N*2002, Pittsburgh, Oct. '02

Beyond the Known Baryon Resonances

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Also

η- Photoproduction and electroproduction:

BS and Z. Li, nucl-th/0202007

Eur. Phys. J. A11 (2001) 217 (nucl-th/0104084)

Q. Zhao, BS, Z. Li, J. Phys. G28 (2002) 1293 (nucl-th/0011069)

Strangeness photo- electro-production:

BS, nucl-th/0105001

W.-T. Chiang, F. Tabakin, H. Lee, BS Phys. Lett B517 (2001) 101 (nucl-th/0104052)

T. Mizutani, C. Fayard, G.-H. Lamot, BS Phys. Rev. C58 (1998) 75 (nucl-th/9712037)

WHY?

We all know!

HOW?

One possible approach:

- Formalism: *Chiral Constituent Quark Approach*
  - Based on the SU(6)⊗O(3) symmetry
  - Configuration mixing

$$\gamma + p \rightarrow \text{pseudoscalar meson} + \text{Baryon}$$

$$E_\gamma < 2.5 \text{ GeV}$$

- Observables
  - Differential and total cross sections
  - Polarization observables
- "Missing" resonances

Theoretical frame

- **Transition matrix elements : based on the low energy QCD Lagrangian**

$$\mathcal{L} = \bar{\psi}\left[\gamma_\mu(i\partial^\mu + V^\mu + \gamma_5 A^\mu) - m\right]\psi + \dots$$

- Differential cross section for meson photoproduction in the center of mass frame :

$$\frac{d\sigma^{c.m.}}{d\Omega} = \frac{\alpha_e\alpha_m(E_N + M_N)(E_f + M_f)}{4s(M_f + M_N)^2}\frac{|\mathbf{q}|}{|\mathbf{k}|}|\mathcal{M}'_{fi}|^2$$

$$\mathcal{M}'_{fi} = \langle N_f|H_{m,e}|N_i\rangle + \sum_j\Big\{\frac{\langle N_f|H_m|N_j\rangle\langle N_j|H_e|N_i\rangle}{E_i + \omega - E_j}$$

$$+\frac{\langle N_f|H_e|N_j\rangle\langle N_j|H_m|N_i\rangle}{E_i - \omega_m - E_j}\Big\} + \mathcal{M}_T$$

- **Contributions from the s- channel resonances**

$$\mathcal{M}_{N^*} = \frac{2M_{N^*}}{s - M_{N^*}(M_{N^*} - i\Gamma(q))}e^{-\frac{k^2+q^2}{6\alpha_{ho}^2}}\mathcal{A}_{N^*},$$

- **contributions from each resonance determined by a new set of parameters**

$$\mathcal{A}_{N^*} \to \mathrm{C_{N^*}}\mathcal{A}_{N^*},$$

so that

- Exact $SU(6)\otimes O(3)$ symmetry :

$C_{N^*}=1$; for $S_{11}(1535)$, $P_{11}(1710)$, $P_{13}(1720)$, $D_{13}(1520)$, $F_{15}(1680)$, $\cdots$

$C_{N^*}=0$; for $S_{11}(1650)$, $D_{13}(1700)$, $D_{15}(1675)$

- Broken $SU(6)\otimes O(3)$ symmetry :

$\longrightarrow$ **the configuration mixings caused by the one gluon exchange (Isgur-Karl).**

- **The configuration mixings can be expressed in terms of the mixing angle between the two $SU(6)\otimes O(3)$ states $|N(^2P_M)>$ with the total quark spin 1/2 and $|N(^4P_M)>$ with the total quark spin 3/2**

$$
\begin{aligned}
|S_{11}(1535)> &= |N(^2P_M)_{\frac{1}{2}^-}> \cos\theta_S \;-\; |N(^4P_M)_{\frac{1}{2}^-}> \sin\theta_S, \\
|S_{11}(1650)> &= |N(^2P_M)_{\frac{1}{2}^-}> \sin\theta_S \;+\; |N(^4P_M)_{\frac{1}{2}^-}> \cos\theta_S,
\end{aligned} \tag{1}
$$

and

$$
\begin{aligned}
|D_{13}(1520)> &= |N(^2P_M)_{\frac{3}{2}^-}> \cos\theta_D \;-\; |N(^4P_M)_{\frac{3}{2}^-}> \sin\theta_D, \\
|D_{13}(1700)> &= |N(^2P_M)_{\frac{3}{2}^-}> \sin\theta_D \;+\; |N(^4P_M)_{\frac{3}{2}^-}> \cos\theta_D.
\end{aligned} \tag{2}
$$

- **Isgur-Karl Model (PL 72B, '77):**

$$\theta_{S_{11}} \;=\; -32^\circ \;;\; \theta_{D_{13}} \;=\; 6^\circ.$$

- **How the coefficients C_{N^*} in**

$$\mathcal{A}_{N^*} \rightarrow \mathbf{C_{N^*}}\mathcal{A}_{N^*},$$

are related to the mixing angles?

$$\mathcal{A}_{N^*} \propto < N|H_m|N^* >< N^*|H_e|N >,$$

then

$$\mathcal{A}_{S_{11}(1535)} \propto \Big[< N|H_m|N(^2P_M)_{\frac{1}{2}^-} > \cos\theta_S - < N|H_m|N(^4P_M)_{\frac{1}{2}^-} > \sin\theta_S \Big]$$
$$\Big[< N(^2P_M)_{\frac{1}{2}^-}|H_e|N > \cos\theta_S - < N(^4P_M)_{\frac{1}{2}^-}|H_e|N > \sin\theta_S \Big],$$

$$\propto \Big[\cos^2\theta_S - \sin\theta_S \cos\theta_S \frac{< N|H_m|N(^4P_M)_{\frac{1}{2}^-} >}{< N|H_m||N(^2P_M)_{\frac{1}{2}^-} >} \Big]$$
$$\Big[< N|H_m|N(^2P_M)_{\frac{1}{2}^-} >< N(^2P_M)_{\frac{1}{2}^-}|H_e|N > \Big].$$

Finally,

$$C_{S_{11}(1535)} = \cos\theta_S(\cos\theta_S - \sin\theta_S).$$
$$C_{S_{11}(1650)} = -\sin\theta_S(\cos\theta_S + \sin\theta_S),$$

$$C_{S_{11}(1535)} - C_{S_{11}(1650)} = 1$$

$$C_{D_{13}(1520)} = \cos\theta_D(\cos\theta_D - \sqrt{\frac{1}{10}}\sin\theta_D)$$
$$C_{D_{13}(1700)} = \sin\theta_D(\sqrt{\frac{1}{10}}\cos\theta_D + \sin\theta_D),$$

$$C_{D_{13}(1520)} + C_{D_{13}(1700)} = 1$$

The mixing angle predicted in the Isgur-Karl model leads to

$$C_{S_{11}(1535)} = 1.17 \ ; \ C_{S_{11}(1650)} = -0.17$$

$$C_{D_{13}(1520)} = 0.96 \ ; \ C_{D_{13}(1700)} = 0.04$$

Baryon	Three and four star resonances	One and two star resonances
N^*	$S_{11}(1535)$, $S_{11}(1650)$,	$S_{11}(2090)$,
	$P_{11}(1440)$, $P_{11}(1710)$, $P_{13}(1720)$,	$P_{11}(2100)$, $P_{13}(1900)$,
	$D_{13}(1520)$, $D_{13}(1700)$, $D_{15}(1675)$,	$D_{13}(2080)$, $D_{15}(2200)$,
	$F_{15}(1680)$,	$F_{15}(2000)$, $F_{17}(1990)$,
	$G_{17}(2190)$, $G_{19}(2250)$,	
	$H_{19}(2220)$,	
Λ^*	$S_{01}(1405)$, $S_{01}(1670)$, $S_{01}(1800)$,	
	$P_{01}(1600)$, $P_{01}(1810)$, $P_{03}(1890)$,	
	$D_{03}(1520)$, $D_{03}(1690)$, $D_{05}(1830)$,	$D_{03}(2325)$,
	$F_{05}(1820)$, $F_{05}(2110)$,	$F_{07}(2020)$,
	$G_{07}(2100)$,	
	$H_{09}(2350)$,	
Σ^*	$S_{11}(1750)$,	$S_{11}(1620)$, $S_{11}(2000)$,
	$P_{11}(1660)$, $P_{11}(1880)$, $P_{13}(1385)$,	$P_{11}(1770)$, $P_{11}(1880)$, $P_{13}(1840)$,
		$P_{13}(2080)$,
	$D_{13}(1670)$, $D_{13}(1940)$, $D_{15}(1775)$,	$D_{13}(1580)$,
	$F_{15}(1915)$, $F_{17}(2030)$.	$F_{15}(2070)$,
		$G_{17}(2100)$.

Table 1: Isospin-1/2 baryon resonances [1] with mass $M_{N^*} \leq 2.5$ GeV. Notations are $L_{2I\ 2J}(mass)$ and $L_{I\ 2J}(mass)$ for N^* and Y^*, respectively.

Introduction

$$\gamma p \rightarrow N^* \rightarrow \eta p$$

○ Reaction mechanism

Table 1: Isospin 1/2 resonances with their assignments in $SU(6) \otimes O(3)$ configurations.

States	$SU(6) \otimes O(3)$	Mass (GeV)	Width (GeV)
$S_{11}(1535)$	$N(^2P_M)_{\frac{1}{2}^-}$		
→ $S_{11}(1650)$	$N(^4P_M)_{\frac{1}{2}^-}$	1.650	0.150
$D_{13}(1520)$	$N(^2P_M)_{\frac{3}{2}^-}$	1.520	0.130
→ $D_{13}(1700)$	$N(^4P_M)_{\frac{3}{2}^-}$	1.700	0.150
→ $D_{15}(1675)$	$N(^4P_M)_{\frac{5}{2}^-}$	1.675	0.150
$P_{13}(1720)$	$N(^2D_S)_{\frac{3}{2}^+}$	1.720	0.150
$F_{15}(1680)$	$N(^2D_S)_{\frac{5}{2}^+}$	1.680	0.130
$P_{11}(1440)$	$N(^2S'_S)_{\frac{1}{2}^+}$	1.440	0.150
$P_{11}(1710)$	$N(^2S_M)_{\frac{1}{2}^+}$	1.710	0.100
$P_{13}(1900)$	$N(^2D_M)_{\frac{3}{2}^+}$	1.900	0.500
$F_{15}(2000)$	$N(^2D_M)_{\frac{5}{2}^+}$	2.000	0.490

Notation: $(^{2S+1}L_{\pi})_{J^{\pi}}$ → S, A, M

- **Study of configuration mixing & extraction of mixing angles**
- **Initial state : photo-excitation couplings** $(A_{1/2}, A_{3/2})$
- **Final state : N^* decay to ηN**
- **Extraction of $g_{\eta NN}$ and $\Gamma_{S_{11}}$**
- **Size of the background**
- **WHAT MORE?**

$\gamma p \to \eta p$

Fig. 1

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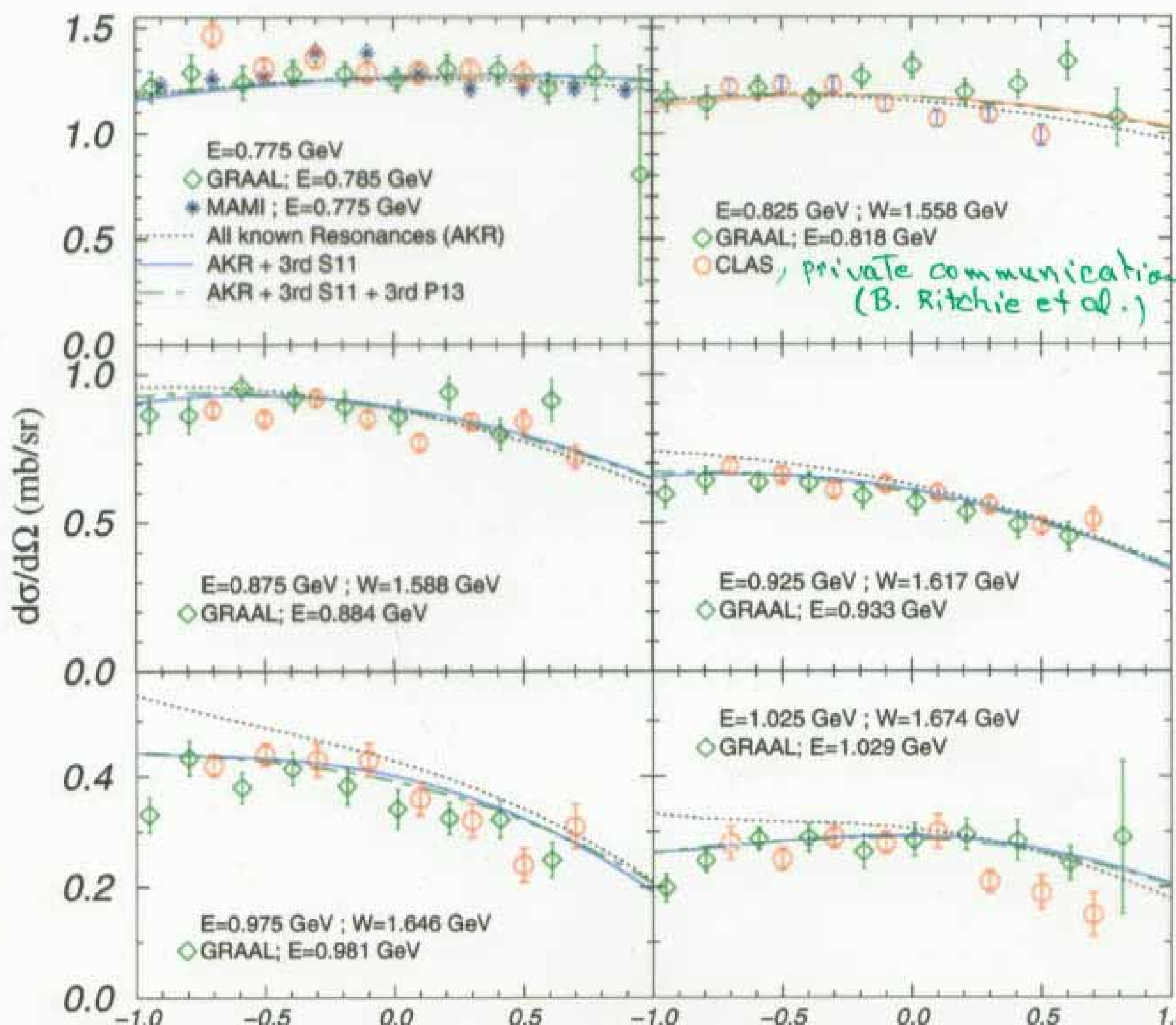
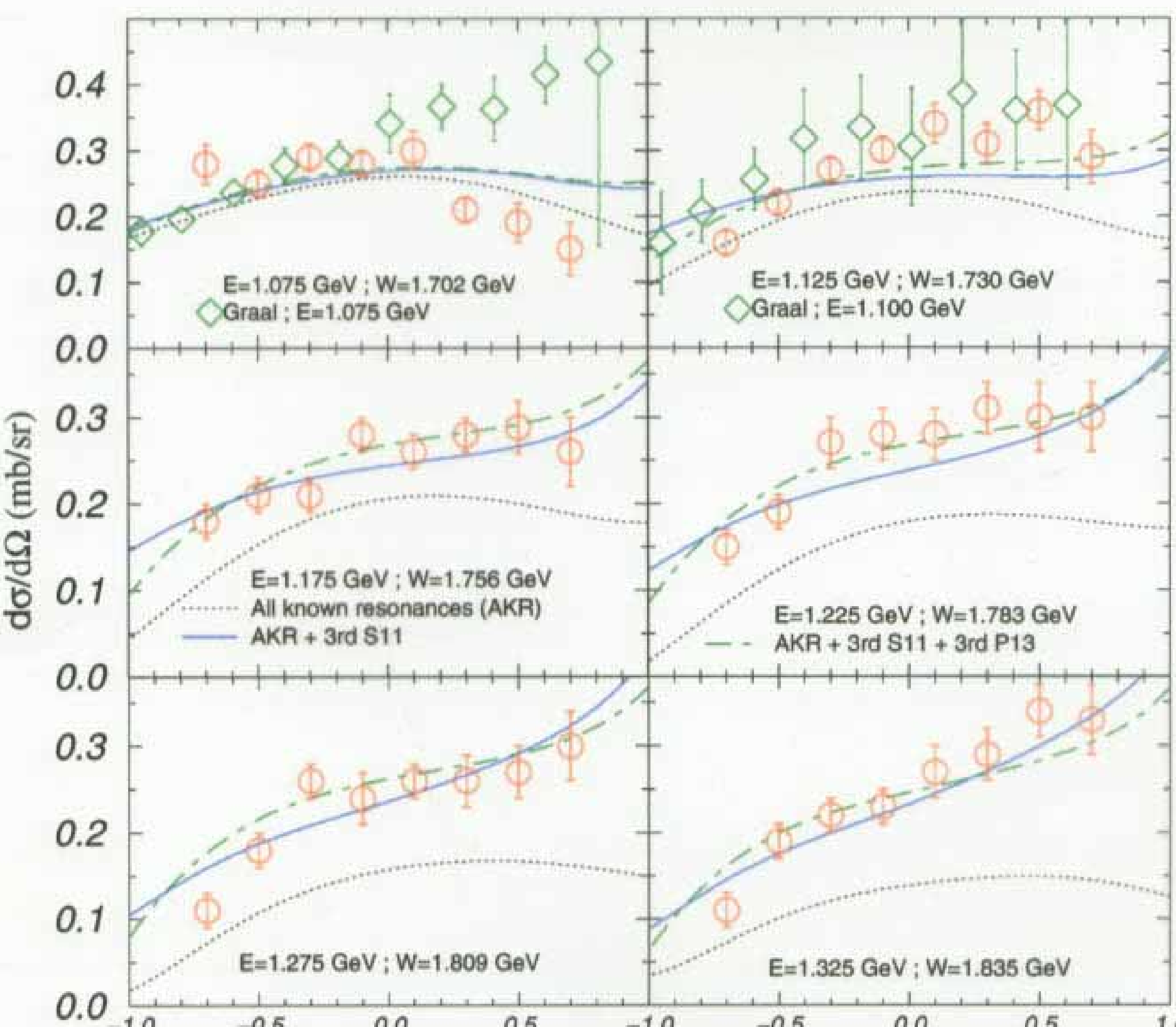


$\gamma p \to \eta p$

Fig. 2

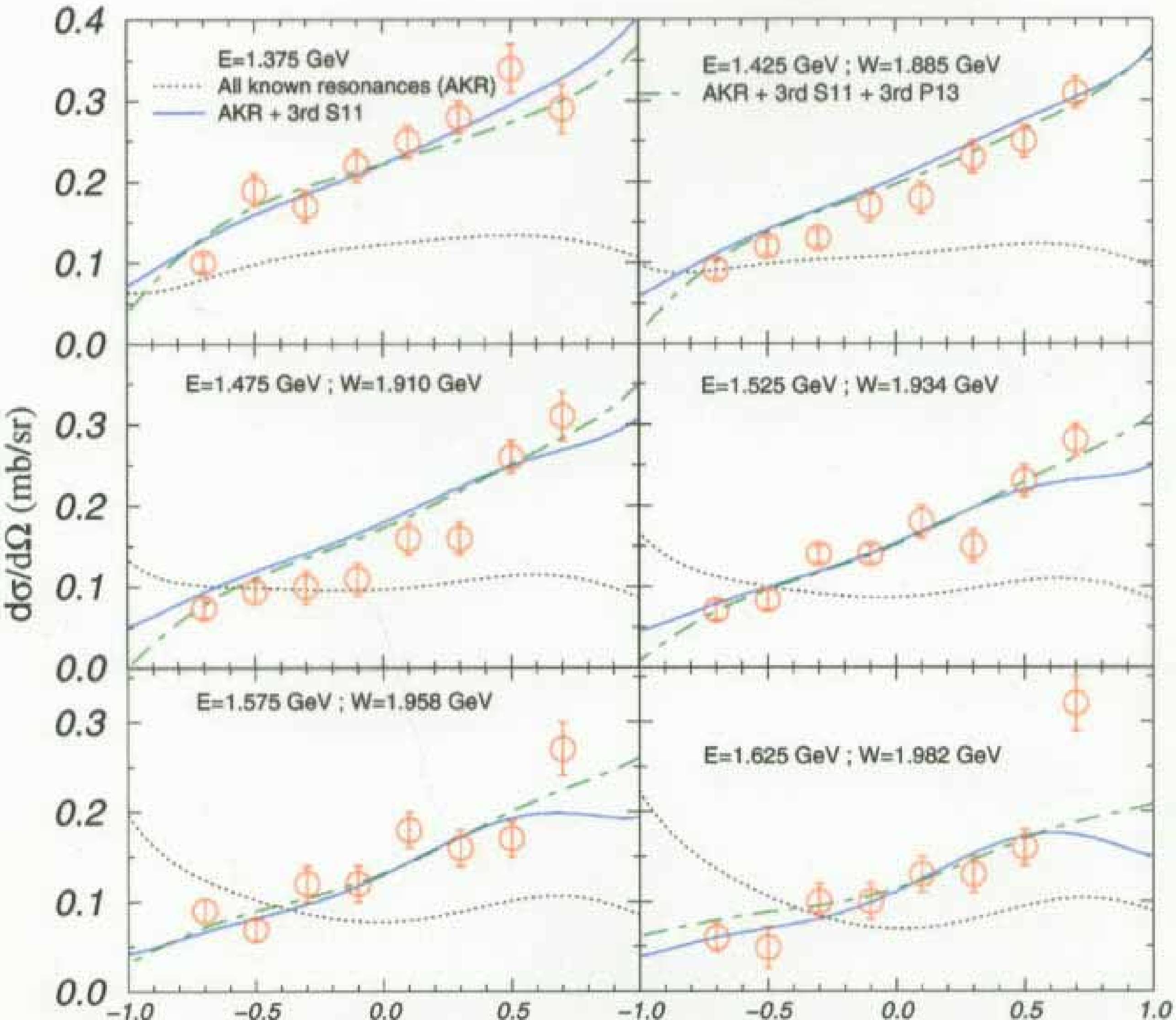
Li & Saghai



$\gamma p \to \eta p$

Fig. 3

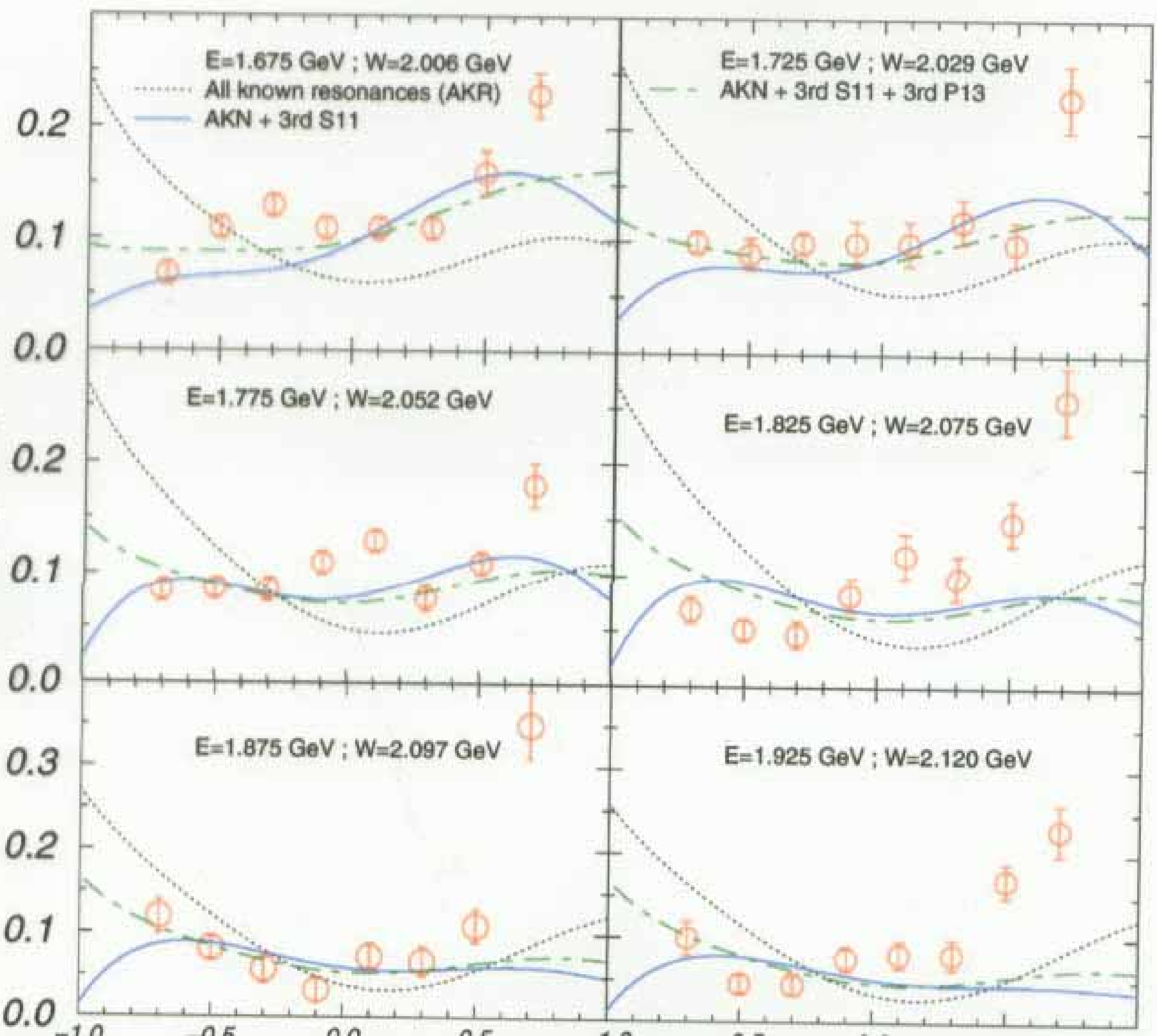
Li & Saghai



$\gamma p \rightarrow \eta p$

Fig. 4

Li & Saghai



$\gamma p \to \eta p$

prediction

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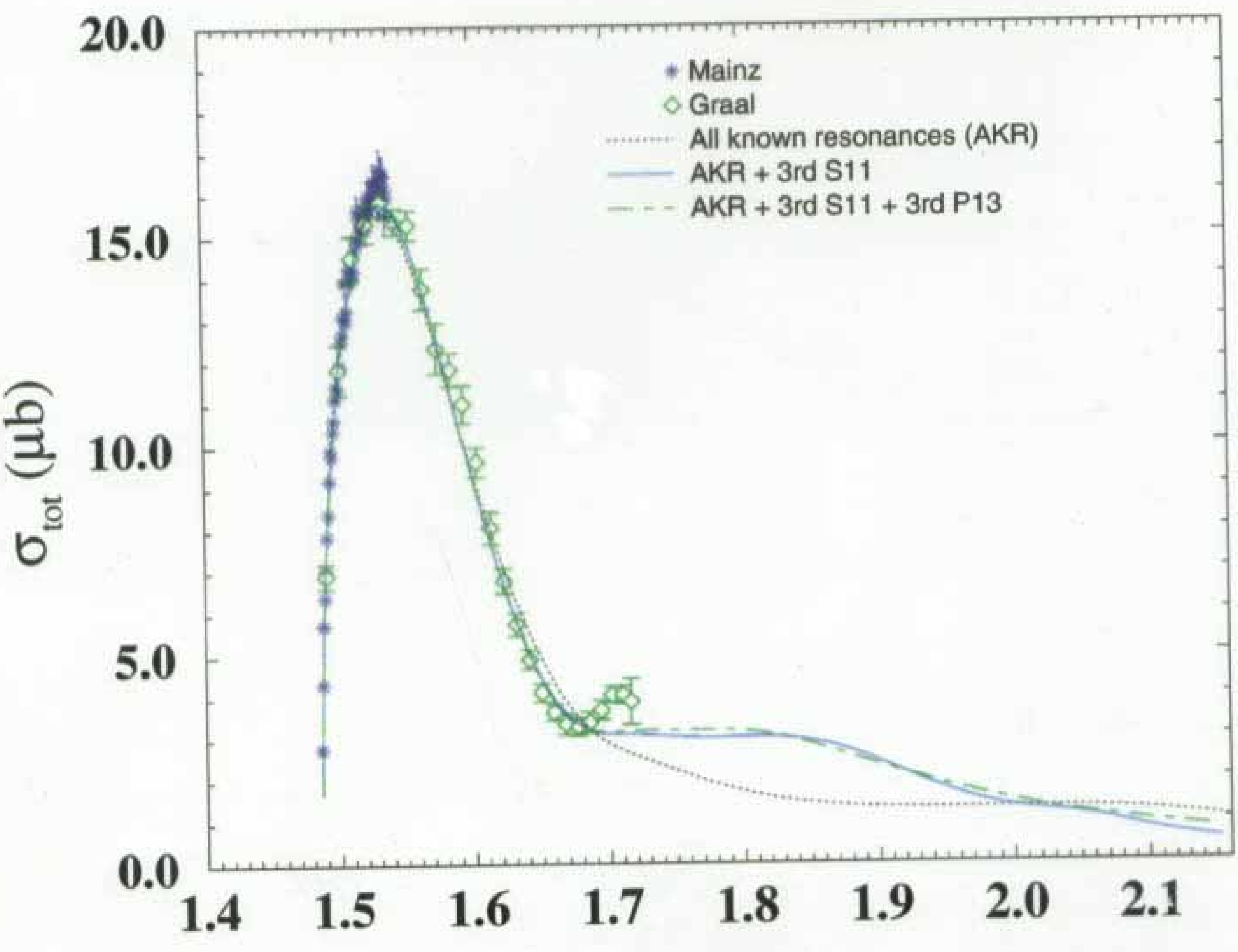
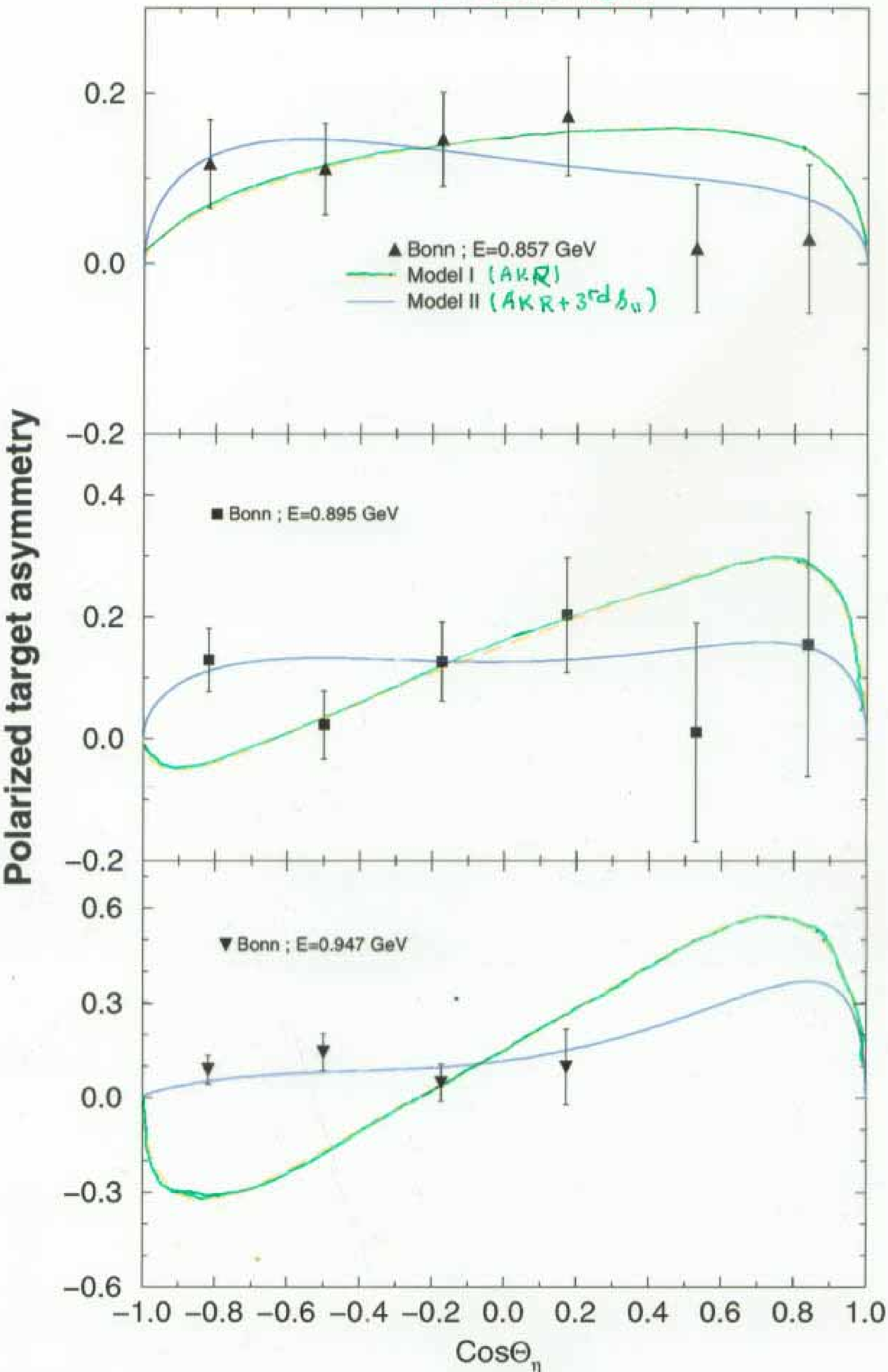
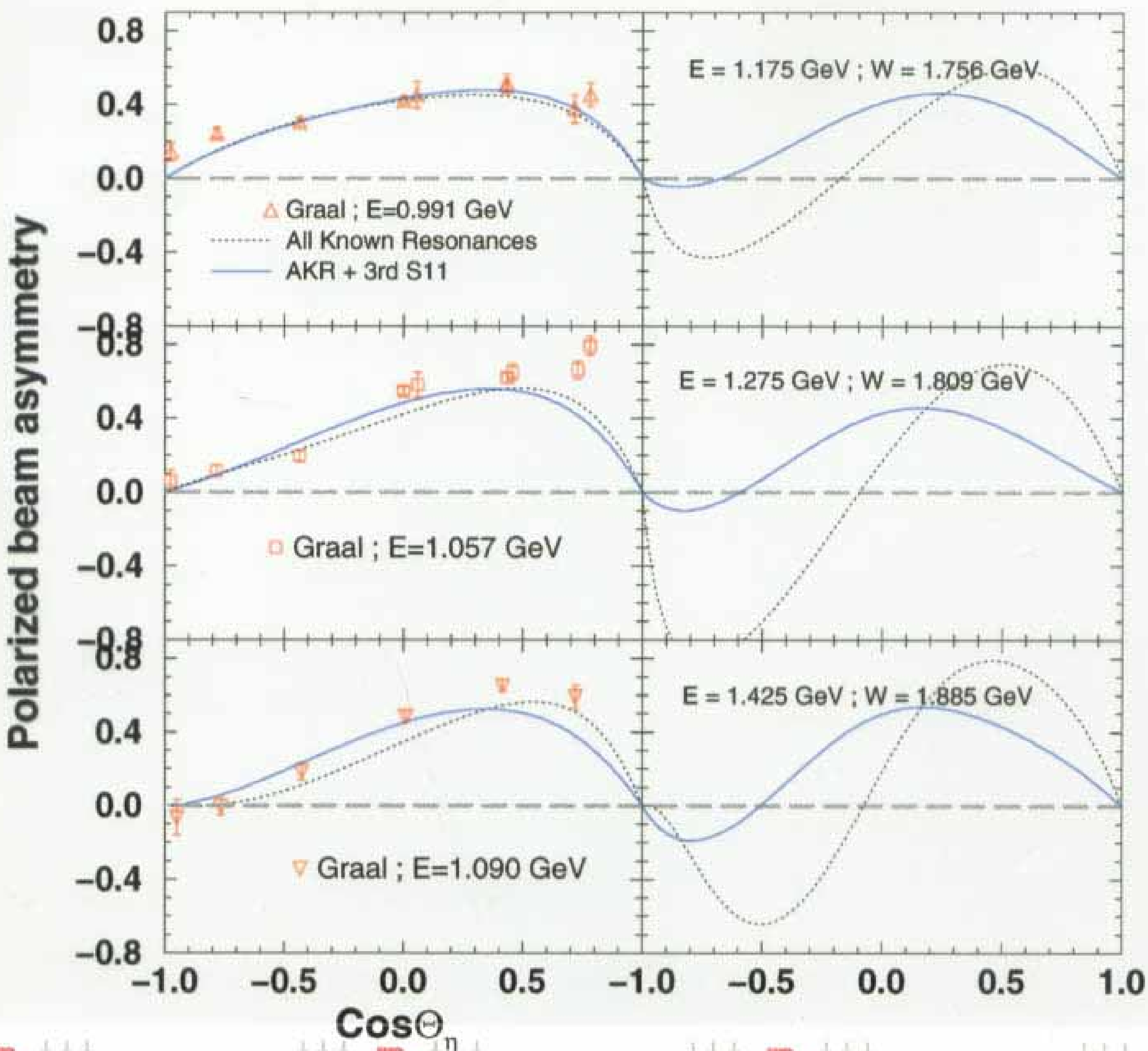


$\gamma \vec{p} \to \eta p$

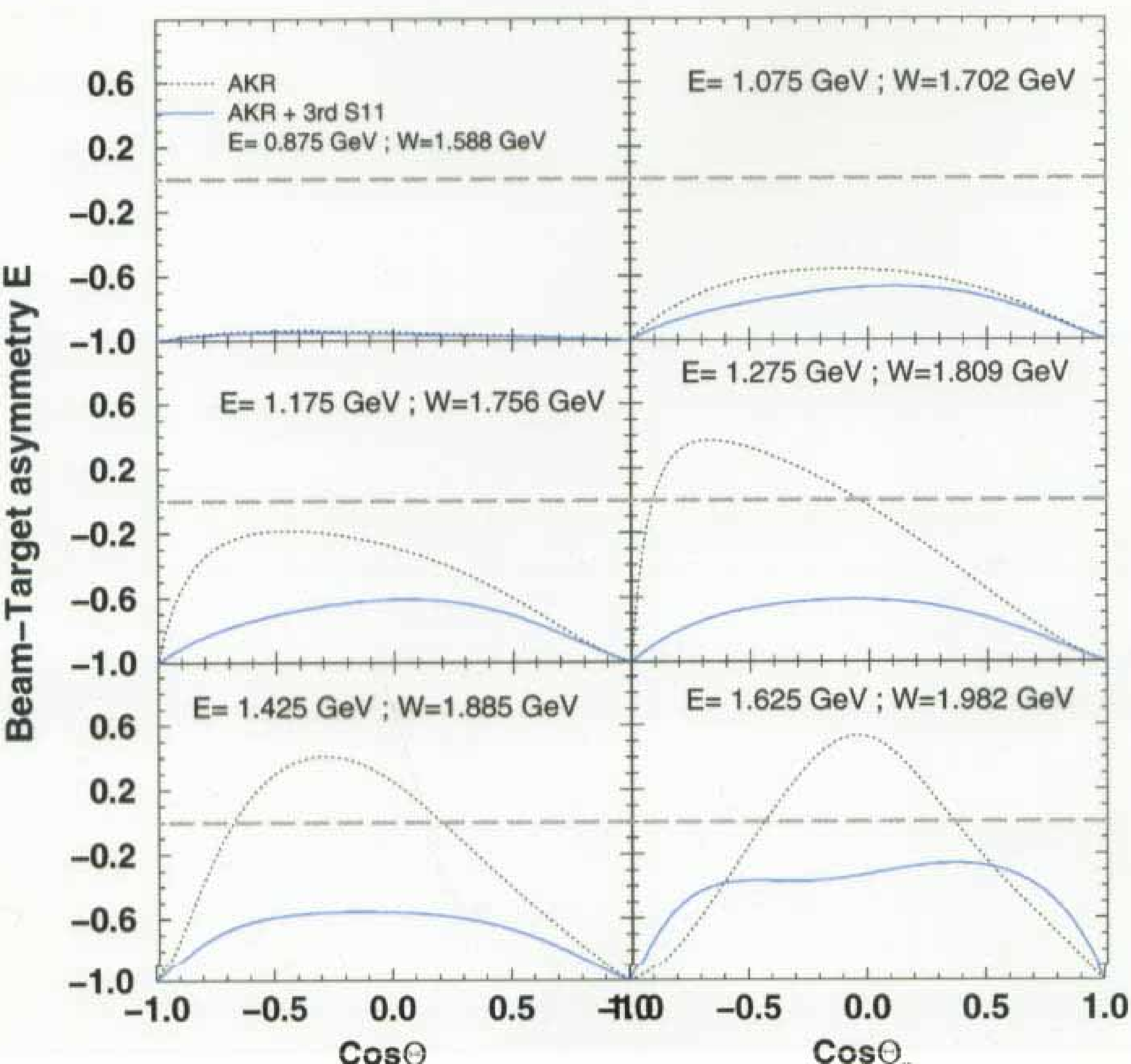
Prediction



$\vec{\gamma} p \to \eta p$



$$\vec{\gamma} + \vec{P} \longrightarrow \eta P$$



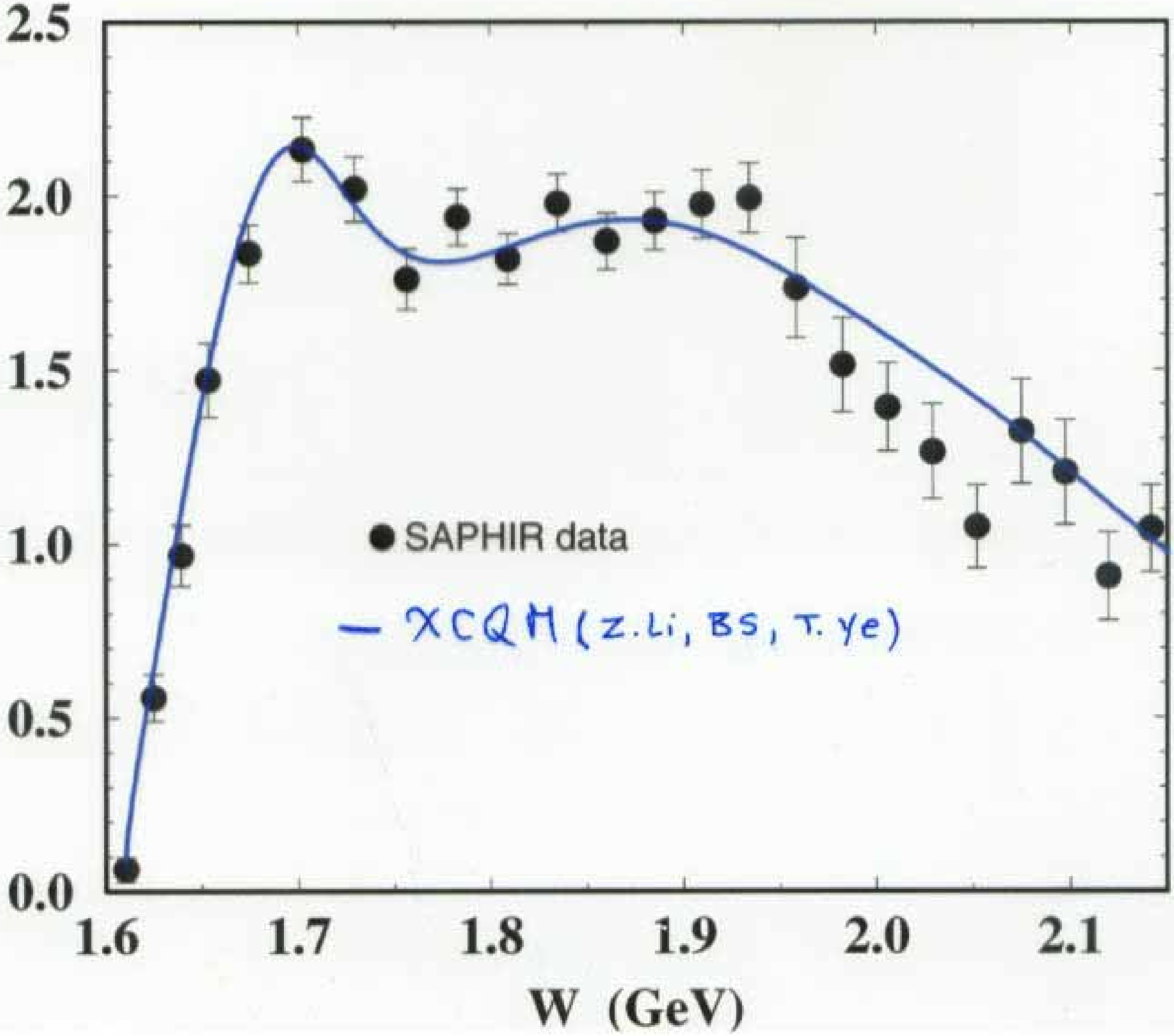
	All known resonances	+ 3rd S_{11}	+ 3rd P_{13}
$\chi^2_{d.o.f}$	6.3	2.9	2.6

	Parameter	Present Work	Isgur-Karl PL 72B (1977)
3rd S_{11}	θ_S	$-35°$	$-32°$
	θ_D	$+10°$	$+6°$
	M (GeV)	1.780	
	Γ (MeV)	280	
⋮	⋮	⋮	
3rd P_{13}	M (GeV)	1.890	
	Γ (MeV)	220	

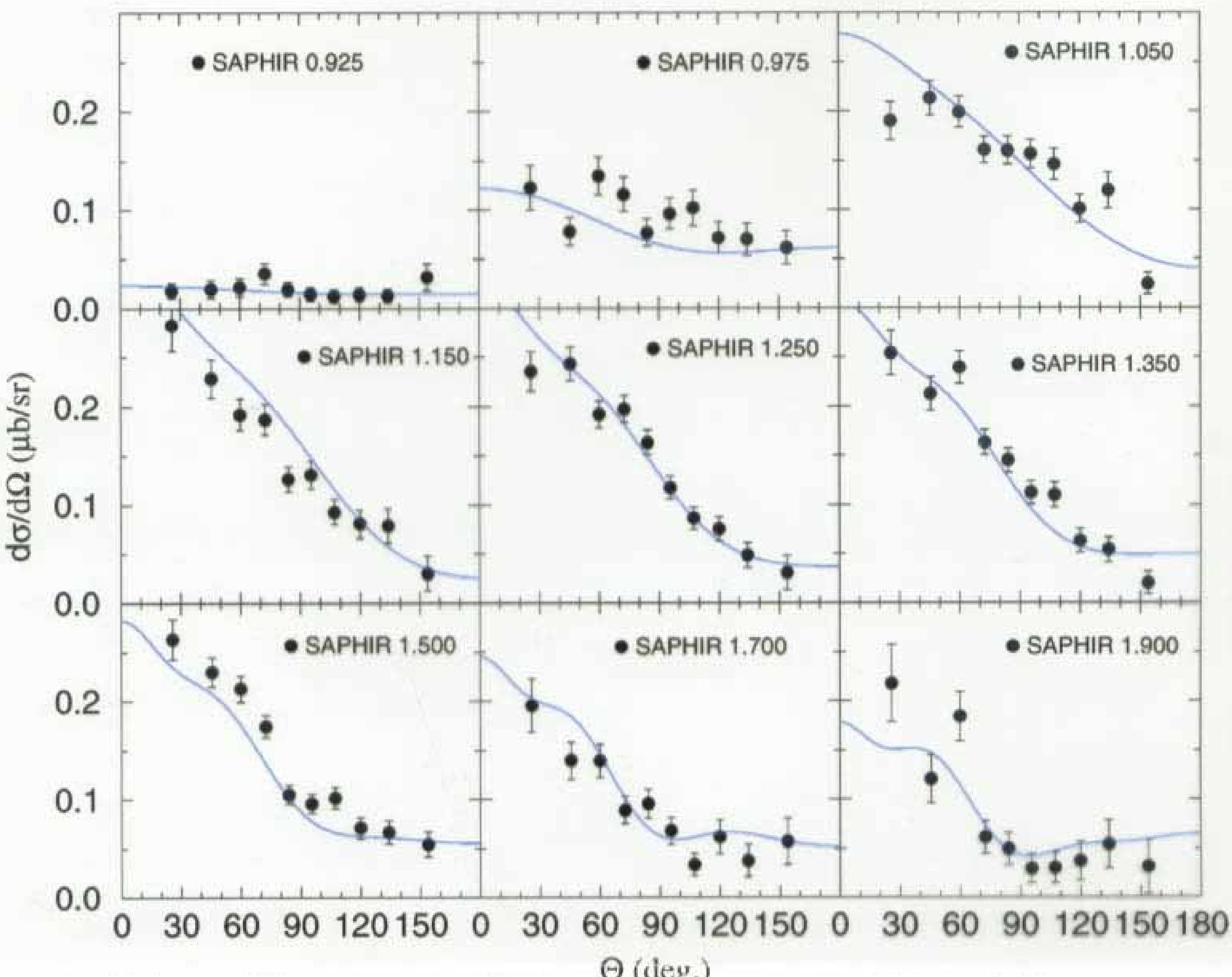
New/Missing Resonances

Resonance	M (MeV)	Γ_{tot} (MeV)	Reference	Comment
S_{11}	1780	280	Present work	
	1730	180	Li-Workman PRC53 '96	KY molecule
	1792 (23)	360 (49)	Batinic et al. Phys. Script 58 '98	Coupled Channel
	1800	165^{+165}_{-85}	BES collaboration PL B510 '01	J/ψ decay
	1861		Giannini et al. nucl-th/0111073	Hypercentral CQM
P_{13}	1890	220	Present work	P_{13} (1720)**** P_{13} (1920)**
	1816 1894 1939		Giannini et al., ibid	ibid
	1870 1910 1950 2030		Capstick - Roberts PR D49 '94	Relativized pair-creation ($^3P_0$) model

$\gamma p \rightarrow K^+ \Lambda$



$\gamma p \to K^+\Lambda$



Concluding Remarks

- A quark model approach was presented for the electromagnetic production of pseudoscalar mesons.

- This approach was applied to the process

$$\gamma p \to \eta p$$

- Recent data for this reaction, including polarization observables, are well reproduced and show the major role played by theknown resonances in the first resonance region , provided the configuration mixing .

- Mixing angles in agreement with previous predictions.

- $\frac{g_{\eta NN}}{\sqrt{4\pi}} = 0.2$

- Photo-excitation helicity amplitudes

- Partial decay widths

- Second and third resonance regions ???

Need for a third S_{11} resonance confirmed

Indications for a third P_{13} resonance