Giessen coupled-channel results for pion and photon induced reactions

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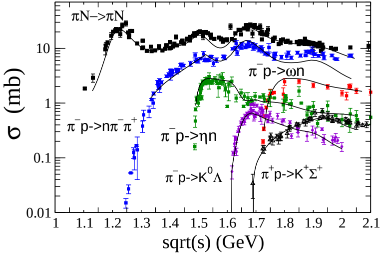
Partial wave version of optical theorem

constraints on partial wave cross sections



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

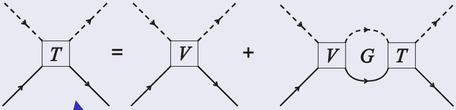
all reaction data are linked

→ **need for coupled-channel unitary analysis**

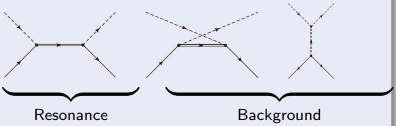
Giessen model. PRC71, 055206 (2005)

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

T-matrtix



Interaction term V



multidmentional T-matrix

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

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:

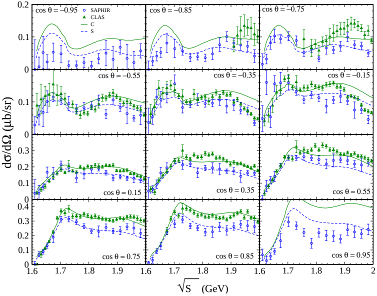
$$\int dq \frac{1}{q^2 - m^2 \pm i\varepsilon} = P \int dq \frac{1}{q^2 - m^2} \mp i\pi \int dq \delta(q^2 - m^2)$$

where all intermediate particles are on-shell.

main features

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

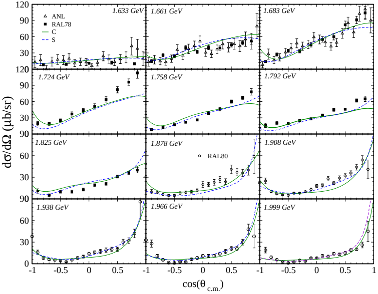
$(\gamma,\pi)N \to K\Lambda$. Giessen model PRC72:015210



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

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.)



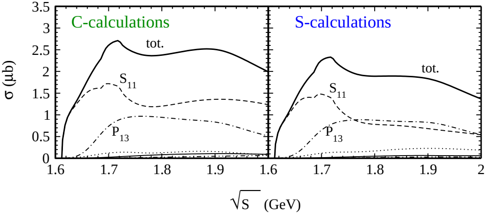
$\pi^- p \to K^0\Lambda$

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).

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

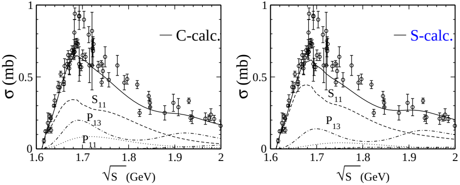


Resonance contributions: $S_{11}(1650)$ $P_{13}(1720)$ and $P_{13}(1900)$

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

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

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

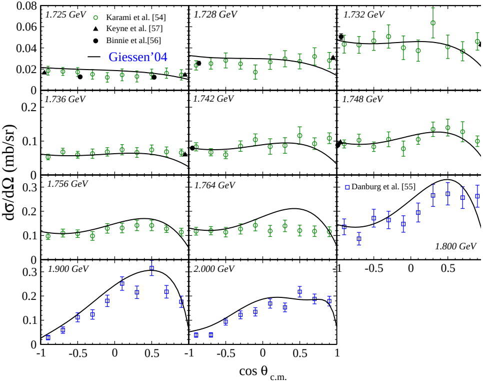


Giessen model. Results for the $(\pi, \gamma)N \to \omega N$ reactions

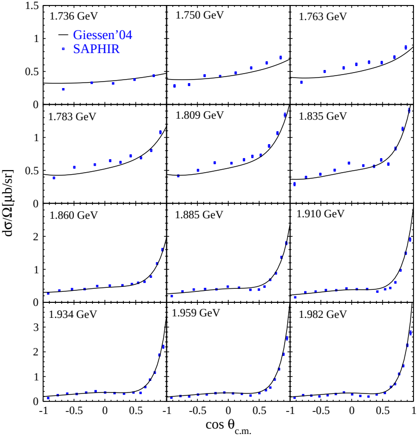
Combined analysis $\Longrightarrow$ more constraint on resonance properties.

Giessen model, PRC 71:055206,2005

$\pi N \to \omega N$

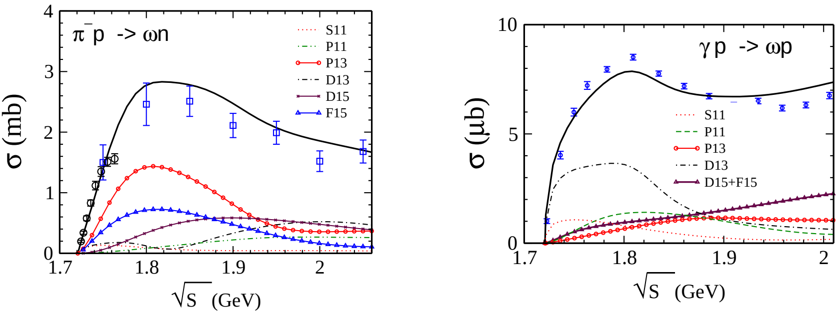


$\gamma N \to \omega N$



Giessen model. Results for $(\pi, \gamma)N \to \omega N$

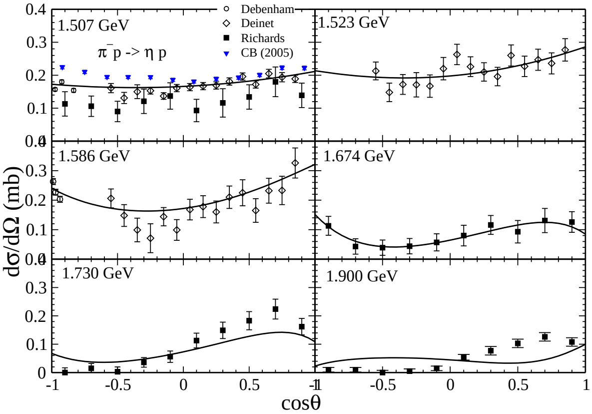
Giessen model, PRC 71:055206,2005



- P_{13}: interference between resonance and background
- strong $N^*(\frac{5}{2})$ coupling to ωN
- $D_{13}(1520)$ minor contributions

- strong Born and π^0-exchange contributions
- D_{13} is due to π^0-exchange

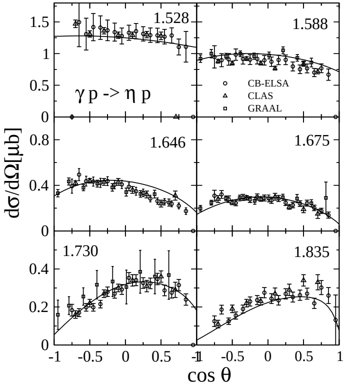
Results for the $\pi^- p \to \eta p$ production



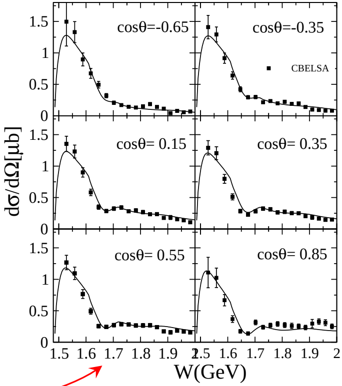
$\pi^- p \to \eta\, n$: Solution from the Giessen coupled-channel analysis V.Shklyar et al, PRC.71. 055206 (2005).

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



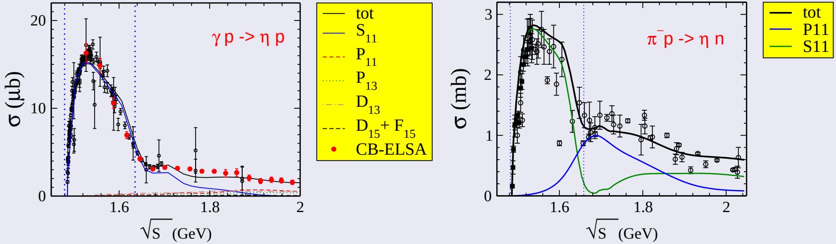
The structure at 1.67 GeV in $\gamma p \to \eta p$ is due to $S_{11}(1650)$
Shklyar et al PLB650, 172(2007)

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



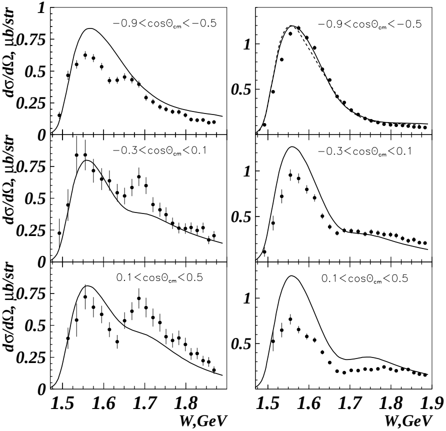
- strong $S_{11}(1535)$ excitation
- kink structure at 1.72 GeV is due to the ωN threshold
- seems no room for other contributions

- 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

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



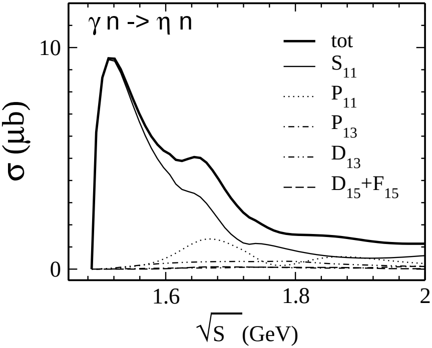
- quasi-free neutron: resonance-like structure at 1.67 GeV
- confirmed by B.Krusche, I. Jaegle at MAMI, CB-ELSA

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

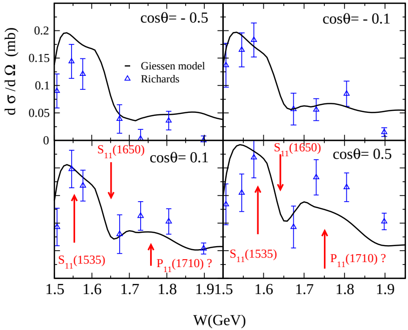


$$A^n_{1/2}(1650) = -9 \times 10^{-3}\mathrm{GeV}^{-\frac{1}{2}}$$

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

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

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

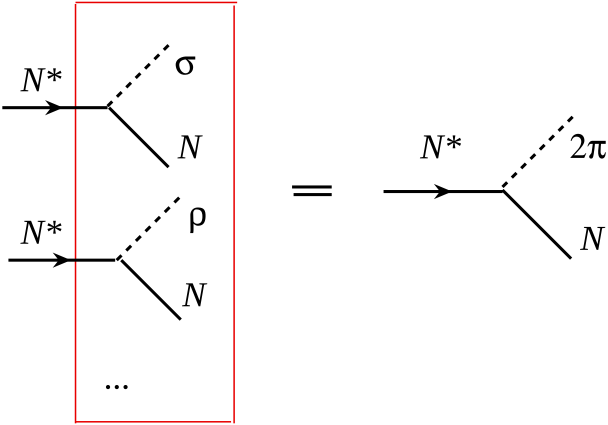


- Richards data show an excess structure at 1.7 GeV
- hard to make conclusion: the data is of poor quality
- Giessen calculations: destructive $S_{11}(1535)$ and $S_{11}(1650)$ interference; $P_{11}(1710)$ excitation.

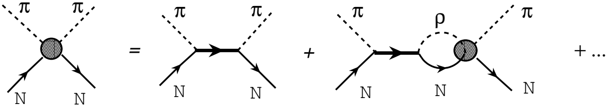
Next step: improve description of the $2\pi N$ channel

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

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



New multichannel problem



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

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

summation instead of integration

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

$$+\mathrm{i}\sum_{m_{\rho_i}} 2m_{\rho_i}\, \Delta m_{\rho_i}\, K^{\mathrm{JI}}_{\pi\rho_i}({m_{\rho_i}}^2)\, A_{\rho_i}({m_{\rho_i}}^2)\, T^{\mathrm{JI}}_{\rho_i\pi}({m_{\rho_i}}^2)$$

N(1520) D_{13} state

Manley et al: PRD(1984)

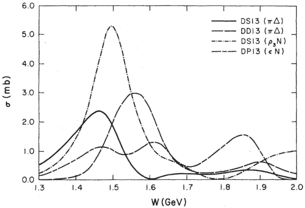
$M_R = 1520\text{MeV}$

Γ_{tot}=120MeV

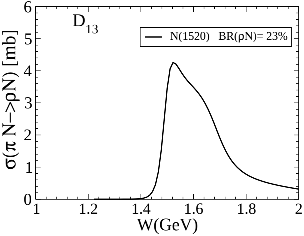
strong N(1520)$\rightarrow 2\pi N$

Br(ρN) ≈20%

Manley analysis:



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



- 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

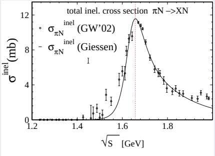
pion beams at HADES contact piotr.salabura@uj.edu.pl

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

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

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

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



Assuming dominant $D_{15}(1675)$

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

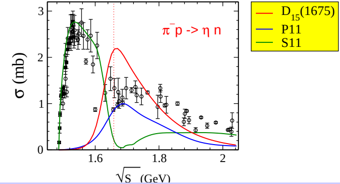
$$T_{\pi N\rightarrow \eta N} \sim \frac{\Gamma^{N(1675)}_{\pi N}\Gamma^{N(1675)}_{\eta N}}{s - m^2_{1675} - i\Gamma_{tot}/2}$$

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

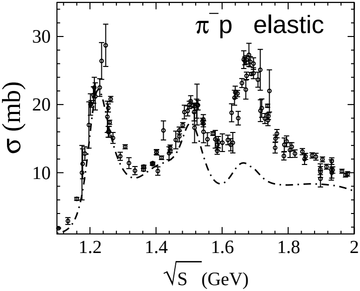
η-MAID L. Tiator (hep-ex/0601002):

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

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



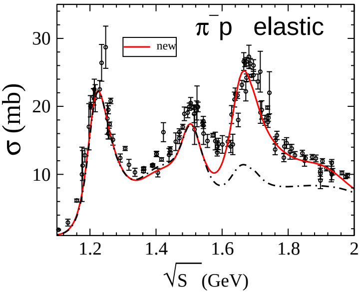
Giessen model



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

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

Giessen model

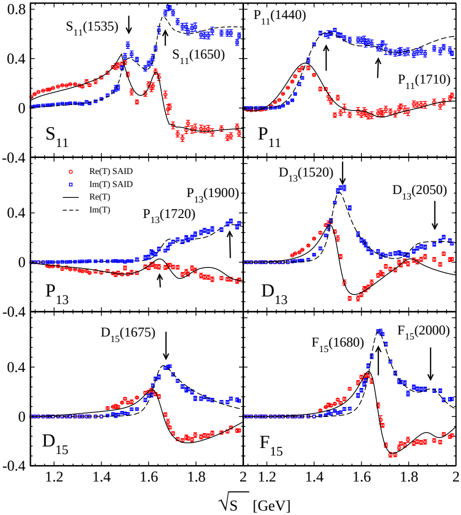


New results:
V. Shklyar et al .PRC71, 055206 (2005)
with spin-$\frac{5}{2}$ resonances !
But! It is so important for the ωN production ?

Optical theorem:

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

Results for pion-induced reactions



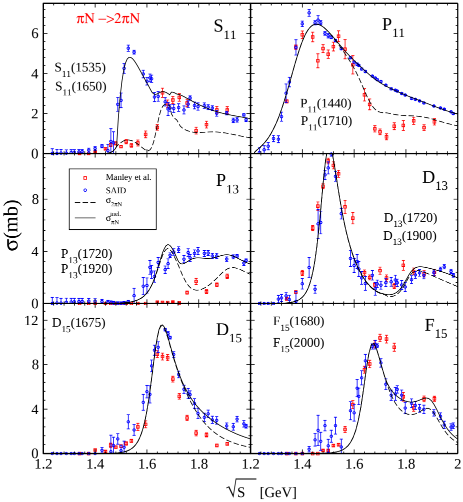
πN elastic amplitudes:

- 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 :

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

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

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

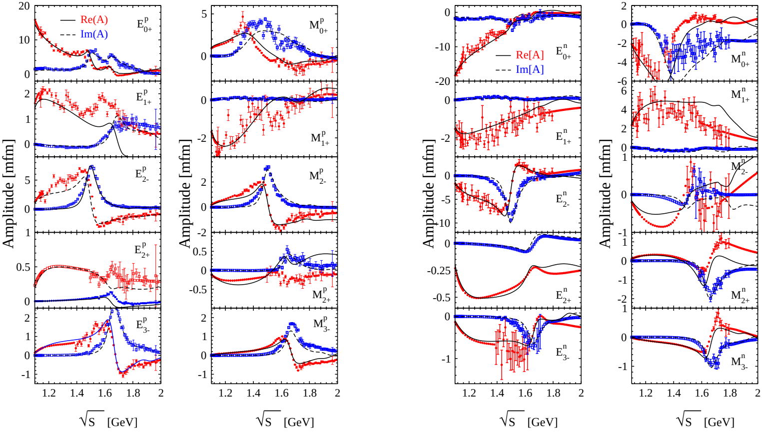
— πN inelasticity

— $2\pi N$ partial wave cross sections

Giessen model. Pion photoproduction

proton multipoles

neutron multipoles



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