Recent results from the Crystal Barrel experiment at ELSA

U. Thoma, Bonn University

- Introduction
- \(\eta\)- photoproduction
- \(2\pi^0\)- photoproduction
- \(\pi^0\eta\)- photoproduction
- Results of the partial wave analysis
- Future
- Summary
QCD: Effects of the running coupling constant $\alpha_s$:

Better understanding of strong QCD and the structure of hadrons:

- What are the relevant degrees of freedom?
- And the effective forces?

⇒ Meson - Spectroscopy, Baryon - Spectroscopy
Good understanding of the spectrum and the properties of resonances

- **Search for new/missing baryon resonances**
  
  Investigate the photoproduction of final states different from $\pi N$
  
  (Missing states are expected to decouple from $\pi N$)

- **Do these missing states really exist?**
  
  Do diquark models describe the spectrum?
  
  $\leftrightarrow P_{11}(2100), P_{13}(1900), F_{15}(2000), F_{17}(1990)$
  
  (both oscillators need to be excited)

- **Do the neg. parity $\Delta^*$-states $\sim 1900$ MeV exist?**

- **Determination of their properties**
  
  $\rightarrow$ Comparison with models
  
  $\rightarrow$ Nature of states, e.g. $P_{11}(1440)$?

$\Leftrightarrow$ At high excitation energies multi-meson final states play a role of increasing importance
The Crystal Barrel experiment at ELSA

Tagging system
- 14 scintillation counters
- 2 wire chambers (352 energy channels)
Tagging range: 25-95 % $E_{e^-}$

Inner detector
- 3 layers of scintillating fibers
- Additional reconstruction point
- Trigger on charged particles
$\eta$ - Photoproduction

**CB-ELSA:**

- Photons are detected
- Proton direction measured

$\gamma p \rightarrow p \eta$:

- $\eta \rightarrow \gamma \gamma$
- $\eta \rightarrow 3\pi^0$

$\sim 2.6$ million $\pi^0 \rightarrow 2 \gamma$

$m_{\gamma\gamma} [\text{MeV/c}^2]$

**CLAS:**

- Proton detected
- $\eta$ from missing mass

$\eta' \rightarrow \pi^0 \pi^0 \eta$

$m_{\pi\pi} [\text{MeV/c}^2]$
Differential cross section $\gamma p \rightarrow p\eta$

V. Crede, O. Bartholomy et al., PRL 94, 012004 (2005)
Total cross section $\gamma p \rightarrow p\eta$

CB-ELSA Isobar model fit:

Data included:

- $\gamma p \rightarrow p\eta, \gamma p \rightarrow p\pi^0$ (CB-ELSA)
- $\gamma p \rightarrow p\eta$ (TAPS)
- $\Sigma(\tilde{\gamma} p \rightarrow p\eta), \Sigma(\tilde{\gamma} p \rightarrow p\pi^0)$ (GRAAL)
- $\Sigma(\tilde{\gamma} p \rightarrow p\pi^0), \sigma(\gamma p \rightarrow n\pi^+) \ (SAID)$

$\Rightarrow S_{11}(1535), D_{13}(1520), S_{11}(1650), F_{15}(1680), P_{13}(1720), D_{13}(2080)$

+ new $D_{15}$: $m = 2068 \pm 22$ MeV,
  $\Gamma = 295 \pm 40$ MeV

$\Leftrightarrow$ No need for a 3rd $S_{11}$!
New $D_{15}$ -state

$D_{15}(2060 \pm 30, 340 \pm 50)$:

- The mass is not well determined. A few early results have been omitted.

\[ I(J^P) = \frac{1}{2}(\frac{5}{2}^-) \] Status: **

Omitted from Summary Table

**RESULTS VARY STRONGLY!**
Search for \( N^*/\Delta^* \rightarrow \Delta \pi \) in \( \gamma p \rightarrow p\pi^0\pi^0 \)

Advantages:

- No diffractive \( \rho(770) \) production
- No direct \( \Delta^{++}\pi^- \) production
- Fewer Born-terms, t-channel exchanges

\[ \Rightarrow \gamma p \rightarrow p\pi^0\pi^0 \text{ very well suited to investigate } N^*/\Delta^* \rightarrow \Delta \pi \]

Bigger contribution of resonant amplitudes!

( e.g. compared to \( \gamma p \rightarrow p\pi^+\pi^- \) )

\[ \Rightarrow \text{CB-ELSA} \]
\( \gamma p \rightarrow p\pi^0\pi^0 \) from TAPS and GRAAL

\[ \begin{align*}
\sigma (\mu b) & \quad \text{Total cross section} \\
E_\gamma \ (MeV) & \quad \text{Data analysed by:} \\
W (MeV) & \quad \begin{cases}
\text{- Oset et al.:} \\
\Rightarrow P_{11}(1440), D_{13}(1520), \\
D_{33}(1700) \\
\text{(limited to low energy)}
\end{cases} \\
\text{- Laget et al.:} \\
\Rightarrow P_{11}(1440), D_{13}(1520), \\
D_{13}(1700), D_{33}(1700), \\
P_{11}(1710)
\end{align*} \]

\[ \iff \text{Big discrepancy:} \]

Oset: \( D_{13}(1520) \) \( \rightarrow \Delta\pi \) dominant, Laget: \( P_{11}(1440) \) \( \rightarrow p\sigma \) dominant
\[ \gamma p \rightarrow p\pi^0\pi^0 \] – CB-ELSA –

Search for \( N^*/\Delta^* \rightarrow \Delta\pi \):

\[ \gamma p \rightarrow p4\gamma: \]

\[ \Rightarrow \gamma p \rightarrow p\pi^0\pi^0 \]

and \( \gamma p \rightarrow p\pi^0\eta \)

clearly observed

• \( \gamma p \rightarrow N^*/\Delta^* \rightarrow \Delta\pi^0 \rightarrow p\pi^0\pi^0 \)

\[ \leq m(p\pi^0) \]

for \( \sqrt{s} = 2000-2200 \text{ MeV} \)

for more details on the data

→ see talk by M.Fuchs
Total cross section $\gamma p \rightarrow p\pi^0\pi^0$ CB-ELSA

Event based maximum likelihood fit
$P_{11}(1440), D_{13}(1520), F_{15}(1680), D_{33}(1700), P_{33}(1920), D_{33}(1940), \ldots$ + background amplitudes
combined fit with single meson photoproduction and $\pi^- p \rightarrow n\pi^0\pi^0$ (CBall) in progress

Angular distributions:

$\Rightarrow D_{13}(1520) \rightarrow \Delta\pi$ clearly dominates

$\Rightarrow$ Our result: incompatible with Laget
Results for our PWA in comparison to $\sigma_{3/2}$, $\sigma_{1/2}$

$\gamma p \rightarrow p \pi^0 \pi^0$ from Daphne at MAMI

Amplitudes adjusted to our unpolarised data only:

Oset et al.:
Total cross section $\gamma p \rightarrow p\pi^0\pi^0$

$\rightarrow$ Extension of the energy range up to 3 GeV

$\rightarrow$ PWA $\Rightarrow$ Determination of resonance properties: $m$, $\Gamma$, couplings ($\leftrightarrow$ combined fit)

$\rightarrow$ Comparison with models

Clear observation of baryon cascades:

$\gamma p \rightarrow N^*/\Delta^* \rightarrow \Delta\pi$

$\gamma p \rightarrow N^*/\Delta^* \rightarrow D_{13}(1520)\pi$

$\gamma p \rightarrow N^*/\Delta^* \rightarrow N^*/\Delta^* (\sim 1660)\pi$

$\Rightarrow$ Observed for the first time in this data

$\Rightarrow \gamma p \rightarrow N^*/\Delta^*$ which do not couple to $\pi N$ or $\gamma N$ could be produced in such cascade decays
\[ \gamma p \rightarrow p \pi^0 \eta \]

- \( \gamma p \rightarrow \Delta^* \rightarrow \Delta(1232) \eta \rightarrow p \pi^0 \eta \)

\[ \Rightarrow \Delta(1232) \] clearly observed!

but there are also additional interesting structures:

\[ \Delta^* \text{ resonances} \]

1/2- \( S_{31} \) 3/2- \( D_{33} \) 5/2- \( D_{35} \) 7/2- \( G_{37} \)

U. Loering et al.
$\gamma p \rightarrow p\pi^0\eta$

Partial wave analysis:

$\Delta^* (\sim 1900)$ $J^P = \frac{3}{2}^-$ needed

+ hints for a possible new resonance
+ observation of baryon cascades
but: 3 ambiguous solutions found ....

Problem of the partial wave analysis

– Especially at higher energies –

$\leftrightarrow$ Ambiguous solutions

( similar quality of data description reached with different sets of contributing amplitudes )

$\Rightarrow$ Need for polarisation experiments !

$\leftrightarrow$ Additional constraints for PWA

- Distinguish between ambiguous solutions
- Higher sensitivity on smaller contributions
- Further confidence in results

$\Rightarrow$ Single and double polarisation experiments necessary
CB-TAPS and linear polarisation

Data taking Sep’2002 - Dec’2003

Crystal Barrel
→ 90 CsI(Tl)-crystals removed

+ linearly polarised photons:

$\Phi$ - asymmetry expected:

$N(\Phi) = N_0 (1 - P_T \cdot \Sigma \cdot \cos 2\Phi)$

$\gamma p \rightarrow p\pi^0\pi^0$

⇒ Data analysis in progress ...

TAPS:
- 528 BaF$_2$- crystals
- High granularity
- Fast trigger

future double polarisation experiments
⇒ see talk by H. Schmieden
Double polarisation experiments \( \gamma p \rightarrow p \eta \) SFB/TR16

Sensitivity on the quantum numbers of the new \( D_{15}(2070) \)

\( -: \) best solution: \( D_{15}(2070) \)

\( -: 1/2^- \) state substitutes \( D_{15}(2070) \)

\( :-: 1/2^+ \) state substitutes \( D_{15}(2070) \)

\( \Rightarrow \) High sensitivity of polarisation variables !!
Summary

- High quality data has been taken
  - Extends the covered angular and energy range

→ First evidence for new resonances: $D_{15}(2070) \rightarrow p\eta$
  (Combined PWA of data on $\gamma p \rightarrow p\pi^0, p\eta, K\Lambda, K\Sigma$ : hints for additonal new states)

→ Determination of resonance properties (combined PWA)

→ Clear observation of baryon cascades in $\gamma p \rightarrow p\pi^0\pi^0, \gamma p \rightarrow p\pi^0\eta$
  - decays via $D_{13}(1520)\pi^0$ and $S_{11}(1520)\pi^0$

$\Leftrightarrow$ Already very interesting!

But there is a lot more to be discovered $\Rightarrow$

$\Leftrightarrow$ Polarisation experiments

$\Rightarrow$ Detailed testing ground for quark models, lattice QCD calculations...
Thank you!
N^*-Resonances with instanton induced forces

U. Loering, B. Metsch, H. Petry et al.
Search for missing resonances

Quark model: More Baryons predicted than observed

Possible explanations:

⇔ Baryons have a quark-diquark structure:

One of the internal degrees of freedom is frozen
Search for missing resonances

⇔ They have not been observed up to now

Nearly all existing data from $\pi N$-scattering experiments
⇔ Missing states decouple from $\pi N$ (supported by theory)

Missing resonances:

→ Many states are predicted to couple significantly to e.g.:
  $N\eta, N\eta', N\omega, \Delta\pi, N\rho, \Delta\eta, \Delta\omega,$ and $\gamma p$

⇒ Big discovery potential of photoproduction experiments

In addition:

Measurement of resonance properties

- Photocouplings, partial widths ....

⇒ Additional information ⇔ Discrimination between different models
Future: Double polarisation experiments

→ Discrimination between ambiguous solutions in the PWA
→ Higher sensitivity to small contributions

Simulations:

- $\gamma p \rightarrow p\pi^0\pi^0$ - circular polarised beam on longitudinal polarised target:

![Graphs showing D_{13} and P_{11} with m(p\pi^0\pi^0) as the x-axis.

Assumes:
- 50% circular polarisation (beam)
- 50% longitudinal polarisation (target)

.... starting 2006 ......
\[ \gamma p \rightarrow N^*/\Delta^* \rightarrow X\pi^0 \rightarrow p\pi^0\pi^0 \]

\[ m^2(p\pi^0) \text{ vs. } m(p\pi^0\pi^0) \]

- For the mass range 1800–2000 MeV:
  - \[ X = \Delta(1232) \]
  - \[ X = D_{13}(1520) \]

- For the mass range 2000–2200 MeV:
  - \[ X = \Delta(1232) \]
  - \[ X = D_{13}(1520) \]
  - \[ X = X(1660) \]
The new states - a comparison with the quark model -

Quark model calculations by:
U. Löring, B. Metsch, H. Petry et al.

$\pi \frac{1}{2}+3/2+5/2+$

Mass [MeV]

$1000$ $1500$ $2000$ $2500$ $3000$

$D_{13}(2170)$

$D_{15}(2070)$

$D_{13}(1875)$

$P_{11}(1840)$
New $P_{11}$

- $P_{11}(1840^{+15}_{-40}, 140^{+30}_{-50})$:

![Graph A](image1.png)

$\chi^2_{\text{total}}$ vs. $M$ (MeV)

$P_{11}$ Breit-Wigner Mass

<table>
<thead>
<tr>
<th>$N(2100)$</th>
<th>$P_{11}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$l(J^P) = \frac{1}{2}(\frac{1}{2}^+)$</td>
<td>Status: *</td>
</tr>
</tbody>
</table>

**OMITTED FROM SUMMARY TABLE**

![Graph B](image2.png)

$\pi\pi^0$, $\eta\eta$ - data

![Graph C](image3.png)

$K\Lambda$, $K\Sigma$ - data

**$N(2100)$ BREIT-WIGNER MASS**

<table>
<thead>
<tr>
<th>VALUE (MeV)</th>
<th>DOCUMENT ID</th>
<th>TECH</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1885 \pm 30$</td>
<td>MANLEY 92</td>
<td>IPWA</td>
<td>$\pi N \rightarrow \pi N &amp; N\pi$</td>
</tr>
<tr>
<td>$2125 \pm 75$</td>
<td>CU TROSKY 86</td>
<td>IPWA</td>
<td>$\pi N \rightarrow \pi N$</td>
</tr>
<tr>
<td>$2050 \pm 20$</td>
<td>HOEHLER 79</td>
<td>IPWA</td>
<td>$\pi N \rightarrow \pi N$</td>
</tr>
<tr>
<td>$2084 \pm 93$</td>
<td>VRANA 00</td>
<td>DPWA Multichannel</td>
<td></td>
</tr>
<tr>
<td>$1986 \pm 26^{+10}_{-30}$</td>
<td>PLOETZKE 98</td>
<td>SPEC</td>
<td>$\gamma p \rightarrow p\eta(958)$</td>
</tr>
<tr>
<td>$2203 \pm 70$</td>
<td>BATIC 95</td>
<td>DPWA</td>
<td>$\pi N \rightarrow N\pi, N\eta$</td>
</tr>
</tbody>
</table>

**$N(2100)$ BREIT-WIGNER WIDTH**

<table>
<thead>
<tr>
<th>VALUE (MeV)</th>
<th>DOCUMENT ID</th>
<th>TECH</th>
<th>COMMENT</th>
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</thead>
<tbody>
<tr>
<td>$113 \pm 44$</td>
<td>MANLEY 92</td>
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<td>$\pi N \rightarrow \pi N &amp; N\pi$</td>
</tr>
<tr>
<td>$260 \pm 100$</td>
<td>CU TROSKY 86</td>
<td>IPWA</td>
<td>$\pi N \rightarrow \pi N$</td>
</tr>
<tr>
<td>$200 \pm 30$</td>
<td>HOEHLER 79</td>
<td>IPWA</td>
<td>$\pi N \rightarrow \pi N$</td>
</tr>
<tr>
<td>$1077 \pm 643$</td>
<td>VRANA 00</td>
<td>DPWA Multichannel</td>
<td></td>
</tr>
<tr>
<td>$296 \pm 100^{+60}_{-10}$</td>
<td>PLOETZKE 98</td>
<td>SPEC</td>
<td>$\gamma p \rightarrow p\eta(958)$</td>
</tr>
<tr>
<td>$418 \pm 171$</td>
<td>BATIC 95</td>
<td>DPWA</td>
<td>$\pi N \rightarrow N\pi, N\eta$</td>
</tr>
</tbody>
</table>
New $D_{13}$ -states

- $D_{13}(1875 \pm 25, 80 \pm 20)$:

- $D_{13}(2166^{+50}_{-80}, 300 \pm 65)$:
New $D_{15}$ -state

- $D_{15}(2060 \pm 30, 340 \pm 50)$:

**$N(2200)$ $D_{15}$**

$l(J^P) = \frac{1}{2}^{(5-)}$ Status: ****

OMITTED FROM SUMMARY TABLE

The mass is not well determined. A few early results have been omitted.

### $N(2200)$ BREIT-WIGNER MASS

<table>
<thead>
<tr>
<th>VALUE (MeV)</th>
<th>DOCUMENT ID</th>
<th>TECN</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1900</td>
<td>BELL</td>
<td>83</td>
<td>DPWA $\pi^- p \to \Lambda K^0$</td>
</tr>
<tr>
<td>2180 ± 80</td>
<td>CUTKOSKY</td>
<td>80</td>
<td>IPWA $\pi N \to \pi N$</td>
</tr>
<tr>
<td>1920</td>
<td>SAXON</td>
<td>80</td>
<td>DPWA $\pi^- p \to \Lambda K^0$</td>
</tr>
<tr>
<td>2228 ± 30</td>
<td>HOEHLER</td>
<td>79</td>
<td>IPWA $\pi N \to \pi N$</td>
</tr>
</tbody>
</table>

• • • We do not use the following data for averages, fits, limits, etc. • • •

2240 ± 65

BATICNIC 95 DPWA $\pi N \to N\pi, N\eta$

varies strongly!

### $N(2200)$ BREIT-WIGNER WIDTH

<table>
<thead>
<tr>
<th>VALUE (MeV)</th>
<th>DOCUMENT ID</th>
<th>TECN</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>130</td>
<td>BELL</td>
<td>83</td>
<td>DPWA $\pi^- p \to \Lambda K^0$</td>
</tr>
<tr>
<td>400 ± 100</td>
<td>CUTKOSKY</td>
<td>80</td>
<td>IPWA $\pi N \to \pi N$</td>
</tr>
<tr>
<td>220</td>
<td>SAXON</td>
<td>80</td>
<td>DPWA $\pi^- p \to \Lambda K^0$</td>
</tr>
<tr>
<td>310 ± 50</td>
<td>HOEHLER</td>
<td>79</td>
<td>IPWA $\pi N \to \pi N$</td>
</tr>
</tbody>
</table>

• • • We do not use the following data for averages, fits, limits, etc. • • •

761 ± 139

BATICNIC 95 DPWA $\pi N \to N\pi, N\eta$

⇔ Results vary strongly!
\[ \gamma p \rightarrow p \pi^0 \pi^0 \]

**Invariant masses:**

\[
\begin{array}{ll}
\gamma p & p(\pi^0 \pi^0) \\
\gamma p & (p\pi^0)\pi^0
\end{array}
\]

- 720 MeV
- 850 MeV
- 1100 MeV
- 1300 MeV

**Beam asymmetry:**

(Compton back-scattered \( \gamma \)-beam ↔ linear polarisation)

\[
\begin{array}{l}
\frac{d\sigma}{d(IM)} \quad \mu b/MeV \\
\end{array}
\]

- Laget

\[
\begin{array}{ll}
\gamma p \rightarrow p(\pi^0 \pi^0) \\
\gamma p \rightarrow (p\pi^0)\pi^0
\end{array}
\]

**Beam Asymmetry:**

\[
\Sigma
\]

\[
\begin{array}{l}
\gamma p \rightarrow p(\pi^0 \pi^0) \\
\gamma p \rightarrow (p\pi^0)\pi^0
\end{array}
\]

\[
\begin{array}{ll}
\text{Beam Asymmetry } \Sigma \\
\end{array}
\]

<table>
<thead>
<tr>
<th>IM(\pi^0 \pi^0) (MeV)</th>
<th>IM(p\pi^0) (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>600</td>
</tr>
<tr>
<td>400</td>
<td>800</td>
</tr>
<tr>
<td>600</td>
<td>1000</td>
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<tr>
<td>800</td>
<td>1200</td>
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<tr>
<td>1000</td>
<td>1400</td>
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<tr>
<td>1200</td>
<td>1600</td>
</tr>
<tr>
<td>1400</td>
<td>1800</td>
</tr>
</tbody>
</table>

**Graphs:**

- Plot of \( \frac{d\sigma}{d(IM)} \) vs. IM(\pi^0 \pi^0) (MeV)
- Plot of \( \frac{d\sigma}{d(IM)} \) vs. IM(p\pi^0) (MeV)
Quality of the data description

\[ E_{e^-} = 1.4 \text{ GeV} : \ E_\gamma = 0.37 - 1.3 \text{ GeV} : \]

\[ E_{e^-} = 3.2 \text{ GeV} : \ E_\gamma = 0.8 - 3.0 \text{ GeV} : \]
Diagrams included by Oset
\[ \gamma p \rightarrow p \pi^0 \pi^0 \text{ and } \gamma p \rightarrow p \pi^+ \pi^- \text{ from CB-ELSA and CLAS} \]

\[ \gamma p \rightarrow N^*/\Delta^* \rightarrow X \pi \]

- \[ X = \Delta(1232) \]
- \[ X = D_{13}(1520) \]
- \[ X = X(1660) \]

⇒ Similar resonance structures in both data sets!
Partial wave analysis of $\gamma p \rightarrow p\pi^0\pi^0$

- Isobar model
- Breit-Wigner (or K-matrix) parametrisation for the resonances
- $s$- and $t$-channel amplitudes included
- Unbinned maximum likelihood fit
  - Event based
  - Takes all correlations properly into account
    (5 independent variables)
  - No fitting of projections!
Total cross section $\gamma p \rightarrow p\pi^0\pi^0$
\(\gamma p \rightarrow p \eta\) - results of different analyses

\(\leftarrow\) not yet including the CB-ELSA data

- **Isobar model, ETA-MAID** (Chiang et al.)

  \[ S_{11}(1535), \quad D_{13}(1520), \quad S_{11}(1650), \quad D_{15}(1675), \quad F_{15}(1680), \quad D_{13}(1700), \quad P_{11}(1710), \quad P_{13}(1720), \quad \rho^- , \omega \ - t\)-channel exchange

- **Giessen coupled channel analysis** (Penner, Mosel)

  \[ S_{11}(1535), \quad D_{13}(1520), \quad S_{11}(1650), \quad D_{15}(1675), \quad F_{15}(1680), \quad P_{11}(1710) \text{ (small)}, \quad \rho^- , \omega \ - t\)-channel exchange

- **Chiral constituent quark model** (Saghai,Li)

  \[ \Rightarrow \text{ all known *** and **** -resonances, no } t\text{-channel exchange} \]

  \[ \Rightarrow 3rd S_{11} \text{ resonance needed } M = 1780 \text{ MeV, } \Gamma = 280 \text{ MeV} \]
## The new $D_{15}(2070)$

<table>
<thead>
<tr>
<th>Resonance</th>
<th>$N(2070)D_{15}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$J^P$</td>
<td>$\Delta \chi^2_{\text{tot}}$</td>
</tr>
<tr>
<td>omitted</td>
<td>1588</td>
</tr>
<tr>
<td>repl. by 1/2$^-$</td>
<td>1027</td>
</tr>
<tr>
<td>repl. by 3/2$^-$</td>
<td>1496</td>
</tr>
<tr>
<td>repl. by 7/2$^-$</td>
<td>1024</td>
</tr>
<tr>
<td>repl. by 9/2$^-$</td>
<td>872</td>
</tr>
<tr>
<td>repl. by 1/2$^+$</td>
<td>832</td>
</tr>
<tr>
<td>repl. by 3/2$^+$</td>
<td>1050</td>
</tr>
<tr>
<td>repl. by 5/2$^+$</td>
<td>766</td>
</tr>
<tr>
<td>repl. by 7/2$^+$</td>
<td>807</td>
</tr>
<tr>
<td>repl. by 9/2$^+$</td>
<td>1129</td>
</tr>
</tbody>
</table>
Best fit with / without the new $D_{15}(2070)$ \( \gamma p \rightarrow p \eta \)

\[
\frac{d\sigma}{d\Omega} \quad [\mu b/sr]
\]

---: best solution with new $D_{15}(2070)$

---: best fit without $D_{15}(2070)$
Best fit with / without the new $D_{15}(2070)$ 

$: best solution with new $D_{15}(2070)$

$: best fit without $D_{15}(2070)$

d$\sigma$/d$\Omega$ $\mu$b/sr

\[ \text{d$\sigma$/d$\Omega$ } \mu \text{b/sr} \]
\[
\gamma p \rightarrow p\eta
\]

\[D_{15}(2070)\]

substituted by a

\[7/2^- \text{ or } 7/2^+ \text{ state}\]

\[
\leftrightarrow \frac{d\sigma_{1/2}}{d\Omega} - \frac{d\sigma_{3/2}}{d\Omega}
\]
Differential cross section
helicity $1/2$ - helicity $3/2$

—: best solution, includes new $D_{15}(2070)$
—: $3/2 -$ state substitutes $D_{15}(2070)$
—: $3/2 +$ state substitutes $D_{15}(2070)$
Differential cross section
helicity 1/2 - helicity 3/2

—: best solution, includes new $D_{15}(2070)$
—: $5/2^+ $ state substitutes $D_{15}(2070)$
\( \gamma p \rightarrow p \pi^0 \eta \)
$\gamma p \rightarrow p\pi^0\eta$
\[ \gamma p \rightarrow p\pi^0\pi^0, \quad m(p\pi^0) \]
\[ \gamma p \rightarrow p\pi^0\pi^0, \quad m(\pi^0\pi^0) \]
\[ \gamma p \rightarrow p\pi^0\pi^0 \]