Bonn-Gatchina partial wave analysis of two meson photoproduction reactions

V.A. Nikonov

Petersburg Nuclear Physics Institute

HISKP (Bonn), PNPI (Russia)

NSTAR 2015, Osaka, May 26, 2015

- **The study of the reactions $\gamma \to p\pi^0\pi^0$ and $\gamma \to p\pi^0\eta$ opens a good chance to search for the missing resonances and to study sequential decays of high-mass resonances.**
- **Polarization observables are important in photoproduction to disentangle the multitude of contributing resonances.**
- **One can define branching ratios to different decay modes.**

The Bonn Gatchina approach

The helicity-dependent amplitude for photoproduction of the final state b in one partial wave is calculated as P-vector:

$$a_b^h = P_a^h (I - i\rho K)_{ab}^{-1}$$

where K is called K matrix, ρ the phase space, and where

$$P_a^h = \sum_\alpha \frac{A_\alpha^h g_a^\alpha}{M_\alpha^2 - s} + F_a \, .$$

and A_α^h is photo-coupling of the K-matrix pole α and F_a is a non-resonant transition. In the BnGa analysis, the K-matrix has up to 9 channels and up to 4 poles. Resonances and background contributions are combined in a K matrix

$$K_{ab} = \sum_\alpha \frac{g_a^\alpha g_b^\alpha}{M_\alpha^2 - s} + f_{ab} \, .$$

The background terms f_{ab} can be arbitrary functions of s. We use

$$f_{ab} = \mathrm{constant}\{\mathrm{mostly}\}; \qquad f_{ab} = \frac{(a + b\sqrt{s})}{(s - s_0)} \quad \{(I)J^P = (\frac{1}{2})\frac{1}{2}^-\}$$

The angular momentum barrier q^L is suppressed by Blatt and Weisskopf form factors.

Resonances with total momentum J up to $\frac{7}{2}$; $t-$ and $u-$channel exchanges; $K-$matrix up to 9 channels; dispersion corrections for meson-nucleon loops.

$$N^*, \Delta^* \to \quad \Delta(1232)\tfrac{3}{2}^+\pi^0 \quad \to p\pi^0\pi^0$$
$$N^*, \Delta^* \to \quad N(1440)\tfrac{1}{2}^+\pi^0 \quad \to p\pi^0\pi^0$$
$$N^*, \Delta^* \to \quad N(1520)\tfrac{3}{2}^-\pi^0 \quad \to p\pi^0\pi^0$$
$$N^*, \Delta^* \to \quad N(1535)\tfrac{1}{2}^-\pi^0 \quad \to p\pi^0\pi^0$$
$$N^*, \Delta^* \to \quad N(1680)\tfrac{5}{2}^+\pi^0 \quad \to p\pi^0\pi^0$$
$$N^* \to \quad N\sigma \quad \to p\pi^0\pi^0$$
$$N^* \to \quad pf_0(980) \quad \to p\pi^0\pi^0$$
$$N^*, \Delta^* \to \quad N(1535)\tfrac{1}{2}^-\pi^0 \quad \to p\pi^0\eta$$
$$\Delta^* \to \quad \Delta(1232)\tfrac{3}{2}^+\eta \quad \to p\pi^0\eta$$
$$N^* \to \quad N(1440)\tfrac{1}{2}^+\eta \quad \to p\pi^0\eta$$
$$N^* \to \quad pa_0(980) \quad \to p\pi^0\eta$$

The data base

We use data on photoproduction, RE and IM of the πN elastic scattering amplitude, and inelastic reactions:

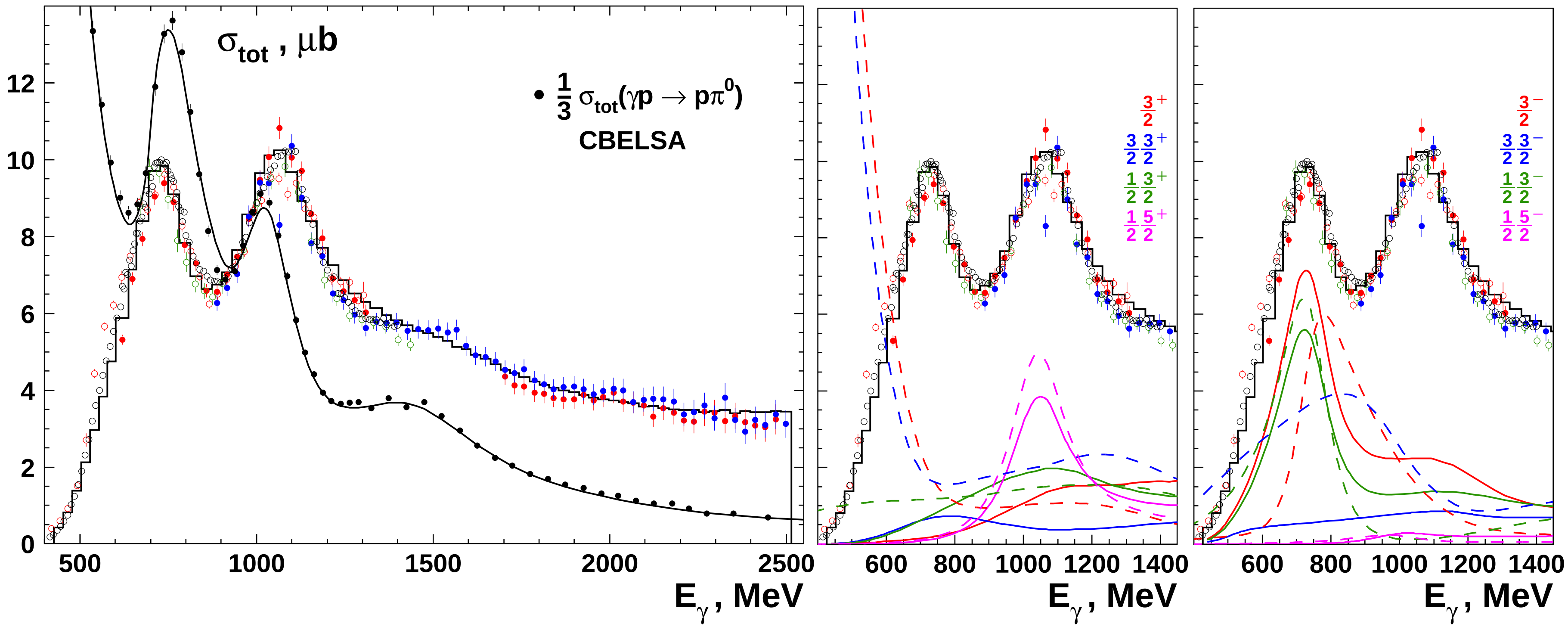
	$\frac{d\sigma}{d\Omega}$	Σ	E	G	T	P	H	C_x	C_z	O_x	O_z	CLAS, CBELSA, MAMI
$\gamma p \to \pi^0 p$	x	x	x	x	x	x	x			x	x	$\gamma p \to \pi^0\pi^0 p$
$\gamma p \to \pi^- n$	x	x	x	x	x	x	x					$(\vec{\gamma} p \to \pi^0\pi^0 p)$
$\gamma p \to \eta p$	x	x	x	x	x	x	x					$\gamma p \to \pi^+\pi^- p$
$\gamma p \to K^+\Lambda$	x	x			x	x		x	x	x	x	$(\vec{\gamma} p \to \pi^+\pi^- p)$
$\gamma p \to K^+\Sigma^0$	x	x			x	x		x	x	x	x	$\gamma p \to \pi^0\eta p$
$\gamma p \to K^0\Sigma^+$	x	x				x						$(\vec{\gamma} p \to \pi^0\eta p)$
$\gamma p \to \omega p$	x	x	x	x								(γp) event based likelihood
$\gamma p \to K^{*+}\Lambda$	x											($\vec{\gamma} p$) fit to distributions

S_{11}	S_{31}	P_{11}	P_{31}	$\pi^- p \to \eta n$	$d\sigma/d\Omega$		
P_{13}	P_{33}	D_{13}	D_{33}	$\pi^+ p \to K^+\Sigma^+$	$d\sigma/d\Omega$	P	β
D_{15}	F_{15}	F_{35}	F_{37}	$\pi^- p \to K^0\Lambda(\Sigma^0)$	$d\sigma/d\Omega$	P	β
F_{17}	G_{17}	G_{19}	H_{19}	$\pi^- p \to \pi^0\pi^0 p$	event based likelihood		

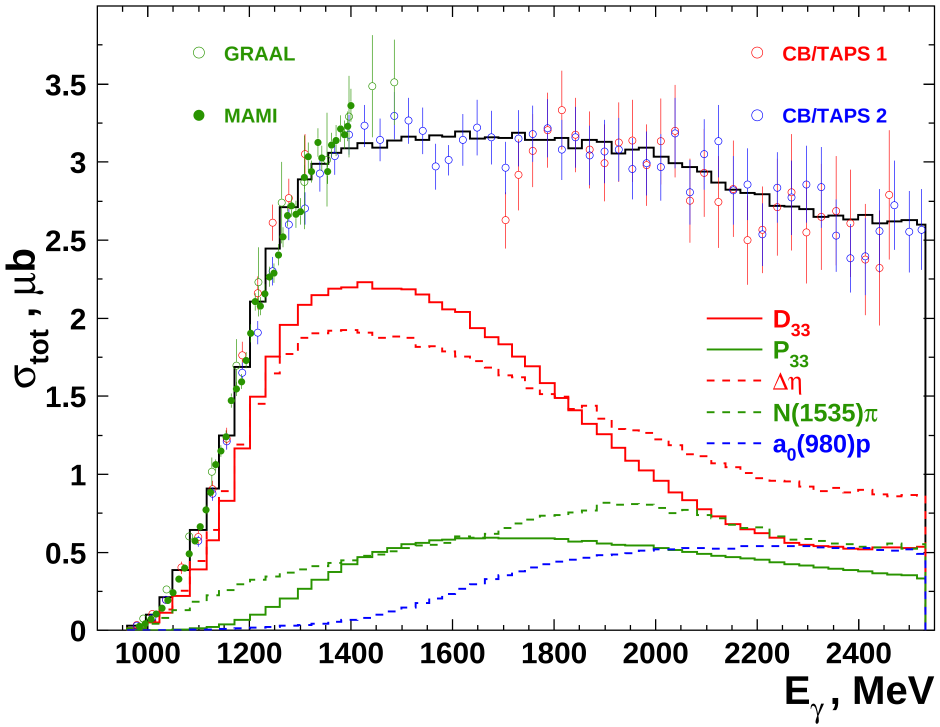
The fit minimizes the total log likelihood defined by

$$-\ln \mathcal{L}_{tot} = \left(\frac{1}{2}\sum w_i \chi_i^2 - \sum w_i \ln \mathcal{L}_i\right) \frac{\sum N_i}{\sum w_i N_i}$$

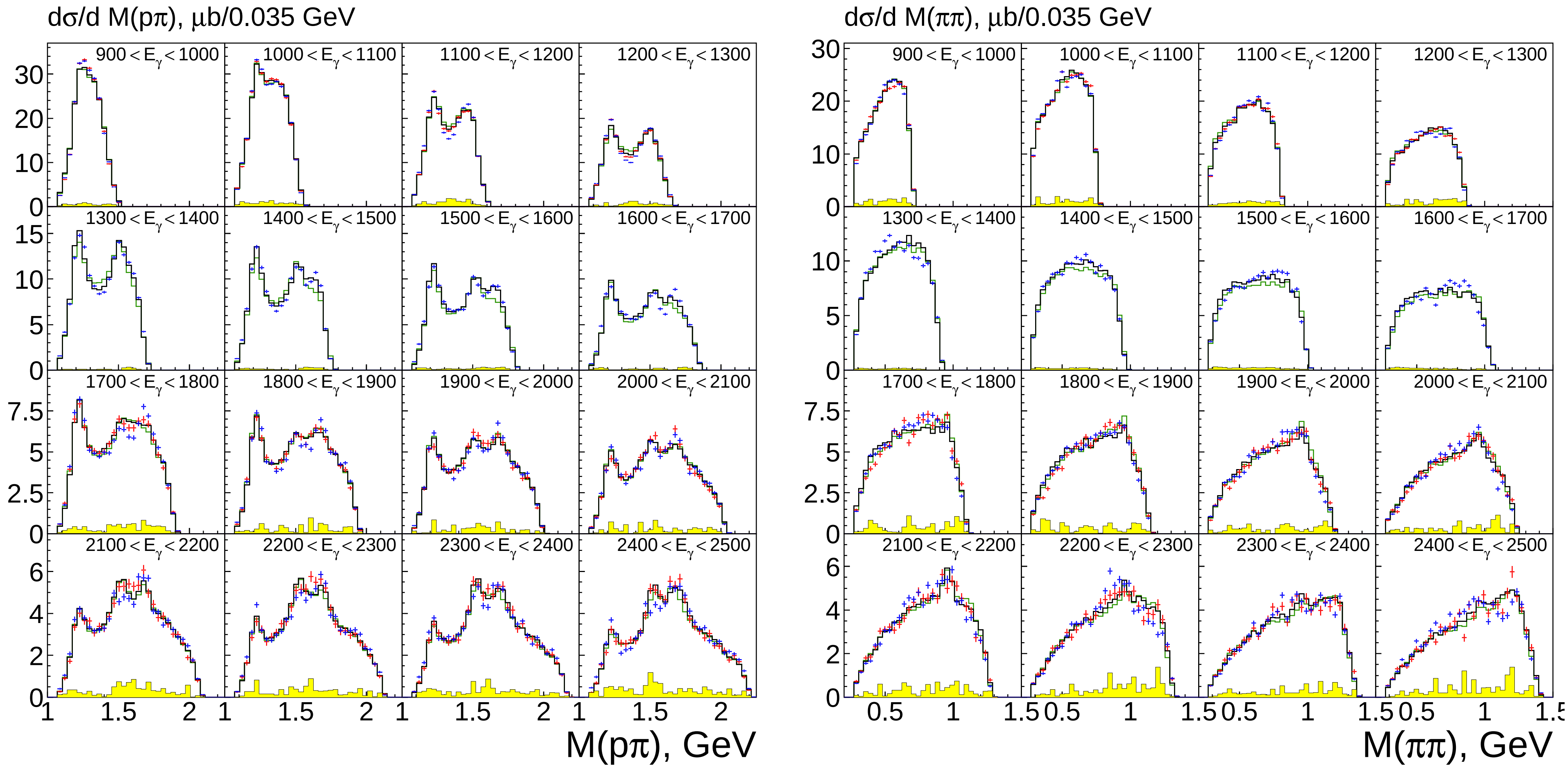
Main contributions to the total cross section of $\gamma p \to p\pi^0\pi^0$



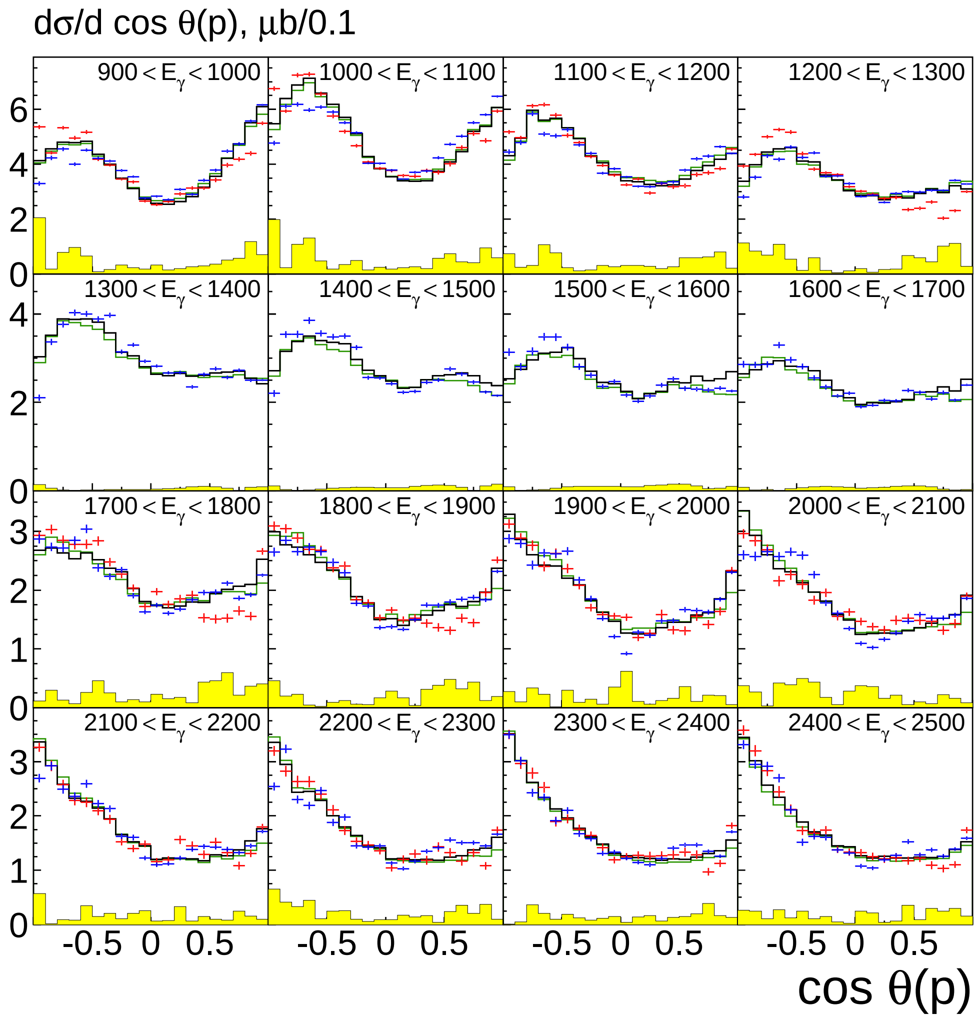
Main contributions to the total cross section of $\gamma p \to p\pi^0\eta$

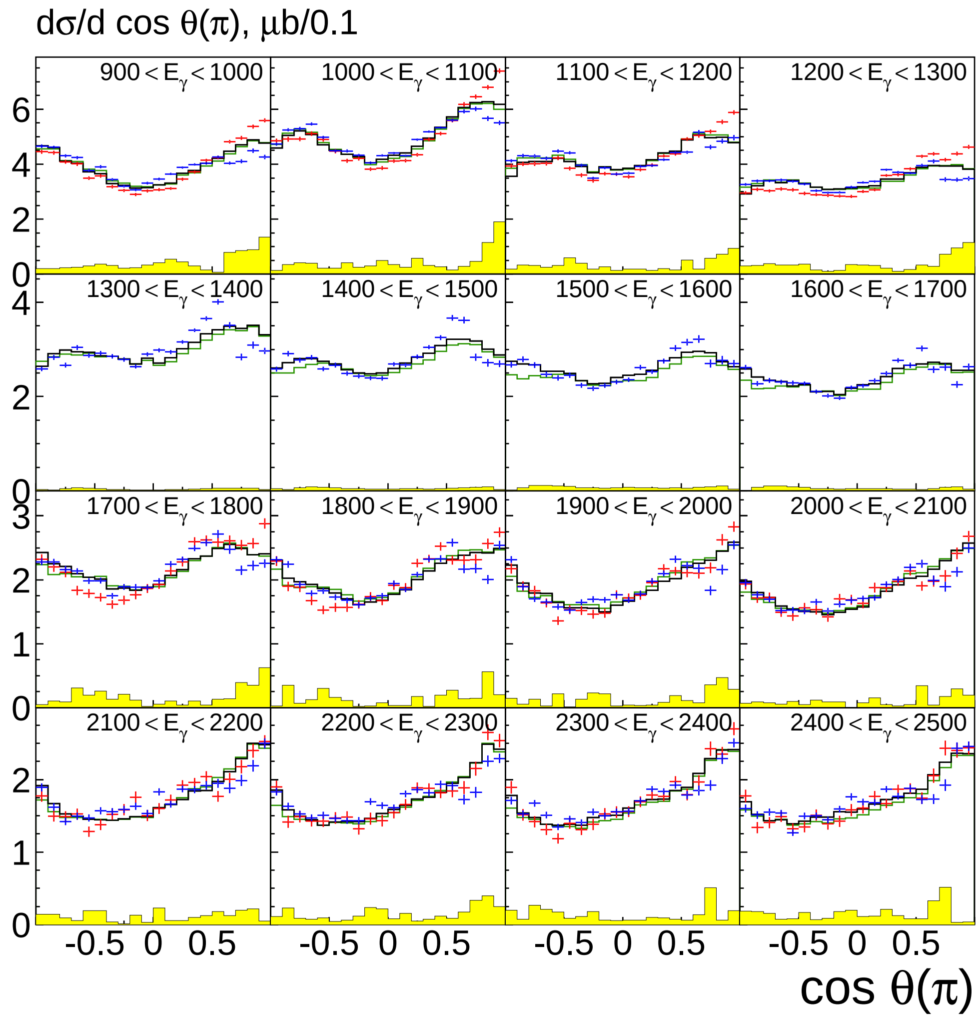


Mass distributions $\gamma p \to p\pi^0\pi^0$

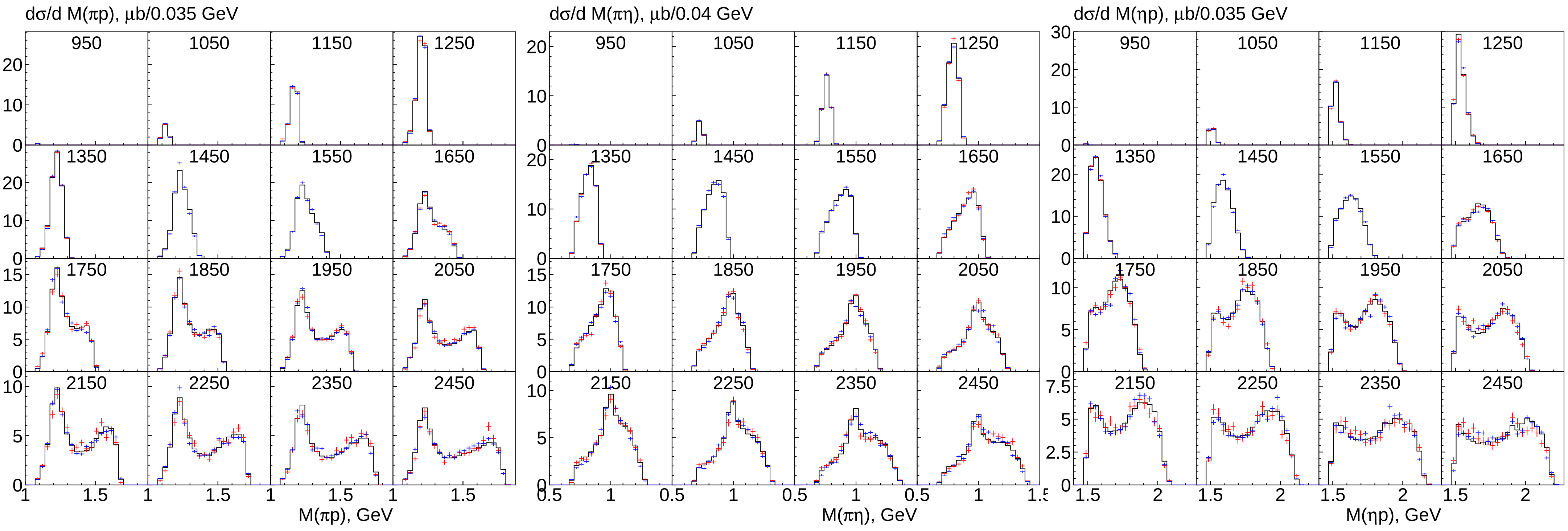


Angular distributions $\gamma p \rightarrow p\pi^0\pi^0$





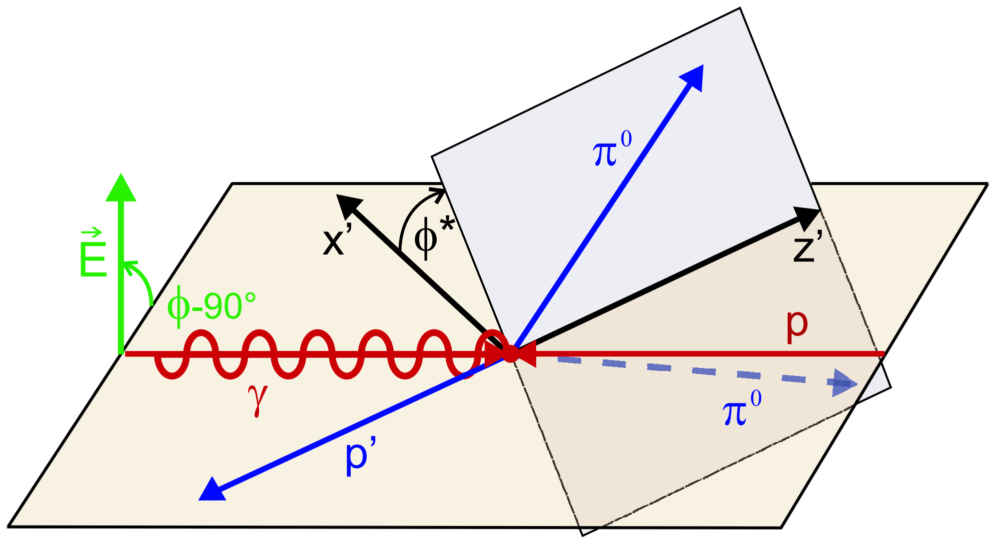
Mass distributions $\gamma p \to p\pi^0\eta$



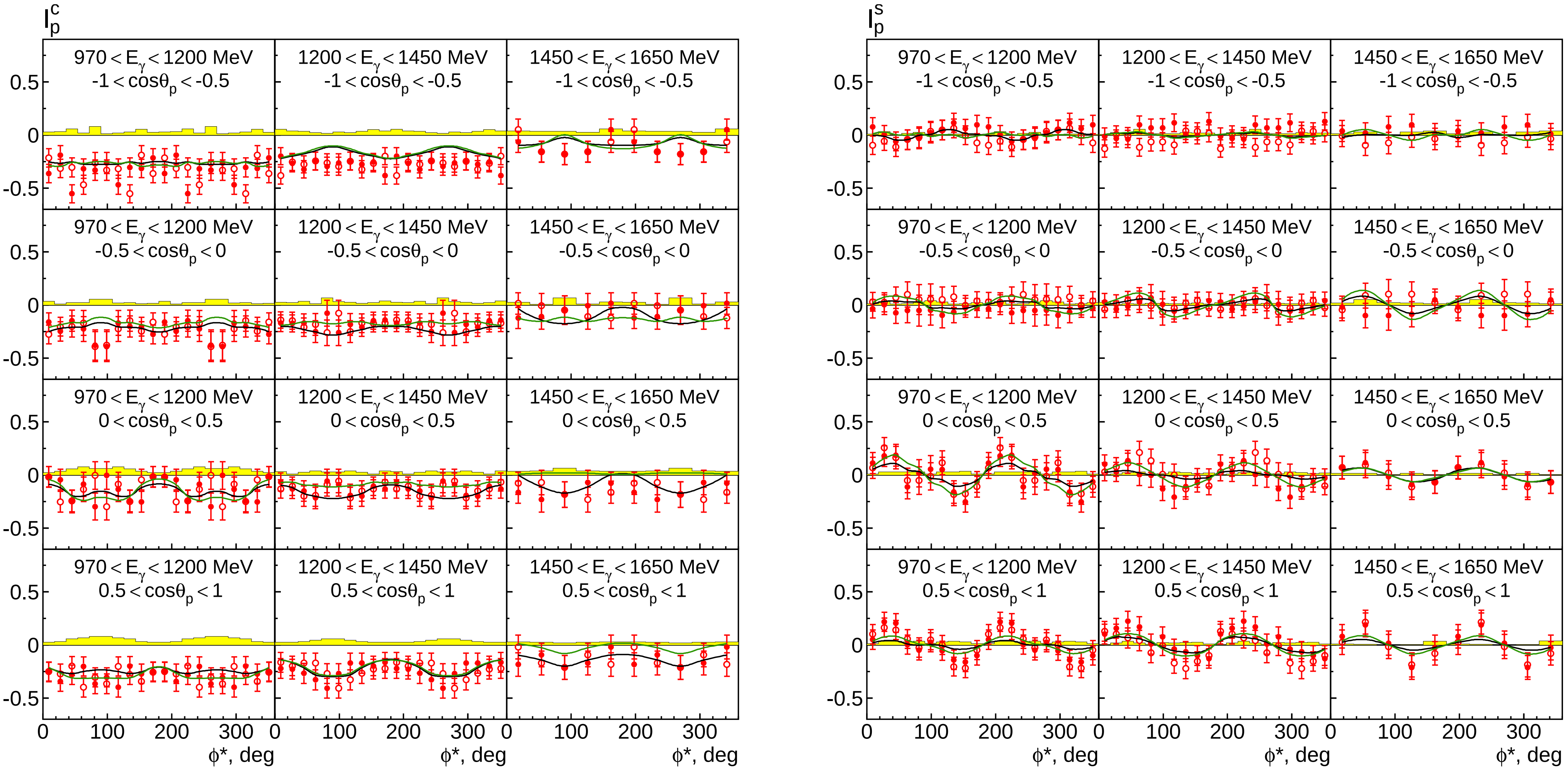
With three particles in the final state new polarization observables can be defined.

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

$$I^c(\phi^*) = I^c(2\pi - \phi^*)\,; \quad I^s(\phi^*) = -I^s(2\pi - \phi^*).$$

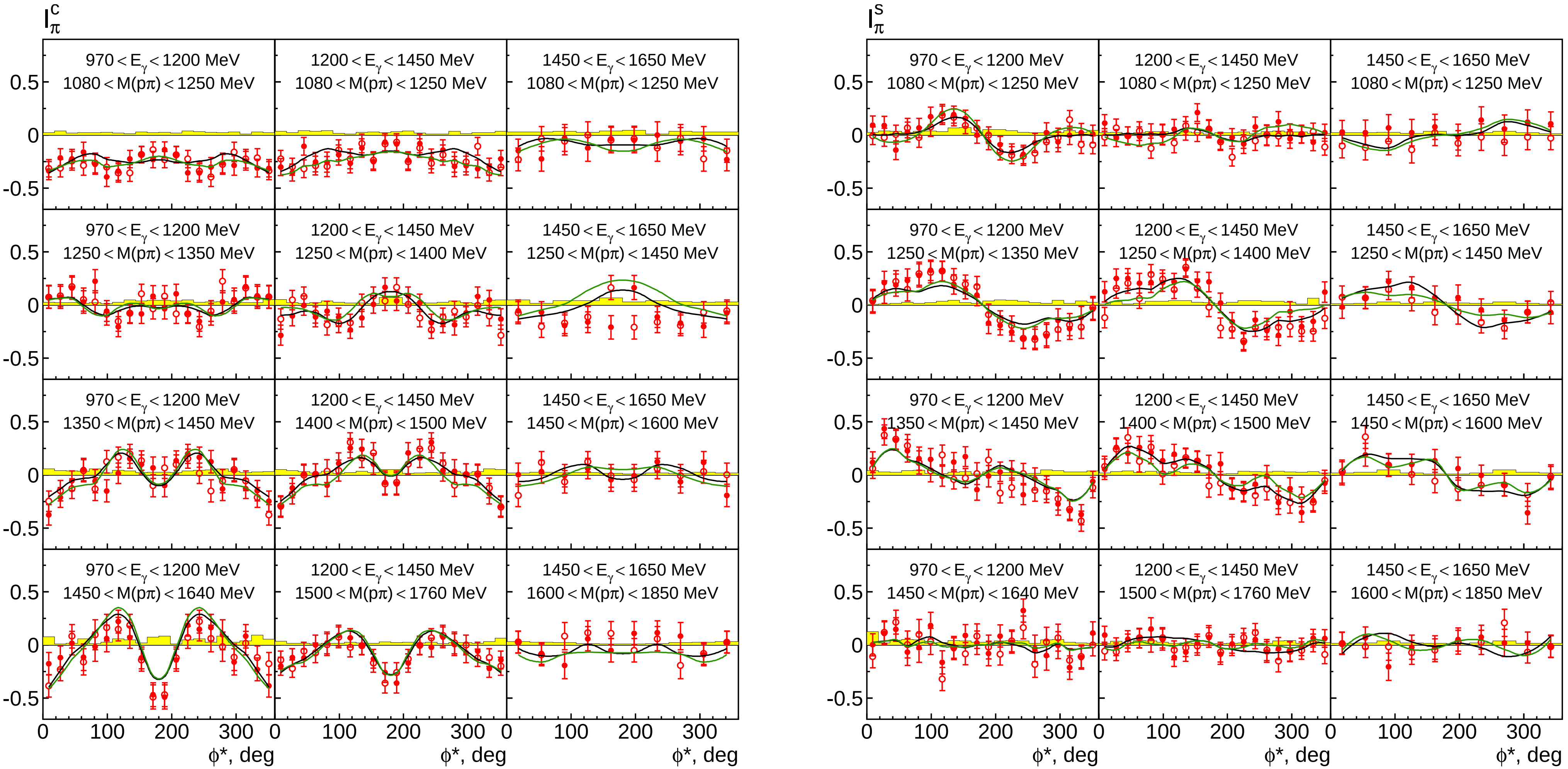


Polarization observables



Polarization observables: red points: CBELSA/TAPS data, black curve: BnGa main PWA fit, green curve: BnGa PWA fit without $N(1900)3/2^+$.

Polarization observables

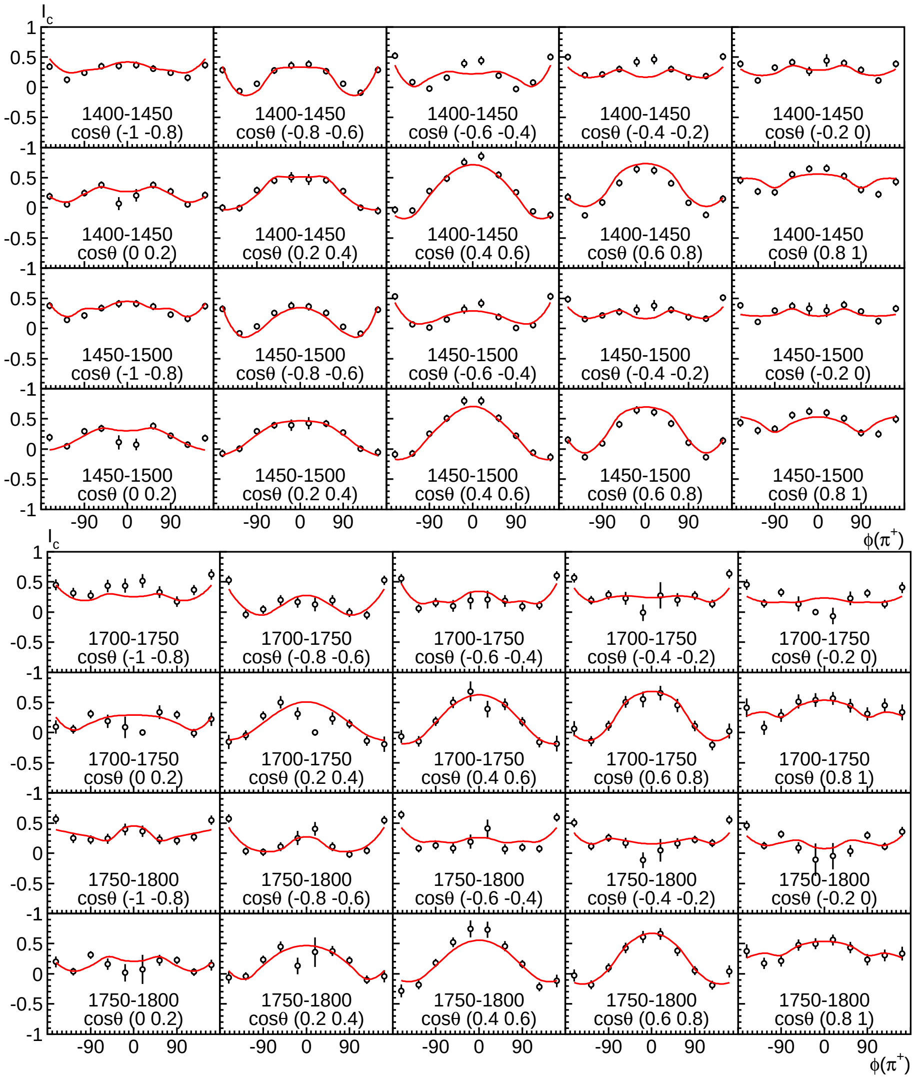


Polarization observables: red points: CBELSA/TAPS data, black curve: BnGa main PWA fit, green curve: BnGa PWA fit without $N(1900)3/2^+$.

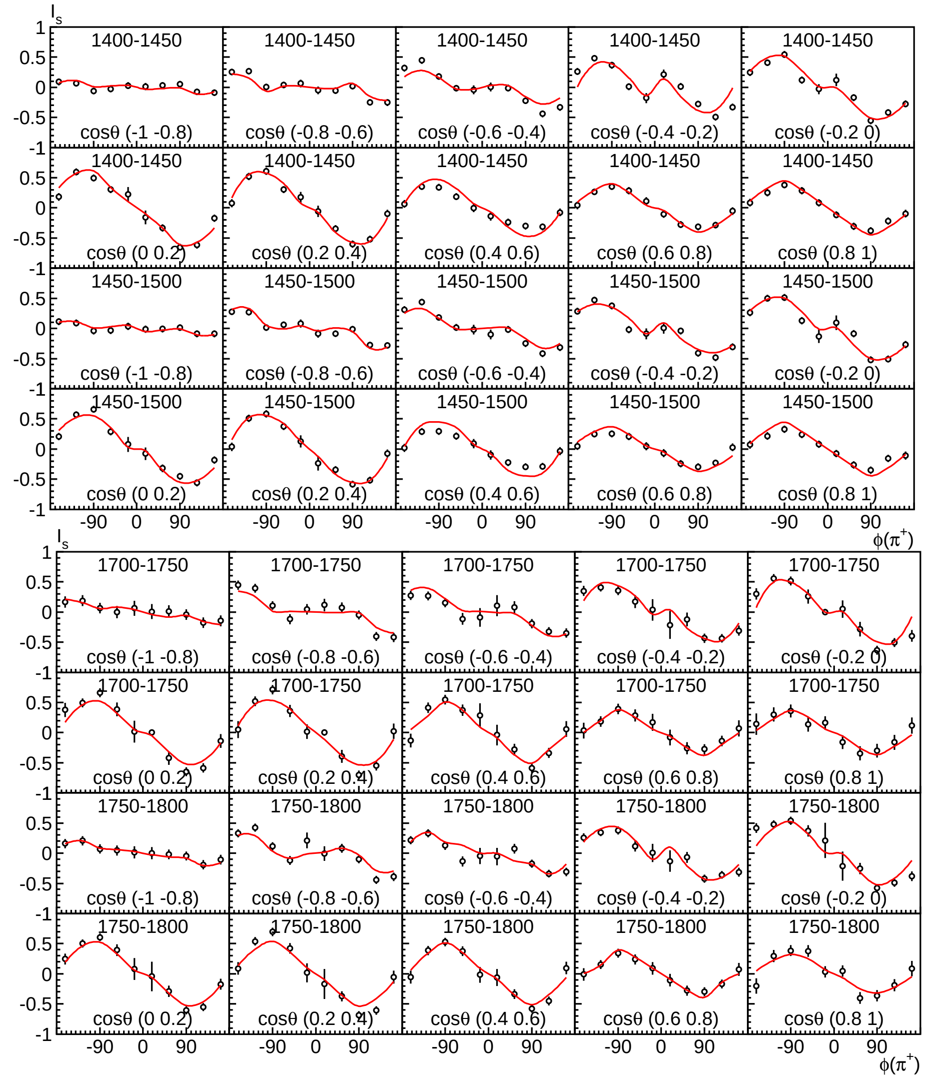
I_c and I_s for $\gamma p \to \pi^+\pi^- p$ from CLAS (Preliminary)

Courtesy of V. Crede, Florida State U

I_c



I_s



$N(1720)3/2^+$ pole parameters			
M_{pole}	1670±25	Γ_{pole}	430±100
$A^{1/2}$	0.115±0.045	Phase	(0±35)°
$A^{3/2}$	0.140±0.040	Phase	(65±35)°
$N(1720)3/2^+$ transition residues			phase
$\pi N \to \pi N$		26±10 (MeV)	-(100±25)°
$2\,(\pi N \to \Delta(1232)\pi_{L=1})/\Gamma$		28±9%	(95±30)°
$2\,(\pi N \to \Delta(1232)\pi_{L=3})/\Gamma$		7±5%	not def.
$2\,(\pi N \to N\sigma)/\Gamma$		8±4%	-(110±35)
$2\,(\pi N \to N(1520)\pi)/\Gamma$		5±4%	not def.
$(\gamma p)^{1/2} \to \Delta(1232)\pi_{L=1}$		50±20 10^{-3}	(120±40)°
$(\gamma p)^{1/2} \to \Delta(1232)\pi_{L=3}$		14±8 10^{-3}	not def.
$(\gamma p)^{1/2} \to N\sigma$		12±6 10^{-3}	-(80±40)°
$(\gamma p)^{1/2} \to N(1520)\pi$		10±7 10^{-3}	not def.
$(\gamma p)^{3/2} \to \Delta(1232)\pi_{L=1}$		65±30 10^{-3}	-(160±40)°
$(\gamma p)^{3/2} \to \Delta(1232)\pi_{L=3}$		15±11 10^{-3}	not def.
$(\gamma p)^{3/2} \to N\sigma$		14±8 10^{-3}	-(10±45)°
$(\gamma p)^{3/2} \to N(1520)\pi$		11±10 10^{-3}	not def.
$\gamma p \to \Delta(1232)\pi_{L=1}$ E_{1+}		30±16 10^{-3}	-(95±35)°
$\gamma p \to \Delta(1232)\pi_{L=3}$ E_{1+}		8±6 10^{-3}	not def.
$\gamma p \to N\sigma$ E_{1+}		6±4 10^{-3}	(60±40)°
$\gamma p \to N(1520)\pi$ E_{1+}		5±5 10^{-3}	not def.
$\gamma p \to \Delta(1232)\pi_{L=1}$ M_{1+}		70±40 10^{-3}	-(10±40)°
$\gamma p \to \Delta(1232)\pi_{L=3}$ M_{1+}		18±12 10^{-3}	not def.
$\gamma p \to N\sigma$ M_{1+}		15±10 10^{-3}	(145±45)°
$\gamma p \to N(1520)\pi$ M_{1+}		12±10 10^{-3}	not def.

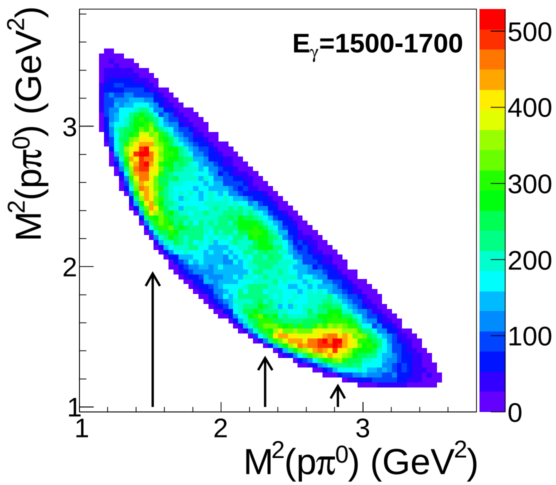
$N_{3/2^+}(1720)$ Breit-Wigner parameters			
M_{BW}	1690±30	Γ_{BW}	420±80
Br(πN)	11±4%	Br($N\sigma$)	8±6%
Br($\Delta(1232)\pi_{L=1}$)	62±15%	Br($\Delta(1232)\pi_{L=3}$)	6±6%
Br($N(1520)\pi$)	3±2%	Br($N(1440)\pi$)	$<$2%
$A^{1/2}_{BW}$	0.115±0.045	$A^{3/2}_{BW}$	0.135±0.040

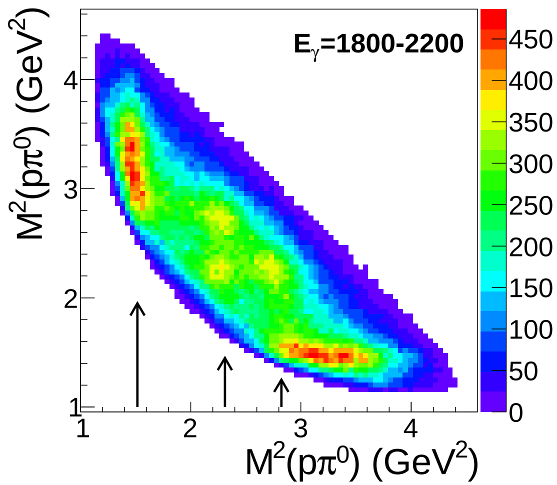
$\boldsymbol{\Delta(1900)1/2^-}$ **

$\Delta(1900)1/2^-$ **pole parameters**			
M_{pole}	**1845±20**	Γ_{pole}	**295±35**
$A^{1/2}$	**0.064±0.015**	**Phase**	**(60±20)°**
$\Delta(1900)1/2^-$ **transition residues**			**phase**
$\pi N \to \pi N$		**11±2 (MeV)**	**-(115±20)°**
$2\,(\pi N \to \Delta(1232)\pi)/\Gamma$		**18±10%**	**(105±25)°**
$2\,(\pi N \to N(1440)\pi)/\Gamma$		**11±6%**	**(115±30)°**
$2\,(\pi N \to N(1520)\pi)/\Gamma$		**6±3%**	**not def.**
$\gamma p \to \Delta(1232)\pi$	E_{0+}	**14±7** 10^{-3}	**(45±25)°**
$\gamma p \to N(1440)\pi$	E_{0+}	**9±6** 10^{-3}	**(50±30)°**
$\gamma p \to N(1520)\pi$	E_{0+}	**4±2** 10^{-3}	**not def.**

$\Delta(1900)1/2^-$ **Breit-Wigner parameters**			
M_{BW}	**1840±20**	Γ_{BW}	**295±30**
Br(πN)	**7±2%**	**Br($\Delta(1232)\pi$)**	**50±20%**
Br($N(1440)\pi$)	**20±12%**	**Br($N(1520)\pi$)**	**6±4%**
$A^{1/2}_{BW}$	**0.065±0.015**		

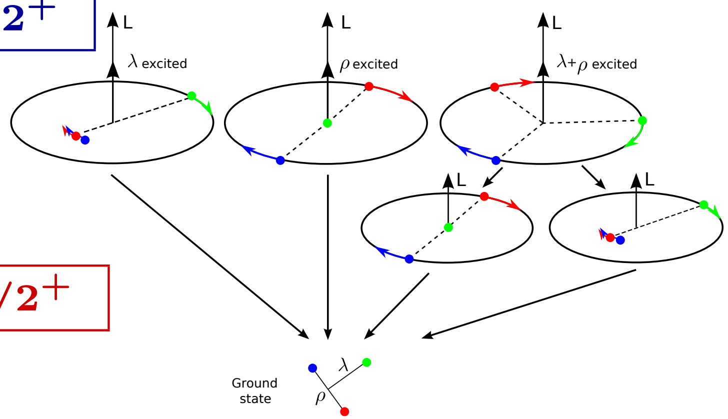
$\mathcal{S}$	space spin isospin
$\mathcal{S}_1$	$\mathcal{SSS}$
$\mathcal{S}_2$	$\mathcal{S}(\mathcal{M_S M_S} + \mathcal{M_A M_A})$
$\mathcal{S}_3$	$(\mathcal{M_S M_S} + \mathcal{M_A M_A})\mathcal{S}$
$\mathcal{S}_4$	$(\mathcal{M_A M_A} - \mathcal{M_S M_S})\mathcal{M_S}$
	$+(\mathcal{M_S M_A} + \mathcal{M_A M_S})\mathcal{M_A}$
$\mathcal{S}_5$	$(\mathcal{M_S S M_S} + \mathcal{M_A S M_A})$
$\mathcal{S}_6$	$\mathcal{A}(\mathcal{M_A M_S} - \mathcal{M_S M_A})$





$\Delta(1910)1/2^+$ $\Delta(1920)3/2^+$ $\Delta(1905)5/2^+$ $\Delta(1950)7/2^+$

$$\mathcal{S} = \frac{1}{\sqrt{2}}\left\{\left[\phi_{0s}(\vec{\rho}) \times \phi_{0d}(\vec{\lambda})\right] + \left[\phi_{0d}(\vec{\rho}) \times \phi_{0s}(\vec{\lambda})\right]\right\}^{(L=2)}$$



$N(1880)1/2^+$ $N(1900)3/2^+$ $N(2000)5/2^+$ $N(1990)7/2^+$

$$\mathcal{M_S} = \frac{1}{\sqrt{2}}\left\{\left[\phi_{0s}(\vec{\rho}) \times \phi_{0d}(\vec{\lambda})\right] - \left[\phi_{0d}(\vec{\rho}) \times \phi_{0s}(\vec{\lambda})\right]\right\}^{(L=2)}$$

$$\mathcal{M_A} = \left[\phi_{0p}(\vec{\rho}) \times \phi_{0p}(\vec{\lambda})\right]^{(L=2)} .$$

	$N\pi$	L	$\Delta\pi$ $L<J$		$\Delta\pi$	$L>J$	$N(1440)\pi$	L	$N(1520)\pi$	L	$N(1535)\pi$	L	$N(1680)\pi$	L	$N\sigma$
$N(1535)1/2^-$	52±5	0	x		2.5±1.5	2	12±8	0	-	1	-	1	-	2	6±4
$N(1520)3/2^-$	61±2	2	19±4	0	9±2	2	<1	2	-	1	-	1	-	2	< 2
$N(1650)1/2-$	51±4	0	x		12±6	2	16±10	0	-	1	-	1	-	2	10±8
$N(1700)3/2^-$	15±6	2	65±15	0	9±5	2	7±4	2	<4	1	<1	1	-	2	8±6
$N(1675)5/2^-$	41±2	2	30±7	2	-	4	-	2	-	1	-	3	-	0	5±2
$\Delta(1620)1/2^-$	28±3	0	x		62±10	2	6±3	0	-	1	-	1	-	2	x
$\Delta(1700)3/2^-$	22±4	2	20±15	0	10±6	2	<1	2	3±2	1	<1	1	-	2	x
$N(1720)3/2^+$	11±4	1	62±15	1	6±6	3	<2	1	3±2	0	<2	2	-	1	8±6
$N(1680)5/2^+$	62±4	3	7±3	1	10±3	3	-	3	<1	2	-	2	-	1	14±5
$\Delta(1910)1/2^+$	12±3	1	x		50±16	1	6±3	1	-	0	5±3	2	-	3	x
$\Delta(1920)3/2^+$	8±4	1	18±10	1	58±14	3	< 4	1	< 5	0	< 2	2	-	1	x
$\Delta(1905)5/2^+$	13±2	3	33±10	1	-	3	-	3	-	2	< 1	2	10±5	1	x
$\Delta(1950)7/2^+$	46±2	3	5±4	3	-	5	-	3	-	2	-	4	6±3	1	x
$N(1880)1/2^+$	6±3	1	x		30±12	1	-	1	-	2	8±4	0	-	3	25±15
$N(1900)3/2^+$	3±2	1	17±8	1	33±12	3	<2	1	15±8	0	7±3	2	-	1	4±3
$N(2000)5/2^+$	8±4	3	22±10	1	34±15	3	-	1	21±10	2	-	2	16±9	1	10±5
$N(1990)7/2^+$	1.5±0.5	3	48±10	3	-	5	<2	1	<2	1	<2	4	-	1	-
$N(1990)7/2^+$	2±1	3	16±6	3	-	5	<2	1	<2	1	<2	4	-	1	-
$N(1895)1/2^-$	2.5±1.5	0	x		7±4	2	8±8	0	-	1	-	1	-	2	18±15
$N(1875)3/2^-$	4±2	2	14±7	0	7±5	2	5±3	2	< 2	1	<1	1	-	2	45±15
$\Delta(1900)1/2^-$	7±2	0	x		50±20	2	20±12	0	6±4	1	-	1	-	2	x
$\Delta(1940)3/2^-$	2±1	0	46±20	0	12±7	2	7±7	2	4±3	1	8±6	1	-	2	x
$N(2120)3/2^-$	5±3	2	50±20	0	20±12	2	10±10	2	15±10	1	15±8	1	-	2	11±4
$N(2060)5/2^-$	11±2	2	7±3	2	-	4	9±5	2	15±6	1	-	3	15±7	0	6±3
$N(2190)7/2^-$	16±2	4	25±6	2	-	4	-	4	-	3	-	3	-	2	6±3
$N(1710)1/2^+$	5±3	1	x		7±4	1	30±10	1	<2	2	-	0	-	3	55±15
$N(1710)1/2^+$	5±3	1	x		25±10	1	<5	1	<2	2	15±6	0	-	3	10±5
$N(2100)1/2^+$	16±5	1	x		10±4	1	-	1	<2	2	30±4	0	-	3	20±6

Summary and future plans

- **High statistical data on the reactions $\gamma \to p\pi^0\pi^0$ and $\gamma \to p\pi^0\eta$ with E_γ up to 2.5 GeV were analysed with the good description**
- **Branching ratios of decays to different modes were calculated**
- **Polarization observables show the evidence of $N(1900)3/2^+$**
- **Analysis of charged data is started**
- **Particularly interesting is the observation that the symmetry properties of the wave functions of resonances have a significant impact on the decay modes. This observation implies that the high-mass resonances must have a three-particle component in their wave functions.**
- **More polarization observables can be fitted (P. Mahlberg talk)**