PWA10/ATHOS5
IHEP, Beijing, China
July 16-20, 2018

International Workshop on Partial Wave Analyses and Advanced Tools for Hadron Spectroscopy

EtaMAID-2018 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

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. H. Osmanović, July 16, Monday, 16:20
2. M. Hadžimehmedović, July 19, Thursday, 14:35

EtaMaid2018

1. Fit for η and η' photoproductions on proton and neutron

2. High energy data up to E_γ = 9 GeVwere included in the fit

3. Model: 21 resonances + Born + Regge cuts

4. Energy dependence coupling constants for Born terms:

$$g \rightarrow g*(W_{thr}/W)**parB$$

5. Damping factor for Regge background

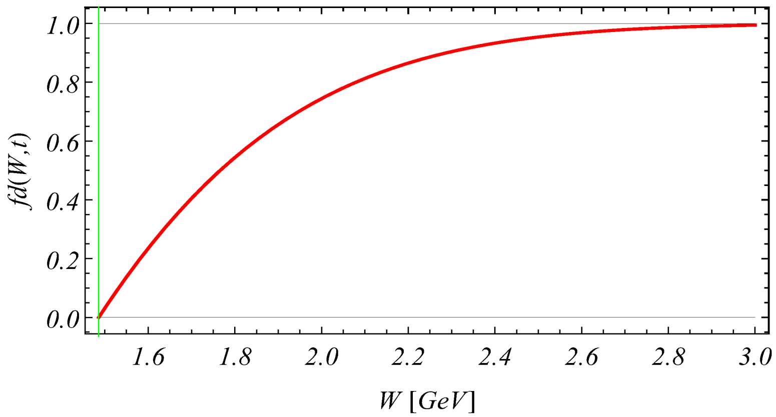
6. Phase shift to background was added for each resonance

7. New data published in 2017 were included in the fit

Modelling the background

- Born + t-channel poles 2015
- Born + Regge (RPR models) 2016
- Born + Regge – s, p, d, f partial waves 2017
- Born + Regge ⋆ damping factor f_d(W) 2018

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

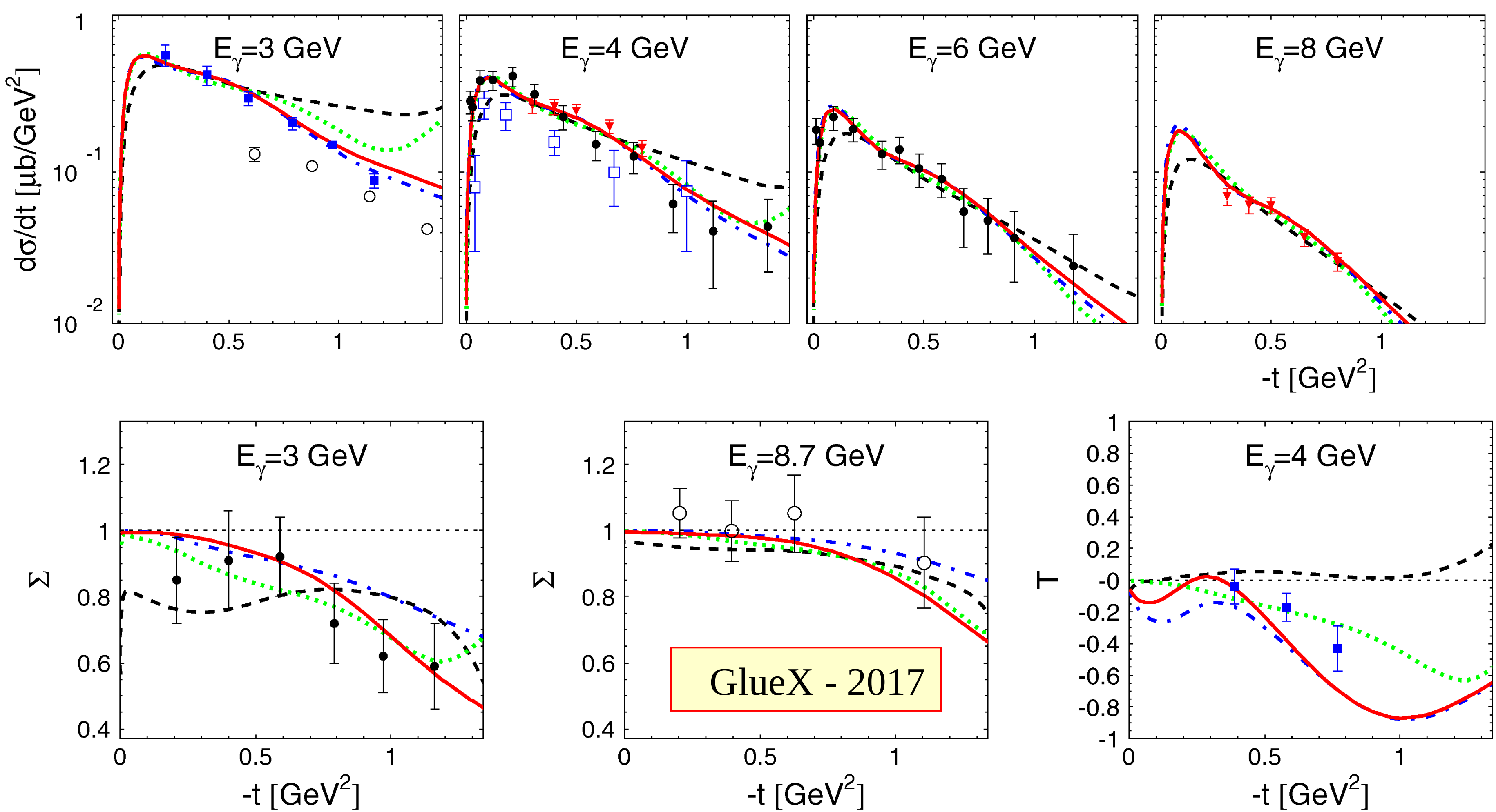


alternative approach: Finite Energy Sum Rules

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

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

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



Unitarity aspects

in previous versions EtaMAID 2000-2017 we simply ignored this phase
in the new EtaMAID2018 version we use this phase as a free parameter

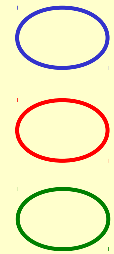
$$t^{\alpha}_{\gamma,\eta}(W) = t^{\alpha,Born}_{\gamma,\eta}(W) + t^{\alpha,VM(Regge)}_{\gamma,\eta}(W) \cdot F_d(W)$$

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

phenomenological phase
taken as a free parameter

New N* Resonances in EtaMAID2018 updates

Particle	J^P	overall	$N\gamma$	$N\pi$	$\Delta\pi$	$N\sigma$	$N\eta$	ΛK	ΣK	$N\rho$	$N\omega$	$N\eta'$	
N	$1/2^+$	****											
$N(1440)$	$1/2^+$	****	****	****	****	***							
$N(1520)$	$3/2^-$	****	****	****	****	**	****						
$N(1535)$	$1/2^-$	****	****	****	***	*	****						
$N(1650)$	$1/2^-$	****	****	****	***	*	****	*					
$N(1675)$	$5/2^-$	****	****	****	***	***	*	*	*				
$N(1680)$	$5/2^+$	****	****	****	****	***	*						
$N(1700)$	$3/2^-$	***	**	***	***	*	*			*			
$N(1710)$	$1/2^+$	****	****	****	*		***	**	*	*	*		
$N(1720)$	$3/2^+$	****	****	****	***	*	*	****	*	*	*		
$N(1860)$	$5/2^+$	**	*	**		*	*						
$N(1875)$	$3/2^-$	***	**	**	*	**	*	*	*	*	*		
$N(1880)$	$1/2^+$	***	**	*	**	*	*	**	**		**		
$N(1895)$	$1/2^-$	****	****	*	*	*	****	**	**	*	*	****	upgraded in 2018
$N(1900)$	$3/2^+$	****	****	**	**	*	*	**	**		*	**	
$N(1990)$	$7/2^+$	**	**	**	*	*	*	*	*				
$N(2000)$	$5/2^+$	**	**	*	**	*	*				*		
$N(2040)$	$3/2^+$	*		*									
$N(2060)$	$5/2^-$	***	***	**	*	*	*	*	*	*	*		
$N(2100)$	$1/2^+$	***	**	***	**	**	*	*		*	*	**	
$N(2120)$	$3/2^-$	***	***	***	**	**		**	*		*	*	
$N(2190)$	$7/2^-$	****	****	****	****	**	*	**	*	*	*		
$N(2220)$	$9/2^+$	****	**	****			*	*	*				
$N(2250)$	$9/2^-$	****	**	****			*	*	*				



7 N* in 2001/2003

21 N* in 2018 for γ,η

12 N* in 2018 for γ,η‘

Data sets

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

dσ/dΩ, A2MAMI-17:	E_γ=0.71–1.57 GeV	[PRL 118 (2017) 212001]
dσ/dΩ, CBELSA/TAPS-09:	E_γ=0.87–2.55 GeV	[PRC 80 (2009) 055202]
dσ/dΩ, CLAS-09:	E_γ=1.46– 3.7 GeV	[PRC 80 (2009) 045213]
T, F A2MAMI-14:	E_γ=0.71–1.4 GeV	[PRL 113 (2013) 102001]
Σ , CLAS-17:	E_γ=1.07–1.84 GeV	[PLB 771 (2017) 213]
Σ , GRAAL-07:	E_γ=0.71–1.5 GeV	[EPJA 33 (2007) 169]
E , CLAS-16:	E_γ=0.71–2.15 GeV	[PLB 755 (2016) 64]
E, A2MAMI-17:	E_γ=0.72–1.40 GeV	[PRC 95 (2017) 055201]
dσ/dt, DESY-70	E_γ=4, 6 GeV	[PLB 33 (1970) 236]
dσ/dt, WLS-71	E_γ=4, 8 GeV	[PLB 37 (1971) 326]
dσ/dt, Σ, Daresbury-76	E_γ=2.5, 3 GeV	[PLB 61 (1976) 479]
dσ/dt, CEA-68	E_γ=4 GeV	[PRL 21 (1968) 1205]
T, Daresbury-80	E_γ=4 GeV	[NP B185 (1981) 269]
Σ , GlueX-17	E_γ=8.7 GeV	[PRC 95 (2017) 042201R]

Σ, T, P, H, CBELSA/TAPS preliminary: J. Hartmann, PhD Thesis, Bonn University, 2017
(These data have not yet been used in our fit)

Data sets

γ p → η' p

- dσ/dΩ, A2MAMI-17: E_γ=1.45–1.57 GeV [PRL 118 (2017) 212001]
- dσ/dΩ, CBELSA/TAPS-09: E_γ=1.53–2.48 GeV [PRC 80 (2009) 055202]
- dσ/dΩ, CLAS-09: E_γ=1.51–3.43 GeV [PRC 80 (2009) 045213]
- Σ , CLAS-17: E_γ=1.46–1.84 GeV [PLB 771 (2017) 213]
- Σ , GRAAL-15: E_γ=1.46–1.48 GeV [EPJA 51 (2015) 77]

γ n → η n

- dσ/dΩ, A2MAMI-14: E_γ=0.72–1.40 GeV [RRC 90 (2014) 015205]
- dσ/dΩ, CBELSA/TAPS-11: E_γ=0.74–2.06 GeV [EPJA 47 (2011) 89]
- dσ/dΩ, CBELSA/TAPS-17: E_γ=0.71–1.81 GeV [EPJA 53 (2017) 58]
- $d\sigma/d\Omega_{1/2,3/2}$ A2MAMI-17: E_γ=0.72–1.40 GeV [RRC 95 (2017) 055201]
- Σ , GRAAL-08: E_γ=0.74–1.44 GeV [PRC 78 (2008) 015203]
- E , A2MAMI-17: E_γ=0.72–1.40 GeV [RRC 95 (2017) 055201]

γ n → η' n

- dσ/dΩ, CBELSA/TAPS-11: E_γ=1.53–2.45 GeV [EPJA 47 (2011) 11]

EtaMAID2018: fit results

Overall χ^2 divided by number of experimental points:

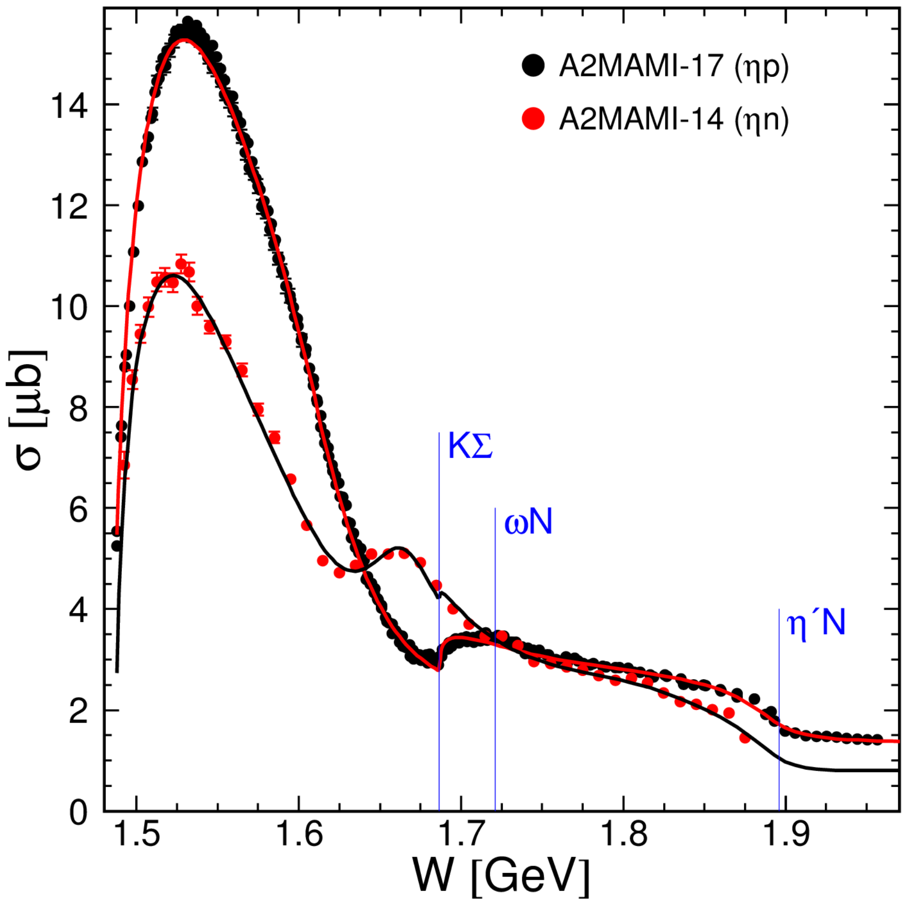
Fit1: $\chi^2 = 16431/6694 \approx 2.45$ (full solution)
Fit2: $\chi^2 = 22212/6694 \approx 3.32$ (no phases)
Fit3: $\chi^2 = 19481/6694 \approx 2.91$ (no Born terms)

for the certain reaction channels (Fit1):

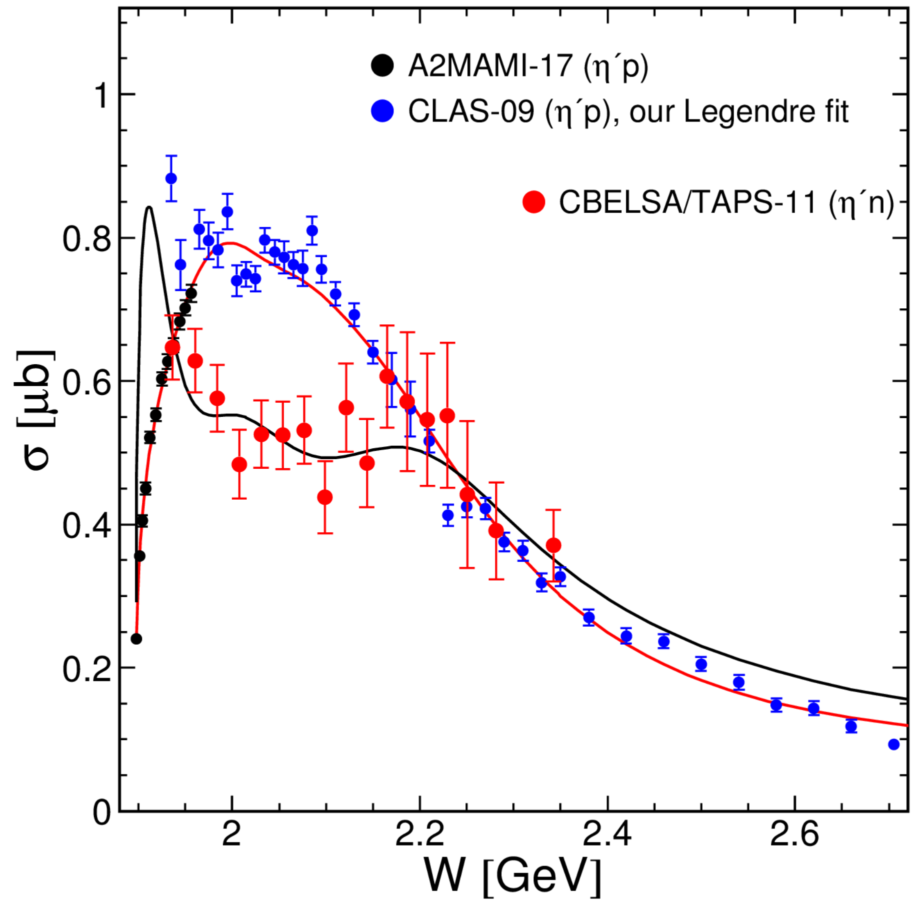
$\gamma\, p \rightarrow \eta\, p$: $\chi^2 = 9614/4493 \approx 2.14$
$\gamma\, n \rightarrow \eta\, n$: $\chi^2 = 4126/1196 \approx 3.45$
$\gamma\, p \rightarrow \eta'\, p$: $\chi^2 = 2383/835 \approx 2.85$
$\gamma\, n \rightarrow \eta'\, n$: $\chi^2 = 279.9/170 \approx 1.65$

Total cross sections

$\gamma N \rightarrow \eta N$



$\gamma N \rightarrow \eta' N$

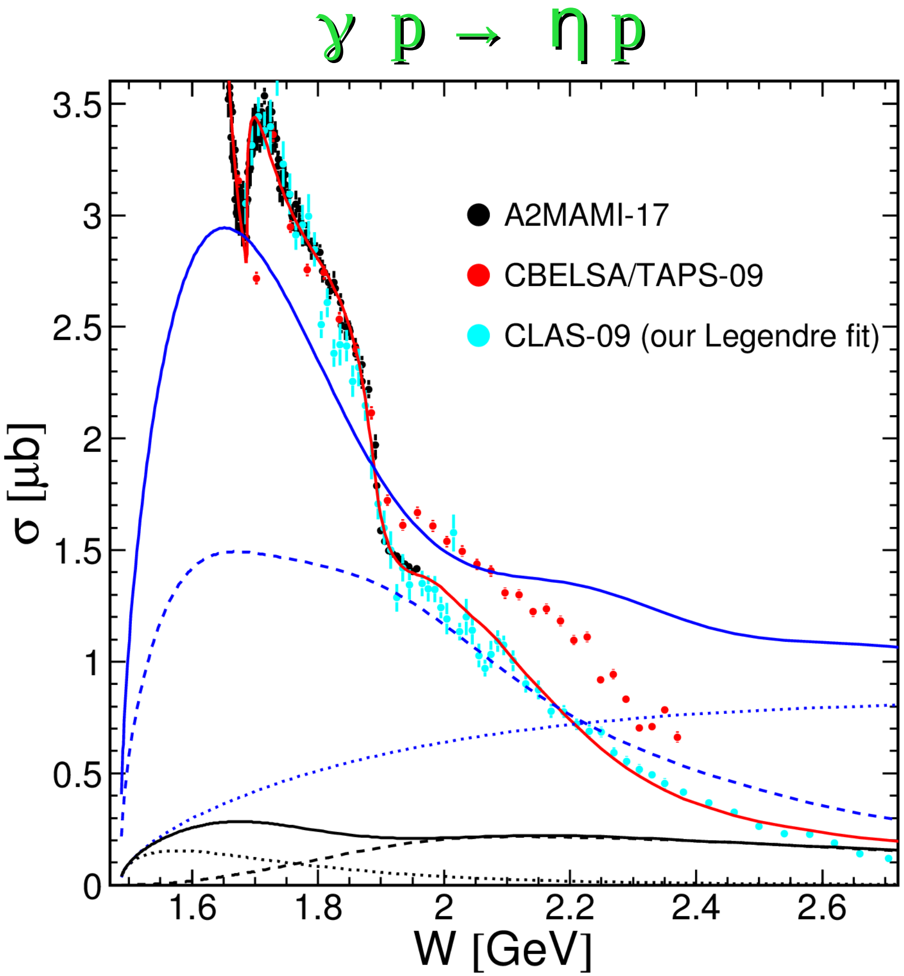


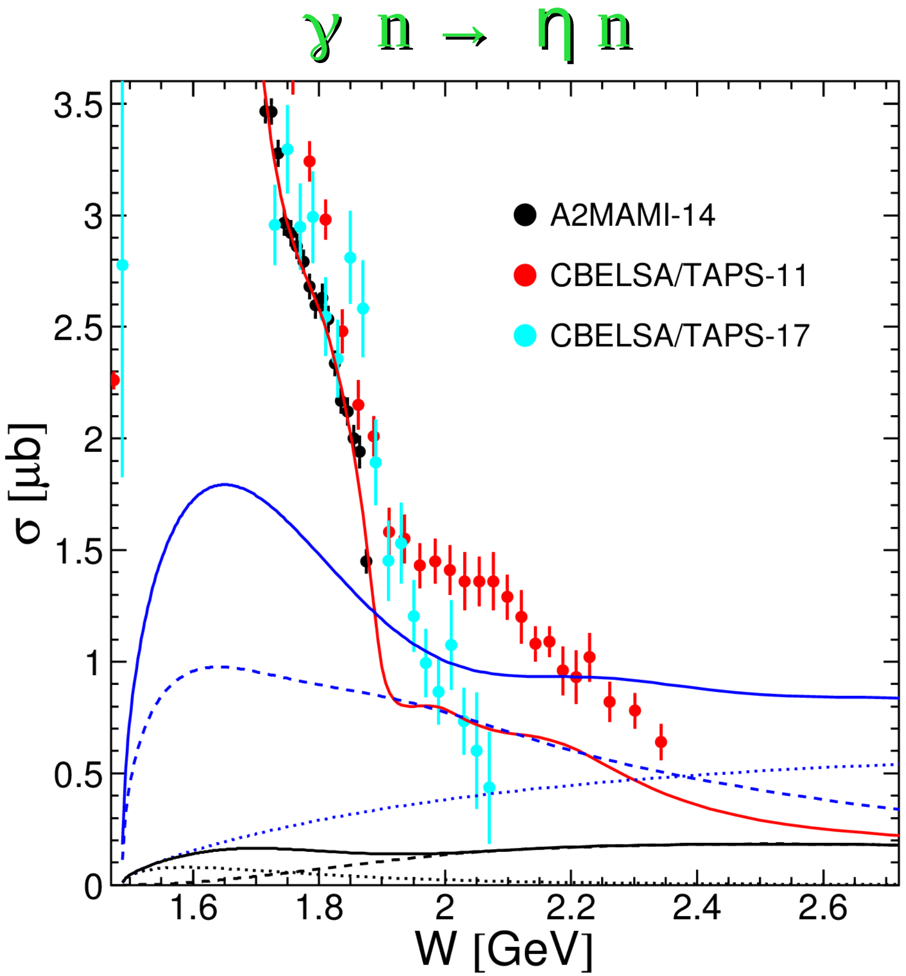
Lines: full solution for γp (red) and γn (black) channels.

$\gamma\, p \rightarrow \eta\, p$: $\chi^2 = 238.6/125 \approx 1.91$;
$\gamma\, n \rightarrow \eta\, n$: $\chi^2 = 120.6/44 \approx 2.74$;

$\gamma\, p \rightarrow \eta'\, p$: $\chi^2 = 9.46/12 \approx 0.79$ (A2MAMI)
$\gamma\, n \rightarrow \eta'\, n$: $\chi^2 = 10.9/17 \approx 0.64$

Partial contributions of the background to the total cross sections

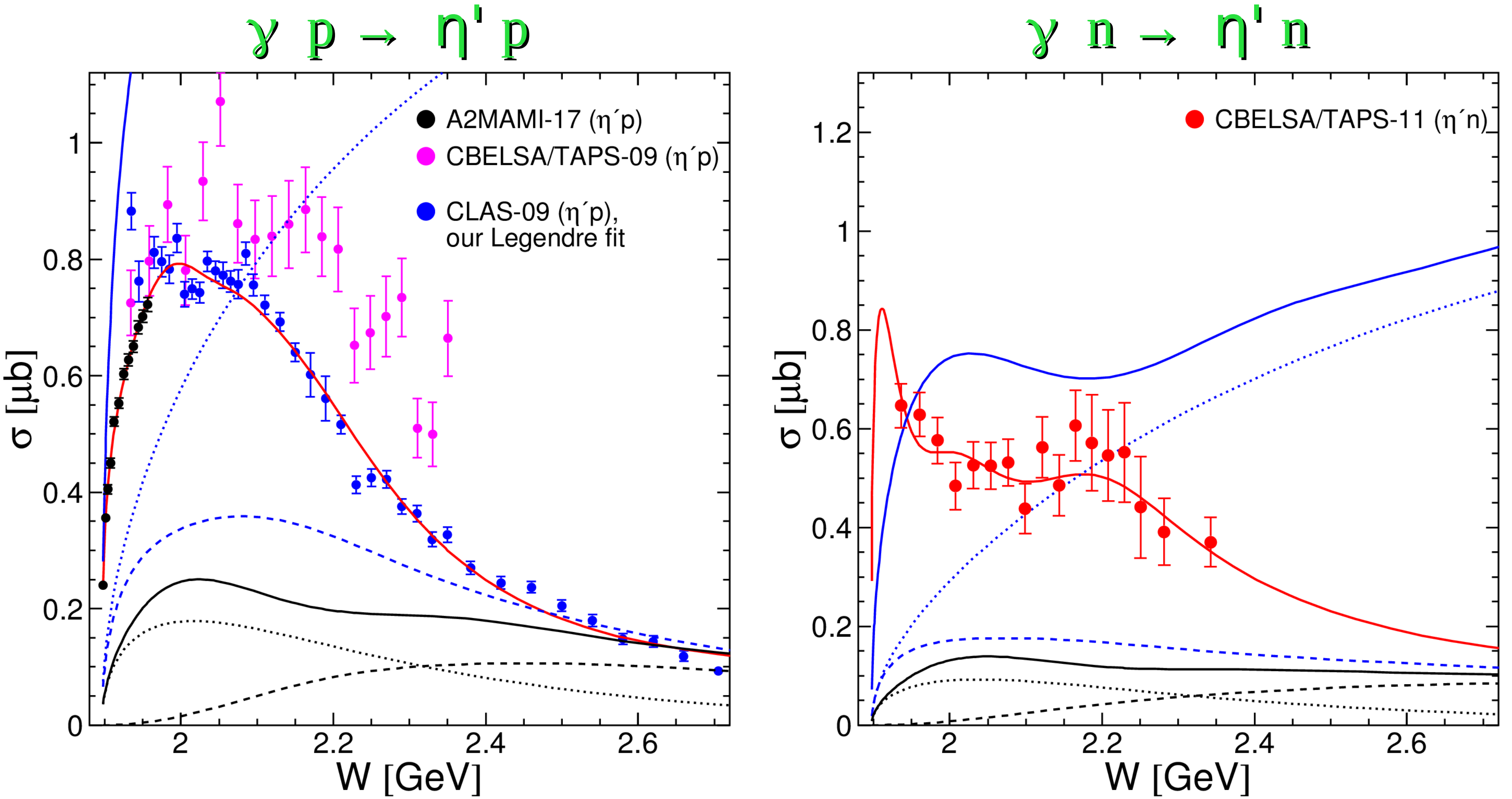




Blue lines – without DF
Black lines – with DF

dashed – Regge contribution
dotted – Born
solid – Regge + Born

Partial contributions of the background to the total cross sections

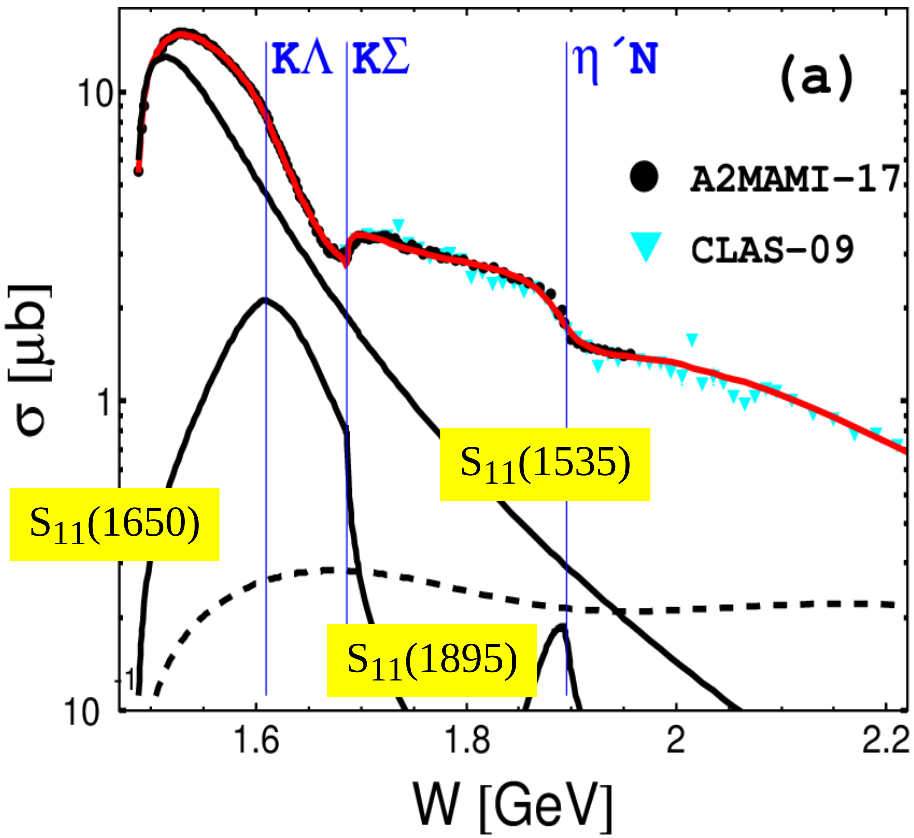


Blue lines – without DF
Black lines – with DF

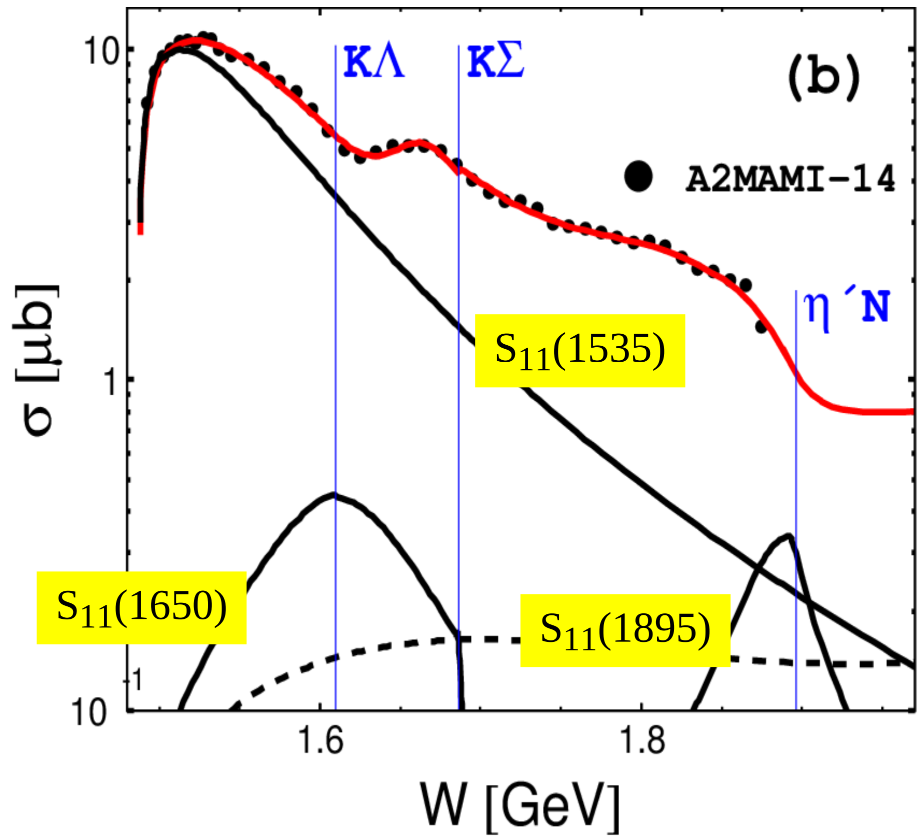
dashed – Regge contribution
dotted – Born
solid – Regge + Born

Partial contributions of the resonances to the total cross sections

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

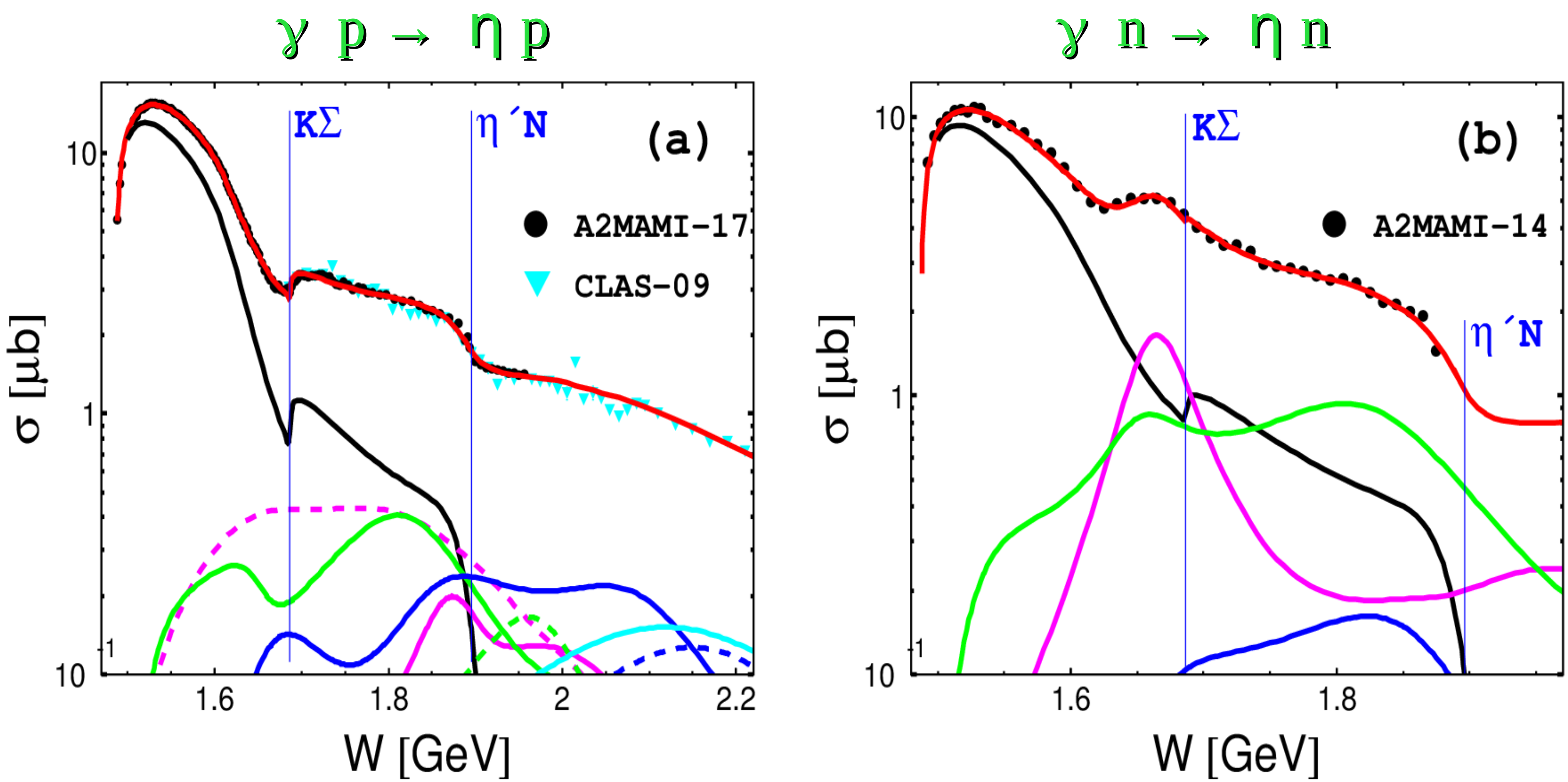


$\gamma\ n \rightarrow\ \eta\ n$



Black dashed line – Regge + Bonrn contribution

Resonance contributions of partial waves to the total cross sections



S_{11} – black solid;

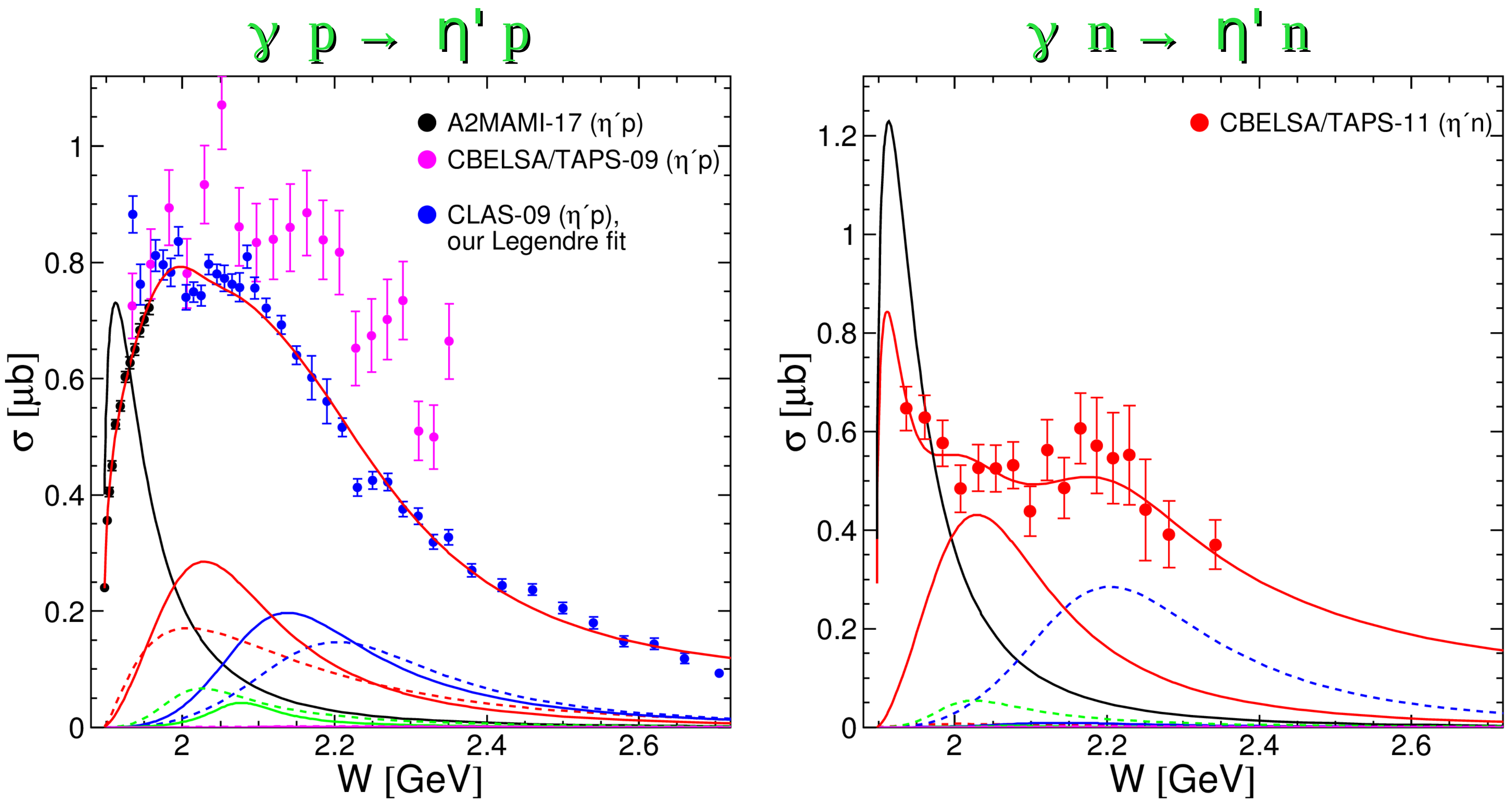
P_{11} – magenta solid; P_{13} – magenta dashed

D_{13} – green solid; D_{15} – green dashed

F_{15} – blue solid; F_{17} – blue dashed

G_{17} – cyan solid

Partial contributions of the resonances to the total cross sections



S11 – black solid;
P11 – red solid; P13 – red dashed
D13 – green solid; D15 – green dashed
F15 – blue solid; F17 – blue dashed
G17 – magenta solid; G19 – magenta dashed

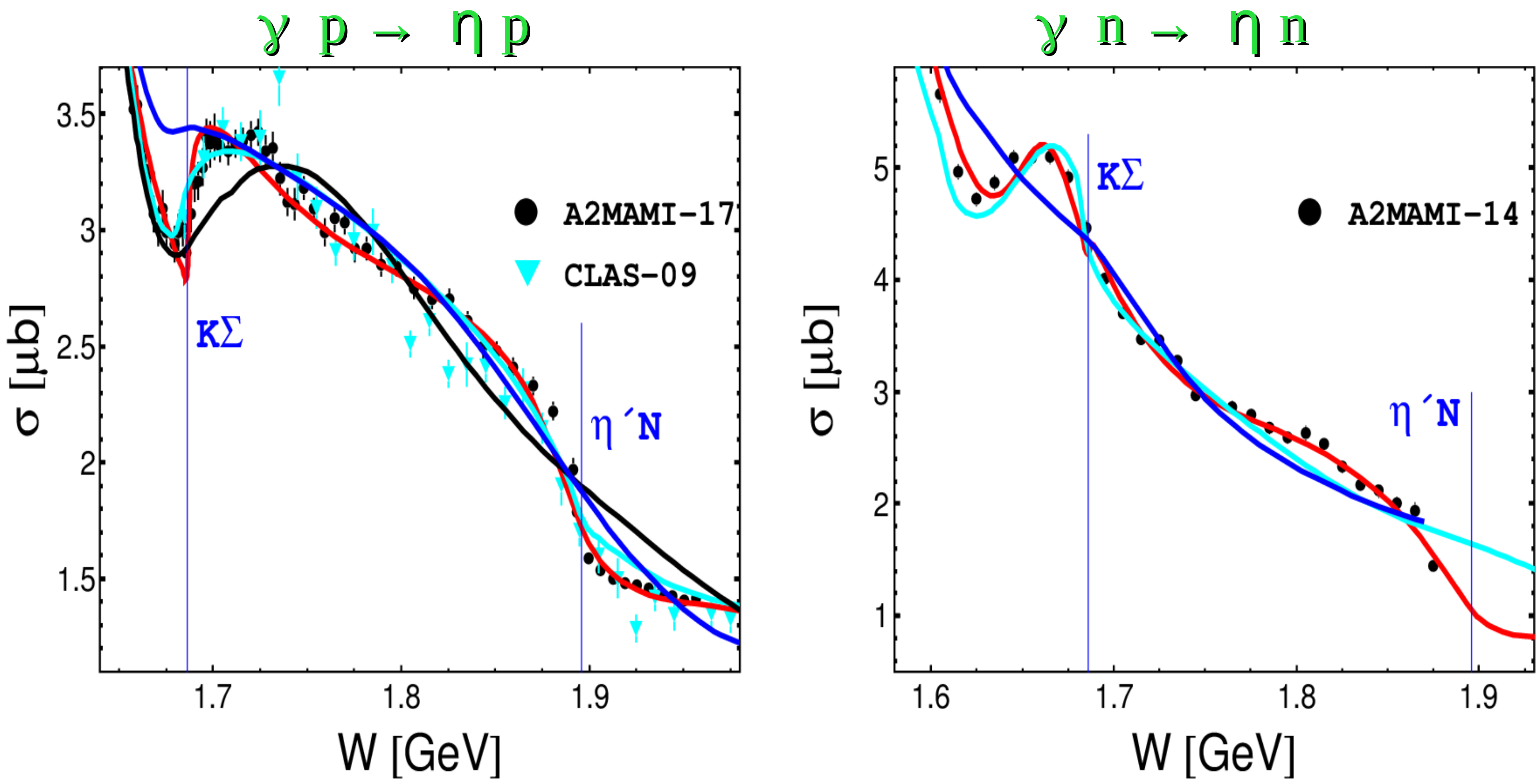
Other PWA groups analyzing new (γ,η) and (γ,η') data

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 (γ,η) p, **n (γ,η) n**, and **p (γ,η') 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 (γ,η) p**

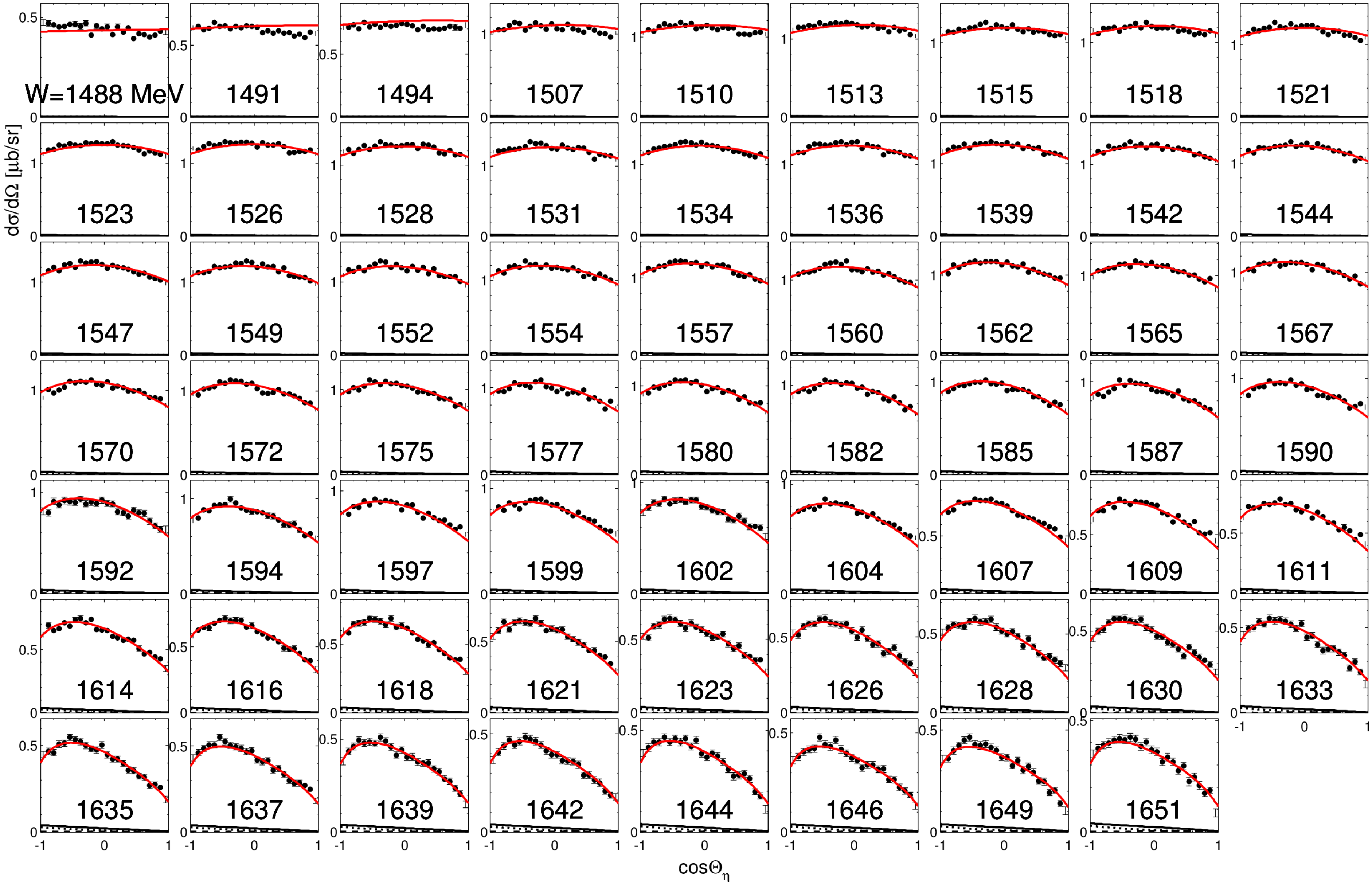
KSU: Kent State University group:
B.C. Hunt and D.M. Manley.
Multi-channel K-matrix model.
Predictions for 2 channels: **p (γ,η) p** up to W=1990 MeV,
n (γ,η) n up to W=1870 MeV

Total cross section in comparison with other new PWA



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

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



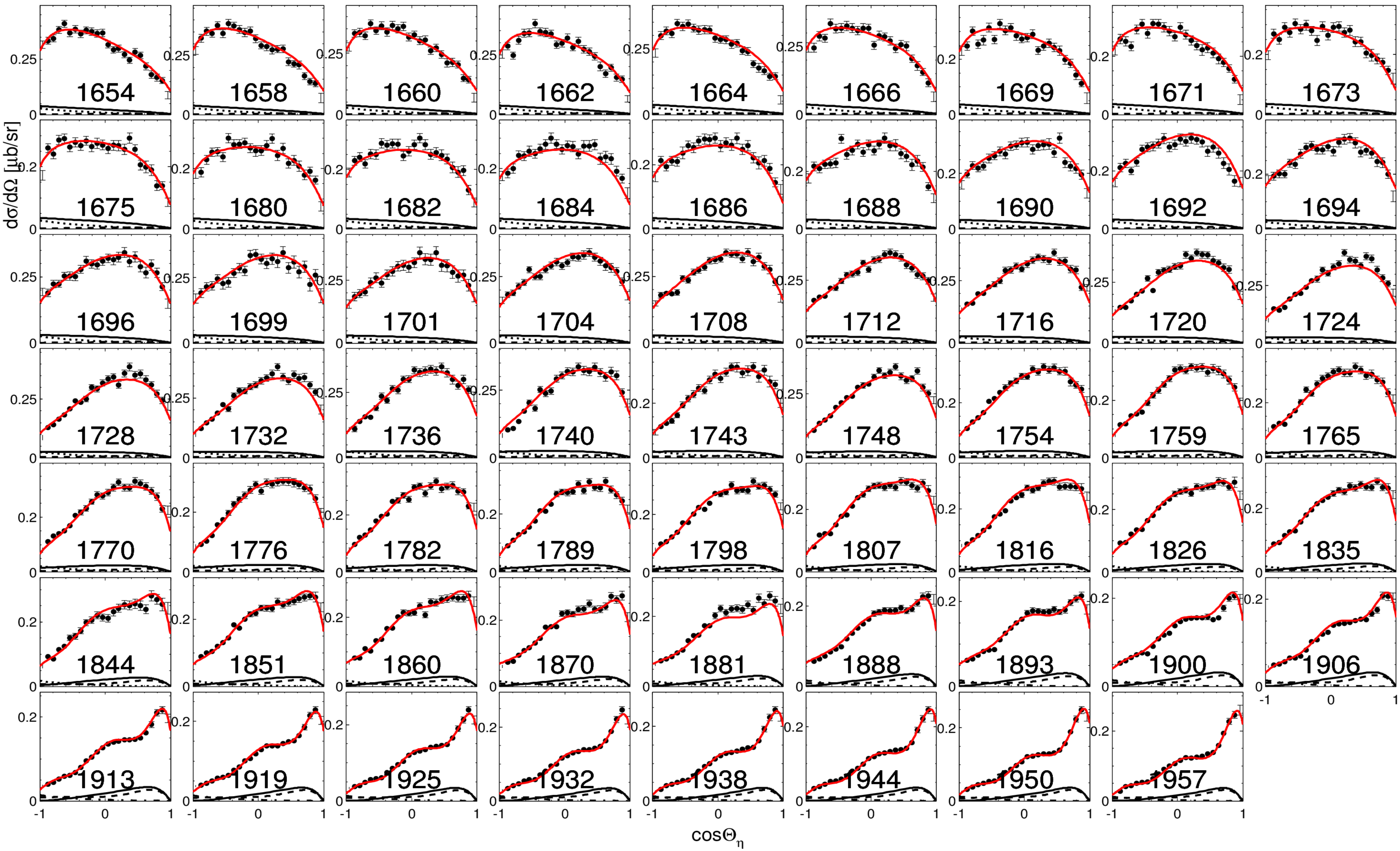
Data: A2MAMI-17;

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

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

Differential cross sections

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

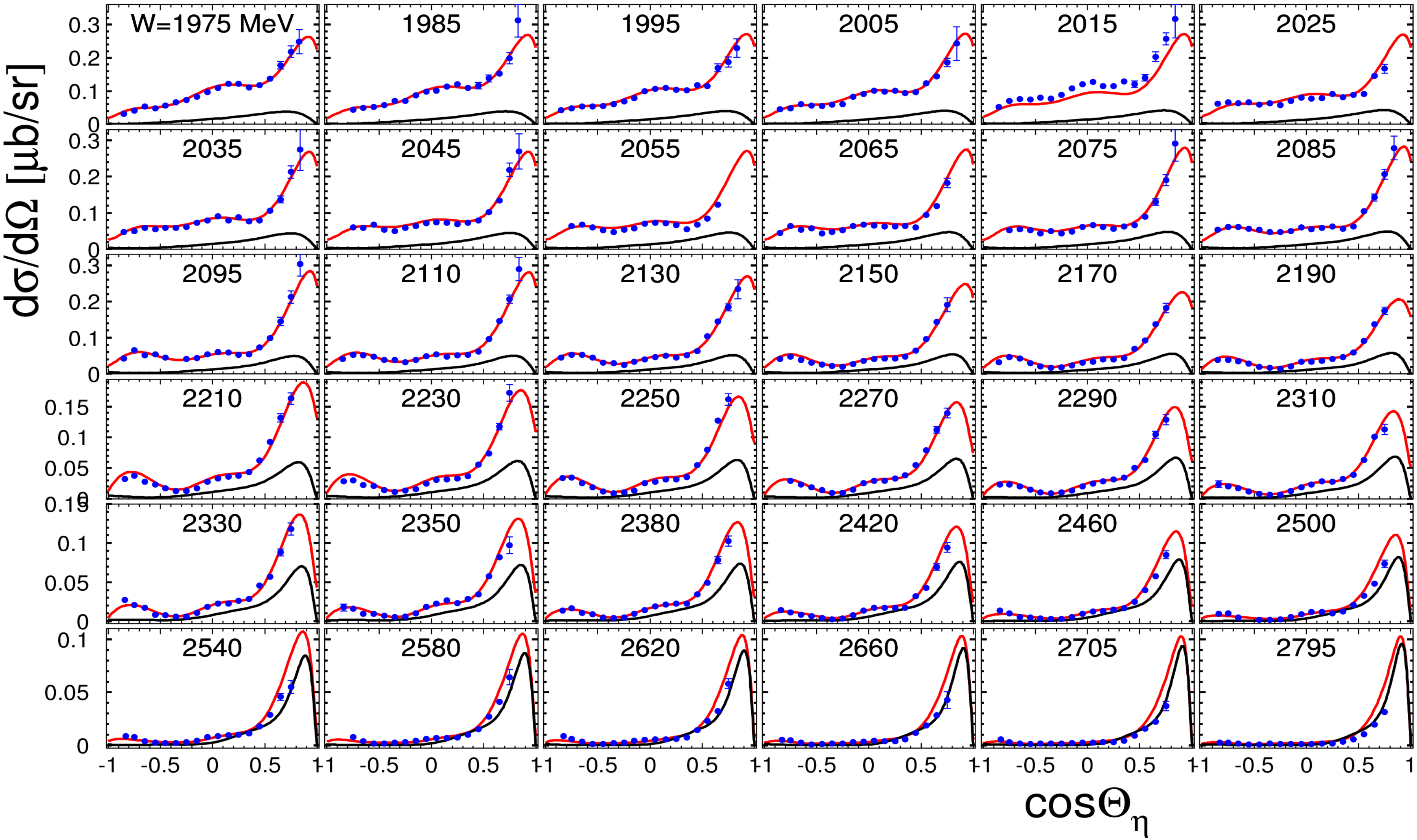


Data: A2MAMI-17;

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

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

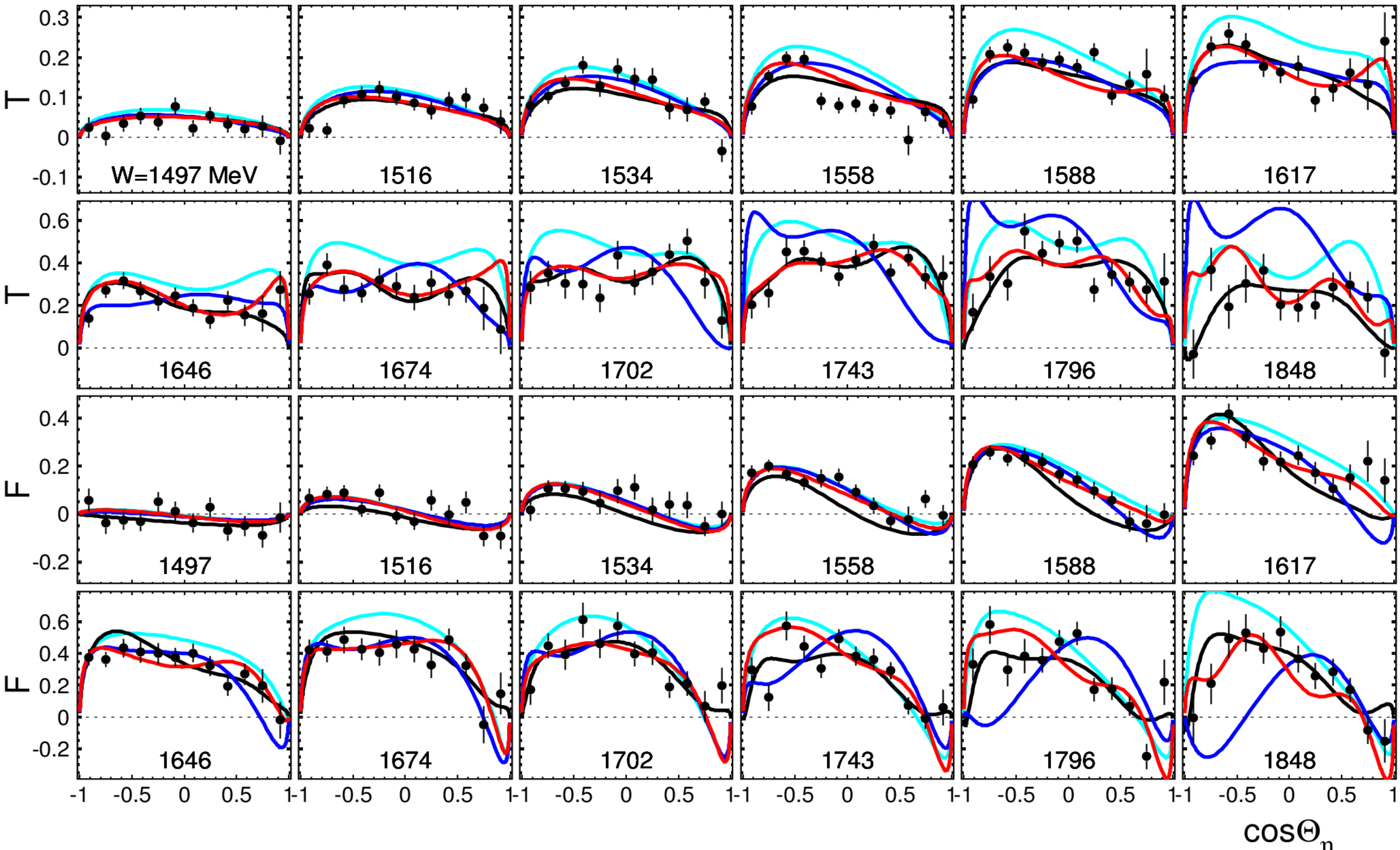
$\chi^2 = 2265/634 \approx 3.57$



Data: CLAS-09

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

$\gamma\ p \to\ \eta\ p$ Polarization observables: T and F

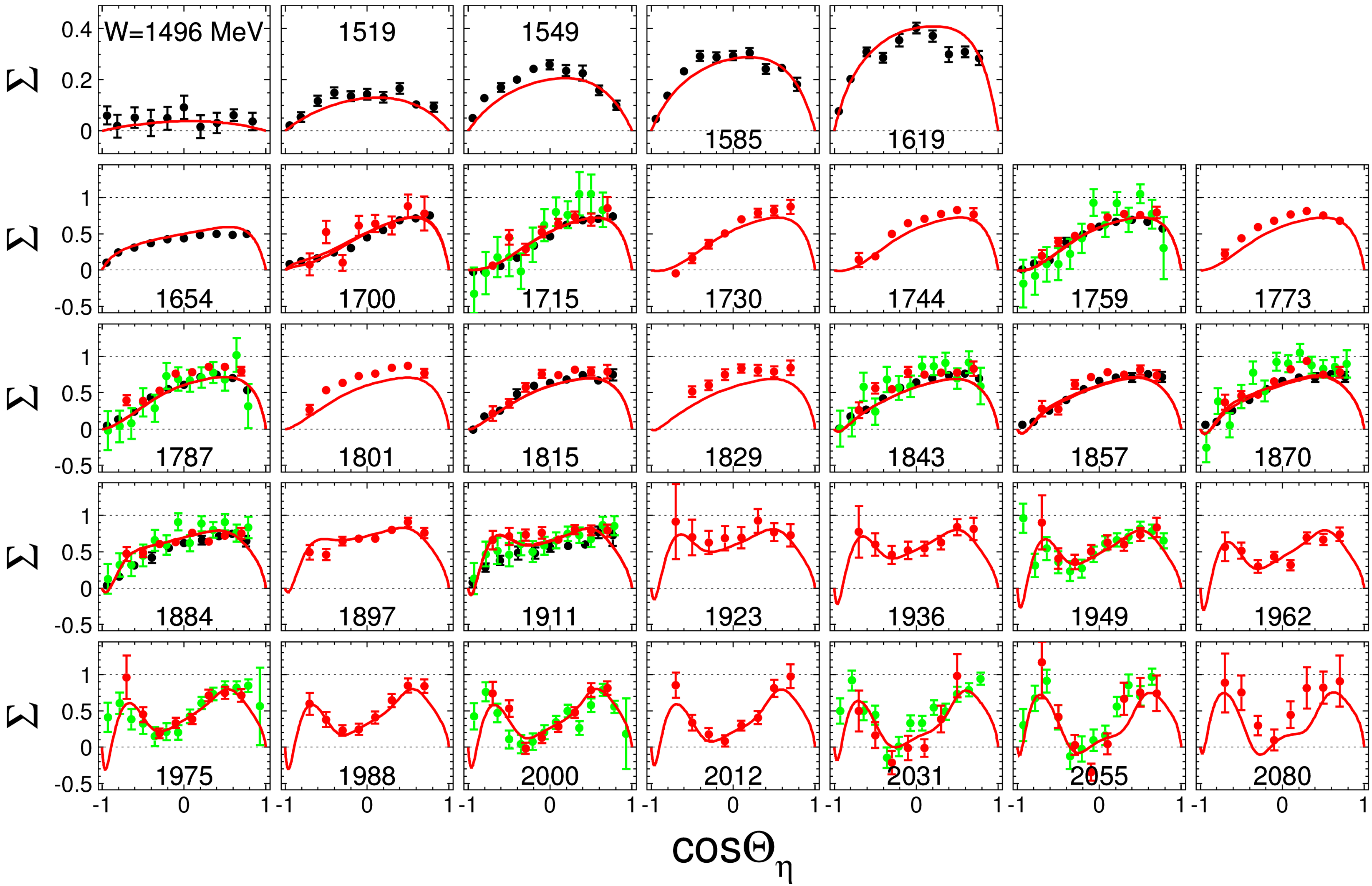


Red line: EtaMAID2018
Cyan line: BnGa
Blue line: KSU
Black line: JüBo

Data: A2MAMI-14

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

$\gamma\, p \to \eta\, p$ Polarization observables: Σ



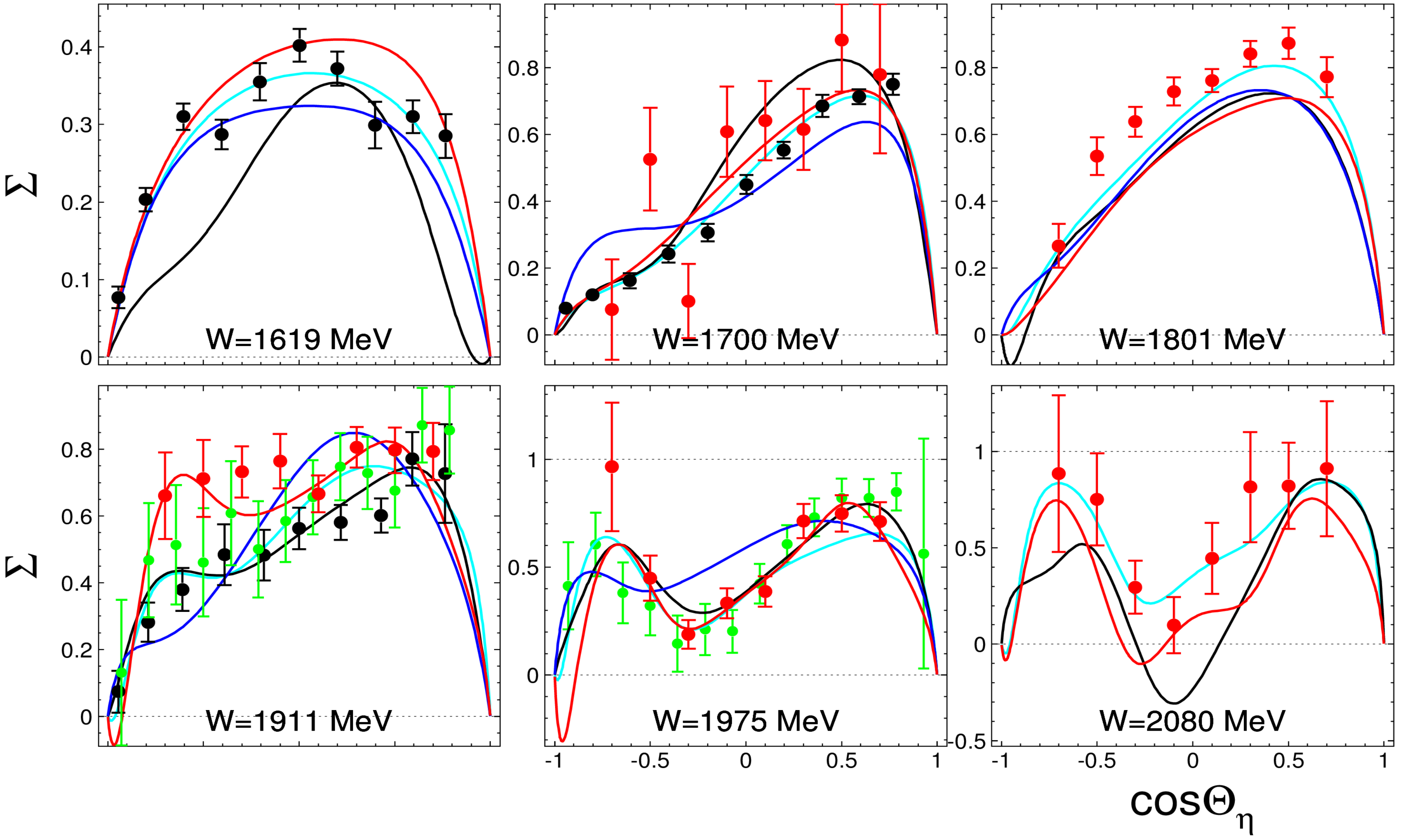
Data: black – GRAAL-07; red – CLAS-17; green – CBELSA/TAPS preliminary

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

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

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

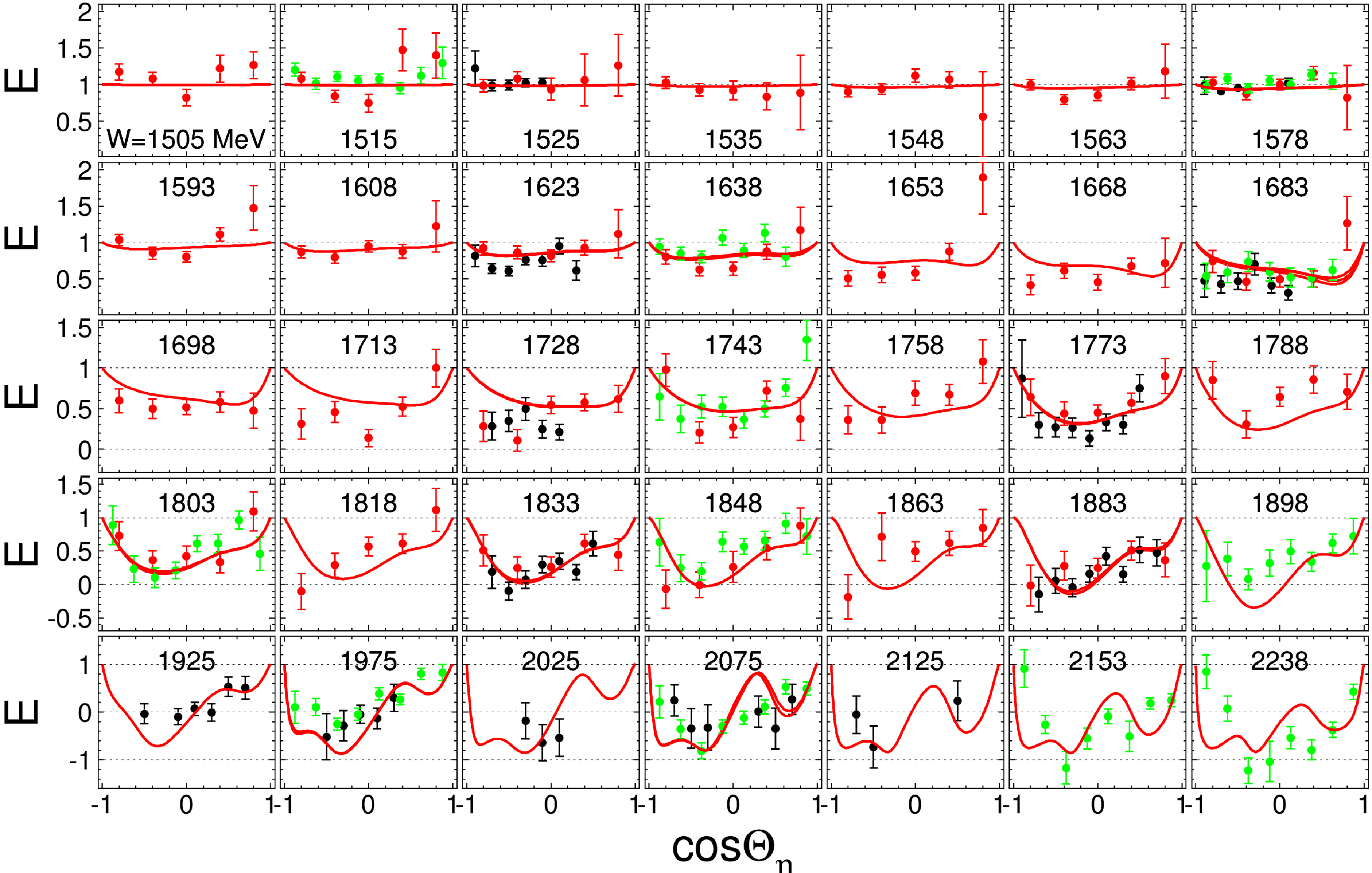
γ p → η p   Polarization observables: Σ



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



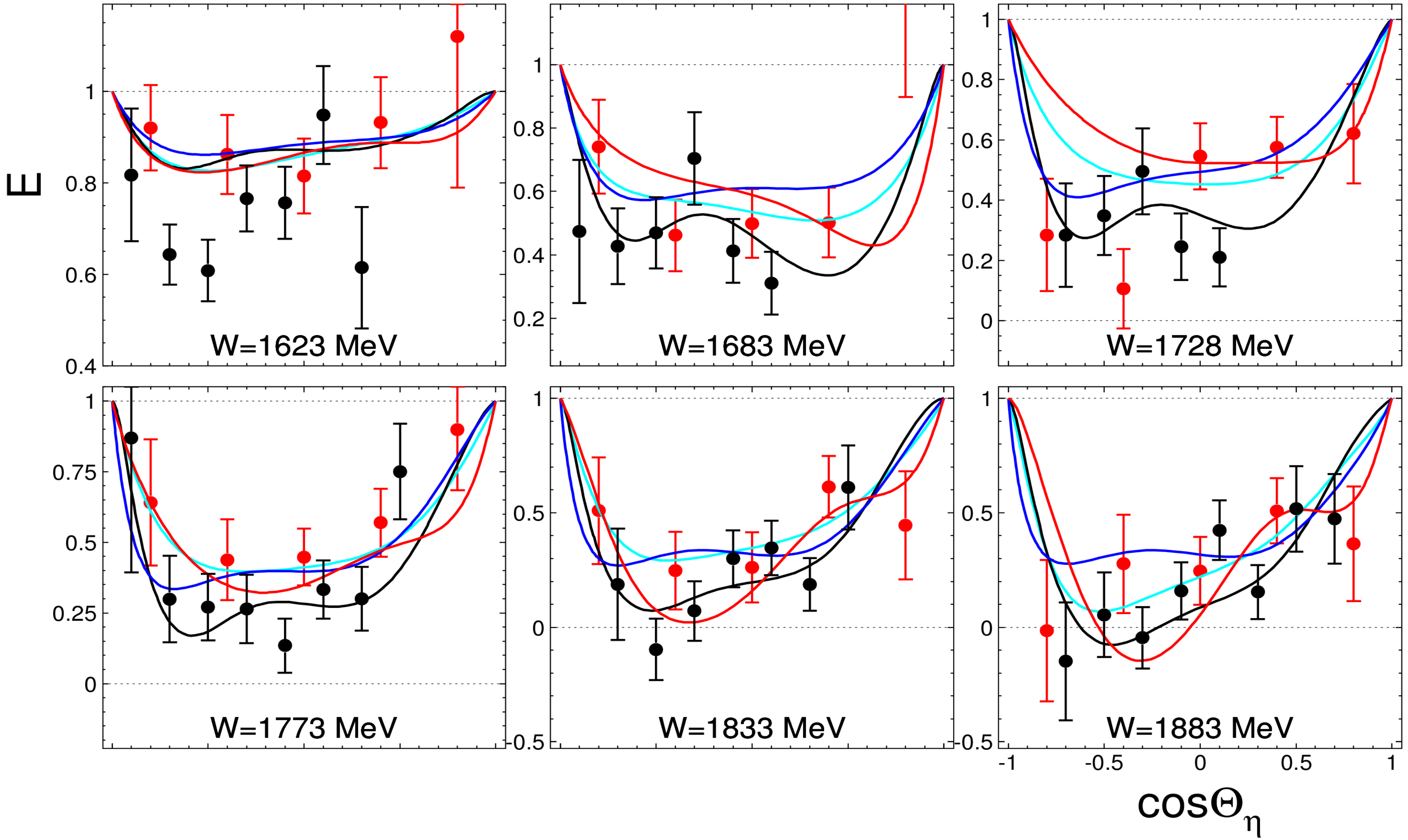
Data: black – CLAS-16; red – A2MAMI-17 “p”; green – CBELSA/TAPS preliminary

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

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

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

$\gamma\, p \rightarrow \eta\, p$ Polarization observables: E

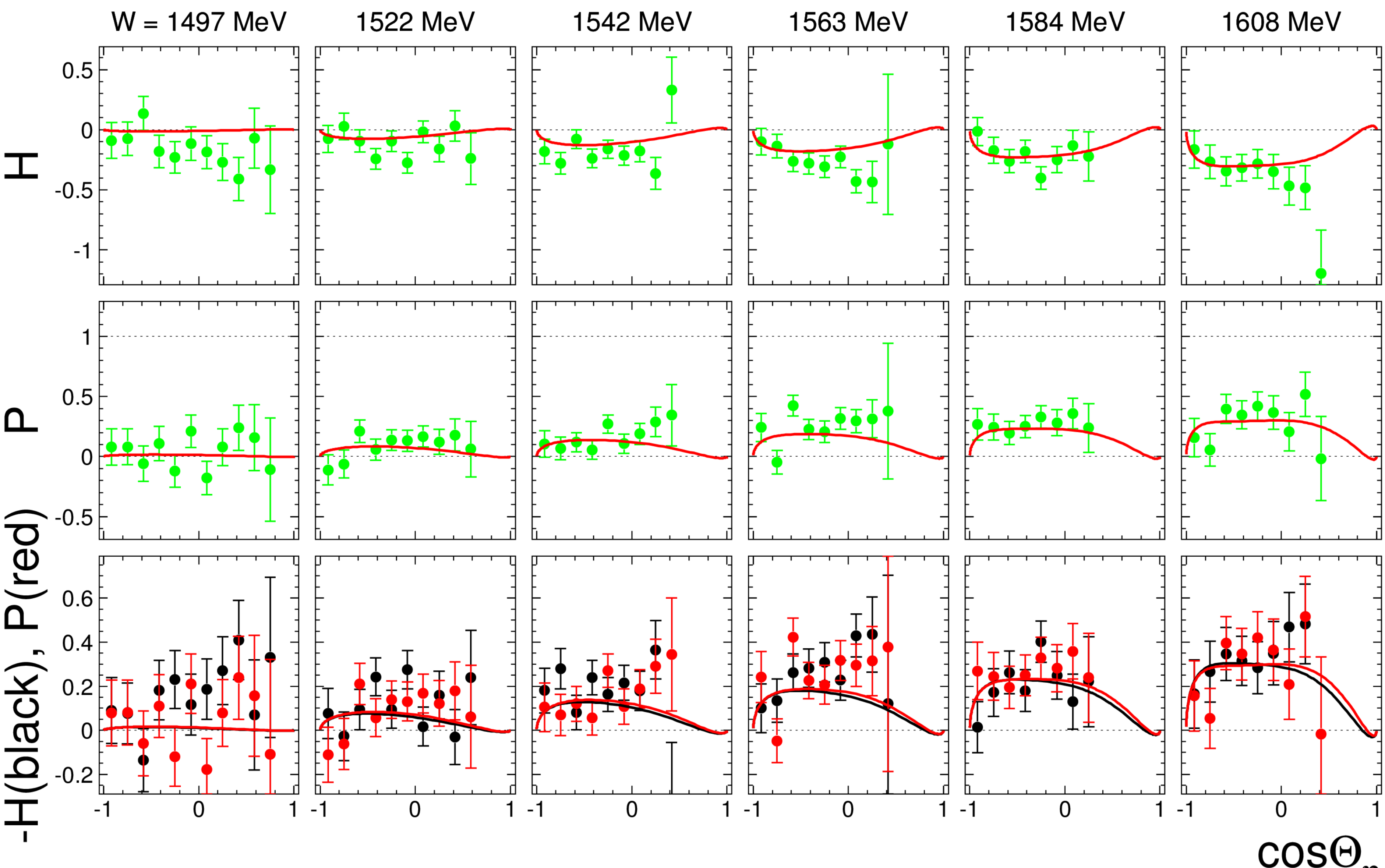


Red line: EtaMAID2018
Cyan line: BnGa
Blue line: KSU
Black line: JüBo

Data: black – CLAS-16
red – A2MAMI-17
green – CBELSA/TAPS preliminary

γ p → η p   Polarization observables: H and P

P ≈ - H ?

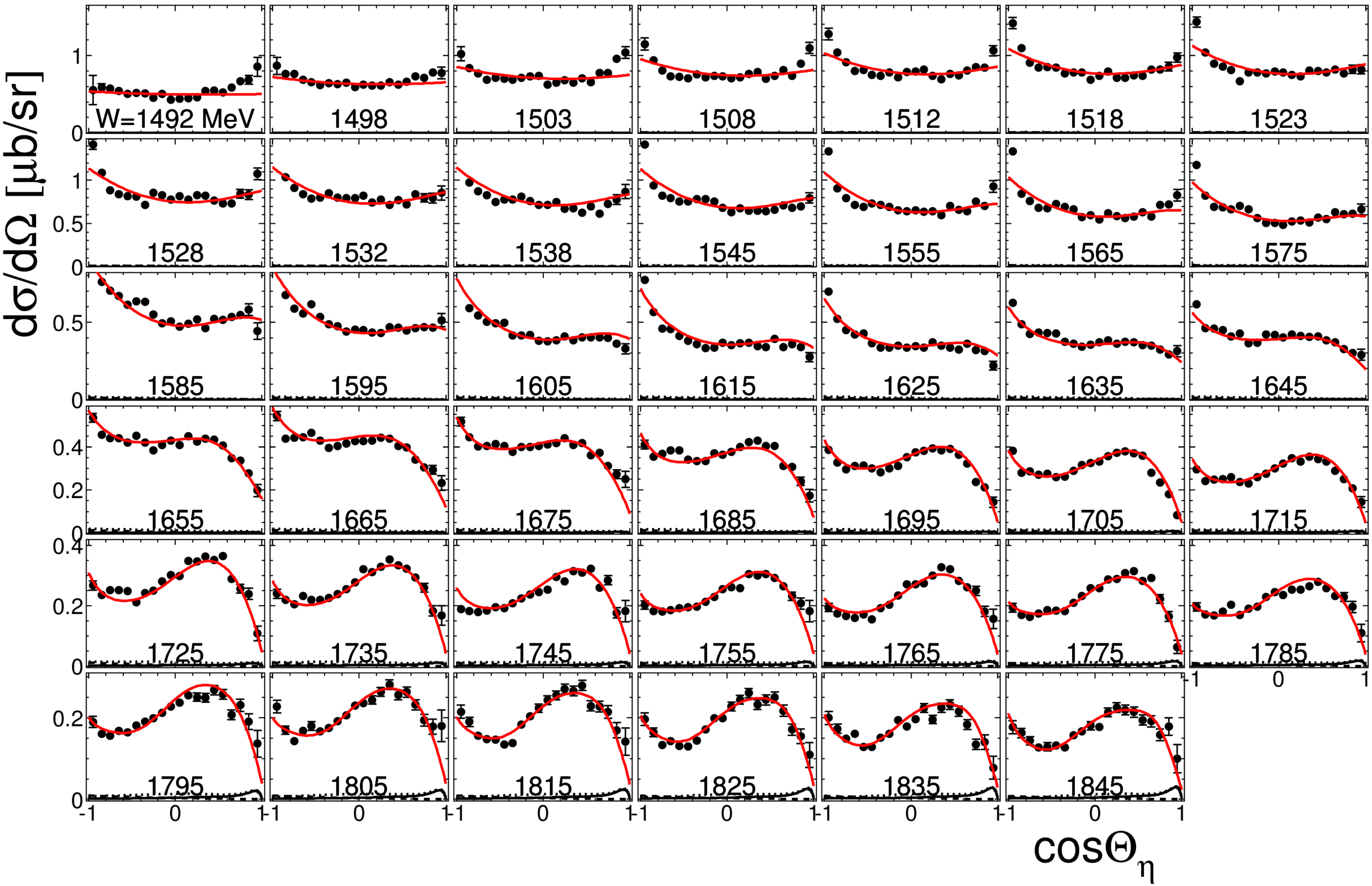


Data: CBELSA/TAPS preliminary
Lines: full solution

H: $\chi^2 = 81.08/56 \approx 1.45$; P: $\chi^2 = 57.07/56 \approx 1.02$

$\gamma\ n \to\ \eta\ n$

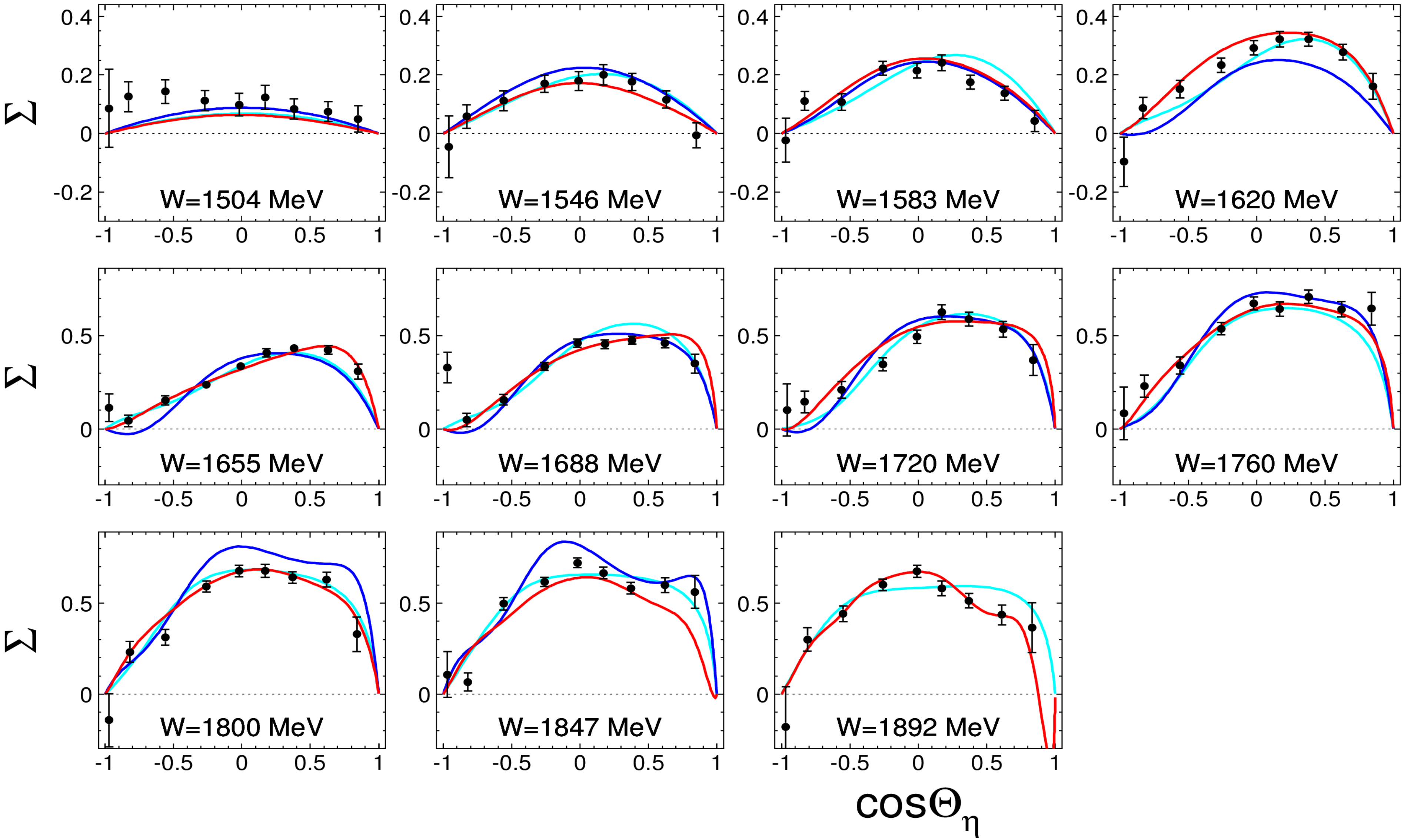
Differential cross sections



Data: A2MAMI-14
Lines: full solution

γ n → η n   Polarization observables: Σ

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

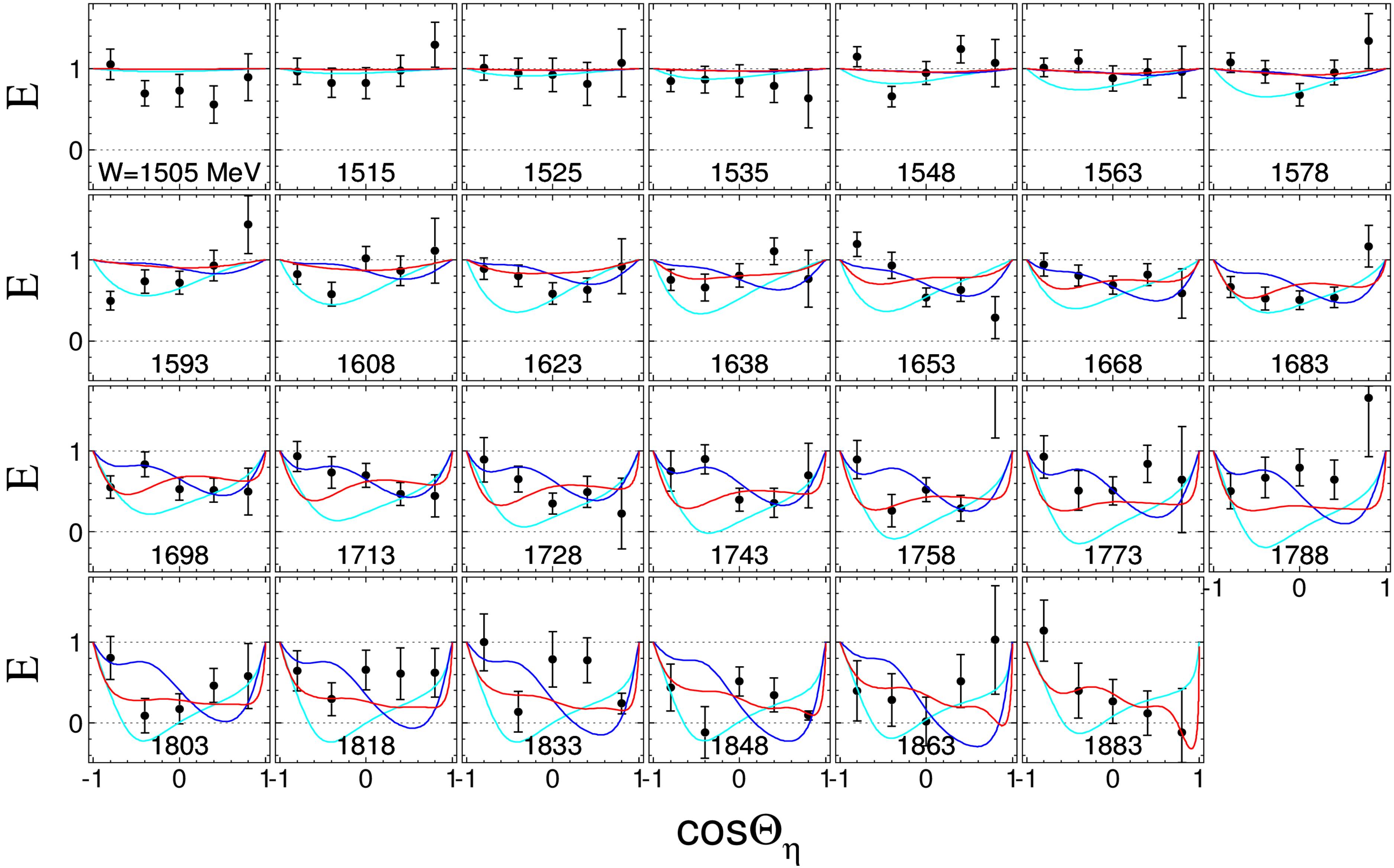


Red line: EtaMAID2018
Cyan line: BnGa
Blue line: KSU

Data: GRAAL-08

$\gamma\, n \rightarrow \eta\, n$ Polarization observables: E

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



Red line: EtaMAID2018

Cyan line: BnGa

Blue line: KSU

Data: A2MAMI-17

Observables in Legendre series

The Legendre expansion can be formulated in terms of associated Legendre polynomials $\{P_\ell^0(x), P_\ell^1(x), P_\ell^2(x)\}$ with the following relations

$$\begin{aligned} P_\ell^0(cos\theta) &= P_\ell(cos\theta)\,, \\ P_\ell^1(cos\theta) &= -sin\theta\; P_\ell^{'}(cos\theta)\,, \\ P_\ell^2(cos\theta) &= sin^2\theta\; P_\ell^{''}(cos\theta)\,. \end{aligned}$$

In particular we can find an expansion

$$O_i(W,\theta) = \sum_{k=0}^{2\ell_{max}} A_k^i(W)\; P_k^0(cos\theta), \text{ for } O_i = \{\sigma_0, \hat{E}\}$$

$$O_i(W,\theta) = \sum_{k=1}^{2\ell_{max}} A_k^i(W)\; P_k^1(cos\theta), \text{ for } O_i = \{\hat{T}, \hat{P}, \hat{F}, \hat{H}\}$$

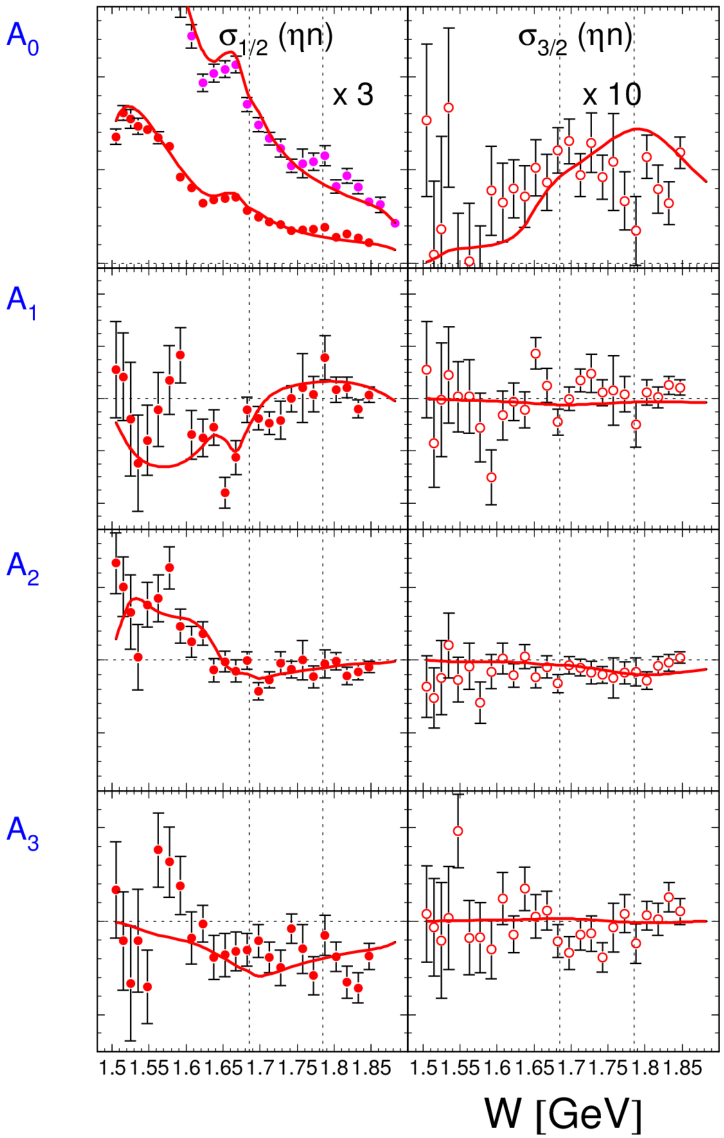
$$O_i(W,\theta) = \sum_{k=2}^{2\ell_{max}} A_k^i(W)\; P_k^2(cos\theta), \text{ for } O_i = \{\hat{\Sigma}, \hat{G}\}$$

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

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

Second narrow resonance in γ n → η n?

L. Witthauer et al, Phys. Rev. C**95** (2017) 055201

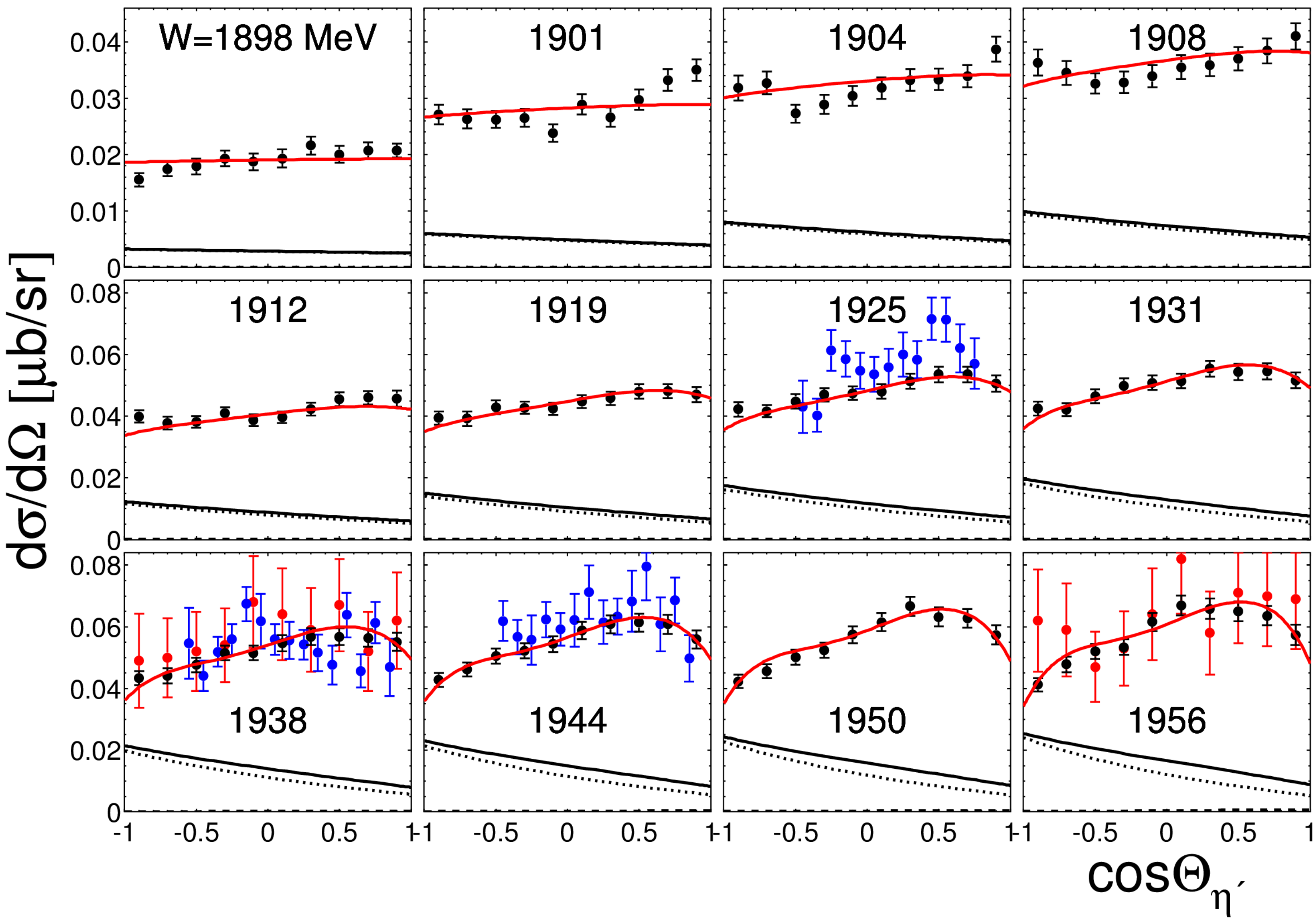


1. Narrow structure at W=1680 appears only in $\sigma_{1/2}$ and is thus related to S_{11} and/or P_{11} (in good agreement with our solution)

2. The second narrow structure at W=1726 MeV (second vertical line) is discused in V. Kuznetsov et al, JETP Lett. 105 (2017) 625. One of explanation is ωn production cusp.

Data: A2MAMI-17;
Red lines: full solution

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



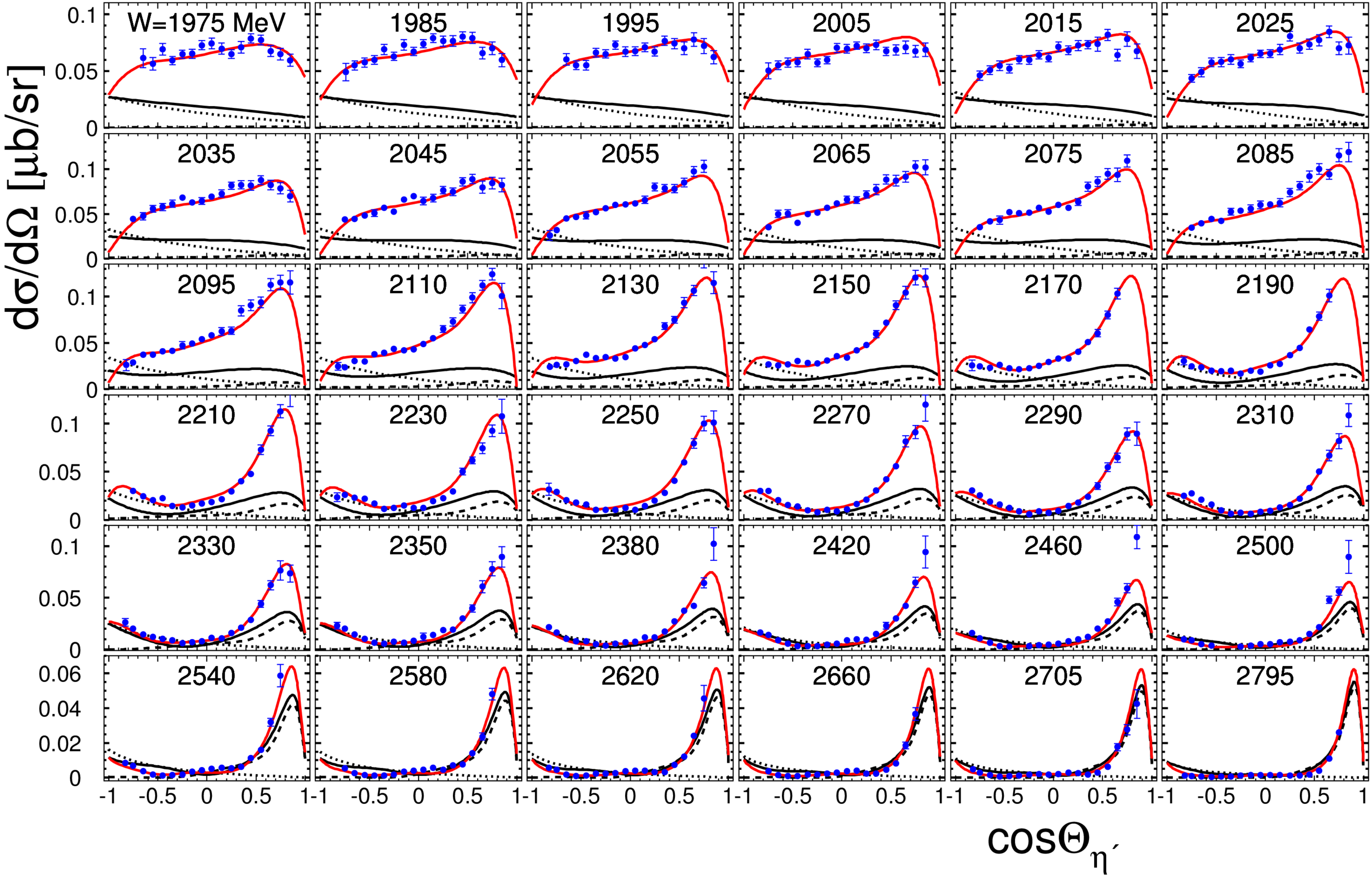
Data: black – A2MAMI-17; blue – CLAS-09; red – CBELSA-09

X^2 = 119.3/120 ≈ 0.99

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

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

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



Data: CLAS-09

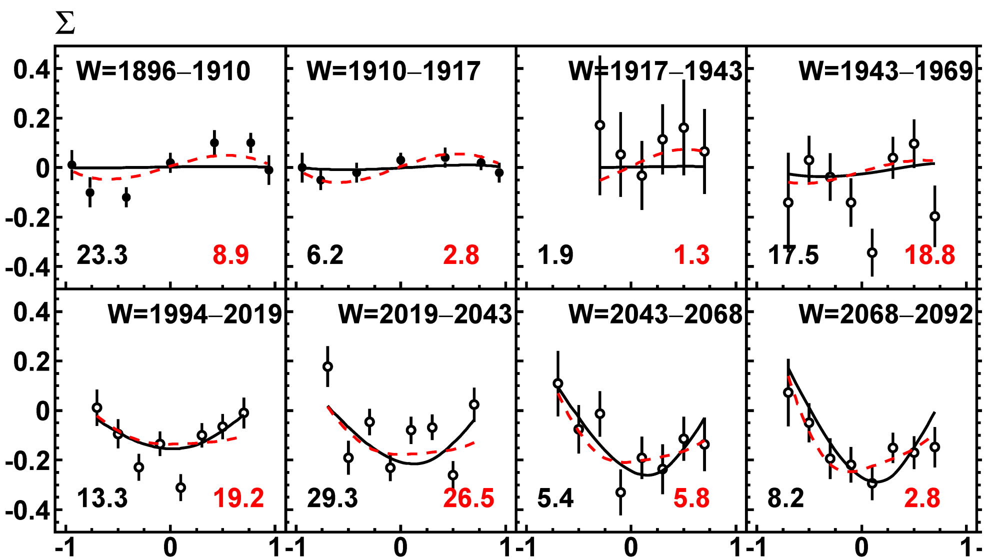
Lines: red – full solution; solid black – Regge+Born; dashed – Regge ; dotted – Born terms

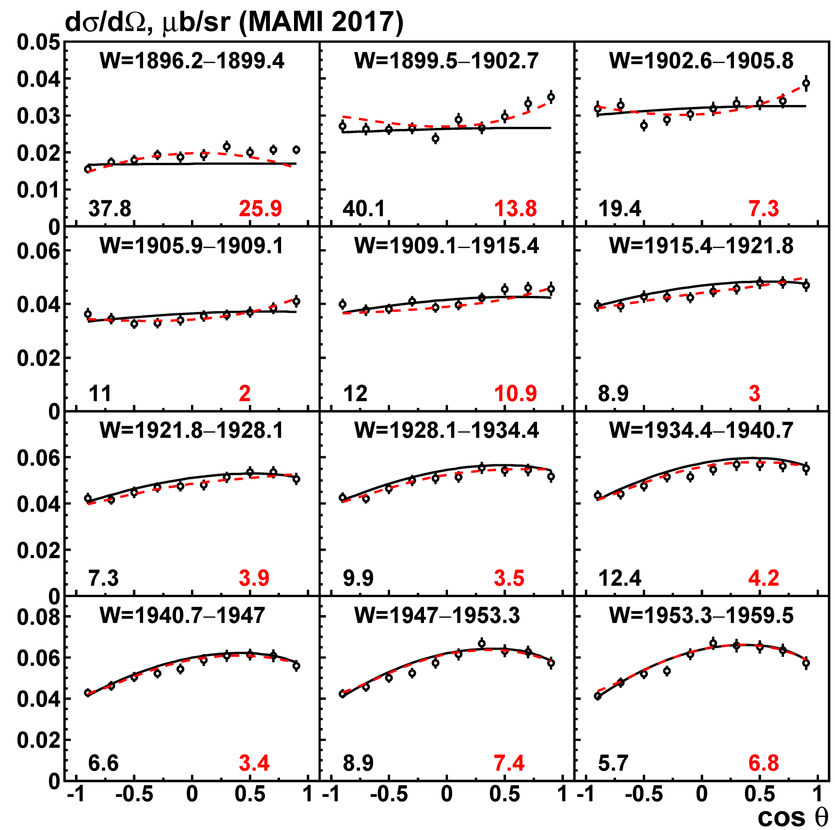
Narrow resonance in η´ photoproduction?

Anisovich, Burkert, Dugger, Klempt, Nikonov, Ritchie, Sarantsev, Thoma, arXiv:1803.06814 (2018)

BnGa-2017 solution without narrow resonance

BnGa2018 solution with a narrow D_{13} : M_R = 1900 ± 1 MeV, Γ < 3 MeV

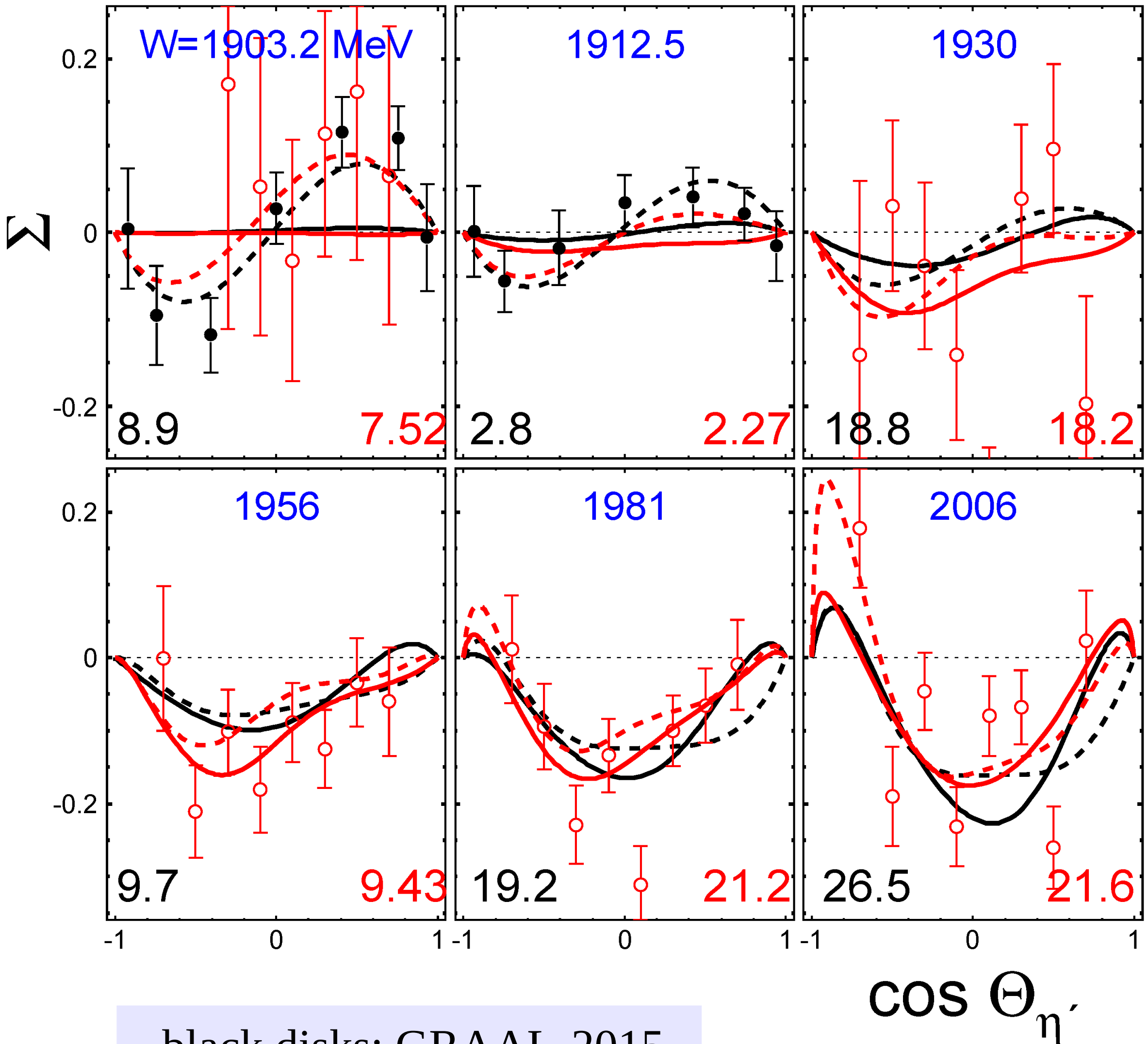




beam asymmetry Σ:
black disks: GRAAL-2015
red circles: CLAS-2017

diff. cross sect. dσ/dΩ:
A2MAMI-2017

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



BnGa 2018

with narrow D_{13}

$M_R = 1900$ MeV

$\Gamma = 1$ MeV

EtaMAID 2018

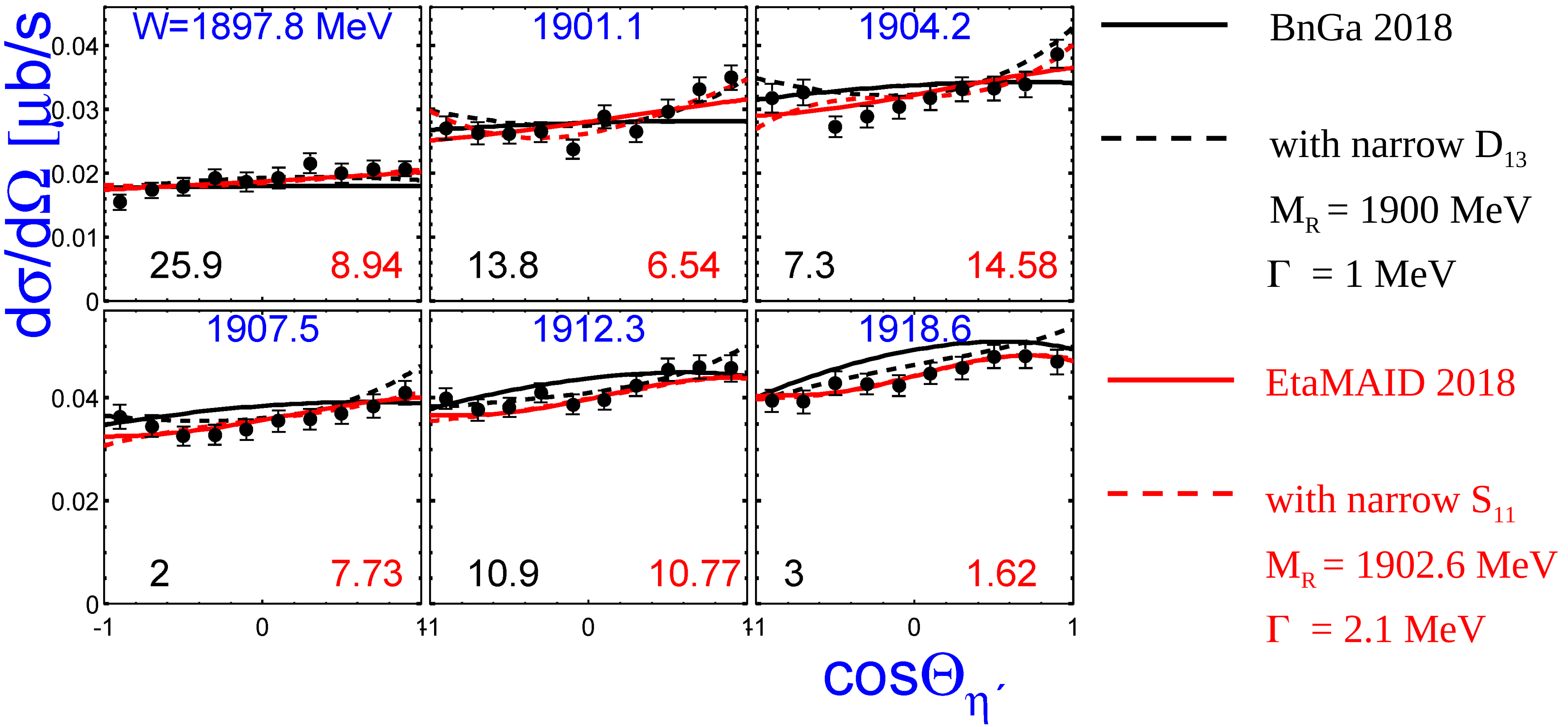
with narrow S_{11}

$M_R = 1902.6$ MeV

$\Gamma = 2.1$ MeV

black disks: GRAAL-2015
red circles: CLAS-2017

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

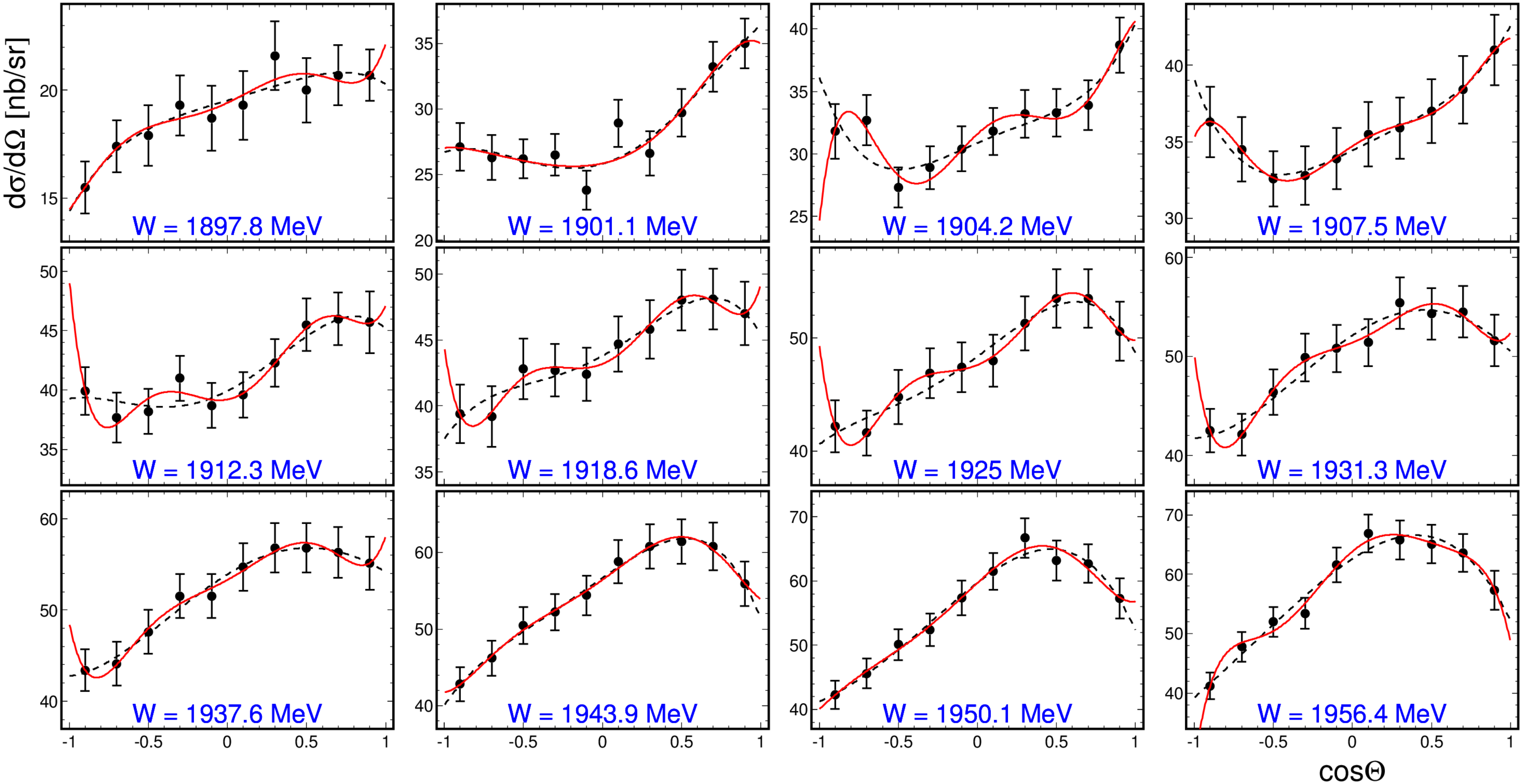


Σ and $d\sigma/d\Omega$ data can well be fitted with a very narrow resonance at W_R=1900 MeV.
In the total c.s. such a resonance is invisible.
It shows up in interferences between *S-F* or *P-D* resonances.

Narrow resonance in η´ photoproduction?

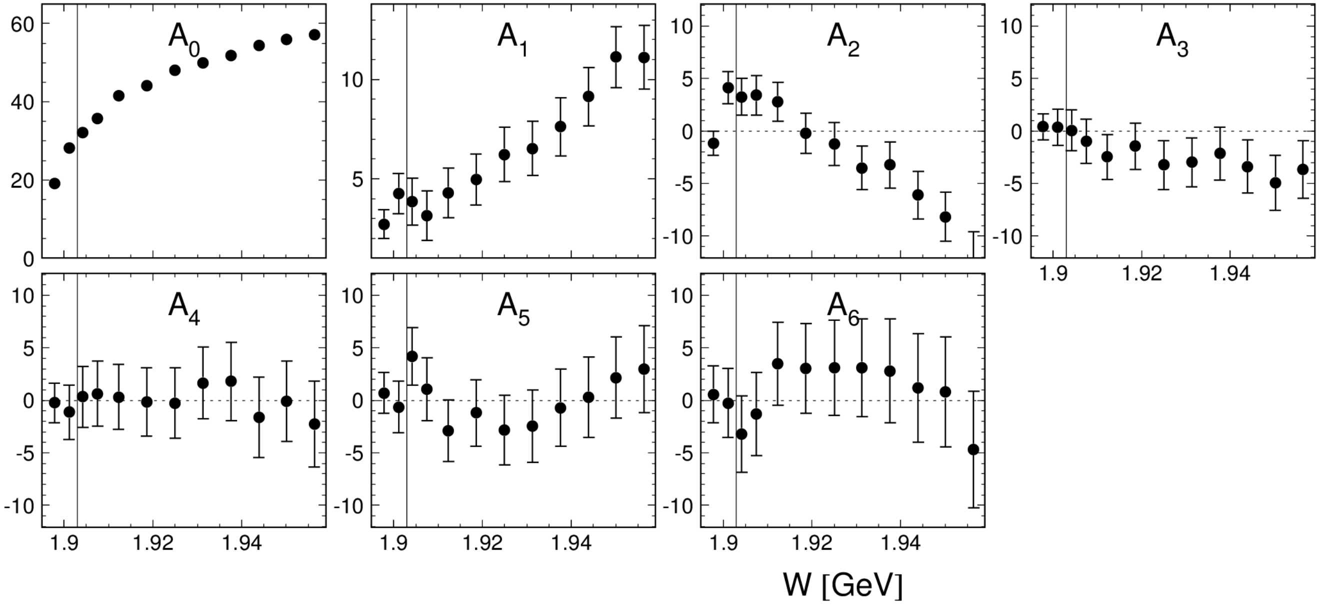
diff. cross sect. dσ/dΩ:
A2MAMI-2017

Legendre fit:
with l_{max} = 2 (D wave) – black dashed
with l_{max} = 3 (F wave) – red solid



Narrow resonance in η´ photoproduction?

Legendre coefficient from fit with $l_{max} = 3$ (F wave)



Vertical line correspond to mass of the narrow S_{11} resonance, M = 1902.6 MeV

Summary and conclusions

1. We have just finished an EtaMAID update, which will soon become available on our MAID webpage. The new EtaMAID2018 describes well all experimental data of 4 channels:

$$\gamma\ p \rightarrow \eta\ p, \quad \gamma\ n \rightarrow \eta\ n, \quad \gamma\ p \rightarrow \eta'\ p, \quad \gamma\ n \rightarrow \eta'\ n$$

2. The cusp in the (η p) total cross section at W=1680, in connection with the steep rise of the (η' p) total cross section from its threshold, is explained by a strong coupling of the S_{11}(1895) resonance to both channels.

3. The narrow bump in (η n) and the dip in the (η p) total cross sections have different origin. The first is a result of an interference of few resonances with a dominant contribution of the P_{11}(1710). The second one is mainly a sum of S_{11}(1520) and S_{11}(1650) with opposite signs. However the narrowness of this structure is explained by a cusp effect due to the opening of the $K\Sigma$ decay channel of the S_{11}(1650) resonance.

4. New narrow S_{11} resonance with M=1902.6 MeV and Γ=2.1 MeV can explain unexpected near threshold behavior of Σ (GRAAL) and $d\sigma/d\Omega$ (A2MAMI) for $\gamma\ p \rightarrow \eta'\ p$. However the evidence for the existence of such resonance is rather weak.

EtaMAID2003

ηMAID is an isobar model for η photo- and electroproduction on nucleons, for more details see:
W.-T. Chiang, S.N. Yang, L. Tiator, D. Drechsel, NP A700 (2002) 429.

Model ingredients:
- Born terms (very small contribution),
- ρ- and ω-meson exchanges in the t-channel, which are described by ρ- and ω poles.
- nucleon resonances parameterized with Breit-Wigner shapes.

Model variable parameters:
- Born terms: coupling η to nucleon $g^2_{\eta NN}$;
- vector mesons: hadronic vector g_v and tensor g_t couplings, dipole form factor Λ_v ;
- resonances: mass M_R , total width Γ_R at the resonance peak , branching ratio $\beta_{\eta N}$; photoexcitation helicity amplitudes $A_{1/2}$, $A_{3/2}$;
- total and partial widths have an energy dependence with an damping factor assumed to be the same for all resonances;
- relative sign between $N^* \rightarrow \eta N$ and $N^* \rightarrow \pi N$ couplings, $\zeta_{\eta N} = \pm 1$.

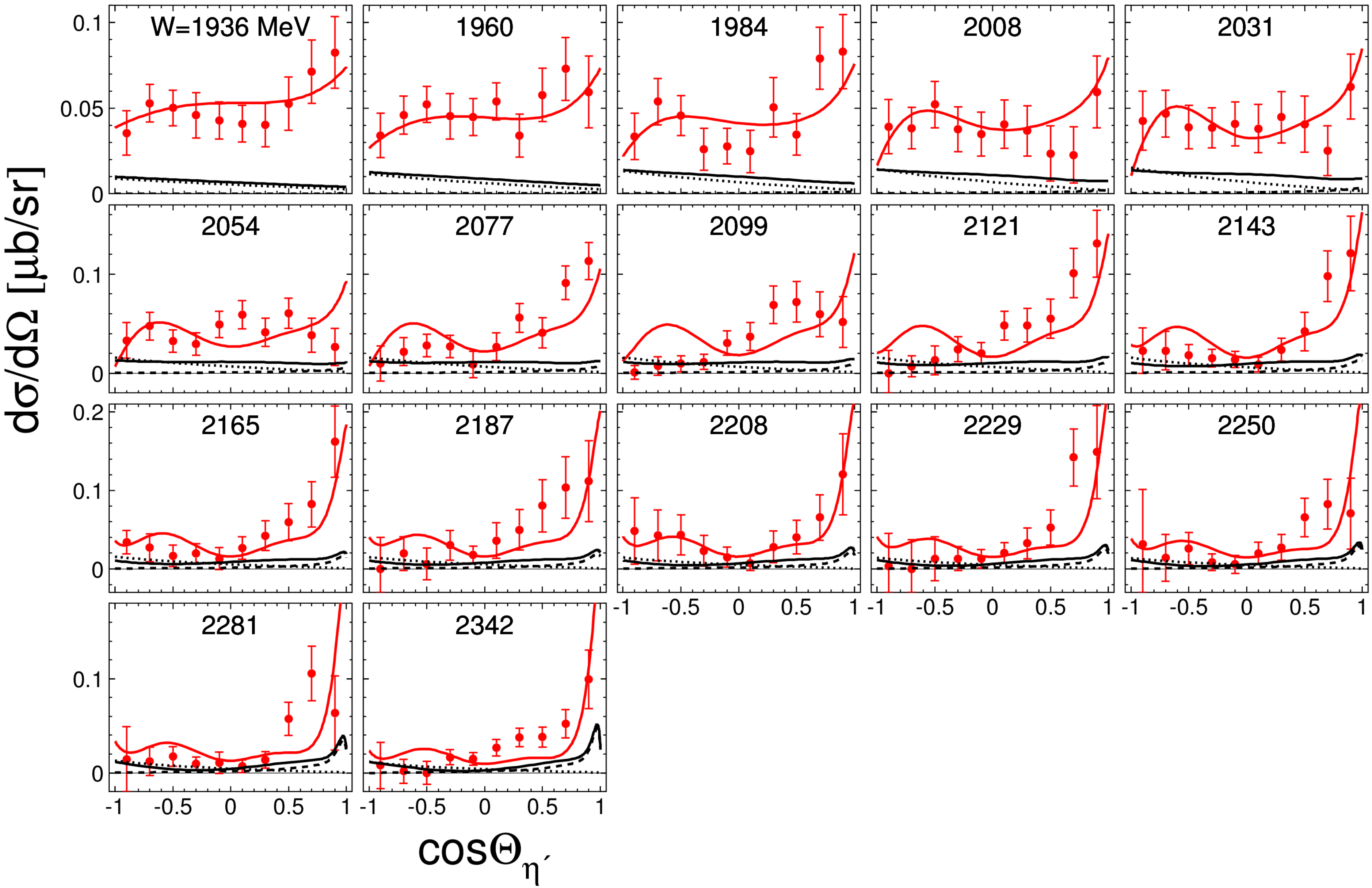
Data set:
- total and differential cross sections of MAMI and GRAAL;
- photon asymmetry of GRAAL (E_γ<1.1 GeV);
- electroproduction cross sections of Jlab.

Reggeized model for η and η' photoprduction,
W.-T. Chiang, S.N. Yang, L. Tiator, M. Vanderhaeghen, D. Drechsel, PRC 68 (2003) 045202.
Main difference: vector meson exchanges are described in terms of Regge trajectories.
It should be important for high energies, W> 3GeV.

γ n → η' n

Differential cross sections

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



Data: CBELSA/TAPS-11

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