THE LABORATORY OF NUCLEAR THEORY

M.A.Zhusupov

The correct accounting of nuclear structure in the study of nuclear processes

1. The spectroscopic approach to nuclear reactions. The nuclear models.
2. Photonuclear reactions. Photodisintegration and radiation capture reactions.
3. Elastic and inelastic scattering of hadrons.
4. The halo-structure of light nuclei.

The spectroscopic approach is the use of nuclear models, the most comprehensive way of reproducing the entire spectroscopic information about the specific nuclei.

- rms (square) radius
- binding energy
- spectrum of low-lying states
- magnetic and quadrupole moments
- spectroscopic factors etc.

Using the spectroscopic approach and if the dominant mechanism of reaction set, the theory describes well the experimental data. Moreover, it also has predictive power.

NUCLEAR MODEL

1. Many-particle nuclear shell model for A = 5-16.

2. The potential cluster models:

- (αNN) for A = 6 (^{6}Li, ^{6}He, ^{6}Be);

- (αt) and $(\alpha \tau)$ for ^{7}Li, ^{7}Be;

- (αtn) and (αtp) for ^{8}Li, ^{8}B;

- $(^7\mathrm{Li}nn)$ for ^{9}Li;

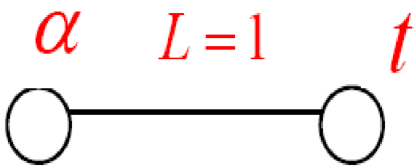
- $(\alpha\alpha n)$ and $(\alpha\alpha p)$ for ^{9}Be, ^{9}B.

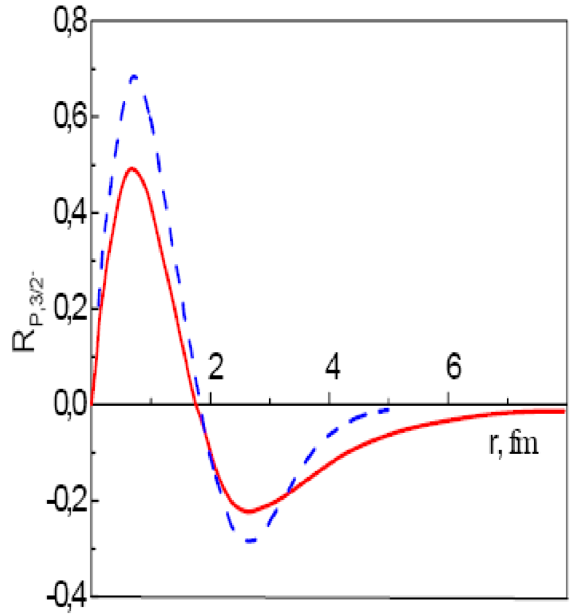
For the potential cluster models the shell model is a guide when choosing configurations of the quantum numbers of levels.

PHOTONUCLEAR REACTIONS

$^{7}\mathrm{Li}(\gamma,t)\alpha$

$^{7}\mathrm{Li}$:



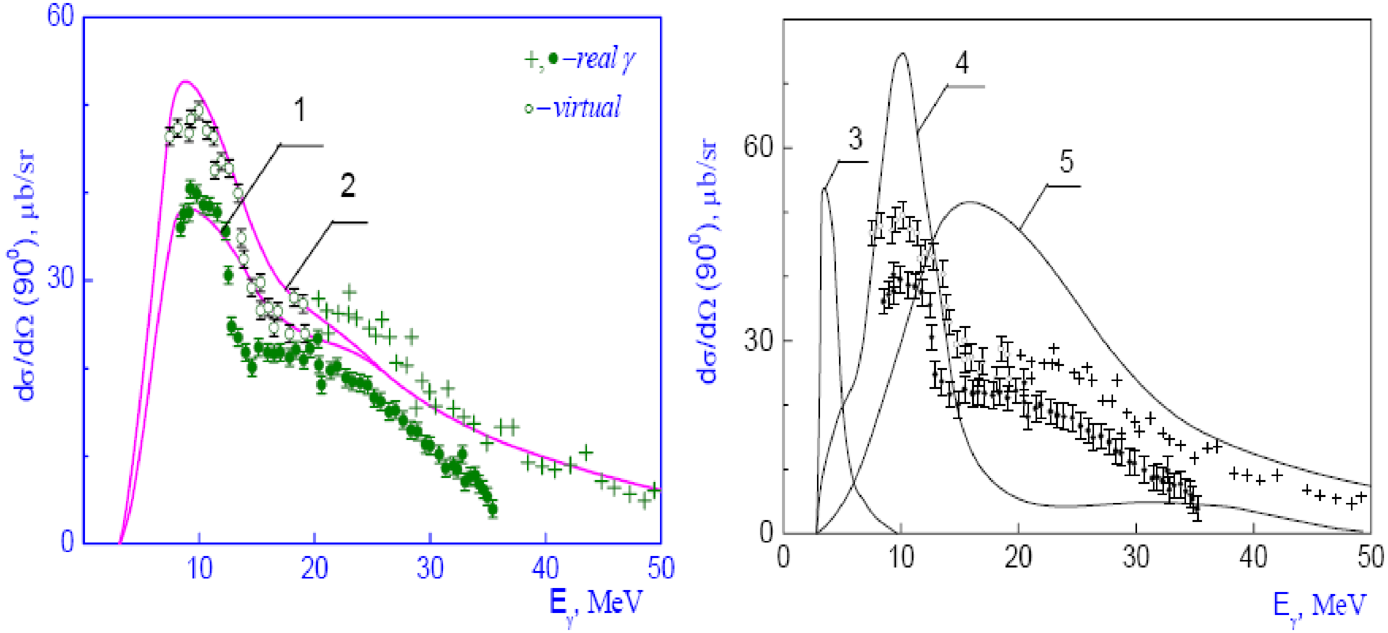


Radial wave function of the αt relative motion in the ground state of the ^{7}Li nucleus. The solid curve corresponds to the calculation with the deep attractive potential; and the dashed curve is calculated in the TISM ($r_0 = 1{,}6$ fm). WF has a node at $\boldsymbol{r = 1, 8}$ fm.

It was shown: E1-transition

$$\mathrm{P} \rightarrow \mathrm{S}, \quad \mathrm{P} \rightarrow \mathrm{D}$$

$^7Li + \gamma \rightarrow t + \alpha$



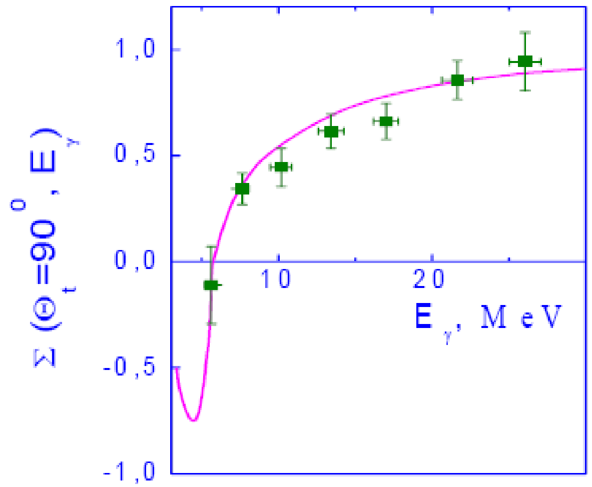
Differential cross sections for the photodisintegration of ^{7}Li nucleus in the $t\alpha$ channal

Theory: 1987-1991;
Experiment: 1 (real photons) – Junghans et al, 1979; Martins, Likhachev et al , Phys. Rev. 1999; **2 (virtual photons)** – Skopik et al, 1979

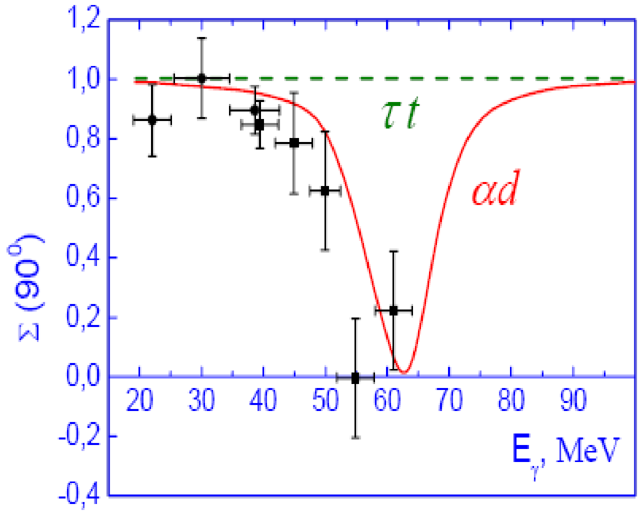
$$^7Li\{\alpha t\} + \vec{\gamma} \rightarrow t + \alpha, \quad ^6Li + \gamma \rightarrow \tau + t$$

OUR PREDICTION: ***a*** - **Asymmetry of the angular distribution of tritons in reaction** $^7Li\{\alpha t\} + \vec{\gamma} \rightarrow t + \alpha$ **with linearly polarized photons.**

b - **Experiment performed at the Kharkov Institute of Physics and Technology 1995 –**
$^6Li + \gamma \rightarrow \tau + t$ $^6Li \rightarrow \alpha d$ or τt? **NOW WE KNOW THE ANSWER!** $^6Li\{\alpha d\}$



a



b

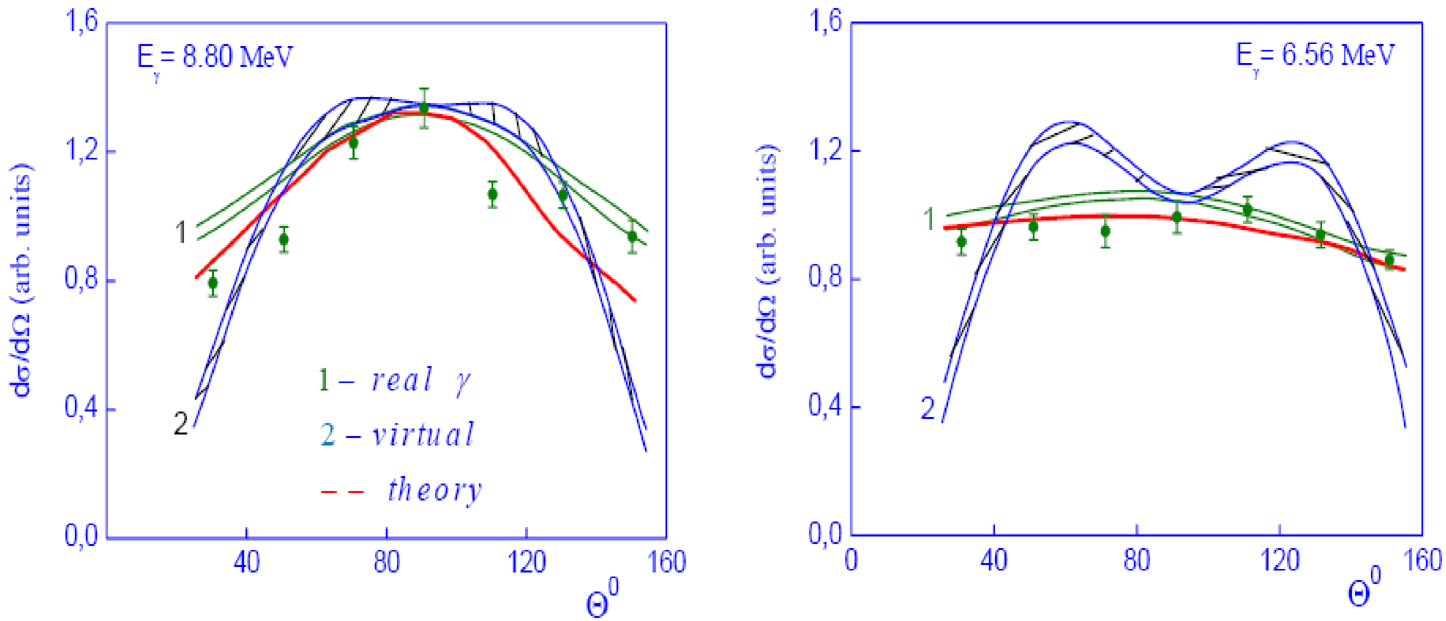
Experiment performed at the Kharkov Institute of Physics and Technology.

a **-Theory: 1987 – was excellently confirmed in the experiments; Experiment 1995 –** ***Nucl. Phys. A. 1995. V.586. P.293-315.***

b **- 1987, 1988 – theory; 1989–experiment, Phys. Lett. B. 1989. V.223. P. 136-138. The experimental data are obtained in the: channel beam,** ***Nucl. Phys. A. 1995. V.586. P.293-315.***

$$^{7}Li\{\alpha t\} + \gamma \rightarrow t + \alpha$$

OUR PREDICTION ANSWERS THE QUESTION: real OR virtual photons?



Angular distributions of tritium nuclei in the $^{7}Li\{\alpha t\} + \gamma \rightarrow t + \alpha$ process for E_γ=8.8 (a)

and 6.65 MeV

Experiment: 1 (real) – Junghans et al, 1979; Martins, Likhachev et al , Phys. Rev. 1999;

2 (virtual) – Skopik et al, 1979

MDMP 2αn-wave function has the following analytic presentation

$$\Psi_{J_iM_i}\left(\vec{x},\vec{y},\vec{\xi}\right)=\Phi_{000}\left(\vec{\xi}_1,\vec{\xi}_2,\vec{\xi}_3\right)\Phi_{000}\left(\vec{\xi}_4,\vec{\xi}_5,\vec{\xi}_6\right)\sum_{LM_L,\lambda\mu,lm,m_n} C^{J_iM_i}_{LM_L\,1/2m_n}\, C^{LM_L}_{\lambda\mu\, lm}\times$$

$$\times\Phi_{\lambda\mu lm}(\vec{x},\vec{y})\cdot\chi^{S_1T_1}_{00}\left(\alpha_1\right)\chi^{S_2T_2}_{00}\left(\alpha_2\right)\chi^{\sigma}_{1/2,m_n}\left(n\right)\chi^{\tau}_{1/2,-1/2}\left(n\right). \qquad (1)$$

$\Phi_{000}(\vec{\xi})$ – internal WF of α-particles. The radial part has the Gaussian expansion form

$$\Phi_{\lambda\mu lm}(\vec{x},\vec{y})=\sum_{ij} C_{ij} e^{-\alpha_i x^2} Y_{\lambda\mu}(\vec{x}) e^{-\beta_j y^2} Y_{lm}(\vec{y}). \qquad (2)$$

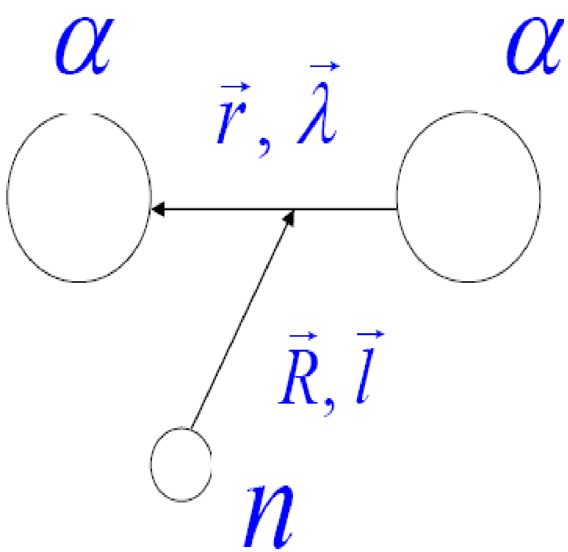
$\vec{r},\vec{R}$ – relative intercluster coordinates, $\vec{\lambda}$ и $\vec{l}$ – conjugated moments

TWO VERSIONS FOR $\mathbf{V}_{\alpha\alpha}$ potentials were used:

- Ali-Bodmer type, the REPULSIVE one (**AB**)
- Buck type, the DEEP ATTRACTIVE one (**B**)

CONFIGURATION WEIGHTS OF THE ^{9}Be NUCLEUS

λ	ℓ	L	P%, **AB model**	P%, **B model**
0	1	1	40,781	42,953
2	1	1	34,710	35,539
2	1	2	21,314	19,566



Prosessors *Shoda K. and Tanaka T.* reported in

EXPERIMENT: *Shoda K. and Tanaka T.* **Clusters in the photodisintegration of ^{9}Be. Phys. Rev. C. 1999. V. 59. P. 239.**

THAT

measured characteristics: **energy** $\frac{d\sigma}{d\Omega}\left(E_\gamma, \theta = 125^\circ\right)$ **and angular** $\frac{d\sigma}{d\Omega}(\theta)\Big|_{E_\gamma = const}$ **distributions**

$$^{9}Be(\gamma, p_0)^{8}Li \qquad \varepsilon = 16,89\ MeV$$

$$^{9}Be(\gamma, d_{0+1})^{7}Li \qquad \varepsilon = 16,69\ MeV$$

$$^{9}Be(\gamma, t)^{6}Li \qquad \varepsilon = 17,69\ MeV$$

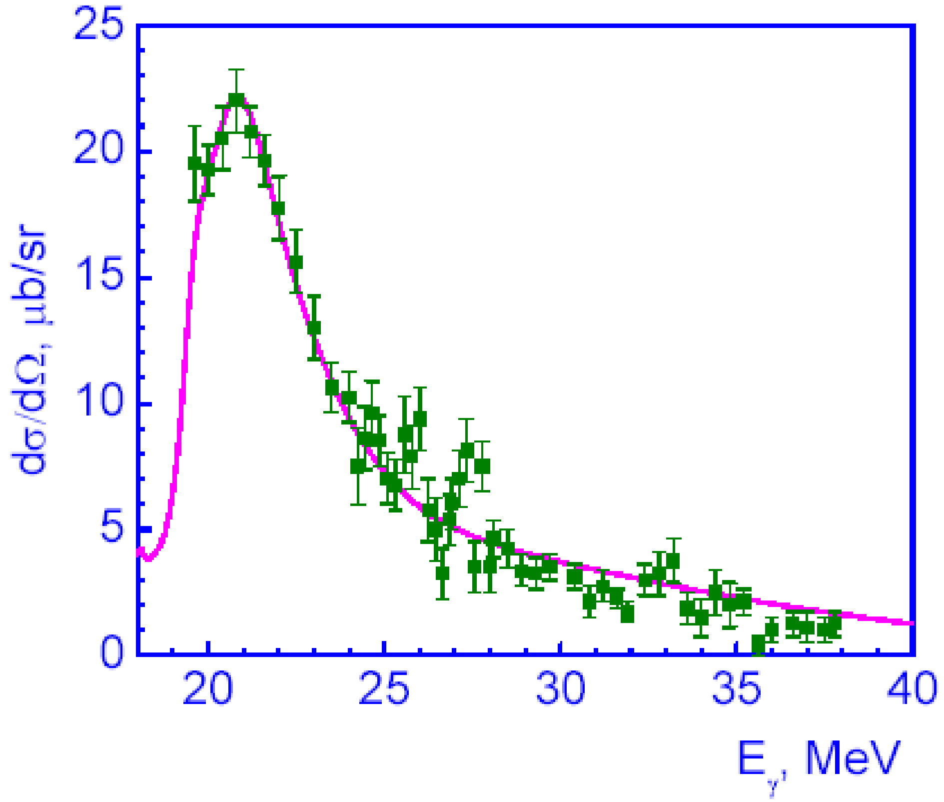
$$^{9}Be(\gamma, \tau)^{6}He \qquad \varepsilon = 21,18\ MeV$$

are COMPARABLE!

$^{9}Be(\gamma, d_{0+1})^{7}Li$

***Experiment**: Shoda et al, 1999*

$$\frac{d\sigma}{d\Omega}(E_\gamma, \Theta) = \frac{d\sigma^{(\mathbf{S})}}{d\Omega} + \frac{d\sigma^{(\mathbf{D})}}{d\Omega}$$



$P_D \simeq 68\%$

$$S(3/2^-) \xrightarrow{E1} p$$
$$S(3/2^-) \xrightarrow{E2} d$$

Traditional approach

$$D(3/2^-) \xrightarrow{E1} p + f$$
$$D(3/2^-) \xrightarrow{E2} s + d + g$$

Our predictions

$$^7Li + \vec{d} \rightarrow {}^9Be + \gamma,\ E_d = 6\ \ MeV$$

* *Schmid G.J., Chasteler R.M.,* ***Weller H.R.****, and Tilley D.R.* ***Radiative capture of polarized deuterons on*** ^7Li. Phys.Rev. C. 1993. V.48, No. 1. P.441-444.

$P_D \simeq 68\%$

$$p \xrightarrow{E1} S(3/2^-)$$
$$d \xrightarrow{E2} S(3/2^-)$$

$$p + f \xrightarrow{E1} D(3/2^-)$$
$$s + d + g \xrightarrow{E2} D(3/2^-)$$

Fig. 2 Traditional approach

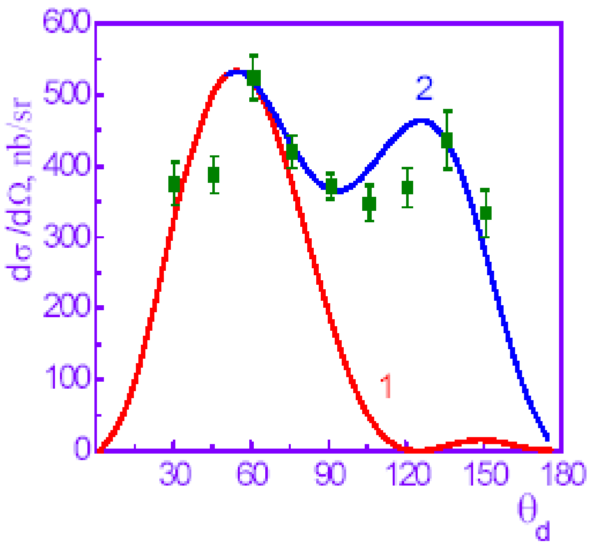
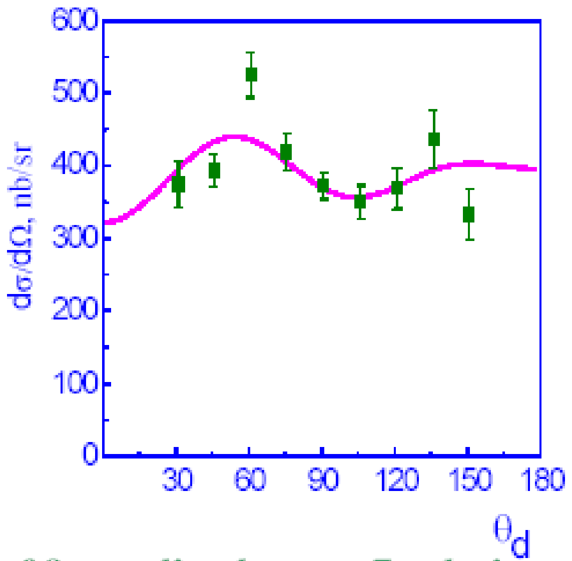


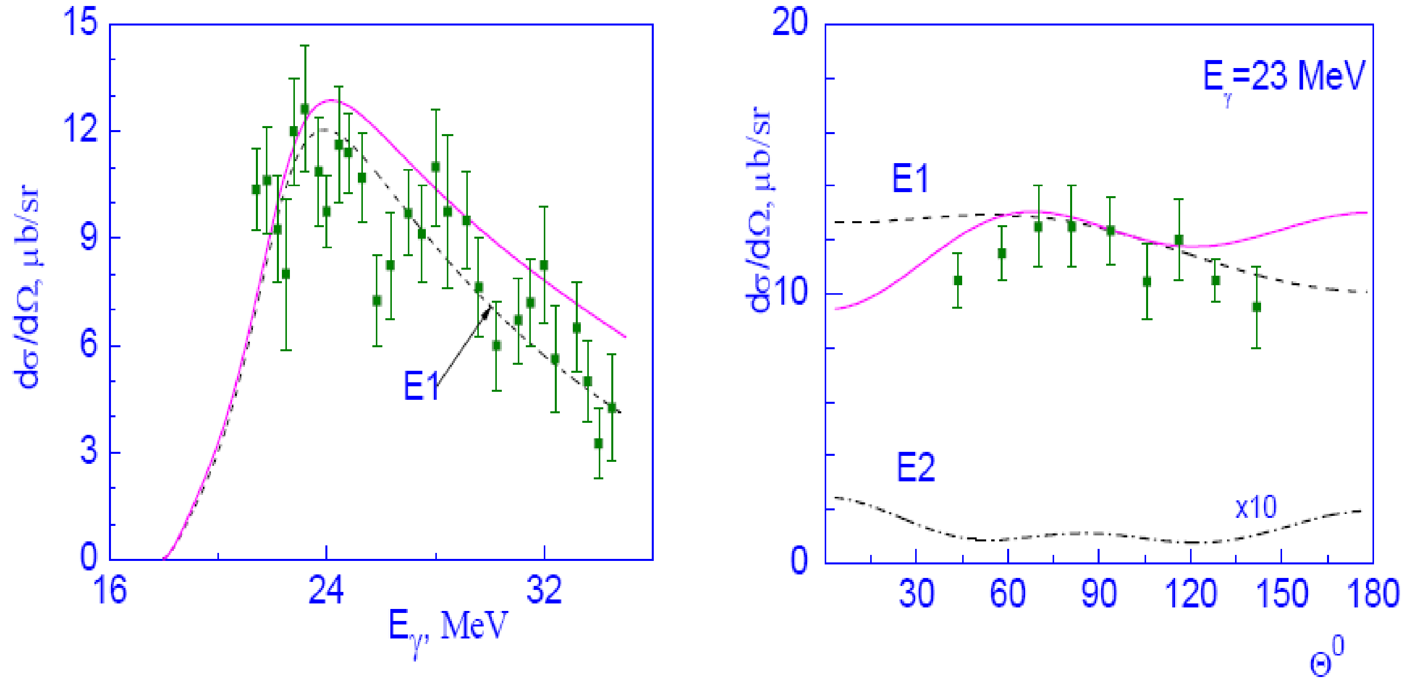
Fig. 3 Our predictions



1 – *transitions to the S state of* ^{9}*Be;* **2** – *variation of 8 amplitudes an 7 relative phases (*)*

$^{9}Be(\gamma,t_0)^{6}Li$

Experiment: Shoda et al, 1999



This Fig. illustrated energy and angular distributions in this channel . As it is seen, the E1 practically dominates and theoretical calculations fit the experimental data. But here You see the large error bars.

- Potential Theory of Cluster Photodisintegration of Light Nuclei // Physics of Particles and Nuclei. 2005. Vol. 36, No 4. P. 801-868.

ONE-NUCLEON SPECTROSCOPY IN LIGHT NUCLEI

In stated above potential cluster models were calculated nucleon spectroscopic factors: $^{6}Li \to {}^{5}He + p$, $^{7}Li \rightleftarrows {}^{6}Li + n$, $^{7}Li \rightleftarrows {}^{6}He + p$, $^{9}Be \to {}^{8}Be + n$, $^{9}Be \to {}^{8}Li + p$. Transitions both on the ground and on the various excited states of final (initial) nuclei were considered.

The results were compared with calculations in many-particle shell-model.

- Spectroscopy of Light Nuclei // Physics of Particles and Nuclei. 2009. Vol. 40, No 2. P. 162-205.

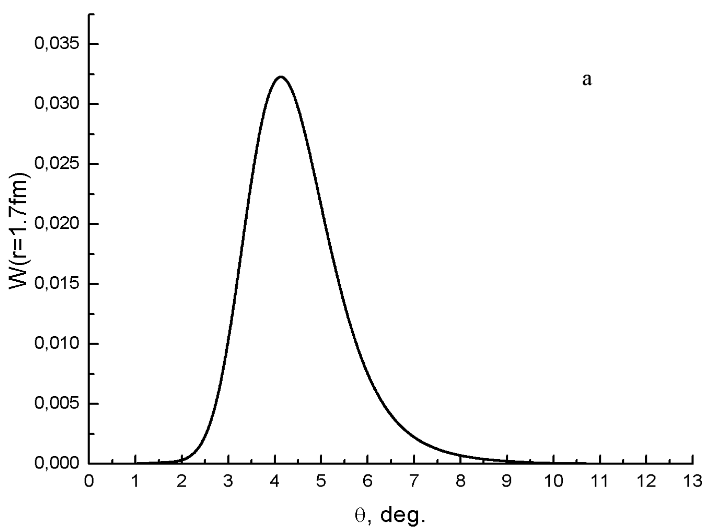
ELASTIC AND INELASTIC SCATTERING OF HADRONS BY LIGHT NUCLEI

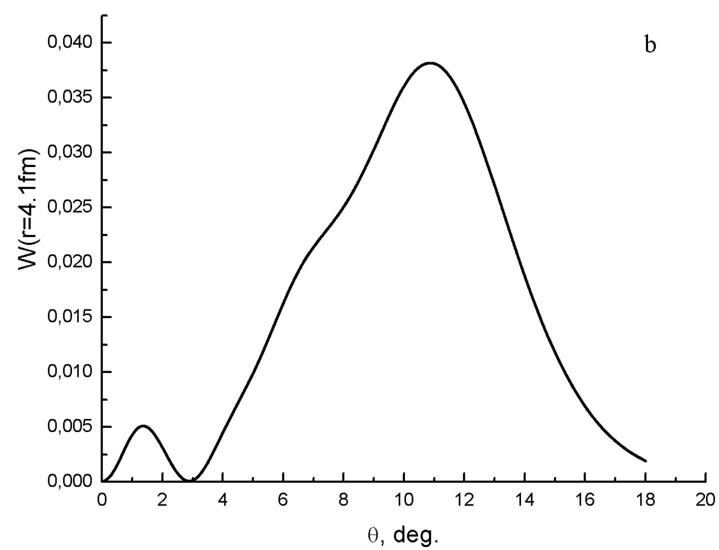
Within the Glauber multiple scattering theory and potential cluster models were calculated differential cross sections and polarization characteristics for the elastic and inelastic scattering of protons (π and κ -mesons) on ^{6}Li, ^{6}He, ^{7}Li, ^{8}Li, ^{9}Li, ^{9}Be nuclei . For ^{15}N and ^{15}C nuclei used particle-hole shell model. The basis of our approach - using realistic WF of the nuclei, and not nucleon densities, as is usually done for even-even ^{4}He, ^{12}C, ^{16}O and etc. nuclei.

- Упругое и неупругое рассеяние адронов на легких ядрах в дифракционной теории // ЭЧАЯ. 2000. Т. 31, вып. 6, С. 1427-1495.
- Study of the Structure of Light, Unstable Nuclei and the Mechanism of Elastic Proton Scattering // Physics of Particles and Nuclei. 2011. Vol. 42, No. 6, P. 847–894.

Model wave functions of the excited states of the ^{9}Be nucleus

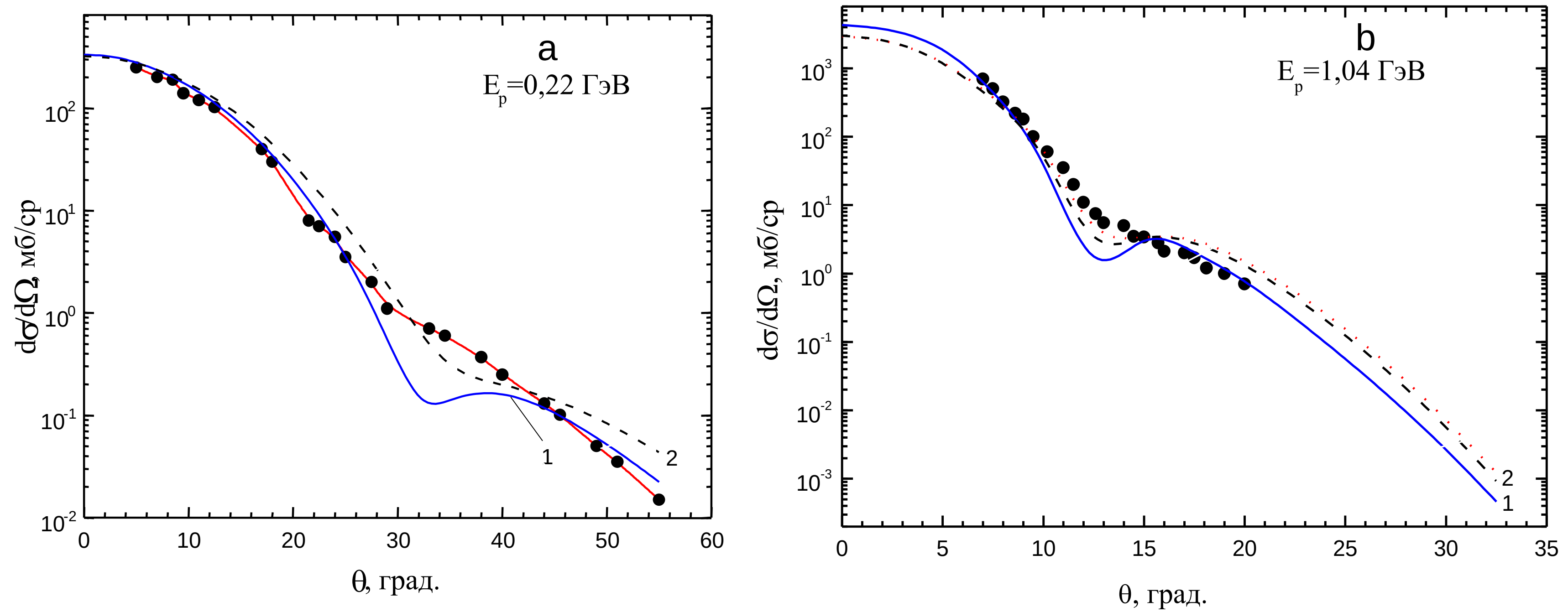
a - model 1: αα – potential of Ali-Bodmer,containing repulsion at short distances, **b – model 2**: αα – deep potential with forbidden states in the form of Buck.



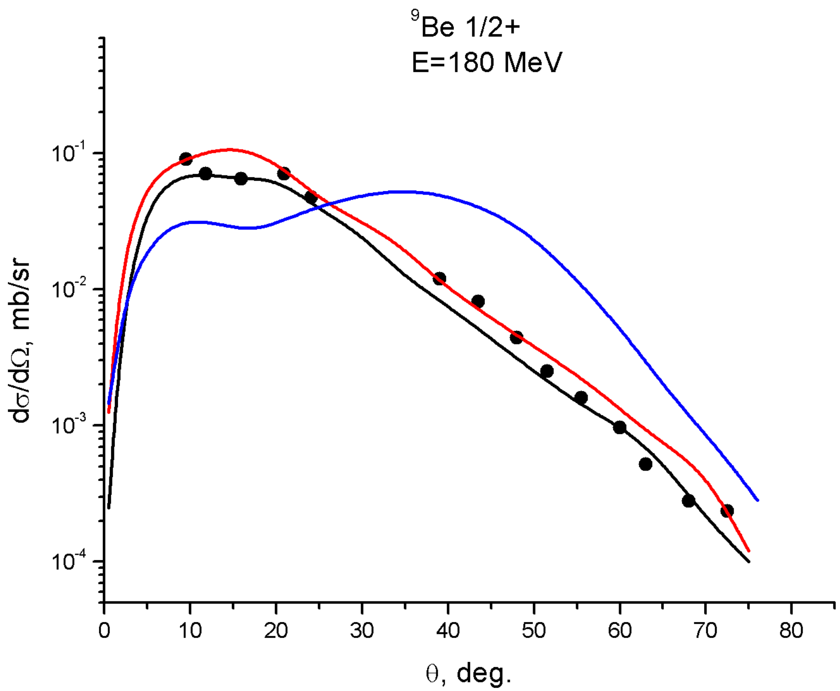


The dependence of the differential cross sections from different model of wave functions of ^{9}Be for scattering of protons

Curve 1 – for the WF in the model 1, curve 2 – for the WF in the model 2, the red curve – the calculation in DWIA



Inelastic scattering of protons in the ^{9}Be



Red and black curves – our calculation of the WF in models 1 and 2, points and the blue curve – experimental data and the calculation in DWIA of work Dixit S., Bertozzi W., Buti T.N. et al. - Phys. Rev.C . 1991. Vol. 43. P. 1758.

HALO-STRUCTURE OF EXCITED STATES OF THE ^{9}BE NUCLEUS

The ground state of ^{9}Be doesn't show halo-structure. Excited states $\frac{1}{2}^{+}$, $\frac{3}{2}^{+}$ and $\frac{5}{2}^{+}$ have such.

$(r^2)^{1/2}_{g.s.}$ **= 2,45 fm;**

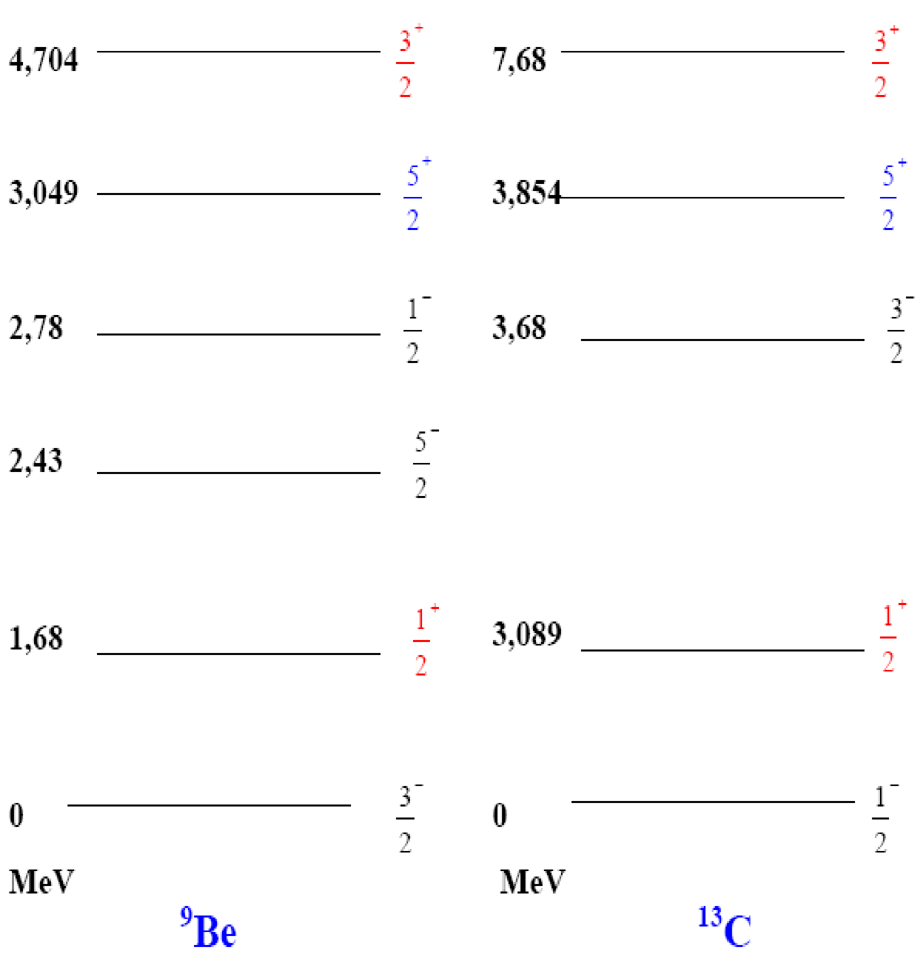
$(r^2)^{1/2}_{\frac{1}{2}^{+}}$ **= 2,83 fm,**

$(r^2)^{1/2}_{\frac{3}{2}^{+}}$ **= 2,98 fm**

– our calculations in $\alpha\alpha n$–model.

- Inelastic p^{9}Be scattering and Halo-structure of excited states of ^{9}Be // Nucl. Phys. A. 2015. Vol. 933. P. 16-33.

The spectrums of low-lying states of nuclei of ^{9}Be and ^{13}C



- Inelastic p^{9}Be scattering and halo structure of the $J^{\pi} = 1/2^{+}$ excited state of the ^{9}Be nucleus // Physics of Atomic Nuclei. 2015. Vol. 78, No. 1. P. 151-158.

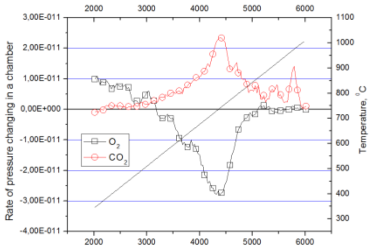
CONCLUSIONS

The *spectroscopic* approach to the study of nuclear reactions allowed on the general basis well to describe the various nuclear processes.

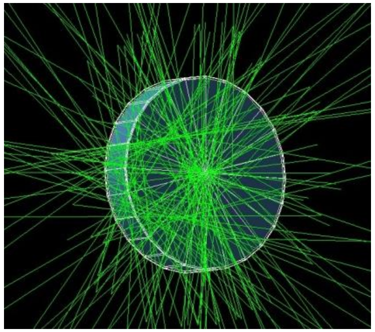
Laboratory of Structural Materials for Nuclear Power Plants of IETP KazNU (V. Shestakov, Y. Chikhray, T. Kulsartov, etc)

1) High-temperature corrosion of reactor graphites
2) Investigation of chemically active gases formation at accidents on high-temperature gas-cooled reactor (HTGR)
3) Development of new technology for hydrogen isotopes refinement and separation based on vanadium alloys VCrTi
4) Modeling of generation and release behavior of tritium in Be
5) Development of the technology of obtaining nanocarbon materials for hydrogen energetics

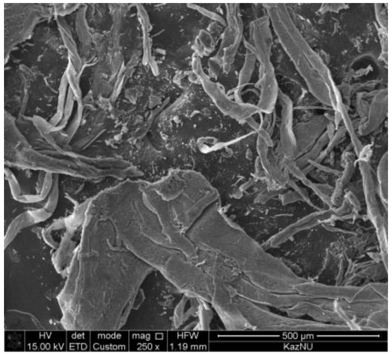
Oxidation set-up



Time dependences of O2 and CO2 partial pressure changes in corrosion experiment



Simulation using geometry with one beryllium sample in aluminum foil



Morphology of one-walled carbon nanotubes

LABORATORY OF COSMIC RAYS VARIATIONS

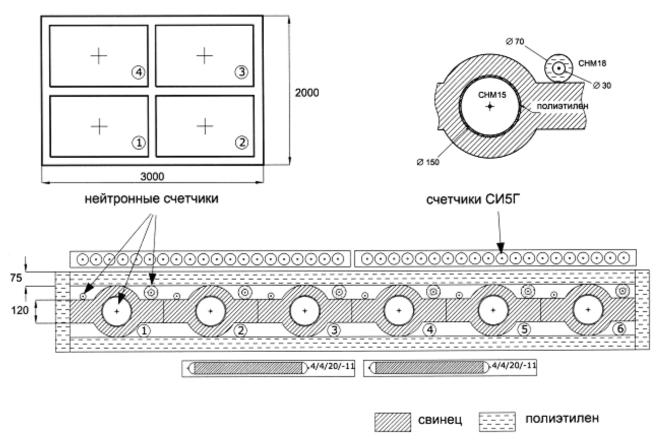
Oskomov V.V., Sedov A.N., Saduyev N.O., Kalikulov O.A., Chebakova E.A. and etc.

Recent grant projects and directions of investigations:

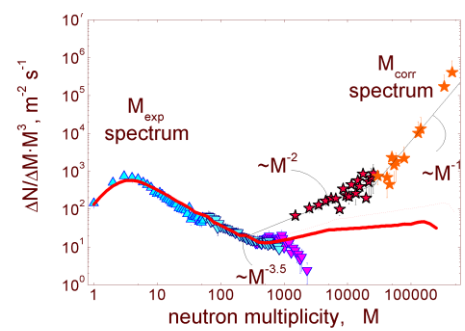
- **"INVESTIGATION OF GEOPHYSICAL PARAMETERS OF ENVIRONMENT USING COSMIC RAYS“**
- **“INVESTIGATION OF SOIL MOISTURE, WATER STOCK IN SNOW AND ABLATION OF GLACIERS USING NEUTRONS AND MUONS OF COSMIC RAYS“**
- **“PROGRAM TECHNICAL COMPLEX OF DATA COLLECTION FOR SCIENTIFIC EXPERIMENTS“**

Setup for search of supermassive particles in cosmic rays.

Japan, the Institute for Advanced Studies



There are three separate experimental setups for the cosmic ray shower registration located at different elevations: ADRON-M (3340 м, 690 g/см^2), PSKL (1750 м, 835 g/см^2) and KAZNU (850 м, 940 g/см^2).



Neutron multiplicity spectra of ground supermonitor 6NM-64

Quantazied systems and elementary particles laboratory

4 main project

- The investigation of the simplest molecules to build precision optical molecular clocks operating in the terahertz and radio bands
- Multiquark states and their decays in the covariant quark model
- The study of the main characteristics of rare decays of baryons and properties of dibaryon systems
- Precision spectroscopy

Руководитель группы

д.ф.-м.н., профессор Минал Динейхан

LABORATORY OF NUCLEAR ASTROPHYSICS

Head of laboratory –prof. N. ZH. TAKIBAEV.

THE STUDIED PROBLEMS:NUCLEAR RESONANCES AND PHYSICS OF NEUTRON STARS.

LABORATORY OF NUCLEAR AND RADIATION PHYSICS

Head of laboratory –prof. A.V. Yushkov

THE STUDIED PROBLEMS: NUCLEAR REACTIONS WITH CLUSTERS, NUCLEAR MEDICINE AND RADIO ECOLOGY

Спасибо за внимание!

Thank You for attention!