Exciting Baryons with MAMI

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A2 Collaboration

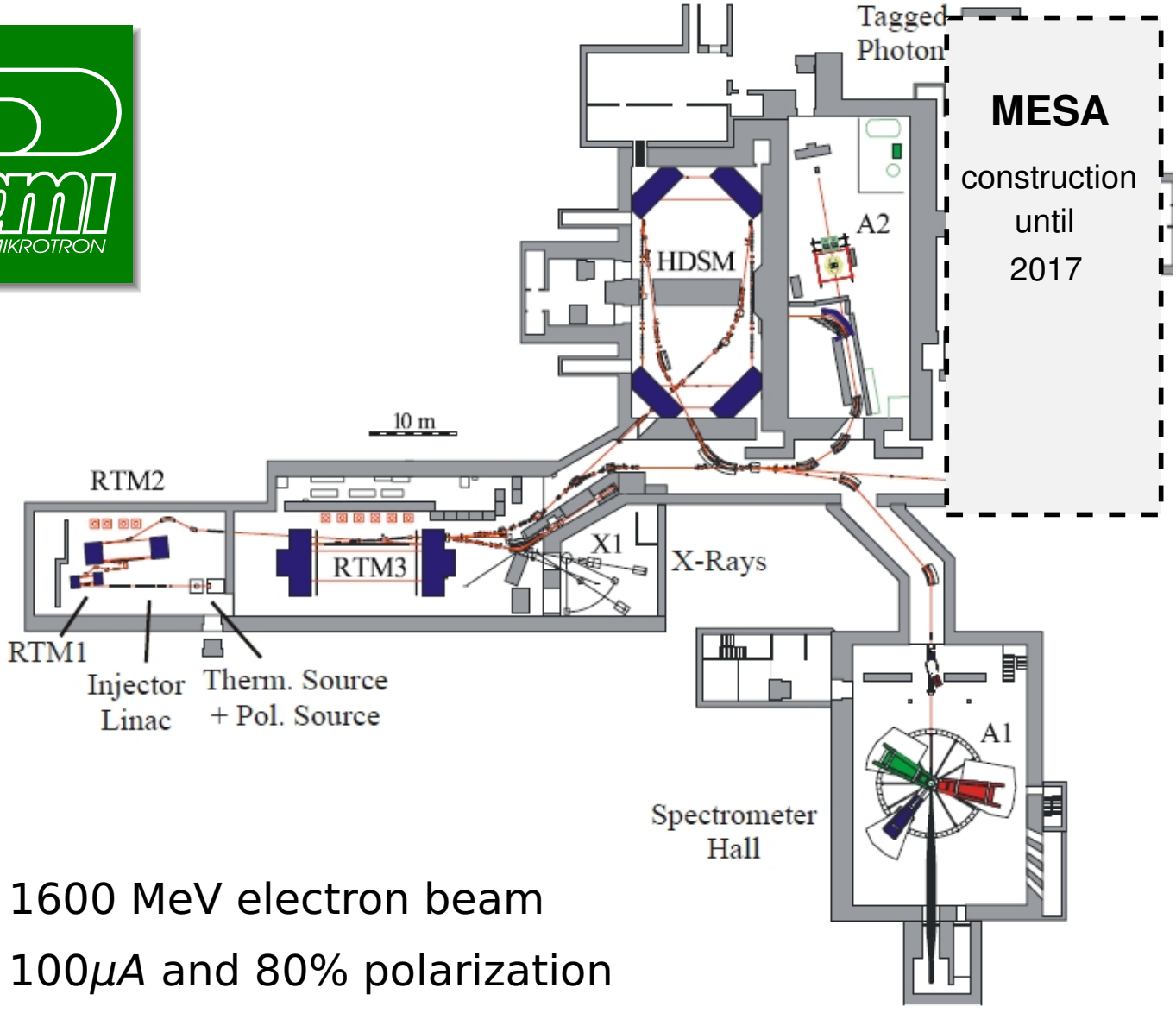
SFB 1044 THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Outline

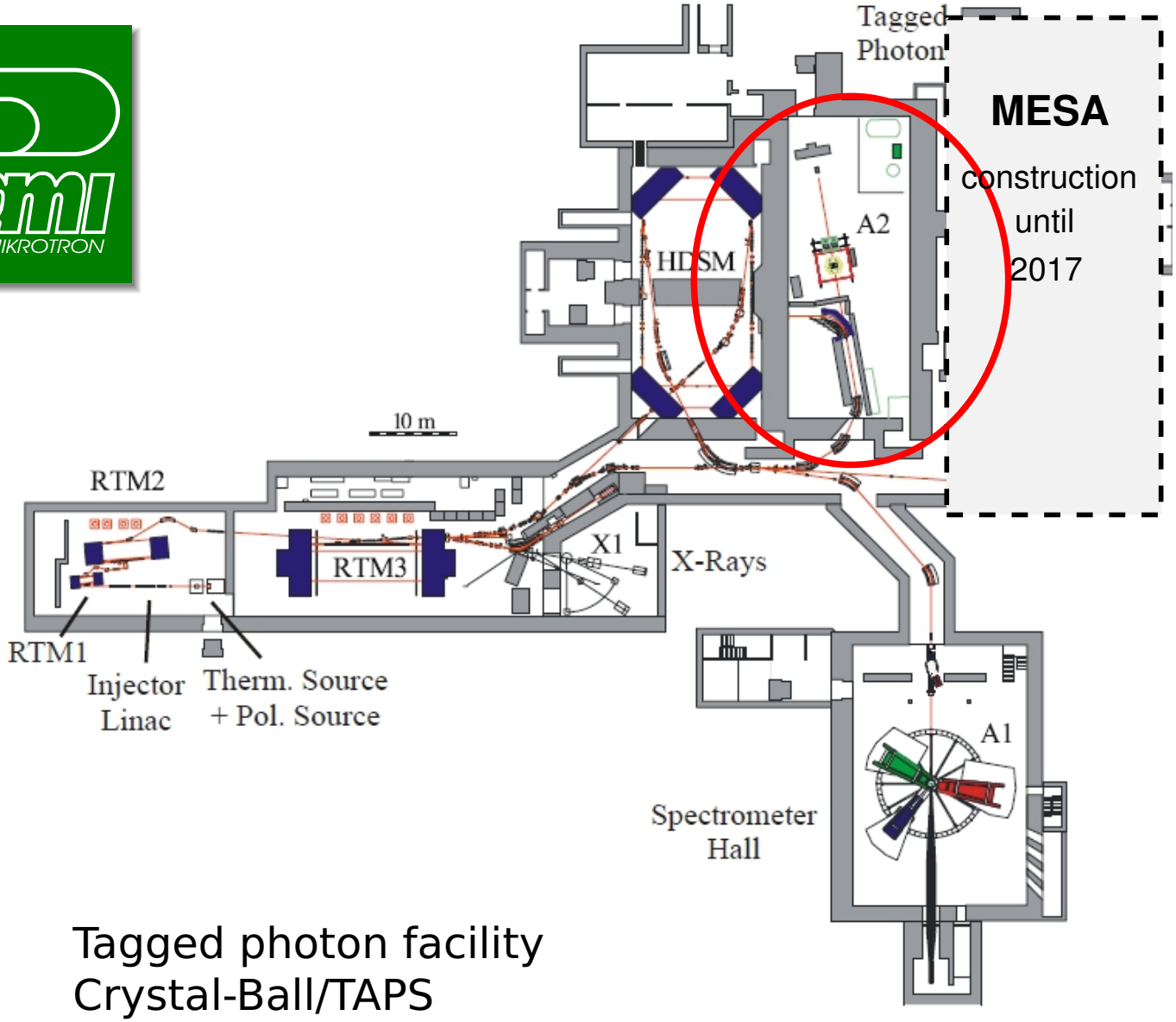
- Instrumentation and Motivation
- Recent Results:
  - $\gamma N \to \pi N$
  - $\gamma p \to \eta p$
  - $\gamma p \to \eta' p$
- Summary and Outlook

The Mainz Microtron MAMI



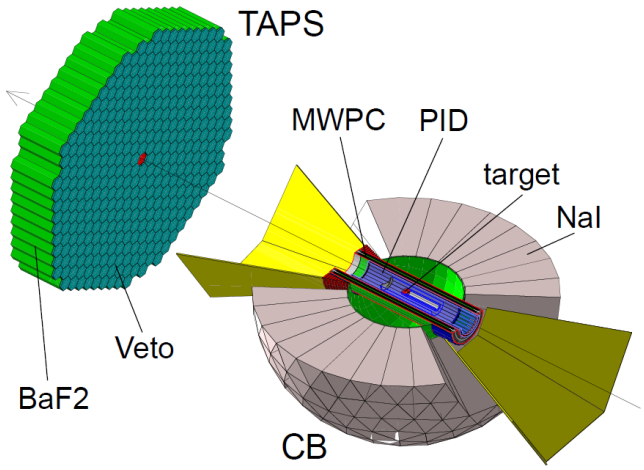
- 180 - 1600 MeV electron beam
- up to 100μA and 80% polarization
- δE ~ 100 KeV

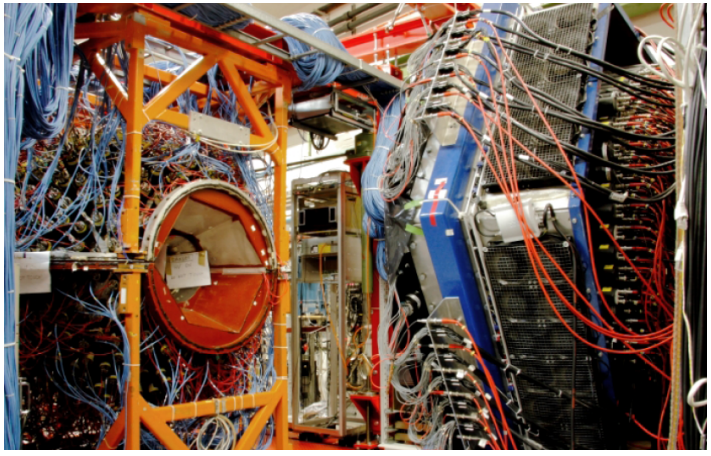
A2-Experiment at MAMI



Tagged photon facility
Crystal-Ball/TAPS

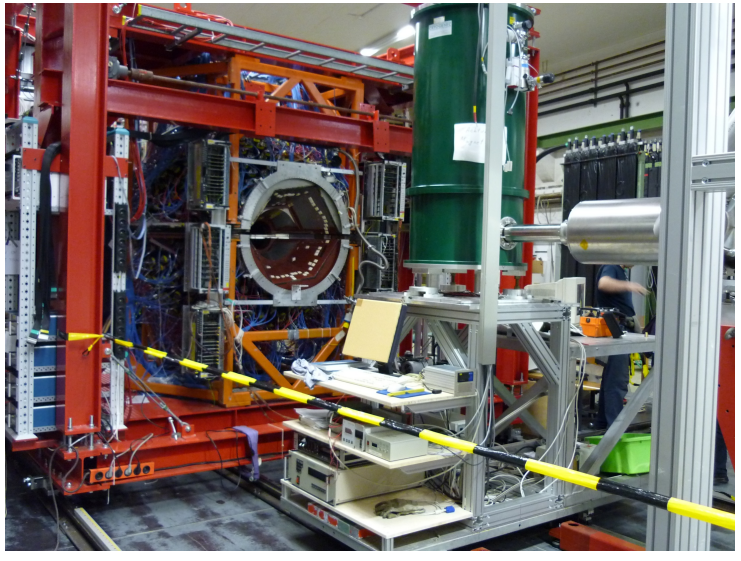
The Crystal Ball at MAMI





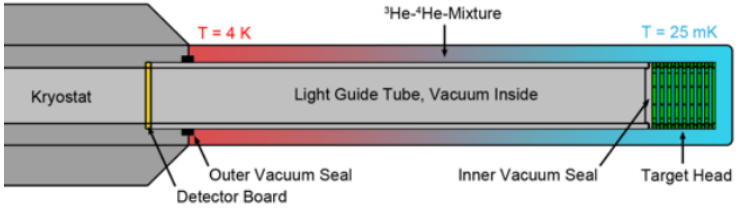
- Crystal Ball:
  672 NaI, $20^o < \theta < 160^o$
- TAPS:
  366 BaF_2 + 72 $PbWO_4$,
  $2^o < \theta < 20^o$
- PID: via $\Delta E - E$,
  plastic scintillator barrel
- charged particle tracking:
  MWPC, no B-field
- Trigger:
  energy deposit in CB,
  clusters of energy deposit

Polarized targets for Crystal Ball at MAMI



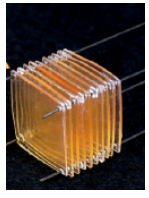
- Frozen spin technique
- Material: buthanol (>80%), D-buthanol(>70%)
- T = 20mK; 2000h relaxation time
- holding coils for transverse and longitudinal spin orientation

New 2015: active polarized target

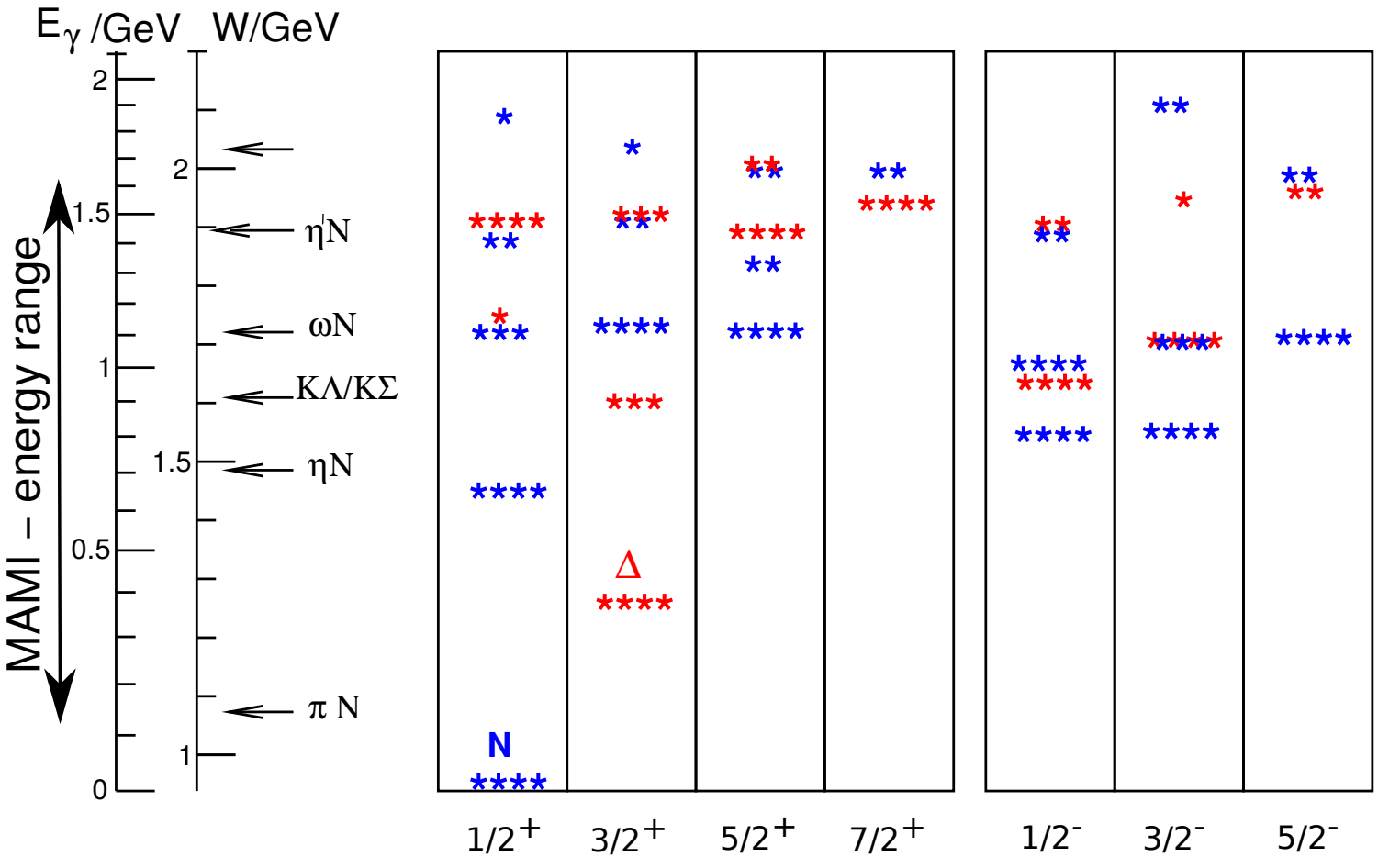


polarizable scintillator

70% polarization
@ 200mK and 2.5 T



Exciting Baryons with MAMI



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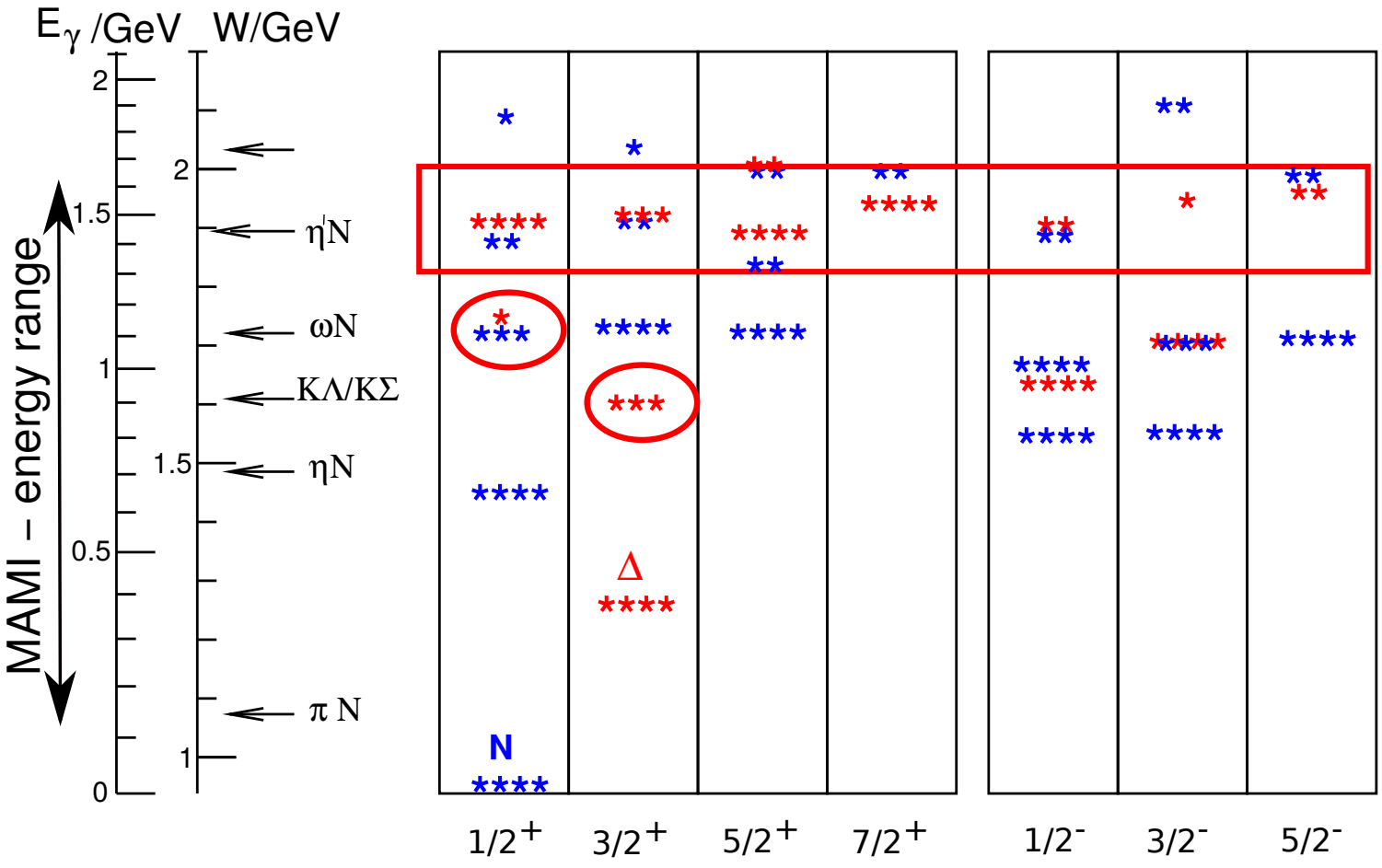
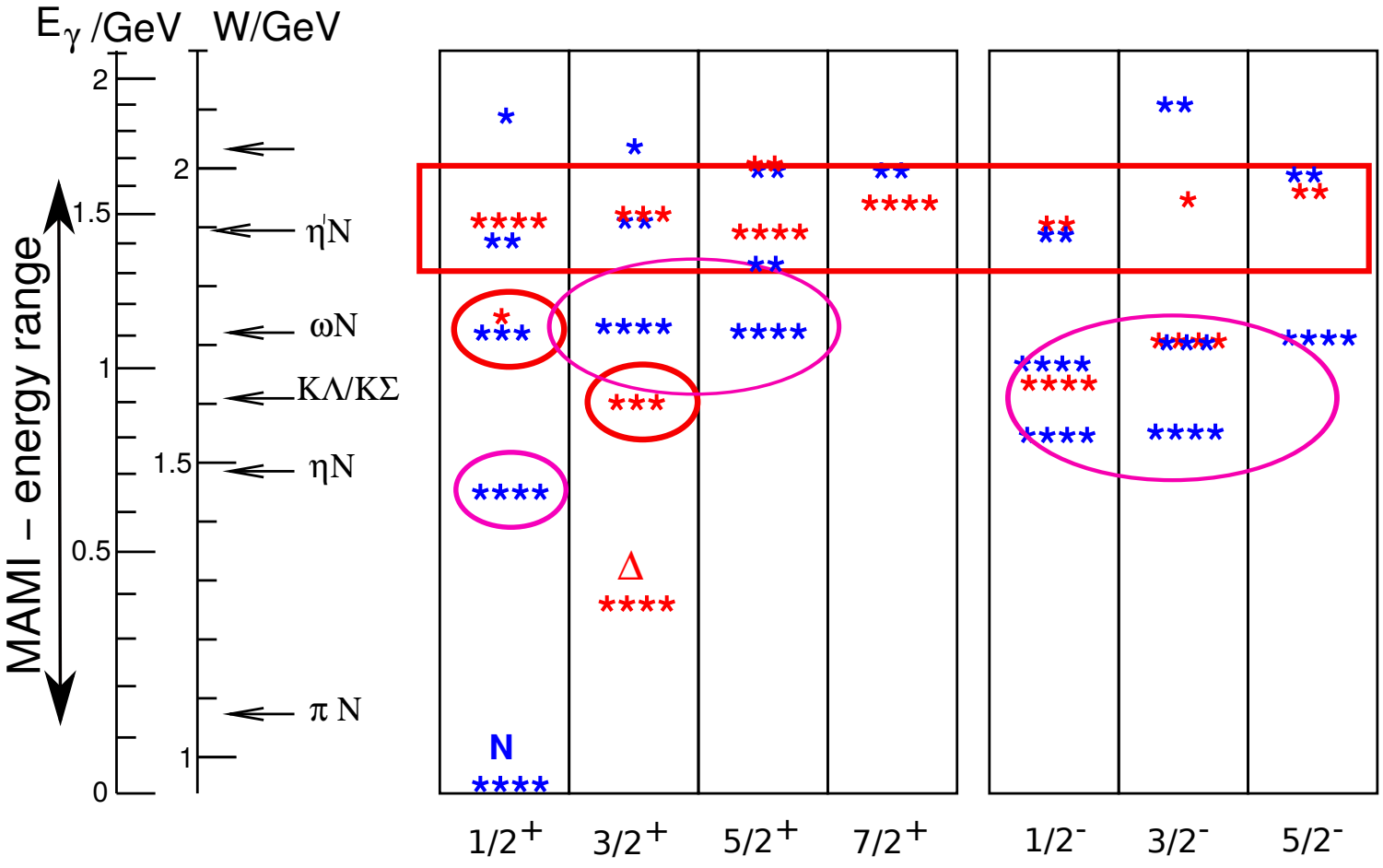


- Several states below 2 GeV need confirmation

Exciting Baryons with MAMI



- Several states below 2 GeV need confirmation
- Pole positions and couplings need to be constrained

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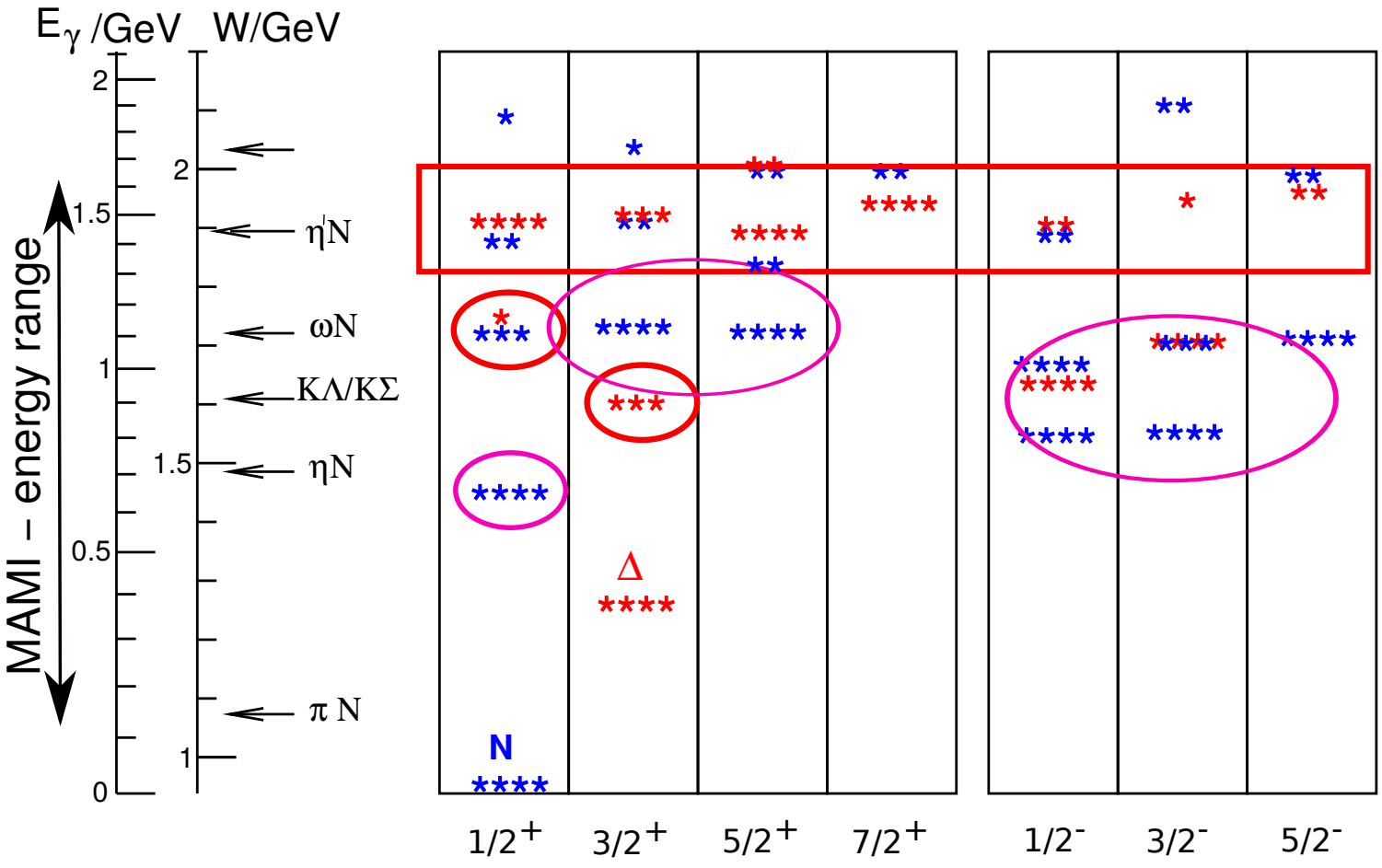


- Several states below 2 GeV need confirmation
- Pole positions and couplings need to be constrained
- Background, thresholds and coupled channel dynamics

Spin Observables in pseudo-scalar meson photoproduction

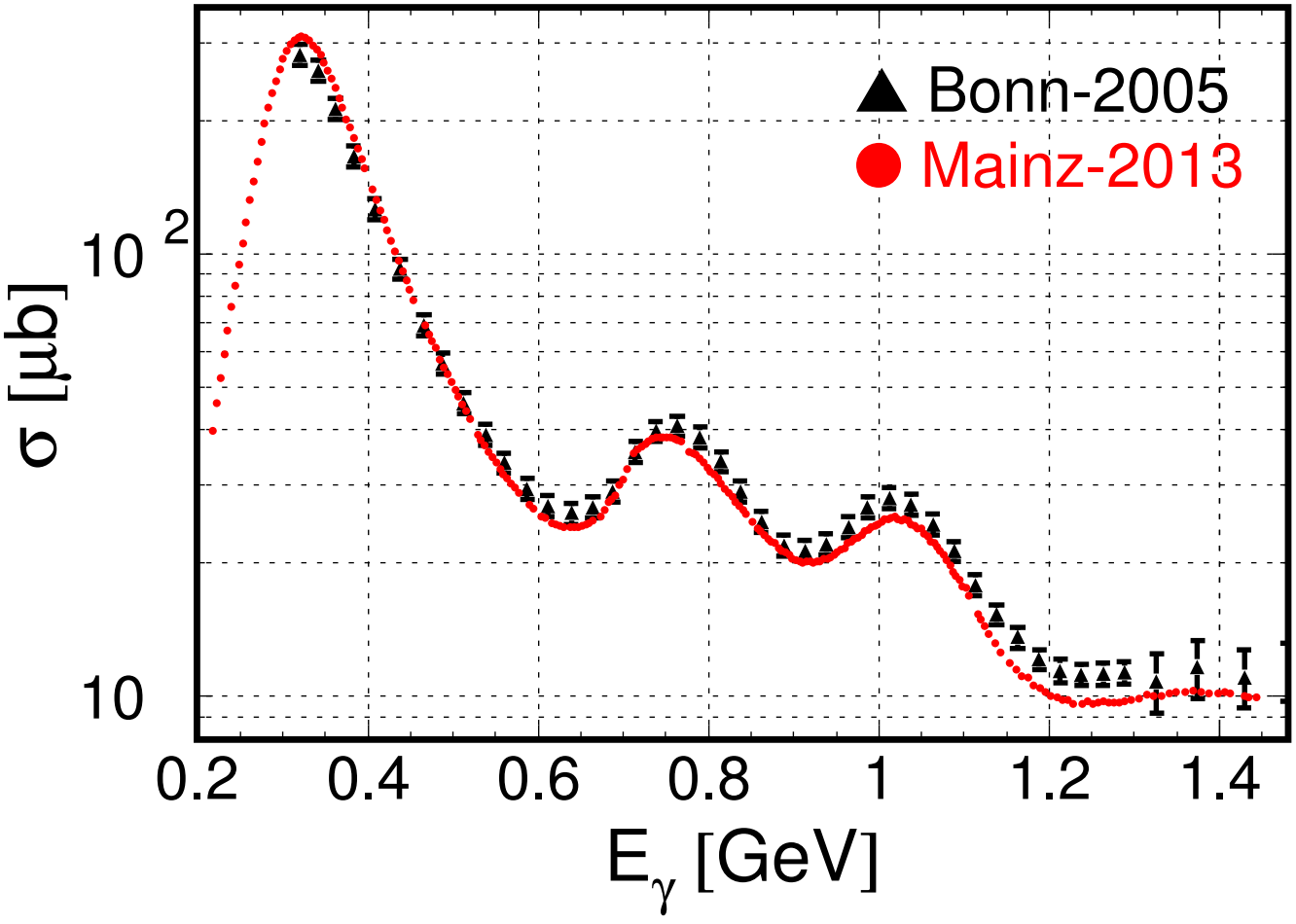
With polarized beam and target

beam polarization		target polarization		
		x	y	z
unpolarized	σ_0	-	T	-
linear	Σ	H	-P	G
circular	-	F	-	E

$$\frac{d\sigma}{d\Omega} = \sigma_0 \Big[1 - P_\gamma^{lin}\Sigma\cos 2\phi + P_T^x(P_\gamma^\odot F - P_\gamma^{lin} H \sin 2\phi) + P_T^y(T - P_\gamma^{lin} P\cos 2\phi) + P_T^z(P_\gamma^{lin} G \sin 2\phi - P_\gamma^\odot E)\Big]$$

→ Farah Afzal's talk (Parallel-A)

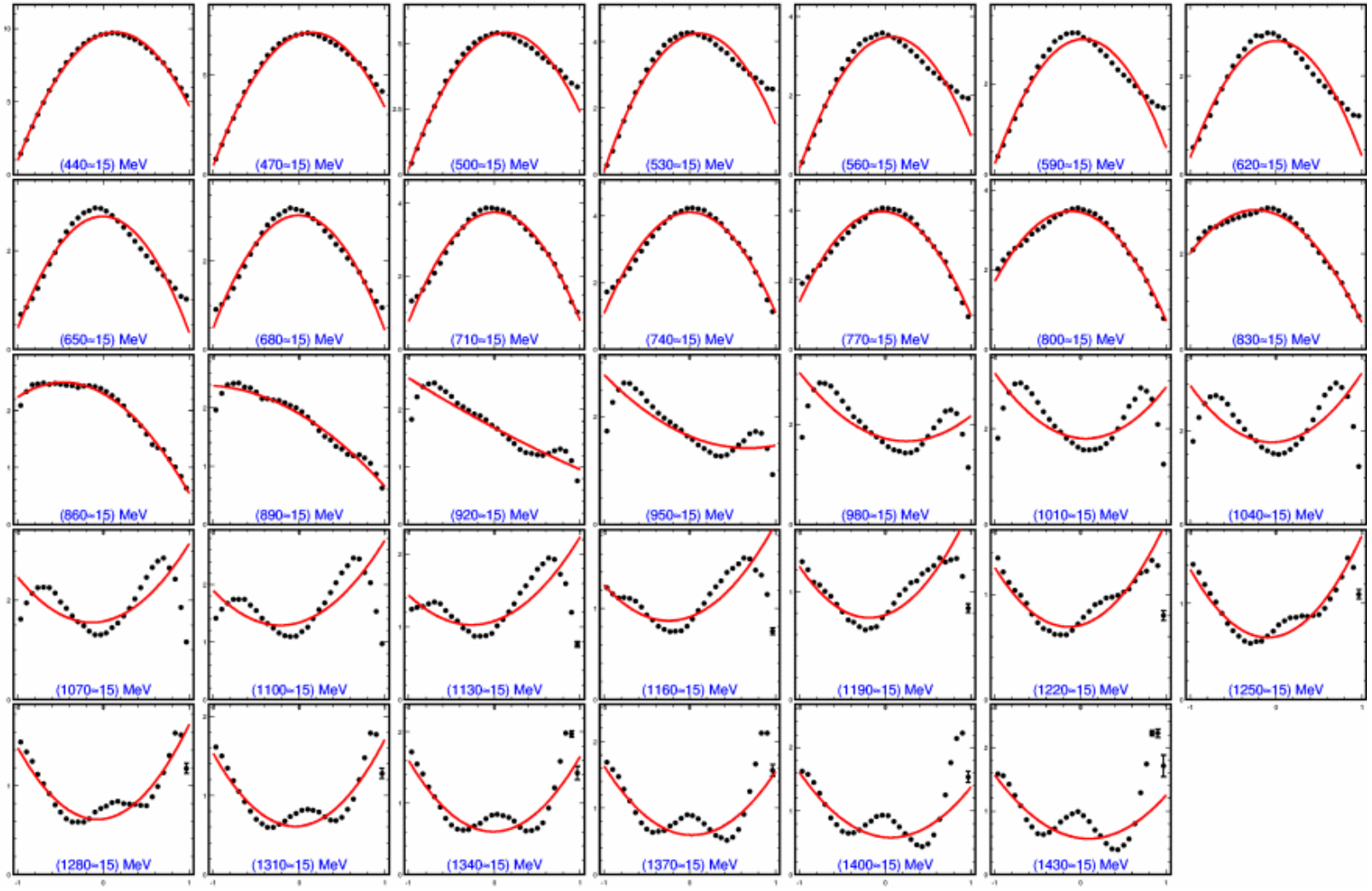
$\gamma p \rightarrow \pi^0 p$ - cross section



30 angular bins for each 4 MeV energy bin

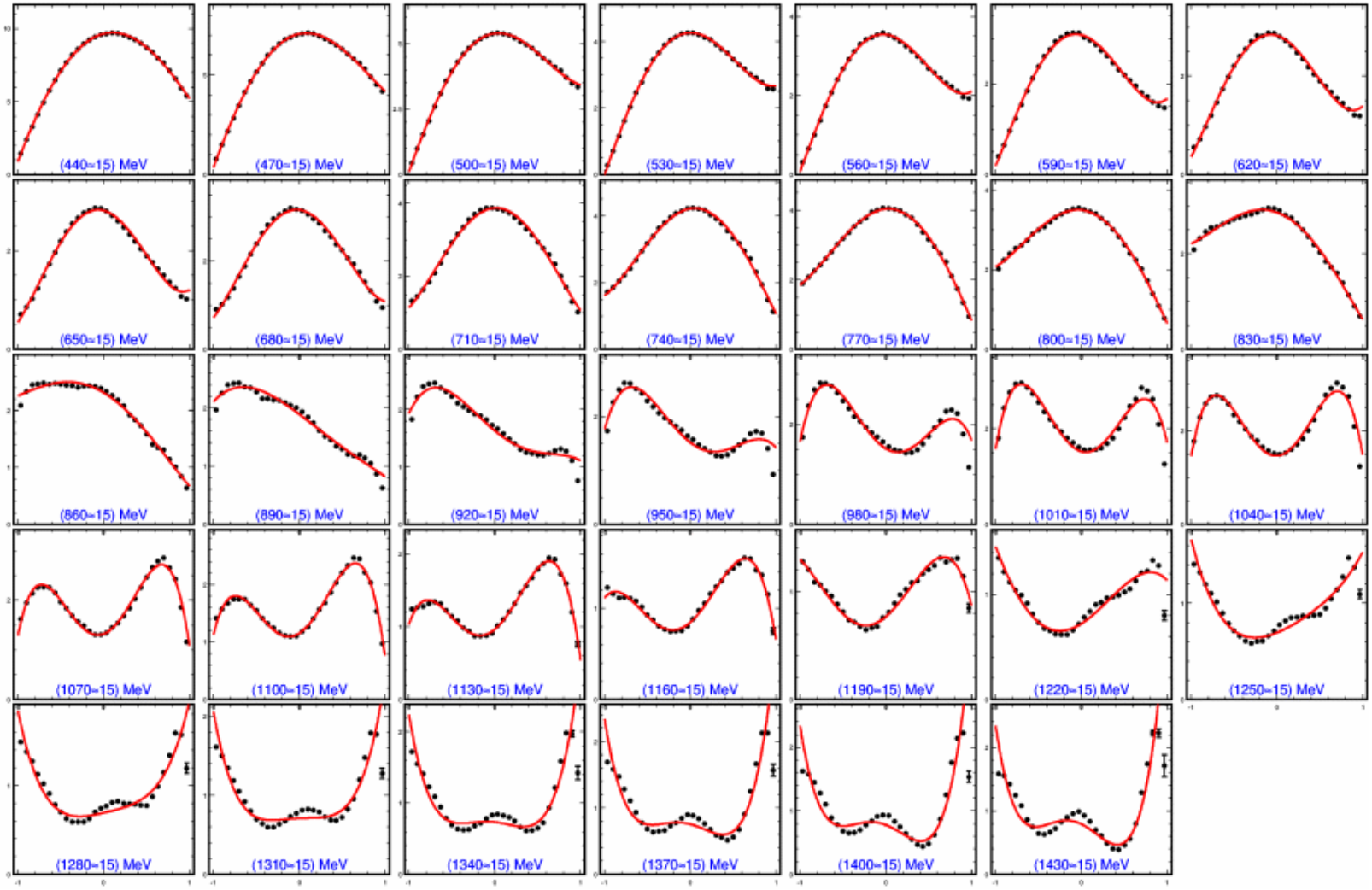
$\gamma p \to \pi^0 p$ - cross section

$$\frac{d\sigma}{d\Omega} = \sum_{k=0}^{2\ell_{max}} A_\sigma^k(W) P_k(\cos\theta); \quad \ell_{max} = 1$$



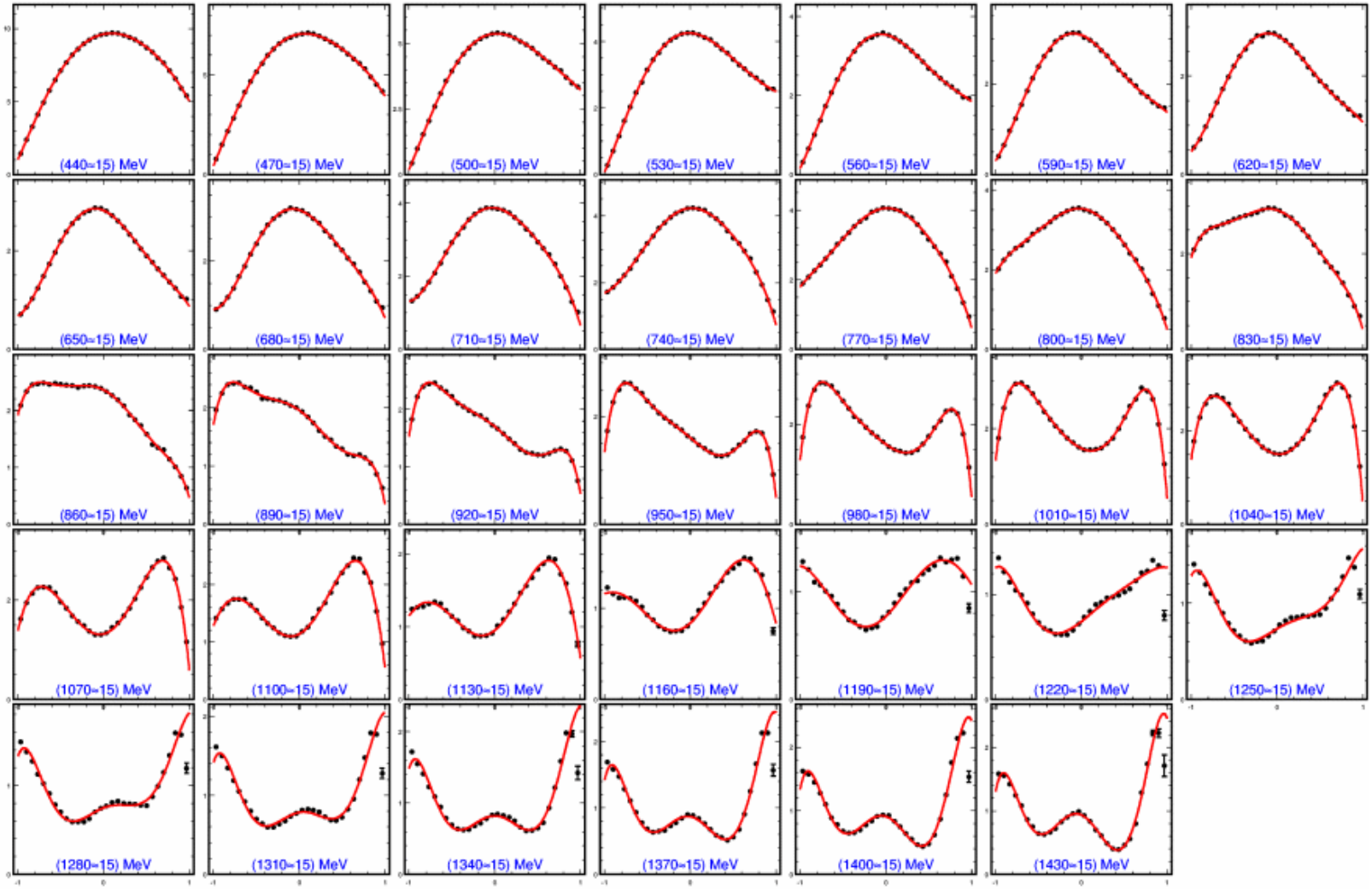
$\gamma p \to \pi^0 p$ - cross section

$$\frac{d\sigma}{d\Omega} = \sum_{k=0}^{2\ell_{max}} A_\sigma^k(W) P_k(\cos\theta); \quad \ell_{max} = 2$$



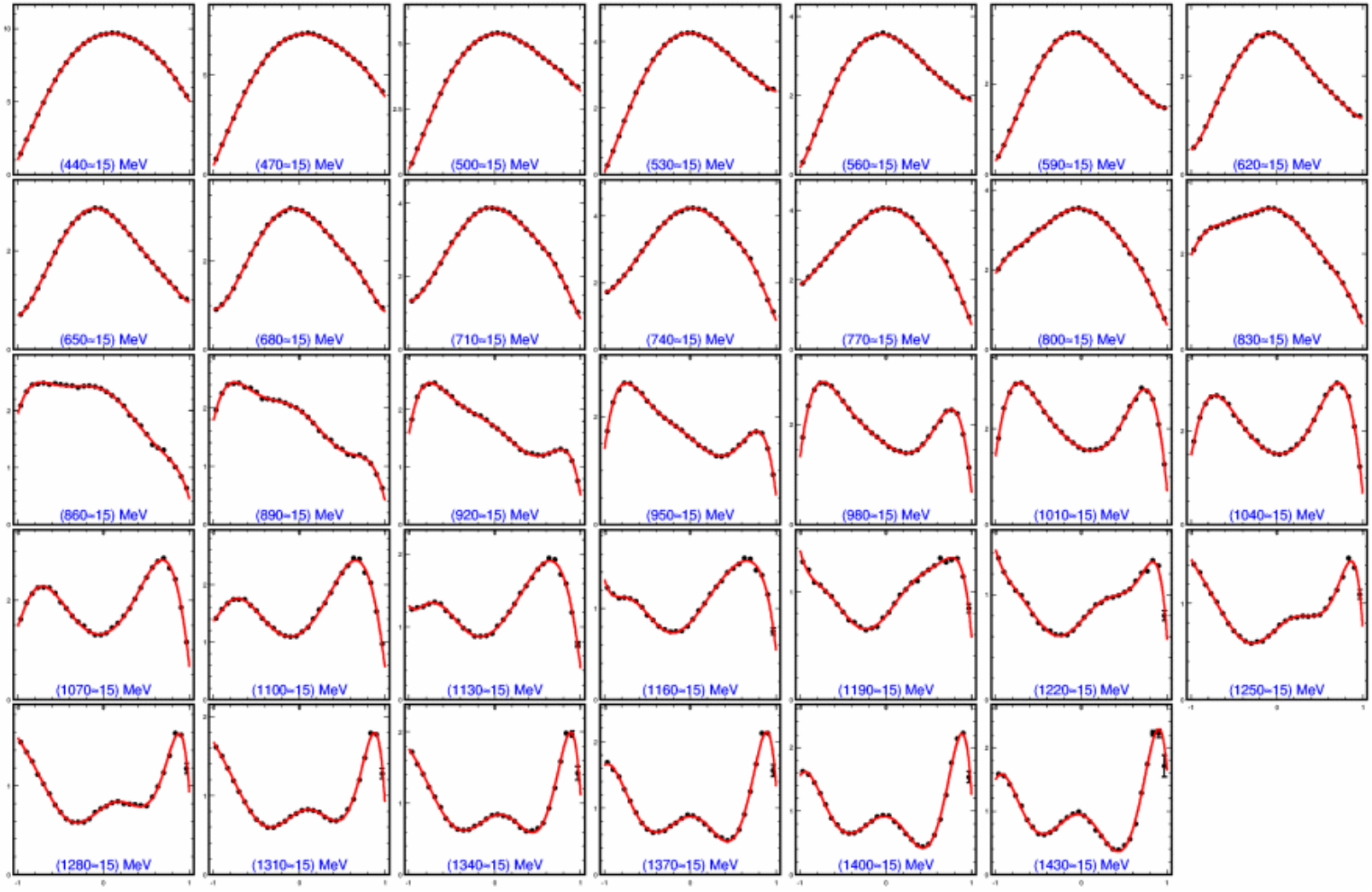
$\gamma p \to \pi^0 p$ - cross section

$$\frac{d\sigma}{d\Omega} = \sum_{k=0}^{2\ell_{max}} A_\sigma^k(W) P_k(\cos\theta); \quad \ell_{max} = 3$$



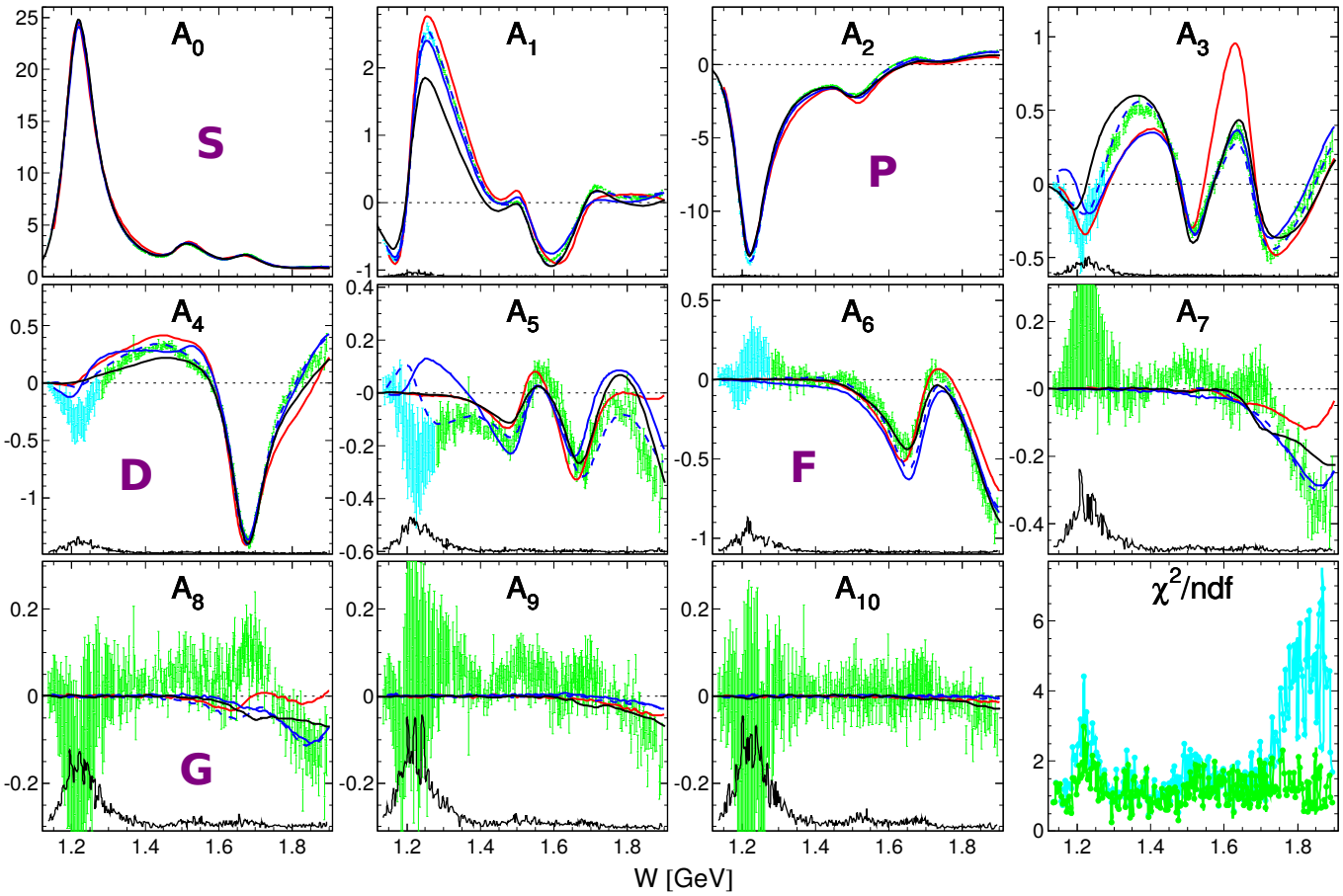
$\gamma p \rightarrow \pi^0 p$ - cross section

$$\frac{d\sigma}{d\Omega} = \sum_{k=0}^{2\ell_{max}} A_\sigma^k(W) P_k(\cos\theta); \quad \ell_{max} = 4$$



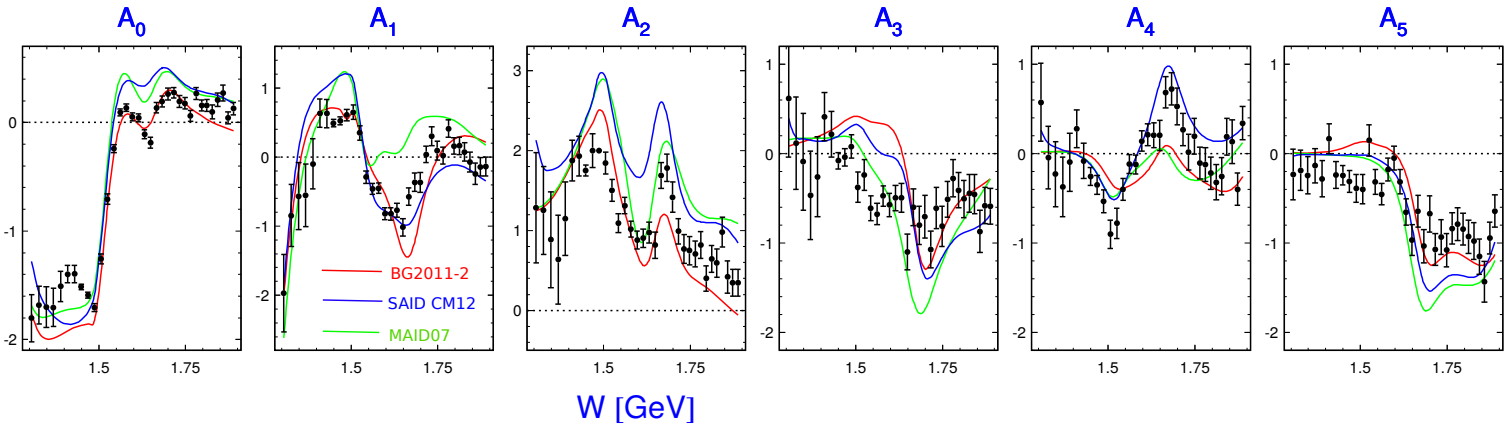
$\gamma p \to \pi^0 p$ - cross section

Legendre coefficients:

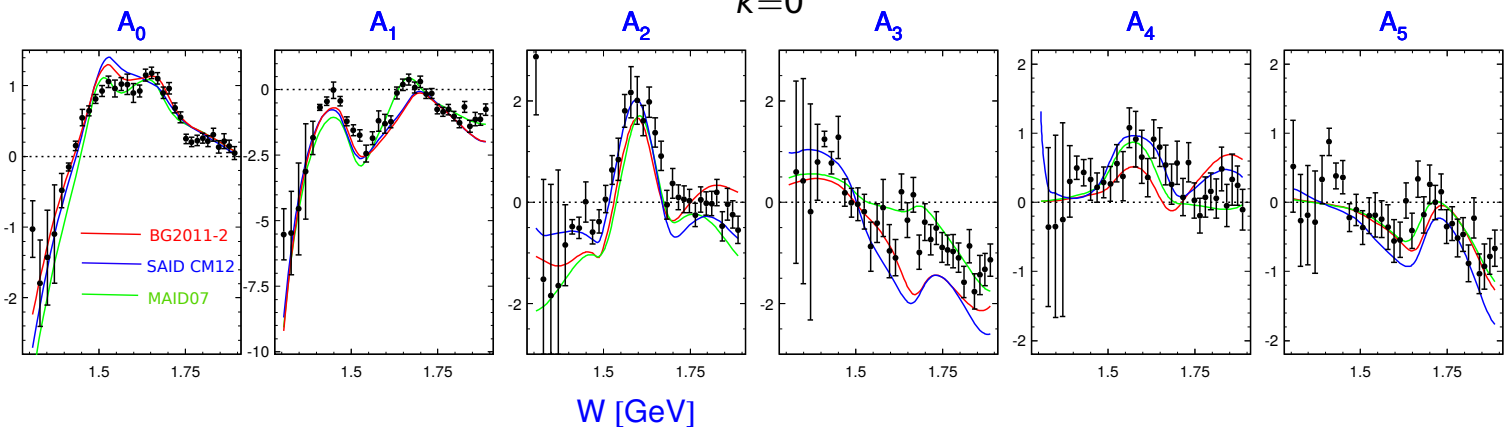


$\gamma p \to \pi^0 p$: transverse spin dependence

$$T \cdot \frac{d\sigma_0}{d\Omega} = \sin\theta \sum_{k=0}^{2\ell_{max}-1} A_T^k(W)\ P_k(\cos\theta)$$



$$F \cdot \frac{d\sigma_0}{d\Omega} = \sin\theta \sum_{k=0}^{2\ell_{max}-1} A_F^k(W)\ P_k(\cos\theta)$$



Single energy partial wave analysis

Legendre coefficients for each observable O
depend quadratically on multipoles: $M_{\ell,k}(W) : E_{\ell\pm},\ M_{\ell\pm}$

$$A_j^O(W) \sim \sum_{\ell,\ell',k,k'} M_{\ell,k}(W)\, M^*_{\ell',k'}(W)$$

$\rightarrow$ coupled quadratic equations

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- Discrete ambiguities
  $\rightarrow$ at least 5 observables (Omelaenko '81, Wunderlich 2014)
- Exp. acceptance and uncertainties $\rightarrow$ ambiguities

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- Discrete ambiguities
  $\rightarrow$ at least 5 observables (Omelaenko '81, Wunderlich 2014)
- Exp. acceptance and uncertainties $\rightarrow$ ambiguities
- Below 2π threshold:
  unitarity (Fermi-Watson theorem) constrains phases

$\gamma p \to \pi^0 p$: threshold ($E_\gamma < 190$ MeV)

→ talks by St. Scherer (Plenary 26-1) and S.N. Yang (Parallel A)

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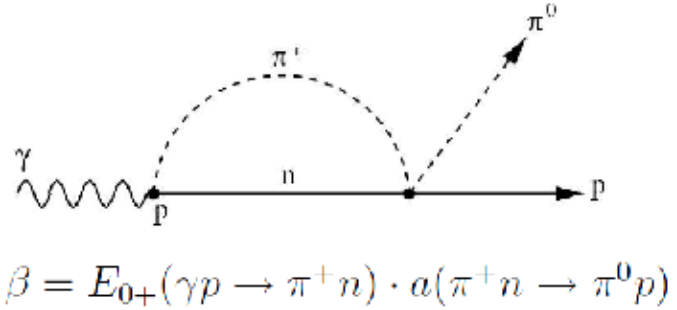
Unitarity:

P-waves are real: $\mathrm{Im}M_{1+} \sim \mathrm{Im}M_{1-} \sim \mathrm{Im}E_{1+} \sim 0$

$$\mathrm{Im}E_{0+} = \beta(E_\gamma)\frac{q_{\pi^+}}{m_{\pi^+}};$$

$$\beta(E_\gamma^{\mathrm{thr}}) = (3.35 \pm 0.08) \cdot 10^{-3}/m_{\pi^+}$$



$$\beta = E_{0+}(\gamma p \to \pi^+ n) \cdot a(\pi^+ n \to \pi^0 p)$$

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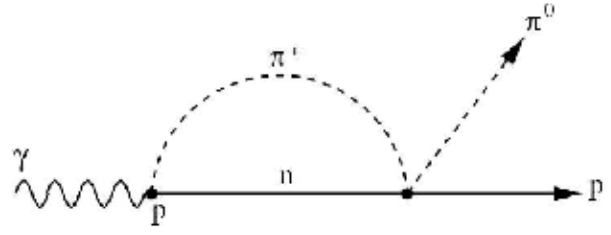

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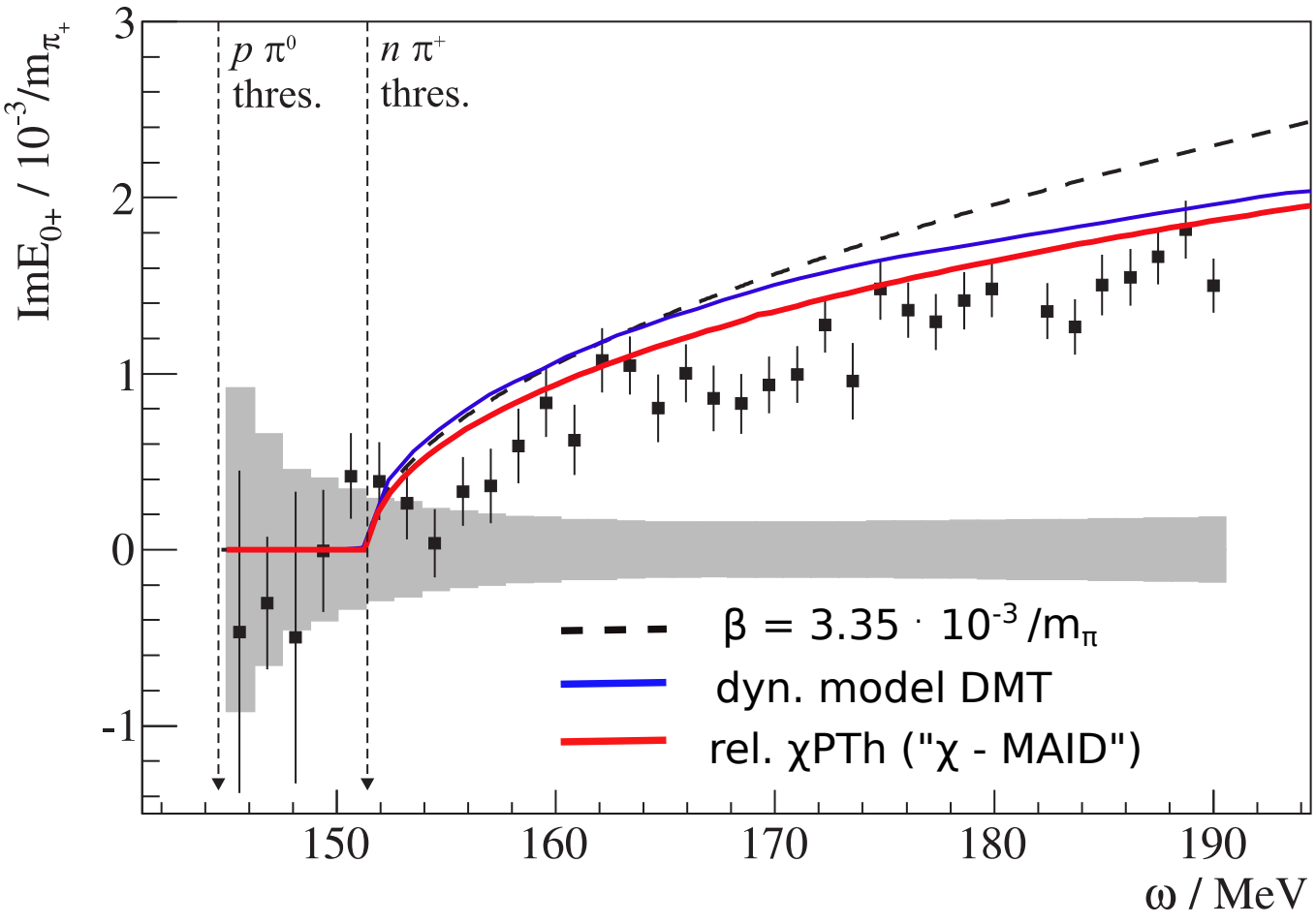
Experiment:

- Measurements of $d\sigma/d\Omega$ and Σ
  determine all real parts ($\mathrm{Re}E_{0+}, \mathrm{Re}M_{1+}, \mathrm{Re}M_{1-}, \mathrm{Re}E_{1+}$)
  → PRL111 (2013) 062004
- Transverse target polarisation T → $\mathrm{Im}E_{0+}$

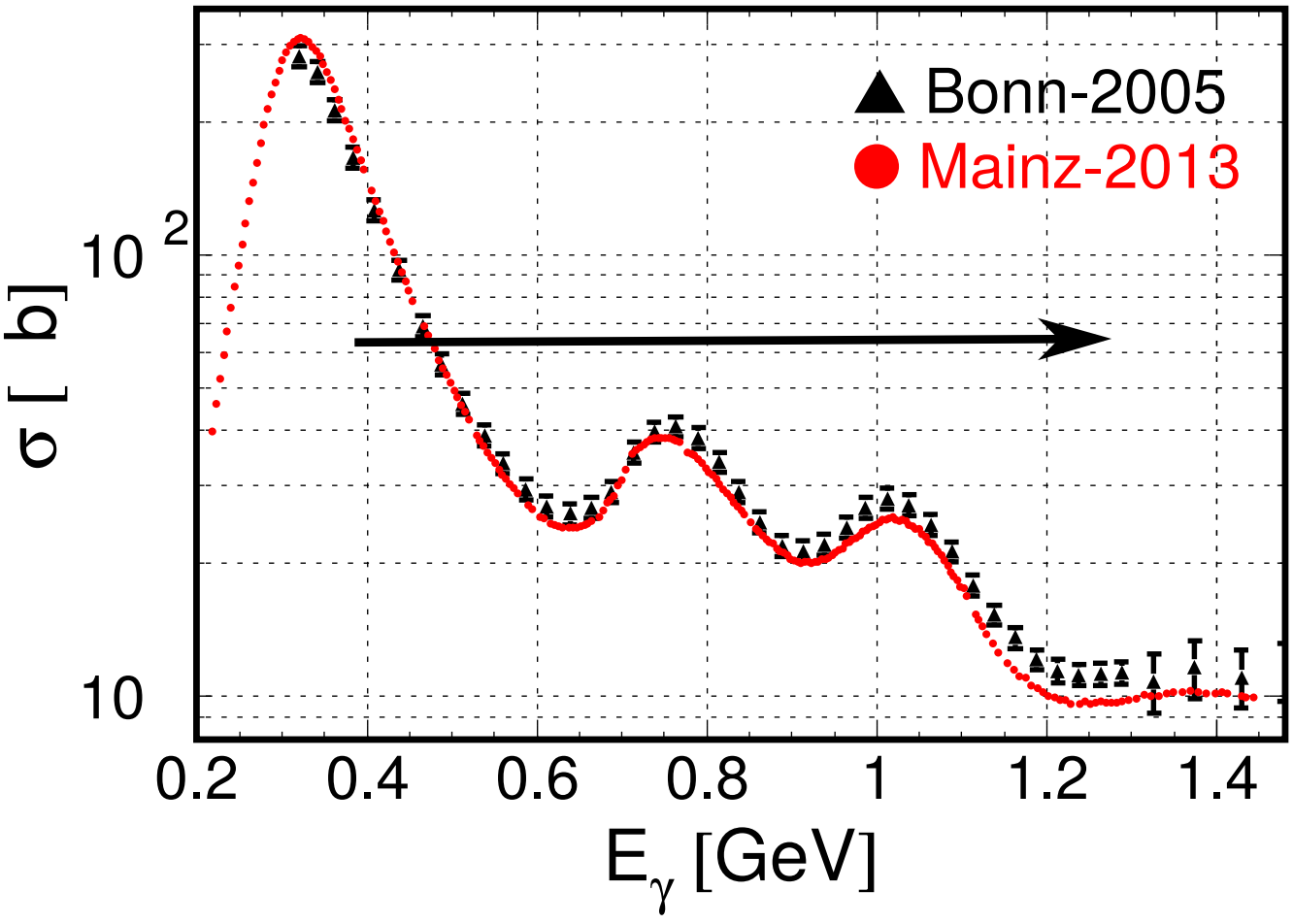
  $$T \cdot \frac{d\sigma}{d\Omega} \sim \mathrm{Im}\left[E_{0+}^*(E_{1+} - M_{1+})\right]$$

$\gamma p \to \pi^0 p$: threshold ($E_\gamma < 190$ MeV)



submitted for publication

$\gamma p \to \pi^0 p$: Single energy partial wave analysis



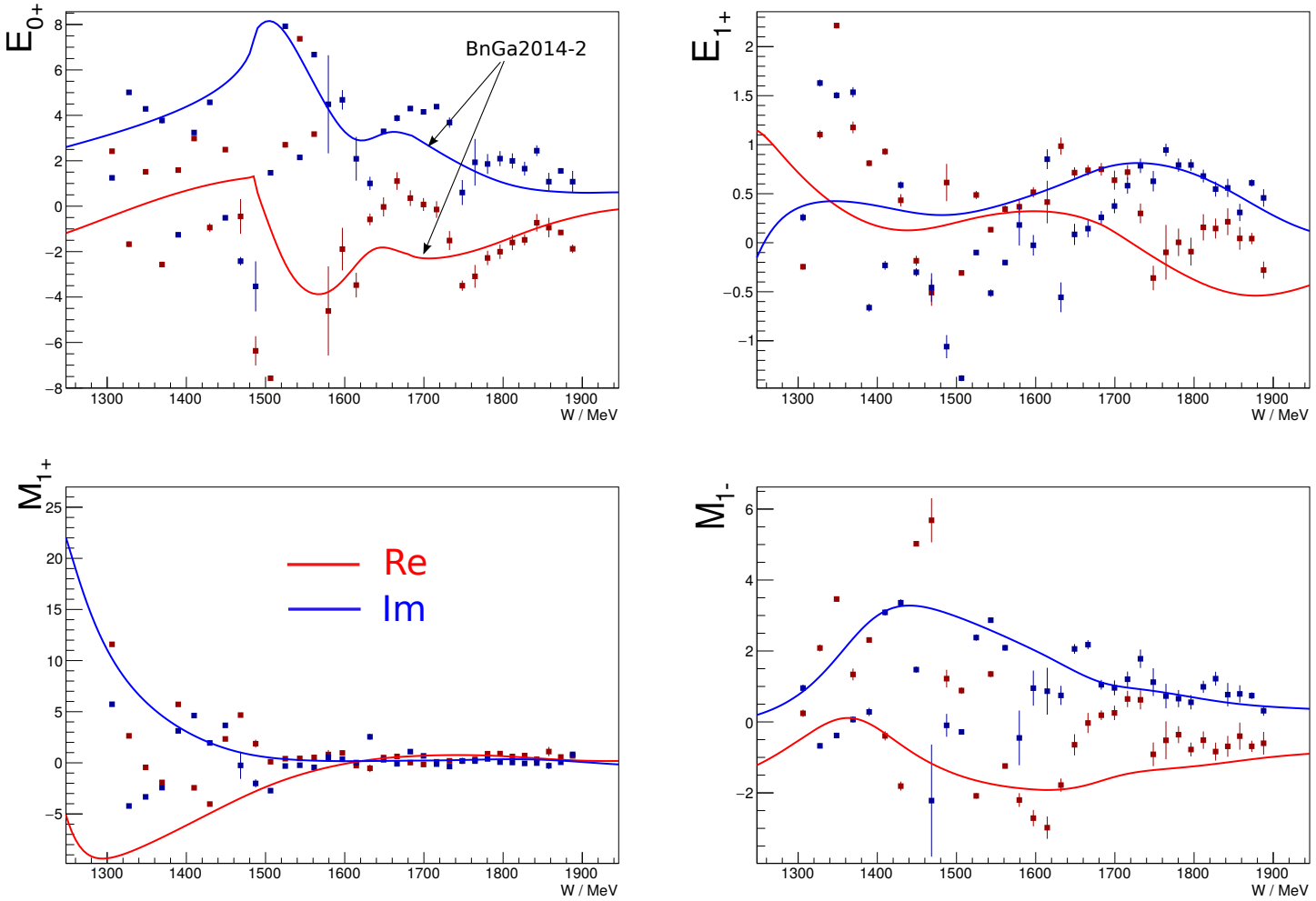
$\gamma p \to \pi^0 p$: Single energy partial wave analysis

beam polarization		target polarization		
		x	y	z
unpolarized	σ_0	-	T	-
linear	Σ	H	-P	(G)
circular	-	F	-	(E)

Procedure:

- Use available "modern" data from ESLA, GRAAL and MAMI
- Fit all s-, p-, d- and f-wave multipoles: 24 parameters
- Constrain higher multipoles (> f-waves) to a model (BnGa2014-2)

$\gamma p \to \pi^0 p$: Single energy partial wave analysis



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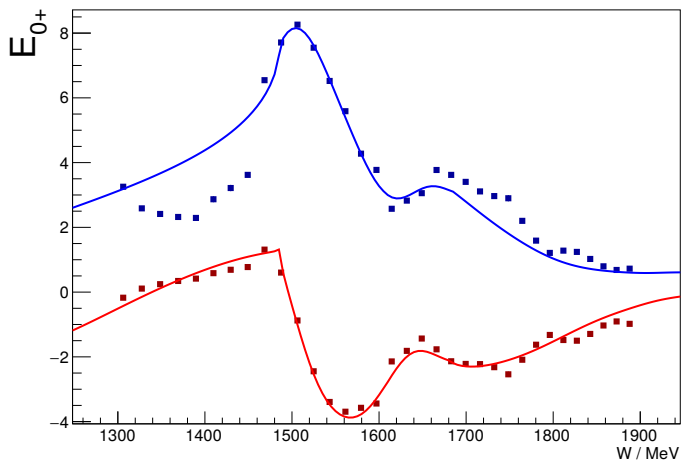
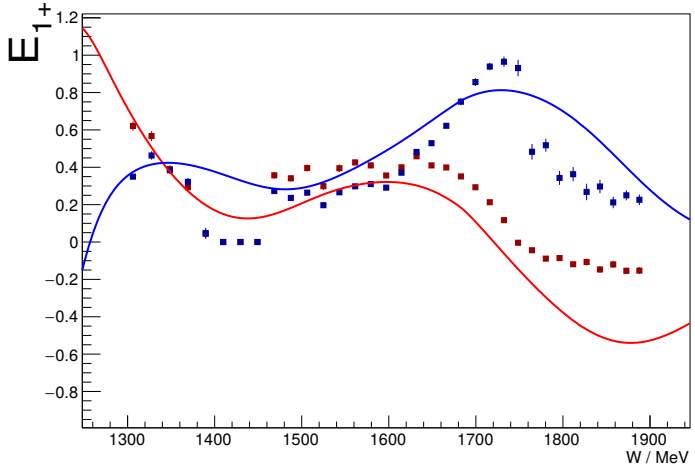
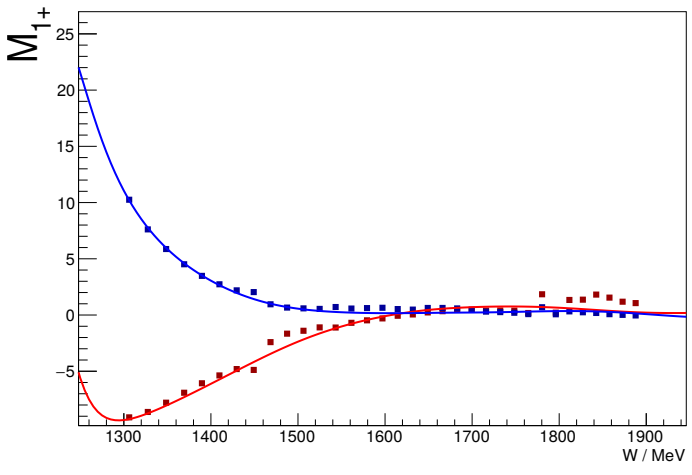
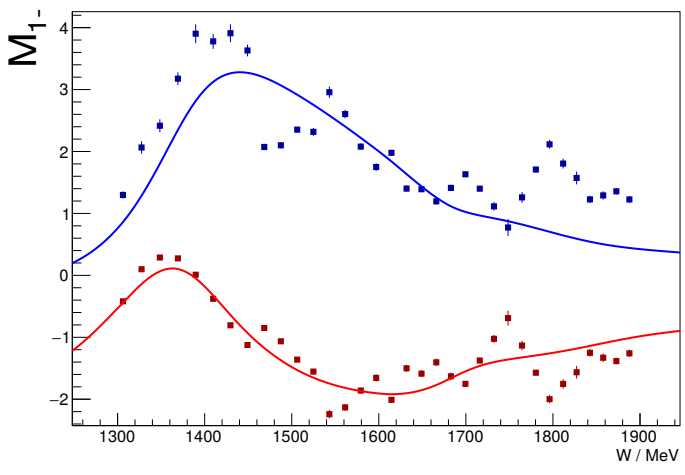


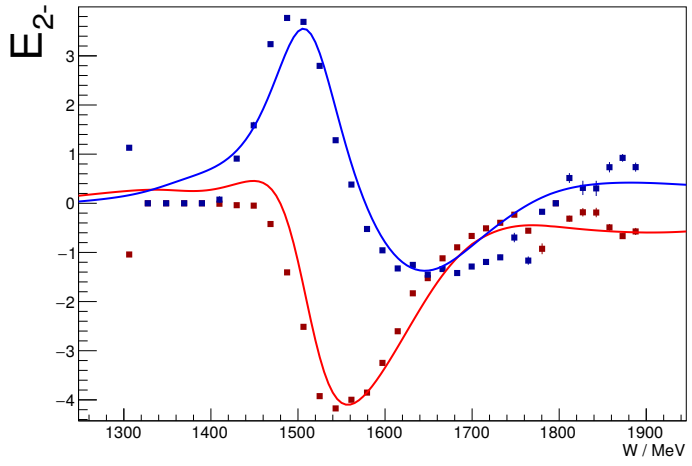


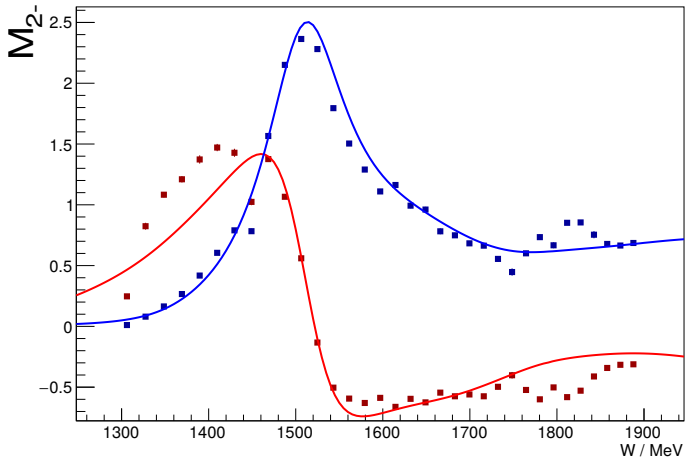


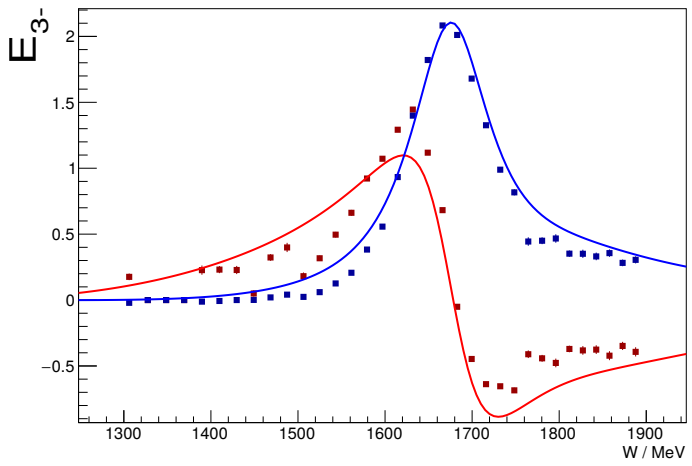


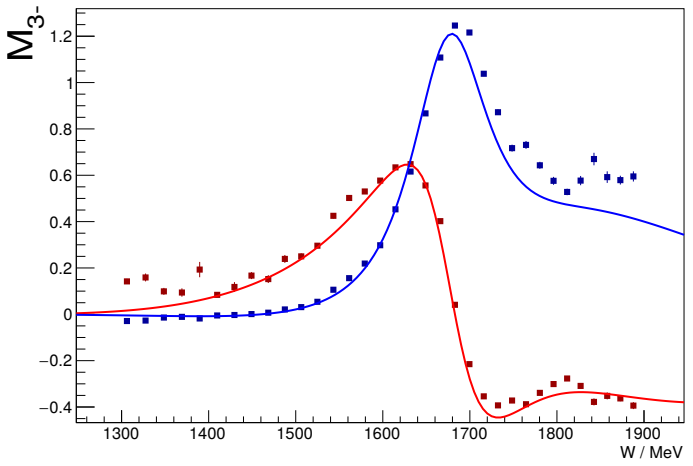
Phases of multipoles fixed to BnGa2014-2 solution

$\gamma p \to \pi^0 p$: Single energy partial wave analysis









Phases of multipoles fixed to BnGa2014-2 solution

$\gamma p \to \pi^0 p$: Single energy partial wave analysis

beam polarization		target polarization		
		x	y	z
unpolarized	σ_0	-	T	-
linear	Σ	H	-P	G
circular	-	F	-	E

- Use available "modern" data from ESLA and MAMI
- Fit all s-, p-, d- and f-wave multipoles: 24 parameters
- Constrain higher multipoles to a model, e.g. BnGa2014-2
- Realistic solutions with additional (phase-)constraints to models

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- Use available "modern" data from ESLA and MAMI
- Fit all s-, p-, d- and f-wave multipoles: 24 parameters
- Constrain higher multipoles to a model, e.g. BnGa2014-2
- Realistic solutions with additional (phase-)constraints to models
- **Goal**: implement constraints from fixed-t analyticity of invariant amplitudes → KH-PWA of πN scattering in the 1980's

Isospin separation

- 3 Isospin amplitudes: $A^{3/2}, A_p^{1/2}, A_n^{1/2}$

$$
\begin{aligned}
A_{\gamma p \to p\pi^0} &= A_p^{1/2} + 2/3\, A^{3/2} \\
A_{\gamma p \to n\pi^+} &= \sqrt{2}\,(A_p^{1/2} - 1/3\, A^{3/2}) \\
A_{\gamma n \to n\pi^0} &= \sqrt{2}\,(-A_n^{1/2} + 2/3\, A^{3/2})
\end{aligned}
$$

- $\gamma p \to \pi^+ n$
- Dedicated neutron programm (LD_2, $^3\vec{H}e$, pol. D-butanol)
  $\gamma n \to \pi^0 n$ and $\gamma n \to \eta n$

→ Manuel Dieterle's talk (Parallel-A 26-2)

Photoproduction of η mesons

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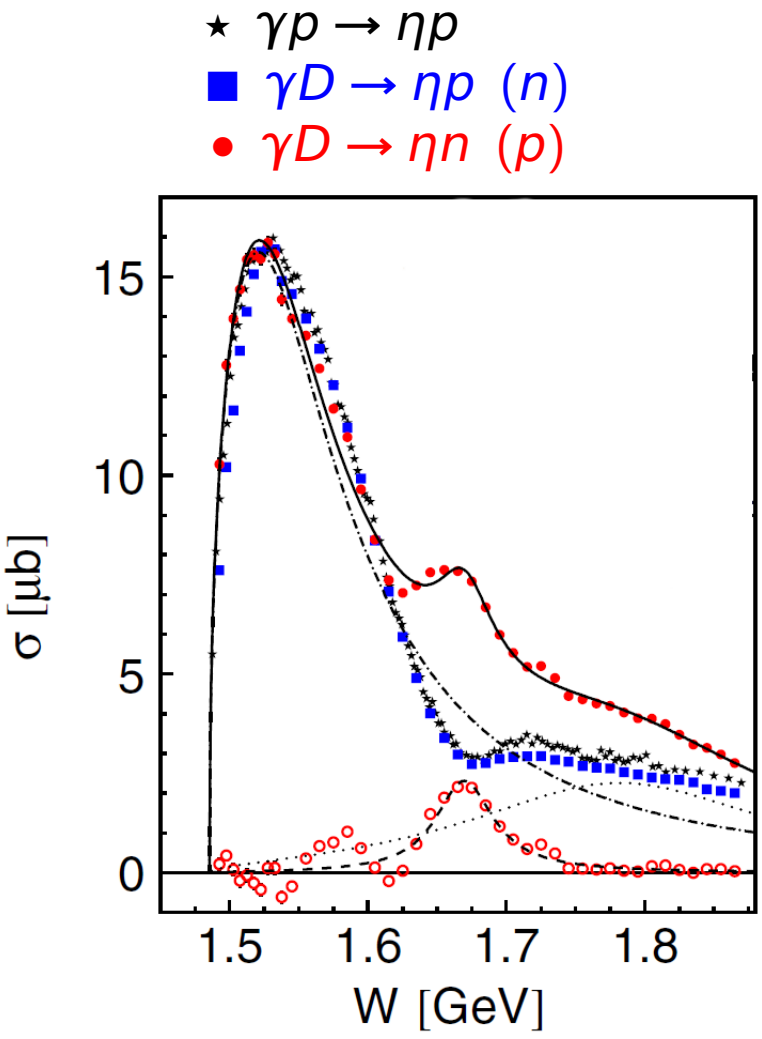
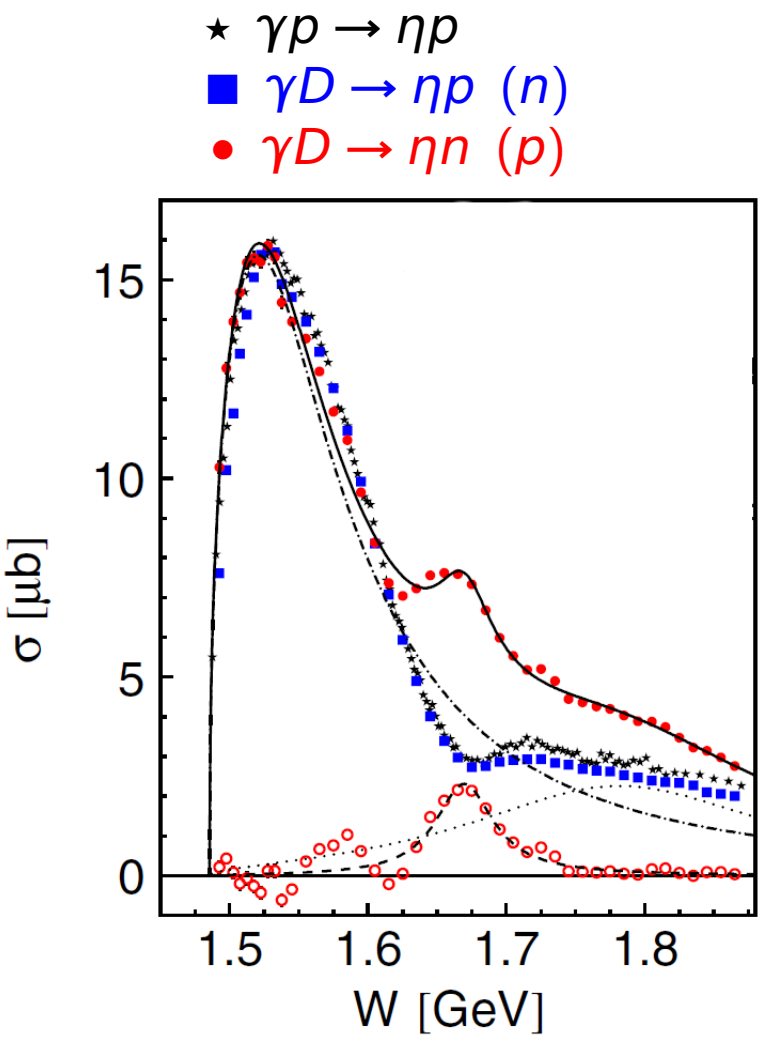


see PRC 82, 035208 (2010) and PRL 111, 232001 (2013)

Photoproduction of η mesons

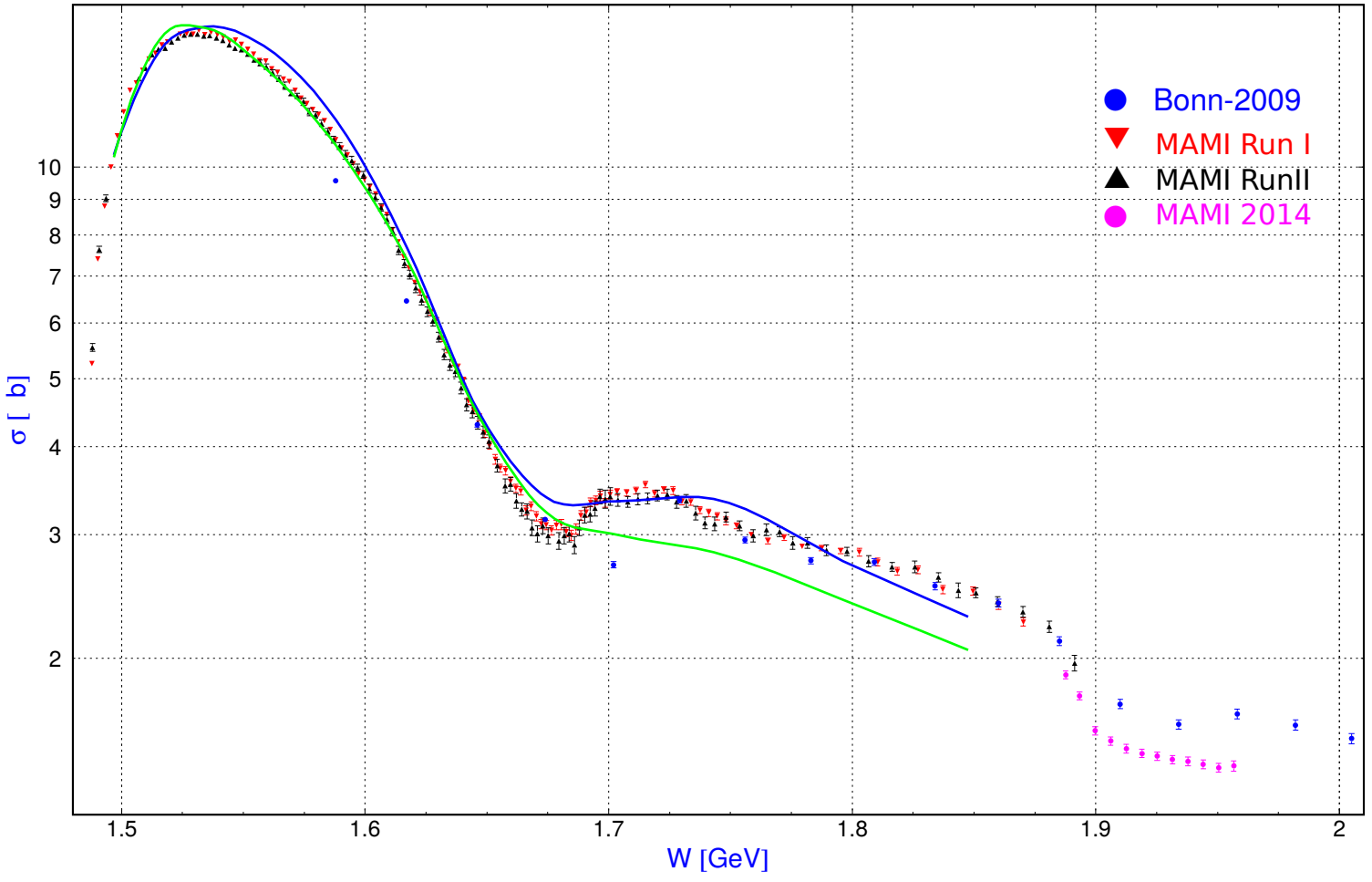


- Resonance dominated
- Large E_{0+} amplitude:
  $N(1535)S_{11}$
  $N(1650)S_{11}$
  $N(1895)S_{11}$
- "bump-dip" structure at 1670 MeV:
  - $N(1535)$-$N(1650)$ interference ?
  - Coupled channel dynamics
    ($K\Lambda$, $K\Sigma$ thresholds)

see PRC 82, 035208 (2010) and PRL 111, 232001 (2013)

$\gamma p \rightarrow \eta p$: cross section

new data from 2014 included:



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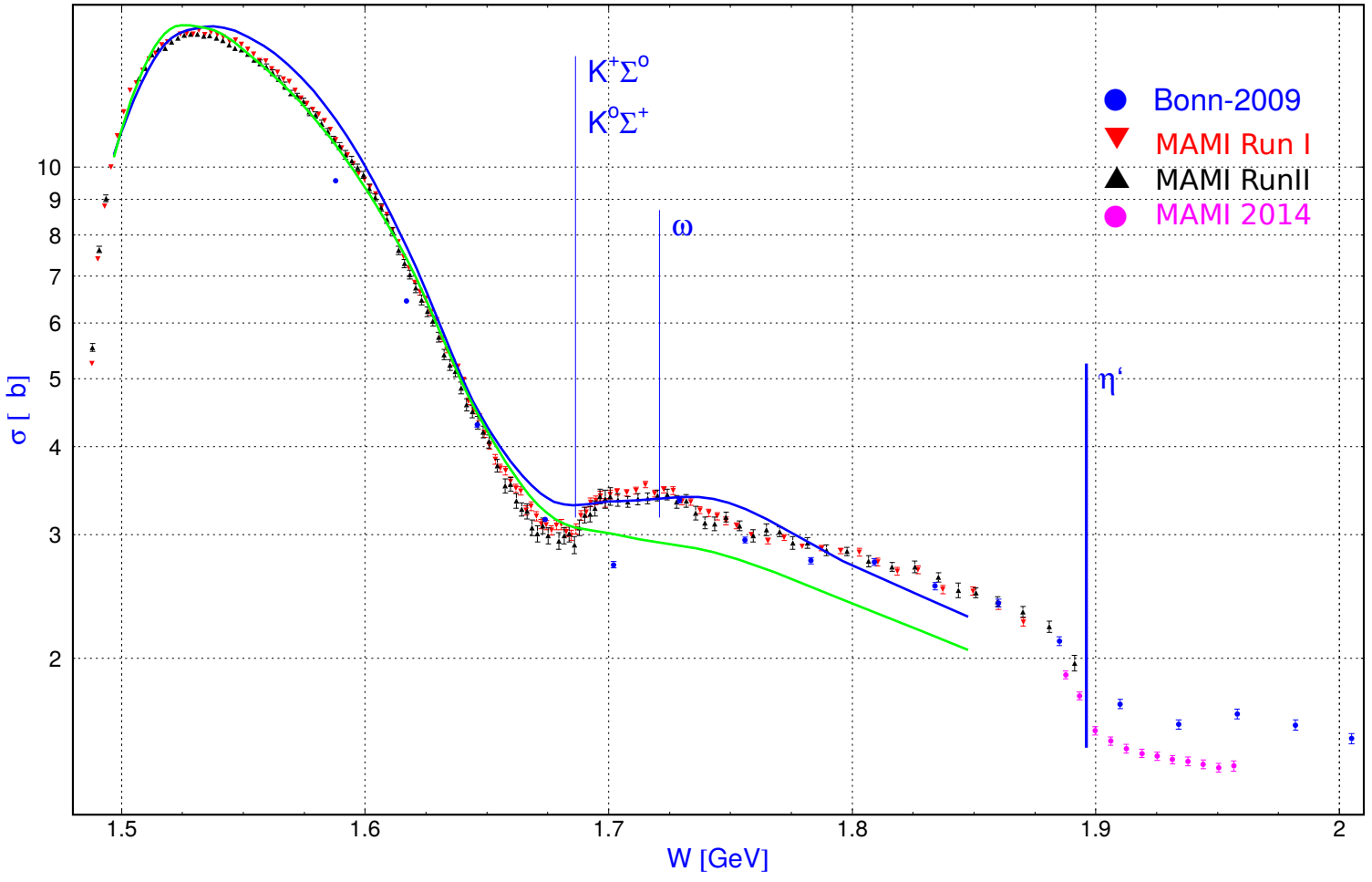
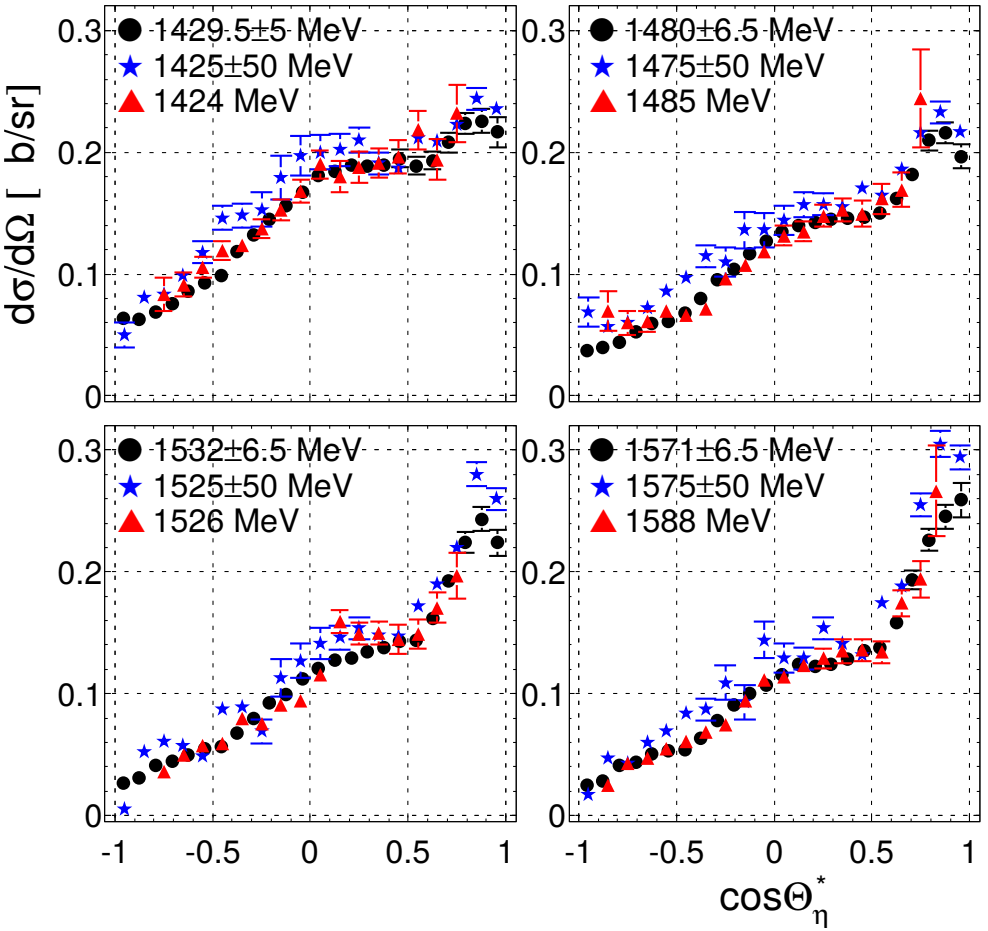


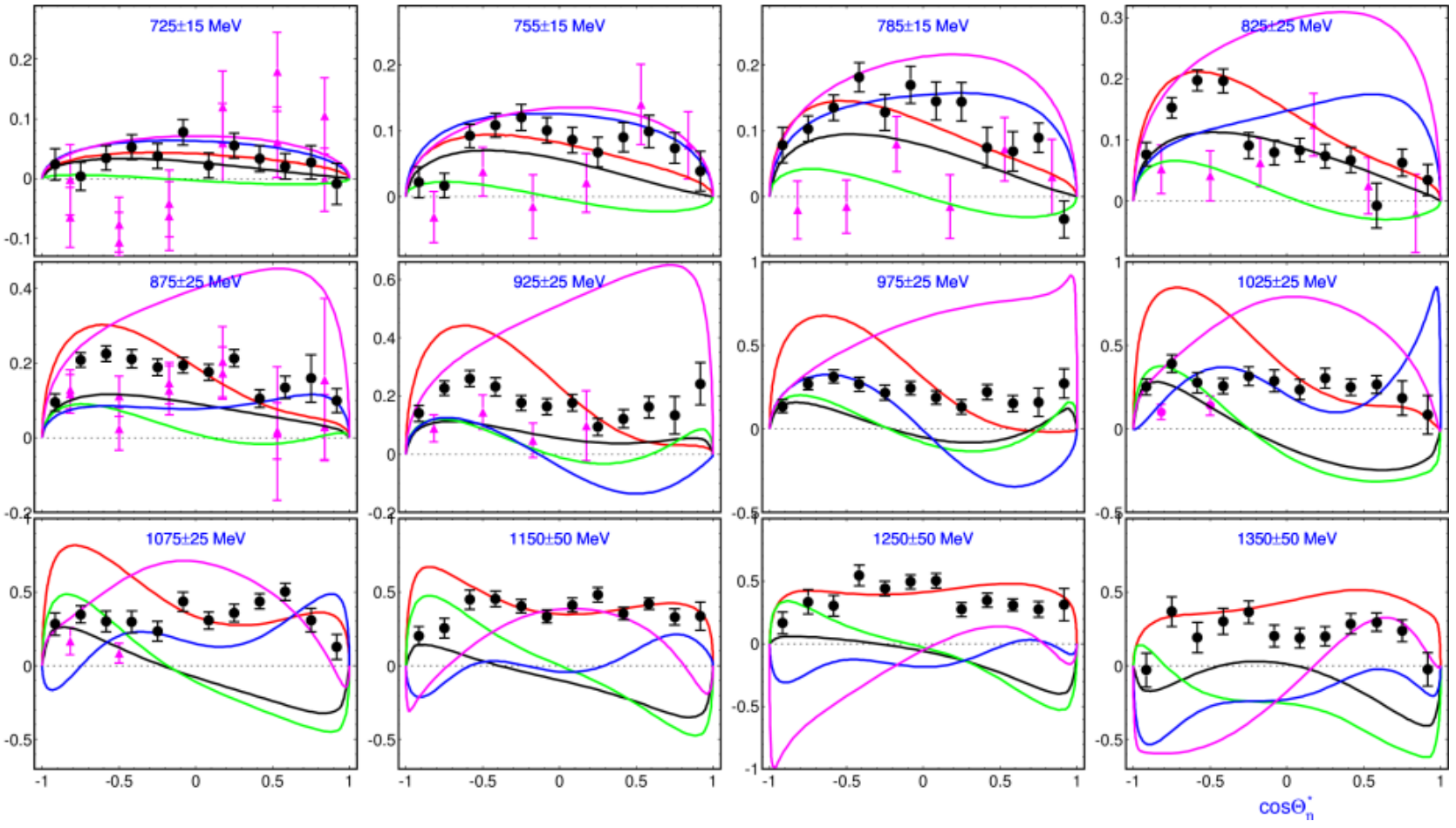
$\gamma p \to \eta p$: differential cross section

new data from 2014 included



- MAMI-2015
- ELSA-2009
- CLAS-2009

$\gamma\vec{p} \rightarrow \eta p$: target asymmetry T



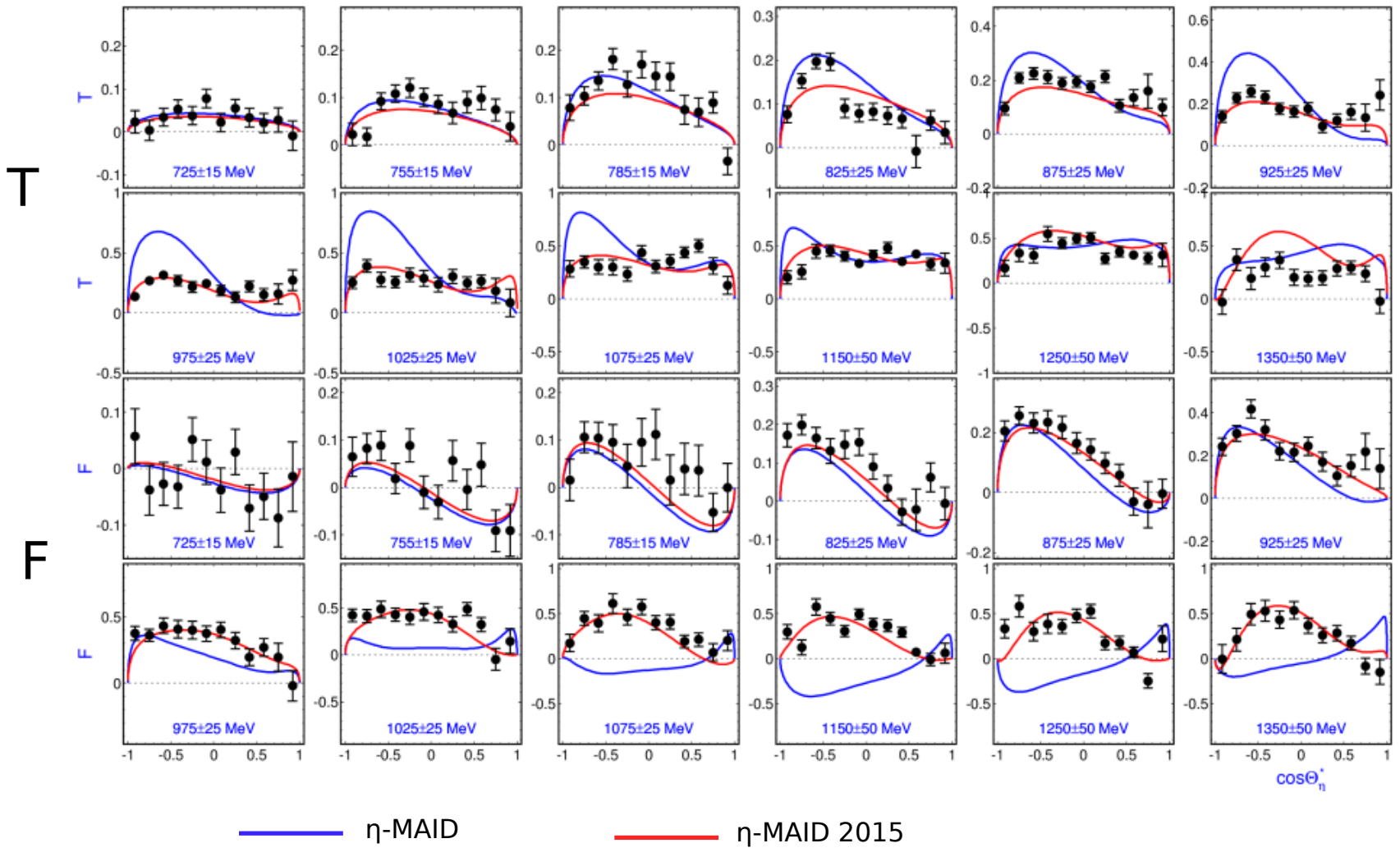
black circles – MAMI-2014
(PRL 113, 102001, 2014)

magenta triangles: Bonn data
(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)

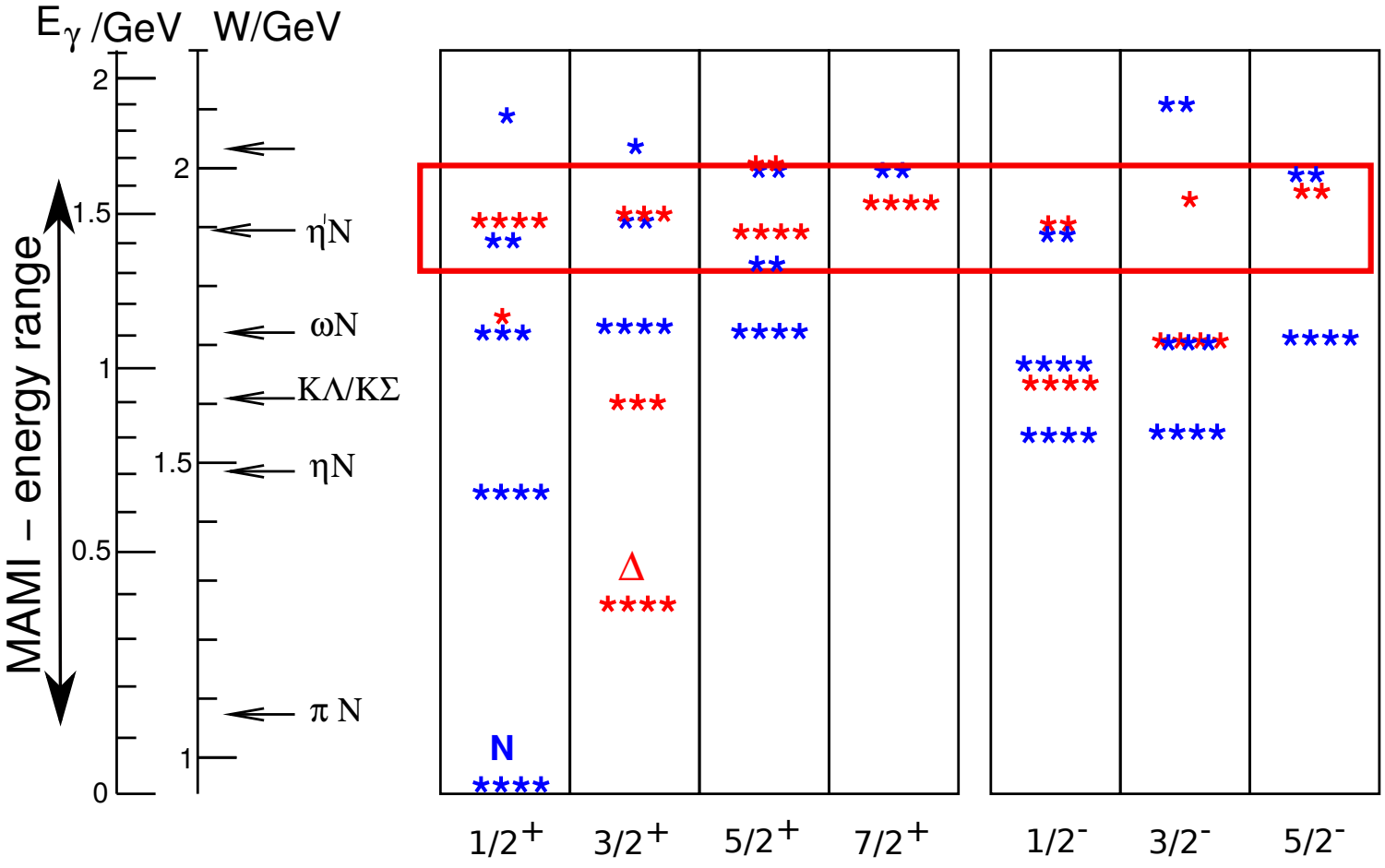
$\gamma\vec{p} \rightarrow \eta p$: η-MAID2015

Refit of η-MAID03 (V.Kashevarov, L.Tiator)



$\gamma\vec{p} \to \eta p$: η-MAID2015

Refit of η-MAID03 (V.Kashevarov, L.Tiator)



Photoproduction of η' mesons

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- Dynamics not well understood
  S_{11} and P_{11} resonances
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- Models:
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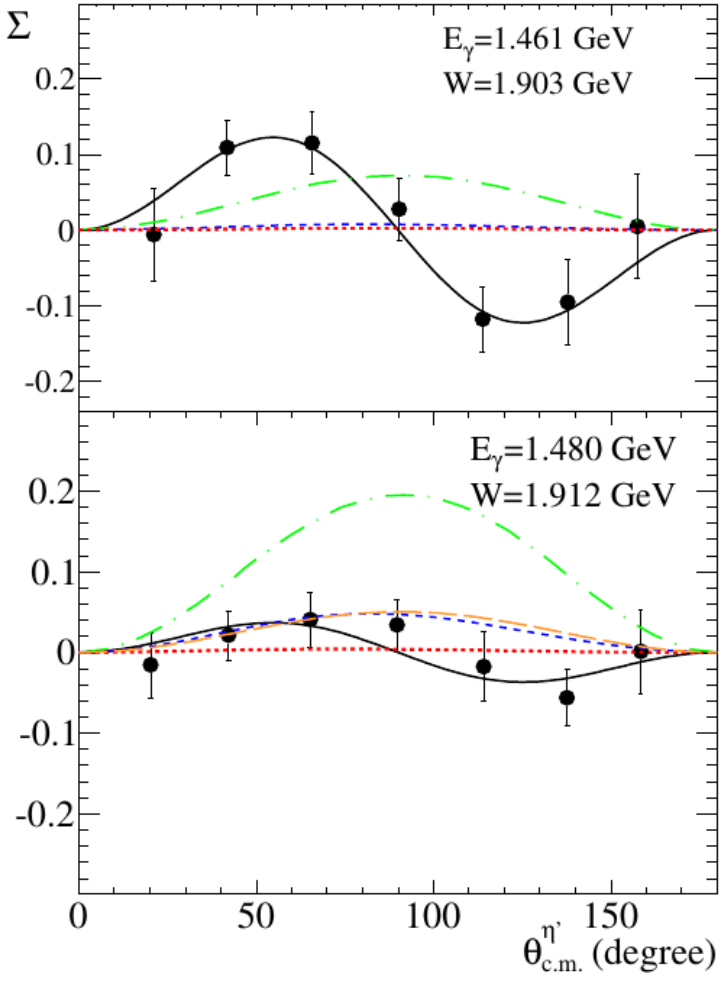
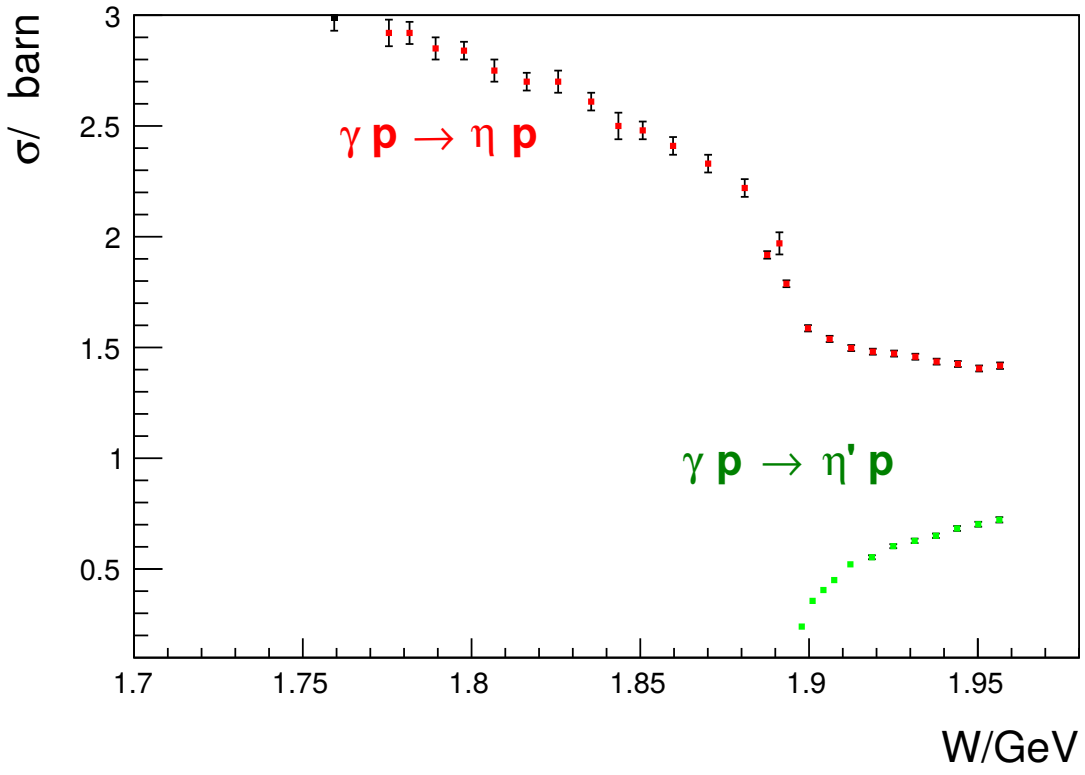
  from GRAAL (arXiv:1407.6991)
  N^* beyond S- and P-waves?



Photoproduction of η' mesons

Total cross section from new MAMI data (2014):



Summary and Outlook

- Precise new data from MAMI
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A2 Collaboration at MAMI