Exotic multi-quark states and baryon spectroscopy workshop

25–27 Jun 2024
Universitätsclub Bonn, the University of Bonn

η and η´ photoproduction on nucleons

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JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Outline

- **Motivation**
- **Experimental data sets**
- **EtaMAID**
- **Regge phenomenology for high energy region**
- **Selected results**
- **Summary**

Motivation

1. Baryon spectroscopy
2. Search for missing resonanses
3. Search for exotic states
4. Reaction mechanism

Data sets

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

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]
T CBELSA/TAPS-		
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]
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]

Data sets

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

- dσ/dΩ, A2MAMI: 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]

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

- 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]
- $d\sigma/d\Omega_{1/2,3/2}$ 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]

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

- dσ/dΩ, CBELSA/TAPS-11: E_γ=1.53–2.45 GeV [EPJA 47 (2011) 11] https://maid.kph.uni-mainz.de

MAID

Photo- and Electroproduction of Pions, Eta, Etaprime 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	EtaMAID2000 isobar model for (e,e'η) EtaMAID2018 isobar model for (γ,η) and (γ,η') NEW
Chiral MAID	chiral perturbation theory approach for (e,e'π)
2-PION-MAID	isobar model for (γ,ππ)
archive	MAID2000 DMT2001original EtaMAID2003 ETAprime2003

EtaMAID 2018

Institut für Kernphysik, Universität Mainz, Germany

NEW update info

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 ($F_1,\ldots,F_4$, $H_1,\ldots,H_4$)**
- **Observables (with beam, target and recoil polarization)**
- **Total Cross Sections**

Now MAID is part of research program of

MTZ Collaboration

Mainz: M. Gorchteyn, V. L. Kashevarov, M. Ostrick, L. Tiator
Tuzla: M. Hadžimehmedović, R. Omerović, H. Osmanović, J. Stahov
Zagreb: Alfred Švarc

Publication of MTZ Collaboration for MAID project:

Eta and Etaprime Photoproduction on the Nucleon with the Isobar Model EtaMAID2018.
Eur.Phys.J.A 54 (2018) 12, 210

Single-energy partial-wave analysis for pi0 n photoproduction with fixed-t analyticity.
Phys.Rev.C 104 (2021) 3, 034605

Single-energy partial wave analysis for π0 photoproduction on the proton with fixed-t analyticity imposed.
Phys.Rev.C 100 (2019) 5, 055203

Role of angle-dependent phase rotations of reaction amplitudes in η photoproduction on protons
Phys.Rev.C 98 (2018) 4, 045206

Fixed-t analyticity as a constraint in single-energy partial-wave analyses of meson Photoproduction reactions
Phys.Rev.C 97 (2018) 1, 015207

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

Details of model

All the most well-known models (MAID, SAID, BnGa, JüBo etc.) are applicable for data analysis and predictions only in the resonance energy region (W <2.5 GeV).

There are several models for higher energies (JPAC and various Regge models). However, all of them are applicable for energies (W >2.5 GeV), for scattering angles only to forward or backward, and for specific reaction channels.

The last version of EtaMAID2018 allows data analysis for energies up to W = 6 GeV,
at any scattering angles, and for 4 reaction channels:

1. $\gamma p \rightarrow \eta p$
2. $\gamma n \rightarrow \eta n$
3. $\gamma p \rightarrow \eta' p$
4. $\gamma n \rightarrow \eta' n$

Details of model

1. EtaMAID 2018 is an isobar model.

2. 22 nucleon resonances, parameterized with Breit-Wigner shapes.

3. The model includes Born terms in s and u channels.
   Contribution is small because of coupling constant < 0.1.
   It is very important for pion photoprduction with coupling constan ~14.

4. Meson exchange in t channel with damping factors (DF).
   Dominates at high energy (W> 2.5 GeV)

5. Fit parameters:
   - Background: only DF parameters.
   - Resonances: mass M, total width G, branching ratios β(ηN) and β(η´N),
     photon helicity amplitudes $pA_{1/2}$, $nA_{1/2}$,
     damping parameters for ηN (η´N) and gN vertices: X and Xg

Details of model: resonances

Breit-Wigner ansatz for s-channel resonance excitations:

$$\mathcal{M}_{\ell\pm}(W) = \bar{\mathcal{M}}_{\ell\pm}\, f_{\gamma N}(W)\, \frac{M_R \Gamma_{\rm tot}(W)}{M_R^2 - W^2 - i M_R \Gamma_{\rm tot}(W)}\, f_{\pi N}(W)\, C_{\pi N}$$

$$f_{\pi N}(W) = \zeta_{\pi N} \left[\frac{1}{(2J+1)\pi} \frac{k}{q} \frac{M_N}{W} \frac{\Gamma_{\pi N}(W)}{\Gamma_{\rm tot}(W)^2} \right]^{1/2}$$

$$f_{\gamma N}(W) = \left(\frac{k}{k_R}\right)^2 \left(\frac{X^2 + k_R^2}{X^2 + k^2}\right)^2$$

isospin factor: $C_{\eta N} = C_{\eta' N} = -1$ $\qquad C_{\pi N} = \begin{cases} -1/\sqrt{3} & : \; I = 1/2 \\ \sqrt{3/2} & : \; I = 3/2 \end{cases}$

relative phase of individual resonance: $\zeta_{\pi N} = 1,\ \zeta_{\eta N} = \pm 1,\ \zeta_{\eta' N} = \pm 1$

Details of model: list of resonances

Resonances included in the fit

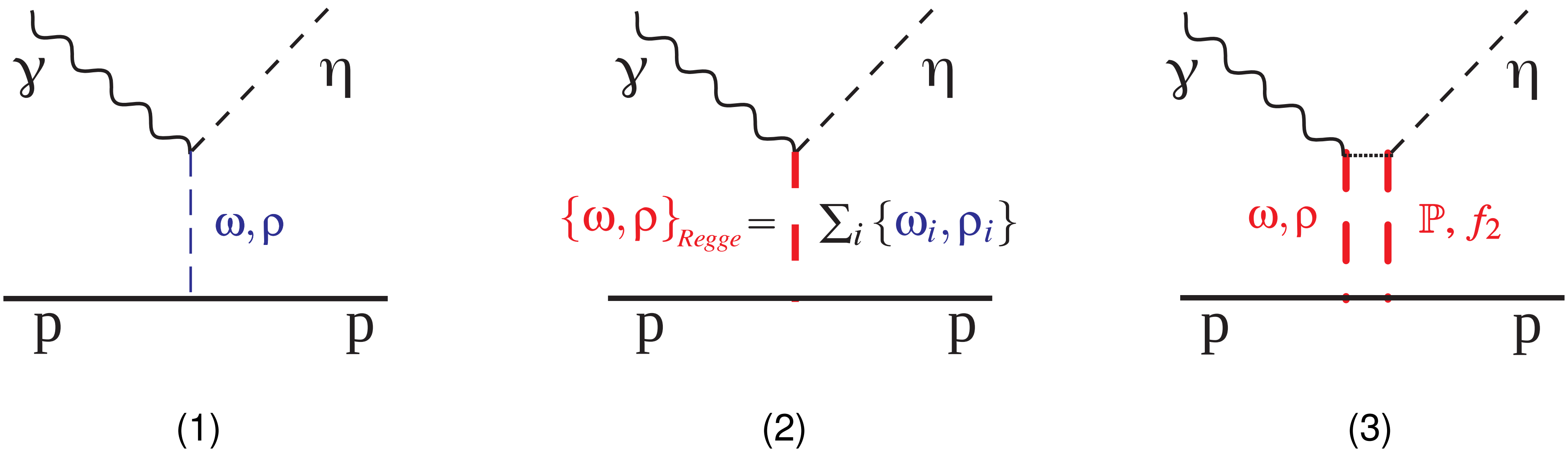
1. $P_{11}(1440)$ **** MAID 2007
2. $D_{13}(1520)$ **** MAID 2007
3. $S_{11}(1535)$ **** MAID 2007
4. $S_{11}(1650)$ **** MAID 2007
5. $D_{15}(1675)$ **** MAID 2007
6. $F_{15}(1680)$ **** MAID 2007
7. $D_{13}(1700)$ ***
8. $P_{11}(1710)$ ****
9. $P_{13}(1720)$ **** MAID 2007
10. $F_{15}(1860)$ **
11. $D_{13}(1875)$ ***
12. $P_{11}(1880)$ **
13. $S_{11}(1895)$ ****
14. $P_{13}(1900)$ ***
15. $F_{17}(1990)$ **
16. $F_{15}(2000)$ **
17. $D_{15}(2060)$ **
18. $P_{11}(2100)$ **
19. $D_{13}(2120)$ **
20. $G_{17}(2190)$ ****
21. $G_{19}(2250)$ ****
22. $H_{19}(2220)$ ****

Resonances not included in the fit (PDG overall rating: two stars and more)

1. $D_{15}(2570)$ **
2. $H_{111}(2600)$ ***
3. $I_{113}(2700)$ **

Details of model: background

t-channel contribution to η photoproduction from single poles (1), Regge amplitudes (2), and Regge cuts (3).



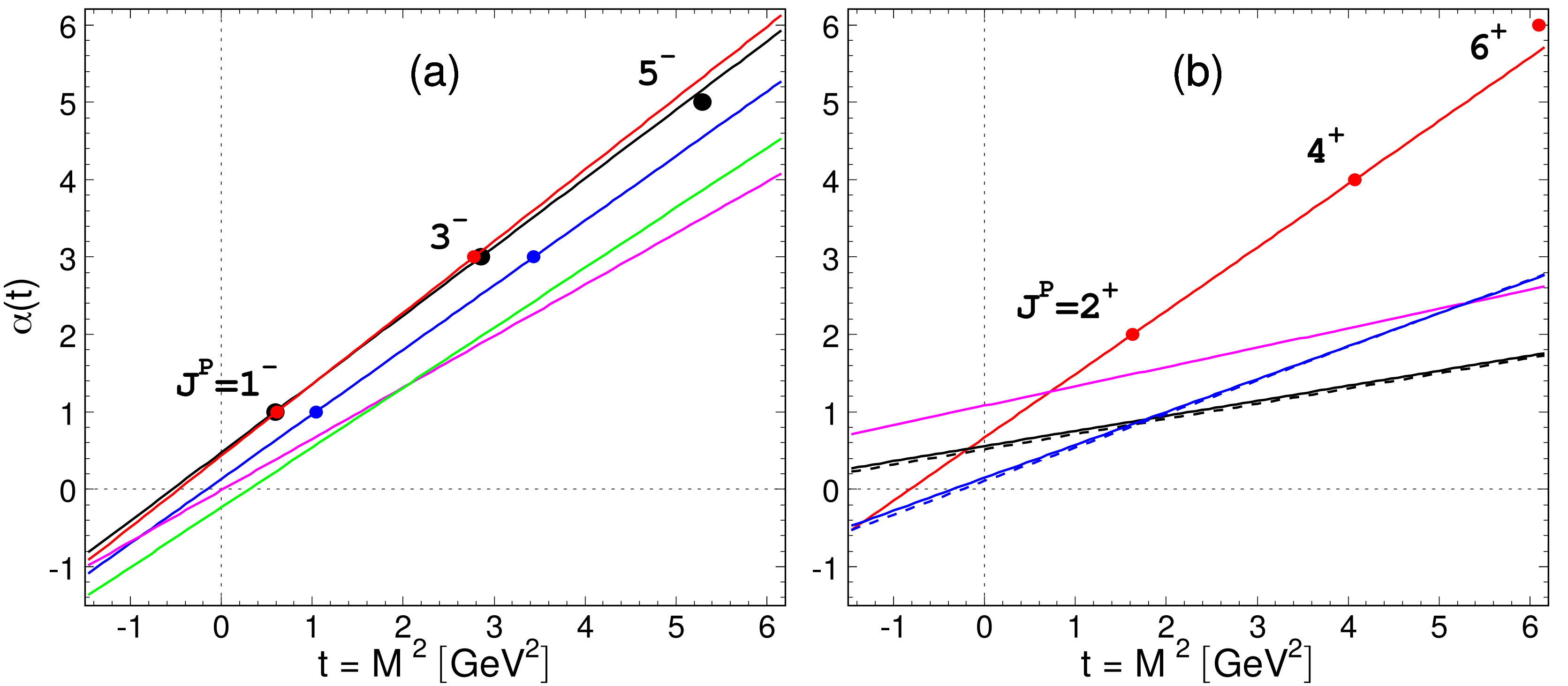
V. L. Kashevarov, M. Ostrick, L. Tiator , Phys. Rev. C**96** (2017) 045207

Regge phenomenology

Chew-Frautchi plots with Regge trajectories

(a) ρ (black), ω (red), φ (blue), b_1, h_1, (green), ρ_2, ω_2 (magenta)

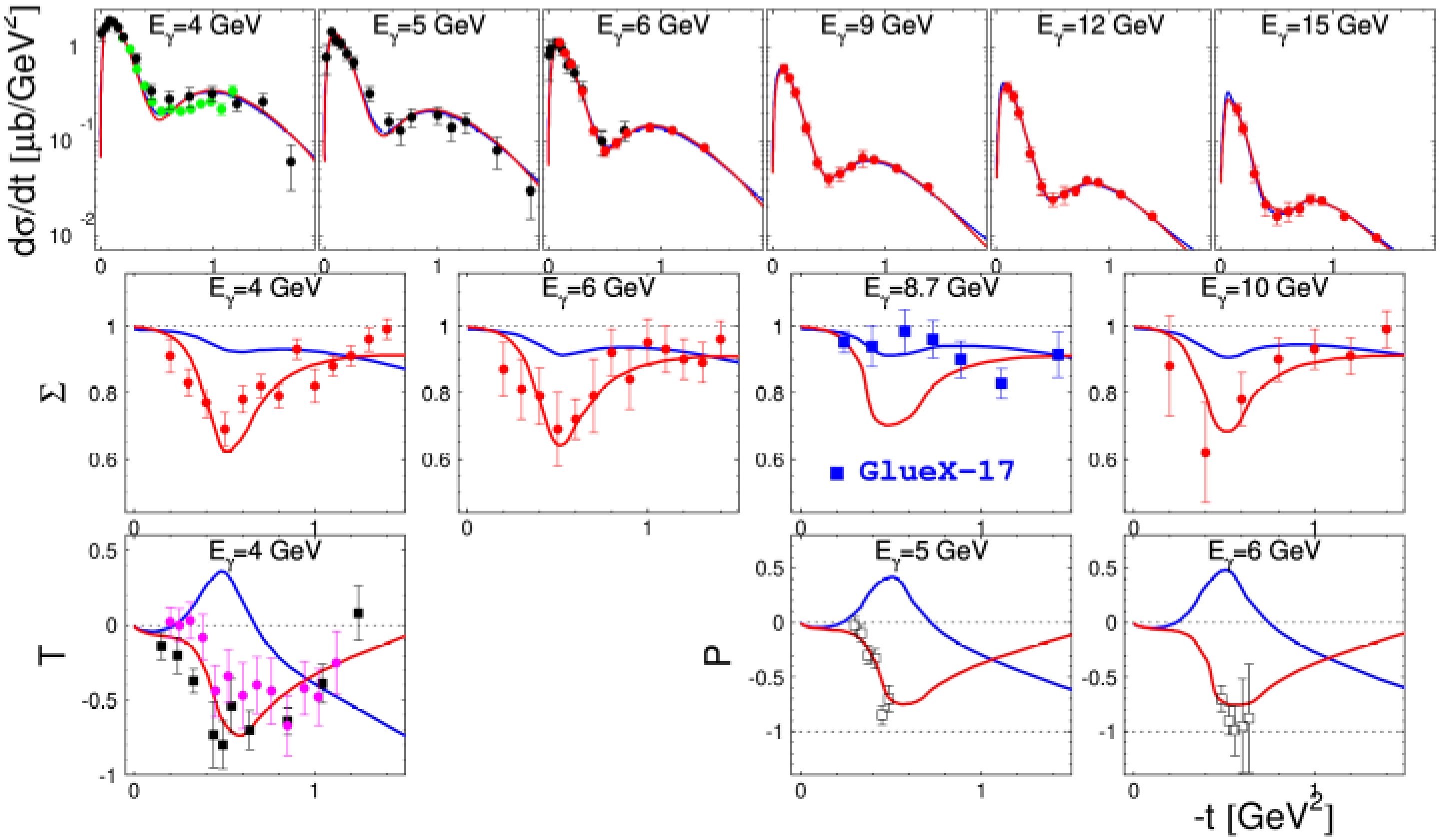
(b) P (magenta), f_2 (red), ρP, ωP(black solid and dashed) and ρf_2, ωf_2 (blue solid and dashed)



Prediction for ρ_2 and ω_2 from relativized quark model: S. Godfrey, N .Isgur, PRD 32 (1985) 189.

Results for high energies

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



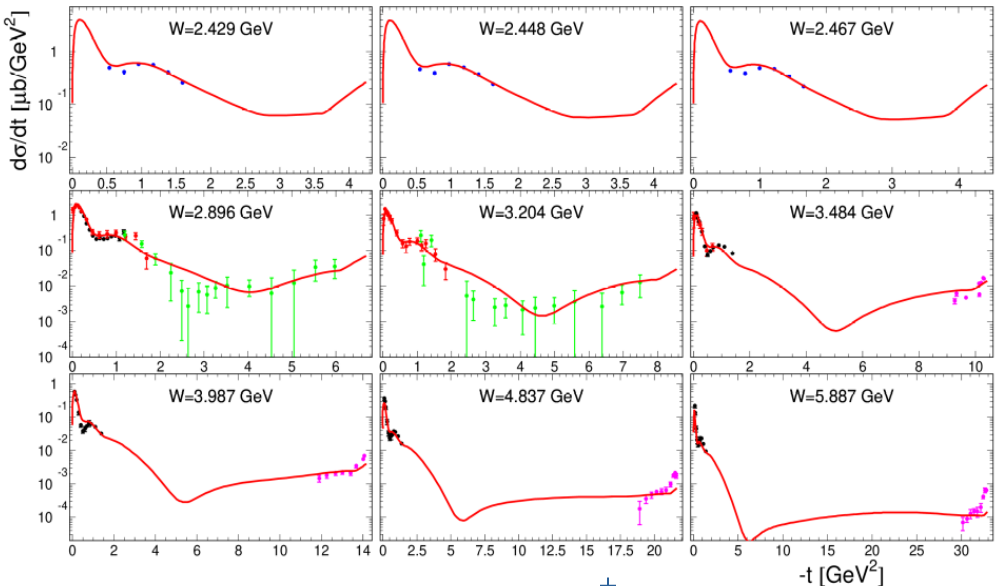
Red lines: our fit result to all data

Blue lines: fit to ds/dt and GlueX-17 data.

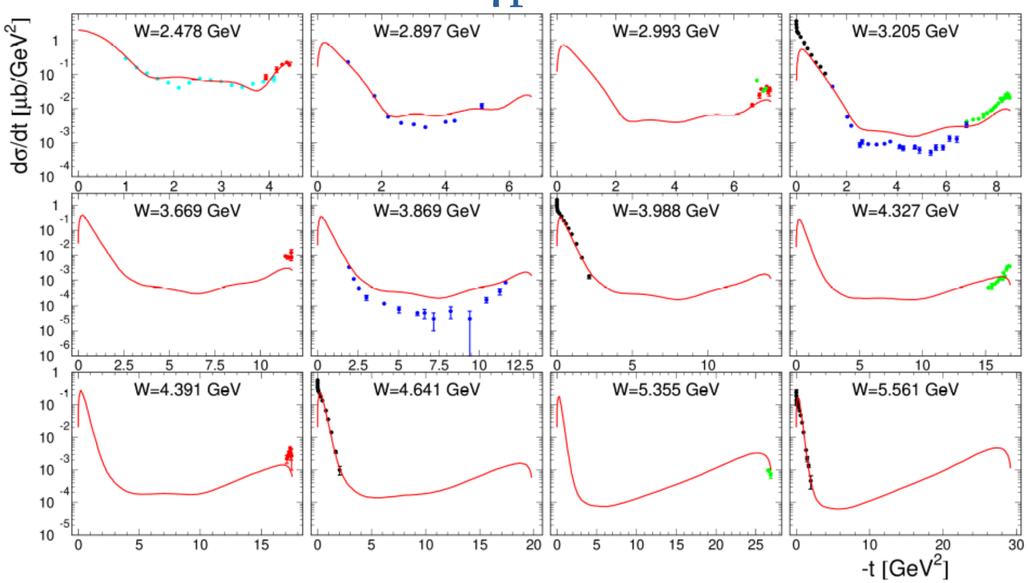
DATA: ds/dt and Σ: SLAC-71 (red), DESY-68 (black discs), DESY-73 (Nucl.Phys. B51) (green)
T: Daresbury-72 (magenta)}, DESY-73 (PL B46) (black full squares),
P: CEA-73 (black open squares).

Details of model: background

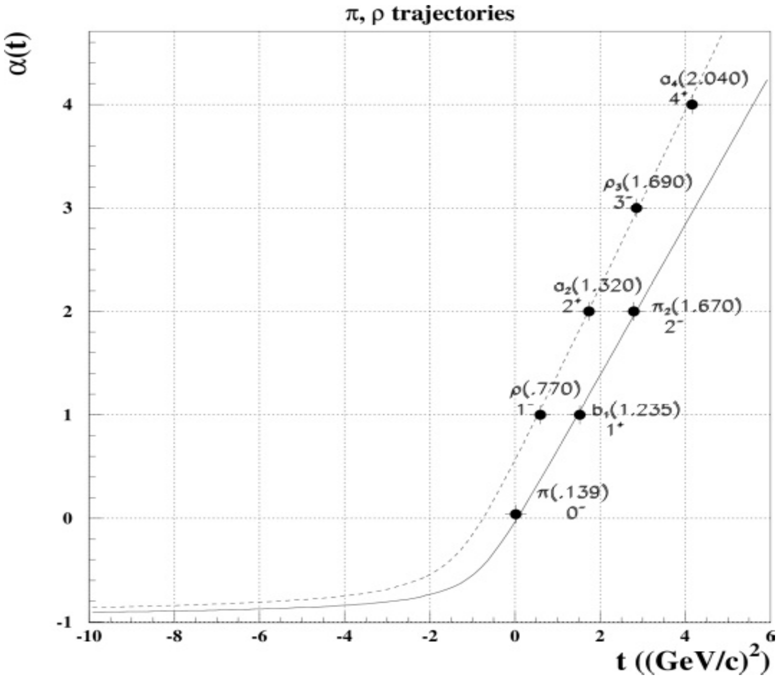
$\gamma p \to \pi^0 p$



$\gamma p \to \pi^+ n$



Saturation of Regge trajectories.
Example for ρ and π reggeons.

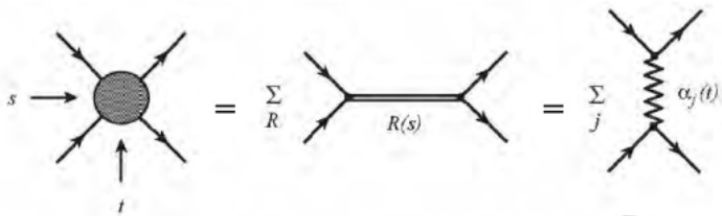


Details of model: duality

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

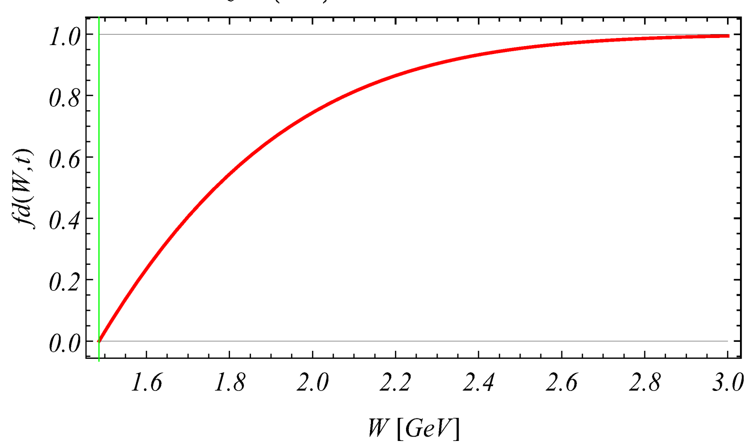


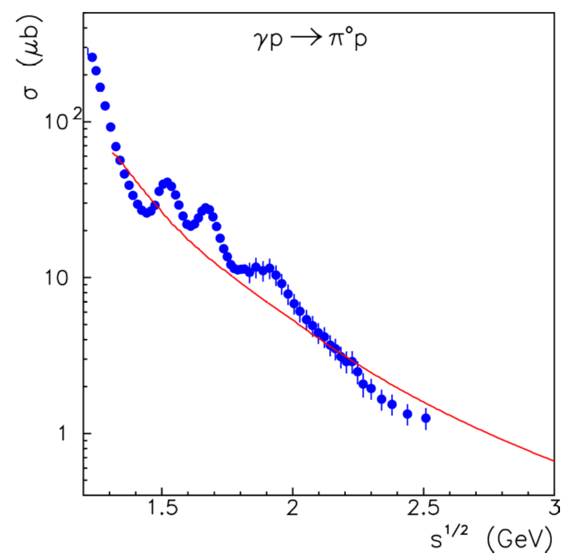
$$M = \sum_{i=1}^{\infty} M_s^{Res_i} = \sum_{i=1}^{\infty} M_t^{Res_i} = \sum_{i=1}^{N} M_s^{Res_i} + \left[\sum_{i=1}^{\infty} M_t^{Res_i} - \sum_{i=1}^{N} M_s^{Res_i}\right]$$

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

: our approach

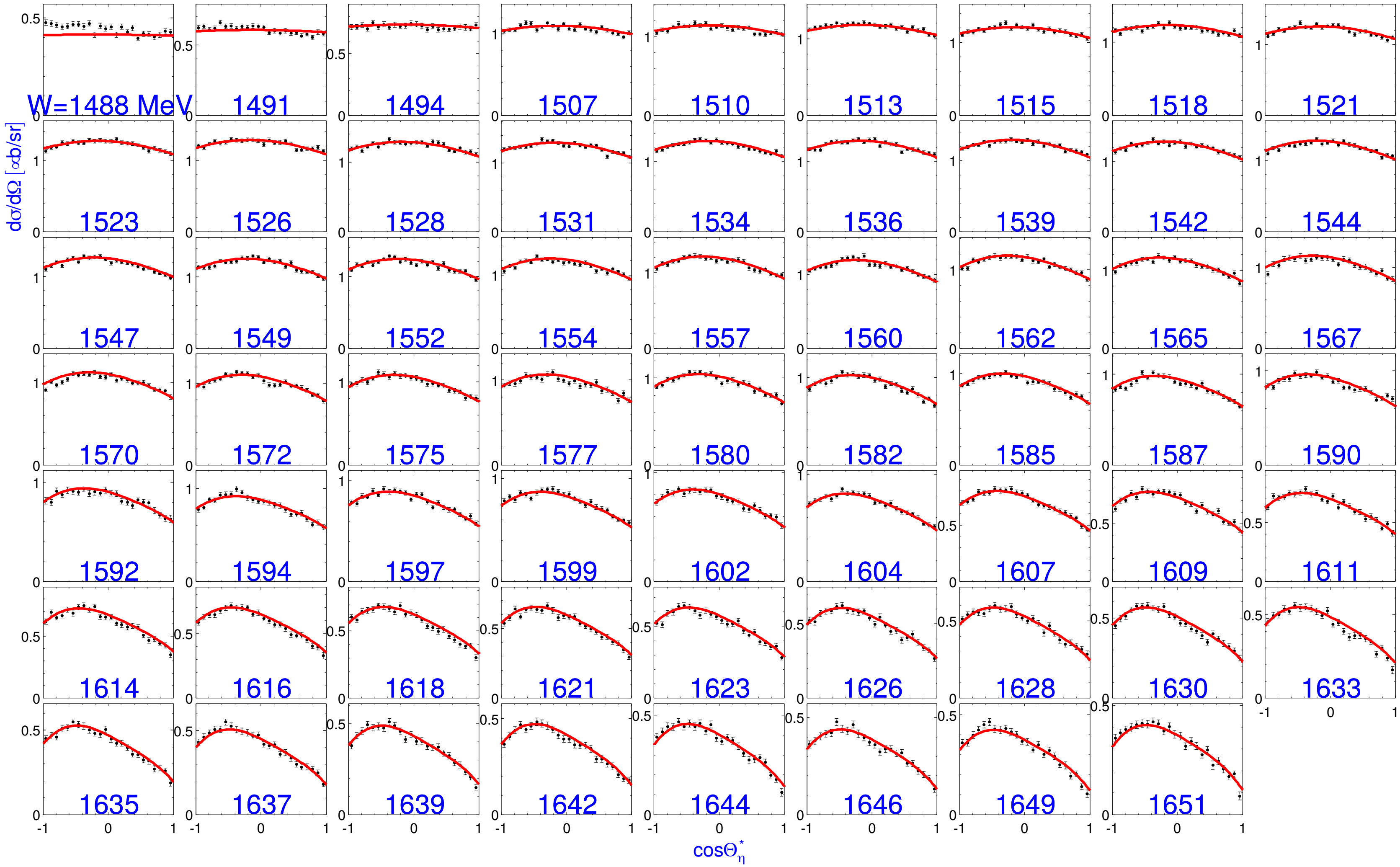
$$f_d(W) = 1 - e^{-\frac{W-W_{thr}}{\Lambda}}$$





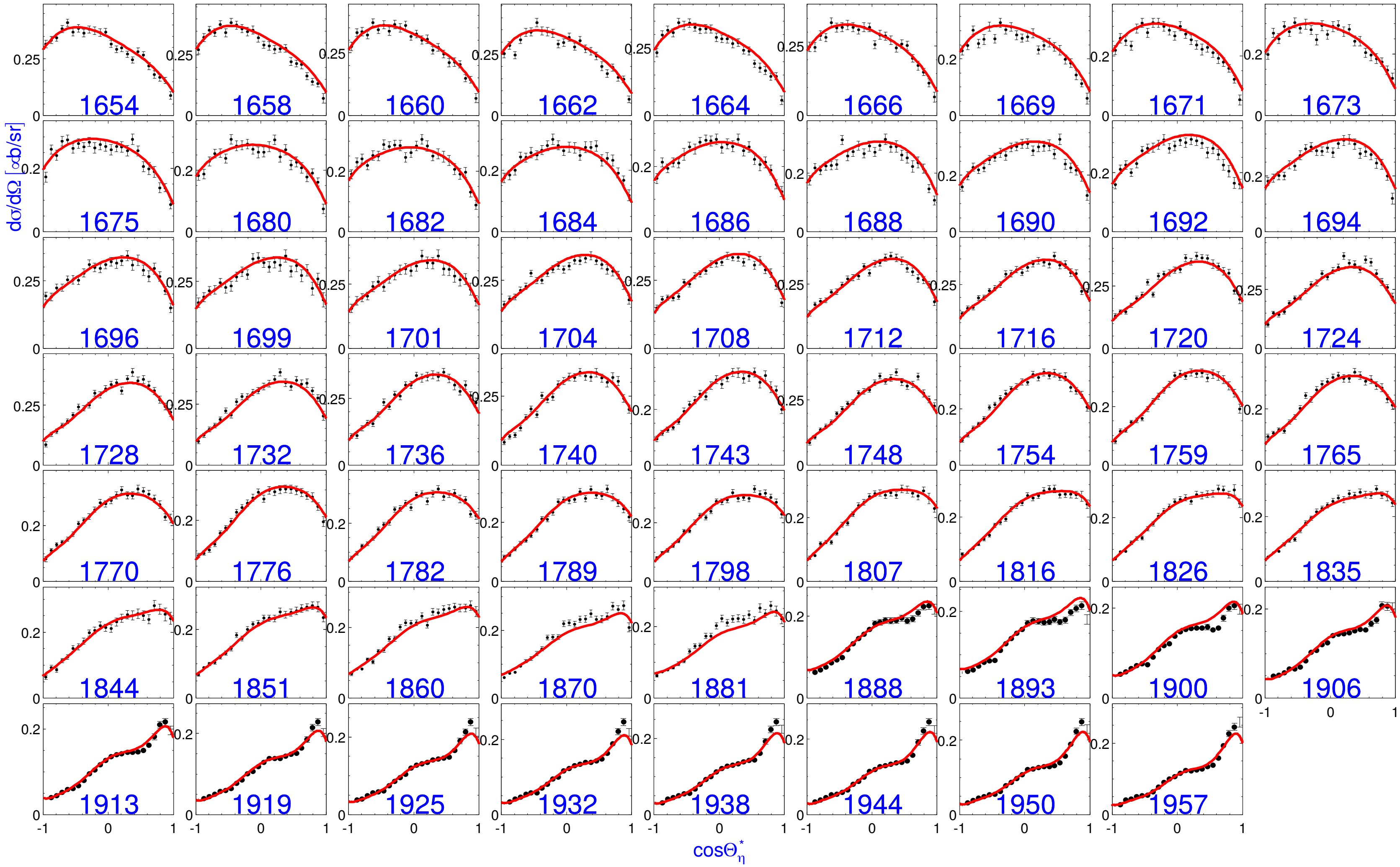
A.~Sibirtsev, J.~Haidenbauer, S.~Krewald, U.~G.~Meissner, and A.~W.~Thomas, EPJA {\bf 41}, 71 (2009) dσ/dΩ for γp → ηp. W = 1488 - 1651 MeV, 24 angular bins

Data: A2MAMI-17, Red line - full solution.

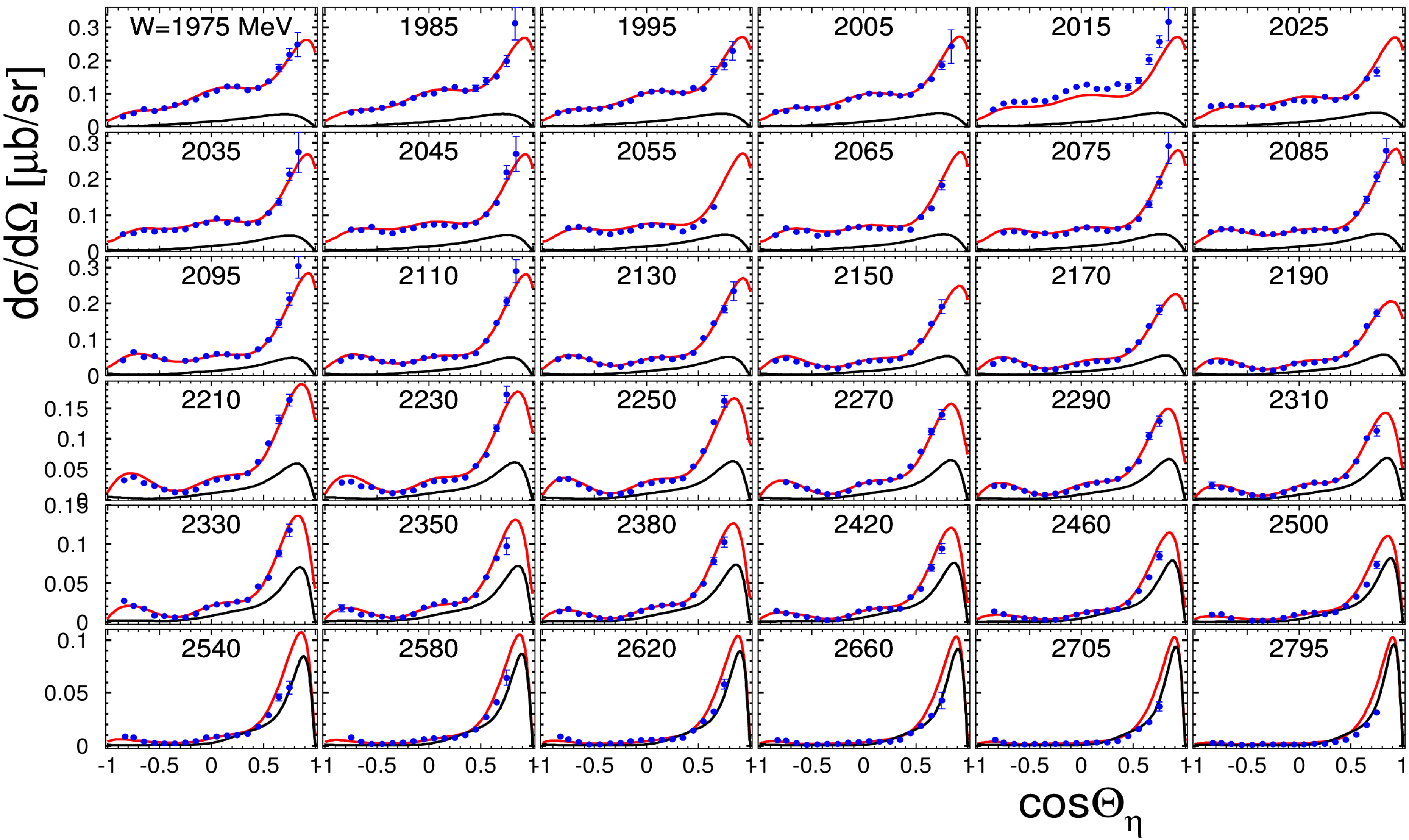


dσ/dΩ for γp → ηp. W = 1654 - 1957 MeV, 24 angular bins

Data: A2MAMI-17, Red line - full solution.



$\gamma\ p \rightarrow\ \eta\ p$ Selected results: $d\sigma/d\Omega$



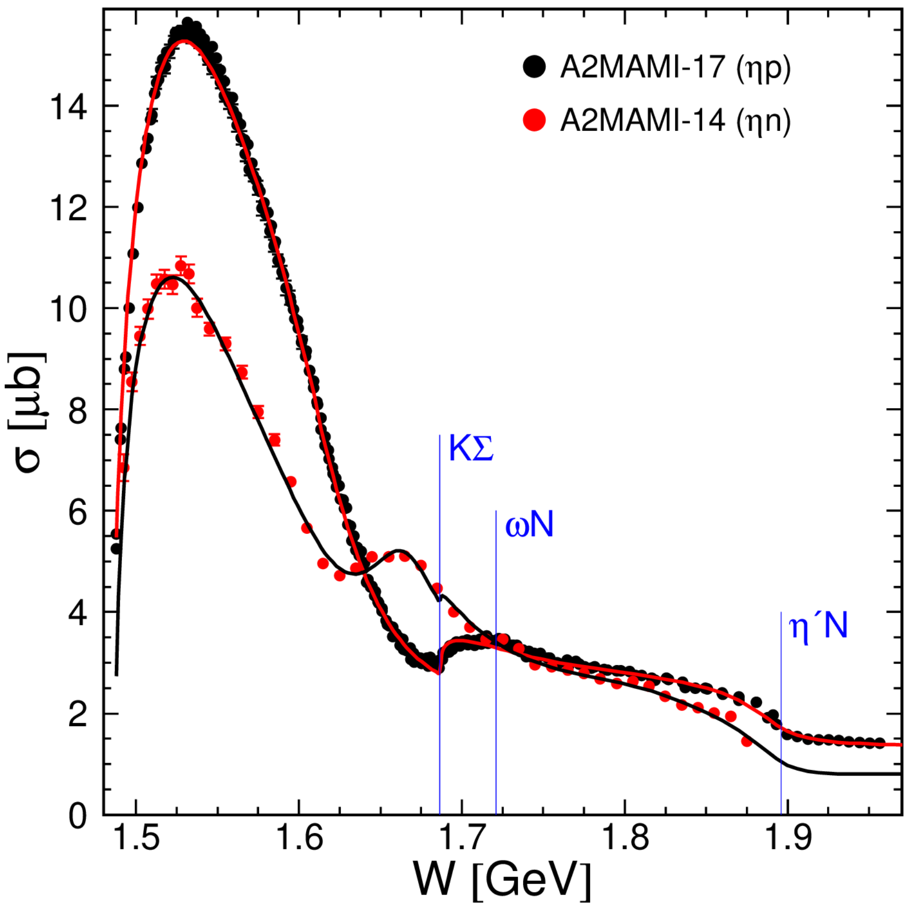
$\chi^2 = 2265/634 \approx 3.57$

Data: CLAS-09

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

Selected results: total cross sections

$\gamma\ N \rightarrow\ \eta\ N$



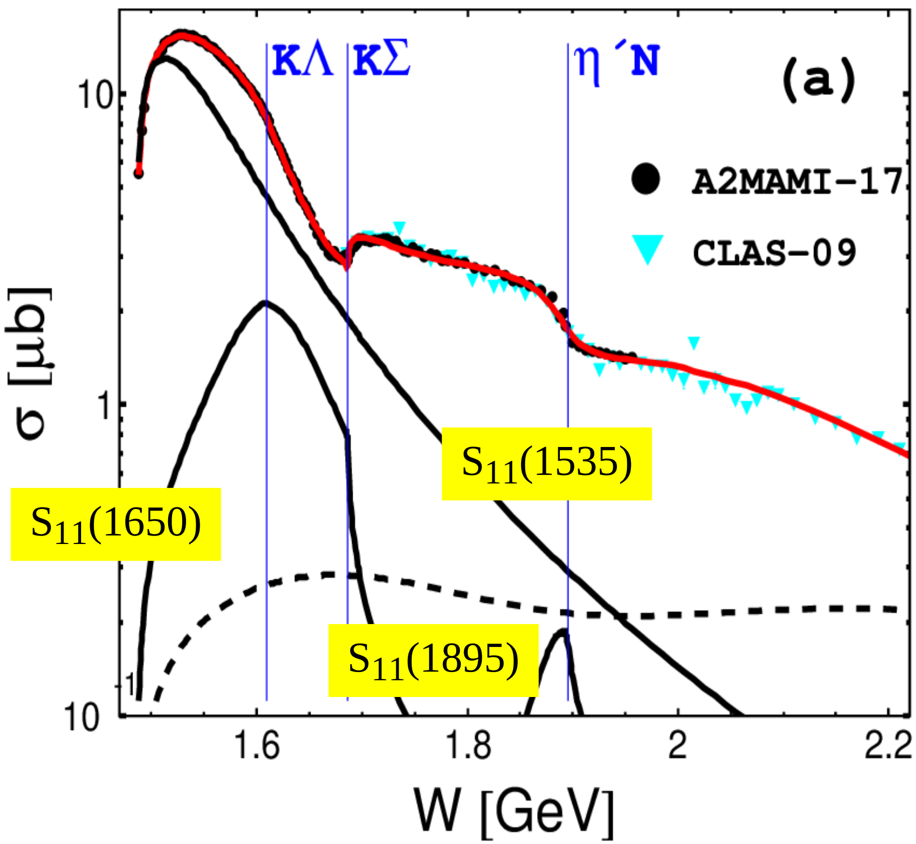
Lines: full solution for γp (red) and γn (black) channels.

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

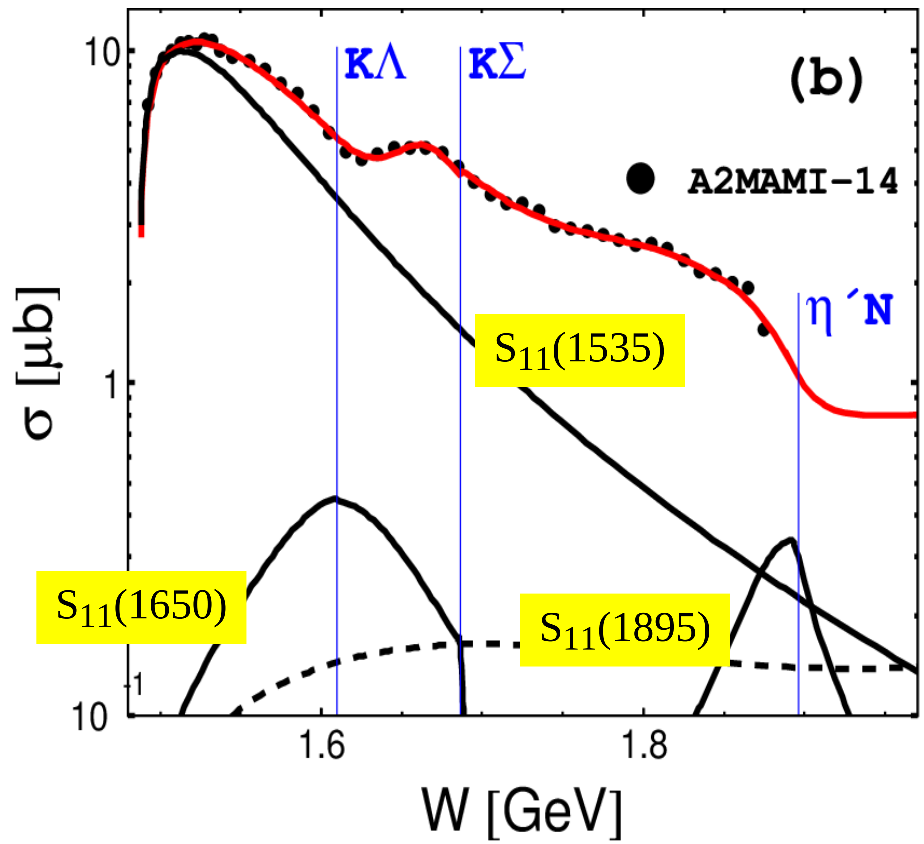
$\gamma\ p \rightarrow \eta'\ p$: $\chi^2 = 9.46/12 \approx 0.79$ (A2MAMI)
$\gamma\ n \rightarrow \eta'\ n$: $\chi^2 = 10.9/17 \approx 0.64$

Selected results: partial contribution of resonances

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

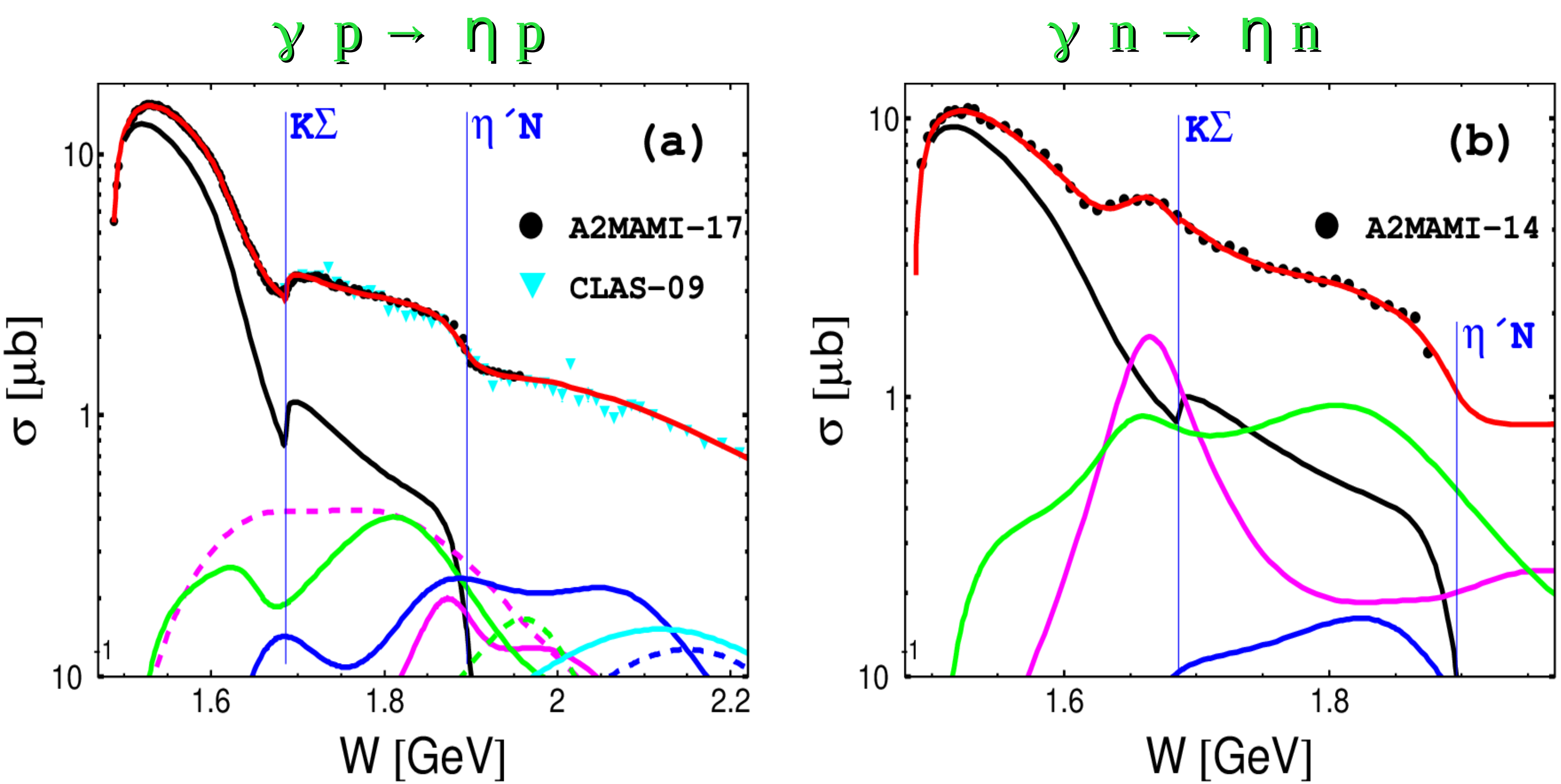


$\gamma\ n \rightarrow\ \eta\ n$



Black dashed line – Regge + Bonrn contribution

Selected results: partial waves contribution (no bgr)



S_{11} – black solid;

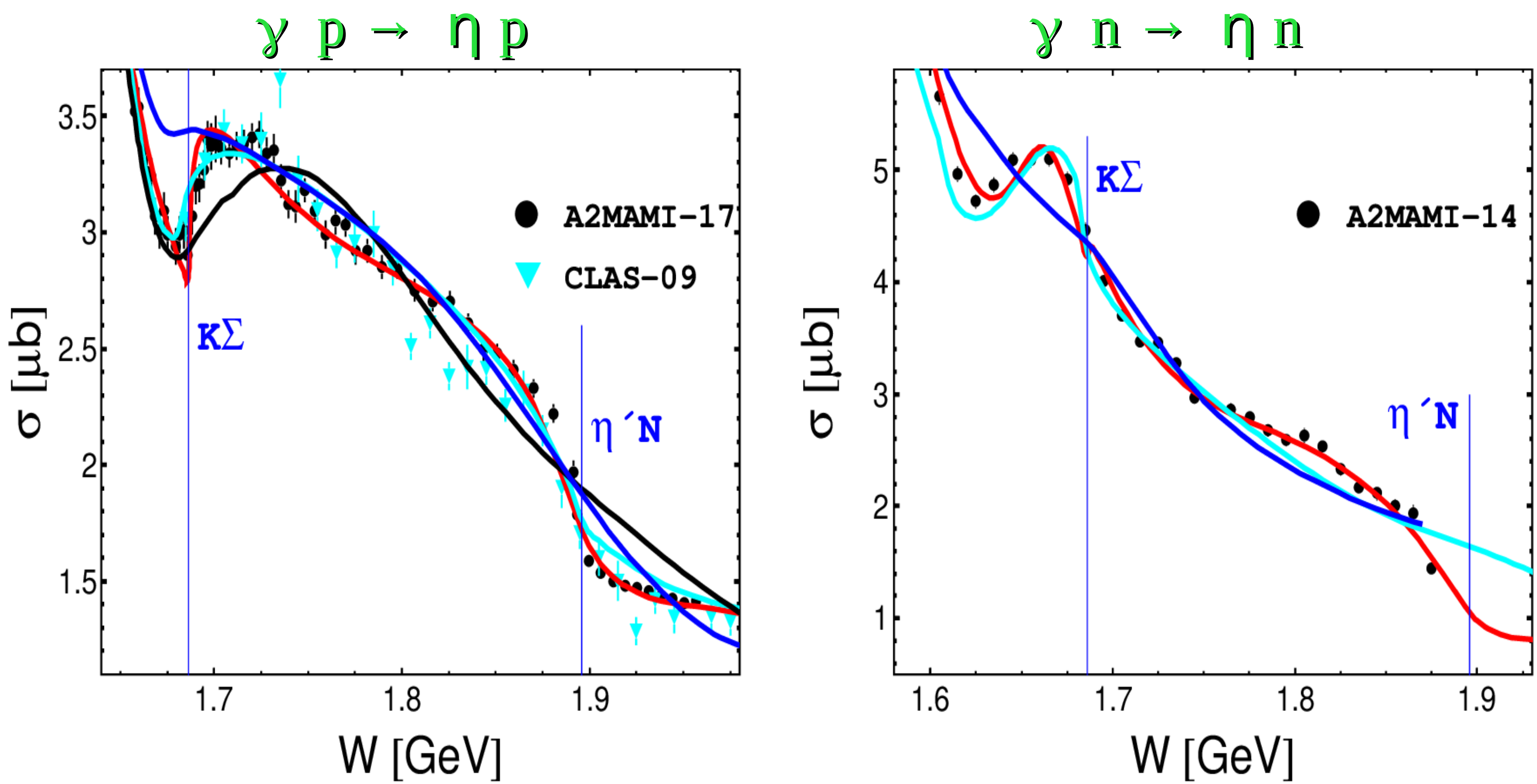
P_{11} – magenta solid; P_{13} – magenta dashed

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

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

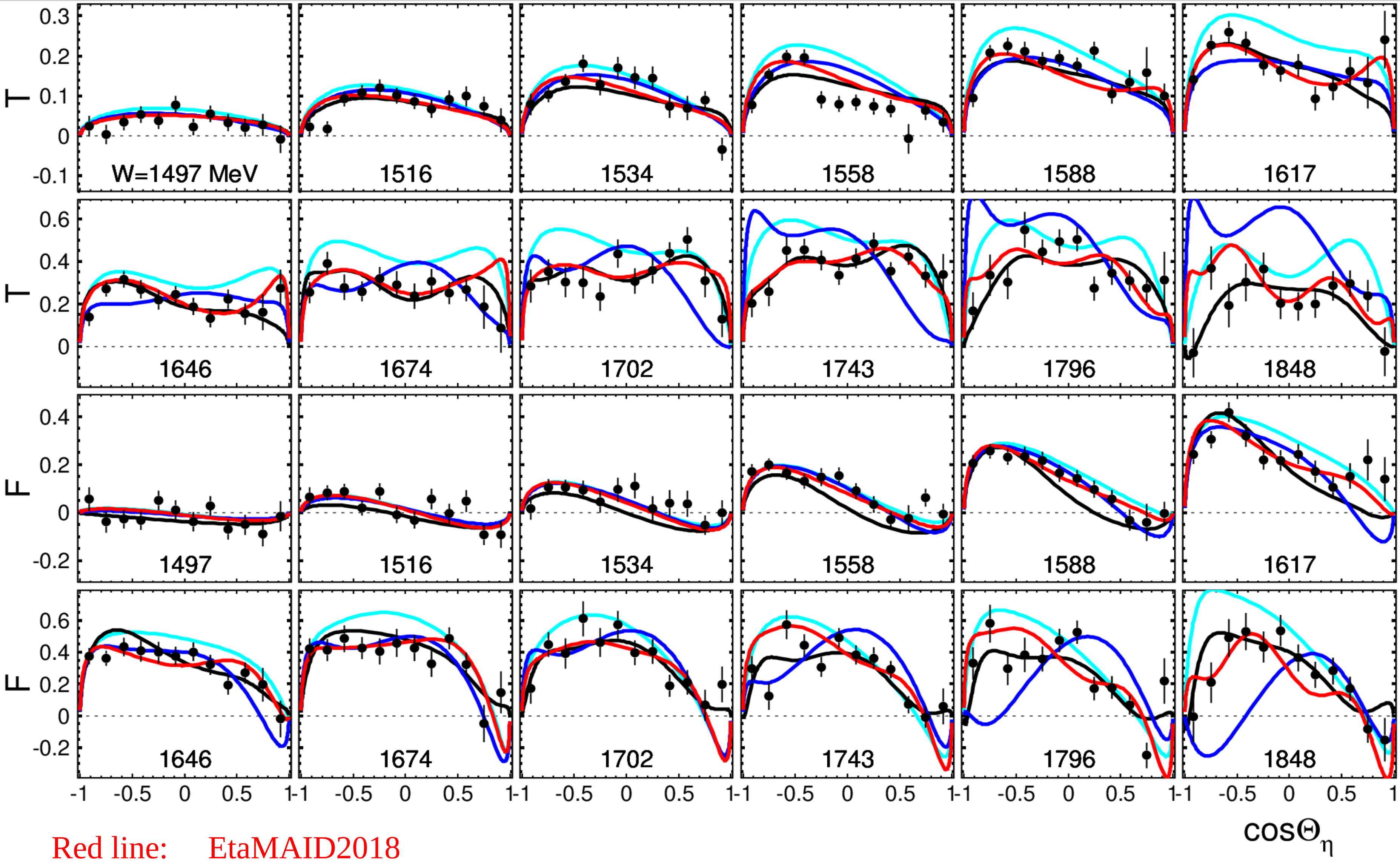
G_{17} – cyan solid

Comparison with other new PWA



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

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

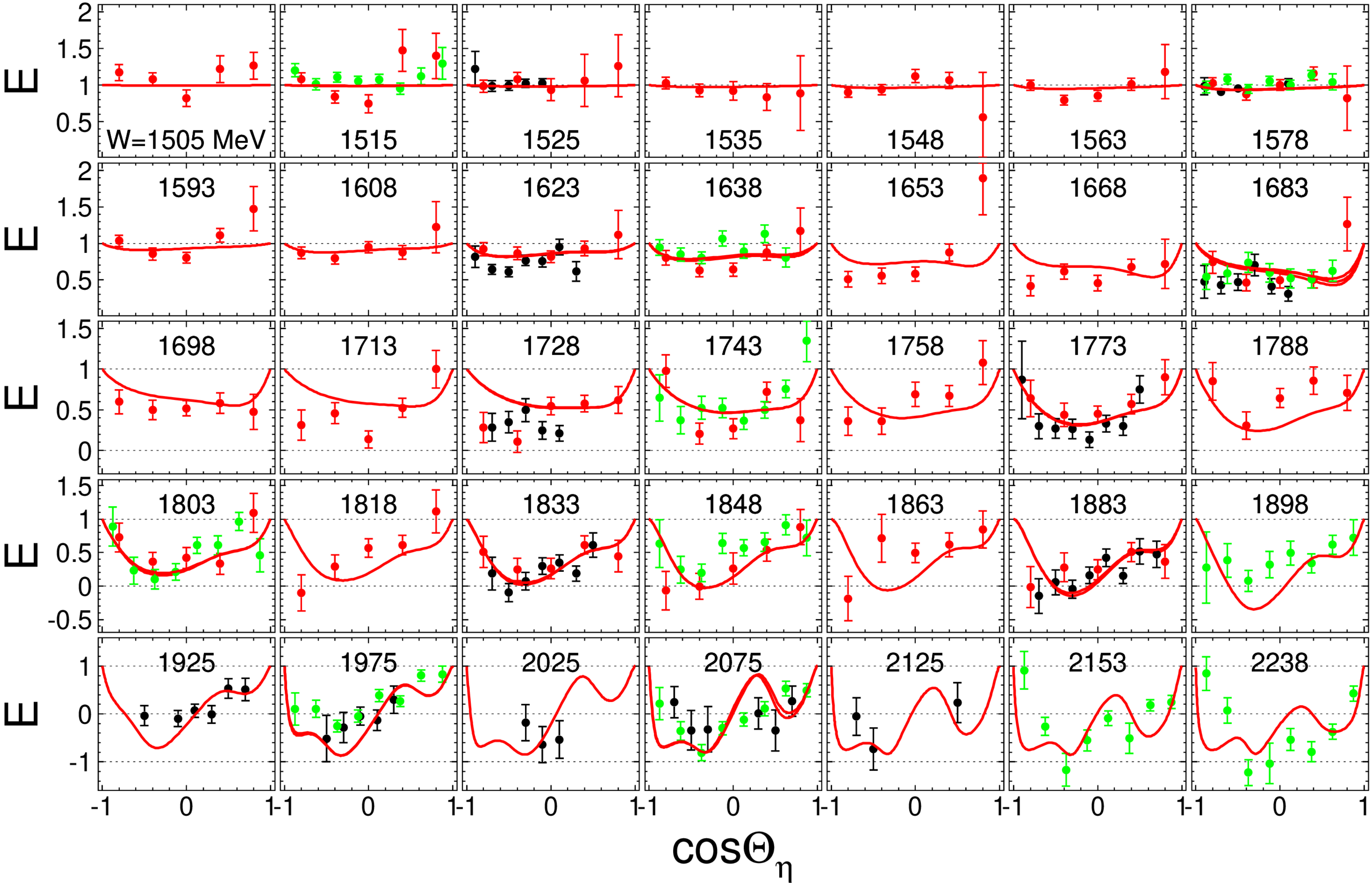


Red line: EtaMAID2018
Cyan line: BnGa
Blue line: KSU
Black line: JüBo

Data: A2MAMI-14

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

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



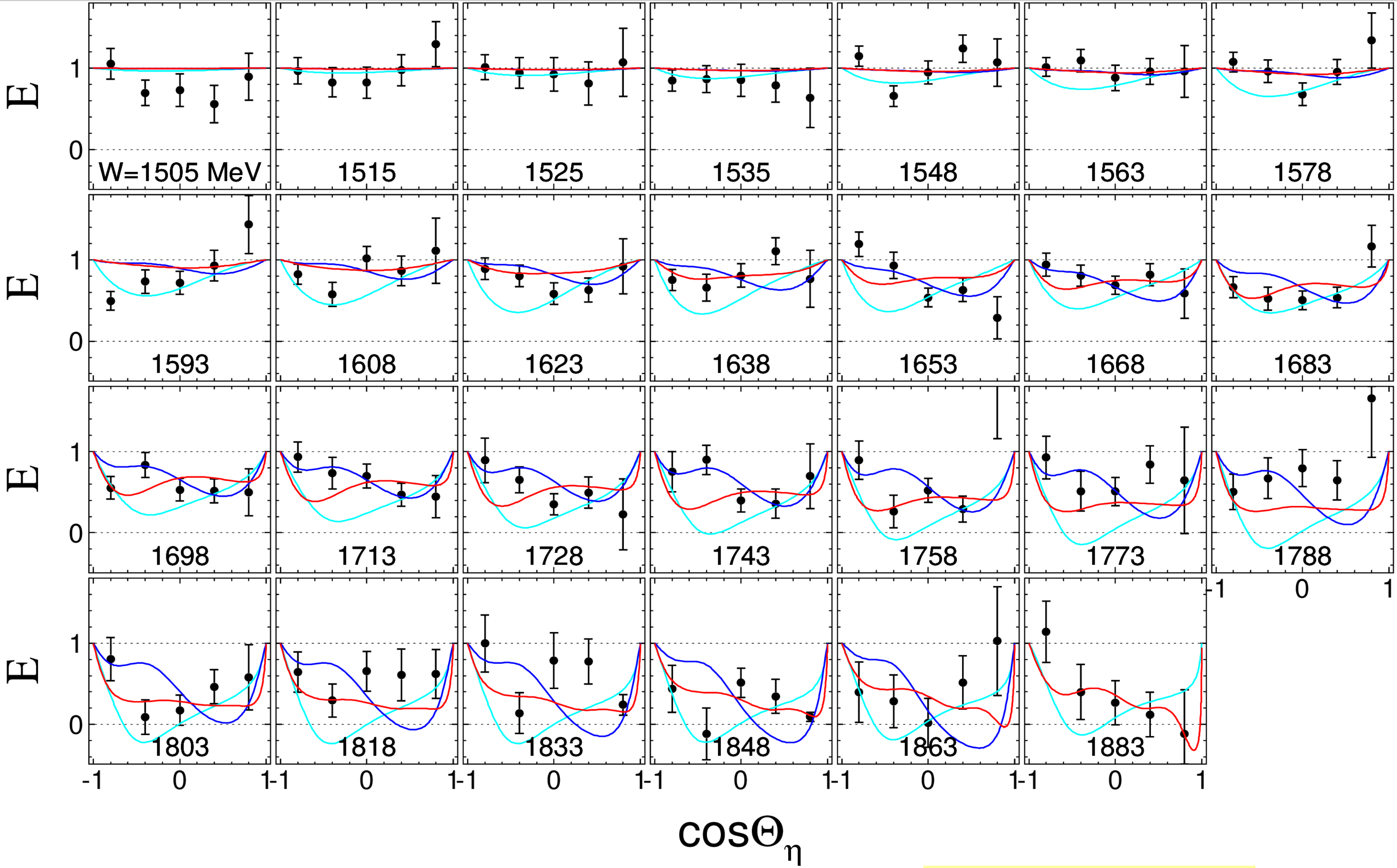
Data: black – CLAS-16; red – A2MAMI-17; green – CBELSA/TAPS

X^2 = 170.6/73 ≈ 2.34

X^2 = 272.3/135 ≈ 2.02

X^2 = 395.5/93 ≈ 4.25

γ n → η n   Helicity beam asymmetry E



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

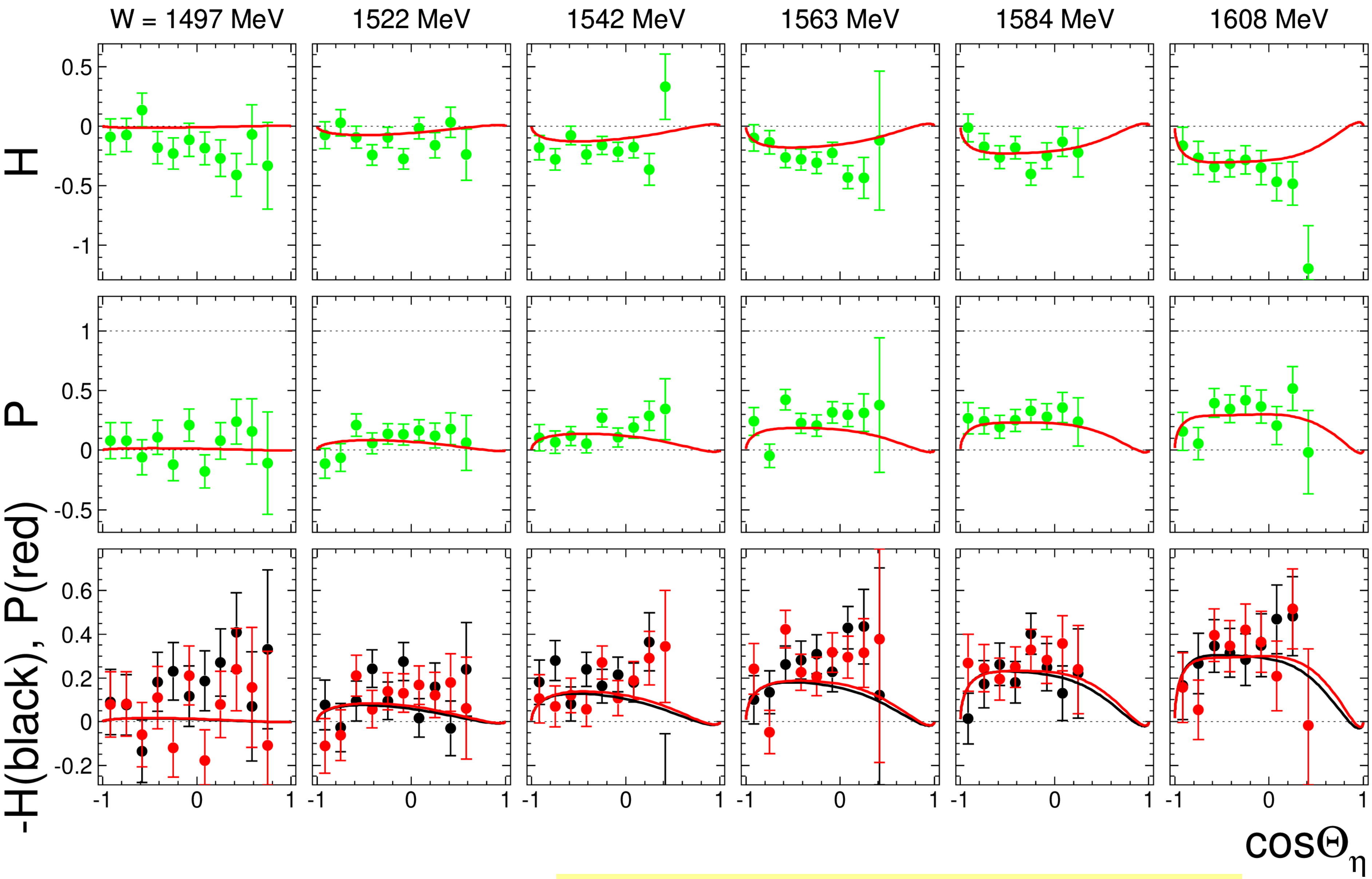
$\chi^2 = 349.8/135 \approx 2.59$

Data: A2MAMI-17

γ p → η p

Polarization observables: H and P

P ≈ - H ?



Data: CBELSA/TAPS
Lines: full solution

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

predictions for unmeasured polarization observables

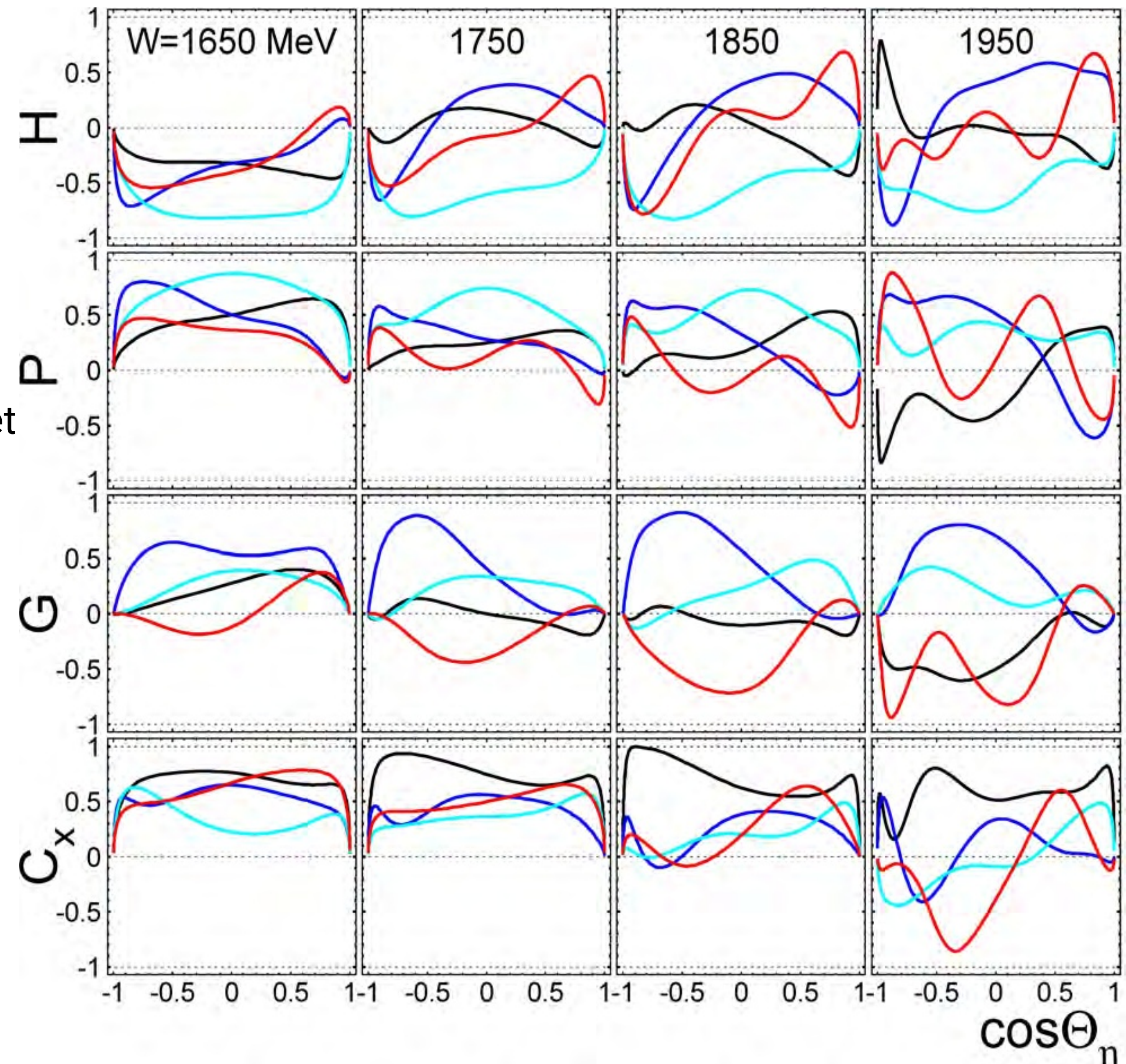
EtaMAID — BnGa — JüBo — KSU

beam-target H

recoil pol. P
equivalent to beam-target

beam-target G

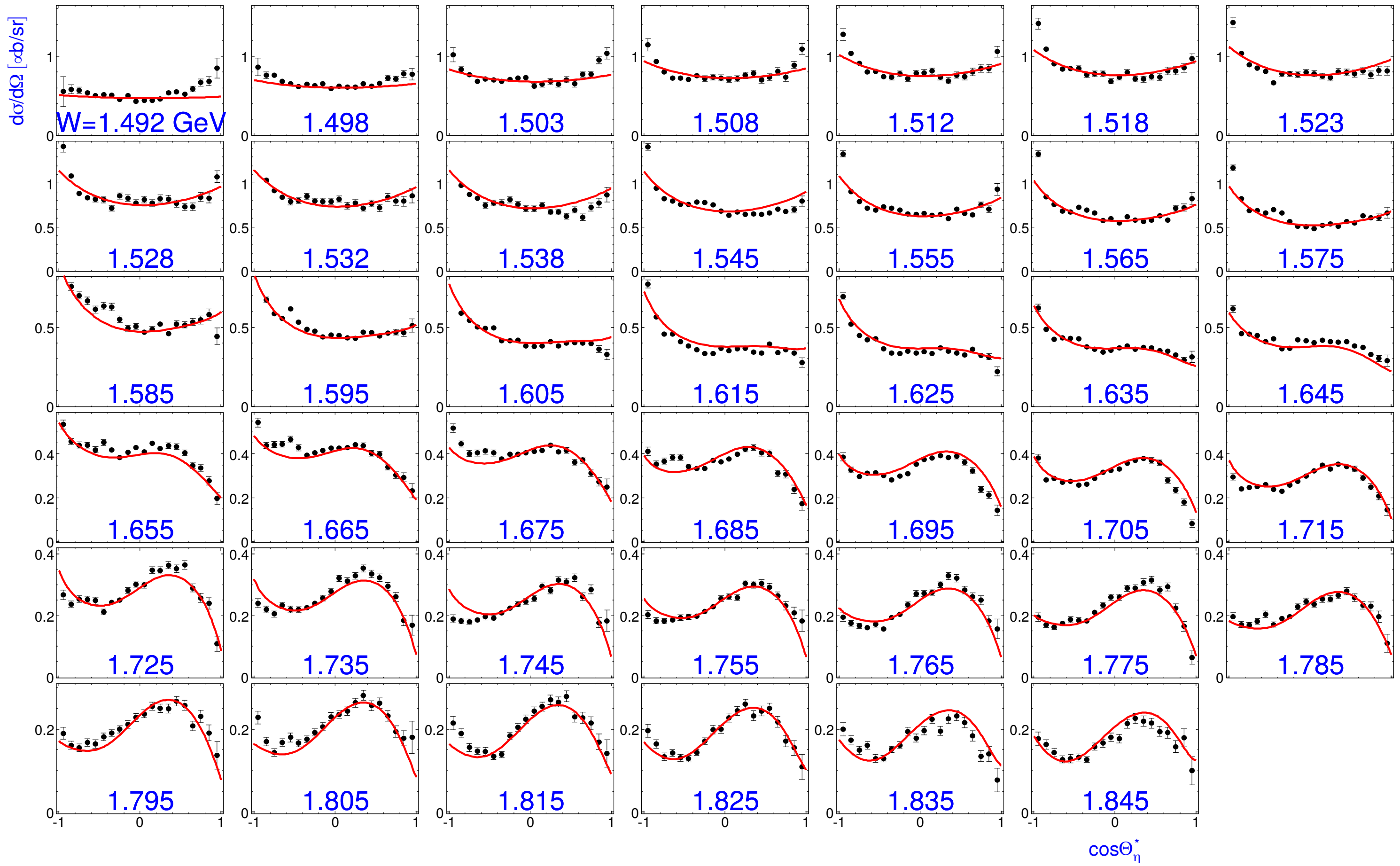
beam-recoil $C_{x'}$
very hard



$d\sigma/d\Omega$ for $\gamma n \rightarrow \eta n$

Data: A2MAMI-14 (black)

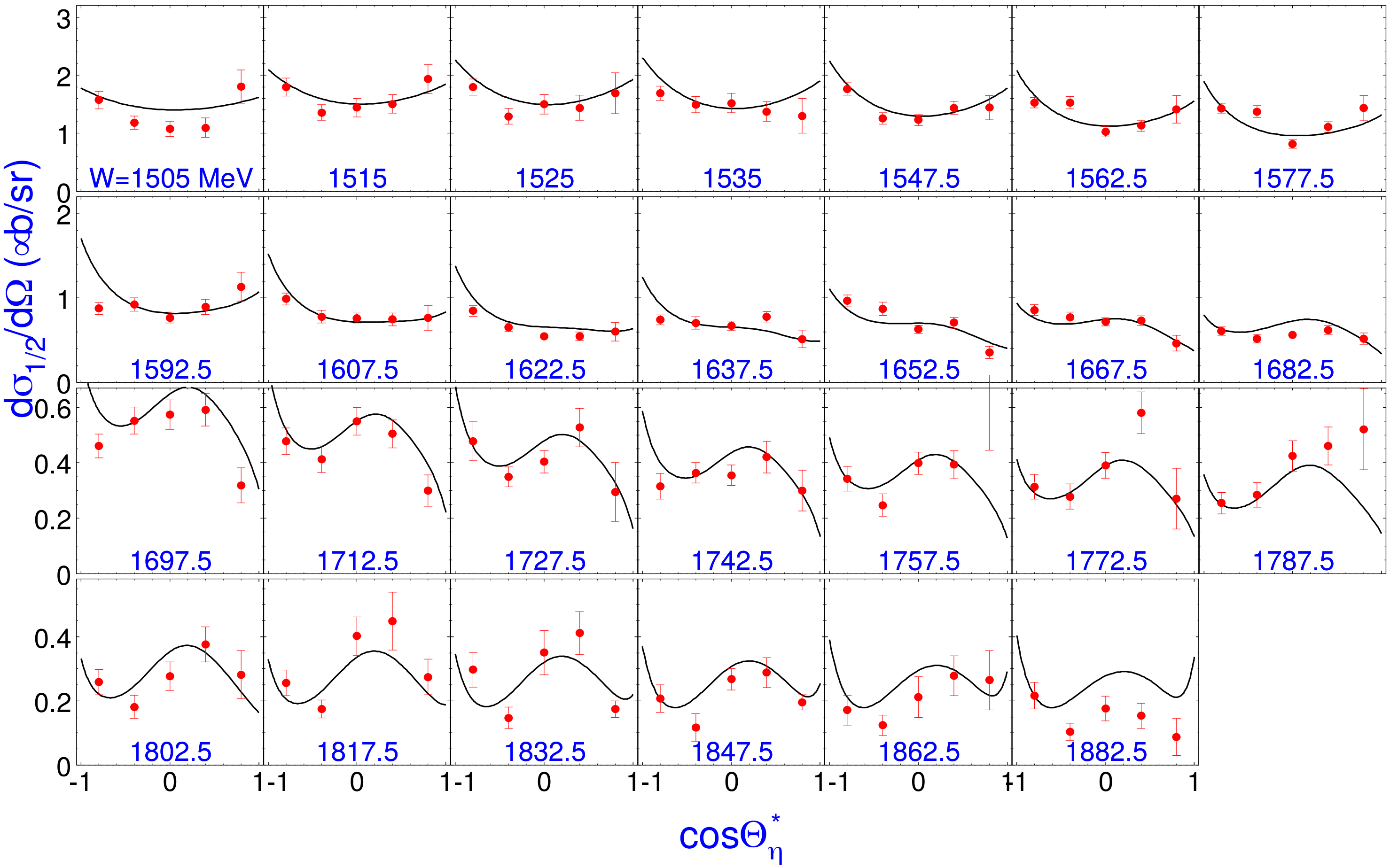
Red line - full solution.



$d\sigma/d\Omega_{1/2}$ for $\gamma n \to \eta n$

Data: A2MAMI-17 (black)

Red line - full solution.

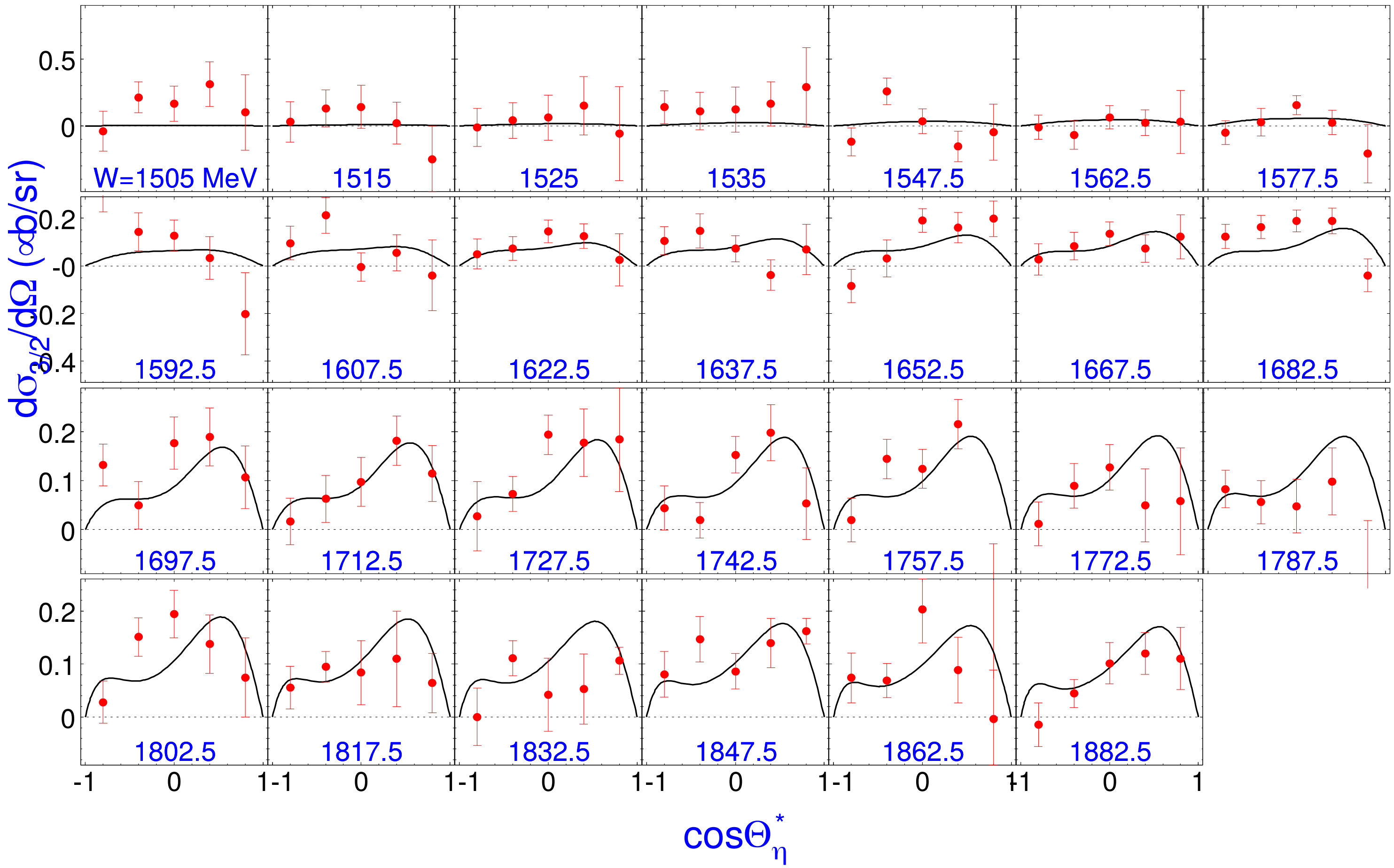


Selected results

$d\sigma/d\Omega_{3/2}$ for $\gamma n \rightarrow \eta n$

Data: A2MAMI-17 (black)

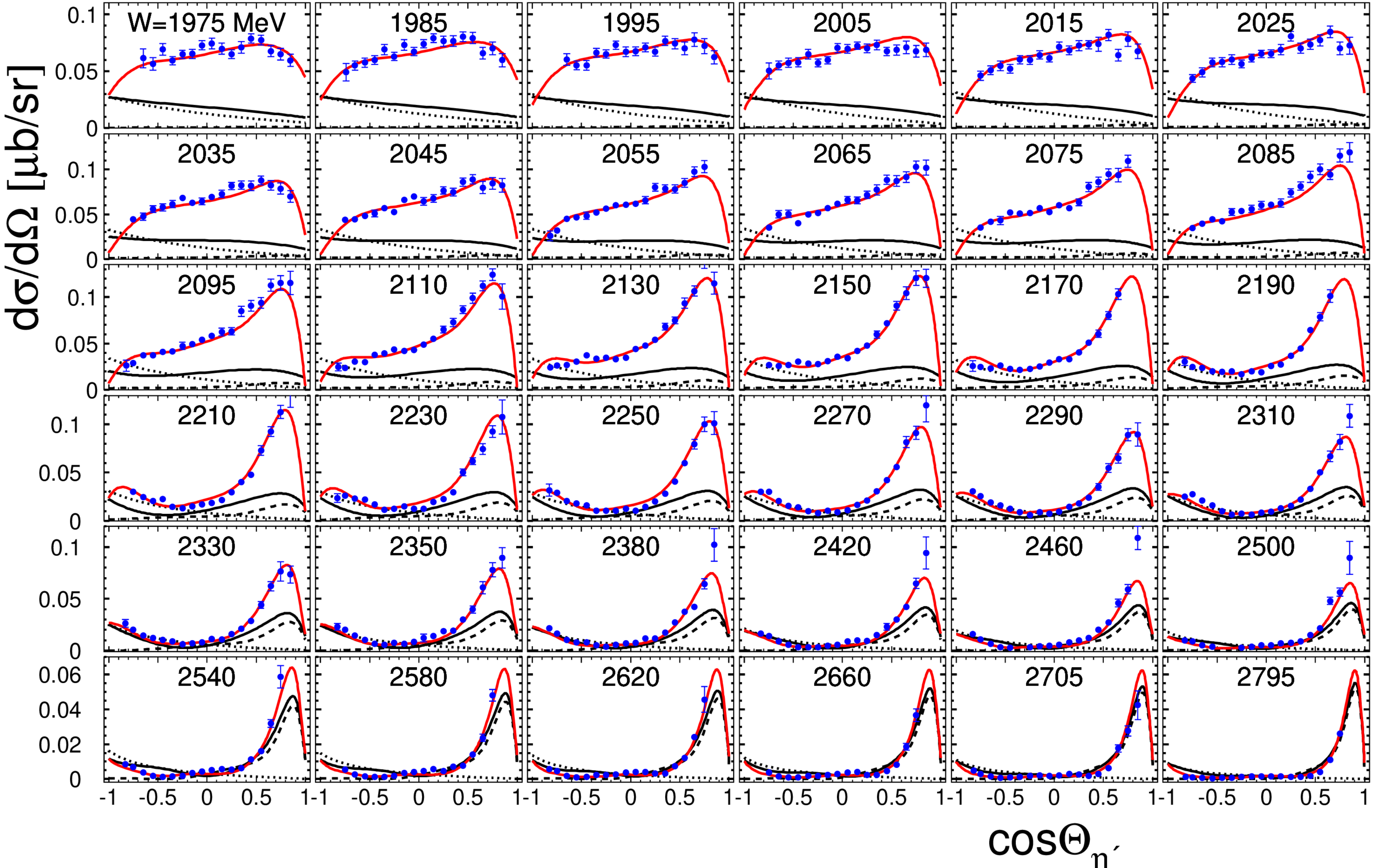
Red line - full solution.



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

Differential cross sections

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



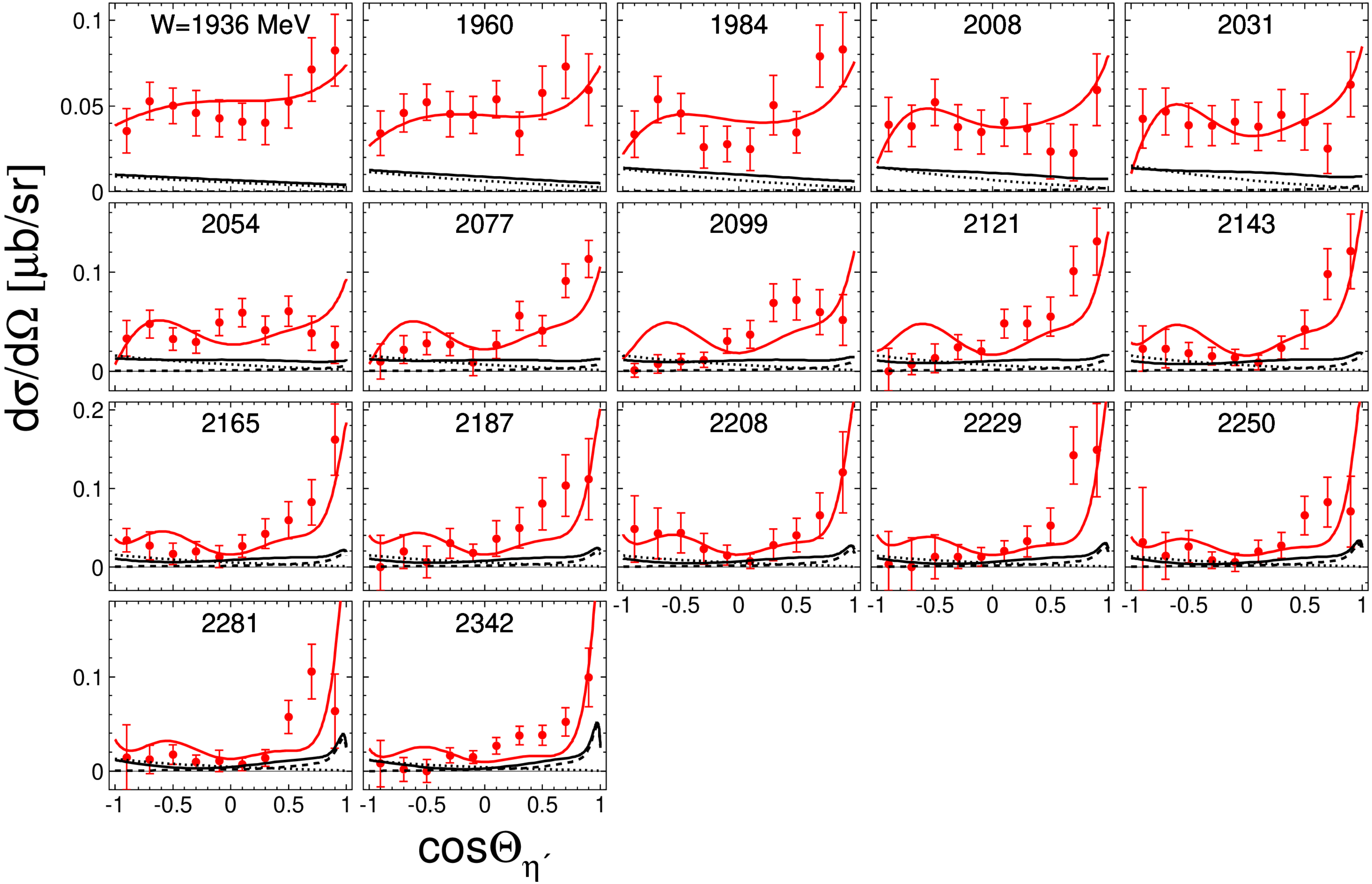
Data: CLAS-09

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

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

Differential cross sections

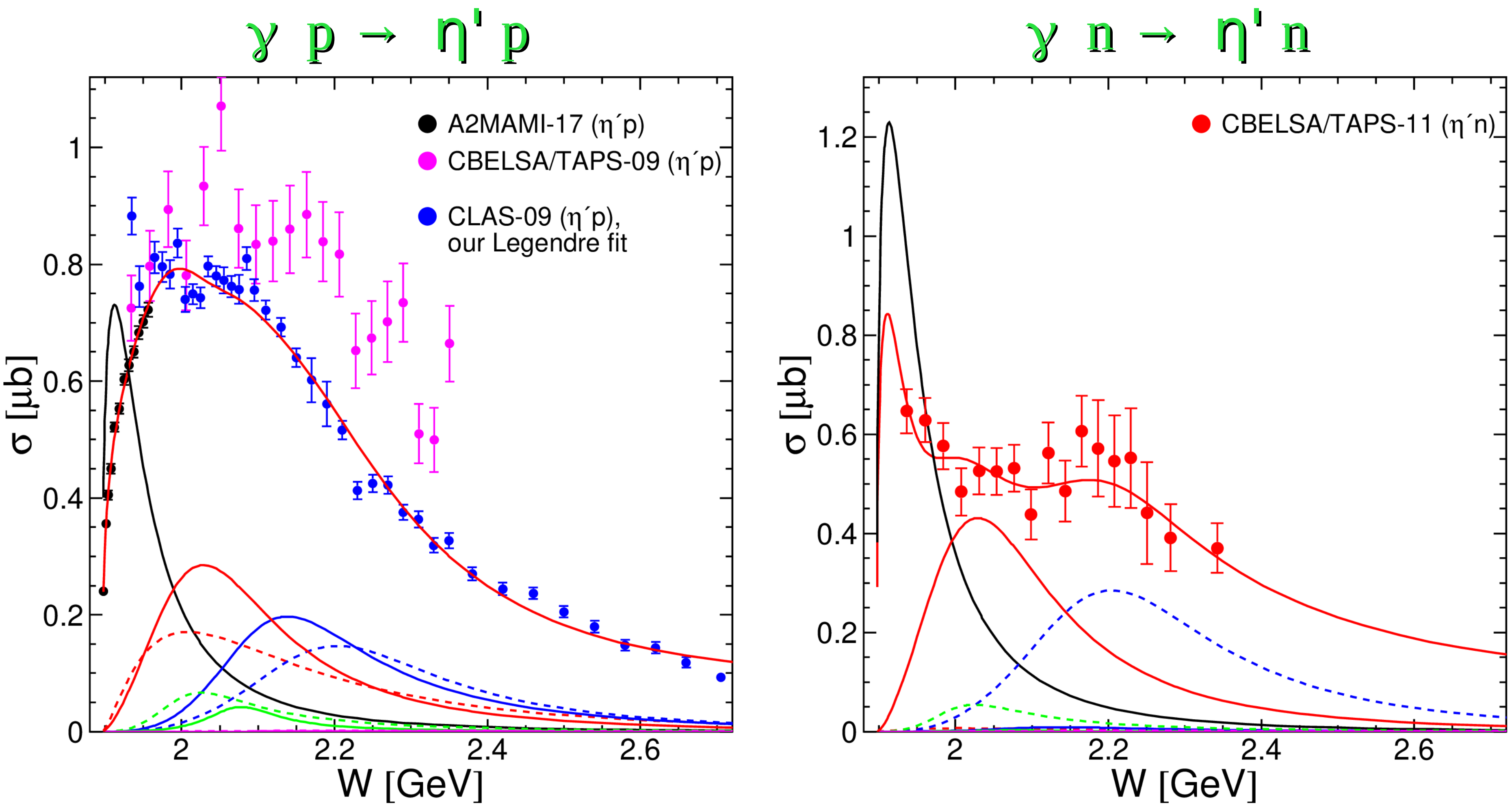
$\chi^2 = 279.9/170 \approx 1.64$



Data: CBELSA/TAPS-11

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

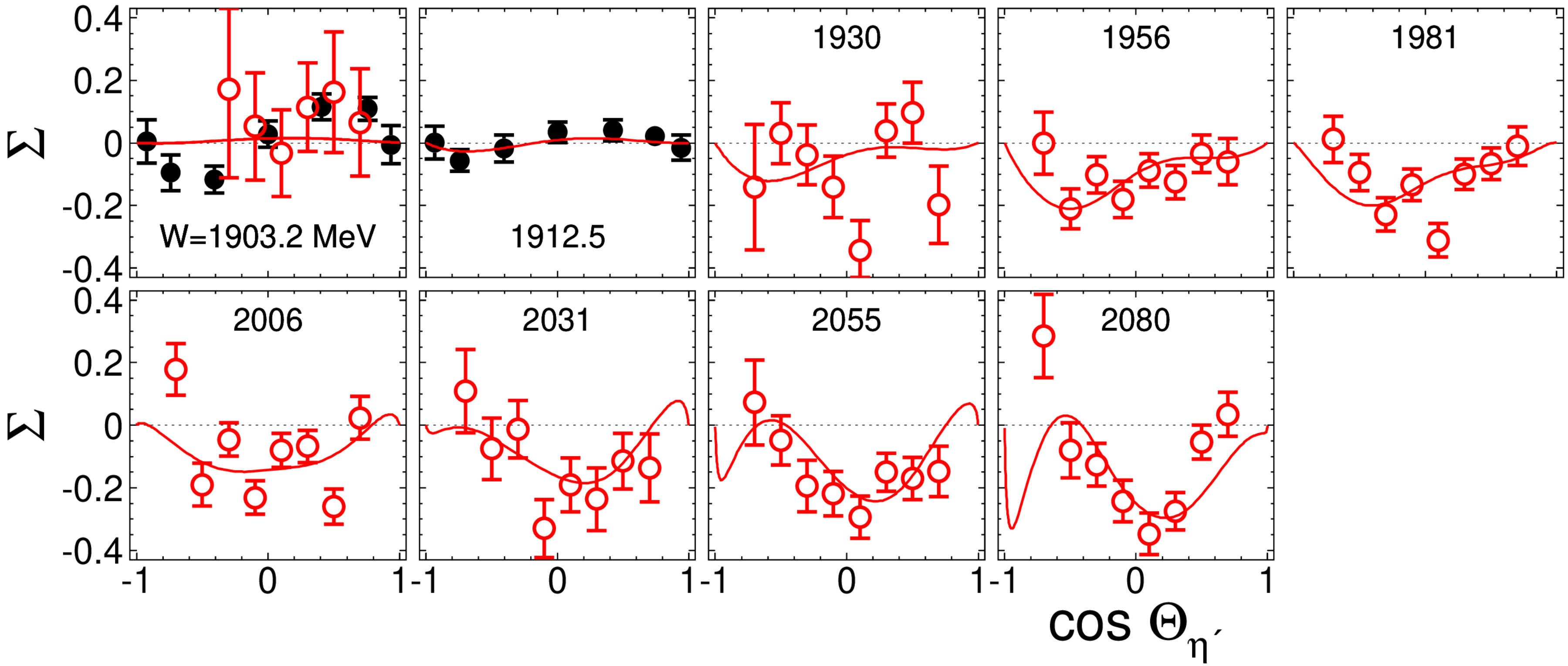
Fit results: partial contribution of resonances



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

γ p → η' p

Beam asymmetry Σ



Data: black – GRAAL-15; red – CLAS-17

$X^2 = 27.89/14 \approx 1.99$

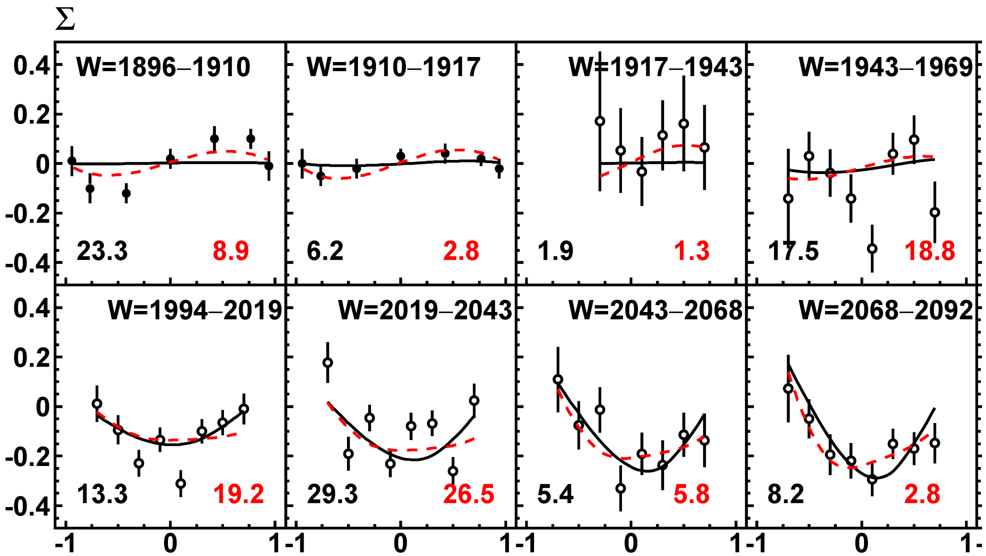
$X^2 = 118.1/62 \approx 1.90$

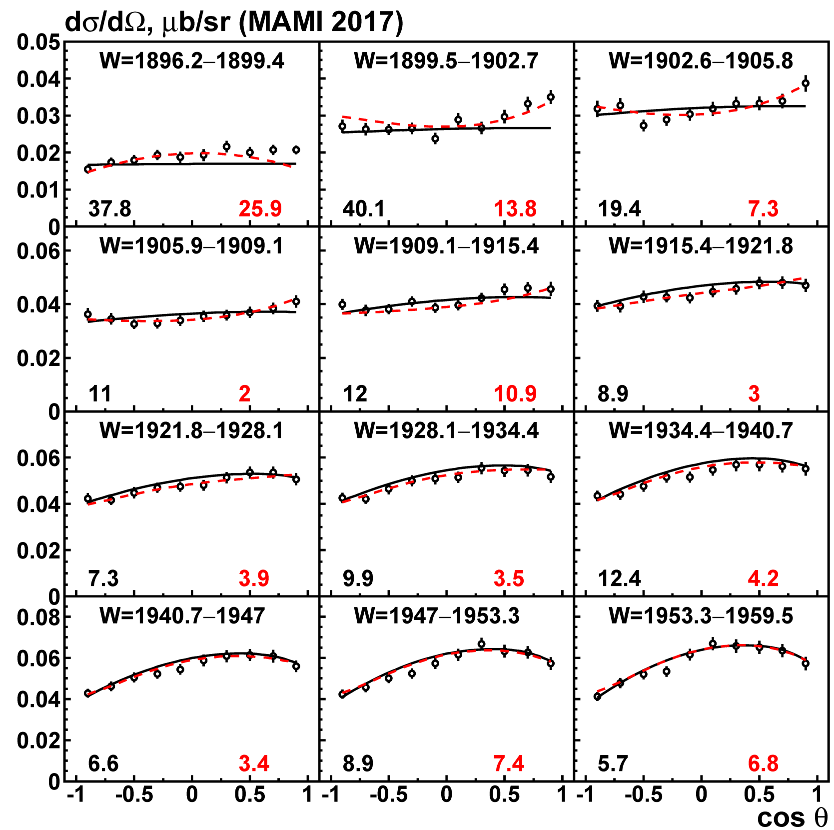
Narrow resonance in η´ photoproduction?

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

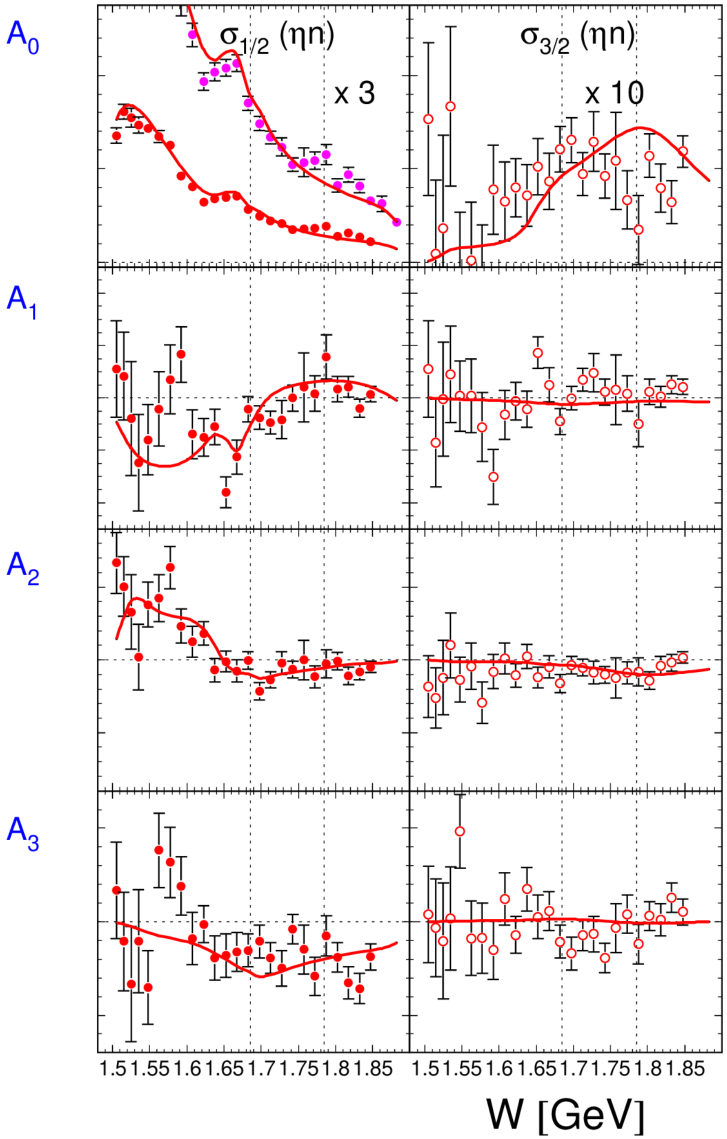




beam asymmetry Σ:
black disks: GRAAL-2015
red circles: CLAS-2017

diff. cross sect. dσ/dΩ:
A2MAMI-2017

$\gamma\ n \rightarrow \eta\ n$ Legendre coefficients



Data: A2MAMI-17;
Red lines: full solution

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

$$A_0 = SS + PP + SD + DD + PF + FF$$
$$A_1 = SP + PD + SF + DF$$
$$A_2 = PP + SD + DD + PF + FF$$
$$A_3 = PD + SF + DF$$
$$A_4 = DD + PF + FF$$
$$A_5 = DF$$
$$A_6 = FF$$

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, K Σ channels and electroproduction.

Selected results

M.Polyakov

$\gamma N \rightarrow \eta' N$

Large violation of the flavour SU(3) symmetry in ηMAID2018 isobar model

(the neutron anomaly case)

1, 2 1, 3

	M_R (MeV)	Γ_R (MeV)	$\lvert g_{\pi N} \rvert$	$\lvert g_{\eta N} \rvert$	$\lvert g_{K\Lambda} \rvert$	$\lvert g_{K\Sigma} \rvert$
$N(1535, \frac{1}{2}^-)$	1521.7	174.7	0.45	0.62	N/A	N/A
$N(1650, \frac{1}{2}^-)$	1626.3	132.5	0.36	0.28	0.20	1.21
$N(1710, \frac{1}{2}^+)$	1669.5	63.2	0.10	0.22	0.52	0