

Baryon spectroscopy results from the Bonn-Gatchina-PWA

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Bonn-Gatchina Partial Wave Analysis



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<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>				

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Last changes: January 26th, 2010.

Search for light baryon states

1. Single and double meson production in pion-induced reactions:

The old data on $\pi N \rightarrow \pi N, \eta N, K\Lambda, K\Sigma, \pi\pi N$, and ωn

2. Single and double meson photoproduction reactions.

$\gamma p \rightarrow \pi N, \eta N, K\Lambda, K\Sigma, \pi\pi N, \pi\eta N, \omega p, K^*\Lambda,$

CB-ELSA, CLAS, MAMI GRAAL, LEPS.

3. The decay of heavy mesons $\Psi' \rightarrow \pi^0 p\bar{p}, \eta p\bar{p}$ (**BES III**).

4. The hyperon production in the kaon-nucleon collision reactions

$K^- p \rightarrow K^- p, K_0 n, \pi\Lambda, \pi\Sigma, \pi\pi\Lambda, \pi\pi\Sigma, K\pi N, \gamma p \rightarrow \Sigma K\pi$

Energy dependent fully covariant approach

In many cases an unambiguous partial wave decomposition at fixed energies is impossible. Then the energy and angular parts should be analyzed together:

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

πN interaction:

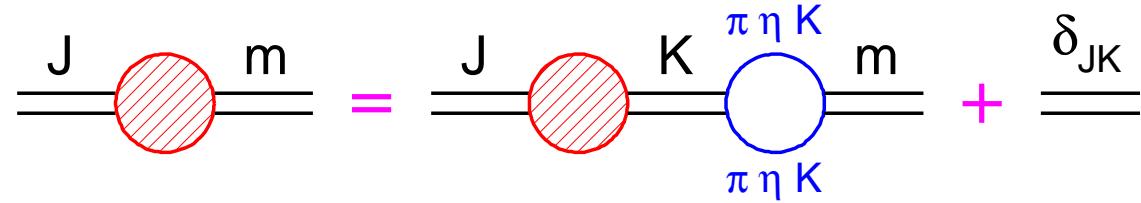
$$Q_{\mu_1\dots\mu_n}^{(+n)} = X_{\mu_1\dots\mu_n}^{(n)} \quad Q_{\mu_1\dots\mu_n}^{(-n)} = i\gamma_\nu\gamma_5 X_{\nu\mu_1\dots\mu_n}^{(n+1)}$$

$$X^0 = 1 ; \quad X_\mu^1 = k_\mu^\perp ; \quad X_{\mu\nu}^2 = \frac{3}{2} \left(k_\mu^\perp k_\nu^\perp - \frac{1}{3} k_\perp^2 g_{\mu\nu}^\perp \right) ;$$

$$X_{\mu\nu\alpha}^3 = \frac{5}{2} \left[k_\mu^\perp k_\nu^\perp k_\alpha^\perp - \frac{k_\perp^2}{5} (g_{\mu\nu}^\perp k_\alpha^\perp + g_{\mu\alpha}^\perp k_\nu^\perp + g_{\nu\alpha}^\perp k_\mu^\perp) \right] ,$$

1. C. Zemach, Phys. Rev. 140, B97 (1965); 140, B109 (1965).
2. S.U.Chung, Phys. Rev. D 57, 431 (1998).
- A. V. Anisovich, V. V. Anisovich, V. N. Markov, M. A. Matveev and A. V. Sarantsev, J. Phys. G 28, 15 (2002)
3. B. S. Zou and D. V. Bugg, Eur. Phys. J. A 16, 537 (2003)

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



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

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

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

Channels included in D-matrix: $\pi N, \eta N, K\Lambda, K\Sigma, \Delta\pi, N\sigma, N\rho(770), N(1520)\pi, N(1535)\pi, N\omega, \text{Black Box}$

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 for γp reaction $\chi^2 = 69435$ for 46644 points. $\chi^2/N_F = 1.49$

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

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

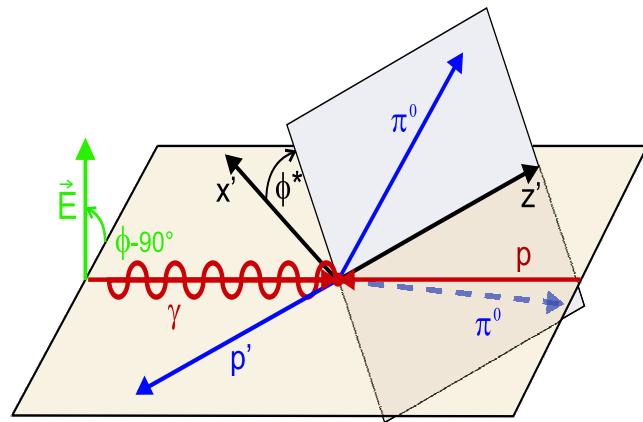
This method allows us to take into account all correlations in many dimensional phase space. Above 1 000 000 data events are taken in the fit.

The included meson photoproduction data

DATA	2011-2019	added in 2019-2022
$\pi N \rightarrow \pi N$ ampl.	SAID	Hoehler (energy fixed)
$\pi^- p \rightarrow \pi\pi N$	$d\sigma/d\Omega (\pi^0\pi^0 n, \pi^+\pi^- n, \pi^-\pi^0 p)$	
$\pi^- p \rightarrow \eta n$	$d\sigma/d\Omega$	
$\pi p \rightarrow K\Lambda, K\Sigma$	$d\sigma/d\Omega, P, \beta$	
$\pi p \rightarrow \omega n$		$d\sigma/d\Omega$
$\gamma p \rightarrow \pi N$	$d\sigma/d\Omega, \Sigma, T, P, E, G, H (\pi^0 p, \pi^+ n)$	
$\gamma p \rightarrow \eta p$	$d\sigma/d\Omega, \Sigma, F, T, P, H, G, E$	
$\gamma p \rightarrow \eta' p$	$d\sigma/d\Omega, \Sigma$	
$\gamma p \rightarrow K\Lambda, K\Sigma$	$d\sigma/d\Omega, \Sigma, P, T, C_x, C_z, O_{x'}, O_{z'}$	
$\gamma p \rightarrow \pi^0\pi^0 p$	$d\sigma/d\Omega, \Sigma, E, I_c, I_s$	$\Sigma, E, T, P, H, F, P_x, P_y$ (CB-ELSA)
$\gamma p \rightarrow \pi^+\pi^- p$	$d\sigma/d\Omega$	I_c, I_s (CLAS)
$\gamma p \rightarrow \omega p$	$d\sigma/d\Omega, \Sigma, \rho_{ij}^k, E, G$ (CB-ELSA), $\Sigma, \text{P,T,F,H}$ (CLAS)	K-matrix channel
$\gamma n \rightarrow \Lambda K, \Sigma^- K$	$d\sigma/d\Omega$ (CLAS), E (CLAS)	Σ, G (CLAS)
$\gamma n \rightarrow \pi^- p$	$d\sigma/d\Omega, \Sigma, P, E, \Sigma$ (CLAS)	
$\gamma n \rightarrow \eta n$	$d\sigma/d\Omega$ (CB-ELSA, MAMI), $\Sigma, d\sigma/d\Omega (h = \frac{1}{2})$ (CB-ELSA)	

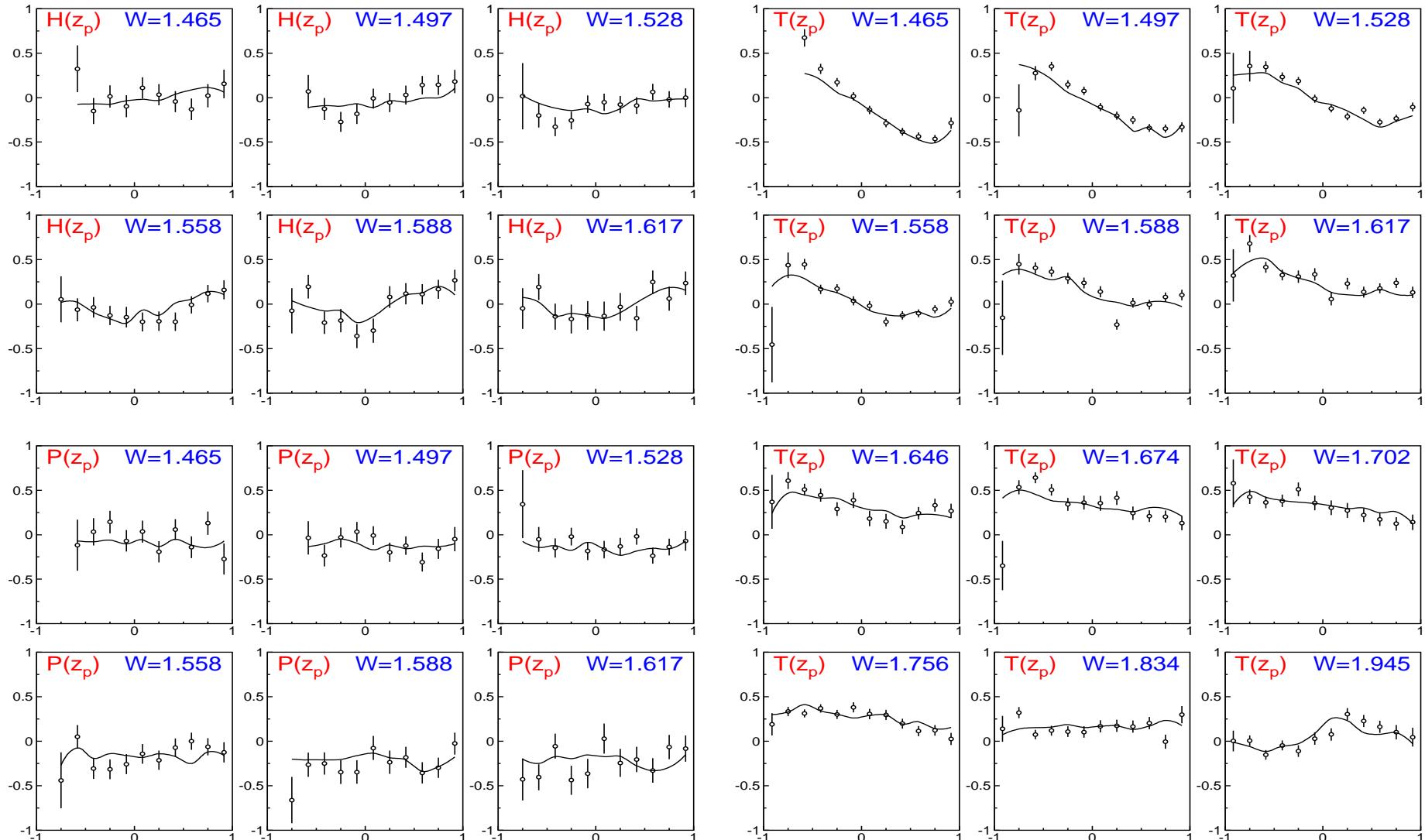
$\gamma p \rightarrow \pi^0 \pi^0 p$ **Polarization observables**

$$\frac{d\sigma}{d\Omega}(\Theta, \varphi) = \frac{d\sigma_0}{d\Omega}(\Theta) [1 - \Sigma(\Theta) \cos(2\varphi) - \Lambda_x H(\Theta) \sin(2\phi) - \Lambda_y P(\Theta) \cos(2\varphi) + \Lambda_y T(\Theta)]$$

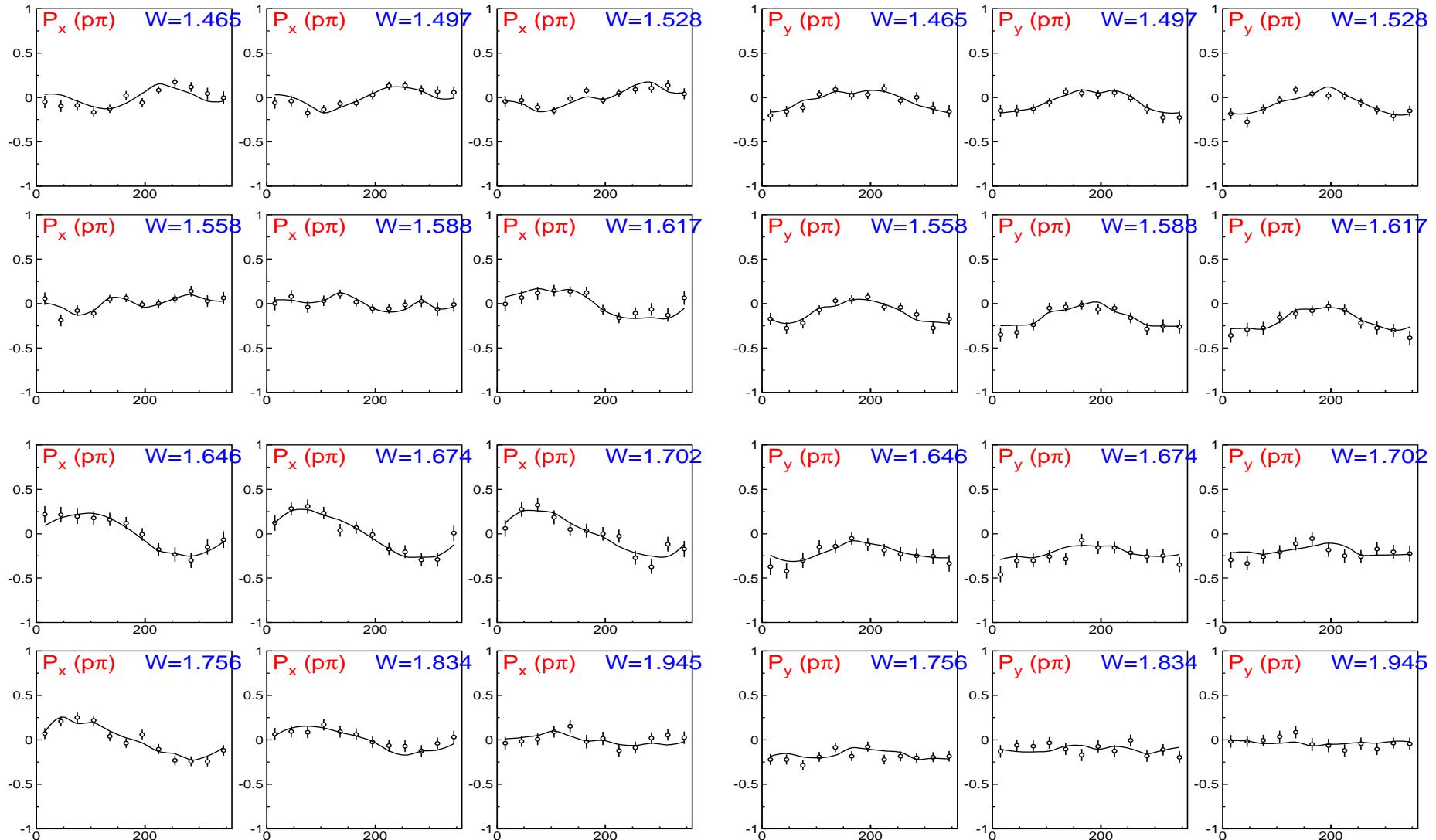


$$\begin{aligned} \frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega}(\Theta) & \left[1 + \Lambda_x P_x + \Lambda_y P_y + \sin(2\varphi) (I^s + \Lambda_x P_x^s + \Lambda_y P_y^s) \right. \\ & \left. + \cos(2\varphi) (I^c + \Lambda_x P_x^c + \Lambda_y P_y^c) \right] \end{aligned}$$

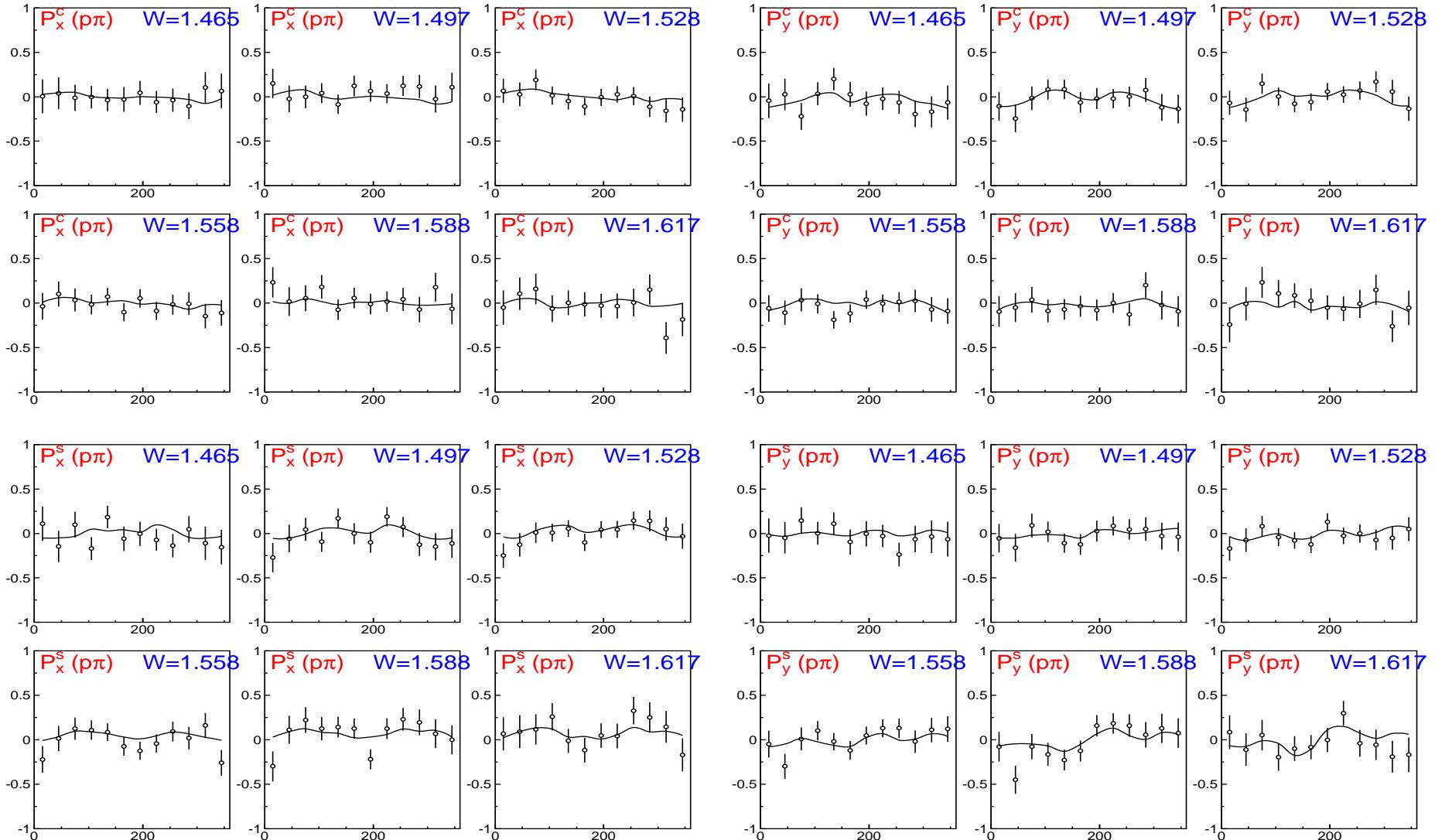
$\gamma p \rightarrow \pi^0 \pi^0 p$ polarization observables from CB-ELSA (T.Seifen)



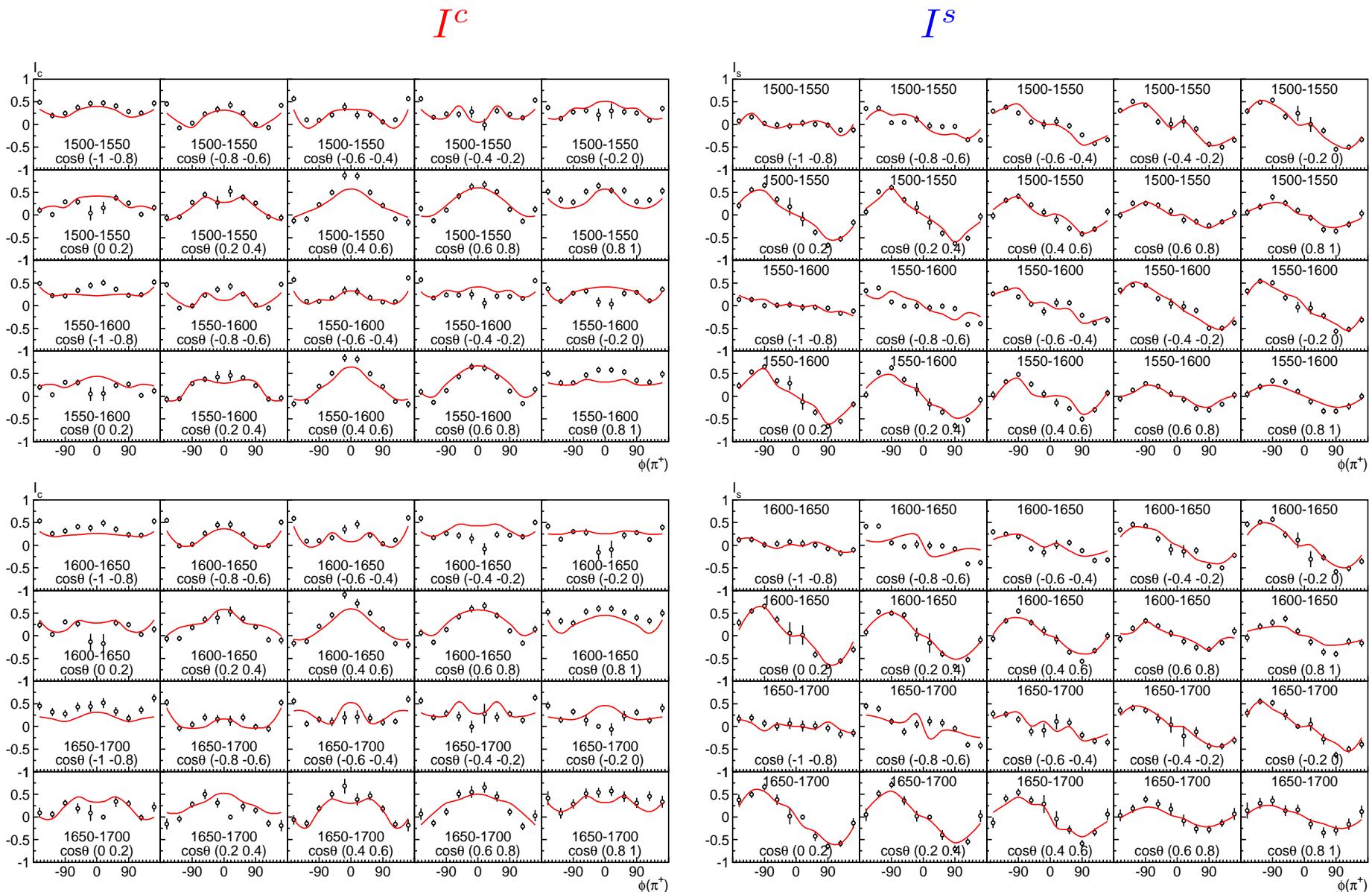
$\gamma p \rightarrow \pi^0 \pi^0 p$ polarization observables from CB-ELSA (T.Seifen)



$\gamma p \rightarrow \pi^0 \pi^0 p$ polarization observables from CB-ELSA (T.Seifen)



$\gamma p \rightarrow \pi^+ \pi^- p$: I^c and I^s polarization observables from CLAS (V.Crede)



	$N\pi$	$\Delta\pi$ ($L < J$)	$\Delta\pi$ ($L > J$)	$N(1440)\pi$	$N(1520)\pi$	$N(1535)\pi$	$N\sigma$
$N(1535) 1/2^-$	46 ± 5 52 ± 5	x	5 ± 3 2.5 ± 1.5	6 ± 5 12 ± 8	-	-	4 ± 2 6 ± 4
$N(1520) 3/2^-$	61 ± 3 61 ± 2	10 ± 4 19 ± 4	10 ± 3 9 ± 2	≤ 1 ≤ 1	-	-	≤ 2 ≤ 2
$N(1650) 1/2^-$	48 ± 4 51 ± 4	x	6 ± 3 12 ± 6	5 ± 3 16 ± 10	-	-	3 ± 2 10 ± 8
$N(1700) 3/2^-$	20 ± 8 15 ± 6	66 ± 17 65 ± 15	7 ± 4 9 ± 5	9 ± 5 7 ± 4	≤ 2 ≤ 4	≤ 1 ≤ 1	6 ± 4 8 ± 6
$N(1675) 5/2^-$	40 ± 1 41 ± 2	19 ± 3 30 ± 7	-	-	-	-	1 ± 1 5 ± 2
$\Delta(1620) 1/2^-$	30 ± 5 28 ± 3	x	28 ± 15 62 ± 10	15 ± 8 6 ± 3	-	-	x
$\Delta(1700) 3/2^-$	22 ± 6 22 ± 4	16 ± 15 20 ± 15	8 ± 6 10 ± 6	3 ± 2 ≤ 1	≤ 1 3 ± 2	≤ 1	x
$\Delta(1600) 3/2^+$	17 ± 4 14 ± 4	70 ± 6 77 ± 5	≤ 2 ≤ 2	≤ 1 22 ± 5	-	-	x
$N(1720) 3/2^+$	13 ± 5 11 ± 4	15 ± 7 62 ± 15	6 ± 6 6 ± 6	6 ± 5 ≤ 2	7 ± 3 3 ± 2	4 ± 2 ≤ 2	20 ± 10 2 8 ± 6
$N(1680) 5/2^+$	68 ± 8 62 ± 4	8 ± 4 7 ± 3	8 ± 4 10 ± 3	-	≤ 1 ≤ 1	-	8 ± 4 2 14 ± 5
$\Delta(1910) 1/2^+$	16 ± 6 12 ± 3	x	17 ± 9 50 ± 16	50 ± 18 6 ± 3	-	4 ± 2 5 ± 3	x
$\Delta(1920) 3/2^+$	12 ± 6 8 ± 4	5 ± 4 18 ± 10	40 ± 20 58 ± 14	9 ± 6 ≤ 4	10 ± 8 ≤ 5	5 ± 5 ≤ 2	x
$\Delta(1905) 5/2^+$	13 ± 4 13 ± 2	20 ± 12 33 ± 10	-	-	-	≤ 1	x
$\Delta(1950) 7/2^+$	46 ± 4 46 ± 2	5 ± 4 5 ± 4	-	-	-	-	x

Density matrix elements for $\gamma p \rightarrow \omega p$

$$\frac{d\sigma}{d\Omega_\omega d\Omega_{dec}} = \frac{d\sigma}{d\Omega_\omega} W(\cos \Theta_{dec}, \Phi_{dec})$$



$$W(\cos \Theta, \Phi) = \frac{3}{4\pi} \left(\frac{1}{2}(1 - \rho_{00}) + \frac{1}{2}(3\rho_{00} - 1) \cos^2 \Theta - \sqrt{2}Re\rho_{10} \sin 2\Theta \cos \Phi - \rho_{1-1} \sin^2 \Theta \cos 2\Phi \right).$$

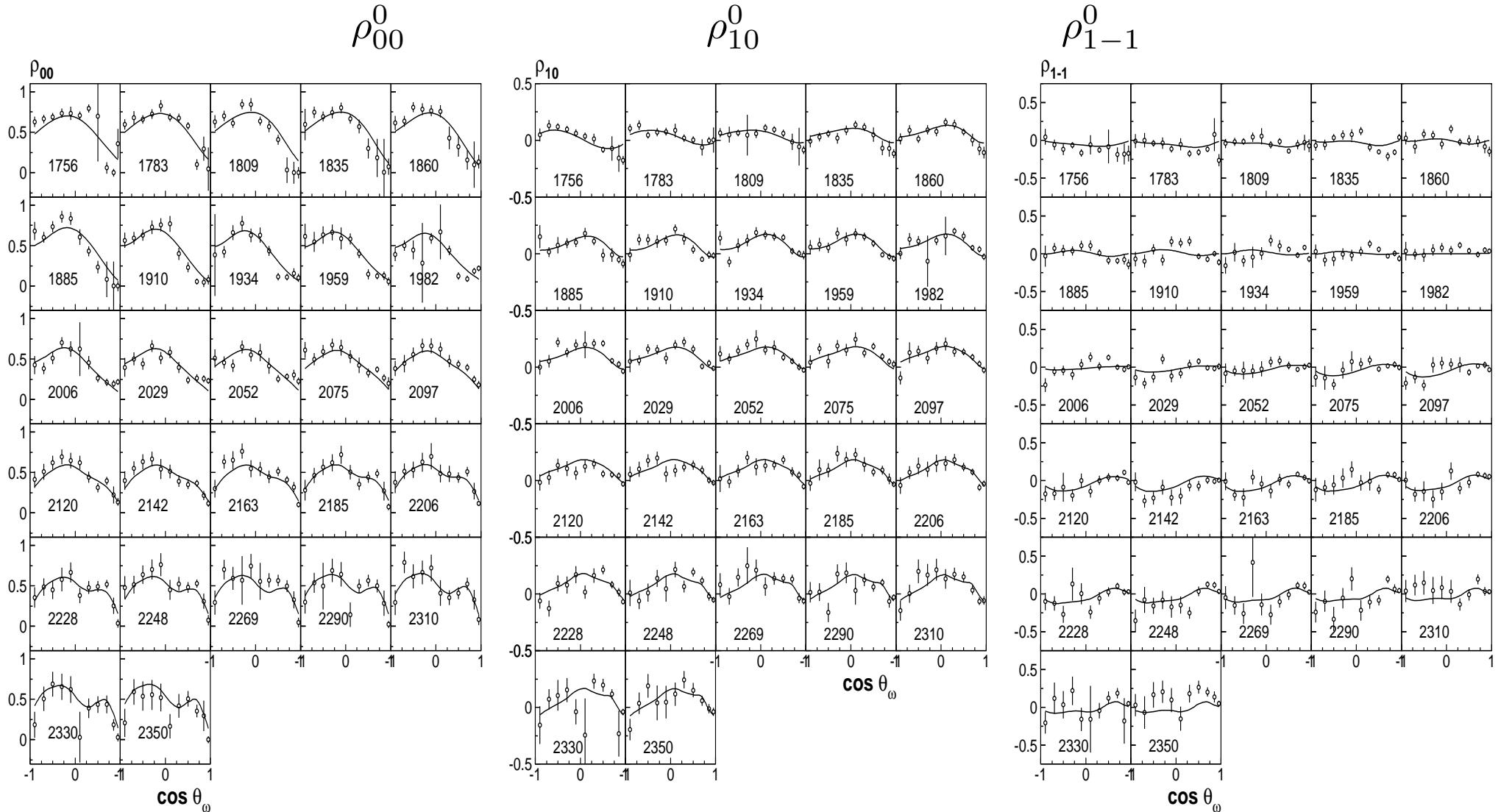
$\cos \Theta, \Phi$ **direction of the vector** $n = \varepsilon_{ijkm} p_j^{\pi^+} p_k^{\pi^-} p_m^{\pi^0}$ **in the ω rest frame.**



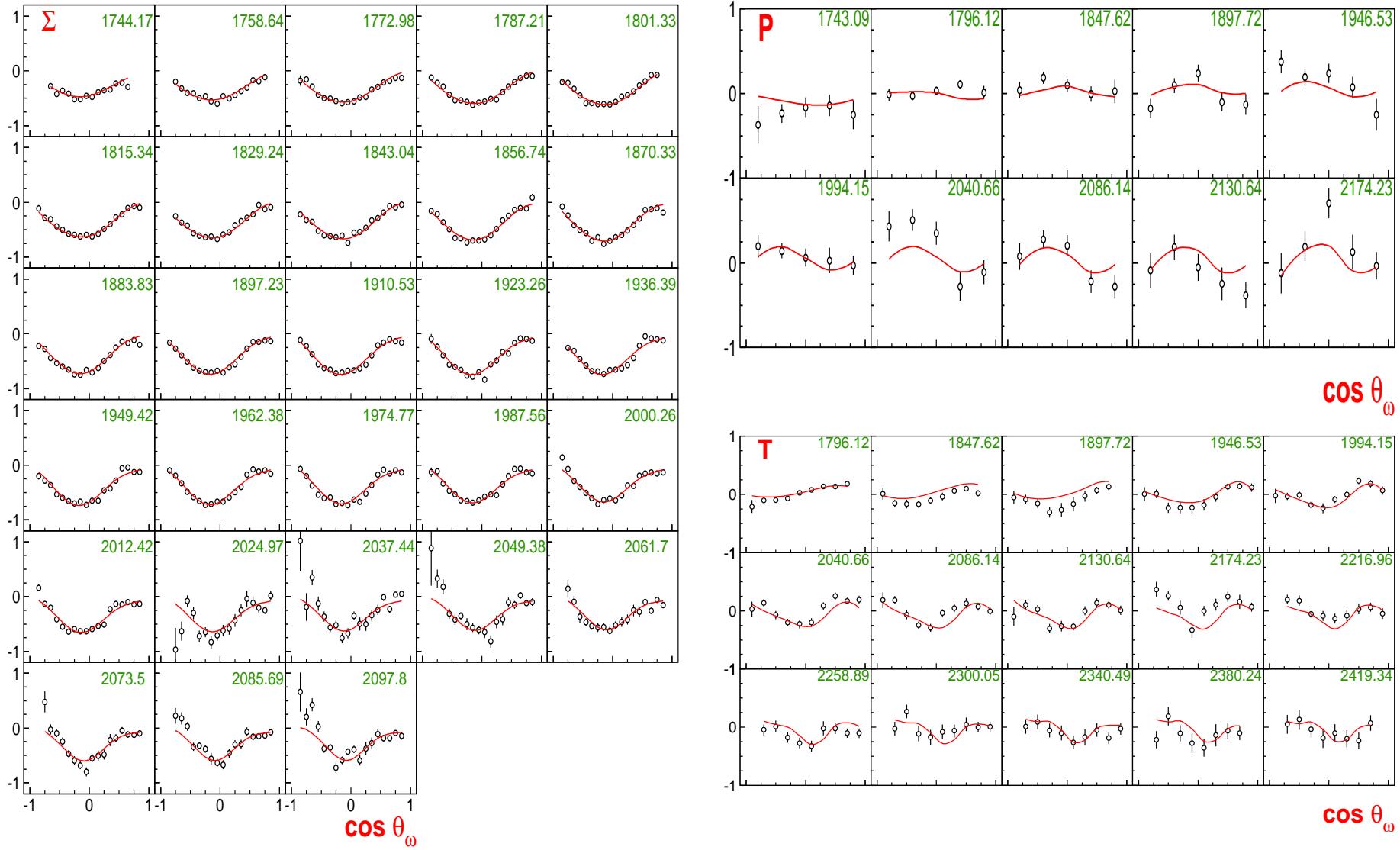
$$W(\cos \Theta, \Phi) = \frac{3}{8\pi} \left(\frac{1}{2}(1 + \cos^2 \Theta) + \frac{1}{2}(1 - 3 \cos^2 \Theta)\rho_{00} + \sqrt{2}Re\rho_{10} \sin(2\Theta) \cos \Phi + \rho_{1-1} \sin^2 \Theta \cos 2\Phi \right).$$

$\cos \Theta, \Phi$ **angles of photon from ω decay in the ω rest frame**

Fit of the density matrix elements $\gamma p \rightarrow p\omega$ (CB-ELSA)



Omega photoproduction and polarization observables from CB-ELSA



There is an indication for the S_{11} state with mass 2160 ± 40 MeV and width 280 ± 60 MeV

Observable	Solution with $S_{11}(2160)$	Basic Solution	N
$d\sigma/d\Omega$	0.92	1.02	648
r_{00}	2.37	2.42	297
r_{10}	1.29	1.38	297
r_{10}	1.61	1.81	297
Σ	1.99	2.12	491
P	1.73	1.94	50
F	1.74	1.85	152
H	1.30	1.43	50
E	2.43	2.50	104
T	1.06	1.36	144

SUMMARY

- The new polarization data on the double pion photoproduction provide an important constrain for the data analysis.
- The branching ratios of the baryon states into $\Delta\pi$, $N\sigma$, $N(1440)\pi$, $N(1520)\pi$, $N(1535)\pi$ and $N(1680)\pi$ decay channels are determined with a good precision.
- The ωN channel is included dynamically in the analysis.
- In many partial waves the unitarity limit was reached in the energy region below 2 GeV.
- The present solution has a strong prediction power, but some properties can be better defined with the double polarization experiments.
- The analysis of the observables from $\gamma p \rightarrow \omega p$ suggests an existence of the S_{11} state in the mass region 2160 MeV. However the present data can not define it unambiguously.

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