The meson production reactions: the analysis methods and recent results

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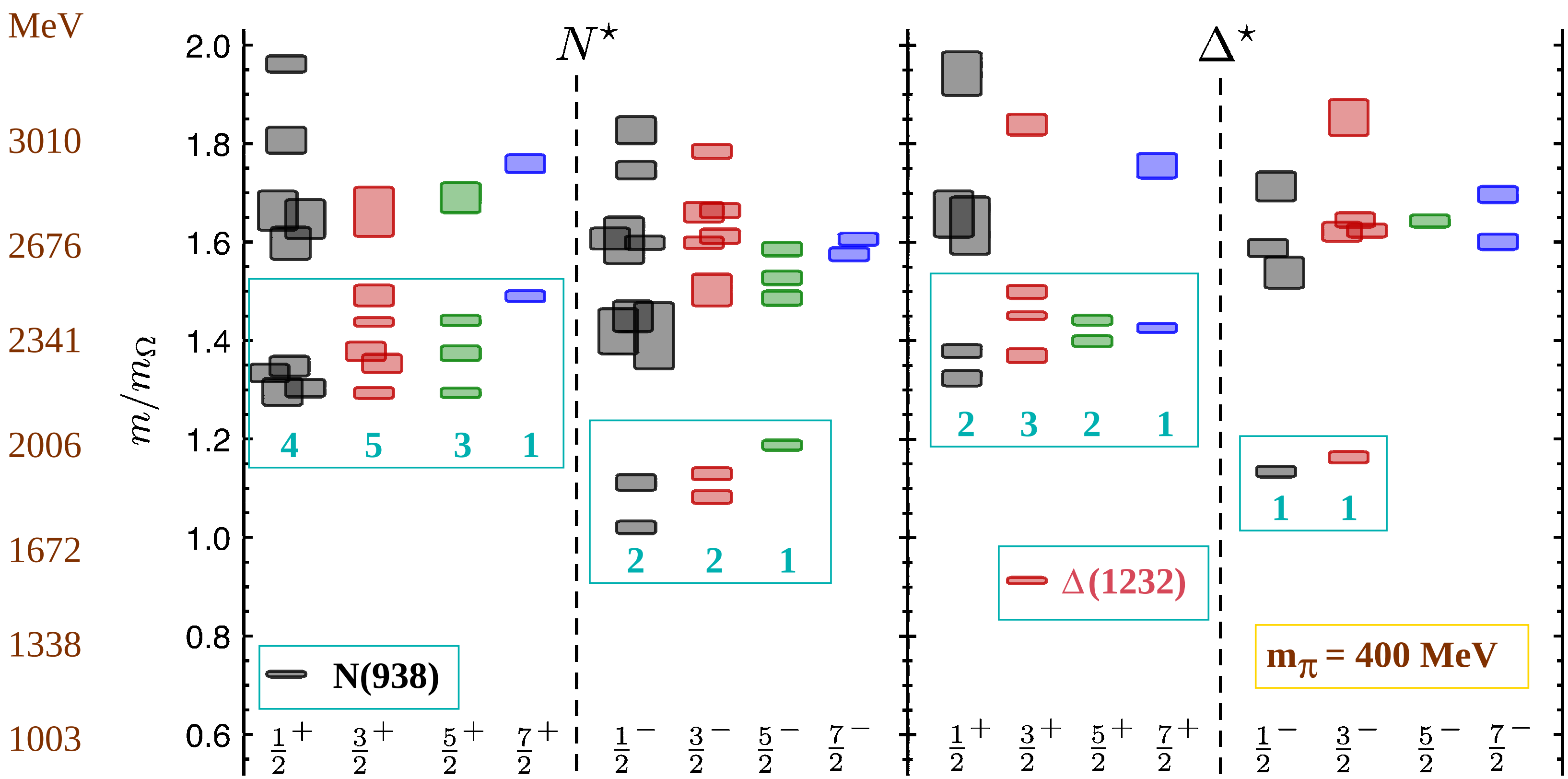
0.0.1 Baryons on the lattice



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

Baryon sector: the partial wave analysis groups

- **SAID (GWU,USA): Analysis of elastic πN data in energy independent method and then in the K-matrix approach. Fit of the $\gamma n \to \pi N, \eta N$ data as a sum of BW amplitudes and now also in the framework of K-matrix/P-vector approach. Recently: analysis of the final states with 2 pions and $\bar{K}N$ collision reactions.**
- **MAID (Mainz): Energy dependent analysis of photoproduction data on γN to πN, ηp, $\eta' p$,$K\Lambda$, $K\Sigma$. Parameterization of partial waves as a sum of Breit-Wigner amplitudes with unitarisation procedure. Development of the approach which takes into account crossing symmetry and dispersion corrections.**
- **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. Recently, the analysis of the $\bar{K}N$ collision reactions.**
- **Juelich group: Energy dependent covariant approach. Pion induced data (elastic and inelastic), $\gamma p \to \pi N, \eta N, K\Lambda, K\Sigma$. Unitarity, analyticity and chiral constraints. Solution of the Bethe-Salpeter equation.**

- **ANL-OSAKA Energy dependent covariant approach. Pion induced data (elastic and inelastic), $\gamma p \to \pi N, \eta N$ (all data) and $\gamma p \to K\Lambda, K\Sigma$. Unitarity and analyticity constraints. Solution of the Bethe-Salpeter equation. Analysis of the KN collision data with one meson in the final state.**

- **M. Manley (Kent Uni) Energy dependent covariant approach. Pion induced data (elastic and inelastic including 2pion production), $\gamma p \to \pi N$ (all data) and $\gamma p \to K\Lambda, K\Sigma$. Unitarity and analyticity constraints.**

Bonn-Gatchina partial wave analysis group:

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

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

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Bonn-Gatchina Partial Wave Analysis

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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

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

Energy dependent approach

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

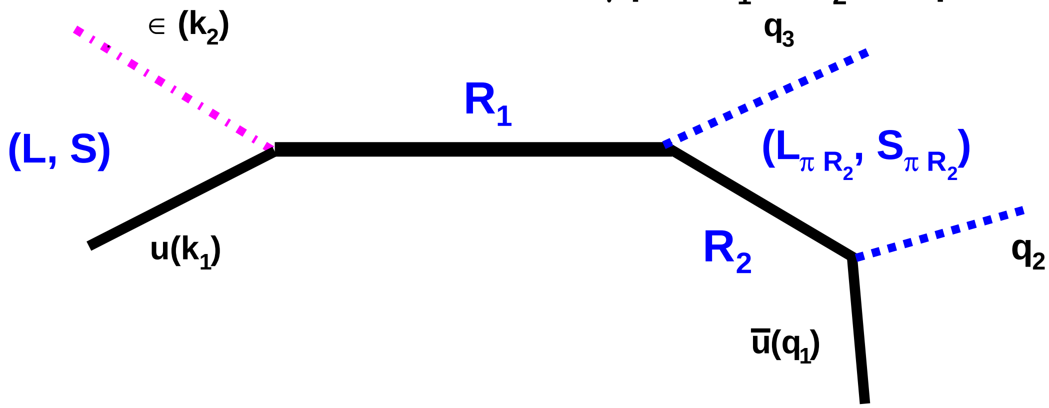
$$A(s,t) = \sum_{\beta\beta' n} A_n^{\beta\beta'}(s) Q^{(\beta)+}_{\mu_1\ldots\mu_n} F^{\mu_1\ldots\mu_n}_{\nu_1\ldots\nu_n} Q^{(\beta')}_{\nu_1\ldots\nu_n}$$

1. A. V. Anisovich, V. V. Anisovich, V. N. Markov, M. A. Matveev and A. V. Sarantsev, J. Phys. G 28, 15 (2002)
2. A. Anisovich, E. Klempt, A. Sarantsev and U. Thoma, Eur. Phys. J. A 24, 111 (2005)
3. A. V. Anisovich and A. V. Sarantsev, Eur. Phys. J. A 30, 427 (2006)
4. A. V. Anisovich, V. V. Anisovich, E. Klempt, V. A. Nikonov and A. V. Sarantsev, Eur. Phys. J. A 34, 129 (2007).

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.**

1. C. Zemach, Phys. Rev. 140, B97 (1965); 140, B109 (1965).
2. S.U.Chung, Phys. Rev. D 57, 431 (1998).
3. B. S. Zou and D. V. Bugg, Eur. Phys. J. A 16, 537 (2003)

Resonance amplitudes for meson photoproduction



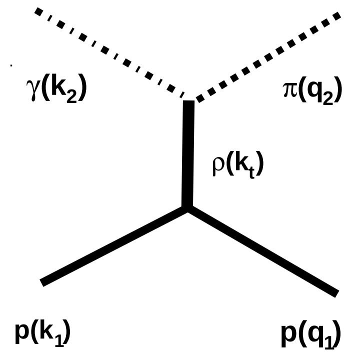
General form of the angular dependent part of the amplitude:

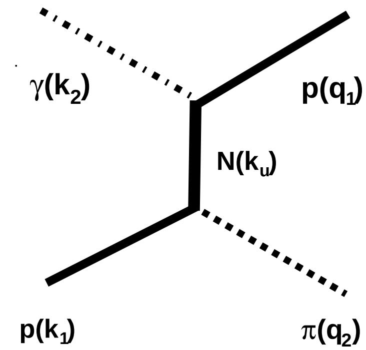
$$\bar{u}(q_1)\tilde{N}_{\alpha_1\ldots\alpha_n}(R_2\to\mu N)F^{\alpha_1\ldots\alpha_n}_{\beta_1\ldots\beta_n}(q_1+q_2)\tilde{N}^{(j)\beta_1\ldots\beta_n}_{\gamma_1\ldots\gamma_m}(R_1\to\mu R_2)$$
$$F^{\gamma_1\ldots\gamma_m}_{\xi_1\ldots\xi_m}(P)V^{(i)\mu}_{\xi_1\ldots\xi_m}(R_1\to\gamma N)u(k_1)\varepsilon_\mu$$

$$F^{\mu_1\ldots\mu_L}_{\nu_1\ldots\nu_L}(p)=(m+\hat{p})O^{\mu_1\ldots\mu_L}_{\alpha_1\ldots\alpha_L}\frac{L+1}{2L+1}\Big(g^{\perp}_{\alpha_1\beta_1}-\frac{L}{L+1}\sigma_{\alpha_1\beta_1}\Big)\prod_{i=2}^{L}g_{\alpha_i\beta_i}O^{\beta_1\ldots\beta_L}_{\nu_1\ldots\nu_L}$$

$$\sigma_{\alpha_i\alpha_j}=\frac{1}{2}(\gamma_{\alpha_i}\gamma_{\alpha_j}-\gamma_{\alpha_j}\gamma_{\alpha_i})$$

Reggezied exchanges:





The amplitude for t-channel exchange:

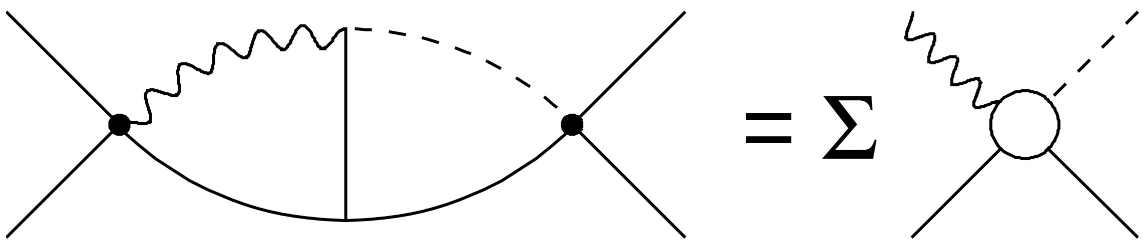
$$A = g_1(t)g_2(t)R(\xi,\nu,t) = g_1(t)g_2(t)\frac{1+\xi exp(-i\pi\alpha(t))}{\sin(\pi\alpha(t))}\left(\frac{\nu}{\nu_0}\right)^{\alpha(t)} \qquad \nu = \frac{1}{2}(s-u).$$

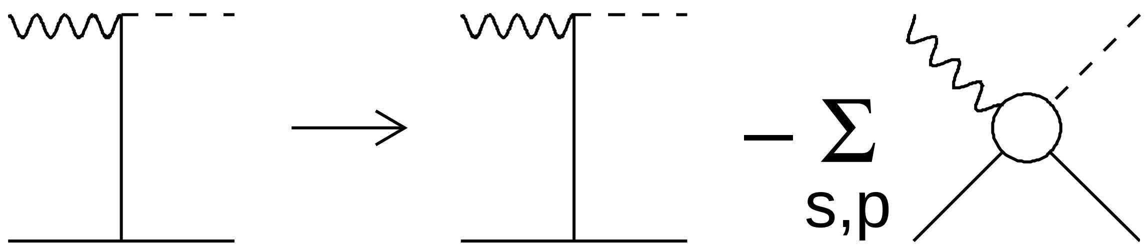
Here $\alpha(t)$ is the reggion trajectory, and ξ is its signature:

$$R(+,\nu,t) = \frac{e^{-i\frac{\pi}{2}\alpha(t)}}{\sin(\frac{\pi}{2}\alpha(t))\Gamma\left(\frac{\alpha(t)}{2}\right)}\left(\frac{\nu}{\nu_0}\right)^{\alpha(t)},$$

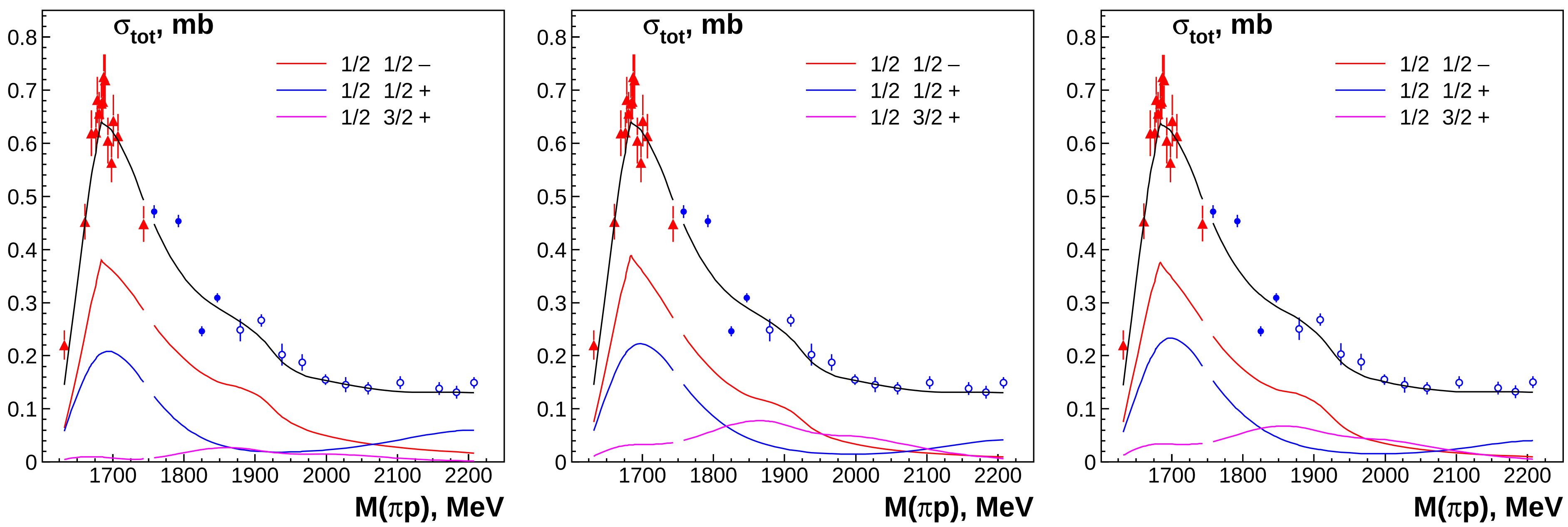
$$R(-,\nu,t) = \frac{ie^{-i\frac{\pi}{2}\alpha(t)}}{\cos(\frac{\pi}{2}\alpha(t))\Gamma\left(\frac{\alpha(t)}{2}+\frac{1}{2}\right)}\left(\frac{\nu}{\nu_0}\right)^{\alpha(t)}.$$

t,u-exchange subtraction procedure

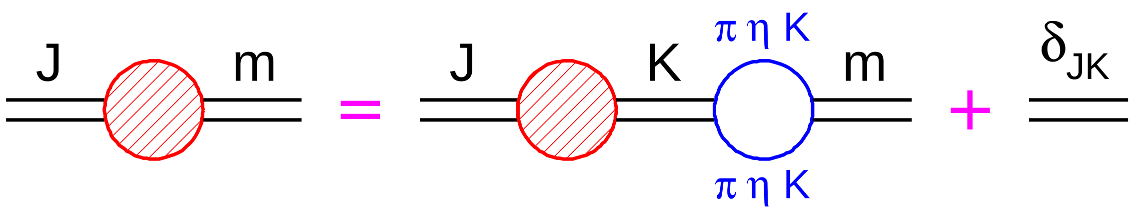




t,u-exchange subtraction procedure



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



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

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

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

Pole parameters of the S_{11} states

	$N(1535)S_{11}$		$N(1650)S_{11}$		$N(1890)S_{11}$	
	K-matrix	D-matrix	K-matrix	D-matrix	K-matrix	D-matrix
M_{pole}	1501$\pm$4	1494	1647$\pm$6	1651	1900$\pm$15	1905
Γ_{pole}	134$\pm$11	116	103$\pm$8	95	90^{+30}_{-15}	106
Elastic residue	31$\pm$4	25	24$\pm$3	23	1$\pm$1	1.5
Phase	-(29$\pm$5)$^\circ$	-38°	-(75$\pm$12)$^\circ$	-62°	–	–
Res$_{\pi N\to N\eta}$	28$\pm$3	25	15$\pm$3	15	4$\pm$2	5
Phase	-(76$\pm$8)$^\circ$	-69°	(132$\pm$10)$^\circ$	140	(40$\pm$20)$^\circ$	42°
Res$_{\pi N\to \Delta\pi}$	7$\pm$4	4	11$\pm$3	12	–	–
Phase	(147$\pm$17)$^\circ$	157°	-(30$\pm$20)$^\circ$	-40	–	–
$A^{1/2}$ (GeV$^{-\frac{1}{2}}$)	0.116$\pm$0.010	0.107	0.033$\pm$0.007	0.029	0.012$\pm$0.006	0.010
Phase	(7$\pm$6)$^\circ$	1°	-(9$\pm$15)$^\circ$	0°	120$\pm$50°	150°

Minimization methods

1. **The two body final states $\pi N \rightarrow \pi N$, $\pi\pi \rightarrow \pi\pi$, $\gamma p \rightarrow \pi N$, $p\bar{p}(at\,rest) \rightarrow 3\pi$:**
   χ^2 method. For n measured bins we minimize

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

2. **Reactions with three or more final states are analyzed with logarithm likelihood method. The minimization function:**

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

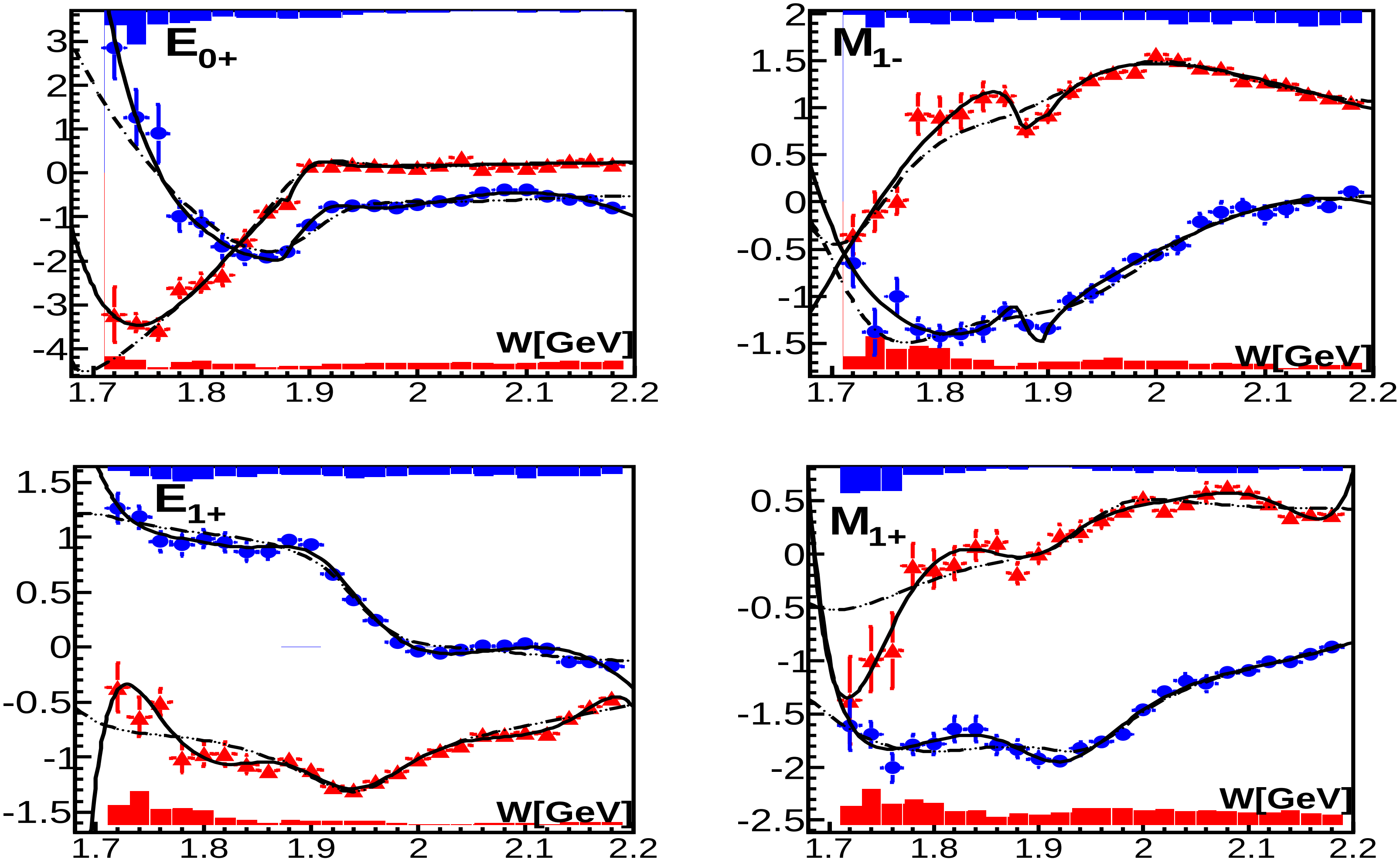
This method allows us to take into account all correlations in many dimensional phase space.

Recently included data

DATA	2011-2016	added in 2016-2018
$\gamma n \to \Lambda K, \Sigma^- K$		$\frac{d\sigma}{d\Omega}$ **(CLAS), E (CLAS)**
$\gamma n \to \pi^- p$	$\frac{d\sigma}{d\Omega}, \Sigma, P$	E **(CLAS)**
$\gamma n \to \eta n$	$\frac{d\sigma}{d\Omega}, \Sigma$	$\frac{d\sigma}{d\Omega}$ **(MAMI)** $\frac{d\sigma}{d\Omega}(h = \frac{1}{2})$ **(CB-ELSA)**
$\gamma p \to \eta p$	$\frac{d\sigma}{d\Omega}, \Sigma(GRAAL)$	$\frac{d\sigma}{d\Omega}, F, T$ **(MAMI)** $T, P, H, G,$**(CB-ELSA)** E, Σ **(CB-ELSA,CLAS)**
$\gamma p \to \eta' p$ $\gamma p \to K^+ \Lambda$ $\gamma p \to K^+ \Sigma^0$	 $\frac{d\sigma}{d\Omega}, \Sigma, P, T, C_x, C_z, O_{x'}, O_{z'}$ $\frac{d\sigma}{d\Omega}, \Sigma, P, C_x, C_z$	$\frac{d\sigma}{d\Omega}, \Sigma$ Σ, P, T, O_x, O_z **(CLAS)** Σ, P, T, O_x, O_z **(CLAS)**
$\pi^- p \to \pi^+ \pi^- n$ $\pi^- p \to \pi^- \pi^0 p$		$d\sigma/d\Omega$ **(HADES)** $d\sigma/d\Omega$ **(HADES)**
$\gamma p \to \pi^0 \pi^0 p$ $\gamma p \to \pi^+ \pi^- p$	$d\sigma/d\Omega, \Sigma, E, I_c, I_s$	T, P, H, F, P_x, P_y **(CB-ELSA)** $d\sigma/d\Omega, I_c, I_s$ **(CLAS)**
$\gamma p \to \omega p$	$d\sigma/d\Omega, \Sigma, \rho^k_{ij}, E, G$ **(CB-ELSA)**	Σ **(CLAS)** **P,T,F,H (CLAS)**
$\gamma p \to K^* \Lambda$		$d\sigma/d\Omega$**,** ρ_{ij}

Energy independent analysis of the $\gamma p \to K\Lambda$ reaction

Bonn-Gatchina-Tusla-Zagreb analysis

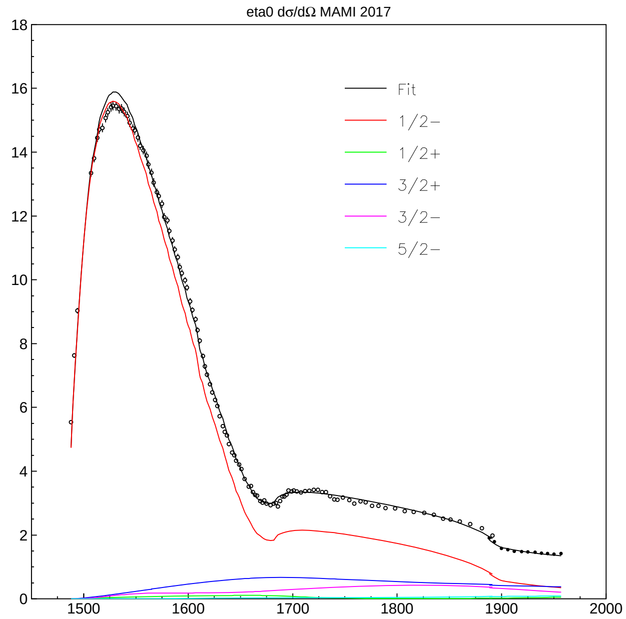


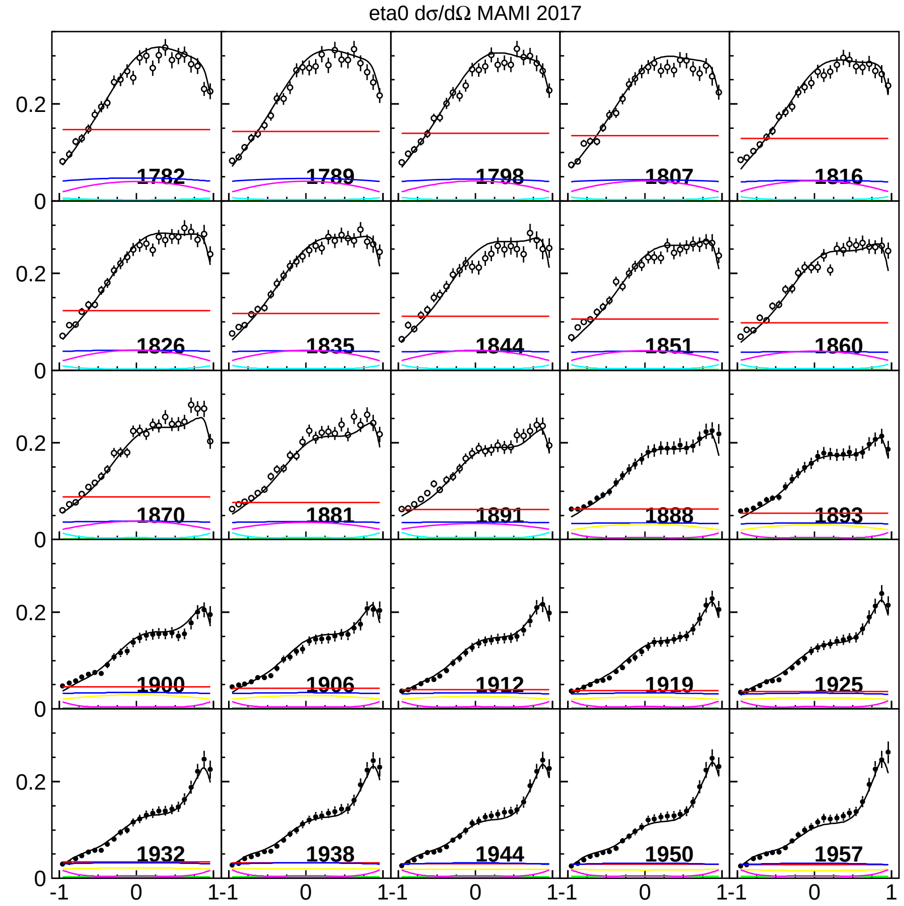
The resonance parameters from the Bonn-Gatchina solution and from the analysis of the energy-independent data

	$J^P = 1/2^-$		$J^P = 1/2^+$		$J^P = 3/2^+$	
	BnGa	**L+P**	**BnGa**	**L+P**	**BnGa**	**L+P**
M$_1$	1658 ± 10	1660 ± 5	1690 ± 15	1697 ± 23	-	-
Γ_1	102 ± 8	59 ± 16	155 ± 25	84 ± 34	-	-
$\|Res\|$	0.26 ± 0.10	0.10 ± 0.10	0.16 ± 0.05	$0.12^{+0.24}_{-0.12}$	-	-
Θ_1	$(110 \pm 20)^0$	$(95 \pm 33)^0$	$-(160 \pm 25)^0$	$-(119 \pm 83)^0$	-	-
M$_2$	1895 ± 15	1906 ± 17	1860 ± 40	1875 ± 11	1945 ± 35	1912 ± 30
Γ_2	132 ± 30	100 ± 10	230 ± 50	33 ± 9	235^{+70}_{-30}	166 ± 30
$\|Res\|$	0.09 ± 0.03	0.06 ± 0.02	0.05 ± 0.02	0.30 ± 0.10	0.03 ± 0.02	$-$
Θ_2	$(8 \pm 30)^0$	$(87 \pm 27)^0$	$(27 \pm 30)^0$	$(82 \pm 9)^0$	$(90 \pm 40)^0$	$-$

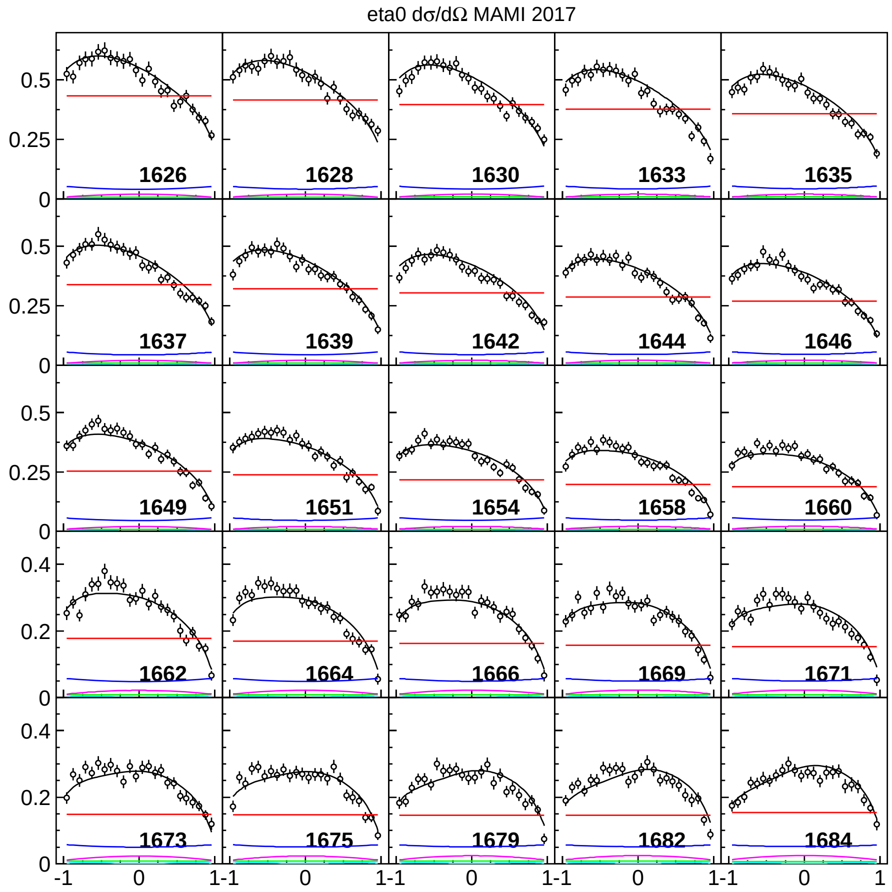
The analysis of the new $\gamma p \to \eta p$ data.

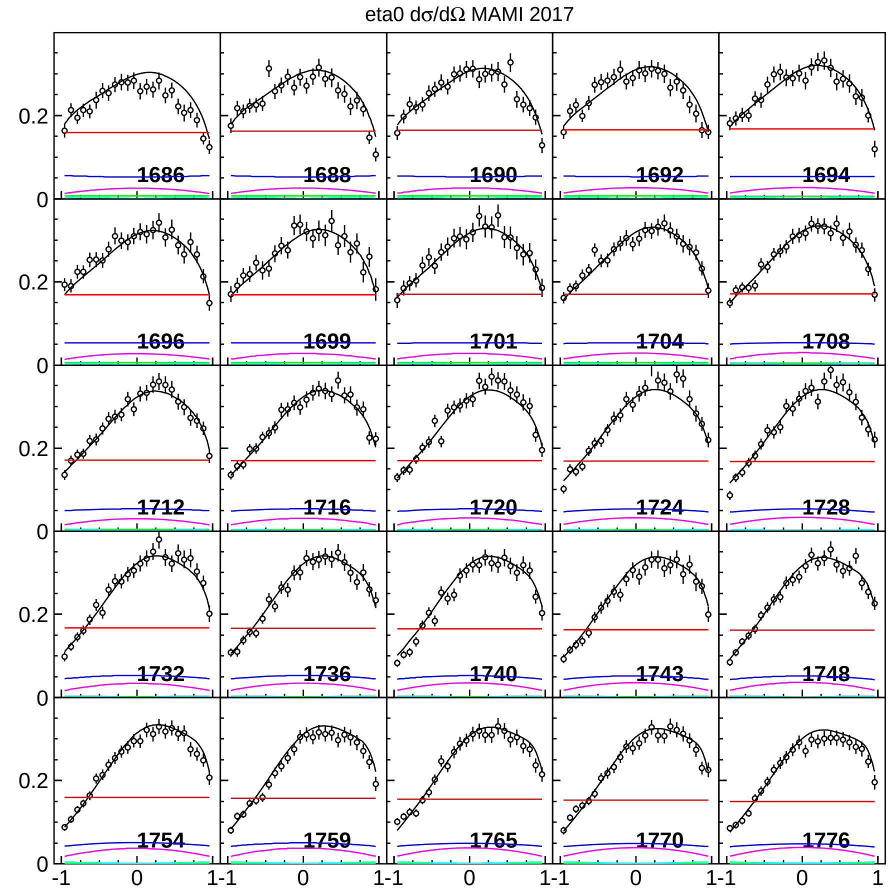
New MAMI data: a strong cusp effect from the $\eta' p$ channel



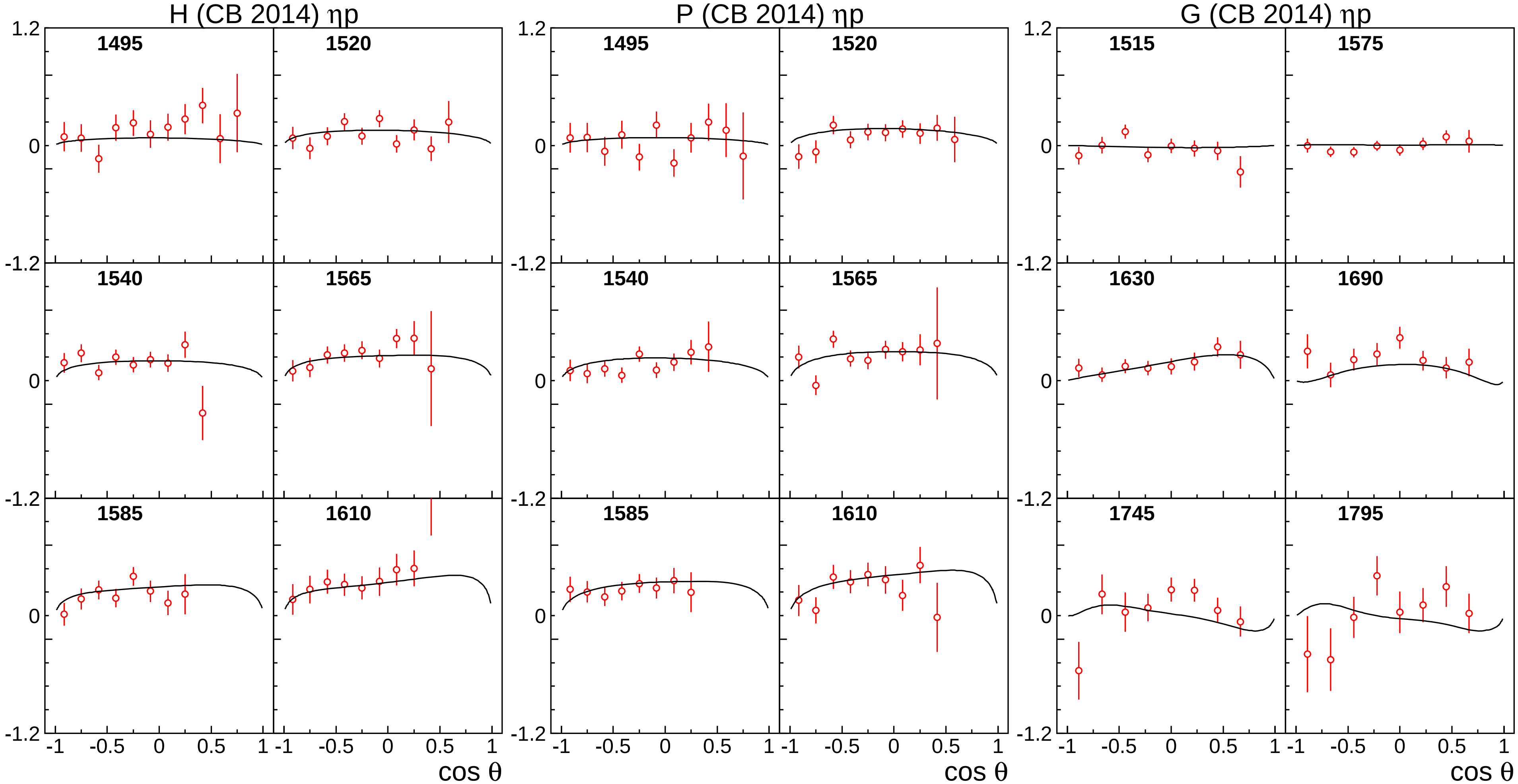


The analysis of the new $\gamma p \to \eta p$ data. $d\sigma/d\Omega$ (MAMI)

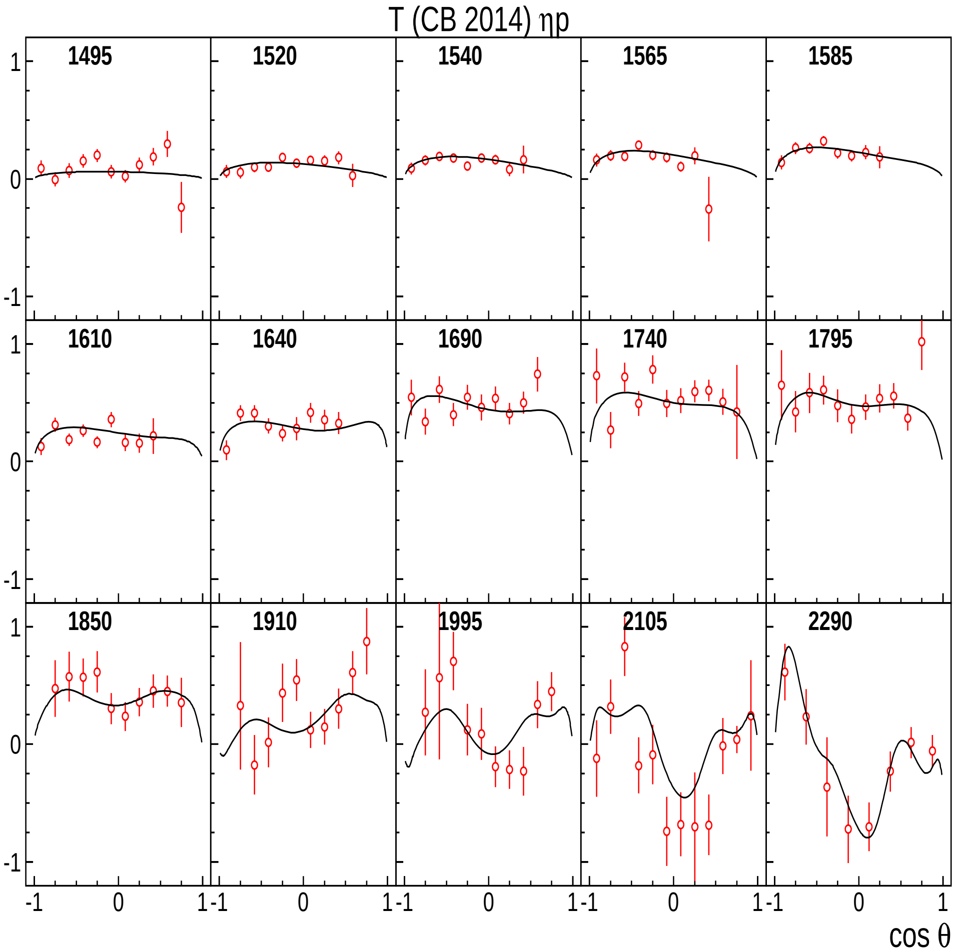


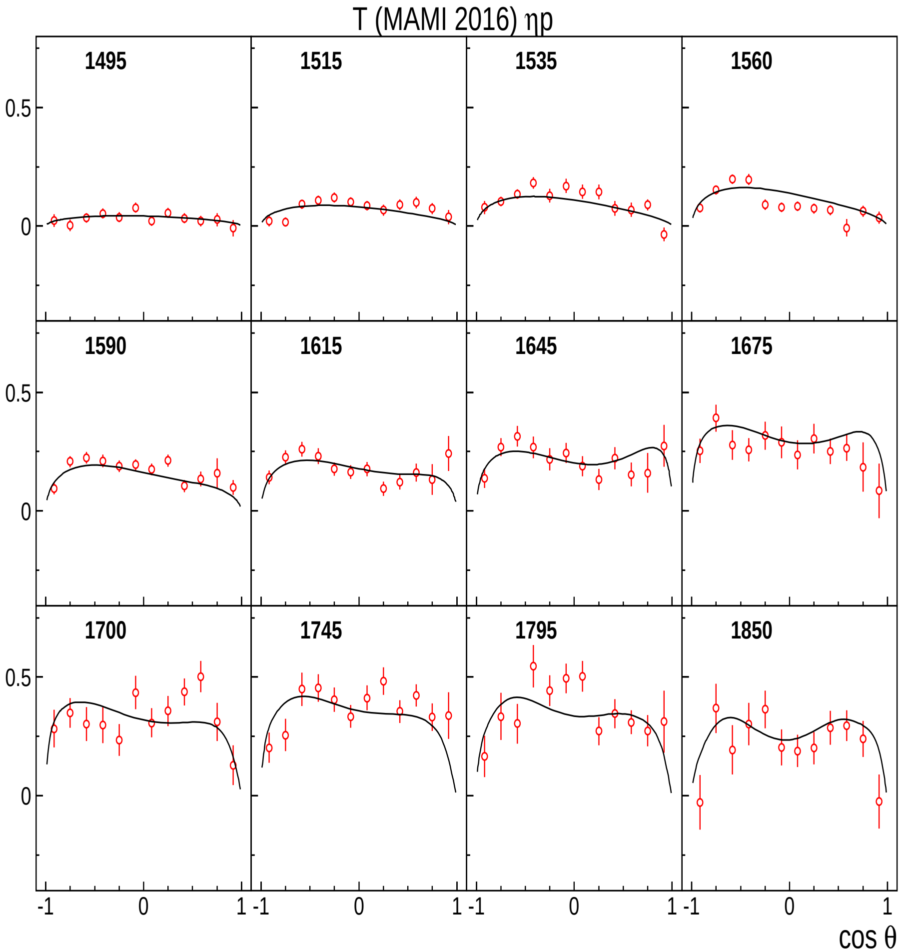


The analysis of the new $\gamma p \to \eta p$ data. H, P, T (CB-ELSA)

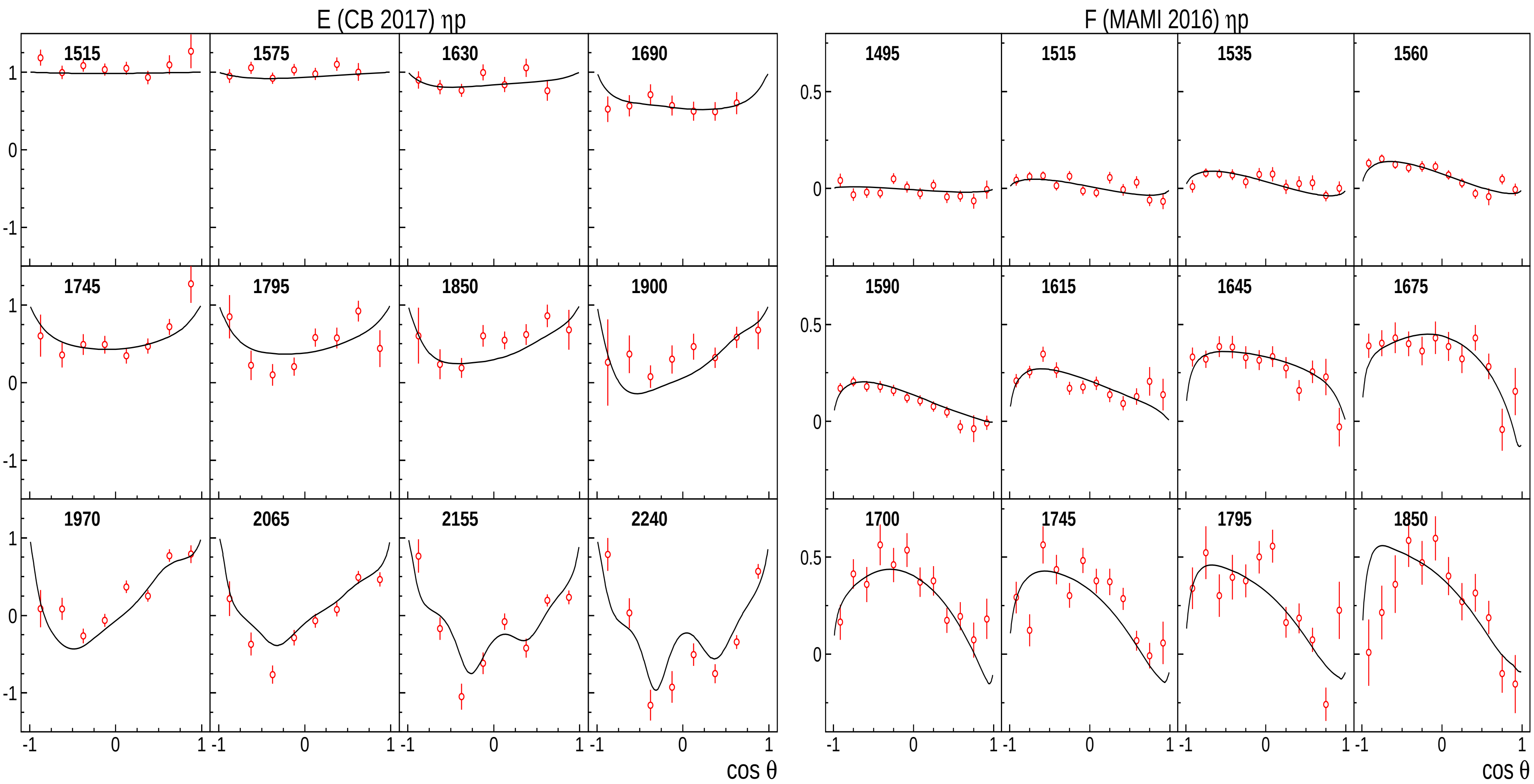


The analysis of the new $\gamma p \to \eta p$ data. T (CB-ELSA), (MAMI scale 1.4)

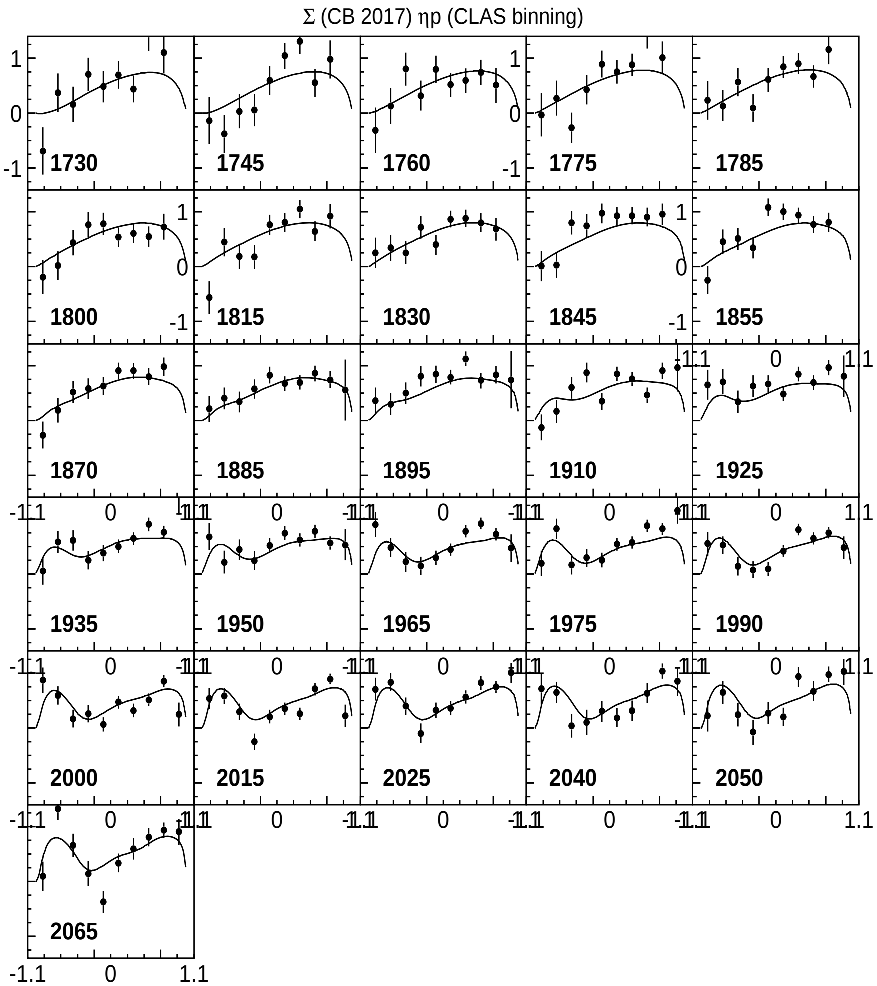


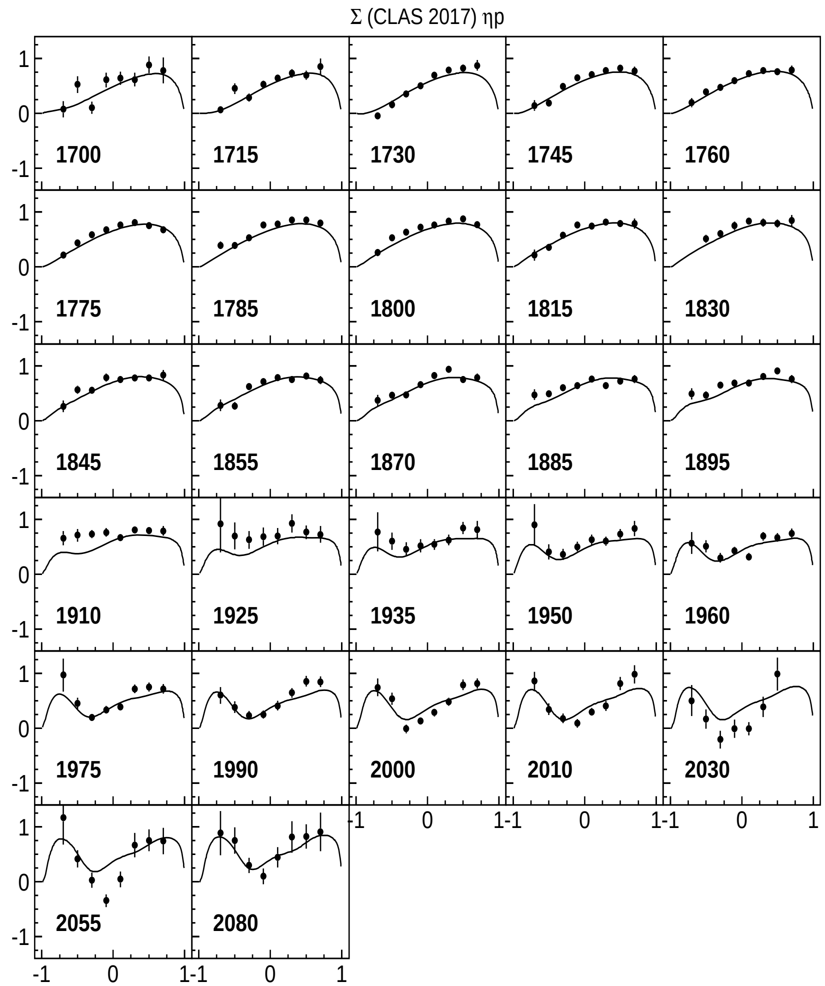


The analysis of the new $\gamma p \to \eta p$ data. E (CB-ELSA), F (MAMI) (scale 1.4)



The analysis of the new $\gamma p \to \eta p$ data. Σ (CB-ELSA and CLAS)

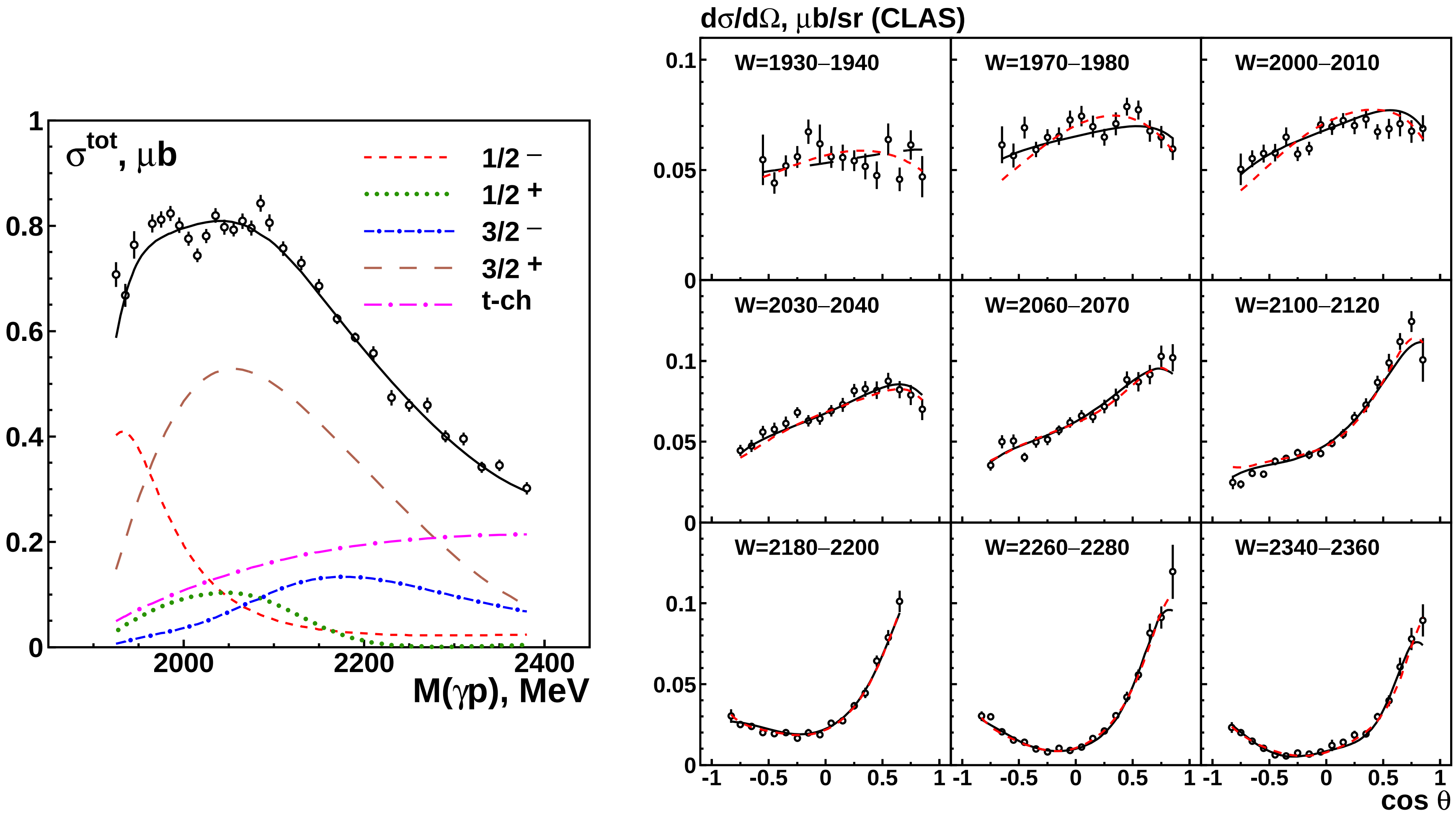




Resonance branchings to the ηN channel

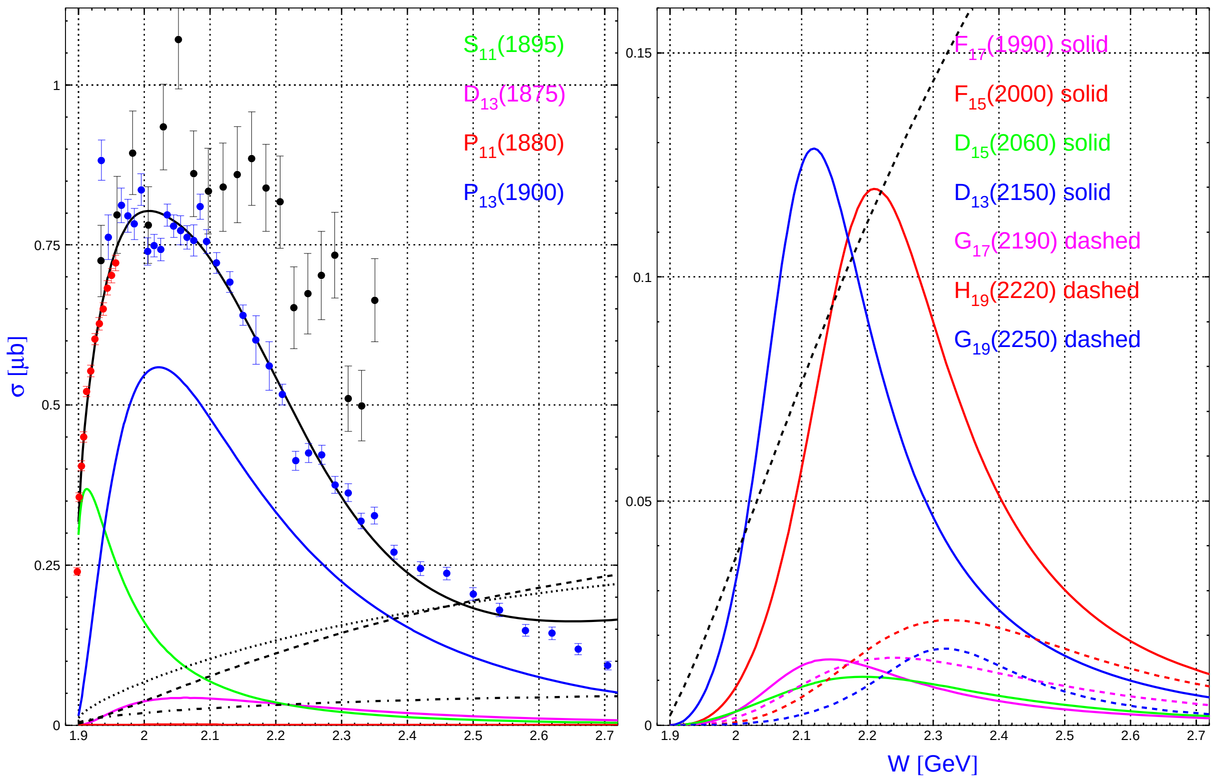
Res.	BR	Res.	BR	Res.	BR
$N(1535)$ $1/2^-$	**0.42$\pm$0.04** **0.42$\pm$0.10**	$N(1650)$ $1/2^-$	**0.32$\pm$0.04** **0.05 - 0.15**	$N(1895)$ $1/2^-$	**0.10$\pm$0.05** **(0.21$\pm$0.06)**
$N(1710)$ $1/2^+$	**0.25$\pm$0.09** **0.10 - 0.30**	$N(1880)$ $1/2^+$	**0.19$\pm$0.07** $(0.25^{+0.30}_{-0.20})$	$N(2100)$ $1/2^+$	**0.25$\pm$0.10** **0.61$\pm$0.61**
$N(1520)$ $3/2^-$	< 0.001 **0.0023$\pm$0.0004**	$N(1700)$ $3/2^-$	**0.01$\pm$0.01** **0$\pm$0.01**	$N(1875)$ $3/2^-$	**0.02$\pm$0.01** **0.012$\pm$0.018**
$N(1720)$ $3/2^+$	**0.03$\pm$0.02** **0.021$\pm$0.014**	$N(1900)$ $3/2^+$	**0.03$\pm$0.01** **$\sim$0.12**	$N(2120)$ $3/2^-$	**$\leq$0.01** **-**
$N(1675)$ $5/2^-$	**0.005$\pm$0.005** **0$\pm$0.007**	$N(2060)$ $5/2^-$	**0.04$\pm$0.01** **0.04$\pm$0.02**	$N(2190)$ $7/2^-$	**0.025$\pm$0.005** **0$\pm$0.01**
$N(1680)$ $5/2^+$	**0.002$\pm$0.001** **0$\pm$0.007**	$N(2000)$ $5/2^+$	**0.002$\pm$0.001** **0.002$\pm$0.002**	$N(1990)$ $7/2^+$	**$\leq$0.01** **-**

The analysis of the $\gamma p \to \eta' p$ data.



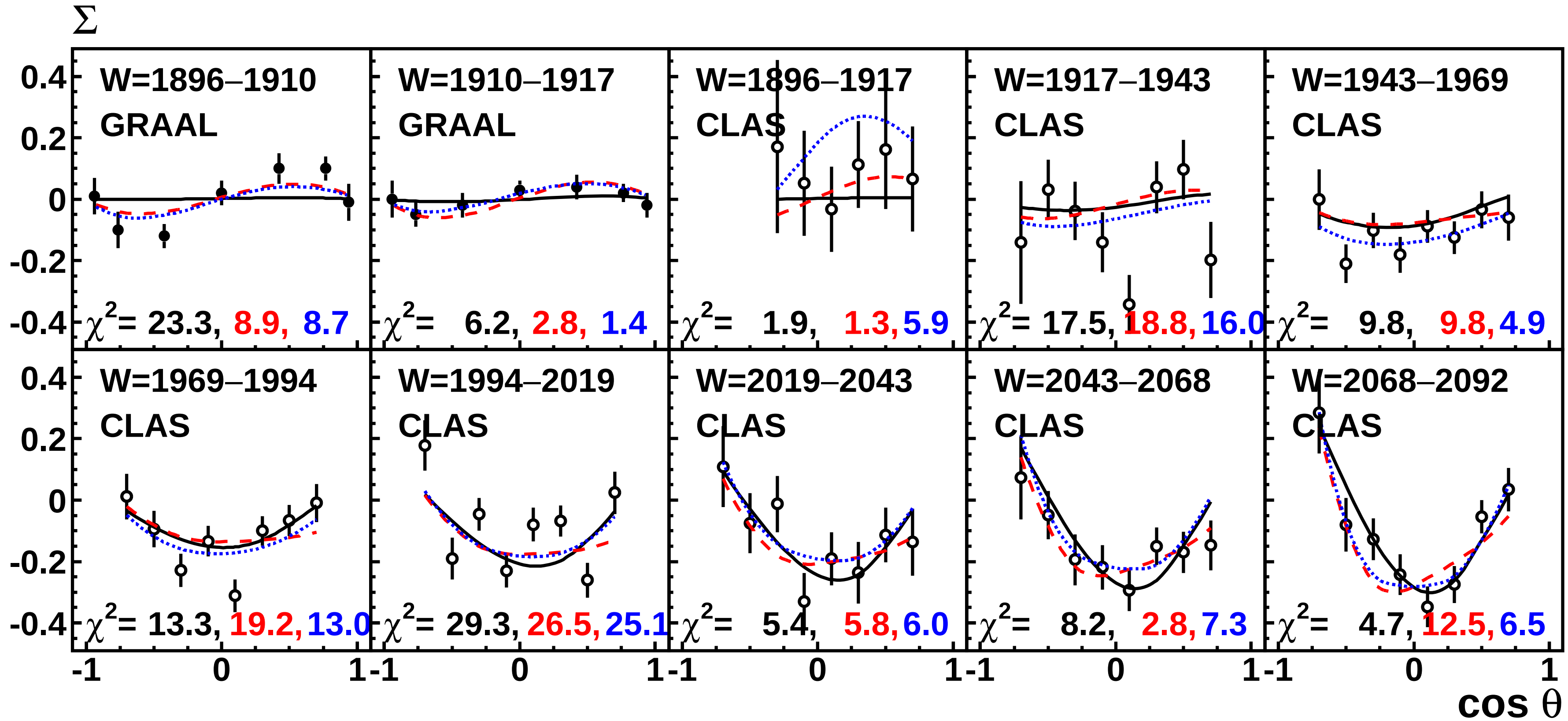
Strong contribution from the $S_{11}(1895)$, $P_{13}(1900)$, $P_{11}(2100)$ and $D_{13}(2120)$ states.

MAID analysis of the new $\gamma p \to \eta' p$ data



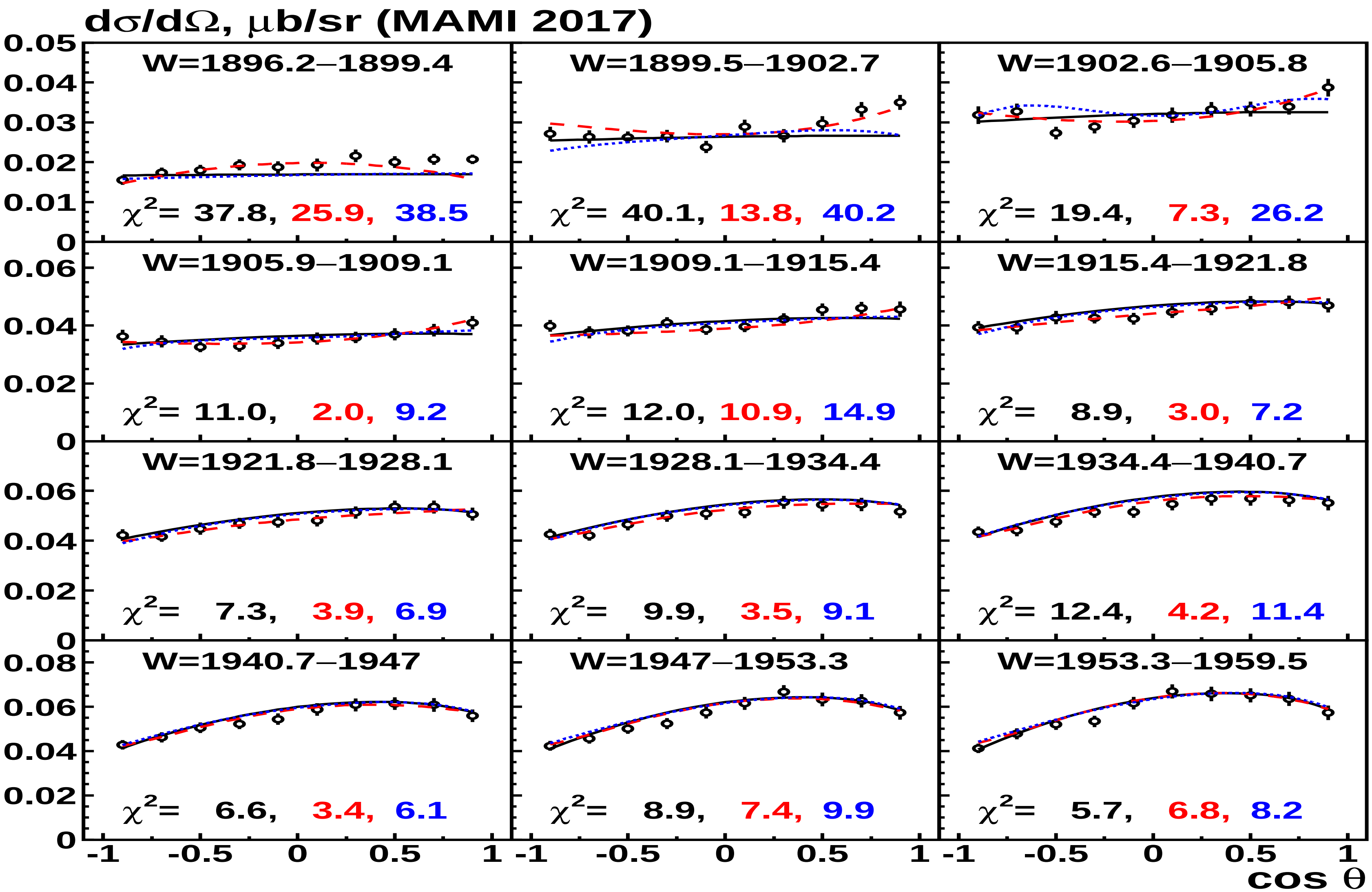
	Bonn-Gatchina	MAID
Mass (MeV)	1895 ± 15	1896 ± 1
Width (MeV)	90^{+30}_{-15}	93 ± 13

The beam asymmetry on $\gamma p \to \eta' p$



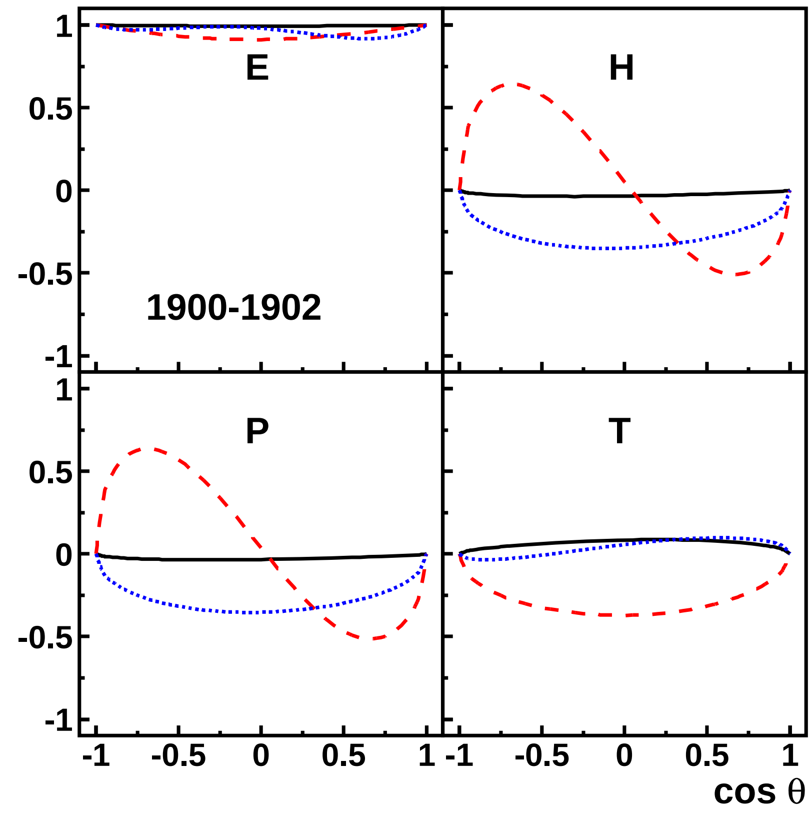
No narrow states $D_{15}(1903)$ $D_{13}(1900)$

The differential cross section from MAMI on $\gamma p \to \eta' p$

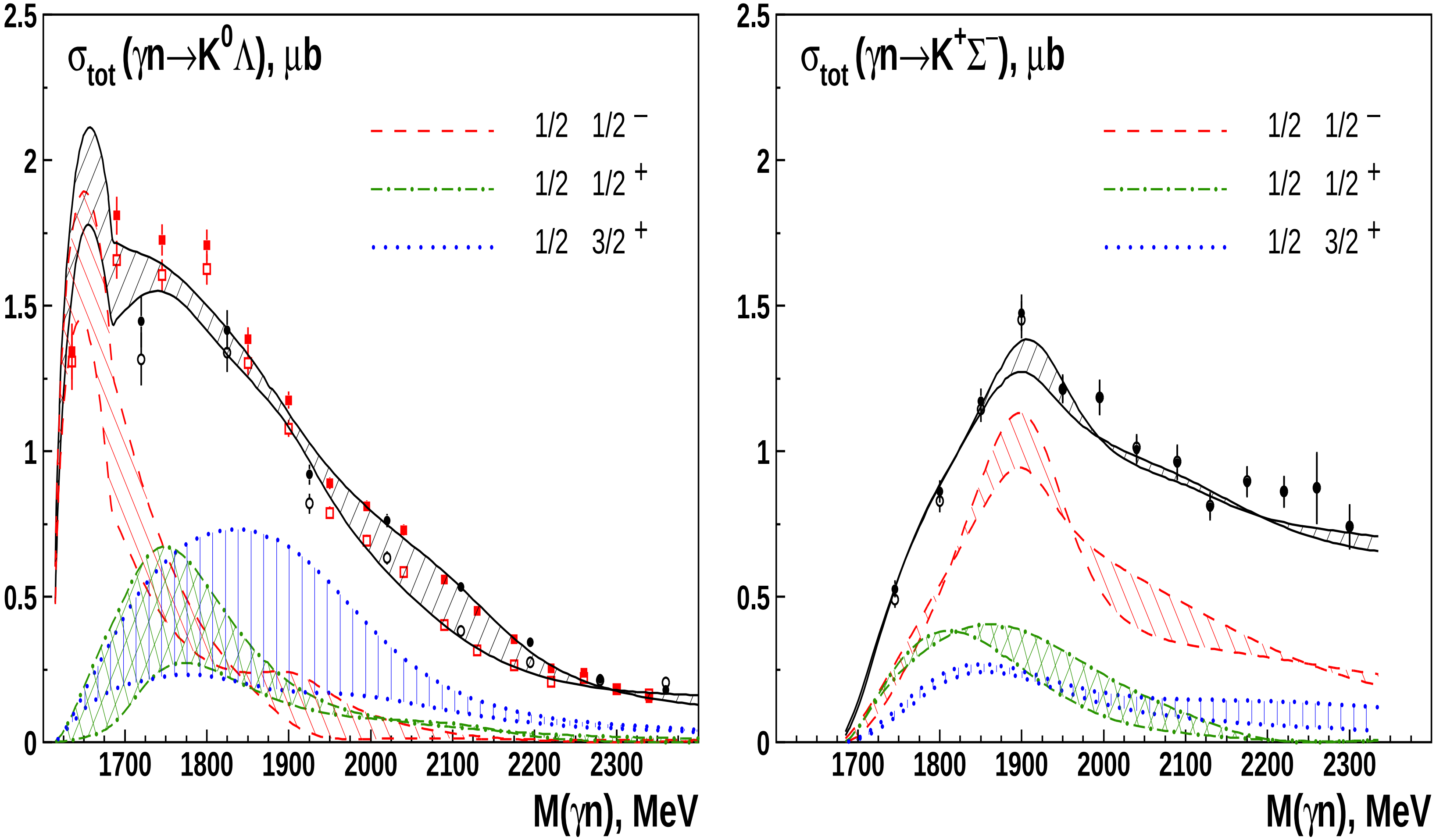


The description of the data below W=1917 MeV and the prediction of other observables

Resonance	N	Basic	D_{13}	D_{15}
M (MeV)			1900	1903
Γ (MeV)			1	1
χ^2 (Σ)	13	29.5	11.7	10.1
χ^2 $(\frac{d\sigma}{d\Omega})$	50	120.3	59.9	129.0

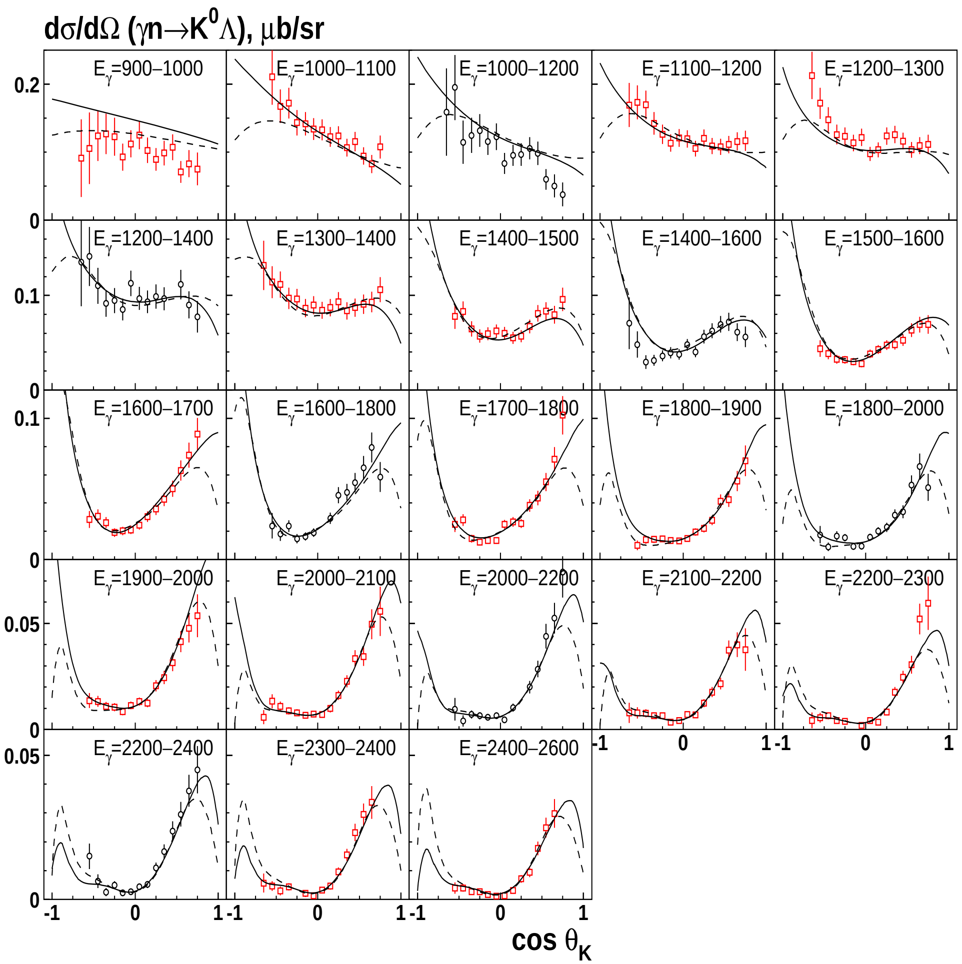


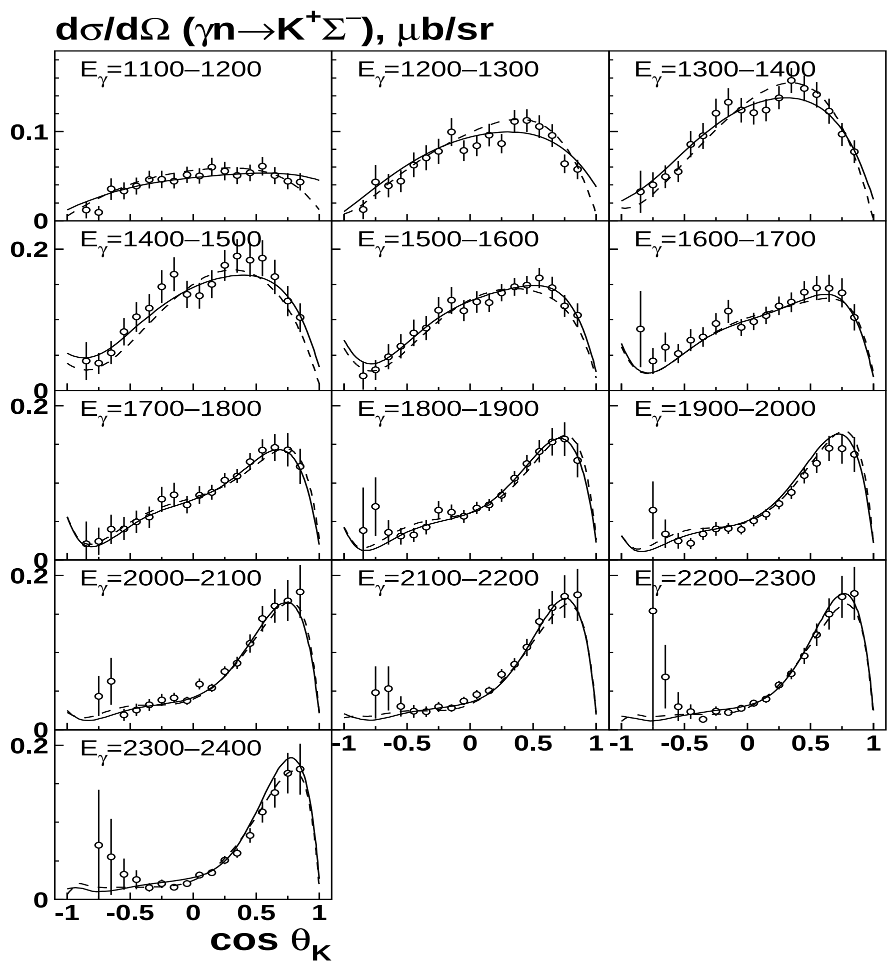
The analysis of the $\gamma n \to K\Lambda$ data and the $\gamma n \to K^+\Sigma^-$ data (Practically no free parameters)



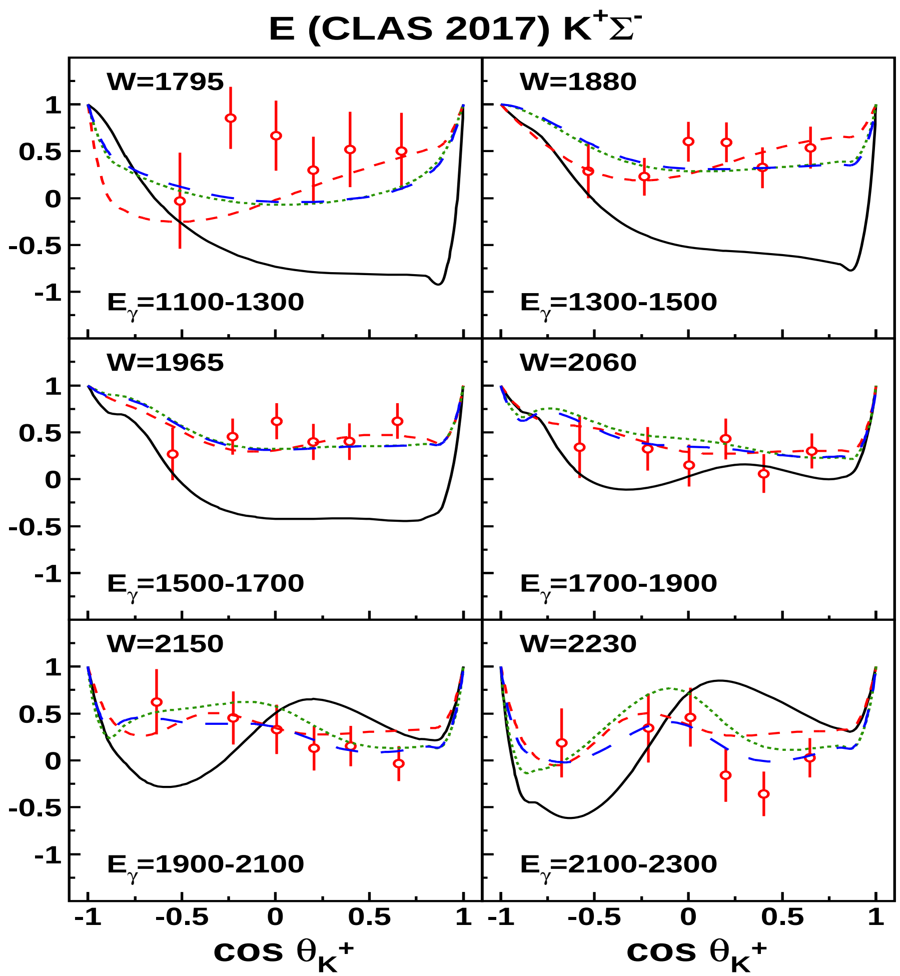
Clear contributions from the $S_{11}(1895)$ and $P_{13}(1900)$ states.

Description of the differential cross section





New CLAS data on the helicity asymmetry $\gamma n \to K^+\Sigma^-$



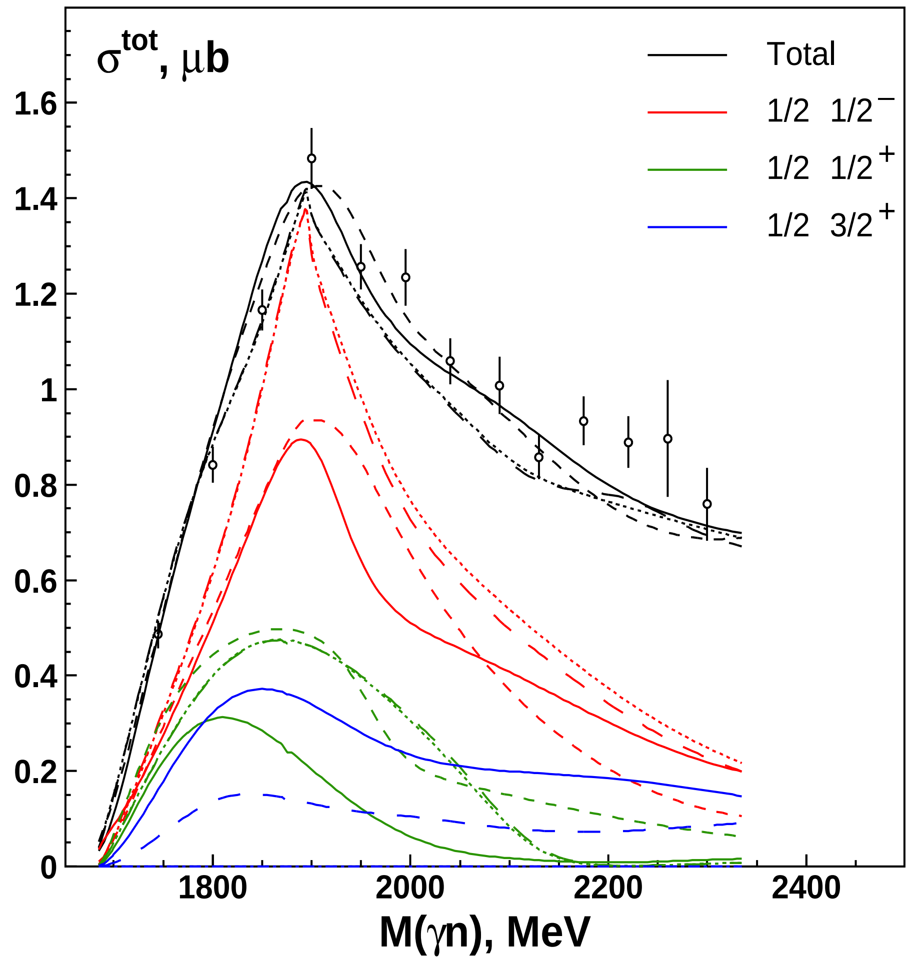
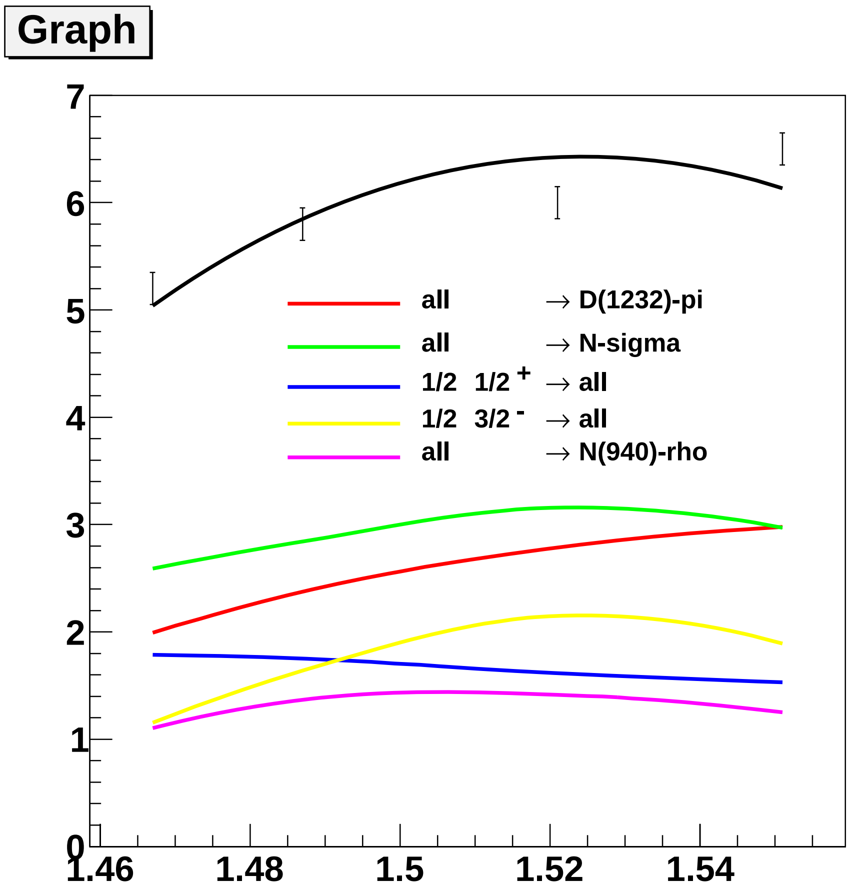
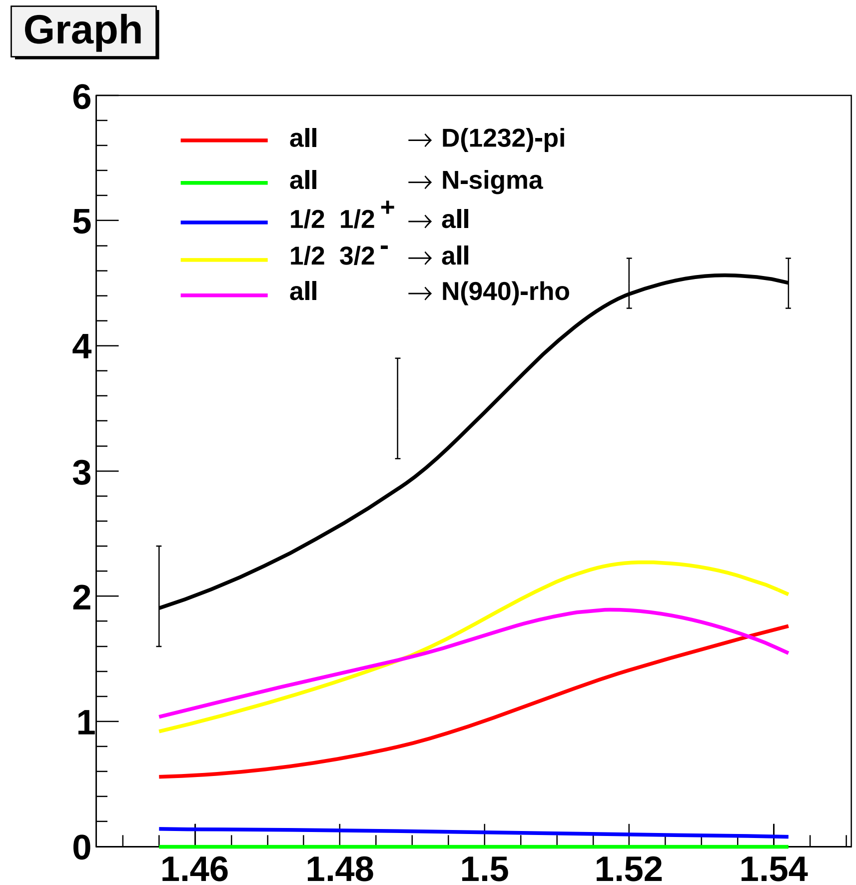


Table 1: The γN couplings (GeV$^{-1/2}10^{-3}$) at the pole position

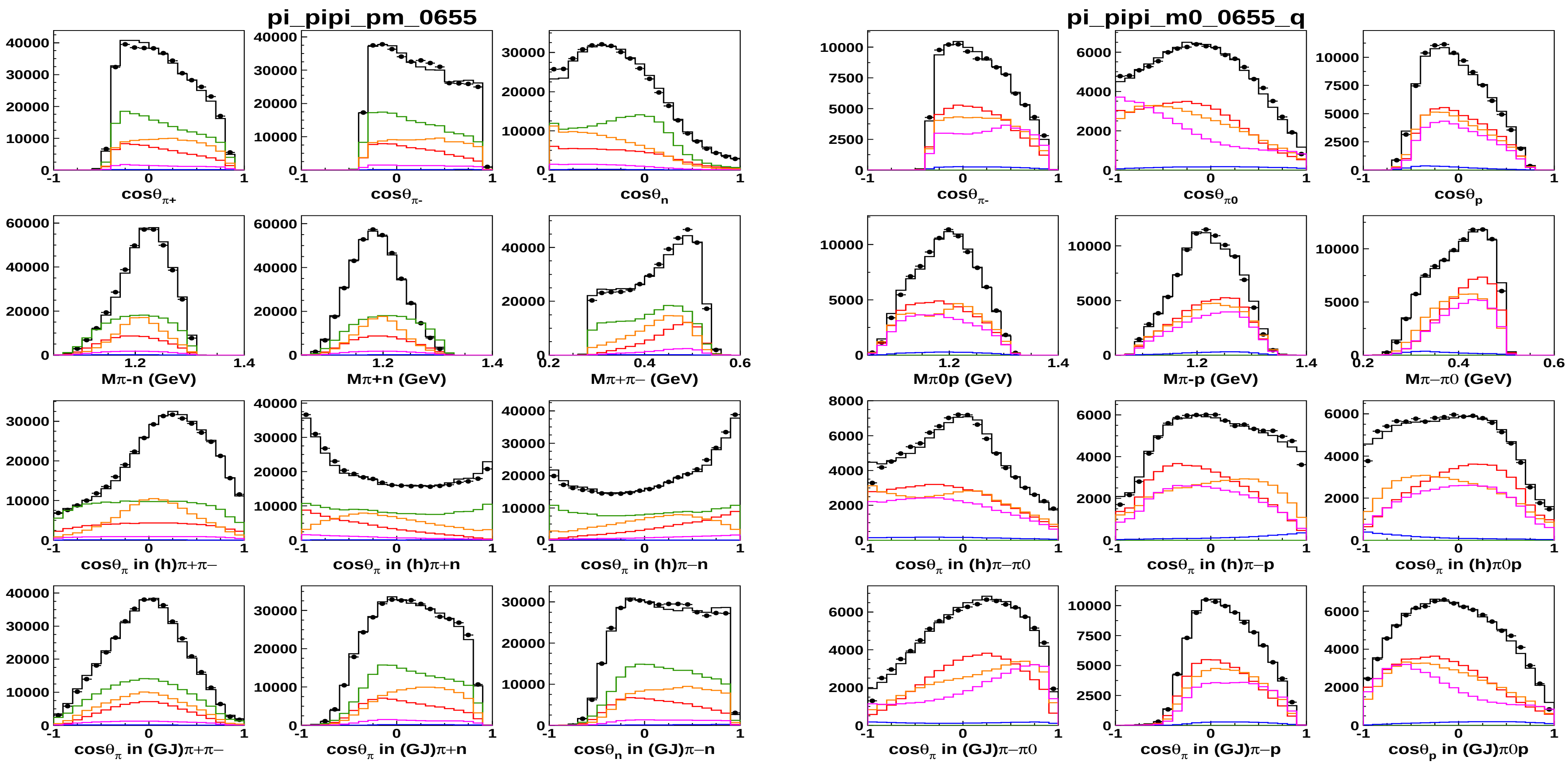
	$A_{1/2}$	Phase	$A_{3/2}$	Phase
$N(1535)1/2^-$	-88$\pm$4	5$\pm$4°		
$N(1650)1/2^-$	16$\pm$4	-28$\pm$10°		
$N(1895)1/2^-$	-15$\pm$10	60$\pm$25°		
$N(1440)1/2^+$	41$\pm$5	23$\pm$10°		
$N(1710)1/2^+$	29$\pm$7	80$\pm$20°		
$N(1880)1/2^+$	72$\pm$24	-30$\pm$30°		
$N(2100)1/2^+$	29$\pm$9	35$\pm$20°		
$N(1520)3/2^-$	-45$\pm$5	-5$\pm$4°	-119$\pm$5	5$\pm$4°
$N(1875)3/2^-$	4$\pm$3	-85$\pm$35°	-6$\pm$4	-85$\pm$45°
$N(2120)3/2^-$	80$\pm$30	15$\pm$25°	-33$\pm$20	-60$\pm$35°
$N(1720)3/2^+$	$-(25^{+40}_{-15})$	-75$\pm$35°	100$\pm$35	-80$\pm$35°
$N(1900)3/2^+$	-98$\pm$20	-13$\pm$20°	74$\pm$15	5$\pm$15°
$N(1975)3/2^+$	-26$\pm$13	8$\pm$25°	-77$\pm$15	5$\pm$20°
$N(1675)5/2^-$	-53$\pm$4	-3$\pm$5°	-73$\pm$5	-12$\pm$5°
$N(2060)5/2^-$	52$\pm$25	-5$\pm$20°	12$\pm$7	-40$\pm$35°
$N(1680)5/2^+$	32$\pm$3	-7$\pm$5°	-63$\pm$4	-10$\pm$5°
$N(2000)5/2^+$	19$\pm$10	-80$\pm$40°	11$\pm$5	82$\pm$30°
$N(1990)7/2^+$	-32$\pm$15	5$\pm$20°	-70$\pm$25	0$\pm$20°
$N(2190)7/2^-$	30$\pm$7	5$\pm$15°	-23$\pm$8	13$\pm$20°

The total cross section from the HADES data $\pi^- p \to \pi^+ \pi^- n$ and $\pi^- p \to \pi^- \pi^0 p$ data (W.Przigoda)





HADES data on $\pi^- p \to \pi^+ \pi^- n$ and $\pi^- \pi^0 p$ at P=656 MeV/c (W.Przigoda) (Preliminary)



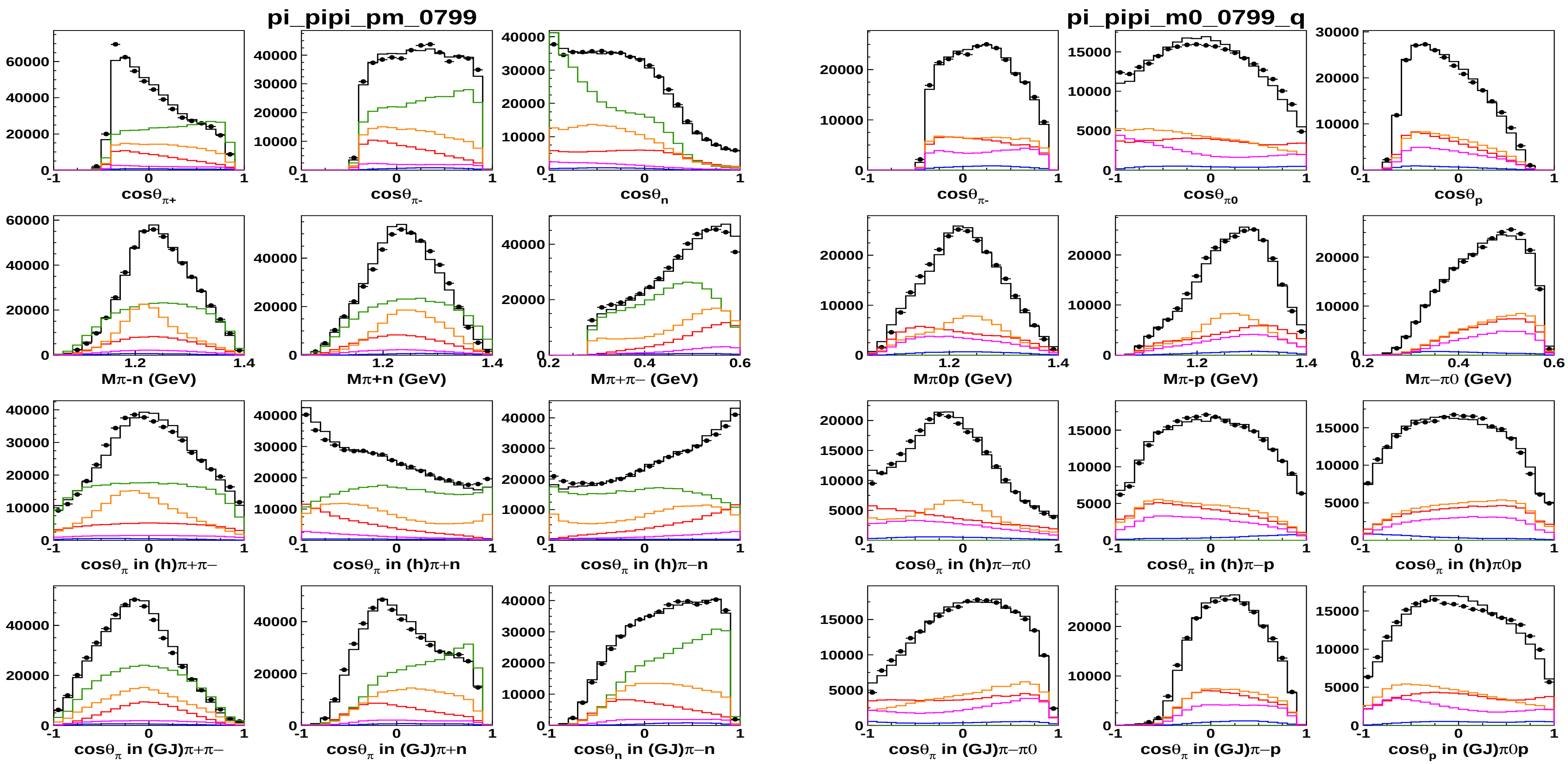
— $\Delta(1232)\pi$

— $\rho N(940)$

— $N\sigma$

— $\frac{1}{2}\frac{3}{2}^-$

HADES data on $\pi^- p \to \pi^+\pi^- n$ and $\pi^-\pi^0 p$ at P=656 MeV/c (W.Przigoda) (Preliminary)



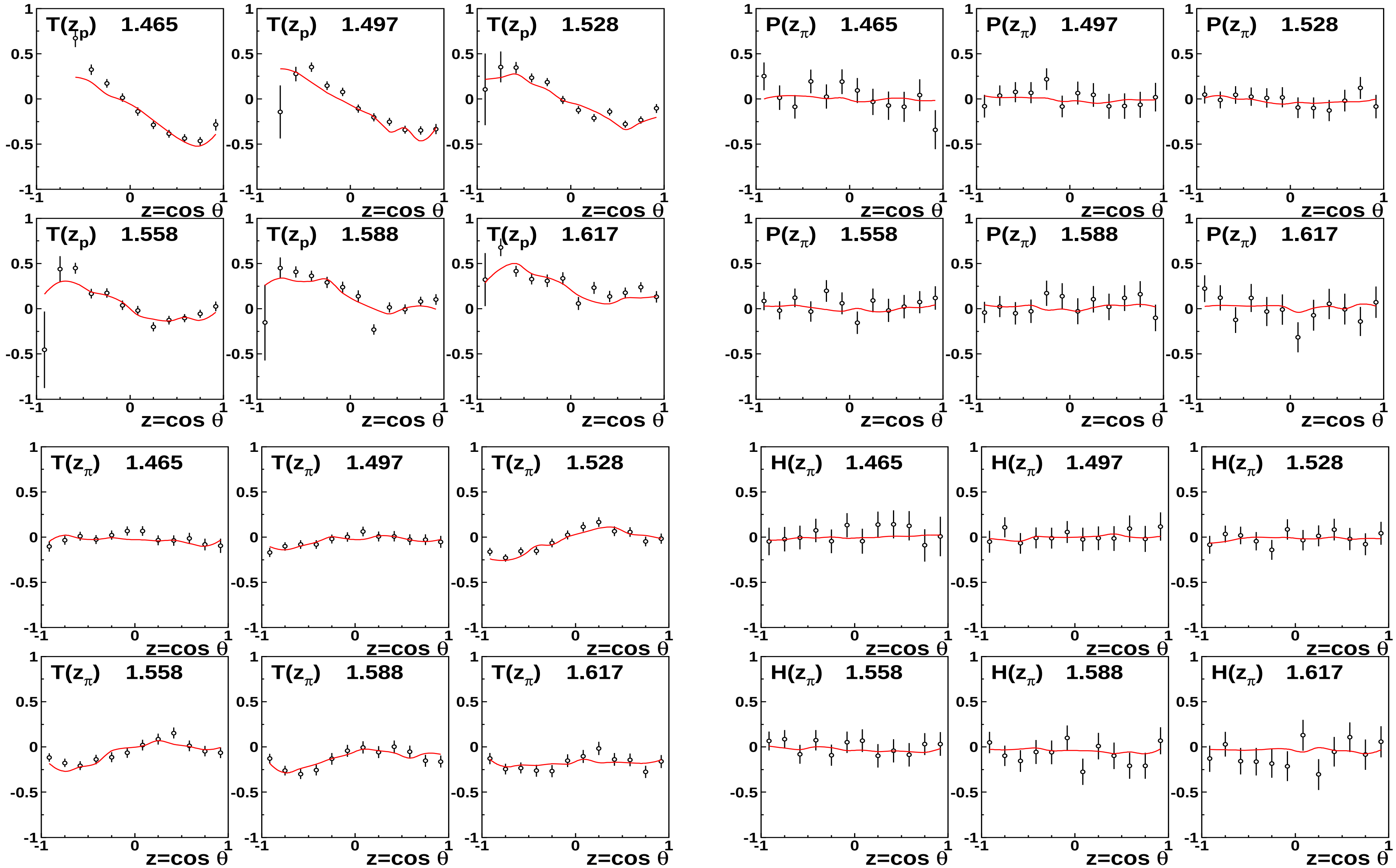
— $\Delta(1232)\pi$

— $N\sigma$

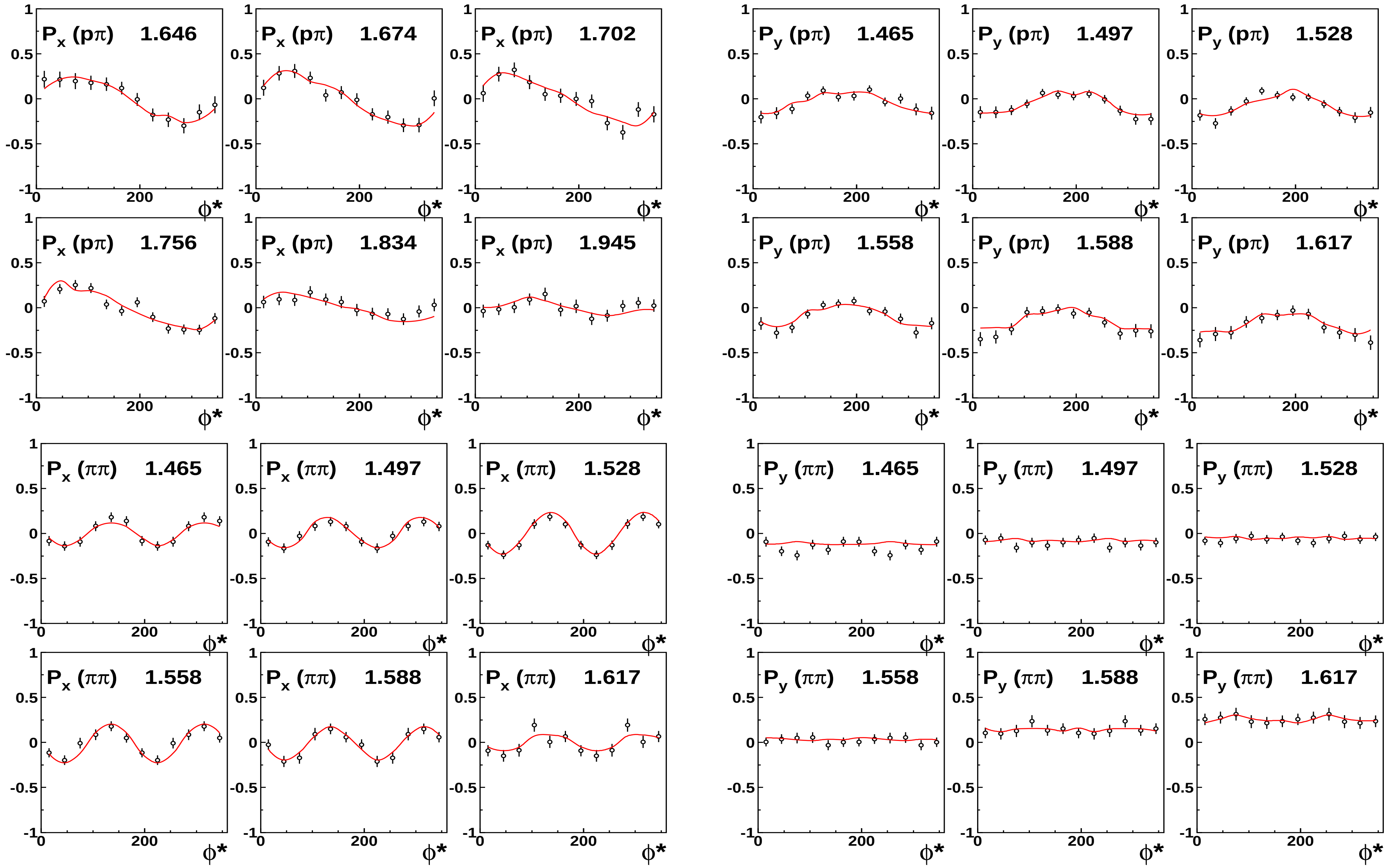
— $\rho N(940)$

— $\frac{1}{2}\frac{3}{2}^-$

Fit of the H, P, T ($\gamma p \to \pi^0 \pi^0 p$) from CB-ELSA (T. Seifen, Preliminary)



Fit of the P_x, P_y, P_x^S, P_y^s observables ($\gamma p \to \pi^0\pi^0 p$) from CB-ELSA (T. Seifen, Preliminary)



$N\rho(770)$ **branching ratio (Preliminary)**

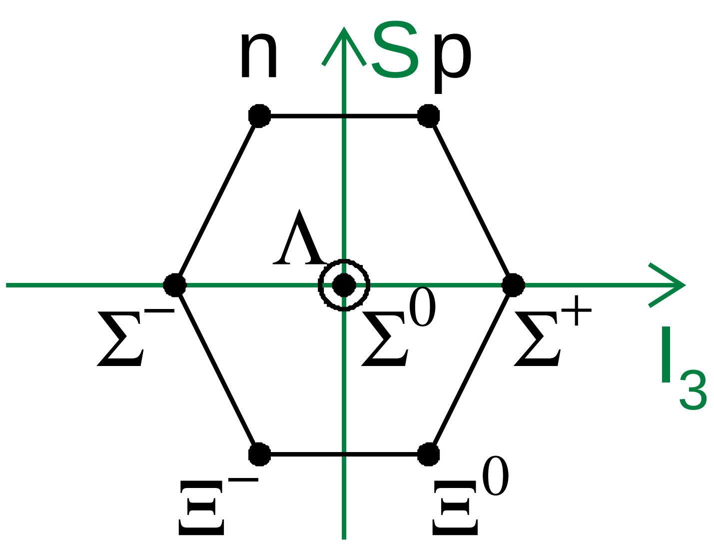
$N(1440)1/2^+$	$<$**1%**	$N(1520)3/2^-$	**12$\pm$2%**	$N(1535)1/2^-$	**2$\pm$1%**
$N(1650)1/2^-$	**13$\pm$2%**	$N(1675)5/2^-$	$<$**1%**	$N(1685)5/2^+$	**12$\pm$2%**
$N(1710)1/2^+$	**9$\pm$3%**	$N(1720)3/2^+$	**60$\pm$18%**	$N(1880)1/2^+$	**30$\pm$8%**
$N(1895)1/2^-$	**55$\pm$10%**	$N(1875)3/2^-$	**60$\pm$14%**	$N(2060)5/2^-$	**12$\pm$8%**
$N(2120)3/2^-$	**50$\pm$17%**	$N(2000)5/2^+$	**20$\pm$12%**	$N(1900)3/2^+$	**25$\pm$10%**
$\Delta(1600)3/2^+$	**2$\pm$2%**	$\Delta(1620)1/2^-$	**40$\pm$5%**	$\Delta(1940)3/2^+$	**8$\pm$4%**
$\Delta(2200)3/2^+$	**20$\pm$8%**	$\Delta(1700)3/2^-$	**12$\pm$4%**	$\Delta(2100)3/2^-$	**11$\pm$5%**
$\Delta(1750)1/2^+$	**40$\pm$12%**	$\Delta(1900)1/2^-$	**30$\pm$8%**	$\Delta(1905)5/2^+$	**35$\pm$8%**

0.1 N^* and Δ spectrum

Resonance	Rating	$N_{\rm pp}$	Resonance	Rating	$N_{\rm pp}$	Resonance	Rating	$N_{\rm pp}$
$N(1440)1/2^+$	****	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
$\Delta(2000)5/2^+$	**		$\Delta(2150)1/2^-$	*		$\Delta(2200)7/2^-$	*	
$\Delta(2300)9/2^+$	**		$\Delta(2350)3/2^-$	*		$\Delta(2390)7/2^+$	*	
$\Delta(2420)11/2^+$	****		$\Delta(2400)9/2^-$	****		$\Delta(2750)13/2^-$	**	
$\Delta(2950)15/2^+$	**							

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

Octet



Decuplet

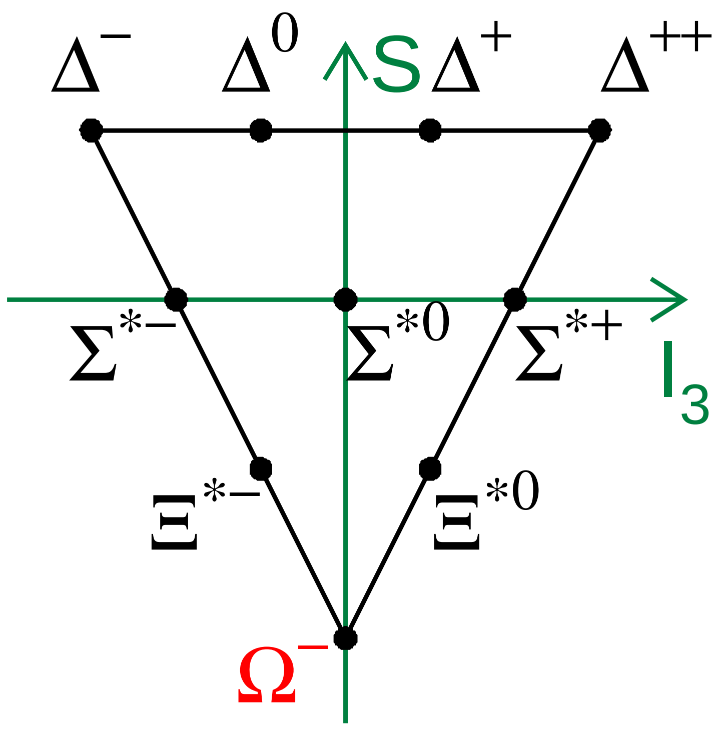


Table 2: Λ-hyperons used in the first fit of the data.

		J^P	**Status**	**Mass**	**Width**
singlet	$\Lambda(1405)$	$1/2^-$	****	$1405^{+1.3}_{-1.0}$	50.5 ± 2.0
$N(1535)$	$\Lambda(1670)$	$1/2^-$	****	$1660 - 1680$	$25 - 50$
$N(1650)$	$\Lambda(1800)$	$1/2^-$	***	$1720 - 1850$	$200 - 400$
singlet	$\Lambda(1520)$	$3/2^-$	****	1519.5 ± 1.0	15.6 ± 1.0
$N(1520)$	$\Lambda(1690)$	$3/2^-$	****	$1685 - 1695$	$50 - 70$
$N(1675)$	$\Lambda(1830)$	$5/2^-$	****	$1810 - 1830$	$60 - 110$
$N(2190)$	$\Lambda(2100)$	$7/2^-$	****	$2090 - 2110$	$100 - 250$
$N(1440)$	$\Lambda(1600)$	$1/2^+$	***	$1560 - 1700$	$50 - 250$
$N(1710)$	$\Lambda(1810)$	$1/2^+$	***	$1750 - 1850$	$50 - 250$
$N(1710)$	$\Lambda(1890)$	$3/2^+$	****	$1850 - 1910$	$60 - 200$
$N(1680)$	$\Lambda(1820)$	$5/2^+$	****	$1815 - 1825$	$70 - 90$
$N(2060)$	$\Lambda(2110)$	$5/2^+$	***	$2090 - 2140$	$150 - 250$

Table 3: Σ-Hyperons used in the first fit of the data.

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

Many Σ states are missing.

Kaon beam motivation

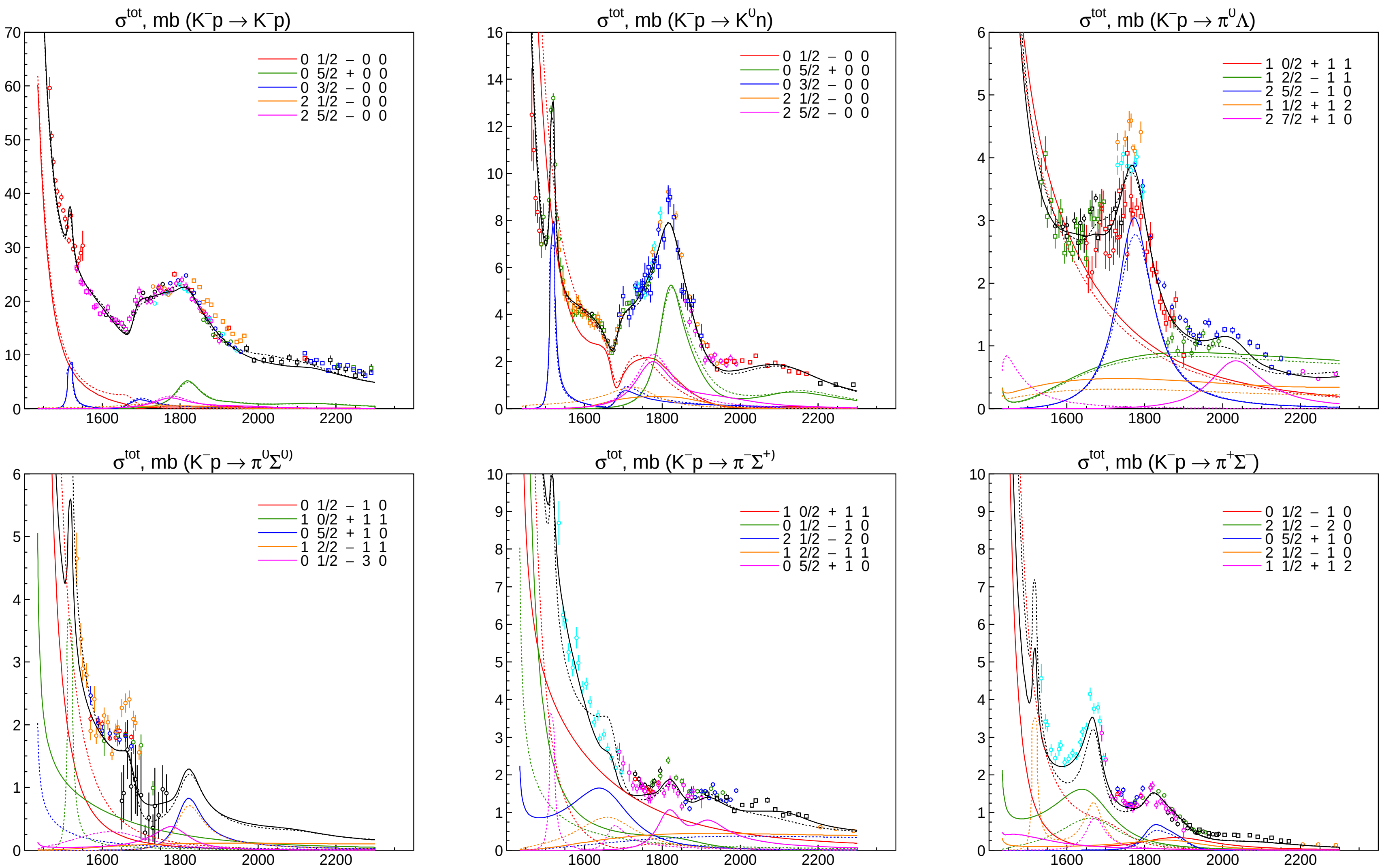
There is a hope to observe the baryon multiplets and therefore to confirm the states observed in the Nucleon and Delta sector.

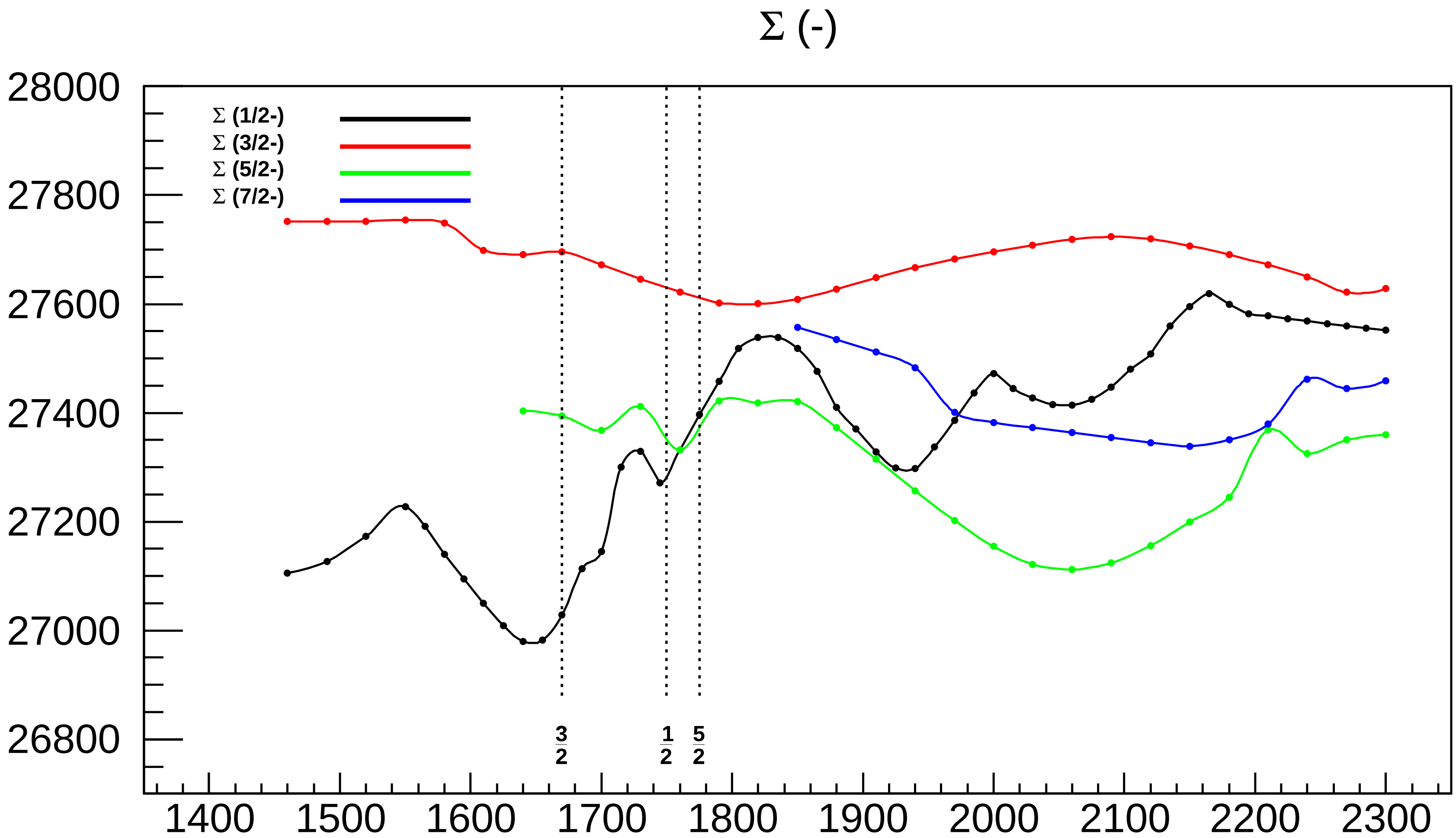
Table 4: List of reactions used in the partial wave analysis.

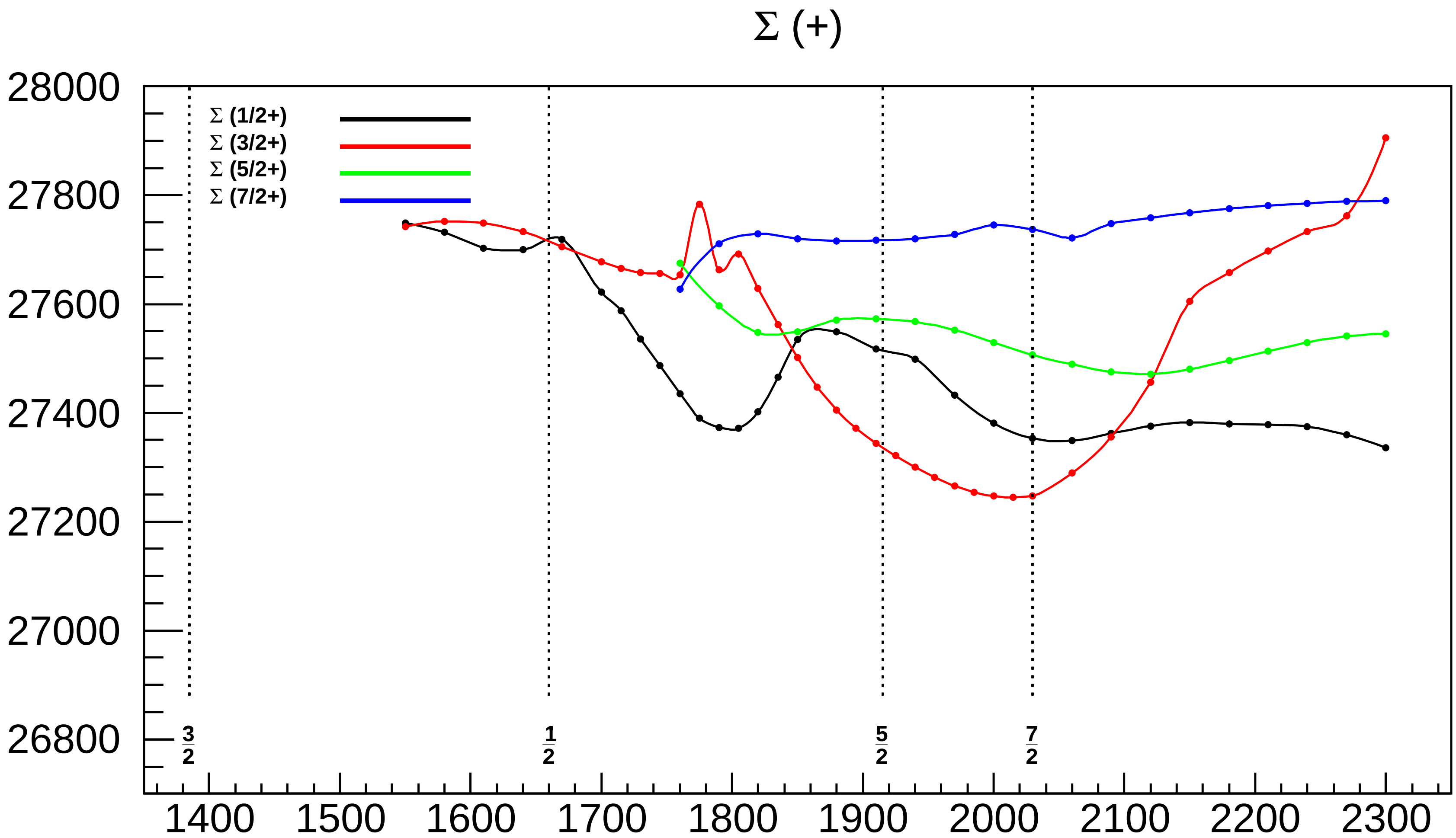
$K^- p \to K^0 n$	$K^- p \to K^- p$	$K^- p \to \omega\Lambda$
$K^- p \to \pi^0\Lambda$	$K^- p \to \eta\Lambda$	$K^- p \to \pi^+\Sigma^-$
$K^- p \to \pi^0\Sigma^0$	$K^- p \to \pi^-\Sigma^+$	$K^- p \to \pi^0\pi^0\Lambda$
$K^- p \to K^+\Xi^-$	$K^- p \to K^0\Xi^0$	$K^- p \to \pi^0\pi^0\Sigma^0$

W range is 1.57 – 1.68

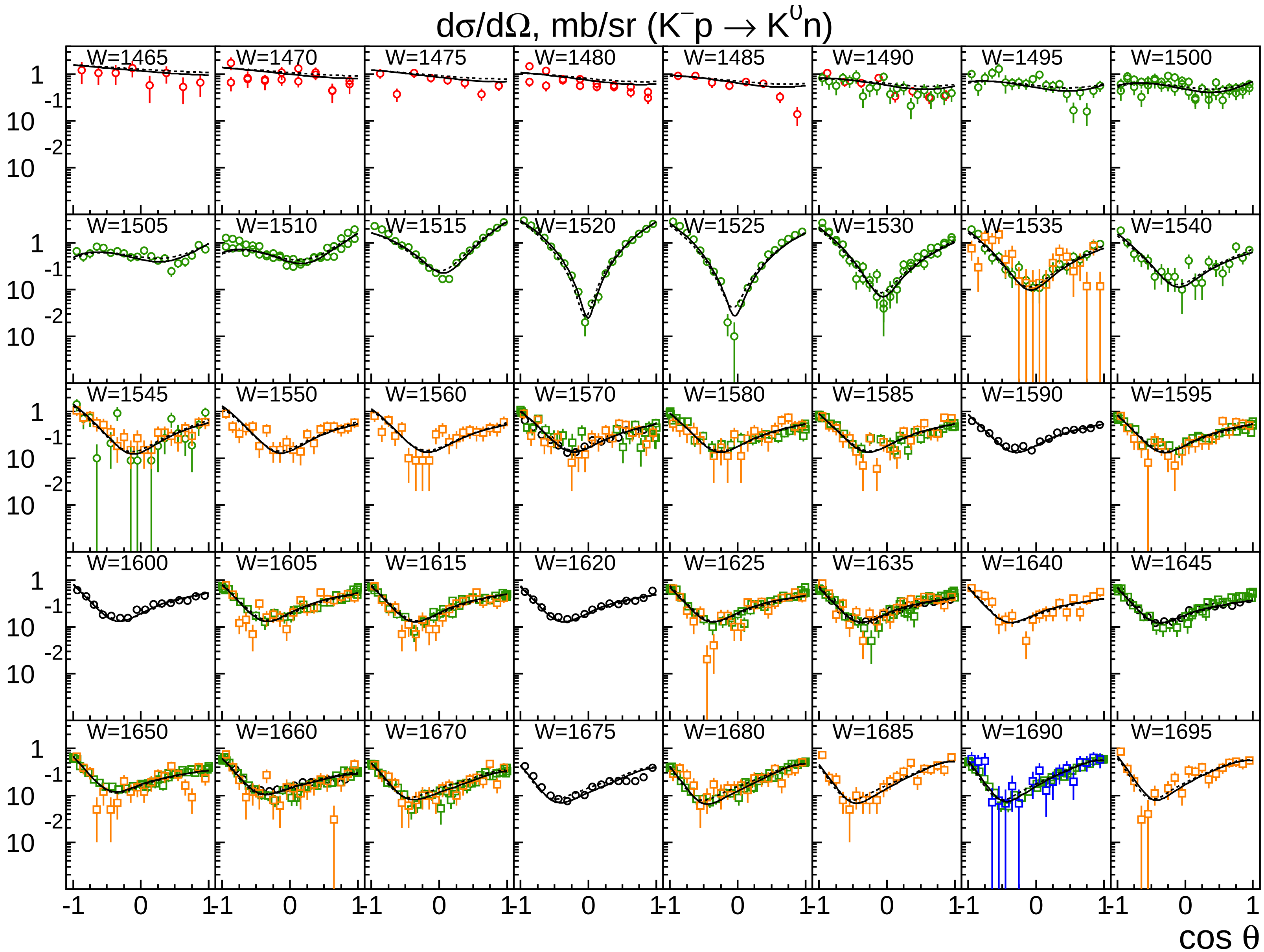
Analysis of the Kp collision reactions (Preliminary) (M.Matveev)

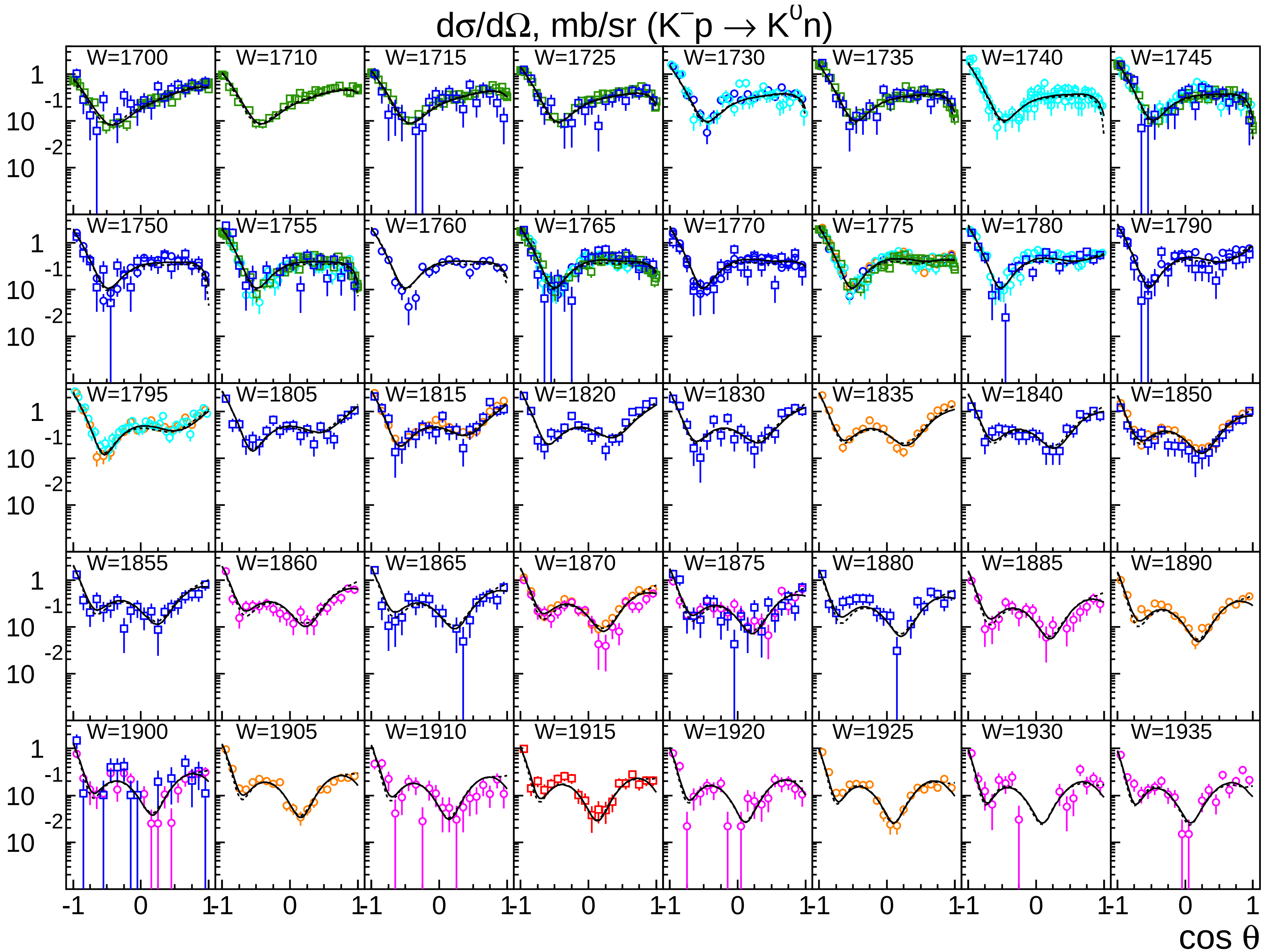



Σ (-)
Σ (1/2-)
Σ (3/2-)
Σ (5/2-)
Σ (7/2-)
28000
27800
27600
27400
27200
27000
26800
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
3/2
1/2
5/2

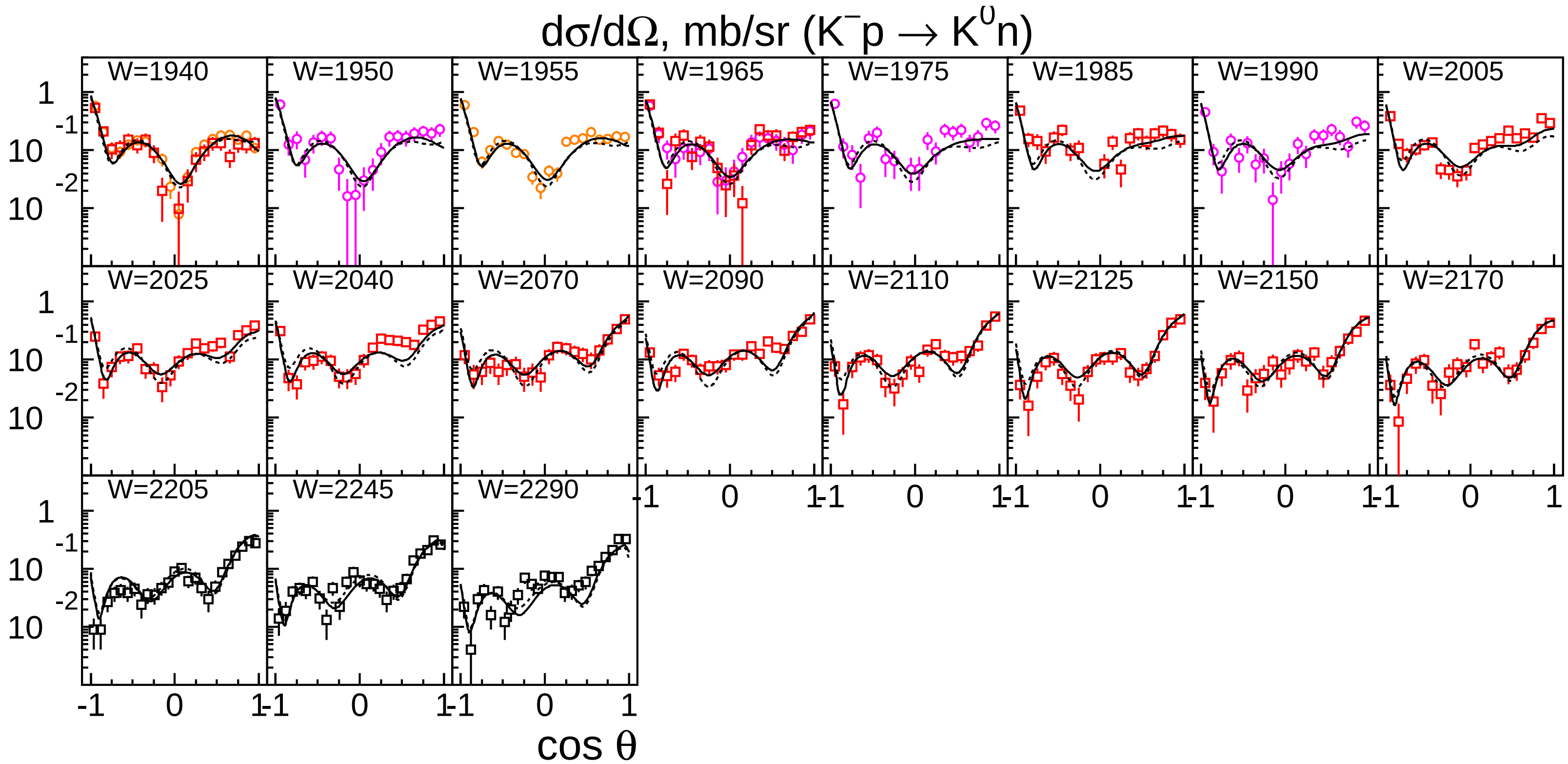


Σ (+)
Σ (1/2+)
Σ (3/2+)
Σ (5/2+)
Σ (7/2+)
28000
27800
27600
27400
27200
27000
26800
3/2
1/2
5/2
7/2
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300

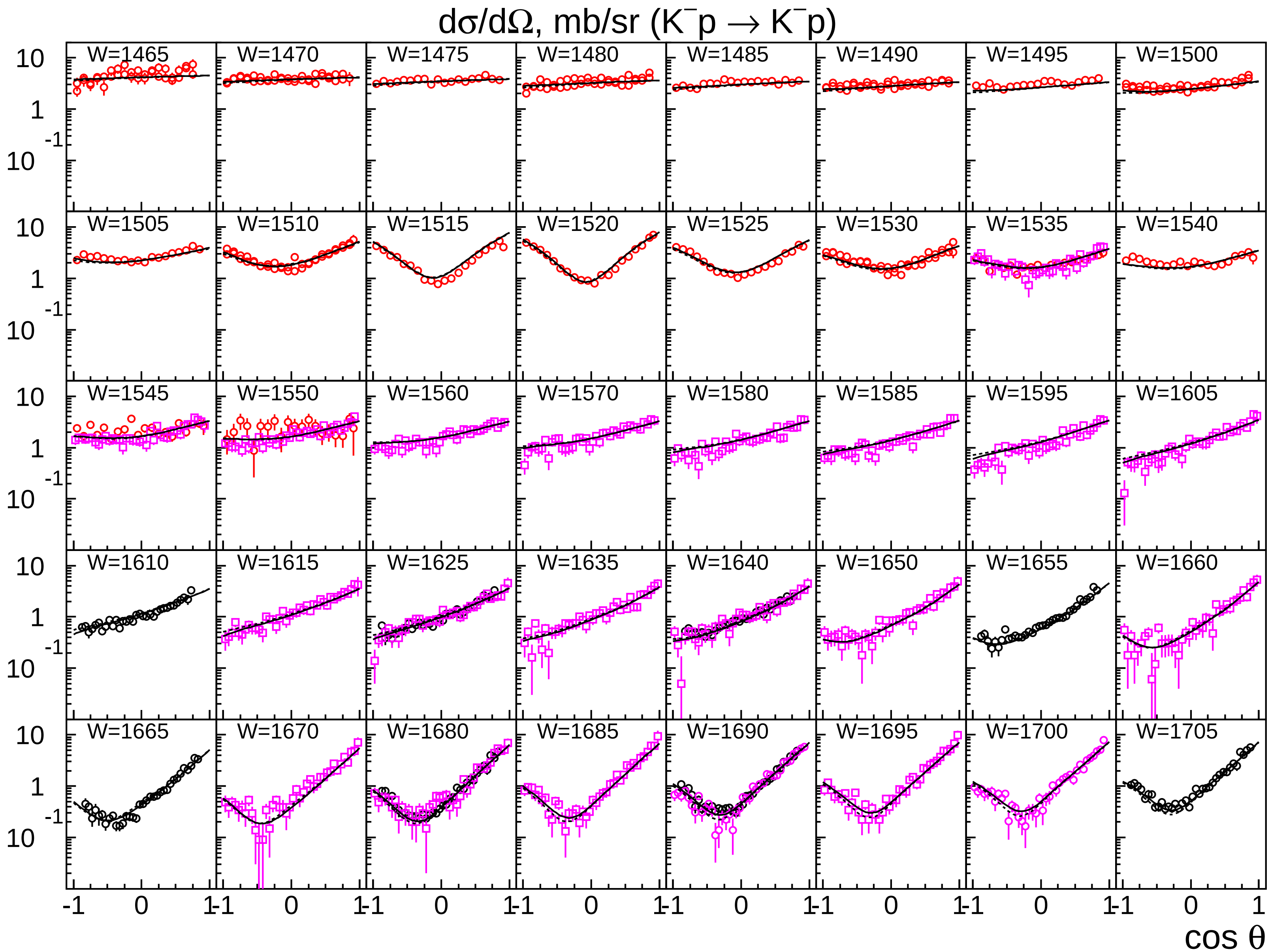

dσ/dΩ, mb/sr (K⁻p → K⁰n)
W=1465
W=1470
W=1475
W=1480
W=1485
W=1490
W=1495
W=1500
W=1505
W=1510
W=1515
W=1520
W=1525
W=1530
W=1535
W=1540
W=1545
W=1550
W=1560
W=1570
W=1580
W=1585
W=1590
W=1595
W=1600
W=1605
W=1615
W=1620
W=1625
W=1635
W=1640
W=1645
W=1650
W=1660
W=1670
W=1675
W=1680
W=1685
W=1690
W=1695
cos θ



dσ/dΩ, mb/sr (K⁻p → K⁰n)
W=1700
W=1710
W=1715
W=1725
W=1730
W=1735
W=1740
W=1745
W=1750
W=1755
W=1760
W=1765
W=1770
W=1775
W=1780
W=1790
W=1795
W=1805
W=1815
W=1820
W=1830
W=1835
W=1840
W=1850
W=1855
W=1860
W=1865
W=1870
W=1875
W=1880
W=1885
W=1890
W=1900
W=1905
W=1910
W=1915
W=1920
W=1925
W=1930
W=1935
1
10^-1
10^-2
-1
0
1
cos θ



dσ/dΩ, mb/sr ($K^-p \to K^0n$)
W=1940
W=1950
W=1955
W=1965
W=1975
W=1985
W=1990
W=2005
W=2025
W=2040
W=2070
W=2090
W=2110
W=2125
W=2150
W=2170
W=2205
W=2245
W=2290
cos θ



dσ/dΩ, mb/sr (K⁻p → K⁻p)
W=1465
W=1470
W=1475
W=1480
W=1485
W=1490
W=1495
W=1500
W=1505
W=1510
W=1515
W=1520
W=1525
W=1530
W=1535
W=1540
W=1545
W=1550
W=1560
W=1570
W=1580
W=1585
W=1595
W=1605
W=1610
W=1615
W=1625
W=1635
W=1640
W=1650
W=1655
W=1660
W=1665
W=1670
W=1680
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W=1690
W=1695
W=1700
W=1705
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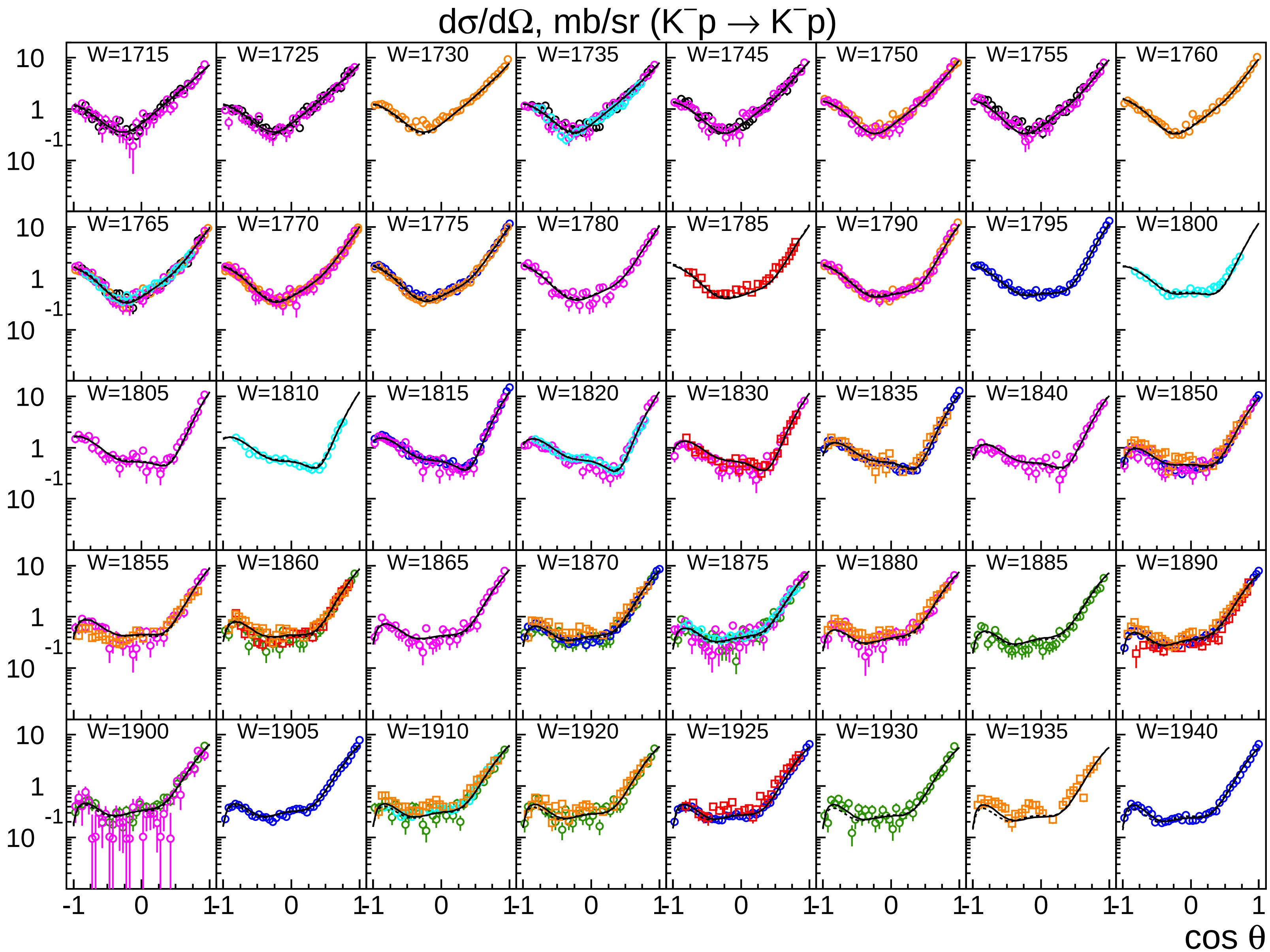
1
10^-1
-1
0
1
cos θ


dσ/dΩ, mb/sr (K⁻p → K⁻p)
W=1715
W=1725
W=1730
W=1735
W=1745
W=1750
W=1755
W=1760
W=1765
W=1770
W=1775
W=1780
W=1785
W=1790
W=1795
W=1800
W=1805
W=1810
W=1815
W=1820
W=1830
W=1835
W=1840
W=1850
W=1855
W=1860
W=1865
W=1870
W=1875
W=1880
W=1885
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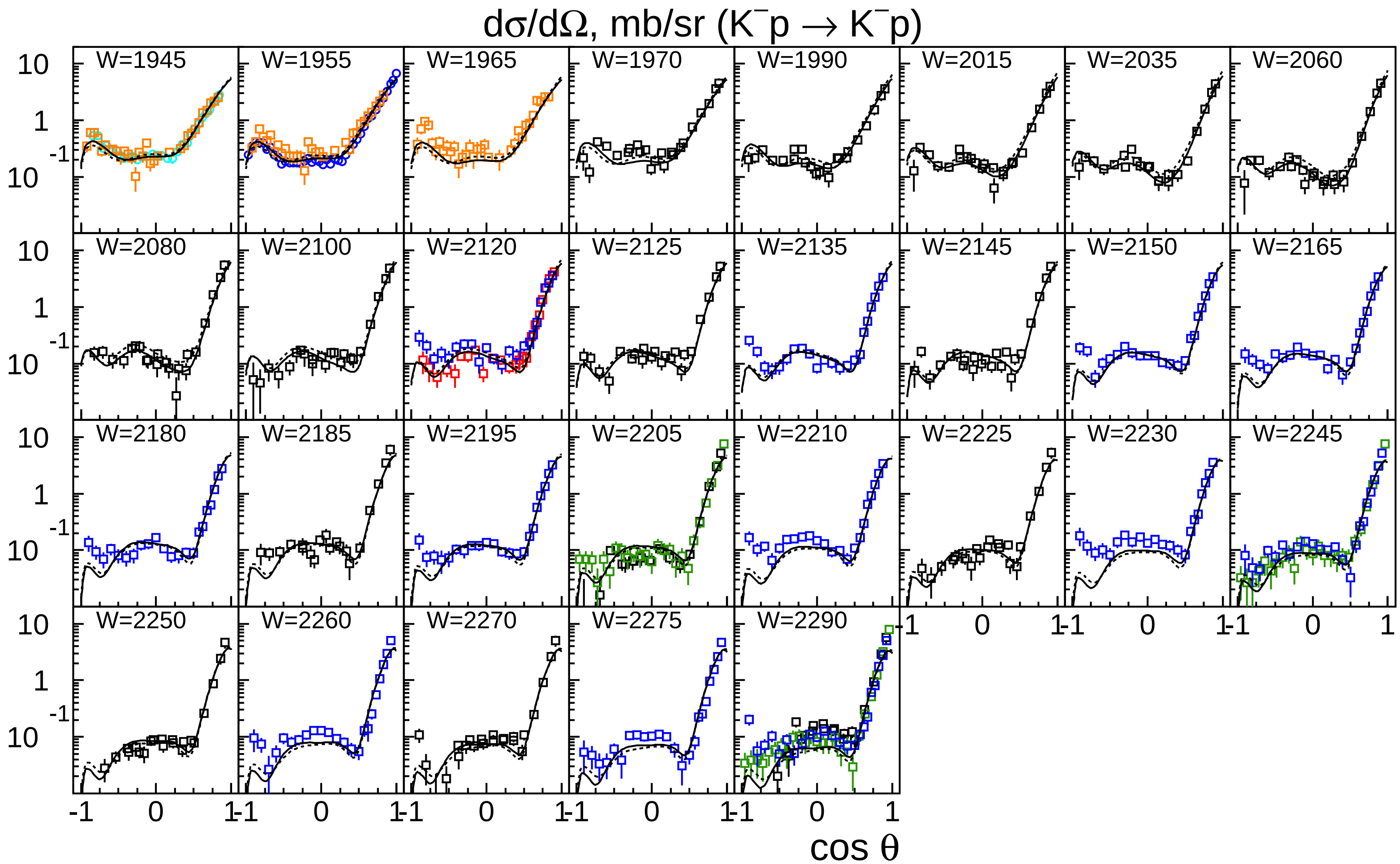
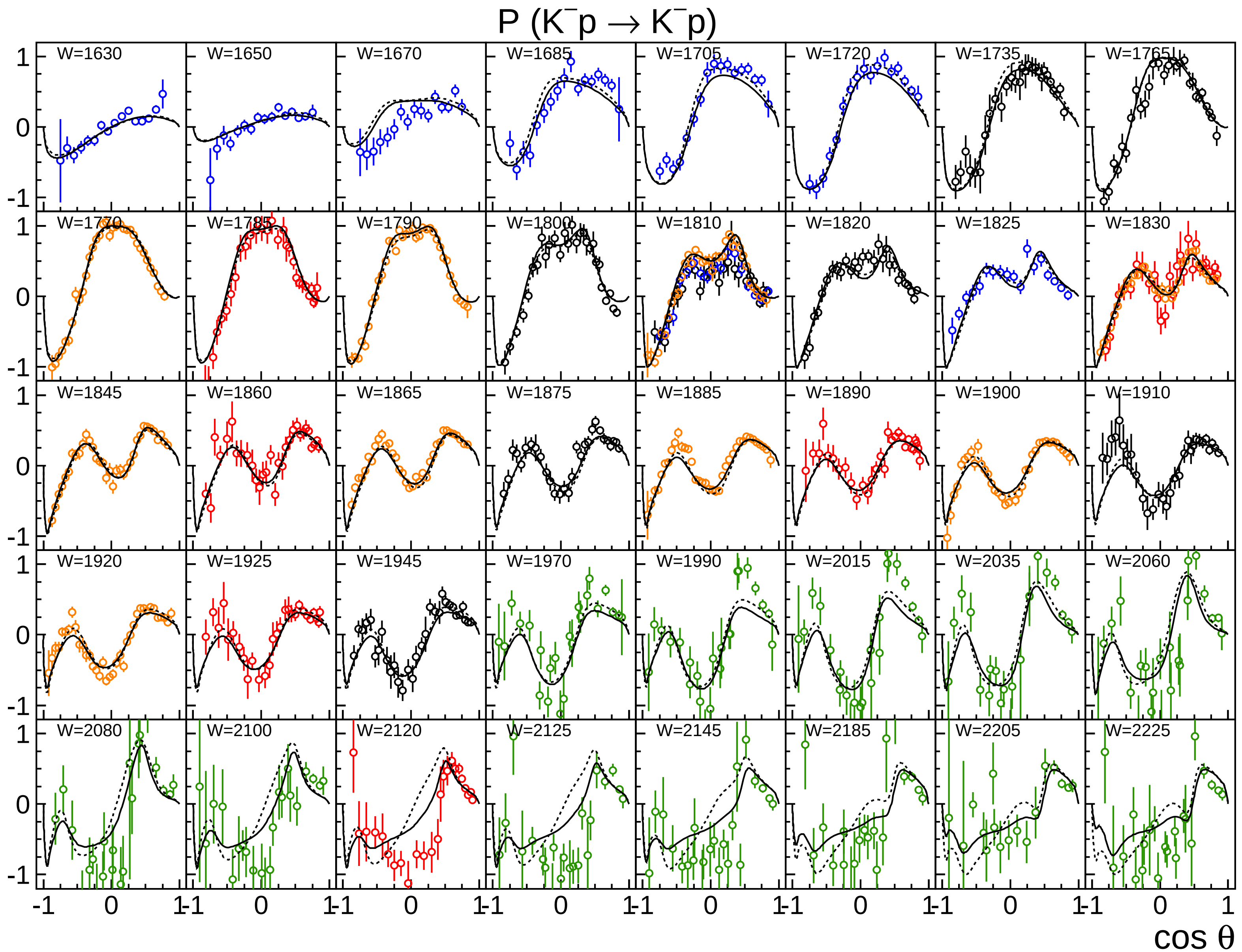
W=1900
W=1905
W=1910
W=1920
W=1925
W=1930
W=1935
W=1940
cos θ


dσ/dΩ, mb/sr (K⁻p → K⁻p)
W=1945
W=1955
W=1965
W=1970
W=1990
W=2015
W=2035
W=2060
W=2080
W=2100
W=2120
W=2125
W=2135
W=2145
W=2150
W=2165
W=2180
W=2185
W=2195
W=2205
W=2210
W=2225
W=2230
W=2245
W=2250
W=2260
W=2270
W=2275
W=2290
cos θ


P (K⁻p → K⁻p)
W=1630
W=1650
W=1670
W=1685
W=1705
W=1720
W=1735
W=1765
W=1770
W=1785
W=1790
W=1800
W=1810
W=1820
W=1825
W=1830
W=1845
W=1860
W=1865
W=1875
W=1885
W=1890
W=1900
W=1910
W=1920
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W=1945
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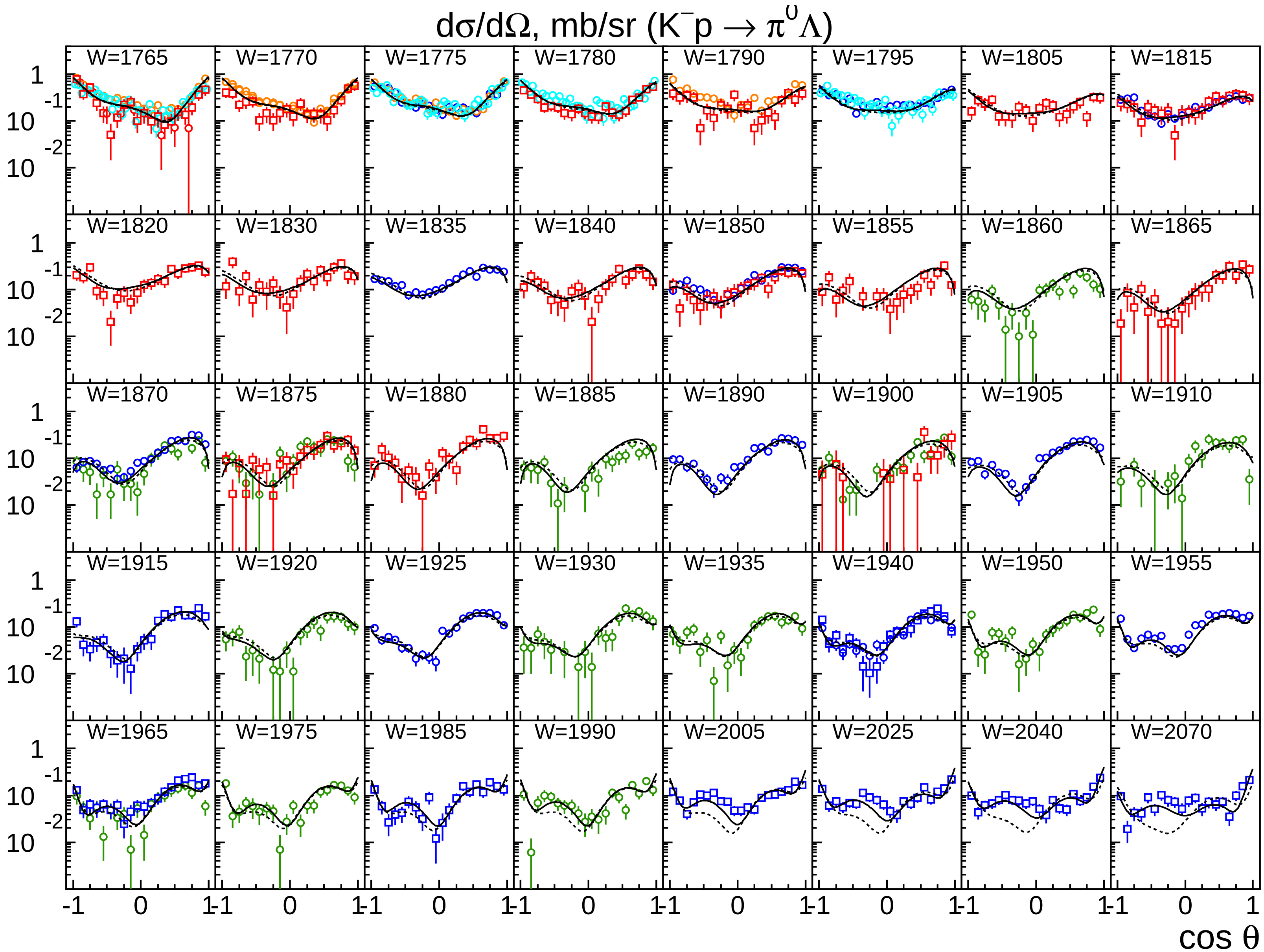
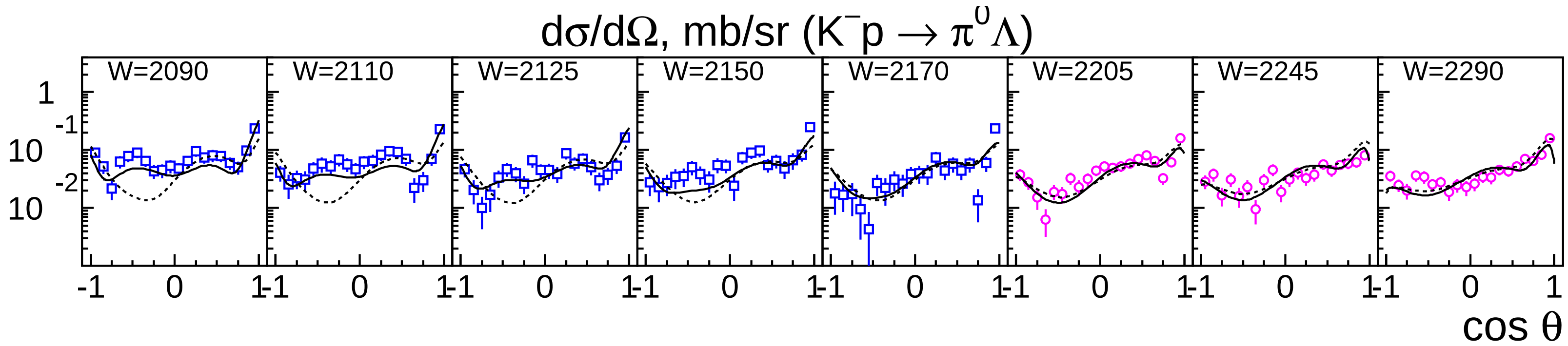
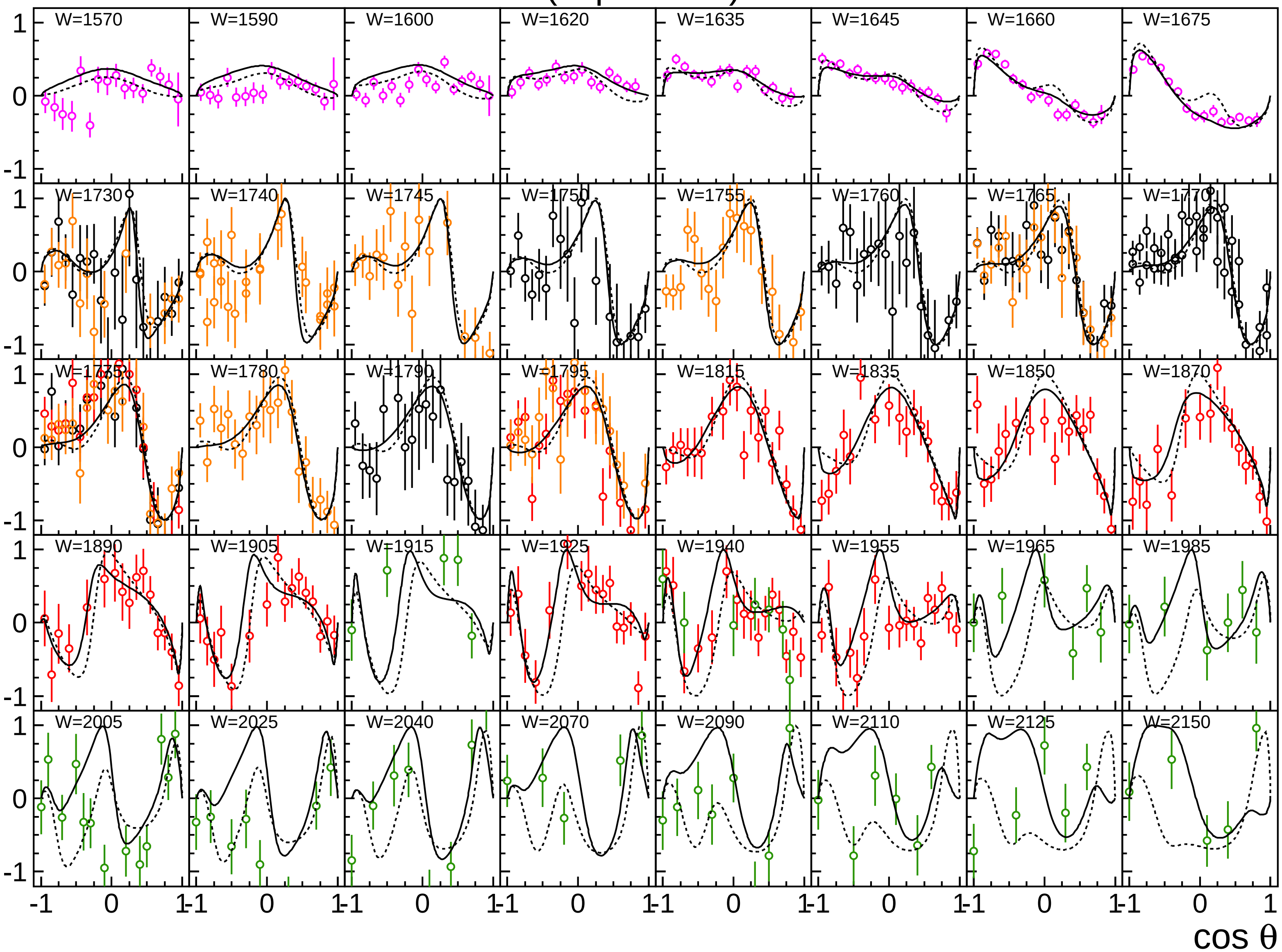
W=1990
W=2015
W=2035
W=2060
W=2080
W=2100
W=2120
W=2125
W=2145
W=2185
W=2205
W=2225
cos θ

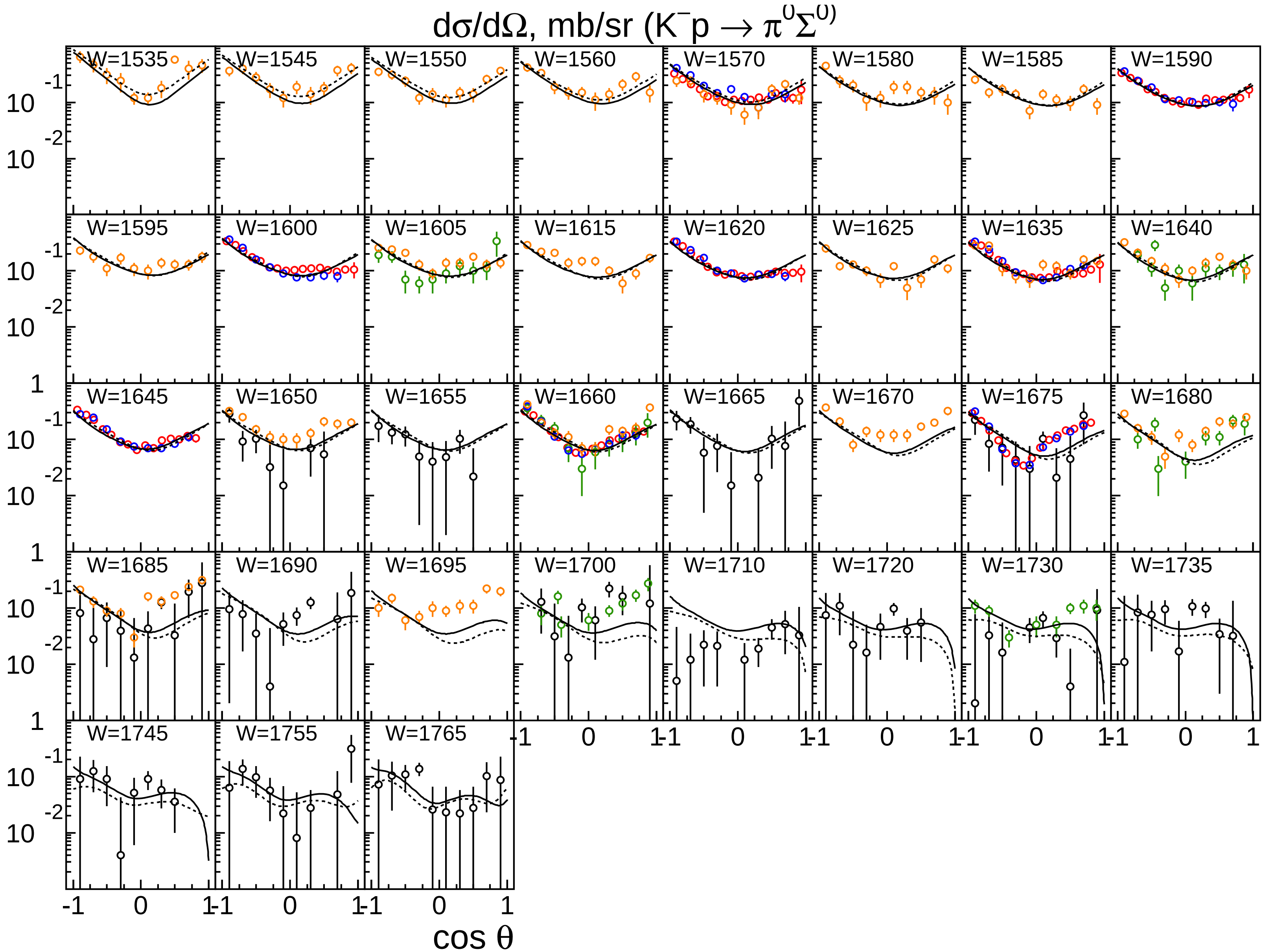


dσ/dΩ, mb/sr (K⁻p → π⁰Λ)
W=1765
W=1770
W=1775
W=1780
W=1790
W=1795
W=1805
W=1815
W=1820
W=1830
W=1835
W=1840
W=1850
W=1855
W=1860
W=1865
W=1870
W=1875
W=1880
W=1885
W=1890
W=1900
W=1905
W=1910
W=1915
W=1920
W=1925
W=1930
W=1935
W=1940
W=1950
W=1955
W=1965
W=1975
W=1985
W=1990
W=2005
W=2025
W=2040
W=2070
1
10^-1
10^-2
-1
0
1
cos θ

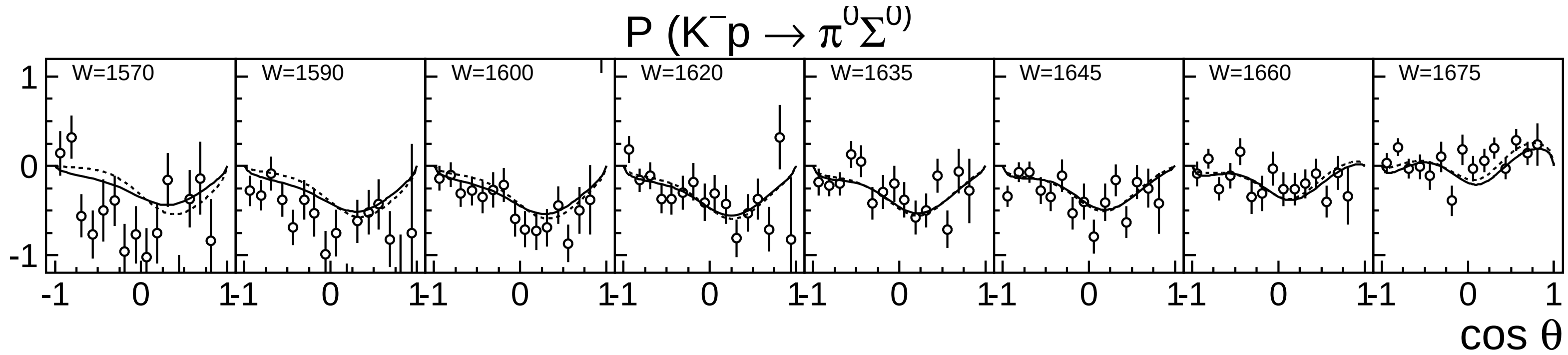

dσ/dΩ, mb/sr (K⁻p → π⁰Λ)
W=2090
W=2110
W=2125
W=2150
W=2170
W=2205
W=2245
W=2290
1
10^-1
10^-2
-1
0
1
cos θ

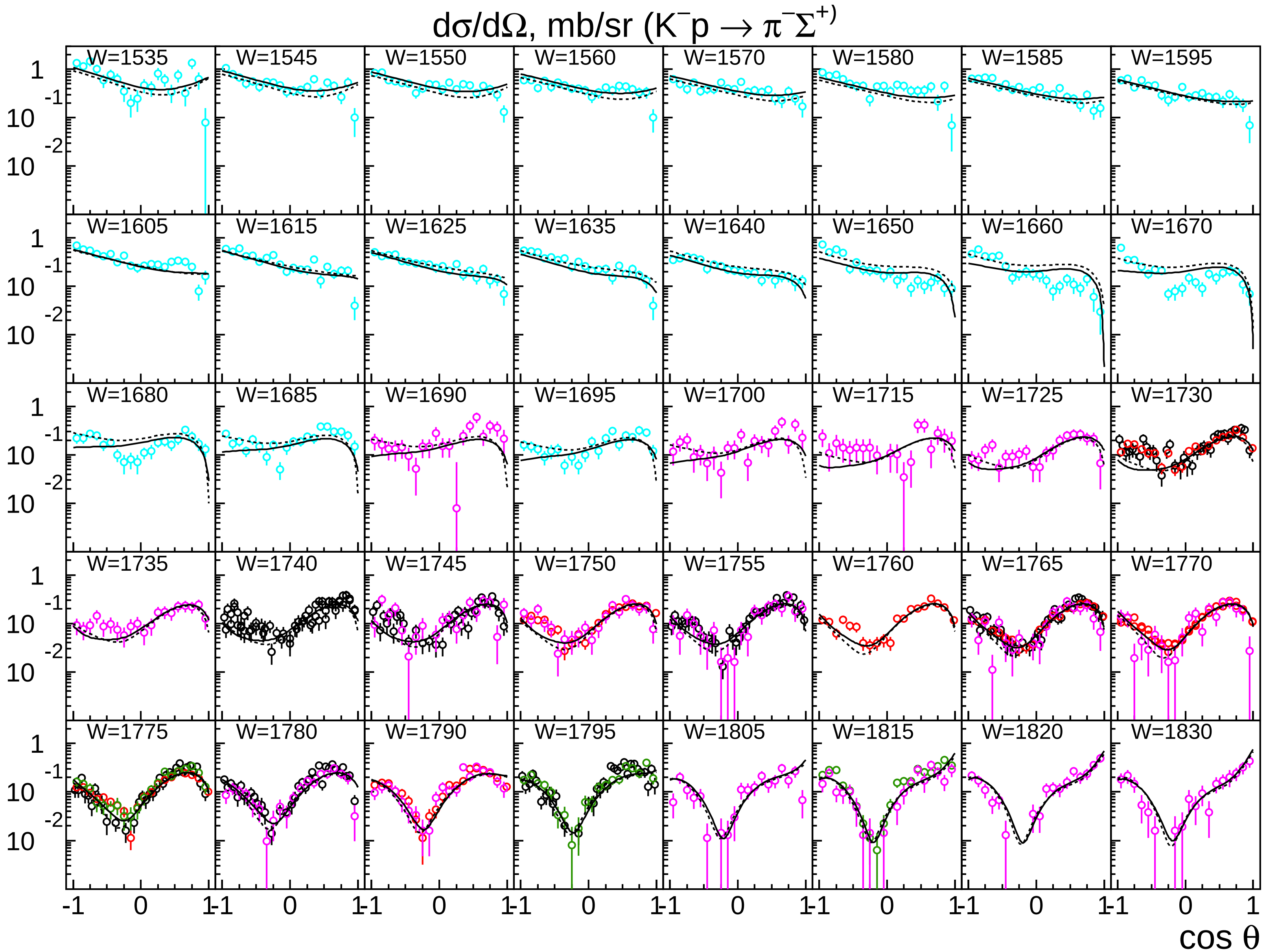
$P\ (K^- p \rightarrow \pi^0 \Lambda)$



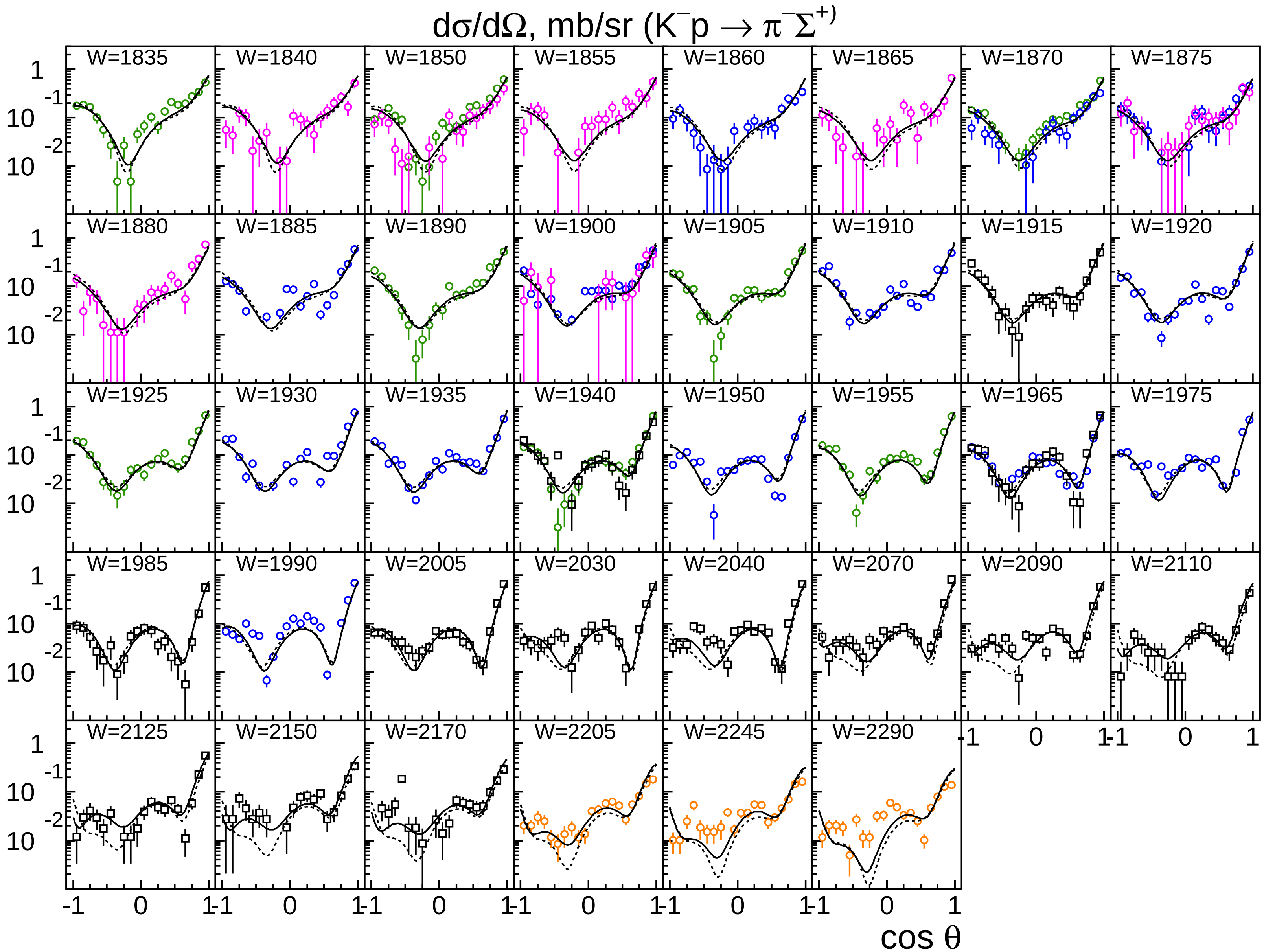


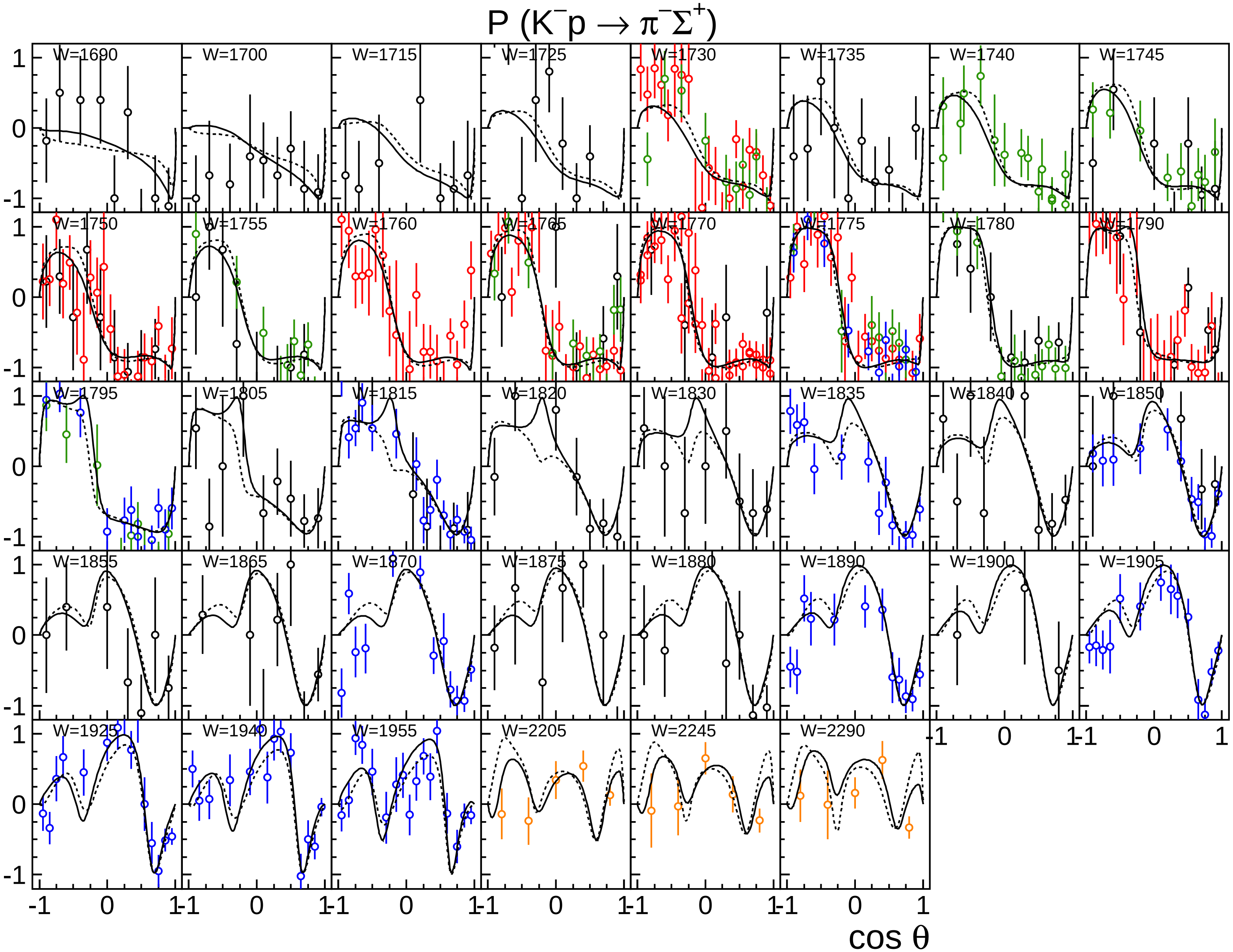
dσ/dΩ, mb/sr (K⁻p → π⁰Σ⁰)
W=1535
W=1545
W=1550
W=1560
W=1570
W=1580
W=1585
W=1590
W=1595
W=1600
W=1605
W=1615
W=1620
W=1625
W=1635
W=1640
W=1645
W=1650
W=1655
W=1660
W=1665
W=1670
W=1675
W=1680
W=1685
W=1690
W=1695
W=1700
W=1710
W=1720
W=1730
W=1735
W=1745
W=1755
W=1765
cos θ


P (K⁻p → π⁰Σ⁰)
W=1570
W=1590
W=1600
W=1620
W=1635
W=1645
W=1660
W=1675
1
0
-1
cos θ

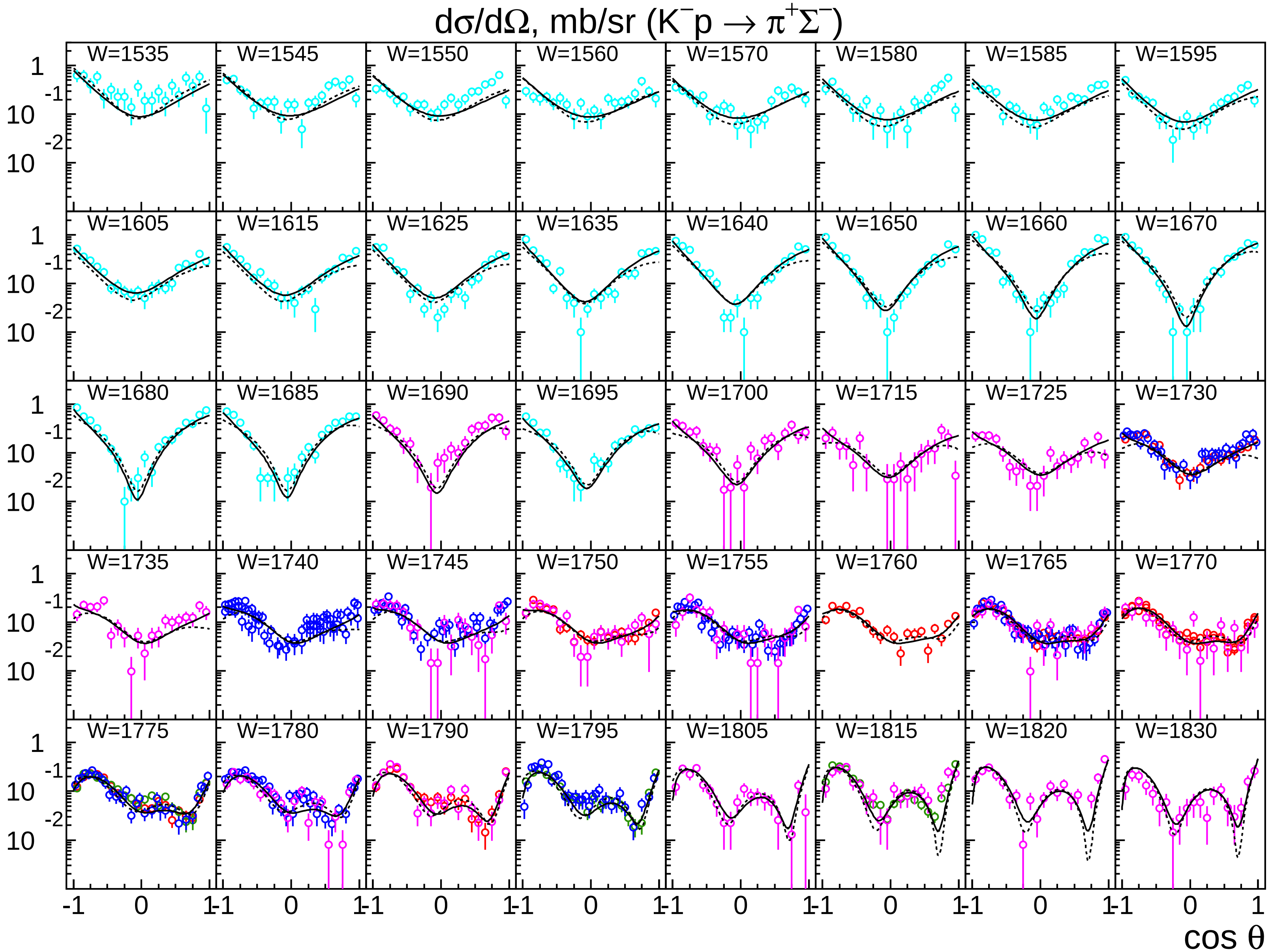


dσ/dΩ, mb/sr (K⁻p → π⁻Σ⁺)
W=1535
W=1545
W=1550
W=1560
W=1570
W=1580
W=1585
W=1595
W=1605
W=1615
W=1625
W=1635
W=1640
W=1650
W=1660
W=1670
W=1680
W=1685
W=1690
W=1695
W=1700
W=1715
W=1725
W=1730
W=1735
W=1740
W=1745
W=1750
W=1755
W=1760
W=1765
W=1770
W=1775
W=1780
W=1790
W=1795
W=1805
W=1815
W=1820
W=1830
1
10⁻¹
10⁻²
-1
0
1
cos θ

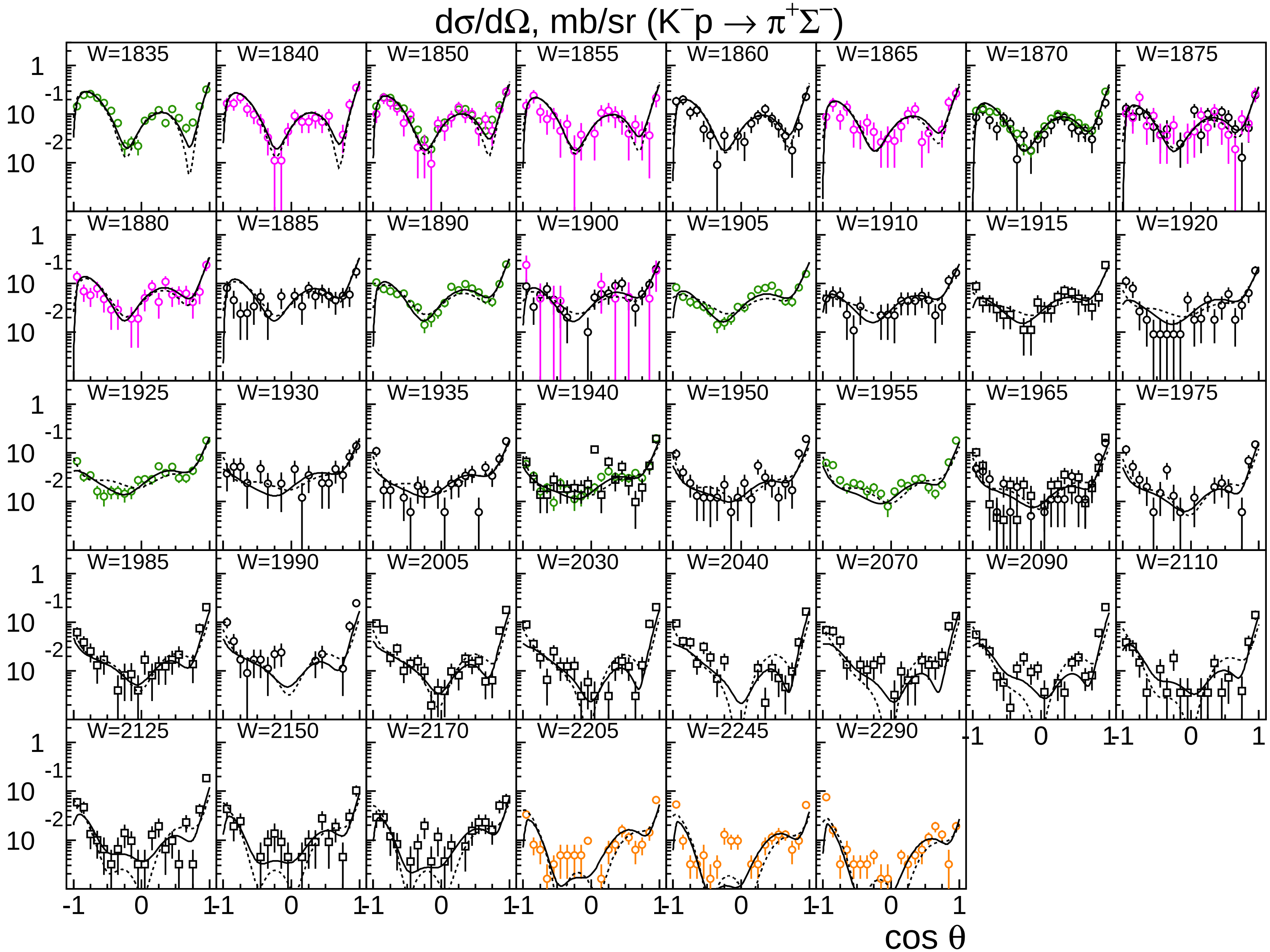

dσ/dΩ, mb/sr (K⁻p → π⁻Σ⁺)
W=1835
W=1840
W=1850
W=1855
W=1860
W=1865
W=1870
W=1875
W=1880
W=1885
W=1890
W=1900
W=1905
W=1910
W=1915
W=1920
W=1925
W=1930
W=1935
W=1940
W=1950
W=1955
W=1965
W=1975
W=1985
W=1990
W=2005
W=2030
W=2040
W=2070
W=2090
W=2110
W=2125
W=2150
W=2170
W=2205
W=2245
W=2290
cos θ



P (K⁻p → π⁻Σ⁺)
W=1690
W=1700
W=1715
W=1725
W=1730
W=1735
W=1740
W=1745
W=1750
W=1755
W=1760
W=1765
W=1770
W=1775
W=1780
W=1790
W=1795
W=1805
W=1815
W=1820
W=1830
W=1835
W=1840
W=1850
W=1855
W=1865
W=1870
W=1875
W=1880
W=1890
W=1900
W=1905
W=1925
W=1940
W=1955
W=2205
W=2245
W=2290
cos θ

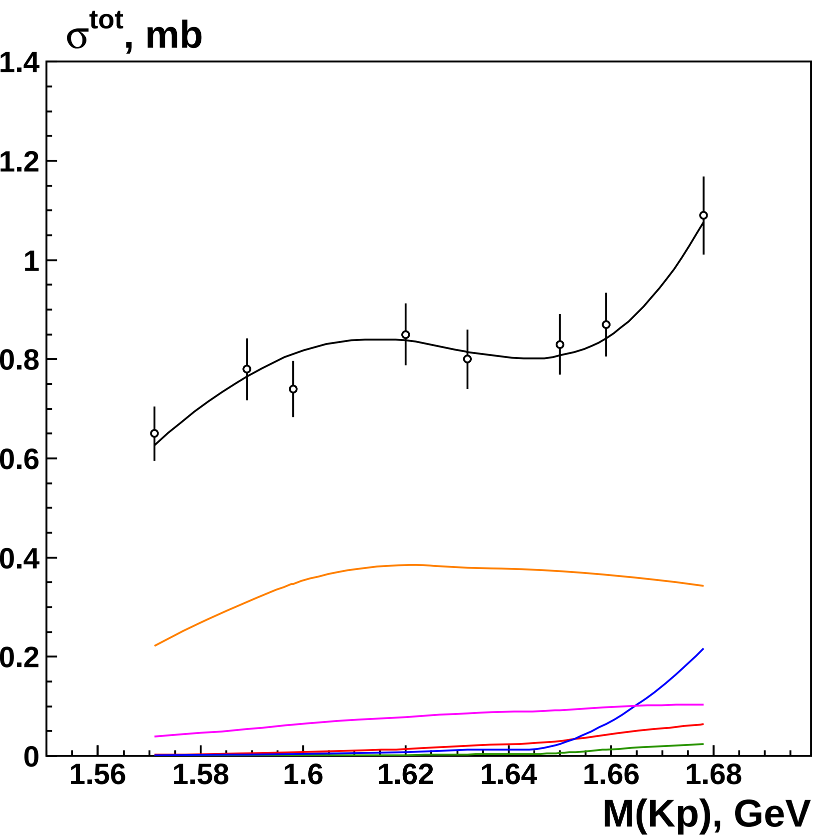


dσ/dΩ, mb/sr (K⁻p → π⁺Σ⁻)
W=1535
W=1545
W=1550
W=1560
W=1570
W=1580
W=1585
W=1595
W=1605
W=1615
W=1625
W=1635
W=1640
W=1650
W=1660
W=1670
W=1680
W=1685
W=1690
W=1695
W=1700
W=1715
W=1725
W=1730
W=1735
W=1740
W=1745
W=1750
W=1755
W=1760
W=1765
W=1770
W=1775
W=1780
W=1790
W=1795
W=1805
W=1815
W=1820
W=1830
1
10^-1
10^-2
-1
0
1
cos θ

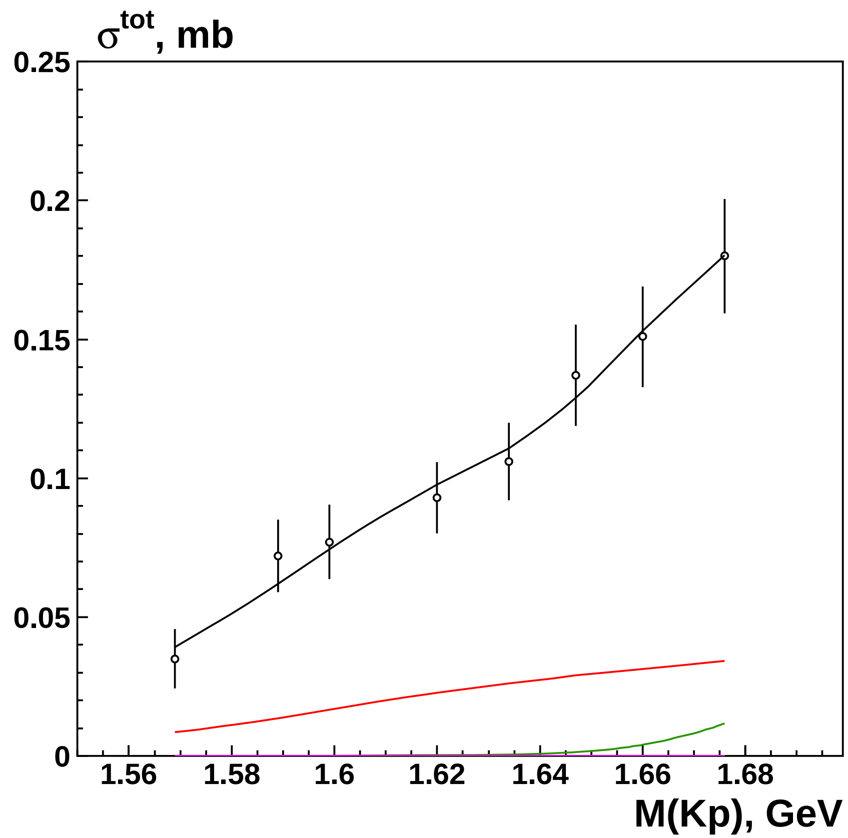

dσ/dΩ, mb/sr (K⁻p → π⁺Σ⁻)
W=1835
W=1840
W=1850
W=1855
W=1860
W=1865
W=1870
W=1875
W=1880
W=1885
W=1890
W=1900
W=1905
W=1910
W=1915
W=1920
W=1925
W=1930
W=1935
W=1940
W=1950
W=1955
W=1965
W=1975
W=1985
W=1990
W=2005
W=2030
W=2040
W=2070
W=2090
W=2110
W=2125
W=2150
W=2170
W=2205
W=2245
W=2290
cos θ

		ANL-Osaca	Bn-Ga	Model A	Model B	Bn-Ga
$K^- p \to K^- p$	$d\sigma/d\Omega$	3962	5495	3.07	2.98	2.28
	P	510	859	2.04	2.08	1.79
$K^- p \to \bar{K}^0 n$	$d\sigma/d\Omega$	2950	3445	2.67	2.75	1.62
$K^- p \to \pi^- \Sigma^+$	$d\sigma/d\Omega$	1792	2095	3.37	3.49	3.17
	P	418	578	1.30	1.28	2.06
$K^- p \to \pi^0 \Sigma^0$	$d\sigma/d\Omega$	580	581	3.68	3.50	3.57
	P	196	124	6.39	5.80	1.51
$K^- p \to \pi^+ \Sigma^-$	$d\sigma/d\Omega$	1786	2082	2.56	2.18	1.80
$K^- p \to \pi^0 \Lambda$	$d\sigma/d\Omega$	2178	2478	2.59	3.71	1.82
	P	693	732	1.41	1.73	1.73
$K^- p \to \eta \Lambda$	$d\sigma/d\Omega$	160	160	2.69	2.03	1.52
	P	18	—	0.94	3.83	—
$K^- p \to K^0 \Xi^0$	$d\sigma/d\Omega$	33	67	1.24	1.61	1.20
$K^- p \to K^+ \Xi^-$	$d\sigma/d\Omega$	92	193	2.05	1.74	1.38
$K^- p \to \Lambda \omega$	$d\sigma/d\Omega$	–	300	—	—	1.08

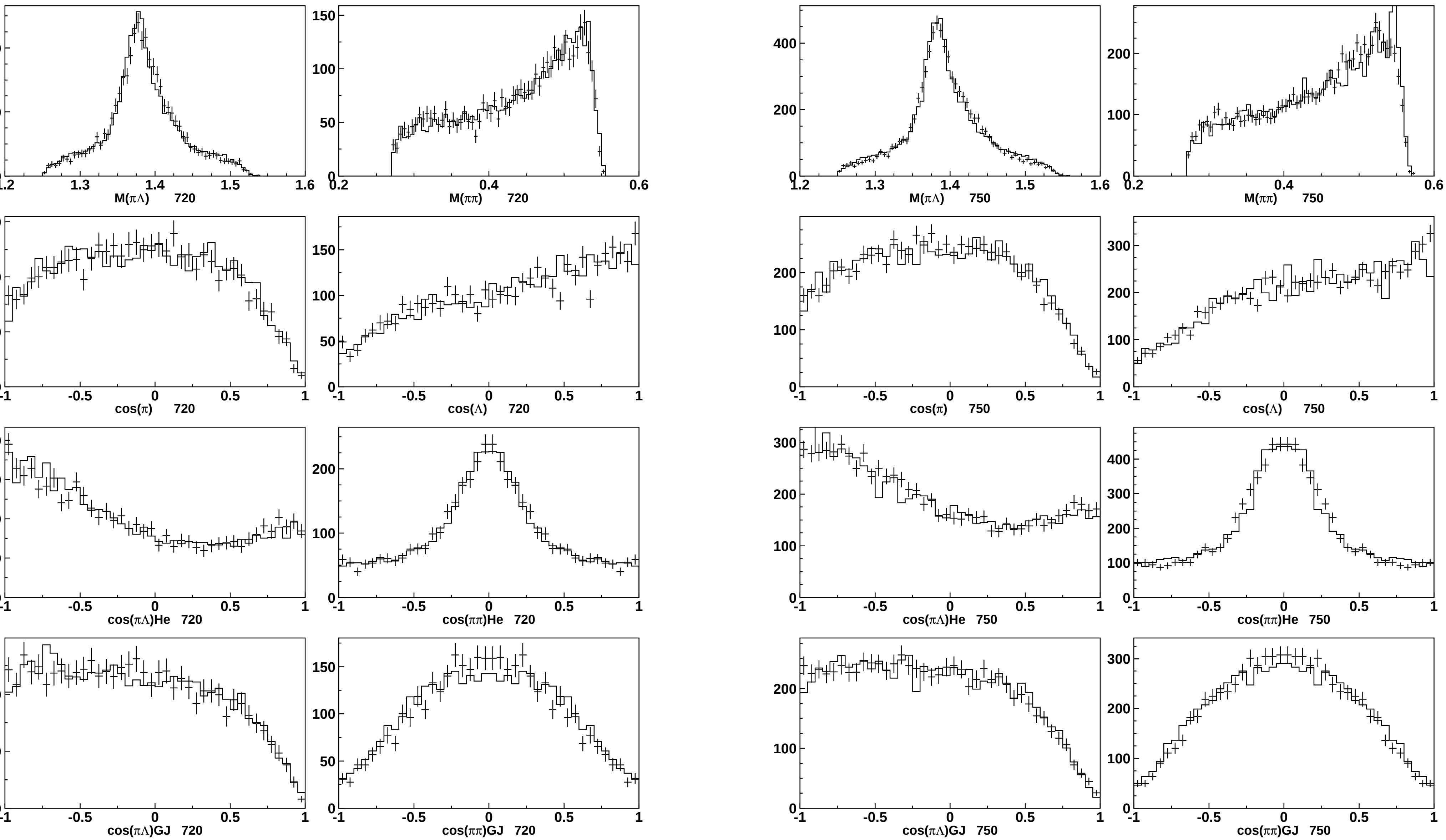
$K^- p \to \pi^0 \pi^0 \Lambda$



$K^- p \to \pi^0 \pi^0 \Sigma^0$



$K^- p \to \pi^0 \pi^0 \Lambda$ (beam momenta 720 and 750 MeV/c)



$K^- p \to \pi^0 \pi^0 \Sigma^0$ (beam momenta 720 and 750 MeV/c)

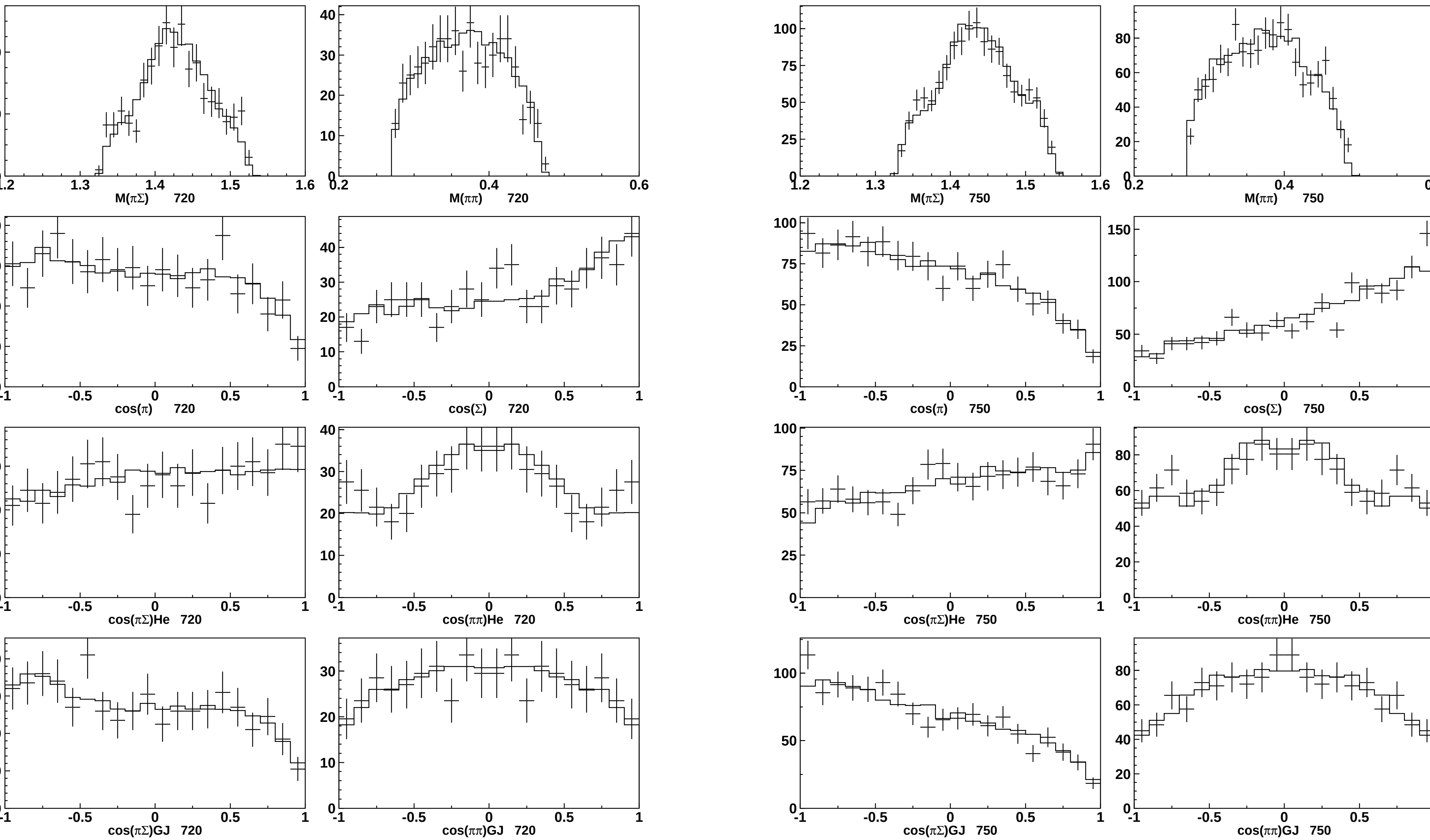


Table 5: Σ-Hyperons used in the first fit to the data.

	J^P	**Status**	**Mass**	**Width**
$\Sigma(1660)$	$1/2^+$	***	$1630 - 1690$	36.0 ± 0.7
$\Sigma(1385)$	$3/2^+$	****	1382.80 ± 0.35	$40 - 200$
$\Sigma(1915)$	$5/2^+$	****	$1900 - 1935$	$80 - 160$
$\Sigma(2030)$	$7/2^+$	****	$2025 - 2040$	$150 - 200$
$\Sigma(1670)$	$3/2^-$	****	$1665 - 1685$	$40 - 80$
$\Sigma(1750)$	$1/2^-$	***	$1730 - 1800$	$60 - 160$
$\Sigma(1775)$	$5/2^-$	****	$1770 - 1780$	$105 - 135$
$\Sigma(1940)$	$3/2^-$	***	$1900 - 1950$	$150 - 300$
$\Sigma(1665)$	$1/2^-$		1670 ± 15	210 ± 20
$\Sigma(2150)$	$1/2^-$		2160 ± 20	220 ± 25
$\Sigma(2250)$	$5/2^-$		2250 ± 30	330 ± 40

SUMMARY

- The energy independent analysis of the $\gamma p \to K\Lambda$ data is consistent with the energy dependent analysis.
- The analysis of the new data on the η and η' photoproduction confirms the observed earlier $S_{11}(1895)$ state. There is puzzling behavior of the data near the $\eta' p$ threshold.
- The analysis of the $\gamma n \to K\Lambda$ and $\gamma n \to K\Sigma$ reactions confirms states in the mass region around 1900 MeV.
- The analysis of the reactions with two pion production provides an important information for the classification of the observed states and branching to the two meson final states.
- The analysis of the Kp collision data reveals the presence of the unknown Σ-hyperons. There is a hope to observe the baryon multiplets and therefore to confirm the states found in the Nucleon-Delta sector.