Dielectron pairs from η meson decays at WASA detector

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Abstract. We present the results of the analysis of $\eta \to e^+e^-\gamma$ and $\eta \to e^+e^-$ decays. The experimental data were collected in proton-proton collisions at incident proton kinetic energy 1.4 GeV using the WASA detector and the COSY storage ring. We describe the extraction procedure of the η meson transition form factor, based on a sample of around 10^8 η mesons, and show an attempt to search for physics beyond the Standard Model that led to the setting of an upper limit on the coupling between photons and hypothetical dark bosons. We also provide an estimate of the branching ratio upper limit for the very rare $\eta \to e^+e^-$ decay.

1 Introduction

The data sample used in this paper was collected by the WASA-at-COSY collaboration in proton-proton collisions at 1.4 GeV beam kinetic energy. The experiment took place in 2012 at Forschungzentrum Jülich in Germany at the COSY storage ring. An internal proton beam interacted with a pellet target of frozen hydrogen (see [1] for details about the WASA detector). We constrained the data sample with a set of selection criteria in order to extract the $\eta \to e^+e^-\gamma$ event candidates. This is a rare electromagnetic decay of the η meson with branching ratio of about $6.9 \cdot 10^{-3}$ (see e.g. [2]). The resulting set of events served as the basis for three analysis. First, we extracted the η transition form factor that is a function depending on the inner quark and gluon structure of the meson.

The second analysis was the search for a narrow structure on the e^+e^- invariant mass in the selected sample of $\eta \to e^+e^-\gamma$ candidates. Many theoretical models (see references [3], [4] and [5]) and some astrophysical and particle physics measurements (see references [6], [7], [8] and [9]) suggest the existence of a new vector boson, also called the dark photon, that couples to both dark and to Standard Model particles. This particle would decay mainly to e^+e^- pairs of well defined mass and therefore could be detected by looking for narrow peaks in the e^+e^- invariant mass spectra. WASA-at-COSY collaboration has published a similar analysis for $\pi^0 \to e^+e^-\gamma$ decay (see [10]).

The third objective was to search for $\eta \to e^+e^-$ decay. This is a very rare channel in the Standard Model and therefore sensitive to physics beyond the Standard Model.

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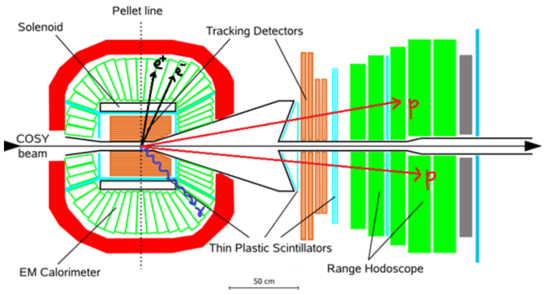

Figure 1. A typical η meson decay in the WASA (Wide Angle Shower Apparatus) detector.

2 The $\eta \to e^+e^-\gamma$ decay

The first observations of $\eta \to e^+e^-\gamma$ channel, also called the η meson Dalitz decay, were performed in the 70's (see reference [11]). They were based on limited data samples with high background contribution (mostly from photon conversion in the target and the detector material). The Feynmann diagram of this decay is shown in Fig. 2. We use the properties of the WASA detector such as the negligible pair production in the windowless $\sim 35\ \mu m$ thick pellet target and its exclusive channel measurement capacity to extract a clean sample of this channel.

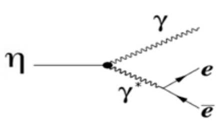

Figure 2. The Feynmann diagram of the $\eta \to e^+e^-\gamma$ decay.

2.1 Extraction of the η meson transition form factor

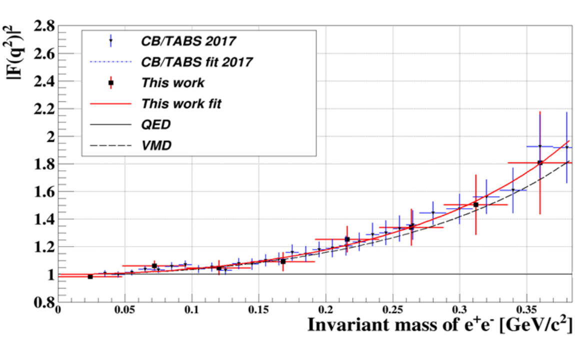

Figure 3. η transition form factor comparison between this work, CB/TABS result, pure QED and Vector Meson Dominance theorical model. Black points correspond to experimental data. They are fitted by the following function: $\frac{1}{1-\beta_\eta m_{ee}^2}$ where m_{ee} is the e^+e^- invariant mass and β_η is the η transition form factor slope parameter.

The η transition form factor can be extracted by comparing (dividing) the experimental spectrum of e^+e^- invariant mass from $\eta \to e^+e^-\gamma$ decay with the theoretical pure QED distribution (i.e. where the form factor is equal to one). In order to obtain a reliable result we had to select a clean sample of $\eta \to e^+e^-\gamma$ candidates. This was performed by the application of several selection criteria on data events based on characteristics such as: the relative time of tracks, particle identification (using the distribution of deposited energy vs track momentum), event multiplicity, track angular distribution, missing particle momenta, missing mass of two protons, invariant mass of $e^+e^-\gamma$, etc.

In addition to those conditions, we used a dedicated fitting procedure to the pp missing mass spectra for different e^+e^- invariant mass bins to eliminate remaining background from non-η events (mostly from direct pion production). The resulting transition form factor slope parameter is shown in Fig. 3. The fitted value of this parameter is: $1.97 \pm 0.29_{\mathrm{stat}}{}^{+0.13_{\mathrm{sys}}}_{-0.23_{\mathrm{sys}}}$ GeV^{-2}.

2.2 Search of the dark photon

The signature of a hypothetical massive dark boson (photon) decaying into e^+e^- pair (see Fig. 4) is a narrow peak, smeared by detector resolution and reconstruction features, superimposed on the usual Dalitz distribution of the e^+e^- invariant mass spectrum. Figure 5 shows the final e^+e^- spectrum for data and Monte Carlo simulations of the main background channels - $\eta \rightarrow \gamma\gamma$, $pp \rightarrow pp\pi^0\pi^0$ with one Dalitz decay and the combinatorial background contribution. We do not observe any statistically significant peak and therefore we can set an upper limit on the branching ratio for a hypothetical $\eta \rightarrow U\gamma$ decay, directly related to the U-γ coupling strength parameter ε. This upper limit calculated with a 90% confidence level is presented in Fig. 6.

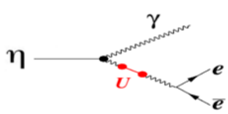

Figure 4. The Feynmann diagram for the $\eta \rightarrow e^+e^-\gamma$: dark photon contribution.

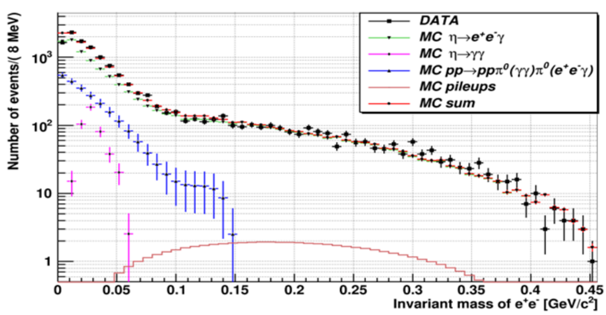

Figure 5. The distribution of the invariant mass of e^+e^- for selected data and Monte Carlo simulations of signal and background channels. Black points are experimental data.

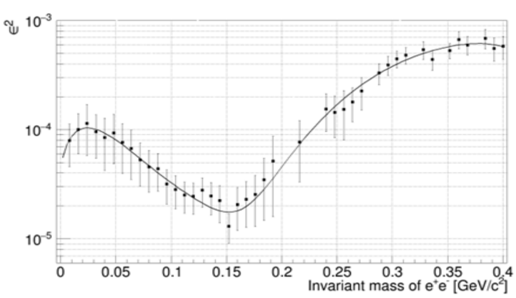

Figure 6. The upper limit (90% C.L.) on the dark photon-photon coupling parameter (ε^2).

3 The $\eta \rightarrow e^+e^-$ decay

We fit the two proton missing mass distribution with a polynomial representing the background and a Lorentz function representing the signal. The latter is centered at the η meson mass (547 MeV/c^2) and the width is limited to the 8 – 9 MeV/c^2 range. The illustration of this fit, for an initial selection is shown in Fig. 7. After applying a dedicated analysis chain (with very stringent conditions to select this extremely rare decay) on the data sample, we find 166 subsisting $\eta \to e^+e^-$ candidates (see Fig. 8). This constraint on the signal width is determined from Monte Carlo simulation. No $\eta \to e^+e^-$ event is found and the upper limit on the branching ratio for this channel is set (including the fit uncertainties) to $4.14 \cdot 10^{-6}$ with 90% C.L.

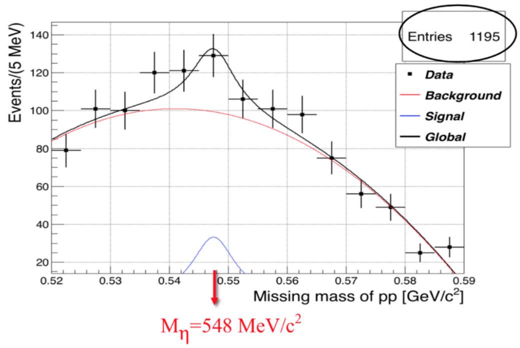

Figure 7. Illustration of the *pp* missing mass fitting procedure for an initial selection of events.

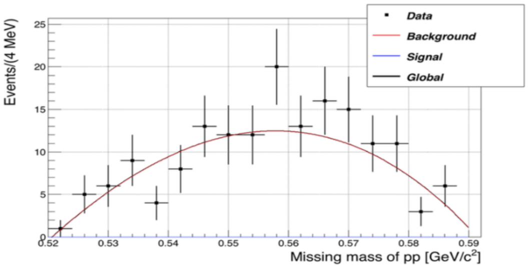

Figure 8. Illustration of the fitting procedure for the final selection of $\eta \to e^+e^-$ candidates. We observe no statistically significant signal.

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