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Triangle singularity in the $\gamma p \to p\pi^0\eta$ reaction ??

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Abstract. The $\gamma p \to p\pi^0\eta$ reaction has been studied with the CBELSA/TAPS detector system to search for experimental evidence for triangle singularities. Kinematically these singularities exist in the decay chain $\Delta^* \to \eta\Delta(1232) \to \eta\pi^0 p$ but do not show an experimental effect because of the weakness of the $\pi^0 - \eta$ interaction at low $\sqrt{s}$ near threshold far below the $a_0(980)$ resonance.

1 Introduction

With the large amount of experimental results on particle reactions and resonances the importance of triangular singularities in hadron physics has recently been noticed, although early theoretical studies date back to the 1960's [1]. Structures in invariant mass plots are not necessarily associated with new resonant states but may also be of kinematical origin. One of the best examples is the $a_1(1420)$ with spin, parity and C-parity quantum numbers $J^{PC} = 1^{++}$ observed by the COMPASS collaboration in diffractive π^- dissociation [2]. Its decay exclusively into the $\pi f_0 980$ channel indicated its exotic nature. It was, however, soon realized by Mikhasenko et al. [3], and Aceti et al. [4] that the structure at a mass of 1420 MeV could as well originate from a kinematic effect due to a triangle singularity, where all particles in the triangle are on shell. The structure arises from the decay mode of the well-known broad $a_1(1260)$ resonance into the $\pi^0 f_0(980)$ channel. Analogously, Debastiani et al. [5] discuss the excitation function of the $\gamma p \to p\pi^0\eta$ reaction, described on tree level by Fig. 1-a, and the impact of a triangle singularity as depicted in Fig. 1-b. The recombination of the proton and the η meson to form the $S_{11}(1535)$ resonance leads to an enhancement in the $\pi^0 S_{11}(1535) \to \pi^0\eta p$ channel near an incident photon energy of 1220 MeV. A partial wave decomposition into the latter channel and the channels $\eta\Delta(1232) \to \eta\pi^0 p$ and $a_0 N \to \eta\pi^0 p$ in [6], however, shows a steady increase of the $\pi S_{11}(1535)$ contribution with increasing incident photon energy. This will have to be re-investigated based on the present data.
In this contribution an alternative possibility is discussed, diagramatically described in Fig. 1-c. Here it is assumed that after photoexcitation, a higher lying $\Delta*$ resonance decays via η emission into the $\Delta(1232)$ which subsequently decays into a π^0 and a proton. If the π^0 is emitted in the same direction as the η, the π^0 may catch up with the η and rescatter. A triangle singularity with elastic scattering of two mesons in the final state was considered by Schmid [1]. Applying formulae Eq. (5)-(9) in [1] triangle singularities are found to occur for all incident photon energies in the range from 1220-1750 MeV at $\pi^0\eta$ invariant masses of 685 - 750 MeV as shown in Fig. 2.

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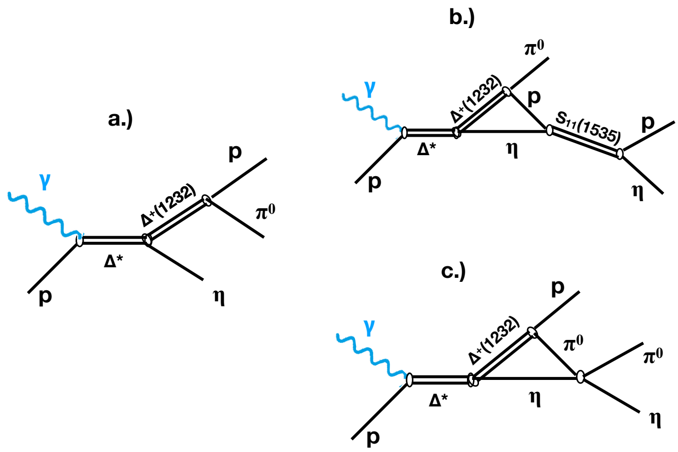

Figure 1. Diagrams describing the $\gamma p \to p\pi^0\eta$ reaction: a.) tree level; b.) triangle diagram for the $\pi^0 S_{11}(1535)$ channel; c.) triangle diagram for the $\pi^0\eta$ rescattering channel.

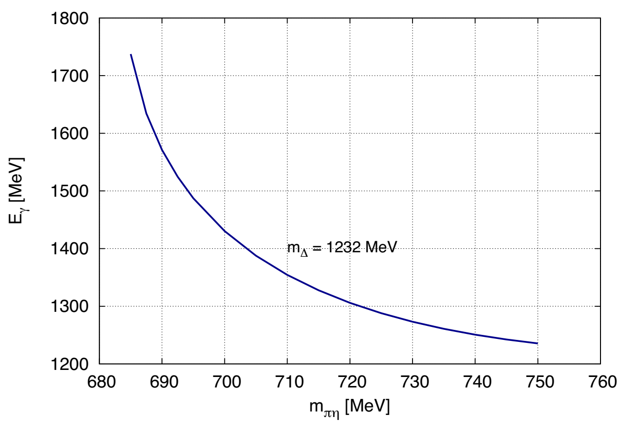

Figure 2. Triangle singularity according to the diagram in Fig. 1-c for a given incident photon energy E_γ as a function of the $\pi^0\eta$ invariant mass.

2 Search for experimental evidence for a triangle singularity in the $\gamma p \to p\pi^0\eta$ reaction

In a search for this triangle singularity, the $\gamma p \to p\pi^0\eta$ reaction has been studied with the CBELSA/TAPS detector system using tagged photon beams from the ELSA accelerator at Bonn impinging on a LH_2 target. Details of the accelerator facility and the experimental setup are found in [7, 8], respectively. For the data analysis events with one proton and four photons in the final state have been selected. A kinematic fit has been performed to

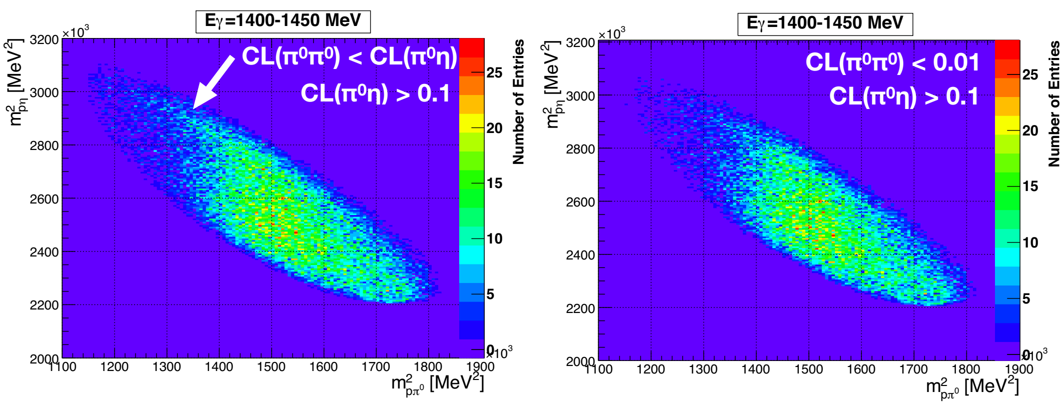

Figure 3. Dalitz plot of $m^2_{p\eta}$ versus $m^2_{p\pi^0}$ for E_γ = 1400 - 1450 MeV for a confidence level for $p\pi^0\eta$ events CL($\pi^0\eta$) > 0.1 and two different conditions to reject $p\pi^0\pi^0$ events. Tailing events along the diagonal are marked with an arrow. The Dalitz plots are not corrected for acceptance.

identify the $p\pi^0\eta$ final state and to suppress the much more numerous events in the $p\pi^0\pi^0$ channel. Fig. 3 shows as an example the Dalitzplot of $m^2_{p\eta}$ versus $m^2_{p\pi^0}$ for the incident photon energy range of 1400 - 1450 MeV and a confidence level for $p\pi^0\eta$ events CL($\pi^0\eta$) >

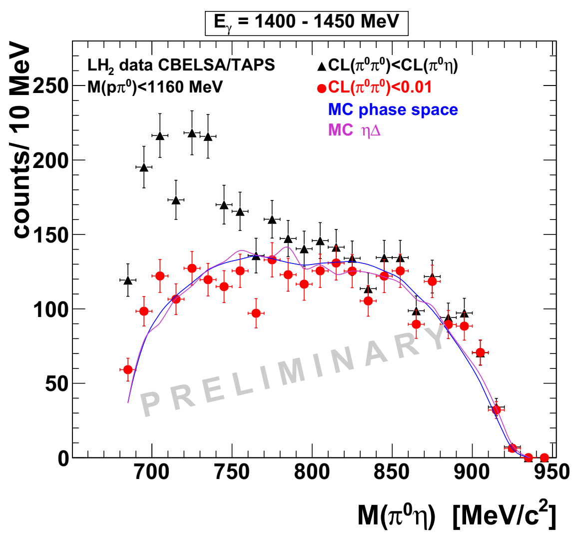

Figure 4. $\pi^0\eta$ invariant mass distribution for E_γ= 1400-1450 MeV and $m_{p\pi^0}$ < 1160 MeV and for different $\pi^0\pi^0$ rejection cuts in comparison to a phase space simulation and a simulation of the $\Delta^* \rightarrow \eta\Delta(1232) \rightarrow \eta\pi^0 p$ decay chain. The Monte Carlo simulations are normalised to the same area as for the distribution of the red (circle) data points. All distributions are not acceptance corrected.

0.1.The Dalitz plot on the left has been obtained for a less restrictive $\pi^0\pi^0$ rejection cut, requesting the confidence level for $p\pi^0\eta$ events to be larger than that for $p\pi^0\pi^0$ events. For the Dalitz plot on the right all events with CL($\pi^0\pi^0$) > 0.01 are removed from the data sample.

A tail of events along the diagonal is seen - more pronounced in the left plot - indicating a correlation between π^0 and η mesons corresponding to an invariant $\pi^0\eta$ mass of 700 - 720 MeV, which might be interpreted as a rescattering band as a consequence of a triangle singularity, as described by Schmid [1]. The fact that this intensity decreases with more restrictive $\pi^0\pi^0$ anti-cuts, however, indicates that most likely these events are remnants of a $\pi^0\pi^0$ background. A true $\pi^0\eta$ correlation would show up as a deviation from phase space in the $\pi^0\eta$ invariant mass distribution shown in Fig. 4. For the restrictive $\pi^0\pi^0$ anti-cut the measured distribution follows the phase space distribution and the distribution assuming the reaction chain $\Delta^* \to \eta\Delta(1232) \to \eta\pi^0 p \to p4\gamma$. A deviation from these distributions is only seen for an insufficient suppression of $\pi^0\pi^0$ events. Corresponding results obtained by the A2 collaboration at MAMI can be found in [9].

Although the triangle singularities exist kinematically in the given incident photon energy range their effect is not observed experimentally since the $\pi^0\eta$ interaction near threshold is obviously very small. This is consistent with recent studies of the $\chi_{c1} \to \eta\pi^+\pi^-$ decay by the BESSIII collaboration [10] and with calculations of the $\pi\eta$ phase shift in a T-matrix model which satisfies elastic unitarity below the $K\bar{K}$ threshold [11]. Since Schmid [1] points out that the tree level diagram (Fig. 1-a) also has singularities of exactly the same form and at the same energy as the triangle diagram (Fig. 1-c) it will be important to further search for effects of these singularities.

3 Summary and conclusions

A detailed study of the $\gamma p \to p\pi^0\eta$ reaction has been performed for incident photon energies in the range of 1300-1500 MeV. A kinematic fit is required to select the $p\pi^0\eta$ final state and very restrictive anti-cuts are needed to suppress $\pi^0\pi^0$ background. Triangle singularities are expected kinematically but are not observed experimentally because of the weakness of the $\pi^0\eta$ interaction below the $a_0(980)$ resonance, preventing sizeable $\pi^0 - \eta$ rescattering in the final state at low energies.

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