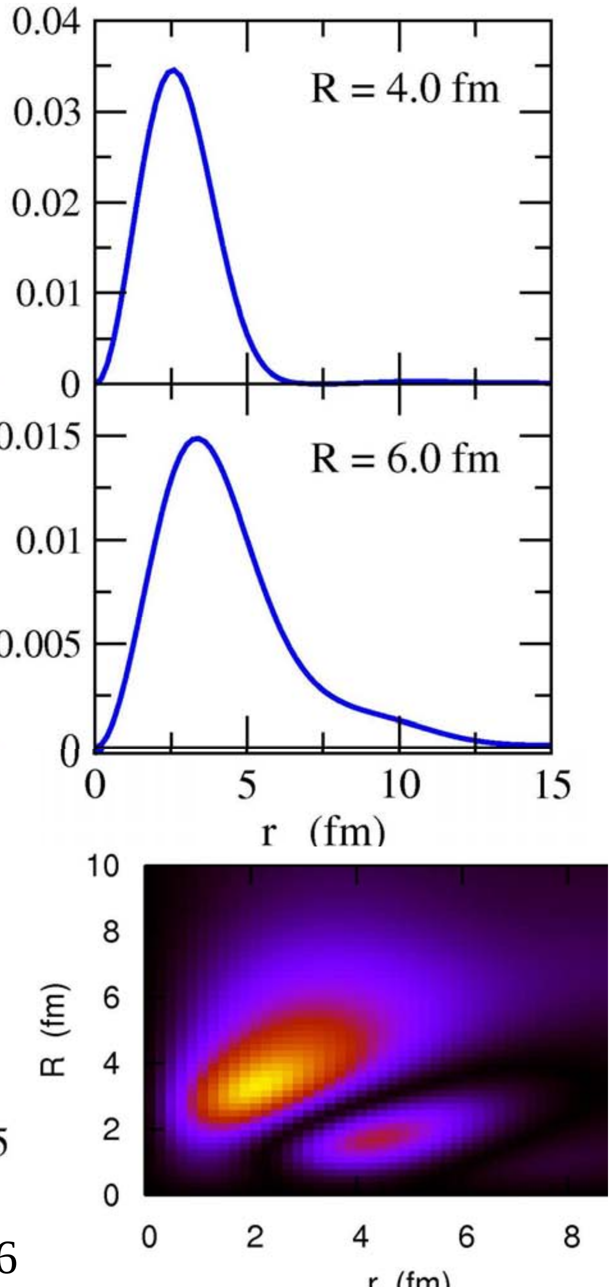
$$v_{nn} = F[\rho(R)] \cdot \delta(\boldsymbol{r})$$

Probing the behavior
at several densities



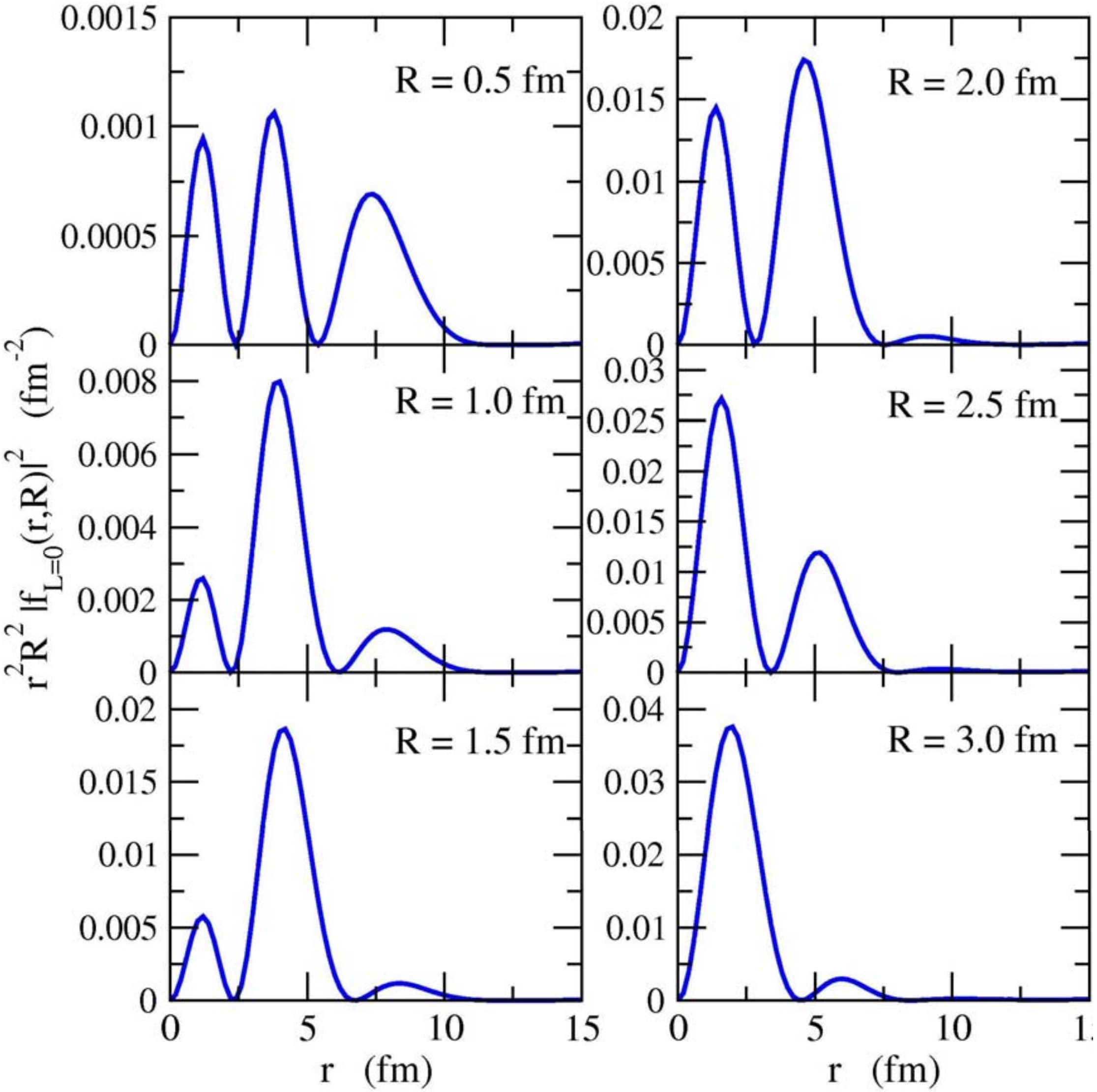
$$r^2 R^2 |f_{L=0}(r,R)|^2$$

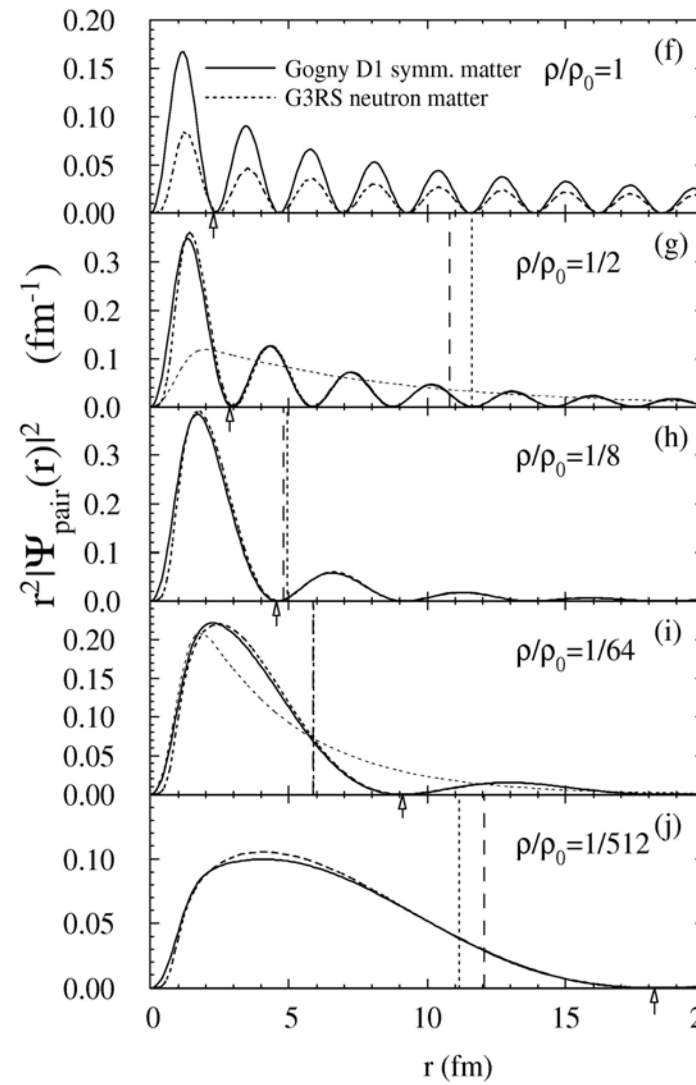




K.H., H. Sagawa, J. Carbonell, and P. Schuck, PRL99('07)022506 good correspondence

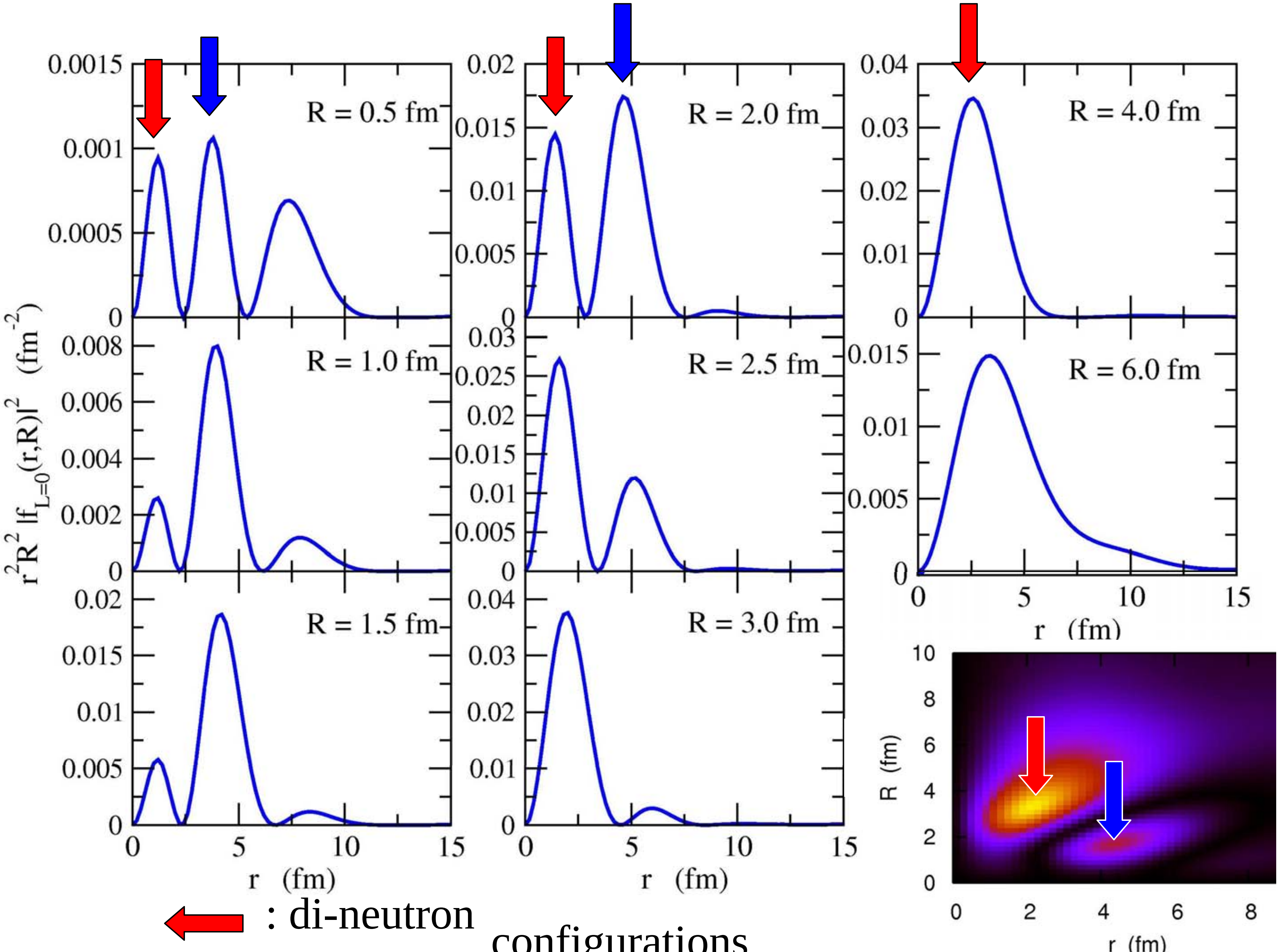
^{11}Li ⟷ Nulcear Matter Calc.





K.H., H. Sagawa, J. Carbonell, and P. Schuck, PRL99('07)022506

M. Matsuo, PRC73('06)044309



: di-neutron

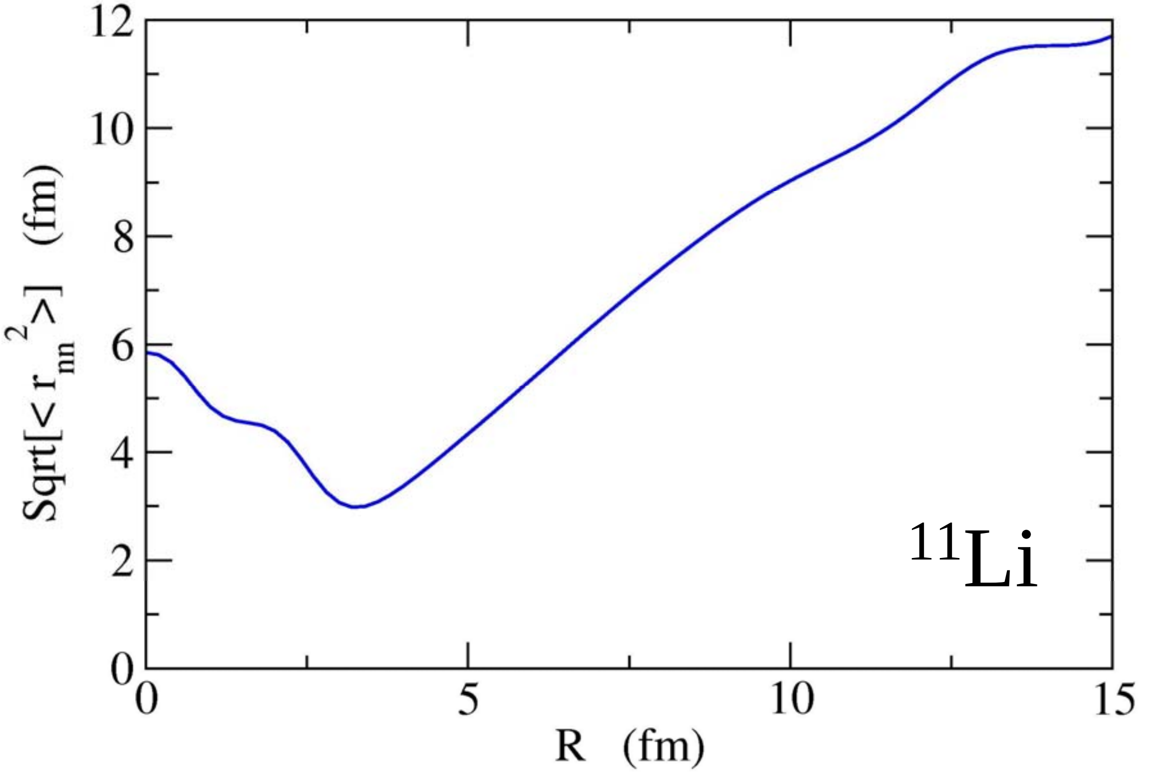
: cigar-like

configurations

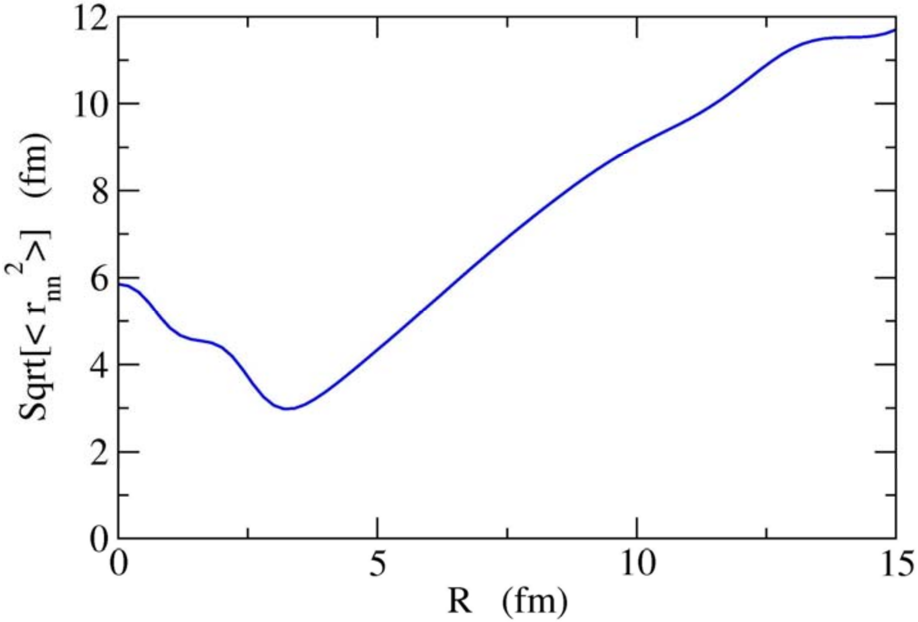
2-neutron rms distance

$$\sqrt{\langle r_{nn}^2 \rangle}(R) = \sqrt{\frac{\int r^4 dr\, |f_{L=0}(r,R)|^2}{\int r^2 dr\, |f_{L=0}(r,R)|^2}}$$

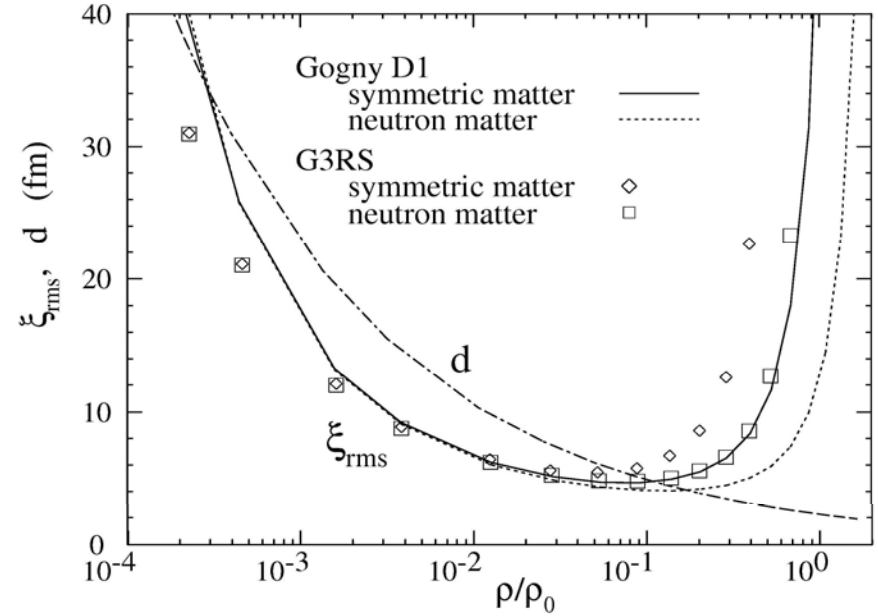
$$\Psi^{(S=0)}(\boldsymbol{r}_1, \boldsymbol{r}_2) = \sum_L f_L(r,R)[Y_L(\hat{\boldsymbol{r}})Y_L(\hat{\boldsymbol{R}})]^{(00)}$$



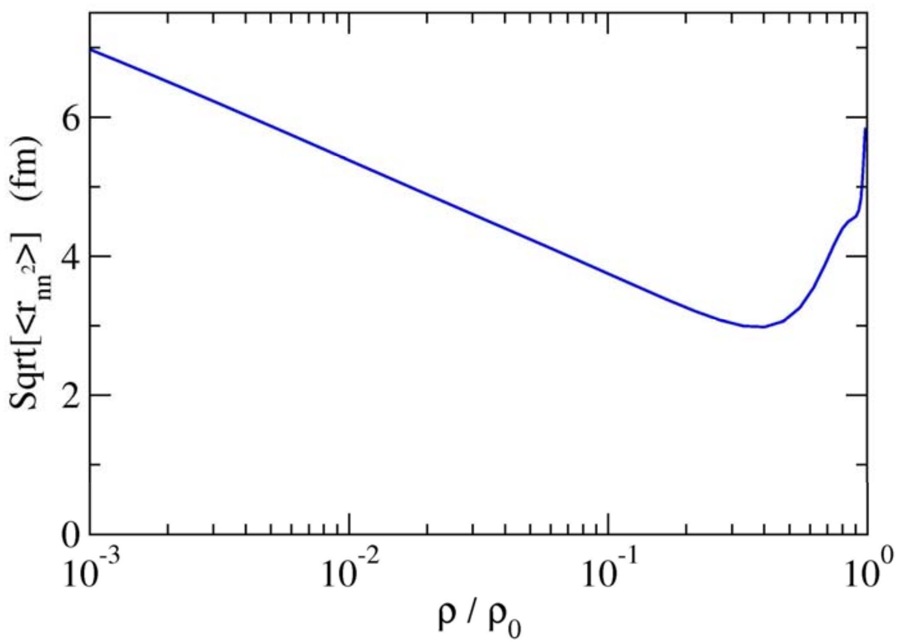
$$\sqrt{\langle r_{nn}^2\rangle}(R) = \sqrt{\frac{\int r^4 dr\, |f_{L=0}(r,R)|^2}{\int r^2 dr\, |f_{L=0}(r,R)|^2}}$$



Matter Calc.



M. Matsuo, PRC73('06)044309

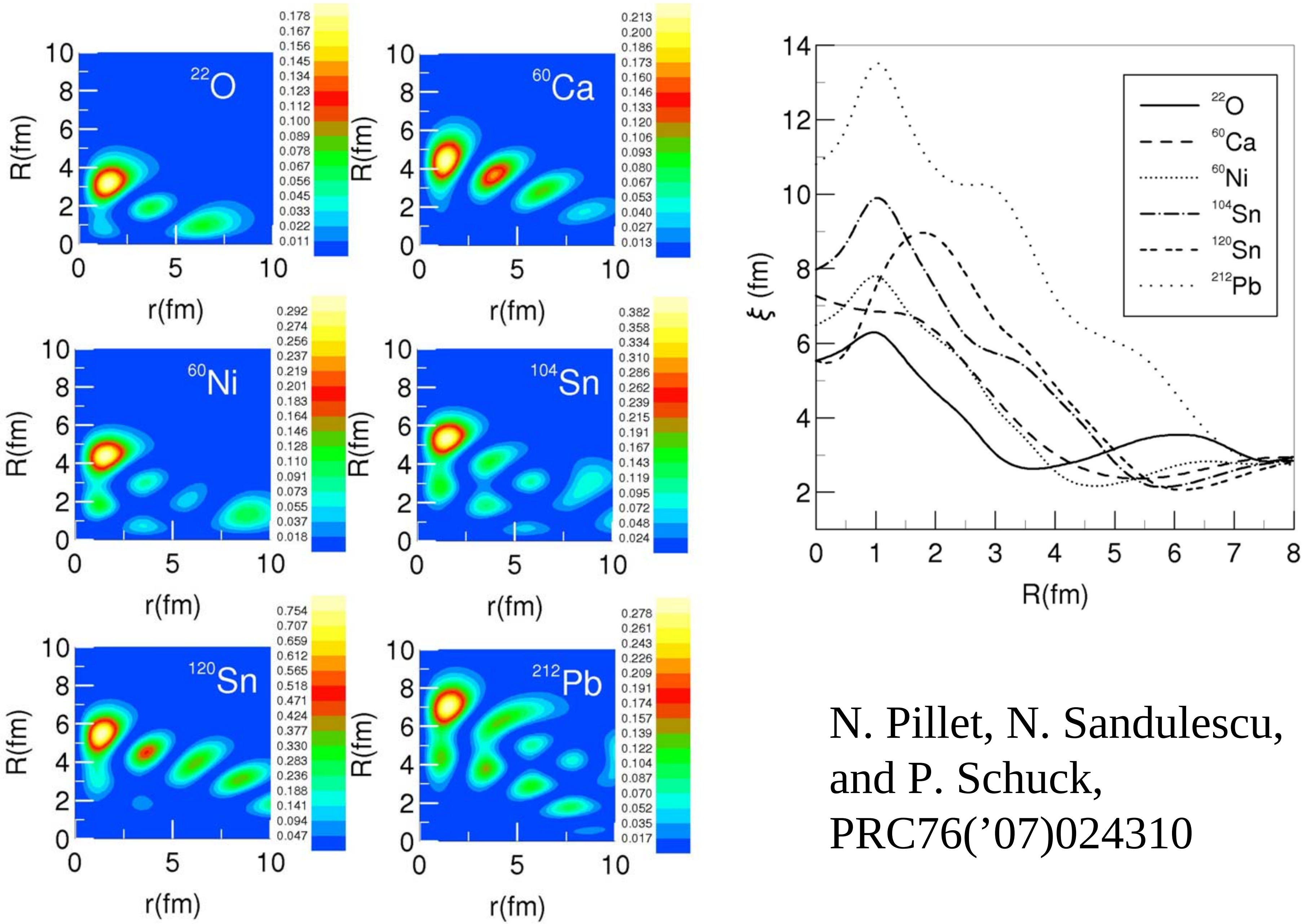


cf. Free n-n system

virtual state around zero energy

⇒ < r > ~ 12 fm (Nijmegen potential)

Gogny HFB calculations



N. Pillet, N. Sandulescu, and P. Schuck, PRC76('07)024310

Di-neutron correlation in ^{8}He

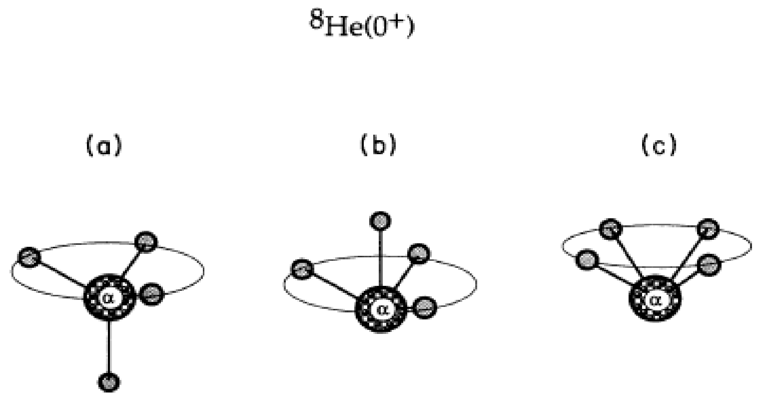


FIG. 2. Three configurations with maximum probability for the angular part of the spatial correlation function [(6)] are shown.

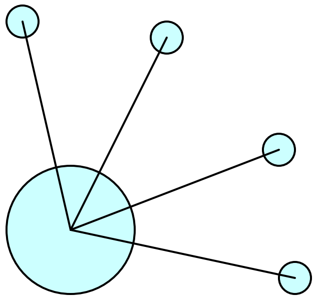
M.V. Zhukov et al., PRC50('94)R1

$(1p_{3/2})^4$ configuration in H.O. pot.

lack of continuum couplings
(mixing of several ang. mom.)

α + 4n model (see also Varga, Suzuki, Ohbayasi, PRC50('94)189)

$$H = \sum_{i=1}^{4} \left(\frac{\boldsymbol{p}_i^2}{2m} + V_{n\alpha}(\boldsymbol{r}_i) \right) + \sum_{i<j} v_{nn}(\boldsymbol{r}_i - \boldsymbol{r}_j)$$



$V_{n\alpha}$: Woods-Saxon
v_{nn}: density-dependent contact force

⟹ Hartree-Fock-Bogoliubov (HFB) + PNP (VBP)

Hartree-Fock-Bogoliubov approximation

quasi-particle operators: $\beta_k^\dagger = \sum_l \left(U_{lk}\, c_l^\dagger + V_{lk}\, c_l \right)$

$\Rightarrow$ $|\mathrm{HFB}\rangle = \prod_k \beta_k |0\rangle$

$$\begin{pmatrix} \hat{h} - \lambda & \Delta(r) \\ \Delta(r) & -\hat{h} + \lambda \end{pmatrix} \begin{pmatrix} U_k(r) \\ V_k(r) \end{pmatrix} = E_k \begin{pmatrix} U_k(r) \\ V_k(r) \end{pmatrix}$$

For $H = \sum_{i=1}^{4} \left(\frac{\boldsymbol{p}_i^2}{2m} + V_{n\alpha}(\boldsymbol{r}_i) \right) + \sum_{i<j} v_0 \left(1 - \frac{\rho_t(\boldsymbol{r})}{\rho_0} \right) \delta(\boldsymbol{r}_i - \boldsymbol{r}_j); \qquad \rho_t(\boldsymbol{r}) = \rho_\alpha(\boldsymbol{r}) + \rho_{4n}(\boldsymbol{r})$

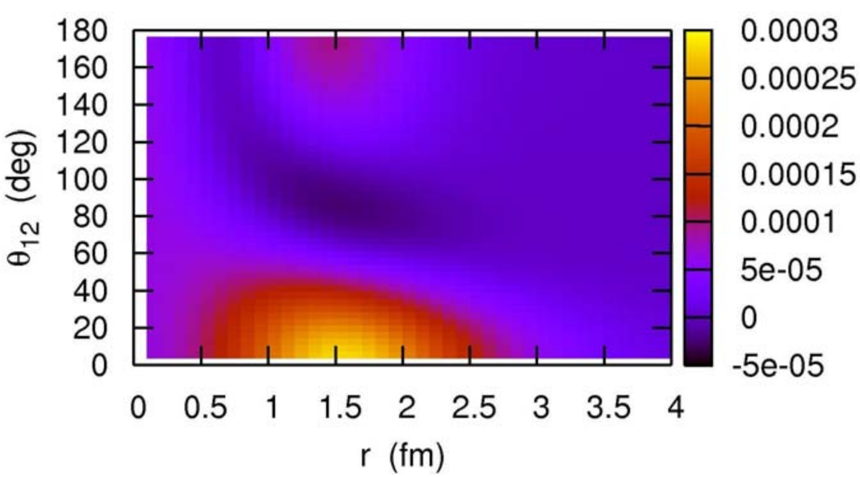
$$\hat{h} = \frac{\delta E}{\delta \rho} = -\frac{\hbar^2}{2m}\nabla^2 + \frac{1}{2} v_0 \left(1 - \frac{\rho_\alpha(r)}{\rho_0} \right) \cdot \rho_{4n}(r) + V_{n\alpha}(r) - \frac{3}{4} v_0 \frac{\rho_{4n}(r)^2}{\rho_0} - \frac{1}{4} v_0 \frac{\tilde{\rho}_{4n}(r)^2}{\rho_0}$$

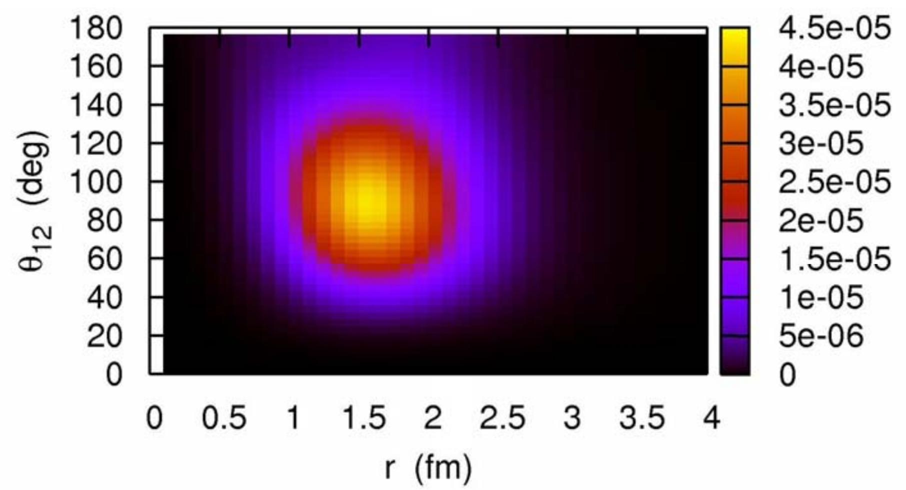
$$\Delta(r) = \frac{\delta E}{\delta \tilde{\rho}} = \frac{1}{2} v_0 \left(1 - \frac{\rho_t(r)}{\rho_0} \right) \cdot \tilde{\rho}_{4n}(r)$$

$$\rho_{4n}(\boldsymbol{r}) = \sum_k V_k(\boldsymbol{r}) V_k^*(\boldsymbol{r}); \qquad \tilde{\rho}_{4n}(\boldsymbol{r}) = -\sum_k V_k(\boldsymbol{r}) U_k^*(\boldsymbol{r})$$

two-body correlation density

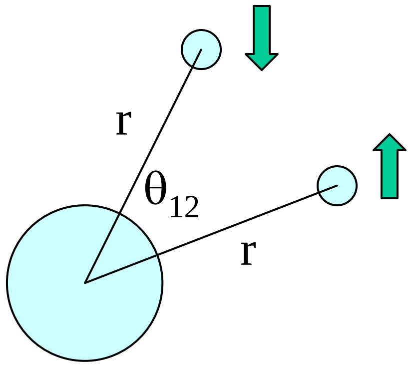
4 particle density
(dineutron-dineutron configuration)

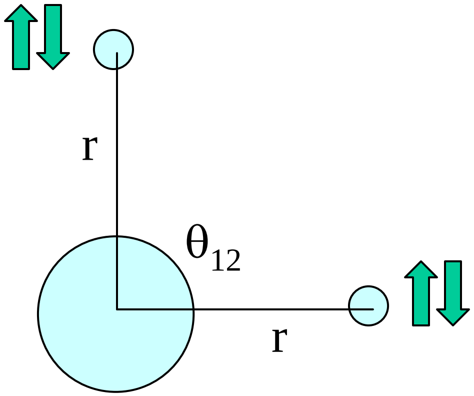




$$\rho_2(\boldsymbol{r},\boldsymbol{r}') \sim \langle \mathrm{HFB}|c^\dagger_{\boldsymbol{r}\uparrow}c^\dagger_{\boldsymbol{r}'\downarrow}c_{\boldsymbol{r}'\downarrow}c_{\boldsymbol{r}\uparrow}|\mathrm{HFB}\rangle,$$

$$\rho_4(\boldsymbol{r},\boldsymbol{r}') = \langle \mathrm{HFB}|c^\dagger_{\boldsymbol{r}\uparrow}c^\dagger_{\boldsymbol{r}\downarrow}c^\dagger_{\boldsymbol{r}'\uparrow}c^\dagger_{\boldsymbol{r}'\downarrow} \times c_{\boldsymbol{r}'\downarrow}c_{\boldsymbol{r}'\uparrow}c_{\boldsymbol{r}\downarrow}c_{\boldsymbol{r}\uparrow}|\mathrm{HFB}\rangle$$



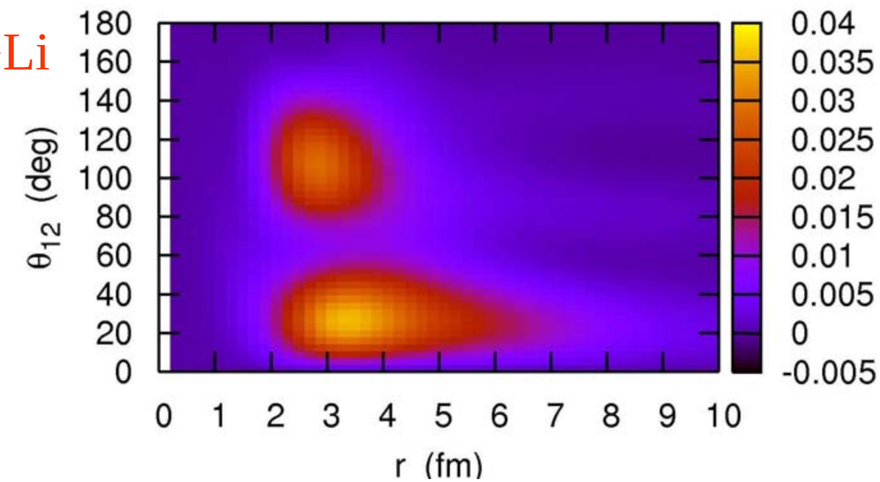


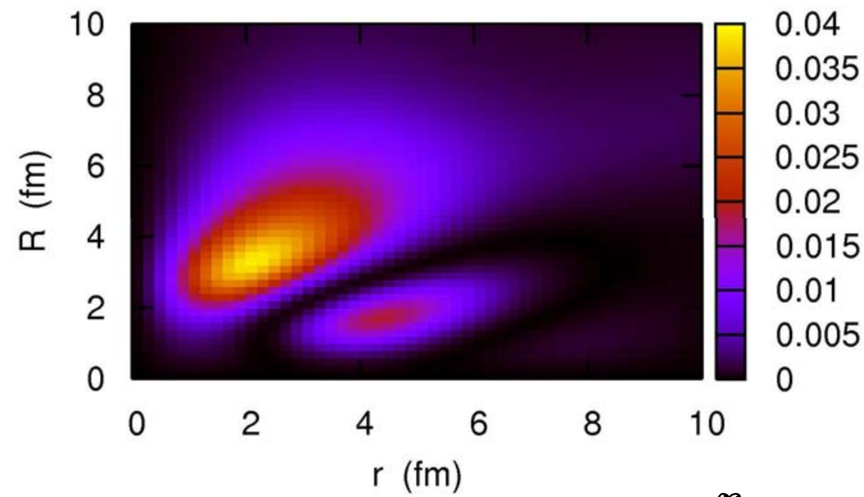
K.H. and N. Takahashi, in preparation

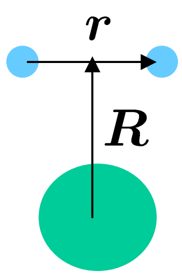
Summary

➢Application of three-body model to Borromean nuclei

^{11}Li







➢E1 response and geometry of Borromean nuclei

➢Di-neutron wave function for each *R*

- Close correspondence to the matter calculations
- BCS/BEC crossover phenomenon
- Concentration of a Cooper pair on the nuclear surface
- Also in other superfulid nuclei (universality)

➢Strong di-neutron correlation in ^{8}He