Measurement of the Beam Asymmetry Σ in the Forward Direction for $\gamma p \rightarrow p\pi^0$

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Photoproduction of neutral pions has been studied with the CBELSA/TAPS detector for photon energies between 0.9 and 1.66 GeV at the electron accelerator ELSA. The beam asymmetry Σ has been extracted for $155^\circ < \theta_{c.m.} < 155^\circ$ of the $\pi^0$ meson and for $\theta_{c.m.} < 60^\circ$. For the first time, these beam-asymmetry data cover the very forward region and improve the world database for photon energies above 1.5 GeV. The angular dependence of Σ shows an overall good agreement with the SAID parametrization.

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I. INTRODUCTION

Baryon resonances exhibit a rich excitation spectrum due to their complicated substructure. Understanding this structure of the nucleon and its excited states is one of the key questions in hadronic physics. Though most quark models based on three constituent quark degrees of freedom can describe ground-state baryons well, they fail in some important details. Known as the missing-of freedom can describe ground-state baryons well, they quark models based on three constituent quark degrees of the key questions in hadronic physics. Though most this structure of the nucleon and its excited states is one due to their complicated substructure. Understanding of the resonance problem, these quark models have predicted fail in some important details. Known as the missing-of freedom can describe ground-state baryons well, they quark models based on three constituent quark degrees of the key questions in hadronic physics. Though most this structure of the nucleon and its excited states is one due to their complicated substructure. Understanding

Since the $\pi$ meson has isospin $I = 1$, both excited nucleon resonances ($I = 1/2$) and $\Delta$ resonances ($I = 3/2$) can contribute to $\pi^0$ photoproduction off the proton. The total $\pi^0$ cross section exhibits three clear peaks and a broad enhancement around $W \approx 1900$ MeV/$c^2$ representing the four known resonance regions below 2 GeV/$c^2$. The first resonance region below 1500 MeV/$c^2$ is dominated by the well-known $\Delta(1232)F_{33}$ resonance with very small contributions of the $N(1440)P_{11}$ Roper resonance. The $N(1520)D_{13}$ and the two $S_{11}$-resonances combined, $N(1535)S_{11}$ and $N(1650)S_{11}$, contribute with about equal strength to the second resonance region around 1550 MeV/$c^2$. The third bump in the $\pi^0$ total cross section is mainly due to three major resonance contributions: $\Delta(1700)D_{33}$, $N(1680)F_{15}$, and $N(1650)S_{11}$, e.g. $[1-3]$. In the less known fourth resonance region, the two well-established $\Delta$ excitations, $\Delta(1950)F_{37}$ and $\Delta(2010)P_{33}$, have been found to contribute, e.g. $[1]$. The inclusion of polarization observables as additional constraints in the analysis of $\pi^0$ photoproduction data will not only help reveal contributions of resonances coupling only weakly to the $\pi^0$, but also help understand better the properties of these well-established resonances, e.g. the structure of the transition current.

In this paper, we present the beam asymmetry Σ for the reaction:

$$\gamma p \rightarrow p\pi^0, \quad \text{where } \pi^0 \rightarrow 2\gamma.$$  

The polarization data cover an incoming photon energy range between about 915 MeV and 1660 MeV and in ad-
FIG. 1: (Color online) Beam asymmetries $\Sigma$ versus $\theta_{c.m.}$ of the $\pi^0$ for the energy range $E_\gamma \in [145, 2000]$ MeV measured by various experiments before this analysis. The data are summarized in [16]; picture taken from [16].

To addition to $115^\circ < \theta_{c.m.} < 155^\circ$, the most forward angular range of the $\pi^0$ meson, $\theta_{c.m.} < 60^\circ$.

The paper has the following structure. Section II summarizes the data which were published before this analysis. An introduction to the CBELSA/T APS experimental setup is given in section III. The data reconstruction and selection is discussed in section IV and the extraction of beam asymmetries is described in section V. Experimental results are finally presented in section VI.

II. PREVIOUS RESULTS

Cross section data for $\pi^0$ photoproduction were obtained and studied at many different laboratories over a wide kinematic range [4–14]. A review of the main data sets and a corresponding comparison of their coverage in energy and solid angle can be found in [15].

Polarization observables for single-$\pi^0$ photoproduction have been determined mostly using a linearly-polarized beam [11, 14, 17–24]. In the following, a summary is given of the experiments performed after 1970 which allowed the extraction of the beam asymmetry $\Sigma$. Most of the experiments accumulated data at very low energies ($< 500$ MeV); only very recently have data been taken above 1 GeV in the incoming photon energy.

In the seventies, one of the earlier experiments used linearly-polarized photons of energies from 610 to 940 MeV. The experiments were carried out using the back-scattered laser beam and the 82-in. bubble chamber at SLAC [17]. At the Cambridge Electron Accelerator, beam asymmetries and cross sections at $\theta_{c.m.} = 90^\circ$ were measured with photon energies ranging from 0.8 to 2.2 GeV [18]. Finally, the Daresbury synchrotron allowed a study of the photon asymmetry over a range of photon energies from 1.2 to 2.8 GeV and over a range of $-t$ from $0.13 \text{ GeV}/c^2$ to $1.4 \text{ GeV}/c^2$ [19, 20].

Belyaev et al. measured $\Sigma$ in addition to the target asymmetry $T$ and the double-polarization observable $P$ using linearly-polarized photons and a transversely-polarized proton target. The measurements were made in the energy range $E_\gamma \in [280, 450]$ MeV and at $\pi^0$ c.m. angles between $60^\circ$ and $135^\circ$ [21].

Beck et al. measured differential cross sections at the electron accelerator MAMI between the threshold at 144 MeV up to photon energies of 157 MeV [7] as well as for energies between 270 MeV and 420 MeV [8]. Both experiments used a linearly-polarized photon beam produced via coherent bremsstrahlung. In [8], $\pi^0$ photoproduction was studied with the DAPHNE detector, which covered $\sim 94\%$ of the solid angle.

In another experiment at the Mainz Microtron MAMI, Schmidt et al. measured the photon asymmetry between threshold and 166 MeV using the photon spectrometer TAPS. Total and differential cross sections were extracted simultaneously and compared to predictions of chiral perturbation theory and low-energy theorems [11].

Blanpied et al. extracted unpolarized differential cross sections and beam-asymmetry angular distributions at BNL using LEGS for photon beam energies in the range from 213 MeV to 333 MeV [12, 22]. Final-state particles were detected in an array of six NaI crystals.

The Erevan group published data from several experiments. More recently, Adamian et al. extracted asymmetry data in the energy range 500-1000 MeV and for $\pi^0$ angles between $85^\circ$ and $125^\circ$ with energy and angle steps of 25 MeV and $5^\circ$, respectively [23].

More recently, the GRAAL collaboration at ESRF in Grenoble extracted $\Sigma$ over a wide angular range, though limited to $\cos \theta_{c.m.} < 0.7$. The data cover incoming photon energies between 550 MeV and 1475 MeV [14].
GRAAL, Compton backscattering of low-energy photons off ultra-relativistic electrons reached almost 100% beam polarization at the Compton edge.

Recent CBELSA/TAPS asymmetry data cover photon energies between 760 MeV and 1400 MeV and an angular range mostly in the backward direction of the $\pi^0$ meson ($110^\circ < \theta < 160^\circ$) with a few data points between $50^\circ < \theta < 60^\circ$ [24].

III. EXPERIMENTAL SETUP

The results presented here are partially based on a reanalysis of the data discussed in [24]. The experiment was carried out at the electron accelerator facility ELSA [25] at the University of Bonn, Germany, using a combination of the Crystal Barrel [26] and TAPS [27, 28] calorimeters. A schematic drawing of the experimental setup at the ELSA facility is shown in Fig. 2.

Electrons with an energy of $E_0 = 3.175$ GeV were extracted from ELSA via slow (resonant) extraction. The electron beam then hit the radiator target positioned in front of the tagging magnet. The goniometer setup and its performance is fully described in [24, 29]. Since the development of the hardware and the production of linearly-polarized photons is not part of the analysis presented here, only a very brief description of the setup is given. Several amorphous copper radiators with different radiation lengths surrounded the diamond crystal (Fig. 3). The crystal measured 500 $\mu$m in thickness and had a front surface of (4 x 4) mm; it was glued to a 12.5 $\mu$m kapton foil and accurately positioned by a dedicated commercial 5-axis goniometer. A wobble along the axes limited the maximum angular uncertainty to $\delta < 170$ $\mu$rad. All other uncertainties were negligible.

The electrons undergoing the bremsstrahlung process were deflected in the dipole magnet according to their energy loss; the remaining energy was determined in a tagging detector consisting of 480 scintillating fibers above 14 scintillation counters in a configuration with adjacent paddles partially overlapping. The corresponding energy of an emitted photon was $E_\gamma = E_0 - E_e$. Electrons not undergoing bremsstrahlung were deflected at small angles and guided into a beam dump located behind the tagger detectors. The energy resolution is about 2 MeV for the high-energy photons and 25 MeV for the low-energy part of the bremsstrahlung spectrum.

For the energy calibration of the tagging system, a polynomial was determined in simulations using the measured field map of the bending magnet and the known positions of the fibers. The calibration was then cross-checked by measurements with the ELSA electron beam at two different energies. At 600 and 800 MeV, a low-current beam was guided directly into the tagger, while the magnetic field was slowly varied. More details of the calibration can be found in [30].

The photons hit the liquid hydrogen target in the center of the Crystal Barrel (CB) calorimeter. The target cell (5 cm in length, 3 cm in diameter) was surrounded by a scintillating-fibre detector [31], which provided an unambiguous impact point for charged particles (due to the arrangement of its three layers) leaving the target. The CB-calorimeter in its CBELSA/TAPS configuration of 2002/2003 consisted of 1290 CsI(Tl) crystals with a length of 16 $X_R$. The modules have an excellent photon detection efficiency; a detailed description can be found in [26]. For this series of experiments, the (downstream) rings 11-13 were removed to combine the detector with...
TAPS in the forward direction. The CB-calorimeter covered the complete azimuthal angle and polar angles from 30° to 168°. All crystals are of trapezoidal shape pointing to the center of the target (Fig. 4, top).

The TAPS detector consisted of 528 hexagonal BaF$_2$ crystals with a length of about 12 R$_\text{h}$. It was configured as an hexagonal wall serving as the forward end cap of the Crystal Barrel calorimeter (Fig. 4, bottom). TAPS provided a high granularity in the forward direction covering polar angles between 5° and 30° (full φ coverage). A 5 mm thick plastic scintillator in front of each TAPS module allowed the identification of charged particles. The combination of the Crystal Barrel and TAPS calorimeters covered 99% of the 4π solid angle and served as an excellent setup to detect multi-photon final states.

The fast response of the TAPS modules provided the first-level trigger. The second-level trigger was based on a cellular logic (FACE), which determined the number of clusters in the barrel. The trigger required either two hits above a low-energy threshold in TAPS (LED-low) or one hit above a higher-energy threshold in TAPS (LED-high) in combination with at least two FACE clusters. The shape of the logical segmentation for the TAPS trigger is shown in (Fig. 4, bottom).

A. Linearly-Polarized Photons

Two methods are usually applied to prepare a linearly-polarized photon beam: coherent bremsstrahlung and Compton backscattering. The latter technique uses linearly-polarized laser photons which are backscattered off a high-energy electron beam, e.g. [14, 32]. The degree of polarization that can be achieved using this technique is proportional to that of the initial laser beam. Although high degrees of polarization can in principle be reached, the photon beam intensities are usually lower than those from coherent bremsstrahlung due to limitations resulting from the operation of a multi-user storage ring. In contrast, many facilities have successfully produced linearly-polarized beams using coherent electron bremsstrahlung [24, 33], where the recoil momentum of the recoiling nucleus embedded in the crystal is transferred to the crystal lattice. For the CBELSA/TAPS experiment, a diamond crystal was used. For certain orientations of this diamond, the recoil momentum can be entirely transferred to the crystal; this defines the deflection plane of the electrons and results in a strong linear polarization of the photon beam.

For the beam-asymmetry data presented in this paper, the crystal alignment was achieved by the so-called Stonehenge Technique [34]. An overview of the alignment process for the CBELSA/TAPS goniometer including a brief description of the Stonehenge Technique is given in [24]. The stability of the beam position was monitored online to preserve the alignment during the experiment. The coherent peak itself was used for this procedure because the position of the coherent edge in the energy spectrum is extremely sensitive to the angle of the incident beam [30].

The degree of linear polarization was determined in [29] by comparing the measured photon spectrum with a model calculation using the ANB (“analytic bremsstrahlung calculation”) software [35]. Fig. 5 shows photon intensity spectra normalized to incoherent spectra [24] for the two different positions of the coherent edge used in this analysis. The curves represent calculations using an improved version of the original ANB code [29], which takes into account the effects of beam divergence, beam spot-size, energy resolution, and multiple scattering. The description of the measured spectra is excellent at all energies and coherent peak positions. An absolute error of δP$_\text{L} < 0.02$ is estimated using variations of the calculated relative intensity by ± 5% [24]. These worst-

![Graph](http://example.com/graph.png)

**FIG. 5:** (Color online) The measured coherent bremsstrahlung intensities normalized to an incoherent spectrum [24]. The full curve shows how well the data are described by the model calculations [29]. For this experiment, the diamond radiator was oriented such that intensity maxima at $E_\gamma = 1305$ MeV (left) and $E_\gamma = 1610$ MeV (right) were reached. The boxes at the bottom of each distribution indicate the ranges covered by the 14 scintillation counters of the tagger. The description of the measured spectra is excellent at all energies and coherent peak positions.
case estimates account for deviations from the shape of the spectrum due to combined statistical and systematic effects.

IV. PREPARATION OF FINAL STATE

The data presented here were accumulated in March and May of 2003 in two run periods with an ELSA beam energy of 3.175 GeV. Events for coherent peak positions at 1305 MeV and 1610 MeV were recorded. These CBELSA/TAPS polarization data were used to extract the beam asymmetries for a large variety of photo-production reactions [24, 36–39]. The analysis discussed here for the peak position at 1305 MeV is partially a reanalysis of the data published in [24]. The event reconstruction and selection of the $\pi^0$ channel (1) is presented in this section. A total number of $\sim 1.06 \times 10^6$ $\pi^0$ events has been included in this analysis.

A. Event Reconstruction

Events with two or three (neutral or charged) particles in the final state were selected. The experimental setup allows the identification of charged clusters in TAPS by using the plastic scintillators mounted in front of each BaF$_2$ crystal. The efficiencies of these (photon)-veto detectors were determined and modelled in the Monte Carlo program. Though these detectors have been used in a retraction reactions [24, 36–39]. The analysis discussed here for the peak position at 1305 MeV is partially a reanalysis of the data published in [24]. The event reconstruction and selection of the $\pi^0$ channel (1) is presented in this section. A total number of $\sim 1.06 \times 10^6$ $\pi^0$ events has been included in this analysis.

B. Background Subtraction

Mass distributions for $(E_\gamma, \theta_{\text{c.m.}}, \phi)$ bins in the forward direction of the $\pi^0$ meson show some residual background under the meson peak. Separating background events from signal events is typically done using the side-band subtraction method. In this approach, events from outside the signal region are subtracted from those inside the signal region to remove the background from the distribution.
We decided to use an event-based approach which assigns a signal probability, $Q_i$, to each event. The approach is described in detail in [41]. In most of our forward bins, the functional form of the background shape, $B(m, \xi)$, is unknown, where each $\gamma p \rightarrow p \gamma \gamma$ event has kinematic variables $\xi = (E_{\gamma}, \cos \theta_{c.m.}^{\gamma}, M_{\gamma\gamma}, \phi^*, \theta^*)$; the two variables $\phi^*$ and $\theta^*$ denote the polar and azimuthal angle in the rest frame of the two photons. The polar angle, $\phi^*$, is also given by the angle between the reaction plane and the two-photon decay plane, where the reaction plane is spanned by the beam axis as well as the proton and the two photons in the c.m. system. The invariant $\gamma\gamma$ mass was chosen as the reference variable, for which the background dependence was studied. The distance between any two events in the space spanned by $\xi$ is given by [41]:

$$d_{ij}^2 = \sum_{k=1}^{5} \left[ \frac{\xi_{ik} - \xi_{jk}}{r_k} \right]^2,$$

(3)

where the $r_k$ denote the ranges of $\xi$ and the reference variable is excluded. We then found the closest 100 events for each event $i$, with kinematics $\xi_i$ and mass $M_i$, according to (3). Since these 100 events occupy a very small region around $\xi_i$, a linear approximation is validated for the mass dependence of the background in addition to a Gaussian shape of the $\pi^0$ signal. We have used the unbinned maximum likelihood method to obtain the parameters describing the mass distributions. Using these fit results, the expected number of signal and background events, denoted as $s_i$ and $b_i$ respectively, can be calculated at $M_i$ and for each event, the $Q$-factor can be written as:

$$Q_i = \frac{s_i}{s_i + b_i}, \quad \text{where} \quad N_{\text{signal}} = \sum_{i}^{N} Q_i.$$  

(4)

This method delivered a reliable subtraction of the background in our mass distributions. The background visible in Fig. 6 has been determined using this method. The $Q$-value errors (or systematic uncertainties on signal-yield extractions) contribute strongly to the total systematic uncertainty of the extracted polarization observables. A full discussion of the error estimation and event correlations goes beyond the scope of this publication and can be found in [41].

C. Monte Carlo Simulations

The performance of the detector was simulated in GEANT3-based Monte Carlo studies. We used a program package that has been built upon a program developed for the CB-ELSA experiment. The Monte Carlo program reproduces accurately the response of the TAPS and Crystal Barrel crystals when hit by a photon.

The acceptance for reaction (1) was determined by simulating events, which were evenly distributed over the available phase space. The Monte Carlo events were analyzed using the exact same reconstruction criteria, which were also applied to the (real) measured data. The same 1C-hypothesis was tested in the kinematic fits and events selected with the same confidence-level cuts. The acceptance is defined as the ratio of the number of generated to reconstructed Monte Carlo events

$$A_{\gamma p \rightarrow p X} = \frac{N_{\text{rec,MC}}}{N_{\text{gen,MC}}} (X = \pi^0).$$

(5)

In the analysis presented here, we have applied an acceptance cut of at least 8% on $(E_{\gamma}, \theta_{c.m.})$ bins and removed the other data points from the analysis.

For the extraction of beam asymmetries, it is important to study possible systematic (non-physics related) contributions to the $\phi$ distributions. Of particular importance is the influence of the hardware trigger. It required either a hit above a lower-energy threshold in at least two different segments of the TAPS LED-low logical segmentation (Fig. 4, bottom left); alternatively, a higher-energy hit in one of the TAPS high-trigger segments (Fig. 4, bottom right) in combination with at least two clusters in the Crystal Barrel was needed (trigger condition 2). If the event kinematics is such that only one particle hits TAPS (possibly leading to condition 2), condition 1 can also be fulfilled simultaneously in case the hit occurs close to the edge of a segment. The electromagnetic shower leaking into the adjacent trigger segment then increases the trigger efficiency along the boundaries imposing a modulation on the $\phi$ distribution. Fig. 7 shows examples of this effect for $E_{\gamma} \sim 1560$ MeV. The three peaks are due to the
three boundaries in the logical segmentation of the LED-low trigger. Since this effect is $\phi$ dependent, it can in some cases significantly contribute to the $\phi$ modulations depending on event kinematics. The $\phi$ distributions in the forward region have thus been acceptance corrected to account for the described trigger effect.

V. EXTRACTION OF $\Sigma$

The polarized cross section in single-$\pi$ photoproduction using linearly-polarized photons is proportional to the unpolarized cross section $(d\sigma/d\Omega)_0$ and given by:

$$\frac{d\sigma}{d\Omega} = \left( \frac{d\sigma}{d\Omega} \right)_0 \left( 1 - P_l \Sigma \cos (2\phi) \right),$$

(6)

where $P_l$ denotes the degree of linear beam polarization at an angle $\phi$ with respect to the reaction plane, which is spanned by the incoming photon and the recoiling nucleon. The reaction is schematically shown in Fig. 9. In the experiment, the orientation of the photon polarization is given in the laboratory frame by an angle $\alpha$ and thus, $\phi = \alpha - \phi$. For our measurements, the diamond crystal was oriented such that the direction of the beam polarization was perpendicular to the floor of the experimental area ($\alpha = \pi/2$):

$$\frac{d\sigma}{d\Omega} = \left( \frac{d\sigma}{d\Omega} \right)_0 \left( 1 + P_l \Sigma \cos (2\phi) \right).$$

(7)

If the detector setup is invariant with respect to the azimuthal angle, then the observable $\Sigma$ can be extracted as the amplitude of the $\phi$ modulation of the $\pi^0$ meson corrected for the degree of polarization.

Fig. 8 shows typical $\phi$ distributions in the forward region. From fits to these azimuthal event distributions using a function of the form

$$f(\phi) = A + B \cos (2\phi),$$

(8)

the product of beam asymmetry and photon polarization, $P_l \Sigma$, is given by the ratio $B/A$ for each bin of photon energy and $\pi^0$ angle, $\theta_c$. The normalization factor $A$ depends on the available statistics and thus, scales with the amount of beam time.

A. Systematic Uncertainties

The reconstruction of neutral mesons decaying into photons and the identification of final states requires a sequence of cuts including the use of kinematic fitting. Since the extraction of beam asymmetries is based on fits to $\phi$ distributions, the statistical and systematic errors of $\Sigma$ cannot easily be separated. For this reason, the error bars (of the data points) in Fig. 10 and 11 consist of both contributions. The statistical errors are determined from the number of events in each $(E_\gamma, \cos \theta_{\text{cm}}, \phi)$ bin and in a separate analysis step, added quadratically (in the $\phi$ distributions) to the uncertainties in the yield extractions ($Q$-values) to determine the corresponding systematic errors.

Further contributions to the systematic uncertainties determined from Monte Carlo studies and acceptance corrections, for example error contributions accounting for the slightly different effects of confidence-level cuts.
FIG. 10: (Color online) The photon beam asymmetries extracted from the data set with a coherent peak position at 1305 MeV.

VI. EXPERIMENTAL RESULTS

Fig. 10 shows the $\pi^0$ beam asymmetries for our data set with a coherent peak position at 1305 MeV. The unusual energy bin width of 33 MeV was chosen to facilitate the comparison with the GRAAL [14] and previous CBELSA/TAPS [24] results; small energy shifts among the different data sets are still possible. The data points in the forward region for incoming photon energies below 1 GeV (top row) are statistically limited and have very small degrees of polarization, thus showing increased error bars. The beam asymmetries for the data set with a coherent peak position at 1610 MeV are shown in Fig. 11 using the same energy binning. For energies above 1400 MeV, the data are extracted from the higher-energy data set alone. In the overlap region between 1200 MeV and 1400 MeV, we have averaged the results from the two data samples (shown in Fig. 11) based on their good agreement.

Although the experimental acceptance for the first
FIG. 11: (Color online) The photon beam asymmetries extracted from the data set with a coherent peak position at 1610 MeV. The filled (red) circles (•) denote this analysis, the (green) stars (⋆) our previous CBELSA/TAPS analysis [24], and the open (blue) circles (◦) the GRAAL results [14]. The black solid line shows the recent solution of the Bonn-Gatchina partial wave analysis [1] and the grey solid line shows the SAID SP09 prediction [16, 42]. The width of the energy bins is 33 MeV, consistent with the published earlier results. The energy of the bin centers is given in each distribution. For energies below 1400 MeV, we have averaged the results from both data samples.

couple of θ bins is better than 10%, the corresponding error bars show big increases due to the differential π⁰ cross section going toward zero in this angular region (cos θ > 0.94). The trigger conditions during the data taking were not optimized for the production of π⁰ mesons over the full angular range. For this reason, the Σ distributions exhibit a region of very small acceptance between about 65° and 115°. Our acceptance cut of 8% removes these data points.

The results from this analysis are in excellent agreement with previous measurements. Overall, the new photon beam asymmetries in the forward region and above 1500 MeV agree also nicely with the predictions of the SAID model. However, small deviations are observed for energies above 1400 MeV where the broad structure in the forward direction seems to underestimate the data for θ_{c.m.} < 50°. The solution of the Bonn-Gatchina partial wave analysis [1] is in excellent agreement with the data and SAID over the full range of previously available data, but tends to systematically underestimate the data in the forward region. Though it will be possible to modify the solutions of these models to better describe the data presented here, double-polarization observables are needed to unambiguously extract the scattering amplitude.

VII. SUMMARY

In summary, we have presented the results of a reanalysis of previously published CBELSA/TAPS data and new measurements of the beam asymmetry Σ for the photon-produced π⁰π⁰ final state. New data points have been added to the very forward direction of the π⁰ meson in the center-of-mass system. The continuous beam from the ELSA accelerator and the goniometer setup of the experiment provided a linearly-polarized tagged-photon beam for the coherent peak positions at 1305 MeV and 1610 MeV. The results are in very good agreement with the earlier measurements at ELSA and also with previous results from other facilities.
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