Meson Production on the Nucleon in the Giessen K-Matrix Approach

H. Lenske

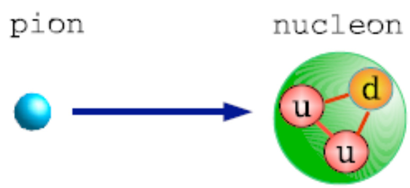
Institut für Theoretische Physik, U. Giessen

Agenda:

- Probing Baryons by Resonance excitation
- Unitary K-Matrix Approach to Meson Production
- Photoproduction on the Nucleon: ωN and $K\Lambda$
- Outlook: Hadronic and Leptonic Production on Nuclei
- Summary

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

Probing Baryons by Hadronic and Electromagnetic Probes



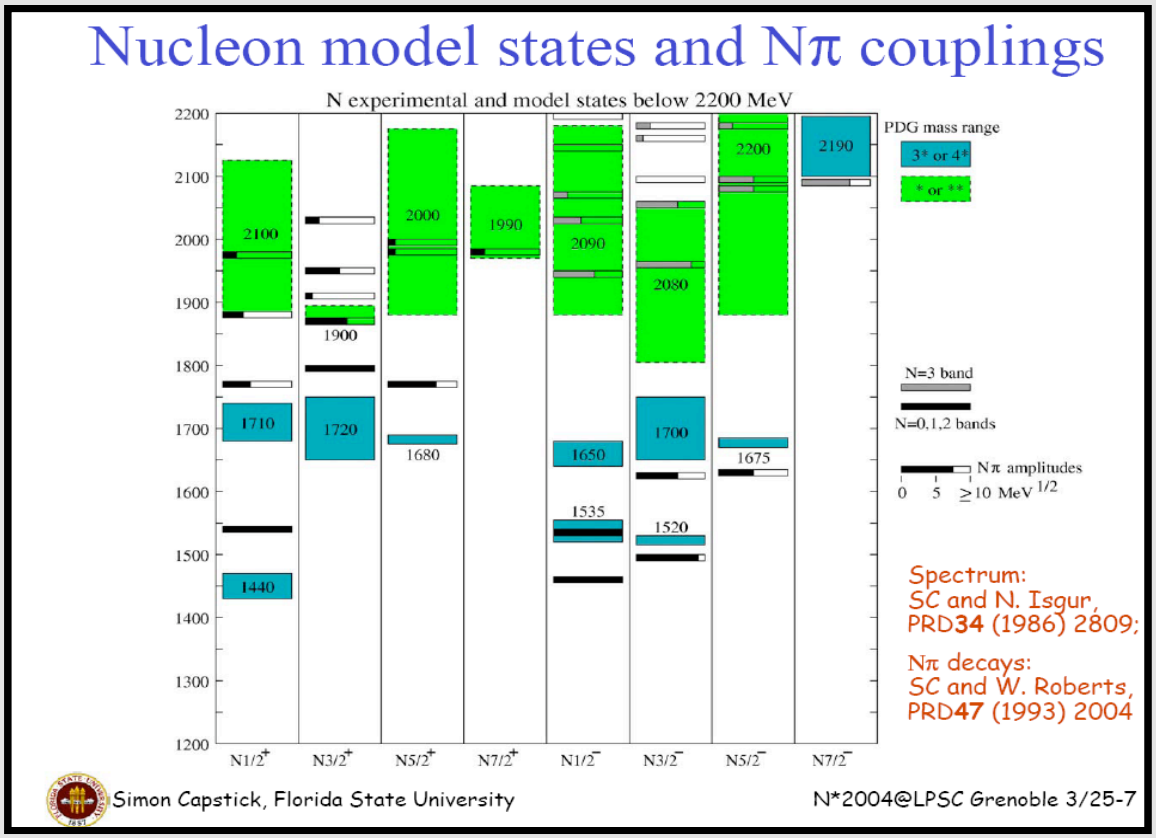
First resonance: $\Delta^{\frac{3}{2}}(1232)$

=> first indication to nucleon structure

both in πN and γN scattering!

Problem:

Missing Resonances!



Confronting Theory with Reality:

Hunting missing resonances: photoproduction.

Recent years:
new photoproduction data, new opportunity

Motivation

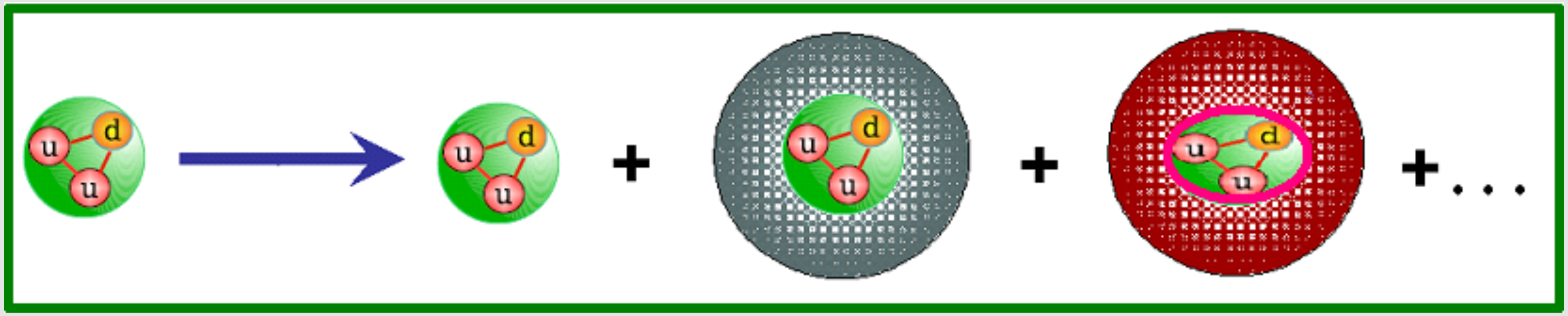
- γN ◊ ωN (SAPHIR)

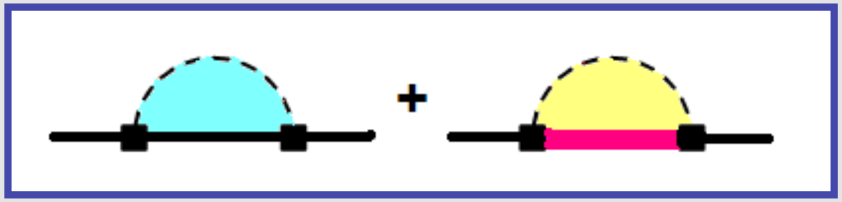
  Search for nucleon resonances which couples strongly to ωN channel

- γN ◊ KΛ (SAPHIR, CLAS, SPring-8)

  New physical domain:
  search for 'missing' states which
  couple strongly to the associated strangeness channel.

Baryons: Quark Model vs. Dynamical Models





Our Choice of Degrees of Freedom (besides photon):

- asymptotic hadronic states: mesons and baryons
- empirical hadron masses
- Lagrangian model with phenomenological coupling constants
- regularization by form factors
- unitary coupled channels approach

Structure of the Lagrangian:

Born and t-channel terms:

$$\mathcal{L}_{Born} + \mathcal{L}_t = -\bar{u}_{B'}(p')\left[\frac{g_{\tilde{\varphi}}}{m_B + m_{B'}}\gamma_5\gamma_\mu(\partial^\mu\tilde{\varphi}) + g_\eta i\gamma_5\eta + g_S\Phi_S \right.$$
$$\left. + g_V\left(\gamma_\mu V^\mu + \frac{\kappa_V}{2m_N}\sigma_{\mu\nu}V^{\mu\nu}\right)\right]u_B(p)$$
$$-\frac{g_S}{2m_\pi}(\partial_\mu\varphi')(\partial^\mu\varphi)\Phi_S - g_V\varphi'(\partial_\mu\varphi)V^\mu - \frac{g_V}{4m_\varphi}\epsilon_{\mu\nu\rho\sigma}V^{\mu\nu}V'^{\rho\sigma}\varphi.$$

positive-parity spin-$\frac{1}{2}$ resonances, PV coupling is used:

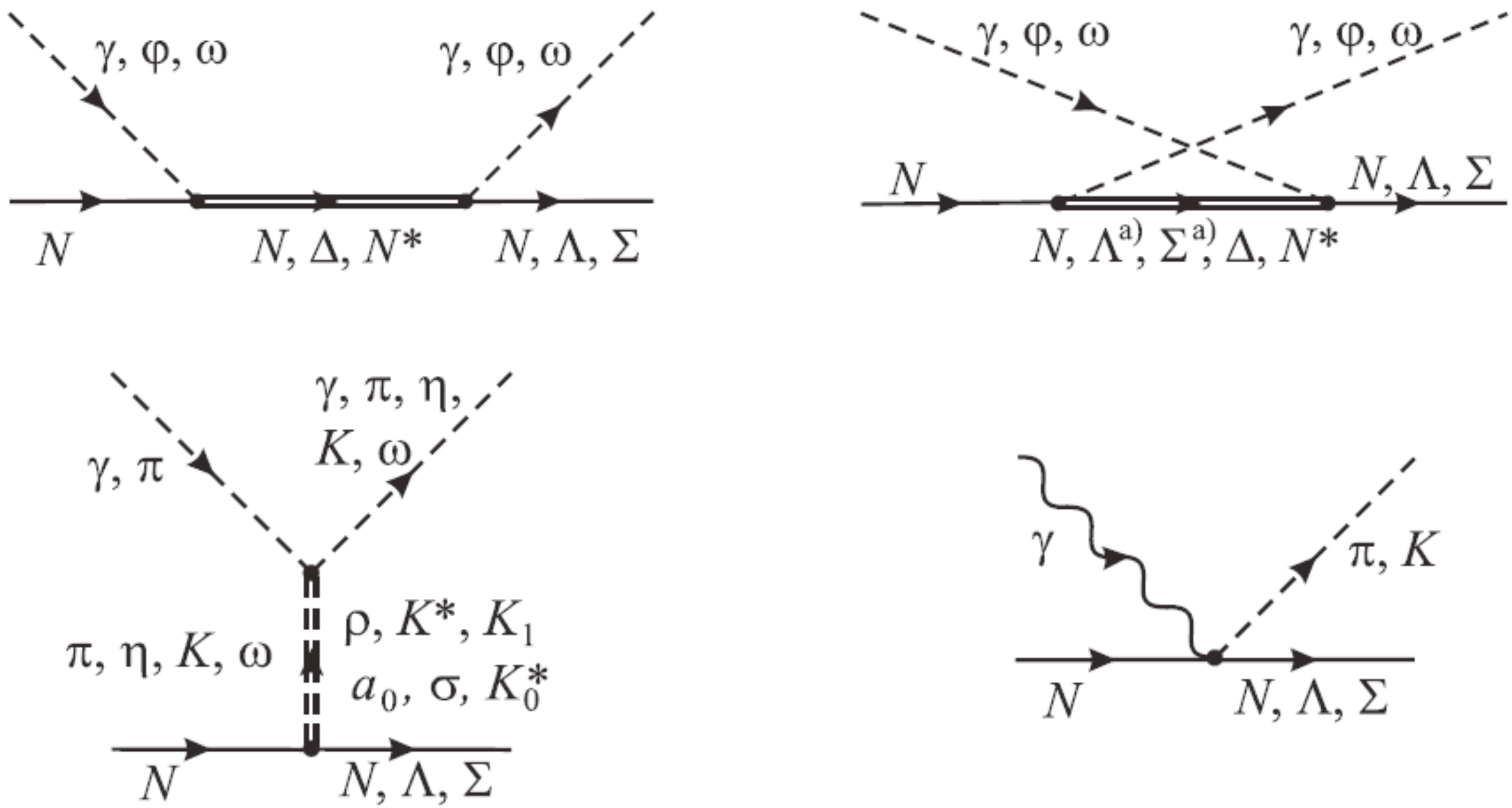
$$\mathcal{L}^{PV}_{\frac{1}{2}B\varphi} = -\frac{g_{RB\varphi}}{m_R \pm m_B}\bar{u}_R\begin{pmatrix}\gamma_5\\ i\end{pmatrix}\gamma_\mu u_B\partial^\mu\varphi\ .$$

negative-parity spin-$\frac{1}{2}$ resonances, PS coupling is used:

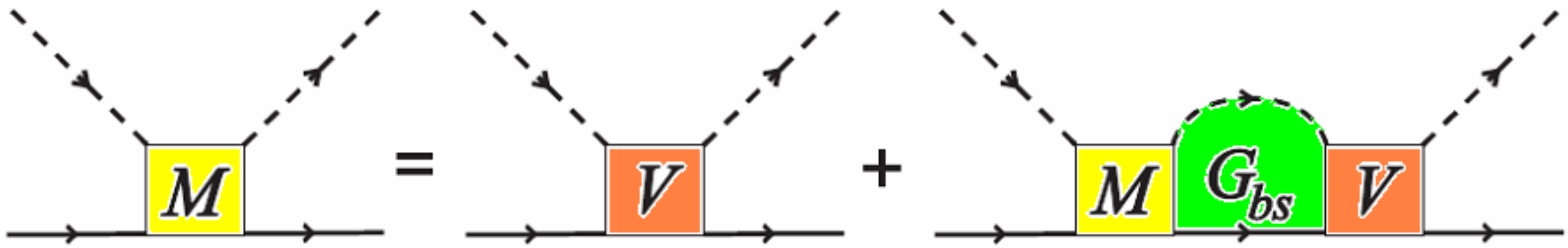
$$\mathcal{L}^{PS}_{\frac{1}{2}B\varphi} = -g_{RB\varphi}\bar{u}_R\begin{pmatrix}1\\ -i\gamma_5\end{pmatrix}u_B\varphi\ .$$

π,η,K

Tree-Level Diagrams in the BS Equation



The Giessen Model: Coupled Channels K-Matrix



$$G_{bs} \equiv \frac{P}{H-\omega} + i\pi\delta(H-\omega):$$

$$\mathcal{K} = \mathcal{V} + \mathcal{V}\frac{P}{H-\omega}\mathcal{K} \sim \mathcal{V}$$
$$\mathcal{M} = \mathcal{K} + i\mathcal{K}\delta(H-\omega)\mathcal{M}$$

$$\mathcal{M}_{\alpha\beta} \equiv \left[\frac{\mathcal{K}}{1-i\mathcal{K}}\right]_{\alpha\beta} \sim \left[\frac{\mathcal{V}}{1-i\mathcal{V}}\right]_{\alpha\beta}$$

- Widths Γ_{N*} are generated dynamically
- Unitarity for $K=K^+$, Resonances and background!

The Giessen Model: Multi-Channel T-Matrix

Coupled Channel Picture of Resonance Excitation

- Each resonance can be reached through each asymptotic channel
- T matrix provides unitary, analytic structure
- all channels (e.g. πN, ρN) couple to all other channels in intermediate state
- photon multipoles ($E_{l\pm}$, $M_{l\pm}$) directly related to T

$$T(J^\pi) = \begin{pmatrix}
T_{\pi N\to\pi N} & T_{\eta N\to\pi N} & T_{\gamma N\to\pi N} & T_{\rho N\to\pi N} & T_{\sigma N\to\pi N} & T_{K\Lambda\to\pi N} & T_{K\Sigma\to\pi N} \\
T_{\pi N\to\eta N} & T_{\eta N\to\eta N} & T_{\gamma N\to\eta N} & T_{\rho N\to\eta N} & T_{\sigma N\to\eta N} & T_{K\Lambda\to\eta N} & T_{K\Sigma\to\eta N} \\
T_{\pi N\to\gamma N} & T_{\eta N\to\gamma N} & T_{\gamma N\to\gamma N} & T_{\rho N\to\gamma N} & T_{\sigma N\to\gamma N} & T_{K\Lambda\to\gamma N} & T_{K\Sigma\to\gamma N} \\
T_{\pi N\to\rho N} & T_{\eta N\to\rho N} & T_{\gamma N\to\rho N} & T_{\rho N\to\rho N} & T_{\sigma N\to\rho N} & T_{K\Lambda\to\rho N} & T_{K\Sigma\to\rho N} \\
T_{\pi N\to\sigma N} & T_{\eta N\to\sigma N} & T_{\gamma N\to\sigma N} & T_{\rho N\to\sigma N} & T_{\sigma N\to\sigma N} & T_{K\Lambda\to\sigma N} & T_{K\Sigma\to\sigma N} \\
T_{\pi N\to K\Lambda} & T_{\eta N\to K\Lambda} & T_{\gamma N\to K\Lambda} & T_{\rho N\to K\Lambda} & T_{\sigma N\to K\Lambda} & T_{K\Lambda\to K\Lambda} & T_{K\Sigma\to K\Lambda} \\
T_{\pi N\to K\Sigma} & T_{\eta N\to K\Sigma} & T_{\gamma N\to K\Sigma} & T_{\rho N\to K\Sigma} & T_{\sigma N\to K\Lambda} & T_{K\Lambda\to K\Sigma} & T_{K\Sigma\to K\Sigma}
\end{pmatrix}$$

ωN photoproduction

ωN final state: Hard to analyze

- Vector mesons:
  γN: different helicity states $\frac{1}{2}-1,\ \frac{1}{2}+1$
  ωN: different helicity states $\frac{1}{2}-1,\ \frac{1}{2}+1,\ \ \frac{1}{2}+0$
  => different resonance coupling to helicity states.
- photoproduction
  analogy with $\gamma N \to \pi N$: needs $\pi N \to \pi N$ as an input.

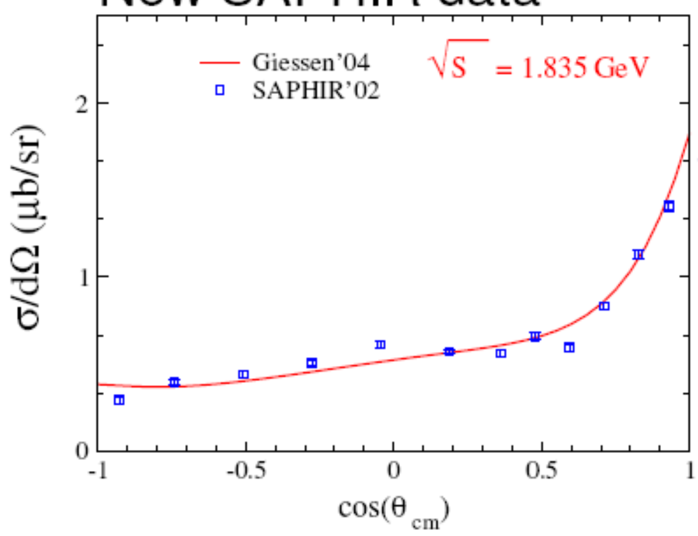
  Same for $\gamma N \to \omega N$ photoproduction:
  knowledge about $\pi N \to \omega N$ channel is mandatory.

New channel: include also j=5/2 states

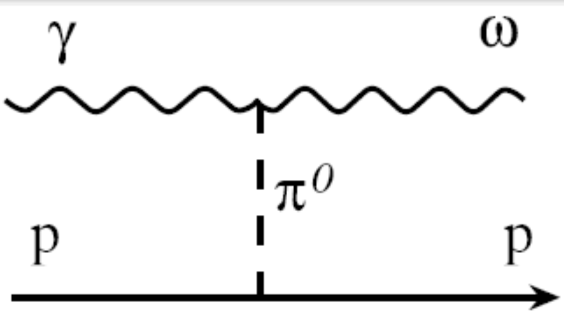
Production Dynamics of ω Photoproduction

ω photoproduction

New SAPHIR data

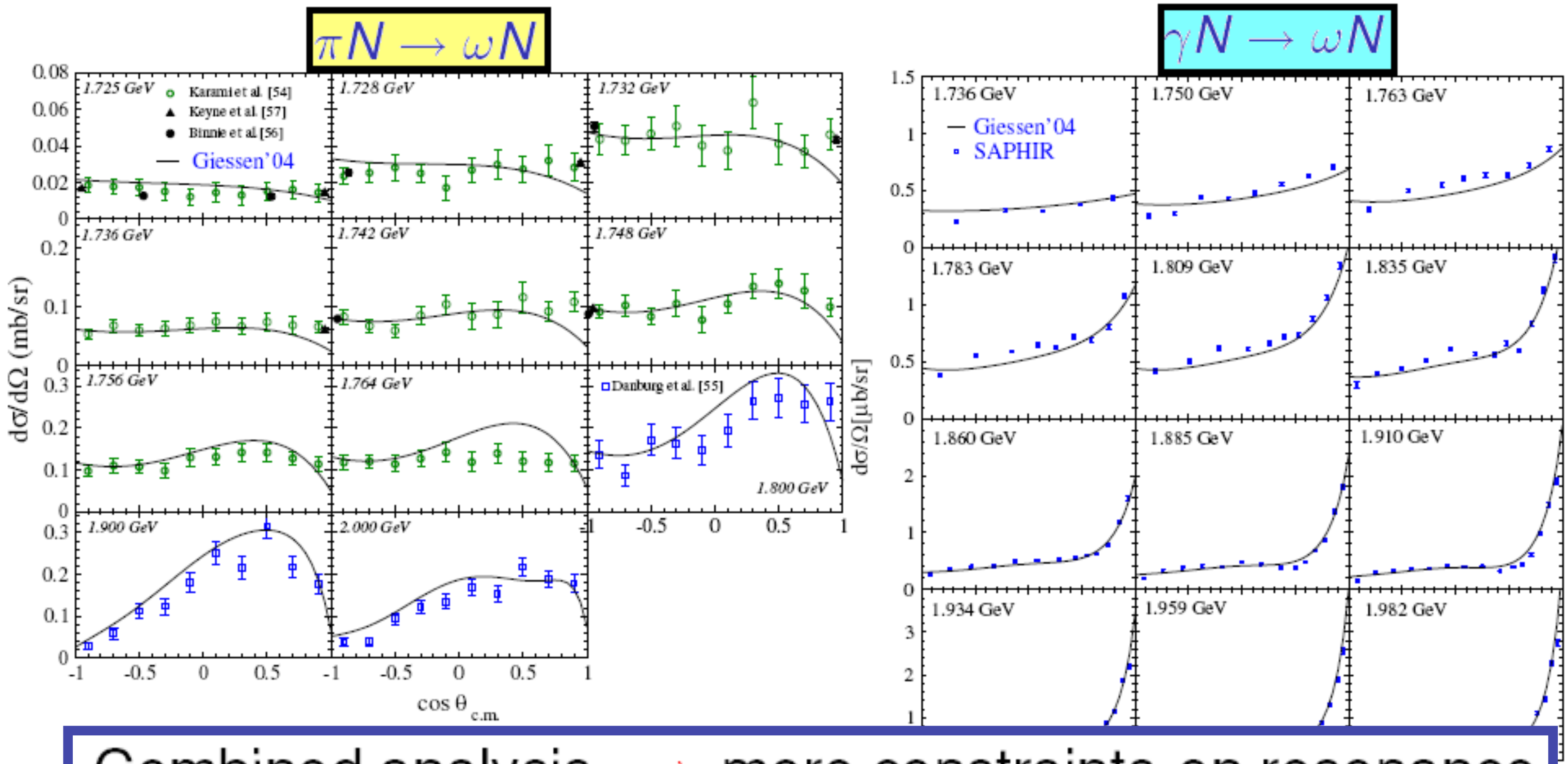


Friman and Soyeur NPA600:477
Forward directions: π^0 exchange !



=> π^0-exchange generates strong background contributions

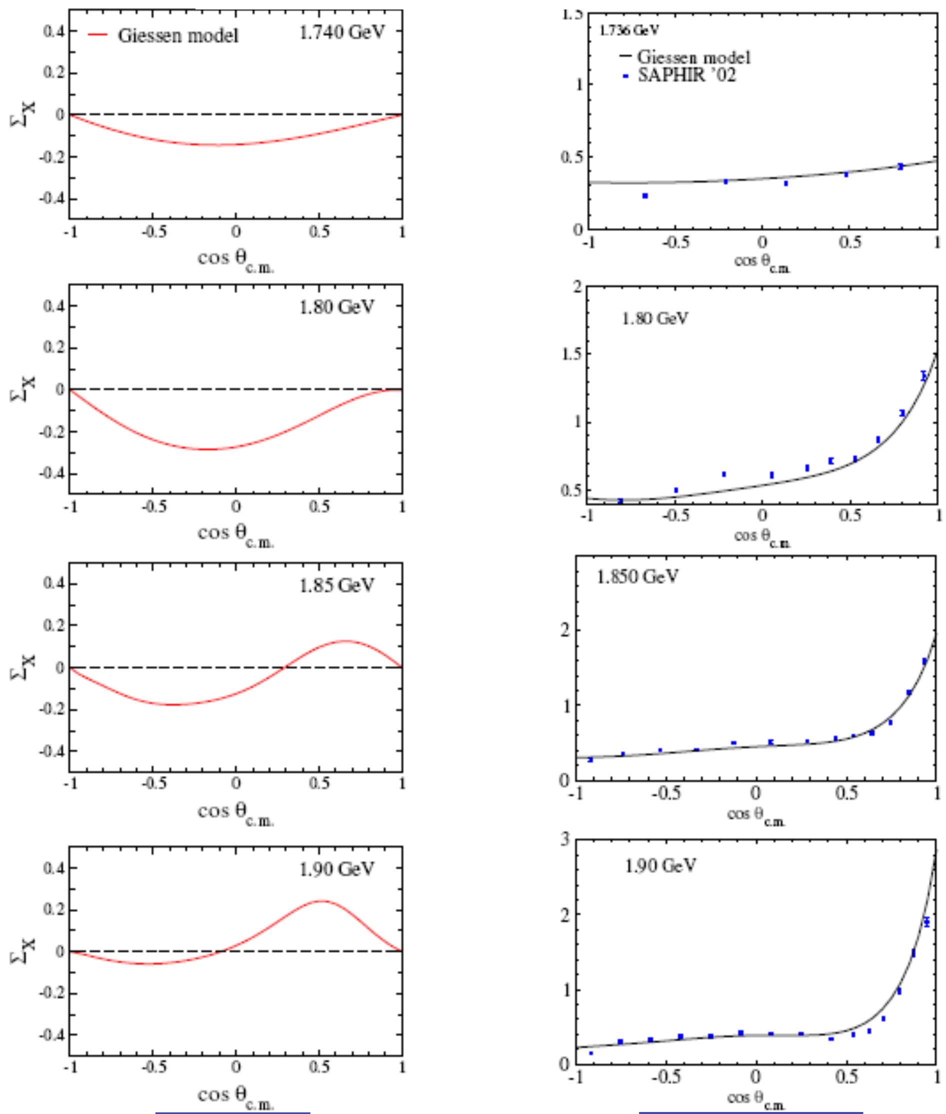
Giessen model. Results for the $(\pi, \gamma)N \to \omega N$ reactions



Combined analysis $\Longrightarrow$ more constraints on resonance properties. V. Shklyar et al. PRC71, 055206 (2005)

$\pi N \to \omega N$: More precise data needed

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



Σ_x | $d\sigma/d\Omega$

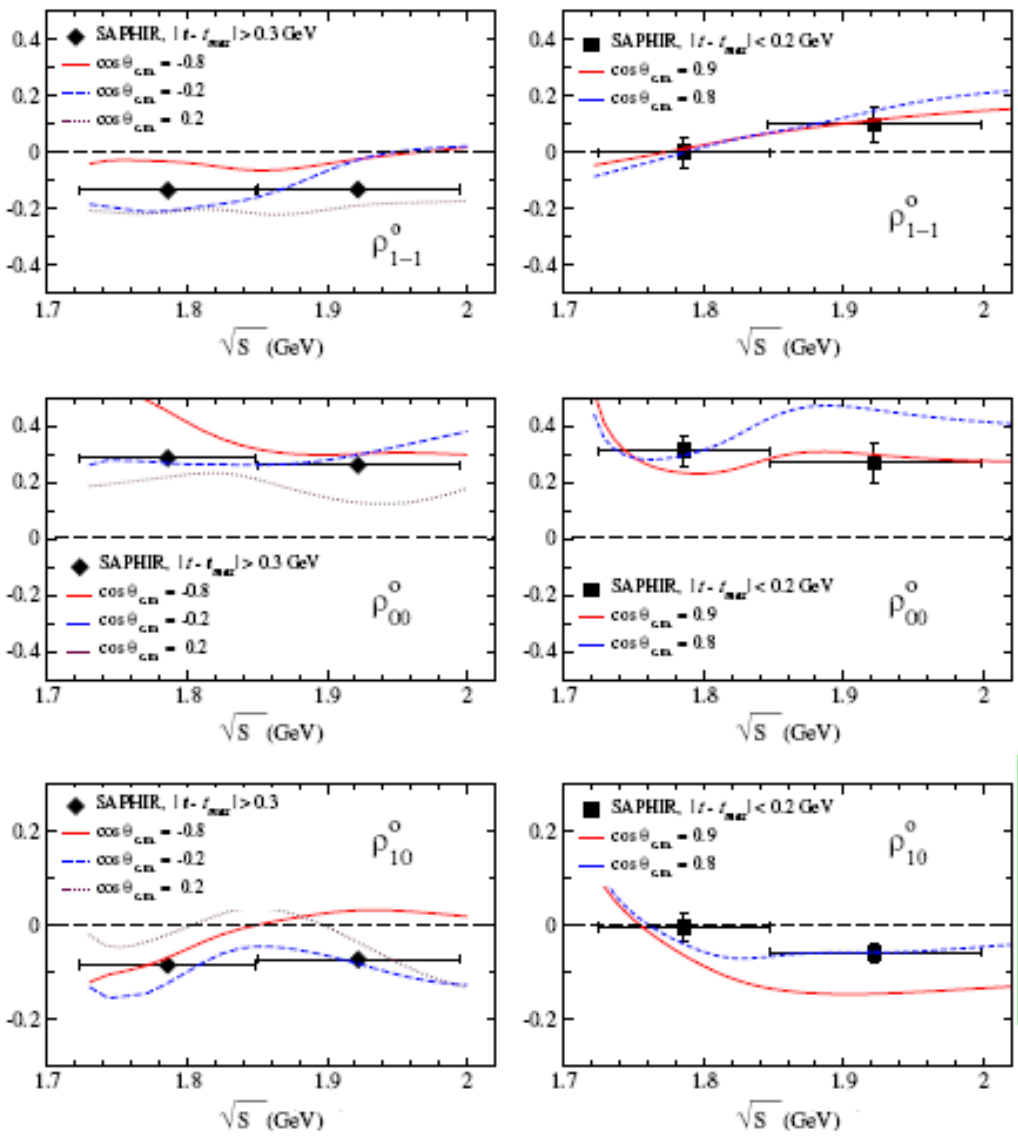
A. Titov, T.-S.H. Lee
PRC66:015204
and
Q. Zhao PRC63:025203

Asymmetry is sensitive to the production mechanism !

Beam asymmetry:

Changes sign with increasing energy:
t-channel dominates the forward directions.

γN → ωN Spin Density Matrix



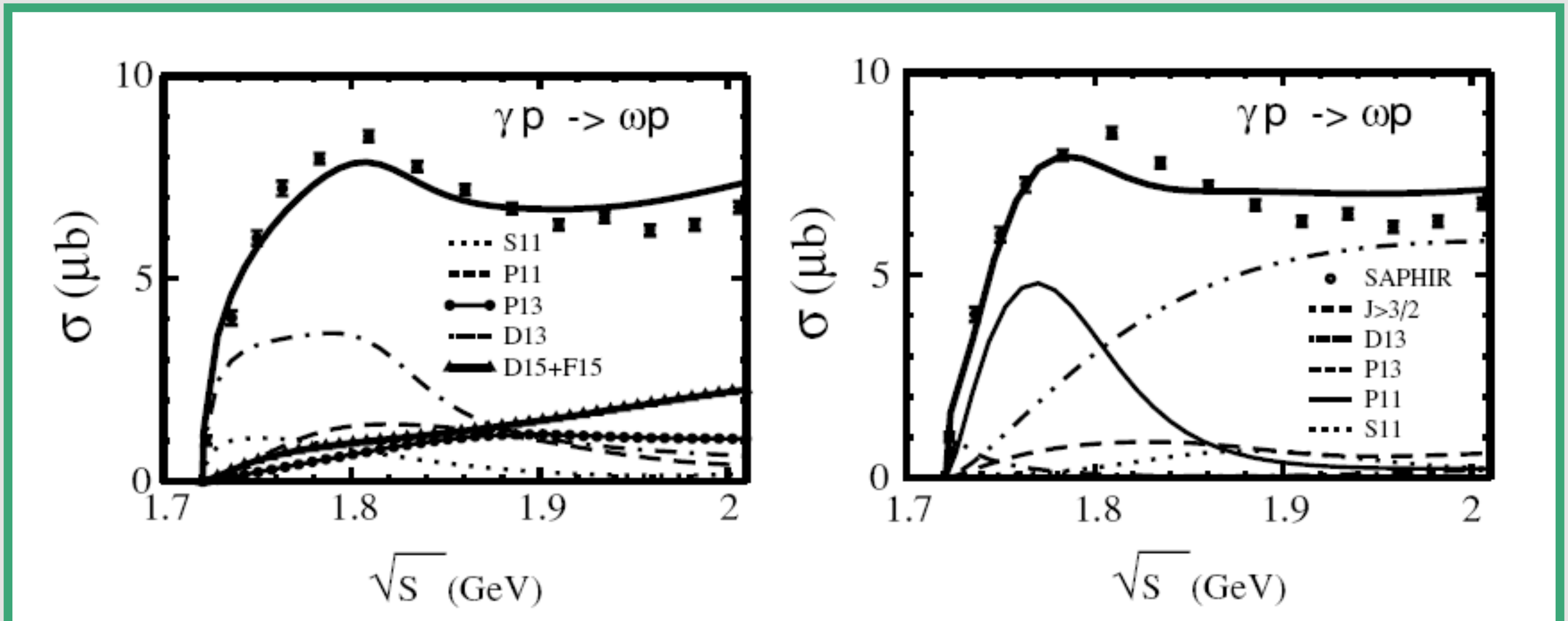
V.Shklyar, H. Lenske, U. Mosel, G. Penner, PRC71, 055206 (2005)

$$\rho_{\lambda_\omega \lambda'_\omega} = \frac{\sum_{s_i s_f \lambda_\gamma} T_{s_i \lambda_\gamma s_f \lambda_\omega} T_{s_i \lambda_\gamma s_f \lambda'_\omega}}{\sum_{s_i s_f \lambda_\gamma \lambda_\omega} T_{s_i \lambda_\gamma s_f \lambda_\omega} T_{s_i \lambda_\gamma s_f \lambda_\omega}}$$

Spin density matrix prodives an additional constraint on the reaction amplitude.

Sensitivity on Reaction Input: Spin Density Data and Cross Sections

with ω spin density matrix data | **without ω spin density matrix data**

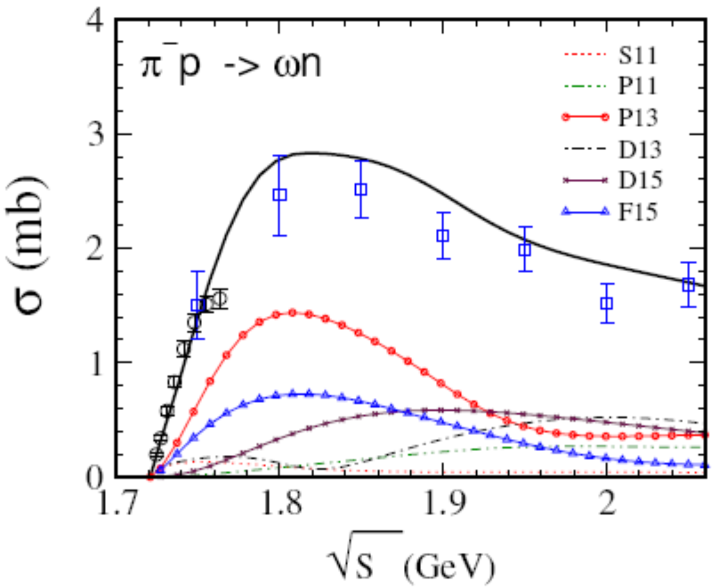


$\chi^2 \approx 4.2$ **(SAPHIR Data)** $\chi^2 \approx 6.5$

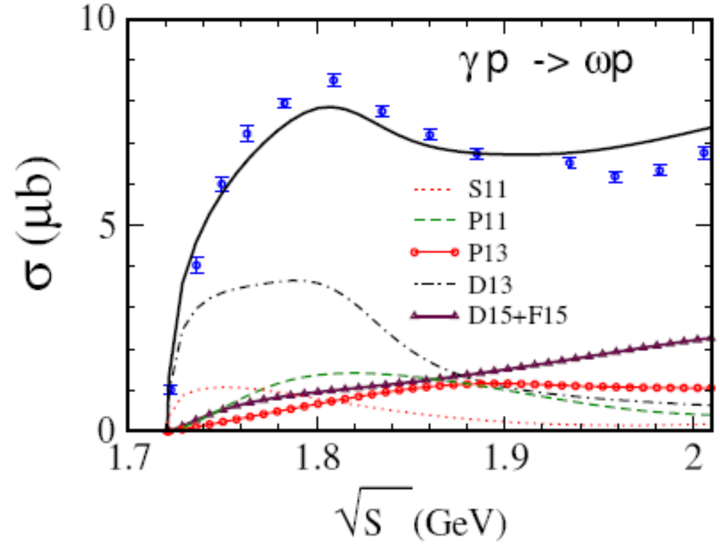
V. Shklyar et al ., PRC71 055206 (2005) | **G. Penner et al ., PRC66 055211 (2002)**

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

$\pi N \to \omega N$



$\gamma N \to \omega N$

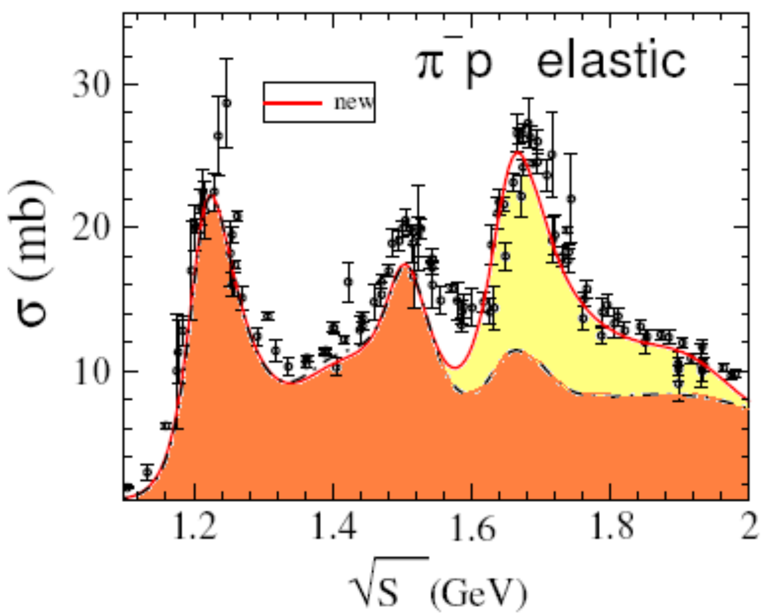


- P_{13}: interference between resonance and background
- strong $N^*(\frac{5}{2})$ coupling to ωN
- D_{13} shows minor influence

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

Phys.Rev.C71:055206,2005

Contributions of j > 3/2 Resonances to πN?



New results:

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

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

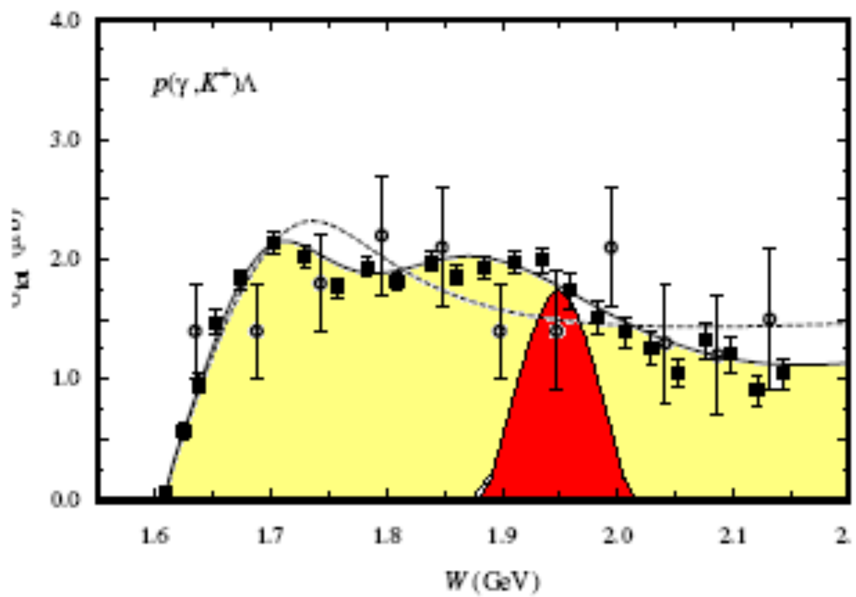
Optical theorem:

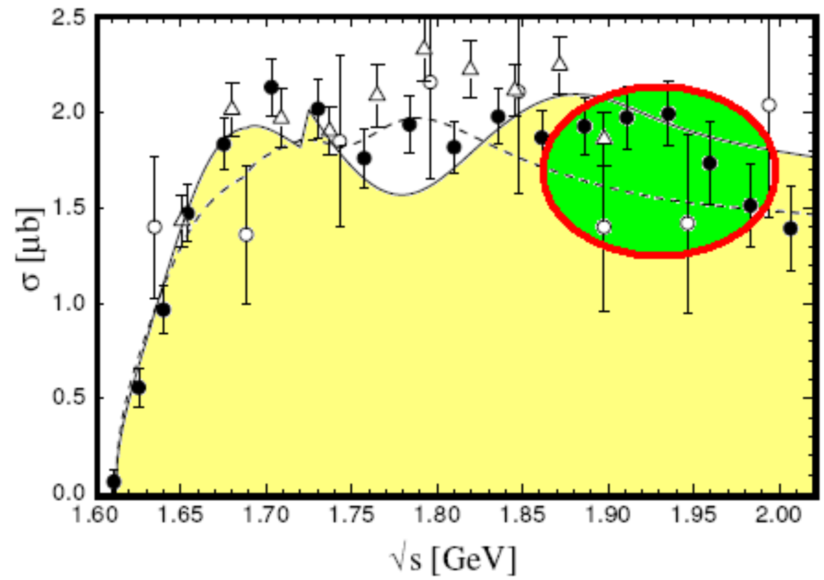
$$ImT_{\pi N \to \pi N} \sim \sigma_{\pi N \to \omega N} + \dots$$

πN and ωN:
$D_{15}(1675)$, $F_{15}(1680)$, $F_{15}(2000)$

New Resonances in γ+N → K+Λ ?

SAPHIR, Tran et al. (1998): structure at about 1.9 GeV in $\gamma + N \rightarrow K + \Lambda$

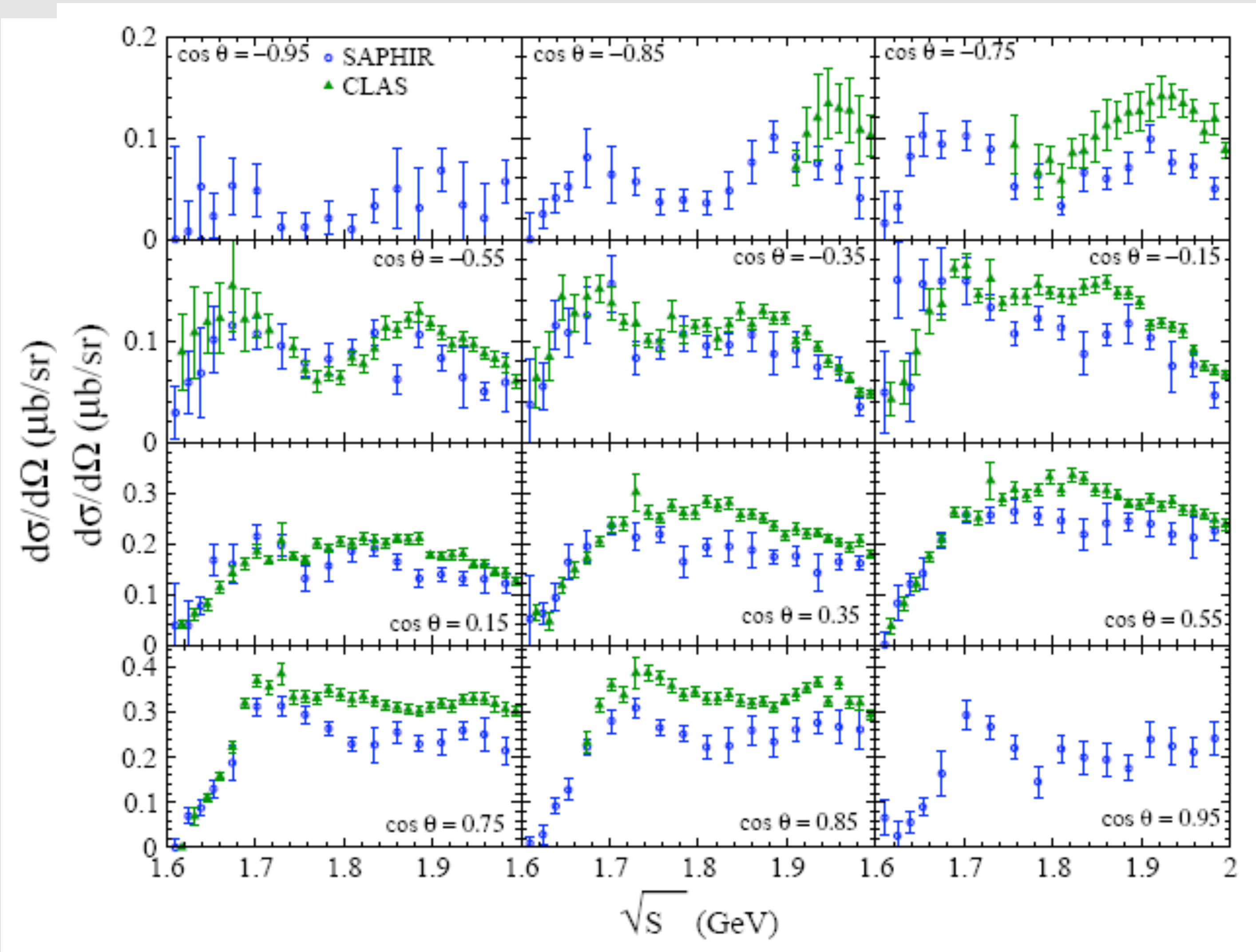




Mart, Bennhold (PRC 61: 012201): claim for a new *D*13(1960) resonance

Penner, Mosel (PRC66: 055212): Born term and *t*-channel interference

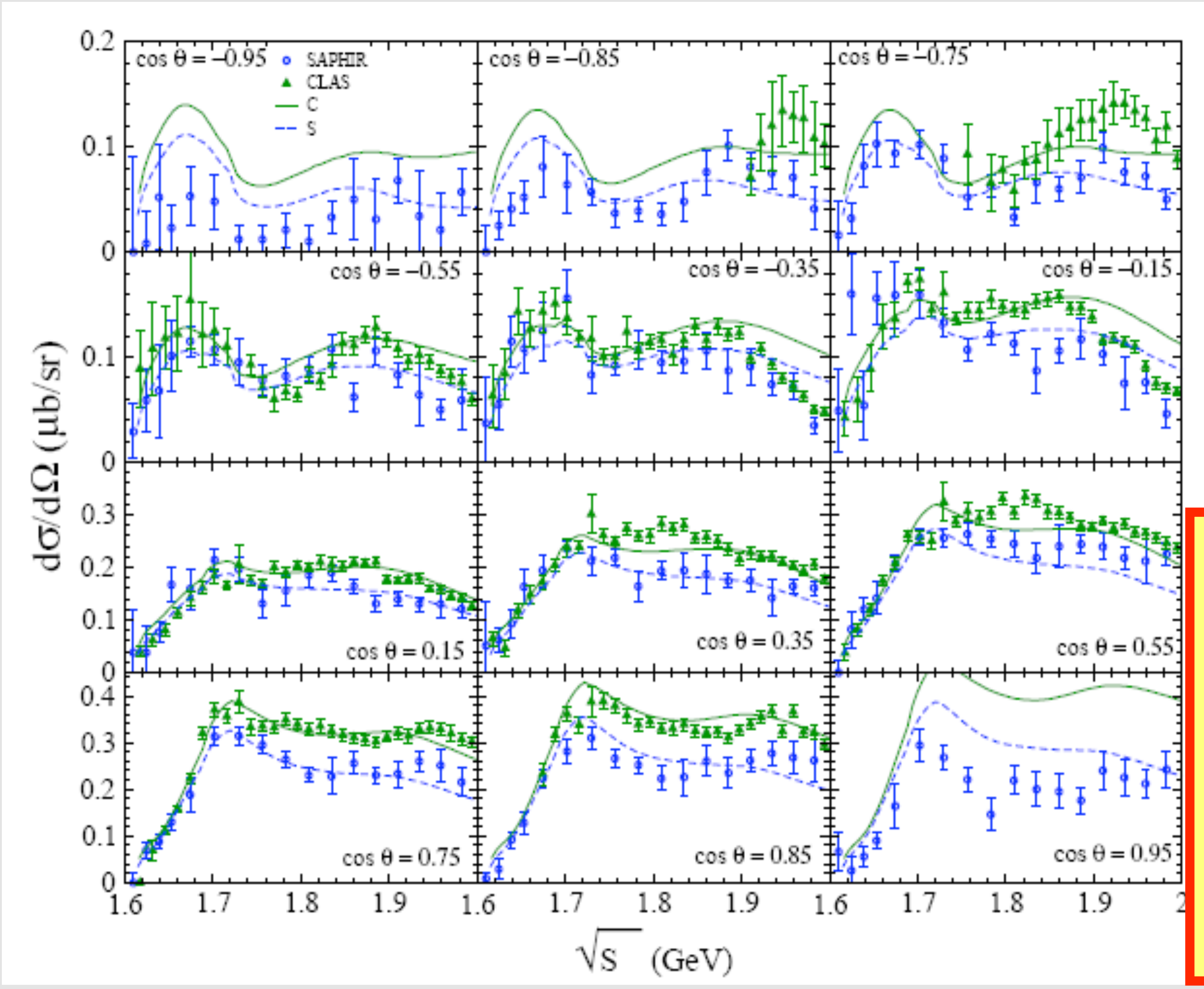
New γN → KΛ Data from SAPHIR and CLAS



sagree in the
teresting energy
near 1.9 GeV.

lata: position of
ond peak is not
fined.

γN → KΛ Results from the Giessen Model



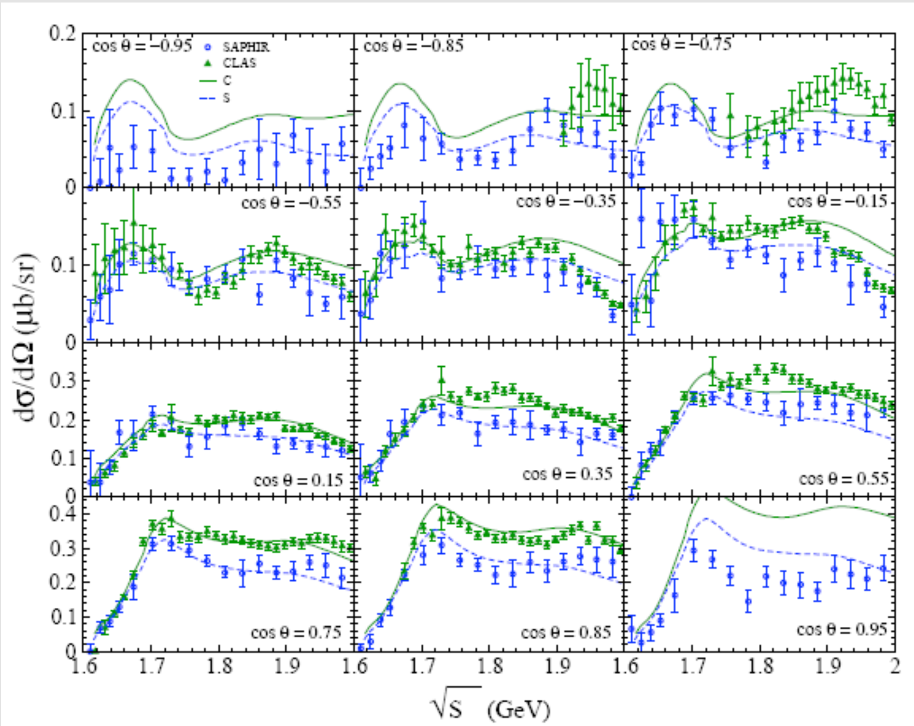
- separate fits to **SAPHIR** and **CLAS** data
- constraints from other hadronic and γ channels

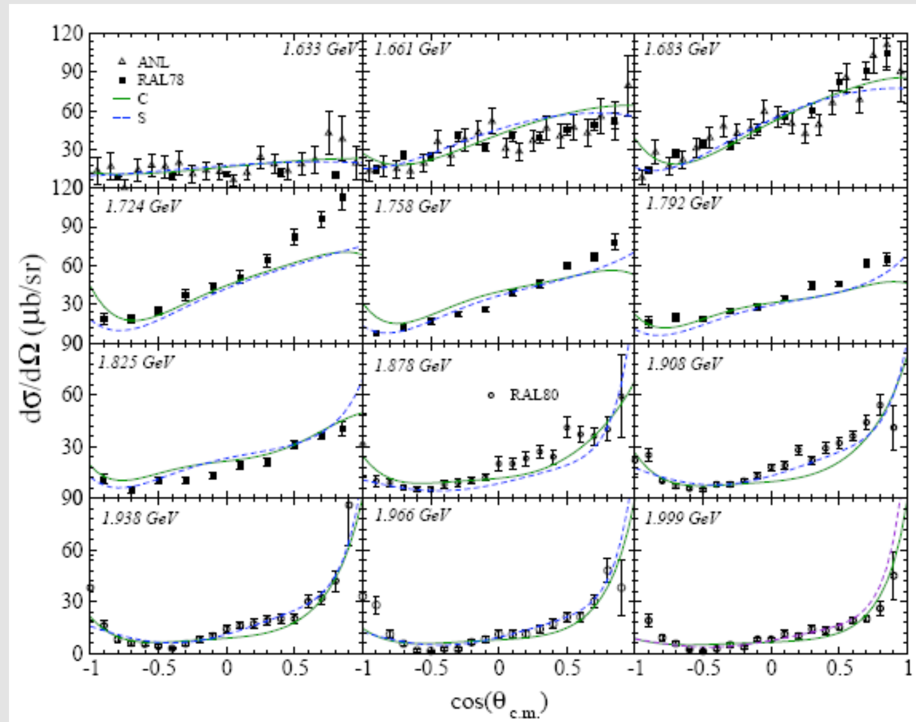
$$\pi N \to K\Lambda$$
$$+$$

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

V. Shyklar, H.L., U. Mosel, nucl-th/0505010/PRC 72:015210 (2005)

$\gamma N \rightarrow K\Lambda$: Influence on other Channels





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

separate fits to SAPHIR and CLAS data

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

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

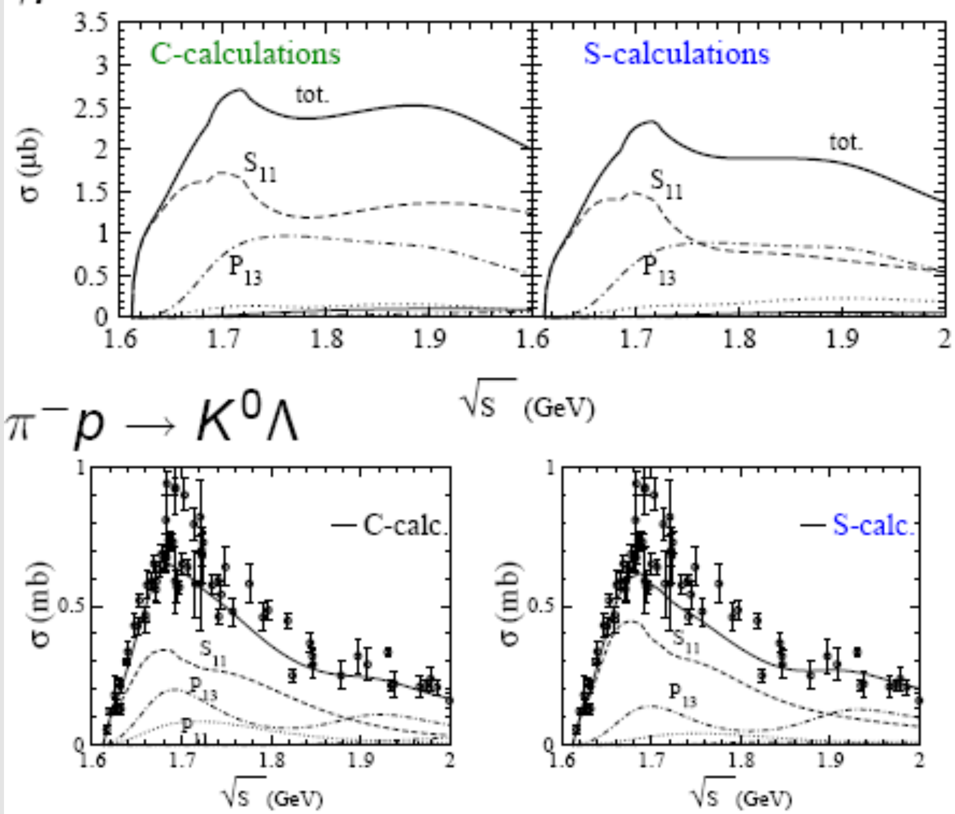
Consequences on Reaction Dynamics of KΛ Channels from CLAS/SAPHIR Solutions

Resonance contributions:

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

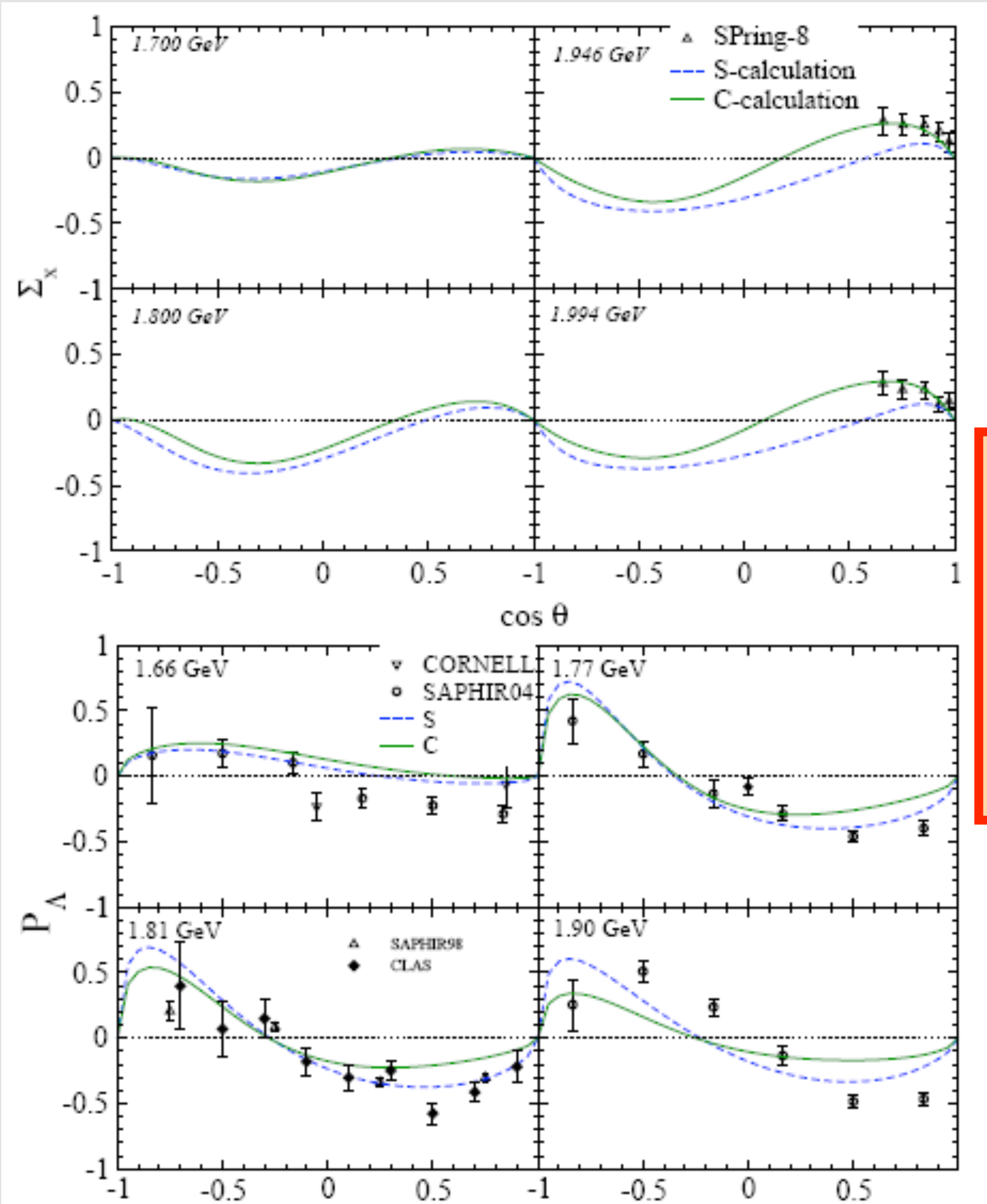
$\gamma p \to K^+\Lambda$

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



$L_{2I,2S}$	$R_{K\Lambda}(C)$	$R_{K\Lambda}(S)$
$S_{11}(1535)$	1.3^b	1.26^b
$S_{11}(1650)$	$3.2(+)$	$4.6(+)$
$P_{11}(1440)$	1.48^b	-0.71^b
$P_{11}(1710)$	$6.8(+)$	$3.1(+)$
$P_{13}(1720)$	$4.6(+)$	$4.0(+)$
$P_{13}(1900)$	$2.4(+)$	$2.3(+)$
$D_{13}(1520)$	-0.58^b	-0.33^b
$D_{13}(1950)$	$0.1(+)$	$0.1(-)$
$D_{15}(1675)$	$0.2(+)$	$0.1(+)$
$F_{15}(1680)$	$0.0(+)$	$0.0(+)$
$F_{15}(2000)$	$0.0(+)$	$0.2(-)$

N^* decay ratios to $K\Lambda$ for the C and S calculations.



Predicted photon beam asymmetry.

(LEPS data: R. G. T. Zegers *et al.*, Phys. Rev. Lett. 91, 092001 (2003))

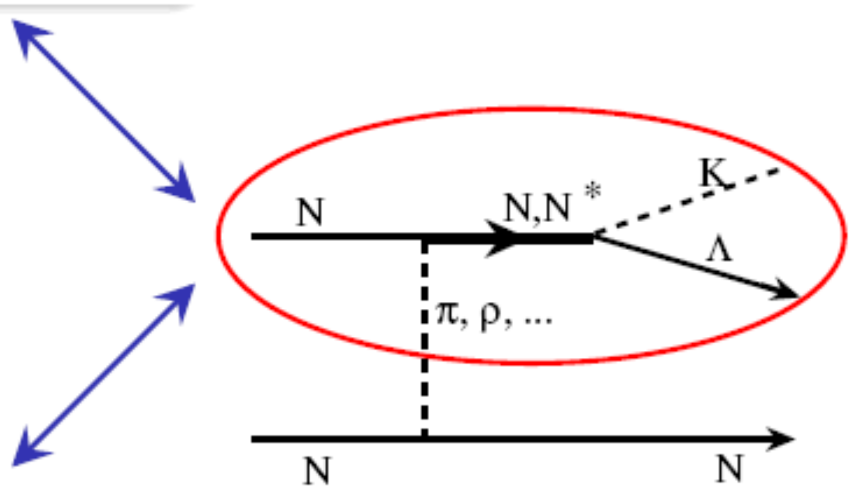
Differences between SAPHIR and CLAS cross section data have minor influence on the spin observables! (PRC 72:015210 (2005))

Λ polarization for γ+*p* → *K* +Λ.

Data: SAPHIR98, SAPHIR04, CLAS, and CORNELL.

Relation to Hadronic KΛ Production on the Nucleon and on Nuclei

- reaction $pp \to pK^+\Lambda$
- hypernuclei: $A(p,K^+)_\Lambda B$

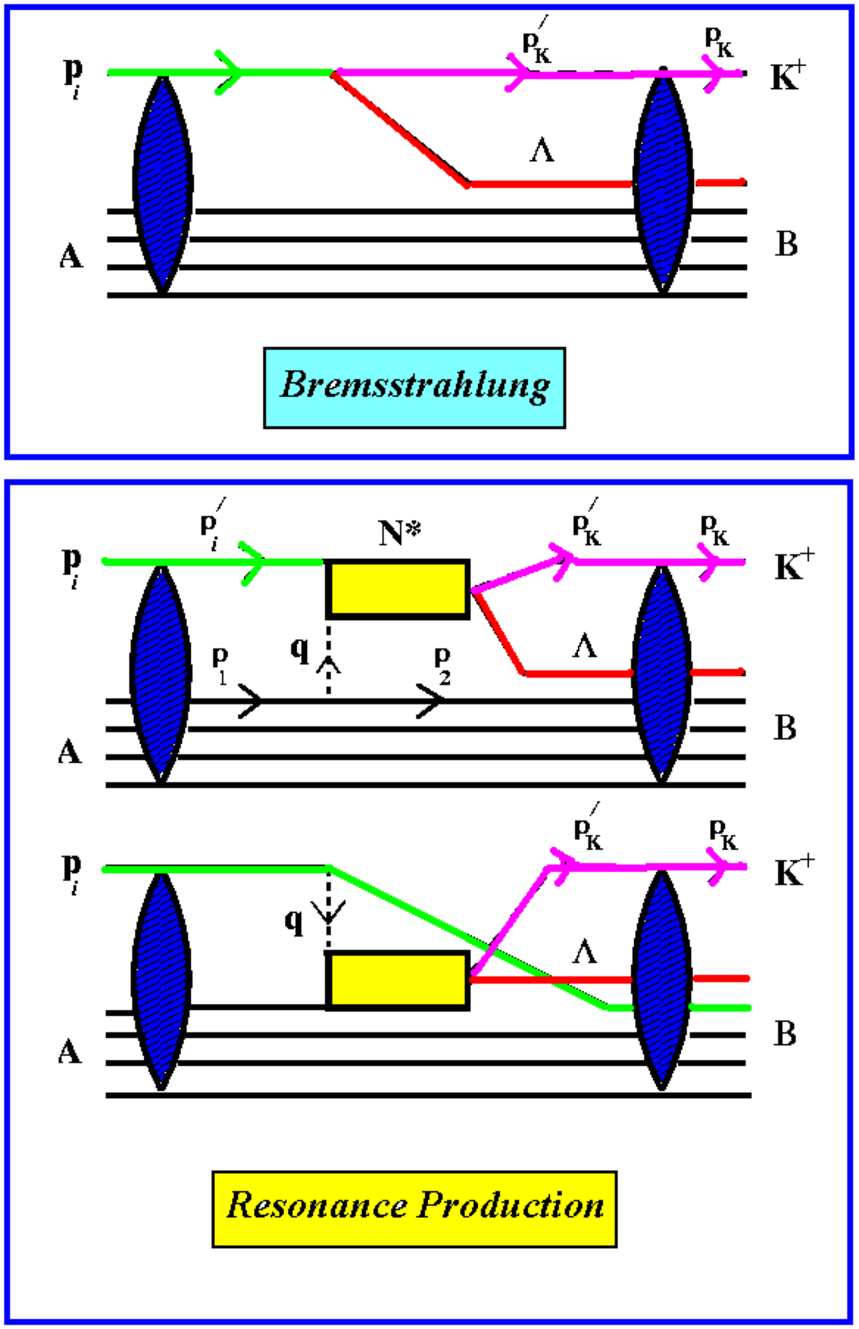


To constrain $pp \to pK\Lambda$ reaction:
combined analysis of

- $\pi N \to K\Lambda$
- $\gamma N \to K\Lambda$

is necessary

R. Shyam, H. Lenske, U. Mosel:
nucl-th/0505043 &
Nucl.Phys. A (2005);
nucl-th/0308085 &
Phys.Rev. C69 (2004) 065205



Associated (p,Λ) Strangeness Production

- exploratory for hadronic production at COSY
- elementary process for HI production
- extension to electro-production at ELSA, MAMI and JLAB in preparation

$N^*(1650)[\frac{1}{2}^-], N^*(1710)[\frac{1}{2}^+], N^*(1720)[\frac{3}{2}^+]$

R.Shyam, H.L., PRC 69: 065205 (2004), nucl-th/0505043 & NPA (2005) in print

Summary and Outlook

- The Giessen Model: Lagrangian Approach to Coupled Channels K-Matrix
- Coherence of resonance and background contributions
- Simultanuous description of photo- and hadro-production
- Photoproduction and reaction dynamics of ωN and $K\Lambda$ states
- Spectral structures: interference effects or resonances?
- in progress: dynamical correlations in 2-pion channels
- hadro- and electro-production of $K\Lambda$ on nucleons and nuclei

In collaboration with: V. Shklyar, U. Mosel

EuroGK

SFB/TR 16

MCTS