Results of polarization observables in photoproduction reactions from the CBELSA/TAPS experiment

PANIC2021 conference

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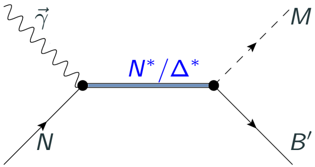
08.09.2021

University of Bonn

Baryon spectroscopy

Baryon spectroscopy

- Study dynamics of constituents inside the nucleon
- Baryon spectroscopy $\leftrightarrow$ QCD



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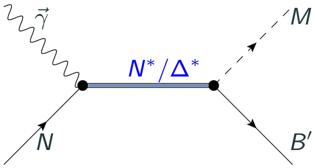

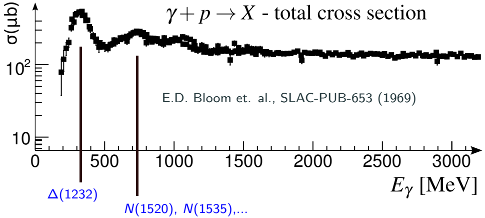

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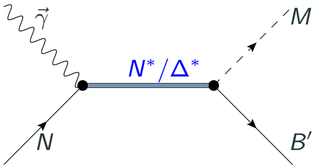
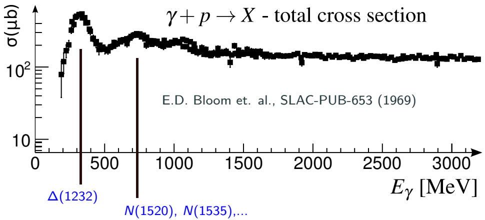
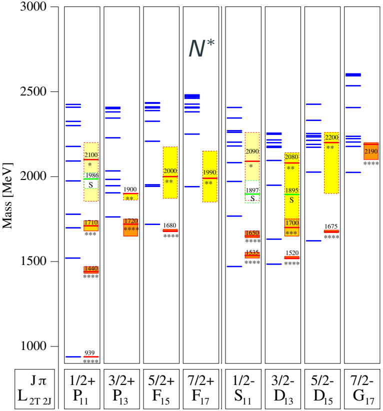




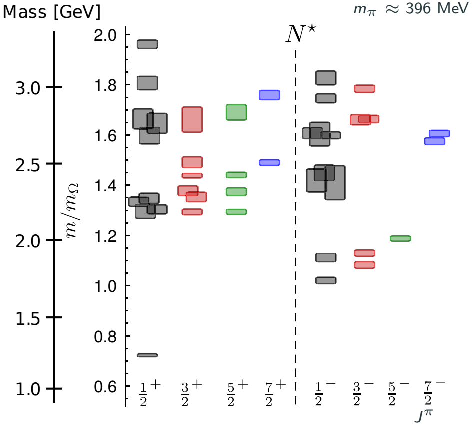
Disentanglement of the contributing resonances is a challenging task!

Theoretical description of nucleon excitation spectra

Quark model vs. experimental data



Lattice QCD predictions



U. Loering, B.C. Metsch, H.R. Petry, EPJA 10 (2001) 395-446

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

- Discrepancy between theory and experiment: missing resonances, ordering of states

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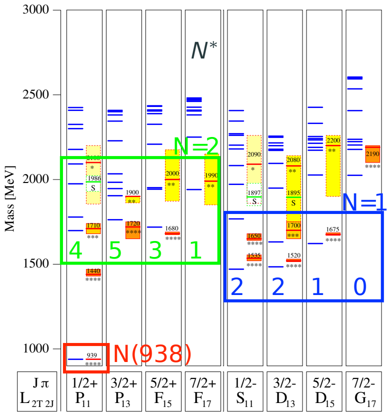

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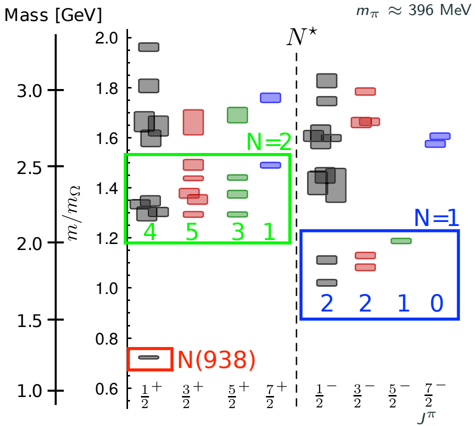

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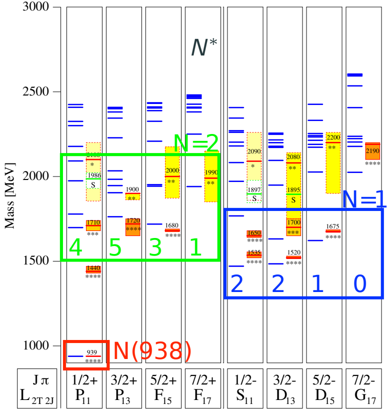

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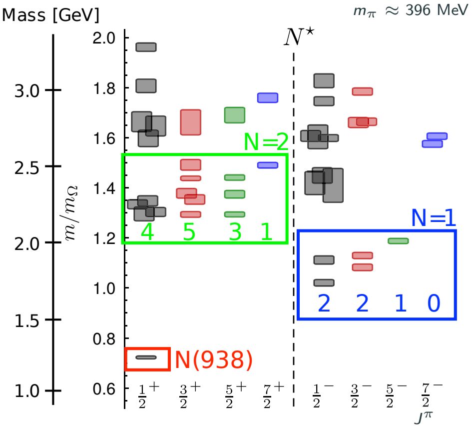


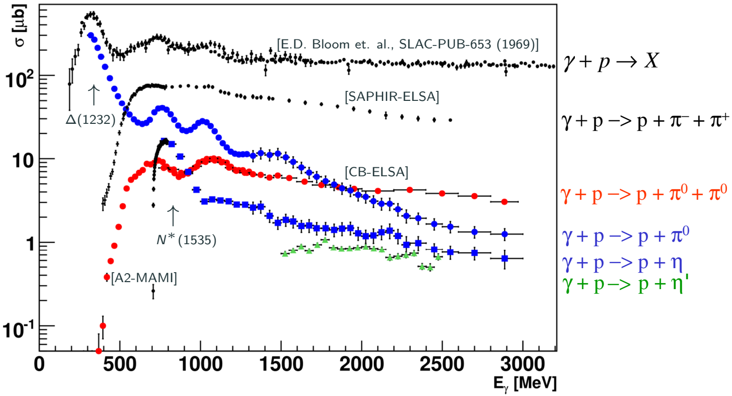
R. G. Edwards et al., Phys. Rev. D 84 (2011) 074508

- Discrepancy between theory and experiment: missing resonances, ordering of states
- relevant degrees of freedom of model?
- most resonances observed in πN scattering $\rightarrow$ experimental bias?

Photoproduction reactions

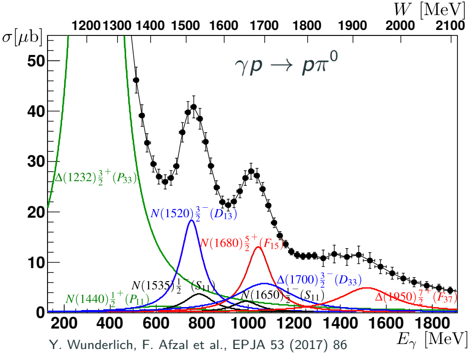
Study of different reaction channels gives access to different resonant structures

⇒ Worldwide effort to get high precision data (ELSA,MAMI, JLab, ...)



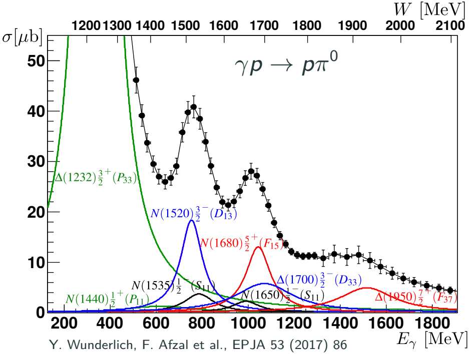
Photoproduction reactions are an excellent tool to probe excitation spectra!

Unpolarized cross section



Y. Wunderlich, F. Afzal et al., EPJA 53 (2017) 86

Unpolarized cross section



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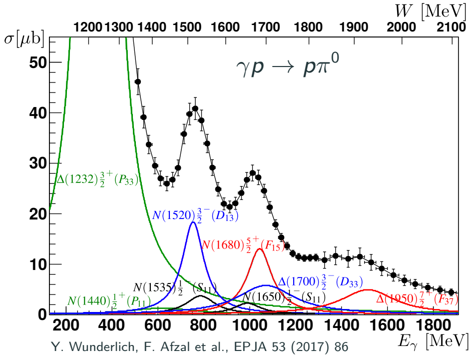
$$\frac{d\sigma}{d\Omega}_0(W,\theta) \propto \sum_{\text{spins}} | < f|\mathcal{F}|i > |^2$$

Unpolarized cross section



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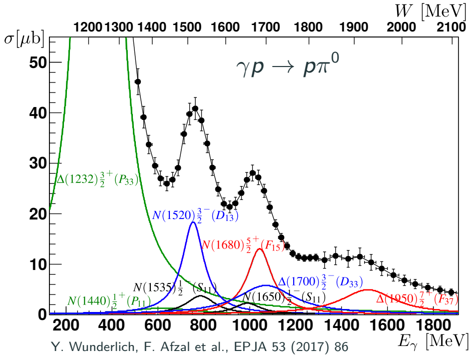
Photoproduction amplitude $\mathcal{F}$

$\leftrightarrow$ 4 complex amplitudes

e.g. CGLN amplitudes: F_1, F_2, F_3, F_4

Unpolarized cross section



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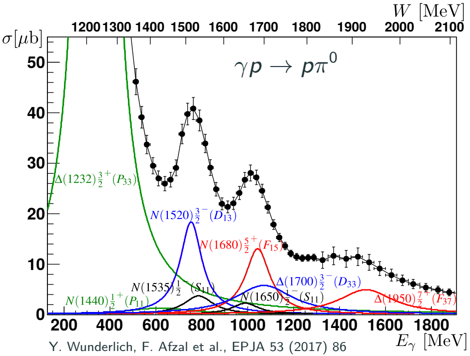
- PWA: e.g. $F_1 = \sum_{l=0}^{\infty}(lM_{l+} + E_{l+})P'_{l+1} + [(l+1)M_{l-} + E_{l-}]P'_{l-1}$
  - $E_{l\pm}(W), M_{l\pm}(W)$: Multipoles
  - $P'_{l\pm1}(\cos\theta_{cm})$: Legendre polynomials

Unpolarized cross section



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  - $E_{l\pm}(W), M_{l\pm}(W)$: Multipoles
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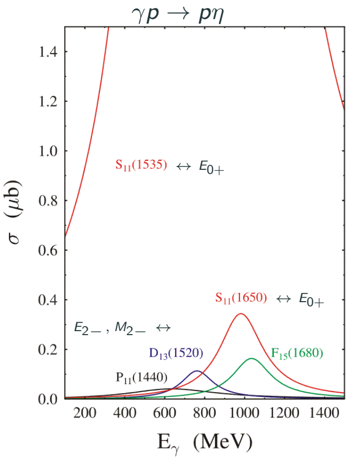
- $\sigma \sim |E_{0+}|^2 + |E_{1+}|^2 + |M_{1+}|^2 + |M_{1-}|^2 + \ldots$
  $\to$ unpolarized cross section is sensitive to dominant contributing resonances

For a unique determination of the complex amplitudes:

Photon polarization		Target polarization			Recoil nucleon polarization			Target and recoil polarizations			
		X	Y	Z(beam)	X'	Y'	Z'	X' X	X' Z	Z' X	Z' Z
unpolarized	σ	-	T	-	-	P	-	$T_{x'}$	$L_{x'}$	$T_{z'}$	$L_{z'}$
linear	-Σ	H	(-P)	-G	$O_{x'}$	(-T)	$O_{z'}$	$(-L_{z'})$	$(T_{z'})$	$(L_{x'})$	$(-T_{x'})$
circular	-	F	-	-E	$C_{x'}$	-	$C_{z'}$	-	-	-	-



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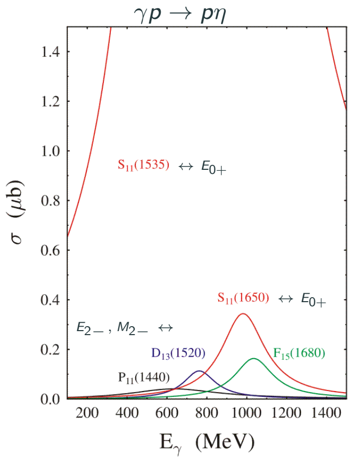
circular	-	F	-	-E	$C_{x'}$	-	$C_{z'}$	-	-	-	-

$$\Sigma \sim \underbrace{-2E_{0+}^{*}E_{2+} + 2E_{0+}^{*}E_{2-} - 2E_{0+}^{*}M_{2+} + 2E_{0+}^{*}M_{2-}}_{<S,D>} + \ldots$$



→Polarization observables are sensitive to interference terms!

→Interferences with the dominant S-wave (E_{0+}) important in η photoproduction!

Experimental setup

The CBELSA/TAPS experiment in Bonn

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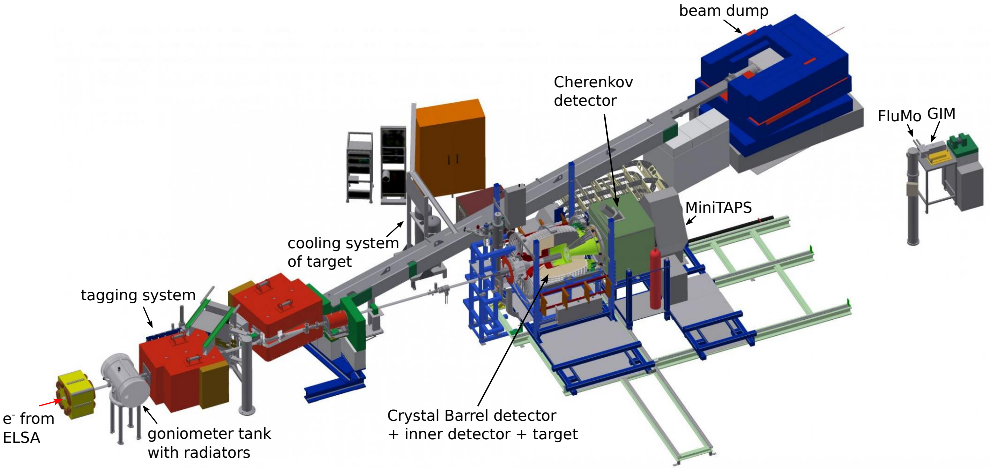

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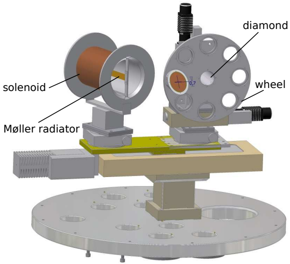

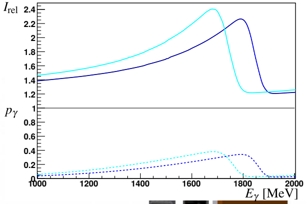

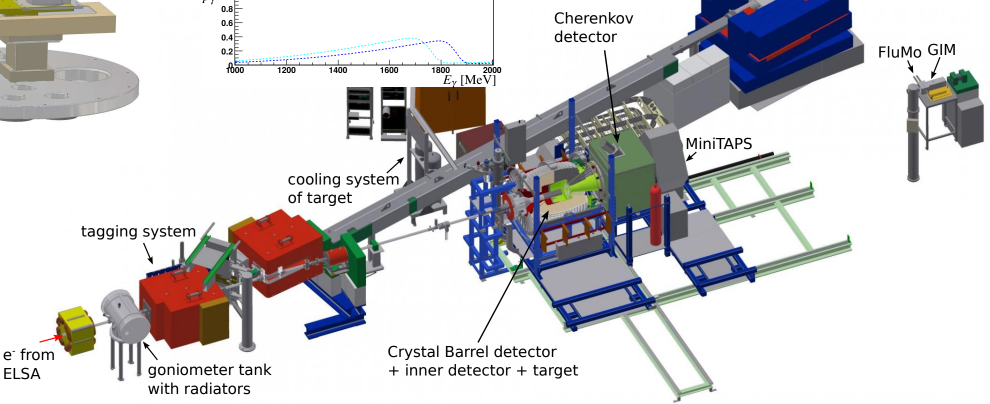

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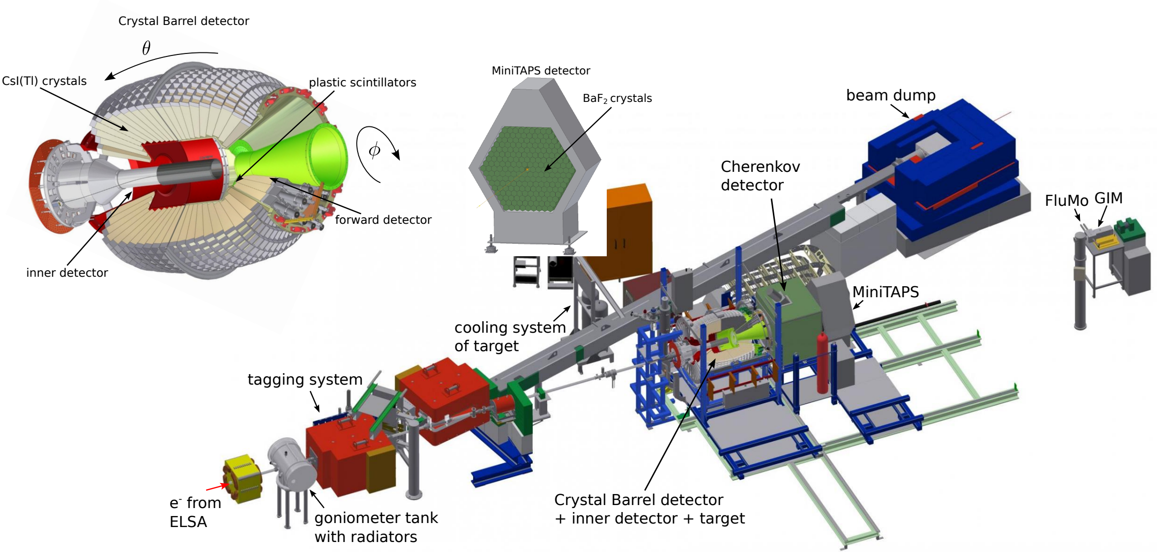

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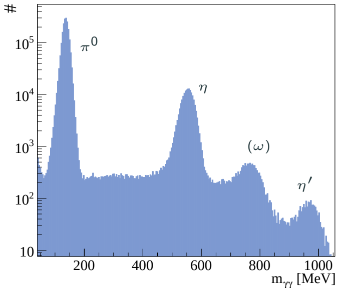
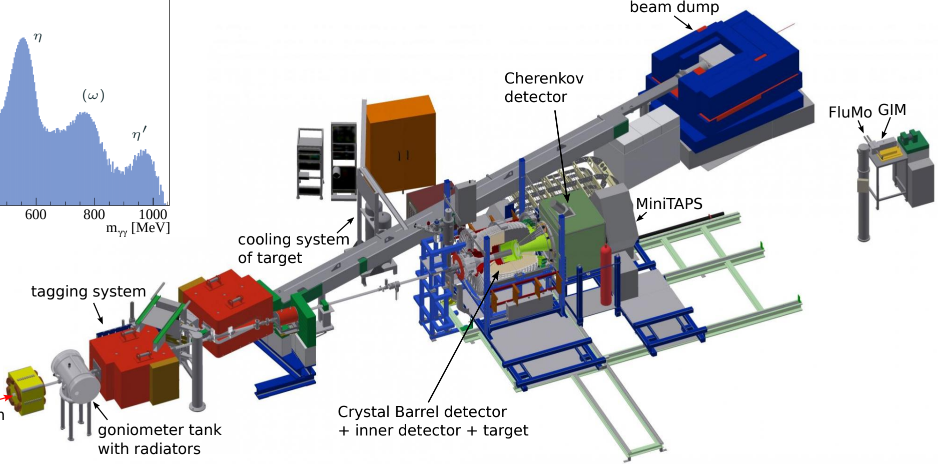
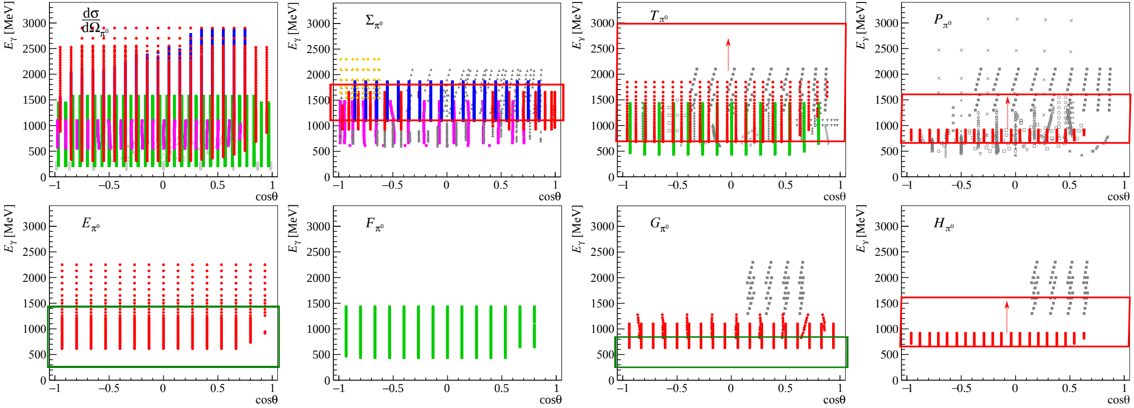




Discussion of results

Current database in $\gamma p \to p\pi^0$

● CBELSA/TAPS data ● CLAS data ● A2 data ● GRAAL data

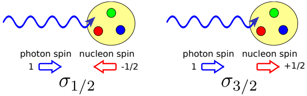


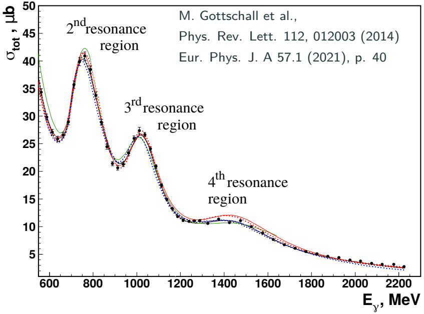
- Large energy and angular coverage by CBELSA/TAPS experiment
- [red box] new CBELSA/TAPS data
- [green box] new A2 data (F. Afzal et al., K. Spieker et al.)

$\gamma p \rightarrow p\pi^0$: Double polarization observable E

- Circularly polarized photons and longitudinally polarized target
- helicity asymmetry: $E = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$
- Spin dependent cross sections

$\sigma_{1/2(3/2)} = \sigma_0 \cdot (1 \pm E)$





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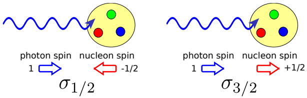
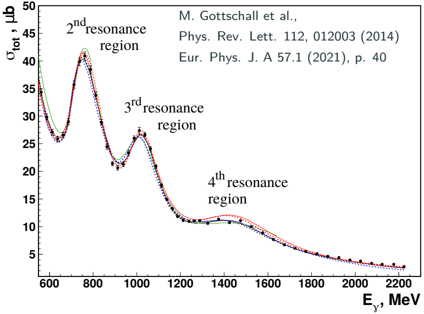
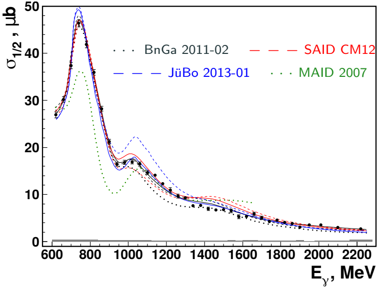
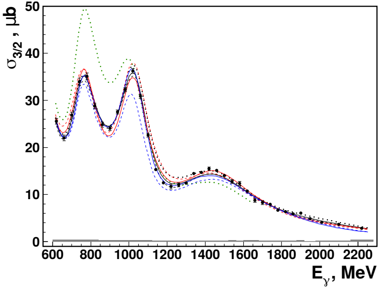
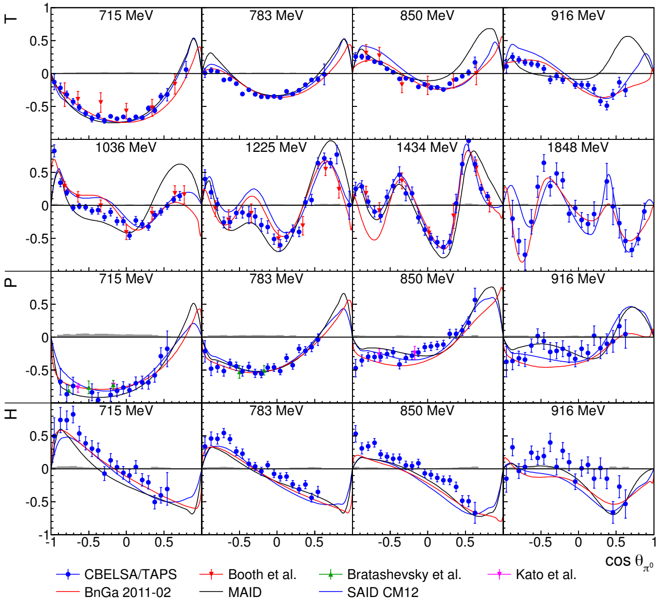








$\gamma p \rightarrow p\pi^0$: Polarization observables T, P, H



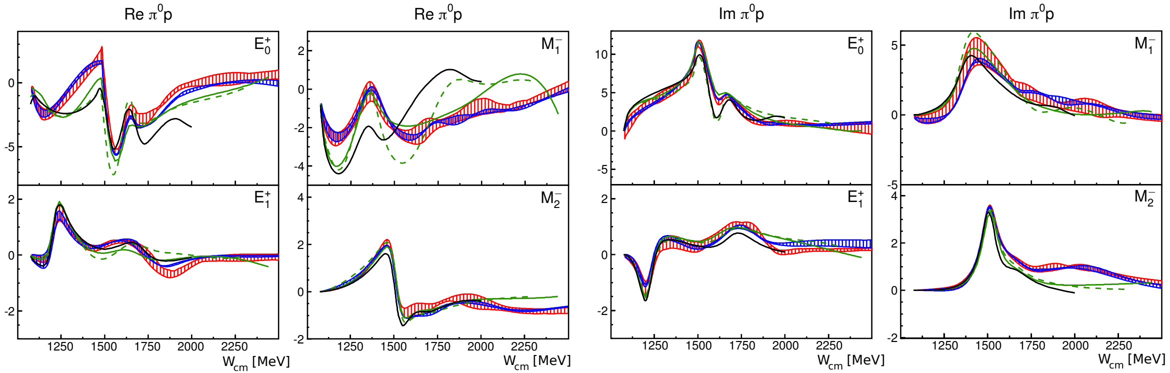
Only selected bins shown!

High quality data with large angular and energy coverage!

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

Impact of polarization observables in $\gamma p \to p\pi^0$

- Including new polarization observables, the BnGa fit error bands get smaller by a factor 2.25
- Still large differences in the different PW analyses visible

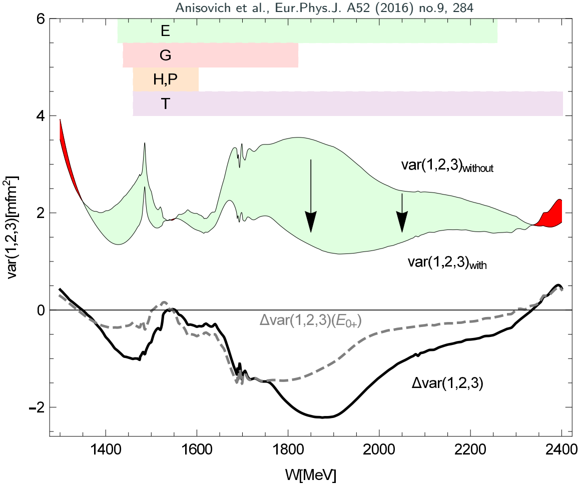


J. Hartmann et al., Phys.Lett. B748 (2015) 212

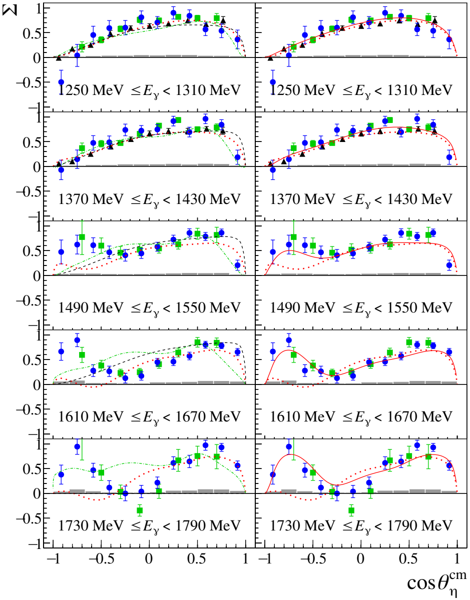
MAID, SAID CM12 (solid) SN11 (dashed), BnGa, BnGa with double pol. obs

Impact of polarization observables in $\gamma p \to p\pi^0$

- The variance of all the three PWAs (JüBo, SAID, BnGa) summed over all $\gamma p \to p\pi^0$ multipoles up to $L = 4$ is shown
- Variance between the different PWAs decreases
- E_{0+} multipole contributes the most to the improvements



Results for Σ in $p\eta$ photoprodution



F. Afzal et al., Phys. Rev. Lett. 125, 152002 (2020)

- ● CBELSA/TAPS data (F. Afzal et al.)
- ▲ GRAAL data (O. Bartalini et al., Eur. Phys. J. A33 (2007) 169)
- ■ CLAS data (P. Collins et al., Phys. Lett. B 771 (2017) 213-221)

BnGa-2014-02 JüBo-2015-FitB ηMAID

BnGa-2019

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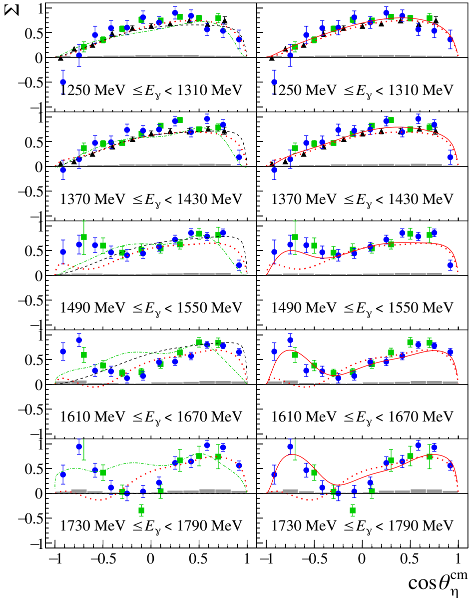

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BnGa-2014-02 · JüBo-2015-FitB · ηMAID · BnGa-2019

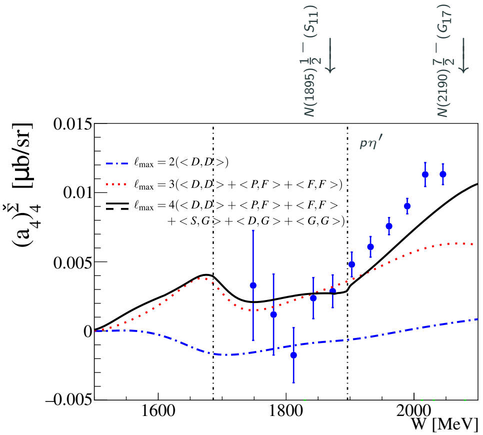
PWA predictions (BnGa, JüBo, ηMAID) can not describe backward peak in data!

$\rightarrow$ What is the issue with the PWAs?

Dominant partial wave contributions (Σ (CBELSA/TAPS), $\gamma p \to p\eta$)

$$\check{\Sigma}(W, \cos\theta) = \Sigma(W, \cos\theta) \cdot \frac{d\sigma}{d\Omega}(W, \cos\theta) = \sum_{k=2}^{2L_{max}} (a_L(W))_k \cdot P_k^2(\cos\theta)$$

(Y. Wunderlich, F. Afzal, A. Thiel and R. Beck, EPJA 53:86 (2017))



Compare extracted fit coefficient to BnGa-2019 solution

$$\left(a_5\right)_4^{\check{\Sigma}} = \langle D, D \rangle$$

$+ \langle P, F \rangle + \langle F, F \rangle$

$+\langle \boldsymbol{S}, \boldsymbol{G} \rangle + \langle D, G \rangle + \langle G, G \rangle$

F. Afzal et al., Phys. Rev. Lett. 125, 152002 (2020)

$p\eta'$ channel needs to be included in PWA to describe data

Evidence for $N(1895)\frac{1}{2}^-(S_{11})$ resonance due to strong $p\eta'$ cusp in $p\eta$ S wave

Impact of photoproduction data on PDG in the last two decades

Particle	J^P	overall	$N\gamma$	$N\pi$	$\Delta\pi$	$N\sigma$	$N\eta$	ΛK	ΣK	$N\rho$	$N\omega$	$N\eta'$
N	$1/2^+$	****										
$N(1440)$	$1/2^+$	****	****	****	****	***	-			-		
$N(1520)$	$3/2^-$	****	****	****	****	**	****			- - - -		
$N(1535)$	$1/2^-$	****	****	****	***	*	****			- -		
$N(1650)$	$1/2^-$	****	****	****	***	*	****	*- -	- -	- -		
$N(1675)$	$5/2^-$	****	****	****	****	***	*	*	*	-		
$N(1680)$	$5/2^+$	****	****	****	****	***	*	*	*	- - - -		
$N(1700)$	$3/2^-$	***	**	***	***	*	*	- -	-	-		
$N(1710)$	$1/2^+$	****	****	****	*-		***	**	*	*	*	
$N(1720)$	$3/2^+$	****	****	****	***	*	*	****	*	*-	*	
$N(1860)$	$5/2^+$	**	*	**		*	*					
$N(1875)$	$3/2^-$	***	**	**	*	**	*	*	*	*	*	
$N(1880)$	$1/2^+$	***	**	*	**	*	*	**	**		**	
$N(1895)$	$1/2^-$	****	****	*	*	*	****	**	**	*	*	****
$N(1900)$	$3/2^+$	****	****	**	**	*	*	**	**	-	*	**
$N(1990)$	$7/2^+$	**	**	**			*	*	*			
$N(2000)$	$5/2^+$	**	**	*-	**	*	*	-	-	- -	*	
$N(2040)$	$3/2^+$	*		*								
$N(2060)$	$5/2^-$	***	***	**	*	*	*	*	*	*	*	
$N(2100)$	$1/2^+$	***	**	***	**	**	*	*		*	*	**
$N(2120)$	$3/2^-$	***	***	**	**	**		**	*		*	*
$N(2190)$	$7/2^-$	****	****	****	****	**	*	**	*	*	*	
$N(2220)$	$9/2^+$	****	**	****			*	*	*			
$N(2250)$	$9/2^-$	****	**	****			*	*	*			
$N(2300)$	$1/2^+$	**		**								
$N(2570)$	$5/2^-$	**		**								
$N(2600)$	$11/2^-$	***		***								
$N(2700)$	$13/2^+$	**		**								

- mostly πN data were used until 2010
- photoproduction data is now used by most PWA groups and new fit values for resonance parameters have entered the PDG
- Still a lot of work to do!

- CBELSA/TAPS collaboration have measured many high-precision data in various different final states
  → Data have been included in the different PWA and the multipoles are converging
  → Existence of third *S*-wave resonance $N(1895)\frac{1}{2}^{-}(S_{11})$ has been confirmed
- Outlook: APD-Upgrade of the Crystal Barrel detector successfully completed and new data is/will be taken
  → more data to be expected on multi-meson final states, photoproduction on the neutron
- Still a lot of open questions that need answers through more data!