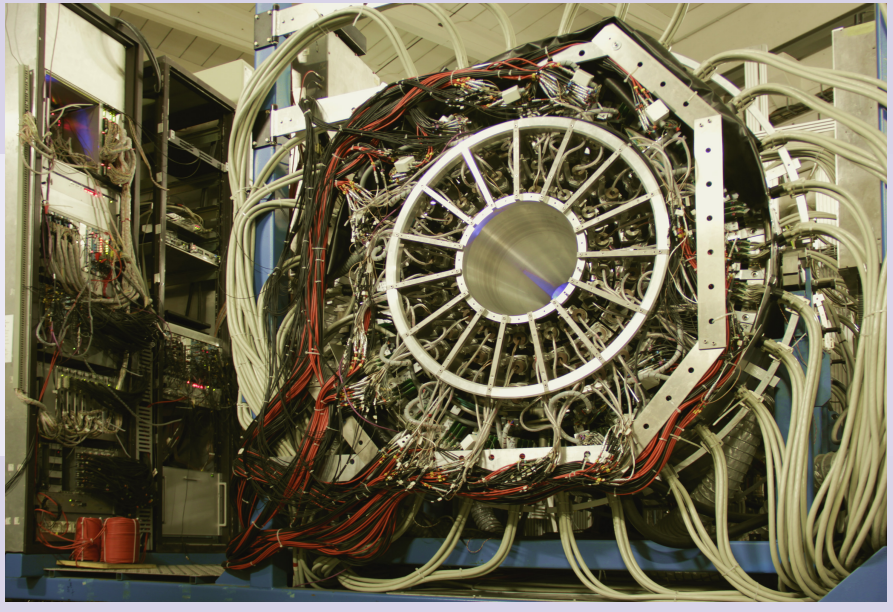
UNIVERSITÄT BONN

Light quark baryons - Recent results from photoproduction experiments

U. Thoma, Bonn

Contents:

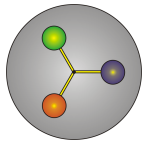
- Introduction
- Experimental data, polarisation observables
- Results
- Summary



Baryon Spectroscopy

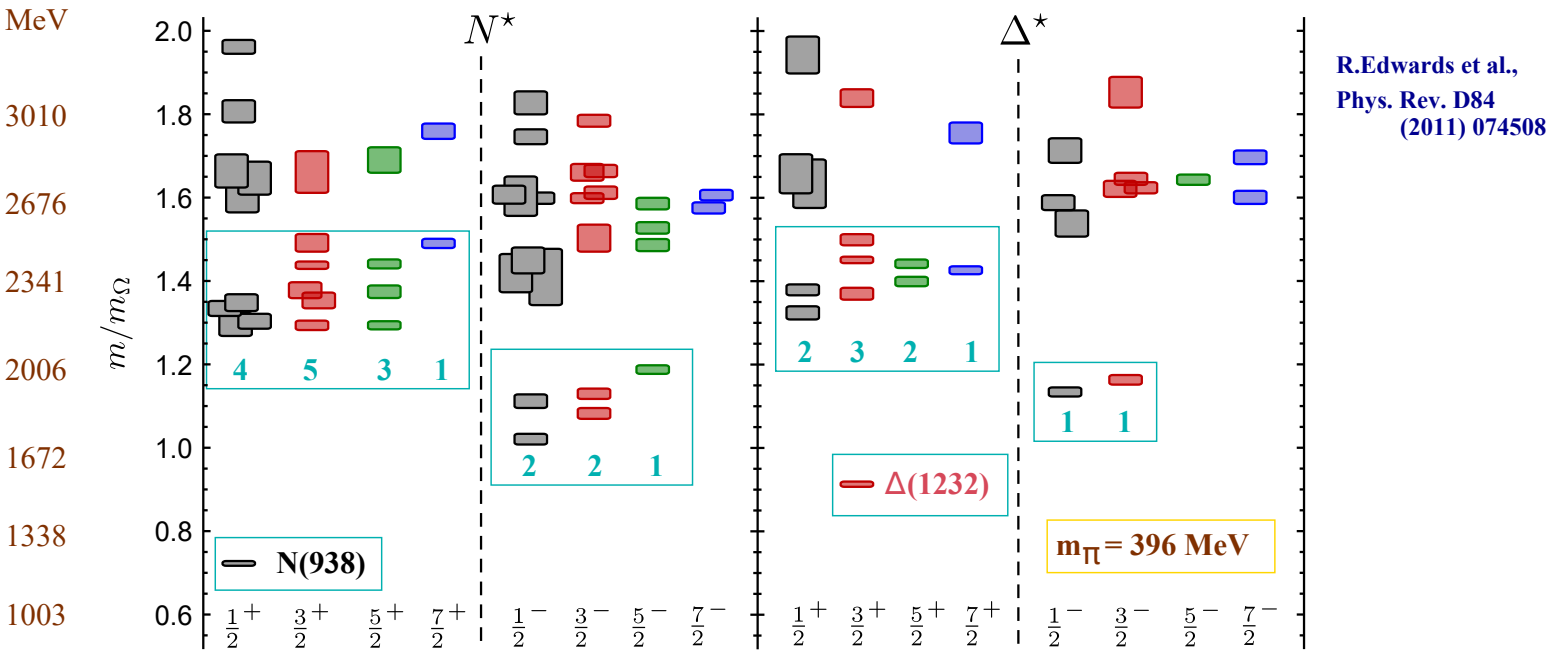
Aim: Good understanding of the spectrum and the properties of baryon resonances = the bound states of strong QCD

- Relevant degrees of freedom ? / Effective forces between them ?



or e.g. meson-baryon

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 ⇔ "missing resonances"

→ no parity doubling

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

Baryon Spectroscopy

⇒ Good understanding of the spectrum and properties of baryon resonances

Experimentally:
Broad and strongly overlapping resonances

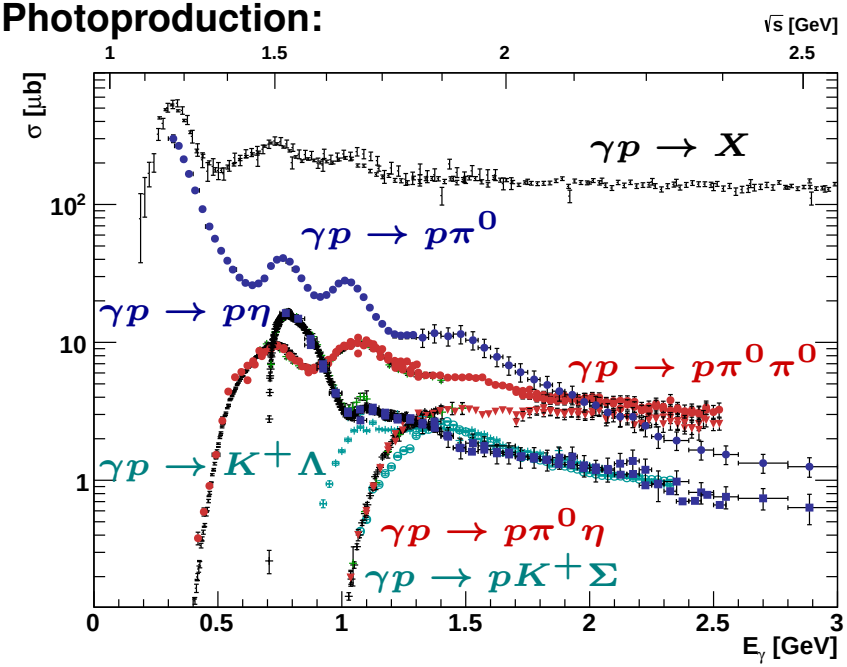
Important:

→ **Investigation of different final states**

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

→ **Measurement of polarization observables (unambiguous PWA)**

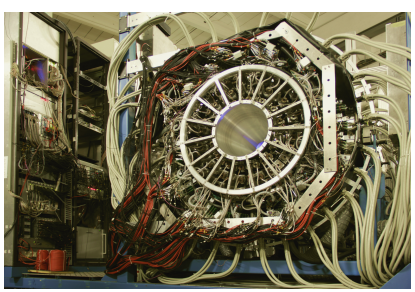
Photoproduction:



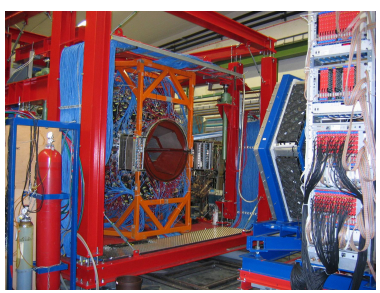
Recently: a lot of progress from photoproduction experiments:

CLAS (JLab),

CBELSA/TAPS (ELSA),



CBALL (MAMI),



LEPS (Spring-8), ...

⇔ **polarized beam, polarized target**

Baryon Spectroscopy

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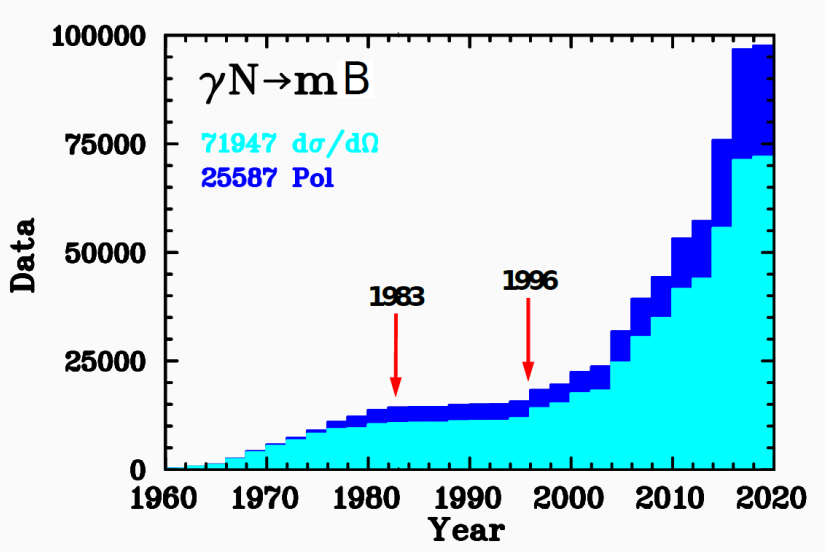

D. Ireland et al., Prog. Part. Nucl. Phys. 111 (2020) 103752

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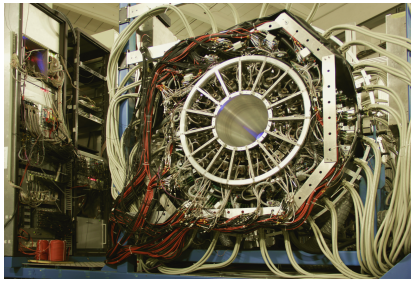

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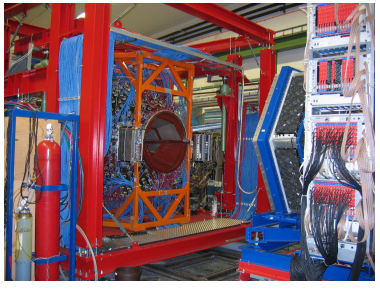
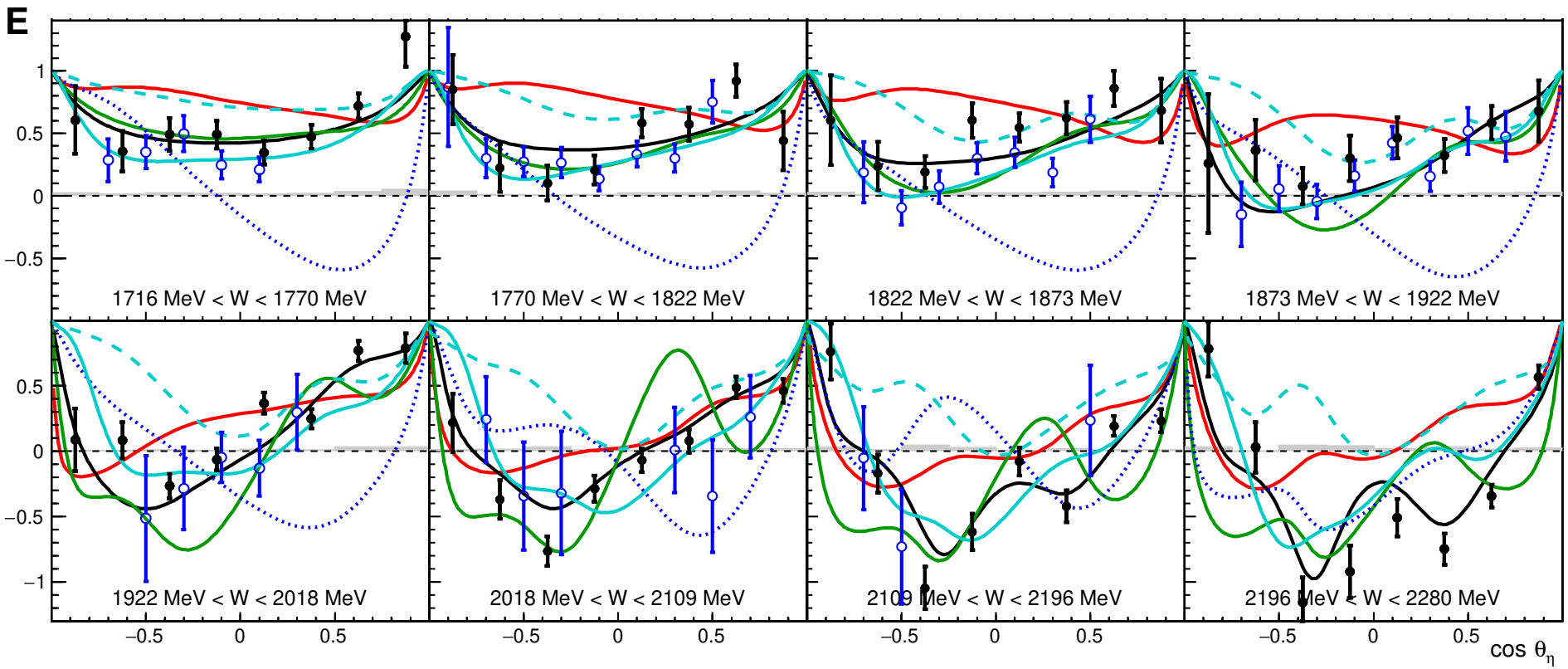


LEPS (Spring-8), ...

⇔ **polarized beam, polarized target**

Results: $\vec{\gamma}\vec{p} \to p\eta$ — Polarization observables —

circ. pol. photons, long. pol. target, CBELSA/TAPS high energy bins, blue: CLAS



⇓

⇔ **Large sensitivity!**

⇒ **data approaches the high mass region**

— **new BnGa-fit : Determination of precise $p\eta$-branching ratios for resonances**

J.Müller et al. (CBELSA/TAPS), PLB 803, 135323 (2020)

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**

⇔ Additional constraints from new (polarization) data fix PWA-solutions much better than before

⇓

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

Next step:

Comparison of PWA-results of different groups including the new data ⇔ convergence towards consistent results ?

J.Müller et al. (CBELSA/TAPS), PLB 803, 135323 (2020)

Results: The Spectrum of Baryon Resonances

Multi-channel Bonn-Gatchina PWA:

⇒ Confirmation known resonances, better determination of their properties

⇒ New resonances observed

	RPP 2010	our analyses	RPP (2018/20)
N(1710)1/2$^+$	***	****	****
N(1860)5/2$^+$		*	**
N(1875)3/2$^-$		***	***
N(1880)1/2$^+$		**	***
N(1895)1/2$^-$		****	****
N(1900)3/2$^+$	**	****	****
N(1990)7/2$^+$	**	**	**
N(2000)5/2$^+$	**	**	**
N(2060)5/2$^-$		***	***
N(2120)3/2$^-$		**	***
Δ(1900)1/2$^-$	*	**	**
Δ(1920)3/2$^+$	***	***	***
Δ(1940)3/2$^-$	*	**	**
Δ(2200)7/2$^-$	*	**	***

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

↔ 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"

⇒ better determination of resonance properties

BnGa-PWA: A. V. Anisovich et al., EPJA 48 (2012) 15, PRL 119 (2017) 062004, PLB 772 (2017) 247, J. Müller et al.,PLB 803 (2020) 135323 ...

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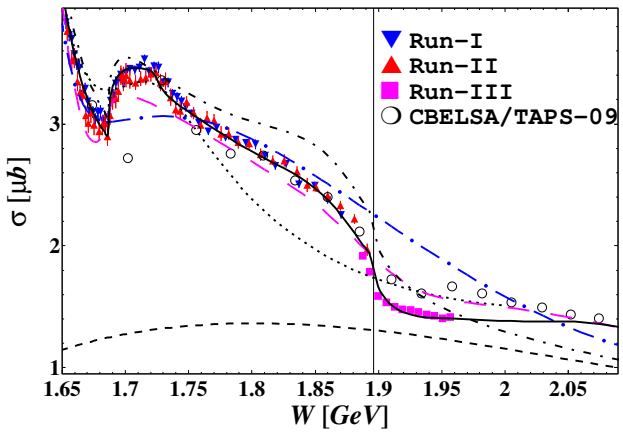
N(1880)1/2$^+$		**	***
N(1895)1/2$^-$		****	****
N(1900)3/2$^+$	**	****	****
N(1990)7/2$^+$	**	**	**
N(2000)5/2$^+$	**	**	**
N(2060)5/2$^-$		***	***
N(2120)3/2$^-$		**	***
Δ(1900)1/2$^-$	*	**	**
Δ(1920)3/2$^+$	***	***	***
Δ(1940)3/2$^-$	*	**	**
Δ(2200)7/2$^-$	*	**	***

$\Leftrightarrow$

Interesting recent MAMI-data:

$\gamma p \to \eta p$



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

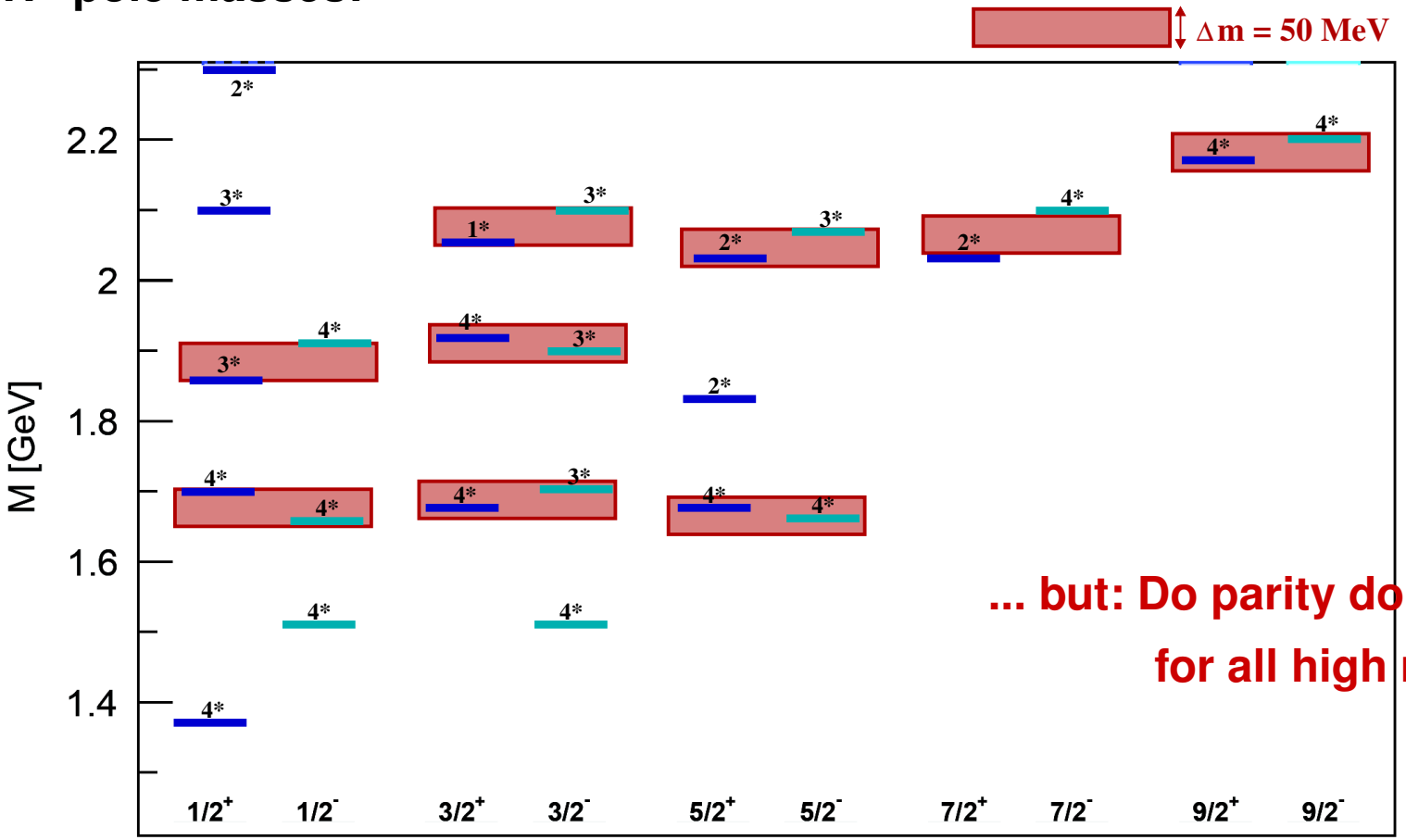
⇒ cusp effect $\eta' p$-threshold observed

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

BnGa-PWA: A. V. Anisovich et al., EPJA 48 (2012) 15, PRL 119 (2017) 062004, PLB 772 (2017) 247, J. Müller et al.,PLB 803 (2020) 135323 ...

Baryon Resonances - Parity doublets -

N* pole masses:



... but: Do parity doublets exist for all high mass states ?

Parity doublets not expected by:

- present lattice QCD calculations or constituent quark-models

⇔ Strong QCD not yet understood !

Search for parity doublets - Δ-states at $\sim$1900 MeV

$\Rightarrow$ **Do ALL high mass states have parity partners?**

$\Downarrow$

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)**$5/2^-$ **???** $7/2^-$

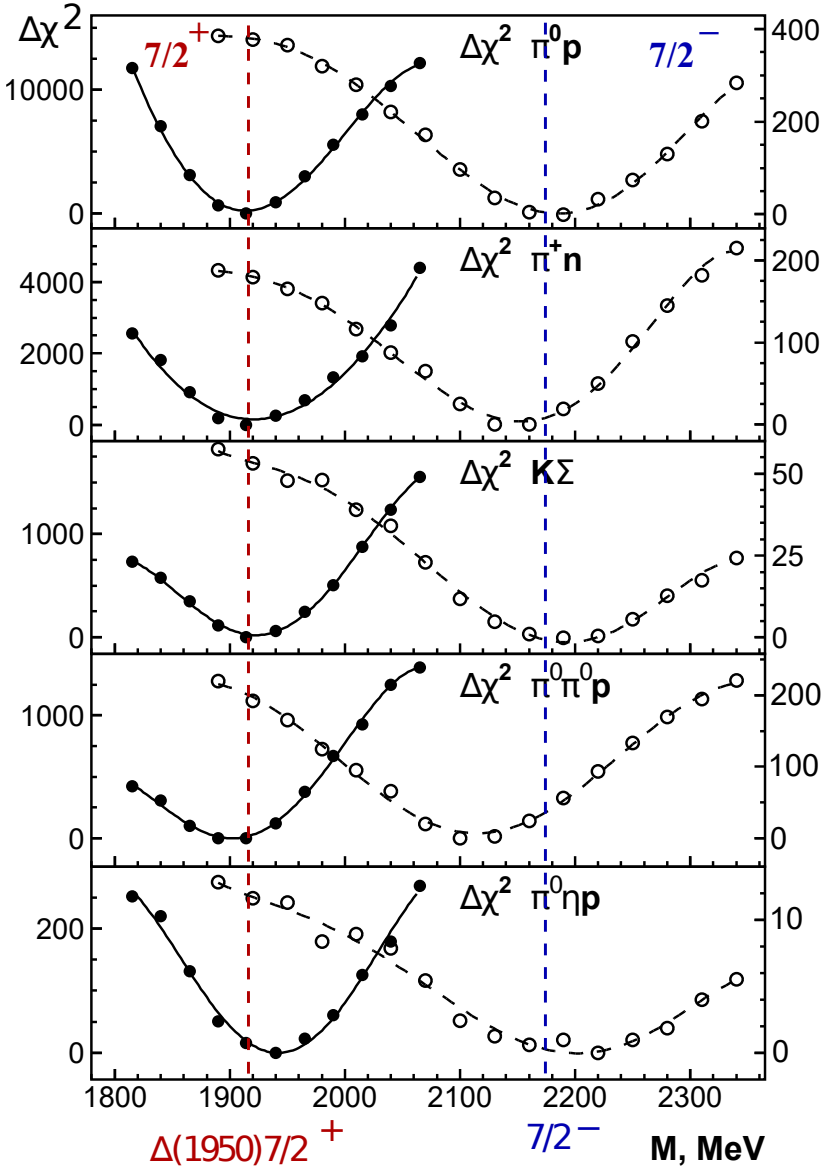
Search for the parity partner of the well known Δ(1950)$7/2^+$ (4*) $\Longrightarrow$

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

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

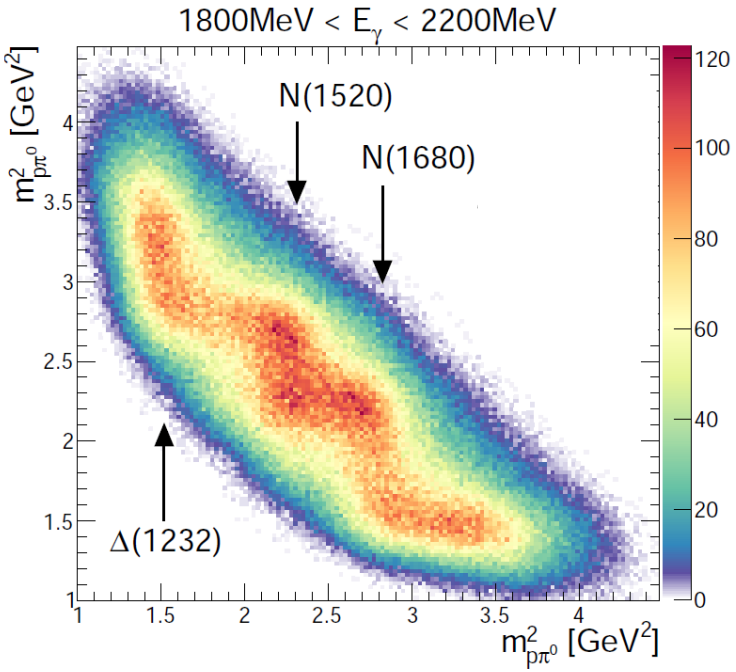
$\Leftrightarrow$ **No parity-partner found**

$\Rightarrow$ **Certain states have parity partners, others not**
$\Rightarrow$ **Not yet understood!**

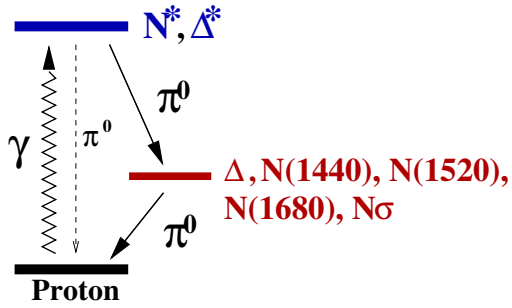


V. Anisovich et al. (BnGa-PWA), Phys.Lett. B766 (2017) 357

Multi-Meson-Photoproduction: $\gamma p \to p\pi^0\pi^0, \gamma p \to p\pi^0\eta$



⇔ **Observation of cascade decays:**



- **Event based maximum likelihood fit of unpolarised data,**
- **including single and double polarisation observables in the fit**

- $\Delta(1910)1/2^+, \Delta(1920)3/2^+, \Delta(1905)5/2^+, \Delta(1950)7/2^+$

  in average: negligible decay fraction into:

  $\mathrm{N}(1520)3/2^-\pi, \mathrm{N}(1535)1/2^-\pi, \mathrm{N}(1680)5/2^+\pi$ ($L \neq 0$-resonances)

- $\mathrm{N}(1880)1/2^+, \mathrm{N}(1900)3/2^+, \mathrm{N}(2000)5/2^+, \mathrm{N}(1990)7/2^+$

  in average: 22% decays into:

  $\mathrm{N}(1520)3/2^-\pi, \mathrm{N}(1535)1/2^-\pi, \mathrm{N}(1680)5/2^+\pi, \mathrm{N}\sigma$ ($L \neq 0$-resonances)

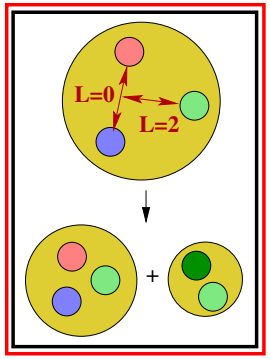
V. Sokhoyan et al. (CBELSA/TAPS-collaboration), EPJA 51 (2015) 95
A. Thiel et al. (CBELSA/TAPS-collaboration), PRL 114 (2015) 091803, T.Seifen et al., to be submitted

... Why ?

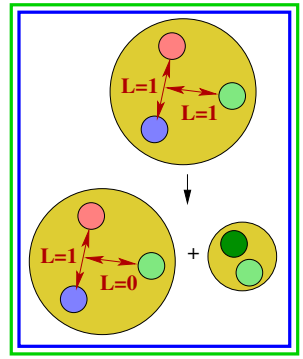
Multi-Meson-Photoproduction: $\gamma p \to p\pi^0\pi^0, \gamma p \to p\pi^0\eta$

An (maybe naive) interpretation using quarkmodel-wave-functions:

Δ^*'s @1900 MeV:

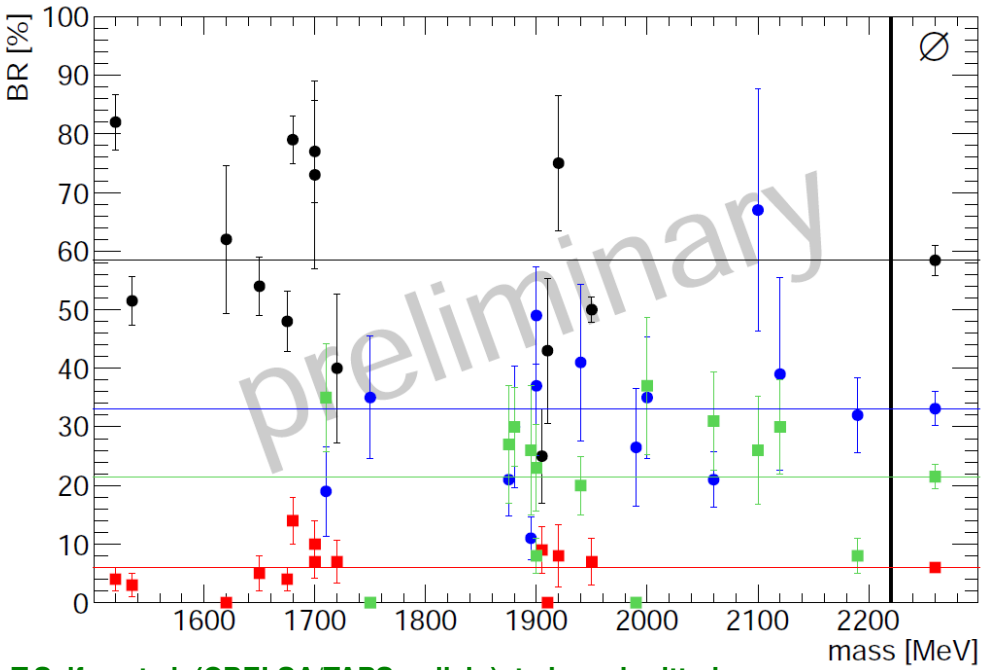


N*'s @1900 MeV:



$\Rightarrow$ would explain the observation!

... and it seems to hold more general:



single oscillator decays into $N(938)\pi$ or $\Delta(1232)\pi$

decays into $N(1520)\pi$, $N(1535)\pi$, $N(1680)\pi$ or $N\sigma$

mixed oscillator decays into $N(938)\pi$ or $\Delta(1232)\pi$

decays into $N(1520)\pi$, $N(1535)\pi$, $N(1680)\pi$ or $N\sigma$

$\Leftrightarrow$ would support the two-oscillator picture of resonances

T.Seifen et al. (CBELSA/TAPS-collab.), to be submitted

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 and to be analysed

e.g. also electroproduction.:
CLAS: up to $Q^2 \sim 5\,GeV^2$, $W < 1.8\,GeV$

CLAS 12: extend these studies for $0.05 < Q^2 < 12\,GeV^2$

D. Carman HADRON'2021 - KY-data

$\Rightarrow$ 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!