

Baryon spectroscopy from analysis of meson photoproduction data

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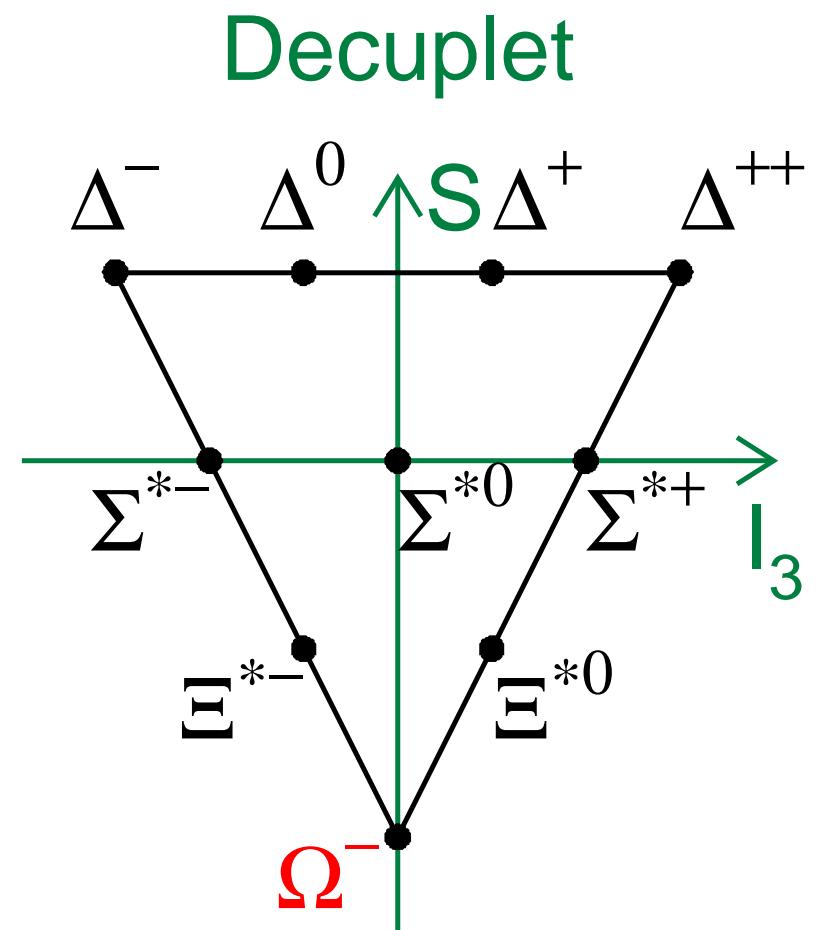
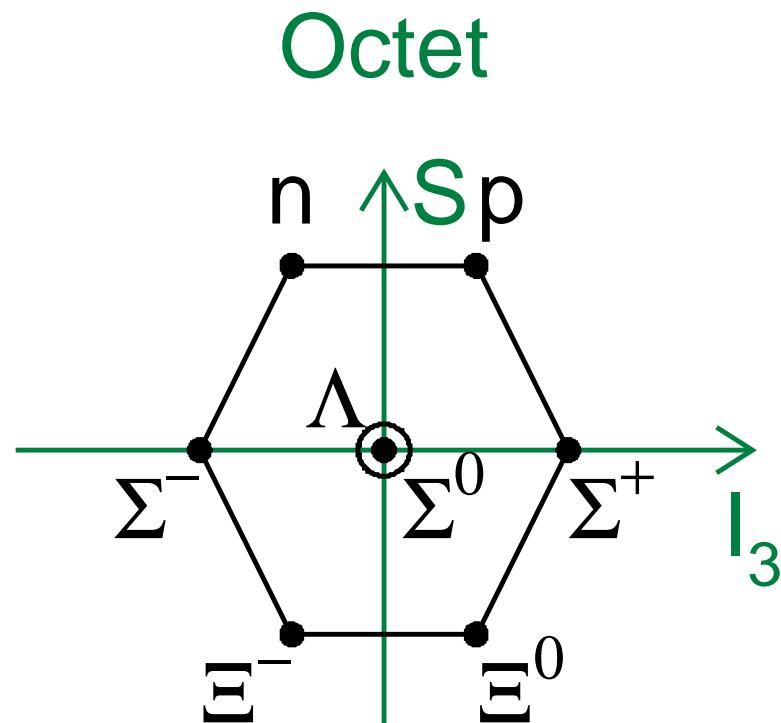
PNPI NRC Kurchatov Institute (Russia)

HISKP (Bonn University)

23-27 June 2014

3 generations of quarks

$$3 \otimes 3 \otimes 3 = 10_S \oplus 8_M \oplus 8_M \oplus 1_A$$



0.0.1 The spin wave function

$$S = 3/2 : \quad \uparrow\uparrow\uparrow \quad \text{fully symmetric}$$

$$S = 1/2 : \quad \frac{1}{\sqrt{2}}(\uparrow\downarrow - \downarrow\uparrow)\uparrow \quad \text{mixed symmetry}$$

0.0.2 The flavor wave function

$$\mathrm{SU}(2) \otimes \mathrm{SU}(3) = \mathrm{SU}(6).$$

$$6 \otimes 6 \otimes 6 = 56_S \oplus 70_M \oplus 70_M \oplus 20_A$$

$$56 = {}^410 \oplus {}^28.$$

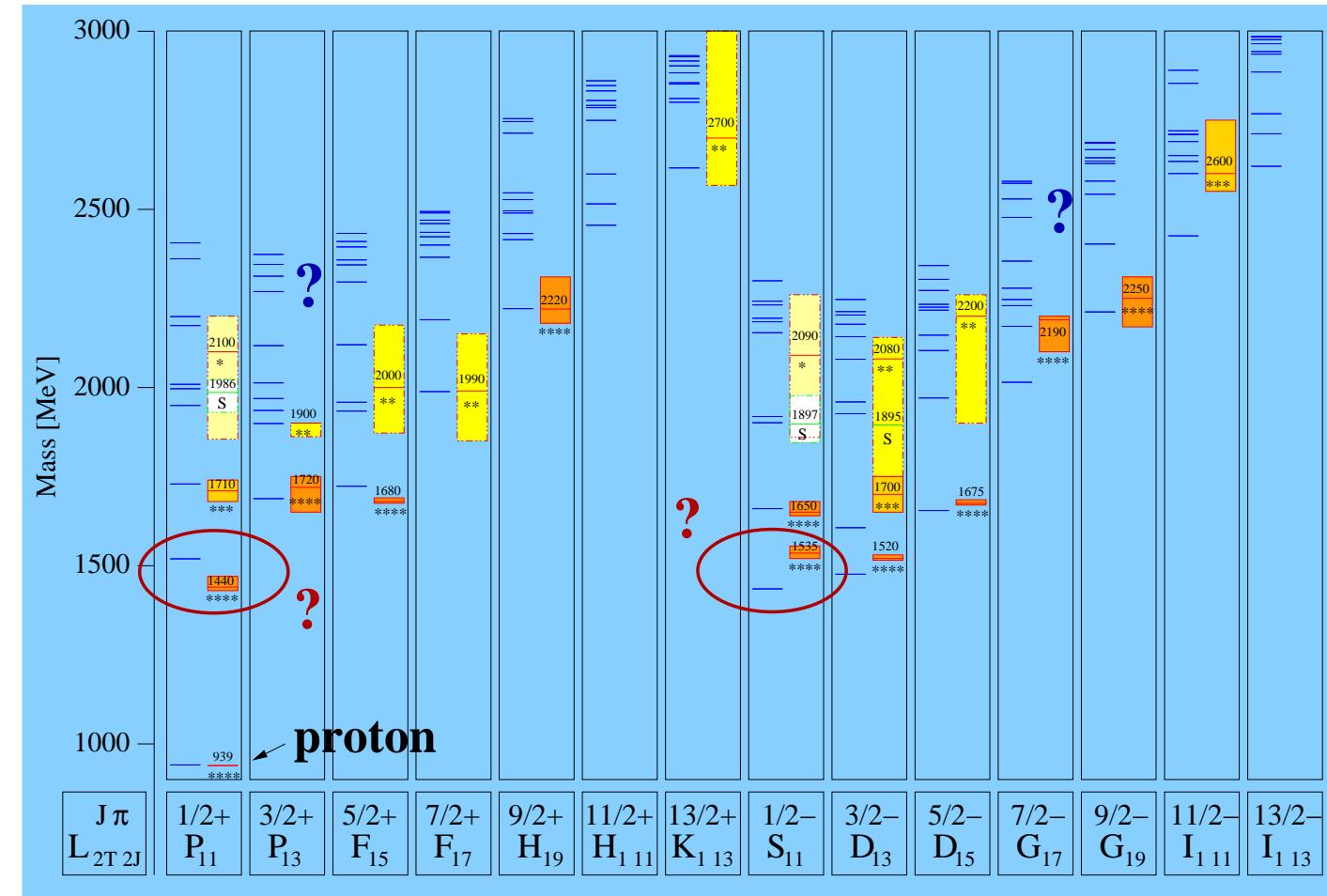
$$70 = {}^210 \oplus {}^48 \oplus {}^28 \oplus {}^21.$$

$$20 = {}^28 \oplus {}^41.$$

3 rd band	(56, 1 ₃ ⁻)	S_1	$S = 3/2; L = 1; N=1$	$\Delta_{1/2-}(1900)$	$\Delta_{3/2-}(1940)$	$\Delta_{5/2-}(1930)$		1950 MeV
		S_2	$S = 1/2; L = 1; N=1$	N_{1/2-}(1895)	N_{3/2-}(1875)	Δ_{5/2-}(2223)		1866 MeV
	(70, 3 ₃ ⁻)	S_3	$S = 1/2; L = 3; N=0$			$\Delta_{7/2-}(2200)$		2223 MeV
		S_5	$S = 3/2; L = 3; N=0$	N_{3/2-}(2150)	N_{5/2-}(2060)	$N_{7/2-}(2190)$		2223 MeV
		S_4	$S = 1/2; L = 3; N=0$			$N_{9/2-}(2250)$		2151 MeV
	(56, 3 ₃ ⁻), (20, 3 ₃ ⁻), (70, 2 ₃ ⁻), (70, 1 ₃ ⁻), (70, 1 ₃ ⁻), (20, 1 ₃ ⁻) :				Many states predicted, no candidates known			
2 nd band	(56, 2 ₂ ⁺)	S_1	$S = 3/2; L = 2; N=0$	$\Delta_{1/2+}(1910)$	$\Delta_{3/2+}(1920)$	$\Delta_{5/2+}(1905)$	$\Delta_{7/2+}(1950)$	1950 MeV
		S_2	$S = 1/2; L = 2; N=0$		$N_{3/2+}(1720)$	$N_{5/2+}(1620)$		1779 MeV
	(70, 2 ₂ ⁺)	S_3	$S = 1/2; L = 2; N=0$		$\Delta_{3/2+}$	$\Delta_{5/2+}$		1950 MeV
		S_5	$S = 3/2; L = 2; N=0$	N_{1/2+}(1880)	$N_{3/2+}(1960)$	N_{5/2+}(2000)	$N_{7/2+}(1990)$	1950 MeV
		S_4	$S = 1/2; L = 2; N=0$		$N_{3/2+}(1900)$	$N_{5/2+}(1860)$		1866 MeV
	(20, 1 ₂ ⁺)	S_6	$S = 1/2; L = 1; N=0$	$N_{1/2+}$	$N_{3/2+}$			~1800 MeV
	(56, 0 ₂ ⁺)	S_1	$S = 3/2; L = 0; N=1$		$\Delta_{3/2+}(1600)$			1631 MeV
		S_2	$S = 1/2; L = 0; N=1$	$N_{1/2+}(1440)$				1423 MeV
	(70, 0 ₂ ⁺)	S_3	$S = 1/2; L = 0; N=1$	$\Delta_{1/2+}$				1631 MeV
		S_5	$S = 3/2; L = 0; N=1$		$N_{3/2+}$			1631 MeV
		S_4	$S = 1/2; L = 0; N=1$	$N_{1/2+}$				1530 MeV
1 st band	(70, 1 ₁ ⁻)	S_3	$S = 1/2; L = 1; N=0$	$\Delta_{1/2-}(1620)$	$\Delta_{3/2-}(1700)$			1631 MeV
		S_5	$S = 3/2; L = 1; N=0$	$N_{1/2-}(1650)$	$N_{3/2-}(1700)$	$N_{5/2-}(1675)$		1631 MeV
		S_4	$S = 1/2; L = 1; N=0$	$N_{1/2-}(1535)$	$N_{3/2-}(1520)$			1530 MeV
Ground state	(56, 0 ₀ ⁺)	S_1	$S = 3/2; L = 0; N=0$		$\Delta_{3/2+}(1232)$			1232 MeV
		S_2	$S = 1/2; L = 0; N=0$	$N_{1/2+}(939)$				939 MeV

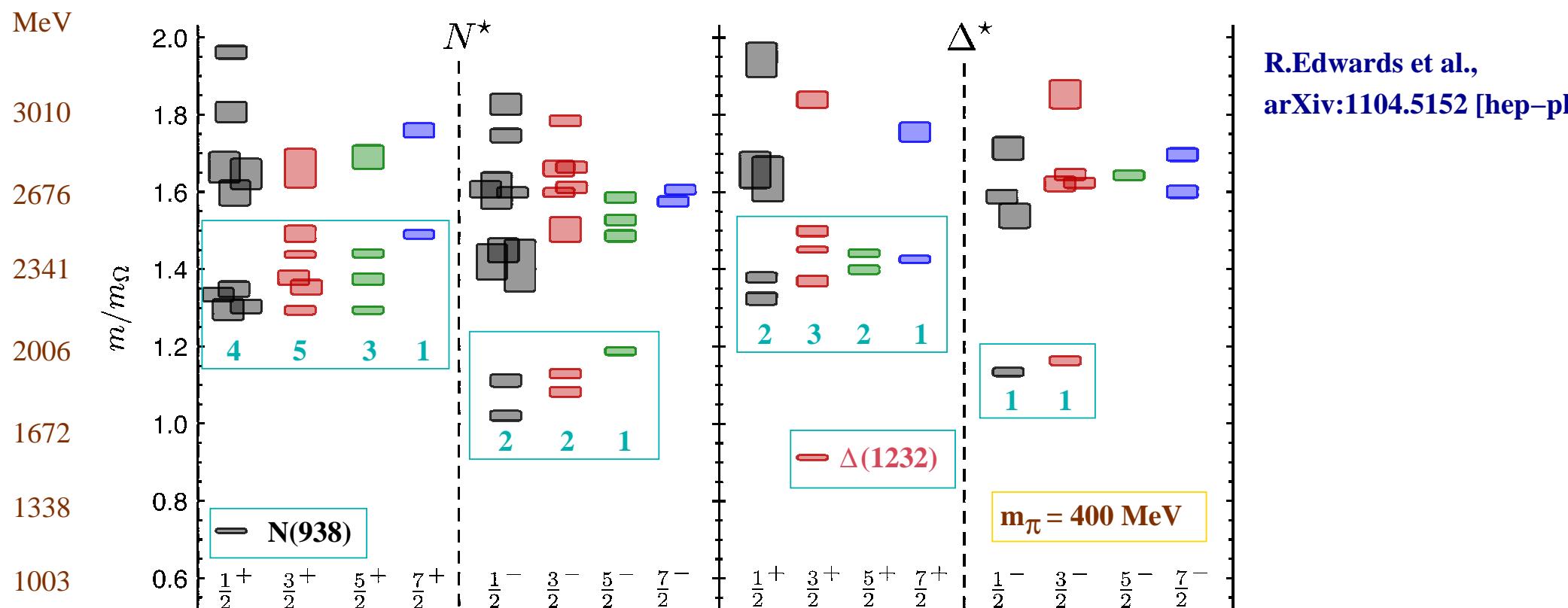
N^{*}- resonances in the quark model

U. Loering, B. Metsch, H. Petry et al. (Bonn)



- ↔
- Constituent quarks
- Confinement-potential
- Residual interaction

0.0.3 Baryons on the lattice



- a Lattice and quark models predict more states than observed (missing resonances)
- b Lattice and quark models predict even-odd staggering (exp: parity doublets)
- c $3/2^+$: 5 states expected, $N(1720)3/2^+$, $N(1900)3/2^+$, tentative $N(1960)3/2^+$, $N(2200)3/2^+$

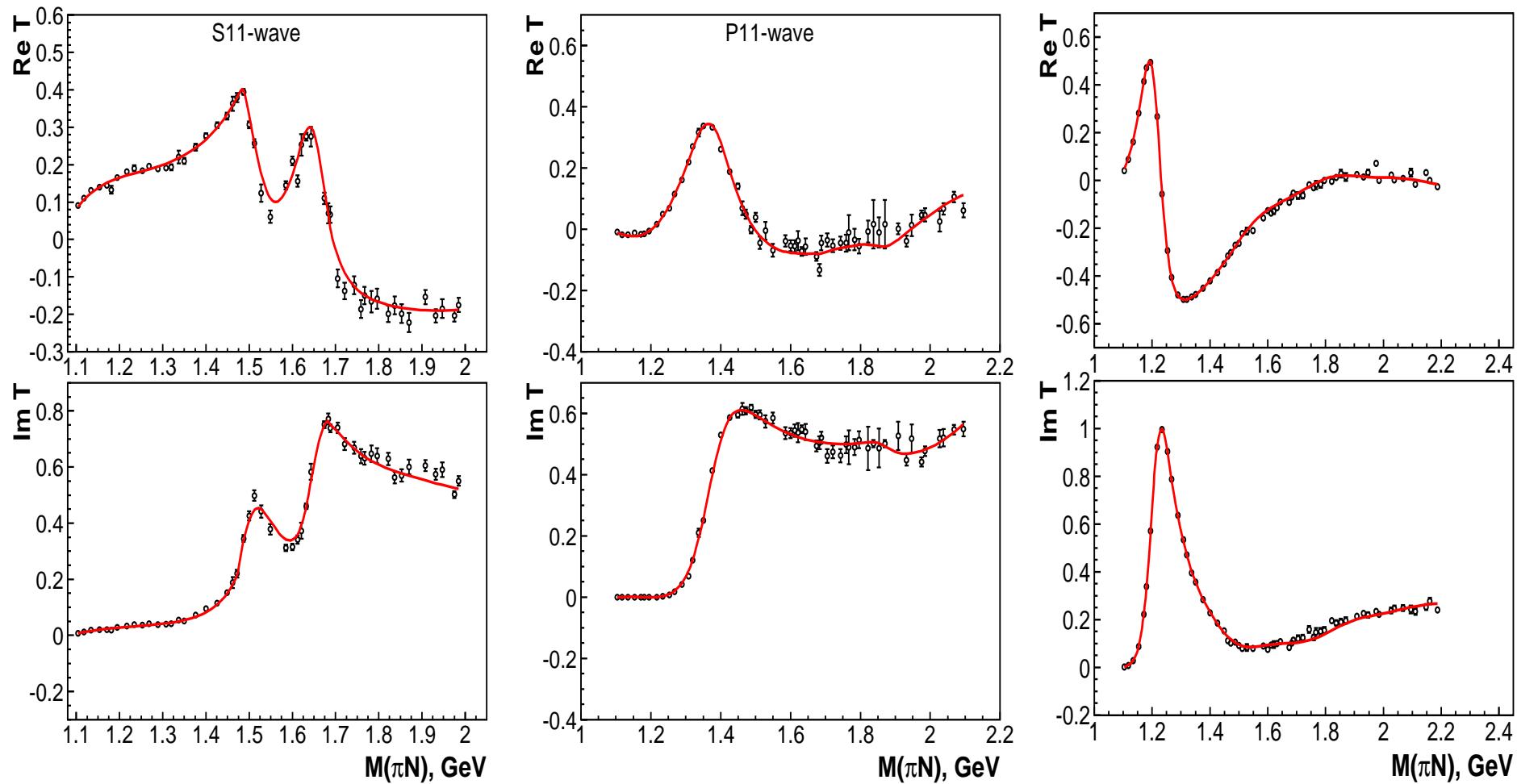
**Before recent time our knowledge of baryons is based on the analysis of
 $\pi N \rightarrow \pi N$ data**

Hoehler et al.(Karlsruhe-Helsinki), Cutcosky et al.(Carnegie Mellon), Arndt et al.(George Washington)

The latest analysis of SAID (GWU) of πN elastic data as well as $\gamma p \rightarrow \pi^0 p$ and $\gamma p \rightarrow \pi^+ n$ did
not confirm the set of states observed in earlier analysis of
 πN elastic data. CLAS (M. Dugger et al.). Phys.Rev.C79:065206,2009.

State	PDG (Pole position)(MeV)		Bonn-Gatchina PWA (MeV)	
	Mass	Width	Mass	Width
$P_{11}(1710)***$	1720 ± 50	230 ± 150	1687 ± 17	160 ± 25
$P_{33}(1600)***$	1550 ± 100	300 ± 100	1500 ± 25	230 ± 50
$P_{33}(1920)***$	1900 ± 50	200^{+100}_{-50}	1890 ± 30	300 ± 60
$D_{13}(1720)***$	1680 ± 50	100 ± 50	1770 ± 40	420 ± 180
$D_{13}(1875)$			1860 ± 25	200 ± 25
$P_{11}(1880)$			1860 ± 35	235 ± 65
$S_{11}(1895)$			1900 ± 15	90^{+30}_{-15}
$P_{13}(1900)$			1900 ± 30	260^{+100}_{-60}
$D_{15}(2060)$			2040 ± 15	390 ± 25

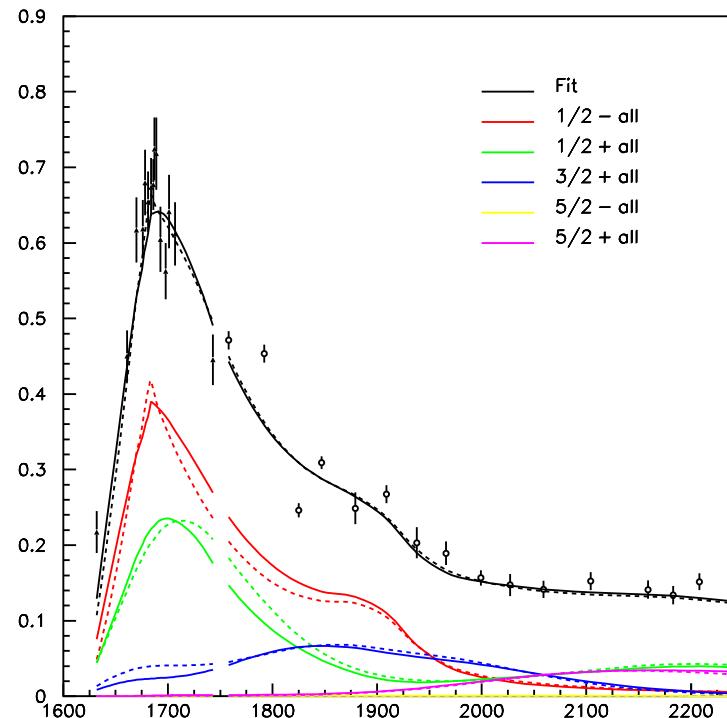
$N\pi \rightarrow N\pi S_{11}, p_{11}$ and P_{33} waves



The fit of the the $\pi^- p \rightarrow K\Lambda$ reaction

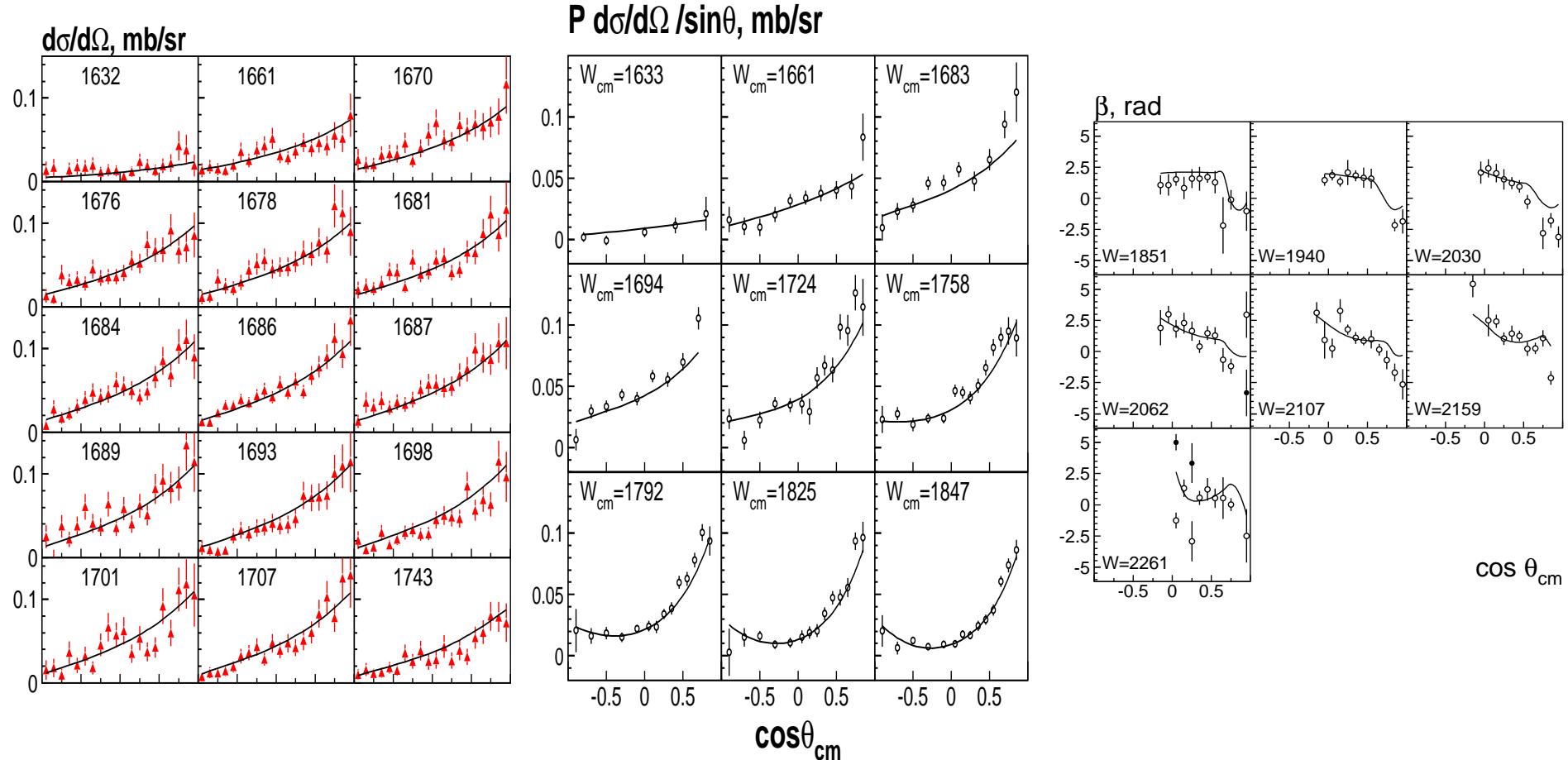
Full experiment for $\pi N \rightarrow K\Lambda$:
differential cross section, analyzing
power, rotation parameter.

A clear evidence for resonances which
are hardly seen (or not seen) in
the elastic reactions: $N(1710)P_{11}$,
 $N(1900)P_{13}$,



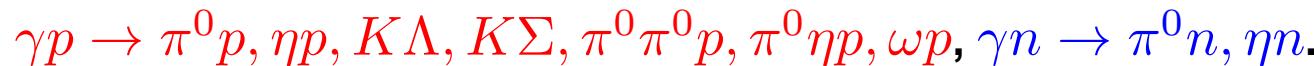
The total cross section for the reaction $\pi^- p \rightarrow K^0 \Lambda$ and contributions from leading
partial waves.

The fit of the the $\pi^- p \rightarrow K\Lambda$ reaction (differential cross section)



Meson Photoproduction experiments

- **GRAAL (Grenoble): Polarized beam. Ideal for the beam asymmetry and double polarization observables for hyperon final states.**



- **MAMI (Mainz): High statistic, very good detector of neutral particles: (Crystal Ball):**
 $\gamma p \rightarrow \pi^0 p, K\Lambda, K\Sigma, \pi^0 \pi^0 p, \pi^0 \eta p, \gamma n \rightarrow \eta n, \pi^0 n, \pi^0 \pi^0 n, \pi^0 \eta n.$

Energy is only up to W=1.85 GeV. Analysis: MAID and Bonn-Gatchina.

- **CB-ELSA (Bonn): Moderate statistic, very good detector of neutral particles: (Crystal Barrel):** $\gamma p \rightarrow \pi^0 p, \eta p, \pi^0 \pi^0 p, \pi^0 \eta p, \omega p, \gamma n \rightarrow \eta n, \pi^0 n$. **Energy is up to W=2.3 GeV. Analysis: Bonn-Gatchina.**

- **CLAS (JLAB): High statistic, very good detector of charged particles:**
 $\gamma p \rightarrow \pi^- n, K\Lambda, K\Sigma, \pi^+ \pi^- p, \omega p$. **As missing mass data** $\gamma p \rightarrow \pi^0 p, \eta p$.
Data on deuterium target. Energy is up to W=2.5 GeV.
Analysis: EBAC, SAID and recently Bonn-Gatchina.

- The main task: search for new baryon resonances
- Polarization data are sensitive to weak signals
- Double polarization data are available $C_x, C_z, O_x, O_z, E, G, H$.
- Double polarization observables (assuming XZ is the reaction plane)

Photon		Target			Recoil			Target + Recoil			
	—	—	—	—	x'	y'	z'	x'	x'	z'	z'
	—	x	y	z	—	—	—	x	z	x	z
unpol.	σ_0	0	T	0	0	P	0	$T_{x'}$	$-L_{x'}$	$T_{z'}$	$L_{z'}$
lin.pol.	$-\Sigma$	H	$-P$	$-G$	$O_{x'}$	$-T$	$O_{z'}$	$-L_{z'}$	$T_{z'}$	$-L_{x'}$	$-T_{x'}$
circ.pol.	0	F	0	$-E$	$-C_{x'}$	0	$-C_{z'}$	0	0	0	0

The main baryon partial wave analysis groups

- **SAID (GWU,USA):** Analysis of elastic πN data in K-matrix approach. (energy independent method). Energy dependent analysis of $\gamma n \rightarrow \pi N, \eta N$ final states. Parameterization of partial waves as a K-matrix/P-vector approach.
- **MAID (Mainz):** Energy dependent analysis of photoproduction data on γN to πN , ηp , $K\Lambda$, $K\Sigma$. Parameterization of partial waves as sum of Breit-Wigner amplitudes with dispersion corrections. Development of energy independent approach for photoproduction.
- **Bonn-Gatchina:** Energy dependent analysis of pion induced (inelastic) and almost all photoproduction data. K-matrix/P-vector and now N/D-dispersion approach. Minimization: χ^2 for 2 body final state and maximum likelihood for multi-body final states. Development of energy independent approach for photoproduction.
- **Juelich group:** Energy dependent approach. Pion induced data (elastic and inelastic), $\gamma p \rightarrow \pi N$ (all data) and $\gamma p \rightarrow K\Lambda$ (low energy). Unitarity, analyticity and chiral constraints.
- **Other PWA groups:** OSAKA (T. Sato), Giessen (V. Shklyar), M. Manley (Kent Uni)

Baryon data base

DATA	MAID	SAID	BnGa
$\pi N \rightarrow \pi N$ ampl.	SAID energy fixed	all data	SAID or Hoehler energy fixed
$\gamma p \rightarrow \pi N$	$\frac{d\sigma}{d\Omega}, \Sigma, T, P, E$		+G, H, E
$\gamma n \rightarrow \pi N$	$\frac{d\sigma}{d\Omega}, \Sigma, T, P$		$\frac{d\sigma}{d\Omega}, \Sigma, T, P$
$\gamma n \rightarrow \eta n$			$\frac{d\sigma}{d\Omega}, \Sigma$
$\gamma p \rightarrow \eta p$	$\frac{d\sigma}{d\Omega}, \Sigma, T$	$\frac{d\sigma}{d\Omega}, \Sigma$	$\frac{d\sigma}{d\Omega}, \Sigma, T, P, H, E$
$\gamma p \rightarrow K^+ \Lambda$	$\frac{d\sigma}{d\Omega}, P$	-	$\frac{d\sigma}{d\Omega}, \Sigma, P, T, C_x, C_z, O_{x'}, O_{z'}$
$\gamma p \rightarrow K^+ \Sigma^0$	$\frac{d\sigma}{d\Omega}, P$	-	$\frac{d\sigma}{d\Omega}, \Sigma, P, C_x, C_z$
$\gamma p \rightarrow K^0 \Sigma^+$	-	-	$\frac{d\sigma}{d\Omega}, \Sigma, P$
$\pi^- p \rightarrow \eta n$	-	$\frac{d\sigma}{d\Omega}$	$\frac{d\sigma}{d\Omega}$
$\pi^- p \rightarrow K^0 \Lambda$	-	-	$\frac{d\sigma}{d\Omega}, P, \beta$
$\pi^- p \rightarrow K^0 \Sigma^0$	-	-	$\frac{d\sigma}{d\Omega}, P$
$\pi^+ p \rightarrow K^+ \Sigma^+$	-	-	$\frac{d\sigma}{d\Omega}, P, \beta$
$\pi^- p \rightarrow \pi^0 \pi^0 n$	-	-	$\frac{d\sigma}{d\Omega}$
$\gamma p \rightarrow \pi^0 \pi^0 p$	-	-	$\frac{d\sigma}{d\Omega}, \Sigma, E, I_c, I_s, G$
$\gamma p \rightarrow \pi^0 \eta p$	-	-	$\frac{d\sigma}{d\Omega}, \Sigma, I_c, I_s$
$\gamma p \rightarrow \omega p$	-	-	$\frac{d\sigma}{d\Omega}, \Sigma, E, G, \rho_{ij}^0, \rho_{ij}^2, \rho_{ij}^2$

Bonn-Gatchina partial wave analysis group:

A. Anisovich, E. Klempt, V. Nikonov, A. Sarantsev, U. Thoma, I. Denisenko

<http://pwa.hiskp.uni-bonn.de/>



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Bonn-Gatchina Partial Wave Analysis



Address: Nussallee 14-16, D-53115 Bonn Fax: (+49) 228 / 73-2505

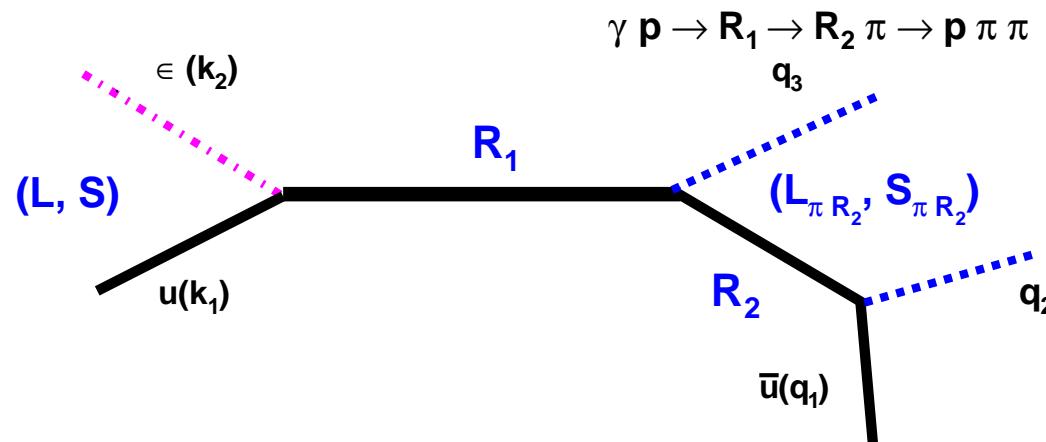
<u>Data Base</u>	<u>Meson Spectroscopy</u>	<u>Baryon Spectroscopy</u>	<u>NN-interaction</u>	<u>Formalism</u>
Analysis of Other Groups <ul style="list-style-type: none">• SAID• MAID• Giessen Uni	BG PWA <ul style="list-style-type: none">• Publications• Talks• Contacts		Useful Links <ul style="list-style-type: none">• SPIRES• PDG Homepage• Durham Data Base• Bonn Homepage	
<u>CB-ELSA Homepage</u>				

Responsible: Dr. V. Nikonov, E-mail: nikonov@hiskp.uni-bonn.de
Last changes: January 26th, 2010.

Energy dependent approach

$$A(s, t) = \sum_{\beta\beta'n} A_n^{\beta\beta'}(s) Q_{\mu_1 \dots \mu_n}^{(\beta)} F_{\nu_1 \dots \nu_n}^{\mu_1 \dots \mu_n} Q_{\nu_1 \dots \nu_n}^{(\beta')}$$

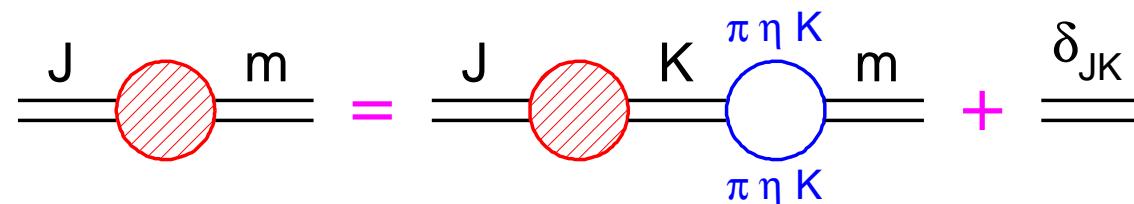
1. Correlations between angular part and energy part are under control
2. Unitarity and analyticity can be introduced from the beginning
3. Parameters can be fixed from a combined fit of many reactions



$$\bar{u}(q_1) \tilde{N}_{\alpha_1 \dots \alpha_n}(R_2 \rightarrow \mu N) F_{\beta_1 \dots \beta_n}^{\alpha_1 \dots \alpha_n}(q_1 + q_2) \tilde{N}_{\gamma_1 \dots \gamma_m}^{(j)\beta_1 \dots \beta_n}(R_1 \rightarrow \mu R_2)$$

$$F_{\xi_1 \dots \xi_m}^{\gamma_1 \dots \gamma_m}(P) V_{\xi_1 \dots \xi_m}^{(i)\mu}(R_1 \rightarrow \gamma N) u(k_1) \varepsilon_\mu$$

N/D based (D-matrix) analysis of the data



$$D_{jm} = D_{jk} \sum_{\alpha} B_{\alpha}^{km}(s) \frac{1}{M_m - s} + \frac{\delta_{jm}}{M_j^2 - s} \quad \hat{D} = \hat{\kappa}(I - \hat{B}\hat{\kappa})^{-1}$$

$$\hat{\kappa} = diag \left(\frac{1}{M_1^2 - s}, \frac{1}{M_2^2 - s}, \dots, \frac{1}{M_N^2 - s}, R_1, R_2 \dots \right)$$

$$\hat{B}_{ij} = \sum_{\alpha} B_{\alpha}^{ij} = \sum_{\alpha} \int \frac{ds'}{\pi} \frac{g_{\alpha}^{(R)i} \rho_{\alpha}(s', m_{1\alpha}, m_{2\alpha}) g_{\alpha}^{(L)j}}{s' - s - i0}$$

Minimization methods

1. The two body final states $\pi N, \gamma N \rightarrow \pi N, \eta N, K\Lambda, K\Sigma, \omega N, K^*\Lambda$: χ^2 method.

For n measured bins we minimize

$$\chi^2 = \sum_j^n \frac{(\sigma_j(PWA) - \sigma_j(exp))^2}{(\Delta\sigma_j(exp))^2}$$

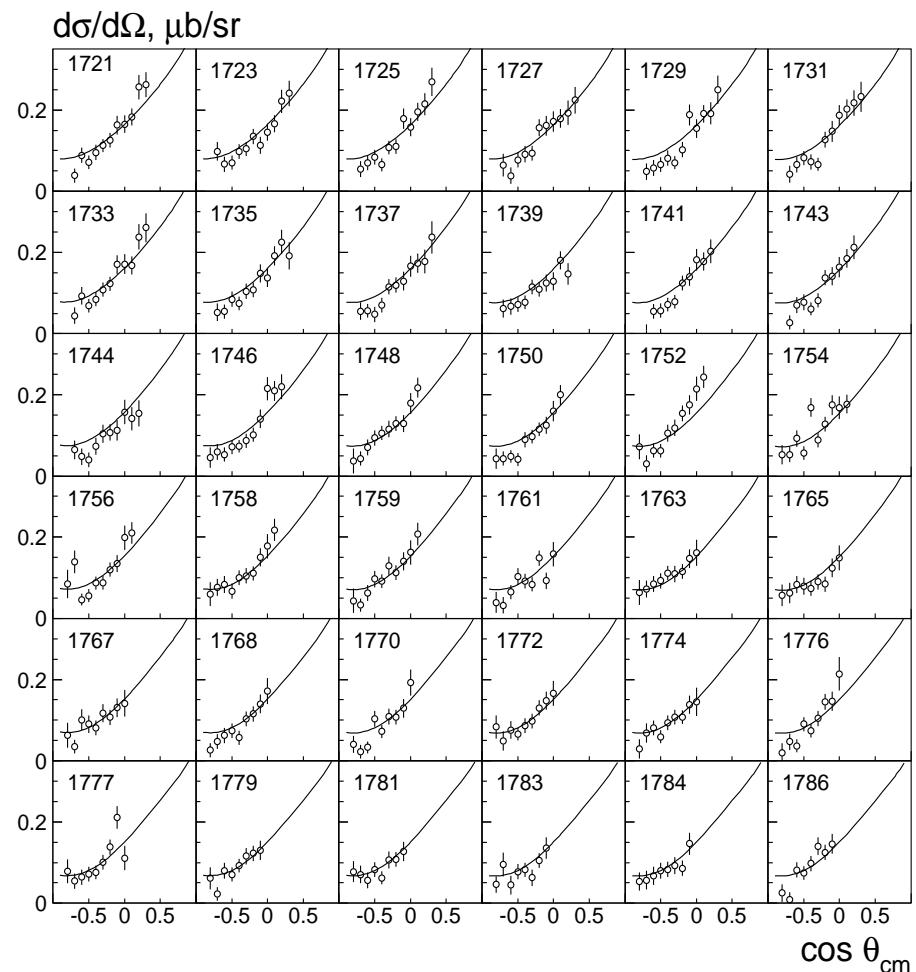
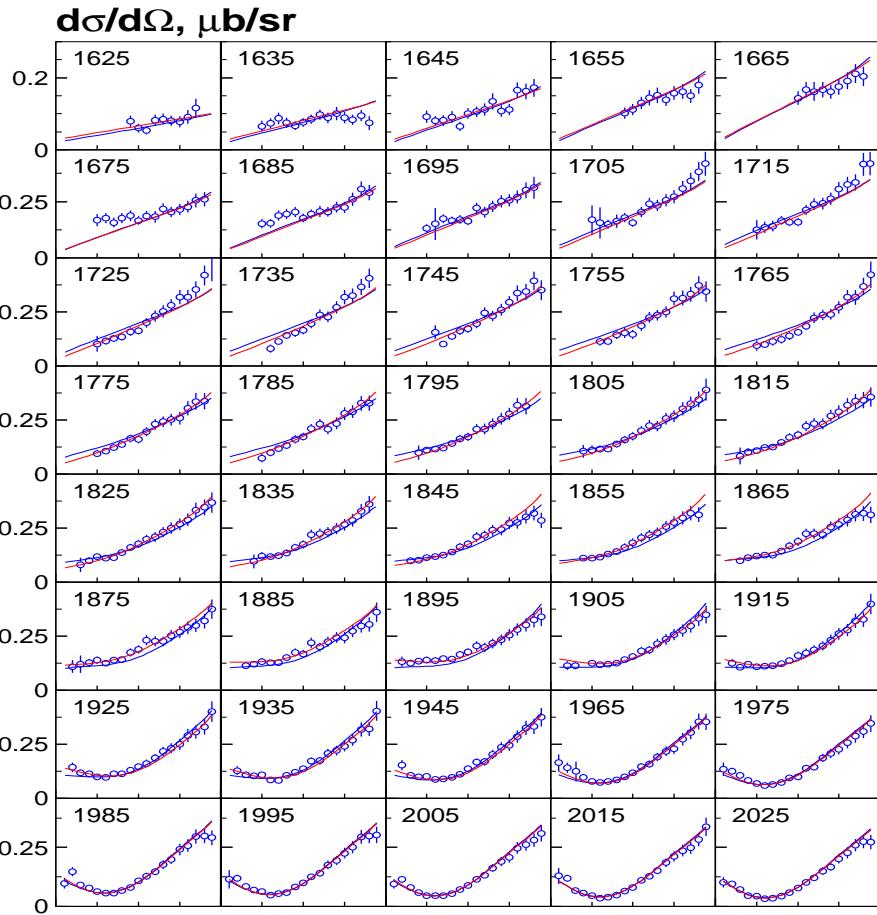
Present solution $\chi^2 = 48710$ for 31180 points. $\chi^2/N_F = 1.6$

2. Reactions with three or more final states are analyzed with logarithm likelihood method. $\pi N, \gamma N \rightarrow \pi\pi N, \pi\eta N, \omega p, K^*\Lambda$. The minimization function:

$$f = - \sum_j^{N(data)} \ln \frac{\sigma_j(PWA)}{\sum_m^{N(rec\ MC)} \sigma_m(PWA)}$$

This method allows us to take into account all correlations in many dimensional phase space. Above 500 000 data events are taken in the fit.

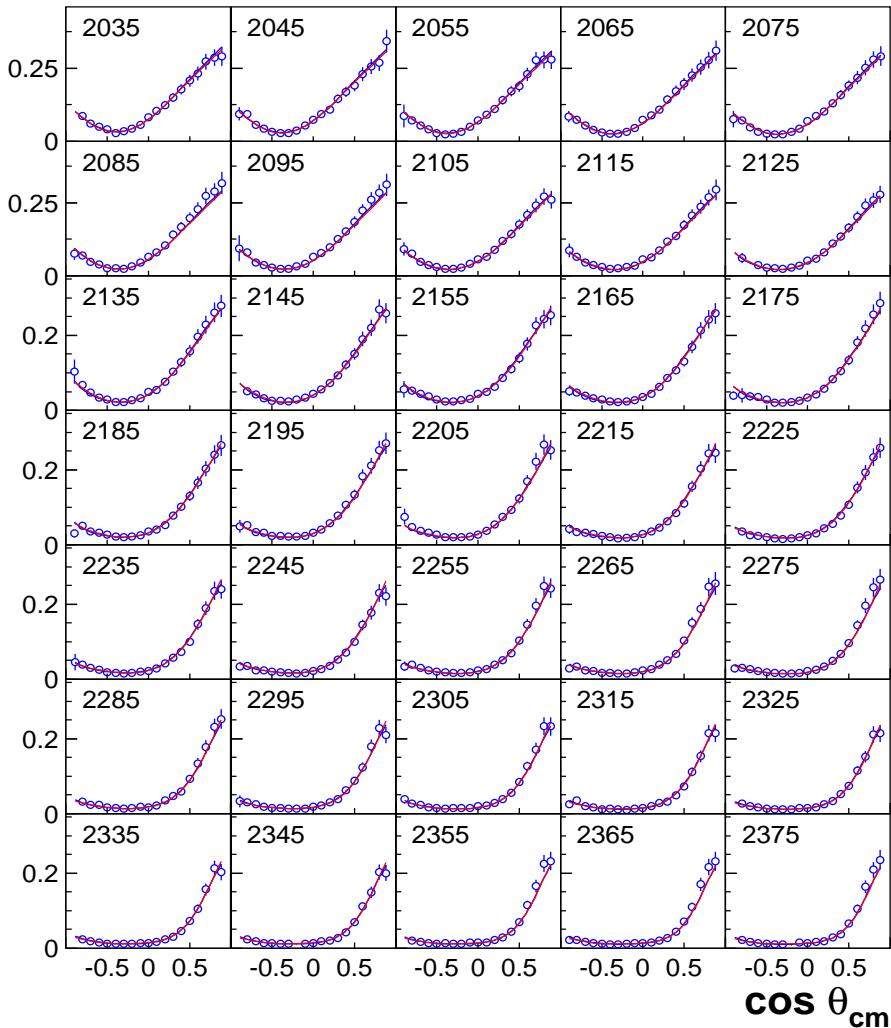
The $\gamma p \rightarrow K\Lambda$ reaction (CLAS 2009) and MAMI.



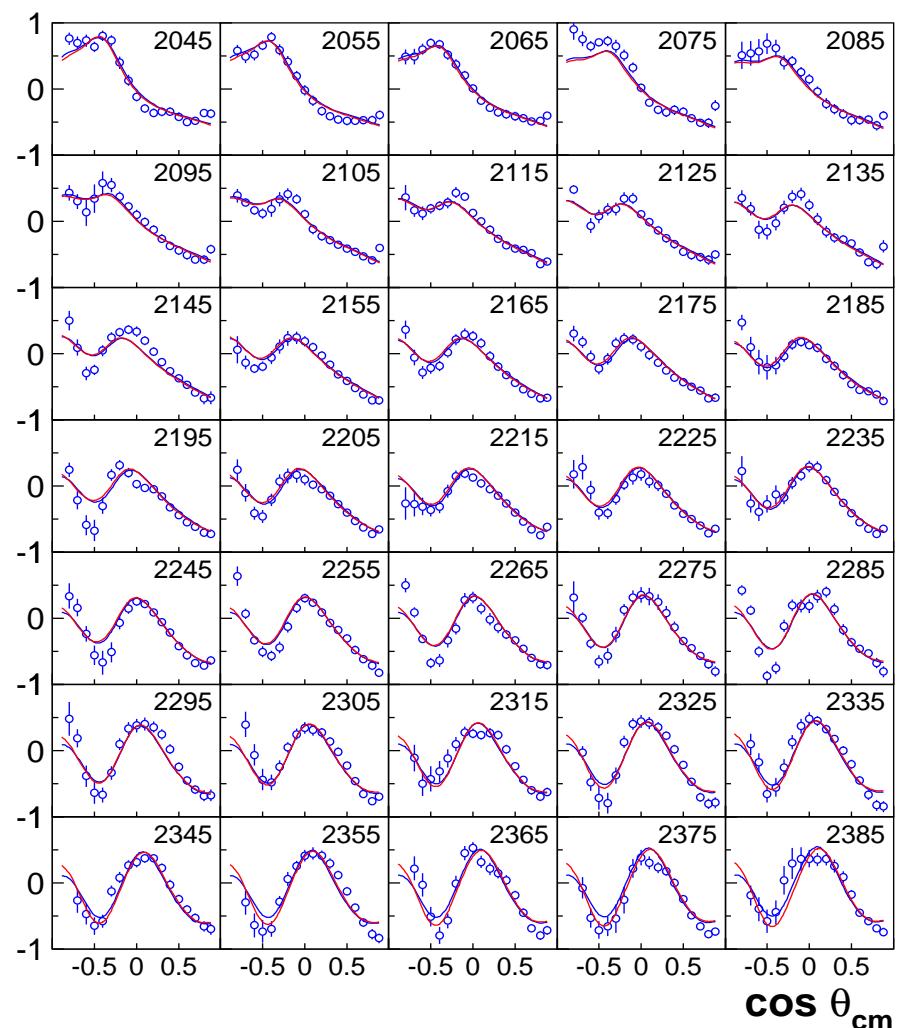
New S_{11} state with mass 1890 ± 10 MeV and width 90 ± 10 MeV improves description of the data.

The $\gamma p \rightarrow K\Lambda$ data

$\frac{d\sigma}{d\Omega} (\mu b/sr)$

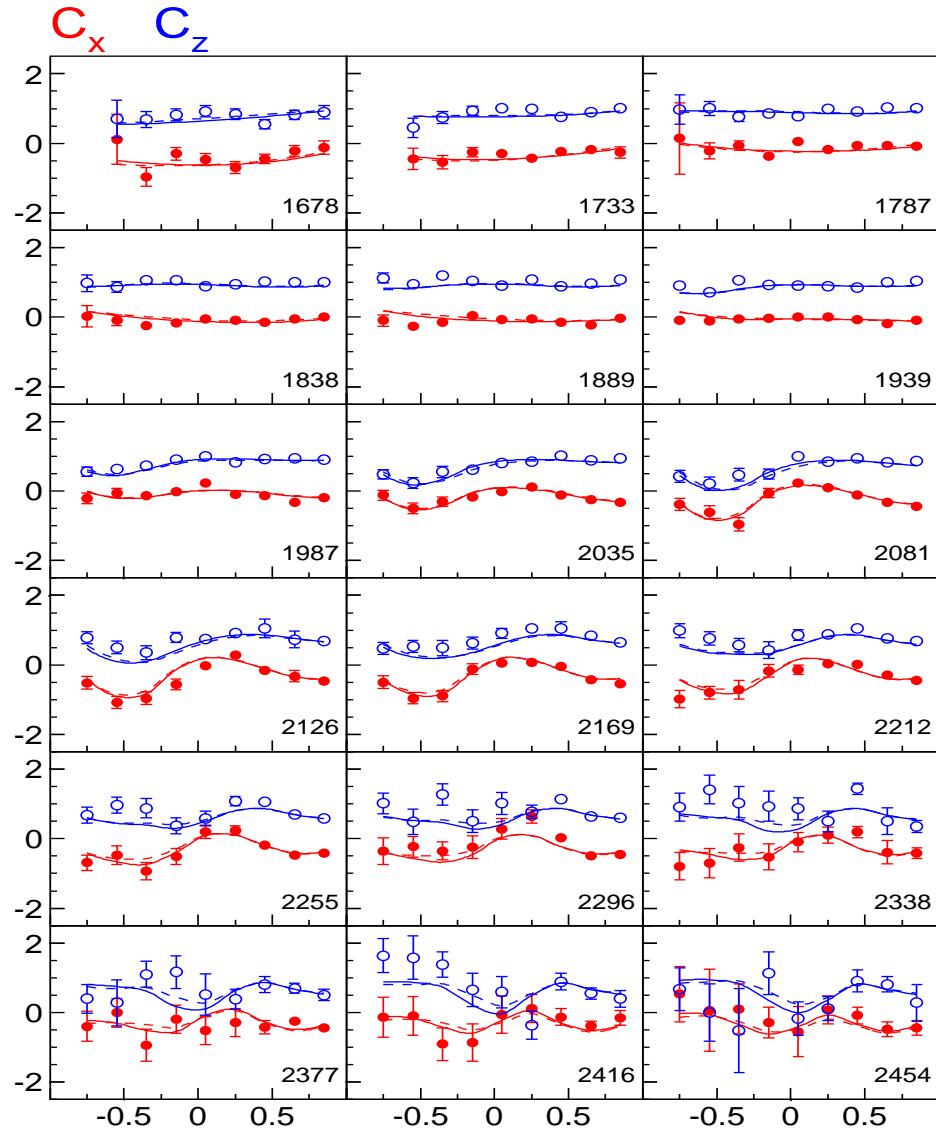


recoil asymmetry

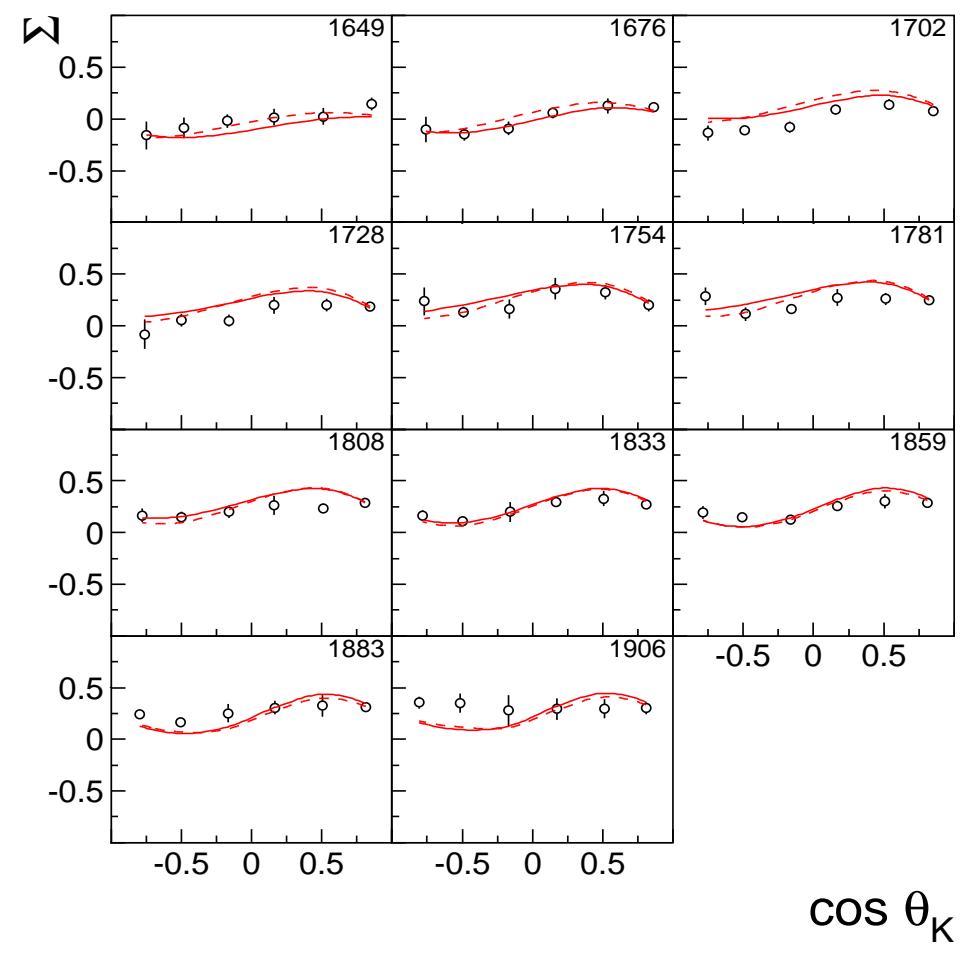


The $\gamma p \rightarrow K^+ \Lambda$: C_x, C_z (CLAS) and beam asymmetry (GRAAL)

BG2011-02 M (dashed)

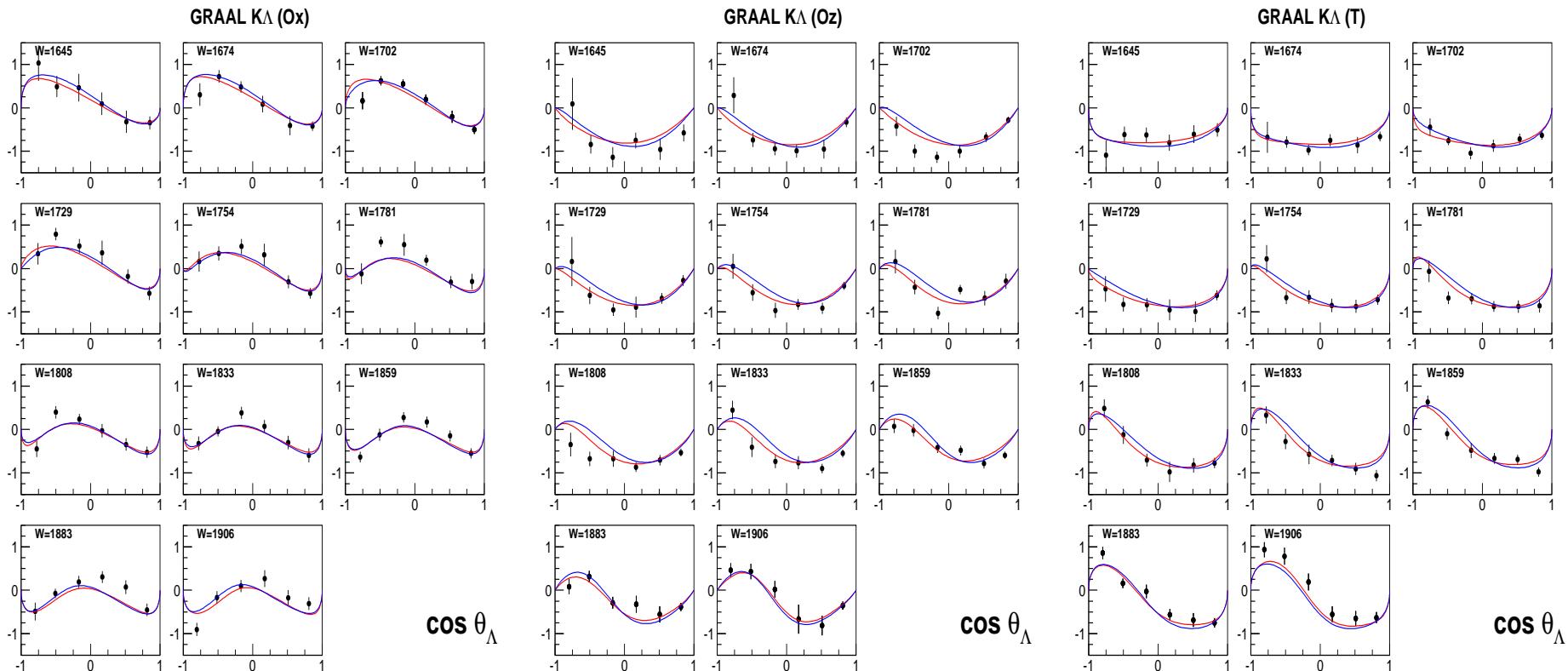


BG2013-02 (solid)

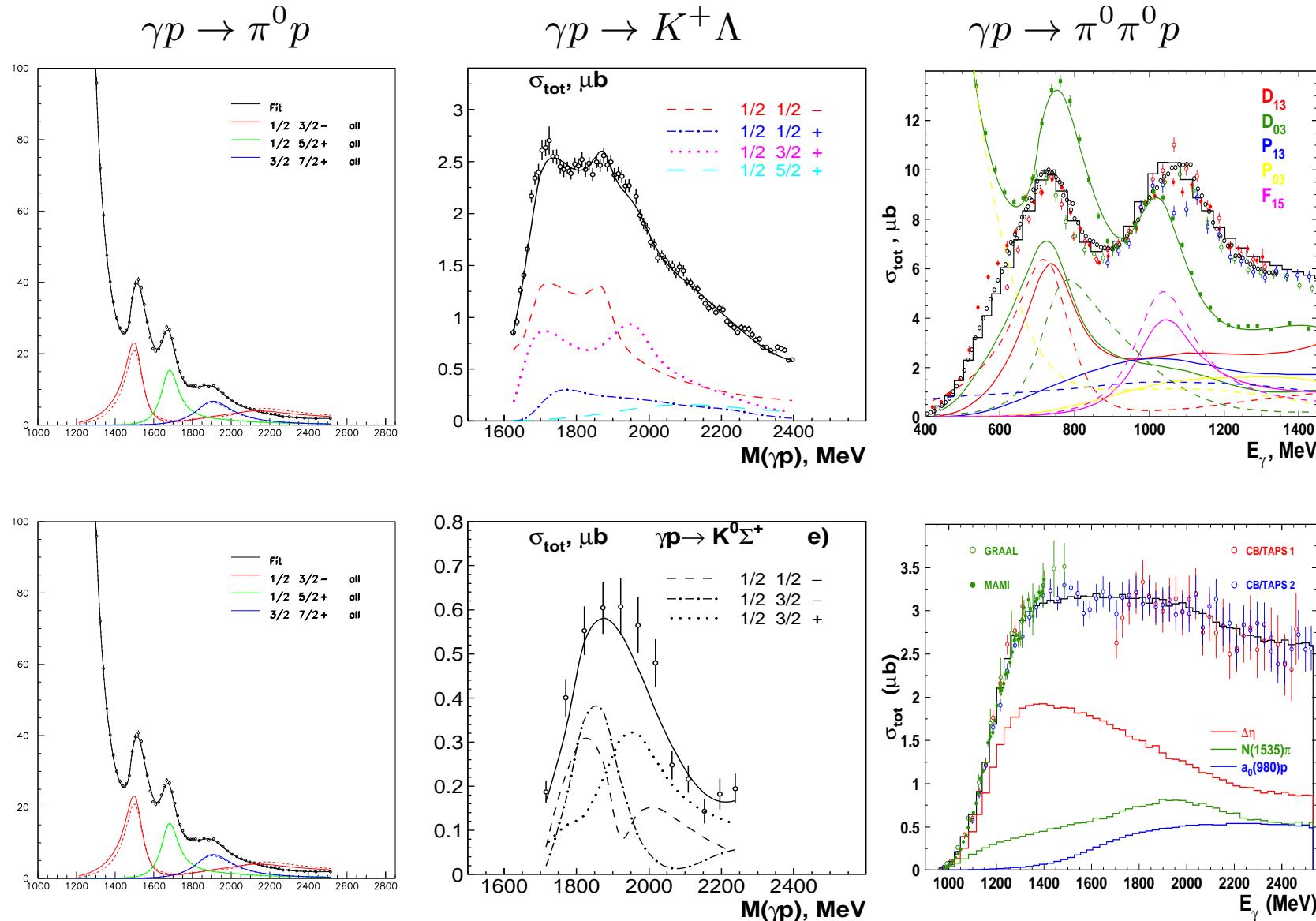


The O_x , O_z and T (GRAAL) observables from $\gamma p \rightarrow K\Lambda$

description is notably improved with $S_{11}(1890)$



The partial wave contributions to photoproduction reactions



New resonances are found. One of them has 3* and was proposed to be defined as 4* state

Citation: J. Beringer *et al.* (Particle Data Group), PR **D86**, 010001 (2012) and 2013 partial update for the 2014 edition (URL: <http://pdg.lbl.gov>)

N(1895) 1/2⁻

$I(J^P) = \frac{1}{2}(\frac{1}{2}^-)$ Status: ***

OMITTED FROM SUMMARY TABLE

The latest GWU analysis (ARNDT 06) finds no evidence for this resonance.

N(1895) BREIT-WIGNER MASS

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
≈ 2090 OUR ESTIMATE			
1895 ± 15	ANISOVICH	12A	DPWA Multichannel
2180 ± 80	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
1880 ± 20	HOEHLER	79	IPWA $\pi N \rightarrow \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •			
1910 ± 15	SHRESTHA	12A	DPWA Multichannel
1812 ± 25	BATINIC	10	DPWA $\pi N \rightarrow N\pi, N\eta$
1822 ± 43	VRANA	00	DPWA Multichannel
1897 ± 50 ⁺³⁰ ₋₂	PLOETZKE	98	SPEC $\gamma p \rightarrow p\eta'(958)$
1928 ± 59	MANLEY	92	IPWA $\pi N \rightarrow \pi N & N\pi\pi$

N(1895) BREIT-WIGNER WIDTH

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
90 ^{+ 30} _{- 15}	ANISOVICH	12A	DPWA Multichannel
350 ± 100	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
95 ± 30	HOEHLER	79	IPWA $\pi N \rightarrow \pi N$

Citation: J. Beringer *et al.* (Particle Data Group), PR **D86**, 010001 (2012) and 2013 partial update for the 2014 edition (URL: <http://pdg.lbl.gov>)

N(1900) 3/2⁺

$I(J^P) = \frac{1}{2}(\frac{3}{2}^+)$ Status: ***

The latest GWU analysis (ARNDT 06) finds no evidence for this resonance.

N(1900) BREIT-WIGNER MASS

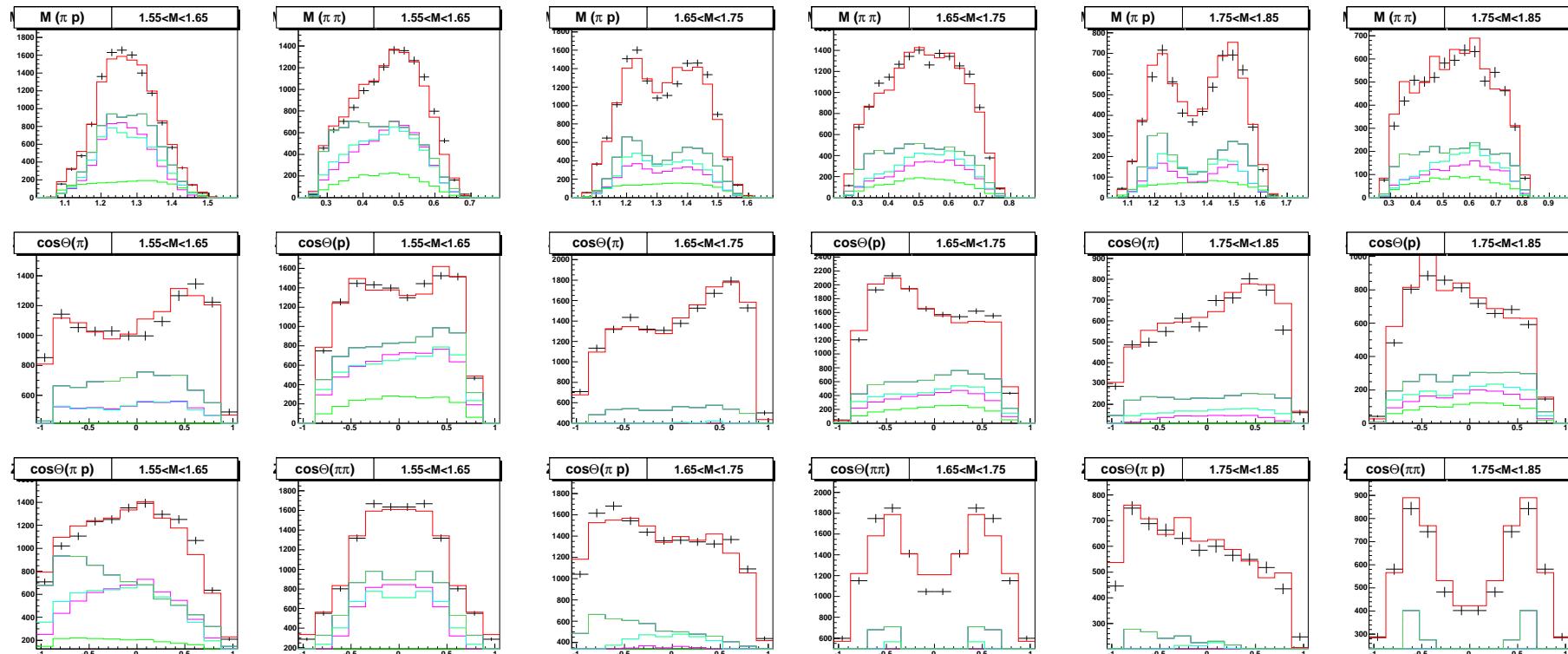
VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
≈ 1900 OUR ESTIMATE			
1905 ± 30	ANISOVICH	12A	DPWA Multichannel
1915 ± 60	NIKONOV	08	DPWA Multichannel
• • • We do not use the following data for averages, fits, limits, etc. • • •			
1900 ± 8	SHRESTHA	12A	DPWA Multichannel
1951 ± 53	PENNER	02C	DPWA Multichannel
1879 ± 17	MANLEY	92	IPWA $\pi N \rightarrow \pi N & N\pi\pi$

N(1900) BREIT-WIGNER WIDTH

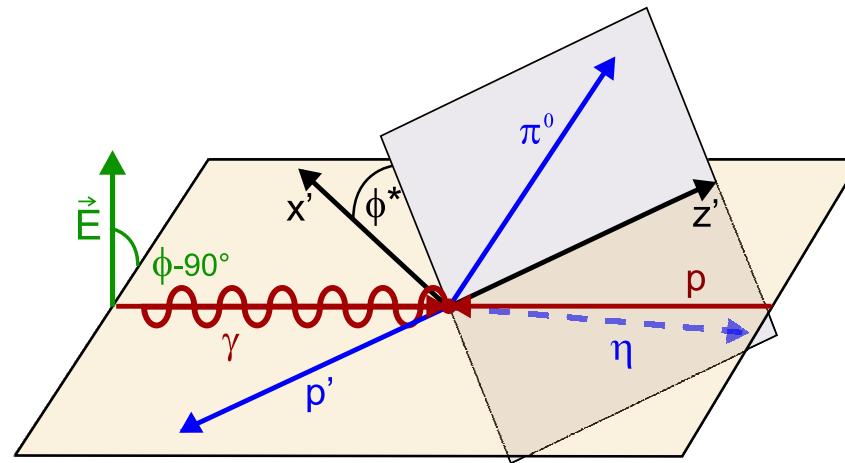
VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
≈ 250 OUR ESTIMATE			
250 ⁺¹²⁰ ₋₅₀	ANISOVICH	12A	DPWA Multichannel
180 ± 40	NIKONOV	08	DPWA Multichannel
• • • We do not use the following data for averages, fits, limits, etc. • • •			
101 ± 15	SHRESTHA	12A	DPWA Multichannel
622 ± 42	PENNER	02C	DPWA Multichannel
498 ± 78	MANLEY	92	IPWA $\pi N \rightarrow \pi N & N\pi\pi$

$\gamma p \rightarrow p\pi^0\pi^0$ (Crystal Barrel)

Differential cross sections.

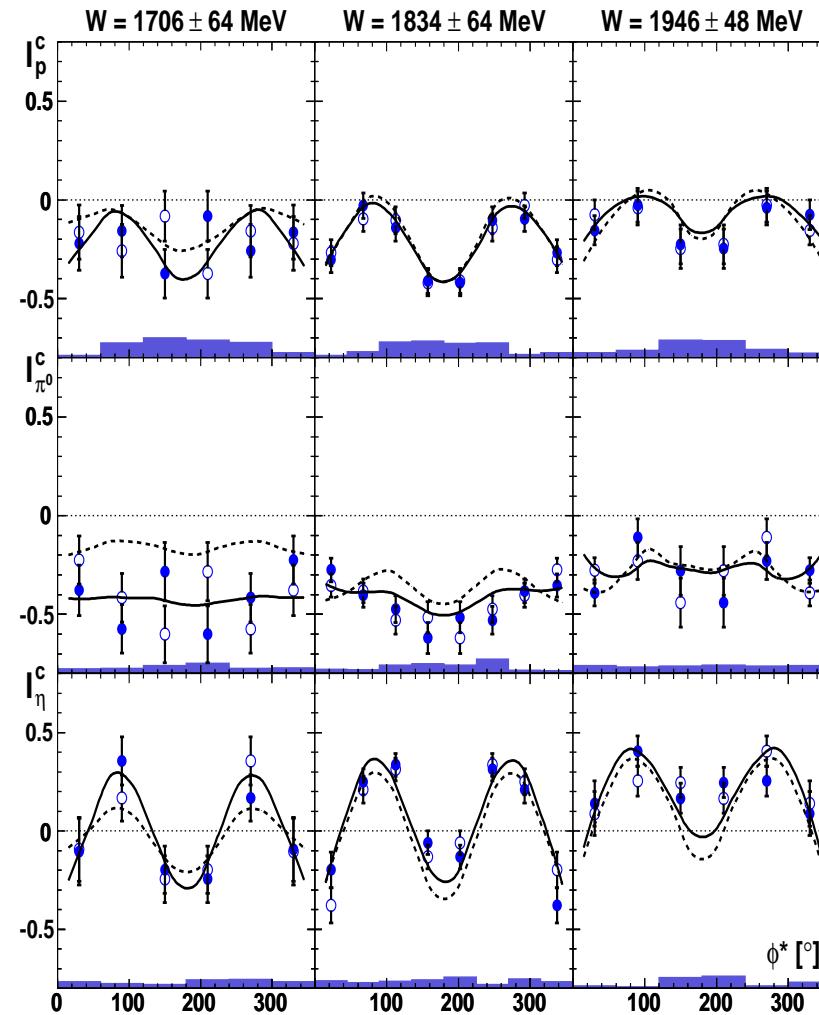
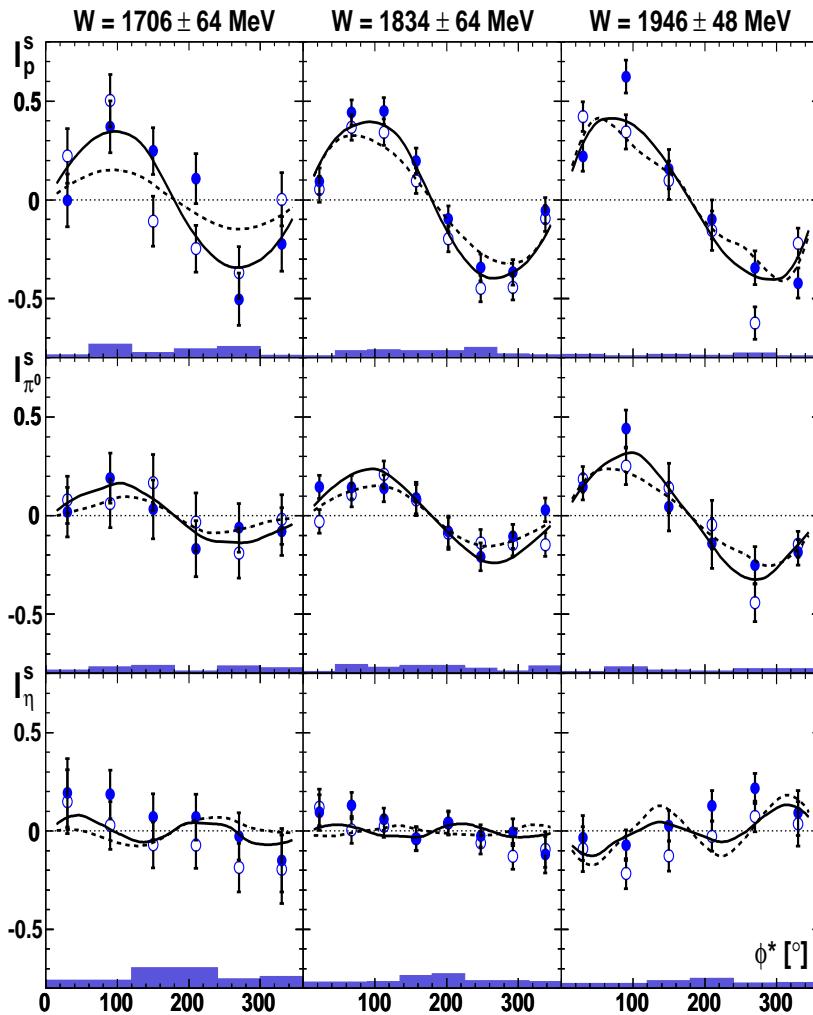


$\gamma p \rightarrow p\pi^0\eta$ (**CB-ELSA**) with linear polarized photon



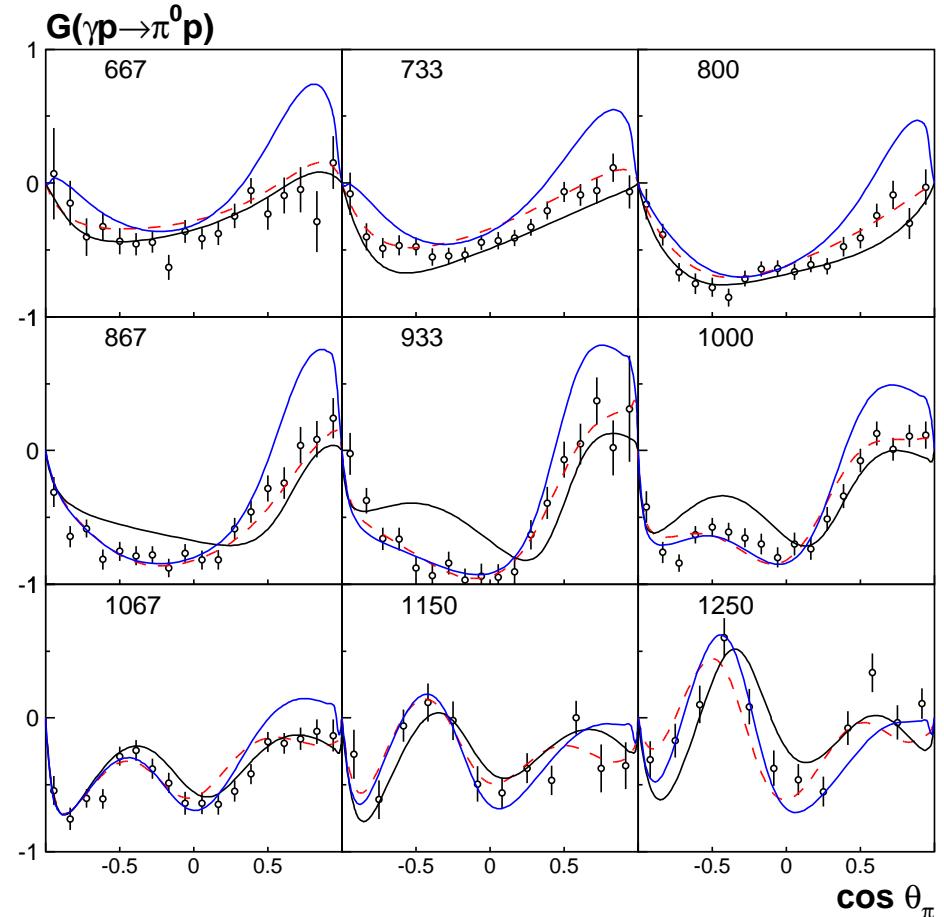
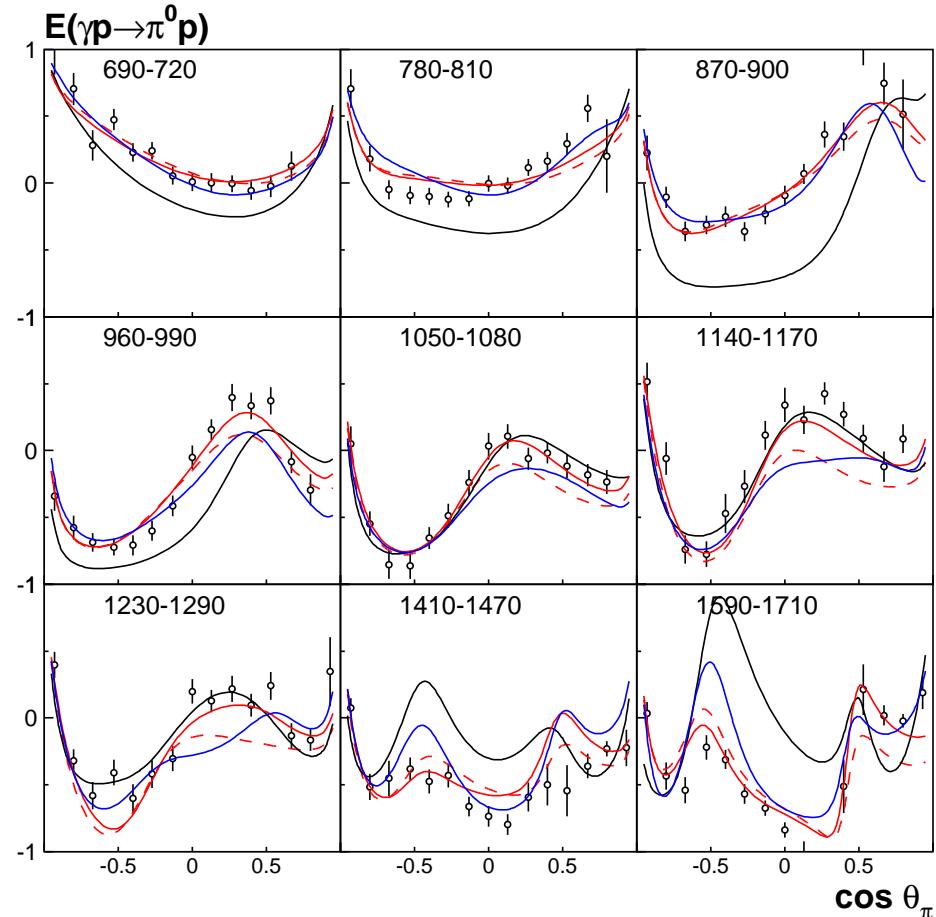
$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega} \right)_0 \{ 1 + \delta_l [I^s \sin(2\phi) + I^c \cos(2\phi)] \}, \quad (1)$$

$$\Sigma = \int_0^{2\pi} I^c d\phi^*$$

I^c and I^s for $\gamma p \rightarrow p\pi^0\eta$ (CB-ELSA)


First double polarization data from CB-ELSA:

Helicity asymmetry and G observable in $\gamma p \rightarrow \pi^0 p$



Bonn-Gatchina, SAID (CM12), MAID
dashed - predicted, full - fit

Bonn-Gatchina, SAID (CM12), MAID

0.1 New results

J. Beringer et al. (Particle Data Group), Phys. Rev. D86, 010001 (2012).

Resonance	Rating	N_{PP}	Resonance	Rating	N_{PP}	Resonance	Rating	N_{PP}
$\mathbf{N(1440)1/2^+}$	****	13	$\mathbf{N(1520)3/2^-}$	****	17	$\mathbf{N(1535)1/2^-}$	****	15
$\mathbf{N(1650)1/2^-}$	****	18	$\mathbf{N(1675)5/2^-}$	****	14	$\mathbf{N(1680)5/2^+}$	****	17
$\mathbf{N(1685)}$	*		$\mathbf{N(1700)3/2^-}$	***	15	$\mathbf{N(1710)1/2^+}$	***	14
$\mathbf{N(1720)3/2^+}$	****	17	$\mathbf{N(1860)5/2^+}$	**	9	$\mathbf{N(1875)3/2^-}$	***	16
$\mathbf{N(1880)1/2^+}$	**	20	$\mathbf{N(1895)1/2^-}$	**	17	$\mathbf{N(1900)3/2^+}$	***	18
$\mathbf{N(1990)7/2^+}$	**	9	$\mathbf{N(2000)5/2^+}$	**	11	$\mathbf{N(2040)3/2^+}$	*	
$\mathbf{N(2060)5/2^-}$	**	13	$\mathbf{N(2100)1/2^+}$	*		$\mathbf{N(2150)3/2^-}$	**	11
$\mathbf{N(2190)7/2^-}$	****	11	$\mathbf{N(2220)7/2^-}$	****	7	$\mathbf{N(2250)9/2^-}$	****	
$\mathbf{N(2600)11/2^-}$	***		$\mathbf{N(2700)13/2^+}$	**				
$\Delta(1232)$	****	8	$\Delta(1600)3/2^+$	***	12	$\Delta(1620)1/2^-$	***	10
$\Delta(1700)3/2^-$	****	11	$\Delta(1750)1/2^+$	*		$\Delta(1900)1/2^-$	**	13
$\Delta(1905)5/2^+$	****	11	$\Delta(1910)1/2^+$	****	13	$\Delta(1920)3/2^+$	***	21
$\Delta(1930)5/2^-$	***		$\Delta(1940)3/2^-$	*	5	$\Delta(1950)7/2^+$	****	13
$\Delta(2000)5/2^+$	**		$\Delta(2150)1/2^-$	*		$\Delta(2200)7/2^-$	*	
$\Delta(2300)9/2^+$	**		$\Delta(2350)3/2^-$	*		$\Delta(2390)7/2^+$	*	
$\Delta(2420)11/2^+$	****		$\Delta(2400)9/2^-$	****		$\Delta(2750)13/2^-$	**	
$\Delta(2950)15/2^+$	**							

E.g.: V. Kuznetsov et al., Phys. Lett. B 647, 23 (2007); V. Kuznetsov et al., Phys. Rev. C 83, 022201 (2011); I. Jaegle et al., Eur. Phys. J. A 47, 89 (2011).

M. Ablikim et al. [BES Collaboration], Phys. Rev. D 80, 052004 (2009).

A. V. Anisovich, R. Beck, E. Klempt, V. A. Nikonov, A. V. Sarantsev and U. Thoma, Eur. Phys. J. A 48, 15 (2012);

N_{PP} particle properties were determined; 400 in total. Be cautious, there are ambiguities !

Promoted to three-star resonance

Holographic QCD (AdS/QCD)

L, S, N	κ_{gd}	Resonance			Pred.		
$0, \frac{1}{2}, 0$	$\frac{1}{2}$	$N(940)$			input: 0.94		
$0, \frac{3}{2}, 0$	0	$\Delta(1232)$			1.27		
$0, \frac{1}{2}, 1$	$\frac{1}{2}$	$N(1440)$			1.40		
$1, \frac{1}{2}, 0$	$\frac{1}{4}$	$N(1535)$	$N(1520)$		1.53		
$1, \frac{3}{2}, 0$	0	$N(1650)$	$N(1700)$	$N(1675)$	1.64		
$1, \frac{1}{2}, 0$	0	$\Delta(1620)$	$\Delta(1700)$	$L, S, N=0, \frac{3}{2}, 1:$	$\Delta(1600)$	1.64	
$2, \frac{1}{2}, 0$	$\frac{1}{2}$	$N(1720)$	$N(1680)$	$L, S, N=0, \frac{1}{2}, 2:$	$N(1710)$	1.72	
$1, \frac{1}{2}, 1$	$\frac{1}{4}$	$N(1890)$	$N(1880)$			1.82	
$1, \frac{3}{2}, 1$	0	$\Delta(1900)$	$\Delta(1940)$	$\Delta(1930)$		1.92	
$2, \frac{3}{2}, 0$	0	$\Delta(1910)$	$\Delta(1920)$	$\Delta(1905)$	$\Delta(1950)$	1.92	
$2, \frac{3}{2}, 0$	0	$N(1875)$	$N(1900)$	$N(1880)$	$N(1980)$	1.92	
$0, \frac{1}{2}, 3$	$\frac{1}{2}$	$N(????)$				2.03	
$3, \frac{1}{2}, 0$	$\frac{1}{4}$	$N(2075)$	$N(2185)$	$L, S, N=1, \frac{1}{2}, 2:$	$N(????)$	2.12	
$3, \frac{3}{2}, 0$	0	$N(2200)$	$N(2250)$	$L, S, N=1, \frac{1}{2}, 2:$	$\Delta(2223)$	$\Delta(2200)$	2.20
$4, \frac{1}{2}, 0$	$\frac{1}{2}$	$N(2220)$				2.27	
$4, \frac{3}{2}, 0$	0	$\Delta(2390)$	$\Delta(2300)$	$\Delta(2420)$	$ L, N=3, 1: \Delta(2400) \Delta(2350) $	2.43	
$5, \frac{1}{2}, 0$	$\frac{1}{4}$	$N(2600)$				2.57	

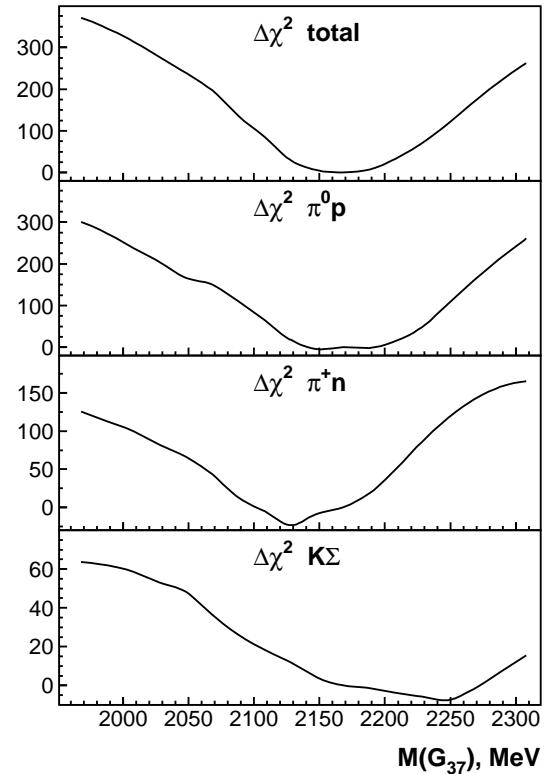
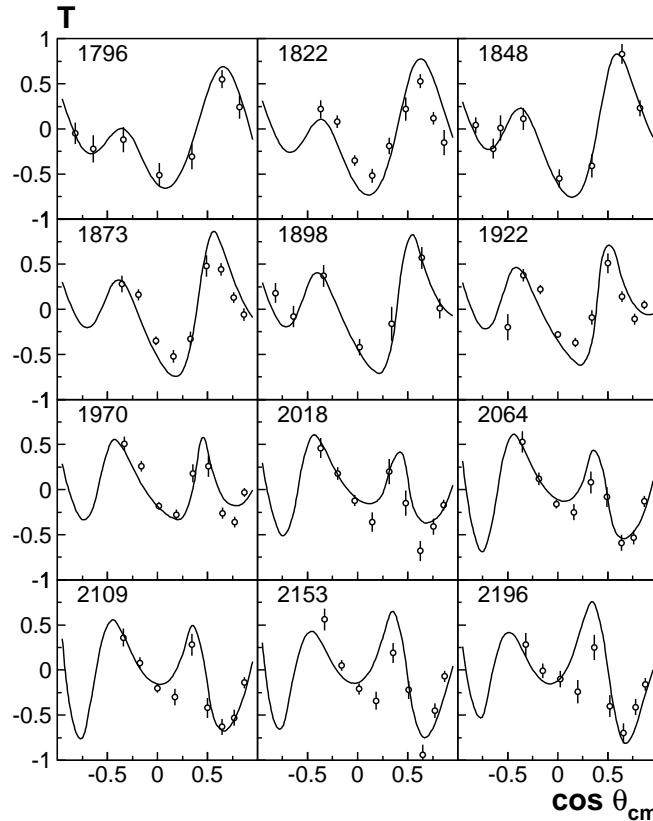
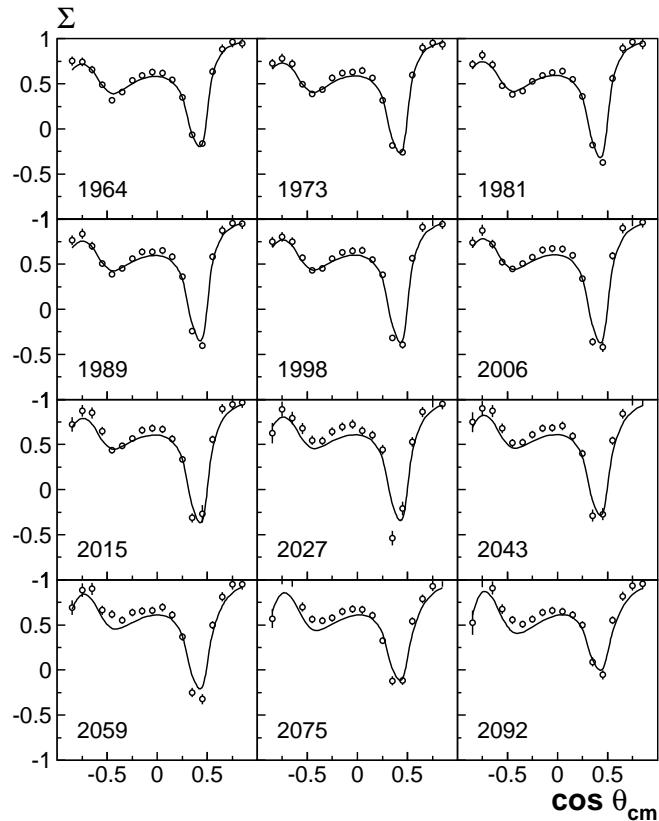
Parity doublets of N and Δ resonances at high mass region

Parity doublets must not interact by pion emission
and could have a small coupling to πN .

$J=\frac{1}{2}$	$\textbf{N}_{1/2+}(1880)$	**	$\textbf{N}_{1/2-}(1890)$	**	$\Delta_{1/2+}(1910)$	****	$\Delta_{1/2-}(1900)$	**
$J=\frac{3}{2}$	$\textbf{N}_{3/2+}(1900)$	***	$\textbf{N}_{3/2-}(1875)$	**	$\Delta_{3/2+}(1940)$	***	$\Delta_{3/2-}(1990)$	**
$J=\frac{5}{2}$	$\textbf{N}_{5/2+}(1880)$	**	$\textbf{N}_{5/2-}(2060)$	**	$\Delta_{5/2+}(1940)$	****	$\Delta_{5/2-}(1930)$	***
$J=\frac{7}{2}$	$\textbf{N}_{7/2+}(1980)$	**	$\textbf{N}_{7/2-}(2170)$	****	$\Delta_{7/2+}(1920)$	****	$\Delta_{7/2-}(2200)$	*
$J=\frac{9}{2}$	$\textbf{N}_{9/2+}(2220)$	****	$\textbf{N}_{9/2-}(2250)$	****	$\Delta_{9/2+}(2300)$	**	$\Delta_{9/2-}(2400)$	**

$J=\frac{5}{2}$	$\textbf{N}_{5/2+}(2090)$	**	$\textbf{N}_{5/2-}(2060)$	**	$\Delta_{5/2+}(1940)$	****	$\Delta_{5/2-}(1930)$	***
$J=\frac{7}{2}$	$\textbf{N}_{7/2+}(2100)$	**	$\textbf{N}_{7/2-}(2150)$	****	$\Delta_{7/2+}(1950)$	****	$\Delta_{7/2-}(2200)$	*
$J=\frac{9}{2}$	$\textbf{N}_{9/2+}(2220)$	****	$\textbf{N}_{9/2-}(2250)$	****	$\Delta_{9/2+}(2300)$	**	$\Delta_{9/2-}(2400)^a$	**

Observation of the $\Delta(\text{????})\frac{7}{2}^-$

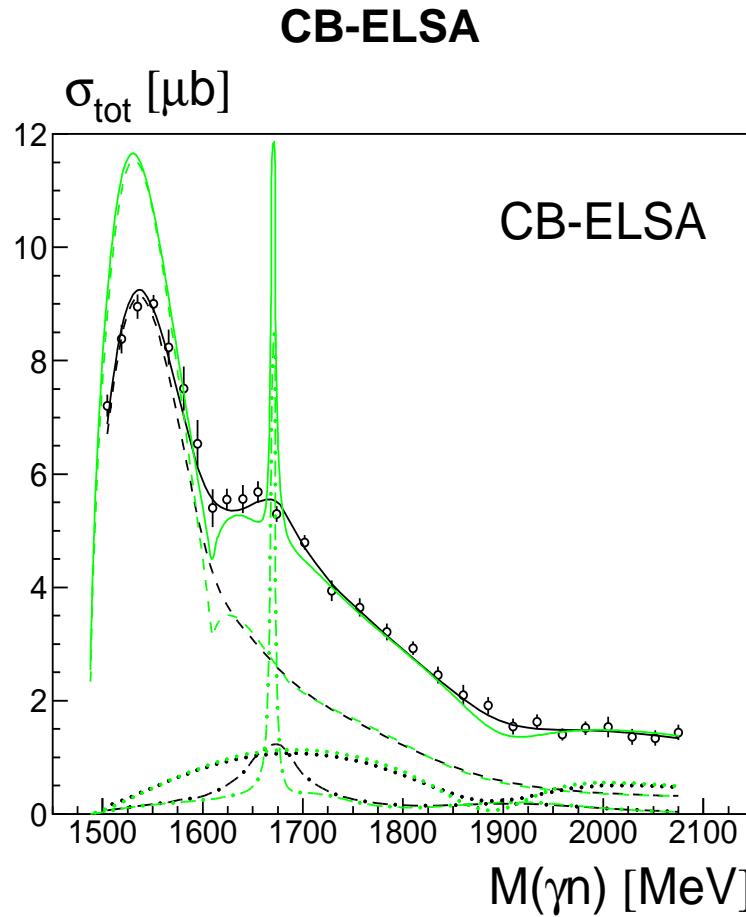


$\Delta(\text{????})\frac{7}{2}^-$: $M=2140^{+60}_{-30}$ MeV $\Gamma=160\pm30$ MeV.

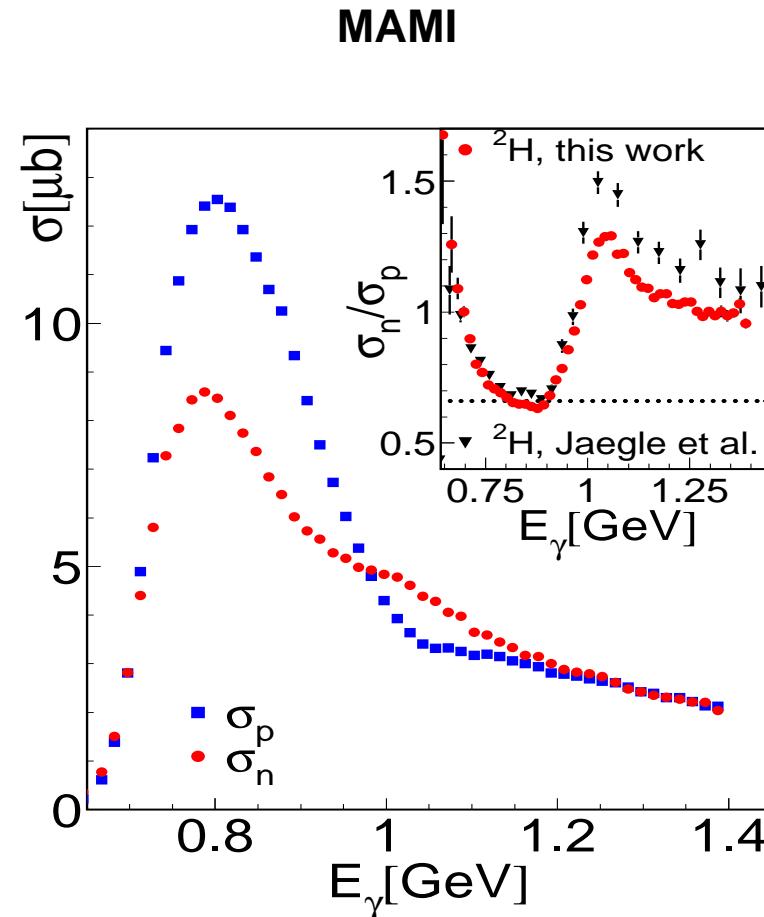
This state can not be a chiral partner of the $\Delta(1950)\frac{7}{2}^+$ state.

New MAMI Data on $\gamma n \rightarrow \eta n$ reaction

Fermi motion smearing



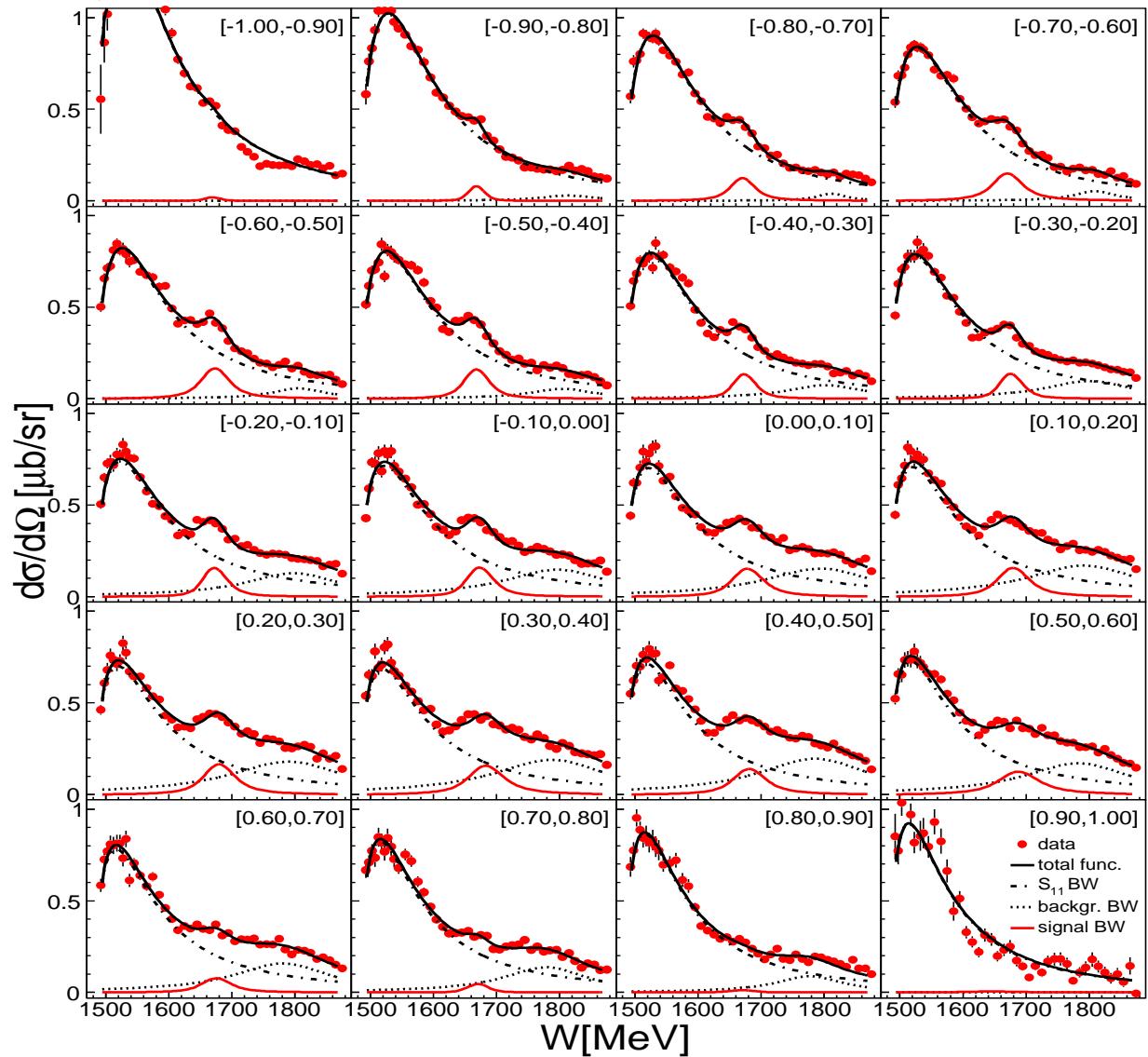
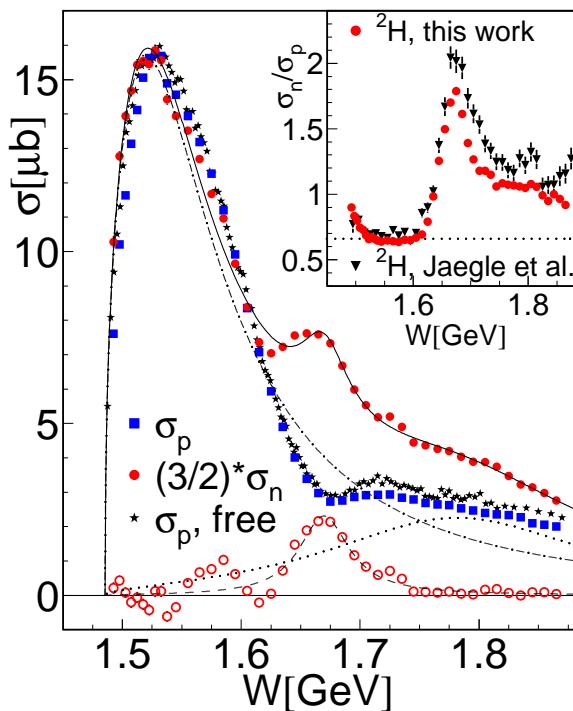
B. Krusche group



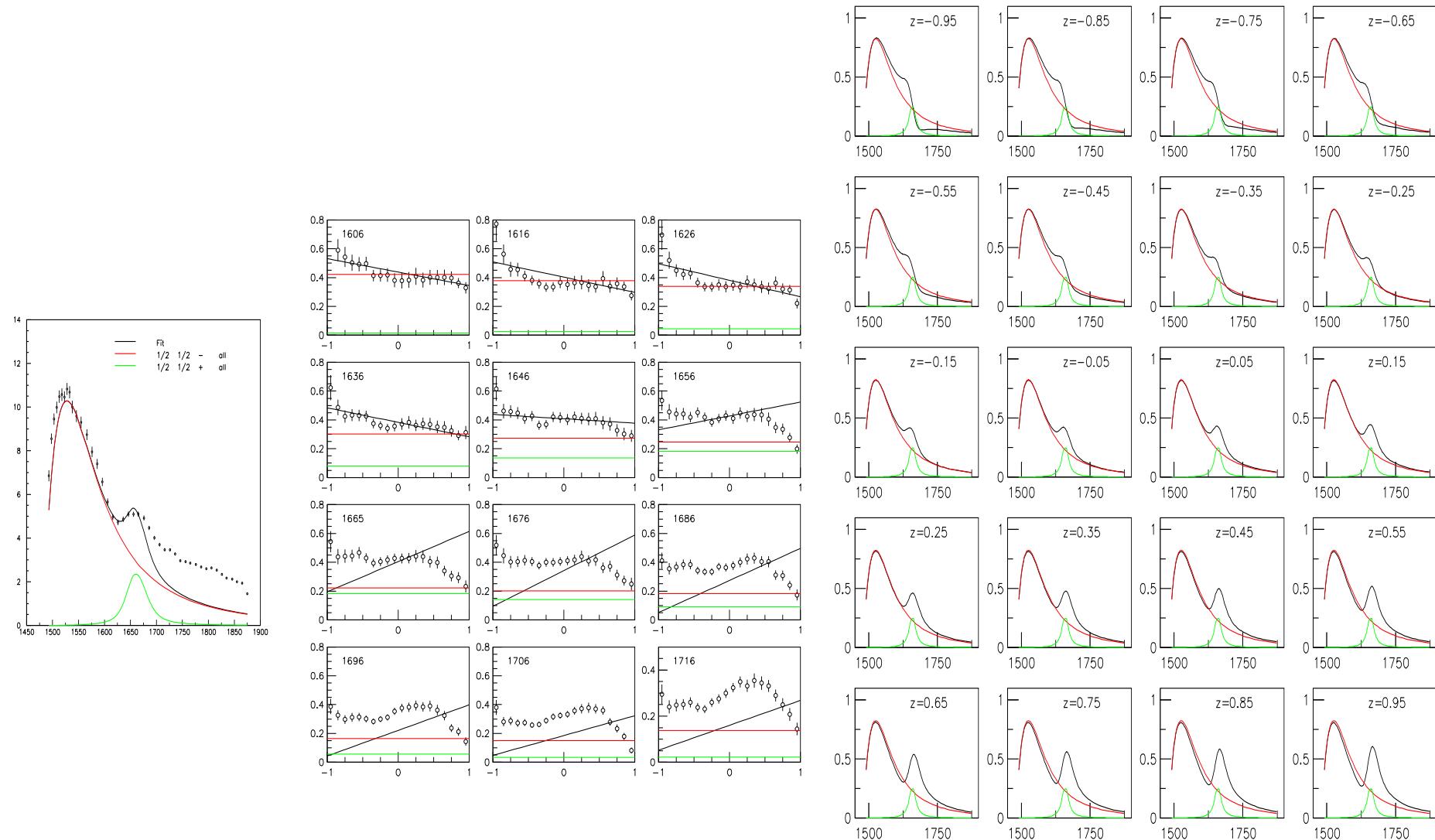
B. Krusche group

Full event reconstruction

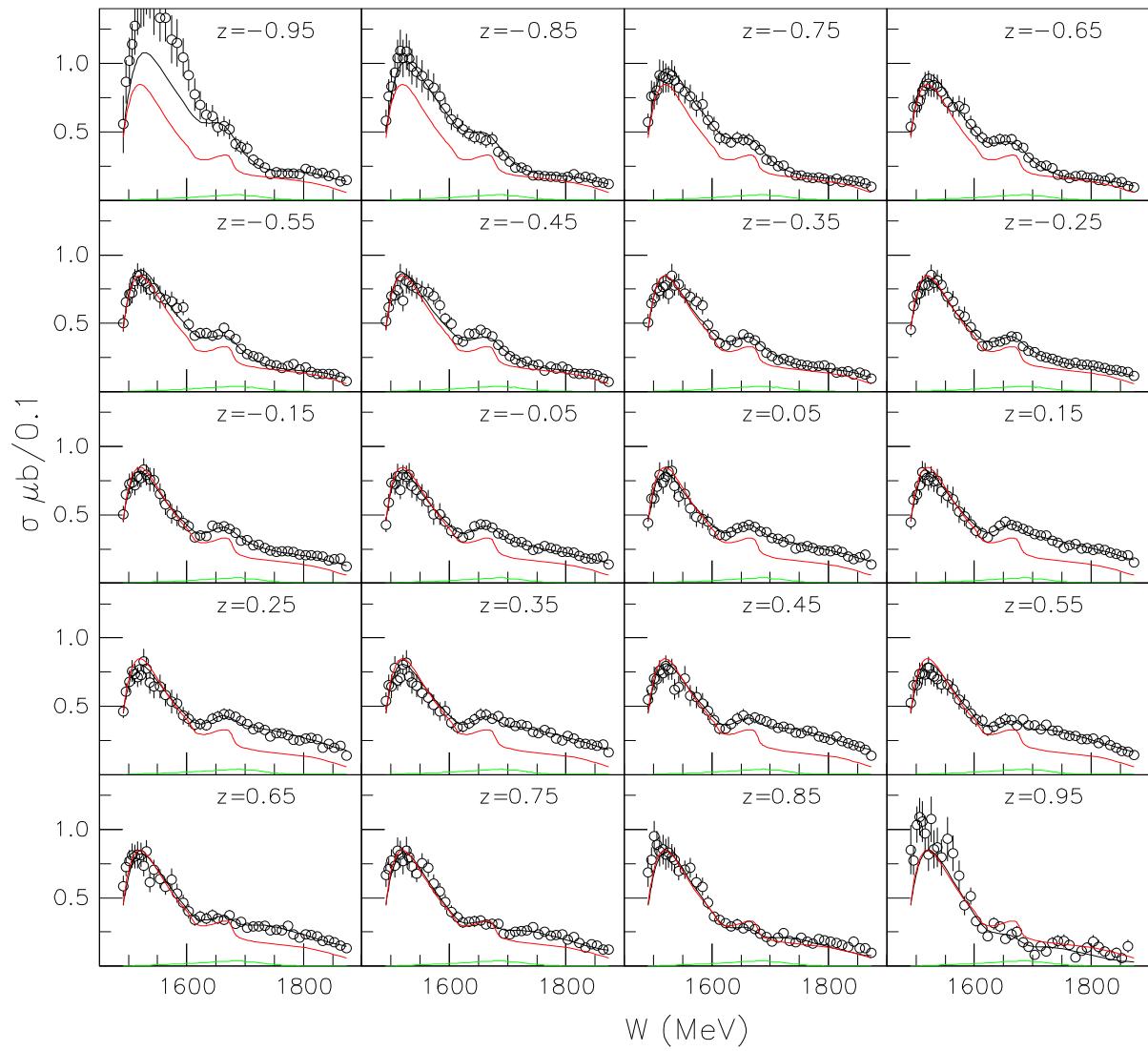
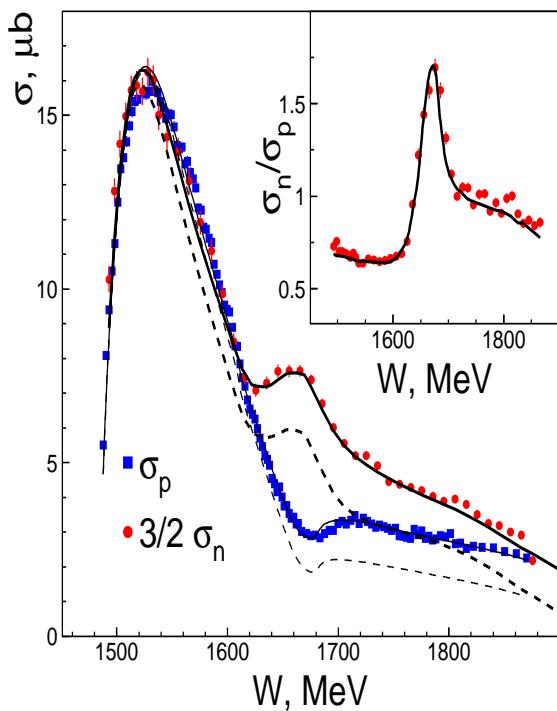
Energy resolution of η : $\Delta W = 10\text{-}42 \text{ MeV}$ ($W = 1500\text{-}1850 \text{ MeV}$)



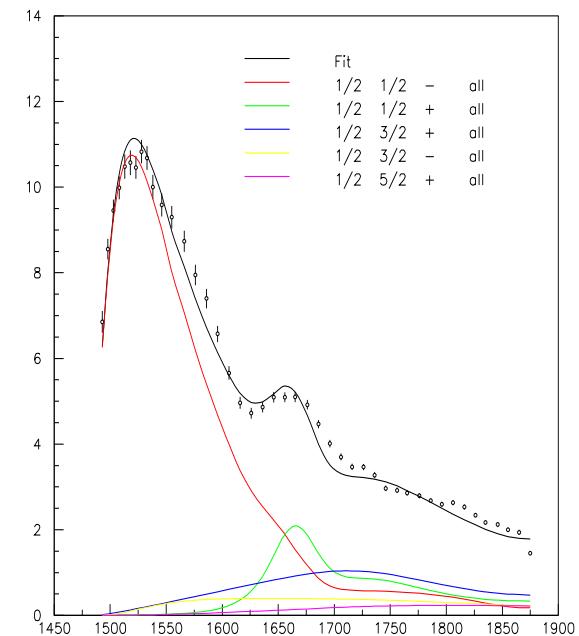
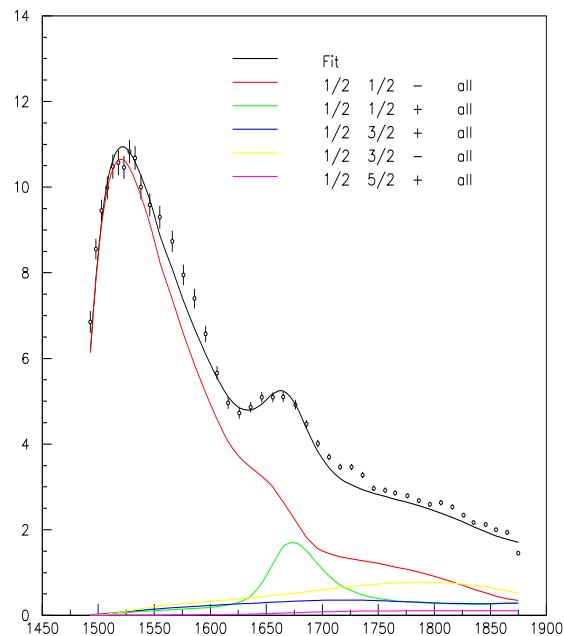
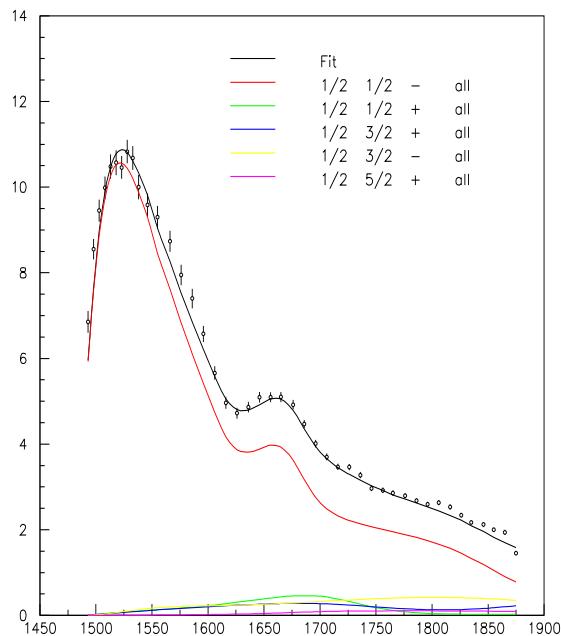
Simulation for the S_{11} and P_{11} interference



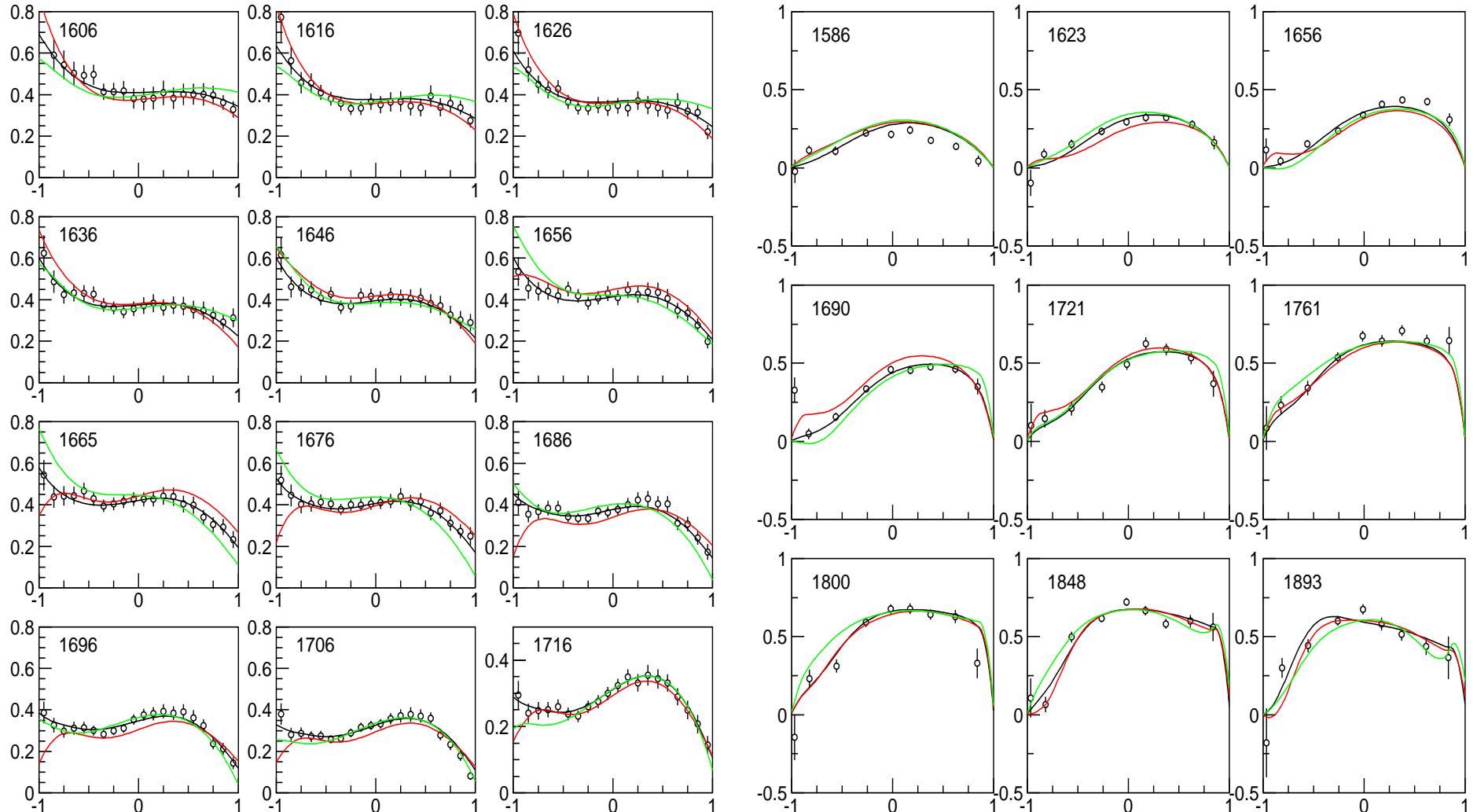
Solution with interference between S_{11} states



Solutions with the $P_{11}(1680)$ states



The description of the new data as well as GRAAL data is notably worse



Limit for the production of $P_{11}(1680)$: $|A|^{\frac{1}{2}} |Br(\eta n)| < 5 \text{ GeV}^{-\frac{1}{2}} 10^{-3}$