Helicity amplitudes in the hypercentral Constituent Quark Model

M.G. & E. Santopinto

- The hypercentral Constituent Quark Model
- Results for the longitudinal and transverse helicity amplitudes
- Meson cloud and/or quark-antiquark pair effects
- Conclusions

Hypercentral Model (1)

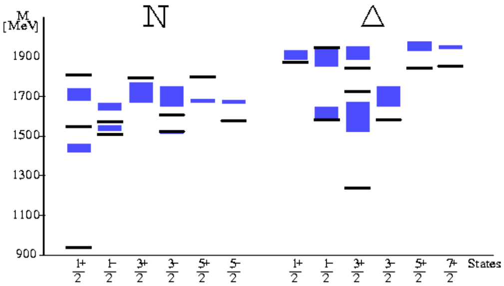
$$H_{3q} = 3m + \sum_{i=1}^{3} \frac{\mathbf{p}_i^2}{2m} + V(x) + H_{hyp}$$

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 $\tau\ \alpha\ A \leftarrow$ fixed to the spectrum, $m = \frac{M}{3}$

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

hyperradius



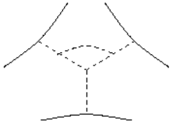
$\tau = 4.59$

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

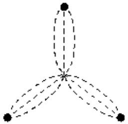
$A \Leftarrow (N - \Delta)$

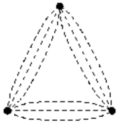
Motivations

- QCD fundamental mechanism



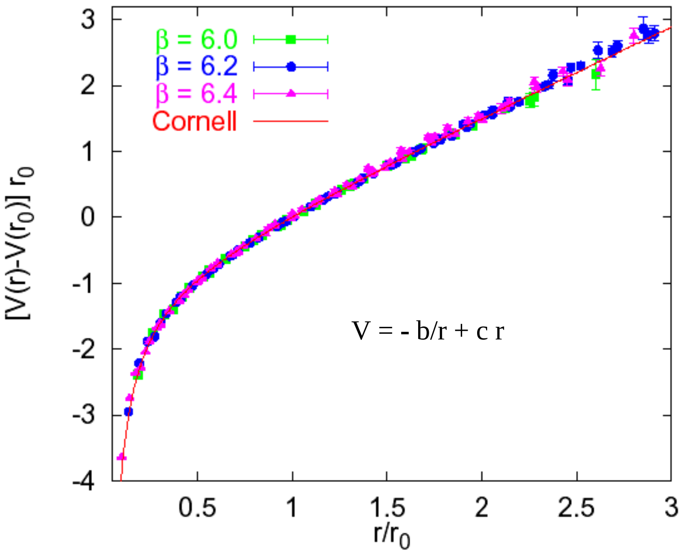
- Flux tube model



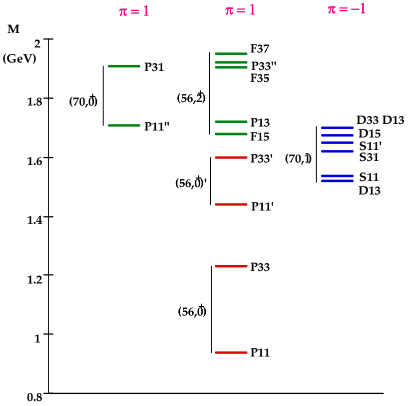


- Hypercentral approximation

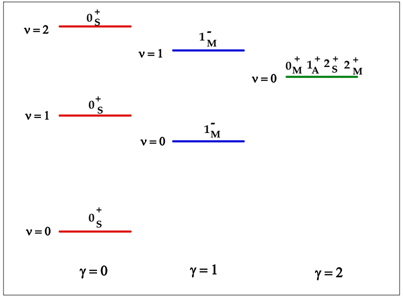
$$\sum_{i<j} V(\mathbf{r}_{ij}) \approx V(x) + \ldots$$


β = 6.0
β = 6.2
β = 6.4
Cornell
V = - b/r + c r
[V(r)-V(r0)] r0
r/r0
3
2
1
0
-1
-2
-3
-4
0.5
1
1.5
2
2.5
3

PDG 4* & 3*



$V = \alpha \quad x - \tau \quad / x$



hCQM & Electromagnetic properties

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

Fixed parameters → predictions

HELICITY AMPLITUDES

Definition

$$A_{1/2} = \langle N^* \; J_z = 1/2 \,|\, H^T_{em} \,|\, N \; J_z = -1/2 \rangle * \zeta \qquad \S$$

$$A_{3/2} = \langle N^* \; J_z = 3/2 \,|\, H^T_{em} \,|\, N \; J_z = 1/2 \rangle * \zeta \qquad \S$$

$$S_{1/2} = \langle N^* \; J_z = 1/2 \,|\, H^L_{em} \,|\, N \; J_z = 1/2 \rangle * \zeta$$

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

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

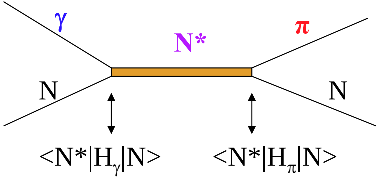
ζ overall sign -> problem

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

Photoproduction amplitude

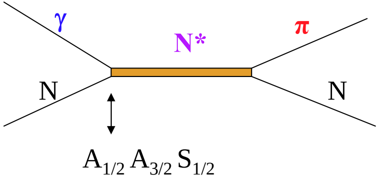
Theory:
states are defined up to a phase factor

N -> N $e^{i\phi}$ N* -> 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

Q^2 = 0 values with hCQM

10^{-3} GeV$^{-1/2}$

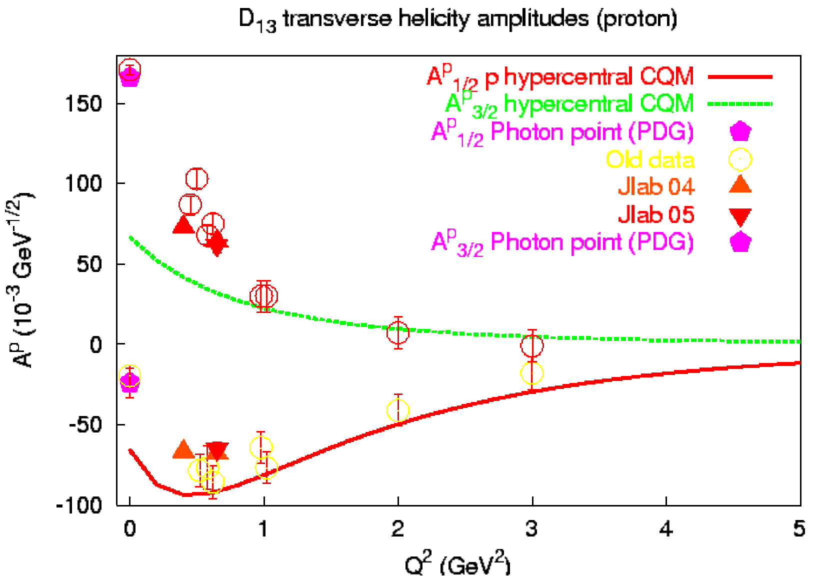
	Ap 1/2	Ap 3/2	Sp 1/2	An 1/2	An 3/2	Sn 1/2
D13 (1520)	-65.7	66.8	78.2	-1.4	-61.1	-79.6
D13 (1700)	8	-10.9	-7.9	12	70.1	8.1
D15 (1675)	1.4	1.9	0	-36.6	-51.1	-0.2
D33(1700)	80.9	70.2	78.2			
F15 (1680)	-35.4	24.1	27.4	37.7	14.8	-0.6
F35(1905)	-16.6	-50.5	-4.6			
F37(1950)	-28	-36.2	-0.4			
P11(1440)	-87.7		65.4	57.9		-0.9
P11(1710)	42.5		-22.6	-21.7		18,4
P13(1720)	94.1	-17.2	-35.8	-47.6	3	13.5
P33(1232)	-96.9	-169	-0.6			
S11(1535)	108		-48.4	-81.7		49.2
S11(1650)	68.8		-27.5	-21		28.2
S31(1620)	29.7		-55.3			

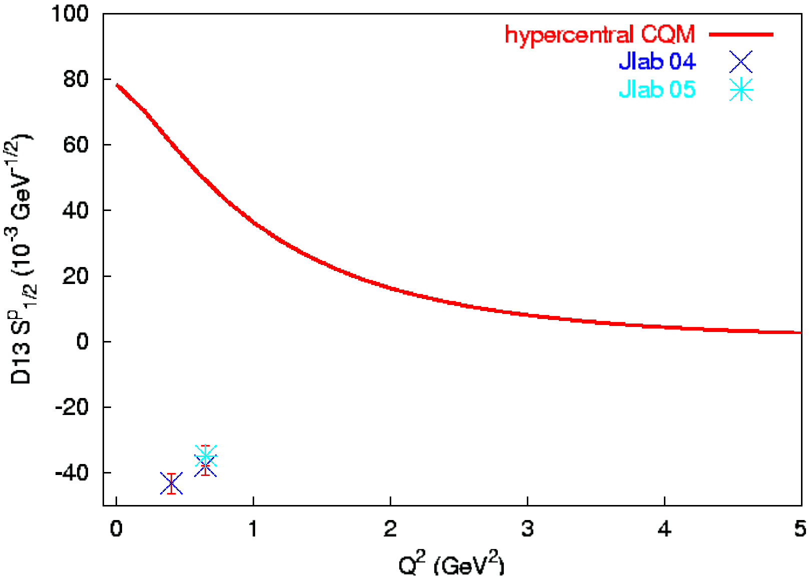
zero for no Hyp

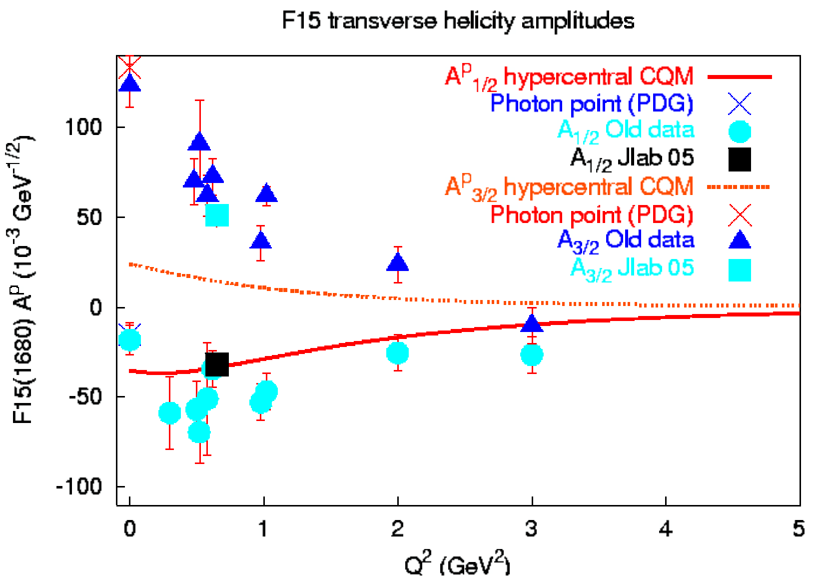
10^(-5) no Hyp

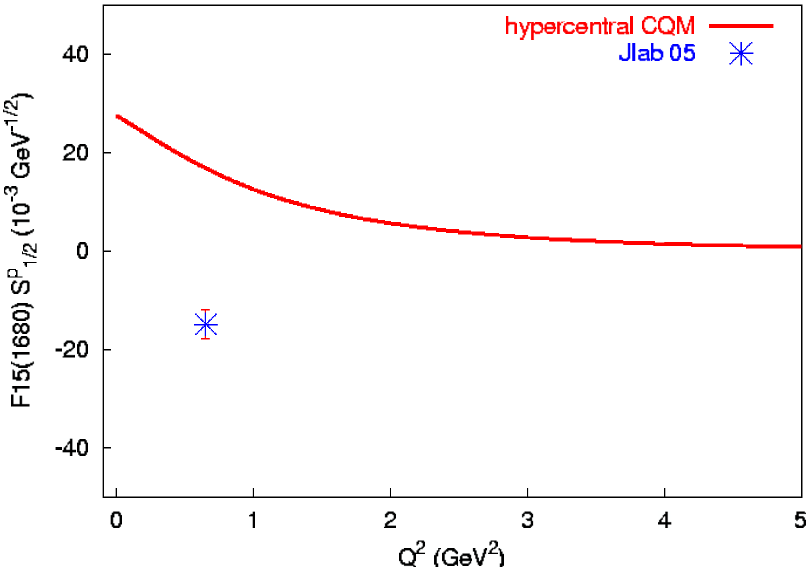
identicall zero

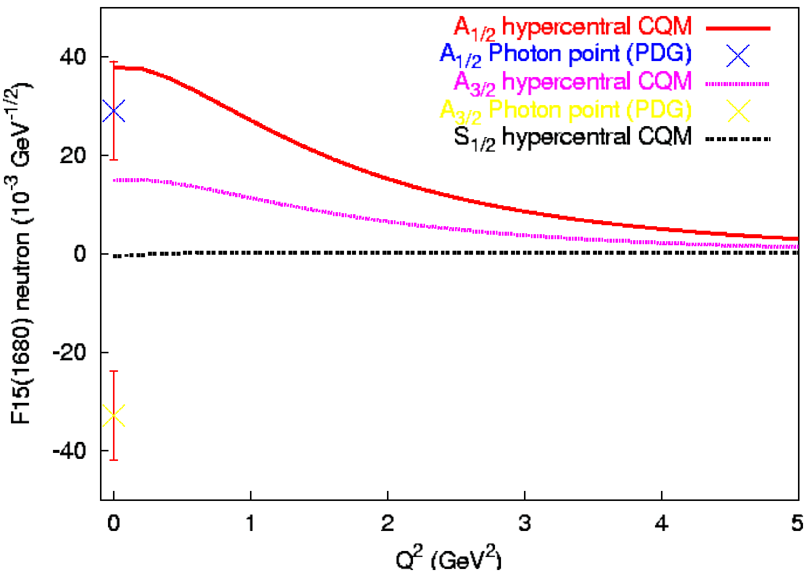
for a comparison with data: M. Aiello et al., Phys. Lett. B387, 215 (1996)


D13 transverse helicity amplitudes (proton)
A^p 1/2 p hypercentral CQM
A^p 3/2 hypercentral CQM
A^p 1/2 Photon point (PDG)
Old data
Jlab 04
Jlab 05
A^p 3/2 Photon point (PDG)
A^p (10^-3 GeV^-1/2)
Q^2 (GeV^2)
150
100
50
0
-50
-100
0
1
2
3
4
5

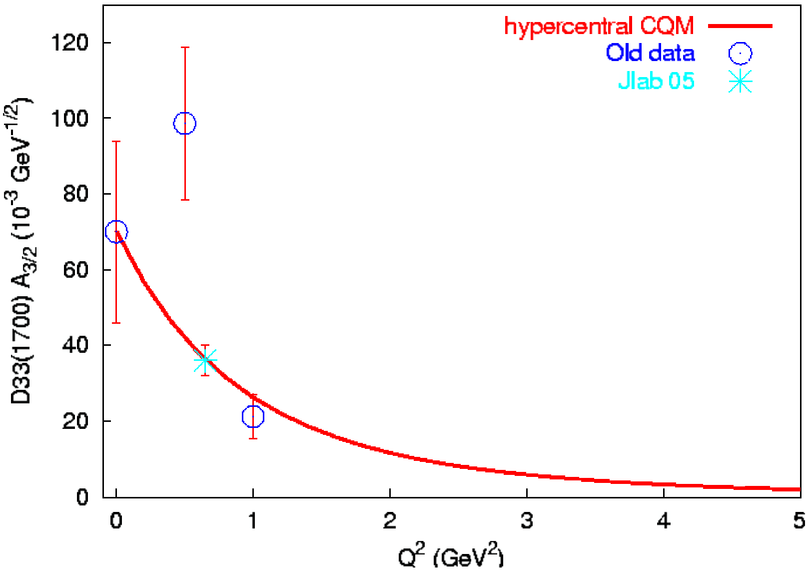

hypercentral CQM
Jlab 04
Jlab 05
D13 S^p_1/2 (10^-3 GeV^-1/2)
Q^2 (GeV^2)
100
80
60
40
20
0
-20
-40
0
1
2
3
4
5

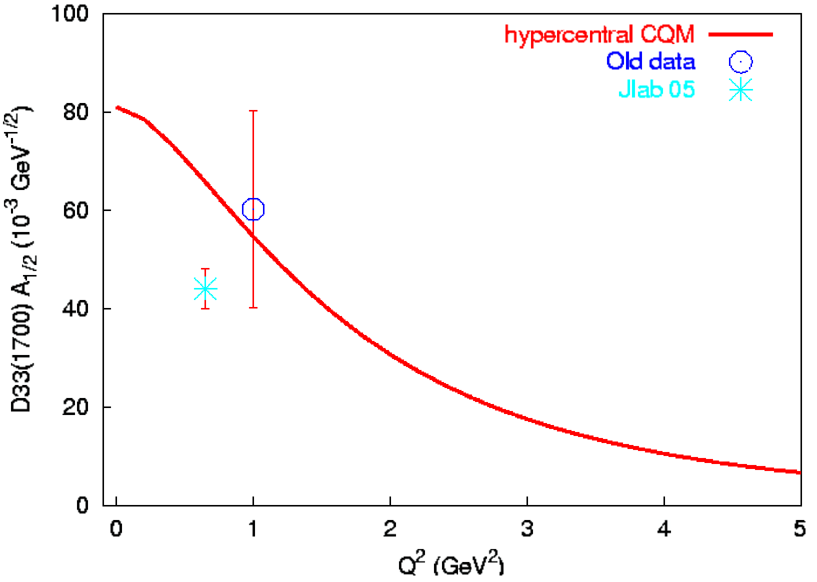

F15 transverse helicity amplitudes
$A^P_{1/2}$ hypercentral CQM
Photon point (PDG)
$A_{1/2}$ Old data
$A_{1/2}$ Jlab 05
$A^P_{3/2}$ hypercentral CQM
Photon point (PDG)
$A_{3/2}$ Old data
$A_{3/2}$ Jlab 05
F15(1680) A^P (10^{-3} GeV$^{-1/2}$)
100
50
0
-50
-100
0
1
2
3
4
5
Q^2 (GeV^2)

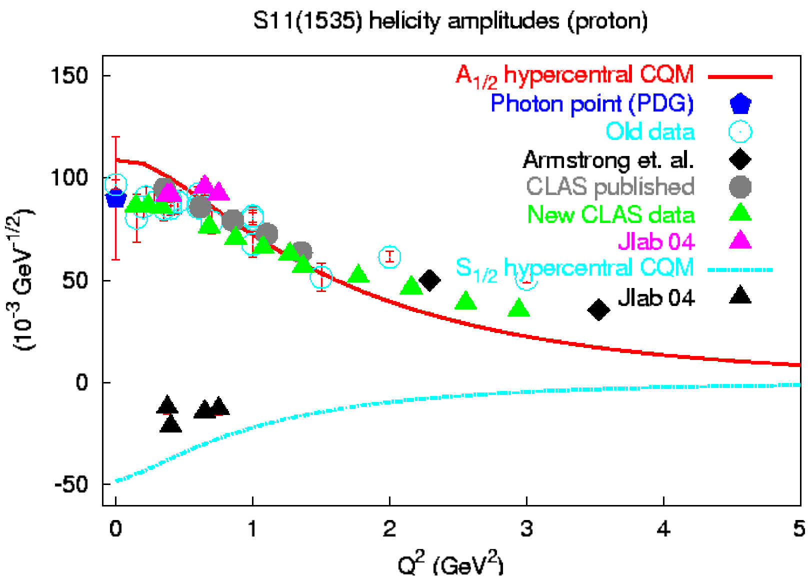

hypercentral CQM
Jlab 05
F15(1680) $S^p_{1/2}$ (10^{-3} $GeV^{-1/2}$)
Q^2 (GeV^2)
40
20
0
-20
-40
0
1
2
3
4
5

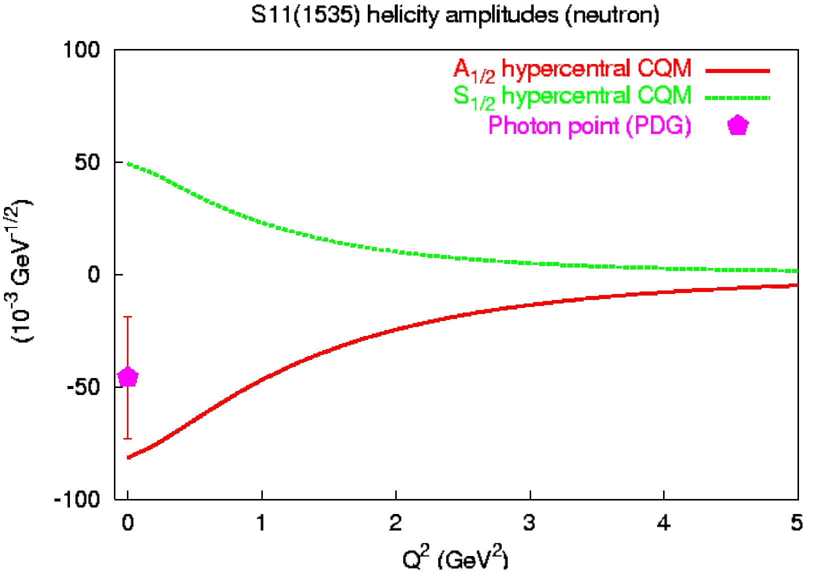


$A_{1/2}$ hypercentral CQM
$A_{1/2}$ Photon point (PDG)
$A_{3/2}$ hypercentral CQM
$A_{3/2}$ Photon point (PDG)
$S_{1/2}$ hypercentral CQM
F15(1680) neutron (10^{-3} GeV$^{-1/2}$)
Q^2 (GeV^2)
40
20
0
-20
-40
0
1
2
3
4
5


hypercentral CQM
Old data
Jlab 05
120
100
80
60
40
20
0
0
1
2
3
4
5
D33(1700) $A_{3/2}$ (10^{-3} GeV$^{-1/2}$)
Q^2 (GeV^2)


hypercentral CQM
Old data
Jlab 05
D33(1700) A1/2 (10-3 GeV-1/2)
100
80
60
40
20
0
0
1
2
3
4
5
Q2 (GeV2)


S11(1535) helicity amplitudes (proton)
$A_{1/2}$ hypercentral CQM
Photon point (PDG)
Old data
Armstrong et. al.
CLAS published
New CLAS data
Jlab 04
$S_{1/2}$ hypercentral CQM
Jlab 04
150
100
50
0
-50
0
1
2
3
4
5
$(10^{-3}\ GeV^{-1/2})$
$Q^2\ (GeV^2)$


S11(1535) helicity amplitudes (neutron)
$A_{1/2}$ hypercentral CQM
$S_{1/2}$ hypercentral CQM
Photon point (PDG)
100
50
0
-50
-100
$(10^{-3}\ GeV^{-1/2})$
0
1
2
3
4
5
$Q^2\ (GeV^2)$

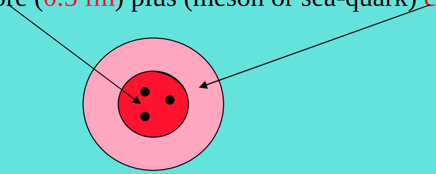
please note

- 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).

Bare vs dressed quantities

QM calculations

- the aim is the description of observables not a fit

  (dressed quantities)

- with success: spectrum, magnetic moments, …
- the separation between bare and dressed quantities is meaningful within a definite theoretical approach
- CQ have a mass, some dressing is implicitly taken into account

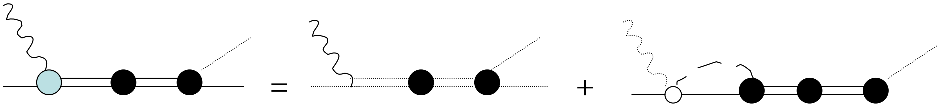
  in fact CQs are effective degrees of freedom

- something similar may occur in the spectrum

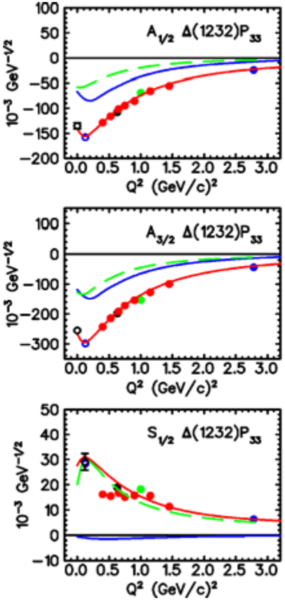
  e.g. the consistent inclusion of quark loops effects in the meson description does not alter the form of the qqbar potential but renormalizes the string constant (Geiger-Isgur)

- a consistent and systematic CQM approach may be helpful in order to put in evidence explicit dressing effects

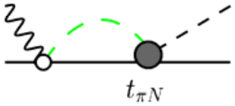
Explicit evaluation of the meson cloud contribution to the excitation of the nucleon resonances (Mainz Group and coworkers)



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



pion cloud contribution



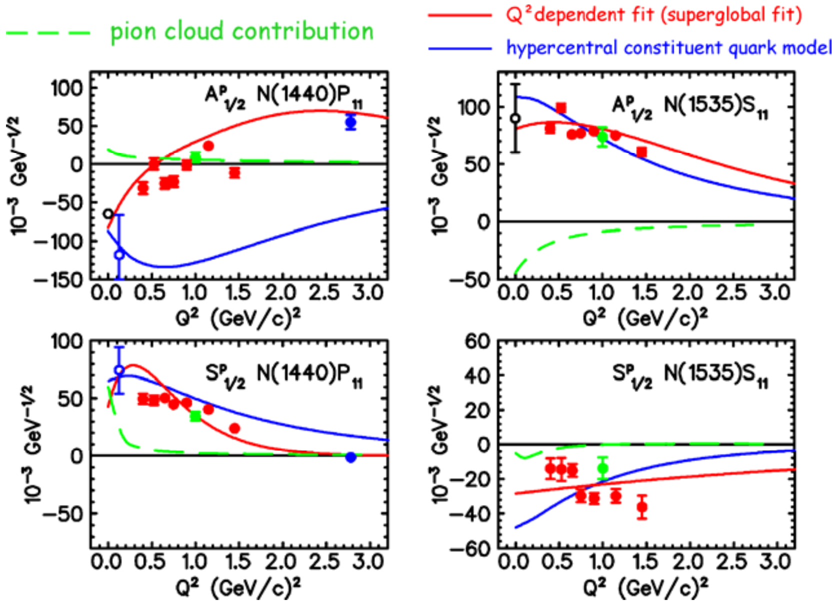
is included in phenomenlogical approach

but not in the constituent quark model

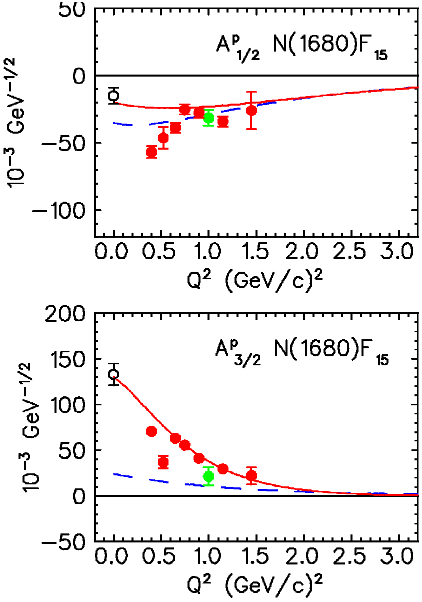
Q^2 dependent fit (superglobal fit)

hypercentral constituent quark model

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



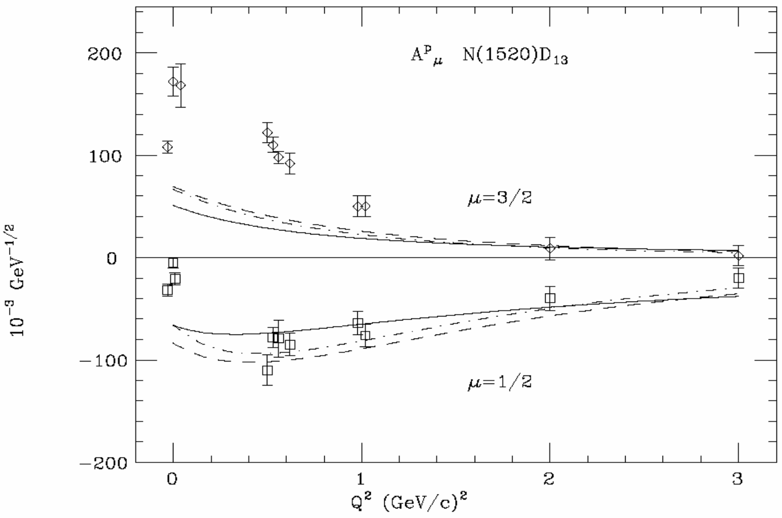
GE-MZ coll., EPJA 2004 (Trieste 2003)



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

Conclusions

- Phenomenological problems
  - Sign of helicity amplitudes
  - PDG values (often average of quite different sets)
  - Need for more data
- A comparison of systematic CQM results and 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
- Theoretical problems
  - Relativity (not important for helicity amplitudes)
  - Consistent inclusion of quark-antiquark pair creation effects



A^p_μ N(1520)D_{13}
μ=3/2
μ=1/2
200
100
0
−100
−200
0
1
2
3
10^{-3} GeV$^{-1/2}$
Q^2 (GeV/c)^2