PROCEEDINGS OF SCIENCE

Measurement of Polarization Observables with the CBELSA/TAPS Experiment

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To determine the excitation spectra of the nucleons, the measurement of different polarization observables is necessary. To access these observables with the CBELSA/TAPS experiment, linearly or circularly polarized photon beams impinging on transversely or longitudinally polarized nucleon targets were used. Several single and double observables like Σ, T, P, E, G and H were measured with high precision and wide angular coverage, providing new information for the different partial wave analyses.

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		Target			**Recoil**			**Target+Recoil**			
		–	–	–	x'	y'	z'	x'	x'	z'	z'
Photon		x	y	z	–	–	–	x	z	x	z
unpolarized	σ	–	T	–	–	P	–	$T_{x'}$	$-L_{x'}$	$T_{z'}$	$L_{z'}$
linearly polarized	Σ	H	-P	-G	$O_{x'}$	-T	$O_{z'}$	–	–	–	–
circularly polarized	–	F	–	-E	$-C_{x'}$	–	$-C_{z'}$	–	–	–	–

Table 1: Polarization observables for the photoproduction of pseudoscalar mesons.

1. Introduction

To understand the dynamics inside the nucleons, the knowledge of the excitation spectrum is essential. Since the QCD is not solvable in this energy regime, one has to rely on different models like constituent quark models [1] or lattice QCD [2] calculations. These models predict more resonances than there have been observed so far, which is known as the problem of the *missing resonances*. To solve this puzzle, an exact measurement of the excitation spectrum is necessary.
The excitation spectrum consists of several strongly overlapping resonances. To identify their exact contributions, a measurement of the total cross section alone is not sufficient since it is only sensitive on quadratic amplitude contributions. Further knowledge can be gained by the measurement of polarization observables, which give access to the interference terms between the amplitudes and allow therefore the extraction of small resonance contributions.
In photoproduction of a single pseudoscalar meson 16 different observables are available in total, see Tab. 1. By using a polarized photon beam and a polarized target 8 observables of these become accessible. Several of these observables in different reactions have been measured with the CBELSA/TAPS experiment, which is further described in the next section. An important feature is the possibility to use either a linearly or a circularly polarized beam in combination with a polarized nucleon target. This topic of polarization is covered in Sec. 3. In Sec. 4 a few highlights of the extracted observables is presented.

2. Experimental Setup

The CBELSA/TAPS experiment (see Fig. 1) was located at the Electron Stretcher Accelerator ELSA in Bonn, which provided unpolarized or longitudinally polarized electrons with up to 3.2 GeV energy. The electrons created photons via bremsstrahlung on different radiator targets in a goniometer. Additionally to radiators for beam alignment, copper radiators of different thickness were available. To create linearly polarized photons a diamond crystal was used, while a circularly polarized photon beam was created by bremsstrahlung on a polarized foil, which is further described in the next section.
To determine the energy of the photons, a tagging system was used. It consisted of a tagging magnet and 96 scintillating bars to measure the deflection angle of the electrons in the magnetic field. Additionally, 480 scintillating fibers were mounted in the region of the lower photon energies for a better energy resolution.
The photon beam impinged on a target in the center of the calorimeter system. Different targets were available, like a liquid hydrogen target and a carbon foam target for background studies. To

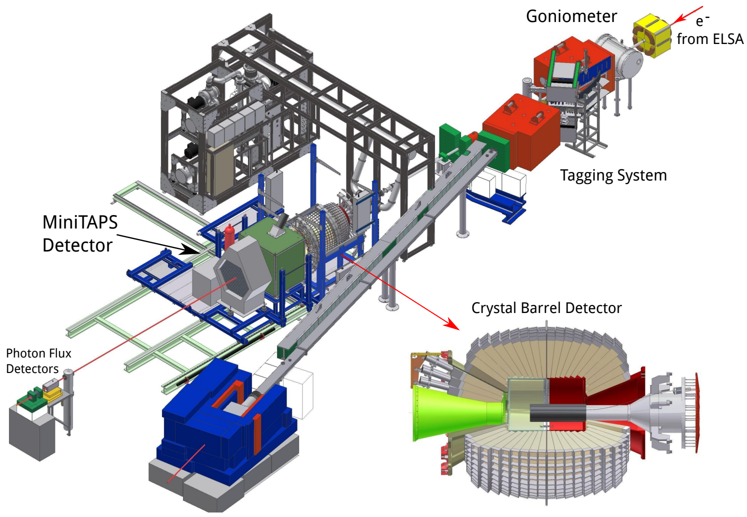

Figure 1: The setup of the CBELSA/TAPS experiment. Inset: the Crystal Barrel detector, the main calorimeter of the experiment.

measure polarization observables a polarized nucleon target was used, which provided either longitudinally or transversely polarized protons or neutrons. Further details will be given in section 3. The main calorimeter surrounding the target was the Crystal Barrel detector, which consisted of 1320 CsI(Tl) crystals mainly with PIN photo diode readout. In forward direction the crystals were read out via photomultipliers to create fast trigger signals. To close the forward angle down to 1° the MiniTAPS forward wall was installed, consisting of 216 BaF_2 crystals with photomultiplier read-out. Inside the main calorimeter was also a cylindrical detector of scintillating fibers to identify charged particles. Additionally scintillating plates were installed in front of the crystals in forward direction of the Crystal Barrel and the MiniTAPS detector to ensure a correct identification of charged particles like protons.
At the end of the photon beam line two different detectors were located to measure the photon flux during the beam times.

3. Polarized Beam and Target Setups

One important task in the measurement of polarization observables was the target system and the photon beam. Two different beam types were used to measure these observables: linearly and circularly polarized photon beams. The target system allowed us to measure with either transversely or longitudinally polarized protons or neutrons.

3.1 Polarized Photon Beam

For the production of linearly polarized photons, an unpolarized electron beam was provided by the ELSA accelerator. The photons were then created by bremsstrahlung on a diamond crystal. By precise alignment of the diamond crystal in the electron beam, the contributing lattice vectors could be selected. By adjustment of these lattice vectors the region of linearly polarized photons can be selected. Fig. 2 (left) shows three different settings of the diamond crystal. By combination

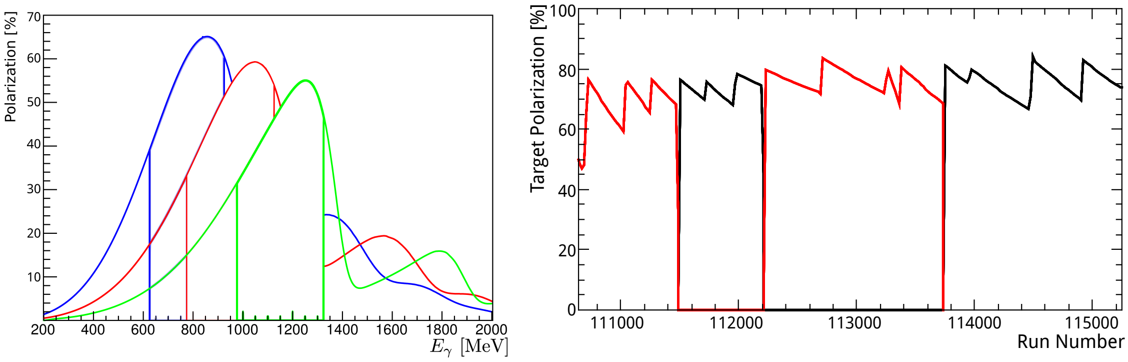

Figure 2: Left: Three different settings of the coherent edge as it was used to determine the double polarization observable G [9]. The marked areas show the energy region which was used for the determination of the observable. Right: A typical run of the target polarization during one beam time. The different colors mark the different target polarization direction.

of these settings, it was possible to cover a wide energy range with linearly polarized photons. The position of the coherent edge was carefully monitored during the beam times and the plane of the polarized photons was switched about 90° every 15 minutes to avoid systematic effects. The polarization degree was afterwards determined by the software ANB [4].
To create circularly polarized photons, a longitudinally polarized electron beam was used. The helicity of the electrons was switched every few seconds. The electrons created the polarized photons by bremsstrahlung on a polarized foil with well-known polarization degree. To determine the polarization degree of the photons, the polarization degree of the electron needs to be known. This was measured by four coincident detectors located behind the tagging system. These detectors measure Møller electrons, which were produced on the polarized foil. By comparison of the two different helicity states, the polarization degree of the electrons could be deduced.

3.2 Polarized Nucleon Target

The polarized target was provided by the Bonn Frozen Spin Target group [3]. Two different coils were available, allowing the measurement on transversely or longitudinally polarized nucleons. As a target material butanol (C_4H_9OH) was used for the data shown here to provide polarized protons. Measurements on deuterated butanol were also done, which allow investigations of reactions on polarized neutrons.
To polarize to target, the whole calorimeter system was mounted on a rail system and could be removed from the target. The repolarization procedure were repeated every few days to guarantee a high polarization degree. The direction of the polarization was switched a few times during a beam time to avoid systematic effects. The typical development of the polarization degree of one beam time are shown in Fig. 2 (right).

4. Results of the Observables

Polarization observables have been extracted in several different reactions. The observables E [10] and G [9] for single pion photoproduction on longitudinally polarized protons are shown in

Fig. 3 in comparison to predictions by the partial wave analyses.
By using a transversely polarized target, three observables become accessible: T, P and H, see Fig. 4. The recoil polarization P can in this case be measured in a double polarization measurement, which avoids the difficulties of a recoil polarimeter.
Furthermore, the same observables have been extracted for the reaction $\gamma p \rightarrow p\eta$ and will soon be published [12]. Reactions with multiple meson like $\gamma p \rightarrow p\pi^0\pi^0$ are also published for single polarization observables [13] and double polarization observables are currently extracted.
All new measurements show differences to the predictions of the different partial wave analyses. By including the newly extracted data point, the amplitudes of all analyses should converge to a single solution. First indications of this effect are studied in a new publication [14].

5. Conclusion

To gain further knowledge about the excitation spectrum of the nucleons, polarization observables were successfully measured with the CBELSA/TAPS experiment. The measurement of these observables required a polarized photon beam and a target providing polarized nucleons. Several observables were extracted over a wide angular and energy range. A comparison of the newly extracted observables with the predictions of the different partial wave analyses showed differences, which are now further investigated. By including these observables in the partial wave analyses, new informations about the contributing resonances and their parameters can be gained.
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References

[1] U. Löring, B. C. Metsch and H. R. Petry, Eur. Phys. J. A **10**, 395 (2001).

[2] R. G. Edwards, J. J. Dudek, D. G. Richards and S. J. Wallace, Phys. Rev. D **84**, 074508 (2011).

[3] See contributions by H. Dutz and St. Goertz to this conference.

[4] D. Elsner *et al.* [CBELSA and TAPS Collaborations], Eur. Phys. J. A **39**, 373 (2009) doi:10.1140/epja/i2008-10708-1 [arXiv:0810.1849 [nucl-ex]].

[5] D. Drechsel, S. S. Kamalov and L. Tiator, Eur. Phys. J. A **34**, 69 (2007) [arXiv:0710.0306 [nucl-th]].

[6] R. L. Workman, M. W. Paris, W. J. Briscoe and I. I. Strakovsky, Phys. Rev. C **86**, 015202 (2012).

[7] D. Rönchen *et al.*, Eur. Phys. J. A **50**, no. 6, 101 (2014) [arXiv:1401.0634 [nucl-th]].

[8] A. V. Anisovich, et al., Eur. Phys. J. A **48**, 15 (2012).

[9] A. Thiel *et al.* [CBELSA/TAPS Collaboration], Phys. Rev. Lett. **109**, 102001 (2012),
A. Thiel *et al.* [CBELSA/TAPS Collaboration], submitted for publication in Eur. Phys. J. A.

[10] M. Gottschall *et al.* [CBELSA/TAPS Collaboration], Phys. Rev. Lett. **112**, no. 1, 012003 (2014),
M. Gottschall *et al.* [CBELSA/TAPS Collaboration], to be submitted for publication in EPJ A.

[11] J. Hartmann *et al.* [CBELSA/TAPS Collaboration], Phys. Lett. B **748**, 212 (2015),
J. Hartmann *et al.* [CBELSA/TAPS Collaboration], Phys. Rev. Lett. **113**, 062001 (2014).

[12] J. Müller *et al.* [CBELSA/TAPS Collaboration], to be submitted for publication in Phys. Rev. Lett.

[13] V. Sokhoyan *et al.* [CBELSA/TAPS Collaboration], Eur. Phys. J. A **51**, no. 8, 95 (2015).

[14] A.V. Anisovich et al., to be submitted for publication in Eur. Phys. J. A.

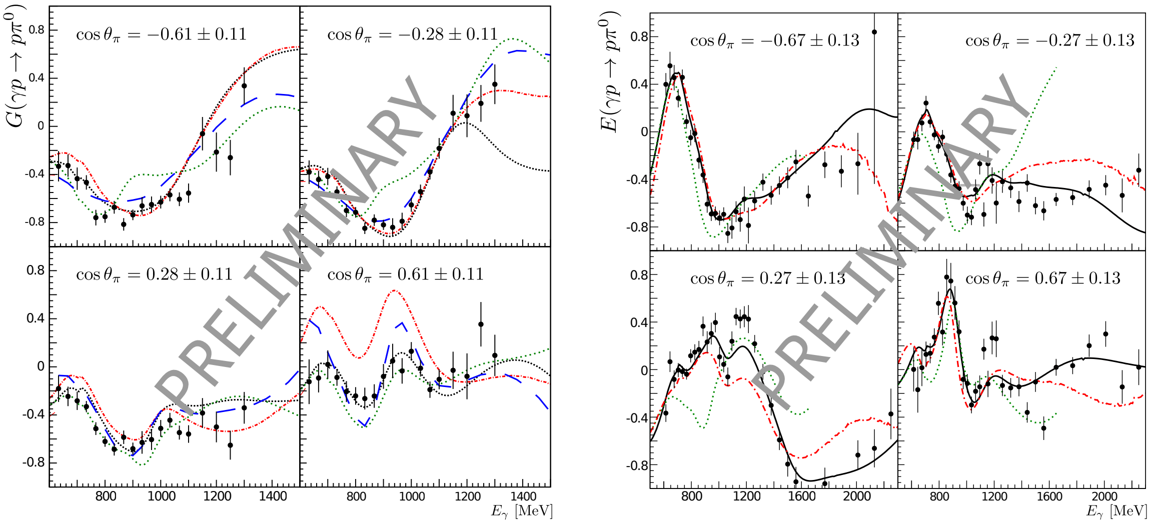

Figure 3: The data of the observables G (left) [9] and E (right) [10] for four different angular bins compared to different PWA predictions: MAID (green dotted) [5], SAID CM12 (red dashed-dotted) [6], BnGa 2011-02 (black solid) [8] and JüBo 13-01 (blue dashed) [7].

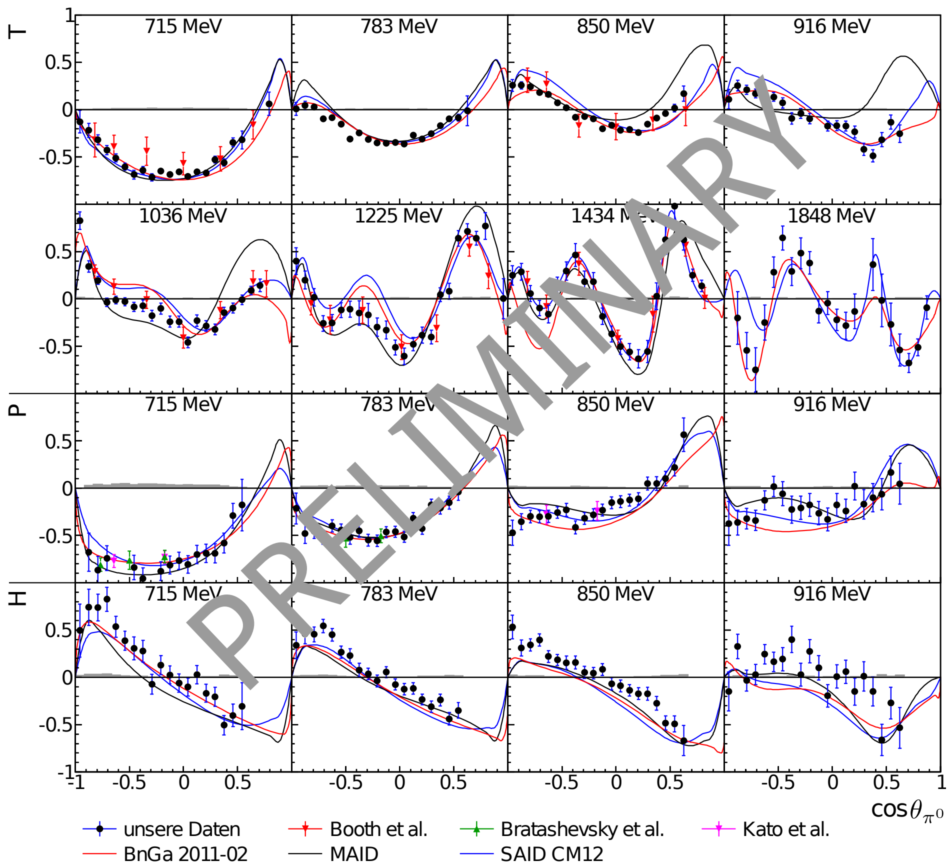

Figure 4: The observables T, P and H for pion photoproduction off the proton [11] compared to solutions of the different models and to previous measurements. Only every second energy bin is shown.