Leptonic η decays from WASA experiment at CELSIUS

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Introduction

Radiative processes are among the most common for the decays of the lightest pseudoscalar mesons π°, η and η' [Fig. 1]. Therefore, as a simple consequence of the Quantum Electrodynamics (QED), they are accompanied by a process where a photon converts into an electron-positron pair. The conversion decays are suppressed by a factor of the order of the fine structure constant α. The virtual photon probes the structure of the decaying meson and the interaction region in time-like region of momentum transfer squared, which is equal to the invariant mass squared of the lepton pair q^2.

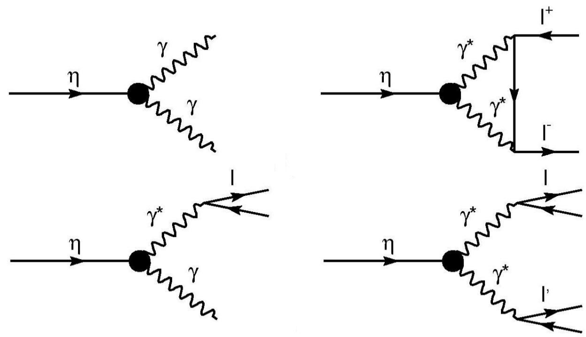

Fig. 1. Feynman diagrams for the various η decays. Letter l represents an electron or a muon.

The rare decays of pseudoscalar mesons $P \rightarrow l^+l^-$ represent potentially important channels to look for effects of new physics. The dominant mechanism within Standard Model is the second order in electromagnetism going through two virtual photons $P \rightarrow \gamma^*\gamma^*$. In QED this process is suppressed by α^2 and by $(m_l/m_P)^2$ ratio from helicity suppression, and theory got expected SM BR for $\eta \rightarrow e^+e^-$ decay equal to $(5.8\pm0.2)\cdot10^{-9}$ [1][2]. The present experimental limit by PDG is $<7.7\cdot10^{-5}$ (90% CL) [3]. The decay $\eta \rightarrow e^+e^-$ is sometimes quoted as a sensitive probe for the possible existence of leptoquark particles since the quark-antiquark pair couples to the electron-positron pair and the SM mechanism leads to quite low BR (of the order of 10^{-9}). An observation of a signal above this level could be evidence for an unconventional process that enhances this decay rate.

The most frequent η decay into an e^+e^- pair is $\eta \rightarrow e^+e^-\gamma$ with only a few hundred events that were collected in recent experiments and branching ratio from PDG equal to $(6.0\pm0.8)\cdot10^{-3}$ [4].

As for η double Dalitz decay no event was experimentally seen and theoretically BR limit is $<6.9\cdot10^{-5}$.

Experimental method

The experiment was performed at the CELSIUS storage ring in Uppsala, using WASA detector setup. Proton beam interacted with frozen droplets of deuterium. The η mesons were produced in the reaction $pd \rightarrow {}^3He\eta$. The energy of the proton beam was 893 MeV, close to the production threshold. An observation of ^{3}He ion in "zero-degree spectrometer" (ZD) provided a clean, η decay channel independent trigger. The ^{3}He energy was measured and cuts on it permitted to select the η production with background level at about 1%. The ZD detector provides trigger rate around few Hz (with proton beam luminosity $\sim5\cdot10^{30}cm^{-2}s^{-1}$) which yields on average one η event per second collected in the data acquisition. During the nearly two weeks of the experiment (distributed over half a year period) nearly $3\cdot10^5$ η events were collected.

The charged products of the η decays were tracked using cylindrical drift chamber (MDC) that was placed inside thin wall superconducting solenoid, which provided magnetic field of 1T. The chamber was surrounded by plastic scintillator barrel. Measurement of photon energy and emission angle was performed in the electromagnetic calorimeter (SEC). Comparison of momentum from the curvature of the tracks and energy deposited in SEC permitted to distinguish electrons from charged pions.[5]

Analysis and results

Off-line, events with exactly two charged tracks reconstructed in MDC were required to form a vertex close to the intersection region of the beam and the target. Only events with equal number of positive and negative charged particles in MDC were accepted for further analysis. The results on $\eta \rightarrow \pi^+\pi^-e^+e^-$ decay channel with four charged particles were already presented in [6].

In figure [Fig. 2] the e^+e^- invariant mass distribution was shown for events with number of neutral cluster greater than zero and less than four (left) and the $e^+e^-\gamma$ mass for $M_{ee}<0.125$ GeV (right). On both figures only selected background has been shown. Only events with neutral cluster with energy larger than 200 MeV were taken into account. The η peak at about 547 MeV is seen in the right figure. After selection cuts: angle between electron & positron, invariant mass of electron-positron pair and γ, missing mass to ^{3}He, angle between γ and γ^*, emission angle of η, invariant mass of electron-positron pair and removing π^o we were left with 479 $\eta\rightarrow e^+e^-\gamma$ event candidates.

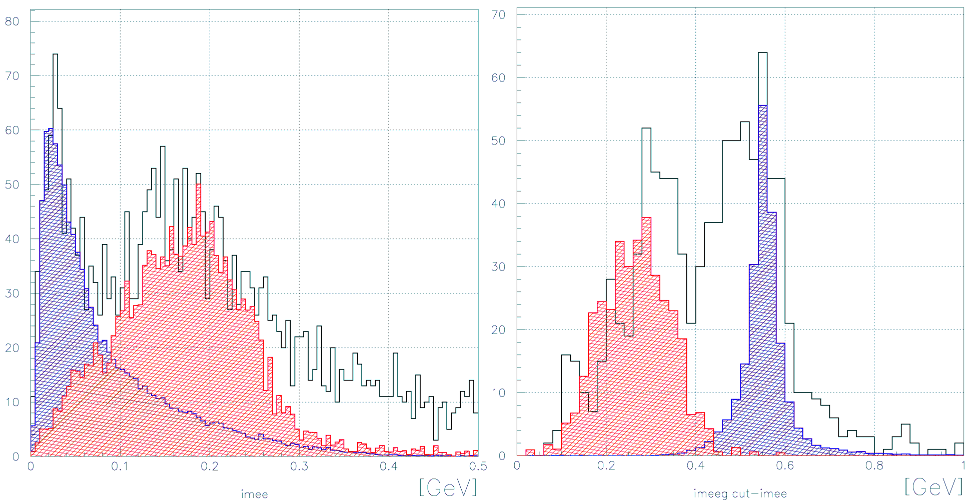

Fig. 2. (Left) Invariant mass of electron-positron pair. (Right) Invariant mass of $e^+e^-\gamma$. Black curve represents data points, blue Monte Carlo, red curve MC for $\eta\rightarrow\pi^+\pi^-\gamma$ (Right), and $\eta\rightarrow\pi^o\pi^o\pi^o$ with $\pi^o\rightarrow e^+e^-\gamma$ (Left)

In search for $\eta\rightarrow e^+e^-e^+e^-$ decay only events with 4 charged tracks and equal number of positive and negative charged particles were selected. After several selection cuts performed (angle between electron-positron pairs, invariant mass of electron-positron pairs, missing mass to ^{3}He, angle in each pair, invariant mass of each pair, emission angle of η) we were left with only 2 event candidates. One of them was with large number of neutral clusters that can be due to background from $\eta\rightarrow\pi^o\pi^o\pi^o$ with two neutral pions Dalitz decays (4.5 events obtained from MC simulations), and the other candidate is on [Fig. 3]. The BR limit (one event assumption) obtained was $<6.5\cdot10^{-5}$ at CL=90%. This channel was never experimentally seen.

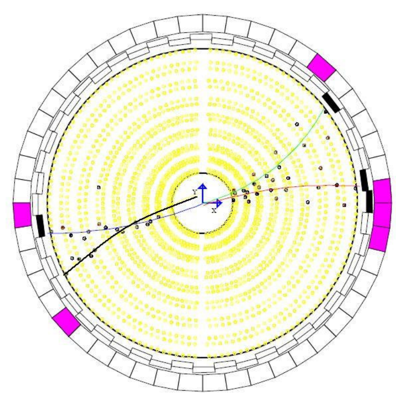

Fig. 3. $\eta\rightarrow e^+e^-e^+e^-$ event candidate.

The $\eta\rightarrow e^+e^-$ decay has a distinctive topology: two energetic (>150 MeV) electrons emitted at large relative angle (about 134°). The selection of events has been done by choosing two charged particles with different sign. After kinematical cuts (momentum of electron-positron pair, angle between electron & positron, invariant mass of electron-positron pair, missing mass to ^{3}He, emission angle of η) we observed no events in the region populated by $\eta\rightarrow e^+e^-$ candidates in the simulation (120-160 degrees) fulfilling the identification criteria p/E <1.65. Taking into account the detector acceptance 41% estimated from MC simulations the upper limit for the BR($\eta\rightarrow e^+e^-$) $<2.8\cdot10^{-5}$ (CL=90%) has been obtained.

Conclusion

In presented data from CELSIUS/WASA (~232k events – this number of η was obtained by normalization to the $\eta\rightarrow\pi^+\pi^-\pi^o$), BR limit can be estimated only to 10^{-5} level. We have clear signal from $\eta\rightarrow e^+e^-\gamma$, and we can distinguish between various channels with e^+e^- pairs and background. There is no significant background to $\eta\rightarrow e^+e^-$ after applied selection method. The BR limits for $\eta\rightarrow e^+e^-$ and $\eta\rightarrow e^+e^-e^+e^-$ were obtained.

Bibliography

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