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Electromagnetic Transition Form Factor of the η meson with WASA-at-COSY

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Abstract. In this work we present a study of the Dalitz decay $\eta \rightarrow \gamma e^+e^-$. The aim of this work is to measure the transition form factor of the η meson. The transition form factor of the η meson describes the electromagnetic structure of the meson. The study of the Dalitz decay helps to calculate the transition form factor of the η meson. When a particle is point-like it's decay rate can be calculated within QED. However, the complex structure of the meson modifies its decay rate. The transition form factor is determined by comparing the lepton-antilepton invariant mass distribution with QED. For this study data on proton-proton reaction at a beam energy of 1.4 GeV has been collected with WASA-at-COSY detector at Forschungszentrum Juelich, Germany. In the higher invariant mass region recent theoretical calculations slightly deviate from the fit to the data. We expect better results in the higher invariant mass region than previous measurements. The preliminary results of the analysis will be presented.

1 Introduction

The η meson is a Pseudoscalar meson. The Dalitz decay ($\eta \rightarrow \gamma^*\gamma \rightarrow e^+e^-\gamma$) of the η meson which has a branching ratio 6.9×10^{-3}, can be used to extract the information on the it's electromagnetic transition form factor. This kind of study has been proved as a good testing ground for the model like VMD. The transition form factor might also contribute to the hadronic light by light scattering of the g-2 of muon [1] which is a limiting contribution of the Standard Model. The main goal of this analysis is to measure transition form factor of the the η meson in the time-like region. Transition form factor of the η meson describes the electromagnetic structure of the meson. The decay rate of a point-like particle can be calculated within QED. However, the complex structure of the meson modifies its decay rate. The transition form factor is determined by comparing the experimentally measured lepton-antilepton invariant mass distribution of the Dalitz decay of the η with QED. Transition form factor of the η can be calculated using the following equation1[2]:

$$\frac{d\Gamma(\eta \rightarrow \gamma e^+e^-)}{dq^2 \cdot \Gamma(\eta \rightarrow \gamma\gamma)} = \frac{2\alpha}{3\pi}[1 - \frac{4m_e^2}{q^2}]^{1/2}[1 + \frac{2m_e^2}{q^2}]\frac{1}{q^2}[1 - \frac{q^2}{m_\eta^2}]^3 \mid F_\eta(q^2) \mid^2 \tag{1}$$

Where m_e stands for the lepton mass, m_η is the mass of the eta meson and q^2 is the squared four-momentum of $e^\pm$.

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According to VMD, transition form factor is parameterized using single pole approximation:

$$F_\eta(q^2) = \frac{1}{1 - \frac{q^2}{\Lambda^2}} \tag{2}$$

Slope of the form factor is related with the radius of the charge distribution. A recent work from the CB/TAPS at MAMI collaboration reports that the value of the slope of the form factor is $\Lambda^{-2} = (1.95 \pm 0.15_{stat} \pm 0.10_{syst})\ GeV^{-2}$ [3]. Their result significantly agrees with recent theoretical calculations and with the VMD model. We aim to calculate a more precise value of the transition form factor with our high statistics data.

2 Experimental Setup

WASA (Wide Angle Shower Apparatus) is a 4π detector setup [4]. The high intensity proton beam provided by COoler SYnchrotron (COSY) at Forschungzentrum Juelich in combination with a high density pellet target of the WASA detector make possible to achieve high luminosities which is required for the study of rare decays. This detector setup consists of the two parts, the forward detector and the central detector. The recoil protons are detected with the forward detector which covers 3-18 degrees in the polar angle and decay fragments of the η meson are identified with the central part of the detector which covers 20-169 degrees.

3 Analysis

A large data sample of pp→ppη ($10^9 \eta$) has been collected in 2008, 2010 and 2012 at WASA-at-COSY experimental setup. However, in this study data collected in 2010 has been used. In the analysis, the recoil protons are identified in the forward part of the detector using the ΔE-E method as shown in Figure 1 (Left), where ΔE is the energy deposited by protons in the layers of Forward Range Hodoscope (FRH).

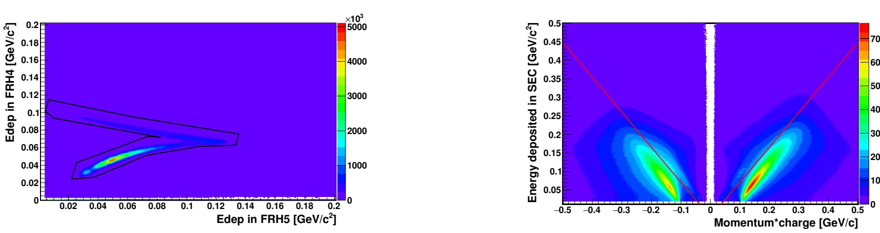

Figure 1: Energy deposited by the charged particles in the FRH4 v/s FRH5 of the forward detector (left) and momentum times charge of the particles v/s energy deposited by the particles in the elctromagnetic calorimeter (Right). The graphical region in the left figure indicates all proton tracks and the lines in the right figure indicate the separation of electrons and protons.

Furthermore, charged decay particles (e^+, e^-) of the produced η meson are identified in the central part of the detector using ΔE-P method as shown in Figure 1 (Right). Here, ΔE is the energy measured by the electromagnetic calorimeter and momentum information is provided by the mini drift chamber in presence of the magnetic field of solenoid. Kinematic conditions have been implemented in the

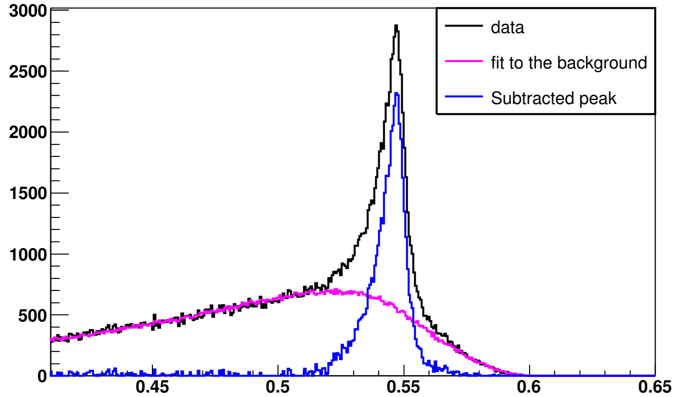

Figure 2: Missing mass of two initial and two final state photons after all kinematic conditions.

data analysis to identify all final state particles and to suppress the background. The missing mass technique is used to tag the η mesons, as shown in Figure 2.

A 4^{th} order polynomial multiplied with the phase space of multipion production pp$\rightarrow$pp$\pi^0\pi^0$ has been used to fit background excluding the peak region (0.53-0.57 GeV). Total 43000 $\eta \rightarrow e^+e^-\gamma$ events have been reconstructed. However, background is still present inside the peak region. Thus, we have performed a detailed study of contributing background channels to identify sources of the background. For that all possible background channels (both phase space and competing) have been simulated which are mentioned in Table 1. The values of cross-section and branching ratios in the table are taken from the Particle Data Group[5].

Table 1: List of simulated background channels.

Channel	Cross-section / Branching ratio
$pp \rightarrow pp\pi^0(e^+e^-\gamma)\pi^0(\gamma\gamma)$	324 μb
$pp \rightarrow pp\pi^+\pi^-\pi^0(e^+e^-\gamma)$	4.6 μb
$pp \rightarrow pp\pi^0(e^+e^-\gamma)\pi^0(\gamma\gamma)\pi^0(\gamma\gamma)$	1.34 μb
$\eta \rightarrow \pi^+\pi^-\pi^0$	22.6%
$\eta \rightarrow \pi^+\pi^-\gamma$	4.68%
$\eta \rightarrow \gamma\gamma$	39%
$\eta \rightarrow \pi^0(e^+e^-\gamma)\pi^0(\gamma\gamma)\pi^0(\gamma\gamma)$	32%

The channel $\eta \rightarrow \gamma\gamma$ contributes as a background if one of the photons interacts with the beampipe material and converts into $e^\pm$ pair. Both $\eta \rightarrow \gamma\pi^+\pi^-$ and $\eta \rightarrow \pi^0\pi^+\pi^-$ channels have a similar topology to the signal channel as in both channels there are two oppositely charged tracks and one neutral track. It is seen in the simulation that pp$\rightarrow$pp$\pi^0\pi^0$ is the main source of the background in the phase space region and 8.4% background still may contribute from the competing decay channels $\eta \rightarrow \gamma\gamma$, $\eta \rightarrow \gamma\pi^+\pi^-$, and $\eta \rightarrow \pi^0\pi^+\pi^-$ inside the peak region. We are also planning to look at the Δ-Δ resonances and $\pi^+\pi^-$ correlations as a part of background study. We plan to perform a study of

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relative branching ratio in order to verify it from the PDG value from the cut based analysis. Finally, we will measure the transition form factor of the η meson.

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