Exciting Baryons

with MAMI and MAID

Lothar Tiator (Mainz)

SFB 1044
THE LOW-ENERGY FRONTIER
OF THE STANDARD MODEL

ECT*

Nucleon Resonances: From Photoproduction to High Photon Virtualities
Trento, October, 12-16, 2015

ECT*

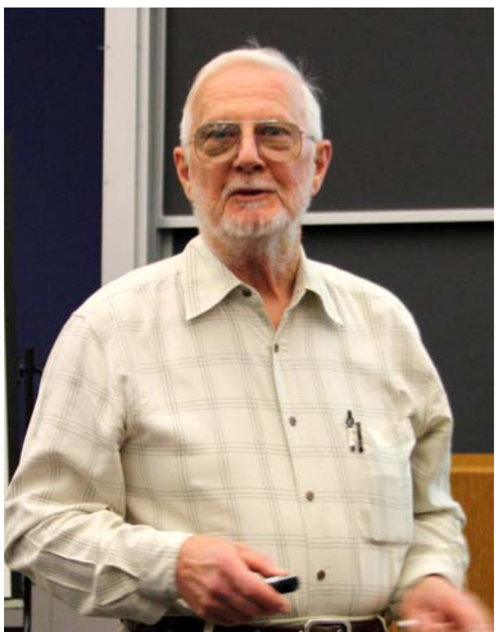
The Roper Resonance

first baryon resonance discovered in PWA, 1964

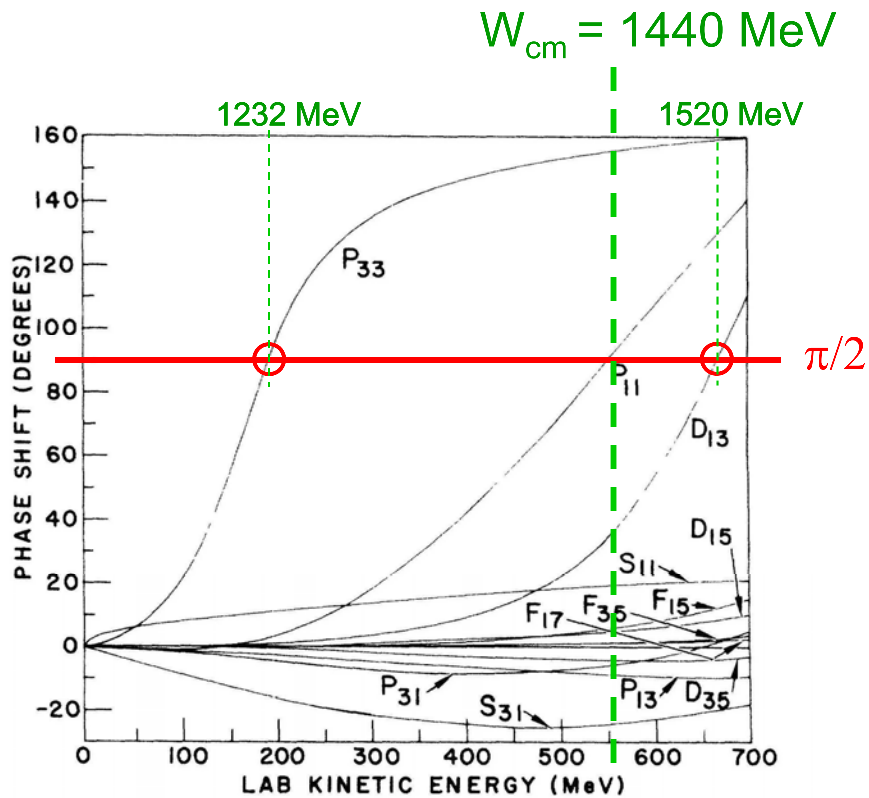
Phys. Rev. Lett. 12 (1964) 340:

EVIDENCE FOR A P_{11} PION-NUCLEON RESONANCE AT 556 MeV†

L. David Roper
Lawrence Radiation Laboratory, University of California, Livermore, California
(Received 17 February 1964)



Dan Roper at GWU in 2011



pion-nucleon phase shifts
from 0 to 700 MeV lab kinetic energy

outline of my talk

- new MAMI data on photoproduction of π^0, η, η‘

  with very high precision cross sections

  and new polarization observables

- update of EtaMAID for γ,η and γ,η‘ with new N* excitations

  and new data from Mainz, Bonn, GRAAL, Jlab

- current status of MAID for γ,π

- transition form factors from low to medium-high Q^2

- outlook

collaboration

Mainz: Michael Ostrick, Viktor Kashevarov, Kirill Nikonov and MAMI-A2 collaboration

Zagreb: Alfred Svarc, Sasa Ceci

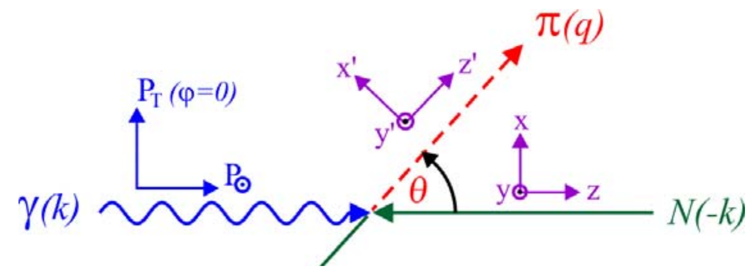
Tuzla: Jugoslav Stahov, Hedim Osmanovic, Mirza Hadzimehmedovic

Dubna: Sabit Kamalov

16 spin observables in photoproduction of π, η, η', K

linear and circular polarized beams

longitudinal and transverse polarized targets



Photon		Beam - Target		
	—	—	—	—
	—	x	y	z
unpolarized	σ	0	T	0
linear polariz.	Σ	H	P	G
circular polariz.	0	F	0	E

recent MAMI data on single π^0, η, η' photoproduction

on proton:

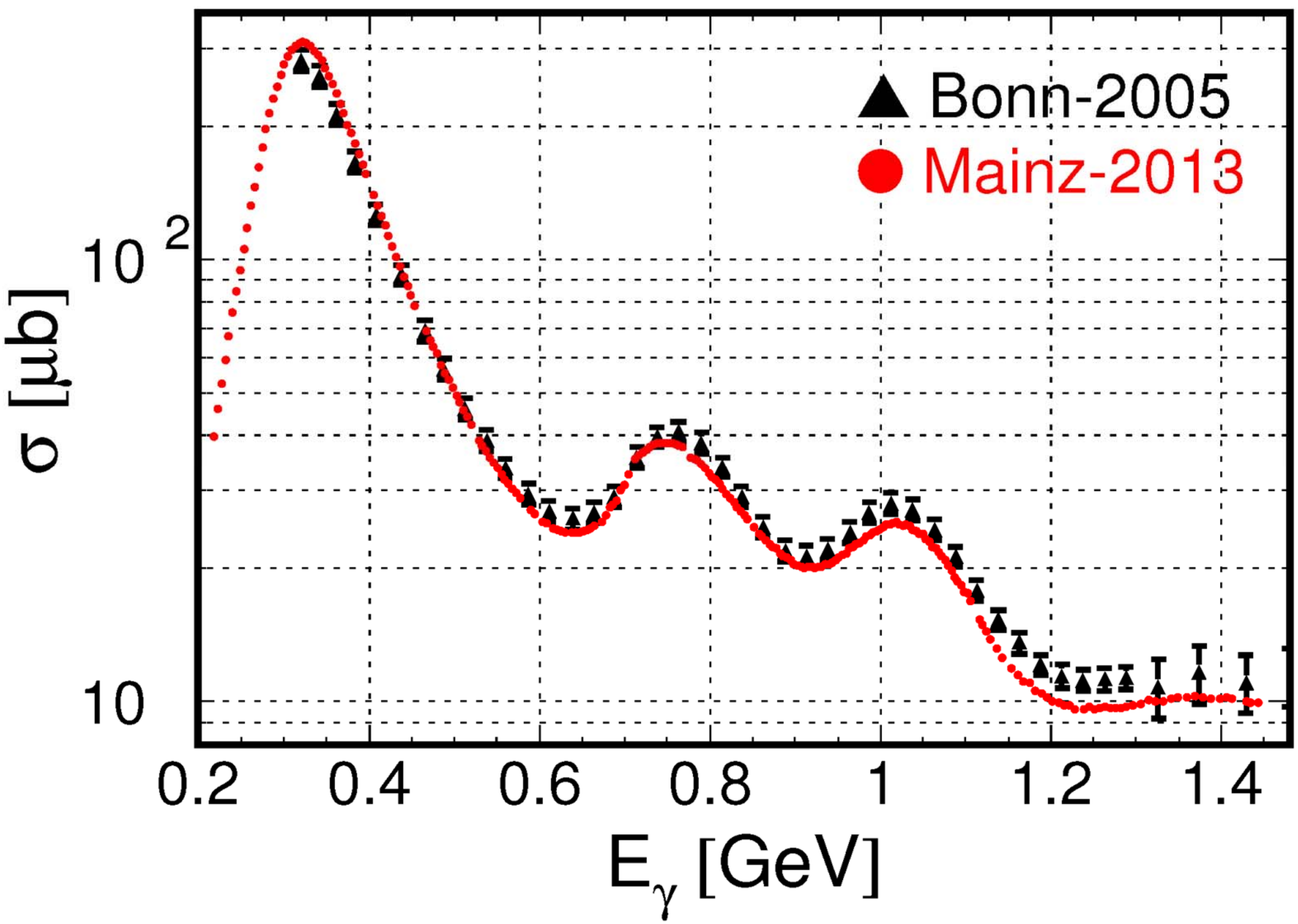
γ,π^0:	$d\sigma/d\Omega$, σ_{total}	*thr < W < 1.9 GeV*	*PRL 111 (2013), PRC 92 (2015)*
	T, F	*thr < W < 1.9 GeV*	*PL B750 and to be published in 2015*
	G	*thr < W < 1.55 GeV*	*not finally analyzed*
	E, $\Delta\sigma_{total}$	*thr < W < 1.9 GeV*	*not finally analyzed*
γ,η:	$d\sigma/d\Omega$, σ_{total}	*thr < W < 1.9 GeV*	*PRC 82 (2010)*
		thr < W < 1.96 GeV	*to be published in 2015*
	T, F	*thr < W < 1.85 GeV*	*PRL 113 (2014)*
	E, $\Delta\sigma_{total}$	*thr < W < 1.9 GeV*	*not finally analyzed*
γ,η':	$d\sigma/d\Omega$, σ_{total}	*thr < W < 1.96 GeV*	*to be published in 2015*

on neutron:

γ,π^0:	$d\sigma/d\Omega$, σ_{total}	*thr < W < 1.9 GeV*	*PRL 112 (2014)*
γ,η:	$d\sigma/d\Omega$, σ_{total}	*thr < W < 1.9 GeV*	*PRC 90 (2014)*
also	*T, F, E, G*	*up to 1.9 GeV*	*in analysis, to be published in 2016*

total cross section of MAMI γ,π^0 data

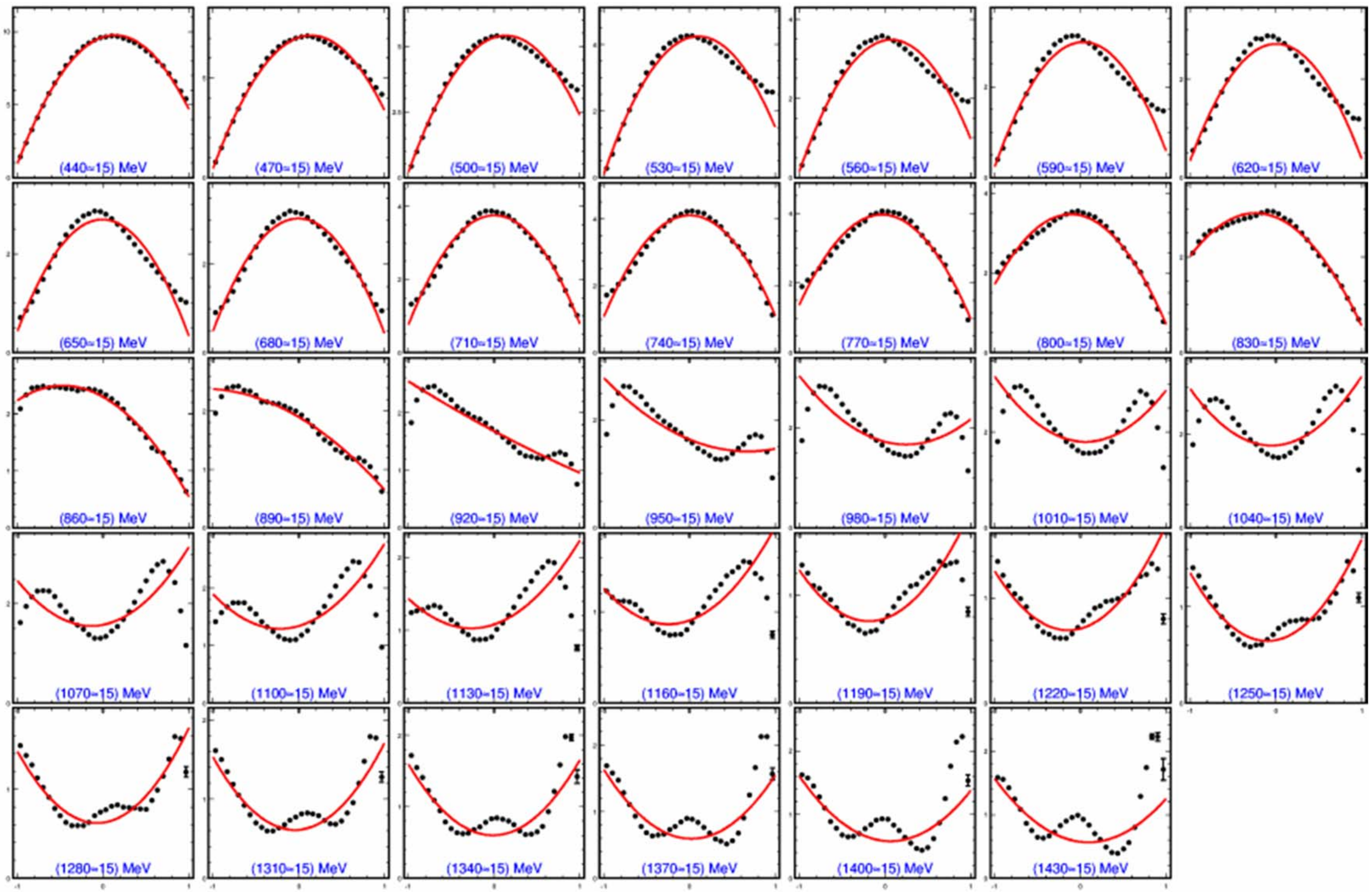
P. Adlarson et al (MAMI A2 Collab.) Phys. Rev. C92 (2015) 2, 024617



the red points are not a calculation, it is data!

Legendre expansion of the diff. cross section

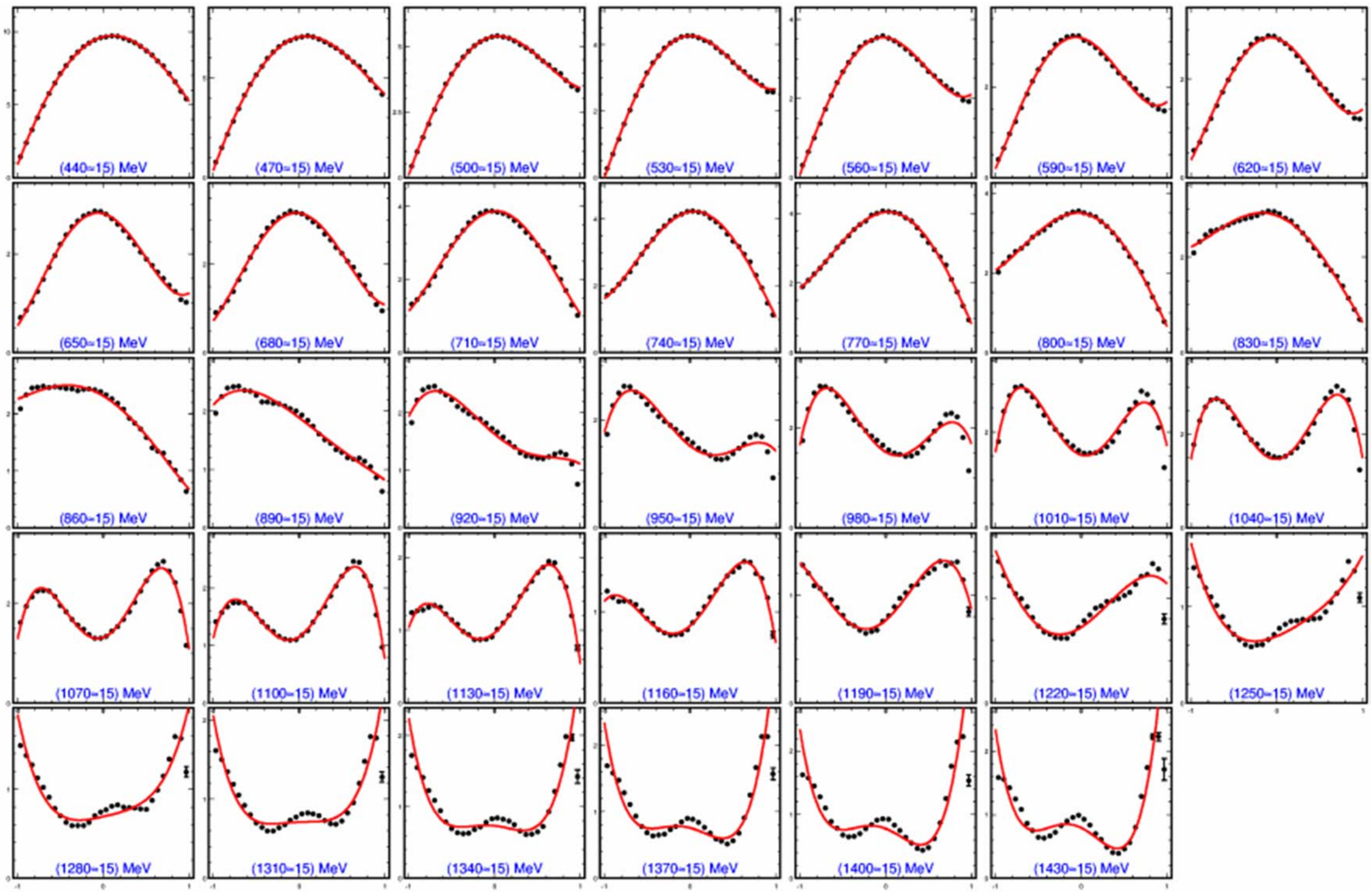
$$\frac{d\sigma}{d\Omega} = \sum_{k=0}^{2\ell_{max}} A_k^{\sigma}(W)\, P_k(\cos\theta) \qquad \ell max = 1$$



S+P waves are only good up to about 400 MeV

Legendre expansion of the diff. cross section

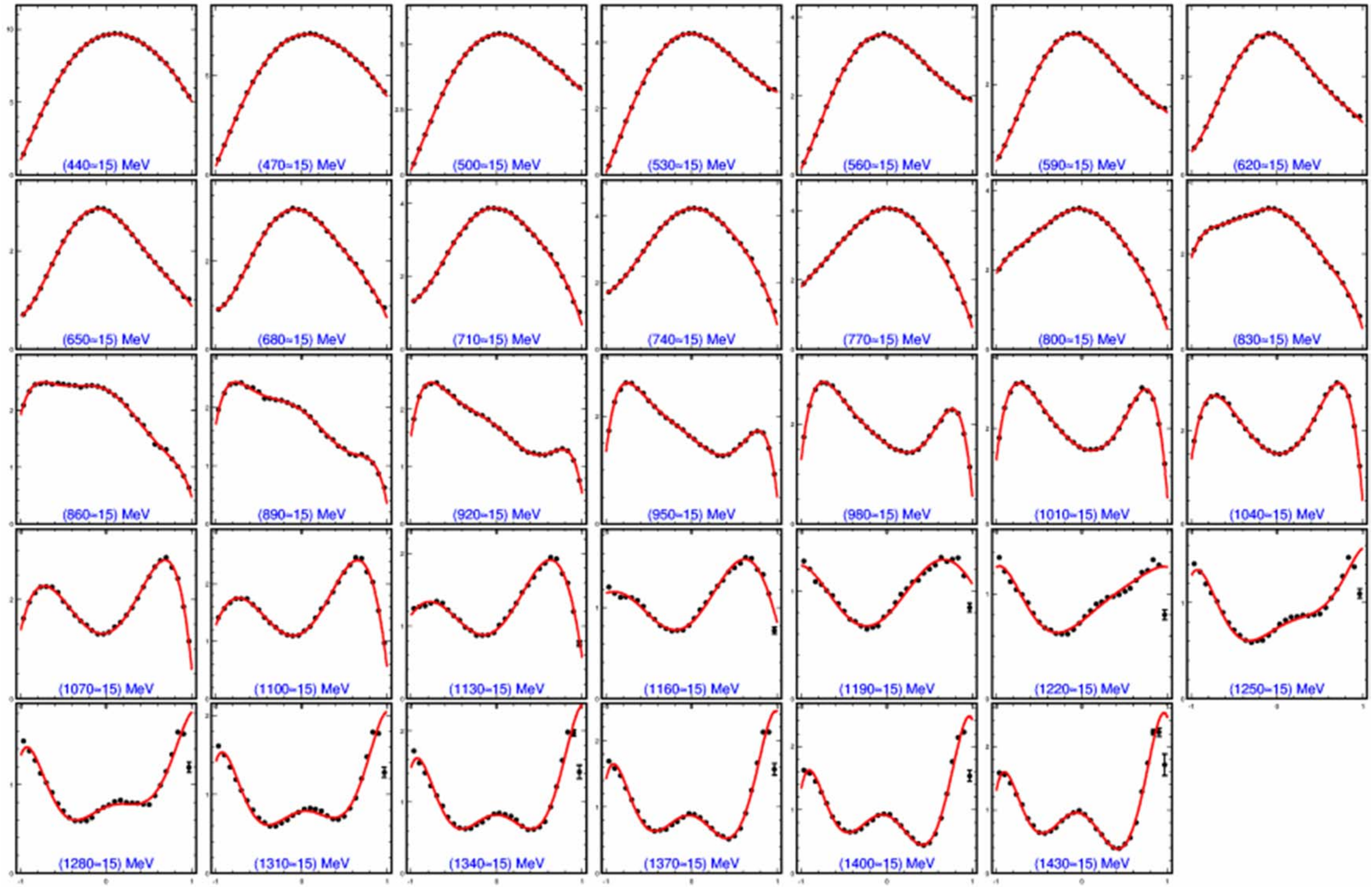
$$\frac{d\sigma}{d\Omega} = \sum_{k=0}^{2\ell_{max}} A_k^{\sigma}(W)\, P_k(\cos\theta) \qquad \ell max = 2$$



S+P+D waves are good up to about 850 MeV

Legendre expansion of the diff. cross section

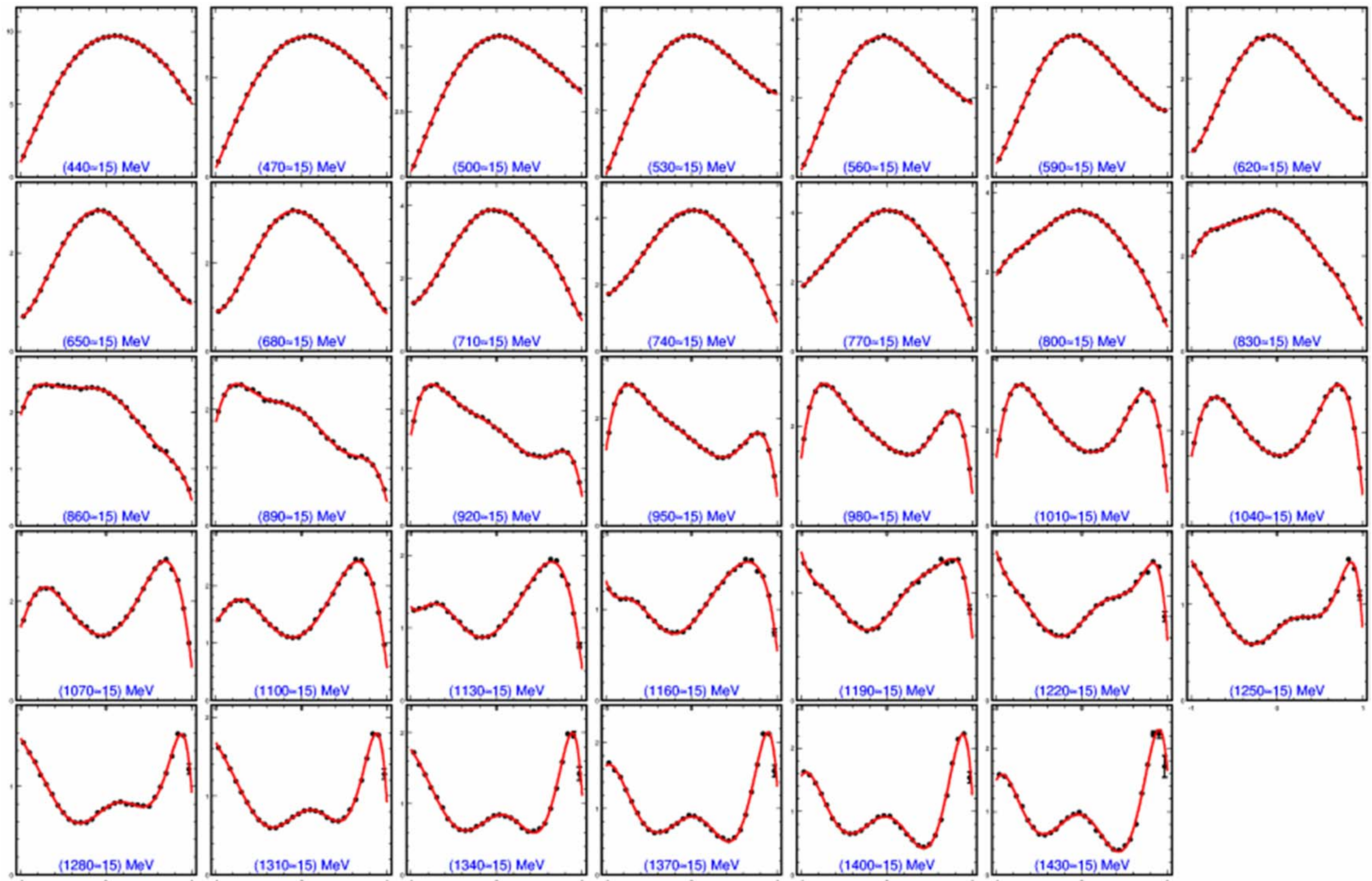
$$\frac{d\sigma}{d\Omega} = \sum_{k=0}^{2\ell_{max}} A_k^{\sigma}(W)\, P_k(\cos\theta) \qquad \ell max = 3$$



F waves become important around 1 GeV

Legendre expansion of the diff. cross section

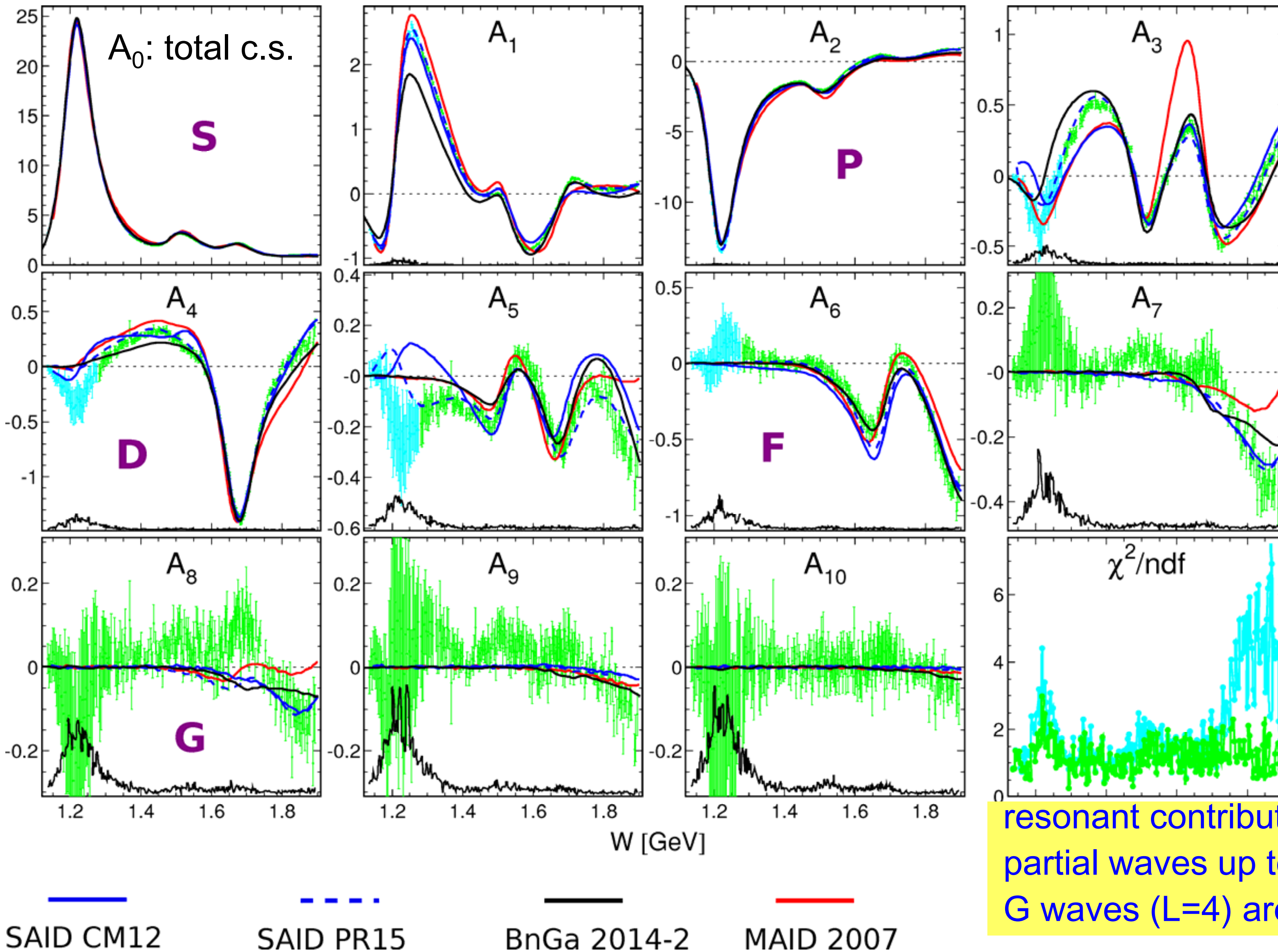
$$\frac{d\sigma}{d\Omega} = \sum_{k=0}^{2\ell_{max}} A_k^{\sigma}(W)\, P_k(\cos\theta) \qquad \ell max = 4$$



around 1.2 GeV also G waves become clearly visible in forward direction

Legendre expansion of differential cross section

P. Adlarson et al (MAMI A2 Collab.) Phys. Rev. C92 (2015) 2, 024617



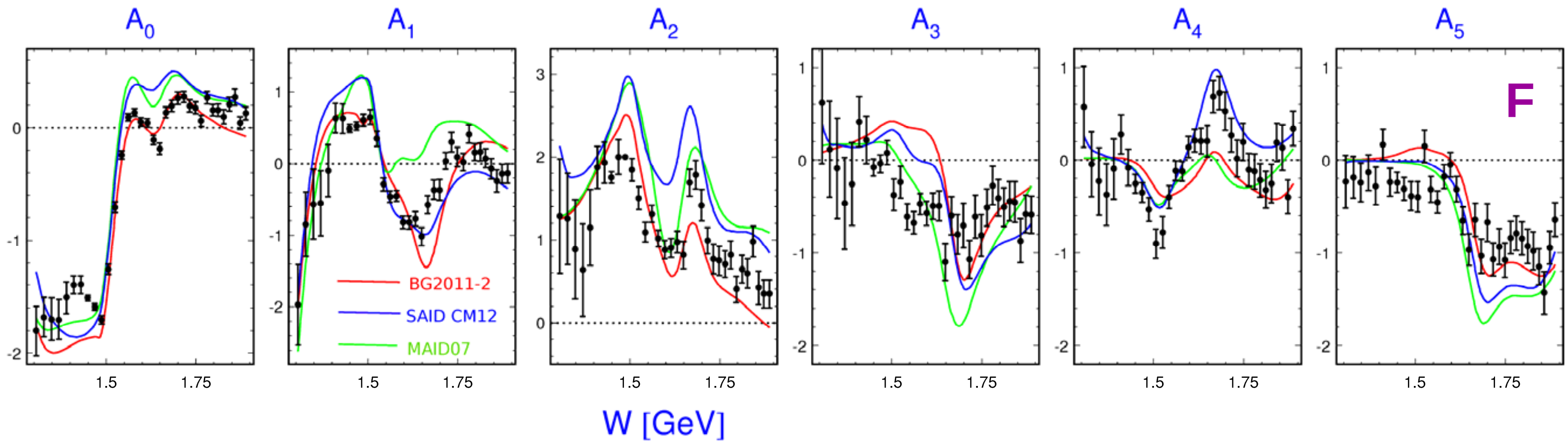
resonant contributions in partial waves up to G waves (L=4) are visible

Legendre expansion of polarization observables for γ,π^0

A2 Collaboration at MAMI, ready for publication (2015)

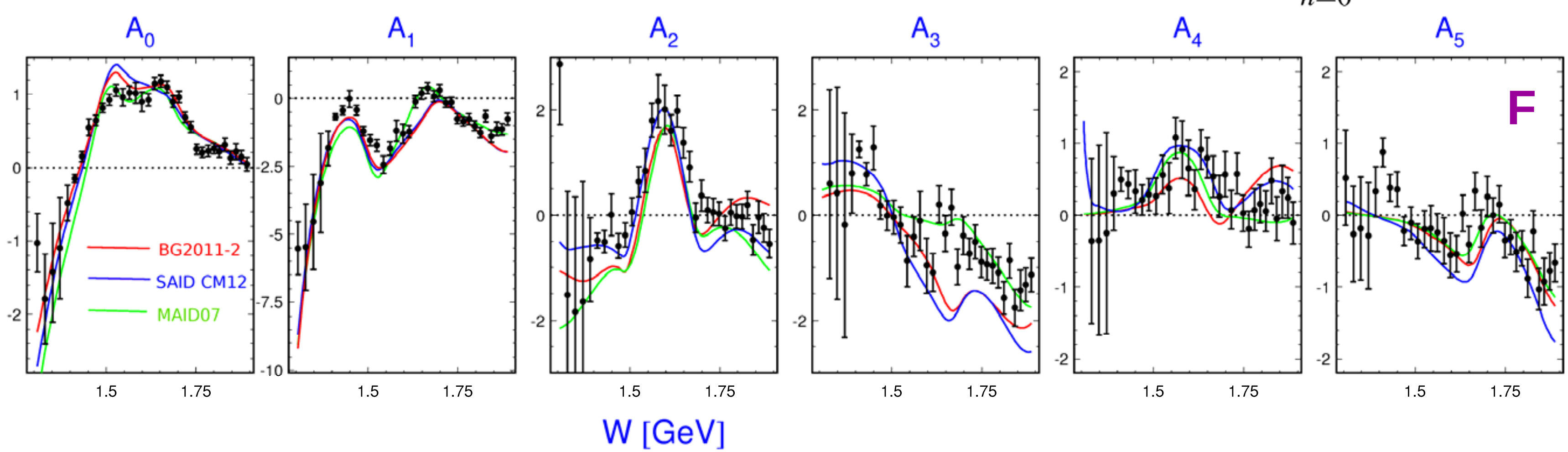
T observable (target polarization)

$$T \cdot \frac{d\sigma}{d\Omega} = \sin\theta \sum_{n=0}^{2\ell_{max}} A_T^n \, P_n(\cos\theta)$$



F observable (beam-target double polarization)

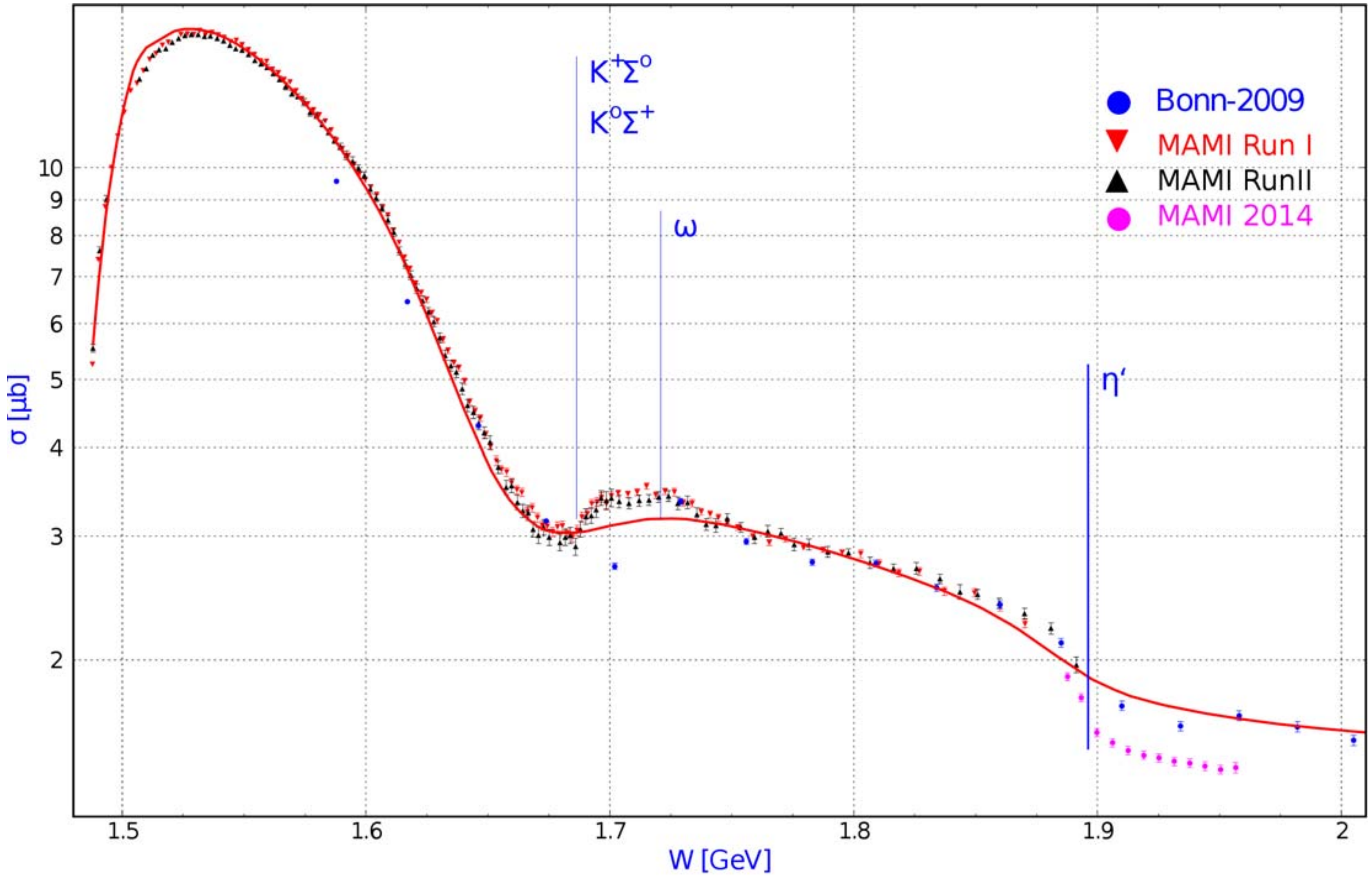
$$F \cdot \frac{d\sigma}{d\Omega} = \sin\theta \sum_{n=0}^{2\ell_{max}} A_F^n \, P_n(\cos\theta)$$



η Photoproduction at MAMI

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

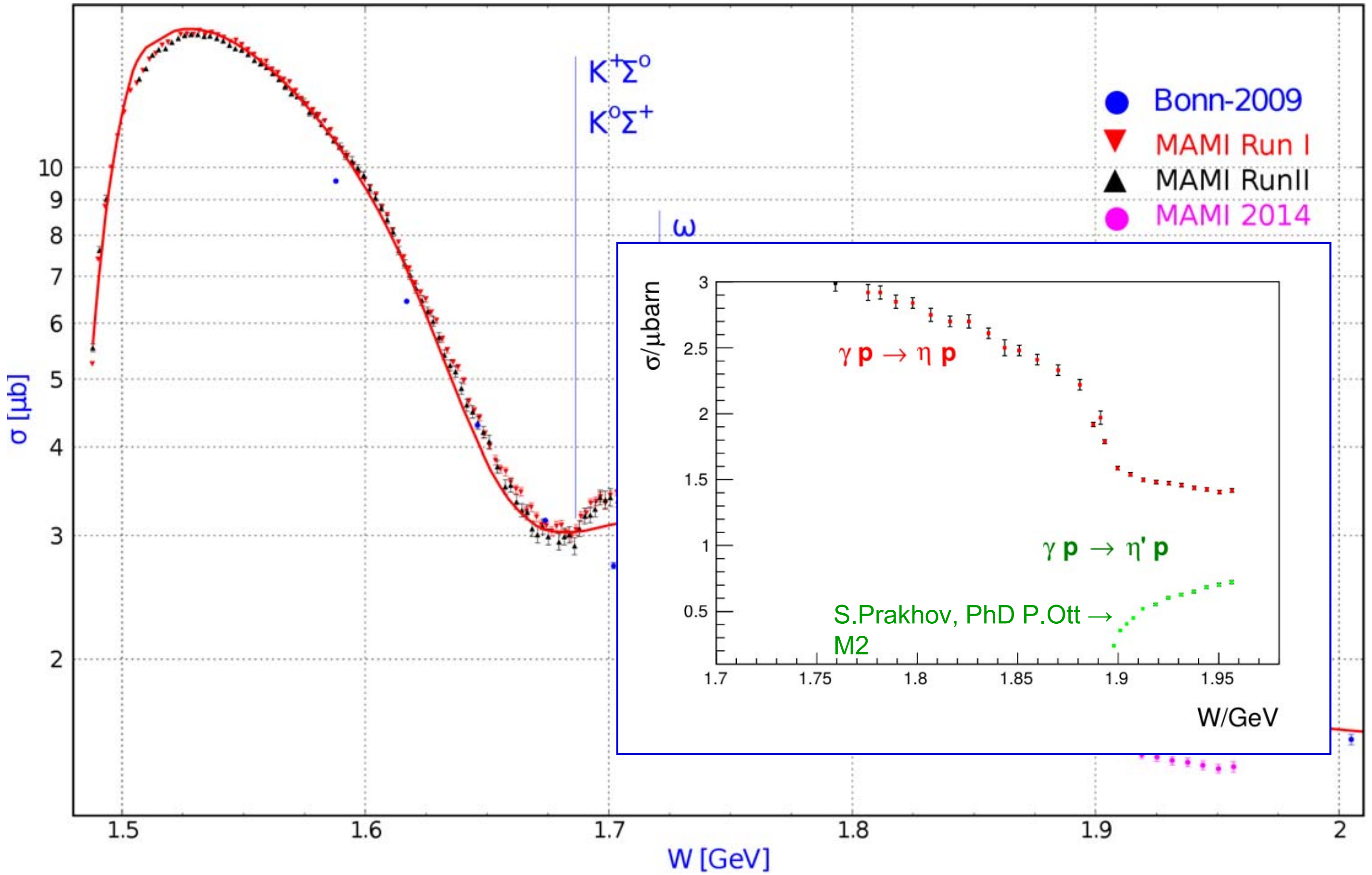
MAMI A2 Collab, preliminary



η Photoproduction at MAMI

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

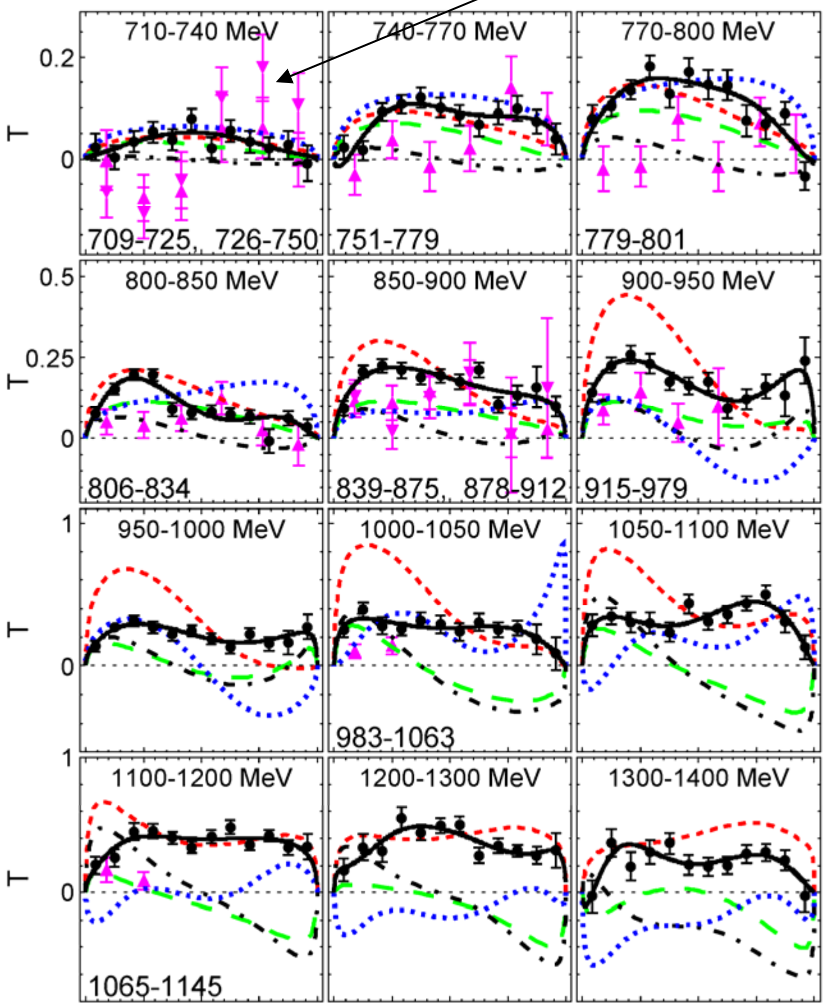
MAMI A2 Collab, preliminary



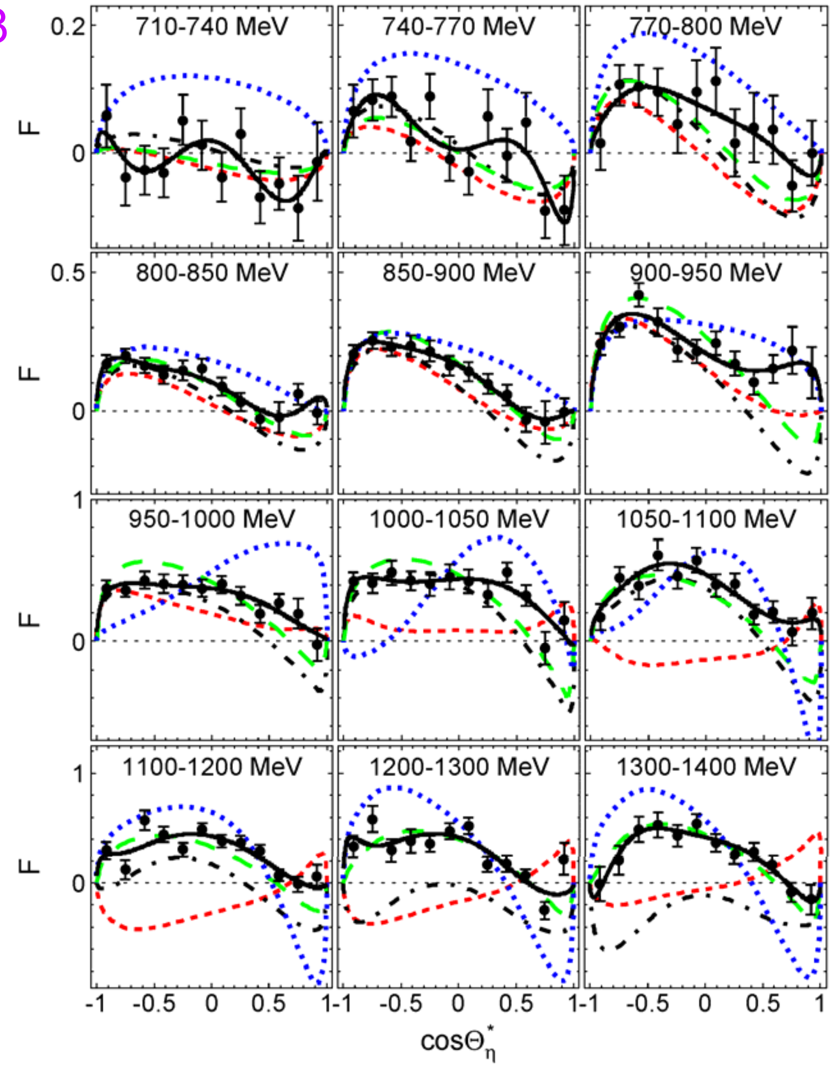
Target Polarization and Beam-Target Asymmetry for γ,η

- - - - η-MAID 2001
- - - - Bonn-Gatchina
········ SAID
- - - - Giessen
——— Legendre-Fit

Bonn data, 1998



A2 Collaboration at MAMI
Phys. Rev. Lett. 113 (2014)



The MAID Ansatz

$$t_{\gamma\pi}(W,Q^2) = t^{B}_{\gamma\pi}(W,Q^2) + t^{R}_{\gamma\pi}(W,Q^2)$$

total amplitude

$$t^{B,\alpha}_{\gamma\pi}(W,Q^2) = v^{B,\alpha}_{\gamma\pi}(W,Q^2)\,[1 + i t^{\alpha}_{\pi N}(W)]$$

unitarized
background amplitude

$$t^{R,\alpha}_{\gamma\pi}(W,Q^2) = \bar{\mathcal{A}}^{R}_{\alpha}(W,Q^2)\,\frac{f_{\gamma N}(W)\Gamma_{tot}(W)\,M_R\,f_{\pi N}(W)}{M_R^2 - W^2 - iM_R\Gamma_{tot}(W)}\,e^{i\phi_R(W,Q^2)}$$

unitarized
reson. amplitude

$$\Gamma_{\pi N}(W) = \beta_\pi\,\Gamma_R \left(\frac{q(W)}{q_R}\right)^{2l+1} \left(\frac{X_R^2 + q_R^2}{X_R^2 + q^2(W)}\right)^{\ell} \frac{M_R}{W}$$

energy-dep. widths

$$f_{\pi N}(W) = C_{\pi N}\left[\frac{1}{(2j+1)\pi}\,\frac{\kappa(W)}{q(W)}\,\frac{M_N}{M_R}\,\frac{\Gamma_{\pi N}(W)}{\Gamma^2_{\mathrm{tot}}(W)}\right]^{1/2}$$

$$f_{\gamma N}(W) = \left(\frac{\kappa(W)}{\kappa_R}\right)^{n} \left(\frac{X_R^2 + \kappa_R^2}{X_R^2 + \kappa^2(W)}\right)$$

vertex functions
depend only on W

phenomenological parametrization of transition form factors:

$$\bar{\mathcal{A}}^{R}_{\alpha}(W,Q^2) \approx \bar{\mathcal{A}}_{\alpha}(Q^2) = \bar{\mathcal{A}}_{\alpha}(0)(1 + a_1Q^2 + a_2Q^4 + a_3Q^6 + a_4Q^8)\,e^{-b_1Q^2}$$

The MAID Ansatz without unitarity, e.g. for γ,η

$$t_{\gamma\pi}(W,Q^2) = t^B_{\gamma\pi}(W,Q^2) + t^R_{\gamma\pi}(W,Q^2)$$

total amplitude

$$t^{B,\alpha}_{\gamma\pi}(W,Q^2) = v^{B,\alpha}_{\gamma\pi}(W,Q^2)\,[1 + i t^{\alpha}_{\pi N}(W)]$$

unitarized background amplitude

$$t^{R,\alpha}_{\gamma\pi}(W,Q^2) = \bar{\mathcal{A}}^R_{\alpha}(W,Q^2)\,\frac{f_{\gamma N}(W)\Gamma_{tot}(W)\,M_R\,f_{\pi N}(W)}{M_R^2 - W^2 - iM_R\Gamma_{tot}(W)}\,e^{i\phi_R(W,Q^2)}$$

unitarized reson. amplitude

$$\Gamma_{\pi N}(W) = \beta_\pi\,\Gamma_R \left(\frac{q(W)}{q_R}\right)^{2l+1} \left(\frac{X_R^2 + q_R^2}{X_R^2 + q^2(W)}\right)^{\ell} \frac{M_R}{W}$$

energy-dep. widths

$$f_{\pi N}(W) = C_{\pi N}\left[\frac{1}{(2j+1)\pi}\,\frac{\kappa(W)}{q(W)}\,\frac{M_N}{M_R}\,\frac{\Gamma_{\pi N}(W)}{\Gamma^2_{\text{tot}}(W)}\right]^{1/2}$$

$$f_{\gamma N}(W) = \left(\frac{\kappa(W)}{\kappa_R}\right)^{n} \left(\frac{X_R^2 + \kappa_R^2}{X_R^2 + \kappa^2(W)}\right)$$

vertex functions depend only on W

phenomenological parametrization of transition form factors:

$$\bar{\mathcal{A}}^R_{\alpha}(W,Q^2) \approx \bar{\mathcal{A}}_{\alpha}(Q^2) = \bar{\mathcal{A}}_{\alpha}(0)(1 + a_1 Q^2 + a_2 Q^4 + a_3 Q^6 + a_4 Q^8)\,e^{-b_1 Q^2}$$

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

(with V. Kashevarov, Mainz)

still very preliminary, 28.09.2015

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-2015d

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

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

(with V. Kashevarov, Mainz)

data used in the fit

$\gamma p \to \eta p$

$d\sigma/d\Omega$	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

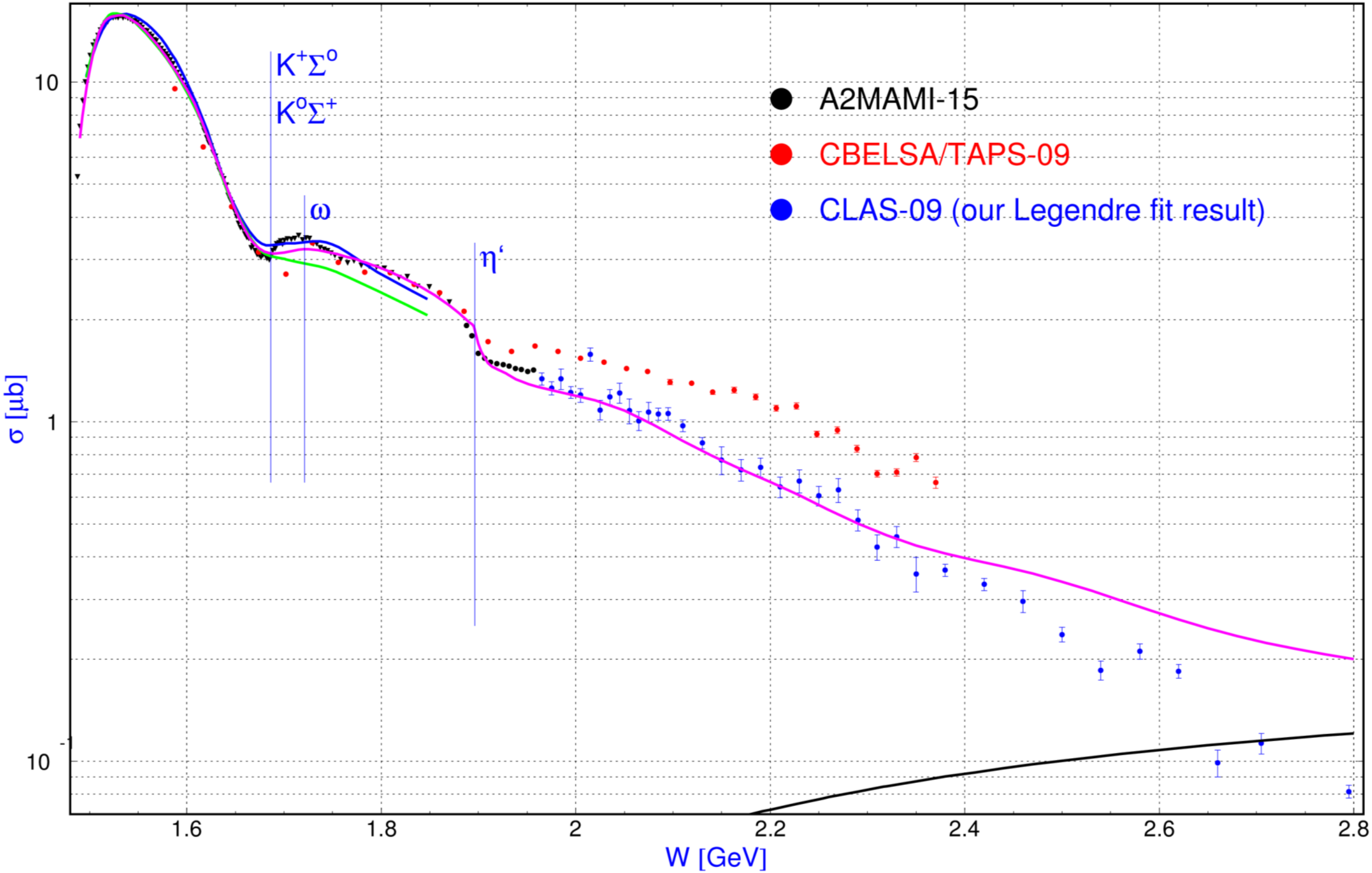
$\gamma p \to \eta' p$

$d\sigma/d\Omega$	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 χ^2 ~ 3.8, below η' threshold ~ 3.4

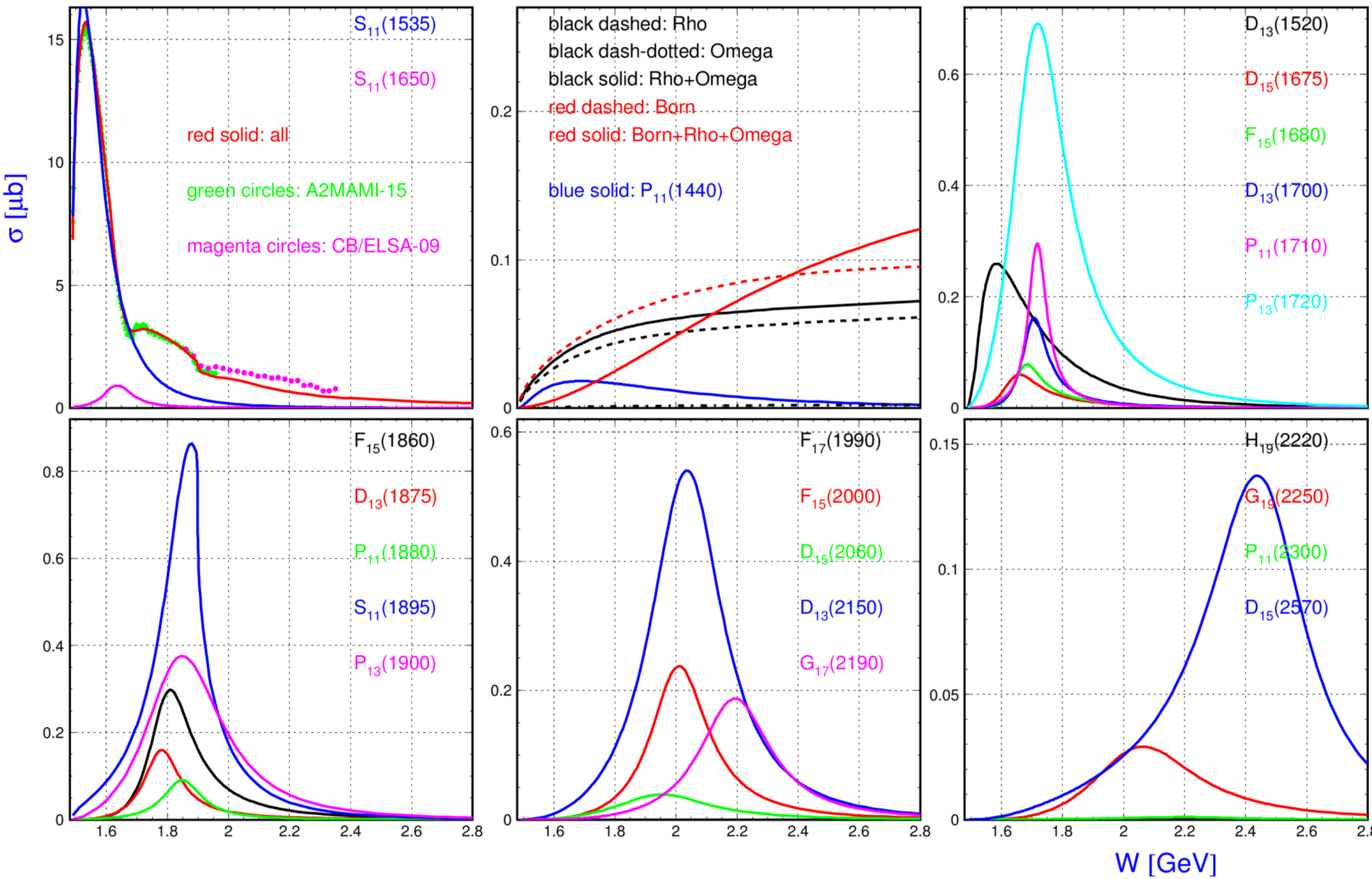
γ p → η p

ηMAID-2015d: total cross sections



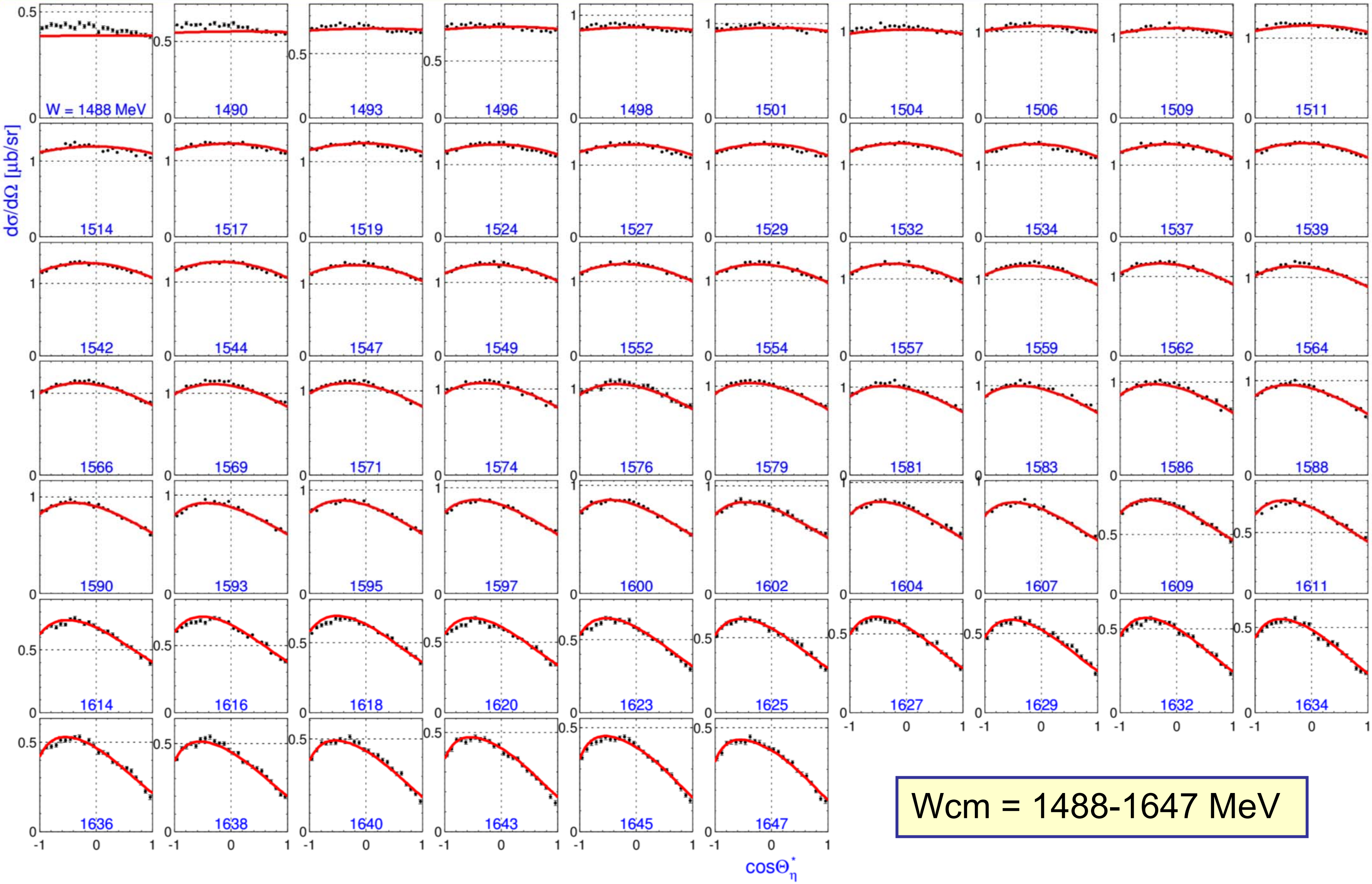
Blue line: ηMAID-2003
Green line: ηMAID-2003regge
magenta line: ηMAID-2015d
black line: ηMAID-2015d background

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



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

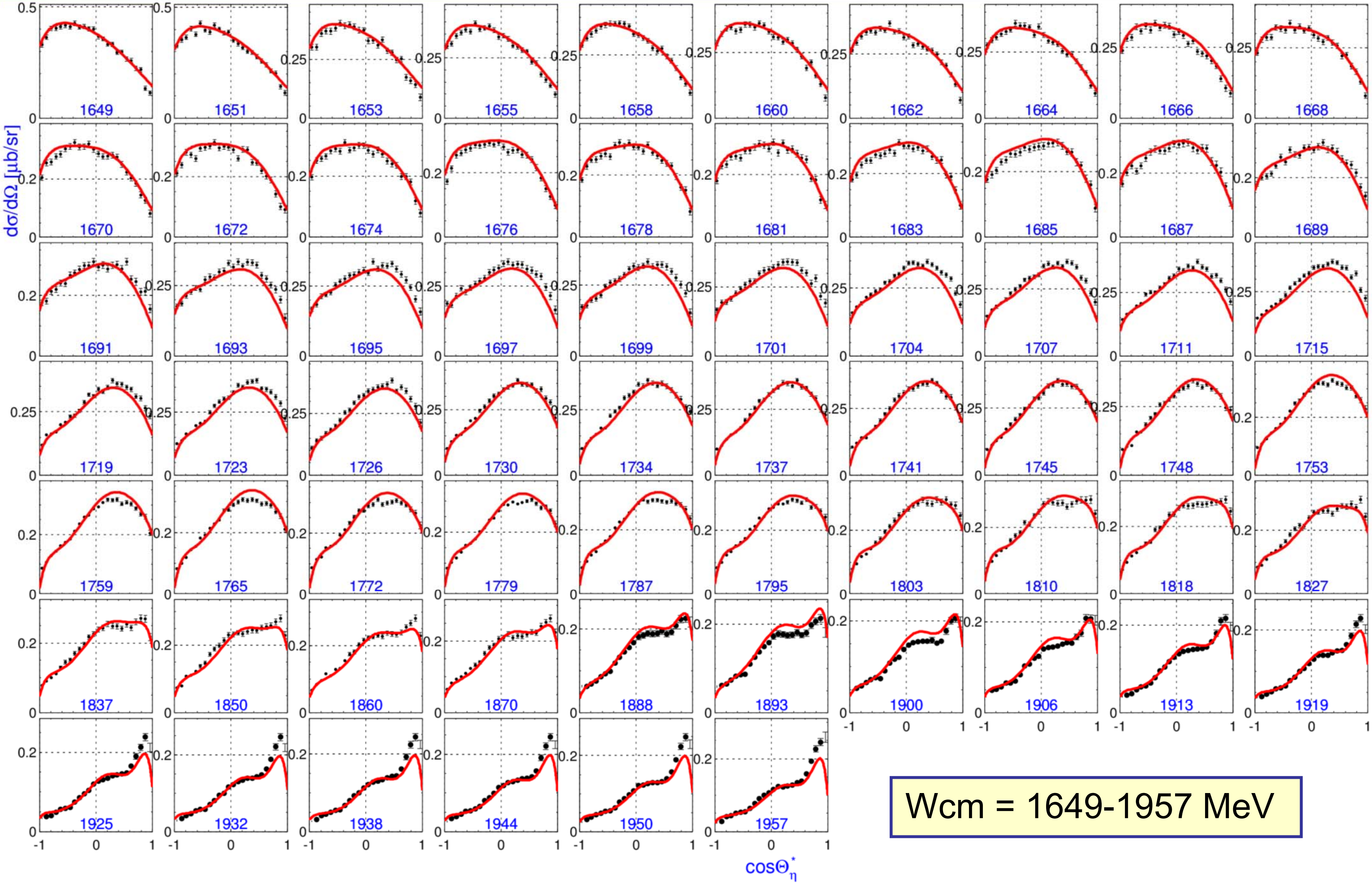
γ p → η p *ηMAID-2015d: differential cross sections, Mainz data*



Wcm = 1488-1647 MeV

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

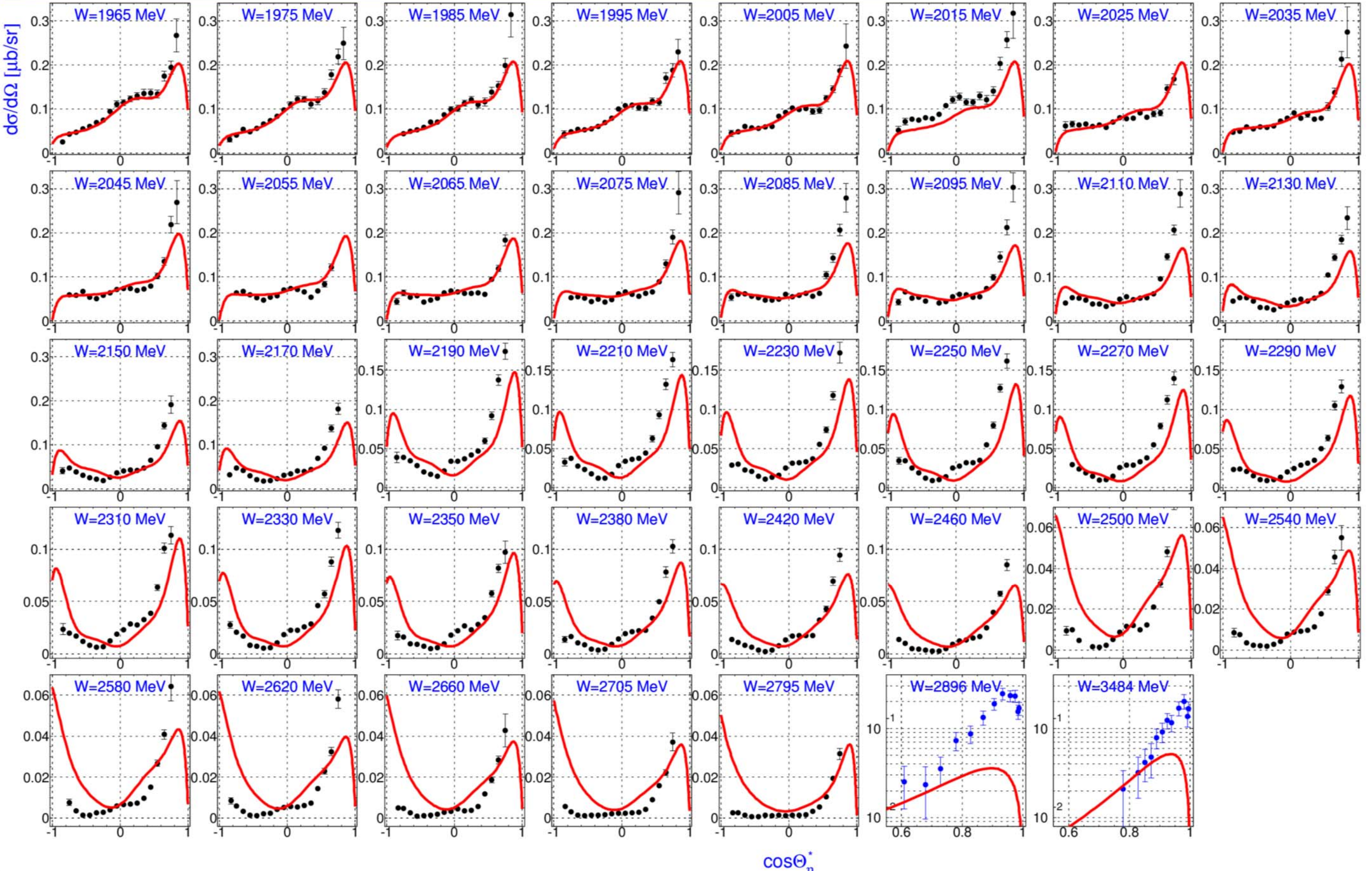
γ p → η p *ηMAID-2015d: differential cross sections, Mainz data*



Wcm = 1649-1957 MeV

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

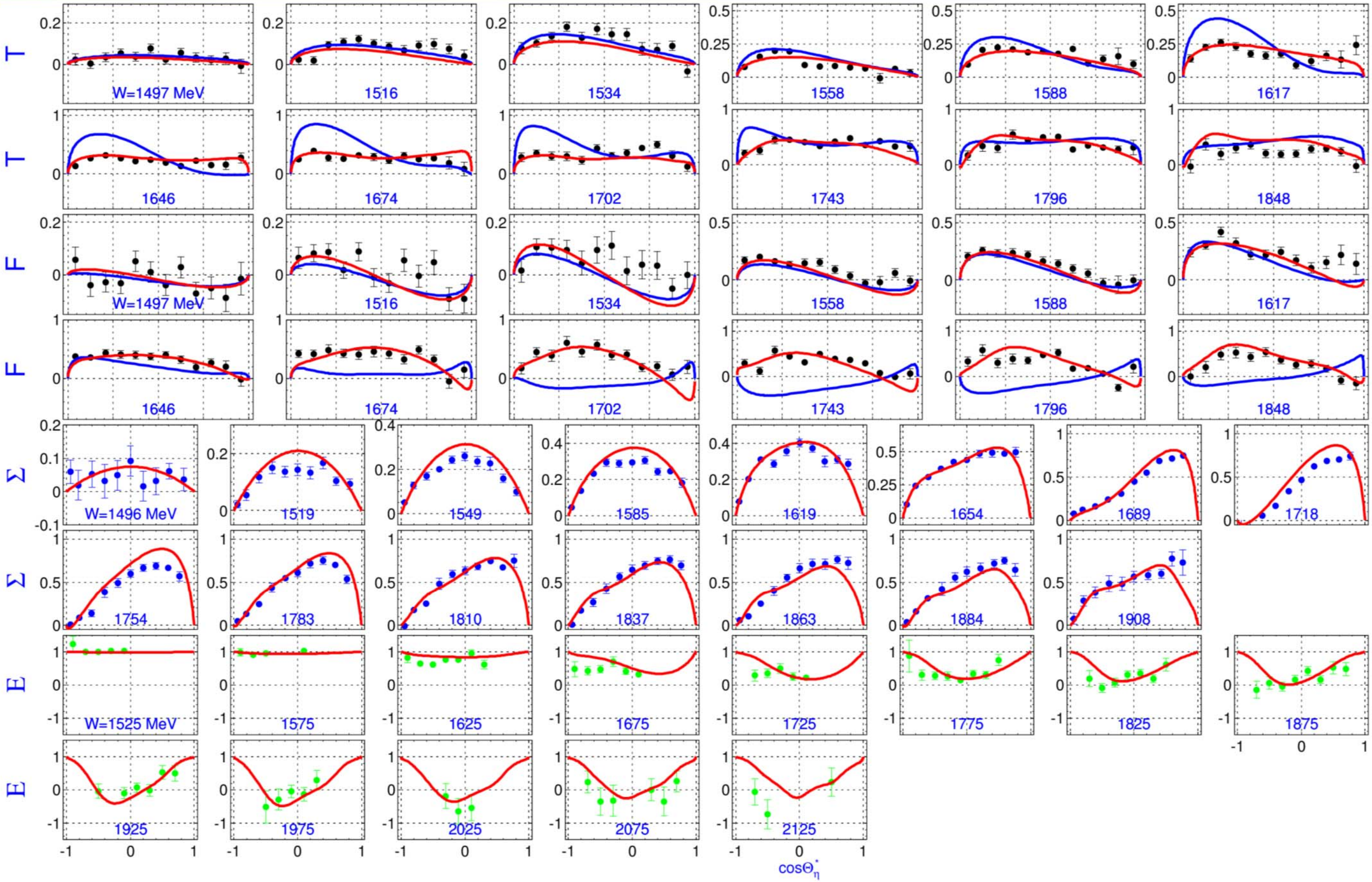
γ p → η p   ηMAID-2015d: differential cross sections JLab/DESY



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

Wcm = 1965-3484 MeV

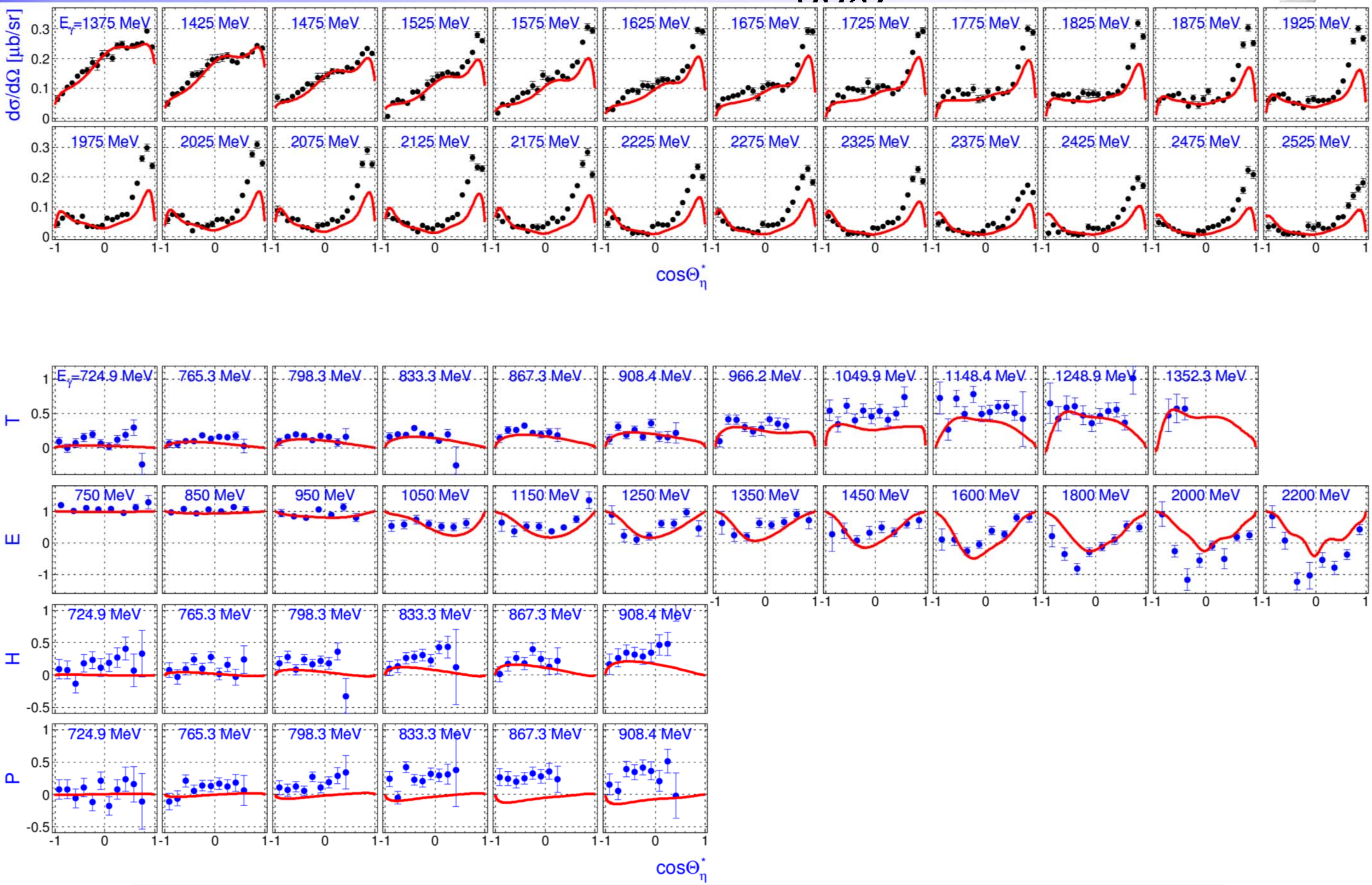
γ p → η p *ηMAID-2015d: T, F, Σ, E data from Mainz/GRAAL/JLab*



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

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

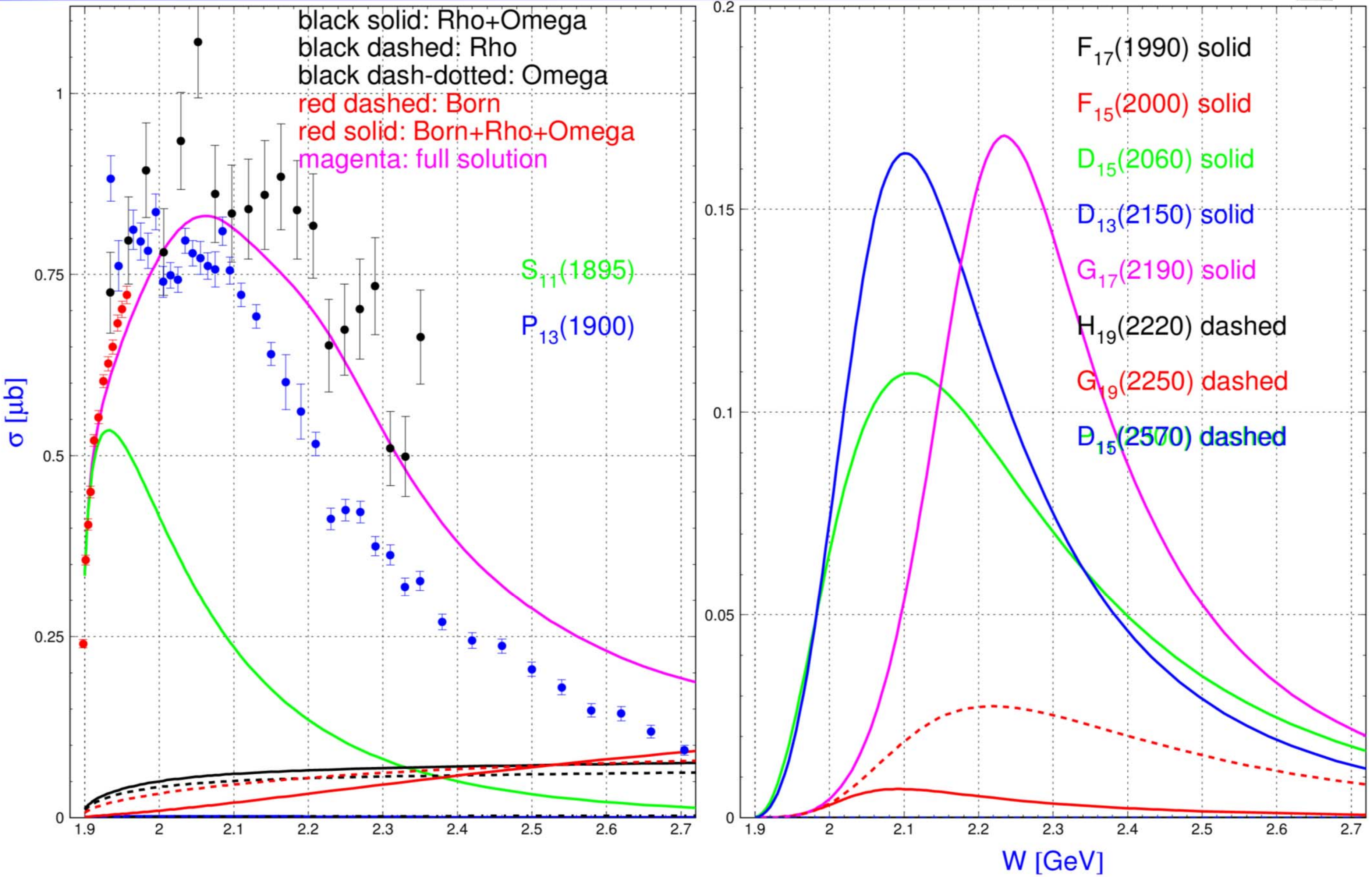
γ p → η p   *ηMAID-2015d predictions for CBELSA/TAPS data*



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

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

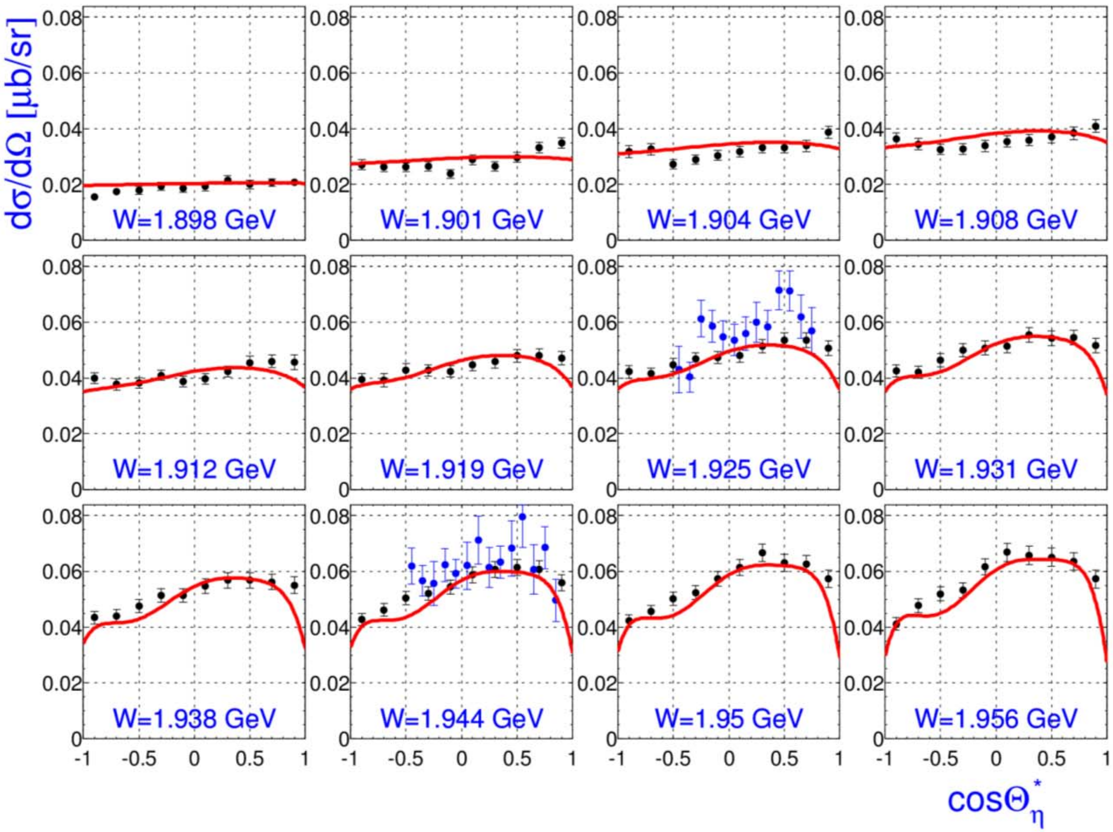
γ p → η' p   *ηMAID-2015d: total cross section Mainz/Bonn/JLab data*



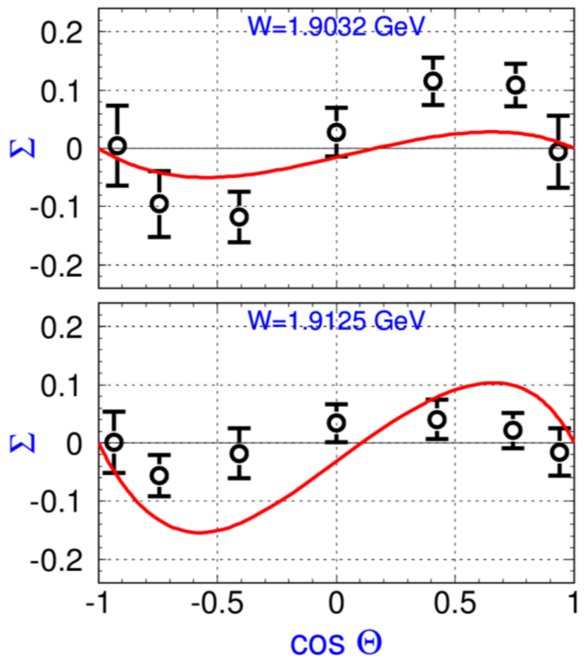
Red circles: A2MAMI-15, black circles: CBELSA/TAPS-09, blue circles: CLAS-09 from Legendre fit

γ p → η' p *ηMAID-2015d and near threshold data*

MAMI - A2 data 2015, preliminary

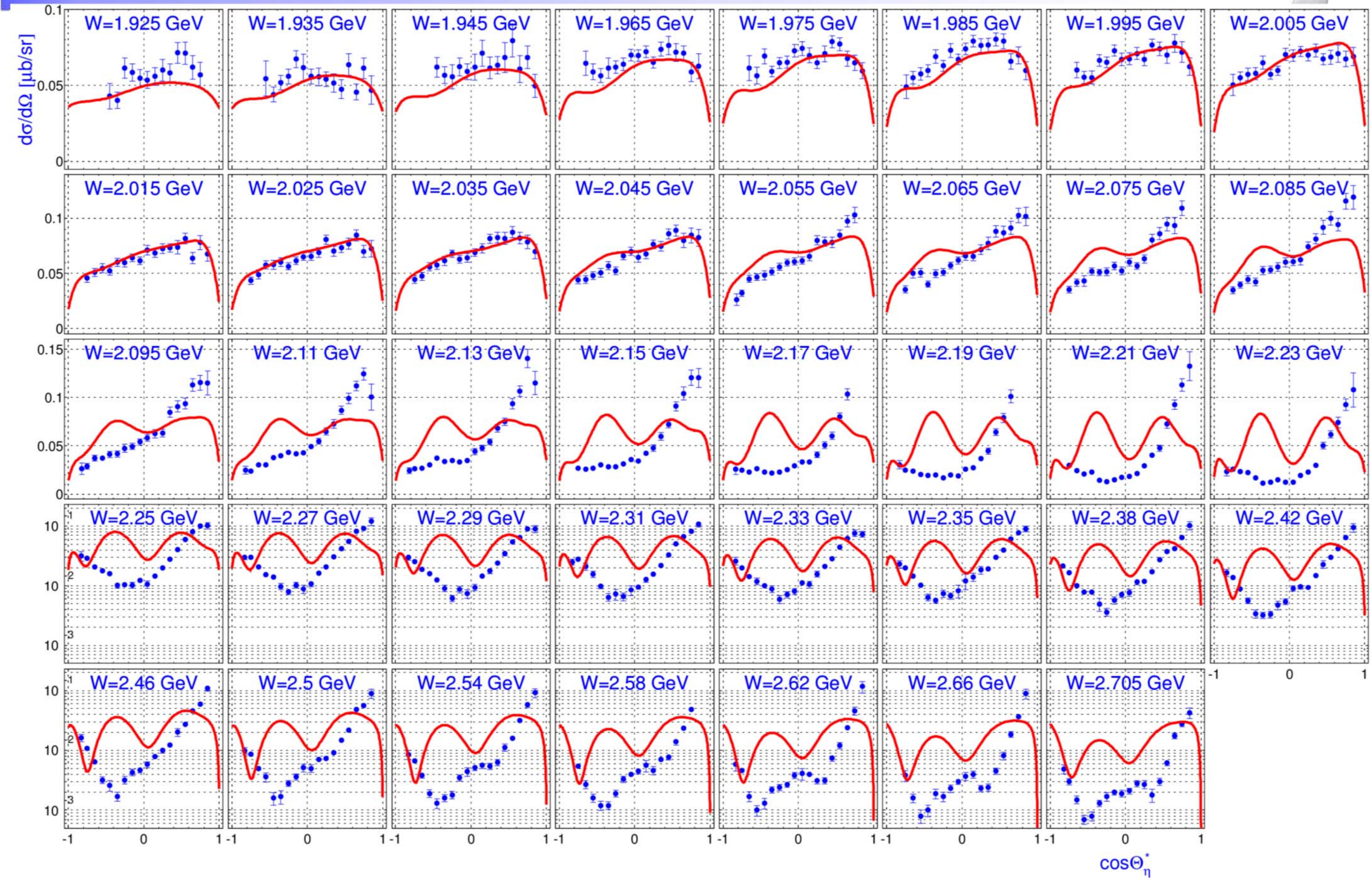


GRAAL data 2015



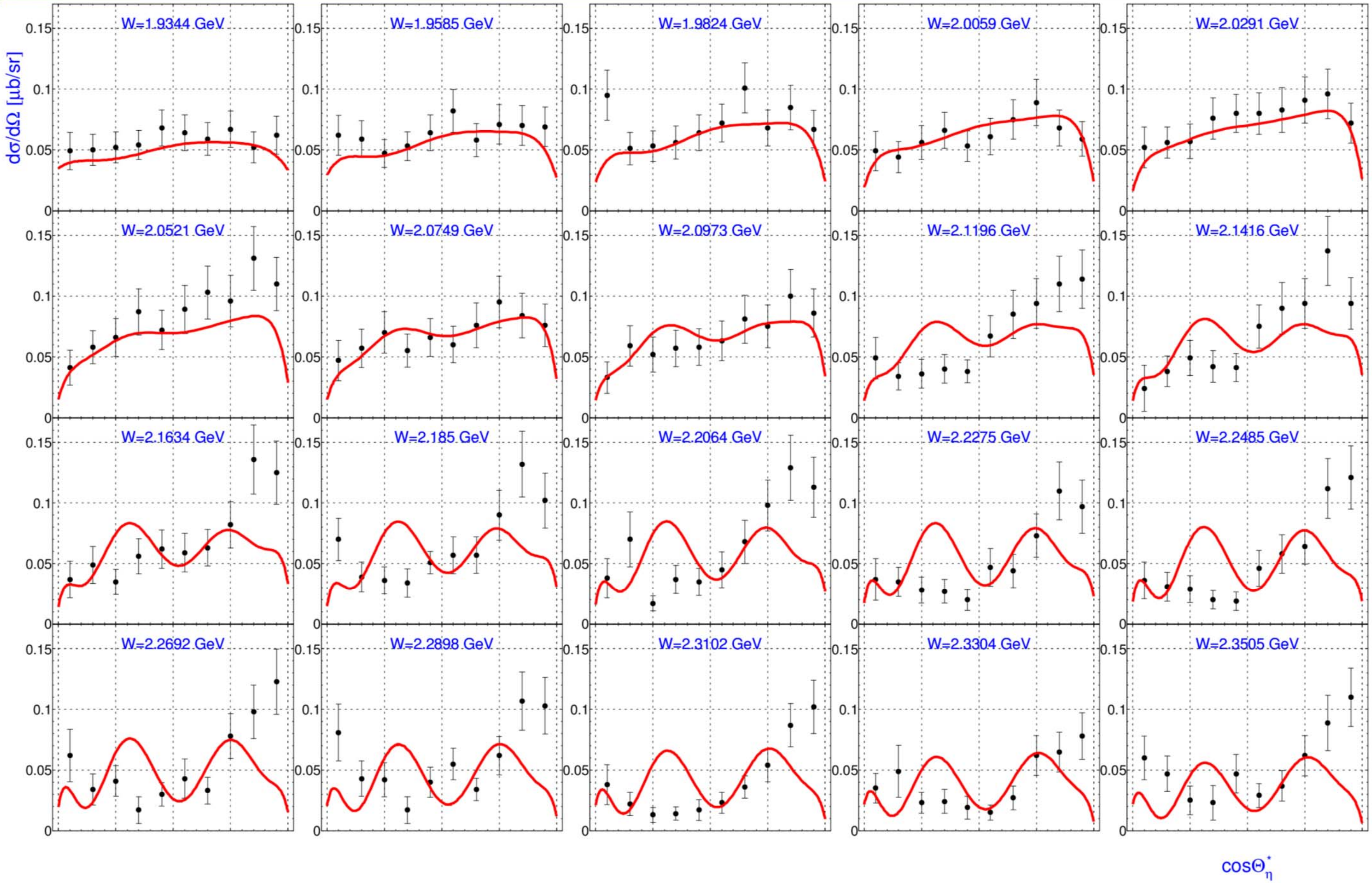
closed circles: A2MAMI-15; open circles : GRAAL-15; Red lines: ηMAID-2015d

$\gamma p \rightarrow \eta' p$ *ηMAID-2015d and CLAS-09 data*



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

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



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

Regge parametrization of *t* - channel vector meson exchange

around the η' threshold, the onset of the Regge regime
becomes visible at forward angles

for η' photoproduction one can use Regge from threshold on
in a single-channel analysis

for η photoproduction a smooth transition
from poles to Regge has to be found

we plan to describe η and η' photoproduction in a coupled-channel approach
for the vector meson exchange we want to use the method of
V. Mathieu, I. Danilkin et al, arXiv:1506.01764,
for matching low-energy analysis with high-energy Regge parametr.

Eta-MAID update 2015 with new resonances

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	Γ	Br Eta	A1/2	A3/2	PDG stars for $N\eta$
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

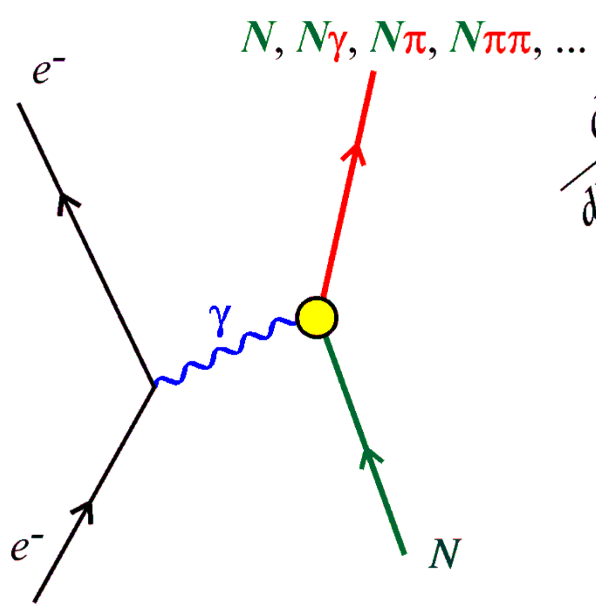
resonance parameters (above η' threshold)

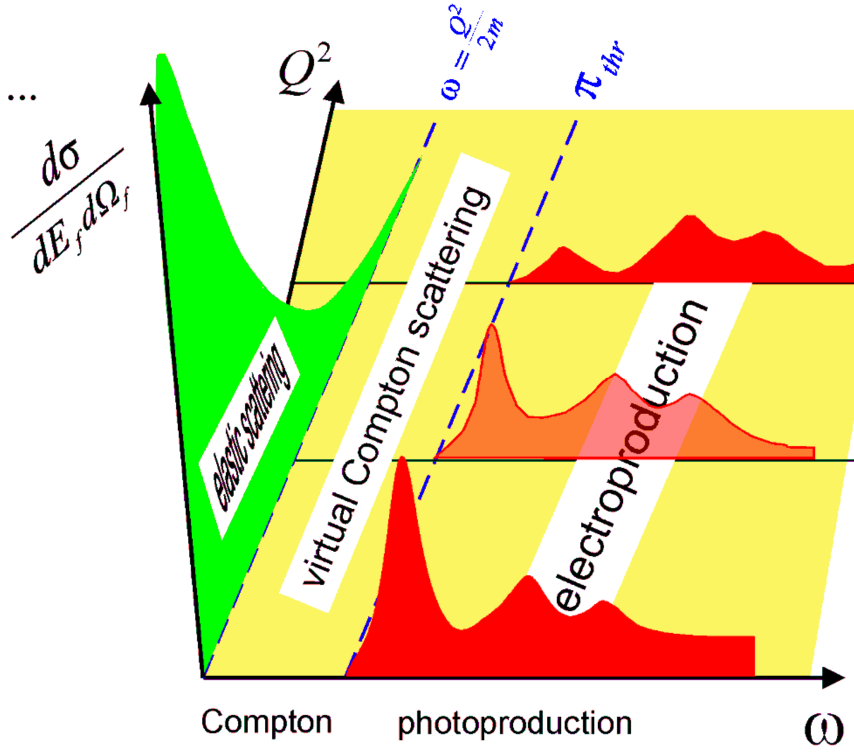
N*	M	Γ	Br Eta	Br Eta'	A1/2	A3/2	PDG stars for Nη
S11(1895)	1895.	220.	26.	5.2	-40.	---	**
P13(1900)	1915.	383.	-14.	-0.017	44.	-21.	**
F17(1990)	1894.	114.	0.046	-0.00	-19.	-93.	new
F15(2000)	2029.	244.	-0.67	0.015	-141.	60.	**
D15(2060)	2014.	454.	0.42	-0.92	-102.	8.9	*
D13(2120)	**2064.**	**305.**	**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 $\sigma_{total}(\gamma,\eta)$

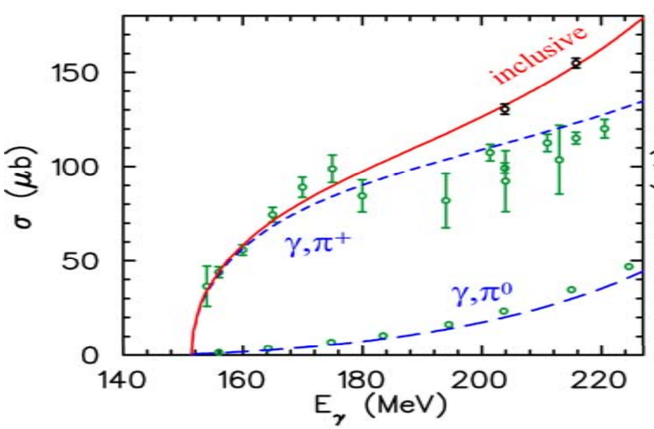
N*	M	Γ	Br Eta	A1/2	A3/2	PDG stars for Nη	
S11(1535)	1534.	161.	42.	115.	---	****	17 μb
S11(1650)	1645.	116.	-12.	45.	---	***	1 μb
S11(1895)	1895.	220.	26.	-40.	---	**	0.85 μb
P13(1720)	**1745.**	**268.**	**7.2**	**70.**	**30.**	*******	0.70 μb
D13(2120)	**2064.**	**305.**	**1.17**	**147.**	**-130.**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

from real to virtual photons

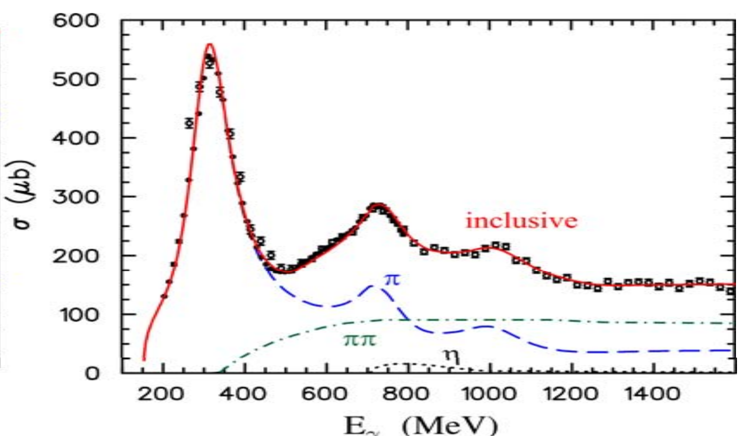




Threshold Region



Resonance Region



The MAID Ansatz for $(e, e' \pi)$

unitarized resonance amplitude

$$t_{\gamma\pi}^{R,\alpha}(W,Q^2) = \bar{\mathcal{A}}_\alpha^R(W,Q^2)\,\frac{f_{\gamma N}(W)\Gamma_{tot}(W)\,M_R\,f_{\pi N}(W)}{M_R^2 - W^2 - iM_R\Gamma_{tot}(W)}\,e^{i\phi_R(W,Q^2)}$$

phenomenological parametrization of transition form factors:

$$\bar{\mathcal{A}}_\alpha^R(W,Q^2) \approx \bar{\mathcal{A}}_\alpha(Q^2) = \bar{\mathcal{A}}_\alpha(0)(1 + a_1 Q^2 + a_2 Q^4 + a_3 Q^6 + a_4 Q^8)\,e^{-b_1 Q^2}$$

last full version of γ,π and $e,e'\pi$:	2007
last transition form factors update:	2009

review on resonances: L.T. , D. Drechsel, S. Kamalov, M. Vanderhaeghen, EPJ ST198 (2011) 141

MAID2007 was designed with minimal number of resonances

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

only 7 N* resonances

in MAID2007

MAID2007 was designed with minimal number of resonances

Particle J^P	overall	$N\gamma$	$N\pi$	$N\eta$	$N\sigma$	$N\omega$	ΛK	ΣK	$N\rho$	$\Delta\pi$
$\Delta(1232)\ 3/2^+$	****	****	****	F						
$\Delta(1600)\ 3/2^+$	***	***	***	o					*	***
$\Delta(1620)\ 1/2^-$	****	***	****		r				***	***
$\Delta(1700)\ 3/2^-$	****	****	****		b				**	***
$\Delta(1750)\ 1/2^+$	*		*		i					
$\Delta(1900)\ 1/2^-$	**	**	**			d		**	**	**
$\Delta(1905)\ 5/2^+$	****	****	****			d		***	**	**
$\Delta(1910)\ 1/2^+$	****	**	****			e		*	*	**
$\Delta(1920)\ 3/2^+$	***	**	***				n	***		**
$\Delta(1930)\ 5/2^-$	***		***							
$\Delta(1940)\ 3/2^-$	**	**	*	F						
$\Delta(1950)\ 7/2^+$	****	****	****	o				***	*	***
$\Delta(2000)\ 5/2^+$	**				r					**
$\Delta(2150)\ 1/2^-$	*		*		b					
$\Delta(2200)\ 7/2^-$	*		*		i					
$\Delta(2300)\ 9/2^+$	**		**			d				
$\Delta(2350)\ 5/2^-$	*		*			d				
$\Delta(2390)\ 7/2^+$	*		*			e				
$\Delta(2400)\ 9/2^-$	**		**				n			
$\Delta(2420)\ 11/2^+$	****	*	****							
$\Delta(2750)\ 13/2^-$	**		**							
$\Delta(2950)\ 15/2^+$	**		**							

only $6\ \Delta$ resonances

in MAID2007

empirical parametrizations

the magnetic NΔ form factors has a very simple form

$$G_M^*(Q^2) = 3\,G_D(Q^2)e^{-0.21Q^2/\mathrm{GeV}^2}$$

Q^2_{max}

10 GeV²

for all other resonances we use the general form:

$$\bar{\mathcal{A}}_\alpha(Q^2) = \bar{\mathcal{A}}_\alpha(0)(1 + a_1 Q^2 + a_2 Q^4 + a_3 Q^6 + a_4 Q^8)\, e^{-b_1 Q^2}$$

numerical examples for a few resonances:

(complete results for protons and neutrons are found in our Review EPJ ST **198** (2011) 141)

N^*, Δ^*		$\bar{\mathcal{A}}_\alpha(0)$	a_1	a_2	a_4	b_1	
$P_{11}(1440)p$	$A_{1/2}$	−61.4	0.871	−3.516	−0.158	1.36	5 GeV²
	$S_{1/2}$	4.2	40.	0	1.50	1.75	5
$D_{13}(1520)p$	$A_{1/2}$	−27.4	8.580	−0.252	0.357	1.20	5
	$A_{3/2}$	160.6	−0.820	0.541	−0.016	1.06	5
	$S_{1/2}$	−63.5	4.19	0	0	3.40	5
$S_{11}(1535)p$	$A_{1/2}$	66.4	1.608	0	0	0.70	5
	$S_{1/2}$	−2.0	23.9	0	0	0.81	5
$D_{15}(1675)p$	$A_{1/2}$	15.3	0.10	0	0	2.00	??
	$A_{3/2}$	21.6	1.91	0.18	0	0.69	4
	$S_{1/2}$	1.1	0	0	0	2.00	??
$F_{15}(1680)p$	$A_{1/2}$	−25.1	3.780	−0.292	0.080	1.25	4
	$A_{3/2}$	134.3	1.016	0.222	0.237	2.41	4
	$S_{1/2}$	−44.0	3.783	0	0	1.85	4

empirical parametrizations for large Q^2

the Maid parametrization with Gaussian forms for large Q^2

is convenient and leads to fewer terms

However, it violates pQCD, which predicts:

$A_{1/2}(Q^2) \sim 1/Q^3$

$A_{3/2}(Q^2) \sim 1/Q^5$

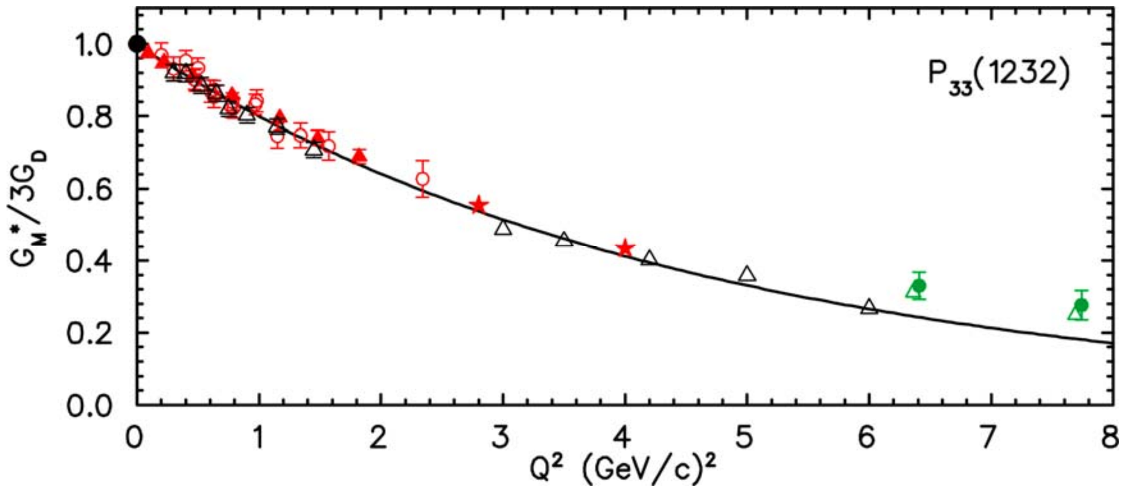
$S_{1/2}(Q^2) \sim 1/Q^3$

improved ansatz:

$$A_{1/2}, S_{1/2} \sim \frac{k(Q^2,M^*)}{k(0,M^*)} \frac{G_{dip}(Q^2)}{\sqrt{1+\frac{Q^2}{(M\pm M^*)^2}}} \frac{P_n(Q^2)}{Q_n(Q^2)} \xrightarrow{Q\to\infty} \frac{1}{Q^3}$$

$$A_{3/2} \sim \frac{k(Q^2,M^*)}{k(0,M^*)} \frac{G_{dip}(Q^2)}{\sqrt{1+\frac{Q^2}{(M\pm M^*)^2}}} \frac{P_{n-1}(Q^2)}{Q_n(Q^2)} \xrightarrow{Q\to\infty} \frac{1}{Q^5}$$

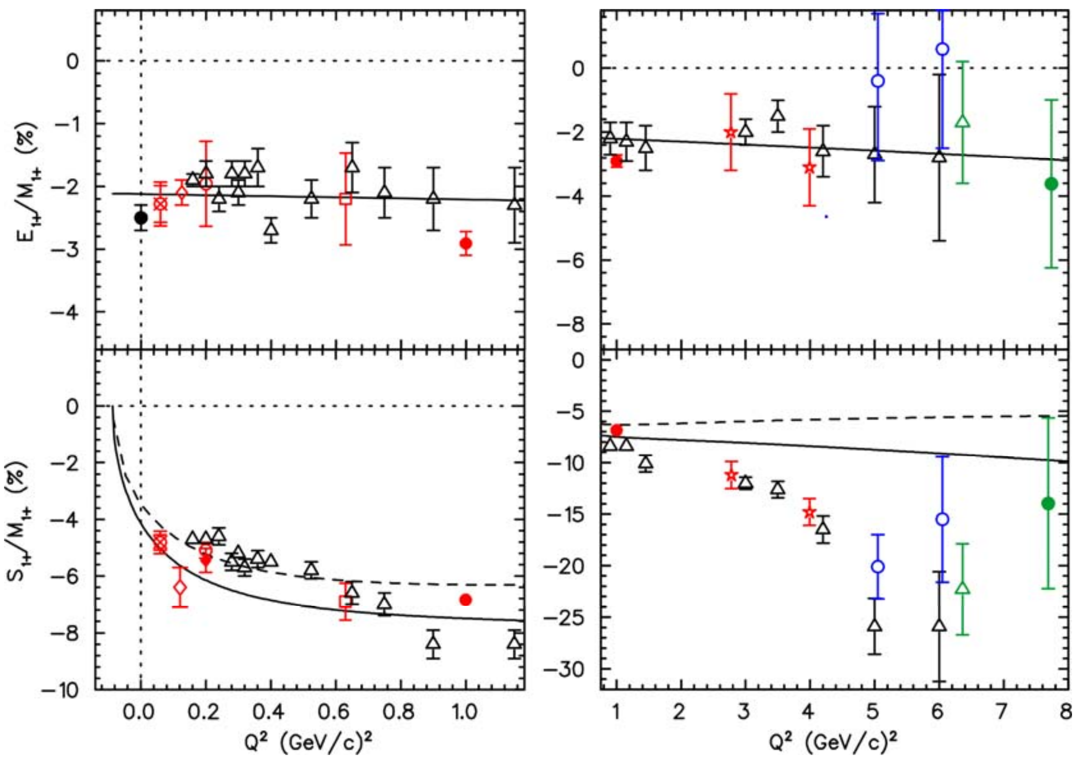
N –> Δ(1232) transition form factors



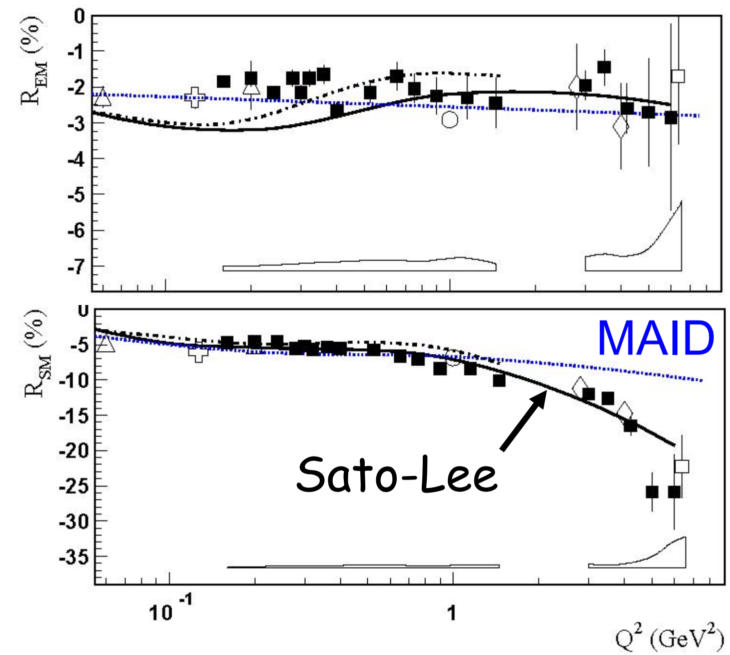
MAID analysis

JLab analysis

MAID analysis revisited
for narrow energy range ~ 1232 MeV

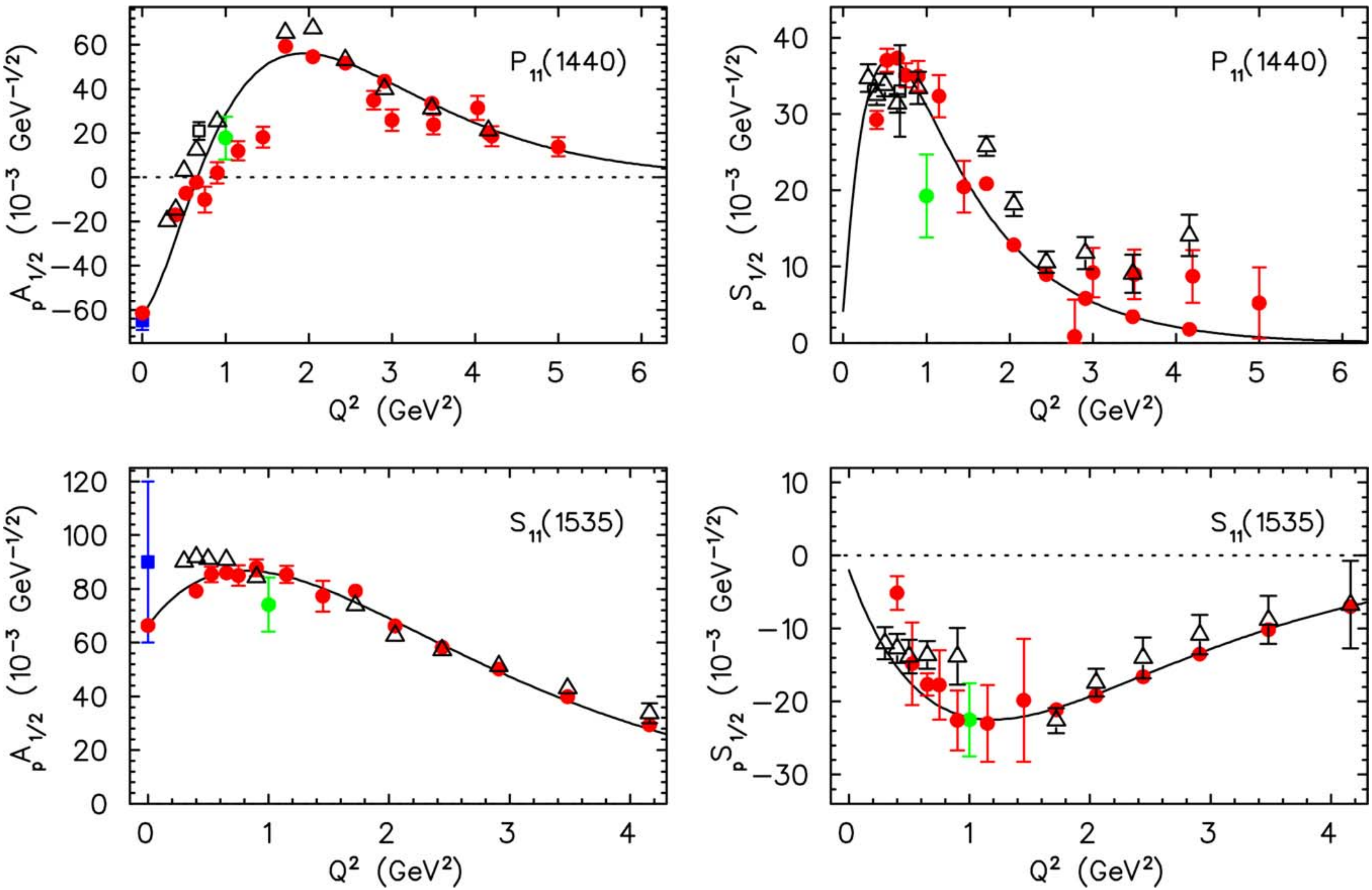


one of few cases with disagreement
between Mainz and JLab analysis

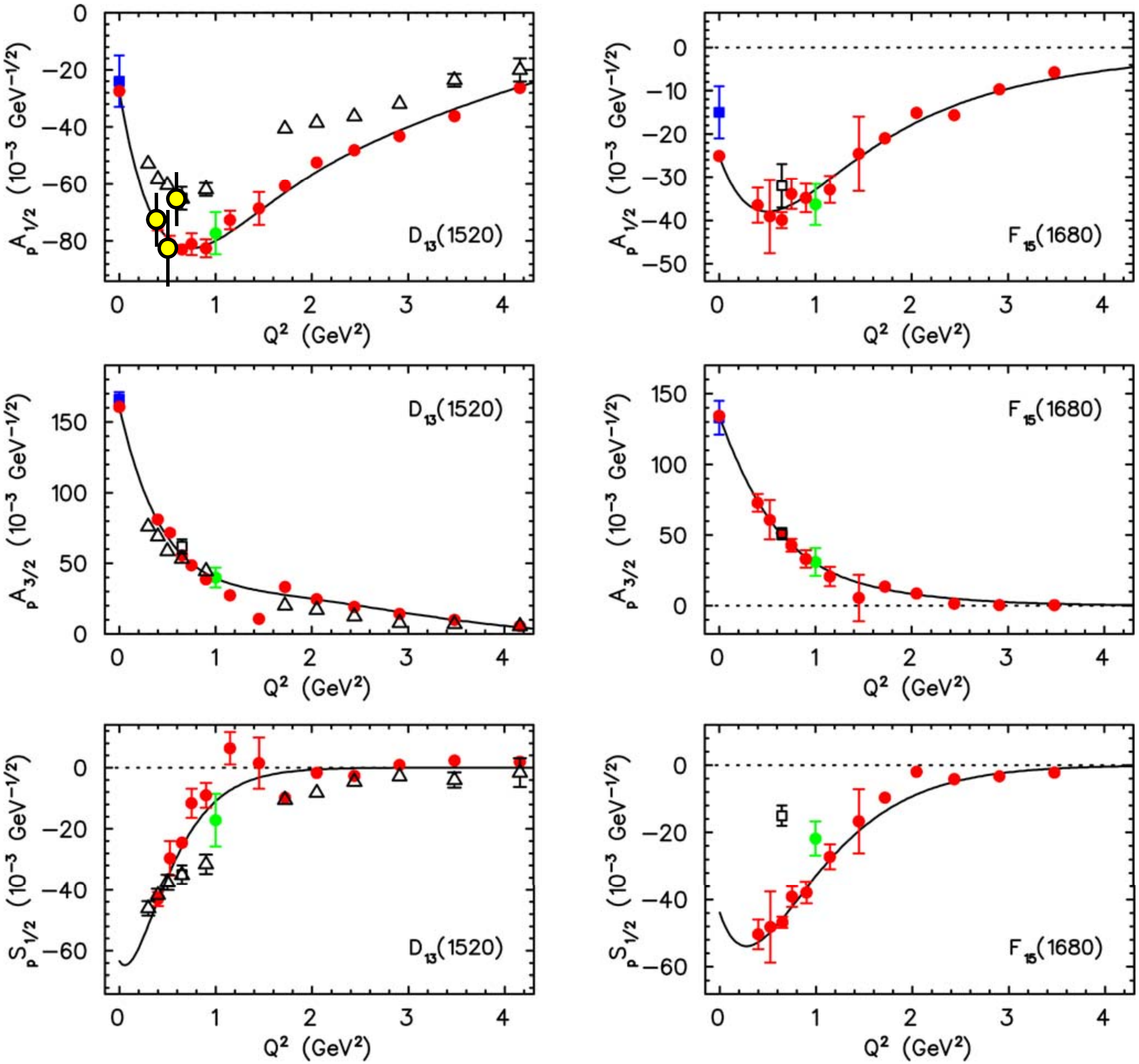


N –> N(1440)1/2$^+$ and N –> N(1535)1/2$^-$ excitation

from MAID and JLab analyses



transition FFs for N –> N(1520)3/2⁻ and N –> N(1680)5/2⁺ excitation



data :

practically all underlying cross sections that went into the fits are from CLAS

analysis :

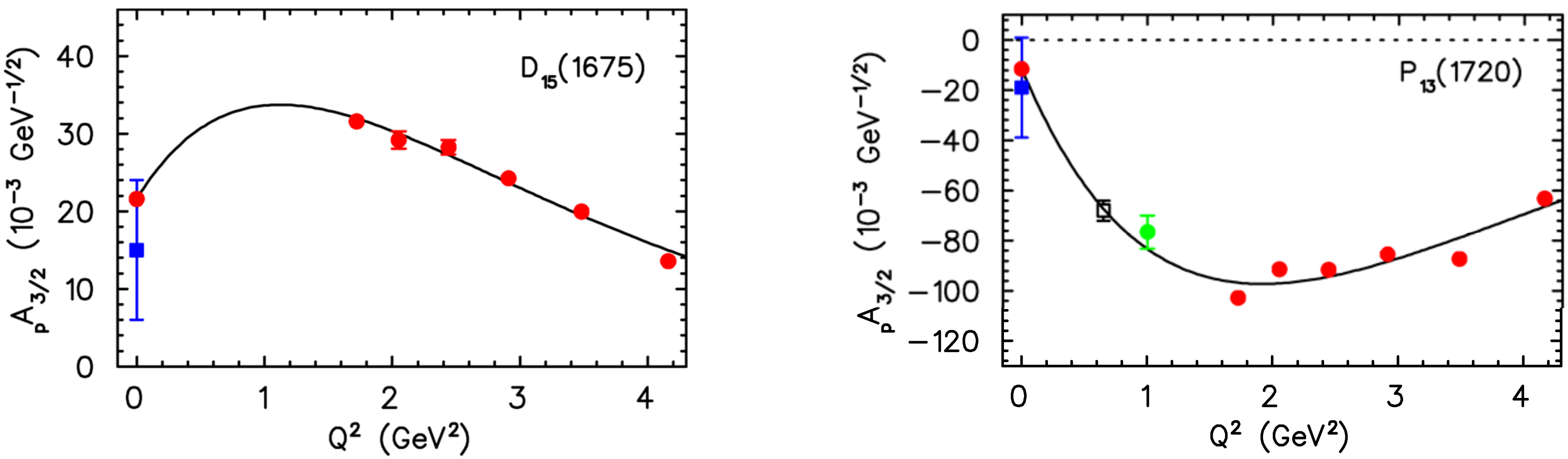
MAID

MAID

JLab

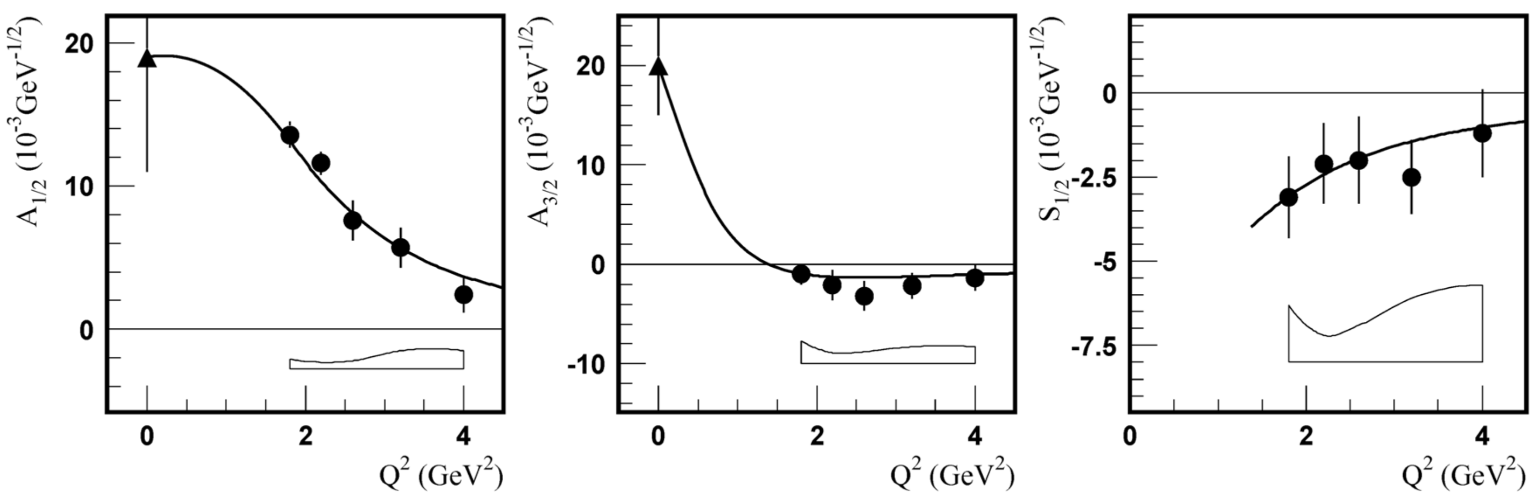
JLab ππ

N –> N(1675)5/2⁻ and N –> N(1720)3/2⁺ excitations



corresponding A1/2 and S1/2 ff were found to be small, consistent with zero

JLab analysis (V. Burkert et al.), new in PDG2015: here e.g. N(1675)5/2⁻ D_{15}

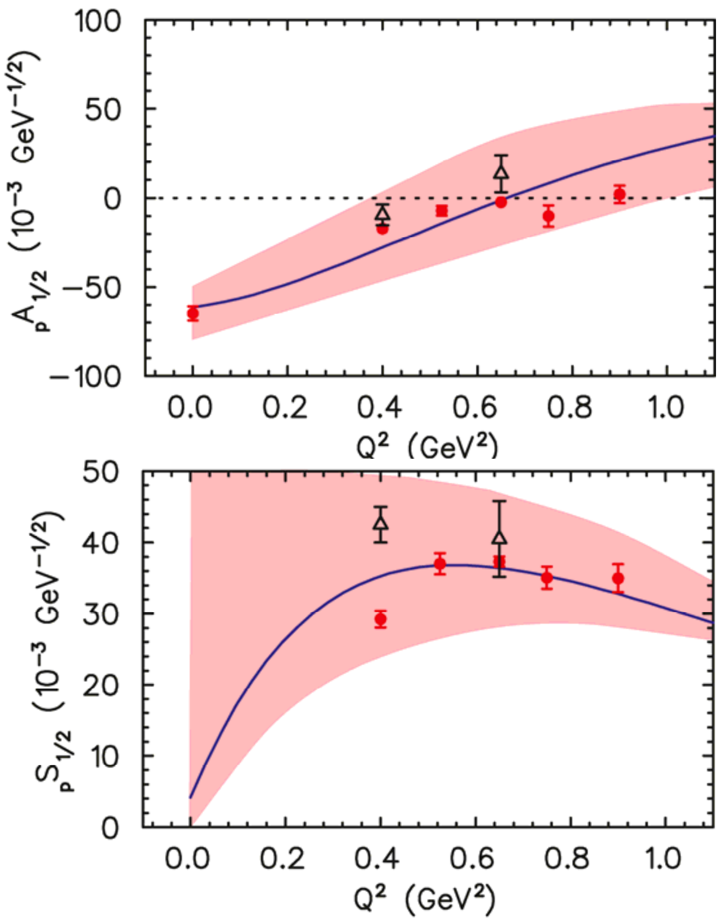


Form factor constraints at low Q^2

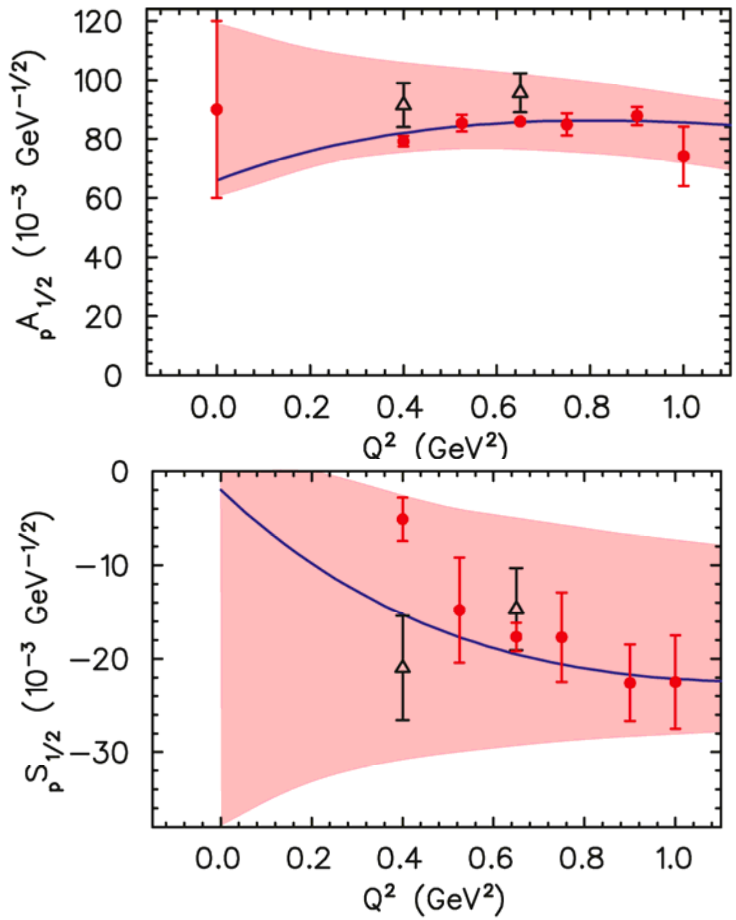
transverse form factors are constrained by photoproduction

longitudinal form factors are un-constrained ???

N –> N(1440)1/2$^+$



N –> N(1535)1/2$^-$



pink error bands are not to be quoted, artistic view

Long-Wavelength Limit (Siegert Theorem, $k_R \to 0$)

In the physical region the 3-momentum of the virtual photon at $W=M_R$ is always finite (positive)

However, the transition form factors can be extrapolated into the unphysical region down to the pseudo-threshold, where $k_R = 0$

The pseudo-threshold is defined by

$$Q^2_{pt} = -(W_R - M)^2$$

for $\Delta(1232)$: $-0.087\ \mathrm{GeV}^2$, for N(1440): $-0.25\ \mathrm{GeV}^2$, for N(1520): $-0.34\ \mathrm{GeV}^2$

In the LWL longitudinal and electric multipoles are no longer independent:

$$S_{\ell+} = \frac{k}{\omega} L_{\ell+} \quad \to \quad \frac{k}{\omega} E_{\ell+} \quad (l \geq 0)$$

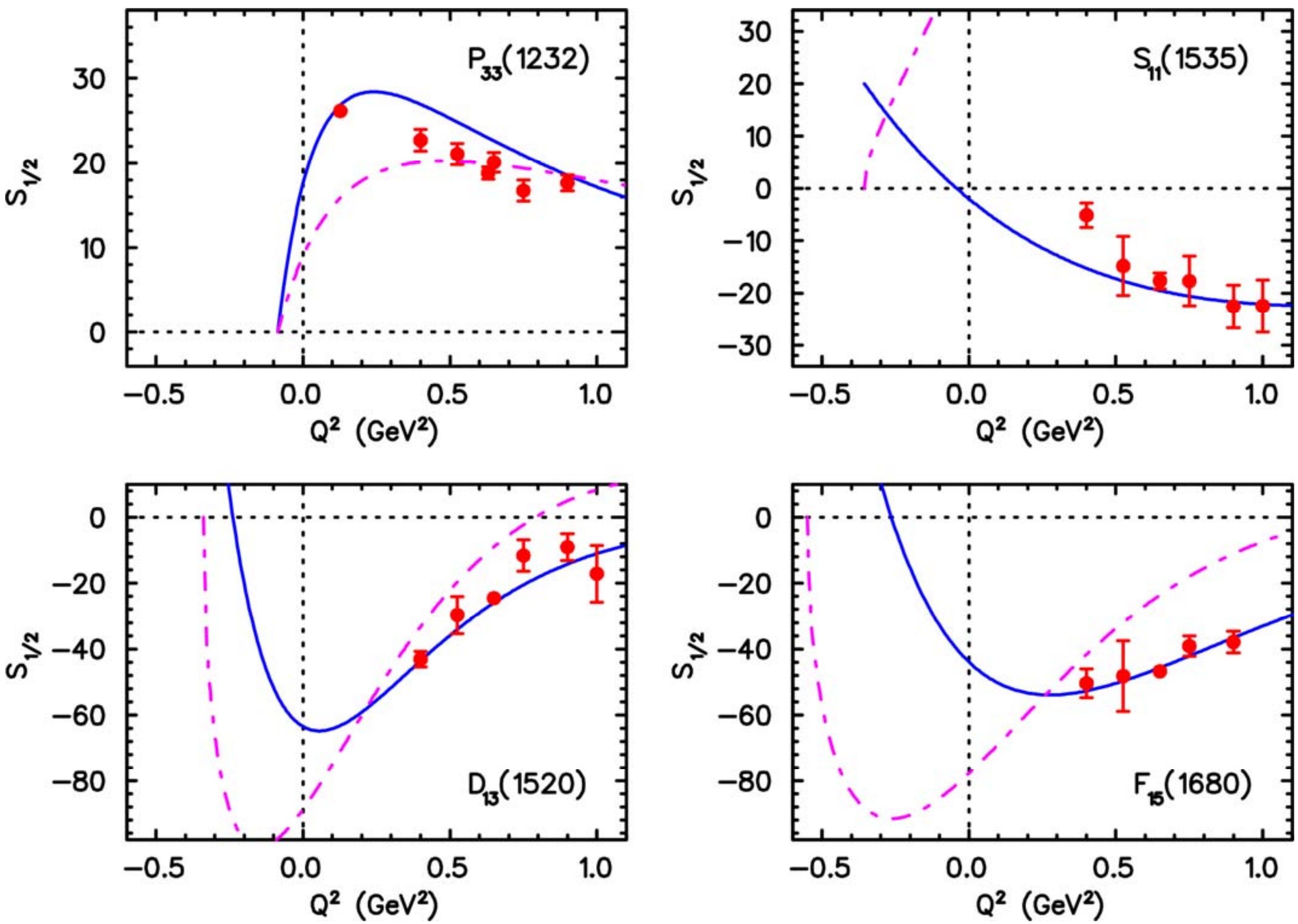
$$S_{\ell-} = \frac{k}{\omega} L_{\ell-} \quad \to \quad -\frac{\ell-1}{\ell}\frac{k}{\omega} E_{\ell-} \quad (l \geq 2)$$

but there is no such restriction for the Roper S_{1-}

transition form factors at low Q^2

empirical fits MAID2007

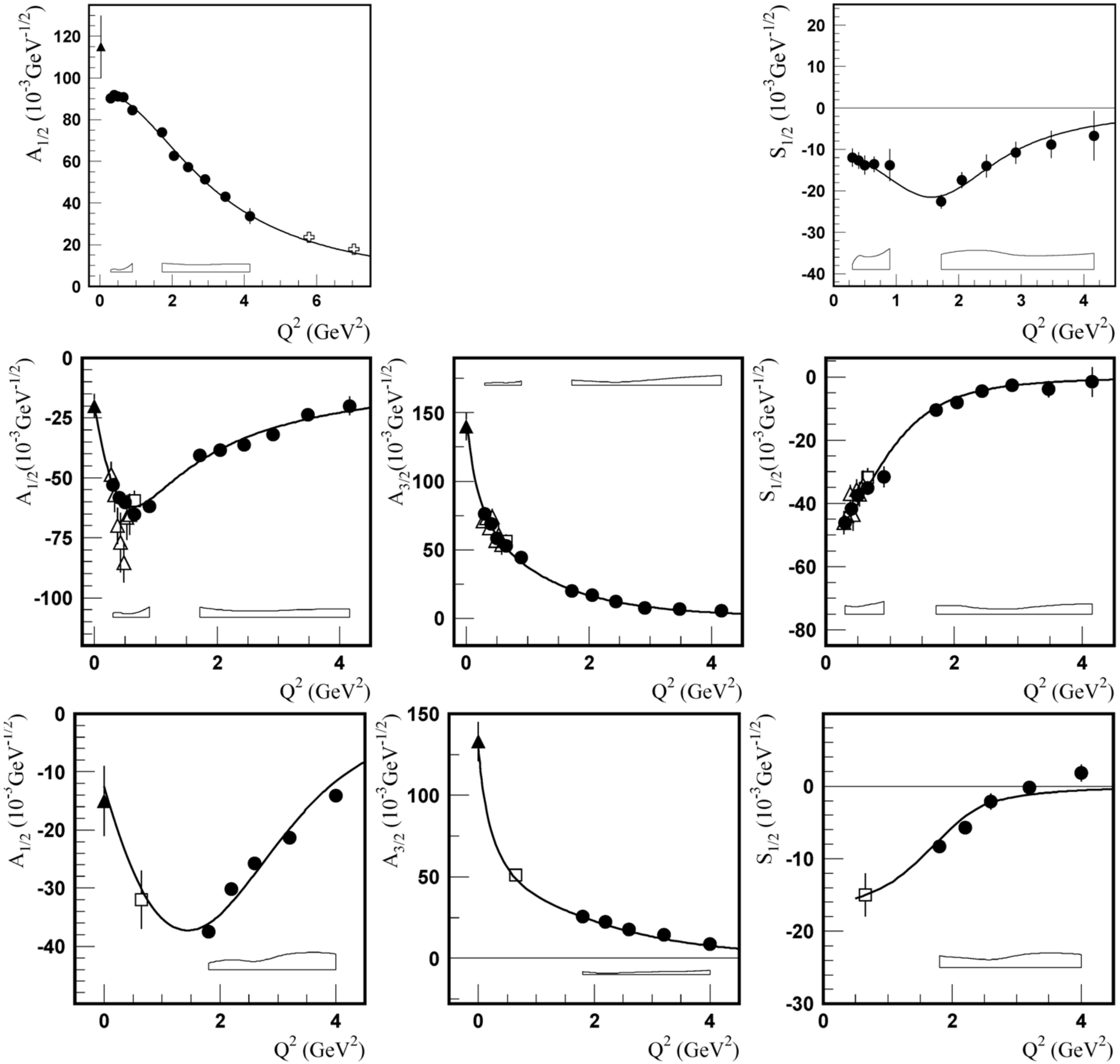
Siegert Theorem (long-wavelength limit)



problem with S11

violation of LWL ?

JLab analysis of transition form factors in PDG 2014



N(1535)1/2⁻ S11

$S_{1/2}(Q^2) < 0$

N(1520)3/2⁻ D13

$S_{1/2}(Q^2) < 0$

N(1680)5/2⁺ F15

$S_{1/2}(Q^2) < 0$

Outlook

work in progress

V. Kashevarov, L.T.

EtaMAID (γ,η and γ,η') with Regge and without
and search for η and η' couplings in all N resonances

Mainz-Tuzla-Zagreb Collaboration

model-independent single-energy PWA with fixed-t analyticity for γ,η

A. Svarc, R. Workman, L.T.

transition form factors at the pole for MAID and SAID solutions
with L+P expansion method in Q^2 region: $0 < Q^2 < 5\ \mathrm{GeV}^2$

work planned for 2016

V. Kashevarov, L.T.

MAID ($e,e'\pi$) update with 2- and 3-star N and Δ resonances