Study of η and η' Photoproduction: From Threshold to High Energies

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Outline

- Our goal:
  an model for η and η′ photoproduction from the thresholds to high energies
- η **photoproduction** $\gamma p \to \eta p$
  - η-MAID : an isobar model for η photo- and electroproduction
    valid only in resonance regions because of the ρ and ω poles in *t*-channel
  - instead, describe *t*-channel ρ and ω exchange in terms of Regge trajectories
    to comply with correct high energy behavior
  - fit high energy data to determine the ρNN and ωNN couplings
  - fit data at resonance regions to extract *N** parameters
- η′ **photoproduction** $\gamma p \to \eta' p$
  - use the same ρNN and ωNN couplings fixed from η photoproduction fit
  - describe η′ photoproduction data and study *N** contributions

Recent η Photoproduction Data

Cross sections

- TAPS, MAMI in Mainz
  Krusche et al., Phys. Lett. B358, 40 (1995) — **TAPS ’95**
- GRAAL, ESRF in Grenoble
  Renard et al., Phys. Lett. B528, 215 (2002) — **GRAAL ’02**
  *Rebreyend’s talk in N*2002* — **GRAAL prel.**
- CLAS, Jefferson Lab
  Dugger et al., to appear in Phys. Rev. Lett. (2002) — **CLAS ’02**

Beam asymmetry

- GRAAL, ESRF in Grenoble
  Ajaka et al., Phys. Rev. Lett. 81, 1797 (1998) — **GRAAL ’98**
  *Rebreyend’s talk in N*2002* — **GRAAL prel.**

Target asymmetry

- PHOENICS, ELSA in Bonn
  Bock et al., Phys. Rev. Lett. 81, 534 (1998) — **Bonn ’98**

More data are coming from CLAS, GRAAL, and CB-ELSA

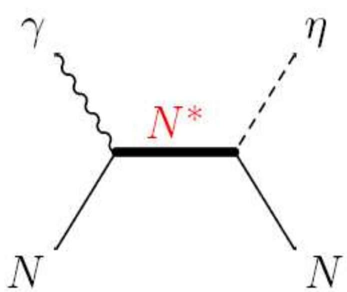
η-MAID

http://www.kph.uni-mainz.de/MAID

This isobar model consists of

- Resonance contributions
- Background
  - Born terms
  - Vector meson exchanges

Resonances



Breit-Wigner form

$$\begin{pmatrix} E_{\ell\pm} \\ M_{\ell\pm} \end{pmatrix} = \begin{pmatrix} \tilde{E}_{\ell\pm} \\ \tilde{M}_{\ell\pm} \end{pmatrix} f_{\gamma N}(W) \frac{\Gamma_{tot} W_R}{W_R^2 - W^2 - i W_R \Gamma_{tot}} f_{\eta N}(W)\, C_{\eta N}$$

isospin factor $C_{\eta N} = -1$

$$f_{\eta N}(W) = \left[\frac{1}{(2j+1)\pi} \frac{k}{|\boldsymbol{q}|} \frac{m_N}{W_R} \frac{\Gamma_{\eta N}}{\Gamma_{tot}^2} \right]^{1/2}$$

$$\Gamma_{\eta N} = \beta_{\eta N} \Gamma_R \left(\frac{|\boldsymbol{q}|}{|\boldsymbol{q_R}|} \right)^{2\ell+1} \left(\frac{X^2 + \boldsymbol{q_R}^2}{X^2 + \boldsymbol{q}^2} \right)^{\ell} \frac{W_R}{W}$$

$$\Gamma_{tot} = \Gamma_{\eta N} + \Gamma_{\pi N} + \Gamma_{\pi\pi N}$$

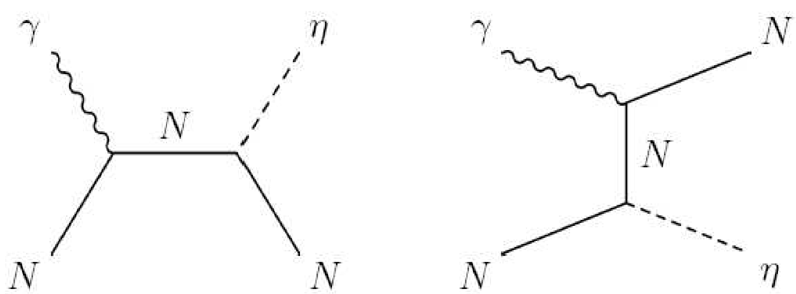
$$f_{\gamma N}(W) = 1$$

Background

- **Born terms**
- **Vector meson exchanges**

The amplitudes of background contributions are obtained by evaluating lowest-order Feynman diagrams using effective Lagrangians

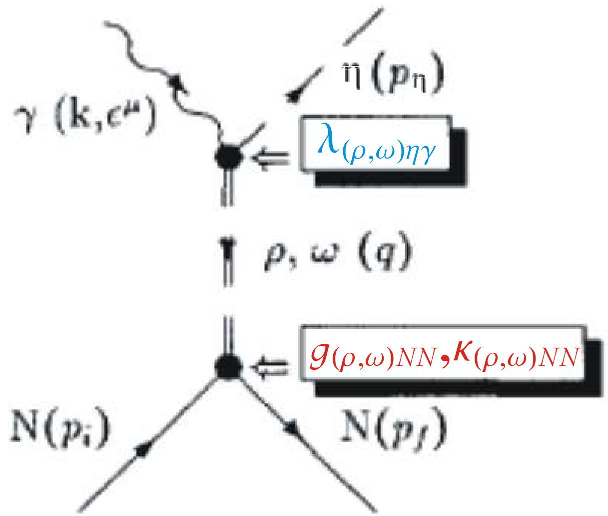
Born Terms



$$\mathcal{L}_{\gamma NN} = -e\bar{\psi}\left[\gamma_\mu A^\mu F_1(Q^2) + \frac{\sigma_{\mu\nu}}{2\,m_N}\partial^\mu A^\nu F_2(Q^2)\right]\psi$$

$$\mathcal{L}_{\eta NN} = -i\, g_{\eta NN}\, \bar{\psi}\,\gamma_5\,\psi\,\phi_\eta$$

Vector Meson Exchanges



$$\mathcal{L}_{VNN} = g_{VNN}\,\bar{\psi}\left(\gamma_\mu + \frac{\kappa_{VNN}}{2\,m_N}\sigma_{\mu\nu}\partial^\nu\right)V^\mu\,\psi$$

$$\mathcal{L}_{V\eta\gamma} = \frac{e\lambda_{V\eta\gamma}}{m_\eta}\varepsilon_{\mu\nu\rho\sigma}(\partial^\mu A^\nu)\phi_\eta(\partial^\rho V^\sigma)$$

$$\Gamma_{V\to\eta\gamma} = \frac{\alpha(M_V^2 - M_\eta^2)^3}{24\,M_V^3\,M_\eta^2}\lambda_{V\eta\gamma}{}^2$$

vector meson propagator $\mathcal{P}^V_{pole} = \dfrac{1}{t - m_V^2}$

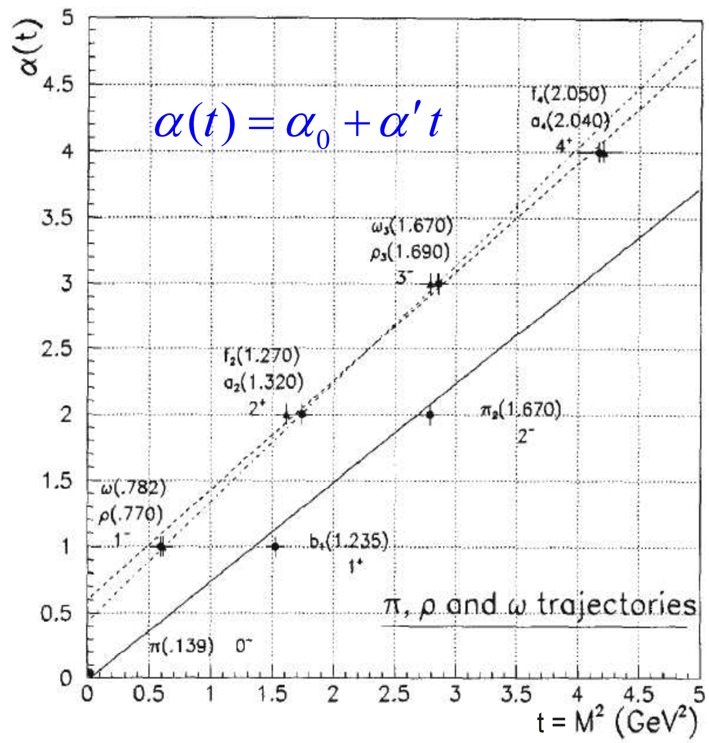
hadronic form factor $F_V(t) = \left(\dfrac{\Lambda_V^2 - m_V^2}{\Lambda_V^2 - t}\right)^2$

This description for vector meson exchanges

- works fine in resonance regions (W < 2 GeV)
- but cannot extend to high energies

Regge Trajectory Exchanges

At high *s* and low *t*, it is known that meson photoproduction can be well described by Regge trajectories in the *t*-channel.



Replace pole-like propagator

$$\mathcal{P}^V_{\text{pole}} = \frac{1}{t - m_V^2}$$

With Regge propagator

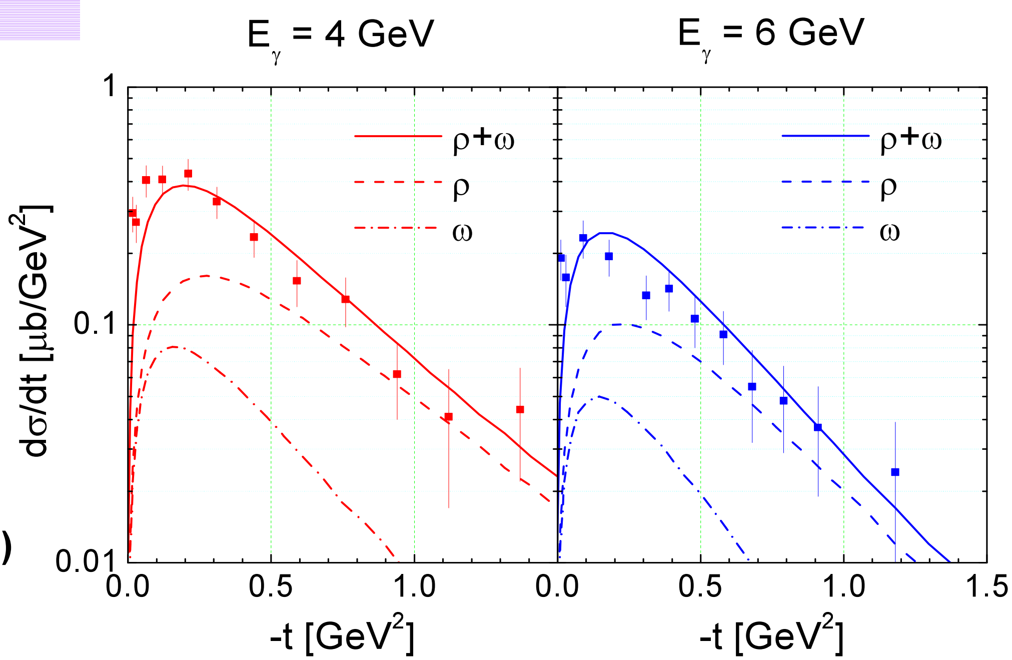
$$\mathcal{P}^V_{\text{Regge}} = \left(\frac{s}{s_0}\right)^{\alpha_V(t)-1} \frac{\pi \alpha'_V}{\sin(\alpha_V(t))} \frac{\mathcal{S}_V + e^{-i\pi\alpha_V(t)}}{2} \frac{1}{\Gamma(\alpha_V(t))}$$

The idea is to economically take into account the exchanges of high-spin particles in the *t*-channel which cannot be neglected at higher energies

Vector Meson Exchanges in $\gamma p \rightarrow \eta p$

Fit high-s, low-t data to determine the vector meson couplings g_{VNN} and κ_{VNN}

Data from **DESY (1970)**



Vector meson parameters

V	m_V	g_{VNN}	κ_{VNN}	$\lambda_{V\eta\gamma}$	$\lambda_{V\eta'\gamma}$	α_V (t)
ρ	768.5 MeV	2.4	3.7	0.810	1.240	$0.55 + 0.8\ t/\mathrm{GeV}^2$
ω	782.6 MeV	9	0	0.291	-0.433	$0.44 + 0.9\ t/\mathrm{GeV}^2$

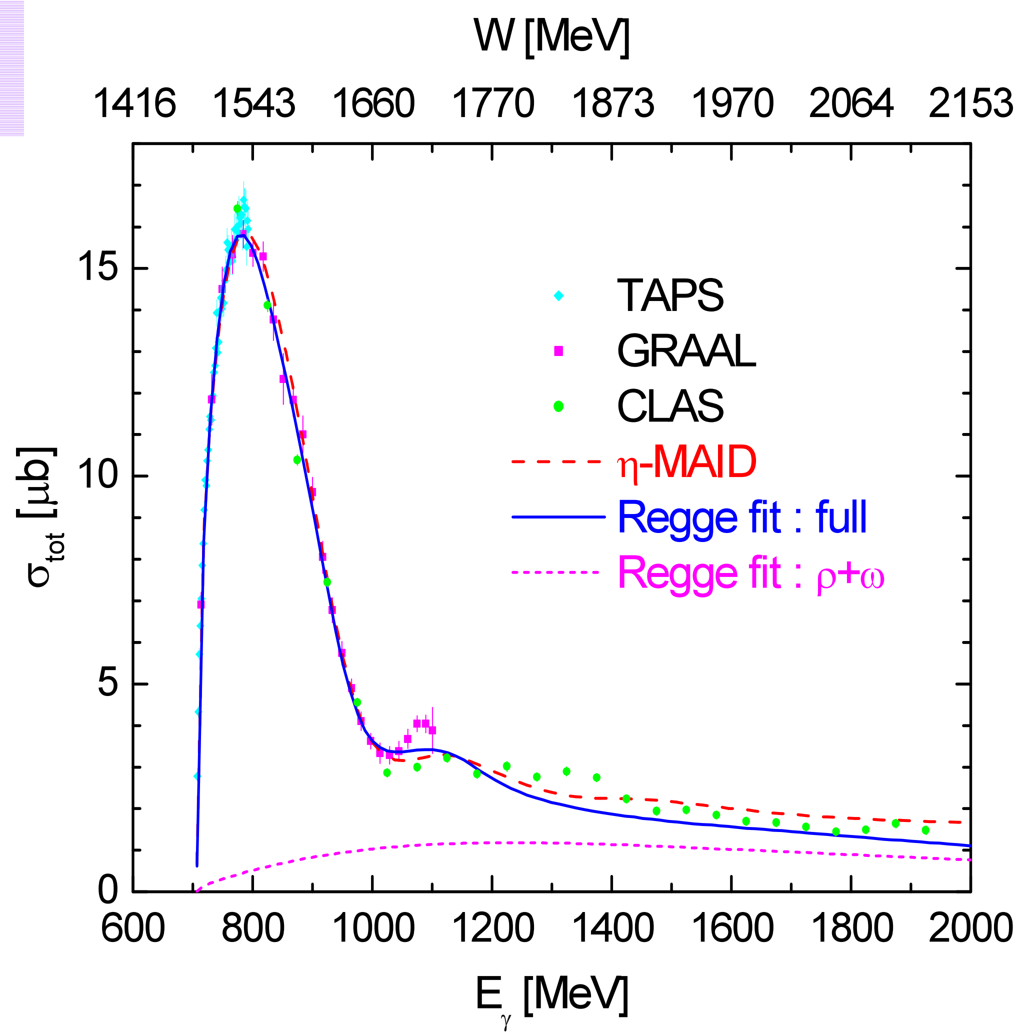
$\gamma p \rightarrow \eta p$ Results

In the following $\gamma p \rightarrow \eta p$ results shown,

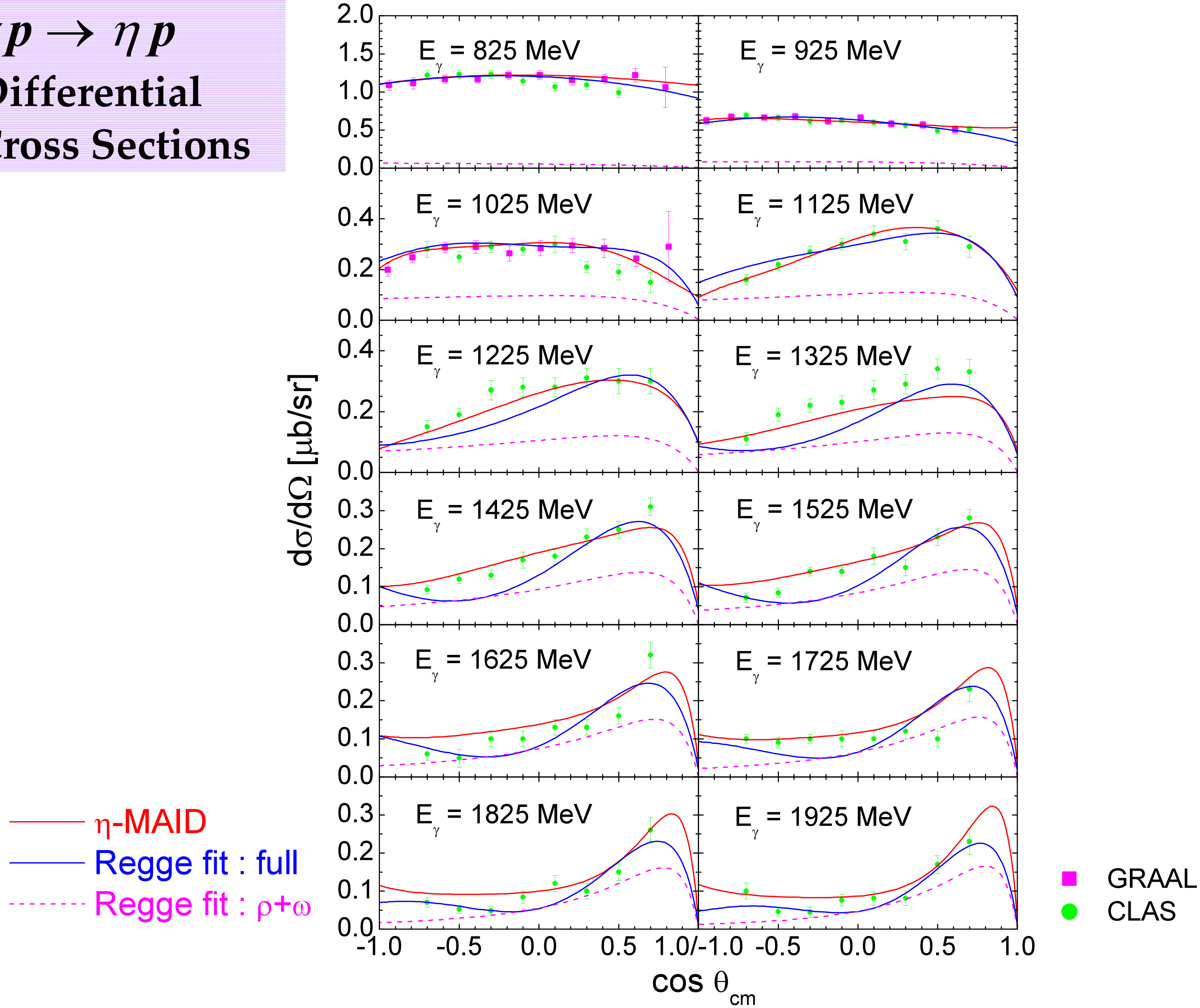
- The **η-MAID** results refers to our isobar model with refitting data which include the recent CLAS cross section data for E_γ = 0.75 to 1.95 GeV
  M. Dugger, *et al.* (CLAS Collaboration), to appear in PRL
- The **Regge fit** refers to the results from the isobar model with the *t*-channel vector meson exchanges described by Regge trajectories

$\gamma p \rightarrow \eta p$
Total Cross Sections

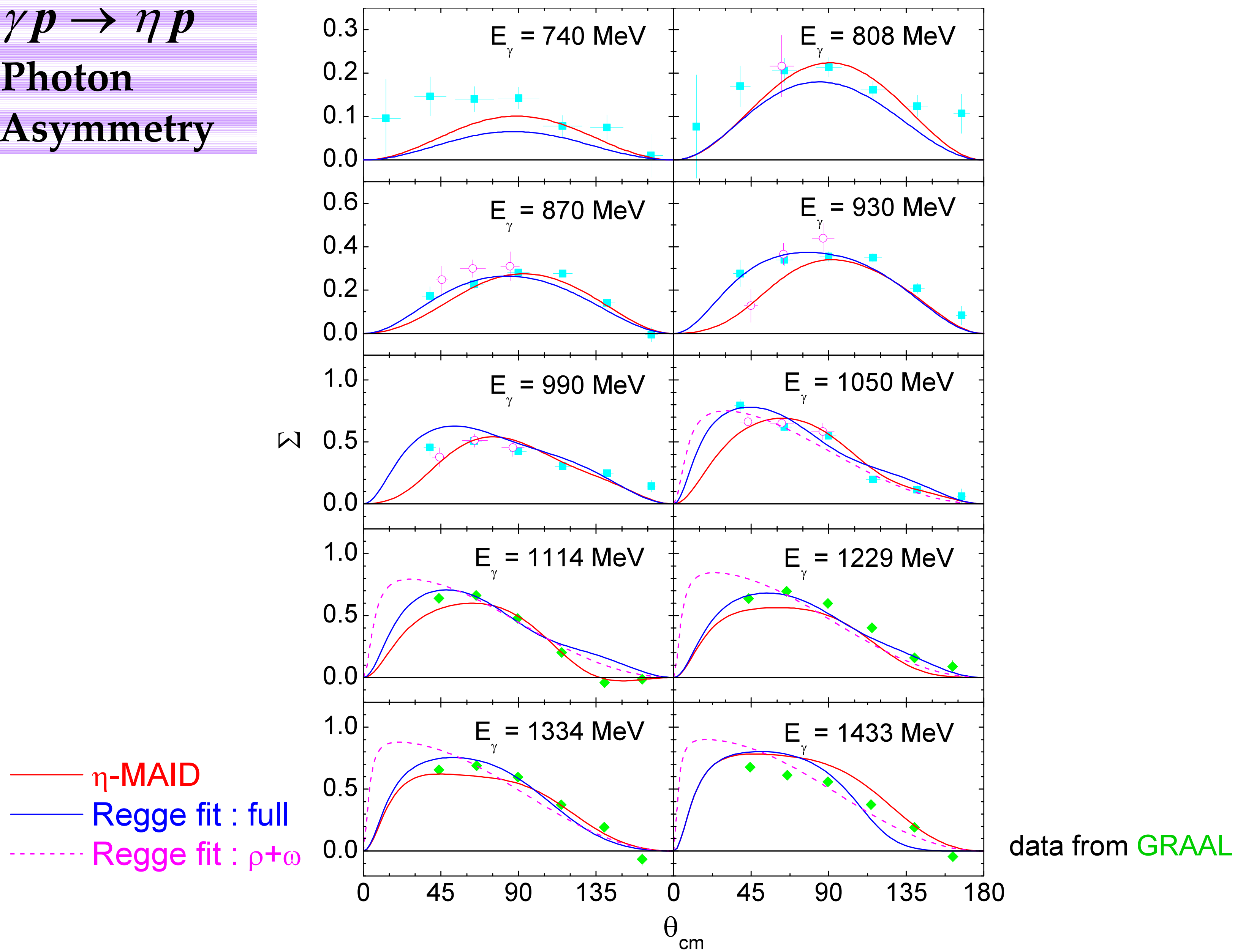
The GRAAL and CLAS total cross sections are integrated from differential cross section data. Extrapolation to unmeasured angles is required; therefore, they are model dependent quantities.



$\gamma p \rightarrow \eta p$
Differential Cross Sections



$\gamma p \rightarrow \eta p$
Photon Asymmetry



Resonance Parameters from η-MAID

N^*	Mass	Width	$\beta_{\eta N}$	$A^p_{1/2}$	$A^p_{3/2}$
$D_{13}(1520)$	1520	120	0.05%	-39	166
$S_{11}(1535)$	1545	203	50%	125	
$S_{11}(1650)$	1640	130	10%	73	
$D_{15}(1675)$	1682	150	17%	17	24
$F_{15}(1680)$	1670	130	0.04%	-9	145
$D_{13}(1700)$	1700	100	0.7%	-18	-2
$P_{11}(1710)$	1725	100	26%	22	
$P_{13}(1720)$	1720	150	6.6%	18	-19

[MeV] [10^{-3} GeV$^{-1/2}$]

Numbers in green are fitting parameters

Resonance Parameters from Regge Fit

N^*	Mass	Width	$\beta_{\eta N}$	$A^p_{1/2}$	$A^p_{3/2}$
$D_{13}(1520)$	1520	120	0.02%	-26	166
$S_{11}(1535)$	1530	150	50%	91	
$S_{11}(1650)$	1635	112	12%	53	
$D_{15}(1675)$	1665	150	2%	11	24
$F_{15}(1680)$	1680	130	0.06%	-21	121
$D_{13}(1700)$	1700	100	4.6%	-18	-2
$P_{11}(1710)$	1740	100	12%	31	
$P_{13}(1720)$	1720	150	0.2%	18	-19

[MeV] [10^{-3} GeV$^{-1/2}$]

Numbers in green are fitting parameters

$\gamma p \to \eta p$
Summary

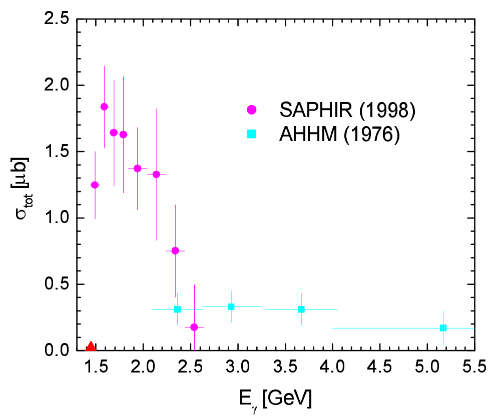
- Both models describe current data up to E_γ = 2 GeV well, but only the Reggeized model can describe the high energy data

- *N** parameters extracted from two models are different
  — extraction of *N** parameters depend on the background
  - some of these *N** are insensitive to current η photoproduction data
  - Γ_0, $\beta_{\eta N}$, $A_{1/2,3/2}$ are highly correlated
  - need to compare with other channels or multichannel analysis

- Preliminary GRAAL $d\sigma/d\Omega$ data (Rebreyend's talk) suggest no dropping in forward angels — something new ?

η' photoproduction
$\gamma p \to \eta' p$

- Use the Regge trajectories in the *t*-channel vector meson exchanges with $\mathbf{g}_{VNN}$ and κ_{VNN} fixed from $\gamma p \to \eta p$
- Born terms are small; neglected at this moment
- The sharp rise of total cross section near threshold, which is similar to $\gamma p \to \eta p$, suggests a S_{11} resonance

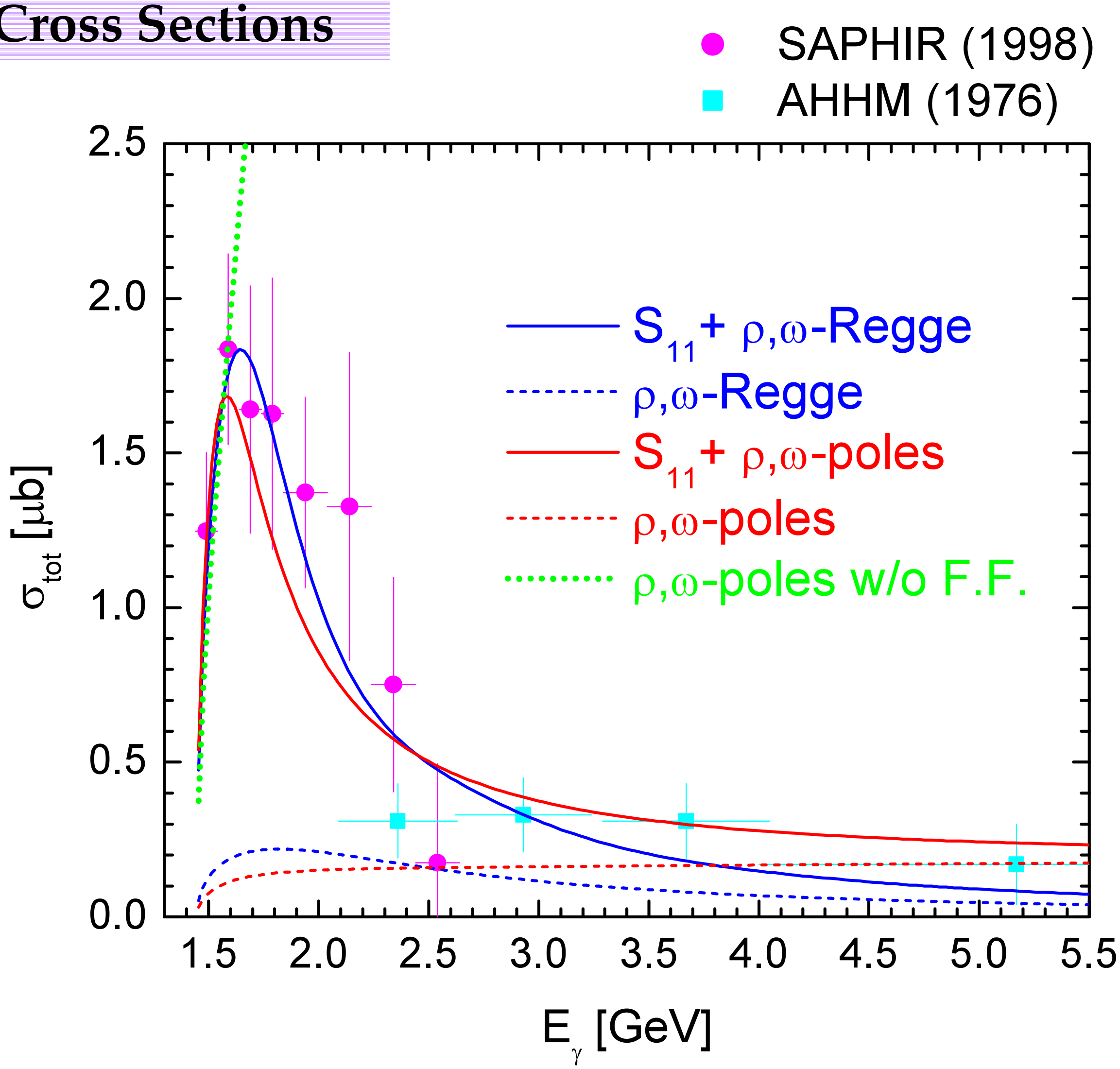


- Therefore, we start with the minimal set:

a S_{11} resonance + Reggeized vector meson exchanges

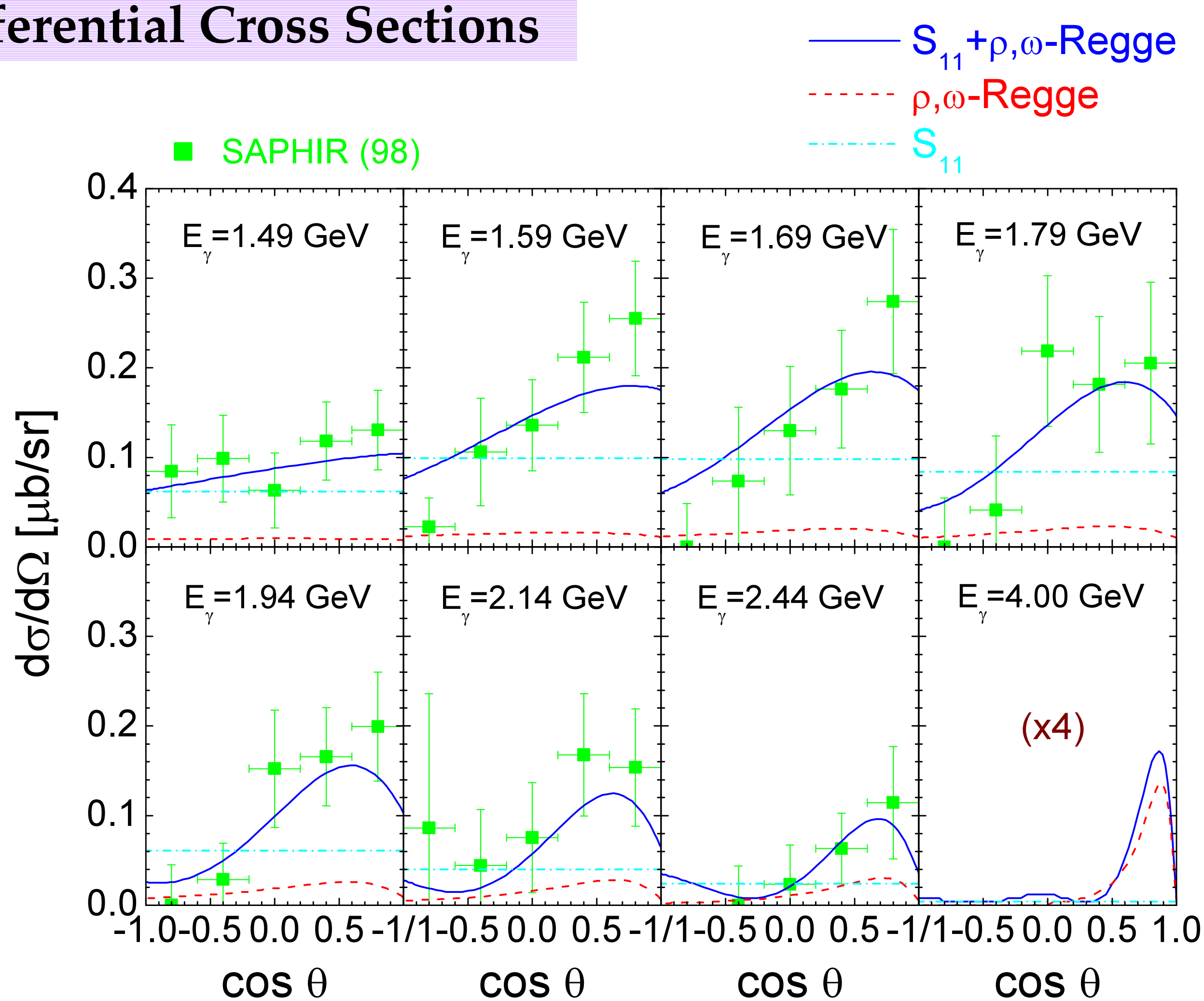
$\gamma p \rightarrow \eta' p$

Total Cross Sections



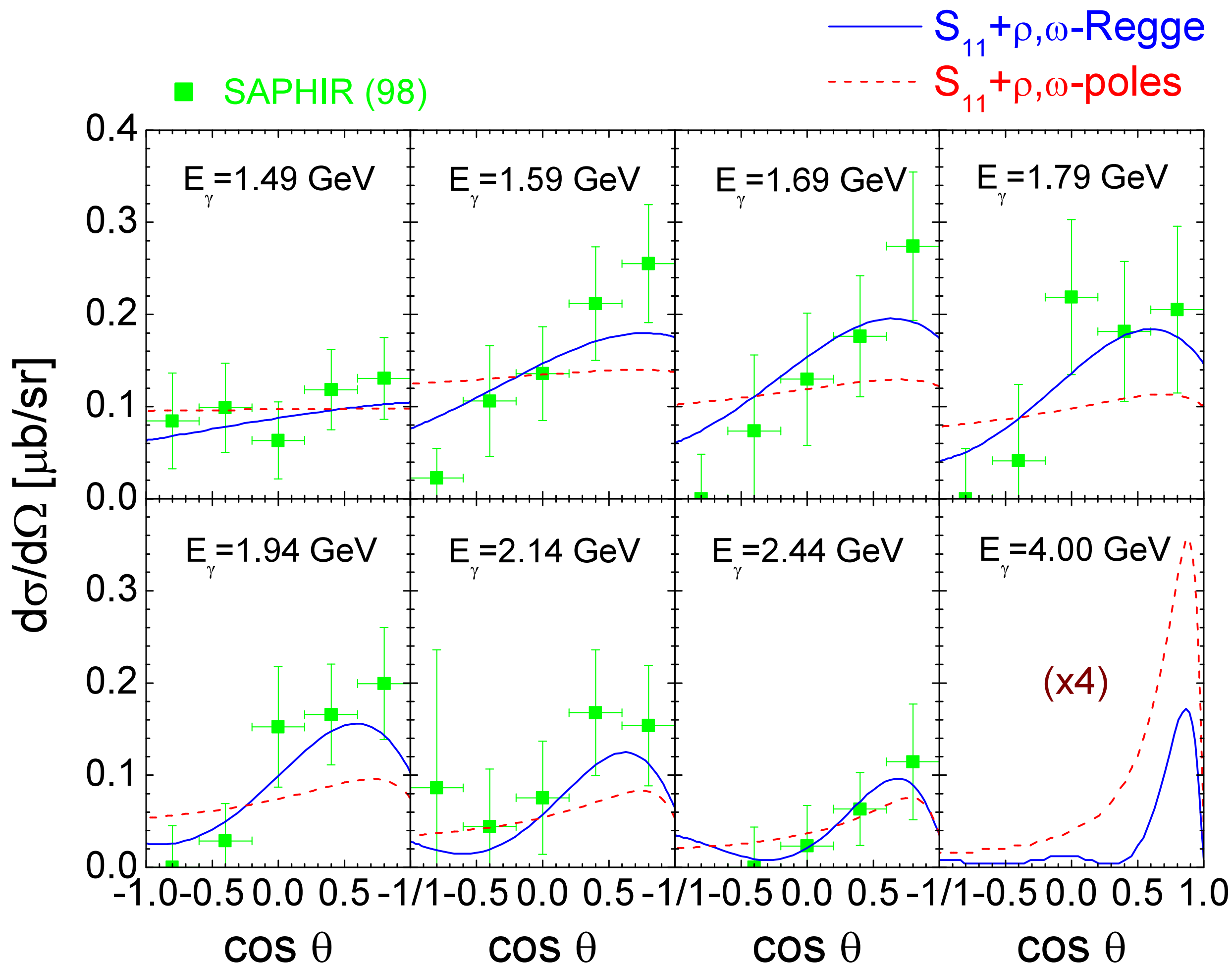
$\gamma p \to \eta' p$

Differential Cross Sections



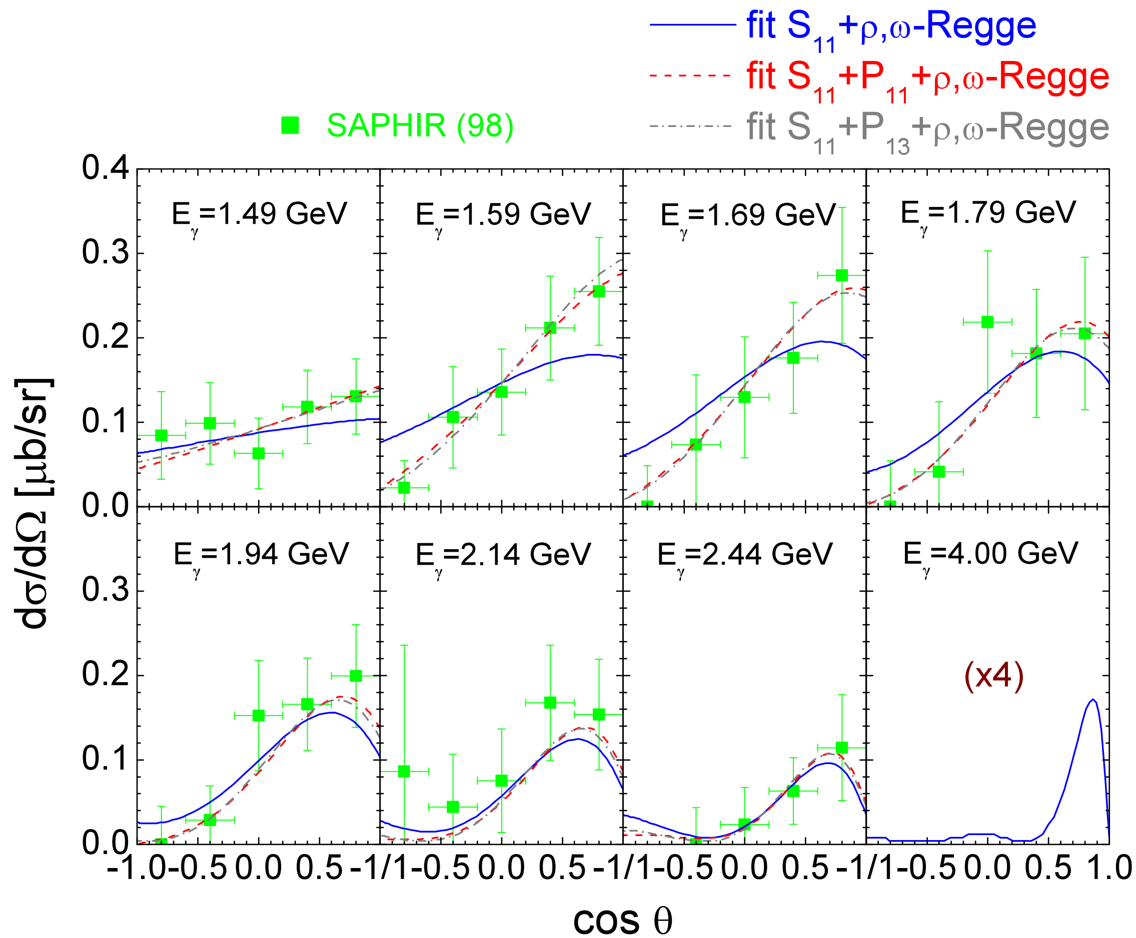
$\gamma p \rightarrow \eta' p$

Differential Cross Sections



$\gamma p \rightarrow \eta' p$ Differential Cross Sections

An additional P_{11} or P_{13} N^* can equally improve the fit.



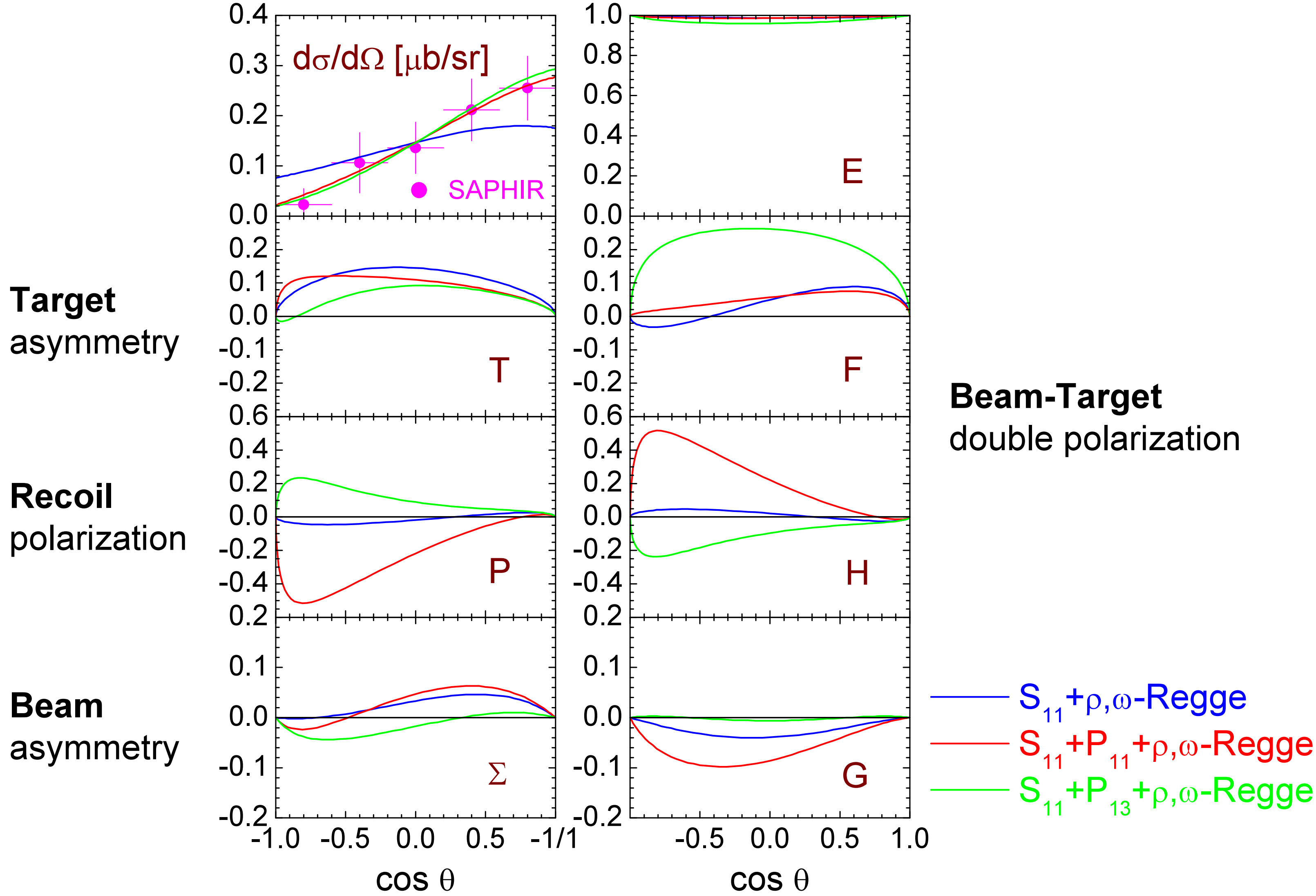
Results:

$S_{11} + \rho,\omega$ fit : $M_{S_{11}}$ = (1959 ± 35) MeV

$S_{11} + P_{11} + \rho,\omega$ fit : $M_{S_{11}}$ = (1932 ± 16) MeV , $M_{P_{11}}$ = (1951 ± 32) MeV

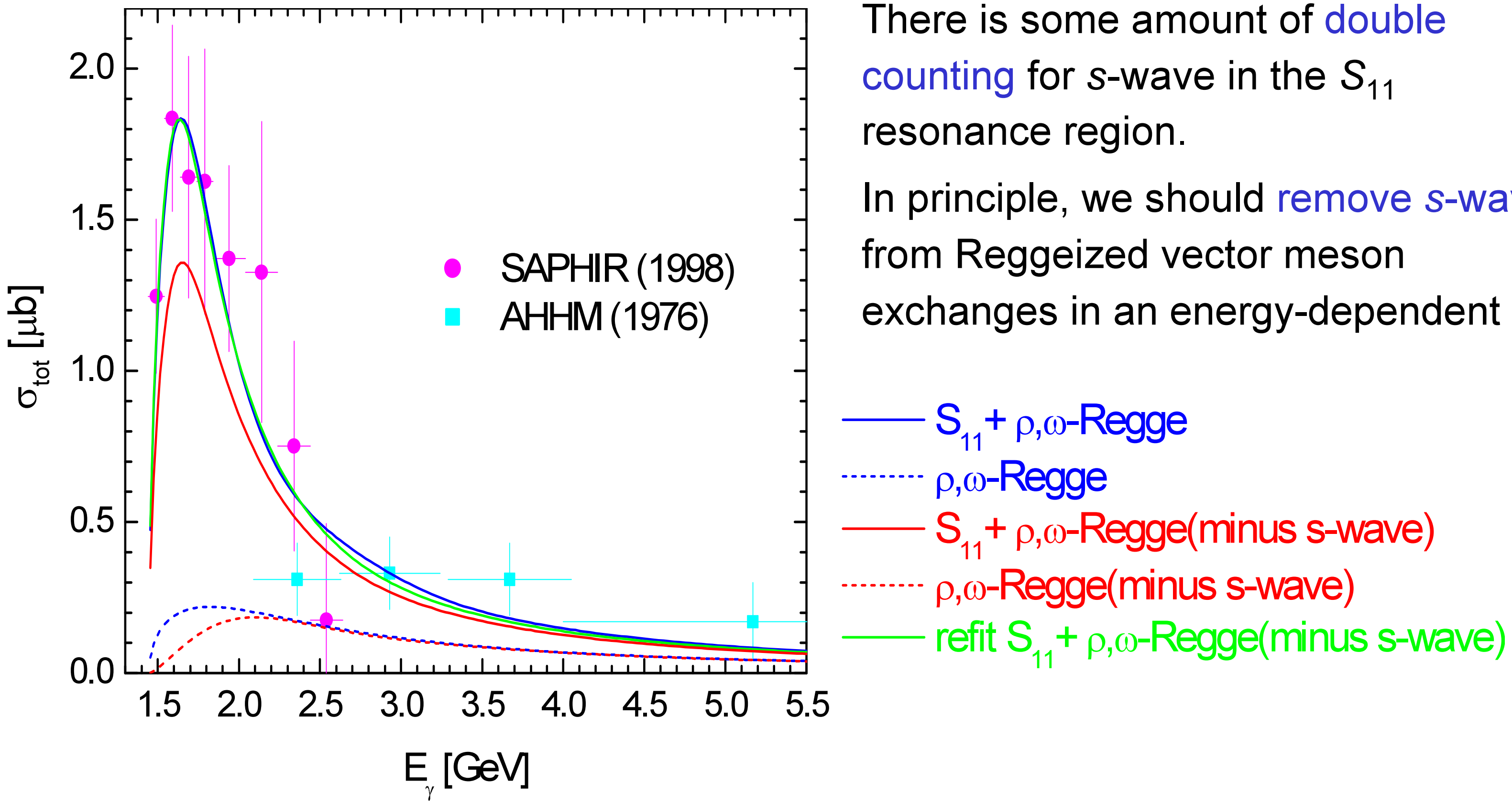
$S_{11} + P_{13} + \rho,\omega$ fit : $M_{S_{11}}$ = (1933 ± 14) MeV , $M_{P_{13}}$ = (1954 ± 37) MeV

$\gamma p \to \eta' p$



Duality

s-channel resonances ↔ *t*-channel Reggeized vector meson exchanges



There is some amount of double counting for *s*-wave in the S_{11} resonance region.

In principle, we should remove *s*-wave from Reggeized vector meson exchanges in an energy-dependent way.

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

- Our isobar model modified by Reggeized *t*-channel exchanges describe current data reasonably well, even without including *P*-wave *N**
- Including either a P_{11} or a P_{13} *N** equally improves the fit; need polarization measurements (e.g. ***H*** and ***F***) to distinguish their contribution
- It is demonstrated that η' photoproduction is a very good reaction to study *N** above W = 1.9 GeV, which are rarely studied
- More precise data are needed for $\gamma p \rightarrow \eta' p$ reaction in order to determine involved *N**

  Good news — data coming from JLab, GRAAL, and Bonn
- Need to understand more about the duality problem and how to avoid the double counting for *s*- and *t*-channels when Regge trajectories are used