Baryon Spectroscopy: Recent Results from the Crystal Barrel/TAPS Experiment at ELSA

- Introduction
- $\eta$- photoproduction
- $2\pi^0$- photoproduction
- Double polarisation experiments at ELSA
- Summary

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U.Thoma, Bonn University
for the CBELSA/TAPS collaboration
Baryon spectroscopy

Aim: Good understanding of the spectrum and the properties of baryon resonances ↔ bound states of strong QCD

- What are the relevant degrees of freedom ?
- Effective forces between them ?

Symmetric quark models:

→ many more resonances expected than observed yet
  - certain configurations completely missing !

• Certain configurations not realised by strong QCD ? Why ?
• Experimentally not found yet (resonances might decouple from $\pi N$)

↔ Photoprod. experiments e.g. $\gamma p \rightarrow N\eta, N\eta', N\omega, \Delta\pi, N\rho, \Delta\eta, ...$

Experimentally:

Broad strongly overlapping resonances

Important:

→ Measurement of polarisation observables (unambiguous PWA)
→ Investigation of different final states
At high excitation energies:
Multi-meson final states play a role of increasing importance.
$\eta$ - Photoproduction

$\eta \rightarrow \gamma \gamma$

$\eta \rightarrow 3\pi^0$

$S_{11}(1535), D_{13}(1520), S_{11}(1650), F_{15}(1680), P_{13}(1720), D_{13}(2080) + \ldots + \rho, \omega$ - t-channel exchange

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

(needed: confirmation in polarisation exp.)

$\leftrightarrow$ No need for a 3rd $S_{11}$!
Multiparticle final states: \( \gamma p \rightarrow p\pi^0\pi^0 \)

CB-ELSA Fit including additional data from:
- single meson photoproduction,
- \( \pi^- p \rightarrow n2\pi^0 \) (CBall),
- \( P_{11}, S_{11}, P_{33}, D_{33} \) - \( \pi N \)-partial waves

\( \Rightarrow \) Event based maximum likelihood fit

\( \Rightarrow \) Determination of resonance properties:
\( m_i, \Gamma_i (\Delta\pi^0, N\sigma, P_{11}\pi, D_{13}\pi, +...) \)

Results contradicting naive expectation:
e.g.: \( D_{13}(1520) \rightarrow \Delta\pi \) decay with \( L=0 \approx L=2 \)
\( D_{13}(1700) \rightarrow \Delta\pi \) decay with \( L=0 < L=2 \)
\( D_{33}(1700) \rightarrow \Delta\pi \) decay with \( L=0 \) or \( L=2 \)

\( \rightarrow \) Measurement of double polarisation observables necessary
\[ \gamma p \rightarrow p\pi^0\pi^0 - \text{CBELSA/TAPS} \]

(V. Sokhoyan, Bonn)

Clear observation of baryon cascades!
\( \vec{\gamma} p \rightarrow p \pi^0 \pi^0 \)

V. Sokhoyan, Bonn

\[ \frac{d\sigma}{d\Omega} = \left( \frac{d\sigma}{d\Omega} \right)_0 \left( 1 - \delta_I \left( \Sigma \cos 2\phi + I^s \sin 2\phi \right) \right) \]

\[ \leftrightarrow \text{Data presently included in the PWA} \]

\((\gamma p \rightarrow p \pi^0 \eta \rightarrow \text{talk by E. Gutz})\)
Polarisation observables, $\vec{\gamma}p \rightarrow p\eta$

- CB/TAPS beam-asymmetries $\Leftrightarrow$ provide additional information for the PWA

Single pseudoscalar meson photoproduction
Complete experiment
$\rightarrow \geq 8$ observables needed

Double pseudoscalar meson photoproduction
$\rightarrow \geq 15$ observables needed
(Roberts, Oed)

$\Rightarrow$ double polarisation experiments needed!

Crystal Barrel/TAPS at ELSA:
Experiments with longitudinally polarised target and circularly/linearly polarised beam

D. Elsner et al., EPJ. A33 (2), 147 (2007)
Circularly polarized beam + longitudinally polarized target

$\eta$-photoproduction

Predictions:

$\eta$-MAID / BoGa-PWA

$$\frac{d\sigma_{(3/2-1/2)}}{d\Omega} = \frac{d\sigma_{3/2}}{d\Omega} - \frac{d\sigma_{1/2}}{d\Omega}$$

![Graph showing d\(\sigma/d\Omega\) [\(\mu b/sr\)] (helicity 1/2 - 3/2)]
Double Polarisation Experiments at ELSA

Online spectra: circularly polarised beam, longitudinally polarised target

$\gamma p \rightarrow p\eta$: $\gamma \rightarrow p\gamma\gamma$

$\gamma p \rightarrow p\eta$: $\gamma \rightarrow p\gamma\gamma$

First asymmetries observed
The new CBELSA/TAPS data $\vec{\gamma}\vec{p} \rightarrow p\eta$

Count rate differences plotted:

$N_{1/2} - N_{3/2}$

Clear asymmetries observed!

$\sim$ complete angular coverage

$\Rightarrow$ New and important information for the PWA
CBELSA/TAPS data  \( \vec{\gamma} \vec{p} \rightarrow p\pi^0 \)  (M.Gottschall,Bonn)

\[ \vec{\gamma} \vec{p} \rightarrow p\pi^0 \]

Clear asymmetries observed !
\( \sim \) complete angular coverage
\( \Rightarrow \) New and important information for the PWA

Count rate differences (prelim. acceptance correction)

\[ E_c \text{[MeV]} \]

\[ \Delta\text{Count} \]

\[ N_{1/2} - N_{3/2} \]
CBELSA/TAPS data \( \vec{\gamma} p \rightarrow p \pi^0 \pi^0 \) (D.Piontek, Bonn)

Count rate differences plotted

first look into differential distributions (very preliminary)
Double Polarisation Experiments ↔ G

First online spectra: linearly polarised beam, longitudinally polarised target

\[
\frac{d\sigma}{d\Omega} = \left( \frac{d\sigma}{d\Omega} \right)_0 \left( 1 - \delta_l (\Sigma \cos 2\phi - \Lambda_z G \sin 2\phi) \right)
\]

\[\vec{\gamma} \vec{p} \rightarrow p\pi^0\]

\((E_\gamma=750-1200\text{ MeV})\)

⇒ Clear effect from \(G\) observed
\[
\vec{\gamma} \vec{p} \rightarrow p\pi^0 \quad (A.\text{Thiel, Bonn})
\]

\[E_{\gamma} = 966 \pm 16 \text{ MeV} \quad E_{\gamma} = 1033 \pm 16 \text{ MeV} \quad E_{\gamma} = 1066 \pm 16 \text{ MeV}\]

- MAID
- BnGa
- SAID

\[\Sigma: \quad \text{preliminary dilution factor included} \quad \leftrightarrow \text{preliminary} \quad \text{(for further details} \rightarrow \text{talk by A. Thiel)} \]
$\vec{\gamma} \vec{p} \rightarrow p\eta$:

$E_\gamma = 950 \pm 50$ MeV

$E_\gamma = 1050 \pm 50$ MeV

$\Sigma$:

CBELSA/TAPS

CB/TAPS (D. Elsner et al)

$G$:

MAID

BnGa

SAID

$\leftrightarrow$ preliminary dilution factor included

(for further details $\rightarrow$ talk by A. Thiel)
Summary

• High quality data has been taken
  \((\gamma p, \gamma p \rightarrow p\pi^0, p\eta, p\pi^0\pi^0, p\pi^0\eta, \gamma p \rightarrow p\omega, \gamma p \rightarrow p\eta', p\pi^0\omega, K^0\Sigma^+, \ldots)\)
  – Extends the covered angular and energy range,
    \(\rightarrow\) determination of resonance properties
  – Decays via higher mass resonances observed,
    baryon cascades e.g. via \(\Delta(1232)\pi^0, D_{13}(1520)\pi^0, S_{11}(1535)\pi^0, X(1660)\pi^0\)

• First double polarisation data has been taken
  (longitudinally polarised target, circularly and linearly pol. beam)
  \(\Rightarrow\) A step closer towards a complete experiment
  \(\Leftarrow\) transversally polarised target in preparation

\(\Rightarrow\) Better understanding of the hadron spectrum
\(\Rightarrow\) Detailed testing ground for quark models,
  models of dynamically generated resonances, lattice QCD calculations ...
Thank you for your attention!
The $\Delta^*$ - states

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

model
$\sim 2n + \ell$
The $\Delta^*$-states

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

Additional experimental information needed!!
Thank you for your attention!
Double Polarisation Experiments at ELSA

Experiments with:
- linear or circular polarised beam
- longitudinal polarised target (frozen spin butanol)
The Crystal Barrel Experiment at ELSA

\[ \gamma p \rightarrow N^* \rightarrow p\eta \rightarrow p\gamma\gamma \]
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.

$N(2200)\ D_{15}$

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

OMITTED FROM SUMMARY TABLE

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

**Results vary strongly!**