MEASUREMENT OF THE $\eta \rightarrow \pi^+ \pi^- \pi^0$ DECAY WITH WASA-at-COSY DETECTOR

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One of the objectives of the physics programme of the WASA-at-COSY facility is to study the isospin violating $\eta$ hadronic decays into $\pi^+ \pi^- \pi^0$ systems driven by the term of QCD Lagrangian which depends on the d and u quark mass difference. These studies can be made in terms of the Dalitz plot parameters describing the density population which is proportional to the square of the amplitude $|A(x, y)|^2$. This contribution describes the current status of the analysis of the $\eta \rightarrow \pi^+ \pi^- \pi^0$ decay in the $pd \rightarrow 3He\eta$ and as well in the $pp \rightarrow pp\eta$ reaction with WASA-at-COSY.

Keywords: Meson production; hadronic decays; ChPT; WASA-at-COSY.

PACS numbers: 11.25.Hf, 123.1K

1. Motivation

The isospin violating strong decay $\eta \rightarrow \pi^+ \pi^- \pi^0$ allows access to light quark mass ratios. At lowest order of chiral perturbation theory (ChPT) the amplitude is proportional to the light quark mass difference $(m_d - m_u)$ and may be written as

$$A \propto \frac{m_d - m_u}{F^2_\pi} \left(1 + \frac{3(s - s_0)}{m^2_\eta - m^2_\pi}\right),$$

where $F_\pi$ is the pion decay constant, $s = (p_{\pi^+} + p_{\pi^-})^2 = (p_{\eta} - p_{\pi^0})^2$ and $s_0 = \frac{1}{4}(m^2_\eta + 2m^2_{\pi^\pm} + m^2_{\pi^0})$. At higher order of ChPT it has been found that final state pion interaction contribute to the decay width.\cite{1,2} The decay width scales as $\Gamma = \left(\frac{Q_D}{m}\right)^4 \tilde{\Gamma}$, where $Q^2 = \frac{m^2_{\eta} - \hat{m}^2}{m^2_{\pi} - m^2_\pi}$, $\hat{m} = \frac{1}{2}(m_u + m_d)$, and the decay width $\tilde{\Gamma}$ and $Q_D = 24.2$ are calculated in the Dashen limit.\cite{3} This scaling works under the pre-requisite that $\tilde{\Gamma}$ is understood reliably. To test this, theoretical predictions and experimental measurements of pion kinematical distributions may be compared in a Dalitz plot, where the axes are defined as $x = \sqrt{\frac{T_+ - T_-}{Q_\eta}}$, $y = \frac{3m_0}{q_\eta} - 1$. Here $T_+$,
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$T_-$ and $T_0$ denote the kinetic energies of pions in the rest frame of the $\eta$ meson, and $Q_\eta = T_+ + T_- + T_0 = m_\eta - 2m_{\pi^+} - m_{\pi^0}$. The standard way to parametrize the Dalitz plot density is a polynomial expansion around the center point:

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

where $a, b, d, f$ are the Dalitz plot parameters. The experimental results are dominated by KLOE with a Dalitz plot containing $1.34 \times 10^6$ events. This result shows a significant deviation of parameters $b$ and $f$ in comparison to the theoretical predictions based on ChPT. It is therefore important to perform an independent measurement, which is one of the aims of the WASA-at-COSY.

2. $pd \to ^3He \eta$ measurement

In 2008 and 2009 WASA-at-COSY measured $pd \to ^3HeX$ reaction at beam energy 1 GeV, collecting $10^7$ and $2 \cdot 10^7$ $\eta$ mesons respectively. The missing mass with respect to $^3He$ is used to tag the $\eta$ meson (Fig. 1 left). In addition two tracks of opposite charge are required in the Mini Drift Chamber in the angular range $30.5^\circ < \theta < 150^\circ$. Furthermore two $\gamma$ with an invariant mass close to $\pi^0$ are required. The $pd \to ^3He\pi\pi$ reaction is reduced by imposing conditions on the missing mass calculated for $^3He\pi^+\pi^-$ and the missing mass calculated for $^3He\pi^0$. The preliminary analysis yields 149 000 $\eta \to \pi^+\pi^-\pi^0$ candidates from the 2008 data, shown in Fig. 1 right. The experimental resolution is better for the $\eta$ four-momenta from $^3He$ compared to the information derived from the $\eta$ decay products. Therefore a kinematical fit for the reaction $pd \to ^3He\pi^+\pi^-\pi^0$ has been used with $^3He$ observables fixed and a cut on the 1% level of the probability density function. To estimate the $\eta$ content in each Dalitz plot bin, a four-degree polynomial fit is performed over the background region. The preliminary experimental results for the $x,y$ projections of the Dalitz plot are compared in Fig. 2 to Monte Carlo simulations of the $\eta \to \pi^+\pi^-\pi^0$ weighted with the tree-level prediction (Eq. (1)).

3. $pp \to p\eta$ measurement

The measurement of the $pp \to ppX$ reaction was conducted in 2008 and in 2010 at beam kinetic energy 1.4 GeV. The collected sample of data yields about $10^8$ produced $\eta$ mesons. Protons and charged pions were detected using scintillators.
Fig. 2. Projections of Dalitz Plot, not corrected for acceptance and normalized to sum of experimental data: (left) X-projection (right) Y-projection. Solid line indicates MC data and points with error bars experimental values.

Fig. 3. (left) Missing mass of the $pp \rightarrow ppX$ reaction. (middle) Invariant mass of two $\gamma$ with cut lines. (right) Missing mass of two protons with the requirement of two $\gamma$ in coincidence.

and straw tube trackers (FPC and MDC). Two protons were used to tag the $\eta$ meson in the missing mass plot showed in Fig. 3 left (here we present data only from one run). The two $\gamma$ originating from the $\pi^0$ meson decay were registered in the electromagnetic calorimeter. The invariant mass of these $\gamma$ is required to be close to the mass of the $\pi^0$ (Fig. 3 middle). Requiring two $\gamma$ in coincidence with the two protons gives the missing mass as shown in Fig. 3 right.

4. Outlook

The work for both $pd$ and $pp$ data will be continued in order to obtain two independent determinations of the Dalitz plot density for the $\eta \rightarrow \pi^+ \pi^- \pi^0$. This includes estimating systematical errors as well as tuning Monte Carlo simulation.

References