Recent results from the CBELSA/TAPS experiment at ELSA

NSTAR 2019

Farah Afzal for the CBELSA/TAPS collaboration

11.06.2019

University of Bonn

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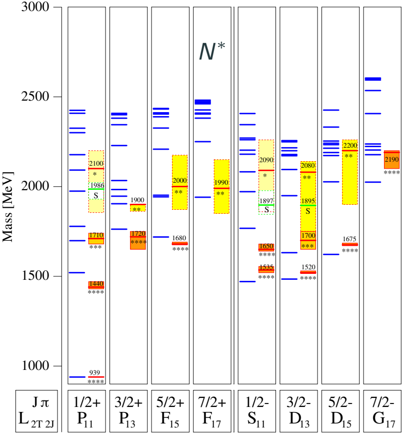
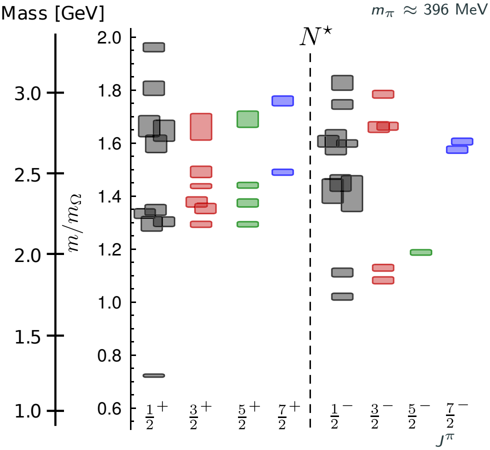
Quark model vs. experimental data



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

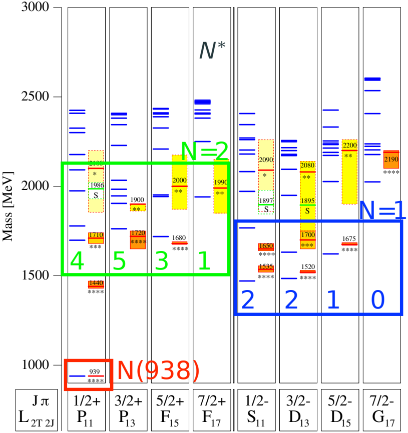
Lattice QCD predictions



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

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

Quark model vs. experimental data



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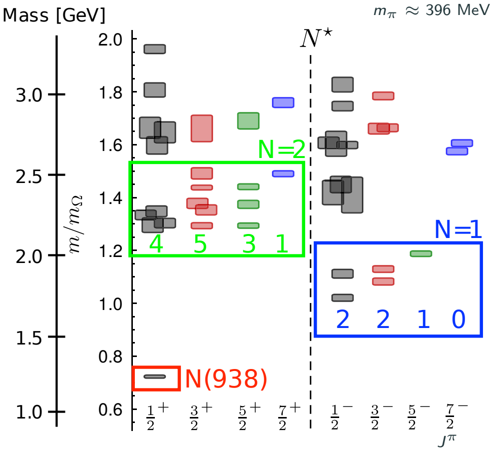

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- Discrepancy between theory and experiment: missing resonances, ordering of states
- relevant degrees of freedom of model?

Theoretical description of nucleon excitation spectra

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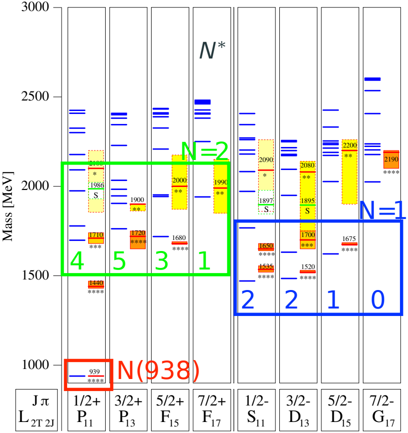
Quark model vs. experimental data



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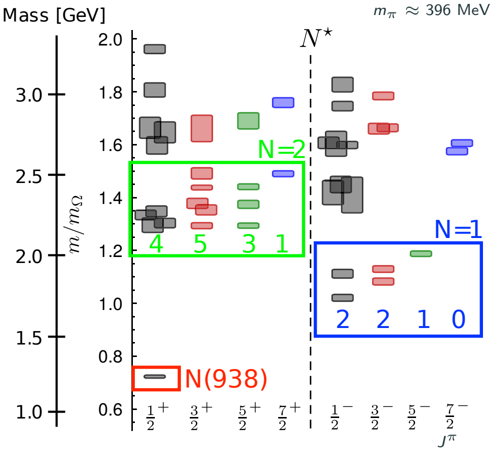


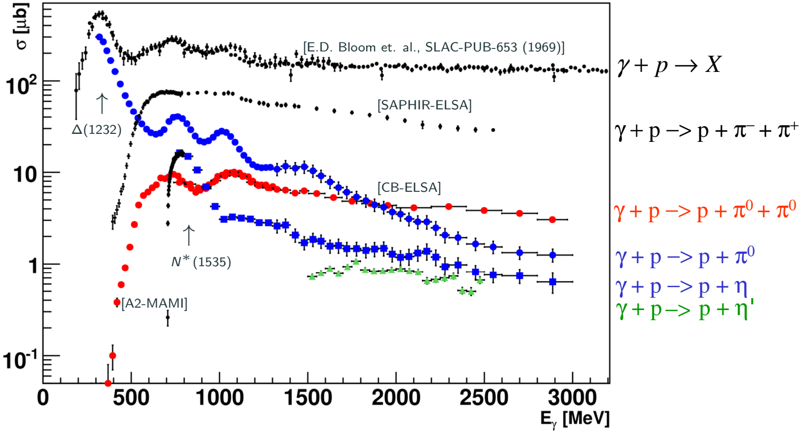
R. G. Edwards et al., Phys. Rev. D 84 (2011) 074508

- 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?

Study of different reaction channels gives access to different resonant structures

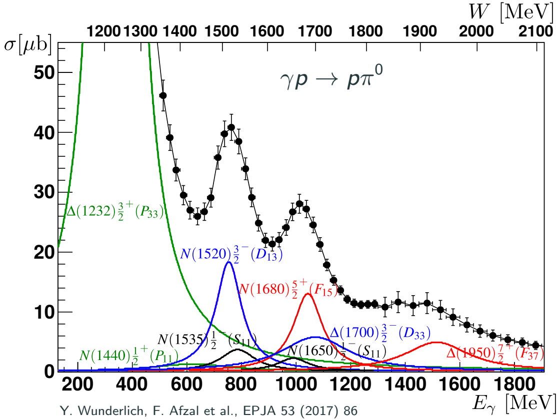
⇒ Worldwide effort to get high precision data (ELSA, MAMI, JLab, ...)

→ see talk by D. Watts, Tuesday 11:15
→ see talk by S. Strauch, Tuesday 12:25



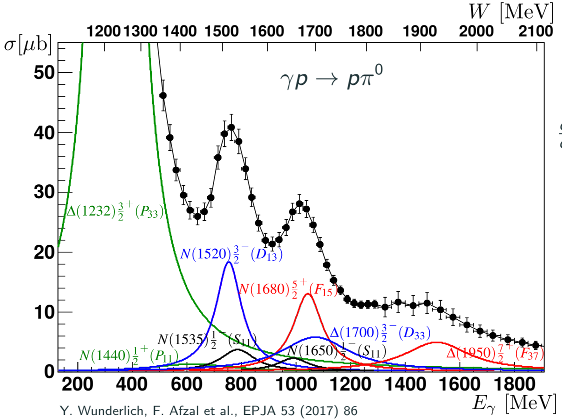
Photoproduction reactions are an excellent tool to probe excitation spectra!

Unpolarized cross section



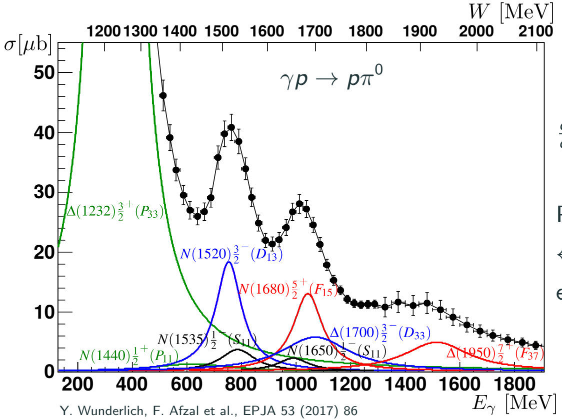
Y. Wunderlich, F. Afzal et al., EPJA 53 (2017) 86

Unpolarized cross section



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

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



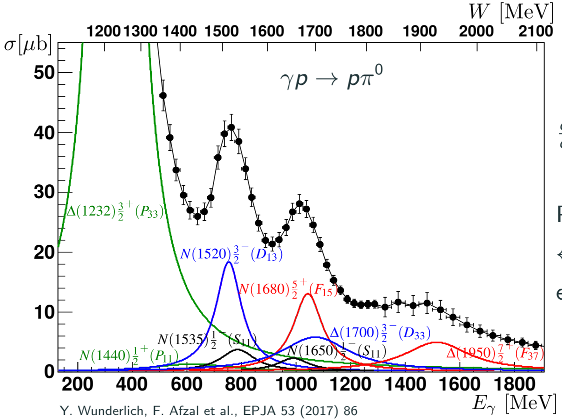
Y. Wunderlich, F. Afzal et al., EPJA 53 (2017) 86

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

Photoproduction amplitude $\mathcal{F}$

$\leftrightarrow$ 4 complex amplitudes

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



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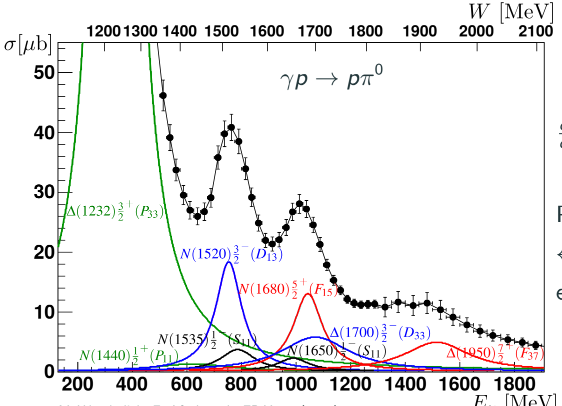
- PWA: e.g. $F_1 = \sum_{l=0}^{\infty}(lM_{l+} + E_{l+})P'_{l+1} + [(l+1)M_{l-} + E_{l-}]P'_{l-1}$
  - $E_{l\pm}(W), M_{l\pm}(W)$: Multipoles
  - $P'_{l\pm1}(\cos\theta_{cm})$: Legendre polynomials

Unpolarized cross section



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  - $E_{l\pm}(W), M_{l\pm}(W)$: Multipoles
  - $P'_{l\pm1}(\cos\theta_{cm})$: Legendre polynomials
- $\sigma \sim |E_{0+}|^2 + |E_{1+}|^2 + |M_{1+}|^2 + |M_{1-}|^2 + \ldots$

  $\rightarrow$ unpolarized cross section is sensitive to dominant contributing resonances

Polarization observables

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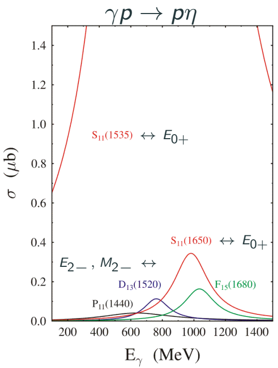
For a unique determination of the complex amplitudes:

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	$-\Sigma$	H	(-P)	-G	$O_{x'}$	(-T)	$O_{z'}$	$(-L_{z'})$	$(T_{z'})$	$(L_{x'})$	$(-T_{x'})$
circular	-	F	-	-E	$C_{x'}$	-	$C_{z'}$	-	-	-	-



Polarization observables

UNIVERSITÄT BONN

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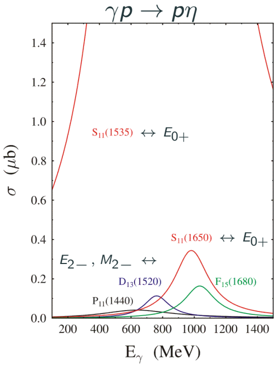
		X	Y	Z(beam)	X'	Y'	Z'	X' X	X' Z	Z' X	Z' Z
unpolarized	σ	-	T	-	-	P	-	$T_{x'}$	$L_{x'}$	$T_{z'}$	$L_{z'}$
linear	-Σ	H	(-P)	-G	$O_{x'}$	(-T)	$O_{z'}$	$(-L_{z'})$	$(T_{z'})$	$(L_{x'})$	$(-T_{x'})$
circular	-	F	-	-E	$C_{x'}$	-	$C_{z'}$	-	-	-	-

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



→Polarization observables are sensitive to interference terms!

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

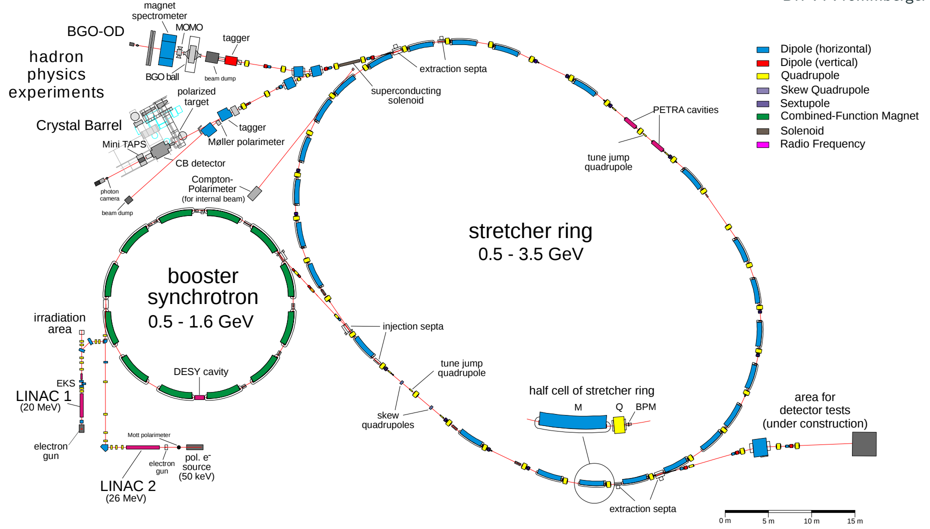
The CBELSA/TAPS experiment

The Electron Stretcher Accelerator (ELSA)

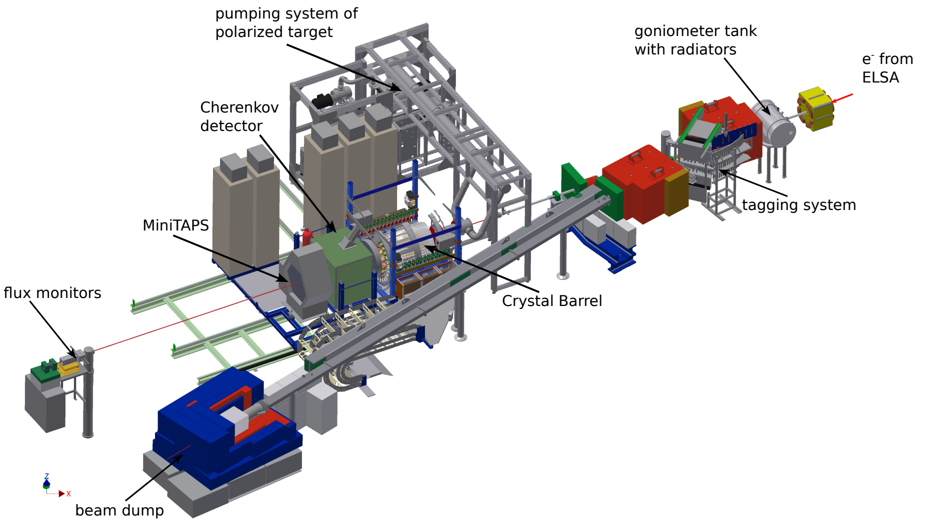
→ see talk by
T. Jude, Thursday 10:10

Physics Institute, University of Bonn

Dr. D. Elsner
Dr. F. Frommberger



The CBELSA/TAPS experiment



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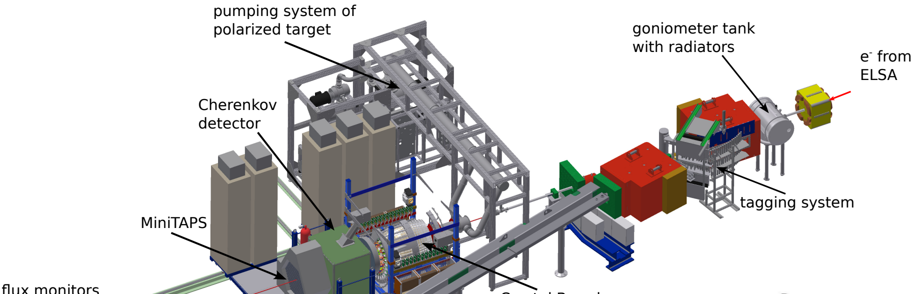
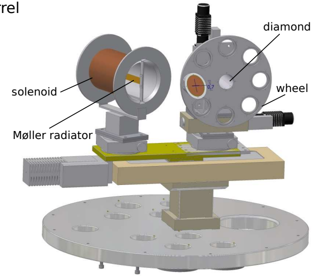
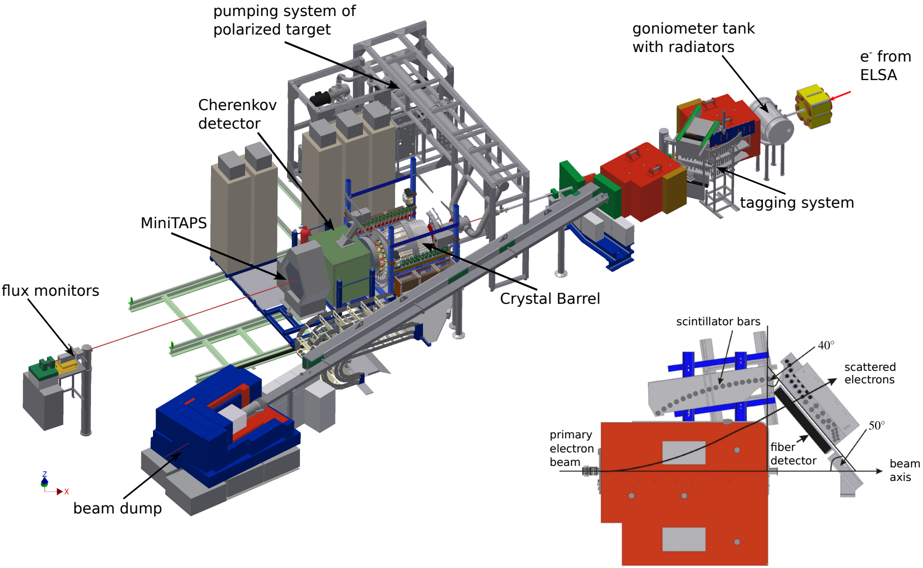
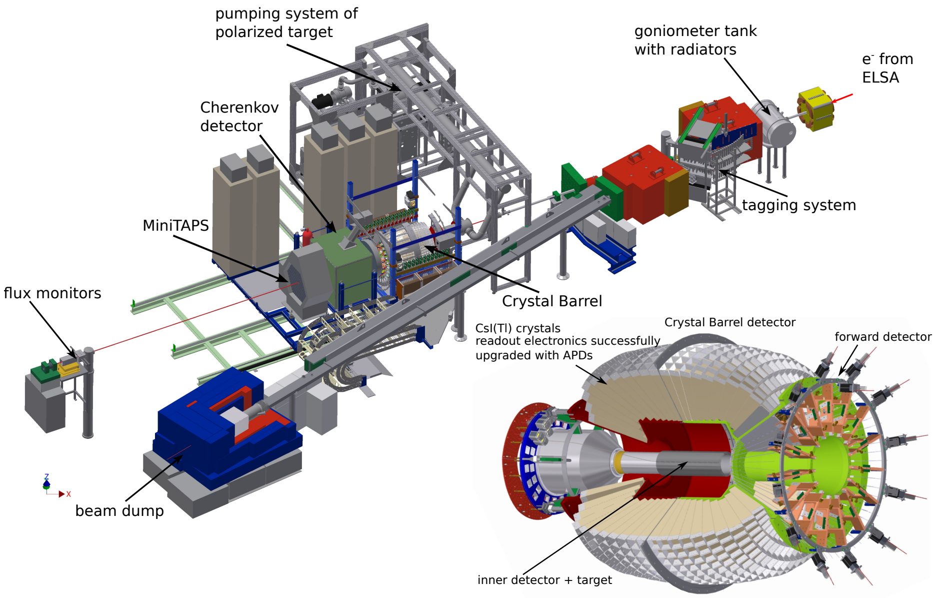




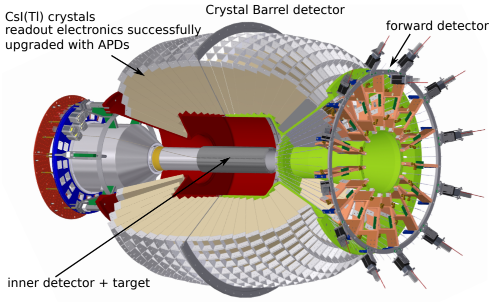
The CBELSA/TAPS experiment

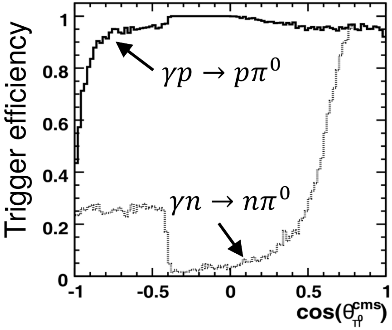


The CBELSA/TAPS experiment



- Before upgrade:
  - fast signals only from inner det., forward det. and MiniTAPS
  - Crystal Barrel $\theta > 30^\circ$ only used as second level trigger
  - limited trigger acceptance for neutral final states





Upgrade of the CBELSA/TAPS experiment

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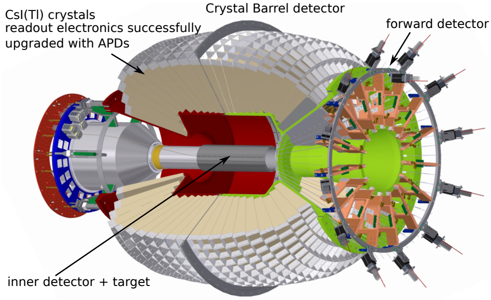
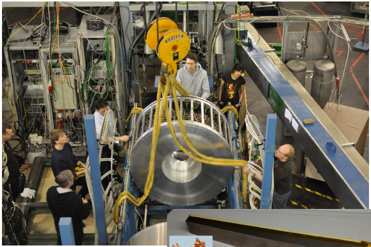
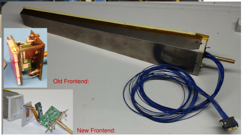
- Before upgrade:
  - fast signals only from inner det., forward det. and MiniTAPS
  - Crystal Barrel $\theta > 30^\circ$ only used as second level trigger
  - limited trigger acceptance for neutral final states
- After upgrade:
  - Each CsI(Tl) crystal readout with 2 APDs instead of PIN photodiodes
  - Each CsI(Tl) crystal with new frontend and readout electronics
  - Crystal Barrel $\theta > 30^\circ$ included in first level trigger
  - Factor of 2 higher statistics per unit time due to the new trigger!





Dr. M. Lang
Dr. D. Walther
Dr. C. Honisch
Dr. M. Urban
P. Klassen
J. Müllers



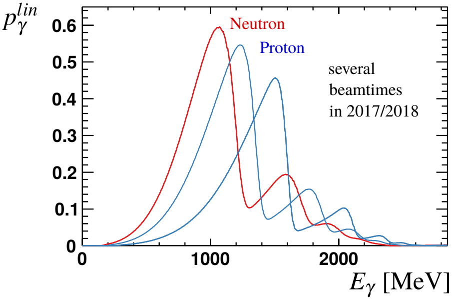
APD with new frontend electronic

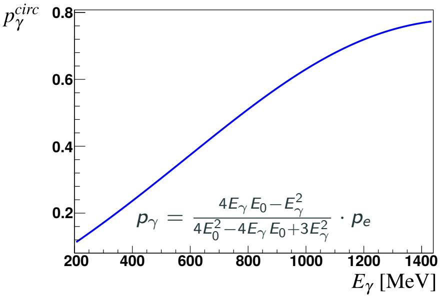
Linearly polarized photons

- diamond radiator needed
- coherent bremsstrahlung
- coherent edges at:
  e.g. 1200 MeV, 1350 MeV, 1600 MeV

Circularly polarized photons

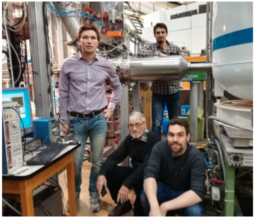
- long. polarized electrons needed
- helicity transfer to photons
- Møller measurement:
  $p_e \approx 75\% - 78\%$





The Mainz Dubna frozen spin polarized target

- polarization via Dynamic Nuclear Polarization DNP
- maximal pol. degree: $p_T \approx 84\%$
- relaxation times: 1800 h - 2000 h



target crew

Bonn: H. Dutz, S. Runkel, . . .

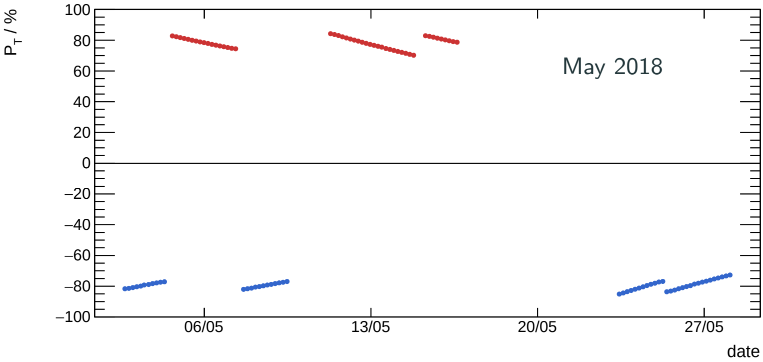
Bochum: G. Reichertz, W. Meyer, . . .

Dubna: Y. Usov, Ivan, . . .

Mainz: A. Thomas, M. Biroth, . . .

→ see talk by

S. Runkel, Tuesday 15:00



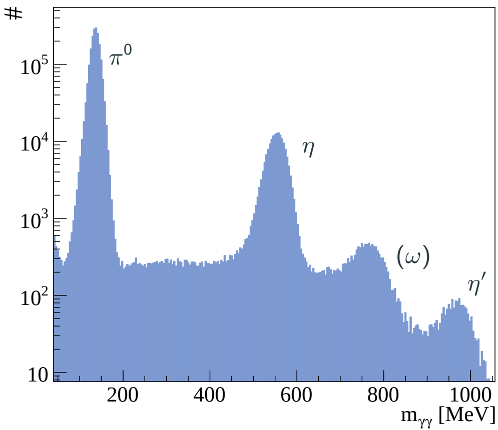
Extraction of polarization observables for $\gamma p \rightarrow p\pi^0$

Selection of single final states

CBELSA/TAPS experiment focuses on neutral meson final states:

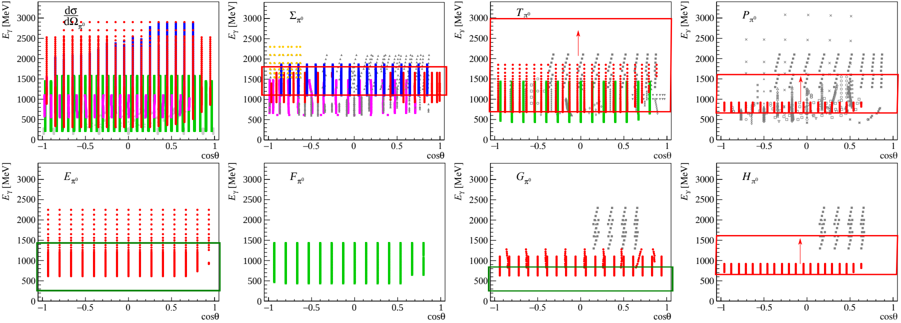
- single meson photoproduction: π^0, η, η' ...

$p\gamma\gamma$ final state



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.)

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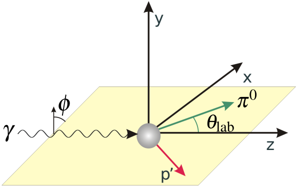
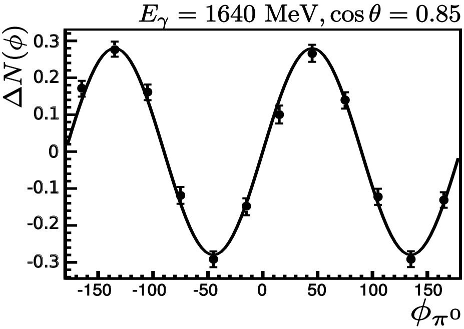
Linearly polarized beam, unpolarized liquid hydrogen target

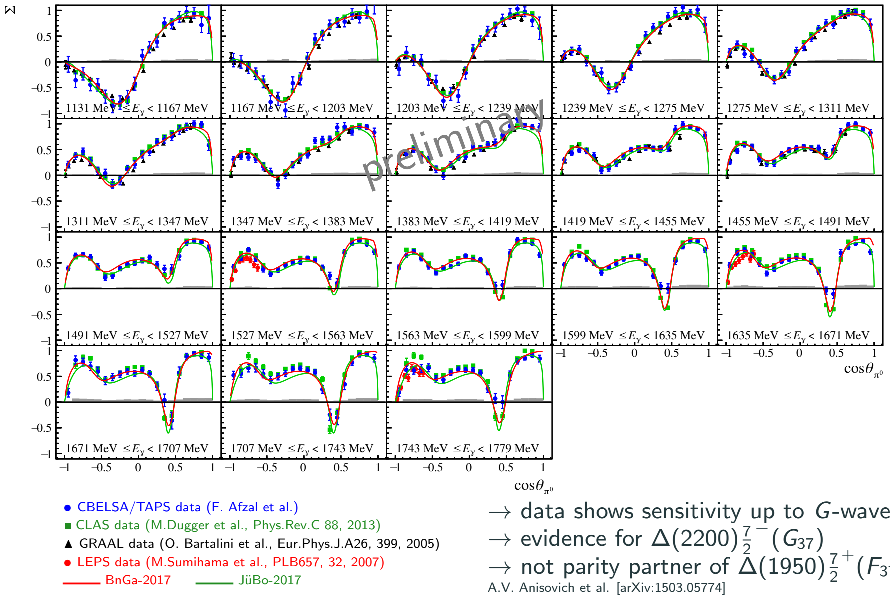


$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega}_0 \left[1 - p_\gamma^{\text{lin}} \Sigma \cos(2\phi)\right]$$



$$\Delta N = \frac{N_\perp - N_\parallel}{N_\perp + N_\parallel}$$

The beam asymmetry Σ in π^0 photoproduction



→ data shows sensitivity up to G-waves

→ evidence for $\Delta(2200)\frac{7}{2}^{-}(G_{37})$

→ not parity partner of $\Delta(1950)\frac{7}{2}^{+}(F_{37})$

A.V. Anisovich et al. [arXiv:1503.05774]

Double polarization observable E

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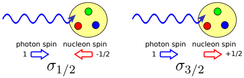
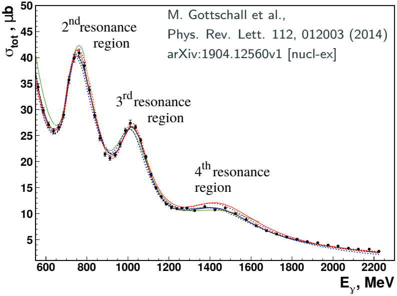
- Circularly polarized photons and longitudinally polarized target
- helicity asymmetry: $E = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$
- Spin dependent cross sections $\sigma_{1/2(3/2)} = \sigma_0 \cdot (1 \pm E)$





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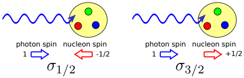
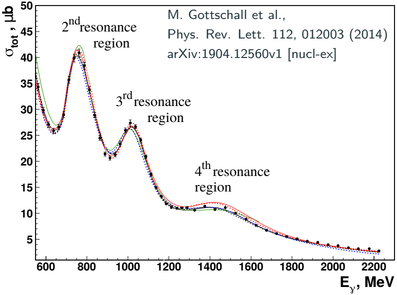
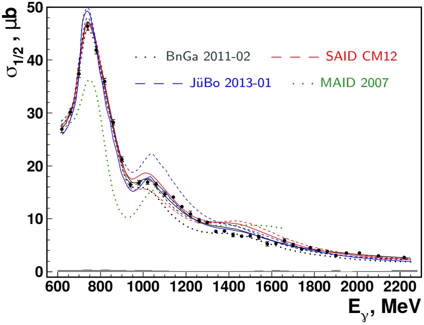
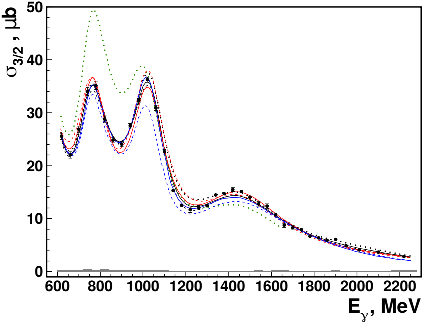


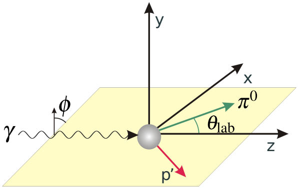




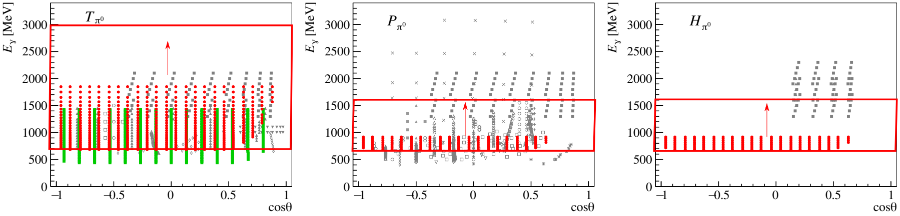


Polarization observables T, P, H

Linearly polarized photons and transversely polarized target



$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega}_0 \left[1 - p_\gamma^{\text{lin}} \Sigma \cos(2\phi) - p_\gamma^{\text{lin}} p_x H \sin(2\phi) - p_\gamma^{\text{lin}} p_y P \cos(2\phi) + p_y T\right]$$



- [red box] new CBELSA/TAPS data

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

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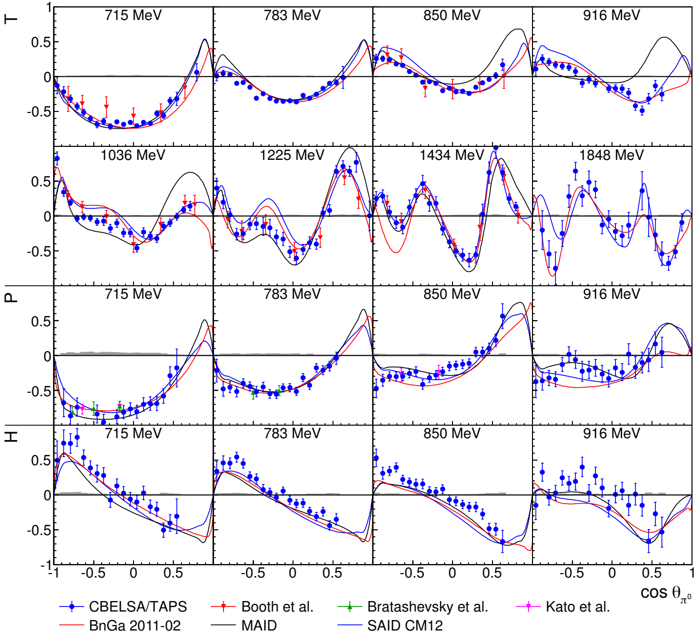
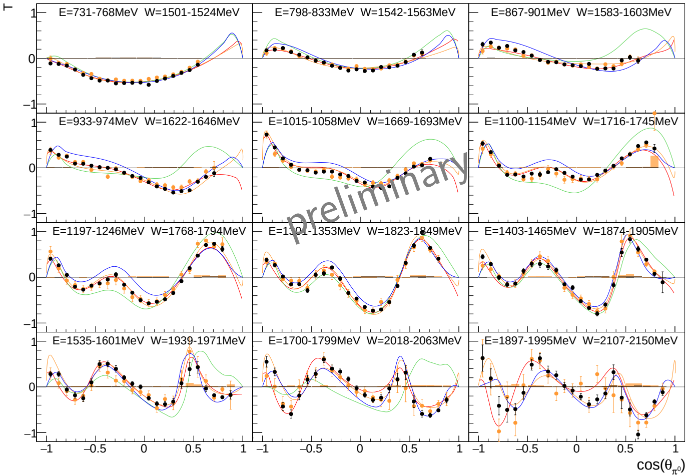


Only selected bins shown!

High quality data with large angular and energy coverage!

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

$\gamma p \rightarrow p\pi^0$: Polarization observable T (new data)



Only selected bins shown!

Very good agreement between old and new data!

Factor of 2 increase in statistics!

- CBELSA/TAPS data (J. Hartmann, Phys.Lett. B748 (2015) 212)
- preliminary CBELSA/TAPS data (N. Stausberg, 2018)

MAID-2007 SAID-CM12 BnGa-2014-02 JüBo-2017

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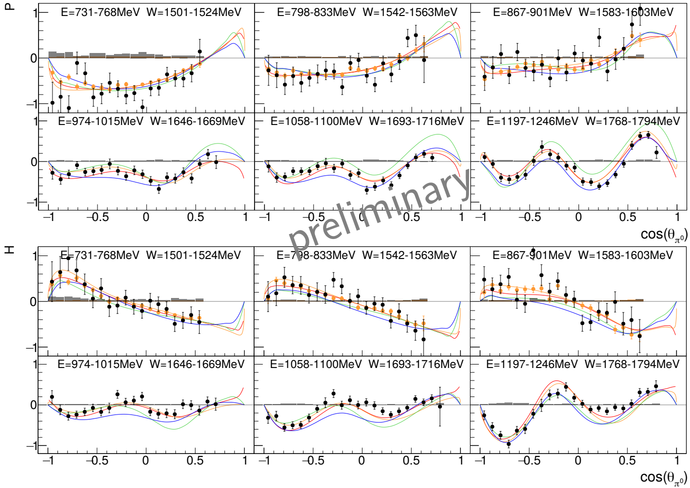

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MAID-2007 SAID-CM12 BnGa-2014-02 JüBo-2017

Only selected bins shown!

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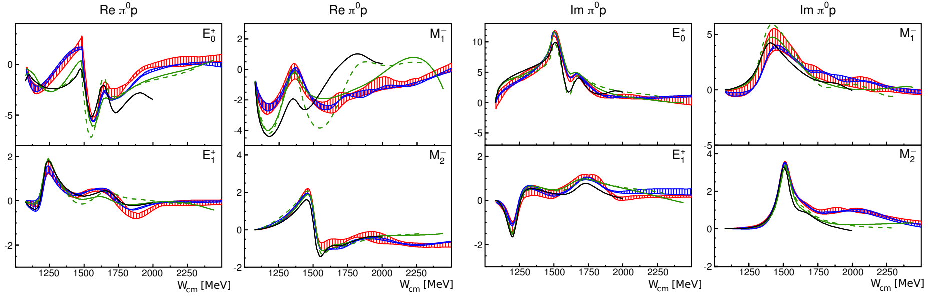
Database for P, H extended to $E_\gamma = 1300$ MeV

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



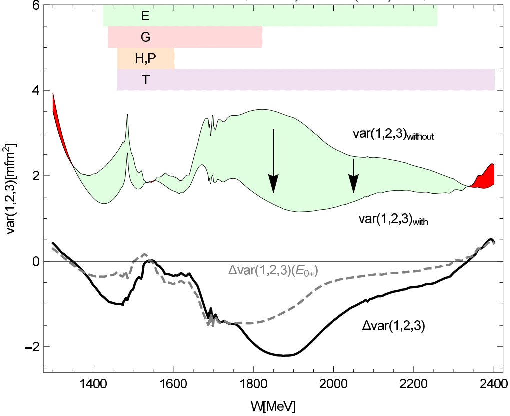
J. Hartmann et al., Phys.Lett. B748 (2015) 212

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

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

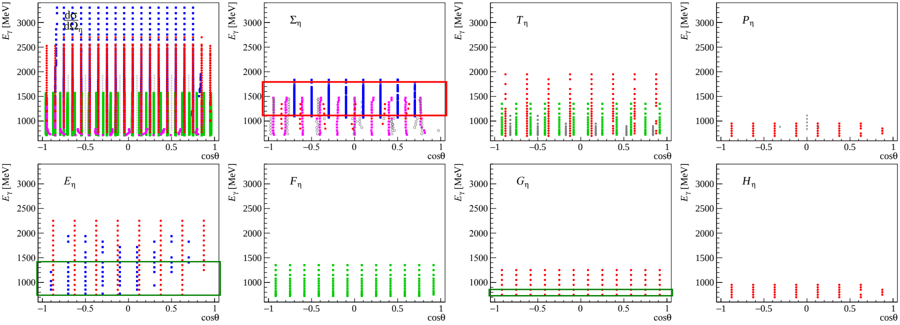
- The variance of all the three PWAs (JüBo, SAID, BnGa) summed over all $\gamma p \to p\pi^0$ multipoles up to $L = 4$ is shown
- Variance between the different PWAs decreases
- E_{0+} multipole contributes the most to the improvements

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



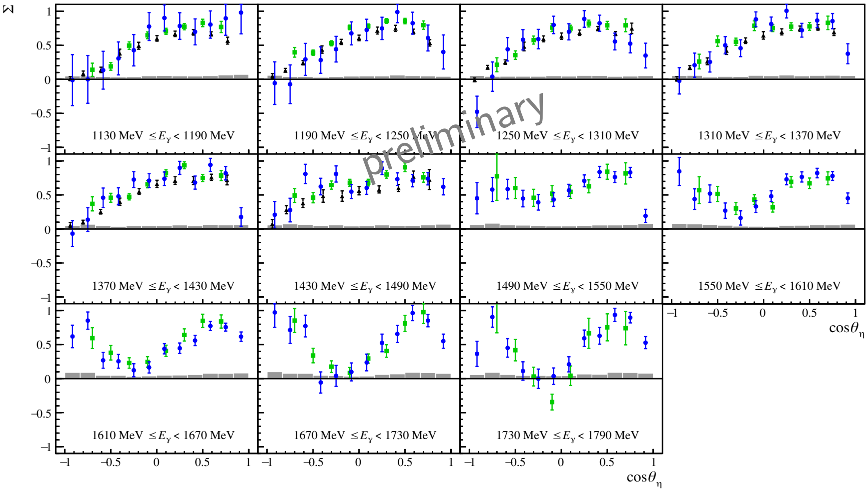
Polarization observables in $\gamma p \to p\eta$

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



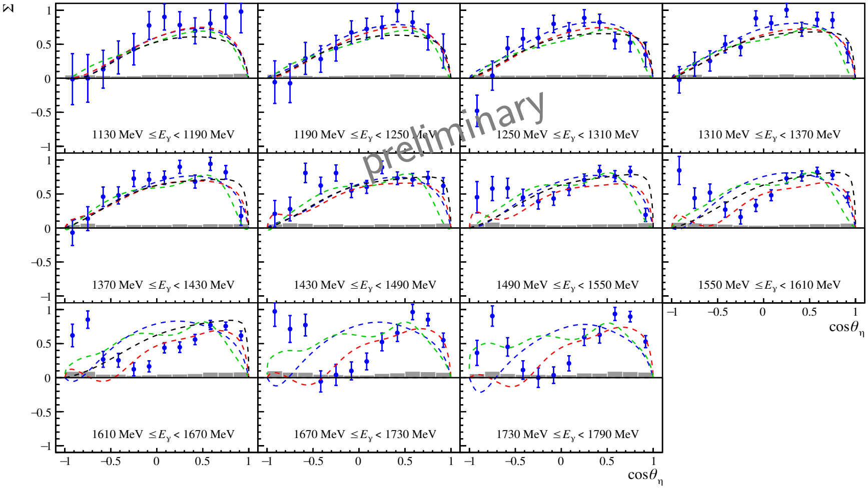
- G, E, T, P, H: J. Müller et al., publication under preparation
- [red box] new CBELSA/TAPS data
- [green box] new A2 data (F. Afzal et al.)
- More data is needed for the $p\eta$ final state!

$\gamma p \to p\eta$: The beam asymmetry Σ



- ● 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)

$\gamma p \to p\eta$: The beam asymmetry Σ



- CBELSA/TAPS data (F. Afzal et al.)
- BnGa-2014-02
- JüBo-2015-FitB
- ηMAID
- SAID-GE09

backward peak cannot be described!

Truncated PWA

$$\check{\Sigma}(W, \cos\theta) = \Sigma(W, \cos\theta) \cdot \tfrac{d\sigma}{d\Omega}(W, \cos\theta) = \sum_{k=2}^{2L_{\mathrm{max}}} (a_{L_{\mathrm{max}}}(W))_k^{\check{\Sigma}} \cdot P_k^2(\cos\theta) \text{ , i.e. } L_{\mathrm{max}} = 2;$$

Truncated PWA

$$\check{\Sigma}(W,\cos\theta) = \Sigma(W,\cos\theta)\cdot\frac{d\sigma}{d\Omega}(W,\cos\theta) = \sum_{k=2}^{2L_{\mathrm{max}}} \left(a_{L_{\mathrm{max}}}(W)\right)_k^{\check{\Sigma}} \cdot P_k^2(\cos\theta)\ \text{, i.e. } L_{\mathrm{max}} = 2;$$

$(a_{L_{\mathrm{max}}})_k^{\check{\Sigma}}$ defined by matrices with $\langle \ell_1, \ell_2 \rangle$-interference blocks

$$\left(a_2\right)_2^{\check{\Sigma}} = \begin{bmatrix} E_{0+}^* & E_{1+}^* & \dots & M_{2-}^* \end{bmatrix} \left[\begin{array}{c|ccc|cccc} 0 & 0 & 0 & 0 & \frac{1}{2} & \frac{1}{2} & -\frac{1}{2} & \frac{1}{2} \\ \hline 0 & -\frac{3}{2} & \frac{1}{2} & -\frac{1}{2} & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{2} & \frac{1}{2} & \frac{1}{2} & 0 & 0 & 0 & 0 \\ 0 & -\frac{1}{2} & \frac{1}{2} & 0 & 0 & 0 & 0 & 0 \\ \hline \frac{1}{2} & 0 & 0 & 0 & -\frac{36}{7} & -\frac{1}{7} & \frac{9}{7} & -\frac{9}{7} \\ \frac{1}{2} & 0 & 0 & 0 & -\frac{1}{7} & -\frac{1}{2} & -\frac{1}{2} & \frac{1}{2} \\ -\frac{1}{2} & 0 & 0 & 0 & \frac{9}{7} & -\frac{1}{2} & \frac{18}{7} & \frac{9}{14} \\ \frac{1}{2} & 0 & 0 & 0 & -\frac{9}{7} & \frac{1}{2} & \frac{9}{14} & \frac{3}{2} \end{array}\right] \begin{bmatrix} E_{0+} \\ E_{1+} \\ M_{1+} \\ M_{1-} \\ E_{2+} \\ E_{2-} \\ M_{2+} \\ M_{2-} \end{bmatrix}$$

Truncated PWA

$$\check{\Sigma}(W,\cos\theta) = \Sigma(W,\cos\theta)\cdot\frac{d\sigma}{d\Omega}(W,\cos\theta) = \sum_{k=2}^{2L_{\max}} \left(a_{L_{\max}}(W)\right)_k^{\check{\Sigma}} \cdot P_k^2(\cos\theta) \text{ , i.e. } L_{\max}=2;$$

$(a_{L_{\max}})_k^{\check{\Sigma}}$ defined by matrices with $\langle \ell_1, \ell_2\rangle$-interference blocks

$$(a_2)_2^{\check{\Sigma}} = \begin{bmatrix} E_{0+}^* & E_{1+}^* & \ldots & M_{2-}^* \end{bmatrix} \left[\begin{array}{c|ccc|cccc} 0 & 0 & 0 & 0 & \frac{1}{2} & \frac{1}{2} & -\frac{1}{2} & \frac{1}{2} \\ \hline 0 & -\frac{3}{2} & \frac{1}{2} & -\frac{1}{2} & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{2} & \frac{1}{2} & \frac{1}{2} & 0 & 0 & 0 & 0 \\ 0 & -\frac{1}{2} & \frac{1}{2} & 0 & 0 & 0 & 0 & 0 \\ \hline \frac{1}{2} & 0 & 0 & 0 & -\frac{36}{7} & -\frac{1}{7} & \frac{9}{7} & -\frac{9}{7} \\ \frac{1}{2} & 0 & 0 & 0 & -\frac{1}{7} & -\frac{1}{2} & -\frac{1}{2} & \frac{1}{2} \\ -\frac{1}{2} & 0 & 0 & 0 & \frac{9}{7} & -\frac{1}{2} & \frac{18}{7} & \frac{9}{14} \\ \frac{1}{2} & 0 & 0 & 0 & -\frac{9}{7} & \frac{1}{2} & \frac{9}{14} & \frac{3}{2} \end{array}\right] \begin{bmatrix} E_{0+} \\ E_{1+} \\ M_{1+} \\ M_{1-} \\ E_{2+} \\ E_{2-} \\ M_{2+} \\ M_{2-} \end{bmatrix}$$

$$\begin{aligned} &= \frac{1}{14}\Big[E_{2-}^*\Big(-7E_{2-}+7E_{0+}-2E_{2+}+7M_{2-}-7M_{2+}\Big)+7E_{0+}^*\Big(E_{2-}+E_{2+}+M_{2-}-M_{2+}\Big) \\ &\quad + E_{2+}^*\Big(-2E_{2-}+7E_{0+}-18(4E_{2+}+M_{2-}-M_{2+})\Big)+M_{2-}^*\Big(7E_{2-}+7E_{0+}-18E_{2+} \\ &\quad + 21M_{2-}+9M_{2+}\Big)+M_{2+}^*\Big(-7E_{2-}-7E_{0+}+9(2E_{2+}+M_{2-}+4M_{2+})\Big) \\ &\quad + 7\Big(E_{1+}^*\Big(-3E_{1+}-M_{1-}+M_{1+}\Big)+M_{1-}^*\Big(M_{1+}-E_{1+}\Big)+M_{1+}^*\Big(E_{1+}+M_{1-}+M_{1+}\Big)\Big)\Big] \end{aligned}$$

$$\check{\Sigma}(W, \cos\theta) = \Sigma(W, \cos\theta) \cdot \frac{d\sigma}{d\Omega}(W, \cos\theta) = \sum_{k=2}^{2L_{\max}} \left(a_{L_{\max}}(W)\right)_k^{\check{\Sigma}} \cdot P_k^2(\cos\theta) \text{ , i.e. } L_{\max} = 2;$$

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$$= \frac{1}{14} \Big[E_{2-}^* \Big(-7E_{2-} + 7E_{0+} - 2E_{2+} + 7M_{2-} - 7M_{2+} \Big) + 7E_{0+}^* \Big(E_{2-} + E_{2+} + M_{2-} - M_{2+} \Big)$$

$$+ E_{2+}^* \Big(-2E_{2-} + 7E_{0+} - 18(4E_{2+} + M_{2-} - M_{2+}) \Big) + M_{2-}^* \Big(7E_{2-} + 7E_{0+} - 18E_{2+}$$

$$+ 21M_{2-} + 9M_{2+} \Big) + M_{2+}^* \Big(-7E_{2-} - 7E_{0+} + 9(2E_{2+} + M_{2-} + 4M_{2+}) \Big)$$

$$+ 7\Big(E_{1+}^* \Big(-3E_{1+} - M_{1-} + M_{1+} \Big) + M_{1-}^* \Big(M_{1+} - E_{1+} \Big) + M_{1+}^* \Big(E_{1+} + M_{1-} + M_{1+} \Big) \Big) \Big]$$

$$= < P, P > + < S, D > + < D, D >$$

$$\check{\Sigma}(W,\cos\theta) = \Sigma(W,\cos\theta)\cdot\frac{d\sigma}{d\Omega}(W,\cos\theta) = \sum_{k=2}^{2L_{\mathrm{max}}} \left(a_{L_{\mathrm{max}}}(W)\right)_k^{\check{\Sigma}} \cdot P_k^2(\cos\theta)\ \text{, i.e. } L_{\mathrm{max}} = 2;$$

$(a_{L_{\mathrm{max}}})_k^{\check{\Sigma}}$ defined by matrices with $\langle \ell_1, \ell_2 \rangle$-interference blocks

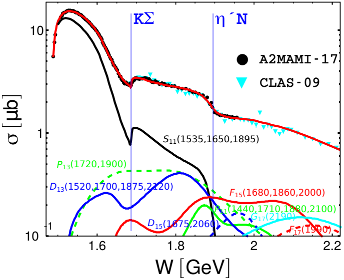
$$(a_2)_2^{\check{\Sigma}} = \left[\begin{array}{cccc} E_{0+}^* & E_{1+}^* & \ldots & M_{2-}^* \end{array}\right] \left[\begin{array}{c|ccc|cccc} 0 & 0 & 0 & 0 & \frac{1}{2} & \frac{1}{2} & -\frac{1}{2} & \frac{1}{2} \\ \hline 0 & -\frac{3}{2} & \frac{1}{2} & -\frac{1}{2} & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{2} & \frac{1}{2} & \frac{1}{2} & 0 & 0 & 0 & 0 \\ 0 & -\frac{1}{2} & \frac{1}{2} & 0 & 0 & 0 & 0 & 0 \\ \hline \frac{1}{2} & 0 & 0 & 0 & -\frac{36}{7} & -\frac{1}{7} & \frac{9}{7} & -\frac{9}{7} \\ \frac{1}{2} & 0 & 0 & 0 & -\frac{1}{7} & -\frac{1}{2} & -\frac{1}{2} & \frac{1}{2} \\ -\frac{1}{2} & 0 & 0 & 0 & \frac{9}{7} & -\frac{1}{2} & \frac{18}{7} & \frac{9}{14} \\ \frac{1}{2} & 0 & 0 & 0 & -\frac{9}{7} & \frac{1}{2} & \frac{9}{14} & \frac{3}{2} \end{array}\right] \left[\begin{array}{c} E_{0+} \\ E_{1+} \\ M_{1+} \\ M_{1-} \\ E_{2+} \\ E_{2-} \\ M_{2+} \\ M_{2-} \end{array}\right]$$

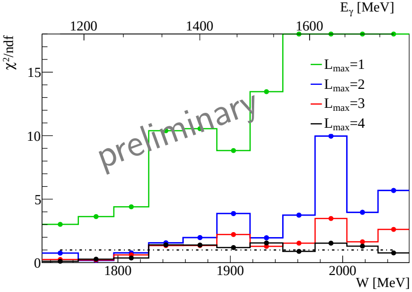
$$= \frac{1}{14}\Big[E_{2-}^*\left(-7E_{2-} + 7E_{0+} - 2E_{2+} + 7M_{2-} - 7M_{2+}\right) + 7E_{0+}^*\left(E_{2-} + E_{2+} + M_{2-} - M_{2+}\right)$$
$$+ E_{2+}^*\left(-2E_{2-} + 7E_{0+} - 18(4E_{2+} + M_{2-} - M_{2+})\right) + M_{2-}^*\Big(7E_{2-} + 7E_{0+} - 18E_{2+}$$
$$+ 21M_{2-} + 9M_{2+}\Big) + M_{2+}^*\left(-7E_{2-} - 7E_{0+} + 9(2E_{2+} + M_{2-} + 4M_{2+})\right)$$
$$+ 7\left(E_{1+}^*\left(-3E_{1+} - M_{1-} + M_{1+}\right) + M_{1-}^*\left(M_{1+} - E_{1+}\right) + M_{1+}^*\left(E_{1+} + M_{1-} + M_{1+}\right)\right)\Big]$$
$$= \langle P, P \rangle + \langle S, D \rangle + \langle D, D \rangle$$

Y.W., F. Afzal, A. Thiel and R. Beck, EPJ A 53: 86 (2017) → talk by Y. Wunderlich, Tuesday 16:30

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

L. Tiator et al., EPJA 54 (2018) 210





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

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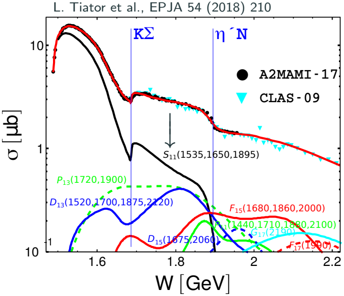
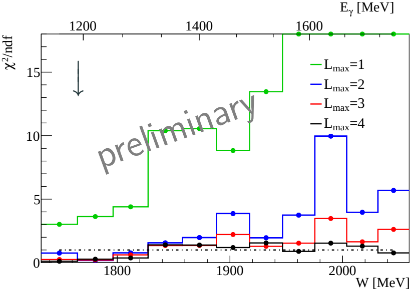
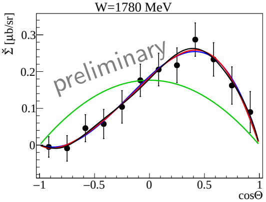
$$\check{\Sigma}(W,\cos\theta) = \Sigma(W,\cos\theta)\cdot\frac{d\sigma}{d\Omega}(W,\cos\theta) = \sum_{k=2}^{2L_{max}}(a_L(W))_k\cdot P_k^2(\cos\theta)$$



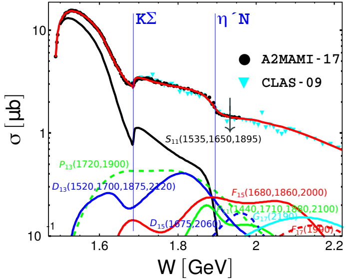


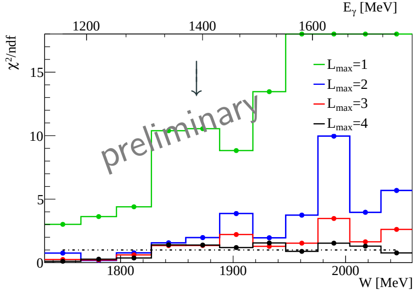


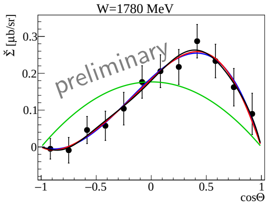
Dominant partial wave contributions (Σ (CBELSA/TAPS), $\gamma p \to p\eta$)

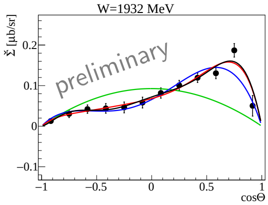
$$\check{\Sigma}(W, \cos\theta) = \Sigma(W, \cos\theta) \cdot \frac{d\sigma}{d\Omega}(W, \cos\theta) = \sum_{k=2}^{2L_{max}} (a_L(W))_k \cdot P_k^2(\cos\theta)$$

L. Tiator et al., EPJA 54 (2018) 210





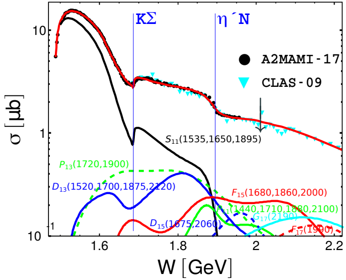


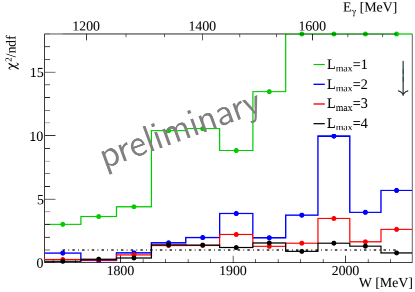


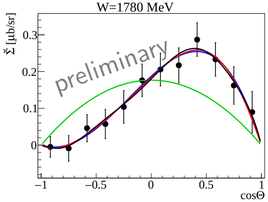
Dominant partial wave contributions (Σ (CBELSA/TAPS), $\gamma p \to p\eta$)

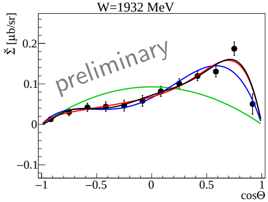
$$\check{\Sigma}(W, \cos\theta) = \Sigma(W, \cos\theta) \cdot \frac{d\sigma}{d\Omega}(W, \cos\theta) = \sum_{k=2}^{2L_{max}} (a_L(W))_k \cdot P_k^2(\cos\theta)$$

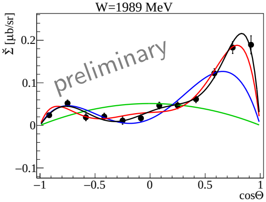
L. Tiator et al., EPJA 54 (2018) 210



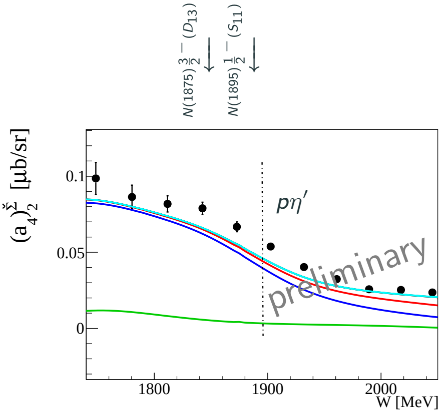








$$\check{\Sigma}(W,\cos\theta) = \Sigma(W,\cos\theta) \cdot \frac{d\sigma}{d\Omega}(W,\cos\theta) = \sum_{k=2}^{2L_{max}} (a_L(W))_k \cdot P_k^2(\cos\theta)$$

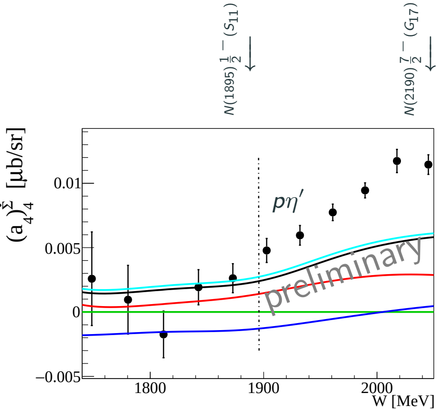


Compare extracted fit coefficient to BnGa-2014-02 prediction

$$(a_5)_2^{\check{\Sigma}} = \langle P,P\rangle + \langle S,D\rangle + \langle D,D\rangle + \langle P,F\rangle + \langle F,F\rangle + \langle D,G\rangle + \langle G,G\rangle + \langle F,H\rangle + \langle H,H\rangle$$

S-wave is important for the $p\eta$ final state.

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



Compare extracted fit coefficient to BnGa-2014-02 prediction

$$(a_5)_4^{\check{\Sigma}} = \langle D,D\rangle$$
$$+\langle P,F\rangle + \langle F,F\rangle$$
$$+\langle \boldsymbol{S},\boldsymbol{G}\rangle + \langle D,G\rangle + \langle G,G\rangle$$
$$+\langle P,H\rangle + \langle F,H\rangle + \langle H,H\rangle$$

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

Evidence for $N(1895)\frac{1}{2}^{-}(S_{11})$ resonance

Strong η' cusp in η S-wave

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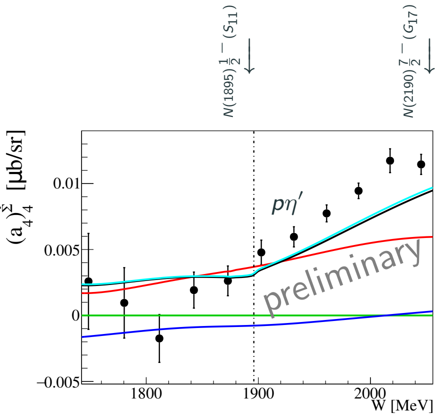
$$\check{\Sigma}(W, \cos\theta) = \Sigma(W, \cos\theta) \cdot \frac{d\sigma}{d\Omega}(W, \cos\theta) = \sum_{k=2}^{2L_{max}} (a_L(W))_k \cdot P_k^2(\cos\theta)$$



Compare extracted fit coefficient to BnGa-2017 solution

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

$+ \langle P, F \rangle + \langle F, F \rangle$ (red)

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

$+ \langle P, H \rangle + \langle F, H \rangle + \langle H, H \rangle$ (cyan)

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

Evidence for $N(1895)\frac{1}{2}^-(S_{11})$ resonance

Strong η' cusp in η S-wave

new BnGa-2017 fit to Σ (CBELSA/TAPS, CLAS) and $\frac{d\sigma}{d\Omega}$ (A2) data

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

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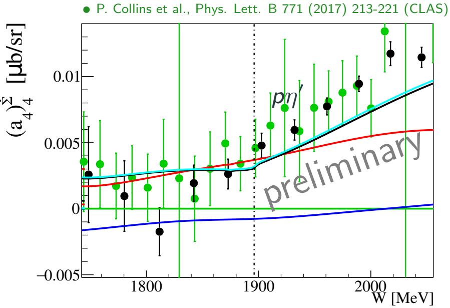
$$\check{\Sigma}(W, \cos\theta) = \Sigma(W, \cos\theta) \cdot \frac{d\sigma}{d\Omega}(W, \cos\theta) = \sum_{k=2}^{2L_{max}} (a_L(W))_k \cdot P_k^2(\cos\theta)$$

Compare extracted fit coefficient to BnGa-2017 solution



$$(a_5)_4^{\check{\Sigma}} = \langle D, D\rangle$$
$$+\langle P, F\rangle + \langle F, F\rangle$$
$$+\langle \boldsymbol{S}, \boldsymbol{G}\rangle + \langle D, G\rangle + \langle G, G\rangle$$
$$+\langle P, H\rangle + \langle F, H\rangle + \langle H, H\rangle$$

Full angular coverage is very important for $< S, G >$ interference

new BnGa-2017 fit to Σ (CBELSA/TAPS, CLAS) and $\frac{d\sigma}{d\Omega}$ (A2) data

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

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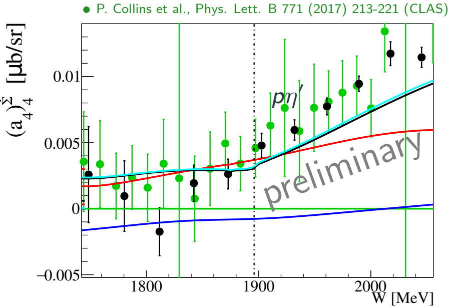
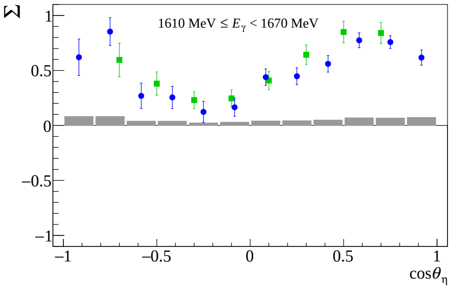
$$\check{\Sigma}(W,\cos\theta) = \Sigma(W,\cos\theta)\cdot\frac{d\sigma}{d\Omega}(W,\cos\theta) = \sum_{k=2}^{2L_{max}} (a_L(W))_k \cdot P_k^2(\cos\theta)$$

Compare extracted fit coefficient to BnGa-2017 solution





Full angular coverage is very important for $< S, G >$ interference

new BnGa-2017 fit to Σ (CBELSA/TAPS, CLAS) and $\frac{d\sigma}{d\Omega}$ (A2) data

$\gamma p \to p\eta$: The beam asymmetry Σ

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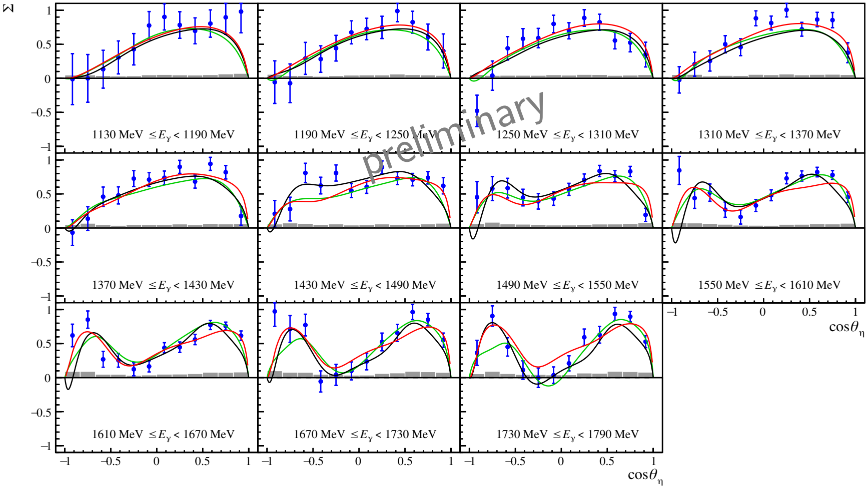
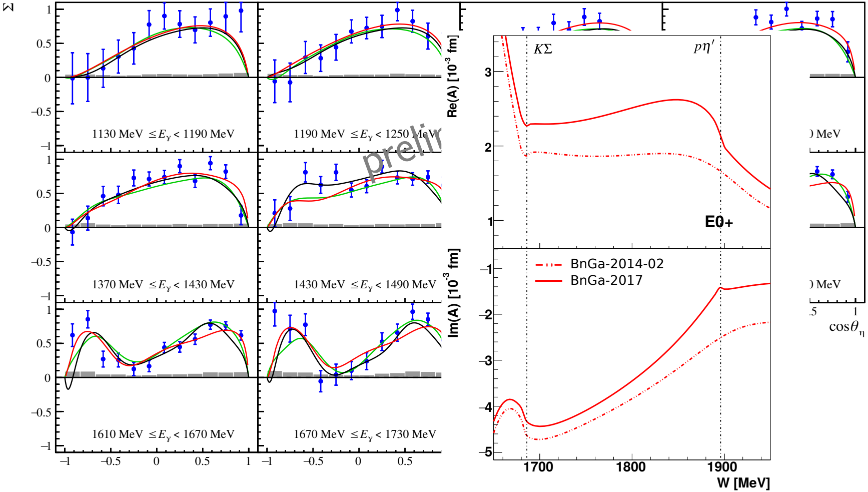


- CBELSA/TAPS data (F. Afzal et al.)
- BnGa-2017 (A.V. Anisovich et al., Phys. Lett. B 785 (2018) 626)
- JüBo-2017 (D. Rönchen et al., Eur. Phys. J. A 54 (2018) 110)
- ηMAID-2018 (L. Tiator et al. Eur. Phys. J. A 54 (2018) 210)

new η PWA fits discussed in afternoon session (Tuesday, 14:30-16:00)!

$\gamma p \to p\eta$: The beam asymmetry Σ



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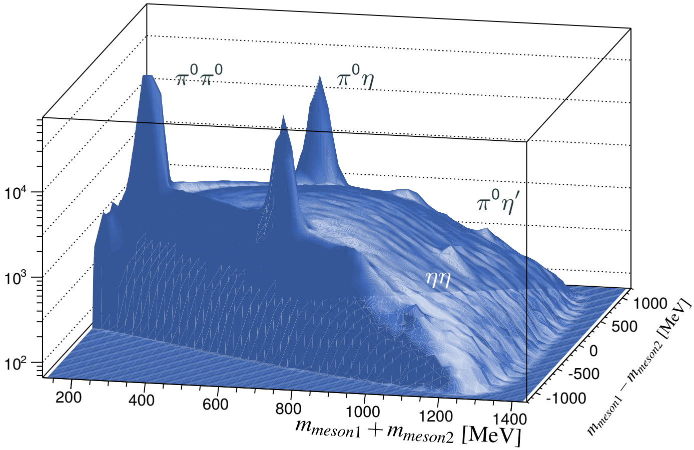
new η PWA fits discussed in afternoon session (Tuesday, 14:30-16:00)!

Polarization observables in multi-meson final states

CBELSA/TAPS experiment focuses on neutral meson final states:

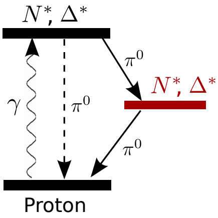
- double meson photoproduction: $\pi^0\pi^0, \pi^0\eta, \eta\eta\ \ldots$

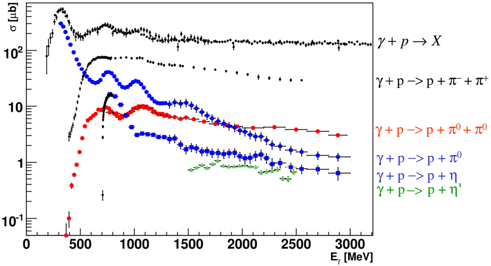
$p\gamma\gamma\gamma\gamma$ final state

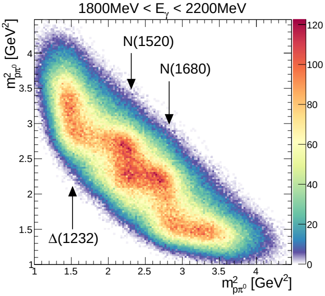


$\gamma p \to p\pi^0\pi^0$: Importance of cascade decays

- Multi-meson final states like $p\pi^0\pi^0$ are preferred at higher energies
- help to observe cascading decays
  $\to$ probe high mass region where missing masses are predicted

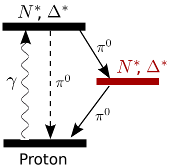




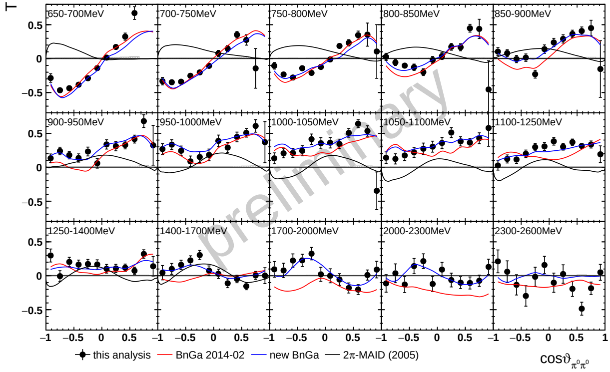


$\gamma p \to p\pi^0\pi^0$: Importance of cascade decays

- Two quartets of baryon resonances (N^* and Δ^*) observed in the fourth resonance region:
  $N(1880)\frac{1}{2}^+, N(1900)\frac{3}{2}^+, N(2000)\frac{5}{2}^+, N(1990)\frac{7}{2}^+$
  $\Delta(1910)\frac{1}{2}^+, \Delta(1920)\frac{3}{2}^+, \Delta(1905)\frac{5}{2}^+, \Delta(1950)\frac{7}{2}^+$
- N^* resonances decay more often into orbitally excited intermediate resonances ($\approx 23\%$) than Δ^*



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



data analyzed in full 3 body kinematics

new fit performed by BnGa
$\to$ new branching ratios

$\to$ see talk by T. Seifen
Wednesday 17:00

New results have entered the PDG (2017 $\rightarrow$ 2018)

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⋆: PDG-upgrades based on the BnGa-PWA including latest polarization data from several collaborations: CBELSA/TAPS, A2, CLAS, GRAAL ...

		overall	$N\gamma$	$N\pi$	$\Delta\pi$	$N\sigma$	$N\eta$
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)	$7/2^-$	∗∗∗∗	∗∗∗∗	∗∗∗∗	⋆⋆⋆⋆	⋆⋆	⋆
...							

Summary and Outlook

Summary and Outlook

Summary:

- Many reactions like $\gamma p \rightarrow p\pi^0, p\eta, p\pi^0\pi^0$ have been measured with polarized photons and protons with the CBELSA/TAPS experiment
- Data for the observables Σ, G, E, T, P and H have been published for π^0 photoproduction, other channels will follow soon
- APD-Upgrade of the Crystal Barrel detector successfully completed
  $\rightarrow$ data from new beamtimes look promising
  $\rightarrow$ data also already taken with pol. neutron target (talk by B. Krusche, Thursday 14:30)
- Data have been included in the different analyses and the multipoles are converging

Outlook:

- More data will be taken for T, P, H with coherent edge at 1600 MeV
- Analysis of different final states ($p\pi^0, p\eta, p\eta', p\pi^0\pi^0, p\pi^0\eta$...) and PWA of the data

Enjoy your stay in Bonn!

Backup Slides

$\gamma p \to p\pi^0\pi^0$: Importance of cascade decays

- Two quartets of baryon resonances (N^* and Δ^*) observed in the fourth resonance region:
  $N(1880)\frac{1}{2}^+, N(1900)\frac{3}{2}^+, N(2000)\frac{5}{2}^+, N(1990)\frac{7}{2}^+$
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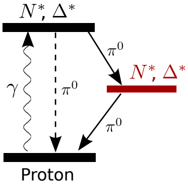
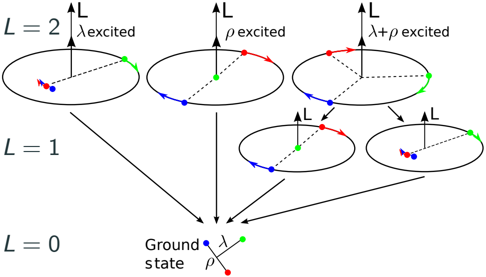


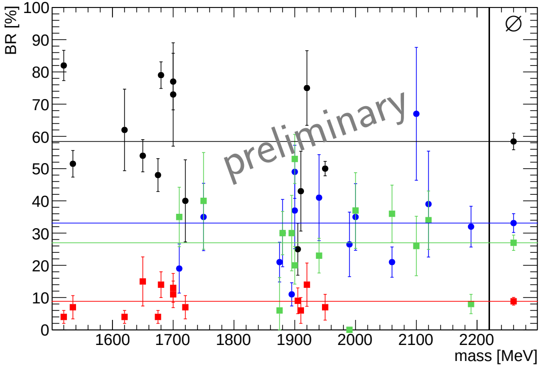


A. Thiel et al., Phys. Rev. Lett. 114, 091803

- N^* resonances decay more often into orbitally excited intermediate resonances ($\approx 23\%$) than Δ^*
- N^* resonances contain sizeable component in their wave function in which two oscillators are excited
- favors three-body dynamics and challenges quark-diquark model

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

- Polarization observables T, P, H were determined
- baryon excitations can be divided into one-oscillator and mixed-oscillator excitations
- one-oscillator excitations have higher BR into the ground states ($N\pi$, $\Delta\pi$) than into excited states ($N(1440)\pi$, $N(1520)\pi$, $N(1535)\pi$, $N(1680)\pi$ or $N\sigma$)
- mixed-oscillator excitations like to de-excite in a two step process



One-oscillator excitations decay into the ground states

One-oscillator excitations decay into excited states

Mixed-oscillator excitations decay into the ground states

Mixed-oscillator excitations decay into the excited states

T. Seifen et al., publication in preparation

→ see talk by T. Seifen, Wed. 15:00