The tools for evaluation of the $\gamma_v NN^*$ electrocouplings from the CLAS data

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Hadron Spectroscopy meeting, 25 February 2016

Major Directions in the Studies of N* Structure with CLAS

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

- $\gamma_v NN^*$ electrocouplings at photon virtualities up to 5.0 GeV^2 for most of the excited proton states through analyzing major meson electroproduction channels

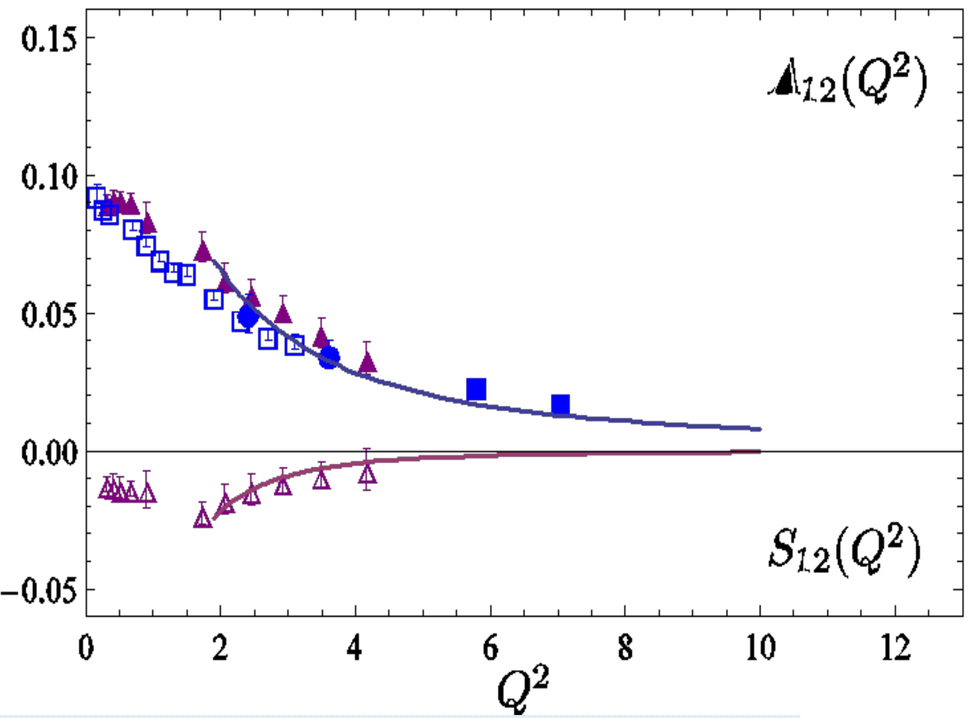
A unique source of information on different manifestations of the non-perturbative strong interaction in generating different excited nucleon states as relativistic bound systems of quarks and gluons.

Studies of N*-states of distinctively different structure are critical for a credible access to the basic ingredients of non-perturbative strong interaction, such as dressed quark mass function and dressed quark-gluon vertex.

Review papers:

1. **I.G. Aznauryan and V.D.Burkert, Progr. Part. Nucl. Phys. 67, 1 (2012).**
2. **I.G. Aznauryan et al., Int. J. Mod. Phys. E22, 133015 (2013).**
3. **C.D. Roberts, J. Phys. Conf. Ser. 630, 012051 (2015).**

N(1535)1/2$^-$



I.V. Anikin, V.M. Braun, N. Offen, Phys. Rev. D92, 014018 (2015)

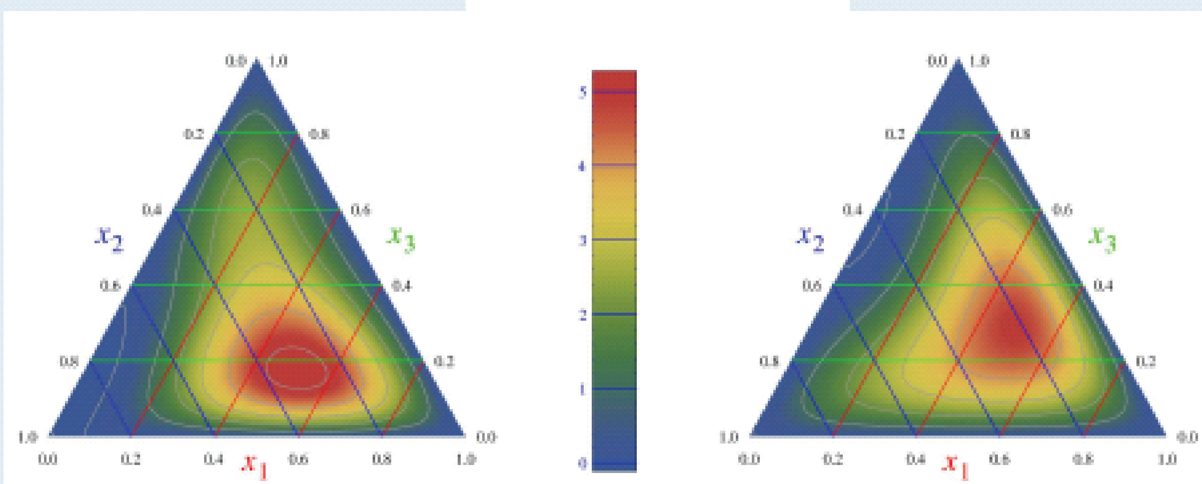
The shape parameters of N(1535)1/2$^-$ leading twist quark distribution amplitude (DA) φ_{ij}, η_{ij} were fit to the CLAS electrocoupling data within LCSR, while normalization parameters λ_{1N^*}, f_{N^*} were taken from the LQCD evaluations at the central values (V.M. Braun et al., Phys. Rev D89, 094511 (2014)).

Differences in the quark distributions in Nucleon and its chiral partner N(1535)1/2$^-$ elucidate the Dynamical Chiral Symmetry Breaking

Nucleon

$N^*(1535?)$

Nucleon DA from LCSRs for comparison (N. Offen)

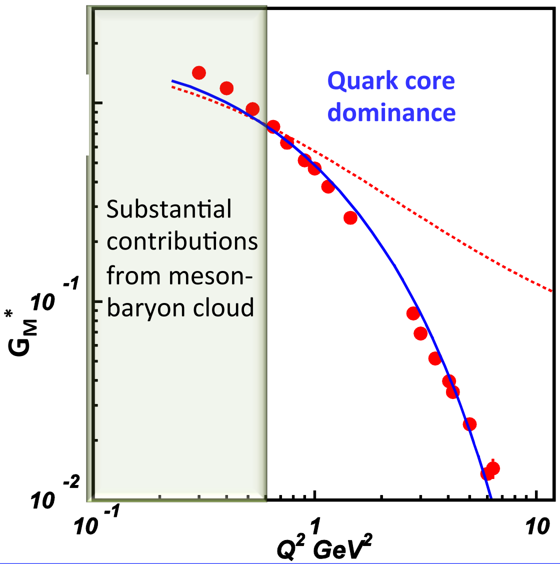


x1,x2,x3 – momentum fraction of the valence quarks

Access to the Dressed Quark Mass Function from the Data on the Transition N→N* Form Factors

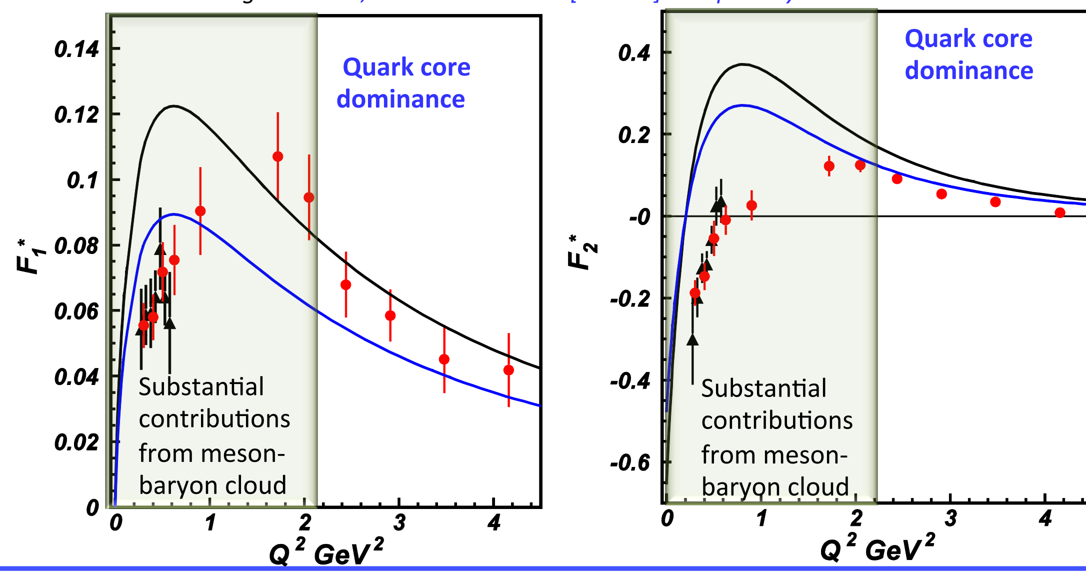
D(1232)3/2+
Jones-Scadron convention

J. Segovia et al., Few Body Syst. 55,1185 (2014).



N(1440)1/2+
Dirac F_1^* and Pauli F_2^*
N→N(1440)1/2+ transition form factors

J. Segovia et al., arXiv: 1504.04386[nucl-th] accepted by PRL



The quark core contributions to transition form factors computed in a common DSEQCD framework starting from the QCD Lagrangian:

Contact qq interaction, frozen constituent quark mass.

Realistic qq interaction, running quark mass.

Realistic qq interaction, running quark mass,

the same but multiplied by the common factor fit to the data on the leading $A_{1/2}$ coupling at Q^2>3.0 GeV^2 (slide#18), which accounts for the product of the quark core fractions in ground and N(1440)1/2+ states

Good data description at Q^2>2.0 GeV^2 achieved with <u>the same dressed quark mass function</u> for the ground and excited nucleon states of distinctively different structure provides strong evidence for:

- **the relevance of dressed quark predicted by DSEQCD;**
- **promising prospect to probe dressed quark mass function from the results on nucleon elastic and transition form factors.**

Fits of the resonances electrocouplings.

P13_missing_(1720)

P13(1720)

P11(1700)

D33(1700)

F15(1685)

D15(1675)

S11(1650)

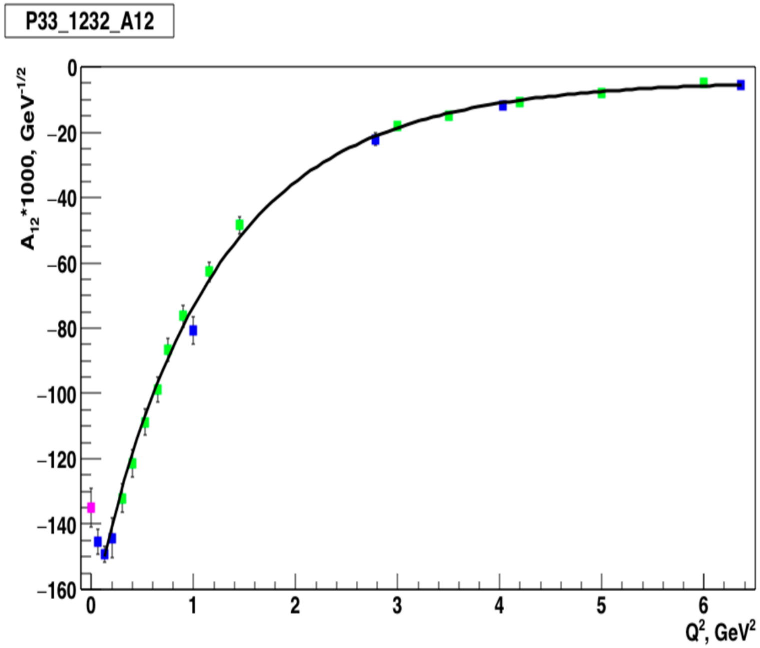
S31(1620)

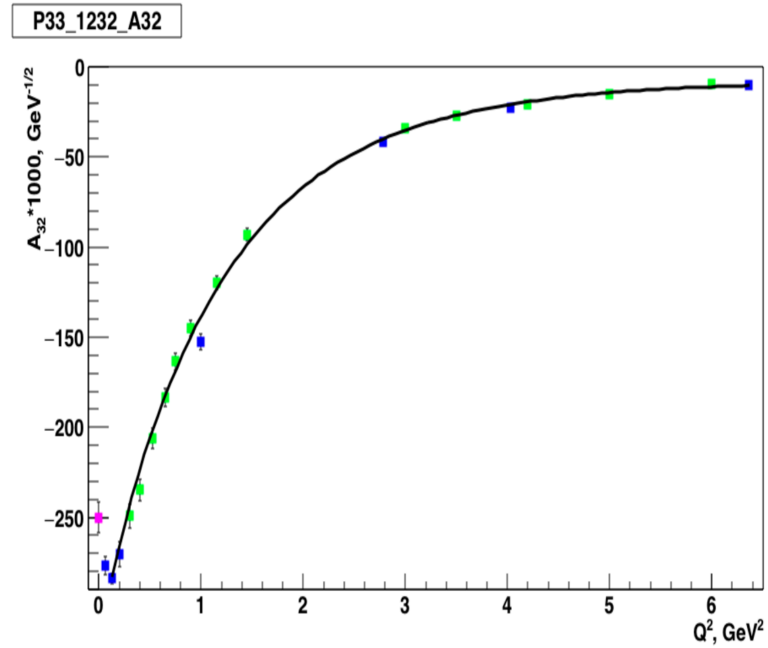
S11(1535)

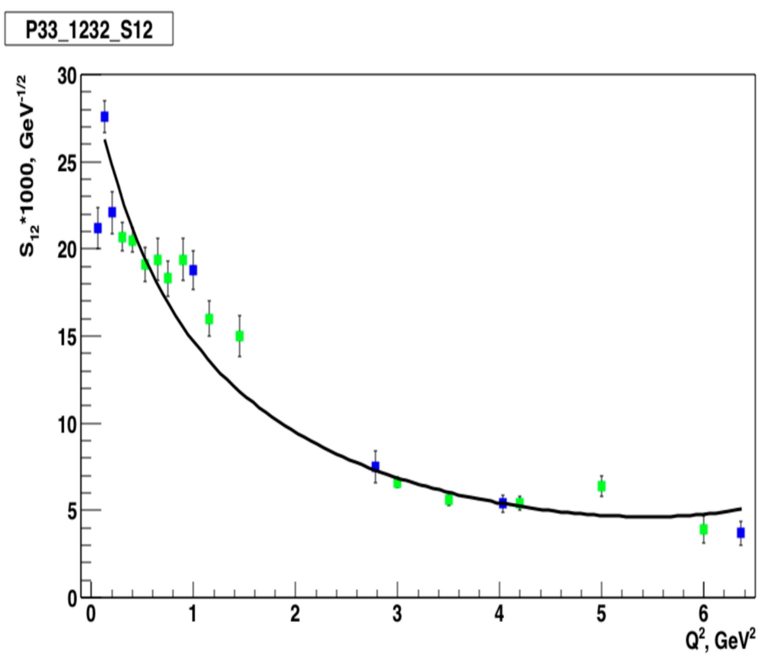
D13(1520)

P11(1440)

P33(1232)







Magenta points — PDG14

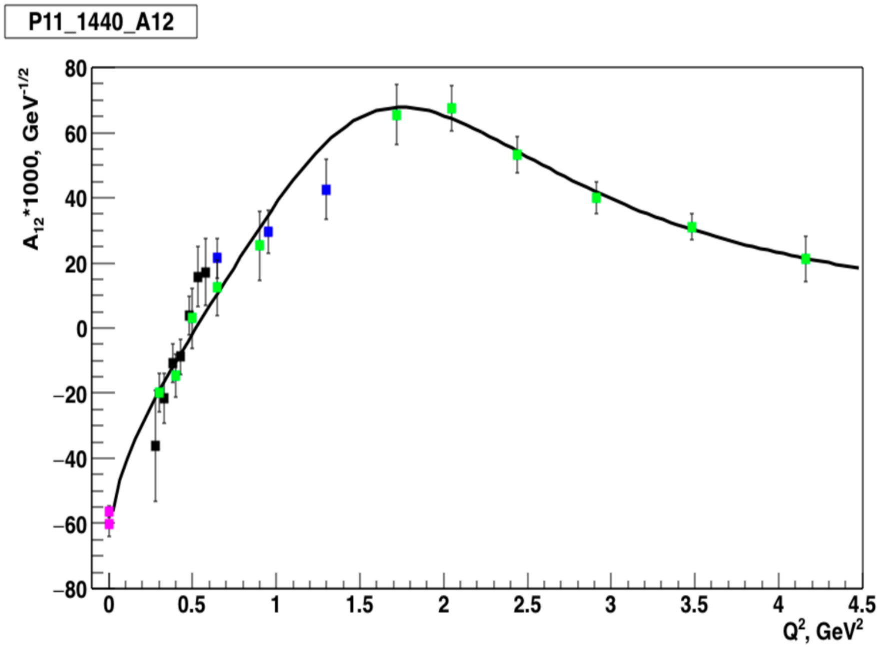
Green points — CLAS analysis of Nπ electroproduction off protons:
- I.G. Aznauryan et al., (CLAS Collaboration), Phys. Rev. C80, 055203 (2009)

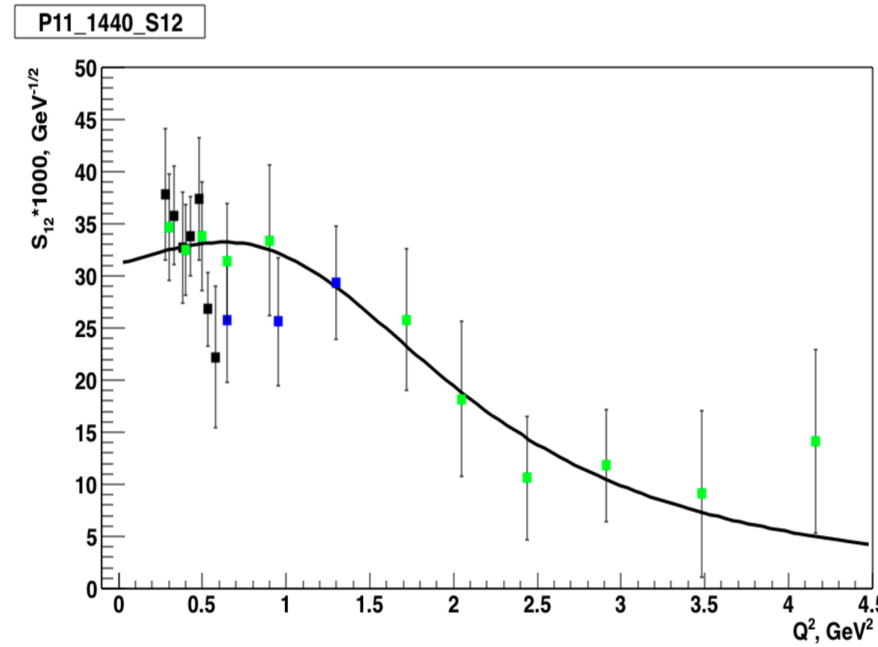
Blue points — JLAB(Hall-A,Hall-C), MAMI, MIT/BATES analysis of Nπ electroproduction off protons:
- A.N. Villano et al., Phys. Rev. C80, 035203 (2009)
- S. Stave et al., Phys. Rev. C78, 025209 (2008)
- N.F. Sparveris et al., Phys. Rev. Lett. 94, 022203 (2005)
- J.J. Kelly et al., Phys. Rev. C75, 025201 (2007)
- V.V. Frolov et al., Phys. Rev. Lett. 82, 45 (1999)

The black curves are phenomenological fits.

p11(1440)

https://www.jlab.org/Hall-B/secure/e1/isupov/couplings/p11_1440.html





Magenta upper point — CLAS analysis of Nπ photoproduction off protons:

- M. Dugger et al., (CLAS Collaboration), Phys. Rev. C79, 065206 (2009)

Magenta lower point — PDG14

Black points — CLAS analysis of pππ electroproduction off protons:

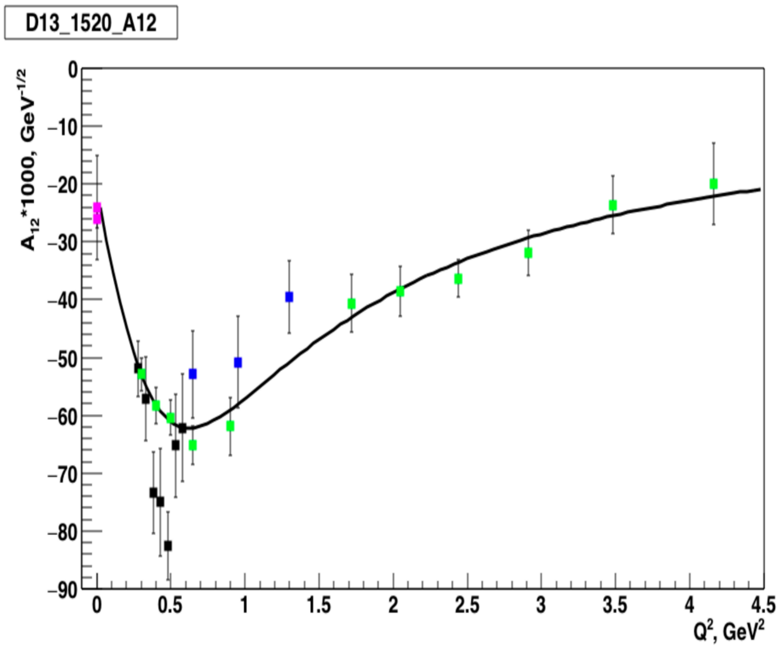
- V.I. Mokeev et al., (CLAS Collaboration), Phys. Rev C86, 055203 (2012)

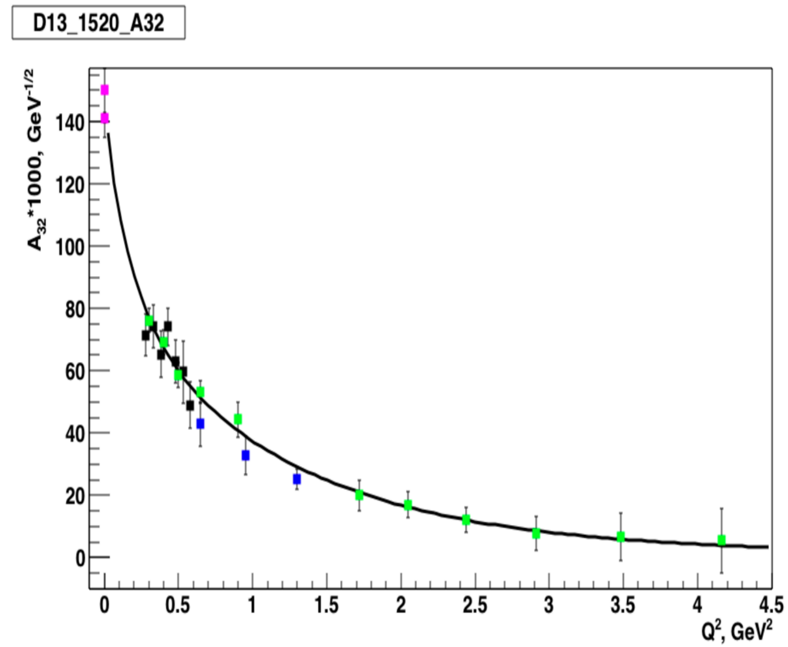
Blue points — CLAS analysis of pππ electroproduction off protons:

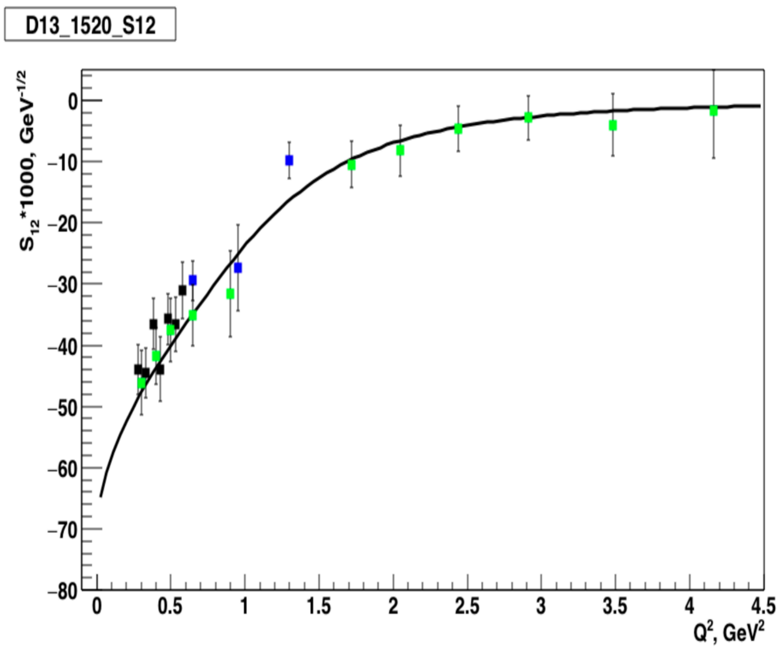
- V.I. Mokeev et al., arXiv:1509.054650[nucl-ex]

Green points — CLAS analysis of Nπ electroproduction off protons:

- I.G. Aznauryan et al., (CLAS Collaboration), Phys. Rev. C80, 055203 (2009)







Magenta lower point for A12 and A32 — CLAS analysis of Nπ photoproduction off protons:
- M. Dugger et al., (CLAS Collaboration), Phys. Rev. C79, 065206 (2009)

Magenta upper point for A12 and A32 — PDG14

Black points — CLAS analysis of pππ electroproduction off protons:
- V.I. Mokeev et al., (CLAS Collaboration), Phys. Rev C86, 055203 (2012)

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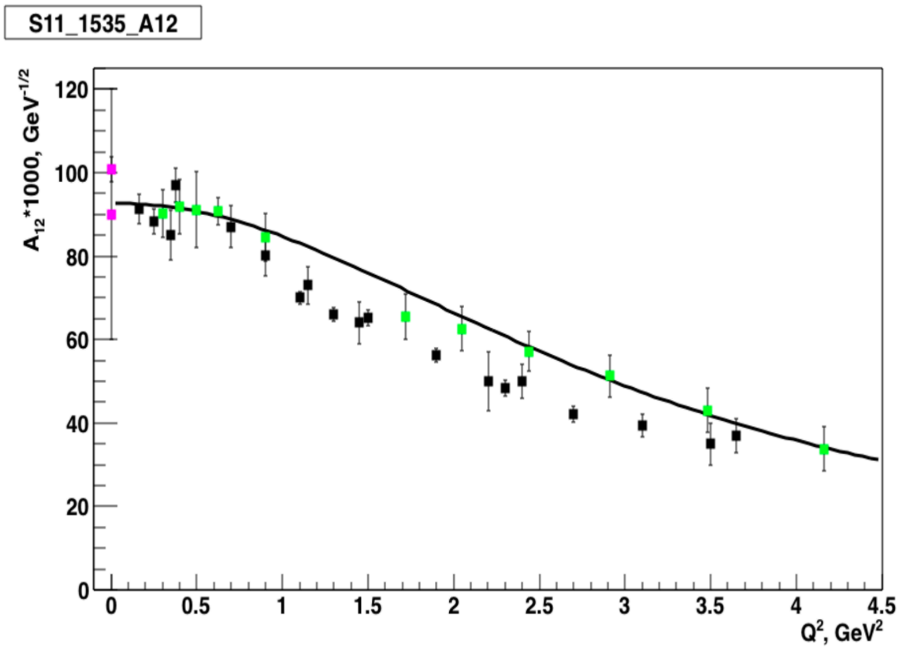
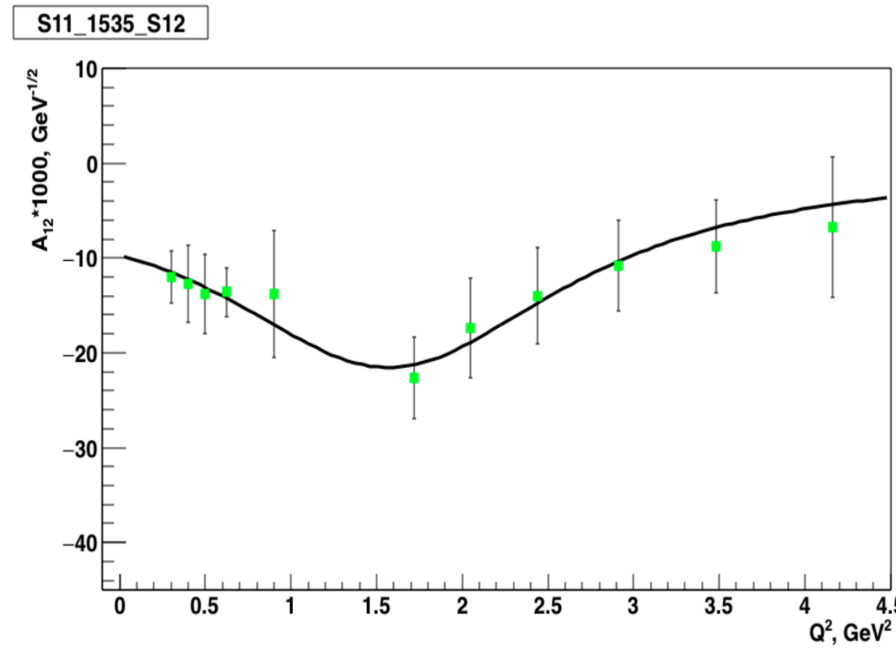
Green points — CLAS analysis of Nπ electroproduction off protons:
- I.G. Aznauryan et al., (CLAS Collaboration), Phys. Rev. C80, 055203 (2009)

s11(1535)

https://www.jlab.org/Hall-B/secure/e1/isupov/couplings/s11_1535.html





Magenta upper point — CLAS analysis of Nπ photoproduction off protons:

- M. Dugger et al., (CLAS Collaboration), Phys. Rev. C79, 065206 (2009)

Magenta lower point — PDG14

Black points — CLAS analysis of Nη electroproduction off protons:
(A12 extracted assuming that S12=0)

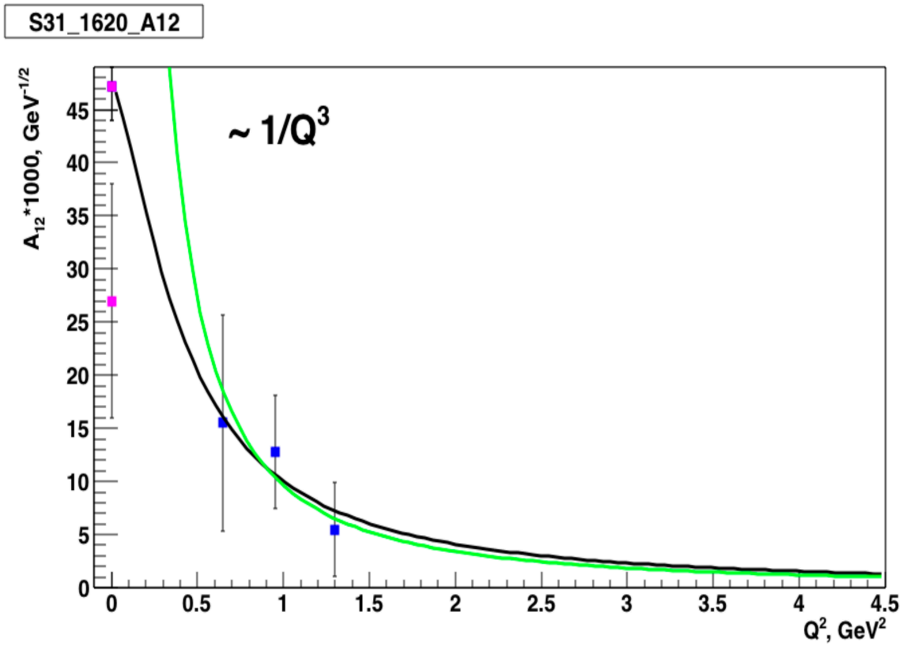
- M.M. Dalton et al., Phys. Rev C80 , 015205 (2009)
- H. Denizli et al., (CLAS Collaboration), Phys. Rev. C76, 015204 (2007)
- R. Thompson et al., (CLAS Collaboration), Phys. Rev. Lett. 86, 1702 (2001)
- C.S. Armstrong et al., Phys. Rev. D 60, 052004 (2009)

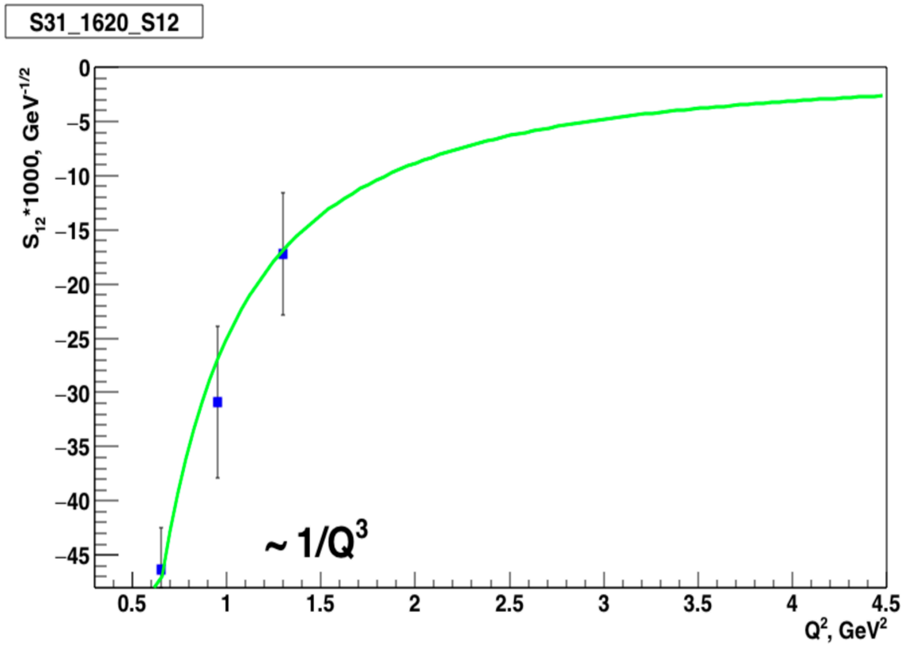
Green points — CLAS analysis of Nπ electroproduction off protons:

- I.G. Aznauryan et al., (CLAS Collaboration), Phys. Rev. C80, 055203 (2009)

s31(1620)

https://www.jlab.org/Hall-B/secure/e1/isupov/couplings/s31_1620.html





Magenta upper point — CLAS analysis of Nπ photoproduction off protons:
- M. Dugger et al., (CLAS Collaboration), Phys. Rev. C79, 065206 (2009)

Magenta lower point — PDG14

Blue points — CLAS analysis of pππ electroproduction off protons:
- V.I. Mokeev et al., arXiv:1509.054650[nucl-ex]

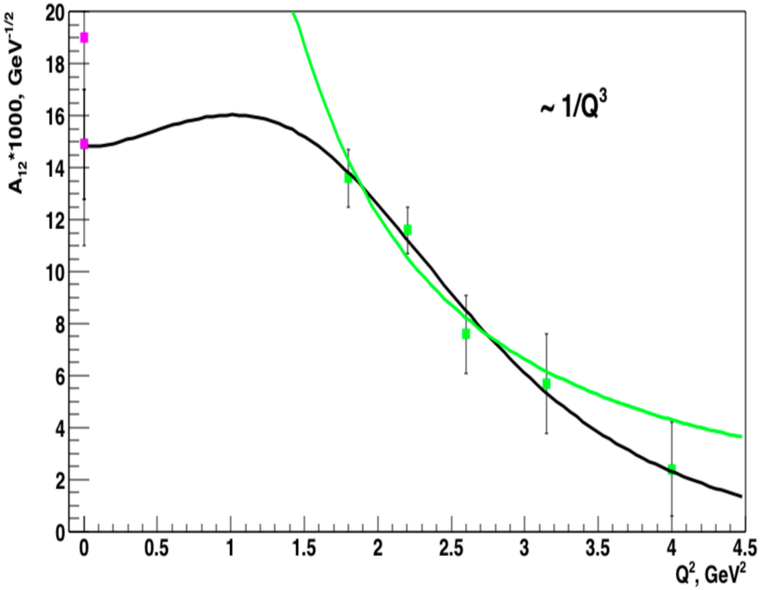
The black curve is a phenomenological fit.
The green curves represent $(1/Q^3)$ fit, inspired by quark counting rules.
For S12 black and green curve coincide.

d15(1675)

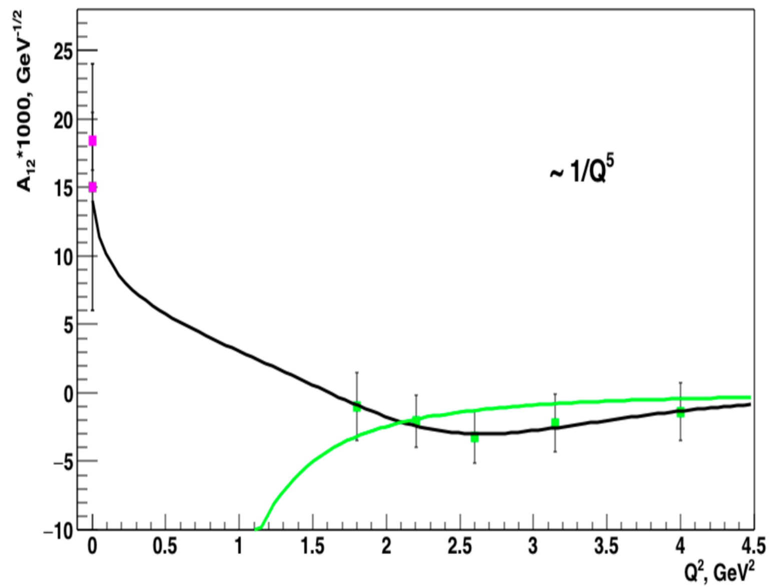
https://www.jlab.org/Hall-B/secure/e1/isupov/couplings/d15_1675.html

Evgeny

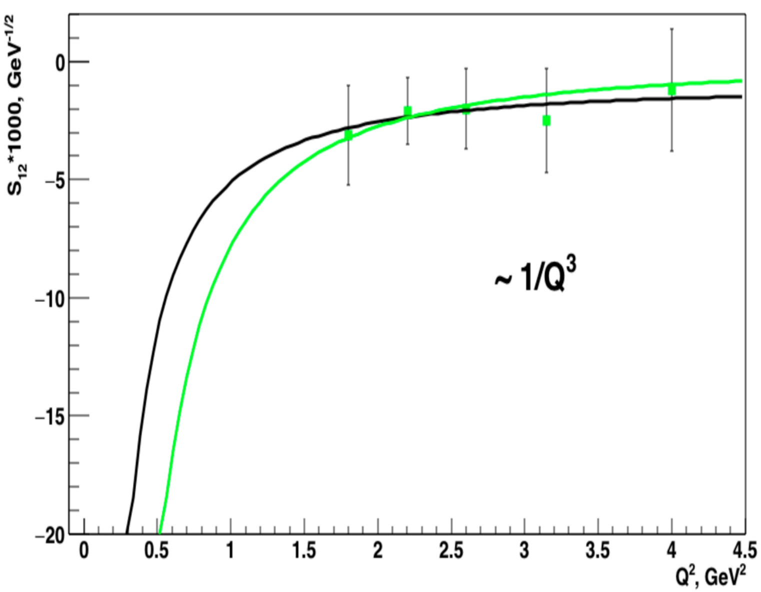
D15_1675_A12



D15_1675_A32



D15_1675_S12



Magenta lower point for A12 and upper for A32 — CLAS analysis of Nπ photoproduction off protons:

- M. Dugger et al., (CLAS Collaboration), Phys. Rev. C79, 065206 (2009)

Magenta upper point for A12 and lower for A32 — PDG14

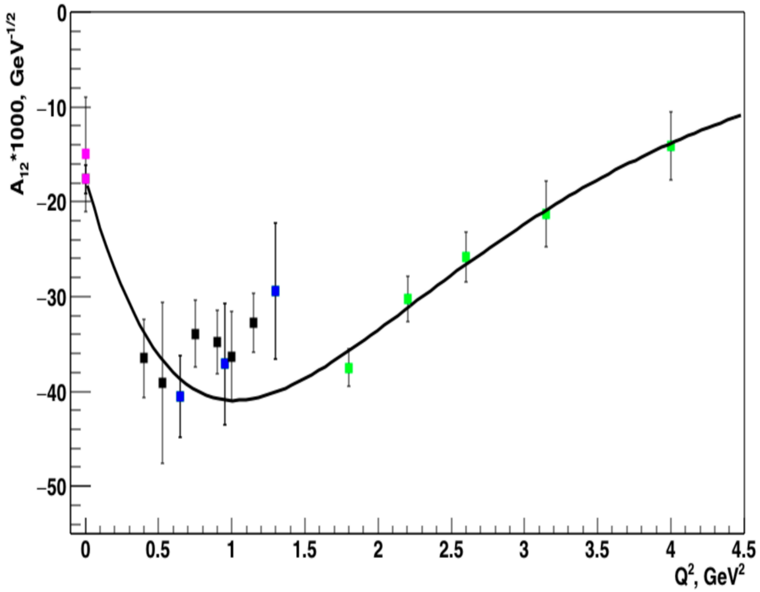
Green points — CLAS analysis of Nπ electroproduction off protons:

- K. Park et al, (CLAS Collaboration) , Phys. Rev. C 91, 045203 (2015)

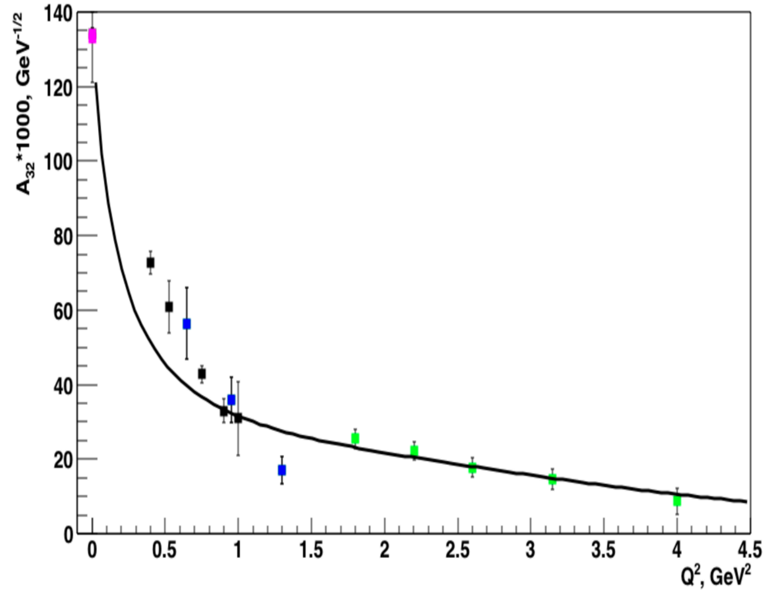
The black curves are phenomenological fits.

The green curves represent ($1/Q^3$,$1/Q^5$) fits, inspired by quark counting rules.

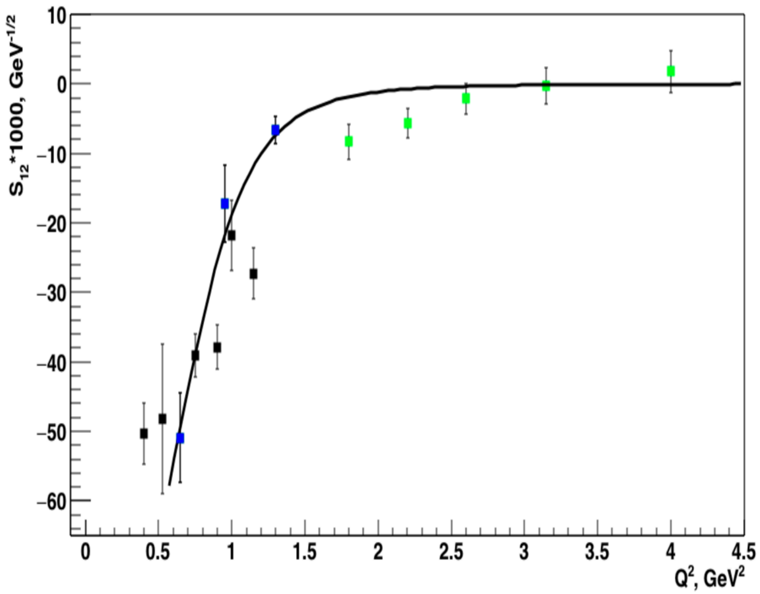
F15_1685_A12



F15_1685_A32



F15_1685_S12



Magenta lower point for A12 and upper for A32 — CLAS analysis of Nπ photoproduction off protons:

- M. Dugger et al., (CLAS Collaboration), Phys. Rev. C79, 065206 (2009)

Magenta upper point for A12 and lower for A32 — PDG14

Blue points — CLAS analysis of pππ electroproduction off protons:

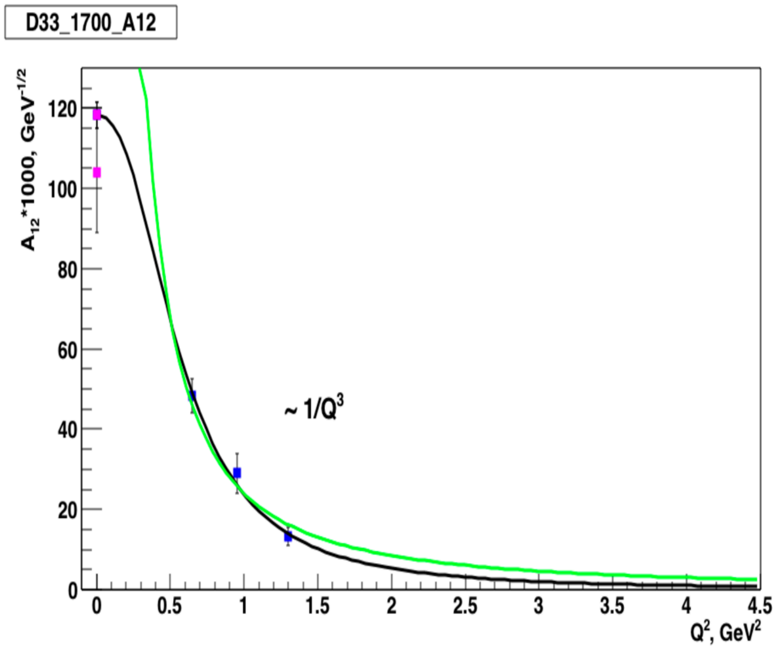
- V.I. Mokeev and I.G. Aznauryan, Int. J. of Modern Phys: Conf. Ser 26, 1460080 (2014)

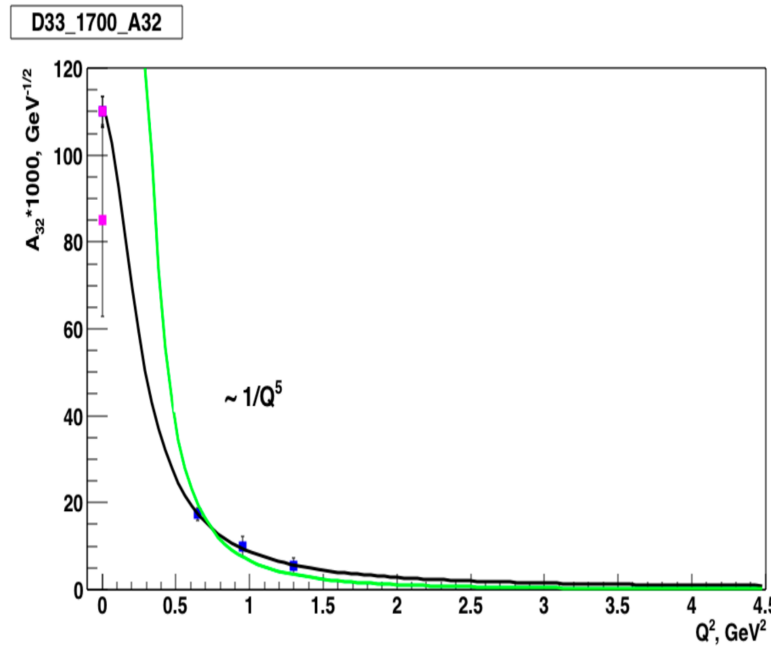
Black points — MAID analysis of Nπ electroproduction data:

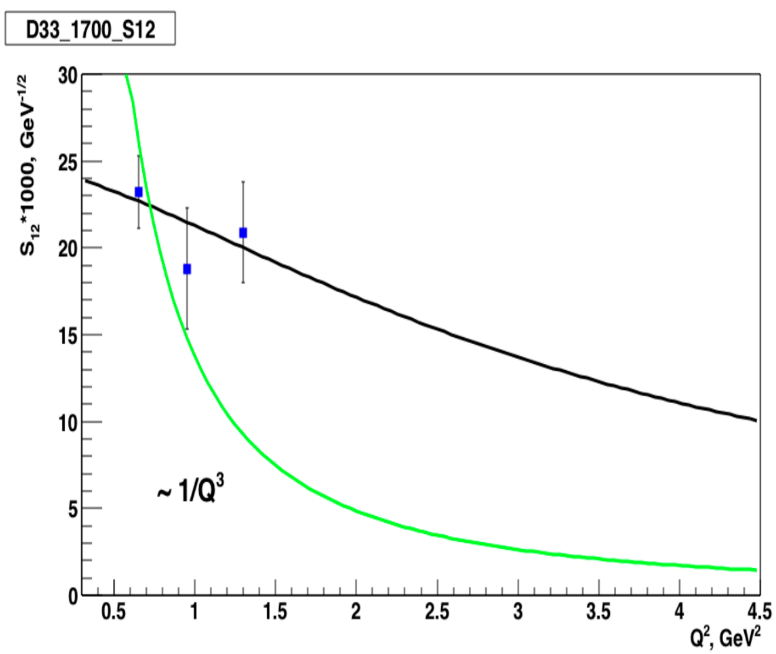
- L. Tiator et al., Eur. Phys. J. ST 198, 141 (2011)

Green points — CLAS analysis of Nπ electroproduction off protons:

- K. Park et al, (CLAS Collaboration) , Phys. Rev. C 91, 045203 (2015)







Magenta upper point for A12 and A32 — CLAS analysis of Nπ photoproduction off protons:
- M. Dugger et al., (CLAS Collaboration), Phys. Rev. C79, 065206 (2009)

Magenta lower point for A12 and A32 — PDG14

Blue points — CLAS analysis of pππ electroproduction off protons:
- V.I. Mokeev et al., arXiv:1509.054650[nucl-ex]

The black curve is a phenomenological fit.
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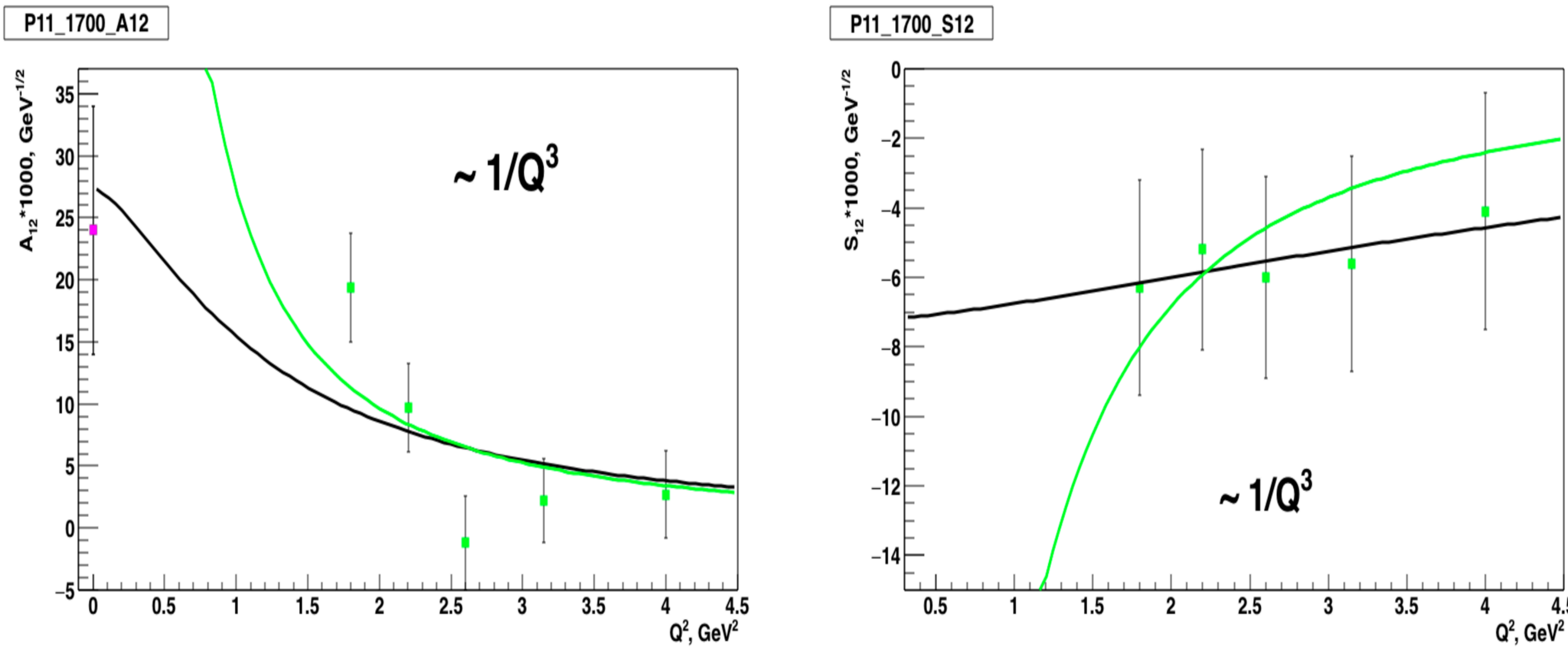
https://www.jlab.org/Hall-B/secure/e1/isupov/couplings/p11_1700.html



Magenta point for A12 — PDG14

Green points — CLAS analysis of Nπ electroproduction off protons:

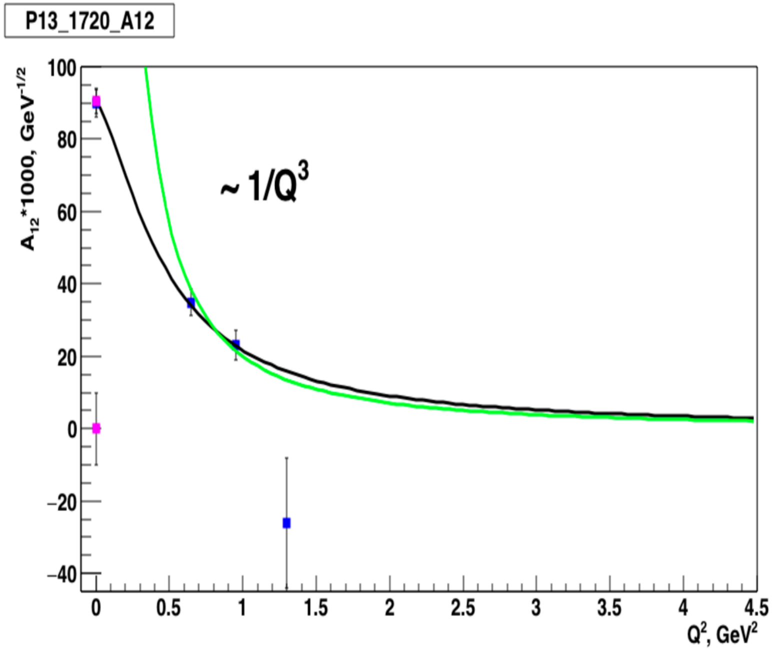
- K. Park et al, (CLAS Collaboration) , Phys. Rev. C 91, 045203 (2015)

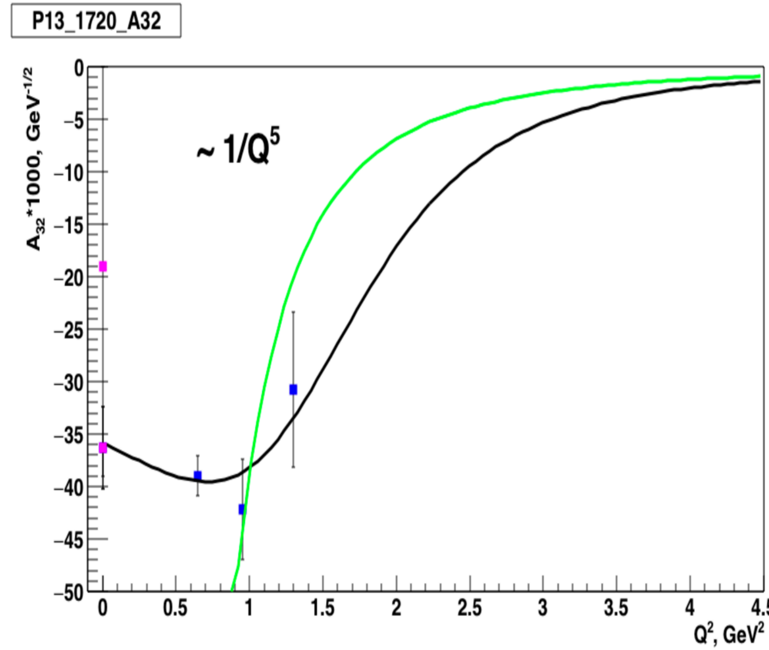
The black curve is a phenomenological fit.

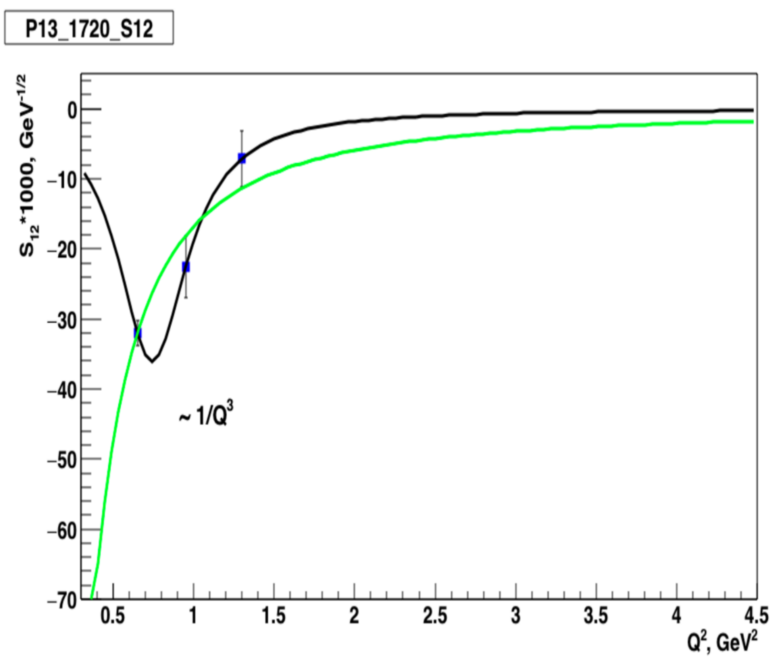
The green curves represent ($1/Q^3$) fits, inspired by quark counting rules.

p13(1720)

https://www.jlab.org/Hall-B/secure/e1/isupov/couplings/p13_1720.html







Magenta upper point for A12 and lower for A32 — CLAS analysis of Nπ photoproduction off protons:

- M. Dugger et al., (CLAS Collaboration), Phys. Rev. C79, 065206 (2009)

Magenta lower point for A12 and upper for A32 — PDG14

Blue points — CLAS analysis of pππ electroproduction off protons:

- V.I. Mokeev et al., arXiv:1509.054650[nucl-ex]

The black curve is a phenomenological fit.

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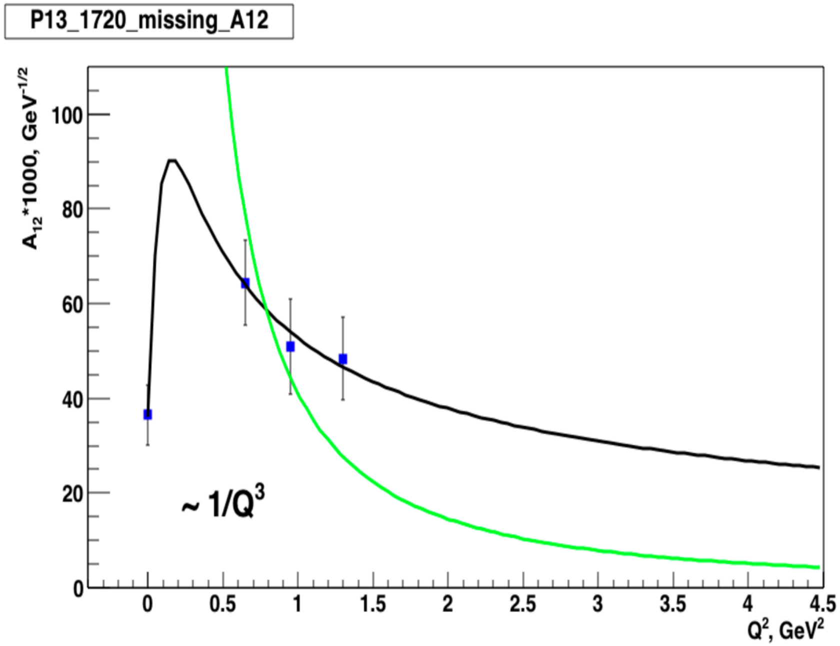
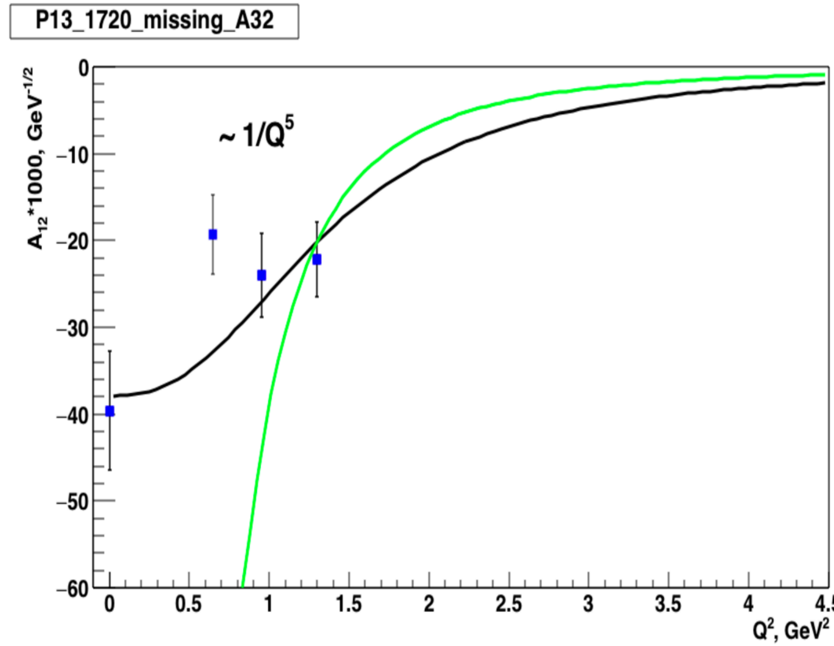
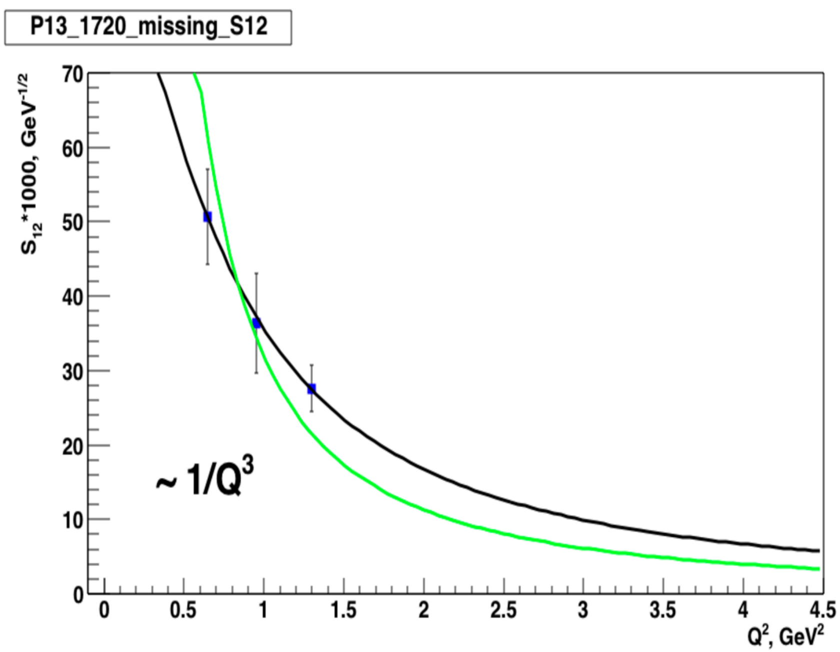
p13(1720) missing

https://www.jlab.org/Hall-B/secure/e1/isupov/couplings/p13_1720_missing.html







Blue points — CLAS analysis of pππ electroproduction off protons:
- V.I. Mokeev, preliminary

The black curves are phenomenological fits.
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File Path ▾ : ~/Downloads/tekuchka/tables_old/ecoupl_reson.f

ecoupl_reson.f (no symbol selected)

```fortran
c        21  is   s31(1620)
c        19  is   s11(1650)
c        6   is   f15(1685)
c        13  is   d33(1700)
c        17  is   p13(1720)
c        14  is   p13(1720) missing state

c       The third argument is Q2 from 0 to 5.0 GeV2


        real function ecoupl(i,j,Q2)  ! i=1 -A12,  i=2 -A32, i=3 -S12  j-resonance number
        implicit none
        real Q2,result,value,A12,A32,S12
        integer i,j

        ecoupl = 0
        value = 0

        if(Q2.lt.0.or.Q2.gt.5.0) return


        if(j.eq.14) then  ! missing p13(1720)
        if(i.eq.1) value =  (36.5+1044.05*Q2)/(1.+19.5*Q2*sqrt(Q2))
c       if(i.eq.2) value = (-39.6+101.4*Q2-119.1*Q2*Q2)/(1.+1.37*Q2**4)
        if(i.eq.2) value = (-37.9)/(1.+0.455*Q2**2*sqrt(Q2))
        if(i.eq.3.and.Q2.gt.0.) value =  (93.056)/(1.+1.61*Q2*sqrt(Q2))
        ecoupl = value
        return
        endif

        if(j.eq.17) then  !  p13(1720)
        if(i.eq.1) value =  (90)/(1.+3.16*Q2*sqrt(Q2))
        if(i.eq.2) value = (-35.87-6.85*Q2)/(1.+ 0.118*Q2**4)
        if(i.eq.3.and.Q2.gt.0.) value=-3.09/(1.-3.7*Q2+2.86*Q2*sqrt(Q2))
        ecoupl = value
        return
        endif
```

Evaluation of Resonant Amplitudes

Regular Breit-Wigner (BW) ansatz as the start point :

$$T_{res} = \sum_{N^*} \frac{\langle \lambda_f | T_{dec} | \lambda_{N^*} \rangle \langle \lambda_{N^*} | T_{em} | \lambda_\gamma \lambda_p \rangle}{M^2_{N^*} - W^2 - i\Gamma_{N^*}(W) M_{N^*}}$$

$\langle \lambda_f | T_{dec} | \lambda_{N^*} \rangle$ **amplitudes are computed from the partial N* decay widths to the hadron final states of definite helicity l_f**

$$\langle \lambda_f | T_{dec} | \lambda_{N^*} \rangle = \langle \lambda_f | T^0_{dec} | \lambda_{N^*} \rangle d^{J_{N^*}}_{\lambda_{N^*}\lambda_f}(\cos(\theta_f)) e^{i\lambda_{N^*}\varphi_f}$$

$$\langle \lambda_f | T^0_{dec} | \lambda_{N^*} \rangle = f_{dec}(J_{N^*}, M_{N^*}, p, p^{N^*}) \sqrt{\Gamma_{\lambda_f}}$$

f_{dec} is the kinematical factor, which depends on resonance spin, mass and abs. CM 3-momenta values of the stable final hadron

The relationships between N* electroproduction amplitudes T_{em} and g_vNN* electrocouplings $A_{1/2}$, $A_{3/2}$, $S_{1/2}$

$$\langle \lambda_{N^*} | T_{em} | \lambda_\gamma \lambda_p \rangle = f_{em}(M_{N^*}, q_\gamma, q_{\gamma N^*}) * \left\{ \begin{array}{l} A_{1/2}(Q^2), A_{3/2}(Q^2) \\ \sqrt{2} S_{1/2}(Q^2) \end{array} \right.$$

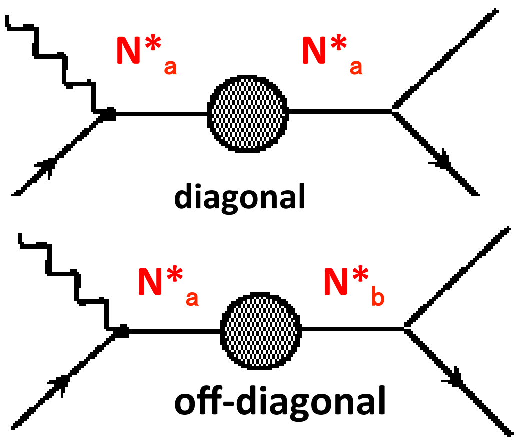
are obtained imposing the requirement: fully integrated resonant cross section should be described by the relativistic Breit-Wigner formula in a case of single contributing resonance.

See detasils in: M.Ripani et al., Nucl. Phys. A673, 220 (2000).

Unitarized Breit-Wigner Ansatz for Resonant Amplitudes

Resonant amplitude :

$$T^{res}_{\gamma p \to MB} = f_{\beta MB} S_{\alpha\beta} f_{\alpha\gamma p}$$



Inverse of the JM unitarized N* propagator:

$$S^{-1}_{\alpha\beta} = M^2_{N^*}\delta_{\alpha\beta} - i\left(\sum_i \sqrt{\Gamma_{\alpha i}}\sqrt{\Gamma_{\beta i}}\right)\sqrt{M_{N^*\alpha}}\sqrt{M_{N^*\beta}} - W^2\delta_{\alpha\beta}$$

Off-diagonal transitions incorporated into the full resonant amplitudes of the JM model:

N(1535)1/2$^-$ ↔ N(1650)1/2$^-$
N(1520)3/2$^-$ ↔ N(1700)3/2$^-$
3/2$^+$(1720) candidate ↔ N(1720)3/2$^+$

See details in: V.I. Mokeev, V.D. Burkert et al., (CLAS Collaboration) Phys. Rev. C86, 035203 (2012).

Employing the Results on g_vNN^* Electrocouplings from CLAS

- Evaluation of the resonant amplitudes in any exclusive meson photo-/electro-production channel off protons.

- Extraction of the resonance parameters from resonant amplitudes at the pole position in the complex energy plain. Help from JPAC will be very appreciated.

- Evaluation of the resonant amplitude contribution to inclusive and semi- inclusive structure functions in order to facilitate the studies of Bloom-Gilman duality and to extend the studies of the structure function behavior at x Bjorken close to unity from the future data on inclusive and semi- inclusive processes with the CLAS12.

- Evaluation of the resonant contributions to exclusive photon-/meson electro-production processes (DVCS, DVMP) in DIS kinematics region.

- Can be of interest for the development of parameterization of the transition $N \to N^*$ GPDs.