Photoproduction of η and η' mesons on proton

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Outline

- ηMAID-2003
- Review of experimental data
- Regge phenomenology for background
- ηMAID-2016 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> 2.5 GeV.

Data sets

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

dσ/dΩ, A2MAMI:	E_γ=0.71–1.57 GeV	[Prakhov, preliminary]
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 , GRAAL-07:	E_γ=0.71–1.5 GeV	[EPJA 33 (2007) 169]
E , CLAS-15:	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]

Data sets

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

dσ/dΩ, A2MAMI:	E_γ=1.45–1.57 GeV	[Prakhov, preliminary]
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 , GRAAL-15:	E_γ=1.46–1.48 GeV	[EPJA 51 (2015) 77]

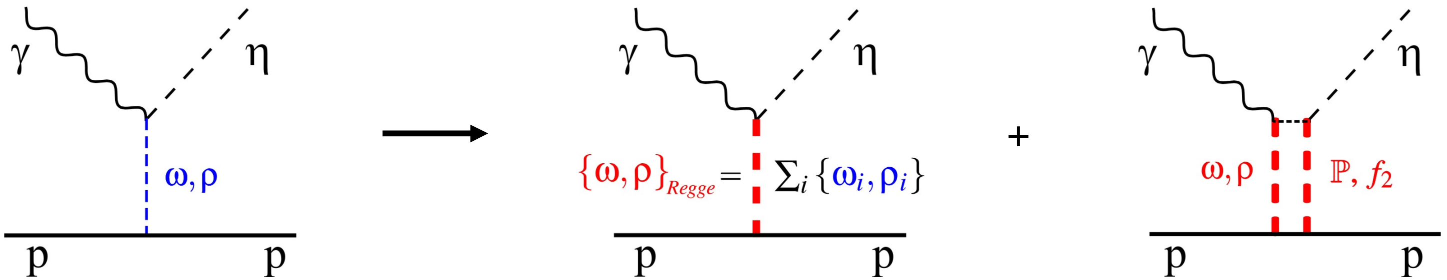
$\gamma\ n \rightarrow \eta\ n$

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]
Σ , GRAAL-08:	E_γ=0.74–1.44 GeV	[PRC 78 (2008) 015203]

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

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

Regge phenomenology



vector meson	vector meson	vector meson
single poles	Regge trajectories	Regge cuts

The pole-like Feynman propagators are replaced by Regge propagators for each vector meson in the t-channel:

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

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

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

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

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

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

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

Regge cuts for π^0 photoproduction

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, PRC 93 (2016) 025203.

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

The exchange of two Reggeons with linear trajectories:

$$\alpha_i(t) = \alpha_i(0) + \alpha_i' t, i = 1, 2 \tag{3}$$

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

$$\alpha_c(t) = \alpha_c(0) + \alpha_c' t \tag{4}$$

were

$$\begin{aligned} \alpha_c(0) &= \alpha_1(0) + \alpha_2(0) - 1 \\ \alpha_c' &= \frac{\alpha_1' \alpha_2'}{\alpha_1' + \alpha_2'} \end{aligned} \tag{5}$$

Regge cuts for π^0 photoproduction

Donnachie and Kalashnikova assumed:

linear ρ and ω trajectories:

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

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

secondary linear 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:

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

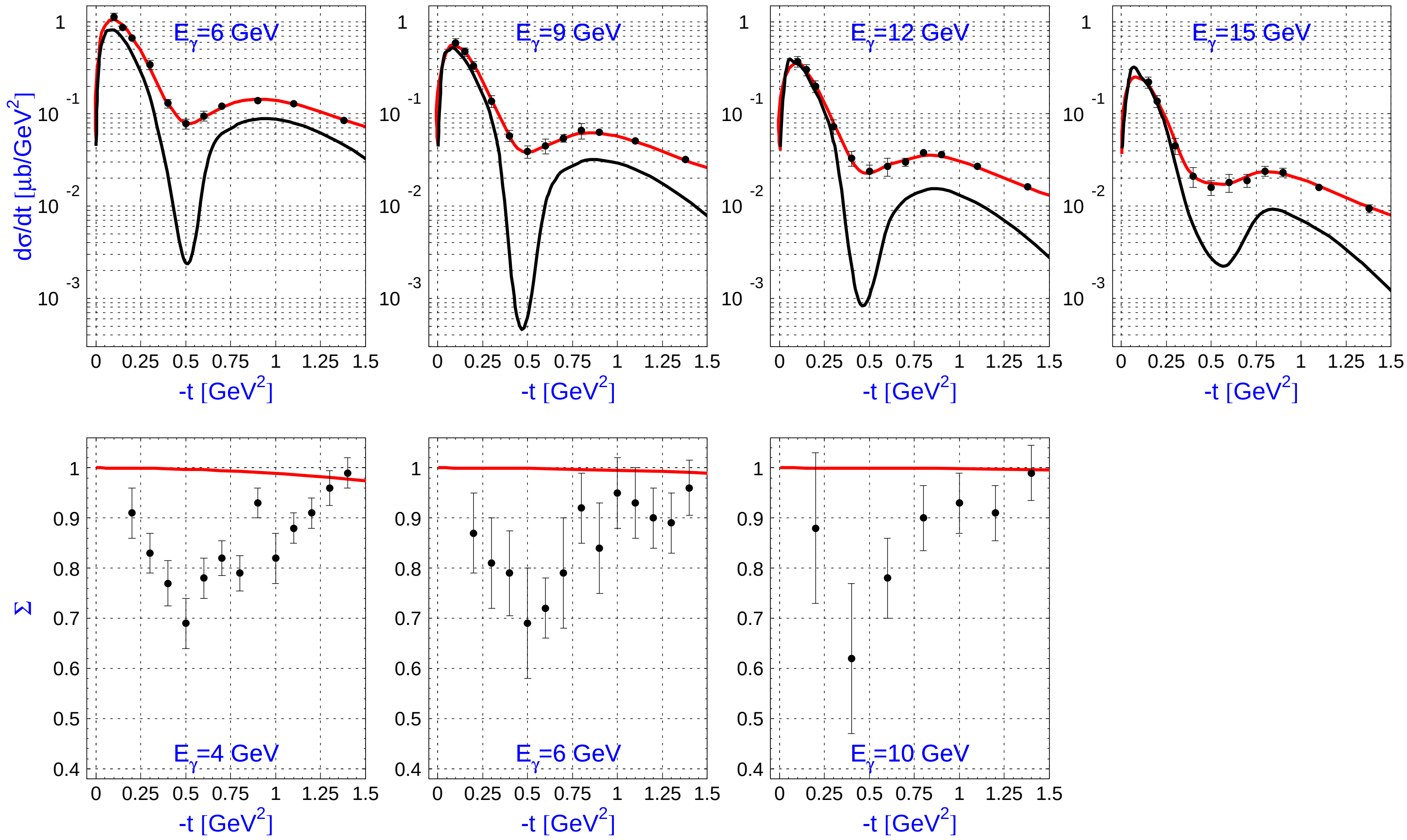
$$\alpha^c_{\omega-P} = 0.52 + 0.196t$$

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

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

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

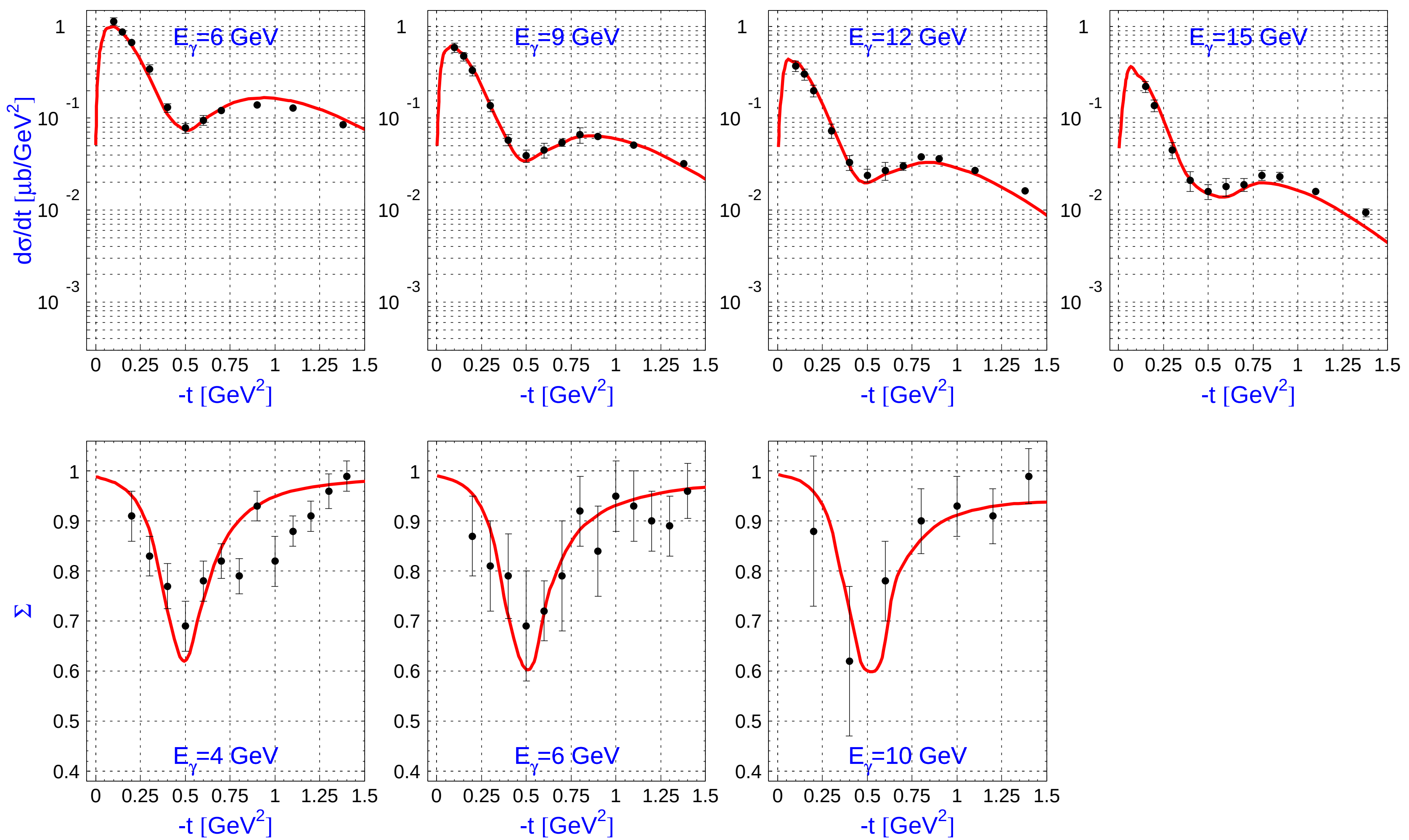
Regge cuts for π^0 photoproduction



Red lines: fit results with Regge cuts of ρ-P, ω-P, ρ-f_2, ω-f_2.

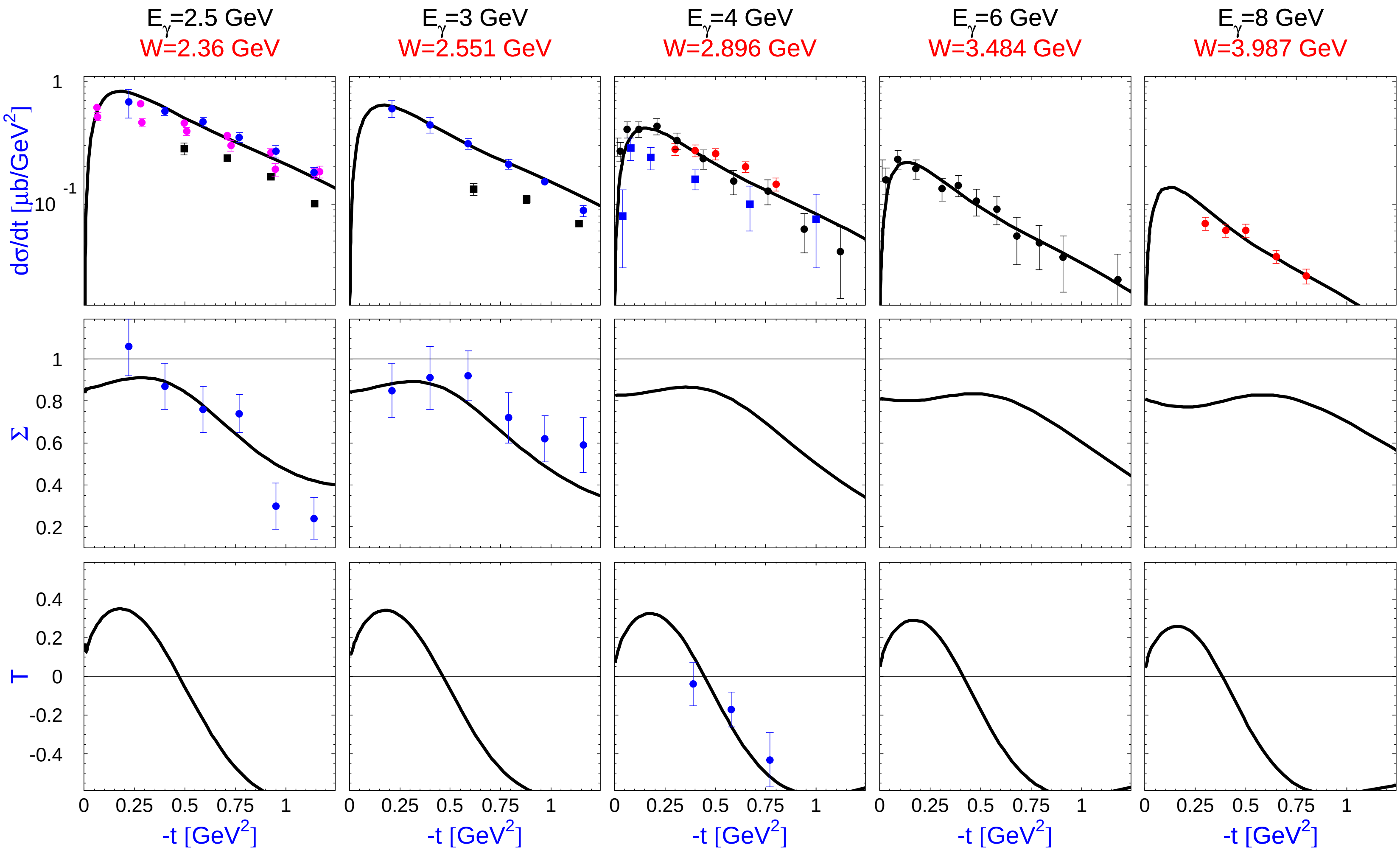
Black lines: without the cuts. Black circles: SLAC-1971 data

Regge cuts for π^0 photoproduction



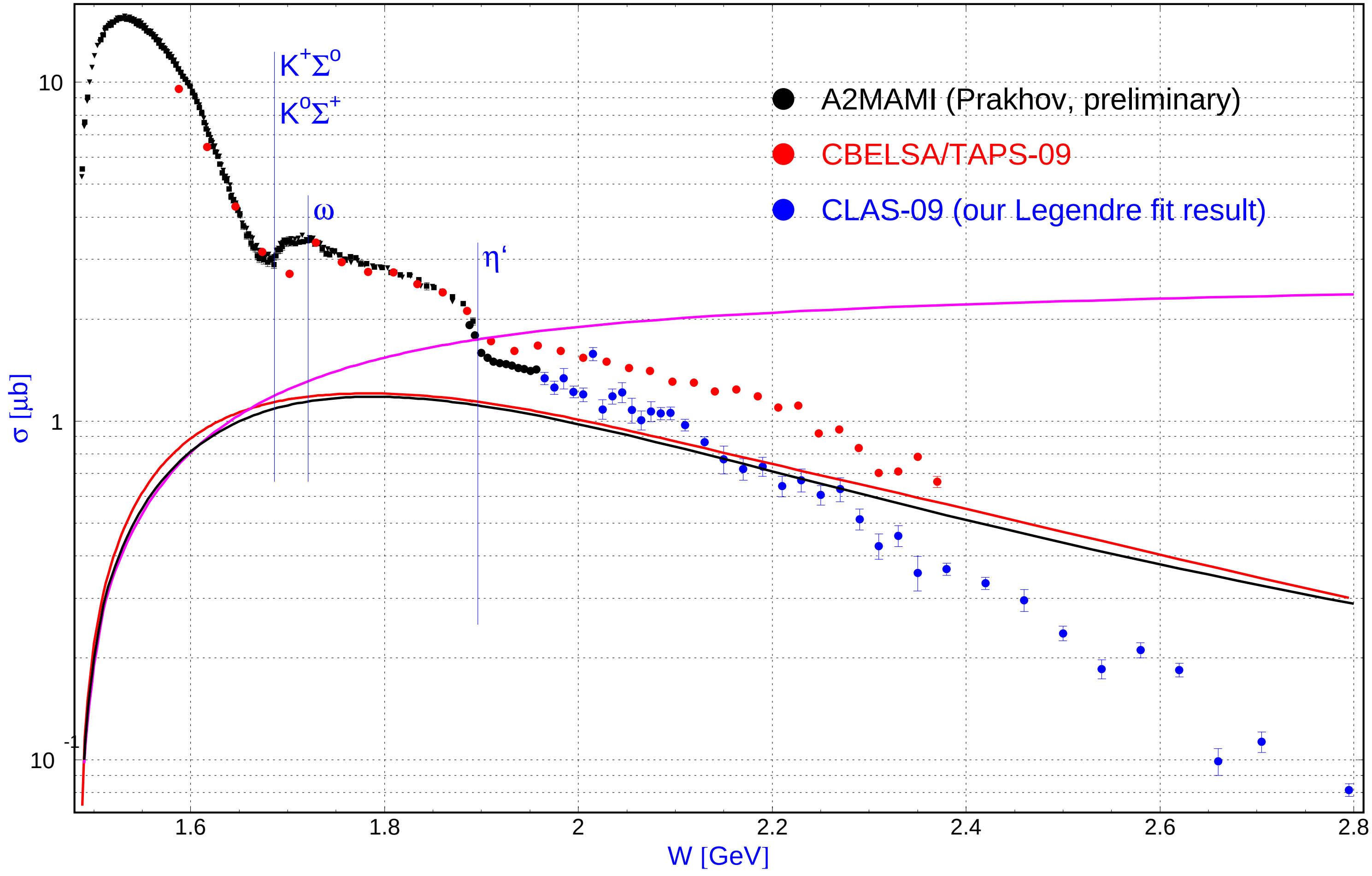
Red lines: fit results with vector and axial-vector (b_1) mesons.

Regge cuts: adaptation to η photoproduction



Black lines: fit results. Circles: black DESY-70, red WLS-71, blue Daresbury-76,80, magenta CBELSA/TAPS-2009. Squares: black CLAS-09, blue CEA-68.

Regge cuts: adaptation to η photoproduction



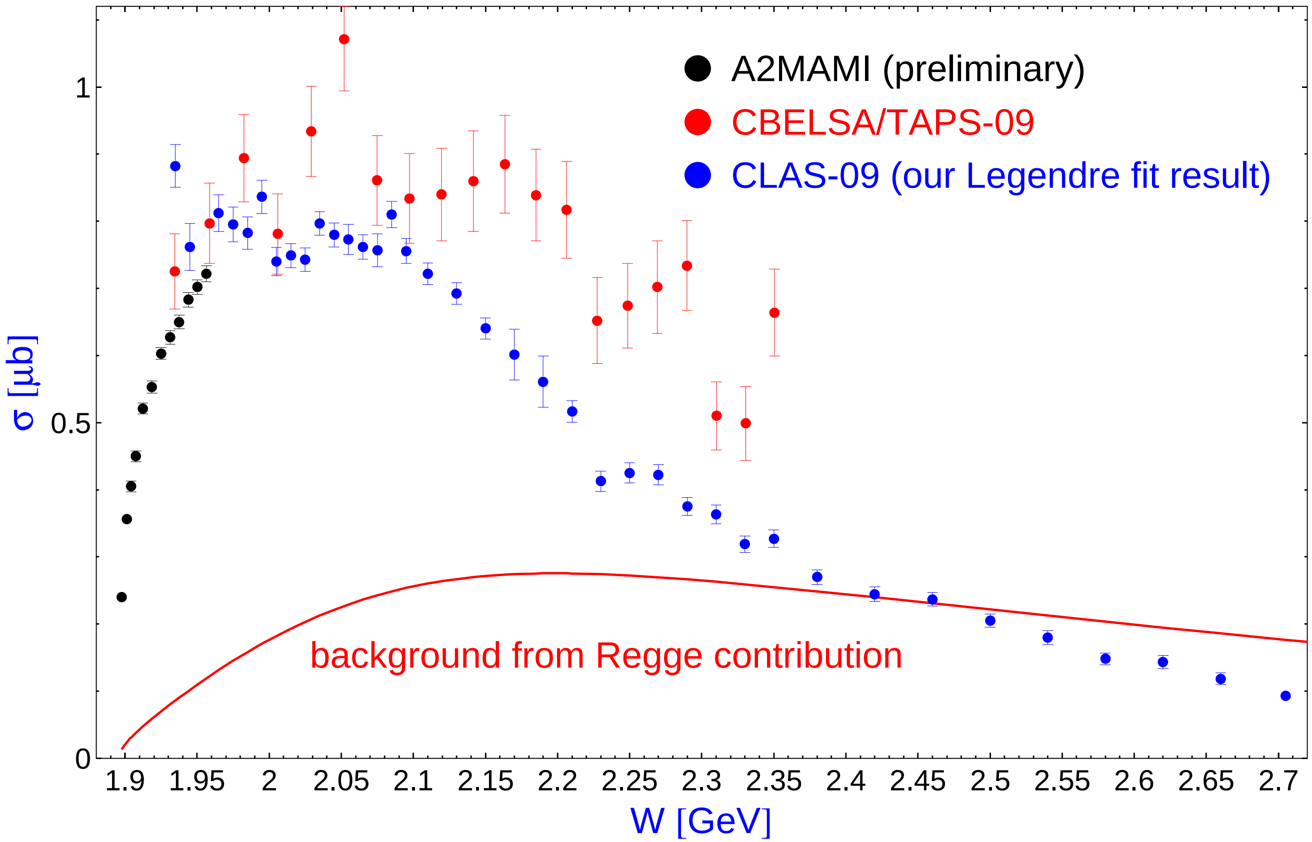
Background contributions:

Red line: present solution, black: ηMAID2003 Regge, magenta: vector mesons as poles.

Regge cuts: adaptation to η' photoproduction

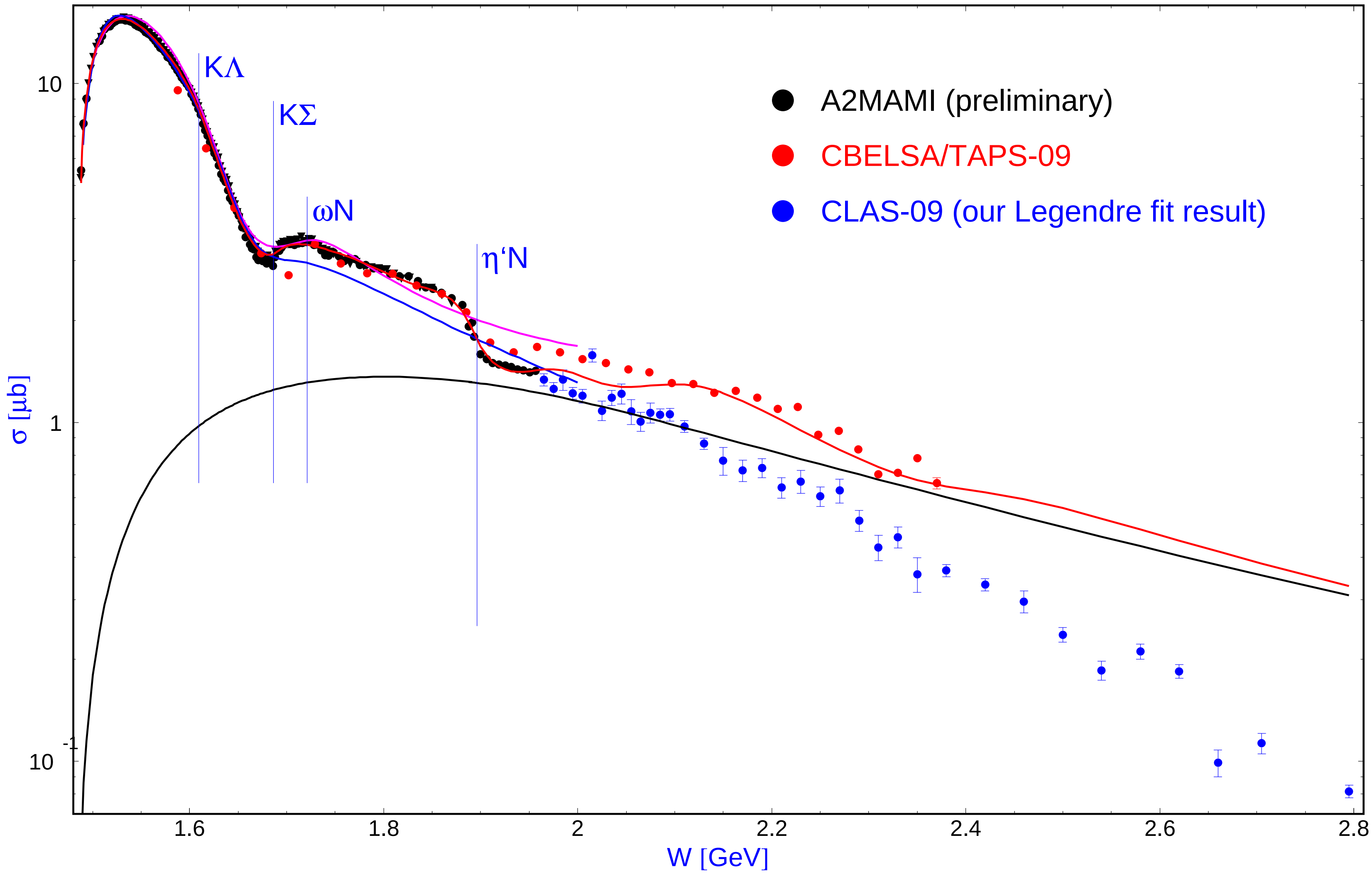
Electromagnetic coupling constants: $\lambda_{\rho\eta'\gamma}$ = 1.05 and $\lambda_{\omega\eta'\gamma}$ = 0.36.

All other parameters are the same as for η photoproduction.



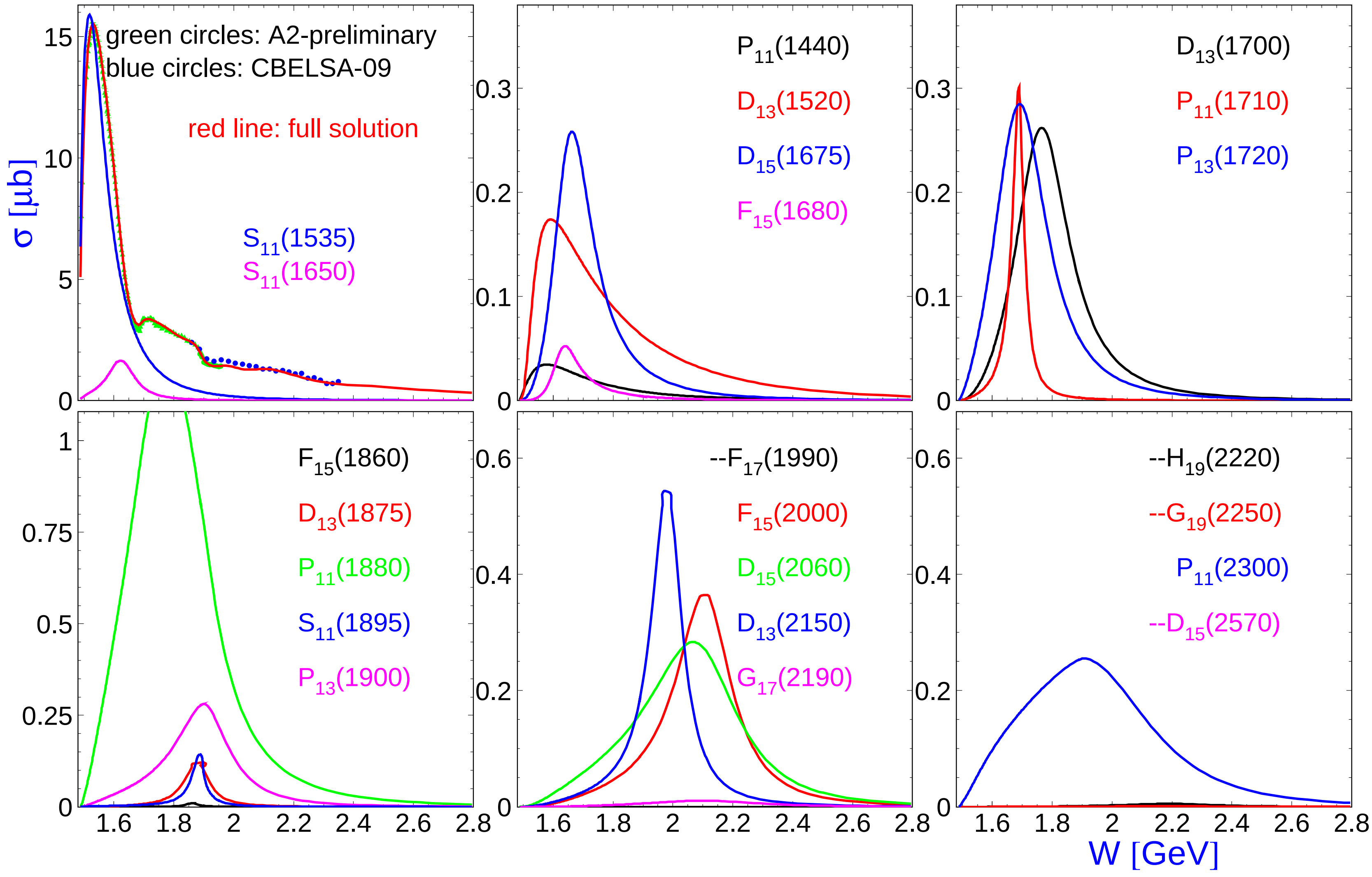
Regge+Resonances for $\gamma p \to \eta p$

Lines: background + resonances, black: background, ηMAID-2003, ηMAID-2003 Regge.



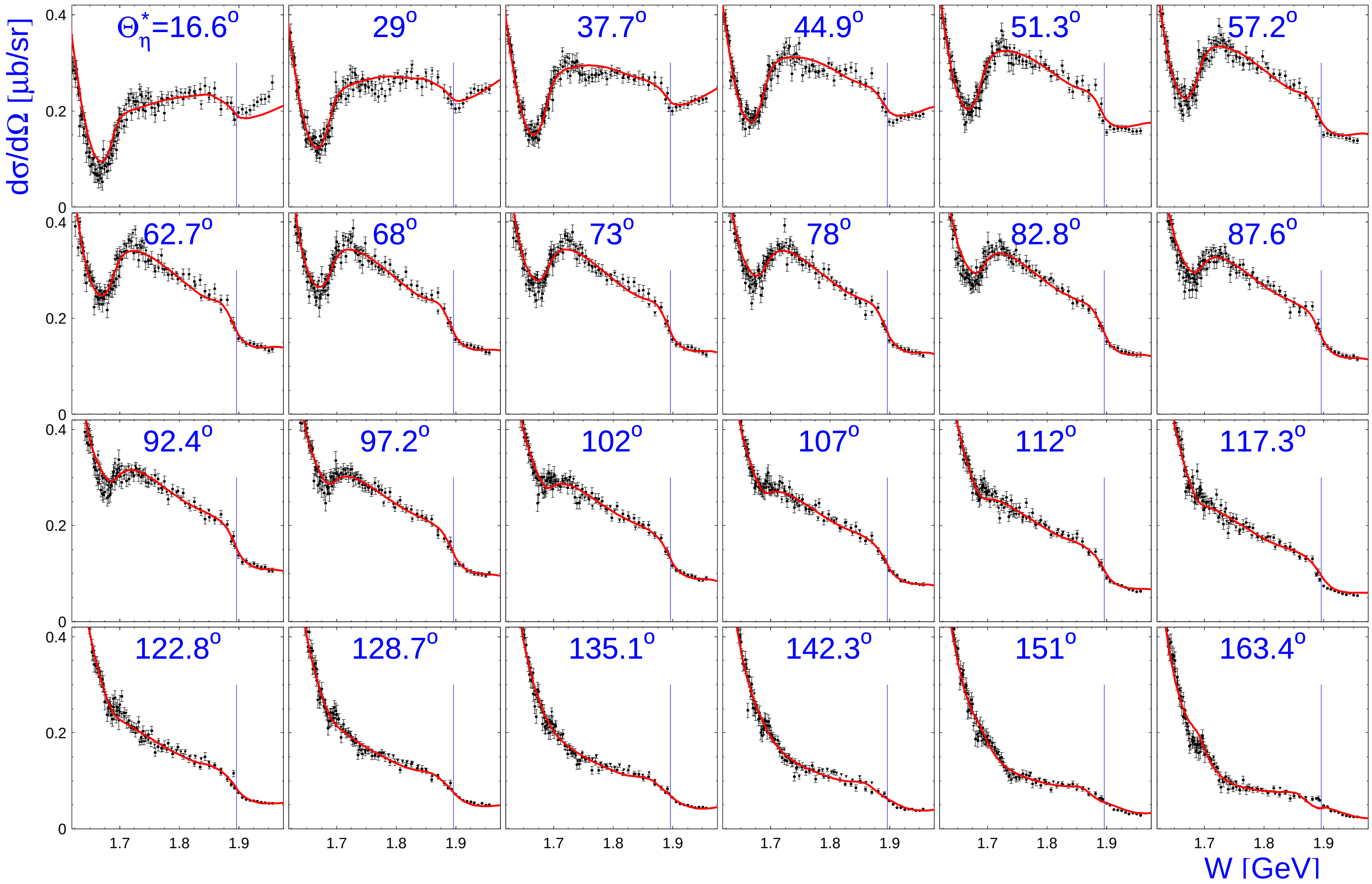
Regge+Resonances for $\gamma p \to \eta p$

Individual resonance contribution to total cross section.



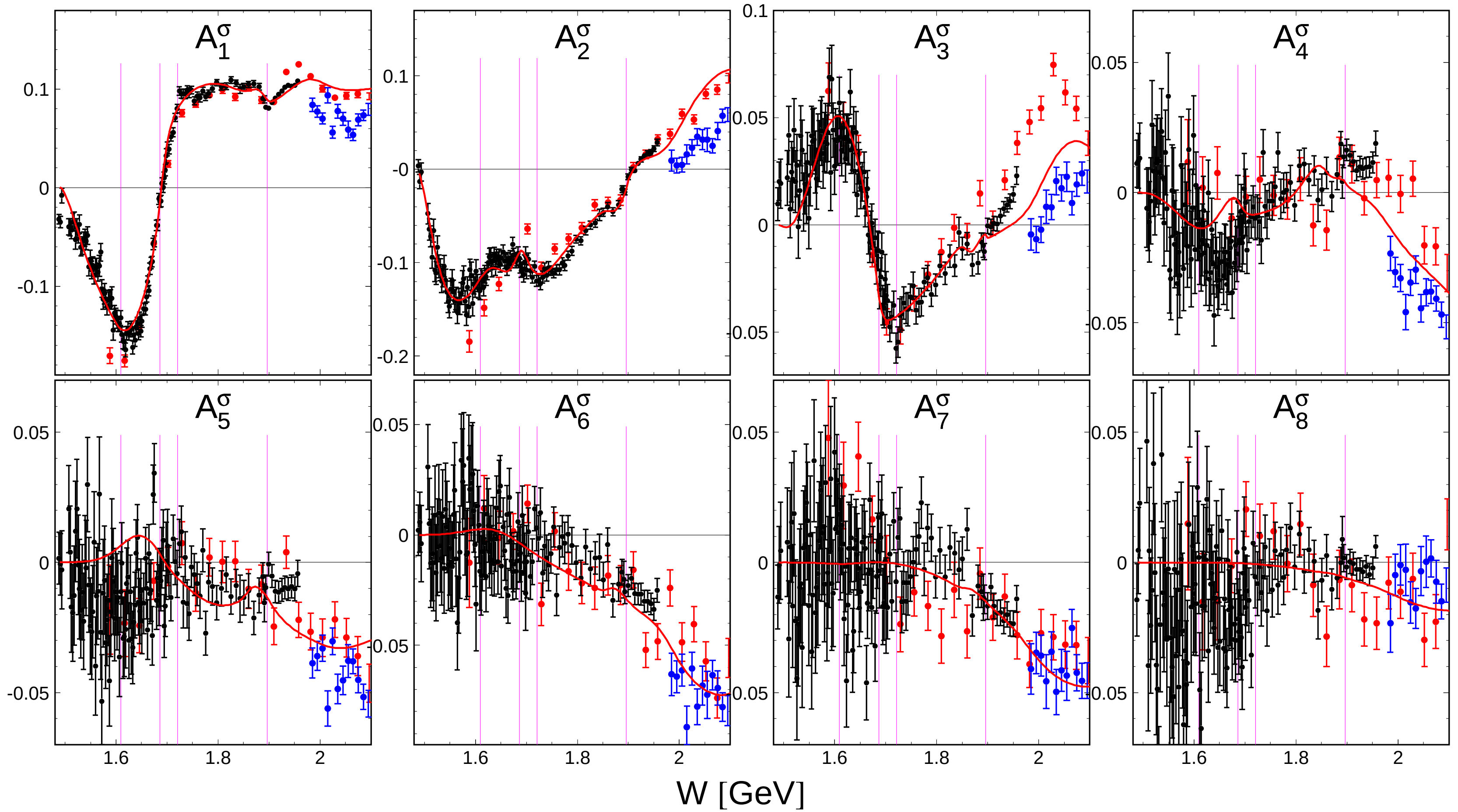
Regge+Resonances for $\gamma p \to \eta p$

Excitation function. Data: A2MAMI (preliminary). Red lines: full solution.



Legendre coefficients. $\gamma p \to \eta p$

Fit with $l_{max} = 8$. Red: A2MAMI, black: CBELSA-09, blue: CLAS-09 Magenta lines: thresholds of $K\Lambda, K\Sigma, \omega N, \eta' N$ decay channels consistently.



Regge+Resonances for $\gamma p \to \eta p$

Data:A2MAMI (preliminary). Red lines: full solution.

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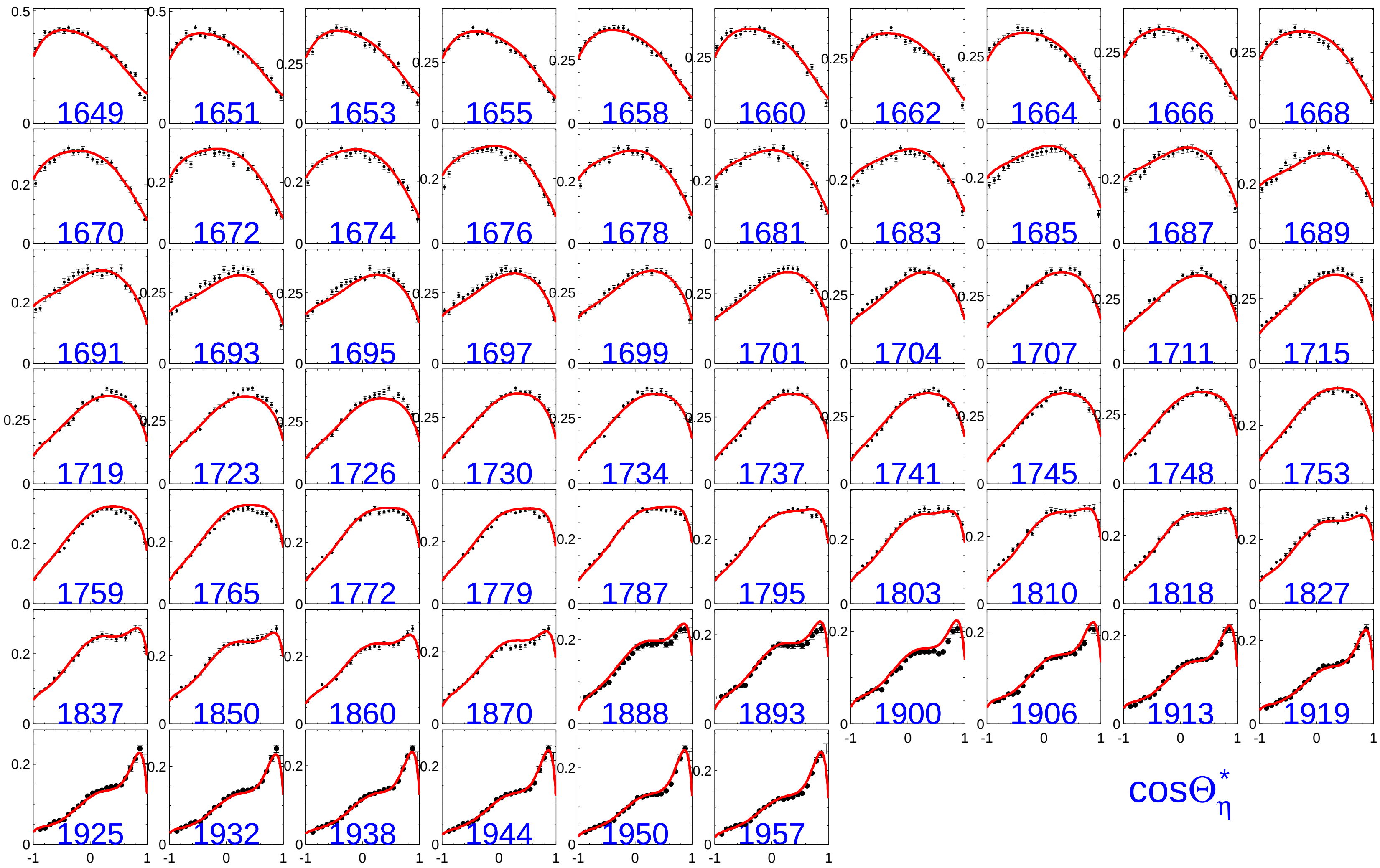
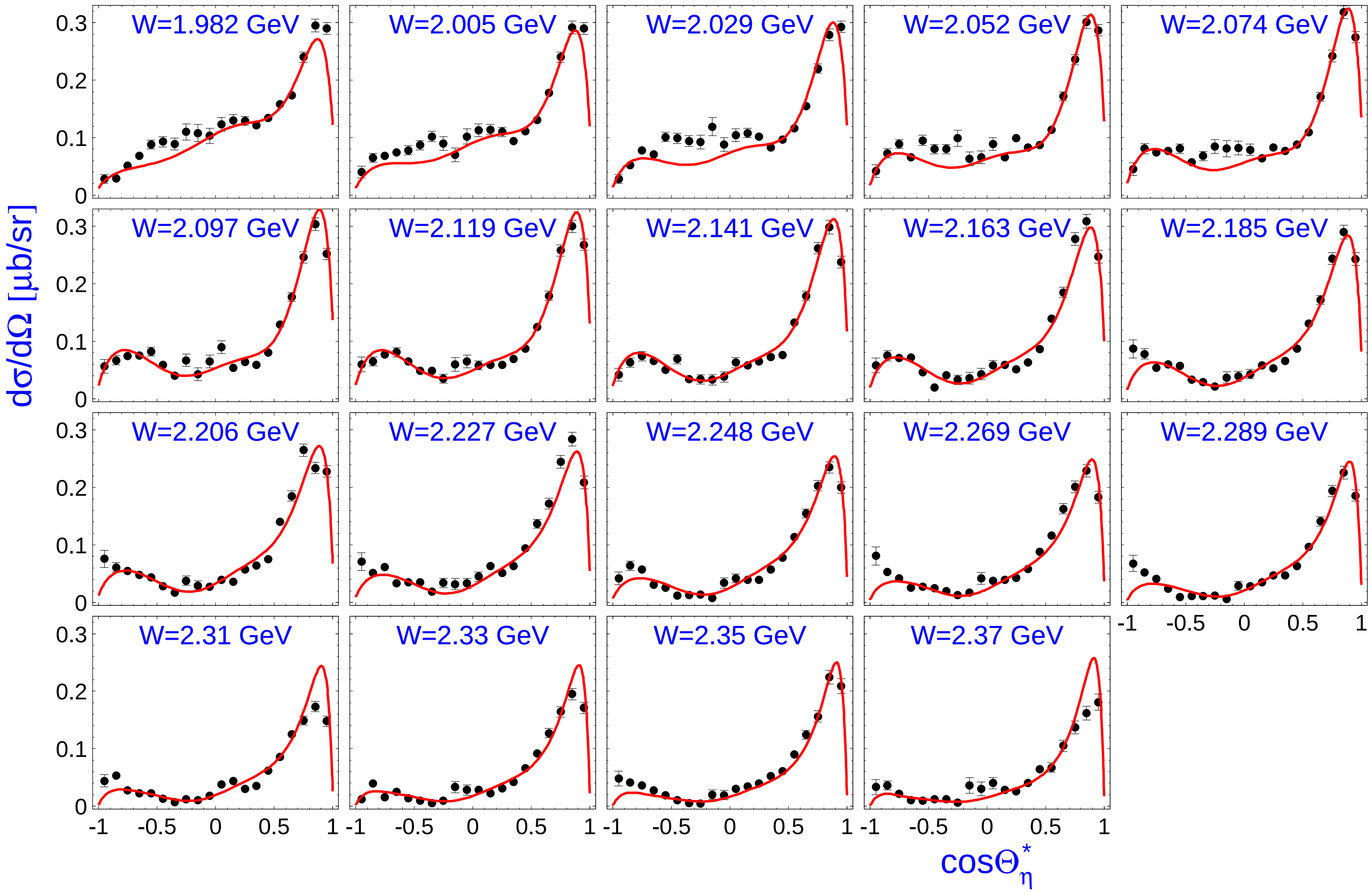


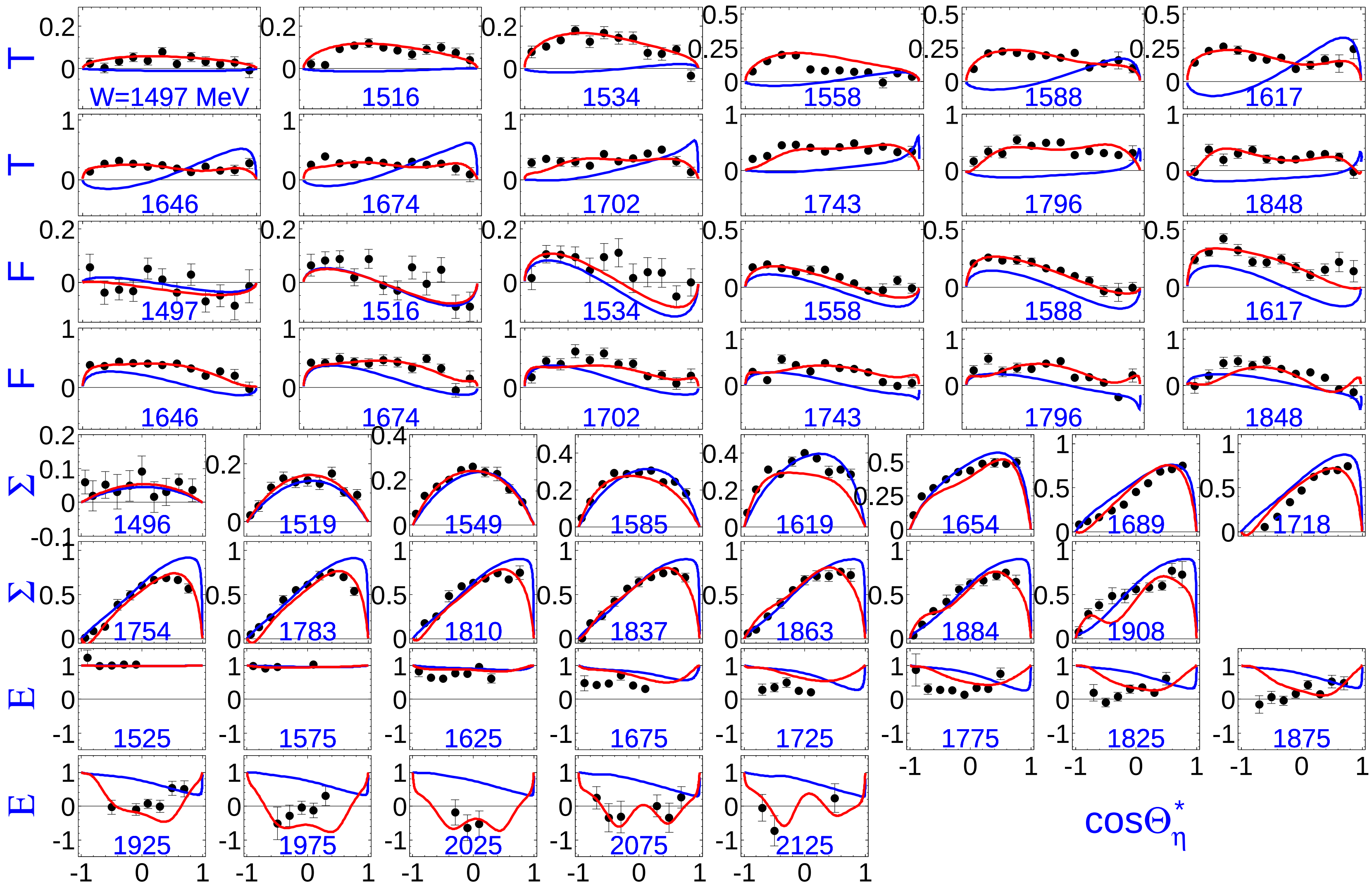
Regge+Resonances for $\gamma p \to \eta p$

Data: CBELSA/TAPS-09. Red lines: full solution.



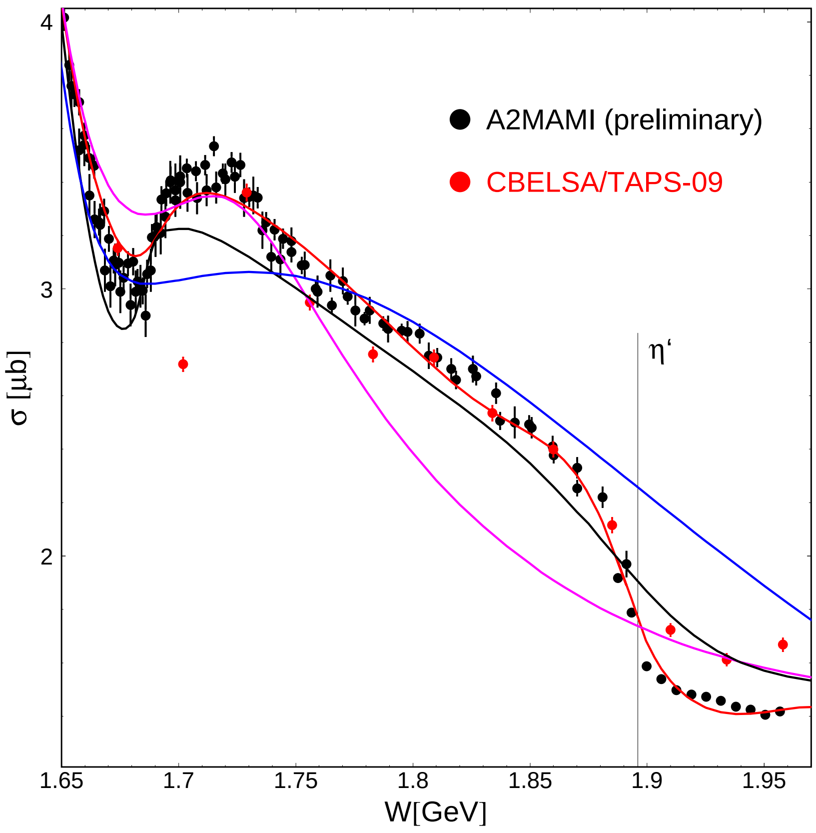
Regge+Resonances for $\gamma p \to \eta p$

data: A2MAMI-15 (T,F), GRAAL-07 (Σ), CLAS-15 (E). Red: full solution, blue: ηMAID03.



Regge+Resonances for $\gamma p \to \eta p$

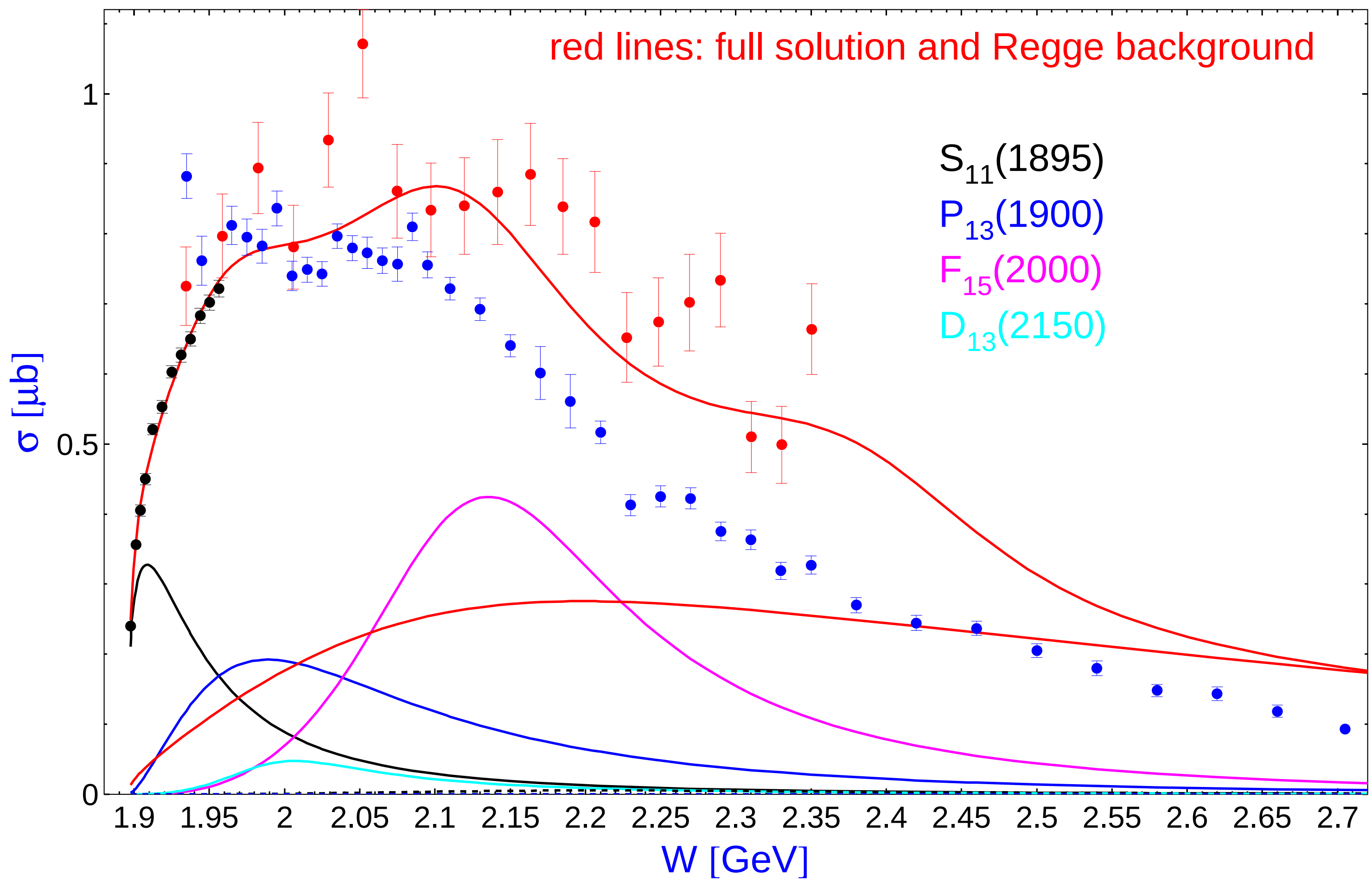
Lines: present solution, ηMAID-2003, BG2014-2, SAID GE09.



Regge+Resonances for $\gamma p \to \eta' p$

Total cross section and individual resonance contributions.

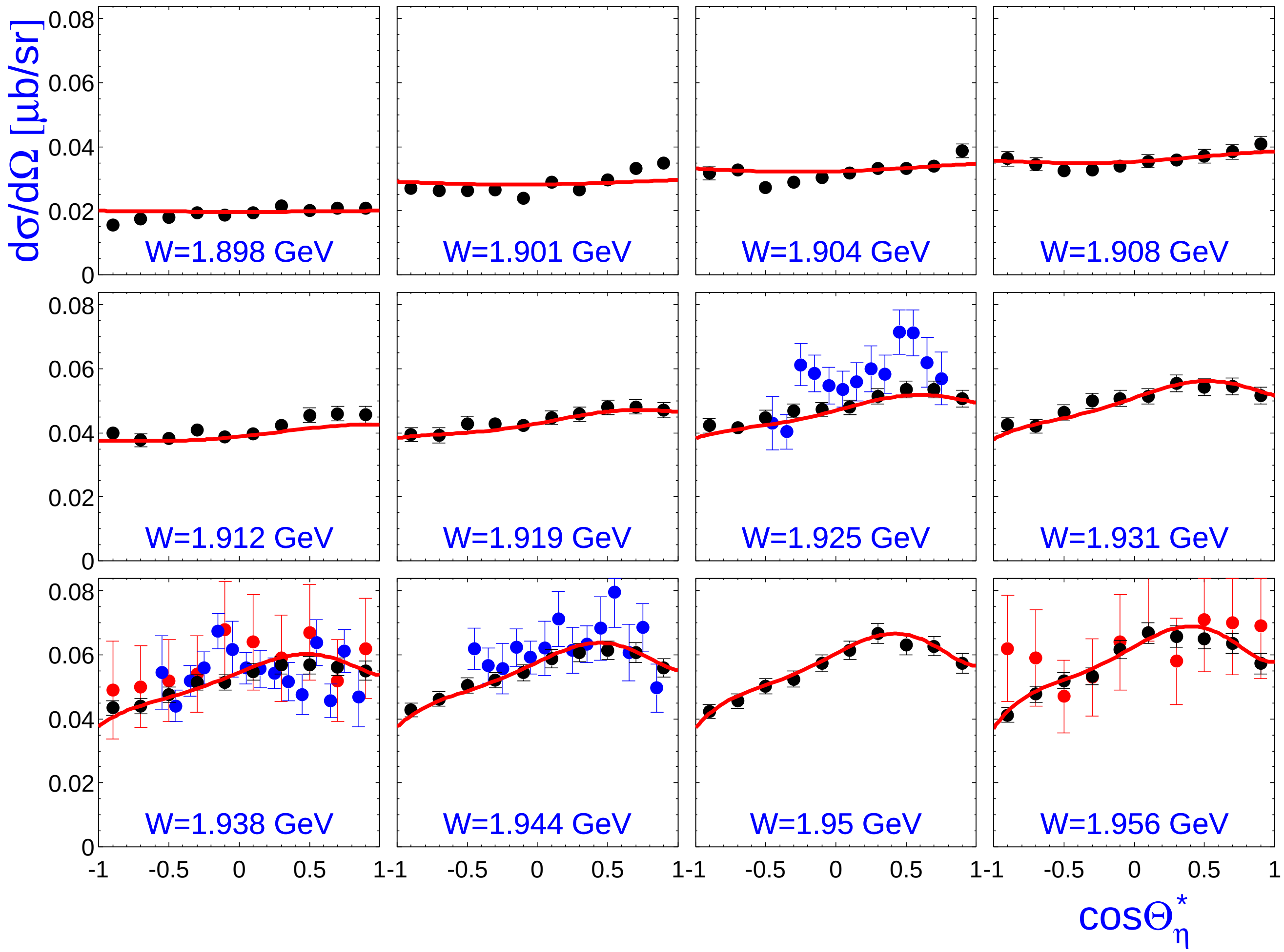
Data: A2MAMI (preliminary), CBELSA/TAPS-09, CLAS-09 (our Legendre fit).



Regge+Resonances for $\gamma p \to \eta' p$

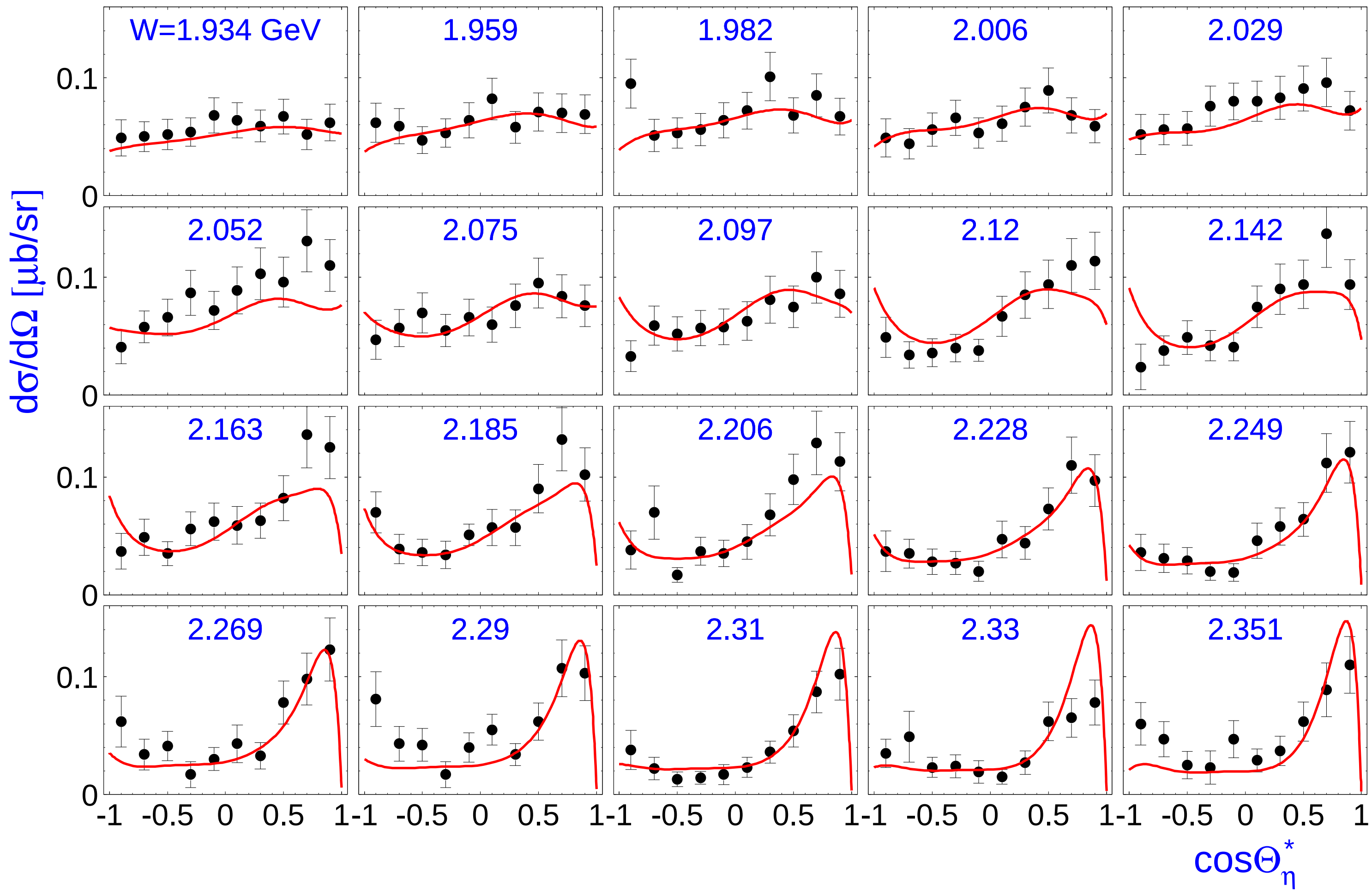
Data: A2MAMI-preliminary (black), CBELSA/TAPS-09, CLAS-09.

Red lines: full solution.



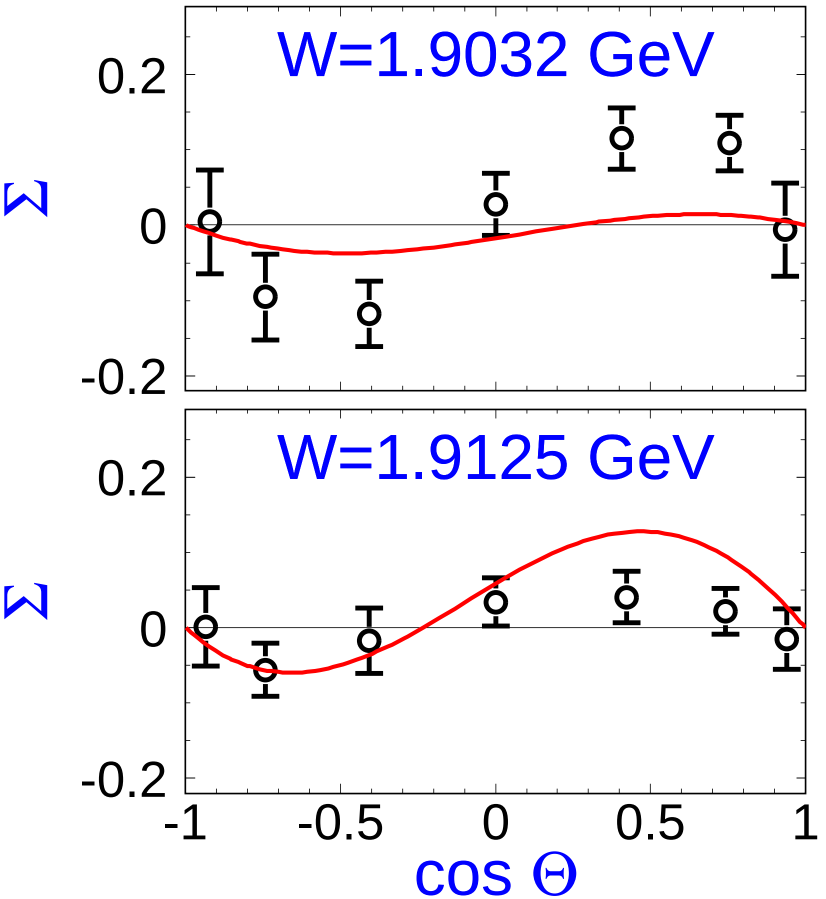
Regge+Resonances for $\gamma p \to \eta' p$

Data: CBELSA/TAPS-2009. Red lines: full solution.



Regge+Resonances for $\gamma p \to \eta' p$

Data: GRAAL-2015. Red lines: full solution.



Summary and Outlook

- A new version of the reggezed model for η and η' photoroduction on nucleons was presented. At energy below W=2.5 GeV dominate nucleon resonances. To decribe the data in this region we increased the N^* resonances from 8 in the original MAID now up to 23.
- At high energies Regge trajectories of ρ, ω, b_1 and Regge cuts of ρ-P, ω-P, ρ-f_2, ω-f_2 were used. The obtained solution describes very well the data up to E_γ=8 GeV.
- Cusp in the total cross section in γp $\rightarrow$ ηp is explained as a threshold effect due to opening the $\eta' p$ decay channel of the $N(1895)1/2^-$ resonance.
- Breit-Wigner parameters of the resonances were determined. Next step is determination of pole positions and residues.
- A dispersion relation approch is in progress to reduce the model dependence.
- A model independent single-energy PWA is in progress with analytical constrains, similar to the Karlsruhe-Helsinki πN PWA.
- New reaction channels γN $\rightarrow$ KΛ, KΣ, ωN will be added to analysis.

Collaboration

- Mainz: Lothar Tiator, Michael Ostrick, Kirill Nikonov, and A2 Collaboration at MAMI.
- Tuzla: Jugoslav Stahov, Hedim Osmanovic, Mirza Hadzimehmedovic, Rifat Omerovic.
- Zagreb: Alfred Svarc.

Donnachie and Kalashnikova:

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

$$A_c(s,t) = C_c D_c(s,t) \tag{6}$$

where C_c is a constant and

$$D_c(s,t) = e^{d_c t} e^{-i\frac{1}{2}\pi\alpha_c(t)} s^{\alpha_c(t)-1}. \tag{7}$$

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 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

$$\lambda_{V\pi^0\gamma} g_{VNN} (D_V(s,t) + C_n^{V-P} D_c^{V-P}(s,t) + C_n^{V-f_2} D_c^{V-f_2}(s,t)), \tag{8}$$

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.

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

$$\lambda_{b_1\pi^0\gamma}g_{b_1NN}D_b(s,t)+\sum_V \lambda_{V\pi^0\gamma}g_{VNN}(C_u^{V-P}D_c^{V-P}(s,t)+C_u^{V-f_2}D_c^{V-f_2}(s,t)), \tag{9}$$

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:

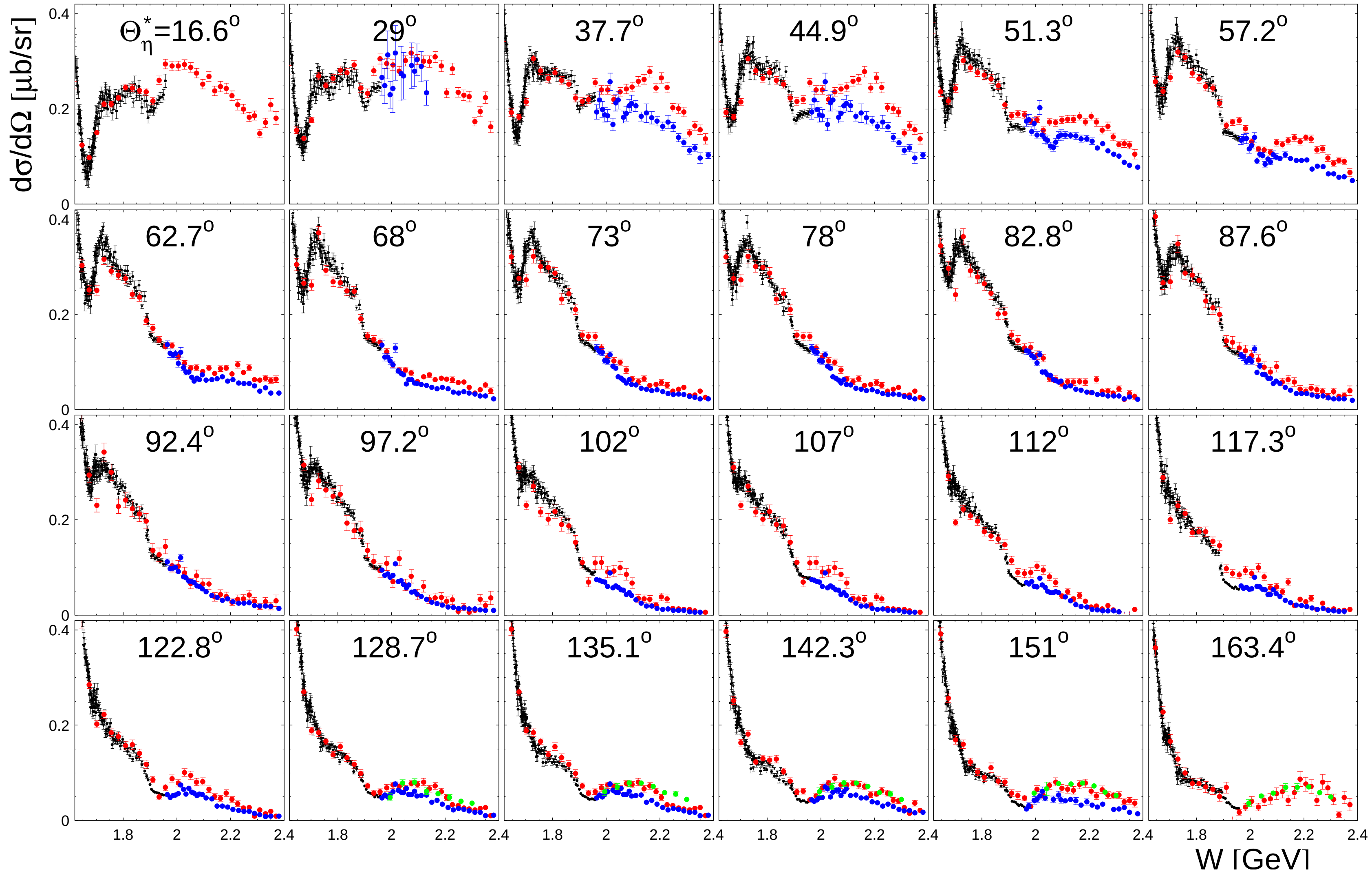
$C_n^{\rho-P}=C_n^{\omega-P}, C_n^{\rho-f_2}=C_n^{\omega-f_2}$,

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

d_c of the exponential also was taken to be the same for all terms.

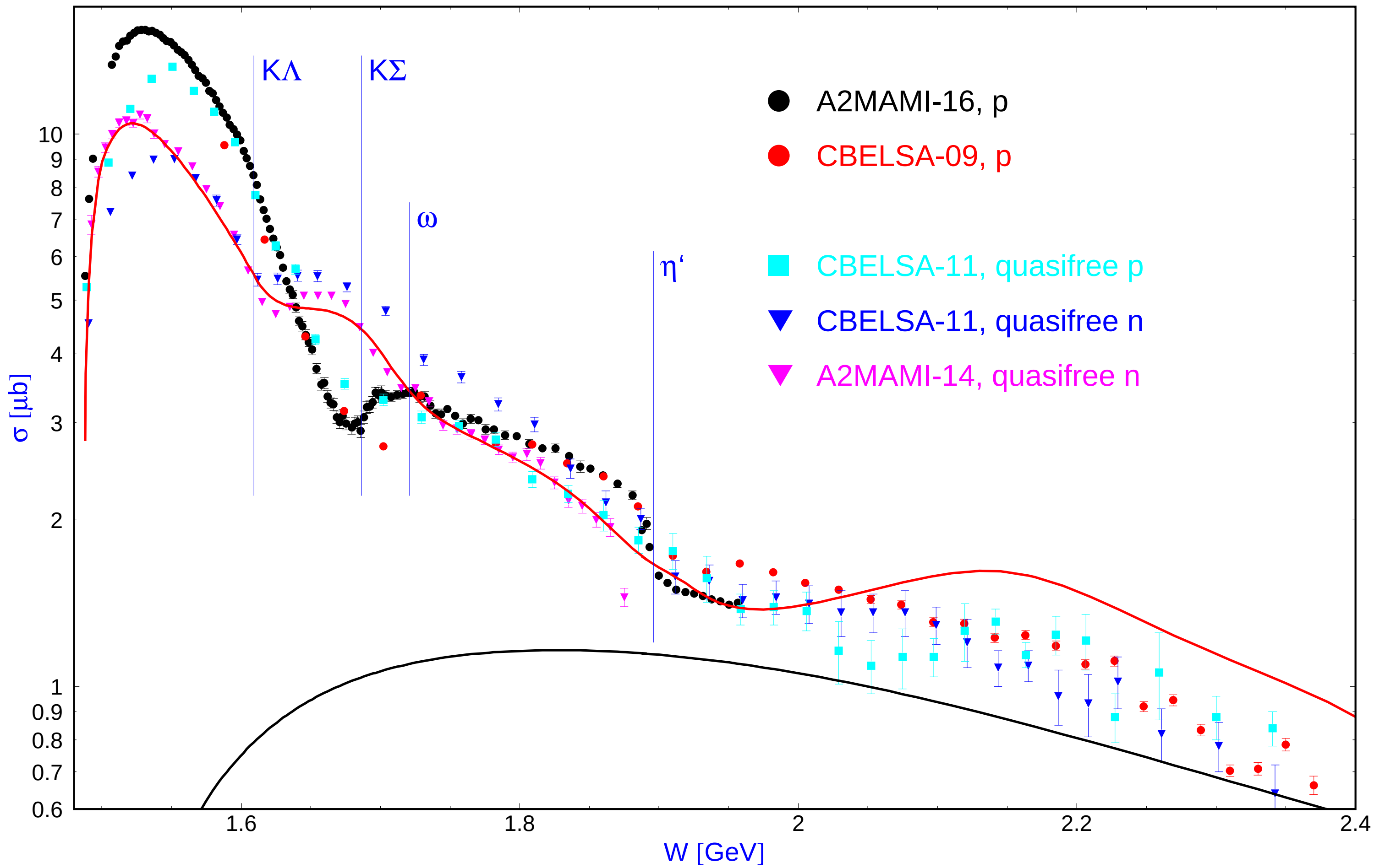
So in practice we have only five free parameters to describe π^0 photoproduction.

Excitation function. Data: A2MAMI, CBELSA-09, CLAS-09



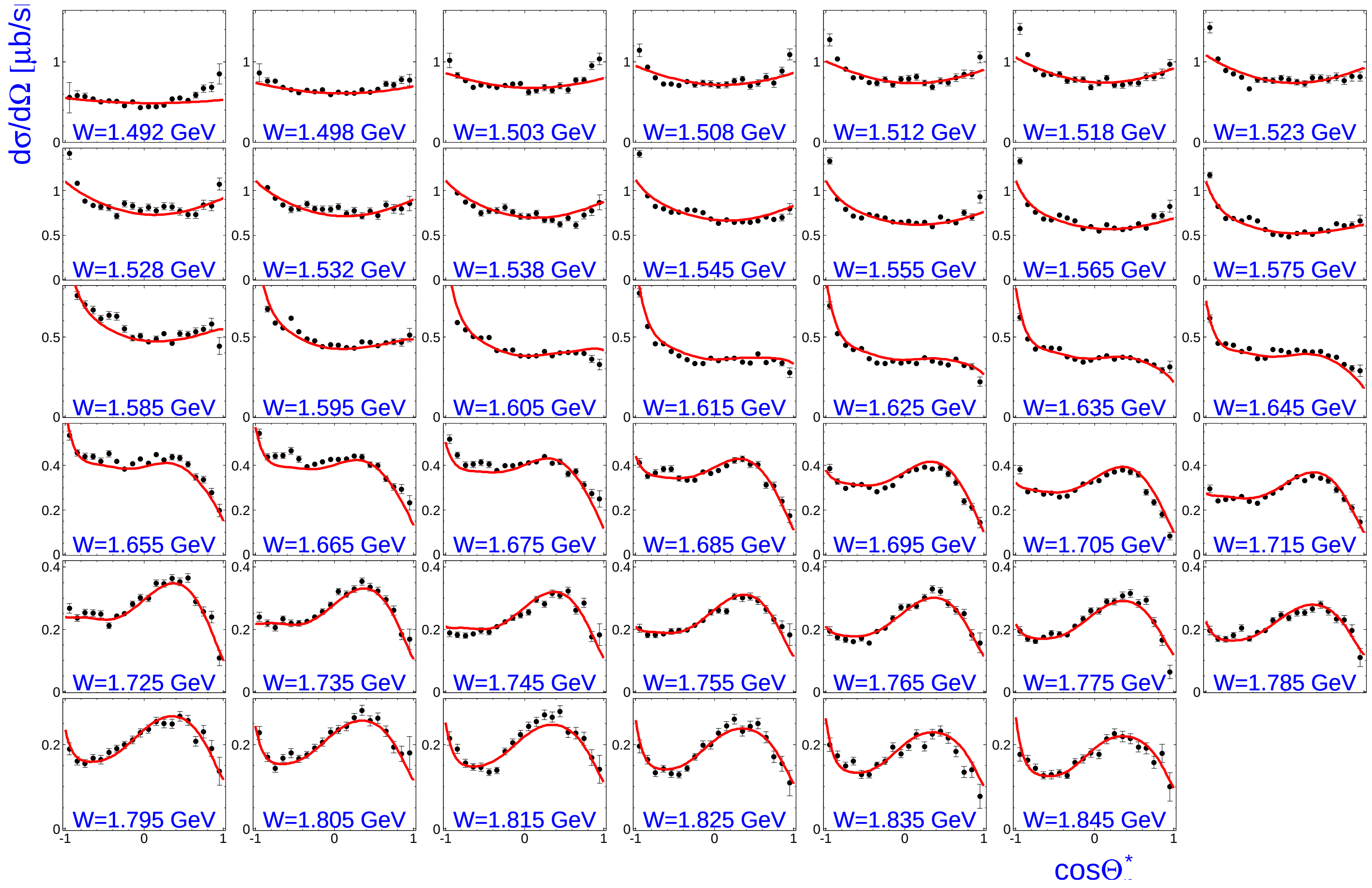
Regge+Resonances for $\gamma n \to \eta n$

Total cross section. Red line: full solution, black line: background.



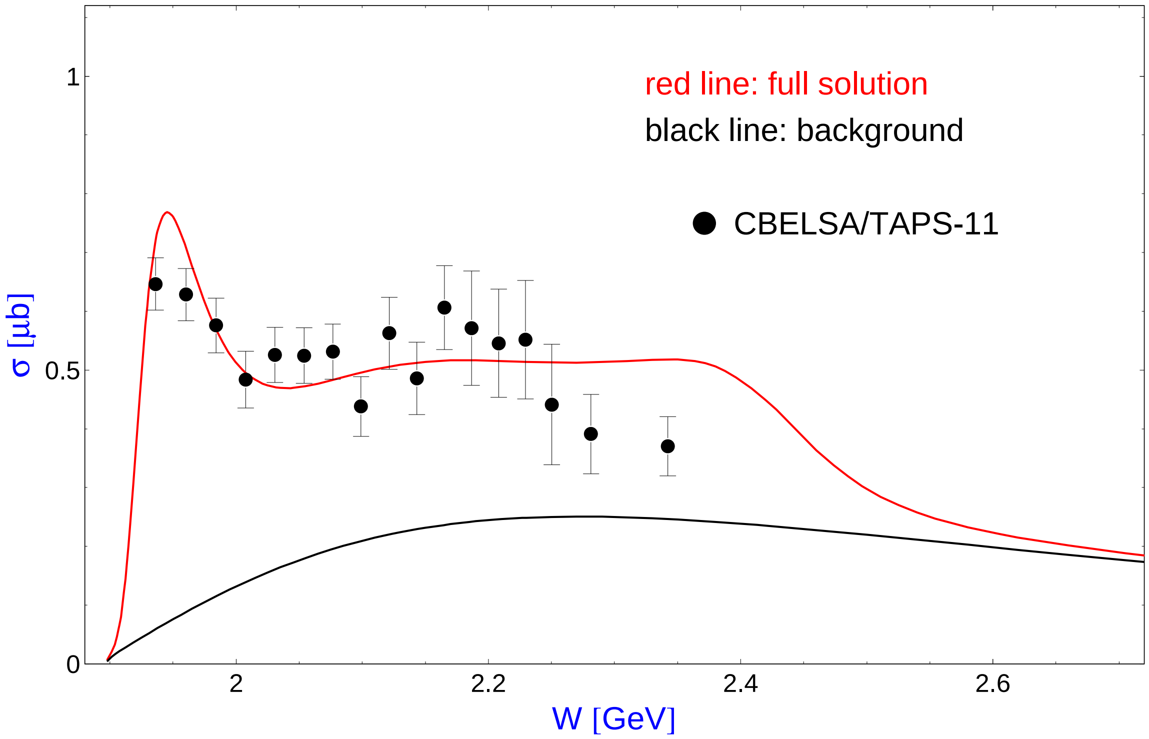
Regge+Resonances for $\gamma n \to \eta n$

Differential cross sections. Data: A2MAMI-14. Red lines: full solution.



Regge+Resonances for $\gamma n \to \eta' n$

Total cross section.



Regge+Resonances for $\gamma n \to \eta' n$

Differential cross sections. Data: CBELSA/TAPS-11 . Red lines: full solution.