Baryon spectroscopy results within the Jülich-Bonn dynamical coupled channel approach

PWA 12 / ATHOS 7

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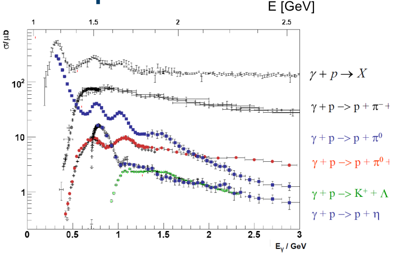
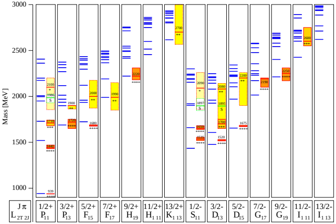
From experimental data to the N^* and Δ^* spectrum



source: ELSA; data: ELSA, JLab, MAMI



Löring *et al.* EPJ A 10, 395 (2001), experimental spectrum: PDG 2000

Jülich-Bonn (JüBo) DCC model

- Lippmann-Schwinger eq. formulated in TOPT
- hadronic potential from effective Lagrangians, fieldtheoretical approach
- photoproduction parameterized by energy-dependent polynomials
- 2-body unitarity and analyticity respected, 3-body unitarity approximately

- resonances as *s*-channel states (“by hand”), dynamical generation possible
- combined fits to pion- and photon-induced data
- NEW: Extension to electroproduction:

Jülich-Bonn-Washington parametrization

EPJ A 49, 44 (2013); EPJ A 50, 101 (2014); EPJ A 54, 110 (2018)

Recent developments of Jülich-Bonn

Extension to $\gamma p \to K^+\Sigma^0,\ K^0\Sigma^+$

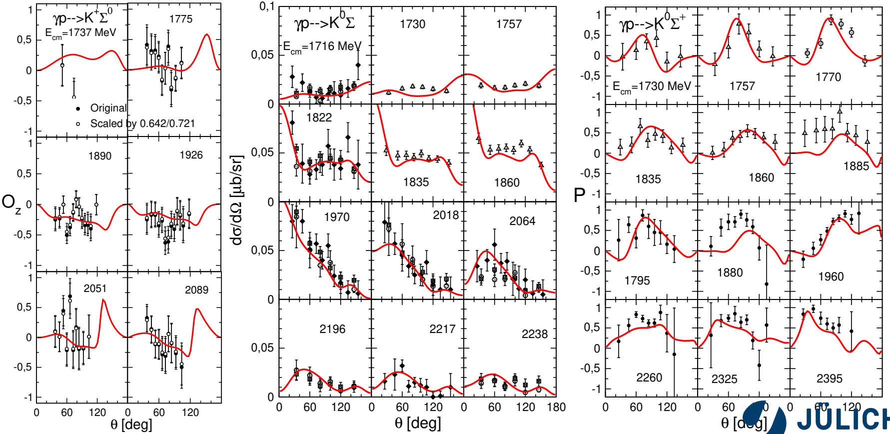
JüBo2021 **(publication in preparation)**

- DCC analysis of all pion- and photon-induced channels: πN, $\gamma p \to \pi N$, ηN, $K\Lambda$, $K\Sigma$
- $>$ 67,000 data points, $>$ 1000 fit parameters
- χ^2 minimization on JURECA supercomputer

  [JSC, Journal of large-scale research facilities, 2, A**62** (2016)]

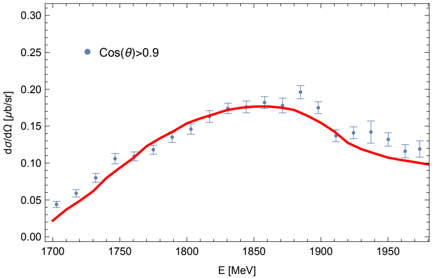
- all 4-star N and Δ states up to $J = 9/2$ are seen (exception: $N(1895)1/2^-$)

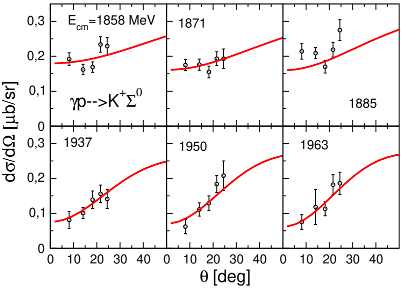
  + some states rated with less than 4 stars
- no additional s-channel diagram included, but indications for new dyn. gen. states



$\gamma p \to K^+\Sigma^0$ cross section at forward angles

Cusp-like structure observed by BGOOD collaboration (Jude et al. PLB 820, 136559 (2021))





Red: JüBo2021

- cusp-like structure related to $N(1900)3/2^+$
  (pole position: $1905 - i42$ MeV, relatively large $K\Sigma$ residue)
- analysis still ongoing

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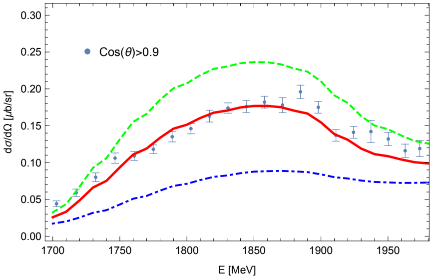
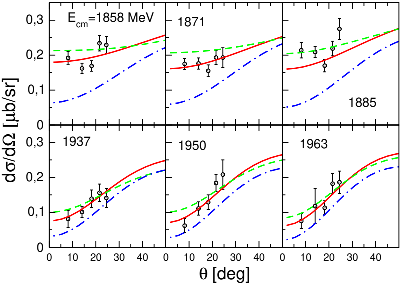




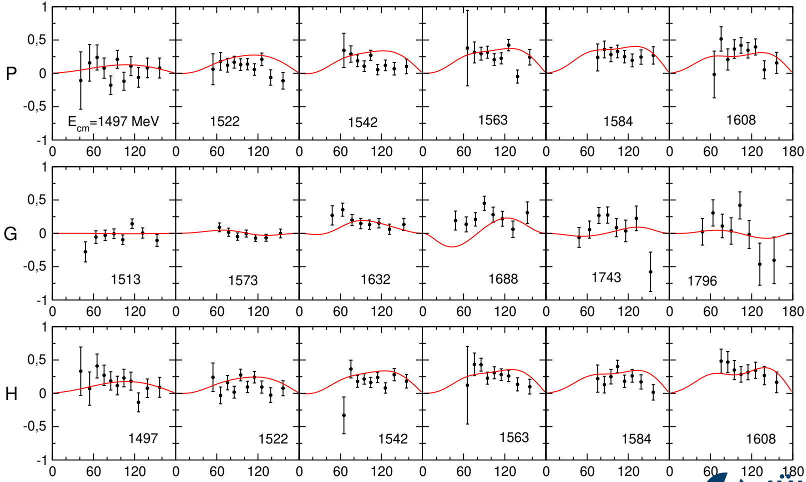
Red: JüBo2021, smaller (green dashed) and larger (blue dashed-dotted) bare $K\Sigma$ coupling of $N(1900)3/2^+$

- cusp-like structure related to $N(1900)3/2^+$
  (pole position: $1905 - i42$ MeV, relatively large $K\Sigma$ residue)
- analysis still ongoing

New pion and eta photoproduction data included

from MAMI and CBELSA

Selected results: P, G, H for $\gamma p \to \eta p$ from CBELSA/TAPS (Müller et al. PLB 803, 135323 (2020))



Challenges

- different data quality, especially between pion- and photon-induced data, stat./sys. errors
- field theoretical approach numerically very demanding + coupled channels

$\Rightarrow$ statistical tools for uncertainty analysis hard to apply

- assess significance of new (dynamically generated) states:

  JüBo2021 some new dyn. gen states: e.g. in D_{35} wave at $2097 - i38$ MeV

  Example $N(2060)5/2^{-}$: - dyn. gen. in JüBo2017 (EPJ A 54,110 (2018)), very clean pole signal
  - not seen in JüBo2021

Electroproduction

Jülich-Bonn-Washington parametrization

M. Mai *et al.* Phys. Rev. C 103, 065204 (2021)

$$\mathcal{M}_{\mu\gamma^*}(k,W,Q^2) = R_{\ell'}(\lambda, q/q_\gamma)\left(V_{\mu\gamma^*}(k,W,Q^2) + \sum_\kappa \int_0^\infty dp\, p^2\, T_{\mu\kappa}(k,p,W) G_\kappa(p,W) V_{\kappa\gamma^*}(p,W,Q^2)\right)$$

(Pseudo)-threshold behavior with meson/photon momenta

$$lim_{k\to 0} E_{\ell+} = k^\ell$$
$$lim_{q\to 0} L_{\ell+} = q^\ell$$
$$\dots$$

For Q^2=0 (real photons) identical to Jülich-Bonn photoproduction amplitude

$$V_{\mu\gamma^*}(k,W,Q^2) = V^{\mathrm{JUBO}}_{\mu\gamma}(k,W)\cdot \tilde{F}_D(Q^2)\cdot e^{-\beta^0_\mu Q^2/m_p^2}\left(1 + Q^2/m_p^2\beta^1_\mu + (Q^2/m_p^2)^2\beta^2_\mu\right)$$

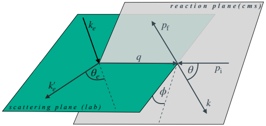
$\leftarrow$ Siegerts's theorem Siegert(1973) Amaldi et al.(1979) Tiator(2016)

$$V^{L_{\ell\pm}} = (\mathrm{const.})\cdot V^{E_{\ell\pm}}$$

...at pseudo-threshold

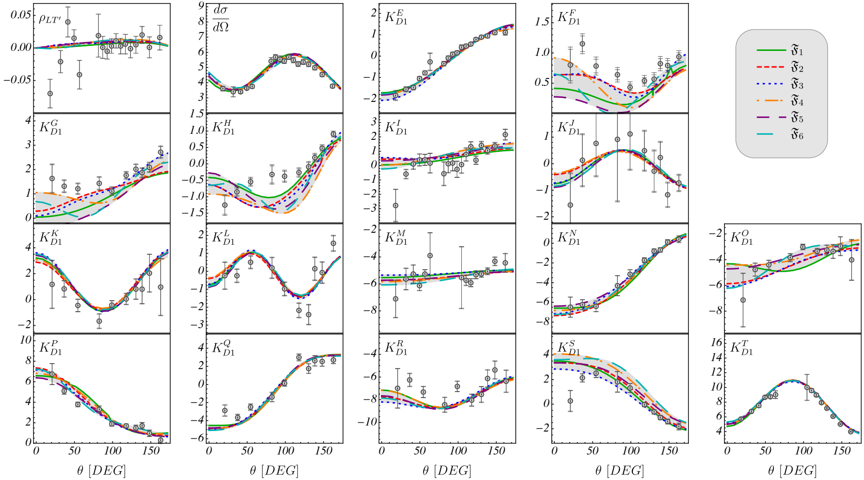
- Free parameters: β, λ + normalization factors not fixed by Siegert's condition $\rightarrow$ 209 fit parameters
- Input from JüBo: $V_{\mu\gamma}(k,W,Q^2=0)$, $T_{\mu\kappa}(k,p,W)$, $G_\kappa(p,W)$

  $\rightarrow$ photoproduction as a boundary condition at $Q^2 = 0$
  $\rightarrow$ universal pole positions and residues (fixed in this study)
- Up to D-waves included (photoproduction part includes up to J=9/2)
- Energy range up to $W \sim 1.6$ GeV, $Q^2 < 6$ GeV^2
- different fit strategies $\mathfrak{F}_1, .., \mathfrak{F}_6$



Selected fit results M. Mai *et al.* Phys. Rev. C 103, 065204 (2021)

- Recoil-polarization response functions, differential cross section:



$\pi^0 p$ final state, $Q^2 = 1$ GeV^2, $W = 1.23$ GeV, $\phi = 15°$

Data: Kelly *et al.* Phys. Rev. Lett. 95 (2005)

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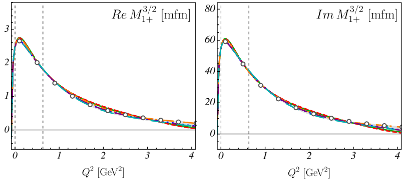
Selected results: multipoles

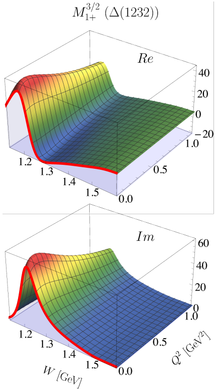
M. Mai *et al.* **Phys. Rev. C 103, 065204 (2021)**

- $M_{1+}^{3/2}$ with $\Delta(1232)$: prominent multipoles well determined

$W = 1230$ MeV

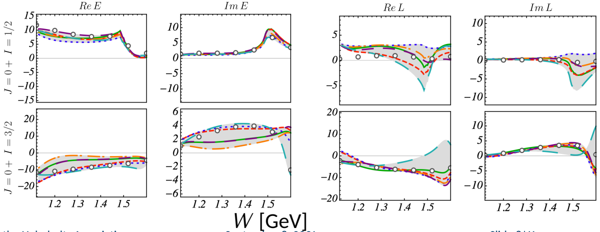


(Dots: MAID2007, Drechsler *et al.* EPJ A 34, 69 (2007))



(Only fit strategy 1 shown)

- S-wave multipoles at $Q^2 = 0.2$ GeV^2:



- less prominent multipoles are sometimes less well determined
- longitudinal multipole L often more difficult to determine than E or M

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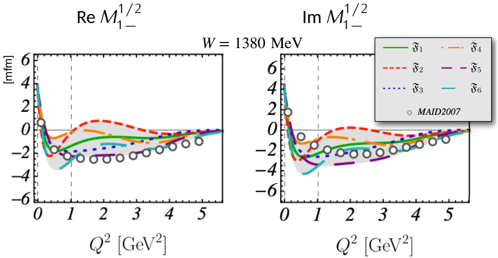
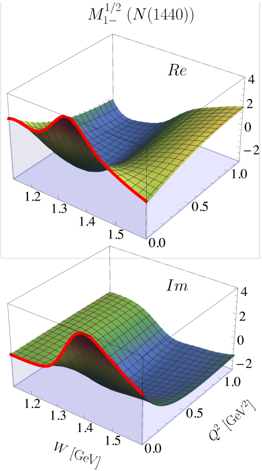
Selected results: Roper multipole

M. Mai *et al.* Phys. Rev. C 103, 065204 (2021)

- Non-trivial structure
- Zero transition
- Helicity couplings still to be extracted





(Only fit strategy 1 shown)

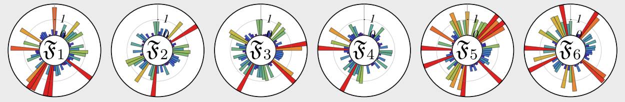
Full results: interactive web interface (under development) at

https://jbw.phys.gwu.edu

Challenges

- data base, inconsistencies: many found by hand, systematic ways? Data pruning? c.f. Phys.Rev.D 99 (2019) 1
- fit in 209 dim parameter space, different local minima

  E.g., distribution of the values for the 62 β^0 fit parameters in the different fit strategies:



$\rightarrow$ statistical challenge: is the smallest χ^2 always the best solution?

systematic uncertainties of the model? Over-parameterization? Gaps in data base?

- to be very challenging in the future: combined fit of pion-, photon- and electron-induced reactions

Summary

Photoproduction:

- Extension of JüBo DCC to include $K\Sigma$ photoproduction, inclusion of new data for pion and eta final states
  $\rightarrow$ Extraction of the N^* and Δ^* spectrum in a **simultaneous analysis of pion- and photon-induced reactions** (publication in preparation)

Electroproduction:

- Jülich-Bonn-Washington (JBW) parametrization
  $\rightarrow$ analysis of pion electroproduction data Phys. Rev. C 103, 065204 (2021)
  - JüBo photoproduction amplitude as boundary condition at $Q^2 = 0$
  - **universal pole parameters** in pion-, photon- and electron-induced reactions
  - towards a combined fit of pion-, photon- and electron data

Thank you for your attention!