Partial wave analysis of $(\gamma/\pi)N \to \eta N$ reactions within coupled-channel unitary Lagrangian model *

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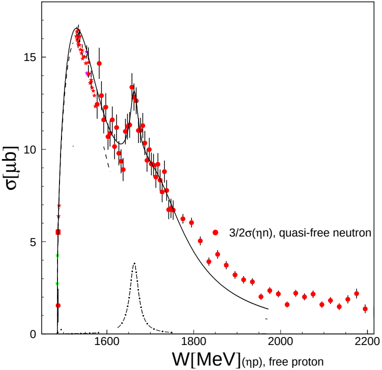
η-photoproduction on the neutron

$\gamma n \rightarrow \eta n$

I.Jeagle, B. Krusche EPJA47, 89



First peak: $S_{11}(1535)$

Is there a second peak in $\gamma p \rightarrow \eta p$?

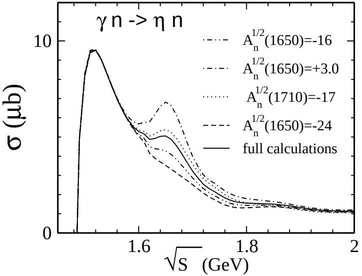
- Azimov, Arndt, Strakovsky; Polyakov, Workman PRC69 (2004), 035208: narrow N(1680) state
- V. Kuznetsov, et al. PLB 647 p23 quasi-free neutron: resonance-like structure at 1.67 GeV
- recent measurements (I.Jeagle et al) EPJA47,89: clean second peak!

Other explanations

- Shklyar, Mosel, Lenske PLB650 (2007),172: well known $S_{11}(1650)$, $P_{11}(1710)$
- Doering, Nakayama PLB683(2010),145 : pole due to $K\Sigma$ rescattering

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

Shklyar er al: PLB650,172

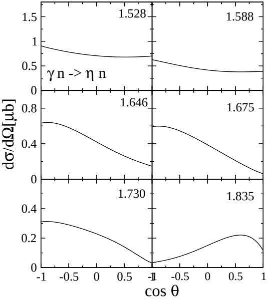


Giessen model: $\gamma n \to \eta n$

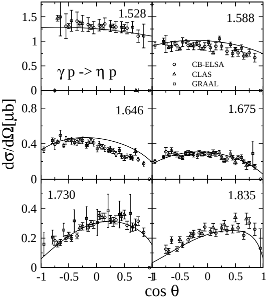
- $S_{11}(1535)$ and $S_{11}(1650)$: positive interference; effect from $P_{11}(1710)$ is large; $S_{11}(1650)$ or $P_{11}(1710)$ or both could be be responsible for the second peak
- but cannot rule out a narrow state

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

$\gamma n \to \eta n$



$\gamma p \to \eta p$



Prediction from the Giessen Model(Shklyar et al PLB650,172)

- $\gamma n \to \eta n$ mostly backward directions up to 1.75 GeV
- above 1.75 GeV $\gamma n \to \eta n$ looks very similar to $\gamma p \to \eta p$

backward distribution is confirmed by recent CB-ELSA/TAPS measurements

Difficulties with the quasi-free photoproduction

Deuteron target

- Fermi-motion,
- quasi-free kinematics,
- experimental resolution (neutron momentum)
- FSI is important ! Tarasov et al PRC84, 035203.
- take care of kinematical cuts Torres, Oset PRL105,092001.

a lot should be done before detailed comparison with data

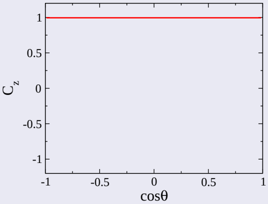
Which resonance is contributing at 1.68 GeV

measurement of the $C_z = \frac{d\sigma(\lambda_\gamma=\uparrow,\lambda_n^z=\uparrow)-d\sigma(\lambda_\gamma=\downarrow,\lambda_n^z=\uparrow)}{d\sigma(\lambda_\gamma=\uparrow,\lambda_n^z=\uparrow)+d\sigma(\lambda_\gamma=\downarrow,\lambda_n^z=\uparrow)}$ asymmetry is very important

- assuming the dominant S_{11} and P_{11} resonance contributions
- then the reaction proceeds from initial $\lambda_{in} = \frac{1}{2}$ helicity

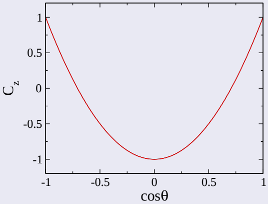
S_{11}

electric interaction (E_0-multipole): no spin flip $C_z(\theta)=1$



P_{11}

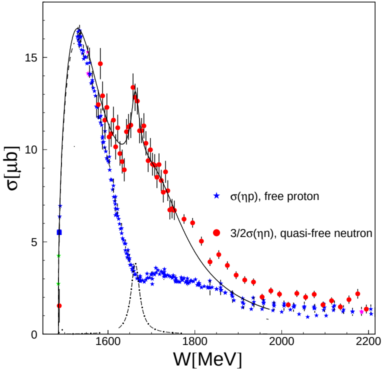
magnetic interaction (M_{1-}-multipole): spin flip at 90^0: $C_z(\theta) = 1 - 2\sin^2(\theta)$



measurement of the C_z might be extremely useful to pin down

η-photoproduction on the neutron and on the proton

I.Jeagle, B. Krusche EPJA47, 89



First peak: $S_{11}(1535)$

- $\gamma n \to \eta n$: resonance-like structure at 1.68 GeV
- $\gamma p \to \eta p$: dip at 1.68 GeV (well seen in new MAMI data PRC82,035208)

Main questions

- Are resonance-like structure in ηn and dip in ηp originated from the same degrees of freedom ?
- Can narrow resonance contribution be attributed to one (or both of these effects)?
- Do these effects have their counterparts in the $\pi^- p \to \eta n$?

η-photoproduction on the proton

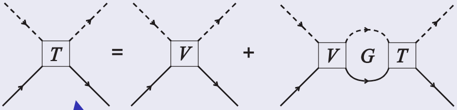
- Which mechanism is responsible for the dip at 1.68 GeV

- Could a narrow state or ωN threshold be responsible for the this effect ?

Giessen model. PRC71, 055206 (2005)

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

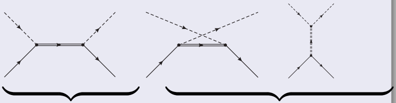
T-matrtix



multidimensional T-matrix

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

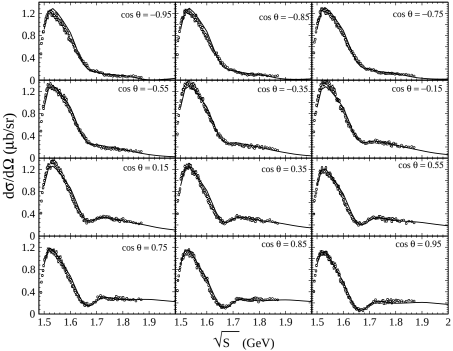
Interaction term V



How many channels?

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

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

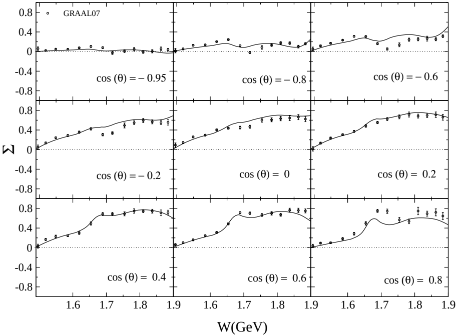


$\gamma p \to \eta p$: updated Giessen analysis vs. new MAMI 2010 data

We corroborate our previous conclusions: Shklyar et al PLB650,172

- $S_{11}(1535)$ and $S_{11}(1650)$: destructive interference - dip at 1.68 GeV; effect from $P_{11}(1710)$ is small
- ωN threshold effect is 50 above the dip position- not decisive
- no room for narrow state of 15...20 MeV width

Results for the $\gamma p \to \eta p$ production: asymmetry



$\gamma p \to \eta p$: updated Giessen analysis vs. GRAAL measurements

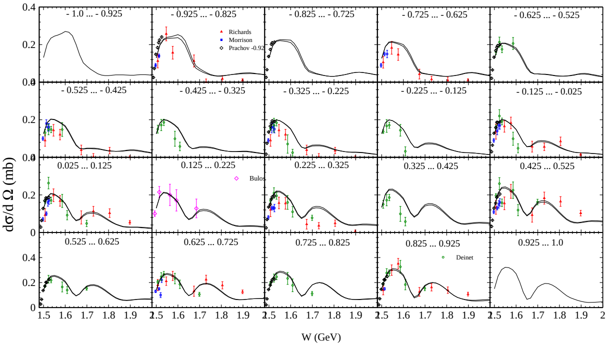
- GRAAL: (15 MeV resolution) no evidence for narrow state
- Updated calculation from Giessen Model: no indication for exotic

Does the peak(dip) in ηn(ηp) at 1.68 GeV have a counterpart in $\pi^- p \to \eta n$?

$\pi N \to \eta N$ database diff. X-sections

- W=1.51 to 2.18 GeV: ~~R.M. Brown et al., NPB153, 89 (1979)~~
- W=1.49 to 1.6 GeV: N.C. Debenham et al., PR 12, 2545 (1975): 45 datapoints, $cos(\theta) \approx$ -0.9 to -0.8
- W=1.51 to 1.7 GeV: W. Deinet, et al NPB11, 495 (1969): 84 datapoints, large uncertainties
- W=1.51 to 1.9 GeV: W.B. Richards et al., PR 1, 10 (1970) 71 datapoints,
- W=1.49 to 1.53 GeV: Crystal Ball S. Prakhov et al., PRC 72 015203, (2005)
- W=1.76 to 2.18 GeV: ~~R.D. Baker et al., NPB156, 93 (1979)~~ Target asymmetry

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



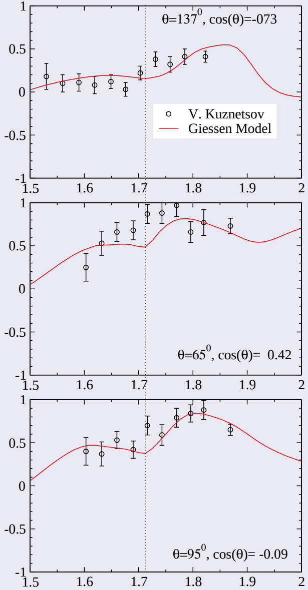
$\pi^- p \to \eta\, n$: updated Giessen coupled-channel analysis

- overlap of $S_{11}(1535)$ and $S_{11}(1650)$ states - destructive interference - dip at 1.68 GeV
- contribution from $P_{11}(1710)$ - second peak
- interference between S_{11} and P_{11} partial waves - second peak at mostly forward angles (prediction from Giessen Model).

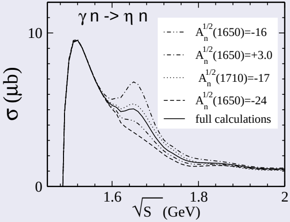
Summary of the $(\pi/\gamma)N \to \eta N$ reactions

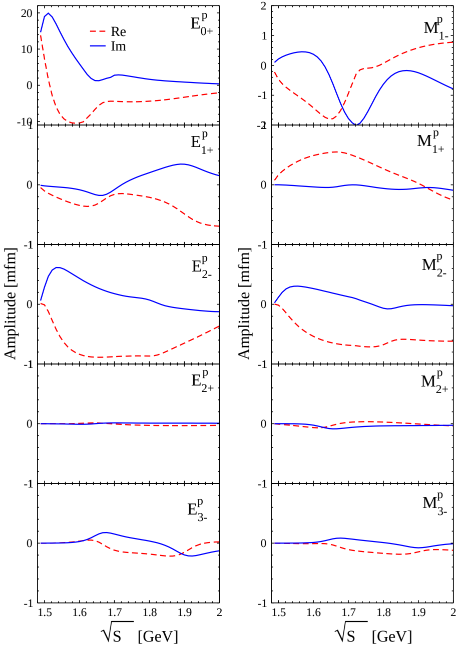
- $\gamma p \to \eta p$ dip at 1.68 GeV
- $\gamma n^* \to \eta n$ **resonance-like structure around 1.68 GeV:** NEW STATE? EXOTIC or already established N(1710), cusp due to $K\Sigma$?
- measurement of C_z **asymmetry** would be crucial to separate S_{11} and P_{11} contributions
- $\pi N \to \eta N$ **promising signal around 1.7 GeV:** but: data of poor quality, hard to make conclusion
- unified picture from Giessen Model **in terms of** $S_{11}(1535)$**,** $S_{11}(1650)$ **and** $P_{11}(1710)$ but other explanations are possible.
- **NO FURTHER PROGRESS without new** $\pi N \to \eta N$ **measurements**

asymmetry $\gamma n \to \eta n$

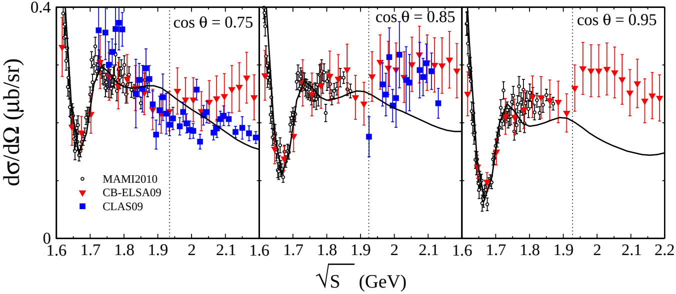


total $\gamma n \to \eta n$





$\gamma p \to \eta p$ photoproduction multipoles



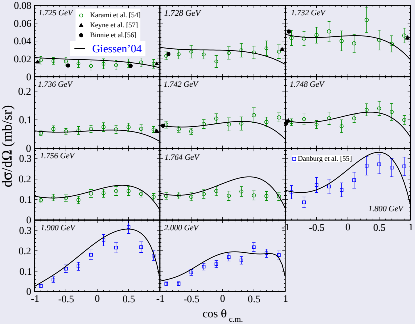
$\gamma p \to \eta p$ above 1.89 GeV

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

ωN: coupled channel analysis Shklyar et al PRC 71:055206:

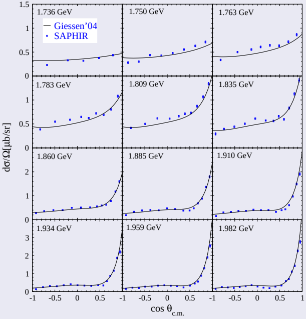
Aim: extract resonance coupling to ωN

$\pi N \to \omega N$



few measurements, low statistic

$\gamma N \to \omega N$

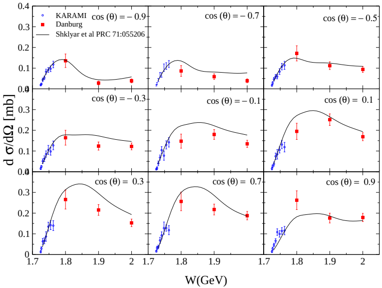


strong t-channel pion exchange shadow other reaction mechanisms

$\pi N \to \omega N$ database

- W=1.72 to 1.76 GeV: H. Karami, et al NPB154 503 (1979) : 80 datapoints threshold region
- W=1.8 to 2.1 GeV: J.S. Danburg, PR2, 2564(1970) from $\pi^+ D \to \pi^+\pi^-\pi^0 p(p)$: 41 datapoints Fermi-motion, final state interaction!

Shklyar et al,
PRC 71:055206,2005



Difficulties:

- ωN has three helicities: need ω-polarization measurements
- Karami data - close to threshold
- region 1.76...2.0 GeV is almost empty - standard PWA not possible
- no polarization measurements
- Problem: N^* extraction ...

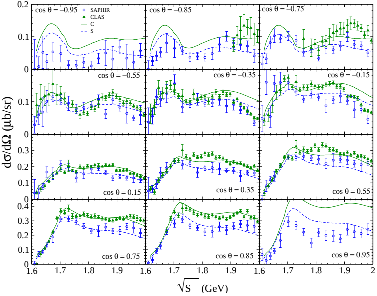
Summary of $(\pi/\gamma)N \to \omega N$ reactions

- $\gamma p \to \omega p$: strong t-channel background $\to$ other reaction mechanisms are shadowed: hard to see any resonance contributions
- $\pi N \to \omega N$: almost NO data in the region region 1.76...2.0 GeV - standard PWA not possible
- contributions from many groups: Lutz, Wolf, Friman, Titov, Sibirtsev, Zhao, Shklyar, Mosel, Penner - no general conclusion on N^* contributions

NEED $\pi^- p \to \omega p$ measurements in order to

- get information on N^* couplings to ωN - fill white pages in PDG
- construct microscopical model of ω-dynamics in nuclear medium; explain large collisional broading

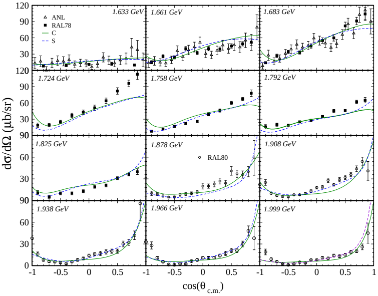
$(\gamma, \pi)N \to K\Lambda$. Shklyar et al PRC72, 015210 (2005).



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

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.)



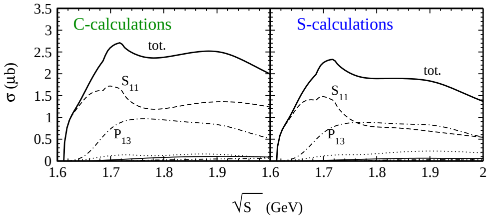
$\pi^- p \to K^0\Lambda$

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

$K\Lambda$-production. Reaction mechanism

Shklyar et al PRC72, 015210 (2005).

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

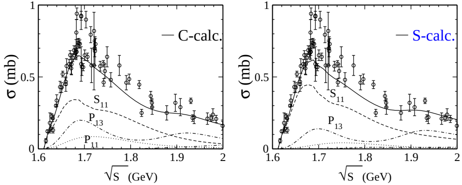


Resonance contributions: $S_{11}(1650)$ $P_{13}(1720)$ and $P_{13}(1900)$

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

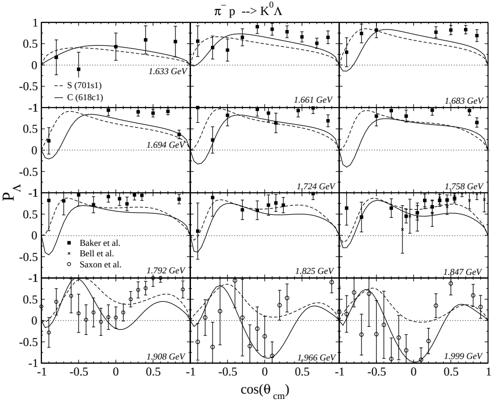
Table: N^* decay ratios to $K\Lambda$

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



$\pi N \to K\Lambda$. Polarization

Shklyar PRC72, 015210 (2005).



We need new $\pi N \to K\Lambda$ measurements !

$\pi N \to K\Lambda$, $K\Sigma$

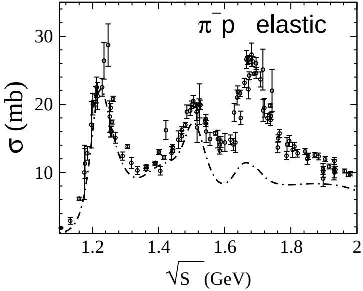
$\pi N \to K\Lambda$, $K\Sigma$ problems to be addressed

- Chiral models: Meissner, Weise, Lutz, Oset et al: some resonances e.g. $S_{11}(1535)$ $S_{11}(1650)$ are not genuine but poles in $K\Lambda$ and $K\Sigma$
- if $K\Lambda$ and $K\Sigma$ produce dynamical resonances in S_{11} partial wave, PWA needed to confirm
- N^* couplings are needed to be constrained

present $\pi N \to K\Lambda$

- experiment: strong admixture of higher partial waves
- extraction of the S_{11} partial wave is hard: some inconsistencies between various measurements, large error bars, new polarization measurement is needed.

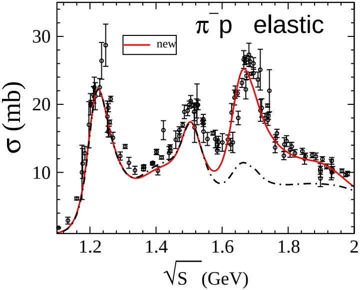
Giessen model



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 ?

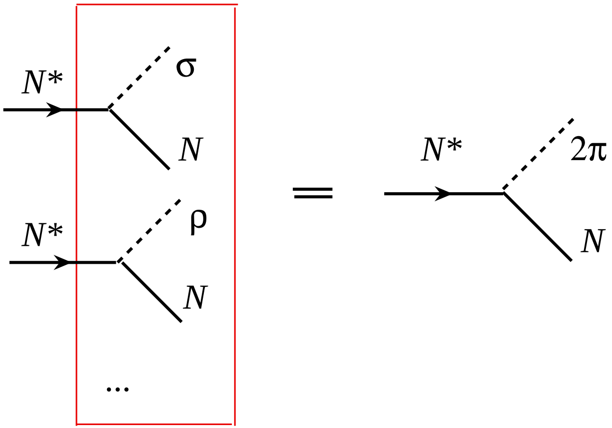
Optical theorem:

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

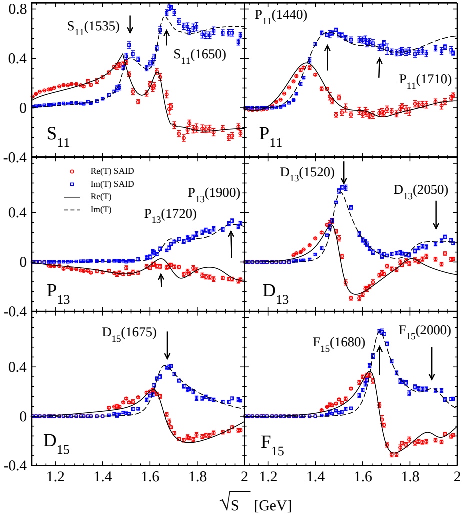
Next step: improve description of the $2\pi N$ channel

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

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



Results for pion-induced reactions



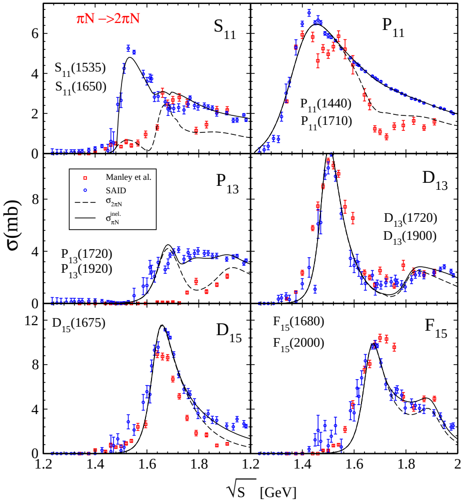
πN elastic amplitudes:

- 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 :

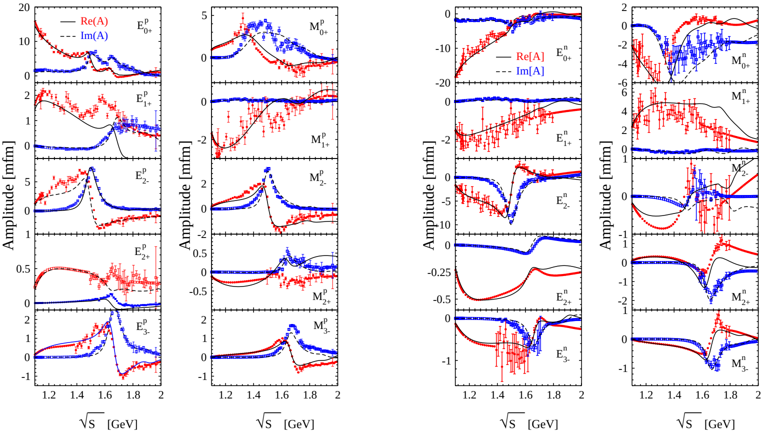
$$\left[\frac{4\pi}{k^2_{\rm cm}} Im T^{JI}_{\pi N} - \sigma^{JI}_{\pi N\to\pi N}\right]$$
$$= \sigma^{JI}_{\pi N\to 2\pi N} + \sigma^{JI}_{\pi N\to\eta N}$$
$$+\sigma^{JI}_{\pi N\to\omega N} + \sigma^{JI}_{\pi N\to K\Lambda} + \sigma^{JI}_{\pi N\to K\Sigma}$$

— πN inelasticity

— $2\pi N$ partial wave cross sections

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