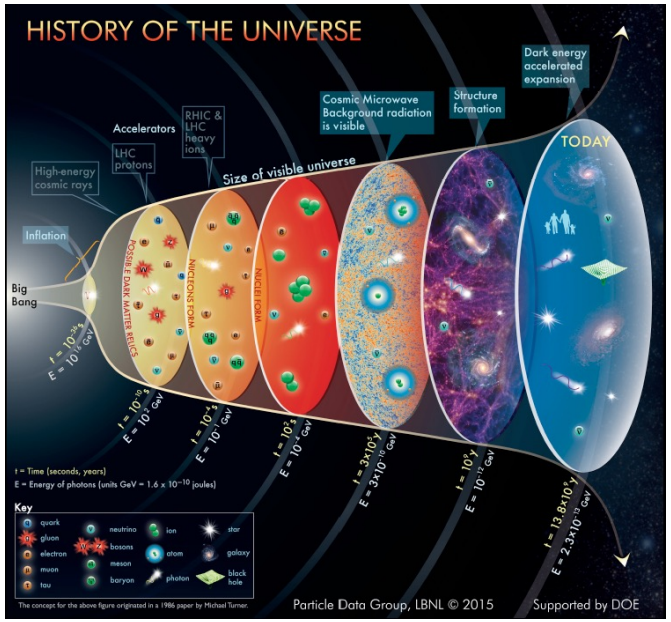
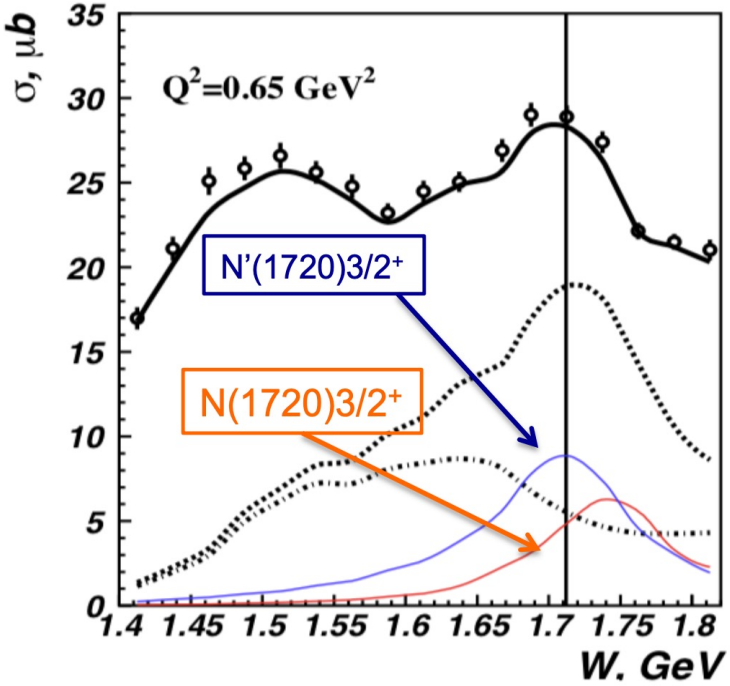
New Baryon State N'(1720)3/2$^+$ from the CLAS $\pi^+\pi^-$p Photo- and Electroproduction Data





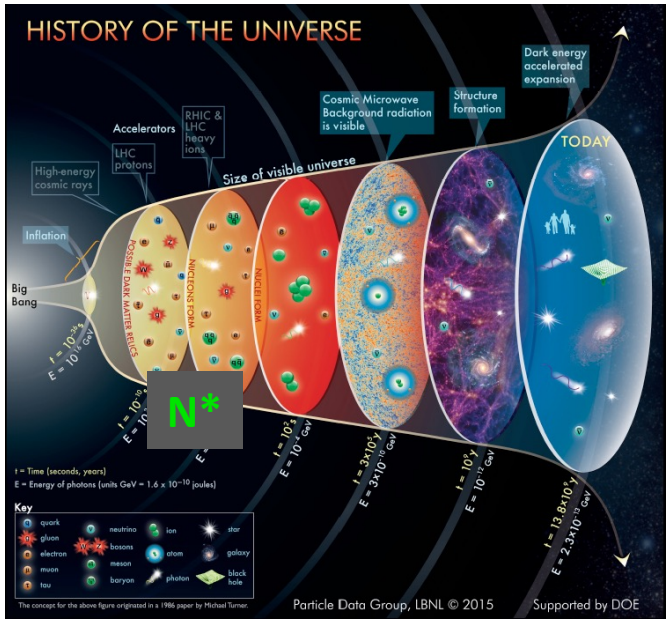
V.I. Mokeev
Jefferson Laboratory

- Hadron spectra and emergence of the strong QCD regime
- New resonances from photoproduction
- New N'(1720)3/2$^+$ state from analysis of $\pi^+\pi^-$p photo-/electroproduction data
- Insight into ``missing'' resonance structure

Office of Science

16th International Workshop on Meson Physics online via ZOOM
17th - 20th May 2021

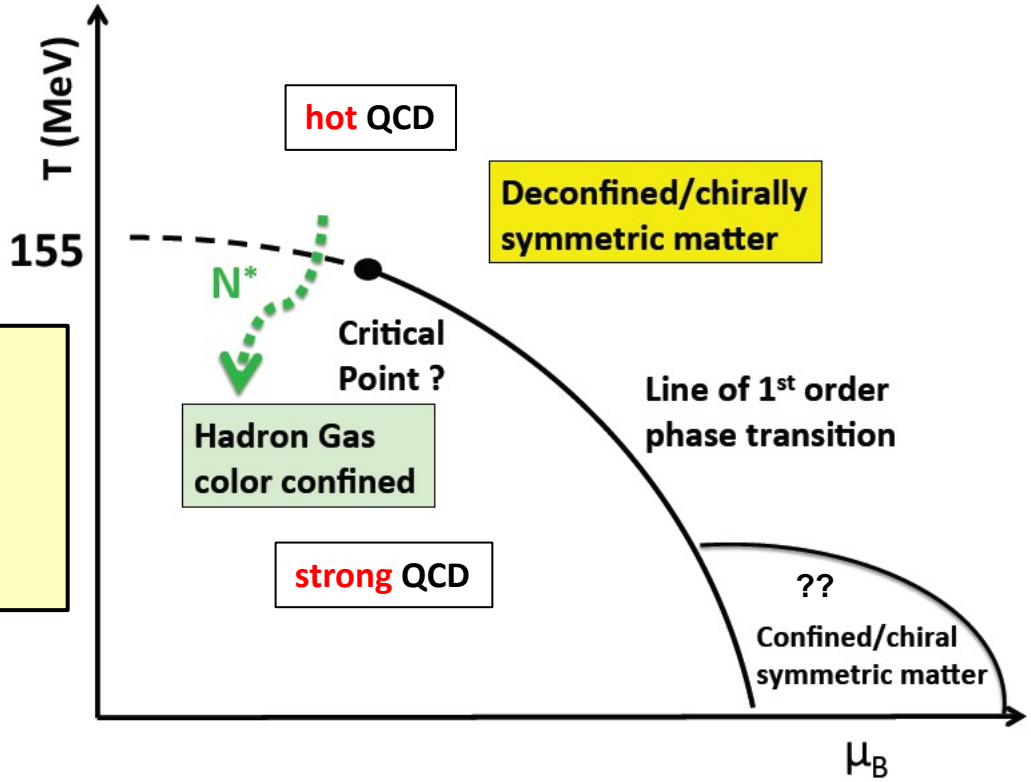
Nucleon Resonances in the Emergence of Hadronic Matter



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

- Quark-gluon confinement emerges
- Chiral symmetry of QCD is broken
- Quarks and gluons acquire mass
- Baryon resonances form

This transition was shaped by the full meson and baryon spectra



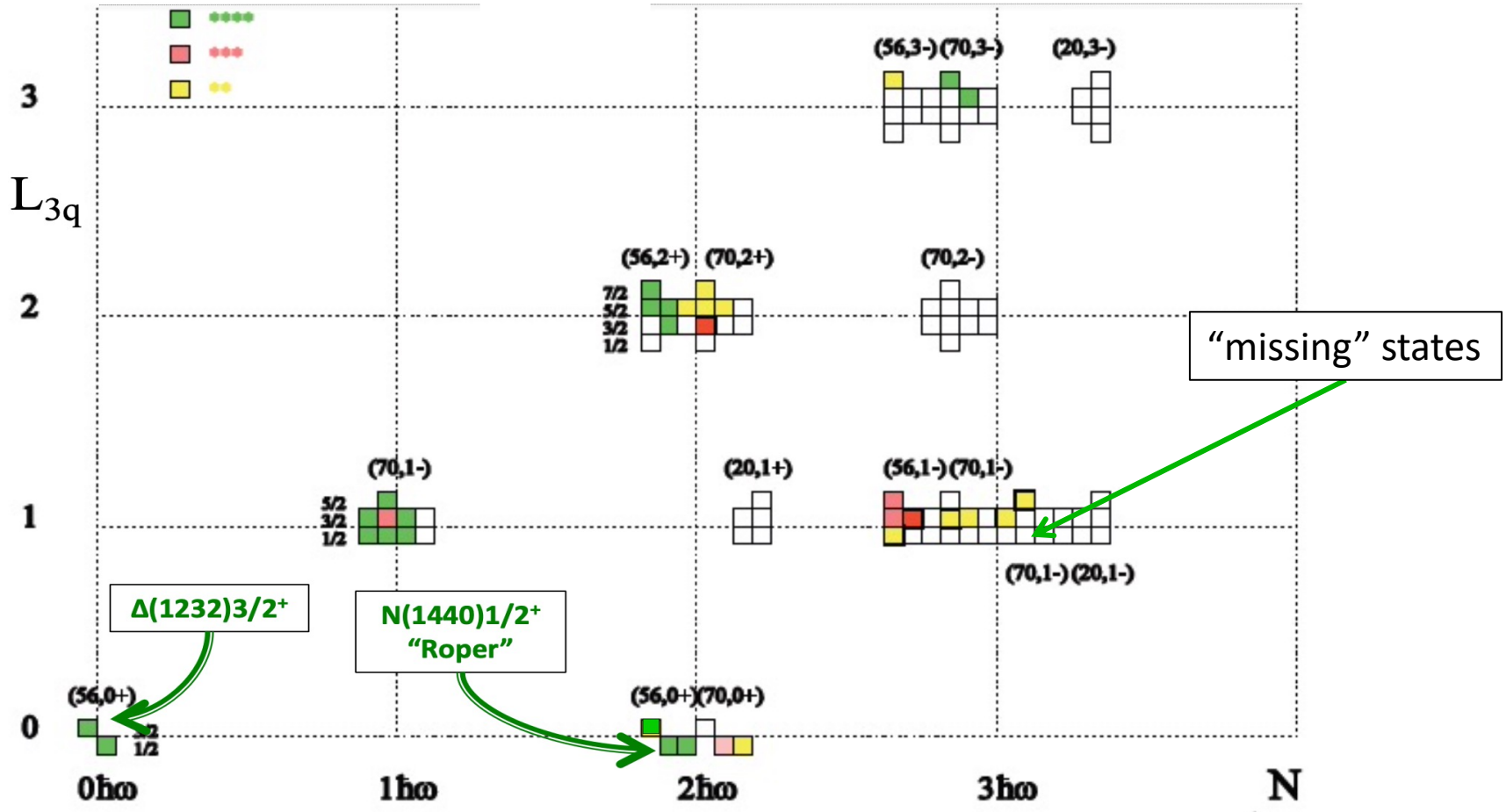
SU(6)xO(3) Spin-Flavor Symmetry and ``Missing" Resonances

PDG2012 status

SU(6)×O(3)

Continuum QCD: C. Chen et al., PRD 100 (2019) 054009; Si-xue Qin et al., FBS 60 (2019) 26

Lattice QCD: R. Edwards et al., PRD 84 (2011) 074508

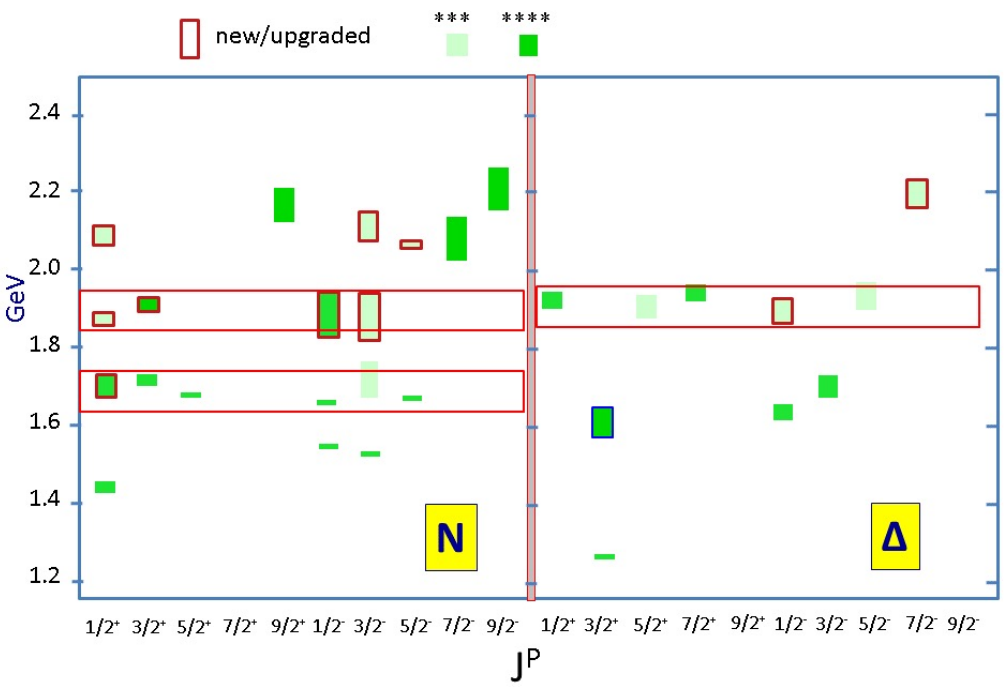


Studies of the N*-spectrum were driven by a guess for the ``missing" baryon states expected from underlying SU(6)xO(3) symmetry and supported by continuum lattice QCD results on the N*-spectrum

Advances in the Exploration of the N* Spectrum in Photoproduction

Several new nucleon resonances were established in a global multi-channel analysis of exclusive photoproduction data

N^*/Δ^* Spectrum 2020



Nucleon resonances listed in Particle Data Group (PDG) tables

State N(mass)J^P	PDG pre 2012	PDG 2020*
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-		***
Δ(1600)3/2+	***	****
Δ(1900)1/2-	**	***
Δ(2200)7/2-	*	***

Description of the exclusive electroproduction data off the proton with the same masses and hadronic decay widths as in photoproduction will validate the existence of new baryon states.

Combined studies of the CLAS $\pi^+\pi^-$p photo-/electroproduction off proton data allow us to observe a new N'(1720)3/2+ baryon state in addition to those listed above.

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*

——— *implementing N'(1720)3/2⁺ candidate or only conventional states with different N(1720)3/2⁺ Nππ decays than in PDG 02*

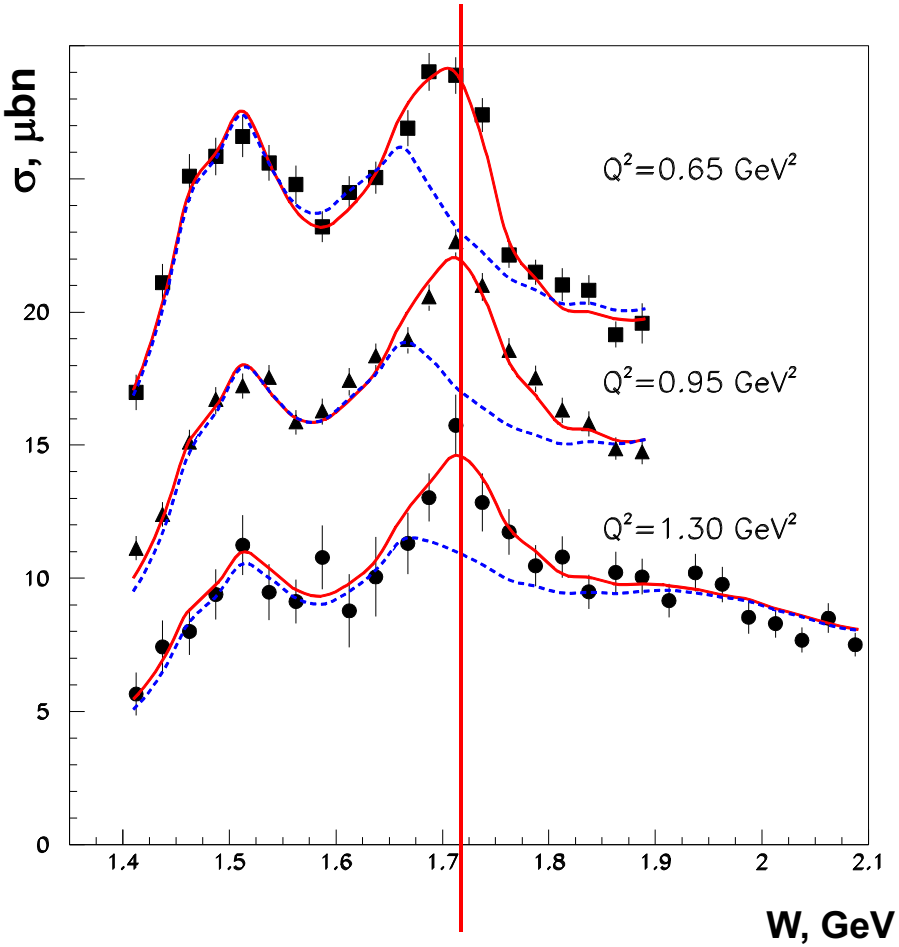
Two equally successful ways for the data description:

No new states, different than in PDG 02'
N(1720)3/2⁺ Nππ hadronic decay widths:

	Γ_{tot}, MeV	BF(πΔ) %	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⁺:

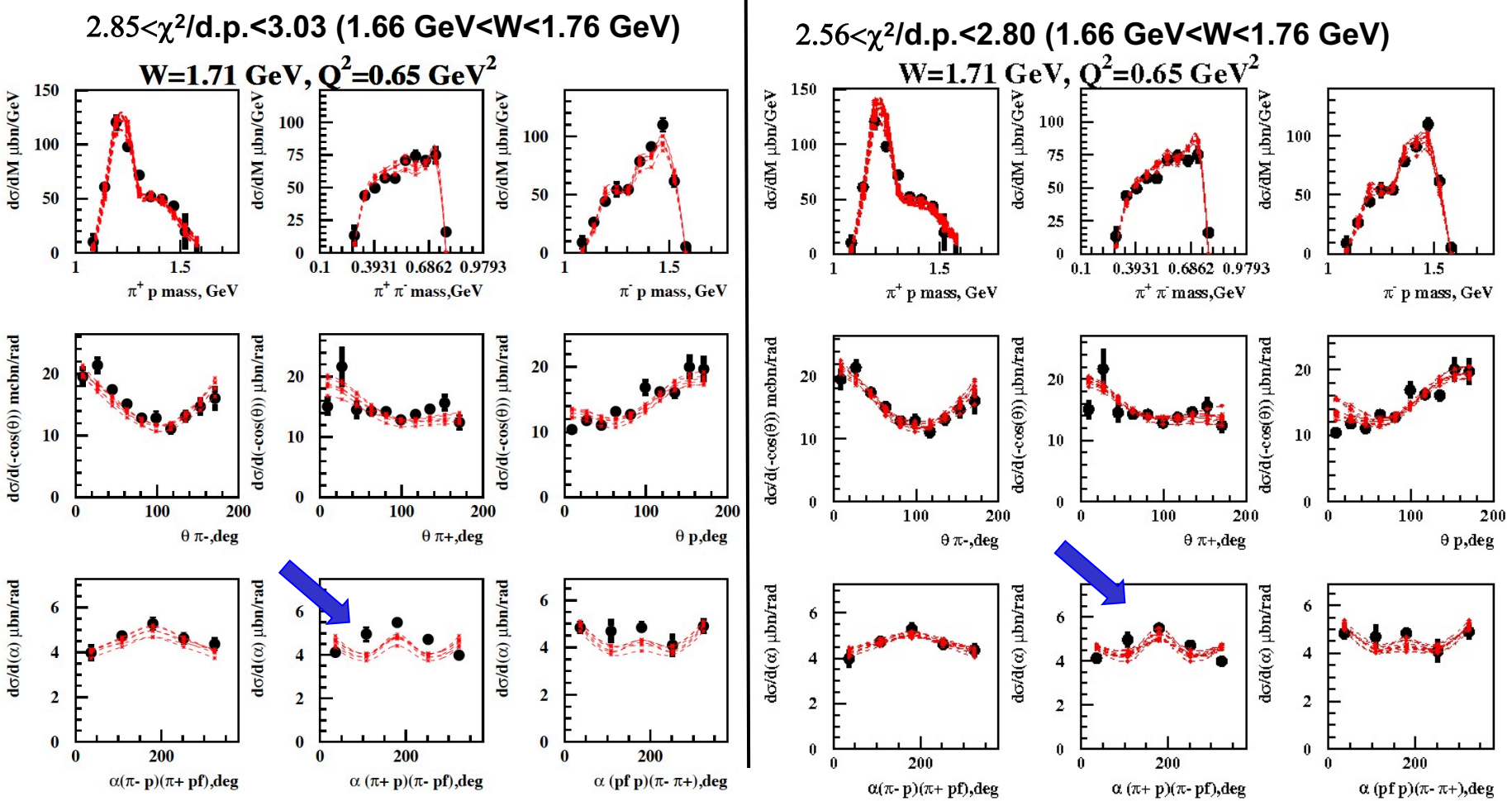
	Γ_{tot}, MeV	BF(πΔ) %	BF(ρp) %
N'(1720)3/2⁺ New	**119±6**	**47-64**	**3-10.**
N(1720)3/2⁺ Conventional	**112±8**	**39-55**	**23-49**



Analysis of the ep→ e'$\pi^+\pi^-$p CLAS data at W~1.7 GeV in the JM model

Conventional N*-states with $\pi\Delta$, ρp couplings fit to the data

N'(1720)3/2$^+$ candidate state is included in the fit

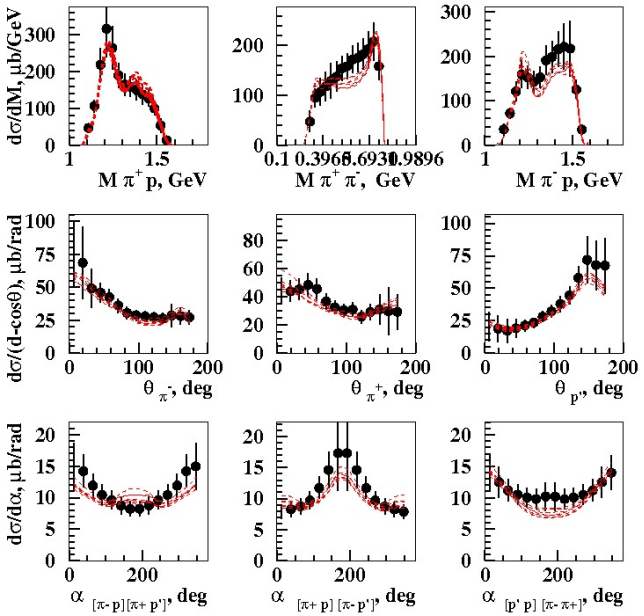


- Fit of $\theta_{\pi-}$, $\theta_{\pi+}$, θ_p angular distributions requires essential contribution(s) from $J^\pi=3/2^+$ resonance(s).
- Single state of $J^\pi=3/2^+$ should have major $\pi\Delta$ (>60%) and minor ρp (<5%) decays in order to reproduce pronounced Δ–peaks in π^+p and to avoid ρ-peak formation in the $\pi^+\pi^-$ mass distribution.

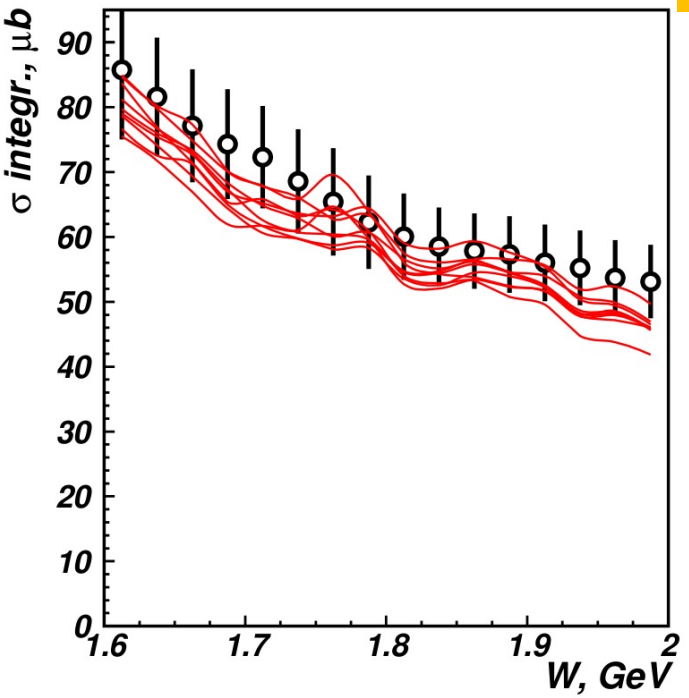
Description of the CLAS $\pi^+\pi^-p$ Photoproduction off Protons Data with/without the New State N'(1720)3/2$^+$

One-fold differential cross sections

W=1.71 GeV



Fully integrated cross sections



E.N. Golovach et al., CLAS Collaboration, Phys. Lett. B 788, 371 (2019).

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

N(1720)3/2$^+$ and N'(1720)3/2$^+$ ⟶ 1.19 < χ^2/d.p. < 1.28

N(1720)3/2$^+$ only ⟶ 1.08 < χ^2/d.p. < 1.26

Would it be possible to describe photo- and electroproduction data with Q^2-independent resonance masses and total and partial hadron decay widths?

Evidence for the Existence of the New State N'(1720)3/2$^+$ from Combined $\pi^+\pi^-$p Analyses in both Photo- and Electroproduction

V.I. Mokeev et al., Phys. Lett. B 805, 135457 (2020)

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

	BF($\pi\Delta$), %	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 ρp 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($\pi\Delta$), %	BF(ρp), %
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
Δ(1700)3/2$^-$ electroproduction photoproduction	 77-95 78-93	 3-5 3-6

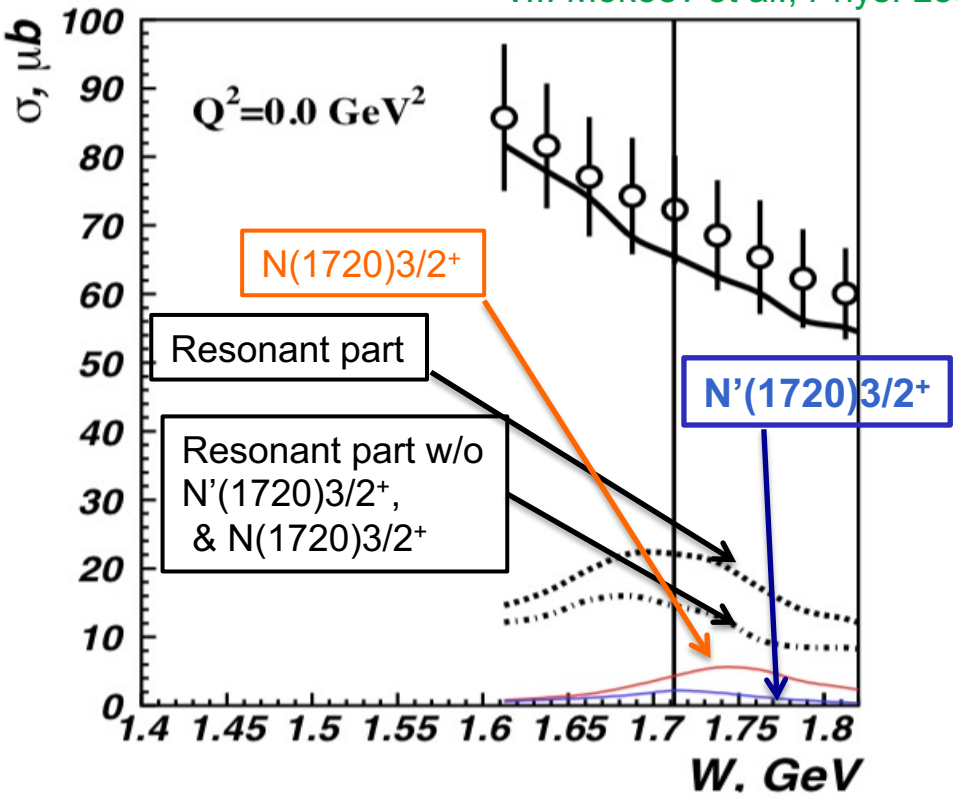
The successful description of the $\pi^+\pi^-$p photo- and electroproduction data achieved by implementing new N'(1720)3/2$^+$ state with Q^2-independent hadronic decay widths of all resonances contributing at W~1.7 GeV provides strong evidence for the existence of the new N'(1720)3/2$^+$ state.

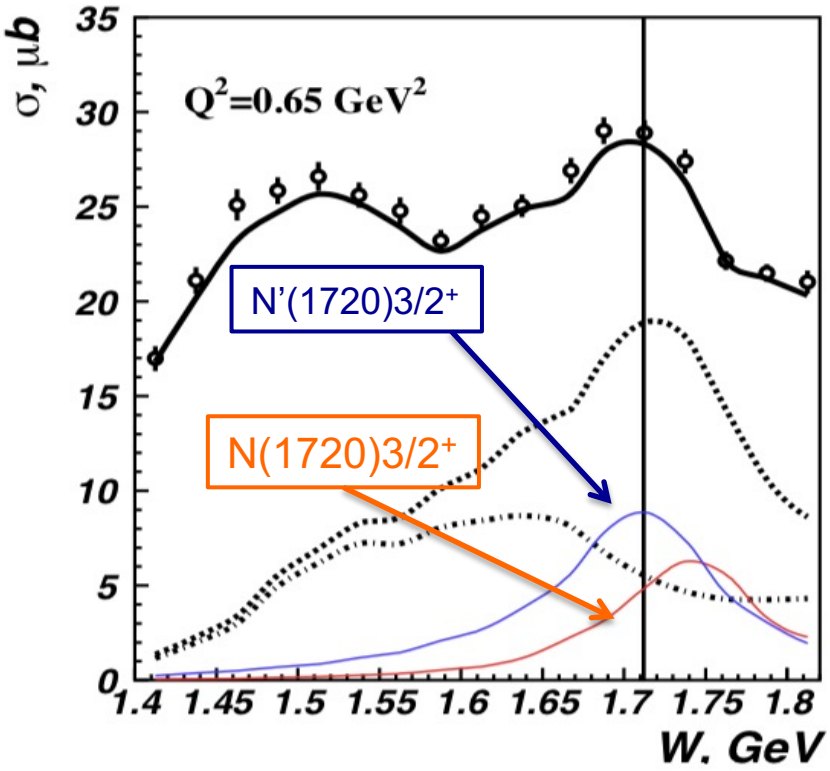
Newly Discovered N'(1720) 3/2$^+$

$\pi^+\pi^-$p photoproduction

$\pi^+\pi^-$p electroproduction

V.I. Mokeev et al., Phys. Lett. B 805, 135457 (2020)

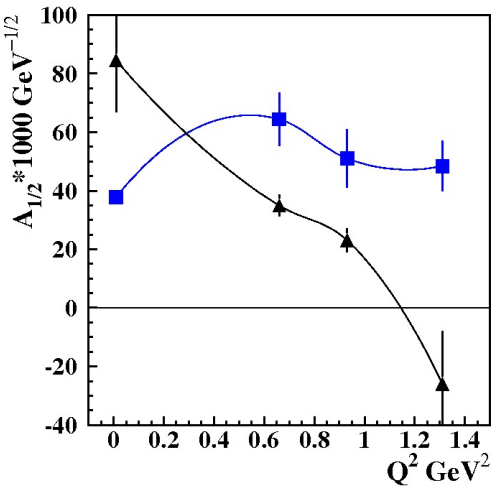


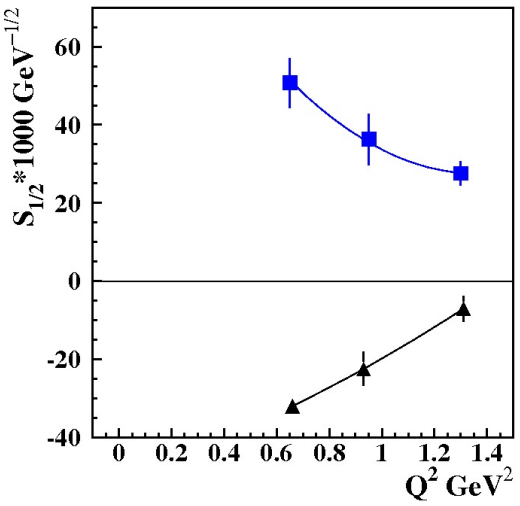


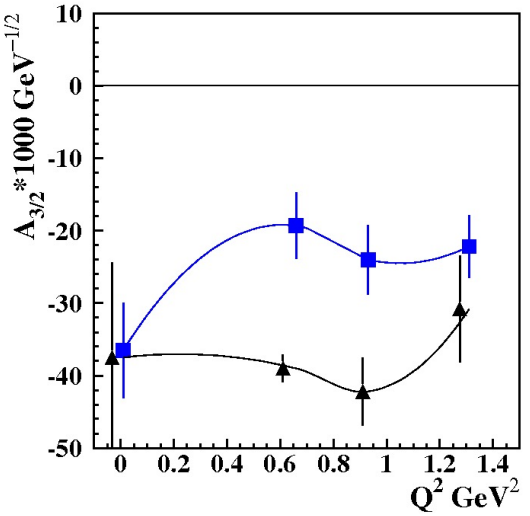
- Evidence of a new N'(1720) 3/2$^+$ resonance in the photo- and electroproduction of the $\pi^+\pi^-$p channel

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$^+$

N(1720)3/2$^+$

Resonance	Mass, GeV	Total width, MeV
N'(1720)3/2$^+$	1.715-1.735	120±6
N(1720)3/2$^+$	1.743-1.753	112±8

- 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.

SU(6)-Assignment for N'(1720)3/2$^+$ and N(1720)3/2$^+$

New resonances discovered from exclusive meson photoproduction data revealed the following pattern of the high-lying resonance spectrum under approximate SU(6)xO(3) symmetry

[70,2$^+$] multiplet

S_q=3/2 N(1880)1/2$^+$ N(1900)3/2$^+$ N(2000)5/2$^+$ N(2000)7/2$^+$

$M_{aver}(S_q=3/2)$=1.96 GeV. $\Delta M(S_q=3/2)$ =0.075 GeV

S_q=1/2 N'(1720)3/2$^+$ N(1860)5/2$^+$

$\Delta M(S_q=3/2\text{-}S_q=1/2)[70,2^+]=\Delta M(S_q=3/2\text{-}S_q=1/2)[70,1^-]$=0.16 GeV

$M_{aver}(S_q=1/2)= M_{aver}(S_q=3/2)- \Delta M(S_q=3/2\text{-}S_q=1/2)[70,2^+]$=1.96-0.16=1.80 GeV
$M(N'(1720)3/2^{+})= M_{aver}(S_q=1/2)- \Delta M(S_q=3/2)$=1.80-0.075=1.73 GeV consistent with the mass of N'(1720)3/2$^+$ inferred from the $\pi^+\pi^-$p photo-/electroproduction data.

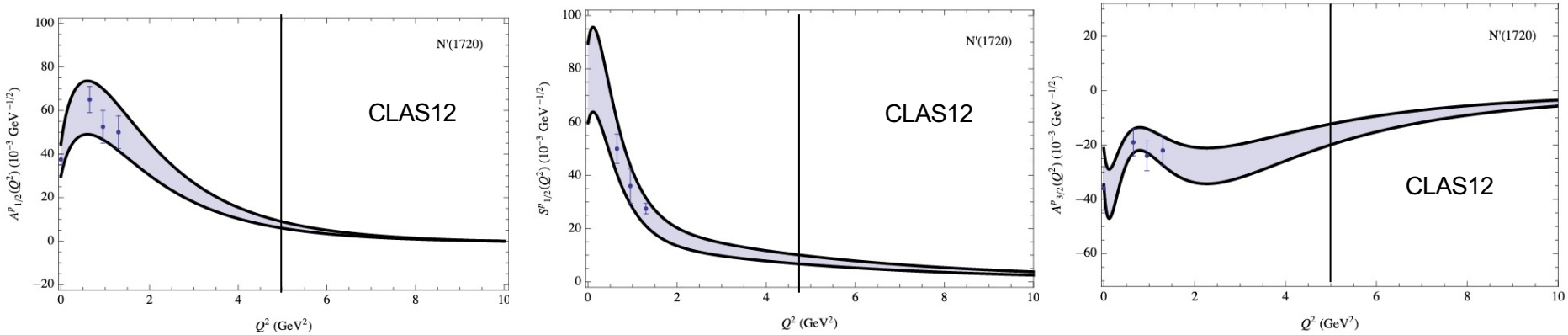
N'(1720)3/2$^+$: three constituent quarks of the total spin S_q=1/2 and of orbital momentum L=2 in [70,2$^+$] multiplet, double orbital excitation

N(1720)3/2$^+$: three constituent quarks of the total spin S_q=1/2 and of orbital momentum L=2 in [56,2$^+$] multiplet

Quark model evaluation of γ_vpN* electrocouplings under the aforementioned assignments for N(1720)3/2$^+$ and N'(1720)3/2$^+$ states will shed light on peculiar features in N'(1720)3/2$^+$ structure

Insight into the Structure of the New N'(1720)3/2$^+$

Soft wall Ads/CFT, V.E. Lyubovitskij and I. Schmidt, e-Print:2009.07115 [hep--ph]



$N \to N(1720)$	$g_{35}^{2A} = -11.58,\ g_{46}^{2A} = 34.50,\ g_{57}^{2A} = -22.60,\ g_{35}^{1B} = 79.15,\ g_{46}^{1B} = 67.11,\ g_{57}^{1B} = 29.95,$ $g_{35}^{1C} = -36.53,\ g_{46}^{1C} = 105.65,\ g_{57}^{1C} = -58.59,\ g_{35}^{1D} = 0.16,\ g_{46}^{1D} = -0.47,\ g_{57}^{1D} = 0.31,$ $g_{35}^{2E} = 12.14,\ g_{46}^{2E} = 10.29,\ g_{57}^{2E} = 4.59,\ g_{35}^{2F} = 5.56,\ g_{46}^{2F} = -16.07,\ g_{57}^{2F} = 8.91$
$N \to N'(1720)$	$g_{35}^{2A} = 30.18,\ g_{46}^{2A} = -54.02,\ g_{57}^{2A} = 24.82,\ g_{35}^{1B} = -1.15,\ g_{46}^{1B} = 6.41,\ g_{57}^{1B} = -2.87,$ $g_{35}^{1C} = -17.77,\ g_{46}^{1C} = 107.19,\ g_{57}^{1C} = -62.71,\ g_{35}^{1D} = 8.48,\ g_{46}^{1D} = -15.18,\ g_{57}^{1D} = 6.97,$ $g_{35}^{2E} = -0.60,\ g_{46}^{2E} = 3.37,\ g_{57}^{2E} = -1.51,\ g_{35}^{2F} = -3.57,\ g_{46}^{2F} = 21.56,\ g_{57}^{2F} = -12.61$

Leading/sub-leading contributions into N'(1720)3/2$^+$ and N(1720)3/2$^+$ are coming from the same/different AdS fields

- Checking [70,2$^+$] and [56,2$^+$] assignments for N'(1720)3/2$^+$ and N(1720)3/2$^+$, respectively (R.Bijker et al., Phys. Rev. D94, 074040 (2016), G.Ramalho, Few Body Syst. 59, 92 (2018)) from the results on γ_vpN* electrocouplings. If confirmed, discovery of N'(1720)3/2+ represents the first observation of the resonance with two non-zero orbital momenta l_λ and l_ρ in three quark system.
- Alternative assignment of N'(1720)3/2$^+$ as a member of 27-SU(3) baryon multiplet of chiral soliton model (G.-S. Yang and H.-C. Kim, PTEP, 093D01 (2019))

Conclusions and Outlook

- **New N'(1720)3/2$^+$ resonance has been observed in combined studies of $\pi^+\pi^-$p photo- and electroproduction data measured with CLAS in addition to several new, so-called ``missing" nucleon resonances, from exclusive meson photo- and hadroproduction data**

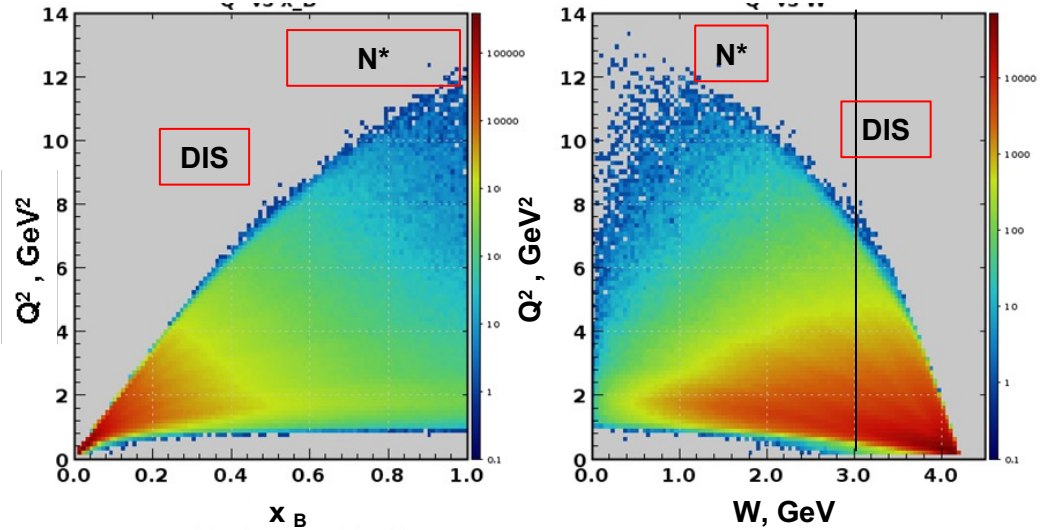
- **New N'(1720)3/2$^+$ state is the only ``missing" resonance for which the results on Q^2-evolution of γ_vpN* electrocouplings have become available. In the future, the information on the N'(1720)3/2$^+$ electrocouplings from the CLAS data will be extended towards Q^2 up to 5.0 GeV^2**

- **Combined studies of exclusive meson photo- and electroproduction will include the efforts on exploration of the N* spectrum with the CLAS12 detector including the hybrid-baryon search. The expected results are of particular importance in order to establish approximate strong QCD symmetries relevant of the N* spectrum generation, as well as to pin-down the exotic components in the N* structure.**

- **Analyses of the results on the new resonance electrocouplings in collaborative efforts with hadron structure theory will shed light on particular features of the ``missing" resonance structure which have made them so elusive for detection.**

Back Up

12 GeV Era with the CLAS12 Detector



Physics run started successfully in February 2018

N* studies at 0.05 GeV^2 < Q^2 < 7.0 GeV^2 with CLAS12

Hybrid Baryons E12-16-010	Search for hybrid baryons (qqqg) focusing on 0.05 GeV^2 < Q^2 < 2.0 GeV^2 in mass range from 1.8 to 3 GeV in KΛ, Nππ, Nπ *(A. D'Angelo, et al.)*
KY Electroproduction E12-16-010A	Study N* structure for states that couple to KY through measurements of cross sections and polarization observables that will yield Q^2 evolution of electrocoupling amplitudes at Q^2<7.0 GeV^2 *(D. Carman, et al.)*

Approved by PAC44

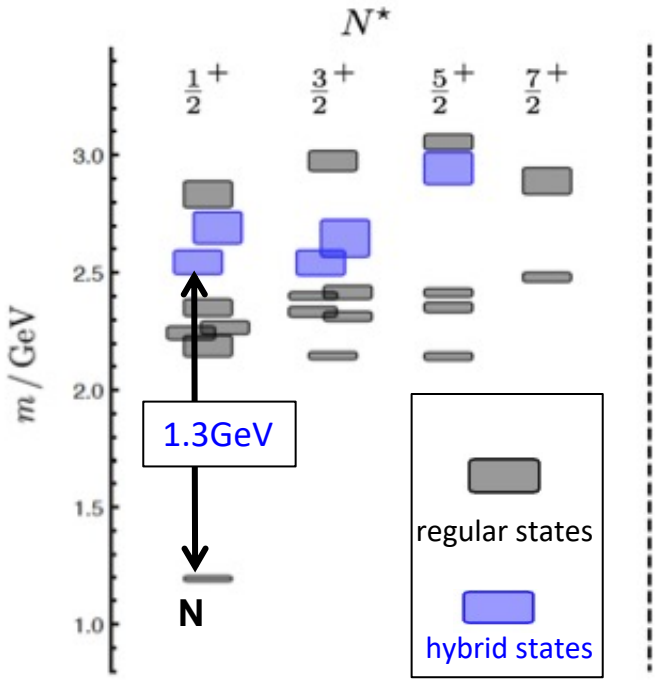
Run Group conditions:
E_b = 6.6 GeV, 50 days
E_b = 8.8 GeV, 50 days

- Polarized electrons, unpolarized LH_2 target
- L = 1x10^{35} cm^{-2}s^{-1}

Hunting for Glue in Excited Baryons with CLAS12

Can glue be a structural component to generate hybrid q^3g baryon states?

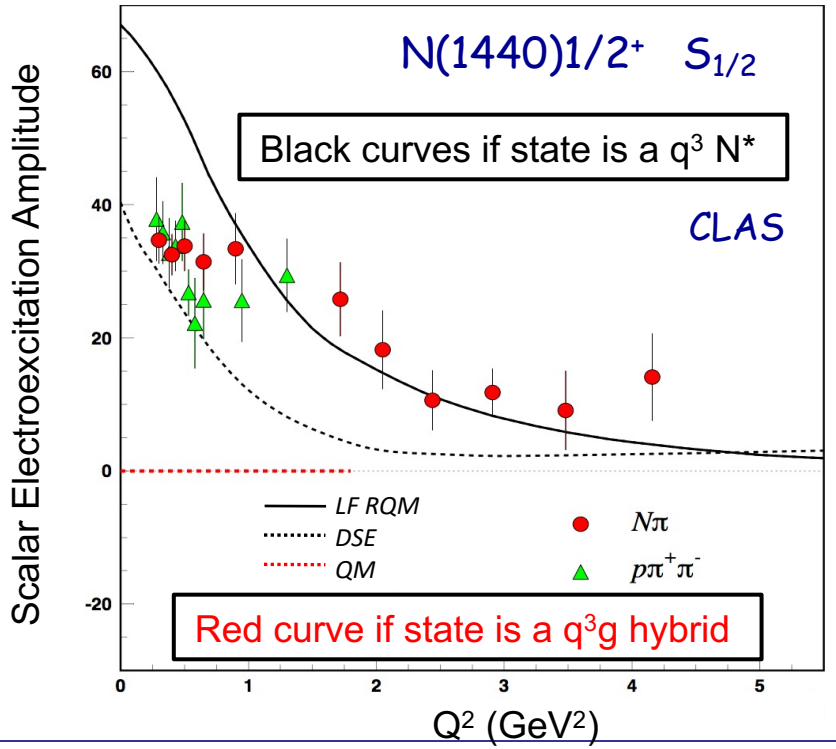
Predictions of the N* spectrum from QCD show both regular q^3 *and* hybrid q^3g states



JLab LQCD group results

Search for hybrid baryons with CLAS12 in exclusive KY and $\pi^+\pi^-$p electroproduction

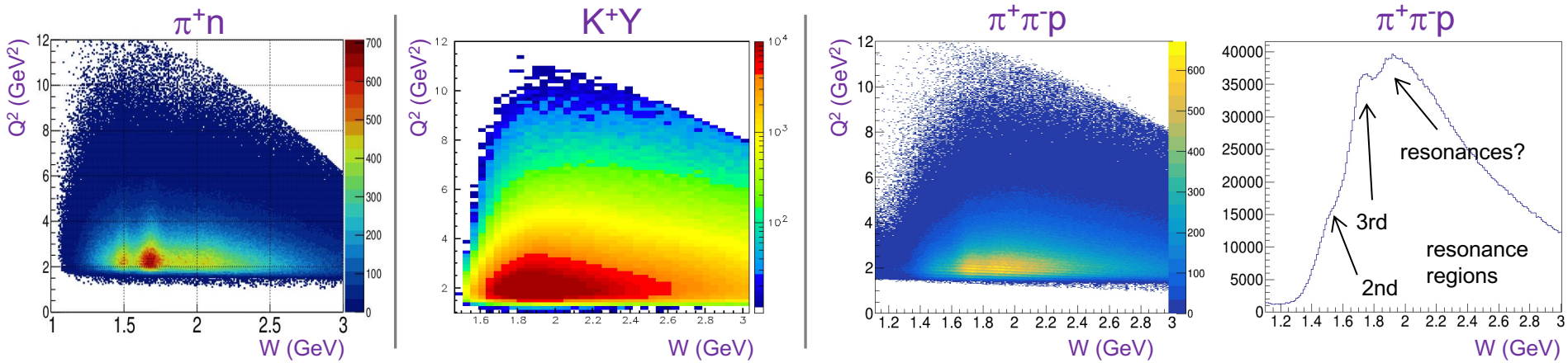
LQCD and/or QM predictions on Q^2 evolution of the hybrid-baryon electroexcitation amplitudes are critical in order to establish the nature of a baryon state



N* Electroexcitation to High Q^2 with CLAS12

Expected outcome: The first results on the $\gamma_v pN^*$ electrocouplings of most N* states from data in the range $W < 3.0$ GeV and $Q^2 > 5.0$ GeV^2 for exclusive reaction channels: πN, $\pi\pi N$, KY, K^*Y, KY^*

kinematic coverage for RG-A data @ 10.6 GeV



Expected events per Q^2/W bin for full RG-A dataset

π^+n			$K^+\Lambda$ & $K^+\Sigma^0$					$\pi^+\pi^-p$		
Q^2 [GeV^2]	W [GeV] 1.5-1.55	W [GeV] 1.7-1.75	Q^2 [GeV^2]	W_Λ [GeV] 1.7-1.75	W_Σ [GeV] 1.7-1.75	W_Λ [GeV] 1.9-1.95	W_Σ [GeV] 1.9-1.95	Q^2 [GeV^2]	W [GeV] 1.7-1.75	W [GeV] 1.9-1.95
			1.4-2.2	63417	6012	66564	33170			
			2.2-3.0	72144	5364	77443	28720			
5.2-5.8	15272	4175	3.0-4.0	52358	3945	51991	18936	5.2-5.8	2813	2808
5.8-6.5	10737	2637	4.0-5.0	24833	3103	26690	5925	5.8-6.5	1822	1969
6.5-7.2	7367	1684	5.0-6.0	11203	1598	11160	2642	6.5-7.2	1159	1294
7.2-8.1	4567	1290	6.0-7.0	5566	648	6300	943	7.2-8.1	661	924
8.1-9.1	2742	540	7.0-8.0	2606	338	3276	633	8.1-9.1	364	414
9.1-10.5	1453	194	8.0-9.0	1440	244	936	86	9.1-10.5	118	179

Collected data will extend the Q^2 range of the $\gamma_v pN^*$ electrocouplings to 8-10 GeV^2 for each of these channels