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NUCLEAR MATTER DENSITY DISTRIBUTIONS OF THE LIGHT WEAKLY BOUND NUCLEI

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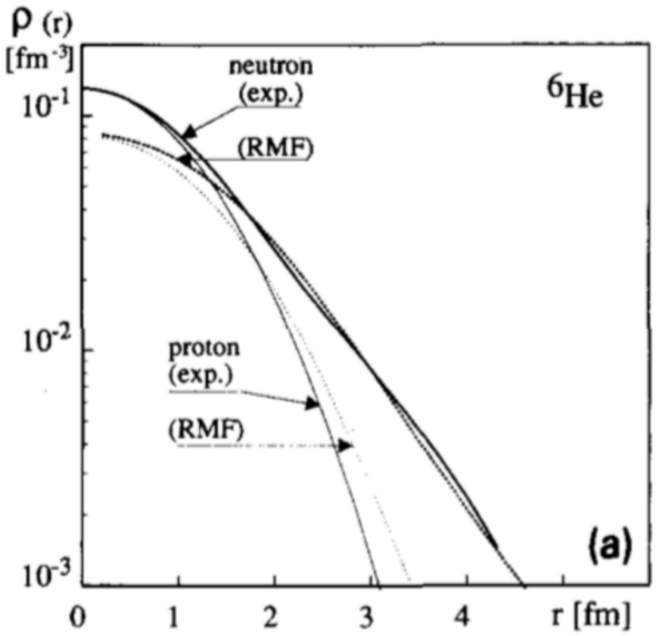
CONTENT

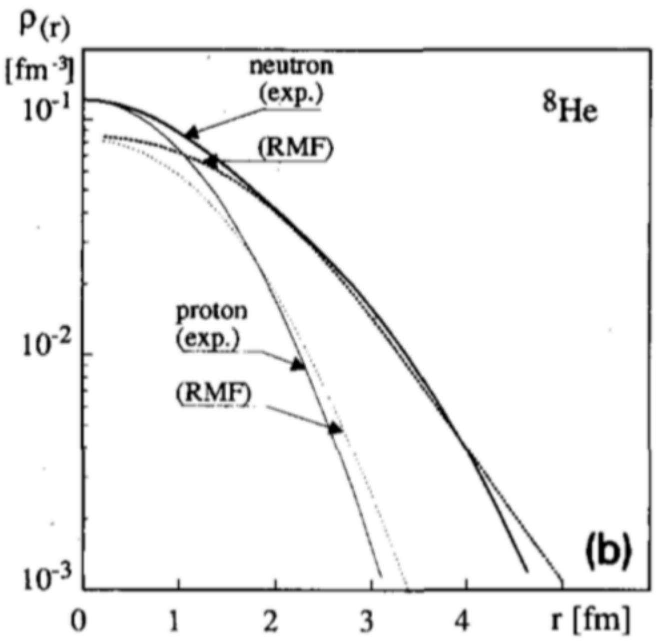
- Why the Density Distribution nuclear matter is important?
- Objects of studying: ^6He, ^6Li and ^9Be
- The three body wave function
- The Density Distribution of nuclear matter within the three body model
- Results and discussions
  - ^6He, ^6Li
  - ^9Be
- Conclusion

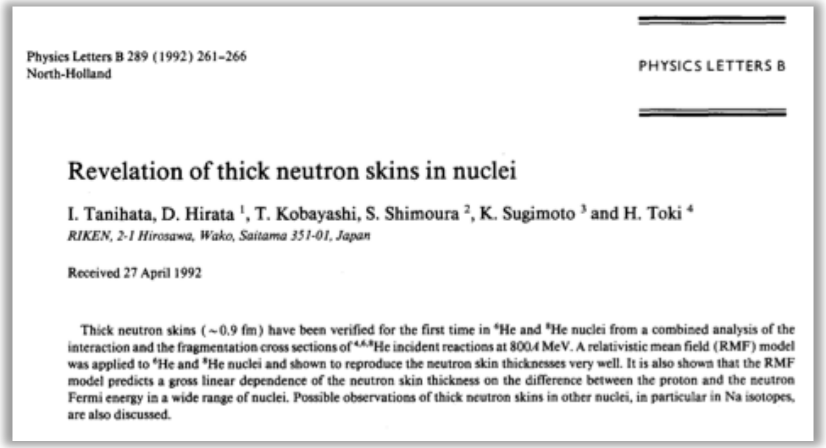
WHY THE DD NUCLEAR MATTER IS IMPORTANT?

NEUTRON SKINS IN ^{6}HE AND ^{8}HE NUCLEI

the Relativistic Mean Field model







Physics Letters B 289 (1992) 261–266
North-Holland

PHYSICS LETTERS B

Revelation of thick neutron skins in nuclei

I. Tanihata, D. Hirata [1], T. Kobayashi, S. Shimoura [2], K. Sugimoto [3] and H. Toki [4]
RIKEN, 2-1 Hirosawa, Wako, Saitama 351-01, Japan

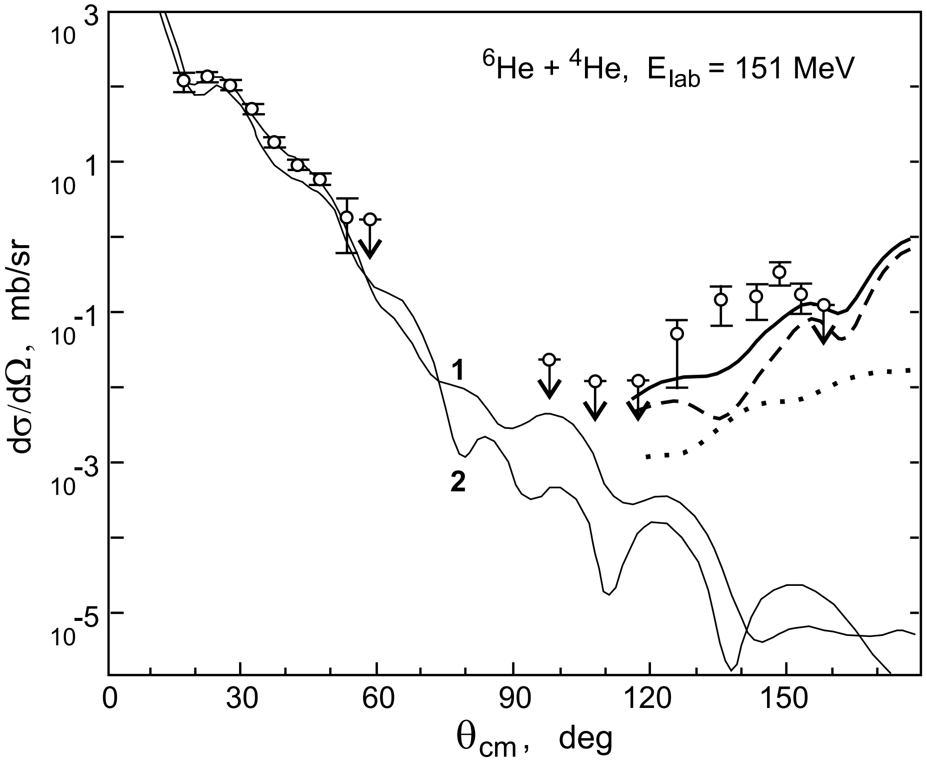
Received 27 April 1992

Thick neutron skins (~0.9 fm) have been verified for the first time in ^{6}He and ^{8}He nuclei from a combined analysis of the interaction and the fragmentation cross sections of ^{4,6,8}He incident reactions at 800.4 MeV. A relativistic mean field (RMF) model was applied to ^{6}He and ^{8}He nuclei and shown to reproduce the neutron skin thicknesses very well. It is also shown that the RMF model predicts a gross linear dependence of the neutron skin thickness on the difference between the proton and the neutron Fermi energy in a wide range of nuclei. Possible observations of thick neutron skins in other nuclei, in particular in Na isotopes, are also discussed.

Tanihata, I., et al. "Revelation of thick neutron skins in nuclei." *Physics Letters B* 289.3-4 (1992): 261-266.

A TWO-NEUTRON TRANSFER REACTION

$\alpha\ (^6He,\ \alpha)\ ^6He$



VOLUME 82, NUMBER 25 PHYSICAL REVIEW LETTERS 21 JUNE 1999

"Di-Neutron" Configuration of ^{6}He

Yu. Ts. Oganessian and V. I. Zagrebaev
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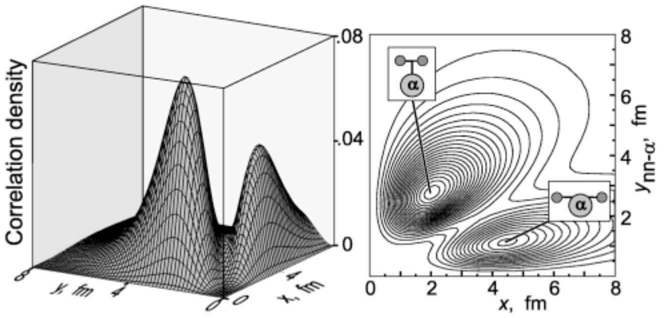
J. S. Vaagen
SENTEF, Institute of Physics, University of Bergen, N-5007 Bergen, Norway
(Received 18 December 1998)

Two-neutron transfer reactions induced by the Borromean nucleus ^{6}He on ^{4}He and ^{1}H targets are analyzed within a realistic four-body model. Available experimental data are well described, and it is the "di-neutron" configuration of the ^{6}He nucleus that is found to make the dominant contribution to the cross sections of the two-neutron transfer reactions. [S0031-9007(99)09437-5]

PACS numbers: 25.60.Je, 24.10.Eq, 25.10.+s, 27.20.+n

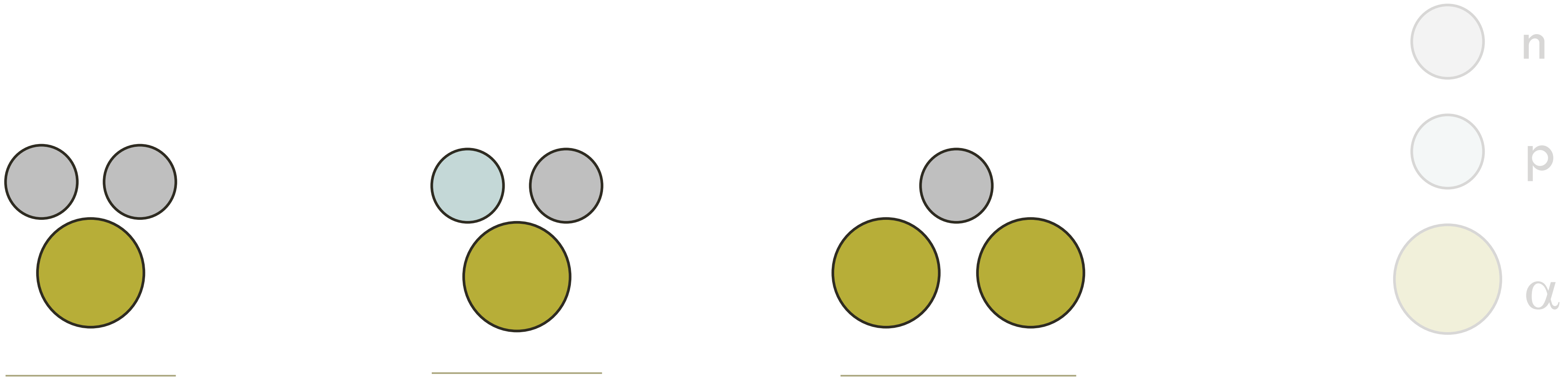


Oganessian, Yu Ts, V. I. Zagrebaev, and J. S. Vaagen. ""Di-Neutron" Configuration of 6 He." *Physical review letters* 82.25 (1999): 4996.

OBJECTS OF STUDYING: ^{6}HE, ^{6}LI AND ^{9}BE

THE THREE BODY NUCLEI

- ✓ cluster structure
- ✓ plenty nuclear reactions
- ✓ interaction potentials of internal clusters



^{6}He ^{6}Li ^{9}Be

THE THREE BODY MODEL

THE SCHRÖDINGER EQUATION

$$H\Psi(\mathbf{r}_1, ..., \mathbf{r}_N) = E\Psi(\mathbf{r}_1, ..., \mathbf{r}_N).$$

$$H = \sum_{i=1}^{N} \frac{\mathbf{p}_i^2}{2m_i} - T_{cm} + \sum_{j>i=1}^{N} V_{ij}.$$

Hamiltonian of the system

$$|\Psi\rangle = \sum_{i=1}^{N} C_i |\varphi\rangle \qquad \sum_{i=1}^{N} |C_i|^2 = 1$$

expansion of the wave function into basis

multiplying bra from the left side

$$\sum_{i=1}^{N} C_i H |\varphi\rangle = E \sum_{i=1}^{N} C_i |\varphi\rangle,$$

one gets

$$\sum_{i=1}^{N} \sum_{k=1}^{N} C_i H_{ik} = E \sum_{i=1}^{N} C_i.$$

Matrix form of the Schrödinger equation for non-orthogonal basis:

$$\begin{pmatrix} H_{11} & H_{12} & \dots & H_{1N} \\ H_{21} & H_{22} & \dots & H_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ H_{N1} & H_{2N} & \dots & H_{NN} \end{pmatrix} \begin{pmatrix} C_1 \\ C_2 \\ \vdots \\ C_N \end{pmatrix} = E \begin{pmatrix} W_{11} & W_{12} & \dots & W_{1N} \\ W_{21} & W_{22} & \dots & W_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ W_{N1} & W_{2N} & \dots & W_{NN} \end{pmatrix} \begin{pmatrix} C_1 \\ C_2 \\ \vdots \\ C_N \end{pmatrix}$$

where
$W_{ik} = \langle\varphi|\varphi\rangle$

THE HAMILTONIAN

Kinetic energy

Sack-Biedenharn-Breit
Nα-potential

Ali-Bodmer
$\alpha\alpha$-potential

$$\tilde{H} = H_0 + \tilde{V}_{\alpha_{1N}} + \tilde{V}_{\alpha_{2N}} + \tilde{V}_{\alpha_1\alpha_2},$$

$$\tilde{V} = V + \Delta = V + \lambda\Gamma$$

Pauli Projector

$$\Gamma = \Gamma(f) = \sum_{m_f} |\varphi_{fm_f}(\mathbf{x})\rangle\langle\varphi_{fm_f}(\mathbf{x}')|\delta(\mathbf{y} - \mathbf{y}')$$

THE BASIS FUNCTION

$$\Psi^{tot}_{JM_J} = \varphi_{J_\alpha=T_\alpha=0}(1,2,3,4)\,\varphi_{J_\alpha=T_\alpha=0}(5,6,7,8)\,\Psi^{JM_J}(\mathbf{x},\mathbf{y})$$

- full WF

$$\Psi^{JM_J}(\mathbf{x},\mathbf{y}) = \sum_{\lambda l L} \Psi^{JM_J}_{\lambda l L}(\mathbf{x},\mathbf{y}),$$

- sum of components

$$\Psi^{JM_J}_{\lambda l L}(\mathbf{x},\mathbf{y}) = \Phi_{\lambda l}(x,y)\,F^{JM_J}_{\lambda l L S}(\hat{x},\hat{y})$$

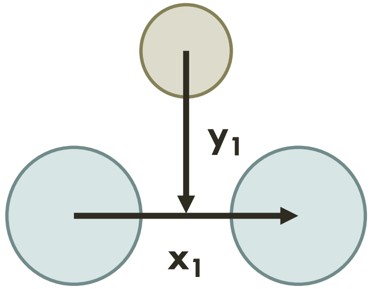
- spin angular part

$$F^{JM_J}_{\lambda l L S}(x,y) = \sum_{M_L M_S} \langle L M_L S M_S |\, J M_J \rangle\, \Upsilon^{LM_L}_{\lambda l}(\hat{x},\hat{y})\,\chi^{SM_S}.$$

$$\Upsilon^{LM_L}_{\lambda l}(\hat{x},\hat{y}) = \sum_{\mu m} \langle \lambda \mu l m |\, L M_L \rangle\, Y_{\lambda\mu}(\hat{x})\,Y_{lm}(\hat{y}),$$

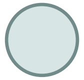
$$\Phi_{\lambda l}(x,y) = \sum_{i=1}^{N} C_i^{(\lambda l)} x^\lambda y^l \exp\left(-\alpha_i^{(\lambda)} x^2 - \beta_i^{(l)} y^2\right)$$

- radial part



x, y – Jacobi coordinates

-neutron



-alpha particle

THE DENSITY DISTRIBUTION FUNCTION OF NUCLEAR MATTER

The function for the 3BS:

$$\rho(\mathbf{R}) = \sum_{cluster=i,j,k} \rho_{cluster}(\mathbf{R}).$$

referring to the (i,jk) Jacobi coordinates set:

$$\rho_{N_i}(\mathbf{R}) = \langle \varphi^{\gamma}(i,jk) | \delta(\mathbf{R} - \mathbf{y}_i) | \varphi^{\gamma}(i,jk) \rangle$$
$$\rho_{\alpha_i}(\mathbf{R}) = \langle \varphi^{\gamma}(i,jk) | \rho_{\alpha}(\mathbf{R} - \mathbf{y}_i) \delta(\mathbf{y}_i - \mathbf{r}_{\alpha}) | \varphi^{\gamma}(i,jk) \rangle$$

referring to the (j,ki) Jacobi coordinates set:

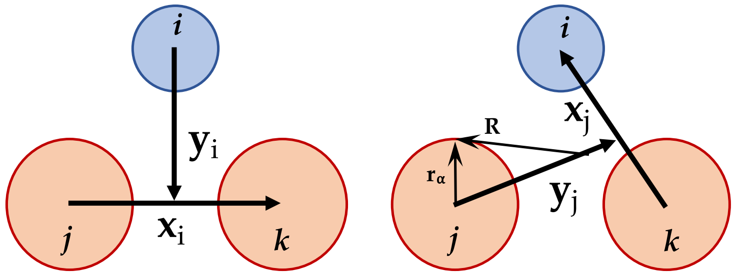
$$\rho_{N_j}(\mathbf{R}) = \sum_{\widetilde{\gamma}} A_{\Omega}^{j\leftarrow i} A_{\Omega}^{j\leftarrow i} \langle \varphi^{\widetilde{\gamma}}(j,ki) | \delta(\mathbf{R} - \mathbf{y}_j) | \varphi^{\widetilde{\gamma}}(j,ki) \rangle$$
$$\rho_{\alpha_j}(\mathbf{R}) = \sum_{\widetilde{\gamma}} A_{\Omega}^{j\leftarrow i} A_{\Omega}^{j\leftarrow i} \langle \varphi^{\widetilde{\gamma}}(j,ki) | \rho_{\alpha}(\mathbf{R} - \mathbf{y}_j) \delta(\mathbf{y}_j - \mathbf{r}_{\alpha}) | \varphi^{\widetilde{\gamma}}(j,ki) \rangle.$$

using certain expression

$$\exp(-\rho_0 \mathbf{R}\cdot\mathbf{y}) = 4\pi \sum_k \sqrt{2k+1}\, i_k(\rho_0 R y) Y_{00}^{kk}\left(\widehat{R}, \widehat{y}\right)$$

$$\int_0^{\infty} y^{2l+k+2} \exp(-\beta y^2) i_k(\mu y) dy = \sqrt{\frac{\pi}{2}} \frac{(2l)!!(\mu)^k}{\left(\frac{1}{2}\beta\right)^{l+k+3/2}} \exp\left(\frac{\mu^2}{\beta}\right) L_l^{k+\frac{1}{2}}\left(-\frac{\mu^2}{\beta}\right)$$

^{9}Be on relative Jacobi coordinate sets with cyclically particle permutations taking into account a size of sub-alpha particles:



Final analytical expression depending on only R:

$$\rho_{N_i}(R) = \frac{1}{2}\left(\frac{R}{y_0}\right)^{2l+2} \Gamma\left(\frac{3}{2}+\frac{\lambda}{2}\right) \sum_{\imath\jmath} C_\imath C_\jmath \frac{\exp\left(-\frac{(\beta_\imath+\beta_\jmath)}{y_0^2} R^2\right)}{(\alpha_\imath+\alpha_\jmath)^{\frac{3}{2}+\frac{\lambda}{2}}}$$

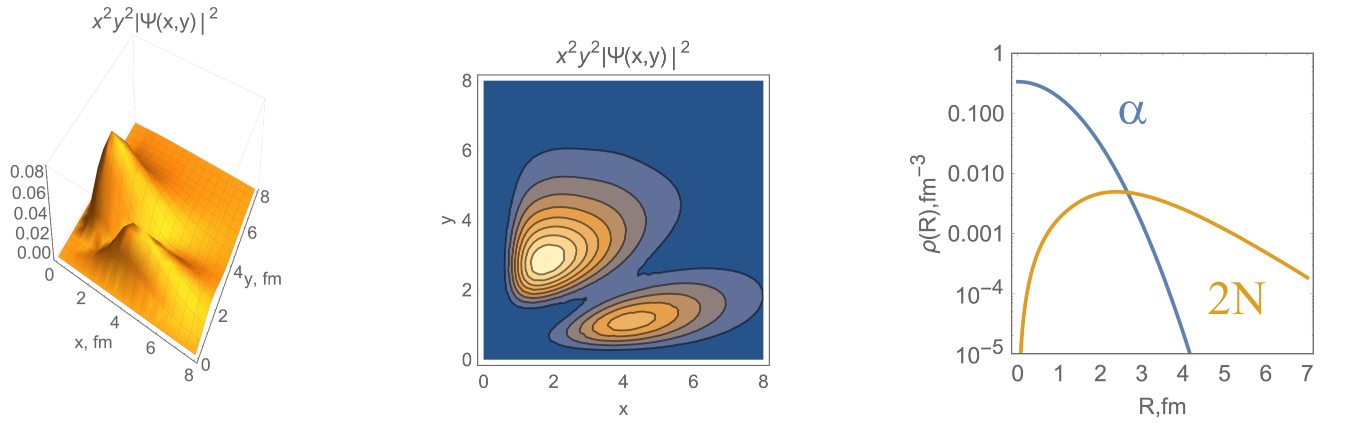
$$\rho_{\alpha_i}(R) = (2\pi)^{\frac{3}{2}} \rho_0 \sum_{\imath\jmath} C_\imath C_\jmath \frac{\Gamma\left(\frac{3}{2}+\lambda\right)\ (2l)!!\ L_l^{1/2}\left(-\frac{(\gamma_0)R^2}{\beta_\imath+\beta_\jmath+\gamma_0}\right)}{(\alpha_\imath+\alpha_\jmath)^{\frac{3}{2}+\lambda} (\beta_\imath+\beta_\jmath+\gamma_0)^{\frac{3}{2}+l}} \times$$
$$\exp\left(\left(-\gamma_0 + \frac{\gamma_0^2}{\beta_\imath+\beta_\jmath+\gamma_0}\right)\left(\frac{R}{y_0}\right)^2\right)$$

RESULTS

^{6}He 0^+

$E_{exp} = -0.975$ MeV

$E_{thr} = -0.228$ MeV

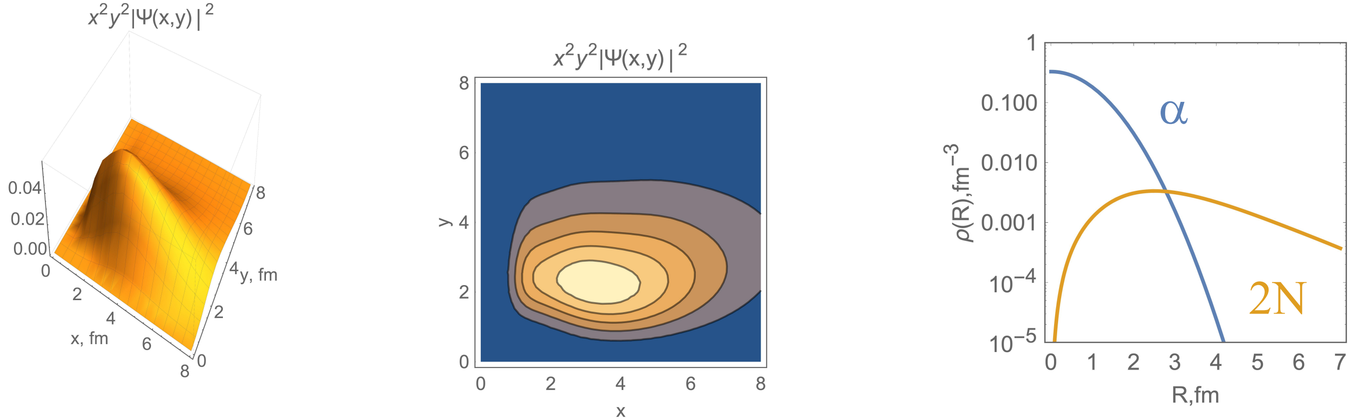


$\langle R^2{}_m \rangle = 2.83$

^{6}He 2^+

$E_{exp} = 0.825$ MeV

$E_{thr} = 1.842$ MeV

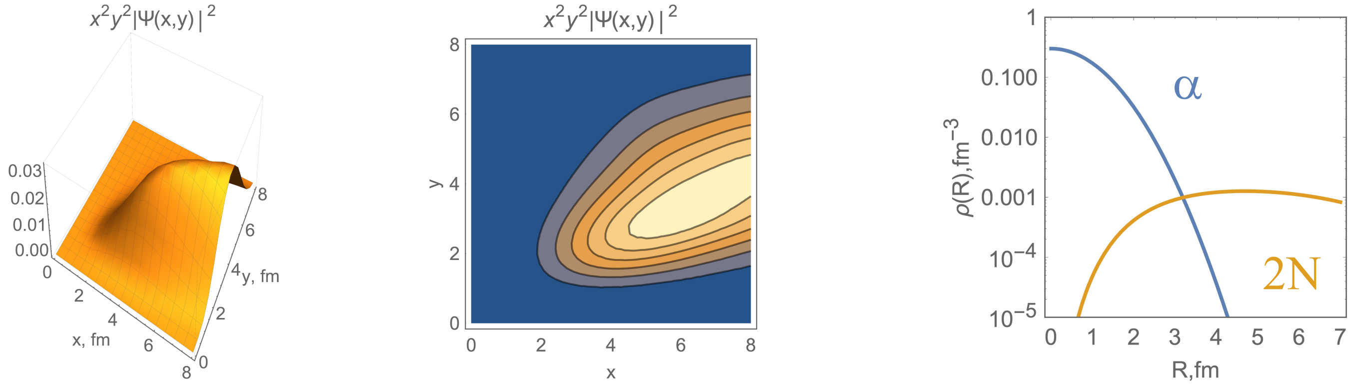


$\langle R^2{}_m \rangle = 3.13$

^{6}He 1^+

$E_{exp} = 4.0$ MeV

$E_{thr} = 3.947$ MeV



$\langle R^2{}_m \rangle = 3.70$

^{6}Li 1^{+}

$E_{exp} = -3.700$ MeV

$E_{thr} = -3.258$ MeV

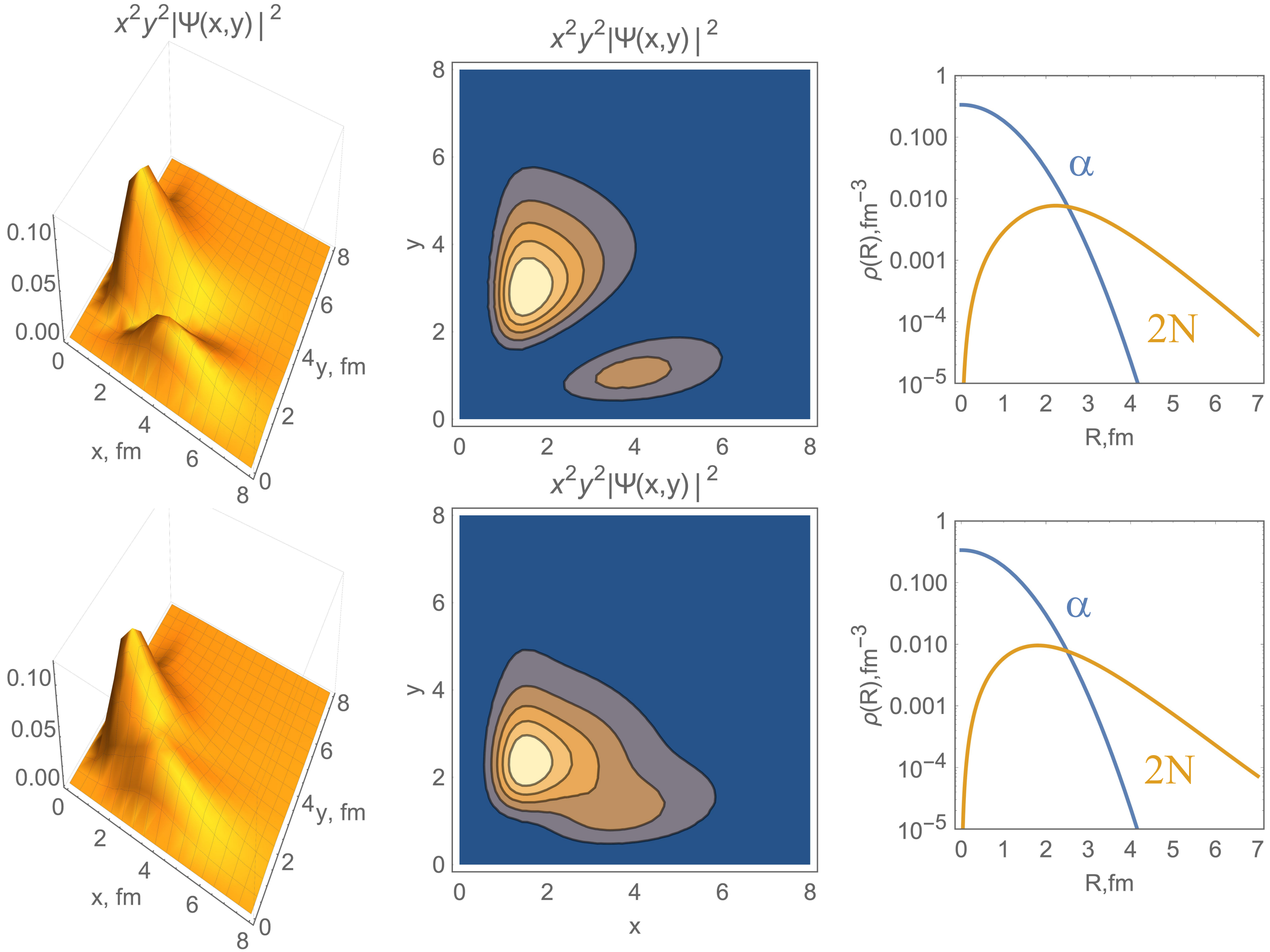
$\langle R^2{}_m \rangle = 2.52$

^{6}Li 3^{+}

$E_{exp} = -1.514$ MeV

$E_{thr} = -1.714$ MeV

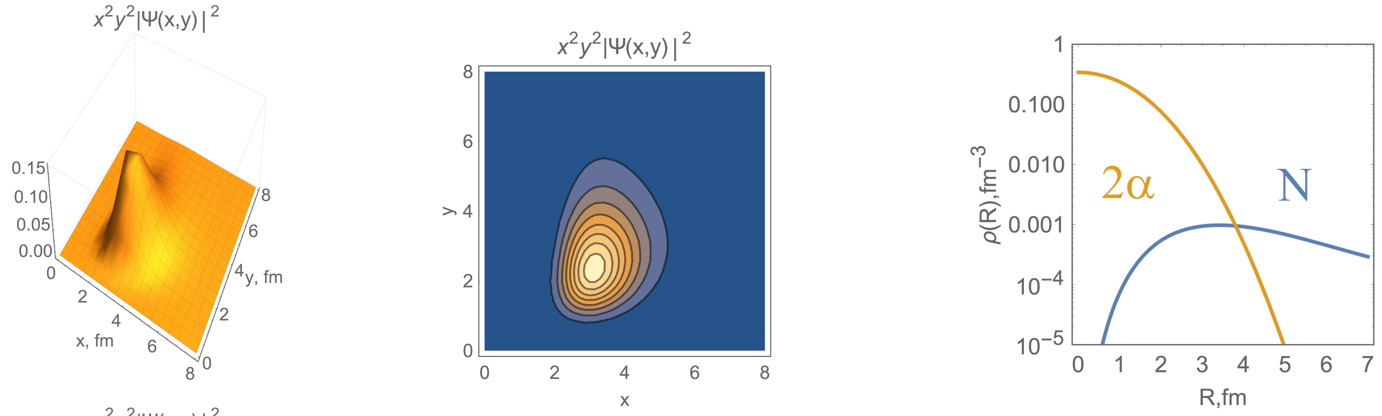
$\langle R^2{}_m \rangle = 2.48$



^{9}Be $3/2^-$

E_{exp} = -1.57 MeV

E_{thr} = -1.417 MeV

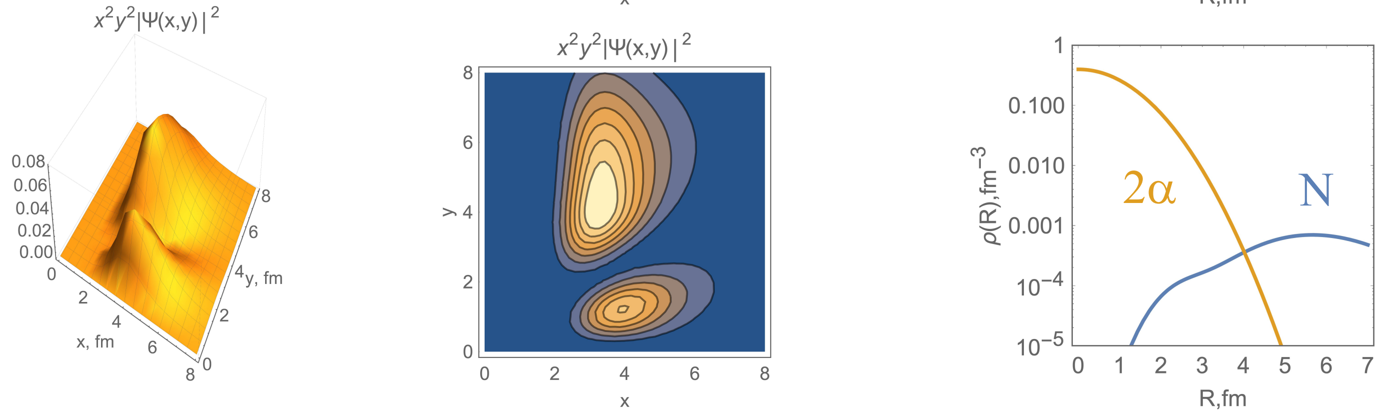


$\langle R^2{}_m \rangle = 2.59$

^{9}Be $1/2^+$

E_{exp} = 0.11 MeV

E_{thr} = 0.874 MeV

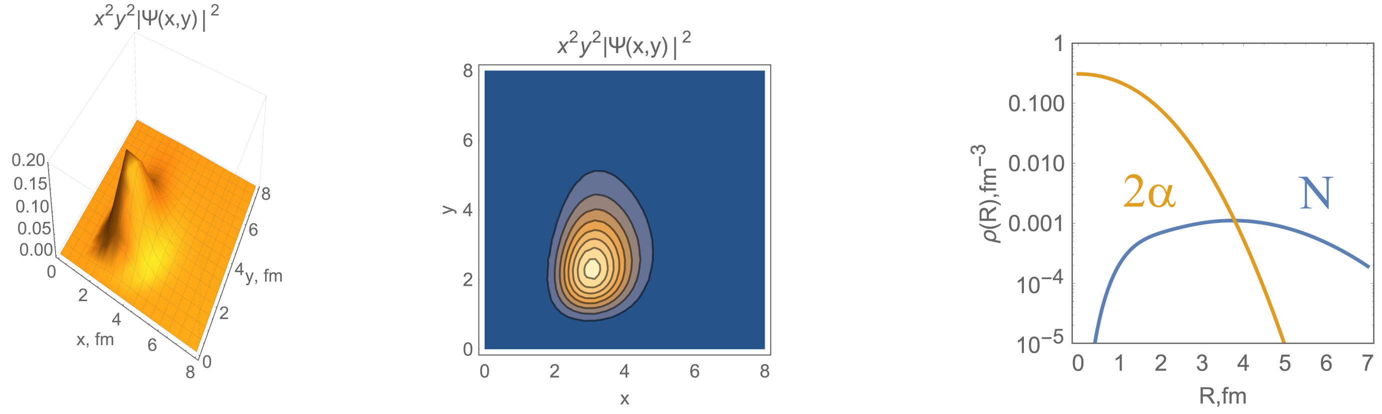


$\langle R^2{}_m \rangle = 2.71$

^{9}Be $5/2^-$

E_{exp} = 0.86 MeV

E_{thr} = 0.696 MeV



$\langle R^2{}_m \rangle = 2.53$

CONCLUSIONS

CONCLUTIONS

- The three body model for the ^{6}He, ^{6}Li and ^{9}Be nuclei has been introduced
- Analytical expressions of the density distribution function of nuclear matter were deduced for the three body system
- Obtained expressions were applied for the ^{6}He, ^{6}Li and ^{9}Be nuclei including ground and low lying excited states
- Demonstrated the structures of nuclei in terms of nuclear matter
- Taken results may be used for the coupling potentials in the Coupled Reaction Channels calculations

THANK YOU FOR YOUR ATTENTION