PROCEEDINGS OF SCIENCE

The $\eta \rightarrow \pi^+\pi^-\pi^0$ decay with WASA-at-COSY

Patrik Adlarson[∗†]
Institute for Physics and Astronomy, Uppsala University
E-mail: patrik.adlarson@physics.uu.se

Recently, a large statistics sample of approximately $3 \cdot 10^7$ decays of the η meson has been collected with the WASA detector at COSY using the $pd \rightarrow {}^3He\,\eta$ reaction at beam kinetic energy 1 GeV. These data are being used to study the not so rare η decays involving charged pions, like $\eta \rightarrow \pi^+\pi^-\pi^0$. This decay proceeds mainly via a strong isospin violating contribution, where the decay width is proportional to the light quark mass difference squared, $(m_d - m_u)^2$. Preliminary results of the analysis are presented.
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∗Speaker.
†For the WASA-at-COSY collaboration.

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1. Introduction

The decay $\eta \to \pi^+\pi^-\pi^0$ is important since it allows access to light quark mass ratios. At lowest order of chiral perturbation theory (ChPT) the amplitude is given by

$$A \propto \frac{m_d - m_u}{F_\pi^2}\left(1 + \frac{3(s-s_0)}{m_\eta^2 - m_\pi^2}\right), \tag{1.1}$$

where F_π is the pion decay constant, $s = (p_{\pi^+} + p_{\pi^-})^2 = (p_\eta - p_{\pi^0})^2$, $s_0 = \frac{1}{3}(m_\eta^2 + 3m_\pi^2)$ and $m_{\pi^\pm} = m_{\pi^0} = m_\pi$. Since electromagnetic corrections are small [1, 2] this decay is a probe for the strong isospin violation. The calculated tree level decay width, $\Gamma_{tree} \approx 70$ eV [3], deviates more than a factor of four from the PDG value $\Gamma = 296 \pm 16$ [4]. Higher order diagrams are needed which, among other things, take into account $\pi\pi$ final state interactions [5, 6, 7]. Alternatively, $\pi\pi$ final state re-scattering can be implemented in dispersive approaches [8, 9, 10, 11, 12] as well as other approaches [13]. The decay width scales as

$$\Gamma = \left(\frac{Q_D}{Q}\right)^4 \bar{\Gamma}, \tag{1.2}$$

where $Q^2 = (m_s^2 - \hat{m}^2)/(m_d^2 - m_u^2)$, $\hat{m} = \frac{1}{2}(m_u + m_d)$, and the decay width $\bar{\Gamma}$ and $Q_D = 24.2$ are calculated in the Dashen limit [14]. Q gives access to light quark mass ratios. The ratios serve also as an important input for lattice QCD [15]. To derive Q, $\bar{\Gamma}$ has to be known reliably from theory which can be tested by comparing with the experimental Dalitz plot distributions. As Dalitz plot variables

$$x = \sqrt{3}\frac{T_+ - T_-}{Q_\eta}, \; y = \frac{3T_0}{Q_\eta} - 1. \tag{1.3}$$

are used. Here T_+, T_- and T_0 denote the kinetic energies of π^+, π^- and π^0 in the η rest frame, and Q_η is the sum of the three kinetic energies. The standard way to parametrize the Dalitz plot density is a polynomial expansion around $x = y = 0$

$$|A(x,y)|^2 \propto 1 + ay + by^2 + dx^2 + fy^3 + gx^2y + \ldots \tag{1.4}$$

where $a, b, \ldots, g$ are called the Dalitz Plot parameters. The most precise experimental result is obtained by KLOE [16] with a Dalitz plot containing $1.34 \cdot 10^6$ events. Parameters b and f in [16] deviate significantly from ChPT predictions. Independent measurements are therefore important and WASA-at-COSY [17] aims at providing two independent data sets with η produced in pp and pd reactions.

2. Experiment

The Wide Angle Shower Apparatus (WASA) is a near 4π detector situated at the COoler Synchrotron (COSY) facility in Jülich, Germany. The design purpose of WASA is to study the production and decay of light mesons. The detector consists of two major parts- the Forward Detector and the Central Detector, covering polar angles from $3^\circ - 18^\circ$ and $20^\circ - 169^\circ$ respectively. In 2008 and 2009 WASA-at-COSY collected approximately $1 \cdot 10^7$ and $2 \cdot 10^7$ η mesons respectively, in the reaction $pd \to {}^3\text{He}X$ at a kinetic beam energy of 1 GeV. The ^{3}He is detected in the Forward Detector and identified from other charged particles by studying the deposited energies in consecutive layers, as shown in the left frame of figure 1. By calculating the missing mass for ^{3}He, a peak at the η mass is seen, clearly distinguishable from other reactions which also contains ^{3}He, shown in the right frame of figure 1.

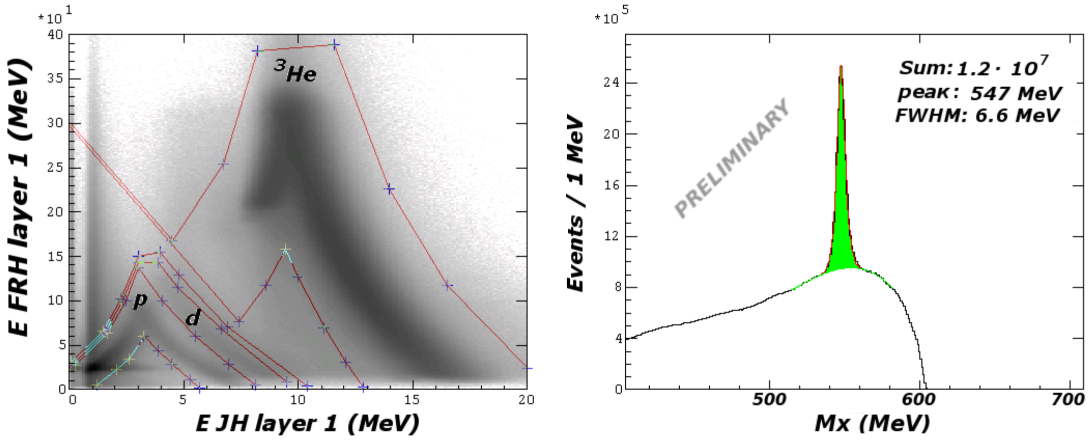

Figure 1: Experiment: (**left**) By studying the energy deposits in different layers of the forward detector and applying a graphical cut ^{3}He is selected. (**right**) Missing mass calculated for ^{3}He gives 12 million η events for the 2008 data with the full width of half the maximum less than 7 MeV.

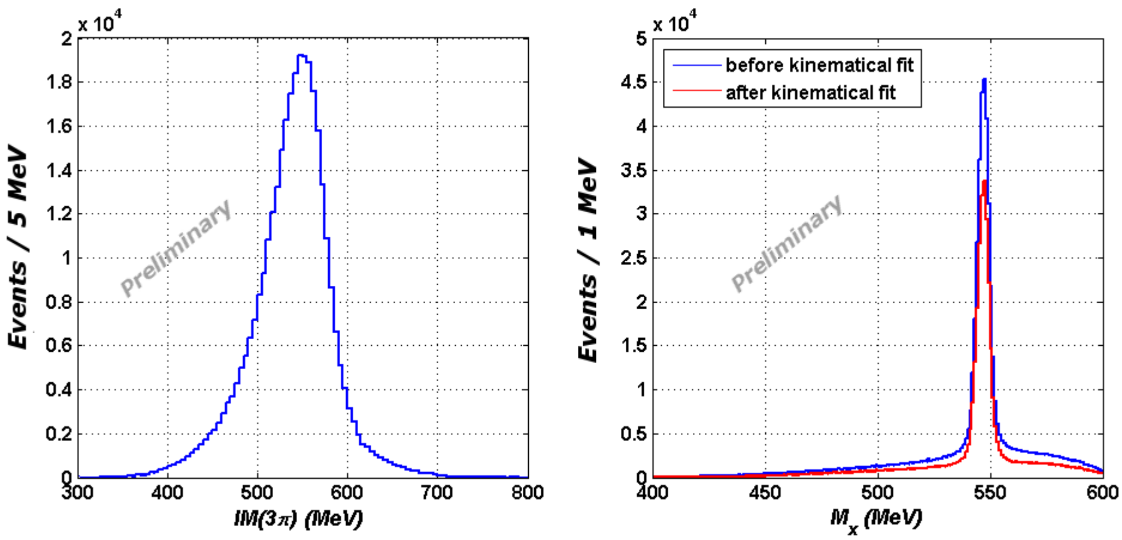

Figure 2: Experiment: (**left**) Invariant mass of $\pi^+\pi^-\pi^0$ for events in the η mass range of the missing mass calculated for ^{3}He after timing, vertex and kinematical conditions have been applied. (**right**) Missing mass calculated for ^{3}He before (blue) and after (red) kinematical fit has been applied. The number of $\eta \to \pi^+\pi^-\pi^0$ candidates after kinematical fit amounts to approximately $2.1 \cdot 10^5$. The full width at half of the maximum of the η peak before and after kinematical fit is 6.1 MeV and 5.9 MeV respectively.

To obtain $\eta \to \pi^+\pi^-\pi^0$ candidates, at least two particles of opposite charge and at least two photons with an invariant mass close to π^0 are required to be detected in the Central Detector. To suppress mixing particles from different events, cuts on vertices and timing requirements are included. To reduce background channels, mainly coming from $pd \to {}^3\text{He}\pi\pi$ reactions, conditions on the missing mass calculated for ${}^3\text{He}\pi^+\pi^-$, ${}^3\text{He}\pi^0$ and $\pi^+\pi^-$ are applied. The experimental resolution is better for the η four-momenta of ^{3}He compared to the information derived from the η decay products measured in the Central Detector. To improve the resolution for the four-momenta of the η decay products and to further reduce background, a kinematical fit for the reaction $pd \to {}^3\text{He}\pi^+\pi^-\gamma\gamma$ has been used keeping events above the 1% level of the probability density function. This improves the full width at half the maximum of the invariant mass of the 3π peak from approximately 70 MeV to 6 MeV. The preliminary analysis gives $2.1 \cdot 10^5$ $\eta \to \pi^+\pi^-\pi^0$ candidates from the 2008 data sample after kinematical fit, shown in the right frame of figure 2.

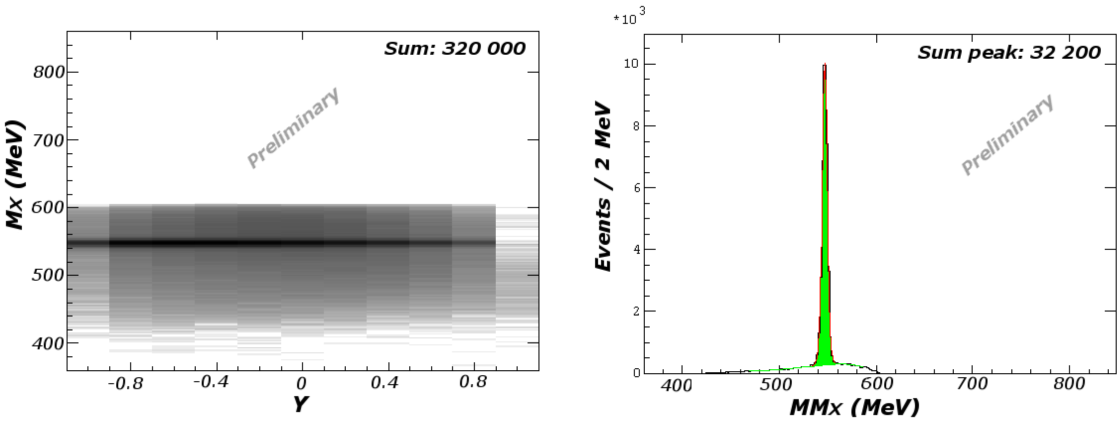

Figure 3: Experiment: (**left**) Scatterplot of the missing mass calculated for ^{3}He versus the Dalitz plot content projected onto the y axis. (**right**) To obtain the number of $\eta \to \pi^+\pi^-\pi^0$ events in the Dalitz plot bin, a polynomial fit is performed over the background region and then subtracted. In addition a double gaussian may be used to fit the number of events in the peak region. The example shows the content for $-0.7 \leq y \leq -0.5$.

The full width of half the maximum of the Dalitz plot variables x and y are both approximately 0.1. To obtain sufficient statistics in each bin, the Dalitz plot bin width 0.2 is chosen for both variables. The main type of events populating the Dalitz plot is ${}^3\text{He}\pi^+\pi^-\pi^0$ and $\eta \to \pi^+\pi^-\pi^0$. The η content in each Dalitz plot bin is obtained by performing a four-degree polynomial fit over the direct 3π background and the fitted polynomial is subtracted from the signal region as shown in the right frame of figure 3. The number of η events in each bin is then corrected for acceptance.

3. Result

The preliminary acceptance corrected experimental results with statistical errors for the x, y projections of the Dalitz plot are compared in figure 4 to the distributions of the $\eta \to \pi^+\pi^-\pi^0$ with Monte Carlo weighted with the set of Dalitz plot parameters calculated for the leading order (LO) in ChPT (solid blue line), next-to-next-to-leading order (NNLO) (dashed-dotted green line) and the central values obtained by KLOE (dashed red line). The Monte Carlo results have been normalized to the WASA experimental data. From the preliminary Dalitz plot projections the WASA data points are in reasonable agreement with the KLOE experimental result.

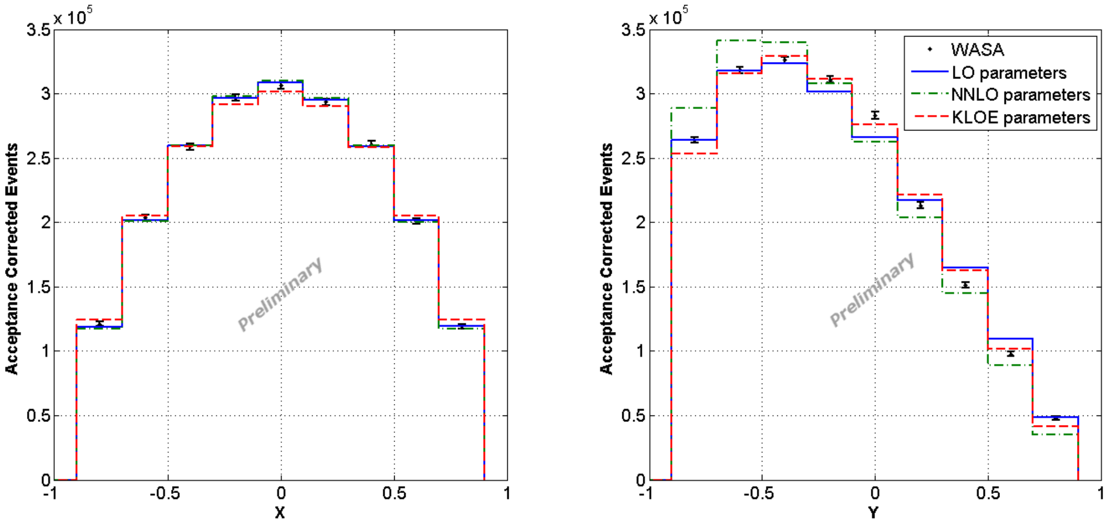

Figure 4: Acceptance corrected data points with statistical errors, projected on x (**left**) and y (**right**), compared to Monte Carlo weighted with the Dalitz plot parameters for the leading order calculation (LO) in ChPT (solid blue line), next-to-next-to-leading order (NNLO) (dashed-dotted green line) and the central values obtained by KLOE (dashed red line). The Monte Carlo results are normalized to the experimental data.

4. Outlook

The work on the *pd* data will be continued in order to obtain the Dalitz plot parameters for $\eta \to \pi^+\pi^-\pi^0$. An effort will also be made to understand the systematical effects.

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