Study of the $\eta \to \pi^+\pi^-\pi^0$ decay as a tool for test of the charge conjugation invariance

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In the Standard Model of particles and fields, the charge conjugation C along with the spatial parity P and time reversal T, is one of the most fundamental symmetries. The C operator in quantum field theory applied to a particle state $|\Psi\rangle$ changes all additive quantum numbers of this particle to opposite sign, leaving the mass, momentum and spin unchanged, and making it an antiparticle state. In the Quantum Electrodynamics (QED) and Quantum Chromodynamics (QCD) it is postulated that C holds in all electromagnetic and strong interactions on the level smaller than 10^{-8}. Therefore the C-invariance should imply the balance between the matter and antimatter, however experimental observations of the Universe shows that there is signicantly larger abundance of matter over antimatter [1]. The known CP breaking effect is insuficient to explain this phenomenon, but it is hoped that investigations of the charge conjugation invariance may help in clarification of this problem.

In the hadronic decay $\eta \to \pi^+\pi^-\pi^0$, the C invariance violation can manifest itself as an asymmetry between energy distribution of the π^+ and π^- mesons in the rest frame of the η meson. The most convenient way to study this invariance is to use Dalitz plot described by the Mandelstam variables. In particular the possible presence of C violation could be observed in three parameters: (i) left-right asymmetry A_{LR}, (ii) quadrant asymmetry A_Q, and (iii) sextant asymmetry A_S [2]. Each of these parameters depends on a different isospin states of the final three pions. For example the left-right asymmetry is defined as:

$$A_{LR} = \frac{N_R - N_L}{N_R + N_L}, \tag{1}$$

where the N_L stands for the number of events where π^- has a larger energy than π^+ and and N_R denotes the number of events where the π^+ has greater energy than π^-.

We have investigated the $\eta \to \pi^+\pi^-\pi^0$ decay, by means of the WASA-at-COSY detector [3]. The η meson was produced via $pp \to pp\eta$ reaction at the proton beam momentum of 2.14 GeV/c. The tagging of the η meson was done by means of the missing mass technique and the decay products were identified by the invariant mass reconstruction [4].

Two scattered protons were registered in the Forward Detector using the scintillator detectors (FRH and FTH) and straw tube tracker (FPC), and identied by means of the energy loss method: $\Delta E - E$. Charged pions π^+ and π^- were registered in Central Detector using the Mini Drift Chamber (MDC) and the four-momentum vectors were reconstructed based on the track curvature in the magnetic field of the Superconducting Solenoid. The gamma quanta originating from the π^0 decay were registered in the Scintillating Electromagnetic Calorimeter (SEC). Furthermore, based on the reconstruction of the invariant mass of two γ quanta, the neutral pion was identified. The background originating from the direct two pion production and other η meson decays has been reduced to negligible level by applying the momentum and energy conservation laws, and by using conditions on the missing and invariant mass distributions. The remaining physical background for the $\eta \to \pi^+\pi^-\pi^0$ decay originating from the direct production of three pions via $pp \to pp\pi^+\pi^-\pi^0$ was subtracted for each studied phase space interval separately.

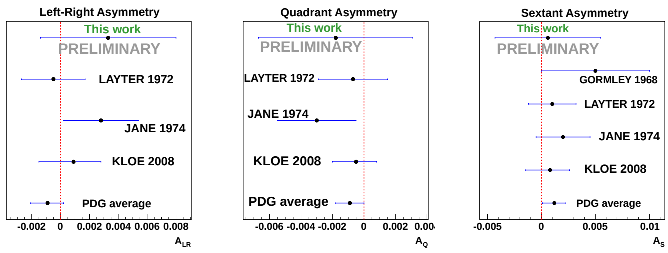

Fig. 1: Comparison of obtained values of asymmetries [9] with results determined by previous experiments [5–7], and a value given by PDG [8].

The three asymmetry parameters were determined by dividing the Dalitz plot into regions [9]. The events were summed up separately for odd and even regions and a corresponding missing mass for the $pp \to pp\eta$ reaction was reconstructed for each region. Furthermore, to determine the number of events corresponding to the $\eta \to \pi^+\pi^-\pi^0$ decay in each region the background was subtracted using the polynomial fit method, and the correction for acceptance and efficiency obtained based on the simulations of signal reaction, was applied.

Established values of the asymmetry parameters are consistent with zero within the range of the statistical and systematic uncertainty (see Fig. 1), which allows to conclude that the charge conjugation symmetry C is conserved in strong interactions on the level of the achieved accuracy. Obtained results are also in agreement with previously measured values [5–7] and the average of the Particle Data Group [8].

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