New Baryon States from Exclusive Meson Photo- and Electroproduction



8th Workshop of the APS Topical Group on Hadronic Physics

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V.I. Mokeev, 8th Workshop of the APS Topical Group on Hadronic Physics, April 10-12, 2019



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Dramatic events occurred in the micro-second old universe during the transition from the deconfined quark and gluon phase to the hadron phase.



SU(6)xO(3) Spin-Flavor Symmetry and ``Missing" Resonances



Studies of the N*-spectrum were driven by a guess for the ``missing" baryon states expected from the underlying SU(6) xO(3) symmetry and supported by exploratory lattice/continuum QCD results on the N*-spectrum.

Exclusive Photoproduction in the Nucleon Resonance Region

Common effort at ELSA, JLab and MAMI.

Combination of continuous electron beams and detectors of $\sim 4\pi$ acceptance allow us to determine types of all final particles and their 4-momenta in each reaction.

Most exclusive photoproduction channels in the resonance region were studied.



2-Body Photoproduction off Protons: Data and Analysis Approaches

 \checkmark - data acquired \checkmark - analyzed/published

Observable	σ	Σ	т	Р	E	F	G	н	T _x	T _z	L _x	Lz	0 _x	0 _z	C _x	C _z
ρπ ⁰	1	1	✓		✓	√	~	~								
nπ⁺	1	1	✓		1	1	✓	✓	class							
рղ	1	✓	✓		1	✓	✓	✓	γp→X							
рղ'	1	✓	~		✓	✓	✓	✓								
K⁺Λ	1	1	1	1	✓	✓	√	√	√	√	√	√	1	1	1	 Image: A set of the set of the
Κ ⁺ Σ ⁰	1	1	1	1	~	1	✓	 ✓ 	 ✓ 	✓	✓	✓	1	1	1	1
К+*Л	1			1					SDME							
K ^{0*} Σ ⁺	1	1							✓ ✓ SDME							

Coupled-channel approaches for N* parameter extraction from exclusive meson photoproduction data off the proton

Bonn-Gatchina A.V. Anisovich et al., Eur. Phys. J. A53, 242 (2017). A.V. Anisovich et al., Eur. Phys. J. A50, 129 (2014). A.V. Anisovich et al., Eur. Phys. J. A48, 15 (2012).

Argonne-Osaka H. Kamano et al., Phys. Rev. C94, 015201 (2016). H. Kamano et al., Phys. Rev. C88, 035209 (2013).

GWU-Julich D. Rönchen et al., Eur. Phys. J. A51, 70 (2015). D. Rönchen et al., Eur. Phys. J. A50, 101 (2014).



Establishing the N* Spectrum

Hyperon photoproduction $\gamma p \rightarrow K^+ \Lambda \rightarrow K^+ p \pi^-$ from CLAS

ANL-Osaka coupled-channel analysis





Establishing the N* Spectrum, cont'd

Hyperon photoproduction $\gamma p \rightarrow K^+ \Lambda \rightarrow K^+ p \pi^-$ from CLAS

Bonn-Gatchina multichannel analysis: 9 new resonances were included







Advances in Exploration of the N*-Spectrum

Several new nucleon resonances (``missing" states) have been discovered with the decisive impact of the CLAS open strangeness photoproduction data. A.V. Anisovich et al., Phys. Lett. B782, 662(2018), V.D. Burkert, Few Body Syst. 59, 57 (2018).



Nucleon resonances listed in Particle Data Group (PDG) tables

State N(mass)J ^p	PDG pre 2016	PDG 2018*
N(1710)1/2+	***	****
N(1880)1/2+		***
N(1895)1/2 ⁻		****
N(1900)3/2+	**	****
N(1875)3/2 ⁻		***
N(2100)1/2+	*	***
N(2120)3/2 ⁻		***
N(2000)5/2+	*	**
N(2060)5/2 ⁻		***
∆(1600)3/2 +	***	****
∆ (1900)1/2 ⁻	**	***
∆(2200)7/2 ⁻	*	***

<u>The next step:</u> A description of the exclusive electroproduction data off the proton with the same masses and hadronic decay widths as in photoproduction will support the existence of new baryon states.



Interpretation of the Structure at W~1.7 GeV in $\pi^+\pi^-p$ Electroproduction

M. Ripani et al., CLAS Collaboration Phys. Rev. Lett. 91, 022002 (2003).

conventional states only, consistent with PDG 02

<u>Two equally successful ways for the data description:</u> No new states, different than in PDG 02' N(1720)3/2⁺ N $\pi\pi$ hadronic decay widths:

	$\Gamma_{tot,} \mathbf{MeV}$	BF(π∆) %	BF(ρp) %
N(1720)3/2 ⁺ decays fit to the CLAS Nππ data	126±14	64-100	<5
N(1720)3/2+ PDG 02'	150-300	<20	70-85

new N'(1720)3/2+ and regular N(1720)3/2+:

	$\Gamma_{tot,}MeV$	BF(π∆) %	BF(ρp) %
N'(1720)3/2+ New	119±6	47-64	3-10.
N(1720)3/2 ⁺ Conventional	112±8	39-55	23-49

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implementing N'(1720)3/2⁺ candidate or only conventional states with different N(1720)3/2⁺ $N\pi\pi$ decays than in PDG 02



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• Fit of $\theta_{\pi-}$, $\theta_{\pi+}$, θ_{p} angular distributions requires essential contribution(s) from the resonance(s) of $J^{\pi}=3/2^{+}$.

• Single state of $J^{\pi}=3/2^+$ should have major $\pi\Delta$ (>60%) and minor ρp (<5%) decays in order to reproduce pronounced Δ -peaks in π^+p and to avoid ρ -peak formation in the $\pi^+\pi^-$ mass distributions.

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Description of the CLAS $\pi^+\pi^-p$ Photoproduction off Protons Data with/without the New State N'(1720)3/2+



Almost the same quality of the photoproduction data description was achieved with and without N'(1720)3/2⁺ new state:

N(1720)3/2⁺ and N'(1720)3/2⁺ \longrightarrow 1.19 < χ^2 /d.p. < 1.28 N(1720)3/2⁺ only $1.08 < \chi^2$ /d.p. < 1.26

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Would it be possible to describe photo- and electroproduction data with Q²-independent resonance masses and total and partial hadron decay widths?

N(1720)3/2+ hadronic decays from the CLAS data fit with conventional resonances only

	BF(π∆), %	BF(ρp), %
electroproduction	64-100	<5
photoproduction	14-60	19-69

The contradictory BF values for N(1720)3/2⁺ decays to the $\pi\Delta$ and ρ p final states deduced from photo- and electroproduction data make it impossible to describe the data with conventional states only. N* hadronic decays from the data fit that incorporates the new N'(1720)3/2+ state

Resonance	BF(πΔ), %	BF(ρ p) , %
N'(1720)3/2+ electroproduction photoproduction	47-64 46-62	3-10 4-13
N(1720)3/2+ electroproduction photoproduction	39-55 38-53	23-49 31-46
∆(1700)3/2 ⁻ electroproduction photoproduction	77-95 78-93	3-5 3-6

The successful description of the $\pi^+\pi^-p$ photoand electroproduction data achieved by implementing new N'(1720)3/2⁺ state with Q²-independent hadronic decay widths of all resonances contributing at W~1.7 GeV provides strong evidence for the existence of the new N'(1720)3/2⁺ state.



The Parameters of the new N'(1720)3/2⁺ State from the CLAS Data Fit

The photo-/electrocouplings of the N'(1720)3/2⁺ and conventional N(1720)3/2⁺ states:



N'(1720)3/2⁺ is the only new resonance for which data on electroexcitation amplitudes have become available.

Gaining insight into the ``missing" resonance structure will shed light on their peculiar structural features that have made them so elusive, as well as on the emergence of new resonances from QCD.



Future Extension of the Results on N'(1720)3/2+ Electrocouplings



In the near term future electrocouplings of the new baryon state N'(1720)3/2+ will become available in 5 Q²-bins at 2.0 GeV²<Q²<5.0 GeV²



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Recent CLAS Data on $\pi^+\pi^-p$ Electroproduction off Protons at 0.4<Q²<1.0 GeV²

1.4

100 150

200 300

15

α_. (deg)

m_{z'p} (GeV)



G. V. Fedotov, Iu. A. Skorodumina et al., CLAS Collaboration, Phys. Rev. C98, 025203 (2018). (USC Group)

Promising prospect to obtain 8 additional points on Q²-evolution of N'(1720)3/2⁺ electrocouplings in the range of 0.4 GeV² < Q^2 < 0.8 GeV².



- CLAS data on exclusive meson photo- and electroproduction have considerably extended our knowledge on the excited nucleon state spectrum.
- The new N(1895)1/2⁻ and N(1900)3/2⁺ resonances with the four star PDG ratings were established in the global multi-channel analysis of the exclusive photo- and hadroproduction channels with a major impact from the CLAS KΛ, KΣ photoproduction data. The long-term objective of the discovery of some of the ``missing" baryon states has been achieved!
- Combined studies of exclusive $\pi^+\pi^-p$ photo-/electroproduction off proton data have revealed convincing evidence for the existence of the new N'(1720)3/2⁺ resonance.
- The results on N'(1720)3/2⁺ electrocouplings offer insight into the particular structural features which make ``missing" resonances different - joint effort with the hadron structure theory developments.
- Observation of new baryon states in exclusive electroproduction data with Q²independent masses, total, and partial hadronic decay widths will support their
 existence in a nearly model-independent way, completing the exploration of the N*
 spectrum in the experiments with electromagnetic probes.







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- CQM evaluation of N(1720)3/2⁺ and N'(1720)3/2⁺ electrocouplings assuming [56,2+] and [20,1+] SU(6)assignments, respectively. If the CLAS results on N'(1720)3/2⁺ electrocouplings will be reproduced, then the N'(1720)3/2⁺ is the long time awaited double-orbital excitations over ρ- and λ-degrees of freedom in three-quark system.
- DSE evaluation of the spectrum of excited nucleon states with J^p=3/2⁺ will either confirm the emergence of N(1720)3/2⁺ and N'(1720)3/2⁺ quark cores from QCD or will elucidate the limit of applicability of the quark-dynamical-di-quark interactions currently employed for the N* spectrum description.
- Observation of N'(1720)3/2⁺ can extend our knowledge on the interactions of three dressed quarks in generation of ``missing" resonance quark core shedding light on potential di-quark radial excitations or extra-components in the quark core structure such as dressed gluons, dressed qq-bar pair, etc.



- Studies of the excited nucleon state spectrum offers an access to the approximate symmetries underlying generation of the N* states in the strong QCD regime.
- Allow us to explore whether almost exact at ~GeV mass scale chiral symmetry of QCD evolves into approximate O(3)xSU(6) symmetry, when the orbital momentum conservation imposed by O(3)-symmetry breaks the chiral symmetry, making impossible the existence of the parity-doublet states, required by the chiral symmetry.
- If it is a case, then we have to observe more excited nucleon states then have been reported in the PDG16 listing.



Extending the Kinematical Coverage of $\pi^+\pi^-p$ Electroproduction off Proton Data





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Polarization Observables in Meson-Baryon Photoproduction Channels

[SHKL, J Phys G38 (11) 053001]

Photon beam		Target			Recoil			Target - Recoil								
					<i>x'</i>	у'	Ζ'	<i>x'</i>	<i>x'</i>	<i>x'</i>	у'	у'	у'	z'	Ζ'	Ζ'
		x	У	Ζ				x	У	Ζ	x	У	Ζ	x	У	Ζ
unpolarized	σ_0	,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	T			Р		$T_{x'}$, 1.0.1.0.1.0.1.0.1.0.1.0.1.0.1	L_{x} ,	*******	\sum		T_{z} ,		L_{z} ,
$P_L^{\gamma} sin(2\phi_{\gamma})$		Н		G	<i>O</i> _{<i>x</i>} ,		O z',		<i>C</i> _z ,		E		F		$-C_{x'}$	
$P_L^{\gamma} \cos(2\phi_{\gamma})$	-Σ		- P			- <i>T</i>		-L _z ,		T _z ,		$-\sigma_0$		$L_{x'}$		$-T_{x'}$
circular P_c^{γ}		F		- E	$C_{x'}$		$C_{z'}$		- O z'		G		-H		O _{x'}	



16 different observables

- They are described by different bi-• linear combinations of amplitudes
- *Combined fit of all observables* • offers rigorous constraints on the reaction amplitude at the real energy axis

Connecting Nucleon Resonance Properties to the Photoproduction Observables



- Constrain exclusive photoproduction amplitudes by fitting them to the differential cross sections and polarization asymmetries.
- Incorporate the FSI effects→ Global multi-channel analyses of all exclusive photo-/hadroproduction channels.
- · Make analytical continuation of reaction amplitudes into the complex energy plane and:
 - a) locate poles Resonance masses (M_{N^*}) and total widths (Γ_{N^*});
 - b) determine residues Resonance photocouplings and partial hadronic decay widths.



JM Model for Analysis of $\pi^+\pi^-p$ Photo-/Electroproduction

Major objectives: extraction of $\gamma_{r,v}$ pN* photo-/electrocouplings and $\pi\Delta$, ρ p decay widths



five channels with unstable intermediate meson/baryon and direct $\pi^+\pi^-p$ production:

N^{*} contribute to $\pi\Delta$ and op channels only;

unitarized Breit-Wigner ansatz for resonant amplitudes;

phenomenological parameterization of the other meson-baryon channel amplitudes (see **Ref. 2)**

- V.I. Mokeev, V.D. Burkert et al., (CLAS Collaboration) Phys. Rev. C86, 035203 (2012). 1.
- V.I. Mokeev, V.D. Burkert et al., Phys. Rev. C80, 045212 (2009). 2.
- V.I. Mokeev, V.D. Burkert et al., Phys. Rev. C93, 025206 (2016). 3.

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Good description of $\pi^+\pi^-p$ photo-/electroproduction off protons cross sections at 1.4 GeV<W<2.0 GeV and 0.2 GeV²<Q²<5.0 GeV²