7TH INTERNATIONAL WORKSHOP ON PION-NUCLEON PARTIAL WAVE ANALYSIS AND THE INTERPRETATION OF BARYON RESONANCES

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CB@MAMI contribution to the spectroscopy

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Outline

- Experimental apparatus
- Single meson photoprduction
- Double meson photoproduction
- Summary



 4π photon spectrometer (97% of 4π) Detection of neutrons and charged particles is also possible at restricted energy regions



Crystal Ball: $20^{\circ} - 160^{\circ} (94\%)$ and TAPS : $1^{\circ} - 20^{\circ} (3\%)$



TAPS (Giessen, Basel)

366 BaF₂ crystals 12 radiation lengths

and 5mm plastic scintilator in front of each module (**VETO**)

Crystal Ball (UCLA, JWU, Mainz)

672 NaI(Tl) crystals 15.7 radiation lengths



MWPC (Pavia)

2 cylindrical chambers

Vertex reconstruction: -target position correction (z), -beam position control (x,y), -improve angular resolution.



VETO detector for photons in CB; ΔE for charged particle identification in CB.

Experimental apparatus: target



Frozen Spin Target (Mainz, Dubna) available since 05.2010

Butanol or D-Butanol;

3He/4He dilution refrigerator;

Superconducting holding magnet;

Longitudinal or transverse polarizations are possible;

Maximal polarization for protons ~90%, for deuterons ~75%;

Relaxation time ~2000 hours

Experimental apparatus: Recoil polarimetry

Recoil proton polarimeter (Edinburg)



Method:

detection of proton scattered in the graphite analyser and comparison its angle with kinematic reconstruction.

Meson photoproduction with MAMI C



 For measurement of polarization observables all combination of beam-target, beam-recoil, and target-recoil are possible

Meson photoproduction with MAMI C

		σ	dơ	Σ	Т	F	Р	$C_{x'}$	I°
1	νο τ ⁰ ο	רוק	+	+	חק	חק		+	0
1. 2	$\gamma p \rightarrow \pi^{+} p$	ΙD	•	•					0
2. 3	$\gamma p \rightarrow \pi^0 n$	רוק	ЪŪ		ТD	ТD			0
Δ	$\gamma \Pi \rightarrow \pi \Pi$	+	• • •		РП	ΡD			0
5	$\gamma p \rightarrow \eta p$ $\gamma n \rightarrow n n$	PD	• D		I D	ТЪ			0
6.	$\gamma n \rightarrow \eta' n$ $\gamma n \rightarrow n' n$	PD	ΙD						0
7.	$V D \rightarrow K^+ \Lambda$	+	+						0
8.	$V D \rightarrow K^+ \Sigma^0$	+	÷						0
9.	$V D \rightarrow K^0 \Sigma^+$	÷	+				+		0 0
10.	$V D \rightarrow \pi^0 \pi^0 D$	÷	+		PD	PD	-		+
11.	$V D \rightarrow \pi^0 \pi^+ D$		-						÷
12.	$V D \rightarrow \pi^+ \pi^- D$								+
13.	$v n \rightarrow \pi^0 \pi^0 n$								+
14.	$\gamma p \rightarrow \pi^o \eta p$	+	+		PD	PD			÷

+ : already published or accepted

PD : preliminary data

red marked: to be presented in this talk

Single meson photoproduction

- 16 observables for pseudoscalar meson photoproduction
- for complete experiment need 8 of them

Beam	Target				Recoil			Target + Recoil			
	_	_		_	x'	y'	z'	x'	x'	z'	z'
		x	y	z	_	_	_	x	z	x	z
unpolarized	σ_0	0		0	0	P	0	$T_{x'}$	$-L_{x'}$	$T_{z'}$	$L_{z'}$
linear pol.	$\left(-\Sigma\right)$	Н	(-P)	$\left(-G\right)$	$O_{x'}$	(-T)	$O_{z'}$	$(-L_{z'})$	$(T_{z'})$	$(-L_{x'})$	$(-T_{x'})$
circular pol.	0 (F	0	(-E)	$\left(-C_{x'}\right)$	0	$-C_{z'}$	0	0	0	0

already done

O started in 2013

The entries in parentheses signify that the same polarization observables also appear elsewhere in the table

$\gamma p \rightarrow \pi^{\circ} p$

P33(1232)

F37(1950)



Bonn-2005: O. Bartholomy et al., PRL 94 (2005) 0122003 Mainz-2013: S. Prakhov, preliminary

$\gamma p \rightarrow \pi^{\circ} p$

Preliminary results for T and F



black circles: MAMI data (preliminary) magenta triangles: world data (before 2000)

 $\gamma p \rightarrow \pi^{\circ} p$

Preliminary results: Legendre expansion



$$\label{eq:max_star} \begin{split} d\sigma/d\Omega \ \{T,F\} &= \sin \Theta_{\pi} \ \sum_{j=0}^{j_{max}} A_{j} \ (W) \ P_{j} \ (\cos \Theta_{\pi}) \\ J_{max} &= 2L_{max} - 1 \end{split}$$

black circles: MAMI data (preliminary) solid lines: Legendre expansion, j_{max}=5

 $\gamma p \rightarrow \pi^{\circ} p$

Legendre coefficients for T and F







black circles: MAMI data (preliminary)

yellow panel: lowest PW contribution

 $\gamma p \rightarrow \pi^+ n$

Very preliminary results for T



black circles: MAMI data (preliminary) magenta triangles: world data (before 2000)

 $\gamma p \rightarrow \pi^+ n$

Very preliminary results for F



black circles: MAMI data (preliminary)

 $\gamma p \rightarrow \pi^{o} p$

Preliminary results for C_{χ}^{*}



black circles: MAMI data (Sikora, Watts, Glazier et. al., sub. to PRL) magenta triangles: Jlab Hall A data (Wijesooria et al., PRC 66, 2002) green short-dash line: SAID SN11 blue long-dash line: SAID CM12 red solid line: BG2011-02 violet dash-dotted line: MAID 2007 $\begin{array}{ccc} \gamma & p \rightarrow \pi^{\circ} p \\ \gamma & p \rightarrow \pi^{+} n \end{array}$

Summary

- preliminary data for T and F asymmetries were obtained for $\gamma p \rightarrow \pi^0 p$ from 0.44 to 1.4 GeV, $\gamma p \rightarrow \pi^+ n$ from 0.44 to 1.01 GeV;
- data for T are in good agreement with all previous experiments;
- F asymmetry was measured at first time;
- data for $C_{x'}$ obtained for $\gamma p \rightarrow \pi^0 p$ from 0.4 to 1.4 GeV and Jlab measurements are consistent where they overlap, providing a convincing verification of the recoil polarimeter technique;
- data are sensitive to the choice of models and will be used for further analyzes of this reaction.



dominance of S₁₁

Bonn-2009: V. Crede et al., PRC 80 (2009) 055202 Mainz-2010: E. F. McNicoll et al., PRC 82 (2010) 035208

Preliminary results for T and F



black circles: MAMI data (preliminary)

magenta triangles: Bonn data (Bock et al., PRL 81, 1998)

dashed green line: MAID 2003 Isobar Model solid green line:MAID 2003 Reggezed Isobar Model solid blue line: SAID GE09; dashed: SAID E429; solid reded line: BG2011-02; dashed: BG20010-02

Preliminary results for T and F



black circles: MAMI data (preliminary)

magenta triangles: Bonn data (Bock et al., PRL 81, 1998) dashed green line: MAID 2003 Isobar Model solid green line:MAID 2003 Reggezed Isobar Model solid blue line: SAID GE09; dashed: SAID E429; solid reded line: BG2011-02; dashed: BG20010-02

$\gamma P \rightarrow \mathbf{D} P$

Preliminary results

A.V.Anisovich et al., PLB 719, 89, 2013 Coupled channel isobar analysis of MAMI data (total and differential cross sections for eta photoproduction from E. F. McNicoll et al., PRC 82, 035208, 2010)



Summary

- experimental data for T and F asymmetries for γp→ηp reaction were obtained in energy region of 0.71 - 1.4 GeV;
- obtained data for T are in reasonable agreement with Bonn data except for near threshold region;
- F asymmetry was measured at the first time;
- data are very sensitive to the choice of models and can be used for further analyzes of this reaction.

Double meson photoproduction

- 64 observables for two pseudoscalar meson photoproduction;
- 28 relations from consideration of the absolute magnitudes of the helicity or transversity amplitudes;
- 21 relations from consideration of their phases;
- 15 independent quantities;
- need 8 helicity or transversity amplitudes;
- 8 observables to obtain the absolute magnitudes of the amplitudes plus 7 for independent phase differences;
- each observable depends on 5 kinematic variable !

W. Roberts and T. Oed, PRC 71, 055201 (2005)

Polarization observables measured in present work

Notations from A. Fix and H. Arenhövel, PRC 83, 015503 (2011) In parentheses: W. Roberts and T. Oed, PRC 71, 055201 (2005)



$$T_{11}^0 = -P_x, \quad S_{11}^0 = -P_y, \quad T_{11}^c = P_x^{\odot}, \quad S_{11}^c = P_y^{\odot}$$

$\gamma p \rightarrow \pi^{\circ} \pi^{\circ} p$

Total cross section



P11(1440) D13(1520) S11(1535) S31(1620) D15(1675) F15(1680) D33(1700) P13(1720)

FA-2005: Fix, Arenhövel, EPJA 25 (2005) 115 and other models:

significant underestimation near threshold for pi0 pi0 channel.

$\gamma p \rightarrow \pi^{\circ} \pi^{\circ} p$

Total cross section



FA-2012: Fix, Arenhövel, PRC 85 (2012) 035502

 $\gamma p \rightarrow \pi^{o} \pi^{o} p$

Preliminary results for P_y (or T)



 $\gamma p \rightarrow \pi^{o} \pi^{o} p$

Preliminary results for P_x° (or F)





Summary

- experimental data for the target and beam-target asymmetries for $\gamma p \rightarrow \pi^0 \pi^0 p$ reaction were obtained in energy region of 500-1400 MeV;
- in the second resonance energy region and below dominate 3 partial wave amplitudes 1/2+, 3/2+, and 3/2-;
- role of D₃₃(1700) in this energy region requires further study.

 $\gamma p \rightarrow \pi^{\circ} \eta p$

Total cross section



dash-dotted: Born terms

dotted: $\Delta(1920)3/2^+$ dash-dotted: $\Delta(1750)1/2^+$

Data: EPJ A42 (2009); Isobar Model: A. Fix et al., PRC 82 (2010)

$\gamma p \rightarrow \pi^{\circ} \eta p$

Preliminary results: target asymmetry P_v (or T)



black circles: MAMI data (preliminary)

red solid line: Isobar Model, solution 1 black dashed line: only D₃₃

Preliminary results: beam-target asymmetry P_x° (or F)



black circles: MAMI data (preliminary)

red solid line: Isobar Model, solution 1 black dashed line: only D₃₃ blue dashed-dotted: BnGa (Nikonov)

$\gamma p \rightarrow \pi^{\circ} \eta p$

$\gamma p \rightarrow \pi^{\circ} \eta p$

Summary

- experimental data for the target and beam-target asymmetries for γp→π⁰ηp reaction were obtained in energy region of 1.05 - 1.45 GeV;
- the polarization observables are sensitive to the contribution of the small components in the reaction amplitude;
- interference between Δ3/2⁻ and the positive states Δ1/2⁺ and Δ3/2⁺ is responsible for the nontrivial angular and invariant mass dependencies of all asymmetries presented.

Crystal Ball at MAMI, TAPS and A2 Collaborations

~70 participants, 18 institutes from 9 countries



22th Crystal Ball @ MAMI Collaboration Meeting, Mainz, July 2013