Spectroscopy of η-mesic Nuclei Using Recoilless (d,^{3}He) Reaction

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Deeply bound pionic atoms were for the first time produced and discovered in 1996 at GSI by a novel technique of using the ^{208}Pb(d,^{3}He) reaction at T_d=600MeV [1]. In contrast to the conventional method to produce exotic atoms, the pion is directly produced in the nuclear reaction and substitutes one of the valence neutrons in the target nucleus. Fulfilling the zero-momentum transfer condition additionally delivers two unique features, namely the enhancement of the cross section to form such deeply bound states, and the selective population of the substitutional state, both of which are important for a precision determination of the binding energy and the width of the states. We performed subsequently a series of experiments for a precise measurement of the deeply bound pionic 1s state, from which we determined the s-wave pion-nucleus optical potential [2,3,4]. With their uniqueness and precision, the data on deeply bound pion-nucleus states initiated an exploration of their sensitivity to the partial restoration of chiral symmetry in the nuclear medium [4,5].

We extended the program to the spectroscopy of even more exotic systems, namely η meson-nucleus bound states. Since the η meson is a neutral particle, the system is bound solely by the strong interaction. Such a system should not be seen as an exotic atom but as a new kind of exotic nucleus. We use the ^{12}C(d,^{3}He) reaction with T_d=3.5GeV provided from SIS. The experimental feasibility and the impact on chiral models are discussed in Refs. [6,7] (Fig.1). A serious problem is the very high rate of protons from the break-up of the incident deuterons reaching up to 10^8/s. We have developed a new type of Cherenkov counter (TORCH) [8], which is only sensitive to the slow ^{3}He nuclei ($\beta \simeq 0.87$) while being totally blind to the fast background protons ($\beta \simeq 0.94$) even at a rate of 10^8/s. This indispensable background suppression capability of the experiment is realized by making use of the different total reflection conditions of the photons at the radiator surface which are created at different Cherenkov emission angles for ^{3}He and protons selected by the Fragment Separator (FRS). To achieve this, the proper refractive index of the Cherenkov radiator has to be chosen. Simultaneously a good position resolution is ensured by measuring the photon intensity distribution as a function of the x coordinate with PMTs (Fig.2). TORCH detectors are placed at the central and final focal plane of the FRS in order to do Time-of-Flight measurements.

Although ready in the beginning of 2004, the TORCH detector was further improved to have better rejection capability for delta-electrons produced from background protons by increasing the quality of the radiator.

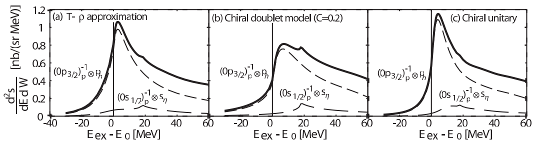

Fig. 1: The theoretical spectra of ^{12}C(d,^{3}He)^{11}B$\otimes\eta$ reaction at T_d=3.5 GeV calculated by (a) the t-ρ approximation, (b) the chiral doublet model with C=0.2, and (c) the chiral unitary approach. From Ref. [7]

Fig. 2: View inside the TORCH detector.

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