CIPANP2015-Strauch
October 27, 2015

Baryon spectroscopy with polarization observables from CLAS

Steffen Strauch[1] for the CLAS Collaboration

Department of Physics & Astronomy
University of South Carolina, Columbia, SC 20208, USA

Meson photoproduction is an important tool in the study of baryon resonances. The spectrum of broad and overlapping nucleon excitations can be greatly clarified by use of polarization observables. The N* program at Jefferson Lab with the CEBAF Large Acceptance Spectrometer (CLAS) includes experimental studies with linearly and circularly polarized tagged photon beams, longitudinally and transversely polarized nucleon targets, and recoil polarizations. An overview of these experimental studies and recent results will be given.

PRESENTED AT

Conference on the Intersections of Particle and Nuclear Physics (CIPANP)
Vail, CO, USA, May 19–24, 2015

[1]Supported in parts by the U.S. National Science Foundation: NSF PHY-1205782.

1 Introduction

The nucleon is a composite object of quarks and gluons. The spectrum of its excited states reveals valuable information about the fundamental theory of strong interaction, quantum chromodynamics (QCD). The spectrum also gives information about the relevant degrees of freedom of the bound system. Various models may differ in their underlying degrees of freedom, e.g. symmetric quark models, quark-diquark models, models which include gluonic excitations, and meson-baryon models. All symmetric quark models predict an overabundance of excited states relative to what has been observed until now, especially in πN scattering. Also recent lattice QCD calculations [1] yield a large number of not yet discovered nucleon resonances.

The large widths of the overlapping resonances make them difficult to detect and cross section data alone are insufficient to isolate resonance contributions and are insufficient to fully constrain partial-wave analyses. Polarization observables are crucial in these analyses. These observables include singe- and double-polarization observables with combinations of polarized beam, target, or the polarization of the recoiling baryon [2]. Eventually, a complete set of certain polarization observables is necessary to unambiguously determine the amplitudes of the reaction. In the photoproduction of pseudoscalar mesons a formally complete experiment requires the measurement of at least eight appropriately chosen observables at each energy and angle [3]. In the photoproduction of two mesons, more observables are needed [4].

In the following, examples of recent photoproduction measurements of polarization observables from the CLAS Collaboration are presented. These studies include single pseudoscalar-meson, vector-meson, double-pion, and hyperon photoproduction off the proton and (quasi-free) off the bound neutron. The experiments were performed at the Thomas Jefferson National Accelerator Facility (JLab). The incident photon beams were energy tagged in the Hall-B Photon Tagger and [5] either unpolarized, circularly, or linearly polarized. The photon beam irradiated the production target. Unpolarized liquid hydrogen or deuterium or the newly developed polarized frozen-spin (FROST) [6] or HDice targets [7, 8] have been used in these experiments. Final-state particles were detected in the CEBAF Large Acceptance Spectrometer (CLAS) [9]. The parity-violating weak decay of hyperons allows the determination of the hyperon polarization by measuring the decay-proton angular distributions.

2 Unpolarized Target

Finely binned beam asymmetries, Σ, have been measured for the reactions $\gamma p \to p\pi^0$ and $\gamma p \to n\pi^+$ with linearly polarized photons and energies from 1.10 to 1.86 GeV [10]. The observables were extracted from angular distributions of the polarized yields with respect to the polarization direction of the photon beam. The data strongly

constrained earlier partial-wave analyses. Resonance couplings have been extracted in fits made with the SAID analysis. The largest change from previous fits was found to occur for the 'well known' $\Delta(1700)3/2^-$ and $\Delta(1905)5/2^+$ resonances [10].

The CLAS Collaboration has measured the Λ recoil polarization, P [11, 12], as well as the beam-recoil observables, C_x and C_z [13], in the reactions $\gamma p \to K^+\Lambda$ and $\gamma p \to K^+\Sigma^0$. These data were instrumental in a coupled-channel analyses of the Bonn-Gatchina group [14, 15]. In particular, the analysis found further evidence for the, at the time, poorly known $N(1900)3/2^+$ resonance. The $N(1900)3/2^+$ is a resonance which is predicted by symmetric three-quark models, but is not expected to exist in earlier quark-diquark models.

These hyperon photoproduction studies are being extended in a new analysis of data with linearly polarized photons off a proton target up to $W \approx 2.2$ GeV. Together with the recoil polarization of the hyperon, this gives access to five polarization observables: Σ, P, T, O_x, and O_z. Energy distributions of the preliminary results of the beam-recoil polarization observable O_x are shown in Fig. 1 for the $\gamma p \to K^+\Lambda$ reaction.

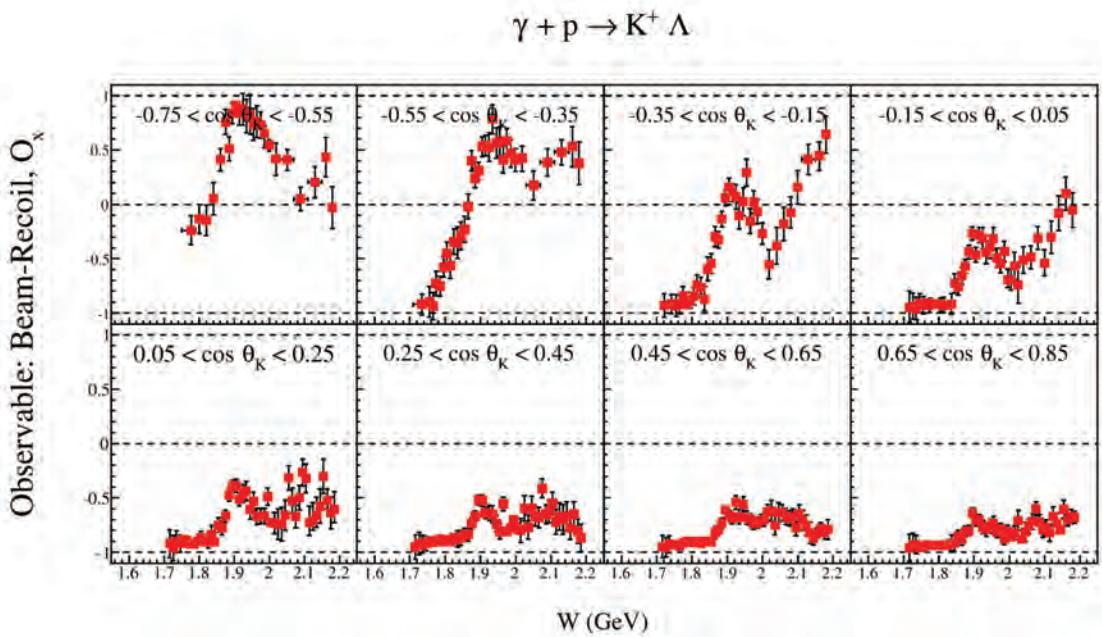

Figure 1: Preliminary results of CLAS data for the double-polarization observable O_x in the $\gamma p \to K^+\Lambda$ reaction. Figure from D. Ireland (University of Glasgow).

3 Polarized Proton Target (FROST)

The CLAS frozen-spin target program combines a series of meson photoproduction experiments [16, 17, 18, 19, 20] to measure single- and double-polarization observables with polarized photons off longitudinally or transversely polarized proton (butanol) targets.

First results have been published for the double-polarization observable E in the $\vec{\gamma}\vec{p} \to \pi^+ n$ with circularly polarized tagged-photon beam, with energies from 0.35 to 2.37 GeV, off longitudinally polarized protons [21]. Previous partial-wave analyses describe the new data at low photon energies reasonably well, at high energies, however, significant deviations are observed; see Fig. 2. The data have been included in new multipole analyses resulting in updated nucleon resonance parameters. One particularly interesting result is strengthened evidence for the poorly known $\Delta(2200)\frac{7}{2}^-$ resonance in improving the Bonn-Gatchina fit at the highest energies [22]. Its mass is significantly higher than the mass of its parity partner $\Delta(1950)7/2^+$ which is the lowest-mass Δ^* resonance with spin-parity $J^P = 7/2^+$. FROST data from other

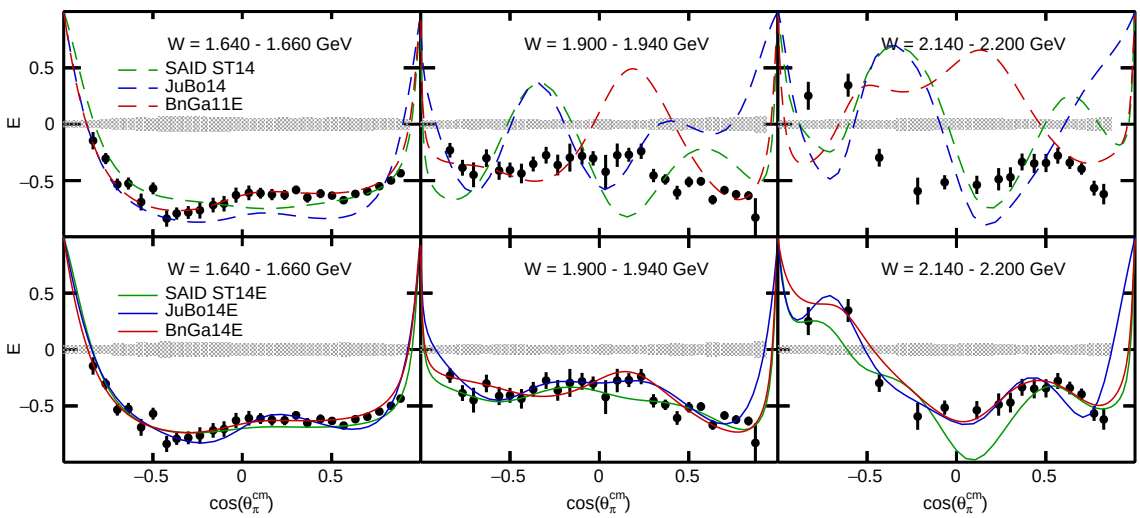

Figure 2: Observable E in the $\vec{\gamma}\vec{p} \to \pi^+ n$ reaction for selected center-of-mass energy bins. Systematic uncertainties are indicated as shaded bands. The curves in the upper panels are results from the SAID ST14 [23], Jülich14 [24], and BnGa11E [25] analyses. The curves in the lower panels are results from updated analyses including the present E data. Figure from Ref. [21].

single-pion photoproduction channels are under analysis by Arizona State University, U. of South Carolina, and U. of Edinburgh groups.

The polarization observable E has also been measured up to $W = 2.15$ GeV in the

$\gamma p \to \eta p$ reaction [26]; this reaction selects isospin-1/2 resonances. Figure 3 shows the data and a fit of the Jülich model. The fit describes the data quite well without the need for an additional narrow resonance near 1.68 GeV, which was previously suggested; see [26].

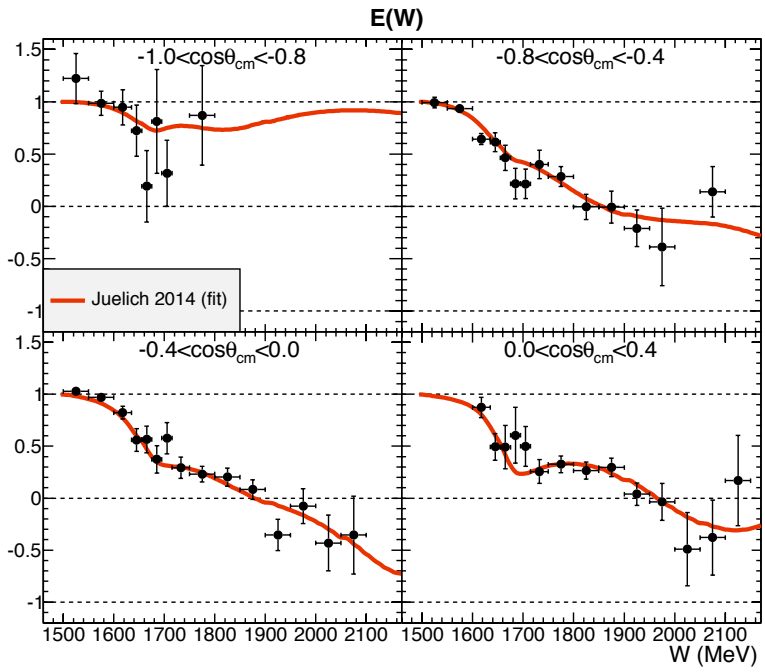

Figure 3: Observable E in the$\gamma p \to \eta p$ as a function of W for various angular bins. Figure from Ref. [26].

Hyperon photoproduction reactions are also studied with data from FROST. Figure 4 shows preliminary results of the double polarization observable F, which can be measured with circularly polarized photons off transversely polarized protons. The data cover energies between $W = 1.7$ GeV and $W = 2.3$ GeV. The data are compared with previous model calculations from the RPR-Ghent [27], KAON-MAID [28], and Bonn-Gatchina [25] models; none of the models describe the data well, showing the new constraints the data will provide.

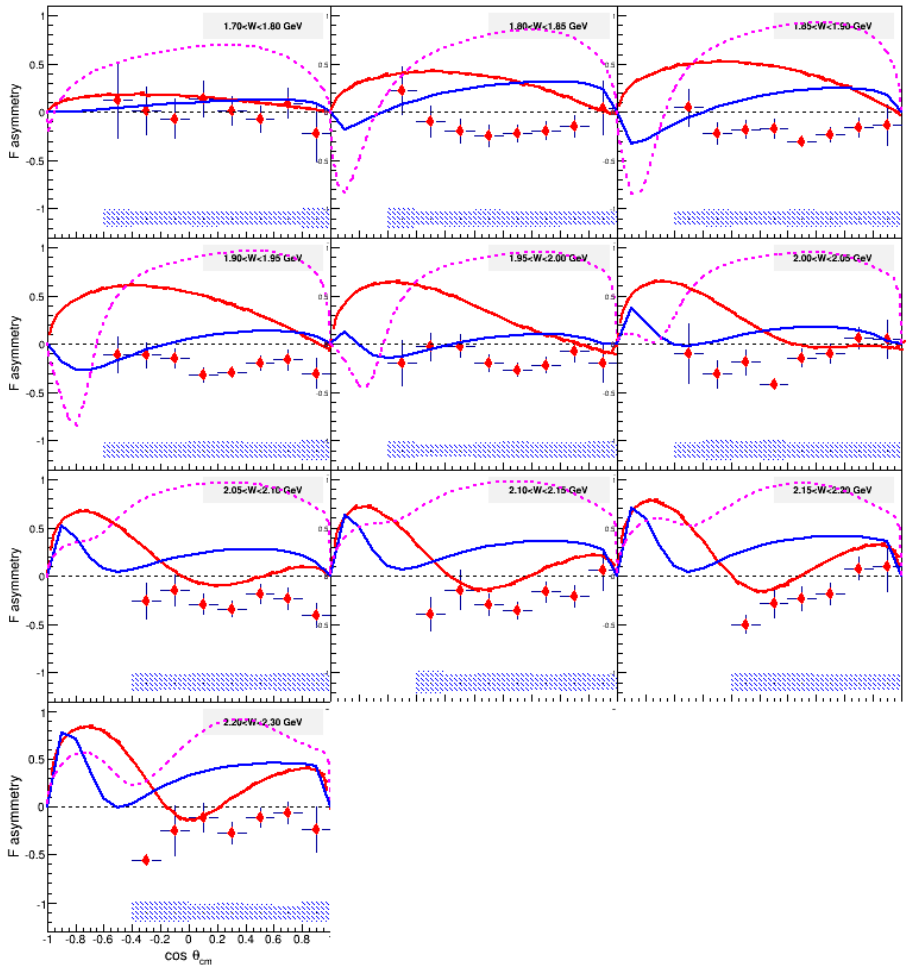

Figure 4: Preliminary angular distributions of the polarization observable F in the $\gamma p \to K^+\Sigma^0$ reaction for various W bins. Model curves are from the RPR-Ghent [27] (red), KAON-MAID [28] (blue), and Bonn-Gatchina [25] (magenta) models. Figure and analysis from N. Walford (U. Basel).

Many nucleon resonances in the mass region above 1.6 GeV decay predominantly through either $\pi\Delta$ or ρN intermediate states into $\pi\pi N$ final states. This makes double-pion photoproduction an important tool in the investigation of the structure of the nucleon. The CLAS Collaboration was first to study the beam-helicity asymmetry $I^{\odot}$ for the two-pion-photoproduction reaction. The measurement covered energies between $W = 1.35$ and 2.30 GeV [29]. With the development of the polarized FROST target many more polarization observables became accessable; see [4] for an overview of polarization observables in two-pion photoproduction reactions. The University of South Carolina and Florida State University groups work on the extraction of twelve different polarization observables from polarized-target $p\pi^+\pi^-$ data. As example,

the preliminary result for the observable P_y is shown in Fig. 5. This observable is accessable in a measurement with unpolarized photons off transversally polarized protons. The data will strongly constrain coupled-channel analyses.

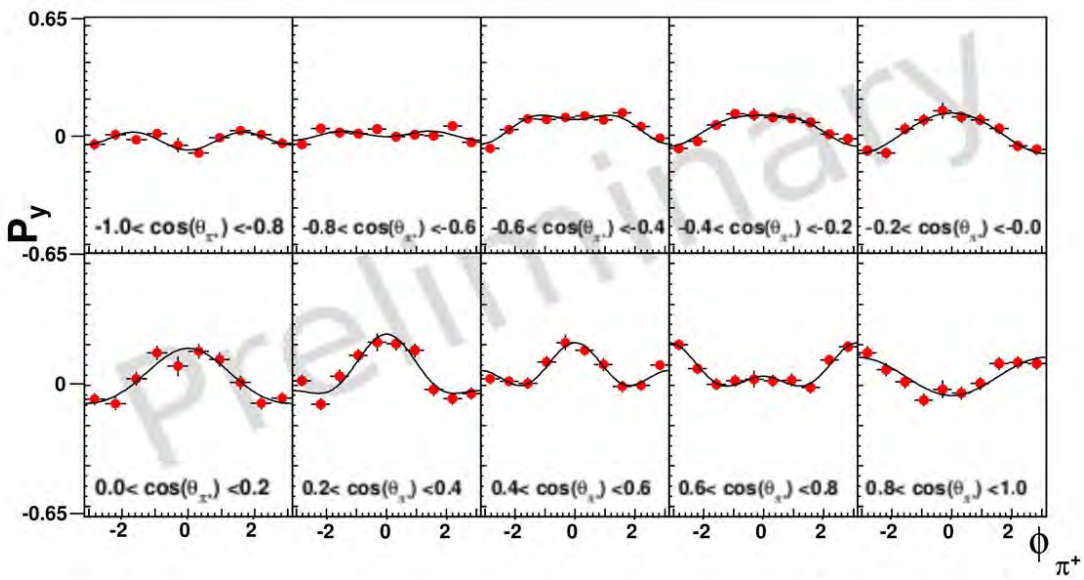

Figure 5: Preliminary results of the target polarization observable P_y in the $\vec{\gamma}p \to p\pi^+\pi^-$ reaction for 1.1 GeV $< E_\gamma <$ 1.2 GeV. The angles θ_{π^+} and ϕ_{π^+} are defined as the polar and azimuthal angles in the rest frame of the $\pi^+\pi^-$ system with the z direction along the total momentum of the $\pi^+\pi^-$ system. The data are fitted with a low-order Fourier series (black curve). Figure and analysis by P. Roy (FSU).

4 Polarized Neutron Target (HDice)

So far, the majority of data have been taken off proton targets. The new data from the FROST program will expand the data base over a large range of energy with many observables for polarized proton reactions. In constrast, data off neutrons are extremely sparse. However, measurements with both proton and neutron targets are needed to completely specify the amplitude of the reaction.

The CLAS collaboration has taken production data with circularly and linearly polarized photons off a polarized solid deuterium-hydride target (HDice) [7, 8] up to center-of-mass energies of $W \approx 2.3$ GeV. The run conditions were optimized for polarized neutron reactions. The ongoing analyses of this run include single- and double pion photoproduction and hyperon photoproduction off the bound neutron.

5 Conclusion

During the past years the knowledge of the baryon spectrum has largely increased, to a large extend due to photoproduction data from JLab, ELSA, GRAAL, and LEPS.

New polarized photoproduction data from CLAS off polarized and unpolarized, proton and neutron targets are under analysis and become available. They will contribute to complete or nearly complete experiments. They challenge previously not sufficiently constrained models. It is very likely that they will have a tremendous impact on the understanding of baryon resonances and may provide evidence for new states found in coupled-channel analyses.

References

[1] R. G. Edwards, J. J. Dudek, D. G. Richards, and S. J. Wallace, Phys. Rev. **D84**, 074508 (2011), `1104.5152`.

[2] I. S. Barker, A. Donnachie, and J. K. Storrow, Nucl. Phys. **B95**, 347 (1975).

[3] W.-T. Chiang and F. Tabakin, Phys. Rev. **C55**, 2054 (1997).

[4] W. Roberts and T. Oed, Phys.Rev. **C71**, 055201 (2005), `nucl-th/0410012`.

[5] D. Sober *et al.*, Nucl. Instrum. Meth. A **440**, 263 (2000).

[6] C. Keith, J. Brock, C. Carlin, S. Comer, D. Kashy, J. McAndrew, D. Meekins, E. Pasyuk, J. Pierce, and M. Seely, Nucl. Instrum. Meth. A **684**, 27 (2012).

[7] A. M. Sandorfi, J. Phys. Conf. Ser. **424**, 012001 (2013).

[8] Jefferson Lab Experiment E06-101, "N* Resonances in Pseudoscalar-meson photo-production from Polarized Neutrons in $\vec{H} \cdot \vec{D}$ and a complete determination of the $\gamma n \to K^0\Lambda$ amplitude", F. Klein and A.M. Sandorfi, spkespersons.

[9] B. A. Mecking *et al.*, Nucl. Instrum. Meth. **A503**, 513 (2003).

[10] M. Dugger *et al.*, Phys. Rev. C **88**, 065203 (2013), `1308.4028`.

[11] J. W. C. McNabb *et al.*, Phys. Rev. **C69**, 042201 (2004), `nucl-ex/0305028`.

[12] M. E. McCracken *et al.*, Phys. Rev. **C81**, 025201 (2010), `0912.4274`.

[13] R. K. Bradford *et al.*, Phys. Rev. **C75**, 035205 (2007), `nucl-ex/0611034`.

[14] A. V. Sarantsev, V. A. Nikonov, A. V. Anisovich, E. Klempt, and U. Thoma, Eur. Phys. J. **A25**, 441 (2005), `hep-ex/0506011`.

[15] V. A. Nikonov, A. V. Anisovich, E. Klempt, A. V. Sarantsev, and U. Thoma, Phys. Lett. **B662**, 245 (2008), `0707.3600`.

[16] Jefferson Lab Experiment E02-112, "Search for Missing Nucleon Resonances in Hyperon Photoproduction", P. Eugenio, F. Klein, and L. Todor, spokespersons.

[17] Jefferson Lab Experiment E03-105, "Pion Photoproduction from a Polarized Target", N. Benmouna, W. Briscoe, G. O'Rielly, I. Strakovsky, S. Strauch, spokespersons.

[18] Jefferson Lab experiment E04-102, "Helicity Structure of Pion Photoproduction", D. Crabb, M. Khandaker, and D. Sober, spokespersons.

[19] Jefferson Lab experiment E05-012, "Measurement of polarization observables in η-photoproduction with CLAS", M. Dugger and E. Pasyuk, spokespersons.

[20] Jefferson Lab Experiment E06-013, "Measurement of $\pi^+\pi^-$ Photoproduction in Double-Polarization Experiments using CLAS", M. Bellis, V. Credé, S. Strauch, spokespersons.

[21] S. Strauch *et al.*, Phys. Lett. **B750**, 53 (2015), `1503.05163`.

[22] A. V. Anisovich, V. Burkert, E. Klempt, V. A. Nikonov, E. Pasyuk, A. V. Sarantsev, S. Strauch, and U. Thoma (2015), `nucl-ex/1503.05774`.

[23] R. L. Workman, M. W. Paris, W. J. Briscoe, and I. I. Strakovsky, Phys. Rev. **C86**, 015202 (2012).

[24] D. Rönchen, M. Döring, F. Huang, H. Haberzettl, J. Haidenbauer, C. Hanhart, S. Krewald, U. G. Meißner, and K. Nakayama, Eur. Phys. J. **A50**, 101 (2014), `1401.0634`.

[25] A. V. Anisovich, R. Beck, E. Klempt, V. A. Nikonov, A. V. Sarantsev, and U. Thoma, Eur. Phys. J. **A48**, 15 (2012), `1112.4937`.

[26] I. Senderovich *et al.* (2015), `nucl-ex/1507.00325`.

[27] T. Corthals, J. Ryckebusch, and T. Van Cauteren, Phys. Rev. **C73** (2006) 045207 and T. Vrancx, personal communication.

[28] F. X. Lee, T. Mart, C. Bennhold, H. Haberzettl, and L. E. Wright, Nucl. Phys. **A695**, 237 (2001), "Kaon-MAID". Available from http://www.kph.uni-mainz.de/MAID/kaon/kaonmaid.html.

[29] S. Strauch *et al.*, Phys. Rev. Lett. **95**, 162003 (2005), `hep-ex/0508002`.