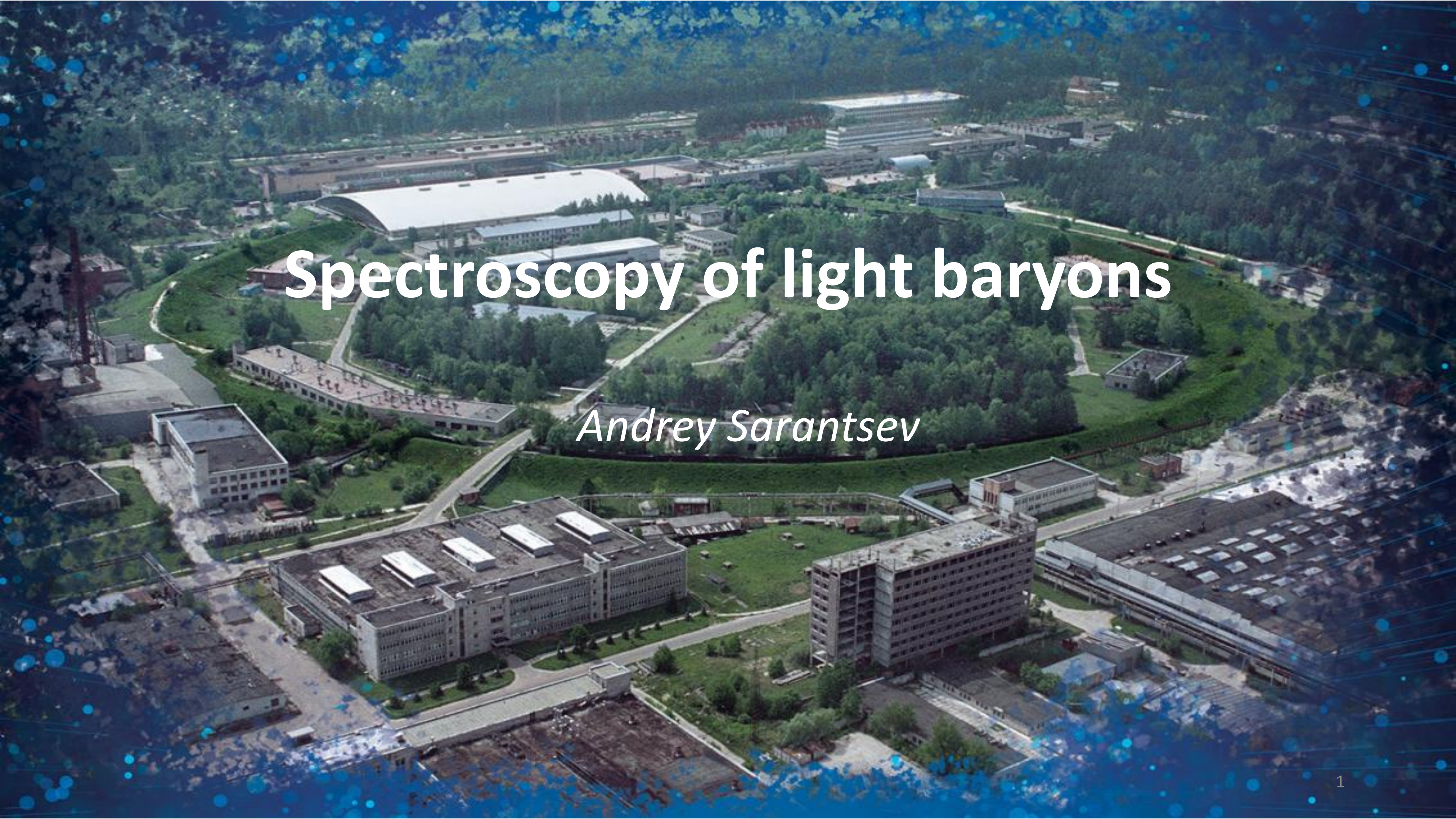


Spectroscopy of light baryons

Andrey Sarantsev

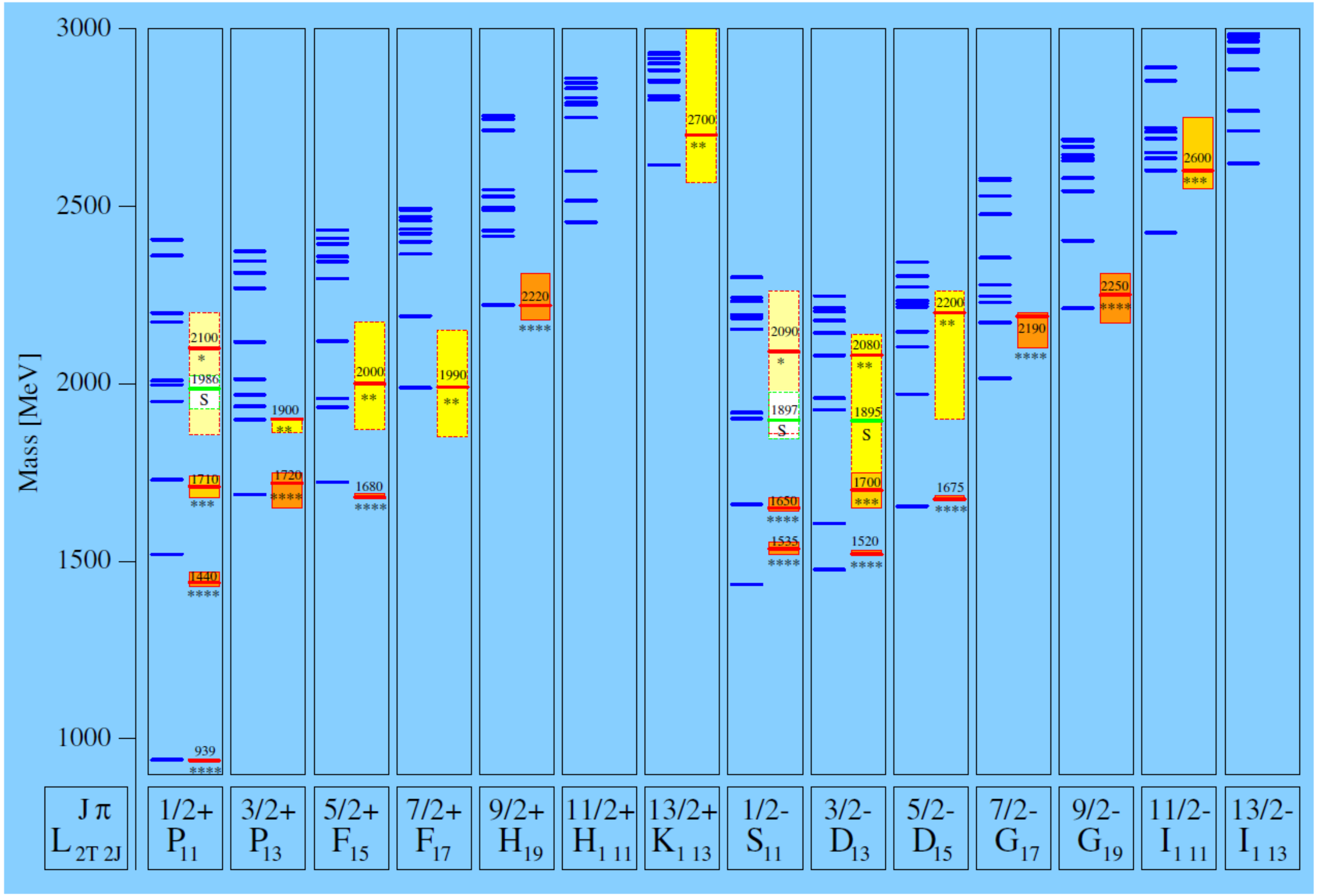
U. Löring, B. C. Metsch, H. R. Petry, Eur. Phys. J. A 10, 395 (2001).

2.1 Models

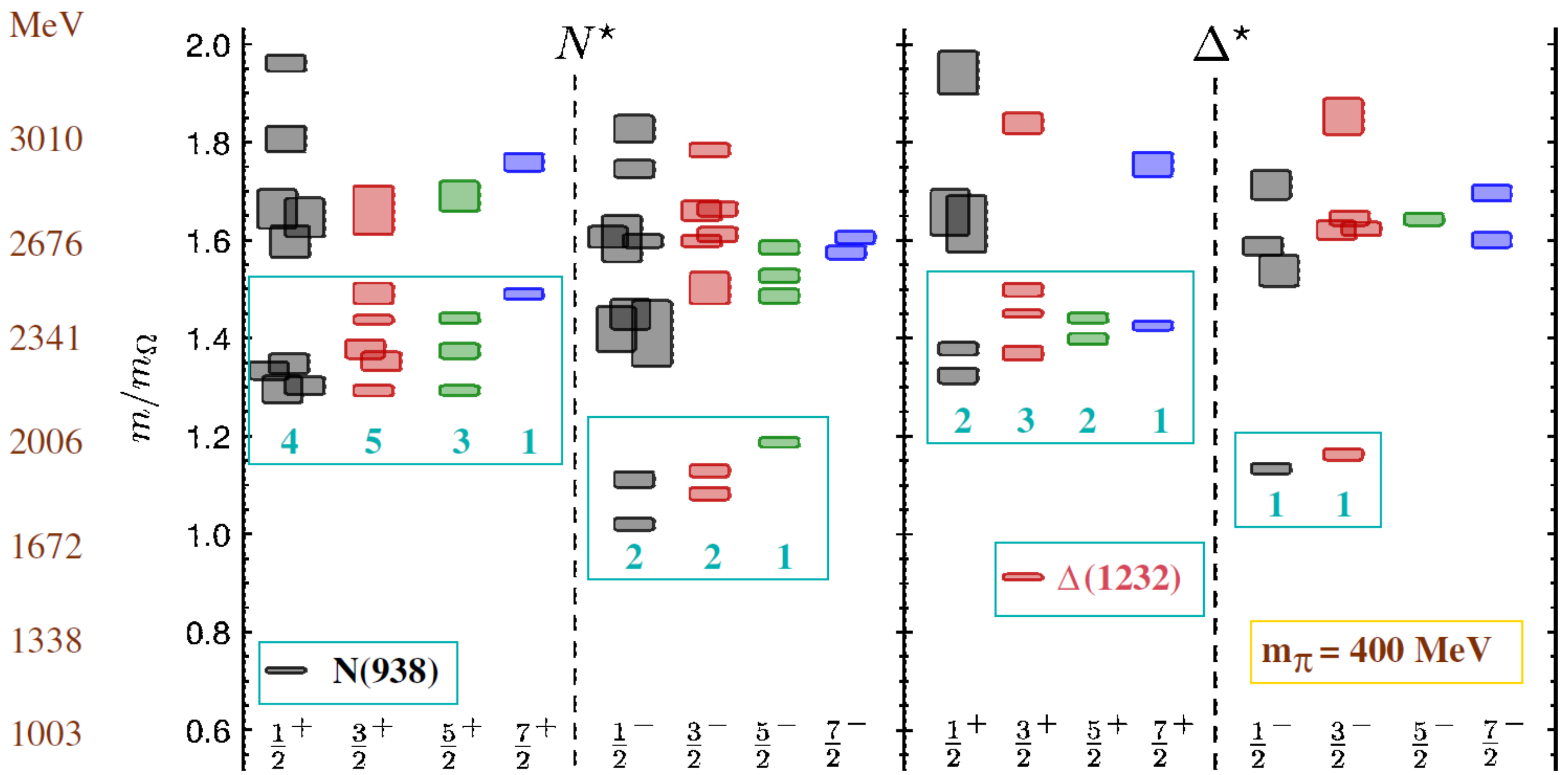
2.1.1 Quark models

Ingredients:

1. constituent quarks with defined rest masses
2. confinement potential
3. some residual interaction, e.g. effective one-gluon exchange, meson exchange, instantons.



2.1.2 Baryons on the lattice



R.Edwards et al., arXiv:1104.5152 [hep–ph]

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 $N(1960)3/2^+$, $N(2200)3/2^+$

Search for light baryon states

1. **Single and double meson production in pion-induced reactions:**
   The old data on $\pi N \to \pi N, \eta N, K\Lambda, K\Sigma$ **and HADES data on** $\pi^- p \to \pi\pi N$

2. **Single and double meson photoproduction reactions.**
   $\gamma p \to \pi N, \eta N, K\Lambda, K\Sigma, \pi\pi N, \pi\eta N$, ωp, $K^*\Lambda$,
   $\gamma n \to \pi N, \eta N, K\Lambda, K\Sigma$,
   CB-ELSA, CLAS, MAMI, GRAAL, LEPS.

3. **The decay of the heavy meson and baryon states** $\Psi' \to \pi^0 p\bar{p}, \eta p\bar{p}$ **(BES III),**
   $\Lambda_b \to J/\Psi K p$, $\Lambda_b \to \gamma K p$ **(LHCB).**

4. **The hyperon production in the kaon-nucleon collision reactions**
   $K^- p \to K^- p, K_0 n, \pi\Lambda, \pi\Sigma, \pi\pi\Lambda, \pi\pi\Sigma, K\pi N$

Meson Photoproduction experiments

- GRAAL (Grenoble): Polarized beam. Ideal for the beam asymmetry and double polarization observables for hyperon final states.
  $\gamma p \rightarrow \pi^0 p, \eta p, K\Lambda, K\Sigma, \pi^0\pi^0 p, \pi^0\eta p, \omega p$, $\gamma n \rightarrow \pi^0 n, \eta n$.
- 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.
- 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.
- Independent analysis groups: Jülich (M.Doering), OSAKA (T. Sato), Giessen (V. Shklyar), M. Manley (Kent Uni)

- For the full reconstruction of the amplitude it is necessary to measure 8 observables.
- Single polarization data are available Σ, T
- Double polarization data are available E, G, H, F, P .
- For the production of the Λ and Σ hyperons all observables can be measured.

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

Bonn-Gatchina partial wave analysis group:

E. Klempt, K. Nikonov, A. Sarantsev, U. Thoma.

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

Petersburg Nuclear Physics Institute

Bonn-Gatchina Partial Wave Analysis

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

Data Base | Meson Spectroscopy | Baryon Spectroscopy | NN-interaction | Formalism

Analysis of Other Groups

- SAID
- MAID
- Giessen Uni

BG PWA

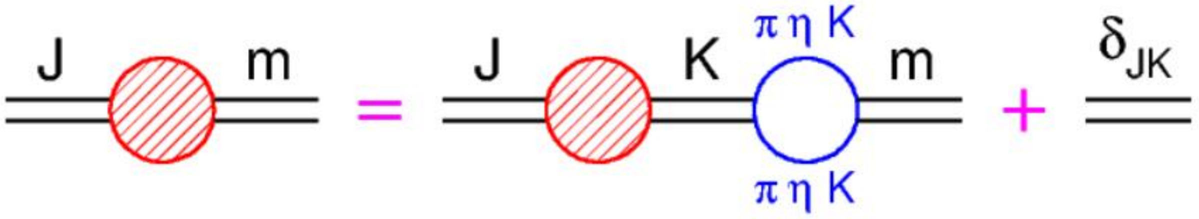
- Publications
- Talks
- Contacts

Useful Links

- SPIRES
- PDG Homepage
- Durham Data Base
- Bonn Homepage

CB-ELSA Homepage

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



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

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

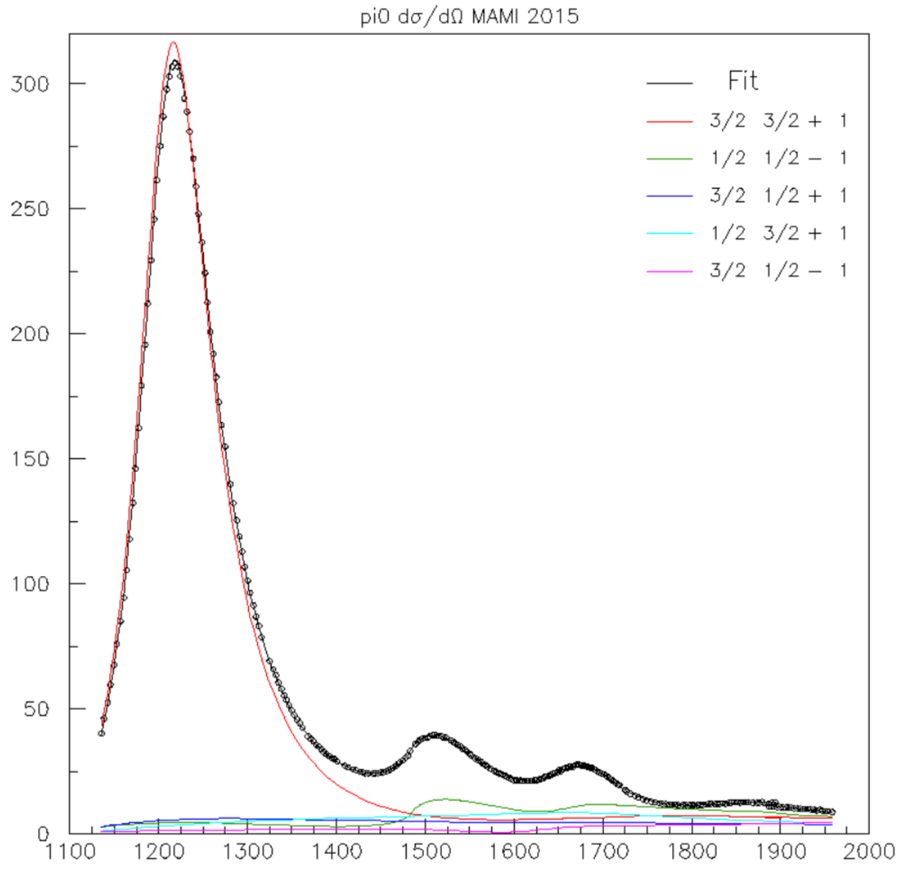
$$\hat{B}_{ij} = \sum_{\alpha} B_{\alpha}^{ij} = \sum_{\alpha} \int \frac{ds'}{\pi} \frac{g_{\alpha}^{(R)i} \rho_{\alpha}(s', m_{1\alpha}, m_{2\alpha}) g_{\alpha}^{(L)j}}{s' - s - i0}$$

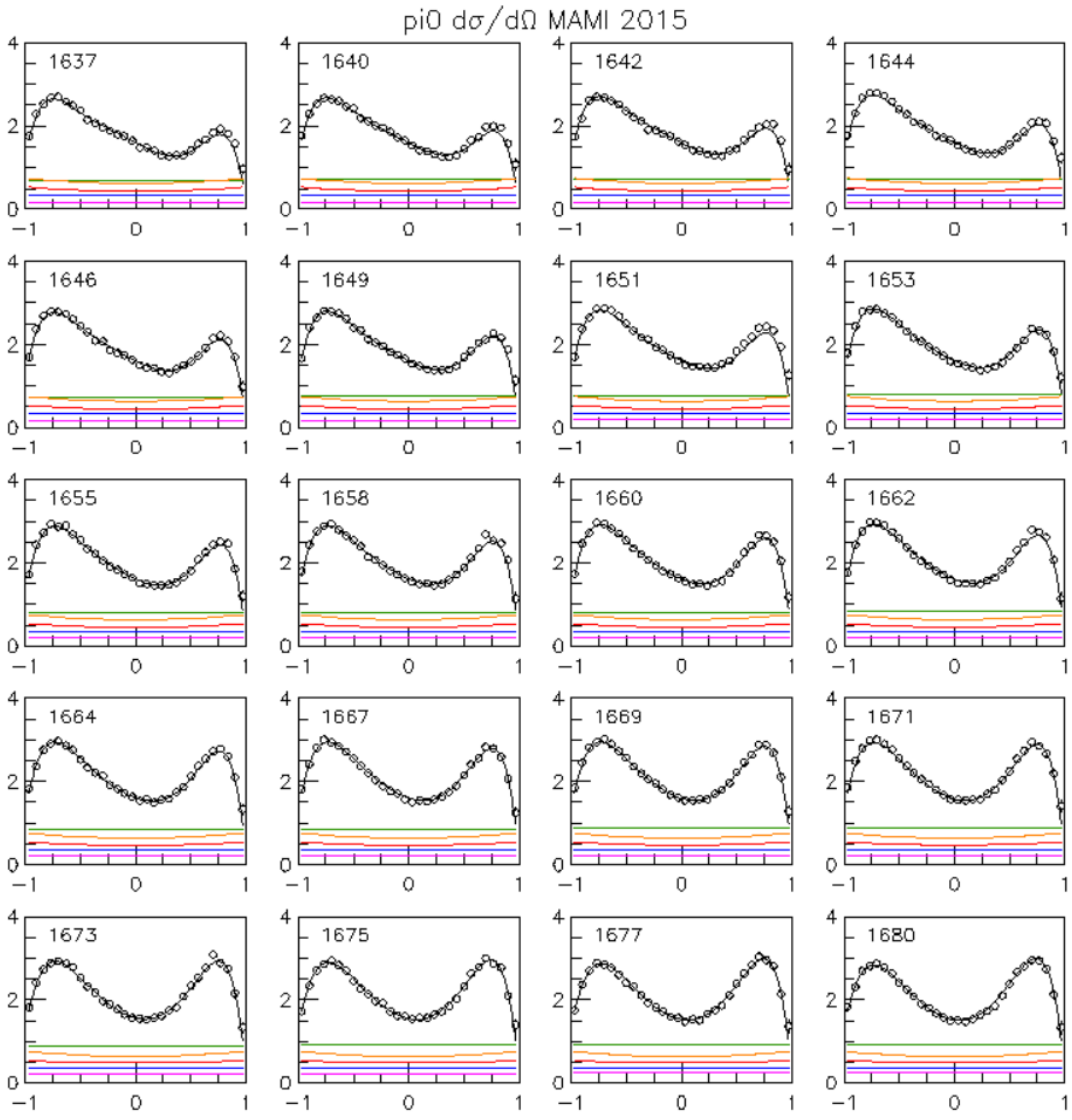
Channels included in D-matrix: $\pi N, \eta N, K\Lambda, K\Sigma, \Delta\pi$, $N\sigma, N\rho(770)$, $N(1520)\pi$, $N(1535)\pi$, $N\omega$, **Black Box**

Data Base of the Bonn-Gatchina analysis

DATA	2011-2022	added in 2024-2026
$\pi N \to \pi N$ **ampl.**	**SAID or Hoehler (energy fixed)**	
$\pi^- p \to \pi\pi N$	$d\sigma/d\Omega$ ($\pi^0\pi^0 n$, $\pi^+\pi^- n$,$\pi^-\pi^0 p$)	
$\pi^- p \to \eta n$	$d\sigma/d\Omega$	
$\pi p \to K\Lambda, K\Sigma$	$d\sigma/d\Omega$, P,β	
$\pi p \to \omega n$	$d\sigma/d\Omega$	
$\gamma p \to \pi N$	$d\sigma/d\Omega, \Sigma, T, P, E, G, H$ ($\pi^0 p$, $\pi^+ n$)	
$\gamma p \to \eta p$	$d\sigma/d\Omega$,Σ, F, T, P, H, G, E	
$\gamma p \to \eta' p$	$d\sigma/d\Omega$, Σ	$d\sigma/d\Omega$, Σ **(BGOegg)**
$\gamma p \to K\Lambda$	$d\sigma/d\Omega, \Sigma, P, T, C_x, C_z, O_{x'}, O_{z'}, T_x, T_z$	C_x, C_z **(CLAS)**
$\gamma p \to K^0\Sigma^+$	$d\sigma/d\Omega$, Σ, $P(ELSA)P$ **(CLAS)**	$d\sigma/d\Omega$,P, E **(CLAS)**
$\gamma p \to K^+\Sigma^0$	$d\sigma/d\Omega, \Sigma, P, T, C_x, C_z, O_{x'}, O_{z'}, T_x, T_z$	
$\gamma p \to \pi^0\pi^0 p$	$d\sigma/d\Omega, \Sigma, E, I_c, I_s, T, P, H, F$	$I_c, I_s, P_x, P_y, P_{xs}, P_{ys}, P_{xc}, P_{yc}$
$\gamma p \to \pi^+\pi^- p$	$d\sigma/d\Omega\ I_c, I_s$	$d\sigma/d\Omega\ I_c, I_s, P_x, P_y$ **(CLAS)**
$\gamma p \to \omega p$	$d\sigma/d\Omega, \Sigma, \rho^k_{ij}, E, G$ **(CB-ELSA)**, Σ, **P,T,F,H (CLAS)**	
$\gamma n \to \Lambda K, \Sigma^- K$	$d\sigma/d\Omega$ **(CLAS)**, E, Σ, G **(CLAS)**	
$\gamma n \to \pi^- p$	$d\sigma/d\Omega$,Σ, P, E, Σ **(CLAS)**	
$\gamma n \to \eta n$	$d\sigma/d\Omega$ **(CB-ELSA, MAMI)**,Σ, $d\sigma/d\Omega\ (h = \frac{1}{2})$ **(CB-ELSA)**	P, T, H **(CB-ELSA)**
$\gamma n \to \pi^0 n$	$d\sigma/d\Omega$	

Photo-production of pion $\gamma N \rightarrow \pi^0 N$

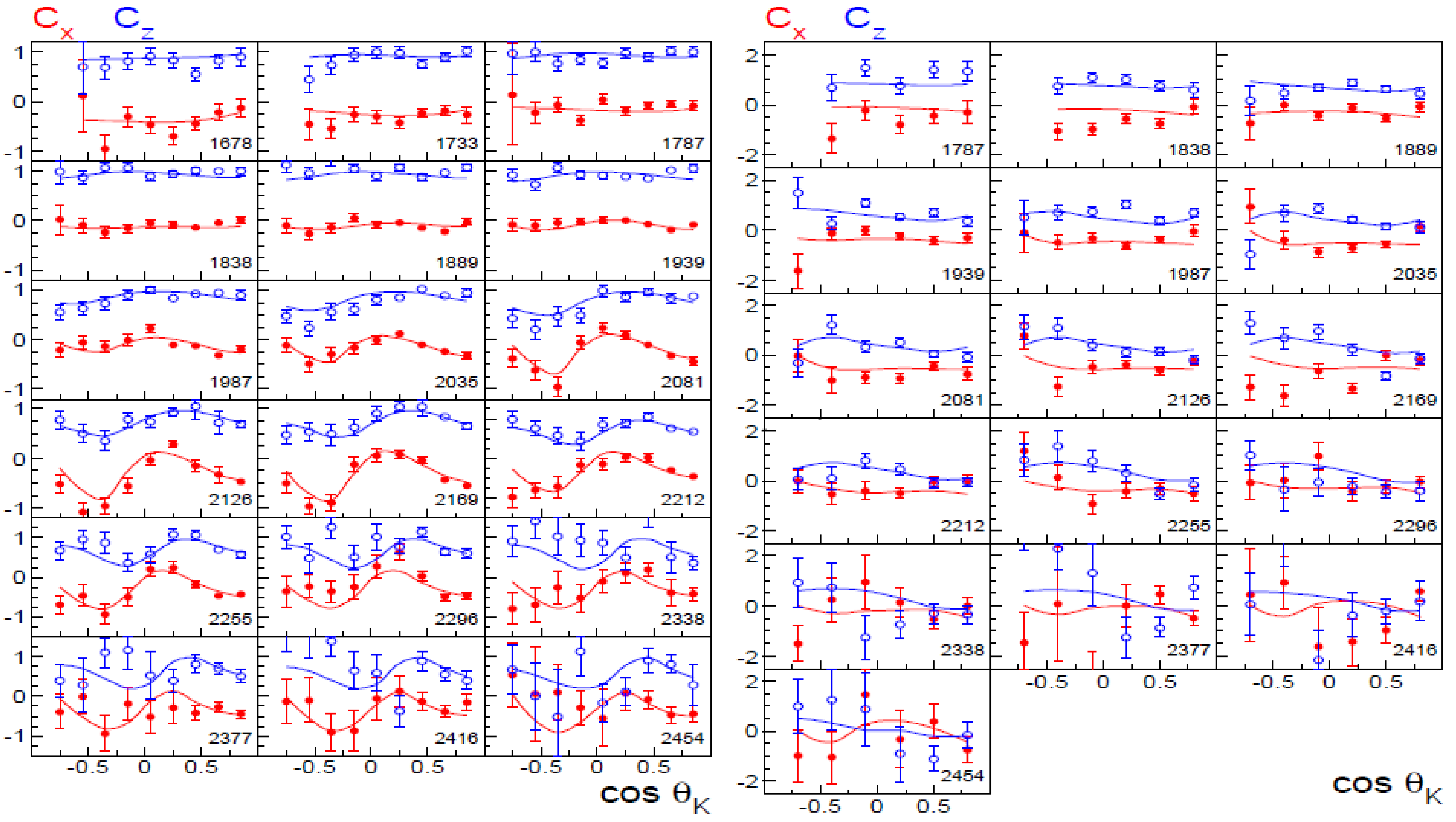




For $\gamma p \to K\Lambda$ and $\gamma p \to K\Sigma$ we have almost complete photoproduction experiment:

σ (CLAS, SAPHIR), Σ (GRAAL, LEP), P (CLAS), C_x, C_z (CLAS), T, O_x, O_z (GRAAL).

The C_x and C_z data can be explained with $P_{13}(1900)$.



New data on Cx and Cz for $\gamma\ \pi \rightarrow K^+\Lambda$

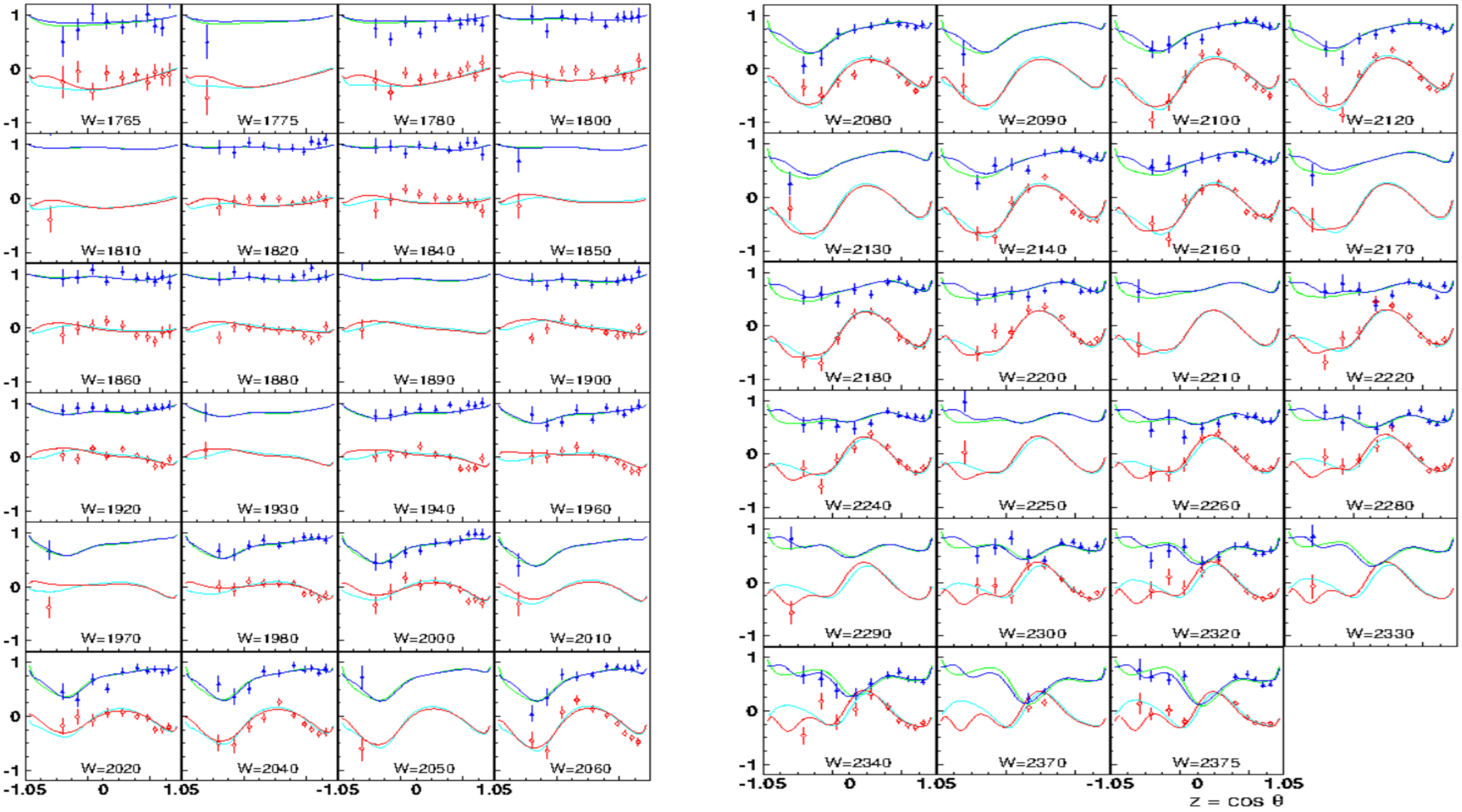
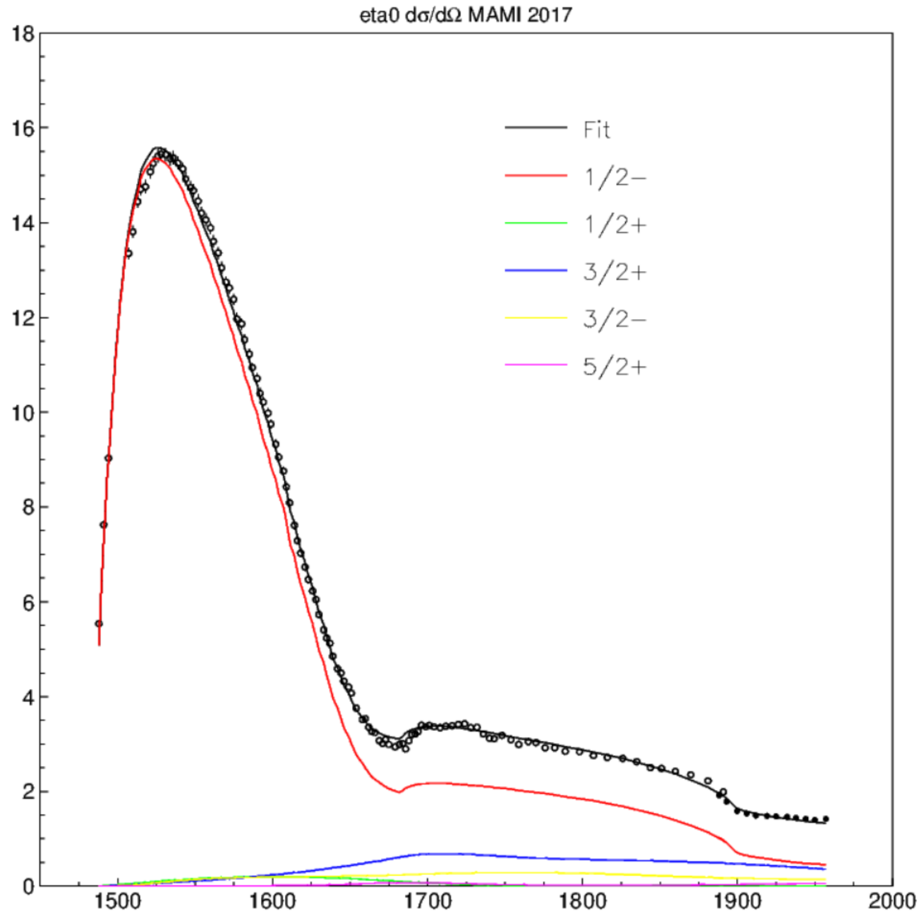
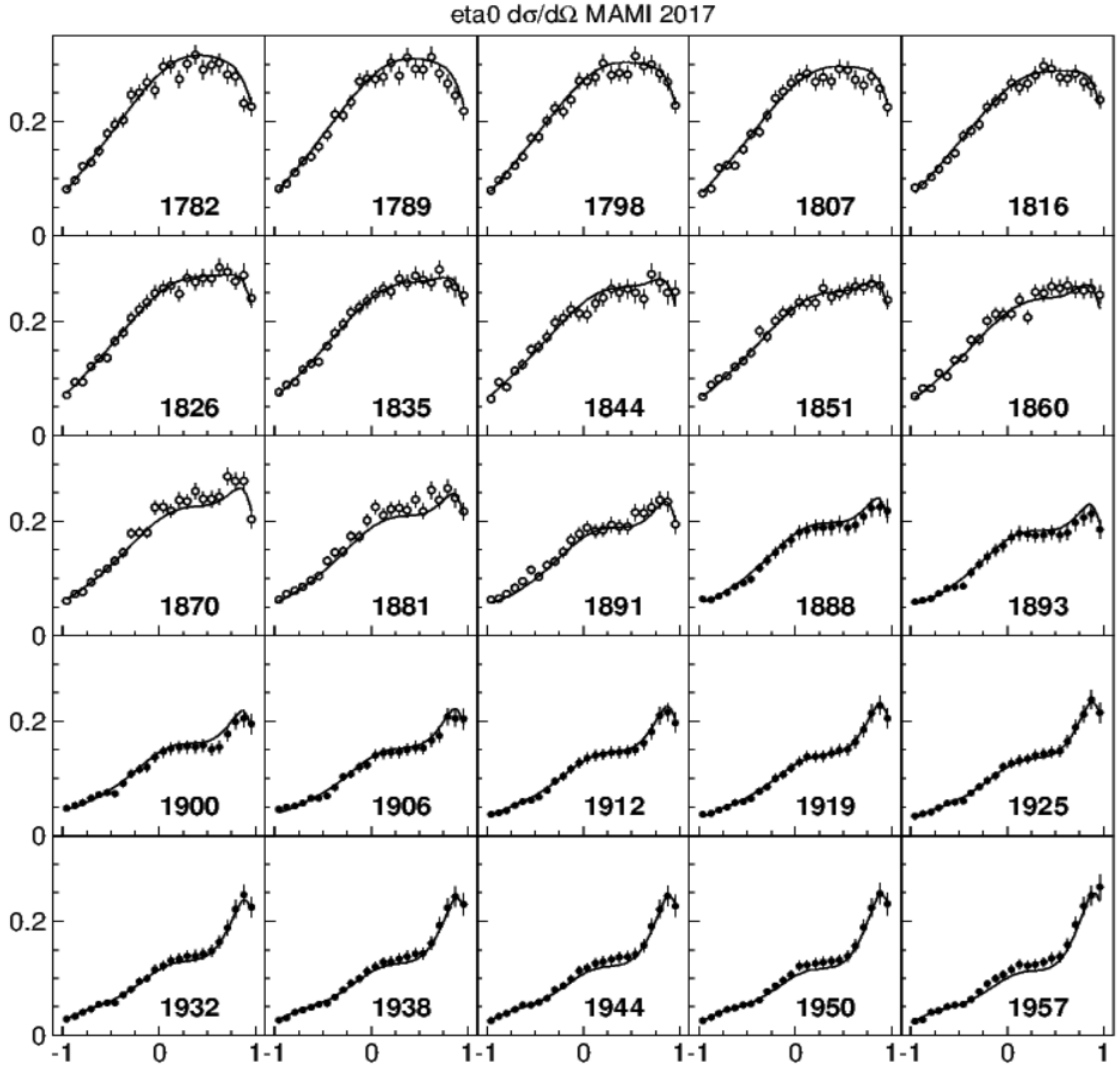
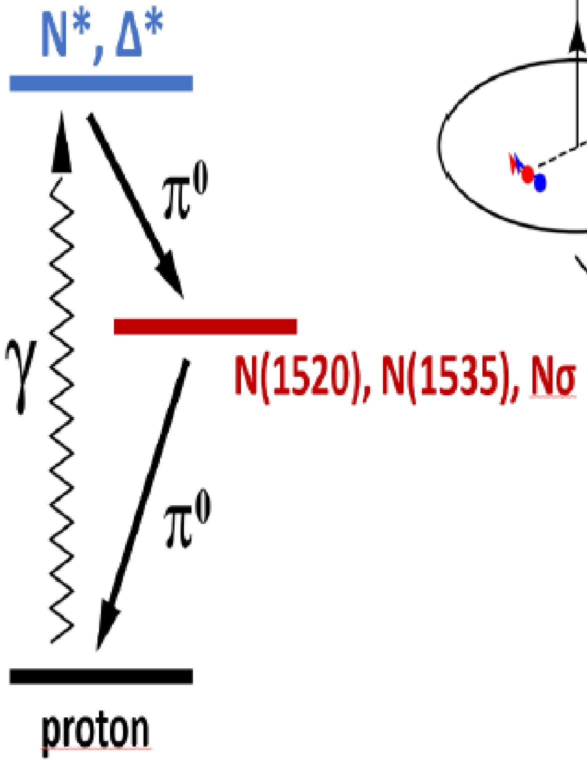


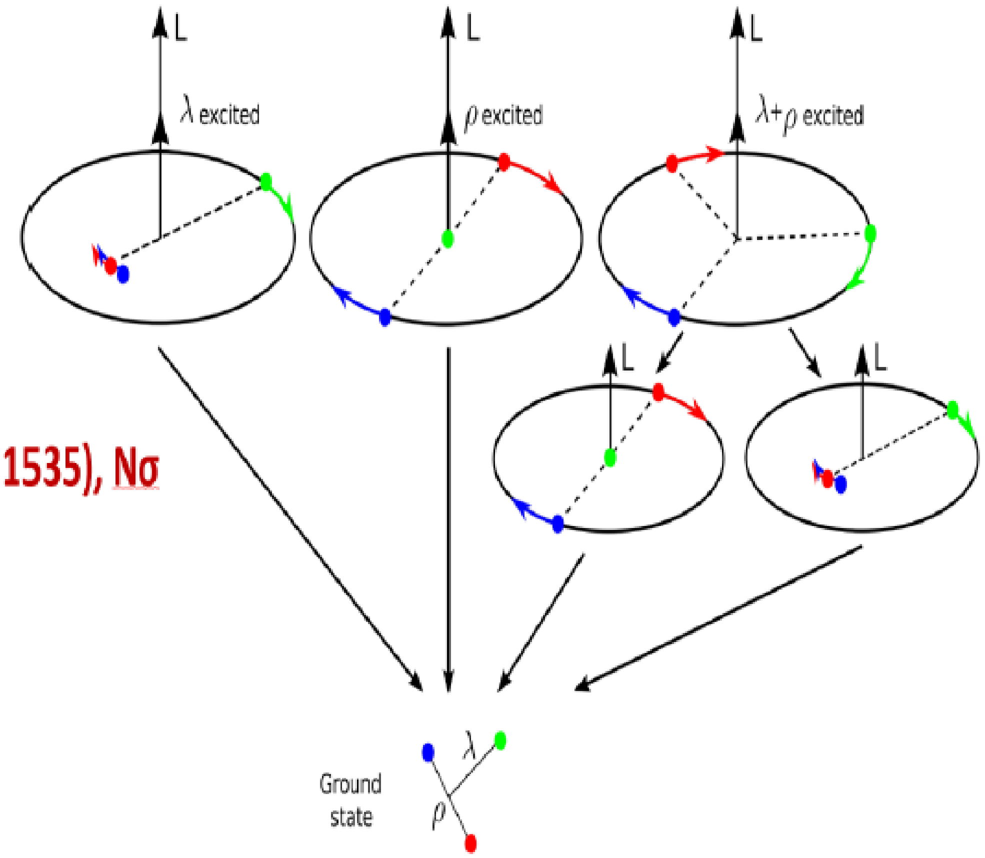
Photo-production of pion $\gamma N \to \eta N$





The decay to multi-meson channel can provide important information about nature of the observed states

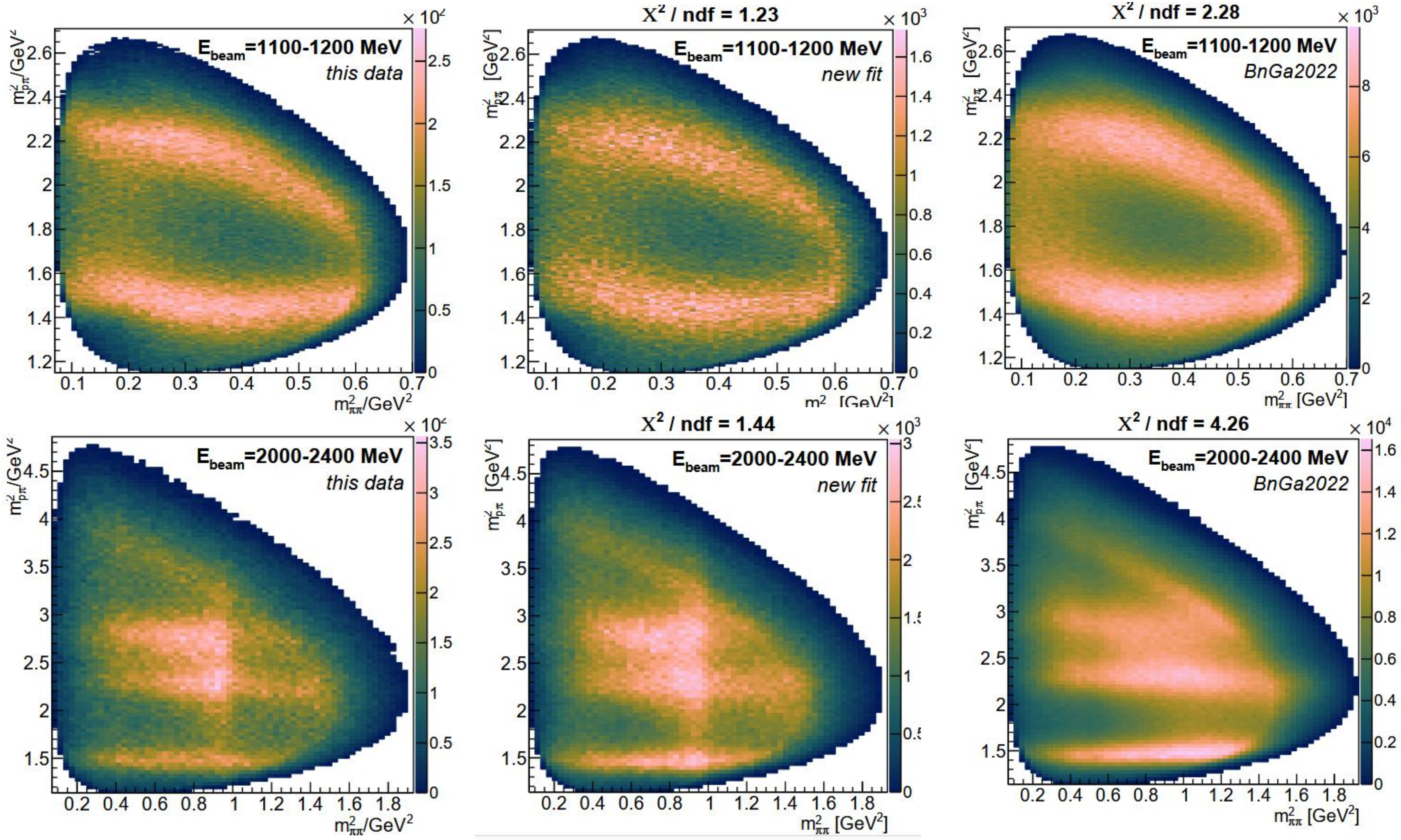




The decay modes in $\pi\pi p$ channels:

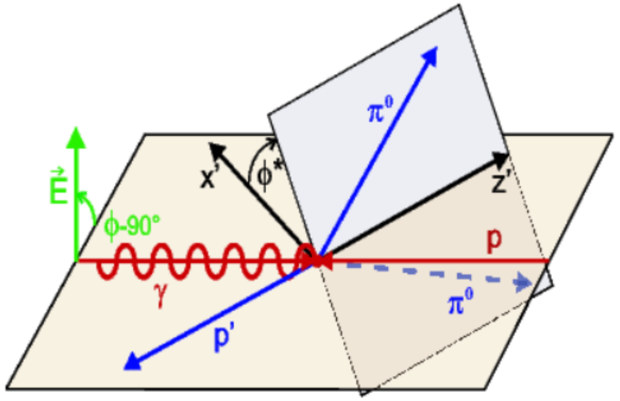
$\Delta(1232)\pi$	$N\mathbf{f}_0(500)$
$N(1440)\pi$	
$N(1520)\pi$	$N\rho(770)$
$N(1535)\pi$	$N\mathbf{f}_0(980)$
$N(1685)\pi$	$N\mathbf{f}_2(1275)$
$N(1710)\pi$	
$N(1720)\pi$	

Analysis of the high statistical data on $\gamma p \rightarrow \pi^0\pi^0 p$



$\gamma p \to \pi^0\pi^0 p$ Polarization observables

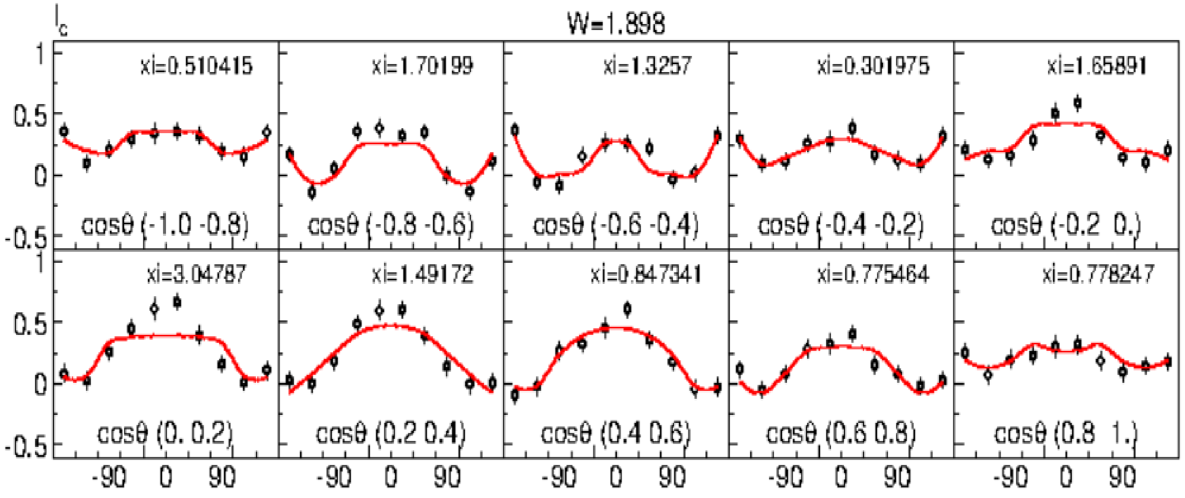
$$\frac{d\sigma}{d\Omega}(\Theta,\varphi) = \frac{d\sigma_0}{d\Omega}(\Theta)\left[1 - \Sigma(\Theta)\cos(2\varphi) - \Lambda_x H(\Theta)\sin(2\phi) - \Lambda_y P(\Theta)\cos(2\varphi) + \Lambda_y T(\Theta)\right]$$

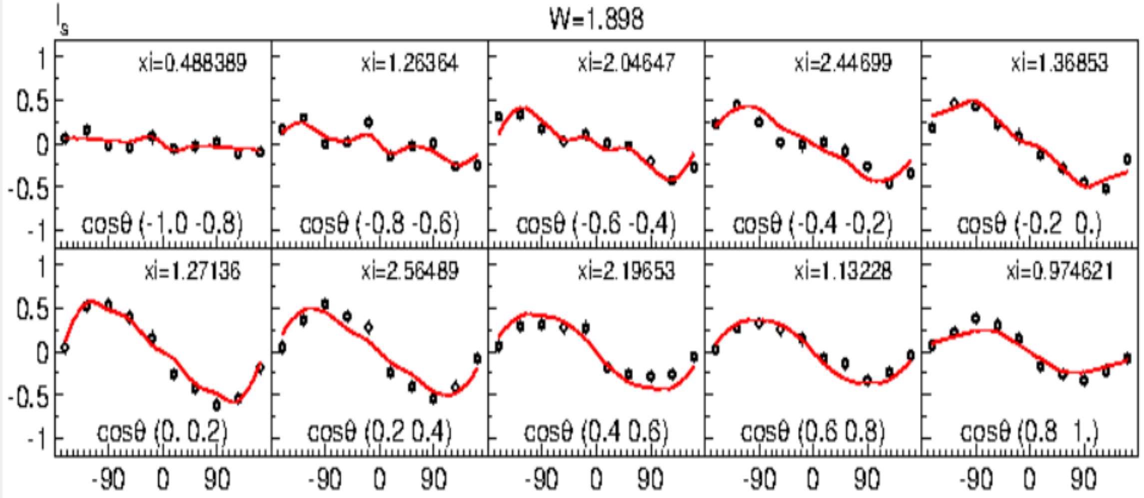


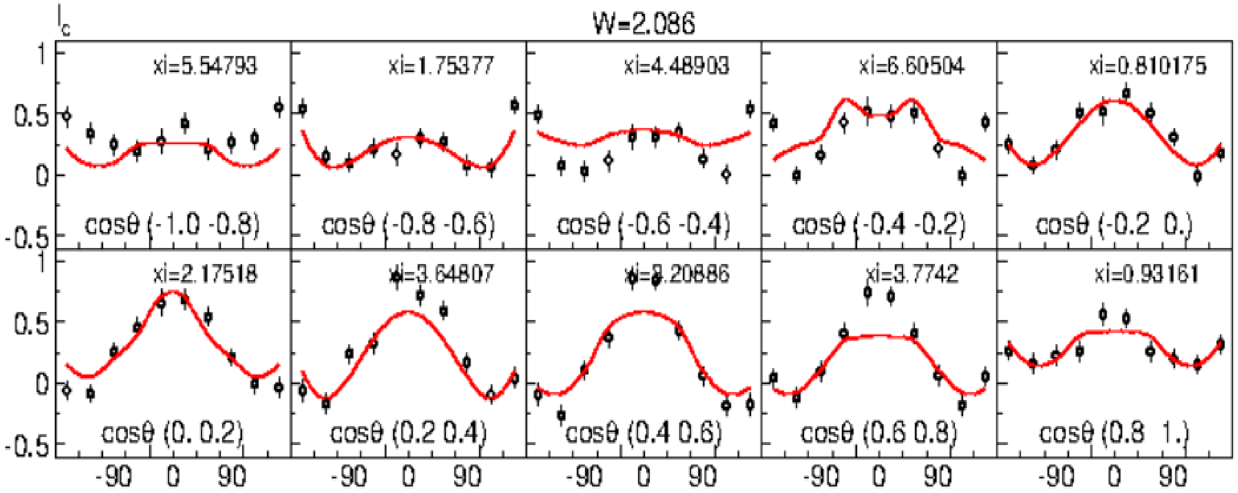
$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega}(\Theta)\Big[1 + \Lambda_x P_x + \Lambda_y P_y \quad + \sin(2\varphi)\left(I^s + \Lambda_x P_x^s + \Lambda_y P_y^s\right)$$
$$+ \cos(2\varphi)\left(I^c + \Lambda_x P_x^c + \Lambda_y P_y^c\right)\Big]$$

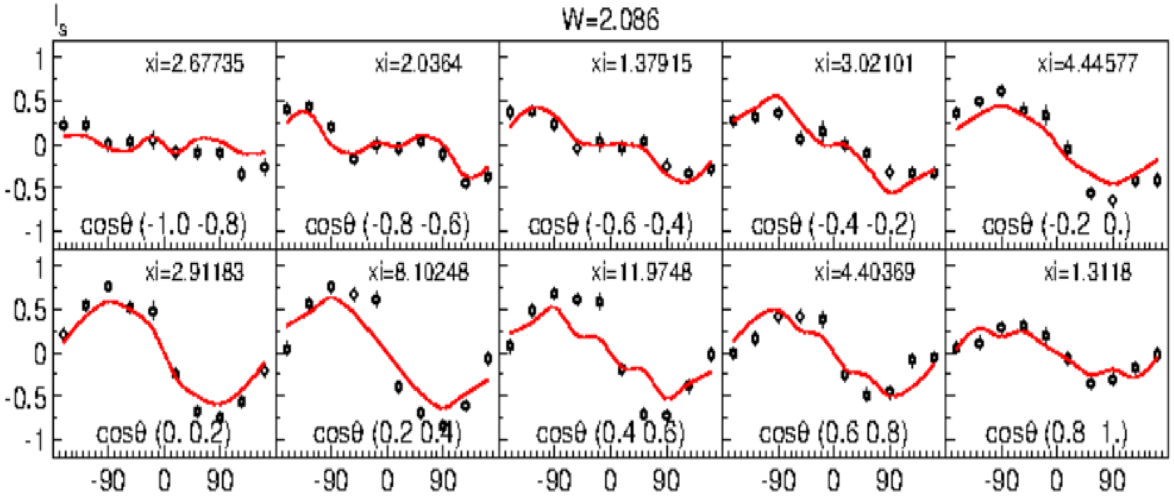
22590 ($\chi^2/N=1.3$) fitted bins for polarization observables.

Ic, Is (Φ^*)observables from $\gamma p \rightarrow \pi^+\pi^- p$ data

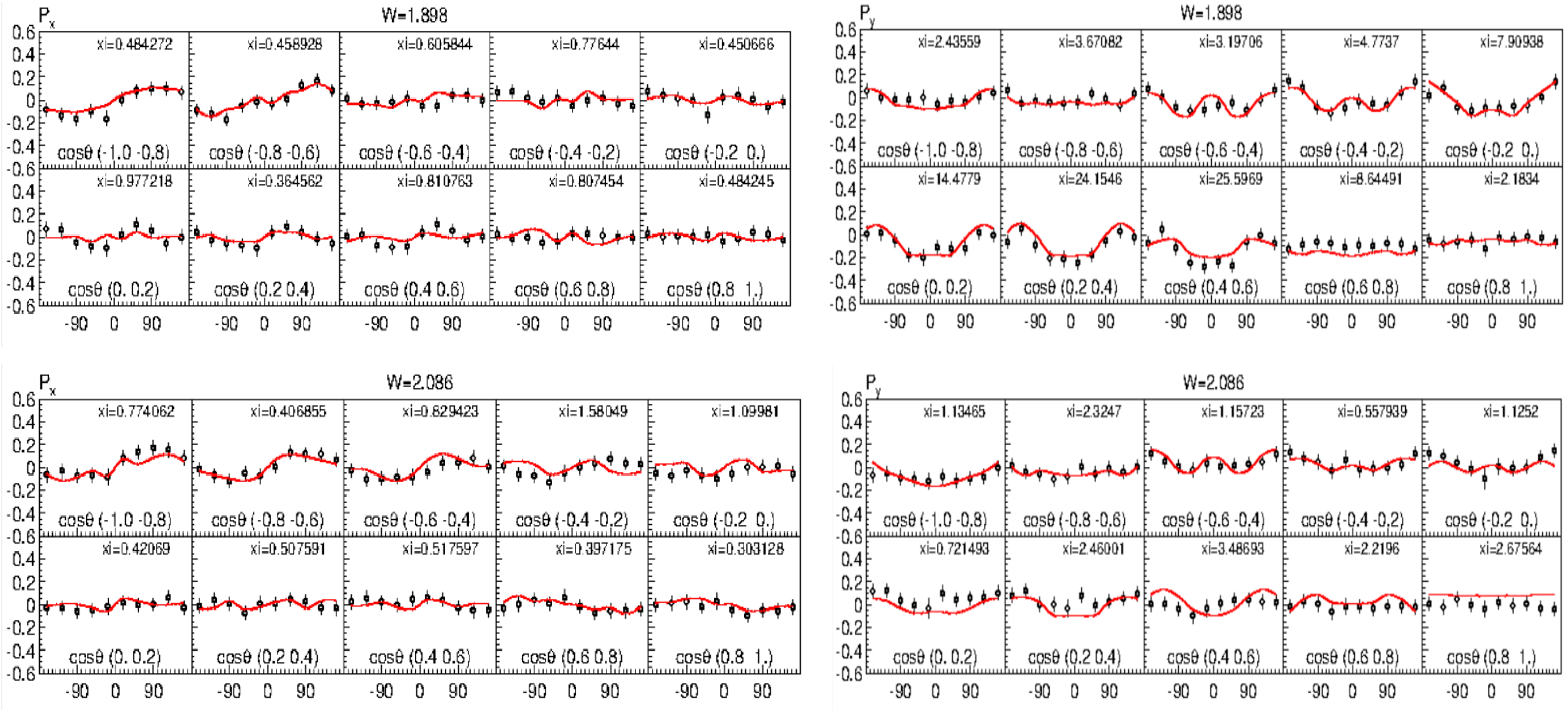






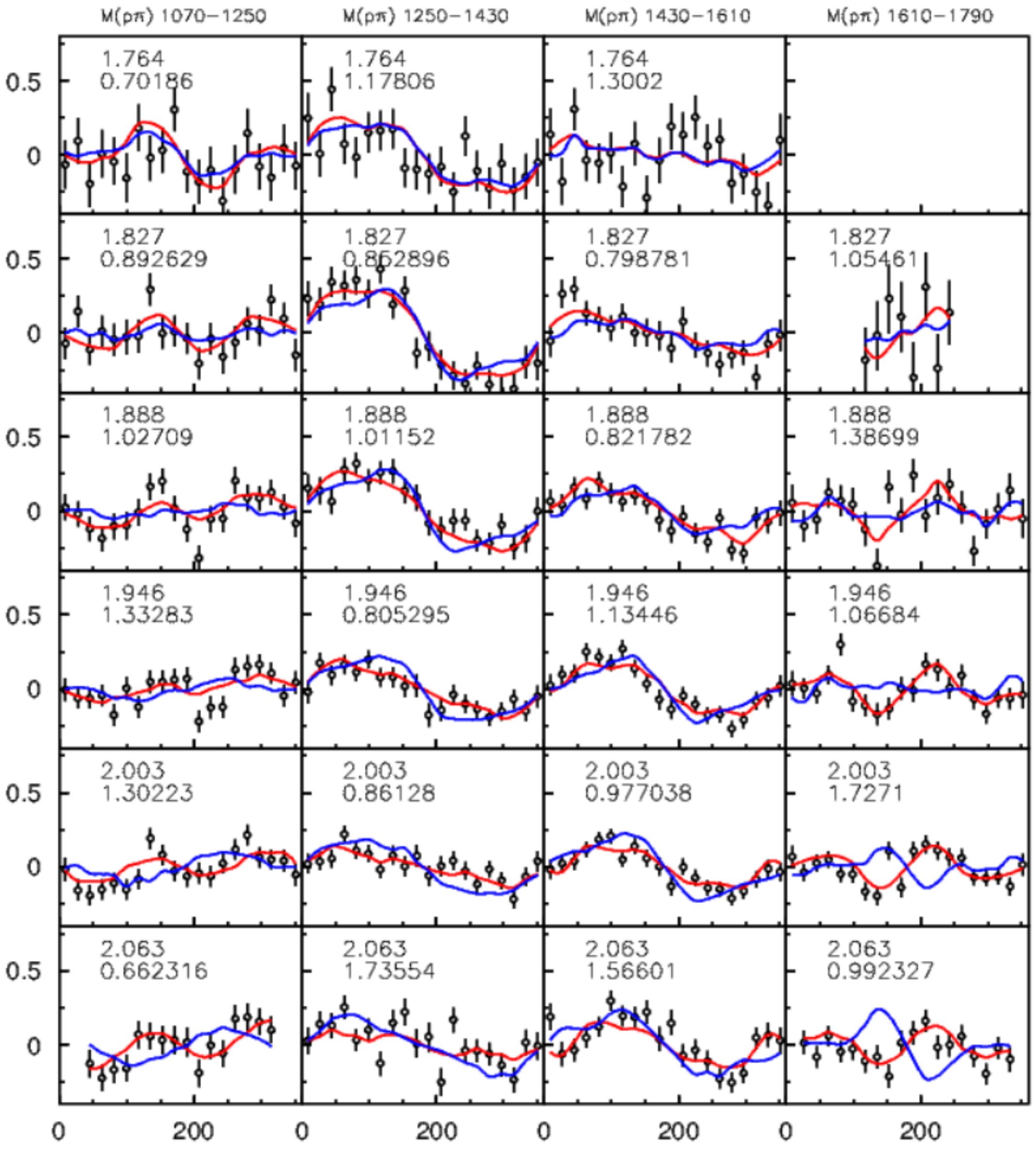


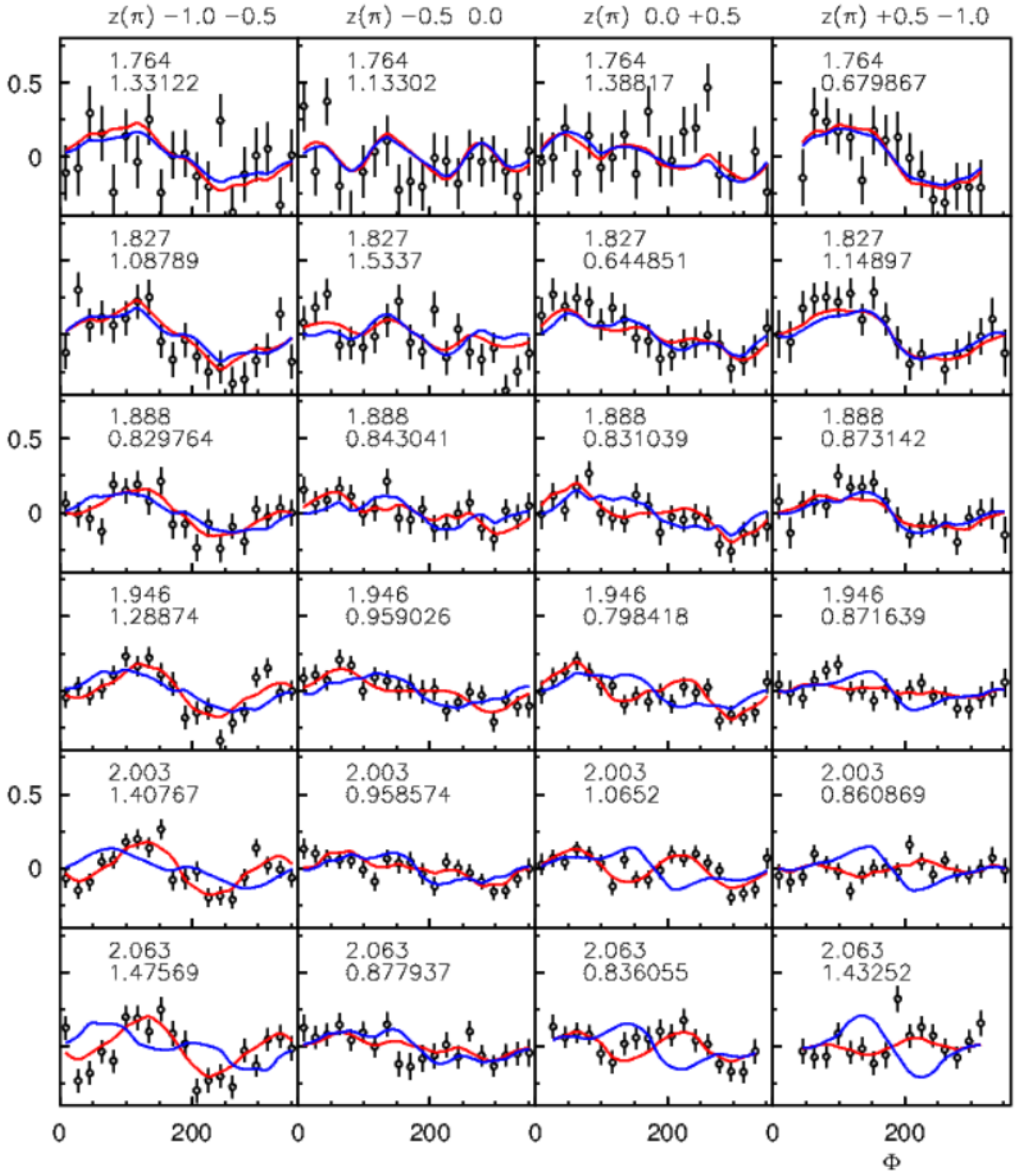
Px, Py (Φ*)observables from $\gamma p \to \pi^+\pi^- p$ data



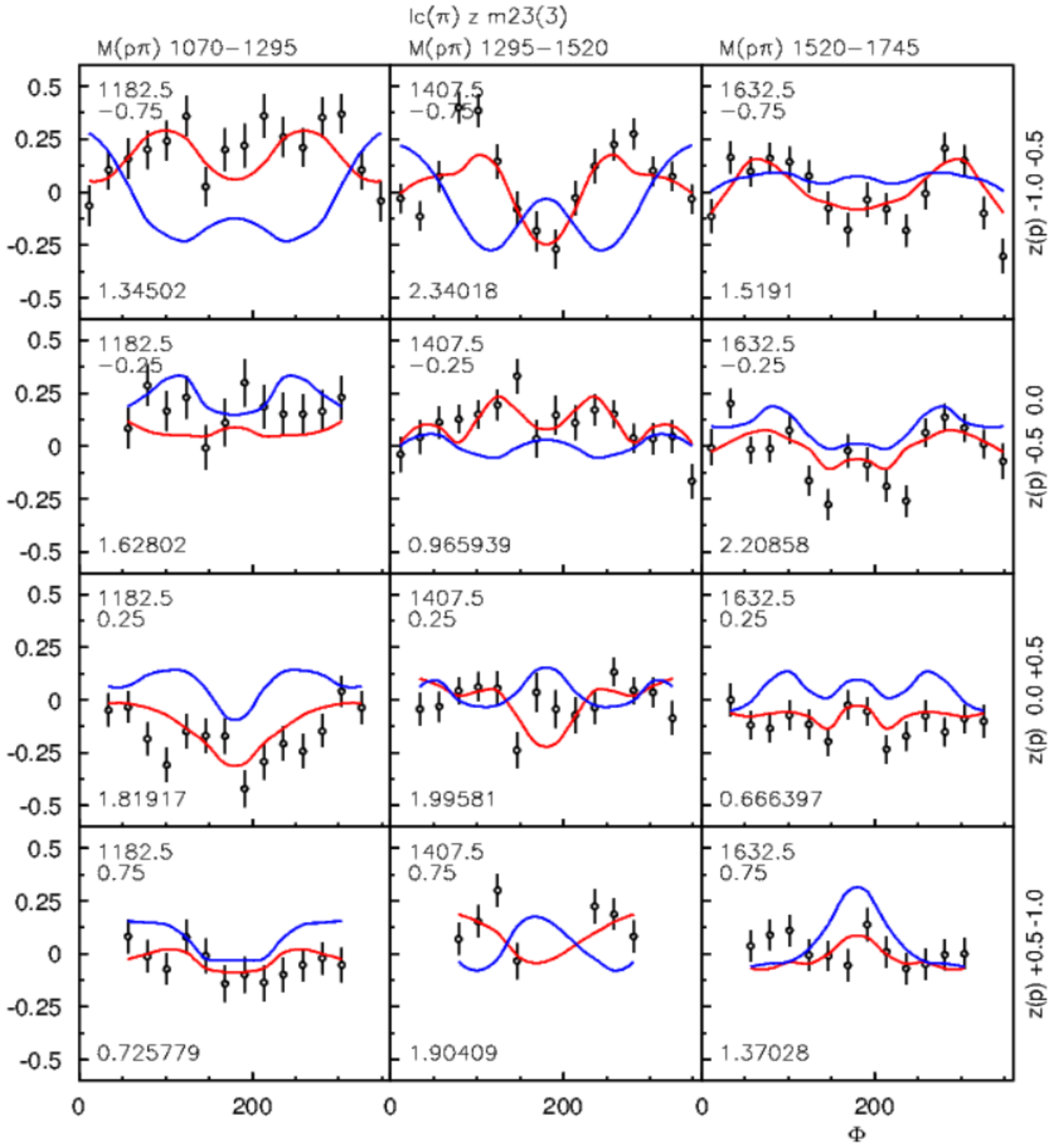
Φ^* dependence of I_S on πp-mass or $\cos\Theta_\pi$

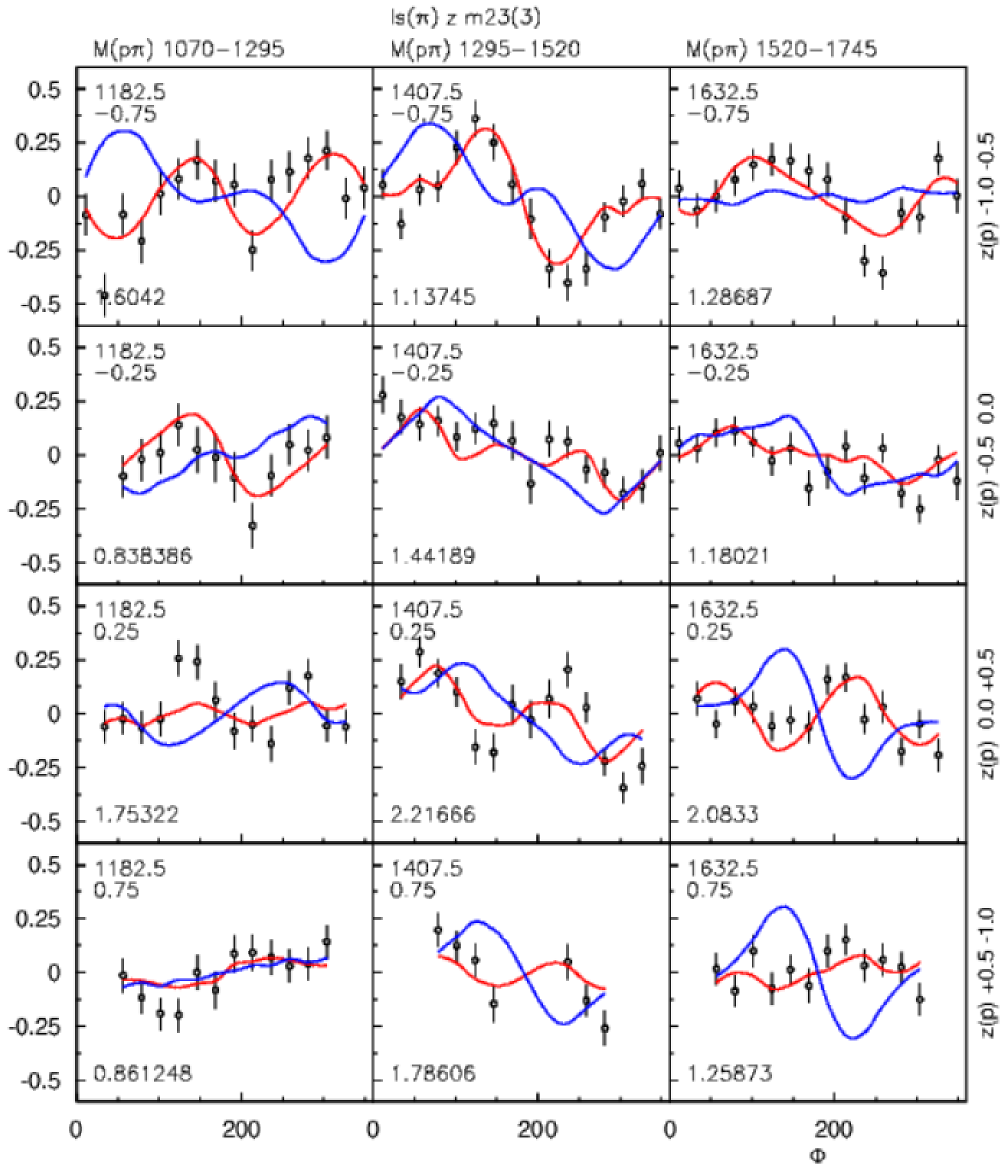
BG-2022 BG-2026





Two-dimension Φ^* dependencies of I_S and I_c





Polarization as key to resolve the baryon spectrum

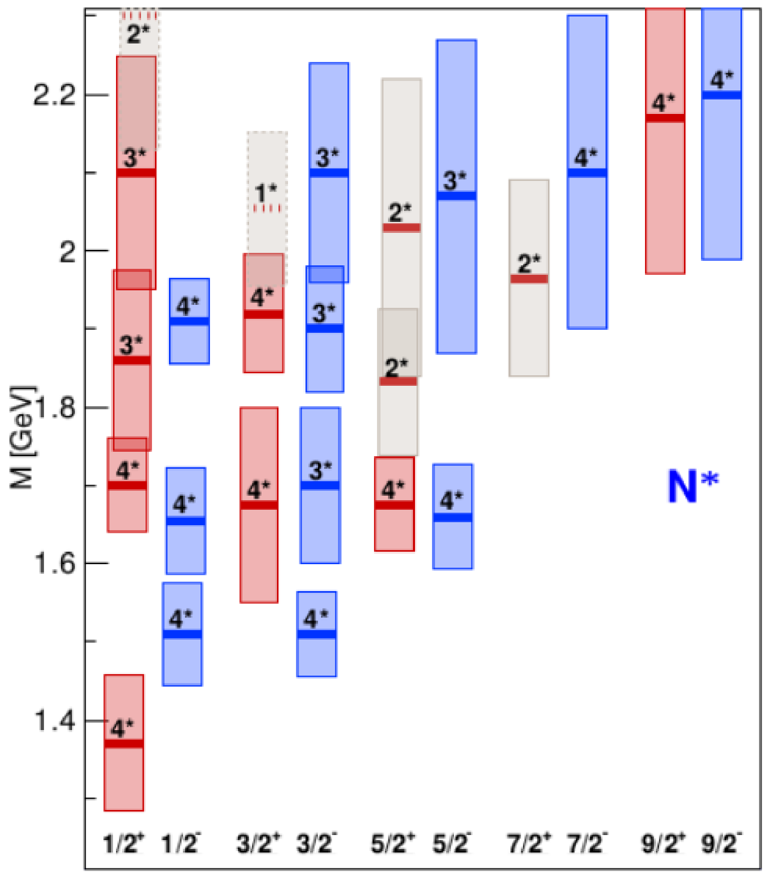
→ huge impact on knowledge of resonances in the second and third resonance region based on data from ELSA + exp. worldwide

	RPP 2010	BnGa-PWA	RPP'25 (2018-25)
$N(1710)1/2^+$	***	****	****
$N(1860)5/2^+$		*	**
$N(1875)3/2^-$		***	***
$N(1880)1/2^+$		***	***
$N(1895)1/2^-$		****	****
$N(1900)3/2^+$	**	****	****
$N(2060)5/2^-$		***	***
$N(2100)1/2^+$	*	***	***
$N(2120)3/2^-$		***	***
$\Delta(1600)3/2^+$	***	***	****
$\Delta(1900)1/2^-$	*	***	***
$\Delta(1940)3/2^-$	*	**	**
$\Delta(2200)7/2^-$	*	***	***

Up to 2.3 GeV:

- **6 new N*-resonances found** (25% of known N*-states)
- **7 N* + 2 Δ* new in the PDG summary tables** (30%)
- Many new resonance properties determined ⇔ RPP

N^*-pole positions:



N^*, Δ^* -parity doublets occur (but not for all states

⇔ **Not expected by present lattice calculations or constituent quark models**

$N(1895)1/2^-$ **

$N(1895)1/2^-$ pole parameters			
M_{pole}	1900±15	Γ_{pole}	330±60
$A^{1/2}_{\gamma p}$	0.040±0.015	Phase:	(65±25)°
$A^{1/2}_{\gamma n}$	0.045±0.014	Phase:	-(90±25)°

$N(1895)1/2^-$ transition residues		phase
$\pi N \to \pi N$	27±6 (MeV)	-(35±15)°
$2\,(\pi N \to N\eta)/\Gamma$	20±7%	(40±20)°
$2\,(\pi N \to N\eta')/\Gamma$	36±10%	(70±30)°°
$2\,(\pi N \to \Lambda K)/\Gamma$	16±5%	-(70±20)°
$2\,(\pi N \to \Sigma K)/\Gamma$	22±8%	(90±25)°
$2\,(\pi N \to N\sigma)/\Gamma^{(1)}$	3±3%	not def.
$2\,(\pi N \to N\rho_{1/2S})/\Gamma$	6±3%	-(135±25)°
$2\,(\pi N \to N\rho_{3/2D})/\Gamma$	24±5%	(140±30)°
$2\,(\pi N \to \Delta(1232)\pi)/\Gamma$	9±3%	-(80±30)°
$2\,(\pi N \to N(1440)\pi)/\Gamma^{(1)}$	3±3%	not def.

$N(1895)1/2^-$ Breit-Wigner parameters			
M_{BW}	1907±15	Γ_{BW}	335±60
$A^{1/2}_{\gamma p BW}$	0.042±0.015	$\lvert A^{1/2}_{\gamma n BW}\rvert$	0.045±0.014

$N(1895)1/2^-$ Branching ratios			
$Br(N\pi)$	11±3%	$Br(\Delta(1232)\pi)$	7±3%
$Br(N(1440)\pi)$	2±2%	$Br(N\sigma)$	2±2%
$Br(\Lambda K)$	9±3%	$Br(\Sigma K)$	12±4%
$Br(N\eta)$	10±3%	$Br(N\eta')$	8±3%
$Br(N\rho_{1/2S})$	10±4%	$Br(N\rho_{3/2D})$	17±4%

$N(1895)1/2^-$			From Integrals
$Br(N\pi)$	10±3%	$Br(\Delta(1232)\pi)$	7±3%
$Br(N(1440)\pi)$	2±2%	$Br(N\sigma)$	2±2%
$Br(\Lambda K)$	8±3%	$Br(\Sigma K)$	10±4%
$Br(N\eta)$	8±3%	$Br(N\eta')$	12±4%
$Br(N\rho_{1/2S})$	10±4%	$Br(N\rho_{3/2D})$	21±6%

$N(1900)3/2^+$ ***

$N(1900)3/2^+$ pole parameters			
M_{pole}	1935±15	Γ_{pole}	270±30
$A^{1/2}_{\gamma p}$	-0.090±0.020	Phase	-(25±25)°
$A^{3/2}_{\gamma p}$	-0.080±0.015	Phase	(0±25)°
$A^{1/2}_{\gamma n}$	-0.012±0.006	Phase	-(20±20)°
$A^{3/2}_{\gamma n}$	0.008±0.006	Phase	-(5±20)°

$N(1900)3/2^+$ transition residues		phase
$\pi N \to \pi N$	3±1 (MeV)	(30±20)°
$2\,(\pi N \to N\eta)/\Gamma$	1±1%	not def.
$2\,(\pi N \to \Lambda K)/\Gamma$	4±2%	-(160±20)°
$2\,(\pi N \to \Sigma K)/\Gamma$	4±2%	(150±25)°
$2\,(\pi N \to N\sigma)/\Gamma$	6±2%	(90±30)°
$2\,(\pi N \to N\rho_{1/2P})/\Gamma$	7±3%	-(70±30)°
$2\,(\pi N \to N\rho_{3/2P})/\Gamma$	12±4%	-(55±30)°
$2\,(\pi N \to N\rho_{3/2F})/\Gamma$	9±3%	-(50±20)°
$2\,(\pi N \to \Delta(1232)\pi_{L=1})/\Gamma$	5±2%	-(175±20)°
$2\,(\pi N \to \Delta(1232)\pi_{L=3})/\Gamma$	3±2%	not def.
$2\,(\pi N \to N(1440)\pi)/\Gamma$	6±2%	-(60±20)°
$2\,(\pi N \to N(1520)\pi)/\Gamma$	2±2%	not def.
$2\,(\pi N \to N(1535)\pi)/\Gamma$	5±2%	not def.

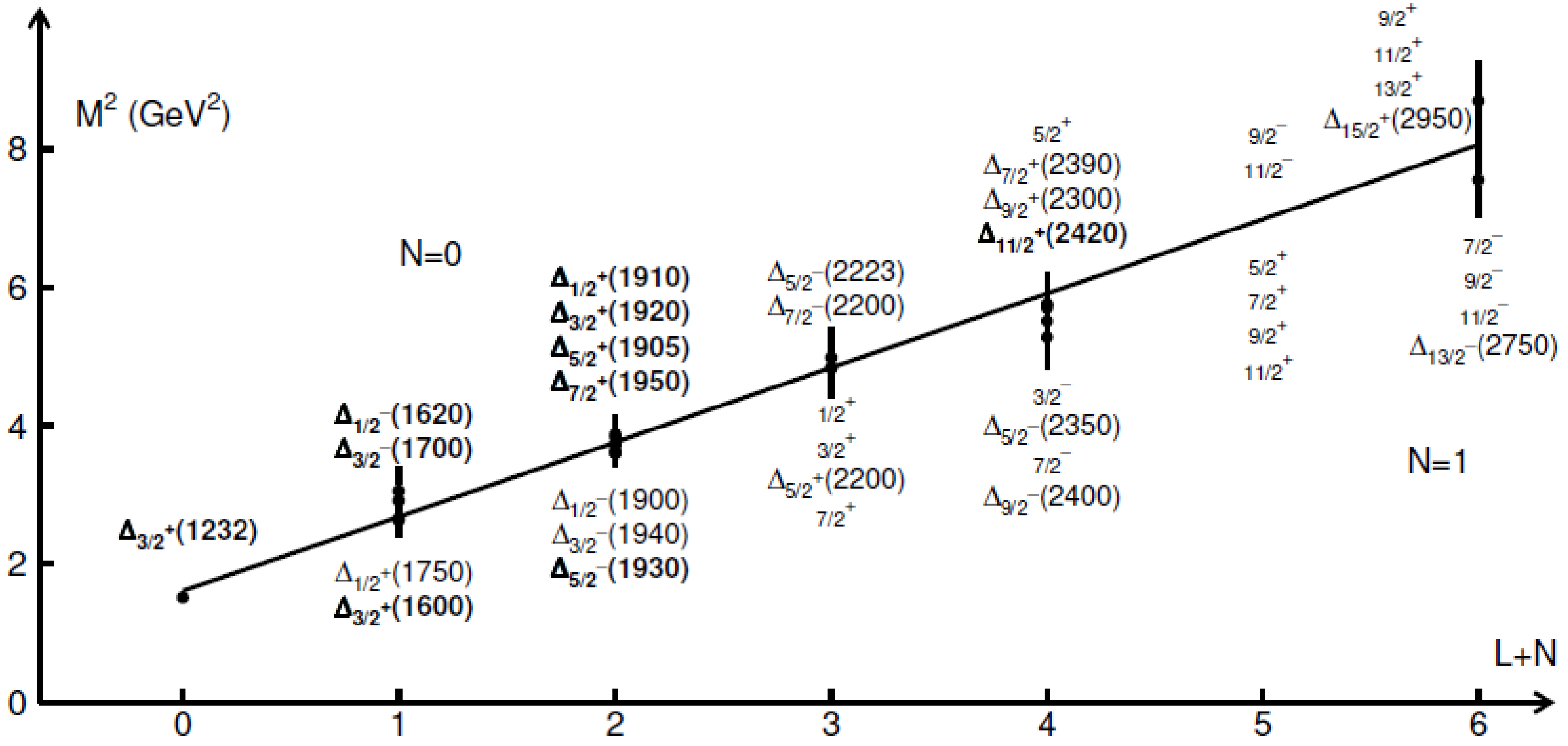
$N_{3/2^+}(1900)$ Breit-Wigner parameters			
M_{BW}	1938±15	Γ_{BW}	270±30
$A^{1/2}_{\gamma p BW}$	-0.093±0.020	$A^{3/2}_{\gamma p BW}$	-0.083±0.015
$A^{1/2}_{\gamma n BW}$	-0.014±0.006	$A^{3/2}_{\gamma n BW}$	0.010±0.006

$N(1900)3/2^+$ Branching ratios			
$Br(N\pi)$	3±2%	$Br(N\sigma)$	6±3%
$Br(\Delta(1232)\pi_{L=1})$	5±2%	$Br(\Delta(1232)\pi_{L=3})$	4±2%
$Br(N(1520)\pi)$	2±2%	$Br(N(1440)\pi)$	6±3%
$Br(N(1535)\pi)$	10±4%	$Br(N\rho_{3/2F})$	14±5%
$Br(N\rho_{1/2P})$	8±3%	$Br(N\rho_{3/2P})$	24±±8%
$Br(\Lambda K)$	6±3%	$Br(\Sigma K)$	5±2%

Analytically solvable model of QCD with constant α_s. The model which contains only one parameter, *size*.

$$\mathbf{M^2 = a \cdot (L + N + 3/2) - b \cdot \alpha_D \; [GeV^2]}$$

$a = 1.04\,\text{GeV}^2$ and $b = 1.46\,\text{GeV}^2$.



N(1720)3/2+ in the photo- and electro-production data

V.~I.~Mokeev, et al. Phys. Lett. B {805} (2020), 135457

Resonance states	Mass, GeV	N^* total width, MeV	Branching fraction for decays to $\pi\Delta$	Branching fraction for decays to ρp
$N(1720)3/2^+$	1.743-1.753	114 ± 6	38-53%	31-46%
$N'(1720)3/2^+$	1.715-1.735	120 ± 6	47-62%	4-10%

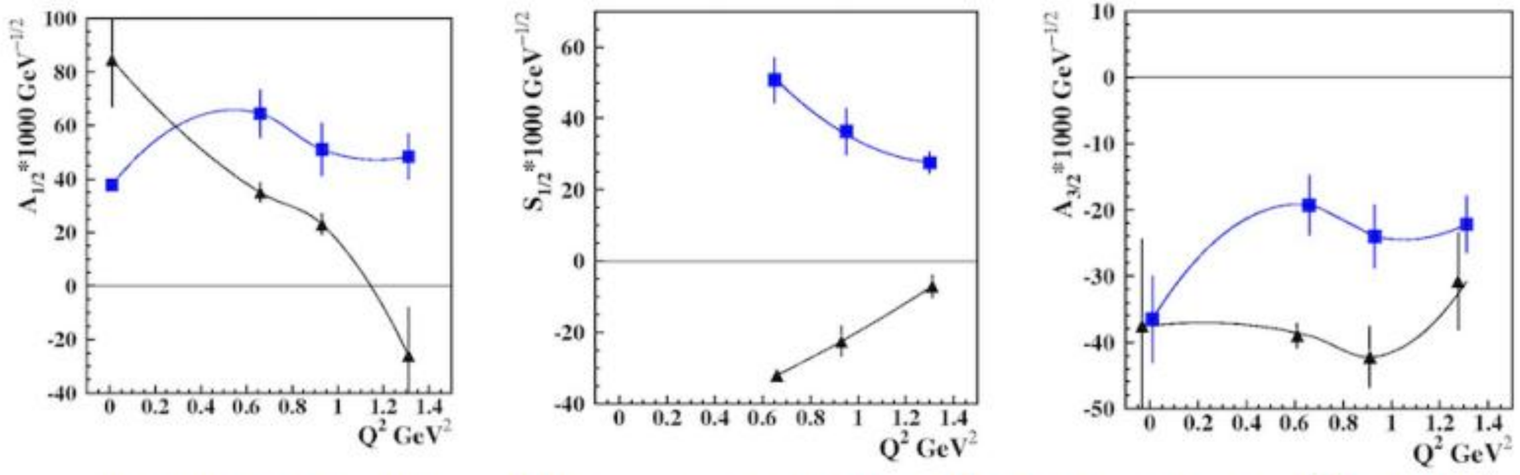
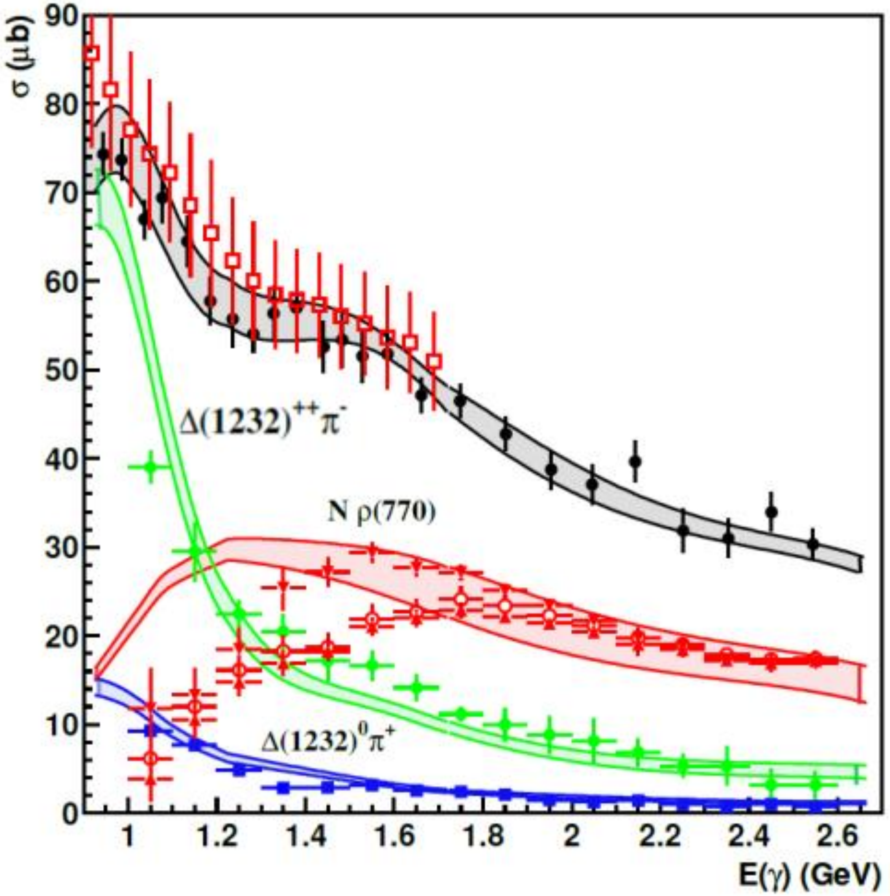


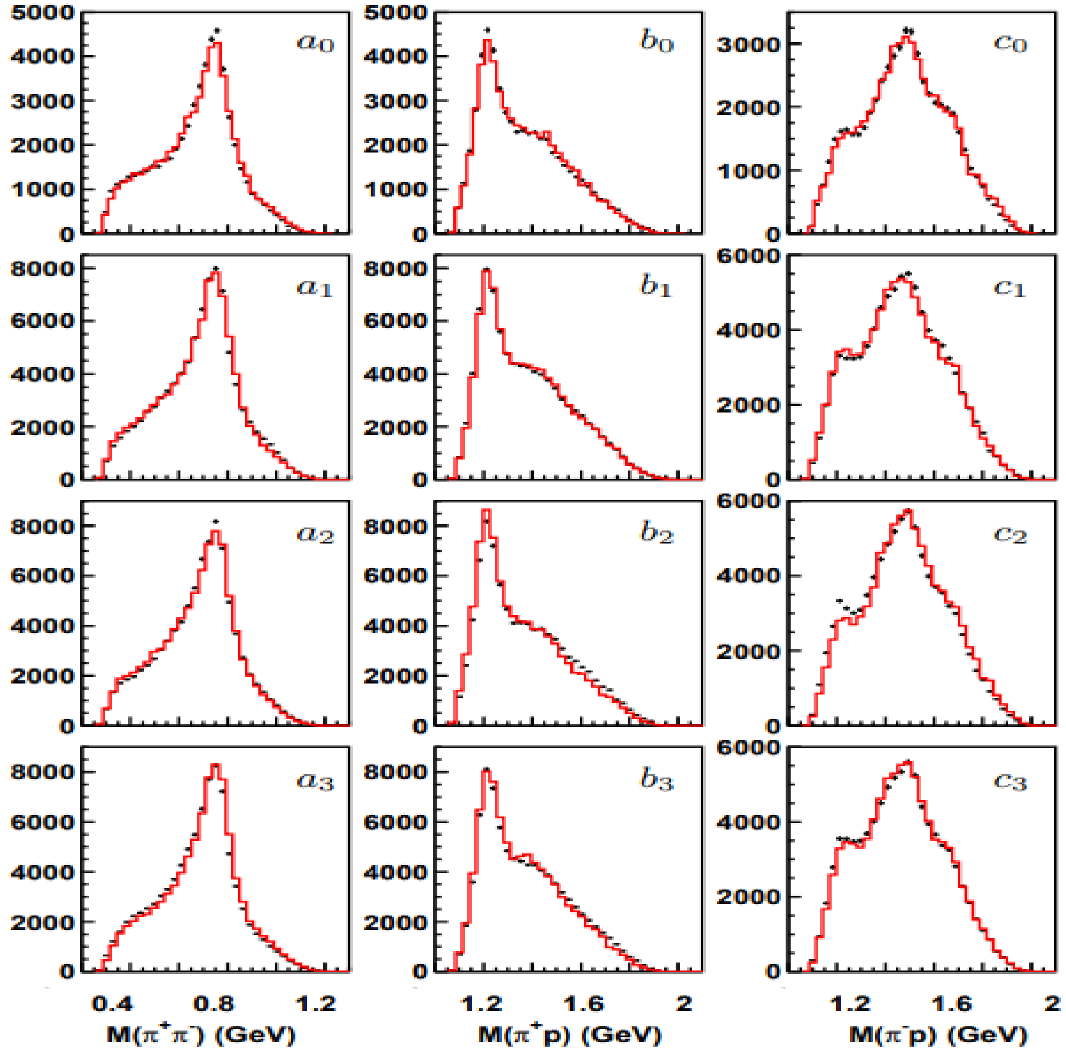
FIGURE 5. The $\gamma_{r,v} p N^*$ photo-/electrocouplings of the conventional $N(1720)3/2^+$ (black) and the new $N'(1720)3/2^+$ (blue) resonances from the $\pi^+\pi^- p$ photo- [18] and electroproduction [25] data fits.

The analysis of the CLAS $\gamma p \to \pi^+\pi^- p$ data

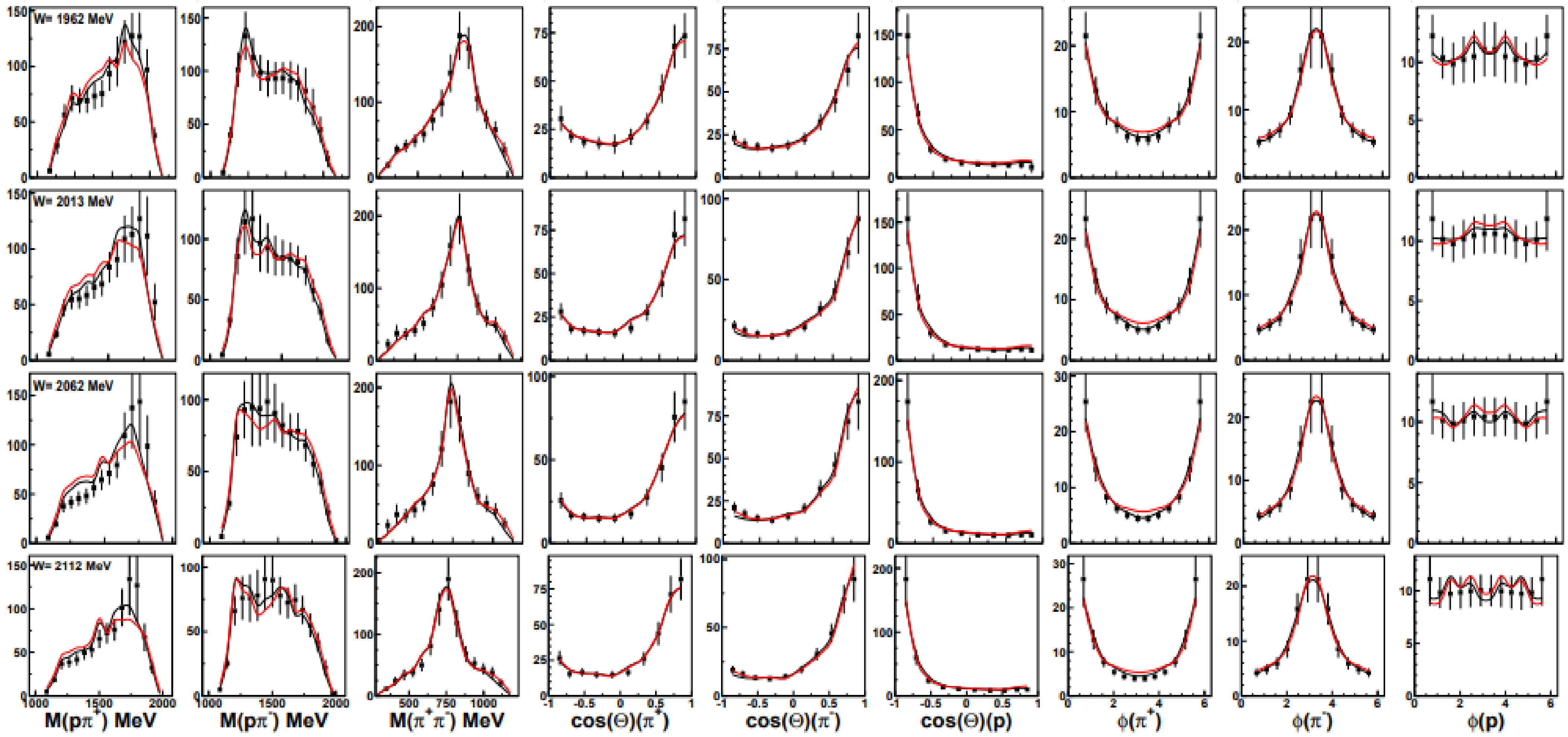
Total



4 topologies



The analysis of the CLAS $\gamma p \rightarrow \pi^+\pi^- p$ data (comparison with CLAS fit)



Structure of the Δ-states (JP=1/2+) in the mass region around 1800 MeV

Δ(1750) 1/2+

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

OMITTED FROM SUMMARY TABLE

Δ(1750) POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1748	ARNDT	04	DPWA	$\pi N \to \pi N, \eta N$
1714	VRANA	00	DPWA	Multichannel

−2×IMAGINARY PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
524	ARNDT	04	DPWA	$\pi N \to \pi N, \eta N$
68	VRANA	00	DPWA	Multichannel

Δ(1910) 1/2+

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

Older and obsolete values are listed and referenced in the 2014 edition, Chinese Physics **C38** 070001 (2014).

Δ(1910) POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1800 to 1900 (≈ 1850) OUR ESTIMATE				
1802± 6	ROENCHEN	22	DPWA	Multichannel
1840±40	SOKHOYAN	15A	DPWA	Multichannel
1896±11	[1] SVARC	14	L+P	$\pi N \to \pi N$
1880±30	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1801	HUNT	19	DPWA	Multichannel
1799	ROENCHEN	15A	DPWA	Multichannel
1840±40	GUTZ	14	DPWA	Multichannel
1850±40	ANISOVICH	12A	DPWA	Multichannel
1771	ARNDT	06	DPWA	$\pi N \to \pi N, \eta N$
1880	VRANA	00	DPWA	Multichannel
1874	HOEHLER	93	SPED	$\pi N \to \pi N$

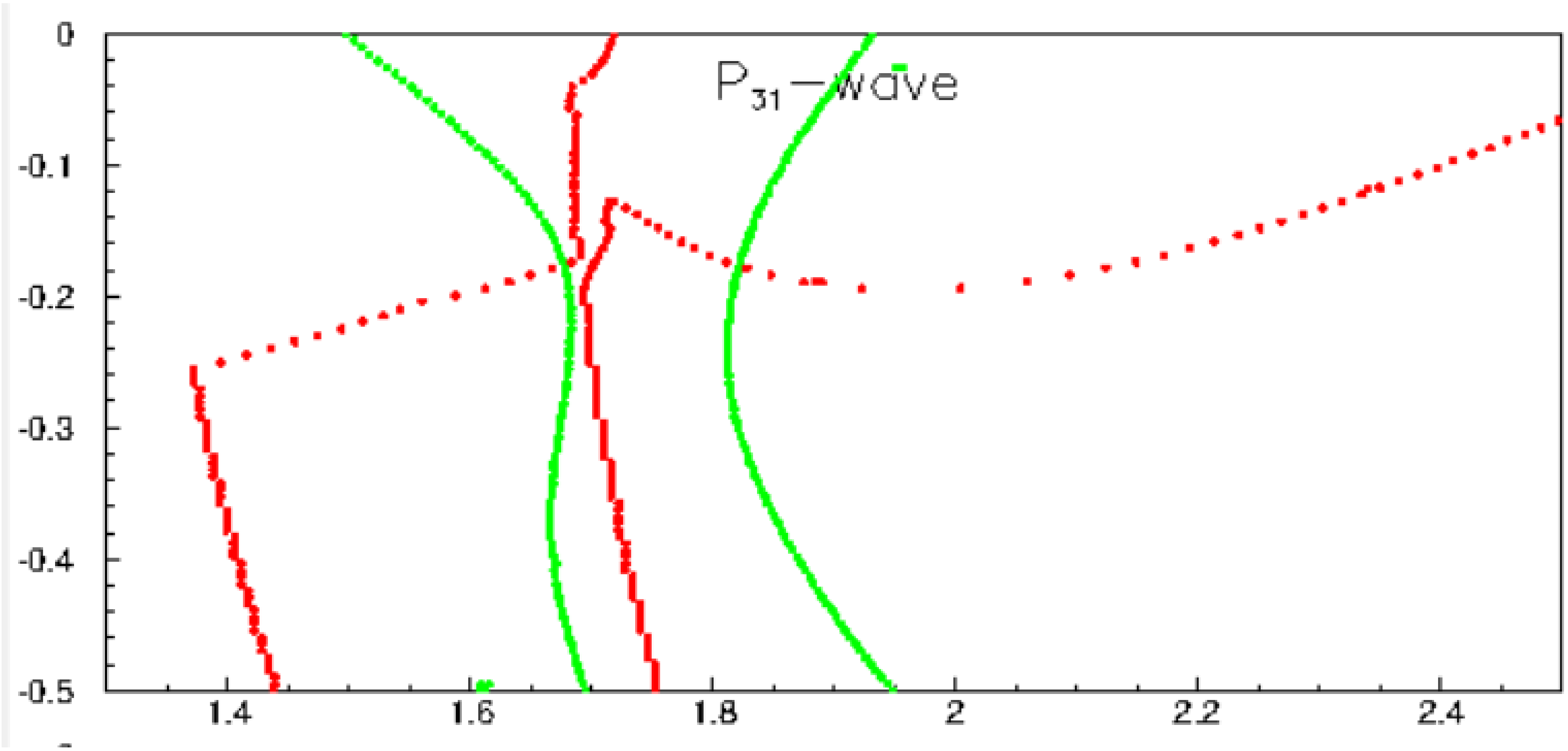
[1] Fit to the amplitudes of HOEHLER 79.

−2×IMAGINARY PART

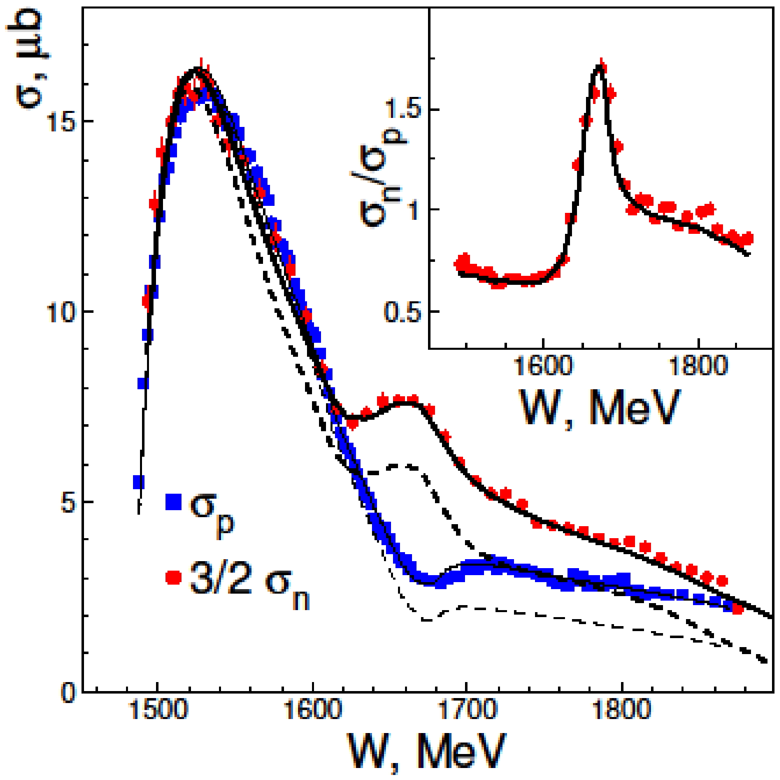
VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
200 to 500 (≈ 350) OUR ESTIMATE				
550±11	ROENCHEN	22	DPWA	Multichannel
370±60	SOKHOYAN	15A	DPWA	Multichannel
302±22	[1] SVARC	14	L+P	$\pi N \to \pi N$
200±40	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
224	HUNT	19	DPWA	Multichannel
648	ROENCHEN	15A	DPWA	Multichannel
370±60	GUTZ	14	DPWA	Multichannel
350±45	ANISOVICH	12A	DPWA	Multichannel
479	ARNDT	06	DPWA	$\pi N \to \pi N, \eta N$
496	VRANA	00	DPWA	Multichannel
283	HOEHLER	93	SPED	$\pi N \to \pi N$

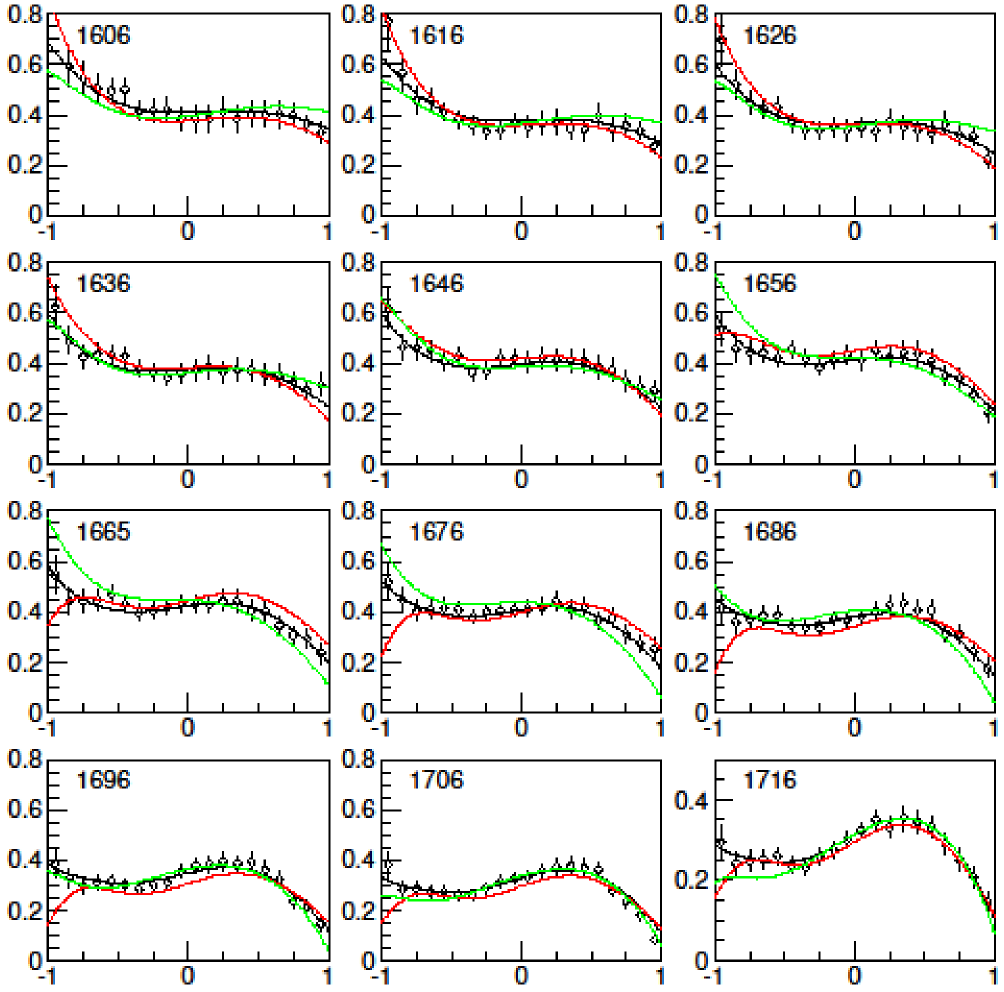
[1] Fit to the amplitudes of HOEHLER 79.

Structure of the P31 partial wave

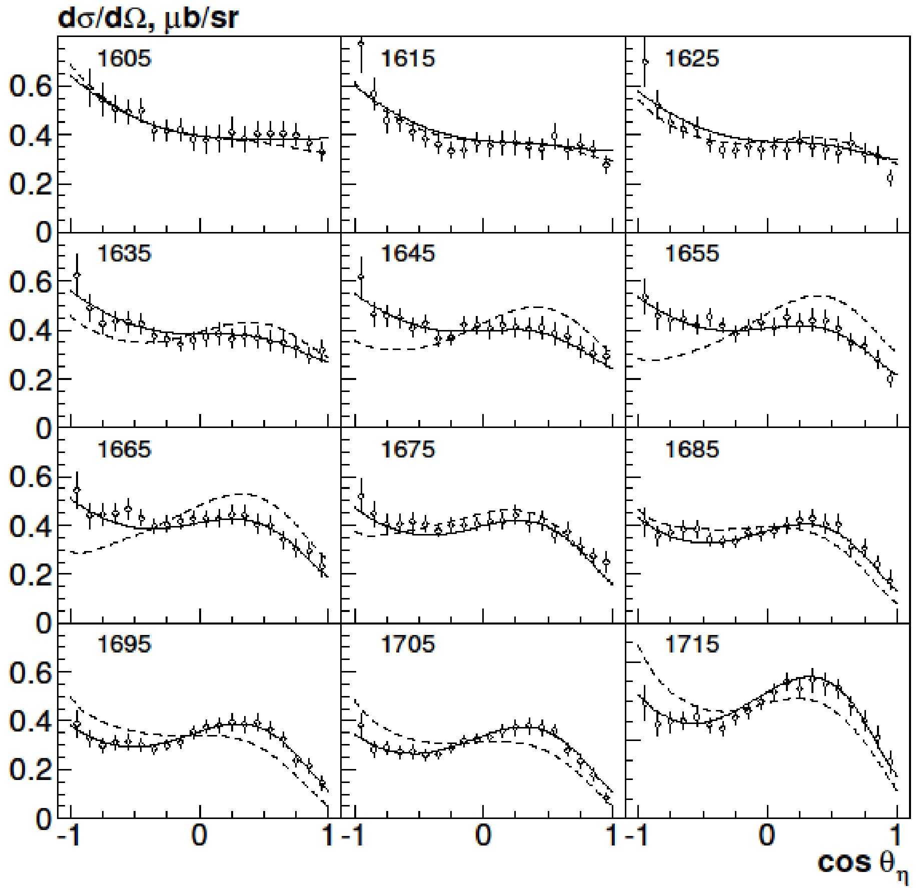


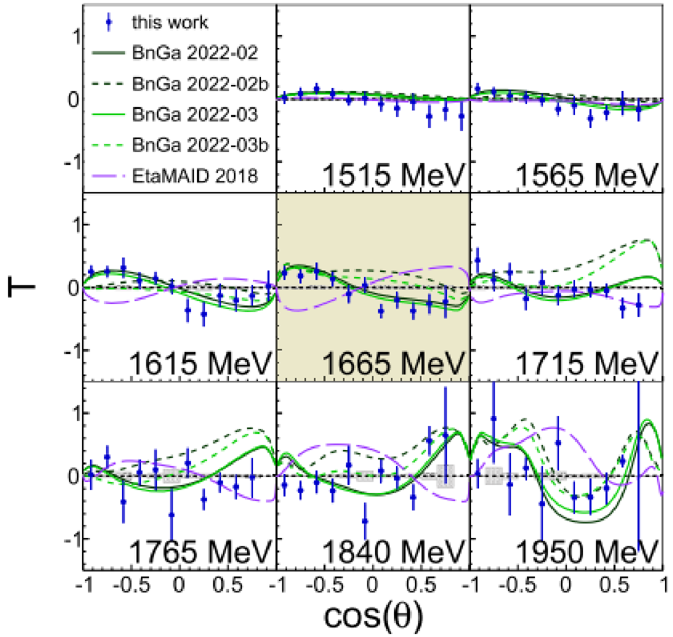
Search for the pentaquark state in $\gamma n \to \eta n$ reaction

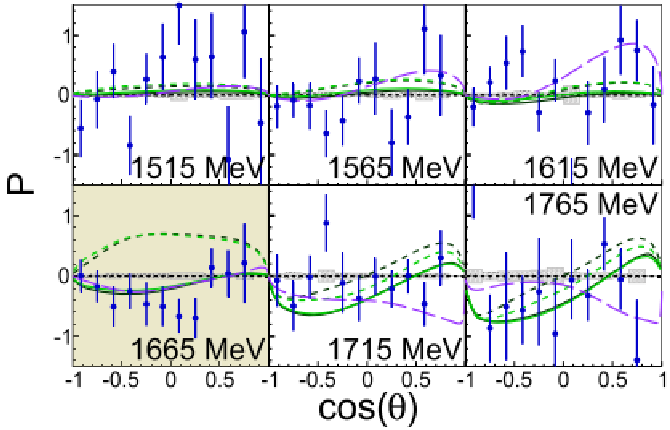


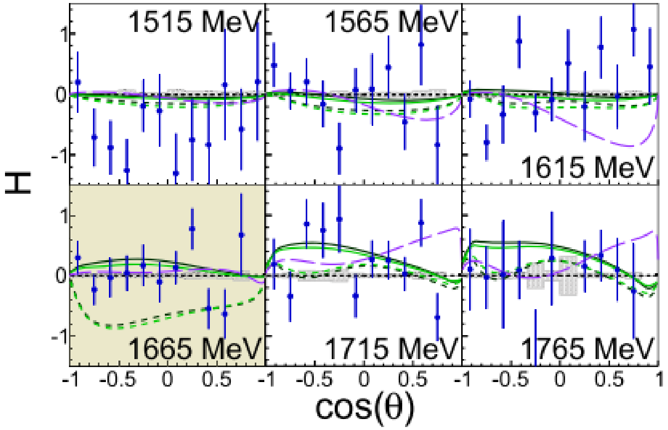


Fit of new polarization observables from the γn->ηn reaction (CB-ELSA/TAPS)









$$\hat{\mathbf{T}} \equiv \mathbf{T}\,\mathcal{I} = 3\sin\theta\,(\mathbf{E}_0^+ - x[(2\mathbf{M}_1^+ + \mathbf{M}_1^-) - 3(\mathbf{E}_1^+ + \mathbf{M}_1^+)]) \otimes (\mathbf{E}_1^+ - \mathbf{M}_1^+).$$

$$\hat{\mathbf{P}} \equiv \mathbf{P}\,\mathcal{I} = \sin\theta\,(-\mathbf{E}_0^+ + 3x\mathbf{M}_1^-) \otimes (3\mathbf{E}_1^+ + 2\mathbf{M}_1^- + \mathbf{M}_1^+),$$

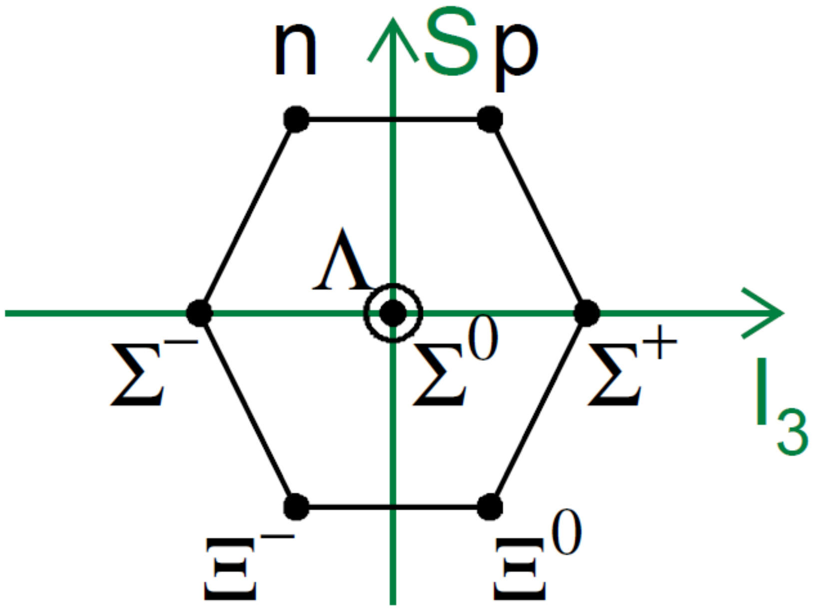
$$\hat{\mathbf{H}} \equiv \mathbf{H}\,\mathcal{I} = \sin\theta\,(-\mathbf{E}_0^+ + 3x\mathbf{M}_1^-) \otimes (3\mathbf{E}_1^+ + 2\mathbf{M}_1^- + \mathbf{M}_1^+)(\text{-}1)$$

Conclusion

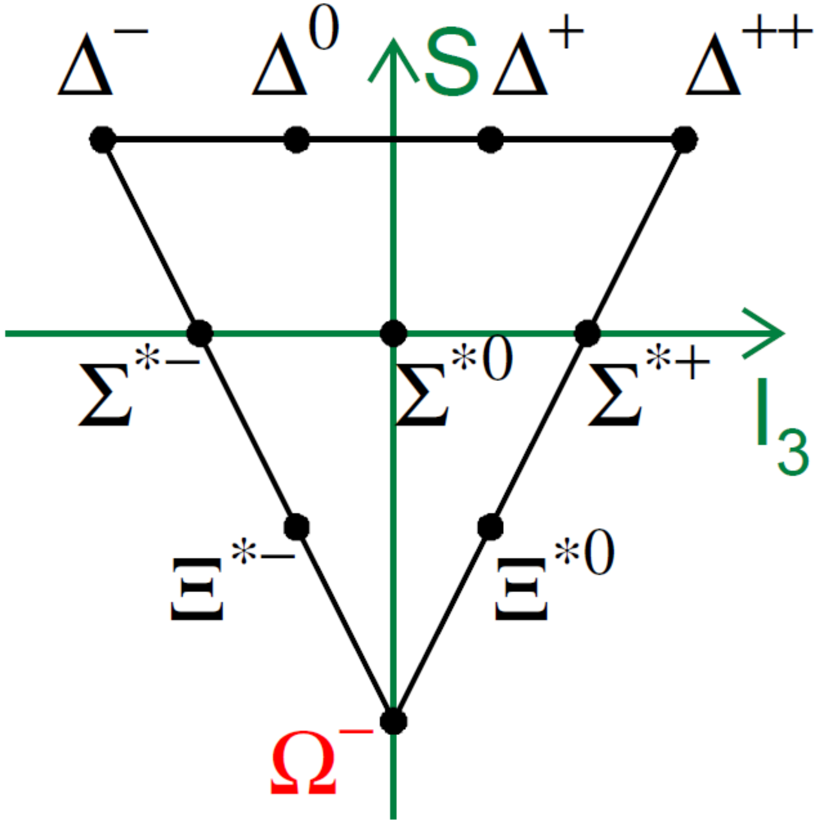
1) Photoproduction experiments lead to discovery of 6 new baryon states.
2) The one star nucleon three one star Δ-states were confirmed.
3) Many properties of the states were determined with a good accuracy. For the decay into two-meson final states many properties were defined for the first time.
4) The latest high precision data confirmed the states observed before but not leaded to a discovery of new states.
5) The new polarization data helped to define the branching ratios to different final states and phases of the coupling constants.
6) It is possible that we have a double pole structure in the mass region 1650-1800 MeV in the P31 partial wave. But this should be carefully investigated.
7) The analysis of the electroproduction data from CLAS predicts two states N(1720) and N'(1720) with similar masses and widths but different branching ratios to $N\rho(775)$ and $\Delta\pi$. Possibly it can be checked in pion-induced experiments.

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

Octet



Decuplet



KN – scattering data

Table 1. List of reactions used in the partial-wave analysis. Δ denotes the $\Delta(1232)3/2^+$, Λ^* the $\Lambda(1520)3/2^-$, Σ^* the $\Sigma(1385)3/2^+$.

$K^-p \to K^-p$	$K^-p \to \bar{K}^0 n$	$K^-p \to \pi^0 \Lambda$
$K^-p \to \omega\Lambda$	$K^-p \to \eta\Lambda$	$K^-p \to \pi^0\Sigma^0, \eta\Sigma^0$
$K^-p \to \pi^\mp\Sigma^\pm$	$K^-p \to K^{+/0}\Xi^{-/0}$	$K^-p \to K^{-/0}\Delta^{+/0}$
$K^-p \to \pi^\pm\Sigma^{*\mp}$	$K^-p \to \pi^0\Lambda^*$	$K^-p \to K^{*-}p$
$K^-p \to K^{*0}n$	$K^-p \to \pi^0\pi^0\Lambda$	$K^-p \to \pi^0\pi^0\Sigma$

Similar reactions (existing data) were fitted by different groups including the Bonn-Gatchina PWA

Example for the fit quality

(and data consistency – many different data sets)

Sarantsev et al. EPJ A55 180 (2019)

$d\sigma/d\Omega$, mb/sr ($K^-p \to \bar{K}^0 n$)

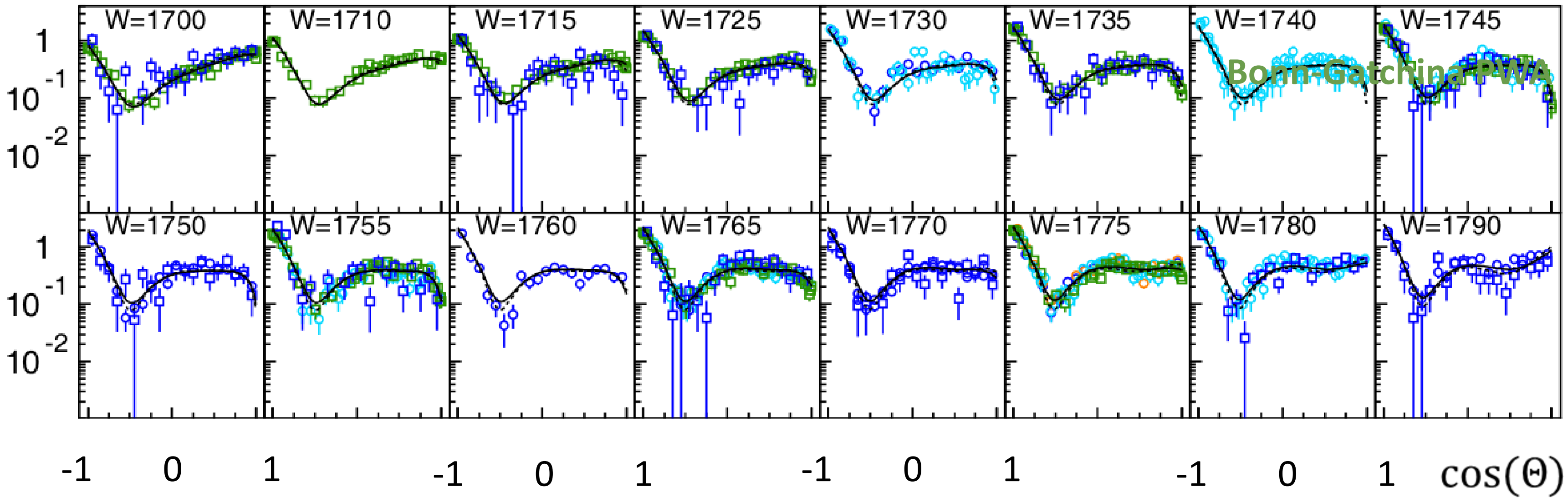


Table 2: Σ-Hyperons used in the first fit of the data.

		J^P	Status	Mass	Width
$N(1440)$	$\Sigma(1660)$	$1/2^+$	***	$1630 - 1690$	$40 - 200$
$\Delta(1230)$	$\Sigma(1385)$	$3/2^+$	****	1382.80 ± 0.35	36.0 ± 0.7
$N(1680), \Delta(1905)$	$\Sigma(1915)$	$5/2^+$	****	$1900 - 1935$	$80 - 160$
$N(1990), \Delta(1950)$	$\Sigma(2030)$	$7/2^+$	****	$2025 - 2040$	$150 - 200$
$N(1520)$	$\Sigma(1670)$	$3/2^-$	****	$1665 - 1685$	$40 - 80$
$N(1535), \Delta(1620), N(1650)$	$\Sigma(1750)$	$1/2^-$	***	$1730 - 1800$	$60 - 160$
$N(1675)$	$\Sigma(1775)$	$5/2^-$	****	$1770 - 1780$	$105 - 135$
$N(1700), \Delta(1700)$	$\Sigma(1940)$	$3/2^-$	***	$1900 - 1950$	$150 - 300$

Many Σ states are missing.

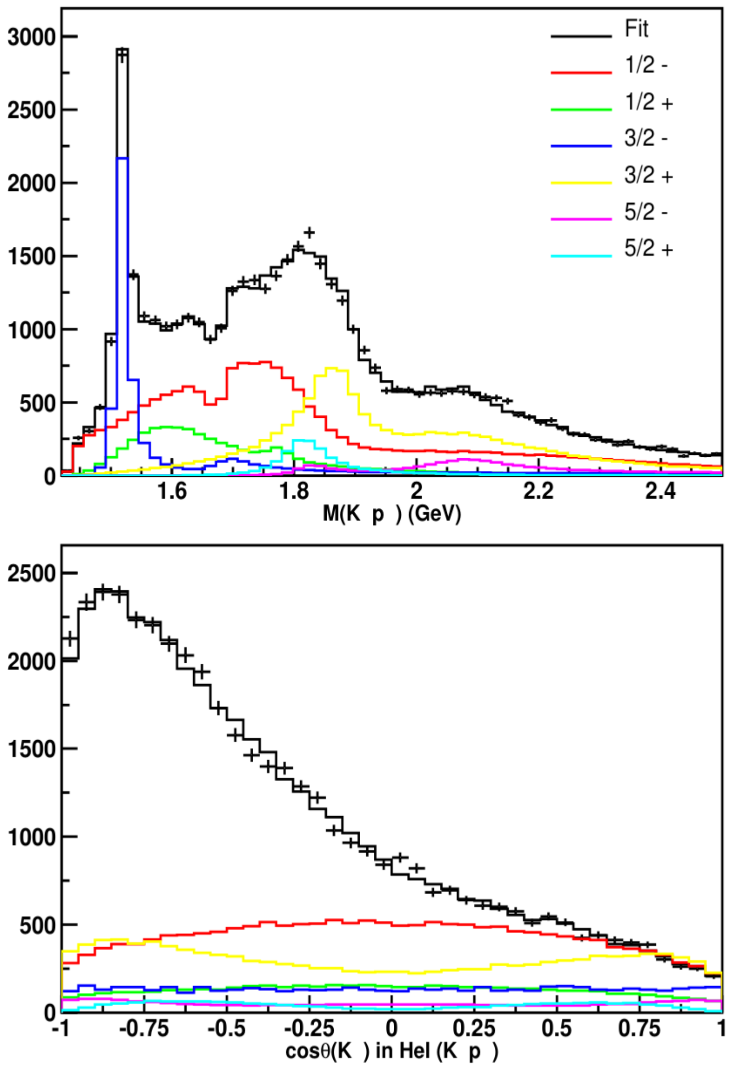
TABLE I. The pole position in the partial wave amplitudes for two ANL-Osaca solutions and for the Bonn-Gatchina solutions.

	M_R (MeV)			
Resonance	ANL-Osaka Model A	ANL-Osaka Model B	Bonn-Gatchina	PDG 2014
$\Lambda(????)1/2^-$		$(1512^{+1}_{-1},370^{+2}_{-4})$		—
$\Lambda(1670)1/2^-$	$(1669^{+3}_{-8}, 18^{+18}_{-2})$	$(1667^{+1}_{-2},24^{+6}_{-2})$	$(1676\pm2, 33\pm4)$	****
$\Lambda(1800)1/2^-$			$(1809\pm9, 205\pm16)$	***
$\Lambda(1600)1/2^+$	$(1544^{+3}_{-3}, 112^{+12}_{-2})$	$(1548^{+5}_{-6}, 164^{+14}_{-14})$	$(1562\pm8, 232\pm15)$	****
$\Lambda(1810)1/2^+$		$(1841^{+3}_{-4}, 62^{+6}_{-4})$	$(1773\pm7, 38\pm14)$	***
$\Lambda(2100)1/2^+$	$(2097^{+40}_{-1}, 166^{+64}_{-12})$			—
$\Lambda(1670)3/2^+$		$(1671^{+2}_{-8}, 10^{+22}_{-4})$		—-
$\Lambda(1890)3/2^+$	$(1859^{+5}_{-7}, 112^{+20}_{-4})$		$(1872\pm5, 101\pm10)$	****
$\Lambda(2070)3/2^+$			$(2044\pm20, 360\pm45)$	—-
$\Lambda(1520)3/2^-$	$(1517^{+4}_{-4}, 16^{+10}_{-8})$	$(1517^{+4}_{-3}, 16^{+12}_{-12})$	$(1517.5\pm0.4, 15.3\pm0.9)$	****
$\Lambda(1690)3/2^-$	$(1697^{+6}_{-6}, 66^{+14}_{-14})$	$(1697^{+6}_{-5}, 74^{+14}_{-14})$	$(1683\pm3, 72\pm5)$	****
$\Lambda(1830)5/2^-$	$(1766^{+37}_{-34},212^{+94}_{-62})$	$(1924^{+52}_{-24}, 90^{+114}_{-34})$	$(1819.5\pm3, 62\pm5)$	****
$\Lambda(2080)5/2^-$	$(1899^{+35}_{-37}, 80^{+100}_{-34})$		$(2070\pm15, 172\pm28)$	
$\Lambda(1820)5/2^+$	$(1824^{+2}_{-1}, 78^{+2}_{-2})$	$(1821^{+1}_{-1}, 64^{+2}_{-2})$	$(1813\pm3, 78\pm7)$	****
$\Lambda(2110)5/2^+$			$(2048\pm10, 255\pm20)$	***
$\Lambda(2085)7/2^+$	(1757, 73)	$(2041^{+80}_{-82},238^{+114}_{-34})$		*
$\Lambda(2100)7/2^-$	-	-	$(2040\pm14, 215\pm29)$	****

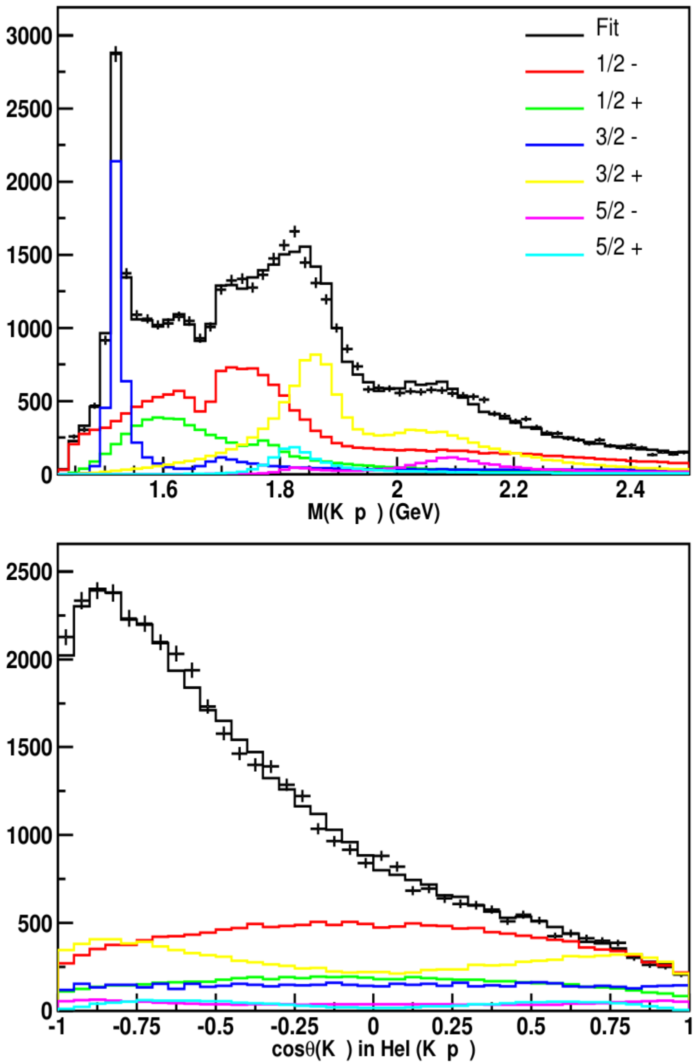
ANL-Osaka: Kamano et al. Phys.Rev. C92 025205 (2015)

Simplified fit with Breit-Wigner amplitudes corresponding to BG and ANL-Osaka poles

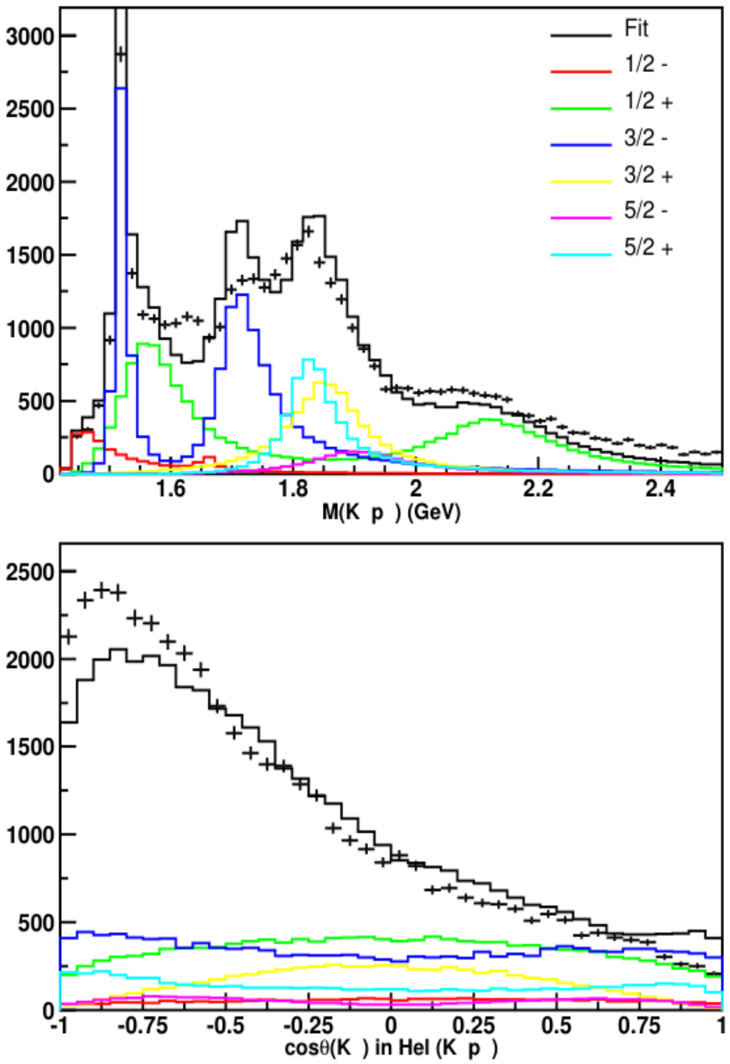
K-matrix BG –log L=-26029



BW-BG -log L=-25730



ANL-Osaka -log L=-22432



Klong experiment (JLAB)

Let us consider the decay of the isospin 0 and isospin 1 states into K^-p and K^0n

$$|A(K^-p)|^2 = \left(A_1\frac{1}{\sqrt{2}} + A_0\frac{1}{\sqrt{2}}\right)^2 = \frac{1}{2}\left(|A_1|^2 + |A_0|^2 + 2Re(A_1A_0^*)\right)$$
$$|A(K^0n)|^2 = \left(A_1\frac{1}{\sqrt{2}} - A_0\frac{1}{\sqrt{2}}\right)^2 = \frac{1}{2}\left(|A_1|^2 + |A_0|^2 - 2Re(A_1A_0^*)\right)$$

$$A_{KN} = \omega^*\left[G(s,t) + H(s,t)i(\vec{\sigma}\vec{n})\right]\omega' \qquad \vec{n}_j = \varepsilon_{\mu\nu j}\frac{q_\mu k_\nu}{|\vec{k}||\vec{q}|}\,.$$

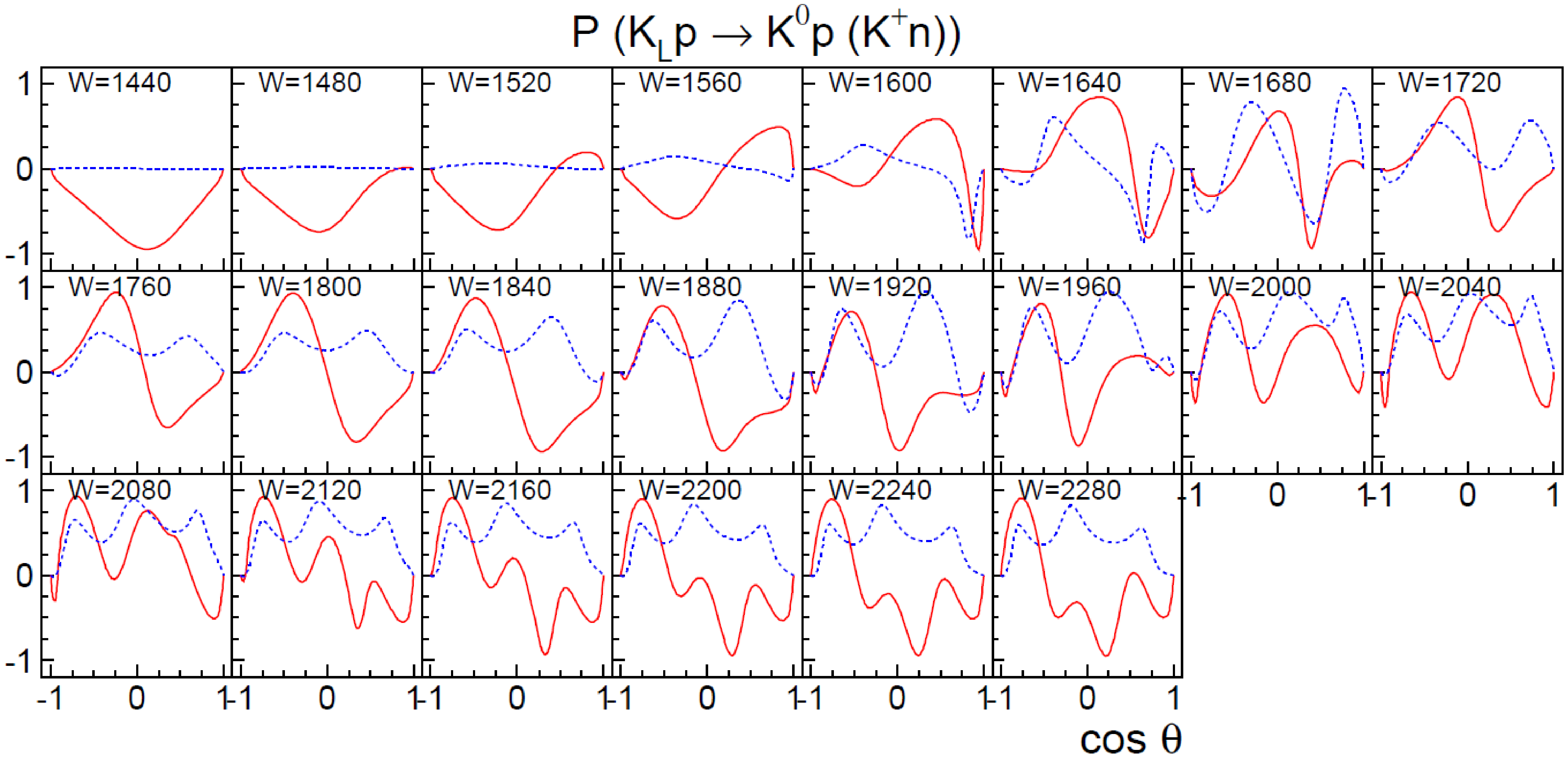
Differential cross section in c.m.s. of the reaction

$$|A|^2 = \frac{1}{2}\mathrm{Tr}\left[A^*_{\pi N}A_{\pi N}\right] = |G(s,t)|^2 + |H(s,t)|^2(1-z^2)$$

the recoil asymmetry:

$$P = \frac{\mathrm{Tr}\left[A^*_{\pi N}\sigma_2 A_{\pi N}\right]}{2|A|^2\cos\phi} = \sin\Theta\frac{2Im\left(H^*(s,t)G(s,t)\right)}{|A|^2}\,.$$

Prediction for the recoil asymmetry $K_L p \to K^0 p (K^+ n)$

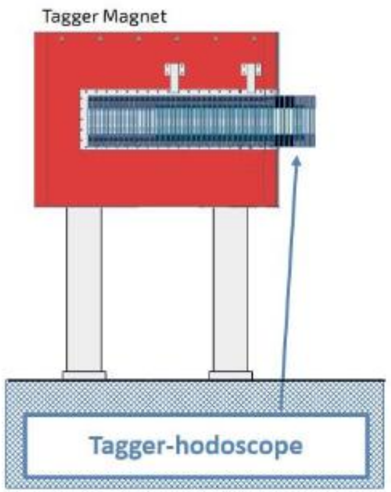


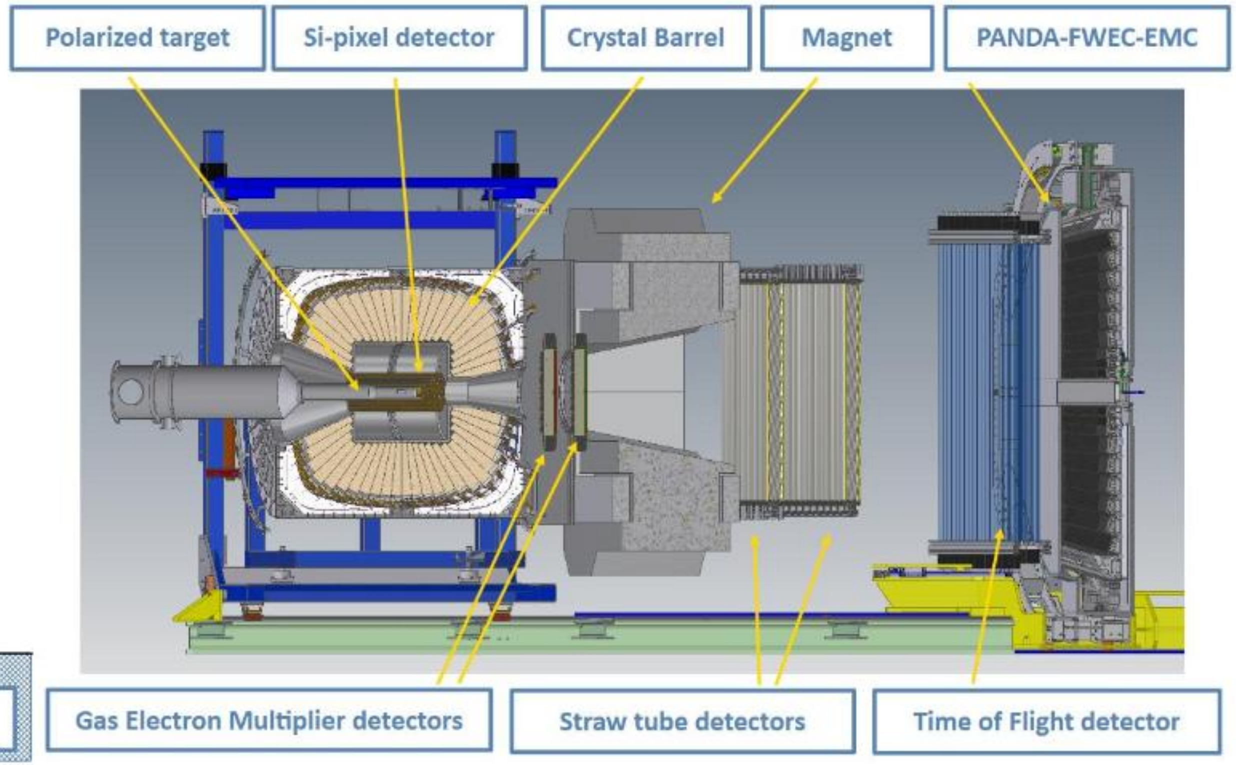
Physics at ELSA - the future

A new experiment as integral part of the new Cluster of Excellence „Color meets Flavor":

color meets flavor

INSIGHT @ELSA
Investigation of the strong interaction in the light flavor sector





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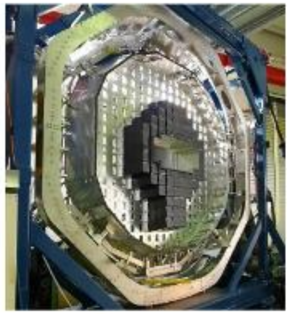
Arrival of the PANDA-FWEC in Bonn



at the FTD

➡ **Over almost the entire 4π-solid angle:**

- **High resolution photon measurements**
- **Precise charged particle detection**

Polarized beam and polarized target

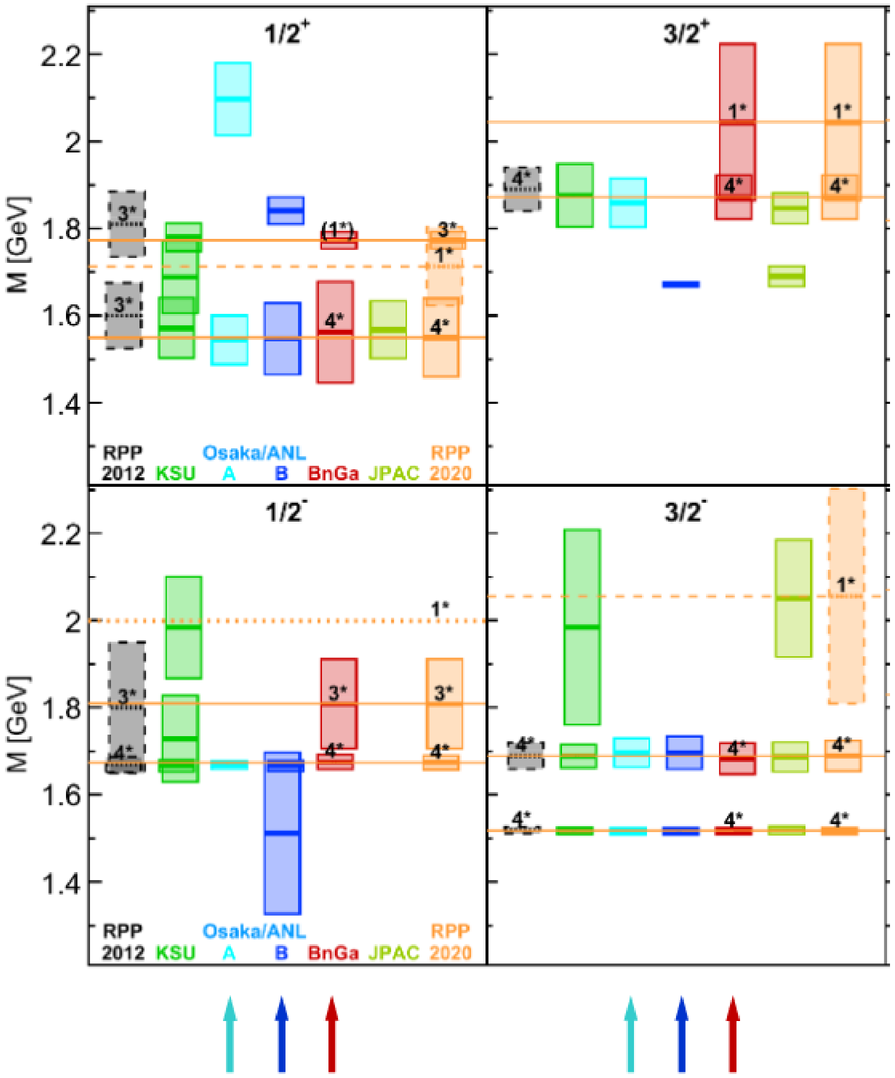
➡ **unique possiblilities!**

@ELSA: Advantage of polarization experiments

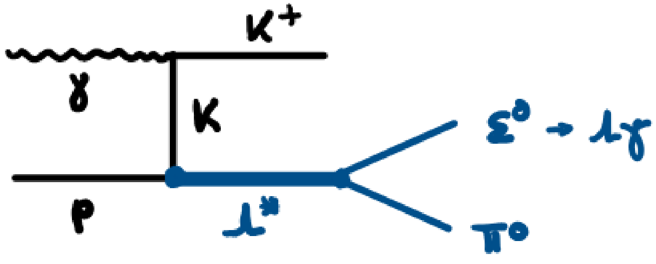
Several PWA groups have re-analysed the exisiting data (KN-scatt.) on strange baryon resonances

(only J=1/2, 3/2, P=+/- shown)

Almost the same data included in the fit, but quite different solutions



Use a PWA-solution toy model
⇔ calculation based on t-channel K-exchange only



Resonances based on
ANL/Osaka- and BnGa-PWA

Use resonance properties and $pK\Lambda^*$ couplings from BnGa
⇔ Predict solution
⇔ Fit to BnGa-"data" with ANL/Osaka pole positions