Coupled Channels Approach to Meson Production on the Nucleon

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Agenda:

- Coupled Channels Description of (γ,N) and (π,N) scattering
- Photo-Production of Strangeness
- eta-Production on the nucleon
- Summary and Outlook

1. The Giessen Coupled Channels Model (GiM)

The K-Matrix Approach

$$\langle f|M(p',p)|i\rangle = \langle f|V(p',p)|i\rangle + \int \frac{d^4q}{(2\pi)^4}\langle f|M(p',q)G_{BS}(q)V(q,p)|i\rangle \ ,$$

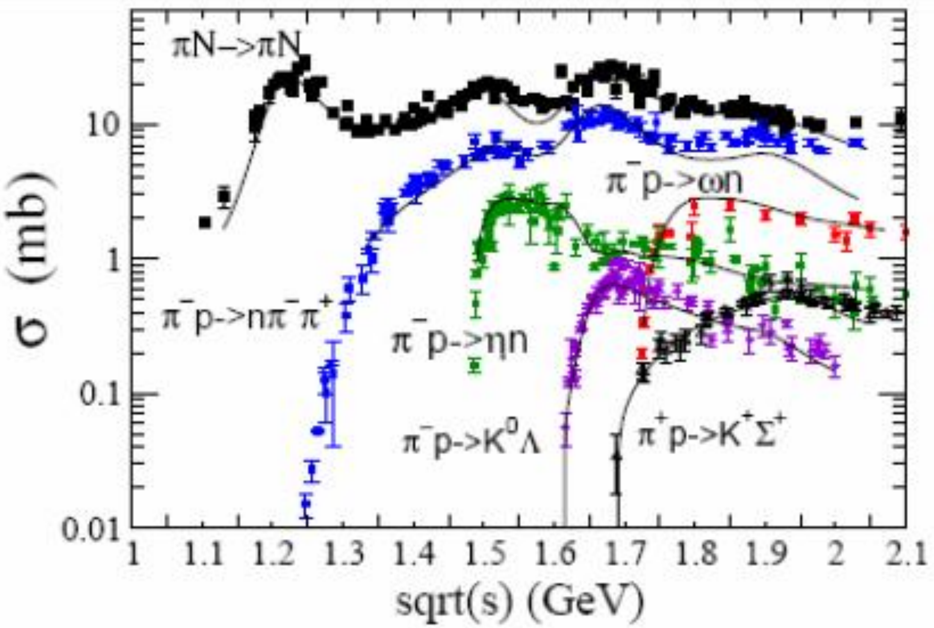
$$\langle f|\tilde{K}(p',p)|i\rangle = \langle f|V(p',p)|i\rangle + \int \frac{d^4q}{(2\pi)^4}\langle f|\tilde{K}(p',q)\mathrm{Re}\left(G_{BS}(q)\right)V(q,p)|i\rangle \ .$$

$$\langle f|M(p',p)|i\rangle = \langle f|\tilde{K}(p',p)|i\rangle + \int \frac{d^4q}{(2\pi)^4}\langle f|M(p',q)\mathrm{i}\mathrm{Im}\left(G_{BS}(q)\right)\tilde{K}(q,p)|i\rangle \ ,$$

...or in short:

$$\mathcal{T}_{fi}^{IJ\pm} = \left[\frac{\mathcal{K}^{IJ\pm}}{1-\mathrm{i}\mathcal{K}^{IJ\pm}}\right]_{fi} \ .$$

Meson Production on the Nucleon



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

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

Giessen model: Good description of the $\pi N \to \pi N, 2\pi N, \eta N, \omega N, K\Lambda, K\Sigma$ reactions in the resonance region

Data are connected → unitarity → Optical theorem

$$ImT_{\pi N \to \pi N}(0) = \frac{k^2}{4\pi}(\sigma_{\pi N \to \pi N} + \sigma_{\pi N \to 2\pi N} + \sigma_{\pi N \to \eta N} + \sigma_{\pi N \to \omega N} + \sigma_{\pi N \to K\Lambda} + \sigma_{\pi N \to K\Sigma})$$

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Effective Lagrangians: PRC72 015210 (2005)

Born and t-channel terms:

$$L_{Born} + L_t = -\bar{u}_{B'}(p')\left[\frac{g_{\tilde{\varphi}}}{m_B + m_{B'}}\gamma_5\gamma_\mu(\partial^\mu\tilde{\varphi}) + g_\eta i\gamma_5\eta + g_S S \right.$$

$$\left. + g_V\left(\gamma_\mu V^\mu + \frac{\kappa_V}{2m_N}\sigma_{\mu\nu}V^{\mu\nu}\right)\right]u_B(p)$$

$$-\frac{g_S}{2m_\pi}(\partial_\mu\varphi')(\partial^\mu\varphi)S - g_V\varphi'(\partial_\mu\varphi)V^\mu - \frac{g}{4m_\varphi}\epsilon_{\mu\nu\rho\sigma}V^{\mu\nu}V'^{\rho\sigma}\varphi.$$

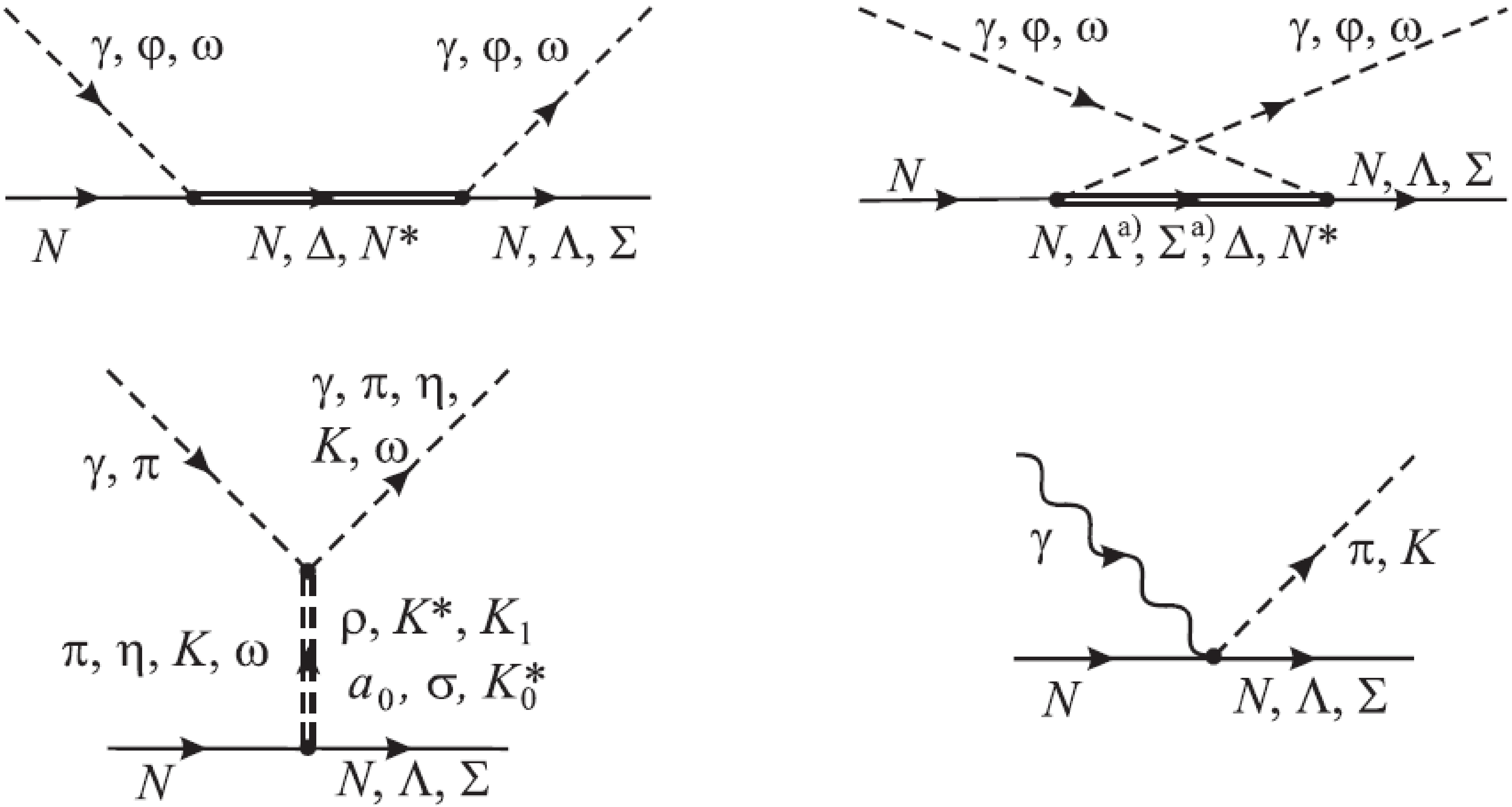
positive-parity spin-$\frac{1}{2}$ resonances, PV coupling is used:

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

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

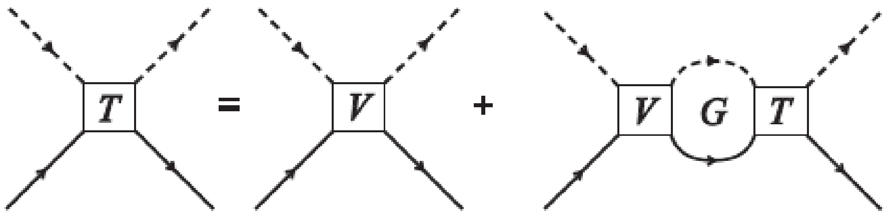
$$L^{PS}_{\frac{1}{2}B\varphi} = -g_{RB\varphi}\bar{u}_R\begin{pmatrix}1\\ -i\gamma_5\end{pmatrix}u_B\varphi\ .$$

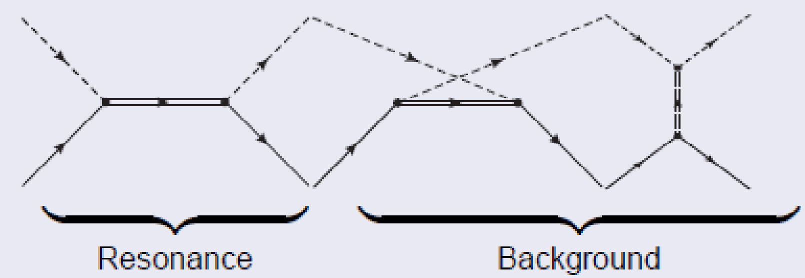
Tree-Level Diagrams:



The CC-Problem:

Bethe-Salpeter in K-matrix: Γ_{N^*} is dynamically generated



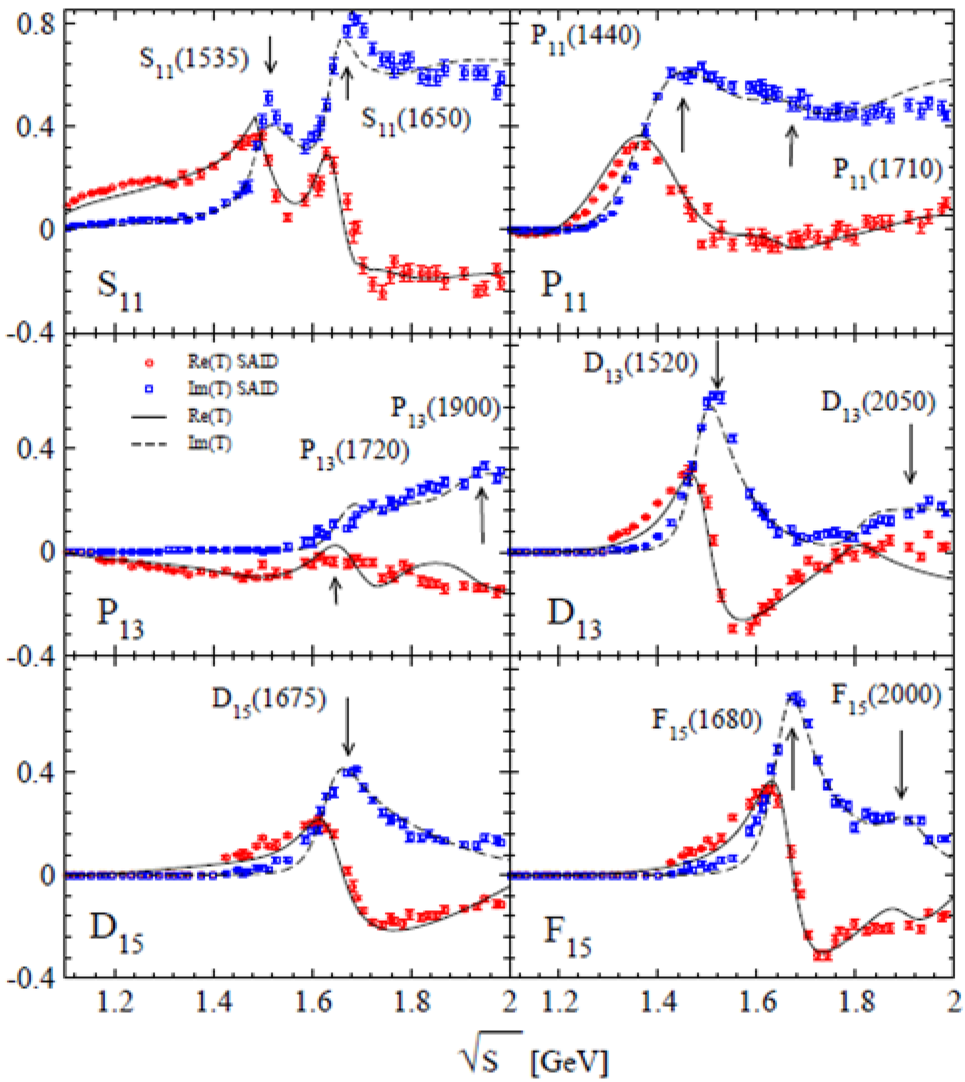
V=


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

How many reaction 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 pion-induced reactions



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

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

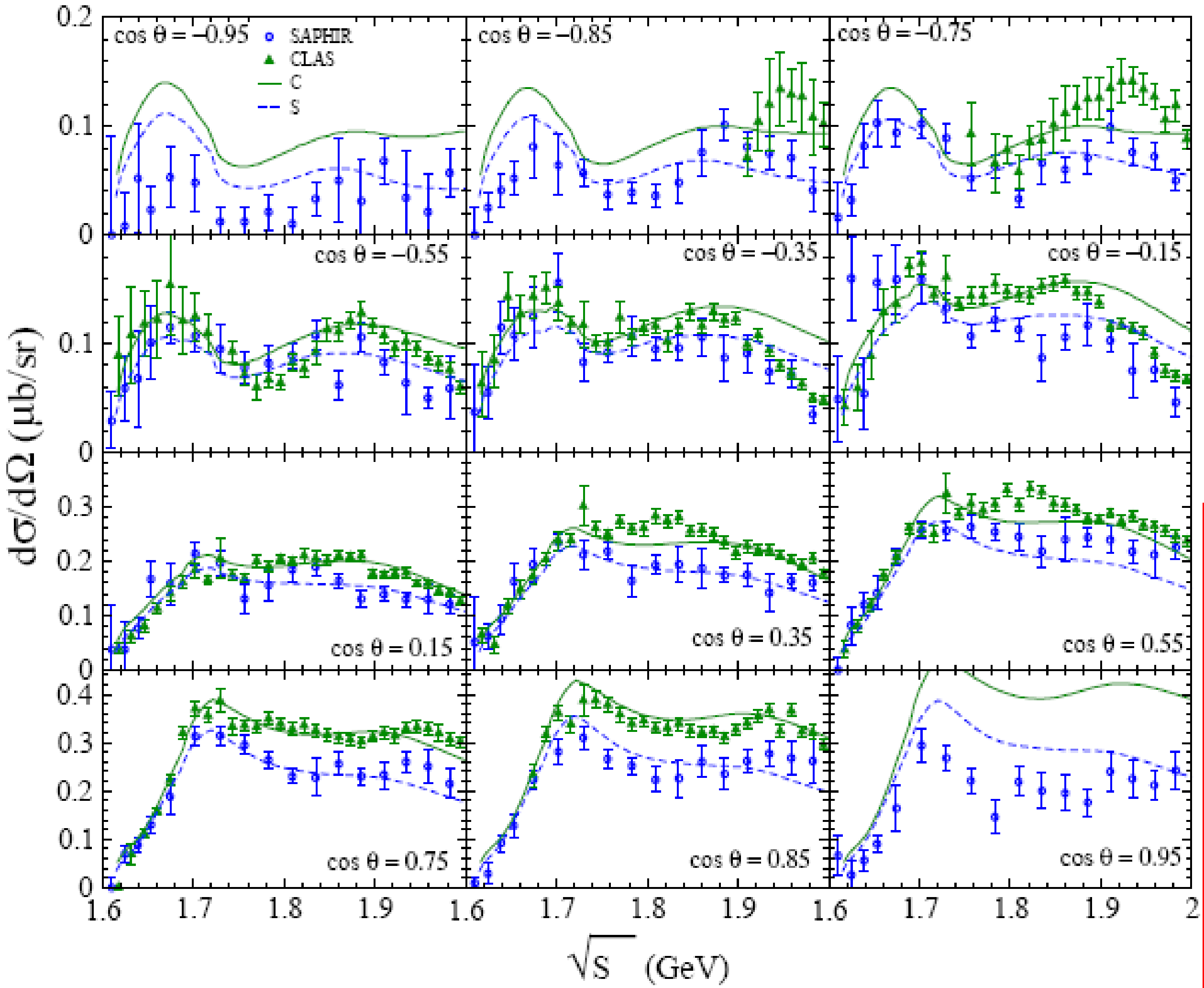
2. Strangeness Production on the Nucleon

Strange decays of non-strange resonances. PDG:

Resonance	$L_{2I\,2J}$	Overall	ΛK	ΣK
$N(939)$	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}	★★	—	

No firm information !

γp → KΛ Results from the Giessen Model



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

$\pi N \rightarrow K\Lambda$

+

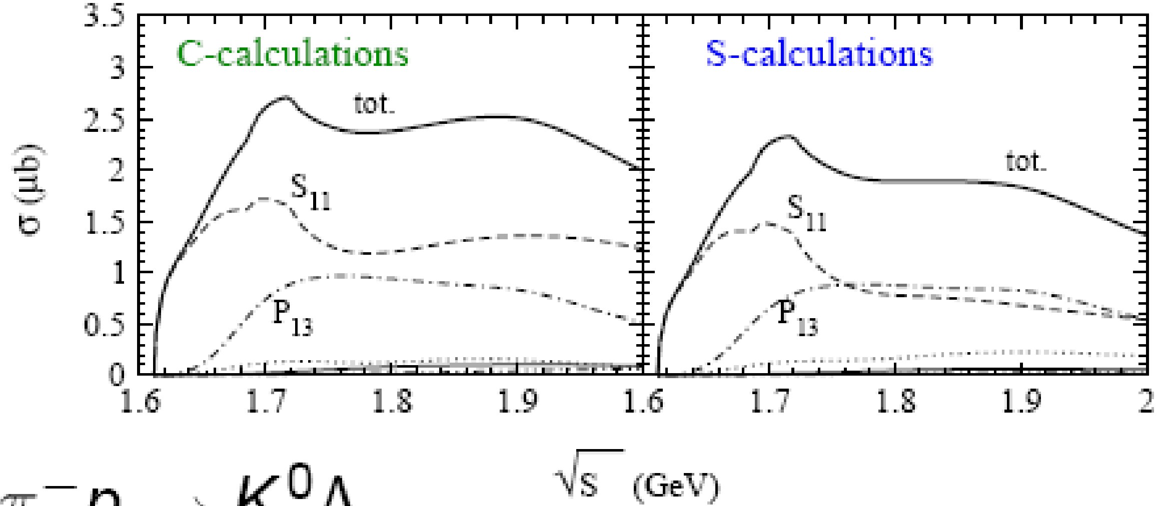
$\gamma N \rightarrow \gamma N$	$\pi N \rightarrow \pi N$
$\gamma N \rightarrow \pi N$	$\pi N \rightarrow 2\pi N$
$\gamma N \rightarrow \eta N$	$\pi N \rightarrow \eta N$
$\gamma N \rightarrow \omega N$	$\pi N \rightarrow \omega N$
$\gamma N \rightarrow K\Sigma$	$\pi N \rightarrow K\Sigma$

V. Shyklar, H.L., U. Mosel, PRC 72:015210 (2005)

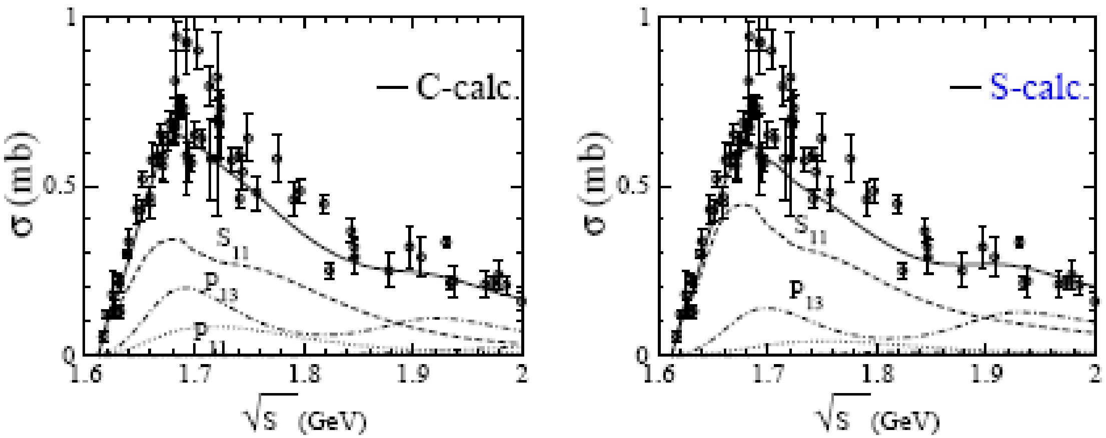
Resonance contributions:

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

$\gamma p \longrightarrow K^{+}\Lambda$



$\pi^{-}p \longrightarrow K^{0}\Lambda$



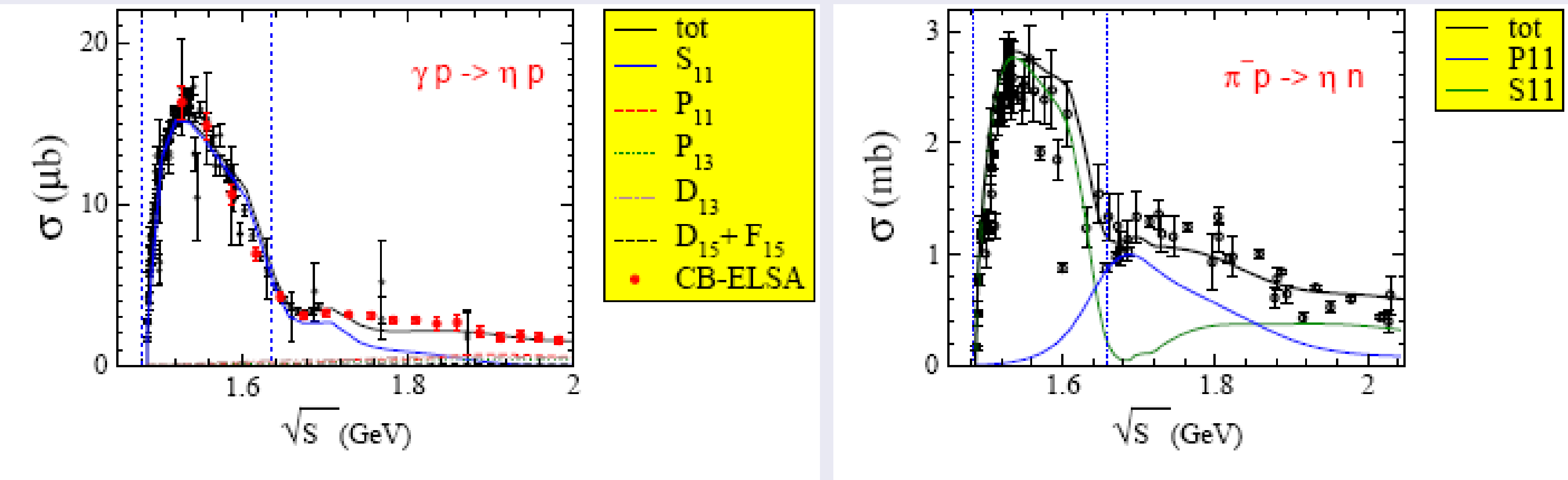
Consequences on Reaction Dynamics of $K\Lambda$ Channels from CLAS/SAPHIR Solutions

3. eta-Production on the Nucleon

Photo- & Hadro-Production of η on the Proton

$S_{11}(1535)$ dominates

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



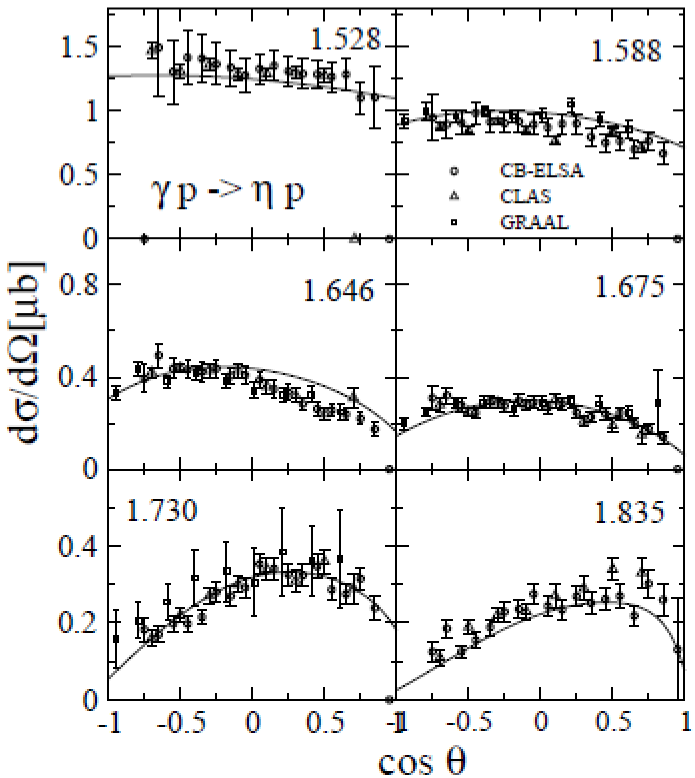
- dominated by S11(1535)
- 5/2-Partial waves account for high energy tail

- destructive interference by $S_{11}(1650)$
- importance of $P_{11}(1710)$ above ~1600MeV

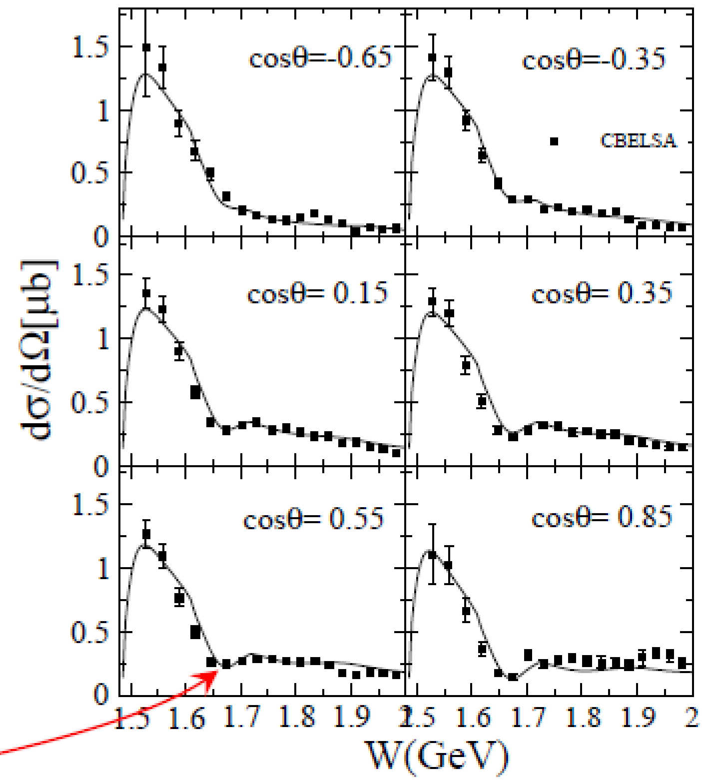
Results for the $\gamma p \to \eta p$

First peak - well known $S_{11}(1535)$

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



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



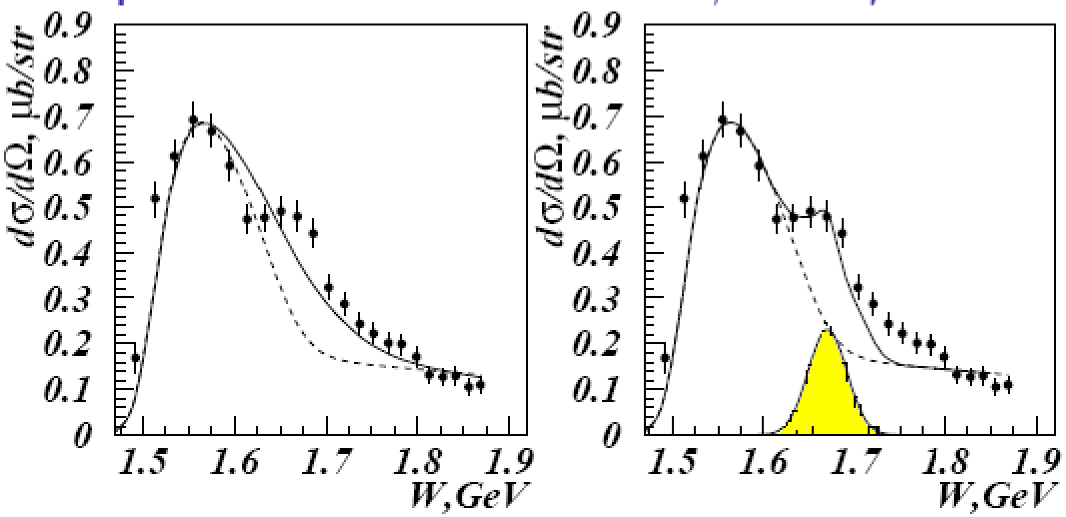
The structure at 1.67 GeV in $\gamma p \to \eta p$ is due to $S_{11}(1650)$

no need for any exotic state!

Excitement in eta-Production on the neutron: Indications for a new sharp resonance?

Polyakov, Azimov, Strakovsky, Arndt, Kuznetsov:

predict a narrow N^* in $\gamma n \rightarrow \eta n$ at 1.67 GeV.



First result from GRAAL:
$\gamma n^* \rightarrow \eta n$ above 1.6 GeV
(V. Kuznetsov et al.,
hep-ex/0601002) observe a resonance-like structure at 1.65 GeV

new resonance ?

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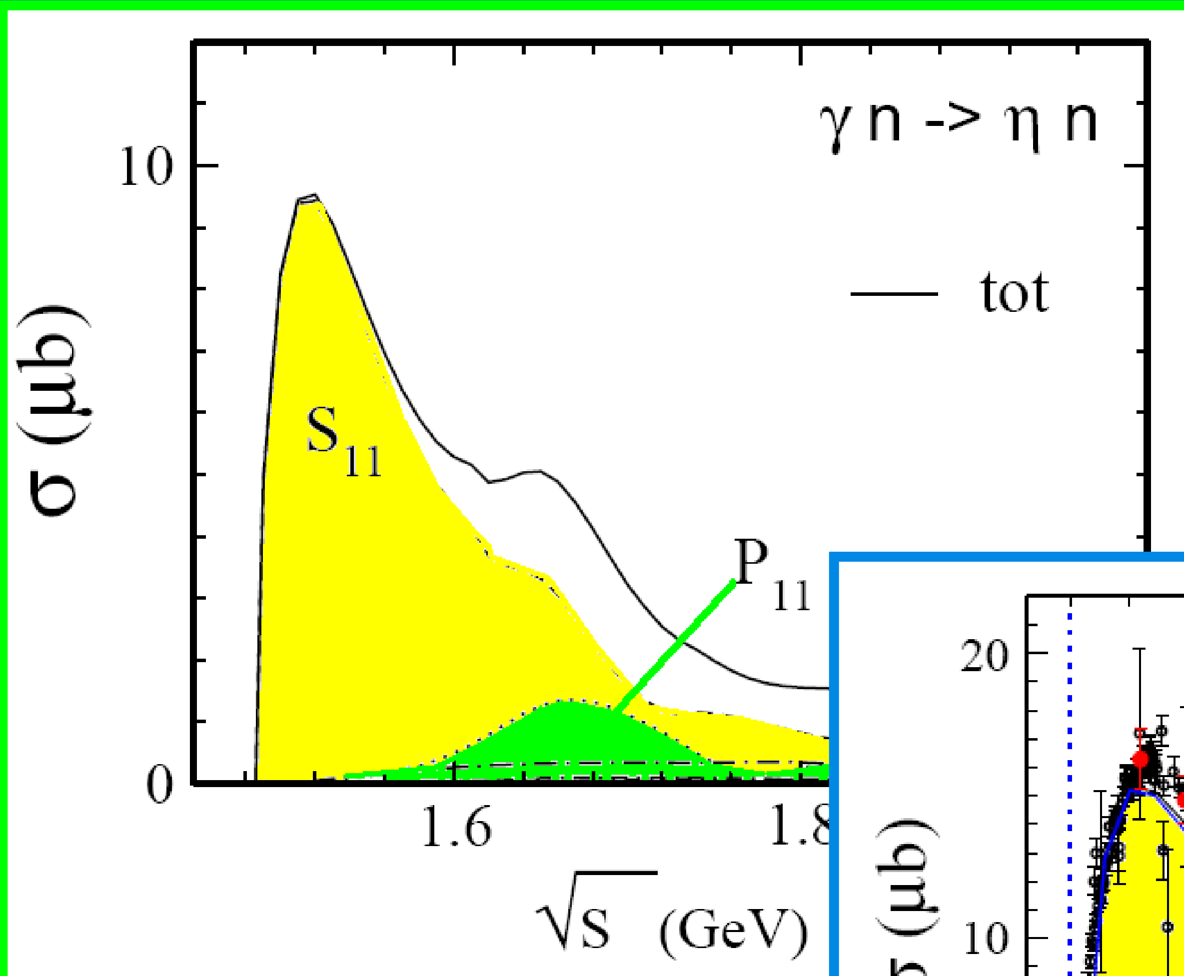
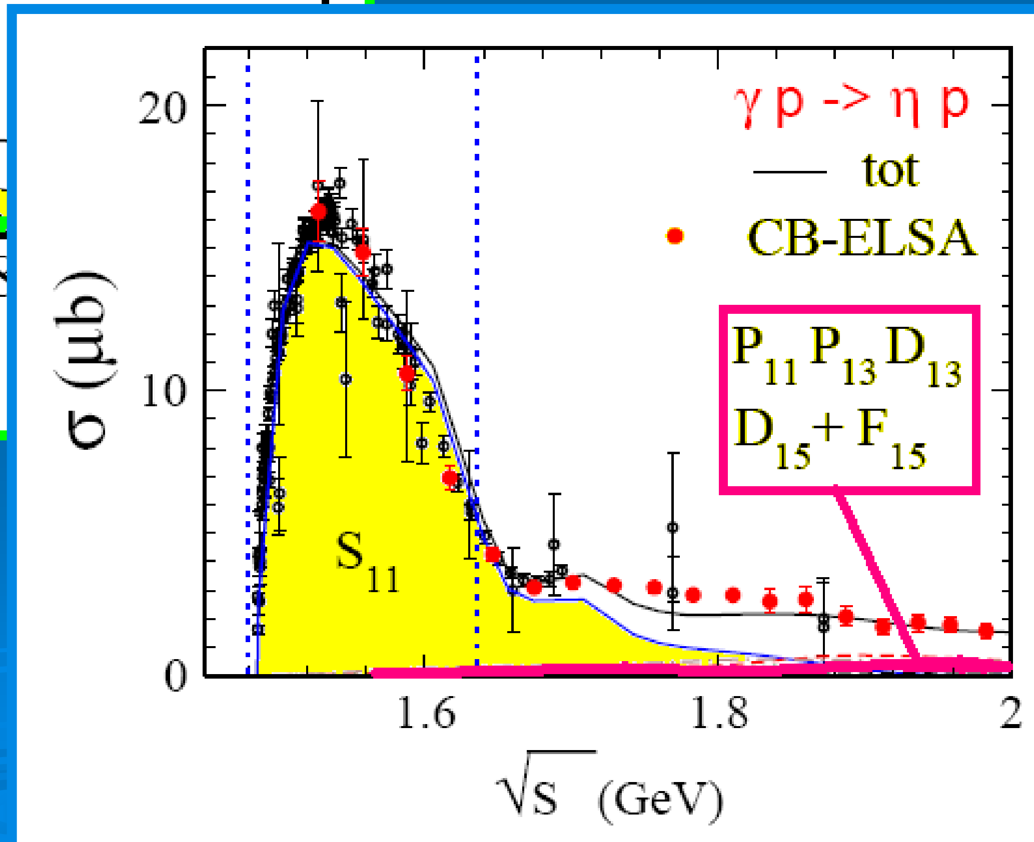
Actual experiment: quasi-free eta-Production on the deuteron

GiM CC-Results eta-Production on the Neutron





GiM CC-Results eta-Production on the Proton

PLB650 172 (2007)

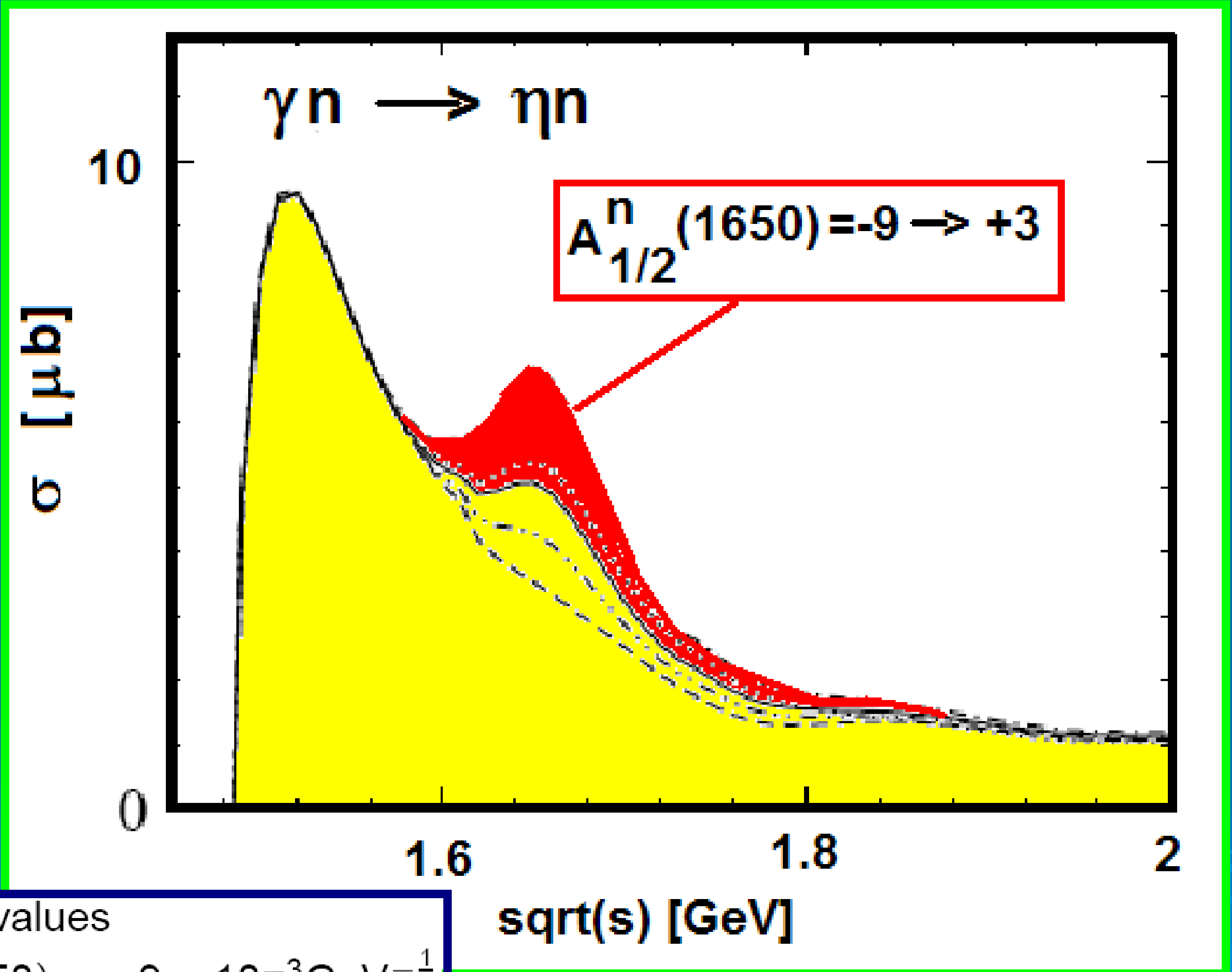
Resonance parameters

Giessen model, PLB650 172 (2007)

	N^*	$\Gamma_{\eta N}$	$A^p_{\frac{1}{2}}$	$A^n_{\frac{1}{2}}$
$S_{11}(1535)$	(Giessen)	56.2	95	-74
	(PDG)	53±1	90±30	-46±27
$S_{11}(1650)$	(Giessen)	2.5	57	-9
	(PDG)	2.3±2	53±16	-15±21
$P_{11}(1710)$	(Giessen)	42	-50	+24
	(PDG)	21±16	+9±22	-2±14

Table: Helicity amplitudes (in $10^{-3}\mathrm{GeV}^{-\frac{1}{2}}$) and branching ratios to ηN. First line: parameters obtained in the present calculations. Second line: PDG values.

Results for γn→ηn: Variation of Partial Wave Amplitude



Central values

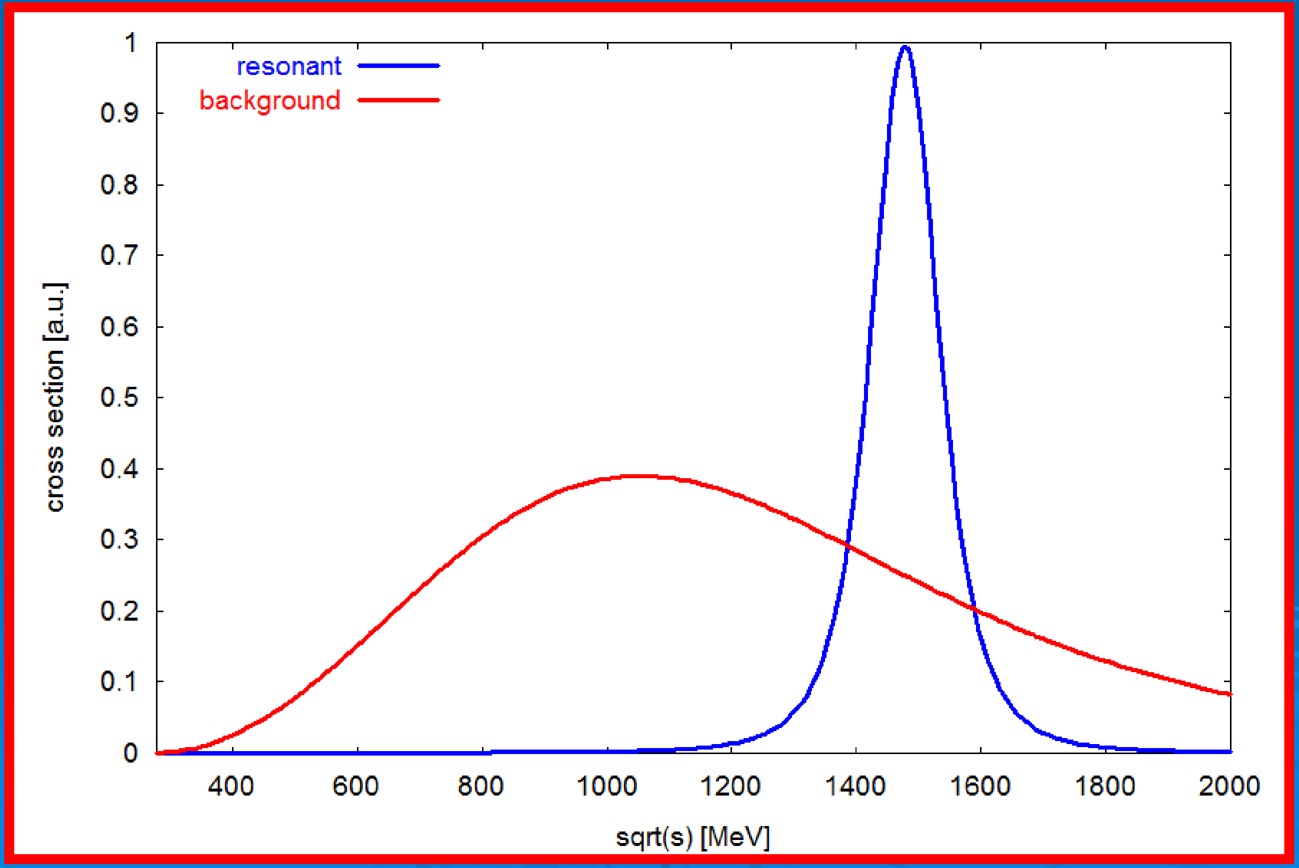
$A^n_{1/2}(1650) = -9 \times 10^{-3}\mathrm{GeV}^{-\frac{1}{2}}$

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

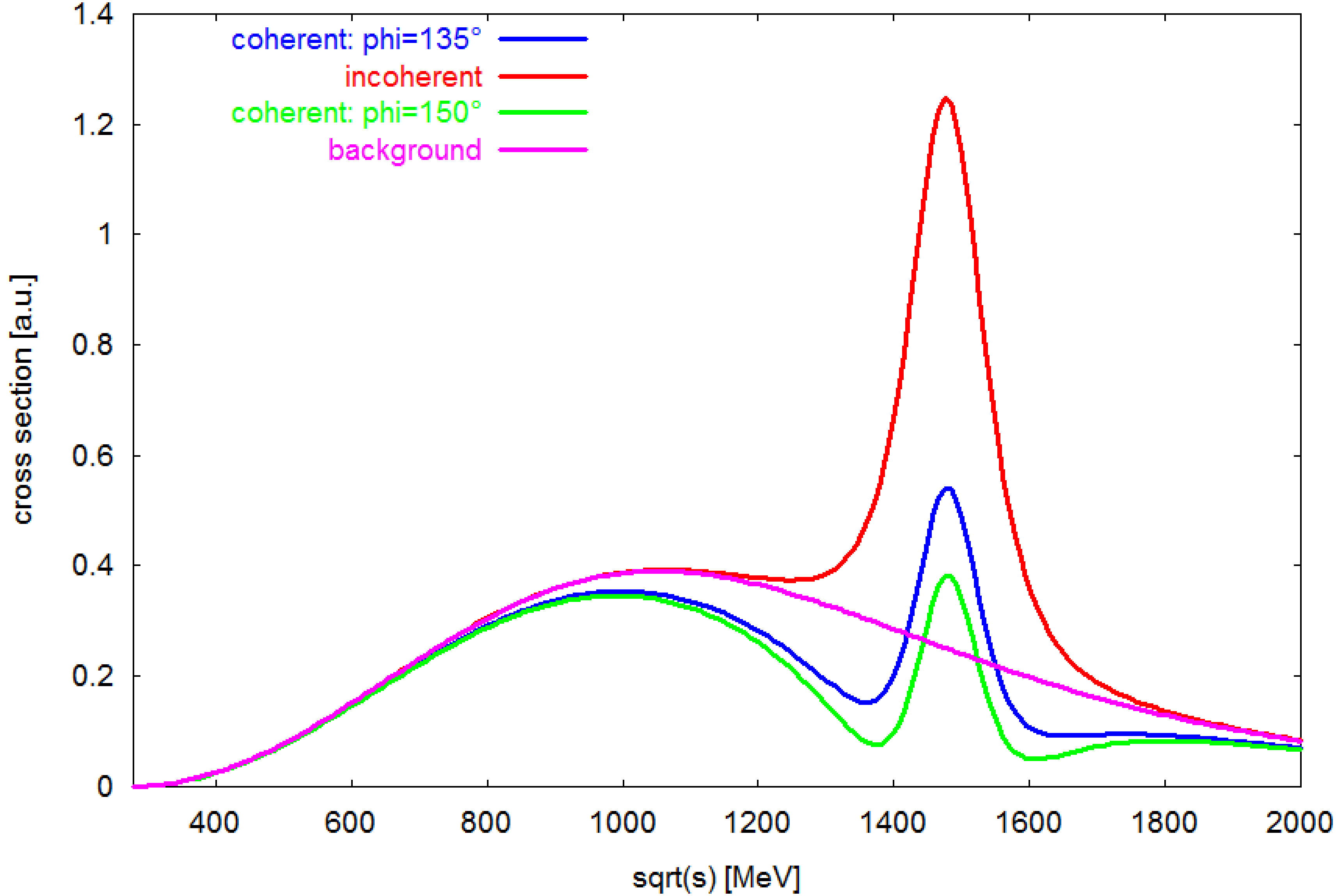
PLB650 172 (2007)

Interference: A simple model:

- Background amplitude $M_b(\sqrt{s})$
- Resonant amplitude $M_r(\sqrt{s}) \sim M_0 e^{i\phi}/(s - m_r^2 - i\sqrt{s}\Gamma(\sqrt{s}))$
- $\sigma_{coh.} \sim |M_b(\sqrt{s}) + M_r(\sqrt{s})|^2$
- $\sigma_{incoh.} \sim |M_b(\sqrt{s})|^2 + |M_r(\sqrt{s})|^2$



Interference Phenomenon



Summary and Outlook

- The Giessen K-Matrix Model
- Kaon (Strangeness) Production on the Proton
- η-Production on the Nucleon
- Caveats in Spectra: *It's a bump but not a resonance…*
- ongoing: 2-Pion dynamics
- also: Pion, Photon, Proton induced Production of Hypernuclei,
- and: Hypernuclei by Fragmentation in HIC (HypHI)
- in progress: S=-1,-2 Hypernuclei by Antiproton Annihilation on Nuclei → PANDA@FAIR, and
- CC-effects and the X,Y,Z states

Main Contributors: V. Shklyar, S. Bender, Th. Gaitanos, R. Shyam