NEUTRONS IN LIGHT NUCLEI AND NEUTRON TRANSFER IN REACTIONS WITH LIGHT NUCLEI

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Role of neutron transfer in dynamics of nucleus-nucleus collisions

- Leads to the transfer channels (stripping, pickup, multi-nucleon transfer)

- Leads to change in the potential energy of nuclei which
  - changes the cross-section of individual channels (e.g., fusion) and the total reaction cross section compared to the model of nuclei with "frozen" neutrons, which is important in the calculation of the cross sections;
  - may justify the use of phenomenological potentials depending on the energy and the orbital momentum within the optical model (OM), the distorted wave Born approximation (DWBA), etc.

All this attracts interest to neutron transfer processes from both experimentalists and theoreticians

Experimental data for reactions
^{6}He+^{45}Sc and ^{6}He+^{197}Au

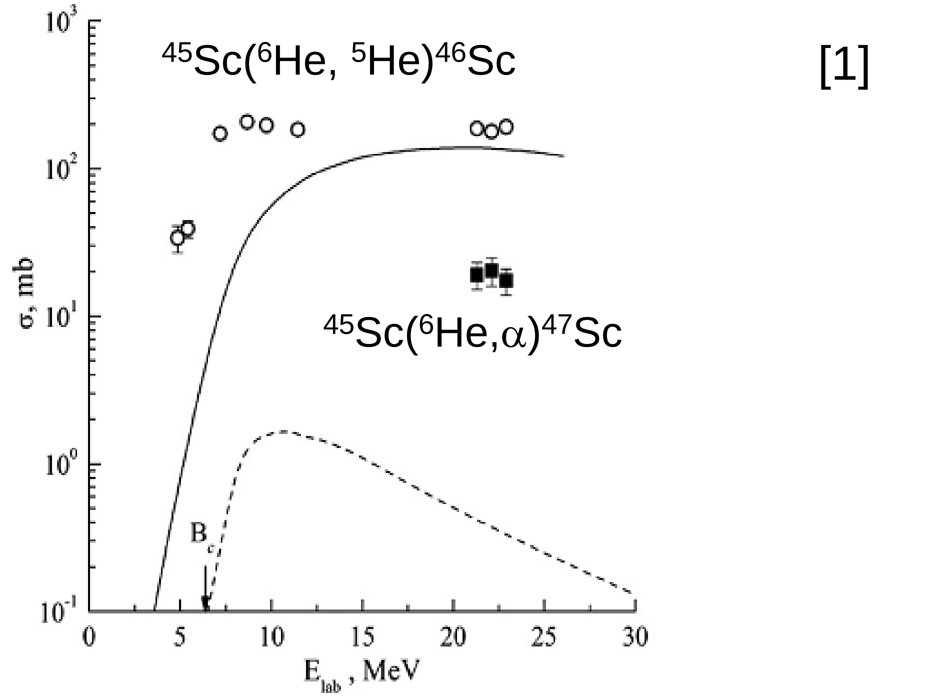


Figure 3. Experimental excitation functions for the ^{45}Sc(^{6}He,^{5}He)^{46}Sc (open circles) and ^{45}Sc(^{6}He,α)^{47}Sc (full squares) reactions. Calculations of the production cross sections for ^{46}Sc (solid line) and ^{47}Sc (dashed line) performed using the codes EMPIRE 2.18 are also shown.

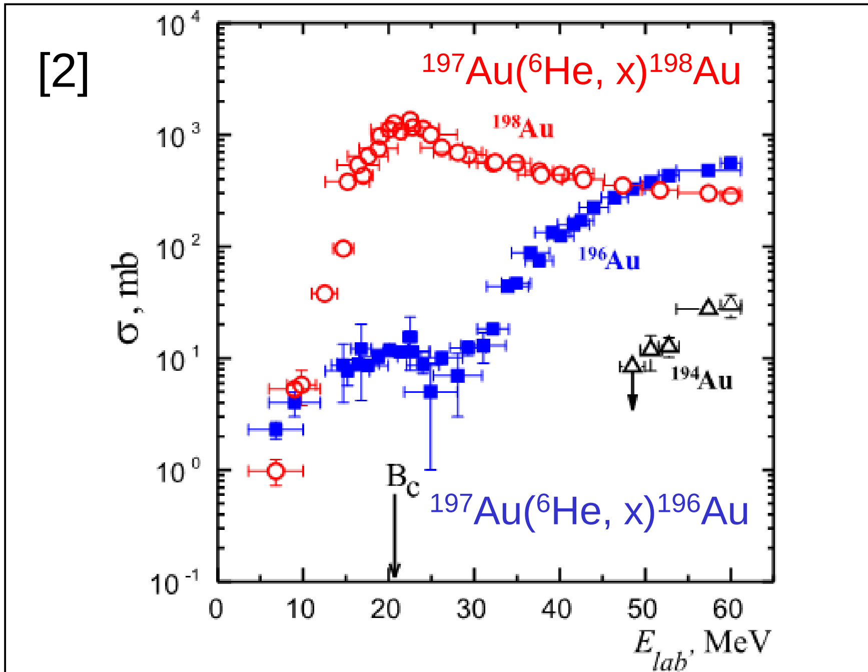


Fig. 9. (Colour online) Experimental excitation functions for the formation of the isotopes: ^{194}Au, triangles; ^{196}Au, squares and ^{198}Au, circles in the ^{197}Au + ^{6}He reaction. B_c is the Coulomb barrier.

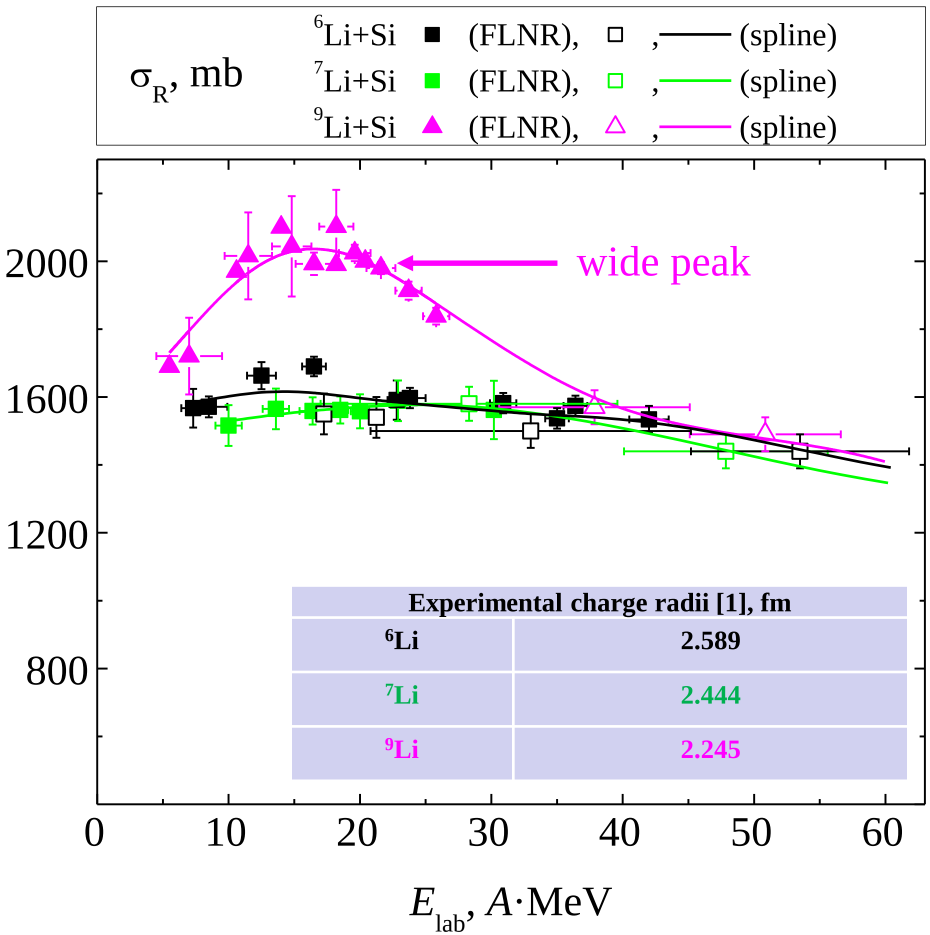
Transfer + Fusion-Evaporation

Transfer to Au and to metastable states and resonances of ^{7}He

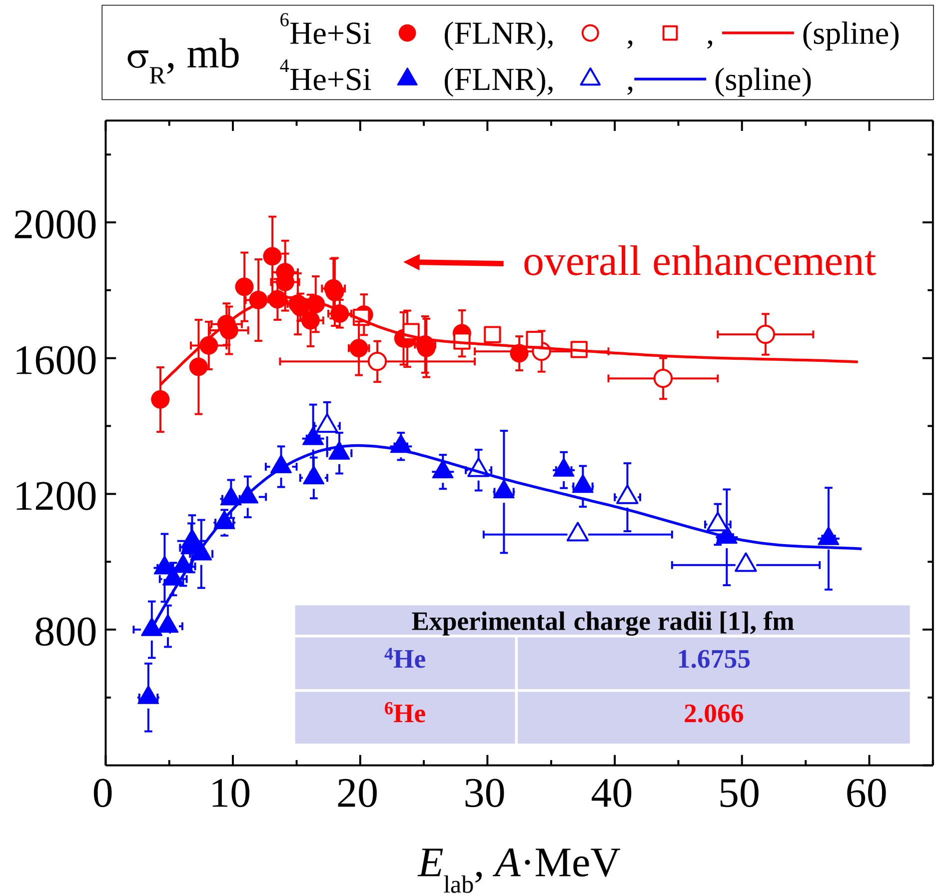
These experimental data have been analyzed in this work

[1] N. K. Skobelev, A. A. Kulko, V. Kroha et al. J. Phys. G: Nucl. Part. Phys. 2011. V. 38. P. 035106.
[2] Yu. E. Penionzhkevich, R. A. Astabatyan, N. A. Demekhina et al. Eur. Phys. J. A. 2007. V. 31. P. 185.

Peculiarities of total reaction cross sections for $^{9}Li + ^{28}Si$ and $^{6}He + ^{28}Si$ compared with $^{6,7}Li + ^{28}Si$ and $^{4}He + ^{28}Si$



Experimental charge radii [1], fm	
^{6}Li	2.589
^{7}Li	2.444
^{9}Li	2.245



Experimental charge radii [1], fm	
^{4}He	1.6755
^{6}He	2.066

These effects were explained in Ref. [2] based on energy-dependent neutron rearrangement during collision

[1] NRV web knowledge base on low-energy nuclear physics. URL: http://nrv.jinr.ru/

[2] Yu. E. Penionzhkevich, Yu. G. Sobolev, V. V. Samarin, M. A. Naumenko. Bull. Russ. Acad. Sci. Phys. 2017 (in press).

Experimental data analyzed in the work

- **Formation of isotopes:**
  - **$^{44,46}Sc$ in reaction ^{3}He + ^{45}Sc,**
  - **$^{196,198}Au$ in reaction ^{3}He + ^{197}Au,**
  - **^{46}Sc in reaction ^{6}He + ^{45}Sc,**
  - **^{65}Zn in reaction ^{6}He + ^{64}Zn,**
  - **$^{196,198}Au$ in reaction ^{6}He + ^{197}Au.**

- **Involved channels:**
  - **neutron pickup,**
  - **neutron stripping,**
  - **fusion-evaporation.**

Basics of time-dependent Schrödinger equation (TDSE) model

- Classical motion of centers of nuclear cores

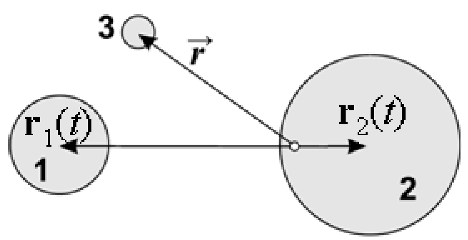
$$m_1\ddot{\vec{r}}_1 = -\nabla_{\vec{r}_1} V_{12}\left(\left|\vec{r}_1 - \vec{r}_2\right|\right),\ m_2\ddot{\vec{r}}_2 = -\nabla_{\vec{r}_2} V_{12}\left(\left|\vec{r}_2 - \vec{r}_1\right|\right).$$

- Transfer of neutrons during collision is described by time-dependent Schrödinger equation with spin-orbit interaction [1]

$$i\hbar\frac{\partial}{\partial t}\Psi(\vec{r},t) = \left\{-\frac{\hbar^2}{2m}\Delta + V_1(\vec{r},t) + V_2(\vec{r},t) + \hat{V}_{LS}^{(1)}(\vec{r},t) + \hat{V}_{LS}^{(2)}(\vec{r},t)\right\}\Psi(\vec{r},t).$$

- The initial wave function is determined from shell model.

How to choose shell model mean field for ^{3}He, ^{6}He?

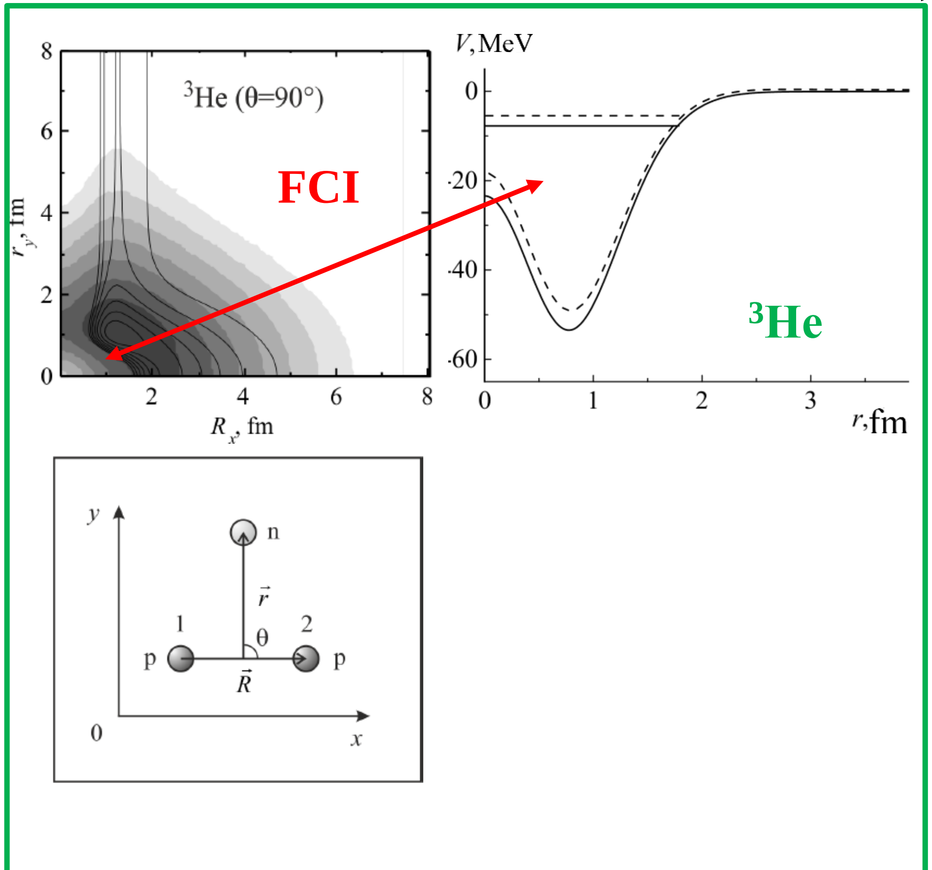


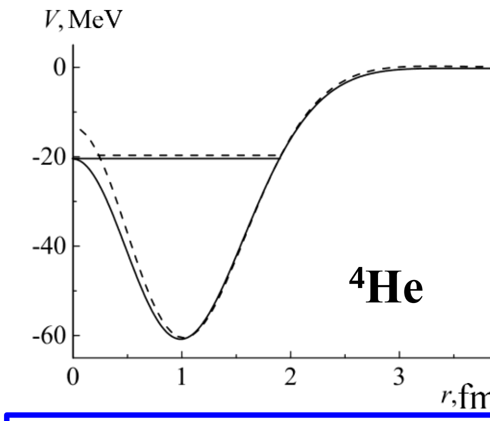
1,2 – two heavy classical particles (nuclear cores);
3 – light quantum particle (neutron of projectile or target).

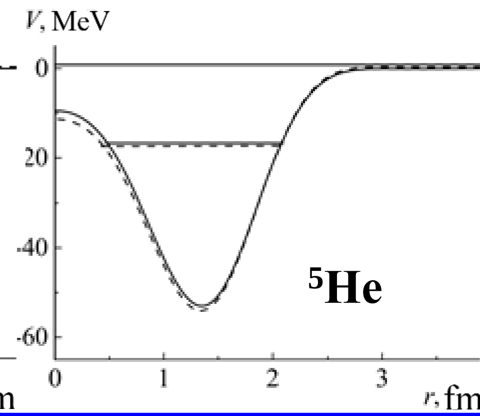
References

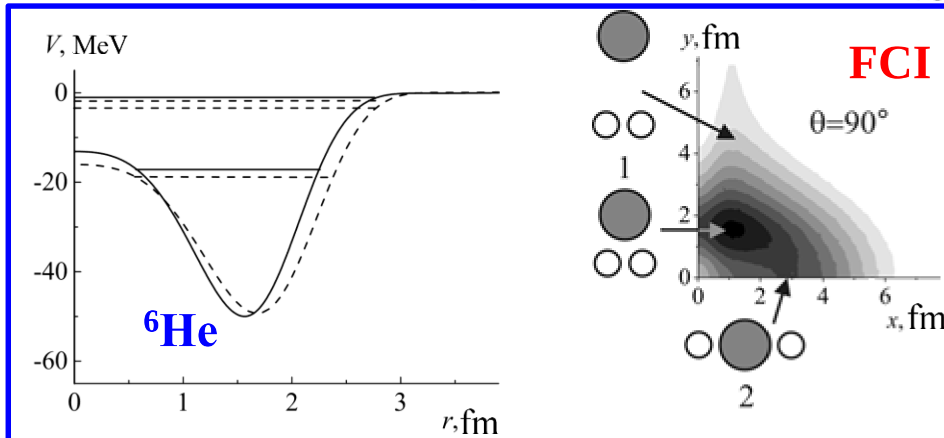
[1] V. V. Samarin, EPJ Web Conf. 66, 03075 (2014); 86, 00040 (2015).
[2] V. I. Zagrebaev, V.V. Samarin, W. Greiner. Phys. Rev. C 75, 035809 (2007).
[3] V. V. Samarin. Phys. At. Nucl. 78,128 (2015).
[4] M. A. Naumenko, V. V. Samarin, Yu. E. Penionzhkevich, N. K. Skobelev. Bull. Russ. Acad. Sci. Phys. 80, 264 (2016).
[5] V. V. Samarin. PEPAN, in press (2016).

Results of calculations within shell model for nuclei ^{3}He, ^{4}He, ^{5}He и ^{6}He









Shell model for nuclei ^{3}He, ^{4}He, ^{5}He and ^{6}He: mean field potentials and levels for neutrons (solid lines) and protons (dashed lines).

For He projectiles $V(r) = \sum_{i=1}^{2} U_i \left[1 + \exp\left((r - R_i)/a_i\right)\right]^{-1}$ (sum of 2 Woods-Saxons)

For heavy target nuclei $V(r) = U\left[1 + \exp\left((r - R)/a\right)\right]^{-1}$ (Woods-Saxon)

Parameters of shell model were chosen based on
results of Feynman's continual integrals (FCI) method +
+ experimental data on neutron separation energies.

Feynman's continual integrals (FCI) method

Feynman's continual integral [1] is propagator - probability amplitude for a particle to travel from one point to another in a given time t

$$K(q,t;q_0,0)=\int Dq(t')\exp\left\{\frac{i}{\hbar}S[q(t')]\right\}=\left\langle q\left|\exp\left(-\frac{i}{\hbar}\hat{H}t\right)\right|q_0\right\rangle$$

Euclidean time $t=-i\tau$

$$K_{\mathrm{E}}(q,\tau;q_0,0)=\lim_{\substack{N\to\infty\\ N\Delta\tau=\tau}}\left(\frac{m}{2\pi\hbar\Delta\tau}\right)^{N/2}\int\cdots\int\exp\left\{-\frac{1}{\hbar}\sum_{k=1}^{N}\left[\frac{m(q_k-q_{k-1})^2}{2\Delta\tau}-V(q_k)\Delta\tau\right]\right\}dq_1dq_2\dots dq_{N-1}$$

$$K_E(q,\tau;q,0)\to|\Psi_0(q)|^2\exp\left(-\frac{E_0\tau}{\hbar}\right),\ \tau\to\infty$$

Parallel calculations by Monte Carlo method [3] using NVIDIA CUDA technology were performed on cluster http://hybrilit.jinr.ru

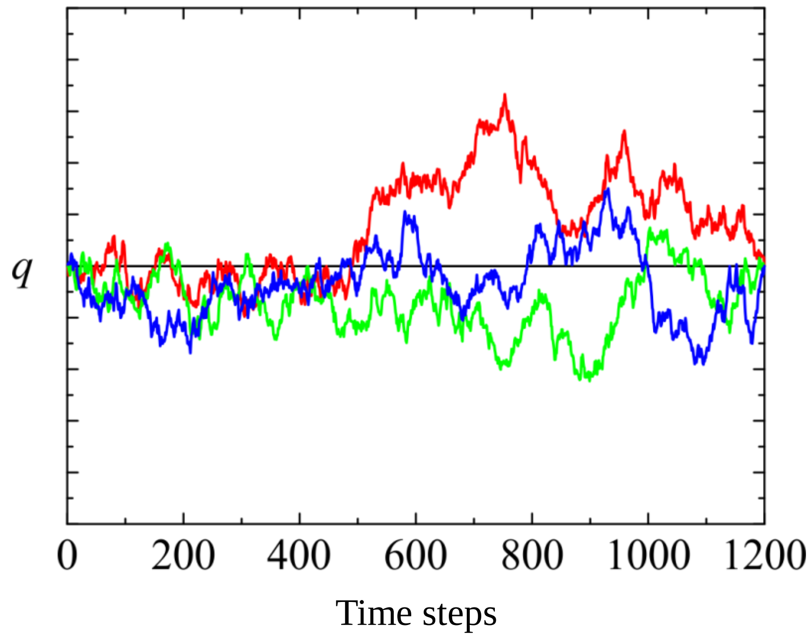
$$K_{\mathrm{E}}(q,\tau;q_0,0)\approx K_{\mathrm{E}}^{(0)}(q,\tau;q_0,0)\left\langle\exp\left[-\frac{\Delta\tau}{\hbar}\sum_{k=1}^{N}V(q_k)\right]\right\rangle_{0,N}$$

averaging over random trajectories with distribution in form of multidimensional Gaussian distribution [4]

$$K_{\mathrm{E}}^{(0)}(q,\tau;q_0,0)=\left(\frac{m}{2\pi\hbar\tau}\right)^{1/2}\exp\left[-\frac{m(q-q_0)^2}{2\hbar\tau}\right]$$

Euclidean propagator of free particle [2]

Example of three random trajectories

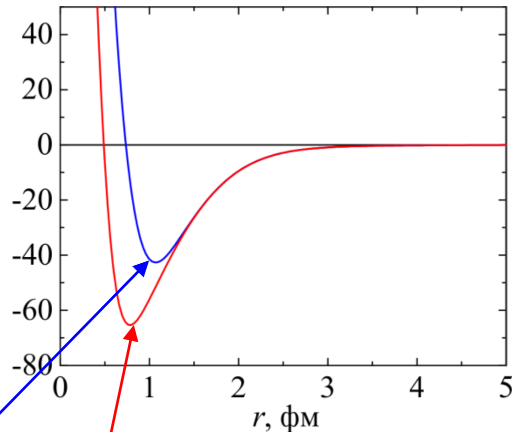


[1] R. P. Feynman, A. R. Hibbs. Quantum Mechanics and Path Integrals. New York, McGraw-Hill, 1965.
[2] D. I. Blokhintsev. Principles of Quantum Mechanics [in Russian]. Moscow, Nauka, 1976.
[3] S. M. Ermakov. Monte Carlo Method in Computational Mathematics [in Russian]. St. Petersburg, Nevskiy Dialekt, 2009.
[4] M. A. Naumenko, V. V. Samarin. Supercomp. Front. Innov. 2016. V. 3. No. 2. P. 80.

Unified set of effective two-body central potentials

Nucleon-nucleon

$V_{p-n}(r),\ V_{n-n}(r) \equiv V_{p-p}^{(\mathrm{N})}(r),$ MeV



$$\boxed{V_{n-n}(r) \equiv V_{p-p}^{(\mathrm{N})}(r) = \sum_{k=1}^{3} u'_k \exp\left(-r^2/b_k'^2\right)}$$

$$\boxed{V_{p-n}(r) = \sum_{k=1}^{3} u_k \exp\left(-r^2/b_k^2\right),}$$

$$V_{p-p}(r) = V_{p-p}^{(\mathrm{N})}(r) + V_{p-p}^{(\mathrm{C})}(r), \qquad V_{p-p}^{(\mathrm{C})}(r) = \frac{e^2}{\sqrt{r^2+\delta^2}},\ \delta = 0.01\ \mathrm{fm}$$

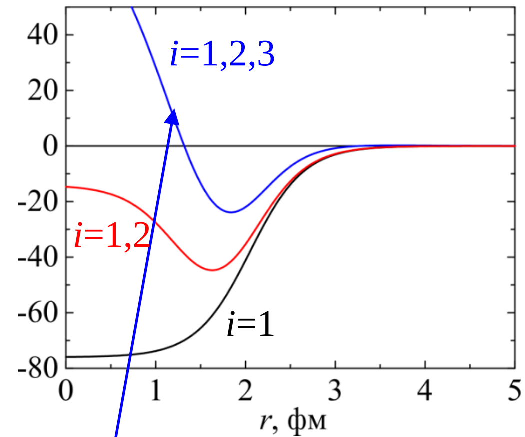
Model parameters

$u'_1 = u_1 = 500,\ u'_2 = u_2 = -102,\ u'_3 = u_3 = -2,$

$b'_1 = 0.53,\ b_1 = 0.37,\ b'_2 = b_2 = 1.26,\ b'_3 = b_3 = 2.67.$

Nucleon-alpha-cluster

$\boxed{V_{n-\alpha}(r) = V_{p-\alpha}^{(\mathrm{N})}(r),\ \text{MeV}}$



$$\boxed{V_{n-\alpha}(r) = V_{p-\alpha}^{(\mathrm{N})}(r) = \sum_{i=1}^{3} U_i \left[1+\exp\left((r-R_i)/a_i\right)\right]^{-1}}$$

$$V_{p-\alpha}(r) = V_{p-\alpha}^{(\mathrm{N})}(r) + V_{p-\alpha}^{(\mathrm{C})}(r)$$

$$V_{p-\alpha}^{(\mathrm{C})}(r) = \begin{cases} \dfrac{2e^2}{2R_\alpha}\left[3-\left(\dfrac{r}{R_\alpha}\right)^2\right], r \le R_\alpha \\ \dfrac{2e^2}{r}, r > R_\alpha \end{cases}$$

R_α = 1.6755 fm;

U_1 = -76 MeV, R_1 = 2.05 fm, a_1 = 0.3 fm;
U_2 = 62 MeV, R_2 = 1.32 fm, a_2 = 0.3 fm;
U_3 = 112 MeV, R_3 = 1 fm, a_3 = 0.5 fm.

Results for ground state of ^{3}He nucleus (p + p + n)

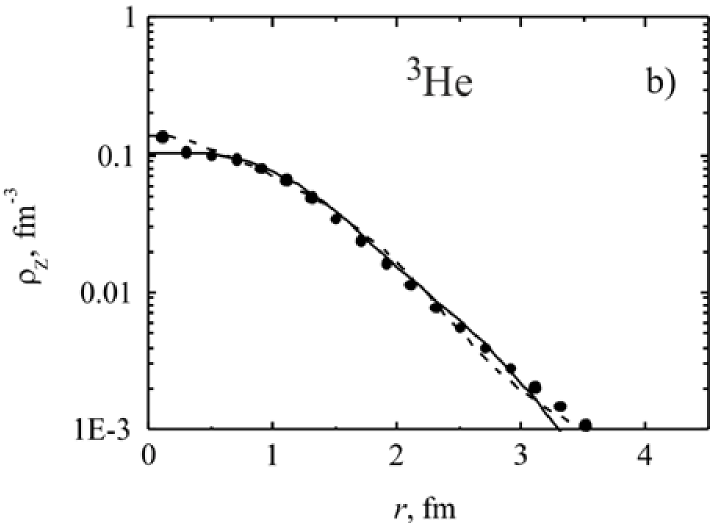
Binding energy, MeV

Theory	Experiment
7.37 ± 0.3	7.718

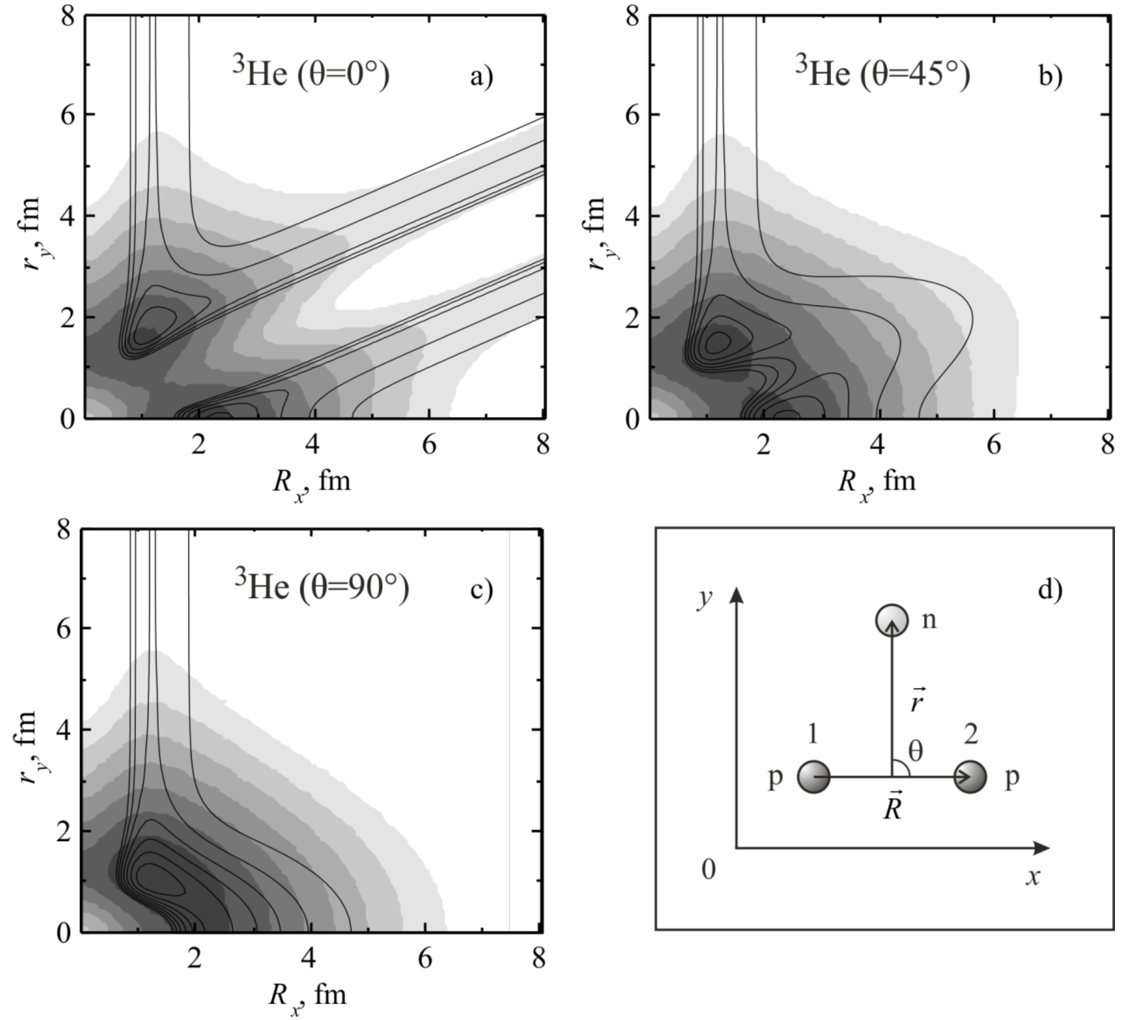
Charge radius, fm

Theory	Experiment
1.94	1.9664

Charge density

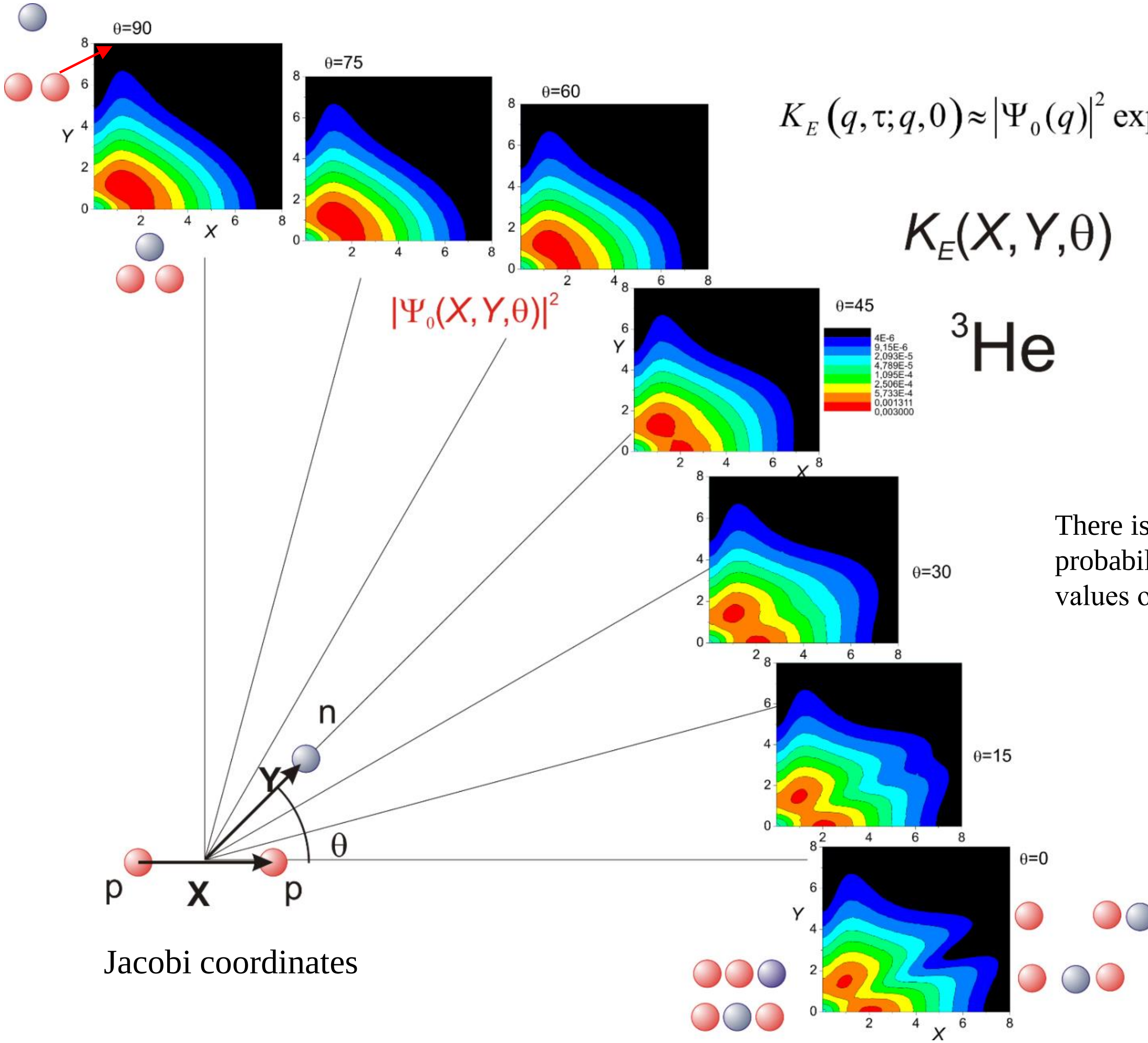


Probability density $|\Psi|^2$ is consistent with potential landscape



Reasonable results and good agreement with experimental data are obtained

Probability density $|\Psi|^2$ for ground state of ^{3}He ($p + p + n$)



$$K_E(q,\tau;q,0) \approx |\Psi_0(q)|^2 \exp\left(-\frac{E_0\tau}{\hbar}\right)$$

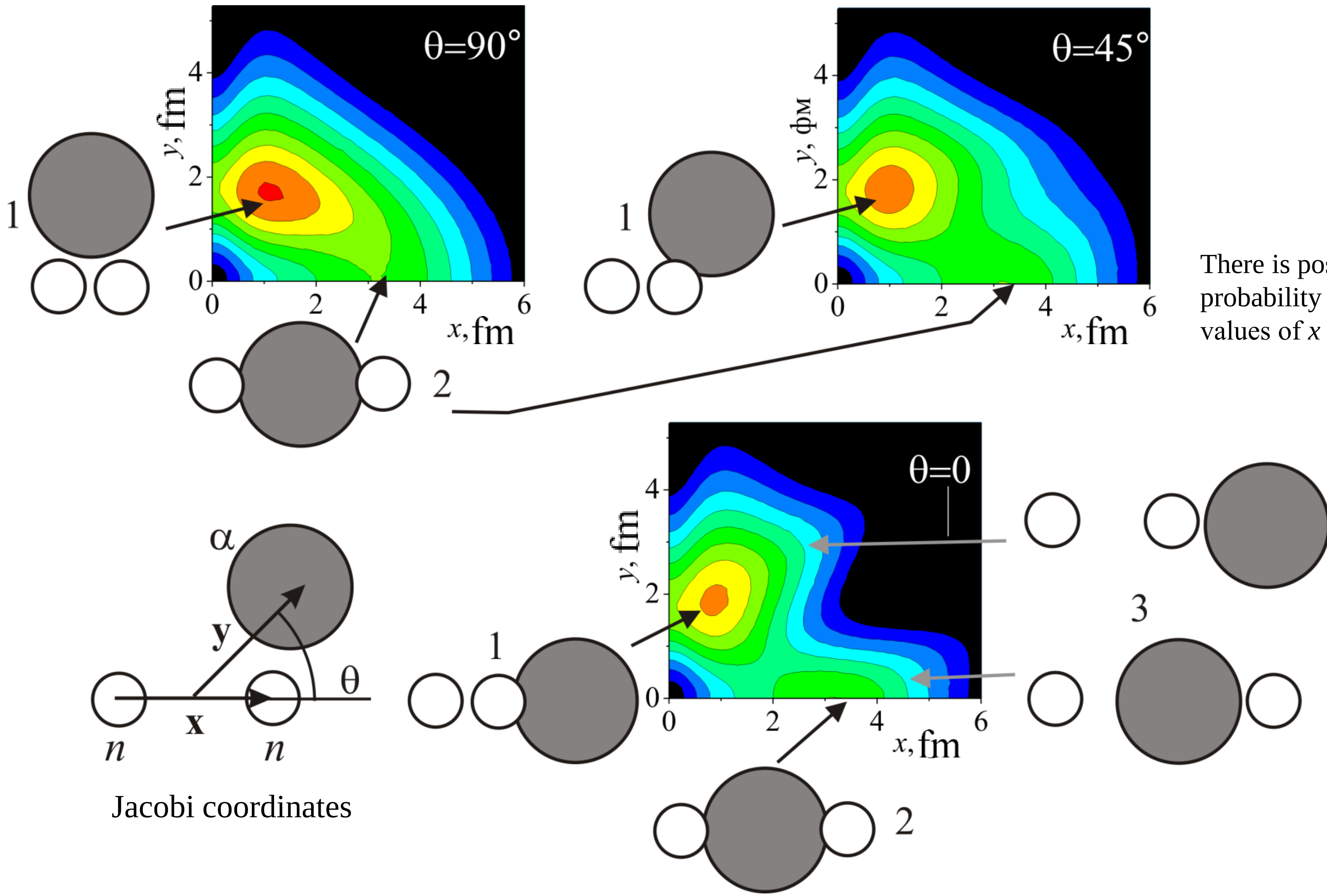
$$K_E(X,Y,\theta)$$

^{3}He

There is possibility of investigating probability density for small values of *x* and *y*

Jacobi coordinates

Probability density $|\Psi|^2$ for ground state of ^{6}He ($\alpha + n + n$)



Jacobi coordinates

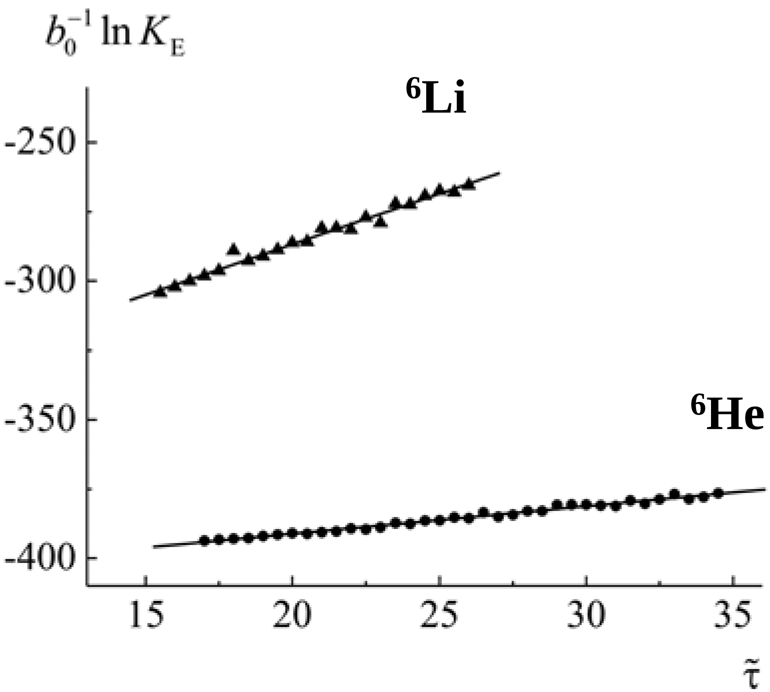
There is possibility of investigating probability density for small values of x and y

Most probable configurations are α-cluster + dineutron (1) and cigar configuration (2).
Configuration n + ^{5}He (3) has low probability.

Results of calculation of binding energies for nuclei ^{2}H, ^{3,4,6}He, ^{6}Li

$$b_0^{-1} \ln K_E\left(q,\tau;q,0\right) \to \ln\left|\Psi_0(q)\right|^2 - \tilde{E}_0\tilde{\tau},\ \tilde{\tau} \to \infty$$

slope coefficient gives ground state energy



Comparison of theoretical and experimental binding energies in unified set of potentials
(*for alpha-cluster nuclei ^{6}He and ^{6}Li energy of separation into alpha particles and nucleons is given).

Atomic nucleus	Theoretical value, MeV	Experimental value [1], MeV
^{2}H	2.22 ± 0.15	2.225
^{3}H	8.21 ± 0.3	8.482
^{3}He	7.37 ± 0.3	7.718
^{4}He	30.60 ± 1.0	28.296
^{6}He*	0.96 ± 0.05	0.97542
^{6}Li*	3.87 ± 0.2	3.637

Good agreement with experimental data

[1] NRV web knowledge base on low-energy nuclear physics. URL: http://nrv.jinr.ru/

TDSE model basics

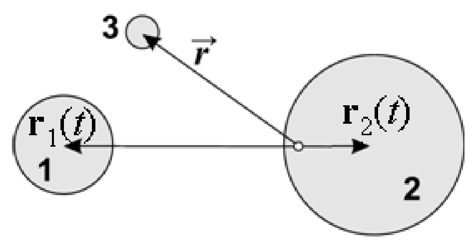
- Classical motion of centers of nuclear cores

$$m_1\ddot{\vec{r}}_1=-\nabla_{\vec{r}_1}V_{12}\left(\left|\vec{r}_1-\vec{r}_2\right|\right),\ m_2\ddot{\vec{r}}_2=-\nabla_{\vec{r}_2}V_{12}\left(\left|\vec{r}_2-\vec{r}_1\right|\right).$$

- Transfer of neutrons during collision is described by time-dependent Schrödinger equation with spin-orbit interaction [1]

$$i\hbar\frac{\partial}{\partial t}\Psi(\vec{r},t)=\left\{-\frac{\hbar^2}{2m}\Delta+V_1(\vec{r},t)+V_2(\vec{r},t)+\hat{V}_{LS}^{(1)}(\vec{r},t)+\hat{V}_{LS}^{(2)}(\vec{r},t)\right\}\Psi(\vec{r},t).$$

- The initial wave function is determined from shell model. Parameters of shell model were chosen based on results of Feynman's continual integrals method for ^{3,6}He + experimental data on charge radii and neutron separation energies.



1,2 – two heavy classical particles (nuclear cores);
3 – light quantum particle (neutron of projectile or target).

References

[1] V. V. Samarin, EPJ Web Conf. 66, 03075 (2014); 86, 00040 (2015).
[2] V. I. Zagrebaev, V.V. Samarin, W. Greiner. Phys. Rev. C 75, 035809 (2007).
[3] V. V. Samarin. Phys. At. Nucl. 78,128 (2015).
[4] M. A. Naumenko, V. V. Samarin, Yu. E. Penionzhkevich, N. K. Skobelev. Bull. Russ. Acad. Sci. Phys. 80, 264 (2016).
[5] V. V. Samarin. PEPAN, in press (2016).

Calculation of probability and cross section for neutron pickup in reaction ^{3}He+ ^{45}Sc

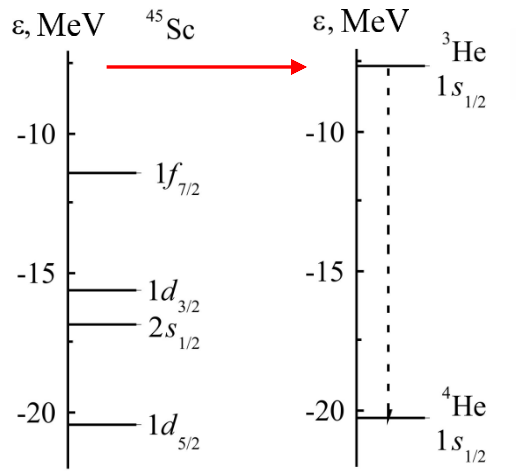
Neutron pickup probability

$$p_1(b,E) = \lim_{t\to\infty} W_1(b,E,t)$$

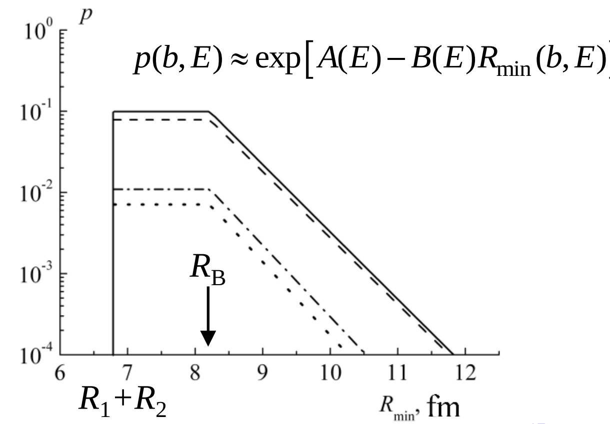
W_1 is integral of probability density in vicinity of projectile nucleus (~3 fm)

Pickup cross section

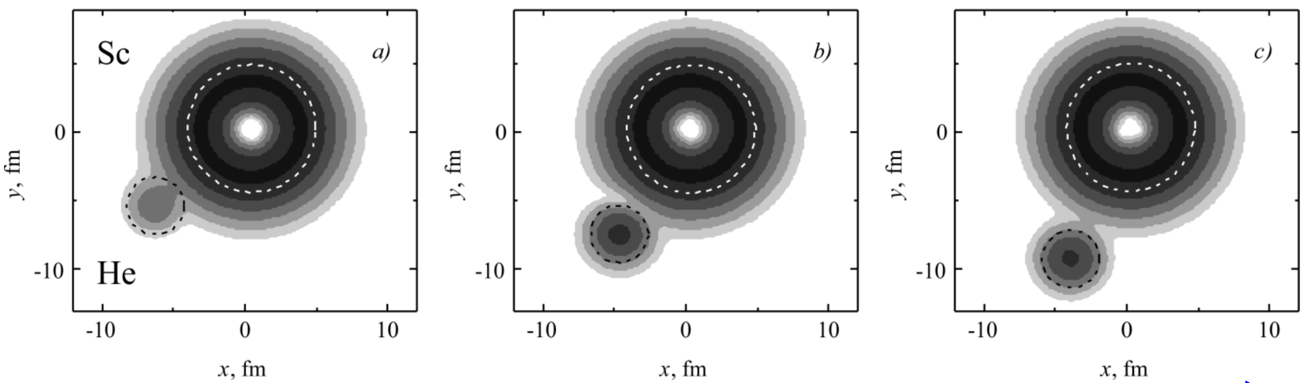
$$\sigma(E) = \int_0^\infty p_1(b,E)\,b\,db$$



Scheme of neutron levels of nuclei ^{45}Sc and ^{3}He in model of pickup reaction.



Total pickup probability for neutron from nucleus ^{45}Sc (solid line) and pickup probabilities from states $1f_{7/2}$ (dashed line), 3*s* (dash-dotted line) and $1d_{3/2}$ (dotted line) at energy E_{cm} = 15 MeV.



time

Example of evolution of probability density for external neutron $1f_{7/2}$ of nucleus ^{45}Sc in collision with ^{3}He, E_{cm} = 8 MeV, impact parameter b = 7 fm.

^{3}He including only 1 neutron in field of heavier core, makes it possible to study transfer process in simplest case

Calculation of probability and cross section for neutron stripping in reaction $^3He + {}^{45}Sc$

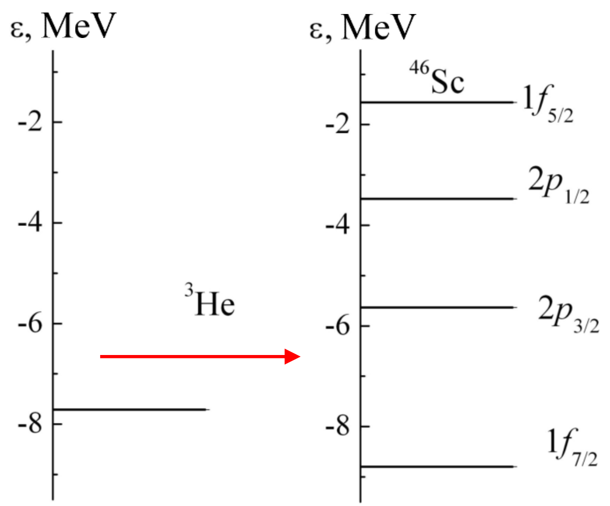
Neutron stripping probability

$$\bar{p}_2(b,E) = \lim_{t\to\infty} \sum_k |a_k(t)|^2$$

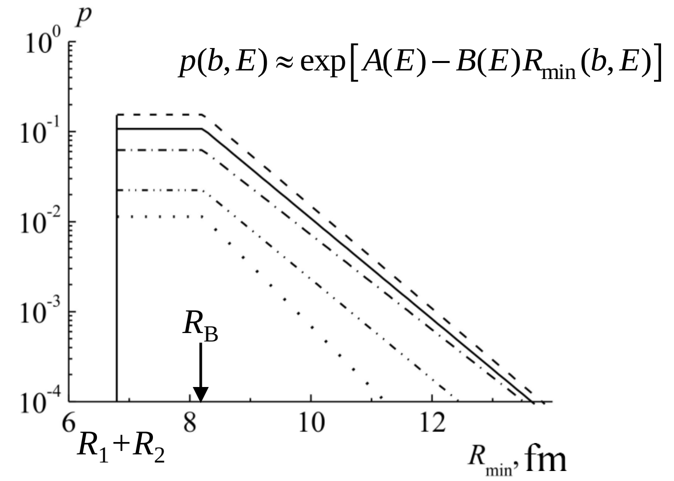
a_κ are occupations of initially free levels (above Fermi level) in target (integral would include occupations of all levels)

Stripping cross section

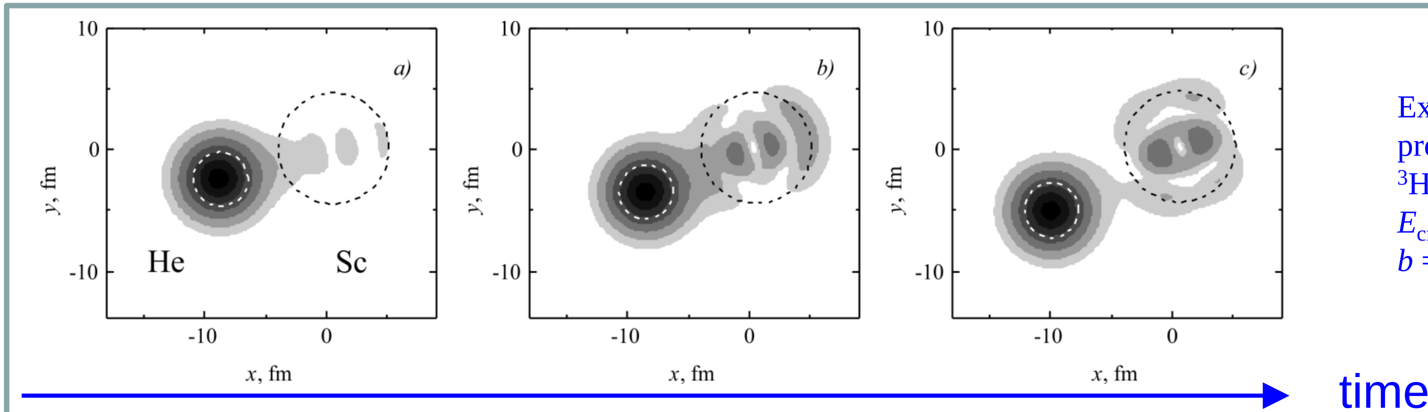
$$\sigma(E) = \int_0^\infty \bar{p}_2(b,E)\, b\, db$$



Scheme of neutron levels of nuclei ^3He and ^{46}Sc in model of stripping reaction.



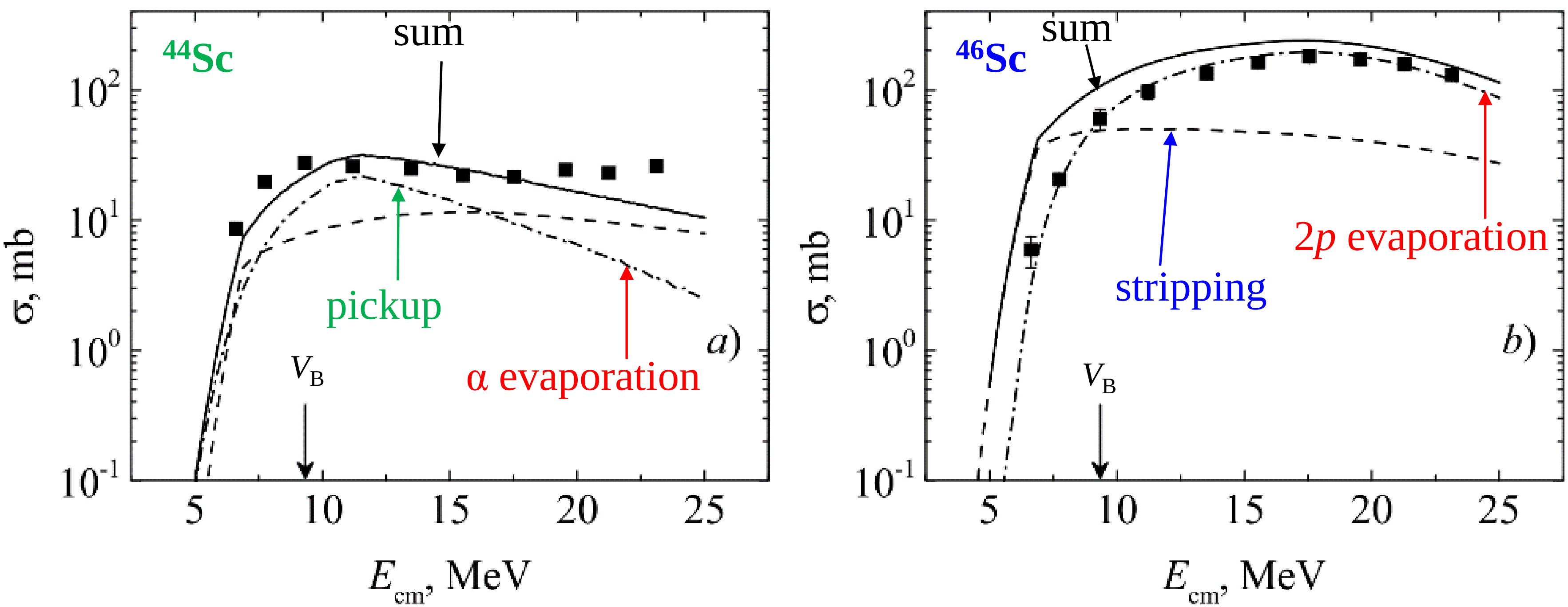
Neutron stripping probability to states $2p_{3/2}$ and $2p_{1/2}$ (dash-dotted), $1f_{5/2}$ (dash-dot-dotted), $1f_{7/2}$ (dotted) at energy E_{cm} = 15 MeV.



Example of evolution of probability density for neutron of ^3He nucleus in collision with ^{45}Sc, E_{cm} = 6.5 MeV, impact parameter b = 1.5 fm.

^3He including only 1 neutron in field of heavier core, makes it possible to study transfer process in simplest case

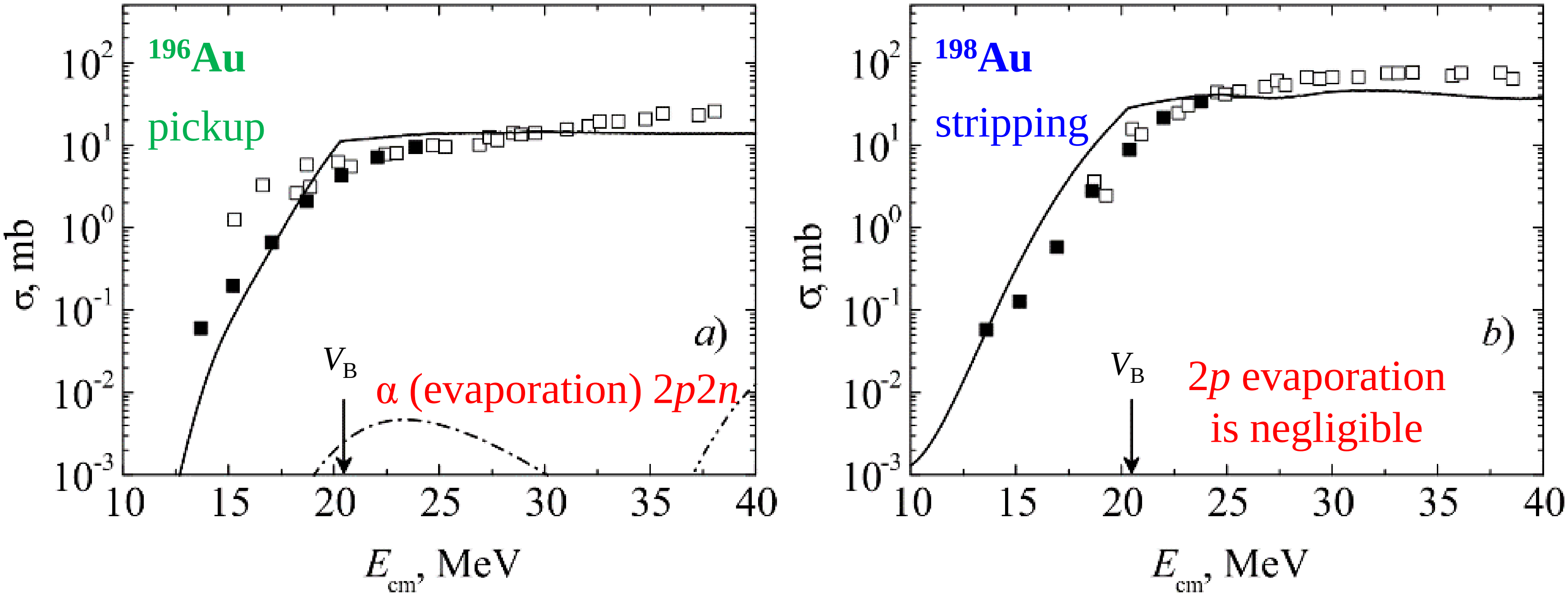
Calculation of cross sections for formation of isotopes ^{44}Sc and ^{46}Sc in reaction $^{3}He + ^{45}Sc$



Good agreement with experimental data.
Contribution of fusion-evaporation is high.

[1] (Experiment) N. K. Skobelev, A. A. Kulko, Yu. E. Penionzhkevich et al. Phys. Part. Nucl. Lett. 2013. V. 10. P. 410.
[2] (Evaporation code) NRV web knowledge base on low-energy nuclear physics. URL: http://nrv.jinr.ru/

Calculation of cross sections for formation of isotopes ^{196}Au and ^{198}Au in reaction ^{3}He + ^{197}Au



Good agreement with experimental data.
Contribution of fusion-evaporation is negligible.

[1] (Experiment ■) N. K. Skobelev, Yu. E. Penionzhkevich, E. I. Voskoboynik et al. Phys. Part. Nucl. Lett. 2014. V. 11. P. 114.
[2] (Experiment □) Y. Nagame, K. Sueki, S. Baba, and H. Nakahara. Phys. Rev. C. 1990. V. 41. P. 889.
[3] (Evaporation code) NRV web knowledge base on low-energy nuclear physics. URL: http://nrv.jinr.ru/

Calculation of probability and cross section for neutron stripping in reaction $^{6}He + {}^{197}Au$

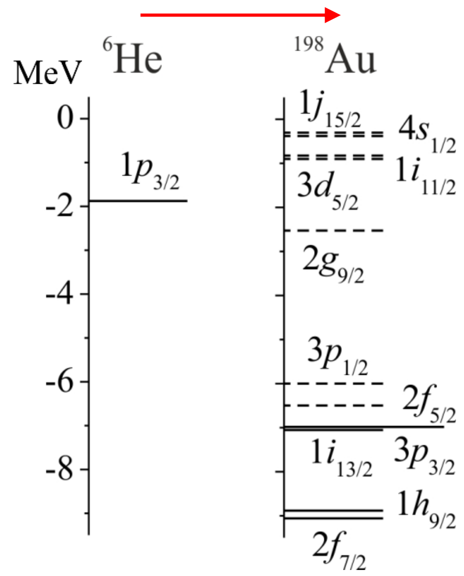
Neutron stripping probability

$$\bar{p}_2(b,E) = \lim_{t\to\infty} \sum_k |a_k(t)|^2$$

a_κ are occupations of initially free levels (above Fermi level) in target (integral would include occupations of all levels)

Stripping cross section

$$\sigma(E) = \int_0^\infty \bar{p}_2(b,E)\, b\, db$$

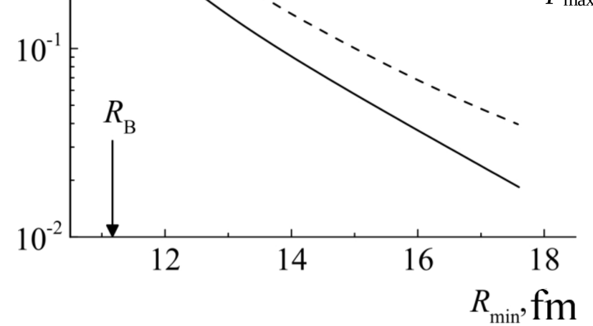


Scheme of neutron levels of nuclei ^{6}He and ^{198}Au in model of stripping reaction.

$$p(b,E) \approx \sum_{i=1}^{2} \exp\left[A_i(E) - B_i(E) R_{\min}(b,E)\right]$$

$$\bar{p}(b,E) = \min\left\{p(b,E),\, p_{\max}\right\}$$

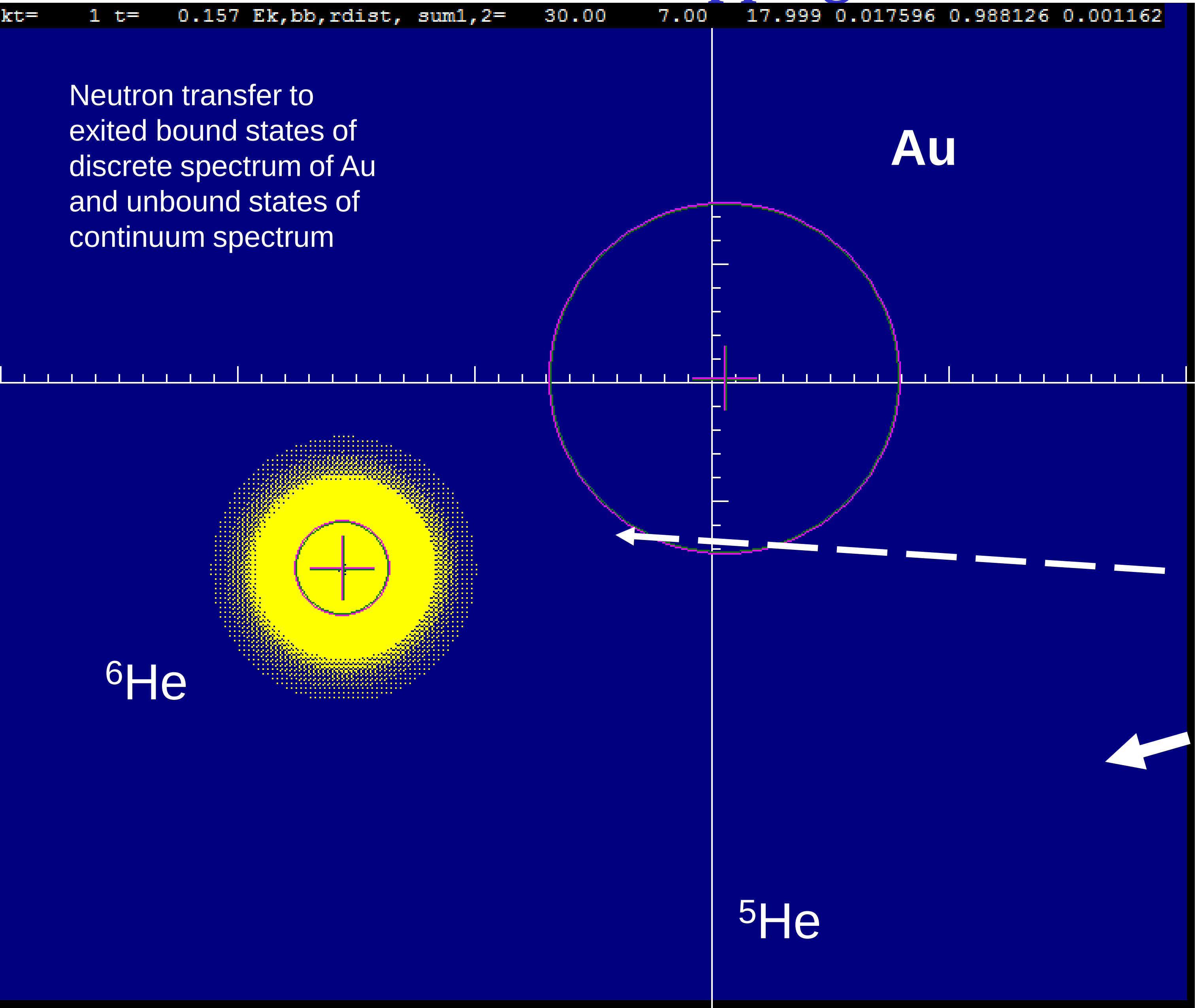
$$p_{\max} \approx 0.3$$



Dependence of neutron stripping probability on distance of minimum approach R_{min} for neutron transfer from ^{6}He to ^{197}Au (E_{cm} = 19 MeV and 25 MeV, dashed and solid curves, respectively).

^{6}He (2 neutrons, halo) is more complicated case compared with ^{3}He

Evolution of neutron probability density for collision $^{6}He + ^{197}Au$: neutron stripping from ^{6}He and breakup



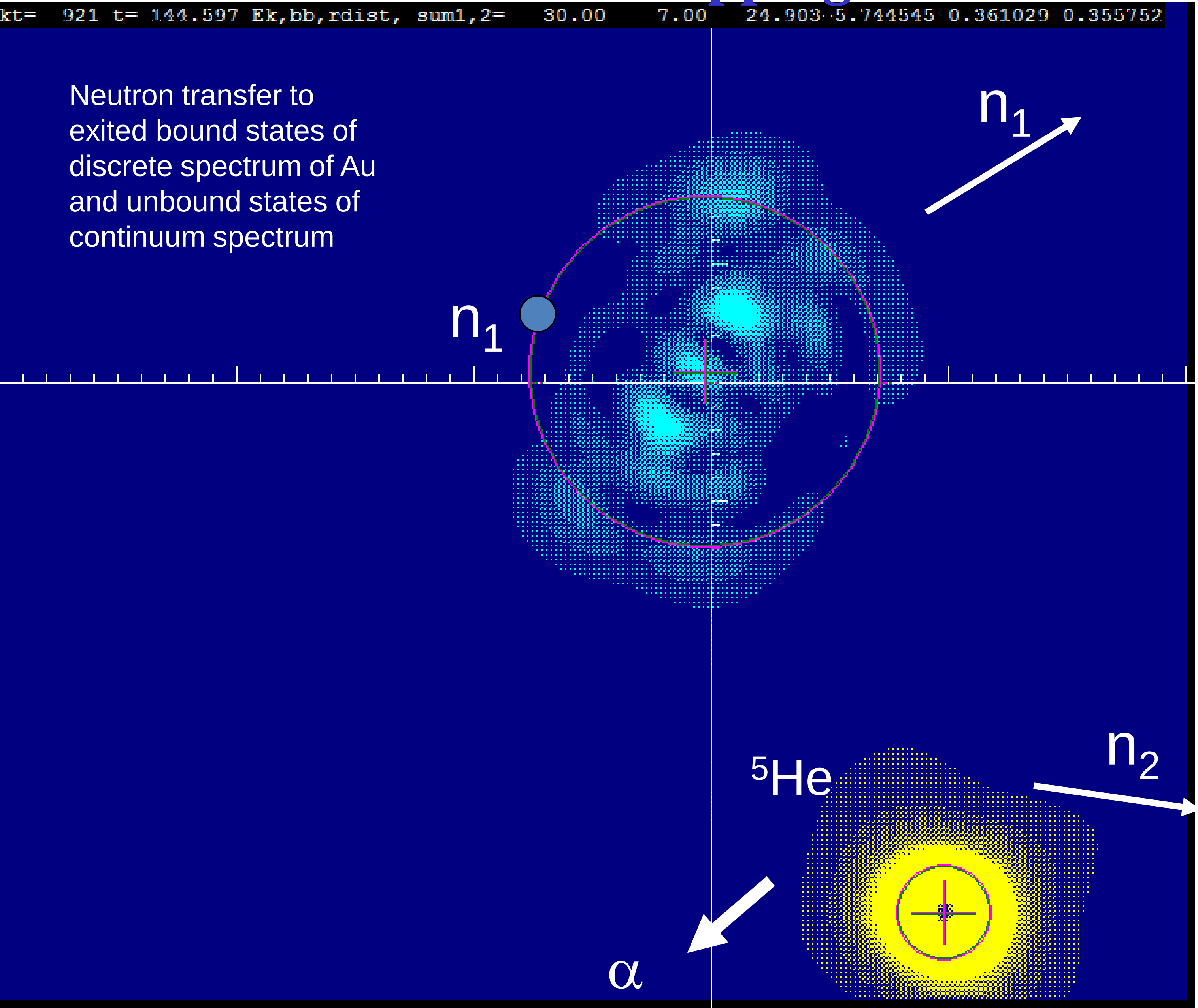
Evolution of probability density for valence neutron of ^{6}He in collision $^{6}He + ^{197}Au$ in model with $E(1p_{3/2}) = -E_{sep}(1n) = -1.8$ MeV, $E_{cm} = 30$ MeV $> V_B$.

Potential well of ^{6}He is transformed into well of ^{5}He after neutron transfer from He to Au.

Breakup of ^{5}He after neutron transfer to Au.

^{6}He (2 neutrons, halo) is more complicated case compared with ^{3}He

Evolution of neutron probability density for collision $^{6}He + ^{197}Au$: neutron **stripping** from ^{6}He and breakup



Evolution of probability density for valence neutron of ^{6}He in collision $^{6}He + ^{197}Au$ in model with $E(1p_{3/2}) = -E_{sep}(1n) =$ $= -1.8$ MeV, $E_{cm} = 30$ MeV $> V_B$.

Potential well of ^{6}He is transformed into well of ^{5}He after neutron transfer from He to Au.

Breakup of ^{5}He after neutron transfer to Au.

^{6}He (2 neutrons, halo) is more complicated case compared with ^{3}He

Calculation of probability and cross section for neutron pickup to metastable states and resonances in reaction ^{6}He + ^{197}Au

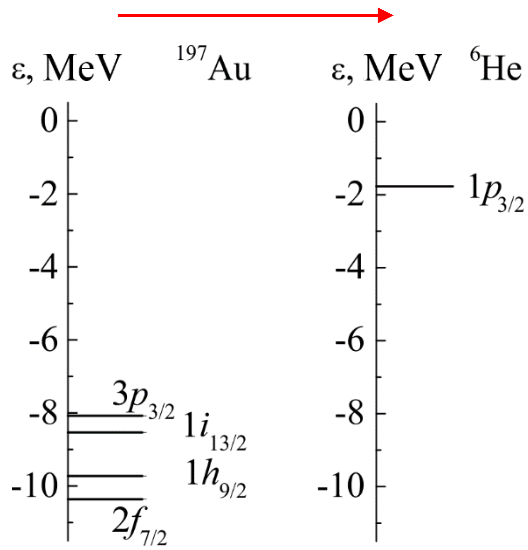
Neutron pickup probability

$$p_1(b,E)=\lim_{t\to\infty}W_1(b,E,t)$$

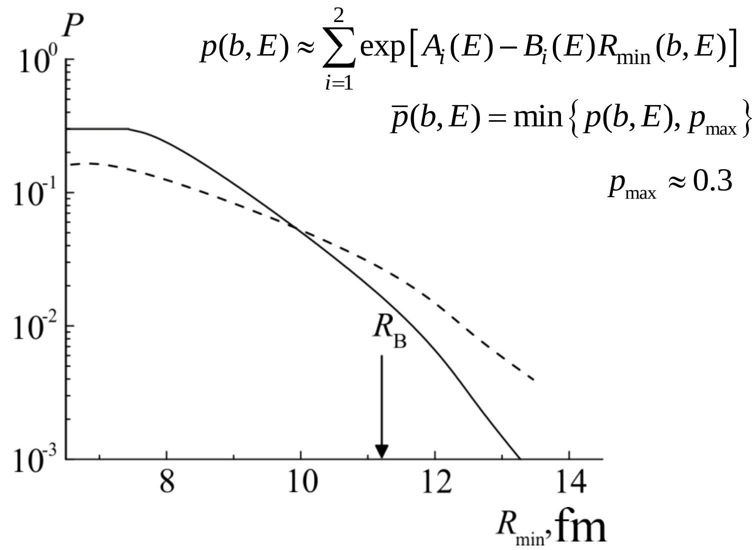
W_1 is integral of probability density in vicinity of projectile nucleus (~6 fm)

Pickup cross section

$$\sigma(E)=\int_0^\infty p_1(b,E)\,b\,db$$



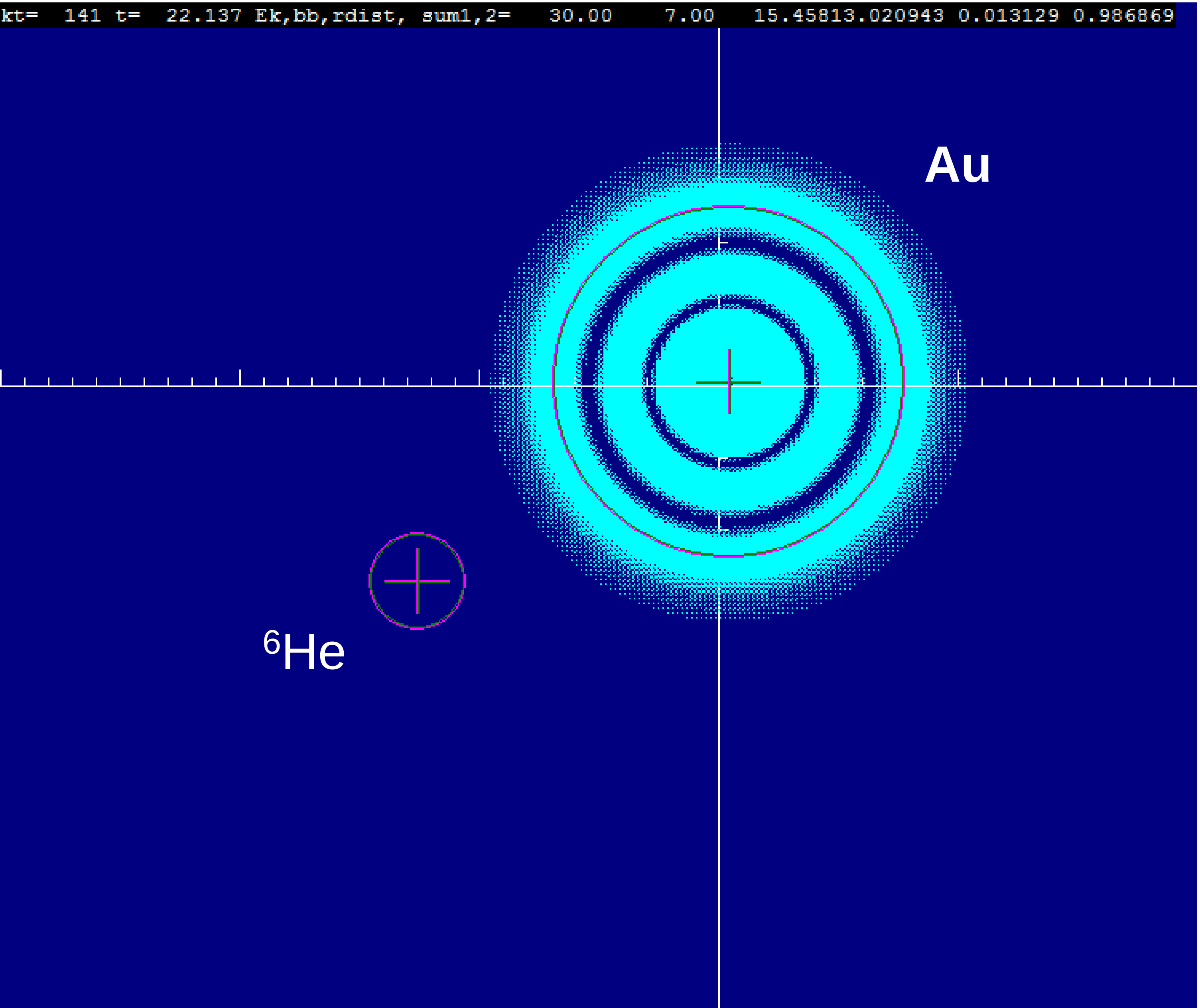
Scheme of neutron levels of nuclei ^{197}Au and ^{6}He in model of pickup reaction.



Dependence of neutron pickup probability on distance of minimum approach R_{min} for neutron transfer from ^{197}Au to ^{6}He (E_{cm} = 50 MeV, from level $3p_{3/2}$ and internal levels {$1j_{13/2}$, $1h_{9/2}$, $2f_{7/2}$}, solid and dashed curves, respectively).

^{6}He (2 neutrons, halo) is more complicated case compared with ^{3}He

Calculation of probability and cross section for neutron pickup to metastable states and resonances in reaction ^{6}He + ^{197}Au

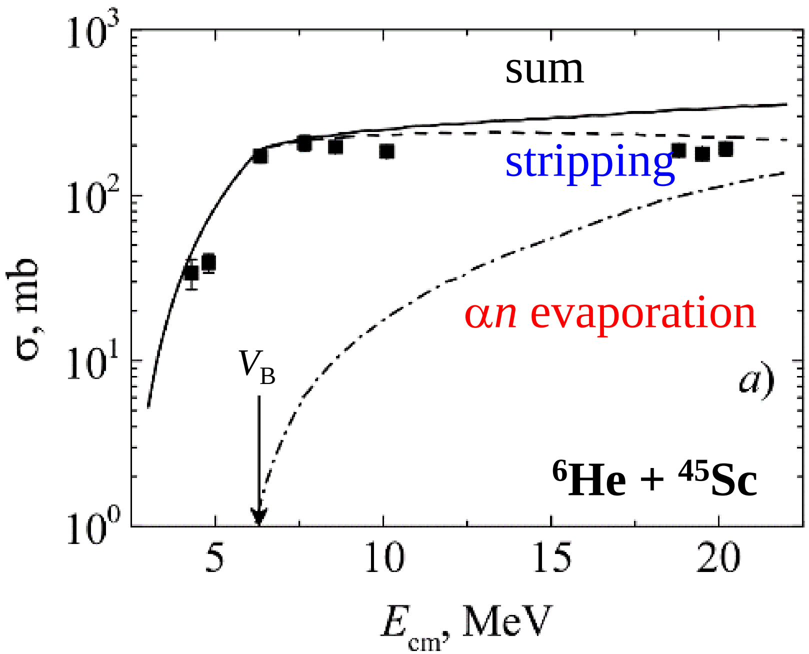


Evolution of probability density for neutron of ^{197}Au from level $3p_{3/2}$ in collision ^{6}He + ^{197}Au at E_{cm} = 30 MeV > V_B.

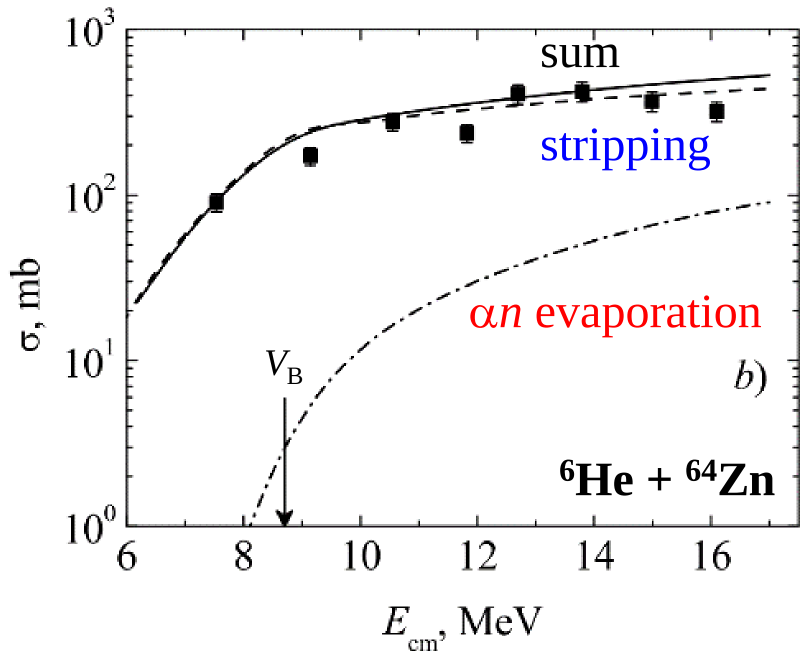
^{6}He (2 neutrons, halo) is more complicated case compared with ^{3}He

Calculation of cross sections for formation of isotopes ^{46}Sc in reaction ^{6}He + ^{45}Sc and ^{65}Zn in reaction ^{6}He + ^{64}Zn

[1]



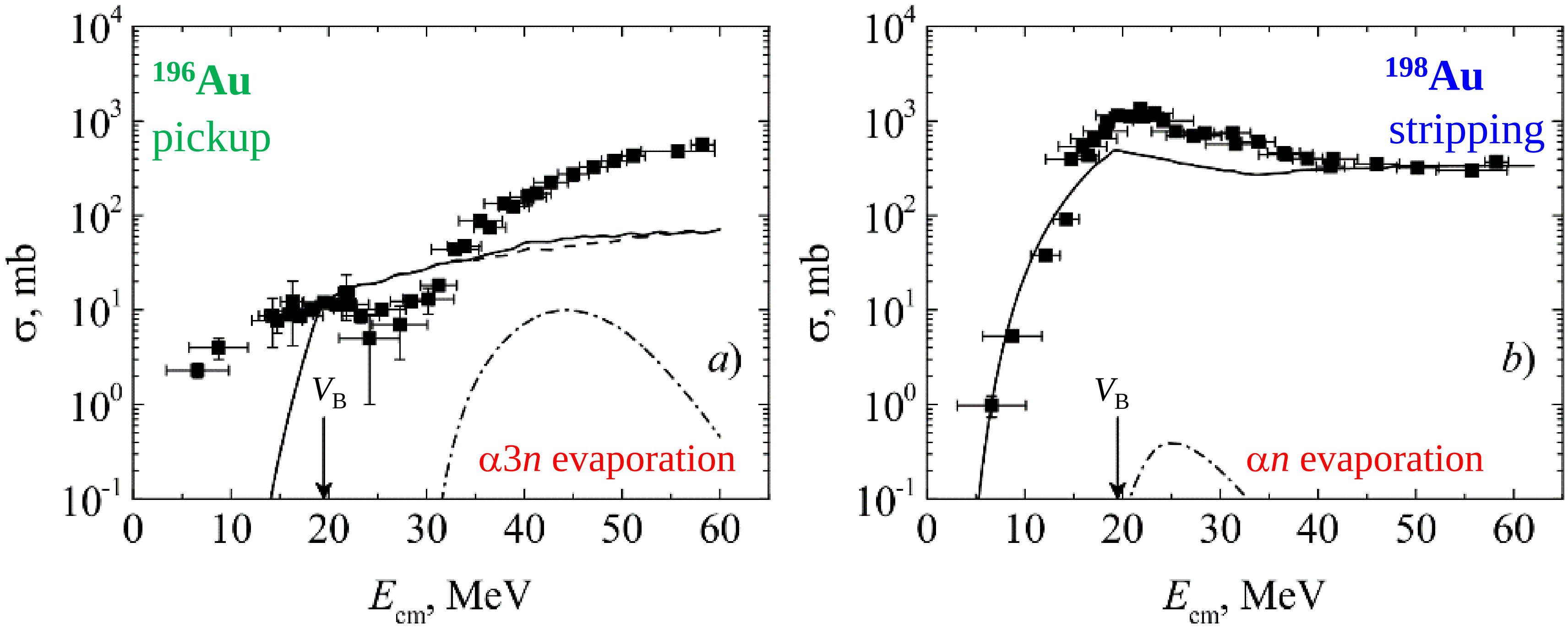
[2]



Good agreement with experimental data.
Contribution of fusion-evaporation is noticeable.

[1] (Experiment with ^{45}Sc) N. K. Skobelev, A. A. Kulko, V. Kroha et al. J. Phys. G: Nucl. Part. Phys. 2011. V. 38. P. 035106.
[2] (Experiment with ^{64}Zn) V. Scuderi, A. Di Pietro, P. Figuera et al. Phys. Rev. C. 2011. V. 84. P. 064604.
[3] (Evaporation code) NRV web knowledge base on low-energy nuclear physics. URL: http://nrv.jinr.ru/

Calculation of cross sections for formation of isotopes ^{196}Au and ^{198}Au in reaction ^{6}He + ^{197}Au



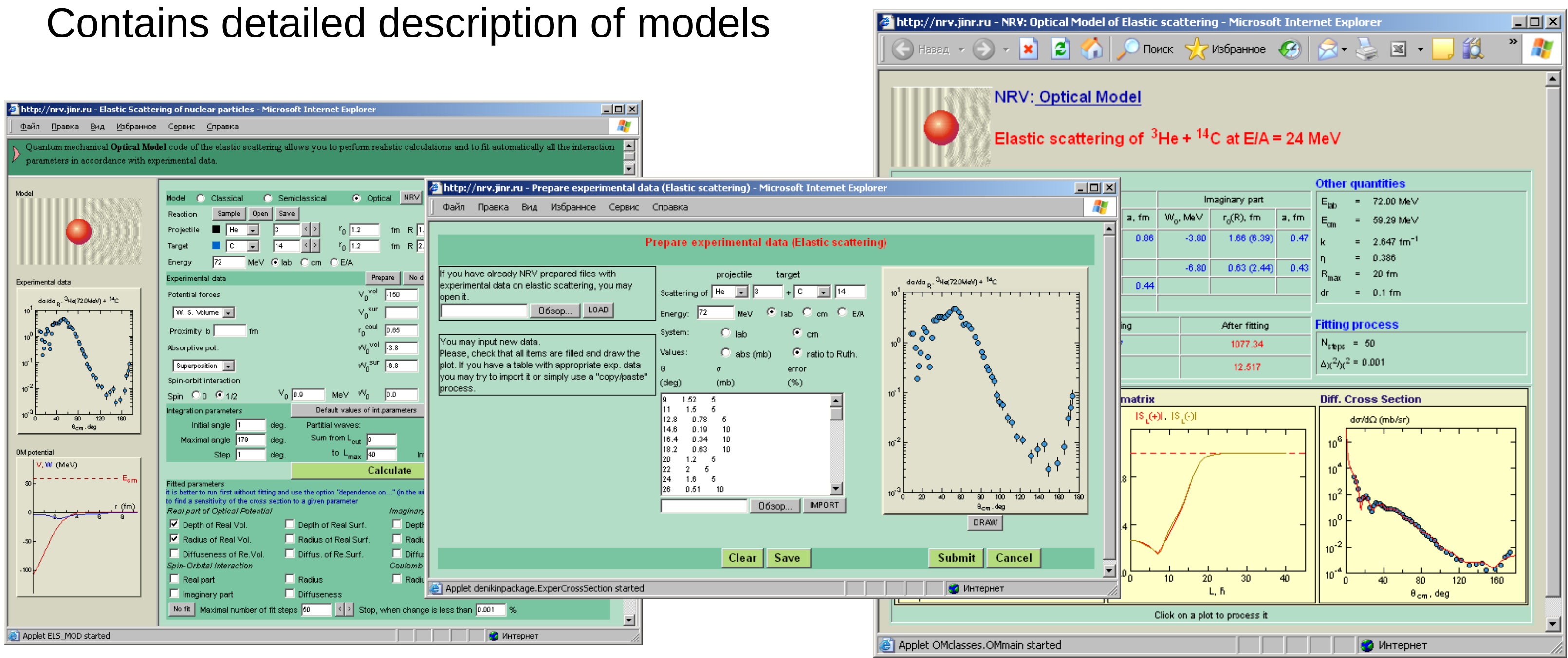
Reasonable agreement with experimental data.
Contribution of fusion-evaporation is low.
Contribution of other channels in ^{196}Au data?

[1] (Experiment) Yu. E. Penionzhkevich, R. A. Astabatyan, N. A. Demekhina et al. Eur. Phys. J. A. 2007. V. 31. P. 185.
[2] (Evaporation code) NRV web knowledge base on low-energy nuclear physics. URL: http://nrv.jinr.ru/

NRV knowledge base http://nrv.jinr.ru

The NRV web knowledge base is a unique interactive research system:

- Allows to run complicated computational codes
- Works in any internet browser supporting Java plugin
- Has graphical interface for preparation of input parameters and analysis of output results
- Combines computational codes with experimental databases on properties of nuclei and nuclear reactions
- Contains detailed description of models



Benefits of TDSE approach

- quantum description of several independent external neutrons,
- small 3D mesh step (0.1 - 0.2 fm, smaller than the length of the probability density oscillations),
- classical description of the motion of centers of nuclei,
- may be used for light nuclei,
- fast calculation,
- intuitive visualization of dynamics.

Conclusions

- The energy and the square modulus of the wave function of the ground states of few-body ^{3}He and cluster halo ^{6}He nuclei have been calculated.

- These results were used to adjust the shell model parameters for neutrons in ^{3}He and ^{6}He.

- Neutron transfer probabilities and transfer cross sections were calculated within the time-dependent Schrödinger equation method.

- Fusion-evaporation was taken into account using the NRV evaporation code.

- Results demonstrate good agreement with experimental data on formation of isotopes:

  - $^{44,46}Sc$ in reaction $^{3}He + {}^{45}Sc$,
  - $^{196,198}Au$ in reaction $^{3}He + {}^{197}Au$,
  - ^{46}Sc in reaction $^{6}He + {}^{45}Sc$,
  - ^{65}Zn in reaction $^{6}He + {}^{64}Zn$,
  - $^{196,198}Au$ in reaction $^{6}He + {}^{197}Au$.


Thank You