Photoproduction of eta-mesons in the presence of a narrow $P_{11}(1675)$ resonance

- introduction
- the isobar model EtaMaid
- $t$-channel exchanges: poles vs. Regge trajectories
- $D_{15}(1675)$ resonance vs. narrow $P_{11}(1675)$
- summary
• **EtaMaid 2001**
  W.-T. Chiang
  C. Bennhold
  D. Drechsel
  L.T.
  Born terms in s- and u-channel
  $\rho,\omega$ pole terms in t-channel
  N* resonances:
  $D_{13}(1520)$, $S_{11}(1535)$, $S_{11}(1650)$, $D_{15}(1675)$
  $F_{15}(1680)$, $D_{13}(1700)$, $P_{11}(1710)$, $P_{13}(1720)$

• **ReggeMaid 2003**
  W.-T. Chiang
  M. Vanderhaeghen
  L.T.
  Born terms
  $\rho,\omega$ Regge trajectories
  N* resonances:
  $D_{13}(1520)$, $S_{11}(1535)$, $S_{11}(1650)$, $D_{15}(1675)$

• **EtaMaid 2006**
  A. Fix
  M. Polyakov
  L.T.
  Regge isobar model as ReggeMaid2003
  with additional narrow $P_{11}(1675)$ resonance
MAID

the Mainz-Dubna Unitary Isobar Model

\[ t_{\gamma,\pi}^{\alpha} = \nu_{\gamma,\pi}^{\alpha}(\text{Born} + \omega, \rho) \left( 1 + i t_{\pi,\pi}^{\alpha} \right) \]

K-matrix unitarization

[\text{Resonances}] \left( e^{i \Phi(W)} \right)

unitarization phase
determined by the Watson theorem, below 2\(\pi\) threshold
relaxed above 2\(\pi\) threshold
ETA-MAID

uses a simpler approach without unitarization

\[ t_{\gamma,\eta} = \nu_{\gamma,\eta}(\text{Born} + \omega, \rho) + t_{\gamma,\eta}(\text{Resonances}) \]

what is missing:
- influence of other coupled channels
- possibly: \( K\Lambda, K\Sigma, \ldots \)
Born terms do not play an important role in eta production

\[ \frac{g^2}{4\pi} \sim 0.1 \]

Vector meson exchanges of \( \omega, \rho \) in the t-channel can be treated in 2 different ways:

1. as t-channel poles (with additional form factors)
2. as Regge trajectories (giving rise to questions about duality and double counting)
Regge Trajectory Exchanges

At high $s$ and low $t$, it is known that meson photoproduction can be well described by Regge trajectories in the $t$-channel.

Replace pole-like propagator

$$P^{\nu}_{\text{pole}} = \frac{1}{t - m^2_{\nu}}$$

With Regge propagator

$$P^{\nu}_{\text{Regge}} = \left( \frac{s}{s_0} \right)^{\alpha'_V(t)-1} \frac{\pi \alpha'_V}{\sin(\alpha_V(t))} \frac{S_V + e^{-i\pi \alpha'_V(t)}}{2} \frac{1}{\Gamma(\alpha_V(t))}$$

The idea is to economically take into account the exchanges of high-spin particles in the $t$-channel which cannot be neglected at higher energies.
Resonances

Breit-Wigner form

\[
\left( \frac{E_{\ell\pm}}{M_{\ell\pm}} \right) = \left( \frac{\bar{E}_{\ell\pm}}{\bar{M}_{\ell\pm}} \right) f_{\gamma N}(W) \frac{\Gamma_{\text{tot}} W_R}{W_R^2 - W^2 - i W_R \Gamma_{\text{tot}}} f_{\eta N}(W) C_{\eta N} \zeta_{\eta N}
\]

isospin factor \( C_{\eta N} = -1 \)

\[
f_{\eta N}(W) = \left[ \frac{1}{(2j + 1)\pi |q| W_R \Gamma_{\text{tot}}^2} \right]^{1/2}
\]

\[
\Gamma_{\eta N} = \beta_{\eta N} \Gamma_R \left( \frac{|q|}{q_R} \right)^{2\ell + 1} \left( \frac{X^2 + q_R^2}{X^2 + q^2} \right) \frac{W_R}{W}
\]

\[
\Gamma_{\text{tot}} = \Gamma_{\eta N} + \Gamma_{\pi N} + \Gamma_{\pi\pi N}
\]

\[
f_{\gamma N}(W) = 1
\]

\[\zeta_{\eta N} = \pm 1 : \text{hadronic phase}\]

8 resonances are included in \( \eta \)-MAID:

- **D\(_{13}(1520)\)** very important
- **S\(_{11}(1535)\)** most important
- **S\(_{11}(1650)\)** very important
- **D\(_{15}(1675)\)** very important
- **F\(_{15}(1680)\)** less important
- **D\(_{13}(1700)\)** unimportant
- **P\(_{11}(1710)\)** important
- **P\(_{13}(1720)\)** unimportant
Resonance Parameters
from $\eta$-MAID 2001

<table>
<thead>
<tr>
<th>$N^*$</th>
<th>mass</th>
<th>width</th>
<th>$\beta_{\eta N}$</th>
<th>$\zeta_{\eta N}$</th>
<th>$A^{p}_{1/2}$</th>
<th>$A^{p}_{3/2}$</th>
<th>$A^{n}_{1/2}$</th>
<th>$A^{n}_{3/2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_{13}(1520)$</td>
<td>1520</td>
<td>120</td>
<td>0.06%</td>
<td>1</td>
<td>-52</td>
<td>166</td>
<td>-41</td>
<td>-135</td>
</tr>
<tr>
<td>$S_{11}(1535)$</td>
<td>1541</td>
<td>191</td>
<td>50.%</td>
<td>1</td>
<td>118</td>
<td>-</td>
<td>-97</td>
<td>-</td>
</tr>
<tr>
<td>$S_{11}(1650)$</td>
<td>1638</td>
<td>114</td>
<td>8.%</td>
<td>-1</td>
<td>68</td>
<td>-</td>
<td>-56</td>
<td>-</td>
</tr>
<tr>
<td>$D_{15}(1675)$</td>
<td>1665</td>
<td>150</td>
<td>17.%</td>
<td>-1</td>
<td>18</td>
<td>24</td>
<td>-43</td>
<td>-58</td>
</tr>
<tr>
<td>$F_{15}(1680)$</td>
<td>1682</td>
<td>130</td>
<td>0.06%</td>
<td>1</td>
<td>-21</td>
<td>124</td>
<td>52</td>
<td>-41</td>
</tr>
<tr>
<td>$D_{13}(1700)$</td>
<td>1700</td>
<td>100</td>
<td>0.3%</td>
<td>-1</td>
<td>-18</td>
<td>-2</td>
<td>0</td>
<td>-3</td>
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<tr>
<td>$P_{11}(1710)$</td>
<td>1720</td>
<td>100</td>
<td>26.%</td>
<td>1</td>
<td>23</td>
<td>-</td>
<td>-2</td>
<td>-</td>
</tr>
<tr>
<td>$P_{13}(1720)$</td>
<td>1720</td>
<td>150</td>
<td>3.%</td>
<td>-1</td>
<td>18</td>
<td>-19</td>
<td>1</td>
<td>-29</td>
</tr>
</tbody>
</table>

Numbers in red are fitted parameters:
photo couplings are fitted in reasonable ranges
strong $\eta N$ coupling is more freely varied
Eta-Maid 2001 compared to data from TAPS@Mainz and GRAAL
The role of the $D_{15}(1675)$ resonance
isobar model Eta-Maid2001

(preliminary data from CB-ELSA, I. Jaegle, priv. comm. 2006)
problems with the D\textsubscript{15}(1675) resonance:

1) in the std EtaMaid model it fits the neutron data very well but needs a large branching ratio of $\beta_{\eta N} = 17\%$
fits with $SU(3)_{fl}$ for baryon octett
gives a prediction of $\beta_{\eta N} = 2.5\%$.
(Guzey and Polyakov, hep-ph/0512355)

2) in the Regge model the $D_{15}(1675)$ would not play any important role.
comparison of our models:

<table>
<thead>
<tr>
<th>$N^*$</th>
<th>mass</th>
<th>width</th>
<th>$\beta_{\pi N}$</th>
<th>$\zeta_{\pi N}$</th>
<th>$A_{1/2}^p$</th>
<th>$A_{3/2}^p$</th>
<th>$A_{1/2}^n$</th>
<th>$A_{3/2}^n$</th>
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<tr>
<td>$D_{13}(1520)$ 1520</td>
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<td>0.06%</td>
<td>1</td>
<td>-52</td>
<td>166</td>
<td>-41</td>
<td>-135</td>
<td></td>
</tr>
<tr>
<td>$S_{11}(1535)$ 1541</td>
<td>191</td>
<td>50.0%</td>
<td>1</td>
<td>118</td>
<td>-</td>
<td>-97</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>$S_{11}(1650)$ 1638</td>
<td>114</td>
<td>8.0%</td>
<td>-1</td>
<td>68</td>
<td>-</td>
<td>-56</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>$D_{15}(1675)$ 1665</td>
<td>150</td>
<td>17.0%</td>
<td>-1</td>
<td>18</td>
<td>24</td>
<td>-43</td>
<td>-58</td>
<td></td>
</tr>
<tr>
<td>$F_{15}(1680)$ 1682</td>
<td>130</td>
<td>0.06%</td>
<td>1</td>
<td>-21</td>
<td>124</td>
<td>52</td>
<td>-41</td>
<td></td>
</tr>
<tr>
<td>$D_{13}(1700)$ 1700</td>
<td>100</td>
<td>0.3%</td>
<td>-1</td>
<td>-18</td>
<td>-2</td>
<td>0</td>
<td>-3</td>
<td></td>
</tr>
<tr>
<td>$P_{11}(1710)$ 1720</td>
<td>100</td>
<td>26.0%</td>
<td>1</td>
<td>23</td>
<td>-</td>
<td>-2</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>$P_{13}(1720)$ 1720</td>
<td>150</td>
<td>3.0%</td>
<td>-1</td>
<td>18</td>
<td>-19</td>
<td>1</td>
<td>-29</td>
<td></td>
</tr>
</tbody>
</table>

EtaMaid 2001

<table>
<thead>
<tr>
<th>$N^*$</th>
<th>mass</th>
<th>width</th>
<th>$\beta_{\pi N}$</th>
<th>$\zeta_{\pi N}$</th>
<th>$A_{1/2}^p$</th>
<th>$A_{3/2}^p$</th>
<th>$A_{1/2}^n$</th>
<th>$A_{3/2}^n$</th>
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<tbody>
<tr>
<td>$D_{13}(1520)$ 1520</td>
<td>120</td>
<td>0.04%</td>
<td>1</td>
<td>-24</td>
<td>166</td>
<td>-59</td>
<td>-139</td>
<td></td>
</tr>
<tr>
<td>$S_{11}(1535)$ 1545</td>
<td>118</td>
<td>50.0%</td>
<td>1</td>
<td>80</td>
<td>-</td>
<td>-65</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>$S_{11}(1650)$ 1635</td>
<td>120</td>
<td>16.3%</td>
<td>-1</td>
<td>46</td>
<td>-</td>
<td>-38</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>$D_{15}(1675)$ 1665</td>
<td>150</td>
<td>0.69%</td>
<td>1</td>
<td>19</td>
<td>15</td>
<td>-43</td>
<td>-58</td>
<td></td>
</tr>
<tr>
<td>$F_{15}(1680)$ 1670</td>
<td>130</td>
<td>0.003%</td>
<td>1</td>
<td>-15</td>
<td>133</td>
<td>29</td>
<td>-33</td>
<td></td>
</tr>
<tr>
<td>$D_{13}(1700)$ 1700</td>
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<td>0.025%</td>
<td>-1</td>
<td>-18</td>
<td>-2</td>
<td>0</td>
<td>-3</td>
<td></td>
</tr>
<tr>
<td>$P_{11}(1710)$ 1700</td>
<td>100</td>
<td>26.0%</td>
<td>-1</td>
<td>9</td>
<td>-</td>
<td>-2</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>$P_{13}(1720)$ 1720</td>
<td>150</td>
<td>4.1%</td>
<td>1</td>
<td>18</td>
<td>-19</td>
<td>1</td>
<td>-29</td>
<td></td>
</tr>
</tbody>
</table>

ReggeMaid 2003
Pentaquark States

anti-decuplet in the chiral soliton model by Diakonov, Petrov and Polyakov (1997)

\[ \begin{align*}
I=0, \ S=+1 & \quad (nK^+ \text{ or } pK^0) \\
I=1/2, \ S=0 & \quad \Theta^+(1540) \\
I=1, \ S=-1 & \quad N(1710) \\
I=3/2, \ S=-2 & \quad \Sigma(1890) \\
\text{ddss\tilde{u}} & \quad \Xi_{3/2}(2070) \\
(\Xi^-\pi^- \text{ or } \Sigma^-K^-) & \\
\text{uuss\tilde{d}} & \quad (\Xi^0\pi^+ \text{ or } \Sigma^+\bar{K}^0) \\
\end{align*} \]
Estimate of Resonance Parameters for Non-Strange Partner of $\Theta^+$

Ya. Azimov, V. Kuznetsov, M.V. Polyakov and I. Strakovsky


triggered by the observation of an irregular behaviour of the cross section for $\gamma n \rightarrow \eta n$ near $W_{c.m.} = 1675$ MeV

Quantum numbers

$J^\pi : 1/2^+ \Rightarrow P_{11}$

Mass

$M^* = 1675$ MeV

total width

$\Gamma_{tot} = 10$ MeV

Branching into $\eta N$ channel

$\Gamma_{\eta N}/\Gamma_{tot} = 40\%$

Neutron magnetic transition moment

$|\mu(n^* \rightarrow n)| = (0.13 - 0.37)\mu_N$

Neutron photon coupling

$A_{1/2}(n) = (20 - 60)10^{-3}/\sqrt{GeV}$

Proton photon coupling

$A_{1/2}(p)/A_{1/2}(n) < 1/3$

In the following we use $A_{1/2}(p)=8$ and $A_{1/2}(n)=25$
$\eta$ photoproduction on the neutron

\[ \sigma_{\text{total}} \ (\mu b) \]

W (MeV)

$P_{11}(1675)$ pentaquark ($A_{1/2} = 30$)

$S_{11}(1535)$

$D_{15}(1675)$
quasifree eta photoproduction on the deuteron
in collaboration with Alexander Fix

( e.g. A. Fix and H. Arenhövel, Z. Phys. A 359 (1997) 427 )

in impulse approximation:
\eta_{NN} fsi is negligible
\NN fsi is larger but only important near threshold

input: EtaMaid with additional pentaquark state P_{11}(1675)
Photoproduction of $\eta$ mesons on the deuteron in the presence of a narrow $P_{11}(1670)$ resonance


resonance parameters for the pentaquark in our calculations:

<table>
<thead>
<tr>
<th>Mass $[MeV]$</th>
<th>Width $[MeV]$</th>
<th>$\beta_{\eta N}$ [%]</th>
<th>$\beta_{\pi\Delta}$ [%]</th>
<th>$\beta_{K\Lambda}$ [%]</th>
<th>$pA_{1/2}$ $[10^{-3}/\sqrt{GeV}]$</th>
<th>$nA_{1/2}$ $[10^{-3}/\sqrt{GeV}]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1670</td>
<td>10</td>
<td>40</td>
<td>30</td>
<td>30</td>
<td>8</td>
<td>30</td>
</tr>
</tbody>
</table>
comparison of GRAAL proton data with narrow resonance solutions

data: Bartalini et al. (GRAAL), EPJ A33 (2007) 169

$\frac{d\sigma}{d\Omega}$ ($\mu$b/sr)

the proton data of Bartalini et al. does not show any pentaquark arrow structure!!
Beam Asymmetry $\Sigma$ in $\eta$ photoproduction on quasi-free neutrons

A. Fantini et al. (GRAAL), Phys. Rev. C78, 015203, 2008

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ReggeMaid

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EtaMaid with strong $D_{15}$

The strong $D_{15}$ model cannot describe the shape of the beam asymmetry!
The effect of a narrow P11(1670) in the $2\pi$ and $K\Lambda$ channels

Evidence of the $\Theta^+$ in the $\gamma d \rightarrow K^+ K^- pn$ reaction

T. Nakano et al., arXiv:0812.1035

$M(pK^-)$ distribution with a fit to the RMM background spectrum

Narrow Nucleon $N^*(1685)$ in the $\gamma p \rightarrow \eta p$

V. Kuznetsov and M.V. Polyakov,

$\Sigma(\eta p)$ with narrow $P_{11}$ or $P_{13}$
Narrow Nucleon N*(1685)
in the γp → ηp

V. Kuznetsov and M.V. Polyakov,

our calculations

γ + p → η + p

Σ(ηp) with narrow P_{11} or P_{13}
narrow resonance signals in recoil polarization
$p(\gamma,\eta)p \ C_{x'}$

Next steps: $O_x, T, P$ also $p(\gamma,2\pi)$ and $p(\gamma,\pi\eta)$ channels

D. Watts, CB@MAMI
Summary on $\eta$ production

- The old EtaMaid 2001 describes new data > 2002 very well.

- $D_{15}$ resonance needs a very large $\eta N$ branching ratio, to describe the photon asymmetry on the proton. This leads to the peak in $\sigma(n)/\sigma(p)$. $ds/dW$ is described very well, but it fails for $S$.

- A non-strange narrow pentaquark state $P_{11}(1675)$: Fermi averaged in the deuteron would also produce such a peak with $1670 \text{ MeV} < M^* < 1685 \text{ MeV}$.

- Other observables which could show strong signals from narrow $P_{11}$ resonances are: $T, P, F, H, Cz$. 