Search for the C forbidden η meson decay into $\pi^0 e^+ e^-$ in proton-proton collisions

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In the framework of the Standard Model and the QED the $\eta \to \pi^0 e^+ e^-$ decay may only proceed via exchange of two virtual photons with the branching ratio of about 10^{-8} [1] according to the reaction: $\eta \to \pi^0 + \gamma^* + \gamma^* \to \pi^0 e^+ e^-$. But in principle it may also be realized by one photon intermediate state, forbidden by the C invariance via transition $\eta \to \pi^0 + \gamma^* \to \pi^0 e^+ e^-$. The decay widths for the first order electromagnetic processes are larger than for second order mechanism. Therefore, experimentally the C-invariance breaking in this decay would manifest itself by increased branching ratio with respoect to the Standard Model expectations.

At present only an experimental upper limit is set for this branching ratio at the level of 4×10^{-5} [2]. Thus, there is still more than three orders of magnitude difference between Standard Model predictions and measured upper limit. Therefore, it is worth to increase the experimental sensitivity which gives a chance to observe a signal which would indicate violation of C symmetry.

For the purpose of the search for the C-forbidden $\eta \to \pi^0 e^+ e^-$ decay the η meson was produced via proton-proton collisions at the proton beam momentum of 2.14 GeV/c. Nucleons emerged from the interaction region have been registered in the WASA [3] forward detector, whereas the decay products of the η meson were detected in the central detector.

In order to select $\eta \to \pi^0 e^+ e^-$ decay and suppress the background reactions as much as possible we have simulated all main processes which may obscure the signal reaction. First the reactions with the direct production of multi-pions were suppressed by applying the cut on the invariant mass of two oppositely charged particles identyfied in the Central Detector where we assumed that searched $e^+ e^-$ will populate small invariant masses and charged pions will have masses larger than 40 MeV/c. Secondly to reduce the split-off events in the calorimeter we have restricted the smallest invariant mass of a charged and neutral particle pairs to the values larger than 120 MeV/c. Additionally the external conversion of photons on the beam pipe resulting in emission of $e^+ e^-$ pair was suppressed by applying the condition on distance between the center of the interaction region and the point of the closest approach of two helices and the invariant mass of leptons calculated under the assumption that they were created in the beam pipe. Finally, to reduce remaining background we have selected only event for which the missing mass of two protons is within the range of 544-552 MeV/c, and the invariant mass of $\pi^0 e^+ e^-$ system is within the range of 555-650 MeV.

After application of all selection criteria to the simulated background reactions, and after taking into account the cross section and the values of the branching ratios, the only background channel left was $pp \to pp\pi^0\pi^0 \to ppe^+e^-3\gamma$, which amounts to $N_B = 13 \pm 4_{stat}$. The same analysis conditions were applied to the experimentally measured data where the number of event candidates for searched $\eta \to \pi^0 e^+ e^-$ decay is $N_{exp} = 10 \pm 3_{stat}$. However, the estimated number of N_{exp} may account not only for events corresponding to the searched decay but it may also be due to the misidentification of the background reactions. One can see that the final number of experimental candidates for searched decay and

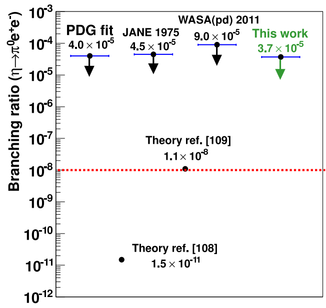

Fig. 1: Comparison of obtained value of the upper limit for the branching ratio of the $\eta \to \pi^0 e^+ e^-$ decay with previous measurements. The red dashed line indicates the limit of the Standard Model predictions.

expected number of background events obtained from the simulations are equal within errors. In such case, it is impossible to calculate the value of the branching ratio, and only an upper limit can be estimated.

In order to calculate the upper limit for the branching ratio one has to know the number of expected: (i) signal, (ii) background, (iii) normalization channel events, (iv) selection efficency, and (v) the branching ratio for the normalization channel. The formula for the investigated branching ratio will take following form of an inequality:

$$BR^{UL}_{\eta \to \pi^0 e^+ e^-} < \frac{N^{UL}_S \cdot BR_{norm} \cdot \varepsilon_{norm}}{N_{norm} \cdot \varepsilon_S} \quad (1)$$

where the N^{UL}_S denotes the number of expected signal events at a given confidence level, and subscript "*norm*" stands for the normalization channel which in this case was $\eta \to \pi^+\pi^-\pi^0$. The value of the upper limit of the expected signal is equal to $N^{UL}_S = 3.95$ at the confidence level of 90% [4]. The final result for the branching ratio equals to [5]:

$$BR^{UL}_{\eta \to \pi^0 e^+ e^-} < 3.7 \times 10^{-5} \quad (CL = 90\%). \quad (2)$$

Obtained result is smaller than presently known upper limit given by the PDG group [2]. This result, constitutes a next step in the search for rare decay of the η meson by means of the WASA-at-COSY detector.

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