Regge phenomenology for π^0, η, and η' photoproduction

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Overview

- ηMAID2003 Regge
- Regge cuts

1. results for $\gamma p \to \pi^0 p$
2. adaptation to $\gamma p \to \eta p$
3. adaptation to $\gamma p \to \eta' p$

- Regge background + nucleon resonances
- Conclusions

ηMAID2003 Regge

Reggeized model for η and η' photoproductin

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.

Tabelle 1: Parameters for the vector mesons in this model.

V	m_V [MeV]	g^v_{VNN}	κ_{VNN}	$\lambda_{V\eta\gamma}$	$\lambda_{V\eta'\gamma}$	$\alpha_V(t)$
ρ	768.5	2.4	3.7	0.81	1.24	$0.55 + 0.8\,t/\mathrm{GeV}^2$
ω	782.6	9	0	0.29	-0.43	$0.44 + 0.9\,t/\mathrm{GeV}^2$

$\kappa_{VNN} = g^t_{VNN}/g^v_{VNN}$, where g^v_{VNN} and g^t_{VNN} are vector and tensor hadronic couplings respectively. The hadronic couplings were derived by a fit to high energy data.

Parameters for Regge trajectories $\alpha(t) = \alpha_0 + \alpha'\,t$ were taken from M. Guidal, J.M. Laget, M. Vanderhaeghen, NP A627 (1997) 645.

$\lambda_{V\eta\gamma}$ and $\lambda_{V\eta'\gamma}$ are electromagnetic coupling constants.

ηMAID2003 Regge

The electromagnetic coupling constants $\lambda_{V\eta\gamma}$ and $\lambda_{V\eta'\gamma}$ can be determined from the radiative decay widths,

$$\Gamma_{V\to\eta\gamma} = \frac{\alpha(m_V^2 - m_\eta^2)^3}{24\, m_V^3\, m_\eta^2}\, \lambda_{V\eta\gamma}^2\,, \tag{1}$$

$$\Gamma_{\eta'\to V\gamma} = \frac{\alpha(m_{\eta'}^2 - m_V^2)^3}{24\, m_V^2\, m_{\eta'}^3}\, \lambda_{V\eta'\gamma}^2\,, \tag{2}$$

where α is the fine-structure constant.

The values of $\lambda_{V\eta\gamma}$ and $\lambda_{V\eta'\gamma}$ were obtained from the widths $\Gamma_{\rho\to\eta\gamma} = 36\,\mathrm{keV}$, $\Gamma_{\omega\to\eta\gamma} = 5.5\,\mathrm{keV}$, $\Gamma_{\eta'\to\rho\gamma} = 89\,\mathrm{keV}$, and $\Gamma_{\eta'\to\omega\gamma} = 9.1\,\mathrm{keV}$ (PDG-2000).

ηMAID2003 Regge

The pole-like Feynman propagator was replaced by a Regge propagator for each vector meson:

$\rho\,(1^-)$ exchange:

$$\frac{1}{t-m_\rho^2} \Longrightarrow \mathcal{P}^{\rho}_{\mathrm{Regge}} = \left(\frac{s}{s_0}\right)^{\alpha_\rho(t)-1} \frac{\pi\alpha'_\rho}{\sin(\pi\alpha_\rho(t))} \frac{\mathcal{S}_\rho + e^{-i\pi\alpha_\rho(t)}}{2} \frac{1}{\Gamma(\alpha_\rho(t))}\,, \quad (3)$$

$\omega\,(1^-)$ exchange:

$$\frac{1}{t-m_\omega^2} \Longrightarrow \mathcal{P}^{\omega}_{\mathrm{Regge}} = \left(\frac{s}{s_0}\right)^{\alpha_\omega(t)-1} \frac{\pi\alpha'_\omega}{\sin(\pi\alpha_\omega(t))} \frac{\mathcal{S}_\omega + e^{-i\pi\alpha_\omega(t)}}{2} \frac{1}{\Gamma(\alpha_\omega(t))}\,. \quad (4)$$

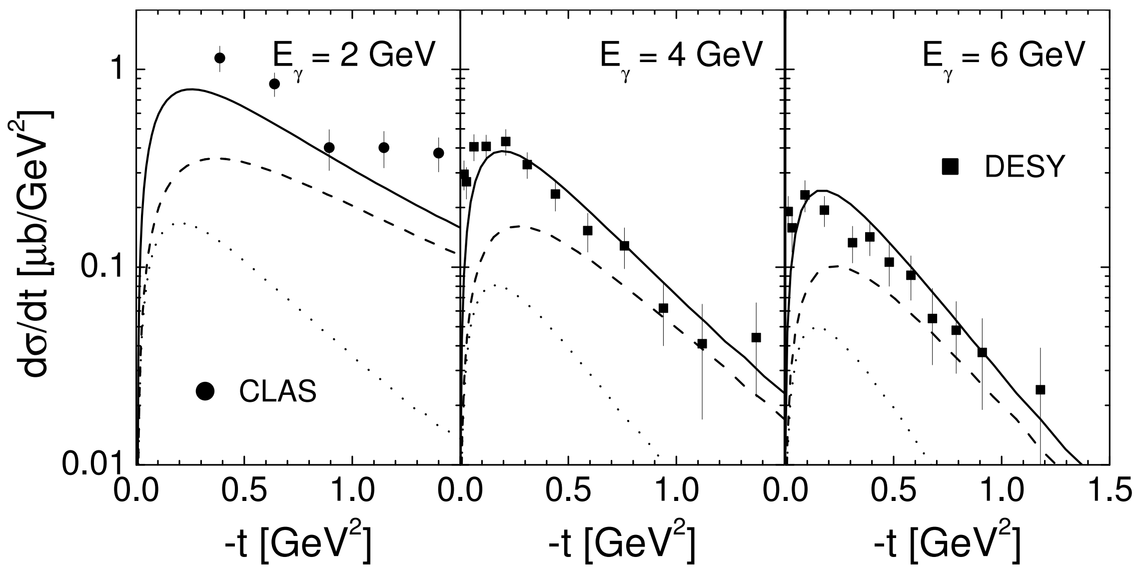
The parameter s_0 is a mass scale taken as $s_0 = 1\ \mathrm{GeV}^2$.

$\mathcal{S} = \pm 1$ is the signature of the trajectory.

The gamma function $\Gamma(\alpha(t))$ suppresses poles of the propagator in the unphysical region.

ηMAID2003 Regge

Differential cross section $d\sigma/dt$ for $\gamma p \to \eta p$.

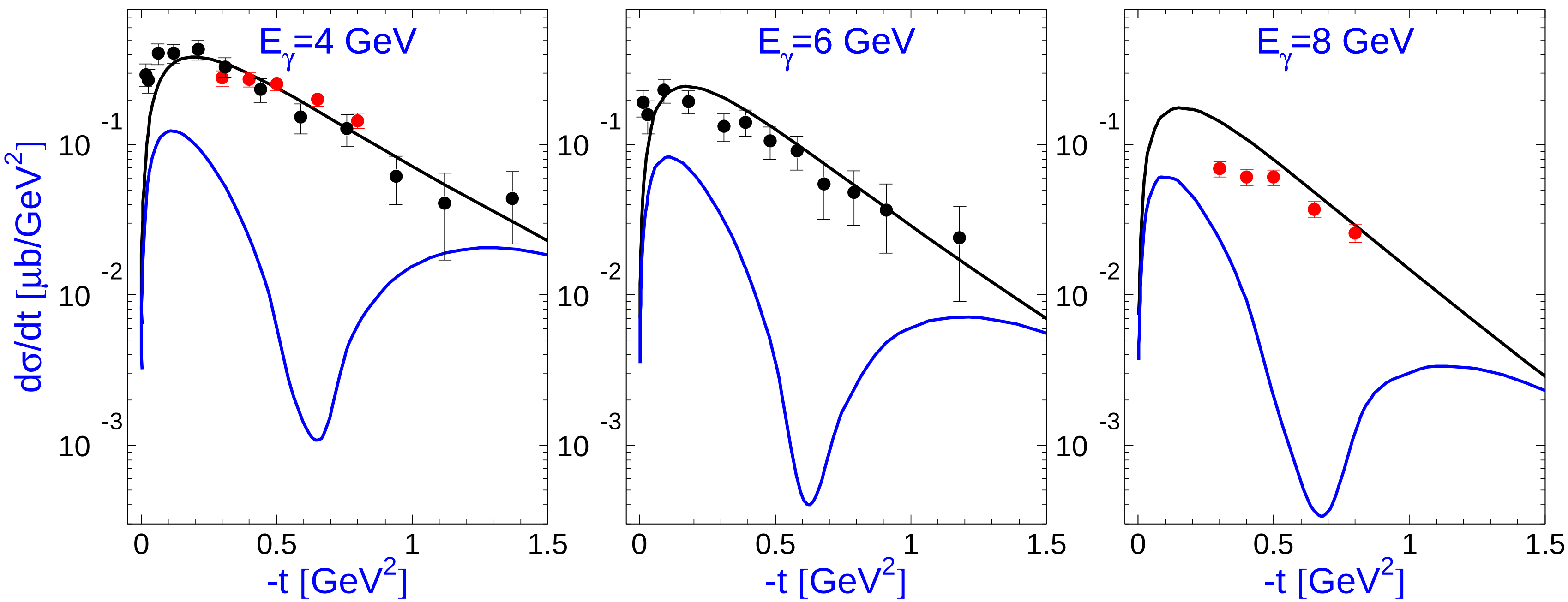


The solid lines are the predictions from t-channel exchange using Regge trajectories, the dashed (dotted) lines indicate the ρ (ω) contributions only.

The data at $E_\gamma^{\rm lab} = 4$ GeV and 6 GeV are from DESY-1970, at $E_\gamma^{\rm lab} = 2$ GeV are from CLAS-2002.

ηMAID2003 Regge

For bosons $\mathcal{S} = (-1)^J$, so for the vector mesons $\mathcal{S} = -1$.



Black lines are ηMAID2003 Regge without nucleon resonances.

Blue lines are the same, but with $\mathcal{S} = -1$.

Black circles: DESY-1970

Red circles: WLS-1971

Regge cuts: π^0 photoprduction

G.R. Goldstein, J.F. Owens III, PRD 7 (1973) 865.

I.S. Barker, J.K. Storrow, NP B137 (1978) 413.

A. Donnachie, Yu.S. Kalashnikova, arXiv:1507.07408v1, 27 Jul 2015.

Regge cuts arise from rescattering two Reggeons R_1 and R_2 (or more).

The exchange of two Reggeons with linear trajectories:

$$\alpha_i(t) = \alpha_i(0) + \alpha_i' t, i = 1, 2 \tag{5}$$

yields a cut with a linear trajectory $\alpha_c(t)$:

$$\alpha_c(t) = \alpha_c(0) + \alpha_c' t \tag{6}$$

were

$$\begin{aligned} \alpha_c(0) &= \alpha_1(0) + \alpha_2(0) - 1 \\ \alpha_c' &= \frac{\alpha_1' \alpha_2'}{\alpha_1' + \alpha_2'} \end{aligned} \tag{7}$$

Regge cuts: π^0 photoprduction

Donnachie and Kalashnikova (DoKa) assumed:

linear non-degenerate ρ and ω trajectories:

$$\alpha_\rho = 0.55 + 0.8t$$

$$\alpha_\omega = 0.44 + 0.9t$$

secondary linear non-degenerate Pomeron (P) and f_2 trajectories:

$$\alpha_P \sim 1.08 + 0.25t$$

$$\alpha_{f_2} = 0.672 + 0.817t$$

trajectory of the associated $\rho - P$ and $\omega - P$ cuts:

$$\alpha^c_{\rho-P} = 0.64 + 0.160t$$

$$\alpha^c_{\omega-P} = 0.52 + 0.196t$$

trajectories of the associated $\rho - f_2$ and $\omega - f_2$ cuts:

$$\alpha^c_{\rho-f_2} = 0.222 + 0.404t$$

$$\alpha^c_{\omega-f_2} = 0.112 + 0.428t$$

Regge cuts: π^0 photoprduction

Tabelle 2: Parameters of the vector mesons used by Donachie and Kalashnikova.

V	g^v_{VNN}	κ_{VNN}	$\lambda_{V\pi^0\gamma}$
ρ	$3.4(2.4)$	$6.1(3.7)$	0.119
ω	$15(9)$	$0(0)$	0.322

$\kappa_{VNN} = g^t_{VNN}/g^v_{VNN}$, where g^v_{VNN} and g^t_{VNN} are vector and tensor hadronic couplings respectively.

Values in parentheses are parameters used in ηMAID2003 Regge.

$\lambda_{\rho\pi^0\gamma}$ and $\lambda_{\omega\pi^0\gamma}$ are electromagnetic coupling constants.

Regge cuts: π^0 photoprduction

Donnachie and Kalashnikova:

As a physical mass cannot be be associated with a cut, the simplest form of amplitude for a cut term is

$$A_c(s,t) = C_c D_c(s,t) \quad (8)$$

where C_c is a constant and

$$D_c(s,t) = e^{d_c t} e^{-i\frac{1}{2}\pi\alpha_c(t)} s^{\alpha_c(t)-1}. \quad (9)$$

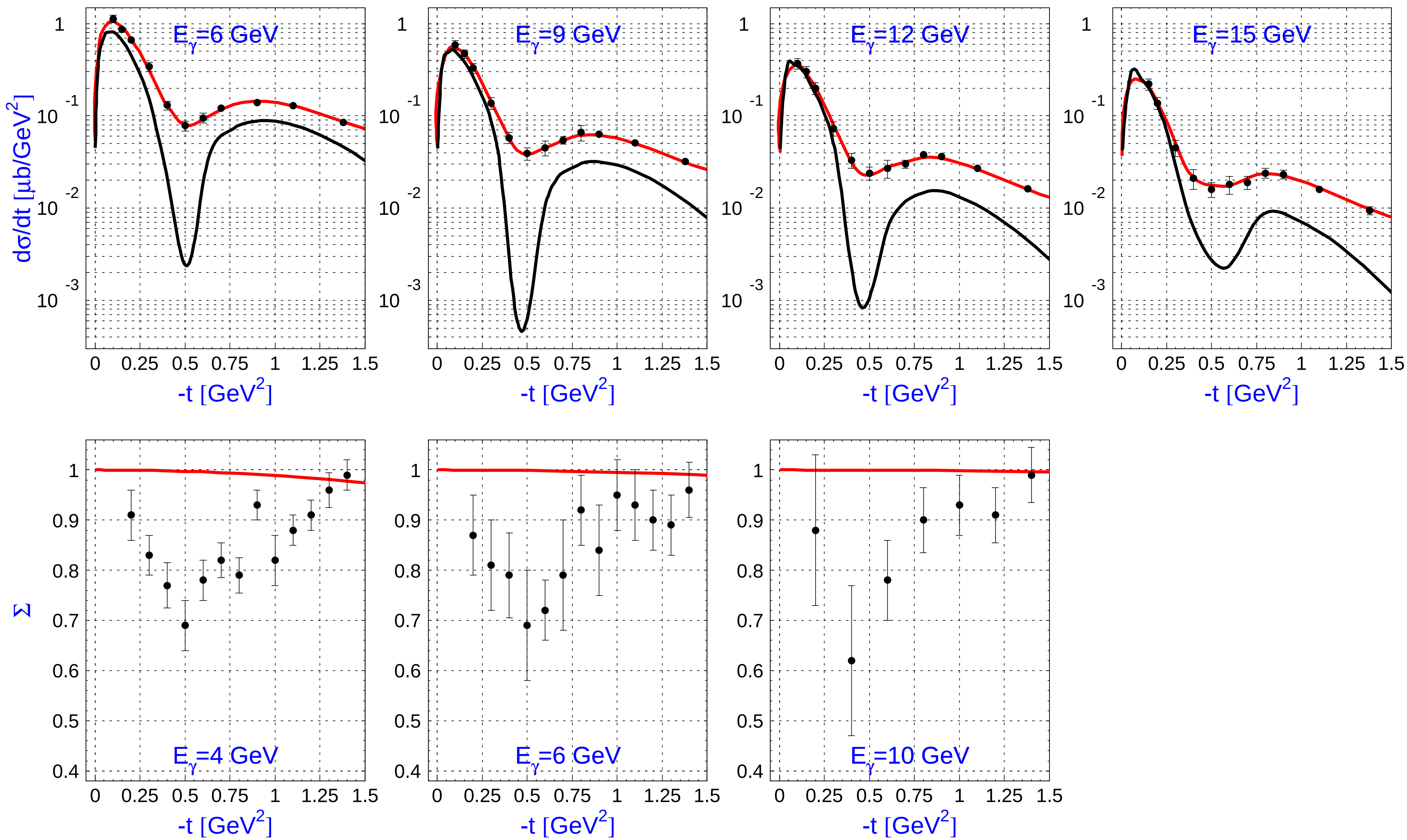
where we have retained only the Regge phase and absorbed the rest of the t-dependence in the exponential, $\alpha_c(t)$ is the cut trajectory and the constants C_c and d_c for each cut term are obtained by fitting data.

We need a mechanism to allow us to transfer the π^0 cut model to scalar photoproduction. The simplest way is to take the cut terms proportional to the dominant ω and ρ exchanges, retaining the kinematical structure and replacing $\lambda_{V\pi^0\gamma} g_{VNN} D_V(s,t), V = \rho, \omega$ by

$$\lambda_{V\pi^0\gamma} g_{VNN} (D_V(s,t) + C_n^{V-P} D_c^{V-P}(s,t) + C_n^{V-f_2} D_c^{V-f_2}(s,t)), \quad (10)$$

where C_n^{V-P} and $C_n^{V-f_2}$ are respectively the natural-parity constants for the V-P and V-f_2 cuts.

Regge cuts: π^0 photoprduction



Red lines: fit results with the cuts (Fit 1).

Black lines: without the cuts. Black circles: SLAC-1971 data

Regge cuts: π^0 photoprduction

Donnachie and Kalashnikova:

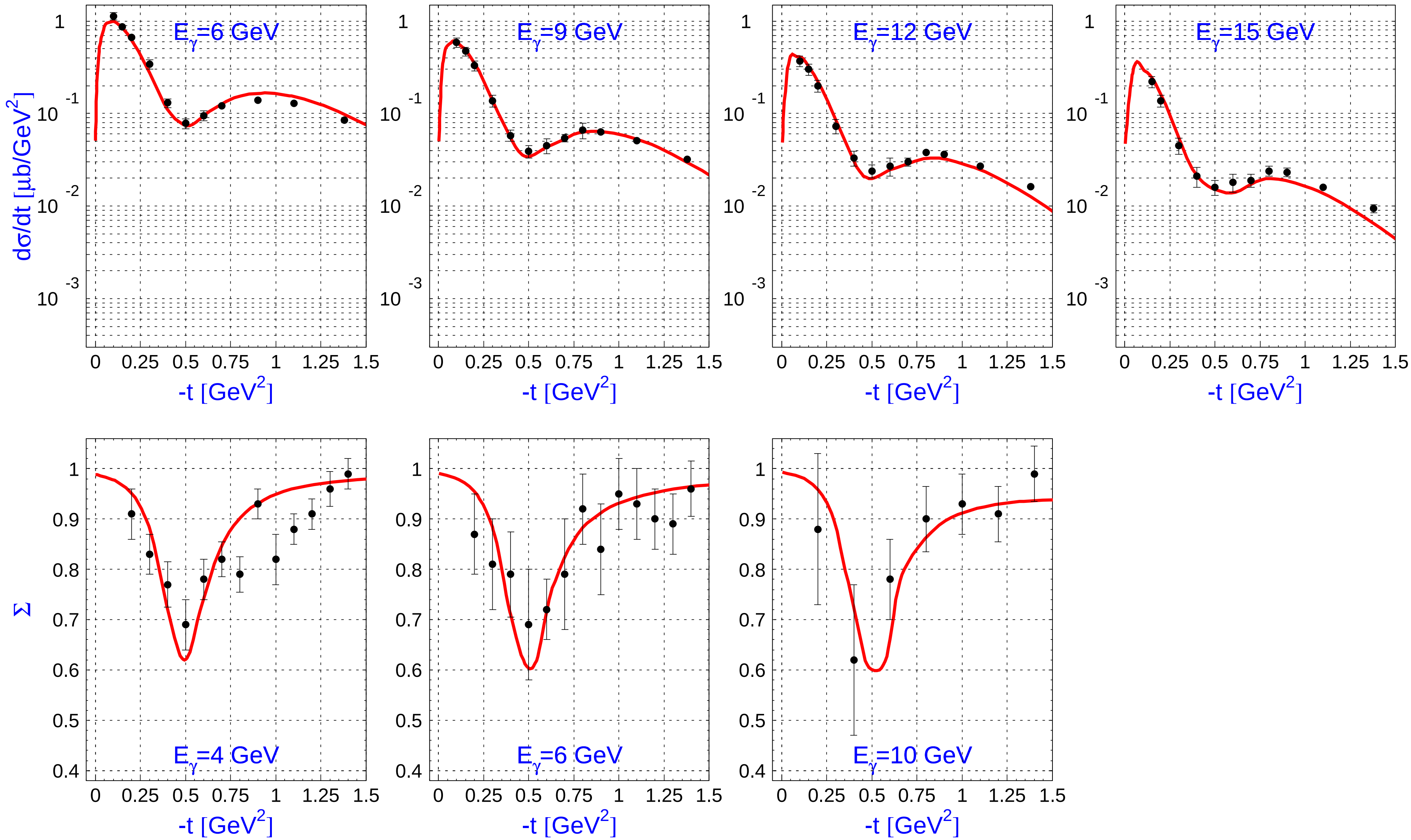
These cuts also feed into the unnatural-parity exchange term and are much larger than any cuts generated by $b_1(1235)$ exchange due to its small contribution. So b1 pole term $\lambda_{b_1\pi^0\gamma} g_{b_1NN} D_b(s,t)$ is replaced by

$$\lambda_{b_1\pi^0\gamma} g_{b_1NN} D_b(s,t) + \sum_V \lambda_{V\pi^0\gamma} g_{VNN} (C_u^{V-P} D_c^{V-P}(s,t) + C_u^{V-f_2} D_c^{V-f_2}(s,t)), \tag{11}$$

where the C_u^{V-P} and $C_u^{V-f_2}$ are the unnatural-parity constants. It turns out that the cuts dominate unnatural parity exchange so in practice the b_1 pole term could be omitted.

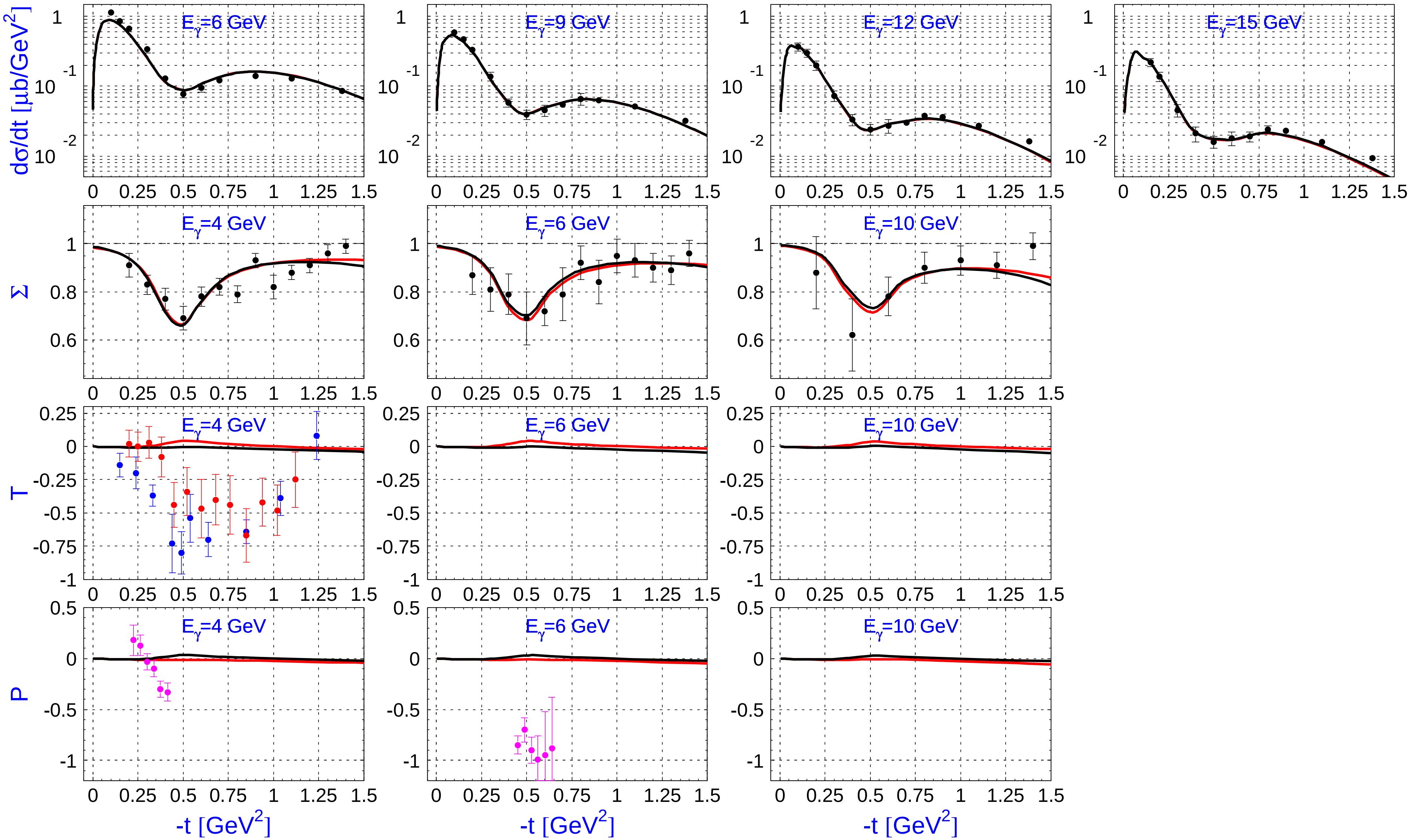
The parameters for ρ and ω were taken to be the same:
$C_n^{\rho-P} = C_n^{\omega-P}$, $C_n^{\rho-f_2} = C_n^{\omega-f_2}$,
$C_u^{\rho-P} = C_u^{\omega-P}$, $C_u^{\rho-f_2} = C_u^{\omega-f_2}$.
d_c of the exponential also was taken to be the same for all terms.
So in practice we have only five free parameters to describe π^0 photoproduction.

Regge cuts: π^0 photoprduction



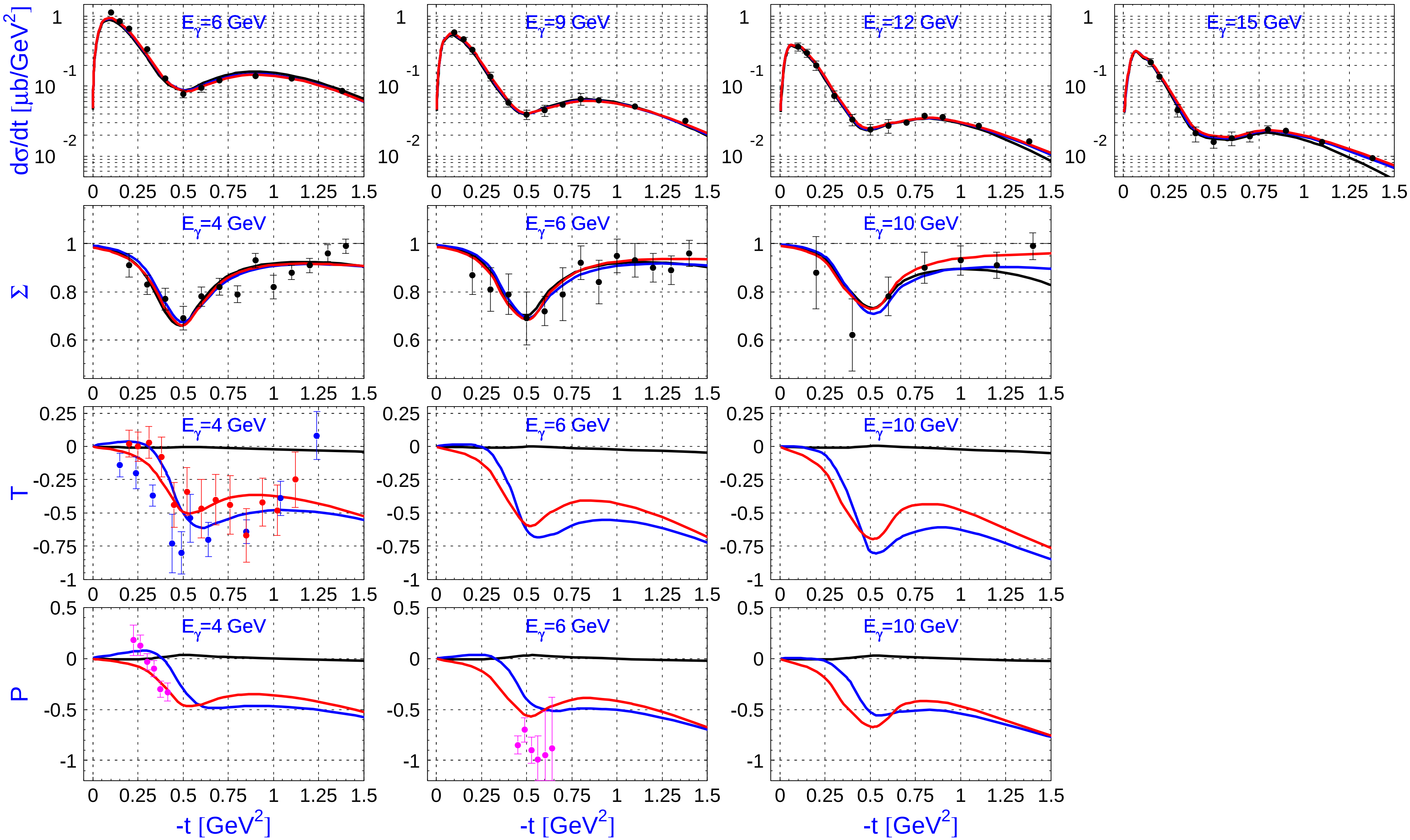
Red lines: fit results with vector and axial-vector mesons (Fit 2).

Regge cuts: π^0 photoprduction



Black lines: Fit 2. Red lines: fit to SLAC-1971 (black), Botth-1972 (blue), Beinlein-1973 (red), Deutsch-1972 (magenta) data (Fit 3).

Regge cuts: π^0 photoprduction



Black lines: Fit 3

Blue lines: Fit with 6 parameters to all data (Fit 4). Red lines: same as Fit 4, but without P data

Regge cuts: adaptation to η photoproduction

Electromagnetic coupling constants were recalculated according to new experimental data for the radiative decay widts:

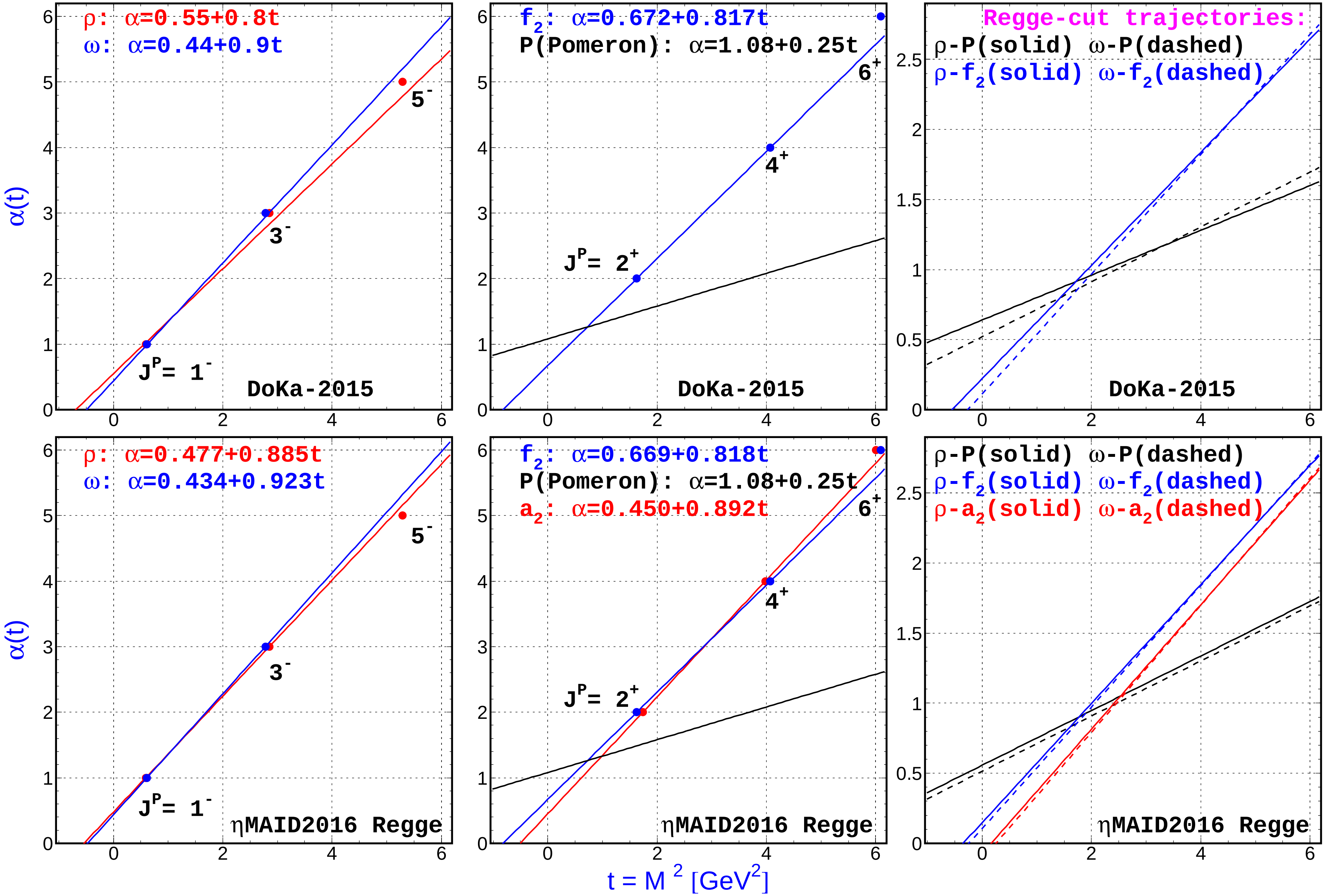
Parameter [keV]	ηMAID-03 Regge	PDG-14
$\Gamma_{\rho\to\eta\gamma}$	36	50.6
$\Gamma_{\omega\to\eta\gamma}$	5.5	3.9
$\Gamma_{\eta\prime\to\rho\gamma}$	89	58
$\Gamma_{\eta\prime\to\omega\gamma}$	9.1	5.5

Regge cuts: adaptation to η photoproduction

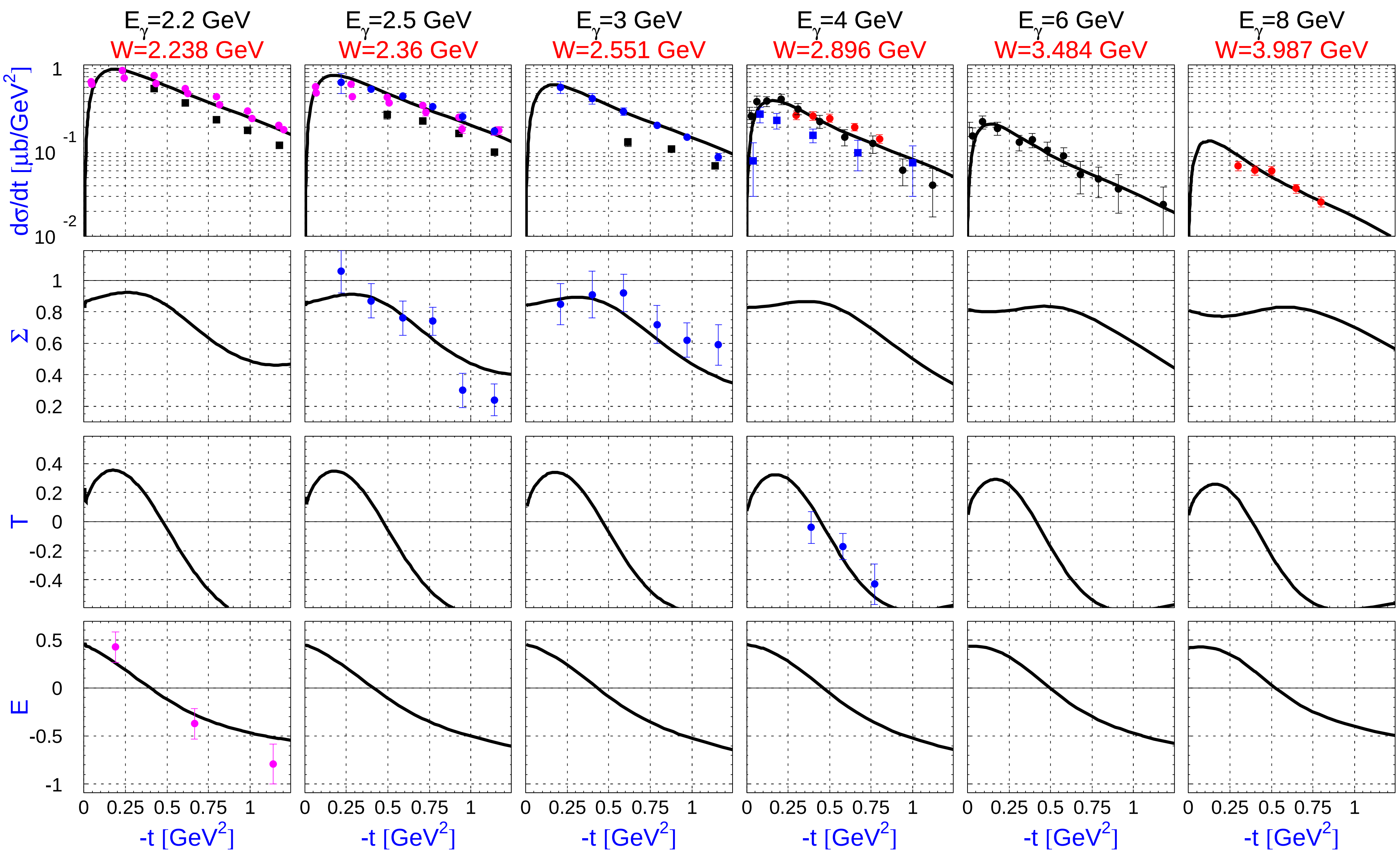
Vector and tensor hadronic coupling constants

Parameter	ηMAID-03	ηMAID-03 Regge	Laget-PRC72(2005)	DoKa
$g^v_{\rho NN}$	2.4	2.4	0.92	3.4
$k_{\rho NN}$	6.1	3.7	6.1	6.1
$g^v_{\omega NN}$	16	9	17.9	15
$k_{\omega NN}$	0	0	0	0

Regge cuts: adaptation to η photoproduction



Regge cuts: adaptation to η photoproduction



Black lines: fit results with 9 parameters

Regge cuts: adaptation to η photoproduction

Tabelle 3: Fit parameters

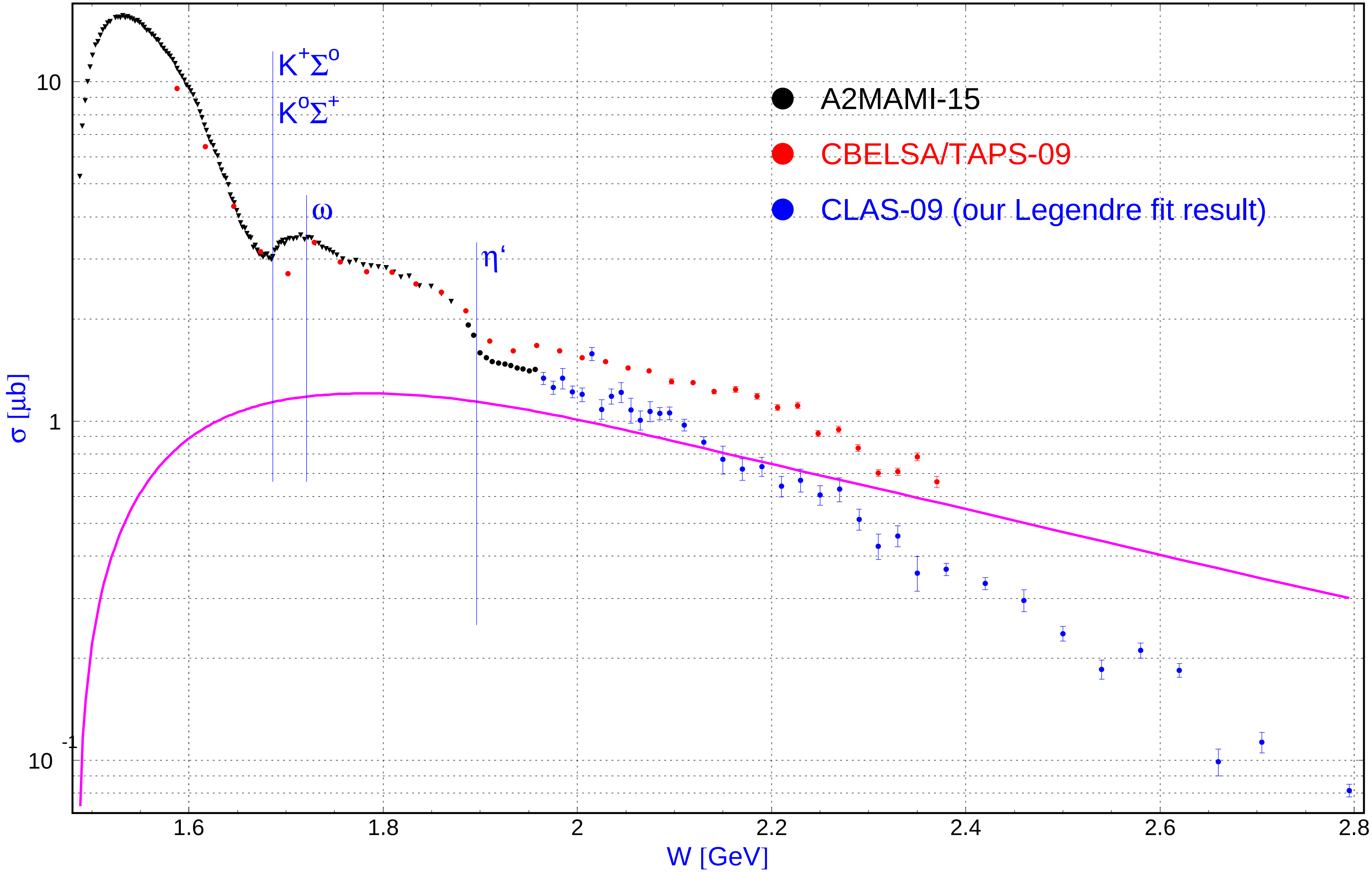
$channel$	d_c	$C_n^{\rho-P}$	$C_n^{\omega-P}$	$C_n^{\rho-f_2}$	$C_n^{\omega-f_2}$	$C_u^{\rho-P}$	$C_u^{\rho-f_2}$
η	2.01	-1.31	0.50	9.08	-5.37	0.13	1.01
π^0	0.82	-0.84	0.03	1.50	-0.47	0	0.18

$C_u^{\omega-P} = C_u^{\rho-P}$
$C_u^{\omega-f_2} = C_u^{\rho-f_2}$

Two additional fit parameters for η photoproduction:

$\lambda_{b_1\eta\gamma}\, g^v_{b_1NN} = 15.3$,
$\lambda_{b_1\eta\gamma}\, g^t_{b_1NN} = 9.1$,
where $g^v_{b_1NN}$ and $g^t_{b_1NN}$ are vector and tensor hadronic coulings respectively,
and $\lambda_{b_1\eta\gamma}$ is electrmagnetic coupling constant of the b_1 meson.

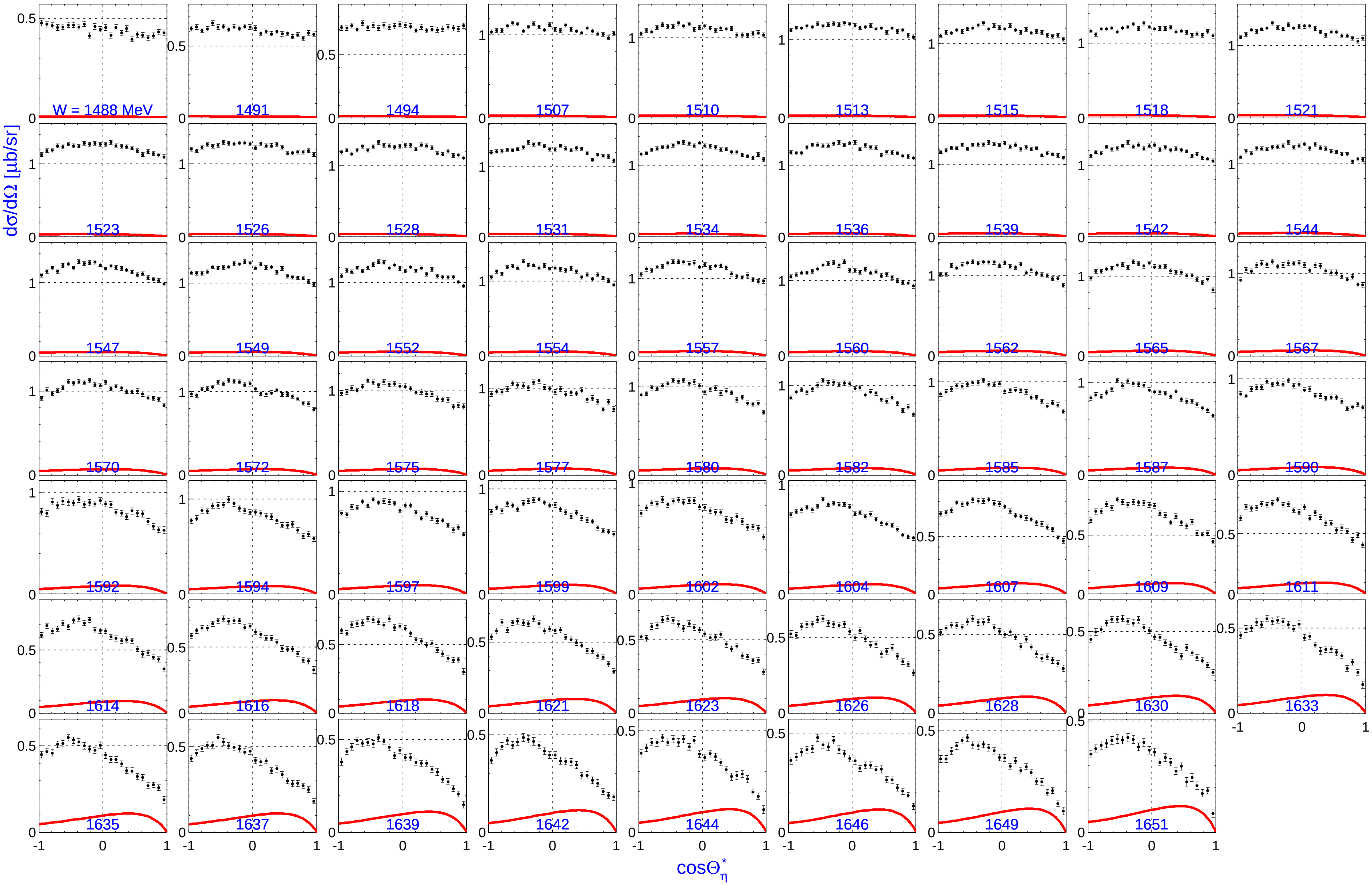
Regge cuts: adaptation to η photoproduction



magenta line: background contribution

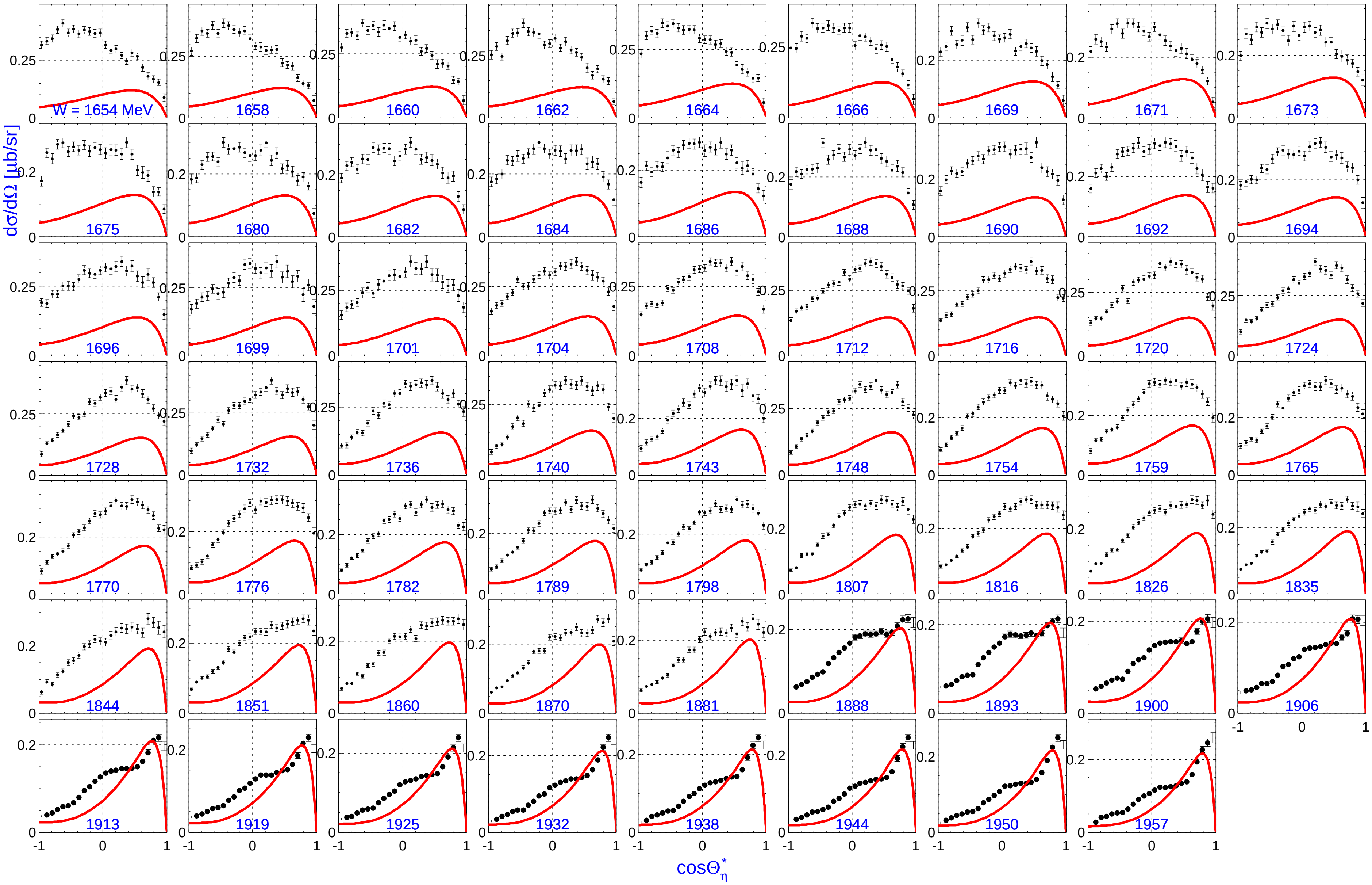
Regge cuts: adaptation to η photoproduction

data: A2MAMI (preliminary). Red lines: background contribution



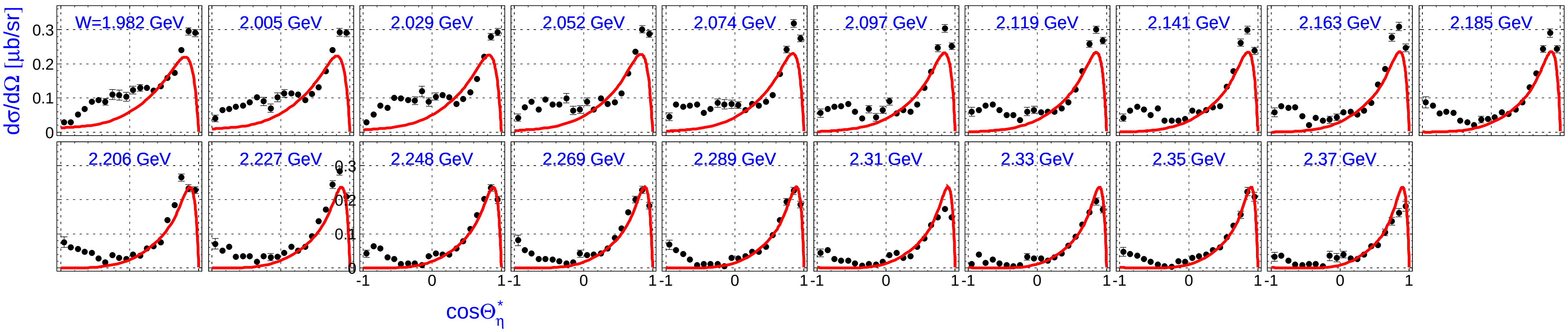
Regge cuts: adaptation to η photoproduction

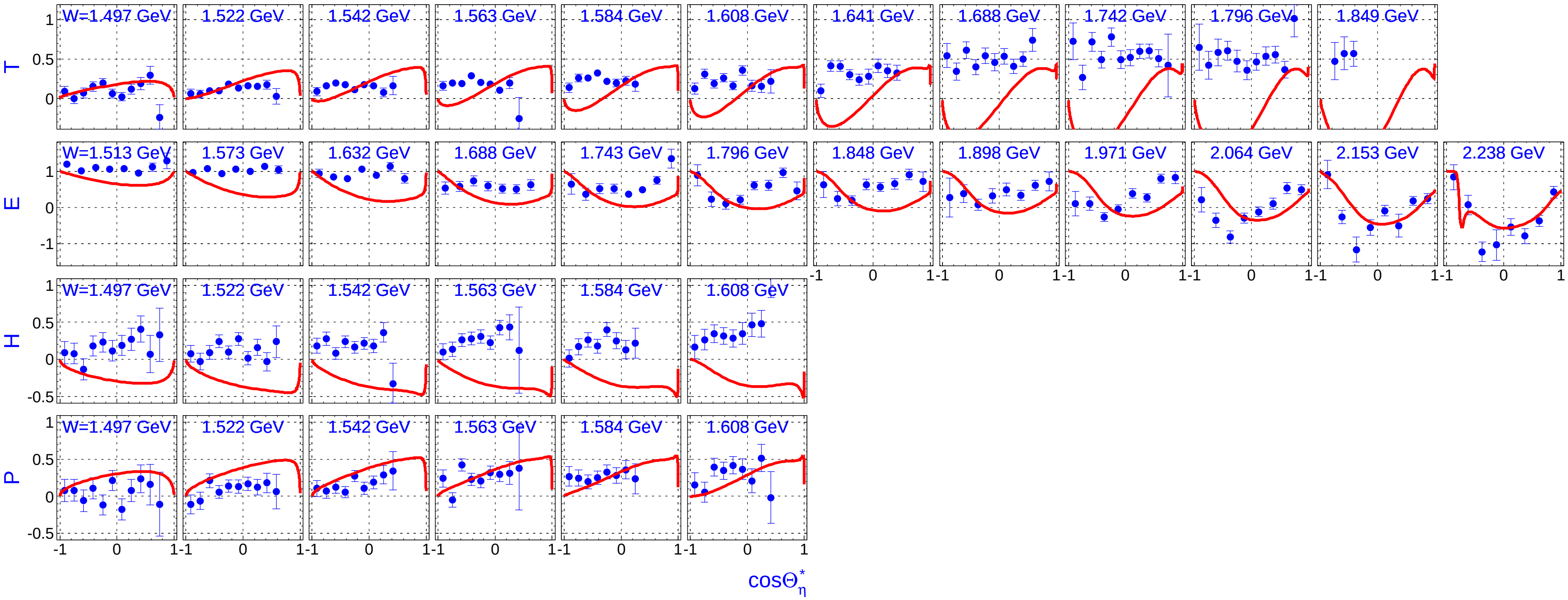
data: A2MAMI (preliminary). Red lines: background contribution.



Regge cuts: adaptation to η photoproduction

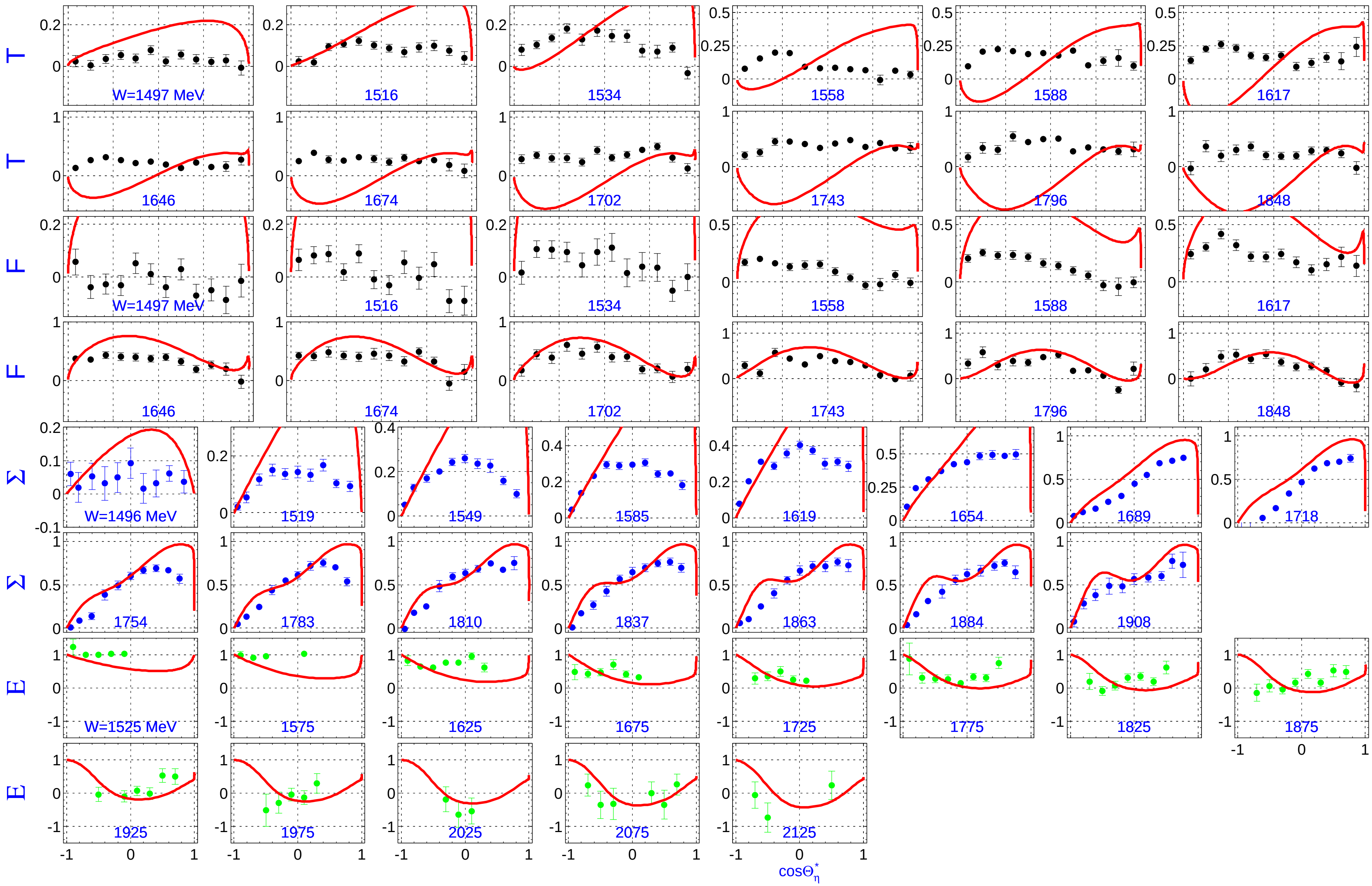
CBELSA/TAPS data: $d\sigma/d\Omega$ - 2009, T,E,H,P - preliminary





Regge cuts: adaptation to η photoproduction

data: A2MAMI-2015 (T,F), GRAAL-2007 (Σ), CLAS-2015 (E)



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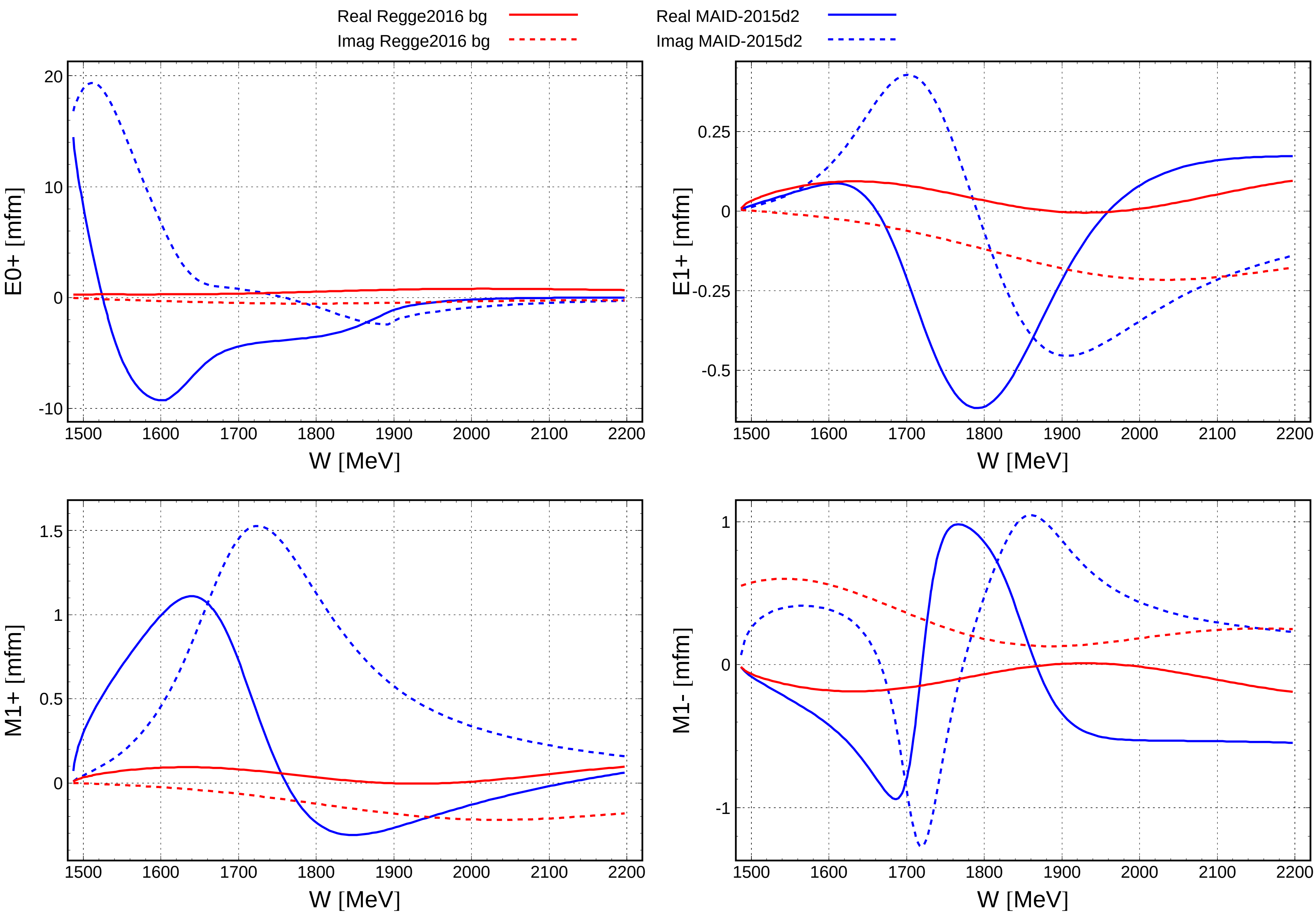

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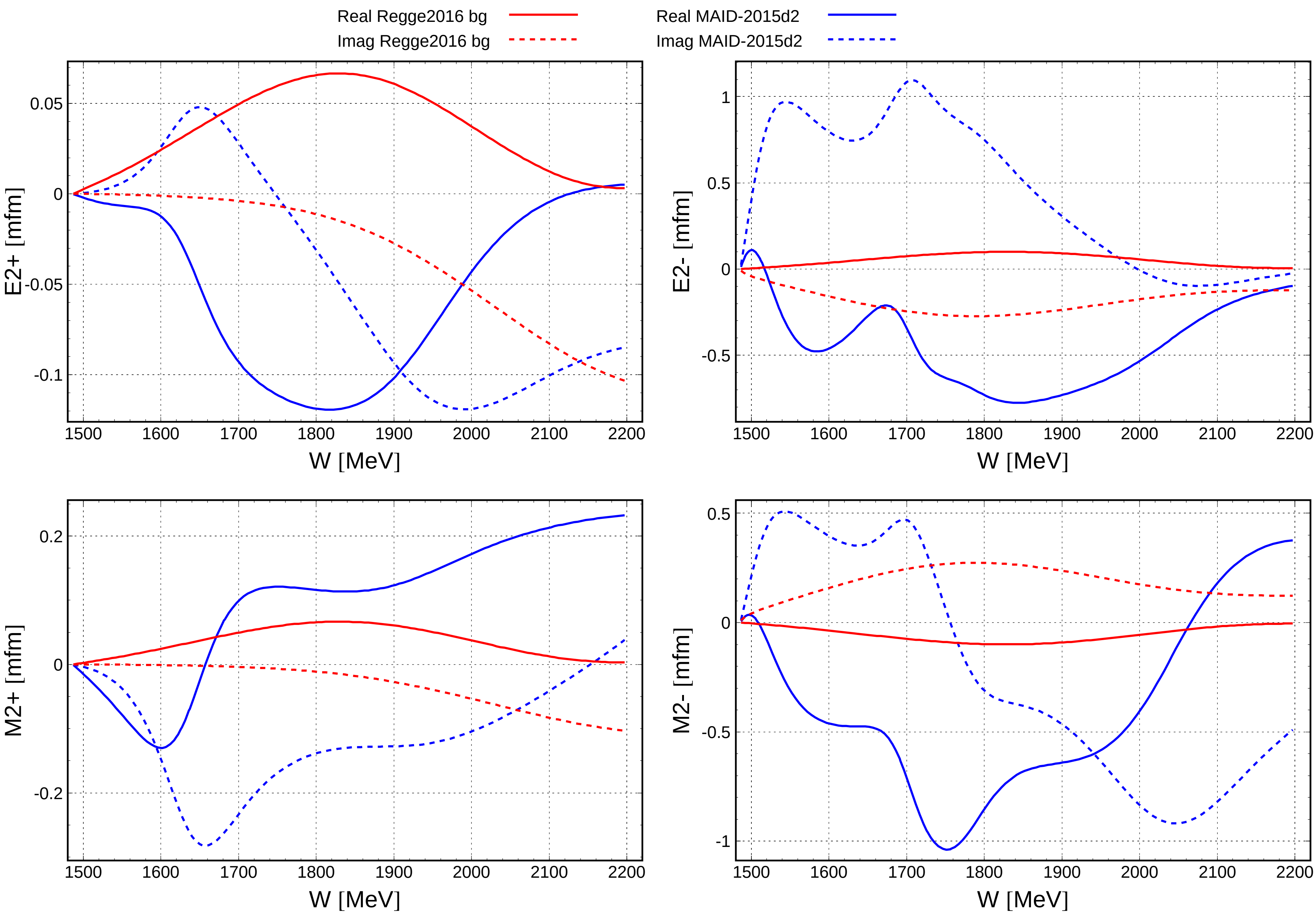

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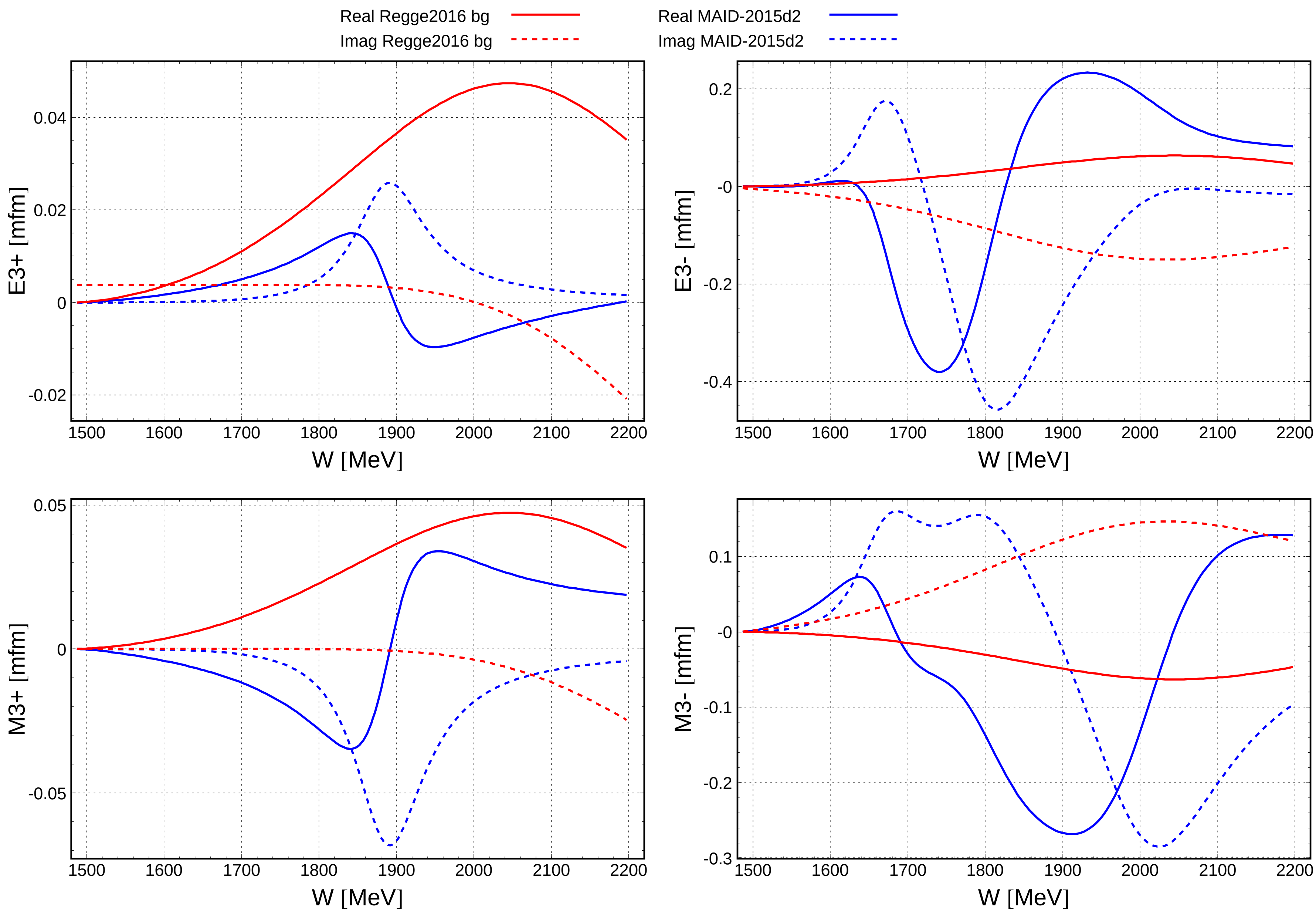

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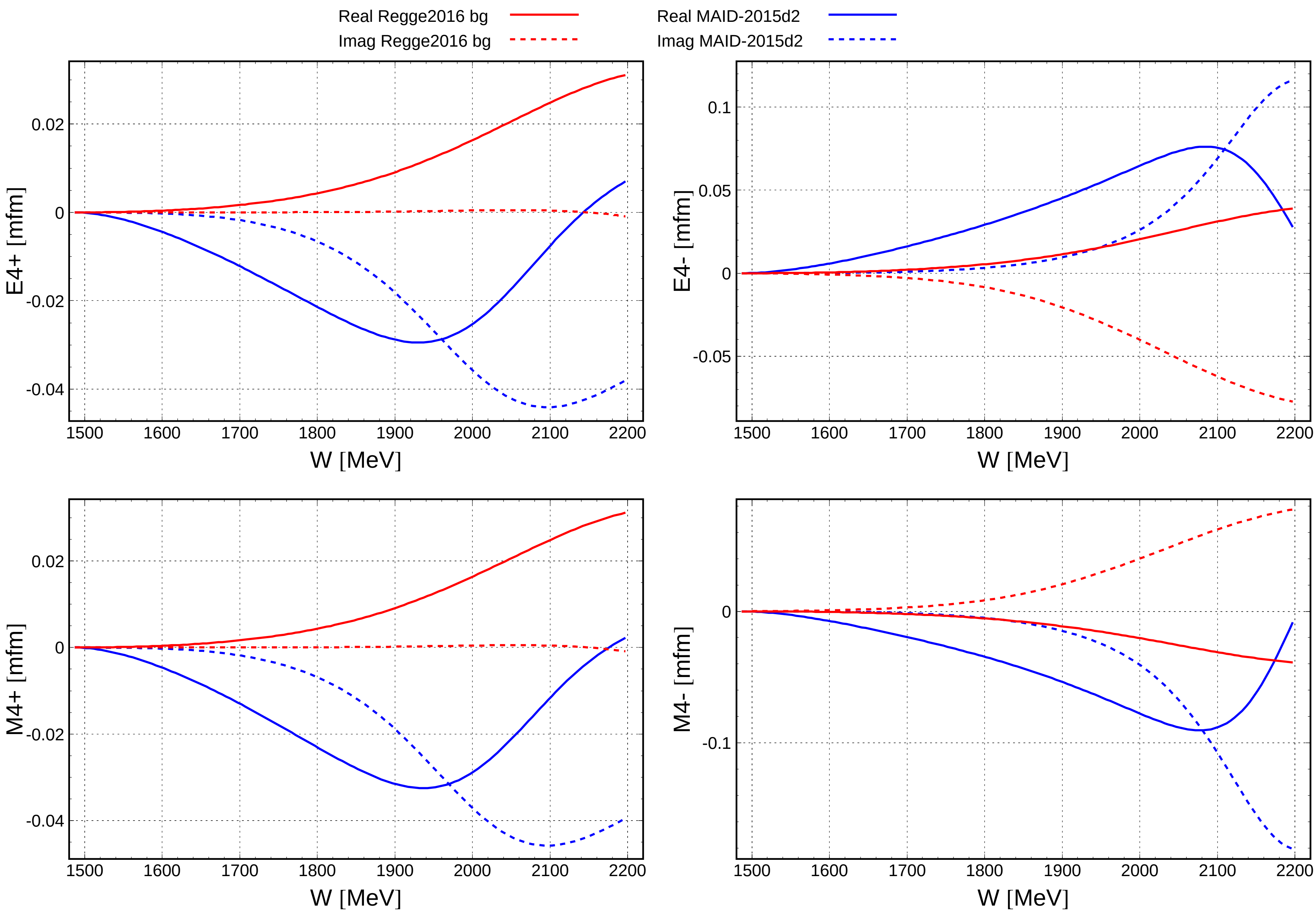

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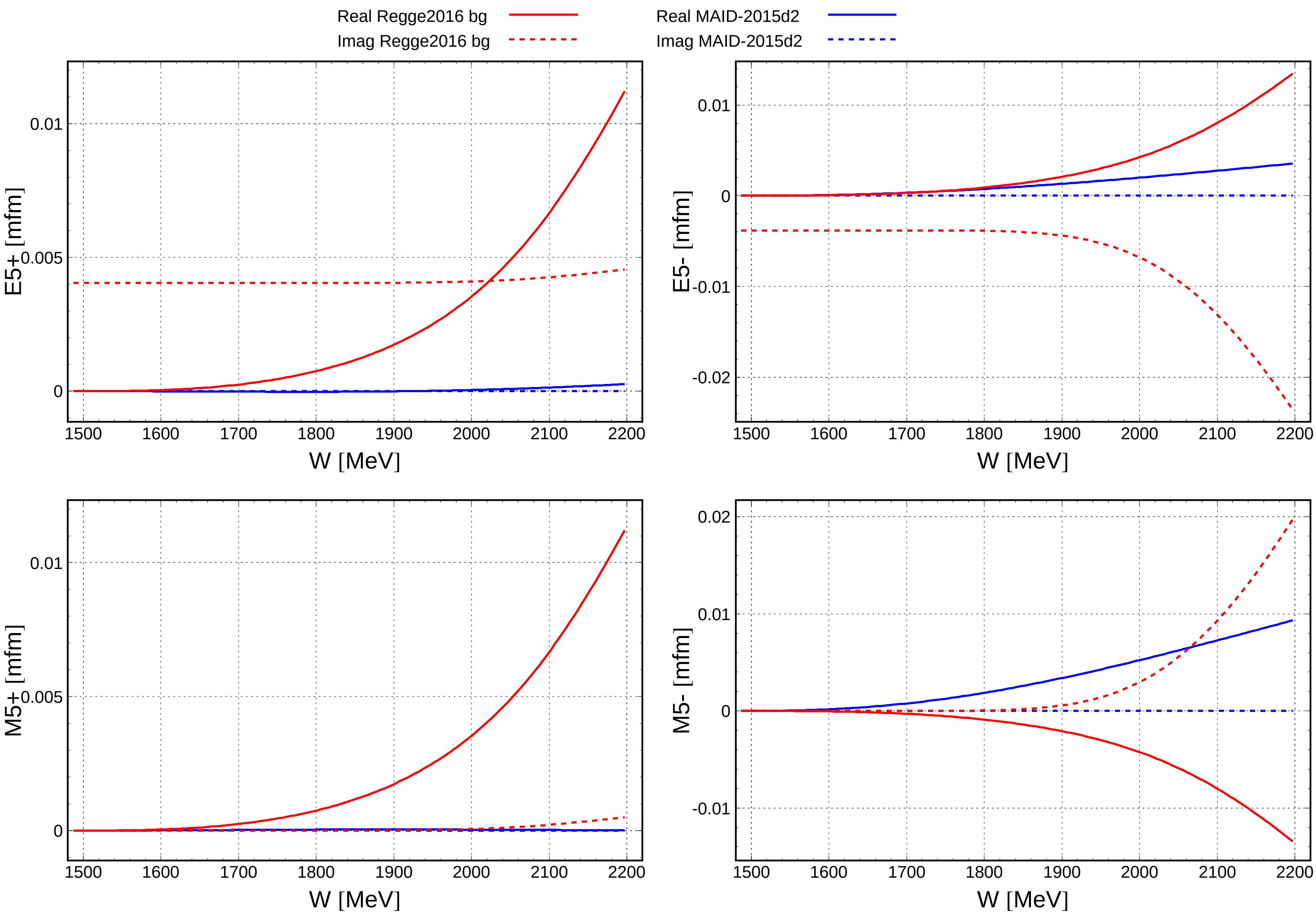
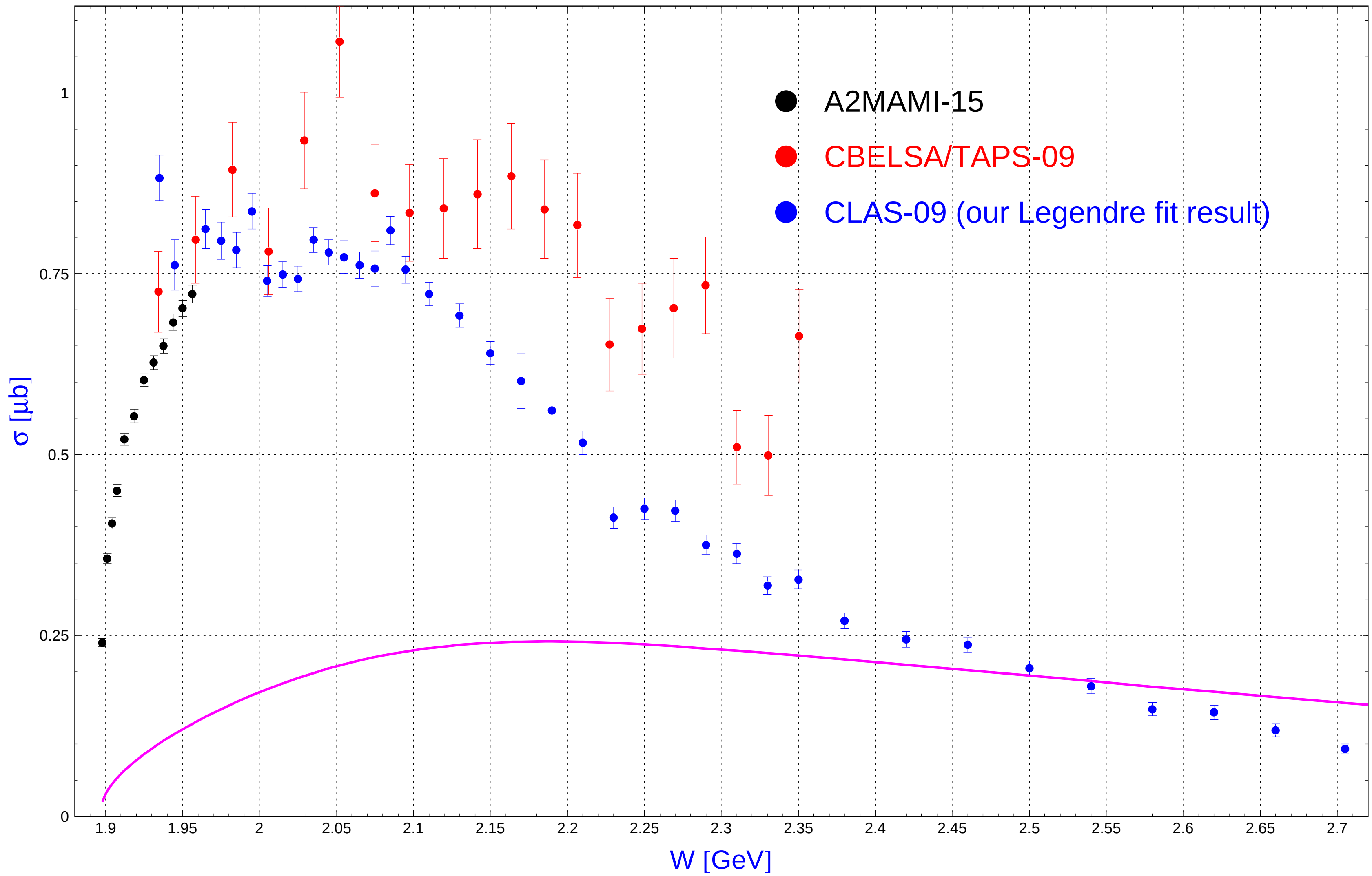


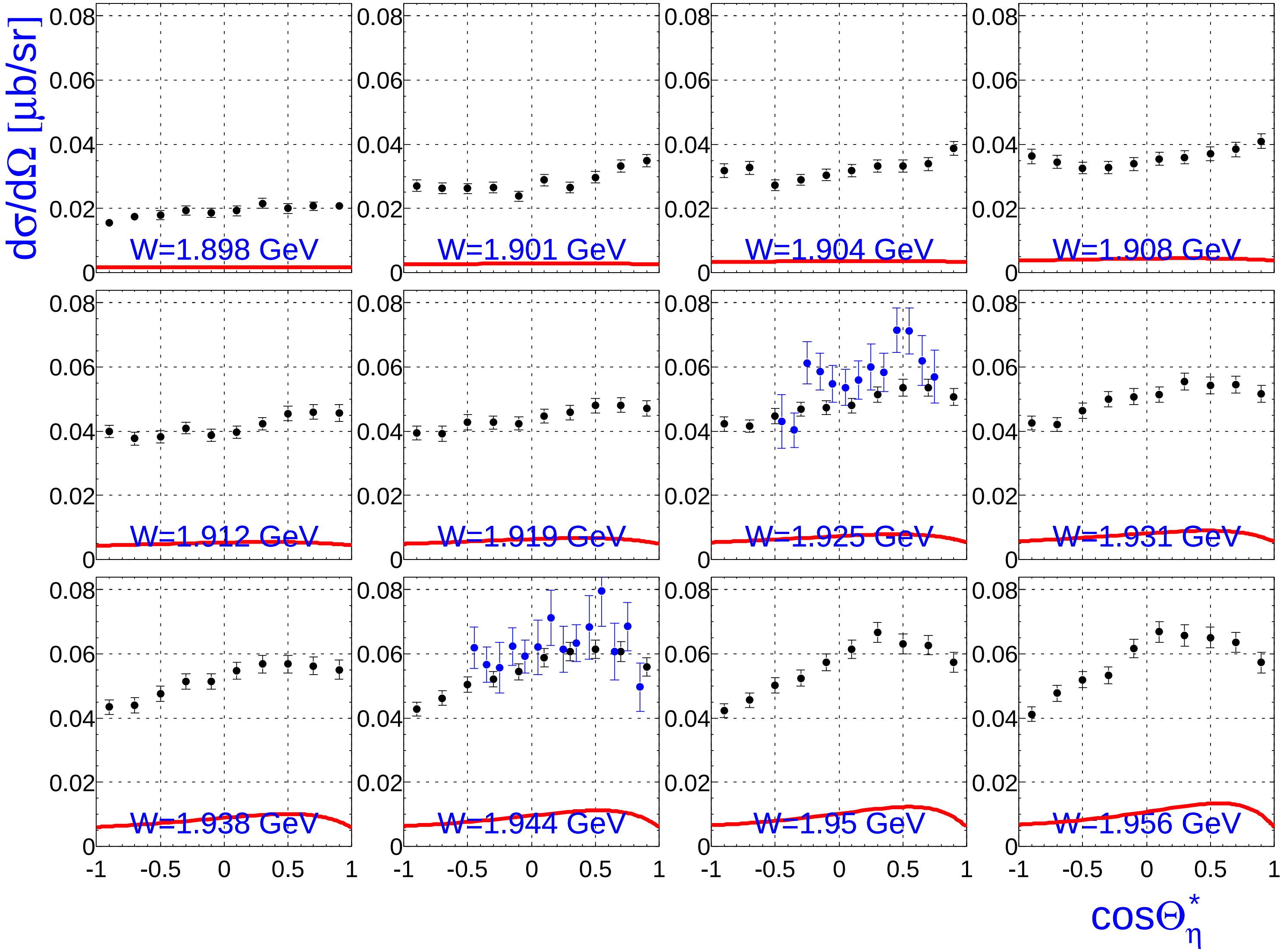
Regge cuts: adaptation to η' photoproductin



magenta line: Regge background

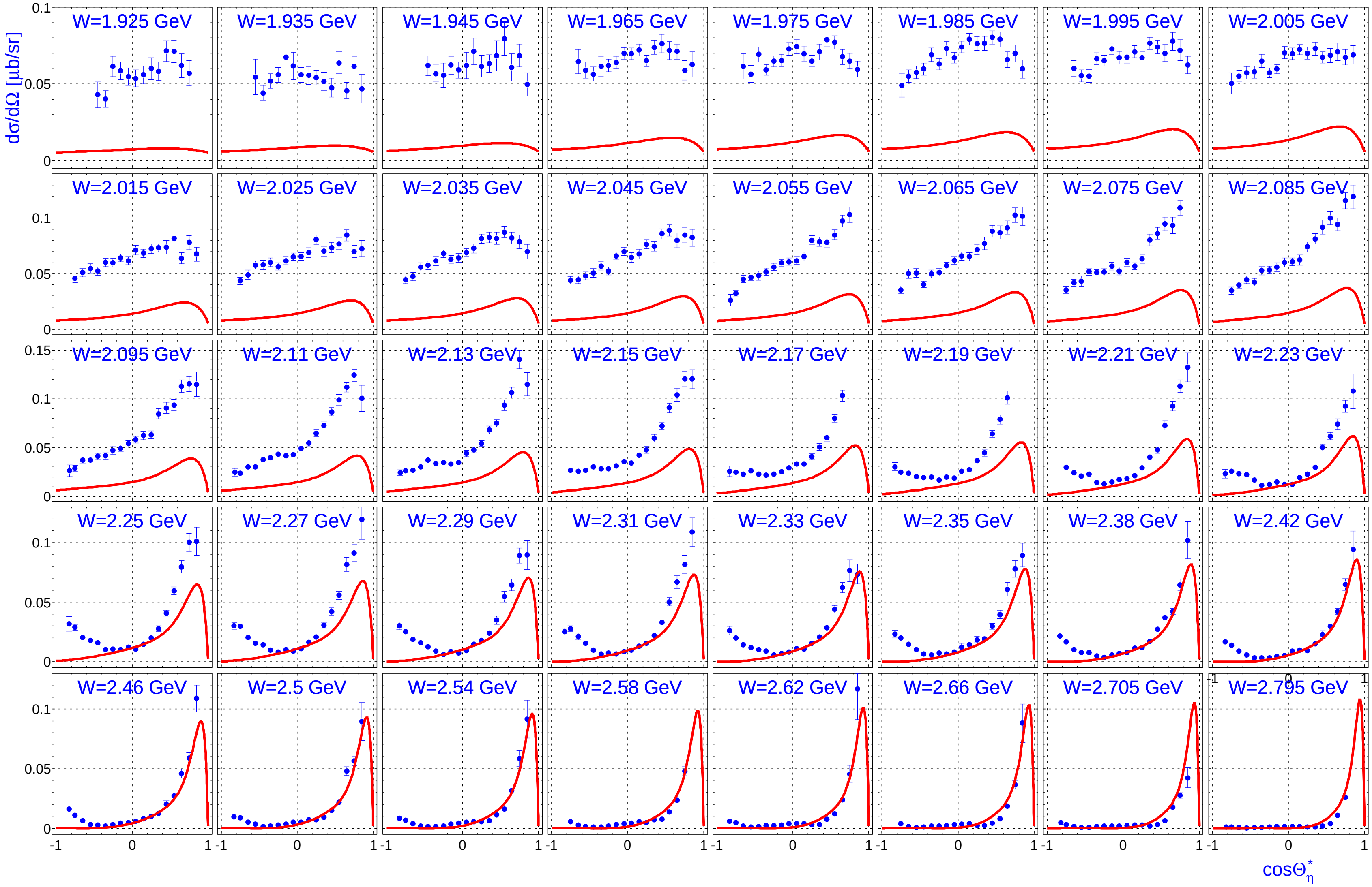
Regge cuts: adaptation to η' photoproductin

black: A2MAMI (preliminary), blue: CLAS-2009. Red lines: Regge background



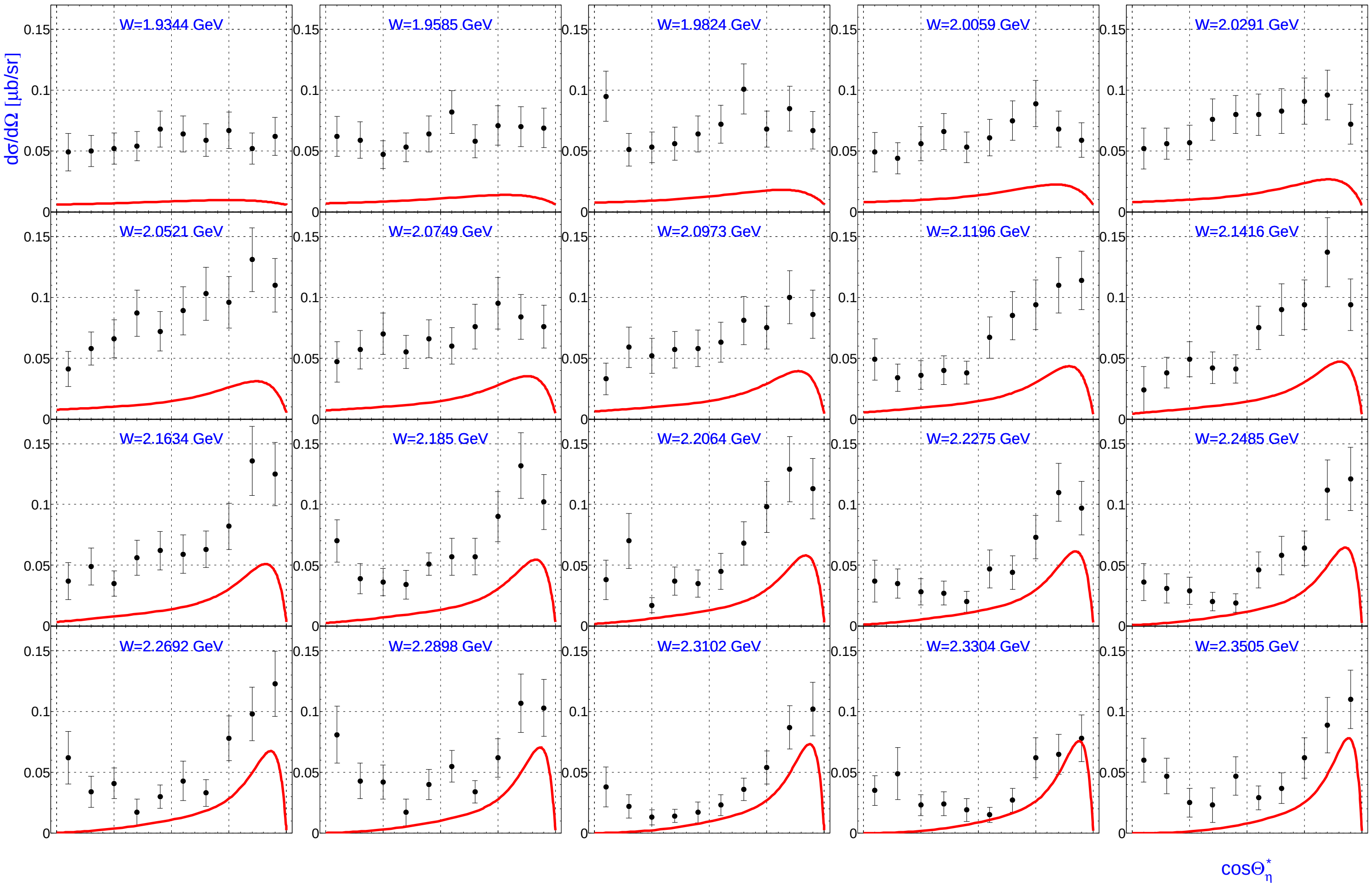
Regge cuts: adaptation to η' photoproductin

data: CLAS-2009. Red lines: Regge background



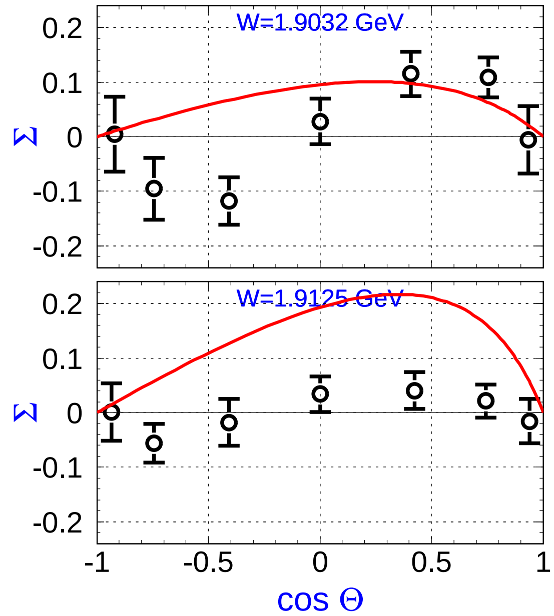
Regge cuts: adaptation to η' photoproductin

data: CBELSA/TAPS-2009

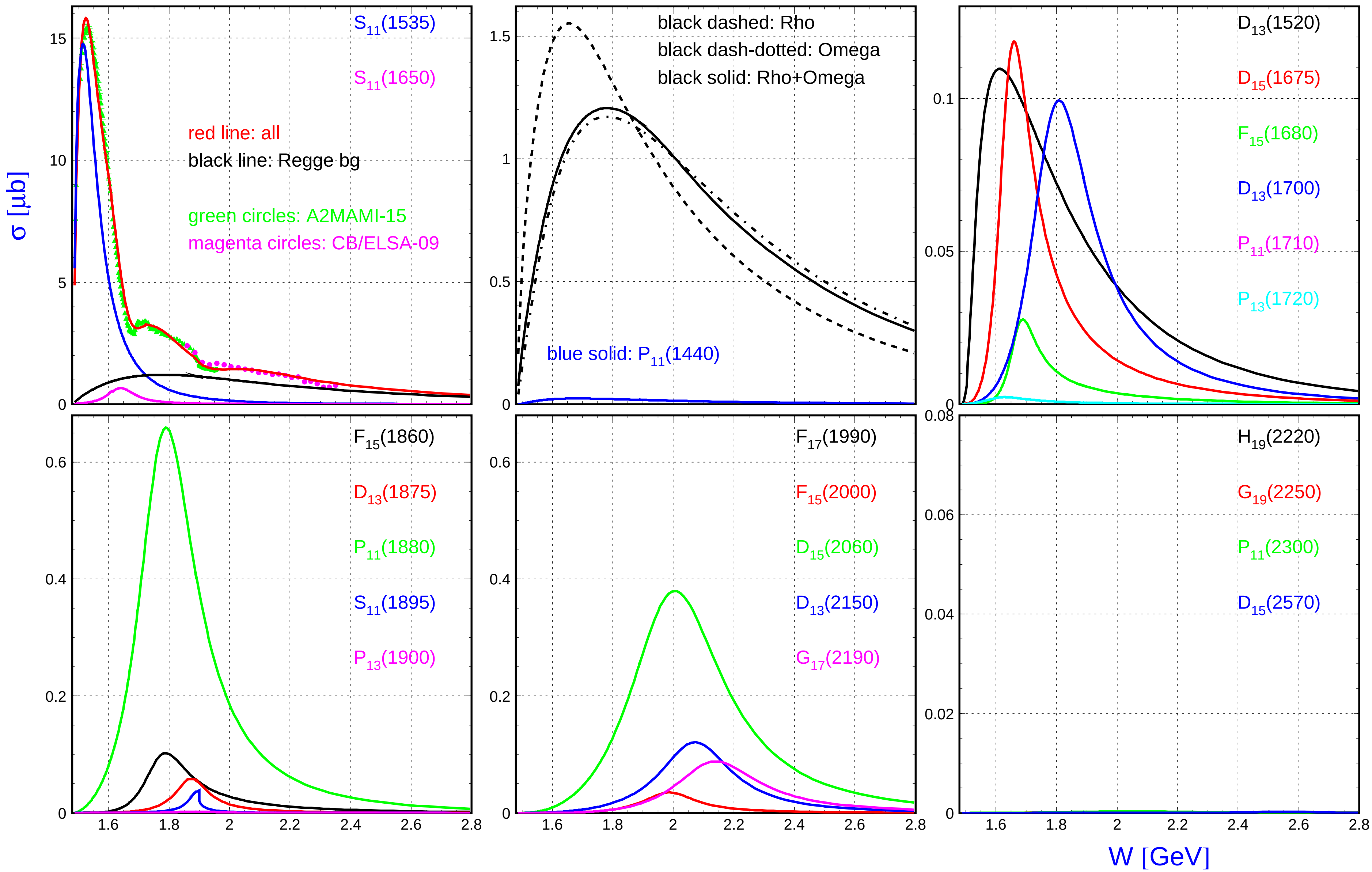


Regge cuts: adaptation to η' photoproductin

data: GRAAL-2015. Red lines: Regge background

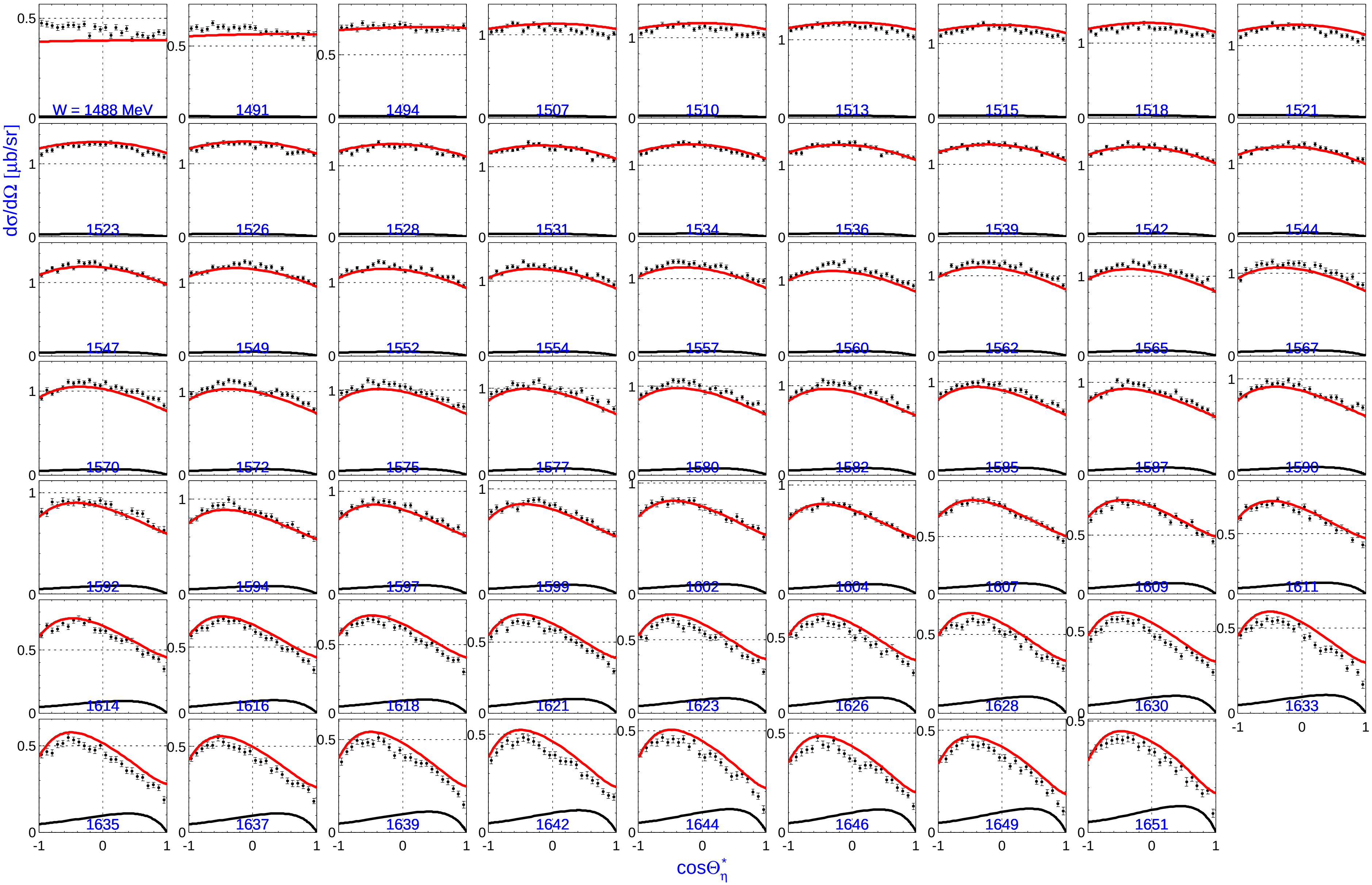


Regge+Resonances for η photoproductin



Regge+Resonances for η photoproductin

data:A2MAMI (preliminary). Red lines: bg + resonances, black: bg



Regge+Resonances for η photoproductin

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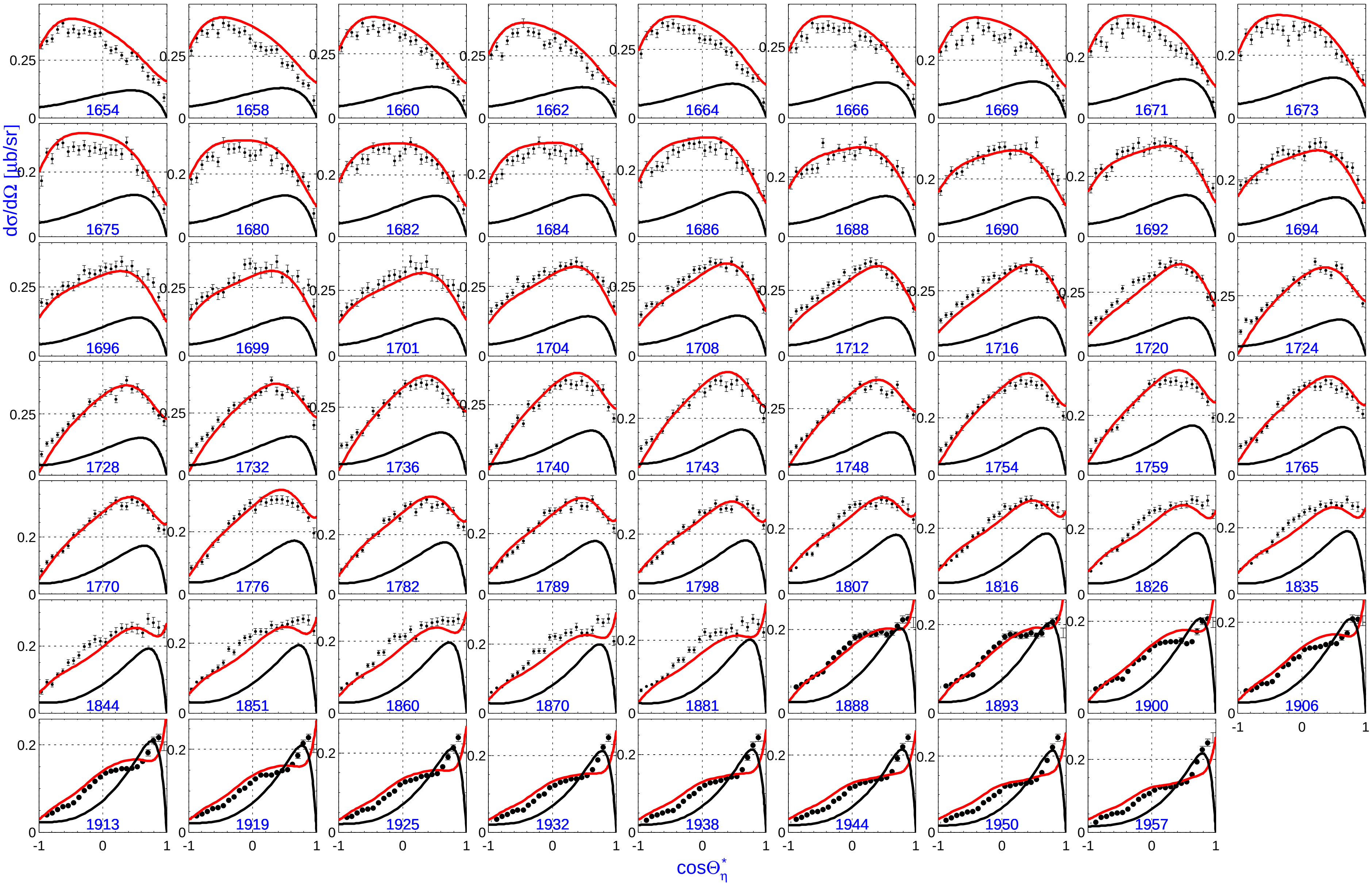
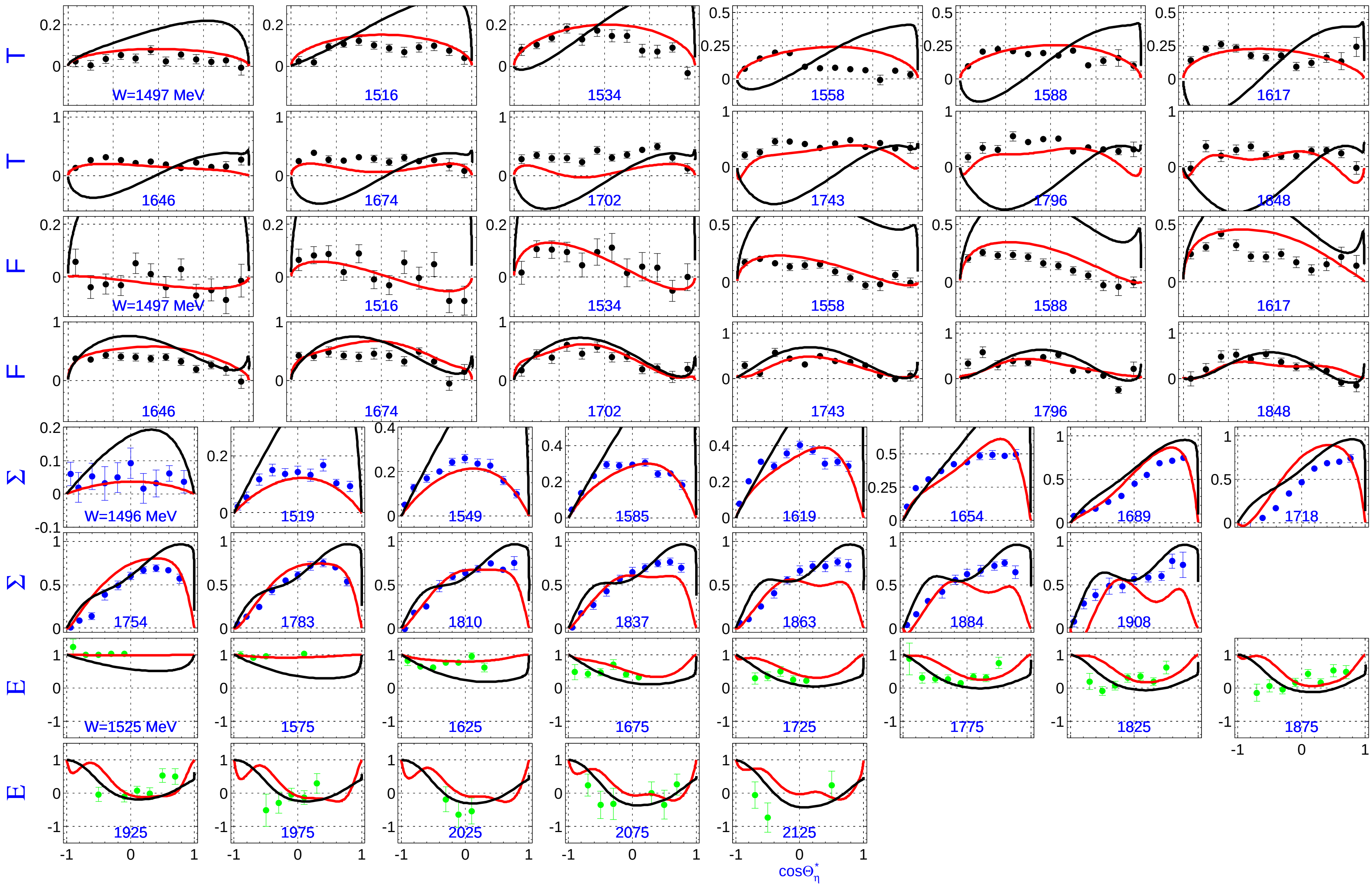


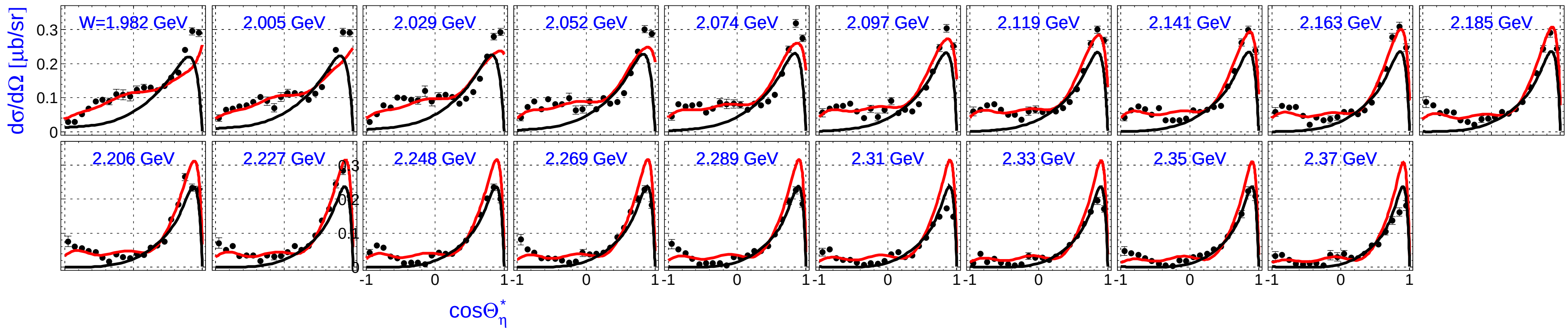
Regge+Resonances for η photoproductin

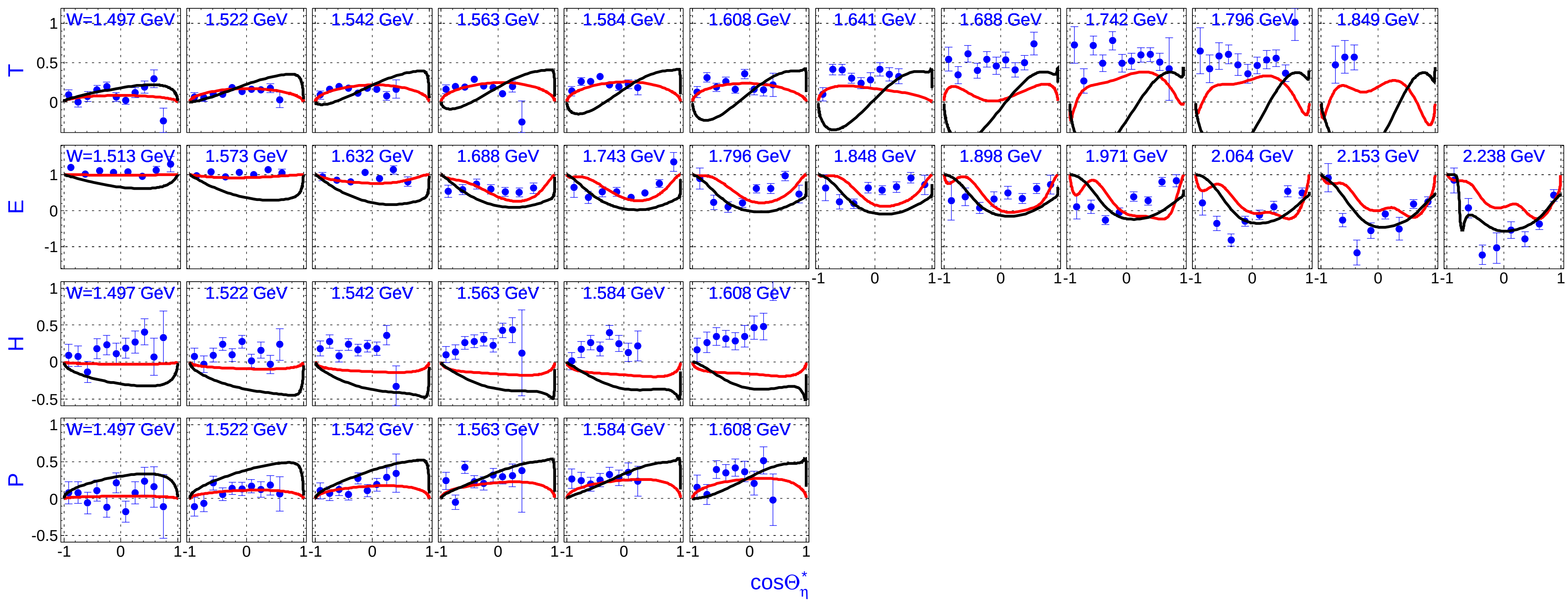
data: A2MAMI-2015 (T,F), GRAAL-2007 (Σ), CLASS-2015 (E)



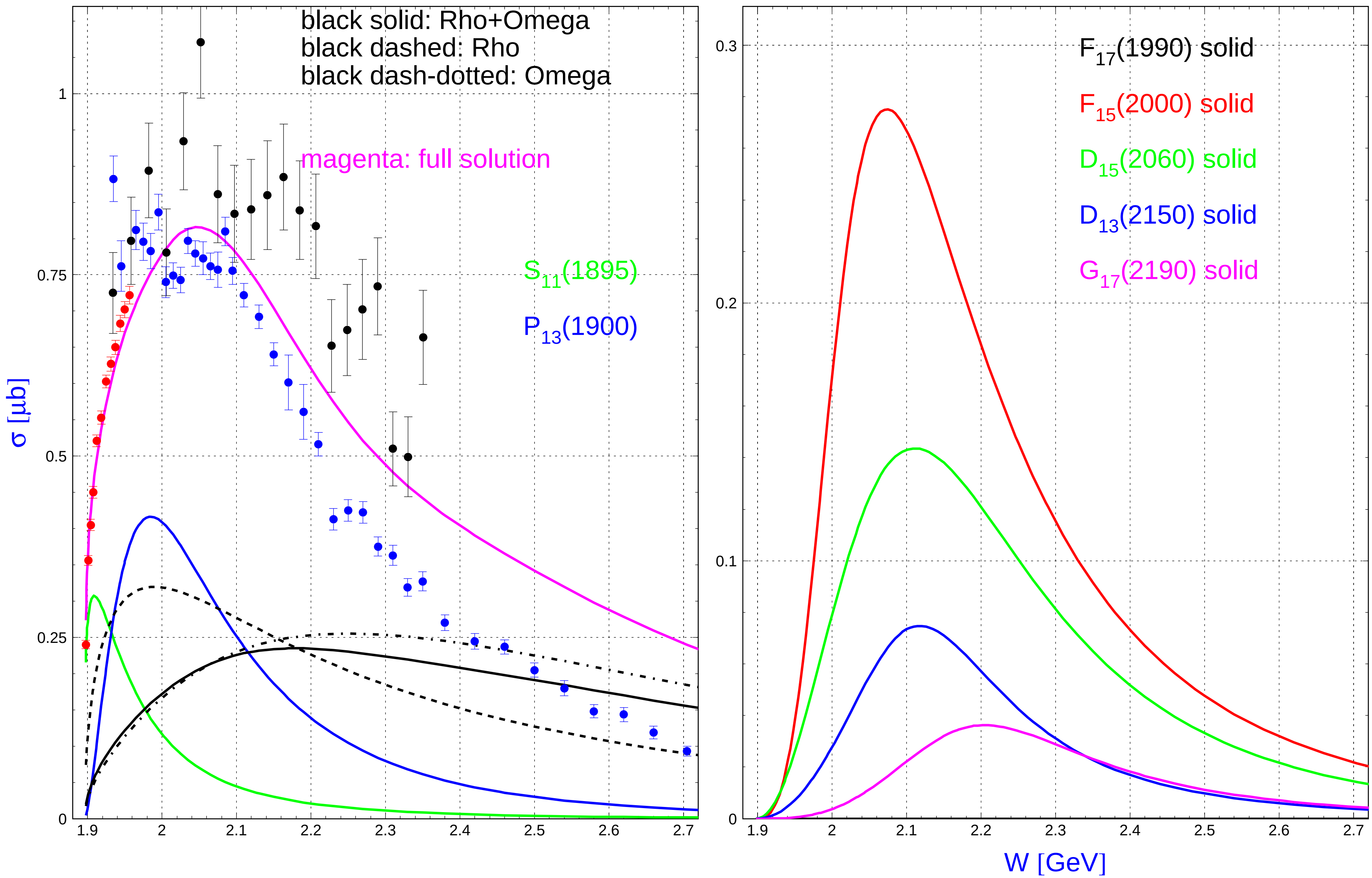
Regge+Resonances for η photoproductin

CBELSA/TAPS data: $d\sigma/d\Omega$ - 2009, T,E,H,P - preliminary



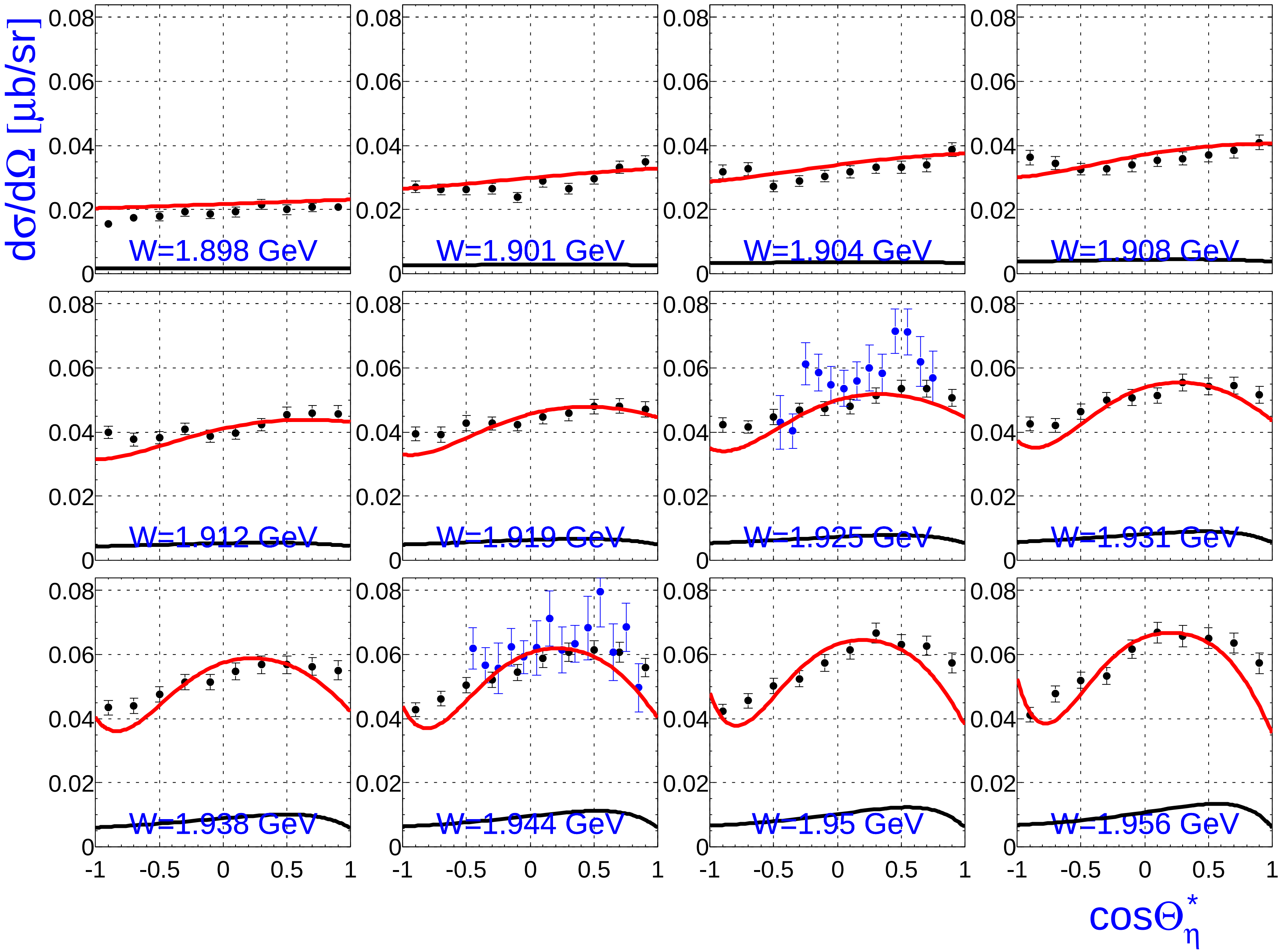


Regge+Resonances for η' photoproductin



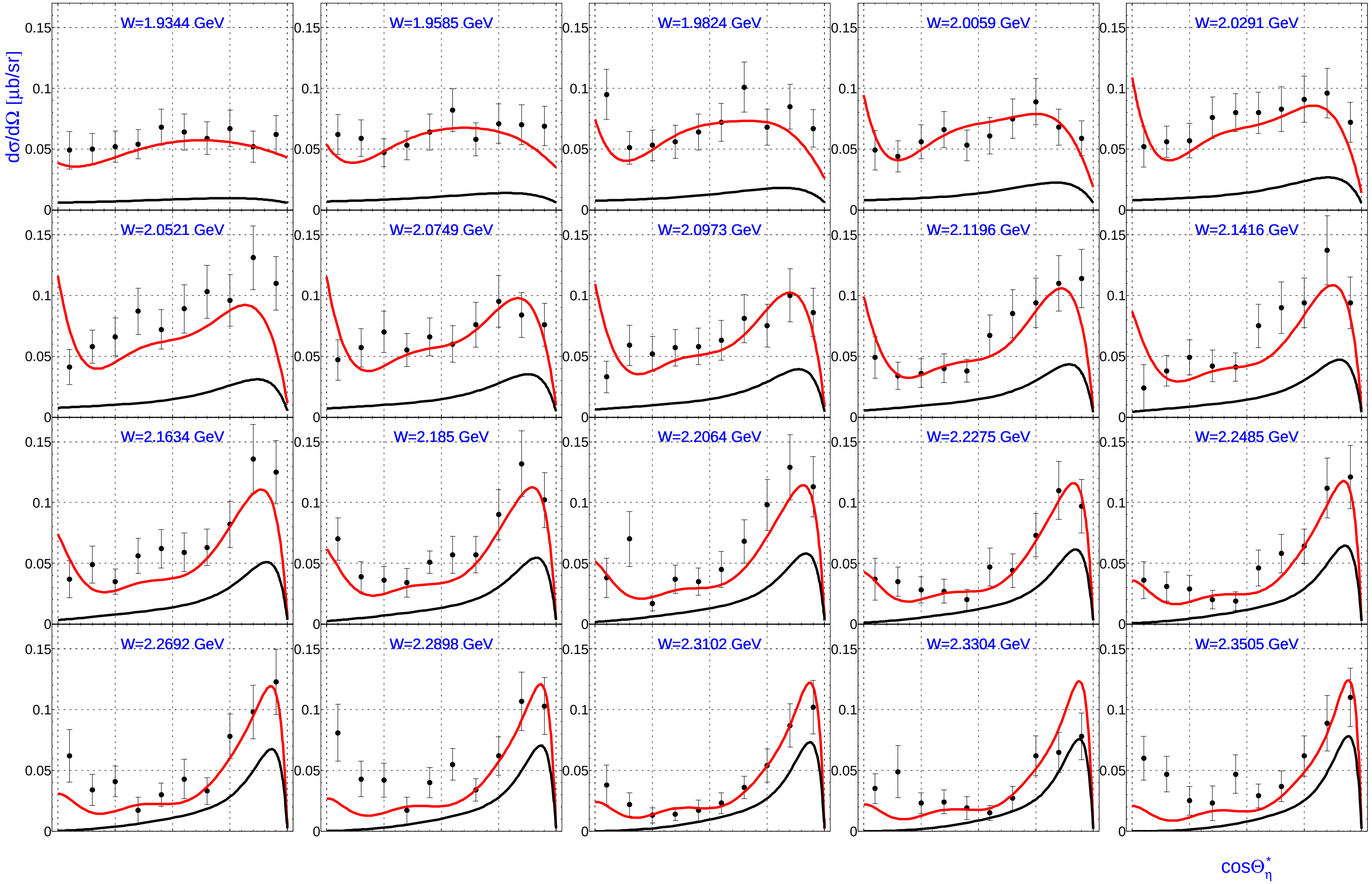
Regge+Resonances for η' photoproductin

data: A2MAMI (preliminary). Red lines: bg + resonances, black: bg



Regge+Resonances for η' photoproductin

data: CBELSA/TAPS-2009. Red lines: bg + resonances, black: bg



Regge+Resonances for η' photoproductin

data: GRAAL-2015. Red lines: bg + resonances, black: bg