Recent Progress with EtaMAID

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THE LOW-ENERGY FRONTIER
OF THE STANDARD MODEL

SFB/S3/MTZ Collaboration Meeting, Mainz, February 15-19, 2016

quark-hadron duality

from quark-hadron-duality it is known:

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

therefore: doing both leads to double counting

W. Melnitchouk et al. / Physics Reports 406 (2005) 127–301 141

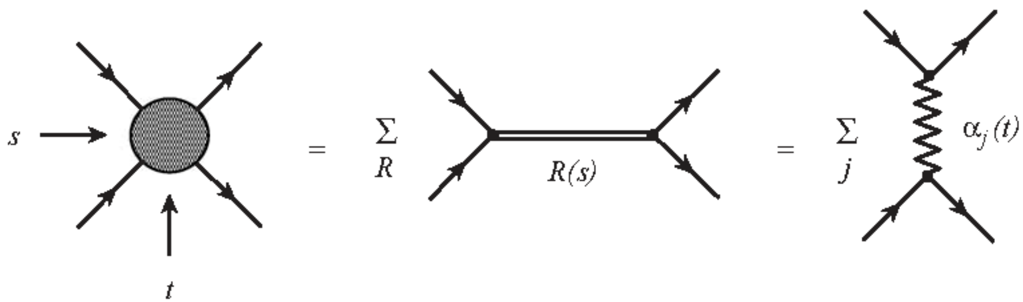
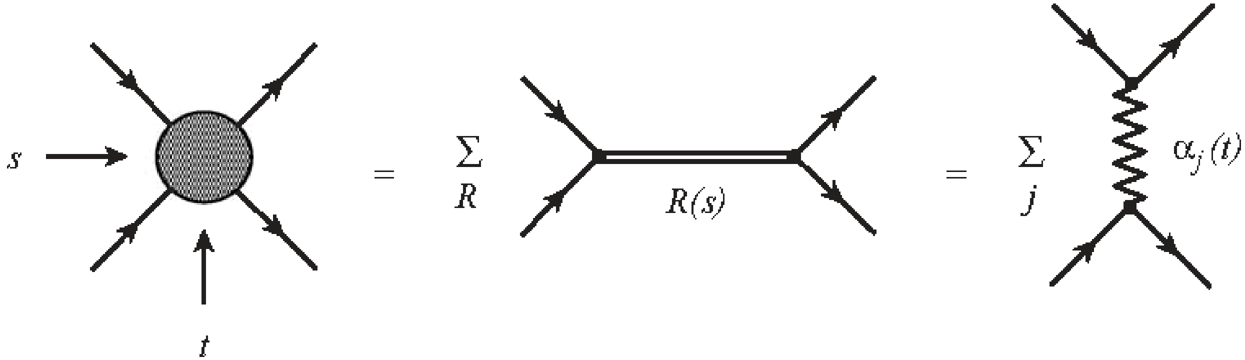
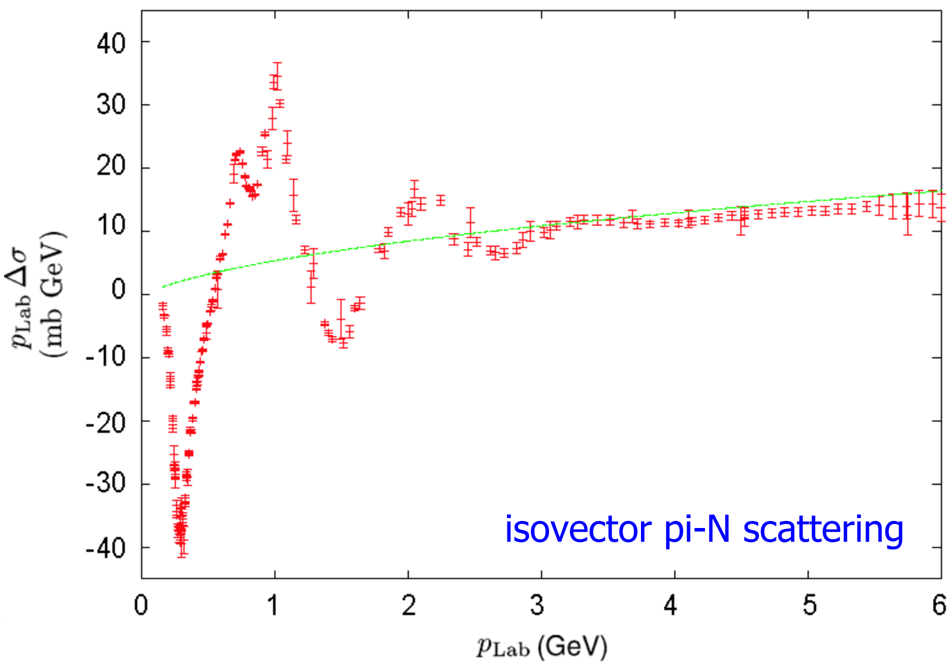


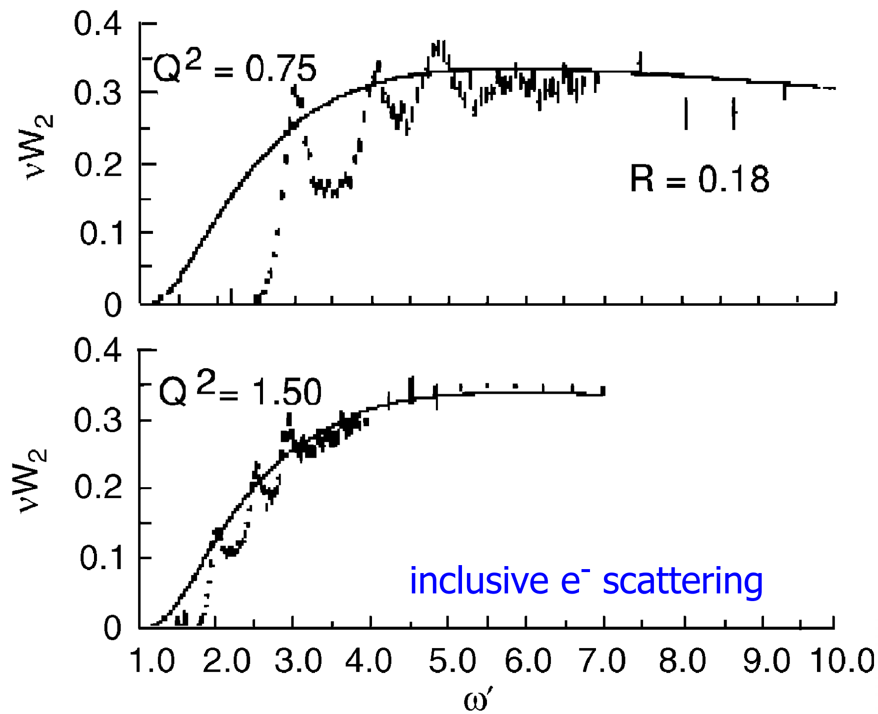
Fig. 3. Dual descriptions of the scattering process, in terms of a sum over s-channel resonances $R(s)$, and in terms of t-channel Reggeon exchanges $\alpha_j(t)$ (see text).

quark-hadron duality

W. Melnitchouk et al. / Physics Reports 406 (2005) 127–301







Regge-Plus-Resonance Models

e.g. Gent group around Jan Ryckebusch, for kaon photoproduction
Marc Vanderhaeghen and coll for pion and eta photoproduction

for pion and eta photoproduction models below W=2 GeV
resonance models work well without Regge phenomenology

for kaon photoproduction it does not work so well
Regge phenomenology is doing much better and mostly applied

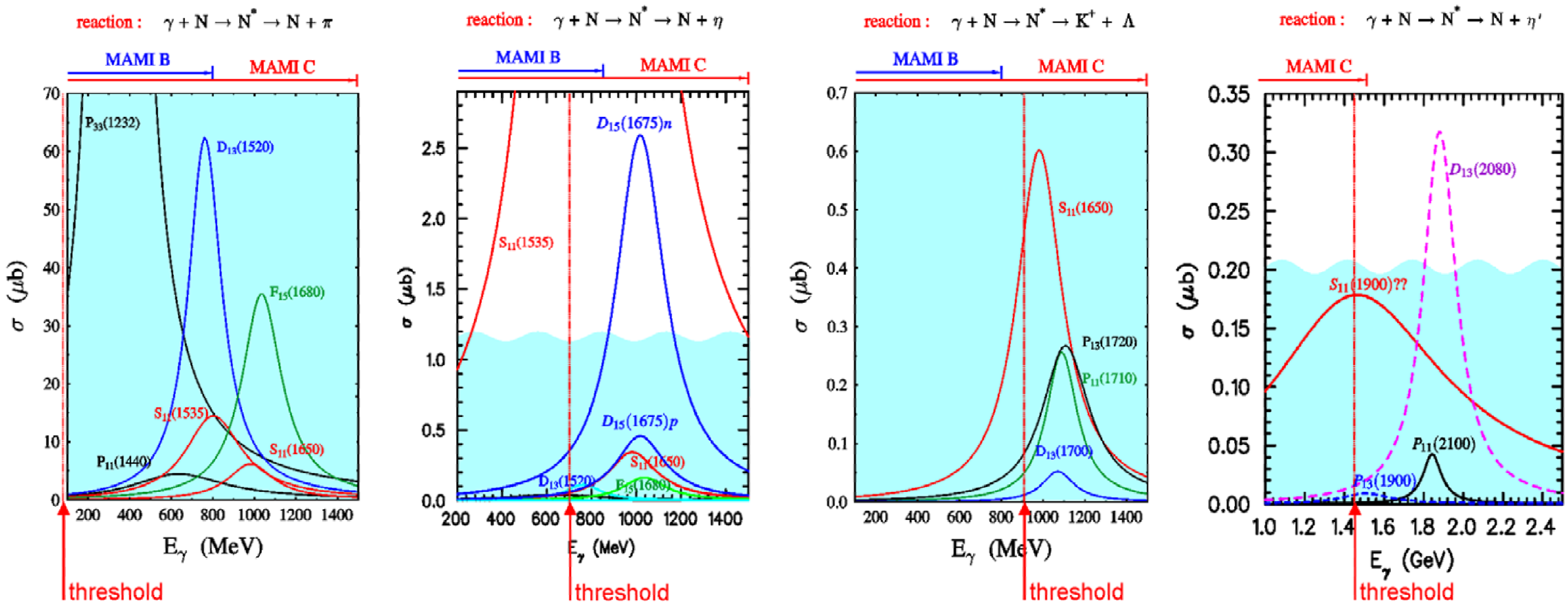
for etaprime photoproduction it also seems necessary
threshold is already around W~1.9 GeV

different techniques to reduce/avoid double counting have been tried:

projection techniques to subtract specific partial waves from Regge amplitudes

finite energy sum rules to get smooth transitions from resonance to Regge
(V. Matthieu et al. 2015)

Photoproduction of π, η, K, η`



$\sigma^{max}(P_{33}) \gtrsim 400\,\mu b$ $\sigma^{max}(S_{11}) \gtrsim 17\,\mu b$

background is very different:

large for γ,π and γ,K, small for γ,η', very small for γ,η

MAID

the Unitary Isobar Model

$$t^{\alpha}_{\gamma,\pi} = v^{\alpha}_{\gamma,\pi}(Born + \omega, \rho)\,(1 + i t^{\alpha}_{\pi,\pi})$$

K-matrix unitarization

$$+\ t^{\alpha}_{\gamma,\pi}(Resonances)\ e^{i\Phi(W)}$$

unitarization phase
determined by the Watson theorem, below 2π threshold
relaxed above 2π threshold

ETA-MAID

uses a simpler approach
without additional unitarization:

$$t_{\gamma,\eta} = v_{\gamma,\eta}(Born + \omega, \rho) + t_{\gamma,\eta}(Resonances)$$

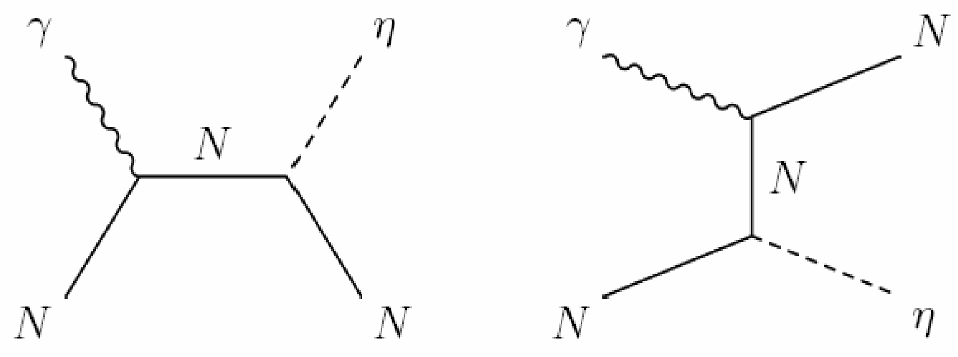
this is probably not so good and most likely violates unitarity

crossing symmetry is also more or less violated in isobar models

both can be cured by using fixed-t dispersion relations

Background

Born Terms



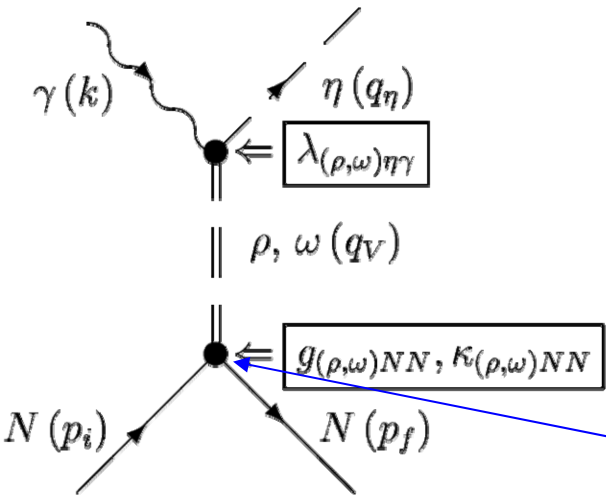
$$\mathcal{L}_{\gamma NN} = -e\bar{\psi}\left[\gamma_\mu A^\mu F_1(Q^2) + \frac{\sigma_{\mu\nu}}{2\,m_N}\partial^\mu A^\nu F_2(Q^2)\right]\psi$$

$$\mathcal{L}_{\eta NN} = -i\, g_{\eta NN}\,\bar{\psi}\,\gamma_5\,\psi\,\phi_\eta$$

very small coupling constant: $0 < g^2_{\eta NN}/4\pi < 0.1$ (SU(3): 0.8 - 1.9)

Vector Meson Exchanges

with single-pole terms



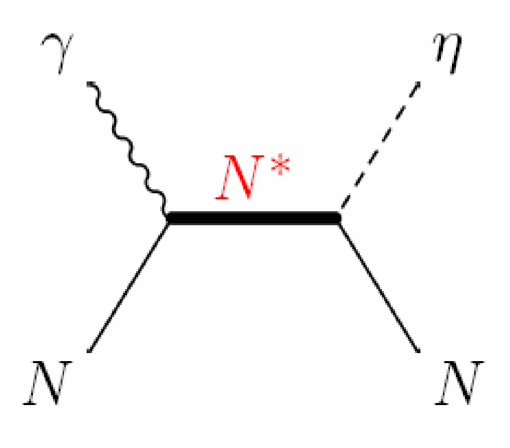
$$\mathcal{L}_{VNN} = g_{VNN}\,\bar{\psi}\left(\gamma_\mu + \frac{\kappa_{VNN}}{2\,m_N}\,\sigma_{\mu\nu}\partial^\nu\right)V^\mu\,\psi$$

$$\mathcal{L}_{V\eta\gamma} = \frac{e\lambda_{V\eta\gamma}}{m_\eta}\,\varepsilon_{\mu\nu\rho\sigma}(\partial^\mu A^\nu)\phi_\eta(\partial^\rho V^\sigma)$$

$$\Gamma_{V\to\eta\gamma} = \frac{\alpha(M_V^2 - M_\eta^2)^3}{24\,M_V^3\,M_\eta^2}\,{\lambda_{V\eta\gamma}}^2$$

hadronic form factor $F_V(t) = \left(\frac{\Lambda_V^2 - m_V^2}{\Lambda_V^2 - t}\right)^2$

Resonances



only isospin ½ resonances

no Deltas

8 resonances in η-MAID2001 :

D_{13}(1520) very important for Σ

S_{11}(1535) most important

S_{11}(1650) very important

D_{15}(1675) very important for Σ

F_{15}(1680) less important

D_{13}(1700) unimportant

P_{11}(1710) important

P_{13}(1720) unimportant

Breit-Wigner form:

$$\begin{pmatrix} E_{\ell\pm} \\ M_{\ell\pm} \end{pmatrix} = \begin{pmatrix} \tilde{E}_{\ell\pm} \\ \tilde{M}_{\ell\pm} \end{pmatrix} f_{\gamma N}(W) \frac{\Gamma_{tot} W_R}{W_R^2 - W^2 - iW_R \Gamma_{tot}} f_{\eta N}(W)\, C_{\eta N}$$

$$\text{isospin factor } C_{\eta N} = -1$$

$$f_{\eta N}(W) = \left[\frac{1}{(2j+1)\pi} \frac{k}{|\boldsymbol{q}|} \frac{m_N}{W_R} \frac{\Gamma_{\eta N}}{\Gamma_{tot}^2} \right]^{1/2}$$

$$\Gamma_{\eta N} = \beta_{\eta N} \Gamma_R \left(\frac{|\boldsymbol{q}|}{|\boldsymbol{q_R}|} \right)^{2\ell+1} \left(\frac{X^2 + \boldsymbol{q_R}^2}{X^2 + \boldsymbol{q}^2} \right)^{\ell} \frac{W_R}{W}$$

$$\Gamma_{tot} = \Gamma_{\eta N} + \Gamma_{\pi N} + \Gamma_{\pi\pi N}$$

$$f_{\gamma N}(W) = 1$$

EtaMAID update for coupled γ,η and γ,η'

(with V. Kashevarov, Mainz)

still preliminary

background: Born terms with very small coupling $g^2_{\eta NN} = 0.0076$
ρ,ω t-channel single-pole terms (very different from new Regge approach)

Resonances in ηMAID-2003

$D_{13}(1520)$**** $S_{11}(1535)$**** $S_{11}(1650)$****
$D_{15}(1675)$**** $F_{15}(1680)$**** $D_{13}(1700)$***
$P_{11}(1710)$*** $P_{13}(1720)$****

Additional resonances in ηMAID-2015d-2

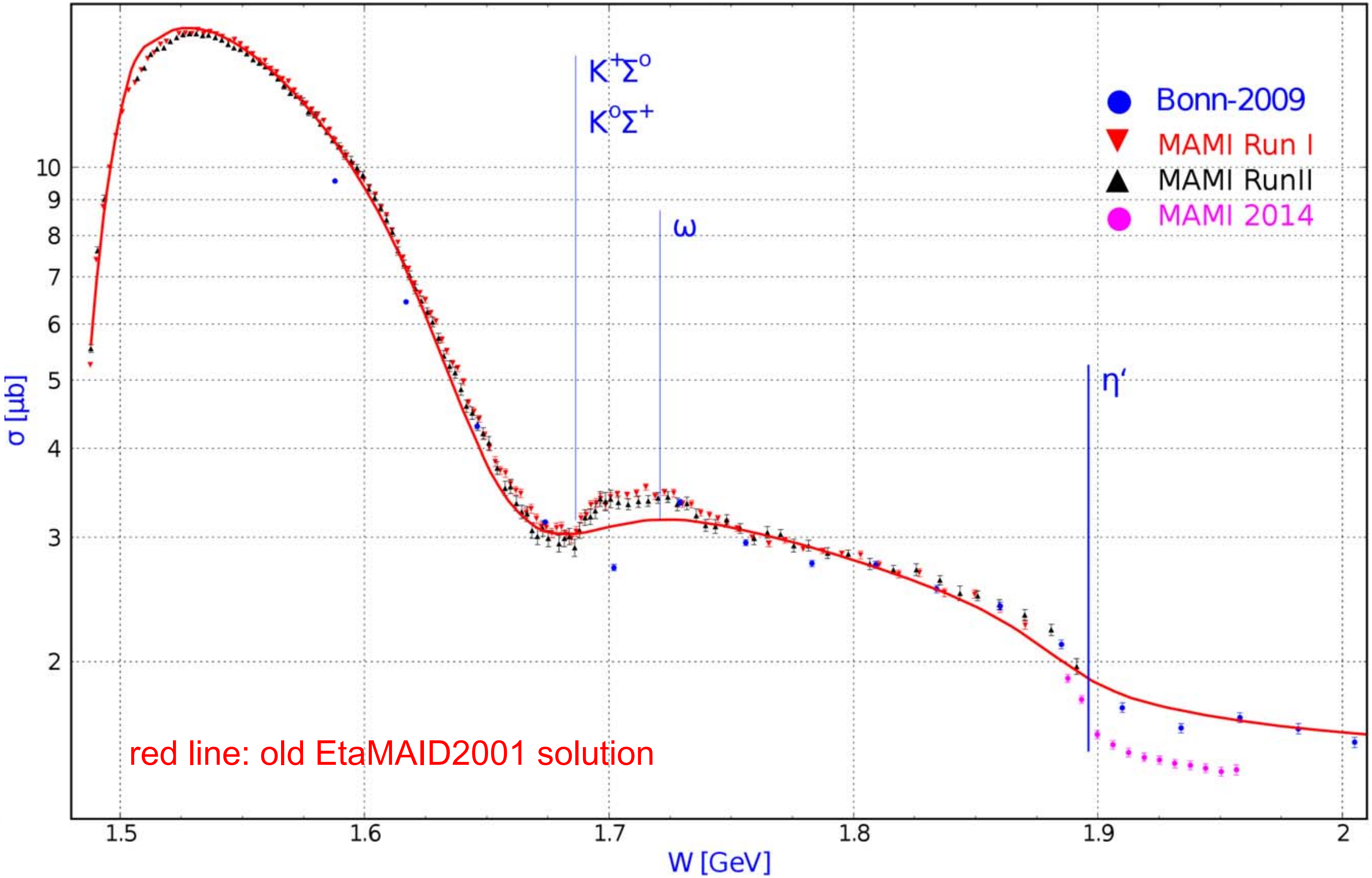
$F_{15}(1860)$**	$D_{13}(1875)$***	$P_{11}(1880)$**	$S_{11}(1895)$**
$P_{13}(1900)$***	$F_{17}(1990)$**	$F_{15}(2000)$**	
$D_{15}(2060)$**	$D_{13}(2150)$**	$G_{17}(2190)$****	
$H_{19}(2220)$****	$G_{19}(2250)$****		
$P_{11}(1440)$****	$P_{11}(2300)$**	$D_{15}(2570)$**	

red marked resonances have very small contributions and were excluded from fit

η Photoproduction at MAMI

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

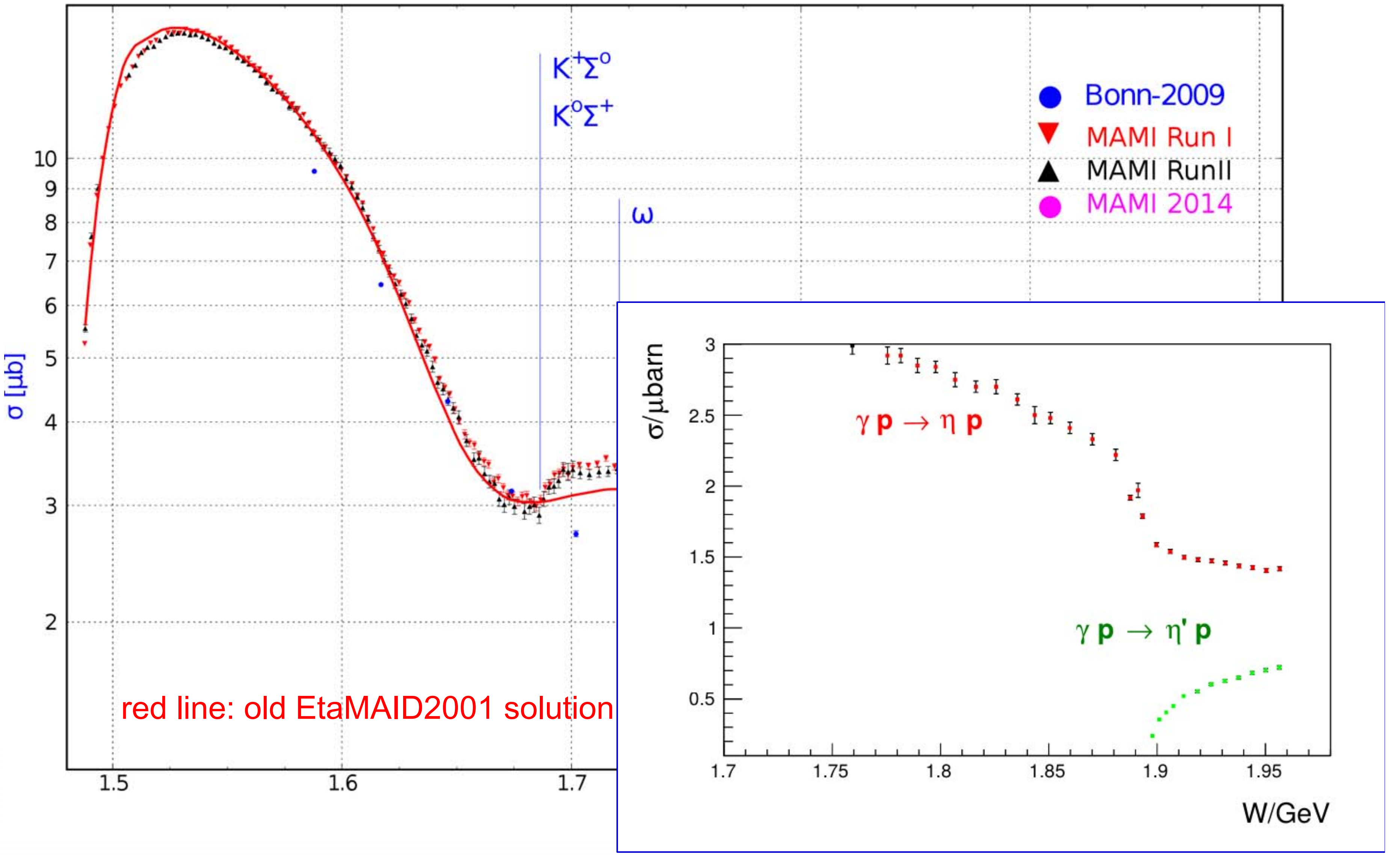
MAMI A2 Collab, preliminary



η Photoproduction at MAMI

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

MAMI A2 Collab, preliminary



EtaMAID update for coupled γ,η and γ,η'

(with V. Kashevarov, Mainz)

data used in the fit

$\gamma p \rightarrow \eta p$

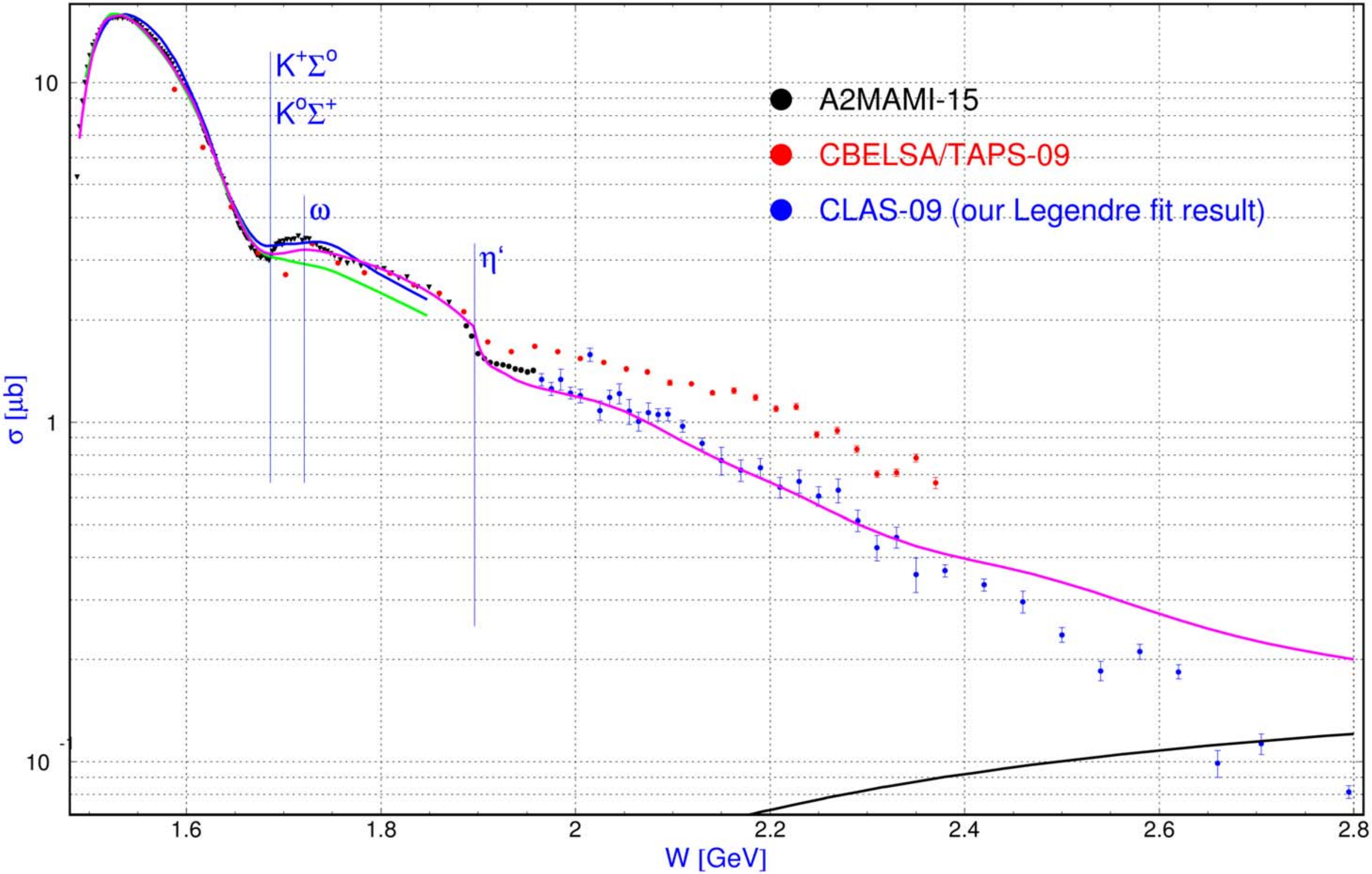
$d\sigma/d\Omega$	W=1.488 – 1.957 GeV	MAMI 2015, Prakhov, preliminary
$d\sigma/d\Omega$	W=1.965 – 2.075 GeV	CLAS 2009, PR C80 (2009) 045213
T	W=1.497 – 1.848 GeV	MAMI 2014, PRL 113 (2014) 102001
F	W=1.497 – 1.848 GeV	MAMI 2014, PRL 113 (2014) 102001
Σ	W=1.496 – 1.908 GeV	GRAAL 2007, EPJ A33 (2007) 169
E	W=1.525 – 2.125 GeV	CLAS 2015, arXiv:1507.00325v1

$\gamma p \rightarrow \eta' p$

$d\sigma/d\Omega$	W=1.898 – 1.956 GeV	MAMI 2015, Prakhov, preliminary
$d\sigma/d\Omega$	W=1.925 – 2.045 GeV	CLAS 2009, PR C80 (2009) 045213
Σ	W=1.903 – 1.913 GeV	GRAAL 2015, EPJ A51 (2015) 77

overall $\chi^2 \sim 3.8$, below η' threshold $\chi^2 \sim 3.4$

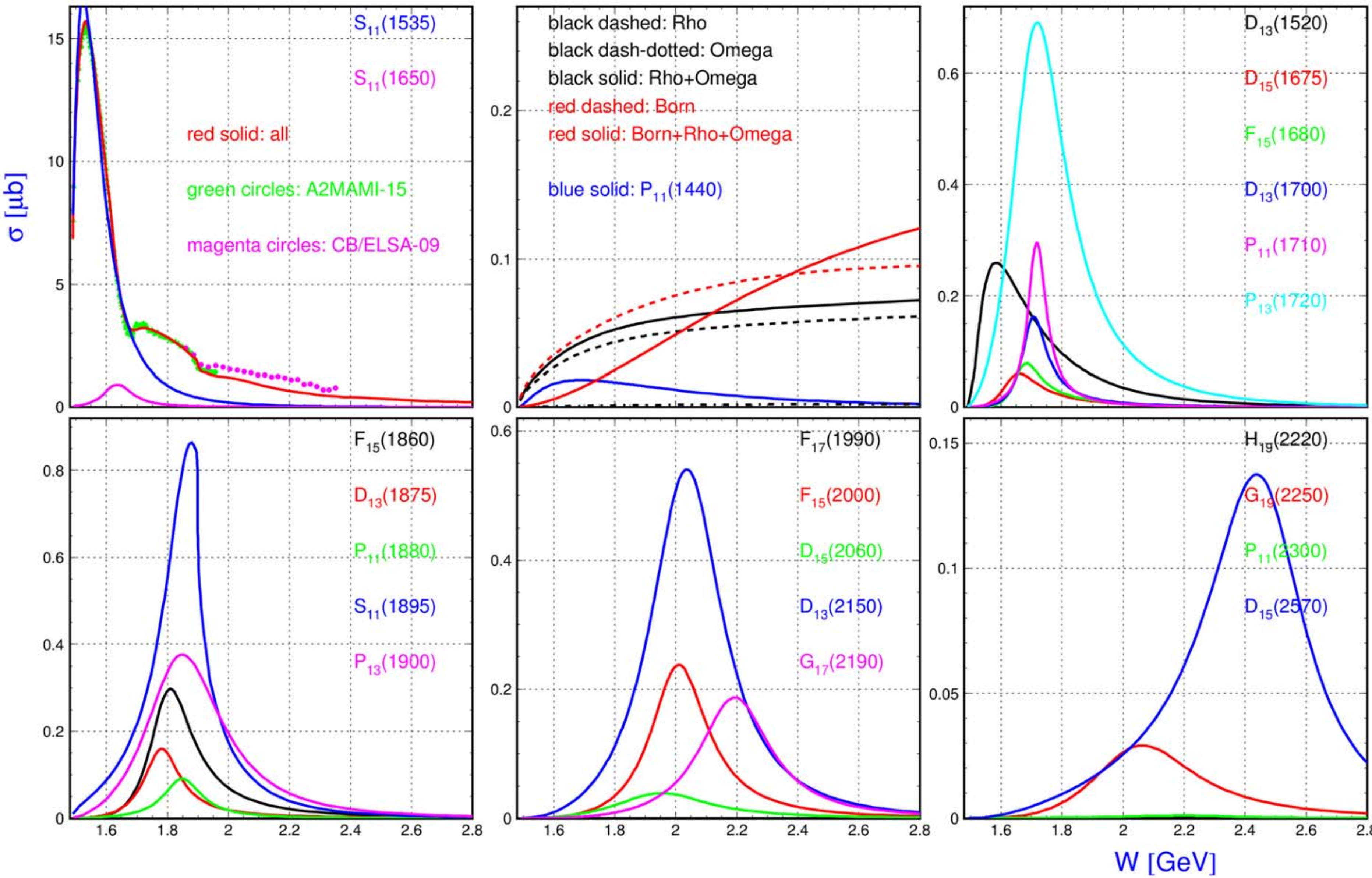
γ p → η p   ηMAID-2015d-2: total cross sections



Blue line: ηMAID-2003
Green line: ηMAID-2003regge

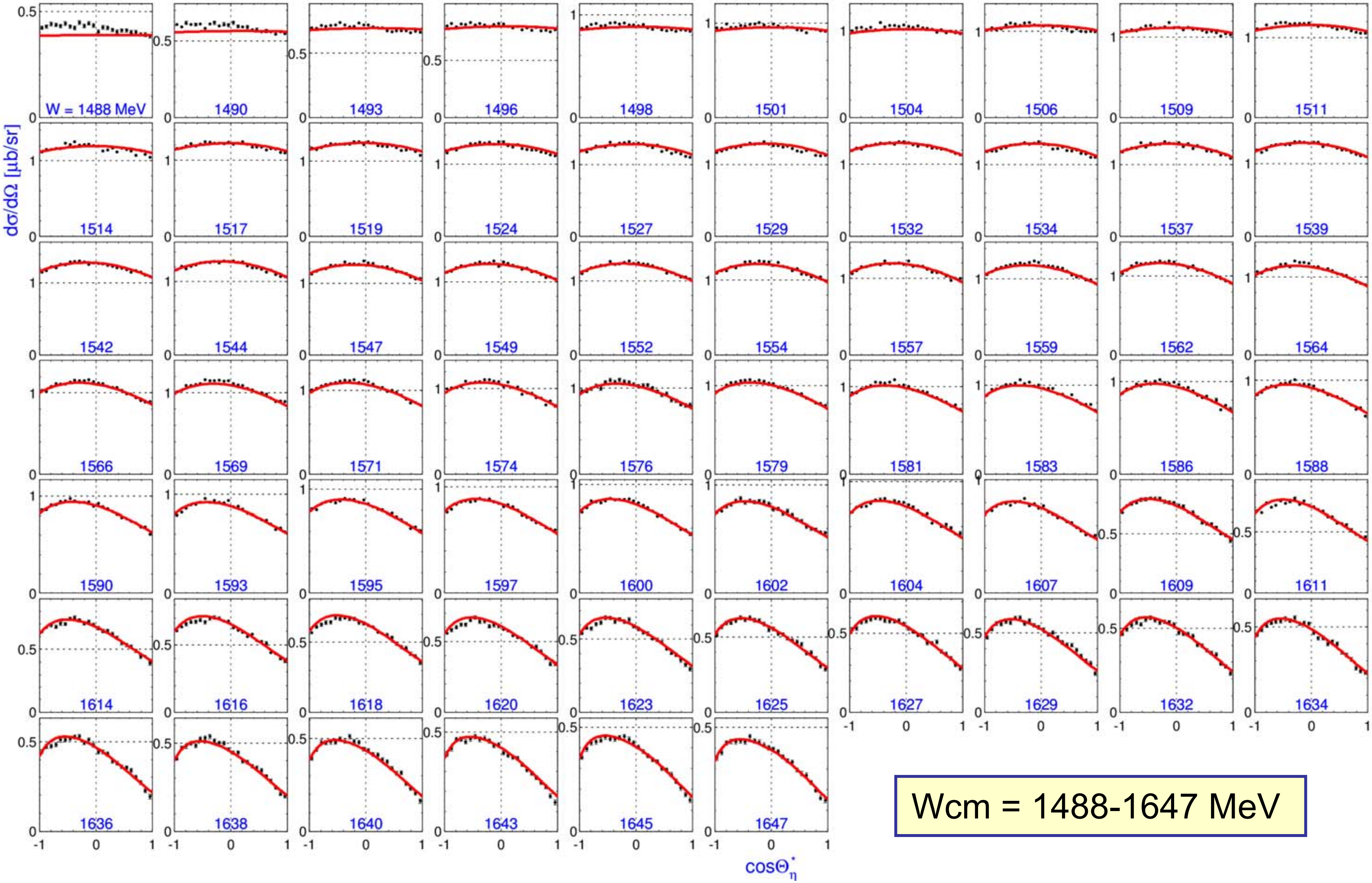
magenta line: ηMAID-2015d-2
black line: ηMAID-2015d-2 background

$\gamma\, p \to \eta\, p$ *ηMAID-2015d-2: total cross sections*



dominant states: S11(1535), S11(1650), S11(1895), P13(1720), D13(2120)[new], P13(1900), ...

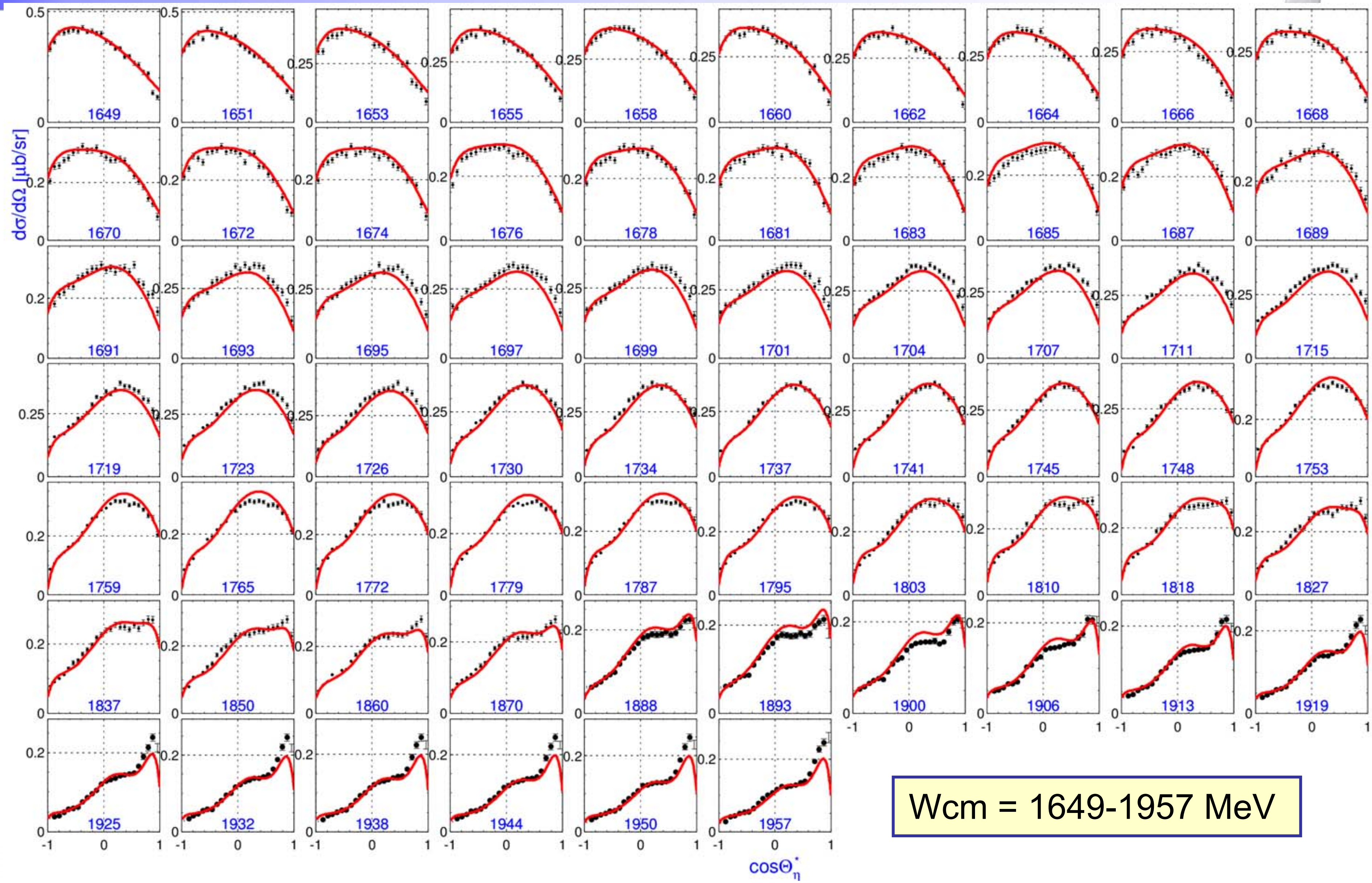
γ p → η p   *ηMAID-2015d-2: differential cross sections, Mainz data*



Wcm = 1488-1647 MeV

black circles: A2MAMI-15   red: ηMAID-2015d-2

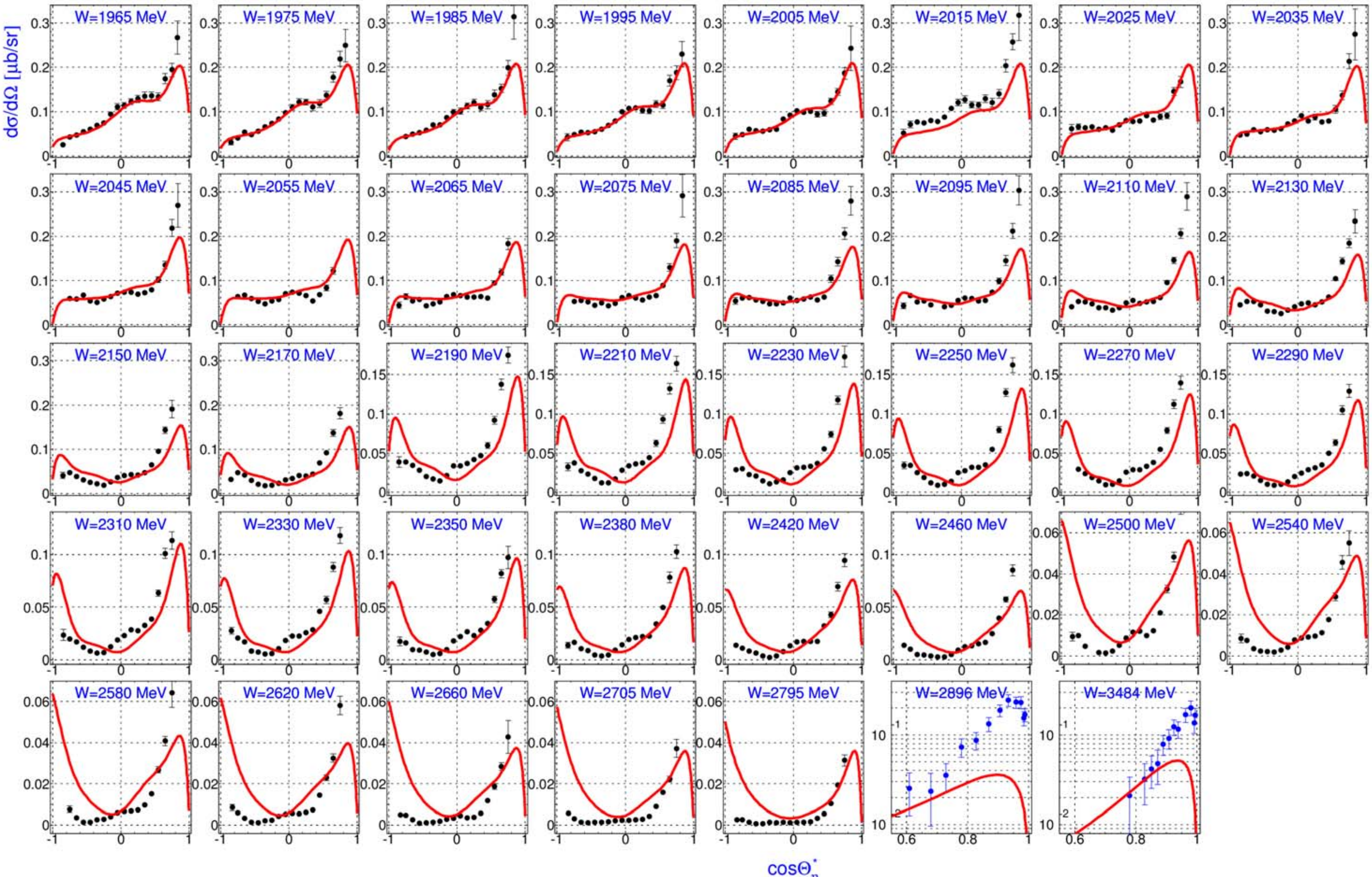
$\gamma\, p \rightarrow \eta\, p$ *ηMAID-2015d-2: differential cross sections, Mainz data*



Wcm = 1649-1957 MeV

black circles: A2MAMI-15 red: ηMAID-2015d-2

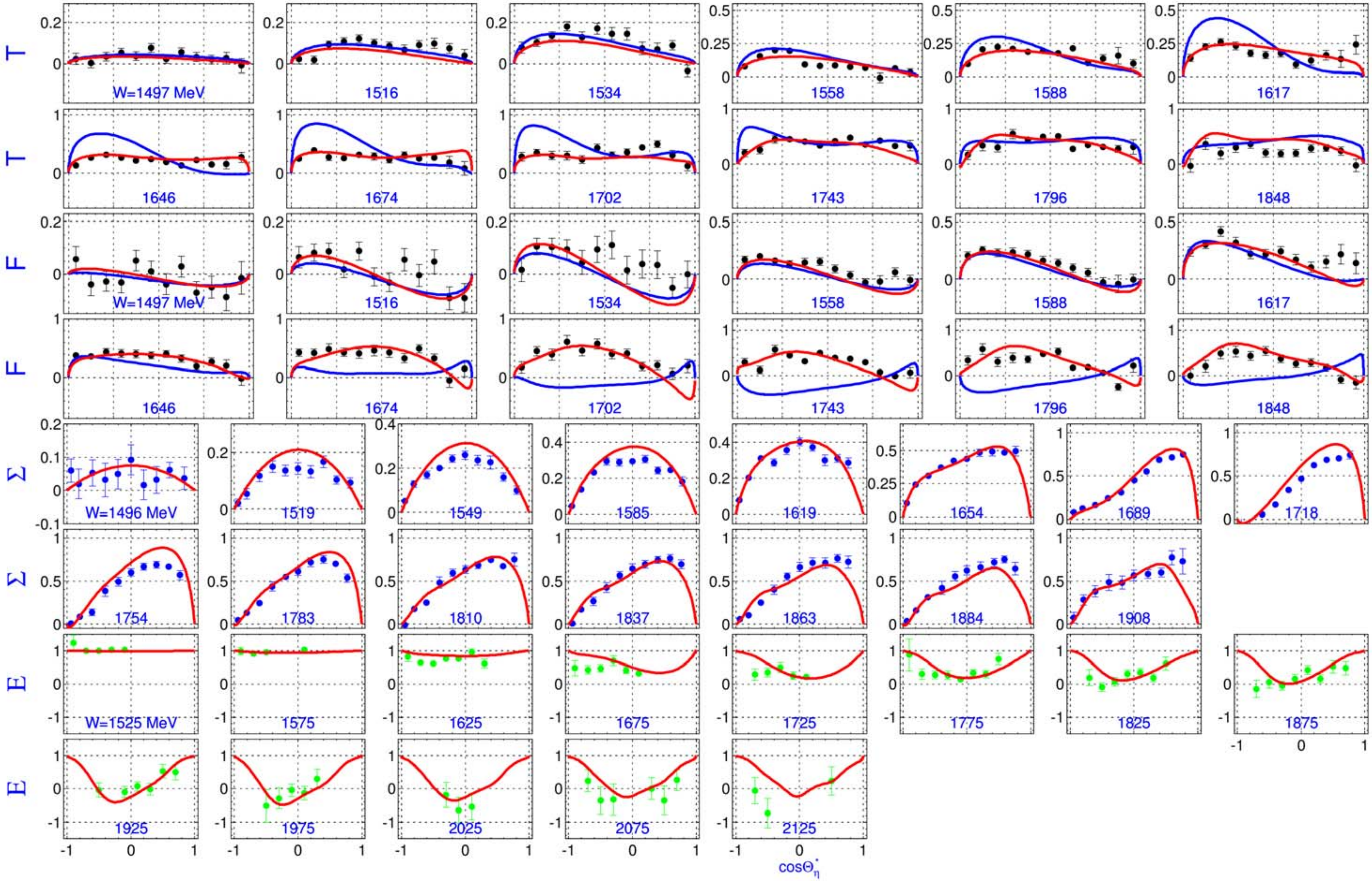
$\gamma\, p \rightarrow \eta\, p$ *ηMAID-2015d-2: differential cross sections JLab/DESY*



black circles: CLAS-09 (in the fit were included data up to W=2075 MeV)
Blue circles: DESY-70 red line: ηMAID-2015d-2

Wcm = 1965-3484 MeV

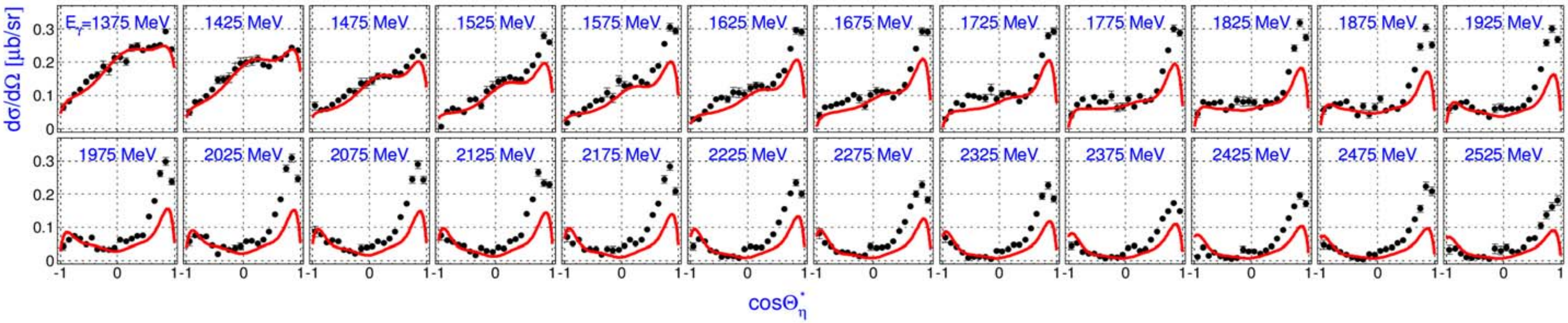
γ p → η p *ηMAID-2015d-2: T, F, Σ, E data from Mainz/GRAAL/JLab*

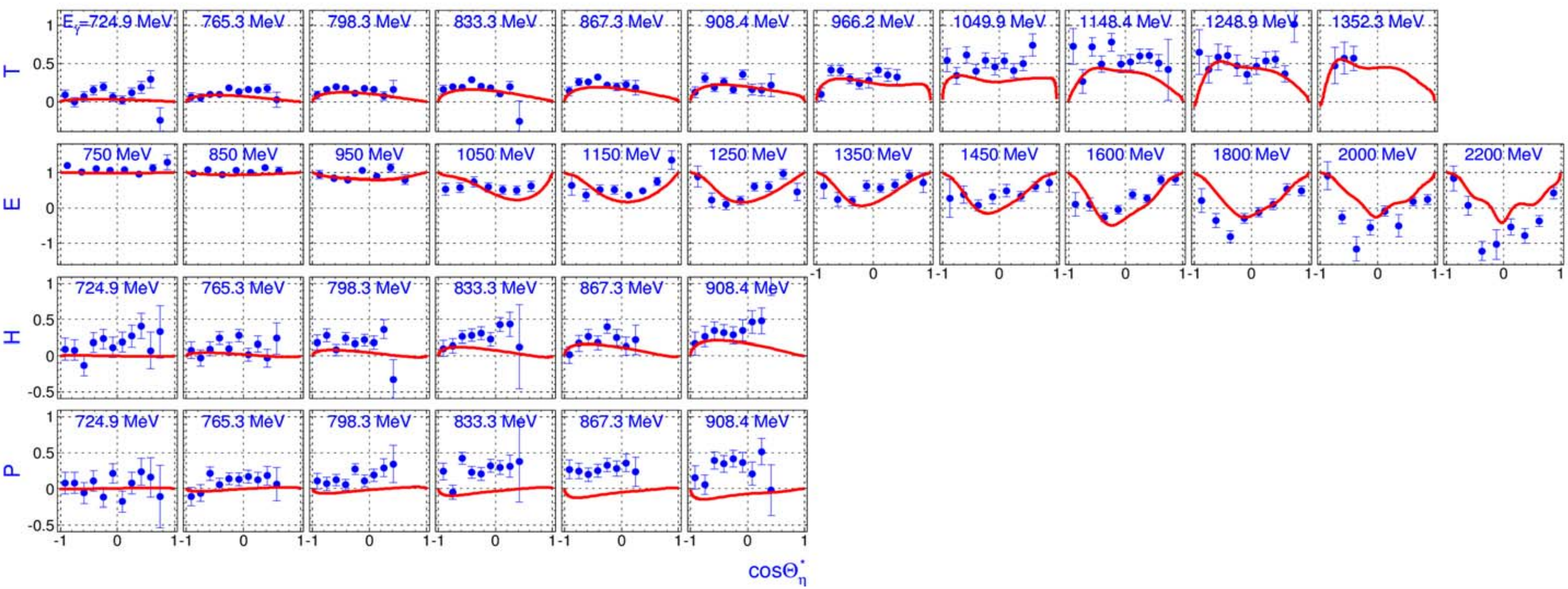


black circles: A2MAMI-14
blue circles: GRAAL-07; green: CLAS-15

blue lines: ηMAID-2003
red lines: ηMAID-2015d-2

γ p → η p ηMAID-2015d-2 predictions for CBELSA/TAPS data

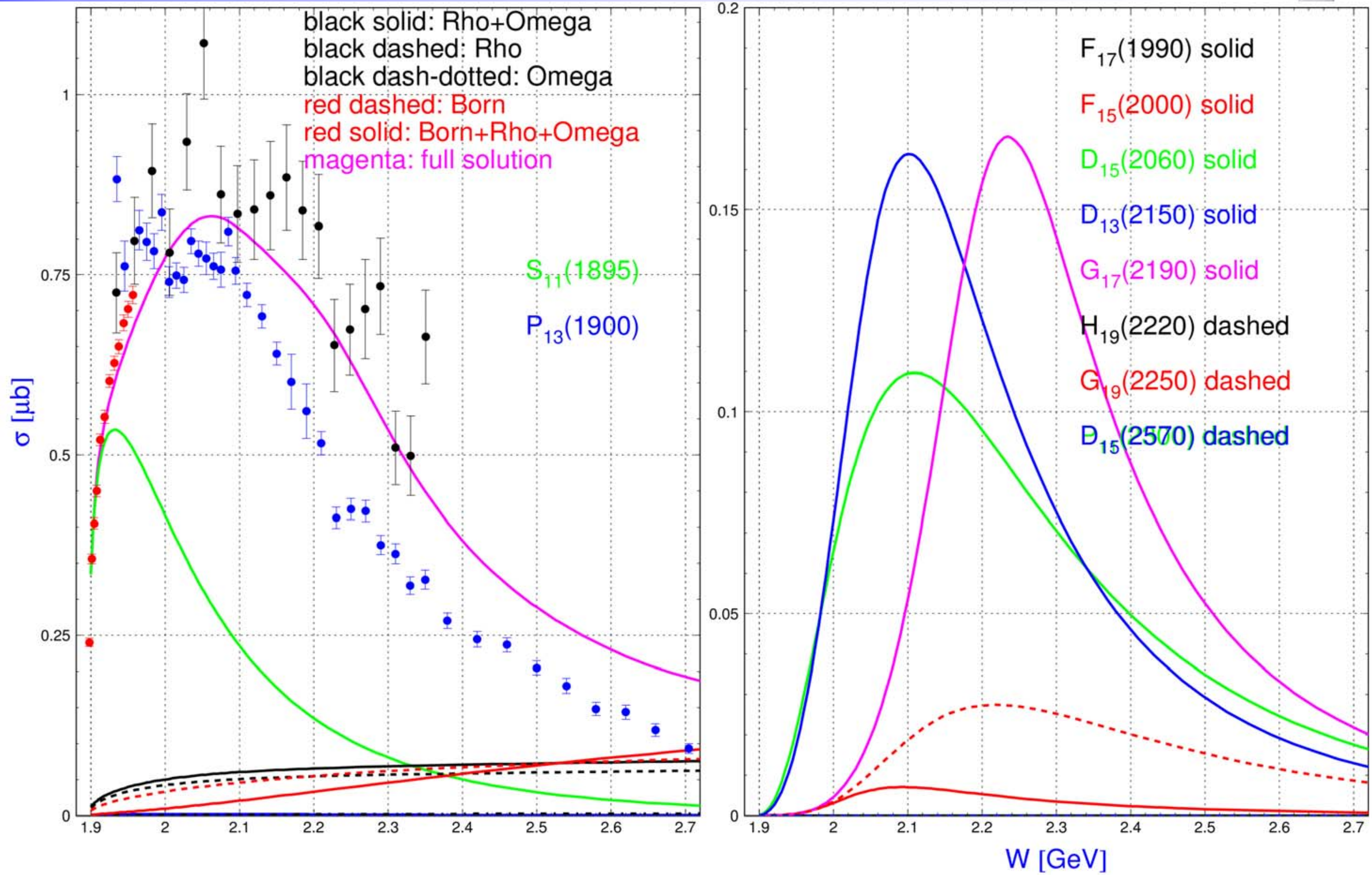




black circles: CBELSA/TAPS-09, red lines: ηMAID-2015d-2

blue circles: CBELSA/TAPS-15 (J. Hartmann: **T**,**P**,**H**, J. Müller: **E**, preliminary)

γ p → η' p *ηMAID-2015d-2: total cross section Mainz/Bonn/JLab data*

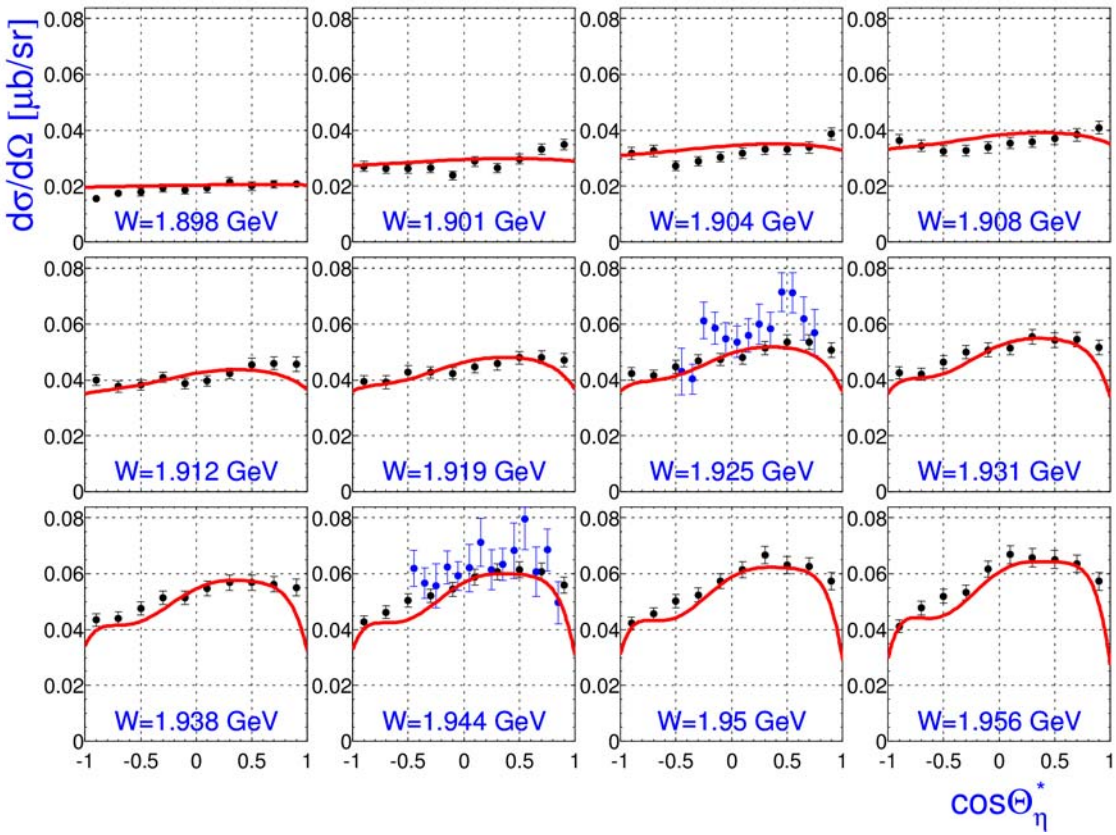


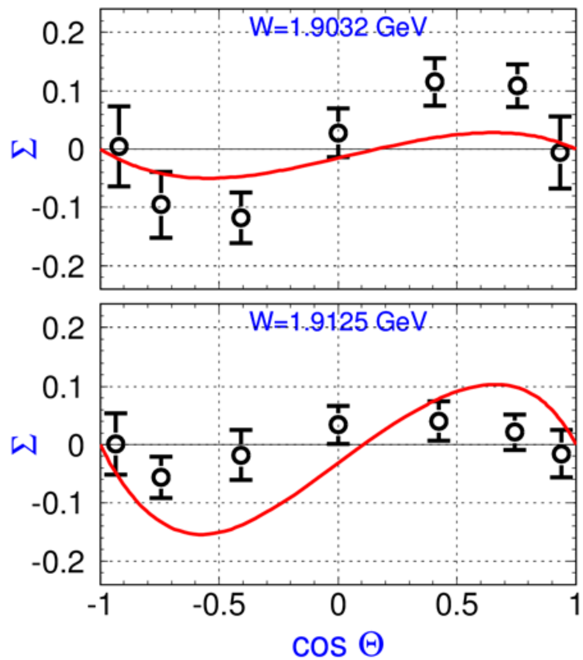
Red circles: A2MAMI-15, black circles: CBELSA/TAPS-09, blue circles: CLAS-09 from Legendre fit

$\gamma p \rightarrow \eta' p$ *ηMAID-2015d-2 and near threshold data*

MAMI - A2 data 2015, preliminary

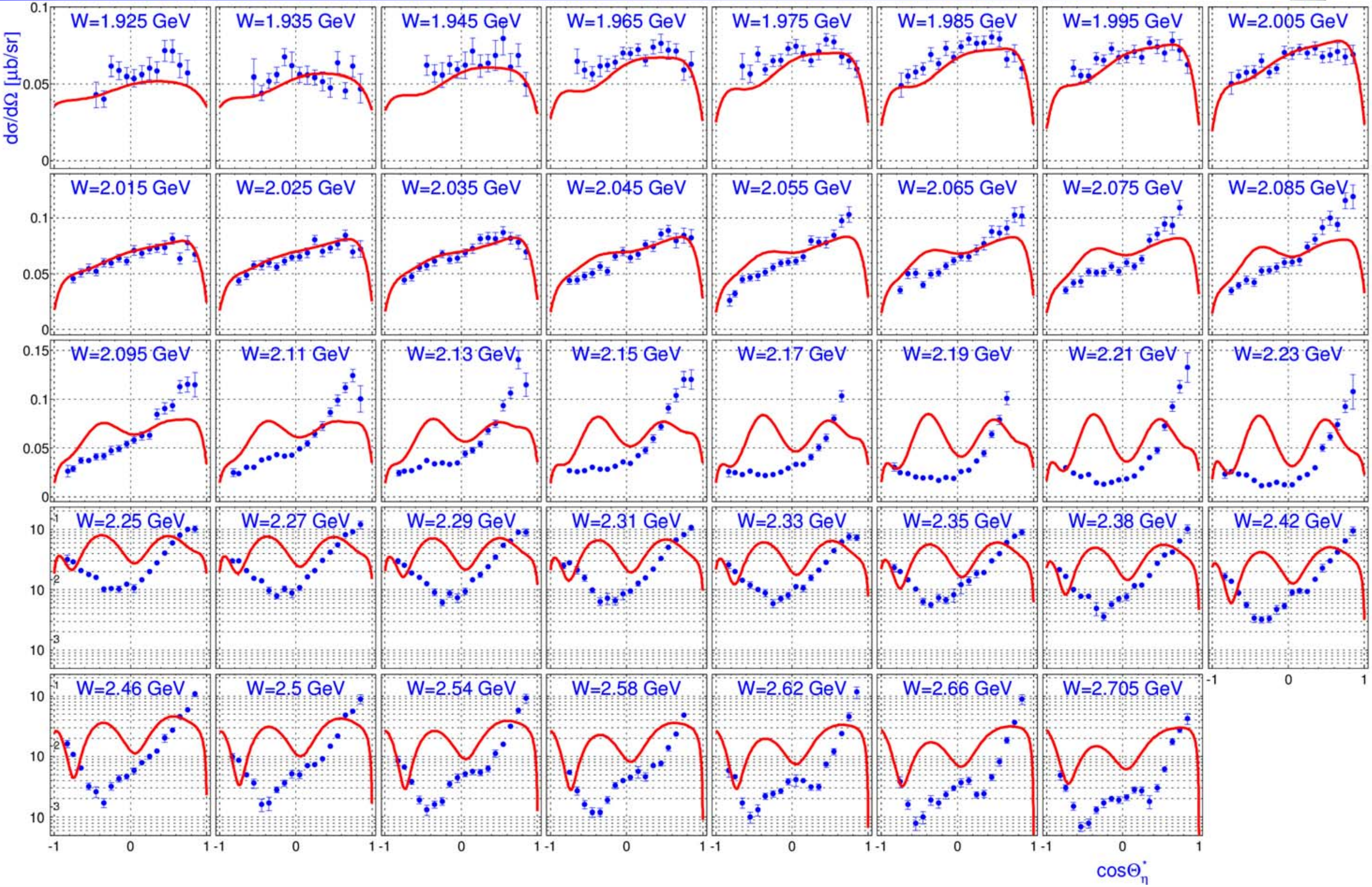
GRAAL data 2015





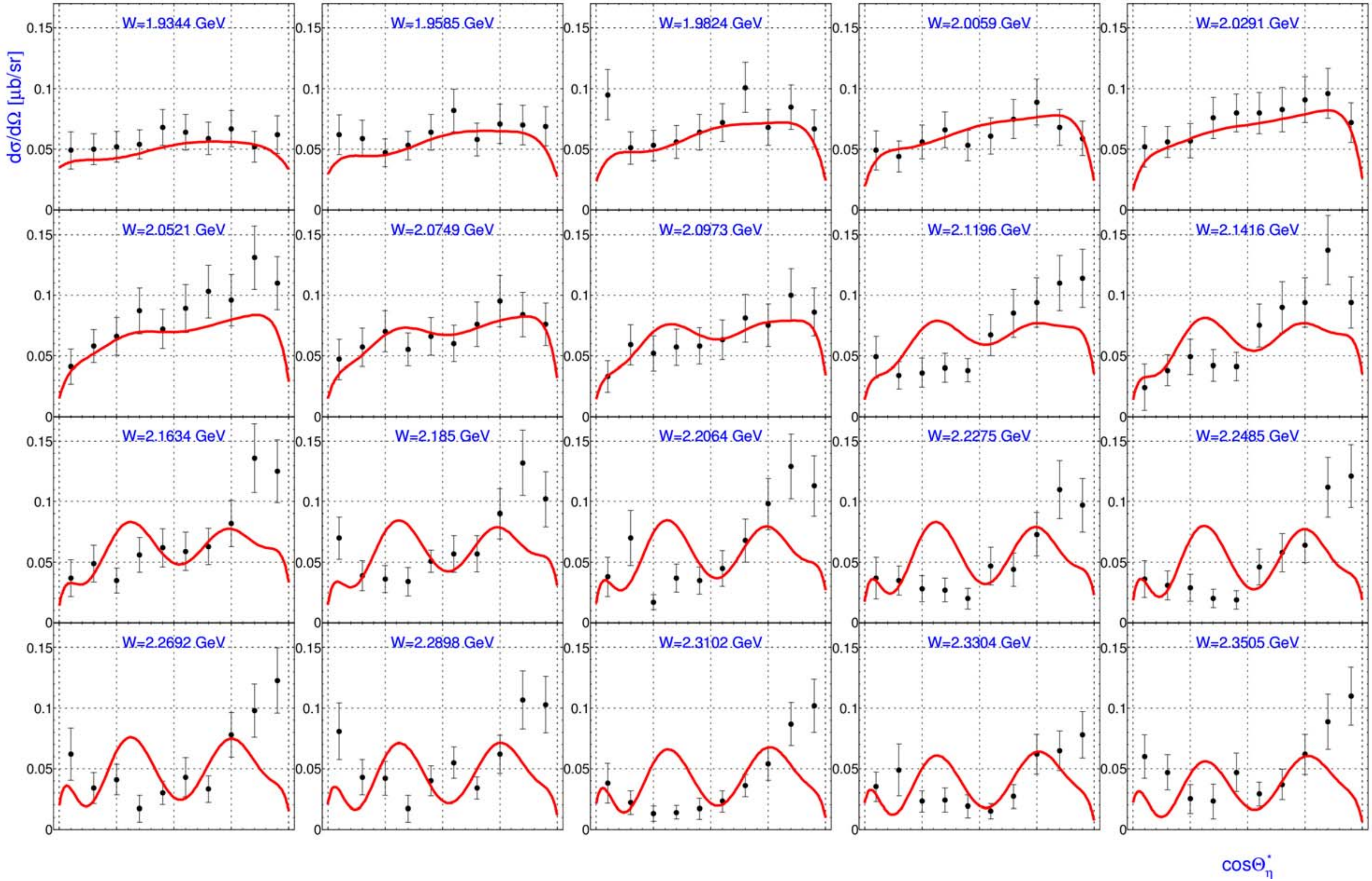
closed circles: A2MAMI-15; open circles : GRAAL-15; Red lines: ηMAID-2015d-2

γ p → η' p *ηMAID-2015d-2 and CLAS-09 data*



blue circles: CLAS-09 (in the fit were included data up to W=2045 MeV) red line: ηMAID-2015d-2

$\gamma\, p \rightarrow \eta'\, p$ *ηMAID-2015d-2 and CBELSA/TAPS-09 data*



black circles: CBELSA/TAPS-09 (not included in the fit) red line: ηMAID-2015d-2

new resonances in Eta-MAID update 2015

Particle J^P	overall	$N\gamma$	$N\pi$	$N\eta$	$N\sigma$	$N\omega$	ΛK	ΣK	$N\rho$	$\Delta\pi$
$N(1440)\ 1/2^+$	****	****	****		***				*	***
$N(1520)\ 3/2^-$	****	****	****	***					***	***
$N(1535)\ 1/2^-$	****	****	****	****					**	*
$N(1650)\ 1/2^-$	****	****	****	***			***	**	**	***
$N(1675)\ 5/2^-$	****	****	****	*			*		*	***
$N(1680)\ 5/2^+$	****	****	****	*	**				***	***
$N(1700)\ 3/2^-$	***	**	***	*			*	*	*	***
$N(1710)\ 1/2^+$	****	****	****	***		**	****	**	*	**
$N(1720)\ 3/2^+$	****	****	****	***			**	**	**	*
$N(1860)\ 5/2^+$	**		**						*	*
$N(1875)\ 3/2^-$	***	***	*			**	***	**		***
$N(1880)\ 1/2^+$	**	*	*		**		*			
$N(1895)\ 1/2^-$	**	**	*	**			**	*		
$N(1900)\ 3/2^+$	***	***	**	**		**	***	**	*	**
$N(1990)\ 7/2^+$	**	**	**					*		
$N(2000)\ 5/2^+$	**	**	*	**			**	*	**	
$N(2040)\ 3/2^+$	*		*							
$N(2060)\ 5/2^-$	**	**	**	*				**		
$N(2100)\ 1/2^+$	*		*							
$N(2120)\ 3/2^-$	**	**	**				*	*		
$N(2190)\ 7/2^-$	****	***	****			*	**		*	
$N(2220)\ 9/2^+$	****		****							
$N(2250)\ 9/2^-$	****		****							
$N(2300)\ 1/2^+$	**		**							
$N(2570)\ 5/2^-$	**		**							

7 N* in 2001/2003

15 N* new in 2015

only 3 N* resonances in PDG below 2.6 GeV, where we do not find evidence for γ,η

but everything is still preliminary

resonance parameters (below η' threshold)

N*	M	G	Br Eta	A1/2	A3/2	PDG stars for Nη
D13(1520)	1513.	125.	0.11	-28.0	124.	***
S11(1535)	1534.	161.	42.	115.	---	****
S11(1650)	1645.	116.	-12.	45.	---	***
D15(1675)	1659.	165.	-1.9	11.	33.	*
F15(1680)	1680.	115.	0.10	-9.0	145.	*
D13(1700)	1711.	106.	-2.6	14.0	-37.	*
P11(1710)	1724.	80.	2.2	50.	---	***
P13(1720)	**1745.**	**268.**	**7.2**	**70.**	**30.**	*******
F15(1860)	1819.	192.	1.1	-96.	-64.	new
D13(1875)	1831.	275.	-2.2	-59.	7.0	new
P11(1880)	1862.	158.	20.	-13.	---	new

resonance parameters (above η' threshold)

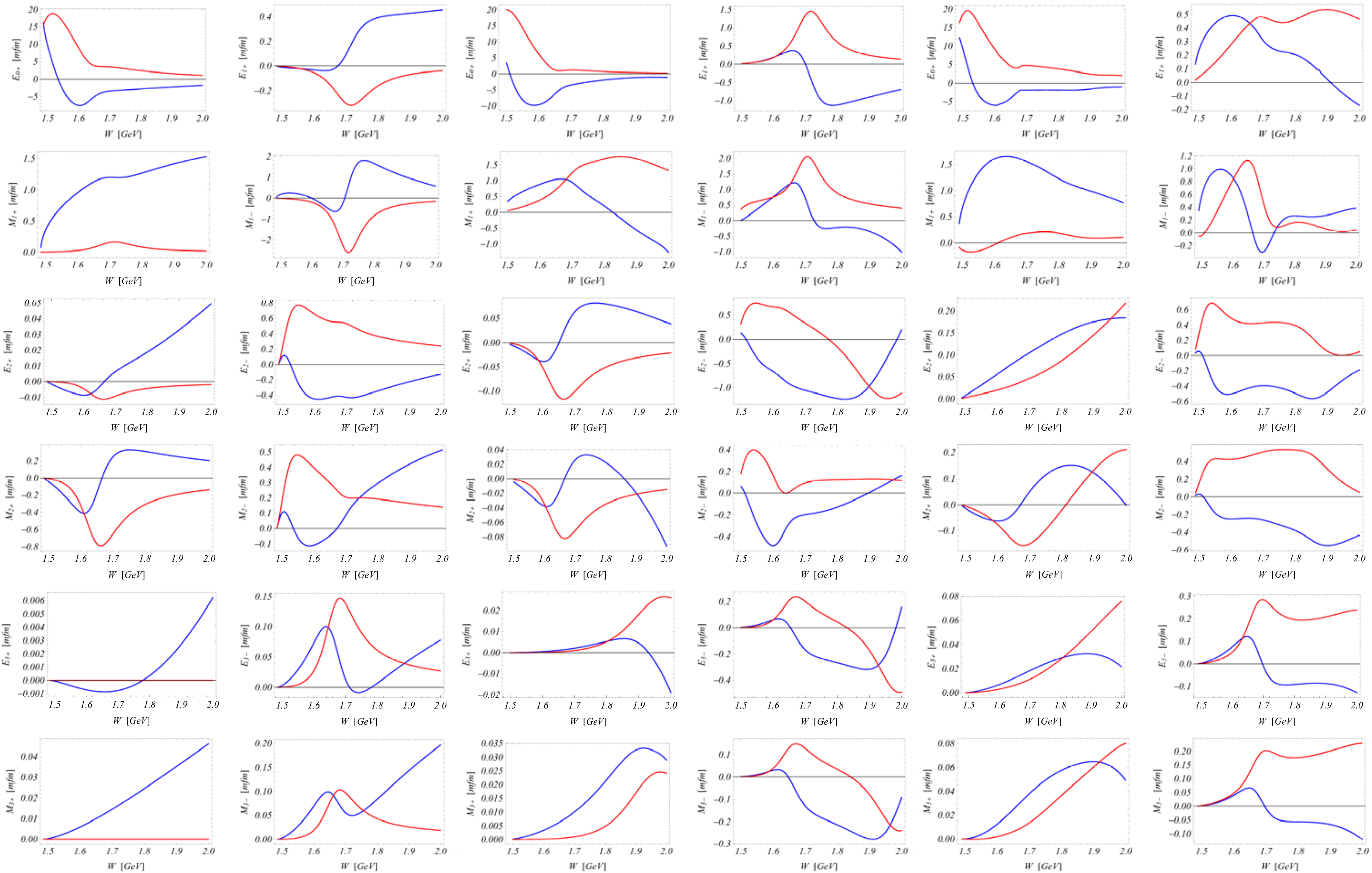
N*	M	G	Br Eta	Br Eta'	A1/2	A3/2	PDG stars for Nη
S11(1895)	1895.	220.	26.	5.2	-40.	---	**
P13(1900)	1915.	383.	-14.	-0.017	44.	-21.	**
F17(1990)	1894.	114.	0.046	-0.00	-19.	-93.	new
F15(2000)	2029.	244.	-0.67	0.015	-141.	60.	**
D15(2060)	2014.	454.	0.42	-0.92	-102.	8.9	*
D13(2120)	**2064.**	**305.**	**1.17**	**-0.34**	**147.**	**-130.**	**new**
G17(2190)	2223.	303.	2.07	1.9	88.	-18.	new
G19(2250)	2149.	575.	-2.05	-2.0	46.	0.8	new
D15(2570)	2475.	398.	-4.08	-0.29	-20.	-63.	new

10 resonances according to their importance in $\sigma_{total}(\gamma,\eta)$

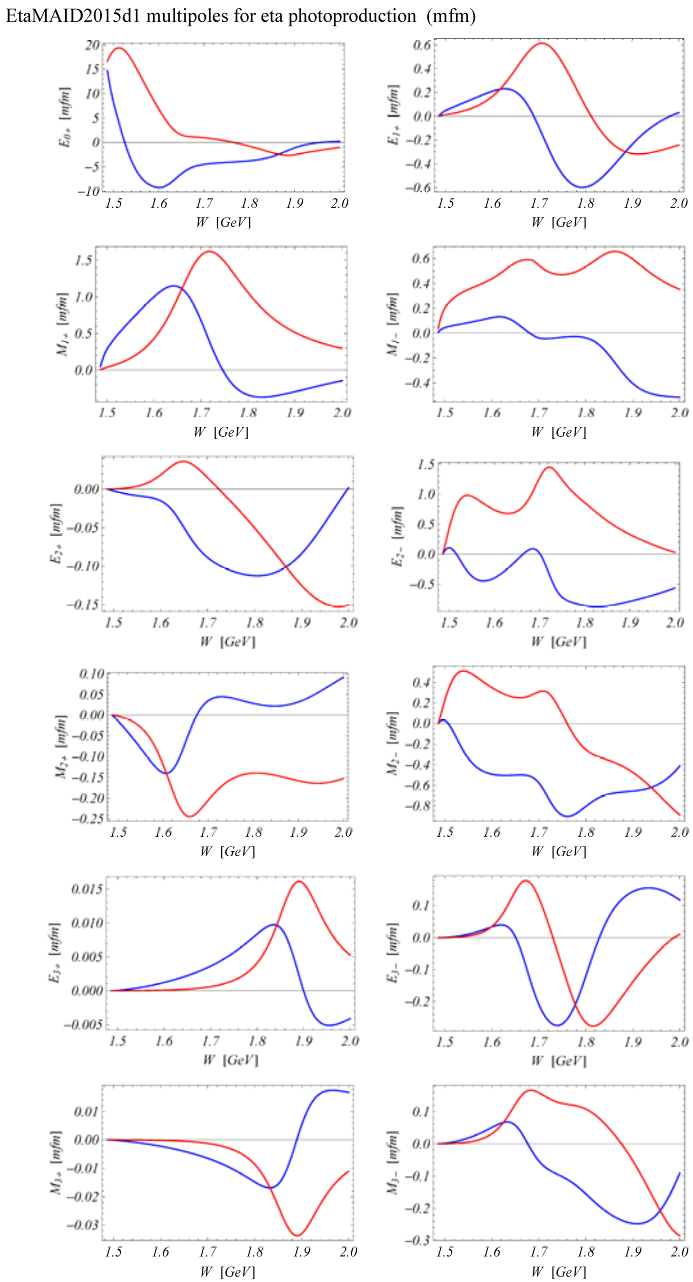
N*	M	G	Br Eta	A1/2	A3/2	PDG stars for Nη	
S11(1535)	1534.	161.	42.	115.	---	****	17 mb
S11(1650)	1645.	116.	-12.	45.	---	***	1 mb
S11(1895)	1895.	220.	26.	-40.	---	**	0.85 mb
P13(1720)	**1745.**	**268.**	**7.2**	**70.**	**30.**	*******	0.70 mb
D13(2120)	**2064.**	**305.**	**1.17**	**147.**	**-130.**	**new**	0.55 mb
P13(1900)	1915.	383.	-14.	44.	-21.	**	0.40 mb
P11(1710)	1724.	80.	2.2	50.	---	***	0.30 mb
F15(1860)	1819.	192.	1.1	-96.	-64.	new	0.30 mb
D13(1520)	1513.	125.	0.11	-28.0	124.	***	0.25 mb
F15(2000)	2029.	244.	-0.67	-141.	60.	**	0.25 mb

EtaMAID 2001 Aznauryan (DR) 2003 BnGa 2014-02

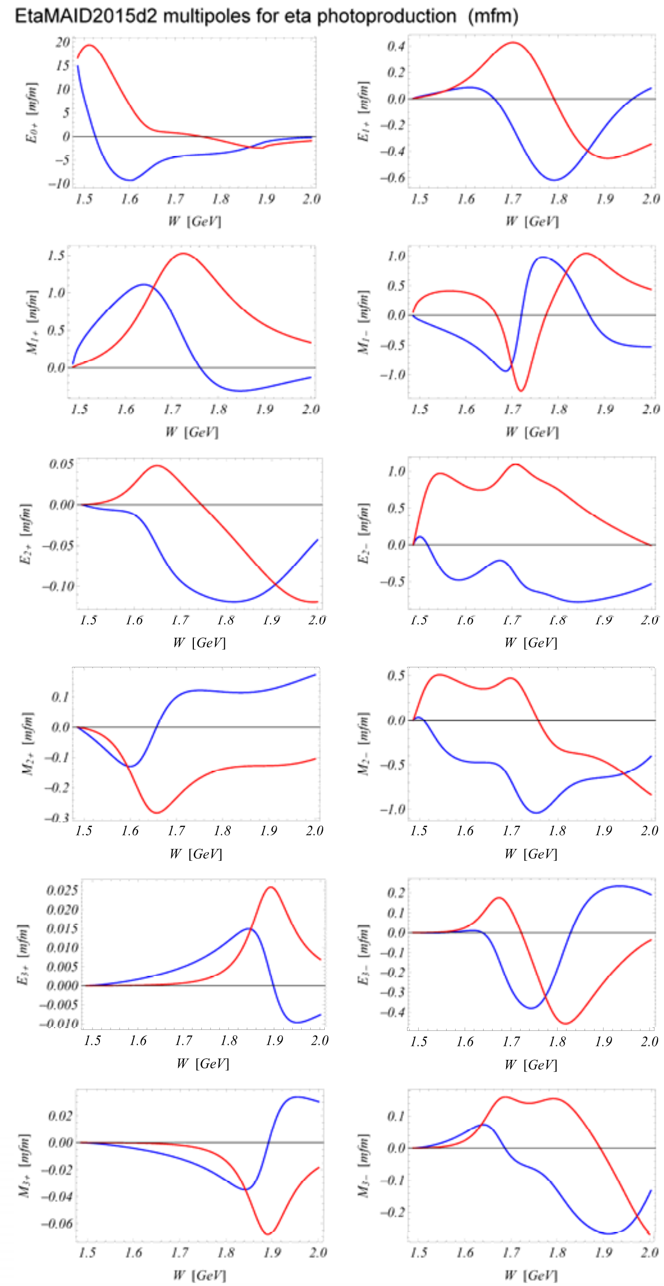
EtaMAID2001 multipoles for eta photoproduction (mfm) Aznauryan 2003 multipoles for eta photoproduction (mfm) Bonn-Gatchina 2004-2 multipoles for eta photoproduction (mfm) ⋆(−1)



EtaMAID 2015d-1



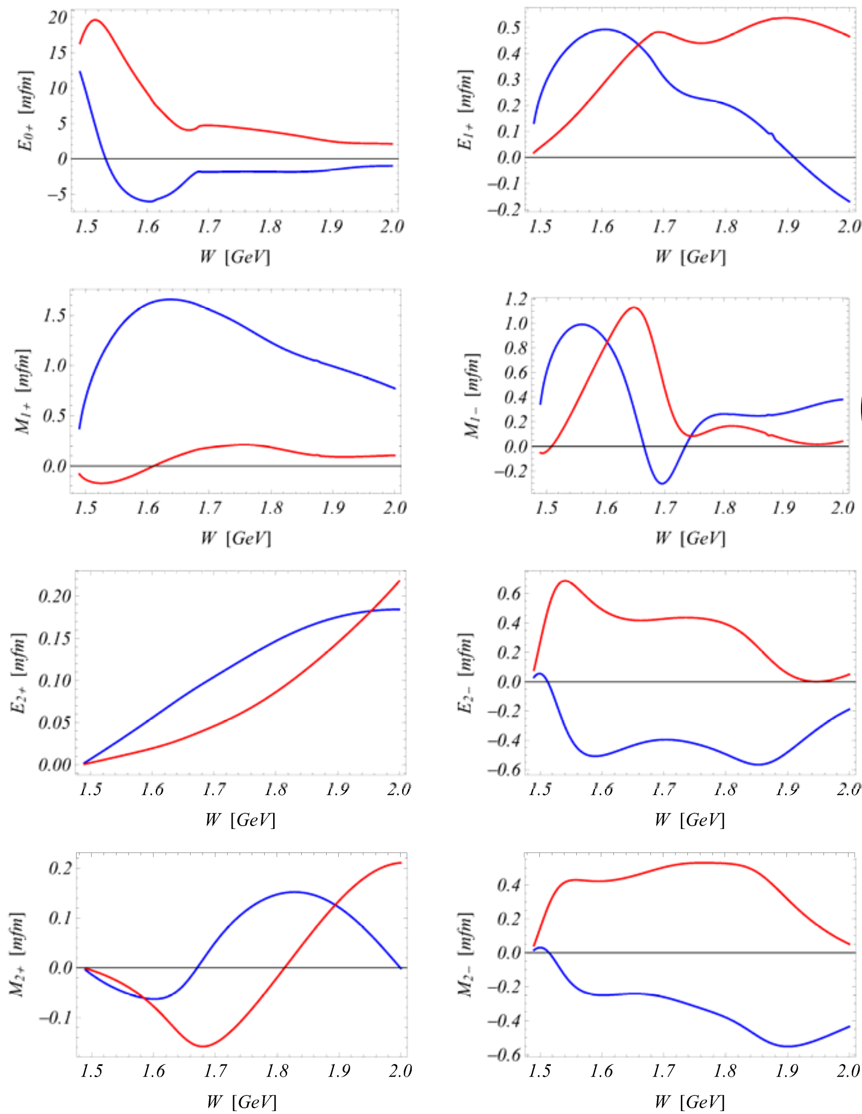
EtaMAID 2015d-2



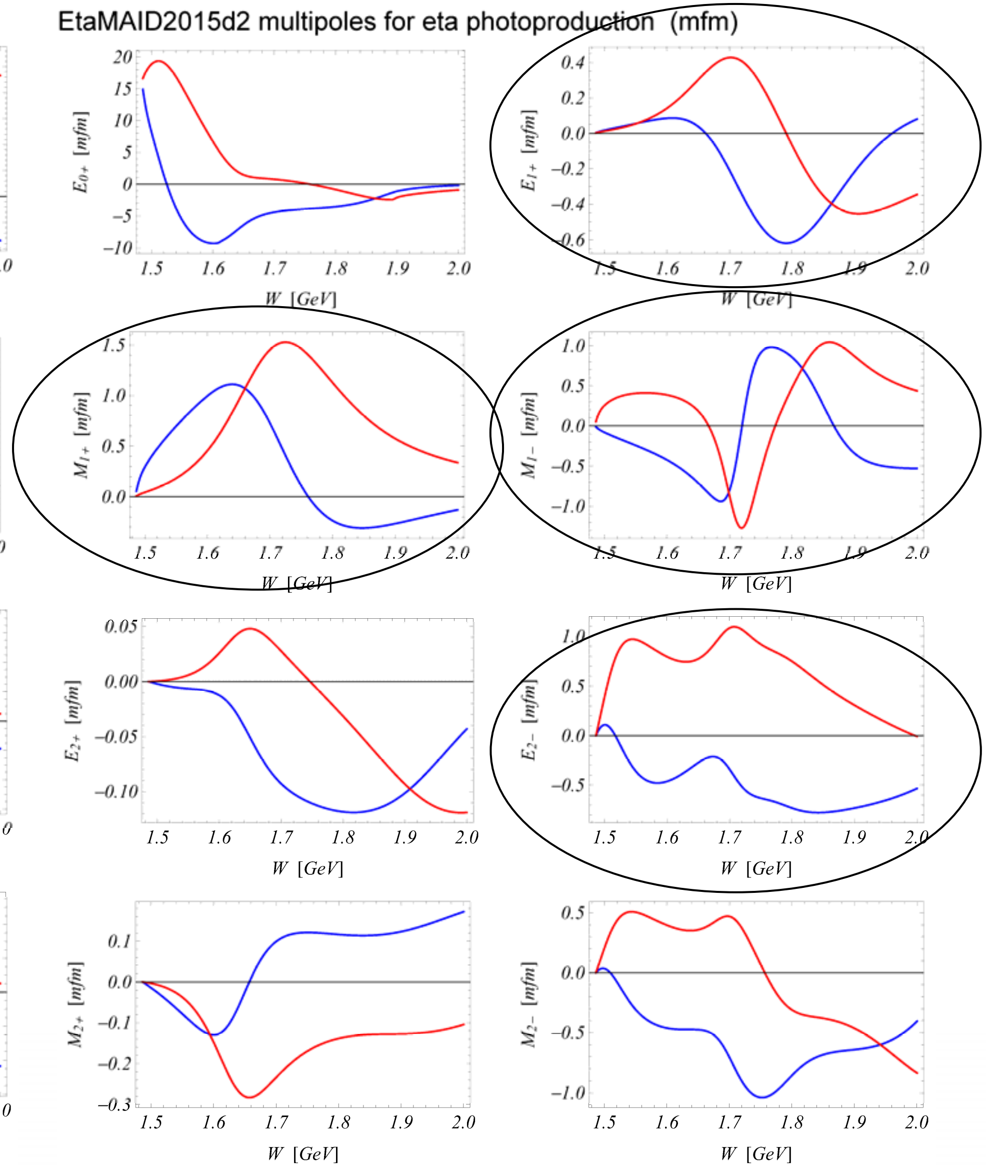
BnGa 2014-02 EtaMAID 2015d-2

only S wave almost agrees, other amplitudes show very large differences

Bonn-Gatchina 2004-2 multipoles for eta photoproduction (mfm) *(−1)

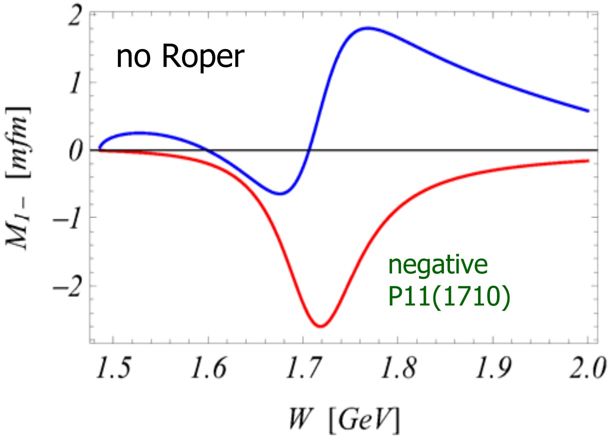


EtaMAID2015d2 multipoles for eta photoproduction (mfm)

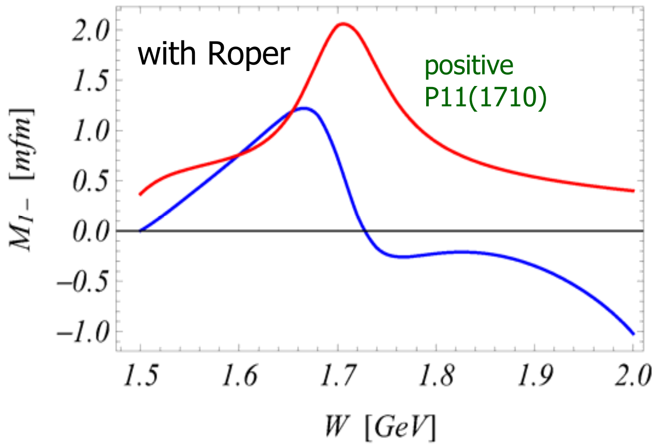


P11- M1- multipole

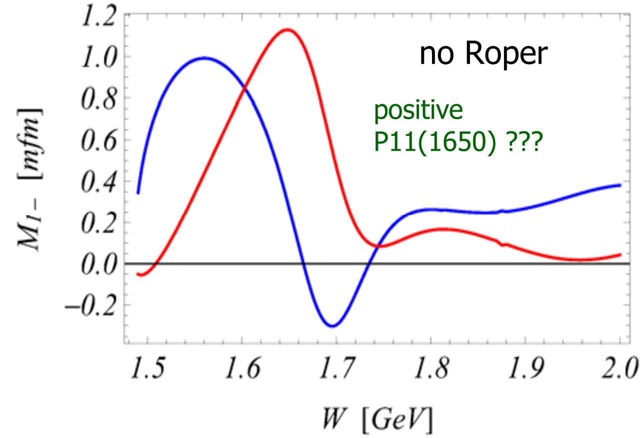
EtaMAID 2001



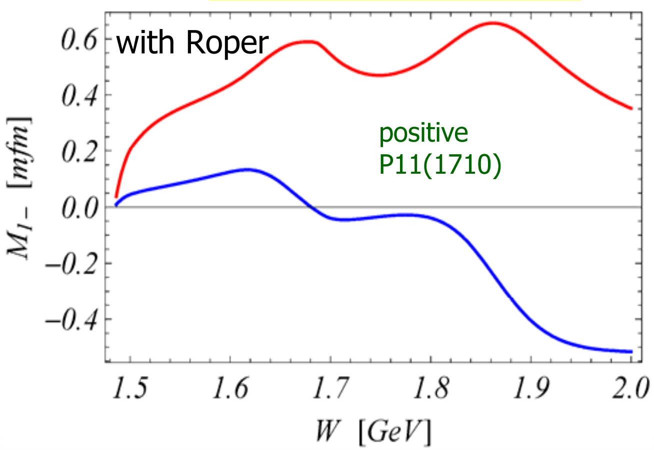
Aznauryan (DR) 2003



BnGa 2014-02



EtaMAID 2015d-1



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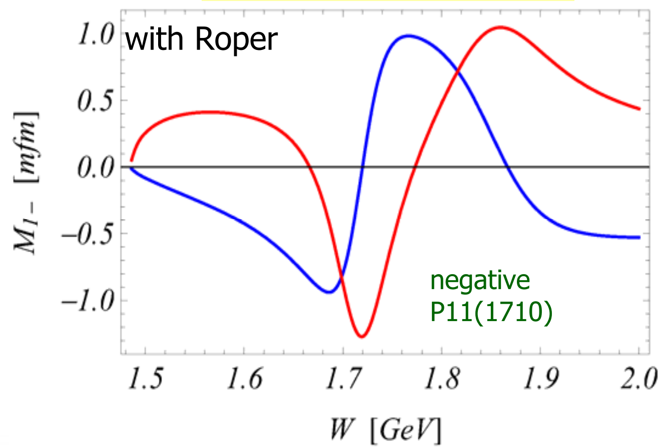

Summary and Outlook

to update the old EtaMAID model from 2001-2003 with new data
we need to increase the N* resonances from originally 7 now up to 23!

the background of Born and vector meson poles is rather small
and the whole new structure has to be described with N* resonances
this is possible!

on the other hand, the Regge approach that Viktor presented can even
describe a lot of structure in the resonance region down to eta threshold,
but the Regge region is commonly expected to start around etaprime threshold!

how can we proceed?