Recent results from the CBELSA/TAPS experiment at ELSA

Annika Thiel

for the CBELSA/TAPS collaboration

Space-like and time-like electromagnetic baryonic transitions
ECT* Trento

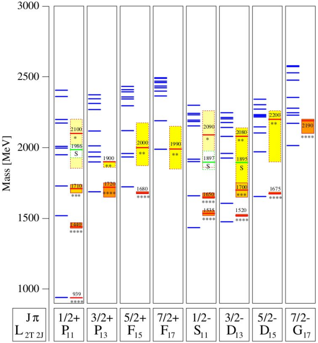
05/09/2017

HISKP, University of Bonn, Germany

Motivation

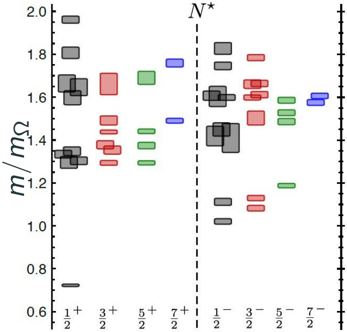
Theoretical Predictions

Quark models



[Löring et al. 2001]

Lattice QCD calculations

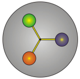


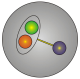
[Edwards et al. 2011]

$m_\pi \approx 400$ MeV

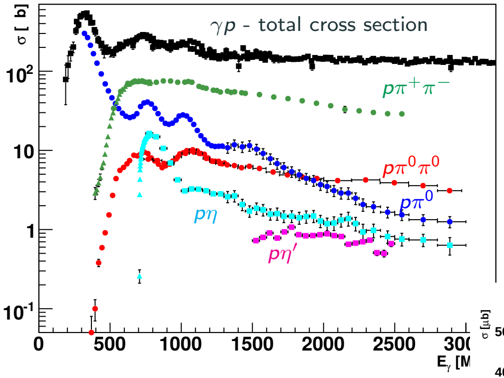
Calculations predict more resonances than have been measured ("missing resonances")

→ What are the relevant degrees of freedom?



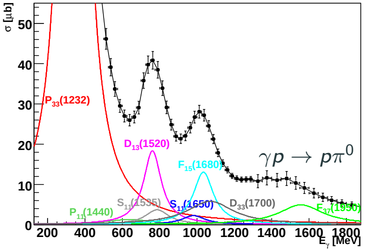


Resonances

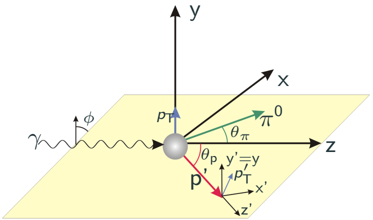


Resonances overlap strongly with different strengths and widths
→ Weak resonance contributions difficult to measure

Partial wave analysis needed to disentangle the resonances.



Polarization Observables



16 Polarization Observables in photoproduction of pseudoscalar mesons:

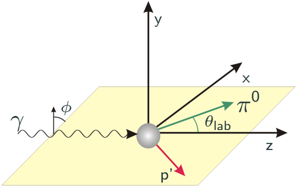
Photon		Target			Recoil			Target+Recoil			
		–	–	–	x'	y'	z'	x'	x'	z'	z'
		x	y	z	–	–	–	x	z	x	z
unpolarized	σ	–	T	–	–	P	–	$T_{x'}$	$-L_{x'}$	$T_{z'}$	$L_{z'}$
linearly pol.	Σ	H	(-P)	-G	$O_{x'}$	(-T)	$O_{z'}$	–	–	–	–
circularly pol.	–	F	–	-E	$-C_{x'}$	–	$-C_{z'}$	–	–	–	–

For a complete model-independent partial wave analysis ('complete experiment'):

At least 8 well-chosen observables needed

[Chiang, Tabakin Phys. Rev. C55 (1997)]

Cross Section with Beam und Target Polarization

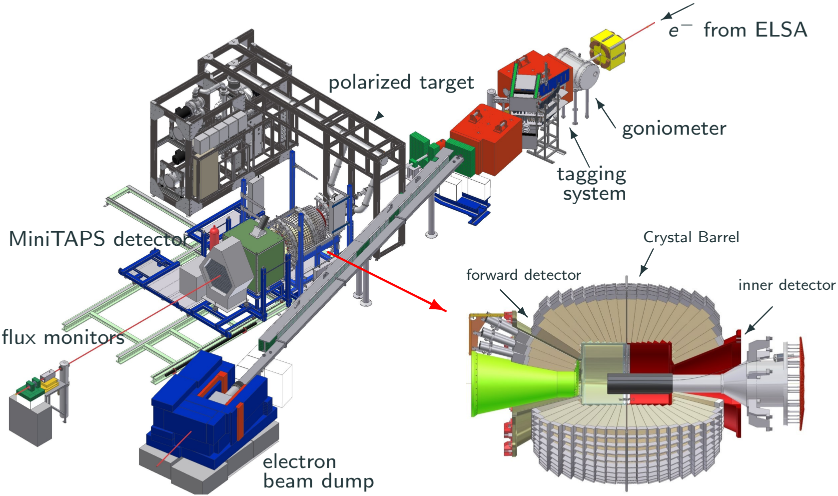


$$
\begin{aligned}
\frac{d\sigma}{d\Omega}(\theta,\phi) &= \frac{d\sigma}{d\Omega}(\theta)\cdot\Big[1 - p_\gamma^{lin}\Sigma\cos(2\phi) \\
&+ p_x(-p_\gamma^{lin}H\sin(2\phi) + p_\gamma^{circ}F) \\
&- p_y(-T + p_\gamma^{lin}P\cos(2\phi)) \\
&- p_z(-p_\gamma^{lin}G\sin(2\phi) + p_\gamma^{circ}E)\Big]
\end{aligned}
$$

		Target Polarization		
Photon Polarization		x	y	z
unpolarized	σ	–	T	–
linearly polarized	Σ	H	P	G
circularly polarized	–	F	–	E

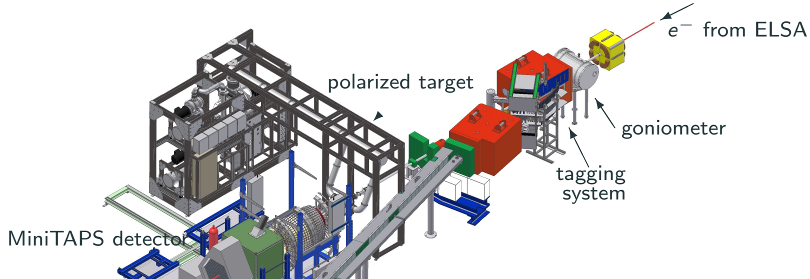
Experimental Setup

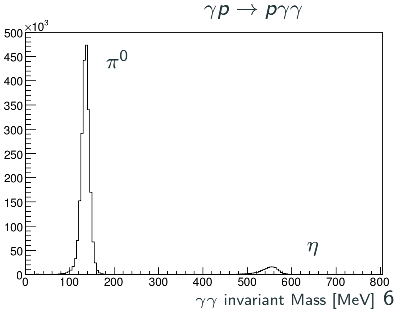
The Setup of the CBELSA/TAPS Experiment



$\rightarrow$ nearly full 4π angular coverage

The Setup of the CBELSA/TAPS Experiment





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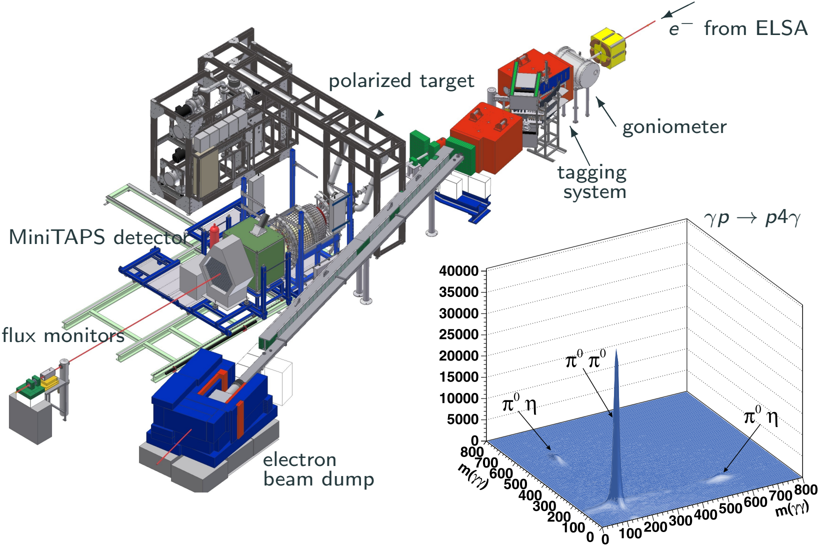
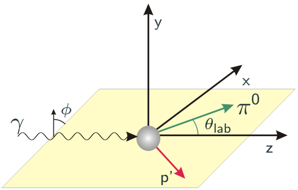


Extraction of the observables for photoproduction of pseudoscalar mesons

Cross Section with Beam und Target Polarization



$$\frac{d\sigma}{d\Omega}(\theta,\phi) = \frac{d\sigma}{d\Omega}(\theta)\cdot\Big[1 - p_\gamma^{lin}\Sigma\cos(2\phi) + p_x(-p_\gamma^{lin}H\sin(2\phi) + p_\gamma^{circ}F) - p_y(-T + p_\gamma^{lin}P\cos(2\phi)) - p_z(-p_\gamma^{lin}G\sin(2\phi) + p_\gamma^{circ}E)\Big]$$

Photon Polarization		Target Polarization x	y	z
unpolarized	σ	–	T	–
linearly polarized	Σ	H	P	G
circularly polarized	–	F	–	E

π^0-photoproduction:

G: A.Thiel et al., PRL 109 (2012) 102001
Eur.Phys.J. A53 (2017) 1, 8

E: M. Gottschall et al., PRL 112 (2014) 012003

T, **P**, **H**: J. Hartmann et al., PRL 113 (2014) 062001
Phys.Lett. B748 (2015) 212

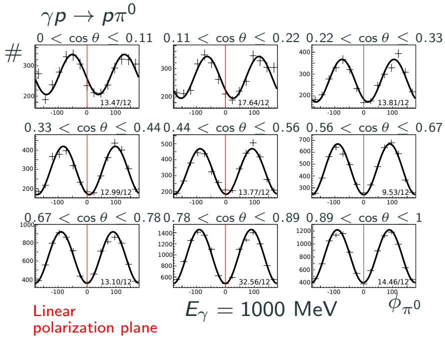
η-photoproduction:

publication in preparation

ϕ-Distribution of the Mesons

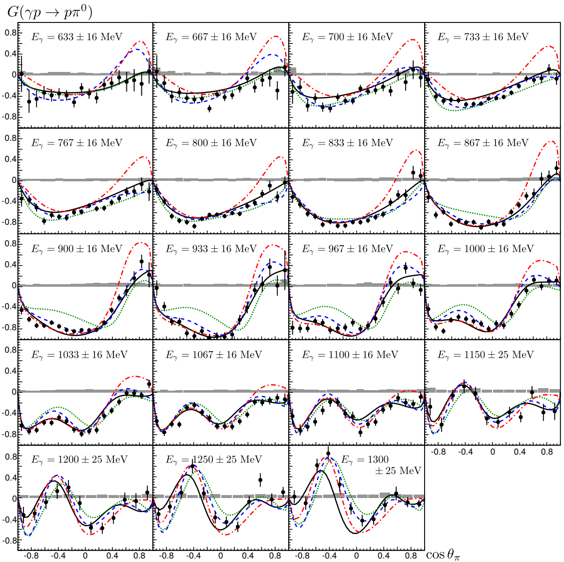
Cross section with longitudinally polarized target and linearly polarized photons:

$$\frac{d\sigma}{d\Omega}(\theta,\phi) = \frac{d\sigma}{d\Omega}(\theta)\cdot\left[1 - p_\gamma^{lin}\Sigma\cos(2\phi) + p_z p_\gamma^{lin} G\sin(2\phi)\right]$$



- Influence of polarization observables directy visible
- Symmetric around linear polarization plane
  $\rightarrow \Sigma$ dominating
- Deviation from symmetry
  $\rightarrow$ influence of double polarization observable G

$\gamma p \to p\pi^0$: Double Polarization Observable G



Predictions to the data:

BnGa11-02

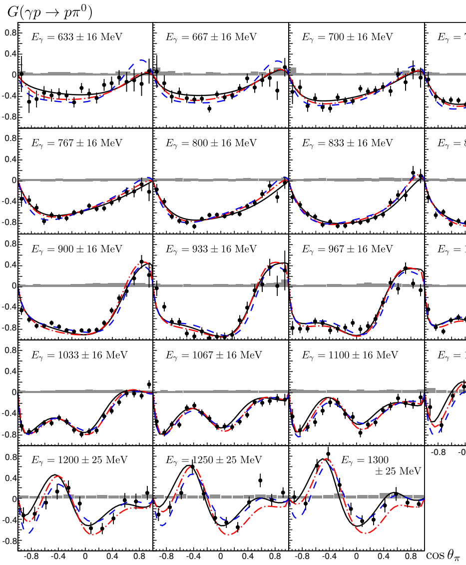
SAID (CM12)

MAID07

JüBo13-1

A.Thiel et al.,
PRL 109 (2012) 102001
Eur.Phys.J. A53 (2017) 1, 8

$\gamma p \to p\pi^0$: Double Polarization Observable G



Fits to the data:

BnGa14-02

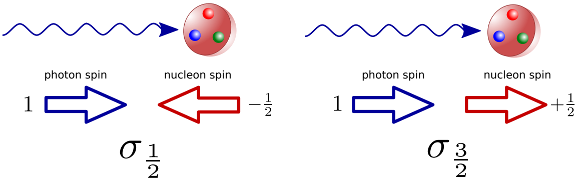
SAID

JüBo15-B

A.Thiel et al.,
PRL 109 (2012) 102001
Eur.Phys.J. A53 (2017) 1, 8

The Double Polarization Observable E

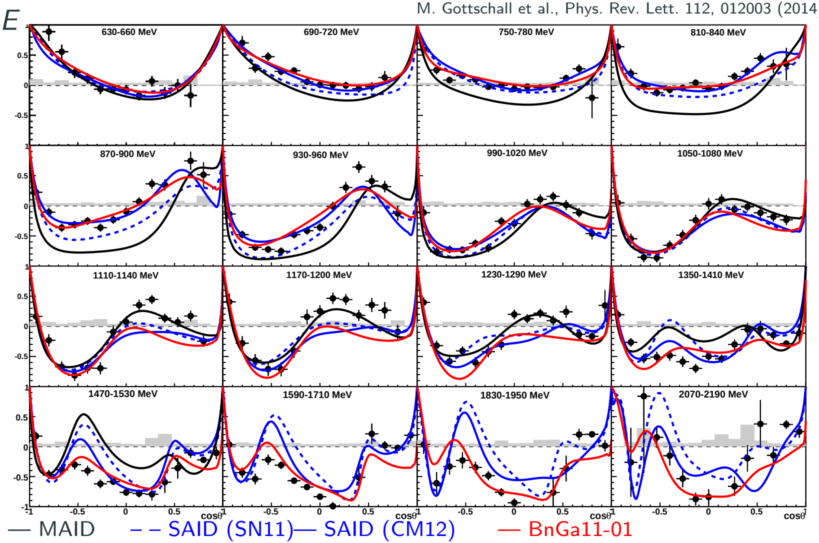
- Circularly polarized photons on a longitudinally polarized target
- Observable is a helicity asymmetry
- Two spin configurations possible:



$$E(\theta, E_\gamma) = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$$

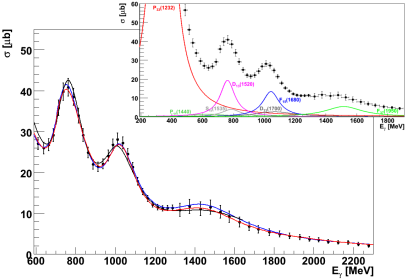
$\gamma p \to p\pi^0$: Double Polarization Observable E

M. Gottschall et al., Phys. Rev. Lett. 112, 012003 (2014)



Only every second energy bin shown!

$\gamma p \to p\pi^0$: $\sigma_{1/2}$ vs. $\sigma_{3/2}$



- Different models show good description of the cross section
- Spin dependent cross section can be extracted: $\sigma^{1/2(3/2)} = \sigma_0 \cdot (1 \pm E)$

M. Gottschall et al. PRL 112 (2014) 012003

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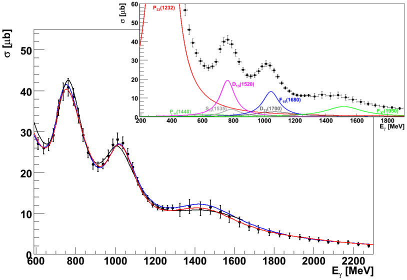
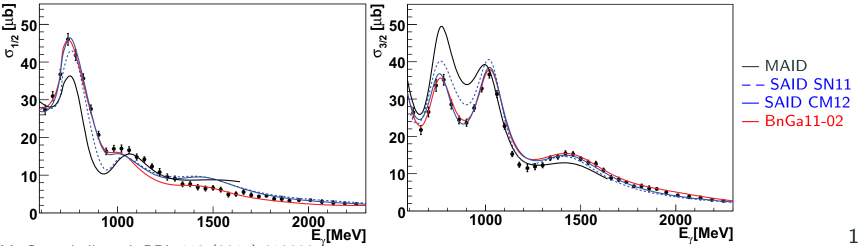
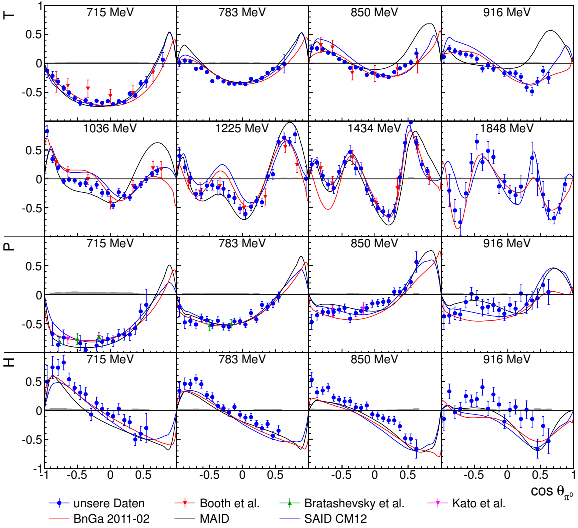


- Different models show good description of the cross section
- Spin dependent cross section can be extracted: $\sigma^{1/2(3/2)} = \sigma_0 \cdot (1 \pm E)$
- Large differences occur in $\sigma^{1/2}$ and $\sigma^{3/2}$ cross sections



M. Gottschall et al. PRL 112 (2014) 012003

$\gamma p \rightarrow p\pi^0$: Polarization Observables T, P and H



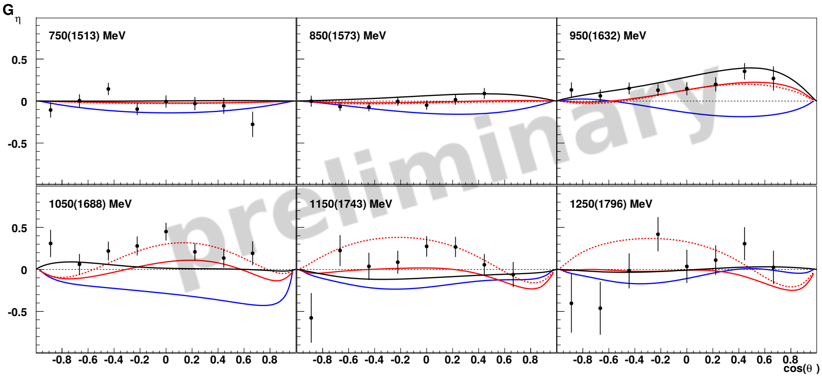
High quality data set with large angular coverage and wide energy range

Only selected bins shown here

J. Hartmann et al.,
PRL 113 (2014) 062001
Phys.Lett. B748 (2015) 212-220

$\gamma p \to p\eta$: Polarization Observable G

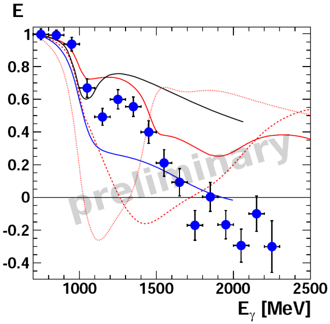
M. Grüner



— BnGa14-02 — — BnGa14-01 — ηMAID — SAID (GE09)

Additional data was taken by the A2 experiment in Mainz

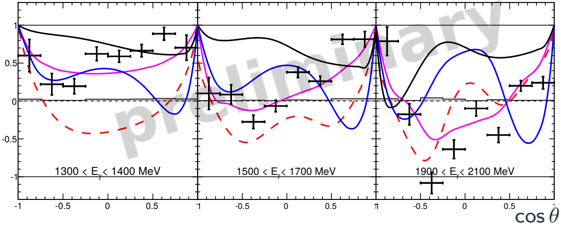
$\gamma p \rightarrow p\eta$: Double Polarization Observable E



$$E(\theta, E_\gamma) = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$$

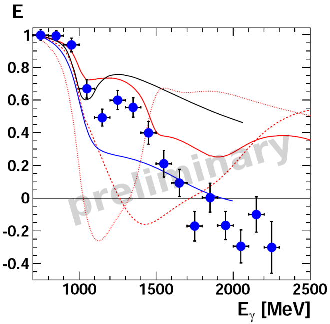
- At threshold: E close to 1 due to $S_{11}(1535)$ dominating
- At higher energies: large discrepancies in the predictions

— BnGa 2011-02
– – BnGa 2011-01
· · · BnGa-PWA (w/o P11 (1710))
— MAID
— SAID (GE09)
— BnGa14



J. Müller,
publication in preparation

$\gamma p \rightarrow p\eta$: Double Polarization Observable E



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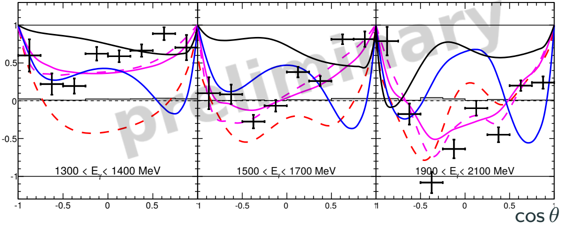
— BnGa 2011-02
– – BnGa 2011-01
· · · BnGa-PWA (w/o P11 (1710))
— MAID
— SAID (GE09)
— BnGa14
– – BnGa14 with additional resonance

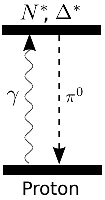


J. Müller,
publication in preparation

Observables in multi-meson final states

Observables in Multi-Meson Final States

- Multi-meson final states like $\gamma p \to p\pi^0\pi^0$ or $\pi^0\eta$ preferred at higher energies
- Probes the high mass region, where the missing resonances occur
- Can help to observe cascading decays



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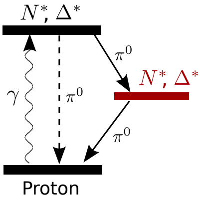

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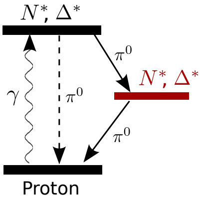
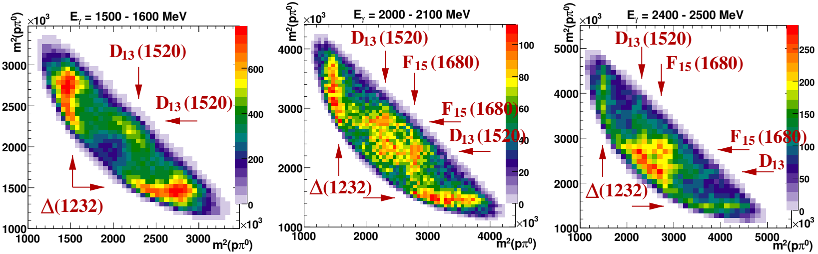
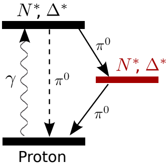




V. Sokhoyan et al., Eur.Phys.J. A51 (2015) no.8, 95

$\gamma p \to p\pi^0\pi^0$: New Interpretation of the Cascade Decays

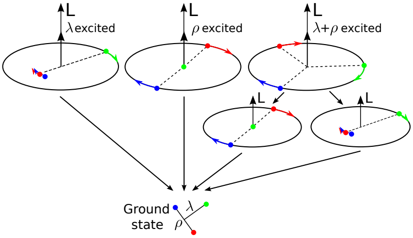


Two quartets of baryon resonances (N^* and Δ^*) observed in the fourth resonance region:

$\Delta(1910)1/2^+$, $\Delta(1920)3/2^+$, $\Delta(1905)5/2^+$, $\Delta(1950)7/2^+$
$N(1880)1/2^+$, $N(1900)3/2^+$, $N(2000)5/2^+$, $N(1990)7/2^+$

N^* decay more often in orbitally excited intermediate states than Δ^*
Both oscillators λ and ρ excited?

Cascade decay needed to de-excite both oscillators sequentially
$\to$ direct decay into $N\pi$ reduced.

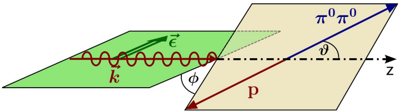


A. Thiel et al., Phys. Rev. Lett. 114, 091803

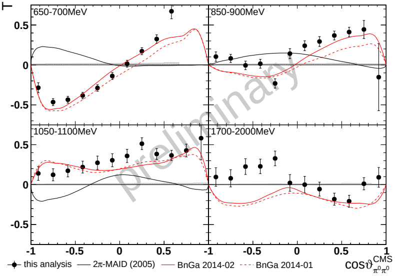
$\gamma p \to p\pi^0\pi^0$: Polarization Observables T, P, H

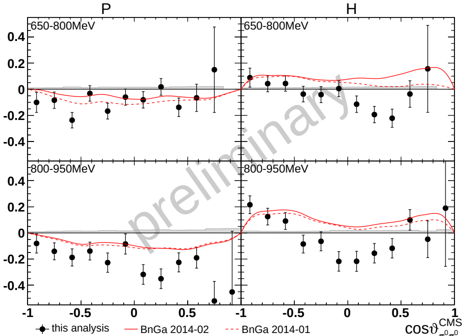
Here:

only results shown in quasi two-body kinematics



T. Seifen





Observables also extracted for different kinematic variables

Full three-body kinematics allows the measurement of further observables.

Interpretation

First Interpretation with a Truncated Partial Wave Analysis

Observable described by

$$\check{T} = T \cdot \sigma = \frac{q}{k} \sin\theta \left[\sum_{h=0}^{2L_{max}-1} A_h (\cos\theta)^h \right]$$

- using S- and P-waves ($L_{max} = 1$):

$$\check{T} = \frac{q}{k} \sin\theta \left[A_0 + A_1 \cdot \cos\theta\right]$$

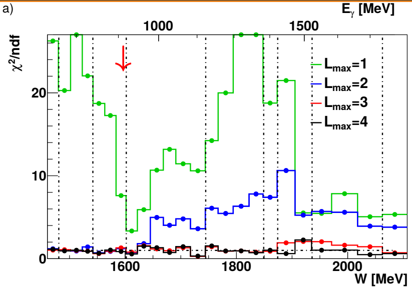
- using S-, P- and D-waves ($L_{max} = 2$):

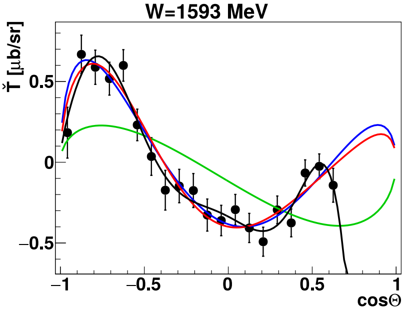
$$\check{T} = \frac{q}{k} \sin\theta [A_0 + A_1 \cdot \cos\theta + A_2 \cdot \cos^2\theta + A_3 \cdot \cos^3\theta]$$

- using S-, P-, D- and F-waves ($L_{max} = 3$):

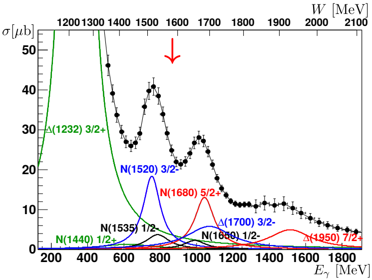
$$\check{T} = \frac{q}{k} \sin\theta [A_0 + A_1 \cdot \cos\theta + A_2 \cdot \cos^2\theta + A_3 \cdot \cos^3\theta + A_4 \cdot \cos^4\theta + A_5 \cdot \cos^5\theta]$$

First Interpretation with a Truncated Partial Wave Analysis



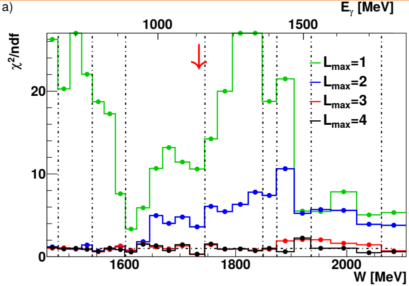


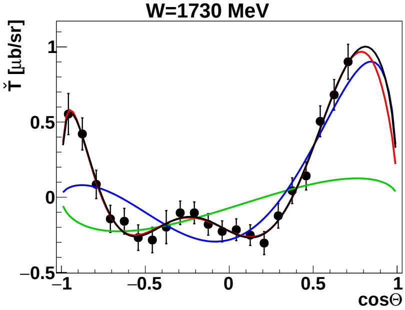
Y. Wunderlich, F. Afzal, A. Thiel, R. Beck, accepted for publication in EPJA



- Sensitivity to different angular momenta directy visible in the observables!
- Energies below $W \lesssim 1650$ MeV: $L = 2$ sufficient
- $L = 3$ strength visible for $W \gtrsim 1650$ MeV
- Above $W \gtrsim 1850$ MeV indication for $L = 4$ signal

First Interpretation with a Truncated Partial Wave Analysis





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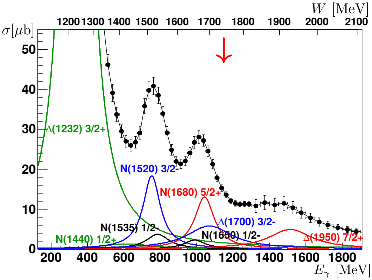

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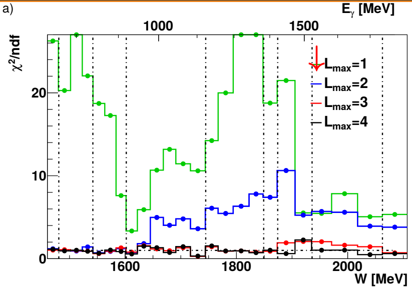

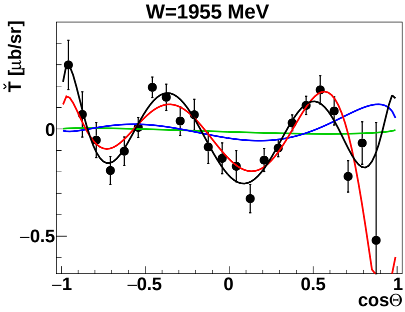

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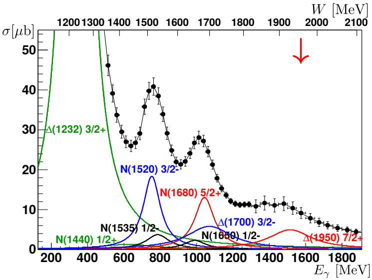

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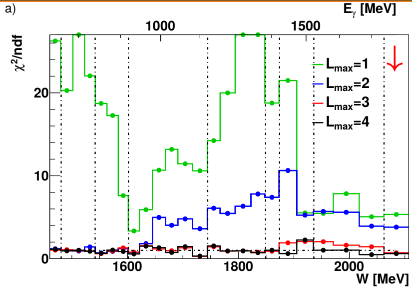
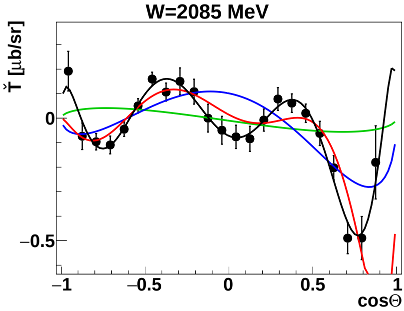
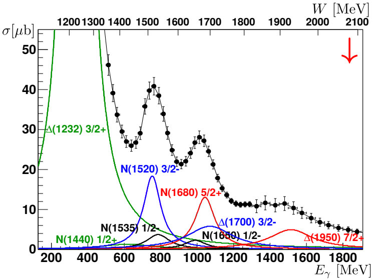
First Interpretation with a Truncated Partial Wave Analysis



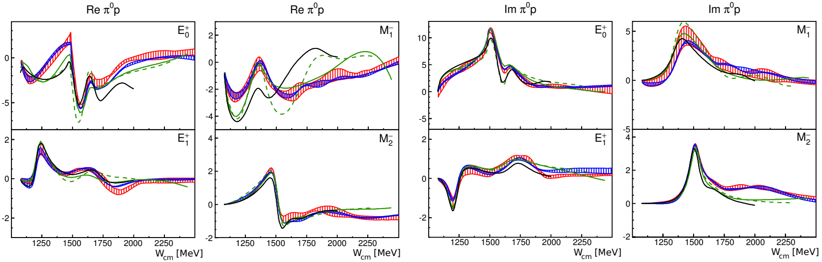


Y. Wunderlich, F. Afzal, A. Thiel, R. Beck, accepted for publication in EPJA



- Sensitivity to different angular momenta directy visible in the observables!
- Energies below $W \lesssim 1650$ MeV: $L = 2$ sufficient
- $L = 3$ strength visible for $W \gtrsim 1650$ MeV
- Above $W \gtrsim 1850$ MeV indication for $L = 4$ signal

New Fit from BnGa



J. Hartmann et al., Phys.Lett. B748 (2015) 212

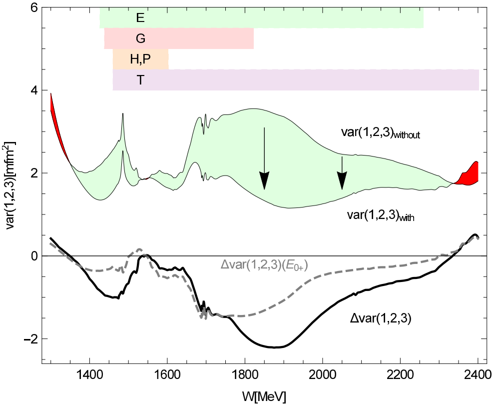
MAID, SAID CM12 (solid) SN11 (dashed), BnGa, BnGa with double pol. obs.

- Still large differences in the different PW analyses visible
- By using additional observables, the fit error bands get smaller

New Fits from different Analyses

New double polarization observables fitted by BnGa, JüBo and SAID analysis groups

Variance between the different analyses decreases!



Anisovich et al., Eur.Phys.J. A52 (2016) no.9, 284

$\rightarrow$ Including more polarization observables will converge all analyses to the same solution

Comparison between PDG values and BnGa results

- Until 2010: almost only results from pion nucleon scattering used in the PDG, only few pion photoproduction data used
- BnGa group included photoproduction data with different final states from several experiments
- Now: new values from the BnGa fits are entering the PDG

	PDG 2010	BnGa-PWA	PDG 2012	GWU'06
$N(1860)5/2^+$		*	**	
$N(1875)3/2^-$		***	***	
$N(1880)1/2^+$		**	**	
$N(1895)1/2^-$		**	**	
$N(1900)3/2^+$	**	***	***	no evidence
$N(2060)5/2^-$		***	**	
$N(2150)3/2^-$		**	**	
$\Delta(1940)3/2^-$	*	*	**	no evidence

$\rightarrow$ Same effect with the double polarization data?

Summary

Conclusion

- Reactions like $\gamma p \rightarrow p\pi^0$, $p\eta$, $p\eta'$, $p\pi^0\pi^0$ have been measured with polarized photons and protons with the CBELSA/TAPS experiment

- Different single and double polarization observables have been successfully extracted over a wide energy range

- Data for the observables Σ, G, E, T, P and H has been published for π^0 photoproduction, other channels will follow soon

- Data has been included in the different analyses and the multipoles are converging

Outlook

- Crystal Barrel detector is currently upgarded for a higher detection efficiency for photoproduction off the neutron
- Several other experiments (CLAS, Crystal Ball/MAMI, BGO-OD) will help to create a comprehensive database of polarization observables in different reactions
- New polarization data will help to understand the resonance spectrum and will provide an experimental basis for comparison with constituent quark models, lattice QCD or other methods

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Thank you
for your attention.

Supported by the
DFG