Dynamical Model of $\gamma p \to K^+\Lambda$

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Motivated by :

New accurate data of $\gamma p \to K\Lambda, K\Sigma$

- **J.W.C. McNabb** *et al.*, **PRC 69 (2004) 042201 (JLab)**
- **K.H. Glander** *et al.*, **EPJA 19 (2004) 251 (SAPHIR)**
- **More to come**

$\to$

Objectives :

- **Explore the hyperon production mechanisms**
- **Explore several "missing" nucleon resonances**

General Considerations

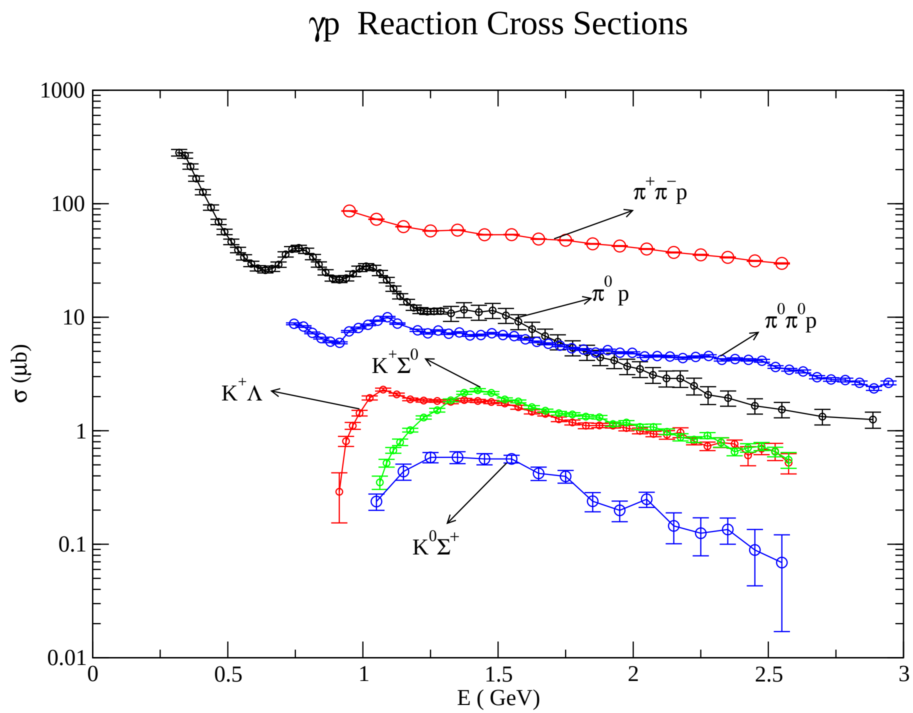
Unitarity Condition :

$S^\dagger S = 1 \qquad S = 1 + iT$

$\rightarrow$

$$Im[T_{\gamma N,KY}] \propto \sum_{MB} [T^\dagger]_{\gamma N,MB} T_{MB,KY}$$
$$\propto \sqrt{\sigma_{\gamma N,MB}}\sqrt{\sigma_{MB,KY}}$$

- $T_{a,b}$: **reaction amplitude**
- $MB = KY, \pi N, \pi\pi N(\rho N, \pi\Delta) \cdots$
- $\sigma_{a,b}$: **cross section of** $a \rightarrow b$



$\rightarrow$

$\gamma p \rightarrow (\pi N, \pi\pi N) \rightarrow KY$ **must be included**

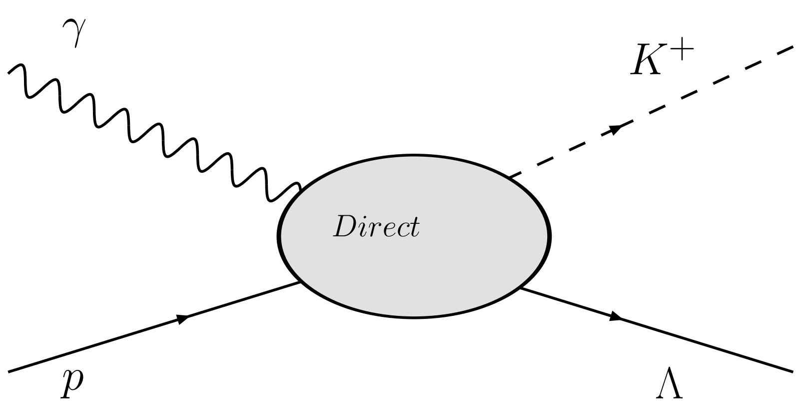
First step :

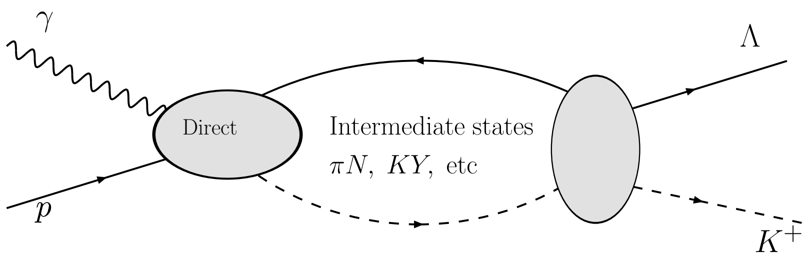
- Consider only the effects due to πN channel

$\rightarrow$

Ingredients of a reaction Model :

- A direct reaction mechanism
- Accounts for coupled channel effects





Formulation

- **Extend a dynamical model of $\gamma N \to \pi N$ (Sato and Lee) to include KY channel**
- **Channels included :**

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

- **Apply a unitary transformation to derive Hamiltonian H from SU(3) Lagrangians**
  $\to$
  H is energy independent and hermitian

  $\to$
  Unitarity condition is trivially satisfied

$\rightarrow$

Coupled channel equations :

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

Resonant term:

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

Non-resonant term :

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

Dressed vertex:

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

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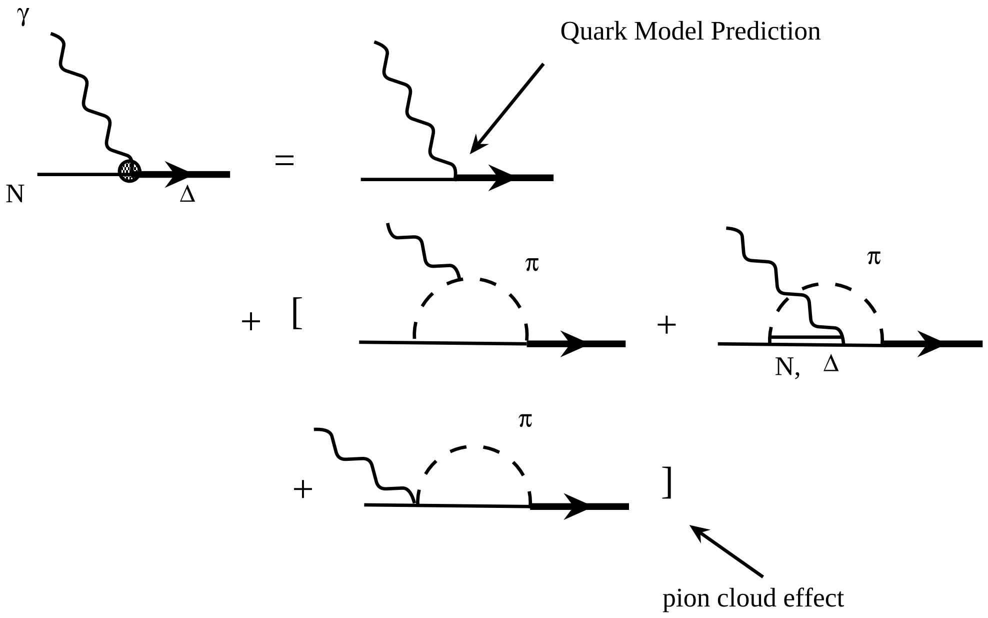


Photoproduction Amplitude

Dynamical Model :

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

Tree-diagram models :

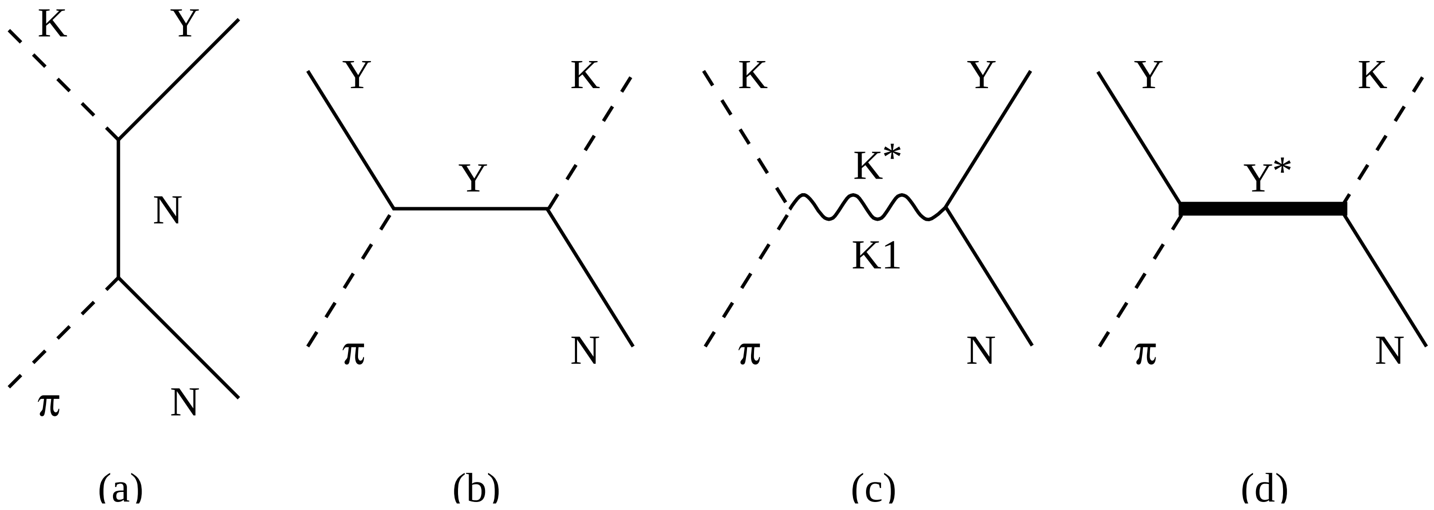
$$a^{\gamma N \to KY}_{\ell\pm}(q_{KY}, k) = b^{\gamma N \to KY}_{\ell\pm}(q_{KY}, k)$$

- **Not unitary**
- **No coupled-channel effects**

Procedures

1. **Determine** $\pi N \to KY$ **and** $KY \to KY$

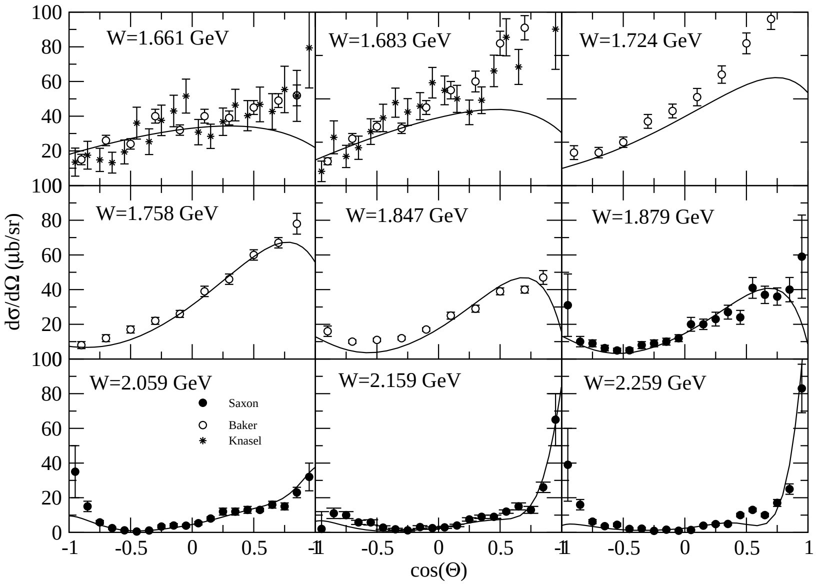
- $v_{\pi N, \pi N}$ **: Sato-Lee model**
- $v_{\pi N, KY}$**, and** $v_{KY,KY}$ **: by SU(3)**

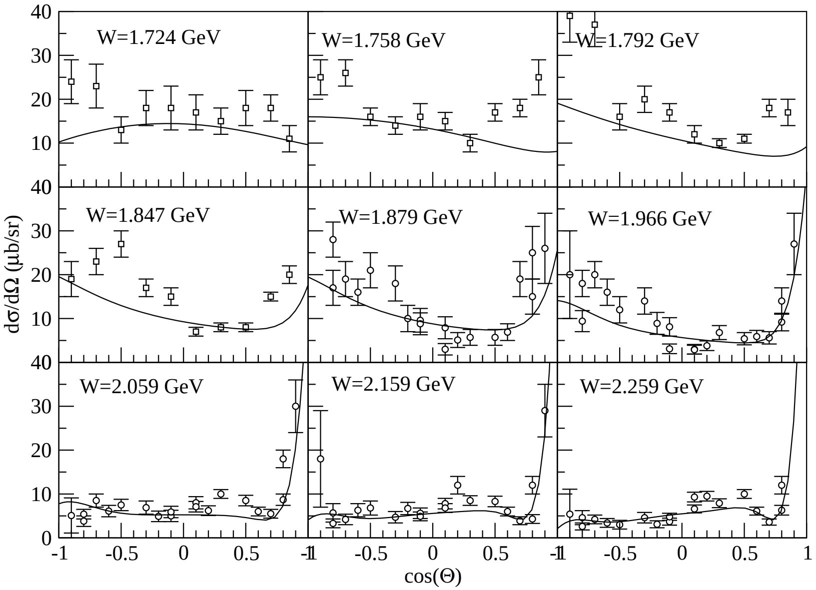


- **Solve coupled-channel equation to get non-resonant $t_{\pi N,KY}$**
- **calculate resonant amplitude $t^R_{\pi N,KY}$ from known N^***
- **adjust form factors and N^* parameters to fit data of $\pi N \to KY$**

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

$\to K^0\Lambda$ $\to K^0\Sigma^0$





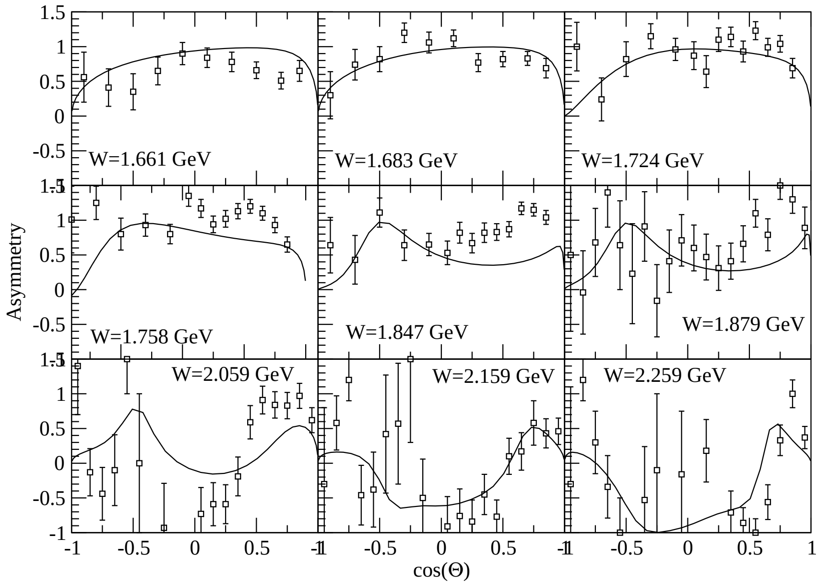
Parameters in the meson-baryon potential are varied to reproduce the experimental data

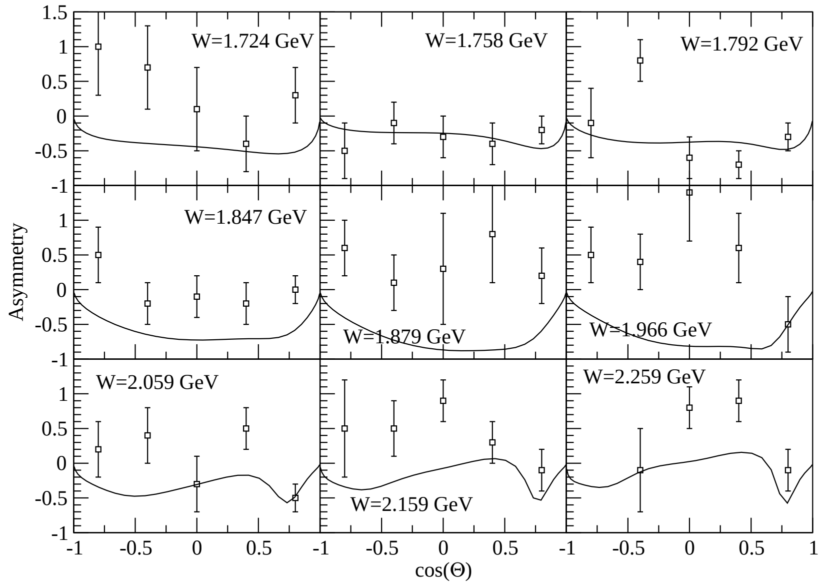
R.D. Baker et al, NP(1978); T.M. Knasel et al, PRD (1975);
D.H. Saxon et al. NPb (1980); J.C. Hart *et al.* NPB (1980)

$\pi N \to KY$: Asymmetry

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

$\to K^0\Lambda$ $\qquad\qquad$ $\to K^0\Sigma^0$





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

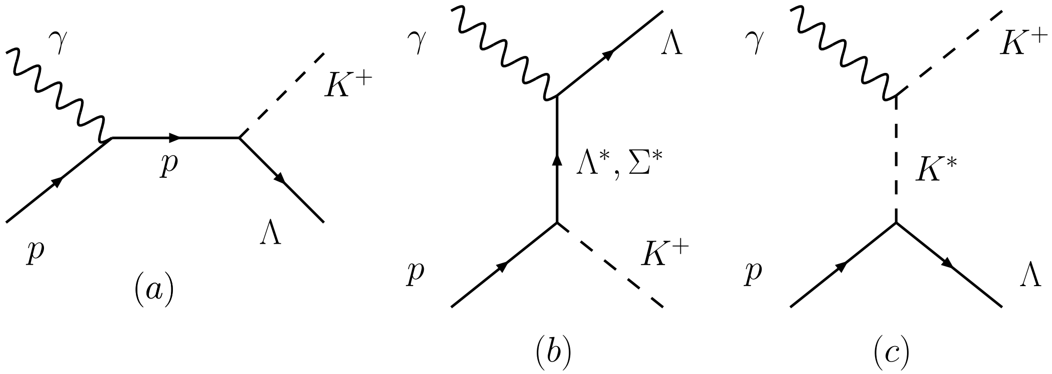
future data on $KY - KY$ would help to further constrain the model

Procedures

2. Calculate $\gamma p \to K^+\Lambda$ ampitudes

- **The direct contributions $t_{\gamma p \to K^+ \Lambda}$:**

  quark model (Li-Saghai)



- The resonance term $t^{R}_{\gamma p\to K^+\Lambda}$ 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: $S_{31}(1900), P_{31}(1900), P_{33}(1920), D_{33}(1700)$
- Non-resonant $t_{\gamma p\to\pi N}$:
  - $t_{\gamma p\to\pi N} = T^{exp} - t^{R}_{\gamma p\to\pi N}$
  - T^{exp} from SAID
  - Resonance $t^{R}_{\gamma p\to\pi N}$ from Capstick-Roberts quark model

- Adjust N^* parameters to **fit** data

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

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).

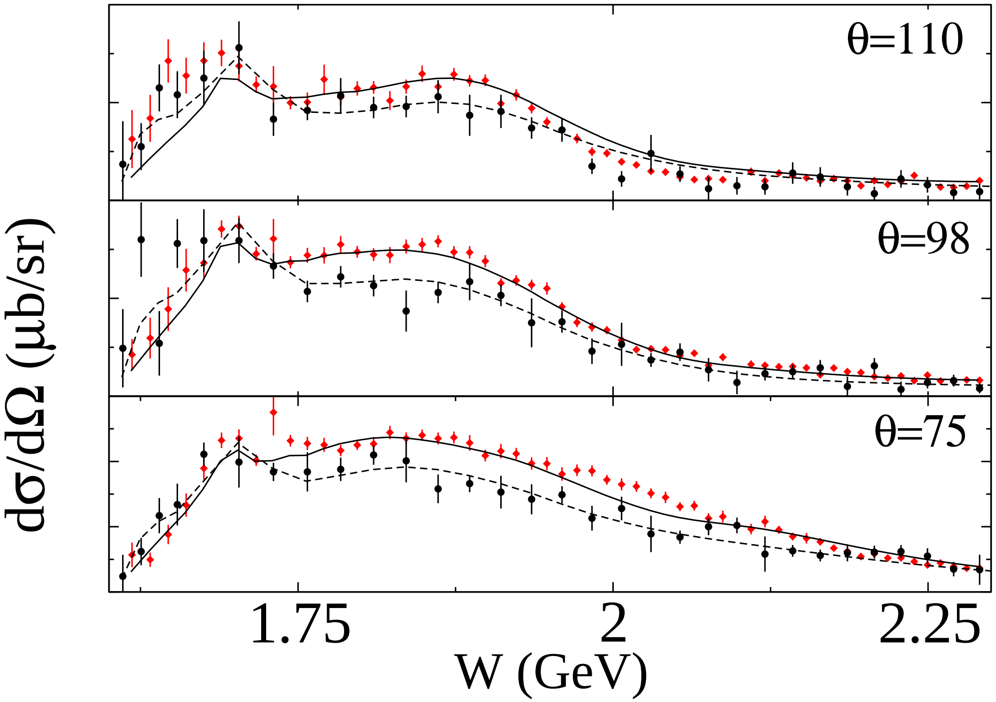
Note on parameters

- SU(3) breaking parameters , one for each resonance, are varied in the fits
- To study the proposed new resonances, a $3^{rd} S_{11}$ and a $3^{rd} P_{13}$ are included in the fits

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

Red: JLAB
Black: SAPHIR

-Discrepancies in the two data sets
-We choose to fit them independently



Most relevant:

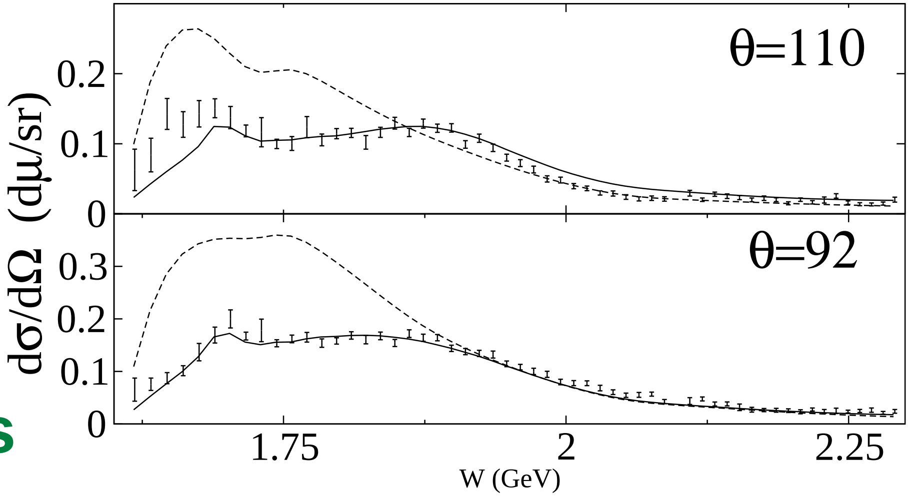
$S_{11}(1535)$, $S_{11}(1650)$, $F_{15}(1680)$

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

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

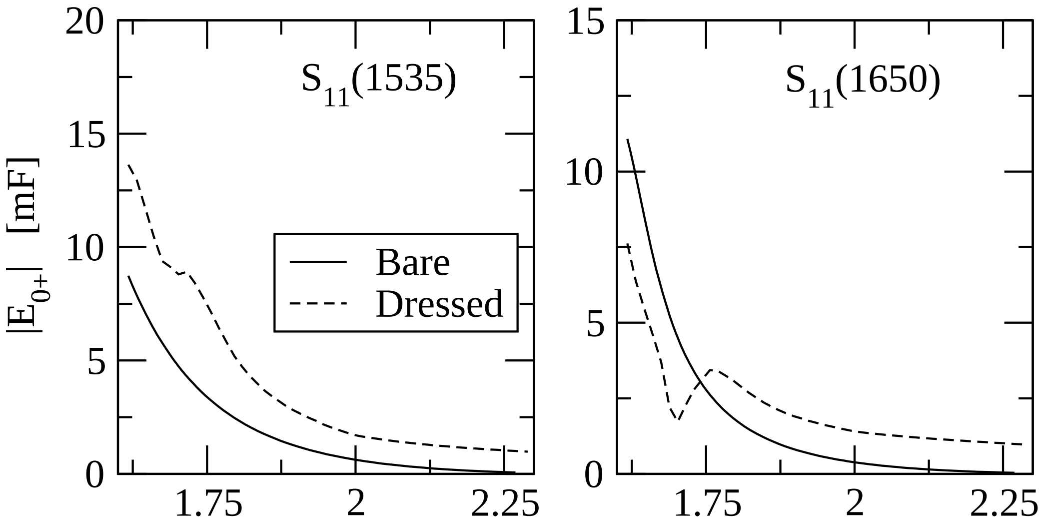
which could be hidden in coupling values in other approaches

Confirms prev. results

(WTChiang et al 2000)

Similar effect for most angles

Effects on N^* properties



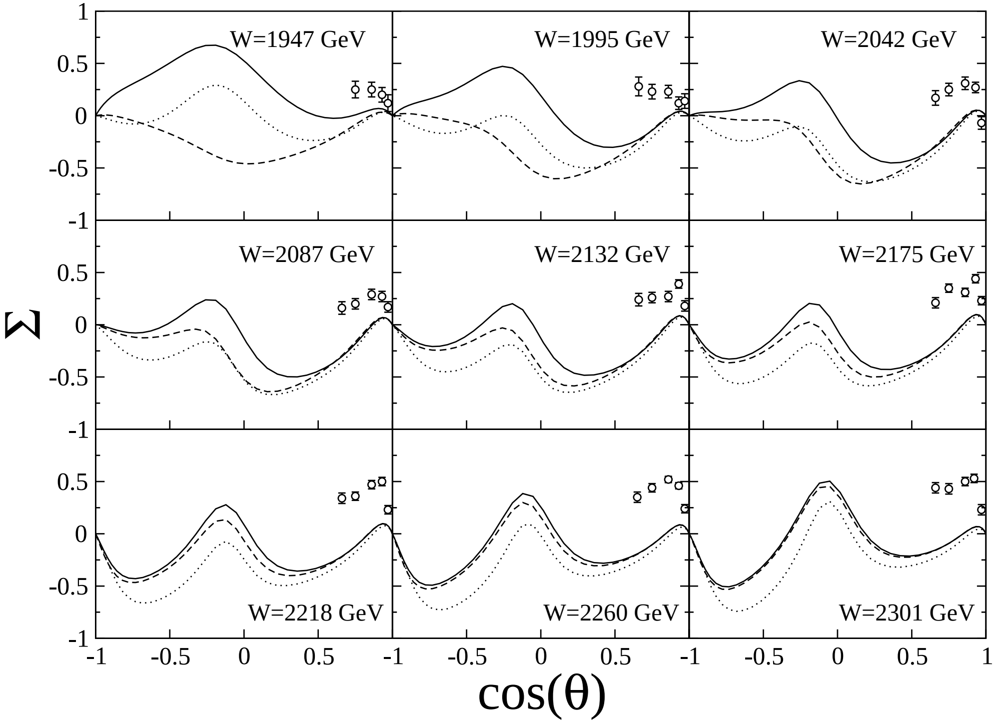
Bare: **the resonance is directly excited by the incident photon**

Dressed: **The photon first excites a πN intermediate state**

Polarization data

γ polarized

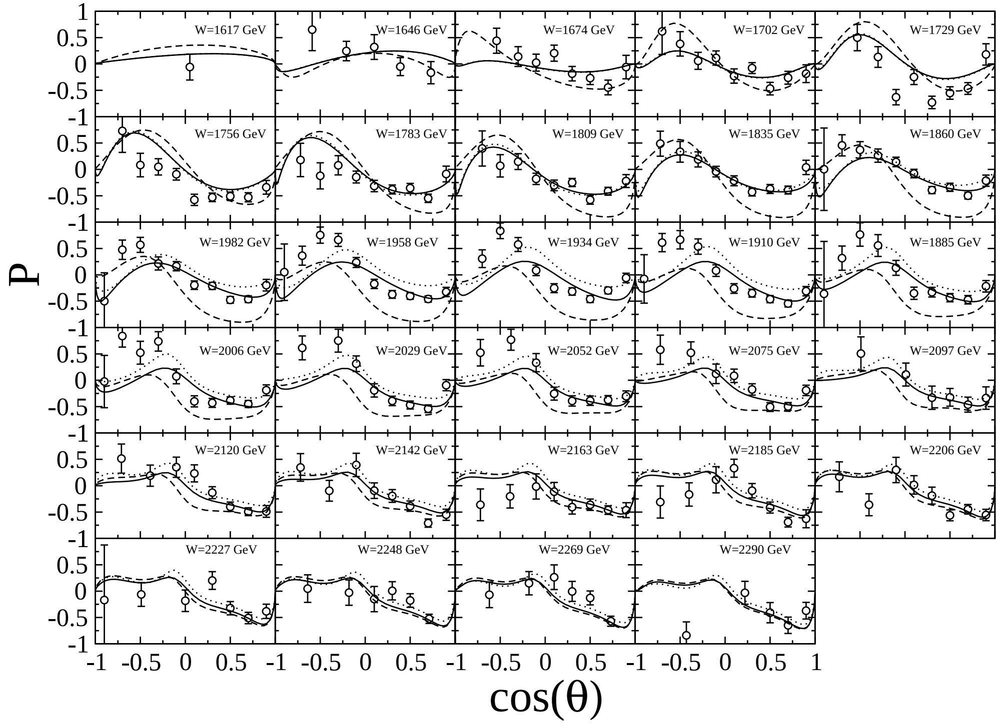
We have now included polarization data in the fits



Polarization data

Λ polarized

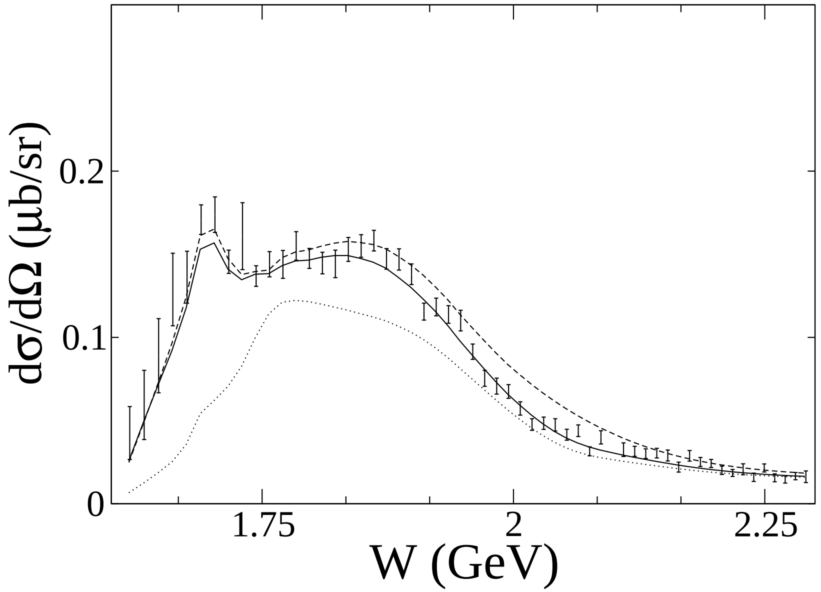
- Results from new fits (Oct. 8, 2005)



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)



(θ=98 deg) Solid, dotted and dashed:

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

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

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

Our fitted values are:

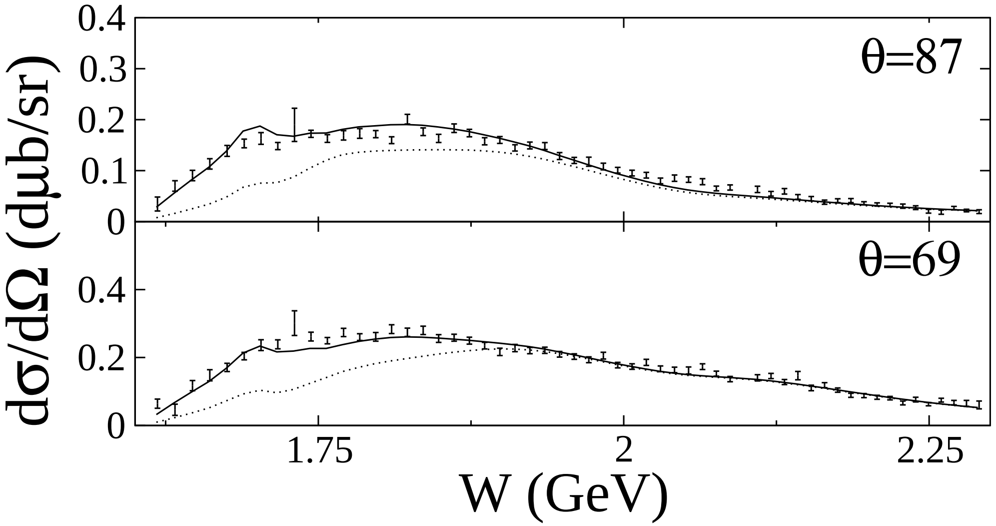
New Resonances	Model A	Model B
S_{11} Mass (GeV)	1.820	1.818
Width (MeV)	210	270
P_{13} Mass (GeV)	2.053	2.045
Width (MeV)	158	390

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 $\gamma p \to \eta p$	Saghai-Li (2003)
1.835	246	CQM, applied to $\gamma p \to K^+ \Lambda$ data from SAPHIR	Saghai (2003)
1.852	187	CQM, applied to $\gamma p \to K^+ \Lambda$ 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 $3^{rd} S_{11}$



Summary

- A dynamical coupled-channel model has been develped to fit the data of
  - $\pi^- p \to K^0\Lambda, K^0\Sigma^0$
  - $\gamma p \to K^+\Lambda$
- Coupled-channel effects due to πN channel are found to be important
- Our results support the 3^{rd} S_{11} N^* ($M \sim 1820$ MeV, $\Gamma \sim 210 - 270$ MeV)
- No strong evidence of 3^{rd} P_{13} N^* ($M \sim 2050$ MeV)

Future Developments

- Analyze $\gamma p \to K\Sigma$ data
- Include $\pi\pi N$ channel
  - apply the unitary $\pi\pi N$ model of Matsuyama, Sato and Lee (in progress)