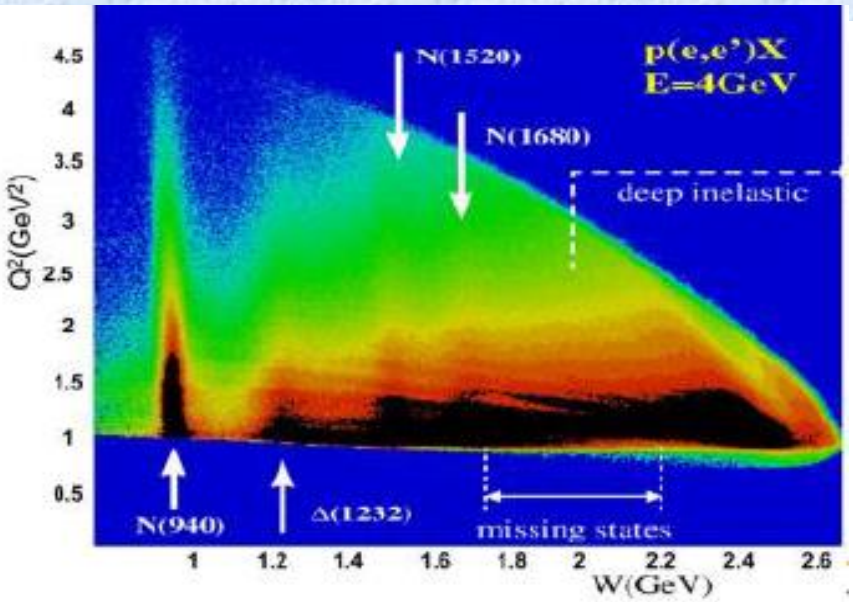
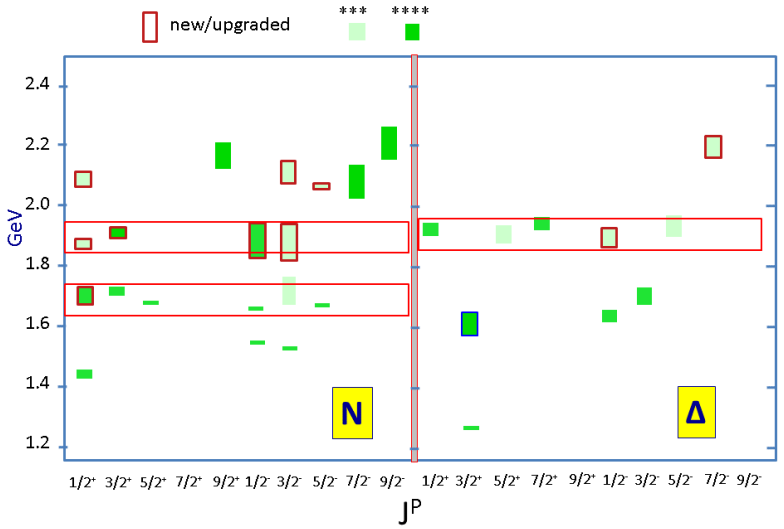
Spectrum and Structure of Excited Nucleons from Experiments with Electromagnetic Probes.





V.I. Mokeev,
Jefferson Laboratory

Talk outline:

- **N* spectrum from exclusive meson photoproduction**
- **$\gamma_v pN^*$ electrocouplings from CLAS data**
- **Insight to strong QCD from the N* stadies with the CLAS**
- **New opportunities in addressing strong QCD challenges from the N* studies with the CLAS12**

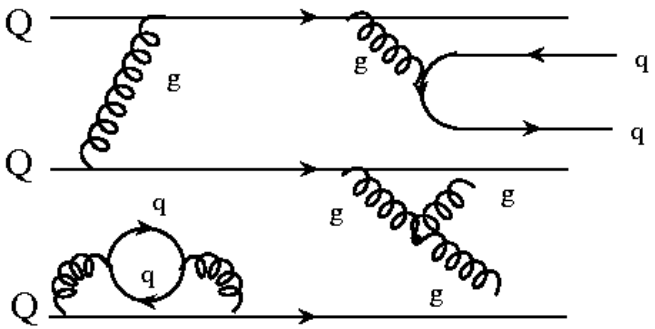
Office of Science

XV International Seminar on Electromagnetic Interactions of Nuclei
October 08-11, 2018, Moscow, Russia

The Ground Nucleon Structure and Evidence for the Excited State Spectrum

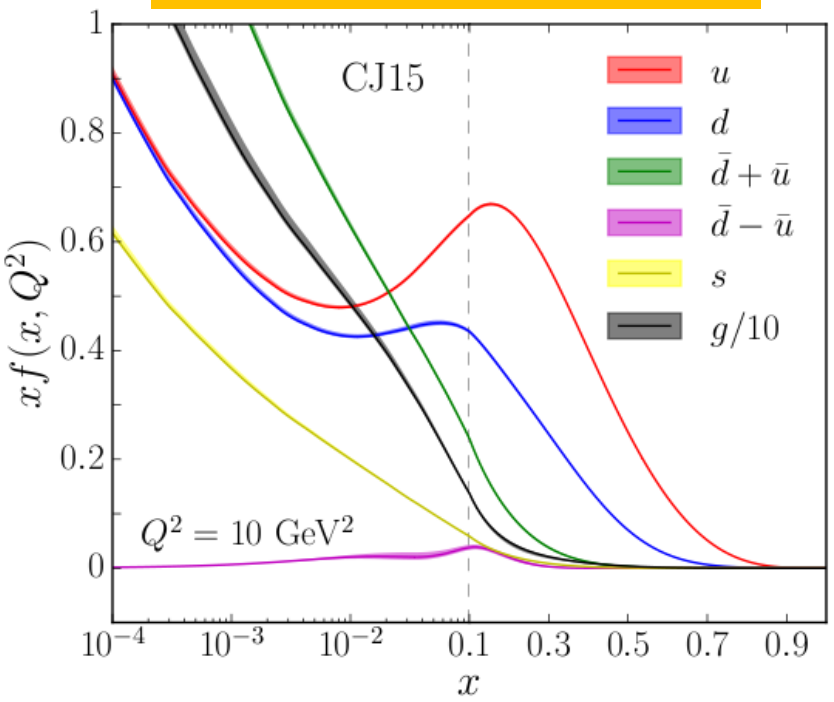
Nucleons and atomic nuclei account for most of the visible mass in the Universe

The structure of the nucleon ground states



Three valence current quarks (Q) embedded in a sea of gauge gluons (g) and quark+antiquark pairs

Parton distributions in the ground proton state



A. Accardi et al., PRD 93, 114017 (2016)

Particular features of nucleon structure:

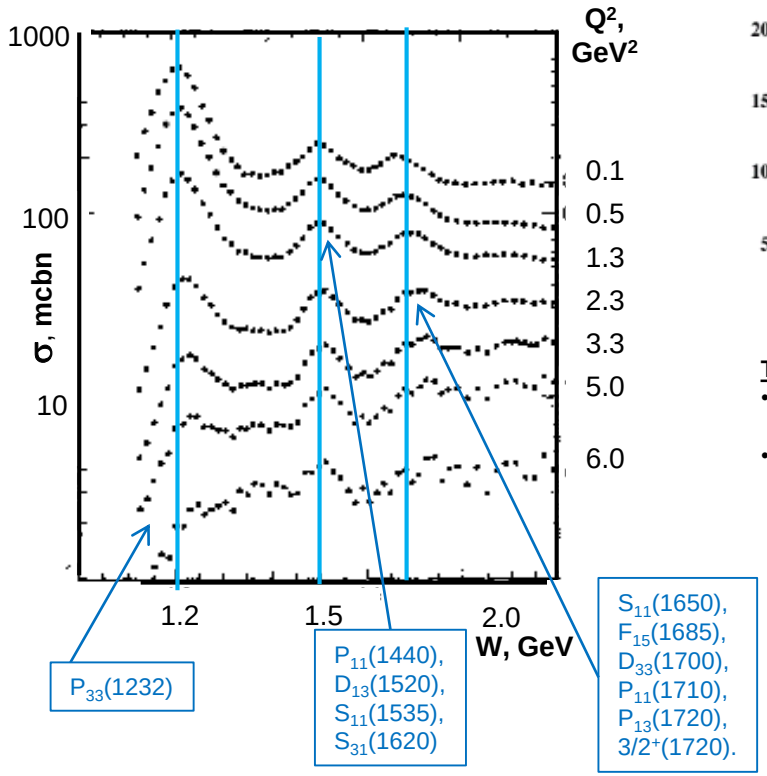
- **the current quarks and gauge gluons are in permanent creation/annihilation processes;**
- **relativistic objects moving with velocities comparable with the velocity of light;**
- **quarks and gluons are always confined inside the hadrons; they are never free.**

Such a complex composite system should possess a spectrum of excited states.

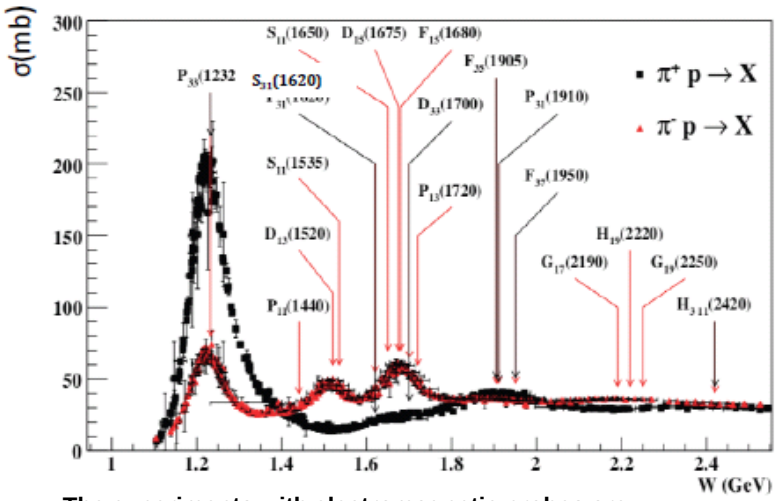
Nucleon Resonances (N*) in Inclusive Processes with Electron and Hadron Beams

Nucleon resonances in total virtual photon cross section

F. Foster and G.Hughes, Rep. Progr. Phys. 46, 1445 (1983).

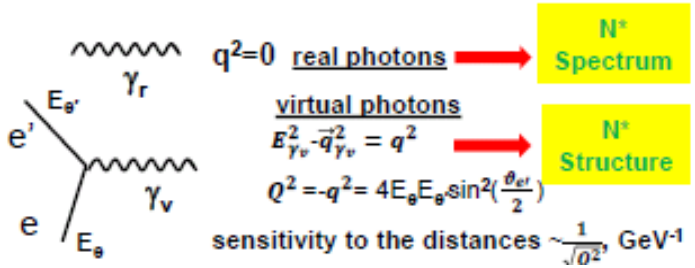


Nucleon resonances from hadroproduction data



The experiments with electromagnetic probes are:

- **the only source of information on the structure of excited nucleon states;**
- **promising tool for new baryon state search and high-lying resonance studies**

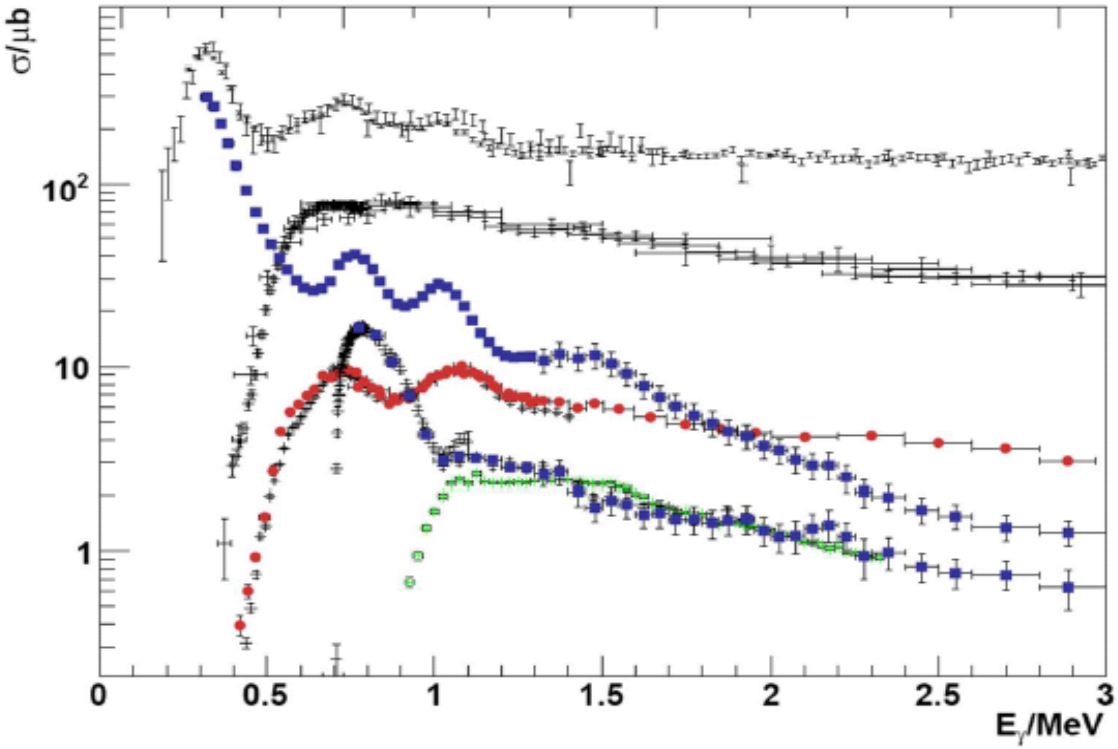


Exclusive Photoproduction in the Nucleon Resonance Region

Common effort at ELSA, JLab and MAMI.

Combination of continuous electron beams and detectors of ~4π 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.



$\gamma + p \to X$

$\gamma + p \to p + \pi^- + \pi^+$

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

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

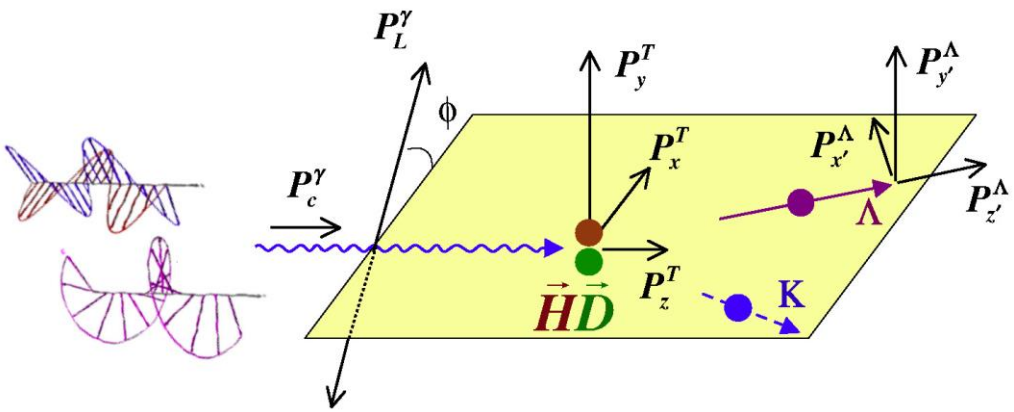
$\gamma + p \to K^+ + \Lambda$

$\gamma + p \to p + \eta$

Observables in 2-body Meson-Baryon Photoproduction Channels

[SHKL, J Phys G**38** (11) 053001]

Photon beam		***Target***			***Recoil***			***Target - Recoil***								
					x'	y'	z'	x'	x'	x'	y'	y'	y'	z'	z'	z'
		x	y	z				x	y	z	x	y	z	x	y	z
unpolarized	σ_0		T			P		$T_{x'}$		$L_{x'}$		Σ		$T_{z'}$		$L_{z'}$
$P_L^\gamma \sin(2\phi_\gamma)$		H		G	$O_{x'}$		$O_{z'}$		$C_{z'}$		E		F		$-C_{x'}$	
$P_L^\gamma \cos(2\phi_\gamma)$	$-\Sigma$		$-P$			$-T$		$-L_{z'}$		$T_{z'}$		$-\sigma_0$		$L_{x'}$		$-T_{x'}$
circular P_c^γ		F		$-E$	$C_{x'}$		$C_{z'}$		$-O_{z'}$		G		$-H$		$O_{x'}$	



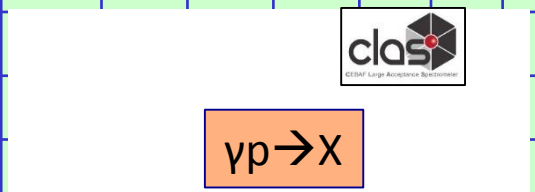
16 different observables

- ***They are described by different bi-linear combination of amplitudes***
- ***Fit of all observables combined offers rigorous constraints on reaction amplitude at real energy axis***

2-Body Photoproduction off Protons: Data and Analysis Approaches

✓ - *data acquired* ✓ - *analyzed/published*

Observable	σ	Σ	T	P	E	F	G	H	T_x	T_z	L_x	L_z	O_x	O_z	C_x	C_z
$p\pi^0$	✓	✓	✓		✓	✓	✓	✓								
$n\pi^+$	✓	✓	✓		✓	✓	✓	✓								
$p\eta$	✓	✓	✓		✓	✓	✓	✓								
$p\eta'$	✓	✓	✓		✓	✓	✓	✓								
$K^+\Lambda$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$K^+\Sigma^0$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$K^{+*}\Lambda$	✓			✓					SDME							
$K^{0*}\Sigma^+$	✓	✓									✓	✓	SDME			



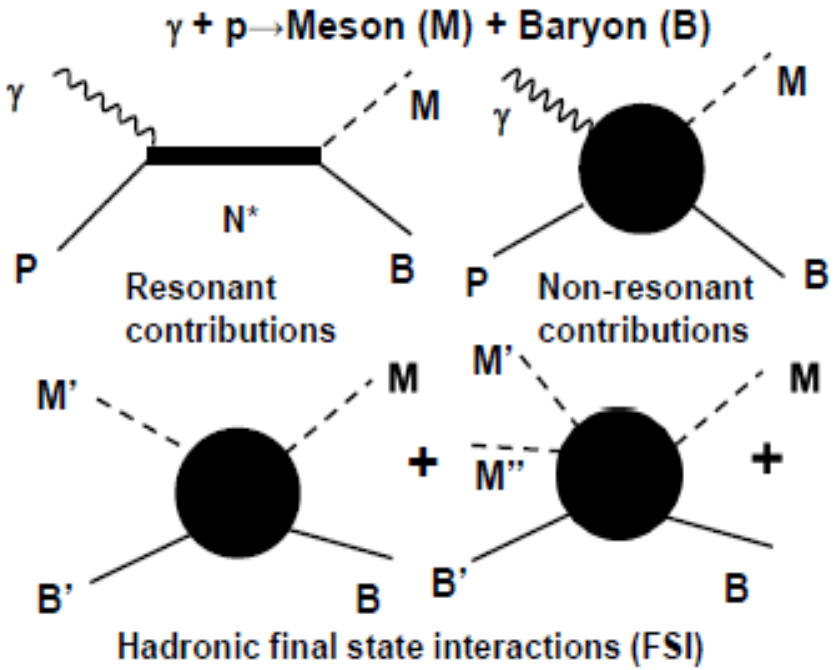
Coupled-channel approaches for N* parameters extraction from exclusive meson photoproduction off protons data

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).

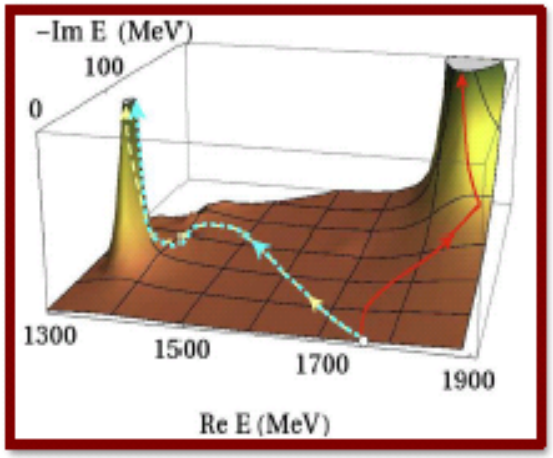
GWU-Julich D. Rönchen et al., Eur. Phys. J. A51, 70 (2015).
D. Rönchen et al., Eur. Phys. J. A50, 101 (2014).

Connecting Nucleon Resonance Properties to the Photoproduction Observables



Breit-Wigner parameterization and the amplitude poles:

$$T_{res} = \frac{T(R \to MB)\,T(\gamma p \to R)}{M_{N^*}^2 - W^2 - i\Gamma_{N^*}(W)\,M_{N^*}}$$



- 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-/hadro-production channels.
- Make analytical continuation of reaction amplitudes into the complex energy plane and:

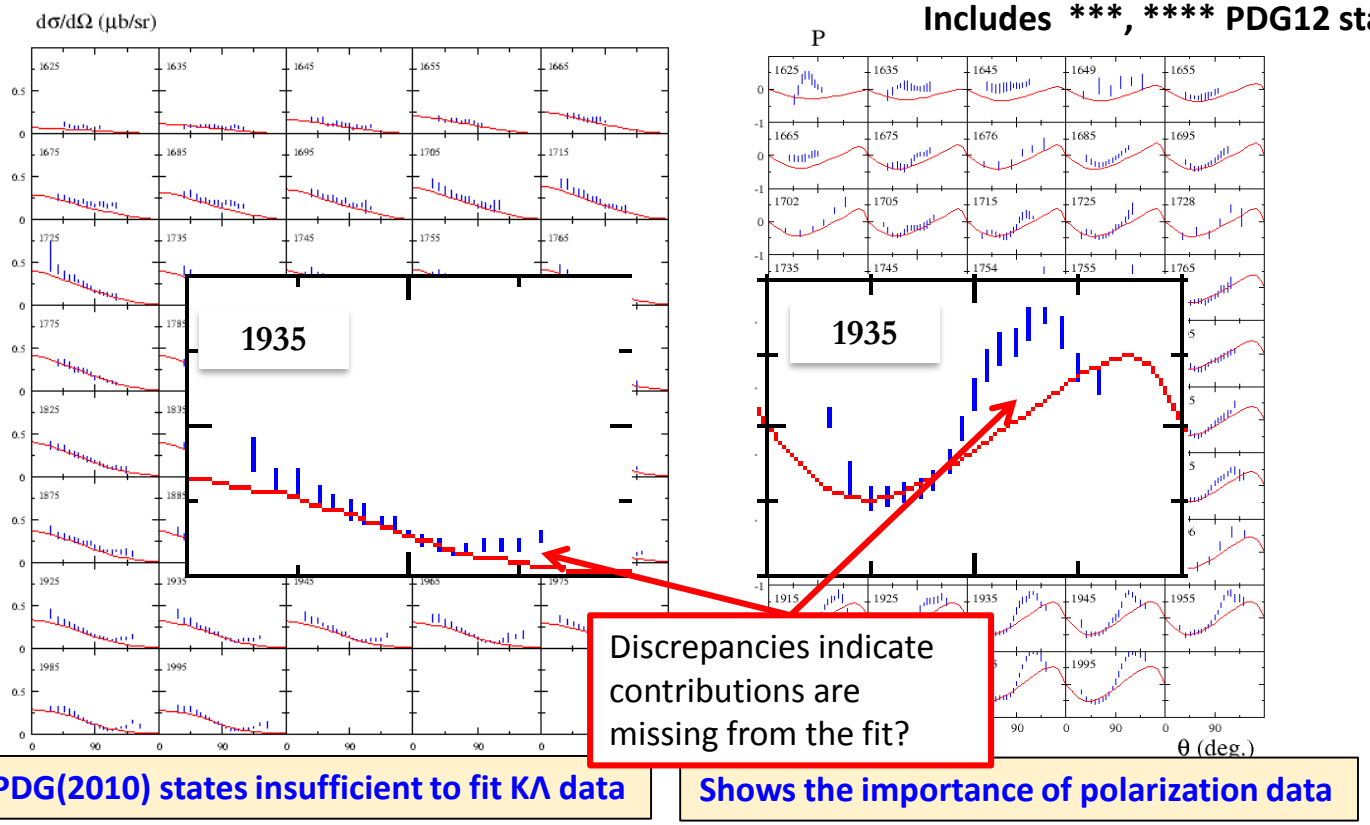
a) locate poles ⇒ Resonance masses (M_{N^*}) and total widths (Γ_{N^*}) ;
b) determine residues ⇒ Resonance photocouplings and partial hadronic decay widths.

Establishing the N* spectrum

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

ANL-Osaka 8 coupled-channel analysis

Includes *, **** PDG12 states**



Discrepancies indicate contributions are missing from the fit?

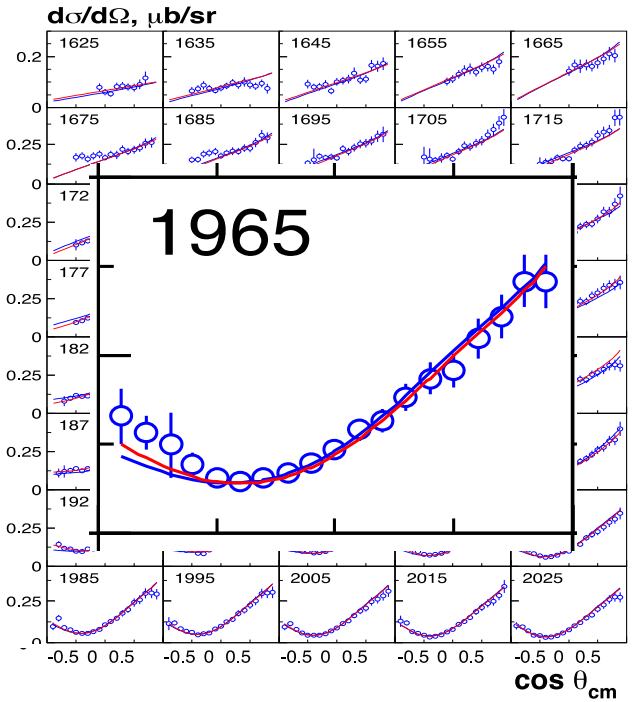
PDG(2010) states insufficient to fit KΛ data

Shows the importance of polarization data

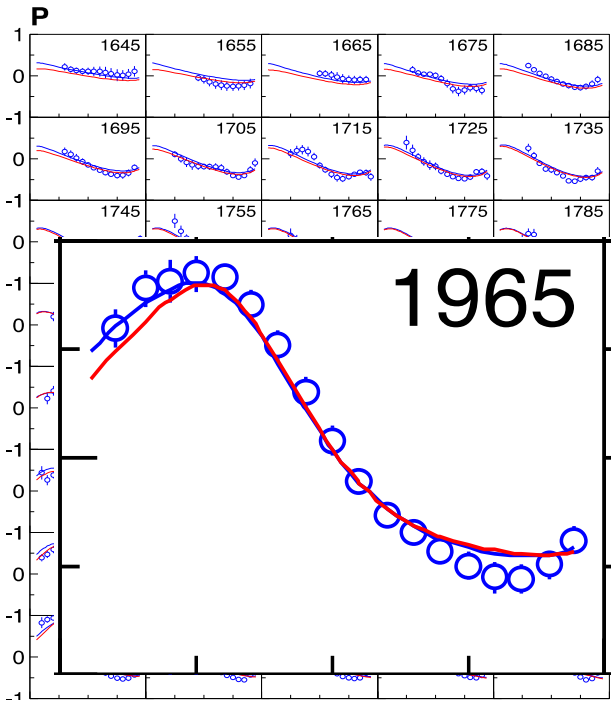
Establishing the N* spectrum, cont'd

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

Bonn-Gatchina multichannel analysis:
9 new resonances were included



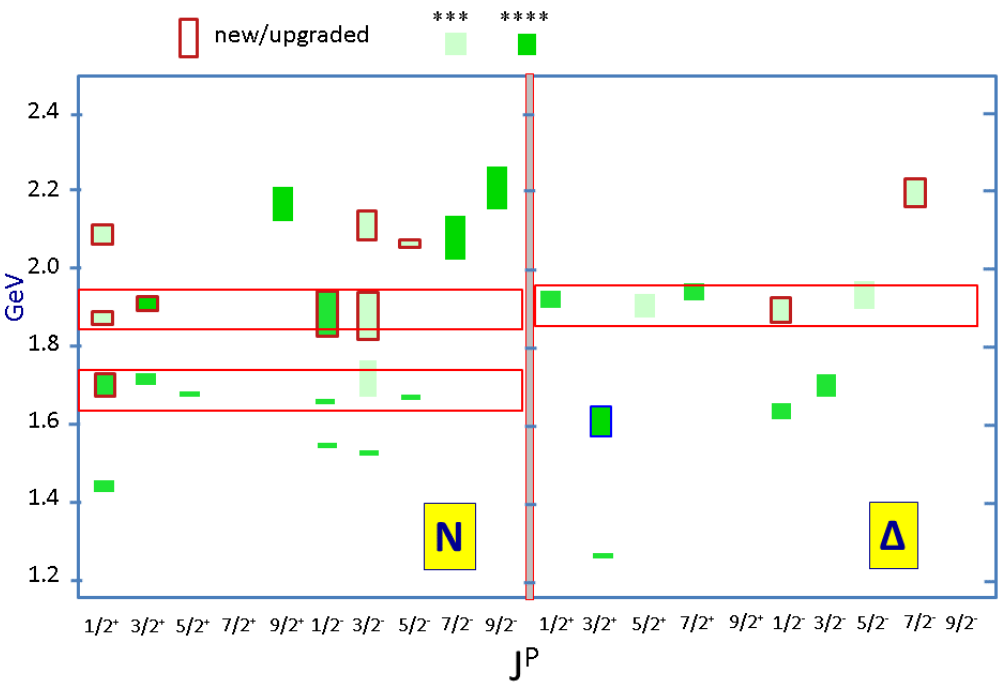
M. McCracken et al. (CLAS), Phys. Rev C 81, 025201 (2010)



A.V. Anisovich et al, EPJ A48, 15 (2012)

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

N^*/Δ^* Spectrum 2018

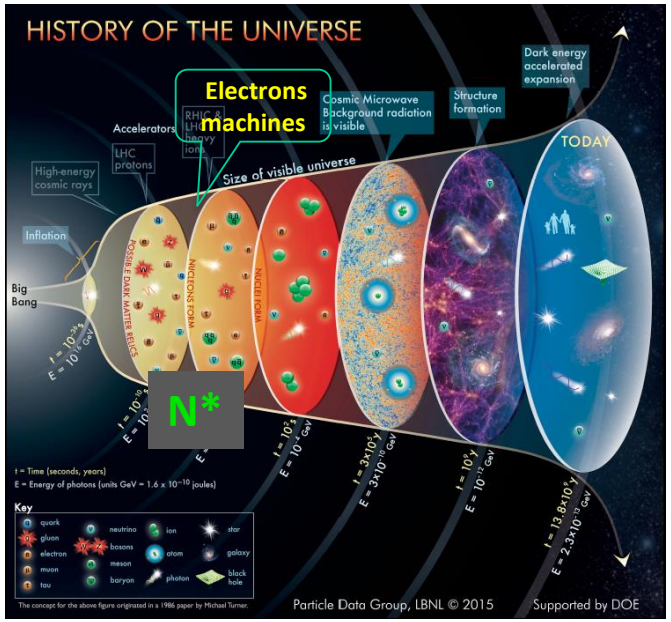


Nucleon resonances listed in Particle Data Group (PDG) tables

State $N(mass)J^P$	PDG pre 2012	PDG 2018*
$N(1710)1/2^+$	***	****
$N(1880)1/2^+$		***
$N(1895)1/2^-$		****
$N(1900)3/2^+$	**	****
$N(1875)3/2^-$		***
$N(2100)1/2^+$	*	***
$N(2120)3/2^-$		***
$N(2000)5/2^+$	*	**
$N(2060)5/2^-$		***
$\Delta(1600)3/2^+$	***	****
$\Delta(1900)1/2^-$	**	***
$\Delta(2200)7/2^-$	*	***

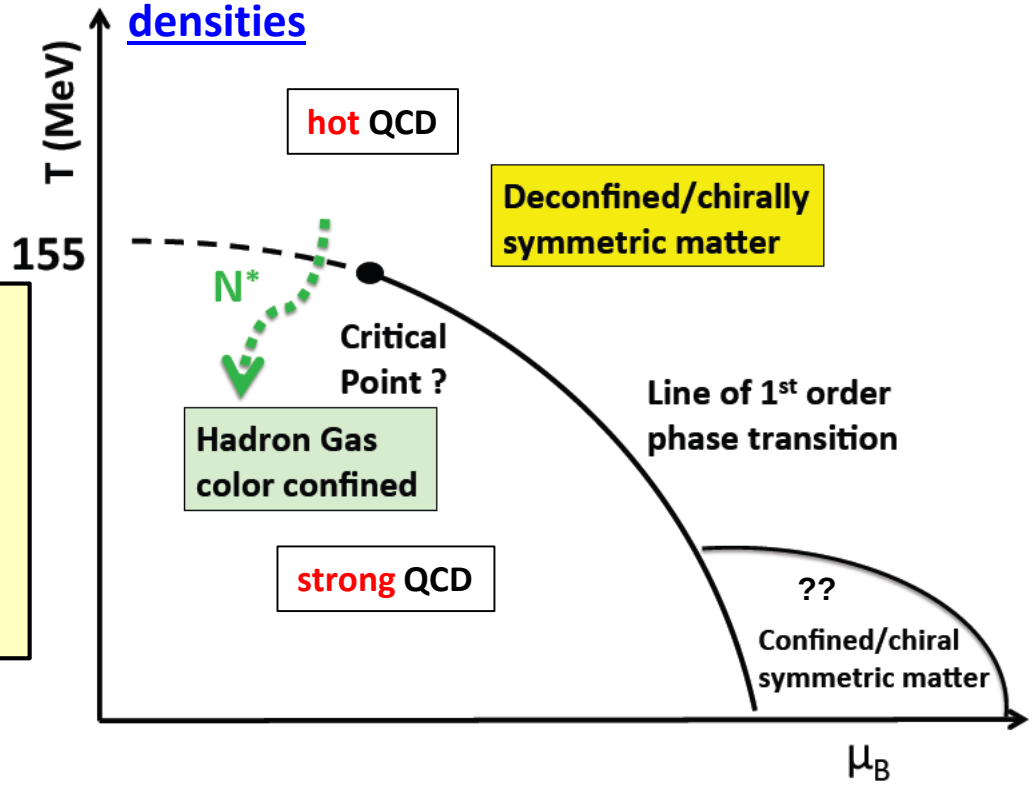
Description of the exclusive electroproduction off protons data with the same as in photoproduction masses and hadronic decay widths will validate the existence of new baryon states

Nucleon Resonances in the History of the Universe



- Chiral symmetry is broken
- Quarks acquire mass
- Baryon resonances occur
- Quark-gluon confinement emerges

- **Dramatic events occur in the micro-second old universe during the transition from the QGP phase to hadron phase.**
- **Full baryon spectrum shaped this transition.**
- **Studies at NICA facility in Dubna will elucidate the transition at high baryon densities**



From the N* Structure to Strong QCD Dynamics in Experiments with CLAS/CLAS12

The experimental program on the studies of N* structure in exclusive meson electroproduction with CLAS/CLAS12 seeks to determine:

- $\gamma_v pN^*$ electrocouplings at photon virtualities up to 5.0 GeV^2 for most of the excited proton states through analyzing major meson electroproduction channels from the CLAS data
- extend accessible Q^2 range up to 12 GeV^2 from the CLAS12 data and explore N* structure evolution in the transition from the strong and pQCD regimes
- explore hadron mass emergence by mapping out dynamical quark mass in the transition from almost massless pQCD quark to fully dressed constituent quark

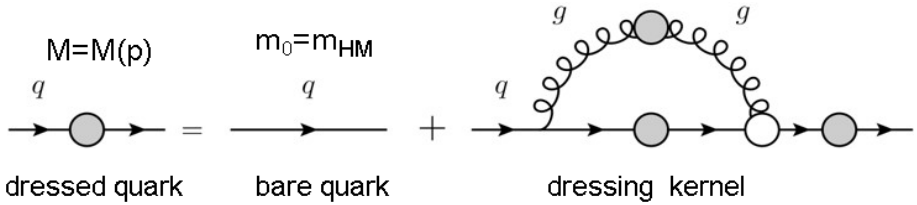
A unique source of information on many facets of strong QCD in generating excited nucleon states with different structural features

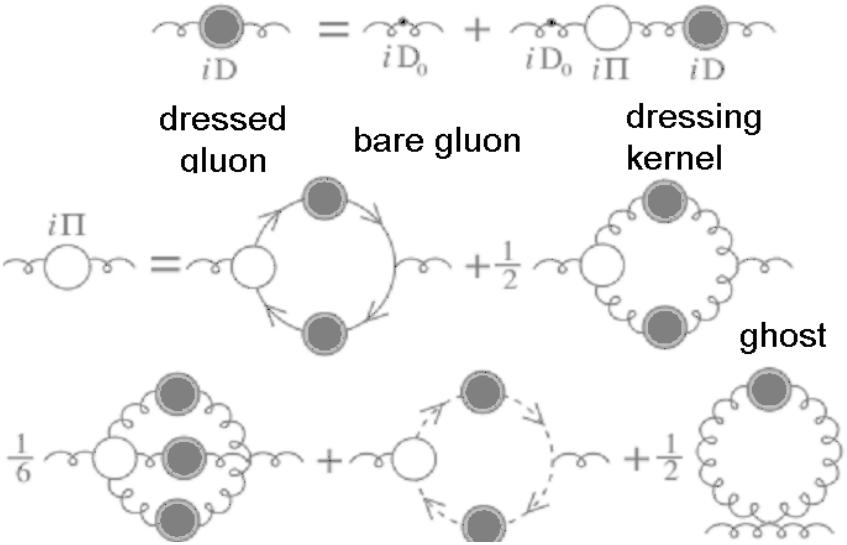
Review papers:

1. I.G. Aznauryan and V.D. Burkert, Prog. Part. Nucl. Phys. 67, 1 (2012).
2. V.D. Burkert and C.D. Roberts, arXiv:1710.02549 [nucl-ex].
3. C.D. Roberts, Few Body Syst. 59, 72 (2018).
4. C.D. Roberts, Few Body Syst. 58, 5 (2017).

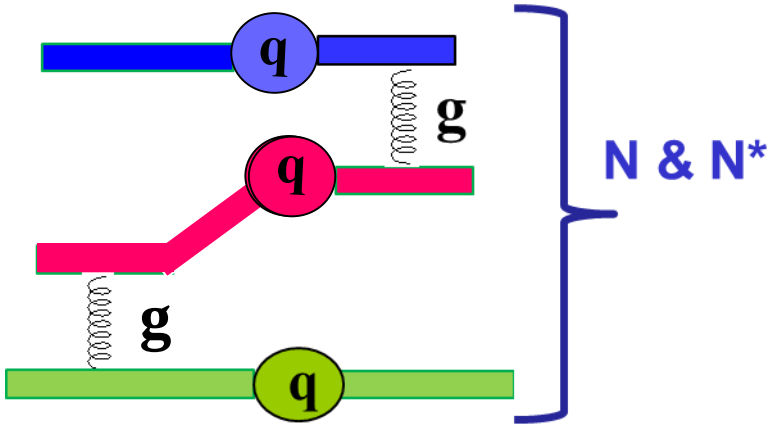
Excited Nucleon States and Insight into Strong QCD Dynamics

Emergence of Dressed Quarks and Gluons
D. Binosi et al, Phys. Rev. D95, 031501 (2017)

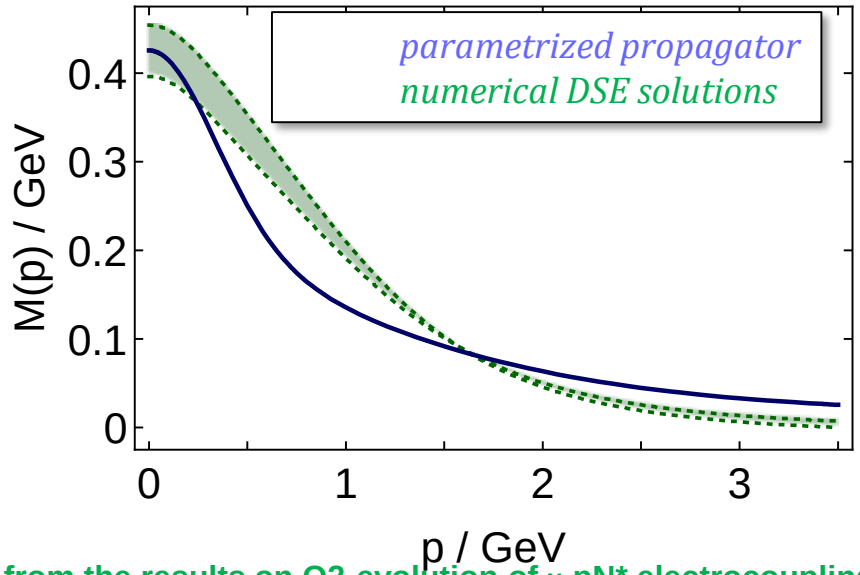




Dressed Quark Borromeo Binding in Baryons
Ch. Chen et al, Phys. Rev. D97, 034016 (2018)



Dressed Quark Mass Function
C.D. Roberts, Few Body Syst. 58, 5 (2017)



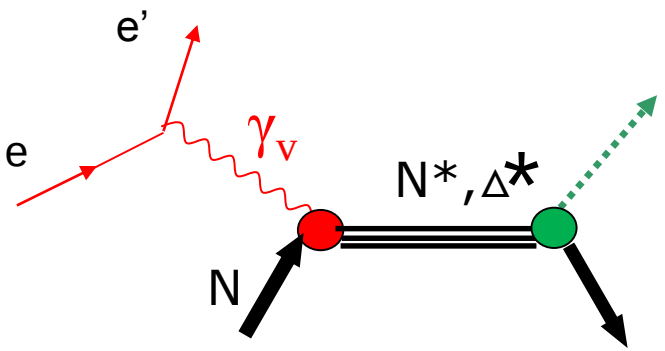
N* structure studies address:

- **Nature of > 98% of hadron mass**
- **Confinement and color charge emergence from QCD**

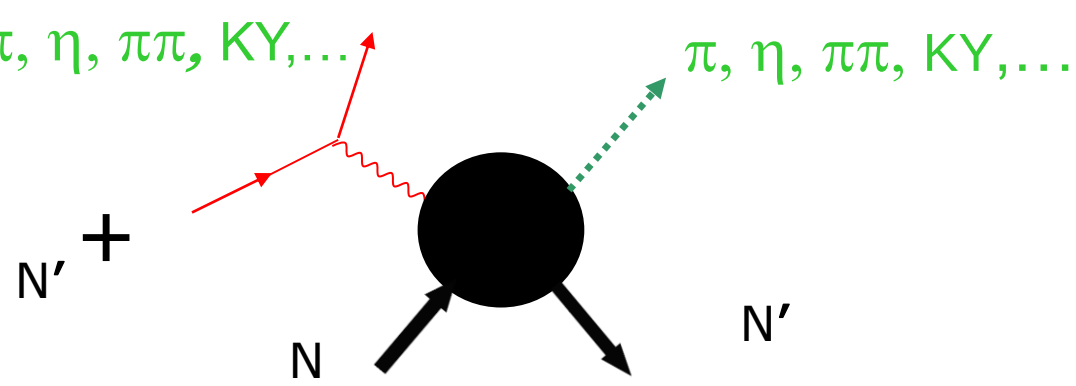
Accessible from the results on Q2-evolution of $\gamma_v pN^*$ electrocouplings

Extraction of γ_vNN* Electrocouplings from Exclusive Meson Electroproduction off Nucleons

Resonant amplitudes



Non-resonant amplitudes



Definition of N* photo-/electrocouplings employed in the CLAS data analyses:

- **Real $A_{1/2}(Q^2)$, $A_{3/2}(Q^2)$, $S_{1/2}(Q^2)$**

I.G. Aznauryan and V.D. Burkert, Prog. Part. Nucl. Phys. 67, 1 (2012).

$$\Gamma_\gamma = \frac{k^2_{\gamma_{N^*}}}{\pi} \frac{2M_N}{(2J_r+1)M_{N^*}} \left[|A_{1/2}|^2 + |A_{3/2}|^2 \right]$$

- **Consistent results on γ_vpN* electrocouplings from different meson electroproduction channels are critical in order to validate reliable extraction of these quantities.**

Summary of Published/Submitted CLAS Data on Exclusive Meson Electroproduction off Protons in N* Excitation Region

Hadronic final state	Covered W-range, GeV	Covered Q^2-range, GeV^2	Measured observables
π^+n	**1.1-1.38** **1.1-1.55** **1.1-1.7** **1.6-2.0**	**0.16-0.36** **0.3-0.6** **1.7-4.5** **1.8-4.5**	**$d\sigma/d\Omega$** **$d\sigma/d\Omega$** **$d\sigma/d\Omega$, A_b** **$d\sigma/d\Omega$**
π^0p	**1.1-1.38** **1.1-1.68** **1.1-1.39**	**0.16-0.36** **0.4-1.8** **3.0-6.0**	**$d\sigma/d\Omega$** **$d\sigma/d\Omega$, A_b,A_t,A_{bt}** **$d\sigma/d\Omega$**
ηp	**1.5-2.3**	**0.2-3.1**	**$d\sigma/d\Omega$**
$K^+\Lambda$	**thresh-2.6**	**1.40-3.90** **0.70-5.40**	**$d\sigma/d\Omega$** **P^0, P'**
$K^+\Sigma^0$	**thresh-2.6**	**1.40-3.90** **0.70-5.40**	**$d\sigma/d\Omega$** **P'**
$\pi^+\pi^-p$	**1.3-1.60** **1.4-2.10** **1.4-2.00** **1.3-1.83** **1.6-2.00**	**0.2-0.6** **0.5-1.5** **2.0-5.0** **0.4-1.0** **0.**	**Nine 1-fold differential cross sections**

- $d\sigma/d\Omega$–CM angular distributions
- A_b,A_t,A_{bt}-longitudinal beam, target, and beam-target asym-metries
- P^0, P' –recoil and transferred polarization of strange baryon

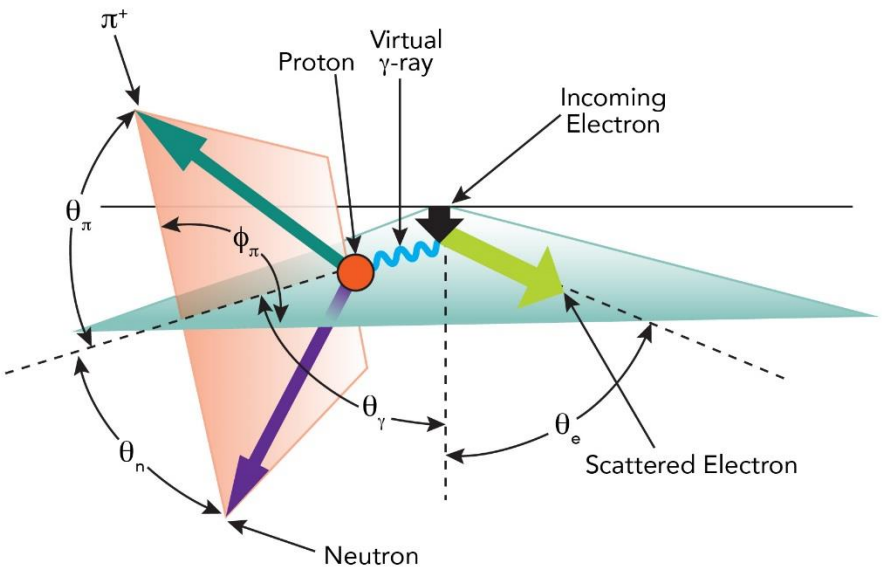
Over 140,000 data points!

Almost full coverage of the final hadron phase space

The measured observables from CLAS are stored in the CLAS Physics Data Base: http://clas.sinp.msu.ru/cgi-bin/jlab/db.cgi

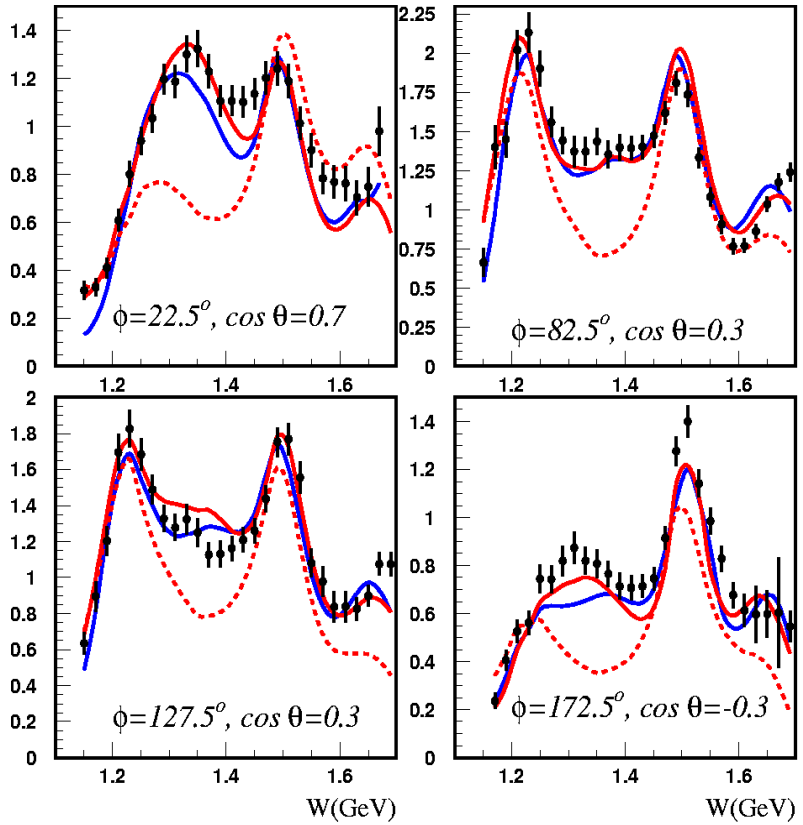
Accessing Resonance Electrocouplings from the π^+n Differential Electroproduction Cross Sections off Protons

Kinematics of exclusive π^+n electroproduction off protons (lab frame)



Q^2=2.05 GeV^2

DR
DR w/o P11
UIM

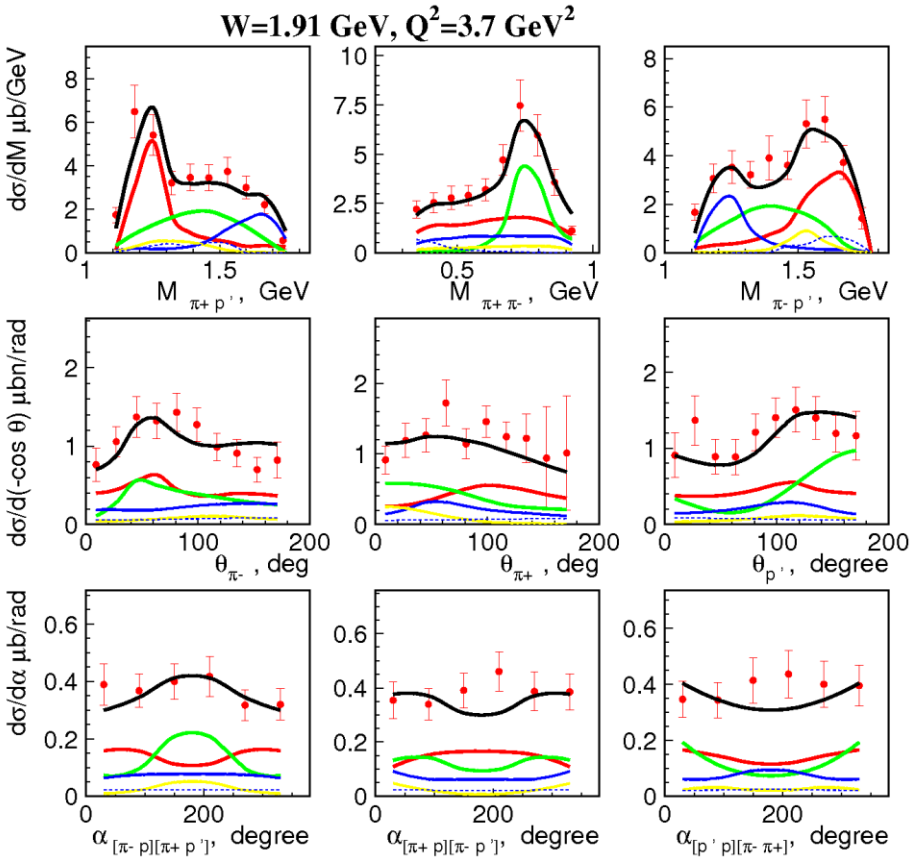


The final pion angles are in the CM-frame of the final hadrons

Accessing Resonance Electrocouplings from the $\pi^+\pi^-p$ Differential Electroproduction Cross Sections off Protons

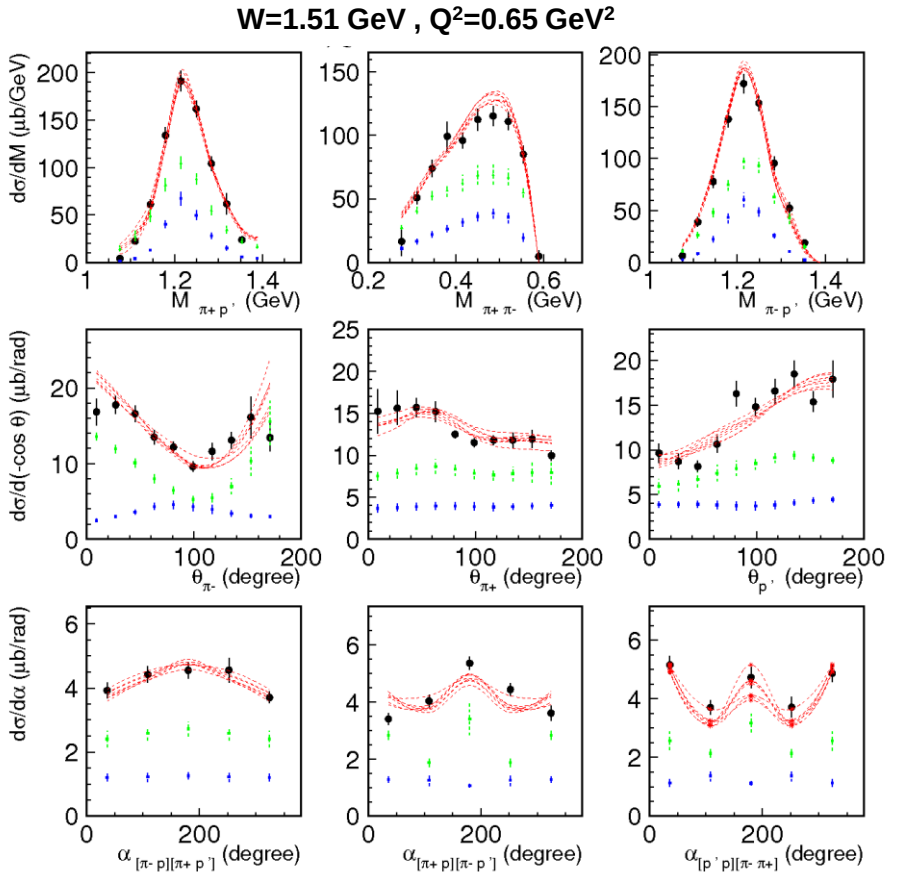
Contributing mechanisms seen in the data

E. Isupov et al. (CLAS), Phys. Rev. C96, 025209 (2017)



Resonant and non-resonant contributions

V.I. Mokeev et al., Phys. Rev. C93, 054016 (2016)



full JM — ρp — π^+ N(1520)3/2$^-$ — data fit within JM under variations of both resonant and background parameters

$\pi^-\Delta^{++}$ — $\pi^+\Delta^0$ — π^+ N(1680)5/2$^+$ — background cross sections

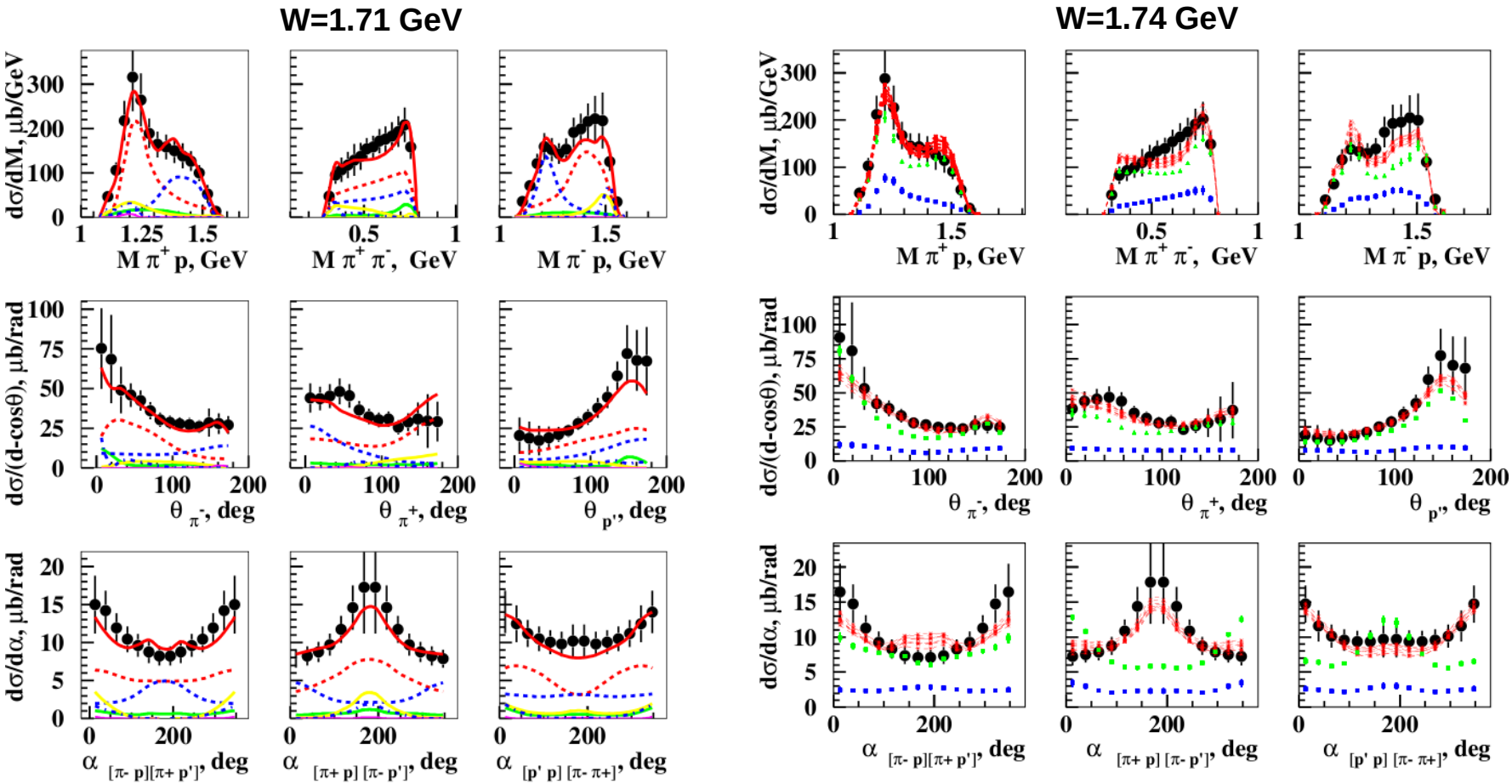
resonant cross sections

$\pi^+\pi^-p$ Differential Photoproduction Cross Sections off Protons in the Resonance Region

Contributing mechanisms seen in the data

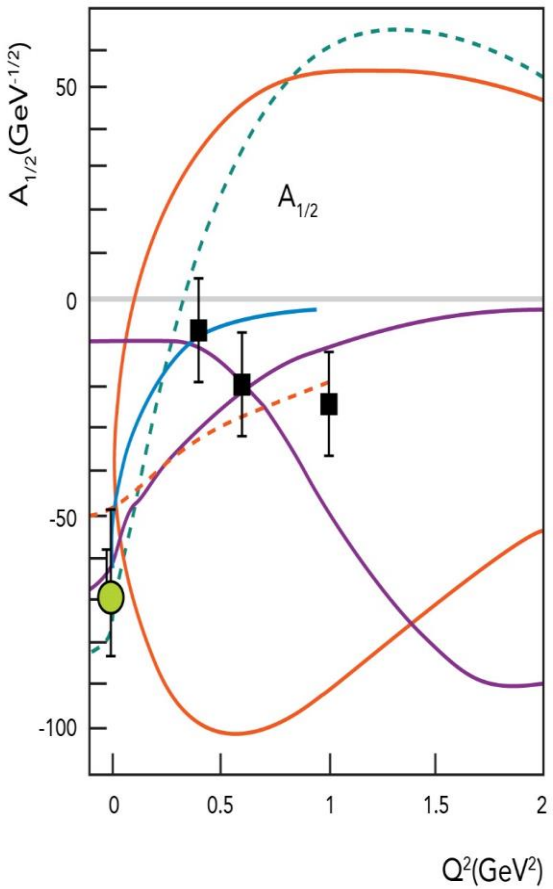
Resonant and non-resonant contributions

E. Golovatch et al. (CLAS), arXiv:1806.01767 [nucl-ex] submitted to Phys. Lett B



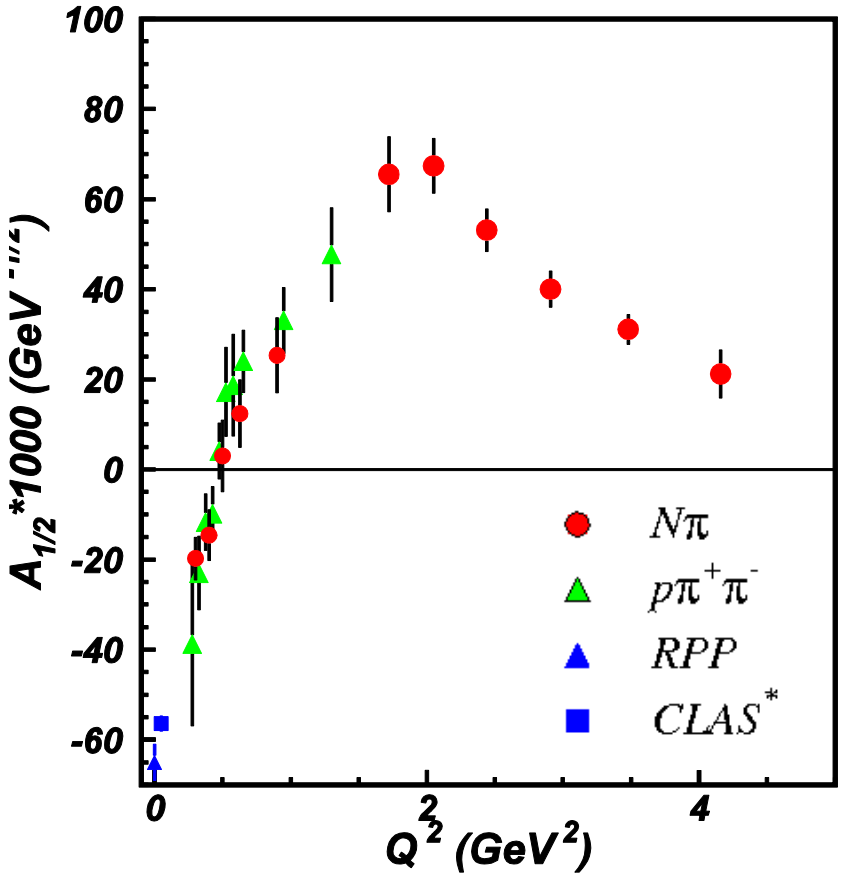
Roper Resonance in 2002 & 2018

2002



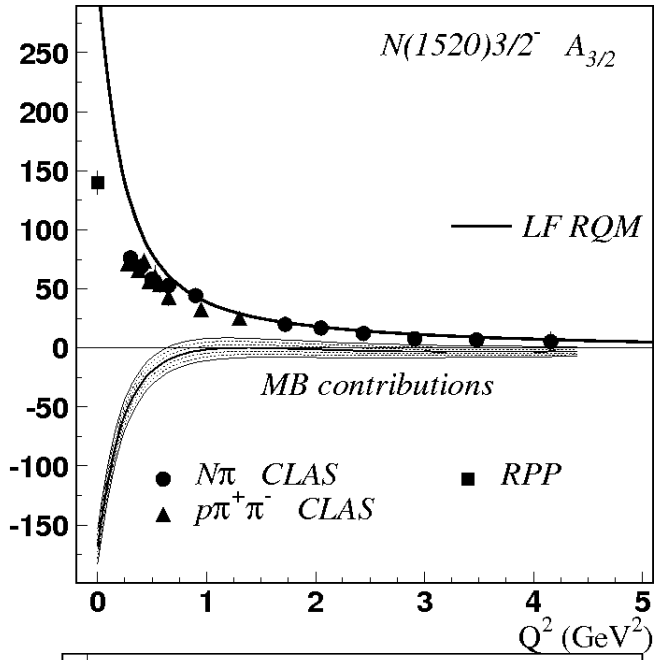
V. D. Burkert, Baryons 2002

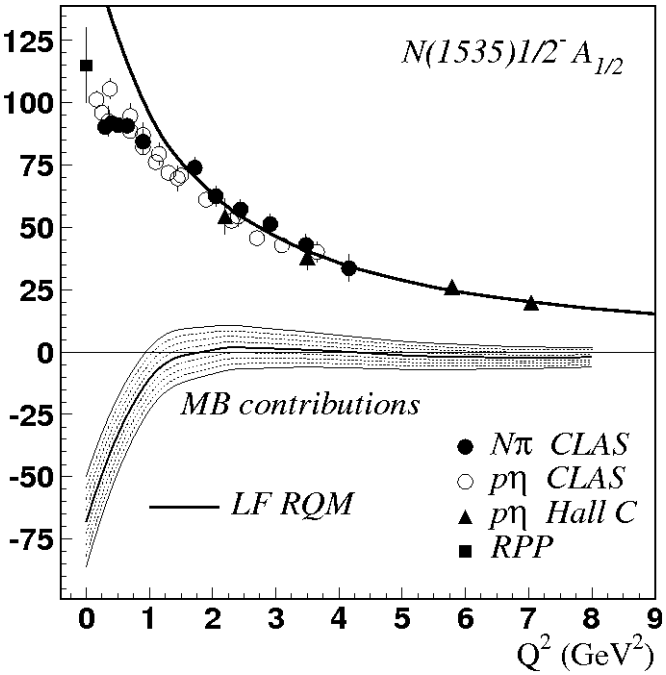
2018

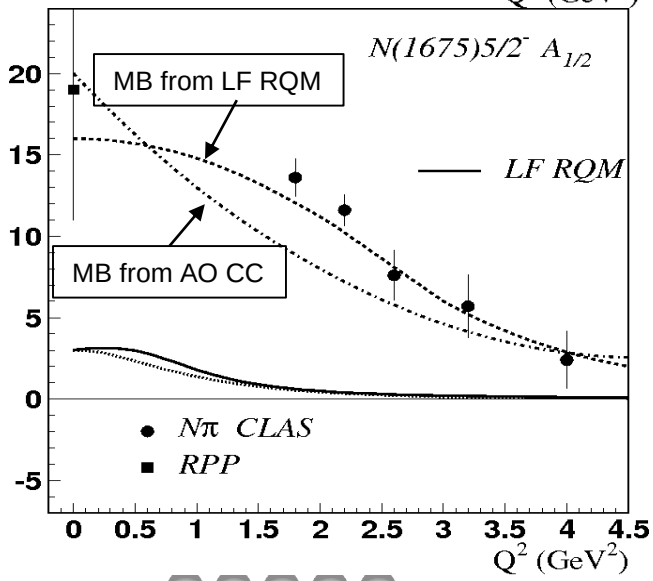


V. D. Burkert, Baryons 2016

$\gamma_v pN^*$ Electrocouplings from $N\pi$, $N\eta$, and $\pi^+\pi^- p$ Electroproduction







CLAS data points from:
I.G. Aznauryan et al., Phys. Rev. C80, 055203 (2009).
K. Park et al., Phys. Rev. C91, 045203 (2015).
V.I. Mokeev et al., Phys. Rev . C86, 035203 (2012).
V.I. Mokeev et al., Phys. Rev.. C93, 025206 (2016).

LF RQM:
I.G. Aznauryan and V.D. Burkert, Phys. Rev. C95, 065207 (2017).
AO CC:
B. Julia-Diaz et al., Phys. Rev. C77, 045205 (2008).

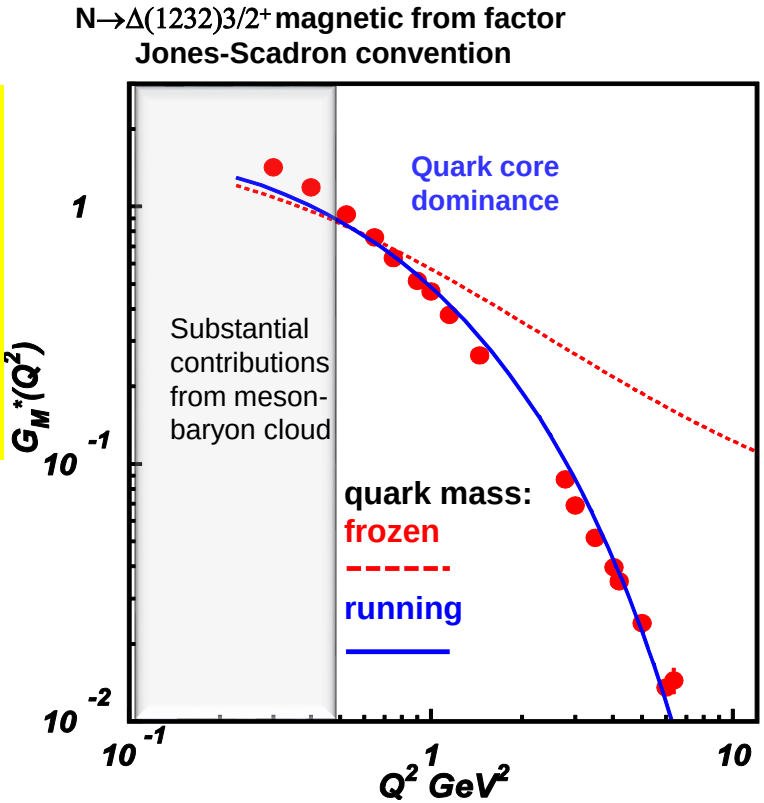
Consistent values of resonance electrocouplings from $N\pi$, $N\eta$, and $\pi^+\pi^- p$ electroproduction strongly support their reliable extraction

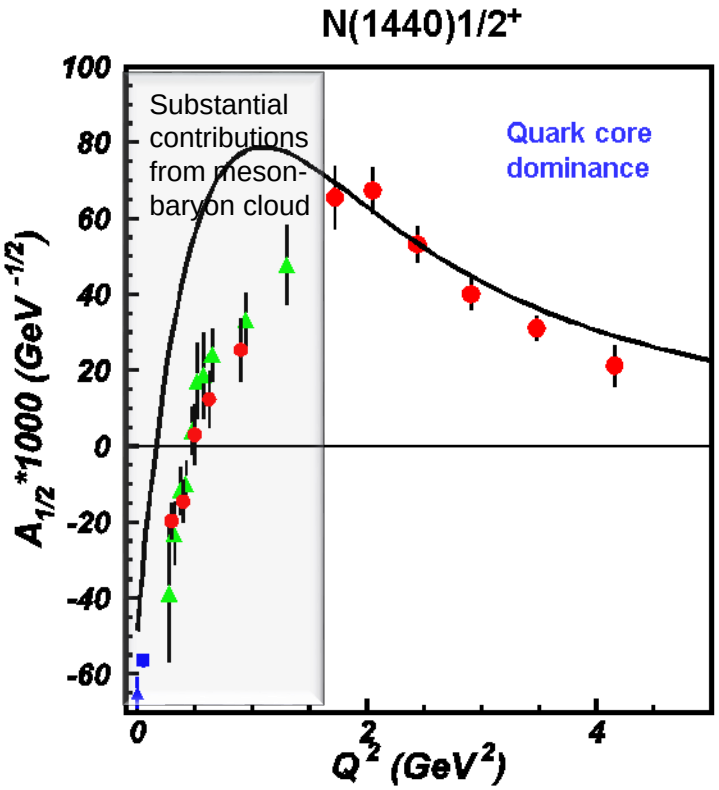
The structure of all resonances studied with CLAS represents a complex interplay between the inner quark core and external meson-baryon cloud.

From Resonance Electrocouplings to Hadron Mass Generation

Dyson-Schwinger Equations (DSE):

- J. Segovia et al., Phys. Rev. Lett. 115, 171801 (2015).
- J. Segovia et al., Few Body Syst. 55, 1185 (2014).

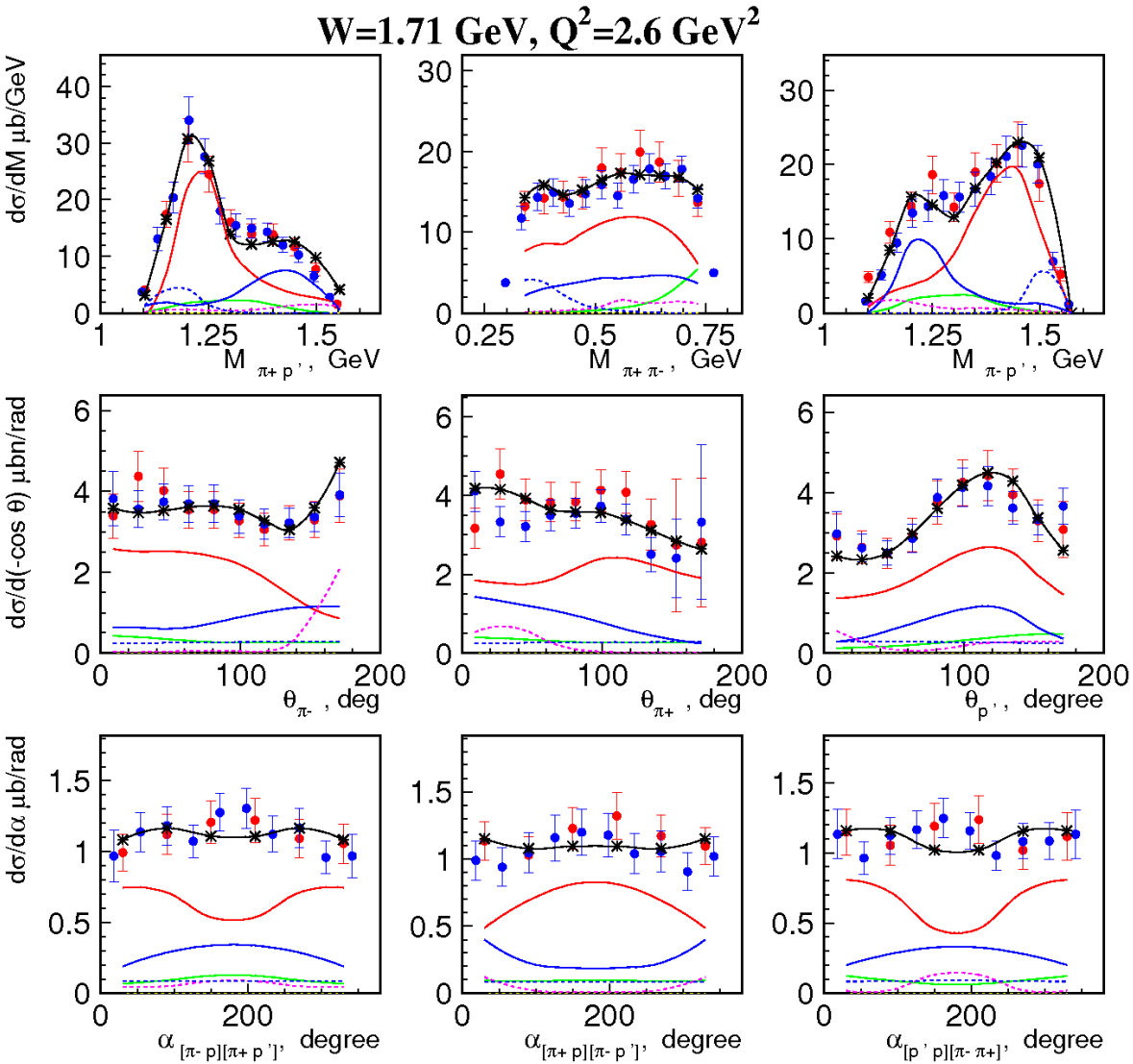




- ***Dressed quark mass is running with momentum***
  - **Good description of the first spin-isospin-flip and radial excited resonance electrocouplings at Q^2>2.0 GeV^2 with the same dressed quark mass function validates relevance of dressed quark with dynamically generated mass in the structure of the ground and excited nucleons.**
  - **Both elastic nucleon form factors and γ_vpN* electrocouplings data for all prominent resonances of different structure are needed in order to map-out dressed quark mass function.**

One of the most important achievements in hadron physics of the last decade in synergistic efforts between experimentalists and theorists.

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



Two data sets at
1.40 GeV <W<2.0 GeV and
2.0 GeV² < Q² < 5.0 GeV² :

red - E. Isupov et al., CLAS Coll., Phys. Rev. C96, 025209 (2017), Mosc. State U., Jlab, Ohio U.

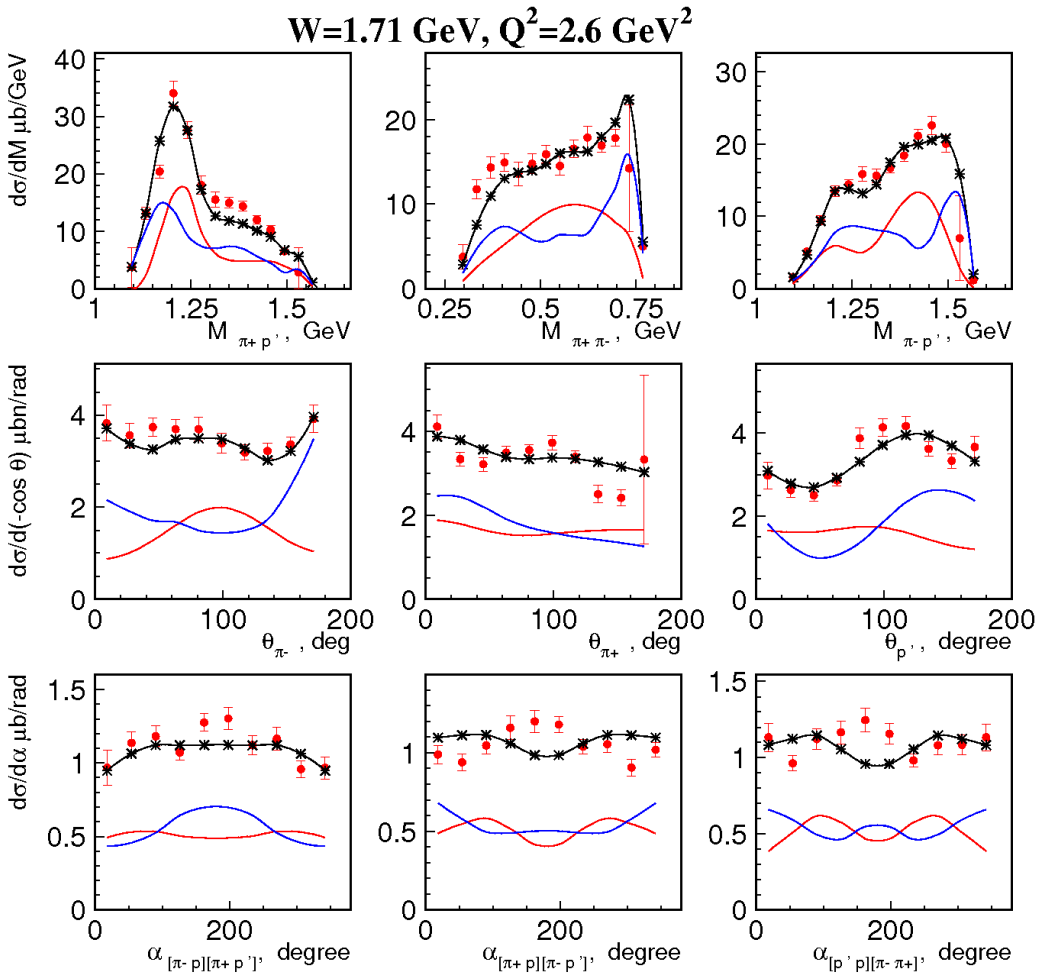
blue - preliminary, A.Trivedi, R.W. Gothe, USC.

JM18 results:

- full JM
- ρp
- $\pi^-\Delta^{++}$
- $\pi^+\Delta^0$
- π^+ N(1520)3/2⁻
- π^+ N(1680)5/2⁺

The JM18 model offers a good description of both $\pi^+\pi^-$p electroproduction off protons data sets

Prospects for $\gamma_v pN^*$ Electrocoupling Extraction



JM18 model version adjusted to the preliminary A.Trivedi & R.W. Gothe data

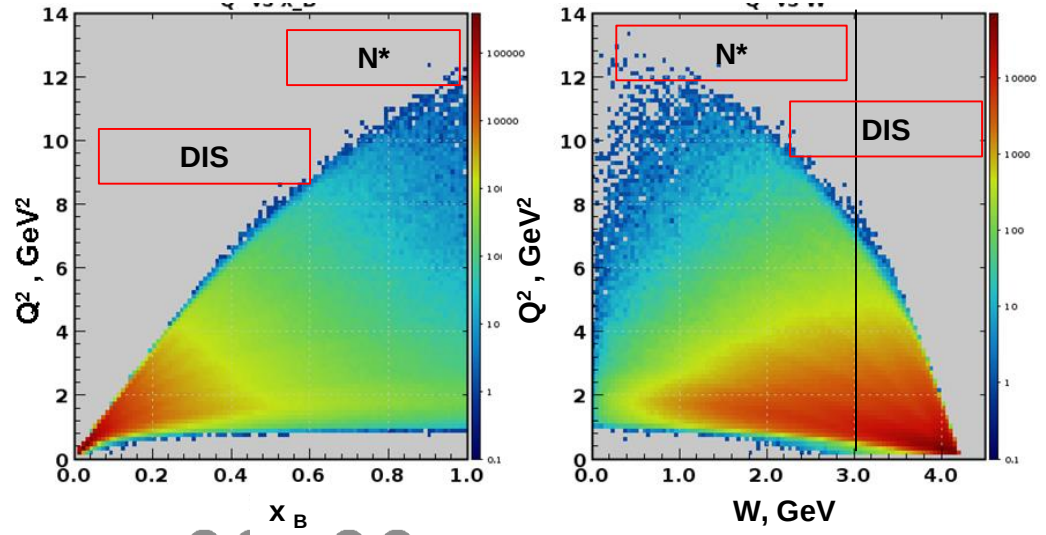
Resonant contributions

Non-resonant contributions

- Significant resonant contributions and pronounced differences in the shapes of the resonant /non-resonant parts.
- Relative growth of the resonant contributions with Q^2 .

In the near term future electrocouplings of most excited nucleon states in the mass range up to 2.0 GeV will become available from these data sets at 2.0 GeV^2<Q^2<5.0 GeV^2

12 GeV Era with the CLAS12 Detector



CLAS12 kinematic coverage from the first inclusive electron scattering events

CLAS12 N* Program at High Q^2

E12-09-003	E12-06-108A
Nucleon Resonance Studies with CLAS12	KY Electroproduction with CLAS12
Gothe, Mokeev, Burkert, Cole, Joo, Stoler	*Carman, Gothe, Mokeev*

- Measure exclusive electroproduction cross sections from an unpolarized proton target with polarized electron beam for $N\pi$, $N\eta$, $N\pi\pi$, KY:

  E_b = 11. GeV, Q^2 = 3 → 12 GeV^2, W → 3.0 GeV with nearly complete coverage of the final state phase space

- Key Motivation

  Study the structure of all prominent N states in the mass range up to 2.0 GeV vs. Q^2 up to 12 GeV^2.*

  CLAS12 is the only facility to map-out the N quark with minimal meson-baryon cloud contributions.*

The experiments already started in February 2018!

Emergence of Hadron Mass and Quark-Gluon Confinement

N* electroexcitation studies at JLab will address the critical open questions:

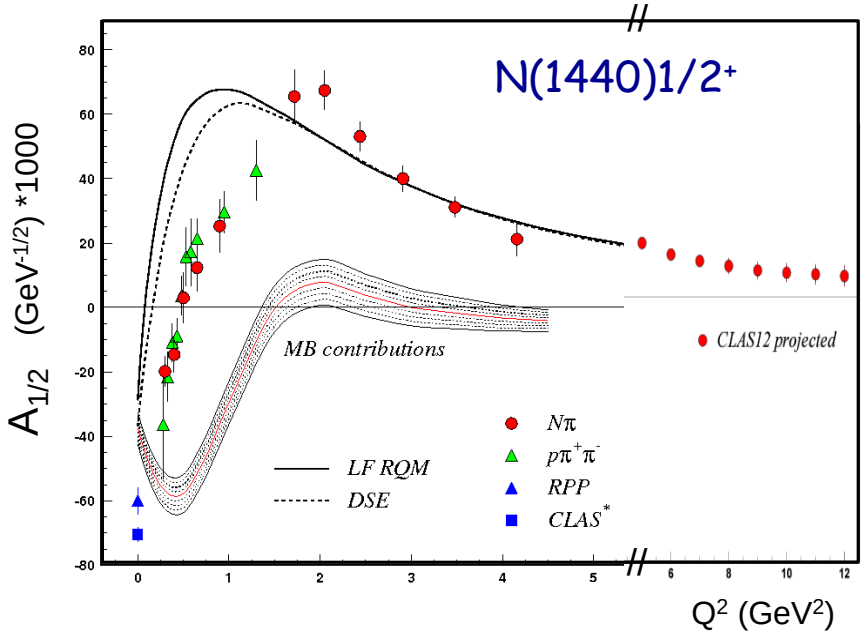
How is >98% of visible mass generated?

How does confinement emerge from QCD and how is it related to Dynamical Chiral Symmetry Breaking?

What is the behavior of QCD's running coupling at infrared momenta?

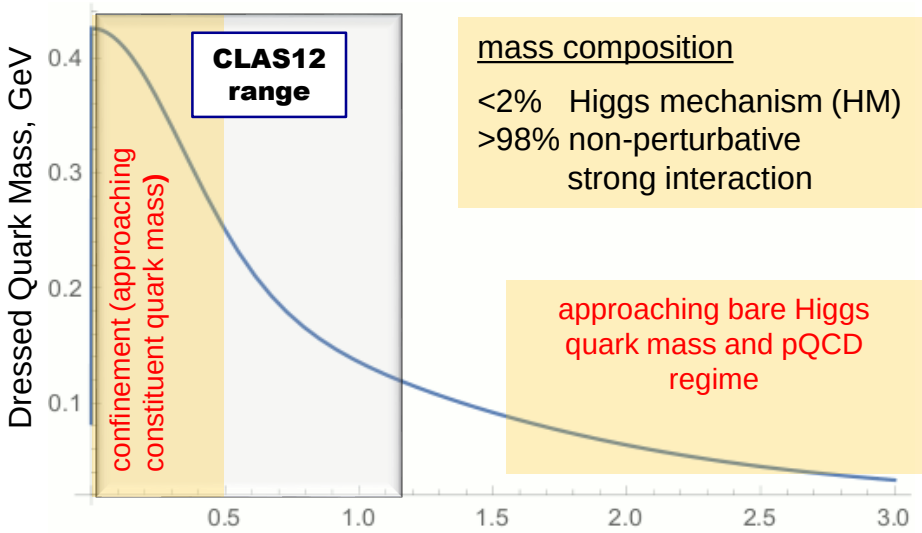
(D. Binosi et al., Phys. Rev. D96, 054026 (2017))

Mapping-out quark mass function from the CLAS12 results on $\gamma_v pN^*$ electrocouplings of spin-isospin flip, radial, and orbital excited nucleon resonances at $5<Q^2<12$ GeV^2 will allow us to explore the transition from strong QCD to pQCD regimes.



CLAS results versus theory expectations with running quark mass

Access to the dressed quark/hadron mass generation



Conclusions and Outlook

- **Progress in the studies of the excited nucleon spectrum/structure contributed essentially in the exploration of strong QCD.**

- **Global multi-channel analysis of the exclusive photo- and hadroproduction data revealed firm evidence for the existence of new N(1895)1/2$^-$, N(1900)3/2$^+$ resonances and considerably improve knowledge on the spectrum of high-lying resonances with a major impact from the CLAS KΛ, KΣ photoproduction data.**

- **High quality meson electroproduction data from CLAS have allowed us to determine the electrocouplings of most resonances in the mass range up to 1.8 GeV with consistent results from analyses of π^+n, π^0p, ηp, and $\pi^+\pi^-$p electroproduction channels.**

- **<u>Profound impact on the exploration of strong QCD dynamics:</u>**
  a) first DSE evaluations of Δ(1232)3/2$^+$ and N(1440)1/2$^+$ electroexcitation amplitudes with a traceable connection to the QCD Lagrangian;
  b) synergistic efforts between the experimental studies of γ_vpN* electrocouplings in Hall B at JLab and the continuum QCD theory at ANL have demonstrated the capability for reliable access to the strong QCD mechanisms underlying the dominant part of the hadron mass generation.

- **Electrocouplings of most resonances in the mass range up to 2.0 GeV will become available at 2.0 GeV^2<Q^2<5.0 GeV^2 from the new CLAS data on $\pi^+\pi^-$p electroproduction in the near term future.**

Conclusions and Outlook

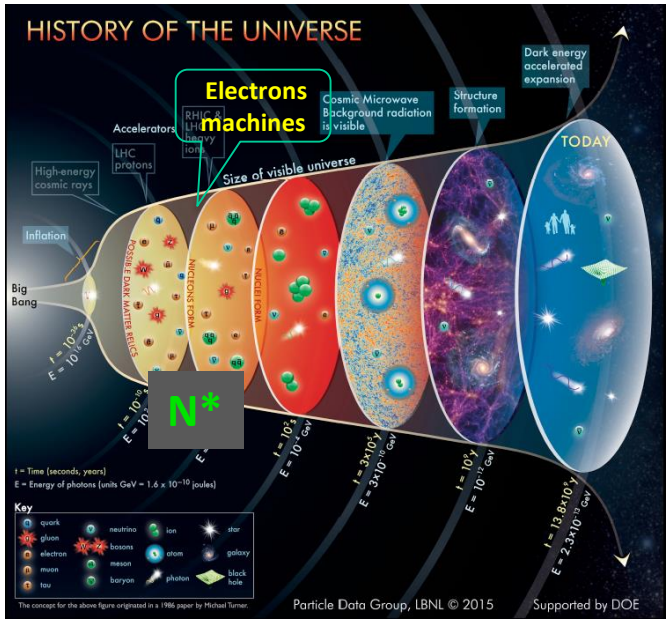
- **CLAS12 is the only facility in the world capable of obtaining electrocouplings of all prominent N* states at still unexplored ranges of highest photon virtualities for exclusive reactions from 5.0 GeV^2 to 12 GeV^2 from measurements of Nπ, $\pi^+\pi^-$p, and KY electroproduction.**

- **The expected results will allow us to map out the dressed quark mass function at the distances where the transition from quark-gluon confinement to pQCD regime is expected, addressing the most challenging problems of the Standard Model on the nature of >98% of hadron mass and of quark-gluon confinement.**

- **Success of the N* program will be very beneficial for the hadron physics community fostering the synergistic efforts between experimentalists, phenomenologists and theorists aimed to get insight into the strong QCD dynamics.**

Back up

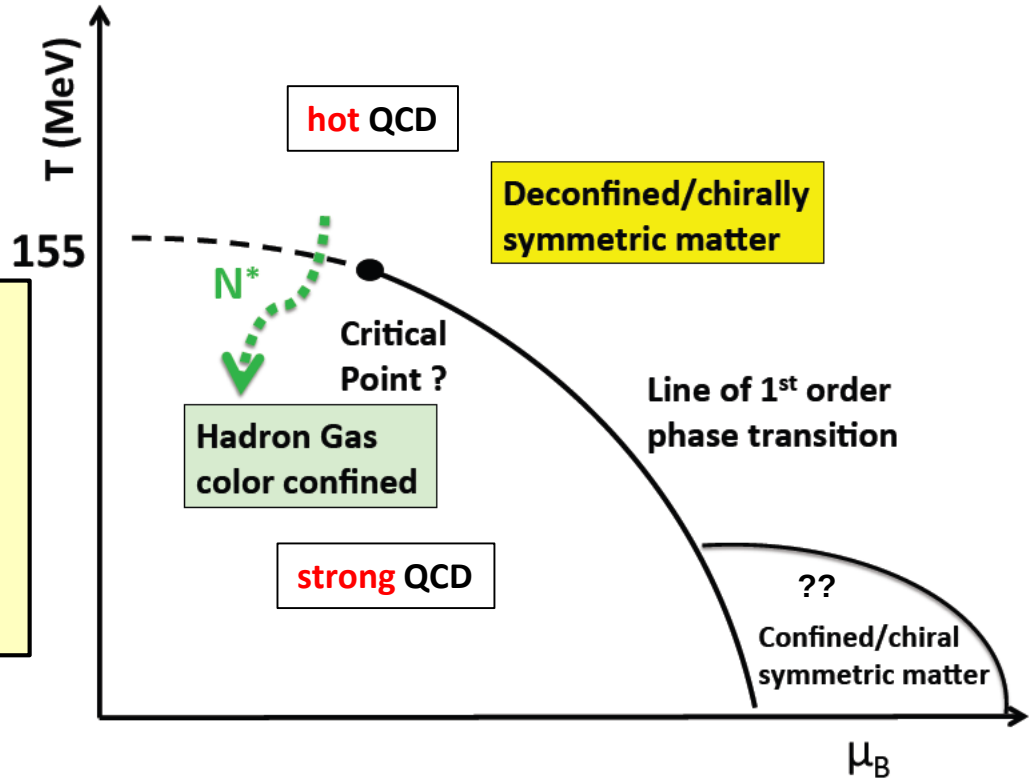
Nucleon Resonances in the History of the Universe



- Chiral symmetry is broken
- Quarks acquire mass
- Baryon resonances occur
- Quark-gluon confinement emerges

Full baryon spectrum shaped this transition

Dramatic events occur in the micro-second old universe during the transition from the QGP phase to hadron phase.



Approaches for Extraction of $\gamma_v pN^*$ Electrocouplings

Analyses of different meson electroproduction channels independently:

- **$\pi^+ n$ and $\pi^0 p$ channels:**
  Unitary Isobar Model (UIM) and Fixed-t Dispersion Relations (DR)
  I.G. Aznauryan, Phys. Rev. C67, 015209 (2003)
  I.G. Aznauryan et al. (CLAS), Phys. Rev. C80, 055203 (2009)
  I.G. Aznauryan et al. (CLAS), Phys. Rev. C91, 045203 (2015)
- **ηp channel:**
  Extension of UIM and DR
  I.G. Aznauryan, Phys. Rev. C68, 065204 (2003)
  Data fit at W<1.6 GeV, assuming $N(1535)1/2^-$ dominance
  H. Denizli et al. (CLAS), Phys. Rev. C76, 015204 (2007)
- **$\pi^+\pi^- p$ channel:**
  Data driven JLab-MSU meson-baryon model (JM)
  V.I. Mokeev, V.D. Burkert et al., Phys. Rev. C80, 045212 (2009)
  V.I. Mokeev et al. (CLAS), Phys. Rev. C86, 035203 (2012)
  V.I. Mokeev, V.D. Burkert et al., Phys. Rev. C93, 054016 (2016)
  E. Golovatch et al., arXiv:1806.01767 [nucl-ex]

Global coupled-channel analysis of $\gamma_{r,v}N$, πN, ηN, $\pi\pi N$, $K\Lambda$, $K\Sigma$ exclusive channels:

H. Kamano, Few Body Syst. 59, 24 (2018)
H. Kamano, JPS Conf. Proc. 13, 010012 (2017)
H. Kamano, arXiv:1610.01710 [nucl-th]

Summary of Results on $\gamma_v pN^*$ Photo-/Electrocouplings from CLAS

Exclusive meson electroproduction channels	Excited proton states	Q^2-ranges for extracted $\gamma_v pN^*$ electrocouplings, GeV^2
$\pi^0 p$, $\pi^+ n$	$\Delta(1232)3/2^+$ $N(1440)1/2^+$,$N(1520)3/2^-$, $N(1535)1/2^-$	0.16-6.0 0.30-4.16
$\pi^+ n$	$N(1675)5/2^-$, $N(1680)5/2^+$ $N(1710)1/2^+$	1.6-4.5
ηp	$N(1535)1/2^-$	0.2-2.9
$\pi^+\pi^- p$	$N(1440)1/2^+$, $N(1520)3/2^-$ $\Delta(1620)1/2^-$, $N(1650)1/2^-$, $N(1680)5/2^+$, $\Delta(1700)3/2^-$, $N(1720)3/2^+$, $N'(1720)3/2^+$ $\Delta(1620)1/2^-$, $N(1650)1/2^-$, $N(1680)5/2^+$, $\Delta(1700)3/2^-$, $N(1720)3/2^+$, $N'(1720)3/2^+$, $\Delta(1905)5/2^+$, $\Delta(1950)7/2+$	0.25-1.50 0.5-1.5 photoproduction

The website with numerical results and references: userweb.jlab.org/ ~mokeev/resonance_ electrocouplings/

The interpolated/extrapolated CLAS results on $\gamma_v pN^*$ electrocouplings in the mass range <1.8 GeV and Q^2<5.0 GeV^2: userweb.jlab.org/~isupov/couplings/

Impact of the Extended CLAS Results on $\gamma_v pN^*$ Electrocouplings on the Exploration of Hadron Mass Generation

- **The $\gamma_v pN^*$ electrocouplings of most resonances in the mass range of W<2.0 GeV will become available in the near term future at Q^2<5.0 GeV^2 from the Nπ and $\pi^+\pi^-$p electro-production off protons data.**
- **First results on electrocouplings of the resonances in the mass range of W<1.6 GeV will become available at 2.0 GeV^2<Q^2<5.0 GeV^2 from independent studies of the Nπ and $\pi^+\pi^-$p electroproduction off proton data.**
- **Electrocouplings of many resonances in the mass range of W >1.6 GeV which decay preferentially to the N$\pi\pi$ final states will be obtained for the first time at 2.0 GeV^2 < Q^2<5.0 GeV^2.**
- **New opportunities to explore Dynamical Chiral Symmetry Breaking (DSCB) from the data on the parity partner electrocouplings: $\Delta(1232)3/2^+$ vs $\Delta(1700)3/2^-$, $N(1520)3/2^-$ vs $N(1720)3/2^+$ shedding light on connection between the hadron mass generation and DCSB.**
- **Exploration of different types of di-quark correlations from the $\gamma_v pN^*$ electrocouplings obtained over full N*-spectrum within the mass range of W <2.0 GeV.**
- **New N* electrocouplings results from CLAS pave a way for exploration of universality or environmental sensitivity of dressed quark mass function. Observation of the dressed quark mass sensitivity to the resonance quantum numbers will open a new avenue in the exploration of hadron mass generation.**

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

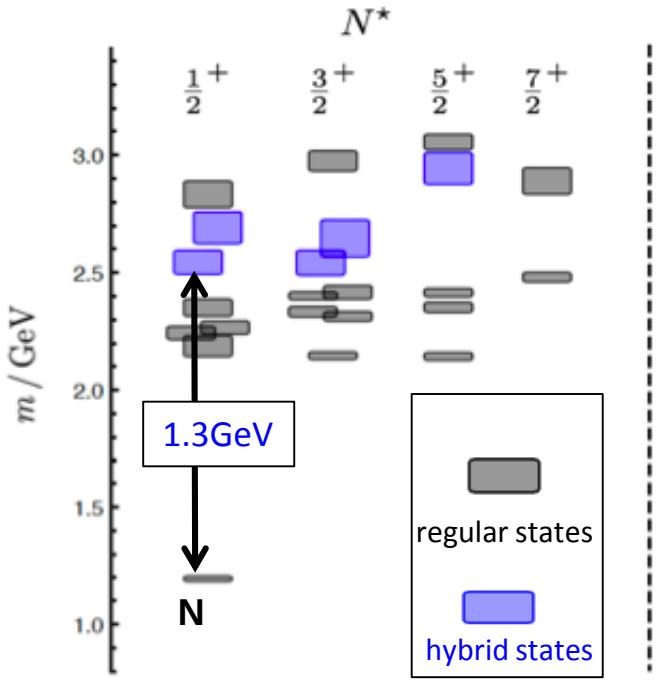
Run Group conditions:
E_b = 6.6 GeV, 50 days
E_b = 8.8 GeV, 50 days

- 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?

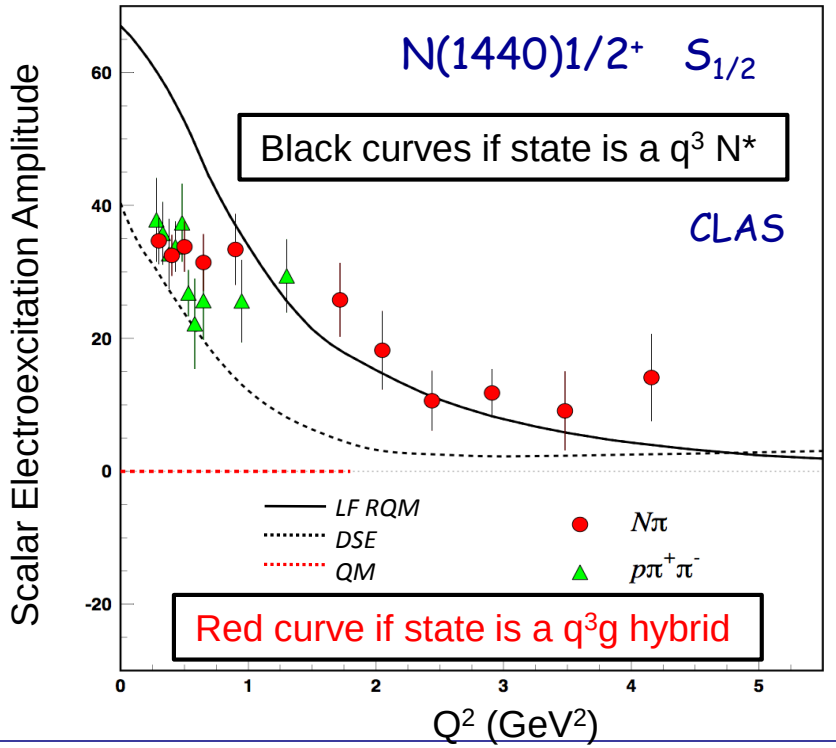
Predictions of the N* spectrum from QCD show both regular q^3 *and* hybrid q^3g states



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



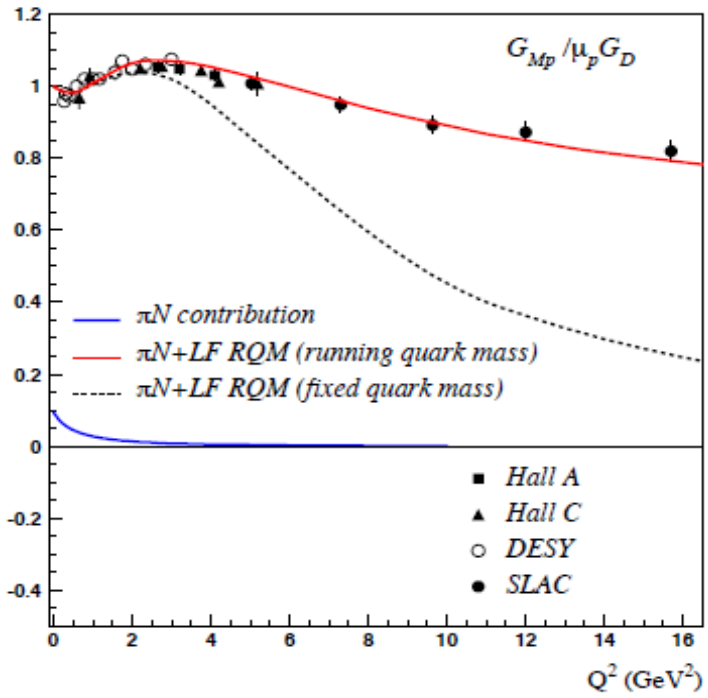
Quark Model with Input from QCD-based Approaches

Light Front QM by I.G. Aznauryan and V.D. Burkert: PRC 85, 055202 (2012).

The approach discussed here is purely phenomenological, and addresses a few topics that have some importance for the direction of the field, in particular:

- obtain a better understanding of the expected meson-baryon contributions
- study the sensitivity of the resonance transition amplitudes to the running quark mass, which is a result of the DSE approach and of LQCD calculations.

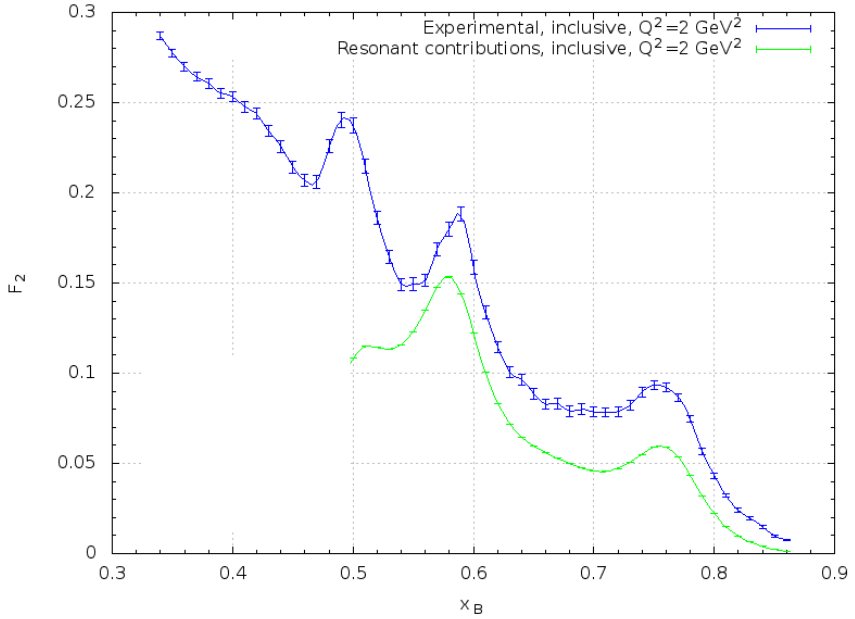
Proton Magnetic Form Factor

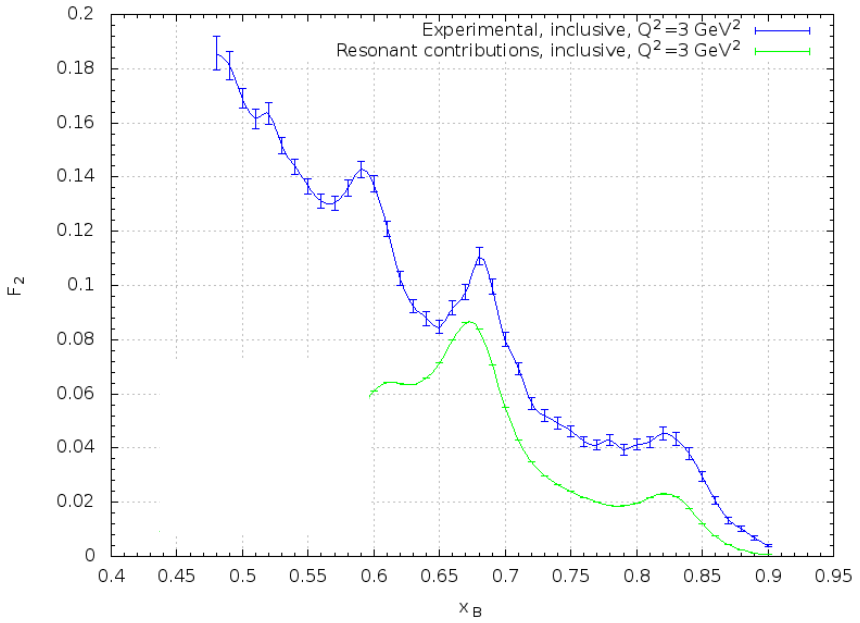


- Nucleon electromagnetic form factors
  → $q^3 + \pi N$ loops contributions in light-front dynamics
  → running quark mass
- Electroexcitation of $\Delta(1232)\frac{3}{2}^+$, $N(1440)\frac{1}{2}^+$, $N(1520)\frac{3}{2}^-$, and $N(1535)\frac{1}{2}^-$
  → q^3 contribution in a LF RQM with running quark mass
  → inferred MB contributions

Implementation of momentum-dependent quark mass is needed in order to reproduce elastic magnetic form factor of proton at Q^2>3.0 GeV^2

Accessing Parton Distributions in the Resonance Region





Interpolation of the CLAS data on $F_2(x,Q2)$ structure function, M.Osipenko et al. (CLAS Coll), Phys. Rev. D67, 092001 (2003).

Resonant contributions from the CLAS results on $\gamma_v pN^*$ electrocouplings stored in: userweb.jlab.org/~mokeev/resonance_electrocouplings, userweb.jlab.org/~isupov/couplings/

The CLAS results on electrocouplings of most N* in the mass range of W <1.8 GeV and at Q^2<5.0 GeV^2 makes it possible to evaluate the resonant contributions to the inclusive electron scattering offering access to the parton distributions at large x_B in the resonance region

See details in the talk: A.N. Hiller Blin ``Constraints from Finite-Energy Sum Rules on Inclusive Electron and Virtual Compton Scattering"