Giessen coupled-channel PWA

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Motivation: investigate strongly interacting systems

What we want to learn ?

- examine the nucleon structure
  - nucleon excitation spectra
- scattering process πN, γN
  - meson-baryon interaction
  - phenomenological Lagrangians
  - reaction mechanisms
- Nucleon resonance properties
  - link to quark model calculations

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Scattering process - how to describe ?

Scattering T-matrix:

- phenomenological models
  + dispersion analysis: GW(SAID), MAINZ, CMB(Zagreb), KHA
- effective Lagrangian approach: Giessen, Jülich, Valensia, EBAC, Bonn-Gatchina PWA

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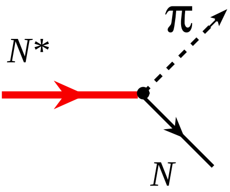
Effective Lagrangian approach

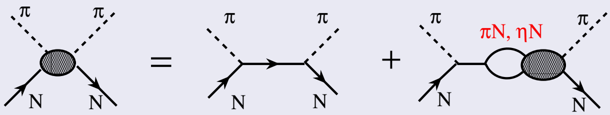
- physical degrees of freedom are mesons and baryons but not quarks and gluons
- maintains symmetries of underlying fundamental theory (QCD)
- use methods of Quantum Field Theory
- N^* properties are defined from interaction Lagrangian



- difficulties: divergences, formfactors

take rescattering in the πN and ηN channels into account

The interaction potentials $V_{\pi N \to \eta N}$ and $V_{\pi N \to \pi N}$ enter to

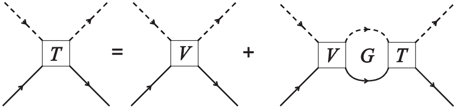


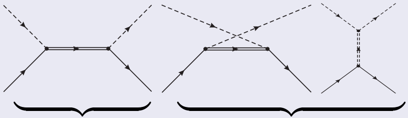
Coupled-channel problem for $\pi N \to \pi N$ scattering:

$$T_{\pi N \to \pi N} = V_{\pi N \to \pi N} + \int d^4p V_{\pi N \to \pi N}\, G_{\pi N}(p)\, T_{\pi N \to \pi N} + \int d^4p V_{\pi N \to \eta N}\, G_{\eta N}(p)\, T_{\eta N \to \pi N}$$

$$T_{\eta N \to \pi N} = V_{\eta N \to \pi N} + \int d^4p V_{\eta N \to \pi N}\, G_{\pi N}(p)\, T_{\pi N \to \pi N} + \int d^4p V_{\eta N \to \eta N}\, G_{\eta N}(p)\, T_{\eta N \to \pi N}$$

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



V=


Imaginary part of the self energy => resonance width.

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

Unitarity – Which data should be included into the analysis?

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

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K-matrix approximation :Phys.Rev.C71:055206(2005)

To solve Bethe-Salpeter equation take the imaginary part of the propagator:

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

The Bethe-Salpeter equation becomes:

$$T_{\pi N,\pi N}(p'q';p\,q) = V_{\pi N,\pi N}(p'q';p\,q)$$
$$-i\frac{|\mathbf{k}|}{8(2\pi)^2\sqrt{s}} \int d\Omega_k T_{\pi N,\pi N}(p'q';k)(\not{k} + m_N)V_{\pi N,\pi N}(k;p\,q)$$

where all intermediate particles are on-shell.

Calculations done in Minkowsky space

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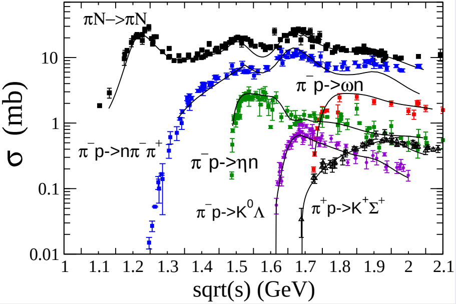
Results for pion-induces reactions

Giessen Model



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

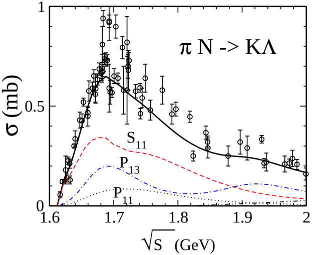
The data are linked: unitarity → Optical theorem

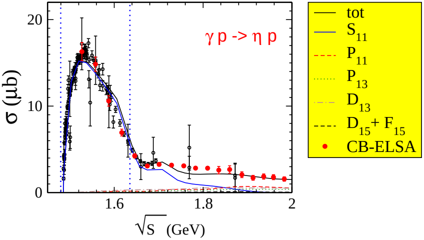
$$ImT_{\pi N\rightarrow\pi N}(0) = \frac{k^2}{4\pi}(\sigma_{\pi N\rightarrow\pi N} + \sigma_{\pi N\rightarrow 2\pi N} + \sigma_{\pi N\rightarrow\eta N} + \sigma_{\pi N\rightarrow\omega N} + \sigma_{\pi N\rightarrow K\Lambda} + \sigma_{\pi N\rightarrow K\Sigma})$$

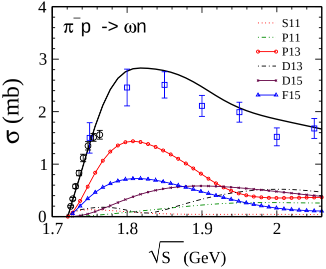
$\rightarrow$ need for multichannel analysis.

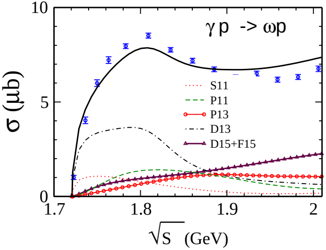
Giessen model. ηN and ωN final states

Giessen Model PRC72 015210 (2005), PRC71,055206(2005).









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η-production: Open questions

$(\gamma/\pi)N \rightarrow \eta N$

Strong $S_{11}(1535)$ contribution in 1.48...1.6 GeV
Which mechanism above 1.6 GeV.?

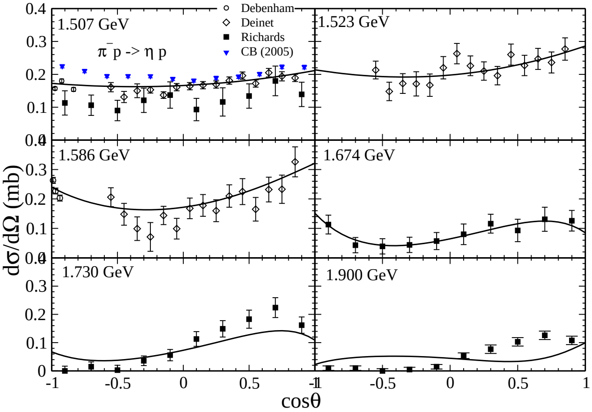
Fix N^* properties, e.g. $S_{11}(1535)$

- branching ratio $\frac{\Gamma(\eta N)}{\Gamma_{tot}}$ and the full width
- $S_{11}(1535)$ from $\gamma N \rightarrow \pi N$: $A_n^{\frac{1}{2}}/A_p^{\frac{1}{2}} \approx -0.5$
- $S_{11}(1535)$ from $\gamma N \rightarrow \eta N$: $A_n^{\frac{1}{2}}/A_p^{\frac{1}{2}} \approx -0.84$ (Krusche et al)

Look for 'hidden'/narrow N^* resonances:

observed resonance-like structure in $\gamma n \rightarrow \eta n$
(V. Kuznetsov; Krusche et al)
Polyakov, Diakonov, Petrov,Arndt, Strakovsky et al
- hidden narrow state or conventional mechanism

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



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

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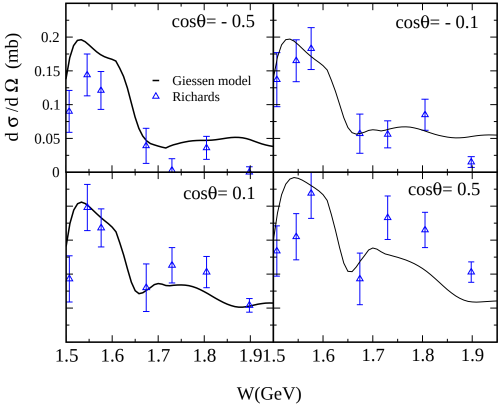
Results for the $\pi^- p \to \eta n$ production

Old data: W.B. Richards et al., PRD**1** 10 (1970).



Old $\pi^- p \to \eta n$ data reveals some structure above 1.7 GeV and forward angles.

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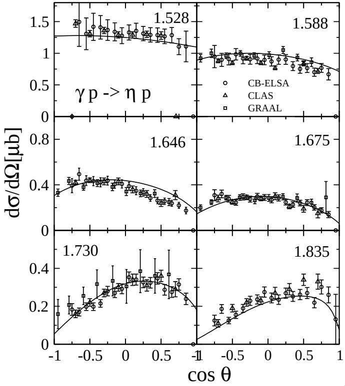
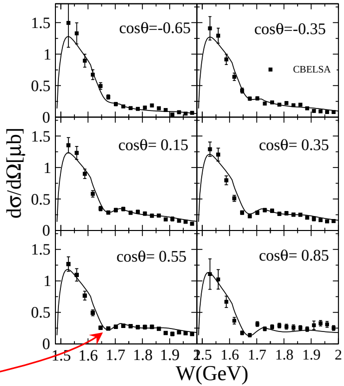
Results for the $\gamma p \to \eta p$

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



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

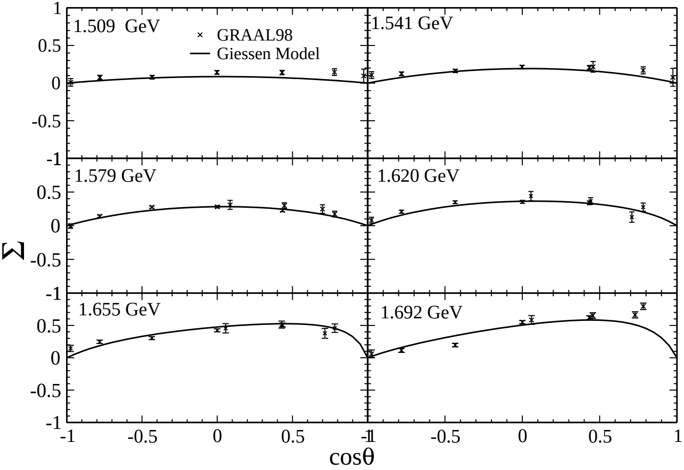


The structure at 1.67 GeV in $\gamma p \to \eta p$ is due to $S_{11}(1650)$

no need for any exotic state!

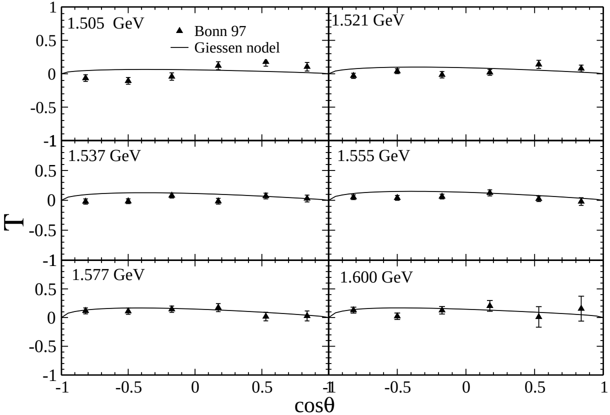
Giessen model. Results for $\gamma p \to \eta p$

$\gamma p \to \eta p$: Beam asymmetry (GRAAL) - Giessen calculations



Giessen model. Results for $\gamma p \rightarrow \eta p$

$\gamma p \rightarrow \eta p$: Target asymmetry (Bonn) vs Giessen results

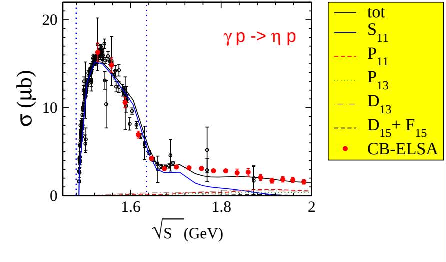


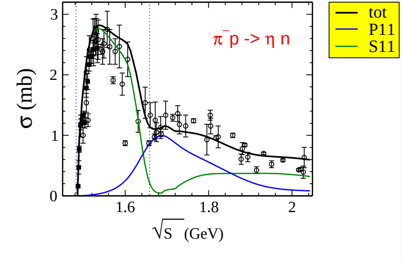
Disagreement at low energies.
Same situation in other models (MAID etc).

Giessen calculations: G.Penner, U.Mosel, H.Lenske, V.Shklyar

$S_{11}(1535)$ dominates

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





- strong $S_{11}(1535)$ excitation
- seems no room for other contributions
- destructive effect from $S_{11}(1650)$
- above 1.6 GeV - $P_{11}(1710)$

Resonance parameters

N^*	$\Gamma_{\eta N}$	$A^p_{\frac{1}{2}}$	$A^n_{\frac{1}{2}}$	$A^p_{\frac{3}{2}}$	$A^n_{\frac{3}{2}}$
$S_{11}(1535)$ (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 $10^{-3}\text{GeV}^{-\frac{1}{2}}$) and branching ratios to ηN. First line: parameters obtained in the present calculations. Second line: PDG values.

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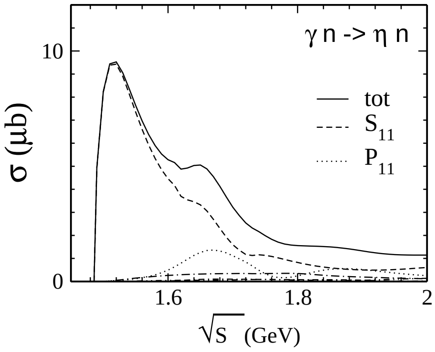
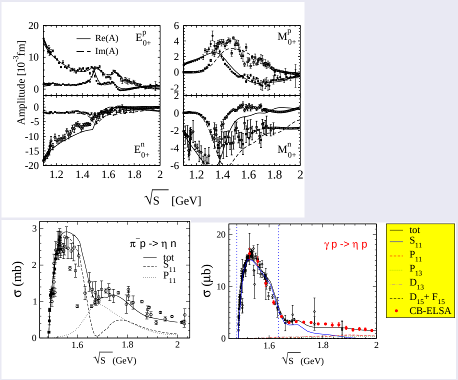
PLB650(2007)172. $\gamma n \to \eta n$ Total partial wave cross sections



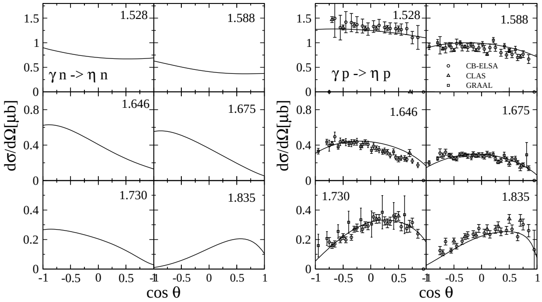


- constrained by $\gamma(p/n) \to \pi(p/n)$ data
- constrained by $\gamma p \to \eta p$ data
- constrained by $\pi - p \to \eta n$ data
- both $S_{11}(1650)$ and $P_{11}(1710)$ contribute at 1.67 GeV.

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

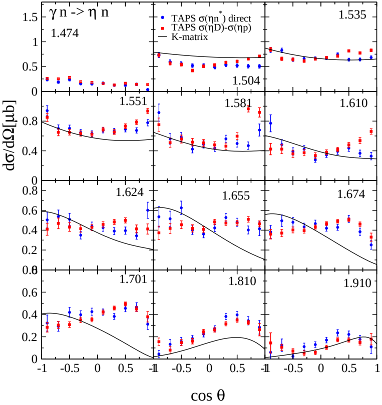
prediction

$\gamma n \to \eta n$ $\gamma p \to \eta p$



- $\gamma n \to \eta n$ mostly backward directions up to 1.75 GeV -result of S- and P-wave interference.
- above 1.75 GeV $\gamma n \to \eta n$ looks very similar to $\gamma p \to \eta p$

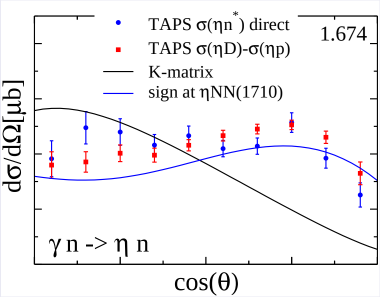
$\gamma n \longrightarrow \eta n$ comparison with the TAPS data



- good agreement in the region 1.490 ... 1.620 GeV and at hight energies
- disagreement in the more interesting region around 1,7 GeV

- backward peaking - result of the *S*- and *P*-interference
  - the phase between the partial waves is crucial.

Interference between S and P waves



- $S_{11}(1650)$ and $P_{11}(1710)$: properties are not well none.
- Changing the sign of $g^{N(1710)}_{\eta NN}$ modify the interference pattern
- $P_{11}(1710)$ - strong $2\pi N$ decay: a proper treatment of the 2π channel is needed

Conclusion

- K-matrix approximation to the BSE provide a simple and powerful tool to analyze experimental data on pion- and photon induced reactions.
- combined description of the reaction
  $\gamma N \to \gamma N, \pi N, \eta N, \omega N, K\Lambda, K\Sigma$
  $\pi N \to \pi N, 2\pi N, \eta N, \omega N, K\Lambda, K\Sigma$
- Old $\pi N \to \eta N$ data shows a promising structure around 1.7 GeV Unfortunately the data is pure.
- $\gamma n \to \eta n$: the resonance like structure seen in the TAPS data can be explained the excitations of $S_{11}(1650)$ and $P_{11}(1710)$ states. Interference effects might be crucial - further analyses is needed.
- more detailed description of the 2π channel is necessary to understand the reaction mechanism

Born and *t*-channel terms:

$$L_{Born} + L_t = -\bar{u}_{B'}(p')\Big[g_{\tilde{\varphi}}\gamma_5\gamma_\mu(\partial^\mu\tilde{\varphi}) + g_\eta i\gamma_5\eta + g_S S + g_V\left(\gamma_\mu V^\mu + \frac{\kappa_V}{2m_N}\sigma_{\mu\nu}V^{\mu\nu}\right)\Big]u_B(p)$$

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

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

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

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

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

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Nucleon resonances in effective field theory

To solve the scattering problem

- Bethe-Salpeter equation
- Dyson-Schwinger equation

  etc

Background and resonance contributions in EFT

Solving the Dyson-Schwinger equation for the potential

V = V(resonance) + V(background)

$$T = \frac{\Gamma(V_R, V_B)}{s - m^2 + \Sigma(V_R, V_B)} \approx \frac{\Gamma(V_R)}{s - m^2 + \Sigma(V_R)} + V_B$$

Breit-Wigner form

similar in QM:

$$\left(\frac{\hat{p}^2}{2m} + V_1 + V_2\right)\Psi_{12} = E\Psi_{12}$$

$\Psi_{12} \neq \Psi_1 + \Psi_2$ (only in perturb. $\Psi_{12} \approx \Psi_1 + \Psi_2$)

Resonance and background contributions are generally not separable

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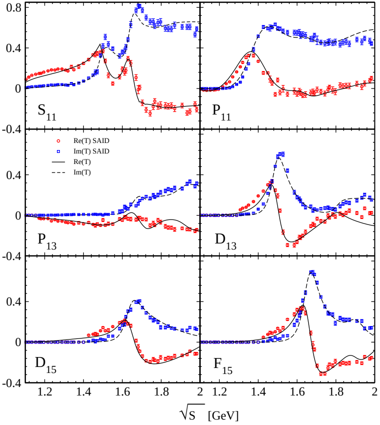
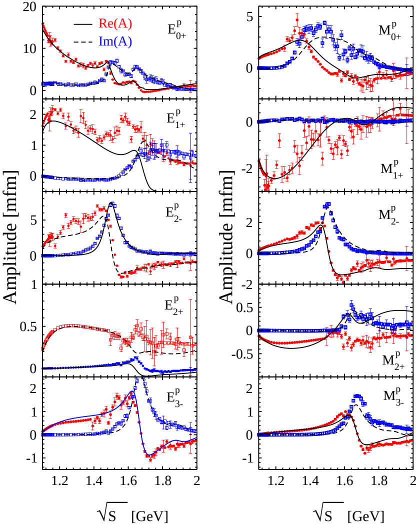
Giessen model. Results for $\pi N \to \pi N, 2\pi N$ scattering

πN scattering amplitudes PRC72,015210(2005) .vs. SAID partial wave analysis FA02 Arndt et al.





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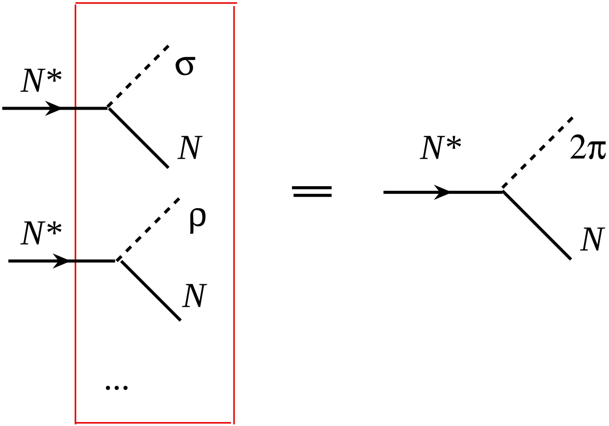

N*
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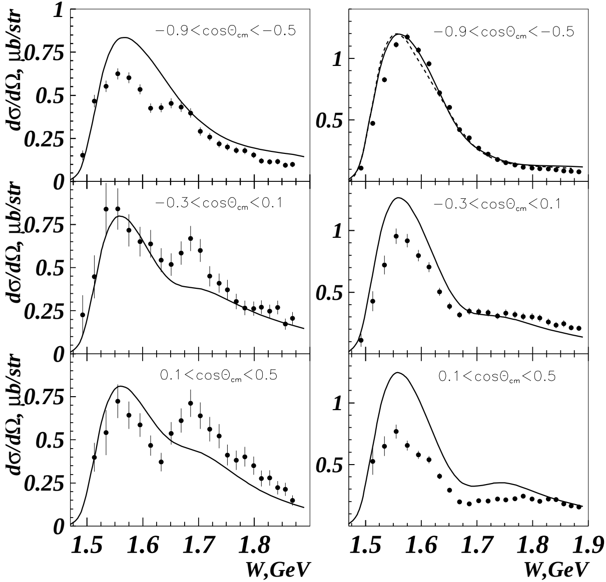

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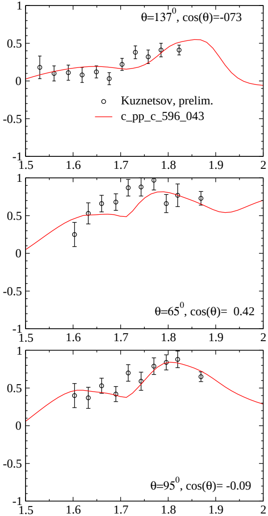
$\gamma n^* \longrightarrow \eta n$ asymmetry

Beam asymmetry: $\Sigma = \frac{d\sigma_\perp - d\sigma_\parallel}{d\sigma_\perp + d\sigma_\parallel}$



- asymmetry is not fitted
- take care: the calculations done without Fermi-motion

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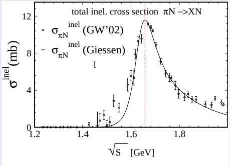
Why $\Gamma_{N(1675)\to\eta N} = 17\%$ has problems

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

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

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



Assuming dominant $D_{15}(1675)$

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

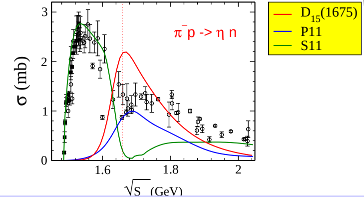
$$T_{\pi N\to \eta N} \sim \frac{\Gamma^{N(1675)}_{\pi N}\Gamma^{N(1675)}_{\eta N}}{s - m^2_{1675} - i\Gamma_{tot}/2}$$

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

η-MAID L. Tiator (hep-ex/0601002):

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

$$\sigma^{\frac{5}{2}}_{\pi N\to\eta N}\Big|_{1675MeV} = 12\left(\frac{17}{40}\right)^2 \approx 2.2\text{mb}$$



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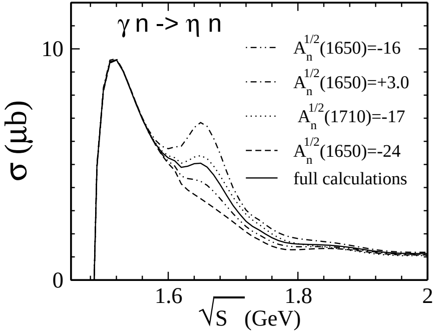
Results for the $\gamma n^* \to \eta n$

- some fitted data are not of good quality
- some of data is still preliminary

How sensitive our calculation to a variation of $N^* \to \gamma n$ couplings ?



The variation of the $N^* \to \gamma n$ couplings strongly affect the magnitude of the peak

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