Vector Meson Production and Nucleon Resonance Analysis in the Giessen Coupled-Channel Model

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G. Penner and U. Mosel, nucl-th/0207066, to appear in Phys. Rev. C
G. Penner and U. Mosel, nucl-th/0207069, to appear in Phys. Rev. C

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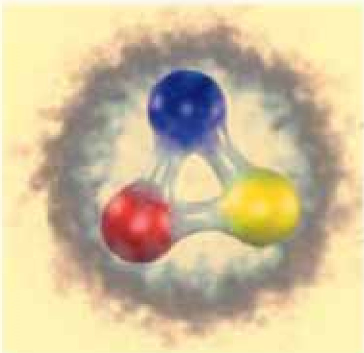
Goal:



Investigation of the nucleon structure via its excitation spectrum

QCD / quark models $\longleftrightarrow$ experimental observables

$\rightsquigarrow$ Simultaneous analysis of as many experim. data as possible:

$$\gamma N \,/\, \pi N \longrightarrow \gamma N,\ \pi N,\ 2\pi N,\ \eta N,\ K\Lambda/\Sigma,\ \omega N$$

Means:

- Use of as wide an energy range as possible: $m_N < \sqrt{s} < 2$ GeV
- Consistent description of all channels within one effective Lagrange model
- Consistent generation of background via Born-, t-, and u-channel diagrams $\rightarrow$ number of parameters enormously reduced
- Incorporation of constraints from physics:
  - unitarity (rescattering) $\rightarrow$ dynamical generation of resonance widths
  - gauge invariance $\rightarrow$ straightforward in EL model

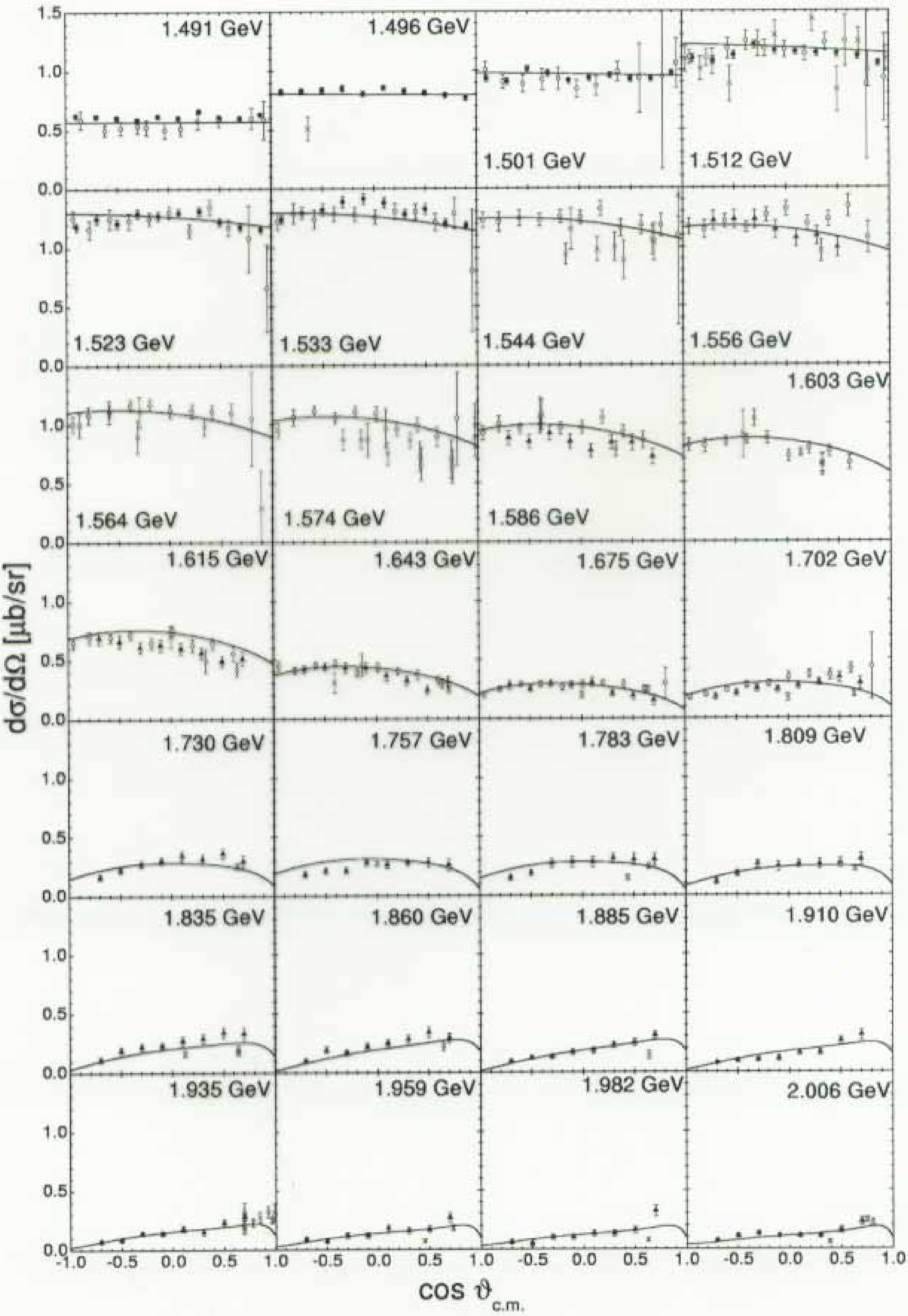
$\rightsquigarrow$ Possible to investigate the influence of model ingredients / data base

PDG Resonances

Resonance	$L_{2I\,2J}$	Overall	$N\pi$	$N\eta$	ΛK	ΣK	$\Delta\pi$	$N\rho$	$N\gamma$	$N\omega$
$N(939)$	P_{11}	****								
$N(1440)$	P_{11}	****	****	*			***	*	***	
$N(1520)$	D_{13}	****	****	*			****	****	****	
$N(1535)$	S_{11}	****	****	****			*	**	***	
$N(1650)$	S_{11}	****	****	*	***	**	***	**	***	
$N(1675)$	D_{15}	****	****	*	*		****	*	****	
$N(1680)$	F_{15}	****	****				****	****	****	
$N(1700)$	D_{13}	***	***	*	**	*	**	*	**	
$N(1710)$	P_{11}	***	***	**	**	*	**	*	***	
$N(1720)$	P_{13}	****	****	*	**	*	*	**	**	
$N(1900)$	P_{13}	**	**					*		
$N(1990)$	F_{17}	**	*	*	*				*	
$N(2000)$	F_{15}	**	*	*	*	*	*	**		
$\Delta(1232)$	P_{33}	****	****	—	—				****	—
$\Delta(1600)$	P_{33}	***	***	—	—		***	*	**	—
$\Delta(1620)$	S_{31}	****	****	—	—		****	****	***	—
$\Delta(1700)$	D_{33}	****	****	—	—	*	***	**	***	—
$\Delta(1750)$	P_{31}	*	*	—	—					—
$\Delta(1900)$	S_{31}	**	**	—	—	*	*	**	*	—
$\Delta(1905)$	F_{35}	****	****	—	—	*	**	**	***	—
$\Delta(1910)$	P_{31}	****	****	—	—	*	*	*	*	—
$\Delta(1920)$	P_{33}	***	***	—	—	*	**		*	—
$\Delta(1930)$	D_{35}	***	***	—	—	*			**	—
$\Delta(1940)$	D_{33}	*	*	—	—					—
$\Delta(1950)$	F_{37}	****	****	—	—	*	****	*	****	—
$\Delta(2000)$	F_{35}	**		—	—			**		—

Photon-induced

$\gamma p \to \eta p$



▲: M. Dugger et al. (CLAS Coll.), submitted to Phys. Rev. Lett.

PDG Resonances

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$\Delta(1232)$	P_{33}	****	****	—	—				****	—
$\Delta(1600)$	P_{33}	***	***	—	—		***	*	**	—
$\Delta(1620)$	S_{31}	****	****	—	—		****	****	***	—
$\Delta(1700)$	D_{33}	****	****	—	—	*	***	**	***	—
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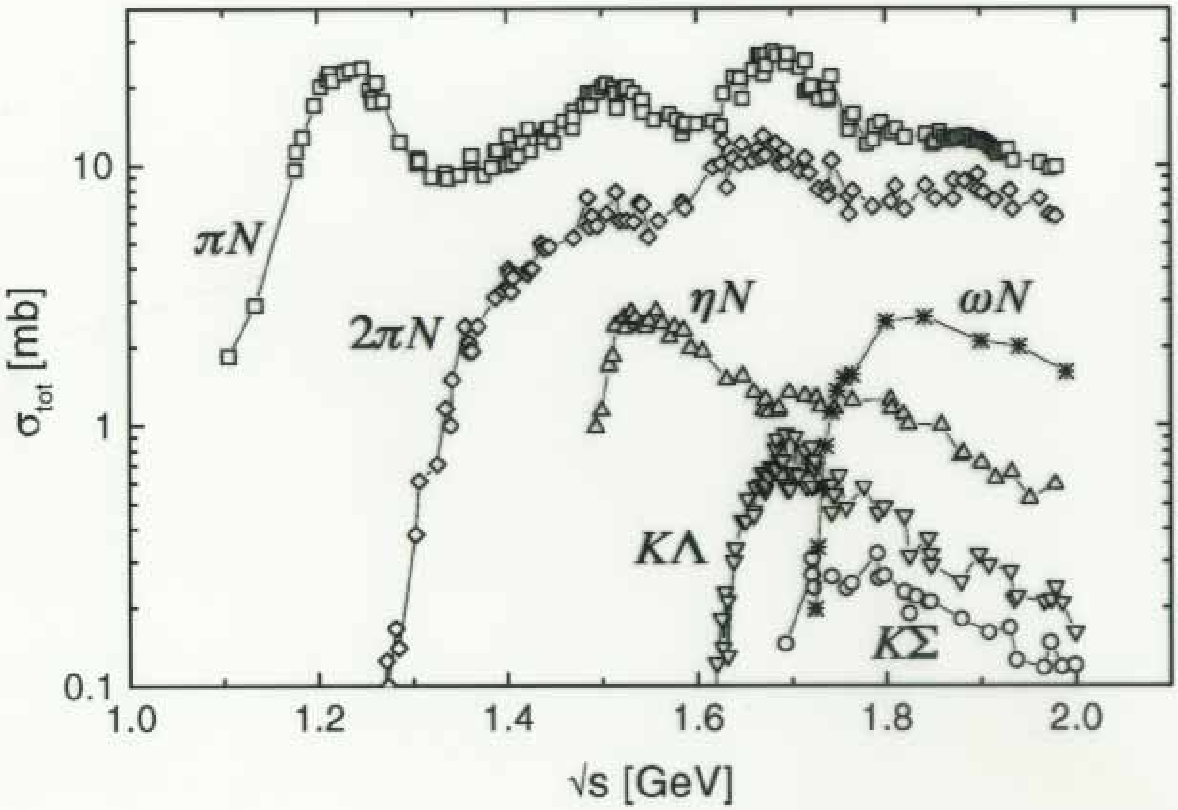
$\Delta(2000)$	F_{35}	**		—	—			**		—

Unitarity – which final states to include?



$\pi^- p \to X$

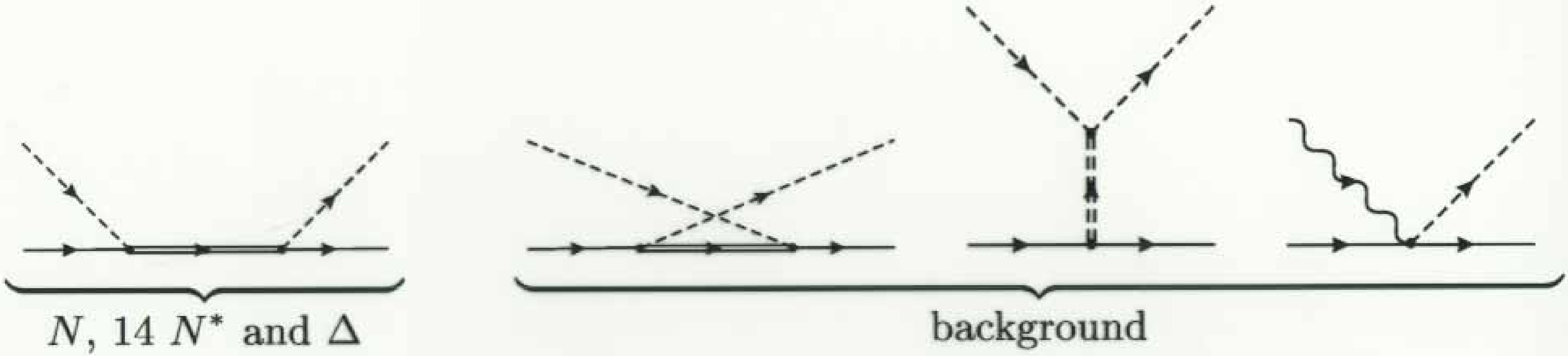
→ Take all important flux contributions into account

→ For $m_N < \sqrt{s} < 2$ GeV minimal set of final states contains

πN, $2\pi N$, ηN, ωN

The Model

Effective Lagrangians to generate the potential V_{fi} via Feynman diagrams:



⇒ **Matrix equation:**

$$[T] = \left[\frac{V}{1 - \mathrm{i}V}\right], \quad \text{with} \quad V = \begin{pmatrix} V_{\gamma\gamma} & V_{\gamma\pi} & V_{\gamma 2\pi} & V_{\gamma\eta} & V_{\gamma\Lambda} & V_{\gamma\Sigma} & V_{\gamma\omega} \\ V_{\pi\gamma} & V_{\pi\pi} & V_{\pi 2\pi} & V_{\pi\eta} & V_{\pi\Lambda} & V_{\pi\Sigma} & V_{\pi\omega} \\ & & & \cdots & & & \end{pmatrix}$$

→ All channels coupled with each other, but rescattering only via

conserved quantum numbers I, J, P $\Longrightarrow$ partial wave decomposition

Inclusion of ωN final state (remember: $\sqrt{s}_{\max} = 2$ GeV)

Standard partial wave decomposition becomes inconvenient (ℓ not conserved!)...

→ **Choose easier and more uniform way!**

For parity conserving interactions $T = \hat{P}^{-1} T \hat{P}$:
direct decomposition of helicity amplitudes $\mathcal{T}_{\lambda'\lambda}(x)$, $x = \cos\vartheta$
into amplitudes of total spin J and parity $P = (-1)^{J \pm \frac{1}{2}}$:

$$\mathcal{T}^{J\pm}_{\lambda'\lambda} \equiv \mathcal{T}^{J}_{\lambda'\lambda} \pm \eta \mathcal{T}^{J}_{\lambda' -\lambda} \qquad \text{with} \quad \mathcal{T}^{J}_{\lambda'\lambda} = 2\pi \int \mathcal{T}_{\lambda'\lambda}(x) d^{J}_{\lambda\lambda'}(x) \mathrm{d}x$$

$$\eta \equiv \eta_1 \eta_2 (-1)^{J - s_1 - s_2 + \frac{1}{2}}$$

with η_1, η_2, s_1, s_2 the intrinsic parities and spins, resp. of the incoming particles

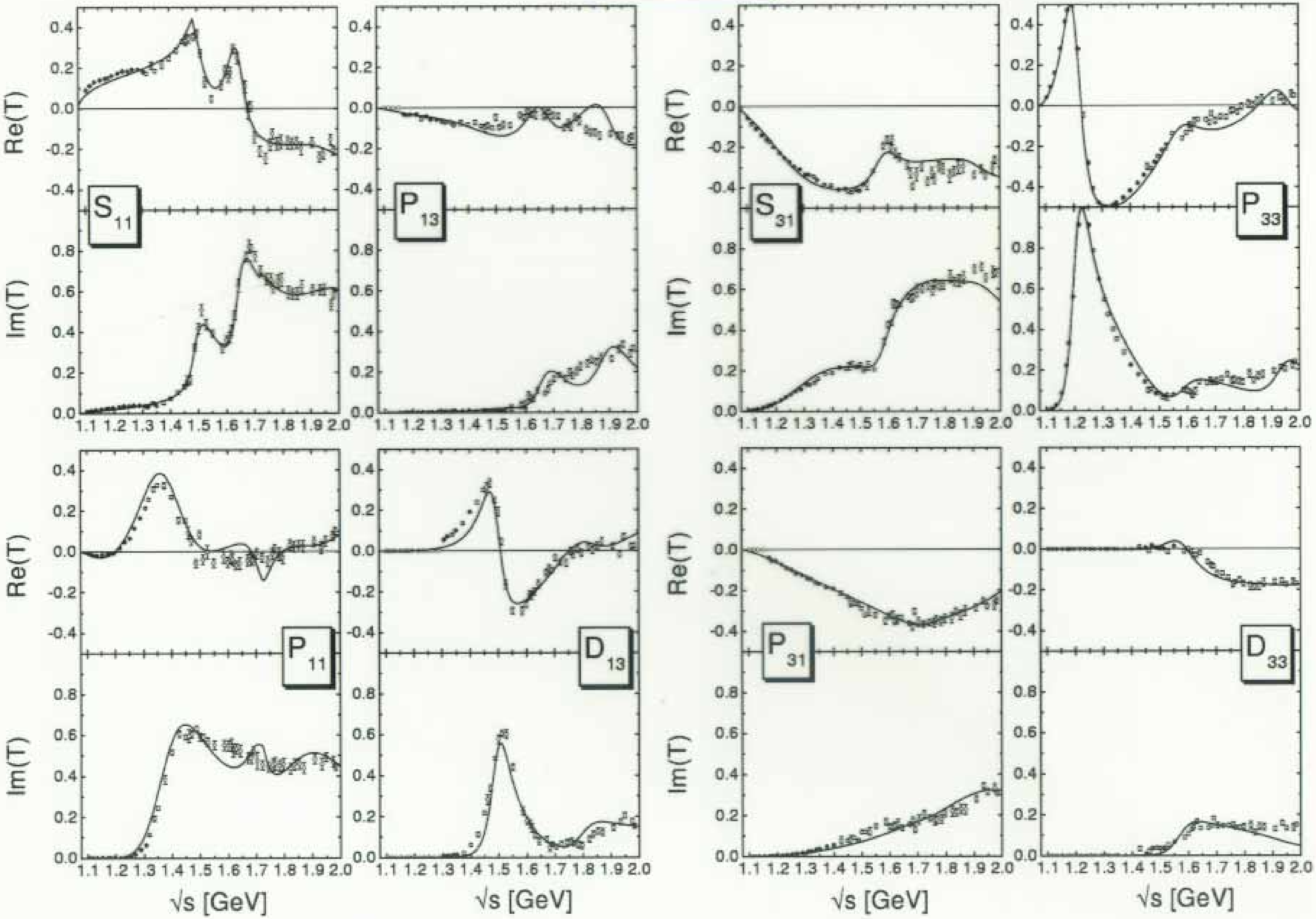
(Legendre polynomials ⇝ Wigner d functions)

Valid for any meson (photon) baryon final state combination

e.g. $\pi N \to \pi N$: $\mathcal{T}^{\mathbf{J}\pm}_{\frac{1}{2}\frac{1}{2}} \equiv \mathcal{T}_{\ell_\pi \pm}$

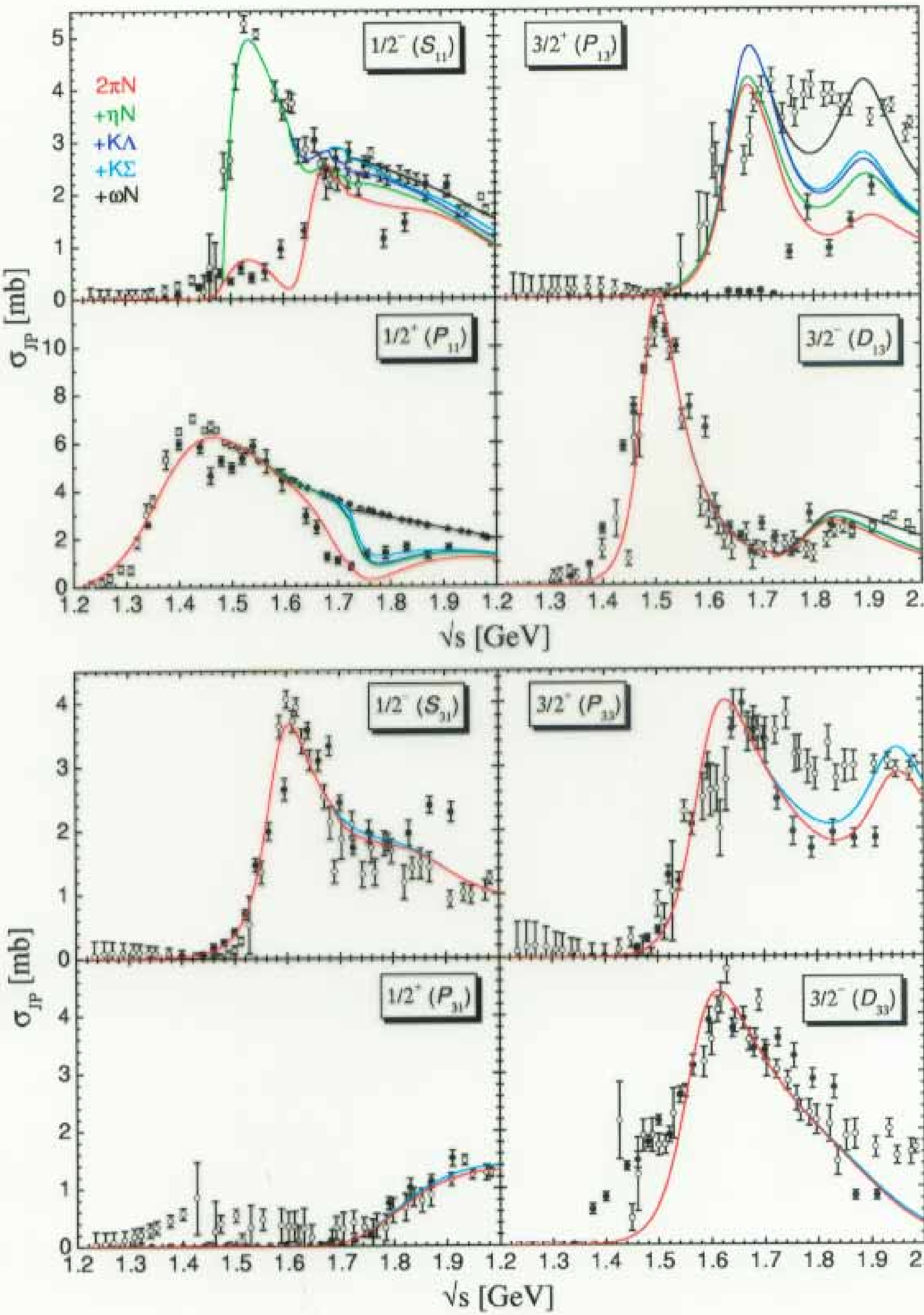
Pion-induced

$\pi N \to \pi N$



Pion-induced

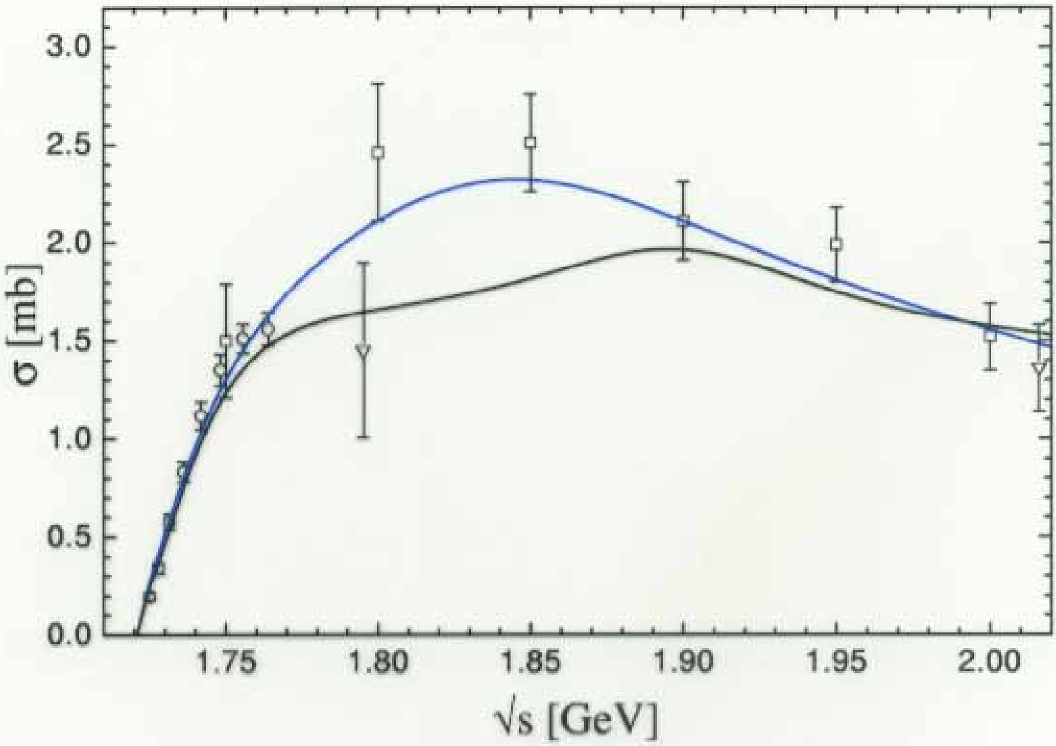
$\pi N \to 2\pi N$

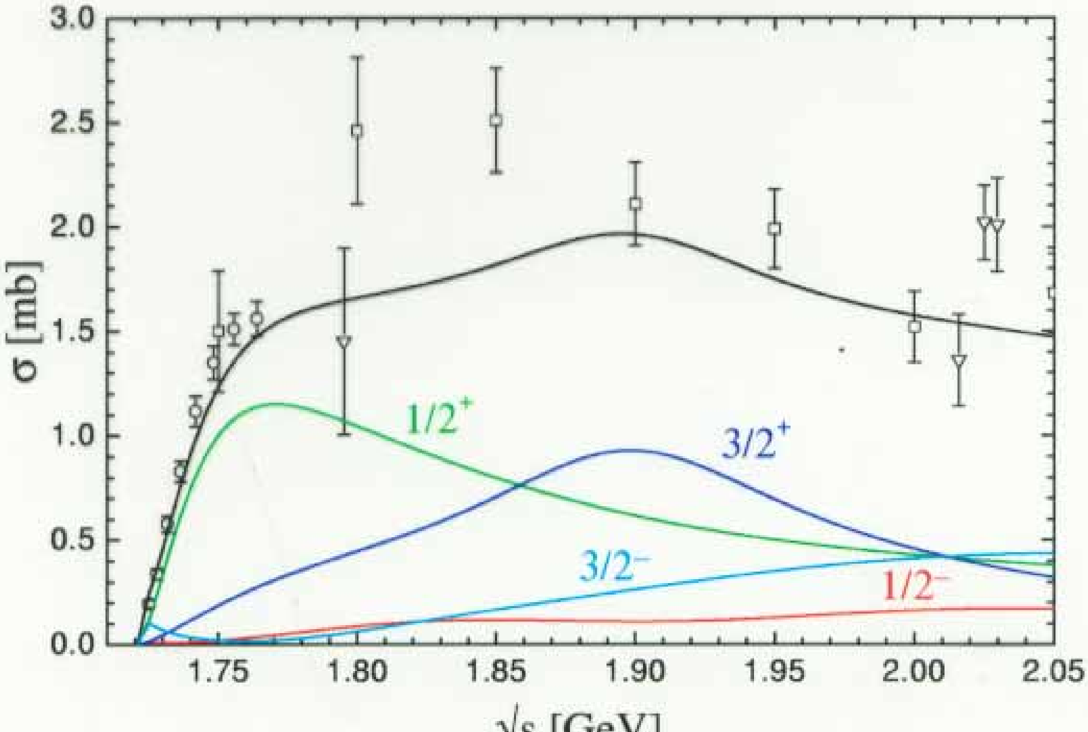


○: $\pi N \to \pi N$ inelasticities (VPI)

●: $\pi N \to 2\pi N$ analysis (Manley 1984)

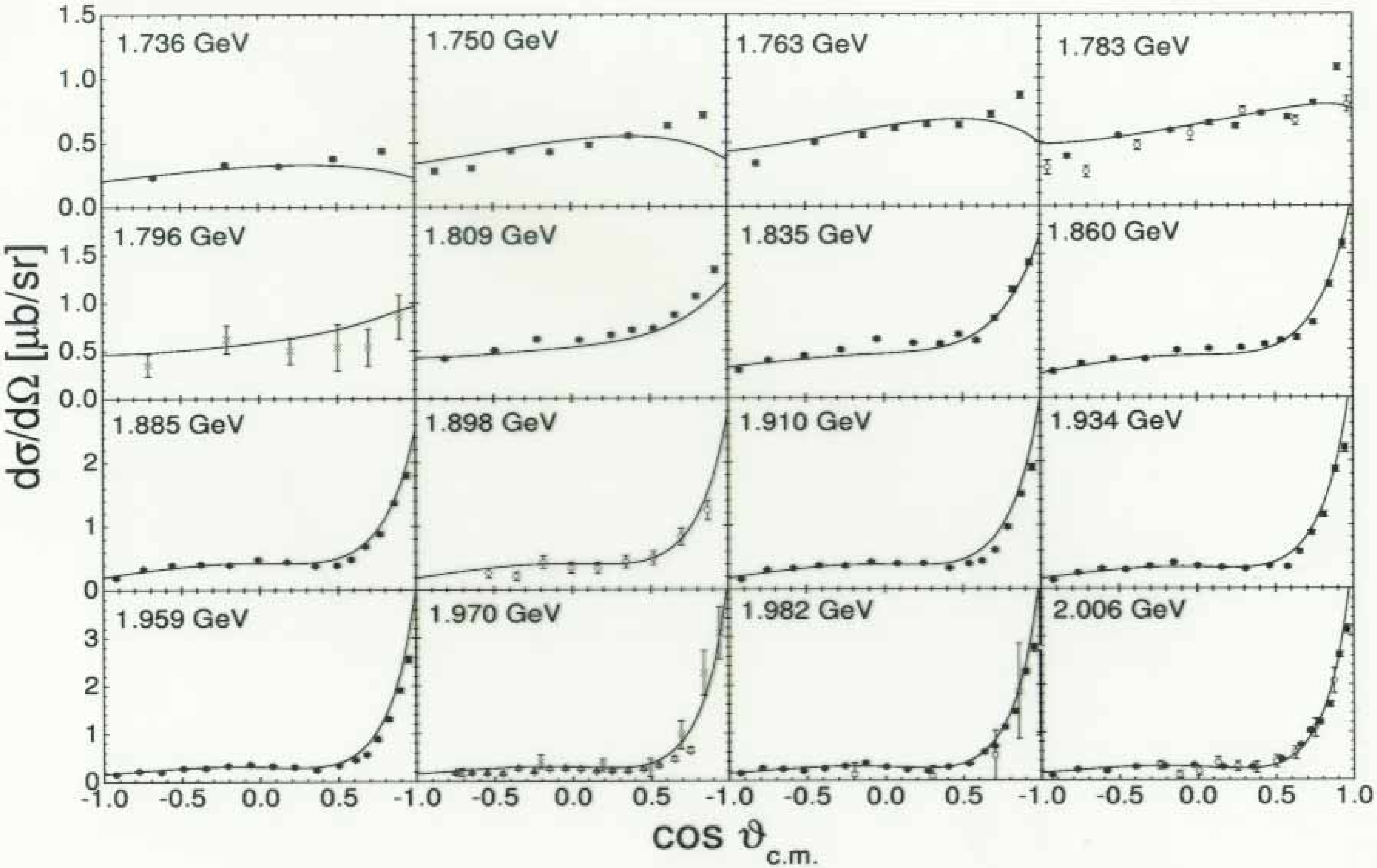
$\pi^- p \to \omega n$





Photon-induced

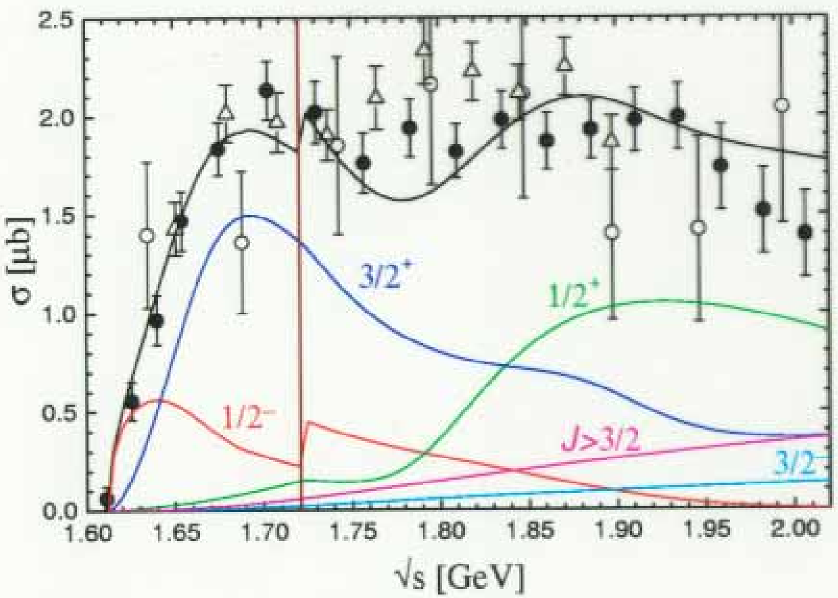
$\gamma p \to \omega p$

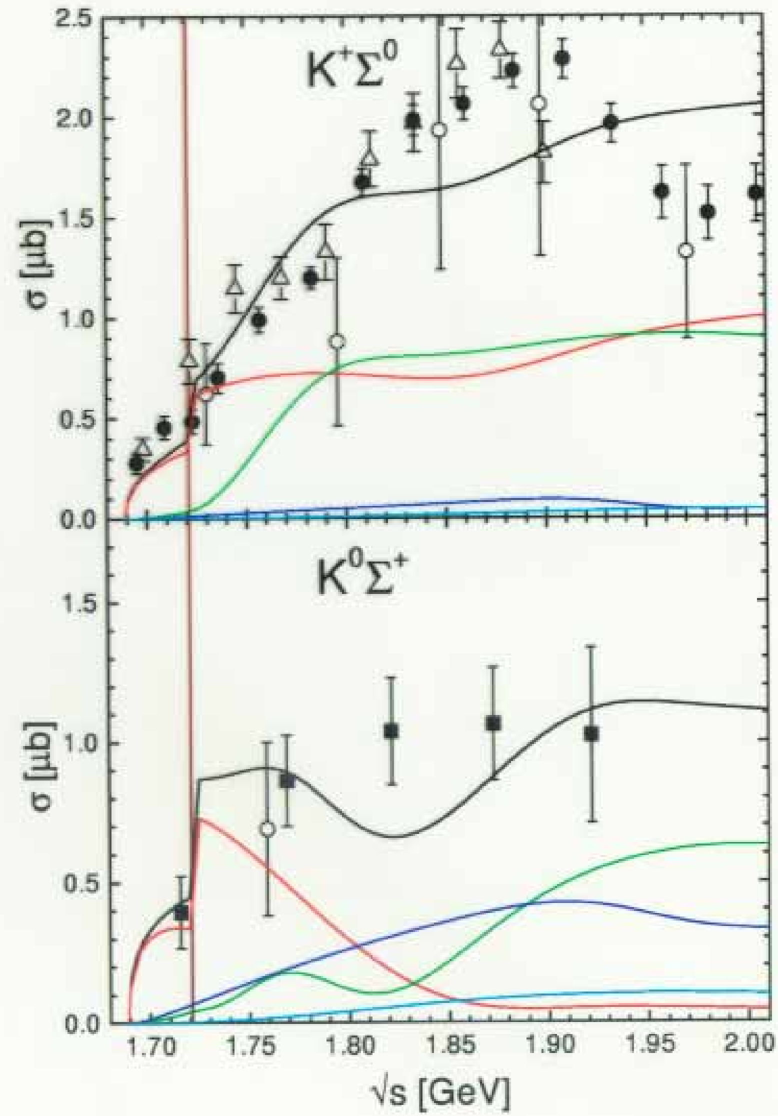


●: J. Barth (SAPHIR Coll.), PhD. dissertation (Bonn 2002), preliminary

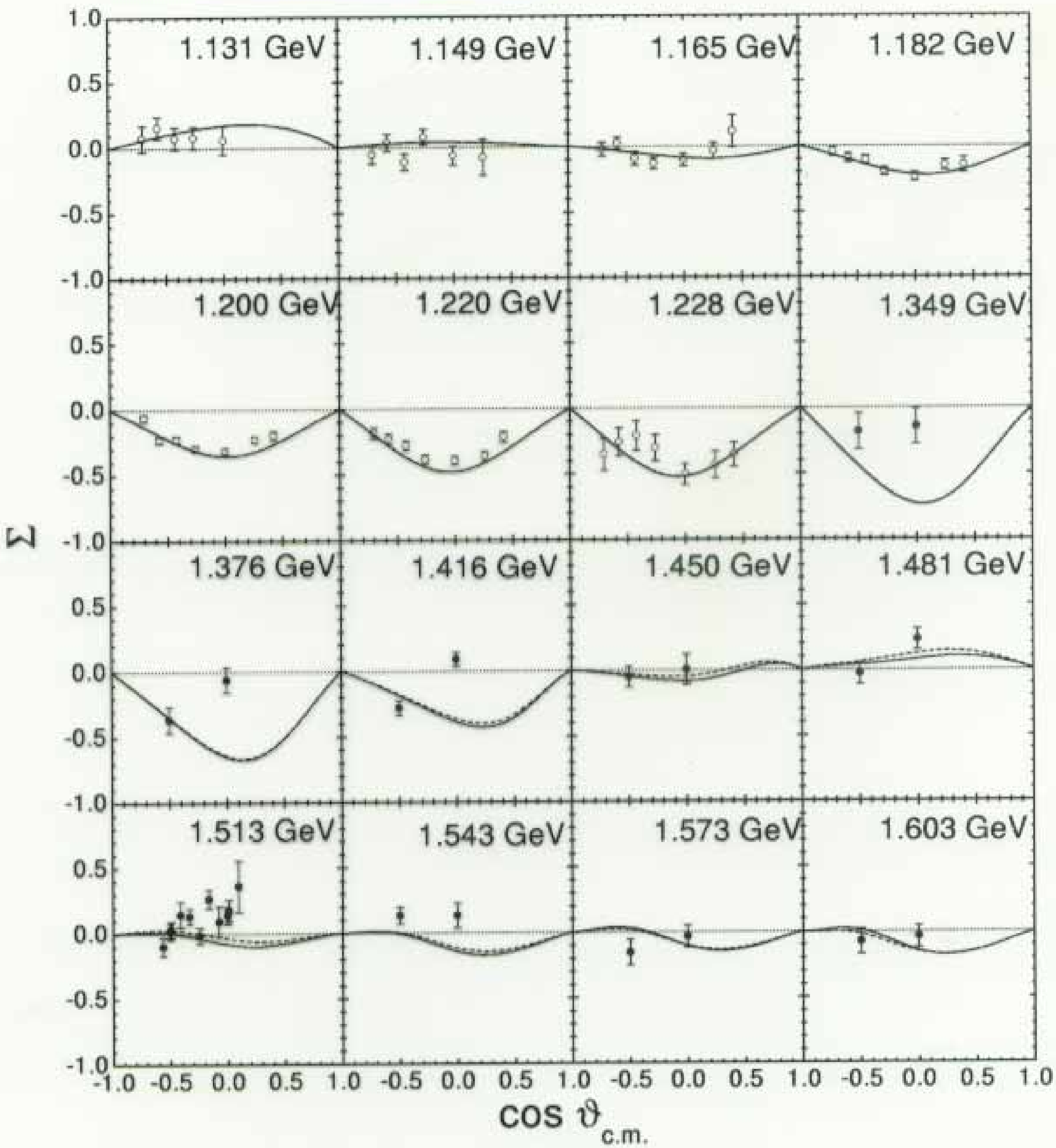
$\gamma p \to K^+\Lambda$

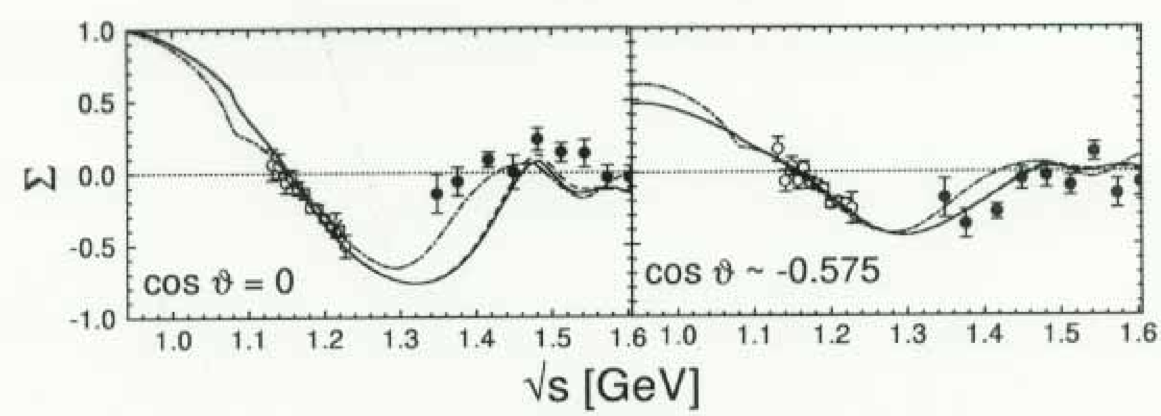
$\gamma p \to K\Sigma$





Compton scattering ($\sqrt{s} \leq 1.6$ GeV)





Summary/Outlook

Summary

- Consistent description of photon- and pion- induced reactions within **one** effective Lagrange model
- Gauge invariance and unitarity (rescattering) fulfilled
- Inclusion of the ωN final state
  $\rightsquigarrow$ generalization of partial wave decomposition
- Good description of all channels
- Photoproduction data inevitable for a reliable resonance analysis
- Strong evidences for missing resonances, e.g. $P_{13}(1900)$

Outlook

- Spin $\frac{5}{2}$ resonances ($\pi/\gamma N \to \pi N$ data)
- More detailed description of $2\pi N$ final state by ρN, $\pi\Delta$ ...
- Inclusion of further final states ($3\pi N$)
- Consideration of analyticity