Mini-Workshop Bled 2015

Exploring Hadron Resonances

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ηMAID-2015: update with new data and new resonances

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SFB 1044 THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

A2

Outline

- ηMAID-2003
- Review of new experimental data
- Truncated PWA with Legendre expansion method
- ηMAID-2015 for η and η' photoproduction
- Summary

ηMAID-2003

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.

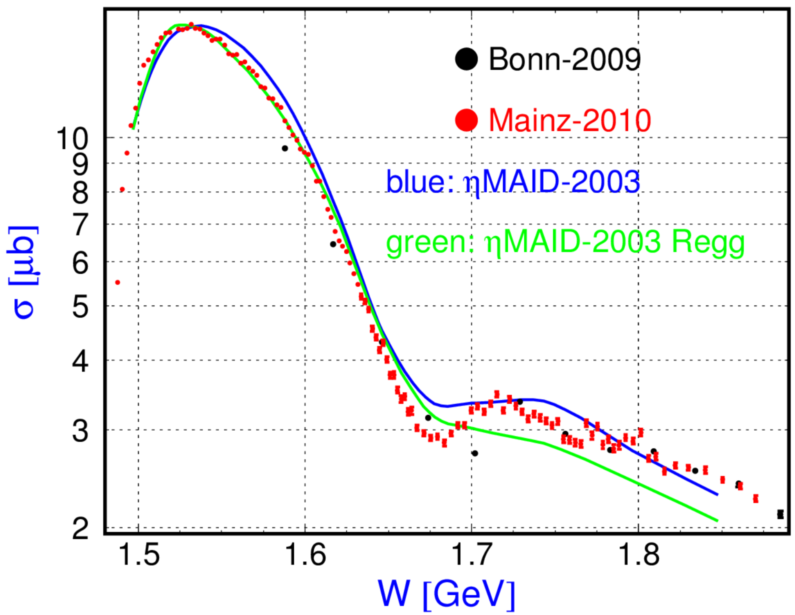
Model variable parameters:
- Born terms: coupling η to nucleon $g^2_{\eta NN}$;
- vector mesons: hadronic vector g_v and tensor g_t couplings, dipole form factor Λ_v ;
- resonances: mass M_R , total width Γ_R at the resonance peak , branching ratio $\beta_{\eta N}$; photoexcitation helicity amplitudes $A_{1/2}$, $A_{3/2}$;
- 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, $\zeta_{\eta N} = \pm 1$.

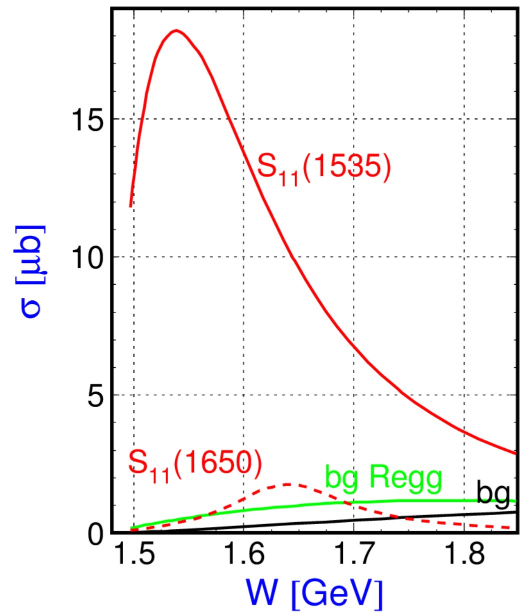
Data set:
- total and differential cross sections of MAMI and GRAAL;
- photon asymmetry of GRAAL (E_γ<1.1 GeV);
- electroproduction cross sections of Jlab.

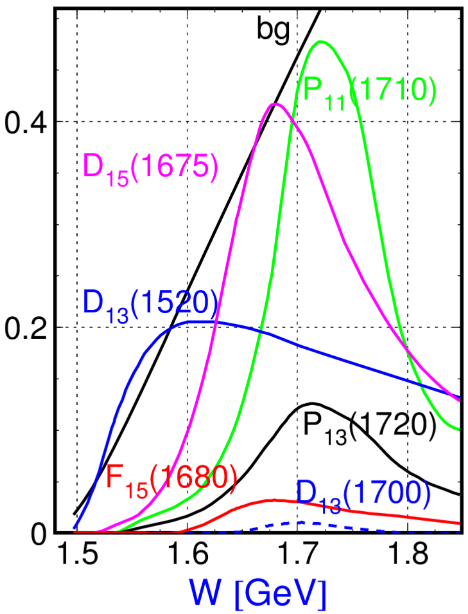
Reggeized model for η and η' photoprduction,
W.-T. Chiang, S.N. Yang, L. Tiator, M. Vanderhaeghen, D. Drechsel, PRC 68 (2003) 045202.
Main difference: vector meson exchanges are described in terms of Regge trajectories.
It should be important for high energies, W> 3GeV.

$\gamma\, p \rightarrow \eta\, p$ ηMAID-2003

$D_{13}(1520)$	$S_{11}(1535)$	$S_{11}(1650)$	$D_{15}(1675)$	$F_{15}(1680)$	$D_{13}(1700)$	$P_{11}(1710)$	$P_{13}(1720)$
$N(1520)3/2^-$	$N(1535)1/2^-$	$N(1650)1/2^-$	$N(1675)5/2^-$	$N(1680)5/2^+$	$N(1700)3/2^-$	$N(1710)1/2^+$	$N(1720)3/2^+$
$D_{13}(1520)^-$	$S_{11}(1535)^-$	$S_{11}(1650)^-$	$D_{15}(1675)^-$	$F_{15}(1680)^+$	$D_{13}(1700)^-$	$P_{11}(1710)^+$	$P_{13}(1720)^+$







- dominance of S_{11}
- small background
- Important role of D_{13} near threshold

Bonn-2009: V. Crede et al., PRC 80 (2009) 055202
Mainz-2010: E. F. McNicoll et al., PRC 82 (2010) 035208

New data sets

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

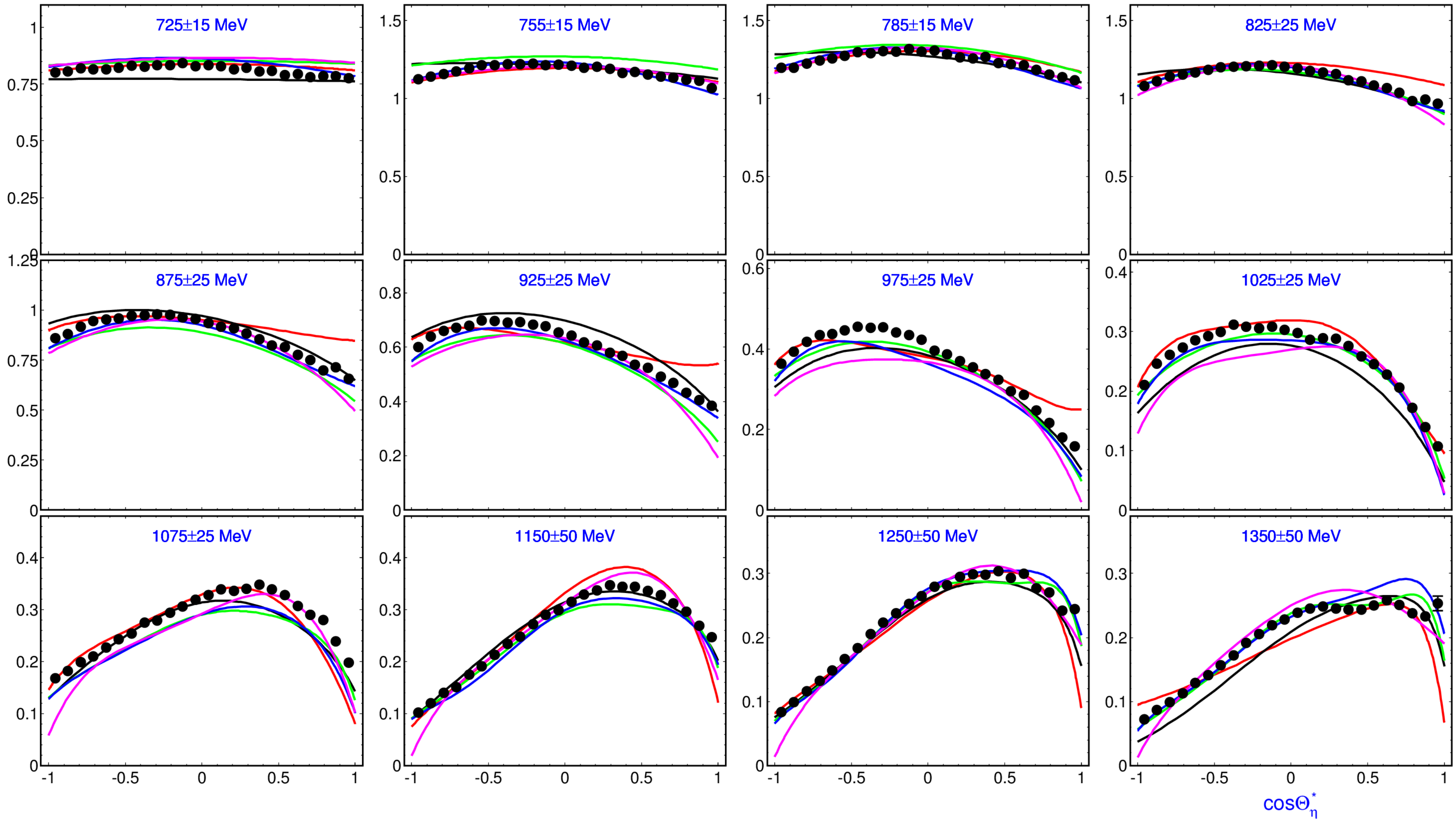
- dσ/dΩ, A2MAMI: E_γ=0.709–1.4 GeV, 120x24 [Prakhov, preliminary]
- dσ/dΩ, A2MAMI: E_γ=0.71–1.44 GeV, 113x24 – // –
- dσ/dΩ, A2MAMI: E_γ=1.43–1.57 GeV, 12x24 – // –
- dσ/dΩ, CBELSA/TAPS-09: E_γ=0.87–2.55 GeV, 34x20 [PRC 80, 055202, 2009]
- dσ/dΩ, CLAS-09: E_γ=1.46– 3.7 GeV, 42x(13-18) [PRC 80, 045213, 2009]
- T , A2MAMI-14: E_γ=0.71–1.4 GeV, 12x12 [PRL 113, 102001, 2014]
- F , A2MAMI-14: – // –
- Σ , GRAAL-07: E_γ=0.71–1.5 GeV, 15x10 [EPJA 33, 169, 2007]
- E , CLAS-15: E_γ=0.71–2.15 GeV [arXiv:1507.00325v1 2015]

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

- dσ/dΩ, A2MAMI: E_γ=1.45–1.57 GeV, 12x10 [Prakhov, preliminary]
- dσ/dΩ, CBELSA/TAPS-09: E_γ=1.53–2.48 GeV, 20x10 [PRC 80, 055202, 2009]
- dσ/dΩ, CLAS-09: E_γ=1.51–3.43 GeV, 39x(13-18) [PRC 80, 045213, 2009]
- Σ , GRAAL-15: E_γ=1.46–1.48 GeV, 2x7 [Sandri et al, EPJA, to be published]

γ p → η p

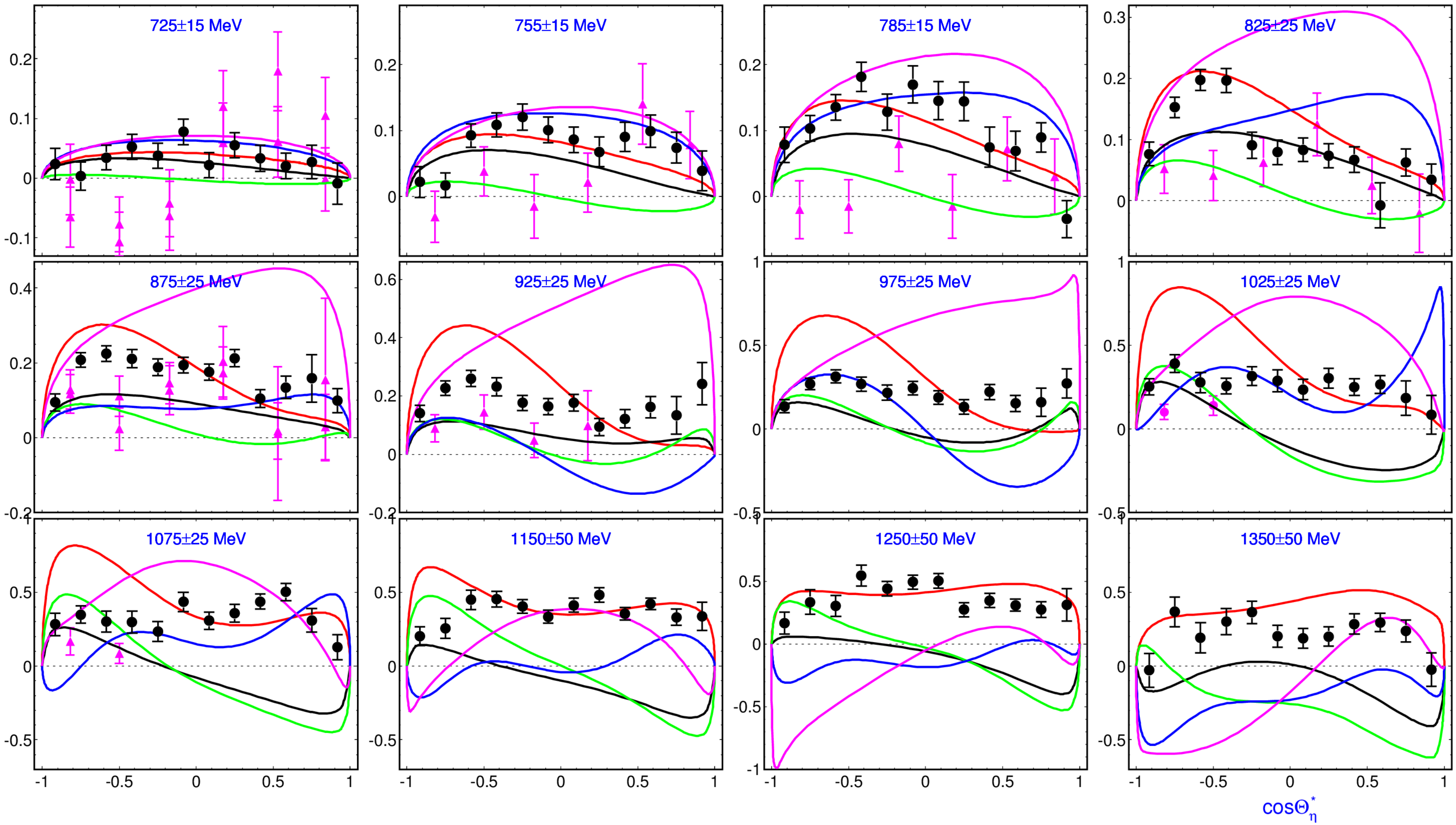
Differential cross section



black circles: A2MAMI (preliminary)

red line: ηMAID-03, NP A700, 429 (2002)
blue: SAID GE09, PRC 82, 035208 (2010)
green: BG2011-02, EPJA 47, 153 (2011)
black: Giessen Model, PRC 87, 015201 (2013)
magenta: Tryasuchev, EPJA 50, 120 (2014)

$\gamma\ p \rightarrow \eta\ p$ *Target asymmetry T*

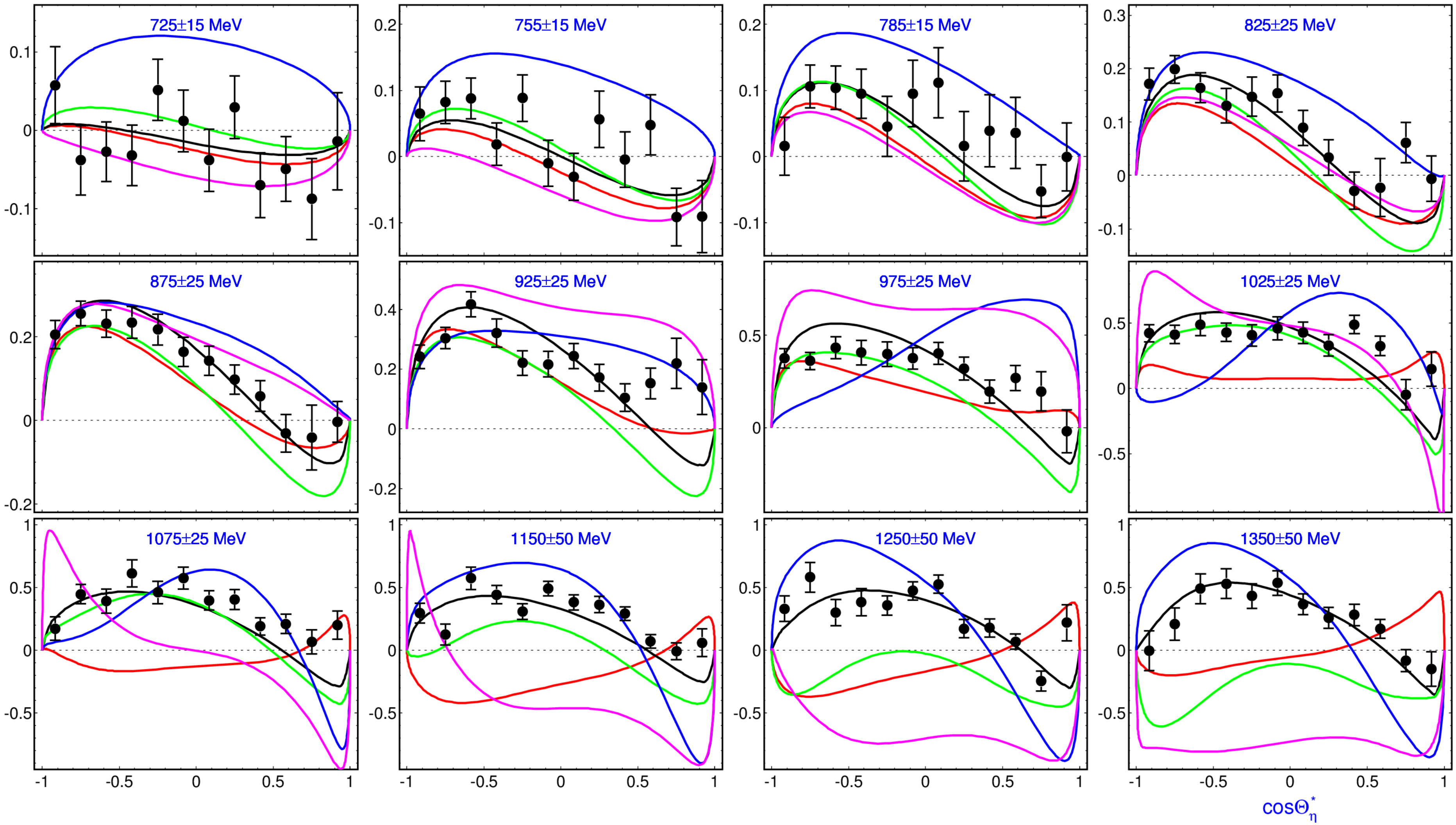


black circles: A2MAMI-14 (PRL 113, 102001, 2014)

magenta triangles: CBELSA-98 (PRL 81, 534, 1998)

red line: ηMAID-03 (NP A700, 429, 2002)
blue: SAID GE09 (PRC 82, 035208, 2010)
green: BG2011-02 (EPJA 47, 153, 2011)
black: Giessen Model (PRC 87, 015201, (2013)
magenta: Tryasuchev (EPJA 50, 120, 2014)

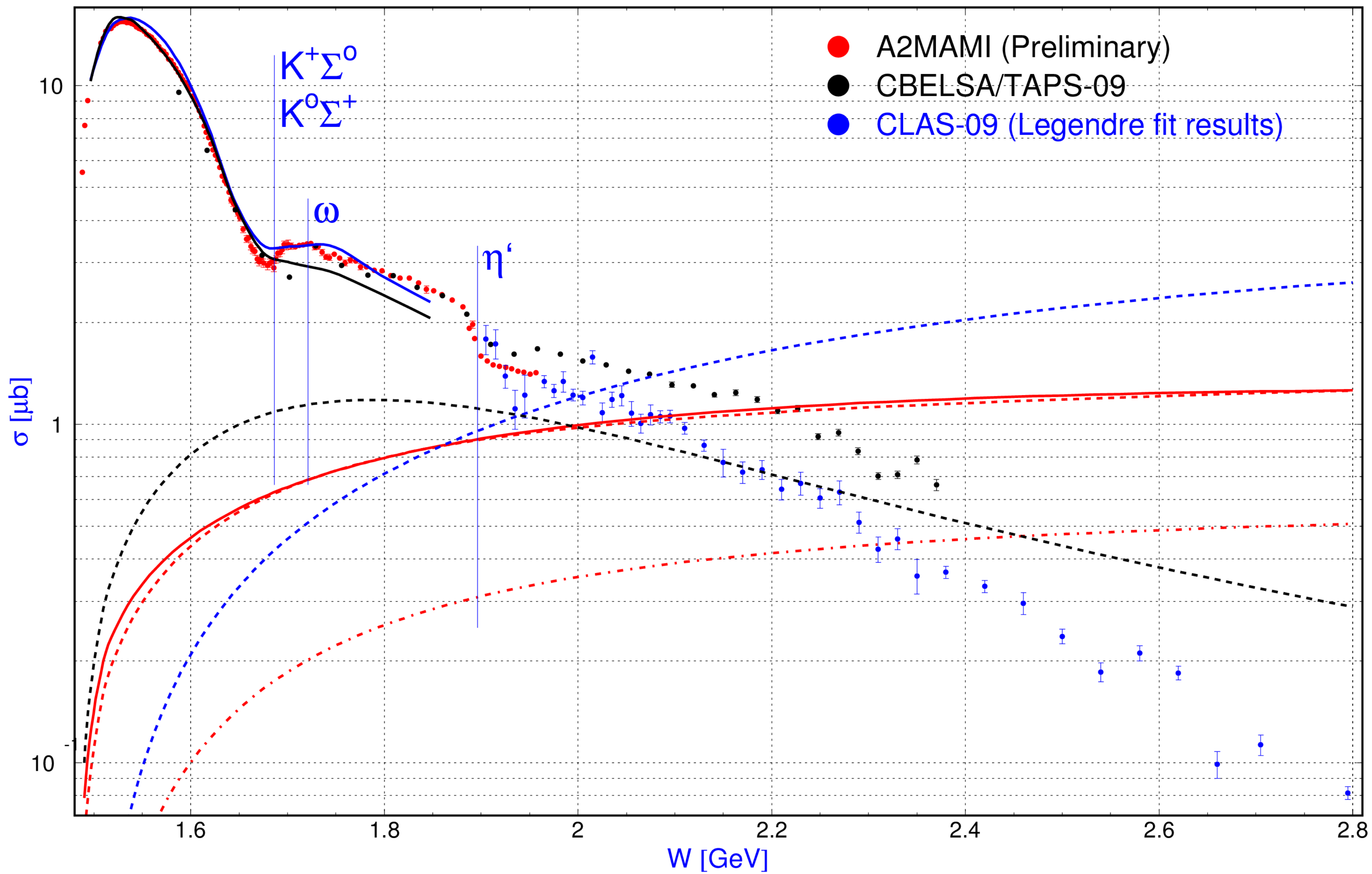
$\gamma\ p \rightarrow \eta\ p$ — *Beam-target asymmetry F*



black circles: A2MAMI-14 (PRL 113, 102001, 2014)

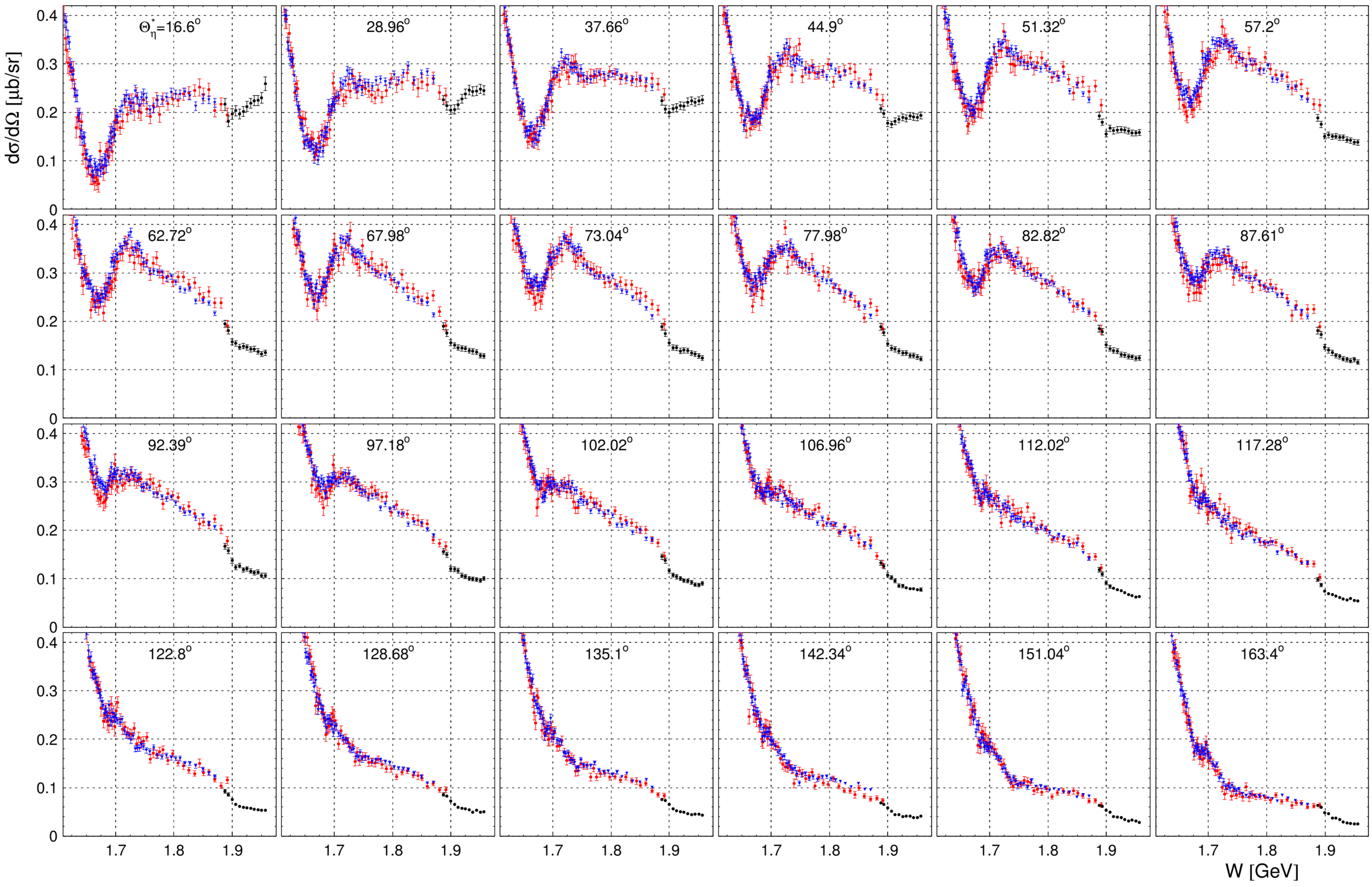
red line: ηMAID-03 (NP A700, 429, 2002)
blue: SAID GE09 (PRC 82, 035208, 2010)
green: BG2011-02 (EPJA 47, 153, 2011)
black: Giessen Model (PRC 87, 015201, (2013)
magenta: Tryasuchev (EPJA 50, 120, 2014)

$\gamma\ p \rightarrow \eta\ p$ *total cross section*

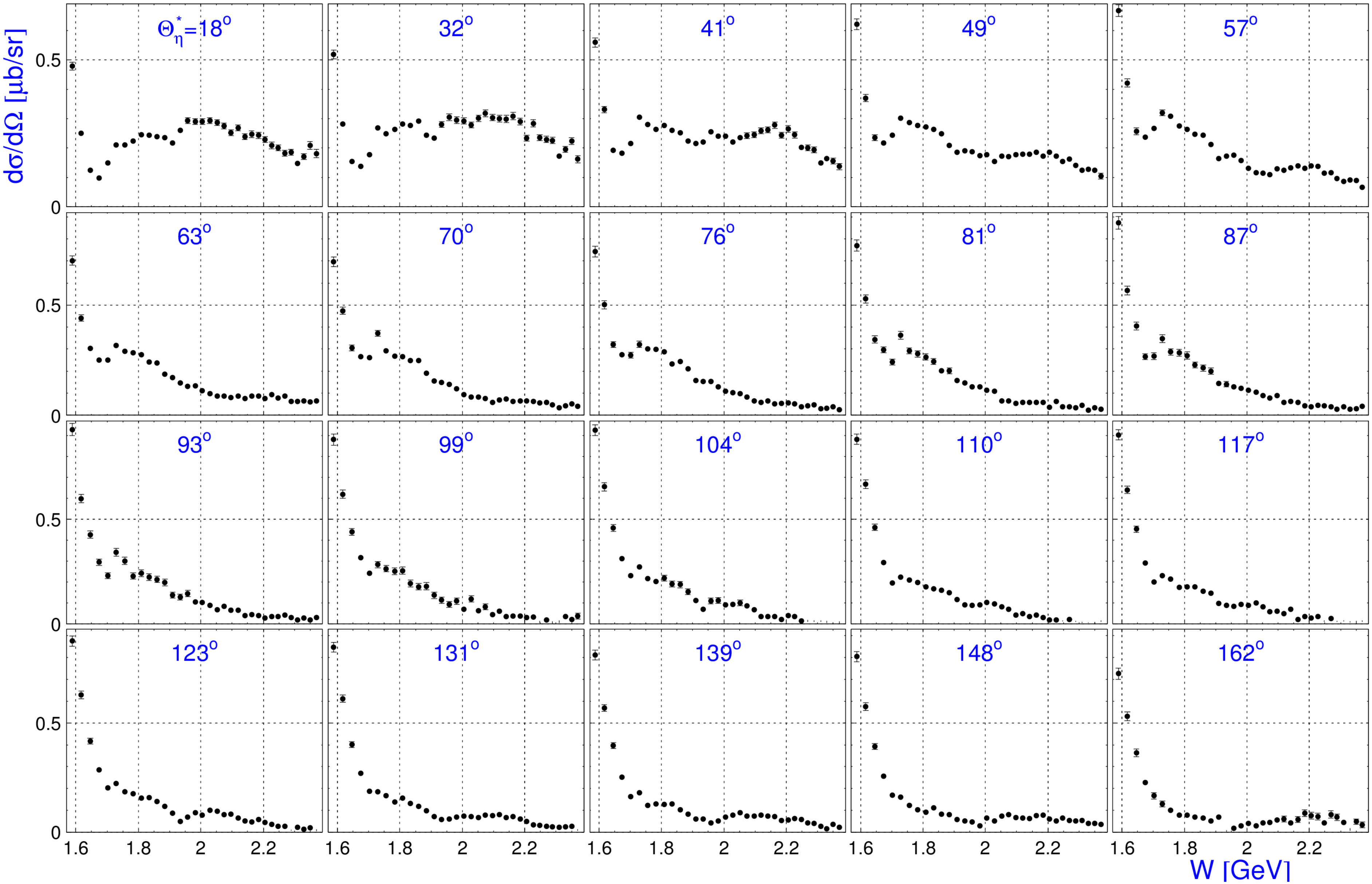


solid blue: ηMAID-2003, dashed: Born+Rho+Omega, red: Born, dashed: Rho, dotted-dashed: Omega
solid black: ηMAID-2003 Regg, dashed: Rho+Omega

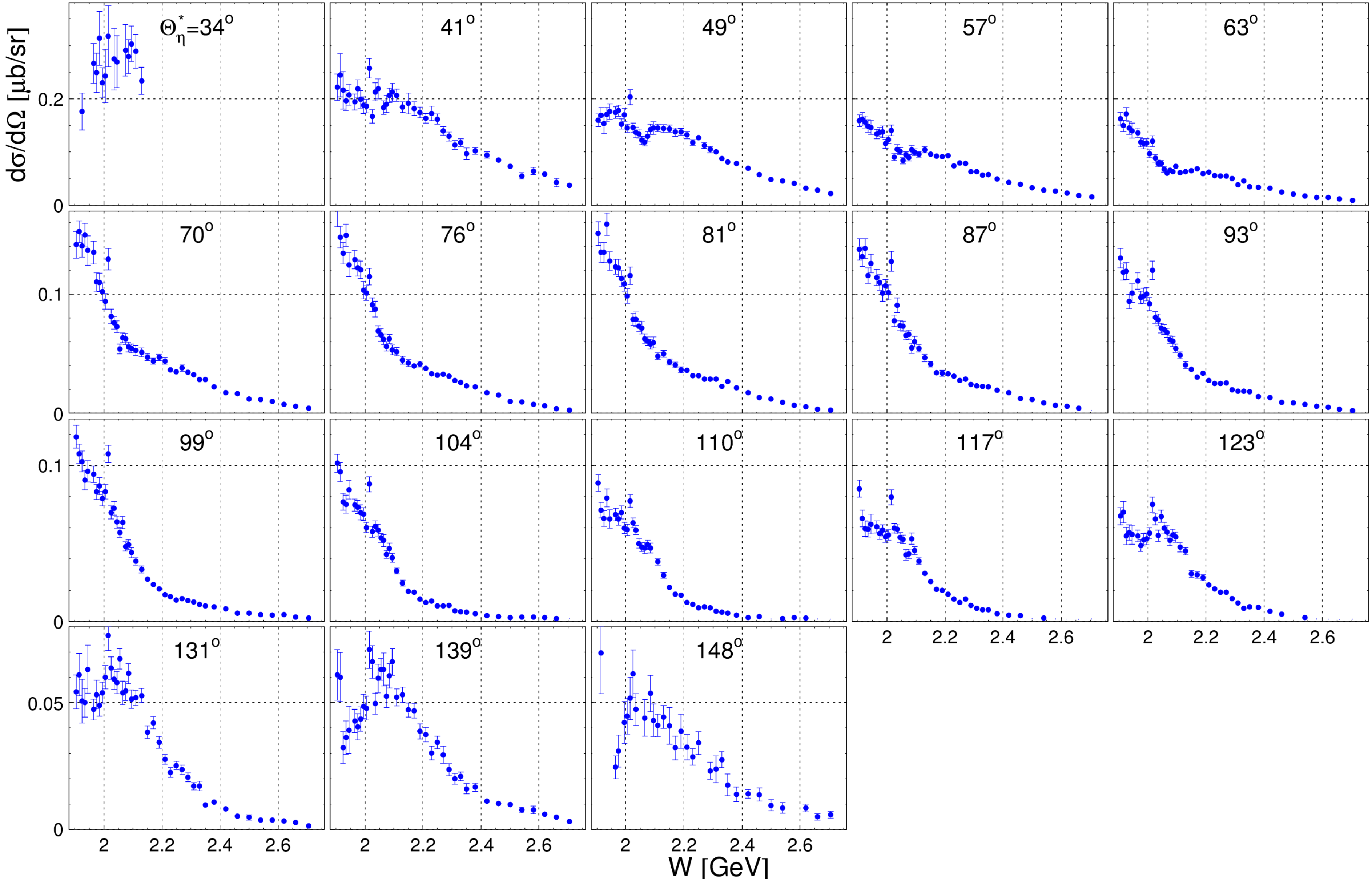
$\gamma\ p \rightarrow \eta\ p$ Excitation function, A2MAMI (preliminary)



$\gamma\ p \rightarrow \eta\ p$ Excitation function, CBELSA/TAPS – 09



$\gamma\ p \rightarrow \eta\ p$ Excitation function, CLAS – 09



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

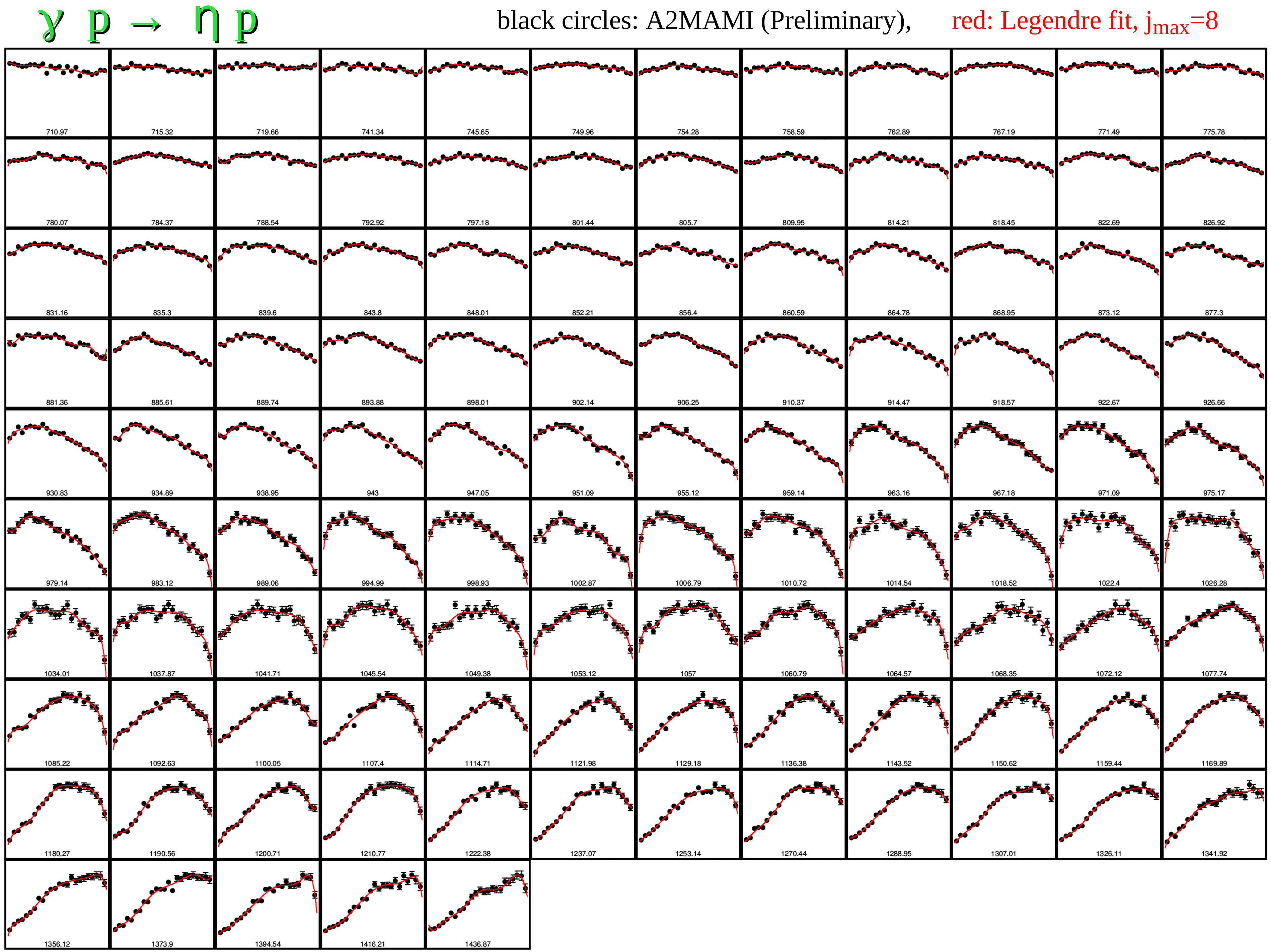
$$\begin{aligned} P_\ell^0(cos\theta) &= P_\ell(cos\theta)\,, \\ P_\ell^1(cos\theta) &= -sin\theta\; P_\ell^{'}(cos\theta)\,, \\ P_\ell^2(cos\theta) &= sin^2\theta\; P_\ell^{''}(cos\theta)\,. \end{aligned}$$

In particular we can find an expansion

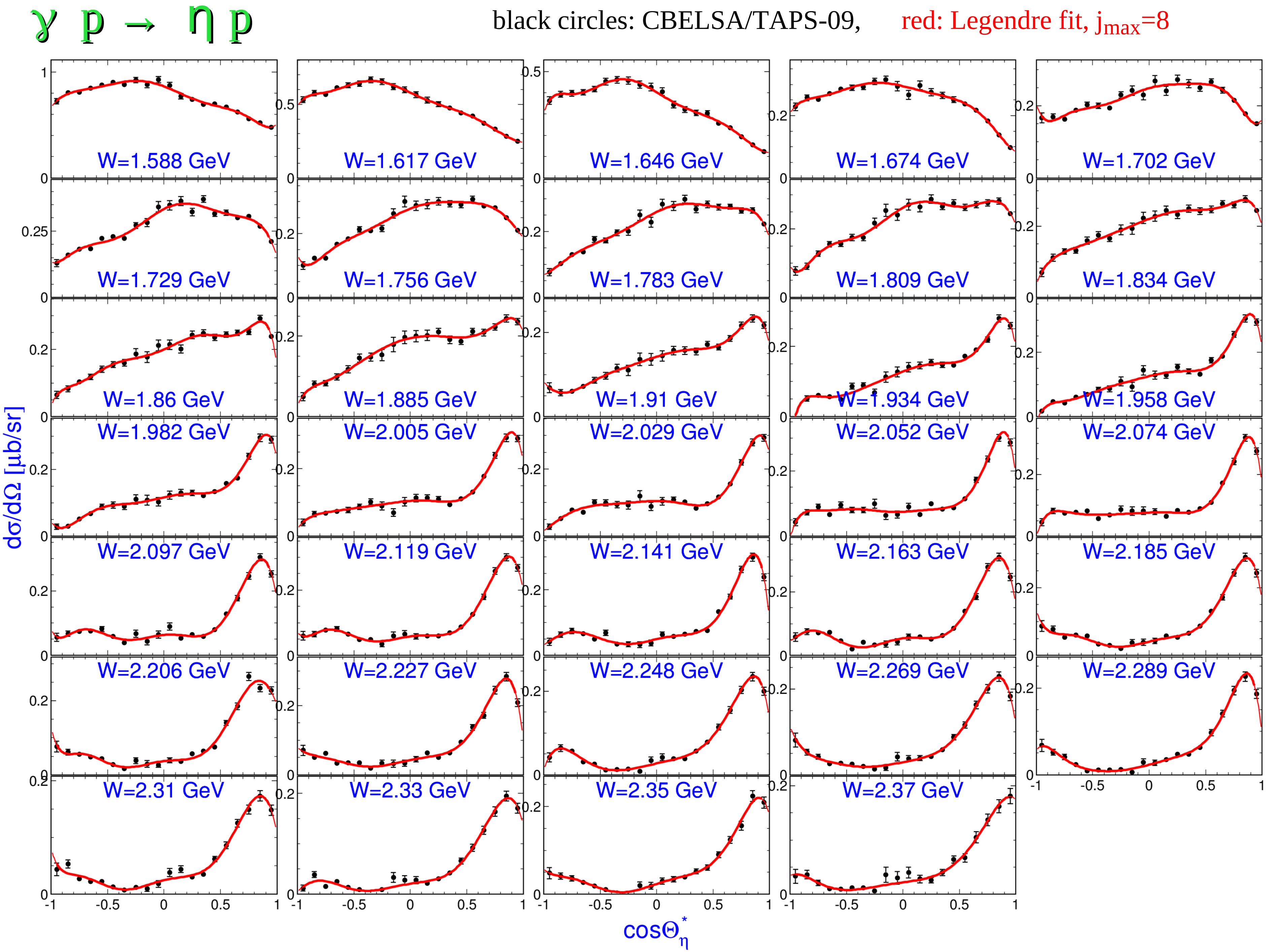
$$\begin{aligned} O_i(W,\theta) &= \sum_{k=0}^{2\ell_{max}} A_k^i(W)\; P_k^0(cos\theta), \text{ for } O_i = \{\sigma_0, \hat{E}\} \\ O_i(W,\theta) &= \sum_{k=1}^{2\ell_{max}} A_k^i(W)\; P_k^1(cos\theta), \text{ for } O_i = \{\hat{T}, \hat{P}, \hat{F}, \hat{H}\} \\ O_i(W,\theta) &= \sum_{k=2}^{2\ell_{max}} A_k^i(W)\; P_k^2(cos\theta), \text{ for } O_i = \{\hat{\Sigma}, \hat{G}\} \end{aligned}$$

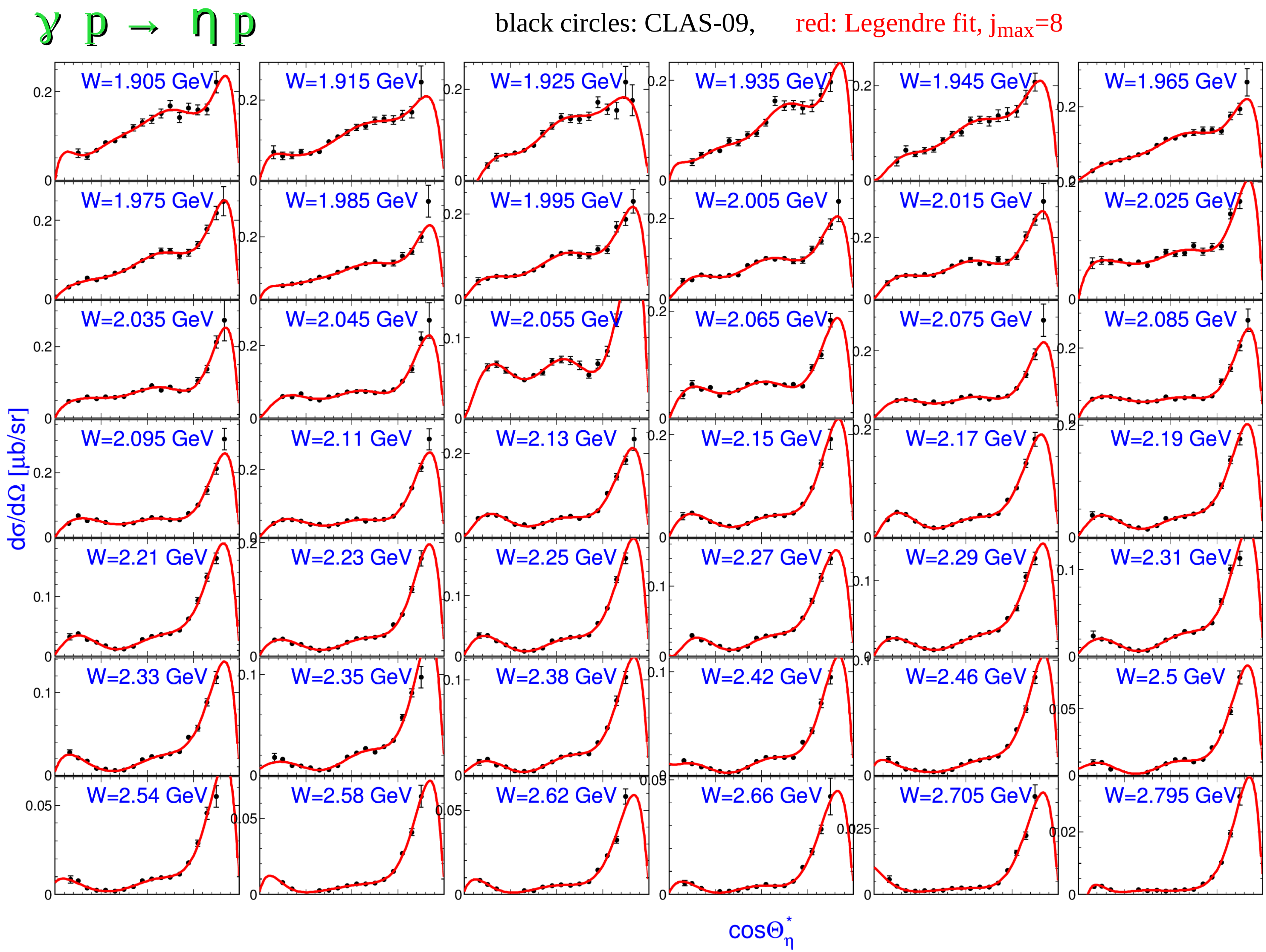
Partial wave content of Legendre coefficients, $l_{max} = 3$

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



γ p → η p
black circles: A2MAMI (Preliminary),
red: Legendre fit, j_{max}=8
710.97
715.32
719.66
741.34
745.65
749.96
754.28
758.59
762.89
767.19
771.49
775.78
780.07
784.37
788.54
792.92
797.18
801.44
805.7
809.95
814.21
818.45
822.69
826.92
831.16
835.3
839.6
843.8
848.01
852.21
856.4
860.59
864.78
868.95
873.12
877.3
881.36
885.61
889.74
893.88
898.01
902.14
906.25
910.37
914.47
918.57
922.67
926.66
930.83
934.89
938.95
943
947.05
951.09
955.12
959.14
963.16
967.18
971.09
975.17
979.14
983.12
989.06
994.99
998.93
1002.87
1006.79
1010.72
1014.54
1018.52
1022.4
1026.28
1034.01
1037.87
1041.71
1045.54
1049.38
1053.12
1057
1060.79
1064.57
1068.35
1072.12
1077.74
1085.22
1092.63
1100.05
1107.4
1114.71
1121.98
1129.18
1136.38
1143.52
1150.62
1159.44
1169.89
1180.27
1190.56
1200.71
1210.77
1222.38
1237.07
1253.14
1270.44
1288.95
1307.01
1326.11
1341.92
1356.12
1373.9
1394.54
1416.21
1436.87


γ p → η p
black circles: CBELSA/TAPS-09,
red: Legendre fit, j_{max}=8
dσ/dΩ [μb/sr]
cosΘ*η
W=1.588 GeV
W=1.617 GeV
W=1.646 GeV
W=1.674 GeV
W=1.702 GeV
W=1.729 GeV
W=1.756 GeV
W=1.783 GeV
W=1.809 GeV
W=1.834 GeV
W=1.86 GeV
W=1.885 GeV
W=1.91 GeV
W=1.934 GeV
W=1.958 GeV
W=1.982 GeV
W=2.005 GeV
W=2.029 GeV
W=2.052 GeV
W=2.074 GeV
W=2.097 GeV
W=2.119 GeV
W=2.141 GeV
W=2.163 GeV
W=2.185 GeV
W=2.206 GeV
W=2.227 GeV
W=2.248 GeV
W=2.269 GeV
W=2.289 GeV
W=2.31 GeV
W=2.33 GeV
W=2.35 GeV
W=2.37 GeV



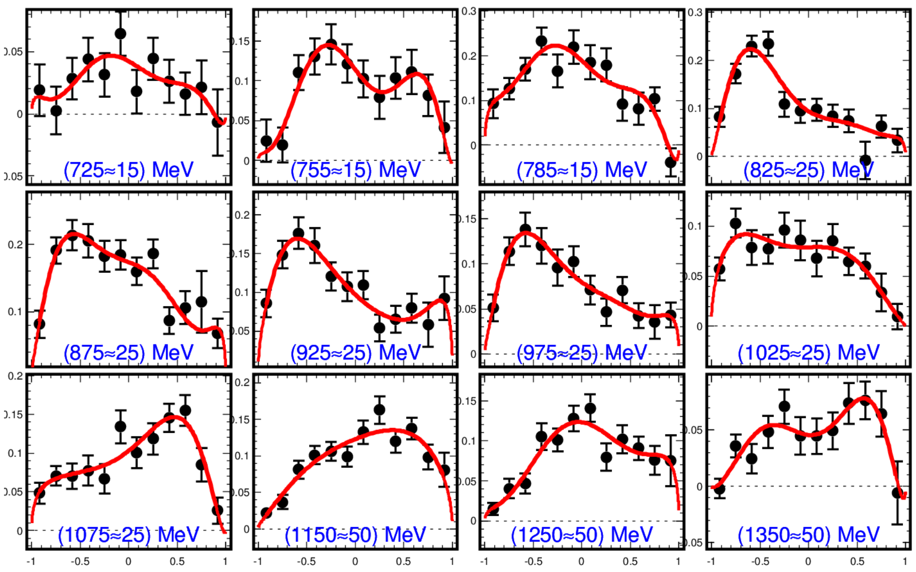
γ p → η p
black circles: CLAS-09,
red: Legendre fit, j_{max}=8
W=1.905 GeV
W=1.915 GeV
W=1.925 GeV
W=1.935 GeV
W=1.945 GeV
W=1.965 GeV
W=1.975 GeV
W=1.985 GeV
W=1.995 GeV
W=2.005 GeV
W=2.015 GeV
W=2.025 GeV
W=2.035 GeV
W=2.045 GeV
W=2.055 GeV
W=2.065 GeV
W=2.075 GeV
W=2.085 GeV
W=2.095 GeV
W=2.11 GeV
W=2.13 GeV
W=2.15 GeV
W=2.17 GeV
W=2.19 GeV
W=2.21 GeV
W=2.23 GeV
W=2.25 GeV
W=2.27 GeV
W=2.29 GeV
W=2.31 GeV
W=2.33 GeV
W=2.35 GeV
W=2.38 GeV
W=2.42 GeV
W=2.46 GeV
W=2.5 GeV
W=2.54 GeV
W=2.58 GeV
W=2.62 GeV
W=2.66 GeV
W=2.705 GeV
W=2.795 GeV
dσ/dΩ [μb/sr]
$\cos\Theta^*_\eta$

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

Legendre fit results for T and F

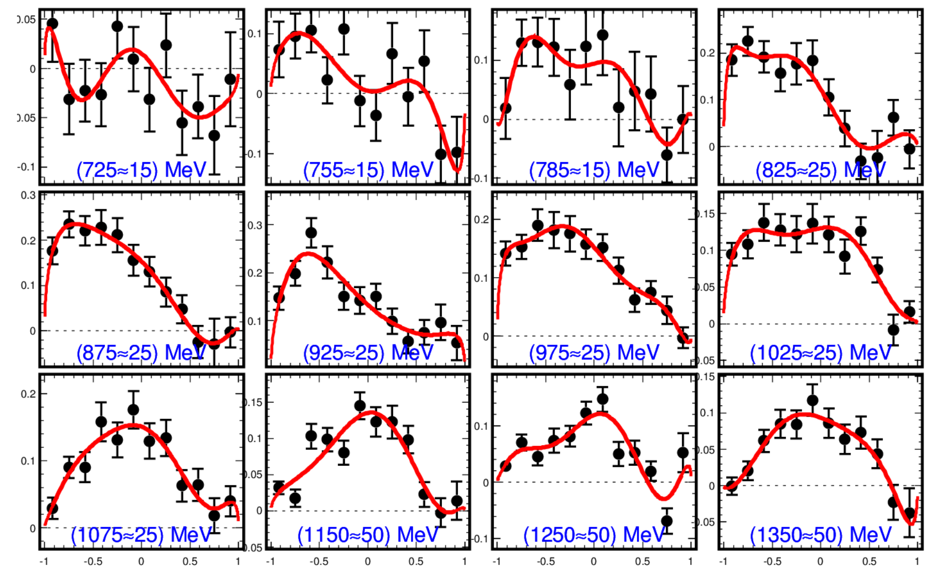
$j_{max}=6$

T dσ/dΩ



$\cos\Theta_\eta$

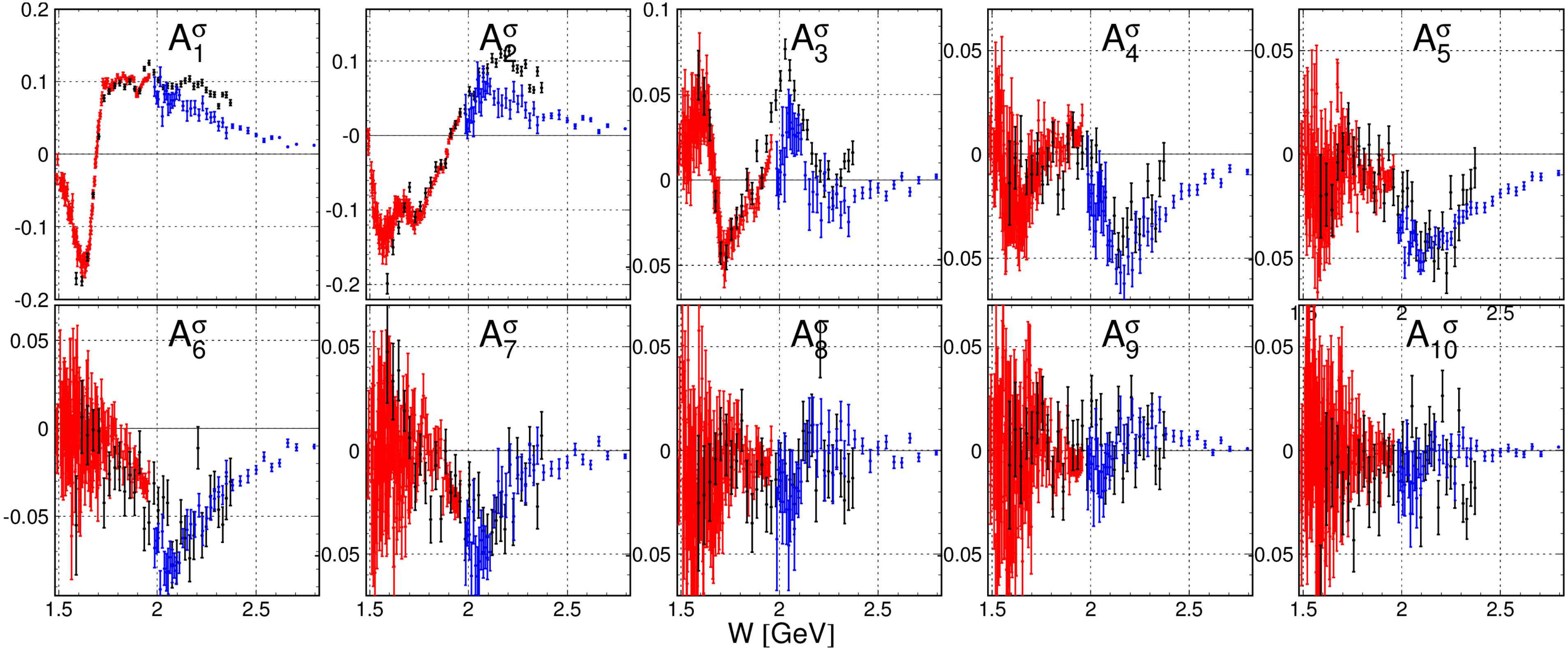
F dσ/dΩ



$\cos\Theta_\eta$

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

Legendre coefficients in μb/sr units from fitting differential cross sections with jmax=10



red: A2MAMI preliminary data black: CBELSA/TAPS-2009 blue: CLAS – 09

ηMAID-2015

Main goals:

- expand ηMAID-2003 to higher energy
- improve description of polarization data
- add η' photoproduction

Main changes in ηMAID-2003:

- included 12 additional resonances
- updated parameters of vector mesons
- updated data base for the fit: last data from A2MAMI, CLAS, and GRAAL for η and η' photoproduction

ηMAID-2015

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-2015

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

Other resonances below 3000 MeV (PDG-2014)

$P_{11}(1440)$**** $P_{11}(2300)$** $D_{15}(2570)$**

N(2600)11/2– *** N(2700)13/2+ **

$P_{13}(2040)$* $P_{11}(2100)$*

Vector meson exchanges in the t-channel

Parameters for vector mesons:

- electomagnetic couplings $\lambda_{\rho\eta\gamma}$, $\lambda_{\omega\eta\gamma}$ and $\lambda_{\rho\eta'\gamma}$, $\lambda_{\omega\eta'\gamma}$ (fixed)
  determined from corresponding radiative decay widths:
  $\Gamma_{\rho\to\eta\gamma}$ and $\Gamma_{\omega\to\eta\gamma}$ for η photoproduction,
  $\Gamma_{\eta'\to\rho\gamma}$ and $\Gamma_{\eta'\to\omega\gamma}$ for η' photoproduction

- hadronic vector $g_{\rho NN}$, $g_{\omega NN}$ couplings and $k_{\rho NN}=g^t_{\rho NN}/g_{\rho NN}$, $k_{\omega NN}=g^t_{\omega NN}/g_{\omega NN}$,
  where $g^t_{\rho NN}$ and $g^t_{\omega NN}$ are tensor couplings (variable)

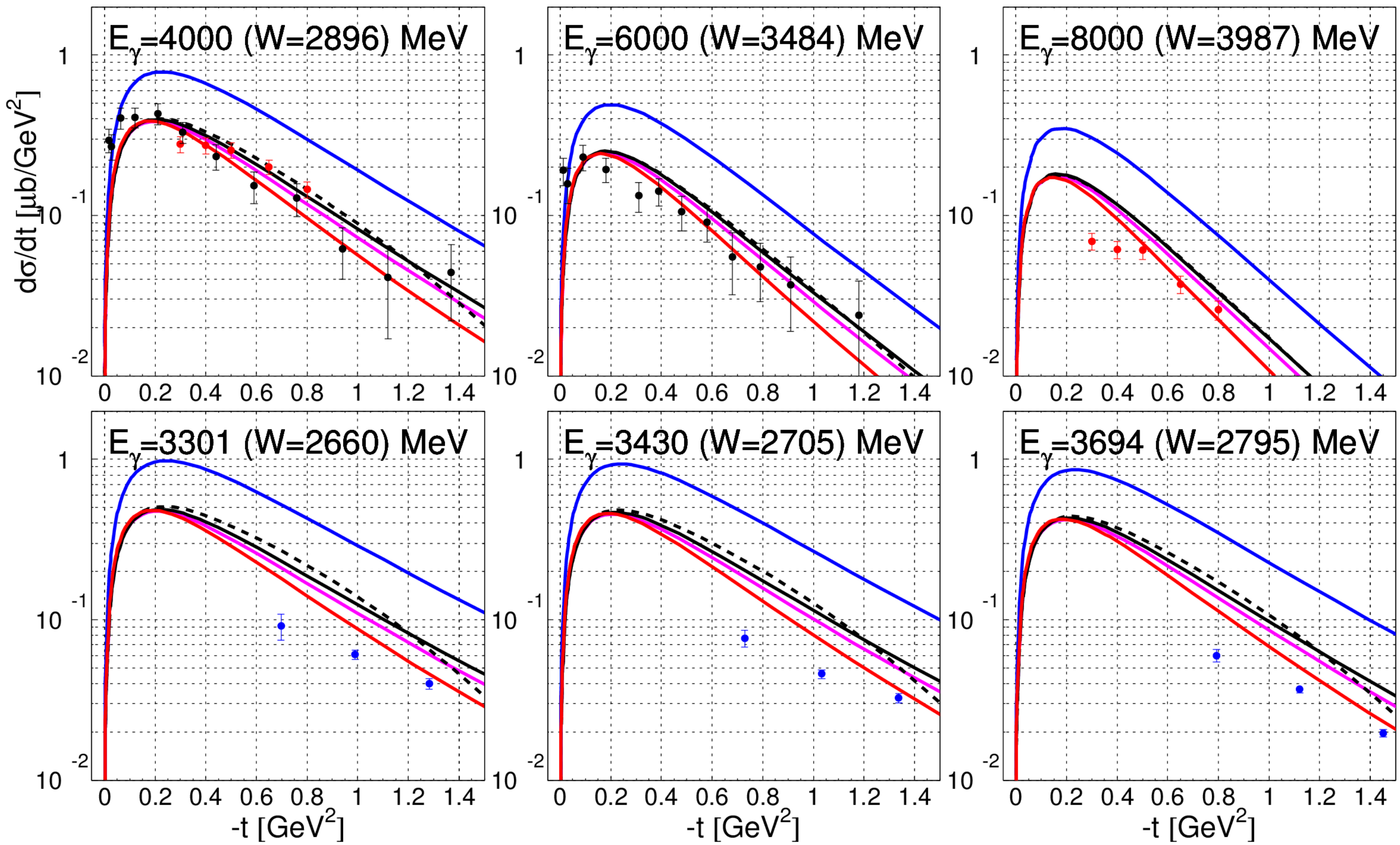
- cutoffs for dipole formfactor Λ_ρ and Λ_ω (variable)

Parameter	MAID-03	MAIDregge-03	Laget-PRC72(2005)
$g_{\rho NN}$	2.4	2.4	0.92
$k_{\rho NN}$	6.1	3.7	6.1
$g_{\omega NN}$	16	9	17.9
$k_{\omega NN}$	0	0	0
Λ_ρ	1.34	-	-
Λ_ω	1.27	-	-

Parameter [keV]	MAID-03	PDG-14
$\Gamma_{\rho\to\eta\gamma}$	36	50.6
$\Gamma_{\omega\to\eta\gamma}$	5.5	3.9
$\Gamma_{\eta'\to\rho\gamma}$	89	58
$\Gamma_{\eta'\to\omega\gamma}$	9.1	5.5

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

ηMAIDregge-2003



black circles: DESY-70 (PL 33B, 236, 1970);

red circles: WLS-71 (PL 37B, 326, 1971);
blue circles: CLAS-09;

1. magenta lines: only background with MAIDregge parameter set;
2. black solid: same as 1 with updated ρ, ω widths;
3. black dashed: same as 2 plus resonances;
4. blue: same as 2 with MAID-03 par. set;
5. red: same as 2 with Laget-05 par. set.

ηMAID-2015: fit procedure

Base model: MAID-03

Fixed parameters:

- updated electromagnetic couplings for the vector mesons;
- hadronic vector and tensor couplings for the vector mesons from Ref. Laget-05;
- branching ratios for hadronic decays of the resonances besides the investigated channel.

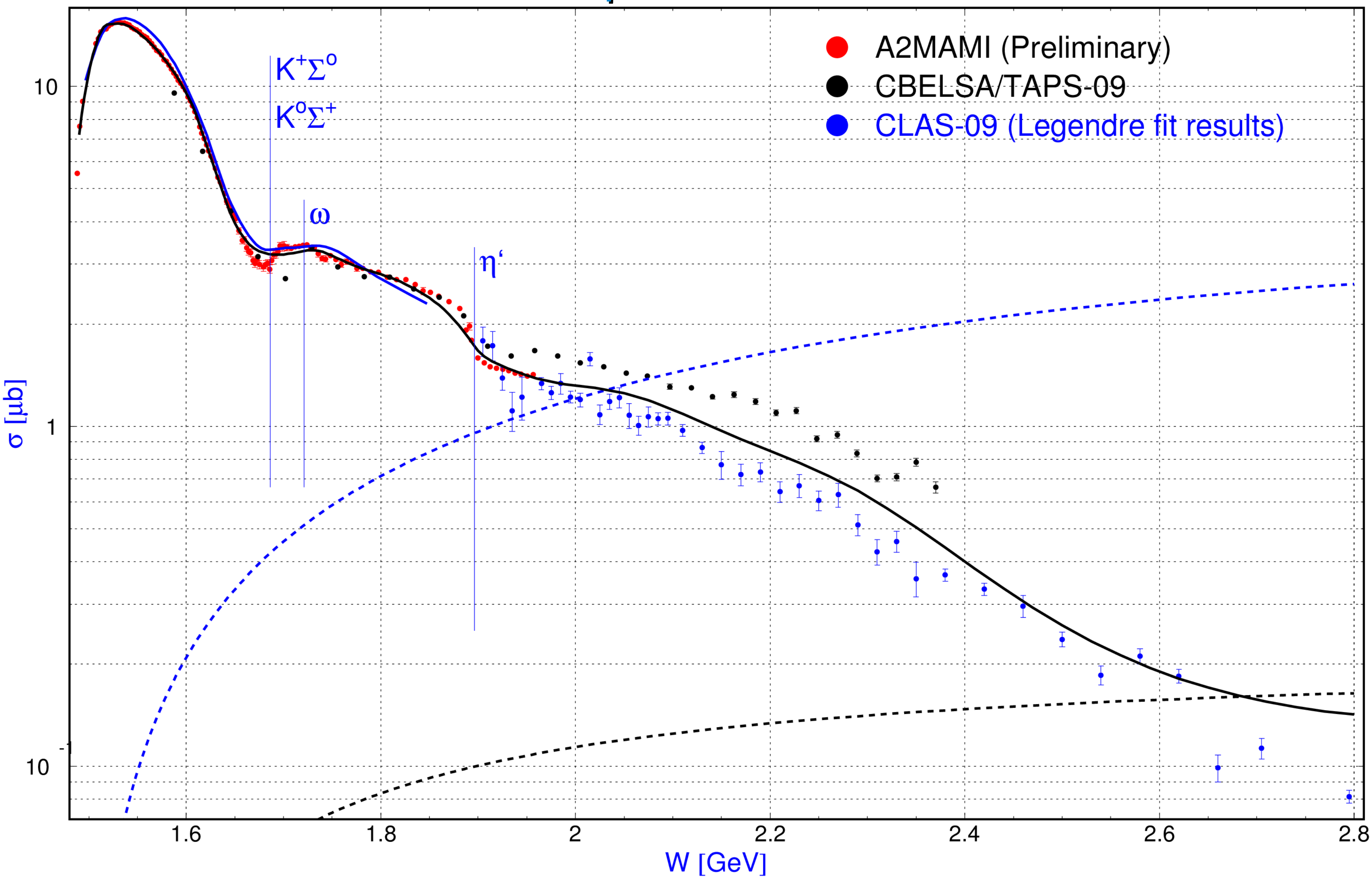
Variable parameters:

- hadronic pseudoscalar coupling for the born term contribution;
- cutoffs for the dipole formfactor Λ_ρ and Λ_ω ;
- for each resonance: mass M_R , total width Γ_R at the resonance peak , branching ratio $\beta_{\eta N}$ (or $\beta_{\eta' N}$), photoexcitation helicity amplitudes $A_{1/2}$ and $A_{3/2}$, relative sign between $N^* \rightarrow \eta N$ and $N^* \rightarrow \pi N$ couplings, $\zeta_{\eta N} = \pm 1$;
- damping parameter for energy dependent total and partial widths, the same for all resonances;
- damping parameter for the electromagnetic form factor, the same for all resonances.

Fit strategy:

- as initial parameter set was used the last BnGa solution;
- as initial parameter limits were used parameter uncertainties from PDG-2014 or BnGa solution;
- on the first step $A_{1/2}$, $A_{3/2}$ are fixed because of a strong correlation with $\beta_{\eta N}$;
- on the second step $\beta\eta N$ obtained on the first step are fixed, but $A_{1/2}$, $A_{3/2}$ are variable, and so on;
- after few iterations the initial limits are changed if necessary;
- fit for the η and η' channels was done independently.

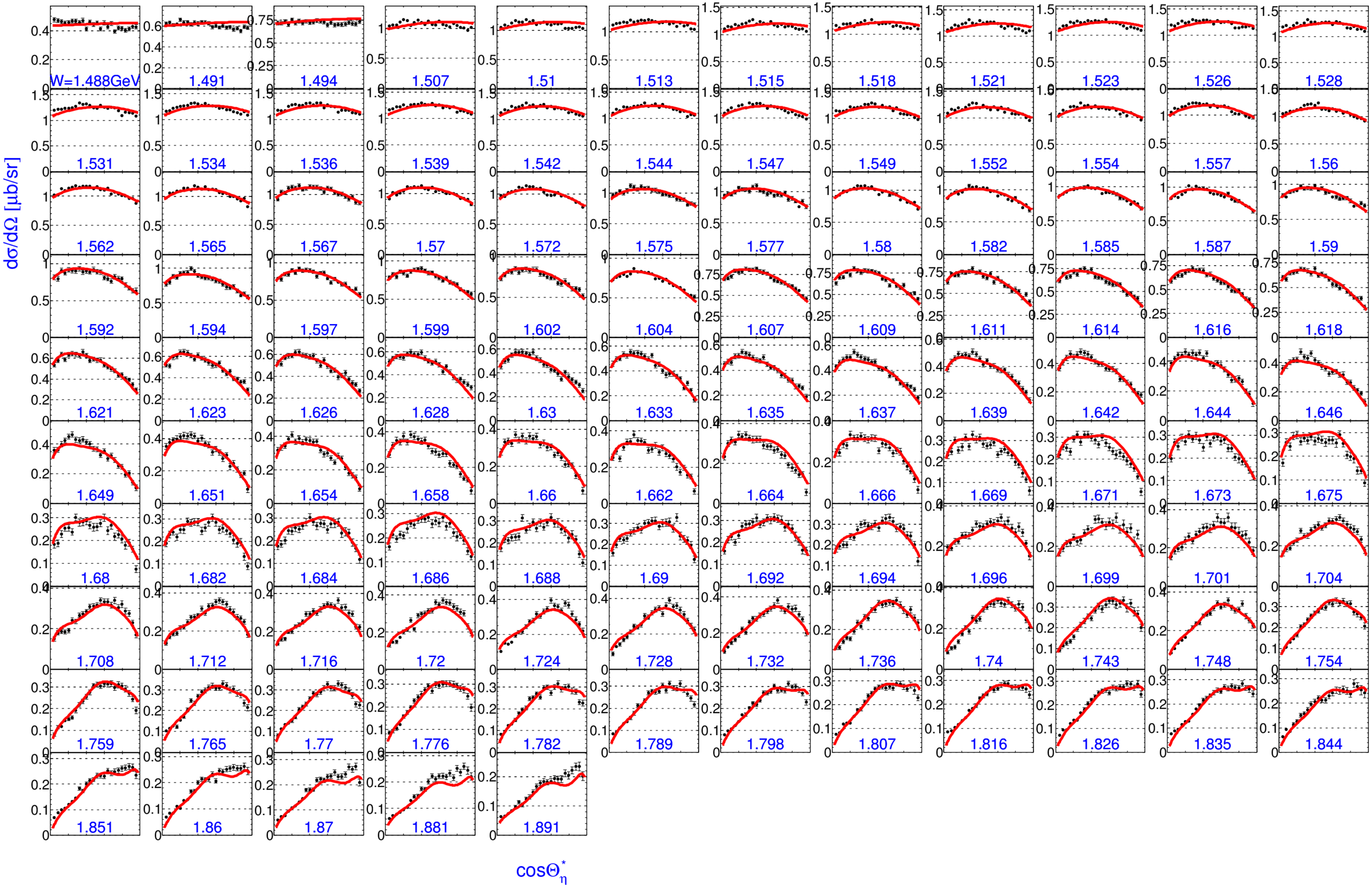
γ p → η p   ηMAID-2015: total cross sections



solid blue: ηMAID-2003, dashed: Born+Rho+Omega for ηMAID-2003
solid black: ηMAID-2015, dashed: Born+Rho+Omega for ηMAID-2015

γ p → η p

ηMAID-2015: differential cross sections

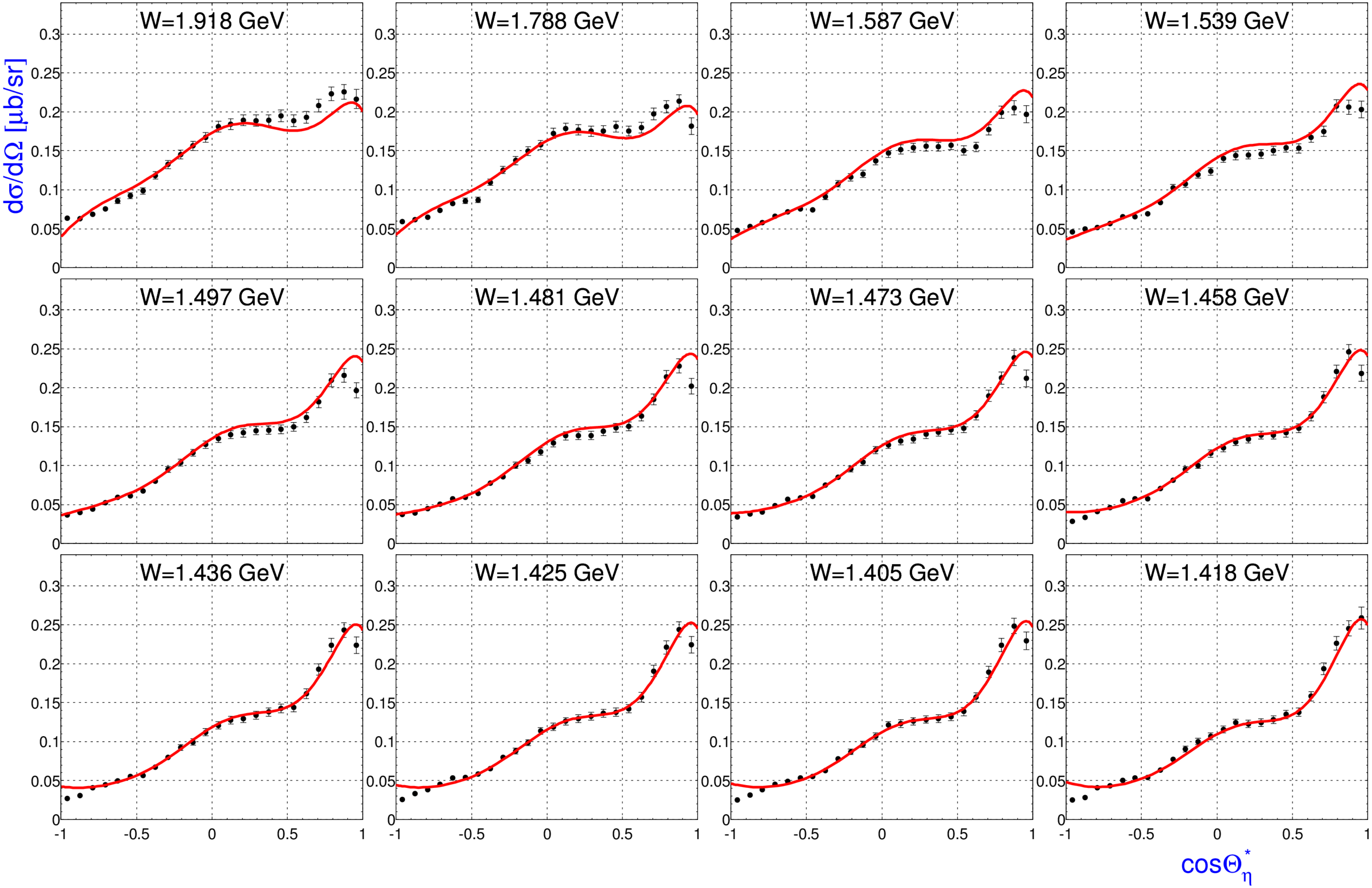


black circles: A2MAMI preliminary data

red: ηMAID-2015

γ p → η p

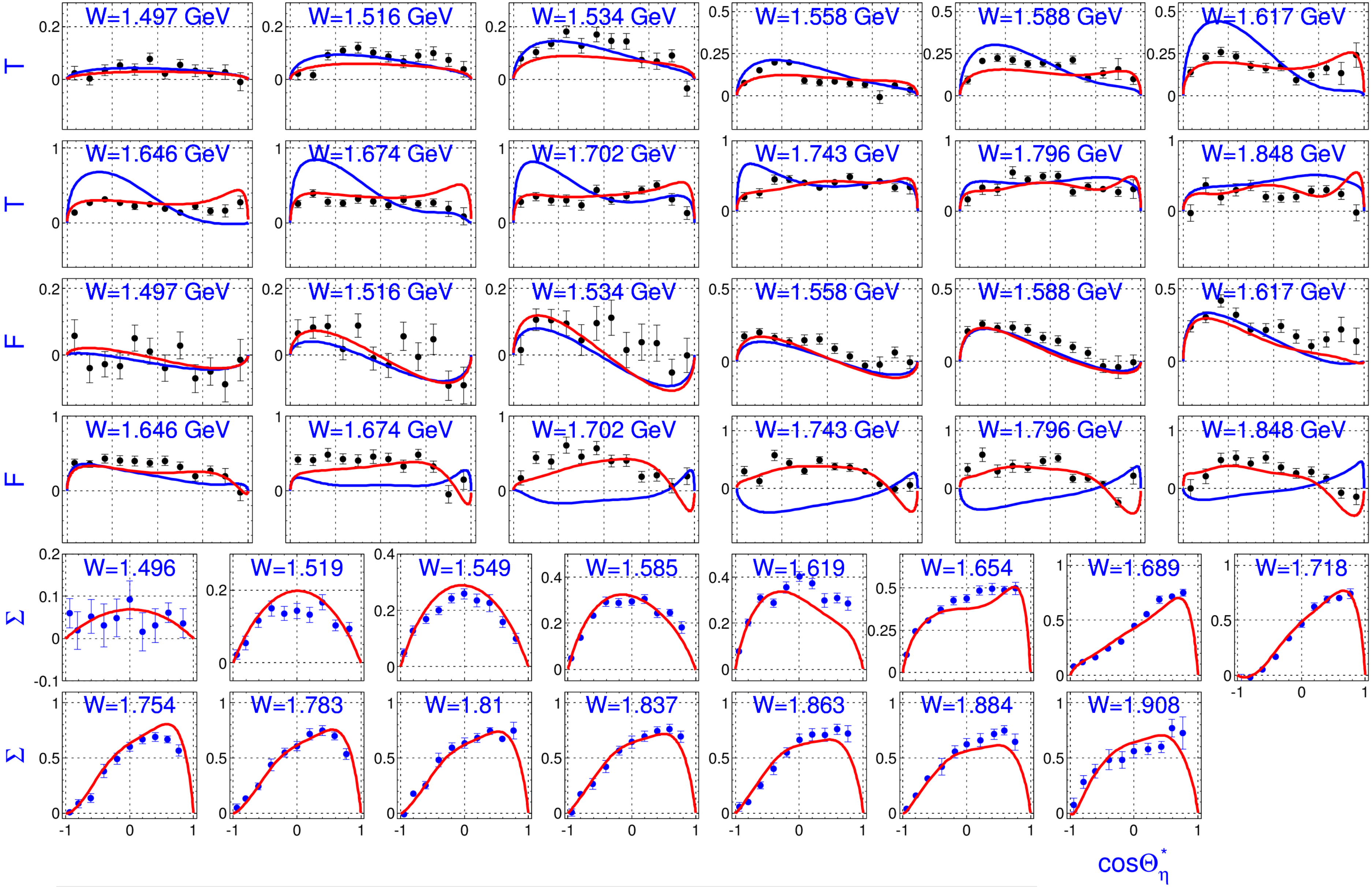
ηMAID-2015: differential cross sections



black circles: A2MAMI preliminary   red line: ηMAID-2015

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

ηMAID-2015: T and F



black circles: A2MAMI-14

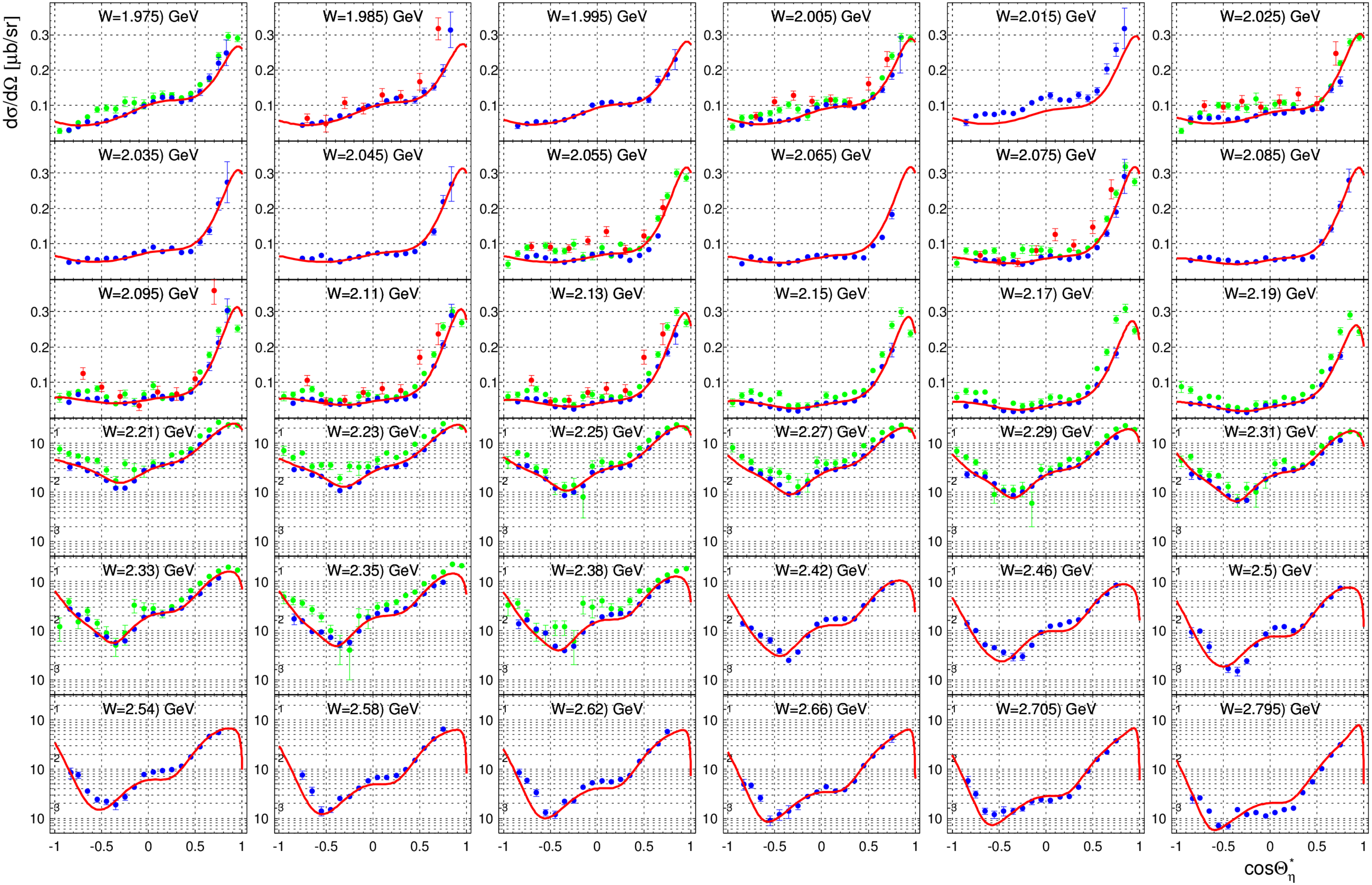
blue circles: GRAAL-07

blue lines: ηMAID-2003

red lines: ηMAID-2015

γ p → η p

ηMAID-2015: differential cross sections



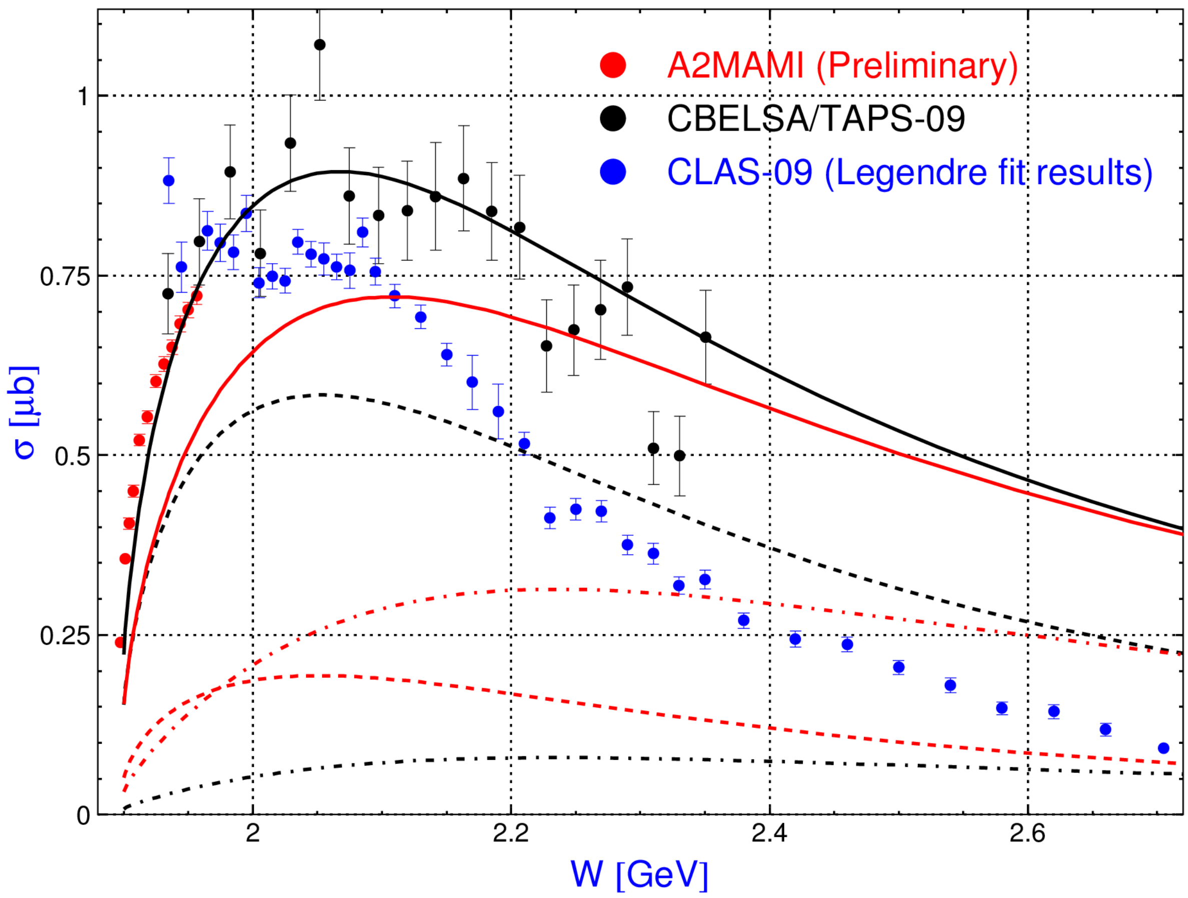
blue circles: CLAS-09

green circles: CBELSA/TAPS-09

red circles: CLAS-02 (Dugger et al, PRL 89, 2002)

red line: ηMAID-2015

$\gamma\ p \rightarrow\ \eta'\ p$ *New data and MAID-2003 Regge*

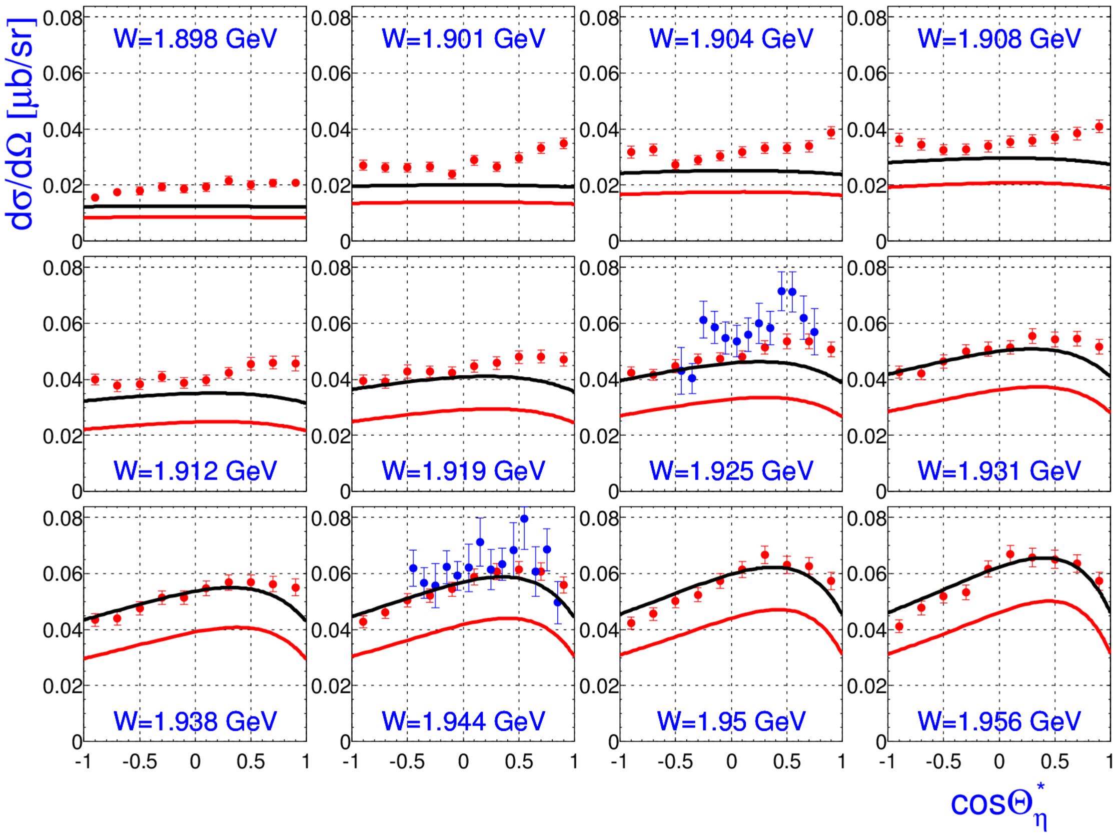


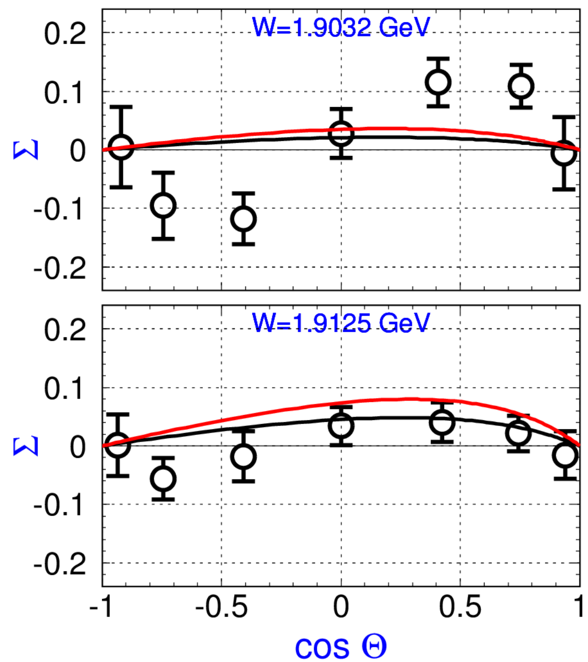
solid black: ηMAID-2003 Regg, dashed: Rho, dot-dashed: Omega

red lines: same as black lines but with Laget-05 parameter set

γ p → η' p

New data and MAID-2003 Regge

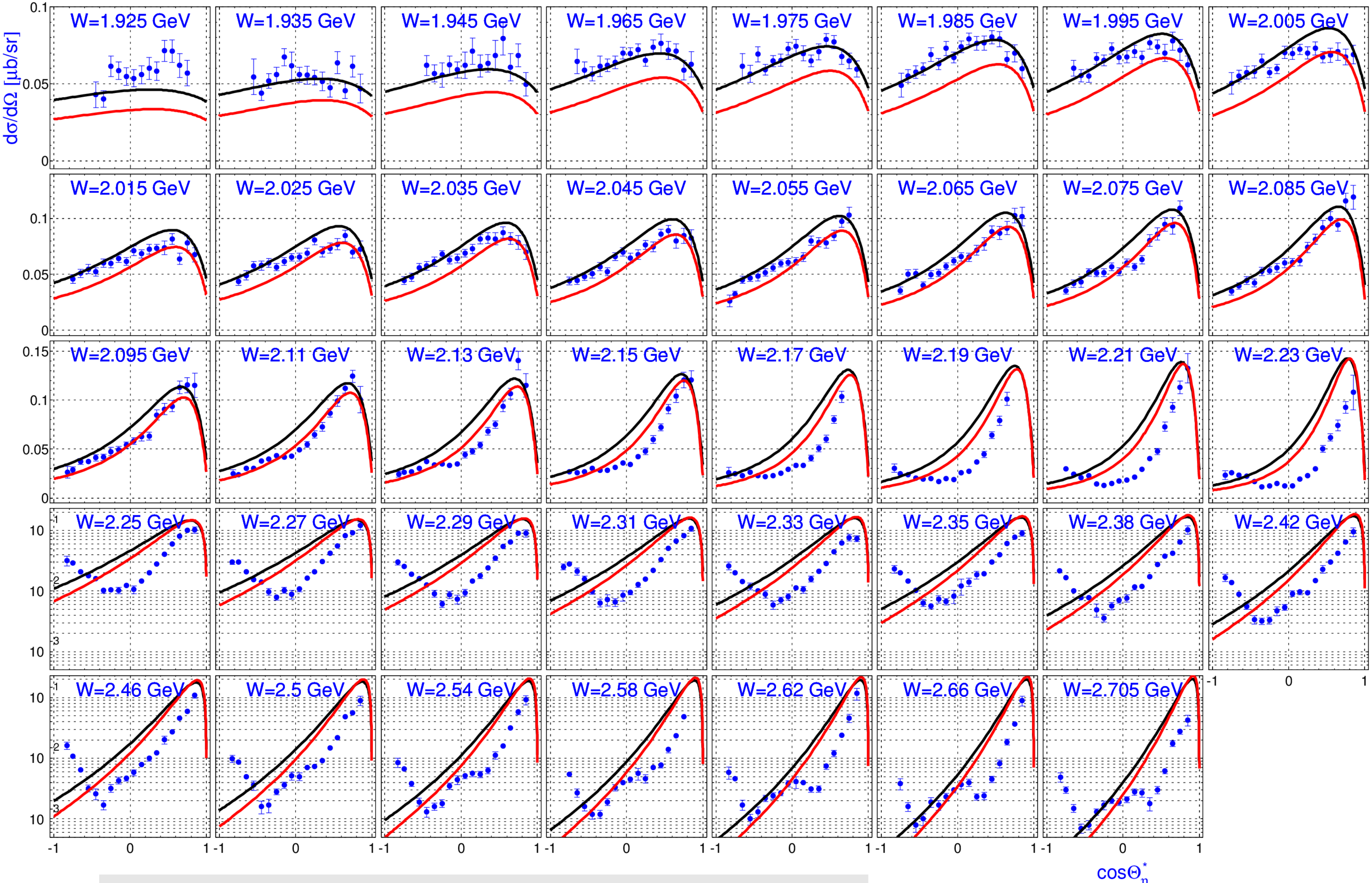




black lines: ηMAID-2003 Regg

red lines: same as black lines but with Laget-05 parameter set

$\gamma\ p \rightarrow\ \eta'\ p$ — *New data and MAID-2003 Regge*

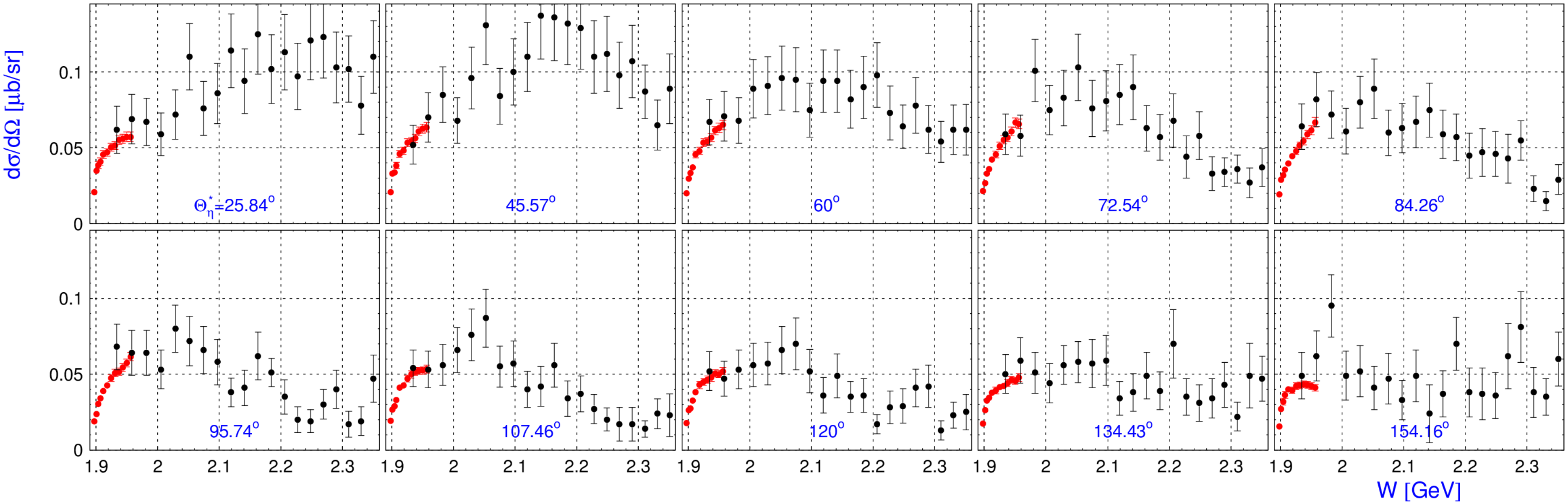


black lines: ηMAID-2003 Regg

red lines: same as black lines but with Laget-05 parameter set

γ p → η' p

Excitation function

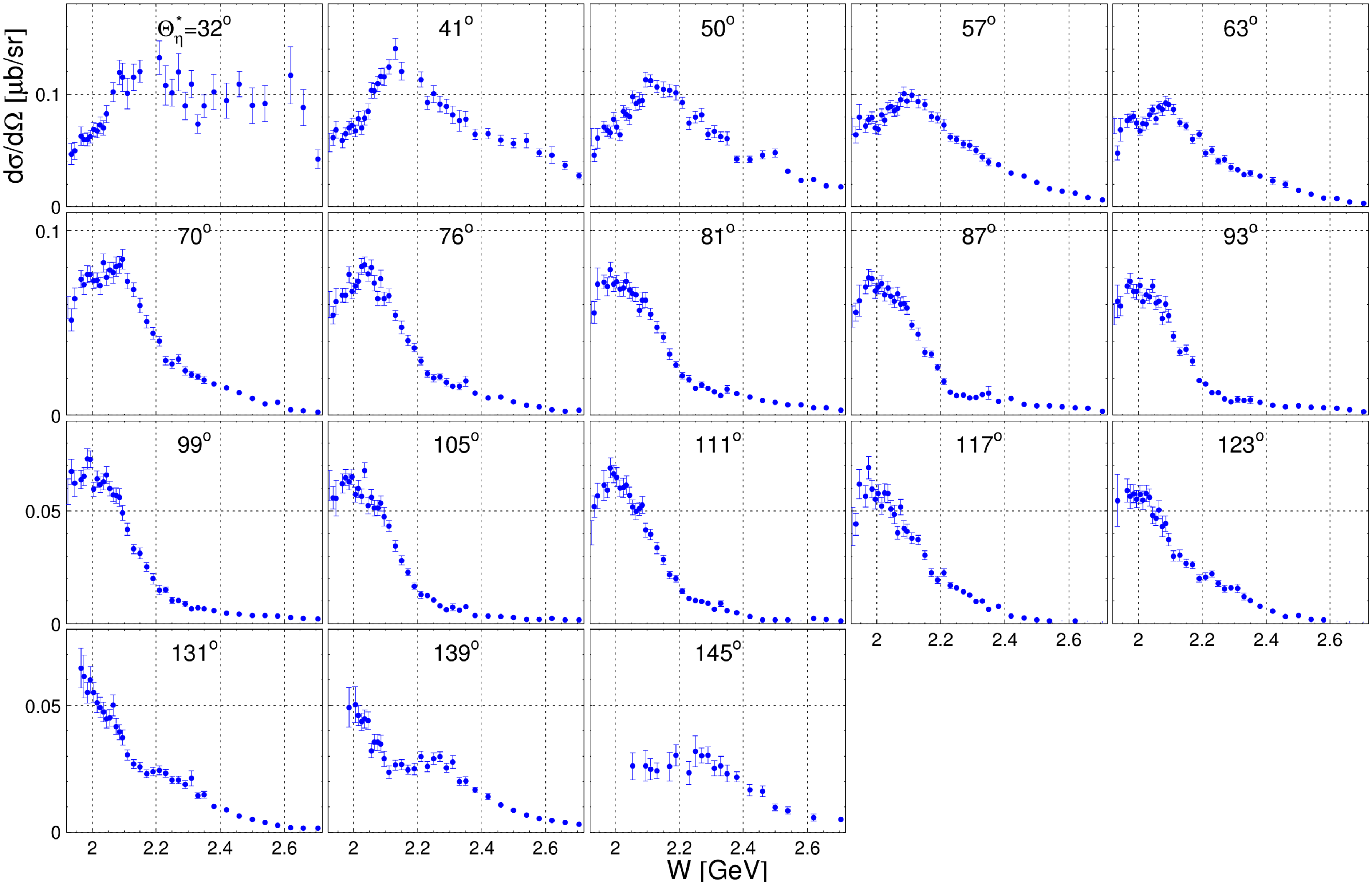


Red circles: A2MAMI (preliminary)

Black circles: CBELSA/TAPS – 09

γ p → η' p

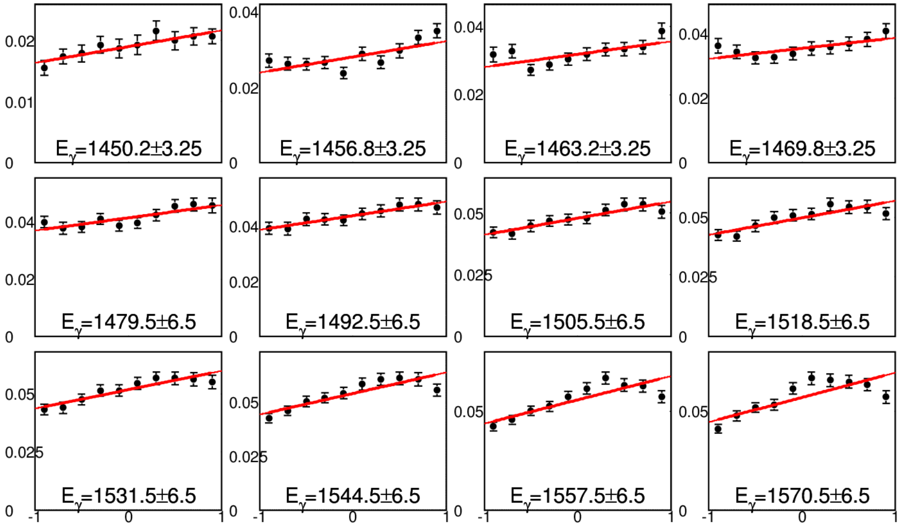
Excitation function, CLAS – 09



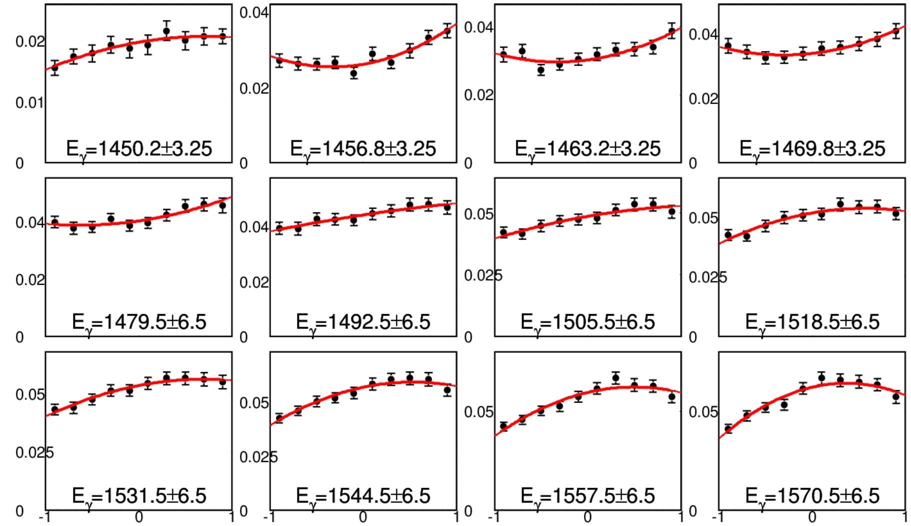
$\gamma\ p \rightarrow\ \eta'\ p$

Legendre fitting experimental data with different j_{max}

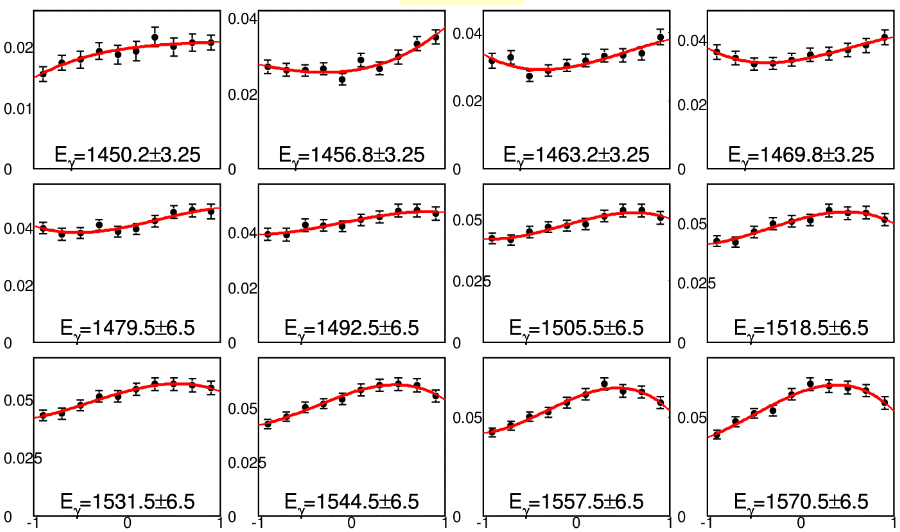
j_{max}=1



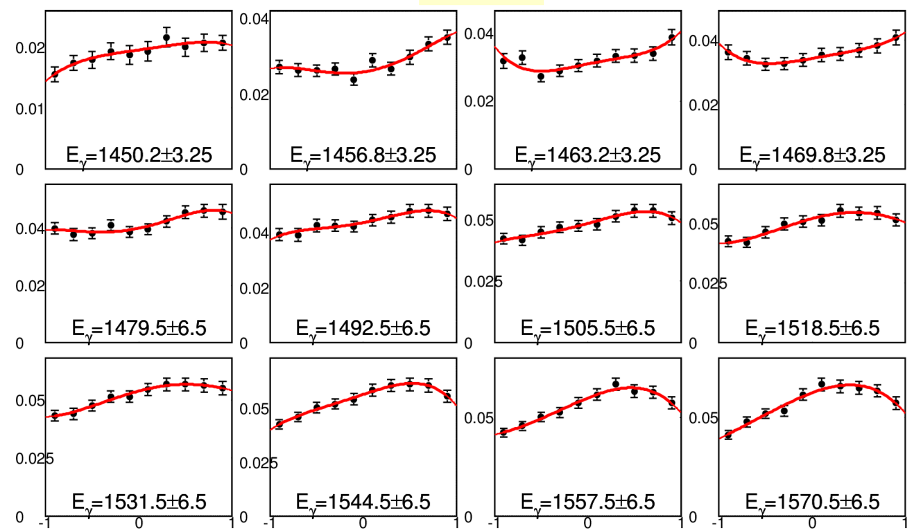
j_{max}=2



j_{max}=3



j_{max}=4

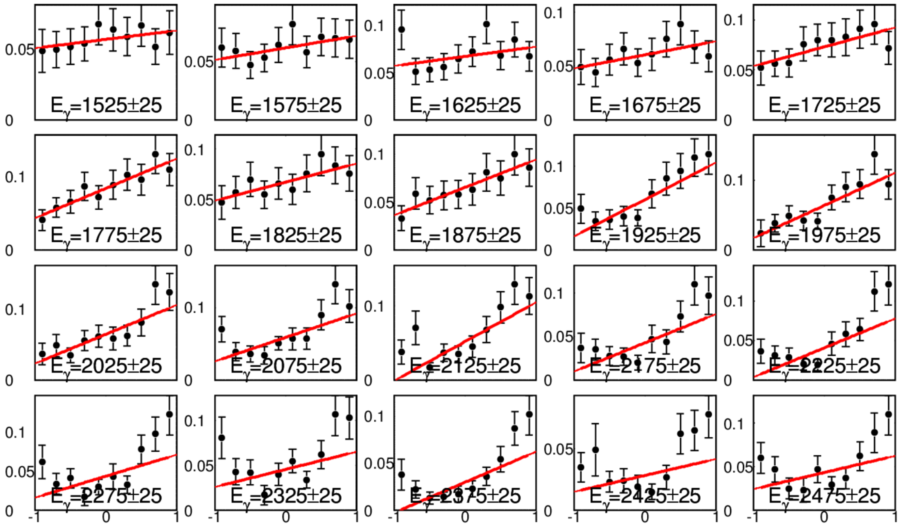


black circles: A2 MAMI preliminary data, red lines: fit result

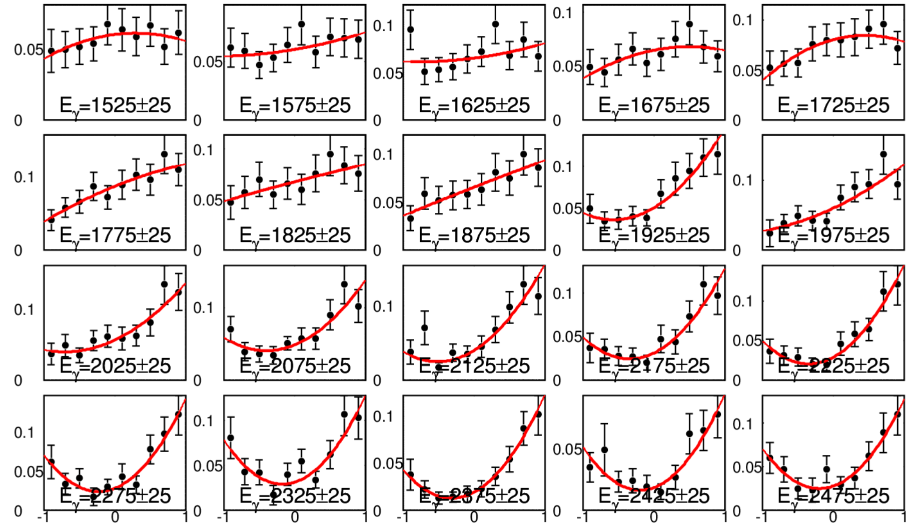
$\gamma\ p \rightarrow\ \eta'\ p$

Legendre fitting experimental data with different j_{max}

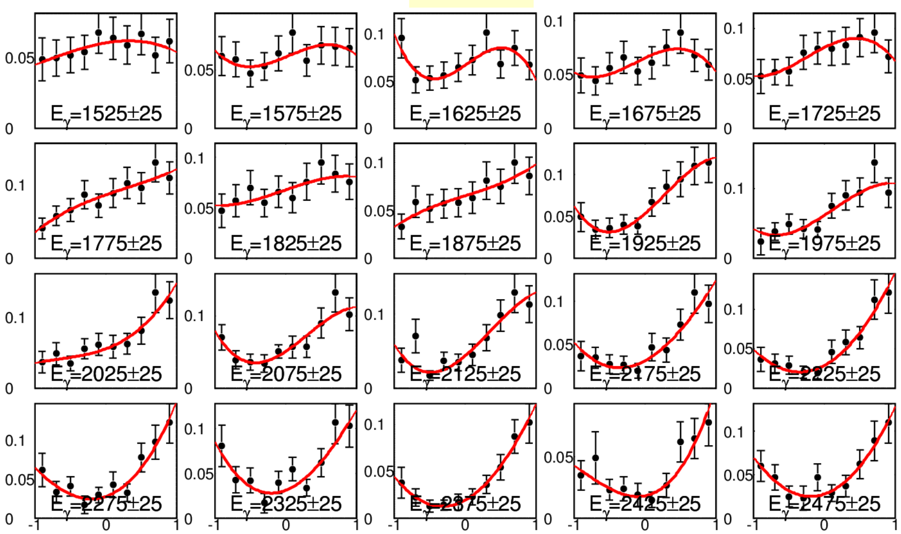
$j_{max}=1$



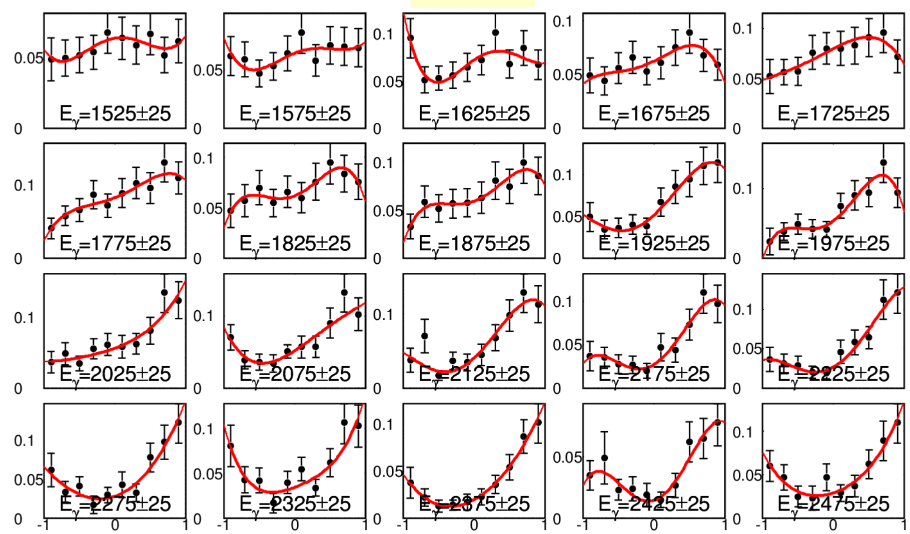
$j_{max}=2$



$j_{max}=3$

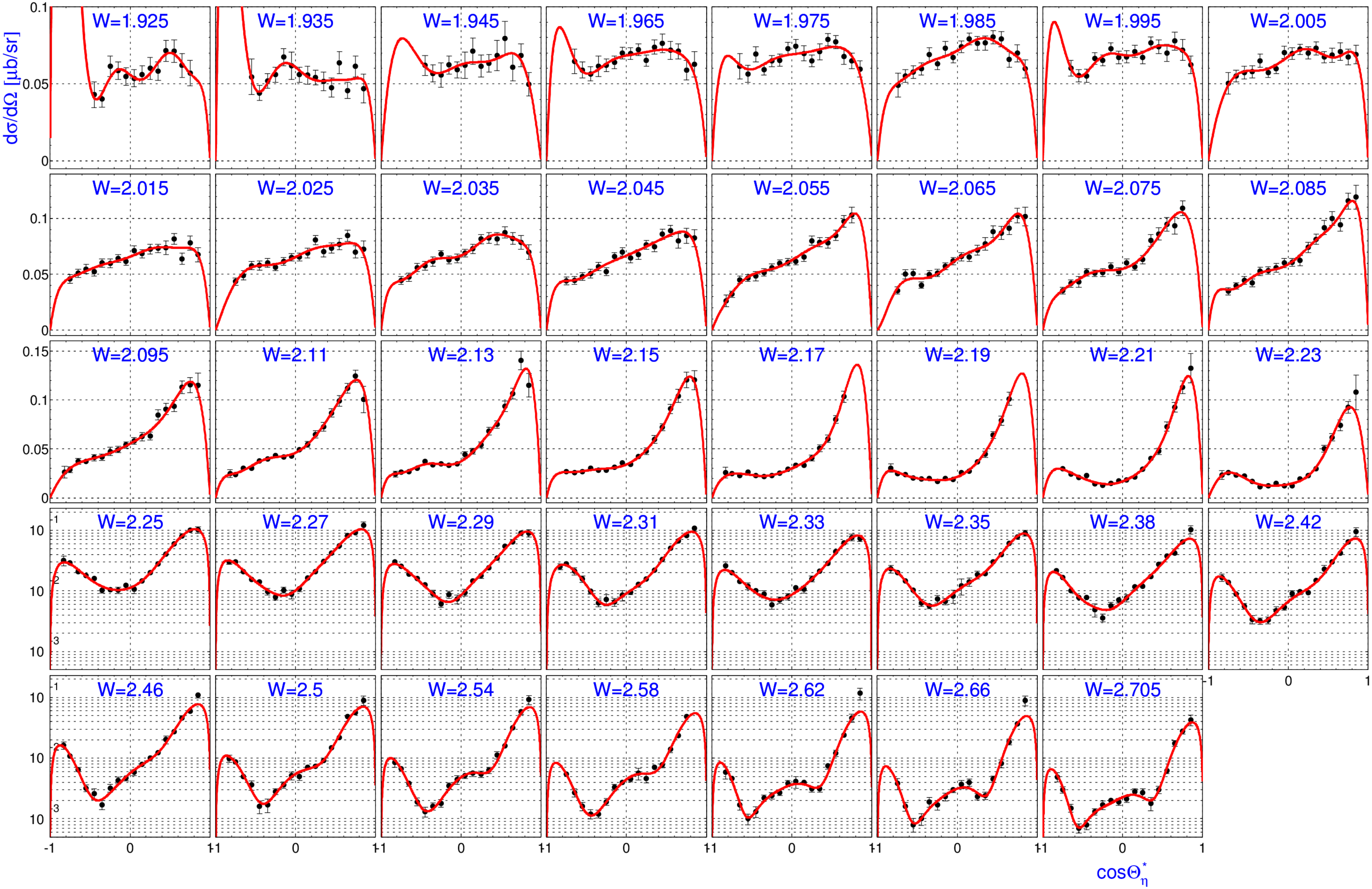


$j_{max}=4$



black circles: CBELSA/TAPS-2009 data, red lines: fit result

$\gamma\ p \rightarrow\ \eta'\ p$ Legendre fitting experimental data with $j_{max} = 8$

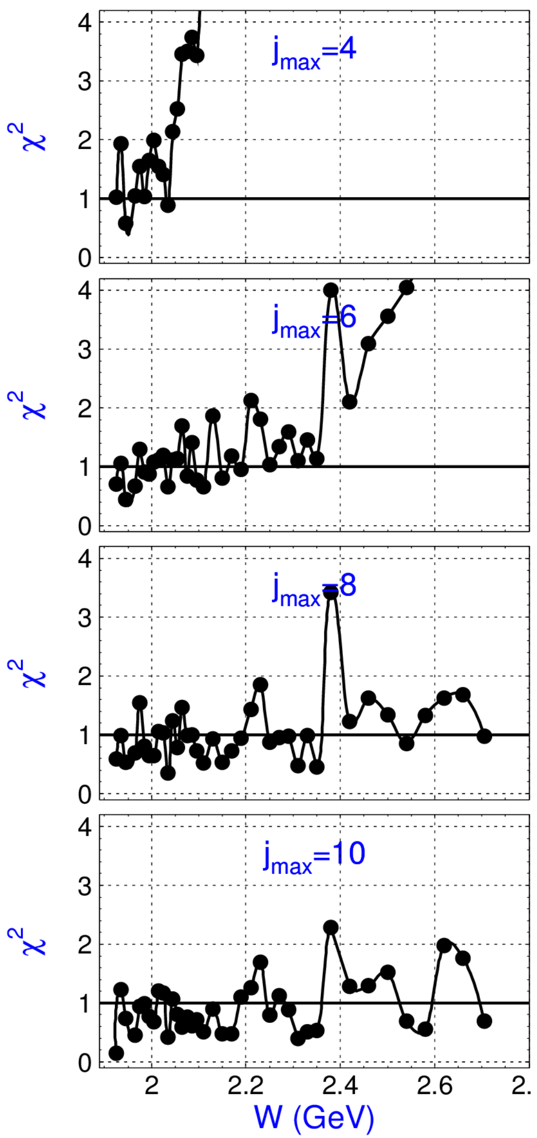


black circles: CLAS-2009 data

red lines: fit result

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

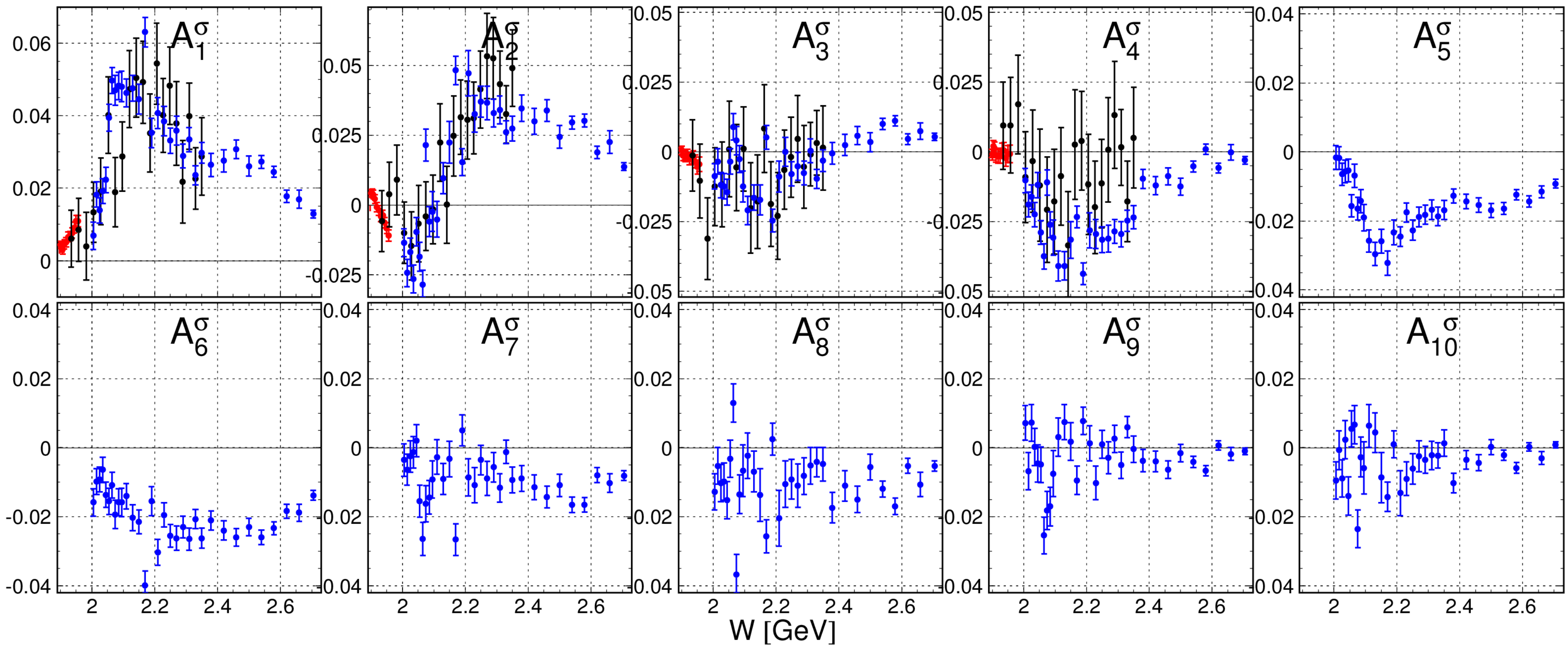
Legendre fitting experimental data with different j_{max}



black circles: fit result for CLAS-2009 data

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

Legendre coefficients in μb/sr units from fitting differential cross sections

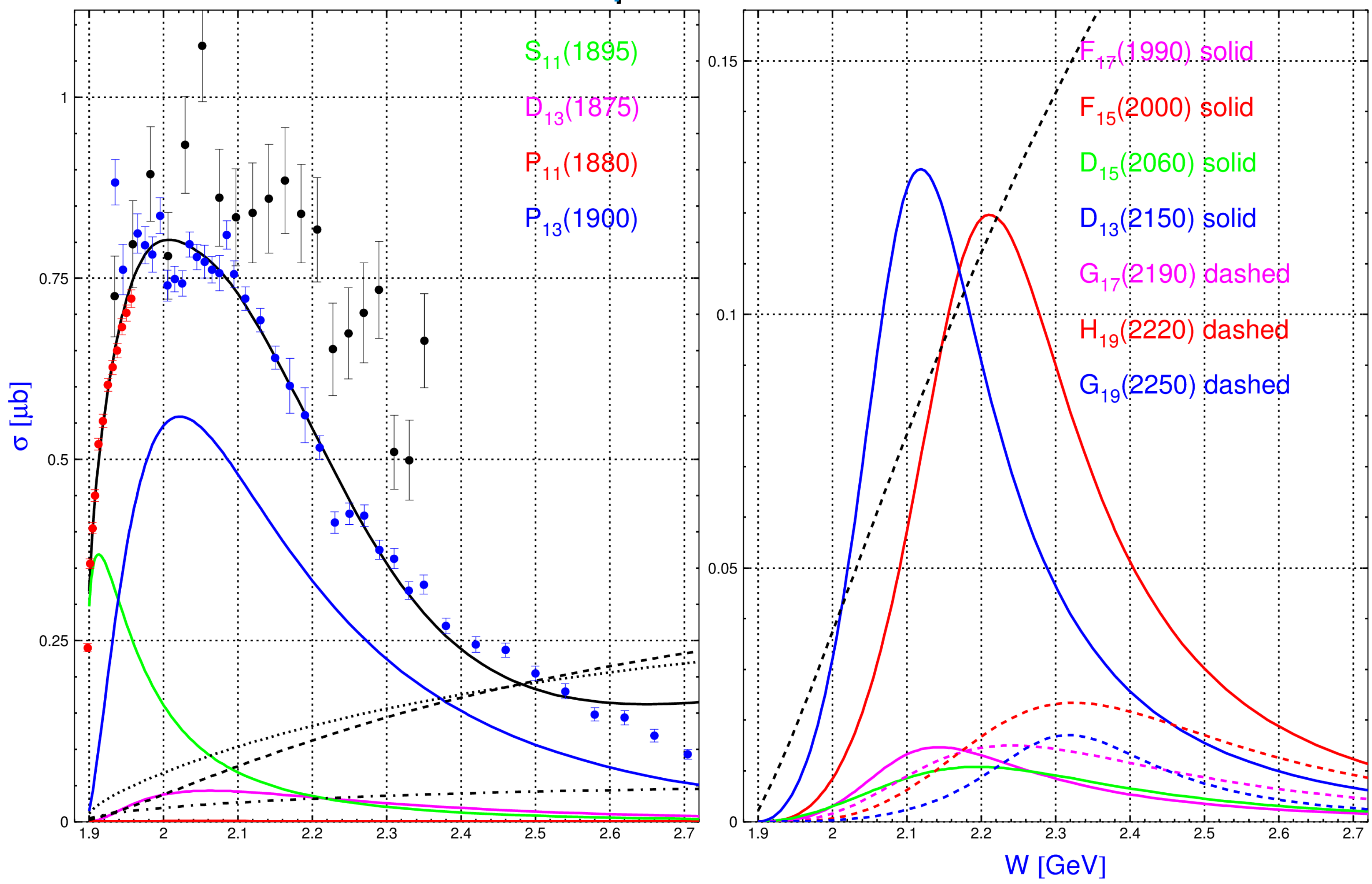


A2 MAMI preliminary data
red circles: fit with j_{max}=4

CBELSA/TAPS-2009
black: fit with j_{max}=4

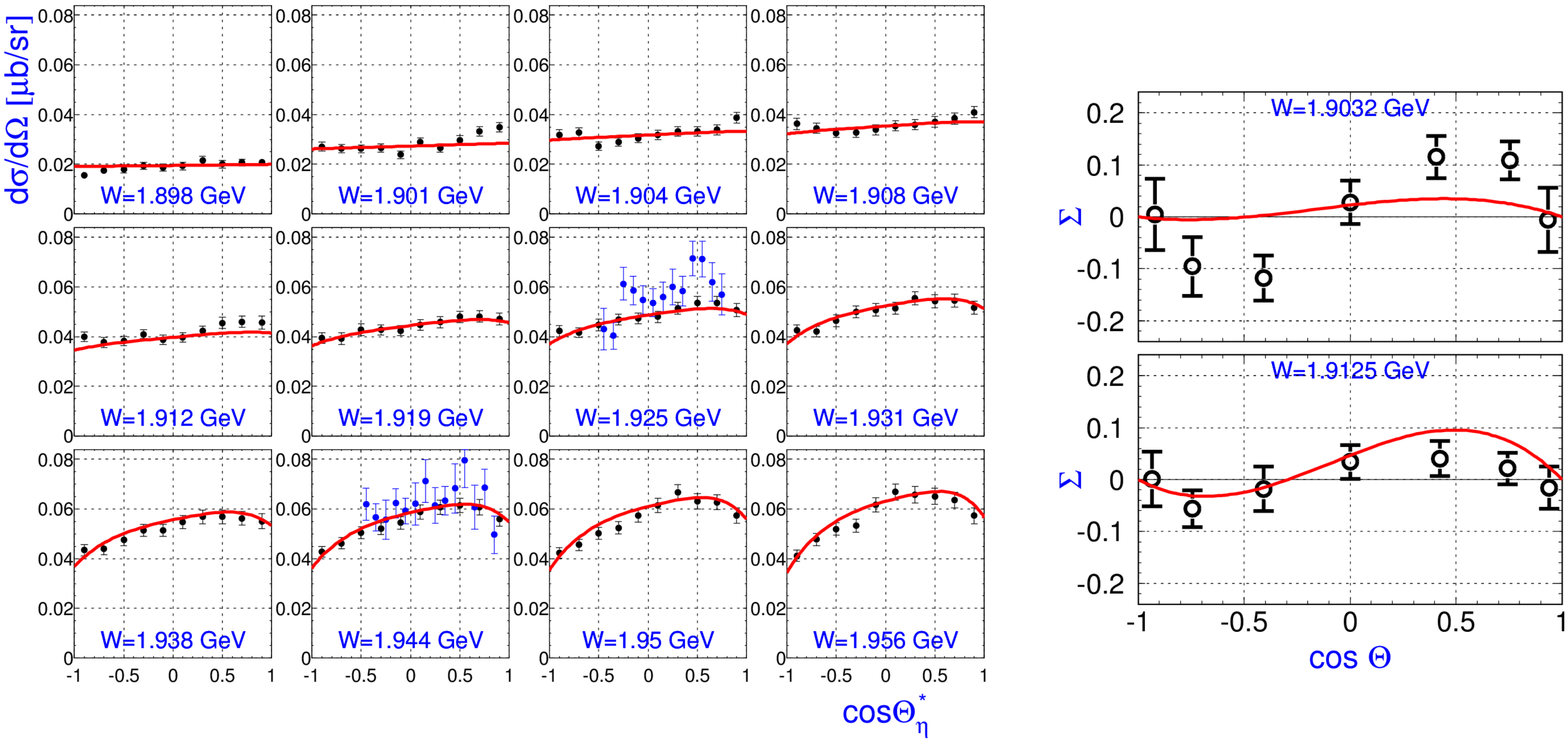
CLAS – 09
blue: fit with j_{max}=10

$\gamma\ p \rightarrow \eta'\ p$ *ηMAID-2015: total cross section*



Black lines: solid is full solution, dashed: background, dot-dashed: ρ+ω, dotted: born term
Red circles: A2MAMI, black circles: CBELSA/TAPS-09, blue circles: CLAS-09 from Legendre fit

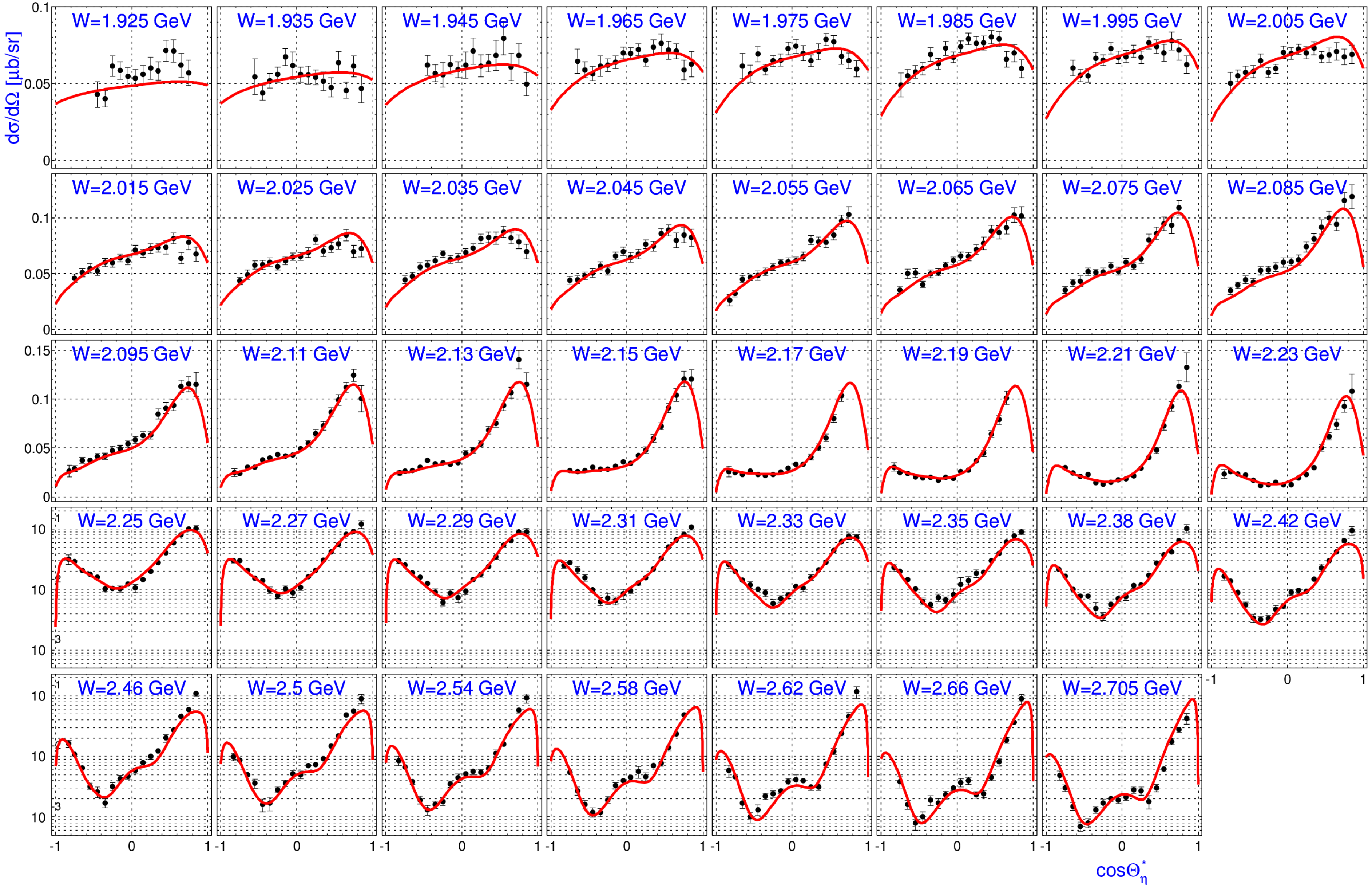
$\gamma\ p \rightarrow \eta'\ p$ *MAID-2015 and near threshold data*



closed circles: A2MAMI (preliminary); open circles : GRAAL-15; Red line: ηMAID-2015

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

MAID-2015 and CLAS-09



black circles: CLAS-09 red line: ηMAID-2015

Summary

- new experimental data for unpolarized and polarized observables for η and η' meson photoproduction reactions were obtained last years by A2@MAMI, CBELSA/TAPS, CLAS, and GRAAL Collaborations;
- most PWA predictions fail to give a consistent description of the new polarization data;
- Legendre decomposition of the new data shows the sensitivity to small partial-wave contributions and allows qualitative analyzing reactions;
- updated ηMAID-2015 good enough describes existing experimental data in all energy region;
- because we are far from “complete experiment” to get model independent description of the reactions, updated isobar model ηMAID-2015 could be contribute to further understanding reaction mechanism and excited nucleon spectra.

Partcle J^P	M_R [MeV]	$\Gamma^R_{tot}(M_R)$ [*MeV*]	$\zeta_{\eta N}$	$\beta_{\eta N}$ [%]	$A_{1/2}$ [$10^{-3}GeV^{-1/2}$]	$A_{3/2}$ [$10^{-3}GeV^{-1/2}$]	*model*
$N(1520)\ 3/2^-$	1514	121	+1	0.14	−27	+102	*MAID*15
or $N(1520)D_{13}$	1517 ± 3	114 ± 5			-22 ± 4	$+131 \pm 10$	*BnGa*12
****	1515 ± 5	115^{+10}_{-15}		0.23 ± 0.04	-20 ± 5	$+140 \pm 10$	*PDG*14
	1520	120	+1	0.056	−52	+166	*MAID*03
	1520	120	+1	0.038	−24	+166	*MAIDreg*03
$N(1535)\ 1/2^-$	1521	159	+1	35	+121		*MAID*15
or $N(1535)S_{11}$	1519 ± 5	128 ± 14		33 ± 5	$+105 \pm 10$		*BnGa*12
****	1535 ± 10	150 ± 25		42 ± 10	$+115 \pm 15$		*PDG*14
	1541.1	190.5	+1	50	+118.5		*MAID*03
	1521.3	117.5	+1	50	+79.6		*MAIDreg*03
$N(1650)\ 1/2^-$	1636	103	−1	15	+43		*MAID*15
or $N(1650)S_{11}$	1651 ± 6	104 ± 10		18 ± 4	$+33 \pm 7$		*BnGa*12
****	1655^{+15}_{-10}	140 ± 30		$5 - 15$	$+45 \pm 10$		*PDG*14
	1637.5	113.8	−1	7.91	+68.4		*MAID*03
	1635	120	−1	16.3	+46		*MAIDreg*03
$N(1675)\ 5/2^-$	1678	180	−1	2.9	+15	+31	*MAID*15
or $N(1675)D_{15}$	1664 ± 5	152 ± 7			$+24 \pm 3$	$+25 \pm 7$	*BnGa*12
****	1675 ± 5	150^{+15}_{-20}		0 ± 0.7	$+19 \pm 8$	$+20 \pm 5$	*PDG*14
	1665.3	150	−1	17.42	+17.7	+24	*MAID*03
	1665	150	+1	0.685	+19	+15	*MAIDreg*03
$N(1680)\ 5/2^+$	1660	159	−1	0.13	−23	+118	*MAID*15
or $N(1680)F_{15}$	1689 ± 6	118 ± 6			-13 ± 3	$+135 \pm 6$	*BnGa*12
****	1685 ± 5	130 ± 10		0 ± 0.7	-15 ± 6	$+133 \pm 12$	*PDG*14
	1681.4	130	+1	0.06	−21	+124.8	*MAID*03
	1670	130	+1	0.003	−15	+133	*MAIDreg*03
$N(1700)\ 3/2^-$	1735	75	−1	1	+12	−44	*MAID*15
or $N(1700)D_{13}$	1790 ± 40	390 ± 140			$+41 \pm 17$	-34 ± 13	*BnGa*12
***	1700 ± 50	150^{+100}_{-50}		0 ± 1	$+15 \pm 25$	-15 ± 25	*PDG*14
	1700	100	−1	0.3	−18	−2	*MAID*03
	1700	100	−1	0.025	−18	−2	*MAIDreg*03
$N(1710)\ 1/2^+$	1691	271	−1	0.3	+69		*MAID*15
or $N(1710)P_{11}$	1710 ± 20	200 ± 18		17 ± 10	$+52 \pm 15$		*BnGa*12
***	1710 ± 30	100^{+150}_{-50}		$10 - 30$	$+40 \pm 20$		*PDG*14
	1720.6	100	+1	25.84	+23.2		*MAID*03
	1700.8	100	−1	26	+9		*MAIDreg*03
$N(1720)\ 3/2^+$	1800	440	−1	2.4	+152	+68	*MAID*15
or $N(1720)P_{13}$	1690^{+70}_{-35}	420 ± 100		3 ± 2	$+110 \pm 45$	$+150 \pm 30$	*BnGa*12
****	1720^{+30}_{-20}	250^{+150}_{-100}		2.1 ± 1.4	$+100 \pm 20$		*PDG*14
	1720	150	+1	3.0	+18.0	−19.0	*MAID*03
	1720	150	−1	4.115	+18.0	−19.0	*MAIDreg*03

Partcle J^P	M_R [MeV]	$\Gamma^R_{tot}(M_R)$ [MeV]	$\zeta_{\eta N}$	$\beta_{\eta N}$ [%]	$A_{1/2}$ $[10^{-3}GeV^{-1/2}]$	$A_{3/2}$ $[10^{-3}GeV^{-1/2}]$	model
$N(1860)$ $5/2^+$	1920	360	+1	1.2	+11	+80	MAID15
or $N(1860)F_{15}$	1860^{+120}_{-60}	270^{+140}_{-50}			-19 ± 11	$+48 \pm 18$	BnGa12
**	1860^{+100}_{-40}						PDG14
$N(1875)$ $3/2^-$	1845	220	−1	3.3	−8	−48	MAID15
or $N(1875)D_{13}$	1880 ± 20	200 ± 25		5 ± 2	$+18 \pm 10$	-9 ± 5	BnGa12
***	1875^{+45}_{-55}			1.2 ± 1.8			PDG14
$N(1880)$ $1/2^+$	1905	160	−1	20	−8		MAID15
or $N(1880)P_{11}$	1870 ± 35	235 ± 65		25^{+30}_{-20}	-13 ± 3 or $+34 \pm 11$		BnGa12
**							PDG14
$N(1895)$ $1/2^-$	1896	106	+1	14	−16		MAID15
or $N(1895)S_{11}$	1895 ± 15	90^{+30}_{-15}		$21 \pm +6$	-11 ± 6		BnGa12
**							PDG14
$N(1900)$ $3/2^+$	1800	740	+1	7	+24	−8	MAID15
or $N(1900)P_{13}$	1905 ± 30	250^{+120}_{-50}		10 ± 4	$+26 \pm 15$	-65 ± 30	BnGa12
***	≈ 1900	≈ 250		≈ 12			PDG14
$N(1990)$ $7/2^+$	1970(2092)	300(285)	−1	0.013	+96(+24)	+13(+77)	MAID15
or $N(1990)F_{17}$	2060 ± 65	$240^{\pm}50$			$+40 \pm 12$	$+57 \pm 12$	BnGa12
**	≈ 1990						PDG14
$N(2000)$ $5/2^+$	2248(2188)	311(284)	+1	0.9	+14(−1.8)	+77(+72)	MAID15
or $N(2000)F_{15}$	2090 ± 120	460 ± 100			$+32 \pm 14$	$+48 \pm 14$	BnGa12
**	2050 ± 100			2.0 ± 2.0			PDG14
$N(2060)$ $5/2^-$	1912(2134)	570(493)	+1	4.6	+28(+45)	−2.5(+98)	MAID15
or $N(2060)D_{15}$	2060 ± 15	375 ± 25		4 ± 2	$+67 \pm 15$	$+55 \pm 20$	BnGa12
**	≈ 2060						PDG14
$N(2150)$ $3/2^-$	2052(2093)	260(224)	+1	0.5	+247(+23)	+44 + (+250)	MAID15
or $N(2150)D_{13}$	2150 ± 60	330 ± 45			$+130 \pm 45$	$+150 \pm 55$	BnGa12
**							PDG14
$N(2190)$ $7/2^-$	2208(2147)	500(504)	+1	2	27(−50)	+106(−1.6)	MAID15
or $N(2190)G_{17}$	2180 ± 20	335 ± 40			-65 ± 8	$+35 \pm 17$	BnGa12
****	2190^{+10}_{-100}	500 ± 200		0 ± 1			PDG14
$N(2220)$ $9/2^+$	2332(2284)	345(540)	−1	7.8	37(15)	−11(21)	MAID15
or $N(2220)H_{19}$	2200 ± 50	480 ± 60			$\|A\| < 10$	$\|A\| < 10$	BnGa12
****	2250 ± 50	400^{+100}_{-50}					PDG14
$N(2250)$ $9/2^-$	2240(2304)	800(297)	−1	4.3	+7.3(−32)	+1.8(20)	MAID15
or $N(2250)G_{19}$	2280 ± 40	520 ± 50			$\|A\| < 10$	$\|A\| < 10$	BnGa12
****	2275 ± 75	500^{+300}_{-170}					PDG14

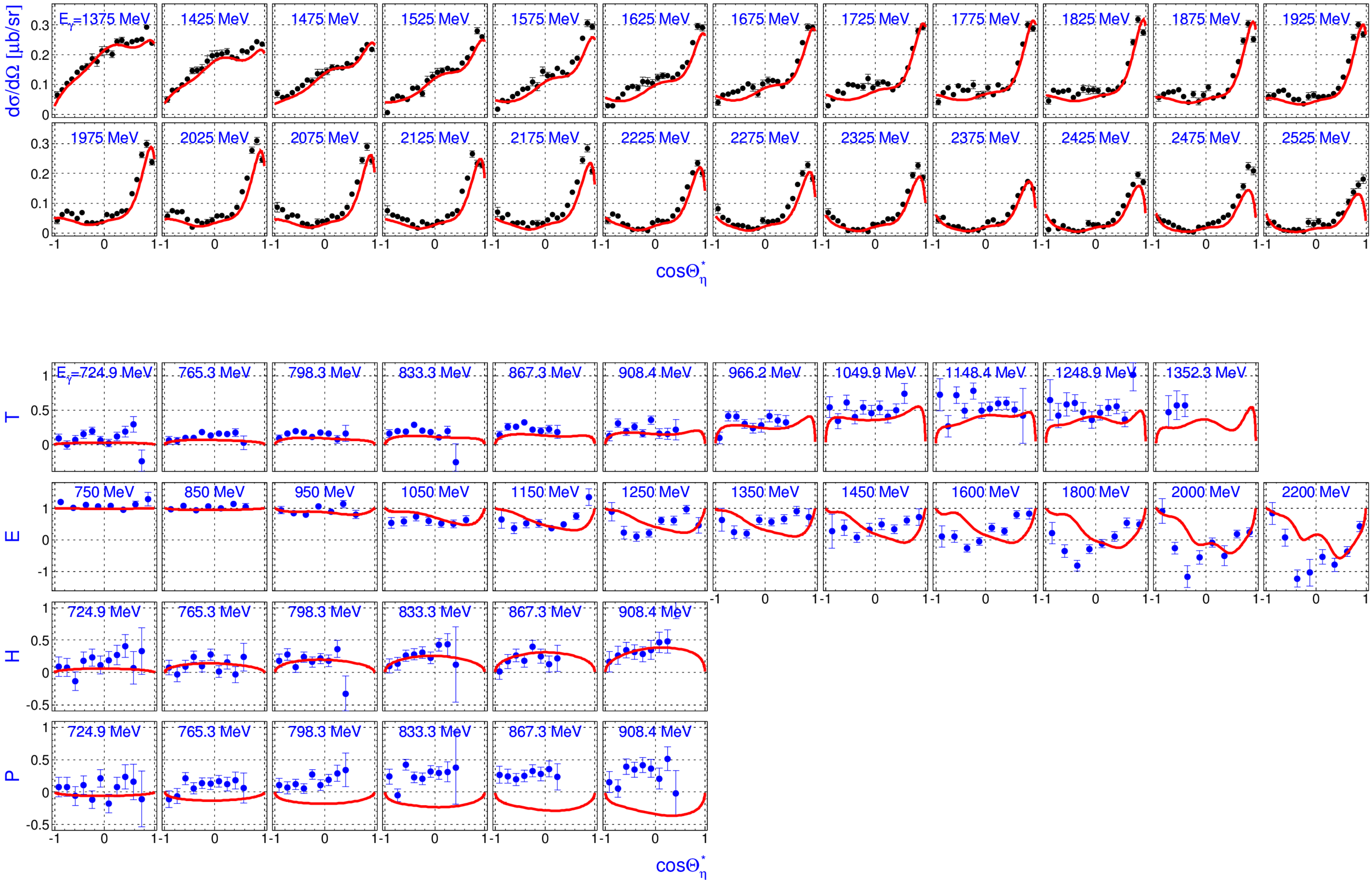
$\gamma\ p \rightarrow \eta'\ p$

MAID-2015: fit parameters

gEtaNN	gRho1	gRho2	gOm1	gOm2	LamR	LamO
0.0044	0.92	6.10	17.90	0.00	0.94	1.10

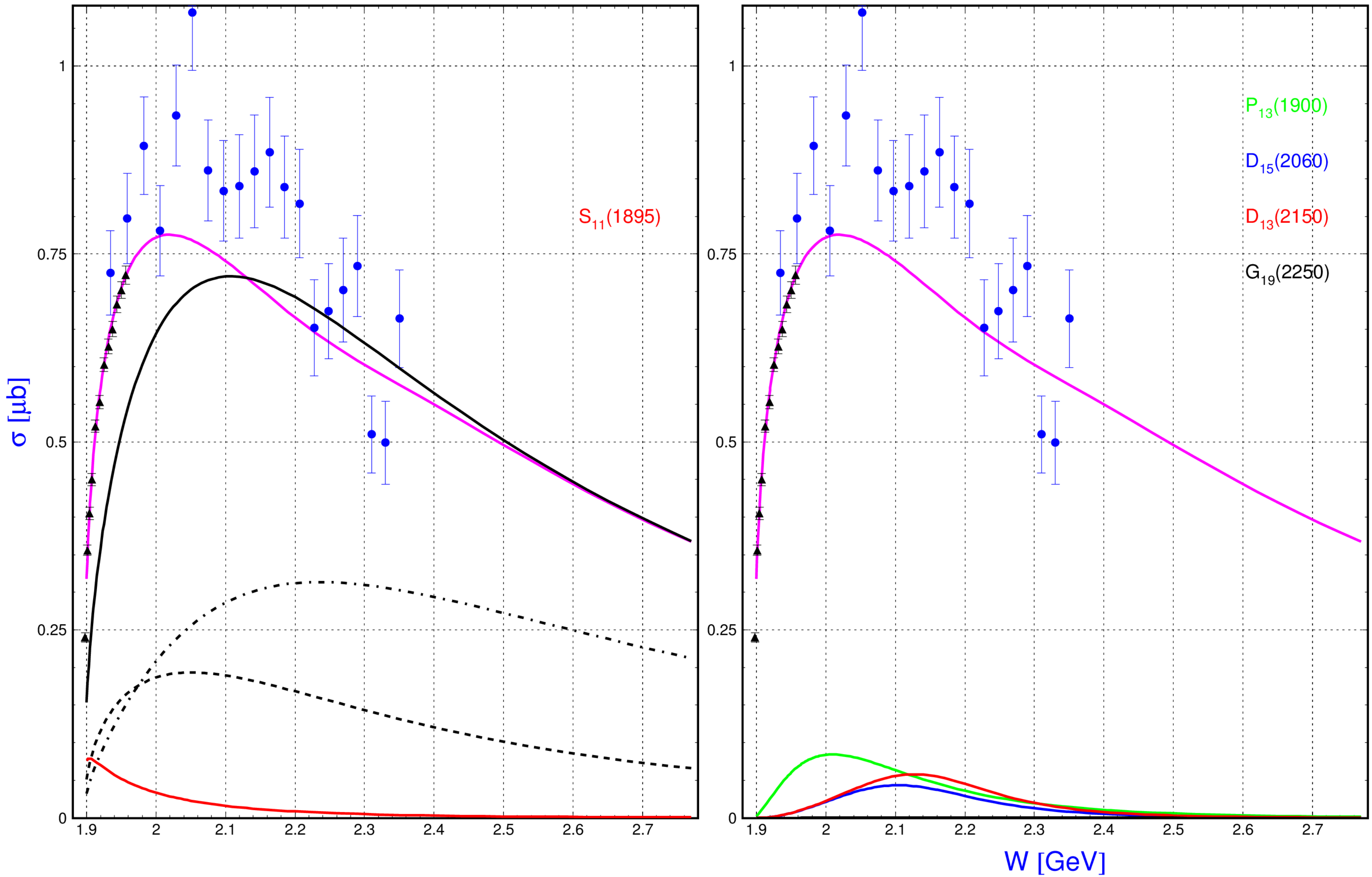
1852.00	175.00	0.6071	-58.5289	-16.1568	D13(1875)
1870.00	369.80	-0.0142	42.9101		P11(1880)
1896.06	80.00	6.4531	-18.7773		S11(1895)
1908.09	289.32	-0.1326	5.2474	-193.9637	P13(1900)
2092.00	284.64	0.1569	24.0000	77.4992	F17(1990)
2188.49	284.47	1.8923	-1.7543	72.3619	F15(2000)
2134.00	492.99	0.1225	45.0002	97.9980	D15(2060)
2093.74	223.60	0.0350	23.8704	471.2545	D13(2150)
2147.16	504.46	-0.7297	-50.0263	-1.5989	G17(2190)
2284.00	539.00	5.7733	14.9495	20.9818	H19(2220)
2304.40	296.85	-1.0779	-32.6542	20.1285	G19(2250)

γ p → η p *MAID-2015 predictions for CBELSA/TAPS data*



black circles: CBELSA/TAPS-09, red lines: ηMAID-2015
blue circles: CBELSA/TAPS-15 (J. Hartmann: TPH, J. Müller: E, preliminary)

γ p → η' p   *MAIDregge-2015 and total cross section*

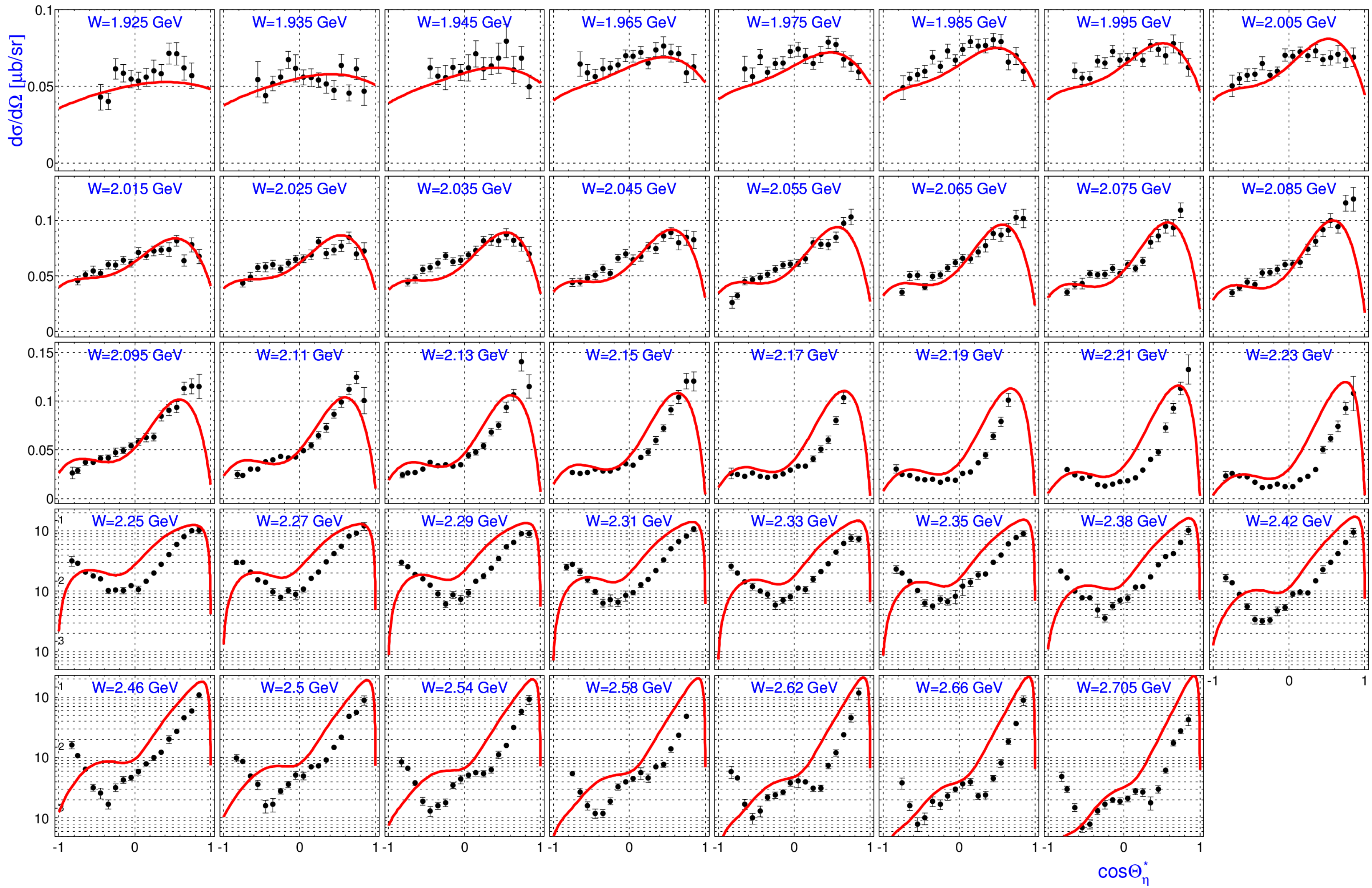


Black triangles: A2MAMI (preliminary);
Blue circles: CBELSA/TAPS-09;

magenta line: ηMAIDregge-2015
black lines: background contributions
(solid: ρ and ω, dashed: ρ, dot-dashed: ω)

γ p → η' p

MAIDregge-2015 and CLAS-09



Black circles: CLAS-09 data; red line: ηMAIDregge-2015

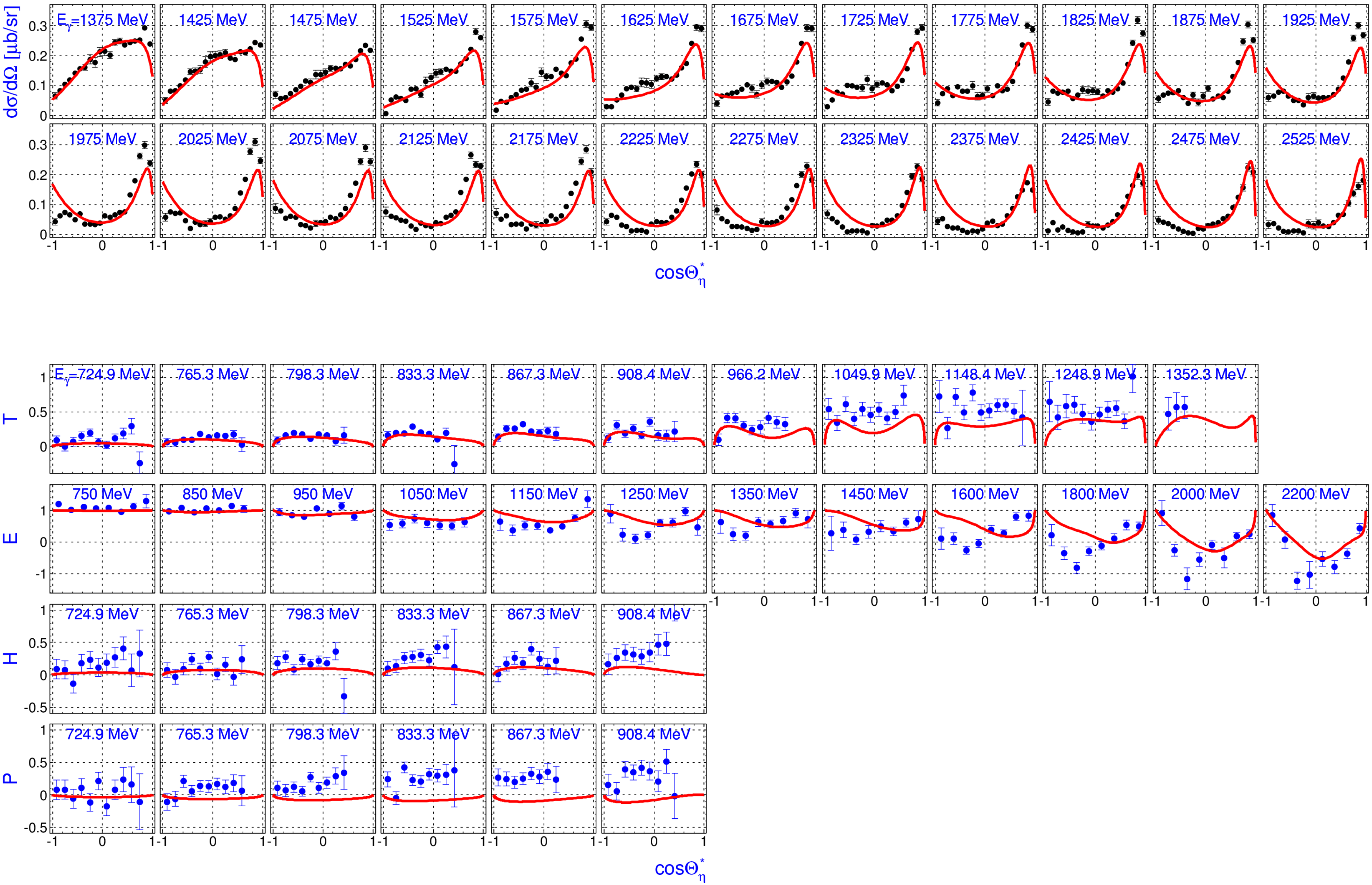
$\gamma\ p \to \eta'\ p$

MAIDregge-2015: fit parameters

gEtaNN	gRho1	gRho2	gOm1	gOm2	LamR	LamO
0.0	0.92	6.1	17.9	0.0	–	–

	M	G	Br.	A1/2	A3/2
S11(1895):	1895.9	83.2	-9.96	-8.	
P13(1900):	1935.	370.	-0.46	40.	-88.7
D15(2060):	2120.	350.	-0.46	55.	80.
D13(2150):	2150.	330.	-0.14	130.	150.

$\gamma\ p \to \eta\ p$ MAIDregge-2015 predictions for CBELSA/TAPS



black circles: CBELSA/TAPS-09, red lines: ηMAIDregge-2015
blue circles: CBELSA/TAPS-15 (J. Hartmann: TPH, J. Müller: E, preliminary)