Giessen coupled-channel results for pion and photon induced reactions

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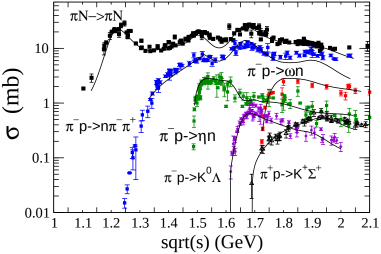
Partial wave version of optical theorem

constraints on partial wave cross sections



$$ImT^{JP}_{\pi N\to\pi N} = \frac{k^2}{4\pi}(\sigma^{JP}_{\pi N\to\pi N} + \sigma^{JP}_{\pi N\to 2\pi N} + \sigma^{JP}_{\pi N\to\eta N} \\ +\sigma^{JP}_{\pi N\to\omega N} + \sigma^{JP}_{\pi N\to K\Lambda} + \sigma^{JP}_{\pi N\to K\Sigma} + \ldots)$$

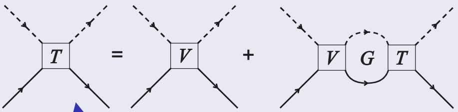
all reaction data are linked

→ need for coupled-channel unitary analysis

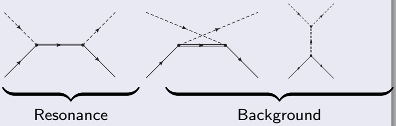
Giessen model. PRC71, 055206 (2005)

Bethe-Salpeter in K-matrix: dynamical model: based on eff. L_{mBB}

T-matrtix



Interaction term V



multidmentional T-matrix

$$T = \begin{pmatrix} T_{\gamma\gamma} & T_{\gamma\pi} & T_{\gamma\eta} & T_{\gamma\omega} & \cdots \\ T_{\pi\gamma} & T_{\pi\pi} & T_{\pi\eta} & T_{\pi\omega} & \cdots \\ T_{\eta\gamma} & T_{\eta\pi} & T_{\eta\eta} & T_{\eta\omega} & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \end{pmatrix}$$

How many channels?

$\gamma N \to \gamma N$	$\pi N \to \pi N$
$\gamma N \to \pi N$	$\pi N \to 2\pi N$
$\gamma N \to \eta N$	$\pi N \to \eta N$
$\gamma N \to \omega N$	$\pi N \to \omega N$
$\gamma N \to K\Lambda$	$\pi N \to K\Lambda$
$\gamma N \to K\Sigma$	$\pi N \to K\Sigma$

K-matrix approximation:

To solve Bethe-Salpeter equation take the imaginary part of the propagator:

$$\int dq \frac{1}{q^2 - m^2 \pm i\varepsilon} = P \int dq \frac{1}{q^2 - m^2} \mp i\pi \int dq \delta(q^2 - m^2)$$

where all intermediate particles are on-shell.

main features

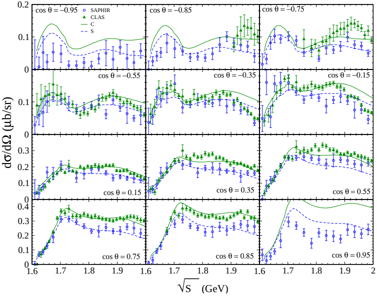
- neglect real part of self energy
- Minkowsky space
- resonance parameters: coupling constants at interaction Lagrangians

Our aim

What we want to learn

- construct the reaction theory
  (talk of C. Roberts at NSTAR 2011)
- understand the reaction dynamics in terms of mesonic and baryonic degrees of freedom
- derive N^* parameters: couplings at eff. Lagrangians
- make predictions for new experiments

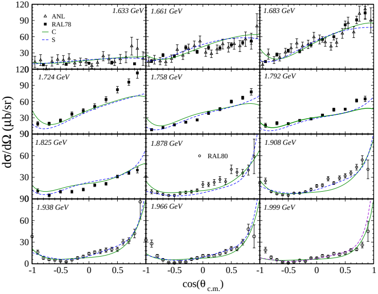
$(\gamma,\pi)N \to K\Lambda$. Giessen model PRC72:015210



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

Two independent solutions: C(CLAS) and S(SAPHIR)

The difference between the C and S-calculations is mostly due to non-resonance contributions. (next transp.)



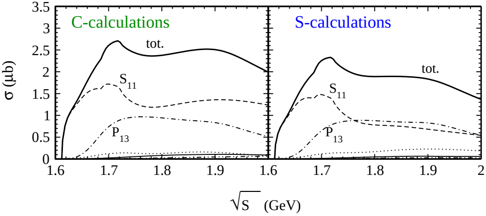
$\pi^- p \to K^0\Lambda$

Disagreement between the CLAS and SAPHIR data does not affect the the $\pi^- p \to K^0\Lambda$ reaction.

$K\Lambda$-production. Reaction mechanism

Giessen PRC72, 015210 (2005).

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

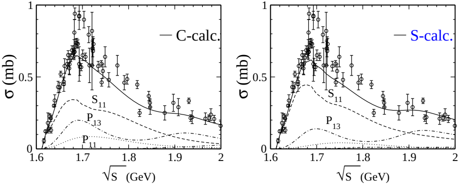


Resonance contributions: $S_{11}(1650)$ $P_{13}(1720)$ and $P_{13}(1900)$

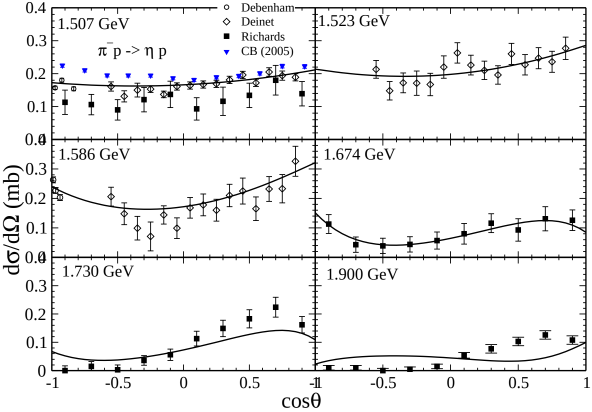
$L_{2I,2S}$	$R_{K\Lambda}(C)$	$R_{K\Lambda}(S)$
$S_{11}(1650)$	3.2(+)	4.6(+)
$P_{13}(1720)$	4.6(+)	4.0(+)
$P_{13}(1900)$	2.4(+)	2.3(+)

Table: N^* decay ratios to $K\Lambda$

$\pi^- p \to K^0\Lambda$



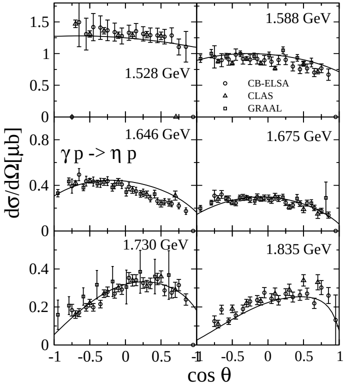
Results for the $\pi^- p \to \eta p$ production



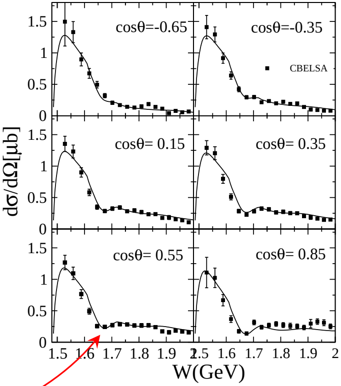
$\pi^- p \to \eta\, n$: Solution from the Giessen coupled-channel analysis
V.Shklyar et al, PRC.71. 055206 (2005).

Results for the $\gamma p \to \eta p$

$\frac{d\sigma}{d\Omega}$ as a function of $\cos(\theta)$



$\frac{d\sigma}{d\Omega}$ as a function of W



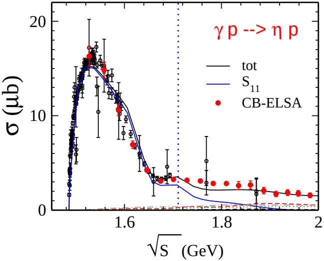
The structure at 1.67 GeV in $\gamma p \to \eta p$ is due to $S_{11}(1650)$
Shklyar et al PLB650, 172(2007)

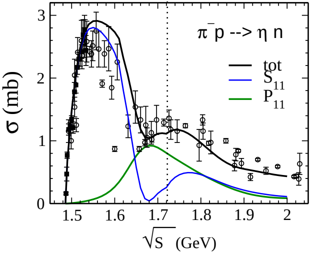
no need for any exotic state!

Giessen model

$S_{11}(1535)$ dominates

both $\gamma p \to \eta p$ and $\pi^- p \to \eta n$ reactions





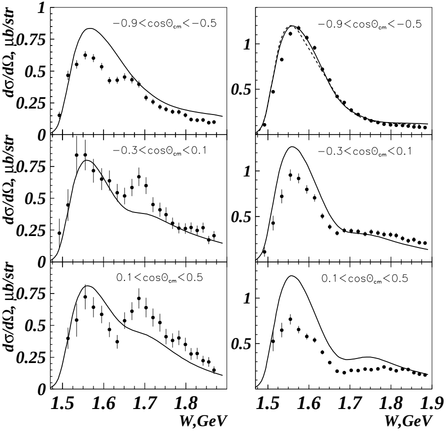
- strong $S_{11}(1535)$ excitation
- kink structure at 1.72 GeV is due to the ωN threshold
- seems no room for other contributions

- destructive effect from $S_{11}(1650)$
- above 1.6 GeV - $P_{11}(1710)$ - consistent with πN inelasticity

$\gamma n^* \to \eta n$

V. Kuznetsov, et al. PLB 647 (2007) 23 for GRAAL collaboration

$\gamma n^* \to \eta n$ $\gamma p^* \to \eta p$



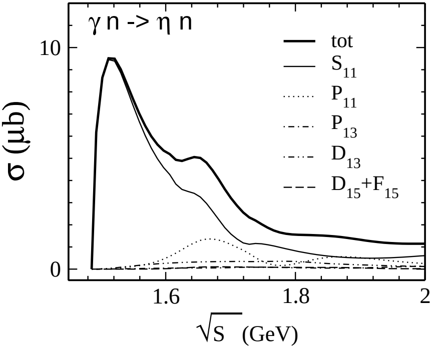
- quasi-free neutron: resonance-like structure at 1.67 GeV
- confirmed by B.Krusche, I. Jaegle at MAMI, CB-ELSA

Possible explanations

- Polyakov, Strakovsky, Arndt, Workman; Polyakov Kuznetzov: pentaquark parthner
- Shklyar, Mosel, Lenske: well known $S_{11}(1650)$, $P_{11}(1710)$
- M. Doering: cusp in $K\Sigma$

Results for the $\gamma n \to \eta n$

Giessen Model PLB650, 172(2007): total $\gamma n \to \eta n$ cross section



$$A^n_{1/2}(1650) = -9 \times 10^{-3}\mathrm{GeV}^{-\frac{1}{2}}$$
$$A^n_{1/2}(1710) = 24 \times 10^{-3}\mathrm{GeV}^{-\frac{1}{2}}$$

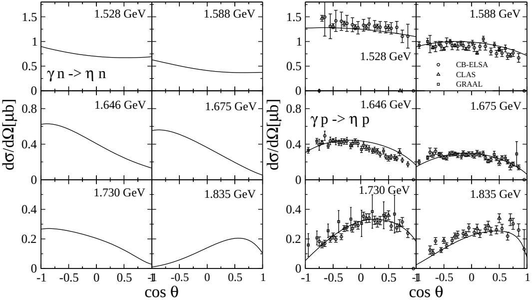
Results for the $\gamma n \to \eta n$ vs. $\gamma p \to \eta p$

Comparison of $\gamma n \to \eta n$ and $\gamma p \to \eta p$
differential cross sections

prediction

$\gamma n \to \eta n$

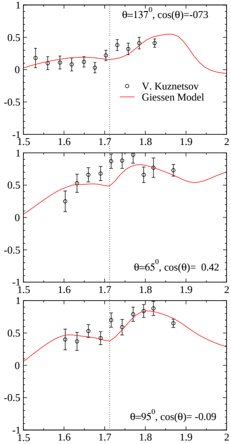
$\gamma p \to \eta p$



- $\gamma n \to \eta n$ mostly backward directions up to 1.75 GeV -result of S- and P-wave interference.
- above 1.75 GeV $\gamma n \to \eta n$ looks very similar to $\gamma p \to \eta p$

$\gamma n^* \to \eta n$

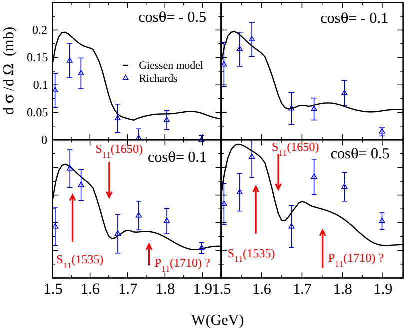
V. Kuznetsov, et al. PLB 647 (2007) 23 for GRAAL collaboration vs. Giessen Model PLB650, 172(2007): asymmetry for $\gamma n^* \to \eta n$



cusp structure at 1.72 GeV is due to ωN threshold

$\pi^- p \rightarrow \eta n$

Giessen Model: Shklyar, Mosel, Lenske PLB650, 172(2007) vs. data Richards etl al PR 1, 10 (1970)

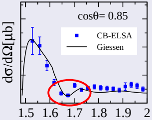


- Richards data show an excess structure at 1.7 GeV
- hard to make conclusion: the data is of poor quality
- Giessen calculations: destructive $S_{11}(1535)$ and $S_{11}(1650)$ interference; $P_{11}(1710)$ excitation.

Summary of the $(\pi/\gamma)N \to \eta N$ reactions

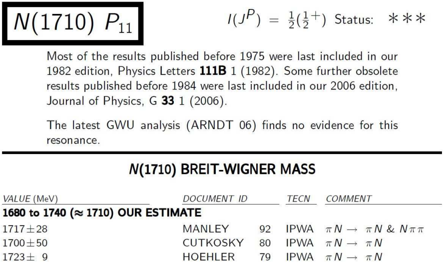
Giessen Model

- $\gamma p \to \eta p$: strong $S_{11}(1535)$
- $S_{11}(1535)$ and $S_{11}(1650)$ interference leads to the deep at 1.67 GeV seen in CB-ELSA and MAMI data



- $\gamma n^* \to \eta n$ **resonance-like structure around 1.67 GeV:** NEW STATE? EXOTIC?
  Giessen Model:$S_{11}(1650)/P_1 1(1710)$ resonances
  backward distribution at 1.67 GeV
- $\pi N \to \eta N$ **promising signal around 1.7 GeV:** but: data of poor quality, hard to make conclusion
- **need new $\pi N \to \eta N$ measurements**

$\pi N \to 2\pi N$ and $P_{11}(1710)$ state



$N(1710)$ P_{11} $\qquad I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$ Status: ∗∗∗

Most of the results published before 1975 were last included in our 1982 edition, Physics Letters **111B** 1 (1982). Some further obsolete results published before 1984 were last included in our 2006 edition, Journal of Physics, G **33** 1 (2006).

The latest GWU analysis (ARNDT 06) finds no evidence for this resonance.

$N(1710)$ BREIT-WIGNER MASS

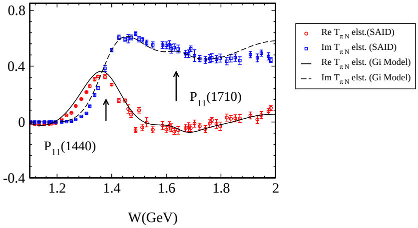
VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
1680 to 1740 (≈ 1710) OUR ESTIMATE				
1717±28	MANLEY	92	IPWA	$\pi N \to \pi N$ & $N\pi\pi$
1700±50	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
1723± 9	HOEHLER	79	IPWA	$\pi N \to \pi N$

PDG 2010:

$\mathrm{Br}(\pi N) \approx$ 10 to 20 %

$\mathrm{Br}(2\pi N) \approx$ 40 to 90 %

$\mathrm{Br}(K\Lambda) \approx$ 5 to 25 %



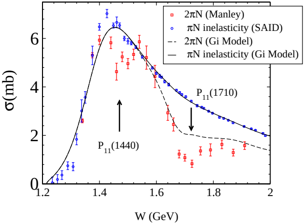
Modern GWU (SAID) PWA:

no signal around 1710 MeV !

Giessen Model: $P_{11}(1710)$:

$\mathrm{Br}(\pi N) \approx 3\%$

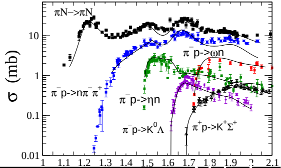
$P_{11}(1710)$: problems



Optical theorem :

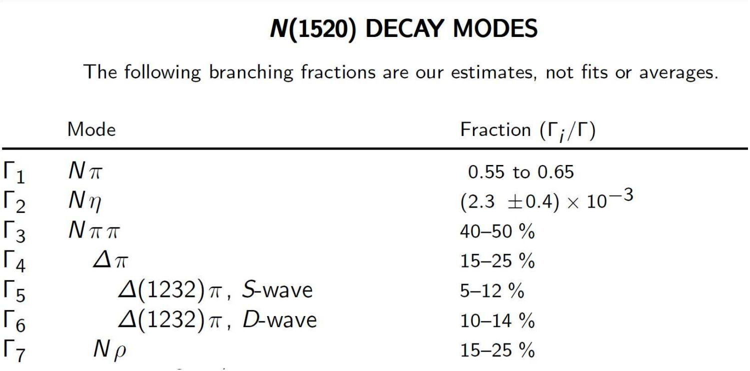
$$\left[\frac{4\pi}{k_{\rm cm}^2} Im T^{JI}_{\pi N} - \sigma^{JI}_{\pi N\to\pi N}\right] = {\color{red}\sigma^{JI}_{\pi N\to 2\pi N}} + \sigma^{JI}_{\pi N\to\eta N} + \sigma^{JI}_{\pi N\to\omega N} + \sigma^{JI}_{\pi n\to K\Lambda} + \sigma^{JI}_{\pi N\to K\Sigma} + \ldots$$

- PDG values are inconsistent with exp. data and modern PWA
- large difference between πN inelasticity and $2\pi N$ channel - cannot be fully absorbed into $K\Lambda$ or $K\Sigma$
- Giessen model: decay $P_{11}(1710) \to \eta N$
- $P_{11}(1710)$ modern status: only indirect indications: more data is needed



$D_{13}(1520)$: resonance

PDG 2010



$N(1520)$ DECAY MODES

The following branching fractions are our estimates, not fits or averages.

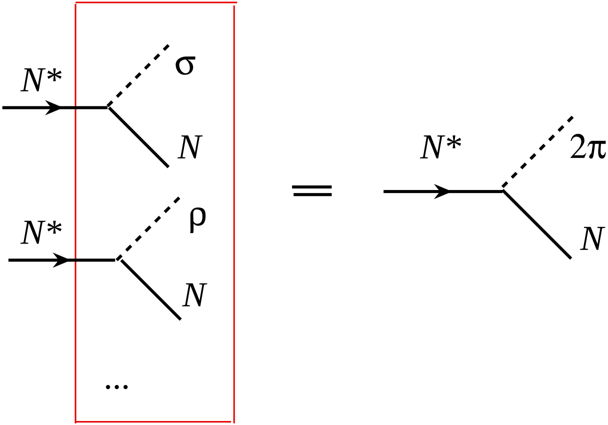
	Mode	Fraction (Γ_i/Γ)
Γ_1	$N\pi$	0.55 to 0.65
Γ_2	$N\eta$	$(2.3 \pm 0.4) \times 10^{-3}$
Γ_3	$N\pi\pi$	40–50 %
Γ_4	$\Delta\pi$	15–25 %
Γ_5	$\Delta(1232)\pi$, S-wave	5–12 %
Γ_6	$\Delta(1232)\pi$, D-wave	10–14 %
Γ_7	$N\rho$	15–25 %

- strong coupling to ρN and $\pi\Delta$
- $m_{1520} << 1.7\ \text{GeV}(m_\rho + m_N)$
- important for in-medium ρ-meson calculations

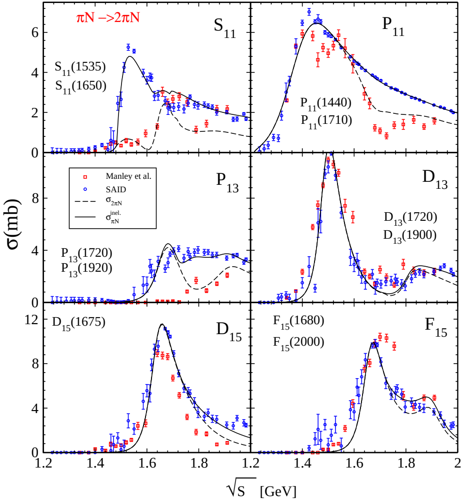
Next step: improve description of the $2\pi N$ channel

so far: N^* decay into 'generic' 2π channel

- take $2\pi N$ inelastic flux into account
- $N^* \rightarrow 2\pi N$ couplings constrained by $\sigma^{JI}_{\pi N \rightarrow 2\pi N}$



πN inelasticity and inelastic channels



Optical theorem :

$$\left[\frac{4\pi}{k^2_{\text{cm}}} Im T^{JI}_{\pi N} - \sigma^{JI}_{\pi N\to\pi N}\right]$$

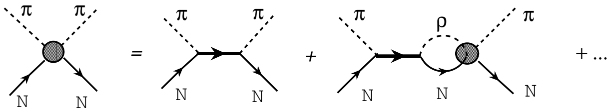
$$= \sigma^{JI}_{\pi N\to 2\pi N} + \sigma^{JI}_{\pi N\to\eta N}$$

$$+\sigma^{JI}_{\pi N\to\omega N} + \sigma^{JI}_{\pi N\to K\Lambda} + \sigma^{JI}_{\pi N\to K\Sigma}$$

— πN inelasticity

— $2\pi N$ partial wave cross sections

New multichannel problem



$$T^{\mathrm{JI}}_{\pi\pi} = K^{\mathrm{JI}}_{\pi\pi} + \mathrm{i} K^{\mathrm{JI}}_{\pi\pi} T^{\mathrm{JI}}_{\pi\pi}$$

$$+\mathrm{i} \int_{4m_\pi^2}^{(\sqrt{s}-m_N)^2} d{\mu'_\rho}^2 \, K^{\mathrm{JI}}_{\pi\rho}({\mu'_\rho}^2) \, A_\rho({\mu'_\rho}^2) \, T^{\mathrm{JI}}_{\rho\pi}({\mu'_\rho}^2)$$

- two body unitarity
- couplings to ρN, $\pi\Delta$, σN
- incorporate final widths of ρ, Δ

N(1520) D_{13} state

Manley et al: PRD(1984)

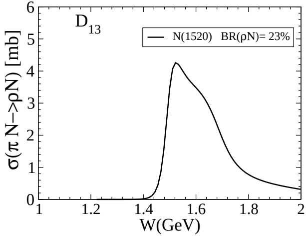
$M_R = 1520\text{MeV}$

Γ_{tot}=120MeV

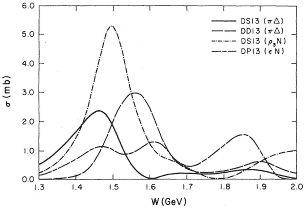
strong N(1520)$\rightarrow 2\pi N$

Br(ρN) ≈20%

Giessen Model (CC): $\pi N \rightarrow \rho N$



Manley analysis:



- distribution:
  Giessen: non-symmetric
  Manley : symmetric
- Gi Model: no contributions below 1.4 GeV
- Manley: no ρ-spectral function: should be revised

Summary of the $\pi N \to 2\pi N$ reactions

- strong contributions to the πN inelasticity
- important for understanding for ρ-meson dynamics and resonance couplings
- could solve many puzzles in non-strange baryon spectroscopy: origin and properties of the $P_{11}(1440)$, $P_{11}(1710)$, $D_{13}(1520)$ etc.

Theory

- analysis of Manley et. al. should be revised!

Experiment

- need for new measurements $\pi N \to 2\pi N$ in region 1.2...2.GeV → challenge for HADES collaboration

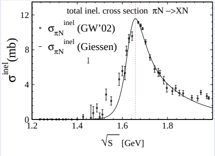
pion beams at HADES contact piotr.salabura@uj.edu.pl

Why $D_{15}(1675)$ with $\Gamma_{\eta N} = 17\%$ is a bad

Optical theorem for $\pi N \to \pi N$ scattering

$$(J+\frac{1}{2}) Im T^{\frac{5}{2}^{+}\frac{1}{2}}_{\pi N\to\pi N} = \frac{k^2}{4\pi}(\sigma^{\frac{5}{2}^{+}\frac{1}{2}}_{\pi N\to\pi N} + \sigma^{\frac{5}{2}^{+}\frac{1}{2}}_{\pi N\to 2\pi N} + \sigma^{\frac{5}{2}^{+}\frac{1}{2}}_{\pi N\to\eta N})$$

$$\sigma^{\frac{5}{2}^{+}\frac{1}{2}}_{inel.} = \sigma^{\frac{5}{2}^{+}\frac{1}{2}}_{\pi N\to 2\pi N} + \sigma^{\frac{5}{2}^{+}\frac{1}{2}}_{\pi N\to\eta N} \approx 12\text{mb}$$



Assuming dominant $D_{15}(1675)$

$$T_{\pi N\to 2\pi N} \sim \frac{\Gamma^{N(1675)}_{\pi N}\Gamma^{N(1675)}_{2\pi N}}{s-m^2_{1675}-i\Gamma_{tot}/2}$$

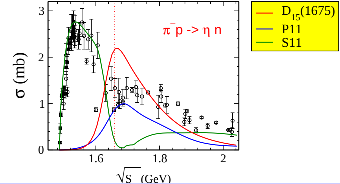
$$T_{\pi N\to \eta N} \sim \frac{\Gamma^{N(1675)}_{\pi N}\Gamma^{N(1675)}_{\eta N}}{s-m^2_{1675}-i\Gamma_{tot}/2}$$

$$\sigma_{\pi N\to\eta N}/\sigma_{\pi N\to 2\pi N} = (\Gamma^{1675}_{\eta N}/\Gamma^{1675}_{2\pi N})^2$$

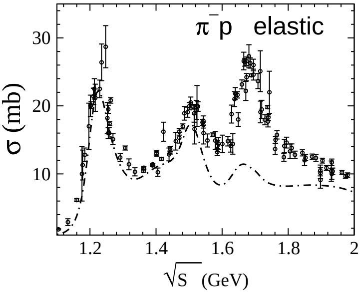
η-MAID L. Tiator (hep-ex/0601002):

$\Gamma_{\eta N} \approx 17\%$, $\Gamma_{2\pi N} \approx 40\%$

$\sigma^{\frac{5}{2}}_{\pi N\to\eta N}|_{1675 MeV} = 12(\frac{17}{40})^2 \approx 2.2$mb



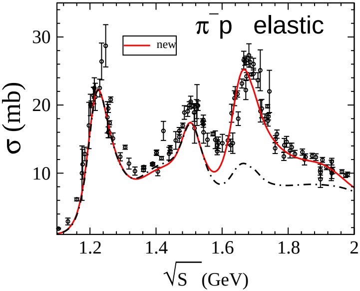
Giessen model



Previous analysis:
Penner and Mosel RRC66, 055211 (2002)

no spin-$\frac{5}{2}$ resonances !

Giessen model



New results:

V. Shklyar et al .PRC71, 055206 (2005)

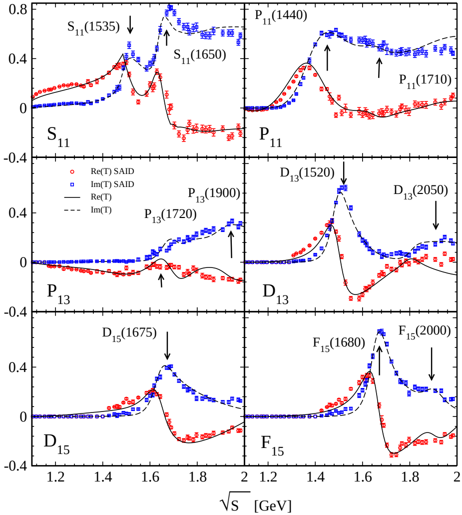
with spin-$\frac{5}{2}$ resonances !

But! It is so important for the ωN production ?

Optical theorem:

$$Im T_{\pi N \to \pi N} \sim \sigma_{\pi N \to \omega N} + \ldots$$

Results for pion-induced reactions



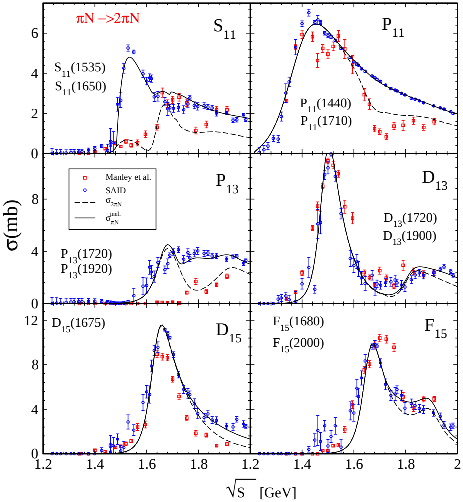
πN elastic amplitudes:

- reach spectrum
- not only πN decay

$I = \frac{1}{2}$ resonances important:

$S_{11}(1535)$, $S_{11}(1650)$
$P_{11}(1440)$, $P_{11}(1710)$
$P_{13}(1720)$, $P_{13}(1900)$
$D_{13}(1520)$, $D_{13}(2050)$
$D_{15}(1675)$
$F_{15}(1680)$, $F_{15}(2000)$

πN inelasticity and inelastic channels



Optical theorem :

$$\left[\frac{4\pi}{k_{\rm cm}^2} Im T^{JI}_{\pi N} - \sigma^{JI}_{\pi N\to\pi N}\right]$$
$$= \sigma^{JI}_{\pi N\to 2\pi N} + \sigma^{JI}_{\pi N\to\eta N}$$
$$+\sigma^{JI}_{\pi N\to\omega N}+\sigma^{JI}_{\pi N\to K\Lambda}+\sigma^{JI}_{\pi N\to K\Sigma}$$

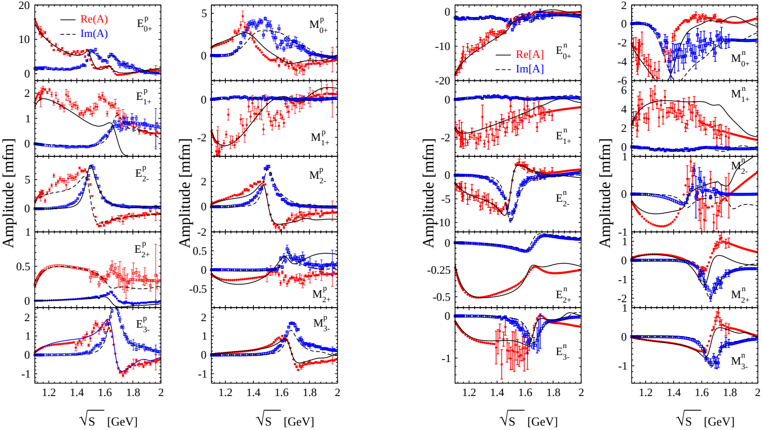
— πN inelasticity

— $2\pi N$ partial wave cross sections

Giessen model. Pion photoproduction

proton multipoles

neutron multipoles



Combined analysis of $(\pi, \gamma)N \to (\pi, \gamma)N$ gives a strong constraint on extracted resonance parameters