Missing Resonances: Searching in Strange Places

C. Bennhold
GWU

- Motivation: why (γ, K)?
- "Aha, a bump!" $D_{13}(1900)$?
- Warning: Beware of single-channel analysis!
- Polarization observables: multipoles
- Conclusions: How to "detect a missing" N^*...

Motivation

Hypothesis: Many N^* undetected since they decouple from πN-channel

→ use different channels!

2-body final state:

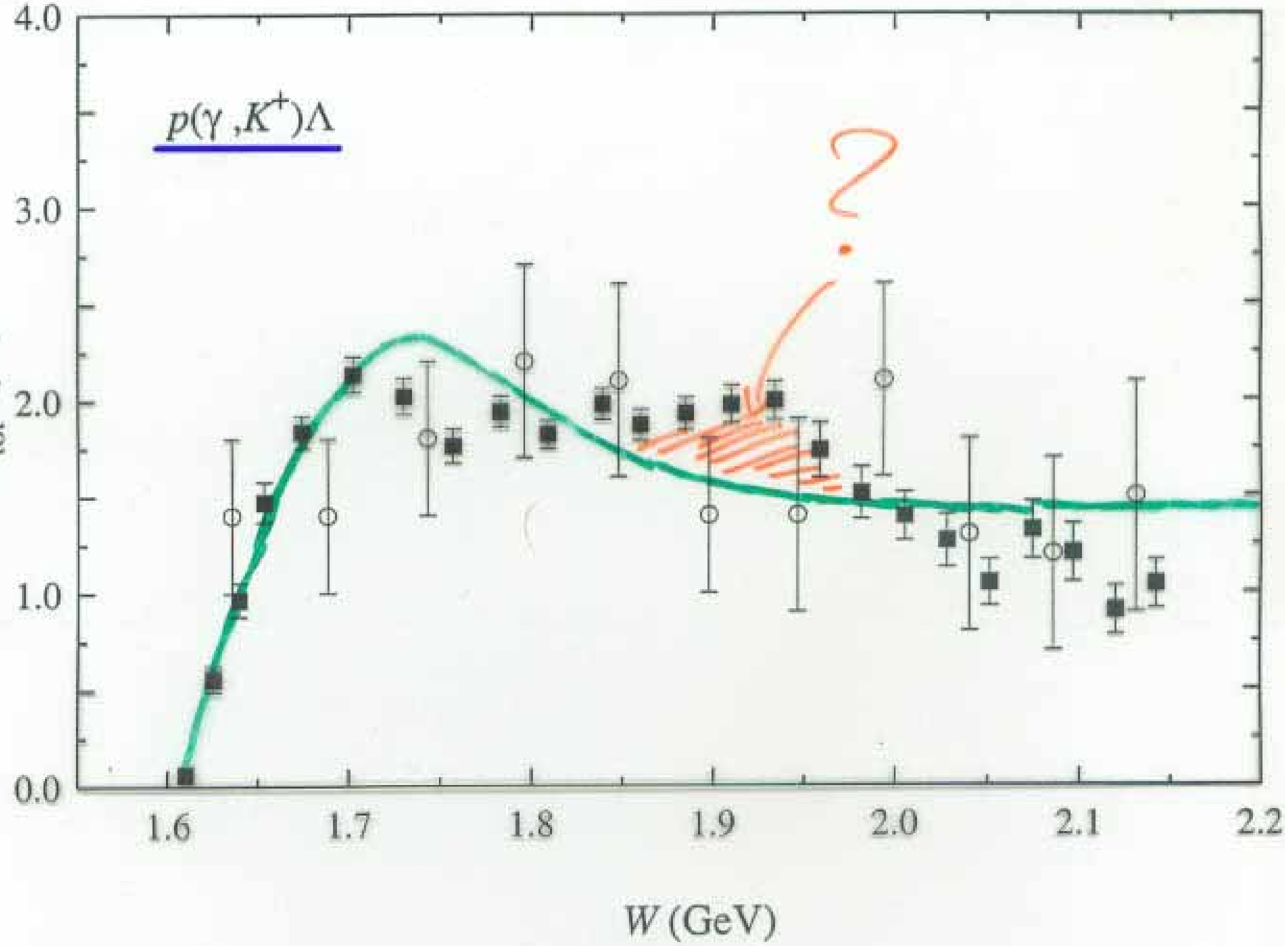
$$\gamma N \to N^* \to \begin{cases} K\Lambda \\ K\Sigma \\ \eta N \\ \omega N \end{cases}$$

→ some undetected N^* should appear here!

3-body final state:

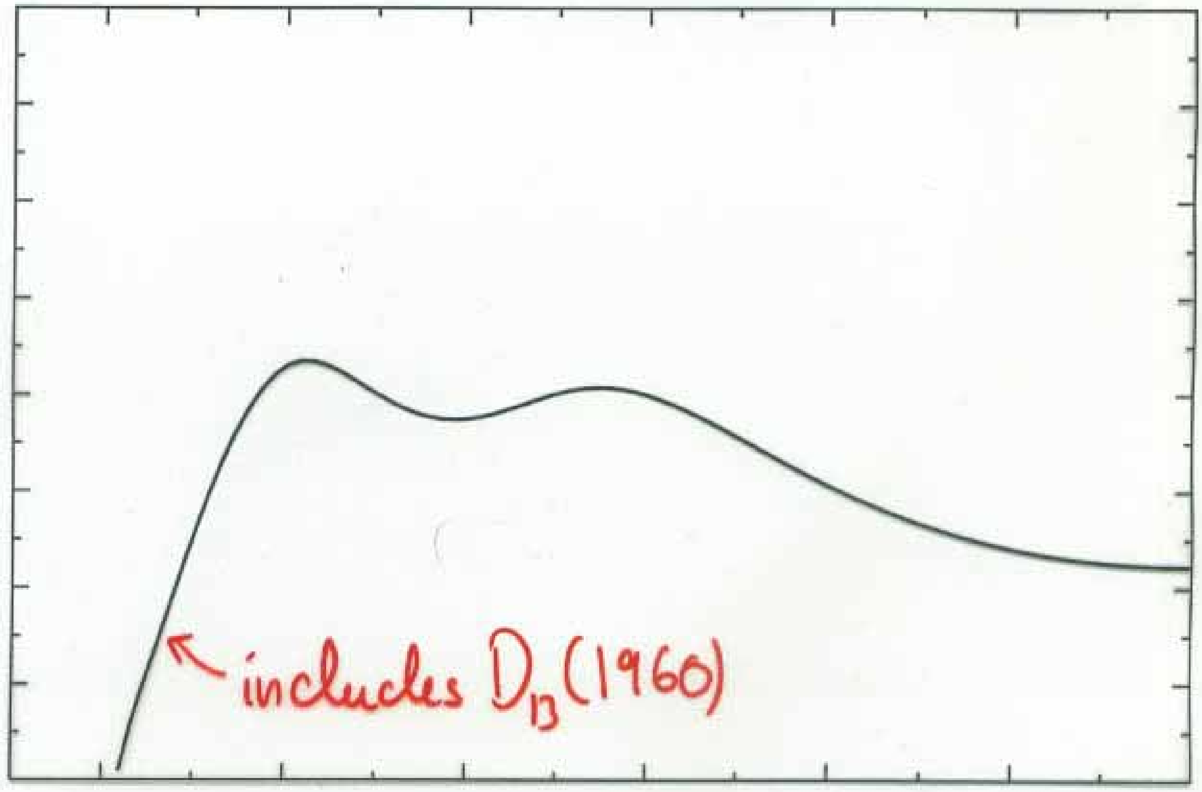
$$\gamma N \to N^*, \Delta^* \to \begin{Bmatrix} N\rho \\ N\sigma \\ \pi\Delta \\ \pi N^* \\ K^*\Lambda(\Sigma) \\ \eta\Delta \end{Bmatrix} \to \begin{matrix} \pi\pi N \\ \pi\eta N \\ \pi K\Lambda(\Sigma) \end{matrix}$$

→ most (all?) N^*, Δ^* must appear here!



Check for predicted N^* around 1900 MeV with
large $K\Lambda$ decay width:

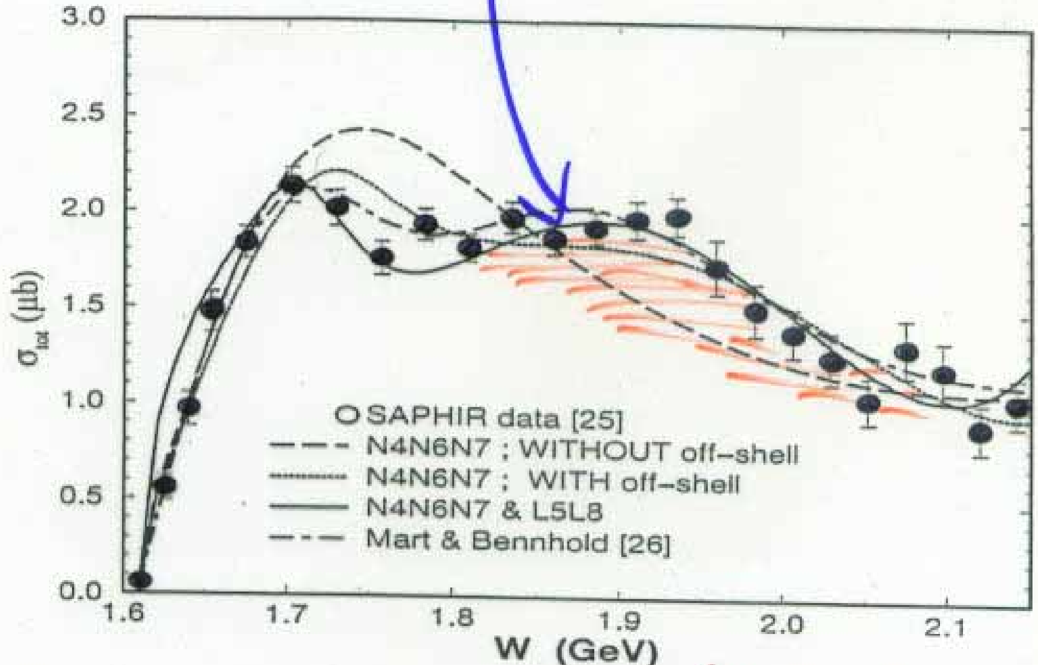
$S_{11}(1945)$ $P_{11}(1975)$ $P_{13}(1950)$ $D_{13}(1960)$ (Capstick, Roberts)



However, only $D_{13}(1960)$ has large $\Gamma_{K\Lambda}$

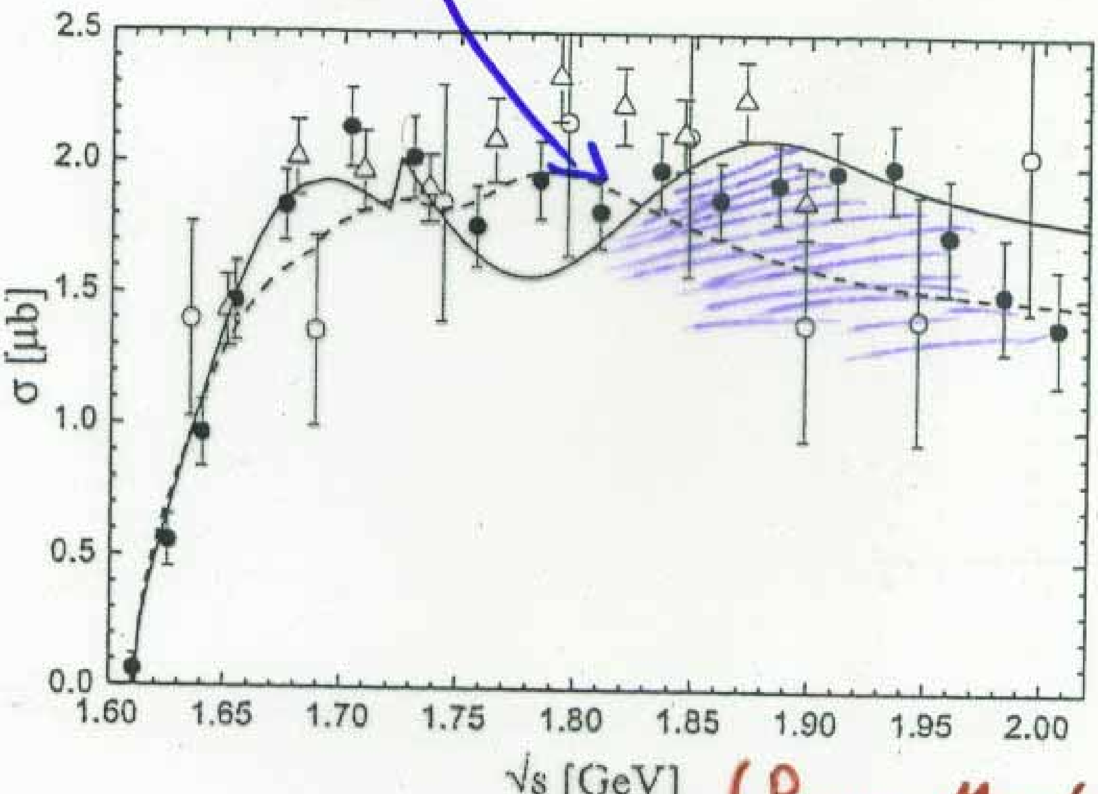
<u>and</u> large $\Gamma_{\gamma N}$!

off-shell parameters of spin 3/2 N^*



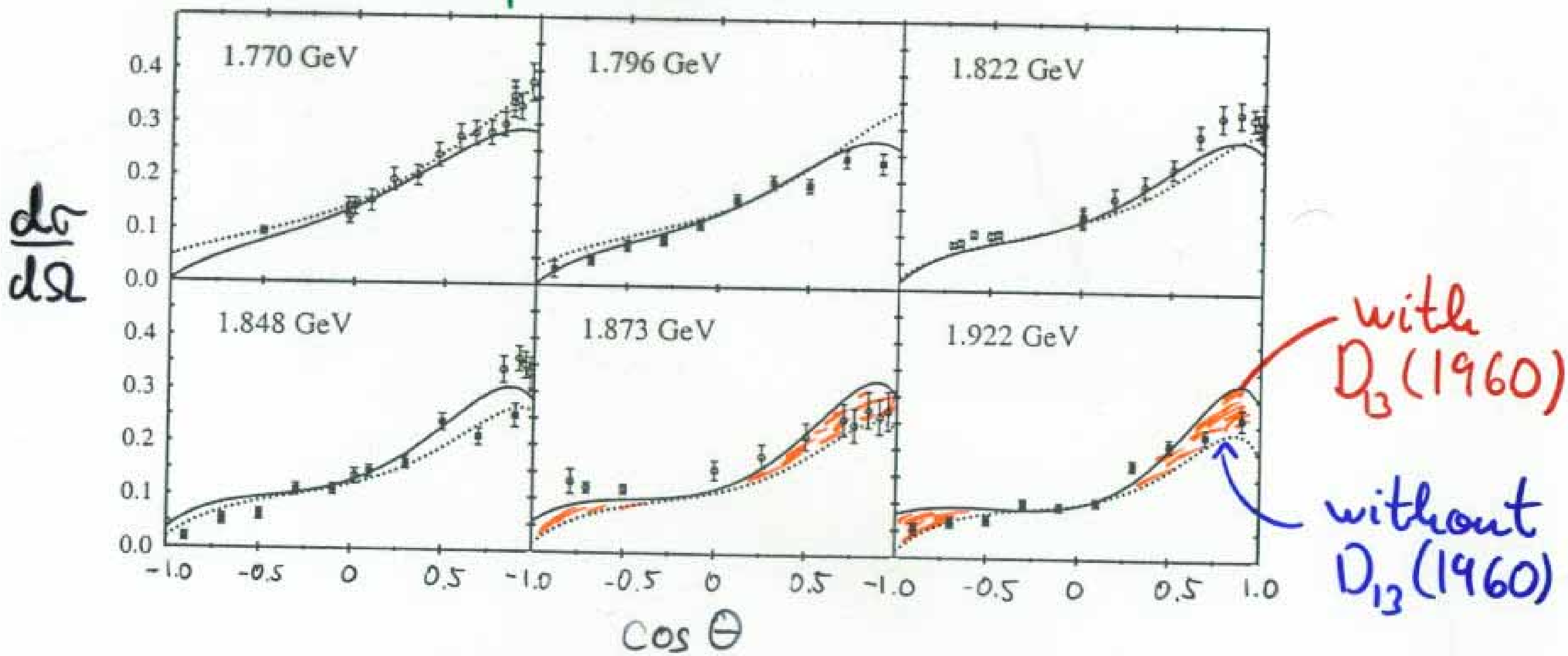
(B. Saghai et.al.)

part background,
part $P_{13}(1900)$

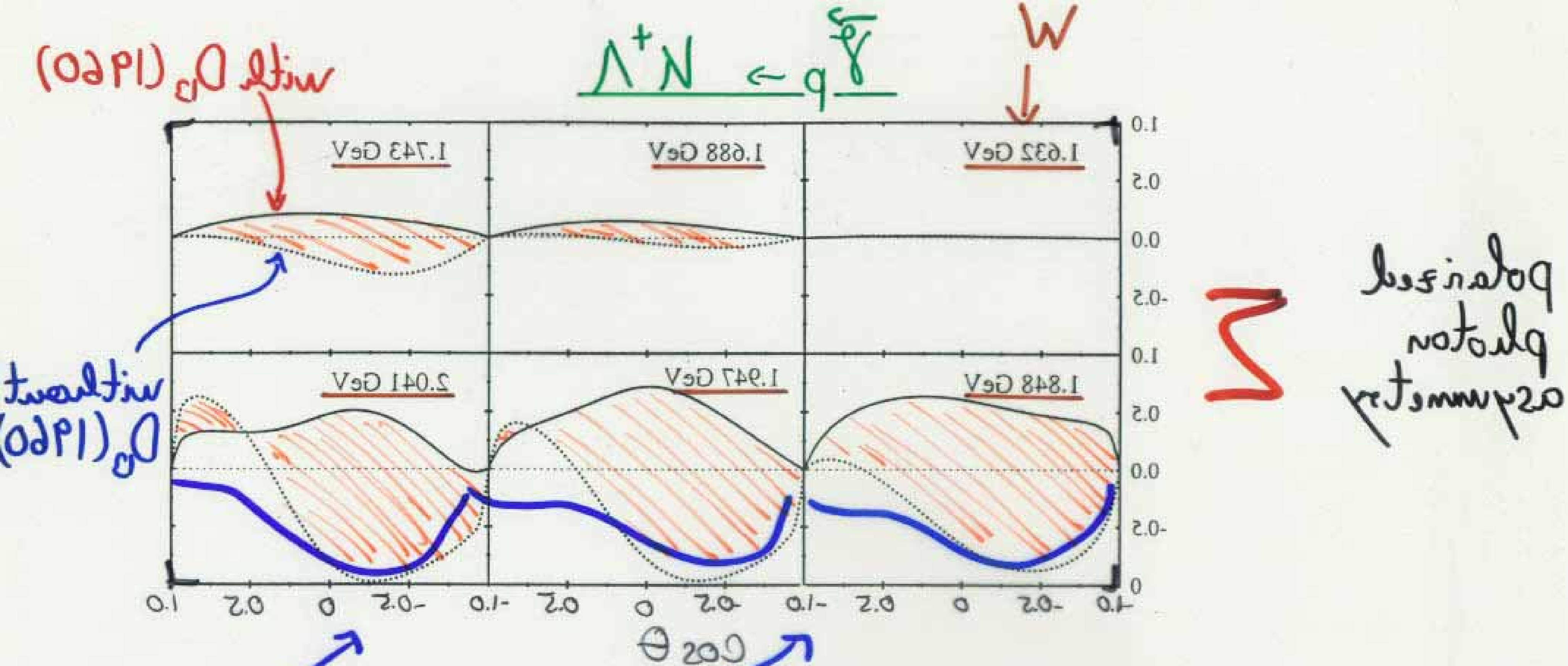


(Penner, Mosel 2002)

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



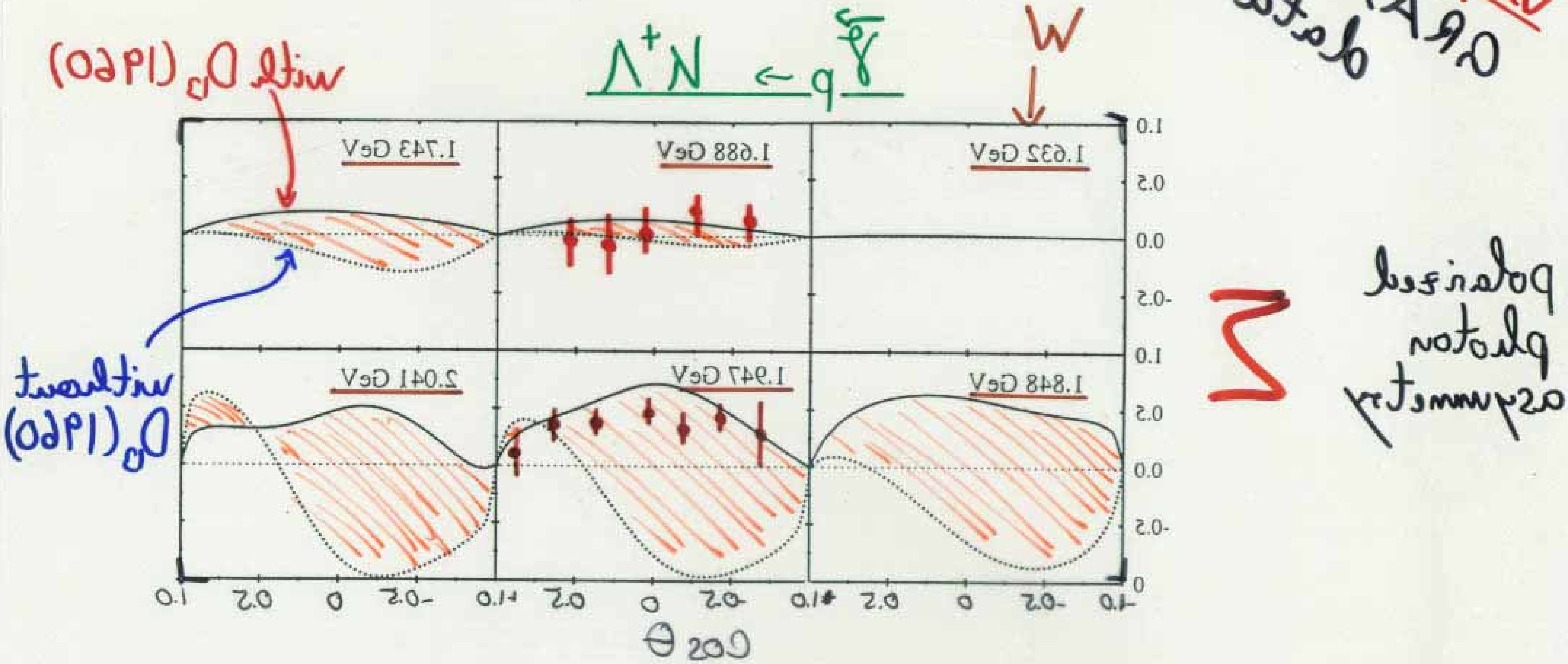
small signal in differential cross section....



... but clear signal in Σ polarization observable!

Background ambiguity can switch sign!

Very new GRAAL data confirm $D_{13}(1960)$!? Not quite...



... but clear signal in Σ polarization observable!

Warning!

Beware! Single Channel Analysis!

Warning!

- most (γ,η)/(γ,K)/$(\gamma,\pi\pi)$ models, Pion/Eta/Kaon-MAID, many others

Problems: $A_{1/2}$ for $S_{11}(1535)$
$A_{1/2}$ for $D_{13}(1520)$
$\Gamma_{\eta N}$ for $D_{15}(1675)$
⋮

To confirm a new N^*: find same N^* in several channels!

→ must use multichannel framework!

What does the PDG-bible say?

PDG	Status	Quark Model
$D_{13}(1520)$	****	$[N\frac{3}{2}^-]_1(1495)$
$D_{13}(1700)$	***	$[N\frac{3}{2}^-]_2(1625)$
$D_{13}(2080)$	**	$[N\frac{3}{2}^-]_3(1960)$
		$[N\frac{3}{2}^-]_4(2055)$
		$[N\frac{3}{2}^-]_5(2095)$
		⋮

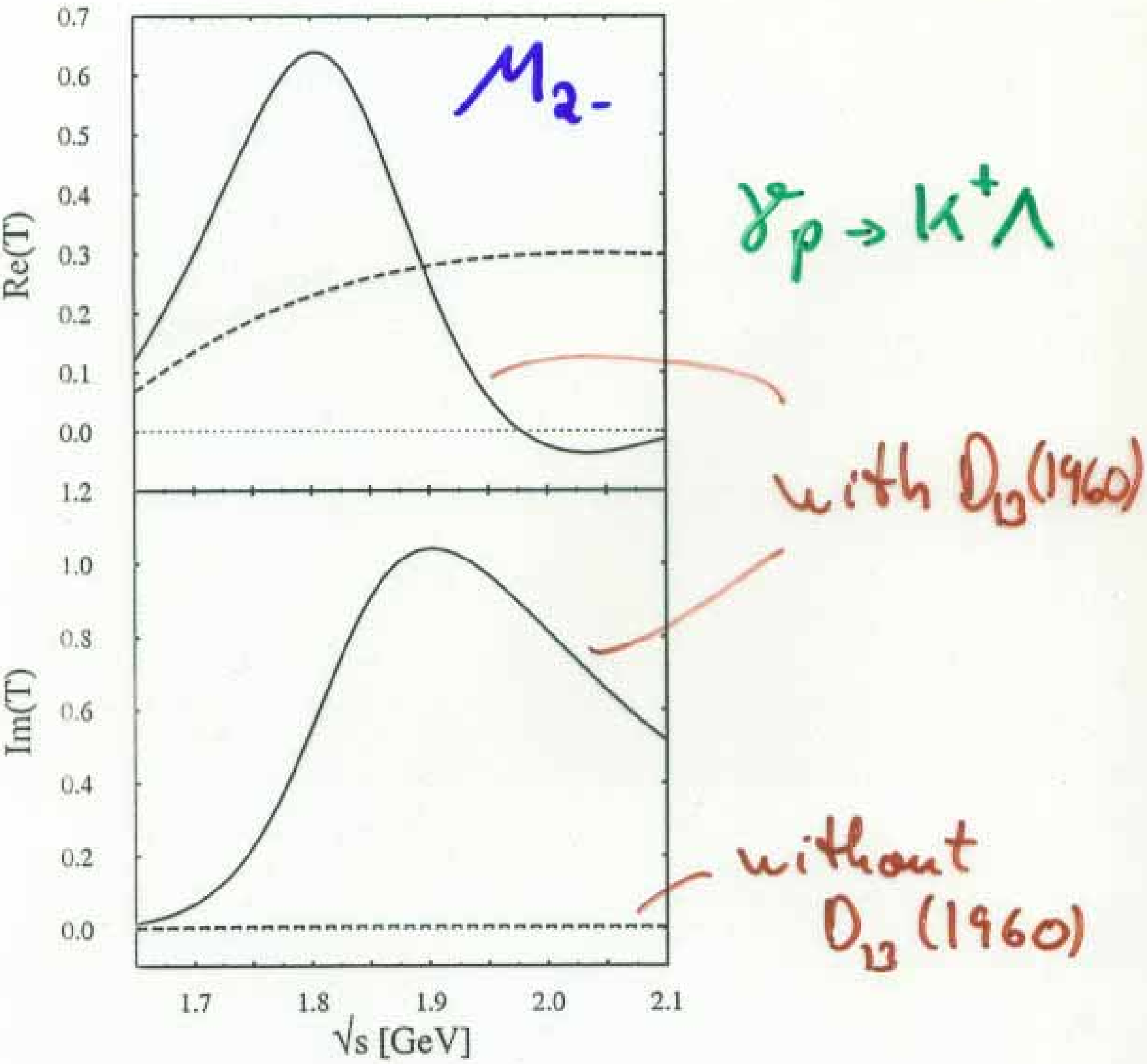
fine print (for $D_{13}(2080)$):

- one state ~ 1900 from $\pi^- p \to K^0 \Lambda$!
- one state ~ 2080 from $\pi N \to \pi N$

New coupled-channels results:

	mass	width
Pitt-ANL	~ 2000	"
GW-Giessen	~ 1950	600 - 700
KSU	~ 2000	"

Needed: multipole analysis!



Clear resonance signal in multipole!

(γ, K) operator is completely specified via

$$t_{(\gamma,K)} = \mathcal{F}_1\, i\vec{\sigma}\cdot\vec{\varepsilon} + \mathcal{F}_2\, \vec{\varepsilon}\,(\vec{\sigma}\times\hat{q})(\vec{\sigma}\cdot\hat{k}) + \mathcal{F}_3(\vec{\varepsilon}\cdot\vec{q})(\vec{\sigma}\cdot\vec{k}) + \mathcal{F}_4(\vec{\varepsilon}\cdot\hat{q})(\vec{\sigma}\cdot\vec{q})$$

$\mathcal{F}_1 - \mathcal{F}_4$ complex amplitudes $\Rightarrow$ 7 experiments

unpolarized: $\frac{d\sigma}{d\Omega}$

single polarization:
- P (polarized recoil)
- Σ (polarized photons)
- T (" target)

double polarization: 3 classes

Beam - Target	Beam - Recoil (spin-transfer)	Target - Recoil (spin-depolarization)
E, F, G, H	$C_{x'}, C_{z'}, O_{x'}, O_{z'}$	$L_{x'}, L_{z'}, T_{x'}, T_{z'}$

Polarization observables are not independent!

→ need ~~4~~ 8 Experiments ← Chiang, Tabakin, Workman, 1997

Since $\vec{\Lambda}$ is self-analyzing

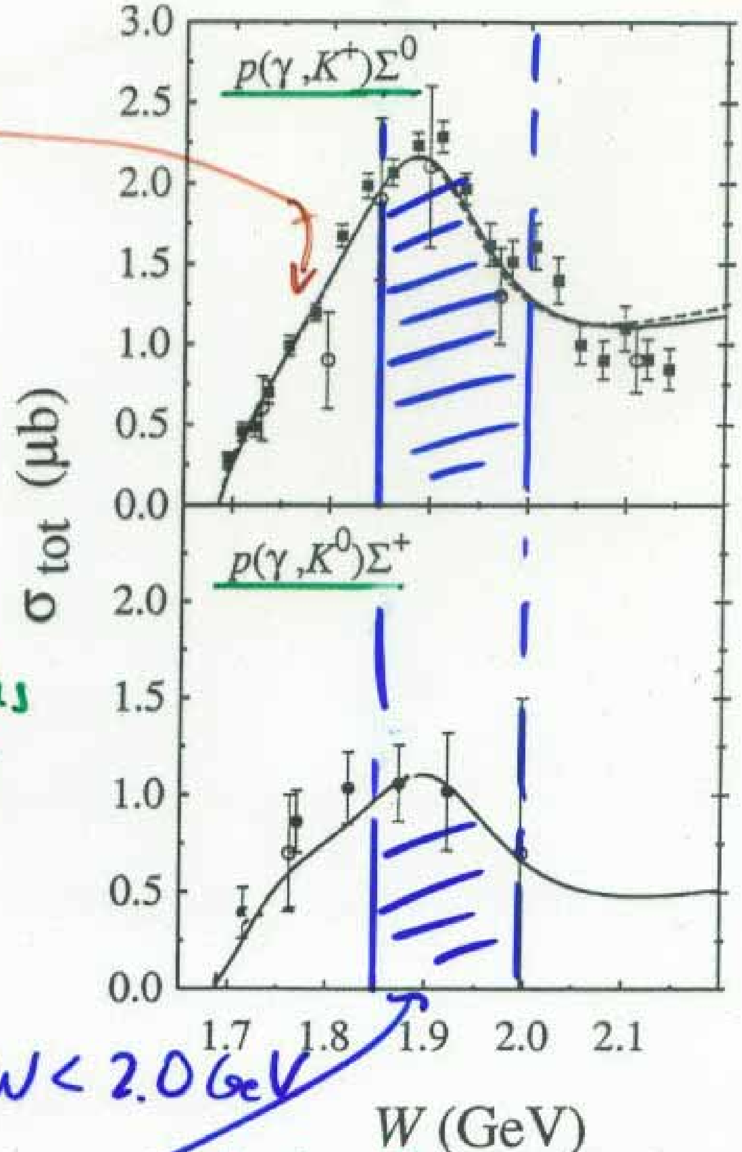
→ "complete" experiment possible!?

$$\gamma p \xrightarrow[\Delta^*]{N^*} \begin{cases} K^+\Sigma^0 \\ K^0\Sigma^+ \end{cases}$$

both $T = 1/2$ and $3/2$ possible: many more resonances!

p-wave onset

→ $P_{11}(1710)$



Cross section peaks at W = 1.9 GeV but ...

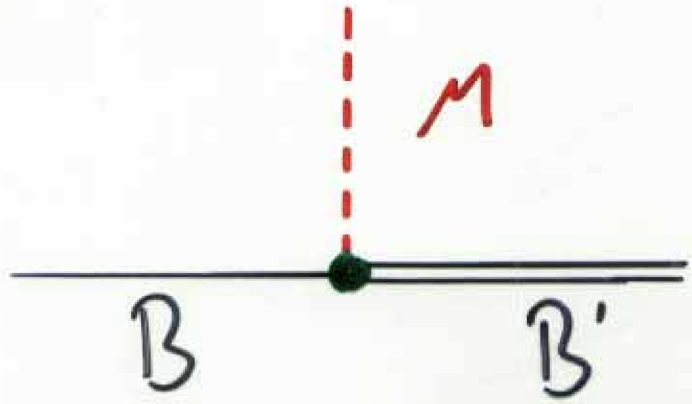
In region $1.85 < W < 2.0$ GeV

11 N^* and Δ^* states, spin $\frac{1}{2}, \frac{3}{5}, \frac{5}{2}, \frac{7}{2}$!

N^* states: $P_{13}(1900)$, $F_{17}(1990)$, $F_{15}(2000)$

Δ^* states: $S_{31}(1900)$, $F_{35}(1905)$, $P_{31}(1910)$, $P_{33}(1920)$, $D_{35}(1930)$, $D_{33}(1940)$, $F_{37}(1950)$, $F_{35}(2000)$

$SU(3)_{Flavor}$ Symmetry



relationships between Coupling constants $g_{MBB'}$

$g_{\pi NN}$: well-known

$$\frac{g^2_{\pi NN}}{4\pi} = 14 \pm 0.2$$

Source	$\frac{g^2_{K\Lambda N}}{4\pi}$	$\frac{g^2_{K\Sigma N}}{4\pi}$
SU(3)	12 - 16	0.9 - 1.4
K N, Y N scatt.	12.5 - 15	1.2 - 2.3
$N\bar{N} \to Y\bar{Y}$	15.4	–
$\gamma p \to K^+ \Lambda(\Sigma)$	0.8 - 16	0.05 - 3.2

large uncertainty!
→ SU(3) symmetry breaking?

what about $g_{\eta NN}$? take into account $\eta - \eta'$ mixing!

$$\frac{g^2_{\eta NN}}{4\pi} \begin{cases} \sim 0.8 \ (SU(3)) \\ 0.1 - 0.4 \ (\gamma p \to \eta p) \end{cases}$$

Conclusions

How do I find myself a "missing" N^*?

Don't use (γ,π)!

use i.e.

$$\gamma N \rightarrow N^* \xrightarrow[\text{Selectivity}]{\text{Isospin}} \begin{cases} K\Lambda \\ \eta N \\ \omega N \end{cases}$$

$K\Lambda$ ← most bang for the buck! ⇓ multipoles!

Confirm existence in $\gamma N \rightarrow \pi\pi N$ channel!

To extract N^* properties:

Use dynamical multichannel approach with: unitarity, analyticity, Lorentz covar., gauge invariance

with constraints for background from:

Chiral symmetry
$1/N_c$ expansion
Regge behavior (duality)