BnGa PWA

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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

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Last changes: January 26th, 2010.

Problems in the baryon spectroscopy and/or quark model:

1. **Problem:** Number of predicted three quark states exceeds dramatically the number of discovered baryons.

2. **Possible solution:** Most of the information comes from analyses of πN elastic reactions. Photoproduction data taken by CLAS, GRAAL, LEPS and CB-ELSA can provide an important information about missing states.

   (a) **problem:** Unambiguous analysis of photoproduction reactions can not be done without polarization information available.

   (b) **problem:** Signals in simple reactions are expected to be mostly weak. Strong signals from new resonances can be found in multi-meson final states.

   (c) **Possible solution 1:** Single polarization observables are measured now by almost all collaborations. Double polarization data are available from CLAS, GRAAL and, in nearest future, from CB-ELSA.

   (d) **Possible solution 2:** A combined analysis of large data sets.

Search for baryon states

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

2. **Analysis of single and double meson production in pion-induced reactions.**
   $\pi N \to \pi N, \eta N, K\Lambda, K\Sigma, \pi\pi N$.

Search for meson states

1. **Analysis of the $p\bar{p}$ annihilation at rest and $\pi\pi$ interaction data.**

2. **Analysis of the $p\bar{p}$ annihilation in flight into two and tree meson final state.**

3. **Analysis of the $\gamma\gamma \to \pi^+\pi^-\pi^0,\ K_S K_S$ (LEP) (tensor mesons nonet)**

4. **Analysis of the BES III data on J/Ψ decays (in collaboration with JINR Dubna).**

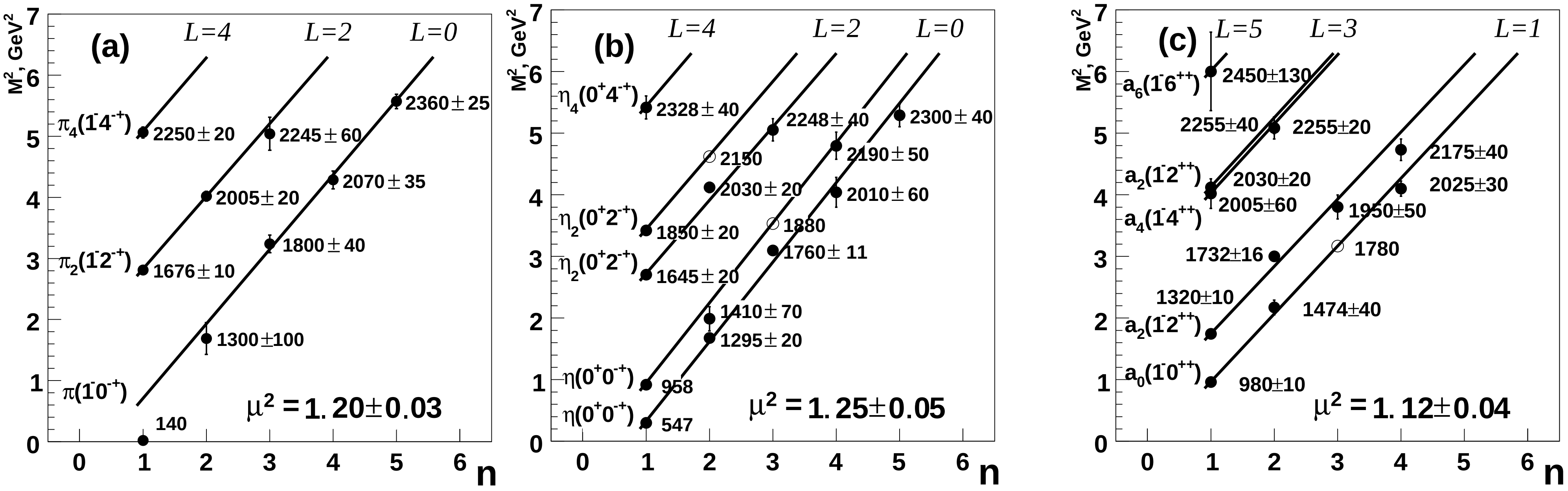
Analysis of NN interaction

1. **Analysis of meson production $NN \to \pi NN$ (Wasa, PNPI, HADES)**

2. **Analysis of hyperon production $NN \to K\Lambda p$ (WASA, HADES)**

Search for meson states

1. more than 30 meson states were discovered
2. linear trajecrtories in the (n, M^2), (J, M^2) planes with the almost equal slopes



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. **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 A. V. Anisovich, V. V. Anisovich, V. N. Markov, M. A. Matveev and A. V. Sarantsev, J. Phys. G G 28, 15 (2002)

4 B. S. Zou and D. V. Bugg, Eur. Phys. J. A 16, 537 (2003)

5 A. Anisovich, E. Klempt, A. Sarantsev and U. Thoma, Eur. Phys. J. A 24, 111 (2005)

6 A. V. Anisovich and A. V. Sarantsev, Eur. Phys. J. A 30, 427 (2006)

7 A. V. Anisovich, V. V. Anisovich, E. Klempt, V. A. Nikonov and A. V. Sarantsev, Eur. Phys. J. A 34, 129 (2007).

Partial wave amplitude:

transition amplitude with fixed initial and final states

Quantum numbers: mesons $I^G\,J^{PC}$, baryons: IJ^P, decay LS basis: $^{2S+1}L_J$

$$I_1^{G_1} J_1^{P_1 C_1} + I_2^{G_2} J_2^{P_2 C_2} \left(^{2S+1}L_J\right) \to I^G J^{PC} \to I_1'^{G_1'} J_1'^{P_1' C_1'} + I_2'^{G_2'} J_2'^{P_2' C_2'} \left(^{2S'+1}L'_J\right)$$

$$G = G_1 G_2 \qquad G = G_1' G_2'$$

$$P = P_1 P_2 (-1)^L \qquad P = P_1' P_2' (-1)^{L'}$$

$$|I_1 - I_2| < I < I_1 + I_2 \qquad |I_1' - I_2'| < I < I_1' + I_2'$$

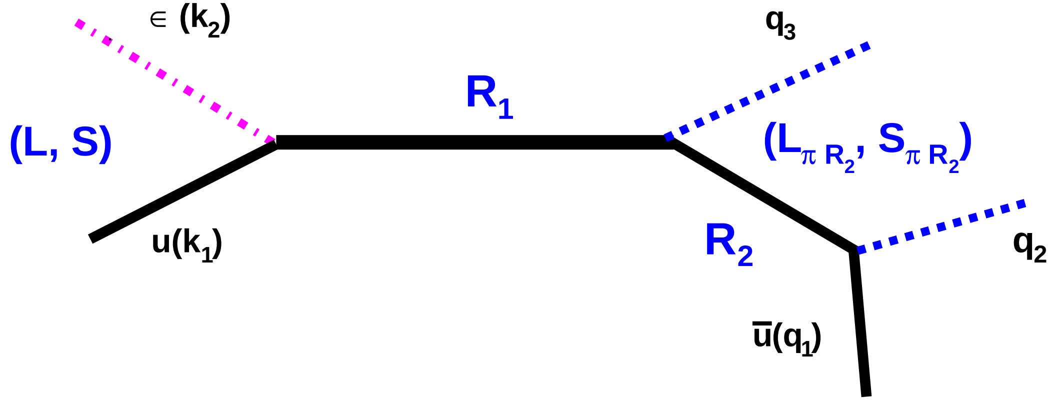
$$|J_1 - J_2| < S < J_1 + J_2 \qquad |J_1' - J_2'| < S' < J_1' + J_2'$$

$$|S - L| < J < S + L \qquad |S' - L'| < J < S' + L'$$

$$A(s,t) = V_{\mu_1 \ldots \mu_n}(S,L)\, P^{\mu_1 \ldots \mu_n}_{\nu_1 \ldots \nu_n}\, V'_{\nu_1 \ldots \nu_n}(S',L') A(s)$$

$n = J$ **mesons** $\qquad n = J - 1/2$ **baryons**

Resonance amplitudes for meson photoproduction



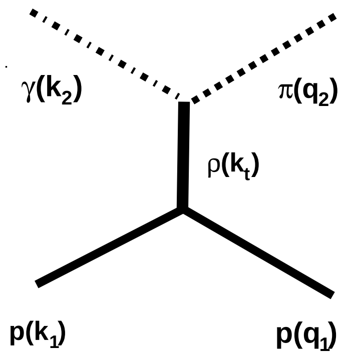
General form of the angular dependent part of the amplitude:

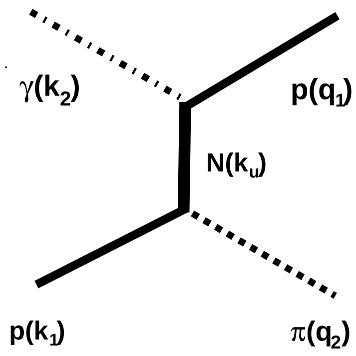
$$\bar{u}(q_1)\tilde{N}_{\alpha_1\ldots\alpha_n}(R_2\to\mu N)F^{\alpha_1\ldots\alpha_n}_{\beta_1\ldots\beta_n}(q_1+q_2)\tilde{N}^{(j)\beta_1\ldots\beta_n}_{\gamma_1\ldots\gamma_m}(R_1\to\mu R_2)$$
$$F^{\gamma_1\ldots\gamma_m}_{\xi_1\ldots\xi_m}(P)V^{(i)\mu}_{\xi_1\ldots\xi_m}(R_1\to\gamma N)u(k_1)\varepsilon_\mu$$

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

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

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 Reggion trajectory, and ξ is its signature:

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

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

Minimization methods

1. **The two body final states $\pi N, \gamma N \to \pi N, \eta N, K\Lambda, K\Sigma, \omega N, K^*\Lambda$: χ^2 method.**
   For n measured bins we minimize

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

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

2. **Reactions with three or more final states are analyzed with logarithm likelihood method. $\pi N, \gamma N \to \pi\pi N, \pi\eta N, \omega p, K^*\Lambda$. 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. Above 500 000 data events are taken in the fit. (Desk !)

Parameterization of the partial wave amplitude

$$A_{1i} = K_{1j}(I - i\rho K)^{-1}_{ji}$$

and

$$K_{ij} = \sum_{\alpha} \frac{g_i^{\alpha} g_j^{\alpha}}{M_{\alpha}^2 - s} + f_{ij}(s) \qquad\qquad f_{ij} = \frac{f_{ij}^{(1)} + f_{ij}^{(2)}\sqrt{s}}{s - s_0^{ij}} \, .$$

where f_{ij} is non-resonant transition part.

For the small coupled initial state, e.g. photoproduction:

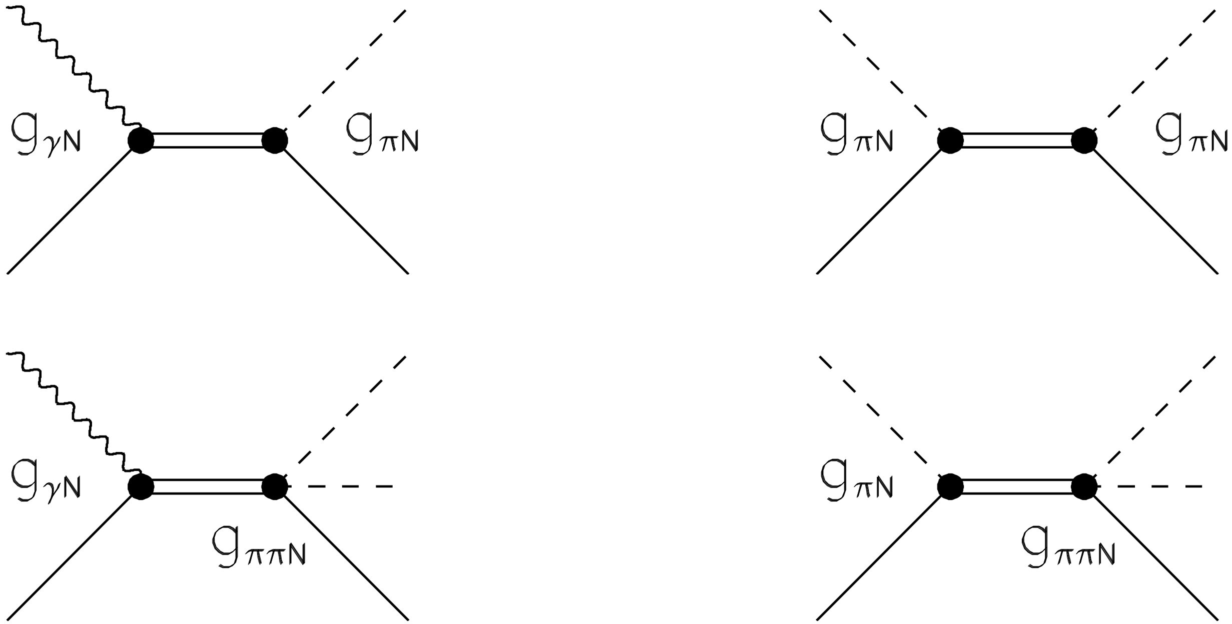
$$A_k = P_j(I - i\rho K)^{-1}_{jk}$$

The vector of the initial interaction has the form:

$$P_j = \sum_{\alpha} \frac{\Lambda^{\alpha} g_j^{\alpha}}{M_{\alpha}^2 - s} + F_j(s)$$

Here F_j is non-resonant production of the final state j.

Combined analysis of the different reactions:



$$BW = \frac{g_i g_j}{M^2 - s - i\sum_k g_k^2 \rho_k}, \qquad g_k = g_{\pi N}, g_{\gamma N}, g_{\pi\pi N}, \ldots$$

$$M\Gamma = \sum_k g_k^2 \rho_k$$

Baryon data base

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

Evidence for the $N(1900)P_{13}$

No good description of C_x, C_z with old set of resonances.

Systematic discrepancies are observed.

As the firsr step, further resonances were introduced as Breit-Wigner amplitudes and different quantum numbers were tested.

The best χ^2 was obtained by introducing the second P_{13} state.

Solution 1: 1885 ± 15 **MeV mass and** 180 ± 25 **MeV width, with** $\Delta\chi^2 = 1540$**.**

Solution 2: 1975 ± 15 **MeV mass and** 200 ± 20 **MeV width.**

Replacing:

S_{11} $\Delta\chi^2$ **= 950.**

D_{15} $\Delta\chi^2$ **= 970.**

P_{11} $\Delta\chi^2$ **= 205.**

F_{15} $\Delta\chi^2$ **small.**

P_{33} $\Delta\chi^2$ **smaller by a factor 2 than for a** P_{13}**.**

F_{17}, G_{17} **did not improve the fit.**

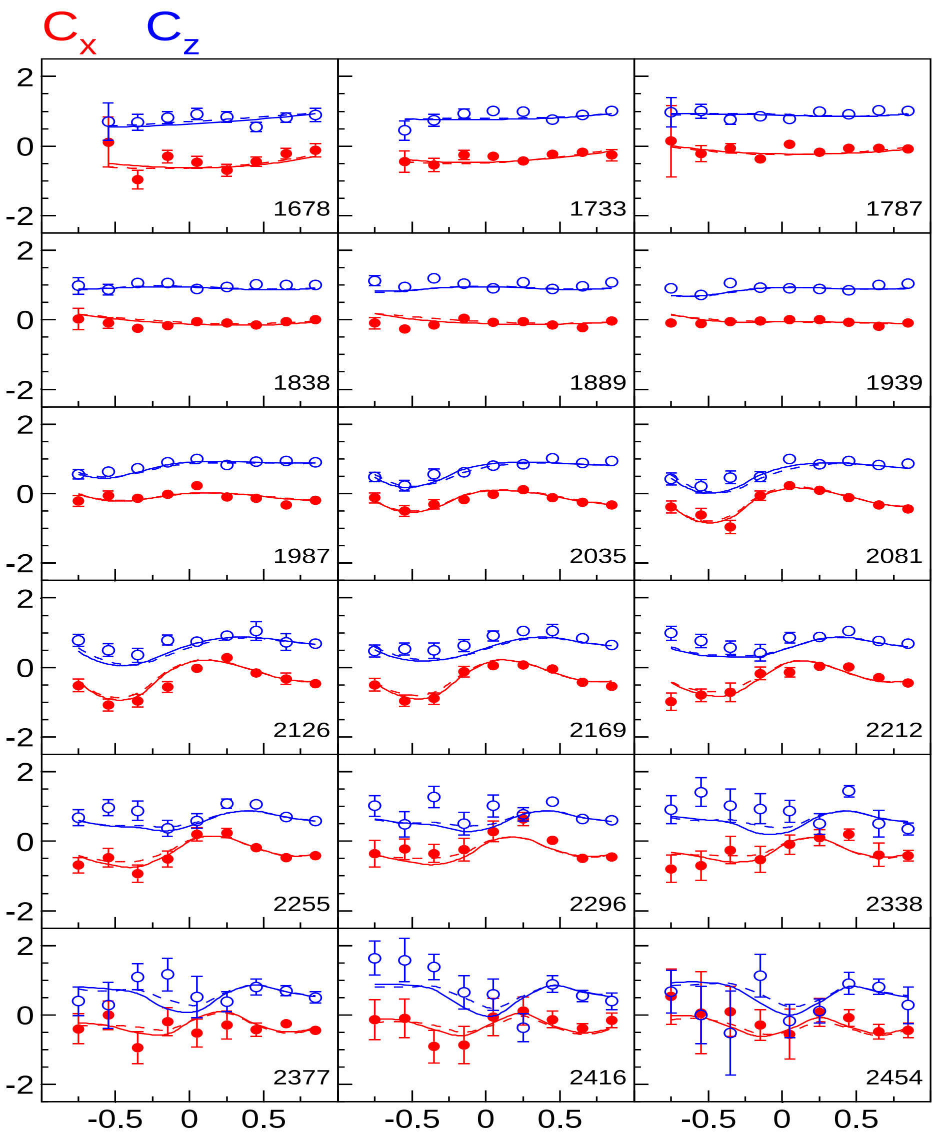
In a final step, the P_{13} was parameterized as 3-pole 8-channel K-matrix with πN, ηN, $\Delta(1232)\pi$ (P and F-waves), $N\sigma$, $D_{13}(1520)\pi$ (S-wave), $K\Lambda$ and $K\Sigma$ channels.

This resulted in the fit solutions 1 and 2 which both are compatible with B-W fits.

In addition, both solutions are compatible with elastic πN scattering.

The $\gamma p \to K^+\Lambda$: C_x, C_z (CLAS)

BG2011-02 M (dashed) **BG2013-02 (solid)**



Data on deuteron target

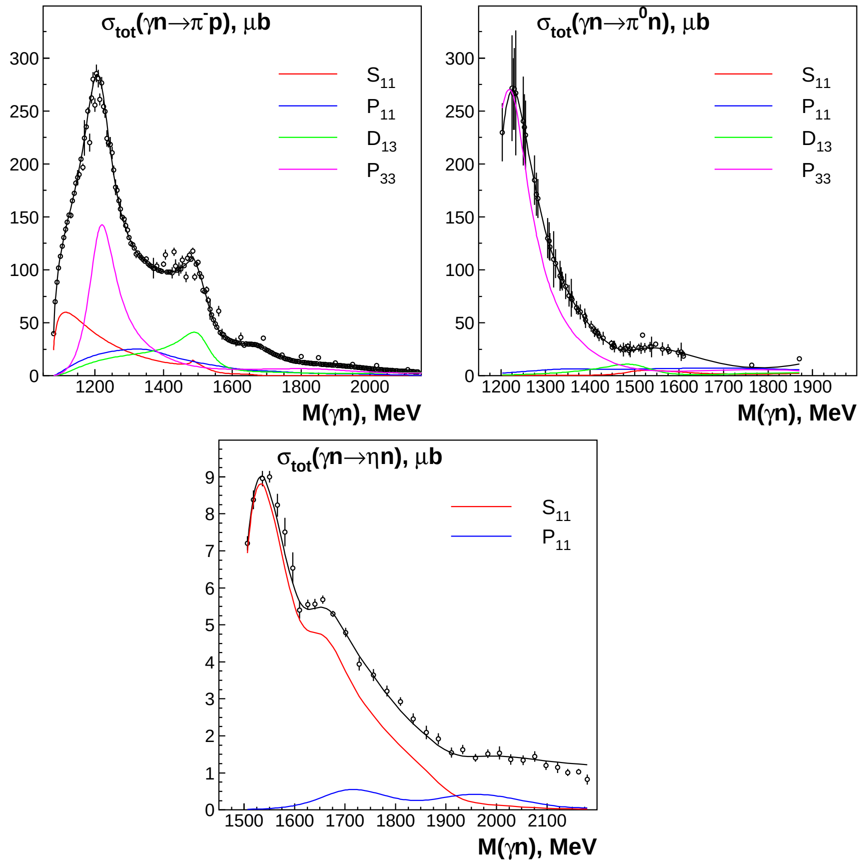
- **Data obtained with a deuteron target are affected by the Fermi motion of the neutron and by rescattering in the final state (Final State Interaction, FSI).**
- **The treatment of the Fermi motion in our approach was made with Paris wave function. For the FSI we use the corrections calculated by the SAID group.**

Analysis procedure

- **Start from BG2011-02 or 01 with only γn couplings open.**
- **From different starting values.**
- **Finally all values were free.**
- **Eur. Phys. J. A 49 (2013) 67**

Analysis of π^0 and η photoproduction off neutron

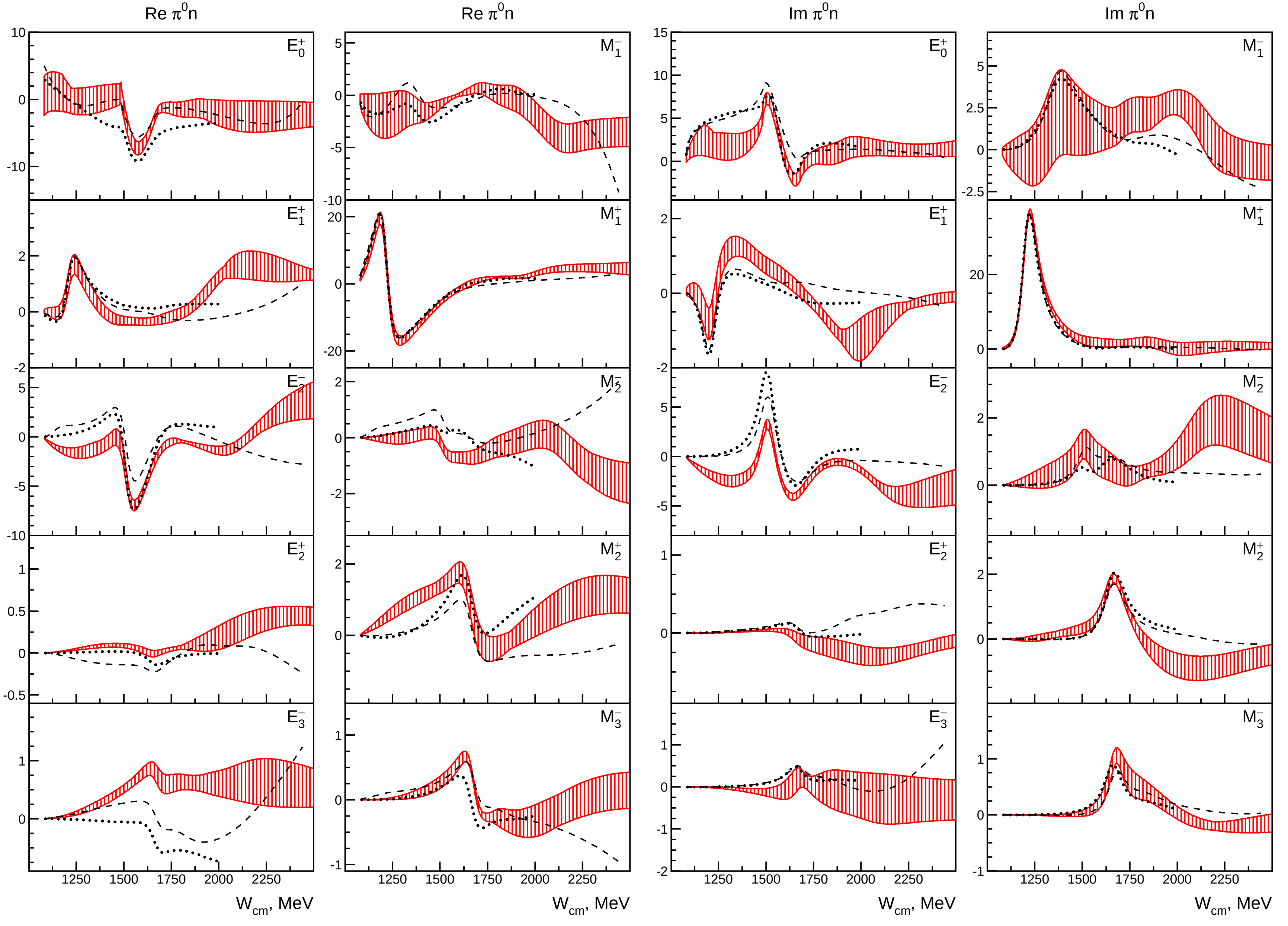
$\gamma n \to \pi^- p$	$N_{\rm data}$	χ^2_0	χ^2_f
$d\sigma/d\Omega$	1298	2.84	2.32
$d\sigma/d\Omega$	529	3.16	3.08
P	20	3.22	3.17
Σ	316	3.74	3.08
T	105	4.96	3.18
$\pi^- p \to \gamma n$			
$d\sigma/d\Omega$	495	1.65	1.53
P	55	4.59	3.11
$\gamma d \to \pi^0 n(p)$			
$d\sigma/d\Omega$	147	3.14	2.98
Σ	216	2.82	1.90
$\gamma d \to \eta n(p)$	$N_{\rm data}$	χ^2_0	χ^2_f
$d\sigma/d\Omega$	330	1.57	1.40
Σ	88	2.42	2.17



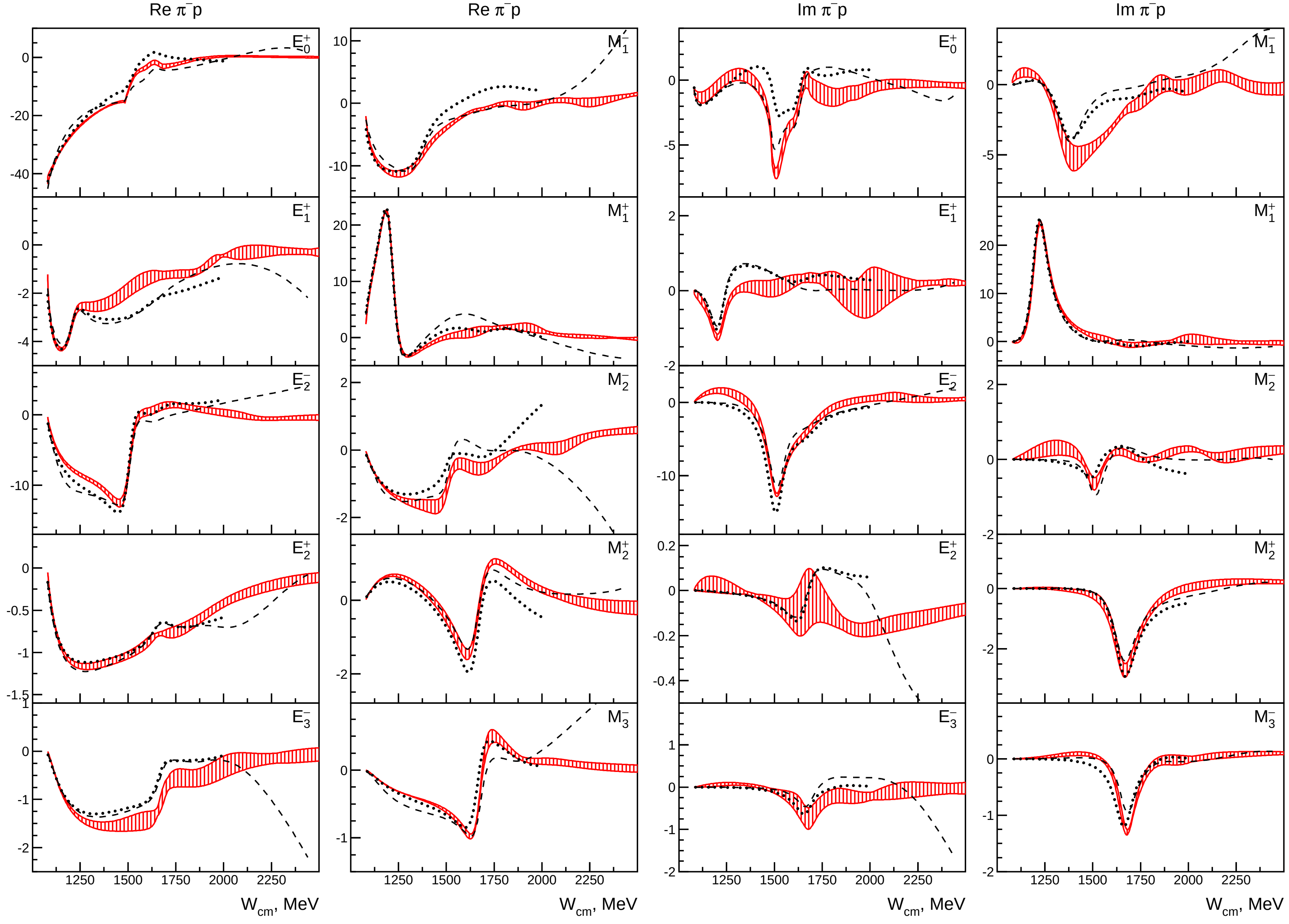
γn BW helicity couplings (GeV$^{-1/2}10^{-3}$)

	$\lvert A^{1/2}_{BW}\rvert$	$\lvert A^{3/2}_{BW}\rvert$		$\lvert A^{1/2}_{BW}\rvert$	$\lvert A^{3/2}_{BW}\rvert$
$N(1535)1/2^-$	-93±11		$N(1440)1/2^+$	43±12	
GB12	-58±6 (-85±15)		GB12	48±4	
SN11	-60±3		SN11	45±15	
MAID	-51		MAID	54	
PDG12	-46±27		PDG12	40±10	
$N(1650)1/2^-$	25±20		$N(1710)1/2^+$	-40±20	
GB12	-40±10 (-20±?)		GB12		
SN11	-26±8		SN11		
MAID	9		MAID		
PDG12	-15±21		PDG12	2±14	
$N(1520)3/2^-$	-49±8	-113±12	$N(1720)3/2^+$	-80±50	-140±65
GB12	-46±6	-115±5	GB12	ambiguous	ambiguous
SN11	-47±2	-125±2	SN11	-21±4	-38±7
MAID	-77	-154	MAID	-3	-31
PDG12	-59±9	-139±11	PDG12	4±15	-10±20
$N(1675)5/2^-$	-60±7	-88±10	$N(1680)5/2^+$	34±6	-44±9
GB12	-58±2	-80±5	GB12	26±4	-29±2
SN11	-42±2	-60±2	SN11	50±4	-47±2
MAID	-62	-84	MAID	28	-38
PDG12	-43±12	-58±13	PDG12	29±10	-33±9

Multipoles for photoproduction of π^0 off neutrons. MAID the dotted, SAID the dashed curve



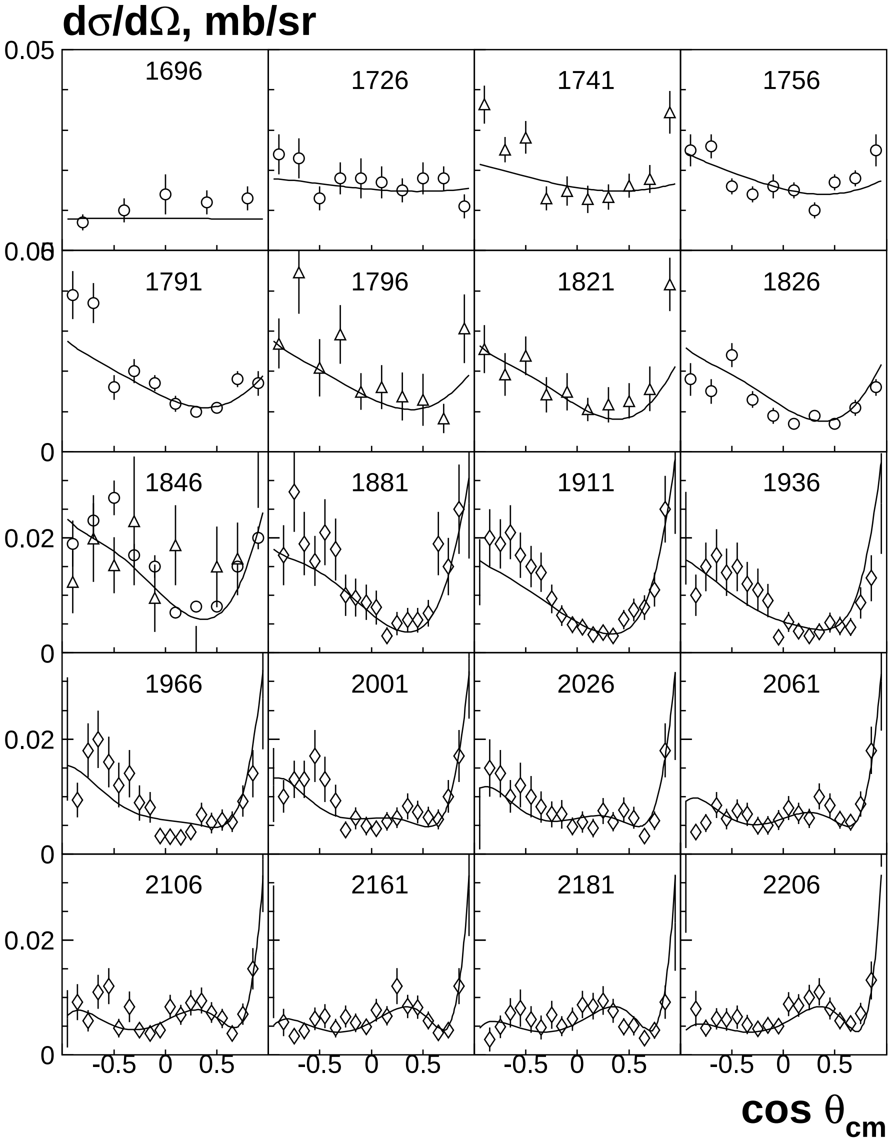
Multipoles for photoproduction of π^- off neutrons. MAID the dotted, SAID the dashed curve



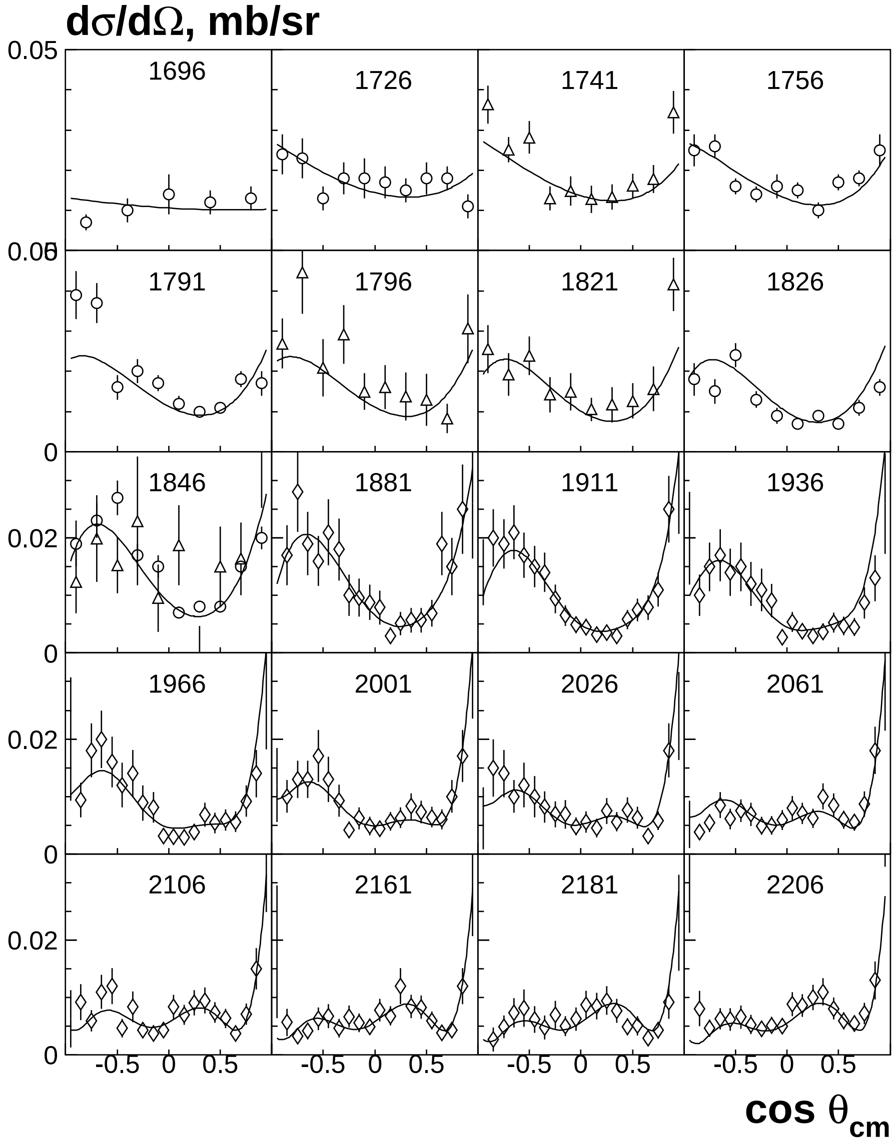
Ambiguities in $K\Sigma$ amplitudes

The fit of the the $\pi^- p \to K^0\Sigma^0$ differential cross section

BG2011-02 M



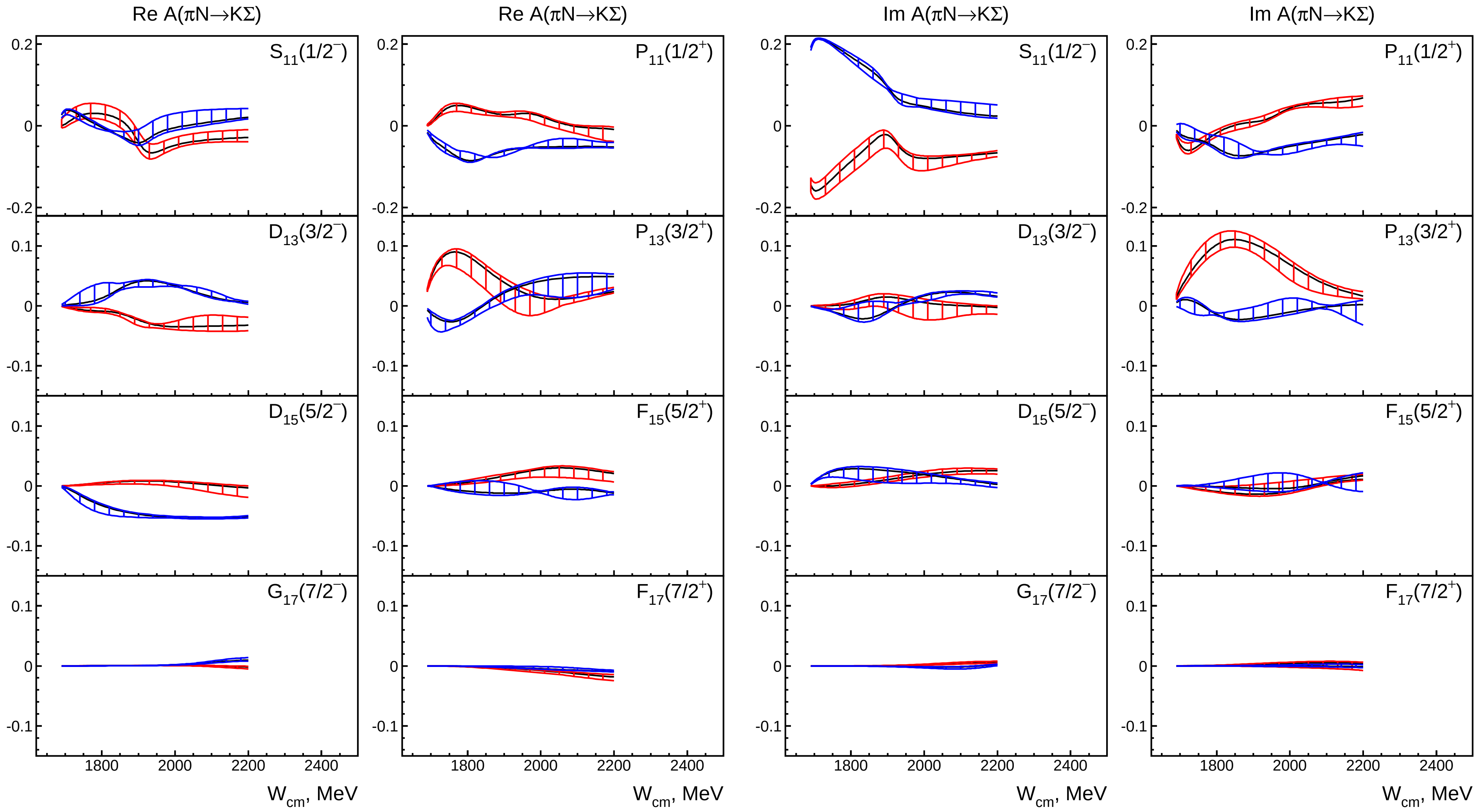
BG2013-02 S_{11}, D_{13}, F_{15}



The best solution was found with changed signs for S_{11}, D_{13} and F_{15} partial waves:

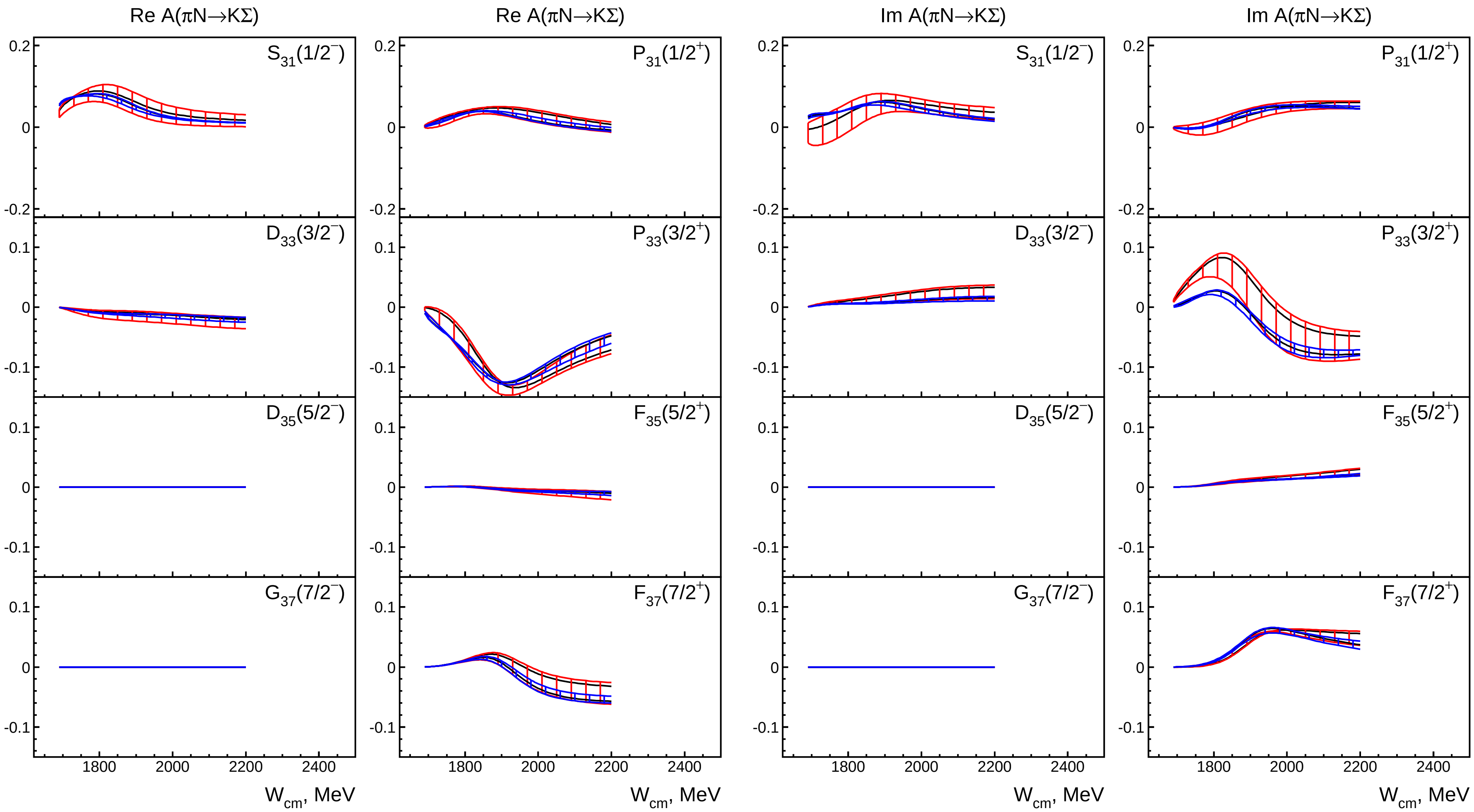
The I=1/2 $\pi N \to K\Sigma$ unitary amplitudes:

BG2011-02 M and BG2013-02



The I=3/2 $\pi N \to K\Sigma$ unitary amplitudes:

BG2011-02 M and BG2013-02

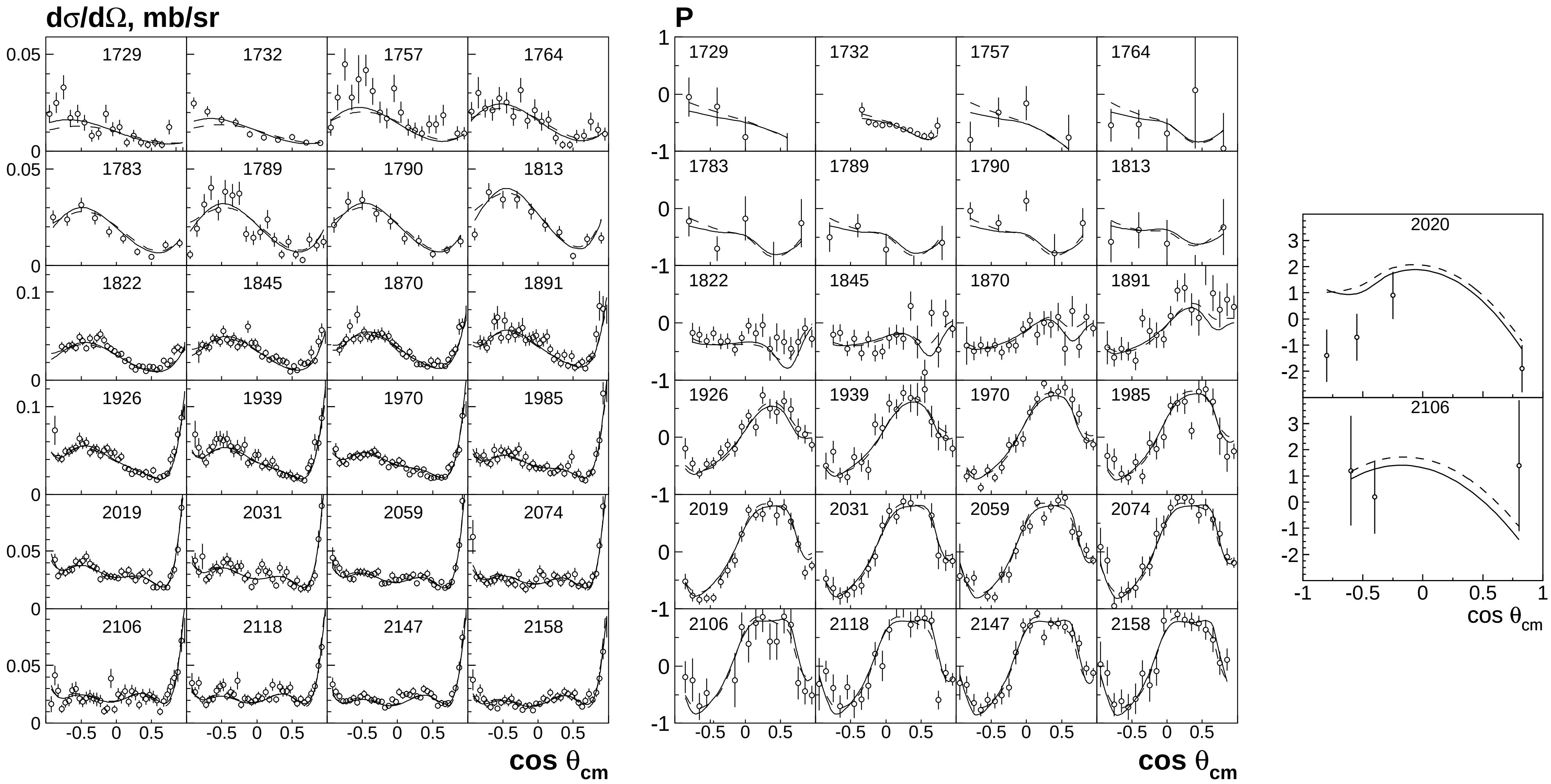


Quality of the description of the $K\Sigma$ data with the solutions BG2011-02 M and BG2013-02

Obs.	BnGa 2011-02M	BnGa 2013-02	N		Obs.	BnGa 2011-02M	BnGa 2013-02	N	
		$\pi^+ p \to K^+\Sigma^+$					$\pi^- p \to K^0\Sigma^0$		
$d\sigma/d\Omega$	1.46	1.35	743	(var.)	$d\sigma/d\Omega$	1.02	0.69	220	(RAL)
P	1.42	1.48	351	(var.)	P	1.53	1.21	85	(RAL)
β	2.09	1.89	7	(RAL)	$d\sigma/d\Omega$	2.22	1.91	95	(RAL)
		$\pi^- p \to K^+\Sigma^-$					$\gamma p \to K^0\Sigma^+$		
$d\sigma/d\Omega$	2.45	2.42	130	(var.)	$d\sigma/d\Omega$	3.25	4.00	48	(CLAS)
		$\gamma p \to K^+\Sigma^0$			$d\sigma/d\Omega$	1.28	1.45	160	(SAPHIR)
$d\sigma/d\Omega$	1.30	1.49	1590	(CLAS)	$d\sigma/d\Omega$	0.87	0.94	72	(CBT)
$d\sigma/d\Omega$	1.45	1.40	1145	(MAMI)	P	0.96	0.82	72	(CBT)
P	2.43	2.17	344	(CLAS)	$d\sigma/d\Omega$	0.61	0.72	72	(CBT)
Σ	2.45	1.99	42	(GRAAL)	P	1.66	1.35	24	(CBT)
C_x	2.13	2.56	94	(CLAS)	Σ	2.04	1.68	15	(CBT)
C_z	2.13	2.06	94	(CLAS)					

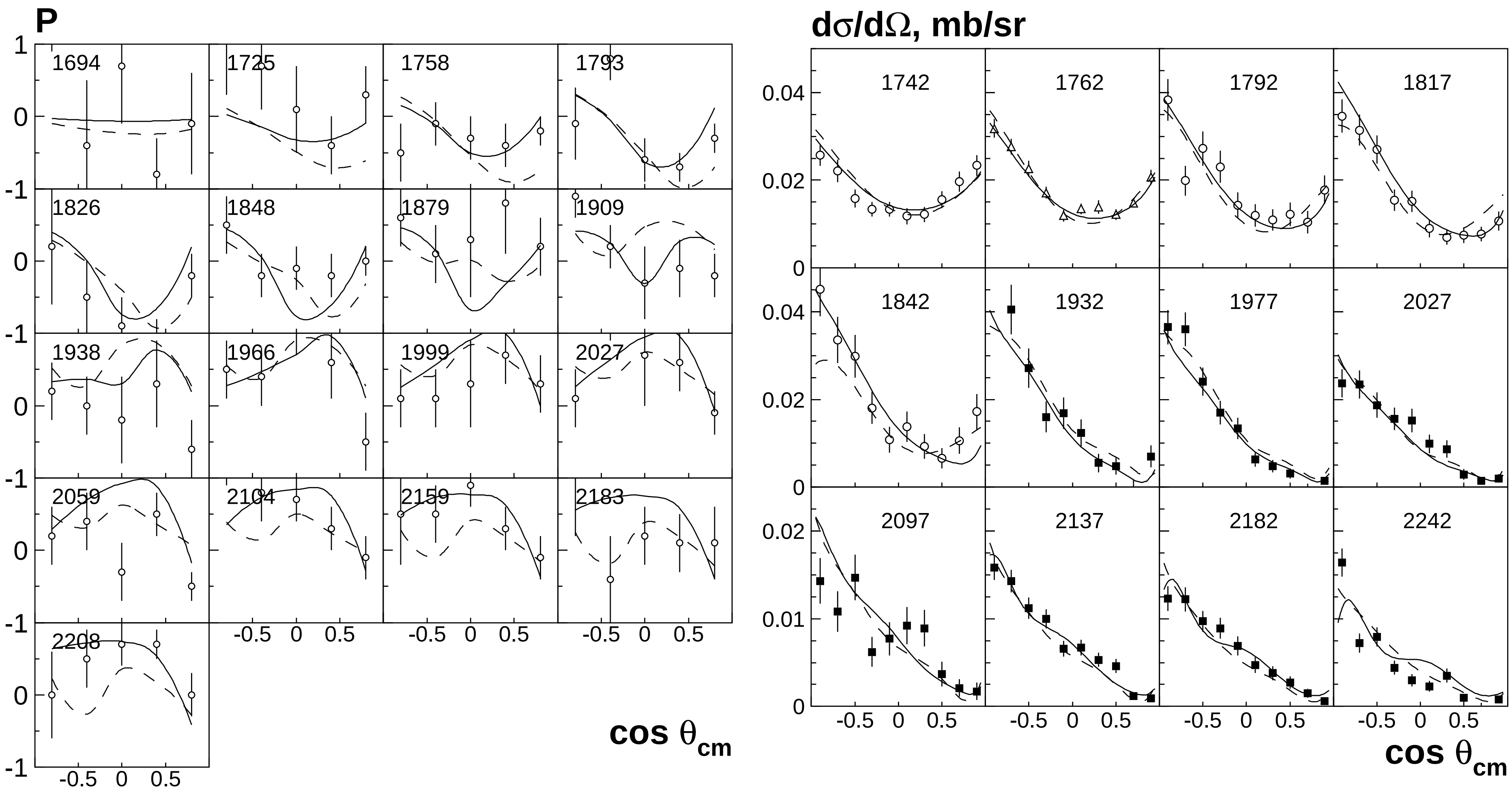
The fit of the the $\pi^+ p \to K^+\Sigma^+$.

BG2011-02 M (dashed) **BG2013-02 (solid)**



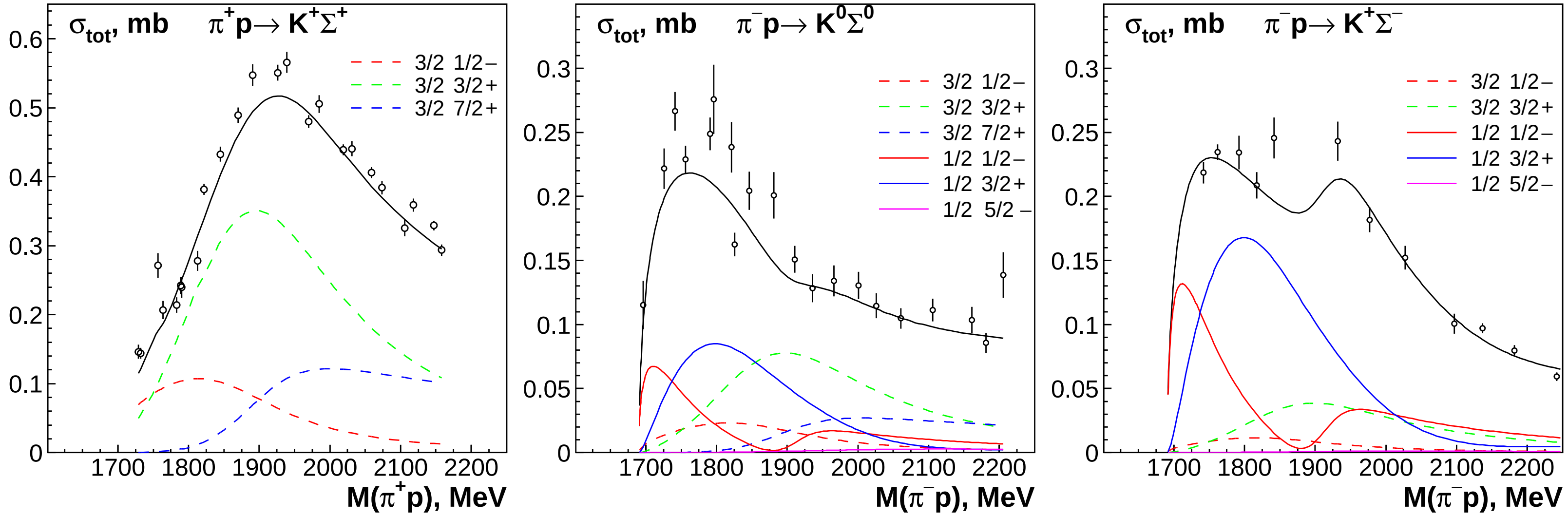
The $\pi^- p \to K^0\Sigma^0$ recoil asymmetry and $\pi^- p \to K^+\Sigma^-$ differential cross section

BG2011-02 M (dashed) **BG2013-02 (solid)**

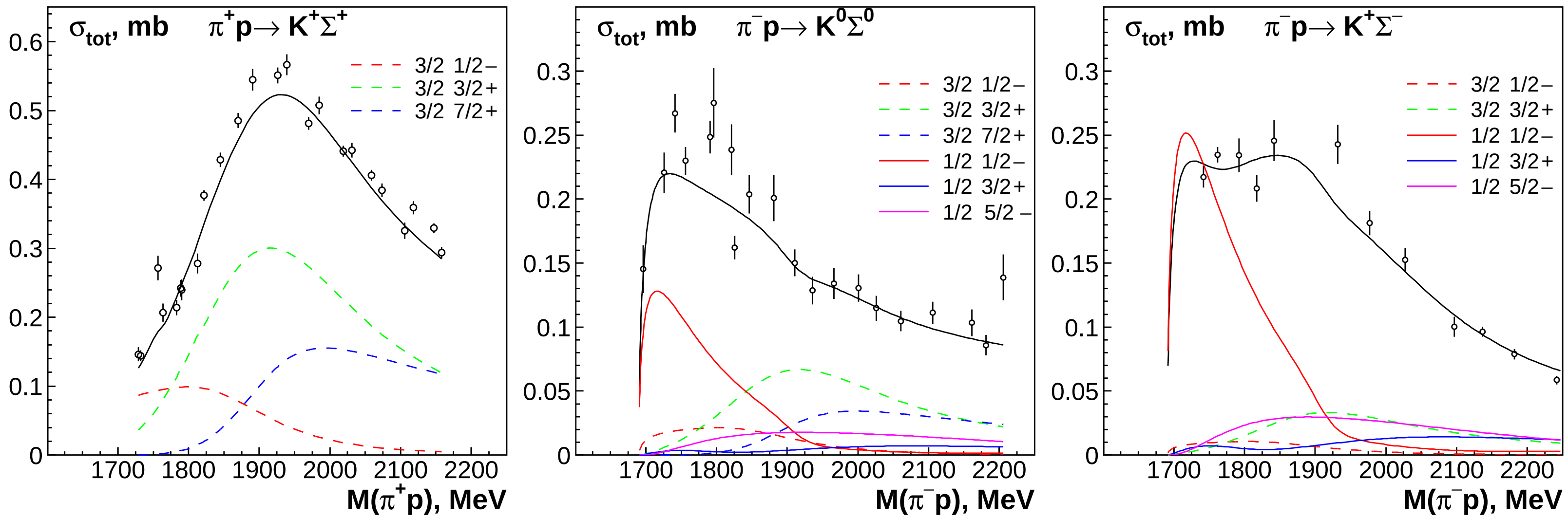


Partial wave contributions to the $\pi N \to K\Sigma$ total cross section

BG2011-02 M



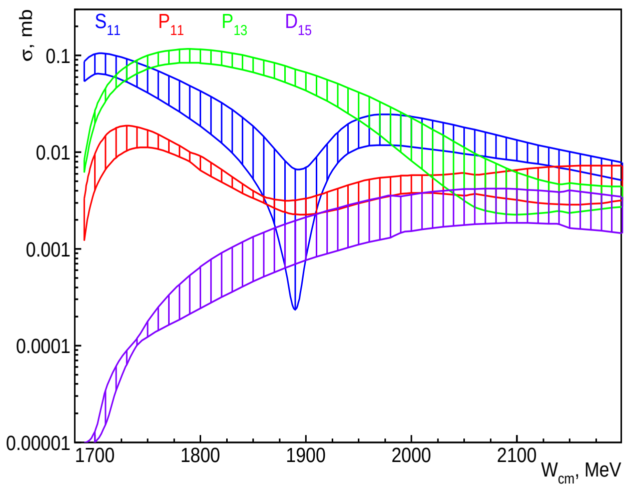
BG2013-02

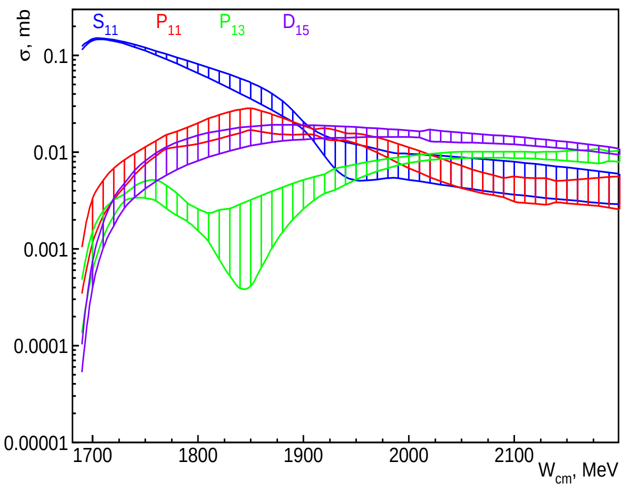


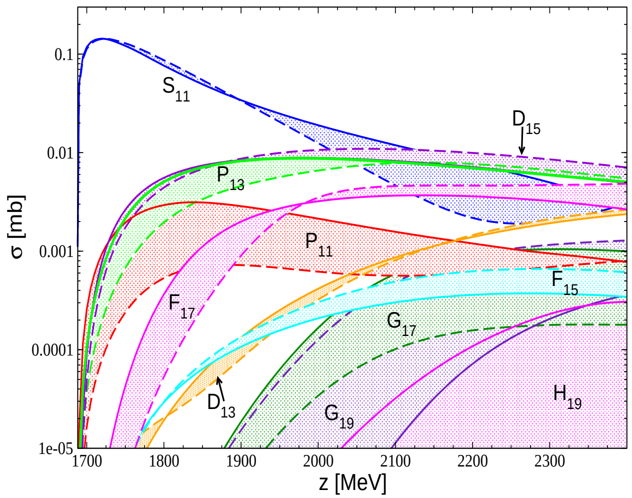
Partial wave contributions to the $\pi^- p \to K^0\Sigma^0$ total cross section

BG2011-02 M **BG2013-02** **Bonn-Jülich**

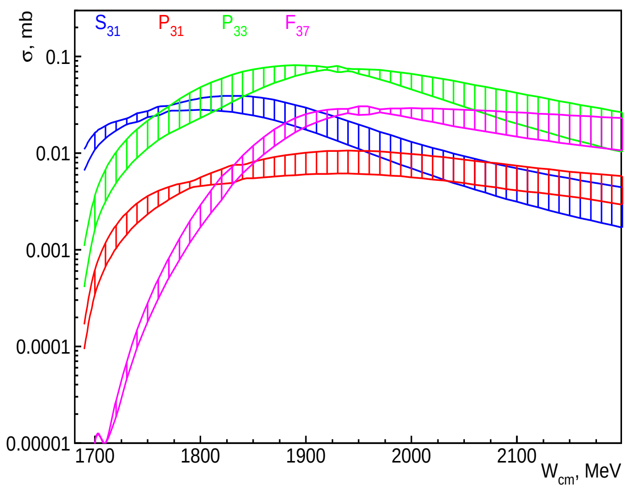
I=1/2

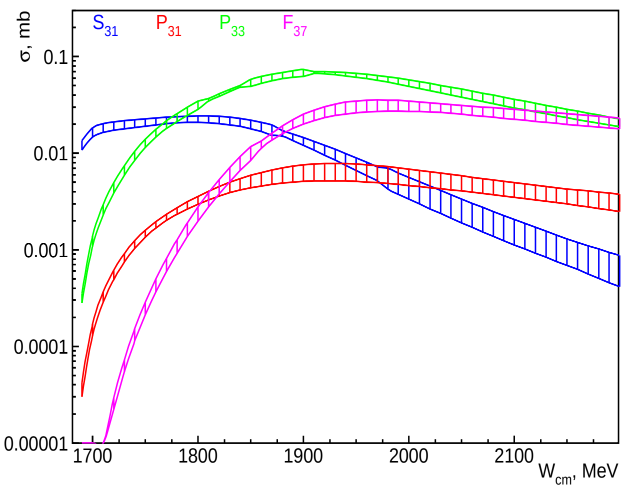


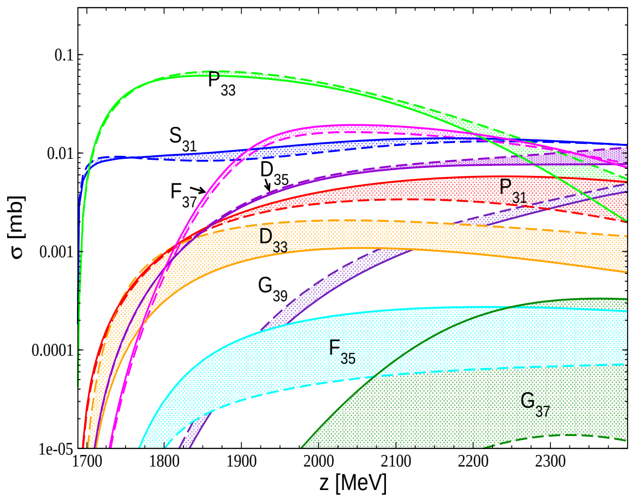




I=3/2



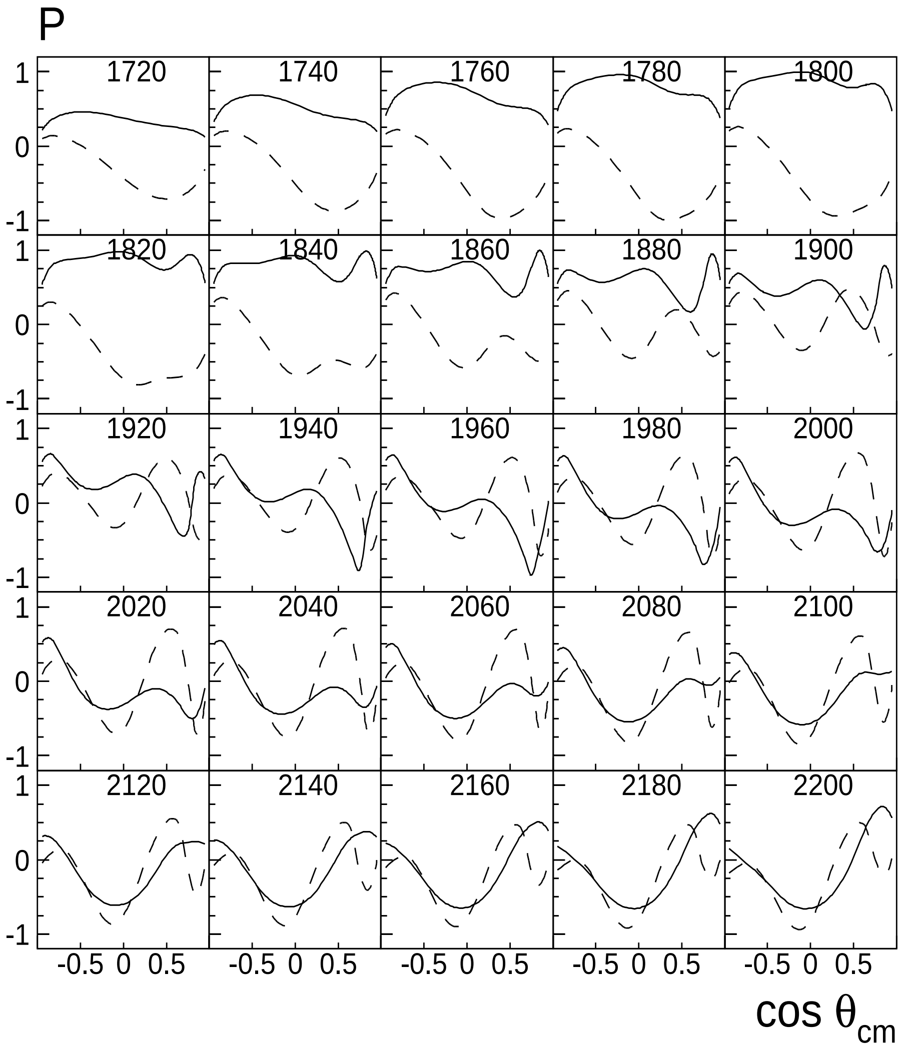




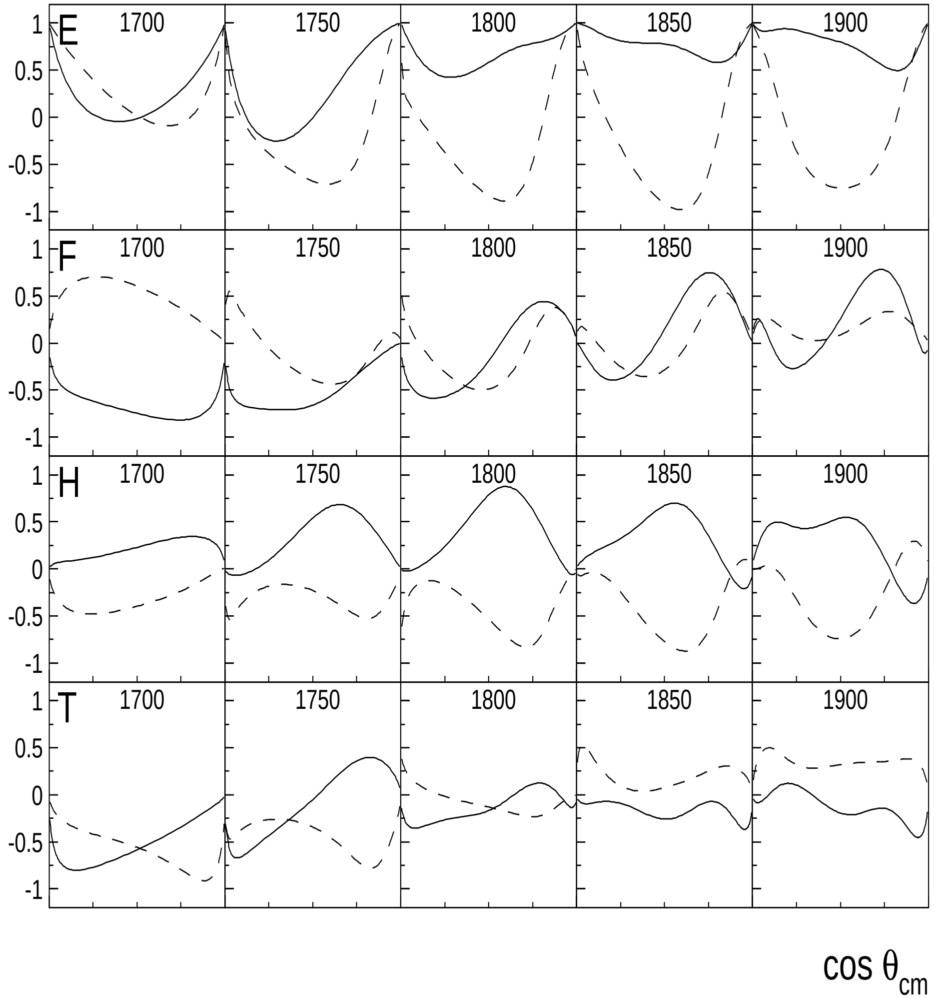
How to resolve this ambiguity? Measure more polarization observables

BG2011-02 M (dashed) **BG2013-02 (solid)**

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



$\gamma p \to K^0 \Sigma^+$



Summary

- **The investigation of the reactions with $K\Sigma$ final state revealed an ambiguity in the sign of the $K\Sigma$ coupling constants of leading nucleon partial wave amplitudes. New data on polarization observables either from reaction $\pi^- p \to K^+\Sigma^-$ or from $\gamma p \to K^0\Sigma^0$ should resolve this ambiguity.**
- **The new solution compares favorably to the solution obtained by the Bonn-Jülich group. It proves, that the result is mainly defined by the data base, but not by the analysis method.**