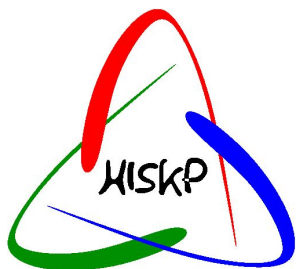


Combined analysis of photoproduction and pion induced data. Ambiguities in $K\Sigma$ amplitudes and omega photoproduction.

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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 <ul style="list-style-type: none">• SAID• MAID• Giessen Uni		BG PWA <ul style="list-style-type: none">• Publications• Talks• Contacts		Useful Links <ul style="list-style-type: none">• SPIRES• PDG Homepage• Durham Data Base• Bonn Homepage
CB-ELSA Homepage				

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

Search for baryon states

1. Analysis of single and double meson photoproduction reactions.

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

CB-ELSA, CLAS, MAMI, GRAAL, LEPS.

2. Analysis of single and double meson production in pion-induced reactions.

$$\pi N \rightarrow \pi N, \eta N, K\Lambda, K\Sigma, \pi\pi N.$$

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 BES III data on J/Ψ decays (in collaboration with JINR Dubna).

Analysis of NN interaction

1. Analysis of single and double meson production $NN \rightarrow \pi NN$ and (Wasa, PNPI, HADES)
2. Analysis of hyperon production $NN \rightarrow K\Lambda p$ (WASA, HADES)

Energy dependent approach

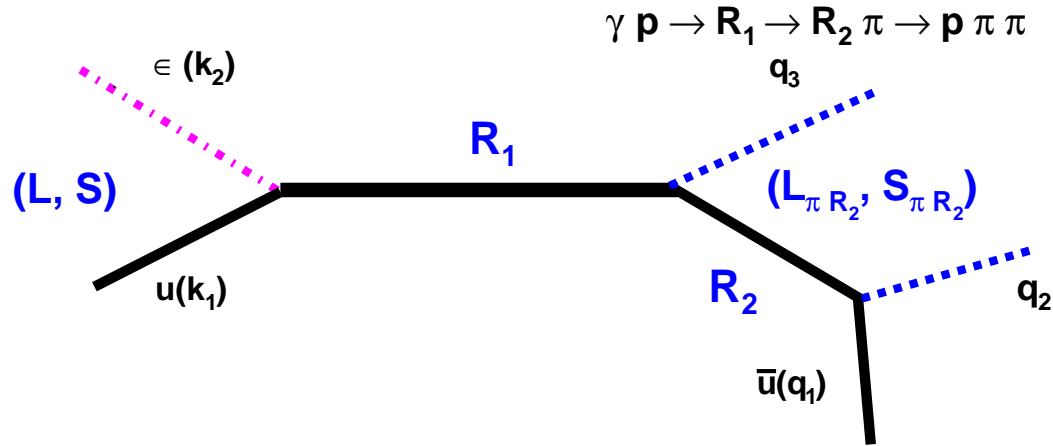
In many cases an unambiguous partial wave decomposition at fixed energies is impossible. Then the energy and angular parts should be analyzed together:

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

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).

Resonance amplitudes for meson photoproduction



General form of the angular dependent part of the amplitude:

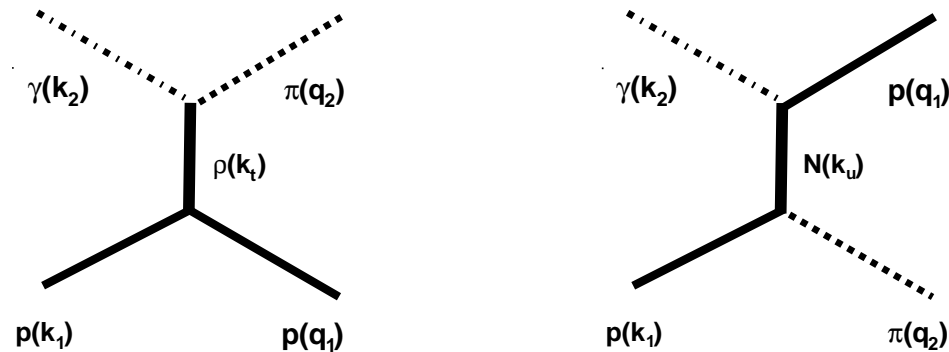
$$\bar{u}(q_1) \tilde{N}_{\alpha_1 \dots \alpha_n} (R_2 \rightarrow \mu N) F_{\beta_1 \dots \beta_n}^{\alpha_1 \dots \alpha_n} (q_1 + q_2) \tilde{N}_{\gamma_1 \dots \gamma_m}^{(j) \beta_1 \dots \beta_n} (R_1 \rightarrow \mu R_2)$$

$$F_{\xi_1 \dots \xi_m}^{\gamma_1 \dots \gamma_m} (P) V_{\xi_1 \dots \xi_m}^{(i) \mu} (R_1 \rightarrow \gamma N) u(k_1) \varepsilon_\mu$$

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

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

Reggeized exchanges:



The amplitude for t-channel exchange:

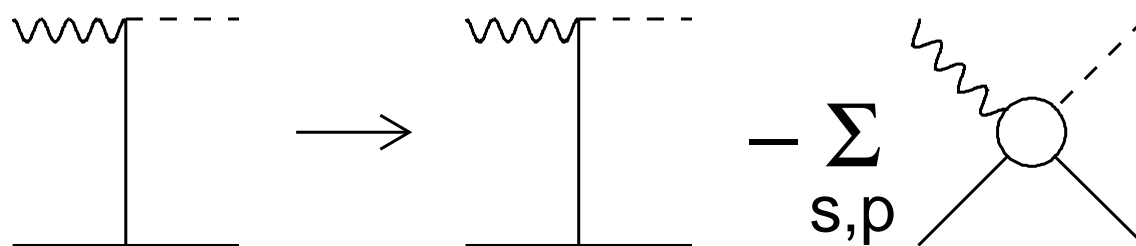
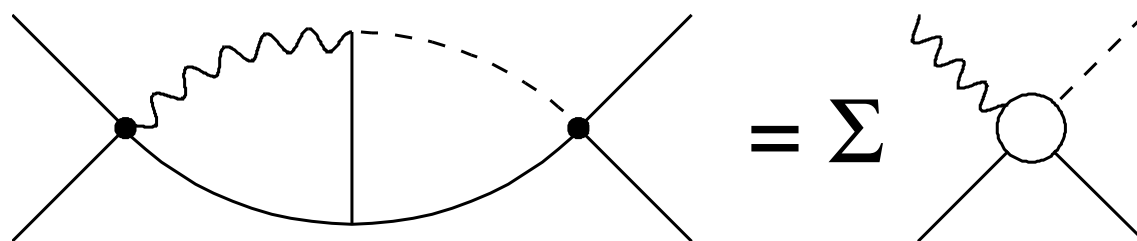
$$A = g_1(t)g_2(t)R(\xi, \nu, t) = g_1(t)g_2(t) \frac{1 + \xi \exp(-i\pi\alpha(t))}{\sin(\pi\alpha(t))} \left(\frac{\nu}{\nu_0} \right)^{\alpha(t)} \quad \nu = \frac{1}{2}(s - u).$$

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

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

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

t,u-exchange subtraction procedure



Parameterization of the partial wave amplitude

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

and

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

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

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

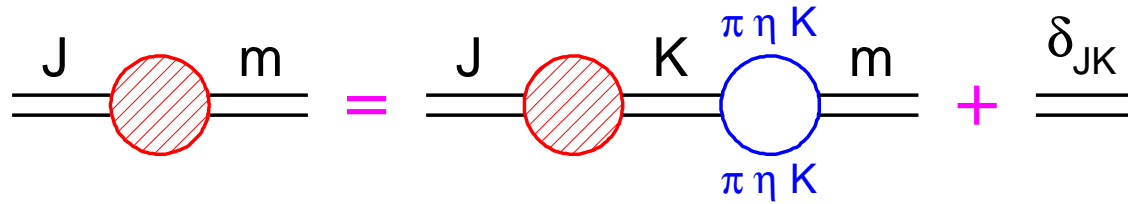
$$A_k = P_j(I - i\rho K)_{jk}^{-1}$$

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 .

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



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

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

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

In the present fits we calculate the elements of the B_α^{ij} using one subtraction taken at the channel threshold $M_\alpha = (m_{1\alpha} + m_{2\alpha})$:

$$B_\alpha^{ij}(s) = B_\alpha^{ij}(M_\alpha^2) + (s - M_\alpha^2) \int_{m_a^2}^{\infty} \frac{ds'}{\pi} \frac{g_\alpha^{(R)i} \rho_\alpha(s', m_{1\alpha}, m_{2\alpha}) g_\alpha^{(L)j}}{(s' - s - i0)(s' - M_\alpha^2)}.$$

In this case the expression for elements of the \hat{B} matrix can be rewritten as:

$$B_\alpha^{ij}(s) = g_a^{(R)i} \left(b^\alpha + (s - M_\alpha^2) \int_{m_a^2}^{\infty} \frac{ds'}{\pi} \frac{\rho_\alpha(s', m_{1\alpha}, m_{2\alpha})}{(s' - s - i0)(s' - M_\alpha^2)} \right) g_\beta^{(L)j} = g_a^{(R)i} B_\alpha g_\beta^{(L)j}$$

and D-matrix method equivalent to the K-matrix method with loop diagram with real part taken into account:

$$A = \hat{K}(I - \hat{B}\hat{K})^{-1} \quad B_{\alpha\beta} = \delta_{\alpha\beta} B_\alpha$$

Minimization methods

1. The two body final states $\pi N, \gamma N \rightarrow \pi N, \eta N, K \Lambda, K \Sigma, \omega N, K^* \Lambda$: χ^2 method.

For n measured bins we minimize

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

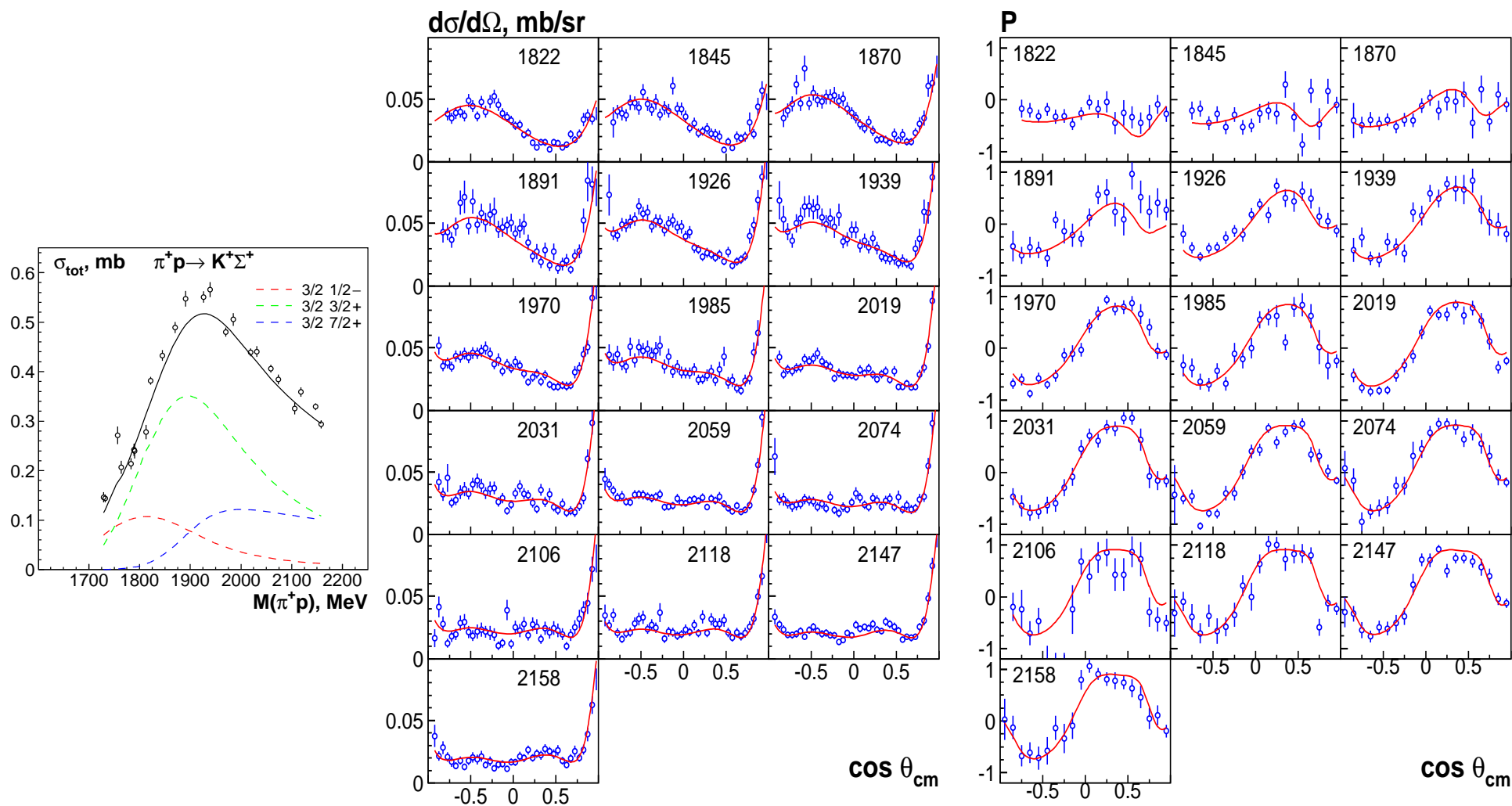
Present solution $\chi^2 = 48710$ for 31180 points. $\chi^2/N_F = 1.6$

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

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

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.

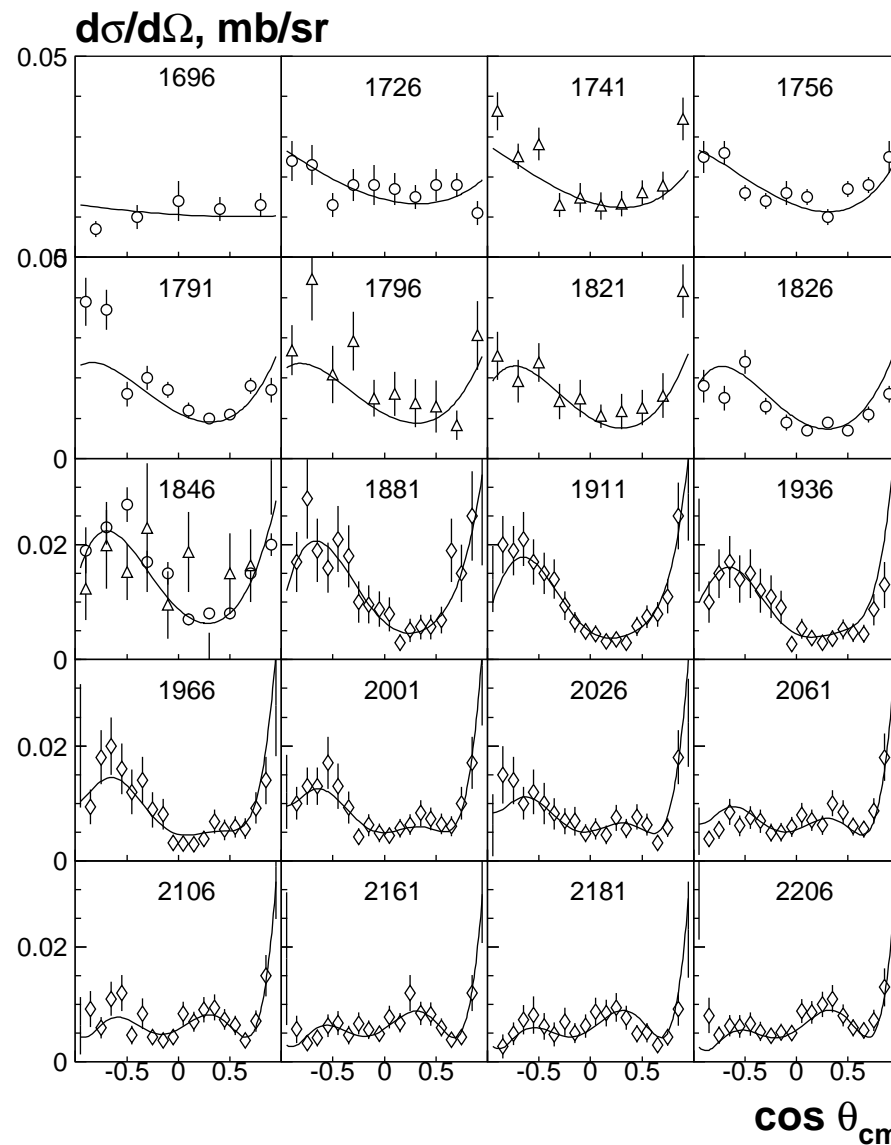
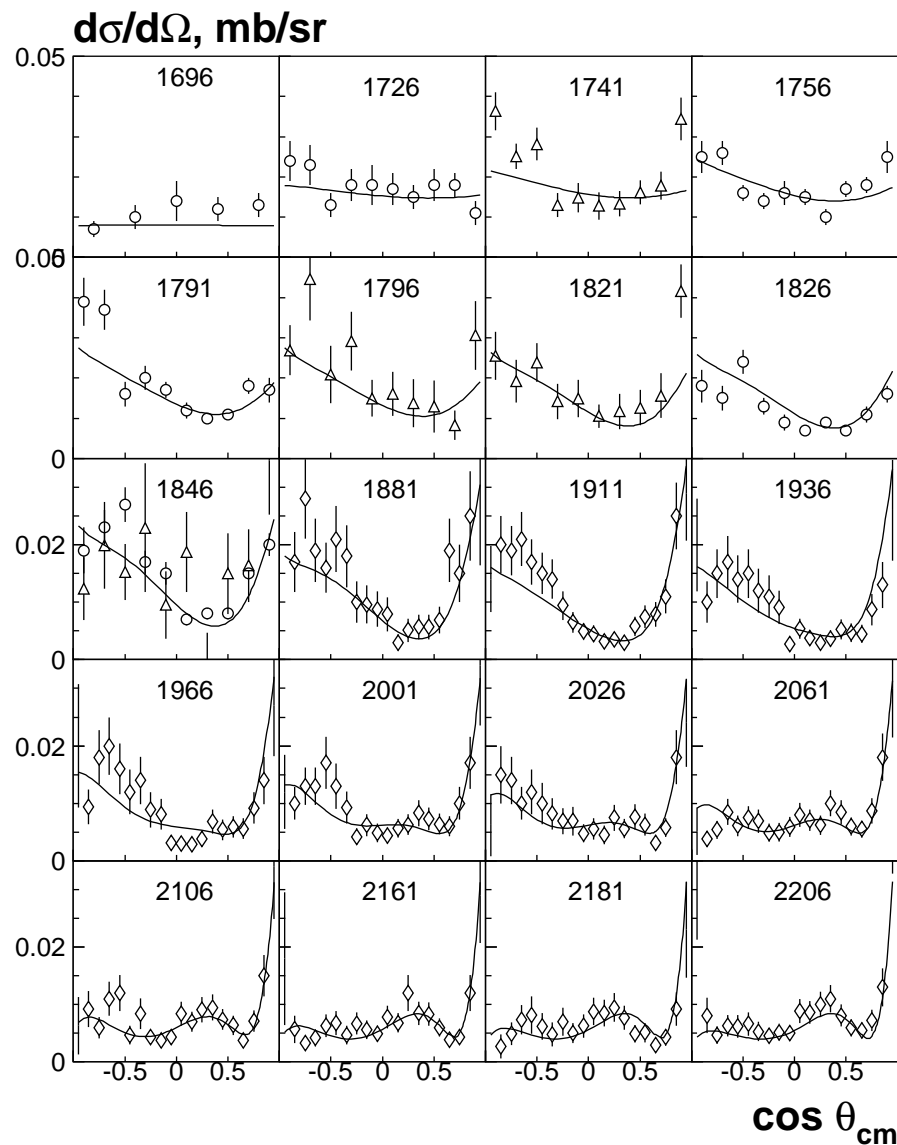
The fit of the the $\pi^+ p \rightarrow K^+ \Sigma^+$ reaction with **BG2011-02**



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

BG2011-02 M

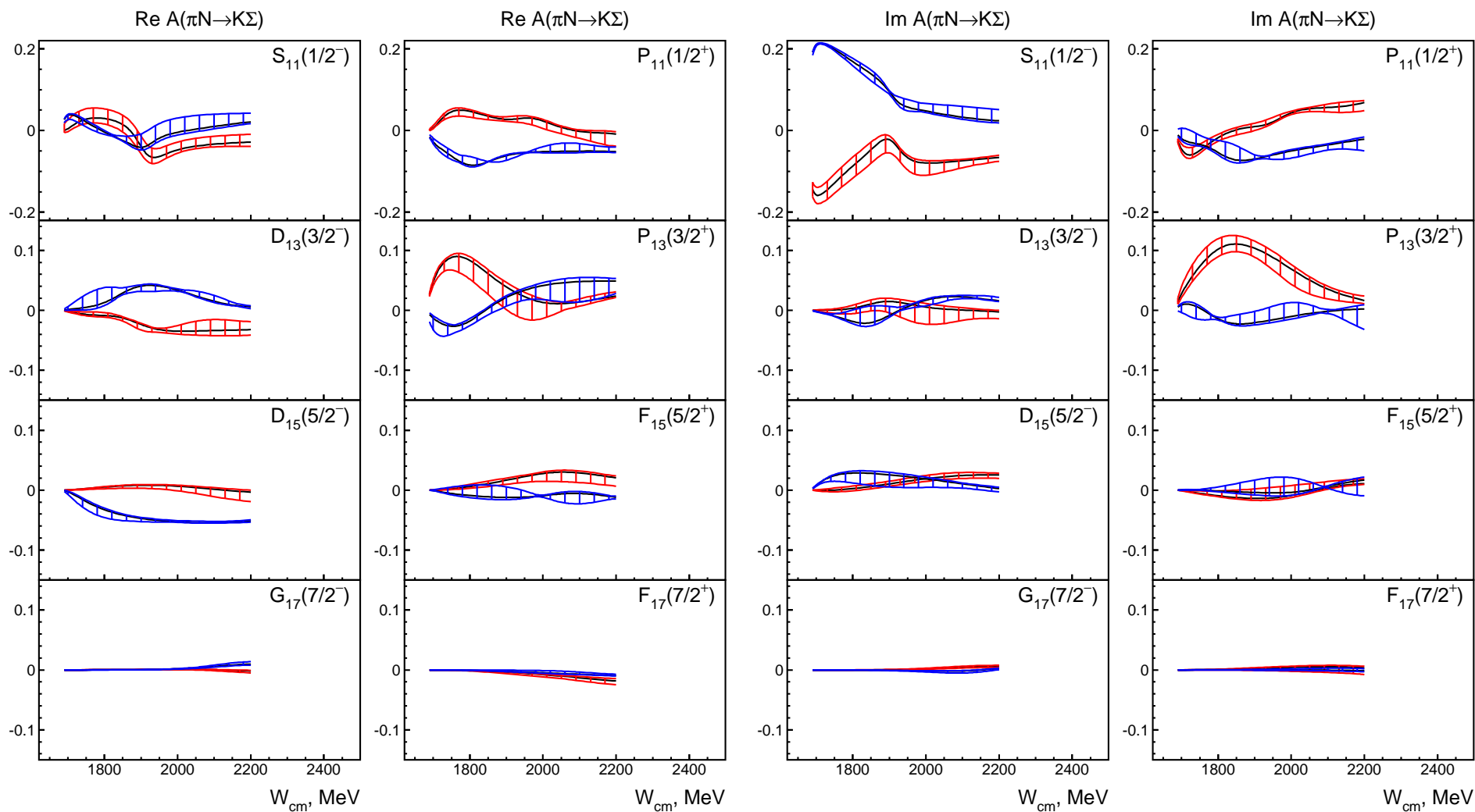
BG2013-02 S_{11}, D_{13}, F_{15}



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

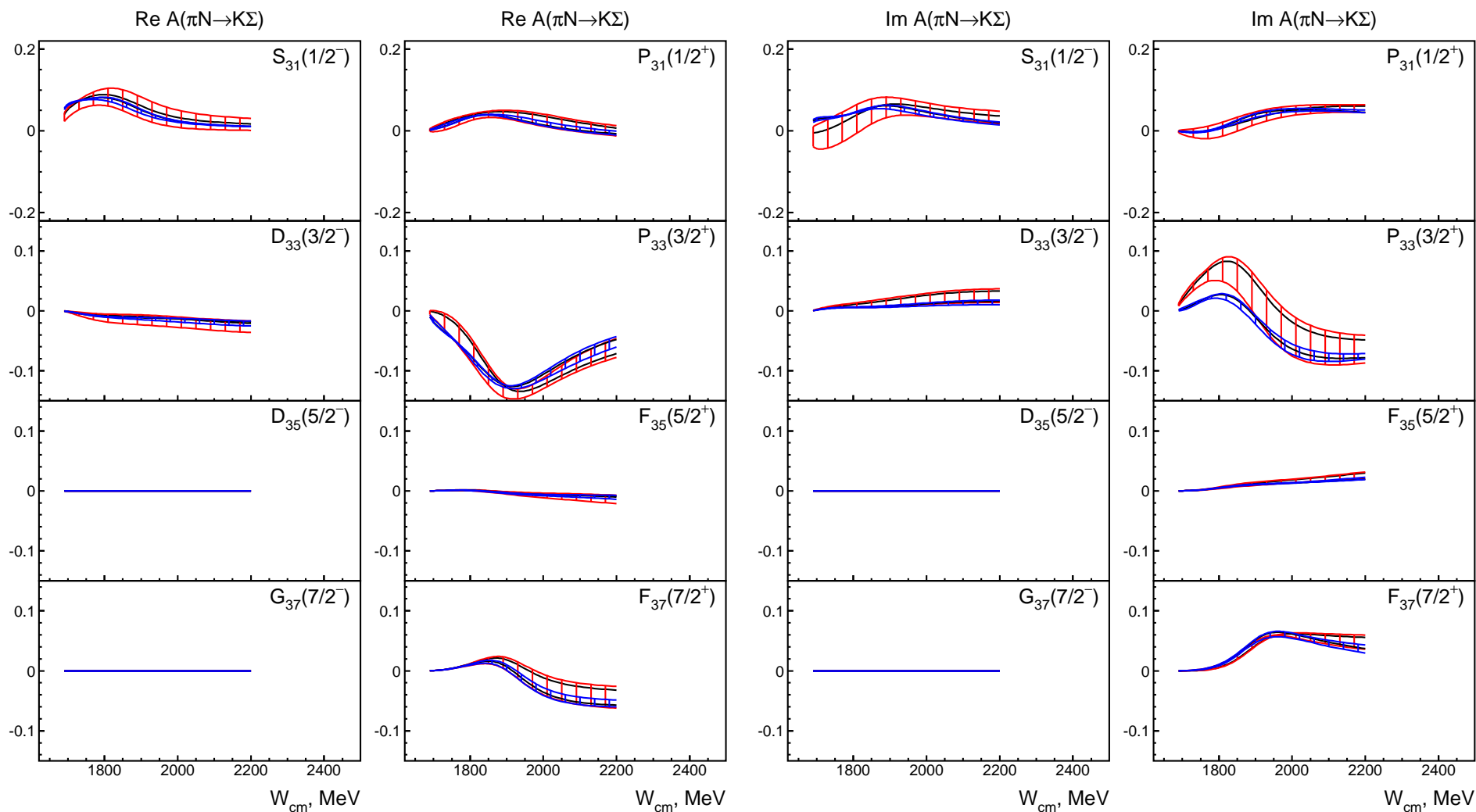
The $l=1/2$ $\pi N \rightarrow K\Sigma$ unitary amplitudes:

BG2011-02 M and **BG2013-02**



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

BG2011-02 M and **BG2013-02**



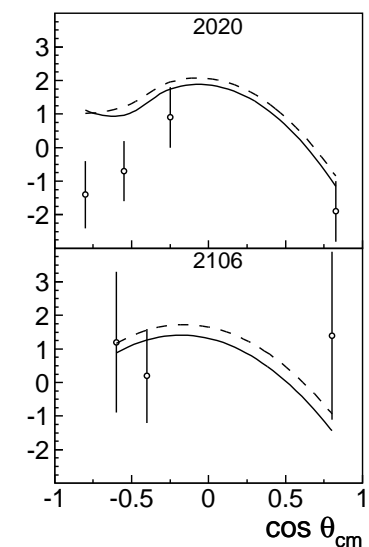
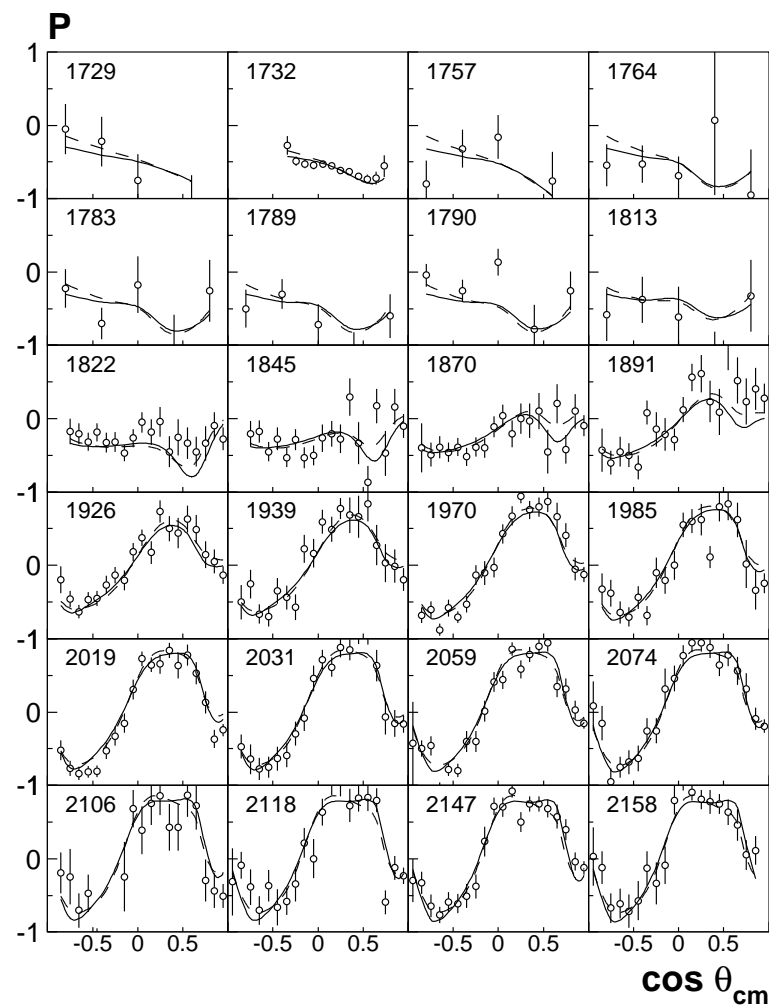
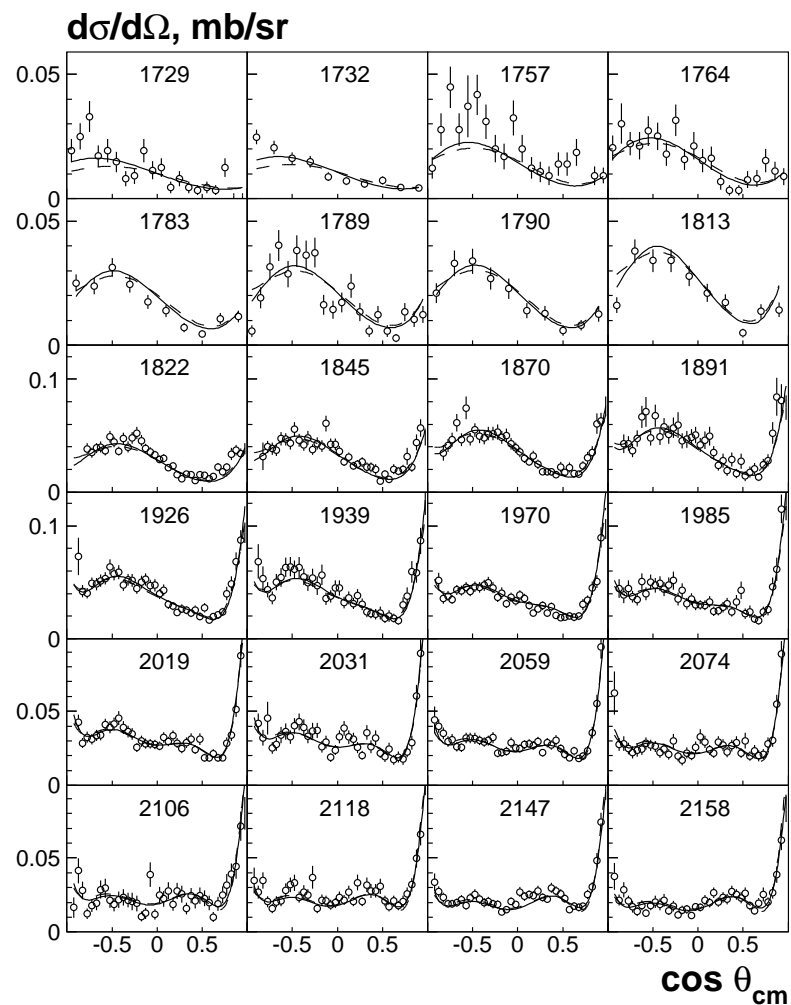
Quality of the description of the $K\Sigma$ data with the solutions **BG2011-02 M** and **BG2013-02**

Obs.	BnGa 2011-02M	BnGa 2013-02	N		Obs.	BnGa 2011-02M	BnGa 2013-02	N	
	$\pi^+ p \rightarrow K^+ \Sigma^+$					$\pi^- p \rightarrow K^0 \Sigma^0$			
$d\sigma/d\Omega$	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)
	$\pi^- p \rightarrow K^+ \Sigma^-$					$\gamma p \rightarrow K^0 \Sigma^+$			
$d\sigma/d\Omega$	2.45	2.42	130	(var.)	$d\sigma/d\Omega$	3.25	4.00	48	(CLAS)
	$\gamma p \rightarrow K^+ \Sigma^0$				$d\sigma/d\Omega$	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 $\pi^+ p \rightarrow K^+ \Sigma^+$.

BG2011-02 M (dashed)

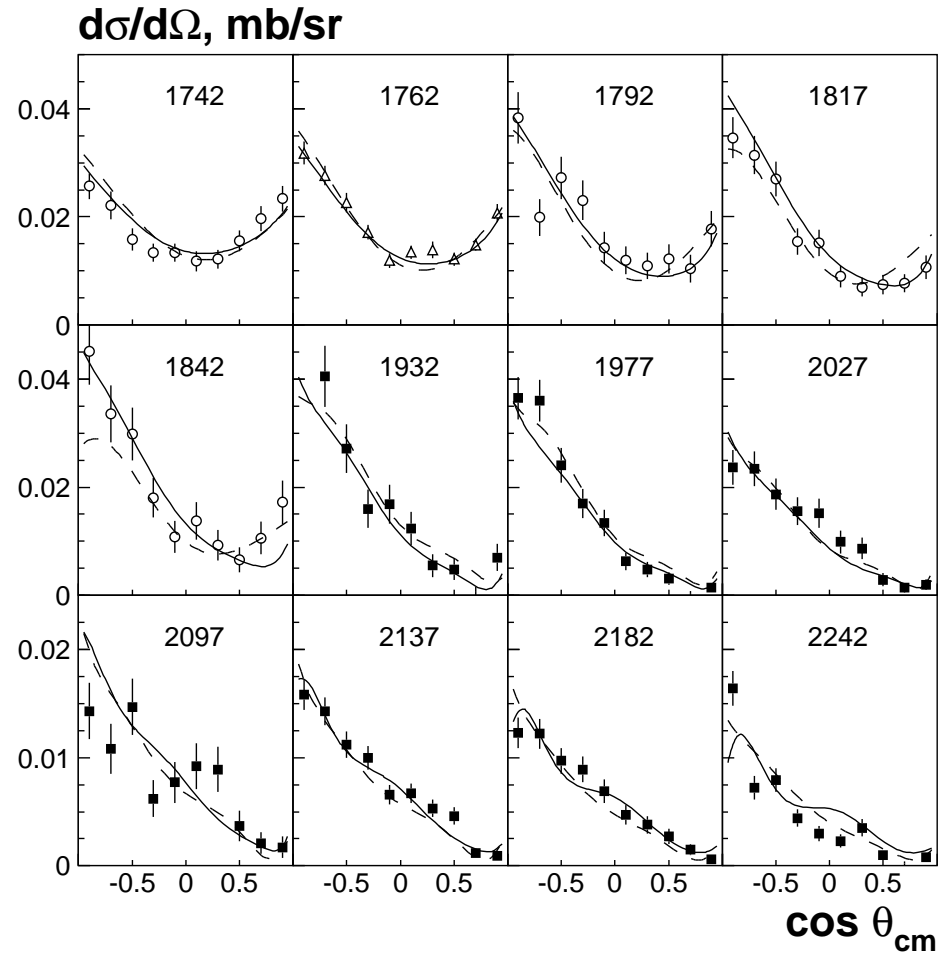
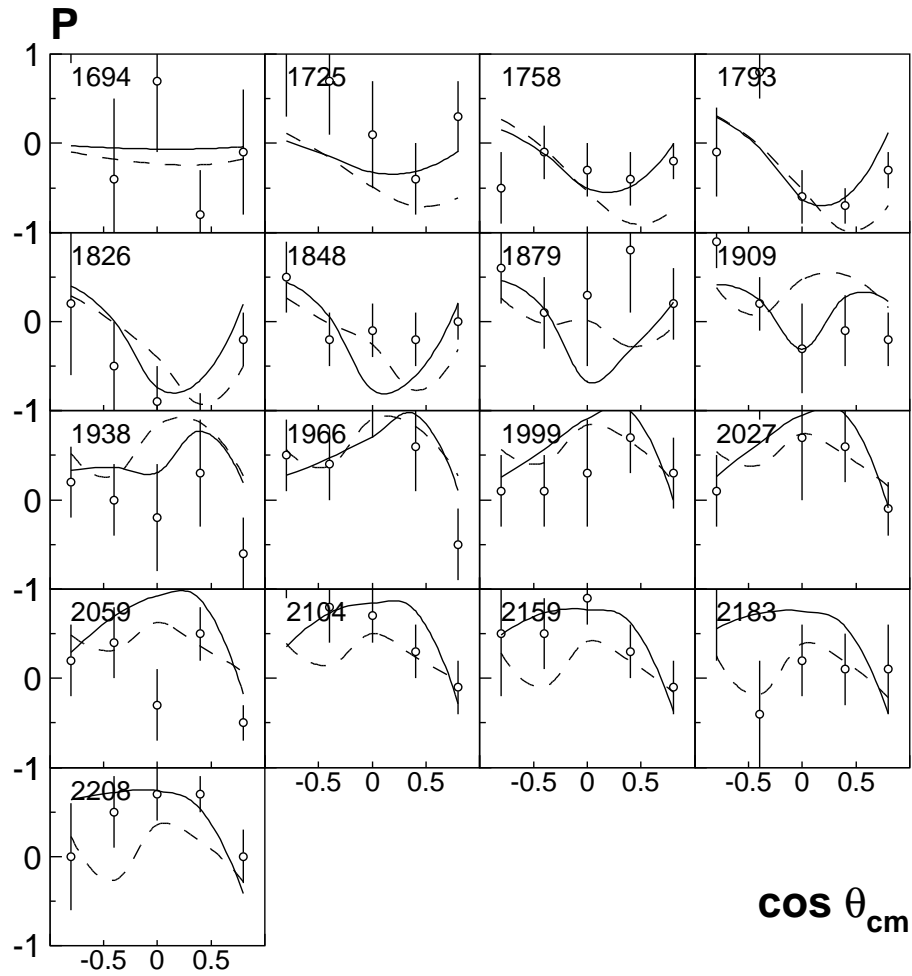
BG2013-02 (solid)



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

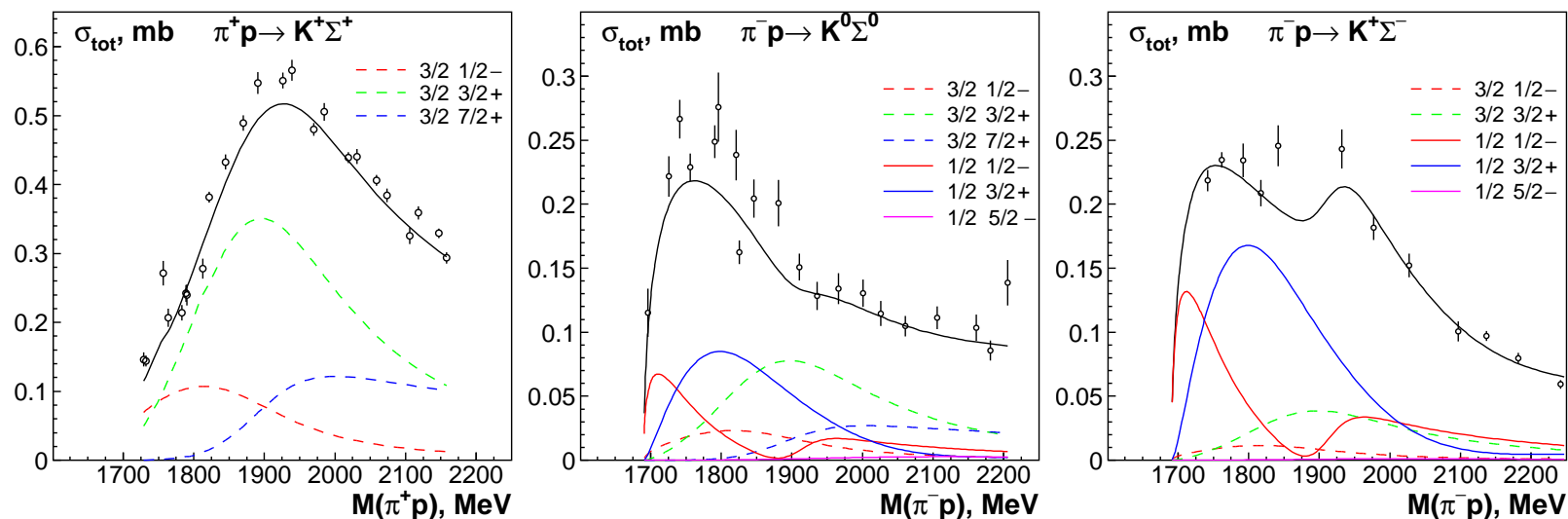
BG2011-02 M (dashed)

BG2013-02 (solid)

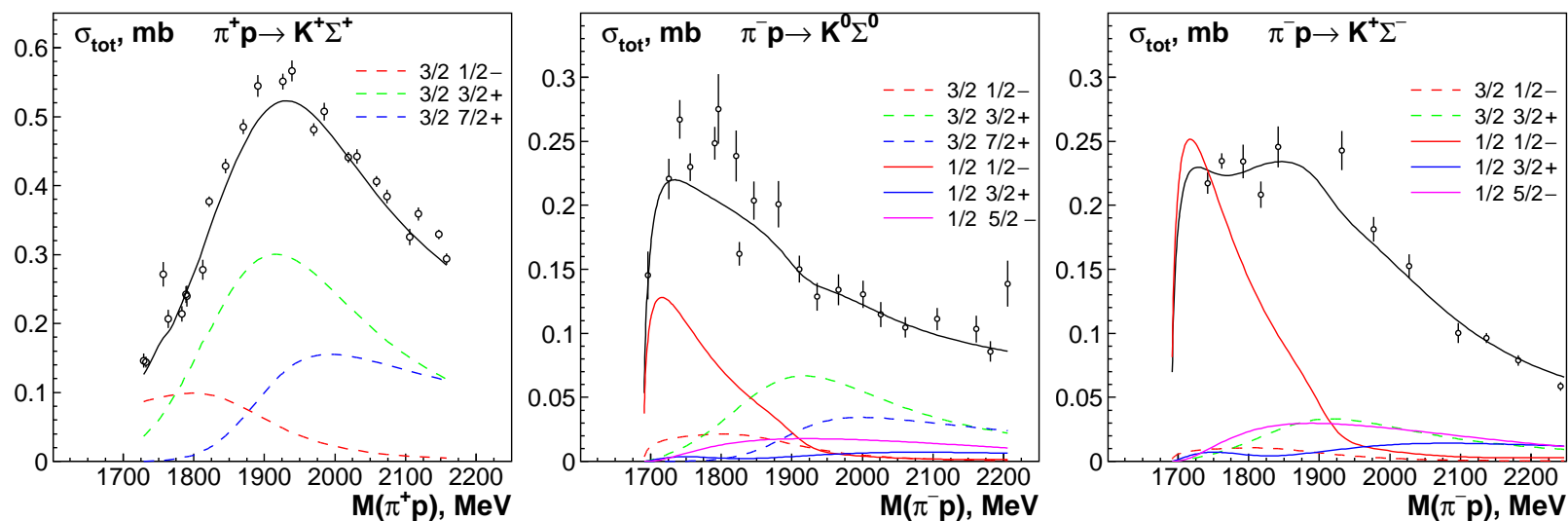


Partial wave contributions to the $\pi N \rightarrow K \Sigma$ total cross section

BG2011-02 M



BG2013-02



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

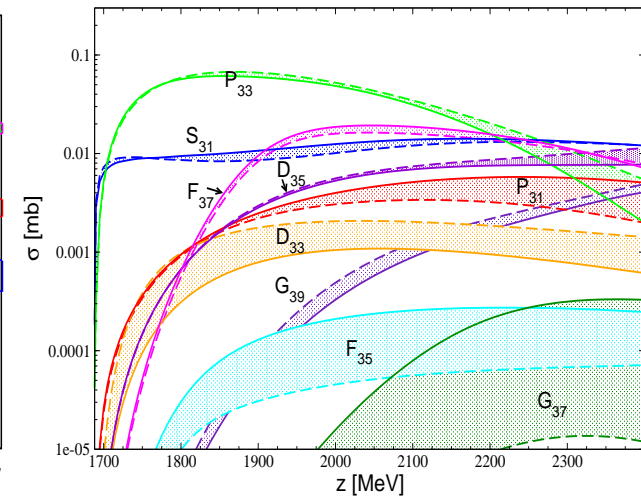
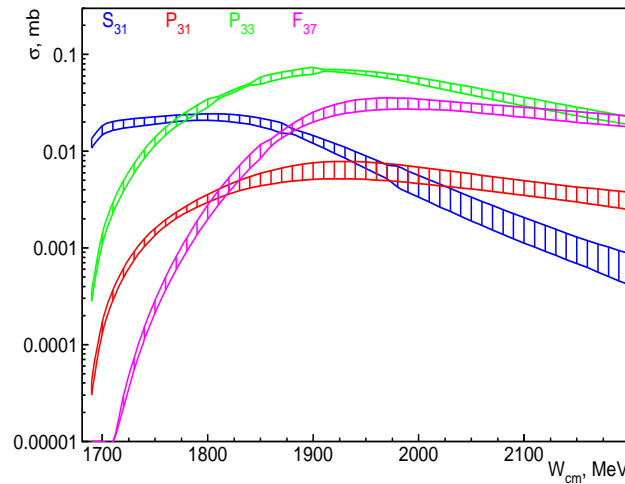
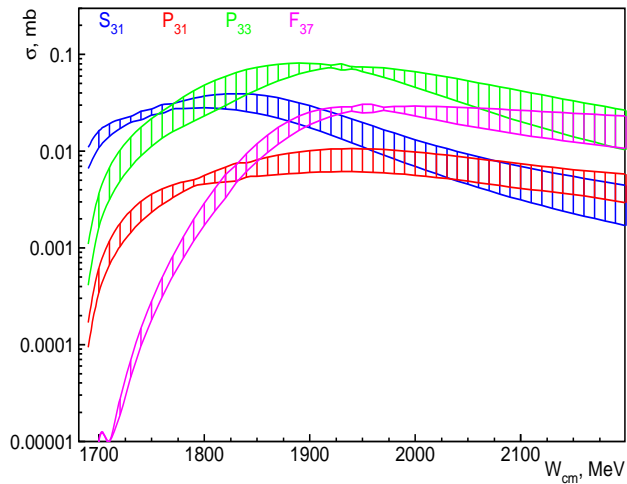
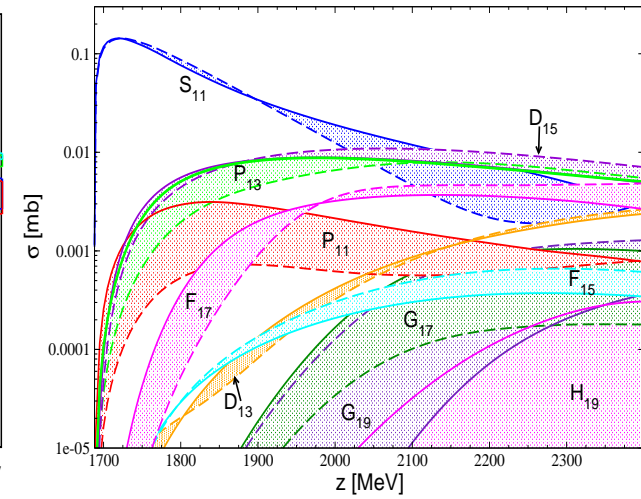
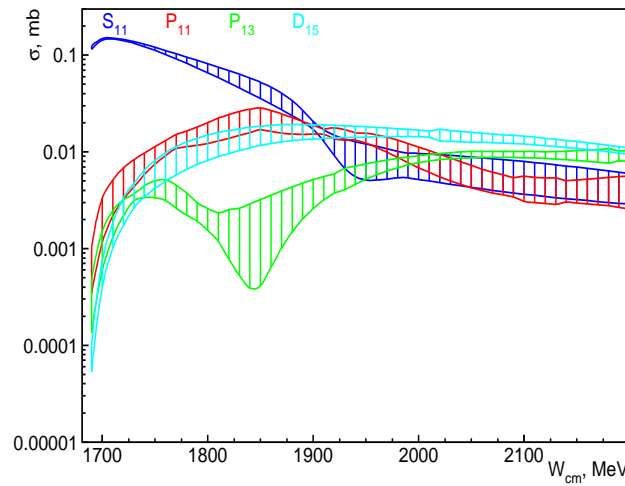
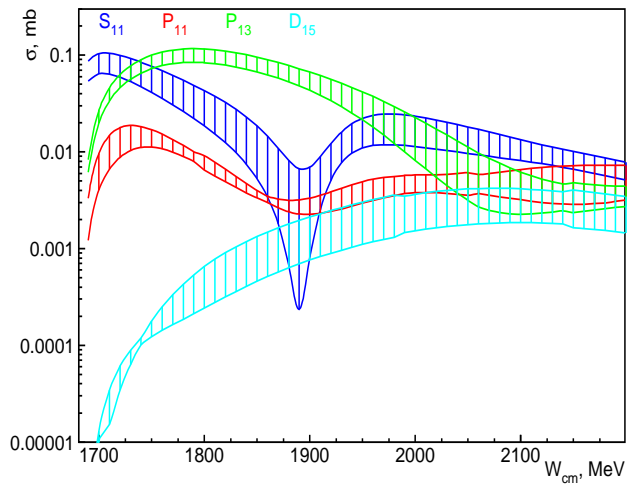
BG2011-02 M

BG2013-02

Bonn-Jülich

I=1/2

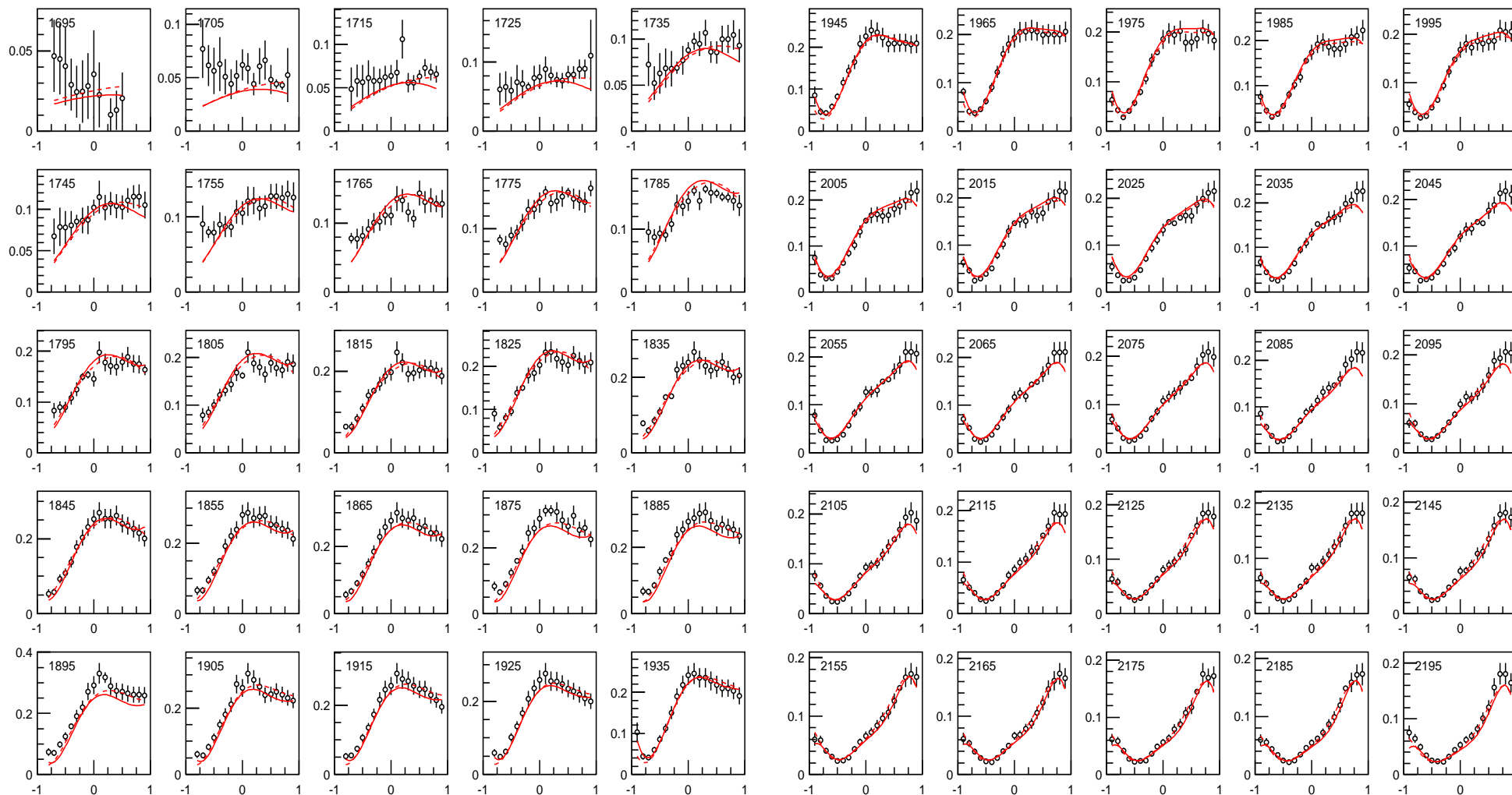
I=3/2



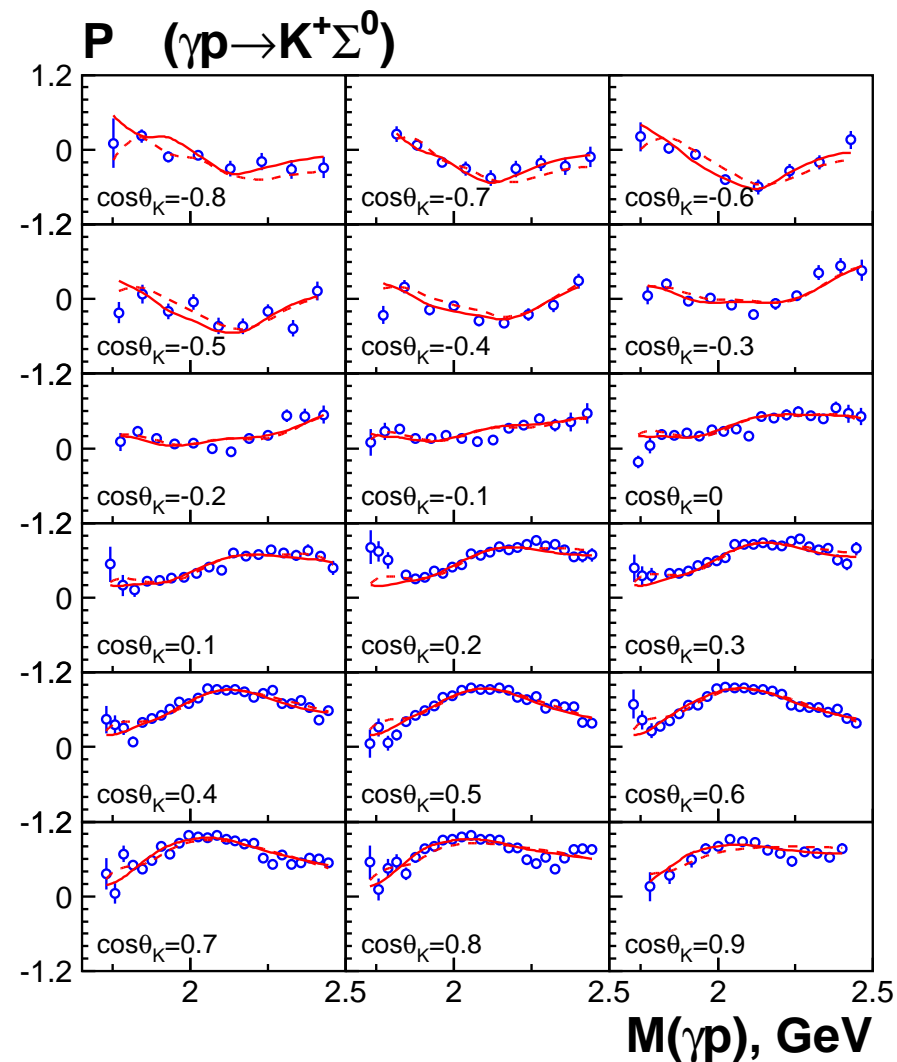
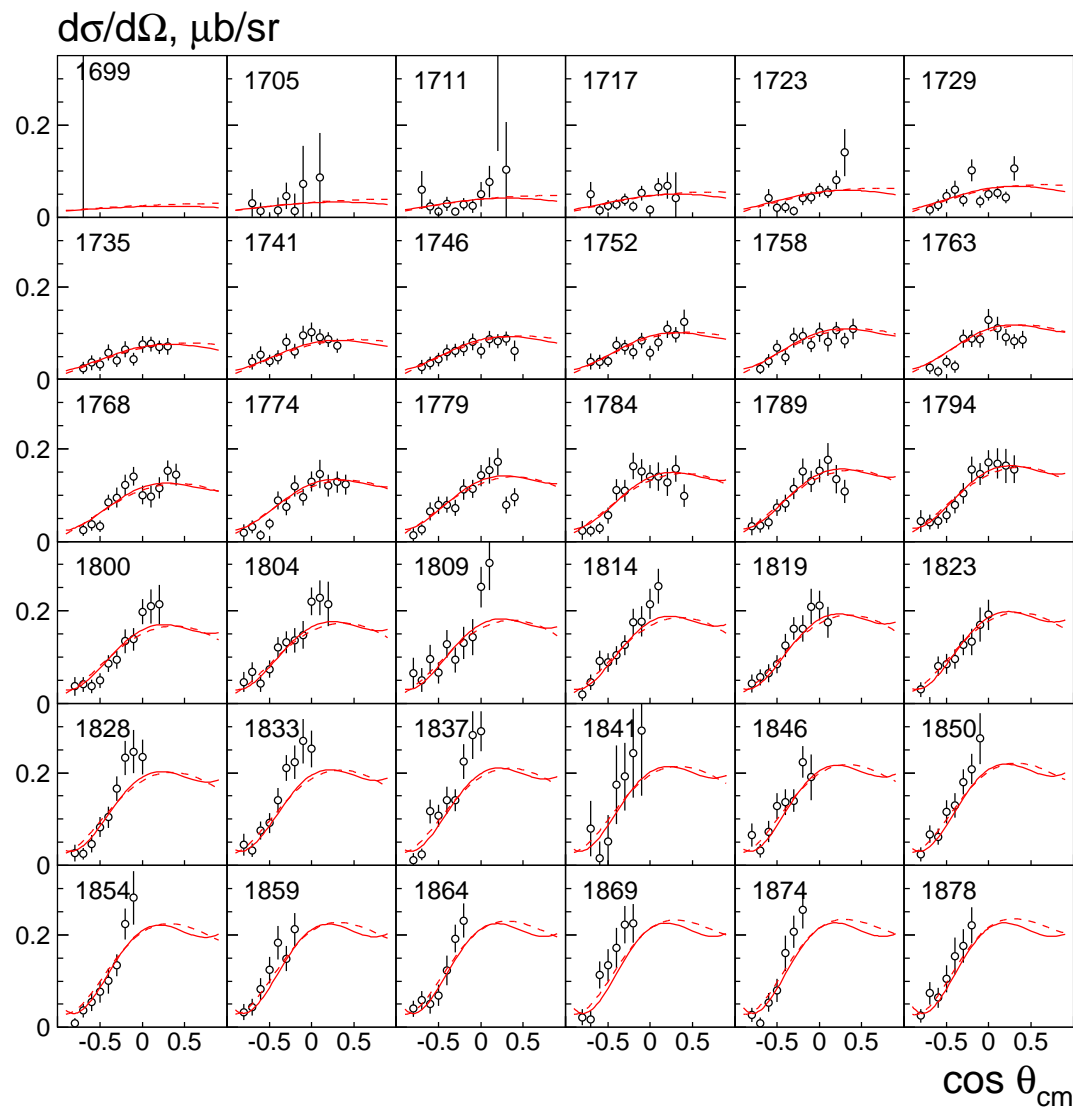
The $\gamma p \rightarrow K^+ \Sigma^0$ differential cross section (CLAS)

BG2011-02 M (dashed)

BG2013-02 (solid)



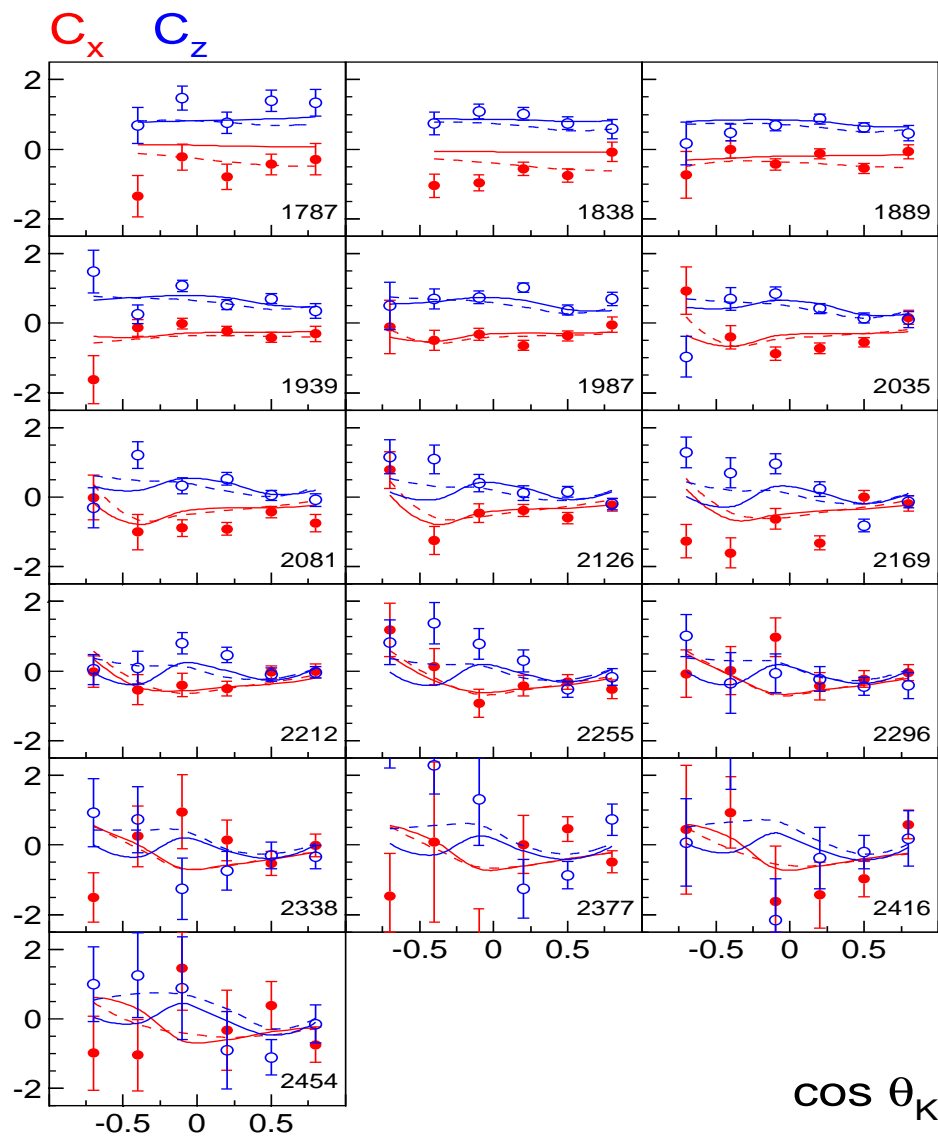
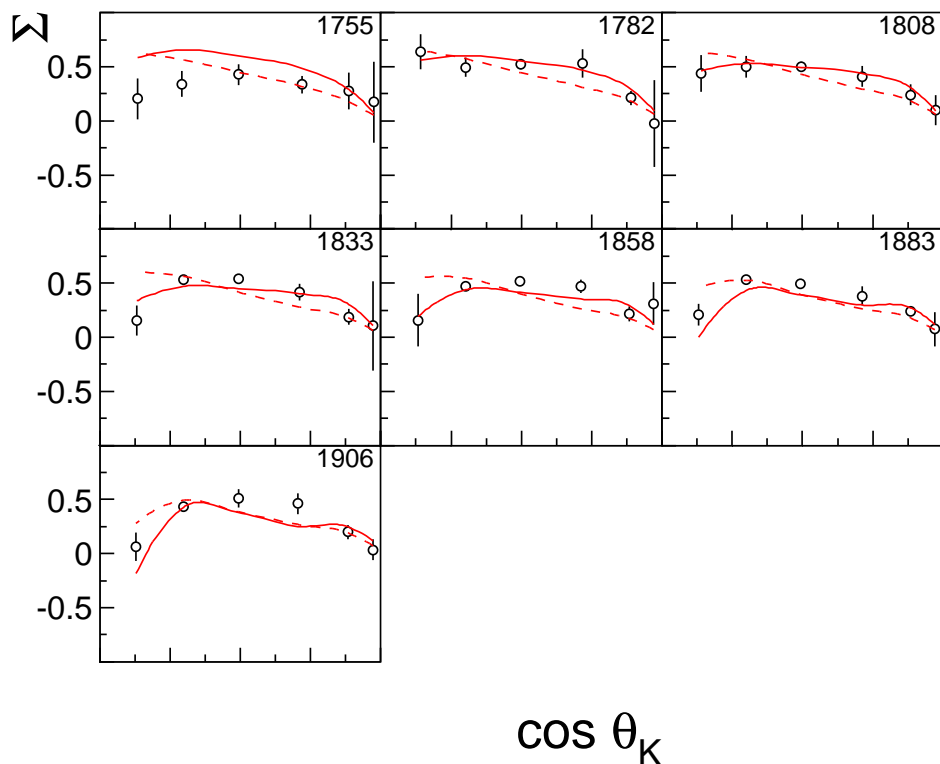
The $\gamma p \rightarrow K^+ \Sigma^0$ differential cross section (MAMI) and recoil asymmetry (CLAS)

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


The $\gamma p \rightarrow K^+ \Sigma^0$ beam asymmetry (GRAAL) and C_x, C_z (CLAS)

BG2011-02 M (dashed)

BG2013-02 (solid)

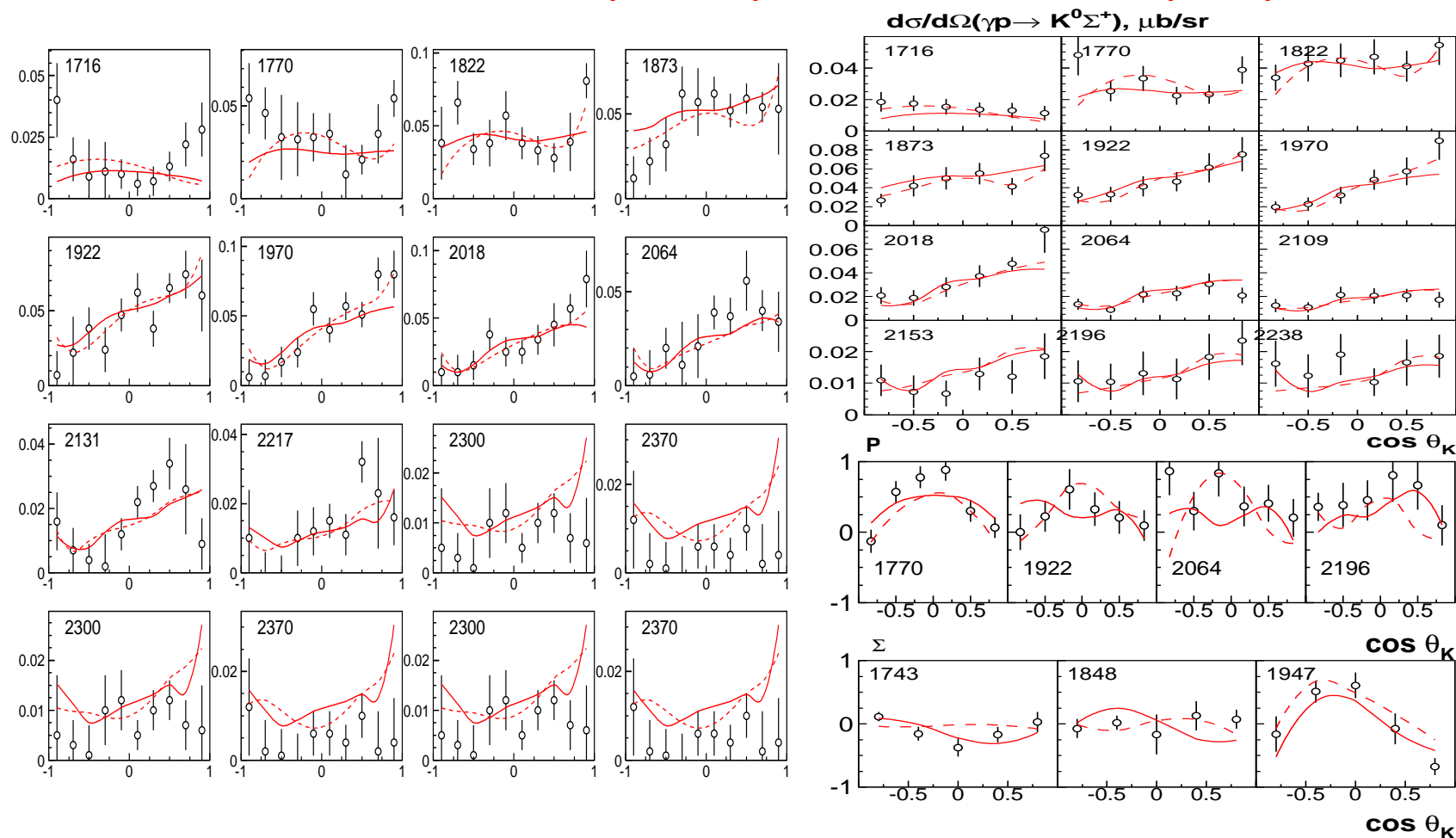


The $\gamma p \rightarrow K^0 \Sigma^+$ $d\sigma/d\Omega$ (SAPHIR), $d\sigma/d\Omega, P, \Sigma$ (CB-ELSA, R. Ewald PIB 713(2012),

PhD thesis

BG2011-02 M (dashed)

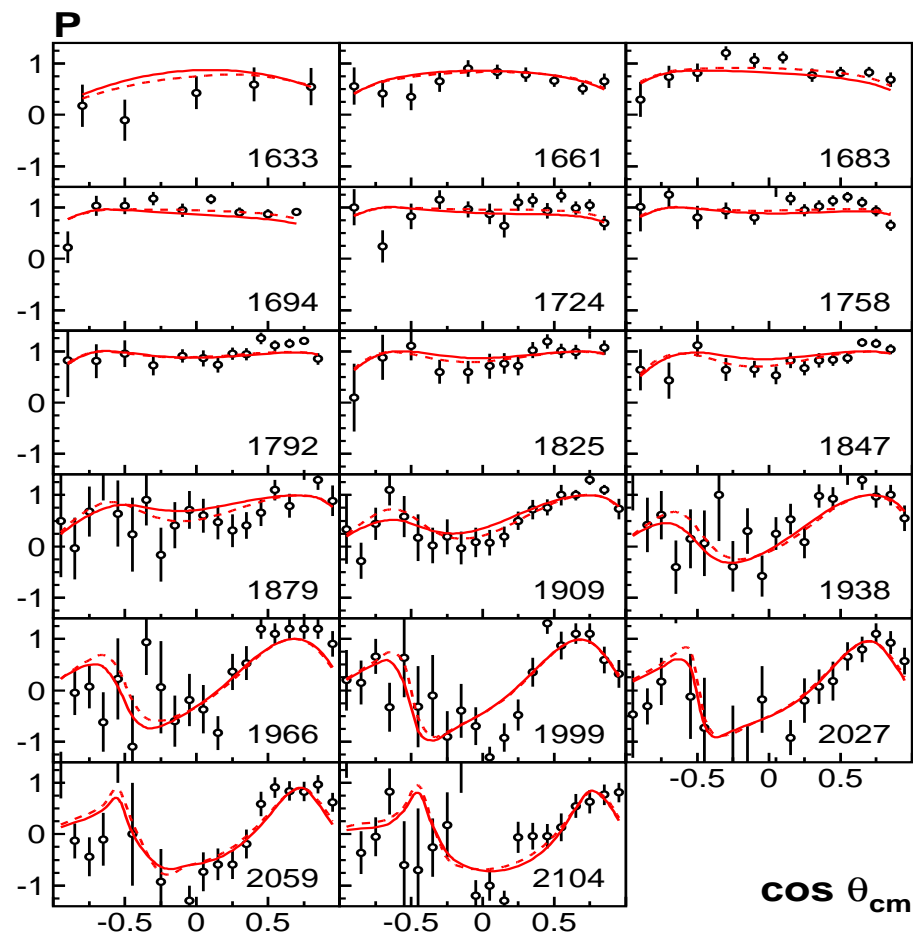
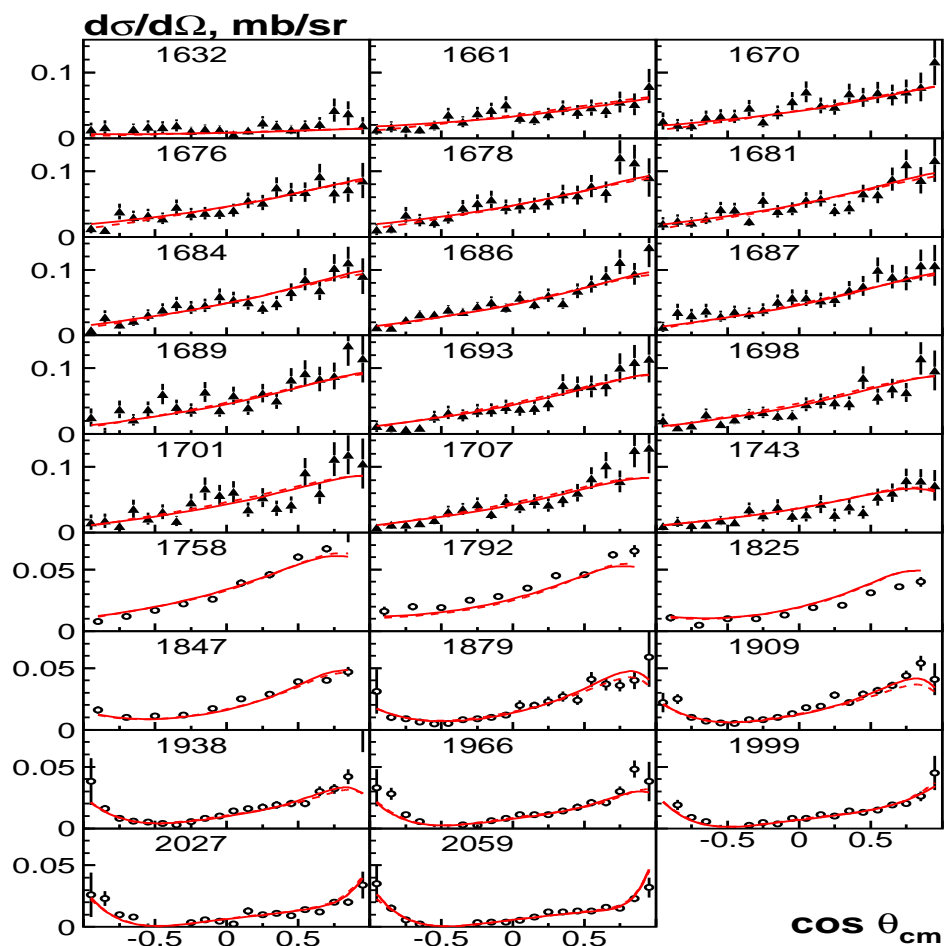
BG2013-02 (solid)



The $\pi^- p \rightarrow K^0 \Lambda$ differential cross section and recoil asymmetry

BG2011-02 M (dashed)

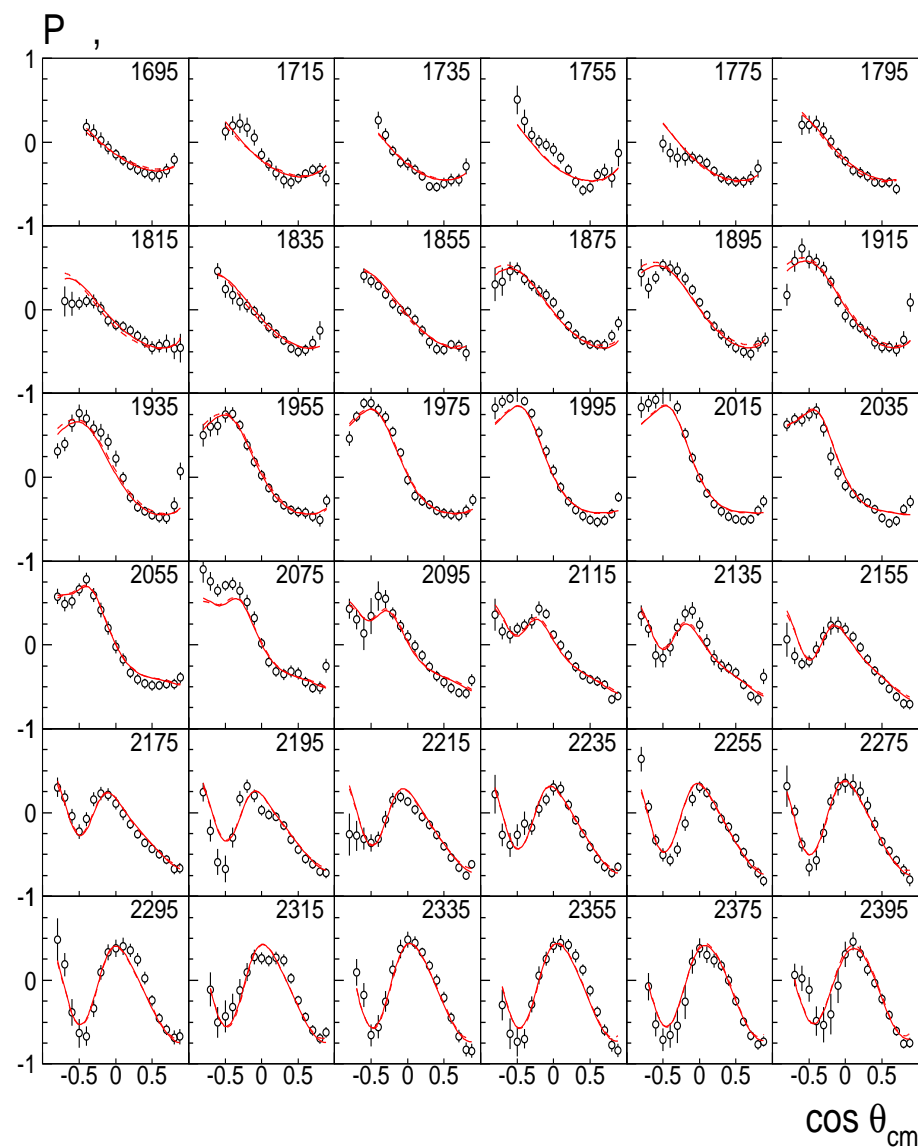
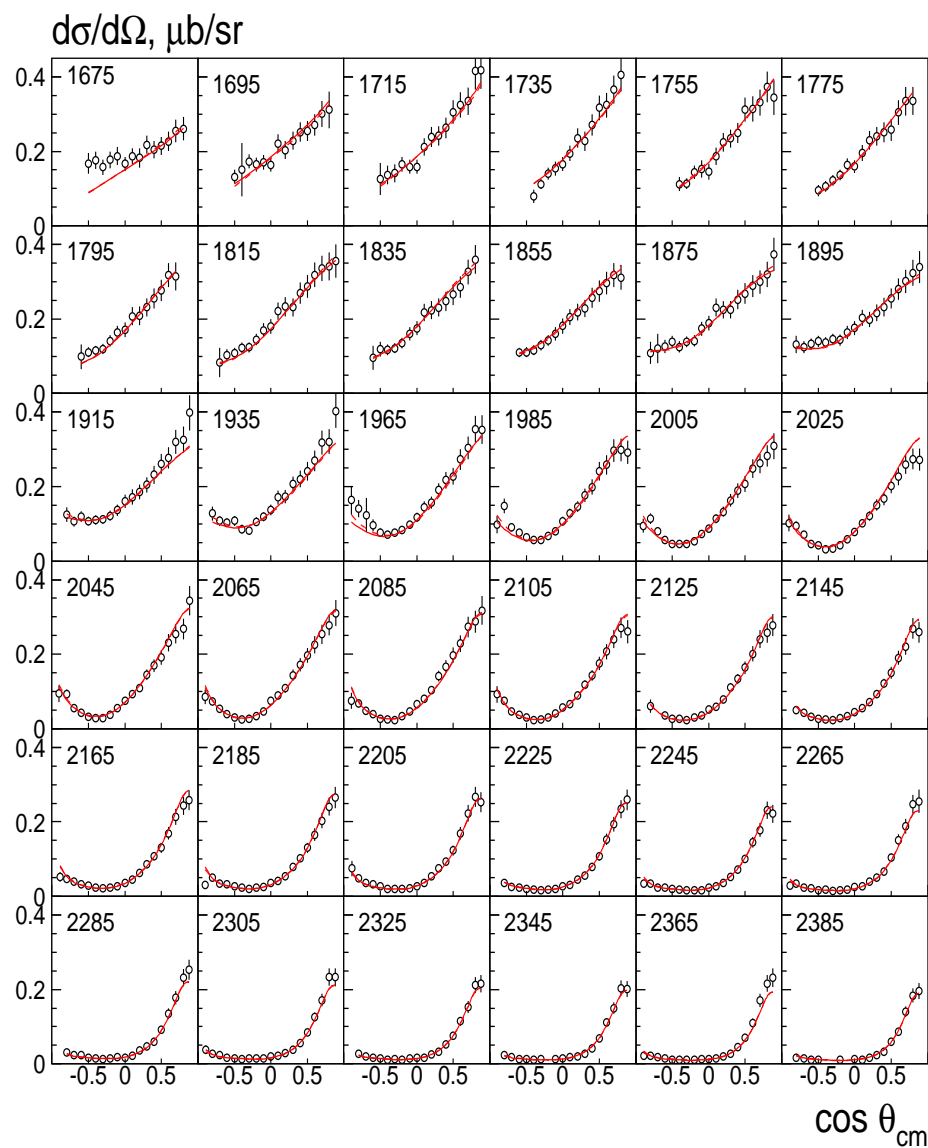
BG2013-02 (solid)



The $\gamma p \rightarrow K^+ \Lambda$ differential cross section and recoil asymmetry

BG2011-02 M (dashed)

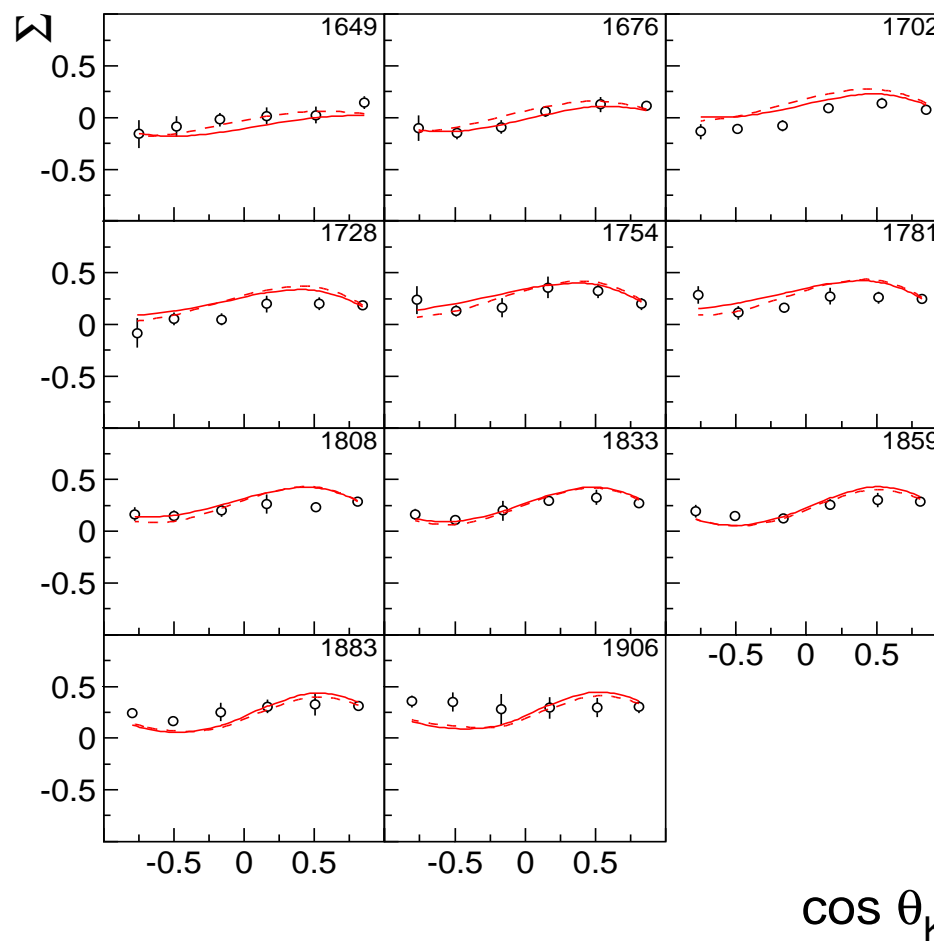
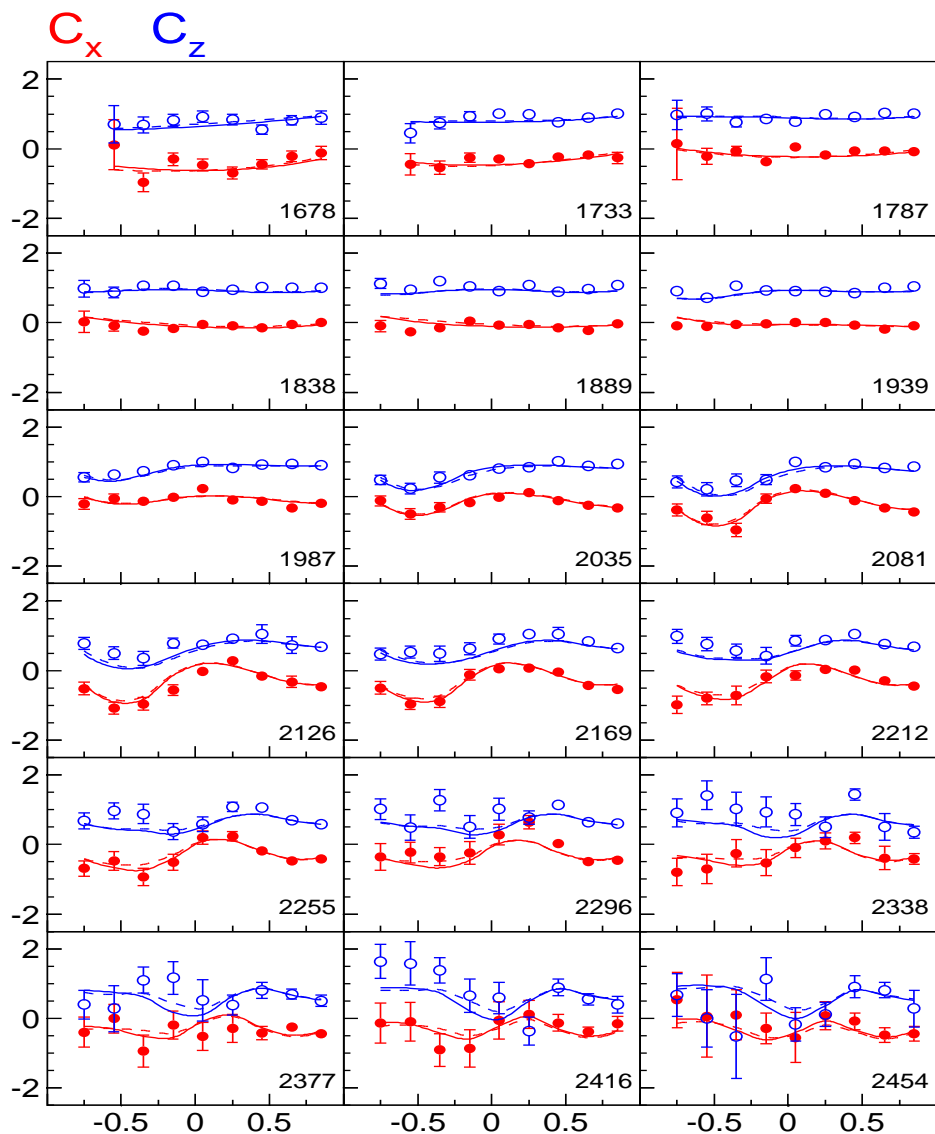
BG2013-02 (solid)



The $\gamma p \rightarrow K^+ \Lambda$: C_x, C_z (CLAS) and beam asymmetry (GRAAL)

BG2011-02 M (dashed)

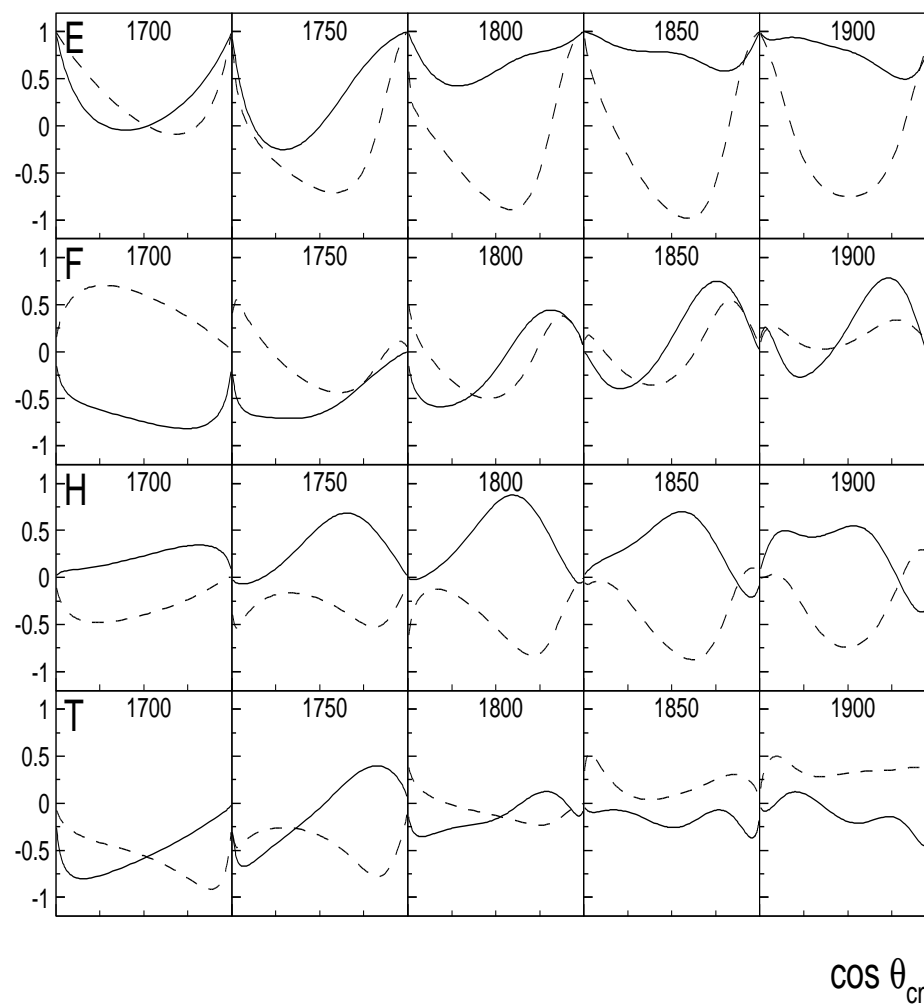
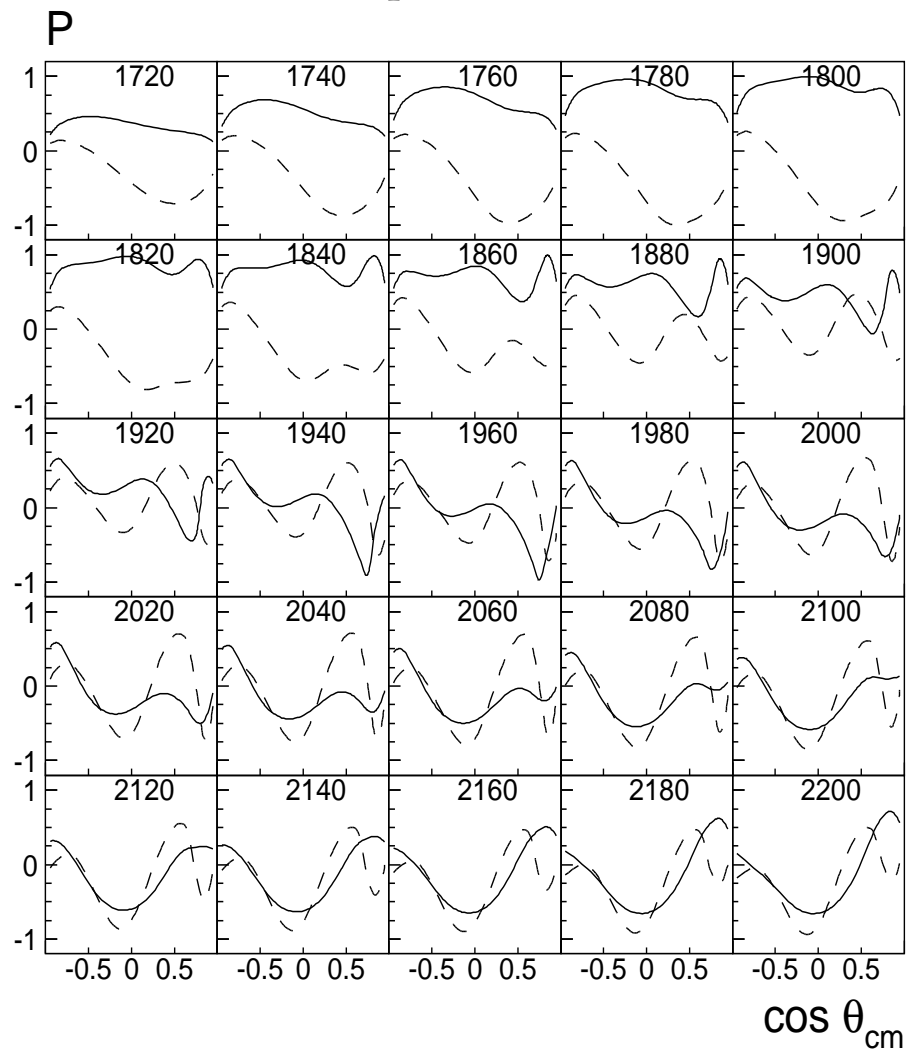
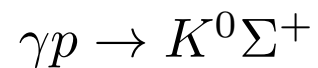
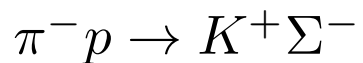
BG2013-02 (solid)



How to resolve this ambiguity? Measure more polarization observables

BG2011-02 M (dashed)

BG2013-02 (solid)

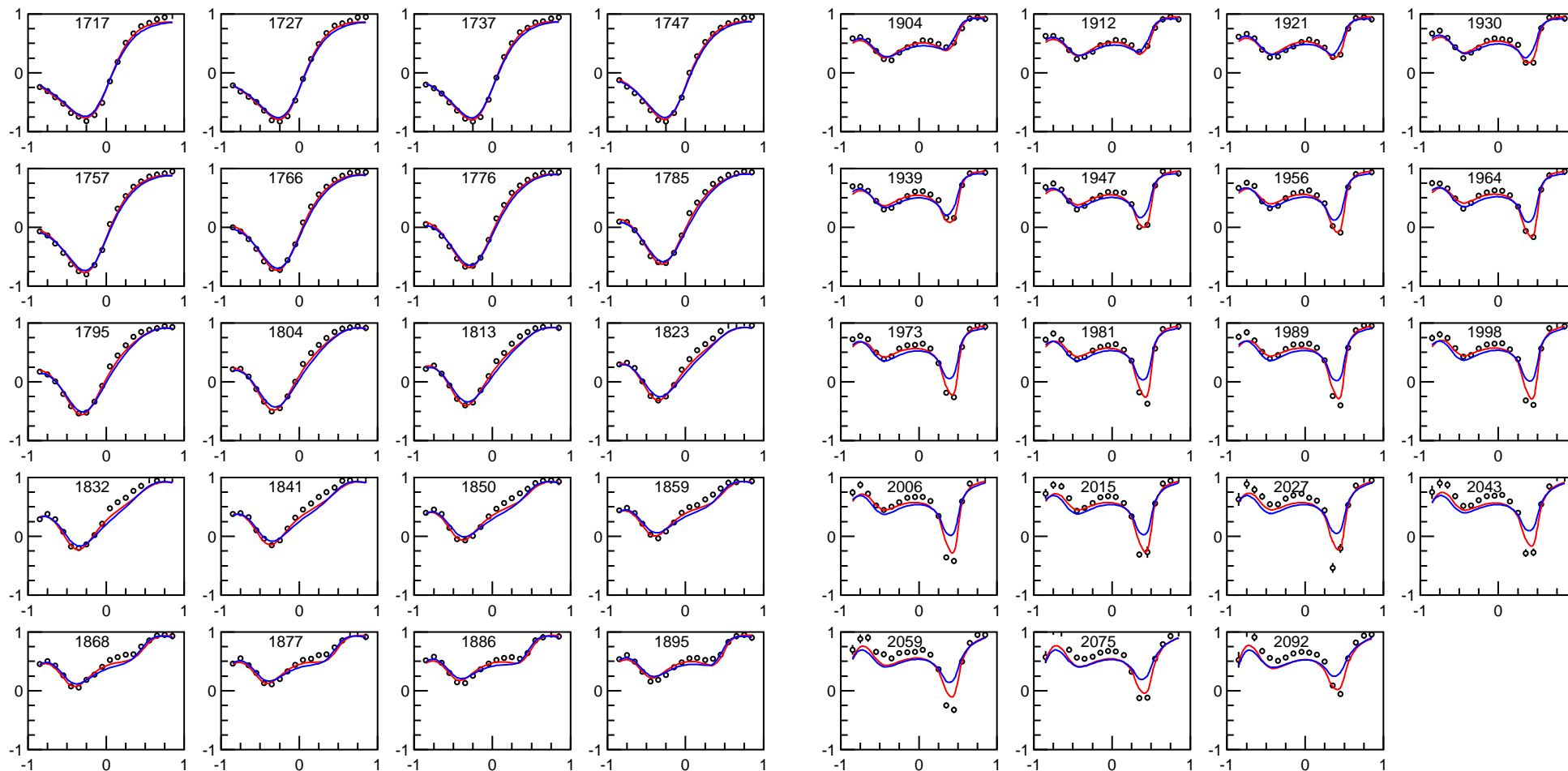


New CLAS data on $\gamma p \rightarrow \pi^0 p$ beam asymmetry

(M.Dugger et al., (2013), arXiv:1308.402)

BG2011-02

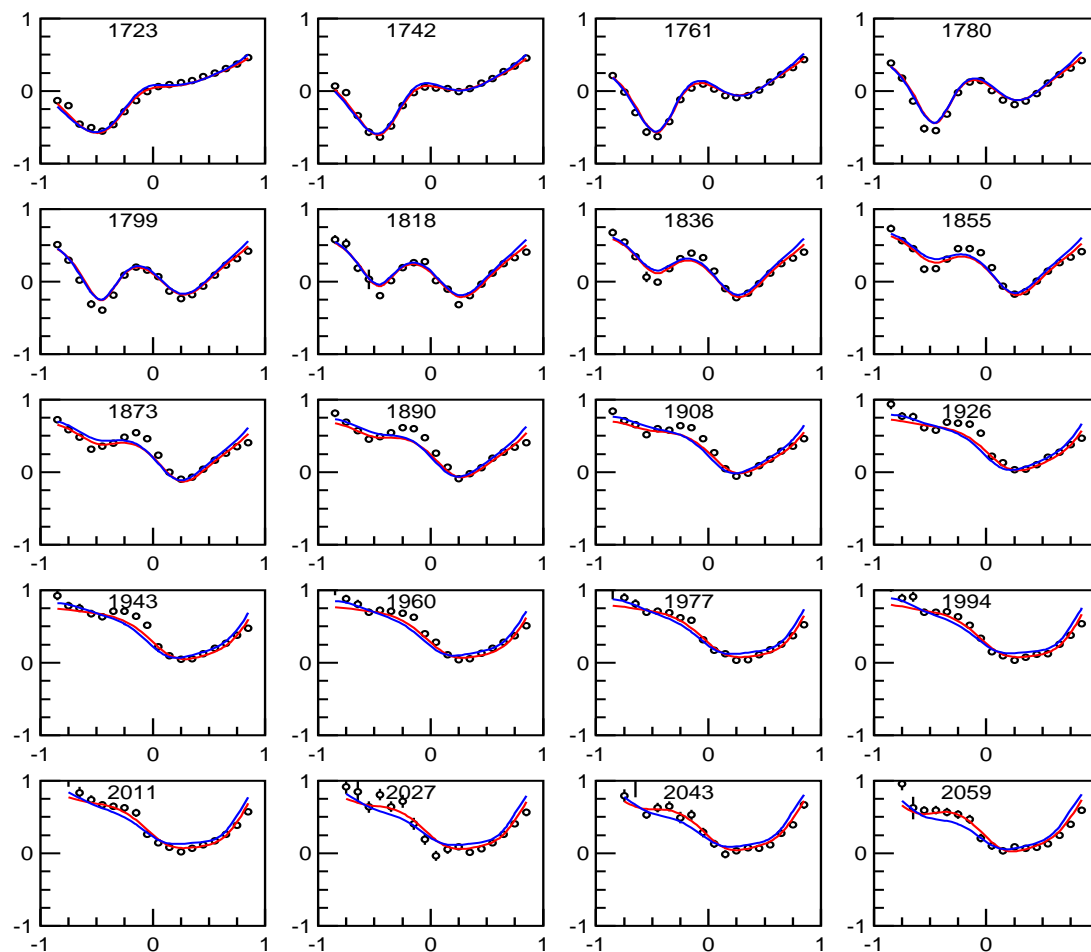
BG2011-02M/BG2013-02



Beam asymmetry from M.Dugger et al., (2013), arXiv:1308.402

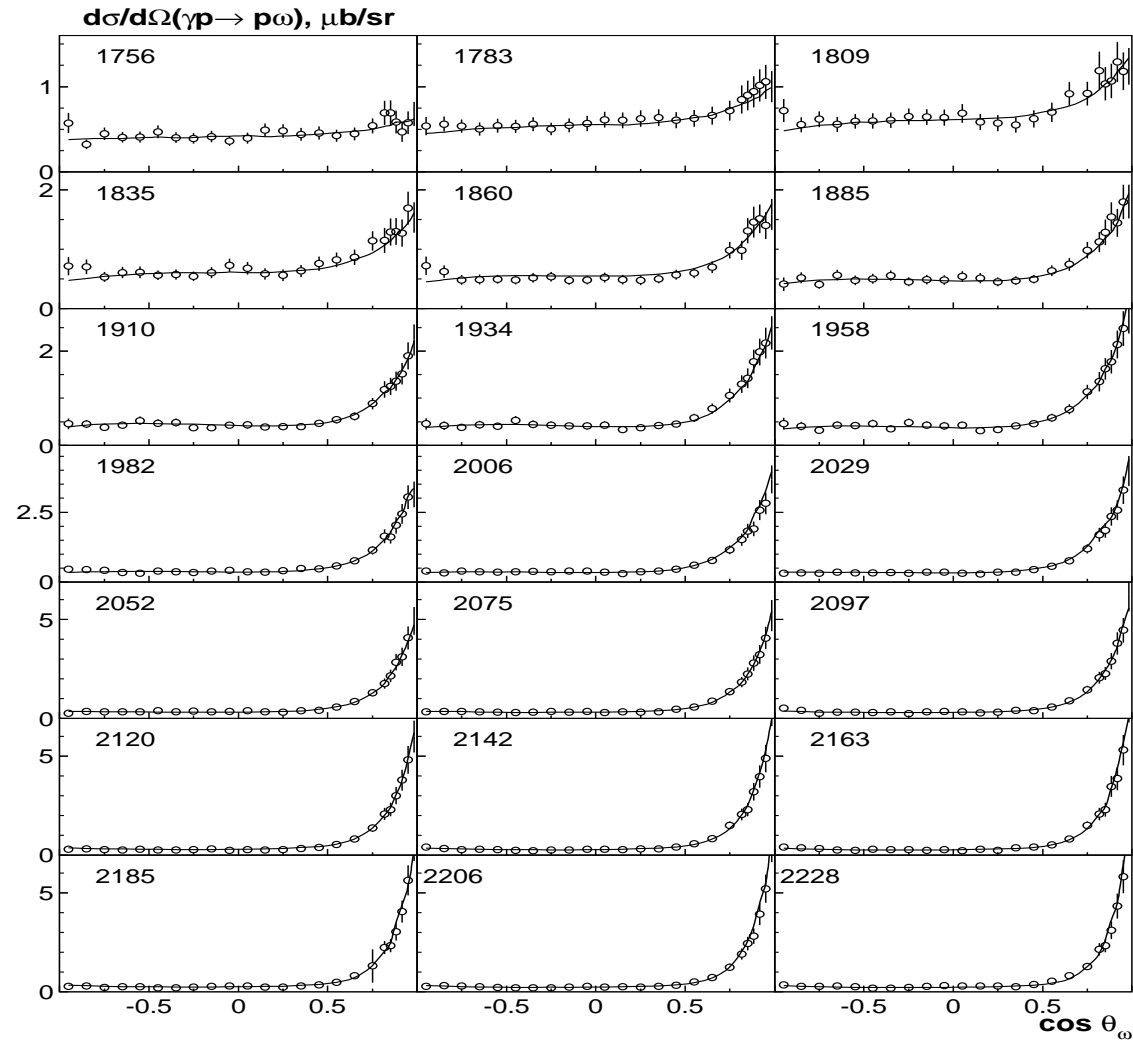
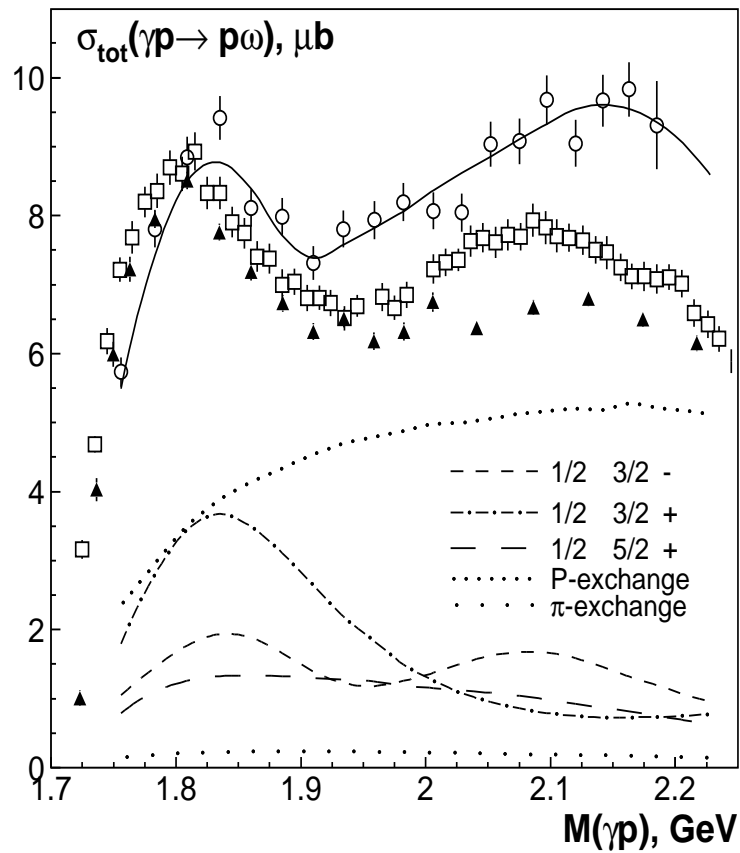
BG2011-02

BG2011-02M/BG2013-02



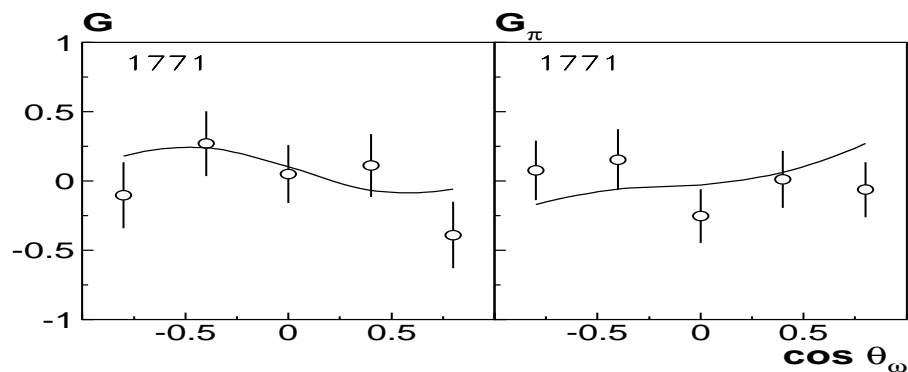
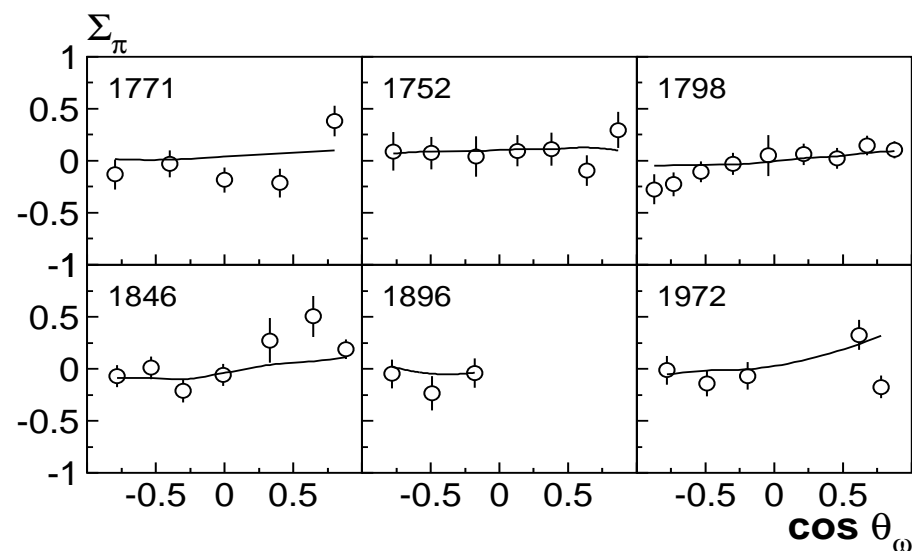
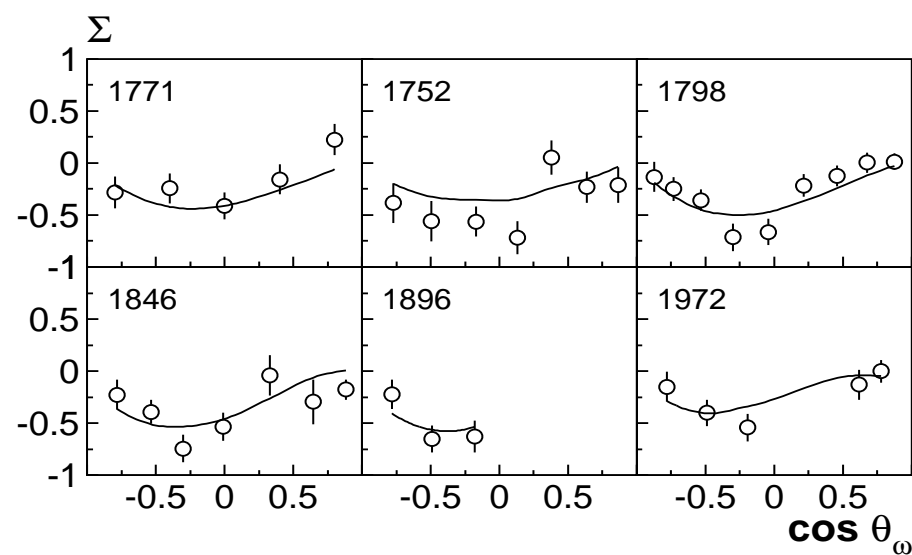
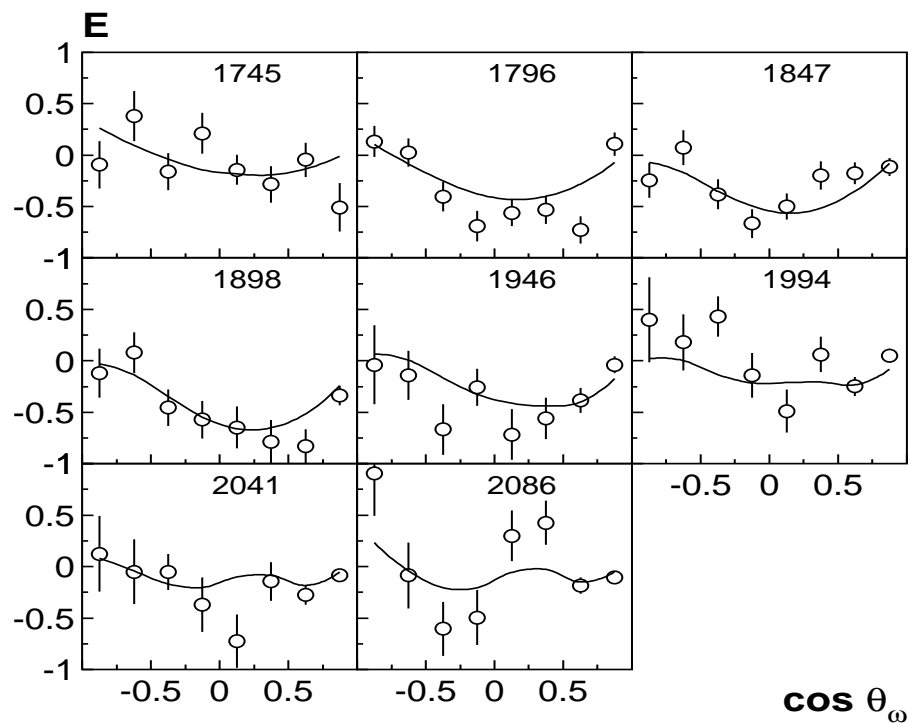
Omega photoproduction (PRELIMINARY)

Likelihood event based analysis of CB-ELSA data on $\gamma p \rightarrow \omega p$ A.Wilson, V.Crede et al.



Omega photoproduction (PRELIMINARY)

and polarization observables from CB-ELSA H.Eberhard (PhD thesis)



Summary

- **Bonn-Gatchina new combined analysis of modern data base is completed.**
- **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 $\pi^- p \rightarrow K^+ \Sigma^-$ or from $\gamma p \rightarrow K^0 \Sigma^0$ 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.**
- **The prediction for new CLAS beam asymmetry data on single pion photoproduction is notably better from 2013 solutions than from BG2011-02. The new analyses includes new polarization data on π^0 photoproduction from CB-ELSA. It supports statement that the solution is mainly defined by the data included in the analysis.**
- **The vector photo production is included in the fitting program and comprehensively tested. First results are obtained and we are ready to start full investigation of these reactions.**