PROCEEDINGS OF SCIENCE

Studies of meson production and decays in pd$\rightarrow^3$HeX with WASA-at-COSY

Anna Jany[*†]
Jagiellonian University
E-mail: anna.jany@uj.edu.pl

The pd$\rightarrow^3$HeX reactions give a possibility of a clean measurement of a number of important decays of low-energy mesons due to the WASA-at-COSY capability of detecting multi-particle coincidences of charged and neutral particles. This allows to study the symmetries, symmetry breaking and reaction dynamics for different final states. The current investigations of the meson production and decays in pd$\rightarrow^3$HeX with WASA-at-COSY are presented.

XLIX International Winter Meeting on Nuclear Physics, BORMIO2011
January 24-28, 2011
Bormio, Italy

[*] Speaker.
[†] for the WASA-at-COSY Collaboration.

PoS(Bormio 2011)048

1. Current investigations of meson production and decays in pd→^{3}HeX

The pd→^{3}HeX reactions (where X stands for light mesons as, *e.g.*, η and ω) are investigated with the WASA-at-COSY detector system [1] located at the Cooler Synchrotron (COSY) [2] in the Research Center Juelich, Germany. Studies of these reactions contribute to each section of the physics program of the WASA-at-COSY Collaboration [1]. With the help of rare decays of light mesons, symmetries and symmetry breaking are investigated. Dalitz decays allow to investigate the hadron structure by studies of the electromagnetic transition form factors. The production of the mesons provides information about the hadron dynamics.

The WASA-at-COSY detector system is very well suited for studies of the meson production in these reactions. That is due to the ability of a reliable identification of ^{3}He by the ΔE-E method, using the forward part of the detector system, and of a clean identification of the mesons via the missing mass technique. The pd→^{3}HeX reactions provide also the possibility to study a number of important decays of the mesons due to the capability of detecting both charged and neutral final state particles in coincidence, in the central part of the detector, covering almost 4π acceptance.

In the 12 weeks run period, October 2008 and August - September 2009, a data sample of unbiased $3 \cdot 10^7 \eta$ meson decays was collected, at a beam kinetic energy of 1.0 GeV. Using the large amount of data, many decay channels are investigated, some of them are summarized below.
The Dalitz plot parameter of the decay $\eta \to \pi^+\pi^-\pi^0$, which violates isospin conservation, is studied in order to get information about the mass difference of the lightest quarks [3].
The $\eta \to \pi^+\pi^-\gamma$ decay mode allows to study the box anomaly of QCD. The current results, concerning the photon energy line shape, are in agreement with Vector Meson Dominance (VMD) model calculations [4].
The rare double Dalitz decay $\eta \to e^+e^-e^+e^-$ is investigated in order to extract the branching ratio and to determine the transition form factor of the η meson. The current estimate of the upper limit of the branching ratio is in agreement with the theoretical predictions based on QED [5].
With the knowledge of the $\eta \to \pi^0\gamma\gamma$ decay precise studies of the Chiral Perturbation Theory can be performed. The differential distribution of the invariant mass of the two photons contains information about the contribution of the intermediate vector mesons. The preliminary analysis of this decay allowed the extraction of the pertinent the branching ratio [6].
The decay $\eta \to \pi^0e^+e^-$, forbidden in first order in the Standard Model by charge symmetry, is measure in order to improve the upper limit for the branching ratio. The preliminary outcome of the analysis of part of the collected data would be compatible with 1 event corresponding to the forbidden decay [7].

In the case of the ω production, the existing data are scarce and cannot be described by the two-step model of Ref. [8]. In addition, more data are needed to describe the ω decays and especially the electromagnetic transition form factor. Note that the standard VMD fails to describe the existing data [9, 10]. The current theoretical approach [11], which exceeds VMD in a systematic way and describes the data significantly better, needs to be further tested by new high-statistics data.
Therefore, a new WASA-at-COSY project arose which concentrates on the ω production and the decay modes. The high-statistics $\omega \to \pi^0\pi^+\pi^-$ Dalitz plot will be measured and the ω transition form factor in the $\omega \to \pi^0e^+e^-$ Dalitz decay will be investigated. The decay $\omega \to \pi^0\gamma$ will be

studied as a reference channel. The beam time is scheduled for February 2011. In a rough estimate, in the 4 weeks of beam time about $2 \cdot 10^6$ ω events will be collected on disk.

2. Angular Distribution Studies of the pd→^{3}He ($\eta \to \gamma\gamma$) reaction at Q=61 MeV

The data available in literature for the production in the pd system, i.e. for the pd →^{3}Heη reaction, are sufficient only at low excess energies, $Q < 11$ MeV. Moreover, they are mainly limited to measurements of the total production cross section, in spite of the fact that information on the angular distribution would allow to obtain a better insight into the reaction mechanism [12]. The existing angular distribution studies, in the energy range $Q < 11$ MeV, show an isotropic (for the lowest energies) or, respectively, a linear dependence of the differential cross section on the cosine of the η production angle, $\cos(\theta)\eta_{CM}$ [12, 13]. This suggests that, in addition to the s-wave, the s-p interference is relevant in this energy region [14].

At larger Q values, the contribution of higher partial waves is expected to become important [15, 16]. However, the data are scarce for these energies and, moreover, the angular distributions obtained at similar energies in various experiments are not identical[15]. Therefore, the measurements with the WASA-at-COSY detector system have been performed.

An experimental data set was taken in October/November 2008, at 1.7 GeV/c beam momentum corresponding to Q=61 MeV. The two-photon decay of the η meson was registered in coincidence with the ^{3}He. The two photons were detected in the central part of the WASA-at-COSY apparatus, whereas the ^{3}He was observed in its forward part [1]. The η meson has been identified via missing mass and invariant mass techniques, as shown in Fig. 1.

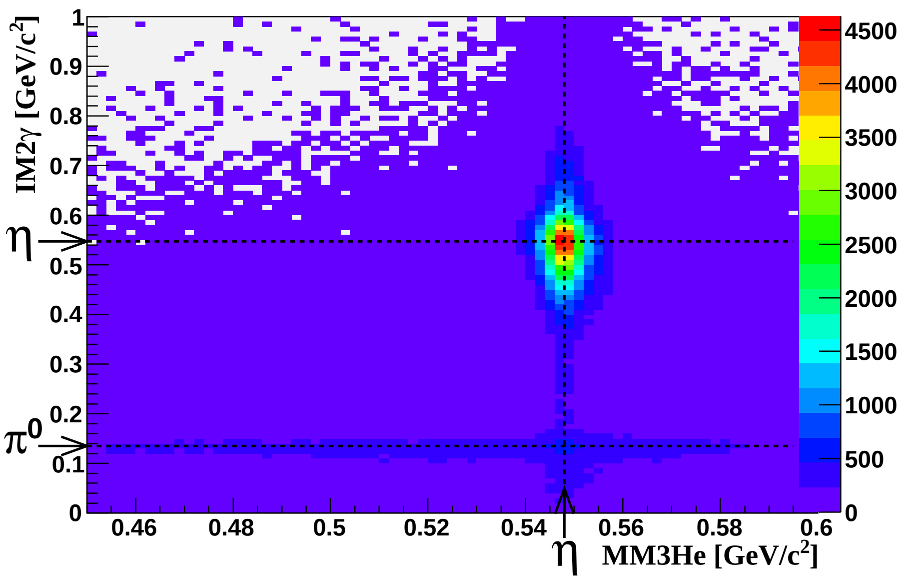

Figure 1: Invariant mass IM2γ versus missing mass MM3He.

In spite of the fact that the cross section for the reaction pd→^{3}He ($\eta \to \gamma\gamma$) is not very large (it is equal to σ=0.16μb, i.e. σ(pd→^{3}He η)=0.4μb, BR($\eta \to \gamma\gamma$)=0.4), the signal-to-background ratio ($\sigma(\eta)/\sigma(2\pi)$=1) is big enough to allow an easy selection of the η meson by putting a gate on the invariant mass of the two photons (IM2γ). The selected events have been used to construct the angular distribution of the η meson in the CM of the ^{3}He-η system. For each individual bin of $\cos(\theta)\eta_{CM}$ of 0.03 length, the still existing background in the missing mass of ^{3}He (MM3He) has been approximated by a second-order polynomial. The preliminary data, corrected with respect to the total efficiency and normalized to the total cross section taken from [15], have been compared with the existing experimental data [15, 16], as presented in Fig. 2.

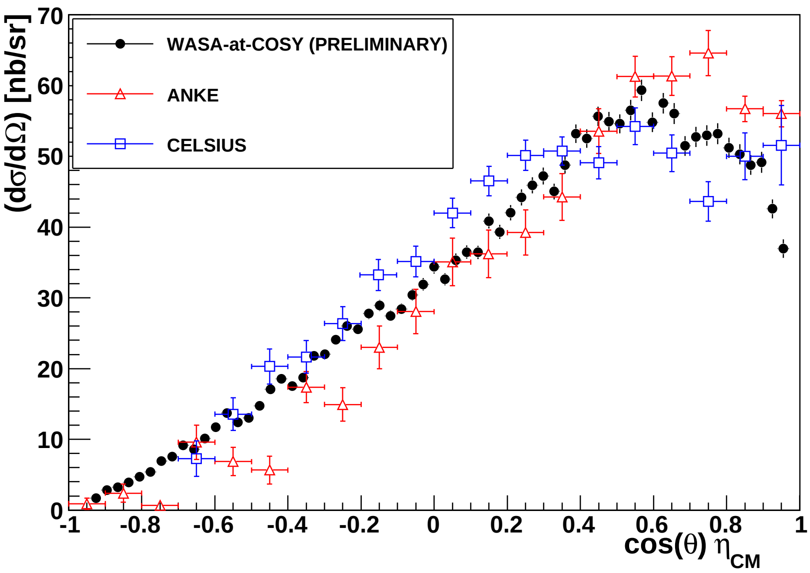

Figure 2: The differential cross section in a function of the $\cos(\theta)\eta_{CM}$. The present result (full circles) compared to the ANKE data [15] measured at Q=60MeV (triangles) and CELSIUS [16] at Q=80 MeV (squares).

It can be seen that the WASA-at-COSY data are in magnitude between the ANKE and CELSIUS data, when normalized to the same total cross section value. Taking into account that different experimental methods were used in both measurements, the agreement between the results is quite good. It should be pointed out that the WASA-at-COSY data were obtained with significantly higher statistics than those from the previous experiments [15, 16]. This allowed to obtain smaller statistical errors even for the smaller $\cos(\theta)\eta_{CM}$ bins.

Using the present, preliminary data, a partial wave analysis has been performed. Since the considered reaction is induced by an unpolarized proton beam impinging onto an unpolarized deuteron target and the polarization of the outgoing ^{3}He is not measured, the angular distribution can be decomposed into a series of Legendre polynomials as follows:

$$\frac{d\sigma}{d\Omega}(\theta) = \frac{1}{4k^2} \cdot |\sum_{l=0}^{l_{max}}(2l+1)S_l P_l(\theta)|^2 \tag{2.1}$$

where k is the CM p+d wave number and the dynamics of the process is determined by complex S-matrix elements S_l. The formula (2.1) was fitted to the experimental angular distribution treating the S_l elements as free parameters. The fit was performed for l_{max} values ranging from 1 to 4, respectively. The result is presented in Fig. 3.

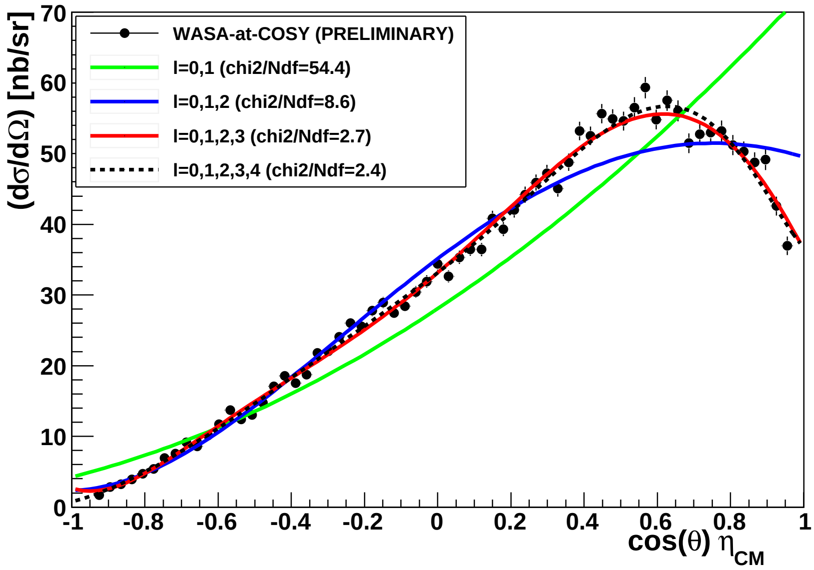

Figure 3: Experimental angular distribution and the results of the partial-wave fits.

The best fit was obtained for $l_{max} = 4$. This is in agreement with the conclusion of [15]. The corresponding probabilities $|S_l|^2$ of the reaction for a given orbital momentum l as well as the relative probabilities $|S_l|^2/|S_0|^2$ are listed in Table 1.

l	$\lvert S_l\rvert^2$ $[10^{-5}]$	$\lvert S_l\rvert^2/\lvert S_0\rvert^2$
0	8.57(98)	1
1	3.86(53)	0.45(1)
2	1.18(40)	0.14(3)
3	0.27(6)	0.031(3)
4	0.016(7)	0.0019(6)

Table 1: The probabilities $|S_l|^2$ of the reaction for a given l and the relative probabilities $|S_l|^2/|S_0|^2$.

As can be seen in Fig. 3 and in Table 1, the contribution of g-wave ($l = 4$) is almost negligible, however all smaller l-values are significant and decrease monotonically with increasing l.

References

[1] H.H.Adam et al., arXiv:nucl-ex/0411038 (2004).

[2] R.Maier, *Nucl. Instr. Meth. A* **390**, 1-8 (1997).

[3] P.Adlarson and M.Zielinski, *IJMP A* **26**, 622 (2011).

[4] C.F.Redmer, PhD Thesis, Bergischen Universitaet Wuppertal, Germany (2010) *http://www2.fz-juelich.de/ikp/wasa/theses/*

[5] L.Yurev, PhD Thesis, Universitaet zu Koeln, Germany (2011) *http://www2.fz-juelich.de/ikp/wasa/theses/*

[6] K.Lalwani, PhD Thesis, IIT Bombay, India (2010) *http://www2.fz-juelich.de/ikp/wasa/theses/*

[7] A.Winnemoeller, Phd Thesis, Universitaet Muenster, Germany (2011) *http://www2.fz-juelich.de/ikp/wasa/theses/*

[8] G.Faeldt and C.Wilkin, *Nucl. Phys. A* **587**, 769 (1995).

[9] L.G.Landsberg, *Phys. Rept.* **128**, 301 (1985).

[10] R.Arnaldi *et al.*, *Phys. Lett. B* **677**, 260 (2009).

[11] C.Terschluesen and S.Leupold, *Phys. Lett. B* **691**, 191 (2010).

[12] T.Mersmann *et al.*, *Phys. Rev. Lett.* **98**, 242301 (2007).

[13] J.Smyrski *et al.*, *Phys. Lett. B* **649**, 258 (2007).

[14] C.Wilkin *et al.*, *Phys. Lett. B* **654**, 92 (2007).

[15] T.Rausmann et al., *Phys. Rev. C* **80**, 017001 (2009)

[16] R.Bilger *et al.*, *Phys. Rev. C* **65**, 044608 (2002).