Search for the C-violating meson decay $\eta \rightarrow \pi^0 e^+ e^-$ with WASA-at-COSY

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Abstract. The WASA-at-COSY experiment is, besides meson production processes, dedicated to studies on rare and forbidden decays of light mesons. In extensive η-production beam times, a high-statistics data set have been collected by means of proton-proton scattering which opens the door to studies on forbidden decays like the C-parity violating process $\eta \rightarrow \pi^0 e^+ e^-$. In this article, an optimized detector calibration leading to a significantly improved missing mass resolution and a preliminary decay analysis are presented.

1 Introduction

Investigations on fundamental symmetries like the C-parity are a main tool for testing standard model predictions. The decay of the η-meson into $\pi^0 e^+ e^-$ via a virtual photon can be described by a vector meson dominance model but violates the C-parity and, hence, is forbidden in the frame of the standard model. The final state can be achieved by higher order processes fulfilling all conservation laws but these highly suppressed, i.e., a relative branching ratio in the order of 10^{-12} to 10^{-9} is expected by calculations. Thus, this decay of the η-meson is a perfect probe for testing the C-parity conservation within the standard model up to a relative branching ratio of $\approx 10^{-9}$ and may give access to physics beyond the standard model by assuming a dark Z-like U-boson as an intermediate state [1]. Up to now, this decay has not been observed and only an upper limit for the branching ratio of 4×10^{-5} is quoted by the PDG [2].

Studies on this decay rely on data sets with very high statistics and an optimal detector resolution to distinguish between possible signal events and the large number of background reactions which may mimic the same signature in the detector.

The WASA detector [3] loacated at the accelerator facility COSY at the Forschungszentrum Jülich, Germany, was utilized to obtain large data sets in η-production runs. Two different production mechanisms were exploited, namely the fusion reaction $p + d \rightarrow {}^3\text{He} + \eta$ characterized by a low fraction of background reactions, i. e. the direct pion production, and the scattering $p + p \rightarrow p + p + \eta$ with a significantly larger cross section leading to $\approx 5 \times 10^8$ η-mesons recorded. This article presents results obtained with the latter data set.

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2 Analysis

The data set is analyzed in order to observe the decay $\eta \rightarrow \pi^0 e^+ e^-$ or, at least, to improve the existing upper limit for the relative branching ration. A key point is the identification of the signal channel and the separation from background reactions like pion production processes. Several methods are used to optimize the analysis. The protons are identified by their characteristic energy loss bands in the forward detector part, pions and electrons are separated by energy-momentum correlations (see Fig. 1). Utilizing the missing mass method, the reaction $p + p \rightarrow p + p + \eta$ can be identified. In the missing mass spectrum of the protons, this reaction forms a narrow peak upon the continuous distribution of background reaction like direct pion production as shown in the left histogram of Fig. 2. The separation efficiency by a missing mass window obvioulsy relies strongly on the energy resolution of the forward detector.

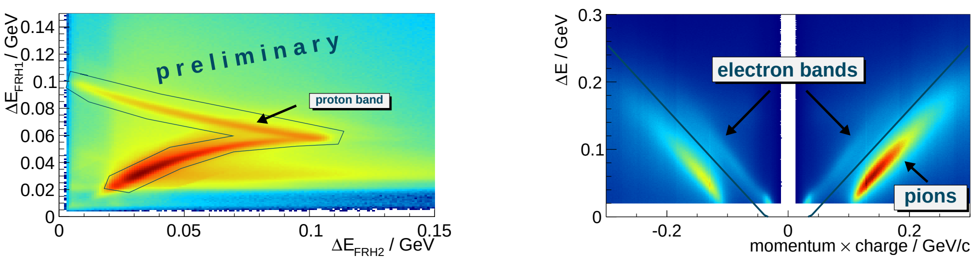

Figure 1. Left: Example of the energy loss correlation in two subsequent scintillator planes of the forward detector. A cut around the characteristic proton band is shown. Right: Separation between electrons and pions by the means of energy-momentum correlation measured in the central detector.

For the calculation of the missing mass, the kinetic energies of the proton ejectiles are used. These are calculated by the energy losses in subsequent scintillator planes. Assuming a perfect calibration of the energy loss detectors, the obtained missing mass peak position is expected to be at the mass of the η-meson of $m_\eta = 547.862\,\text{MeV}$ [2]. The measured data, however, show systematic dependencies of the missing mass position from the polar scattering angle ϑ and the energy deposition E_{dep} in the stopping plane of the protons. To correct for this, a new calibration routine has been developed.

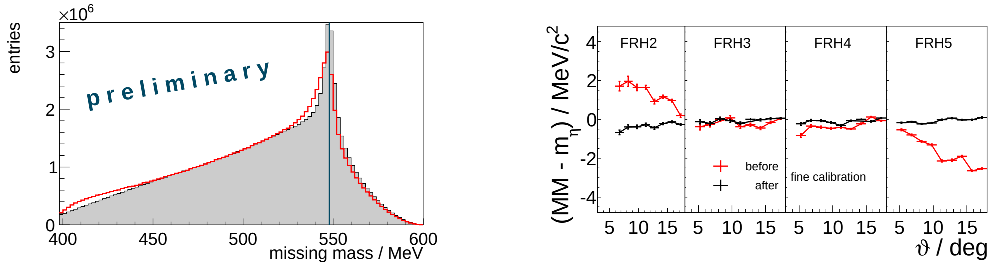

Figure 2. Left: Missing mass spectrum before (red line) and after the fine calibration (shaded filled area). Right: Deviation of the missing mass peak position depending on the polar scattering angle before (red line) and after (black line) the fine calibration.

A scaling factor depending on ϑ and E_{dep} is applied to the reconstructed kinetic energy of each proton. These factors are highly correlated, since the missing mass is always calculated out of two protons, and has to be determined in an iterative way. As a result, the missing mass resolution is improved by 40 %. Fig. 2 shows the shift of the missing mass position before and after this fine calibration for a small data subset.

The data were taken in a beam time lasting for several months. During this time, slight changes in the detector settings are possible, leading to a time depending miscalibration. The effect has been corrected by an additional time depending factor and a steadily high resolution throughout the complete beam time could be realized. Fig. 2 compares the missing mass distribution before and after the fine calibration. The different widths of the η-peak are clearly visible.

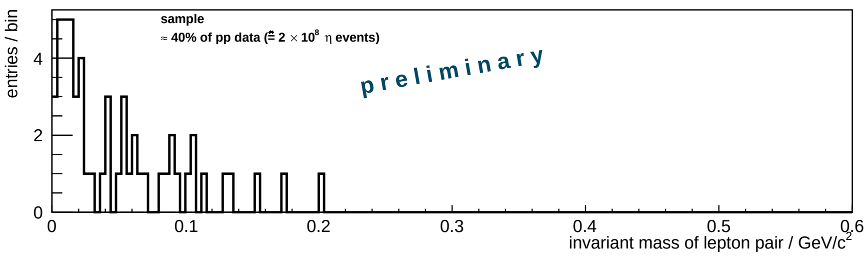

Figure 3. Invariant mass spectrum of the lepton pair after all cuts.

Fig. 3 shows the invariant mass spectrum of the lepton pair for candidates of the decay $\eta \to e^+e^-\pi^0 \to e^+e^-\gamma\gamma$ as a preliminary analysis result for $\approx 40\,\%$ of the data set. Besides a cut on the proton-proton missing mass around the η-mass, cuts on the invariant mass of two photons around the π^0-mass and on the invariant mass of all decay particles around the η-mass are applied. After a final probability cut on a kinematic fit with the hypothesis $pp \to ppe^+e^-\gamma\gamma$ only a few events remain out of $\approx 200 \times 10^6$ η-events.

3 Summary and outlook

The decay $\eta \to \pi^0e^+e^-$ is a perfect probe for testing C-violation and the search for particles beyond the standard model. A large data set, obtained with the WASA-at-COSY experiment by proton-proton scattering, allows for a very sensitive search for this reaction. The missing mass technique is a key tool to separate between η-productions and background reactions like multi-pion production. A new calibration method has been implemented to improve the missing mass resolution drastically.

The analysis will be further improved by adjusted Monte Carlo settings to the new calibration and cut optimizations based on Monte Carlo cocktails with the goal to significantly improve the existing upper limit as well as to study possible contributions from non-standard particles.

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