Physics Letters B 749 (2015) 407–413

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Photoproduction of ω mesons off the proton

CBELSA/TAPS Collaboration

A. Wilson [a,b], V. Crede [b,*], A.V. Anisovich [a,c], J.C.S. Bacelar [e], B. Bantes [d], O. Bartholomy [a], D. Bayadilov [a,c], R. Beck [a], Y.A. Beloglazov [c], K.T. Brinkmann [f], R. Castelijns [e], H. Dutz [d], D. Elsner [d], R. Ewald [d], F. Frommberger [d], M. Fuchs [a], Chr. Funke [a], R. Gregor [f], A. Gridnev [c], E. Gutz [f,a], J. Hannappel [d], W. Hillert [d], P. Hoffmeister [a], I. Horn [a], I. Jaegle [g], T. Jude [d], J. Junkersfeld [a], H. Kalinowsky [a], V. Kleber [d], Frank Klein [d], Friedrich Klein [d], E. Klempt [a], M. Kotulla [g,f], B. Krusche [g], M. Lang [a], H. Löhner [e], I.V. Lopatin [c], S. Lugert [f], T. Mertens [g], J.G. Messchendorp [e,f], V. Metag [f], M. Nanova [f], V.A. Nikonov [a,c], D. Novinski [c], R. Novotny [f], M. Ostrick [d], L.M. Pant [f], H. van Pee [a], M. Pfeiffer [f], A. Roy [f], A.V. Sarantsev [a,c], C. Schmidt [a], H. Schmieden [d], S. Shende [e], V. Sokhoyan [a], N. Sparks [b], A. Süle [d], V.V. Sumachev [c], T. Szczepanek [a], U. Thoma [a], D. Trnka [f], R. Varma [f], D. Walther [a,d], Ch. Wendel [a], U. Wiedner [h]

[a] *Helmholtz-Institut für Strahlen- und Kernphysik, Universität Bonn, D-53115 Bonn, Germany*
[b] *Department of Physics, Florida State University, Tallahassee, FL 32306, USA*
[c] *Petersburg Nuclear Physics Institute, RU-188350 Gatchina, Russia*
[d] *Physikalisches Institut, Universität Bonn, D-53115 Bonn, Germany*
[e] *KVI, 9747 AA Groningen, The Netherlands*
[f] *II. Physikalisches Institut, Universität Gießen, D-35392 Gießen, Germany*
[g] *Physikalisches Institut, Universität Basel, CH-4056 Basel, Switzerland*
[h] *Institut für Experimentalphysik I, Ruhr-Universität Bochum, D-44780 Bochum, Germany*

A R T I C L E   I N F O

Article history:
Received 10 February 2015
Received in revised form 23 July 2015
Accepted 4 August 2015
Available online 7 August 2015
Editor: D.F. Geesaman

Keywords:
Meson production
Light mesons
Baryon resonances
Photoproduction reactions

A B S T R A C T

The differential cross sections and unpolarized spin-density matrix elements for the reaction $\gamma p \to p\omega$ were measured using the CBELSA/TAPS experiment for initial photon energies ranging from the reaction threshold to 2.5 GeV. These observables were measured from the radiative decay of the ω meson, $\omega \to \pi^0\gamma$. The cross sections cover the full angular range and show the full extent of the t-channel forward rise. The overall shape of the angular distributions in the differential cross sections and unpolarized spin-density matrix elements are in fair agreement with previous data. In addition, for the first time, a beam of linearly-polarized tagged photons in the energy range from 1150 MeV to 1650 MeV was used to extract polarized spin-density matrix elements.

These data were included in the Bonn–Gatchina partial wave analysis (PWA). The dominant contribution to ω photoproduction near threshold was found to be the $3/2^+$ partial wave, which is primarily due to the sub-threshold $N(1720)\,3/2^+$ resonance. At higher energies, pomeron-exchange was found to dominate whereas π-exchange remained small. These t-channel contributions as well as further contributions from nucleon resonances were necessary to describe the entire dataset: the $1/2^-$, $3/2^-$, and $5/2^+$ partial waves were also found to contribute significantly.

1. Introduction

The spectrum of excited states has historically given essential information on the nature of any composite quantum system. The

* Corresponding author.
E-mail address: crede@fsu.edu (V. Crede).

http://dx.doi.org/10.1016/j.physletb.2015.08.011

careful mapping of the excited states of baryons shines light on the nature of the nonperturbative regime of quantum chromodynamics (QCD). This spectrum specifically depends on the effective degrees of freedom and the forces confining the quarks. Symmetric quark models, which attempt to describe the baryon system, predict the pattern of low-mass baryons reasonably well. However, the predicted baryon states for masses above 1.8 GeV/c^2 greatly outnumber those which have been found experimentally. Most known light-flavor baryon resonances lie below 2 GeV/c^2 and were discovered in elastic πN scattering experiments. Quark model calculations have shown that many of these so-called "missing" baryons have weak πN couplings; and moreover, they could strongly couple to ηN and ωN without a small coupling to γN. In recent years, many laboratories around the world (ELSA, GRAAL, Jefferson Laboratory, MAMI, SPring-8, etc.) have published differential cross sections and polarization observables in photoproduced reactions. For a recent review on baryon resonances, see [1,2].

According to the predictions of the Constituent Quark Model, e.g. [3], data on ω photoproduction have a good chance of revealing some of the "missing" baryon resonances. However, since the ω meson has the same quantum numbers as the incoming photon, meson exchange (t-channel) processes are likely to contribute strongly. To disentangle the t-channel from the resonant (s-channel) amplitude, data with full angular coverage are needed. Of particular importance is the very forward direction where the t-channel amplitude has its maximum.

Moreover, the ω meson acts as an isospin filter for baryon resonances. Since the isospin of the ω meson is zero, any baryon resonance decaying to $N\omega$ must have isospin $I = 1/2$, and therefore contributions from Δ states are excluded.

In this paper, the differential cross sections and spin-density matrix elements for the reaction

$$\gamma p \to p\omega \tag{1}$$

are presented by reconstructing the ω from the neutral decay,

$$\omega \to \pi^0\gamma \to \gamma\gamma\gamma. \tag{2}$$

2. Experimental setup

The CBELSA/TAPS experiment was conducted at the electron stretcher accelerator (ELSA) facility [4] located at the University of Bonn in Germany. A 3.175 GeV electron beam from ELSA interacted with a radiator target and produced bremsstrahlung photons. The radiator target was situated in a goniometer which contained copper radiators of varying thickness along with a diamond radiator for linear polarization. The unpolarized data utilized a copper radiator of thickness $3/1000\, X_R$ (radiation length). The polarized data used a diamond radiator. The bremsstrahlung electrons were deflected by a dipole magnet into the tagging detector system (tagger). The tagger consisted of 480 scintillating fibers on top of 14 scintillating bar counters which partly overlapped. Using the knowledge of the magnetic field strength and the hit position in the tagger, the energy of each electron was determined and used to tag each bremstrahlung photon with energy and time information.

A fraction of the tagged bremsstrahlung photons continued down the beam line and interacted with the protons in the liquid hydrogen target to produce mesons which decayed to final-state photons. The energy and position of these photons were detected by the crystal modules in the two electromagnetic calorimeters, Crystal Barrel and TAPS. The Crystal Barrel detector, in its configuration during the CBELSA/TAPS experiment of 2002/2003, consisted of 1290 CsI(Tl) crystals, which were read out by photodiodes. The TAPS detector consisted of 528 BaF_2 crystals, which were read out by photomultiplier tubes. They formed a hexagonal wall that covered the forward hole left open by the Crystal Barrel detector. Together the Crystal Barrel and TAPS detectors covered more than 98% of the full 4π solid angle. Protons or any other charged particles were identified by either 5 mm thick plastic scintillators placed in front of each TAPS crystal or by a three layer scintillating fiber detector which closely surrounded the target. For more information on this setup, see [5].

3. Data analysis

The unpolarized data were recorded in October 2002 and November 2002. The linearly-polarized data were recorded in March and May 2003. The polarized data used a diamond radiator optimized to have a coherent polarization edge at 1350 MeV and 1600 MeV with a polarization maximum of 49% and 39%, respectively. More information on the goniometer and the linear beam polarization can be found in [6]. The ELSA beam energy for the unpolarized runs was 3.175 GeV, but for this analysis, only photons up to 2.55 GeV were used due to the lack of tagger scintillating fibers above this energy. The fibers provided a fine energy resolution and additional timing information. The trigger for these datasets relied on Leading–Edge Discriminator (LED) outputs which signaled if the energy deposit in a group of TAPS crystals was above either a low-energy threshold (LED-low) or a higher-energy threshold (LED-high). Each TAPS crystal belonged to one of eight LED-low sectors and one of eight LED-high sectors. The trigger required either 1) two LED-low sectors in the TAPS detector firing above a low energy threshold or 2) one LED-high sector in TAPS above a higher energy threshold and at least one hit (two hits for the polarized data) in the Crystal Barrel. For sector definitions and more information, see [5,7]. The same data were used for several previously published analyses on a variety of final states [5–14].

In order to study Reaction (1), the $p\pi^0\gamma$ final state was reconstructed first using kinematic fitting. All events based on three distinct neutral hits and less than two charged hits were subjected to the $\gamma p \to p_{\text{missing}}\pi^0\gamma$ hypothesis. The ω yields were then extracted from $\pi^0\gamma$ invariant masses by carefully subtracting the background contribution. The proton was chosen as a missing particle in the fit due to the relatively large uncertainty in reconstructing the proton energy and momentum from calorimeter output. The resulting confidence-level (CL) values from kinematically fitting the data events and Monte Carlo simulated $p\omega$ events were used first to reduce background in the analysis. A cut of $\text{CL}_{p_{\text{missing}}\pi^0\gamma} > 0.005$ was applied. This very small CL cut simply guaranteed convergence of the kinematic fit, and therefore energy–momentum conservation, but had essentially no impact on the $p\omega$ yield. The remaining ω background events were removed by applying a probabilistic method which is described below. More information on kinematic fitting used at the CBELSA/TAPS experiment can be found in [5].

To isolate the incoming photon, a coincident timing cut between the tagger and TAPS was used to reduce the number of initial photon candidates. The remaining photons were subjected to kinematic fitting, which required energy and momentum conservation. The beam photon with the largest CL value was chosen as the initial photon. An equivalent analysis of events with timing outside of this coincident timing cut was performed and used to eliminate the effect of accidental background.

The contribution of $p\pi^0$ events which were poorly reconstructed as $p\pi^0\gamma$ events could be effectively separated from good $p\omega$ events by studying the momentum-dependence of the opening angle between the π^0 and the final-state bachelor-photon in the center-of-mass frame, $\theta_{c.m.}^{\pi^0,\gamma}$. In this two-dimensional distribution,