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Monte Carlo studies of $\eta \rightarrow 4\pi^0$ CP symmetry violating decay with WASA-at-COSY detector

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Abstract. We present feasibility studies of the measurement of η meson decay into a $4\pi^0$ system using the WASA-at-COSY detector. Kinematics of the $pp \rightarrow pp\eta \rightarrow pp4\pi^0 \rightarrow pp8\gamma$ reactions and response of the WASA-at-COSY detector were simulated. The identification of the $\eta \rightarrow 4\pi^0 \rightarrow 8\gamma$ decay was based on the invariant mass method for both π^0 and η mesons. As a result, the resolution of the invariant mass determination of the η meson was established to $\sigma = 31\ MeV/c^2$. The efficiency of the WASA-at-COSY detector for the measurement and reconstruction of the $pp \rightarrow pp\eta \rightarrow pp4\pi^0 \rightarrow pp8\gamma$ reaction was determined to be 1.5%.

1 Introduction

In the Standard Model CP symmetry violation is described by the phase in the Cabibbo-Kobayashi-Maskawa quark-mixing matrix. Six quark flavours are grouped into three families. CP violation is related to family-changing weak interactions, while in family-conserving cases CP violation is suppressed in the SM sinceit is of 2nd order. Detailed studies of CP violation may lead us to New Physics that goes beyond the Standard Model. Test of flavour-conserving CP symmetry violation may be carried out with η meson decays into an even number of pions. CP symmetry tests via $\eta \rightarrow 2\pi^0$ decay are hard to improve due to the background connected with direct $2\pi^0$ production in every η production reaction. A possible new test is the decay into four pions [1]:

$$\eta \rightarrow 4\pi^0. \tag{1}$$

The present upper limit for branching ratio $BR(\eta \rightarrow 4\pi^0) < 6.9 \cdot 10^{-7}$ was determined by Crystal Ball Collaboration [2]. The theoretical estimates can be found in [3],[4].

2 Main physical background reaction

In the studies of the $\eta \rightarrow 4\pi^0$ decay via $pp \rightarrow pp\eta \rightarrow pp4\pi^0$ the main physical background is $pp \rightarrow pp4\pi^0 \rightarrow pp8\gamma$ due to the direct pions production. The current available data of cross sections for multipion production in proton-proton collision are shown in Fig. 1. The cross section in the figure is presented as a function of excess energy with respect to the η meson production threshold.

The cross section for $4\pi^0$ production in proton-proton collisions is not established and so far only an upper limit for a single energy point was determined to 5 nb [5]. In order to estimate the background from direct pions production ($pp \rightarrow pp4\pi^0$) we have derived an energy dependence of the upper limit of the total cross section under assumption of the homogeneous phase-space population [6]:

$$\sigma(Q) = const \cdot (Q/\sqrt{s})^{(3m-5)/2}, \tag{2}$$

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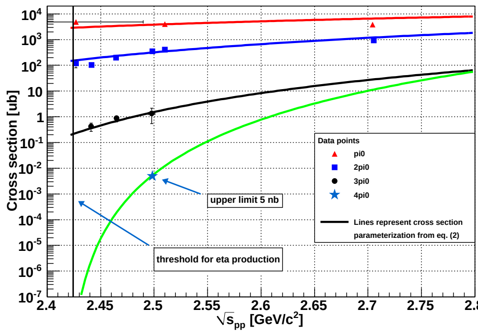

Fig. 1. Experimental cross section for direct pions production in proton-proton collision (points). The superimposed lines denote result of the fit of formula 2 to the experimental points. The values of the fitted parameters are available in reference [7]

where Q and s denote the excess energy and the total energy in the centre-of-mass system respectively and m stands for the number of particles in the exit channel.

The result is shown in Fig. 1 as the lowest, green line for which the absolute value was fitted to the experimental upper limit. For the comparison in Fig. 1 also cross sections for π , 2π and 3π production are shown. The superimposed lines indicate result of the fit of formula 2 with amplitude as the only free parameter.

3 Reconstruction of the $pp \to pp\eta \to pp4\pi^0 \to pp8\gamma$ reaction using the WASA-at-COSY detector via invariant and missing mass technique

Large number of gamma quanta in exit channel of $pp \to pp\eta \to pp4\pi^0 \to pp8\gamma$ cause reconstruction difficulties. In order to identify which gamma quantum comes from the decay of which neutral pion, a matching routine was used. The routine was based on the χ^2 minimalization of the difference of the invariant masses of a given γ pairs combination and the mass of the π^0 meson. For further analysis only those combinations with the minimal χ^2 are taken. Later the invariant mass of all eight gamma quanta originating from the η meson decay was created, and it is shown in Fig. 2. The η meson can be fully reconstructed only for 3% of all simulated reactions.

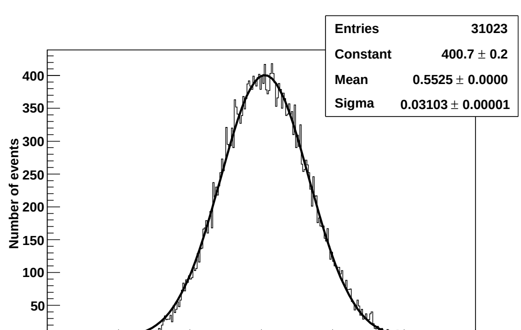

Fig. 2. Distribution of the invariant mass of eight gamma quanta from the η meson decay, reconstructed from simulated events. The solid line corresponds to a Gaussian function fitted to the histogram.

4 Time of measurement with the WASA-at-COSY detector

The statistical error of Branching Ratio for the $\eta \rightarrow 4\pi^0$ reaction can be expressed as:

$$\sigma(BR) = \frac{\sigma(N_{\eta\rightarrow 4\pi^0})}{A_\eta \cdot \sigma_\eta \cdot L \cdot \Delta t}, \tag{3}$$

where $\sigma(N_{\eta\rightarrow 4\pi^0})$ and $\sigma(BR)$ stands for uncertainty of number of observed events and branching ratio respectively, A_η is acceptance of detector, L denotes luminosity, σ_η corresponds to cross section for η meson production and Δt is time of measurement.

Equation 3 is true under the assumption that the uncertainties of A_η, σ_η, L and Δt are negligibly small compared to $\sigma(N_{\eta\rightarrow 4\pi^0})$.

Using equation 3, the statistical error of branching ratio as a function of time can be plotted and, it is shown in Fig. 3 under the assumption that the luminosity is constant and equal to $L = 10^{32}\ cm^{-2}s^{-1}$. The result is obtained for proton-proton collisions with beam kinetic energy of $T_{beam} = 1.3\ GeV$. The upper limit of the branching ratio for the present value of the decay $\eta \rightarrow 4\pi^0$ is marked. It can be achieved in one day of measurement using the WASA-at-COSY detector.

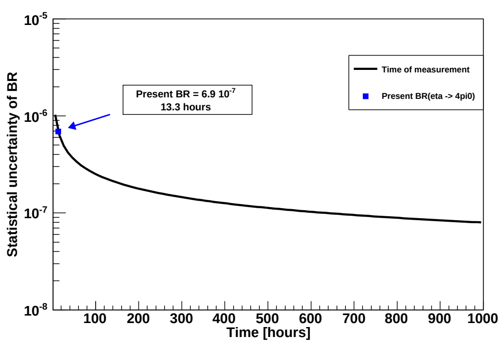

Fig. 3. Statistical error of the branching ratio as a function of time. The blue square presents the value of the upper limit of the branching ratio [2]. The black line shows the value of the statistical error of the measurement which can be achieved using the WASA-at-COSY detector for a measurement at $T_{beam} = 1.3\ GeV$ with $L = 10^{32}\ cm^{-2}s^{-1}$.

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