A "Brief" Summary on the

Electromagnetic N-N* Transition Form Factors Workshop

which took place on **October 13-15, 2008**

at **Jefferson Lab, Newport News, VA**

For more information, see: http://conferences.jlab.org/EmNN/

International Organizing Committee:

V. Burkert
B. Juliá Díaz
R. Gothe
T.-S. H. Lee
V. Mokeev

Presented by Philip Cole
Idaho State University
November 1, 2008.

Electromagnetic N-N* Transition Form Factors Workshop

- Circular
- Circulars
- Registration
- Abstract Submission
- Program
- Participants List
- Visa and Lodging
- Travel

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

Program

All Workshop Presentations to be held in CEBAF Center Room F113
Monday, Oct 13th, 2008

8:00	Registration/Continental Breakfast	
	Convener: V. Mokeev	
9:05-9:15	Introductory Comments	V. Burkert
9:15-9:50	Overview of the Reaction Models of Meson Production Reactions	B. Julia-Diaz
9:55-10:30	N - N* form factors from Mainz	L. Tiator
10:30-11:10	COFFEE BREAK	
	Convener: P. Cole	
11:10-11:45	N - N* form factors from JLab and Quark Model Prediction	I. Aznauryan
11:50-12:25	Extraction of Resonances from Meson-Nucleon Reactions	T. Sato
12:30-14:00	LUNCH ON OWN	
	Convener: A. Sarty	
14:00-14:35	Covariant models of the nucleon and Delta	G. Ramalho
14:40-15:15	Longitudinal and transverse helicity amplitudes in hCQM	M. Giannini
15:20-15:50	COFFEE BREAK	
	Convener: K. Joo	
16:00-18:00	*SHORT CONTRIBUTIONS*	
	16:00-16:15 I.Strakovsky — Partial Wave Analysis of Single Pion Production Reactions	
	16:20-16:35 H.Kamano — Current status of EBAC project	
	16:40-16:55 C.Fernandez-Ramirez — Extraction of nucleon resonances by means of Genetic Algorithm	
	17:00-17:15 M.Paris — Dynamical coupled channel calculations of pion and omega meson production	
	17:20-17:35 K.Hicks — How U-spin is useful in radiative decay of strange baryons	
18:30 - 20:30	RECEPTION - CEBAF Center Lobby	

Tuesday, Oct 14th, 2008

8:30-9:00	Registration/Continental Breakfast	
	Convener: R. Shyam	
9:00-9:35	Excitation of N* s with light-cone probes through non-diagonal DVCS	M. Polyakov
9:40-10:15	Update of quark model calculations for vector meson photoproduction in the nucleon resonance region	Q. Zhao
10:20-10:40	COFFEE BREAK	
	Convener: R. Edwards	
10:40-11:15	Prospect of LQCD on N* states	D. Richards
11:20-11:55	Lattice QCD calculation of N - N* form factors	Huey-Wen Lin
12:00-12:20	Electroproduction of the N* (1535) resonance at large momentum transfer	V. Braun
12:25-14:00	LUNCH ON OWN	
	Convener:T-S. H. Lee	
14:00-14:35	Transition Form Factors from the Dyson-Schwinger Equations	C. D. Roberts
14:40-15:15	Covariant Faddeev calculation of N -Δ (1232) form factors	I. Cloet
15:20-16:00	COFFEE BREAK	
	Convener: K. Hicks	
16:00-16:35	Covariant dynamical models of photo-and electro-production of pions	F. Gross

Wednesday, Oct 15th, 2008

8:30-9:00	Continental Breakfast	
	Convener: L. Elouadrhiri	
9:00-9:35	The potential for "complete" experiments in pseudoscalar meson production	A. M. Sandorfi
9:40-10:15	Extraction of amplitudes from the data of Complete experiments	F. Tabakin
10:20-10:40	BREAK	
10:40-11:25	Proposal on experiments on N - N* form factor with 12 GeV upgrade	R. Gothe
11:30-12:30	Discussion on white paper on 12GeV upgrade	Chair: T.-S.H. Lee & V. Burkert
14:00	END	

42 participants

Electromagnetic Excitation of N*'s

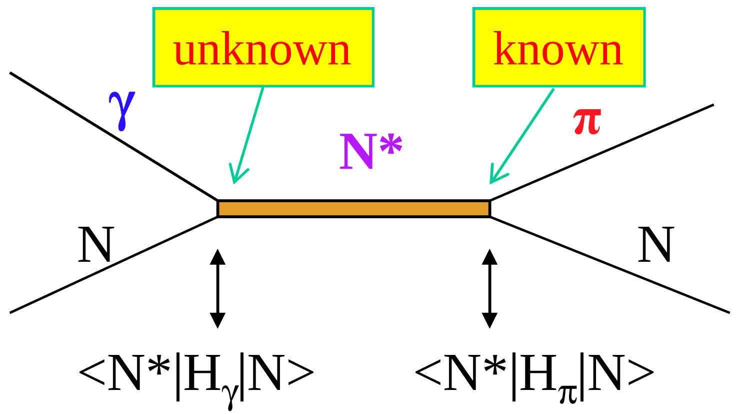
The experimental N* Program has two major components:

1) Transition form factors of known resonances to study their internal structure and confining potential

2) Spectroscopy of excited baryon states, search for new states.

Both parts of the program are being pursued in various decay channels, e.g. $N\pi$, $p\eta$, $p\pi^+\pi^-$, $K\Lambda$, $K\Sigma$, $p\omega$, $p\rho^0$ using cross sections and polarization observables.

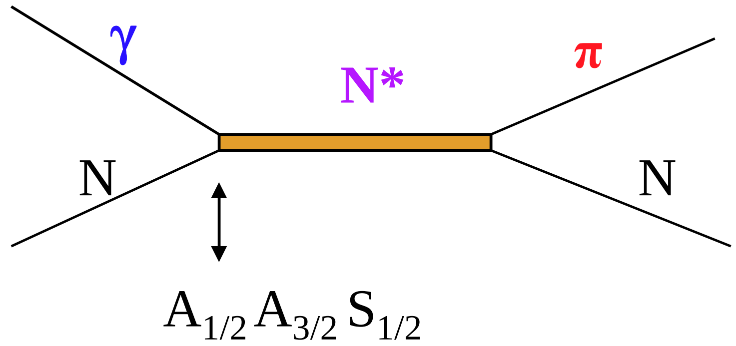
Photoproduction amplitude



Theory:
states are defined up to a phase factor

$N \rightarrow N e^{i\phi}$ $N^* \rightarrow N^* e^{i\phi^*}$

the overall sign is left unchanged



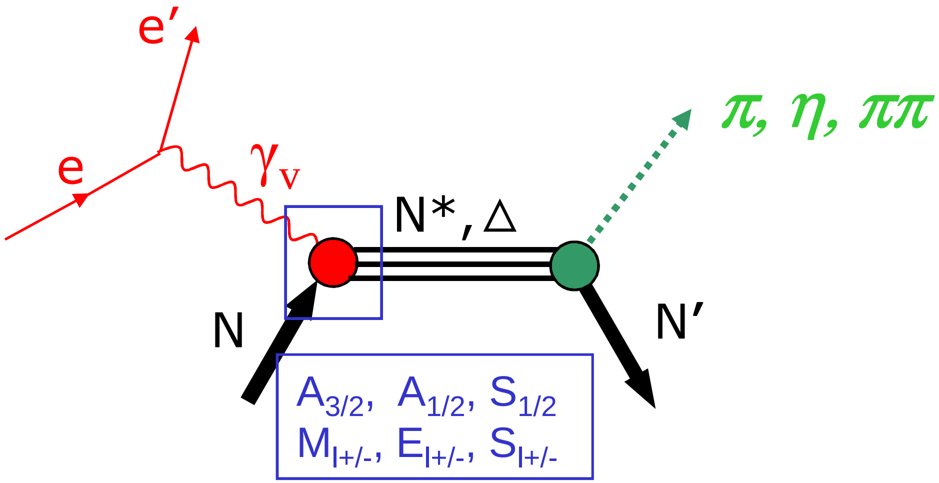
Phenomenology:
Overall sign relative to Born amplitude

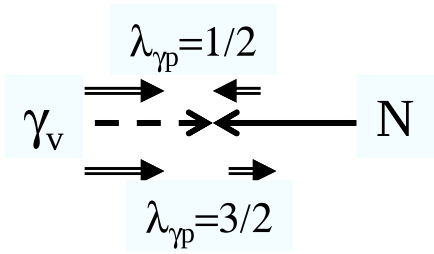
In order to extract the helicity amplitudes the sign of the strong vertex is used

Need for : a definite way of extracting the photon vertex
a general consensus

Mauro Giannini

Electromagnetic Excitation of N*'s





DOE Milestone 2012

Measure the electromagnetic excitations of low-lying baryon states (<2 GeV) and their transition form factors over the range Q^2 = 0.1 – 7 GeV^2 and measure the electro- and photo-production of final states with one and two pseudo-scalar mesons.

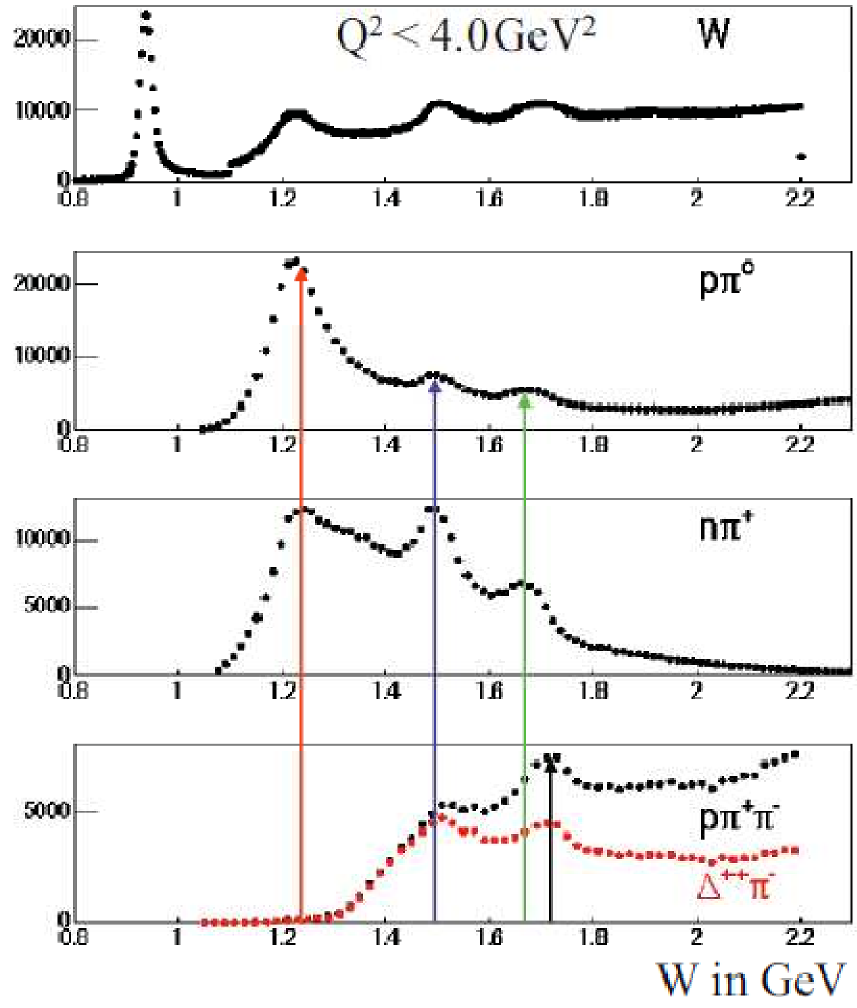
Volker Burkert

Ralf Gothe

N* in meson electroproduction and

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

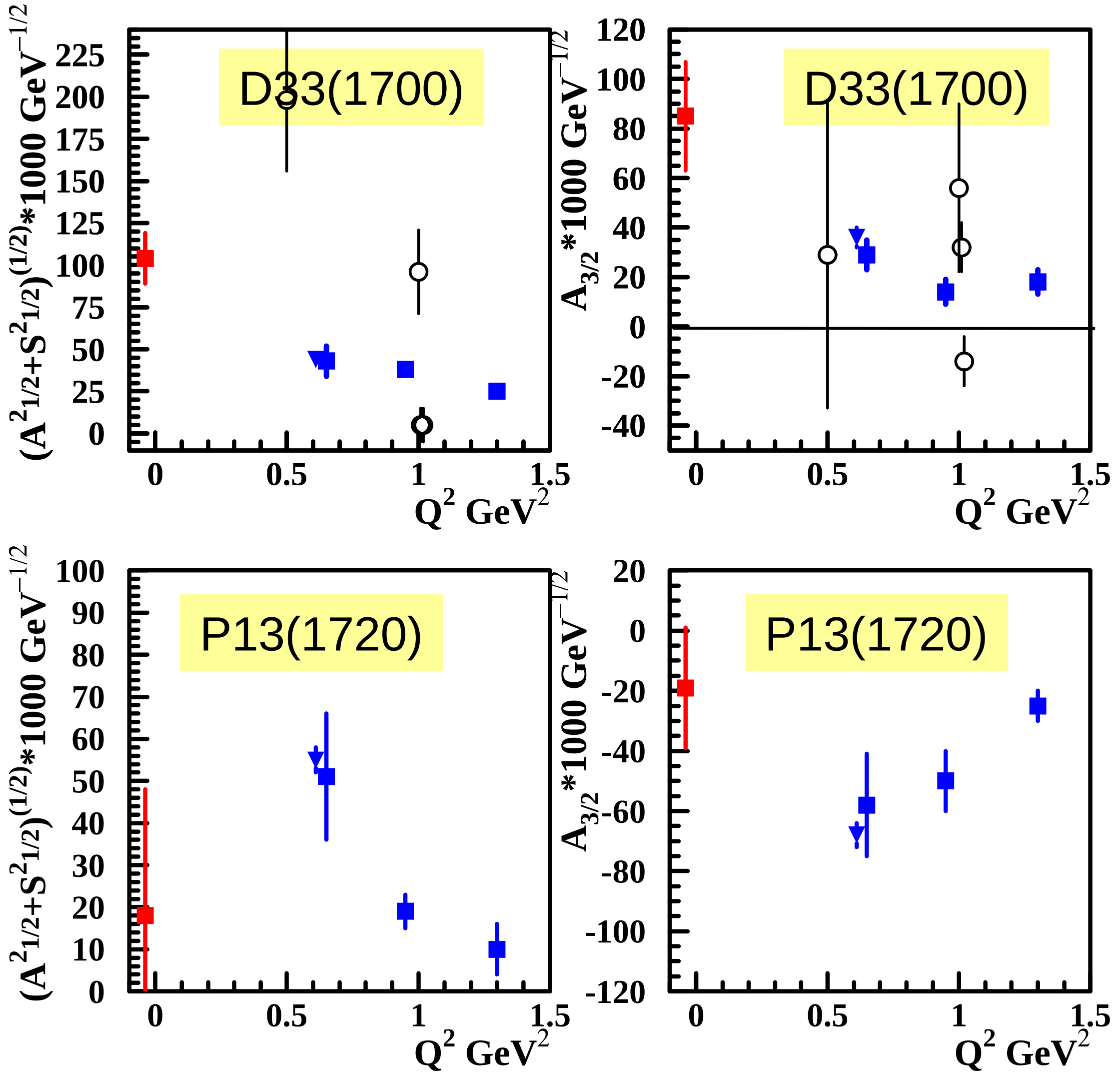
p(e,e'π^+)n

p(e,e'pπ^+)π^-

Electrocouplings of high lying N*'s.

First consistent mapping of Q^2-dependence for D33(1700), P13(1720) electrocouplings

from CLAS data on 2π electroproduction

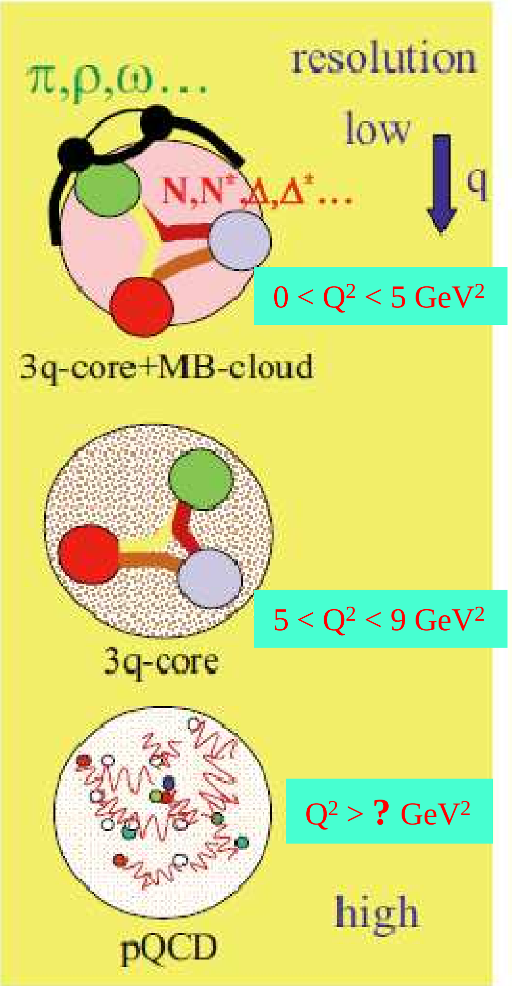


Jefferson Lab

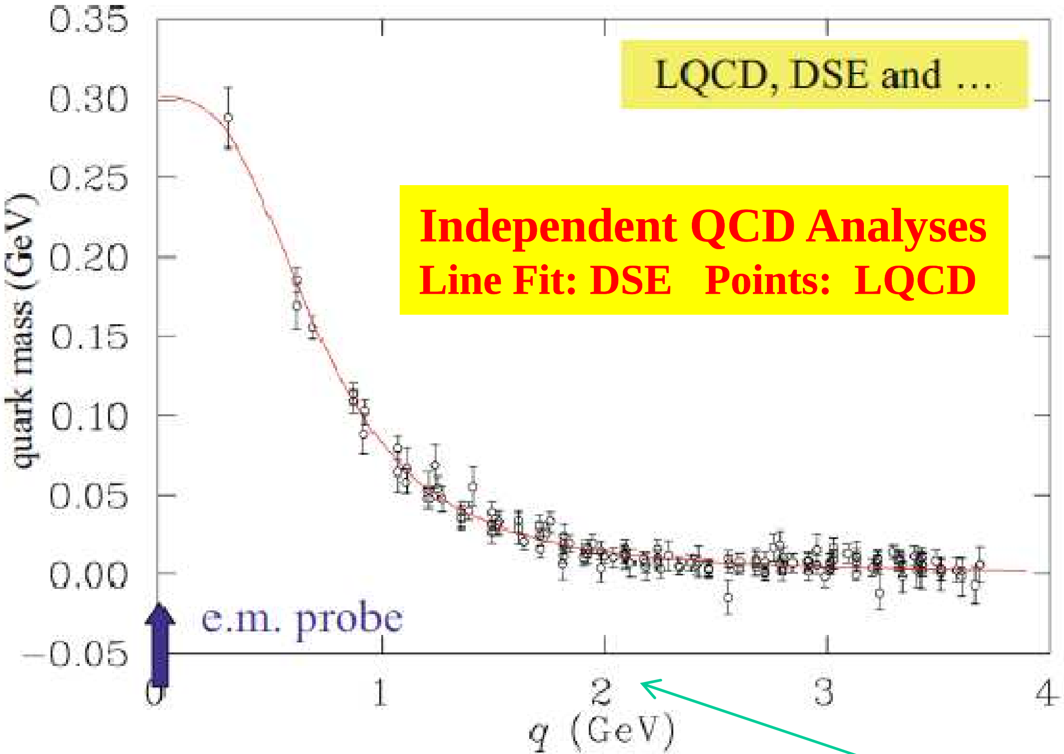
Victor Mokeev

Ralf Gothe

Hadron Structure with Electromagnetic Probes



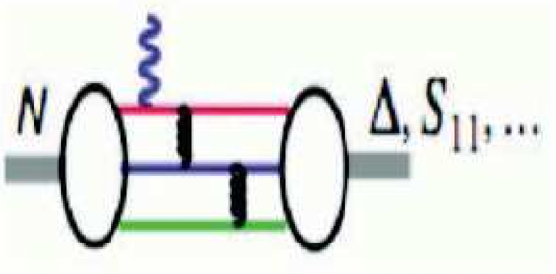
Quark mass extrapolated to the chiral limit, where *q* is the momentum variable of the tree-level quark propagator using the Asquat action.



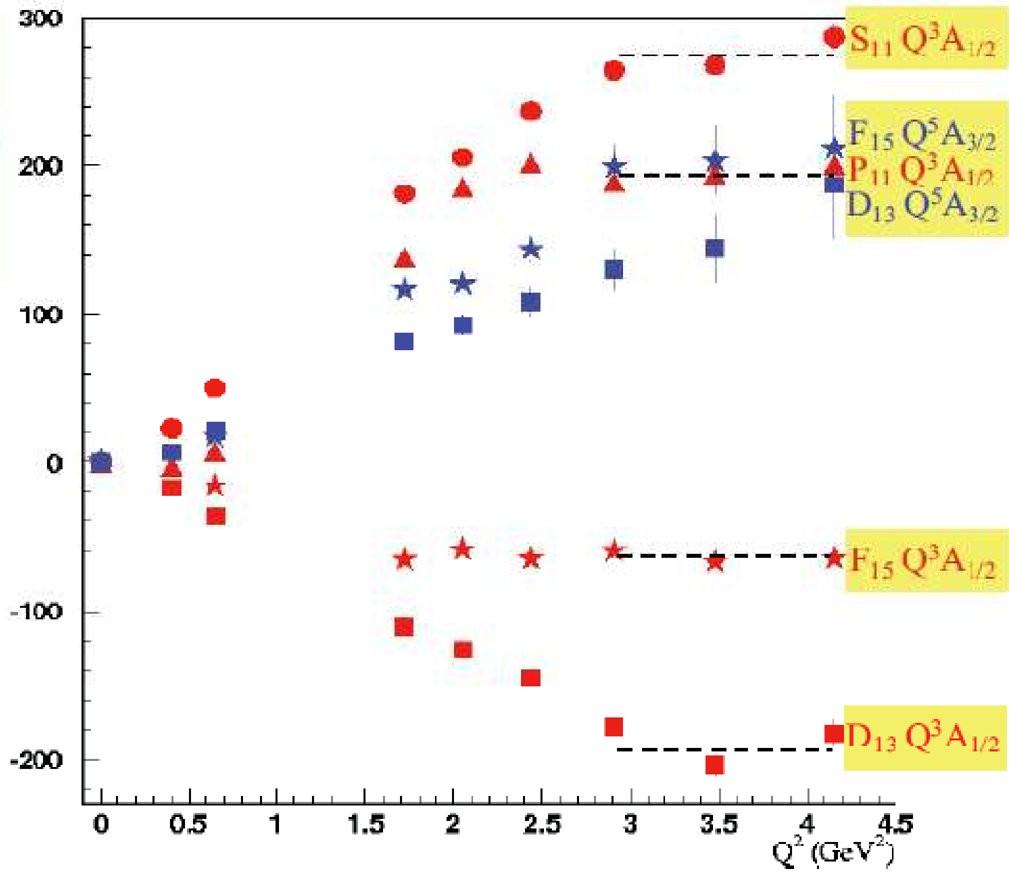
Need to multiply by $3q^2$ to get the Q^2 per quark

Ralf Gothe

Constituent Counting Rule



- $A_{1/2}$ α $1/Q^3$
- $A_{3/2}$ α $1/Q^5$
- G^*_M α $1/Q^4$



Transition of the virtual photon interaction to the constituent quark.
N.B. it is NOT the pQCD regime where photon interacts on the current quark.

Whitepaper on the Excited Baryon Program with the 12 GeV Upgrade

- **Contributors**: All who have contributed significantly
- **Table of Contents**

- **References**

Final Version by: Dec 8, 2008

Focus of Electromagnetic N-N* Transition Form Factors Workshop

within the context of the Whitepaper

Theoretical Developments

- o Lattice QCD (R. Edwards)
- o Models based on Dyson-Schwinger Equations of QCD (C. Roberts)
- o Relativistic constituent quark models (M. Giannini)
- o GPD with N* (M. Polyakov)

Reaction Models

- o Dynamical Analysis at EBAC (B. Julia-Diaz)
- o Isobar model analysis at Mainz (L. Tiator)
- o Isobar model analysis at JLab (I. Aznauryan, V. Mokeev)

Experiments to be Proposed.

- o N→ N* Transition Form Factors with CLAS at 11 GeV (Gothe, Mokeev, Burkert, Joo, Stoler, Cole)
- o Others?

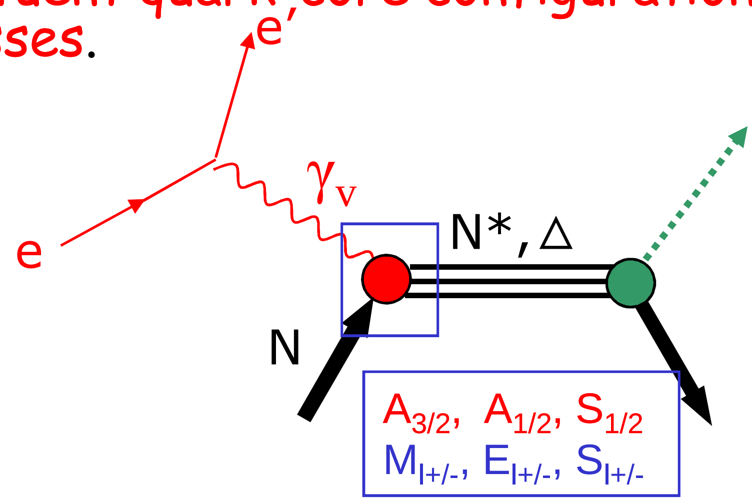
List of the questions relating to the motivation of N* studies using an 11-GeV electron beam for probing photon virtualities from 5.0 to 10 GeV^2.

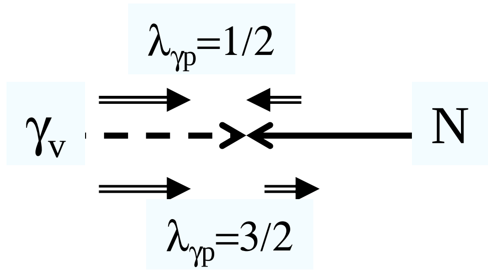
1. How will our proposed N* transition helicity amplitude data in the Q^2 region of 5.0 to 10 GeV^2 impact your theoretical approach and, in general, how will this data extend our overall understanding of strong interactions responsible in the formation of N*s?

A set 7 Questions was sent to all theorists who attended the Workshop

2. We anticipate that by studying N* behavior at photon virtualities ranging from 5.0 to 10 GeV^2, it will give us access to resonance structure at distances, where the expected contributions from meson-baryon dressing to the N-N* vertices are presumably small.

*****Hence this probe will allow for effectively delineating the constituent quark-core configurations from other competing processes.





To justify this claim of being able to access quark-core degrees of freedom at high photon virtualities, we ask you to make estimates of the Q^2-behavior of the two components, *i.e.*

a) constituent quark core

b) meson-baryon dressing of N-N* photon vertices,

which contribute to the $A_{1/2}$, $A_{3/2}$, $S_{1/2}$ N-N* transition amplitudes: for the **N* states**: $P_{33}(1232)$, $P_{11}(1440)$, $D_{13}(1520)$, $S_{11}(1535)$, $F_{15}(1685)$, $P_{13}(1720)$, $D_{33}(1700)$ in the region $5.0 < Q^2 < 10$ GeV^2.

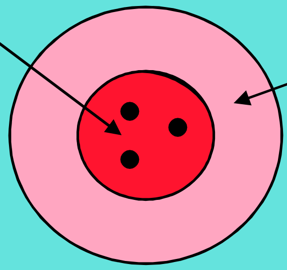
please note

- the calculated proton radius is about 0.5 fm

  (value previously obtained by fitting the helicity amplitudes)
- the medium Q^2 behaviour is fairly well reproduced
- there is lack of strength at low Q^2 (outer region) in the e.m. transitions

  specially for the A 3/2 amplitudes

- emerging picture: quark core (0.5 fm) plus (meson or sea-quark) cloud



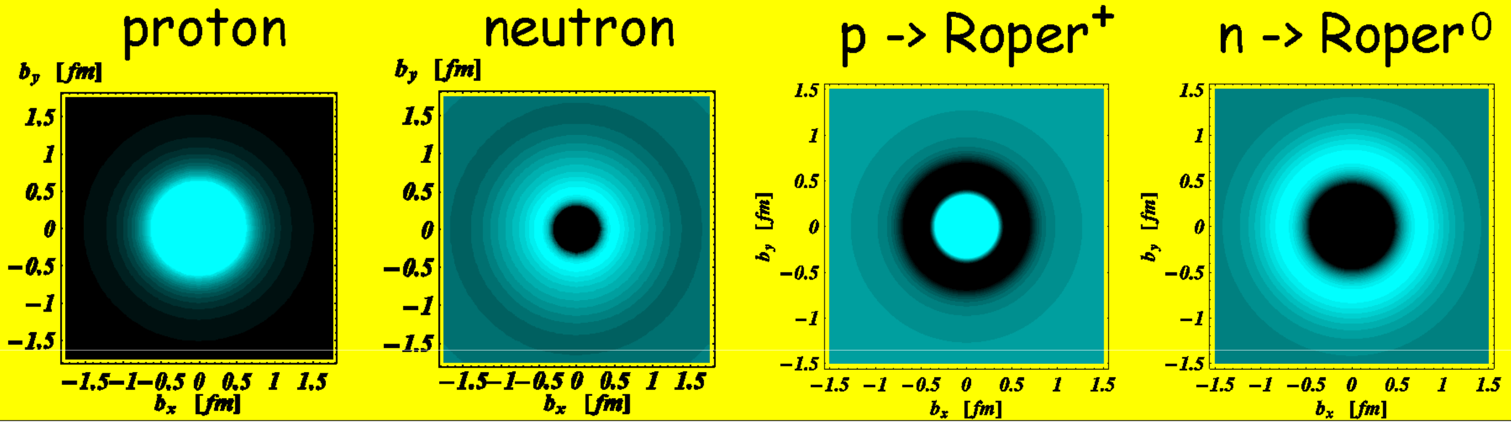
"On the other hand, the confinement radius of ≈ 0.5 fm, which is currently used in order to give reasonable results for the photocouplings, is substantially lower than the proton charge radius and this seems to indicate that other mechanisms, such as **pair production and sea quark** contributions may be relevant."

M. Aiello, M. Ferraris, M.M.G, M. Pizzo, E. Santopinto, Phys.Lett.B387, 215 (1996).

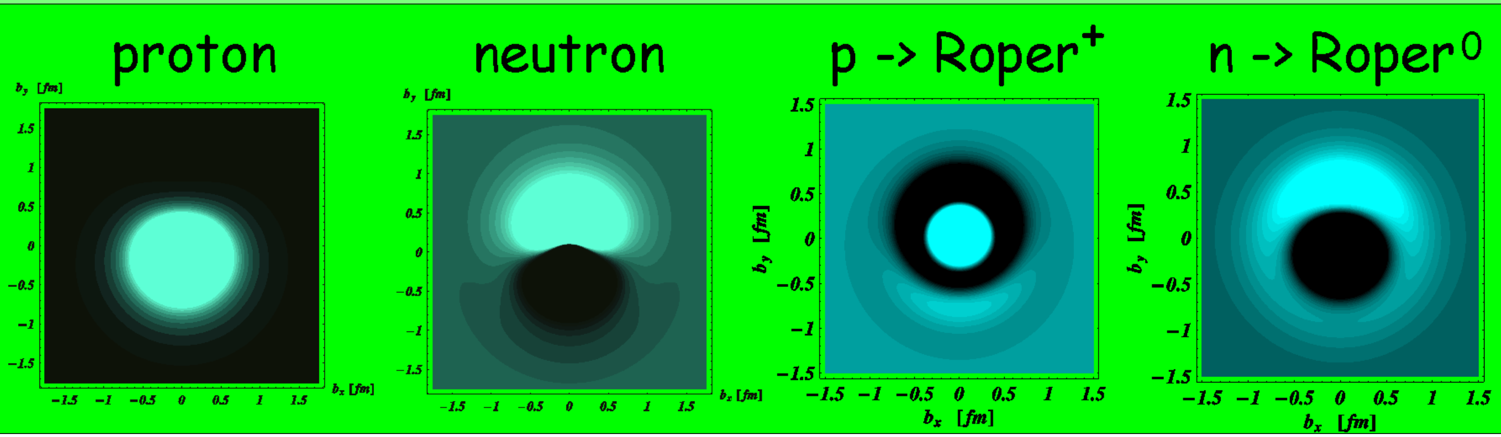
Transverse Charge Densities of the Nucleon and N-> Roper

(Lothar Tiator and Marc Vanderhaeghen)

unpolarized: $$\rho_0(b) = \int_0^\infty \frac{dQ}{2\pi}\, Q\, J_0(b\,Q)\, F_1(Q^2)$$



polarized along $\hat{x}$: $$\rho_T(\vec{b}) = \rho_0(Q^2) + \frac{b_y}{b}\int_0^\infty \frac{dQ}{2\pi}\, \tau(Q^2)\, J_1(b\,Q)\, F_2(Q^2)$$



3. How will the data on N-N* transition helicity amplitudes, obtained at 5.0 < Q^2 < 10 GeV^2, extend our knowledge on the binding potential and effective interactions responsible for 3-quark configuration mixing (i.e. OGE, OPE, instanton,…) within constituent quark models?

  - How will such data on N* electrocouplings at high Q^2 help us in getting access to light-cone wave functions of excited proton states and the associated currents?
  - What can we learn about the evolution constituent quark form factors?
  - What are the prospects of relating the constituent quark, covariant and Dyson-Schwinger models to the underlying QCD and, in turn, how will this data on N* electrocouplings at high Q^2 be useful in establishing these relations?

4. Is it possible or likely that data on N* electrocouplings at high Q^2 will afford us access to excited flux tubes as a possible active degree of freedom in the N* structure? And could this be used to study flux tube self-interactions?

5. How does the rapid rise of the dressed-quark running mass impact the N-N* transition helicity amplitudes, as revealed from both

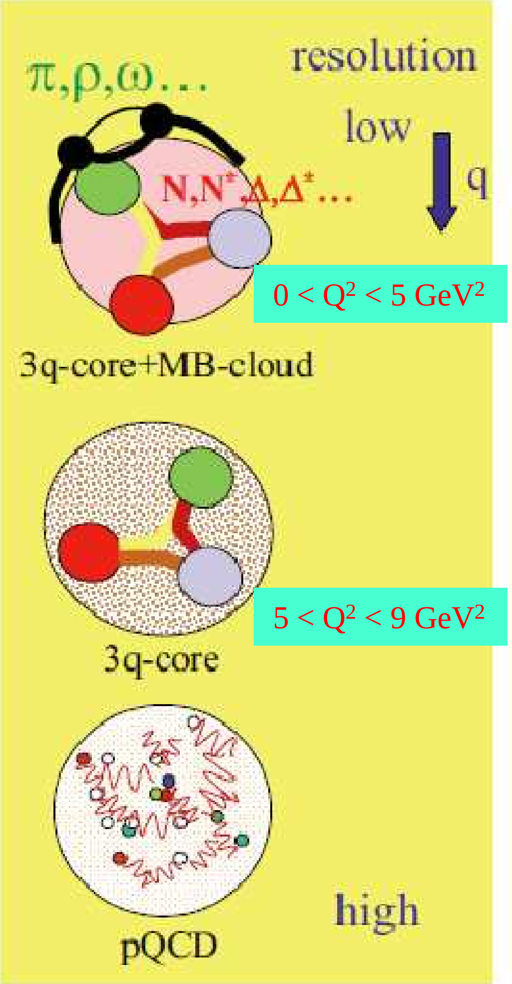
- the studies of the dressed-quark propagator within the framework of Dyson-Schwinger equations
- and from lattice calculations?

How then may this **running mass phenomenon be established in the studies of N* electrocouplings at high Q^2?**

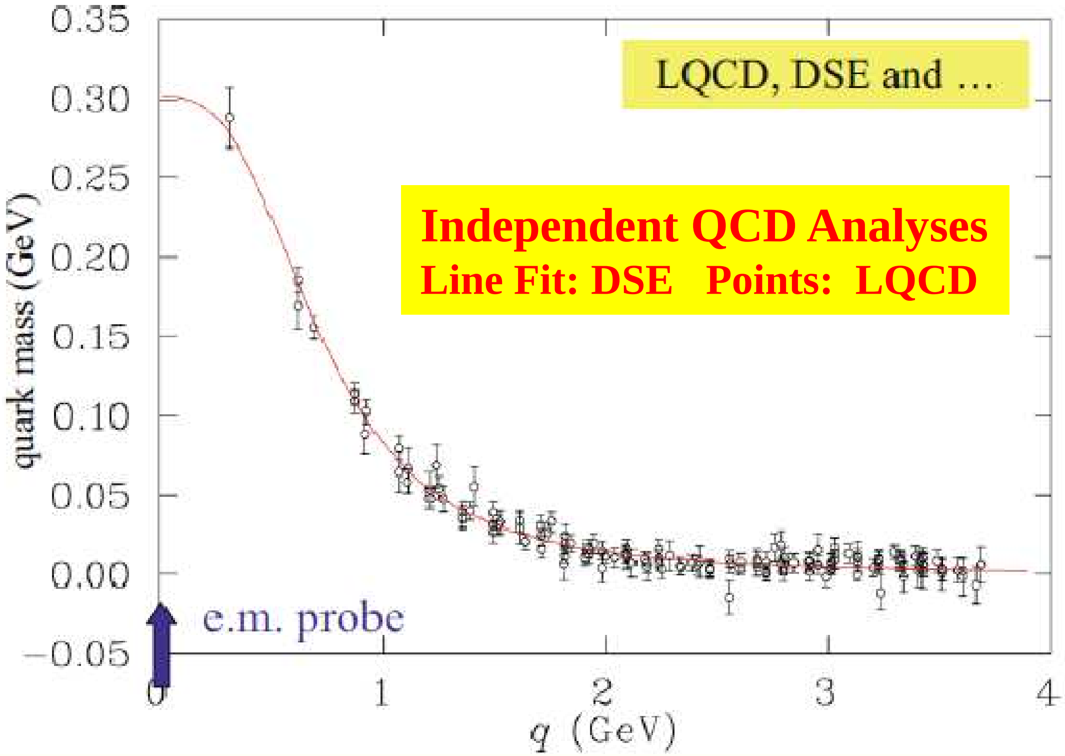
6. What are the prospects of having lattice calculations

- which relate the underlying QCD data in N-N* helicity transition amplitudes at Q^2 up to 10 GeV^2?
- And would such N* electrocoupling data be of significant benefit in making lattice calculations within this high Q2 regime, where the expected contributions from meson-baryon dressing of N-N* photon vertices become negligible?

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.



Need to multiply by $3q^2$ to get the Q^2 per quark

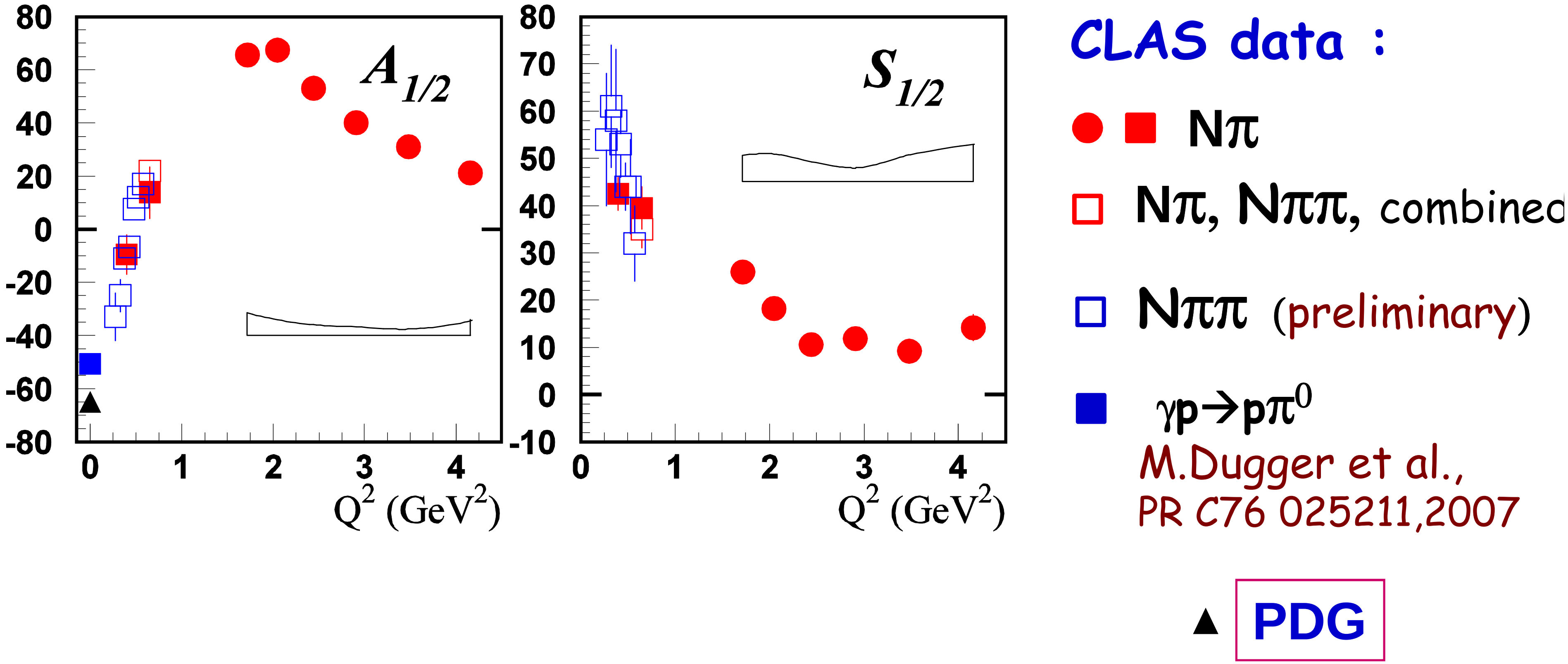
7. What are the prospects of shedding light onto the unique relations among the various N-N* transition helicity amplitudes (or the N-N* transition form factors) in setting constraints on the moments of different combination of the N-N* GPDs?

We can extract reliable results on N* electro-couplings from meson electroproduction data as evidenced, for example, by the slides presented in Inna Aznauryan’s talk:

Helicity amplitudes from the **g^*p** → **P_{11} (1440)**
D_{13} (1520)
S_{11} (1535)

Inna Aznauryan

Helicity amplitudes of the $\gamma^* p \rightarrow P_{11}$ (1440) transition



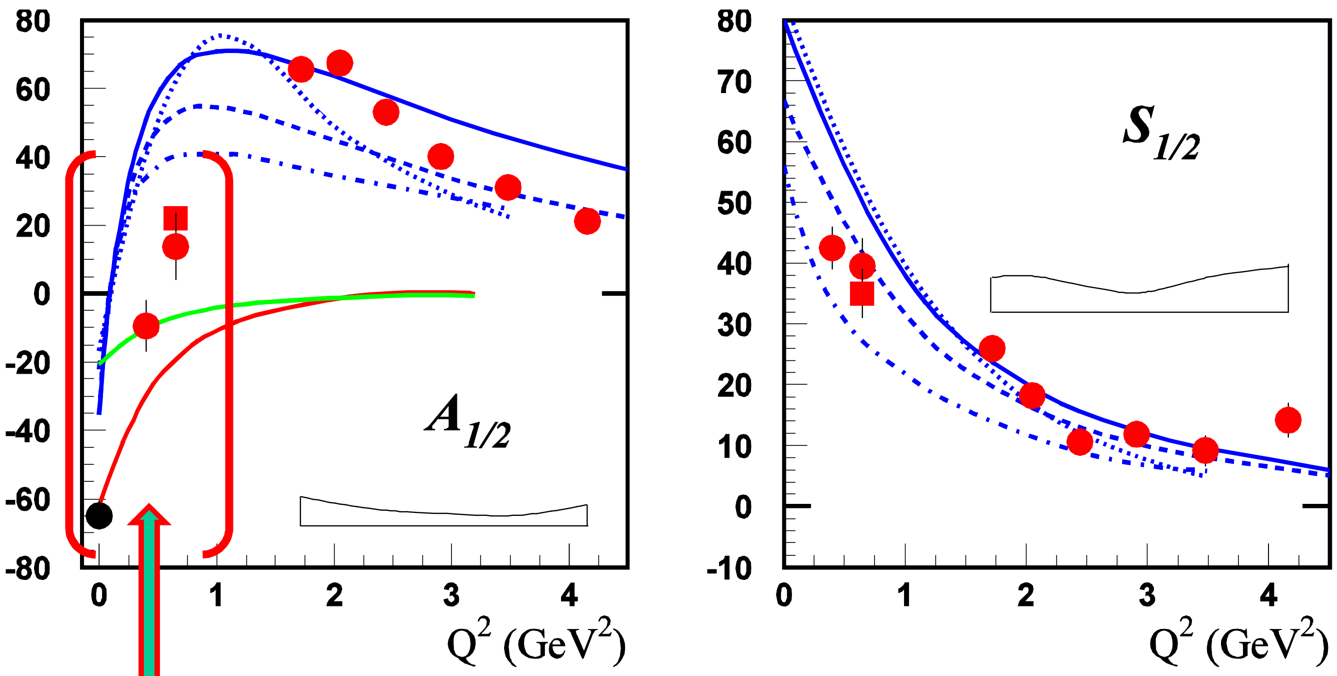
First measurements of $A_{1/2}$ at $Q^2 > 0$

First measurements of $S_{1/2}$

Victor Mokeev

Inna Aznauryan

P_{11} (1440): Additional components and contributions



Pion cloud

EBAC (preliminary)

Julia-Diaz et.al.,

PR C77(2008)045205

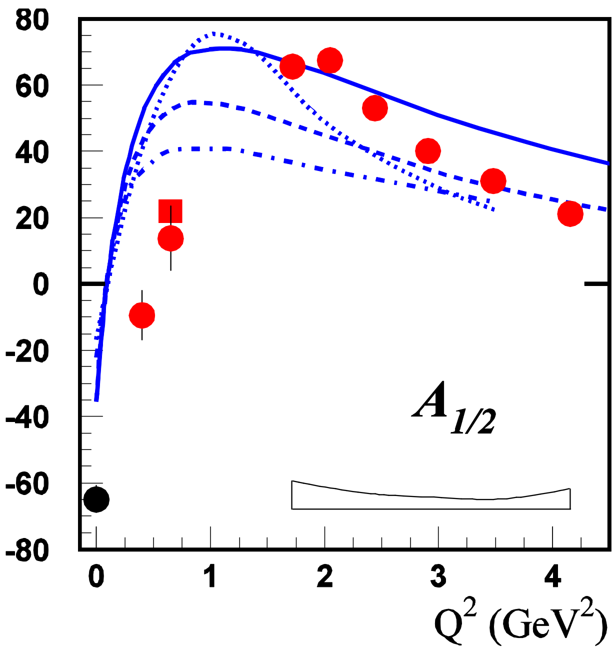
<u>Pion cloud</u> contributions and <u>additional</u> $qqqq\bar{q}$ components in the Roper resonance can improve the description at small Q^2

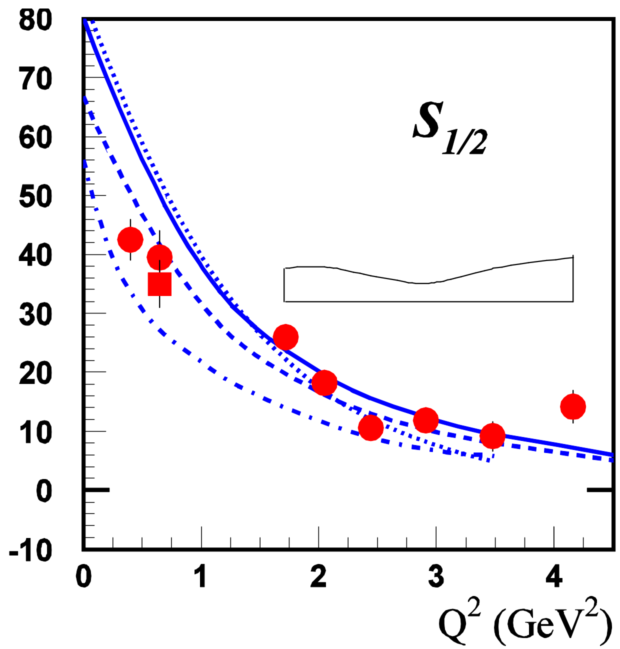
— 30% admixture of $qqqq\bar{q}$ components in the Roper resonance
→ Γ(theory) = Γ (exp) :

Li, Riska, PR C74(2006)015202

Inna Aznauryan

$\gamma^* p \rightarrow P_{11}(1440)$: 3q picture with $P_{11}(1440)$ as $[56,0^+]_r$





All LF RQM describe
sign change of $A_{1/2}$
the amplitude $S_{1/2}$

Strong evidence in favor of
$P_{11}(1440)$ as a first radial excitation of 3q ground state

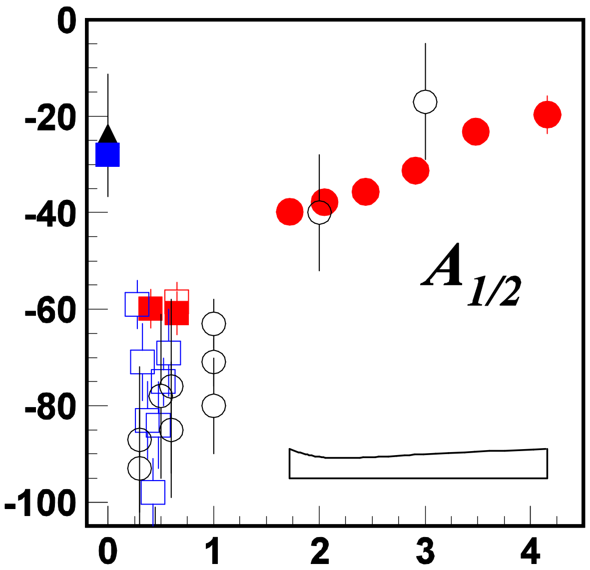
All LF RQM fail to describe the amplitude $A_{1/2}$ at $Q^2 < 1$ GeV^2

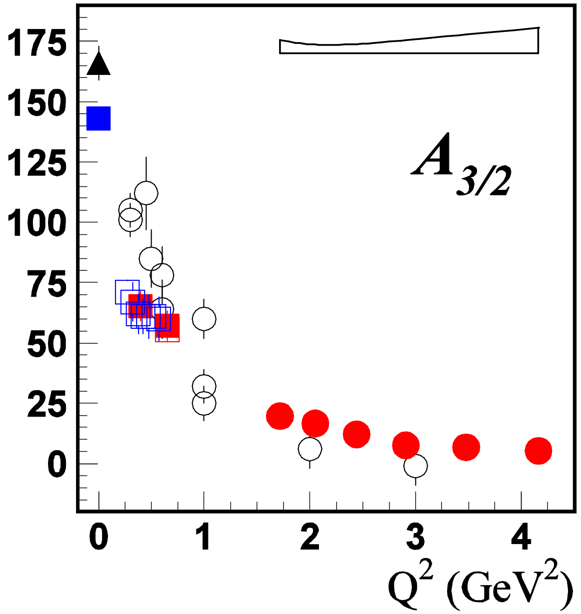
LF RQM:

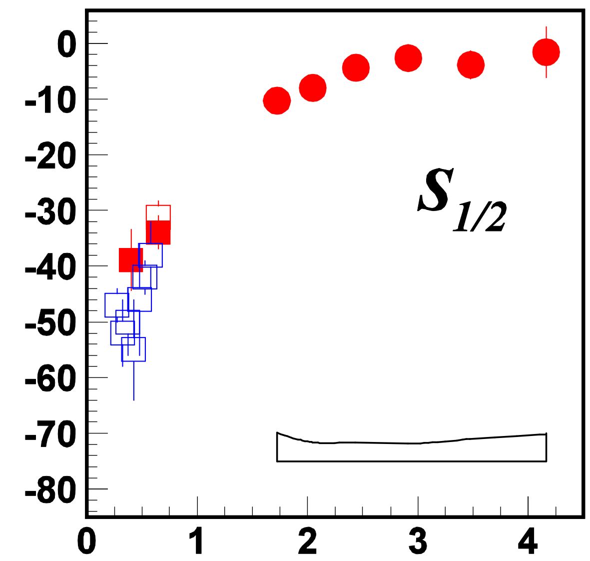
- .... Weber, PR C41 (2783) 1990
- – – – – Capstick, Keister, PR D51 (1995) 3598
- – · – Pace, Simula et.al., PR D51 (1995) 3598
- —— Aznauryan, PR C76 (2007) 025212

Inna Aznauryan
Victor Mokeev

Helicity amplitudes of the $\gamma^* p \rightarrow D_{13}(1520)$ transition







CLAS data :

- ● ■ $N\pi$
- □ $N\pi$, $N\pi\pi$, combined
- □ $N\pi\pi$ (preliminary)
- ■ $\gamma p \rightarrow p\pi^0$, M. Dugger

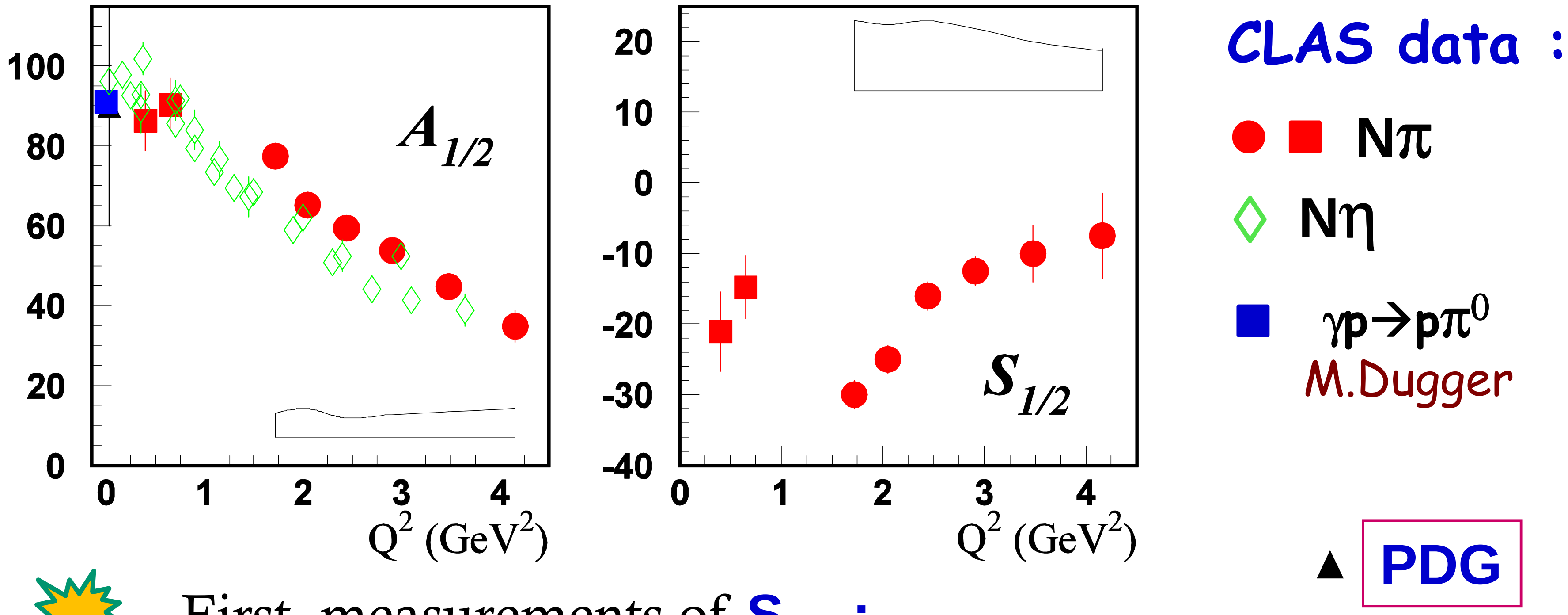
Old data: ○
Bonn, DESY, NINA

▲ **PDG**

- First definite results for $A_{1/2}$, $A_{3/2}$ in wide range of Q^2
- First measurements of $S_{1/2}$

Inna Aznauryan

Helicity amplitudes of the $\gamma^* p \rightarrow S_{11}$ (1535) transition



- First measurements of $S_{1/2}$:
  it is difficult to extract $S_{1/2}$ in η electroproduction

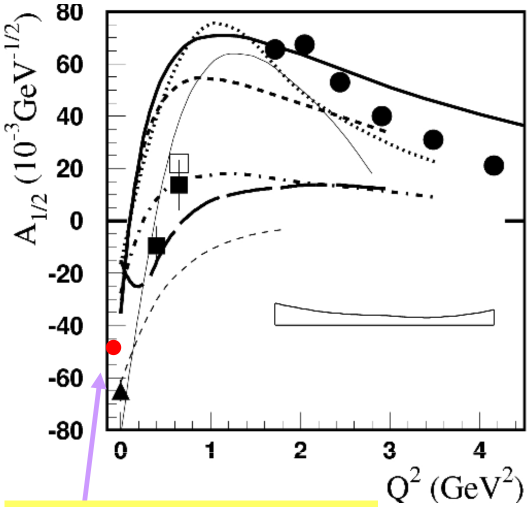
- Results for $A_{1/2}$ obtained in π and η production agree with each other with $\beta_{\pi N} = 0.45$, $\beta_{\eta N} = 0.52$ →
  PDG: $\beta_{\pi N} = 0.35–0.55$, $\beta_{\eta N} = 0.45–0.6$

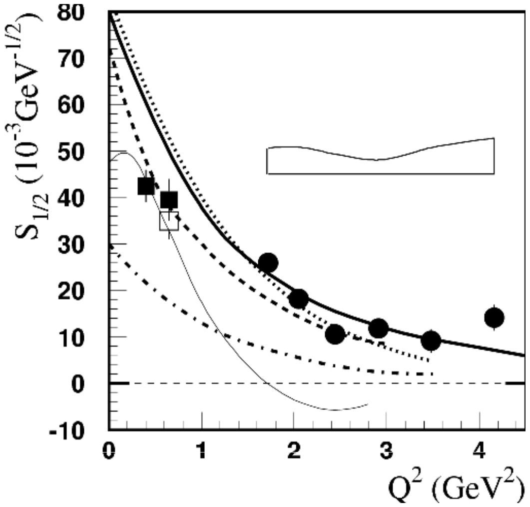
Slow falloff of $A_{1/2}$ observed in η production is confirmed by π data

Resonance Analysis Tools

- Nucleon resonances are broad and overlapping, careful analyses of angular distributions for differential cross sections and polarization observables are needed.
- Amplitude & multipole analysis (GWU-SAID, MAID)
- Jlab/MSU Model (JM06) for N* analysis in charge double pi and electro- and photoproduction.
- Phenomenological analysis procedures have been developed, e.g. unitary isobar models (UIM), dispersion relations (DR), that separate non-resonant and resonant amplitudes in single channels.
- Dynamical coupled channel approaches for single and double pion analysis are being developed within the Excited Baryon Analysis Center (EBAC) effort. They are most important in the extraction of transition form factors for higher mass baryon states.

$N(1440)P_{11}$'s Puzzle





- GW: $A_{1/2}$ = -50.6±1.9

- The analysis of the recent CLAS π^+ electroproduction data [W = 1.15 - 1.69 GeV & Q^2 = 1.7 - 4.5 GeV^2] allows to extract helicities for $\gamma^* p \rightarrow N(1440)P_{11}$ transition [I.G. Aznauryan *et al*, arXiv:0804.0447 [nucl-ex]]

- Model predictions allow to conclude that N(1440) is a first radial excitation of 3q ground state

- Most of analyses of N(1440) are based on its BW parameterization, which assumes that the Res is related to an isolated Pole
- However, the latest GW PWAs for the elastic πN scattering gives evidence that N(1440) corresponds to a more complicated case of several nearby singularities in the amplitude
- Then, the BW description is only an efficient one for N(1440), which could be different in different processes
- Some inelastic data indirectly support this point: they give the N(1440) BW mass and width essentially different from the PDG BW values

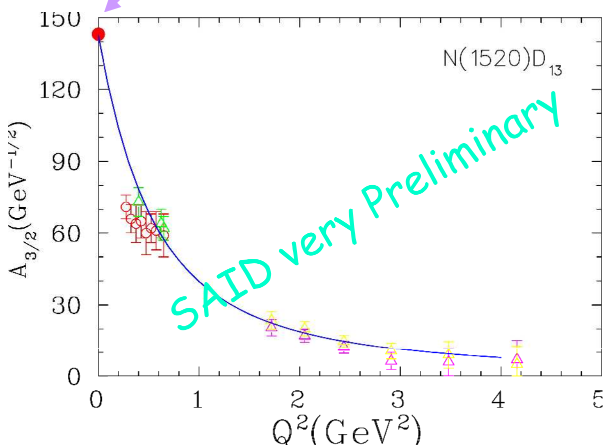
- Since Q^2-dependences for contributions of different singularities may be different, the set of several singularities might provide the N(1440) BW mass and width depending on the Q^2

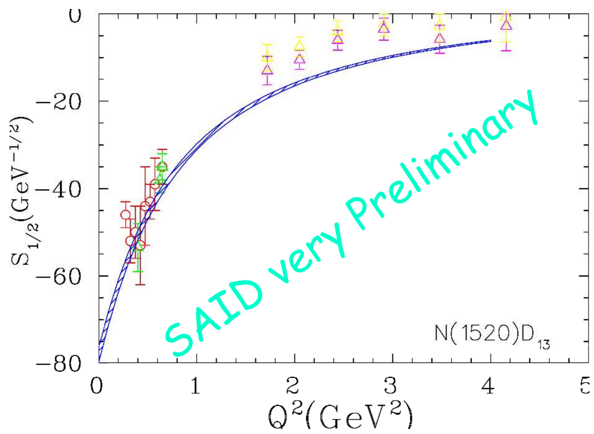
- This problem can be studied in future measurements with CLAS12

Igor Strakovsky

N(1520)D_{13}'s Puzzle

• 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

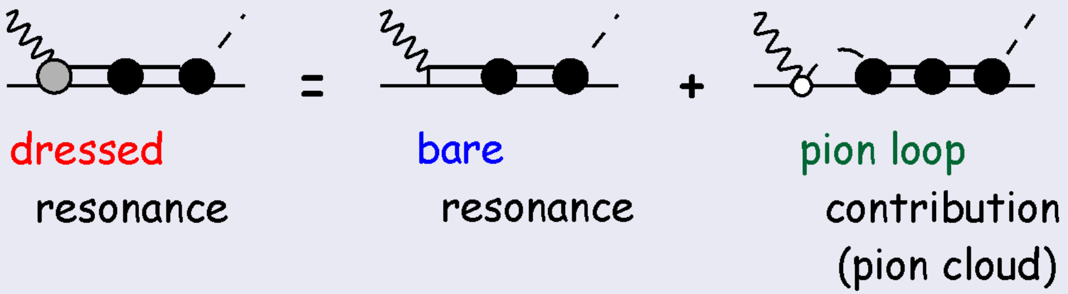
• The good agreement for $A_{3/2}$ and $S_{1/2}$ determination between various resonance extractions gives a more reliable estimate of systematics

• CLAS12 is favorable for Q^2 evaluation

Igor Strakovsky

in our MAID analysis the resonances are dressed

dressed resonance



dressing and undressing can be studied in Dynamical Models:
e.g. Kamalov, Yang, Drechsel, L.T. and Sato, Lee, Julia-Diaz

in most cases quark models calculate the bare resonance couplings
a direct comparison with exp. analysis is not possible,
e.g. Giannini on the hypercentral quark model

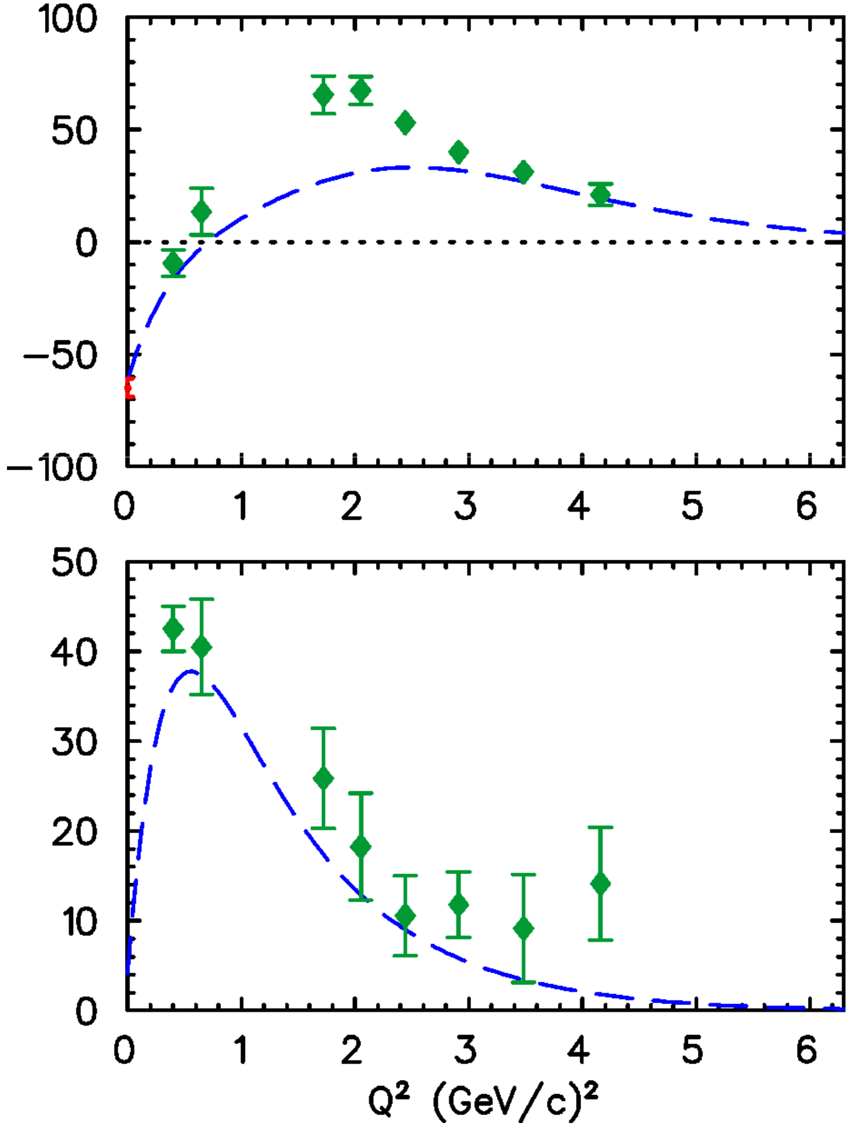
Lothar Tiator

transition form factors of the Roper

comparison of MAID and JLab analysis

$A_{1/2}$

$S_{1/2}$



JLab analysis
with π^+ data of
Joo et al, 2004
Park et al, 2007

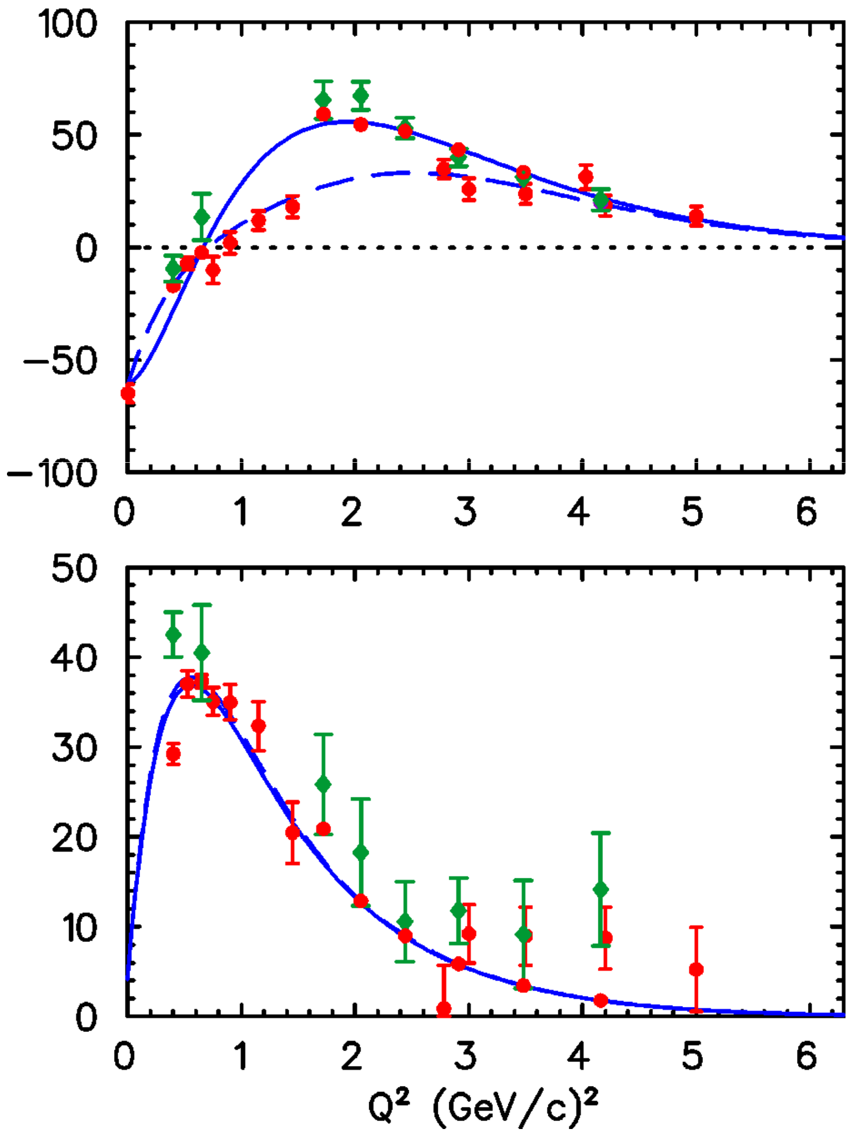
Lothar Tiator

transition form factors of the Roper

comparison of MAID and JLab analysis

$A_{1/2}$

$S_{1/2}$



results from:
Maid07
JLab
and
new Maid analysis
with Park data

Lothar Tiator

Theoretical Models

- Hypercentral Constituent Quark Model
- Covariant Models
- Light Cone Distr. Functions → Light Cone Sum Rules
- Lattice QCD
- Dyson Schwinger Equations
- Generalized Parton Distributions

Hypercentral Model (1)

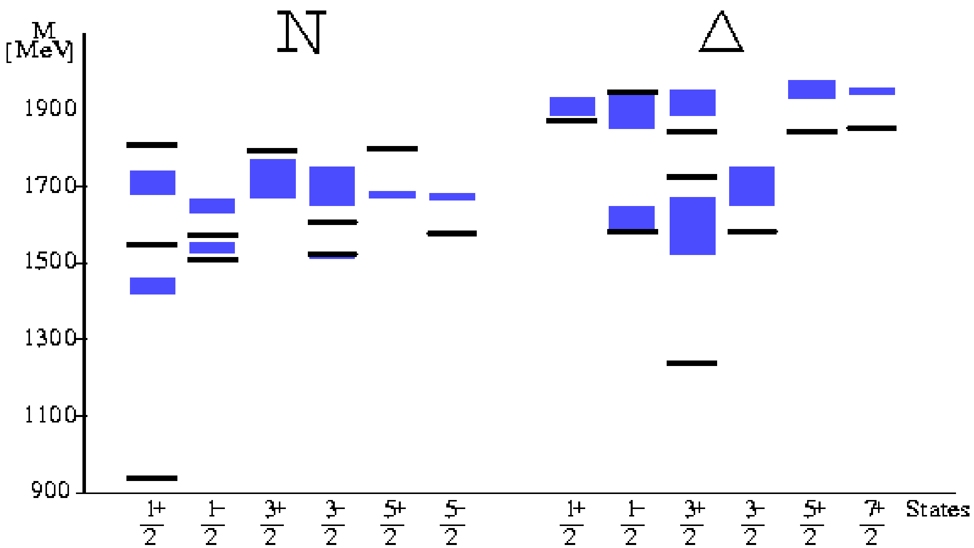
$$H_{3q} = 3m + \sum_{i=1}^{3} \frac{\mathbf{p}_i^2}{2m} + V(x) + H_{hyp}$$

M. Ferraris, M. M. Giannini, M. Pizzo, E. Santopinto, L. Tiator, Phys. Lett. B364 (1995), 231

- $V(x) = -\frac{\tau}{x} + \alpha x;$ $\qquad H_{hyp} = A\left[\sum_{i<j} V^S(\mathbf{r}_i, \mathbf{r}_j)\ \boldsymbol{\sigma}_i \cdot \boldsymbol{\sigma}_j + \text{tensor}\right]$
- 3 parameters $\tau\ \alpha\ A \leftarrow$ fixed to the spectrum, $m = \frac{M}{3}$

$$x = \sqrt{\rho^2 + \lambda^2}$$

hyperradius



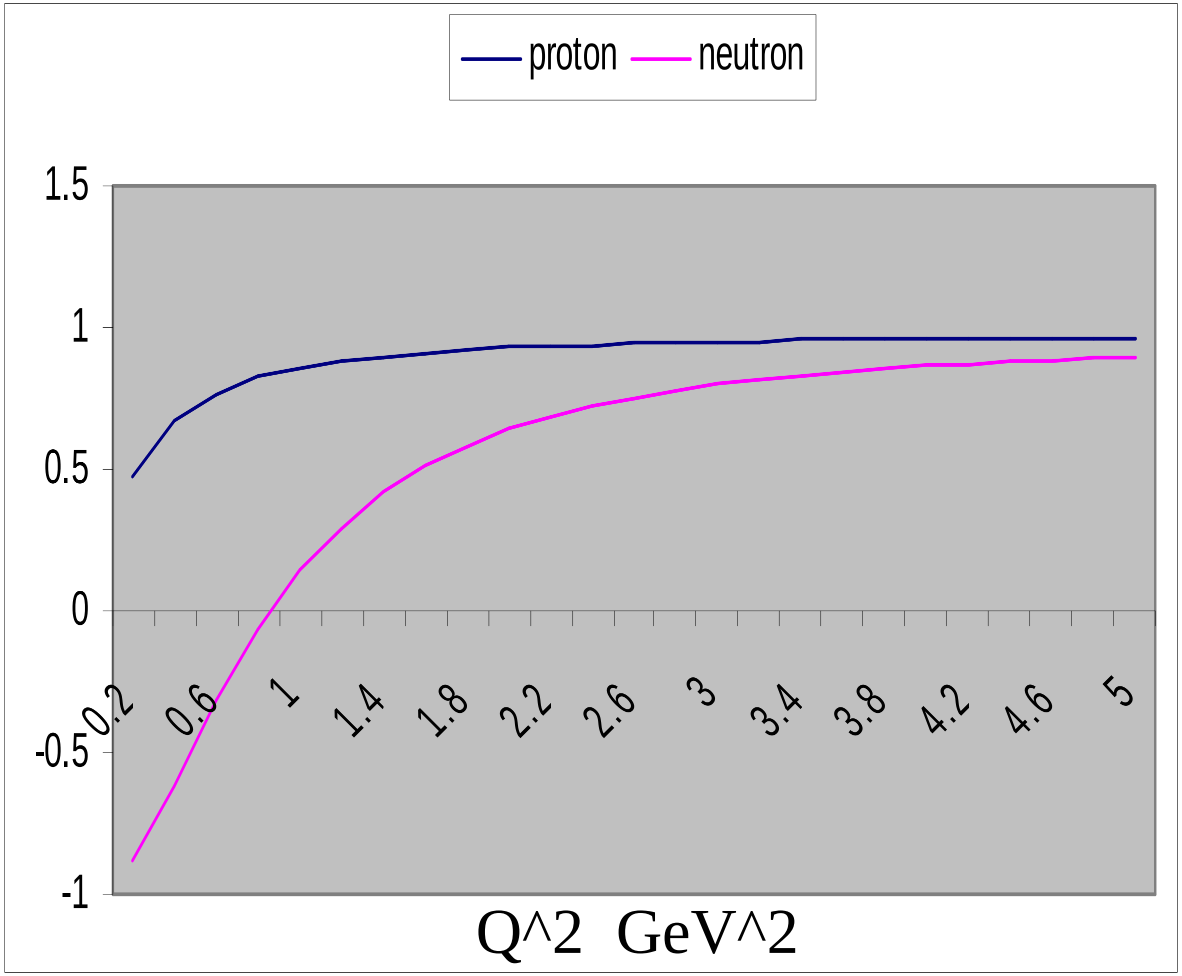
$\tau = 4.59$

$\alpha = 1.61\ \text{fm}^{-1}$

$A \Leftarrow (N - \Delta)$

Mauro Giannini

D13 hCQM predictions



Mauro Giannini

QCD theory

- Direct lattice calculations of form factors
  - restricted to $Q \ll 1/a$, currently $a = 0.06 - 0.08$ fm $\sim 1/(2-3$ GeV); unlikely to go beyond $Q^2 \sim 3$ GeV^2
  - black box
- Light-cone sum rules
  - need N^* light-cone distribution amplitudes (DAs) or at least good interpolating current
  - in approaches based on duality, separation of states of different parity is very difficult:

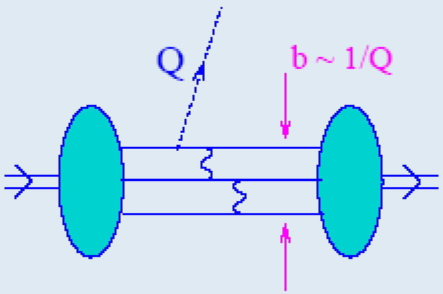
$$\langle 0|qqq|N(p)\rangle = f_N N(p) \qquad \langle 0|qqq|N^*(p)\rangle = f_{N^*}\gamma_5 N(p)$$

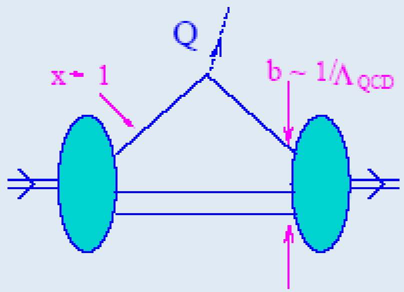
- In this work
  - calculate moments of N^* light-cone distribution amplitudes on the lattice
  - use them as input in LCSRs to calculate form factors

Vladimir Braun

QCD theory

- why light-cone sum rules?





Hard rescattering:

Small b
Average $0 < x < 1$

Soft (Feynman):

Average b
Large $x \to 1$

♡ pQCD 'hard' contributions are included

♡ 'soft' contribution is built as a sum of contributions of DAs of increasing twist: expansion parameter $(\Lambda^2_{QCD}/s_0)^{\text{twist}}$ where s_0 is interval of duality

♡ there is no double counting but separation of 'soft' and 'hard' is scheme- and scale-dependent

This technique provides one with the most direct relation between form factors and parton structure that is available at present, with no other parameters

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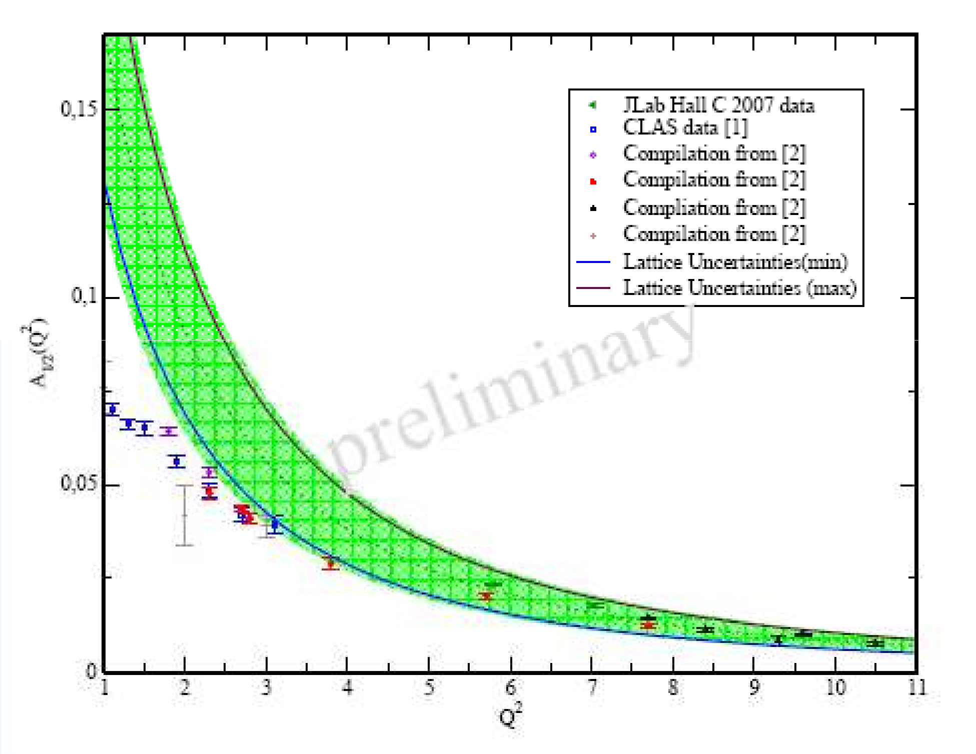
Results: $\gamma^* N \to N^*(1535)$



[1] H. Denizli et al., Phys. Rev. C **76** (2007) 015204

[2] P. Stoler, Phys. Rept. **226** (1993) 103

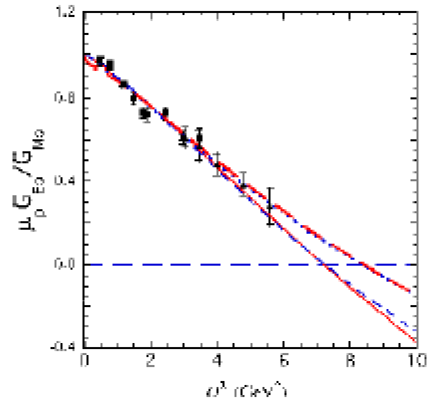
Vladimir Braun

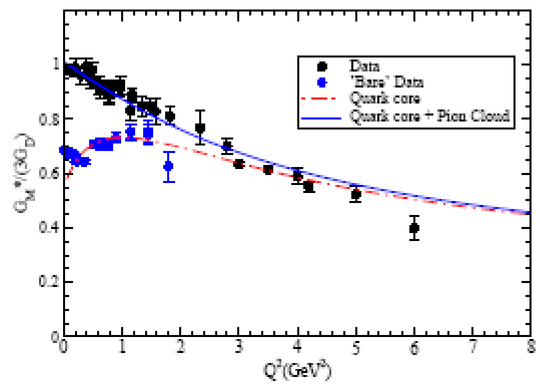
Spectator Quark Model: Nucleon and Delta

S-state approach

- Baryon= interacting quark $\oplus$ spectator diquark
- Nucleon and Δ represented with covariant S-state wave functions
- Describes Nucleon Elastic Form Factors: $\frac{G_{Ep}}{G_{Mp}}$ Jlab data
- Explains dominant contribution of the $\gamma N \to \Delta$ transition
  Quark core $\approx$ 66% of M1 (G_M^*)
- $G_M^* =$ Quark core $\oplus$ Pion Cloud
  Pion Cloud $\approx$ remaining part

  [Pion cloud can be estimated using Dynamical Models]



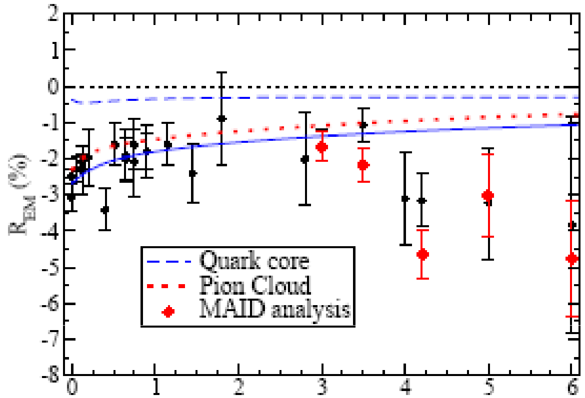


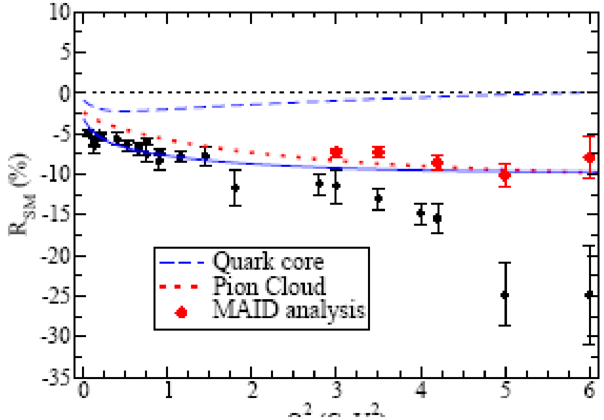
Gilberto Ramalho

Spectator Quark Model: Nucleon and Delta

D-states in the Delta (arXiv:0810.4126 [hep-ph])

- Non-zero contributions for the quadrupole form factors E2 ($\sim R_{EM}$) and C2 ($\sim R_{SM}$)
- Quark degrees of freedom insufficient to explain the data
- G_X^* = Quark core $\oplus$ Pion Cloud
  Pion Cloud contribution derived from large N_c limit
- Pion Cloud dominate, but a small mixture of D-states improves the description of the data
- Pion cloud estimation must be improved (high Q^2)
- Differences between analyses (Jlab *vs* MAID) must be explained



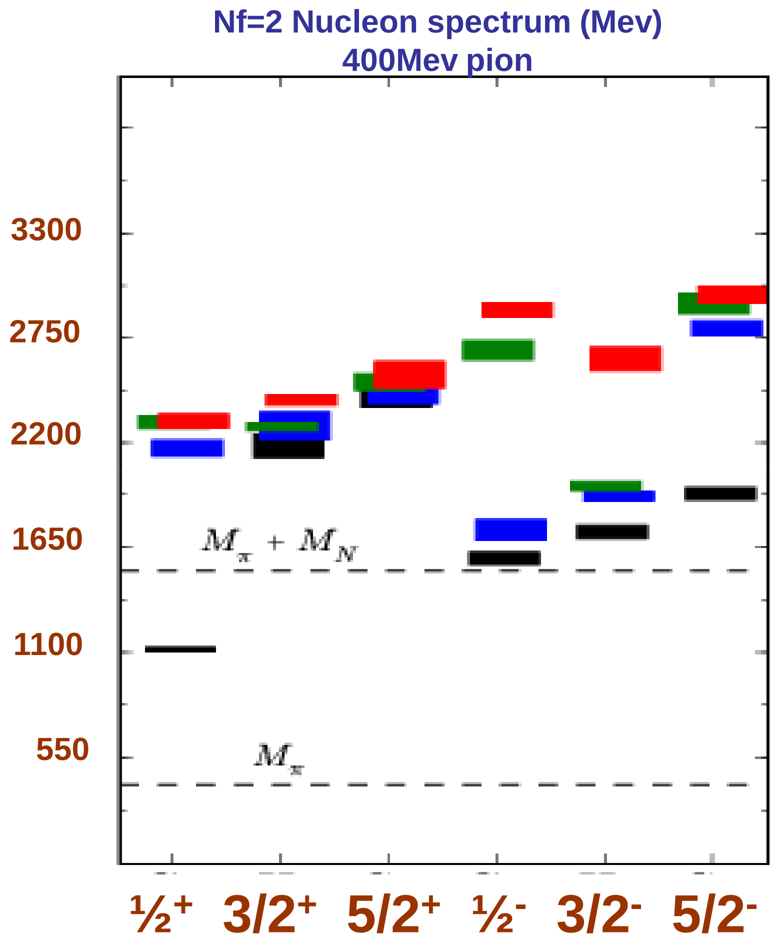


Gilberto Ramalho

Lattice QCD

Excited state nucleon spectrum

- Computation of excited hadron spectrum and meson photocouplings a major focus of the Hadron Spectrum Collaboration (JLab+CMU+UMD+Dublin)
- Key techniques:
  - Use of anisotropic lattices - resolve excited states. New gauge generation required.
  - Variational determination of energies using non-local operators.
- Initial results using quenched lattices
- New work involves dynamical $N_f=2$ lattices: m_π= 400 MeV.
- Current work: using N_f=2+1, lowering pion mass, disentangling decay states

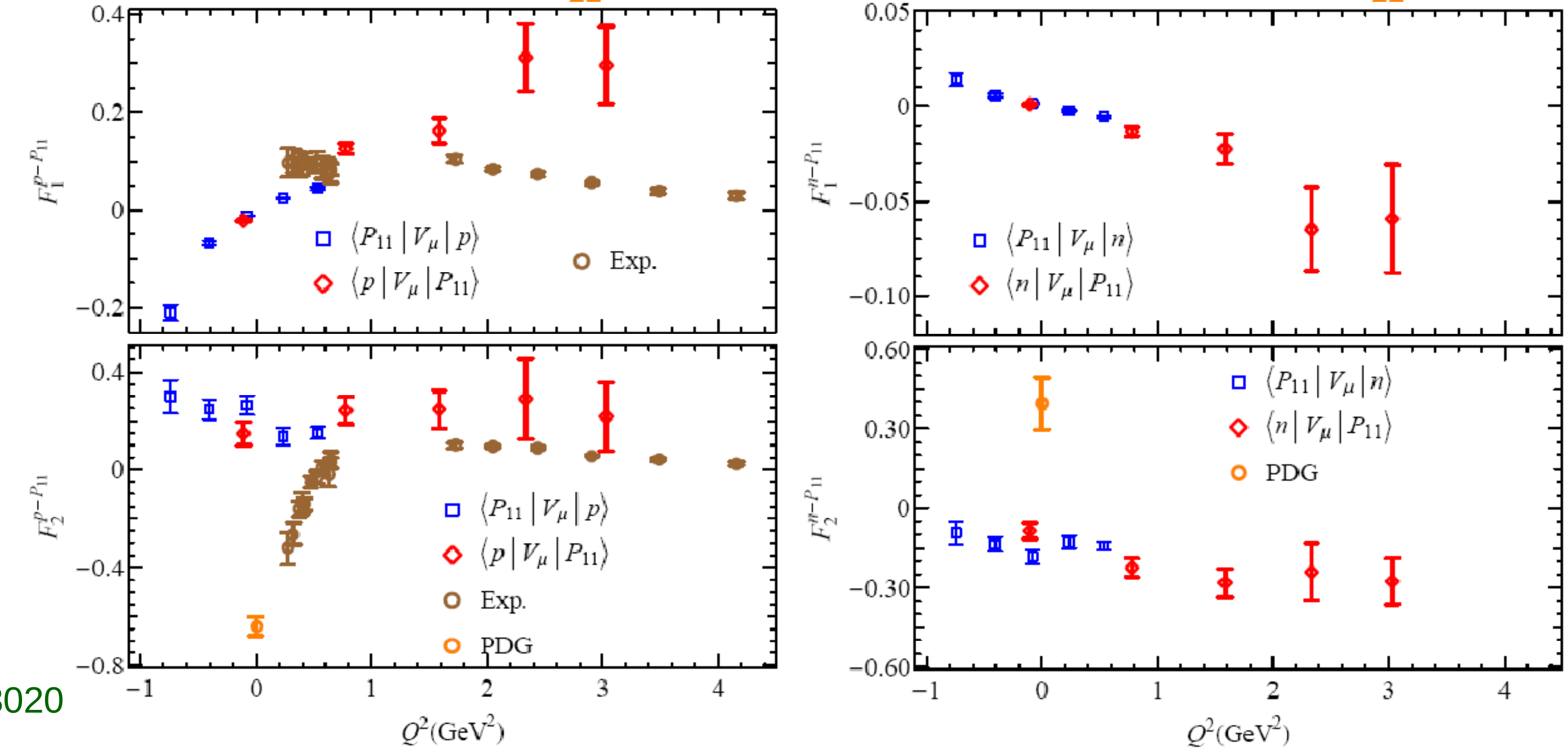


arXiv:0810.0253

Nucleon-Roper form-factors

- Radiative transition form-factors: also major focus of collaboration.
- Exploratory study of excited nucleon form-factors. Quenched lattices: $m_\pi \sim 720$MeV. Reasonable signal. Pion cloud effects important
- Computations in time-like region will shift with decreasing pion mass
- Current work: using N_f=2+1, decrease pion mass, improved baryon operators, disentangle decay states

Proton-P_{11} **Neutron-P_{11}**

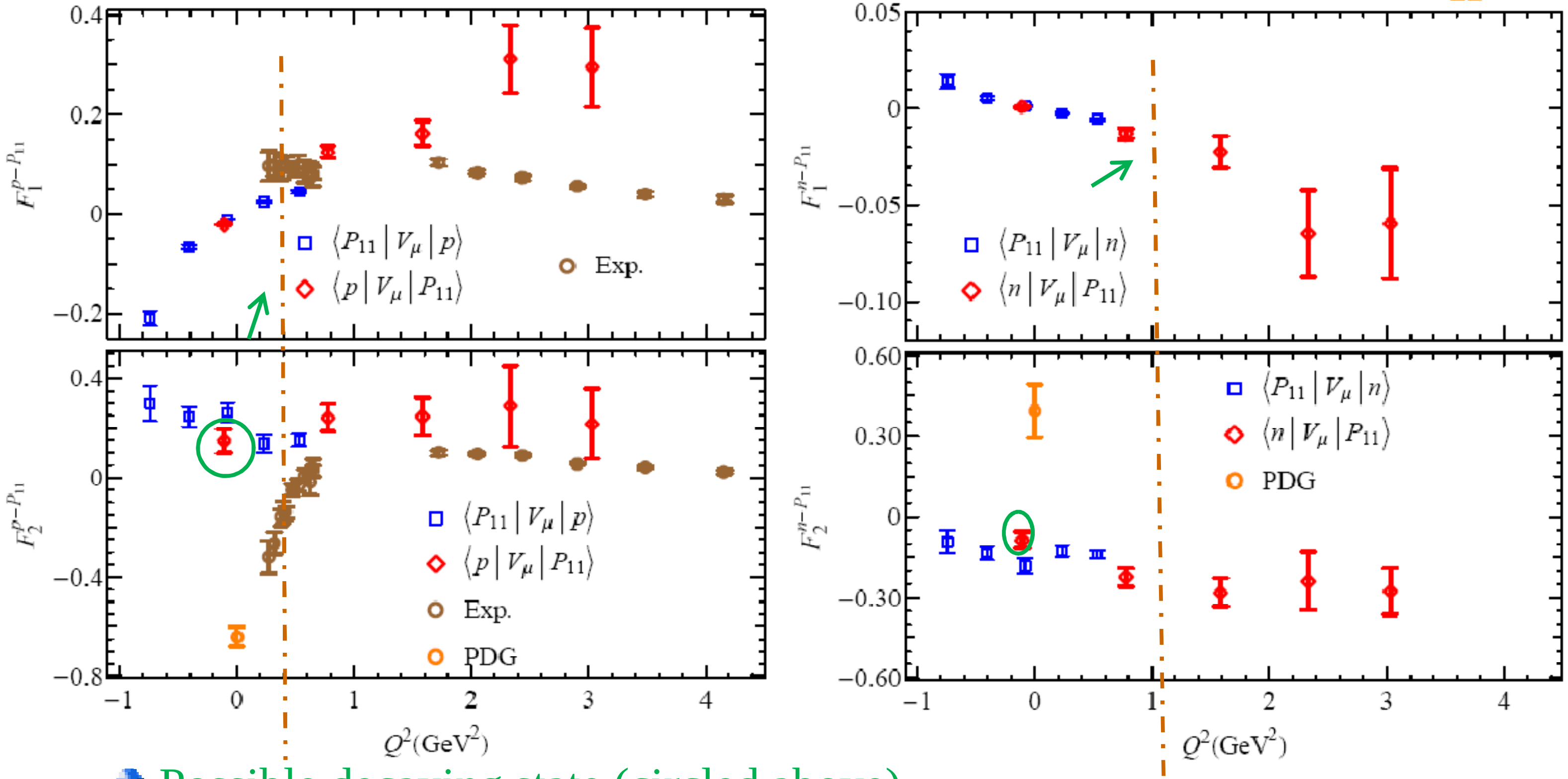


arXiv:0803.3020

Nucleon-Roper Form Factors

- Completed exploratory study on quenched lattices arXiv:0803.3020

Proton-P_{11} **720 MeV Pion** **Neutron-P_{11}**



- Possible decaying state (circled above)
- 200 configurations give us reasonable signal
- Lower pion mass will shift the time-like region to space-like region

Dyson-Schwinger Equations

Dyson-Schwinger Equations
CLAS at 11 GeV

Craig D. Roberts

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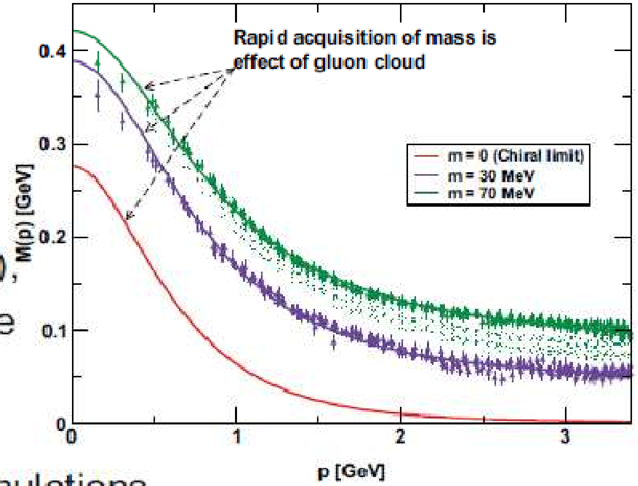
Office of Science

Argonne

Craig Roberts

Dynamical quark mass

- Spectrum of excited states and transition form factors provide unique information about long-range interaction between light-quarks and distribution of hadron's characterising properties amongst its QCD constituents
- Dynamical chiral symmetry breaking (DCSB) is a FACT in QCD
- E.g., Exhibited in the momentum evolution of $M(p^2)$, which connects the nonperturbative and perturbative domains
- Predicted by DSE studies & confirmed by lattice-QCD simulations
- DCSB is most important mass generating mechanism for visible matter in the Universe. Higgs boson is irrelevant to light-quarks



Craig Roberts

Dyson-Schwinger Equations

- Poincaré covariant unification of meson and baryon observables – full machinery of quantum field theory
- All global and pointwise corollaries of DCSB are naturally manifested, without fine-tuning
- Foundation for proof of exact results in QCD
- Confinement is defined and expressed covariantly
- Excited states:
  - Mesons already being studied
  - Baryons are within practical reach
  - Ab-initio study of $N \rightarrow \Delta$ transition underway
- DSEs: Tool enabling insight to be drawn from experiment into long-range piece of interaction between light-quarks
  - Turn data on transition form factors into a map of $M(p^2)$

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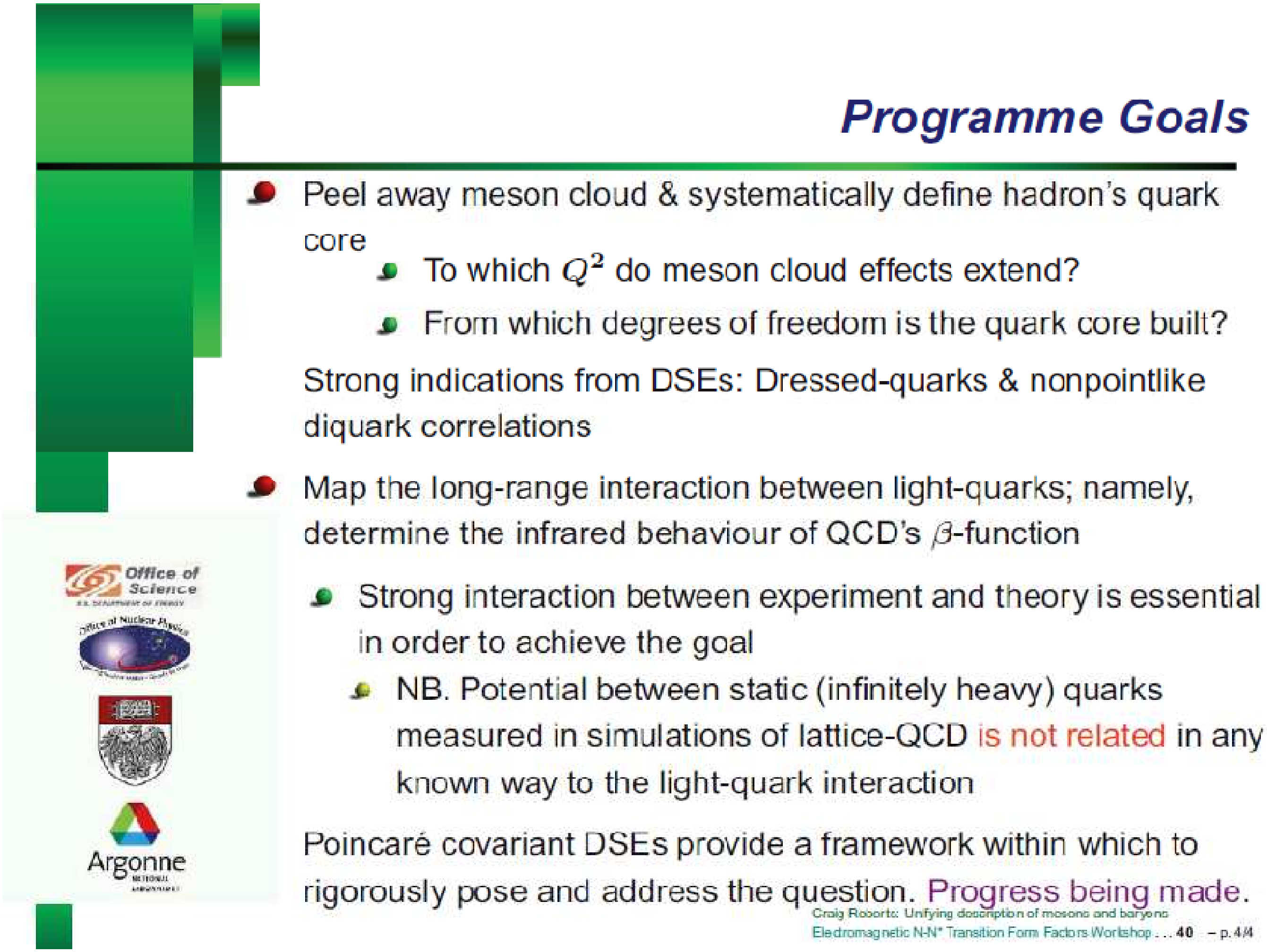


GPDs

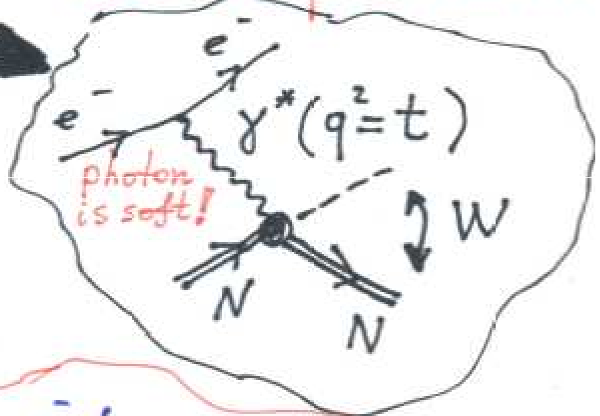
Maxim Polyakov

$N \to$ meson + N GPD-quintessence function

$N(x, t, W, t', \alpha)$ is a complex function

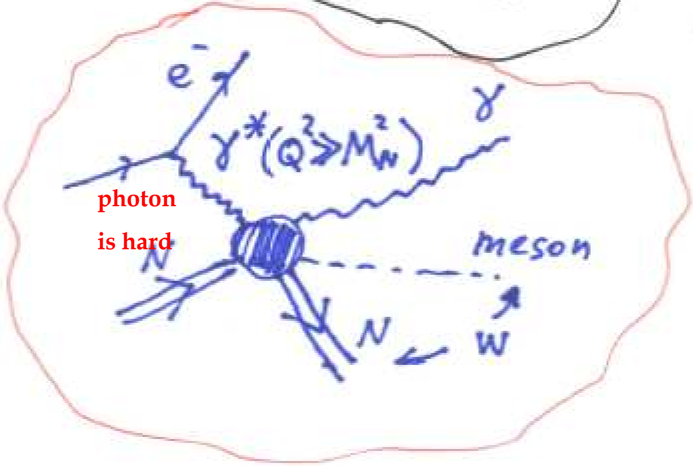
It is analogaus to amplitude of meson electroproductio

- The whole machinery developed for → can be applied to $N(x, t, W, t', \alpha)$



- New is variable x, it is dual to the spin of the QCD string.
  $\int_0^1 dx\, x^{J-1} \ldots$ selects spin **J**

- x-dependence of quintessence function can be obtained from X_{Bj} dependence of DVCS amplitude via tomography formula!



For tomography of DVCS amplitude and GPD quintessence function see Polyakov, PLB659 (2008) 542

There be *Photons*, too!

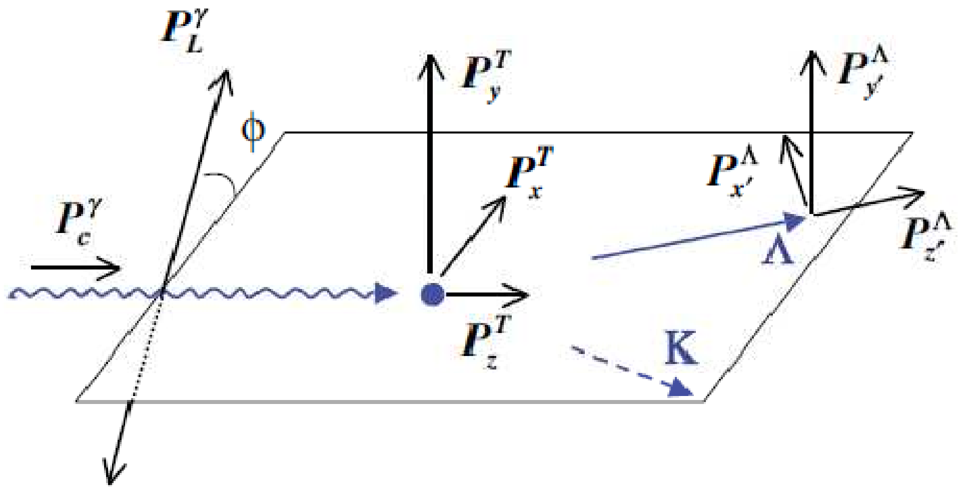
CLAS Search for Excited Baryon States

Experiment	reactions	beam pol.	target pol.	recoil	status
G1/G10	$\gamma p \rightarrow N\pi$, $p\eta$, $p\pi\pi$, $K\Lambda/\Sigma$	-	-	Λ,Σ	complete
G8	$\gamma p \rightarrow p(\rho,\varphi,\omega)$	linear	-	-	complete
G9-FROST	$\gamma p \rightarrow N\pi$, $p\eta$, $p\pi\pi$, $K\Lambda$	lin./circ.	long./trans.	Λ,Σ	2007
G13	$\gamma D \rightarrow K\Lambda$, $K\Sigma$	circ./lin.	unpol.	Λ,Σ	2006/2008
G14-HD	$\gamma(HD) \rightarrow K\Lambda$, $K\Sigma$, $N\pi$	lin./circ.	long./trans.	Λ,Σ	2009/2010

This program will, for the first time, provide complete amplitude information on the $K\Lambda$ final state (more than 7 independent polarization measurements at each kinematics), and nearly complete information on the $N\pi$ final states.

Polarized Pseudoscalar meson photo-production:

$$\vec{\gamma} + \vec{N} \rightarrow K + \vec{\Lambda}$$

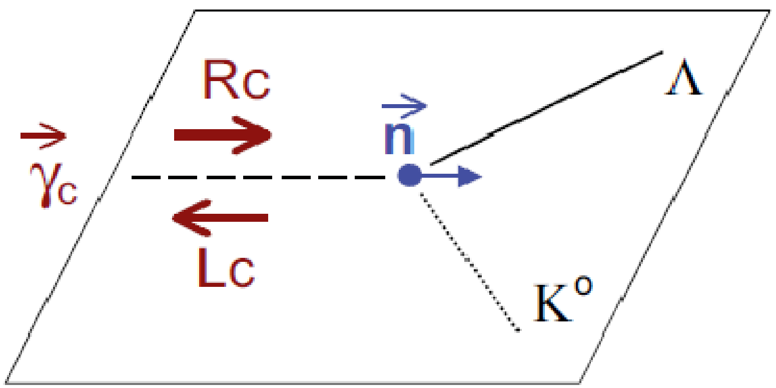


Andy Sandorfi

E asymmetry

leading Pol dependence

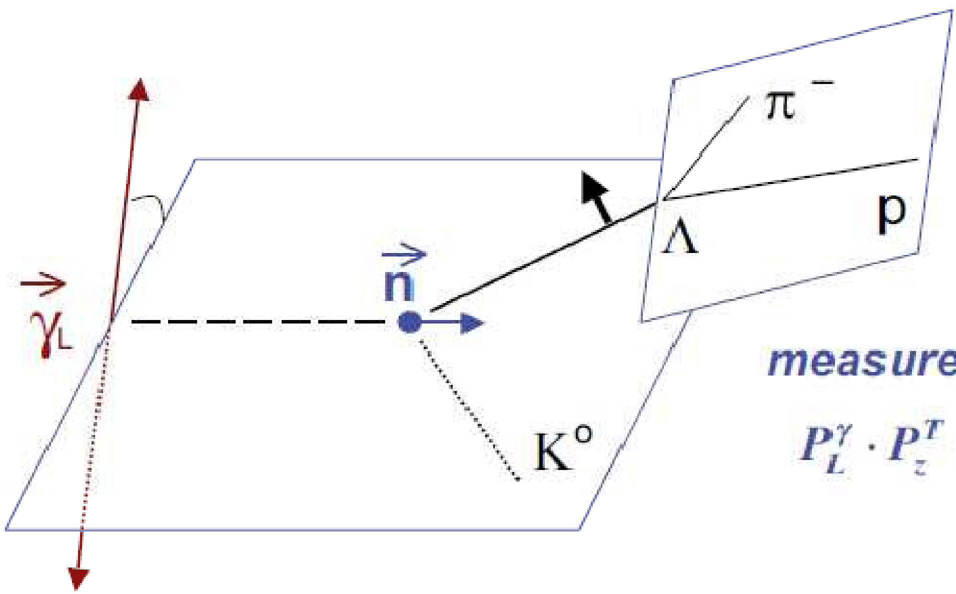
$P_c^{\gamma} \cdot P_z^{T}$



$T_{z'}$ asymmetry

leading Pol dependence

$P_x^{T} \cdot P_{z'}^{\Lambda}$



measured via

$P_L^{\gamma} \cdot P_z^{T} \cdot P_{x'}^{\Lambda}$

Andy Sandorfi

Polarization observables in $J^\pi = 0^-$ meson photo-production :

- *single-pol observables measured from double-pol asy*
- *double-pol observables measured from triple-pol asy*

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		$T_{z'}$		$L_{z'}$
linearly P_γ	Σ	H	P	G	$O_{x'}$	T	$O_{z'}$	$L_{z'}$	$C_{z'}$	$T_{z'}$	E		F	$L_{x'}$	$C_{x'}$	$T_{x'}$
circular P_γ		F		E	$C_{x'}$		$C_{z'}$		$O_{z'}$		G		H		$O_{x'}$	

- *not all are independent:*

$$E^2 + F^2 + G^2 + H^2 = 1 + P^2 - \Sigma^2 - T^2$$

$$FG - EH = P - \Sigma T$$

$$C_{x'}^2 + C_{z'}^2 + O_{x'}^2 + O_{z'}^2 = 1 - P^2 - \Sigma^2 + T^2$$

$$C_{z'}O_{x'} - C_{x'}O_{z'} = T - \Sigma P$$

$$T_{x'}^2 + T_{z'}^2 + L_{x'}^2 + L_{z'}^2 = 1 - P^2 + \Sigma^2 - T^2$$

$$L_{z'}T_{x'} - L_{x'}T_{z'} = -PT + \Sigma$$

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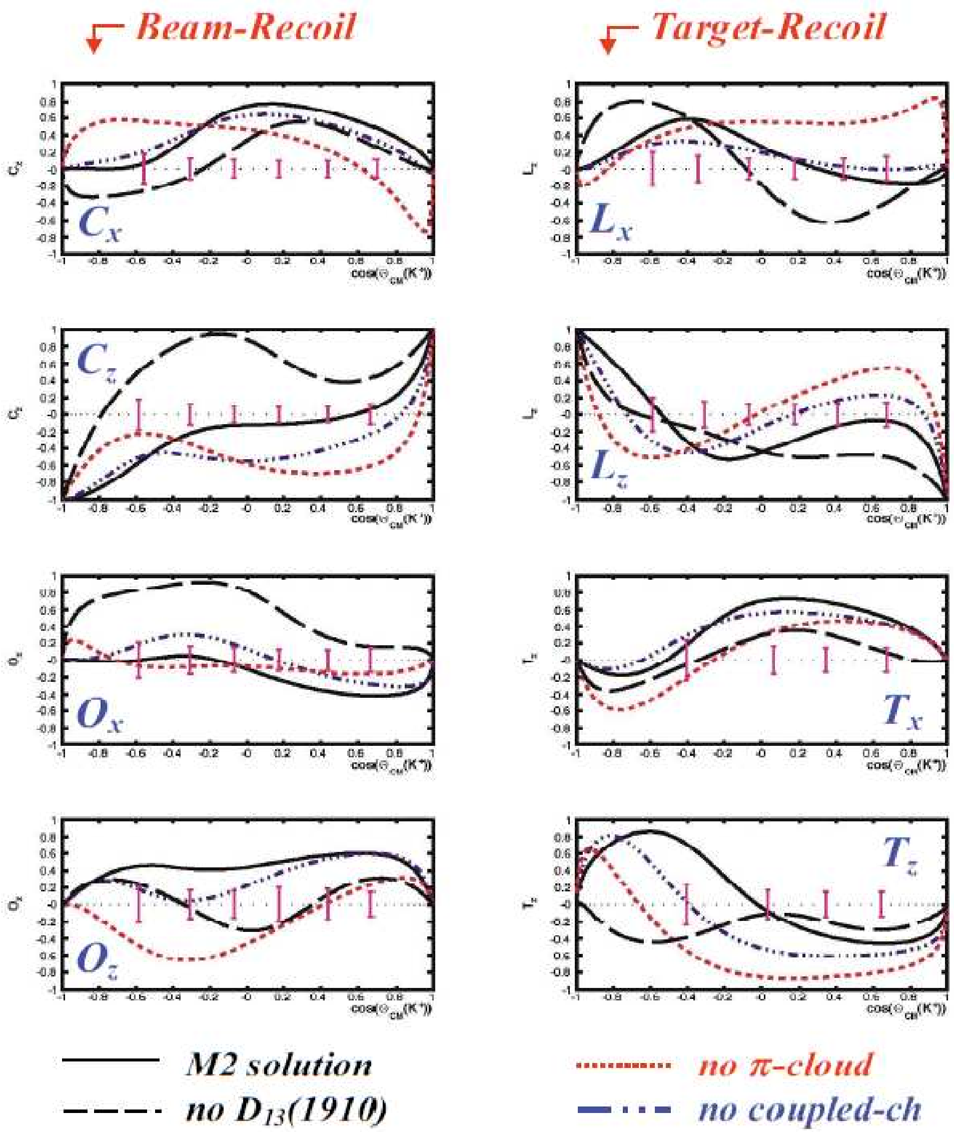
$\gamma n \rightarrow K^0 \Lambda$ $E_\gamma = 1.55$ GeV ($W = 1.95$ GeV)



-B. Juliá-Díaz, T-S. H. Lee (preliminary)

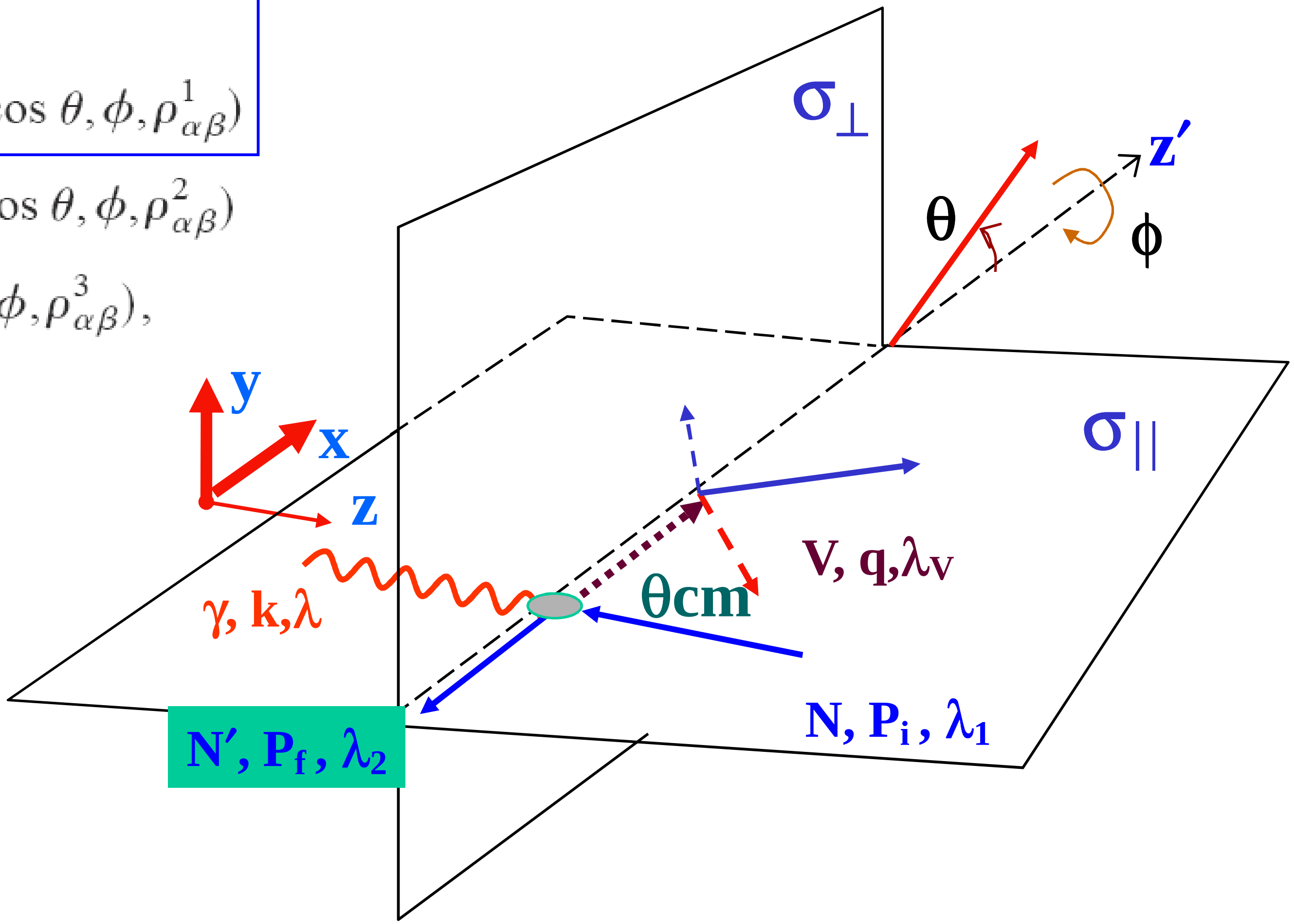
EBAC gn->K0L [BR,TR]

Andy Sandorfi

• **Spin observables in terms of density matrix elements**

Vector meson decay distribution:

$$
\begin{aligned}
&W(\cos\theta,\phi,\Phi) \\
&= W^0(\cos\theta,\phi,\rho^0_{\alpha\beta}) \\
&\quad - P_\gamma \cos 2\Phi\, W^1(\cos\theta,\phi,\rho^1_{\alpha\beta}) \\
&\quad - P_\gamma \sin 2\Phi\, W^2(\cos\theta,\phi,\rho^2_{\alpha\beta}) \\
&\quad + \lambda_\gamma P_\gamma W^3(\cos\theta,\phi,\rho^3_{\alpha\beta}),
\end{aligned}
$$



Qiang Zhao

Qiang Zhao

Unpolarized decay distribution:

$$W^0(\cos\theta,\phi,\rho^0_{\alpha\beta})=\frac{3}{4\pi}\left(\frac{1}{2}\sin^2\theta+\frac{1}{2}(3\cos^2\theta-1)\rho^0_{00}\right.$$
$$-\sqrt{2}\,\mathrm{Re}\,\rho^0_{10}\sin 2\theta\cos\phi$$
$$\left.-\rho^0_{1-1}\sin^2\theta\cos 2\phi\right),$$

Linearly-polarized decay distribution:

$$W^1(\cos\theta,\phi,\rho^1_{\alpha\beta})=\frac{3}{4\pi}(\rho^1_{11}\sin^2\theta+\rho^1_{00}\cos^2\theta$$
$$-\sqrt{2}\,\mathrm{Re}\,\rho^1_{10}\sin 2\theta\cos\phi$$
$$-\rho^1_{1-1}\sin^2\theta\cos 2\phi),$$

$$\left\{\begin{aligned}\rho^0_{ik} &= \frac{1}{A}\sum_{\lambda\lambda_2\lambda_1} H_{\lambda_{v_i}\lambda_2,\lambda\lambda_1}H^*_{\lambda_{v_k}\lambda_2,\lambda\lambda_1},\\ \rho^1_{ik} &= \frac{1}{A}\sum_{\lambda\lambda_2\lambda_1} H_{\lambda_{v_i}\lambda_2,-\lambda\lambda_1}H^*_{\lambda_{v_k}\lambda_2,\lambda\lambda_1},\\ \rho^2_{ik} &= \frac{i}{A}\sum_{\lambda\lambda_2\lambda_1} \lambda H_{\lambda_{v_i}\lambda_2,-\lambda\lambda_1}H^*_{\lambda_{v_k}\lambda_2,\lambda\lambda_1},\\ \rho^3_{ik} &= \frac{i}{A}\sum_{\lambda\lambda_2\lambda_1} \lambda H_{\lambda_{v_i}\lambda_2,\lambda\lambda_1}H^*_{\lambda_{v_k}\lambda_2,\lambda\lambda_1},\end{aligned}\right.$$

e.g. The polarized beam asymmetry:

$$\Sigma\equiv\frac{\sigma_\perp-\sigma_\parallel}{\sigma_\perp+\sigma_\parallel}=\frac{2\rho^1_{11}+\rho^1_{00}}{2\rho^0_{11}+\rho^0_{00}}$$

$$\begin{aligned}\epsilon_\perp &= \hat{y}=i(\epsilon_{\gamma+}+\epsilon_{\gamma-})/\sqrt{2}\\ \epsilon_\parallel &= \hat{x}=-(\epsilon_{\gamma+}-\epsilon_{\gamma-})/\sqrt{2}\end{aligned} \Rightarrow \left\{\begin{array}{l}\sigma_\perp\\ \sigma_\parallel\end{array}\right.$$

Zhao, Al-Khalili & Cole, PRC71, 054004 (2005); Pichowsky, Savkli & Tabakin, PRC53, 593 (1996)

Three ingredients in our quark model approach:

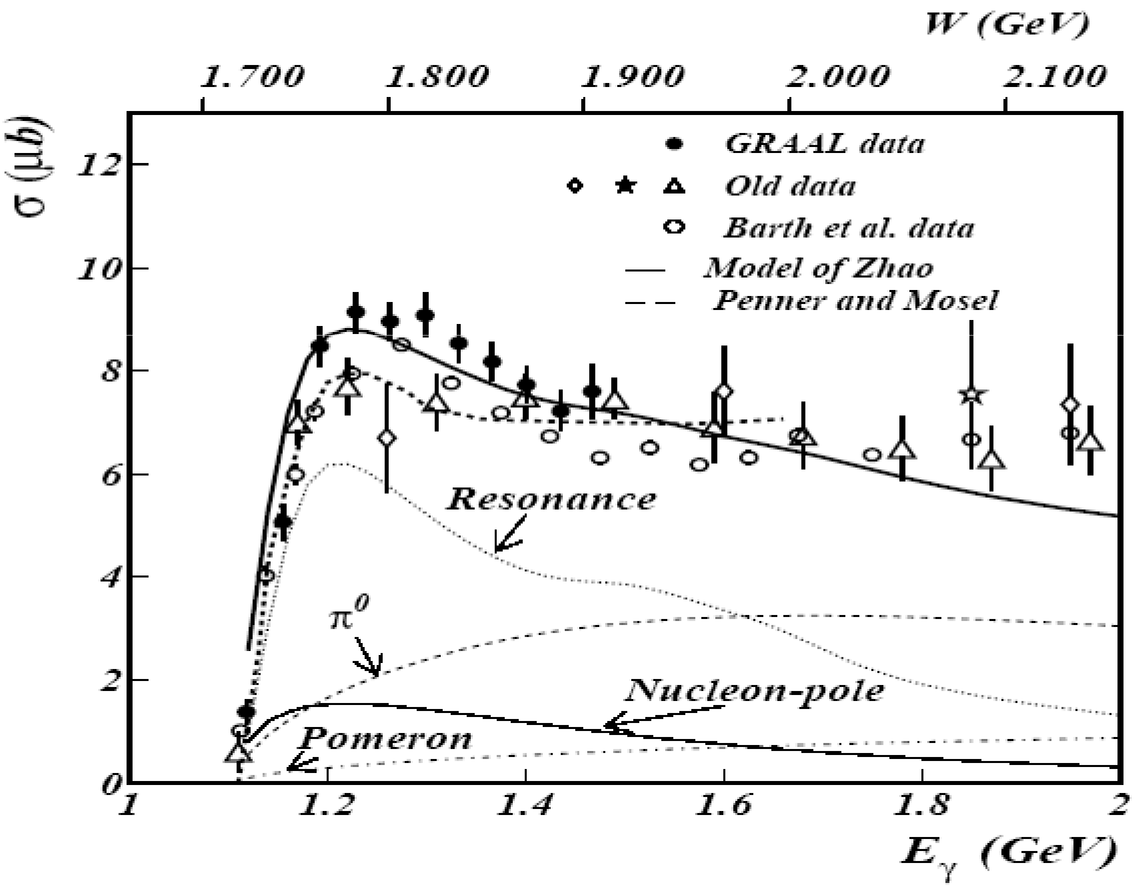
1. **s- and u-channel resonance excitations**
   Vector meson production via an effective Lagrangian for quark-vector-meson interactions in the s- and u-channel;
2. **t-channel natural parity exchange**
   Pomeron exchange for neutral vector meson (ω, ρ^0, ϕ) production in the t-channel, and t-channel scalar meson exchange;
3. **t-channel unnatural parity exchange**
   Light meson exchanges in the t-channel, e.g. π^0 exchange for ω production.

Refs.
Z., Li, & Bennhold, PLB436, 42(1998); PRC58, 2393(1998);
Z., Didelez, Guidal, & Saghai, NPA660, 323(1999);
Z., PRC63, 025203(2001);
Z., Saghai, Al-Khalili, PLB509, 231(2001);
Z., Al-Khalili, & Bennhold, PRC64, 052201(R)(2001); PRC65, 032201(R) (2002);
Z., Al-Khalili, & Cole, PRC71, 054004(2005);
Z. and Close, PRD74, 094014(2006)

Qiang Zhao

Theoretical results for ω production
-- data from GRAAL Collaboration + …

- **Total cross sections**



$\gamma + \mathbf{p} \to \omega + \mathbf{p}$

N ≤ 2
Born terms +

$P_{11}(1440)$, $S_{11}(1535)$,
$D_{13}(1520)$, $P_{13}(1720)$,
$F_{15}(1680)$, $P_{11}(1710)$,
$P_{13}(1900)$, $F_{15}(2000)$

N > 2
degenerate in N

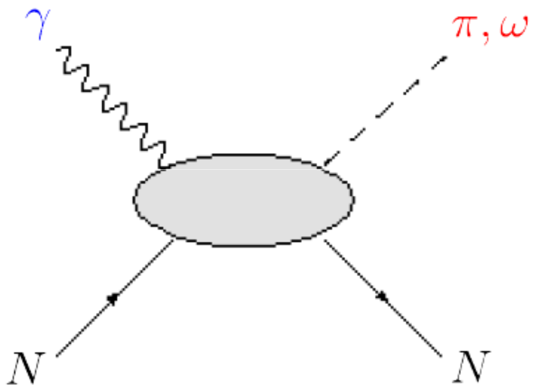
a = 3.67, b = –3.85

GRAAL Collaboration, PRL96, 132003(2006)

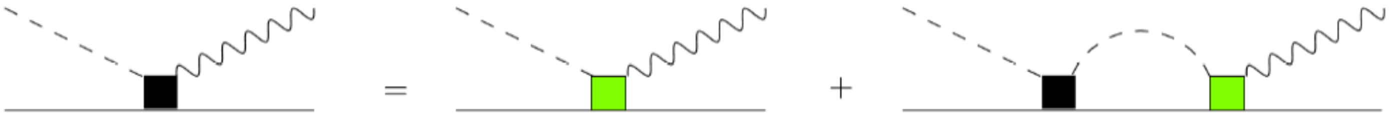
Mark Paris

Outline

- Model
  - 5 channel "core" [B.Julia-Diaz et.al. Phys. Rev. C 76: 065201, 2007] + ωN
- Fitting
  - πN→πN, πN→ωN, YN→πN,YN→ωN
- Predictions
  - Σ_ω photon beam asymmetry
  - $\rho^0_{\lambda\lambda'}$ spin density matrix elements
  - ωN scattering length
- Conclusion

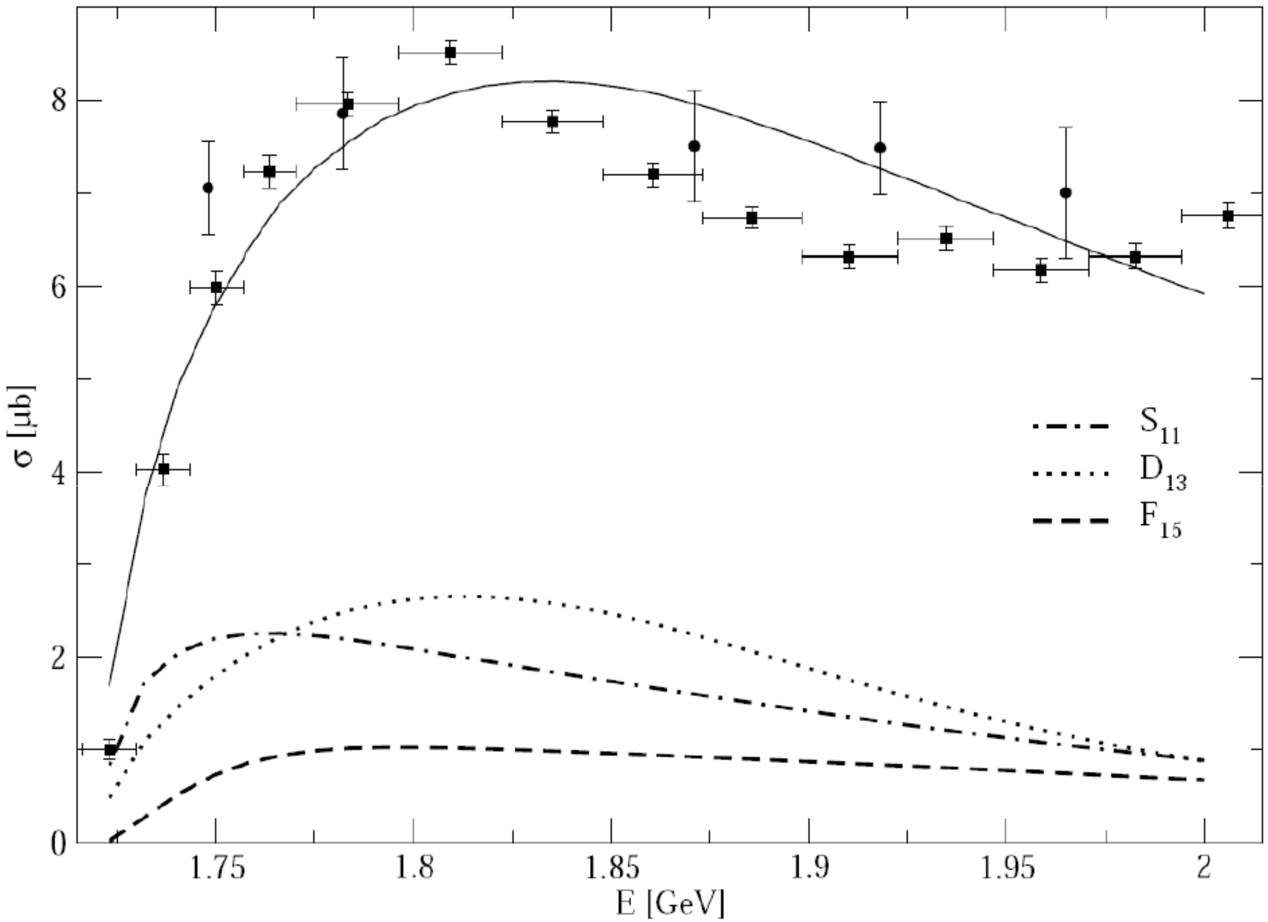


Dynamical coupled channel calculation of pion and omega meson production



Mark Paris

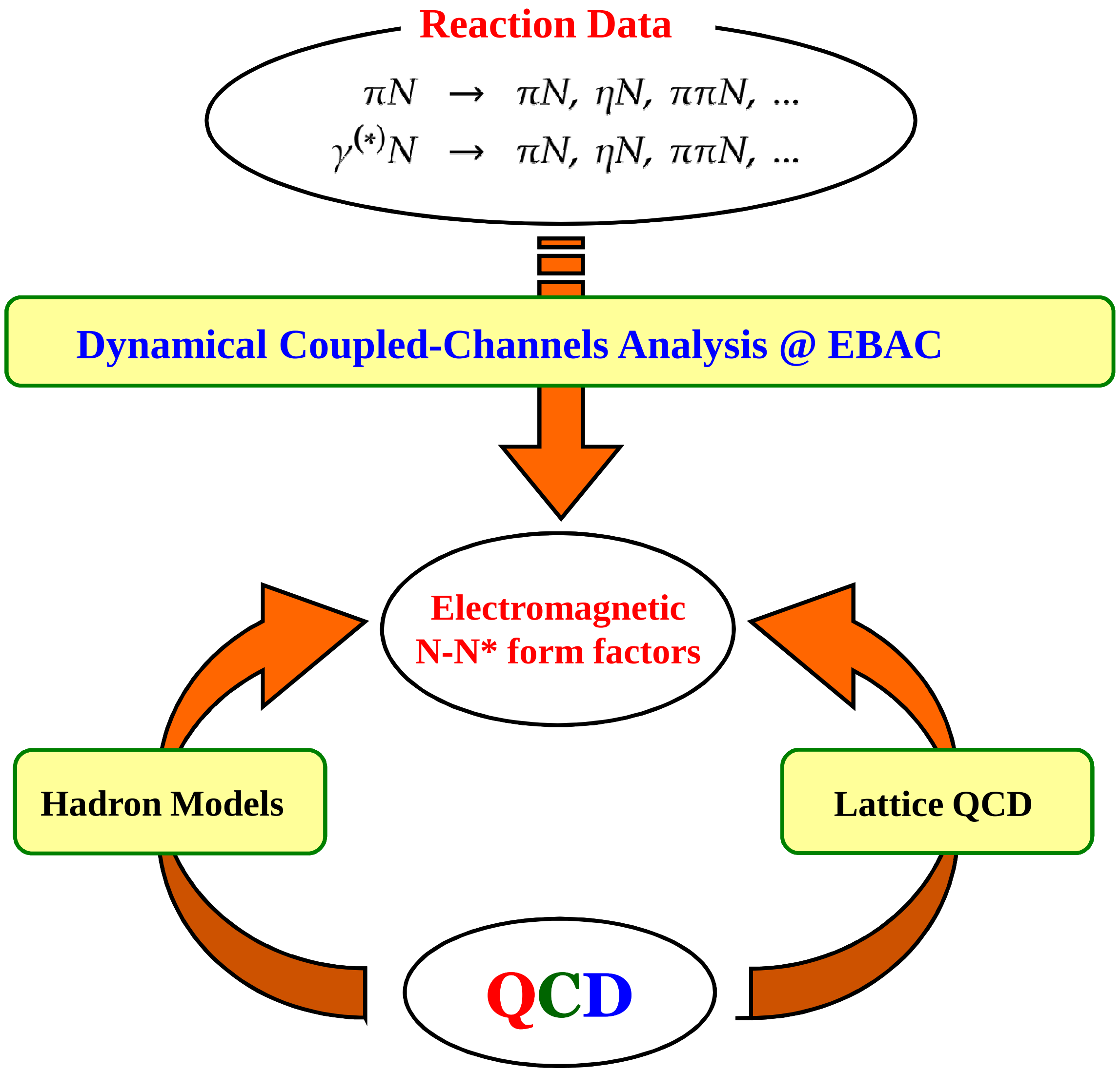
Total cross section $\sigma_{\gamma p \to \omega p}$



Resonance Analysis Tools

- Nucleon resonances are broad and overlapping, careful analyses of angular distributions for differential cross sections and polarization observables are needed.
- Amplitude & multipole analysis (GWU-SAID, MAID)
- Phenomenological analysis procedures have been developed, e.g. unitary isobar models (UIM), dispersion relations (DR), that separate non-resonant and resonant amplitudes in single channels.
- Dynamical coupled channel approaches for single and double pion analysis are being developed within the Excited Baryon Analysis Center (EBAC) effort. They are most important in the extraction of transition form factors for higher mass baryon states.

EBAC strategy (summary)

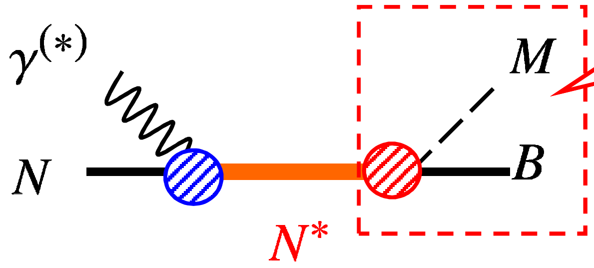


Bruno Juliá Díaz

What is needed for extracting electromagnetic N-N* form factors?

Before analyzing eN → e' πN, e' ππN, … , we need

1. Fixing hadronic parameters



Pure hadronic process;
Determined from
πN → πN, ππN, ηN

2. Good model to describe γN reactions at $Q^2 = 0$.

- ✓ Critical for the model construction
- ✓ Starting point to explore $Q^2 > 0$ region

Determined from
γN → πN, ππN, ηN

Bruno Juliá Díaz

Current status of the analysis @ EBAC

Hadronic part

✓ $\pi N \to \pi N$: fitted to the SAID PWA up to 2 GeV.
Julia-Diaz, Lee, Matsuyama, Sato, **PRC76 065201 (2007)**

✓ $\pi N \to \pi \pi N$: cross sections calculated; not fitted yet.
Kamano, Julia-Diaz, Lee, Matsuyama, Sato, submitted to PRC

✓ $\pi N \to \eta N$: fitted to the data up to 2 GeV (varied only bare $N^* \to \eta N$)
Durand, Julia-Diaz, Lee, Saghai, Sato, **PRC78 025204 (2008)**

Electromagnetic part

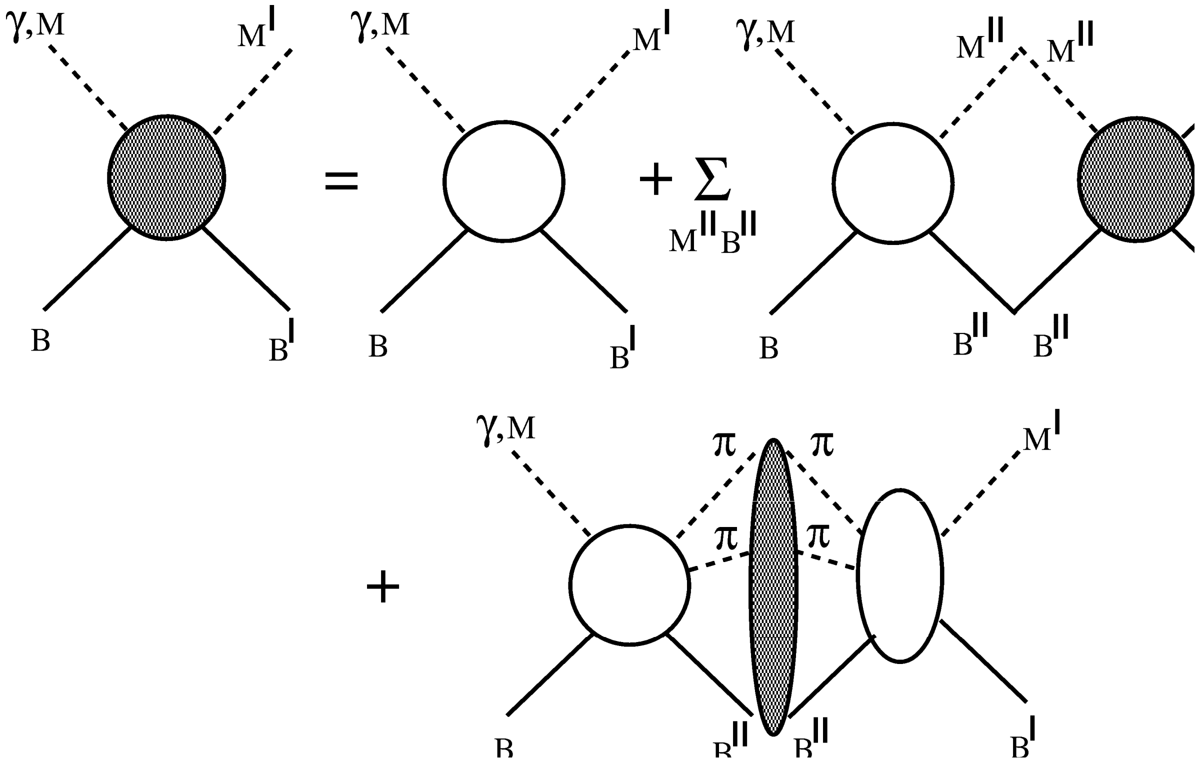
✓ $\gamma N \to \pi N$: fitted to the data up to 1.6 GeV (varied only $\Gamma^{\text{bare}}_{\gamma N \to N^*}$)
Julia-Diaz, Lee, Matsuyama, Sato, Smith, **PRC77 045205 (2008)**

✓ $\gamma^* N \to \pi N$: *in progress* Julia-Diaz, Kamano, Lee, Matsuyama, Sato

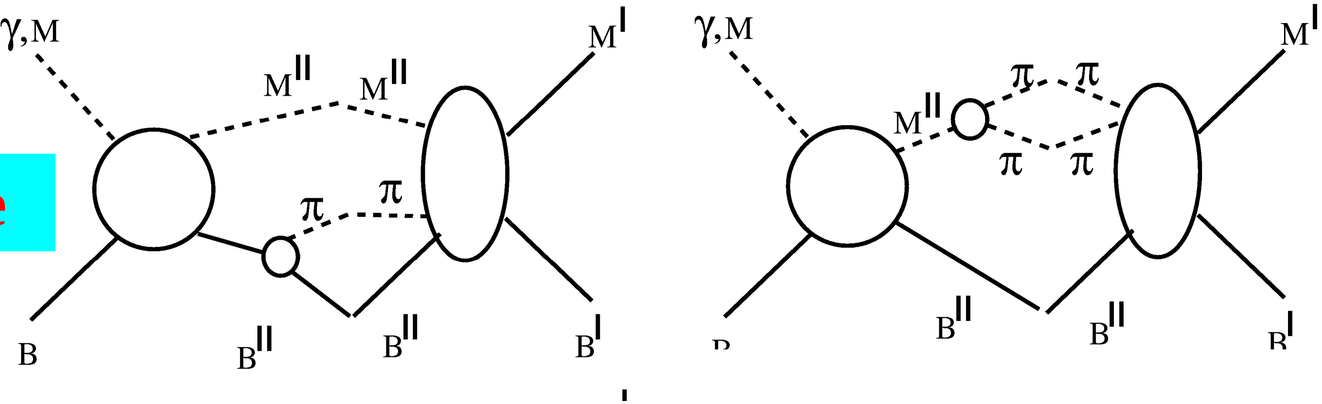
✓ $\gamma N \to \pi \pi N$: *in progress* Julia-Diaz, Kamano, Lee, Matsuyama, Sato

✓ $\gamma N \to \eta N$: *in progress* Durand, Julia-Diaz, Lee, Saghai

Coupled Channel Analysis (EBAC)



- Pion-nucleon and 2-pion-nucleon contributions to the non-resonant T matrix.



T.-S. Harry Lee

Summary-I

- Transition form factors for $P_{33}(1232)$, $P_{11}(1440)$, $D_{13}(1520)$, & $S_{11}(1535)$. measured over large Q^2 range.
  - no sign of approaching asymptotic QCD limit --> need for 12 GeV upgrade
  - pion dressing of vertex needed to describe form factors.

- Roper $P_{11}(1440)$ transition form factor determined for the first time.
  - zero-crossing of magnetic form factor
  - behaves like a Q^3 radial excitation at short distances
  - $Q^2 < 0.7$ GeV^2 determined from the 1π and 2π exclusive channels, as well as from a combined analysis of both these channels, are in a good agreement (also in agreement with MAID – Tiator)

- Able to extract reliable results on N* electrocouplings from meson electroproduction data.
  - the $P_{11}(1440)$ and $D_{13}(1520)$. 1π and 2π channels have completely different nonresonant mechanisms AND ARE IN AGREEMENT!
  - description of all observables in both these channels with common N* electrocouplings good testing ground for efficacy of 2π: JM06, 1π: JLab/GWU-SAID/MAID reaction models.

Summary-II

- Good prospects for relating QCD to the Q^2 evolution of N*s within the framework of Dyson-Schwinger & Bethe-Salpeter approaches and Lattice QCD (with caveat of more powerful computers) as determined through Light Cone wavefunctions.
- Healthy advances in Constituent Quark Models
- Can extract reliable information on N* electrocouplings from combined fit of multiple polarization observables in $N\pi$, $N\pi\pi$, $p\eta$, and KY in electro- and photoproduction needed to resolve ambiguities in baryon resonance analysis.
- EBAC essential to support the baryon resonance program with coupled channel calculations

Take home message

- We have the roadmap (e.g. hCQM, LQCD, DSEs)

- We can extract reliable results on N* electrocoupling from meson electroproduction data as evidenced above.

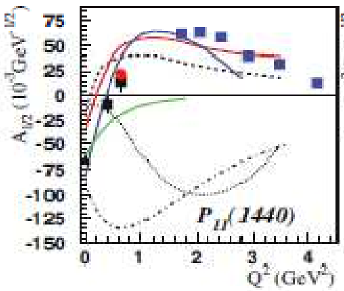
- We need transition form factors at for N* the helicity amplitude data in the Q^2 region of 5.0 to 10 GeV^2.

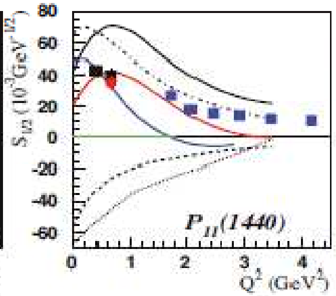
- 12-GeV upgrade imperative to access higher Q^2. This will give access to the transition Form Factors to QCD by probing the regime, which free from meson-baryon dressing effects.

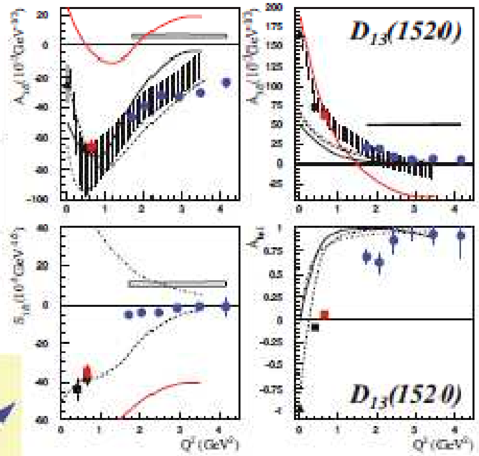
Need Data **Experiments to be Proposed.**

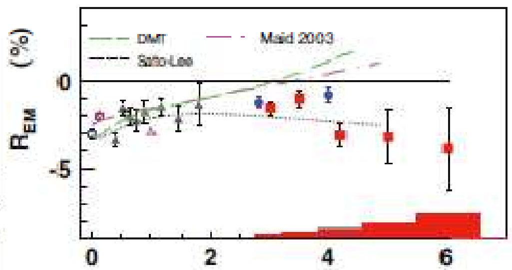
- o N→ N* Transition Form Factors with CLAS at 11 GeV (Gothe, Mokeev, Burkert, Joo, Stoler, Cole)
- o Others?

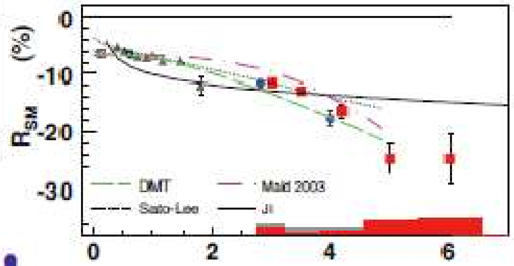
Conclusion: Do Exclusive Electron Scattering

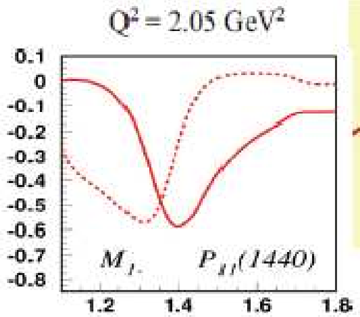


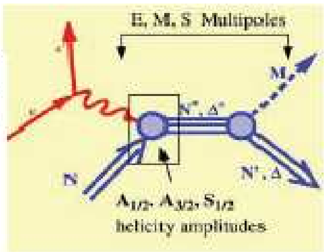






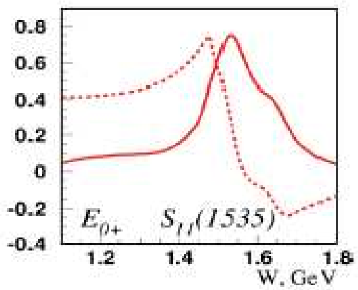


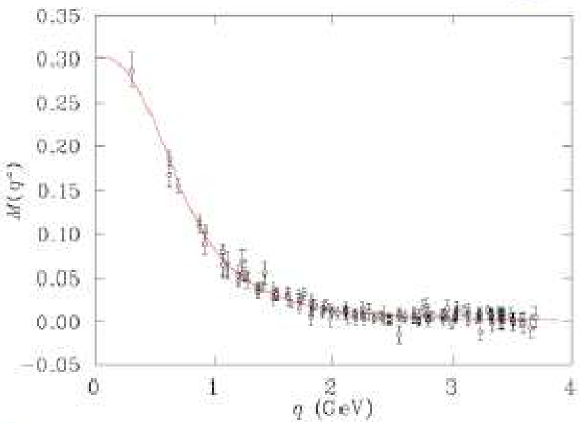


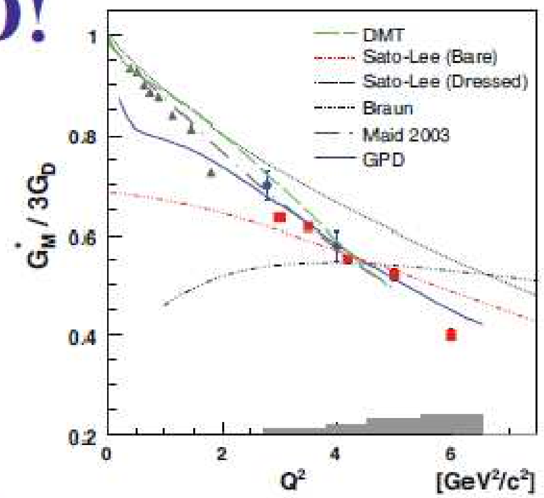


... to

Learn QCD!







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Workshop on the Physics of Excited Nucleon – NSTAR2009, Beijing April 19 – 22, 2009 .

Workshop on the Physics of Excited Nucleon – **NSTAR2009** is to be hosted by the **Institute of High Energy Physics (IHEP)** of Chinese Academy of Sciences (CAS) in **Beijing** on **April 19 – 22, 2009** .

NSTAR is a series held previously in Florida State University (1994), Jefferson Lab (1995), INT in Seattle (1996), George Washington University (1997), ECT* in Trento (1998), Jefferson Lab (2000), Mainz (2001), Pittsburg (2002), LPSC in Grenoble (2004), Florida State University (2005), and University of Bonn (2007).

Scientific Aim:

The study of nucleons and their resonances has provided a rich source of information on strong interaction physics in the non-perturbative QCD regime, and also raised fundamental questions with profound significance for our understanding of Nature.