Understanding of QCD at low momentum transfer through a rare decay mode of light meson

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Introduction

The Standard Model is presently the accepted theory for the structure of matter. According to the Standard Model, matter consists of two kinds of elementary particles: Leptons, Quarks. With the help of these particles the Standard Model is capable to explain strong, weak and electromagnetic force. However, the Standard Model is unsatisfying as a fundamental theory, as it does not incorporate the physics of gravitation and has no explanation for the dark energy. In addition, it contains many free parameters, like the particle masses, the strength of the coupling parameters and the various mixing angles. These cannot be derived from the first principles but must be determined experimentally. It also does not account for neutrino oscillations, which were announced in 1998 by Super-Kamiokande experiment [1] and later confirmed by other experiments. These oscillations imply a non vanishing neutrino mass, whereas the Standard Model requires them to be massless.

Therefore a more fundamental and more complete theory is required, which can naturally explain all these parameters and which should also include the gravitation as the fourth interaction. One possible way to find physics beyond the Standard Model or towards a complete theory is the precise measurement of the processes, which are forbidden or suppressed within the Standard Model. The different decay modes of light mesons are promising test of the Standard Model. Another issue is that the coupling of Quantum Chromo Dynamics (QCD) depends on momentum transfer. QCD, the theory of strong interactions, has been very successful in explaining the interactions between quarks and gluons in high energy regime. This is primarily because, the coupling constant being small, the theory can be applied perturbatively. However, very little is known at energy scales relevant to matter surrounding us, where the theory has to be applied non-perturbatively. This regime is known as Quark Confinement. Because of this quark confinement, quarks are bound inside the hadrons and we require infinite energy to remove a quark from nucleon through the process of scattering. The large coupling constant or low energy makes perturbative calculation impossible. Therefore, it is essential to carry out measurements involving the production and decay of hadrons and mesons and to interpret them in the framework of effective field theories. One of the ways of η-meson production would be by exciting a nucleon inside the target of proton or deuteron to its excited states, which then decays by the emission of η meson with scattered protons or ^{3}He.

Experimental Set-up

To produce proton beam above the threshold energy, we use COSY (COoler Cyclotron) facility at Institute of Nuclear Physics (IKP), Forschungszentrum (FZJ) Juelich in Germany, which delivers beam of polarized and unpolarized proton and deuteron in the momentum range between 0.3 GeV/c - 3.7 GeV/c.

The WASA detector (figure 1) is installed at COSY, designed to study the production of light meson and its decays as laboratory.

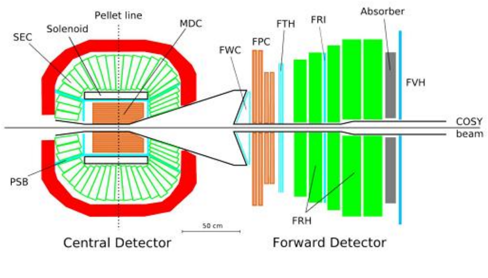

Fig. 1 WASA detector set-up.

At WASA-at-COSY [2], light mesons are produced using two different methods: the fusion reaction pd→^{3}Heη and the elementary reaction pp→ppη. In both cases the mesons are tagged by missing mass analysis using the nucleon ejectiles in the Forward detector. The first reaction allows a clean identification of the ^{3}He in the Forward Detector and guarantees low background from multipion production and the yield is about 10 η meson per second.

Physics Analysis of pd→^{3}Heη

As a first step in analysis, it is desired to measure the total η produced in data. For this ΔE-E method is used to identify ^{3}He in the Forward Detector.

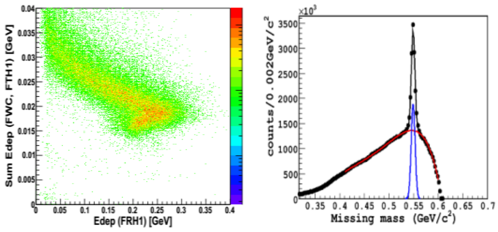

Fig. 1 (a) Identified ^{3}He in FD. (b) Missing mass of ^{3}He

Figure 2 (a) shows the indentified ^{3}He in the Forward detector (FD) and figure 2(b) shows missing mass distribution of ^{3}He in FD. It has a pronounced peak at the η-mass on a smooth background from multipions. To extract the total η produced, the missing mass distribution is fitted by assuming signal to be Gaussian and background to be polynomial of order four.

After subtracting background, the signal spectrum is integrated within three sigma range around the mean value which resulted in $(8.56\pm0.02)\times10^6$ events of η. The reconstruction efficiency of ^{3}He in FD is determined to be 77% from simulation.

Further work on physics analysis on decay channels $\eta\rightarrow3\pi^0$ and $\eta\rightarrow\pi^0\gamma\gamma$ are in progress.

References

[1] Y. Fukuda et al., Evidence for oscillation of Atmospheric Neutrinos, Phys. Rev. Lett. 81, 1562-1567 (1998).

[2] B. Hoistad and J. Ritman, (for WASA collaboration) Proposal for the Wide Angle Shower Apparatus(WASA) at COSY-Juelich WASA at COSY, Juelich (2004).