Conference Paper

Neutron detection in the A2 collaboration experiment on neutral pion photo-production on neutron

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Abstract

Neutron detection is of crucial importance for the neutral pion photo-production study on a neutron target that now is in progress at MAMI. Two electro-magnetic calorimeters, based on NaI and BaF_2 crystals, are used in the A2 experiment. While these calorimeters are optimized for pion decay photon detection, they have a reason able efficiency for neutron detection also. The paper describes the method, which has been used to measure this efficiency using the same data taken for pion photo-production study on deuterium target with tagged photon been of 800 MeV maximal energy. The detection efficiency is a rising function of neutron momentum that reaches 40% near 1 GeV/c.

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1. Introduction

The A2 Collaboration at MAMI (Mainz, Germany) is engaged in a program [1, 2] to study γn-interactions for which neutron detection is of crucial importance. The A2 experiment consists of several detector systems described below. Two of them, the Crystal Ball (CB) and TAPS, have a good neutron detection efficiency. The CB neutron detection efficiency was measured previously in a 1997–1998 run at BNL using the reaction $\pi^- p \rightarrow \pi^0$n and recently [3] using the method which will be described below. Up to now the forward calorimeter TAPS has not been checked for neutron detection. It covers relatively small angle in the laboratory frame approximately 20^o of polar angle. But its acceptance in γn center of mass frame due to relativistic boost amounts to 50^o that is a large part of the full acceptance.

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2. Experimental setup

The measurements were performed at the tagged photon facility of the Mainz Microtron accelerator (MAMI). An electron beam was used to produce bremsstrahlung photons, which were tagged with the upgraded Glasgow magnetic spectrometer. The target was a Kapton cylinder of 4 cm diameter and 10 cm length filled with liquid deuterium. Photons, charged pions, and recoil nucleons, produced in the target, were detected with an almost 4π electromagnetic calorimeters (CB and TAPS[4]), schematically shown in Figure 1.

The CB detector is a sphere consisting of 672 optically isolated NaI(Tl) crystals, shaped a truncated triangular pyramids, which point toward the center of the sphere. The NaI crystals have a length of 40.7 cm, which is equal to 15.7 radiation lengths or $\sim$ 1 hadron interaction length. The sides of the triangular faces are around 5.1 cm at the front of the crystals and 12.7 cm at the back. The CB covers polar angles from 20 to 160^o. The central spherical cavity with a radius of 25 cm holds the target and inner detectors. The target located in the center of the CB was surrounded by a Particle Identification Detector (PID) used to distinguish between neutral and different charged particles based on dE/dx measurements. It was made of 24 scintillator bars (50 cm long and 4 mm thick) arranged as a horizontal cylinder with a radius of 6 cm. The PID was surrounded by two Cylindrical Multiwire Proportional Chambers (MWPC). The inner (outer) chamber has a radius of 7.4 (9.45) cm and a length of 57 cm. Each chamber measured the three-dimensional coordinates of a charged-particle track as a result of a readout of three signals, one from a horizontal anode sense wire and the other two from spiral strip cathodes.

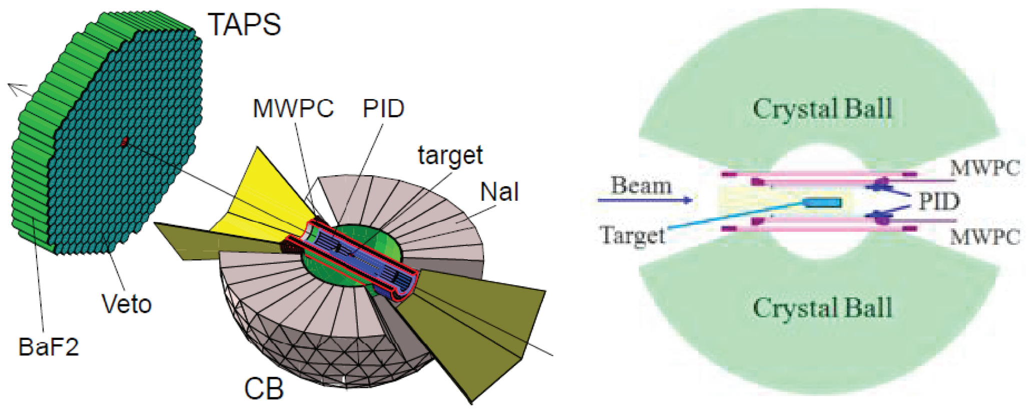

Figure 1: Left: layout of the A2 detector systems. Right: expanded view of the target region.

TAPS is a versatile calorimeter that is configured as forward wall for the current experiment. It covers the full azimuthal angle for polar angles from around 5^o to approximately 20^o. The crystals are arranged in a hexagon-like structure with eleven rings and six logical sectors. In the first version TAPS consisted of 384 barium fluoride (BaF_2) crystals. In 2009, the two most inner rings containing 18 crystals were replaced by smaller lead tungstate (PbWO4) crystals for a better handling of the high rates at smaller forward angles. Each BaF2 crystal was replaced by four PbWO4 crystals, resulting in a total configuration of 72 PbWO4 plus 366 BaF_2 crystals. The BaF_2 crystals have a hexagonal shape with a front face diameter of 5.9 cm. The length is 22.5 cm plus 2.5 cm of the cylindrical endcap with a diameter of 5.4 cm. The overall length of 25 cm corresponds to 12 radiation lengths. This crystals are shorter than NaI, but due to larger density and smaller nuclear interaction length they correspond to approximately the same 1 hadron interaction length. A special property of BaF_2 is the presence of a fast (~0.9 ns) and a slow (~ 650 ns) scintillation light components. The first provides a very good time resolution needed for time-of-flight measurements (up to 170 ps for a single detector), whereas the latter is responsible for the good energy resolution because of the high light yield. Due to the different mechanisms of energy deposition of photons and, e.g., hadrons, these two light components lead to different signal shapes for the corresponding particles. The relative contribution of the fast component to the total light output is higher in the case of photons than for, e.g., protons or neutrons. This can be used for particle identification by integrating the signal over a short and a long time interval and comparing the two resulting calibrated energies.

3. Overview of the method

For the neutron detection efficiency measurement, we chose the π^0 photo-production on deuteron

$$\gamma + d \rightarrow \pi^0 + p + n, \tag{3\_1}$$

where the π^0 decays to two photons. The reaction kinematics is completely determined if the pion and proton are detected and the beam energy is known. The π^0momentum is reconstructed using the energies and directions of the decay photons. The proton momentum is determined by its deposited energy in the CB and track direction in the MWPC and the photon beam energy is given by the tagging spectrometer. The reaction vertex was determined from the intersection of the proton track with the photon beam axis and allowed rejection of events from target walls. Then reaction (3_1) can be identified by the selecting neutron via missing mass. This procedure rejects events with more than one final-state pion and provides a reconstruction of the neutron momentum vector. If neutron momentum points to the TAPS (polar angles $5-15^o$), then a hit in the TAPS is searched for in the same direction. Then the neutron detection efficiency is determined as the ratio of registered hits to all neutrons. The indicated angular range is chosen to be smaller than the full acceptance of the TAPS to eliminate edge regions that inevitably have efficiency losses due to uncertainties in predicted and real hit positions. Apart from being kinematically completely determined, the reaction (3_1) has other advantages for detection efficiency study. It has a large cross section and a broad energy and angle spectrum of neutrons. The energy spectrum extends from nearly zero, when the pion is produced on a proton with a spectator neutron, to the maximum energy from pion production on the neutron with registered spectator proton. The latter was limited by the beam energy and the available statistics. Reaction (3_1) was selected from the events with three clusters in the CB, one hit in the PID and any number of clusters in the TAPS. Two clusters arise from π^0 decay photons, the third one from proton energy loss. A cluster is defined as a group of adjacent crystals each with deposited energy larger than 2 MeV centered around a crystal with maximum energy deposition. The minimum cluster summed energy was set to 15 MeV in this analysis. In the following sections, we describe all above mentioned steps in more detail.

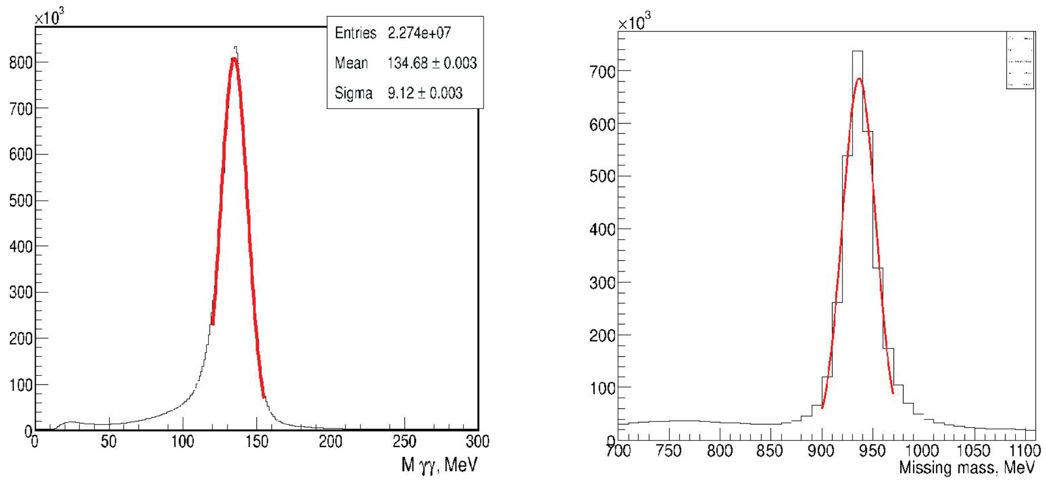

Figure 2: Left: π^0 mass as an effective mass of two gammas, red line is a gauss fit with σ = 9.1 MeV. Right: neutron mass as a missing mass in the reaction γ+d-> π^0 +p+n.

4. Measurement of neutron detection efficiency.

The first step in a reconstruction of reaction (3_1) was neutral pion selection. This was done by choosing the photon pair in the CB with an invariant mass $m_{\gamma\gamma}$ closest to the π^0 mass $m_{\pi 0}$. The $m_{\gamma\gamma}$ distribution is shown in Figure 2 (left) with a Gaussian fit to the peak.

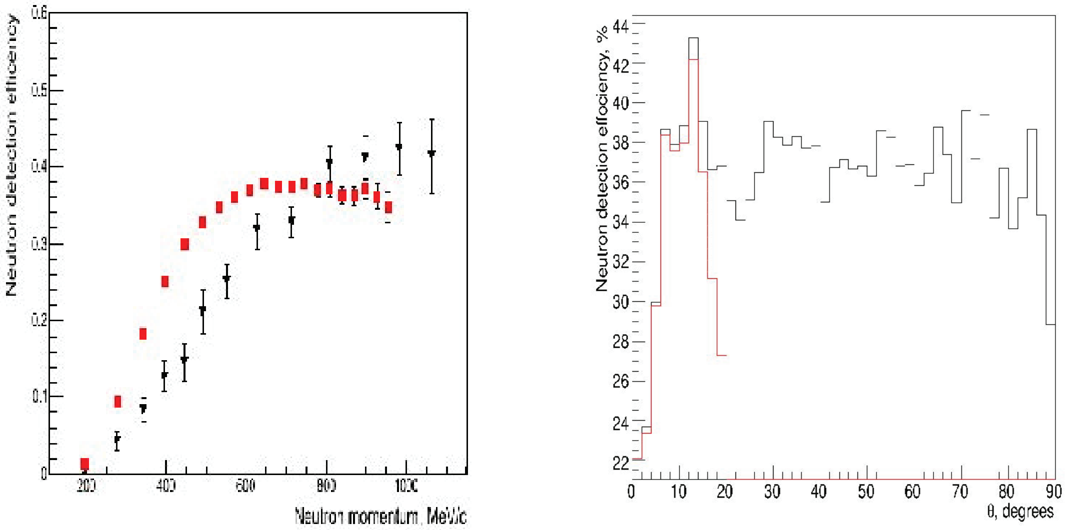

Figure 3: Left: neutron detection efficiency: red squares are for the CB [3], black triangles are this measurements for the TAPS. Right: angular dependence of the neutron detection efficiency in percentage for the neutron momentum larger than 500 MeV/c : black line - CB+TAPS, red line - TAPS only.

The distribution demonstrates the excellent resolution of the NaI CB detector in $m_{\pi 0}$-mass of 9 MeV. For π^0 selection, we used a 120 < mγγ < 150 MeV cut.The separation of protons from pions and electrons/positrons was done on a two dimensional plot of proton energy measured by CB vs dE/dx measured by PID. This proton energy was corrected for energy losses in target and detector materials crossed by proton from beam axis to CB crystals. This procedure has been described in detail in [3]. Now, known momenta of pion, proton and the beam photon were used to determine the mass of the neutron from the reaction (3_1) as a missing mass M_{miss} on deuterium target. This missing mass distribution is given in Figure 2(right) where neutron peak dominates on a background of random beam photons. We selected neutrons with the cut 890<M_{miss} <990 MeV. If selected neutron points to the TAPS angular region $5 - 15^o$ then hits in the TAPS is searched. Ratio of events with hits in the TAPS to all events gives the neutron detection efficiency which is shown in Figure 3(left). An energy threshold for the TAPS clusters was set to be 15 MeV. Statistical errors are given only in Figure 3. An estimate of systematic is yet to be done carefully. But rough estimate that uses the cut on the angle difference between neutron momentum direction, calculated from kinematics, and registered hit in the TAPS shows that systematic errors are comparable to statistical. Neutron detection efficiencies for NaI calorimeter CB and BaF_2 calorimeter TAPS demonstrate different momentum dependence. The TAPS efficiency rises much slower. It is expected because a light output of BaF_2 crystal is 5 times smaller than that of NaI. But for high momentum where the almost equal nuclear interaction lengths of the crystals are of most importance the neutron detection efficiencies are nearly the same. At high neutron energies the TAPS effectively covers the open space of the CB calorimeter at forward angles. It is seen in the Figure 3(right) where the neutron detection efficiency summed over both CB and TAPS calorimeters are presented as a function of polar angle. The TAPS contribution is given by red. It dominates at angles smaller than 20^o.

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