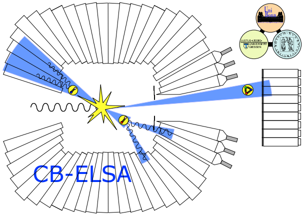
Double Polarization Experiments in Meson Photoproduction

Jan Hartmann

for the CBELSA/TAPS collaboration

HISKP, University of Bonn

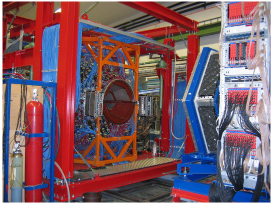


June 04, 2016

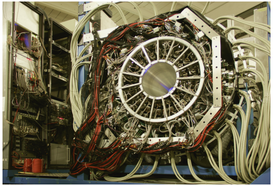
Double Polarization Experiments in Meson Photoproduction

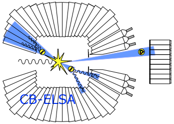
1. Introduction
2. Single-meson photoproduction
   - $\gamma p \to \pi N$
   - $\gamma p \to \eta p$
3. Multi-meson photoproduction
4. Summary and Outlook

Jefferson Lab



MAMI





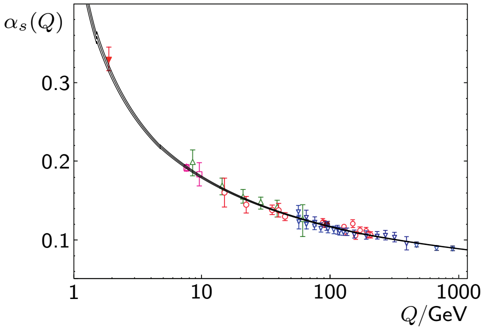
ELSA

Strong Interaction

QCD well established

large Q → "asymptotic freedom"
QCD processes calculable (perturbation theory)

small Q → "confinement"
perturbation theory not possible



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

- What is the nature of confinement?
- How does QCD give rise to hadrons?
- What are the relevant degrees of freedom?
- What are the effective forces?

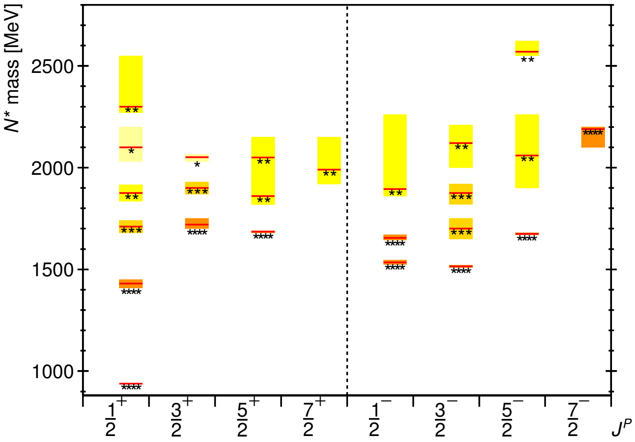
⟶ Baryon spectroscopy

Baryon Spectroscopy

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

- How does QCD give rise to hadrons?
- Which hadrons – bound states of QCD – do exist?

⇒ Baryon spectroscopy



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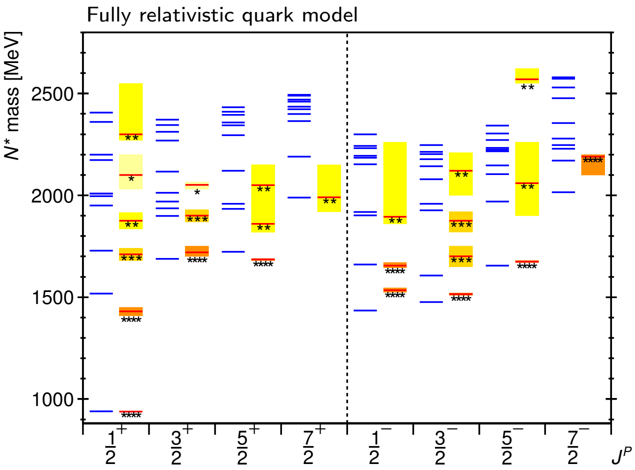

U. Löring, B. Metsch, H. Petry, Eur. Phys. J. A10 (2001) 395

Quark models:

- Many more resonances expected than observed
- Certain configurations completely missing:
  - Wrong degrees of freedom in quark model?
  - Experimentally not found yet?

Baryon Spectroscopy

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

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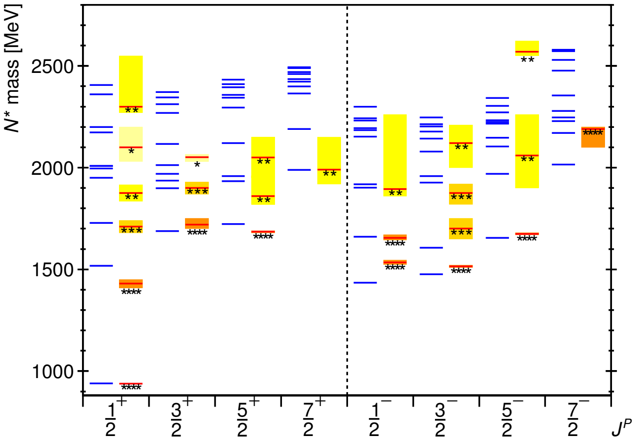
⇒ Baryon spectroscopy

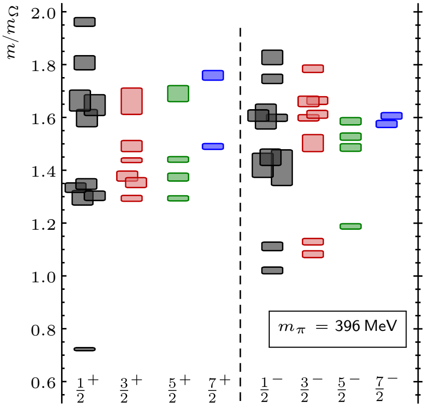
Fully relativistic quark model



U. Löring, B. Metsch, H. Petry, Eur. Phys. J. A10 (2001) 395

Lattice-QCD:

Same pattern as non-rel. QM



R.G. Edwards, Phys. Rev. D84 (2011) 074508

Baryon Spectroscopy in Meson Photoproduction

- Until 2010: Almost all resonances from πN scattering
- 2000–2010: no new baryon resonance considered by the PDG
- Resonances with small πN coupling?
  - Photoproduction
  - Different final states

Baryon Spectroscopy in Meson Photoproduction

- Until 2010: Almost all resonances from πN scattering
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- Resonances with small πN coupling?
  - Photoproduction
  - Different final states
- PDG 2012: photoproduction data included $\rightsquigarrow$ new baryons

  Multi-channel PWA based on data from:
  JLab, ELSA, MAMI, SPring-8, GRAAL, ...

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

A.V. Anisovich *et al.*, Eur. Phys. J. A48 (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

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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

W.-T. Chiang, F. Tabakin, Phys. Rev. C55 (1997) 2054

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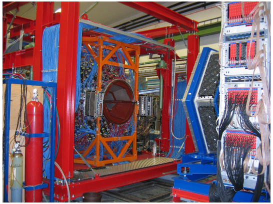

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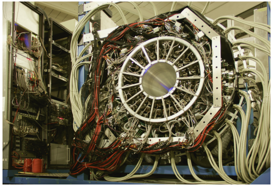
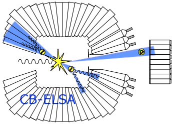




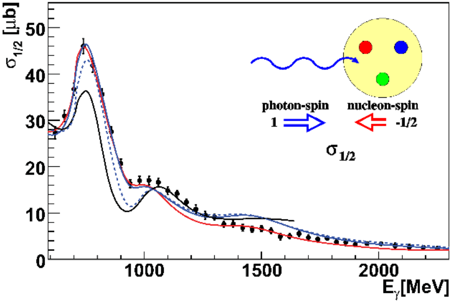
ELSA

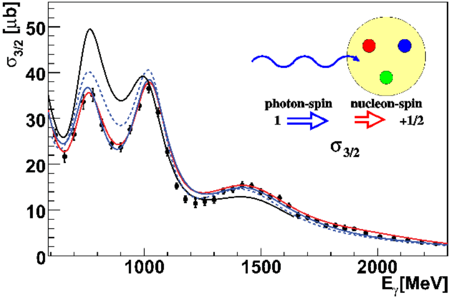
Single-Meson Photoproduction

$\gamma p \to \pi N$:

- well measured differential cross section
- precise data on beam asymmetry Σ available
- contains πN coupling measured using elastic scattering
  $\rightsquigarrow$ only need to determine photocouplings
  - $\left.\begin{array}{lcl} \gamma p & \to & \pi^0 p \\ \gamma p & \to & \pi^+ n \end{array}\right\}$ separate N^* and Δ^*
  - additional data with neutron target needed to separate isoscalar and isovector coupling to N^*
    $\to$ Talk by Natalie Walford (Friday 15:50)

$\gamma p \to \pi^0 p$: Helicity Asymmetry $E = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$





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

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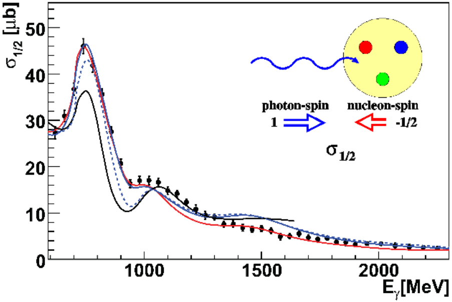
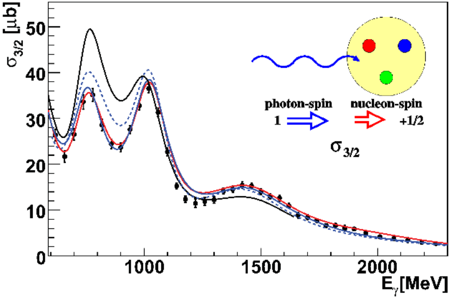
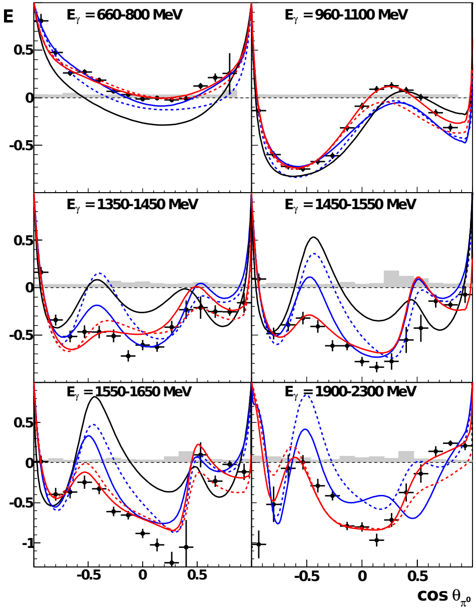


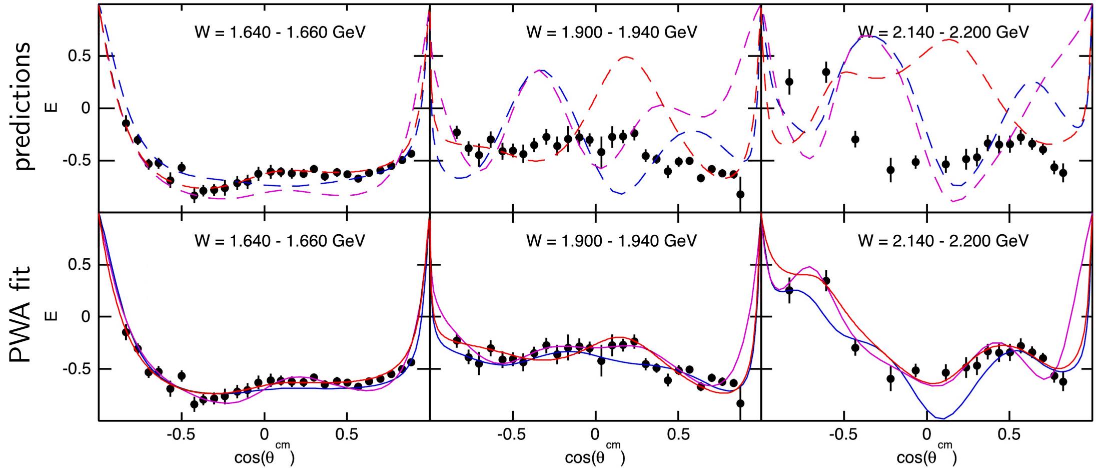




M. Gottschall *et al.*, Phys. Rev. Lett. 112 (2014) 012003

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

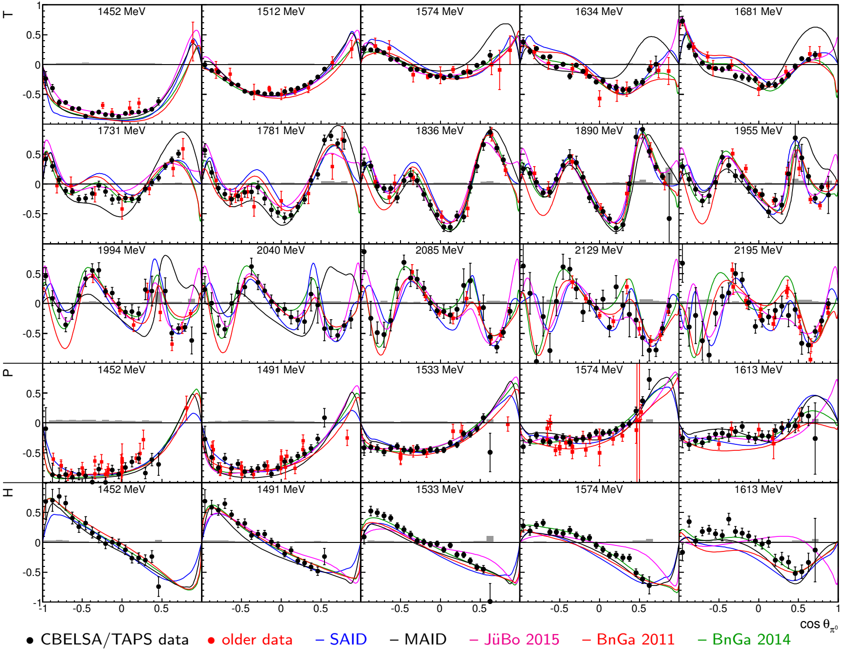
$\gamma p \rightarrow \pi^+ n$: Helicity Asymmetry E



— SAID ST14 — JüBo 2014 — BnGa 2014

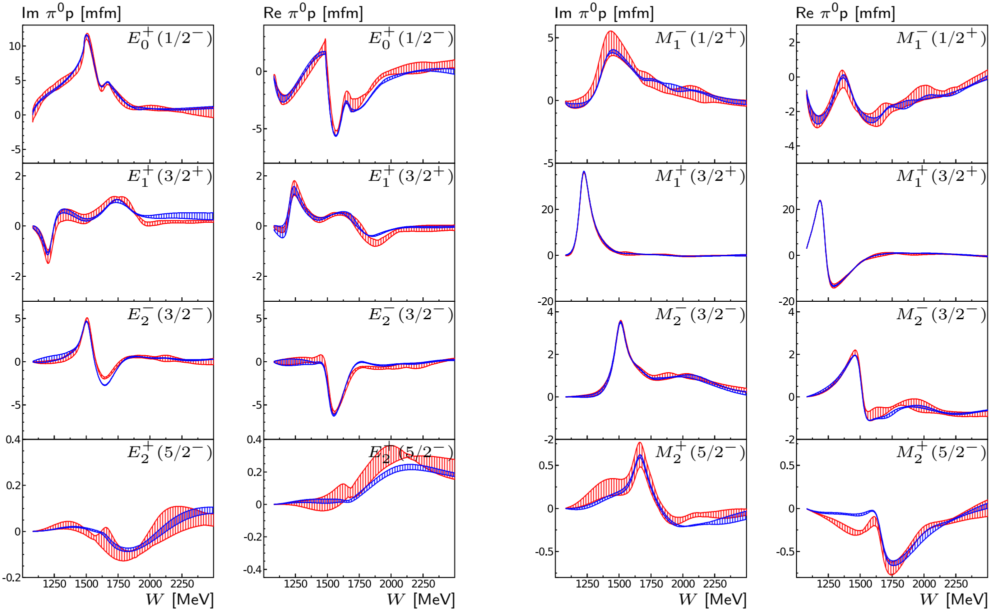
S. Strauch *et al.* (CLAS), Phys. Lett. B750 (2015) 53

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



J. Hartmann, H. Dutz, A. Anisovich *et al.*, Phys. Rev. Lett. 113 (2014) 062001

Impact of the New Double Polarization Data



– BnGa 2014 – BnGa 2011

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

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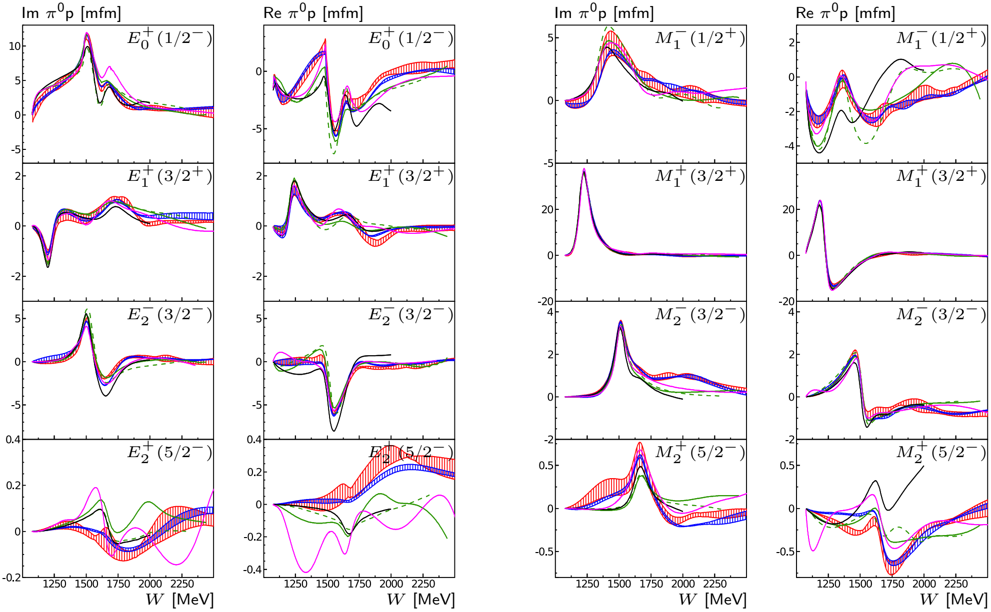

– BnGa 2014 – BnGa 2011 – MAID – SAID CM12 – JüBo 2015

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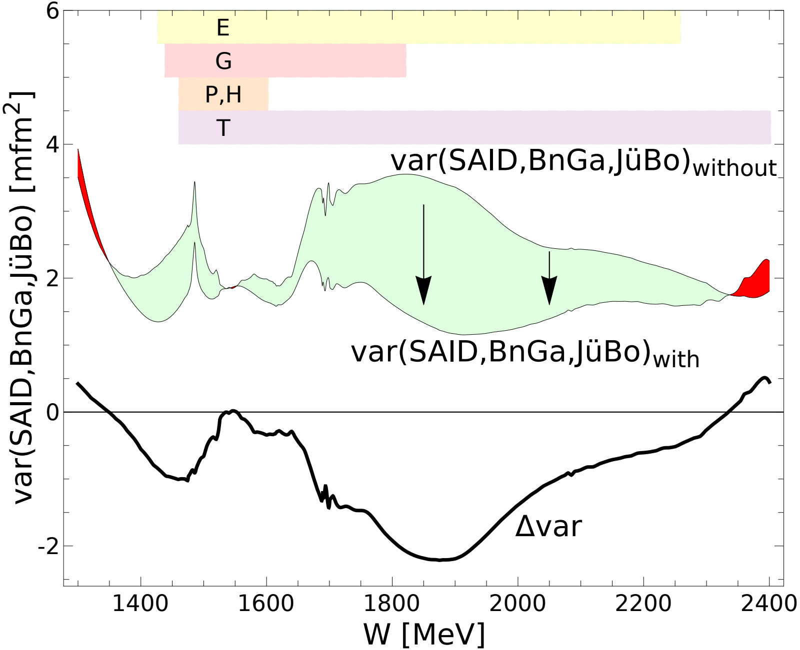


Significantly improved agreement due to double polarization data

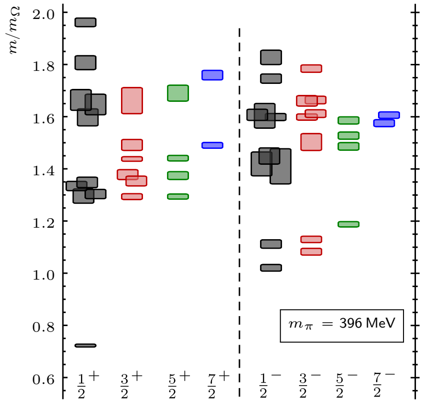
⇝ Different PWAs converge towards single solution

[arXiv:1604.05704]

Spectrum of Baryon Resonances – Parity Doublets

Non-rel. quark model & Lattice calculations:

Alternating pattern of positive and negative parity states

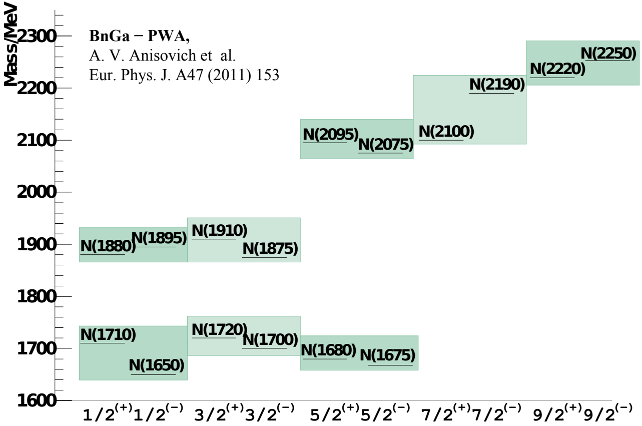


R.G. Edwards, Phys. Rev. D84 (2011) 074508

Observation: Parity doublets occur!

Contradicts QM and lattice QCD

$\rightsquigarrow$ QCD not understood!



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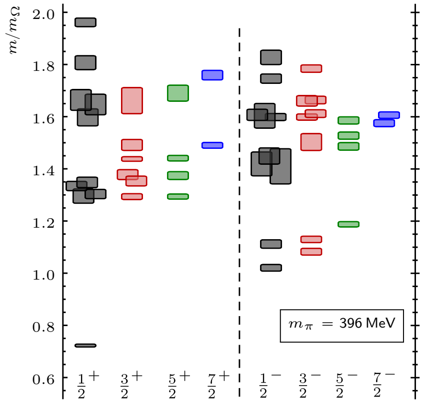

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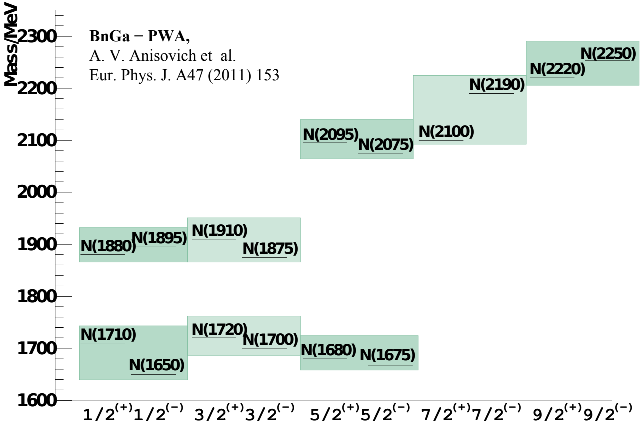

Do parity doublets exist for all high-mass states?

Search for Parity Doublets

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$\Delta(1910)\,\frac{1}{2}^{+} \leftrightarrow \Delta(1900)\,\frac{1}{2}^{-}$

$\Delta(1920)\,\frac{3}{2}^{+} \leftrightarrow \Delta(1940)\,\frac{3}{2}^{-}$

$\Delta(1905)\,\frac{5}{2}^{+} \leftrightarrow \Delta(1930)\,\frac{5}{2}^{-}$

$\Delta(1950)\,\frac{7}{2}^{+} \leftrightarrow \Delta(????)\,\frac{7}{2}^{-}$

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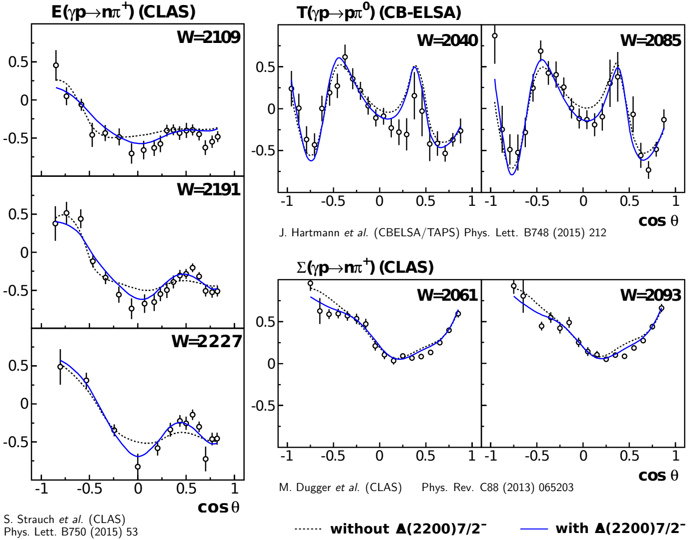
$\Delta(1950)\,\frac{7}{2}^+ \leftrightarrow \Delta(????)\,\frac{7}{2}^-$



S. Strauch *et al.* (CLAS) Phys. Lett. B750 (2015) 53

J. Hartmann *et al.* (CBELSA/TAPS) Phys. Lett. B748 (2015) 212

M. Dugger *et al.* (CLAS) Phys. Rev. C88 (2013) 065203

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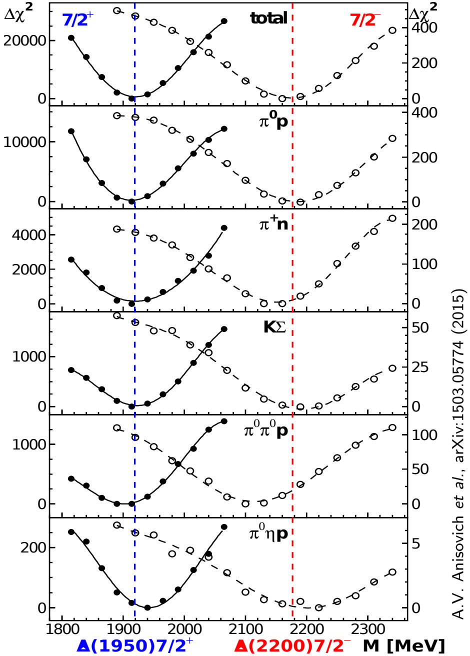
$\Delta(1905)\,\frac{5}{2}^{+} \leftrightarrow \Delta(1930)\,\frac{5}{2}^{-}$

$\Delta(1950)\,\frac{7}{2}^{+} \leftrightarrow \Delta(2200)\,\frac{7}{2}^{-}$



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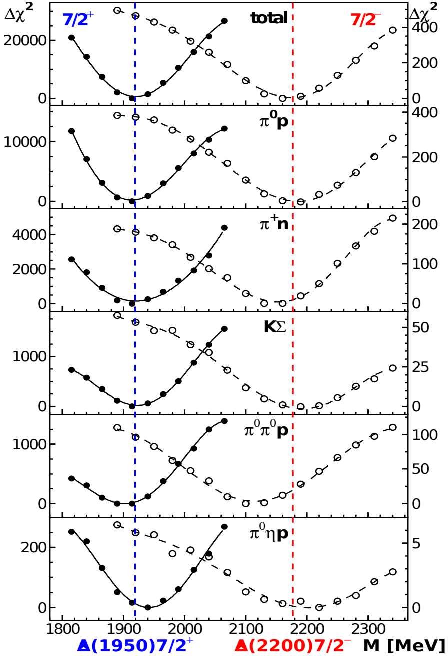
$\Delta(1905)\ \frac{5}{2}^{+} \leftrightarrow \Delta(1930)\ \frac{5}{2}^{-}$

$\Delta(1950)\ \frac{7}{2}^{+} \leftrightarrow \Delta(2200)\ \frac{7}{2}^{-}$

No mass-degenerate parity partner found for $\Delta(1950)\ \frac{7}{2}^{+}$

Contradicts models that predict parity partners for all states

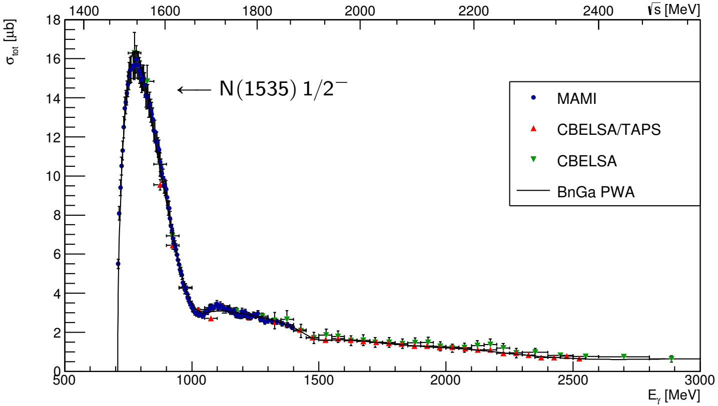


A.V. Anisovich *et al.*, arXiv:1503.05774 (2015)

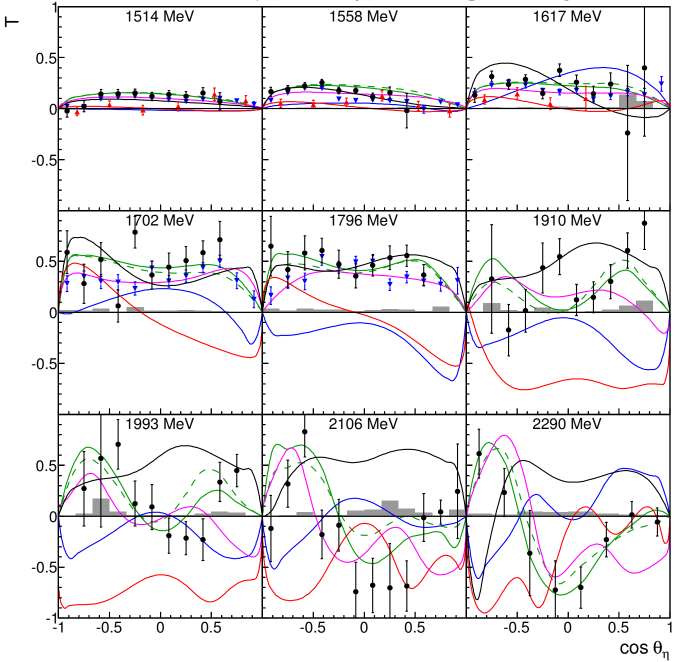
Single-Meson Photoproduction

$\gamma p \to \eta p$:

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



$\gamma p \to \eta p$: Target Asymmetry T

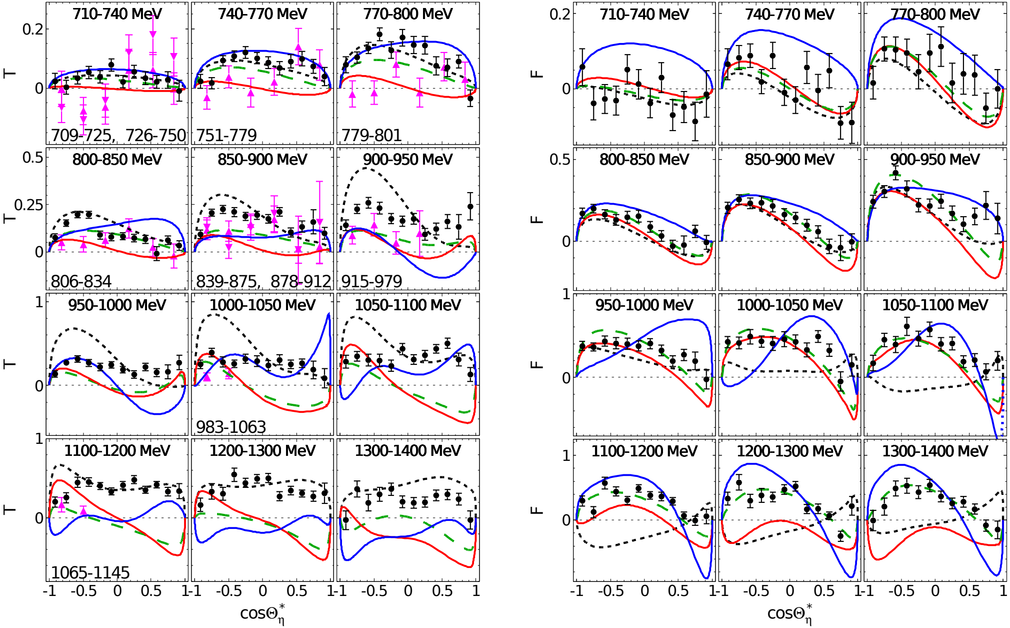


(only every second bin shown)

- old ELSA data
  PRL 81 (1998) 534
- MAMI A2
  PRL 113 (2014) 102001
- CBELSA/TAPS
  preliminary

– SAID
– MAID
– JüBo 2015
– BnGa 2011
– BnGa 2014

$\gamma p \to \eta p$: Asymmetries T and F

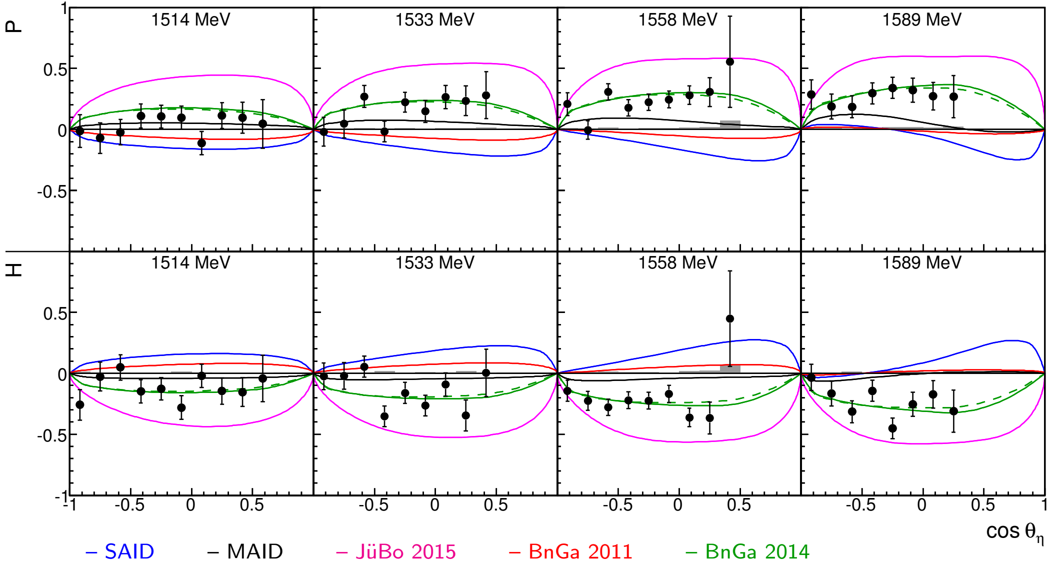


–SAID –MAID –BnGa –Giessen

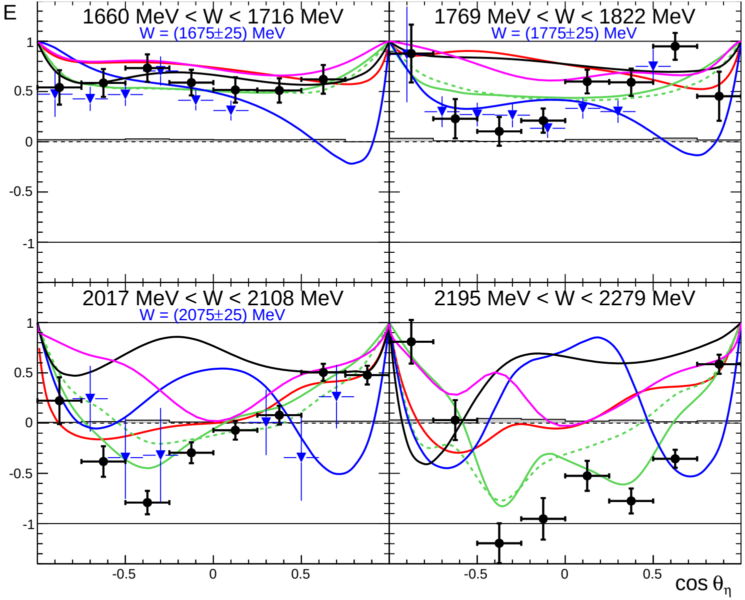
C.S. Akondi *et al.*, Phys. Rev. Lett. 113 (2014) 102001

$\gamma p \to \eta p$: Recoil Polarization P and Observable H

Preliminary results:



$\gamma p \rightarrow \eta p$: Helicity Asymmetry E



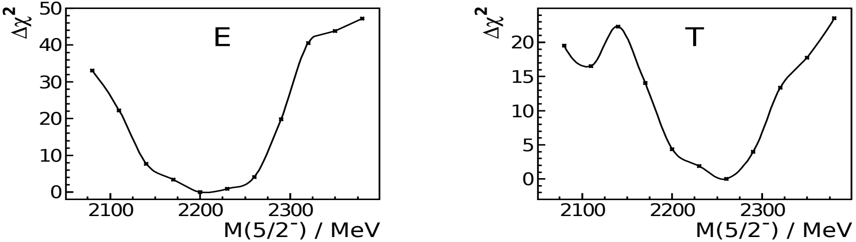
only a few energy bins shown!

- CBELSA preliminary
  J. Müller *et al.*
- CLAS
  I. Senderovich *et al.*
  PLB 755 (2016) 64
- SAID
- MAID
- JüBo 2015
- BnGa 2011
- BnGa 2014

Impact of the New Double Polarization Data

BnGa 2014 refit to the new $\gamma p \rightarrow \eta p$ data: preliminary results

- Indications for new resonance around 2.2 GeV



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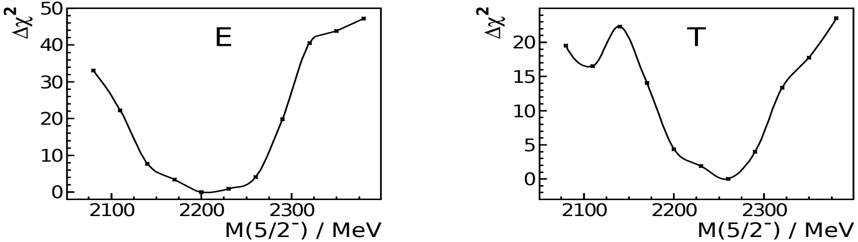

- Precise determination of $N^* \to N\eta$ branching ratios

Res.	$N(1535)\frac{1}{2}^-$	$N(1650)\frac{1}{2}^-$	$N(1710)\frac{1}{2}^+$	$N(1720)\frac{3}{2}^+$	$N(1900)\frac{3}{2}^+$
PDG	0.42 ± 0.10	0.05 to 0.15	0.10 to 0.30	0.021 ± 0.014	≈ 0.12
BnGa					

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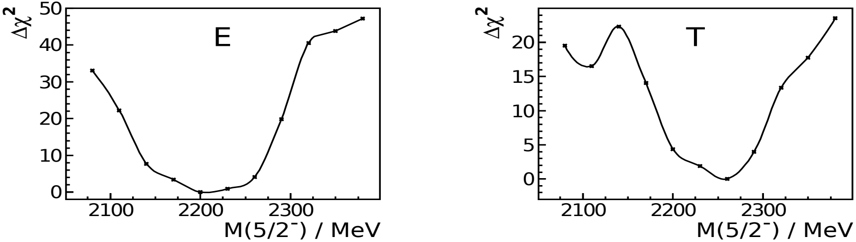

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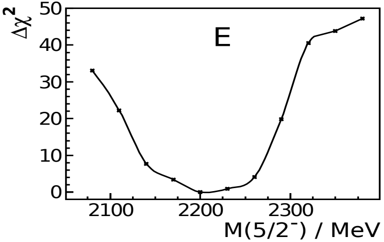
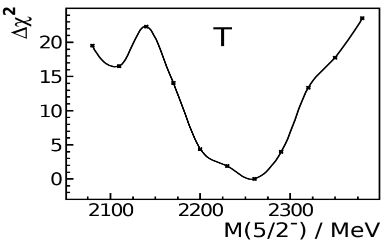




- Precise determination of $N^* \rightarrow N\eta$ branching ratios

Res.	$N(1535)\frac{1}{2}^-$	$N(1650)\frac{1}{2}^-$	$N(1710)\frac{1}{2}^+$	$N(1720)\frac{3}{2}^+$	$N(1900)\frac{3}{2}^+$
PDG	0.42 ± 0.10	0.05 to 0.15	0.10 to 0.30	0.021 ± 0.014	≈ 0.12
BnGa	0.42 ± 0.04	0.32 ± 0.04	0.27 ± 0.09	0.03 ± 0.02	0.03 ± 0.01

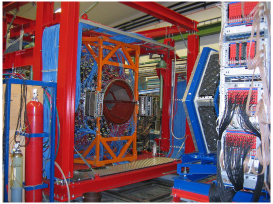
Reduced difference between $N(1535)\frac{1}{2}^-$ and $N(1650)\frac{1}{2}^-$

- Systematic studies in progress

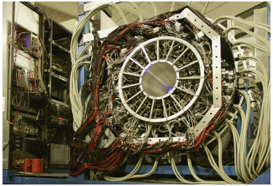
Double Polarization Experiments in Meson Photoproduction

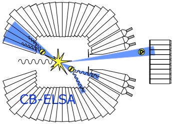
1. Introduction
2. Single-meson photoproduction
   - $\gamma p \to \pi N$
   - $\gamma p \to \eta p$
3. Multi-meson photoproduction
4. Summary and Outlook

Jefferson Lab



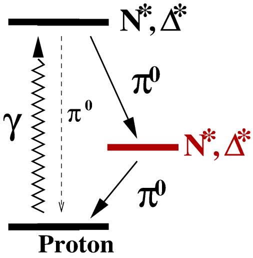
MAMI



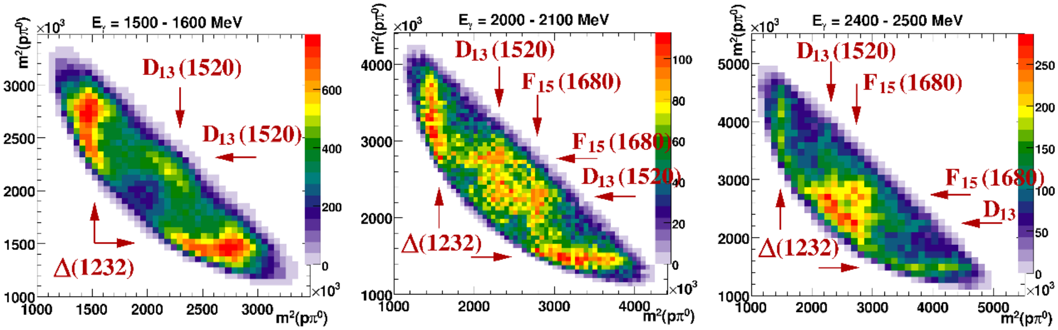


ELSA

Multi-Meson Photoproduction

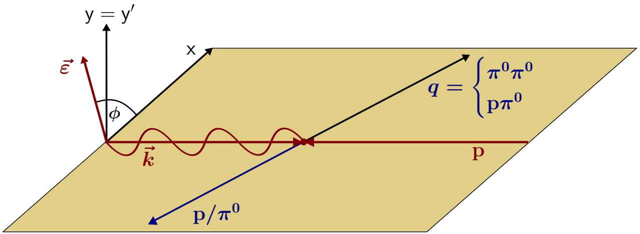


- Resonances can decay into $\Delta\pi^0$, $N^*\pi^0$, $N\sigma$
- $\gamma p \to p\pi^0\pi^0$ provides access to baryon cascade decays
- Rich environment to find new resonances



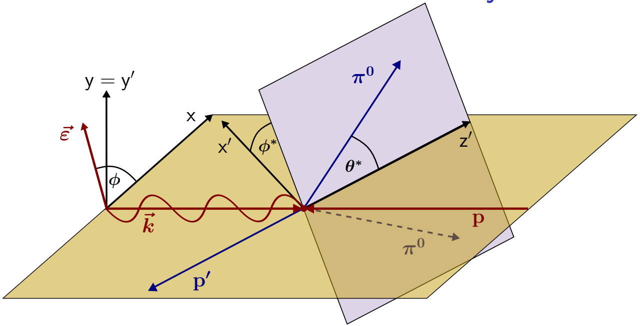
V. Sokhoyan *et al.*, Eur. Phys. J. A51 (2015) 95

3-Body Kinematics



photon pol.		target pol. axis x	y	z
unpolarised	σ		T	
linear $\sin(2\phi)$		H		G
linear $\cos(2\phi)$	Σ		P	
circular		F		E

3-Body Kinematics



5-dim. phase space:

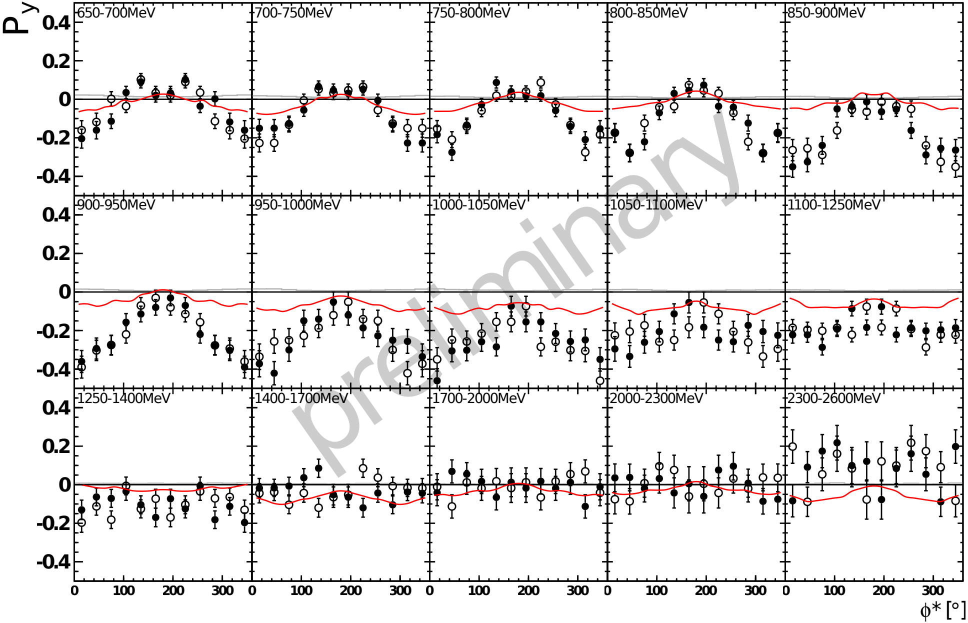
- E_γ
- $\cos\theta_q$
- m_q
- ϕ^*
- θ^*

photon pol.		target pol. axis		
		x	y	z
unpolarized	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	$I^\odot$	$P_x^\odot$	$P_y^\odot$	$P_z^\odot$

$$\begin{aligned}\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega} \cdot \Big\{ & 1 + \vec{\Lambda} \cdot \vec{P} \\ & + \delta_\odot \cdot \left(I^\odot + \vec{\Lambda} \cdot \vec{P}^\odot \right) \\ & + \delta_\ell \cdot \sin(2\phi) \cdot \left(I^s + \vec{\Lambda} \cdot \vec{P}^s \right) \\ & + \delta_\ell \cdot \cos(2\phi) \cdot \left(I^c + \vec{\Lambda} \cdot \vec{P}^c \right) \Big\}\end{aligned}$$

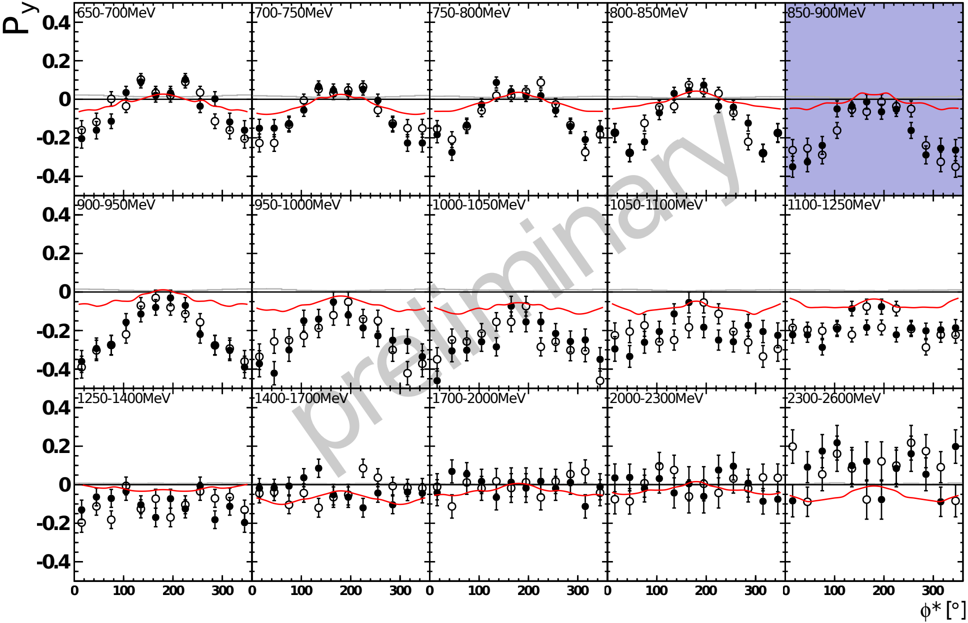
W. Roberts, T. Oed, Phys. Rev. C 71 (2005)

$\gamma p \to p\pi^0\pi^0$: Target Asymmetry P_y



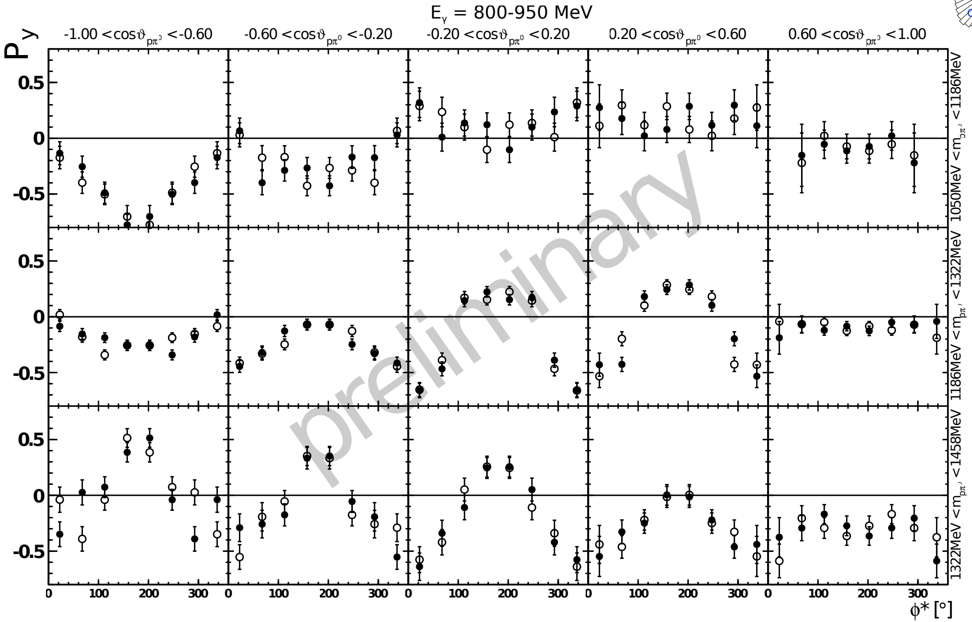
• this analysis ○ symmetrized data — BnGa 2014 T. Seifen *et al.*, to be published

$\gamma p \to p\pi^0\pi^0$: Target Asymmetry P_y



• this analysis ○ symmetrized data — BnGa 2014 T. Seifen *et al.*, to be published

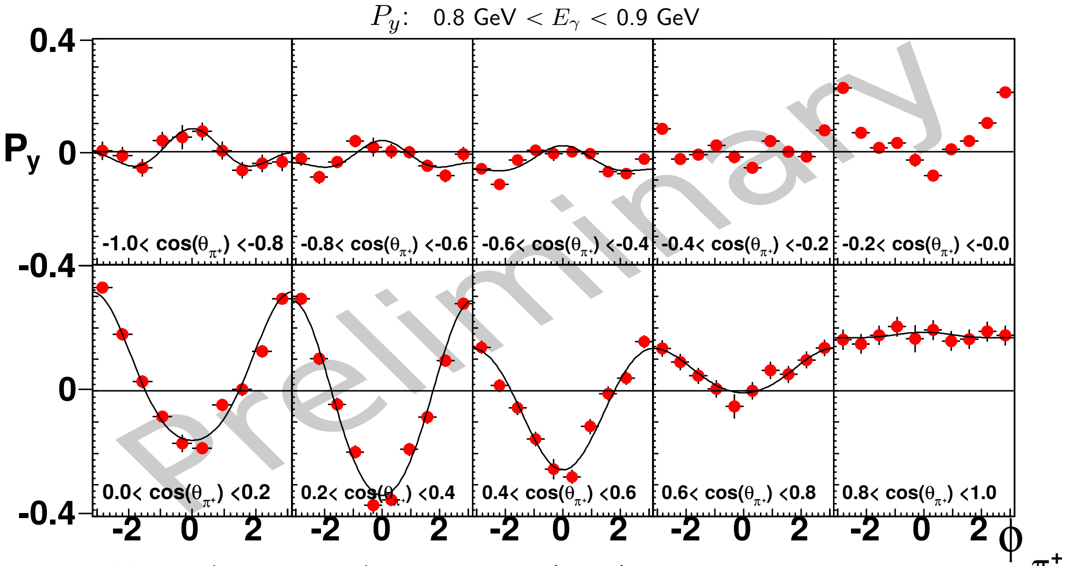
$\gamma p \rightarrow p\pi^0\pi^0$: Target Asymmetry P_y (4D)



• this analysis ○ symmetrized data

T. Seifen *et al.*, to be published

$\gamma p \rightarrow p\pi^+\pi^-$: Target Asymmetry P_y



• FROST g9b (lin. pol. beam) — Fourier fit ($n < 3$)

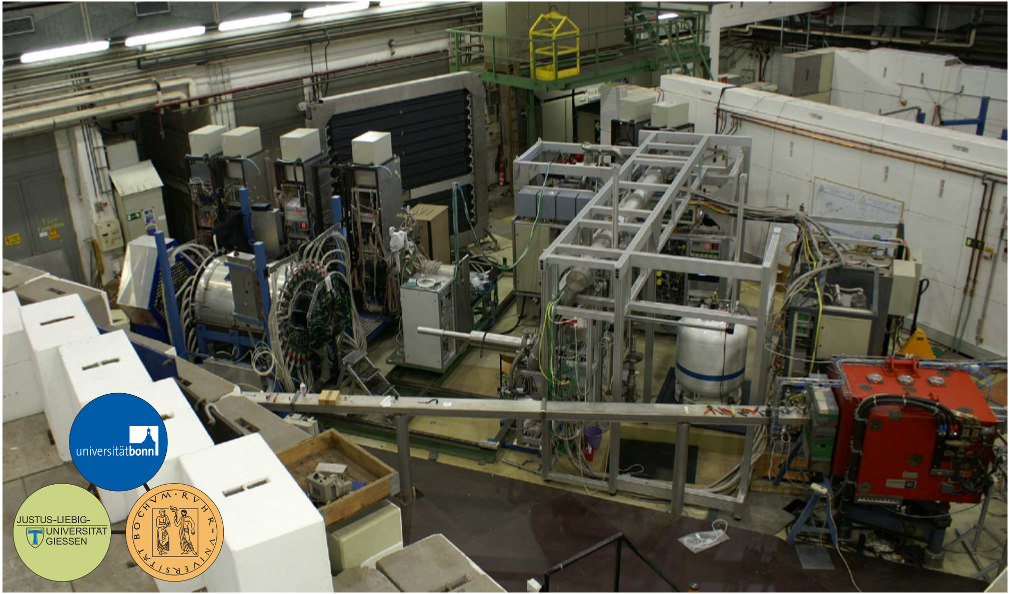
Figure courtesy of Priyashree Roy, CLAS Collaboration

Summary and Outlook

- Double polarization experiments provide new insight to baryon spectroscopy
- π^0 photoproduction: precision measurements
  $\rightsquigarrow$ Large impact on PWA:
  - Better determination of resonance parameters
  - Different PWAs converge towards single solution
- η photoproduction: first data for many observables
  $\rightsquigarrow$ $N^* \rightarrow \eta N$ branching ratios
- Multi-meson photoproduction, e.g. $\pi^0\pi^0$, $\pi^+\pi^-$, $\pi^0\eta$:
  $\rightsquigarrow$ New high-mass resonances?
- Much more data taken
  $\rightsquigarrow$ Many more interesting results can be expected

$\rightsquigarrow$ Better understanding of QCD in the non-perturbative regime!

Thank you for your attention!



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