NSTAR2019

The 12th International Workshop on the Physics of Excited Nucleons
10 -14 June 2019, Bonn, Campus Poppelsdorf

EtaMAID for η and η' photoproduction on nucleons

V. L. Kashevarov (Mainz University, Germany & DLNP JINR Dubna, Russia)
for Mainz – Tuzla – Zagreb Collaboration

SFB 1044
THE LOW-ENERGY FRONTIER
OF THE STANDARD MODEL

JG|U
JOHANNES GUTENBERG
UNIVERSITÄT MAINZ

DZHELEPOV LABORATORY OF NUCLEAR PROBLEMS https://maid.kph.uni-mainz.de

M A I D

Photo- and Electroproduction of Pions, Etas and Kaons on the Nucleon

Institut für Kernphysik, Universität Mainz

Mainz, Germany

MAID2007	unitary isobar model for (e,e'π)
DMT2001	dynamical model for (e,e'π)
KAON-MAID	isobar model for (e,e'K)
ETA-MAID	isobar model for (e,e'η) reggeized isobar model for (γ,η)
Chiral MAID NEW	chiral perturbation theory approach for (e,e'π)
2-PION-MAID	isobar model for (γ,ππ)
archive	MAID2000 MAID2003 DMT2001original ETAprime2003

History of MAID

The first MAID program appeared in 1998:

1. D. Drechsel, O. Hanstein, **S. S. Kamalov**, L. Tiator,
   Unitary isobar model for pion photoproduction and electroproduction on the proton up to 1-GeV, Nucl. Phys. A 645 (1999) 145.

Soon afterwards the Dubna-Mainz-Taipei (DMT) dynamical model was developed:

2. **S. S. Kamalov**, Shin Nan Yang,
   Pion cloud and the Q**2 dependence of gamma* N <---> Delta transition form-factors,
   Phys. Rev. Lett. 83 (1999) 4494.

3. **S. S. Kamalov**, S. N. Yang, D. Drechsel, O. Hanstein, L. Tiator,
   Gamma* N ---> Delta transition form-factors: A New analysis of the JLab data ...
   Phys. Rev. C 64 (2001) 032201.

History of MAID

Sabit Kamalov 15.09.1955 – 24.05.2019

MTZ Collaboration

Now MAID is part of research program of

Mainz – Tuzla – Zagreb Collaboration

Mainz: Misha Gorchteyn, Victor Kashevarov, Kirill Nikonov,
Michael Ostrick, Lothar Tiator

Tuzla: Mirza Hadžimehmedović, Rifat Omerović,
Hedim Osmanović, Jugoslav Stahov

Zagreb: Alfred Švarc

Two more presentations of MTZ Collaboration:

1. Alfred Švarc, June 12, Wednesday, 16:30
2. Misha Gorchteyn, June 12, Wednesday, 17:30

EtaMAID 2018

The first version of EtaMAID:

W. T. Chiang, S. N. Yang, L. Tiator, D. Drechsel, Nucl.Phys. A 700 (2002) 429.

photoproduction amplitudes

$$t_\alpha(W) = t_\alpha^{Bgr}(W) + t_\alpha^{Res}(W)$$

t_α^{Bgr} : Born $+\,t$-channel vector and axial-vector exchanges

t_α^{Res} : $\sum_{i=1}^{n}\{\text{Breit-Wigner resonances } N, \Delta\}$

MAID2007 (γ,π) : 2 S_{11}, for all other channels only 1 resonance N and Δ

EtaMAID2018 (γ,η) : 4 P_{11}, 3 S_{11}, 4 D_{13}, … only N no Δ

problems:

• unitarity	(Watson‘s theorem, coupled channels !)
• fixed-*t* analyticity	(dispersion relations !)
• duality	(problematic with Regge models !)

EtaMAID 2018: unitarity aspects

In previous versions of EtaMAID 2002-2017 this apect was ignored.

EtaMAID 2018:

- No unitarization for background;
- Unitarity phases for Breit-Wigner resonances do not depend on energy W and are determined from fit to data, just like in pion photoproduction above two-pion thresold.

$$t^{\alpha}_{\gamma,\eta}(W) = t^{\alpha,Born}_{\gamma,\eta}(W) + t^{\alpha,VM(Regge)}_{\gamma,\eta}(W) \cdot F_d(W)$$

$$+ \sum_{j=1}^{N_\alpha} t^{\alpha,BW,j}_{\gamma,\eta}(W) \cdot e^{i\Phi_j}$$

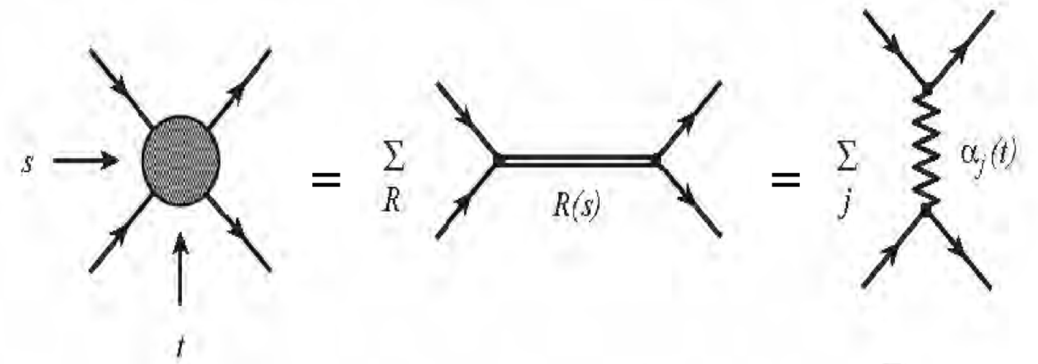
phenomenological phase
taken as a free parameter

EtaMAID 2018: duality

from quark-hadron duality it is known:

sum over all s-channel resonances is equivalent to sum over all t-channel resonances

therefore: keeping both leads to double counting



$$M = \sum_{i=1}^{\infty} M_s^{Res_i} = \sum_{i=1}^{\infty} M_t^{Res_i} = \sum_{i=1}^{N} M_s^{Res_i} + \left[\sum_{i=1}^{\infty} M_t^{Res_i} - \sum_{i=1}^{N} M_s^{Res_i} \right]$$

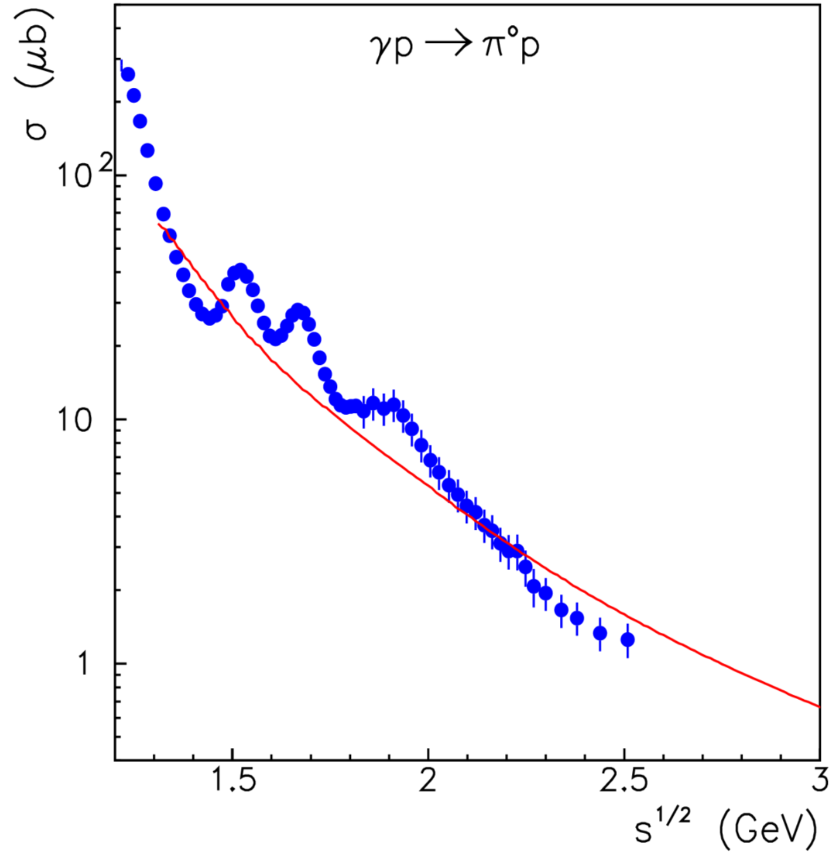
$$\approx \sum_{i=1}^{N} M_s^{Res_i} + M^{Regge} \cdot F_d(W)$$

: our approach

Regge + Resonances

Duality: $\sum \text{Resonances} = \sum \text{Reggeons}$

A. Sibirtsev, J. Haidenbauer, S. Krewald, U. G. Meissner, and A. W. Thomas, EPJA **41**, 71 (2009)



EtaMAID 2018: modelling the background

- Born terms in s and u channels + Regge trajectories in t channel

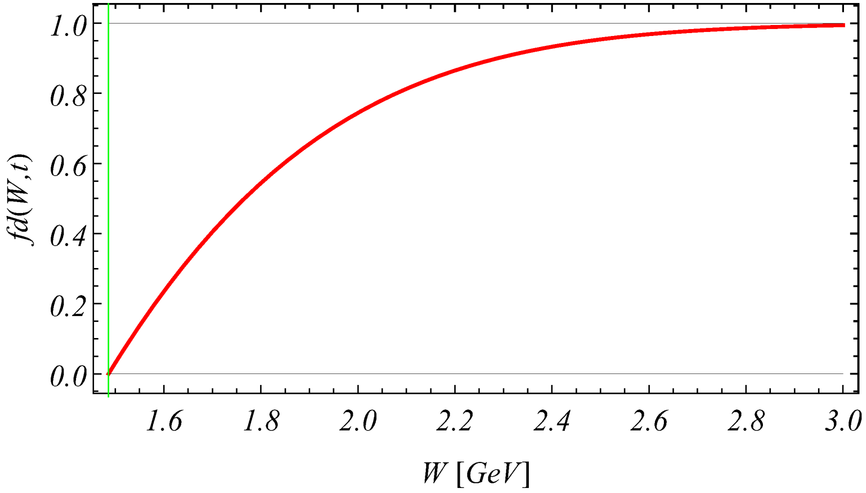
- Energy dependence coupling constants for Born terms:

  g → g ✶ (W_{thr}/W)**parB, fit parameter parB = 4.51 (η), 3.95 (η')

- Regge → Regge ✶ damping factor f_d(W)

  fit parameter Λ = 970 MeV (η), 440 MeV (η')

$$f_d(W) = 1 - e^{-\frac{W - W_{thr}}{\Lambda}}$$



EtaMAID 2018

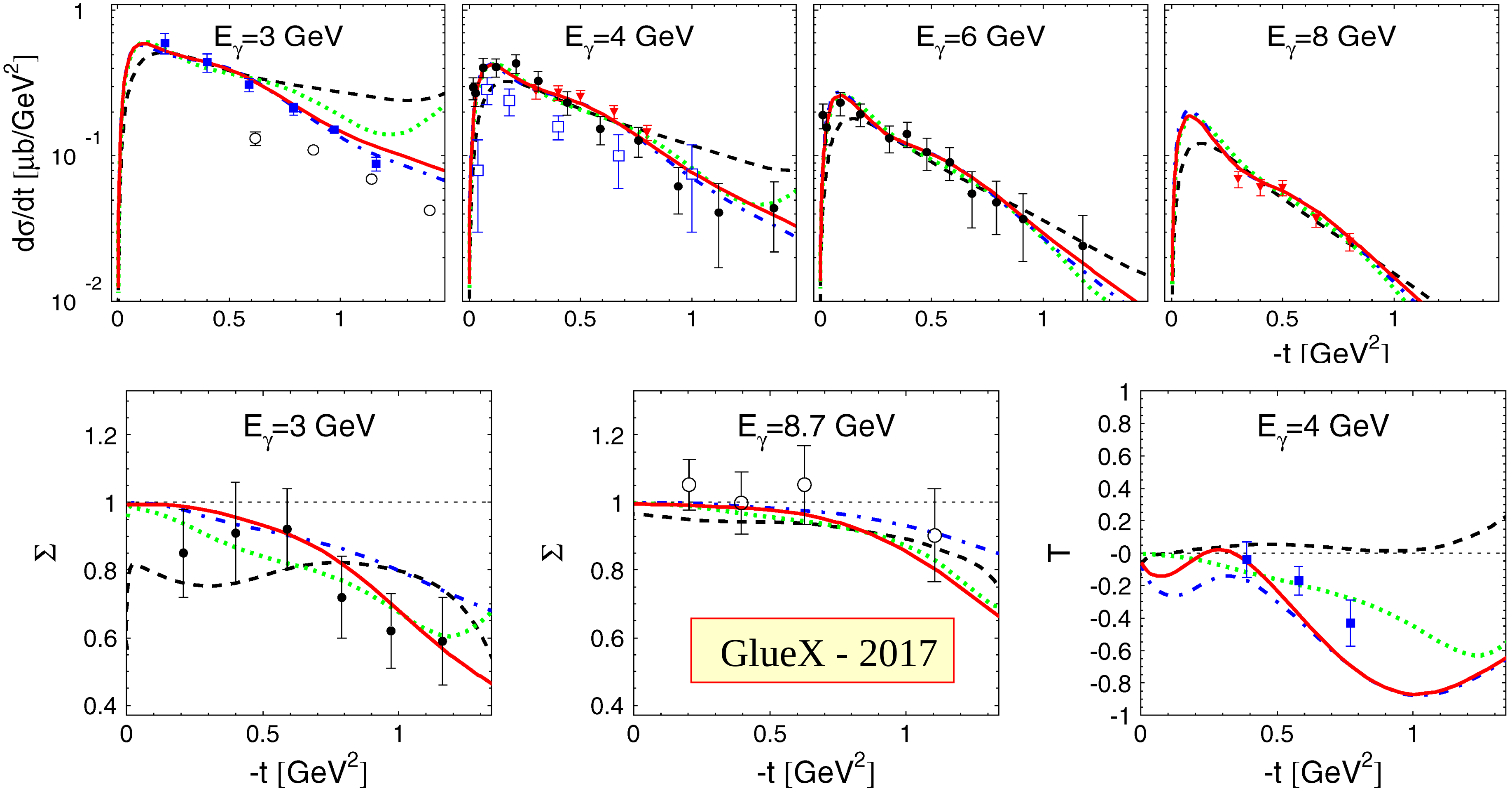
total number of data points: 10,700 - our overall χ^2/data in the fit is 2.46

		Observable	Reaction	used	W [MeV]	N	χ^2	χ^2/N	Reference
η p	5 observables	σ_0	$p(\gamma,\eta)p$	—	1488 – 1870	2880	9502	3.3	A2MAMI-17 (Run I)
		σ_0	$p(\gamma,\eta)p$	✓	1488 – 1891	2712	4437	1.6	A2MAMI-17 (Run II)
		σ_0	$p(\gamma,\eta)p$	✓	1888 – 1957	288	329	1.1	A2MAMI-17 (Run III)
		σ_0	$p(\gamma,\eta)p$	✓	1965 – 2795	634	2276	3.6	CLAS-09
		σ_0	$p(\gamma,\eta)p$	—	1588 – 2370	680	8640	13.	CBELSA/TAPS-09
		Σ	$p(\gamma,\eta)p$	✓	1496 – 1908	150	394	2.6	GRAAL-07
		Σ	$p(\gamma,\eta)p$	✓	1700 – 2080	214	617	2.9	CLAS-17
		T	$p(\gamma,\eta)p$	✓	1497 – 1848	144	246	1.7	A2MAMI-14
		F	$p(\gamma,\eta)p$	✓	1497 – 1848	144	246	1.7	A2MAMI-14
		E	$p(\gamma,\eta)p$	✓	1525 – 2125	73	155	2.1	CLAS-16
		E	$p(\gamma,\eta)p$	✓	1505 – 1882	135	255	1.9	A2MAMI-17
η n	3 obs	σ_0	$n(\gamma,\eta)n$	✓	1492 – 1875	880	3079	3.5	A2MAMI-14
		σ_0	$n(\gamma,\eta)n$	—	1505 – 2181	322	2986	9.3	CBELSA/TAPS-11
		Σ	$n(\gamma,\eta)n$	✓	1504 – 1892	99	177	1.8	GRAAL-08
		E	$n(\gamma,\eta)n$	✓	1505 – 1882	135	209	1.5	A2MAMI-17
η' p	2 obs	σ_0	$p(\gamma,\eta')p$	✓	1898 – 1956	120	198	1.7	A2MAMI-17
		σ_0	$p(\gamma,\eta')p$	✓	1925 – 2795	681	2013	3.0	CLAS-09
		σ_0	$p(\gamma,\eta')p$	—	1934 – 2351	200	278	1.4	CBELSA/TAPS-09
		Σ	$p(\gamma,\eta')p$	✓	1903 – 1913	14	35	2.5	GRAAL-15
		Σ	$p(\gamma,\eta')p$	✓	1904 – 2080	62	85	1.4	CLAS-17
η' n	1	σ_0	$n(\gamma,\eta')n$	✓	1936 – 2342	170	191	1.1	CBELSA/TAPS-11

Regge model for background

Diff. cross sections and polarisation observables for $\gamma p \to \eta p$ at high energies

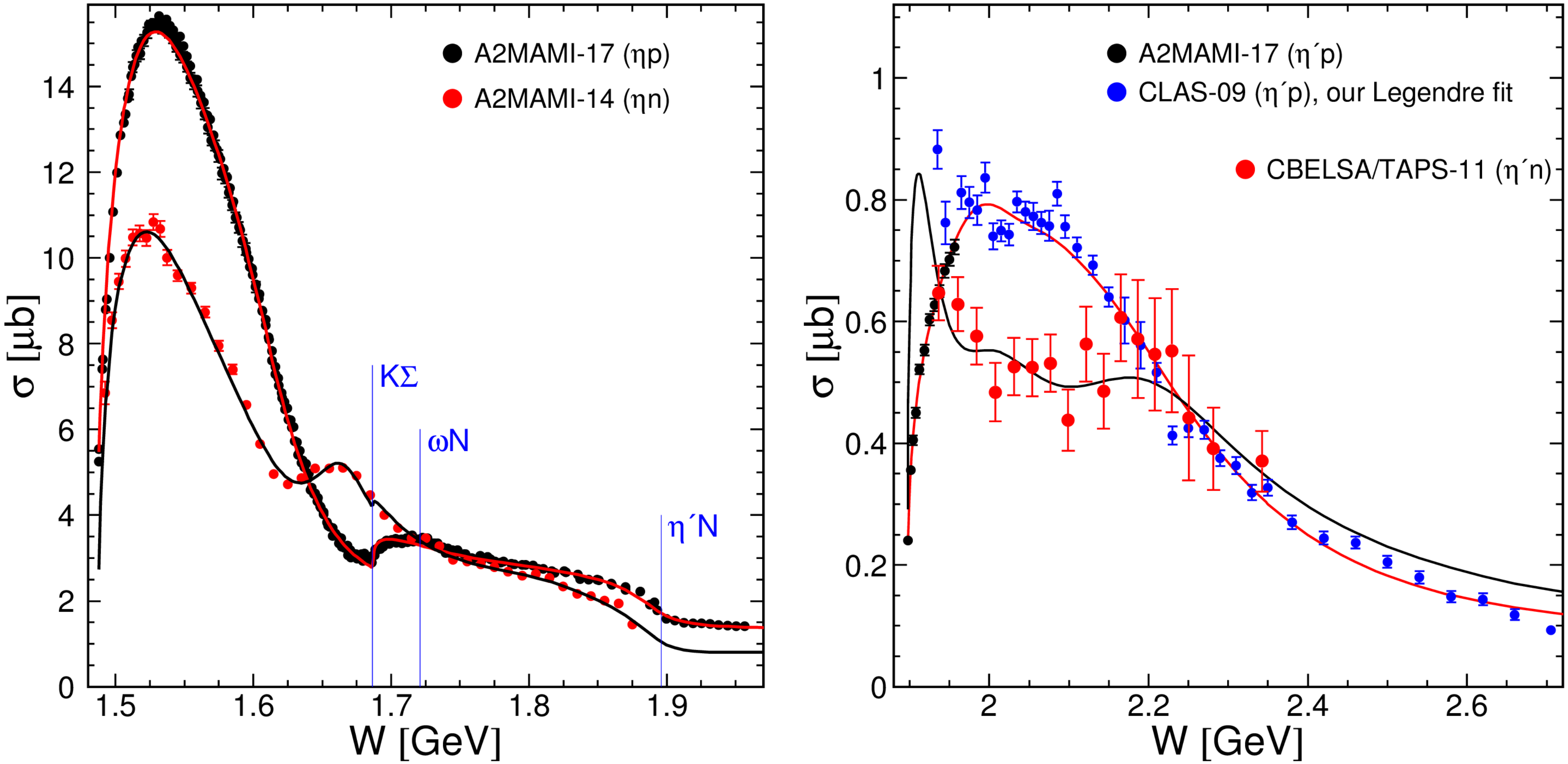
comparison with different Regge models — our favoured Regge-cut model



V. L. Kashevarov, M. Ostrick, L. Tiator , Phys. Rev. C**96** (2017) 045207

Fit results: total cross sections

$\gamma\ N \rightarrow\ \eta\ N$ $\qquad\qquad$ $\gamma\ N \rightarrow\ \eta'\ N$



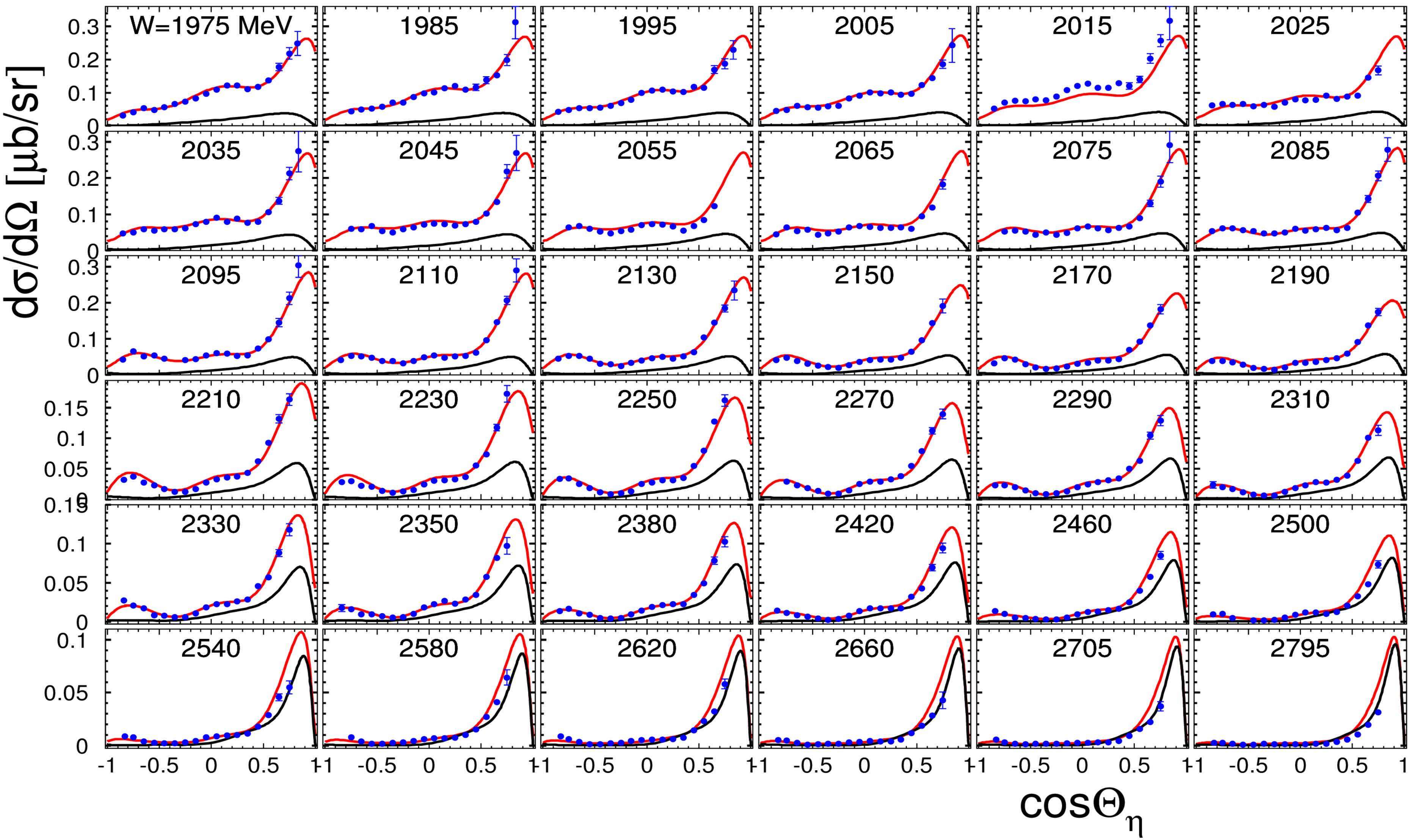
Lines: full solution for γp (red) and γn (black) channels.

γ p → η p: $\chi^2 = 238.6/125 \approx 1.91$; $\qquad$ γ p → η´ p: $\chi^2 = 9.46/12 \approx 0.79$ (A2MAMI)

γ n → η n: $\chi^2 = 120.6/44 \approx 2.74$; $\qquad$ γ n → η´ n: $\chi^2 = 10.9/17 \approx 0.64$

$\gamma\ p \to\ \eta\ p$

Fit results: dσ/dΩ



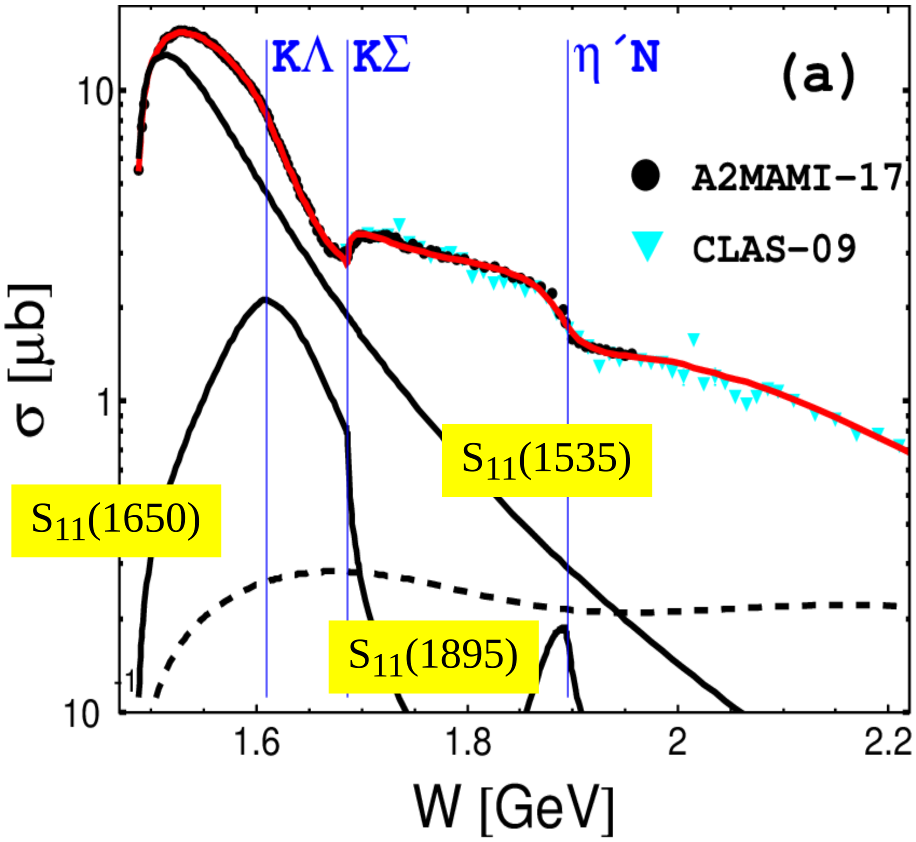
$\chi^2 = 2265/634 \approx 3.57$

Data: CLAS-09

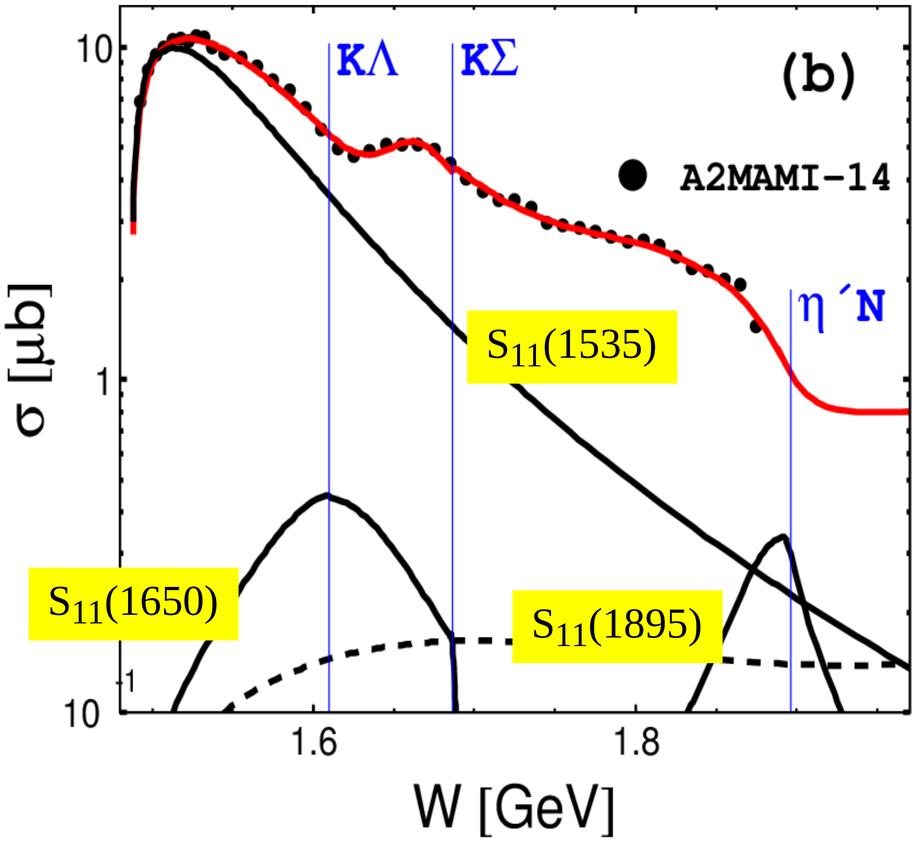
Lines: red – full solution; solid black – Regge+Born; dashed – Regge ; dotted – Born terms

Fit results: partial contribution of resonances

$\gamma\ p \rightarrow\ \eta\ p$

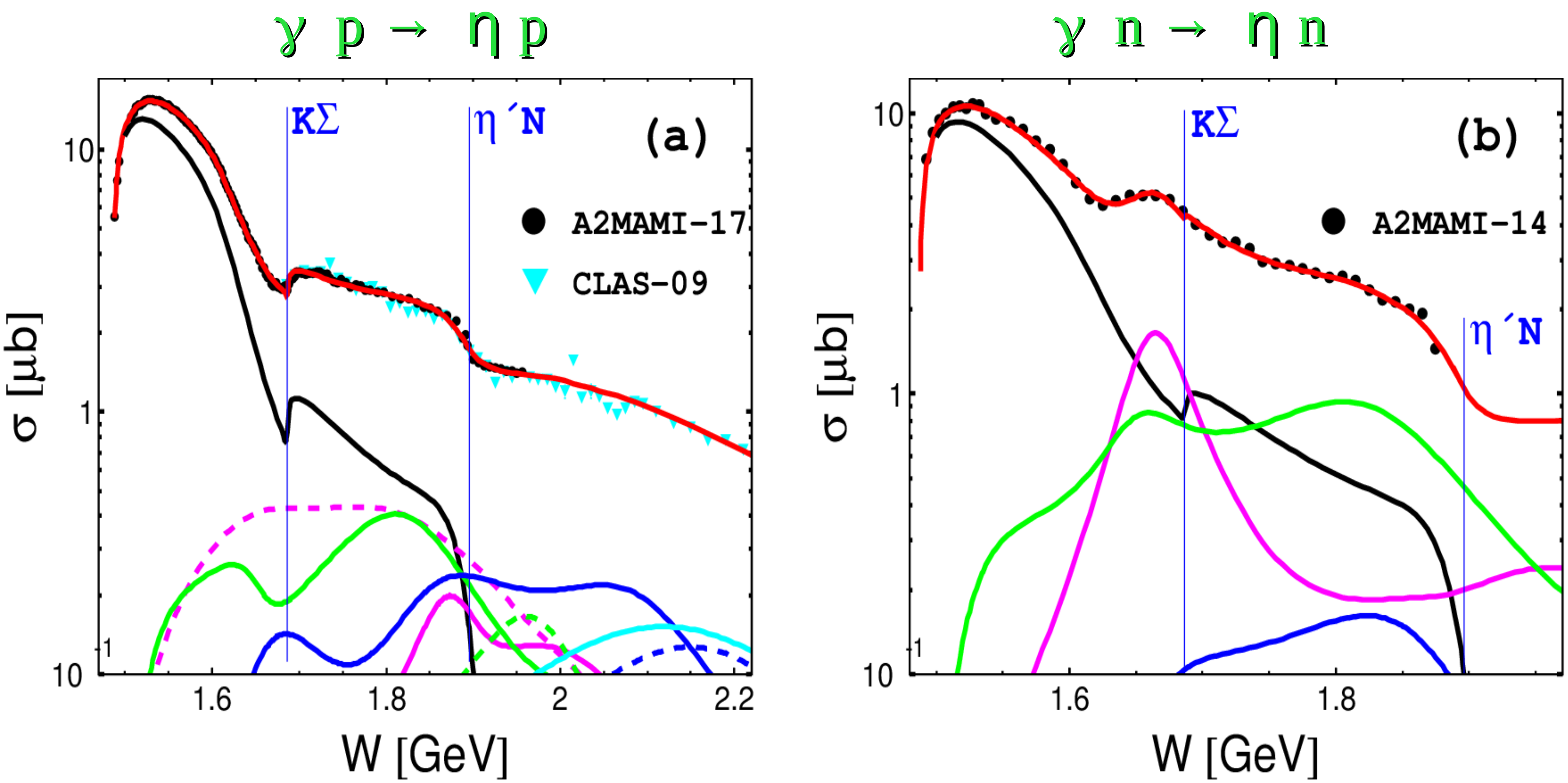


$\gamma\ n \rightarrow\ \eta\ n$



Black dashed line – Regge + Bonrn contribution

Fit results: partial waves contribution (no bgr)

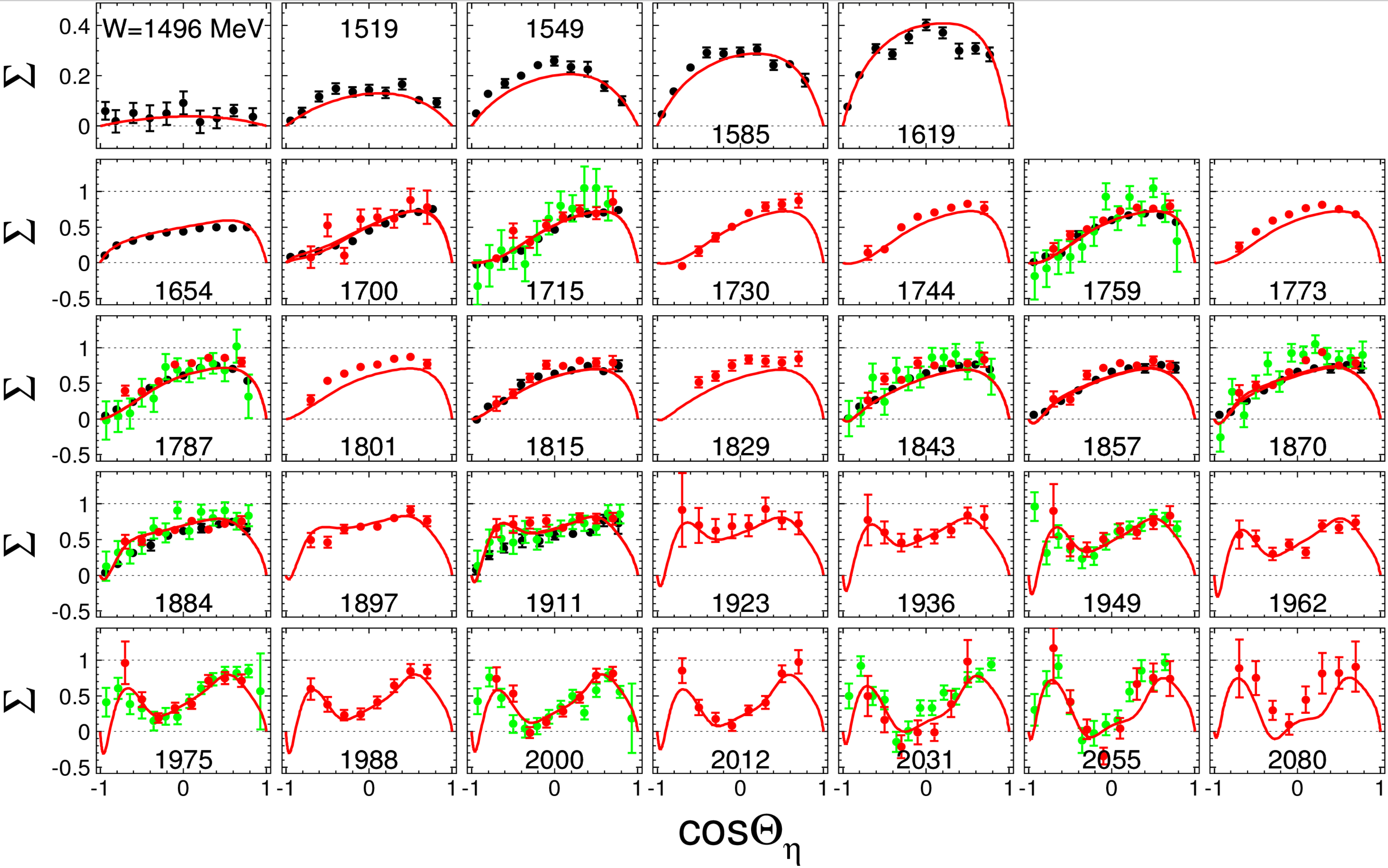


S_{11} – black solid;
P_{11} – magenta solid;
D_{13} – green solid;
F_{15} – blue solid;
G_{17} – cyan solid

P_{13} – magenta dashed
D_{15} – green dashed
F_{17} – blue dashed

$\gamma\ p \rightarrow \eta\ p$

Fit results: Σ



Data: black – GRAAL-07; red – CLAS-17; green – CBELSA/TAPS preliminary

$X^2 = 531.8/150 \approx 3.55$

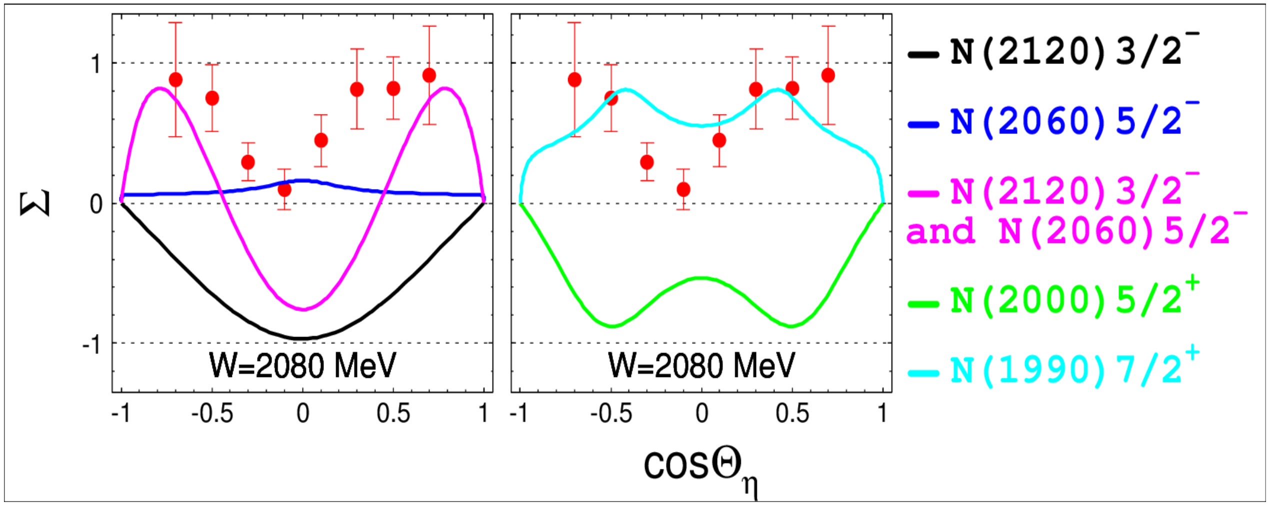
$X^2 = 694.1/214 \approx 3.24$

$X^2 = 309.5/156 \approx 1.98$

$\gamma\ p \to \eta\ p$

Fit results: Σ

Partial contributions of resonances



N(2120)$3/2^-$ and N(2060)$5/2^-$ interference explains the shape of the angular distributions.

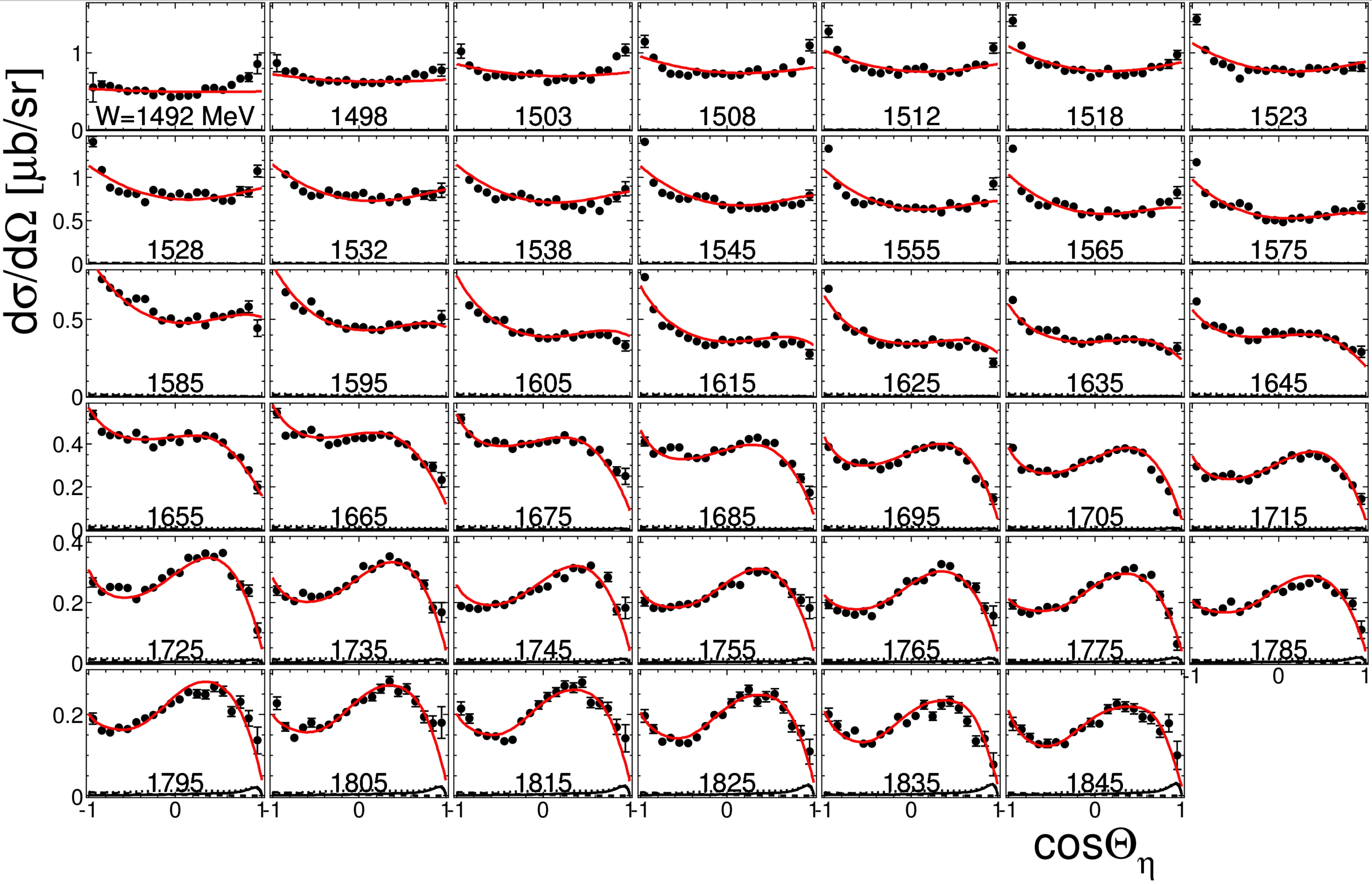
Overall status for both resonances in PDG-2019: ***
But status for (η N): 0 for N(2120)$3/2^-$ and * for N(2060)$5/2^-$

Should be updated!

Excluding N(2000)5/2+ or N(1990)7/2+ from the fit practically does not affect the quality of Σ data description.

γ n → η n

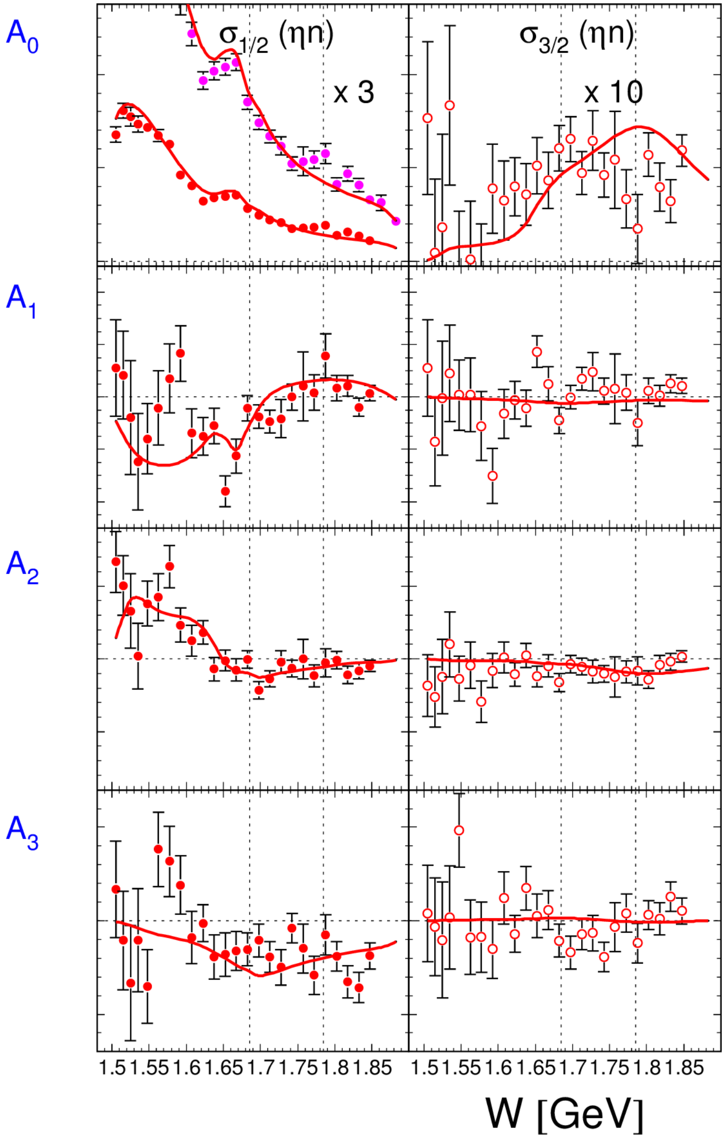
Fit results: dσ/dΩ



Data: A2MAMI-14
Lines: full solution

$\gamma\ n \rightarrow \eta\ n$

Legendre coefficients



Data: A2MAMI-17;
Red lines: full solution

Partial wave content of Legendre coefficients, $l_{max} = 3$

$$
\begin{aligned}
A_0 &= SS + PP + SD + DD + PF + FF \\
A_1 &= SP + PD + SF + DF \\
A_2 &= PP + SD + DD + PF + FF \\
A_3 &= PD + SF + DF \\
A_4 &= DD + PF + FF \\
A_5 &= DF \\
A_6 &= FF
\end{aligned}
$$

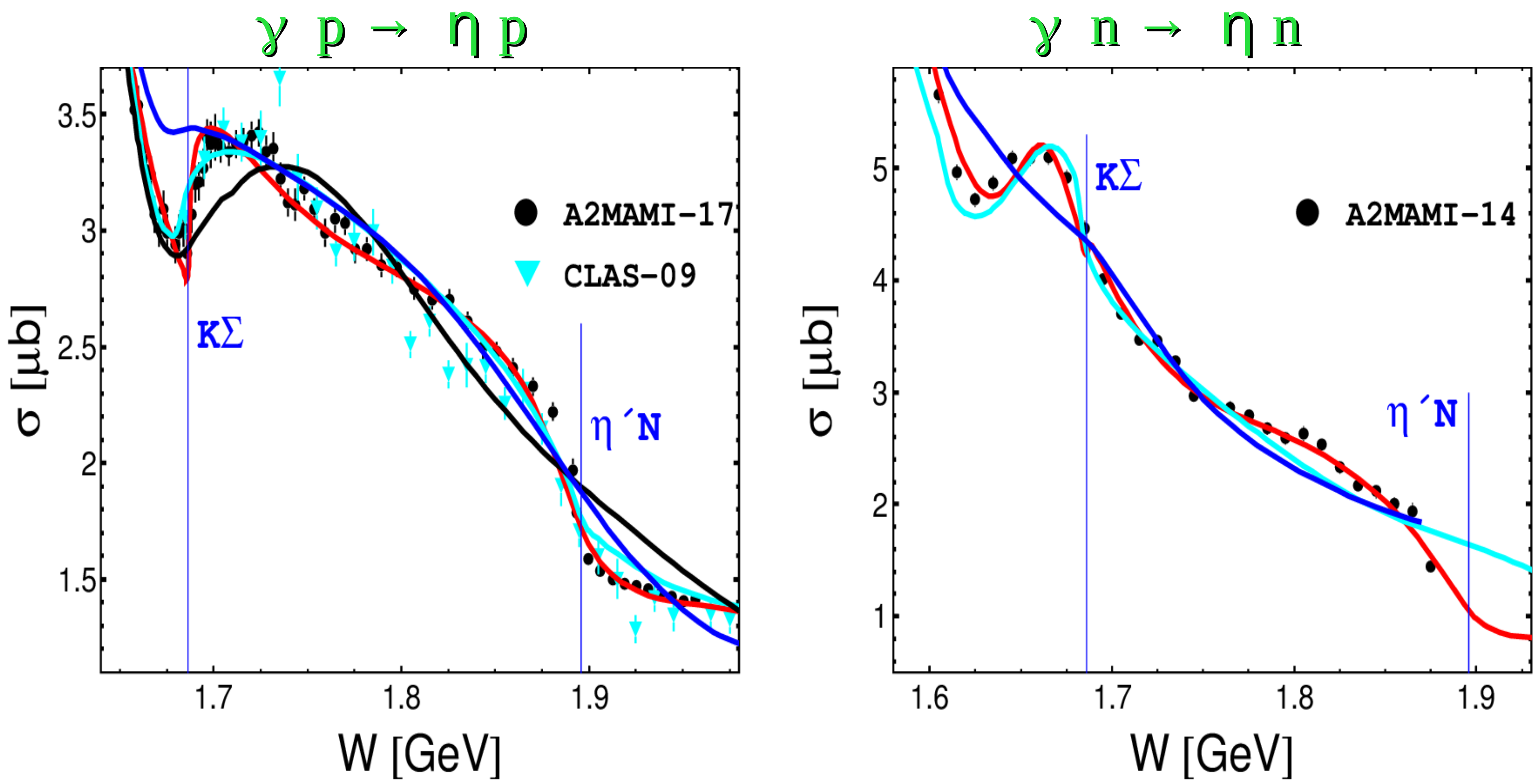
Other PWA groups analyzing (γ,η) and (γ,η') data

BnGa: Bonn-Gatchina group:
A.V. Anisovich, E. Klempt, V.A. Nikonov, A.V. Sarantsev, and U. Thoma.
Multi-channel K-matrix model and N/D dispersion approach.
Predictions up to W=2500 MeV for 3 channels:
$p(\gamma,\eta)p$, **$n(\gamma,\eta)n$**, and **$p(\gamma,\eta')p$**

JüBo: Jülich-Bonn group:
D. Rönchen, M. Döring, H. Haberzettl, J. Haidenbauer, U.-G. Meißner, and K. Nakayama.
Covariant multi-channel dynamical model.
Predictions up to W=2380 MeV for 1 channel: **$p(\gamma,\eta)p$**

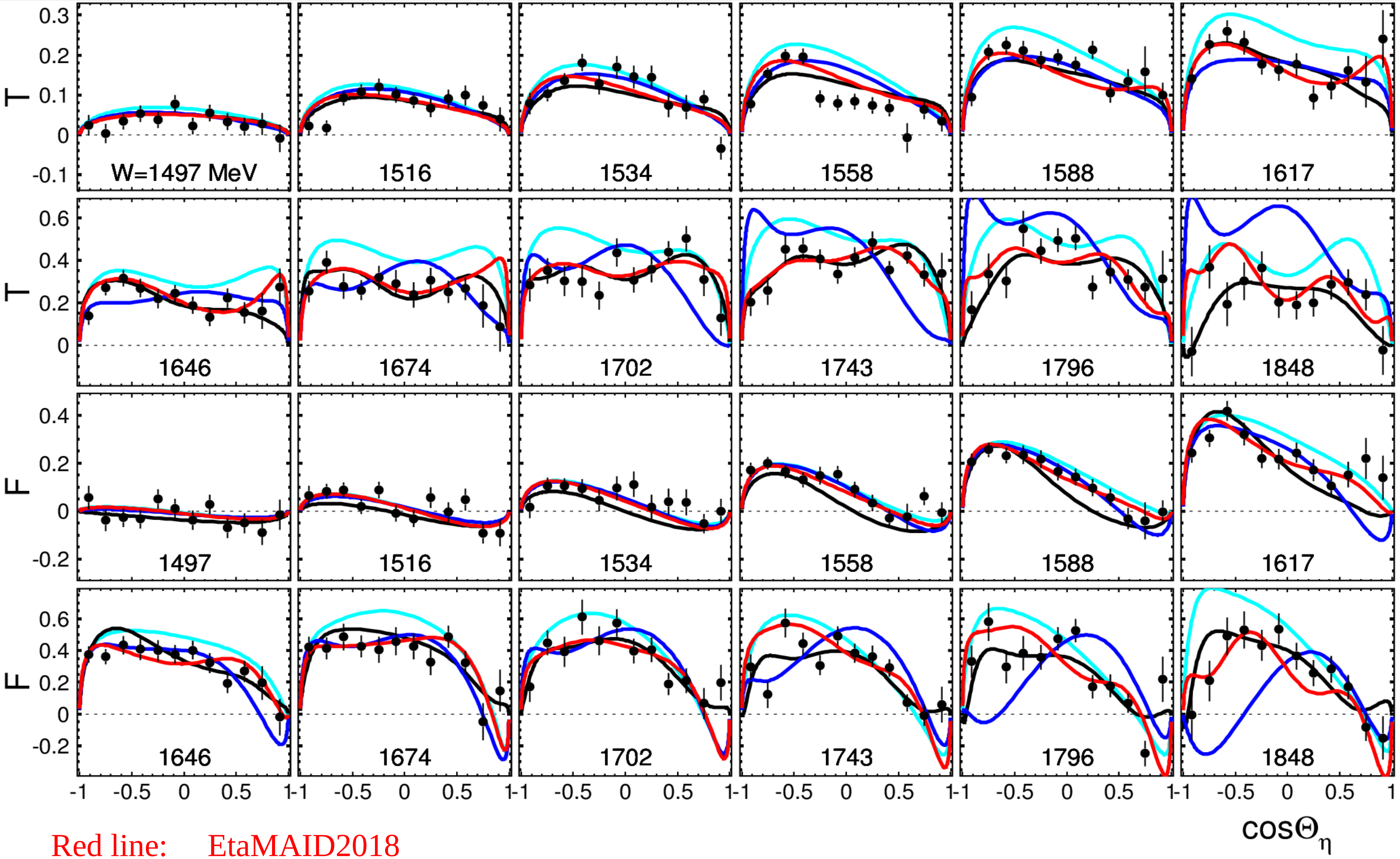
KSU: Kent State University group:
B.C. Hunt and D.M. Manley.
Multi-channel K-matrix model.
Predictions for 2 channels: **$p(\gamma,\eta)p$** up to W=1990 MeV,
$n(\gamma,\eta)n$ up to W=1870 MeV

Comparison with other new PWA



Red line: EtaMAID2018
Cyan line: BnGa
Blue line: KSU
Black line: JüBo

$\gamma\ p \rightarrow \eta\ p$ Polarization observables T and F

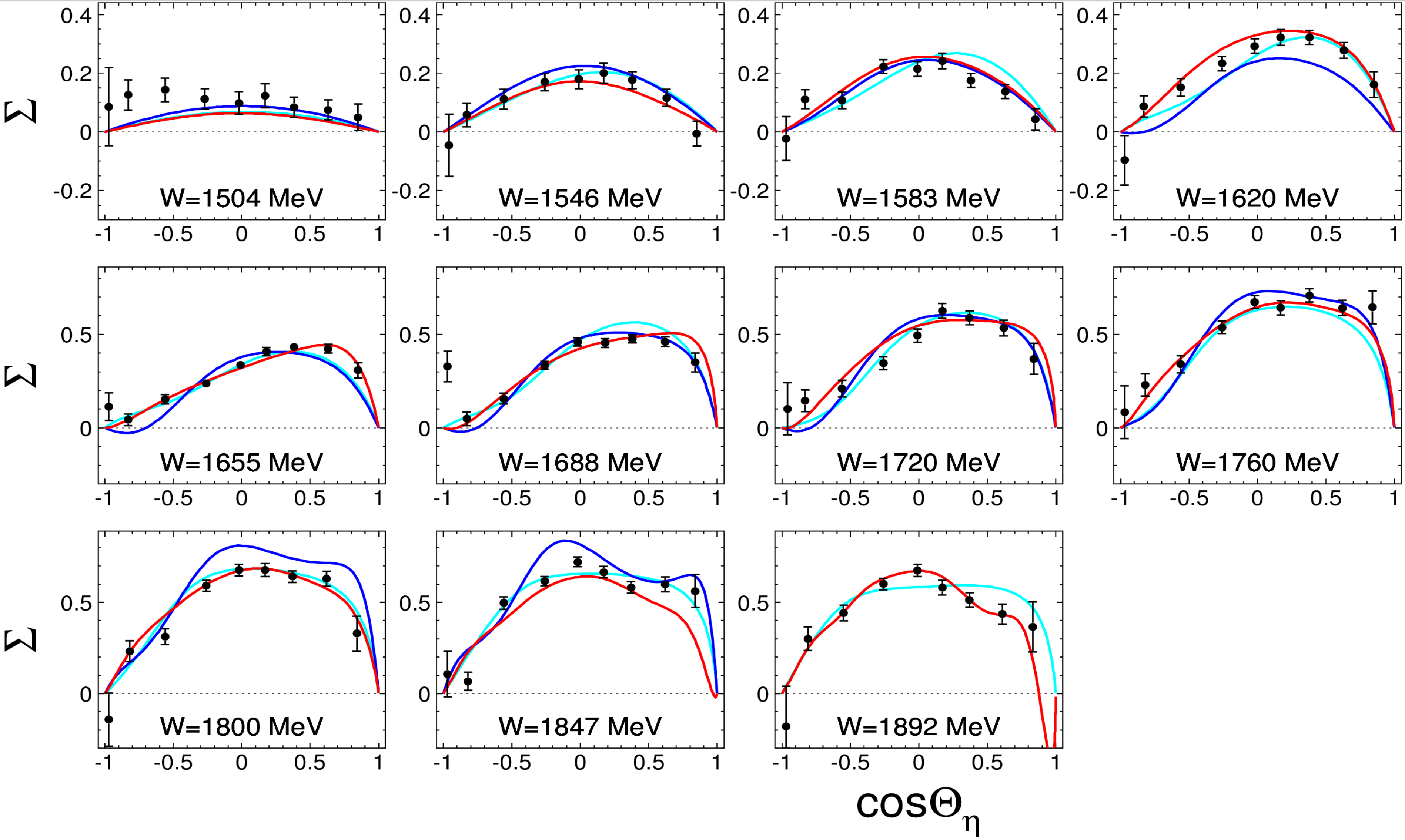


Red line: EtaMAID2018
Cyan line: BnGa
Blue line: KSU
Black line: JüBo

Data: A2MAMI-14

T: $\chi^2 = 255.3/144 \approx 1.77$; F: $\chi^2 = 253.3/144 \approx 1.76$

$\gamma\ n \rightarrow \eta\ n$ Beam asymmetry Σ

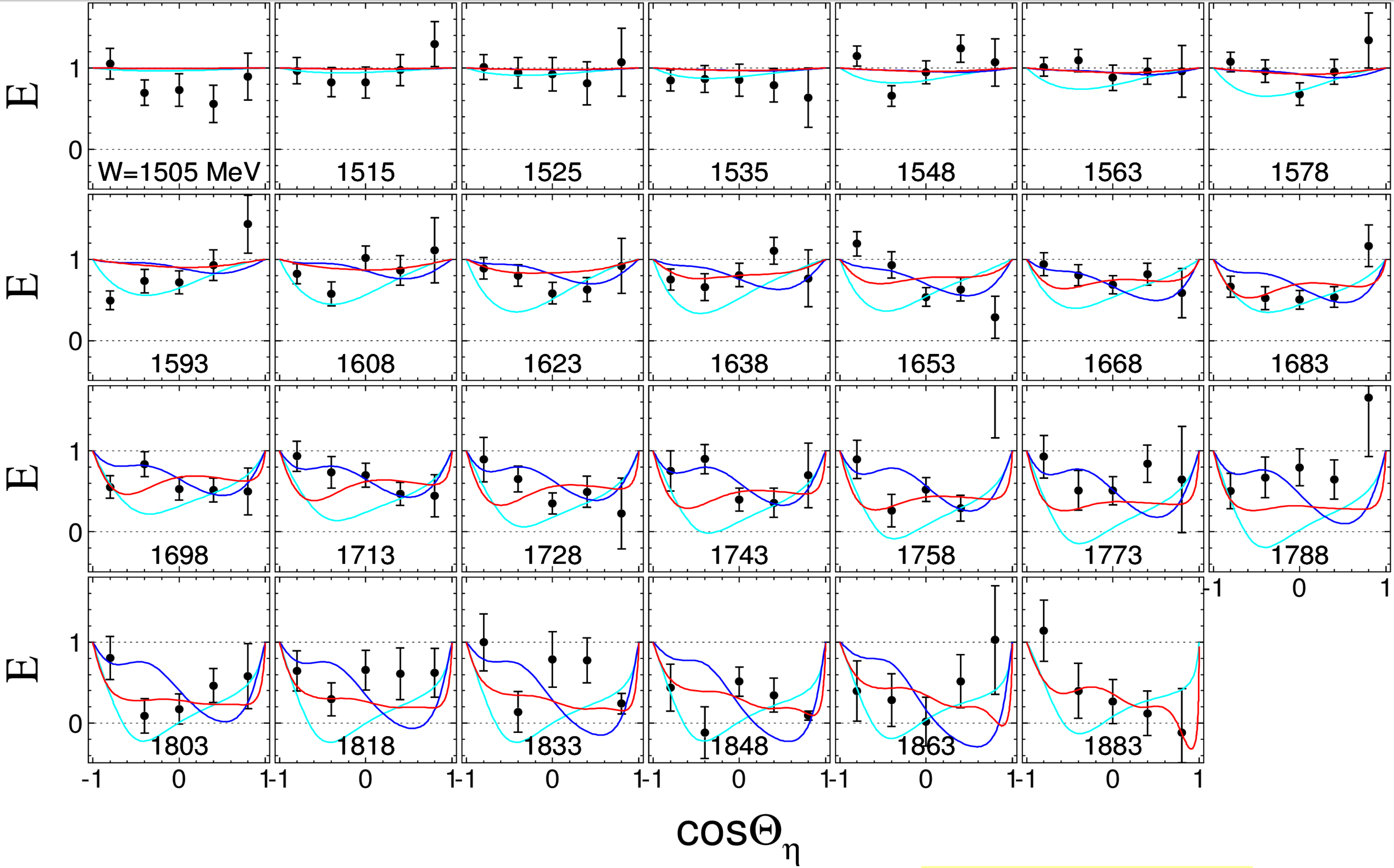


Red line: EtaMAID2018
Cyan line: BnGa
Blue line: KSU

$\chi^2 = 238.5/99 \approx 2.41$

Data: GRAAL-08

$\gamma\ n \rightarrow \eta\ n$ Helicity beam asymmetry E

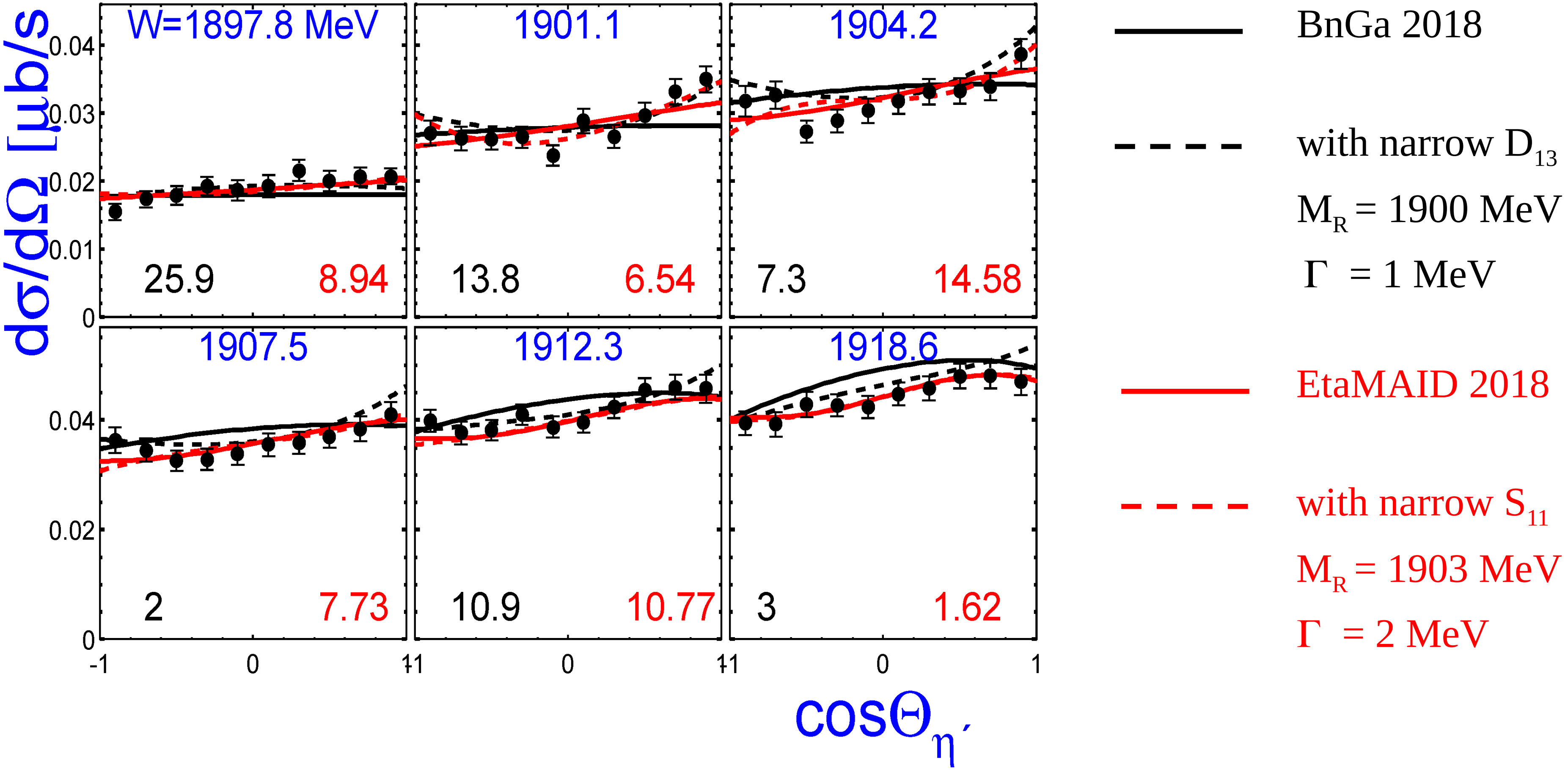


Red line: EtaMAID2018
Cyan line: BnGa
Blue line: KSU

$X^2 = 349.8/135 \approx 2.59$

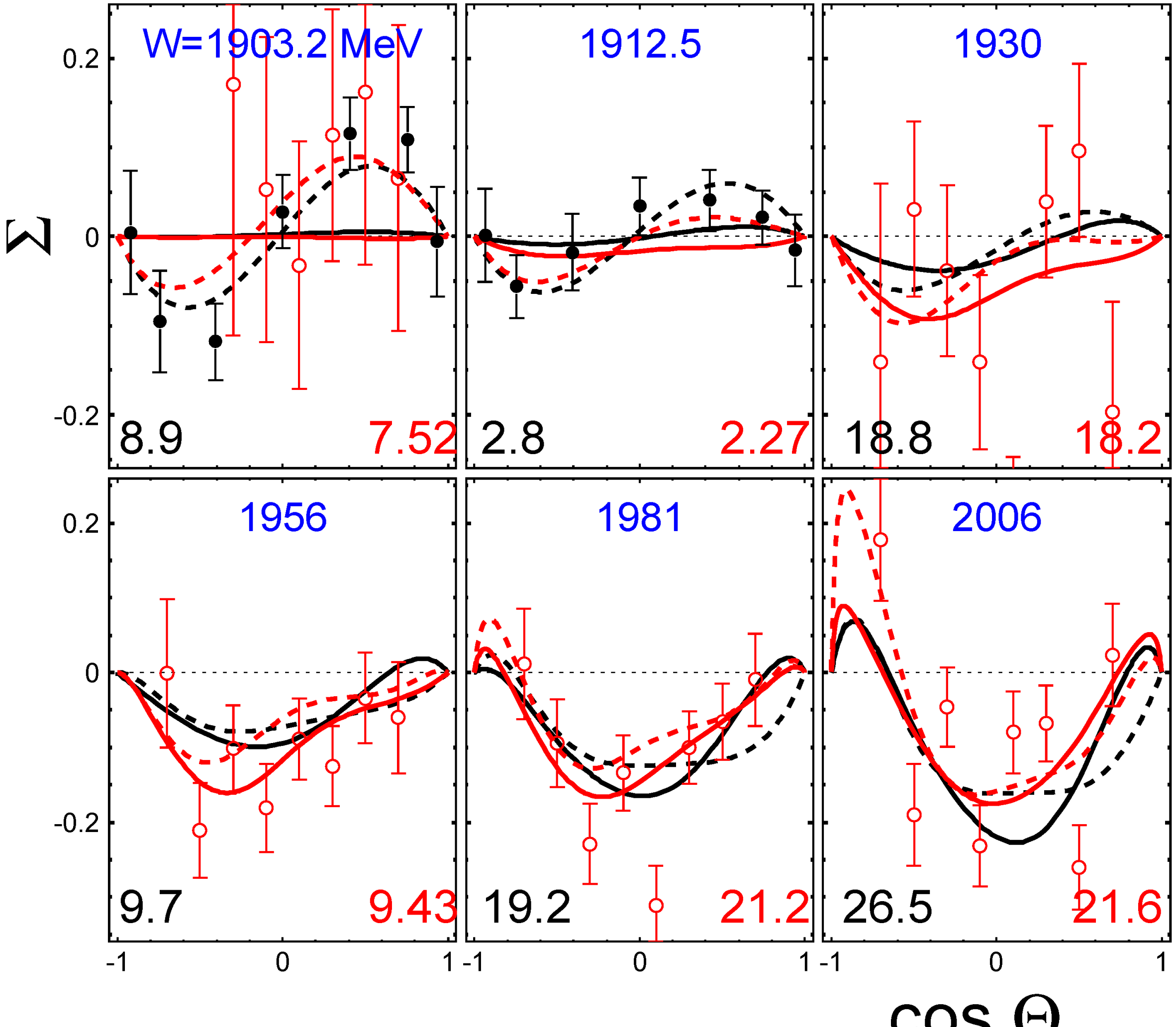
Data: A2MAMI-17

Narrow resonance S_{11}/D_{13} in $p(\gamma,\eta')p$
EtaMAID vs. BNGA



Σ and dσ/dΩ data can well be fitted with a very narrow resonance at W_R=1900 MeV.
In the total cross section such a resonance is invisible.
It shows up in interferences between *S-F* or *P-D* resonances

Narrow resonance S_{11}/D_{13} in $p(\gamma,\eta')p$
EtaMAID vs. BNGA



BnGa 2018

with narrow D_{13}

M_R = 1900 MeV

Γ = 1 MeV

EtaMAID 2018

with narrow S_{11}

M_R = 1903 MeV

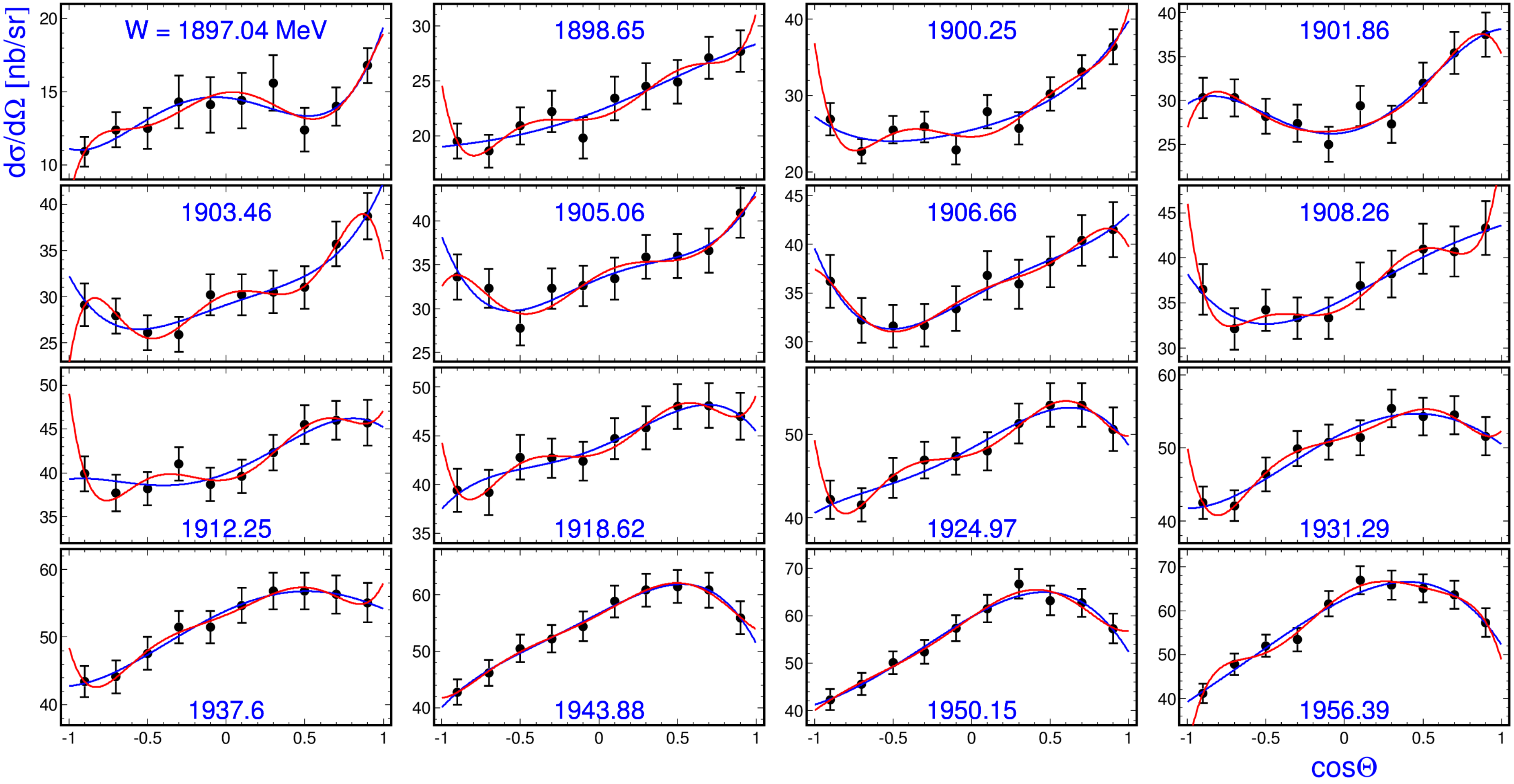
Γ = 2 MeV

black disks: GRAAL-2015

red circles: CLAS-2017

Narrow resonance in $\gamma\ p \to\ \eta'\ p$?

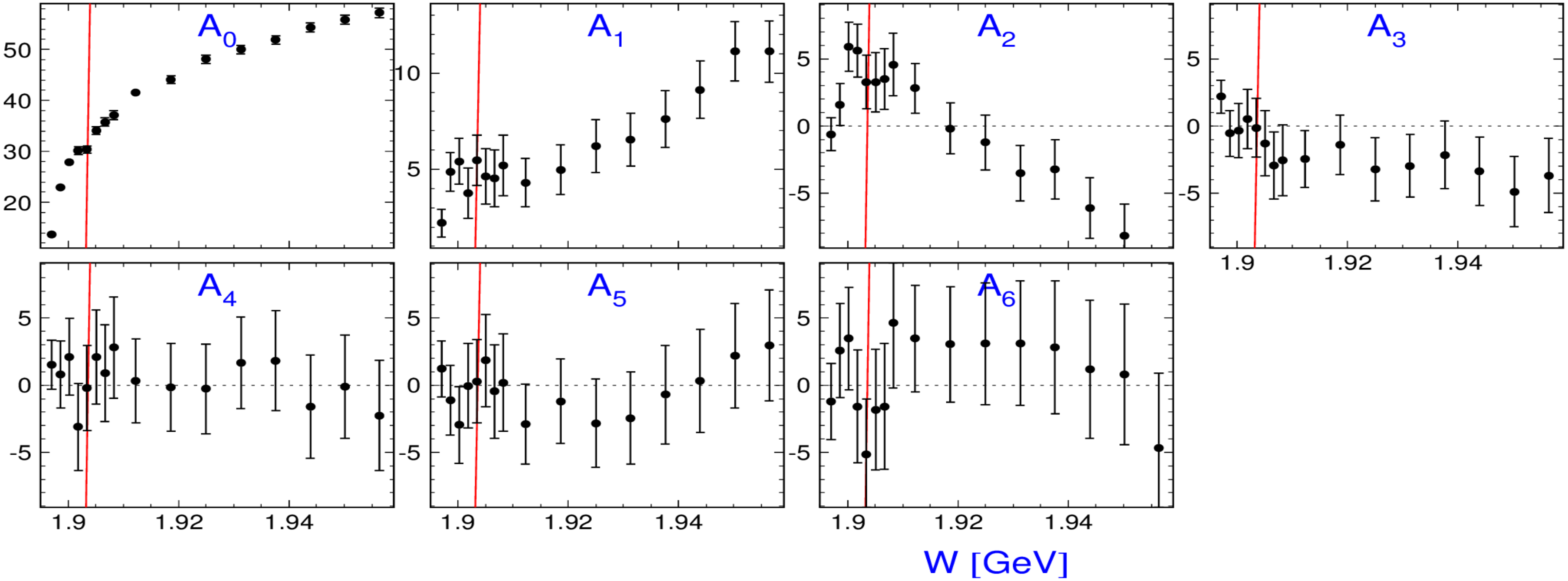
Legendre fit with Lmax = 2 (black dashed) and Lmax = 3 (red solid)



A2MAMI data from threshold up to W=1908.26 are shown for each tagger bin

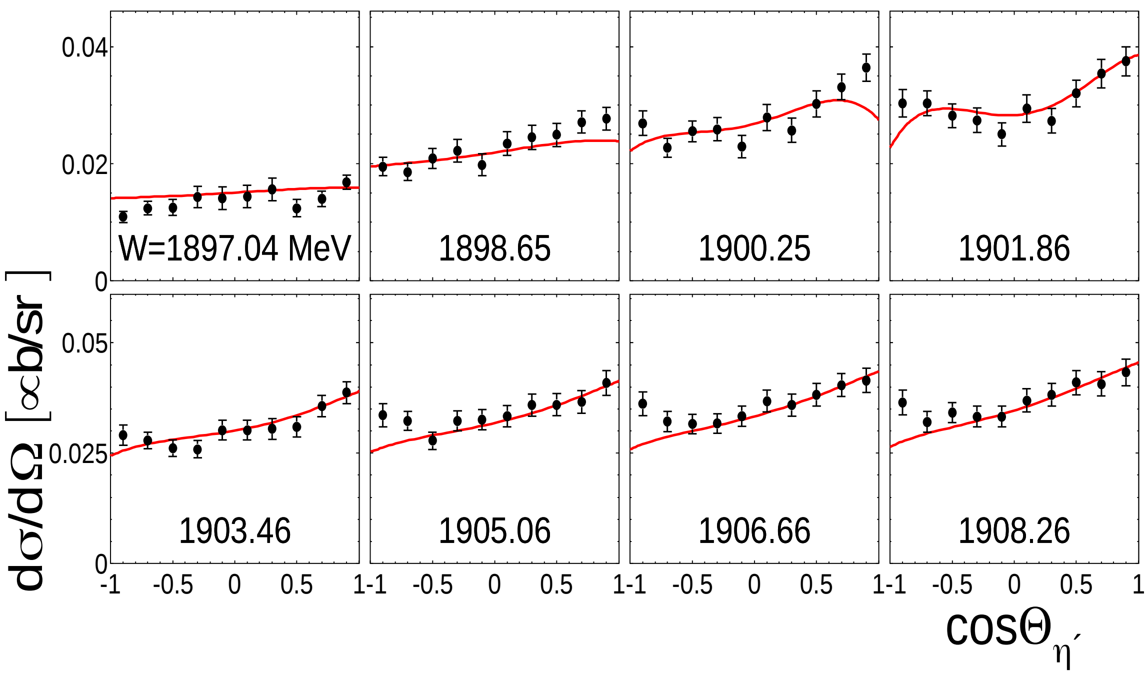
Narrow resonance in $\gamma\ p \rightarrow\ \eta'\ p$?

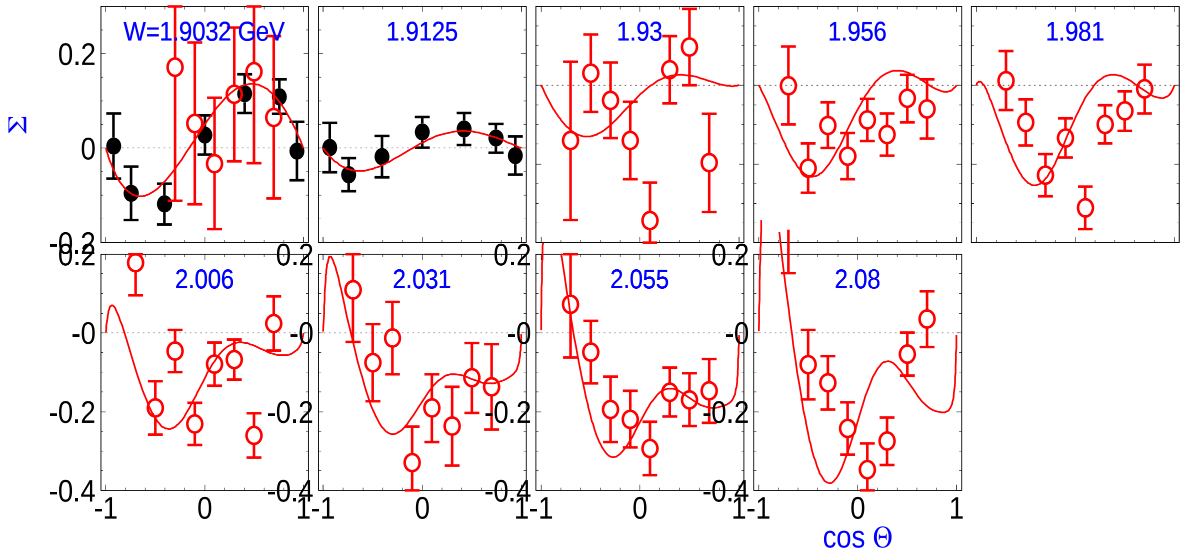
Legendre coefficients from fit with Lmax = 3



Red line at W = 1.904 GeV

Narrow resonance in $\gamma\ p \to\ \eta'\ p$?



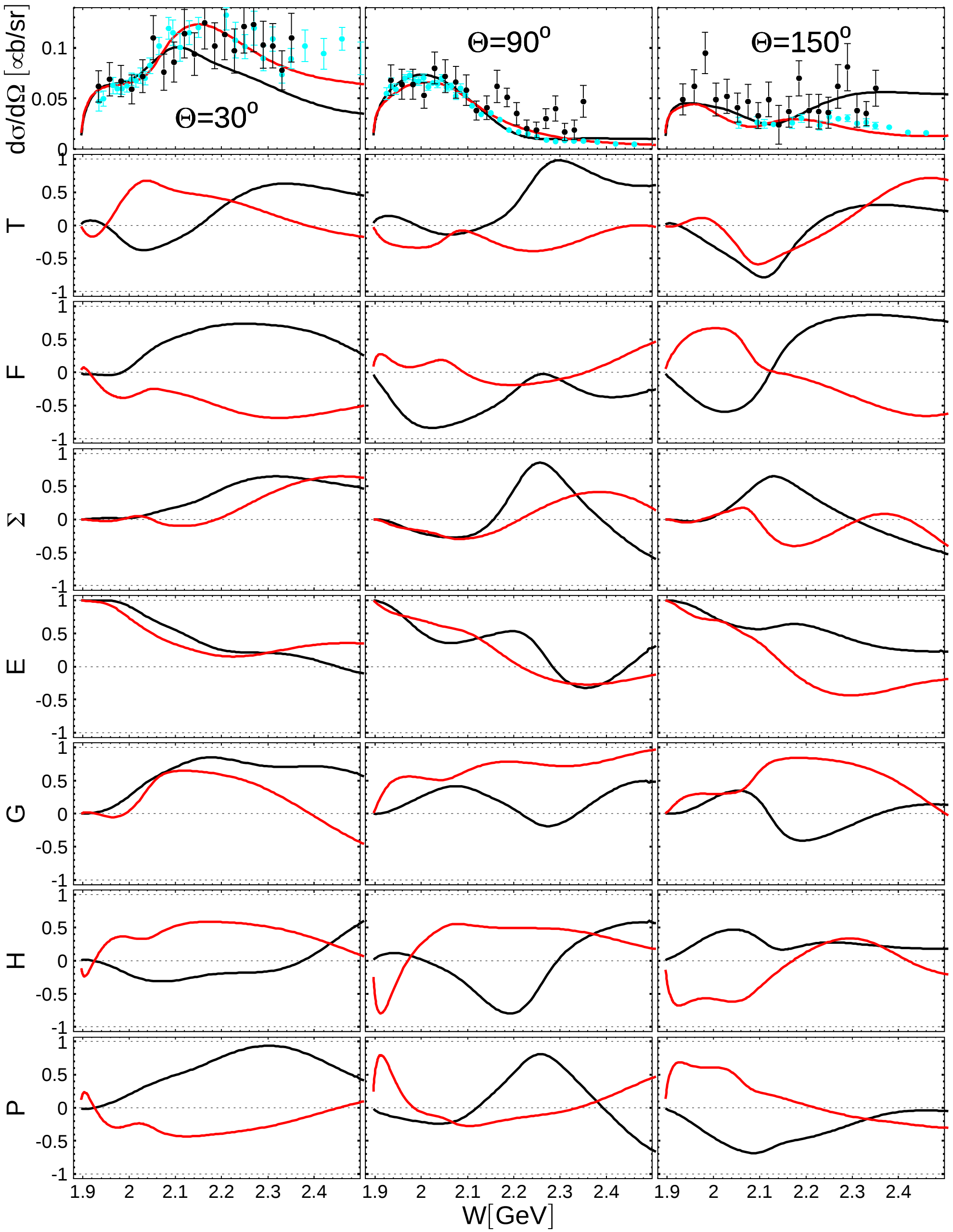


New EtaMAID solution for narrow resonance:

F15(1900)

M = 1901 Mev
G = 1.2 MeV

Predictions for $\gamma\, p \rightarrow \eta'\, p$

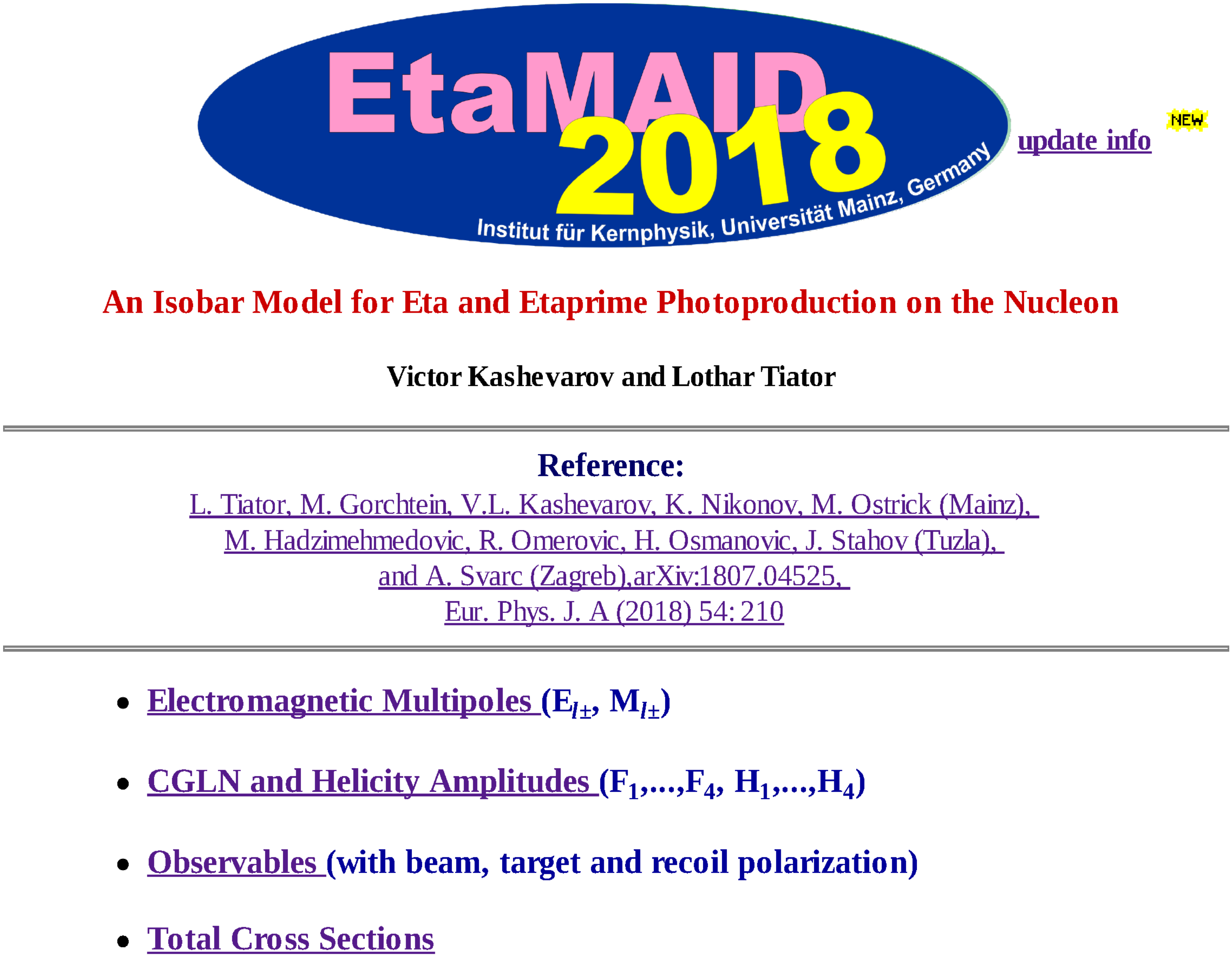


Red lines: EtaMAID 2018

Black lines: BnGa 2017

Black points: CBELSA/TAPS-09

Cyan points: CLAS-09



EtaMAID 2018

Institut für Kernphysik, Universität Mainz, Germany

update info NEW

An Isobar Model for Eta and Etaprime Photoproduction on the Nucleon

Victor Kashevarov and Lothar Tiator

Reference:

L. Tiator, M. Gorchtein, V.L. Kashevarov, K. Nikonov, M. Ostrick (Mainz),
M. Hadzimehmedovic, R. Omerovic, H. Osmanovic, J. Stahov (Tuzla),
and A. Svarc (Zagreb),arXiv:1807.04525,
Eur. Phys. J. A (2018) 54: 210

- **Electromagnetic Multipoles ($E_{l\pm}$, $M_{l\pm}$)**
- **CGLN and Helicity Amplitudes (F_1,...,F_4, H_1,...,H_4)**
- **Observables (with beam, target and recoil polarization)**
- **Total Cross Sections**

Summary and conclusions

1. New version of EtaMAID for η and η' photoproduction on protons and neutrons is finished and available on the MAID webpage.

2. The well-known duality problem is addressed in a new approach with a damping factor removing most of Regge background in the resonance region.

3. Unitarization was done by adding a phase for each resonance as free parameter.

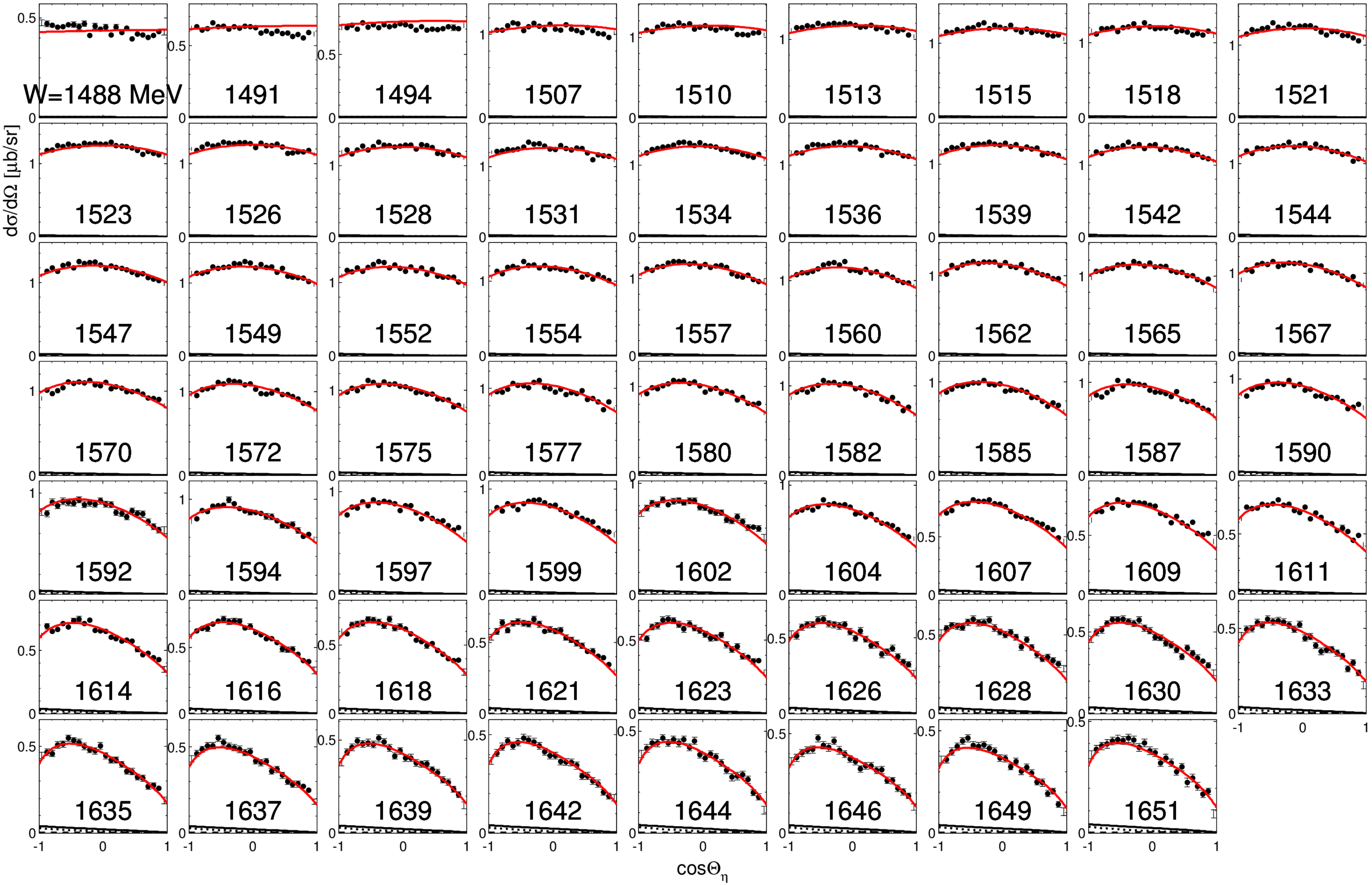
4. New EtaMAID2018 describes all data very well and explains most of them:
   - cusp in eta total cross section, in connection with steep rise of the η´ total cross section from its threshold, is explained by a strong coupling of $N(1895)1/2^-$ to both channels;
   - narrow bump in (η n) and dip in (η p) channels have different origin: the first is a result of interference of a few resonances, and the second is a threshold effect due to opening KΣ decay channel of $N(1650)1/2^-$ resonance;
   - angular dependence of Σ asymmetry for $\gamma p \rightarrow \eta p$ at W>2 GeV is explained by an interference of $N(2120)3/2^-$ and $N(2060)5/2^-$ resonances.

5. The near threshold behavior of Σ for $\gamma p \rightarrow \eta' p$ is still an open question.

6. Possible narrow resonance with M=1726 MeV observed both in $\gamma p \rightarrow \eta p$ and $\gamma n \rightarrow \eta n$ reaction channels for $\sigma_{1/2}$ needs further investigation.

7. Next step: adding π N, ω N, K Λ, and K Σ channels.

$\gamma\ p \rightarrow\ \eta\ p$ Fit results: differential cross sections



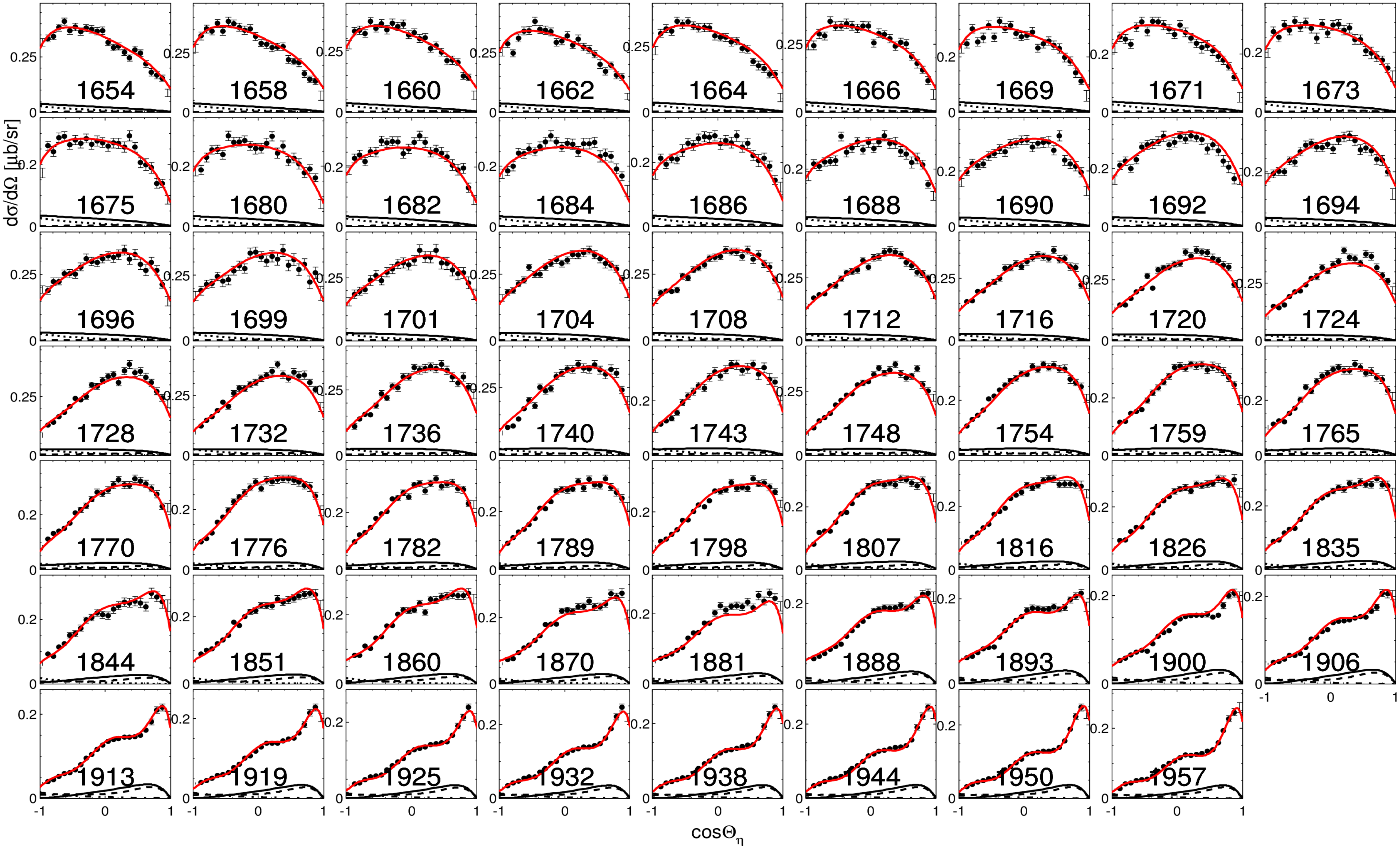
Data: A2MAMI-17;

Lines: red – full solution; solid black – Regge+Born; dashed – Regge ; dotted – Born terms

$\gamma\ p \rightarrow\ \eta\ p$

Differential cross sections

$\chi^2 = 4679/2928 \approx 1.60$

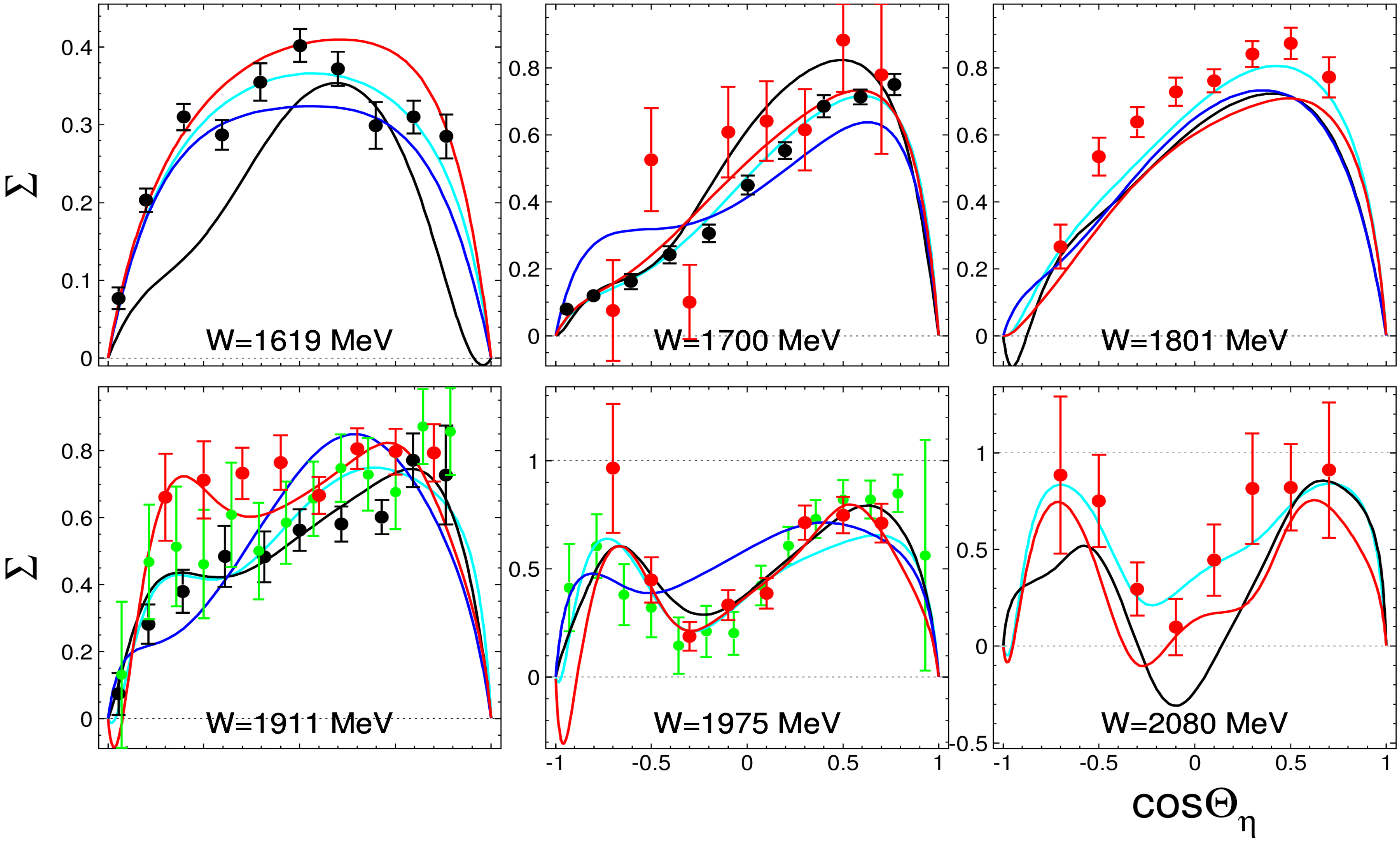


Data: A2MAMI-17;

Lines: red – full solution; solid black – Regge+Born; dashed – Regge ; dotted – Born terms

$\gamma\ p \rightarrow\ \eta\ p$

Polarization observables: Σ

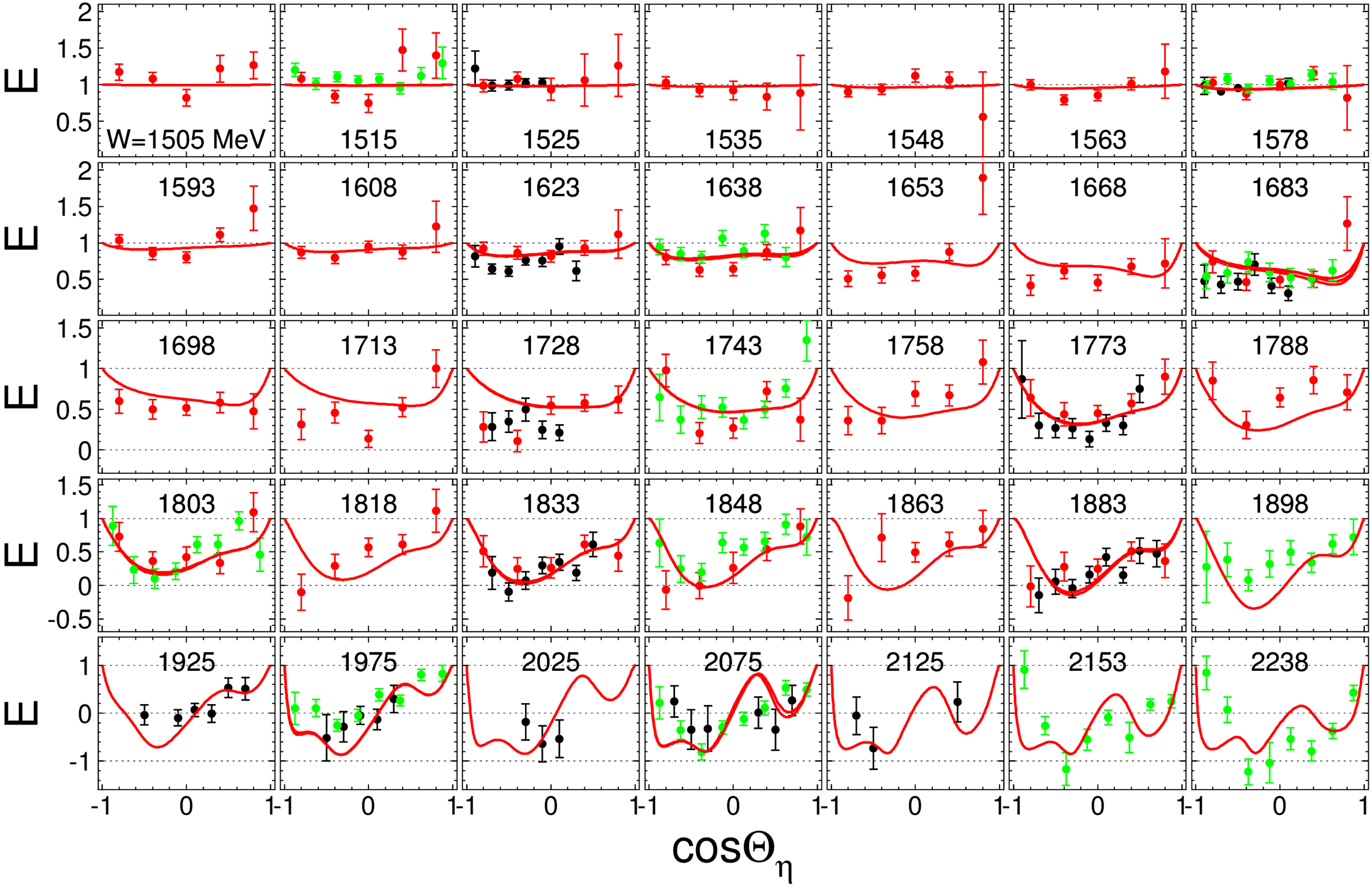


Red line: EtaMAID2018
Cyan line: BnGa
Blue line: KSU
Black line: JüBo

Data: black – GRAAL-07
red – CLAS-17
green – CBELSA/TAPS preliminary

$\gamma\ p \rightarrow\ \eta\ p$

Polarization observables: E



Data: black – CLAS-16; red – A2MAMI-17 “p”; green – CBELSA/TAPS preliminary

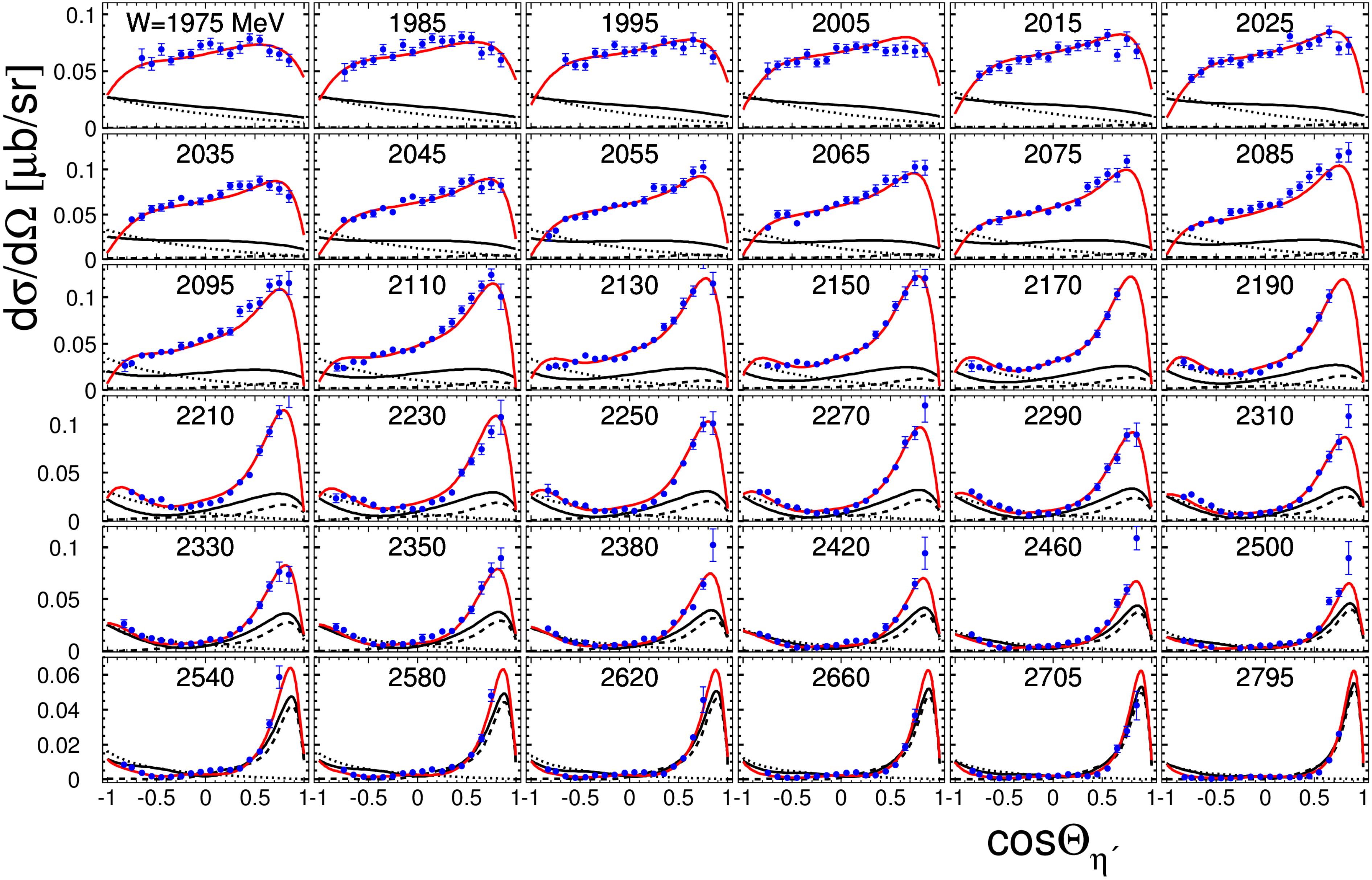
$X^2 = 170.6/73 \approx 2.34$

$X^2 = 272.3/135 \approx 2.02$

$X^2 = 395.5/93 \approx 4.25$

$\gamma\ p \rightarrow\ \eta'\ p$ Differential cross sections

$\chi^2 = 2145.6/639 \approx 3.36$



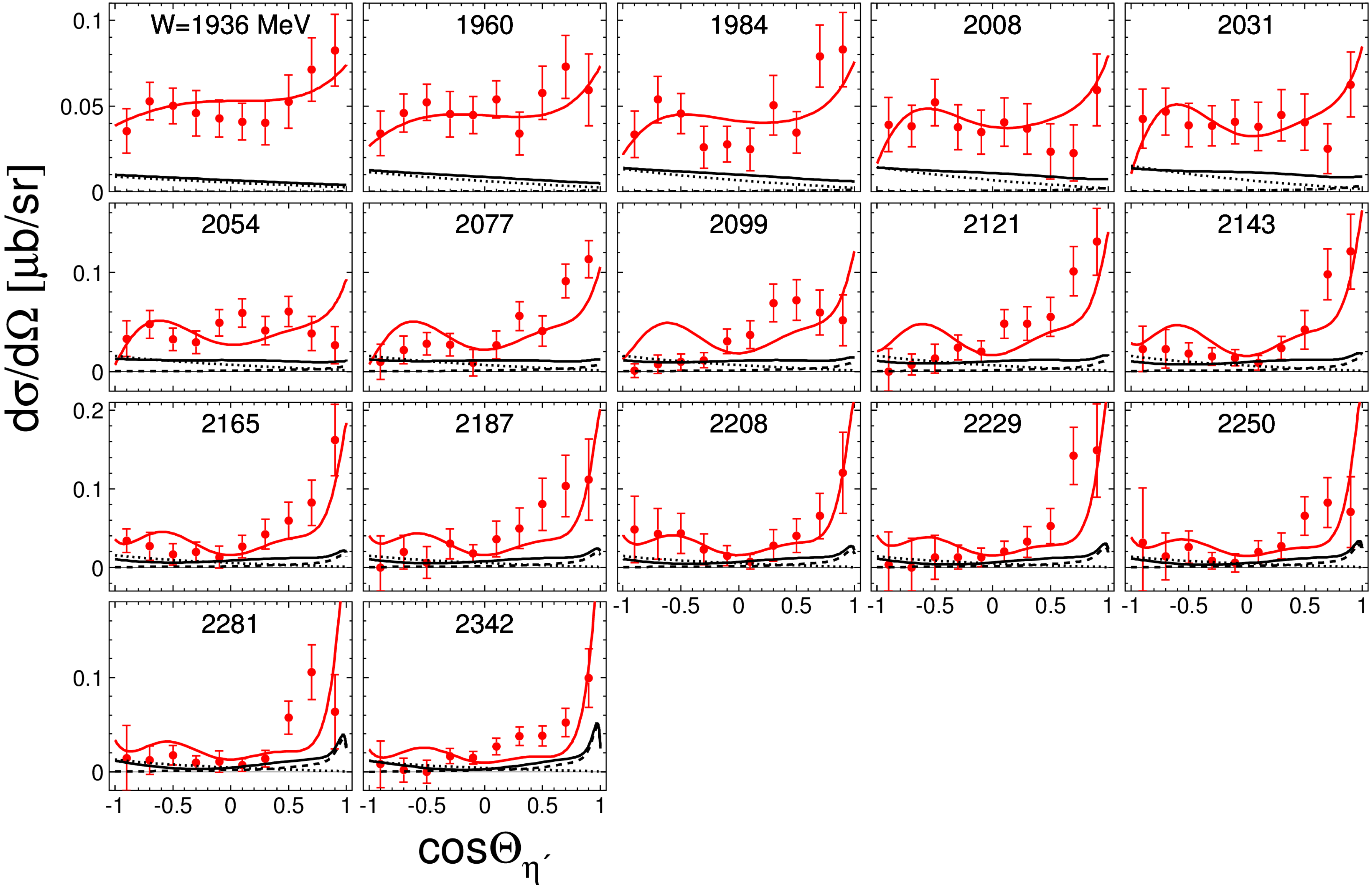
Data: CLAS-09

Lines: red – full solution; solid black – Regge+Born; dashed – Regge ; dotted – Born terms

$\gamma\ n \rightarrow\ \eta'\ n$

Differential cross sections

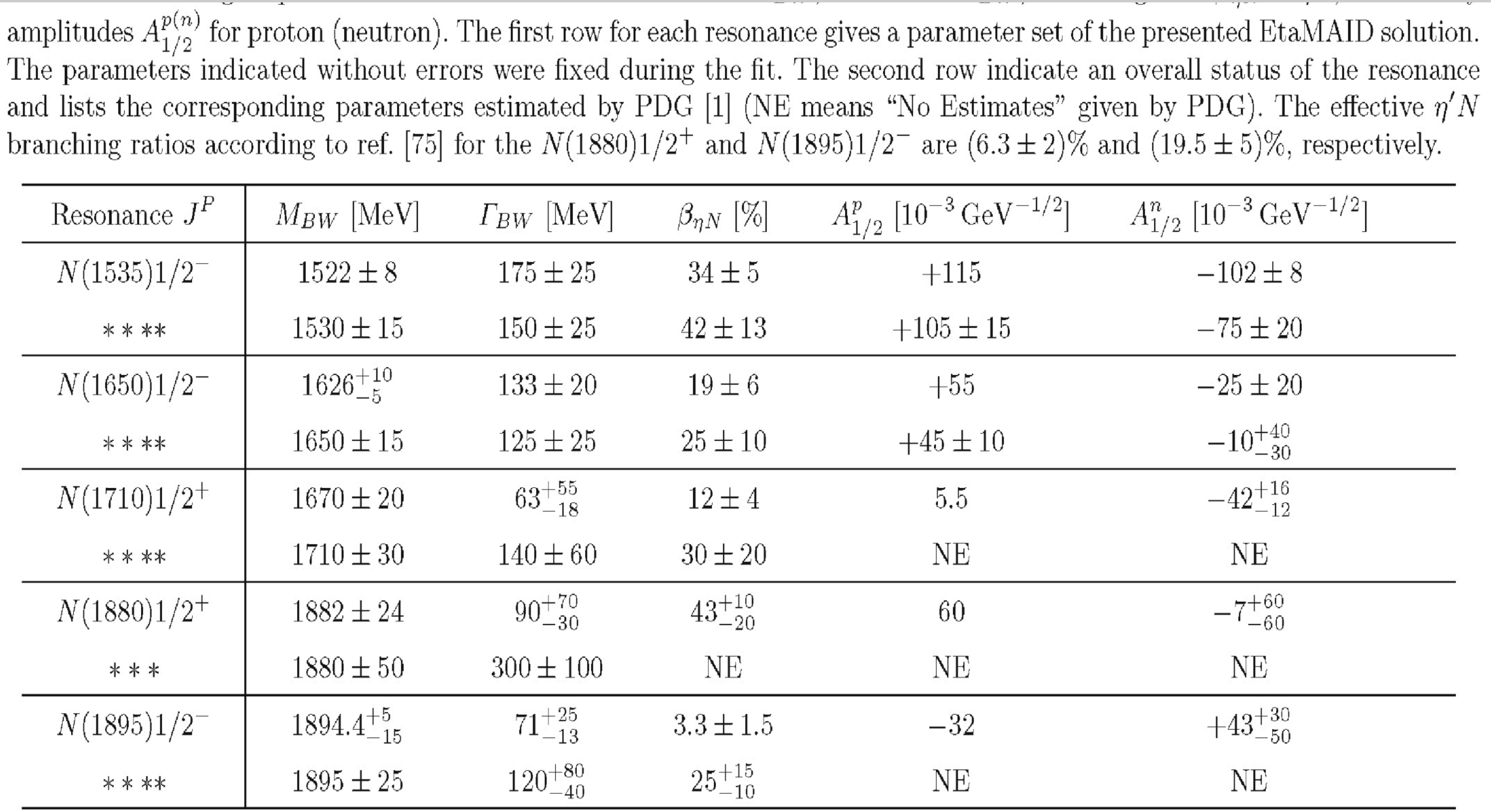
$\chi^2 = 279.9/170 \approx 1.64$



Data: CBELSA/TAPS-11

Lines: red – full solution; solid black – Regge+Born; dashed – Regge ; dotted – Born terms

EtaMAID 2018



amplitudes $A_{1/2}^{p(n)}$ for proton (neutron). The first row for each resonance gives a parameter set of the presented EtaMAID solution. The parameters indicated without errors were fixed during the fit. The second row indicate an overall status of the resonance and lists the corresponding parameters estimated by PDG [1] (NE means "No Estimates" given by PDG). The effective $\eta' N$ branching ratios according to ref. [75] for the $N(1880)1/2^+$ and $N(1895)1/2^-$ are $(6.3 \pm 2)\%$ and $(19.5 \pm 5)\%$, respectively.

Resonance J^P	M_{BW} [MeV]	Γ_{BW} [MeV]	$\beta_{\eta N}$ [%]	$A^p_{1/2}$ [10^{-3} GeV$^{-1/2}$]	$A^n_{1/2}$ [10^{-3} GeV$^{-1/2}$]
$N(1535)1/2^-$	1522 ± 8	175 ± 25	34 ± 5	$+115$	-102 ± 8
$****$	1530 ± 15	150 ± 25	42 ± 13	$+105 \pm 15$	-75 ± 20
$N(1650)1/2^-$	1626^{+10}_{-5}	133 ± 20	19 ± 6	$+55$	-25 ± 20
$****$	1650 ± 15	125 ± 25	25 ± 10	$+45 \pm 10$	-10^{+40}_{-30}
$N(1710)1/2^+$	1670 ± 20	63^{+55}_{-18}	12 ± 4	5.5	-42^{+16}_{-12}
$****$	1710 ± 30	140 ± 60	30 ± 20	NE	NE
$N(1880)1/2^+$	1882 ± 24	90^{+70}_{-30}	43^{+10}_{-20}	60	-7^{+60}_{-60}
$***$	1880 ± 50	300 ± 100	NE	NE	NE
$N(1895)1/2^-$	1894.4^{+5}_{-15}	71^{+25}_{-13}	3.3 ± 1.5	-32	$+43^{+30}_{-50}$
$****$	1895 ± 25	120^{+80}_{-40}	25^{+15}_{-10}	NE	NE

However, our goal for nucleon resonance analysis is
to get the pole positions and residues
and error analysis for these more fundamental N* properties.