Proposal to the n_TOF Collaboration at CERN on IFIN-HH joining *Activities at the neutron time of flight facility at CERN – Second Phase (n_TOF-Ph2)*

http://pceet075.cern.ch/Documents/LoI_2005/n_TOF-Ph2_LoI.pdf

Vlad Avrigeanu, Mihai Mirea

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http://tandem.nipne.ro/~Dante/ http://fp6.cordis.lu/fp6/partners

INTEREST IN FURTHER MEASUREMENTS

- **Activation reactions: (n,p), (n,α), and (n,xc):**
  V. Avrigeanu, M. Avrigeanu, R.A. Forrest (UKAEA-Culham)
- **α-particle optical model / nuclear matter density (T):**
  M. Avrigeanu, V. Avrigeanu, W. von Oertzen (HMI-Berlin)
- **Measurement of fission cross-sections and neutron interferometry:**
  M. Petrascu, A. Isbasescu, H. Petrascu, I. Tanihata (TRIUMF), W.Y. Lynch (MSU)
- **New information on the basic mechanism of nuclear fission:**
  M. Mirea, L. Tassan-Got (IN2P3-Orsay)

Obiectivele principale ale activitatilor din cadrul colaborarii n_TOF faza 2 de la CERN sunt urmatoarele:

a) sectiuni neutronice de interes astrofizic;

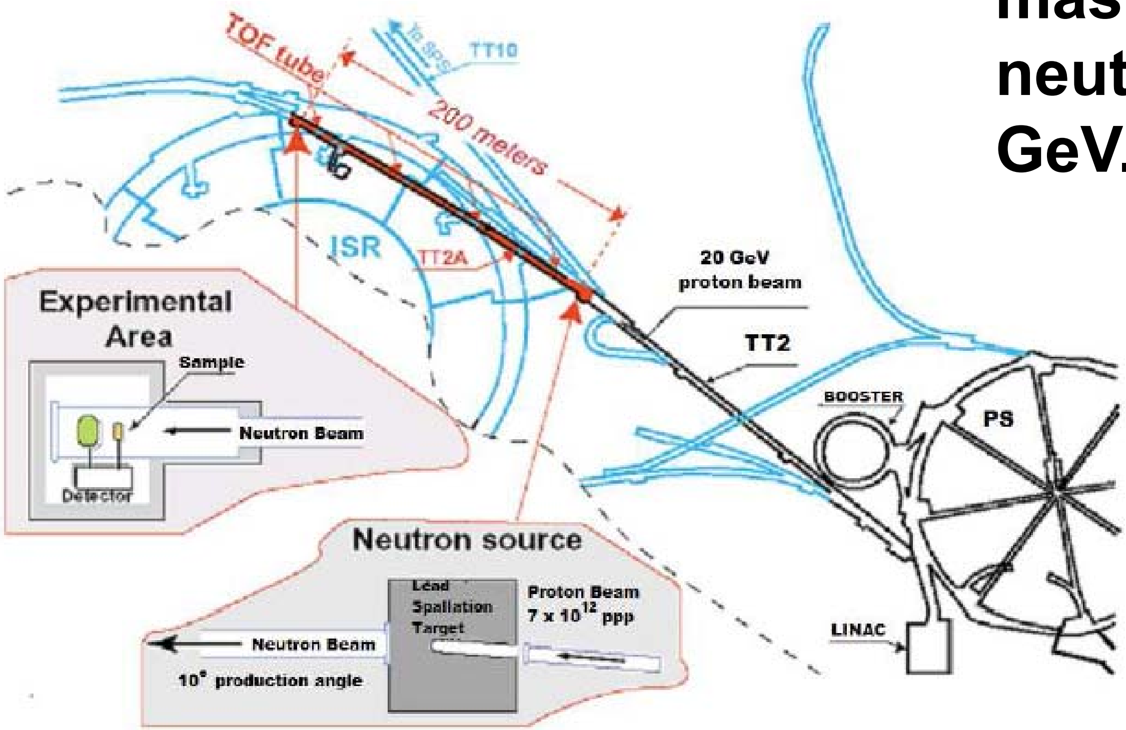
b) masuratori de date nucleare pentru tehnologii nucleare avansate si transmutarea deseurilor radioactive;

c) masuratori de sectiuni eficace neutronice pentru fizica fundamentala.

Ce este n_TOF

Fascicul pulsat de

7 10^{10} protoni cu energii de 20 GeV pe o durata de 7 ns. Prin bombardarea unei tinte masive de Pb se obtin neutroni de la 1 eV la 1 GeV.



Vedere generala a ansamblului n_TOF

Propunerea de participare la colaborarea n_TOF are la baza 2 proiecte CEEX:

Masuratori de date nucleare si evaluari pentru cerinte de securitate nucleara (DANTE)

Abordari fundamentale ale fisunii nucleare pentru aplicatii (ABONA)

- **Actitatile pe care le propunem si care corespund si obiectivelor proiectelor CEEX sunt:**

- **Reactii de activare: (n,p), (n,α), si (n,xc):**
  - V. Avrigeanu, M. Avrigeanu, R.A. Forrest (UKAEA-Culham)
- **Model optic α-particula / densitatea materiei nucleare (T):**
  - M. Avrigeanu, V. Avrigeanu, W. von Oertzen (HMI-Berlin)
- **Masuratori de sectiuni eficace de fisiune si interferometrie de neutroni:**
  - A. Isbasescu, H. Petrascu, I. Tanihata (TRIUMF), W.Y. Lynch (MSU)
- **Noi informatii despre mecanismul de baza a fisiunii nucleare:**
  - M. Mirea, L. Tassan-Got (IN2P3-Orsay)

- EXPERIENTA COLECTIVULUI
- Enumerarea unor publicatii recente in domeniu

PHYSICAL REVIEW C VOLUME 49, NUMBER 4 APRIL 1994

OMPs describing α-emission: not suitable for (α,α_0) @ E_α~25 MeV

Global optical potentials for emitted alpha particles

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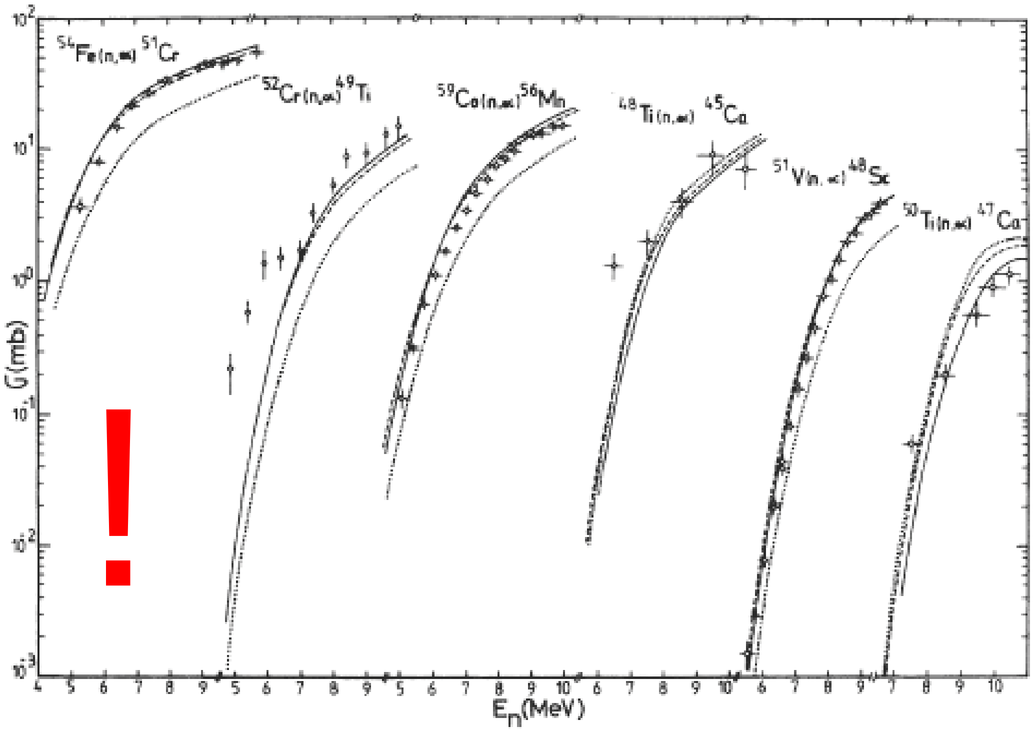
M. Avrigeanu
Institute of Physics and Nuclear Engineering, Bucharest, Romania
(Received 30 August 1993)

A set of global optical potentials for alpha particles with energies above 80 MeV has been extended to lower energies and proved appropriate to describe (n,α) reactions. It is found that the transmission coefficients for alpha-particle emission are rather strongly related to the fusion cross sections and elastic scattering at energies above 80 MeV, but not to elastic scattering at lower energy where specific features are comprised within complex optical potential parametrizations.



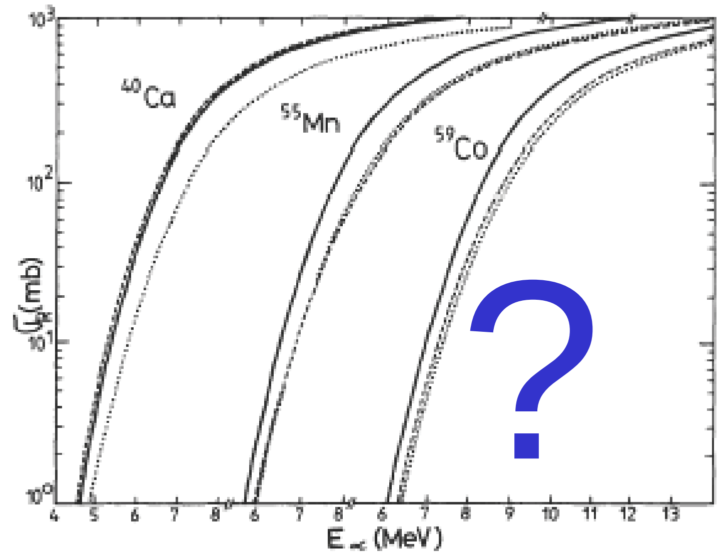


FIG. 3. Calculated alpha-particle total reaction cross sections for the target nuclei ^{40}Ca, ^{55}Mn, and ^{59}Co, by using optical potentials from present work (full curves), the best-fit parameter sets Ca9, Mn3, and Co2, respectively (dashed curves), and average four-parameter set (dotted curves) of Ref. [3].

OMPs from (α,α_0) (at E_α<40 MeV): DO NOT DESCRIBE α-emission (2/3)

PHYSICAL REVIEW C **68**, 015802 (2003)

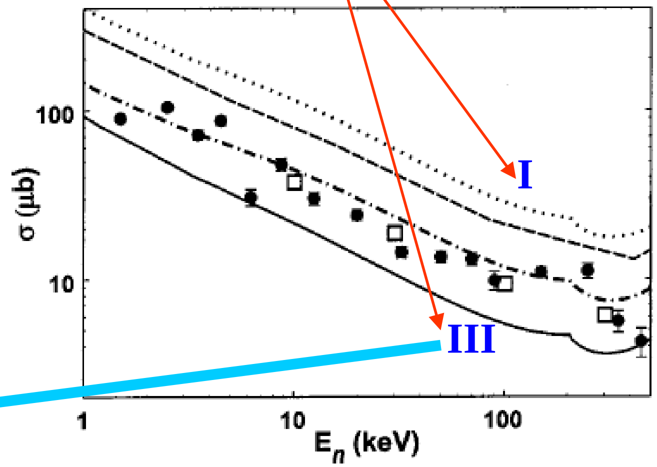
^{95}Mo(n,α) cross section from 1 eV to 500 keV: A test of the α+nucleus optical potential used in calculating reaction rates for explosive nucleosynthesis

W. Rapp,[1,2,*] P. E. Koehler,[1] F. Käppeler,[2] and S. Raman[1,†]
[1]*Physics Division, MS-6354 Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA*
[2]*Forschungszentrum Karlsruhe, Institut für Kernphysik, Postfach 3640, D-76021 Karlsruhe, Germany*

(Received 31 January 2003; published 29 July 2003)

We have measured the ^{95}Mo(n,α) cross section in the energy range from 1 eV to 500 keV at the Oak Ridge Electron Linear Accelerator (ORELA). This work is part of a series of (n,α) measurements for deriving a reliable global α+nucleus potential, which is an essential ingredient in nuclear statistical model calculations of the reaction rates for unstable nuclei involved in explosive *p*-process nucleosynthesis. The ^{95}Mo(n,α) rate shows a strong sensitivity to the α+nucleus potential used in the calculations, and therefore these new data should be very useful in obtaining an improved potential. For example, although there is a factor of 5 variation in the rate calculated using different potentials, an older model and a newer one using one of three recently proposed potentials are in good agreement with our new data.

DOI: 10.1103/PhysRevC.68.015802



BRUSLIB [www-astro.ulb.ac.be]

FIG. 3. Measured ^{95}Mo(n,α) cross section averaged over coarse bins (solid circles with error bars) compared to calculations performed with statistical model codes (dashed curve: NON-SMOKER [9]; open squares: Holmes *et al.* [10]; dotted, dot-dashed, and solid curves: MOST [30] using potentials I, II, and III, respectively).

Almost identical at r >R_7 *(surface tail region)*:

- DF (2003)
- ROP (2003)
- McFadden-Satchler (1966)

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NUCLEAR PHYSICS A

Nuclear Physics A 723 (2003) 104–126

www.elsevier.com/locate/npe

Optical model potentials for α-particles scattering around the Coulomb barrier on $A \sim 100$ nuclei

M. Avrigeanu [a,*], W. von Oertzen [b], A.J.M. Plompen [c], V. Avrigeanu [a]

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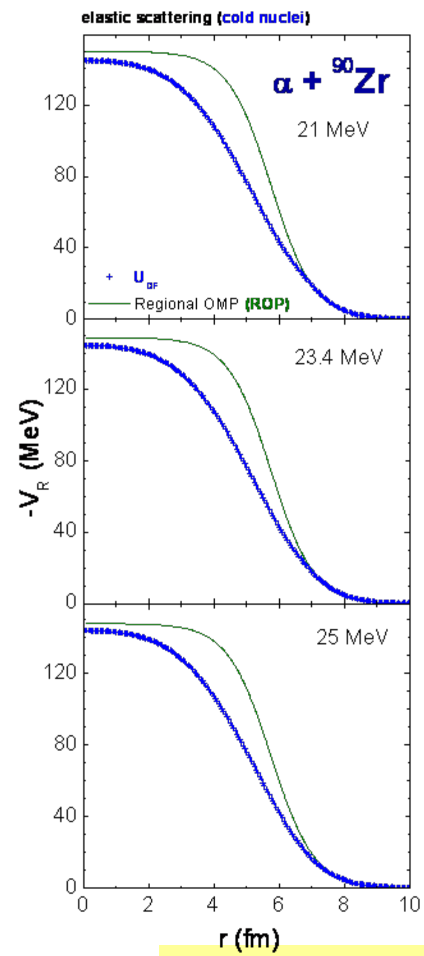
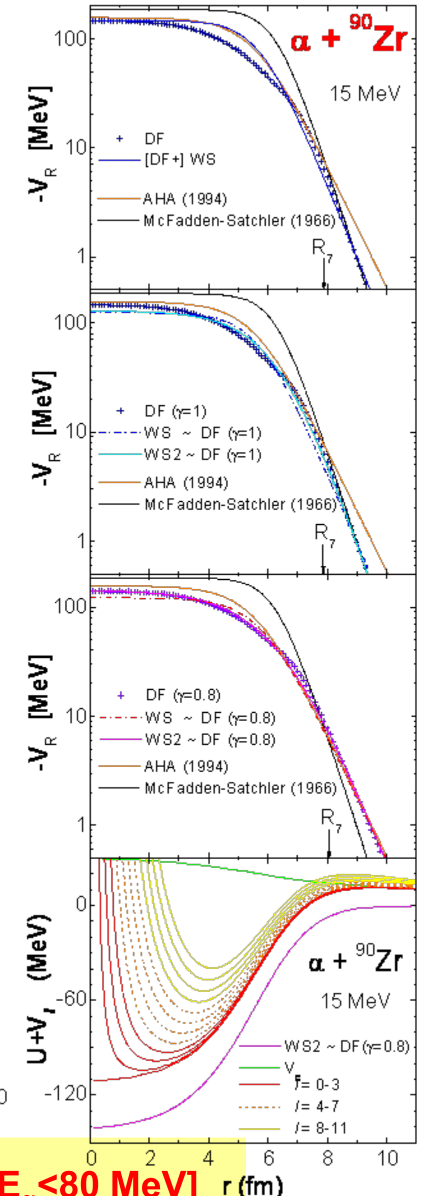
Received 5 December 2002; received in revised form 6 February 2003; accepted 14 March 2003

Abstract

The double-folding formalism of the α-nucleus optical potential is used and appropriate effective nucleon–nucleon (NN) interaction and α-particle density distribution at low energies are obtained by analysis of the α–α elastic-scattering at energies below 35 MeV. Next a semi-microscopic analysis based on the Double Folding Model (DFM) for the α-particle elastic scattering on $A \sim 100$ nuclei at energies below 32 MeV has been carried out. The energy-dependent phenomenological imaginary part for this semi-microscopic optical model potential (OMP) was obtained, making use also of the dispersive correction to the microscopic real potential. This imaginary potential has then been introduced within a complete phenomenological analysis of the same data basis. A regional parameter set of the phenomenological OMP for low-energy α-particles has thus been obtained for nuclei in the mass range $A \sim 100$, which is of interest to basic nuclear physics as well as nuclear technology.





$V_R(R_7)$=-7 MeV [Fernandez-Blair, Phys.Rev. C 1,523(1970)]

Surface tail: V_R<10 MeV [Igo, Phys.Rev.Lett. 1,72(1958)]

Larger a_R-values: AHA (1994) [E_α<80 MeV]

Additional usefulness for consistent description of α-emission

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Nuclear Physics A 764 (2006) 246–260

NUCLEAR PHYSICS A

On temperature dependence of the optical potential for alpha-particles at low energies

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Received 22 June 2005; received in revised form 22 September 2005; accepted 7 October 2005

Available online 21 October 2005

Abstract

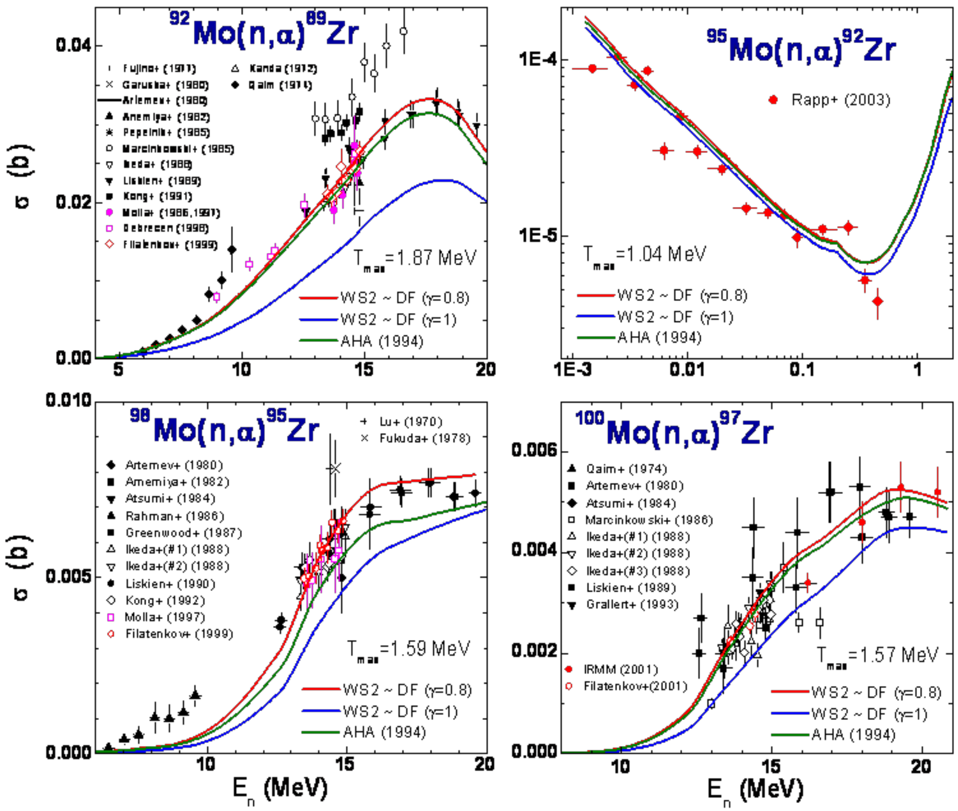
Within the double folding formalism of the α-nucleus optical potential, used previously for a semi-microscopic analysis of the α-particle elastic scattering on $A \sim 100$ nuclei at energies below 32 MeV, effects due to changes of the nuclear density at a finite temperature are considered. Parameterizations of the double-folding (DF) real potential as well as of a regional phenomenological potential have been used in the study of the (n, α) reaction cross sections for the target nuclei ^{92,95,98,100}Mo. Taking into account the microscopic DF potentials based on nuclear density distributions, we are able to fully describe the excitation functions of the (n, α) reactions. It is shown that the temperature dependence of the nuclear density distribution function can be an important aspect that has to be included in statistical model calculations even for a nuclear temperature smaller than 2 MeV.

PACS: 21.30.Fe; 21.65.+f; 24.10.Ht; 24.60.Dr

Keywords: ^{92,95,98,100}Mo(n, α); $E < 20$ MeV; Optical model; Nuclear matter density; Statistical compound-nucleus reactions

DF: $\rho(r,T) = \rho_0 / [1+\exp[(r-c)/a]]^{\gamma}$

γ=1, for T=0
γ<1, for T>0



PHYSICAL REVIEW C 73, 038801 (2006)

Addendum to "Elastic α-scattering on ^{112}Sn and ^{124}Sn at astrophysically relevant energies"

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(Received 27 October 2005; published 20 March 2006)

We show that the new experimental data reported by Galaviz *et al.* [Phys. Rev. C 71, 065802 (2005)] can be used to improve a previous optical potential global parameter set, employing the corresponding former local parameter basis as well as the parameter sets obtained through a similar analysis of the new data.

DOI: 10.1103/PhysRevC.73.038801 PACS number(s): 24.10.Ht, 25.55.Ci, 27.60.+j

Although a large effort has been made in the last decades to measure reaction cross sections, major applications as nuclear astrophysics and accelerator-driven systems still need the use of either microscopic, semimicroscopic, or phenomenological global predictions to estimate unknown data (e.g., Ref. [1] and references therein). In this respect, the α–nucleus optical potential plays a key role, although its uncertainty at energies around and below the Coulomb barrier have still to be reduced. This happens in spite of the new opportunities that have been proved by, e.g. (n,α) cross section measurements [2], comparing resonance parameters rather than cross sections [3], and α-decay half-lives analysis [4]. On the other hand, Galaviz *et al.* [5] have recently shown that even the analysis of α-particle elastic scattering may supply further information about the α-nucleus potentials provided that high accuracy data are obtained along an isotopic chain. Thus, they reported new experimental information of the α-particle elastic scattering on ^{112}Sn and ^{124}Sn at energies just below and above the Coulomb barrier. The high precision of these data, with typical uncertainties generally around 2% and anyway below 3%–4% for all measured data points, including systematic and statistical uncertainties, has pointed out further experimental features. Thus, the ratio of the elastic scattering cross sections of ^{112}Sn and ^{124}Sn at E_α=19.5 MeV, which differ by roughly 30% at backward angles, shows an oscillation pattern at these angles. Moreover, they found that global α-nucleus potentials including that of Ref. [6] fail to reproduce this pattern. Since a global optical model potential (OMP) must be able to describe the scattering cross section data along an isotopic chain in order to demonstrate its reliability when extrapolating to unstable nuclei, they concluded [5] that the use of these global potentials in the extrapolation to more proton-rich species should be questioned. We show in this addendum that is possible to improve the OMP global parameter set [6] by looking for the origin of the respective deviations, and using both the corresponding former local parameter basis and the parameter sets obtained through a similar analysis of the new data.

The phenomenological regional optical potential (ROP) of Ref. [6] was obtained by a semimicroscopic analysis, based on the double folding (DF) model [7], of the low energy α-particle elastic scattering on $A\sim100$ nuclei. The error bars of the corresponding experimental data have been around 10%–15% i.e., by a factor of ~5 larger than those of Galaviz *et a* By using this factor to multiply the uncertainties of the data [5] one may see that the oscillation pattern of the ra the two experimental cross sections, divided by the Ruth cross section, as well as the deficiency of ROP prediction side of Fig. 1) would be hidden. It is true that the syste errors included in the older error bars resulted at least i from overall-normalization uncertainties, so that our enl estimates may not really be representative of the actua errors used effectively within the χ^2 analysis. Howeve obvious that the new features of the data of Galaviz as well as the inaccuracy of the previous global OMI matching just their magnitude.

The analysis of the new data of Galaviz *et al.* [5] by me the above-mentioned method used for the ROP setting u including a χ^2 analysis using the original errors, has led to the Woods-Saxon potential parameters and χ^2 v given in Table I. The comparison of the experimenta calculated angular distributions is shown in Fig. 1 (right Since the latter ones have shown a reduced sensitivity potential geometry parameter values, with the exception surface imaginary potential radius r_D, the best fit was fou searching on V_R, W_V, W_D, and r_D parameters while the r parameters were kept fixed at the ROP values. Neverth the agreement is properly improved and the oscillatic the ratio of angular distributions at 19.5 MeV are almos reproduced.

We have next considered the new local paramete shown in Table I with respect to the corresponding predi of ROP, in order to learn more about the shortcomin the latter. Firstly, it has resulted that a more accurate of the ROP real potential depth would be indeed the si one $V_R = (106.2 + 5.17\,Z/A^{1/3})$ MeV [8]. This formul also obtained as an average value of the V_R data in Tabl Ref. [6] but without taking into account the energy depenc which actually has not been significant in the limit of stat errors. The ROP parameter set taking into account this hereafter referred to as ROP+, is already leading to the c maxima and minima position for the cross section ratio (curves in Fig. 1).

Moreover, the largest parameter change, which is nece for the description of the new data features, concern imaginary potential depth W_D. Thus, by removing the plateau of this OMP parameter for the α-particle en between 16 and 24 MeV, and using only the corresponding

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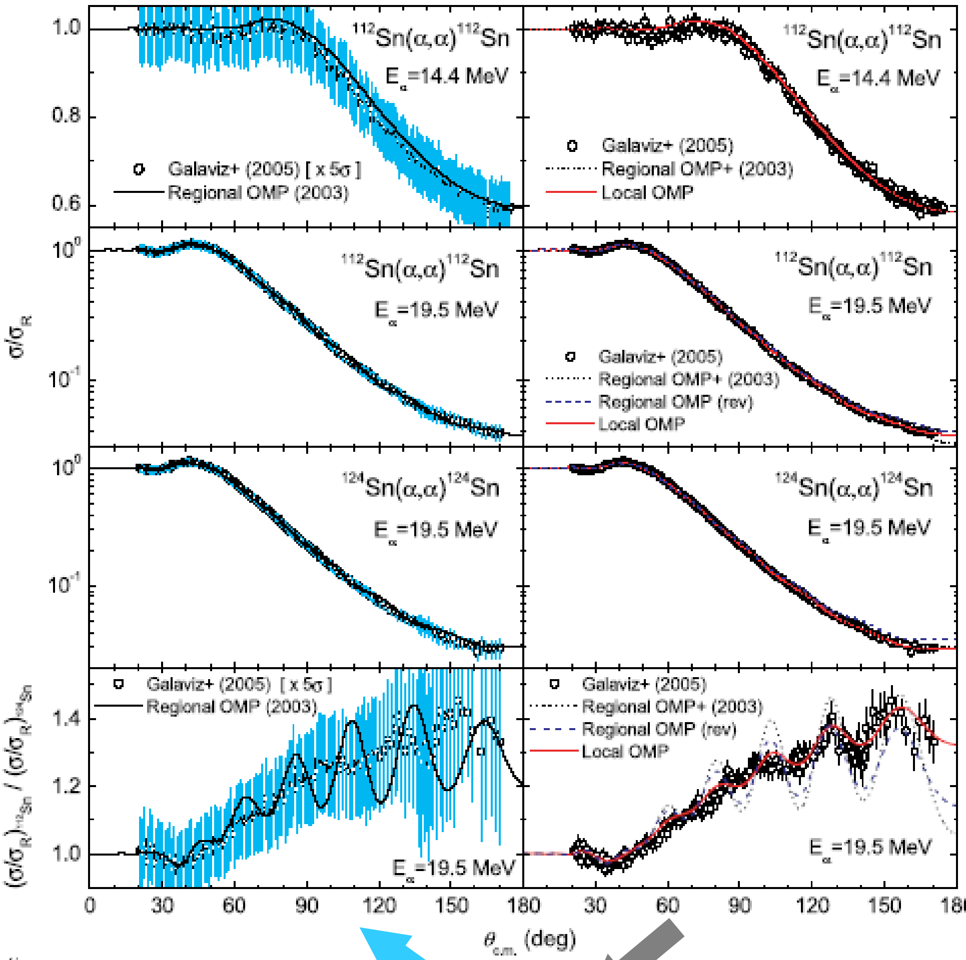
High precision:uncertainties <3-4%
(data basis average: ~15%)

New features of exp. data

New opportunities also for model understanding



x 5σ

Recent IFIN-HH results vs.   n_TOF-Ph2 o

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Nuclear Physics A 806 (2008) 15–39

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Fast-neutron induced pre-equilibrium reactions on ^{55}Mn and ^{63,65}Cu at energies up to 40 MeV

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[d] Brookhaven National Laboratory, PO Box 5000, Upton, NY 11973-5000, USA
[e] Nuclear Reseb and Consultancy Group NRG, PO Box 25, 1755 ZG Petten, The Netherlands
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Available online 21 March 2008

Abstract

The experimental cross sections for all neutron-induced reactions on the stable isotopes of Mn and Cu at incident energies up to 40 MeV are compared with results of pre-equilibrium (PE) and statistical model calculations. Taking advantage of the large sensitivity of statistical model analysis to residual nuclei parameters, for energies up to 20 MeV, our work was then focused on assessing PE model assumptions by data analysis in the energy range 20–40 MeV. The PE model reliance on the nuclear potential finite-depth correction for description of particle–hole state densities (PSD), nuclear-shell effects in the PSD formula, and single-particle level density is thus discussed with regard to the whole data ... The ... variance of the model results has been found as large as the differences between the glob... calculations, while the data basis available between 20 and 40 MeV for the Mn and Cu is too scarce in this respect.

PACS: 24.10.-I; 24.60.Dr; 25.40.-h; 28.20.-v

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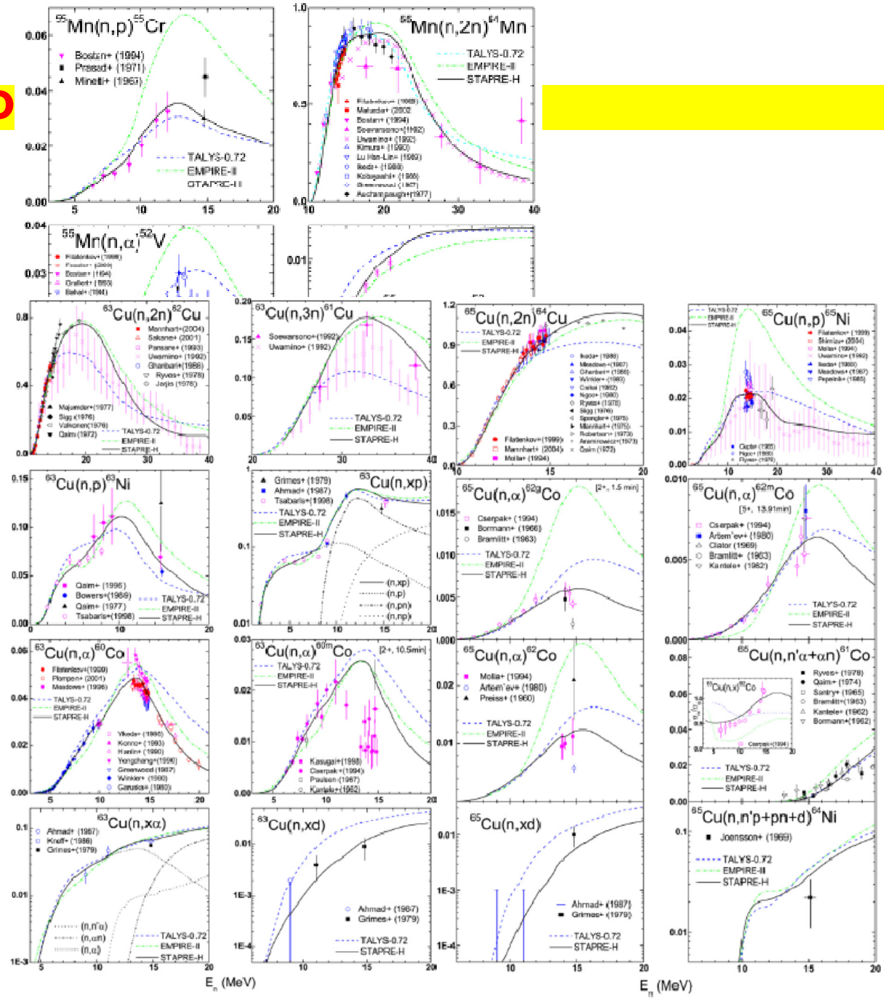
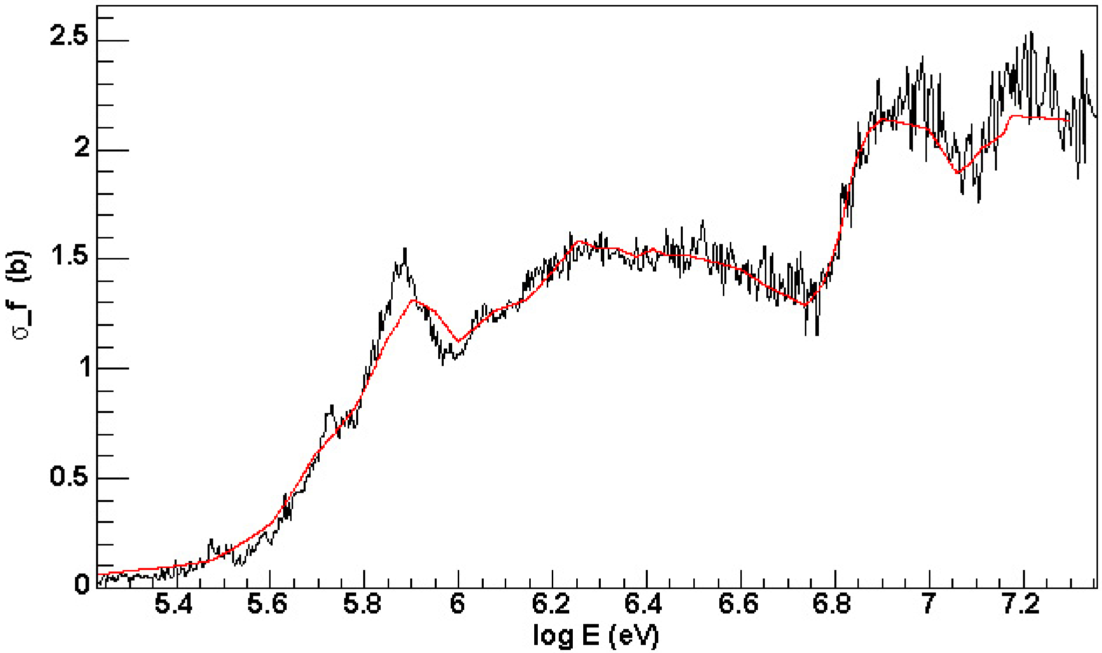


Last but not least, there is indeed great interest in modern nuclear physics at low energies for microscopic dynamical models such as, e.g., DYWAN [13]. However, for the time being this kind of models are used to gain a better understanding of the microscopic mechanisms involved in nucleon-induced reactions in order to obtain valuable information about nuclear interaction properties [13]. Extended/unified semi-classical models may have a rather similar role as it was proved by Ref. [14] according to which no mixing of particle–hole configurations provides a more consistent description of PE reactions. Thus, it will be more difficult to use such models in systematic studies of nucleon-induced reactions as within the recent European program HINDAS (e.g., [15] and references therein), or in the latest SPIRAL2-NFS [16] and n_TOF-Ph2 [17]

[17] A. Mengoni, F. Käppeler, E. Gonzales Romero, et al., n_TOF Collaboration, n_TOF-Ph2 Activities at the Neutron Time of Flight Facility at CERN, CERN, Geneva, 2005, http://www.cern.ch/ntof/Documents/LoI_2005/.

Sectiune eficace (nepublicata) pentru fisiunea indusa de neutroni a 234U obtinuta in cadrul programului n_TOF intre 200 KeV si 20 MeV. Se obtine un numar mare de rezonante care nu sunt de natura statistica si care nu pot fi explicate.



FISSION:

UDERSTANDING THE FISSION MECHANISM / INVESTIGATION OF THE INTERMEDIATESTRUCTURE IN THE RESONANCE REGION
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ISOTOPIC DISTRIBUTION OF FISSION PRODUCTS / IMPROVEMENT OF EVALUATIONS

EUROPHYSICS LETTERS 1 March 2006

Europhys. Lett., **73** (5), pp. 705–711 (2006)
DOI: 10.1209/epl/i2005-10454-x

Fine structure of the 0.7 MeV resonance in the ^{230}Th neutron-induced fission cross-section

M. Mirea[1], L. Tassan-Got[2], C. Stephan[2], C. O. Bacri[2] and R. C. Bobulescu[3]

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[3] *Faculty of Physics - P.O. Box MG-11, Bucharest, Romania*

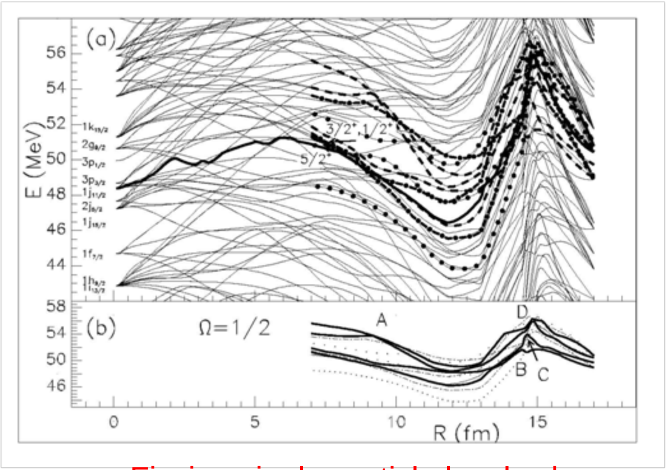
received 10 November 2005; accepted in final form 9 January 2006
published online 18 January 2006

PACS. 24.10.-i – Nuclear reaction models and methods.
PACS. 24.75.+i – General properties of fission.
PACS. 25.85.Ec – Neutron-induced fission.

Abstract. – The fine structure of the 0.7 MeV resonance in the ^{230}Th neutron-induced cross-section is investigated within the hybrid model. A very good agreement with experimental data is obtained. It is suggested that the fine structure of the cross-section quantifies the changes of the intrinsic states of the nucleus during the disintegration process.

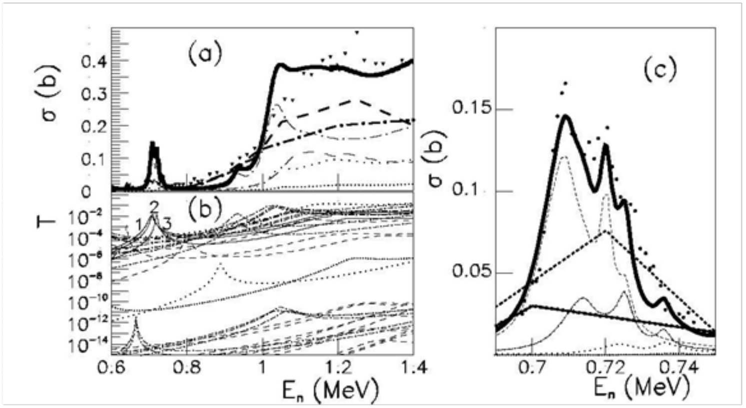
Introduction. – The neutron-induced cross-sections of ^{230,232}Th exhibit multiple fine structures [1,2] superimposed on a gross structure of the threshold cross-section. If the fine structure is interpreted as a series of rotational states constructed on a β-vibrational state produced in some well of the multidimensional barrier, it is straightforward to postulate the existence of a triple-humped barrier. The spacing between the members of the band is so small that it is consistent only with a parent nucleus with prolate deformation that reaches the vicinity of the second-barrier top. Therefore, a shallow minimum can be expected at this deformation to create a β-vibrational state. Up to now, the assumption of a triple-humped barrier seems to be the best interpretation for the fine structure of intermediate cross-section resonances [3]. The principal aim of the present work is to offer an alternative explanation of this phenomenon by taking into account dynamical single-particle effects.

Recently, a Hybrid Model (HM) [4] was developed in order to investigate the intermediate structure of the fission cross-section. In the frame of the HM, the excited states during the deformation process of the parent nucleus and their realization probabilities must be obtained. The occupations of the excited states are determined theoretically by solving microscopic equations of motion. The energy shifts due to these excited states are added to a phenomenological double-humped barrier and new barriers with different shapes are constructed. The energy width in the fission channel is proportional to the weighted summation of the penetrabilities of these barriers. The fine structure of the 0.7 MeV resonance of the ^{230}Th neutron-induced cross-section is studied within our model.



Fission single-particle level scheme
DYNAMICAL SINGLE-PARTICLE EFFECTS

Th anomaly (fine structure)
PERFECT AGREEMENT



INSTITUTE OF PHYSICS PUBLISHING JOURNAL OF PHYSICS G: NUCLEAR AND PARTICLE PHYSICS

J. Phys. G: Nucl. Part. Phys. **31** (2005) 1165–1181 doi:10.1088/0954-3899/31/11/004

Dynamical single-particle effects in the threshold fission cross section

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Received 4 April 2005
Published 24 August 2005
Online at stacks.iop.org/JPhysG/31/1165

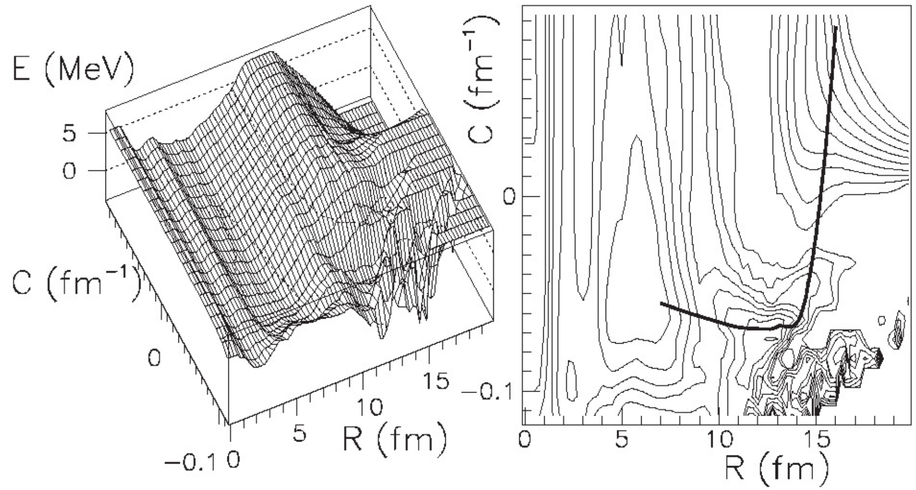
Abstract

A new formalism intended to simulate the cross section of the threshold neutron induced fission is proposed. The barriers corresponding to excited intrinsic single-particle states are taken explicitly into account. The radial coupling damping is treated within the Landau–Zener effect while the second-well damping due to re-emission in other channels is treated within an imaginary potential. In this context, the excitations are strongly dependent on the internuclear velocity between the two nascent fragments, and therefore managed by the dynamics of the system. An example of the neutron induced fission cross section of ^{234}U is given.

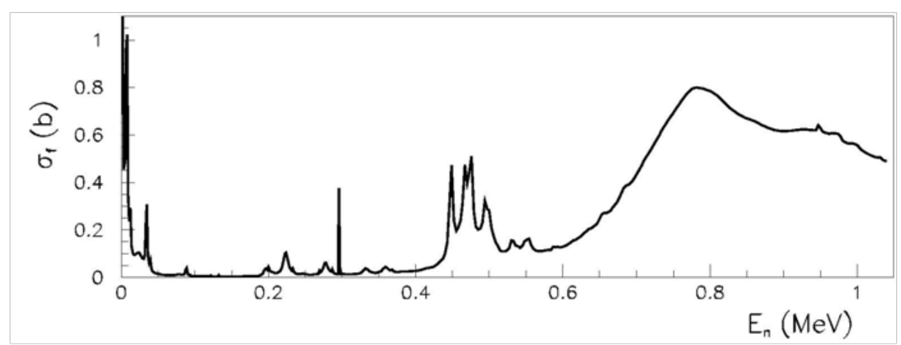
1. Introduction

The development as well as the design of new nuclear reactors requires a more precise knowledge of the cross-section behaviour [1]. The gross features of the fission cross section can be explained by the existence of a double-humped fission barrier which allows vibrational excitations in the second well. Using a suitable parametrization of the double barrier which depends essentially on its height, it is possible to reproduce satisfactorily experimental data. The intermediate structure is explained by the interaction of states constructed in the first and second wells [2]. A resonance appears when the spin and parity of class I states match those of class II. Due to the crude approximation used in evaluating the interaction matrix elements and the poor knowledge of class II states, only qualitative features of the intermediate structure can be extracted. An alternative explanation of the intermediate structure phenomenon is sought in the following by investigating the effects due to single-particle excitations during the deformation of the decaying system. The aim of this work is to improve future simulations.

The calculations presented below show that the rich resonant structure observed in the fission cross section is possibly due to dynamical single-particle effects which increase the number of channels in the fission degree of freedom. Briefly, varying the internuclear distance



Minimal action trajectory in a multidimensional configuration space



234U neutron induced cross section
INTERMEDIATE RESONANCE STRUCTURE

PHYSICAL REVIEW C **76**, 064608 (2007)

Landau-Zener effect in fission

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A model that takes into account the Landau-Zener promotion mechanism during fission was developed recently. The structures observed in the subthreshold neutron-induced fission of ^{232}Th are investigated employing this model. Theoretical single-particle excitations of a phenomenological two-humped barrier are determined by solving a system of coupled differential equations for the motion along the optimal fission path. A rather good agreement with experimental data is obtained using a small number of independent parameters. It is predicted that the structure at 1.4 and 1.6 MeV is mainly dominated by a spin 3/2 partial cross section with a small admixture of spin 1/2, while the structure at 1.7 MeV is given by a large partial cross section of spin 5/2.

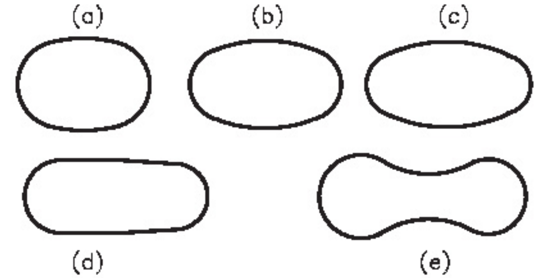

FIG. 4. The shapes obtained along the minimal action trajectory. (a) The ground state with elongation $R = 5.8$ fm and necking coordinate $C = -0.053$ fm^{-1}. (b) The region of the first barrier with $R = 10.57$ fm and $C = -0.04$ fm^{-1}. (c) The region of the second well with $R = 13.69$ fm and $C = -0.0508$ fm^{-1}. (d) The region of the second barrier with $R = 15.139$ fm and $C = -0.008$ fm^{-1}. (e) The region of the exit from the barrier with $R = 17$ fm and $C = 0.085$ fm^{-1}.

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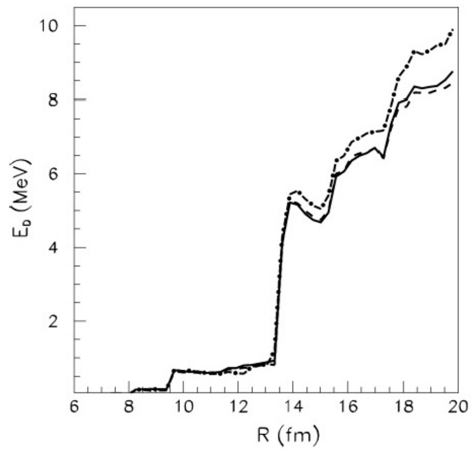

FIG. 12. Dissipated energies during the fission process for three energy paths: full line for trajectory No. 1, dashed line for trajectory No. 7, and dot-dashed line for trajectory No. 20 of Table I.

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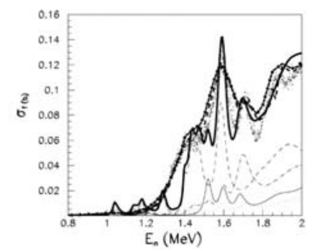

FIG. 10. The thick full line represents neutron-induced cross section for ^{232}Th as a function of the neutron incident energy E_n calculated within the hybrid model. Points are experimental data. The thick dashed line represents the ENDF/B-IV evaluation while the thick dot-dashed line is the JENDL-3.3 one [40]. Experimental data are from Refs. [5,6,41]. A thin full line gives the partial cross-section of spin 1/2, a dashed line is for the spin 3/2, the dot-dashed line is for 5/2, and the dotted line is for 7/2.

the phenomenological barrier. In the work presented in this article, no adjustments are made to improve the agreement, the simulations being based only on the phenomenological barrier parameters and the internuclear velocity.

Our simulations evidence an oscillatory behavior of the cross-section close to 1.4 MeV. This aspect is in agreement with the experimental data given in Ref. [42]. The experimental data combined with theoretical arguments estimate a ratio 2:1 between the partial cross-section of spin 3/2 and 1/2,

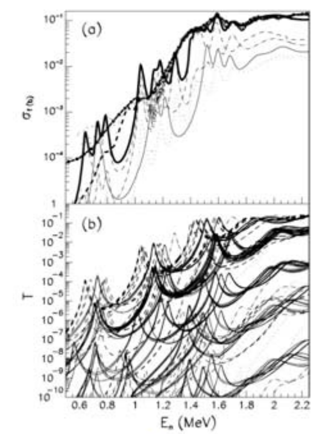

FIG. 11. (a) Same as Fig. 10 in an extended logarithmic scale along the y axis. (b) $L = 0$ fission transmissions for different barriers as a function of the neutron energy E_n. The transmissions for $\Omega = 1/2$ excitations are plotted with full lines, those for 3/2 with a dashed line, those for 5/2 with a dot-dashed line, and those for 5/2 with a dotted line.

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Target screening effect on the pre-emission of neutrons from ^{11}Li halo nuclei

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For the first time to our knowledge the target screening effect on the pre-emission of halo neutrons from ^{11}Li has been quantitatively analyzed. Our work has been performed in the 7.5–15 MeV neutron energy range. In this range the target nuclei are likely to behave as opaque, and therefore the sharp-cutoff calculations are most appropriate for the target screening determination. It has been observed that the ζ probability used in the sharp-cutoff calculations is an observable of the experiment, because it can be directly obtained from measured quantities, which are the number of single detected neutrons and the number of detected neutron pairs. The value of ζ_{exp} obtained this way in the case of a Si target appears to be close to the ζ value calculated for the ^{11}Li halo radius $R_H = 4.8$ fm, independently determined in another experiment [Phys. Lett. **B287**, 307 (1992)]. This property also allows investigation of Borromean halo nuclei such as ^{6}He, ^{14}Be, and ^{17}B, for which R_H was not yet measured. The calculated value within the present approach of the two-neutron pre-emission yield appears to be 3.5 times larger in the case of ^{12}C than in the case of a Si target.

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efficiencies, allow the estimation of the neutron pre-emission probability ζ_{exp}. The ζ probabilities calculated in the case of Si and C targets by use of a sharp-cutoff approach will be presented afterward. It is shown that there is good agreement between ζ_{exp} and the calculated ζ when the value of the ^{11}Li halo radius R_H are taken equal to 4.8 fm [7]. For the

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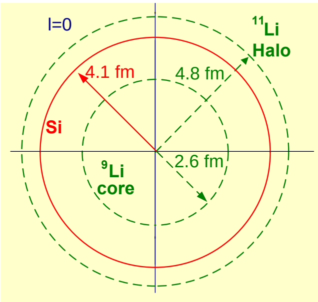

Fig.1. Schematic representation of collision ^{11}Li + Si target

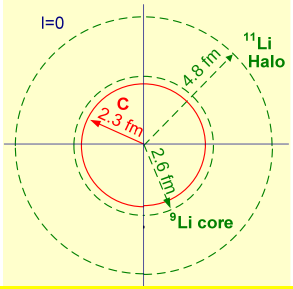

Fig.2. Schematic representation of collision ^{11}Li + C target

One can see from Fig.1 and Fig. 2 that there is a marked difference In the screening between the Si and the C targets. In Table I it is shown that the two neutron pre-emission probability *P{2}* calculated by sharp-cutoff is 0.492 for C target and 0.144 for Si tar-get, that is by about 3.5 times larger for C target than for Si target.

TABLE I. Values of ζ probabilities (column 4) calculated by the sharp-cutoff formula (8), for two targets ^{12}C and Si (column 1) and for three values of R_H (column 2). In column 3 is the value of ζ_{exp} obtained from the number of detected single neutrons and the number of detected neutron pairs (the error ±0.06 has been estimated). In columns 5, 6, and 7 the values of $P^{[1]}$, $P^{[2]}$, and $P_a^{[2]}$, calculated according to formulas (9), (10), and (11) are given. In the last column it is shown that the $P^{[1]}$, $P^{[2]}$, and $P_a^{[2]}$ probabilities satisfy the normalization condition.

Target	R_H(fm)	ζ_{exp}	ζ	$P^{[1]}$	$P^{[2]}$	$P_a^{[2]}$	sum($P^{[i]}$)
^{12}C	4.8		0.701	0.418	0.492	0.089	~1
	4.2		0.610	0.475	0.372	0.151	~1
	3.6		0.469	0.498	0.220	0.281	~1
Si	4.8	0.36	0.379	0.471	0.144	0.384	~1
	4.2		0.286	0.408	0.081	0.509	~1
	3.6		0.205	0.327	0.042	0.630	~1

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EXOTIC NUCLEI AND FUNDAMENTAL INTERACTIONS

Neutron–Neutron Correlation Approach for ^{11}Li Halo Structure Investigation*

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Abstract—The preemission of neutrons from ^{11}Li halo nuclei is considered. The present problems of investigation of ^{11}Li halo nucleus structure by means of the C_{nn} correlation function are briefly presented. The influence of the target screening on the halo neutron preemission is described. It is shown that, owing to the diminishing of the screening effect, the yield of preemission neutron pairs is expected to be much larger in the case of ^{12}C than in the case of Si target. It is shown that a new experiment on a ^{12}C target will allow one to solve the standing problems of C_{nn} and to test experimentally a recent new theory of C_{nn}.

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1. INTRODUCTION

It was predicted in [1] that, owing to the very large radius of ^{11}Li and the very low binding energy of the halo neutrons, one may expect that, in a fusion process on a light target, the halo neutrons may not be absorbed together with the ^{9}Li core, but may be emitted in the early stage of the reaction. Indeed, the experimental investigation of Si (^{11}Li, fusion) has shown that a fair amount of fusion events [2] are preceded by the preemission of one or two halo neutrons,

residual correlation of the halo neutrons [9]. An iterative calculation was proposed in [9] to compensate for the residual correlation. But it was shown in [6, 8] that an iterative calculation increases the error considerably, so that it is not possible to draw any conclusion concerning the theoretical predictions. In [6], an experiment was proposed for getting the intrinsic correlation function by using ^{11}Li and ^{11}Be beams. The halo nucleus ^{11}Be would be ideal denominator of the correlation function construction, because it has only one halo neutron and therefore no residual

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larger in the case of C target than in the case of Si target.

Very recently, a new theory for the C_{nn} correlation function has been proposed [10]. In this theory, the ^{11}Li halo nucleus is modeled as a three-body system consisting of two neutrons and a core. It is shown that an interference minimum is present in C_{nn}, due to

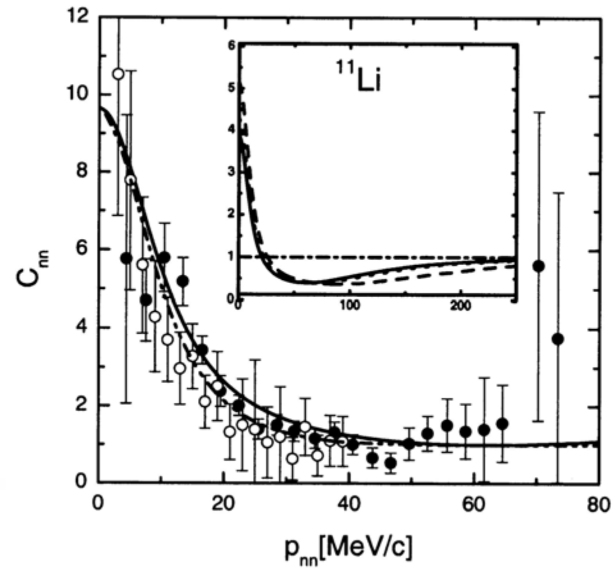
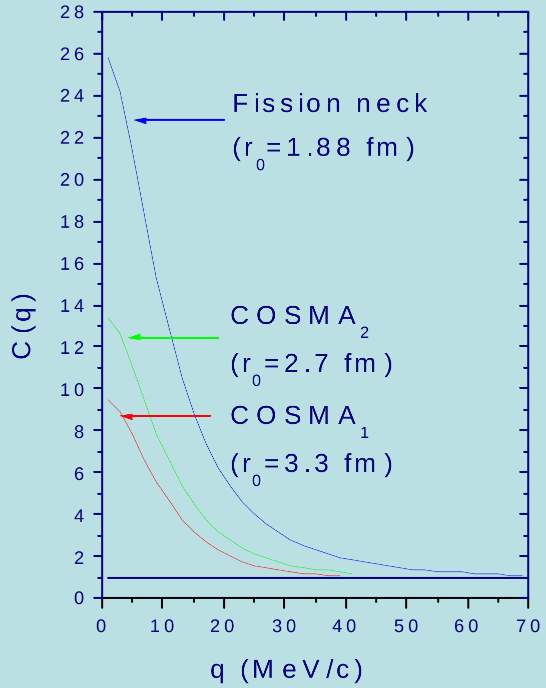


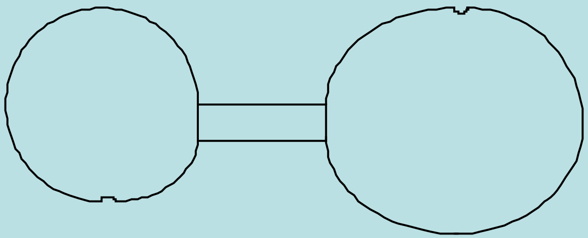
Fig. 1. This fig. is taken from ref. [1]. In the insert is shown the C_{nn} correlation function for ^{11}Li calculated by using a 3-body model [1]. The minimum in the insert is due to the coherence bet-ween the 2 halo neutrons. In Table 3 it is shown that the new theory can be tested (Case 2) for a statistics of nn predicted in previous attached paper.
[1] M.T.Yamashita et al., Phys. Rev. C72, 011601(R) (2005)

Table 3. Statistical errors of measurements of values of correlation function C_{nn} for different values of relative momentum q of two coincidence neutrons and for different statistics of coincidence (cases 1–3 in Section 3.1)

q, MeV/c	Case 1	Case 2	Case 3
21	0.29	0.11	0.09
23	0.49	0.18	0.15
25	0.74	0.28	0.23
27	0.38	0.14	0.12
29	0.54	0.20	0.17
31	0.55	0.21	0.17
33	0.74	0.27	0.23
35	0.52	0.19	0.16
37	0.66	0.25	0.20
39	0.64	0.24	0.20

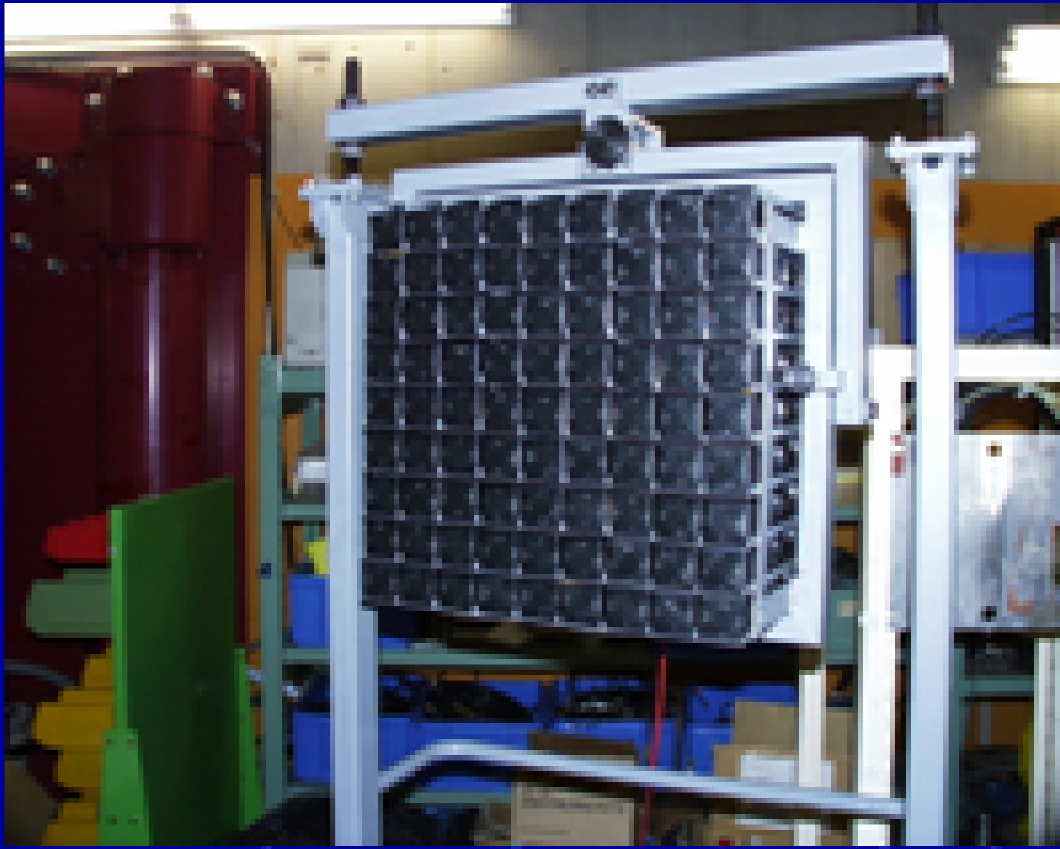
Correlation Functions





The Neutron Array Detector

Consists of 81 detectors, made of 4x4x12 cm^3 BC-400 crystals, mounted on XP2972 phototubes. This detector, placed in forward direction at 138 cm from the target, was used for the neutron energy determination by time of flight technique and for neutron position determination. The distance between adjacent detectors was 0.8 cm. The array components were aligned to a threshold of 0.3 MeVEE, by using the cosmic ray peak at 12 MeV (8 MeVEE).



In IFIN-HH exista experienta privind fizica neutronilor. Speram ca vizibilitatea activitatii noastre in domeniu va creste pe plan international datorita participarii in cadrul colaborarii n_TOF CERN. Fizica abordata prezinta interes de actualitate in contextul dezvoltarii noilor generatii de reactori hibrizi.