Resonant contribution to inclusive electron scattering from the experimental results on resonance electrocouplings

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Outline

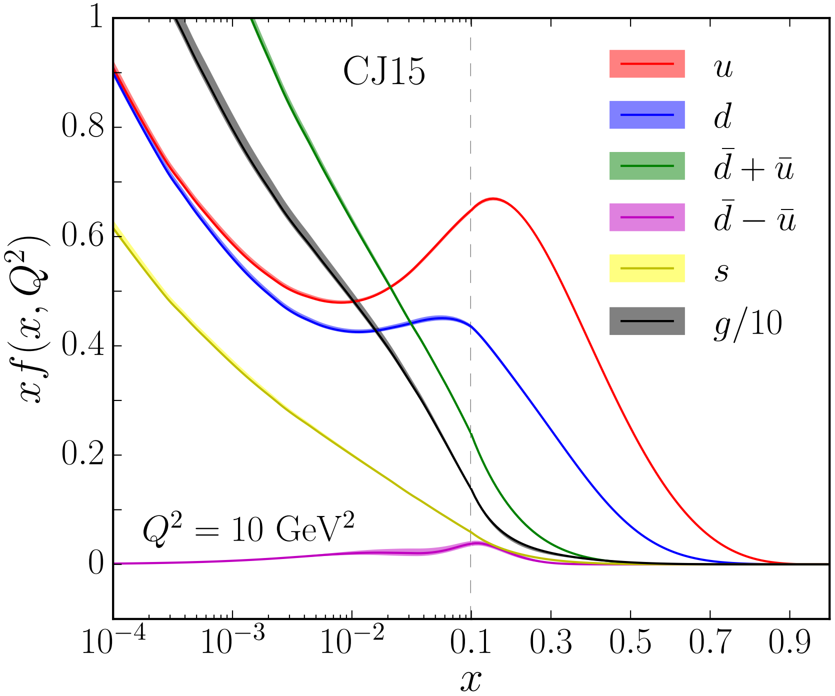
- Introduction
- Inclusive structure functions from the CLAS
- Resonance electrocouplings from the CLAS
- Tools for inclusive structure function evaluations from the CLAS/world data
- Resonant contributions to inclusive structure functions
- Prospects with the CLAS12

Introduction

- Detailed measurements of the inclusive electron scattering reveal the ground nucleon state structure in terms of parton distributions.

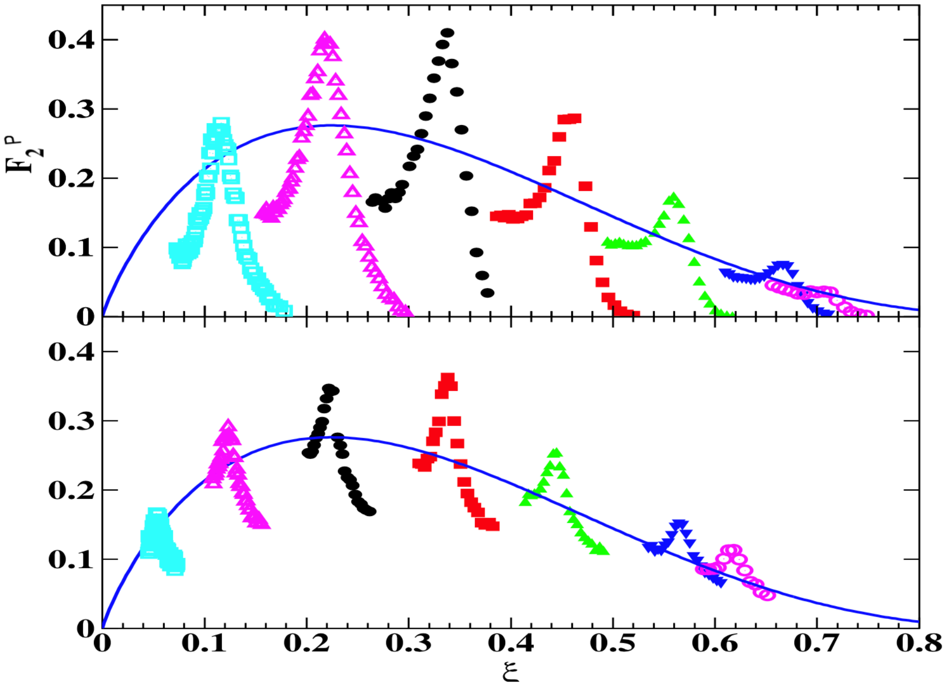
- Results on the distributions of the partons of all flavors and gluons are currently available

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



The focus of my talk will be the studies of the inclusive scattering at $X_b > 0.5$ and in particular in the N* region.

Introduction



Proton F_2 structure function in the Δ (top) and second (bottom) resonance regions from Jefferson Lab Hall C, compared with the scaling curve.

Expression of local duality.

Melnitchouk, Ent, Keppel JLAB_THY_04_266

From Inclusive Cross Sections to the Unpolarized Structure Functions

$$\frac{d^2\sigma}{dE'd\Omega} = \Gamma(\sigma_T + \epsilon\sigma_L)$$

$$\Gamma = \frac{\alpha K}{2\pi^2|q^2|}\frac{E'}{E}\frac{1}{1-\epsilon}$$

$$\sigma_T = \frac{4\pi^2\alpha}{K}W_1(\nu, q^2)$$

$$\sigma_L = \frac{4\pi^2\alpha}{K}[(1-\frac{\nu^2}{q^2})W_2(\nu, q^2) - W_1(\nu, q^2)]$$

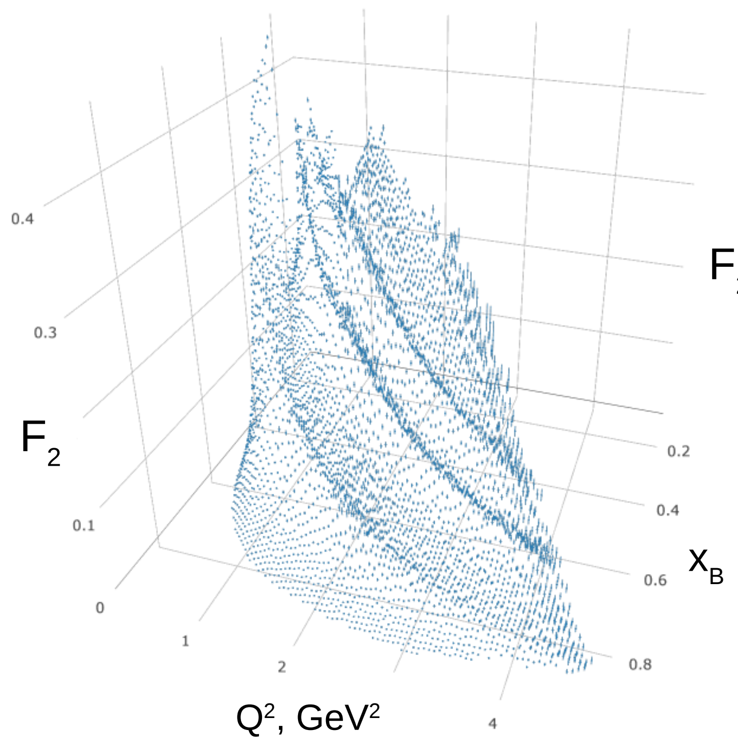
$$MW_1(\nu, Q^2) \longrightarrow F_1(x) = \frac{1}{2x}F_2(x)$$

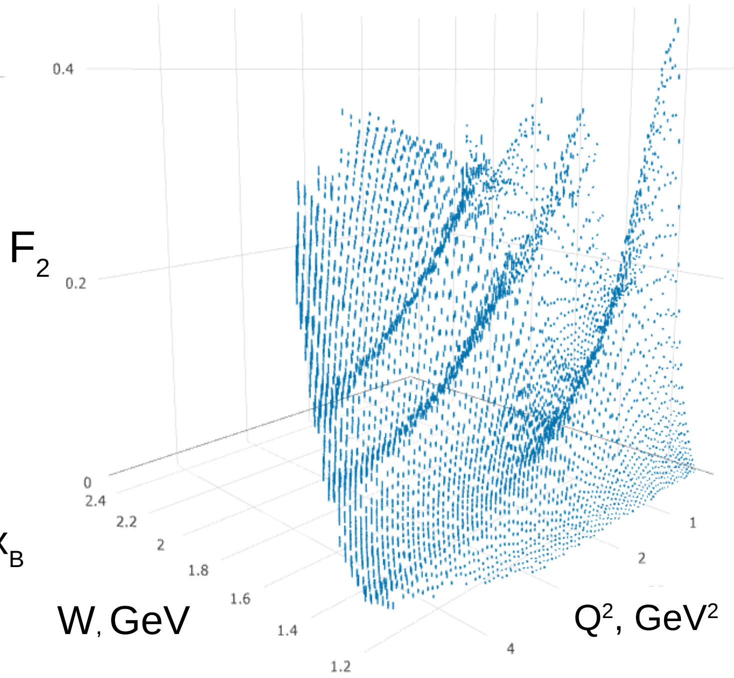
$$\nu W_2(\nu, Q^2) \longrightarrow F_2(x) = \sum_i e_i^2 x f_i(x)$$

CLAS Results on F_2 Structure Function

- Resonance peaks corresponded to the first, second and third resonance regions are clearly seen
- Resonant contributions should be taken into account in relating structure functions to parton distributions
- CLAS data on electrocouplings of most resonances in mass range <1.8 GeV have become available

V. Chesnokov, Moscow State U.



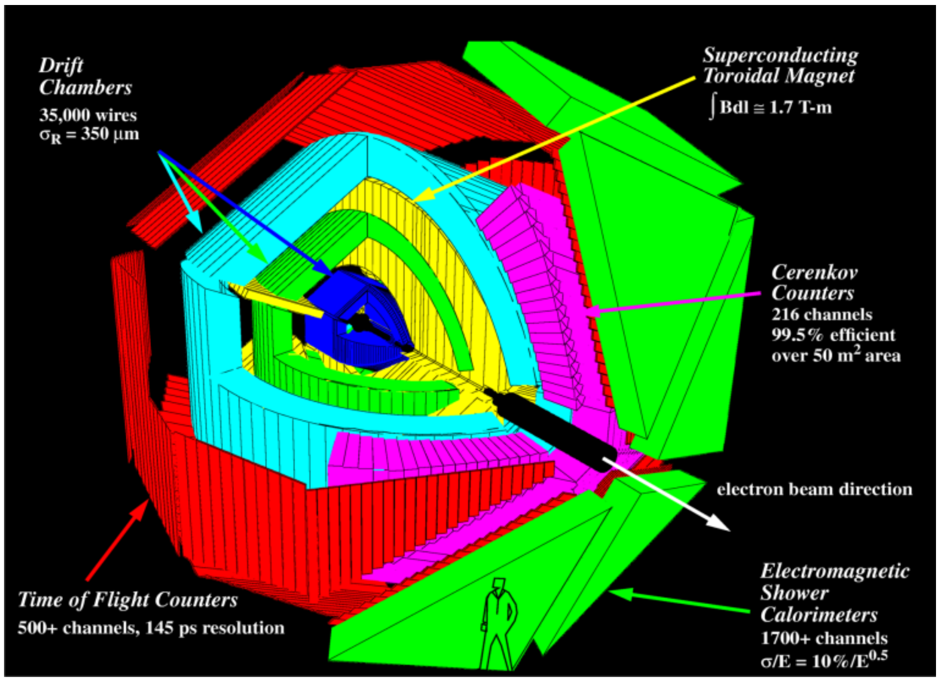


Osipenko et al. (CLAS Collaboration), Phys. Rev. D 67, 092001, 2003
Outside of kinematic coverage of the CLAS data P.Bosted parametrization, Phys.Rev. C81 (2010) 055213

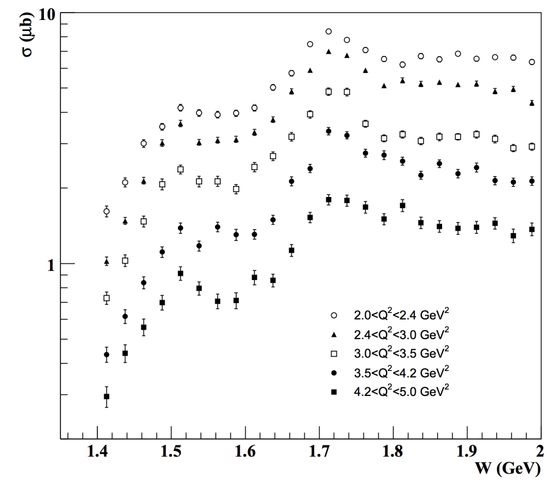
Experimental status

CLAS detector provided the dominant part of information on the inclusive electron scattering in the resonance region.

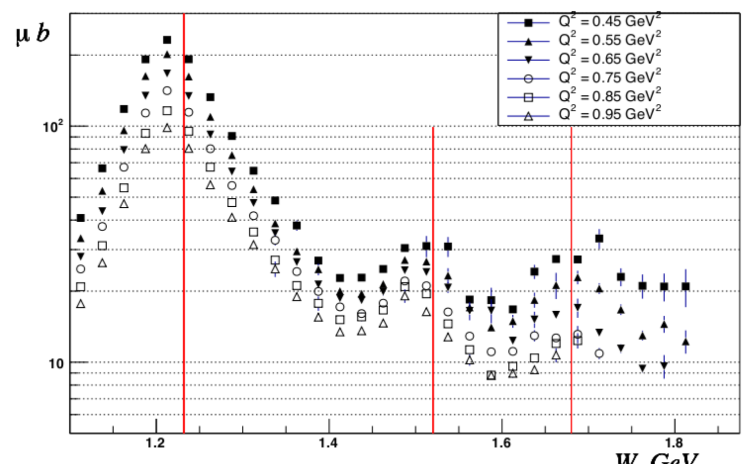
Phys.Rev. C96 (2017) no.2, 025209



γ p → $\pi^-\pi^+$p



γ p → π^0p



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
$\pi^+ n$	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 $d\sigma/d\Omega$
$\pi^0 p$	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 asymmetries
- 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

Approaches for Extraction of $\gamma_v NN^*$ Electrocouplings from the CLAS Exclusive Meson Electroproduction Data

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)

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)

N* Electrocouplings from CLAS

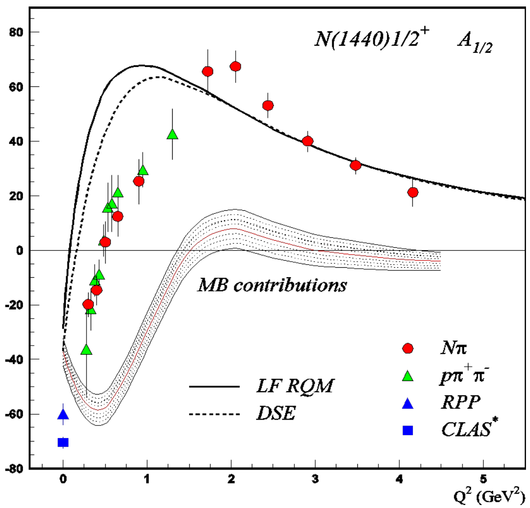
Exclusive meson electroproduction channels	Excited proton states	Q^2-ranges for extracted $\gamma_v pN^*$ electrocouplings, GeV^2
$\pi^0 p$, $\pi^+ n$	$\Delta(1232)3/2^+$ $N(1440)1/2^+$,$N(1520)3/2^-$, $N(1535)1/2^-$	0.16-6.0 0.30-4.16
$\pi^+ n$	$N(1675)5/2^-$, $N(1680)5/2^+$ $N(1710)1/2^+$	1.6-4.5
ηp	$N(1535)1/2^-$	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

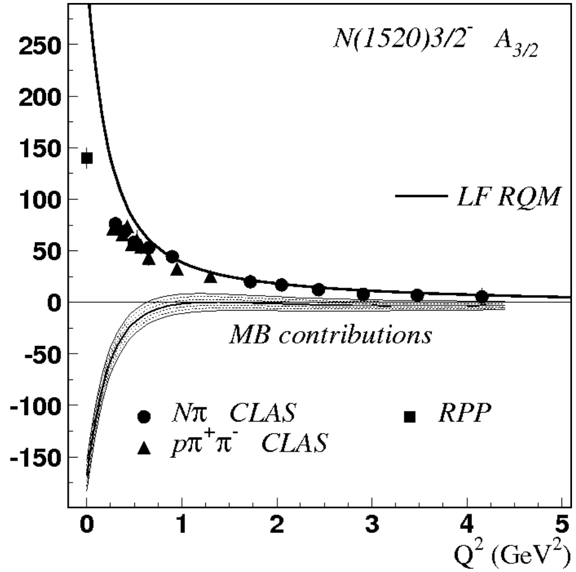
Experimental data 1995 – 2010
Electrocouplings 2005 - 2018

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/

N* Electrocouplings from CLAS





N* electroexcitation amplitudes were extracted from Nπ, $\pi^+\pi^-$p electroproduction off proton channels and found to be consistent in the range of photon virtuality where experimental data from both channels are available.

Strong evidence for credible electrocoupling extraction.

Evaluation of the inclusive structure functions

- CLAS data were used for the interpolation of inclusive cross-sections in the kinematic range covered by CLAS
- For the extrapolation of the data we used P. Bosted fit
- Combination of these interpolation/extrapolation were fitted by this dependence in spirit of operator product expansion

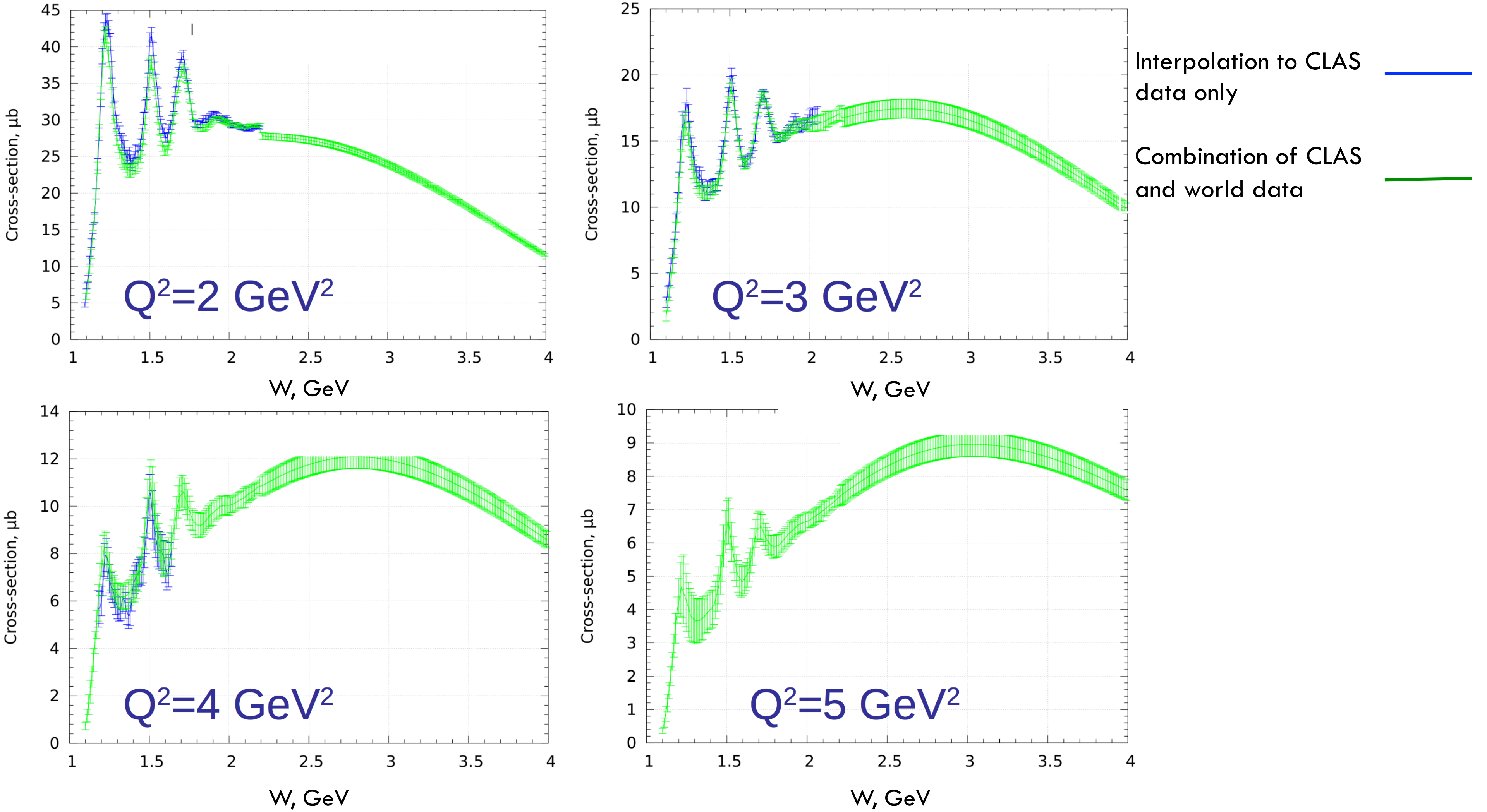
$$F_{1,2}(W,Q^2) = C_0^{1,2}(W) + \frac{C_1^{1,2}}{Q^2} + \frac{C_2^{1,2}}{Q^4} + \dots$$

Objective of the work

- Develop a software to evaluate inclusive structure functions in the region of W up to 4 GeV and photon virtuality $Q^2 < 7$ GeV^2 from the CLAS and world data;
- Evaluate resonance contribution based on the N* parameters in the Breight Wigner ansatz.

Evaluation of the inclusive structure functions

A. Golubenko, Moscow State Univ.



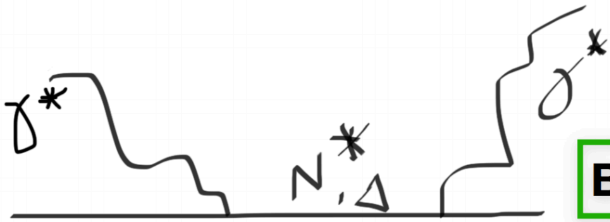
Evaluation of the resonance contribution

A.N Hiller Blin, Mainz Univ./JPAC

Mokeev et al., PRC 86 (2012) 035203

$$\sigma_{T,L}(W,Q^2) = \sigma^{R}_{T,L}(W,Q^2) + \sigma^{NR}_{T,L}(W,Q^2)$$

Christy and Bosted, PRC 86 (2010) 055213



Breit-Wigner resonance model

$\Gamma_{tot}(W = N^*) =$

$$\sigma^{R}_{T,L}(W,Q^2) = \frac{\pi}{q_\gamma^2} \sum_{N^*,\Delta^*} (2J_r+1) \frac{M_r^2 \Gamma_{\mathbf{tot}}(W) \Gamma_\gamma^{T,L}(M_r)}{(M_r^2 - W^2)^2 + M_r^2 \Gamma^2_{\mathbf{tot}}(W)}$$

Electrocouplings from CLAS data and fits

https://userweb.jlab.org/~isupov/couplings/

$$\Gamma_\gamma^T(M_r,Q^2) \sim |A_{1/2}(Q^2)|^2 + |A_{3/2}(Q^2)|^2$$

$$\Gamma_\gamma^L(M_r,Q^2) \sim 2 \quad |S_{1/2}(Q^2)|^2$$

Energy-dependence from decays into πN and ππN

Aznauryan, PRC 67 (2003) 015209

$$\Gamma_{tot} = \Gamma_{\pi N}(W = N^*) + \Gamma_{\pi\pi N}(W = N^*) + \Gamma_{\eta N}(W = N^*)$$

$$\Gamma_{\pi N}(W = N^*) = BF_{\pi N}\Gamma_{tot}$$

$$\Gamma_{\pi\pi N}(W = N^*) = (1 - BF_{\pi N} - BF_{\eta N})\Gamma_{tot}$$

$$\Gamma_{\eta N}(W = N^*) = BF_{\eta N}\Gamma_{tot}$$

Evaluation of resonance contribution

N^*	M_r [MeV]	Γ_r [MeV]	J_r	L_r	$\mathrm{BF}_{\pi N}$	$\mathrm{BF}_{\pi\pi N}$	$\mathrm{BF}_{\eta N}$	X
1440	1430	350	$\frac{1}{2}$	1	0.65	0.35	0	0.3
1520	1515	115	$\frac{3}{2}$	2	0.60	0.4	0	0.1
1535	1535	150	$\frac{1}{2}$	0	0.45	0.13	0.42	0.5
1650	1655	140	$\frac{1}{2}$	0	0.60	0.22	0.18	0.5
1675	1675	150	$\frac{5}{2}$	2	0.40	0.6	0	0.5
1680	1685	130	$\frac{5}{2}$	3	0.68	0.32	0	0.2
1710	1710	100	$\frac{1}{2}$	1	0.13	0.57	0.30	0.5
1720	1720	250	$\frac{3}{2}$	1	0.11	0.86	0.03	0.5

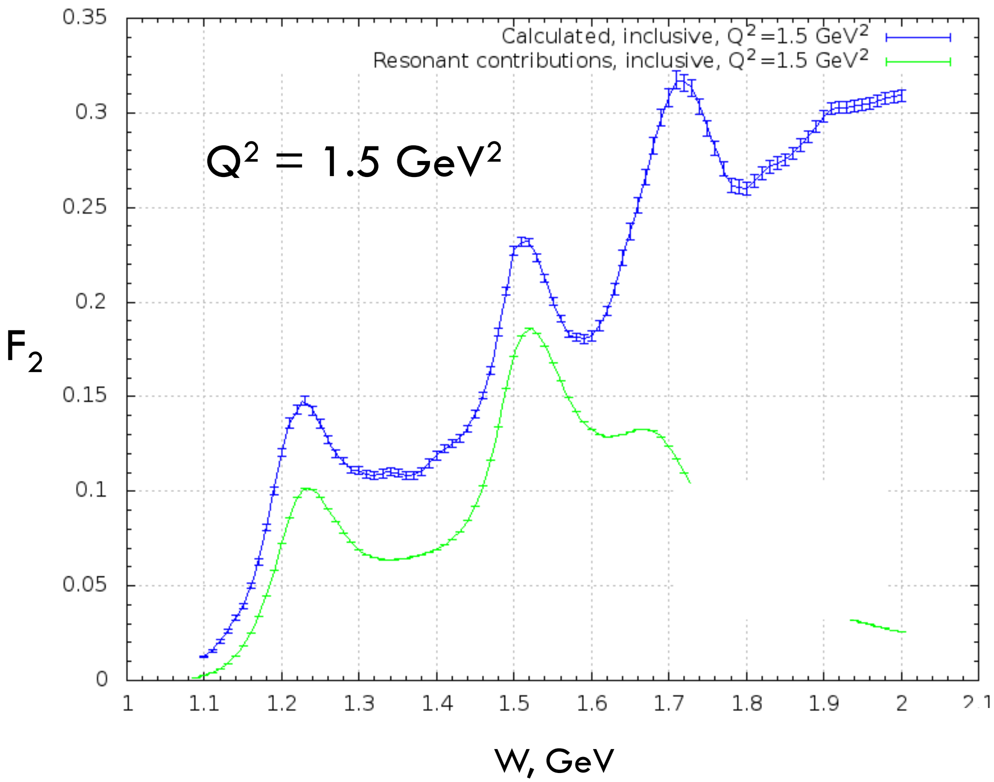
All (****) resonances to be included

$A_{1/2}(Q^2)$, $A_{3/2}(Q^2)$, $S_{1/2}(Q^2)$ are taken from https://www.jlab.org/Hall-B/secure/e1/isupov/couplings/section1.html

Δ	M_r [MeV]	Γ_r [MeV]	J_r	L_r	$\mathrm{BF}_{\pi N}$	$\mathrm{BF}_{\pi\pi N}$	$\mathrm{BF}_{\eta N}$	X
1232	1232	117	$\frac{3}{2}$	1	1	0	0	—
1620	1630	140	$\frac{1}{2}$	0	0.25	0.75	0	0.5
1700	1700	300	$\frac{3}{2}$	2	0.15	0.85	0	0.22

The contributions from resonances in the mass range > 1.9 GeV will be added in the near term future when the results on their electrocouplings will have become available

Resonance contributions from the CLAS results

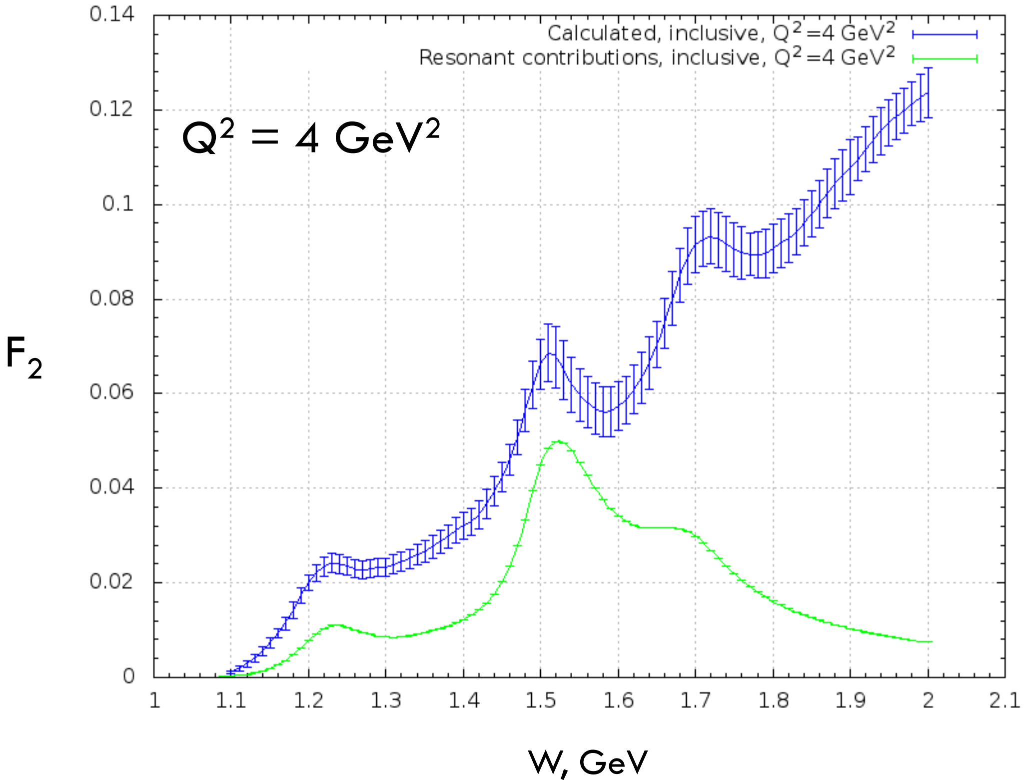


Sizable resonant contributions in the first, second, and third resonant regions

Computed from the experimental results on resonance electrocouplings

Allows us to account properly for the resonant part in relating $F_2(W,Q^2)$ to the parton distributions and in exploration of quark-hadron duality.

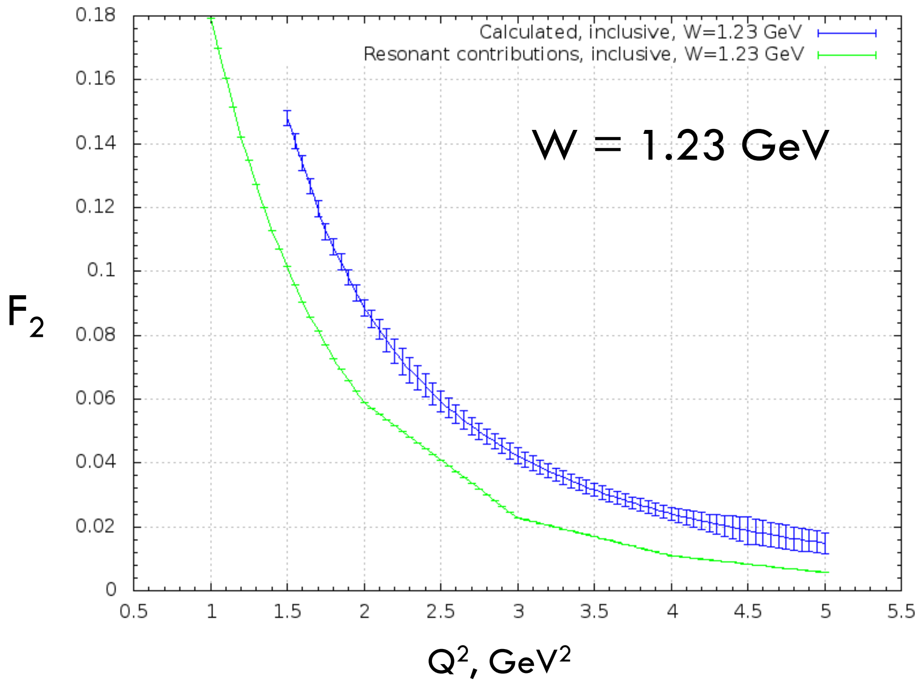
Resonance contribution from the CLAS results

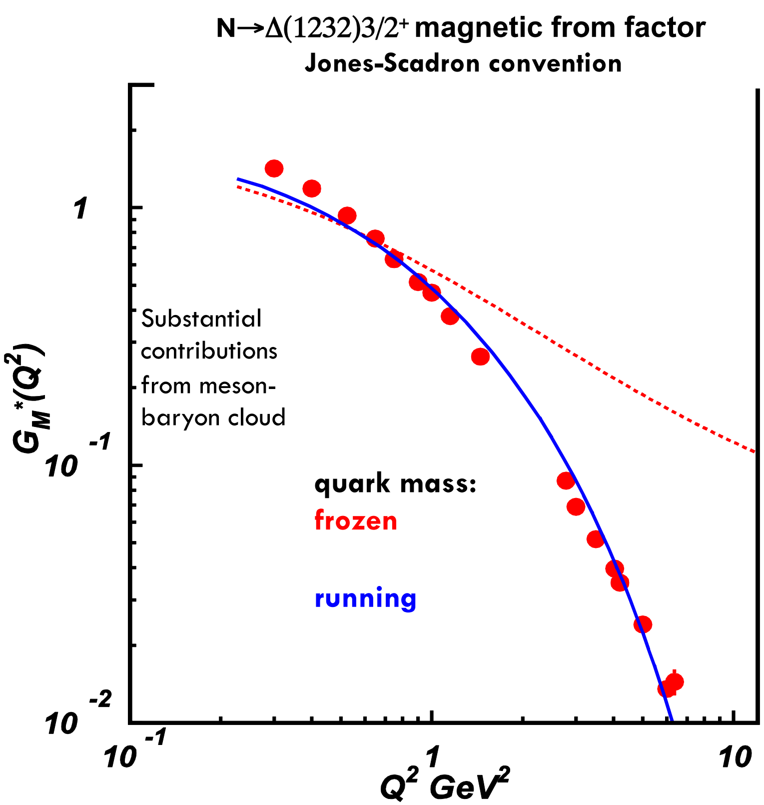


At higher Q^2:

- relative resonant contribution in the first resonance region decreases considerably.
- relative resonant contribution in the second resonance region becomes the biggest.

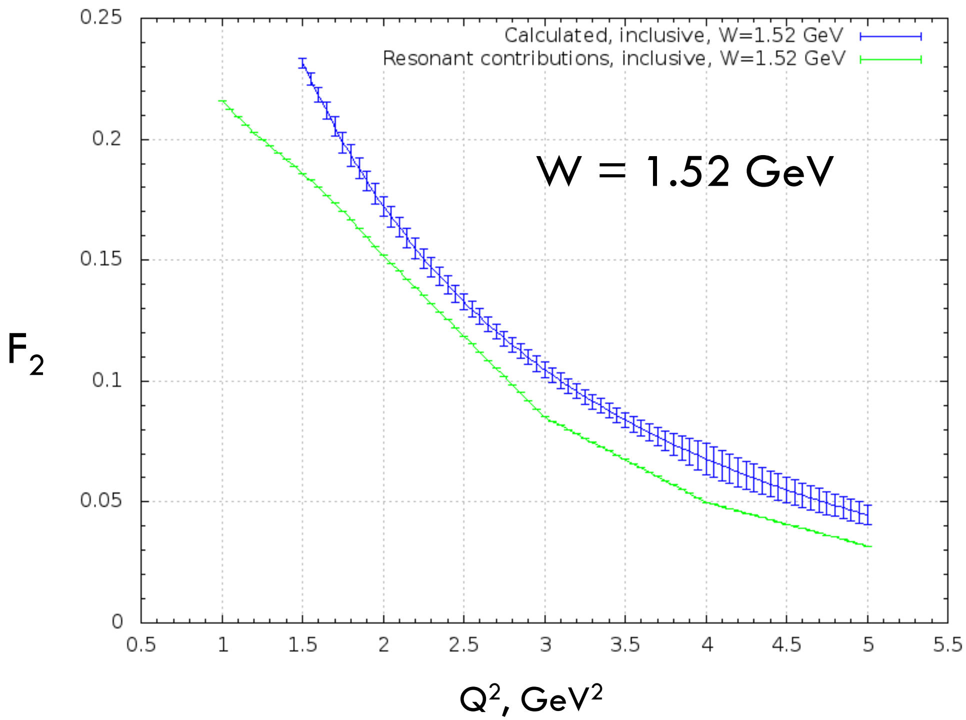
Resonance electrocouplings underlying Q^2 evolution of the resonant contributions

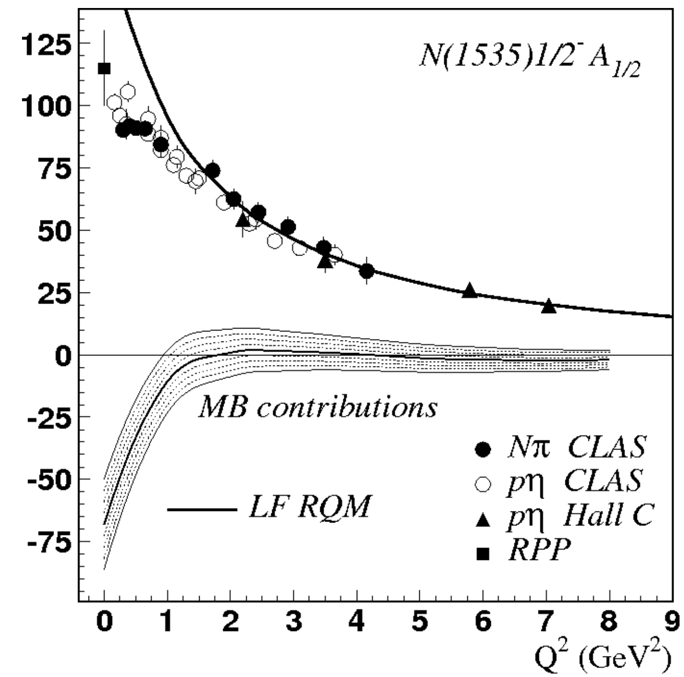




The transition from factor of the Delta resonance drops very fast with Q2.

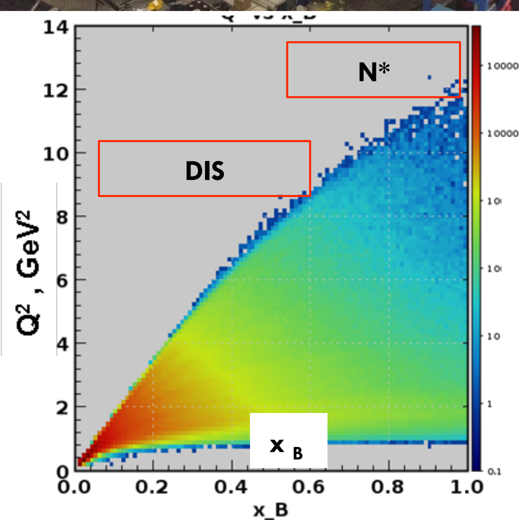
Resonance electrocouplings underlying Q^2 evolution of the resonant contributions

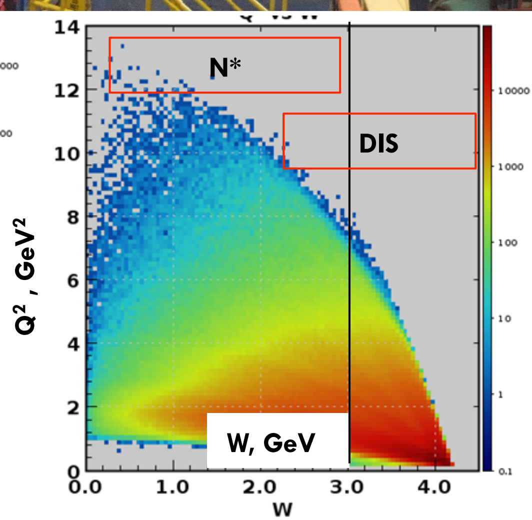




The $A_{1/2}$ transition from factor of the N(1535)1/2$^-$ resonance drops slower with Q^2 than non-resonant contributions, so the relative contribution grows.

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

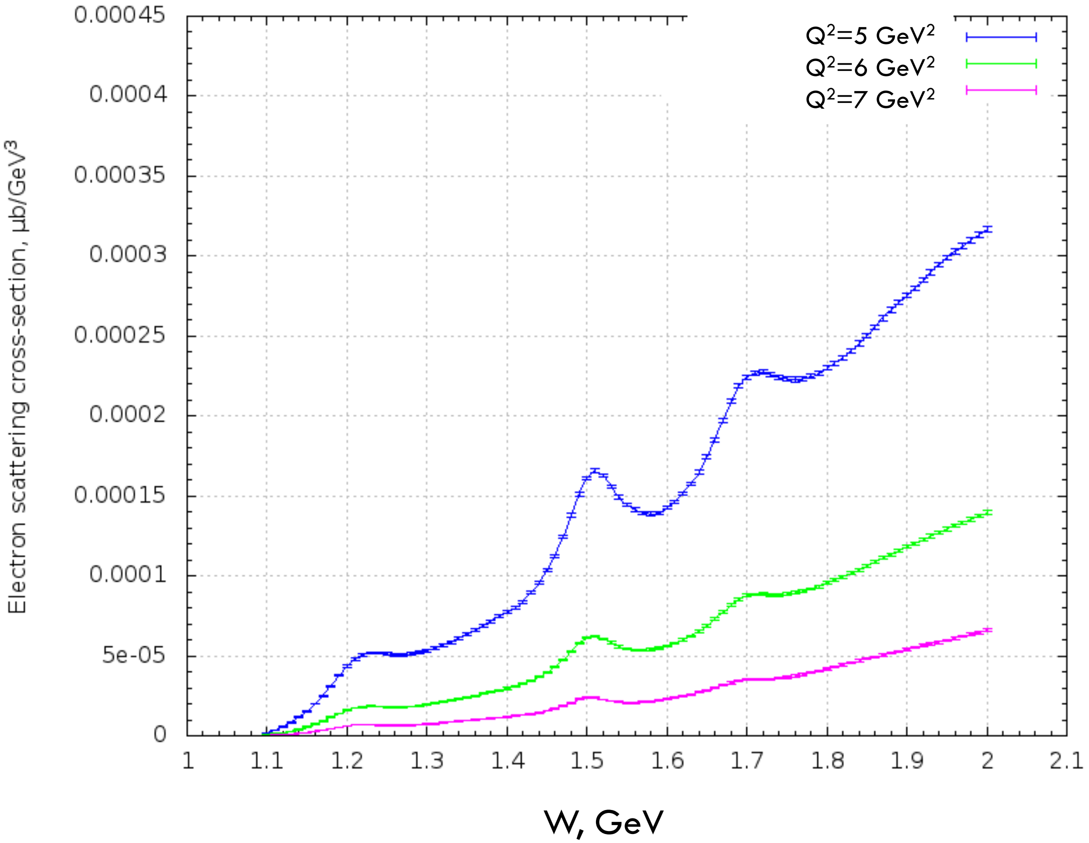
- Key Motivation

  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!

Prospects with CLAS12



Integrated luminosity is12.8e10 μb^{-1}

ΔQ2 = 0.1 GeV2
ΔW = 0.01 GeV

Already collected data during the Spring Run from CLAS12 will allow to measure the inclusive cross section with the unprecedented statistical and systematical precision.

Conclusion and Outlook

- Inclusive structure functions F_1/F_2, virtual photon-proton and electron scattering cross sections were evaluated from the CLAS/world experimental data in the kinematics area of W<4.0 GeV, Q^2<7.0 GeV^2 and available in the web-page http://clas.sinp.msu.ru/strfun-dev/
- Resonance contributions to the aforementioned observables were computed from the experimental CLAS results on resonance electrocouplings for the first time
- Realistic evaluation of the resonant contribution to F1/F2 structure functions offer an access to the parton distributions in protons at large x in the resonance region
- CLAS12 will extend the range of the available data from inclusive structure functions towards high photon virtualities up to 12 GeV2 with unprecedented accuracy.