Bare and Dressed Nucleon Resonance Couplings

(In connection with CQM)

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- Introduction
- The hypercentral Constituent Quark Model
- Results for the longitudinal and transverse helicity amplitudes
- Bare vs dressed resonance couplings
- How to introduce dressing
- Conclusions

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and Interpretation of baryon Resonances
ECT* June 1-5, 2009

Introduction

- the separation between bare and dressed quantities is meaningful within a definite theoretical approach:
  - T-matrix
  - Effective lagrangians
  - Field theory
  - CQM
  - …….
- the various definitions in general do not coincide
- experiments measure dressed quantities
- any theory attempts to describe dressed quantities (even in connection with the related bare objects)

What about CQMs?

Constituent Quark Model calculations

- the aim is the description of observables (dressed quantities), not a fit

  with success: spectrum, magnetic moments,from factors,…
- CQs are effective degrees of freedom

  they have a mass, in some approaches even a form factor

  some dressing is **implicitly** taken into account
- something similar may occur in the spectrum

  e.g. the consistent inclusion of quark loops effects in the meson description does not alter the form of the qqbar potential but renormalizes the string constant (Geiger-Isgur)
- a similar work for baryon states is in progress (Bijker-Santopinto)
- a consistent and systematic CQM approach may be helpful in order to put in evidence explicit dressing effects

→ hypercentral CQM

The hypercentral Constituent Quark Model
hCQM

The description of the spectrum is the first task of a model builder:
it serves to determine a **quark interaction** to be used for the description of other physical quantitites

Since long time it is known (De Rújula, Georgi, Glashow, 1975) that the quark interaction contains

- a long range spin-independent confinement

SU(6) invariant

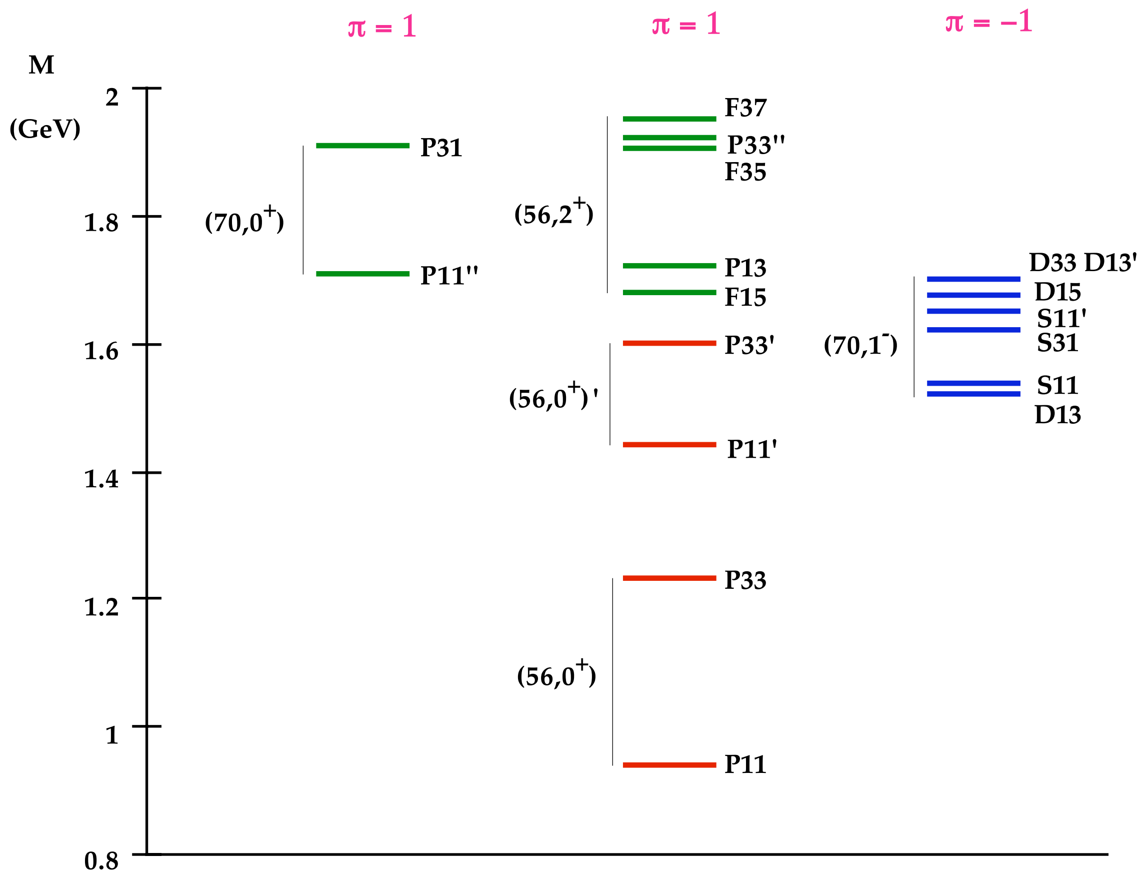
3q states are given by SU(6) configurations

- a short range spin dependent term

SU(6) violation

(it can be obtained also by flavour dependent interactions)

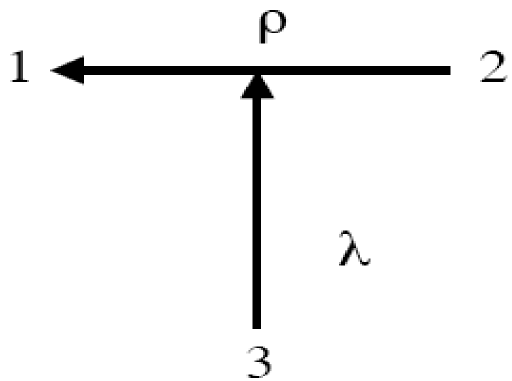
PDG 4* & 3*



π = 1
π = 1
π = −1
M
(GeV)
2
1.8
1.6
1.4
1.2
1
0.8
P31
(70,0+)
P11''
F37
P33''
F35
(56,2+)
P13
F15
P33'
(56,0+)'
P11'
P33
(56,0+)
P11
D33 D13'
D15
S11'
S31
(70,1-)
S11
D13

hCQM

Jacobi coordinates



$$\rho = \frac{r_1 - r_2}{\sqrt{2}}$$

$$\lambda = \frac{r_1 + r_2 - 2 r_3}{\sqrt{6}}$$

Hyperspherical Coordinates: $(\rho, \Omega_\rho, \lambda, \Omega_\lambda) \Rightarrow (x, t, \Omega_\rho, \Omega_\lambda)$

$x = \sqrt{\rho^2 + \lambda^2}$ hyperradius $(size)$

$t = arctg\frac{\rho}{\lambda}$ hyperangle $(form)$

Hypercentral Hypothesis

$$V = V(x)$$

- Factorization

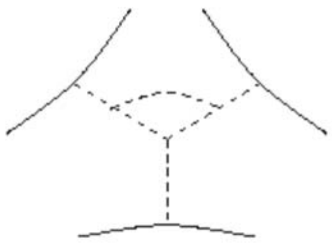
$$\psi(x, t, \Omega_\rho, \Omega_\lambda) = \quad \psi_{\nu\gamma}(x) \qquad Y_{[\gamma, l_\rho, l_\lambda]}$$

("dynamics") ("geometry")

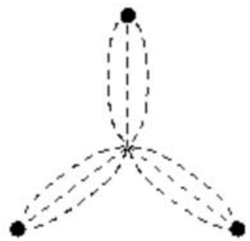
ν hyperradial excitation $\quad \gamma$ grand angular quantum number

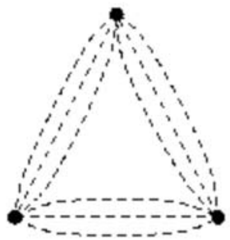
Motivations

- QCD fundamental mechanism



- Flux tube model





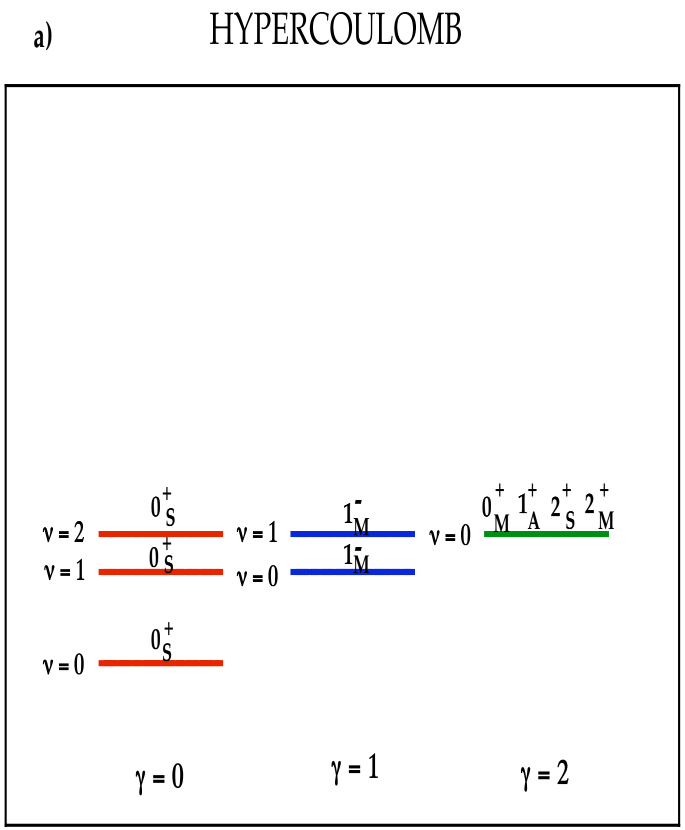
- Hypercentral approximation

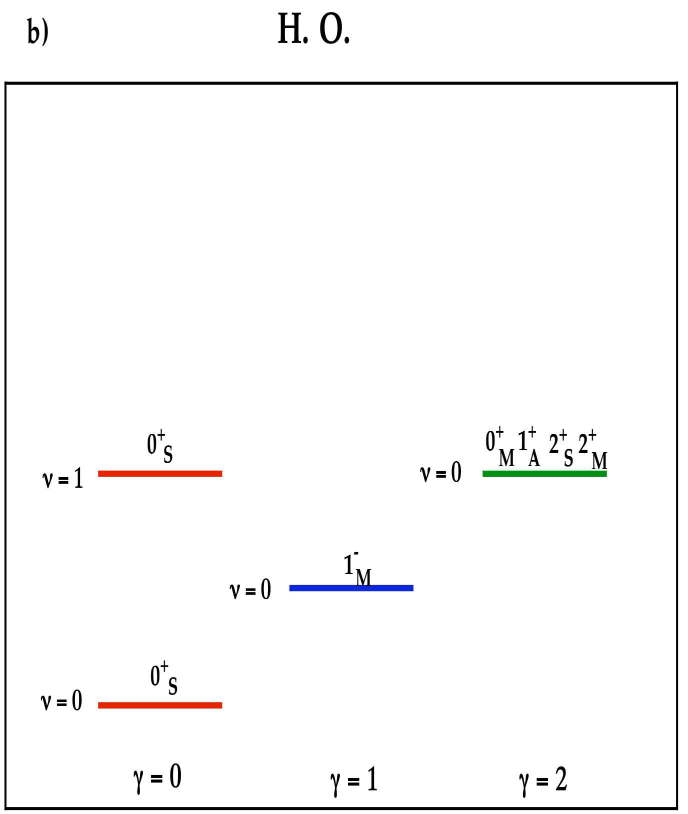
$$\sum_{i<j} V(\mathbf{r}_{ij}) \approx V(x) + \dots$$

Two analytical solutions

hyperCoulomb $- \tau/x$

h. o. $\Sigma_{i<j} 1/2\, k\, (r_i - r_j)^2 = 3/2\ k\, x^2$





Hypercentral Model (1)

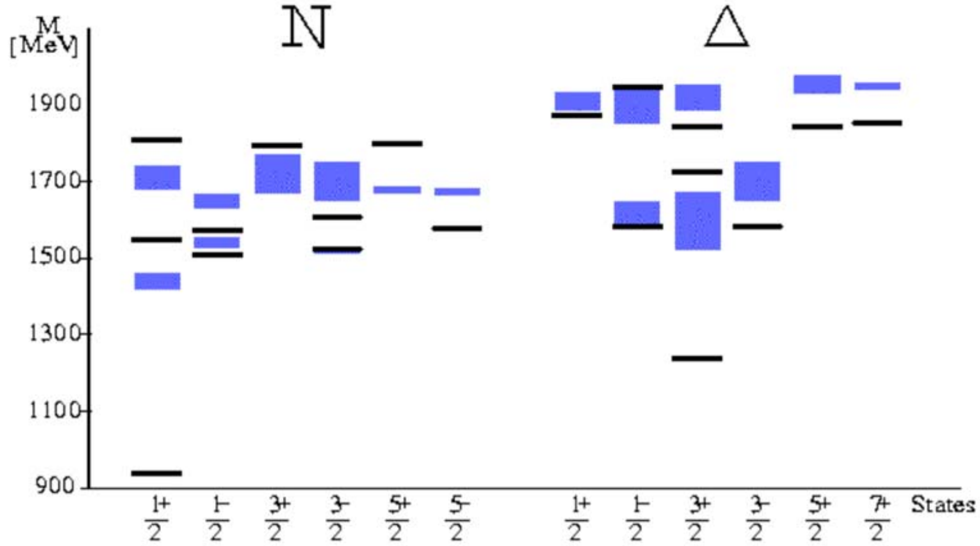
$$H_{3q} = 3m + \sum_{i=1}^{3} \frac{\mathbf{p}_i^2}{2m} + V(x) + H_{hyp}$$

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

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

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

hyperradius

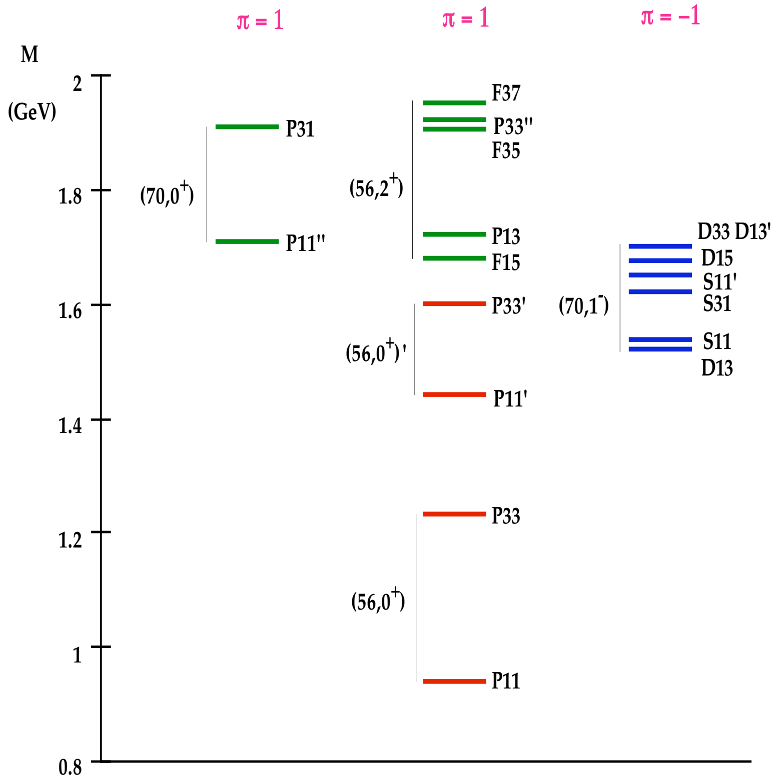


$\tau = 4.59$

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

$A \Leftarrow (N - \Delta)$

PDG 4* & 3*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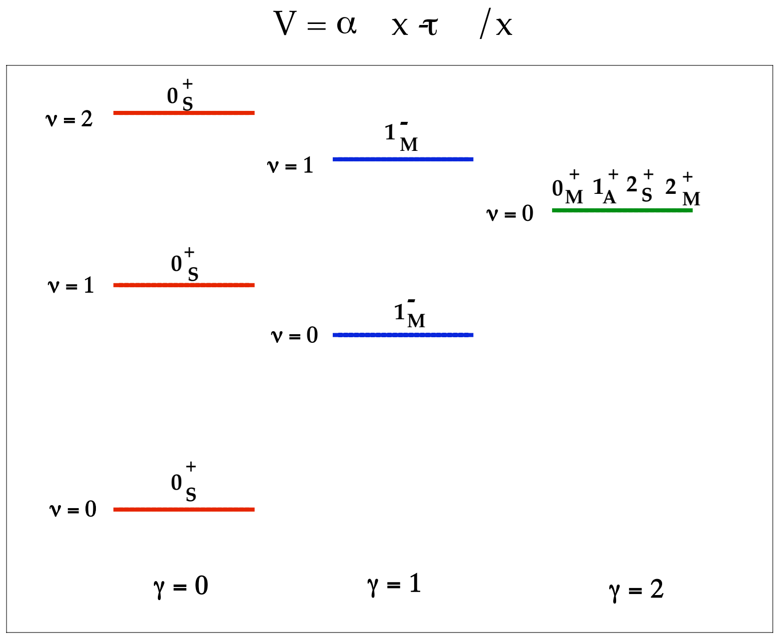
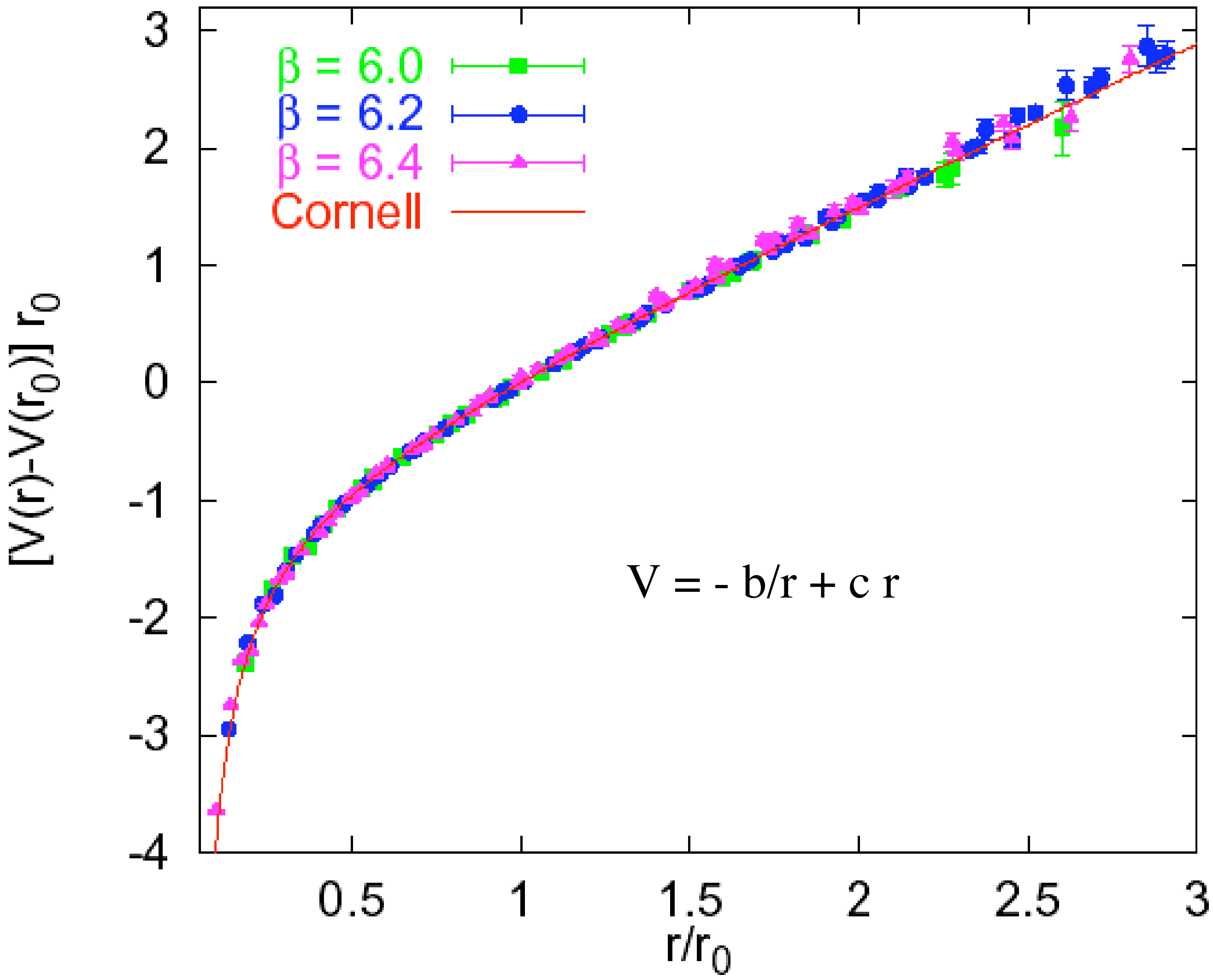
P13
F15
(56,0+)'
P33'
P11'
(56,0+)
P33
P11
(70,1-)
D33 D13'
D15
S11'
S31
S11
D13


V = α x -τ / x
ν = 2
0+S
ν = 1
0+S
ν = 0
0+S
ν = 1
1-M
ν = 0
1-M
ν = 0
0+M 1+A 2+S 2+M
γ = 0
γ = 1
γ = 2

Quark-antiquark lattice potential G.S. Bali Phys. Rep. 343, 1 (2001)



hCQM & Electromagnetic properties

- Photocouplings
- Helicity amplitudes (transition f.f.)
- Elastic form factors of the nucleon
- Structure functions

Fixed parameters $\longrightarrow$ predictions

HELICITY AMPLITUDES

Definition

$A_{1/2} = < N^* \; J_z = 1/2 \mid H^T_{em} \mid N \; J_z = -1/2 > * \zeta$ §

$A_{3/2} = < N^* \; J_z = 3/2 \mid H^T_{em} \mid N \; J_z = 1/2 > * \zeta$ §

$S_{1/2} = < N^* \; J_z = 1/2 \mid H^L_{em} \mid N \; J_z = 1/2 > * \zeta$

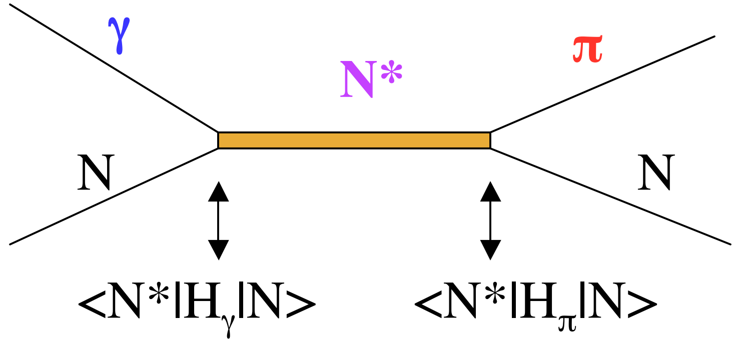
N, N^* nucleon and resonance as 3q states

H^T_{em} H^l_{em} model transition operator

ζ overall sign -> problem

§ **results for the negative parity resonances: M. Aiello et al. J. Phys. G24, 753 (1998)**

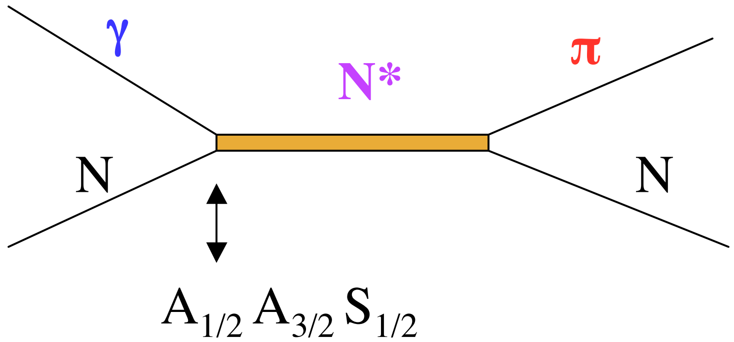
Photoproduction amplitude



Theory:
states are defined up to a phase factor

$N \to N e^{i\phi} \quad N^* \to N^* e^{i\phi^*}$

the overall sign is left unchanged

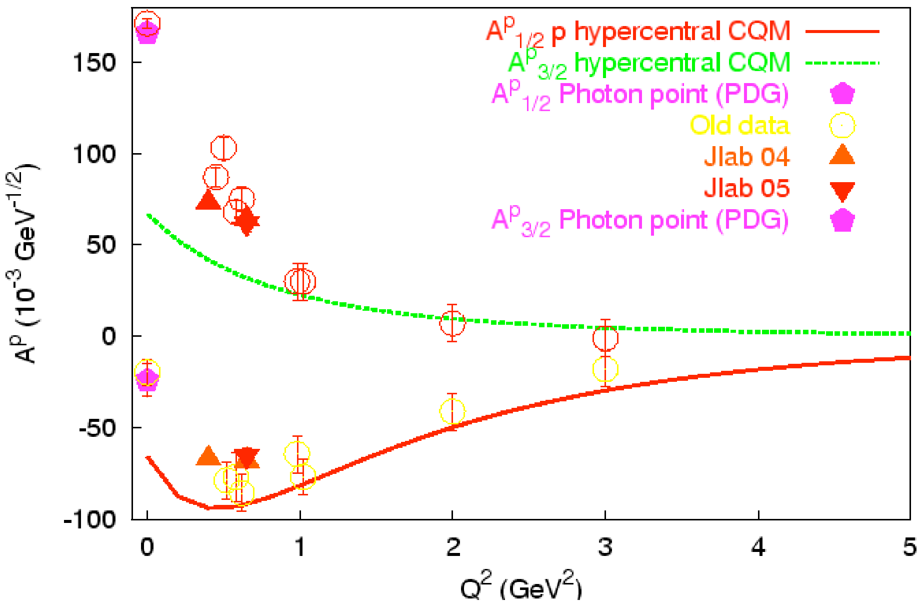


Phenomenology:
Overall sign relative to Born amplitude

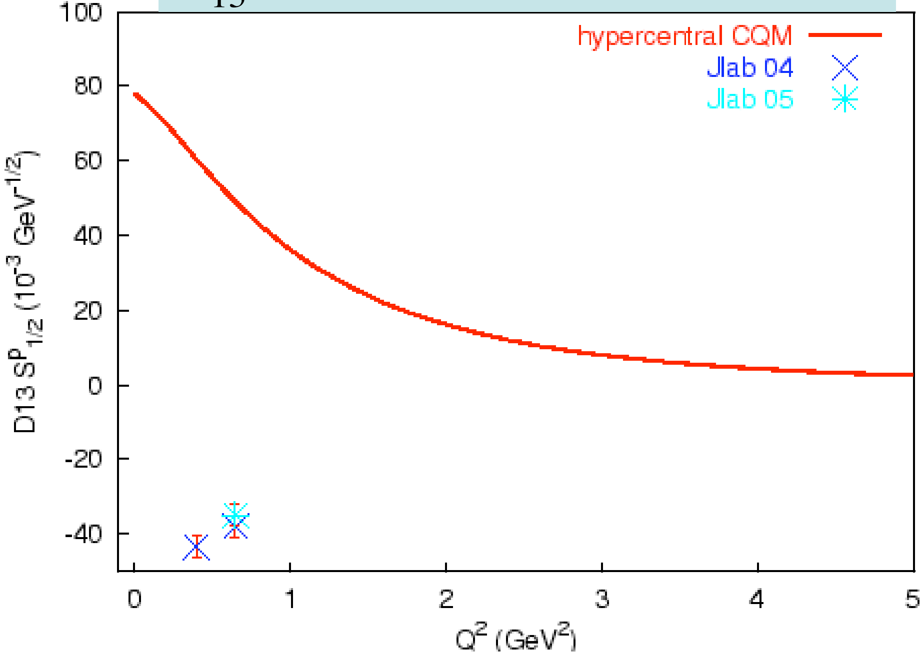
In order to extract the helicity amplitudes the sign of the strong vertex is used

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

D 13 transverse helicity amplitudes (proton)

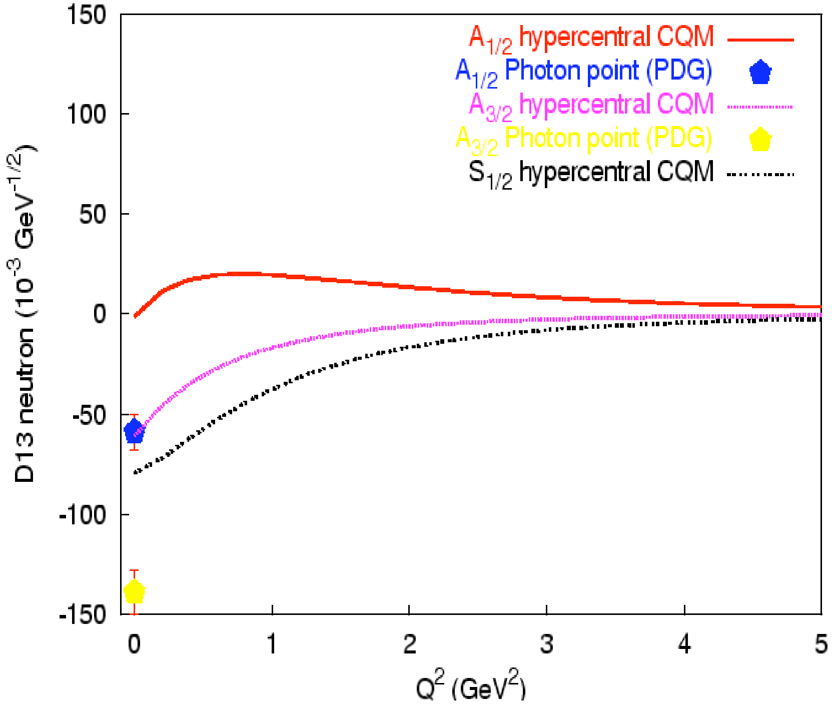


D 13 longitudinal helicity amplitudes (proton)



D_{13}

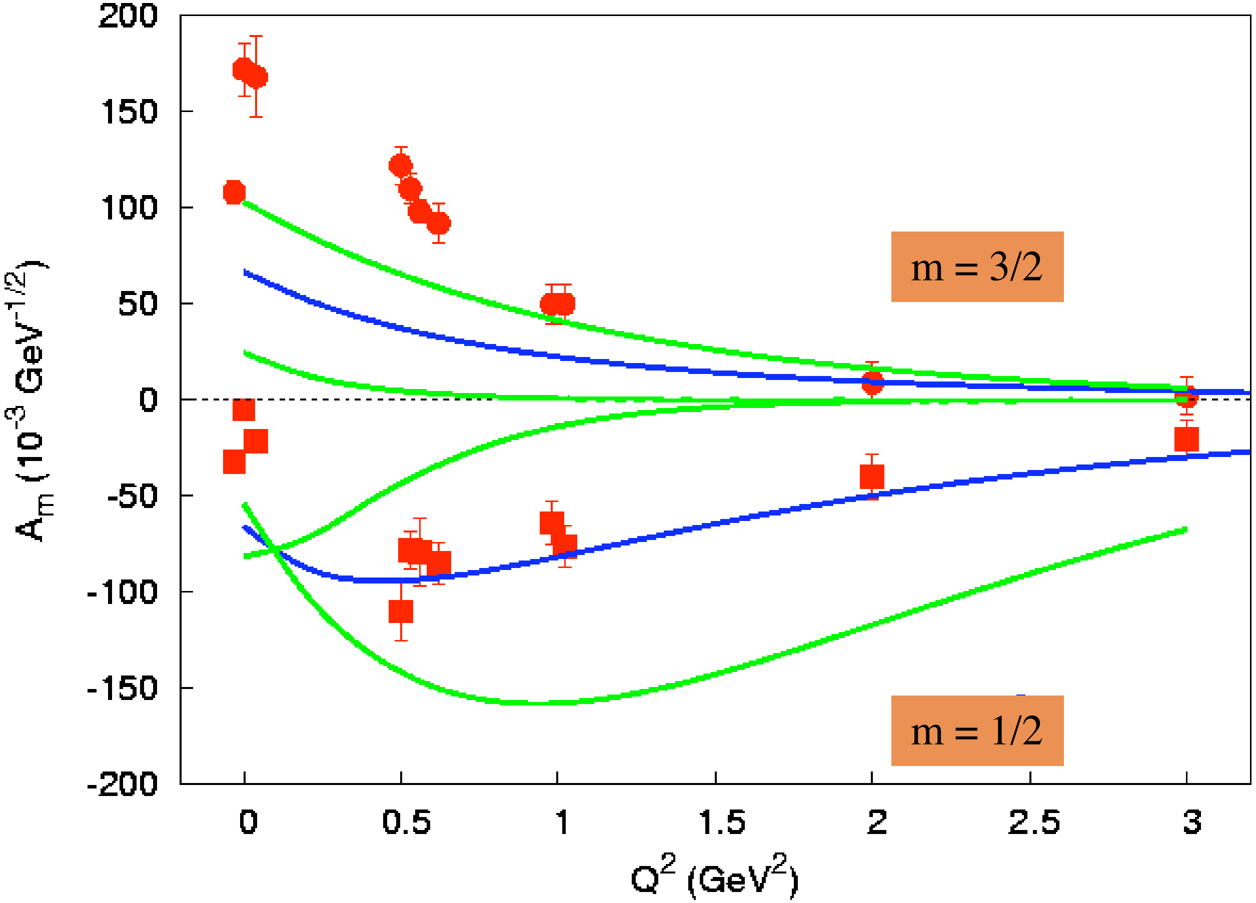
D 13 helicity amplitudes (neutron)



A^p_m $N(1520)D13$

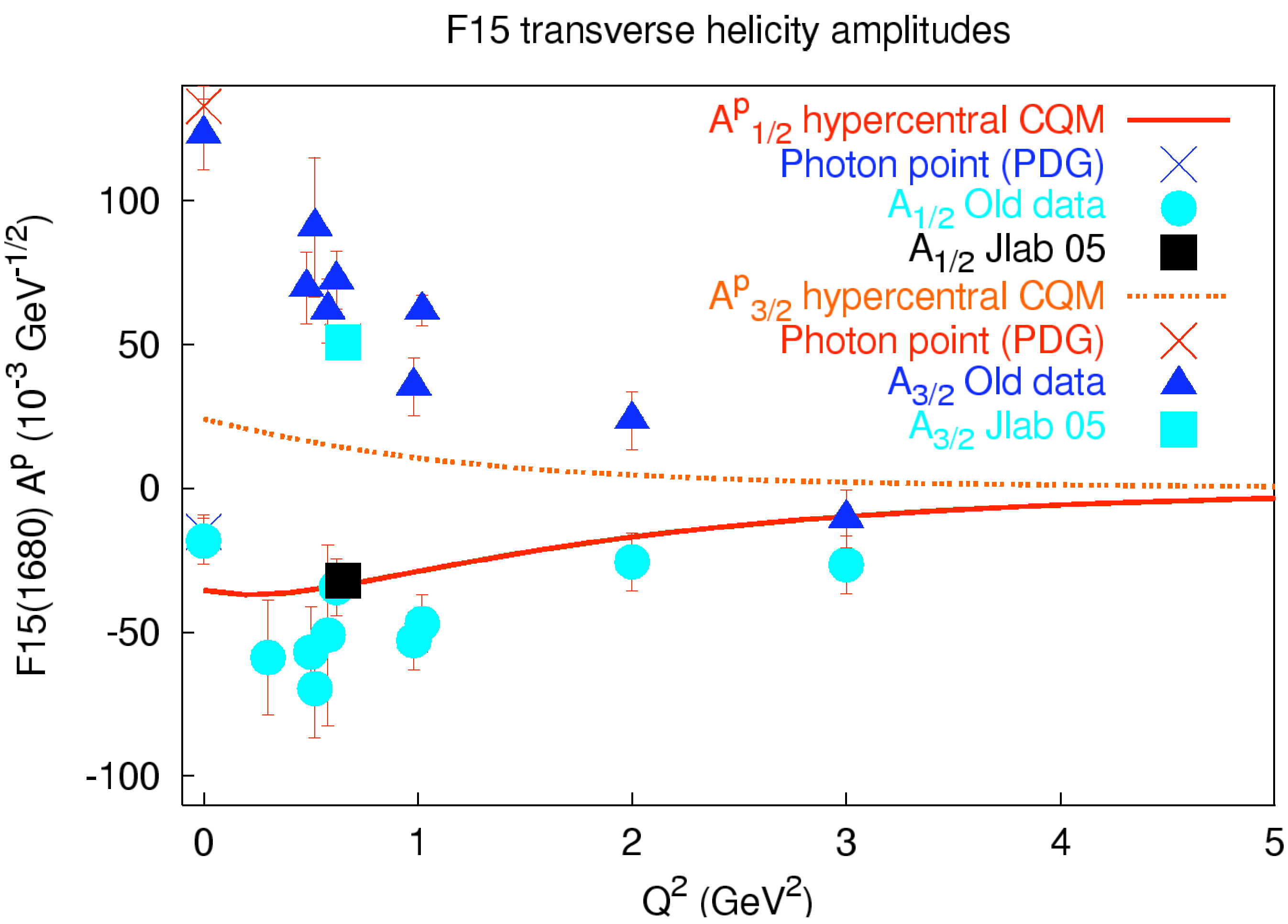
r_p 0.5 fm

r_p 0.86 fm



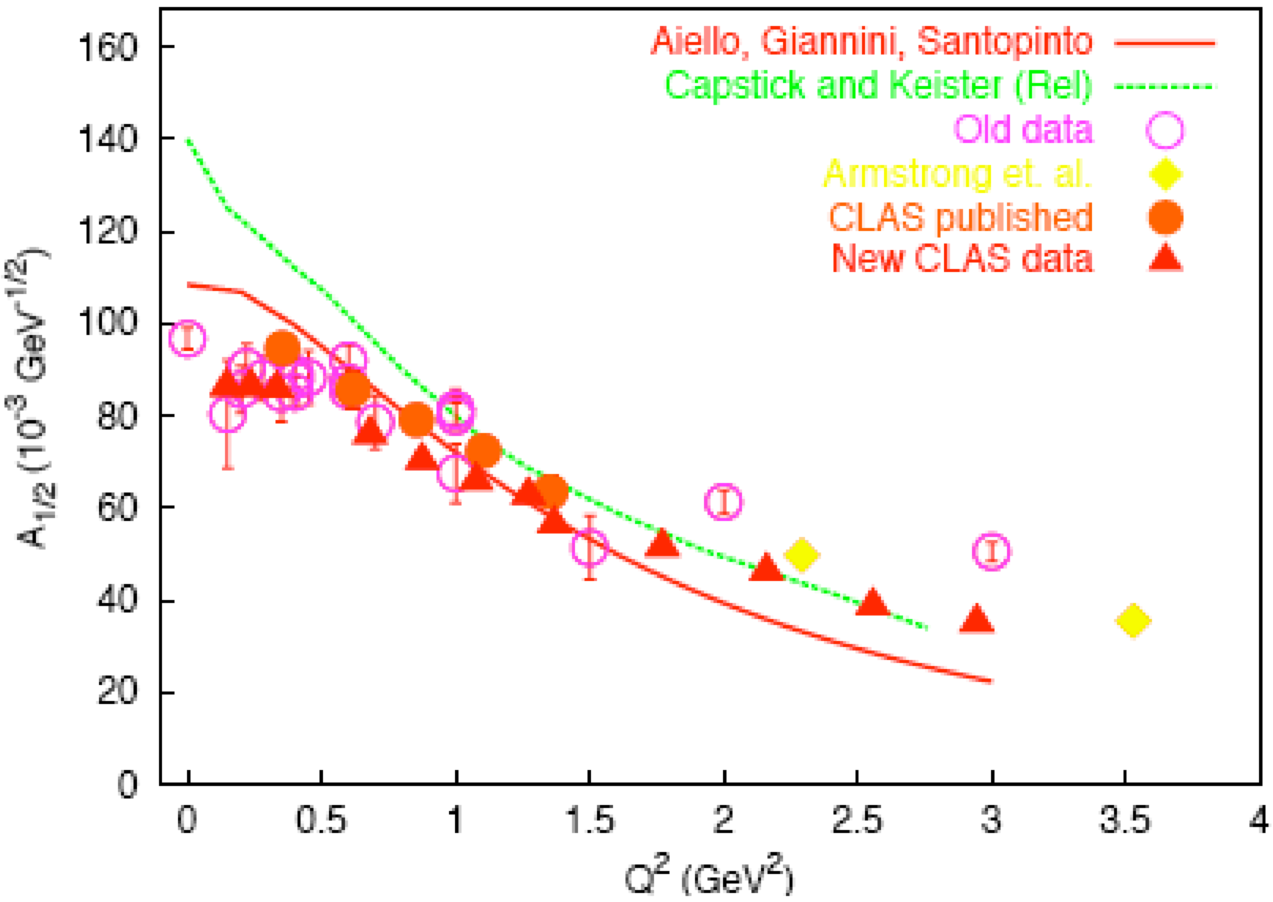
Green curves H.O.

Blue curves hCQM



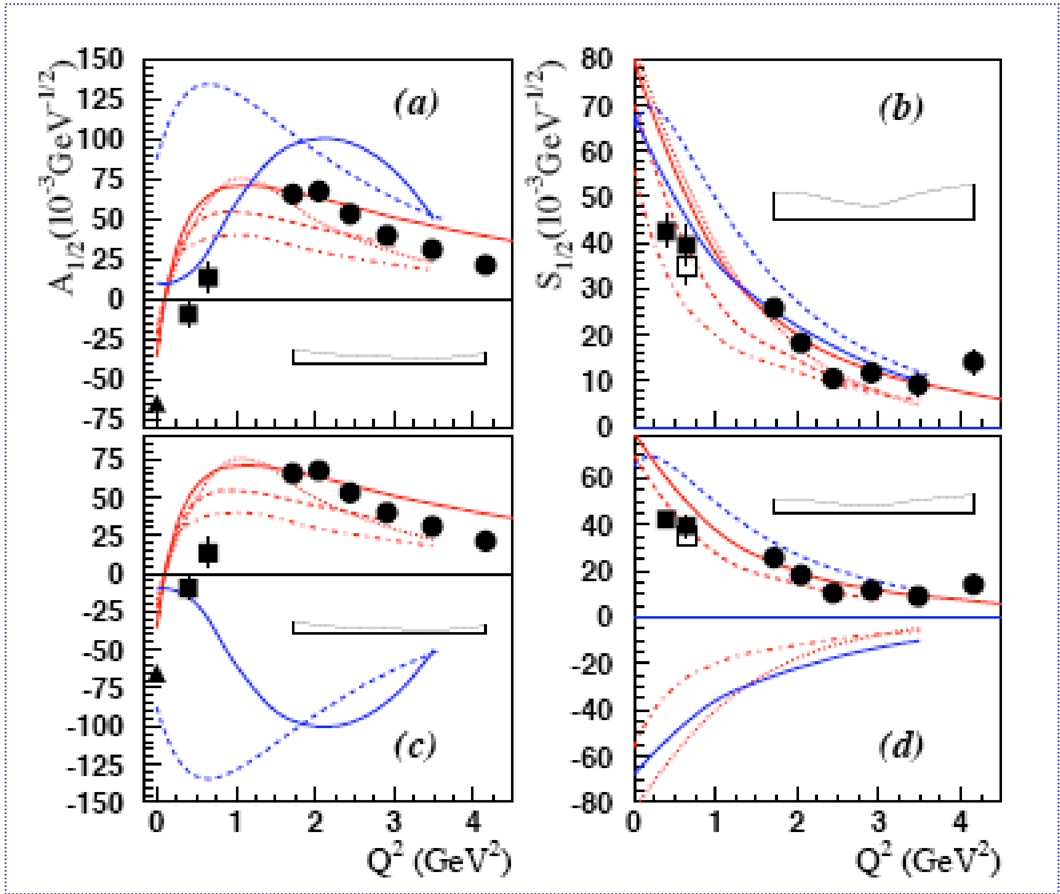
F15 transverse helicity amplitudes
A^p_1/2 hypercentral CQM
Photon point (PDG)
A_1/2 Old data
A_1/2 Jlab 05
A^p_3/2 hypercentral CQM
Photon point (PDG)
A_3/2 Old data
A_3/2 Jlab 05
F15(1680) A^p (10^-3 GeV^-1/2)
Q^2 (GeV^2)
100
50
0
-50
-100
0
1
2
3
4
5

S11(1535)



Aiello, Giannini, Santopinto
Capstick and Keister (Rel)
Old data
Armstrong et. al.
CLAS published
New CLAS data
$A_{1/2}$ (10^{-3} GeV$^{-1/2}$)
Q^2 (GeV^2)
0
20
40
60
80
100
120
140
160
0
0.5
1
1.5
2
2.5
3
3.5
4

Aznauryan, Burkert, Lee, nucl-th 0810-0997v2: discussion of signs



$$\frac{S_{1/2}}{A_{1/2}} > 0$$

hCQM

Analytical check

Blue NR (**dash** hCQM; **full** Warns et al.)

Red Rel (**dash** Capstick-Keister; **full** Aznauryan **dot** Weber; **dash-dot** Pace et al.)

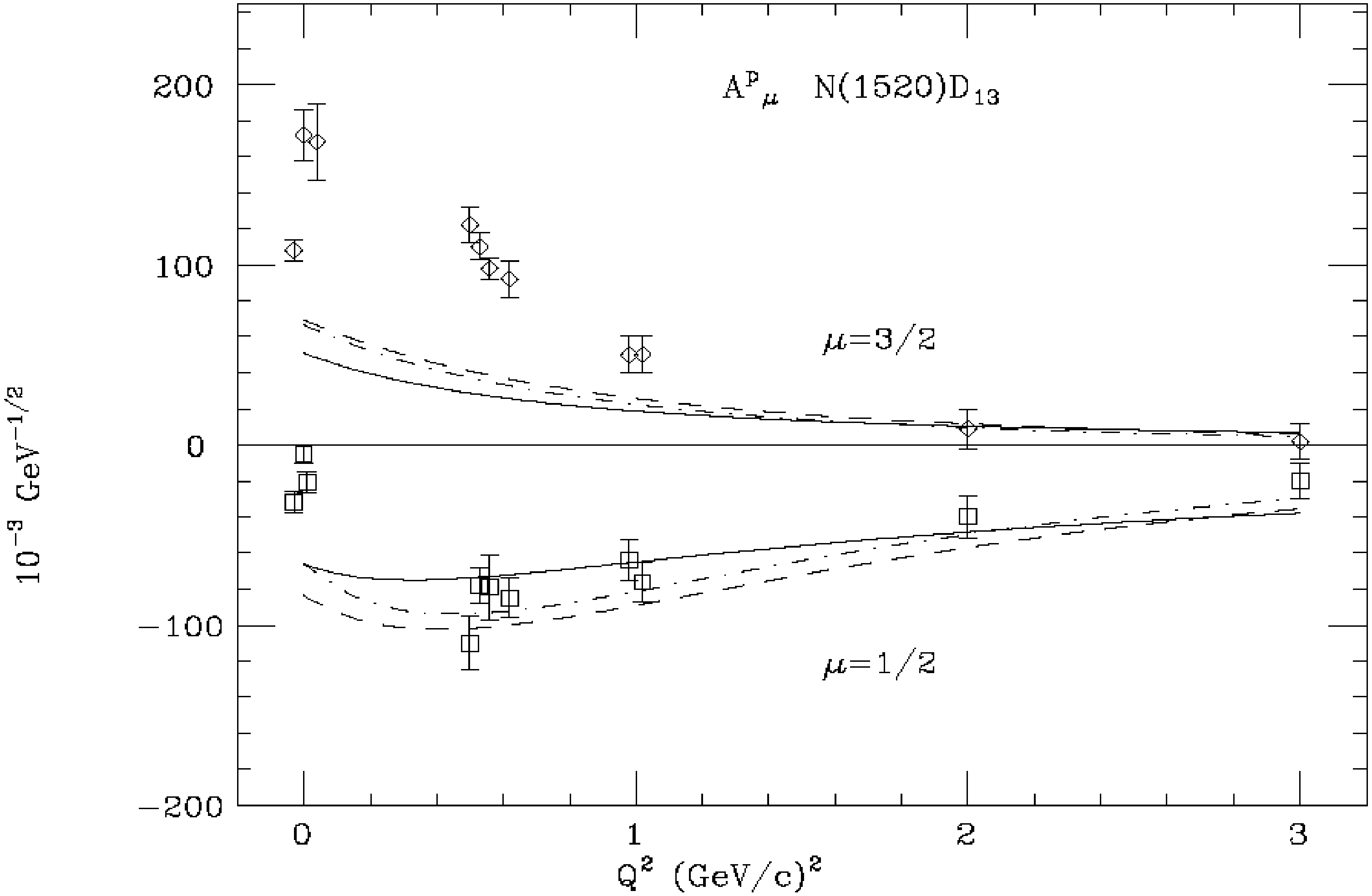
Relativistic corrections to form factors

- Breit frame
- Lorentz boosts applied to the initial and final state
- Expansion of current matrix elements up to first order in quark momentum
- Results

$$A_{rel}(Q^2) = F \; A_{n.rel}(Q^2_{eff})$$

F = kin factor $\qquad Q^2_{eff} = Q^2 \, (M_N/E_N)^2$

De Sanctis et al. EPJ 1998



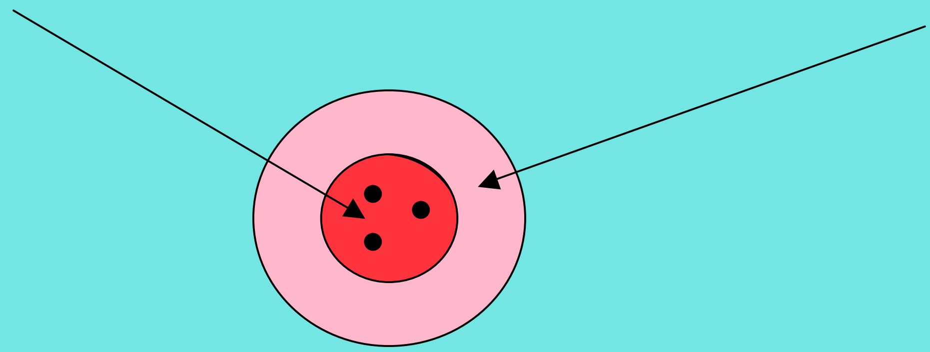
Full curves: hCQM with relativistic corrections
Dashed curves: hCQM in different frames

observations

- 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 (1/x potential)
- there is lack of strength at low Q^2 (outer region) in the e.m. transitions

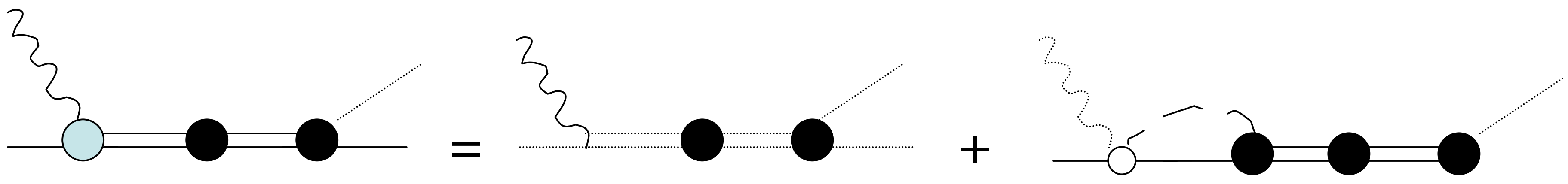
  specially for the A 3/2 amplitudes
- emerging picture: quark core (0.5 fm) plus (meson or sea-quark) cloud



"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."

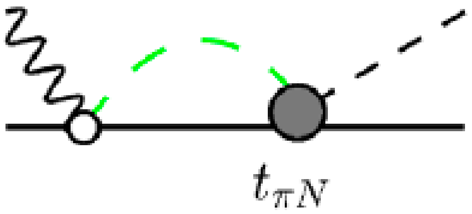
M. Aiello, M. Ferraris, M.M.G, M. Pizzo, E. Santopinto, Phys.Lett.B387, 215 (1996).

Explicit evaluation of the meson cloud contribution to the excitation of the nucleon resonances (Mainz Group and coworkers)



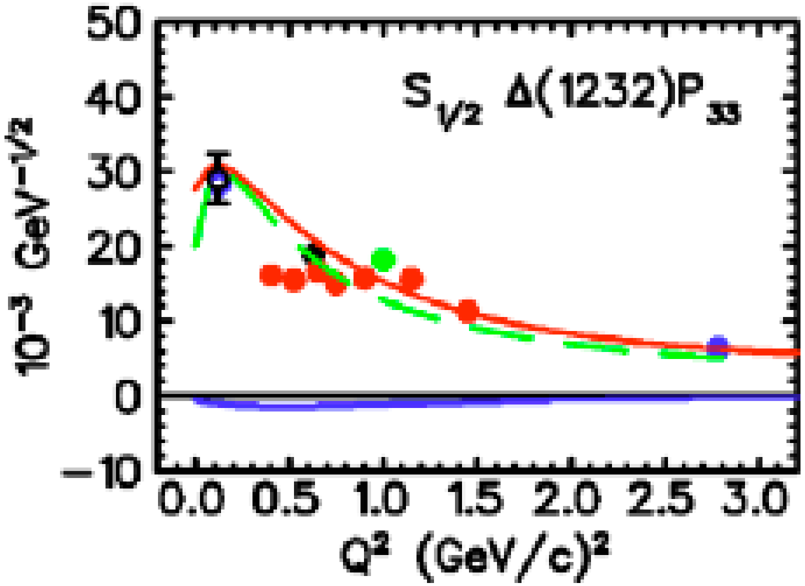
$$\tilde{t}^{R}_{\gamma\pi} = t^{R}_{\gamma\pi} + v^{B}_{\gamma\pi}\,\tilde{t}^{R}_{\pi\pi}$$

pion cloud contribution



is included in phenomenlogical approach

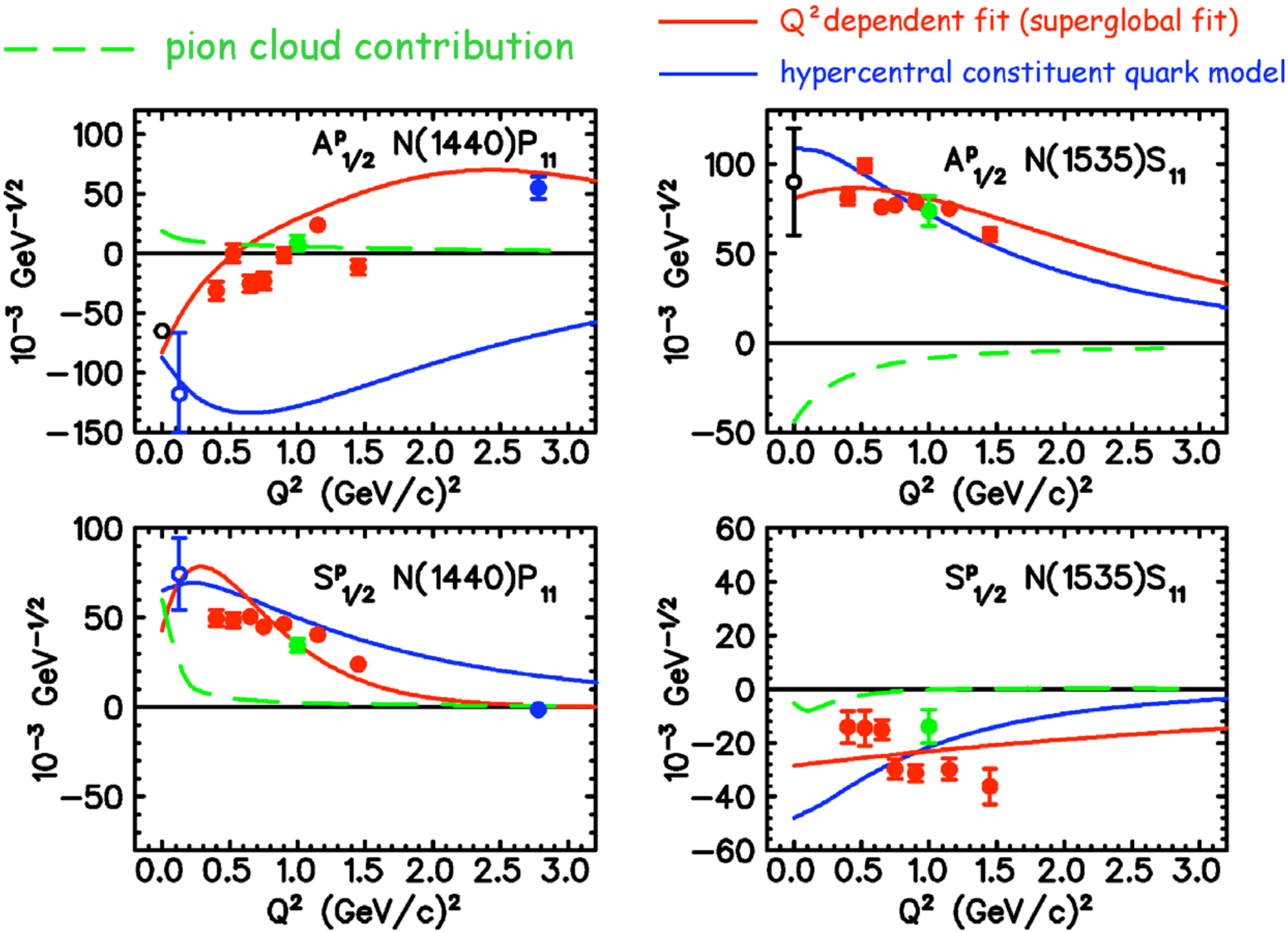
but not in the constituent quark model



Q^2 dependent fit (superglobal fit)

hypercentral constituent quark model

GE-MZ coll., EPJA 2004 (Trieste 2003)



GE-MZ coll., EPJA 2004 (Trieste 2003)

High Q^2 behaviour

- Helicity ratio

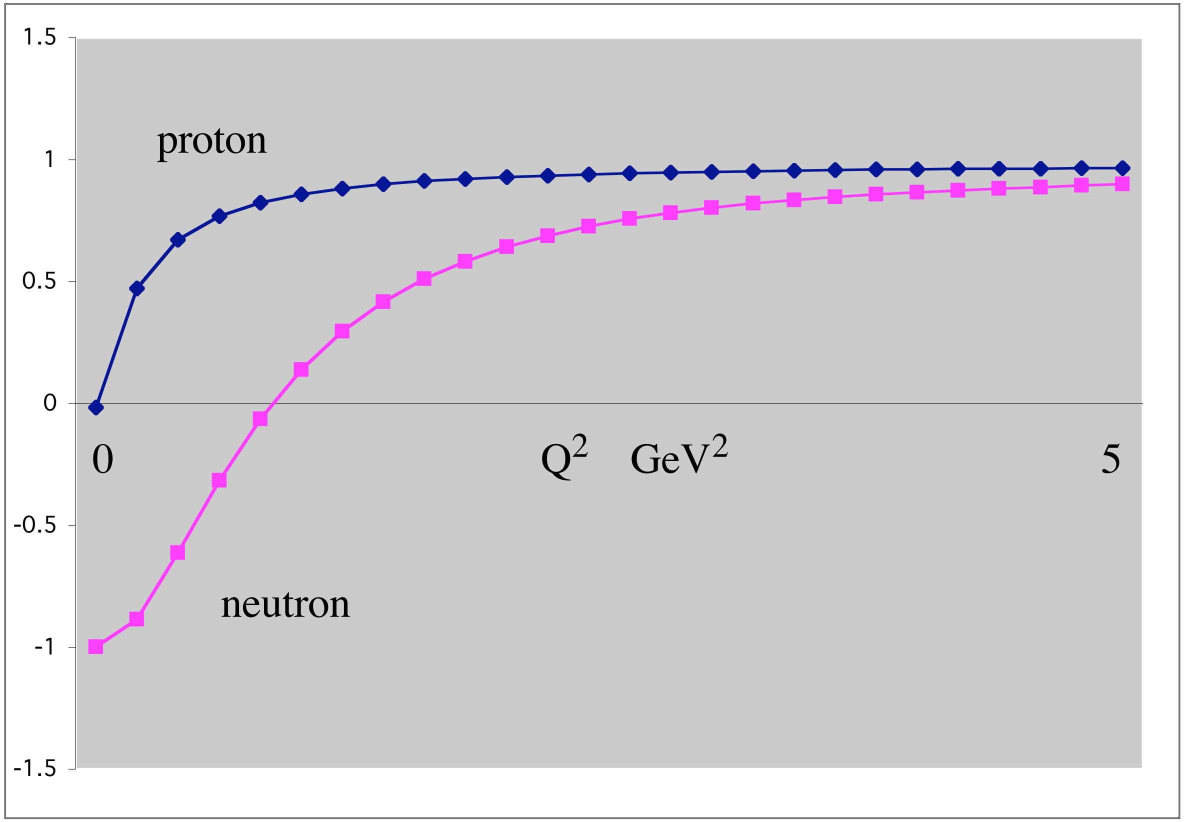
$$\frac{|A_{1/2}|^2 - |A_{3/2}|^2}{|A_{1/2}|^2 + |A_{3/2}|^2}$$

goes to 1 for increasing Q^2

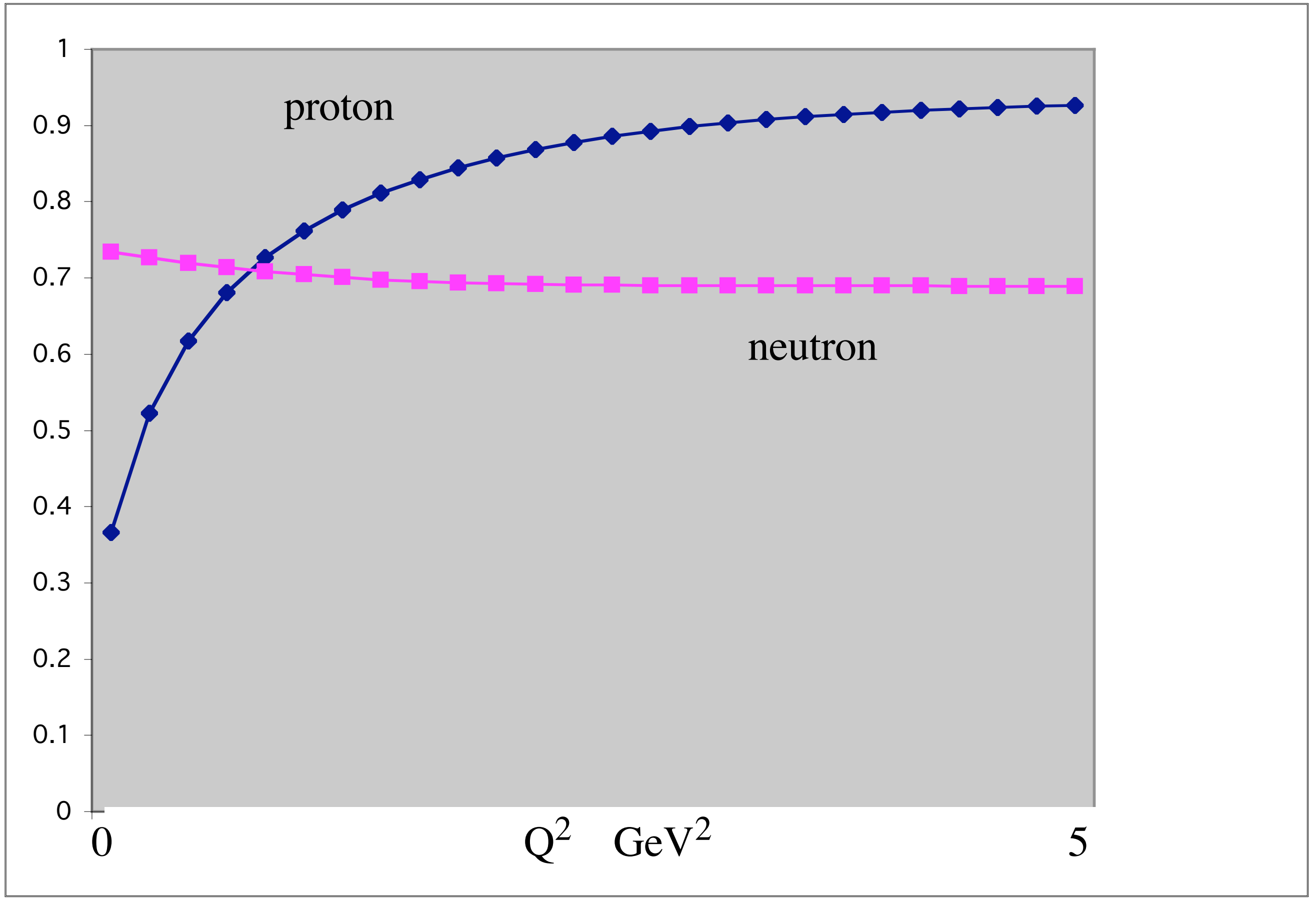
(helicity conservation, Carlson 1986)

Helicity ratio D13

hCQM predictions



Helicity ratio F15
hCQM predictions



Helicity ratio (hCQM predictions)

	proton	neutron
P33	≈ -0.5	
D13	ok	ok
F15	ok	≈ 0.7
D13*	ok	ok
D33	ok	
D15	1/3	≈ 0.32
F35	-0.82	
F37	-0.32	
P13	ok	ok

P33:
Spin-isospin flip
of ground state
Relativity?

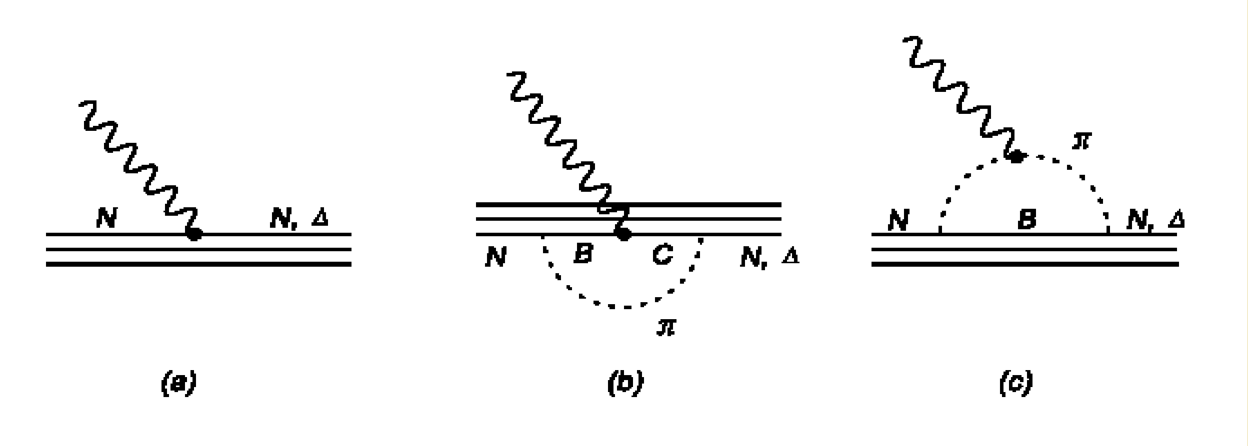
Isospin dependence?

Structure
effects ?

How to introduce dressing

hadronic approach: mesons and baryons (nucleon + resonances)
(equations for amplitudes, coupled channel calculations, lagrangians, …..

hybrid models



at the quark level

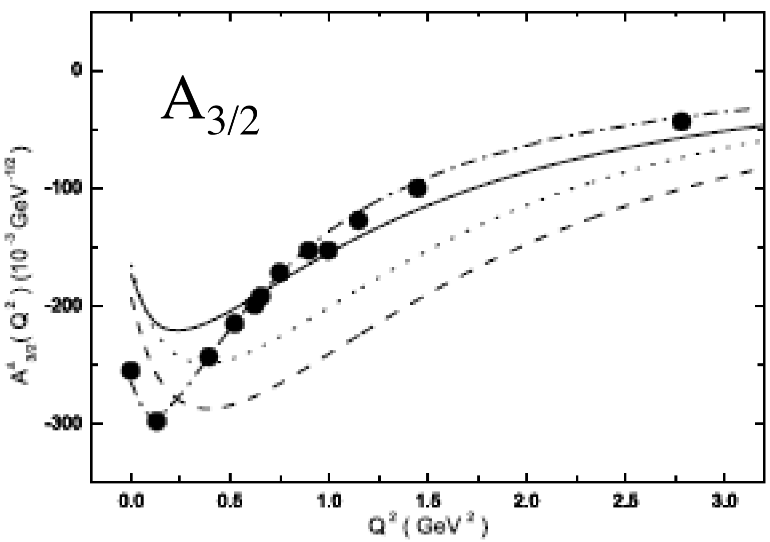
inclusion of higher Fock components in the baryon state

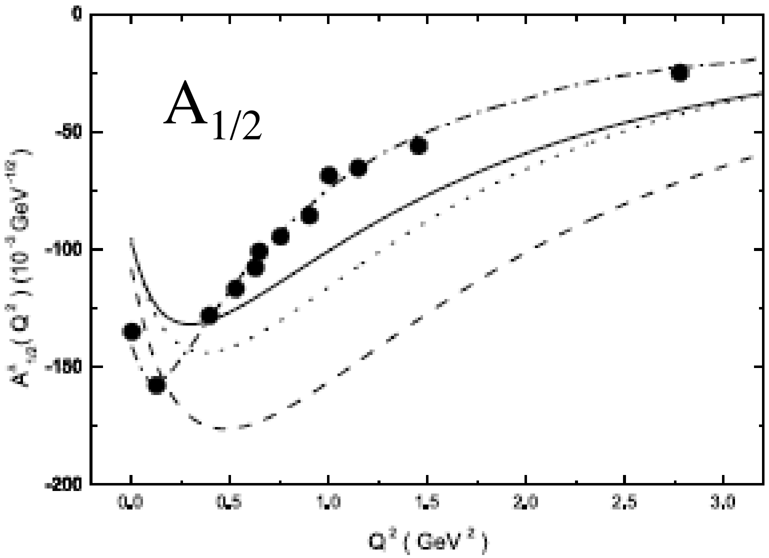
$$|\Psi\rangle = \Psi_{3q} |qqq\rangle + \Psi_{3q\,q\bar{q}} |3q\,q\bar{q}\rangle$$

unquenching the quark model

Geiger-Isgur
Capstick, BRAG 2007
Santopinto-Bijker, Nstar2007, Pisa 2007,…..

Chen, Dong, M.G., Santopinto, Trieste 2006

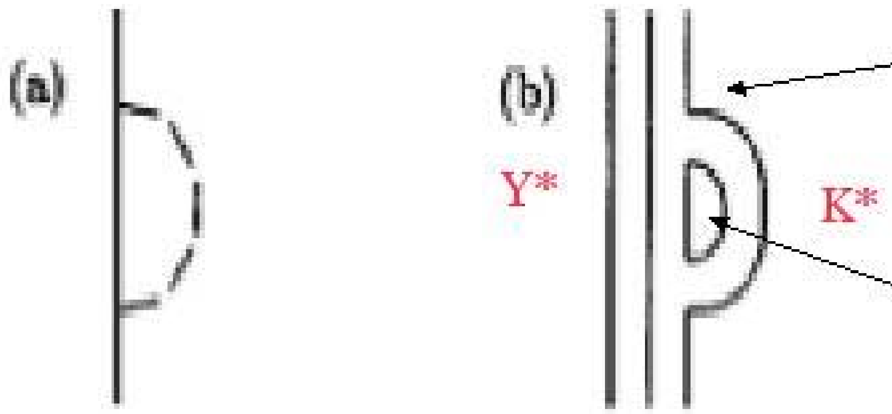




dot bare
dash dressed
full rel. corr
dash-dot MAID

Unquenching the quark model

The qq-pair creation mechanism is introduced at the microscopical level
→ string-like qq pair creation mechanism



Pair creation vertex

Σ over all the big towers of intermediate states

Construction of the formalism (group theory)
Problems that have been solved
- sum over all intermediate states
- permutational symmetry for all identical quarks
- determination of the pair creation vertex

Santopinto, this Workshop

E.Santopinto, R. Bijker
hep-ph/0701227

Conclusions

- Phenomenological problems
  - Masses: T-matrix poles?
  - Reliable resonance states
  - Sign of helicity amplitudes
  - PDG values (often average of quite different sets)
  - Need for more data
- Comparison of systematic CQM results with data
  - understanding where meson cloud or (better) q-qbar effects are important (transition and elastic ff, structure functions,…..)
  - a good basis for including consistently these effects provided by (h)CQM

Conclusions (cont.)

- Theoretical problems
  - Relativity

    boost (not important for helicity amplitudes)

    relativistic formulation (point from, …..)

    necessary for elastic form factors (also for Δ?)
  - Consistent inclusion of quark-antiquark pair creation effects
  - Quark form factors (needed in elastic form factors)
- Consequences of the inclusion of quark-antiquark pair creation effects:
  - Shift of energy levels
  - Non zero width of resonances
  - Better description of baryon structure (Roper?): q-qbar content
  - Consistent evaluation of strong vertices
  - Direct calculation of electroproduction
  - ……….
  - A substantial improvement in CQM calculations!