Proposal to Study the N→N* Transition Form Factors with CLAS at 11 GeV

Ralf W. Gothe
University of South Carolina

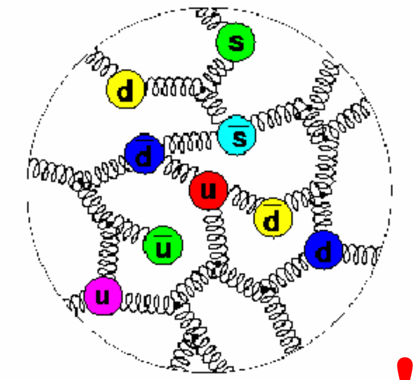
Electromagnetic N-N* Transition Form Factors Workshop

October 13 -15, 2008
Jefferson Lab, Newport News, VA USA

- Motivation: Why Baryon Transition Form Factors?
- Consistency: N→Δ, N→Roper, and other N→N* Transitions
- Experiment: Cross Sections and Beam Time Estimates

Physics Goals

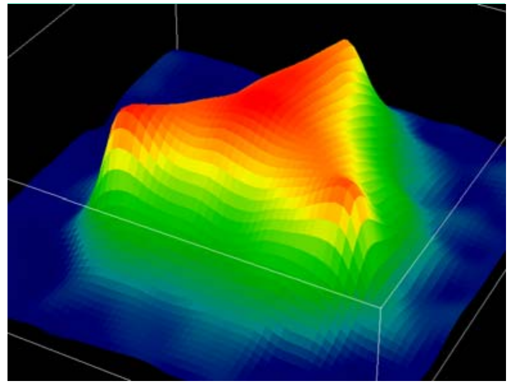
$\ll 0.1\text{fm}$



pQCD

q, g, $q\bar{q}$

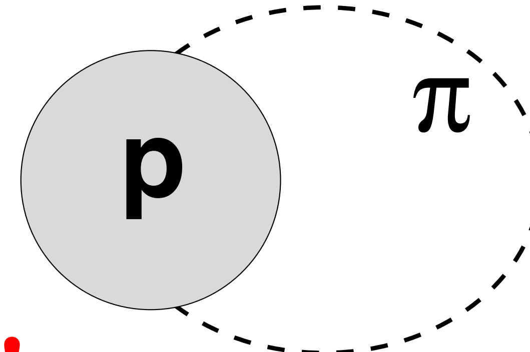
0.1 – 1.0 fm



Models

Quarks and Gluons as Quasiparticles

> 1.0 fm



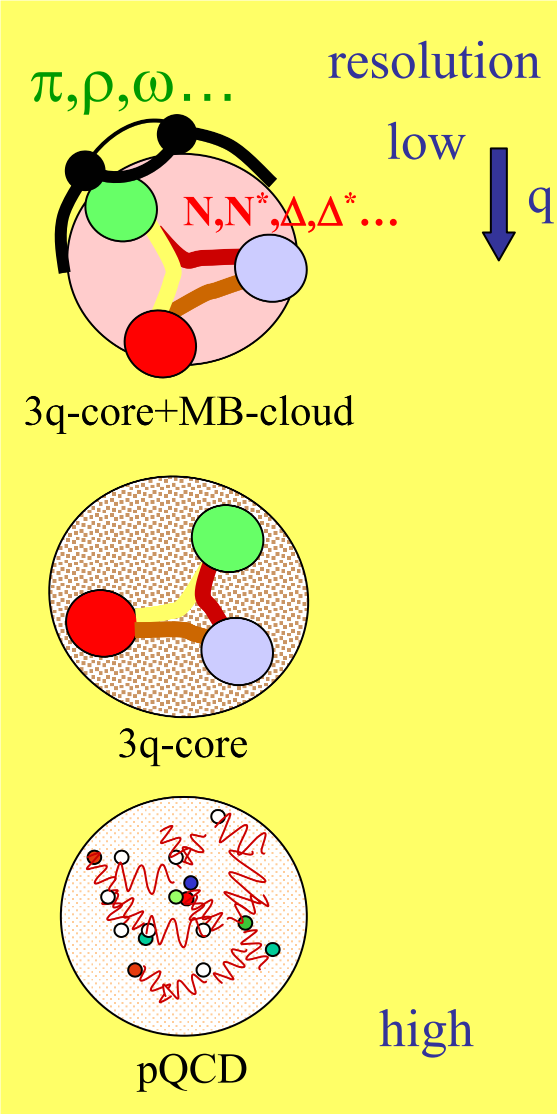
ChPT

Nucleon and Mesons

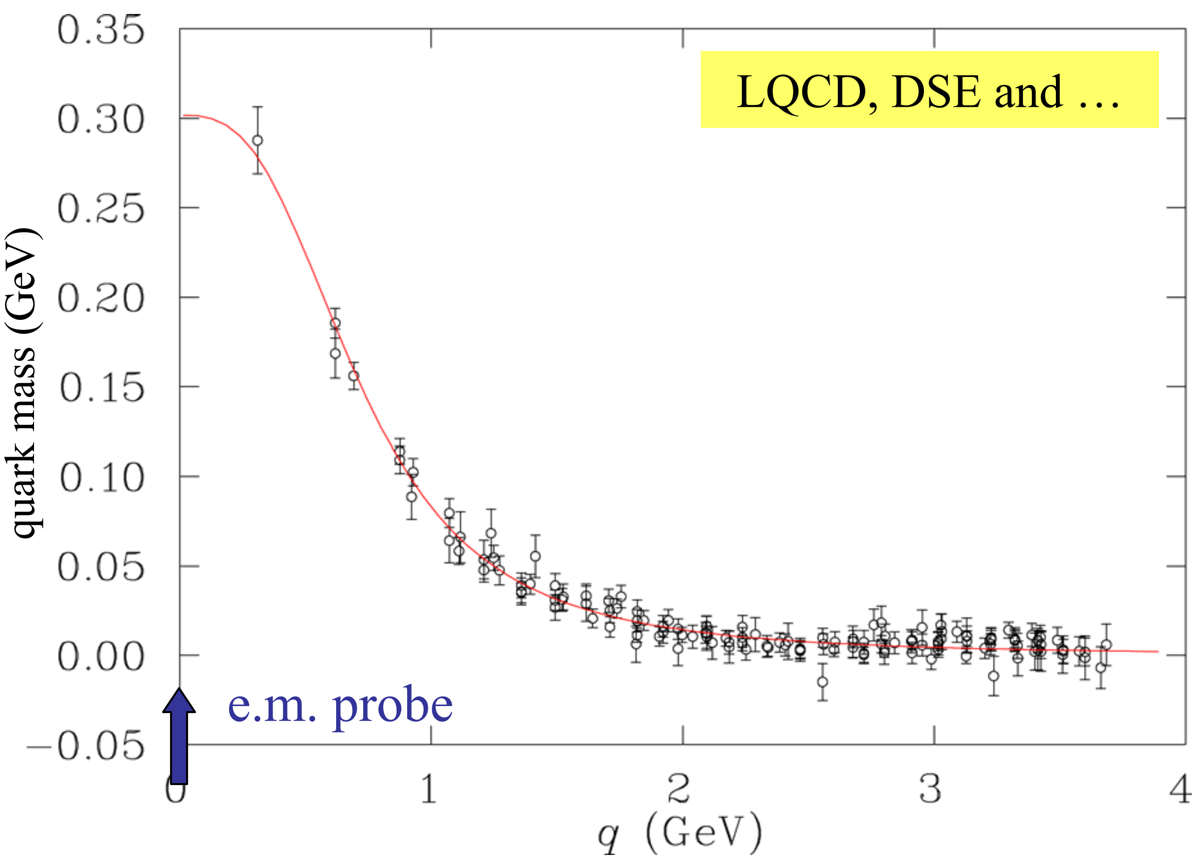
- Understand QCD in the full strong coupling regime
  - transition form factors to nucleon excited states

  allow us to study
  - relevant degrees-of-freedom
  - wave function and interaction of the constituents

Hadron Structure with Electromagnetic Probes

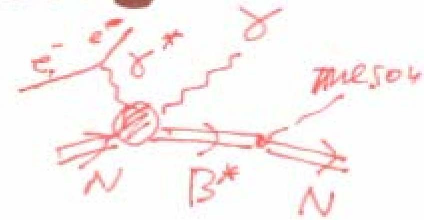


Quark mass extrapolated to the chiral limit, where *q* is the momentum variable of the tree-level quark propagator using the Asquat action.

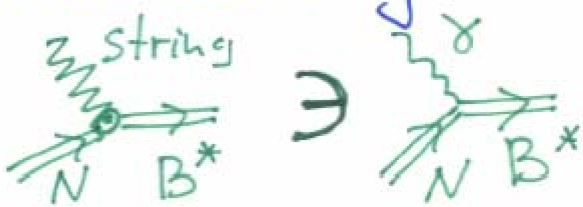


To avoid confusions

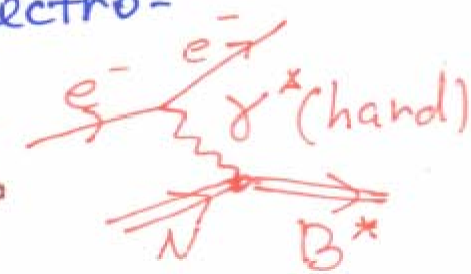
M. Polyakov



Although non-diagonal DVCS is a <u>hard</u> process it probes <u>soft</u> B^* excitation by <u>low-energy</u> **QCD** string. Physics-wise it is more analogous to B^* photoexcitation

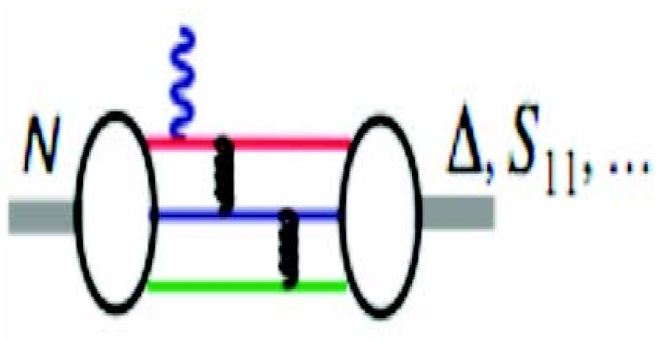


than to <u>hard</u> electro-production of B^*

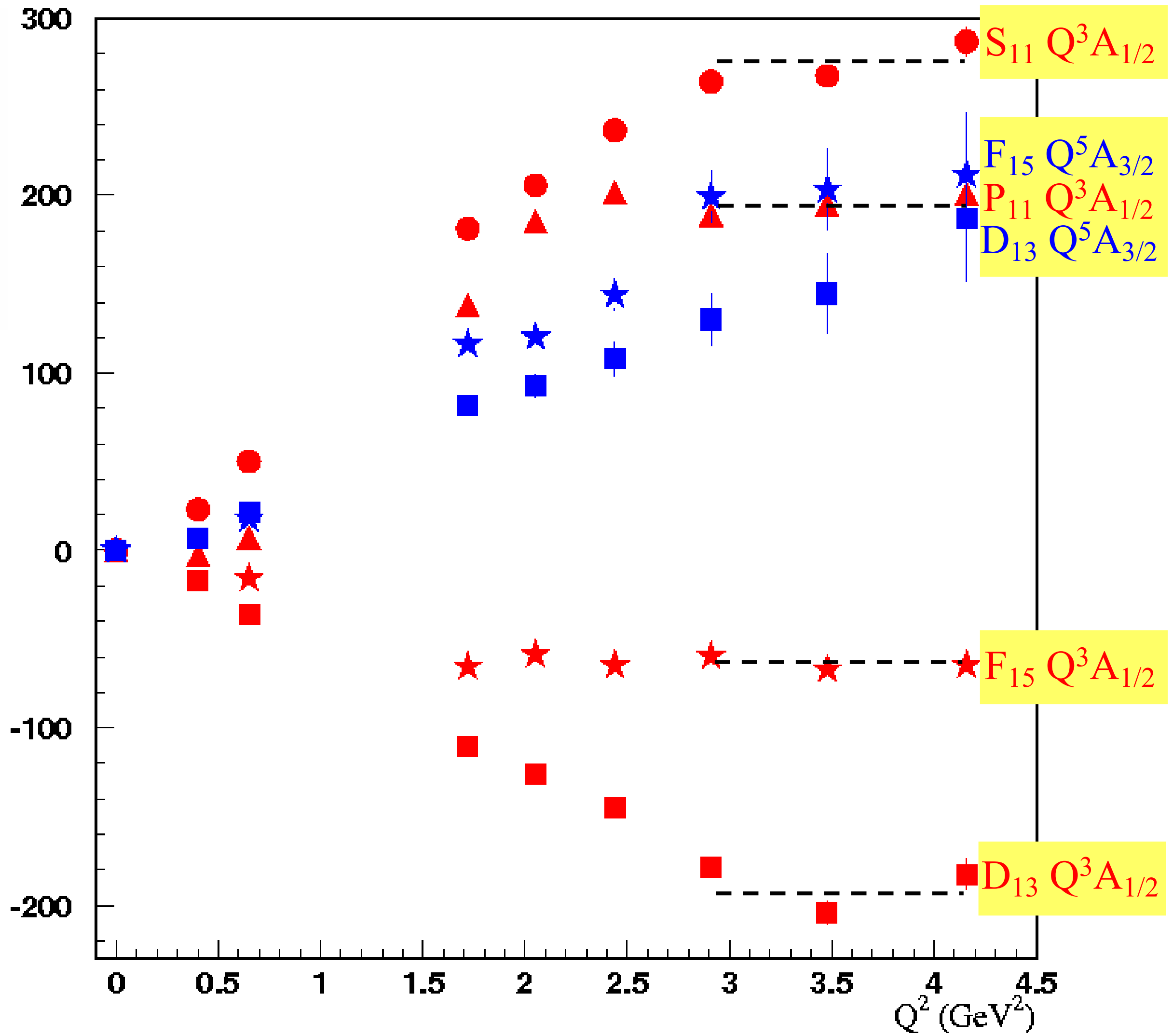


Non-diagonal DVCS probes physics qualitatively different from that in <u>hard</u> B^* electroproduction!

Constituent Counting Rule

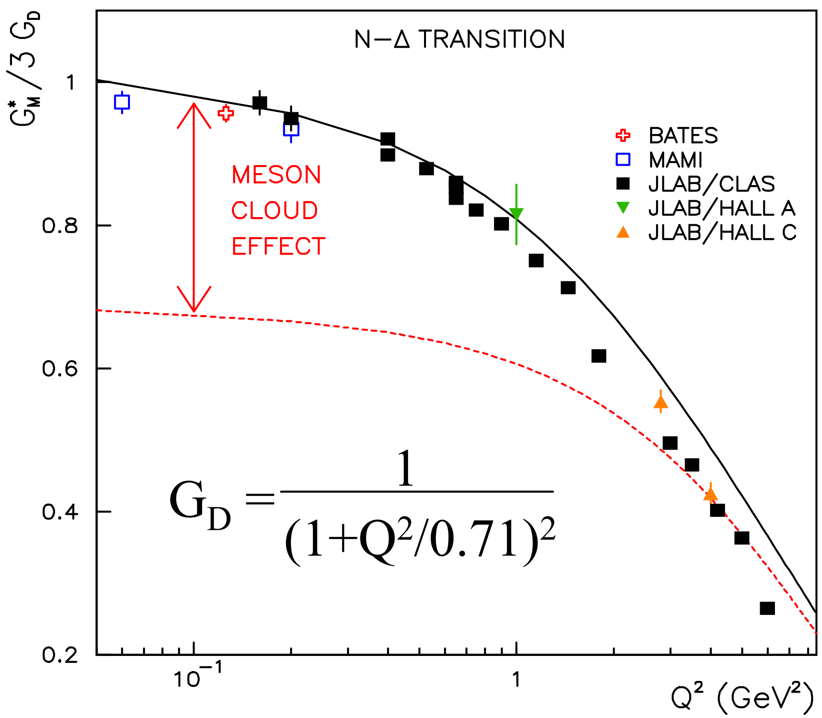


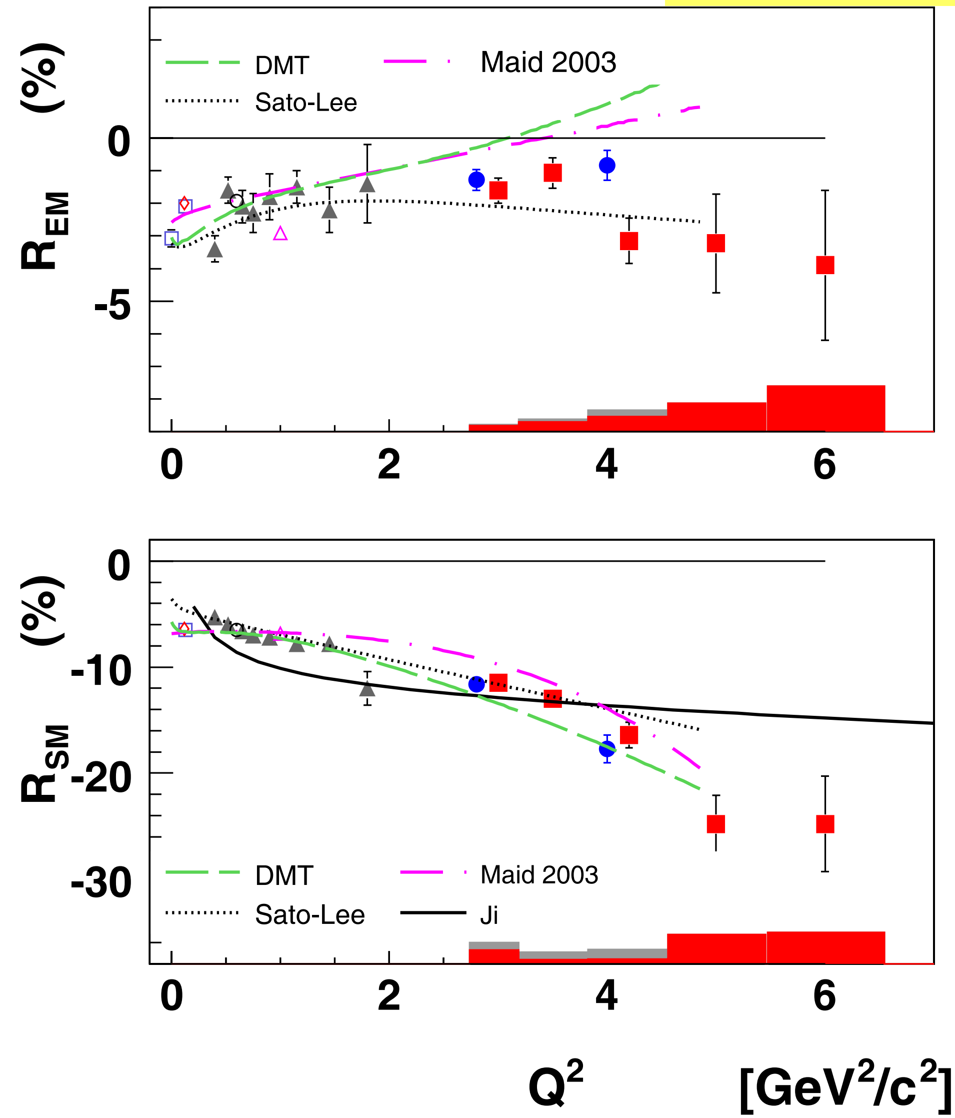
- ➢ $A_{1/2}$ α $1/Q^3$
- ➢ $A_{3/2}$ α $1/Q^5$
- ➢ G_M^* α $1/Q^4$



$N \rightarrow \Delta$ Multipole Ratios R_{EM} , R_{SM}

M. Ungaro



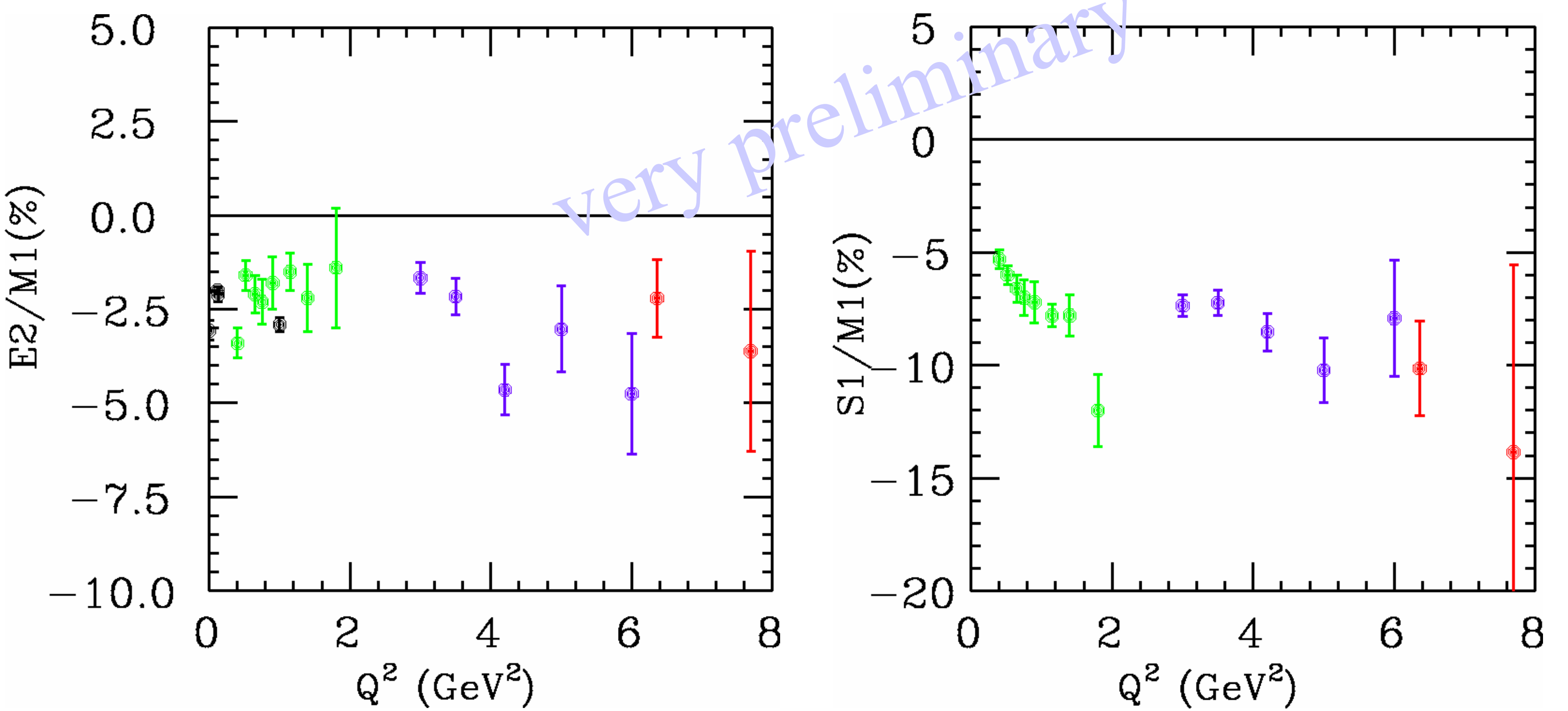


- New trend towards pQCD behavior does not show up.
  - $R_{EM} \rightarrow +1$
  - $G_M^* \rightarrow 1/Q^4$
- CLAS12 can measure R_{EM} and R_{SM} up to Q^2~12 GeV^2.

$N \rightarrow \Delta$ Multipole Ratios R_{EM} , R_{SM}

A. Villano

$\vec{e}\, p \rightarrow e' p \pi^0$



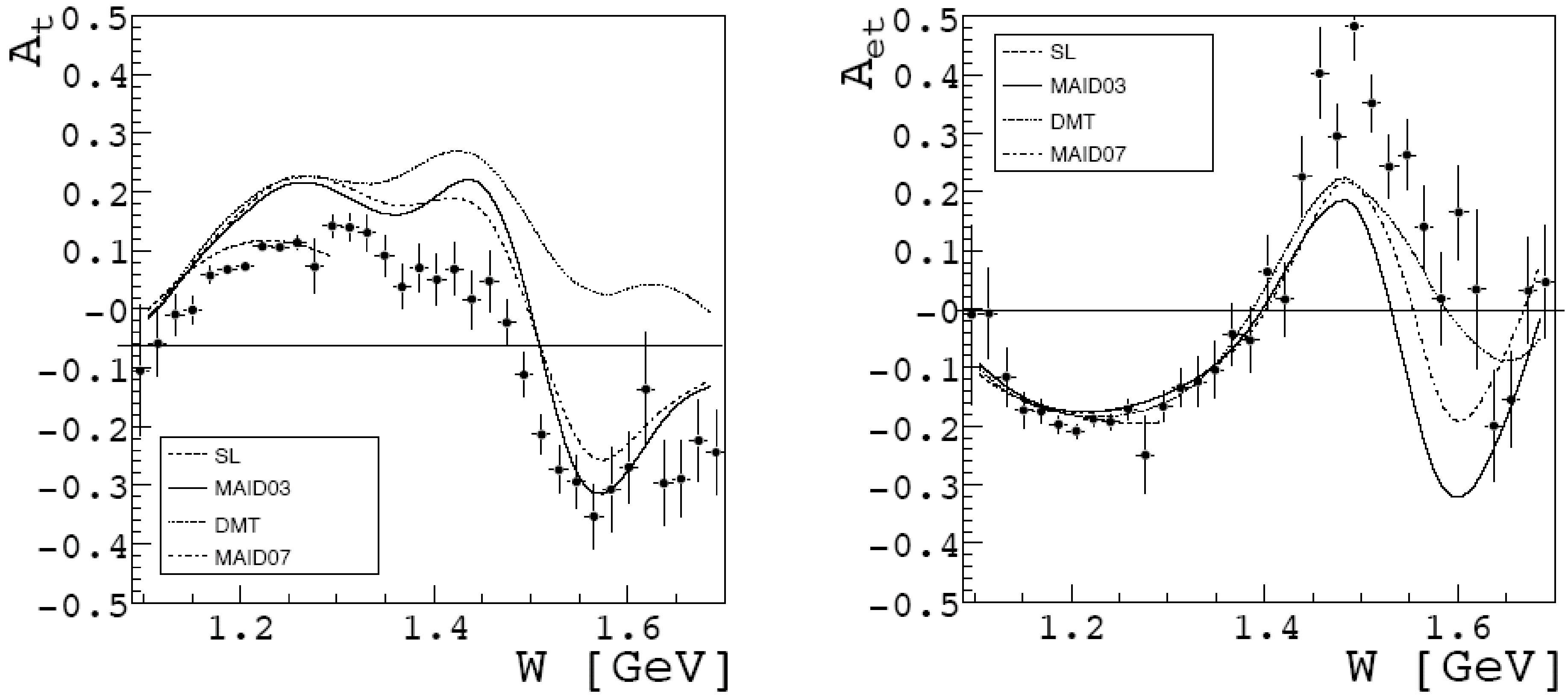
… but the trend that R_{SM} becomes constant in the limit of $Q^2 \rightarrow \infty$ seems to show up in the latest MAID 2007 analysis of the high Q^2 data.

Integrated Target and Beam-Target Asymmetries

CLAS

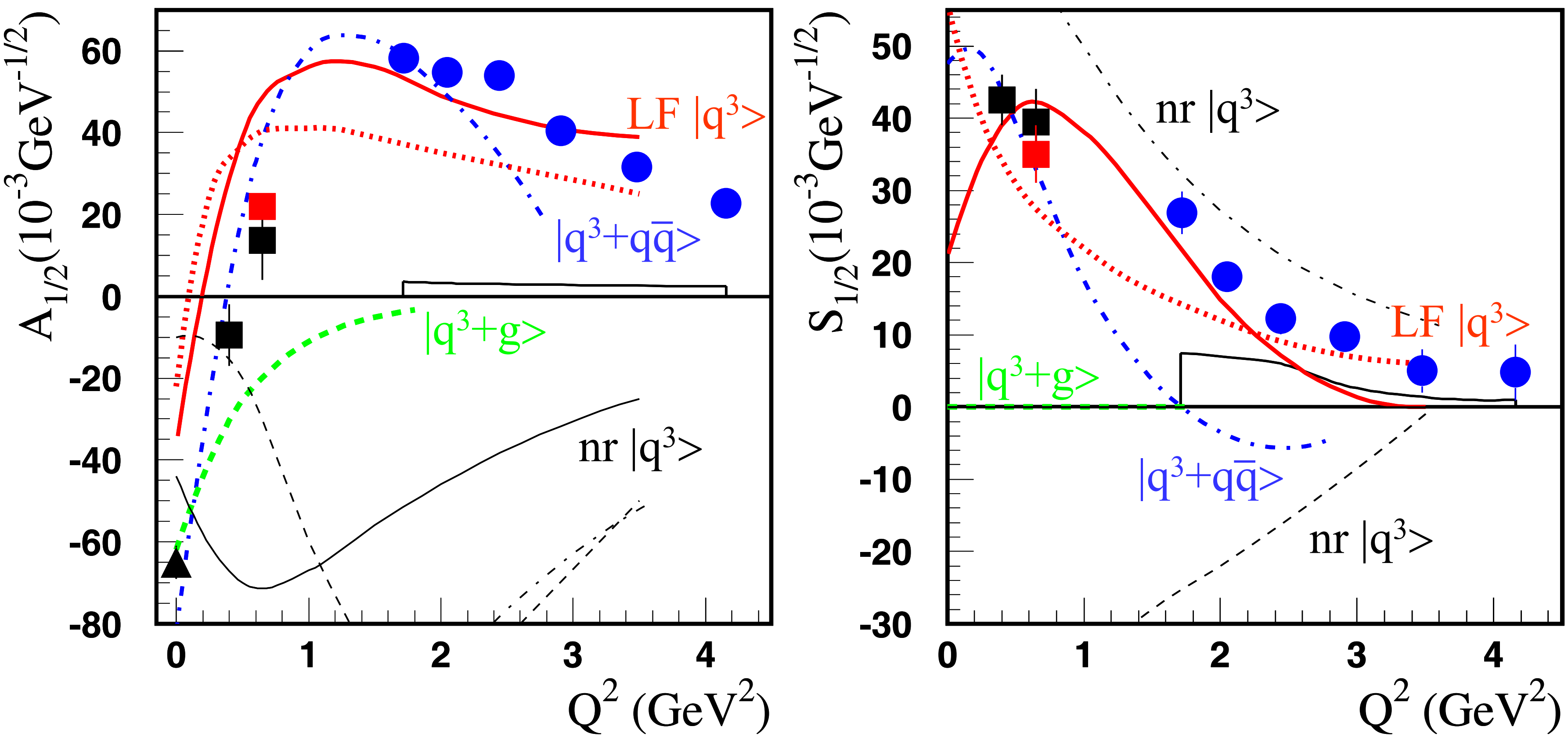
A. Biselli

$\vec{e}\,\vec{p} \rightarrow e'p\pi^0$



The asymmetries are integrated over θ^* and φ^* in the Q^2 range from 0.187 to 0.770 GeV^2 and will further reduce the model dependence of the extracted resonance parameters.

Roper Electro-Coupling Amplitudes $A_{1/2}$, $S_{1/2}$



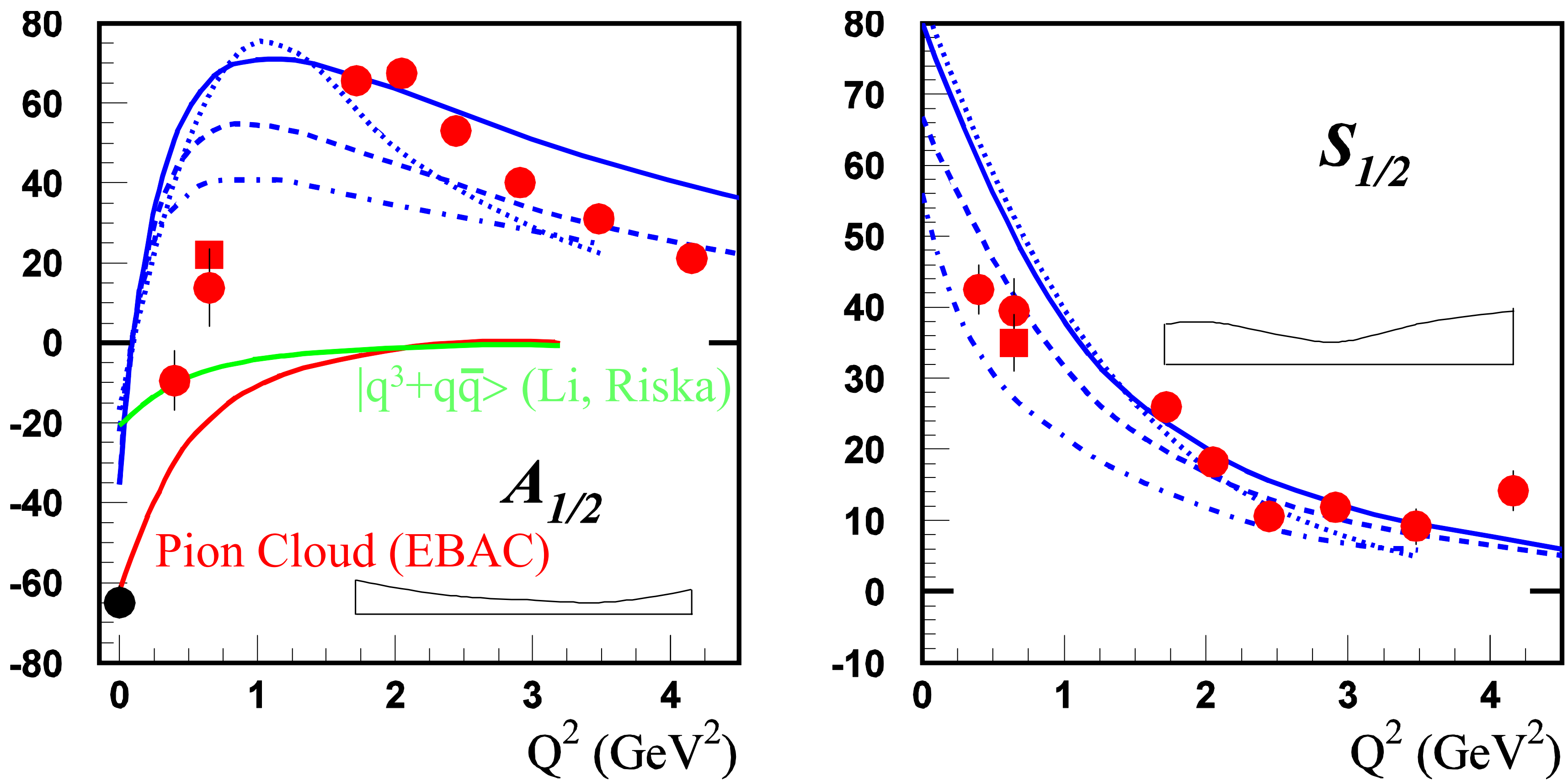
▲ PDG estimation

■ π electro-production (UIM, DR)

■ π, 2π combined analysis

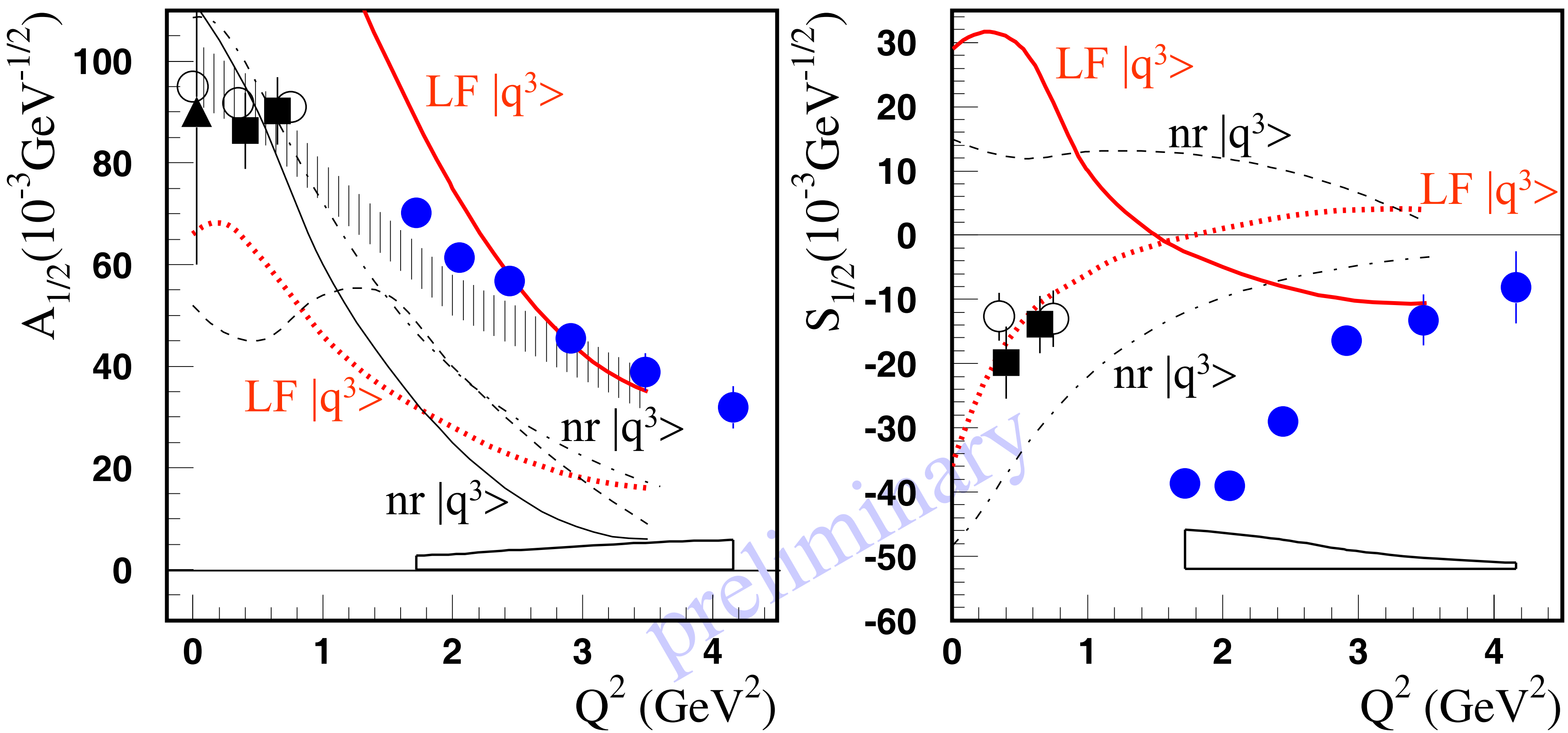
● K. Park (Data)
I. Aznauryan (UIM)

Roper Electro-Coupling Amplitudes $A_{1/2}$, $S_{1/2}$



- PDG estimation
- π electro-production (UIM, DR)
- π, 2π combined analysis
- K. Park (Data)
  I. Aznauryan (UIM)

$S_{11}(1535)$ Electro-Coupling Amplitudes $A_{1/2}$, $S_{1/2}$



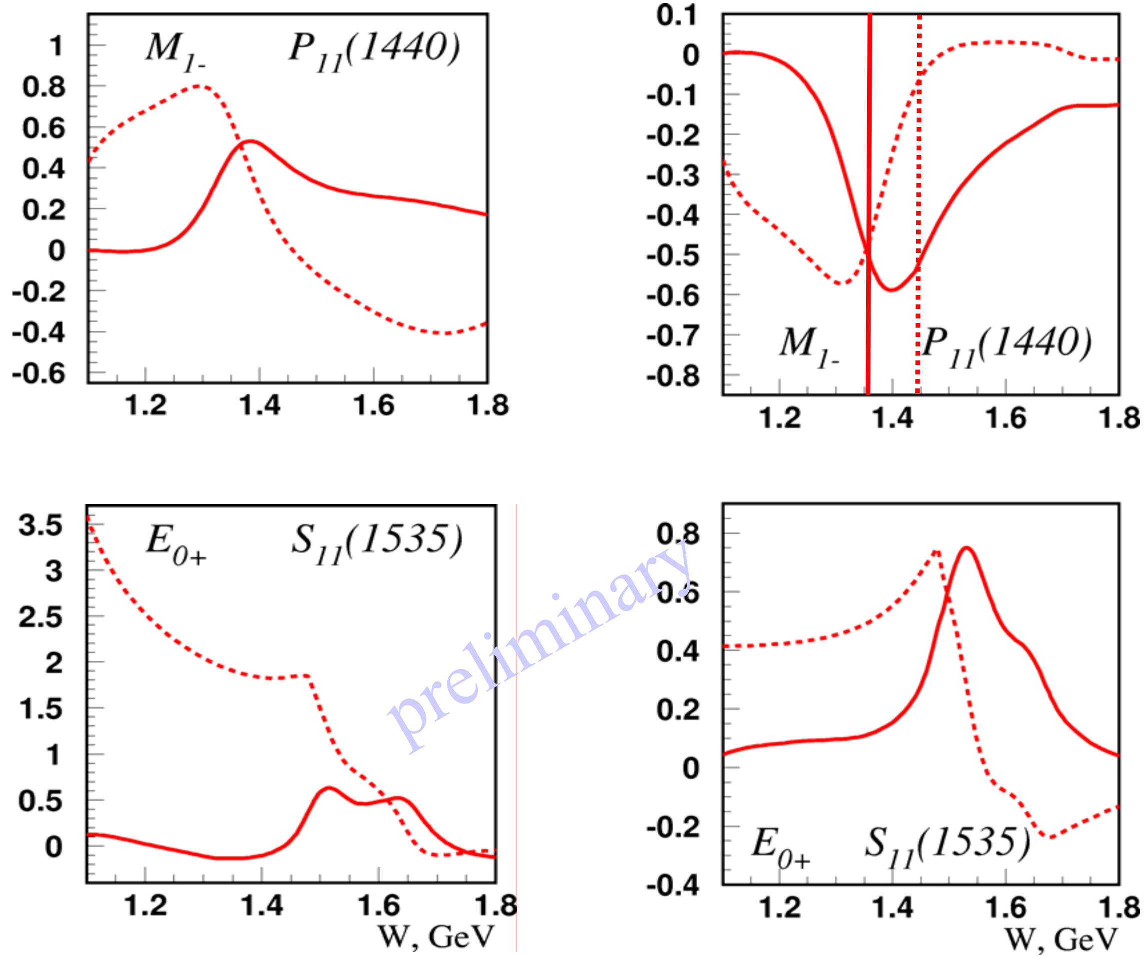
▲	PDG estimation	○	η production (UIM, DR)
■	π electro-production (UIM, DR)	●	K. Park (Data) I. Aznauryan (UIM)
‖‖‖	η production (SQTM S_{11}, D_{13} analysis)		

Energy-Dependence of π^+ Multipoles for P_{11}, S_{11}

I. Aznauryan (UIM)

The study of some baryon resonances becomes easier at higher Q^2.

$Q^2 = 0$ GeV^2 | $Q^2 = 2.05$ GeV^2

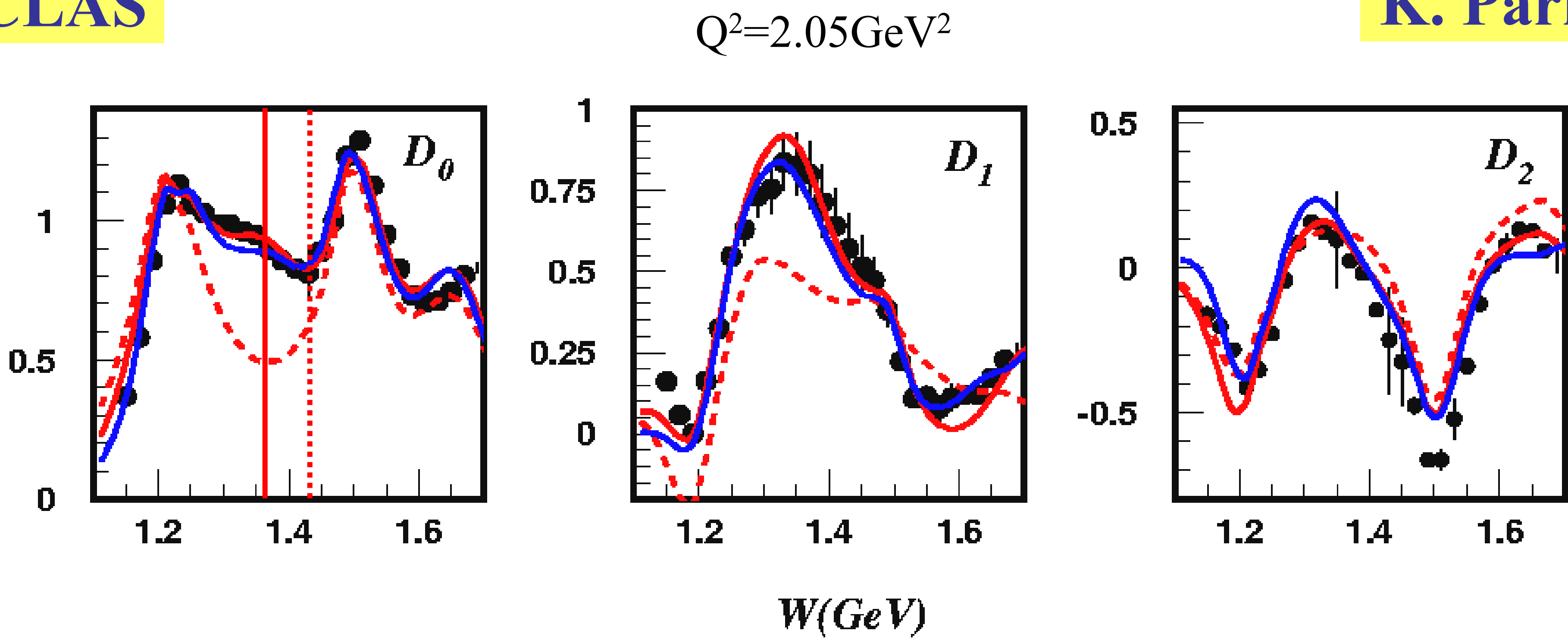


real part
imaginary part

Legendre Moments of Structure Functions

CLAS

K. Park



$$\sigma_T + \epsilon\sigma_L = \sum_{l=0}^{n} D_l^{T+L} P_l(\cos\theta_\pi^*)$$

I. Aznauryan — DR fit

I. Aznauryan - - - DR fit w/o P11

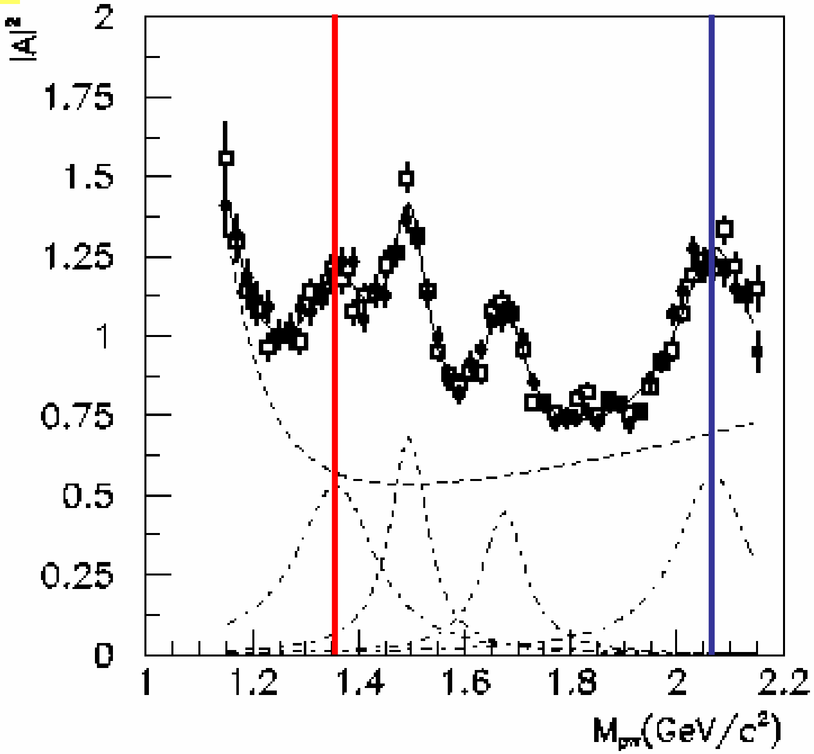
I. Aznauryan — UIM fit

The dominating final state multipole amplitude M_{1-} of the $P_{11}(1440)$ resonance is at high Q^2 are much more prominent than at small Q^2.

$J/\psi \to p\pi^-\bar{n}$ and $J/\psi \to \bar{p}\pi^+ n$

BES

Bing-Song Zou



N*(1440): M = 1358 ± 17
Γ = 179 ± 56

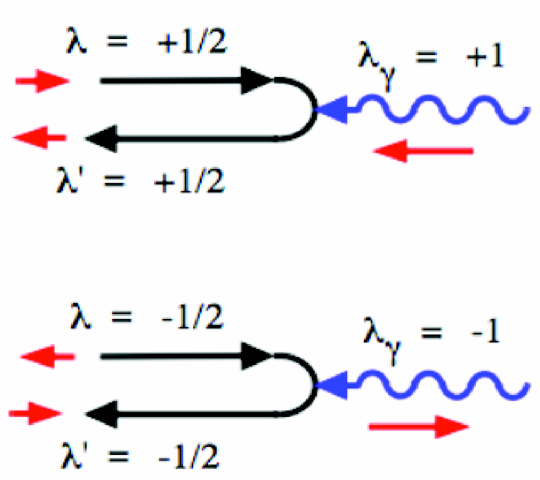
N*(2050): M = 2068 +15-40
Γ = 165 ± 42

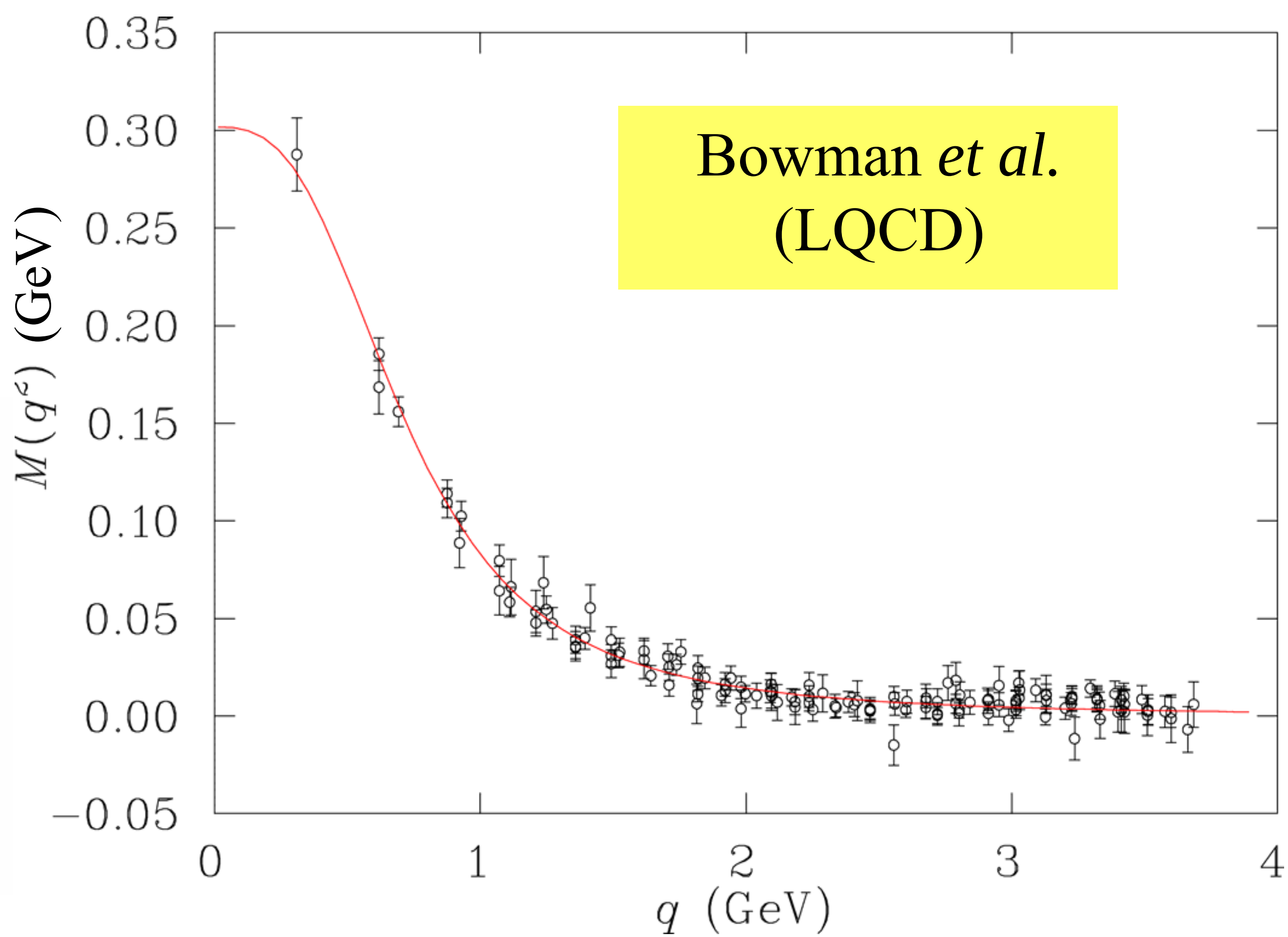
πN invariant mass / MC phase space

BES/BEPC, Phys. Rev. Lett. 97 (2006)

Fermion Helicity Conservation

Helicity Conservation
$\lambda = \lambda'$ for $q \gg M$



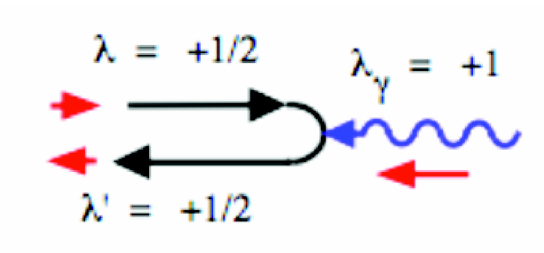


Quark mass extrapolated to the chiral limit, where q is the momentum variable of the tree-level quark propagator using the Asquat action.

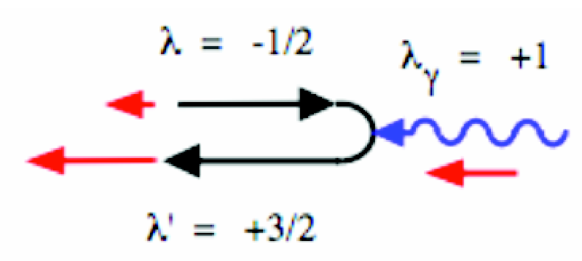
D$_{13}$(1520) Helicity Asymmetry

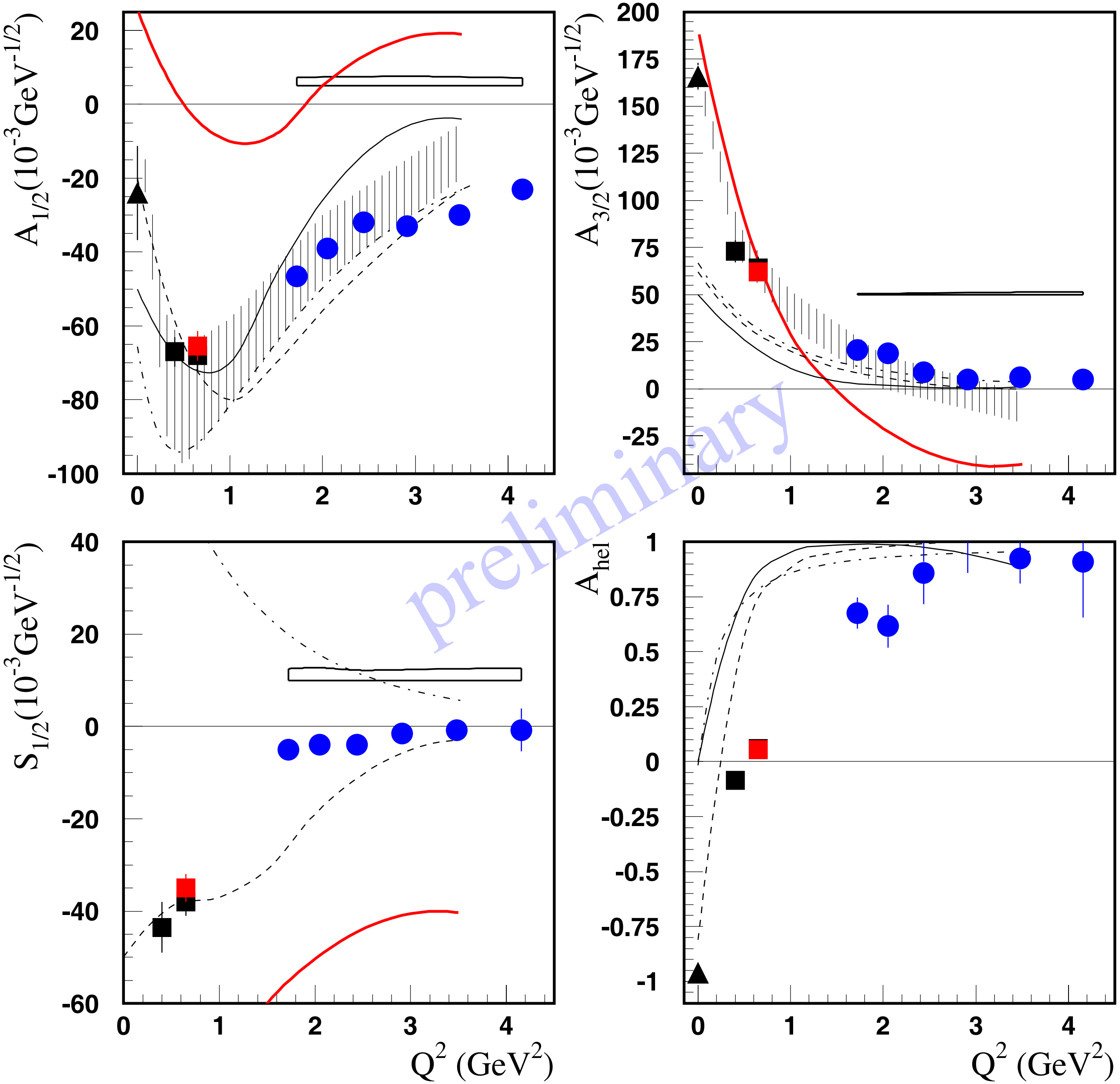
$$A_{hel} = \frac{A_{1/2}^2 - A_{3/2}^2}{A_{1/2}^2 + A_{3/2}^2}$$

$A_{1/2}$



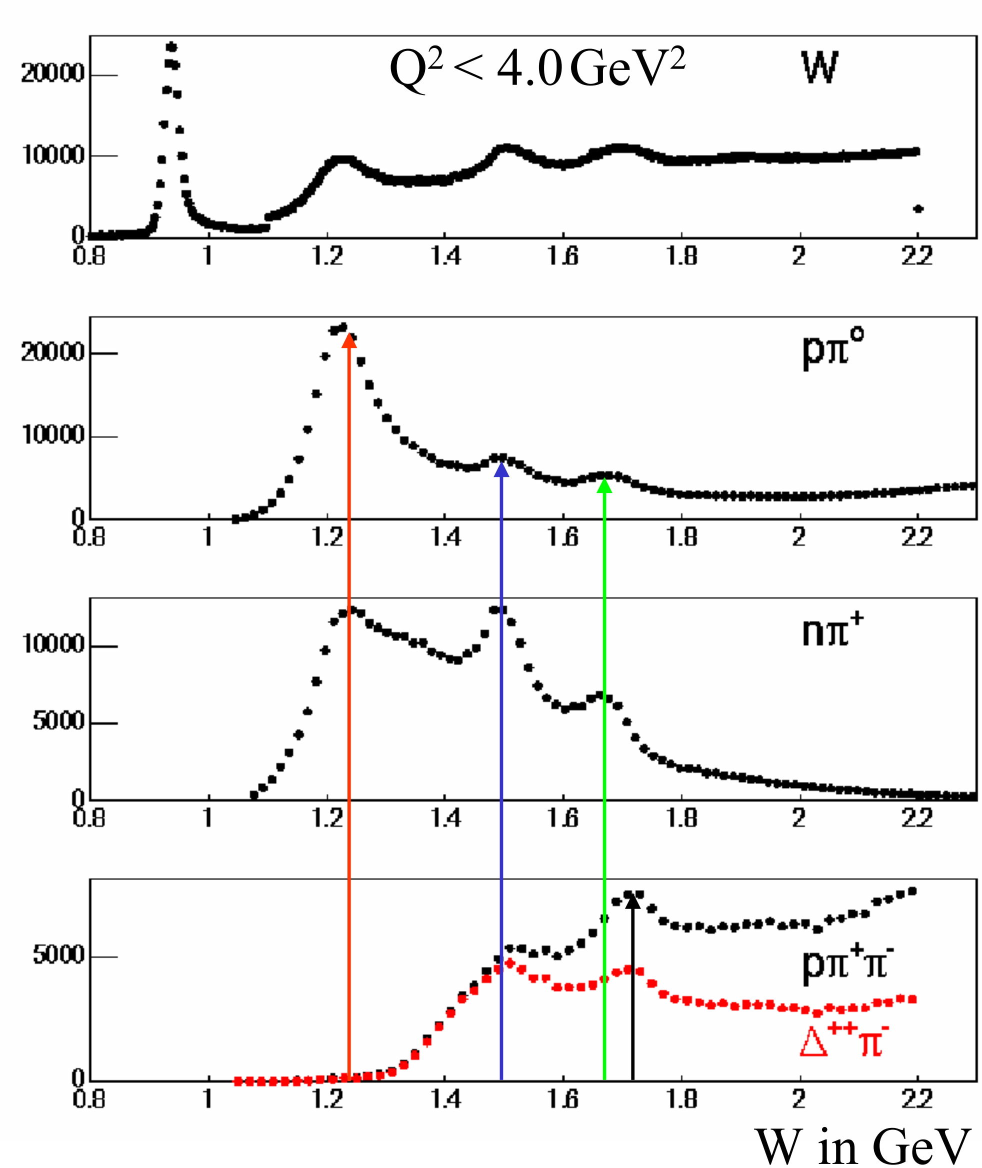
$A_{3/2}$





Nucleon Resonances in 2π Electroproduction

- 2π channel is sensitive to N*'s heavier than 1.4 GeV
- Provides complementary information to the 1π channel
- Many higher lying N*'s decay preferably to ππN final states



Trigger

p(e,e')X

p(e,e'p)π^0

p(e,e'π^+)n

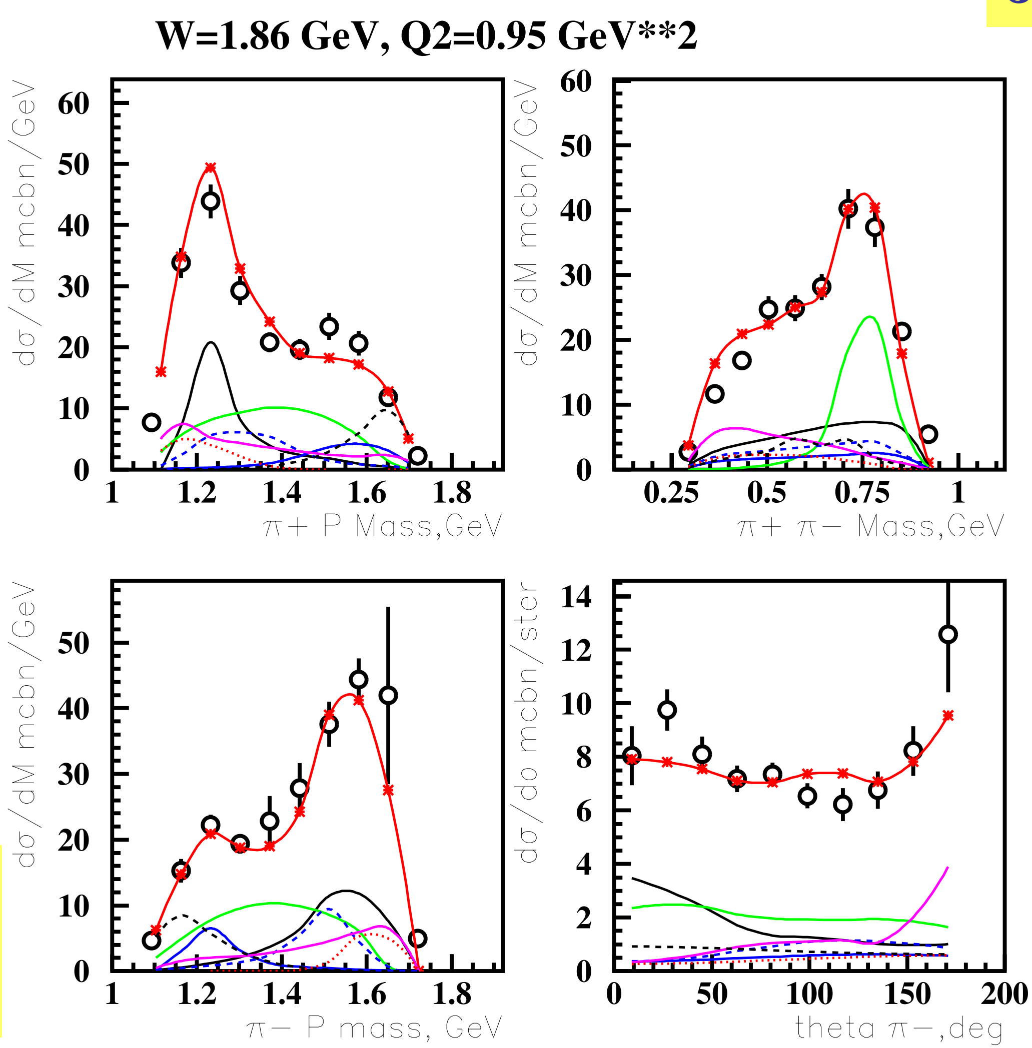
p(e,e'pπ^+)π^-

Contributing Mechanisms to $\gamma^{(*)}p \to p\pi^+\pi^-$

JM

Isobar Model JM05

- Full calculations
- $\gamma p \to \pi^- \Delta^{++}$
- $\gamma p \to \pi^+ \Delta^0$
- $\gamma p \to \pi^+ D_{13}(1520)$
- $\gamma p \to \rho p$
- $\gamma p \to \pi^- \Delta^{++}(1600)$
- $\gamma p \to \pi^+ F^0_{15}(1685)$
- direct 2π production



➢ The combined fit of nine single differential cross sections allowed to establish all significant mechanisms.

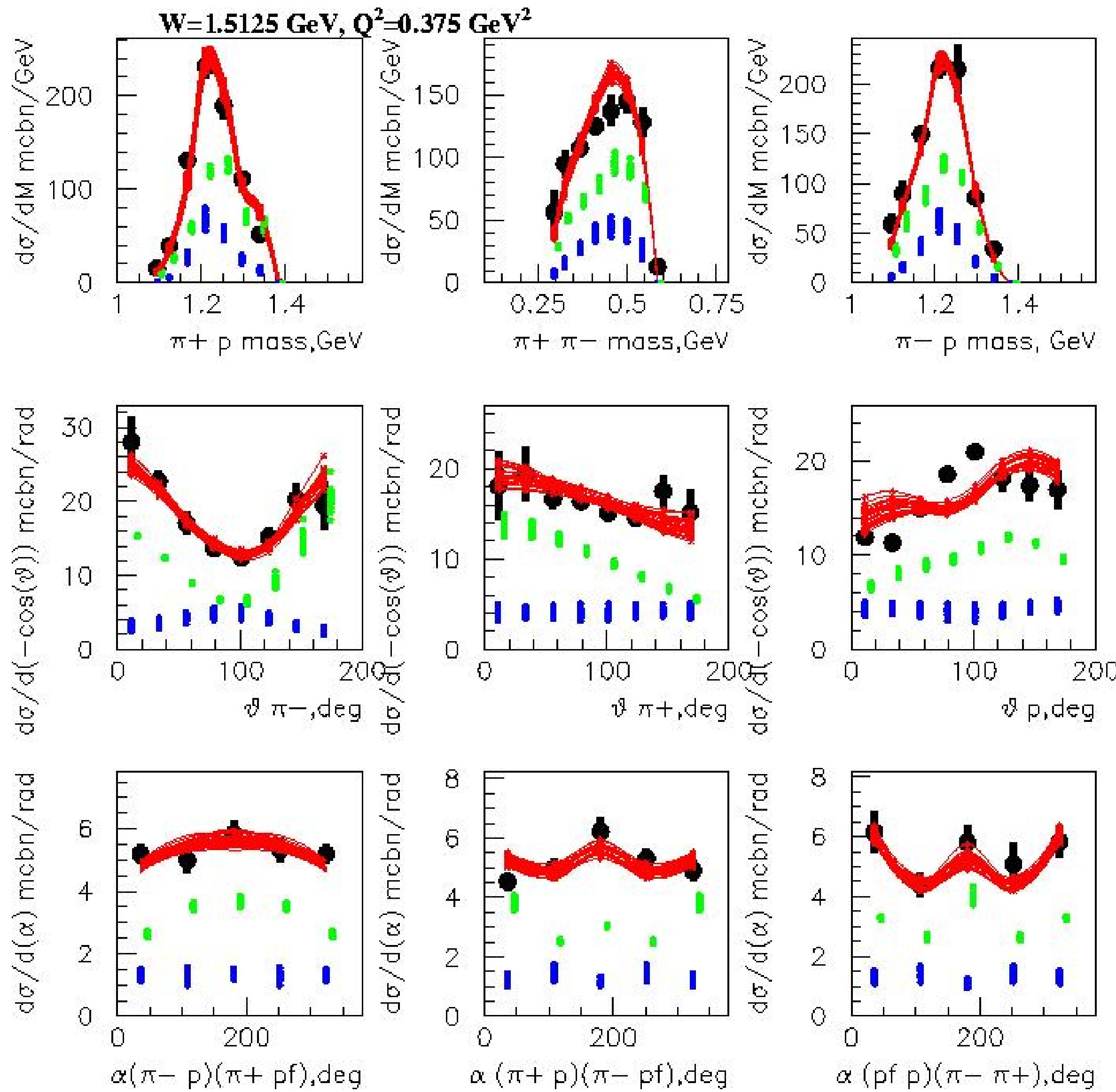
Fit of the CLAS Nππ Data within JM-Model

JM

full cross sections

resonant part

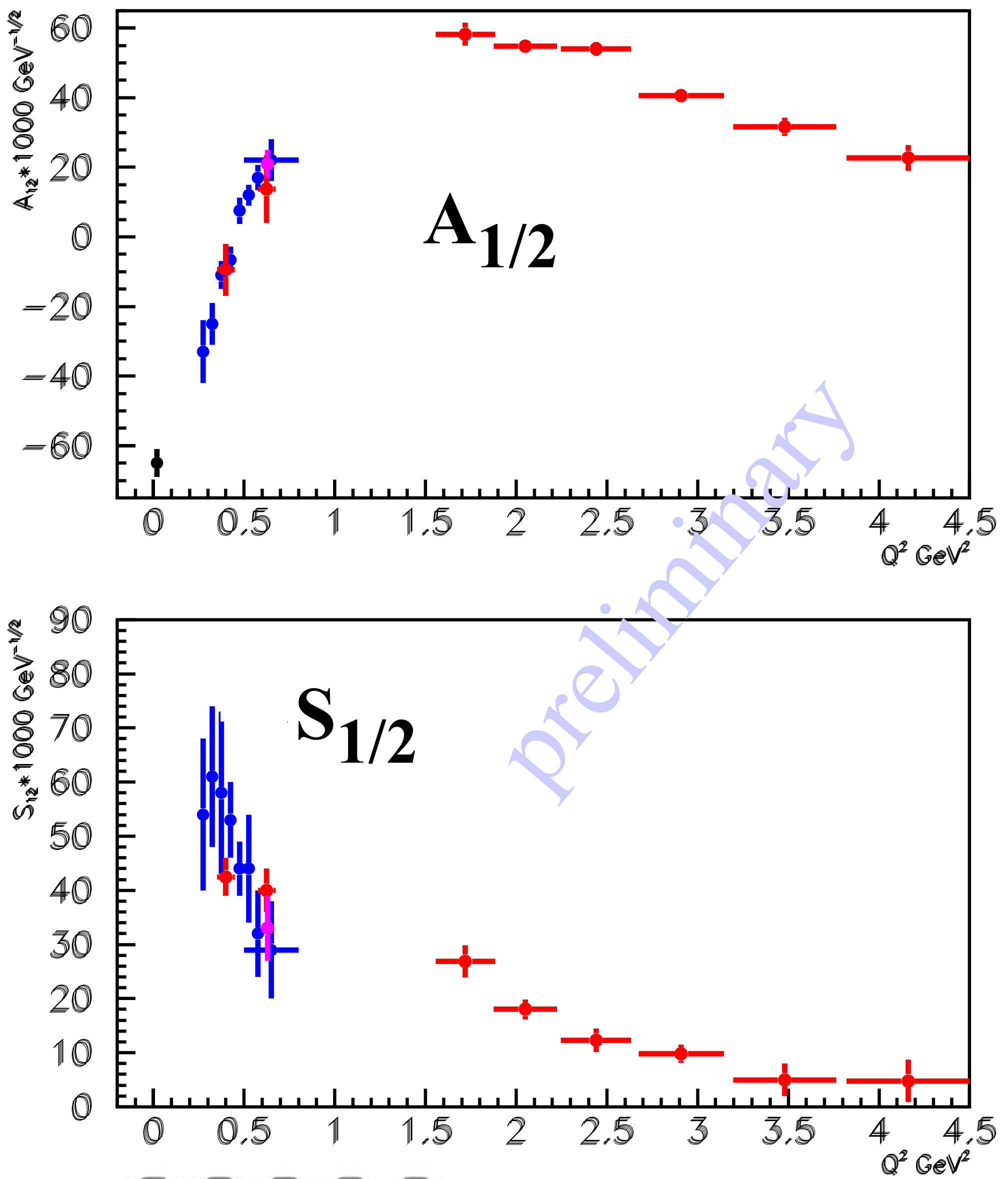
non-resonant part



The reliable resonant / non-resonant cross section separation allows to isolate the N* contribution and demonstrates the degree of model independence.

Roper Electro-Coupling Amplitudes $A_{1/2}$, $S_{1/2}$

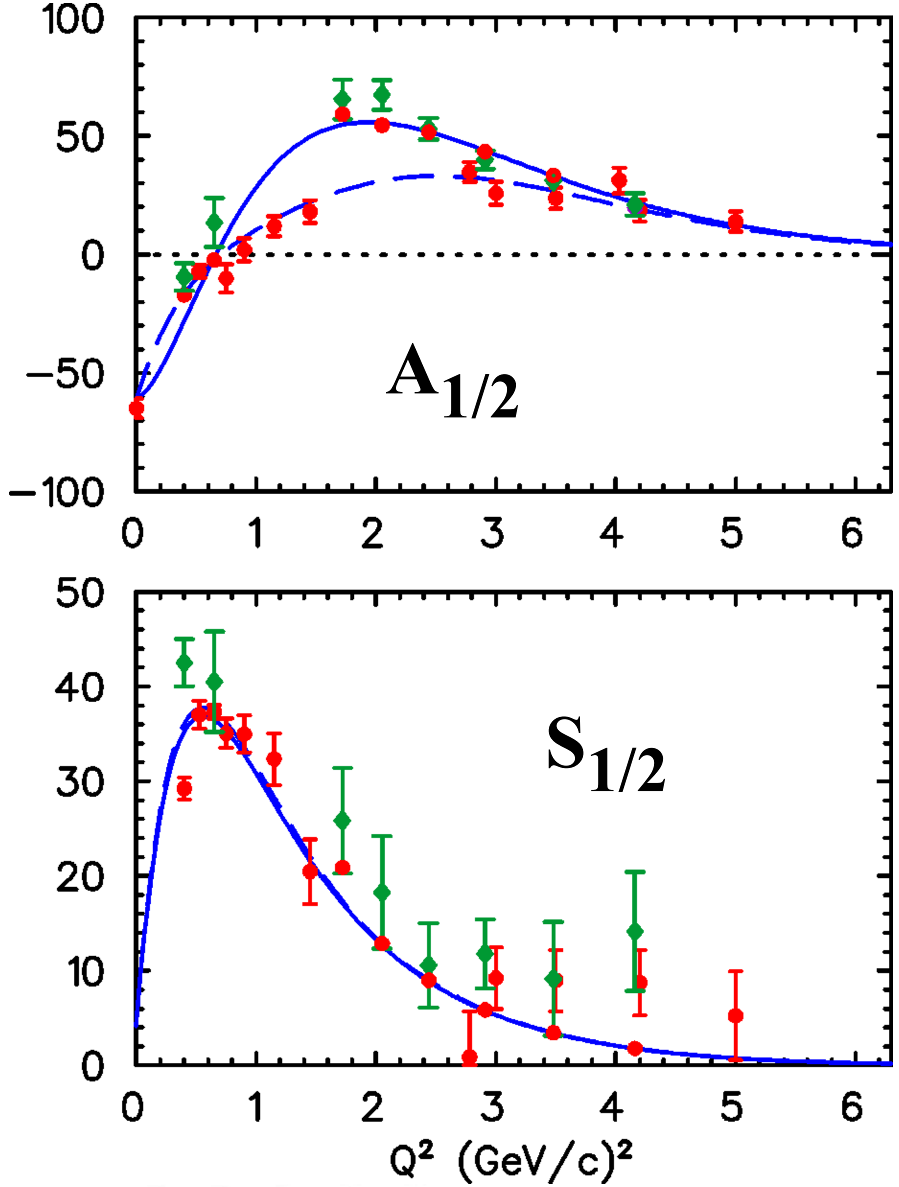
CLAS



- PDG at Q^2=0
- 1π analysis (UIM)
- 1π-2π combined at Q^2=0.65 GeV^2
- Newest 2π analysis at low Q^2 (JM 06)

Roper Electro-Coupling Amplitudes $A_{1/2}$, $S_{1/2}$

L. Tiator



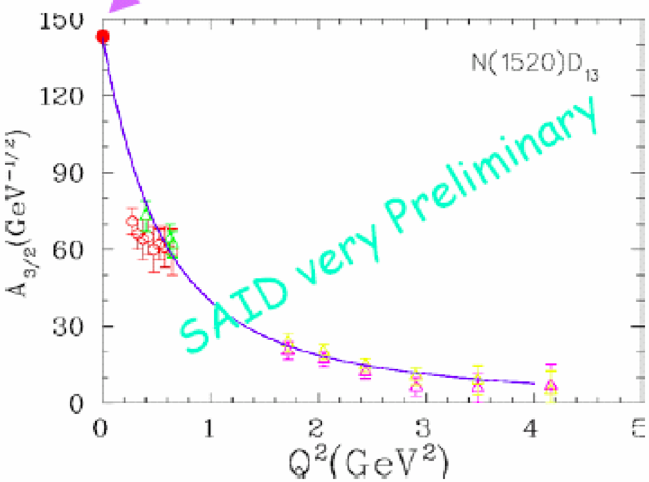
Comparison of **MAID 08** and **JLab** analysis

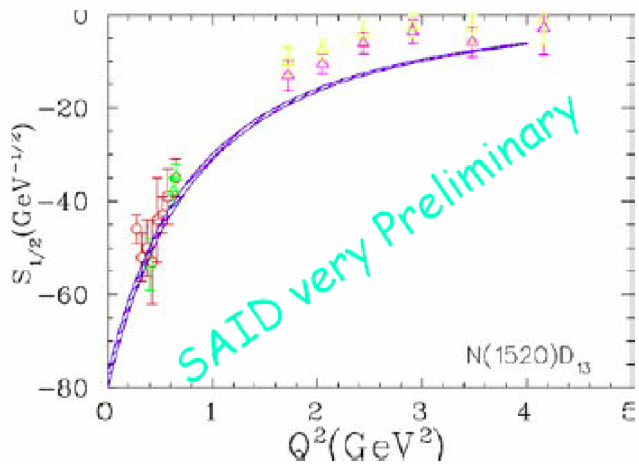
MAID 07 - - - - - - - -
And new Maid analysis with Park data
MAID 08 ————

$D_{13}(1520)$ Electro-Coupling Amplitudes $A_{3/2}$, $S_{1/2}$

I. Starkovski

- GW: $A_{3/2}$ = 143.1±2.0





χ^2/dp

W < 1650 MeV	Q^2 = 0.40±0.05 GeV²			
	SM08	CLAS40	MAID07	Data
π^0	1.6	1.6	1.5	5820
π^+	1.5	1.2	2.2	3352
W < 1650 MeV	**Q^2 = 0.65±0.05 GeV²**			
	SM08	CLAS65	MAID07	Data
π^0	1.3	1.3	1.1	8271
π^+	1.1	1.3	1.8	2515

Resonance fit done over a narrow range in W but for all Q^2
a and b are free prmts
(no W dependence for the polynomial piece of the structure function)

- ___ SM08
- • FA06 [Q^2 = 0]
- o CLAS [2π]
- Δ CLAS [1π]
- Δ DR [1π]
- Δ Isobar [1π]

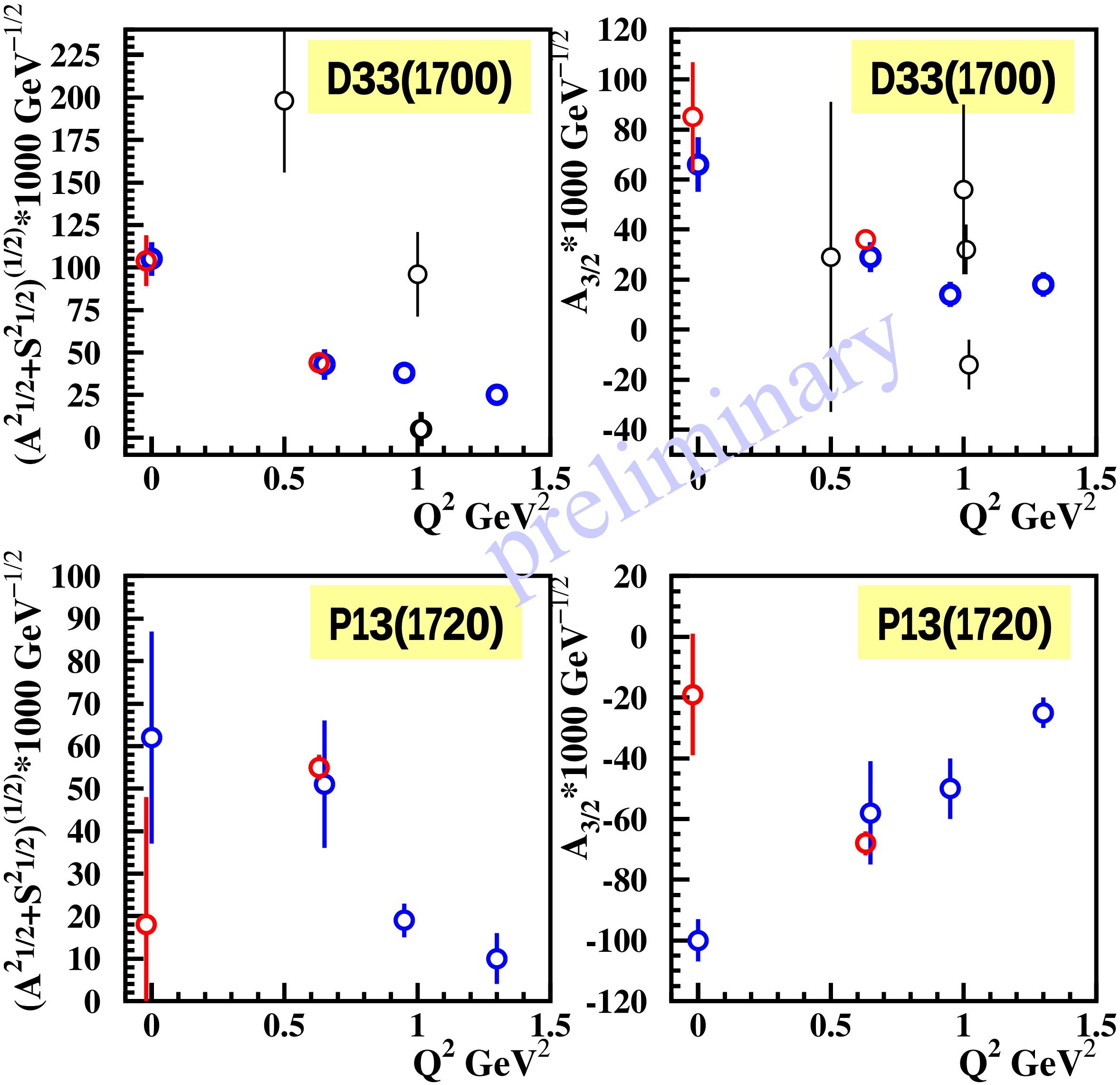
Viktor Mokeev, PC 2008

- The good agreement for $A_{3/2}$ and $S_{1/2}$ determination between various resonance extractions gives a more reliable estimate of systematics

- CLAS12 is favorable for Q^2 evaluation

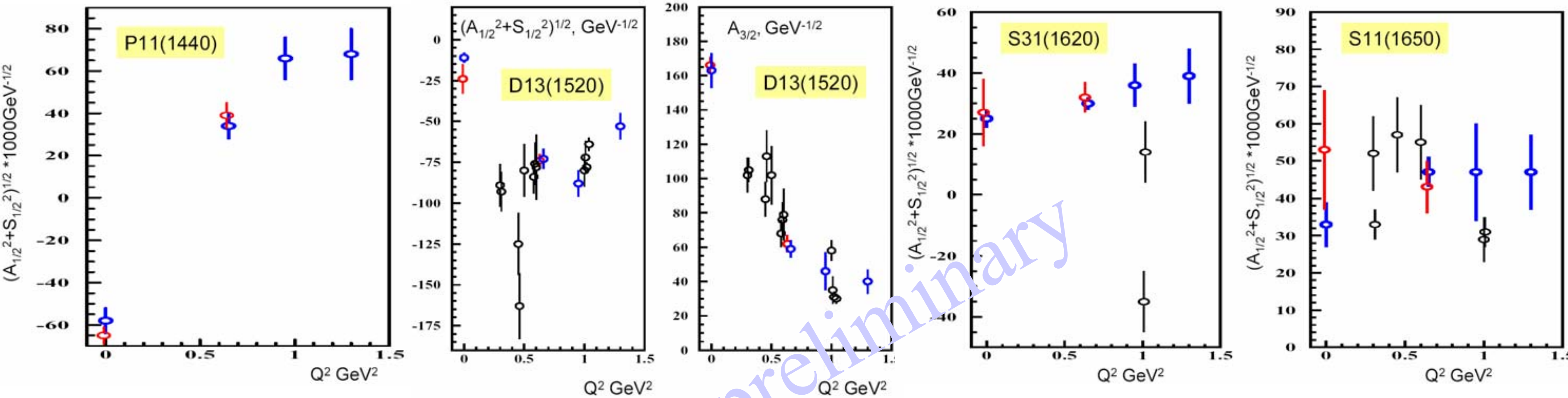
Combined 1π-2π Analysis of CLAS Data

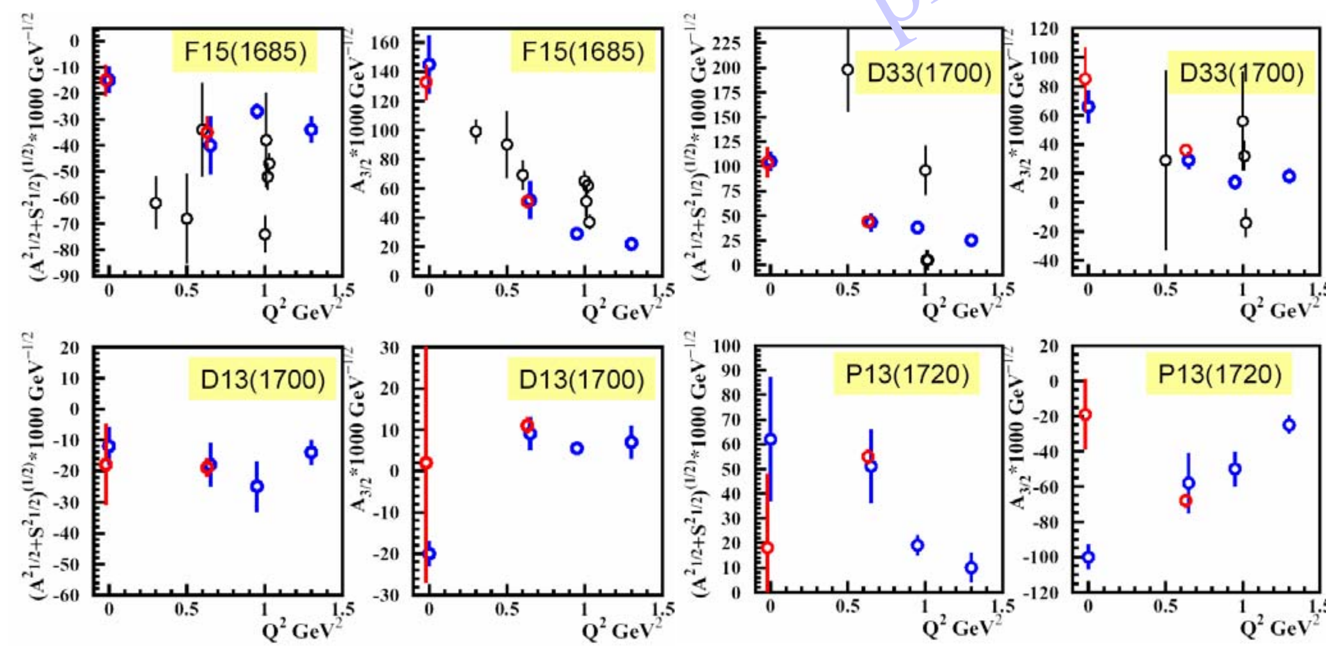
JM05



- PDG at $Q^2=0$
- Previous world data
- 2π analysis
- 1π-2π combined at $Q^2=0.65$ GeV^2
- Many more examples:
  $P_{11}(1440)$, $D_{13}(1520)$, $S_{31}(1650)$, $S_{11}(1650)$, $F_{15}(1685)$, $D_{13}(1700)$, …
- EBAC at JLab:
  Full coupled channel analysis

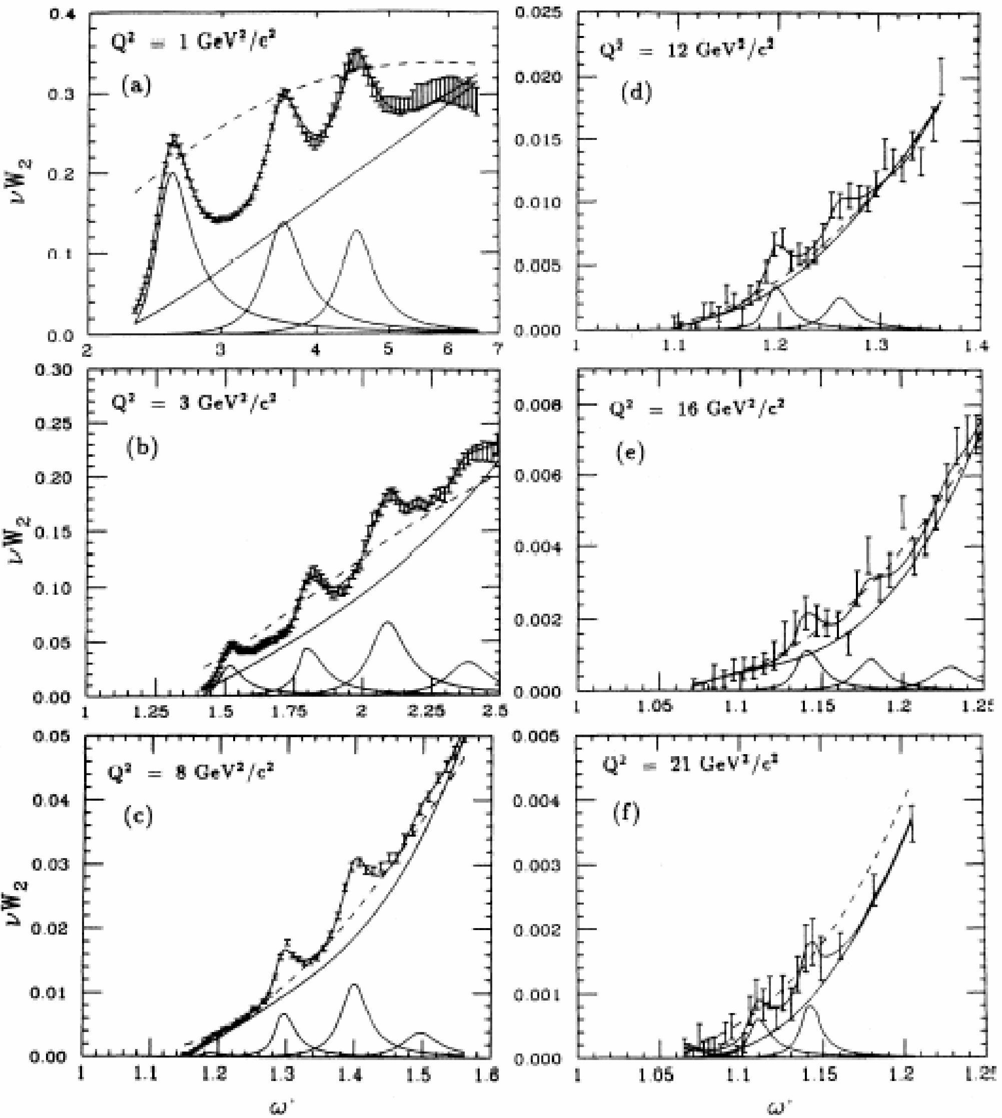
Combined 1π-2π Analysis of CLAS Data

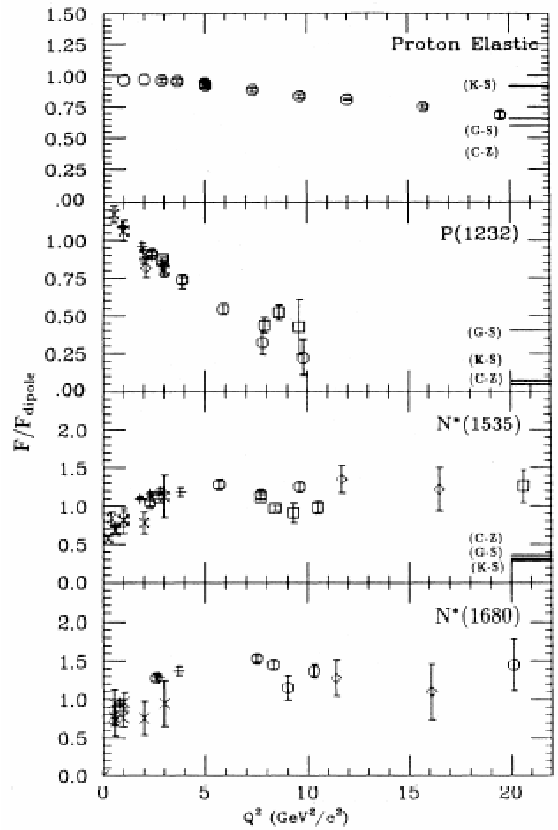




- PDG at Q^2=0
- 2π analysis
- 1π-2π combined at Q^2=0.65 GeV^2
- Previous world data

Inclusive Structure Function in the Resonance Region



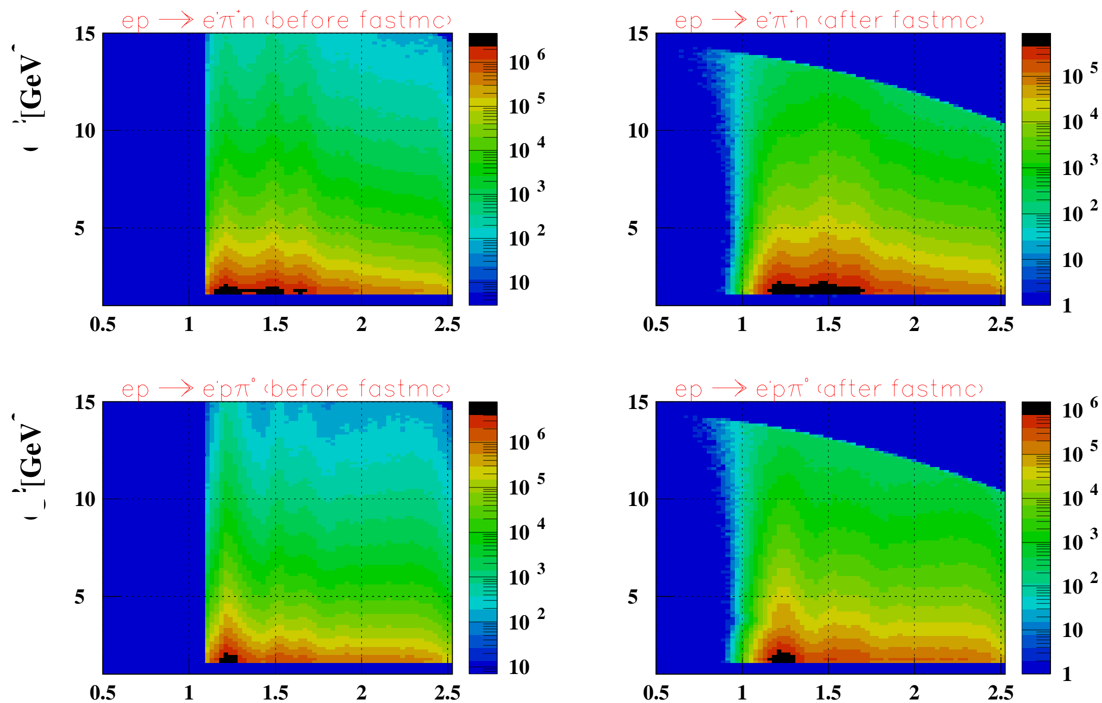


Event Generators

- ➢ Genova-EG: Dipole Form Factor
- ➢ SI-DIS: Deep Inelastic Scattering

Kinematic Coverage of CLAS12

Genova-EG



(e',π+) detected

Genova-EG

(e',p) detected

(E',Q²)	(5.75 GeV, 3 GeV²)	(11 GeV, 3 GeV²)	(11 GeV, 12 GeV²)
$N^{\pi+}$	$1.41*10^5$	$6.26*10^6$	$5.18*10^4$
$N^{p\pi 0}$	-	$4.65*10^5$	$1.45*10^4$
$N^{p\eta}$	-	$1.72*10^4$	$1.77*10^4$

60 days

L= 10^{35} cm^{-2} sec^{-1}, $\Delta W = 0.100$ GeV, $\Delta Q^2 = 0.5$ GeV^2

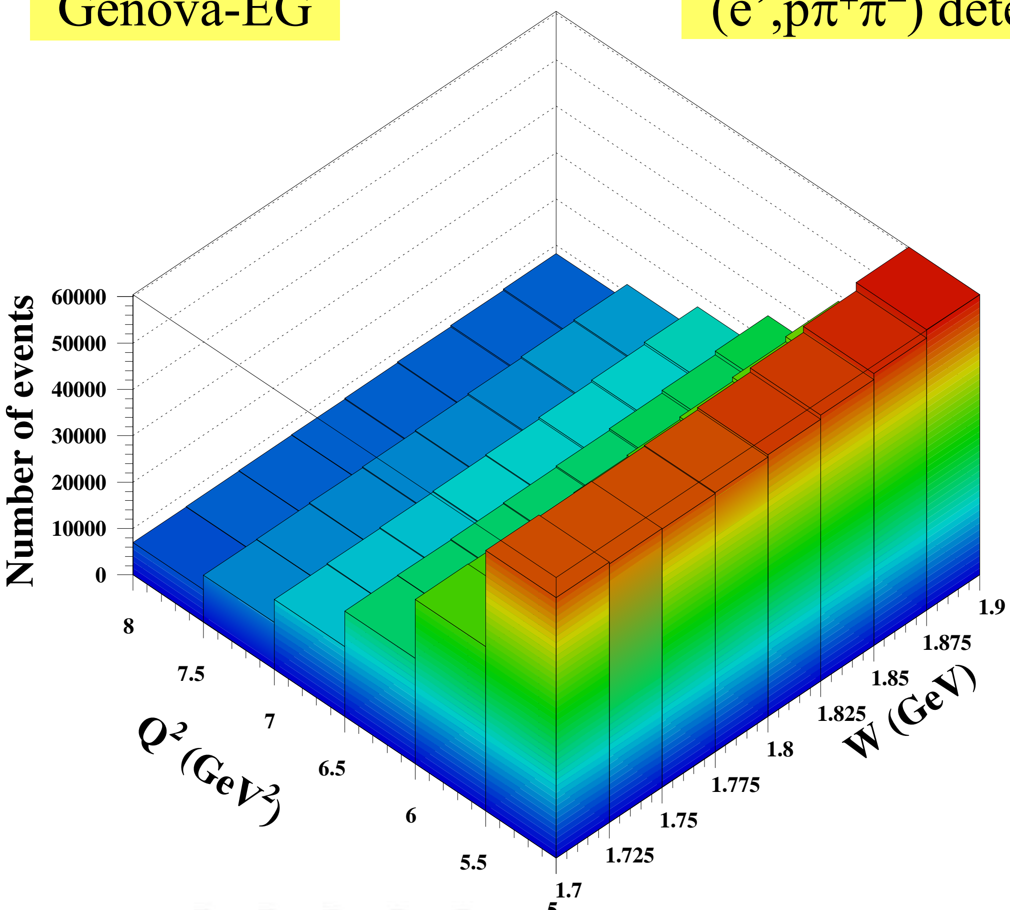
Kinematical Coverage of CLAS12

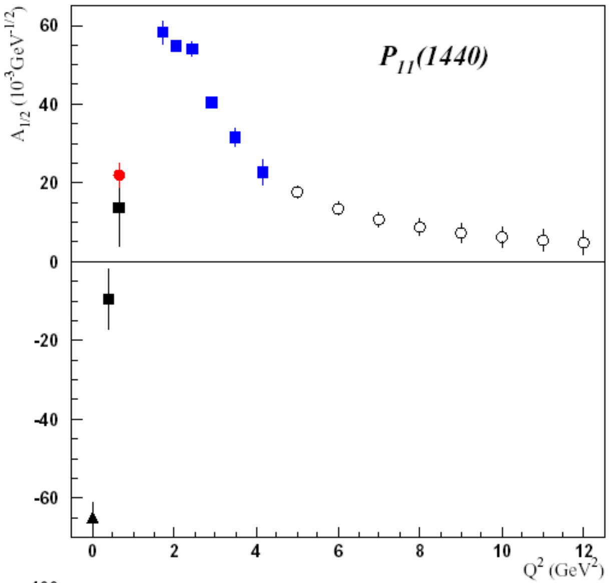
60 days

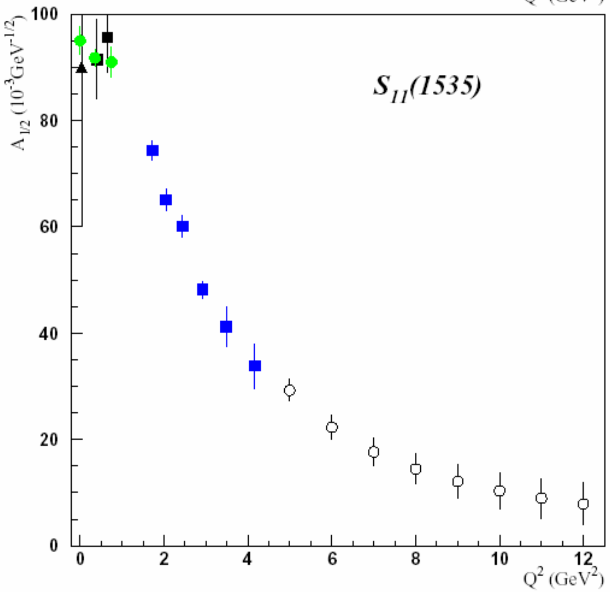
L= 10^{35} cm^{-2} sec^{-1}, $\Delta W = 0.025$ GeV, $\Delta Q^2 = 0.5$ GeV^2

Genova-EG

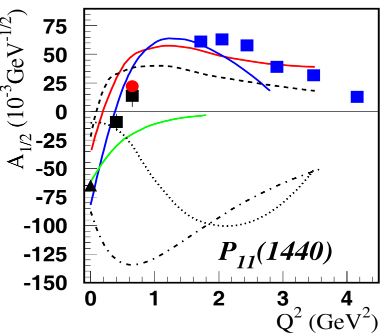
(e',p$\pi^+\pi^-$) detected

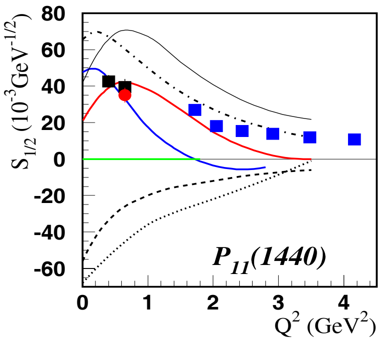


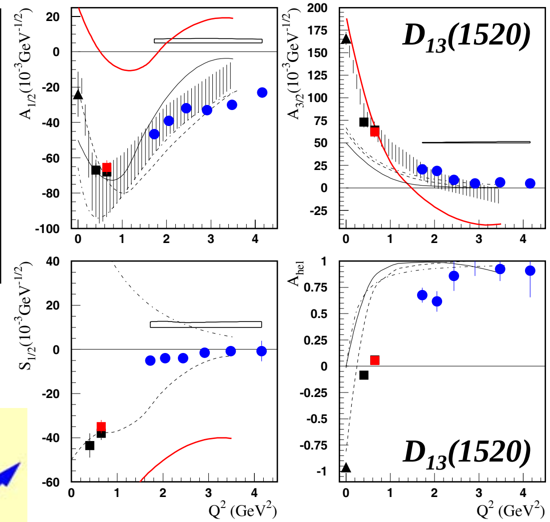


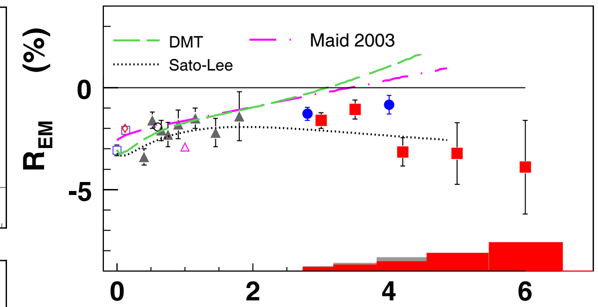


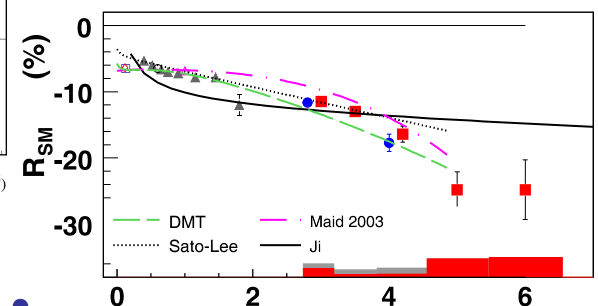
Conclusion: Do Exclusive Electron Scattering



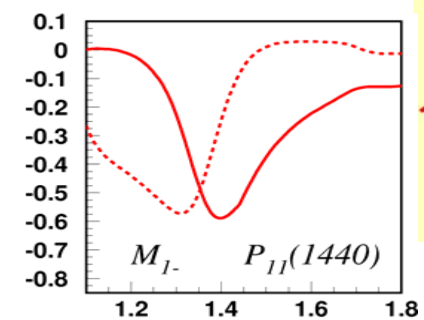


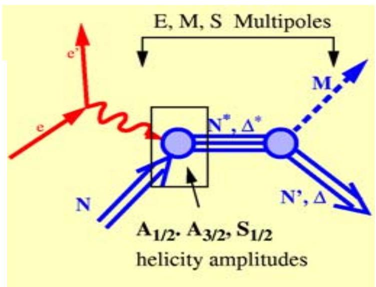






$Q^2 = 2.05$ GeV^2





... to

Learn QCD!