THREE-BODY CORRELATIONS DATA ANALYSIS THROUGH MONTE CARLO SIMULATION IN DECAY OF ^{10}He*

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(Received December 14, 2016)

This work concerns the program for Monte Carlo (MC) simulation of three-body decays data. Three-body events are characterized by complicated correlations hindered by induced distortions due to finite resolution of experimental setups. The MC code is developed and tested by performing the analysis of the ^{10}He experiment which shows the unusual order of first excited states of ^{10}He.

DOI:10.5506/APhysPolB.48.683

1. Introduction

The development of experimental techniques enabled studying of weakly bound three-body systems at the nuclear drip-line. Three-body correlation data are most informative providing insight into research of nuclear structure and reaction mechanisms. However, ability to extract this information is hindered by distortions induced by experimental setup. To overcome this difficulty, the results of theoretical estimations should be modified by the use of MC simulations taking into account peculiarities of the measuring apparatus. The need for fully quantum mechanical MC event generator was first realized in 2005 while studying the population of ^{5}H states [1].

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* Presented at the Zakopane Conference on Nuclear Physics "Extremes of the Nuclear Landscape", Zakopane, Poland, August 28–September 4, 2016.

TEG-DDR (Three-body Event Generator for Decays and Direct Reactions) is the abbreviation of MC event generator developed specially for reactions and decays populating continuous states in systems close to the limits of nuclear stability and beyond them. Nowadays, in the specific field of three-body decay and continuum studies, this code has no analogy in the world and allows considering the three-body dynamics in full complexity if the corresponding theoretical models are available. The development of the generator started at JINR [1]. This code with different modifications was successfully used in data treatment made for several experiments [2–7] which allows to speak about a demand for this program.

TEG-DDR was created to calculate three-body dynamics in nuclear reactions. It is characterized by internal and external correlations. Internal correlations are energy ratio of subsystems and relative angle between the subsystem. External correlations are represented by: *(i)* transferred momentum $\vec{q}$ (which connects the laboratory system to the center-of-mass system), *(ii)* Jacobi momenta of subsystems k_x and k_y, and *(iii)* Euler angles of the reaction plane rotation.

2. Cross-section parameterization for three-body decay

TEG-DDR is based on the MC calculation of the reaction cross section. In general case, the cross section for reactions populating three-body continuum is a 9-fold differential. The most general parameterization in hyper-harmonic representation in terms of the density matrix ρ and three-body amplitudes A looks as [5]

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\vec{q}\,\mathrm{d}E_{\mathrm{T}}\,\mathrm{d}\Omega_5} = \sum_{JM,J'M'} \rho_{JM}^{J'M'}(\vec{q}, E_{\mathrm{T}}) \sum_{SM_S} A_{J'M'}^{\dagger\, SM_S}(E_{\mathrm{T}}, \Omega_5)\, A_{JM}^{SM_S}(E_{\mathrm{T}}, \Omega_5)\,, \quad (1)$$

where E_{T} is total energy of three-body system, Ω_5 is hyper-harmonic angle. J and M are total momentum of the system and its projection. S and M_S are spin and its projection. Density matrix part corresponds to the probability of the reaction channel. In decays, there is no alignment in final state, therefore, the density matrix has an especially simple form in the frame with the z-axis coinciding with the direction of the transferred momentum. Three-body amplitudes A are internal variables of the system. In this work, three-body amplitudes were obtained empirically but it is also possible to calculate them via a theoretical model.

3. Actual problem: analysis of ^{10}He experiment

In [8], ^{10}He was investigated via the missing mass method in the two-neutron transfer reaction ^{3}H(^{8}He$, p)^{10}$He where ^{10}He further decayed into ^{8}He and two neutrons. Spin-parities of the ^{10}He states populated in the reaction were identified by analyzing the angular and energy correlations of the decay products of the investigated nucleus. The experiment revealed the ^{10}He energy spectrum featured a distinct wide peak at $E_{\mathrm{T}} \sim 2$ MeV, which was interpreted as the ^{10}He ground state. At excitation energies of 3–10 MeV, the spectrum showed no pronounced peaks that could be associated with the internal ^{10}He structure. At the same time, the angular (the emission angle of the ^{8}He fragment relative to the transferred momenta direction) and energy (relative energy of ^{8}He fragment in the ^{10}He system) correlations of the ^{10}He decay products exhibited very characteristic features that allowed some quantum states to be distinguished in the smooth spectrum of the ^{10}He nucleus. The angular correlations were obtained by fitting the experimental data with the Legendre polynomials. Analyzing the angular correlations of the ^{10}He decay products allowed to identify the spin and parity of the state from which the decay proceeded. That revealed the inverse sequence of first excited states of ^{10}He which occurred to be unexpected. In order to obtain confirmation of this statement, the complete analysis of the experiment is demanded.

4. Simulation of angular and energy correlations of ^{10}He

^{10}He energy correlations were generated in a realistic approach. Considered states (0^+, 1^-, 2^+ states) were in the first approach represented by sets of two most significant hyper-harmonics for each state except the ground one.

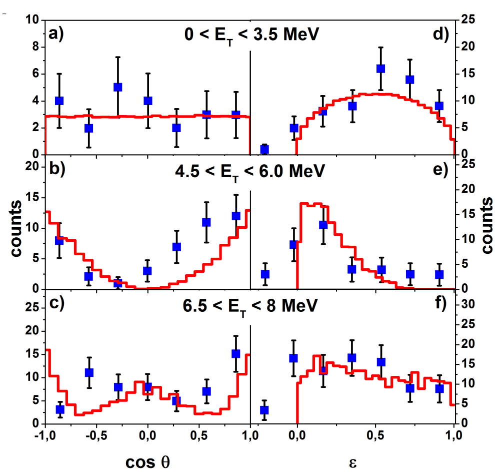

Fig. 1. Plot of ^{10}He correlations measured in three ranges of the ^{10}He excitation energy E_{T} corresponding to the 0^+, 1^- and 2^+ states. (a)–(c): $\cos\theta$ angular distributions of ^{8}He relative to the transferred momentum. (d)–(f): ε energy distributions between neutrons. Squares with error bars are the experimental data [8]. Solid lines are histograms of the simulated data of this work.

In the Fig. 1 (d)–(f), the comparison of simulated and experimental [8] data is shown. The simulated histograms show a good correspondence with the experimental data.

The angular correlations here are presented by simulation of sum of single ^{10}He states (see Fig. 1 (a)–(c)). Although the main trend of angular distributions is similar to the experimental data, their asymmetry indicates the mixture of several states which causes interference. Now, the work on performing calculation taking into account interference of states is under conducting.

5. Conclusions and outlook

A complete analysis of [8] experiment with the help of the TEG-DDR is essential for explanation of unusual order of excited states of ^{10}He. The simulation of energy correlation data showed a good agreement with the experiment. While the simulation of single states sum of ^{10}He enables to draw a conclusion about main contribution of these states into different parts of the energy spectrum, asymmetry of the angular distributions witnesses to the interference of several states. Calculations including interference of three states in the spectrum are being performed at the moment.

The work is carried out with the financial support of FRRC.

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