universitätbonn

Light quark baryons from photoproduction and electroproduction experiments

U. Thoma replacing J. Hartmann, Bonn

Contents:

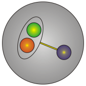
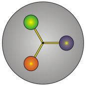
- Introduction
- Experimental Data
- Results (PWA)
- Summary

Baryon Spectroscopy

Aim: Good understanding of the spectrum and the properties of baryon resonances $\leftrightarrow$ bound states of strong QCD

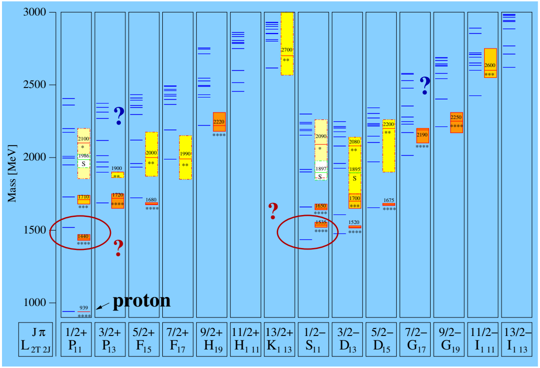
- What are the relevant degrees of freedom ?

- Effective forces between them ?

e.g.:  **or**  **?**

Symmetric quark models:

$\rightarrow$ many more resonances expected than observed yet



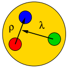
$\leftrightarrow \mathbf{J^P}$

non-strange N*-resonances

U. Loering, B. Metsch, H. Petry et al. (2001)

relativistic quark model

Constituent quarks, confinement potential
+ residual interaction

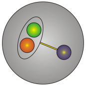
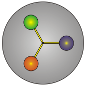


$$|\vec{J}| = |\vec{L} + \vec{S}_{qqq}|$$

Baryon Spectroscopy

Aim: Good understanding of the spectrum and the properties of baryon resonances $\leftrightarrow$ bound states of strong QCD

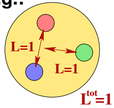
- **What are the relevant degrees of freedom ?**
- **Effective forces between them ?**

e.g.:  **or**  **?**

Symmetric quark models:
$\rightarrow$ **many more resonances expected than observed yet (certain configurations completely missing)**

- **Certain configurations not realised by QCD ? Why ?**
- **Experimentally not found yet**
  (resonances might decouple from πN)

e.g.:

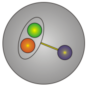
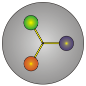


... seems to be missing

Baryon Spectroscopy

Aim: Good understanding of the spectrum and the properties of baryon resonances $\leftrightarrow$ bound states of strong QCD

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

e.g.:  **or**  **?**

Symmetric quark models:
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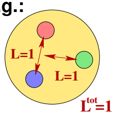


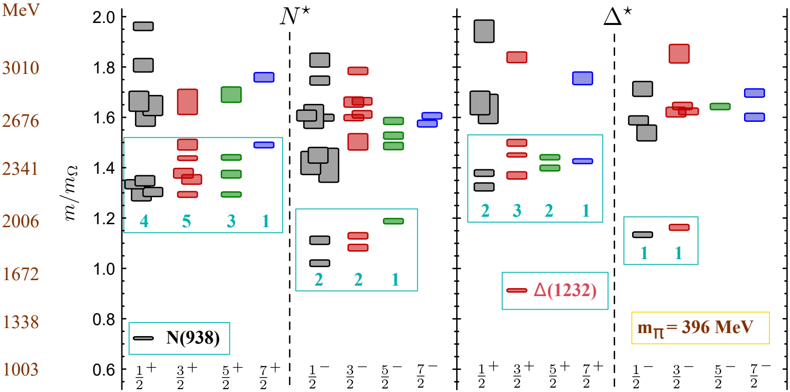
... seems to be missing

Or does the quark model just use the wrong degrees of freedom?

$\leftrightarrow$ **Mesons-Baryon degrees of freedom?**

Baryon Spectroscopy

Excited baryons from Lattice QCD:



R.Edwards et al.,
Phys. Rev. D84
(2011) 074508

Exhibits the broad features expected from SU(6)⊗O(3)-symmetry

→ **Counting of levels consistent with non-rel. quark model**

→ **no parity doubling**

Of course there are also approximations made by lattice QCD (e.g. m_π=396 MeV)

Baryon Spectroscopy

$\Rightarrow$ **Good understanding of the spectrum and properties of baryon resonances**

Experimentally:
Broad and strongly overlapping resonances

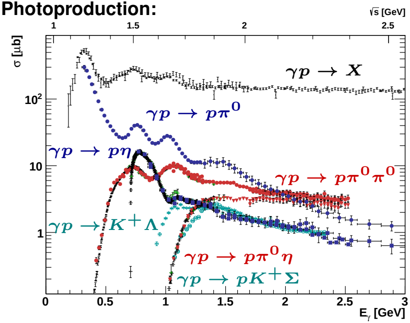
Important:

$\rightarrow$ **Investigation of different final states**

$\rightarrow$ **Investigation of different production processes: πN, γN, $\gamma^* N$, Ψ, Ψ'-decays, ...**

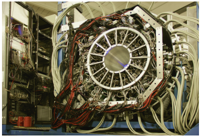
$\rightarrow$ **Measurement of polarization observables (unambiguous PWA)**

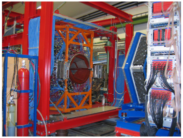
Photoproduction:



Recently: a lot of progress from photoproduction experiments:

CLAS (JLab), **CBELSA/TAPS (ELSA),** **CBALL (MAMI),** **LEPS (Spring-8), ...**





$\Leftrightarrow$ **polarized beam, polarized target**

Double Polarization Experiments - Selected Results -

Circularly polarized photons, longitudinally polarized target

CBELSA/TAPS

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

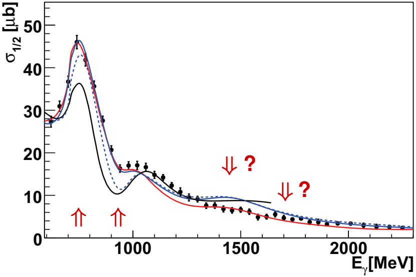
PWAs:

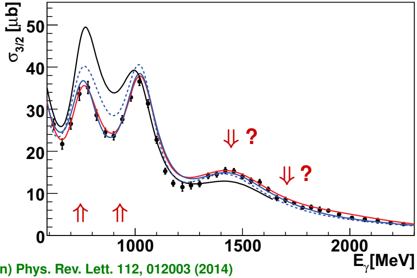
SAID (SN11, CM12), MAID
BnGa (2011_2)

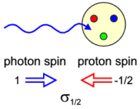
$\leftrightarrow$ **describe the so far existing photoproduction data, but ...**

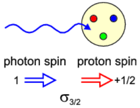
large deviations observed $\rightarrow$

Differences even at low energies where everything was thought to be well understood ... $\rightarrow$









$\Rightarrow$

Sensitivity on high mass resonances !

M. Gottschall et al. (CBELSA/TAPS-collaboration) Phys. Rev. Lett. 112, 012003 (2014)

Photoproduction: double polarization experiments

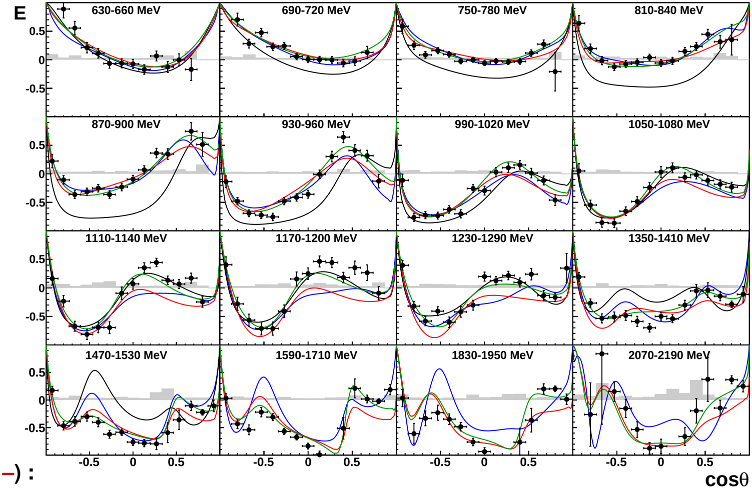
Circularly polarized photons, longitudinally polarized target:

CBELSA/TAPS

$\gamma p \to p\pi^0$:

(only every second bin shown)

$$\mathbf{E} = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$$



PWAs predictions:

- **MAID,**
- **SAID (CM12),**
- **BnGa (2011_2)**

Fit:

- **BnGa**

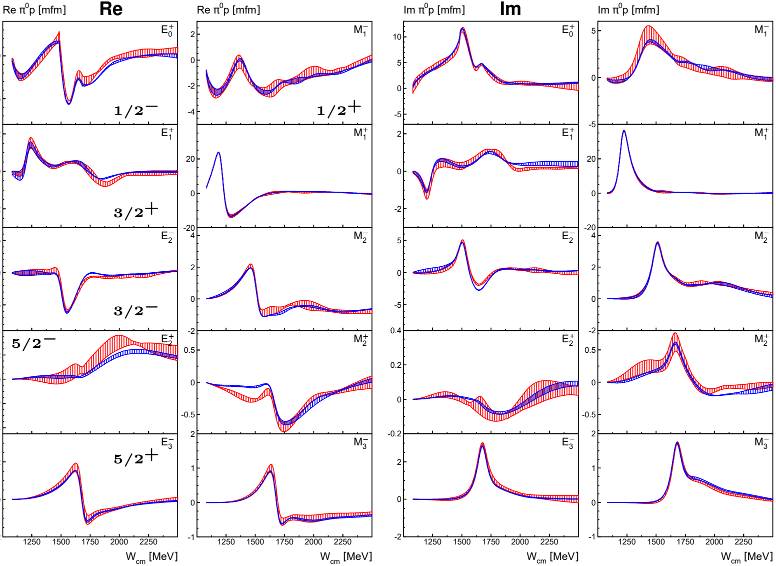
Predictions (–, – , –) :

⇒ Large deviations observed :
High sensitivity of the data on the contributing amplitudes

M. Gottschall et al. (CBELSA/TAPS-collaboration) Phys. Rev. Lett. 112, 012003 (2014)

$\gamma p \to p\pi^0$ - Impact of the new data on E, G, T, P, H

Resulting multipoles - BnGa-PWA

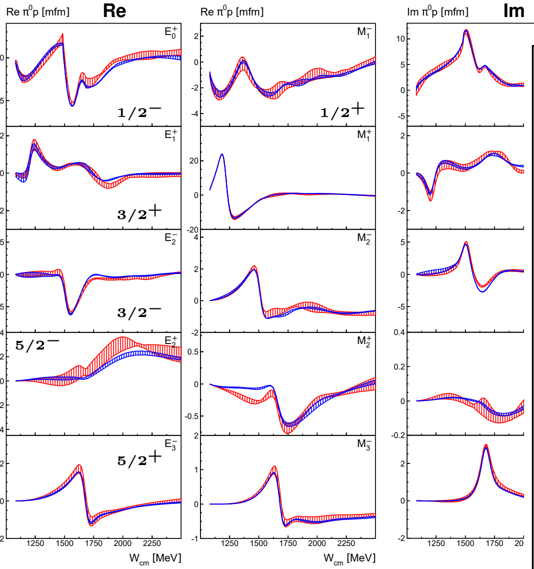


BnGa-PWA
without
→ with the
new data on:
E, G
T, P, H

J. Hartmann et al.
PLB 748 (2015) 212

$\gamma p \to p\pi^0$ - Impact of the new data on E, G, T, P, H

Resulting multipoles - BnGa-PWA

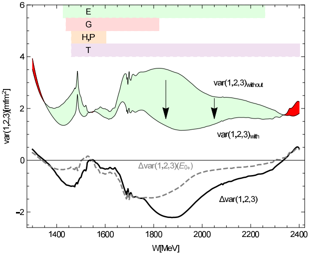


The next step:

⇔ **Inclusion of new data also in the other analyses**

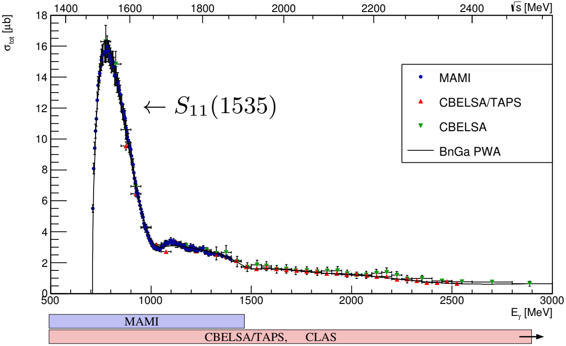
JüBo and SAID analyses
= recent work
(A.V. Anisovich et al., EPJ A52 (2016) 284)

⇒ **Different analyses converge toward similar multipoles!**

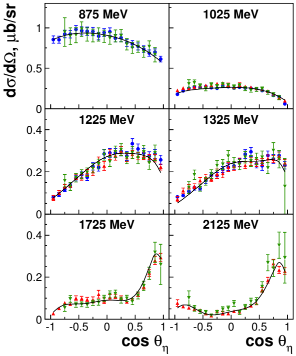


Photoproduction $\gamma p \rightarrow p\eta$

- **Isospin selective: only N* (I=1/2) contribute**
- **Investigation of resonances with small πN-coupling**



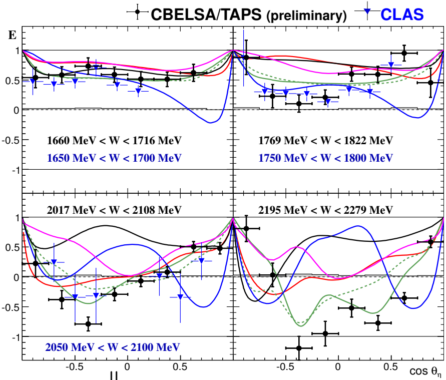
A few differential cross section bins:



Differential cross sections, beam asymmetries included in the different PWAs

$\vec{\gamma}\vec{p} \to p\eta$ – Selected polarization observables –

circ. pol. photons, long. pol. target

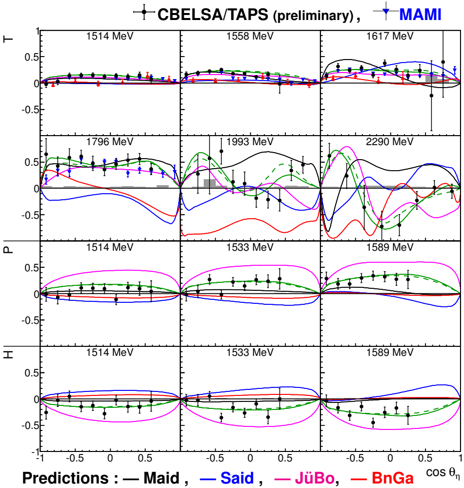


⇓

⇔ **Large sensitivity!** (also true for G (CBELSA/TAPS) and F (MAMI))

⇒ **data approaches the high mass region**

linear pol. photons, transv. pol. target



— new BnGa-fit : Determination of precise $p\eta$-branching ratios for resonances indications for a new resonance (no PDG entry) at 2200 MeV

$\vec{\gamma}\vec{p} \rightarrow p\eta$ - Results including new data on E, G, T, P, H

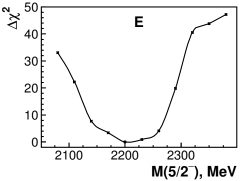
Determination of $p\eta$-branching ratios for various resonances, e.g. :

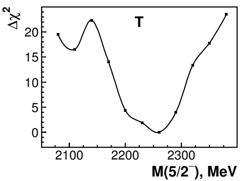
	$N(1535)1/2^-$	$N(1650)1/2^-$	$N(1710)1/2^+$	$N(1720)3/2^+$
BnGa	**0.42±0.04**	**0.32±0.04**	**0.27±0.09**	**0.03±0.02**
PDG	**0.42±0.10**	**0.05 - 0.15**	**0.10 - 0.30**	**0.021±0.014**

$\Downarrow$

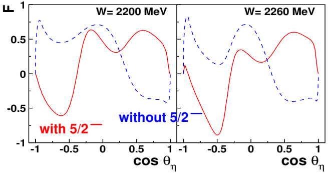
Large and heavily discussed difference in the $p\eta$-branching ratio of N(1535)1/2$^-$ and N(1650)1/2$^-$ now significantly reduced

$\Rightarrow$ Hints for a new resonance around 2200 MeV with J^P=5/2$^-$





Predictions for F:



Higher statistics data on E and T and data of F could further clarify the situation

$\Leftrightarrow$ Proof of the N(2200)5/2$^-$

The Spectrum of Baryon Resonances

Multi-channel Bonn-Gatchina PWA:

$\Rightarrow$ **Confirmation known resonances, better determination of their properties**

$\Rightarrow$ **New resonances observed**

	RPP 2010	our analyses	RPP	GWU'06 (SAID)
$N(1700)3/2^-$	***	***	***	no evidence
$N(1710)1/2^+$	***	***	***	no evidence
$N(1860)5/2^+$		*	**	
$N(1875)3/2^-$		***	***	no evidence
$N(1880)1/2^+$		**	**	no evidence
$N(1895)1/2^-$		**	**	no evidence
$N(1900)3/2^+$	**	***	***	no evidence
$N(1990)7/2^+$	**	**	**	no evidence
$N(2000)5/2^+$	**	**	**	no evidence
$N(2060)5/2^-$		***	**	no evidence
$N(2150)3/2^-$		**	**	no evidence
$\Delta(1900)1/2^-$	*	*	**	no evidence
$\Delta(1920)3/2^+$	***	***	***	no evidence
$\Delta(1940)3/2^-$	*	**	**	no evidence

A.V. Anisovich et al. (BnGa-PWA), EPJA 48 (2012) 15

from 2000-2010 not one new baryon resonance was considered by the PDG

$\leftrightarrow$ **Results from photoproduction do now enter the PDG and determine the properties of baryon resonances!**

(before: almost entirely πN-scattering and some π-photoproduction)

Photoproduction provides access to the "inelastic channels"

$\Rightarrow$ **better determination of resonance properties**

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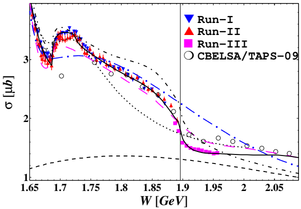
N(1860)5/2$^+$		*	**	
N(1875)3/2$^-$		***	***	no evidence
N(1880)1/2$^+$		**	**	no evidence
N(1895)1/2$^-$		**	**	no evidence
N(1900)3/2$^+$	**	***	***	no evidence
N(1990)7/2$^+$	**	**	**	no evidence
N(2000)5/2$^+$	**	**	**	no evidence
N(2060)5/2$^-$		***	**	no evidence
N(2150)3/2$^-$		**	**	no evidence
Δ(1900)1/2$^-$	*	*	**	no evidence
Δ(1920)3/2$^+$	***	***	***	no evidence
Δ(1940)3/2$^-$	*	**	**	no evidence

A.V. Anisovich et al. (BnGa-PWA), EPJA 48 (2012) 15

Interesting new MAMI-data:

$\gamma p \to \eta p$



(V.L.Kashevarov et al., PRL 118 (2017) 212001

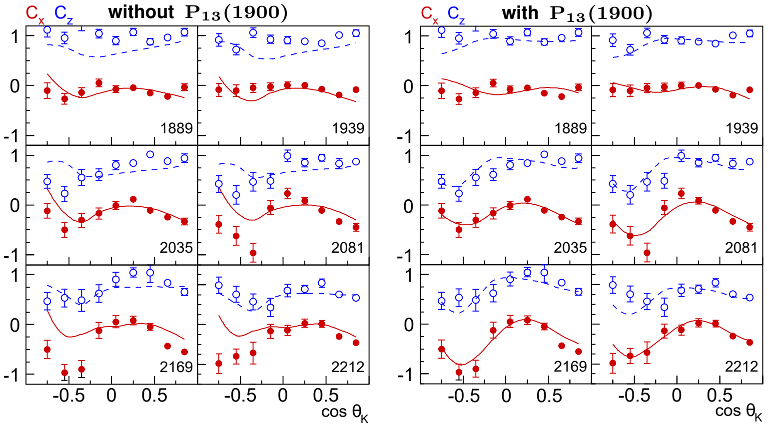
$\Rightarrow$ **cusp effect $\eta' p$-threshold observed**

MAID-analysis of $\gamma p \to \eta p$, $\gamma p \to \eta' p$ confirms N(1895)1/2$^-$ coupling to $p\eta$, $p\eta'$

Strangeness Photoproduction: $\gamma p \rightarrow K^+\Lambda \rightarrow K^+ p\pi^-$

Beam-Recoil polarization:

CLAS



R. K. Bradford et al. (CLAS), PRC75, 035205 (2007)

V. Nikonov et al. (BnGa-PWA), PLB662, 245 (2008)

data for all possible 16 observables has been taken

(only 8 needed for the complete experiment)

⇔ much more to come!

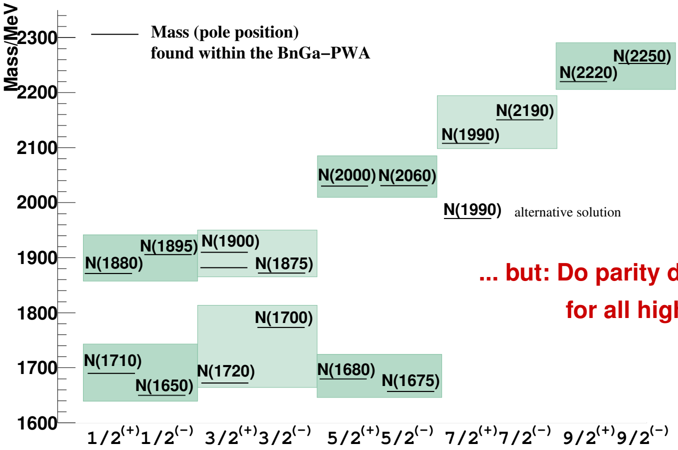
Fit within the Bonn-Gatchina multi-channel PWA: Favours the existence of the $P_{13}(1900)$

(confirmed by O. V. Maxwell, PRC85, 034611 (2012), T. Mart, M. Kholili, PRC86, 022201 (2012))

⇔ Evidence against the quark-diquark model

The Spectrum of Baryon Resonances - Parity Doublets -

Parity doublets occur:



... but: Do parity doublets exist

for all high mass states ?

Not expected by:

- present lattice QCD calculations or constituent quark-models

⇔ **QCD not yet understood !**

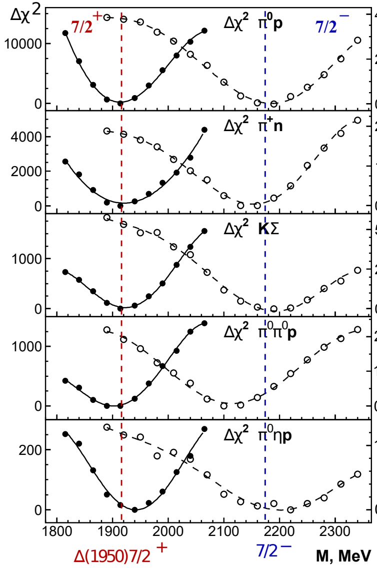
Search for parity doublets

⇒ **Do ALL high mass states have parity partners?**

⇓

Δ(1910)$1/2^+$ **Δ(1920)**$3/2^+$ **Δ(1905)**$5/2^+$ **Δ(1950)**$7/2^+$
Δ(1900)$1/2^-$ **Δ(1940)**$3/2^-$ **Δ(1930)**$5/2^-$ **???** $7/2^-$

Search for the parity partner of the well known Δ(1950)$7/2^+$ (4*) ⟹



⇒ **J^P = 7/2$^-$-state found at a significantly higher mass: m = 2200 MeV**

(7/2$^-$ (2200) - (1*)-resonance (PDG) confirmed)

⇔ **No parity-partner found**

⇒ **Certain states have parity partners, others not**
⇒ **Not yet understood!**

V. Anisovich et al. (BnGa-PWA), arXiv:1503.05774

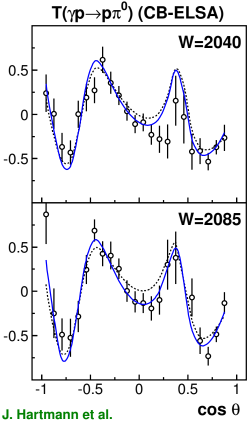
Precise measurements of polarisation observables

CBELSA/TAPS, CLAS-data (only few of the measured bins / data sets shown:)

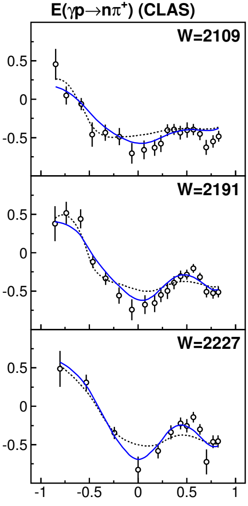
Results from the multi-channel BnGa-PWA:

—— : **fit with Δ(2200)$7/2^-$**

- - - : **fit without Δ(2200)$7/2^-$**



J. Hartmann et al.
(CBELSA/TAPS), PLB 748, 212 (2015)

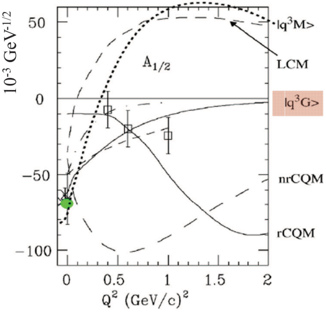


S. Strauch et al. (CLAS),
arXiv:1503.05163 (2015)

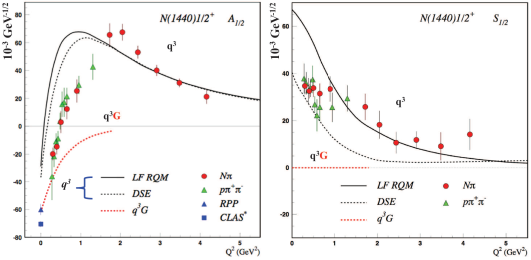
The nature of states: Roper resonance - $N(1440)1/2^+$

Electroproduction data from CLAS: Q^2-dependence of helicity amplitudes

in 2002 Roper was still consistent with a hybrid state



⇒ the new data:



LF RQM descibes helicity amplitudes at Q^2 >1.5-2.5 GeV^2

Interpretation: Meson-baryon contributions dominate low Q^2-behaviour

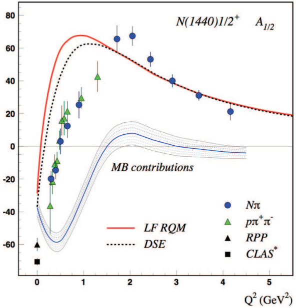
CLAS results: Identify Roper resonance as first radial excitation of the proton

The 1st radial excitation of the 3q-core emerges as the probe penetrates the MB cloud

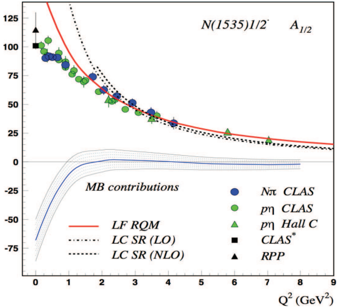
The nature of states: $N(1440)1/2^+$, $N(1535)1/2^-$

Electroproduction data from CLAS: Q^2-dependence of helicity amplitudes

N(1440)1/2$^+$



N(1535)1/2$^-$



LC SR: I. Anikin, V. Braun, N. Offen, PRD92 (2015) 014018

LF RQM: I. Aznauryan, V. Burkert, arXiv:1603.06692

LF RQM descibes helicity amplitudes at Q^2 $>$1.5-2.5 GeV^2

Interpretation: Meson-baryon contributions dominate low Q^2-behaviour

Understanding the nature of the states further: qqq, meson-baryon, hybrid via measurement of the Q^2-dependence of the helicity amplitudes

$\Rightarrow$ Further data to come from CLAS12

Summary

- Based on the new data, our knowledge of the spectrum and the properties of baryons is steadily increasing !

$\leftrightarrow$ **Important contributions from photoproduction experiments**
(single and double polarisation experiments (many final states))

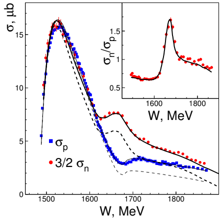
$\Rightarrow$ **Observation of new resonances**

$\Rightarrow$ **Confirmation of known states, determination of their properties**

e.g.: - puzzeling difference between $p\eta$-BR of N(1535)1/2$^-$ and N(1650)1/2$^-$ now very much reduced
- multi-meson-decays of baryon resonances

$\Rightarrow$ **much more interesting data to come**

$\gamma n \to \eta n$:



$\Rightarrow$ **Many interesting results on the spectrum and the properties of baryon resonances**

$\Leftrightarrow$ **Quark models/first lattice calculations do not yet provide the expected systematics in the spectrum**

Experiment: - no alternating pattern of positive and negative parity states
- parity doublets observed (not for all states (?))
- Baryons fall on Regge-trajectories,   Why ?

$\Downarrow$

Bound states of QCD are not yet understood!