Double Polarisation Experiments in Meson Photoproduction and the Impact on the Nucleon Excitation Spectrum

Jan Hartmann

for the CBELSA/TAPS collaboration

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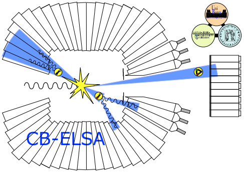


21.10.2014

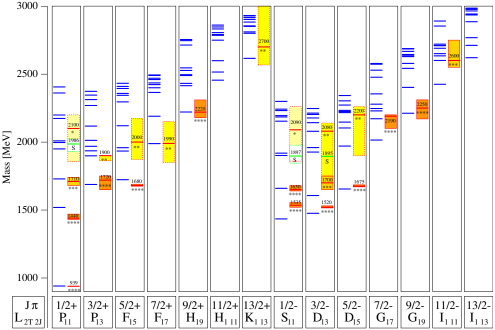
Double Polarisation Experiments in Meson Photoproduction and the Impact on the Nucleon Excitation Spectrum

Light Baryon Spectroscopy

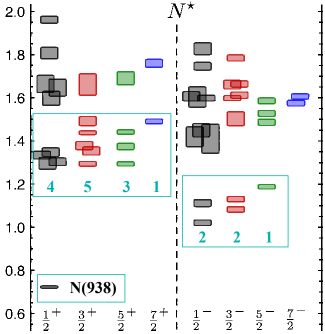
Aim: Better understanding of QCD and the structure of hadrons:

- What are the relevant degrees of freedom?
- What are the effective forces?

⇒ baryon spectroscopy



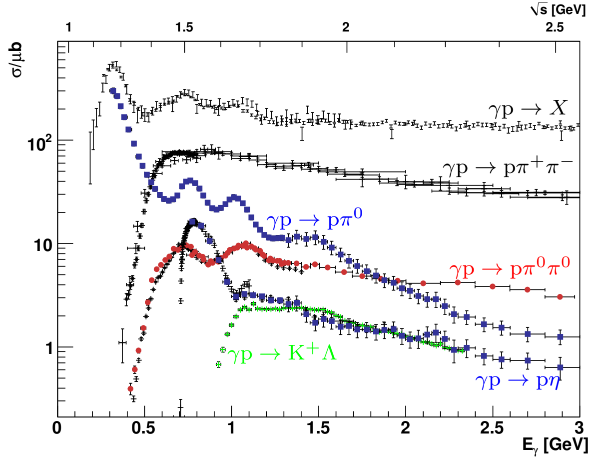
U. Loering, B. Metsch, H. Petry, Eur. Phys. J. A **10** (2001) 395



R.G. Edwards, Phys. Rev. D **84** (2011) 074508

Light Baryon Spectroscopy

- Until 2010: Almost all resonances from πN scattering
- Resonances with small πN coupling?
  - photoproduction
  - different final states



Light Baryon Spectroscopy

- Until 2010: Almost all resonances from $\pi\mathrm{N}$ scattering
- Resonances with small $\pi\mathrm{N}$ coupling?
  - photoproduction
  - different final states
- PDG 2012: photoproduction data included $\rightsquigarrow$ new baryons

	PDG 2010	BnGa PWA	PDG 2012
$\mathrm{N}(1860)5/2^+$		$\star$	$\star\star$
$\mathrm{N}(1875)3/2^-$		$\star\star\star$	$\star\star\star$
$\mathrm{N}(1880)1/2^+$		$\star\star$	$\star\star$
$\mathrm{N}(1895)1/2^-$		$\star\star$	$\star\star$
$\mathrm{N}(1900)3/2^+$	$\star\star$	$\star\star\star$	$\star\star\star$
$\mathrm{N}(2060)5/2^-$		$\star\star\star$	$\star\star$
$\mathrm{N}(2160)3/2^-$		$\star\star$	$\star\star$
$\Delta(1940)3/2^-$	$\star$	$\star$	$\star\star$

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

Polarization Observables

Single pseudoscalar meson photoproduction:

Photon		Target			Recoil			Target - Recoil								
		x	y	z	—	—	—	x	y	z	x	y	z	x	y	z
		—	—	—	x'	y'	z'	x'	x'	x'	y'	y'	y'	z'	z'	z'
unpolarized	σ_0		T			P		$T_{x'}$		$L_{x'}$				$T_{z'}$		$L_{z'}$
linear pol.	Σ	H		G	$O_{x'}$		$O_{z'}$									
circular pol.		F		E	$C_{x'}$		$C_{z'}$									

- 1 unpolarized observable: σ_0
- 3 single polarization observables: Σ, T, P
- 12 double polarization observables: 4 BT, 4 BR, 4 TR

Polarization Observables

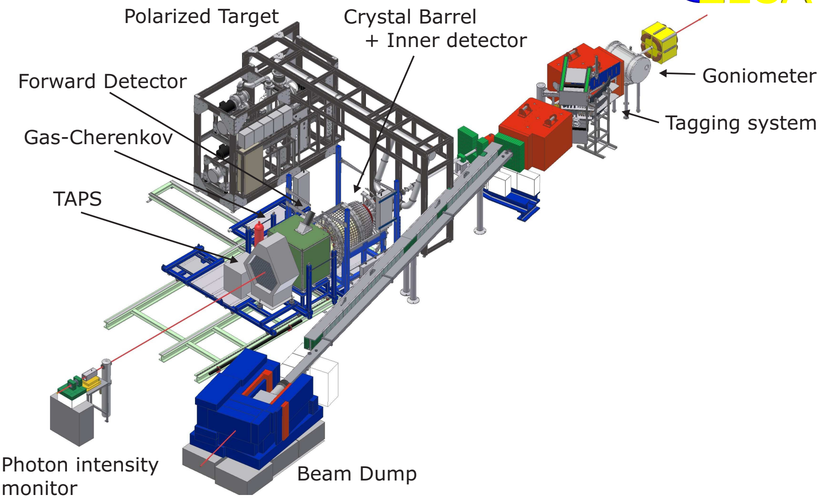
Single pseudoscalar meson photoproduction:

Photon		Target			Recoil			Target - Recoil								
		x	y	z	$-$	$-$	$-$	x	y	z	x	y	z	x	y	z
		$-$	$-$	$-$	x'	y'	z'	x'	x'	x'	y'	y'	y'	z'	z'	z'
unpolarized	σ_0		T			P		$T_{x'}$		$L_{x'}$		Σ		$T_{z'}$		$L_{z'}$
linear pol.	Σ	H	P	G	$O_{x'}$	T	$O_{z'}$	$L_{z'}$	$C_{z'}$	$T_{z'}$	E	σ_0	F	$L_{x'}$	$C_{x'}$	$T_{x'}$
circular pol.		F		E	$C_{x'}$		$C_{z'}$		$O_{z'}$		G		H		$O_{x'}$	

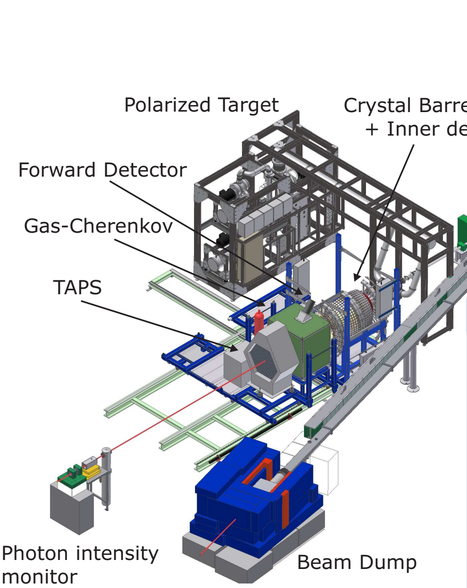
- 1 unpolarized observable: σ_0
- 3 single polarization observables: Σ, T, P
- 12 double polarization observables: 4 BT, 4 BR, 4 TR
- redundant observables:
  - single pol. observables $\longleftrightarrow$ double pol. experiment
  - double pol. observables $\longleftrightarrow$ triple pol. experiment

Complete experiment: at least 8 (carefully chosen) observables

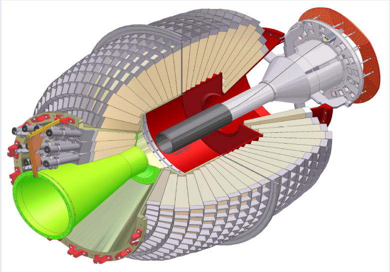
The Crystal Barrel/TAPS experiment



The Crystal Barrel/TAPS experiment



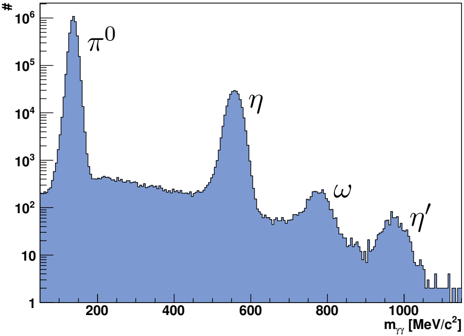
Crystal Barrel

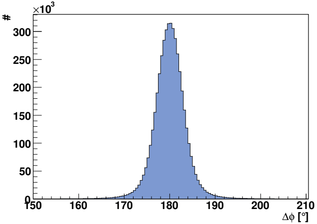


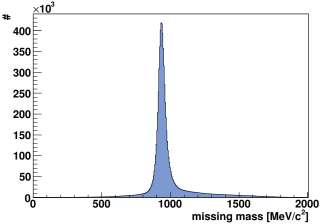
Event Reconstruction

$\gamma p \to p\pi^0 \to p\gamma\gamma$, $\gamma p \to p\eta \to p\gamma\gamma$

- photons detected (E, θ, ϕ)
- proton direction measured (θ, ϕ)

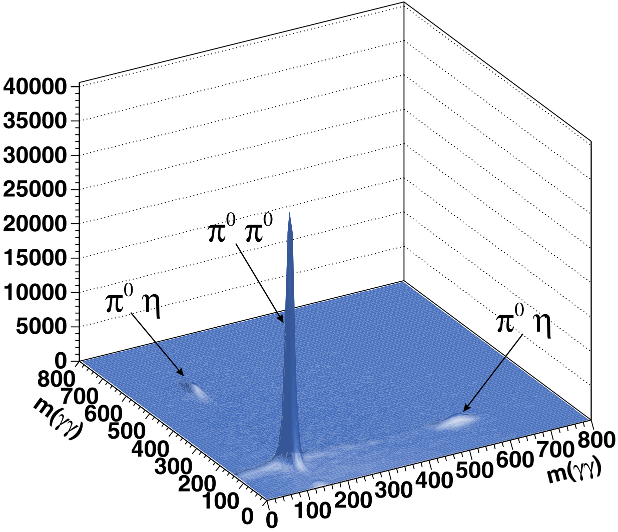






Event Reconstruction

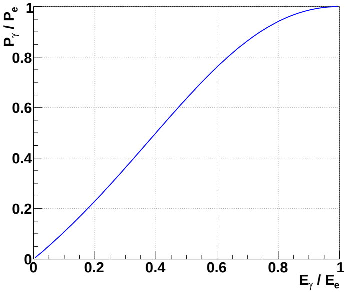
Multi-meson final states, e.g. $\pi^0\pi^0$ or $\pi^0\eta$:



Polarized Photon Beams

Circularly polarized:

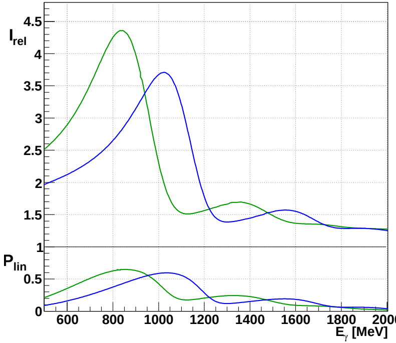
- Bremsstrahlung of longitudinally pol. electrons
- Helicity transfer:



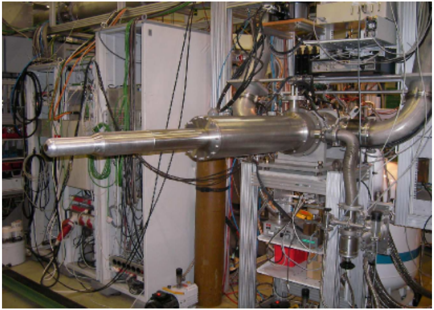
- Measurement of electron polarization using Møller polarimeter

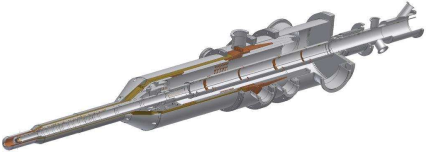
Linearly polarized:

- Coherent Bremsstrahlung using diamond crystal
- Crystal orientation defines plane of linear polarization



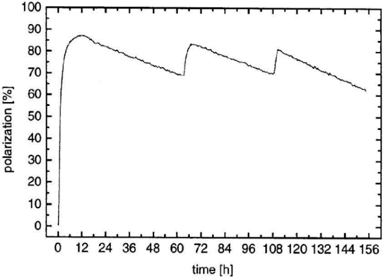
Polarized Target



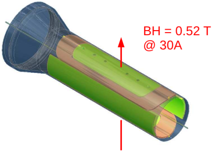


H. Dutz, S. Goertz, W. Meyer

average target pol.: ≈ 75 %



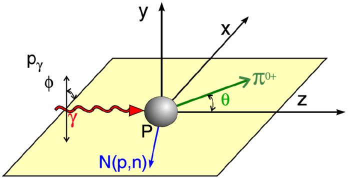
transverse holding coil:



Single-Meson Photoproduction

Polarization Observables

With polarized beam and polarized target, no recoil polarimetry:



Photon Pol.		Target Pol. Axis		
		x	y	z
unpolarized	σ_0		T	
linear	$-\Sigma$	H	$-P$	$-G$
circular		F		$-E$

$$\frac{d\sigma}{d\Omega}(\theta,\phi) = \frac{d\sigma_0}{d\Omega}(\theta) \cdot \Big[1 - P_\gamma^{\text{lin}}\,\Sigma(\theta)\cos(2\phi)$$
$$+P_x \cdot \left(-P_\gamma^{\text{lin}}\,H(\theta)\,\sin(2\phi) + P_\gamma^{\text{circ}}\,F(\theta)\right)$$
$$+P_y \cdot \left(+P_\gamma^{\text{lin}}\,P(\theta)\,\cos(2\phi) - T(\theta)\right)$$
$$-P_z \cdot \left(-P_\gamma^{\text{lin}}\,G(\theta)\,\sin(2\phi) + P_\gamma^{\text{circ}}\,E(\theta)\right)\Big]$$

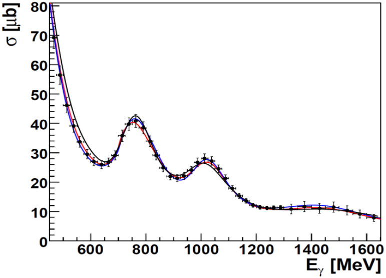
I. S. Barker, A. Donnachie, J. K. Storrow, Nucl. Phys. B95, 347 (1975)

Single-Meson Photoproduction

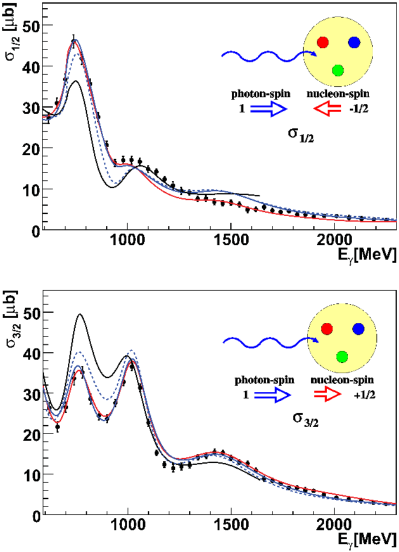
$\gamma p \rightarrow p\pi^0$:

- π^0: lightest meson
- well measured differential cross section
- precise data on beam asymmetry Σ available
- contains πN coupling measured using elastic scattering

$\rightsquigarrow$ should be well understood



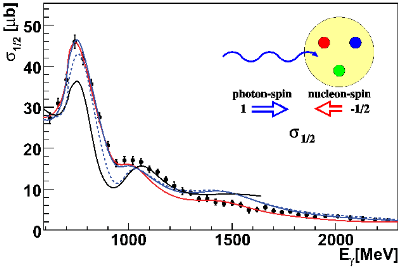
$\gamma p \to p\pi^0$: Helicity Asymmetry E

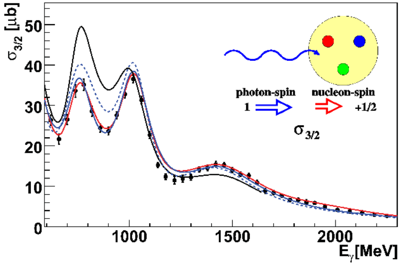


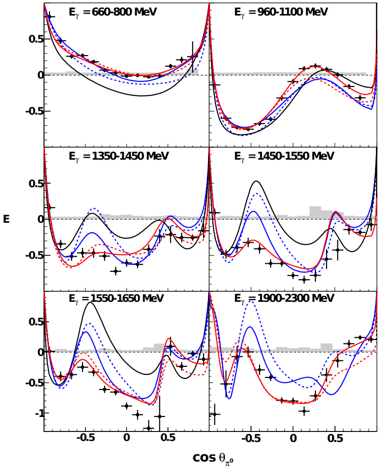
SAID (dashed: SN11, solid: CM12) MAID BnGa (dashed: 2011-02, solid: refit)

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

$\gamma p \rightarrow p\pi^0$: Helicity Asymmetry E







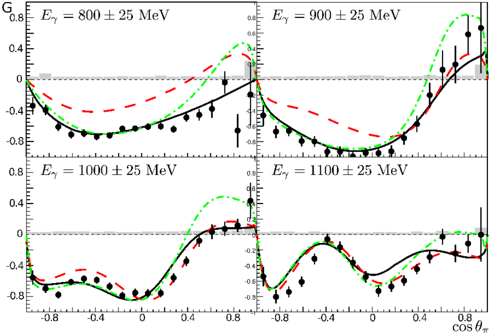
SAID (dashed: SN11, solid: CM12) MAID BnGa (dashed: 2011-02, solid: refit)

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

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

Linearly pol. photon beam, longitudinally pol. target

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}(\phi) = \left(\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}\right)_0 [1 - p_\gamma \Sigma \cos(2\phi) + p_z p_\gamma G \sin(2\phi)]$$



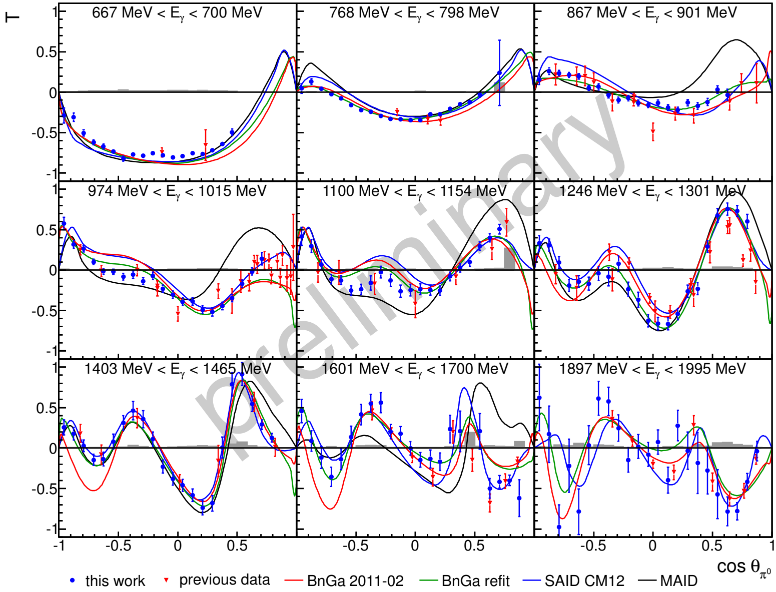
BnGa 2011-02 SAID SN11 SAID CM12

Differences between SAID and BnGa mainly due to E_{0+} and E_{2-} multipoles:

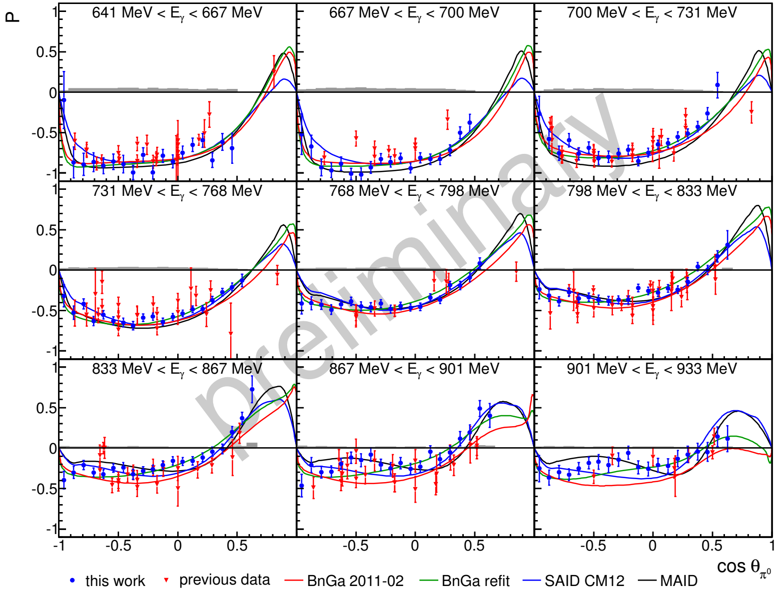
- $\mathrm{N}(1535)\frac{1}{2}^-$
  $\mathrm{N}(1650)\frac{1}{2}^-$
  $\Delta(1620)\frac{1}{2}^-$
- $\mathrm{N}(1520)\frac{3}{2}^-$
  $\Delta(1700)\frac{3}{2}^-$

A. Thiel *et al.*, Phys. Rev. Lett. **109**, 102001 (2012)

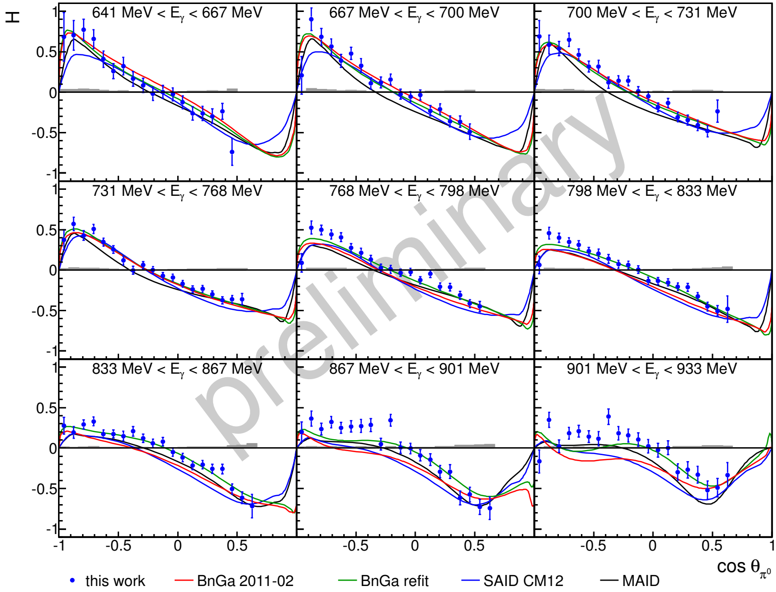
$\gamma p \rightarrow p\pi^0$: Target Asymmetry T



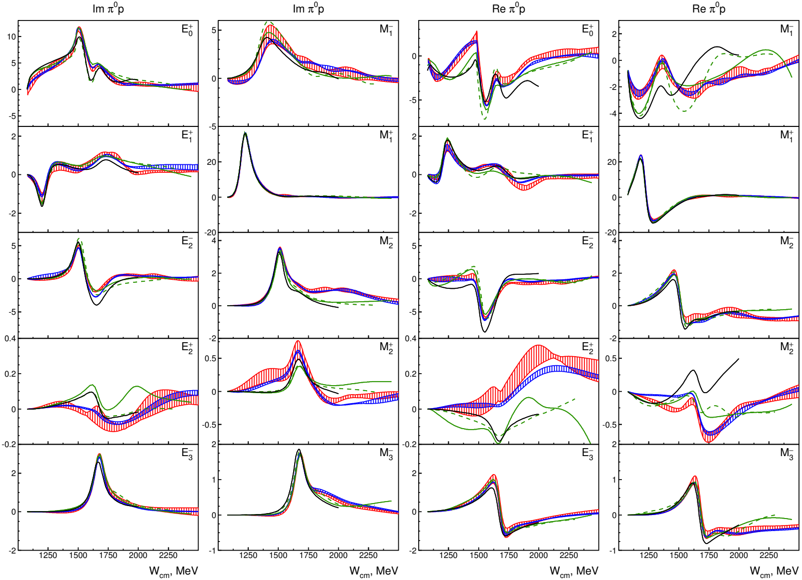
$\gamma p \to p\pi^0$: Recoil Polarization P



$\gamma p \rightarrow p\pi^0$: Double Polarization Observable H



Impact of the New Double Polarization Data

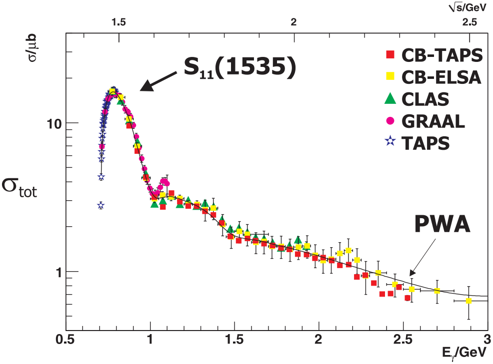


BnGa 2013 (prel.) BnGa 2011 MAID SAID CM12 (solid) and SN11 (dashed)

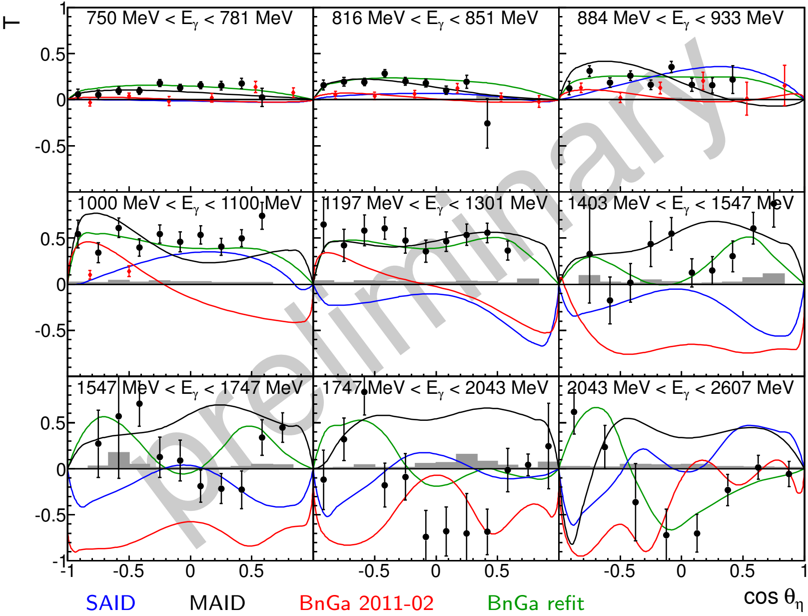
Single-Meson Photoproduction

$\gamma p \rightarrow p\eta$:

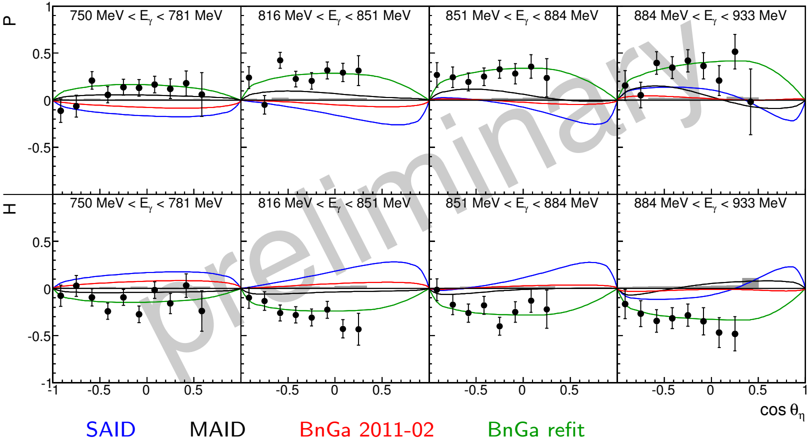
- η: $I = 0$
- only N^* resonances contribute
- ideal to investigate resonances with very small πN, but large ηN coupling.



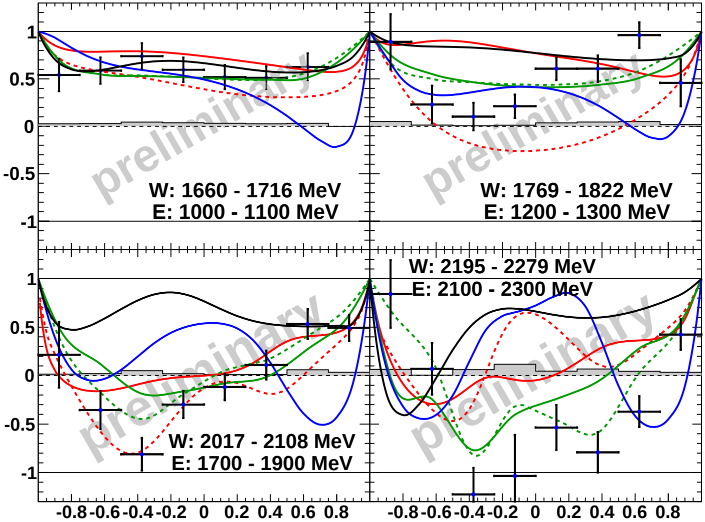
$\gamma p \rightarrow p\pi^0$: Target Asymmetry T



$\gamma p \to p\pi^0$: Recoil Polarization P and Observable H



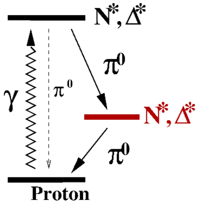
$\gamma p \to p\pi^0$: Helicity Asymmetry E



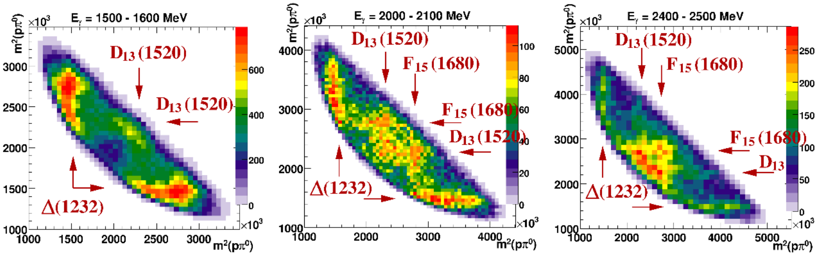
SAID MAID BnGa 2011-02 BnGa refit

J. Müller, CBELSA/TAPS Collaboration

Multi-Meson Photoproduction

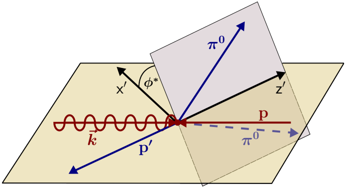


- Resonances can decay into $\Delta^{*}\pi^{0}$, $\mathrm{N}^{*}\pi^{0}$, $\mathrm{N}\sigma$
- $\gamma\mathrm{p} \to \mathrm{p}\pi^{0}\pi^{0}$ provides access to baryon cascade decays
- Rich environment to find new resonances



V. Sokhoyan, CBELSA/TAPS Collaboration

3-Body Kinematics



photon pol.		target pol. axis		
		x	y	z
unpol.	σ	P_x	P_y	P_z
linear $\sin(2\phi)$	I^s	P_x^s	P_y^s	P_z^s
linear $\cos(2\phi)$	I^c	P_x^c	P_y^c	P_z^c
circular	$I^\odot$	$P_x^\odot$	$P_y^\odot$	$P_z^\odot$

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega} \cdot \Big\{ (1 + \Lambda_x P_x + \Lambda_y P_y) + \delta_\ell \cdot \Big[\sin(2\phi) \cdot \big(I^s + \Lambda_x P_x^s + \Lambda_y P_y^s\big) + \cos(2\phi) \cdot \big(I^c + \Lambda_x P_x^c + \Lambda_y P_y^c\big) \Big] \Big\}$$

W. Roberts, T. Oed, Phys. Rev. C 71 (2005)

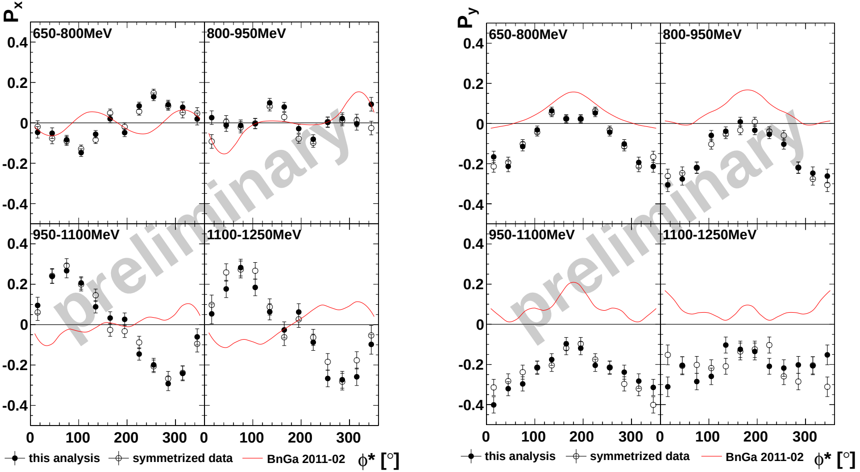
symmetry properties

$$I^s(2\pi - \phi^*) = -I^s(\phi^*) \qquad P_x(2\pi - \phi^*) = -P_x(\phi^*)$$
$$I^c(2\pi - \phi^*) = +I^c(\phi^*) \qquad P_y(2\pi - \phi^*) = +P_y(\phi^*)$$

in case of identical particles in the decay plane:

$$O(\phi^*) = O(\phi^* + \pi)$$

$\gamma p \to (p\pi^0)\pi^0$: Target Asymmetries P_x and P_y



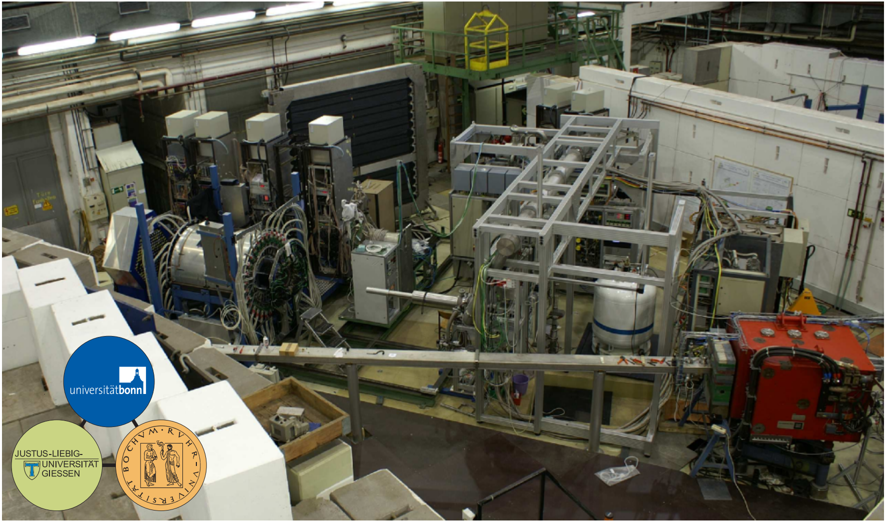
- predictions do not match data
- many more polarization observables under analysis

T. Seifen, to be published

Summary

- Double polarization data has been taken with the Crystal Barrel/TAPS experiment at ELSA:
  - longitudinally or transversely polarized target
  - linearly or circularly polarized photon beam
- π^0 photoproduction: precision measurements
  $\rightsquigarrow$ large impact on PWA:
  - significantly smaller errors on multipoles
  - better determination of resonance parameters
- η photoproduction: first data for many observables
  $\rightsquigarrow$ important constraints for the PWA
- Multi-meson photoproduction, e.g. $\pi^0\pi^0$:
  $\rightsquigarrow$ just the tip of the iceberg
- Detector upgrade in progress
  Access to more final states (including off the neutron)

Thank you for your attention!



Dilution Factor

- not (easily) possible to polarize protons in $\mathrm{H_2}$ molecules
- target material: butanol $\rightsquigarrow$ unpolarized C and O
  - $\vec{\gamma}\vec{\mathrm{p}} \ \to \mathrm{p}\gamma\gamma$
  - $\vec{\gamma}\mathrm{p_C} \to \mathrm{p}\gamma\gamma$
- measured polarization (free protons) diluted by contribution from (unpolarized) bound nucleons.
- in principle: 10 H-Atoms and 32 protons in C and O nuclei $\Rightarrow$ dilution factor $d = \frac{10}{10+32} = 0.24$
- reconstruction efficiency different for both reactions
  - fermi motion
  - final state interaction

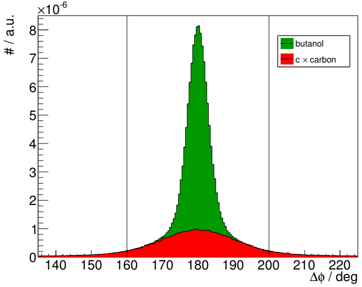
$\rightsquigarrow$ need effective dilution factor

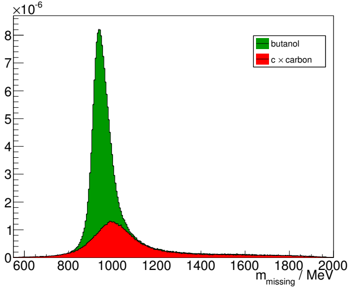
Effective Dilution Factor

$$d = \frac{N_{\text{free}}}{N_{\text{butanol}}} = \frac{N_{\text{butanol}} - N_{\text{bound}}}{N_{\text{butanol}}}$$

Carbon background measurement

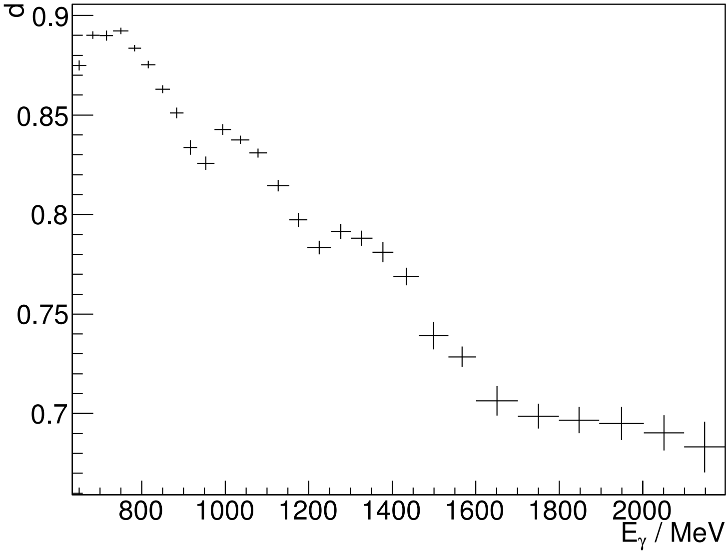
$$N_{\text{bound}} = c \cdot N_{\text{carbon}} \Longrightarrow d = \frac{N_{\text{butanol}} - c \cdot N_{\text{carbon}}}{N_{\text{butanol}}}$$





Dilution Factor

Effective dilution factor for $\gamma p \rightarrow p\pi^0$:



Dilution Factor

effective dilution factor for $\gamma p \to p\eta$: