$\eta'$ photo-production off nucleons

---Some evidence of $D_{15}(2080)$ in the reaction

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In collaboration with Qiang Zhao
Why we study $\eta'$ photo-production?

- The threshold energy of the $\eta'$ photo-production is above the second resonance region, which might be a good place to extract information of the less explored higher nucleon resonances around 2.0 GeV. Thus, the study of $\eta'$ photo-production becomes an interest topic in both experiment and theory.
I. Recent progress in \( \eta' \) photo-production: Experiments
CLAS Results

PRL 96, 062001 (2006)

K. Nakayama et al, PR C 73, 045211 (2006)

$\gamma p \rightarrow \eta' p$
K. Nakayama et al analyzed the data, they predicted a bump structure in the total cross section at 2.09 GeV. If this is confirmed, the $D_{13}(2080)$ and/or $P_{11}(2100)$ resonance may be responsible for this bump.

PR C 73, 045211 (2006)
A bump around 2.1 GeV in the forward angle of the exciting function.
CLAS Results

A bump around 2.1 GeV in the cross section.

\[ \gamma p \rightarrow \eta' p \]

Total cross section

\[ \sigma (\mu b/sr) \]

\[ W (GeV) \]

PR C 80, 045213 (2009)
FIG. 7. (Color online) $\frac{d\sigma}{d\Omega}\ (\mu b/sr)$ versus $\cos(\theta^{n'\gamma}_{c.m.})$ for the $\gamma p \rightarrow p\eta'$ reaction. Note that the vertical axis is linear. The (red) dashed line and (blue) dotted line are the results from Tables II and IV of Ref. [16], respectively.
No obvious structure around 2.1 GeV in the cross section.
CBELSA/TAPS Results

Differential cross sections

PR C 80, 055202 (2009)
CBELSA/TAPS Results

Photoproduction of eta’ meson off the deuteron

A bump-like structure appears around 2.1 GeV in the cross section.

CBELSA/TAPS Results

Fig. 9. Comparison of quasi-free \( \eta' \) production off the bound proton ((blue) squares) to the free proton data: (black) open circles [18], (black) open crosses [31], (magenta) stars [19]. The numbers given in the figure indicate the bin centers in incident photon energy (note: first two bins below free nucleon production threshold). Note: results from [31,19] partly not exactly for the same energy bins as present results. Closest bins or average of overlapping bins chosen. All uncertainties only statistical.

Lines: Solid (black): Legendre fits to data present data, dashed (red): solution 1 NH model, dotted (blue): \( \eta' \)-MAID.
CBELSA/TAPS Results

\( \gamma n \to \eta' n \)

Fig. 12. Angular distributions for the quasi-free \( \gamma n \to \eta \eta' \) reaction. Only statistical uncertainties. Solid (black) lines: Legendre fit to data. Dashed (red) lines: solution (I) of NH model, dotted (blue) lines: \( \eta' \)-MAID model.
II. Our analysis of the $\gamma p \rightarrow \eta'p$ and $\gamma n \rightarrow \eta'n$ in the chiral quark model

Based on our previous work:
Xian-Hui Zhong, Qiang Zhao,
Chiral quark model

Reggeized model

meson exchange model
A. Sibirtsev et al, arXiv:nucl-th/0303044

Some other models ...
The exp. data can be described within the framework of chiral quark model.

Differential cross sections of $\gamma p \to \eta' p$
Total cross sections of $\gamma p \rightarrow \eta' p$

The contributions of $D_{15}(2080)$ (n=3) can explain the bump structure around 2.1 GeV.
The role of $D_{15}(2080)$ in the differential cross sections

Switching off $D_{15}(2080)$, the bowl shape of the differential cross sections are less obvious. The sudden change of the shape around 1.9 GeV is due to the contributions of $D_{15}(2080)$. 
Further evidence of $D_{15}(2080)$ in the exciting function

In the forward angle region, there is an obvious peak in the cross sections. This peak is due to the contributions of $D_{15}(2080)$. 
The predicted beam asymmetry
Differential cross sections of $\gamma n \rightarrow \eta' n$
Total cross section for $\gamma n \rightarrow \eta' n$
Total cross section for $\gamma d \rightarrow \eta' np$
The predicted exciting function $\gamma n \rightarrow \eta' n$
Why does $D_{15}$ play a dominant role in the $n=3$ shell resonances, rather than $D_{13}$?
The resonance amplitudes

\[ M^s_R = \frac{2M_R}{s - M^2_R + iM_R \Gamma_R} O_R e^{-\frac{(k^2 + q^2)}{6\alpha^2}}, \quad (1) \]

**CGLN form**

\[ O_R = i f_1^R \sigma \cdot \epsilon + f_2^R \frac{(\sigma \cdot q) \sigma \cdot (k \times \epsilon)}{|q||k|} \]
\[ + i f_3^R \frac{(\sigma \cdot k)(q \cdot \epsilon)}{|q||k|} + i f_4^R \frac{(\sigma \cdot q)(q \cdot \epsilon)}{|q|^2}, \quad (2) \]
CGLN amplitudes for n=3 shell resonances

<table>
<thead>
<tr>
<th></th>
<th>$f_1^R$</th>
<th>$f_2^R$</th>
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</thead>
<tbody>
<tr>
<td>$S_{11}$</td>
<td>$-\frac{i}{36} \frac{\omega m \omega \gamma}{\mu_q} \left( g_2 + \frac{k}{2m_q} g_1 \right) x^2$ $+$ $\frac{i}{60} \left( g_1 \frac{k}{m_q} + 2g_2 \right) A x^3$</td>
<td>$0$</td>
</tr>
<tr>
<td>$D_{13}$</td>
<td>$\frac{i}{90} \frac{\omega m \omega \gamma}{\mu_q} \left( g_2 + \frac{k}{2m_q} g_1 \right) x^2$ $-$ $\frac{i}{60} \left( g_1 \frac{k}{m_q} + 2g_2 \right) A x^3$</td>
<td>$\frac{i}{180} \frac{\omega m \omega \gamma^2}{\mu_q m_q} g_1 x^2 P_2'(z) - \frac{i}{105} \frac{k}{m_q} (g_1 + g_3/2) A x^3 P_2'(z)$</td>
</tr>
<tr>
<td>$D_{15}$</td>
<td>$\left{ -\frac{i}{90} \frac{\omega m \omega \gamma}{\mu_q} \left( g_2 + \frac{k}{2m_q} g_1 \right) x^2 + \frac{i}{105} \right}$ $[$ $(g_1 - \frac{1}{2} g_3) \frac{k}{m_q} + g_2 ] A x^3 }$ $P_3'(z)$</td>
<td>$-\frac{i}{180} \frac{\omega m \omega \gamma^2}{\mu_q m_q} g_1 x^2 P_2'(z) + \frac{i}{420} \frac{k}{m_q} (5g_1 - 3g_3) A x^3 P_2'(z)$</td>
</tr>
<tr>
<td>$G_{17}$</td>
<td>$-\frac{i}{1890} \left[ (4g_1 + 5g_3) \frac{k}{m_q} \right.$ $+$ $18g_2 ] A x$^3$ $P_3'(z)$</td>
<td>$-\frac{i}{210} \left( 8g_2 - g_1 \frac{k}{m_q} \right) A x^3 P_4'(z)$</td>
</tr>
<tr>
<td>$G_{19}$</td>
<td>$i \frac{2k}{945m_q} (g_1 - g_3) A x^3 P_5'(z)$</td>
<td>$i \frac{k}{378m_q} (g_1 - g_3) A x^3 P_4'(z)$</td>
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CGLN amplitudes for \( n=3 \) shell resonances

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<td>( S_{11} )</td>
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<td>( D_{13} )</td>
<td>(- \frac{i \omega_m \omega_y}{90 \mu_q m_q} g_2 x^2 P''_2 (z) + \frac{i}{420} A x^3 )</td>
<td>(- \frac{i \omega_m \omega_y}{90 \mu_q m_q} g_2 x^2 P''_2 (z) + \frac{i}{420} A x^3 )</td>
</tr>
<tr>
<td>( D_{15} )</td>
<td>(- \frac{i \omega_m \omega_y}{90 \mu_q m_q} g_2 x^2 P''_3 (z) + \frac{i}{420} ) ( [4 g_2 - (g_1 - g_3) \frac{k}{m_q}] A x^3 P''_3 (z) )</td>
<td>(- \frac{i \omega_m \omega_y}{90 \mu_q m_q} g_2 x^2 P''_2 (z) - \frac{i}{420} ) ( [4 g_2 - (g_1 - g_3) \frac{k}{m_q}] A x^3 P''_2 (z) )</td>
</tr>
<tr>
<td>( G_{17} )</td>
<td>( \frac{i}{1890} [(g_1 - g_3) \frac{k}{m_q} - 18 g_2] A x^3 P''_3 (z) )</td>
<td>( \frac{i}{1890} [(g_1 - g_3) \frac{k}{m_q} - 18 g_2] A x^3 P''_4 (z) )</td>
</tr>
<tr>
<td>( G_{19} )</td>
<td>(- \frac{i}{1890 m_q} (g_1 - g_3) A x^3 P''_5 (z) )</td>
<td>( \frac{i}{1890 m_q} (g_1 - g_3) A x^3 P''_4 (z) )</td>
</tr>
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At very forward and backward angles, the magnitude for $D_{15}$ is about an order larger than that of $D_{13}$! At very forward and backward angle regions, the angle distributions are sensitive to the $D_{15}$ partial wave.
Evidence of $D_{15}(2080)$ might exist in the other processes:

\[ \gamma p \rightarrow \eta p \]

\[ \gamma p \rightarrow K^+ \Lambda(1520) \]

\[ J/\Psi \rightarrow N \text{ antiN } \pi \ldots \]
E. Klempt et al fit the data, they suggested that $D_{15}(2070)$ was required in the analysis of the data of the $\gamma p \rightarrow \eta p$ differential cross sections!
Jun He et al also found some effects from a $D_{15}(2090)$ by analyzing the $\gamma p \rightarrow \eta p$ data with the chiral quark model.
BESII observed a structure around 2060 MeV in the πN invariant mass spectrum, which may be one or more of the long-sought missing N star resonance.

PRL 97, 062001 (2006)

J/ψ → N antiN π
LEPS Results

\[ \gamma p \rightarrow K^+\Lambda(1520) \]

LEPS observed a structure around 2.11 GeV in the cross sections.

The bump is not well reproduced by theoretical calculations introducing a nucleon resonance with $J^P \leq 3/2$, This result suggests that the bump might be produced by a nucleon resonance possibly with $J^P \geq 5/2$ or by a new reaction process, for example an interference effect with the photoproduction having a similar bump structure in the cross sections.


Recently, Ju-Jun Xie and J. Nieves analyzed the data, they claimed that the inclusion of the nucleon resonance $D_{13}(2080)$ leads to a fairly good description of the new LEPS differential cross section data.

III. Summary

- The exp. data for eta' photoproduction can be well described in the chiral quark model.

- There is strong evidence of $D_{15}(2080)$ in the $\gamma p \rightarrow \eta' p$. 
Thanks !