Coupled channel approach to $K^+\Lambda$ photoproduction

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References:

Nucl. Phys. A755, 463 (2005), and in preparation.

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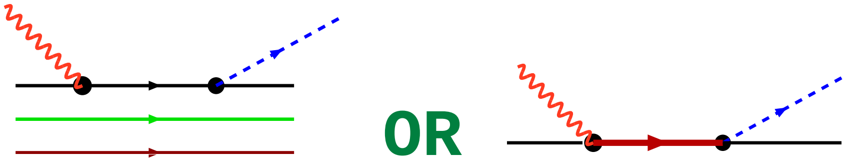

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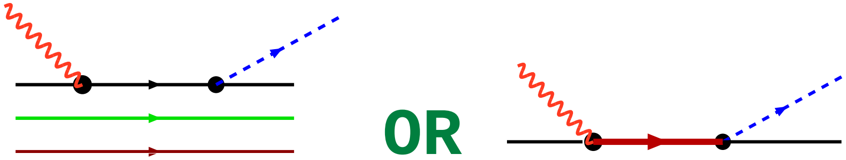

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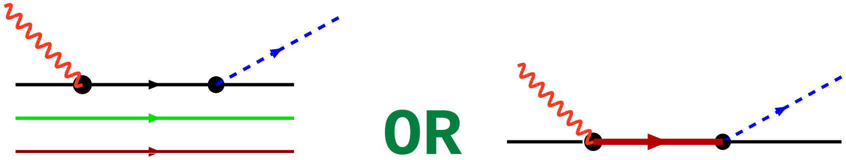

- How does the transition occur?
- New accurate experimental DATA:
  [JLAB] J.W.C. McNabb *et al.*, PRC 69 (2004) 042201.
  [SAPHIR] K.H. Glander *et al.*, EPJA 19 (2004) 251.

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- Inconsistencies in the data?

- Can we pin down the set of “most” relevant resonances?

Experimental status

The recent data we are considering are:

Experiment	Observable	# of data points
JLab	$d\sigma/d\Omega$	920
LEPS	Σ_γ	44
SAPHIR	$d\sigma/d\Omega$	720
JLab	Σ_Λ	233

J.W.C. McNabb *et al.*, Phys. Rev. C 69, 042201 (2004).
J.W.C. McNabb, PhD Thesis, CMU (2002); R. Bradford, PhD Thesis, CMU (2005)
K.H. Glander *et al.*, Eur. Phys. J. A 19, 251 (2004).

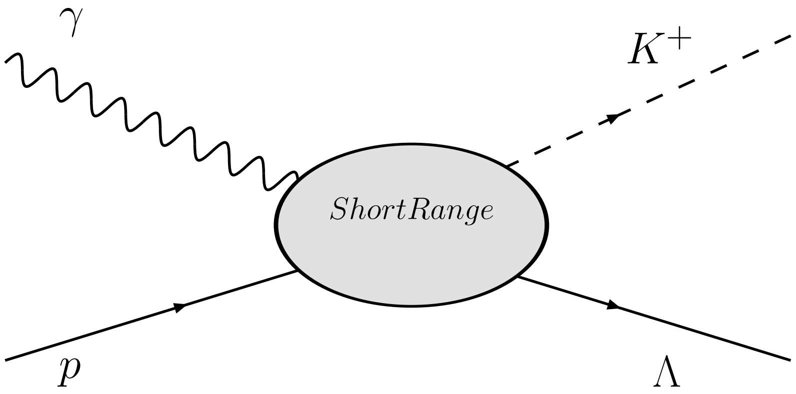
Similarly one could study $\gamma p \rightarrow K^+\Sigma^0$
many data available

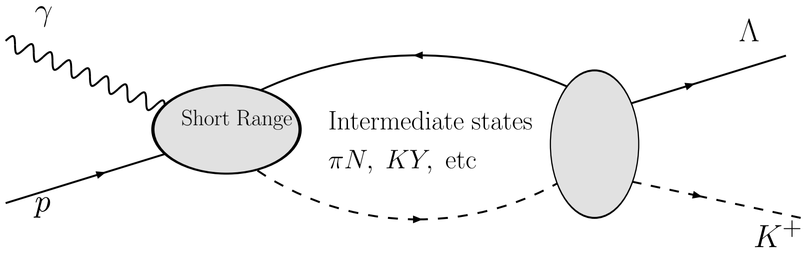
Coupled channel model

A reaction theory is needed to properly interpret the data:

The main two ingredients are:

- A direct reaction mechanism
- An account of external dynamics: coupled channel





Note: the complete problem should include πN, ρN, ωN, $\pi\pi N$, ΣN, ΛN, ηN, etc

Coupled channel model

Our coupled channel equations are written:

$$T_{a,b}(E) = t_{a,b}(E) + t^R_{a,b}(E)\,,$$

with the resonant:

$$t^R_{a,b}(E) = \sum_{N^*_i,N^*_j} \bar{\Gamma}^\dagger_{N^*_i,a}(E)[G^*(E)]_{i,j}\bar{\Gamma}_{N^*_j,b}(E)\,.$$

and non resonant:

$$t_{a,b}(E) = v_{a,b} + \sum_c v_{a,c}G_c(E)t_{c,b}(E)\,,$$

with the dressed vertex:

$$\bar{\Gamma}_{N^*,a}(E) = \Gamma_{N^*,a} + \sum_b \Gamma_{N^*,b}G_b(E)t_{b,a}(E)\,,$$

Coupled Channel Assumptions

On the previous formalism we then make the following assumptions:

- we keep:

$$\gamma p \qquad \pi^+ n, \pi^0 p \qquad K^+\Lambda, K^+\Sigma^0$$

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- It is thus a first approach to the problem.

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$$
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a^{\gamma N \to KY}_{\ell\pm}(q_{KY}, k) &= b^{\gamma N \to KY}_{\ell\pm}(q_{KY}, k) \\
&+ \sum_{\alpha=\mathbf{KY}} \int dp_\alpha p_\alpha^2 \, \mathbf{t}^{\alpha\to\mathcal{KY}}_{\ell\pm}(\mathbf{q}_{\mathbf{KY}}, \mathbf{k}) \mathbf{G}_{\mathbf{0}\alpha}(\mathbf{p}_\alpha) \mathbf{b}^{\gamma\mathbf{N}\to\alpha}_{\ell\pm}(\mathbf{p}_\alpha, \mathbf{k}) \\
&+ \sum_{\alpha=\pi\mathcal{N}} \int dp_\alpha p_\alpha^2 \, \mathbf{t}^{\alpha\to\mathcal{KY}}_{\ell\pm}(\mathbf{q}_{\mathbf{KY}}, \mathbf{k}) \mathbf{G}_{\mathbf{0}\alpha}(\mathbf{p}_\alpha) \mathbf{b}^{\gamma\mathbf{N}\to\alpha}_{\ell\pm}(\mathbf{p}_\alpha, \mathbf{k})
\end{aligned}
$$

where $\mathcal{KY}$, $\pi\mathcal{N}$ refer to the different channels.

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Multistep processes can be isolated

Meson Baryon

Meson-baryon pieces:

- $\pi N \rightarrow \pi N$: **Sato-Lee model for** $v_{\pi N, \pi N}$ **and then compute** $\hat{t}_{\pi N}$
- $\pi N \rightarrow KY$ **and** $KY \rightarrow KY$, **same method as Sato-Lee,** W.-T. Chiang et al. (2004) **with improvements.**

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Pion photoproduction:

- **Resonance part from Capstick-Roberts quark model**
- **Non-resonant defined as SAID minus resonant**

Meson Baryon

The meson-baryon t-matrix:

$$\begin{aligned} t_{KY,KY} &= v^{\text{eff}}_{KY,KY} + \sum_{KY} v^{\text{eff}}_{KY,KY} G_{KY} t_{KY,KY} \\ t_{KY,\pi N} &= \left[v_{KY,\pi N} + t_{KY,KY} G_{KY} \; v_{KY,\pi N} \right] \\ &\times \left[1 + G_{\pi N} \hat{t}_{\pi N,\pi N} \right] . \end{aligned}$$

where

$$v^{\text{eff}}_{KY,KY} = v_{KY,KY} + \sum_{\pi N} v_{KY,\pi N} G_{\pi N} v^{\text{eff}}_{\pi N,KY}$$

with

$$v^{\text{eff}}_{\pi N,KY} = v_{\pi N,KY} + \sum_{\pi N} \hat{t}_{\pi N,\pi N} G_{\pi N} \; v_{\pi N,KY}$$

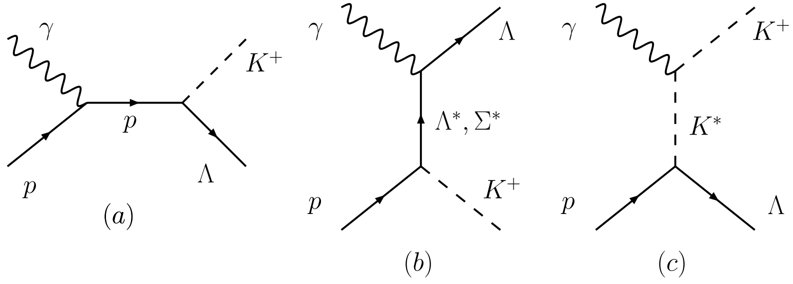
The pure πN scattering t-matrix $\hat{t}_{\pi N,\pi N}$ in the above equations is defined by

$$\hat{t}_{\pi N,\pi N} = v_{\pi N,\pi N} + v_{\pi N,\pi N} G_{\pi N} \hat{t}_{\pi N,\pi N} \, .$$

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

The direct contributions:

$t_{\gamma p\to K^+\Lambda}$ **are obtained in the** **quark model (Li-Saghai)** **Z. Li, PRC (1995); B. Saghai, Z. Li, EPJA (2001).**



The resonance term includes:

N:

$P_{11}(1440), S_{11}(1535), S_{11}(1650), P_{11}(1710), D_{13}(1520), D_{13}(1700)$**,** $P_{13}(1720), P_{13}(1900), D_{15}(1675), F_{15}(1680), F_{15}(2000)$

and

Δ**:** $S_{31}(1900), P_{31}(1900), P_{33}(1920), D_{33}(1700)$

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- Find quark model SU(3) breaking parameters only with direct model
- Compute full coupled channel model and refit parameters of the direct part

Note on parameters

First the SU(3) quark model is used for the resonance terms.

we introduce a SU(3) breaking parameter for each resonance

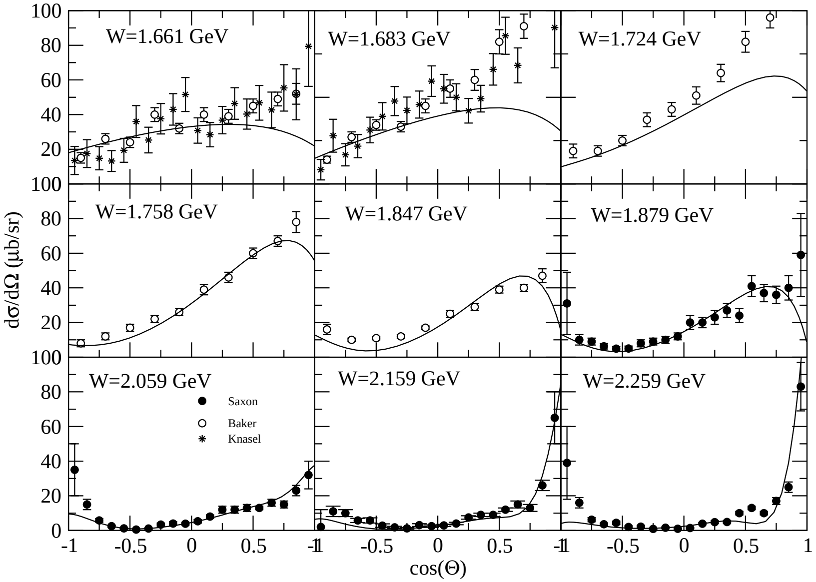
To study new resonances we include a $3^{rd} S_{11}$ and a $3^{rd} P_{13}$

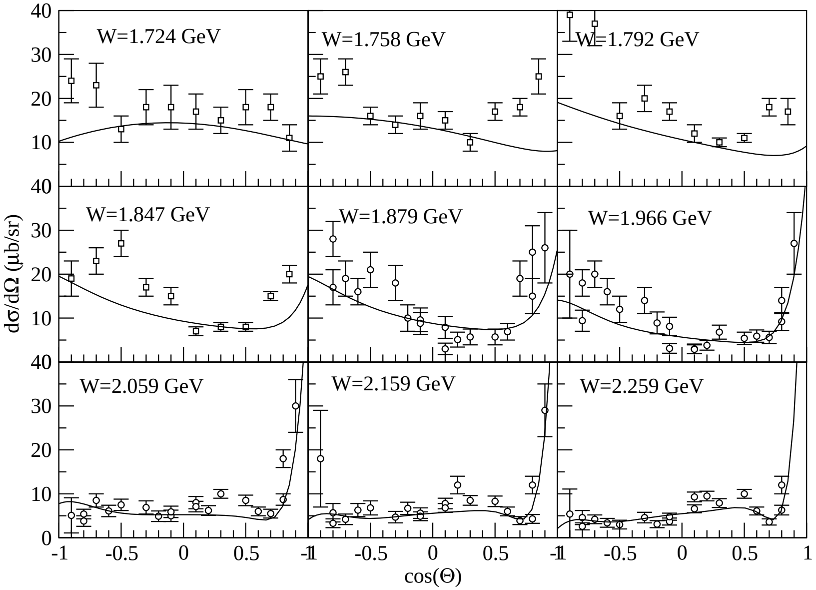
The meson-baryon part is kept fixed

$\pi N \to KY$: $d\sigma/d\Omega$

$\to K^0\Lambda$

$\to K^0\Sigma^0$





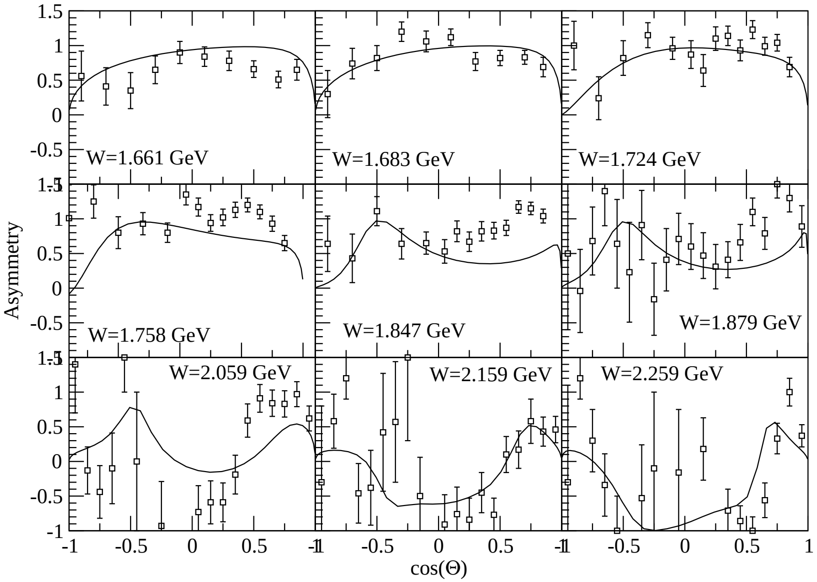
Parameters in the meson-baryon potential are varied to reproduce the experimental data

R.D. Baker et al, NP(1978); T.M. Knasel et al, PRD (1975);
D.H. Saxon et al. NPb (1980); J.C. Hart *et al.* **NPB (1980)**

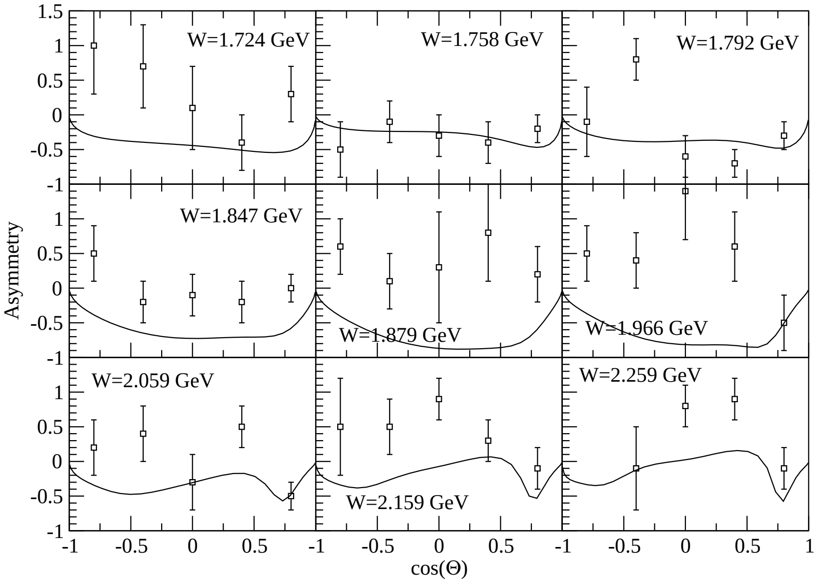
$\pi N \to KY$: Asymmetry

The asymmetries are defined as: $\Sigma \propto \frac{\sigma^{\perp}-\sigma^{||}}{\sigma^{\perp}+\sigma^{||}}$

$\to K^0\Lambda$



$\to K^0\Sigma^0$



The achieved understanding of the $\pi N \to KY$ is enough for our purposes.

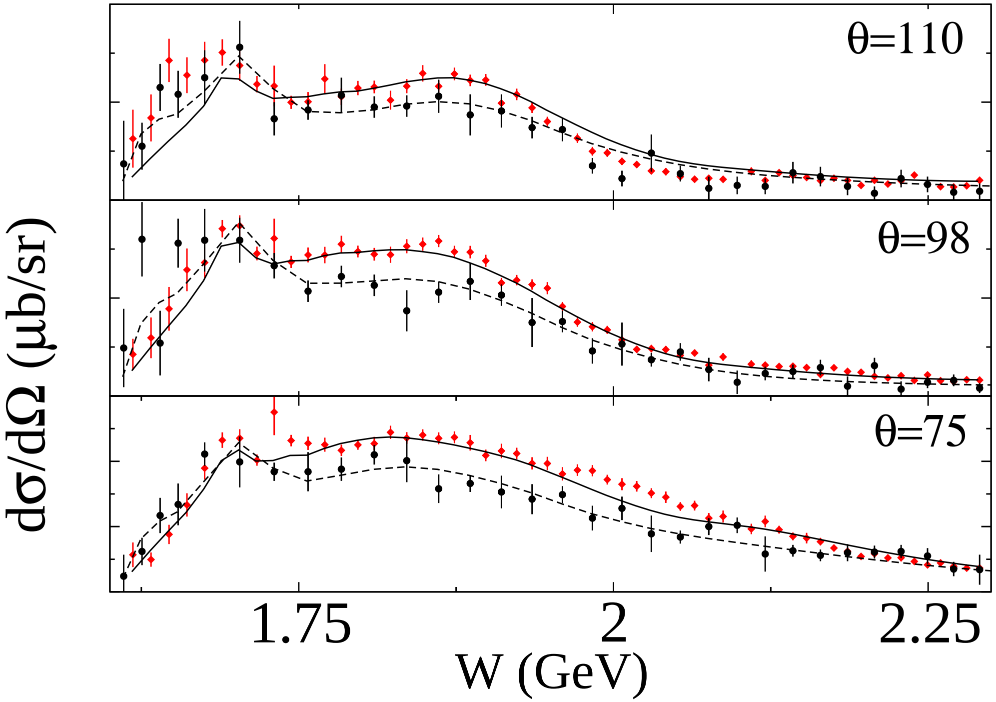
future data on $KY - KY$ would help to further constrain the model

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

Red: JLAB
Black: SAPHIR

-Discrepancies in the two data sets

-We choose to fit them independently



Most relevant:

$S_{11}(1535)$, $S_{11}(1650)$, $F_{15}(1680)$

$P_{13}(1720)$, $P_{13}(1900)$, $F_{15}(2000)$

Model A: Solid line, JLAB data

Model B: Dashed line, SAPHIR data

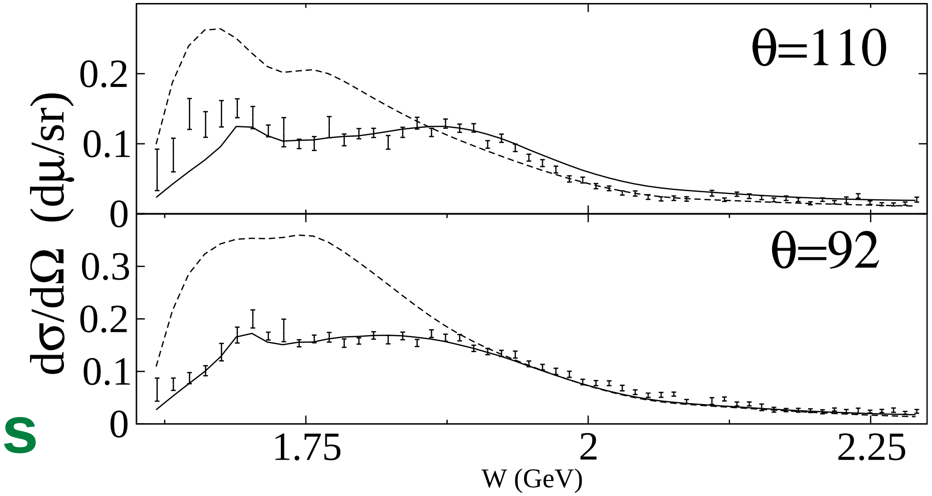
Coupled channel effects

Solid: Model A

Dashed: ” w/o CC

Large CC effects

which could be hidden in coupling values in other approaches

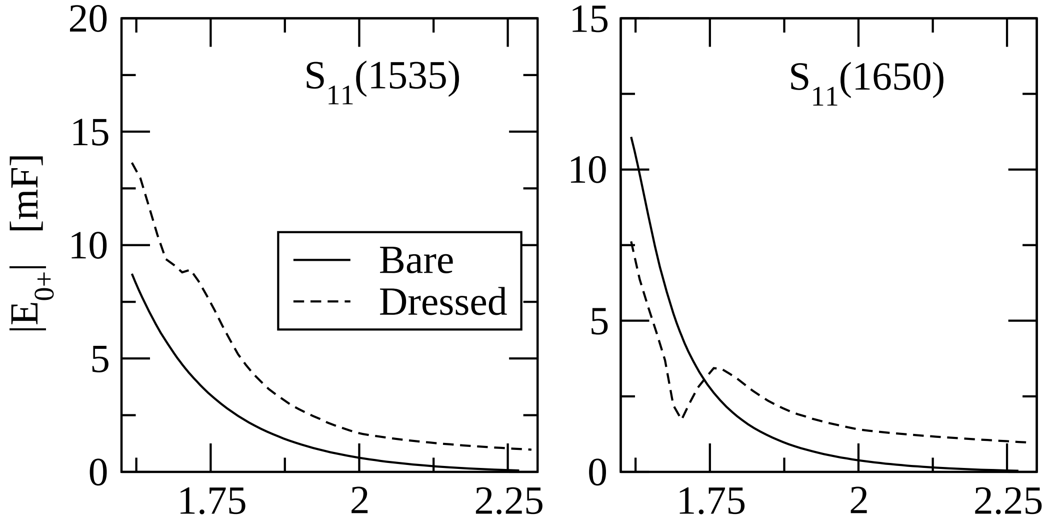


Confirms prev. results

(WTChiang et al 2000)

Similar effect for most angles

Effects on N^* properties



Bare:the resonance is directly excited by the incident photon

Dressed: The photon first excites a πN intermediate state

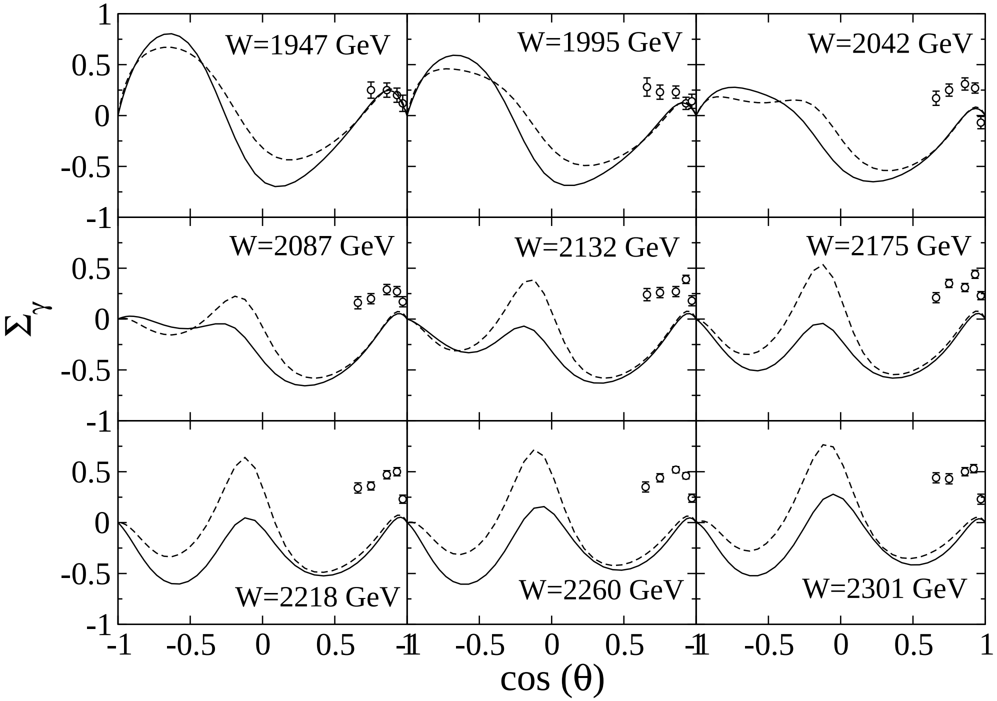
Polarization data

γ **polarized**

We did not include polarization data on Models A (solid) and B (dashed)

Very few data

Polarization data are more sensitive to the precise resonance content



Widely different results in recent studies:

V. Shklyar et al. nucl-th/0505010;

D. G. Ireland et al NPA (2004).

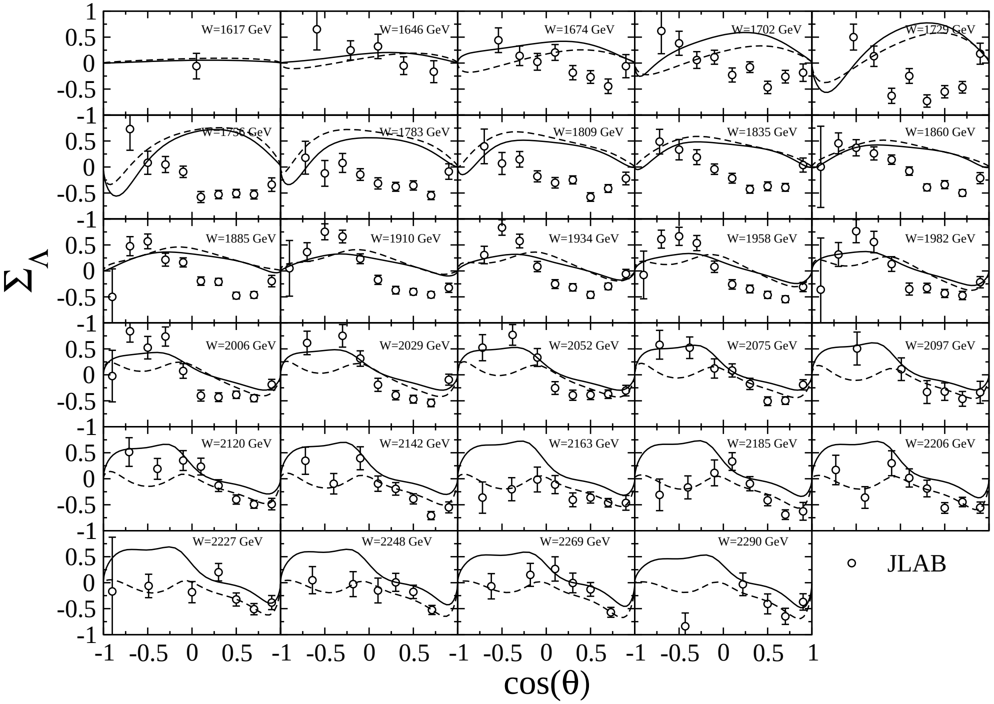
Polarization data

Λ polarized

- Unused to constrain models, up to now

- Peculiarity: Model B does a better job (Saphir)

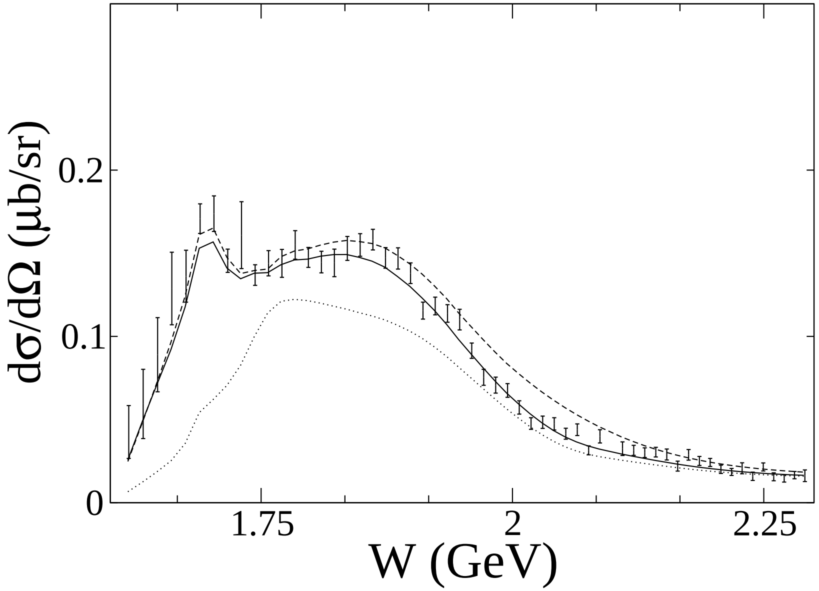
in progress: include them in minimization



Looking for $3^{rd}S_{11}$ and $3^{rd}P_{13}$

Model A and B include a $3^{rd}S_{11}$ and a $3^{rd}P_{13}$.

The fitted values, in the ranges (1.6-2 GeV and 1.6-2.4 GeV)



Effect from $3^{rd}P_{13}$ very small

(θ=98 deg) Solid, dotted and dashed:

full Model A, Model A w/o $3^{rd}S_{11}$ Model A w/o $3^{rd}P_{13}$.

Looking for $3^{rd} S_{11}$

Our fitted values are:

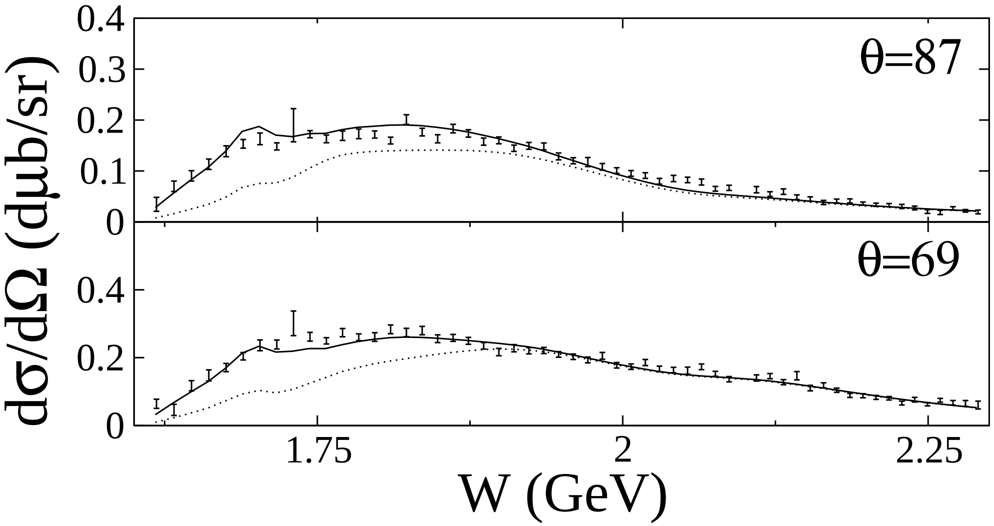
New Resonances	Model A	Model B
S_{11} Mass (GeV)	1.820	1.818
Width (MeV)	210	270
P_{13} Mass (GeV)	2.053	2.045
Width (MeV)	158	390

similar mass in both models, different widths

other $3^{rd} S_{11}$ are

Mass (GeV)	Width (MeV)	Comment	Ref.
1.780	280	CQM applied to $\gamma p \longrightarrow \eta p$	Saghai-Li (2003)
1.835	246	CQM, applied to $\gamma p \longrightarrow K^+ \Lambda$ data from SAPHIR	Saghai (2003)
1.852	187	CQM, applied to $\gamma p \longrightarrow K^+ \Lambda$ data from JLab	Saghai (2003)
1.730	180	KY molecule	Li-Workman (1996)
1.792	360	πN and ηN coupled-channel analysis	Zagreb group (2000)
1.800	165	J/Ψ decay	Bai (2001)
1.861		Hypercentral CQM	Giannini et al (2003)
1.846		Pion photoproduction coupled-channel analysis	Chen et al (2003)

Effect of $3^{rd} S_{11}$



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  - Study of $\gamma p \rightarrow K^+\Sigma^0$