# The Bonn-Gatchina analysis of reaction with production of the $\eta$-meson

Andrey Sarantsev

Petersburg Nuclear Physics Institute

HISKP, Uni-Bonn, Germany

NRC Kurchatov Institute, PNPI, Russia

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## Bonn-Gatchina partial wave analysis group:

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

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

HISKP

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

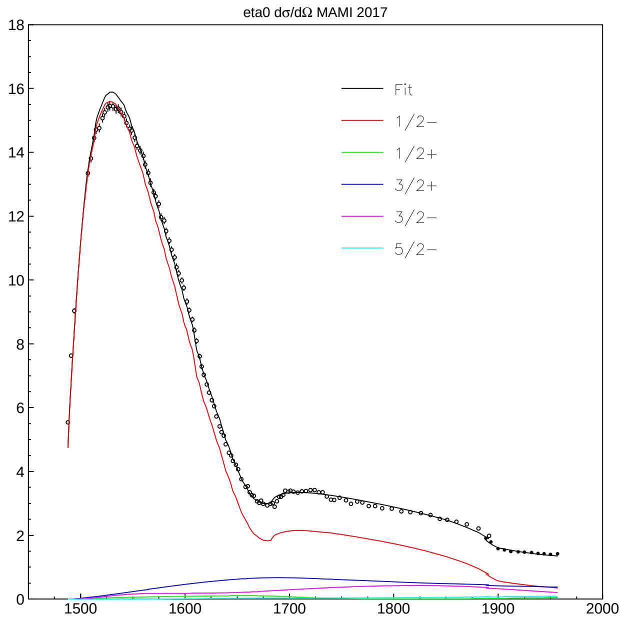
Responsible: Dr. V. Nikonov, E-mail: *nikonov@hiskp.uni-bonn.de*
Last changes: January 26th, 2010.

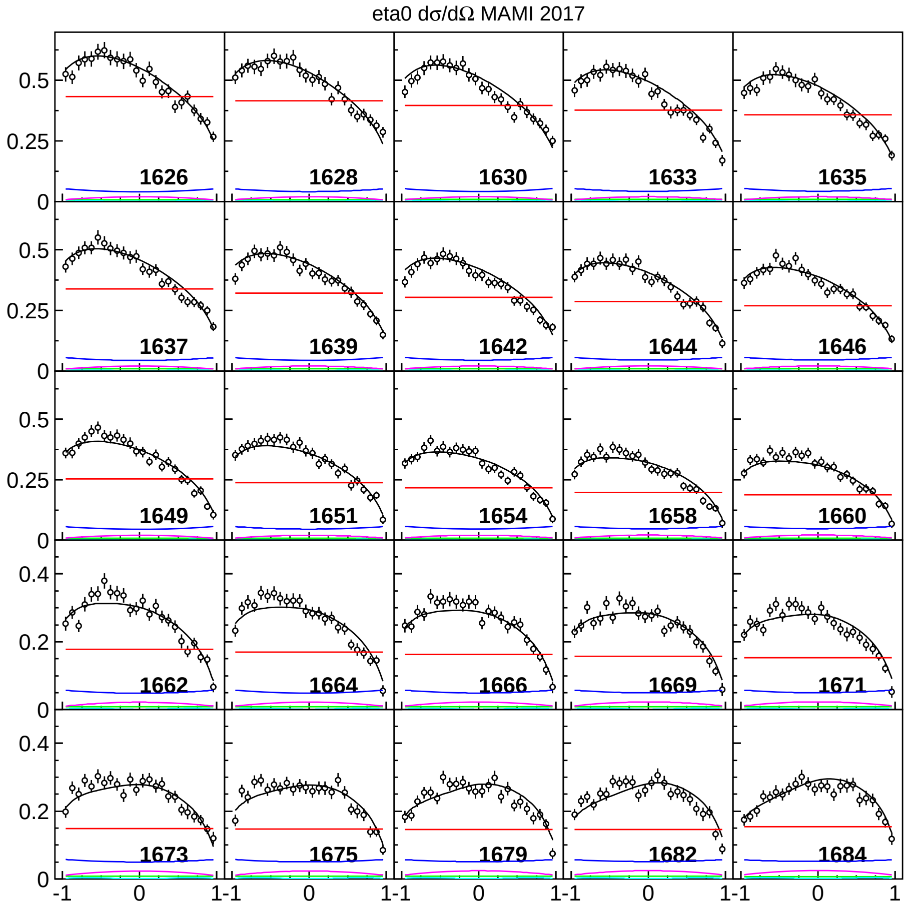
## Recently included data

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

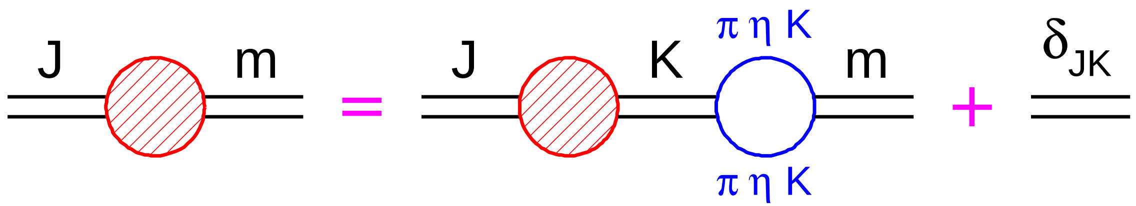
**The analysis of the new $\gamma p \to \eta p$ data.**

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



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




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

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

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

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

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

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

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

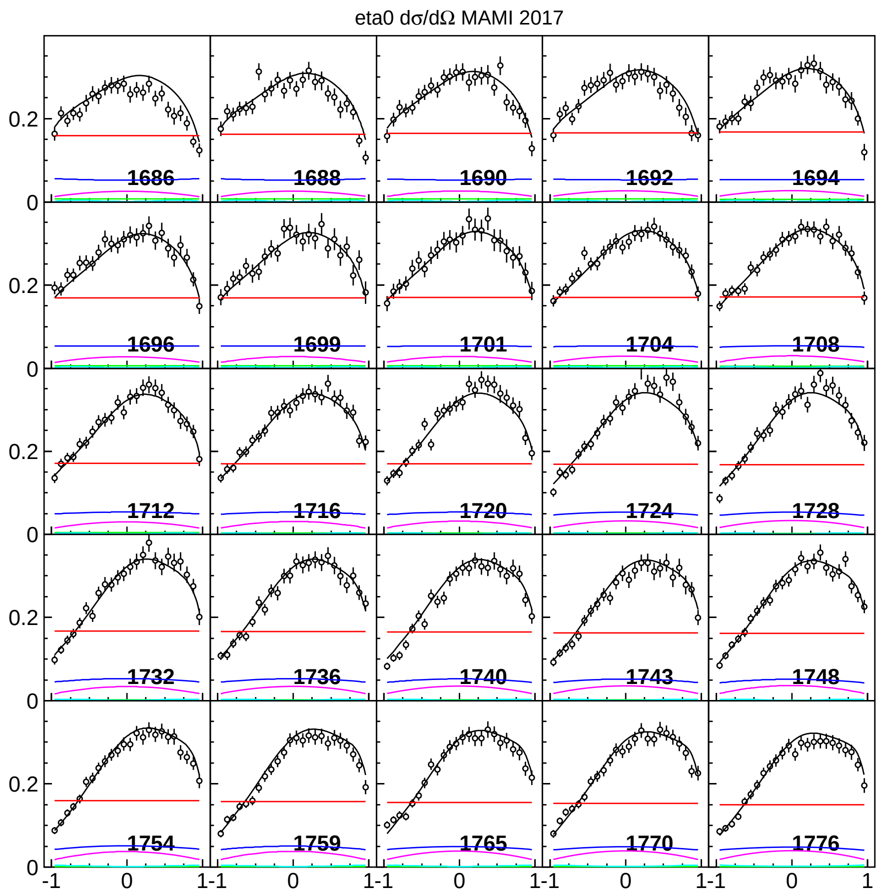
**and D-matrix method equivalent to the K-matrix method with loop diagram with real part taken into account:**

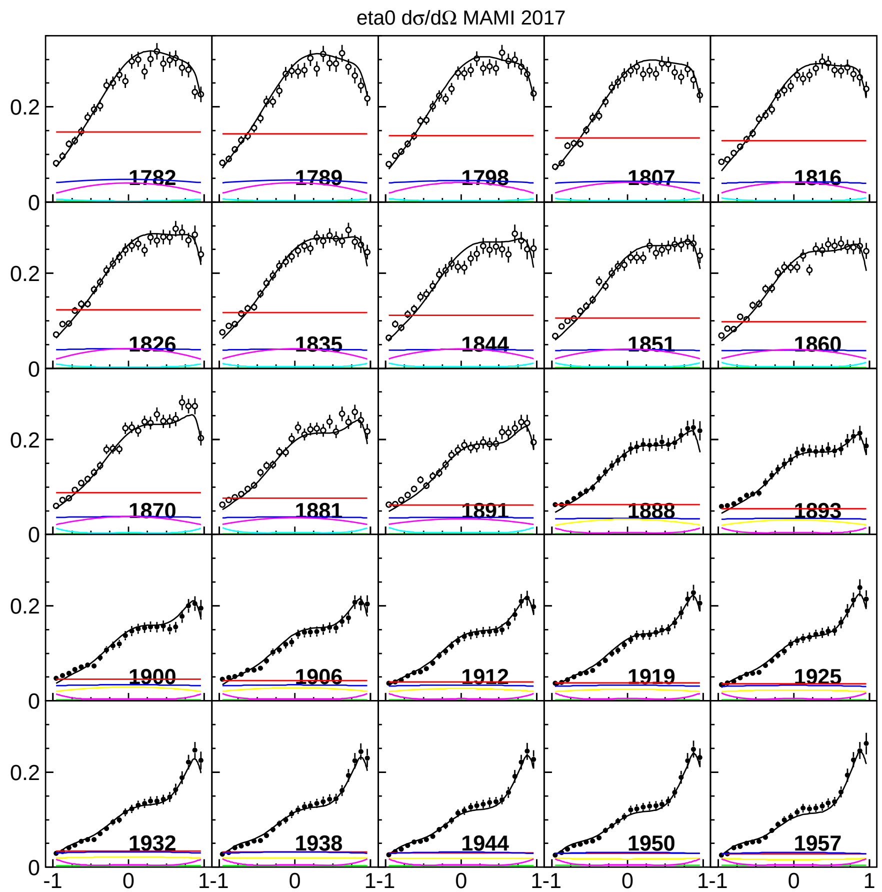
$$A = \hat{K}(I - \hat{B}\hat{K})^{-1} \qquad\qquad B_{\alpha\beta} = \delta_{\alpha\beta} B_\alpha$$

## $S_{11}$-partial wave: $\pi N$, $\eta N$, $K\Lambda$, $K\Sigma$, $\Delta(1232)\pi$, $\rho N$ (S,D).

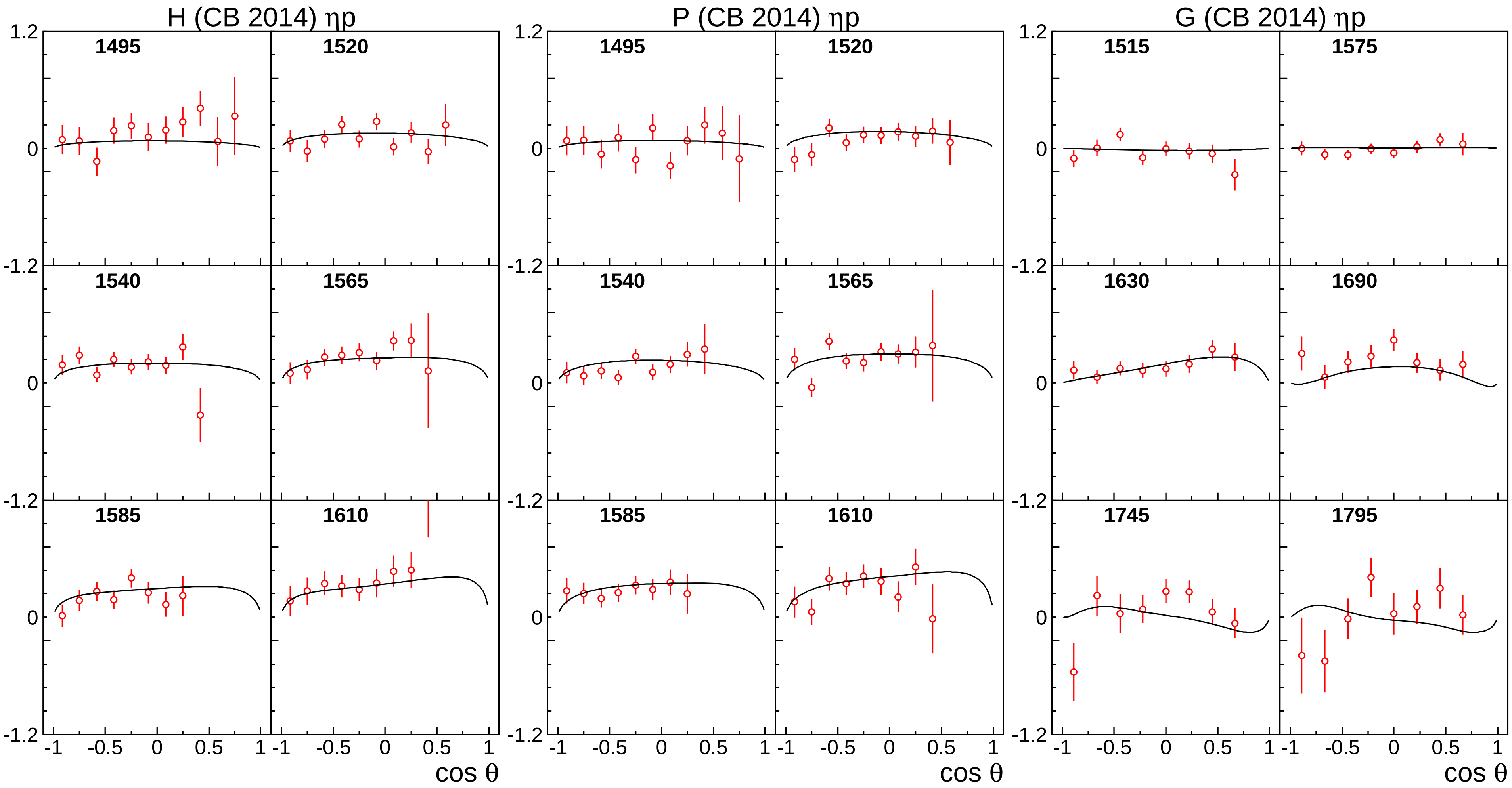
| | $N(1535)S_{11}$ | | $N(1650)S_{11}$ | | $N(1890)S_{11}$ | |
|---|---|---|---|---|---|---|
| | **K-matrix** | **D-matrix** | **K-matrix** | **D-matrix** | **K-matrix** | **D-matrix** |
| $M_{\rm pole}$ | **1501$\pm$4** | **1494** | **1647$\pm$6** | **1651** | **1900$\pm$15** | **1905** |
| $\Gamma_{\rm pole}$ | **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$** | **-38$^\circ$** | **-(75$\pm$12)$^\circ$** | **-62$^\circ$** | **–** | **–** |
| **Res**$_{\pi N\to\Delta\pi}$ | **7$\pm$4** | **4** | **11$\pm$3** | **12** | **–** | **–** |
| **Phase** | **(147$\pm$17)$^\circ$** | **157$^\circ$** | **-(30$\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$** | **1$^\circ$** | **-(9$\pm$15)$^\circ$** | **0$^\circ$** | **120$\pm$50$^\circ$** | **150$^\circ$** |

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

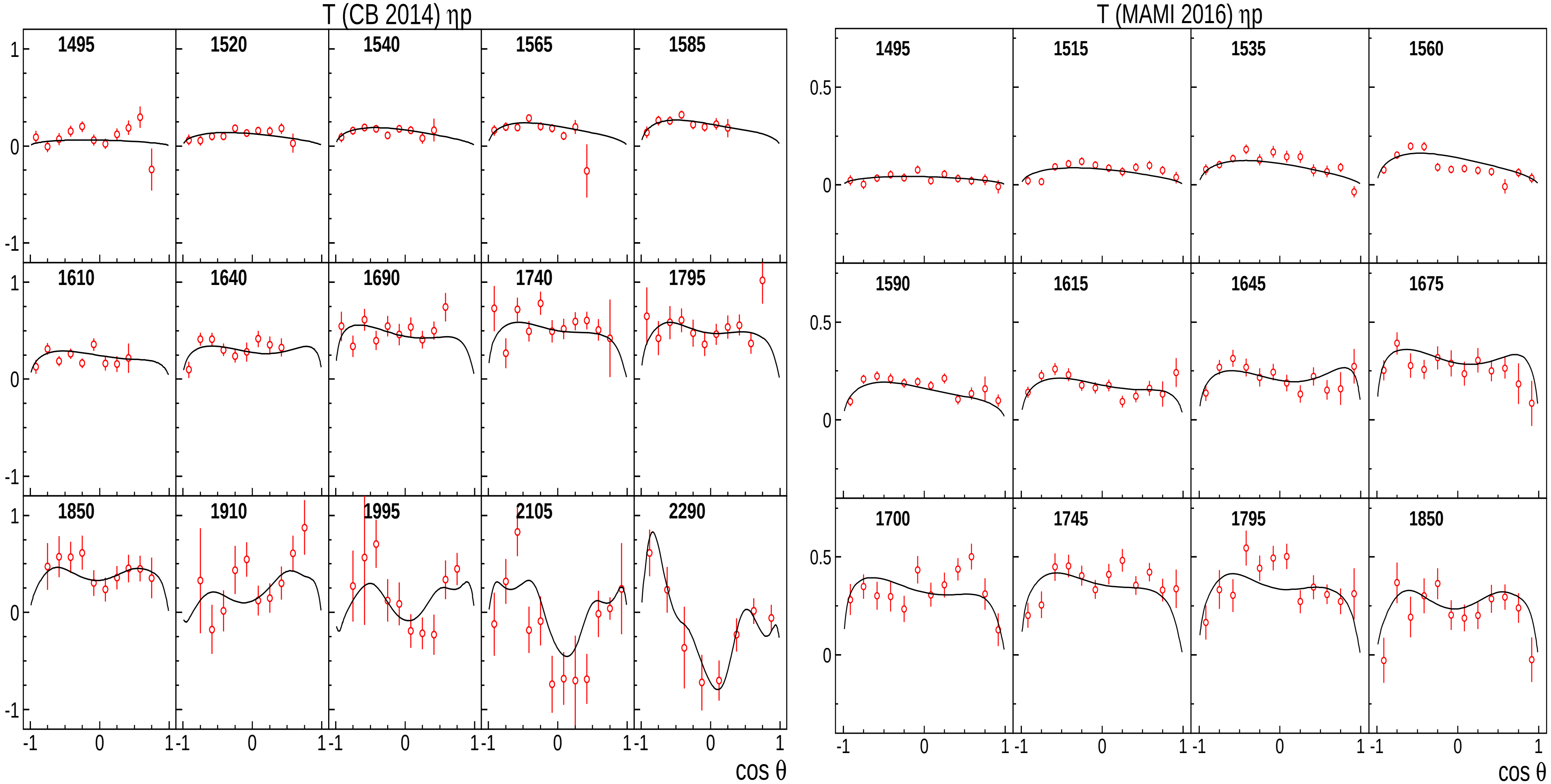


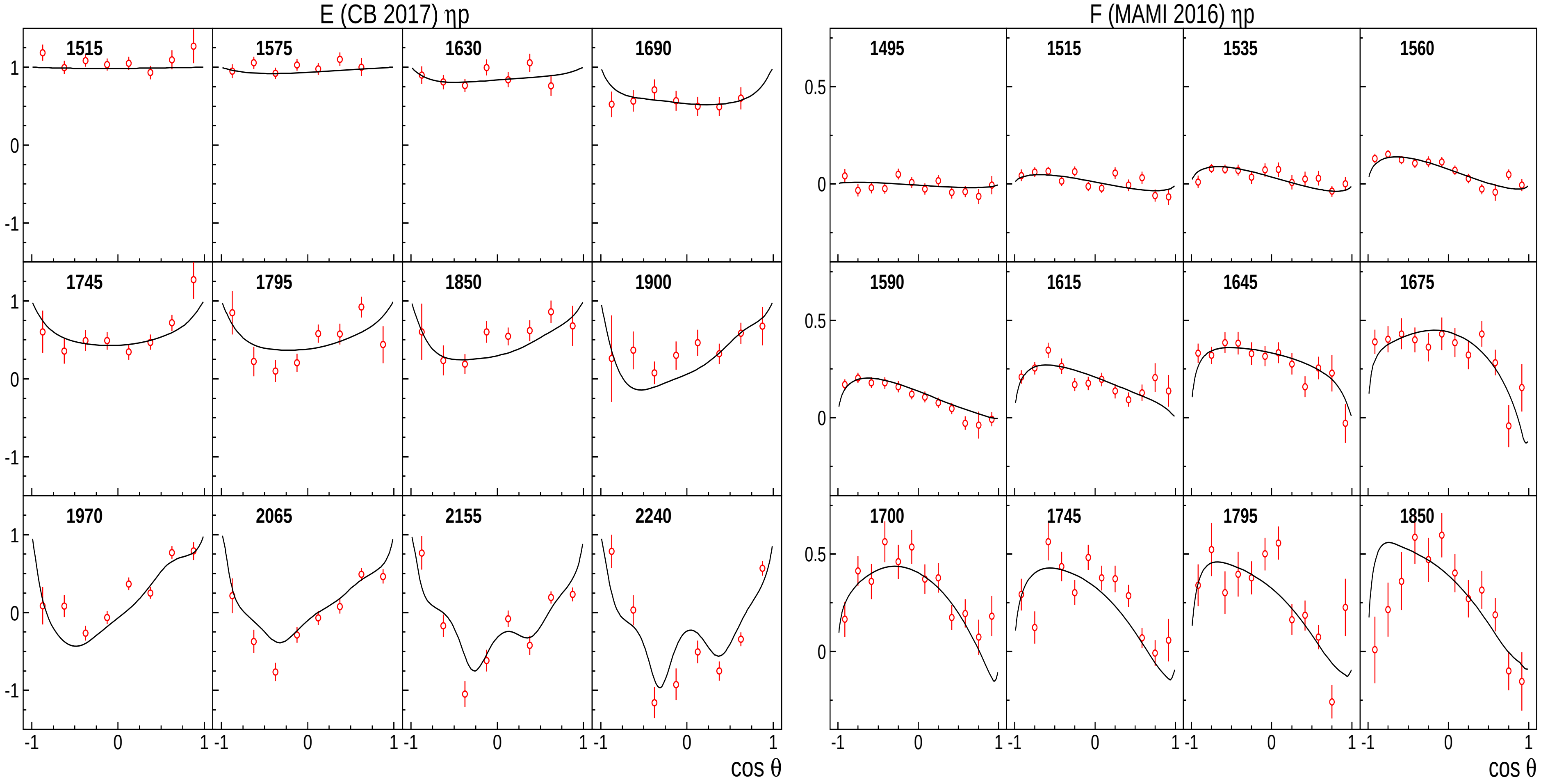
# The analysis of the new $\gamma p \to \eta p$ data. $H, P, T$ (CB-ELSA)



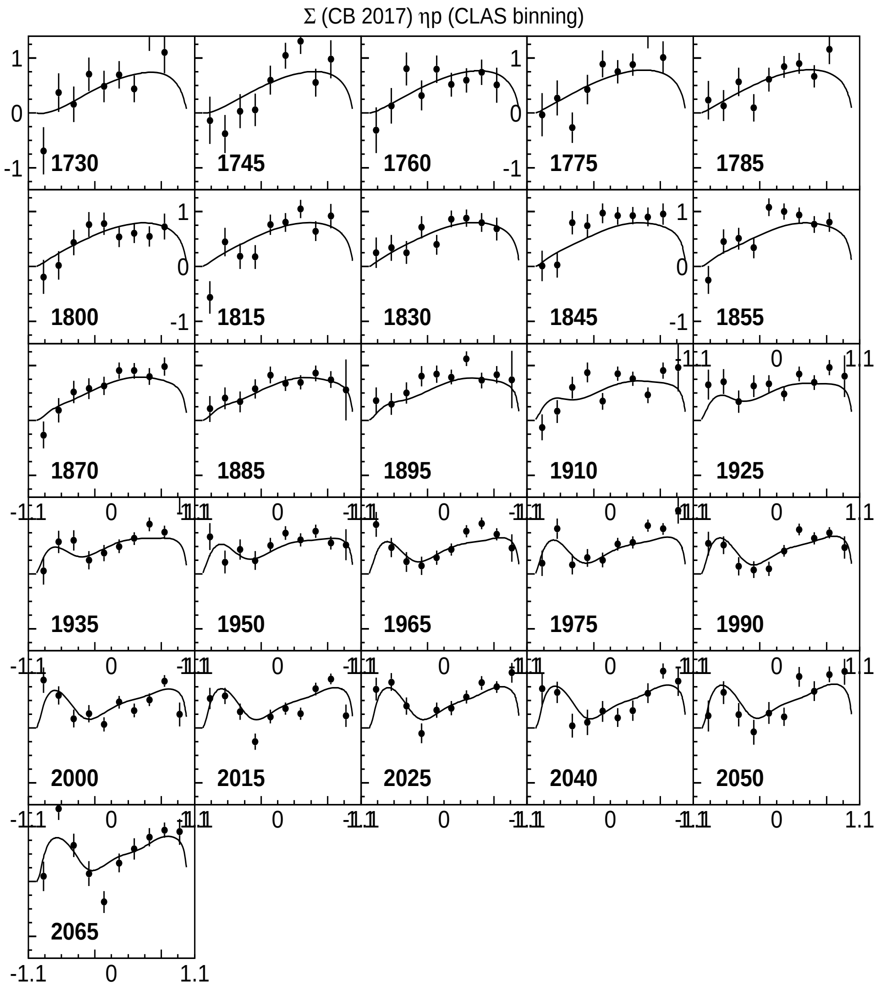
# The analysis of the new $\gamma p \to \eta p$ data. $T$ (CB-ELSA), (MAMI scale 1.4)

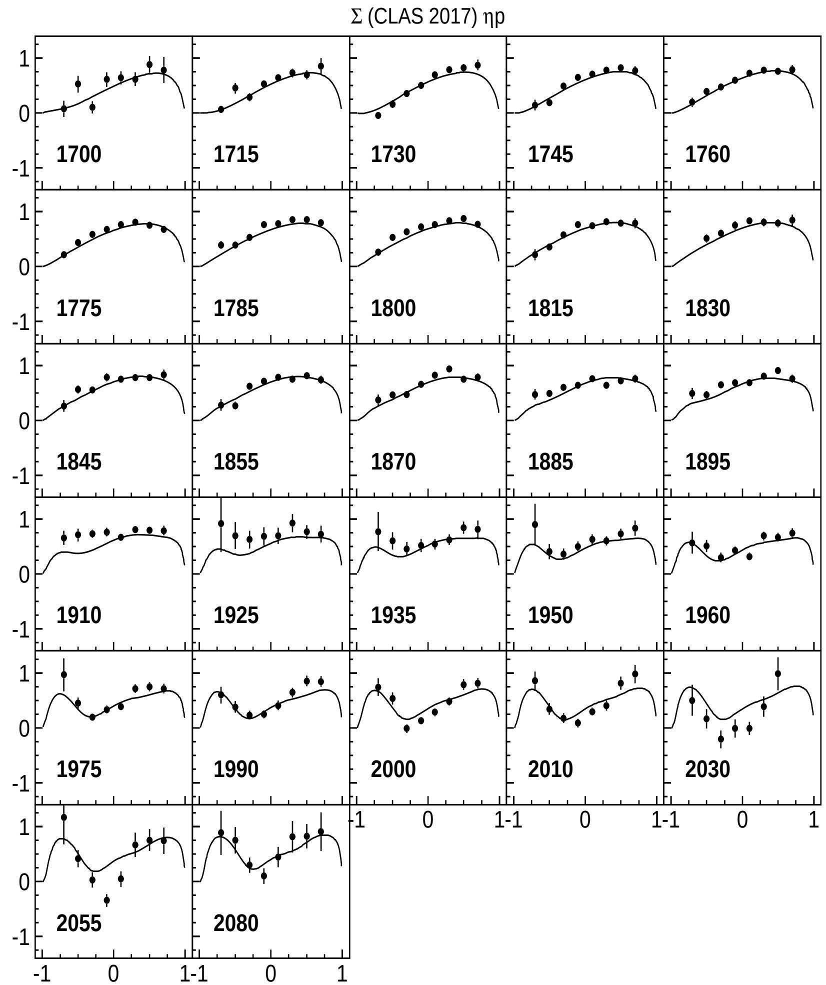


# The analysis of the new $\gamma p \to \eta p$ data. $E$ (CB-ELSA), $F$ (MAMI) (scale 1.4)



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

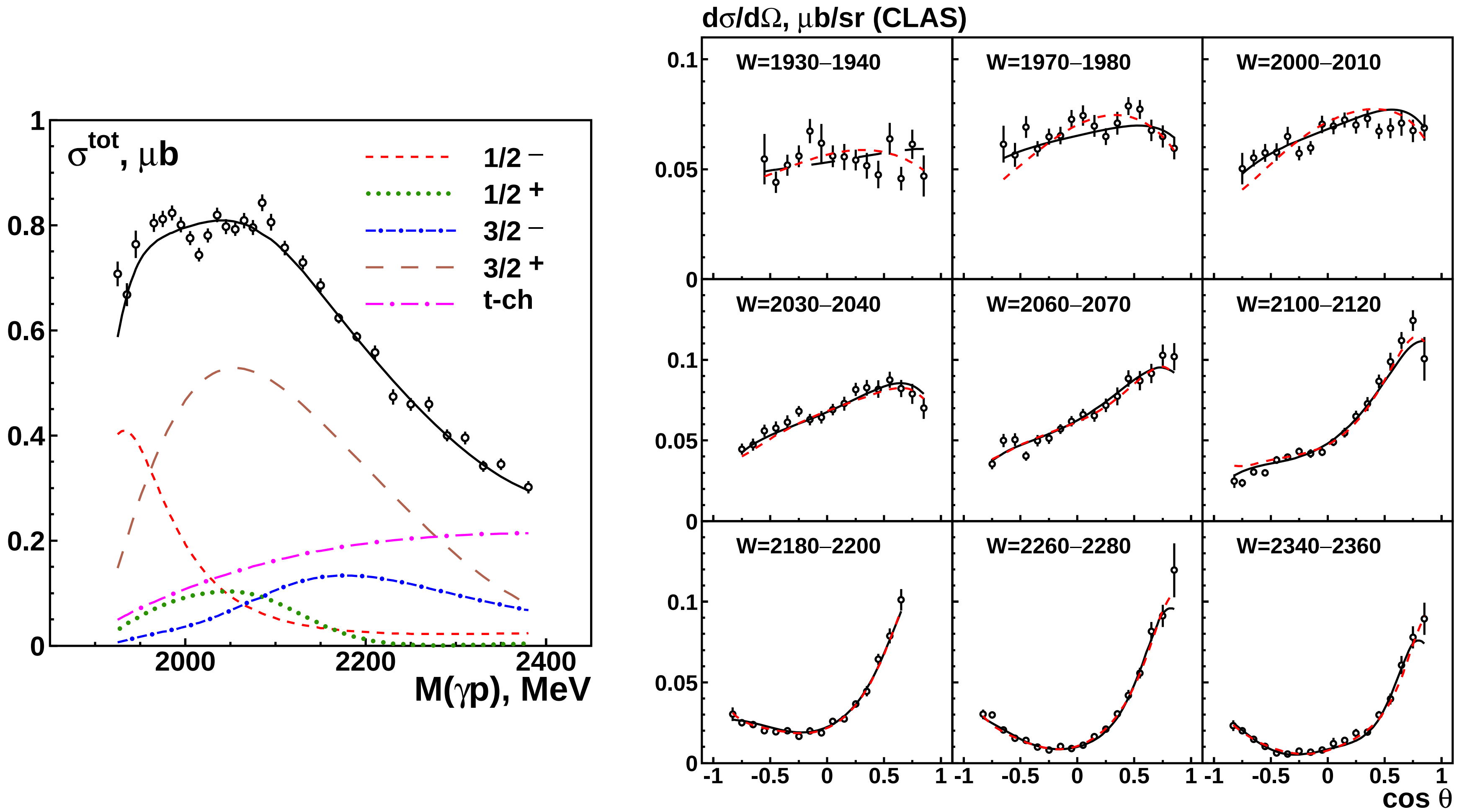


## Resonance branchings to the $\eta N$ channel

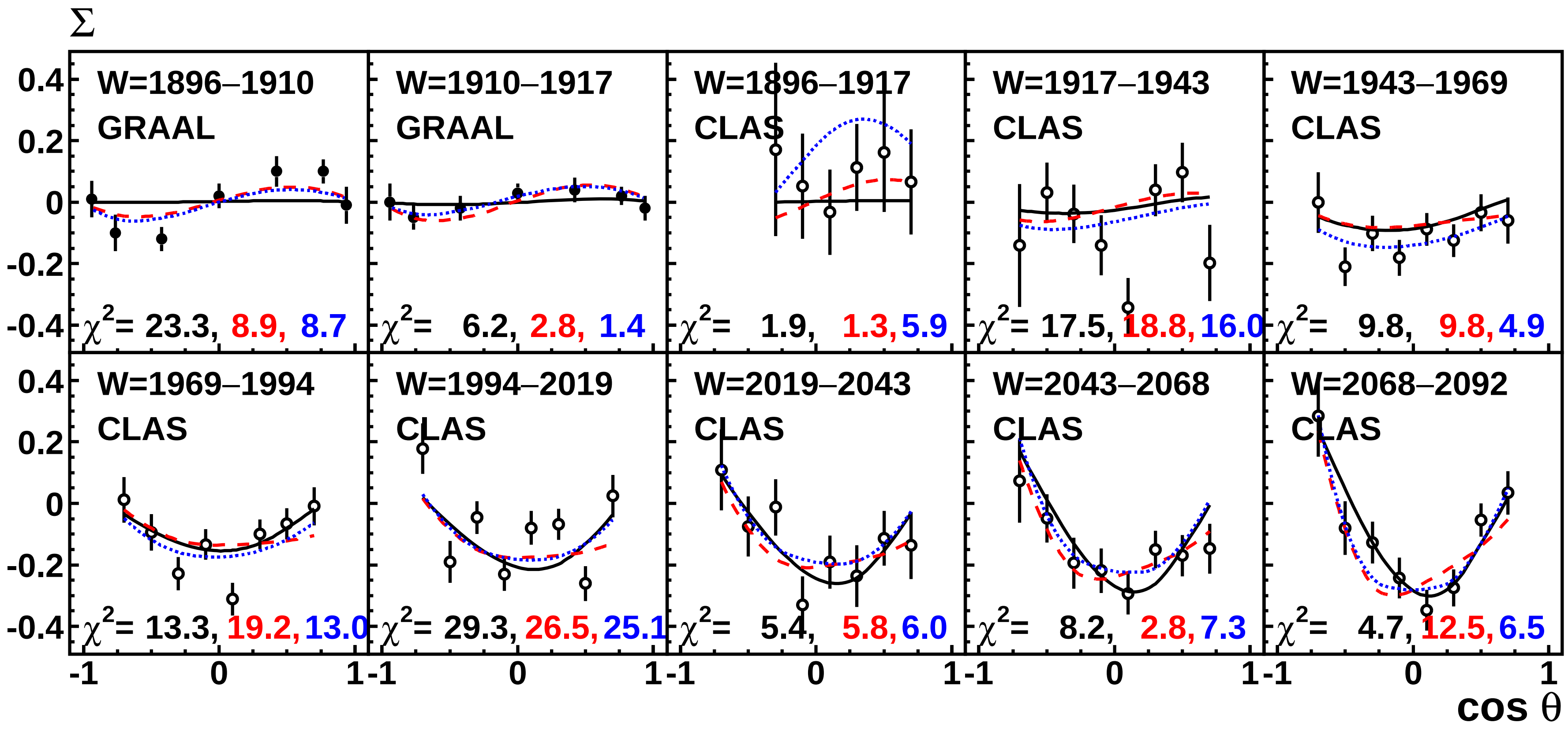
| Res. | BR | Res. | BR | Res. | BR |
|---|---|---|---|---|---|
| $N(1535)$ $1/2^-$ | 0.42$\pm$0.04<br>0.42$\pm$0.10 | $N(1650)$ $1/2^-$ | 0.32$\pm$0.04<br>0.05 - 0.15 | $N(1895)$ $1/2^-$ | 0.10$\pm$0.05<br>(0.21$\pm$0.06) |
| $N(1710)$ $1/2^+$ | 0.25$\pm$0.09<br>0.10 - 0.30 | $N(1880)$ $1/2^+$ | 0.19$\pm$0.07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

# 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.

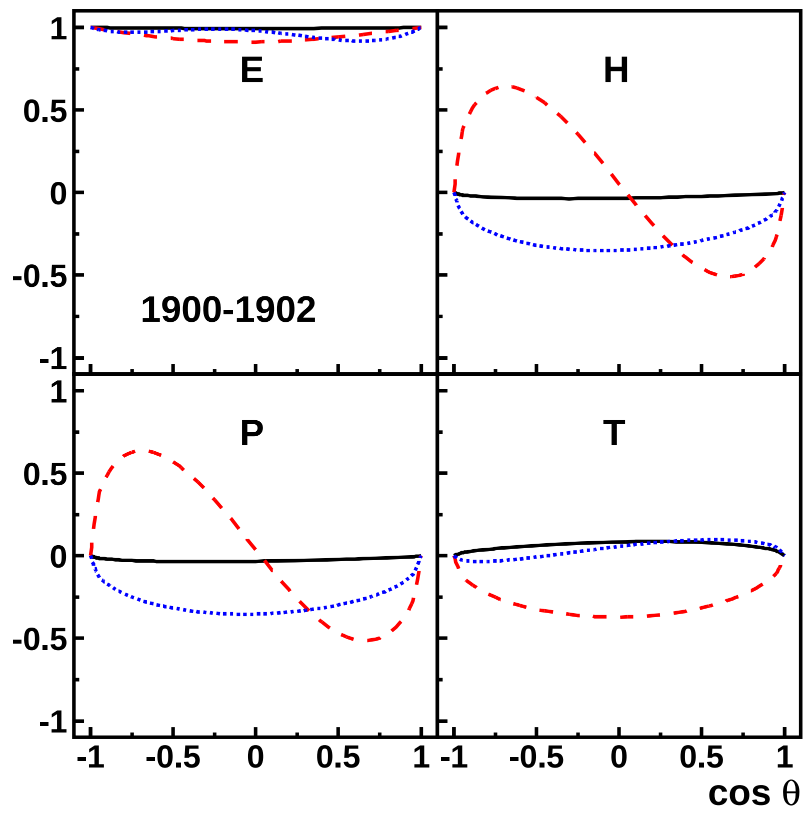
# The beam asymmetry on $\gamma p \to \eta' p$



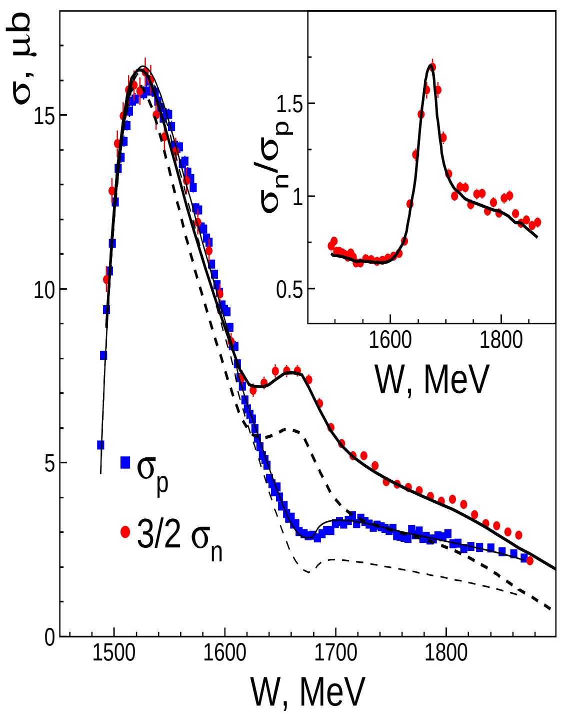

No narrow states $D_{15}(1903)$ $D_{13}(1900)$

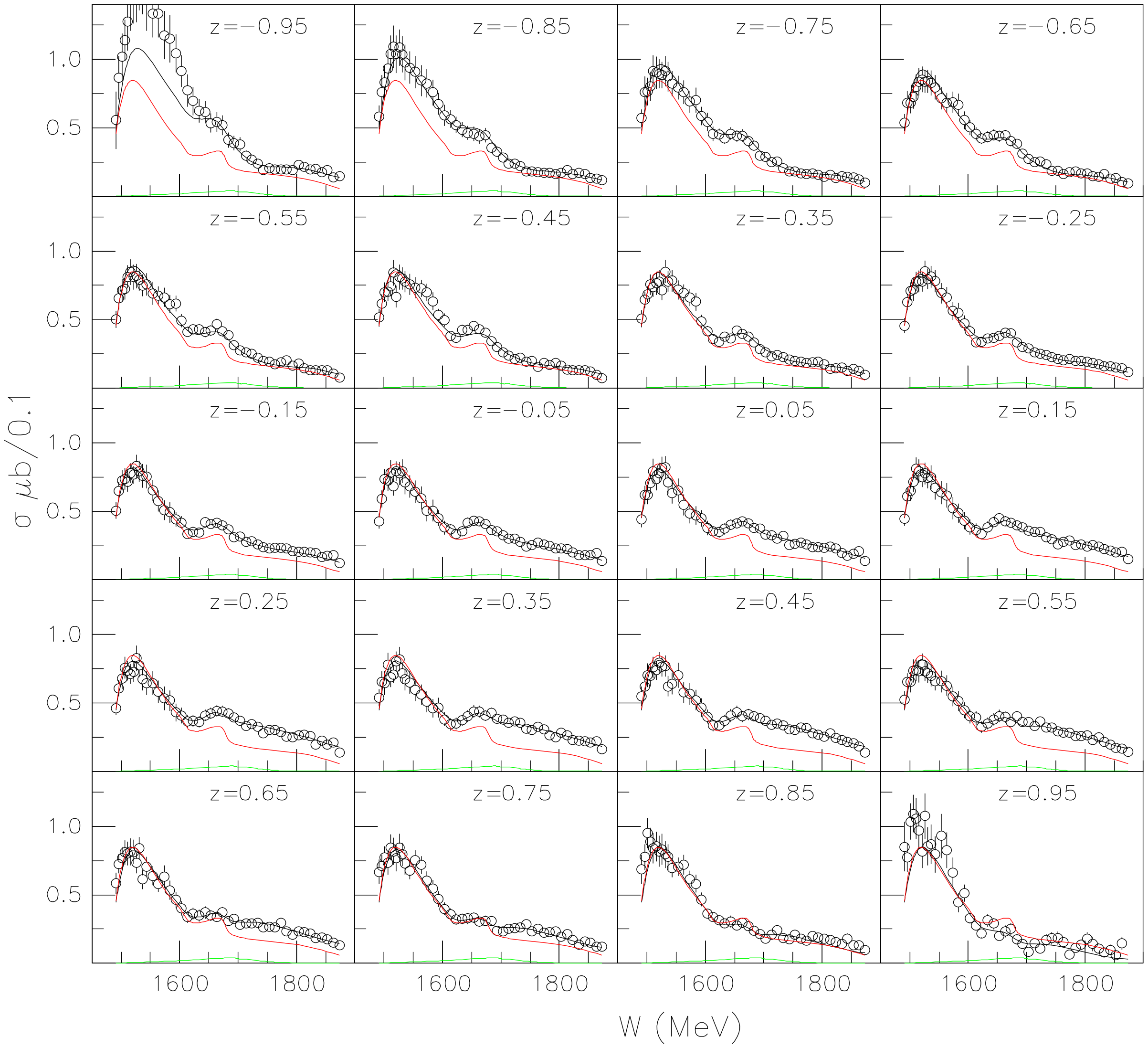
## The description of the data below W=1917 MeV and the prediction of other observables

| Resonance | N | Basic | $D_{13}$ | $D_{15}$ |
|---|---|---|---|---|
| $M$ (MeV) | | | 1900 | 1903 |
| $\Gamma$ (MeV) | | | 1 | 1 |
| $\chi^2\ (\Sigma)$ | 13 | 29.5 | 11.7 | 10.1 |
| $\chi^2\ (\frac{d\sigma}{d\Omega})$ | 50 | 120.3 | 59.9 | 129.0 |

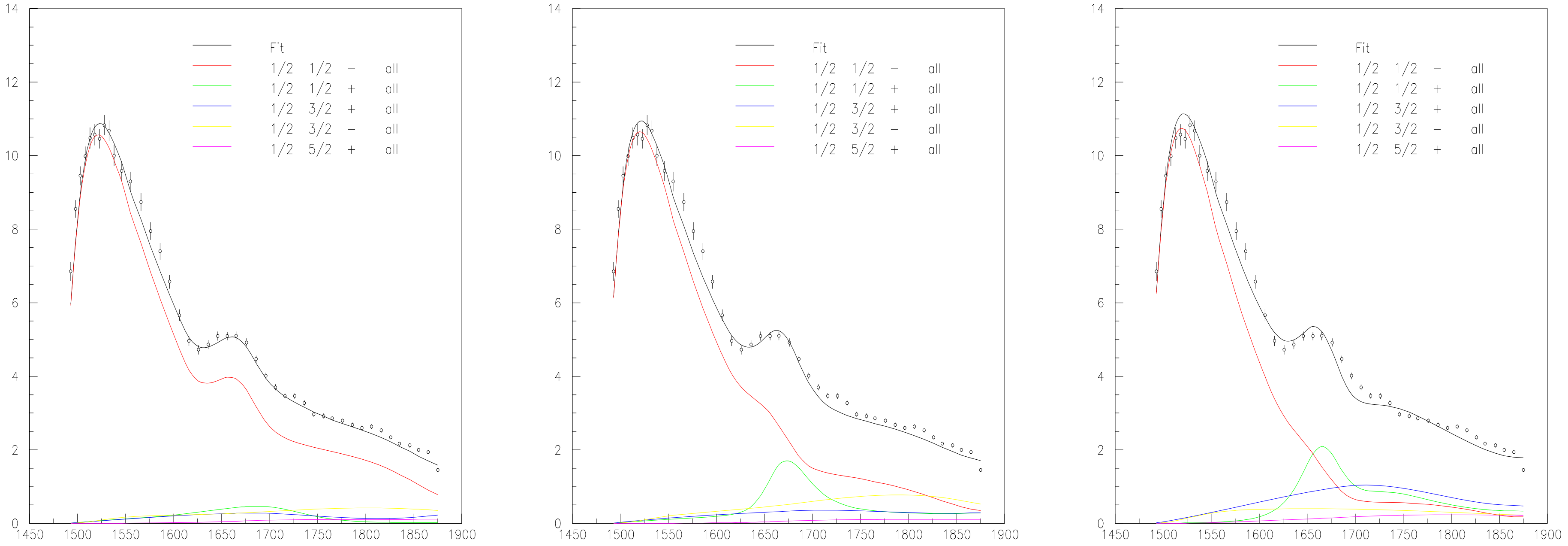


# Solution with interference between $S_{11}$ states

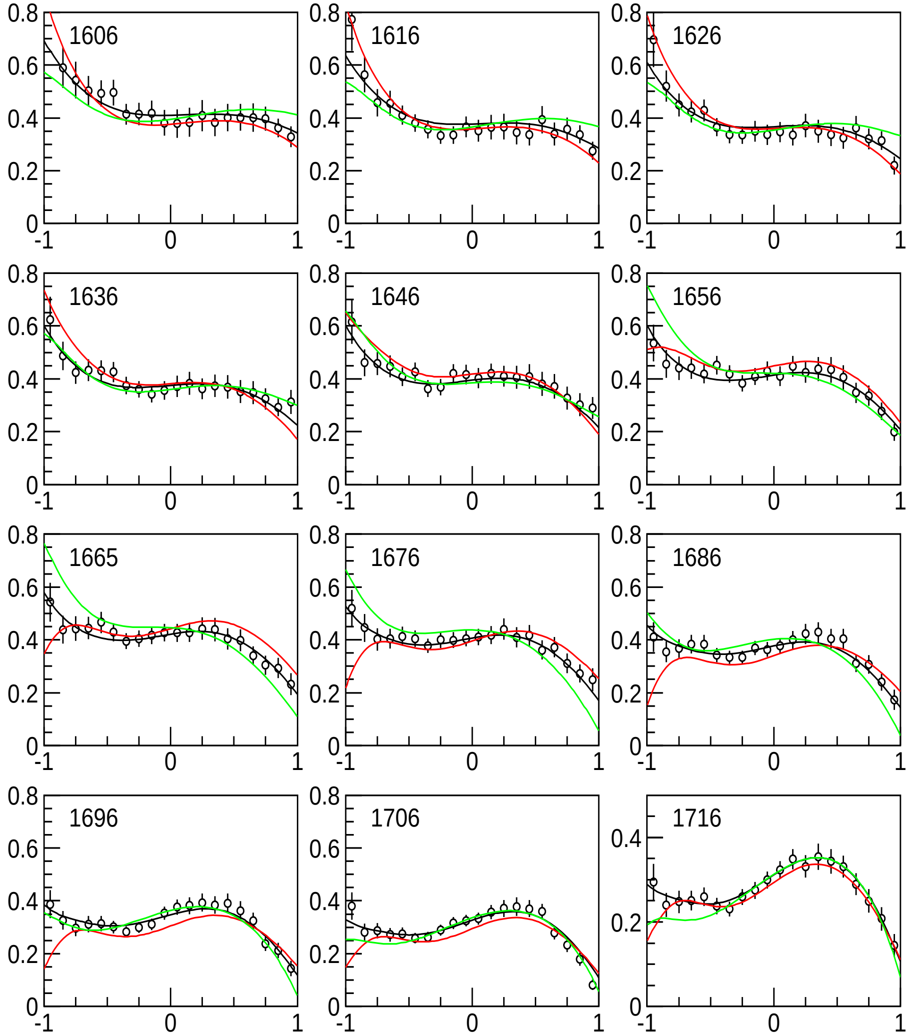


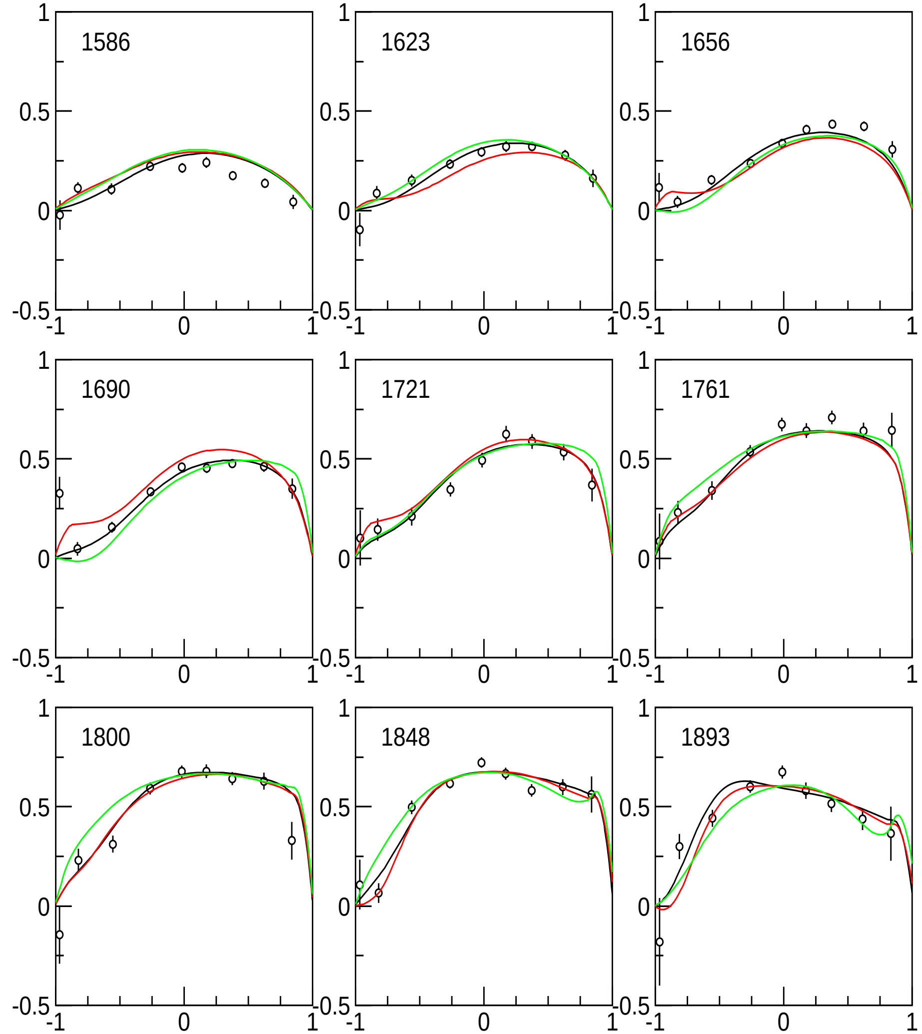



# Solutions with the $P_{11}(1680)$ states



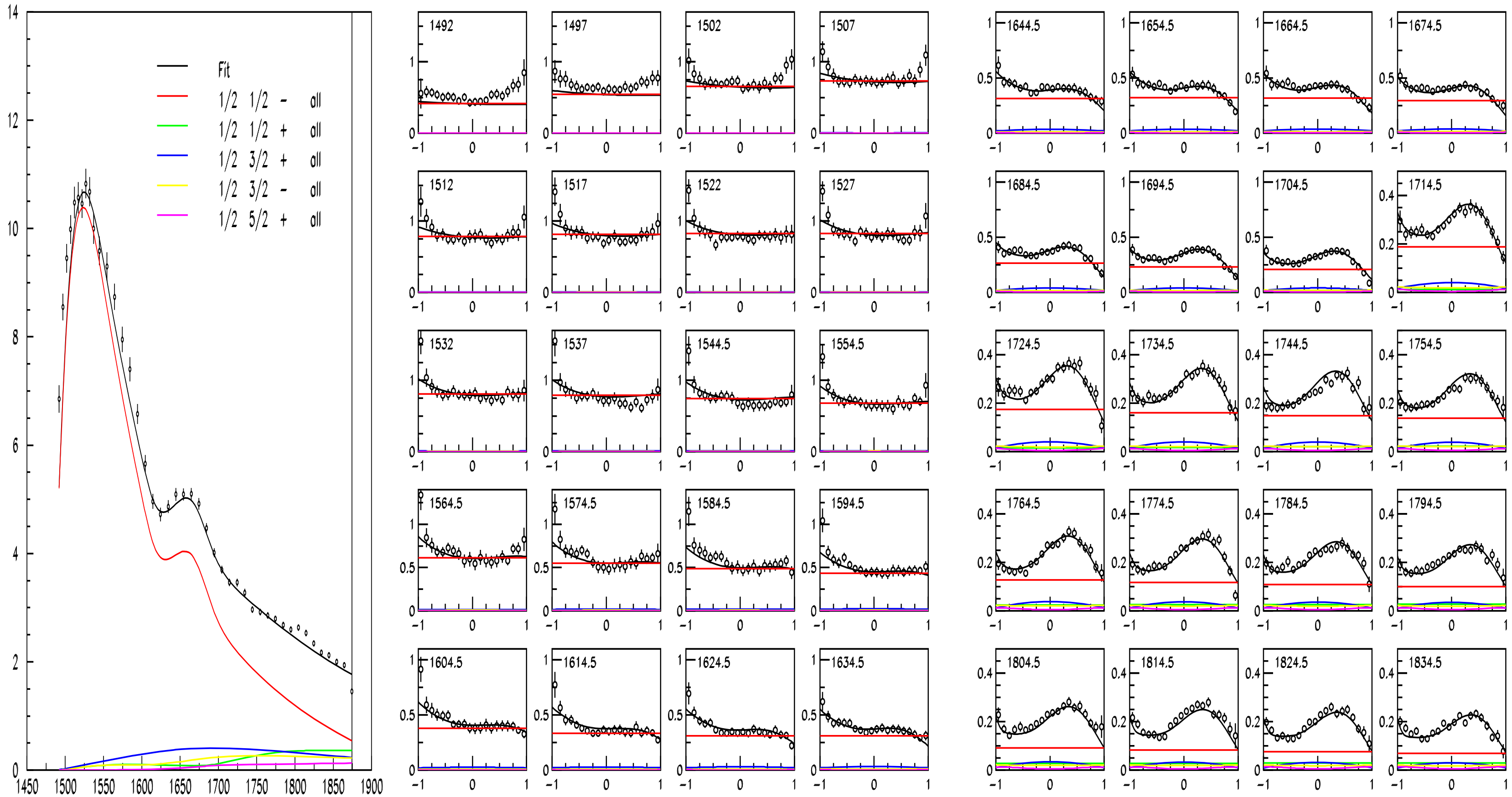
## The description of the new data as well as GRAAL data is notably worse



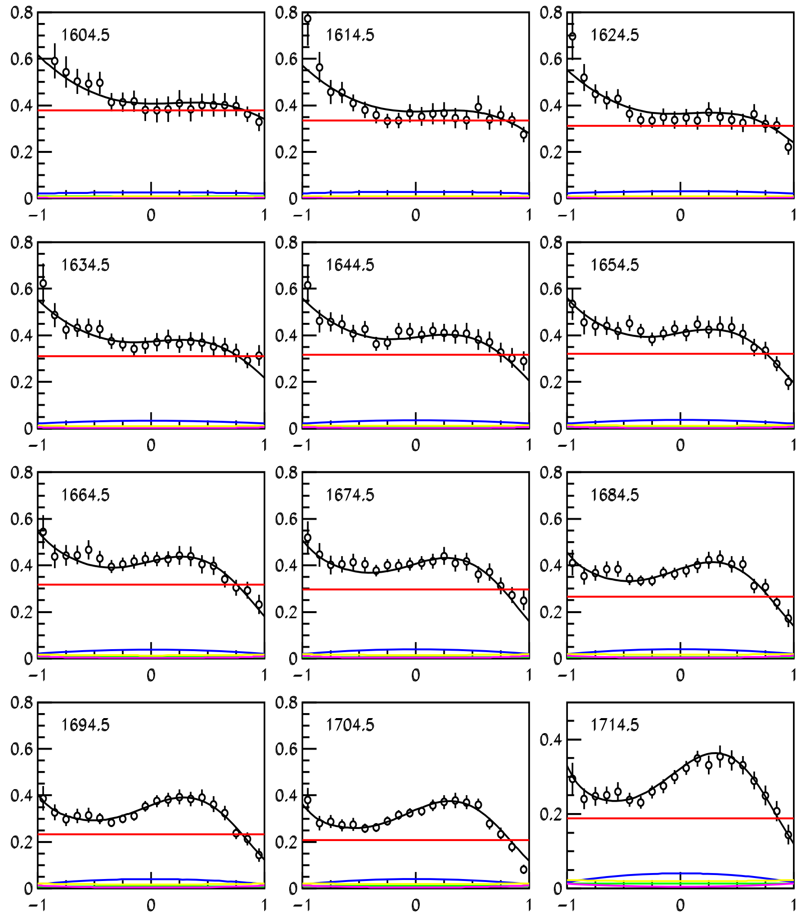



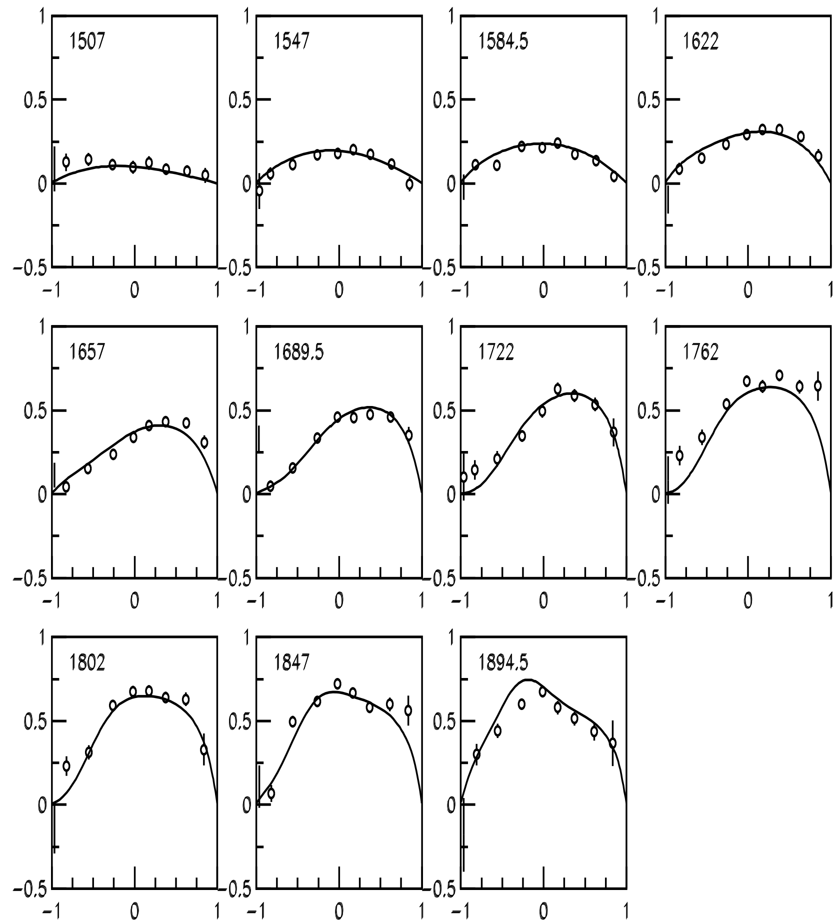

**Limit for the production of** $P_{11}(1680)$**:** $|A^{\frac{1}{2}}|Br(\eta n) <$ **5 Gev**$^{-\frac{1}{2}}10^{-3}$

# The description of the data with N/D-based approach

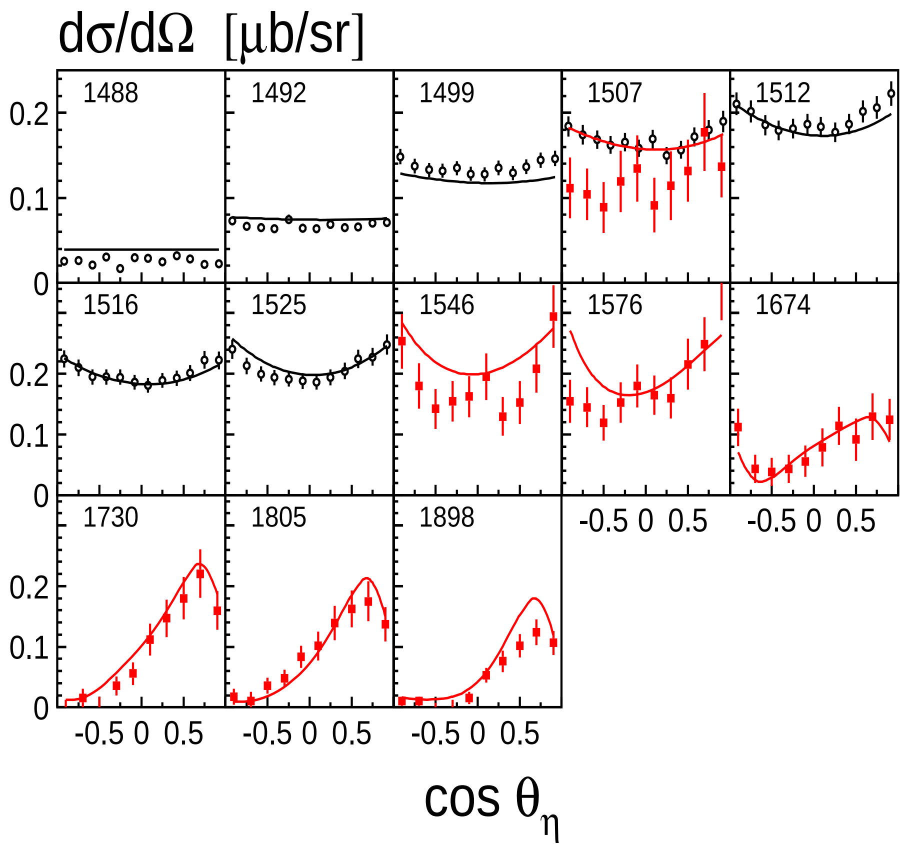


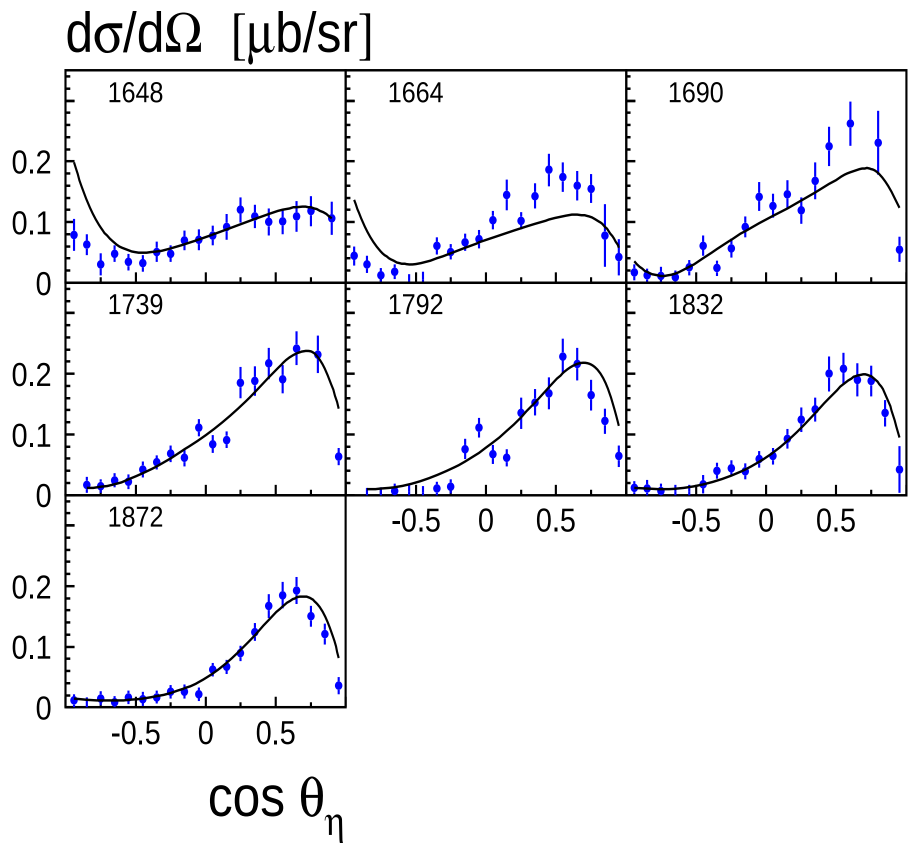
# The description of the differential cross section and beam asymmetry in the selected energy region



## The description of the $\pi p \to \eta p$ data with N/D-based approach



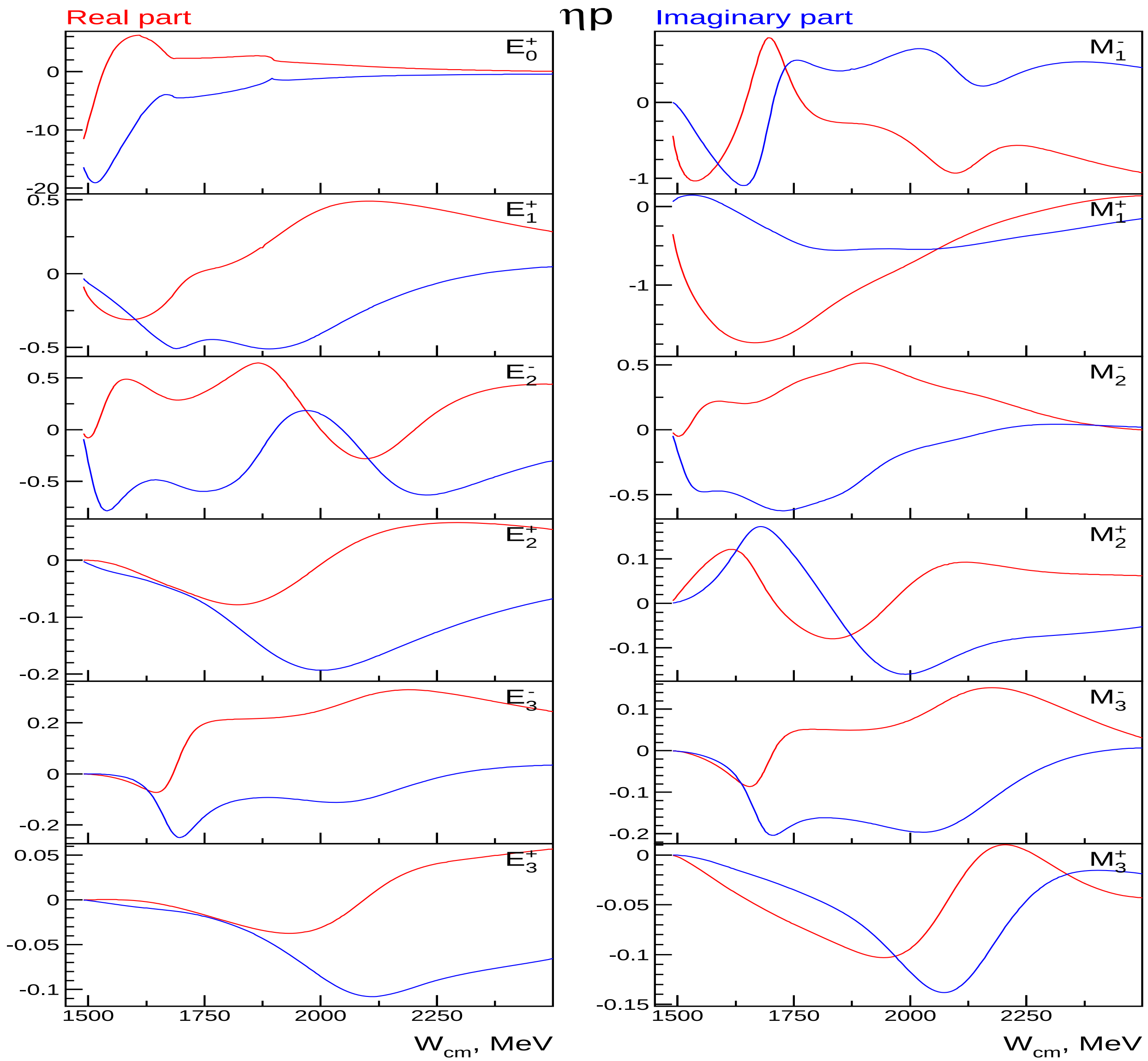




**S. Prakhov et al., Phys. Rev. C72(2005) 015203**

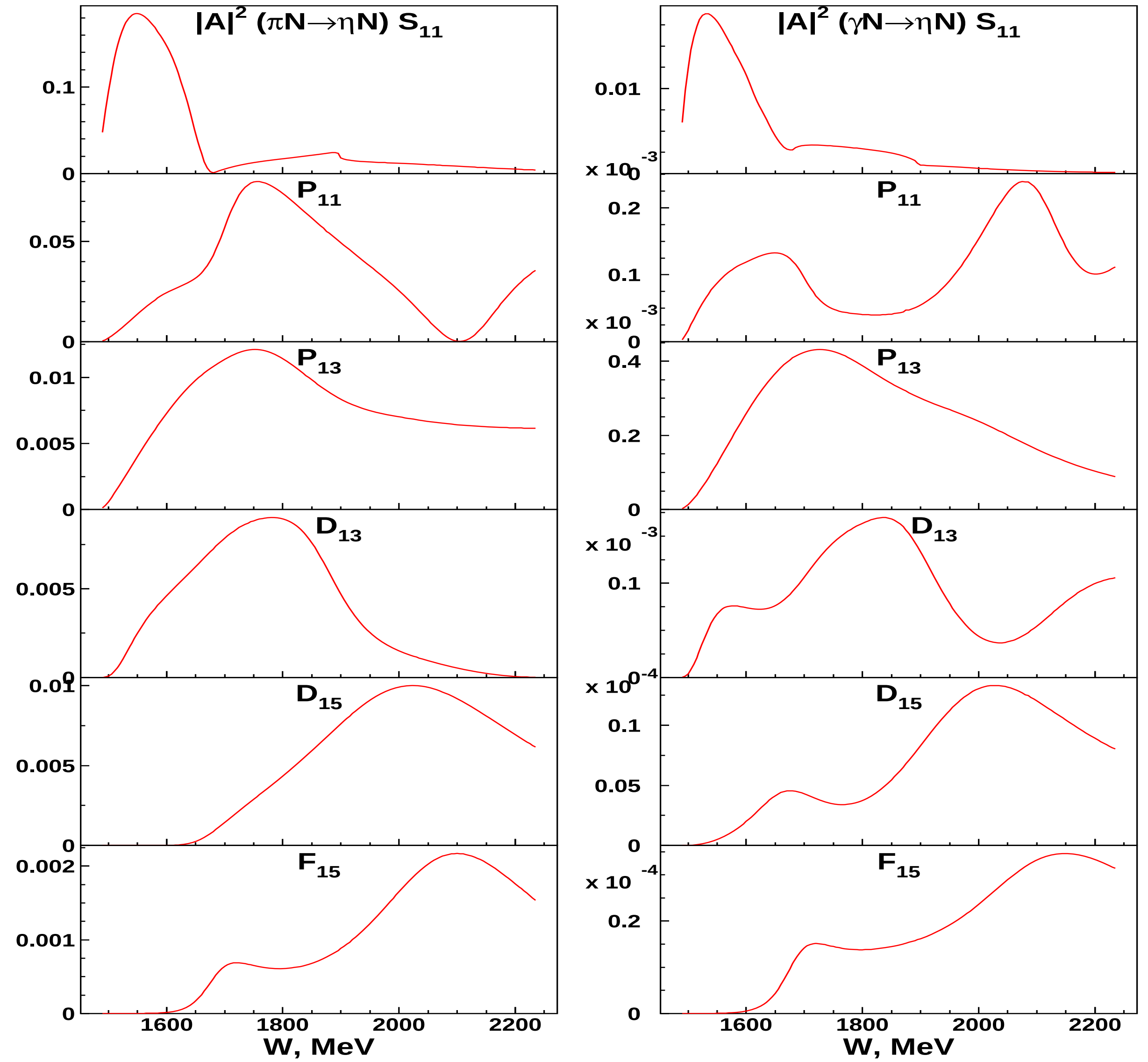
**R.M. Brown et al. Nucl. Phys. B153, 89 (1979)**

**W. B. Richards et al., Phys. Rev. D1, 10 (1970)**

# $\gamma p \to \eta p$ multipoles



# Amplitudes squared for the $\pi N \to \eta N$ and $\gamma p \to \eta p$ reactions



**Residues in the pole for $\pi N \to \eta N$ (MeV) and $\gamma N \to \eta N$ ($10^{-3}$ GeV$^{-\frac{1}{2}}$) reactions amplitudes.**

| **Res** | $N(1535)1/2^-$ | | $N(1650)1/2^-$ | | $N(1895)1/2^-$ | |
|---|---|---|---|---|---|---|
| $\pi N \to \eta N$ | **(29$\pm$2)** | **-(84$\pm$3)$^{o}$** | **-(22$\pm$3)** | **(2$\pm$12)$^{o}$** | **(5$\pm$3)** | **(25$\pm$20)$^{o}$** |
| $\gamma p \to \eta p$ **(E,-**$A^{\frac{1}{2}}$) | **-(19$\pm$2)** | **-(60$\pm$3)$^{0}$** | **(4$\pm$0.3)** | **(31$\pm$10)$^{o}$** | **(1.7$\pm$0.8)** | **(20$\pm$20)$^{o}$** |
| **Res** | $N(1440)1/2^+$ | | $N(1710)1/2^+$ | | $N(1880)1/2^+$ | |
| $\pi N \to \eta N$ | **-(20$\pm$6)** | **(0$\pm$30)$^{o}$** | **(7$\pm$2)** | **(54$\pm$15)$^{o}$** | **(12$\pm$5)** | **(60$\pm$18)$^{o}$** |
| $\gamma p \to \eta p$ **(M,**$A^{\frac{1}{2}}$) | **(5$\pm$2)** | **(15$\pm$30)$^{o}$** | **(2.2$\pm$0.7)** | **-(73$\pm$16)$^{o}$** | **(0.9$\pm$0.35)** | **(60$\pm$17)$^{o}$** |
| **Res** | $N(1520)3/2^-$ | | $N(1720)3/2^+$ | | $N(1900)3/2^+$ | |
| $\pi N \to \eta N$ | **(1.7$\pm$0.4)** | **-(88$\pm$15)$^{o}$** | **(8.1$\pm$2.6)** | **(45$\pm$10)$^{o}$** | **(2.9$\pm$0.8)** | **(55$\pm$30)$^{o}$** |
| $\gamma p \to \eta p$ ($A^{\frac{1}{2}}$) | **(0.22$\pm$0.06)** | **(86$\pm$18)$^{o}$** | **(8.7$\pm$3.0)** | **(49$\pm$10)$^{o}$** | **-(1.3$\pm$0.4)** | **-(40$\pm$25)$^{o}$** |
| $\gamma p \to \eta p$ ($A^{\frac{3}{2}}$) | **(1.18$\pm$0.20)** | **-(74$\pm$17)$^{o}$** | **-(4.0$\pm$2.1)** | **-(53$\pm$12)$^{o}$** | **(12$\pm$5)** | **(14$\pm$10)$^{o}$** |
| $\gamma p \to \eta p$ **(E)** | **-(0.91$\pm$0.15)** | **-(71$\pm$16)$^{0}$** | **-(4.3$\pm$1.7)** | **(35$\pm$15)$^{o}$** | **(4.0$\pm$1.3)** | **(6$\pm$12)$^{o}$** |
| $\gamma p \to \eta p$ **(M)** | **-(0.44$\pm$0.10)** | **-(79$\pm$14)$^{0}$** | **-(6.1$\pm$2.7)** | **-(98$\pm$14)$^{o}$** | **-(10.0$\pm$4)** | **(17$\pm$12)$^{o}$** |