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New status of the project "η-nuclei" at the NUCLOTRON

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In 2006-2010 a set of experimental data on the internal d-beam of the Nuclotron and two-arms time-of-flight setup has been produced. These data indicate the possible existence of η-mesic nuclei. The new project should provide a significant increase of the energy resolution of the upgraded setup, including through the inclusion of a magnetic spectrometer in the experimental installation and increase the time-of-flight base. We review status of the new project on the search of the η-mesic nuclei at the internal target of the Nuclotron, LHEP JINR.

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1. Introduction

A bound system of strongly interacting particles in a nucleus have provided variable information about various aspects of hadron-nucleon interaction in a nucleon environment. In the past, the intensive stydies of the η-meson are predict of the existence of a bound state of η-meson in a nucleus. This phenomenon has been termed as η-mesic nucleus [1]. At the present moment, the experimental status of η-mesic states in nuclei, same measurements give a positive indication of the existance of such states [2]-[6].

2. Formation and decay of η-mesic nuclei

The predictions of the η-meson nuclear bound state based on the analysis of the η-nucleon scattering length $a_{\eta N}$ and the solutions with ηN potentials. Experimental researches are currently limited unavailability of the meson beams. As a result, multi-step reactions are investigated. Where the initial stage is formed meson with is reacted the remainder of the nucleus. In the final stage of the η-meson decays mainly through a nucleon resonance state S_{11} and the products of this decay is analyzed. The random walk inside the nucleus allow of η-meson has independent multiple scatterings on different nucleons $\eta + N_1 \to \eta + N_1 \ldots \eta + N_m \to \eta + N_m$. This chain of rescattering ended conversion η -meson-nucleon to energetic πN or NN-pair which escapes from the nucleus. The η-mesic nuclei in very unstable short lived formation. The width of this process is estimated at the level $\Gamma \approx 10 \div 20$MeV [7, 8]

It is important to recognize that if we register πN pair with approximately equal but opposite momentum components, even with some total energy $E_\pi + E_N \approx m_\eta + m_N$ (1487$\div$1489 MeV/c^2), it does not mean that we have registered the decay products of the η-mesic nucleus. The pair with a small total momentum can be produced from the annihilation of slow unbound η-meson and slow intranuclear nucleon. The criterion of a bound η-meson is two factors: the total energy of the πN pairs should be below the threshold ($E_\pi + E_N < m_\eta + m_N$) and a narrow mass distribution of the πN pairs. The energy and width of this distribution will give information about the energy level of meson bound in a nucleus [9].

Theoretical predictions for the binding energy and width of the η-nuclear levels are highly dependent on the assumed nuclear potential ηA and nucleus size. For example, for the carbon core is predict a binding energy according to 1-10 MeV and a level width is according to 7 MeV and 35 MeV.

The idea of the experiment is in observing decays of resonances excited in a target nucleus after capturing the η-meson. In the case of a recoilless reaction the rest of the target nucleus has a small momentum, so products of the resonance decay are emitted to nearly back-to-back directions. Detection of the particles emitted in opposite direction is the good method for separation of the explored decays from another ones.

The project is aimed on search for η-nuclei at an internal beam of the Nuclotron in the reactions

$$d + A \to (A_2)_\eta + \ldots \to \pi + N + \ldots \tag{2.1}$$

$$d + A \to (A_2)_\eta + \ldots \to N + N + \ldots \quad (2.2)$$

where the A_2-nucleus is part of nucleus A formed in the d + A collision. Hadrons emitted in transverse directions are detected by a spectrometer. The flow of particles includes NN or πN pairs which are products of η-nuclei decays. A bound state of η is expected to be seen as a peak in the total energy spectrum of these pairs.

3. Experimental results

In 2006-2010 the experiment was carried out at the internal deuteron beam of the accelerator Nuclotron with the primary beam energy T_d between 1.5 and 2.1 GeV/nucl. Some experimental results are presented in [11].

In the region of a back-to-back πp pair effective mass $M_{eff} \approx 1450$ MeV/c^2 a visible peak has been registered. A fit of the data with an exponent + a gaussian functions gives the peak position at 1447.8 $\pm$ 3.6 MeV/c^2 with the width 38.8 $\pm$ 10.4 MeV/c^2.

The value of the total cross section has been estimated $\sigma_{A_\eta} \approx 11 \pm 8\mu b$.

Also, narrow peaks in a spectrum of masses were observed experimentally in Mainz [2] (for a nucleus ^{3}He: a binding energy is about 4 MeV, width is about 25 MeV; the peak was observed in a spectrum of π^0p-pairs) and in COSY [3] (for a nucleus ^{25}Mg: a binding energy is about 13 MeV, width is about 10 MeV).

4. Requirements of experiment

Based on the experience we can formulate the basic criteria for an optimal spectrometer. The task of the experiment is the allocation and measurement of the narrow peak in the energy distribution of pairs, which are products of η-nucleus decay. It should assume that the peak width will be about 10 MeV, and therefore the future experiment should provide accurate measurements of particle energies not worse than 3.5 MeV, so that the accuracy of the total energy of the pair will be at least 5-7 MeV.

If we consider the process η + $N_i \to \pi$ + N with initial particles at rest, the kinetic energy, momentum and velocity of the secondary particles must be equal (if we ignore the effect of binding and Fermi motion): Eπ = 313 MeV, E_N = 94 MeV, p_π = p_N = 431 MeV/c, β_{pi} = 0.95, β_N = 0.42. Accordingly, experiment performance demands precisions of measurement of kinetic energy at level of 1% for pions and 3 % for nucleons.

It is necessary to point that besides decay on channel πN η-nuclei can decay with emission NN pair. It occurs at the expense of an Îů-meson annihilation on pair of the intra nuclear nucleons $\eta + N_i + N_j \to N_1 + N_2$.

Channel NN has a relatively low background. If to consider background processes, it is possible to expect that knocking-out of two nucleons with high energy ($\approx$ 270 MeV) and transverse to the beam is less probable, than knocking-out of πN-pair where the nucleon has energy $\approx$94 MeV and the pion energy is $\approx$300 MeV. At comparable outputs of πN and NN pairs from decay of η-nucleus it means essential increase in the relation of a signal/background.

It should be noted that the energy release in the reaction $\eta N_i N_j \to N_1 N_2$ is $m_\eta = 547 MeV/c^2$, so the kinetic energy, momentum and velocity of the emitted nucleons are about $E_1 = E_2 = 273$ MeV,

$p_1 = p_2 = 767$ MeV/c, $\beta_1 = \beta_2 = 0.63$. Accordingly, experiment performance at the declared level demands accuracy in measuring of kinetic energies of such nucleons at level of 1%. It is possible to achieve the required accuracy only by magnetic analysis and study NN-channel of reaction only neutron spectrometry.

5. The new experimental set-up

The new project performed in LHEP JINR provides a significant increase of the energy resolution. This upgrade is include the modernization of one arm to magnetic spectrometer and increasing the time-of-flight base. It allow to measure sign of pions and momentum with good precision. In addition, the neutron registration will be realise in the new project. This modification will expand the number of investigated channels of the reaction and, in particular, it will allow to obtain and analyze data on the decays of η-mesic nuclei into the proton-neutron channel.

A schematic view of the upgraded spectrometer is presented in Fig.1, where (P1, P2, P3, P3, P5) is the ToF-detector for charged particles and neutrons; P1, M1 is the aperture detector of the left (right) arm of the set-up; P2, M2 is the starting ToF-detector of the left(right) arm of the set-up; Pch, Mch is the threshold Cherenkov detector of p - π identifications of the left (right) arm of the set-up; Mc1, Mc2, Mc3 are the drift chambers of a magnetic spectrometer. Taking

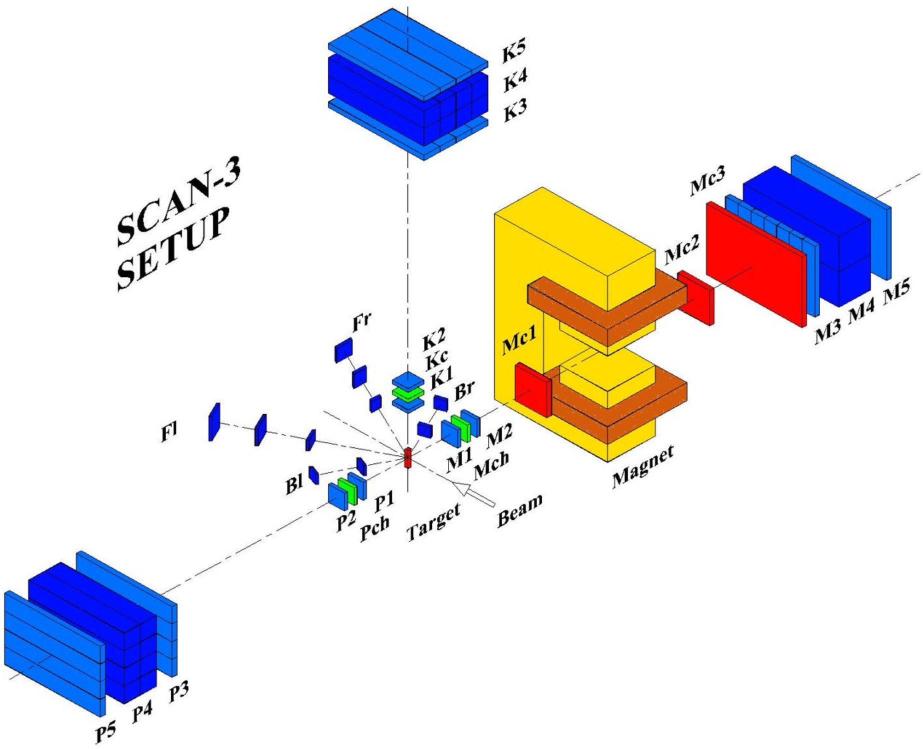

Figure 1: *The experimental setup for studying η-mesic nuclei*

into account the above assessment the new setup is planned as three arm spectrometer. The one arm is been constructing as a magnetic arm for charged particles and another two are time-of-flight spectrometers for registration of the neutrons and protons. This combination of detectors can register π^+n, π^-p, pn and pp pairs. All arm are located in plane. Two are horizontal and one is vertical. This disposition will be used for determination the studied processes and the background simultaneously.

The required energy resolution of resonance δE = $\delta(E_\pi + E_N)$ $\leq$10 MeV means the same requirement to energy resolution for each registered particle. If we propose what $\delta E_\pi = \delta E_N \leq 10/\sqrt{2}$ MeV it is require for time-of-flight measurement $\delta\beta_{TOF} \leq 10^{-2}$ and for the magnetic analyser is $\delta\beta_{MAG} \leq 10^{-3}$. The value $\delta\beta_{TOF}$ is limited of time resolution of detectors (δ_t) and base of flight (L). The values of $\delta t \leq$ 1ns and L $\approx$ 3m are satisfy it.

The accuracy of measured velocity in magnetic analyse $\delta\beta_{MAG}$ is a function of a curvature. It is measured as a transverse deflection of trajectory of particles in a magnetic field. For the charged pion this deflection is equal to X $\approx$ 15cm and δX should be $\leq$ 0.15 mm. The modern detectors have space resolution in ten times better and δX is limited of a multiple scattering of registered particle. We are planning use drift chamber (the space resolution better 0.1 mm) and helium bag for reduction of the multiple scattering to the level 0.1 mm. It allow us to make $\delta X \leq 0.15$ mm and $\delta\beta_{MAG} \leq 10^{-3}$.

Simulation of the new setup have been done using GEANT3 simulation program (root.cern.ch).

We considered the estimates of the outputs of the expected events Y(π^-p), Y(π^+n) and Y(pn) that are associated with the formation of η-mesic nuclei for the experiment on the internal proton beam of the Nuclotron. Outputs will be expected twice as much for the deuteron beam. In the case of 10μm ^{12}C internal target the output of double events Y(π^-p) $\approx$ 1.4 10^2 events/hours, Y(pp) $\approx$ 23 events/hour.

6. Summary

In 2006-2010 a set of experimental data on the internal d-beam of the Nuclotron and two-arms time-of-flight setup has been produced. The regular appearance of a peak in the effective mass spectrum of back-to-back πp pairs in the assumed area requires detailed research. For this studies the existing spectrometer have been almost upgraded. Testing of the elements of the new experimental setup is carried out on a beam of the Nuclotron.

The main objectives of the new experiment are:

- detection of the η-mesic nuclei in dA-collisions as resonance peak in a spectrum of a total energy of the correlated pairs;
- definition of the cross-sections of η-nuclei formation;
- measurements of the energy and A-dependence of the cross-section $\sigma({}_\eta A)$ in the dA-collisions;
- definition of a binding energy of η-meson in a nucleus, it is key parameter characterising potential of an attraction of the η-meson and nucleons at low energies;
- measuring of the ratio of output of (πp) and (pn) events;
- definition of the ratio of resonances widths Γ(πN) and Γ(NN).

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