Unquenching the quark model

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Critical Stability, 9-15 october 2011

Outline of the talk

- Quark models
- Spectrum
- Strong decays
- e.m. Elastic Form Factors
- e.m. Transition F.F.
- q-antiquark pair effects - Higher Fock components i.e

Unquenching the QM

Nucleon excitation spectrum

-> baryon resonances

Comment

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

Other quantities: e.m. form factors, decays,….

A system having an excitation spectrum
and a size
is composite
(Ericson-Hüfner 1973)

Goal: overall description of baryon properties

Nucleon excitation spectrum

-> baryon resonances (masses up to 2

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

Other quantities: e.m. form factors, decays,….

A system having an excitation spectrum
and a size
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(Ericson-Hüfner 1973)

Goal: overall description of baryon properties

LQCD (De Rújula, Georgi, Glashow, 1975)

the quark interaction contains

a long range spin-independent confinement

a short range spin dependent term

Spin-independence → SU(6) configurations

SU(6) configurations for three quark states

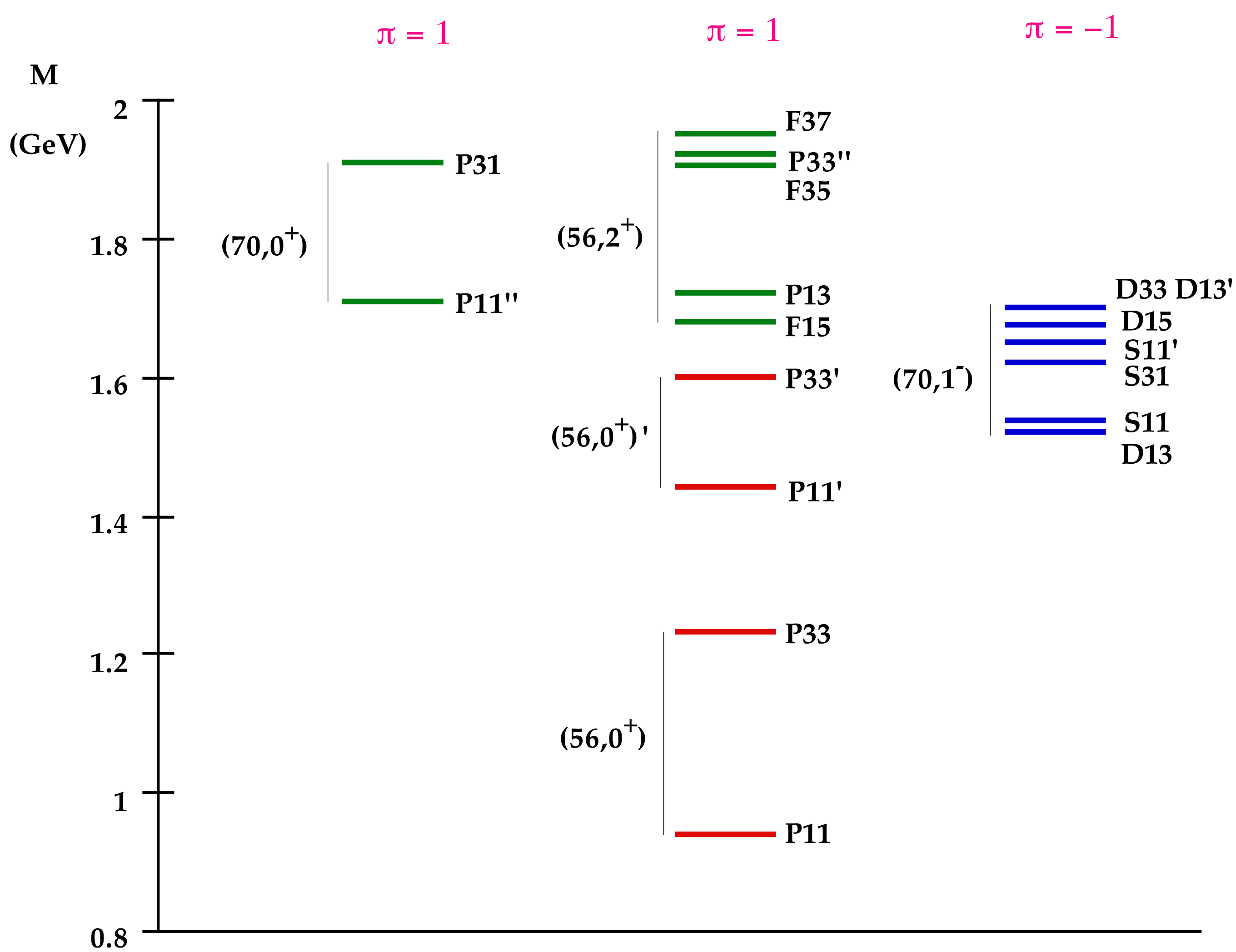
$$6 \times 6 \times 6 = \underset{A}{20} + \underset{M}{70} + \underset{M}{70} + \underset{S}{56}$$

Notation

(d, L^{π})

d = dim of SU(6) irrep
L = total orbital angular momentum
π = parity

PDG 4* & 3*

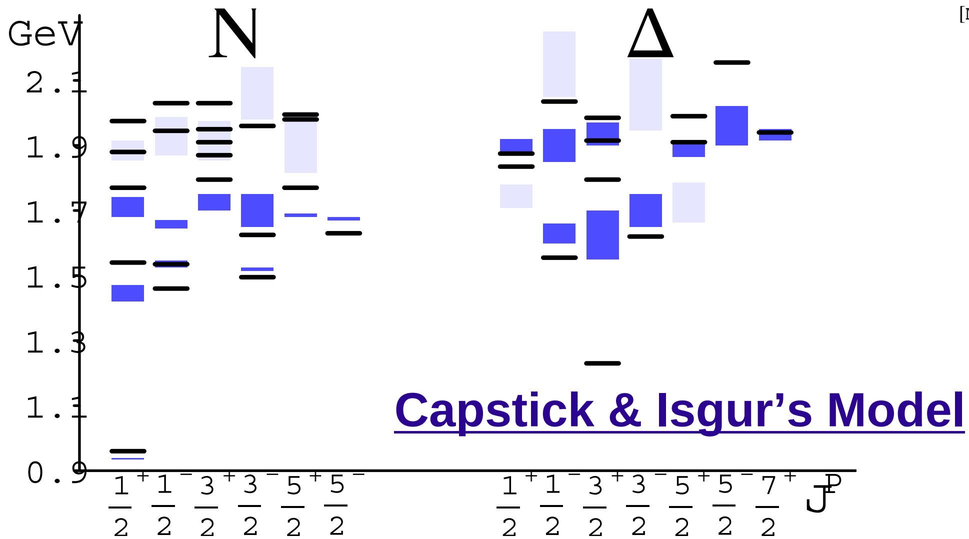


π = 1
π = 1
π = −1
M
(GeV)
2
1.8
1.6
1.4
1.2
1
0.8
P31
P11''
(70,0+)
F37
P33''
F35
(56,2+)
P13
F15
P33'
(56,0+)'
P11'
P33
(56,0+)
P11
D33 D13'
D15
S11'
S31
(70,1-)
S11
D13

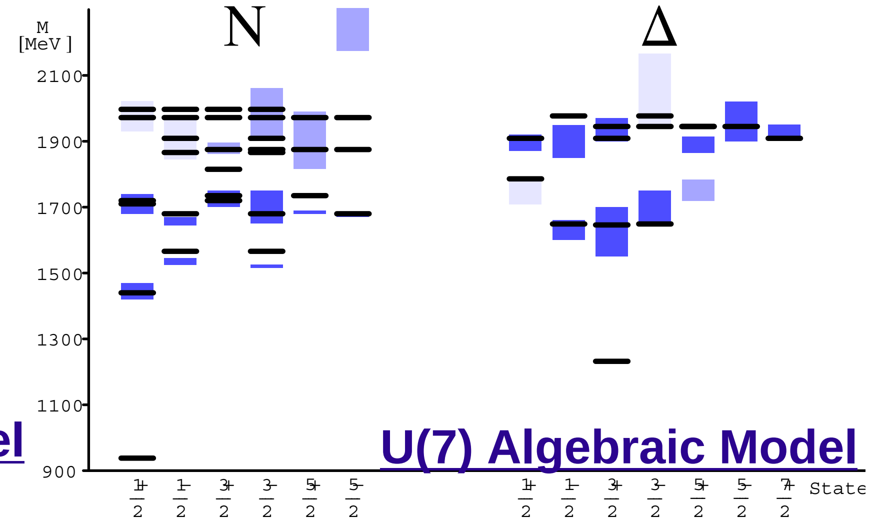
different CQMs for bayons

	Kin. Energy	SU(6) inv	SU(6) viol	date
Isgur-Karl	non rel	h.o. + shift	OGE	1978-9
Capstick-Isgur	rel	string + coul-like	OGE	1986
U(7) B.I.L.	rel M^2	vibr+L	Guersey-R	1994
Hyp. O(6)	non rel/rel	hyp.coul+linear	OGE	1995
Glozman Riska	non rel/rel**Plessas**	h.o./linear	GBE	1996
Bonn	rel	linear 3-body	instanton	2001

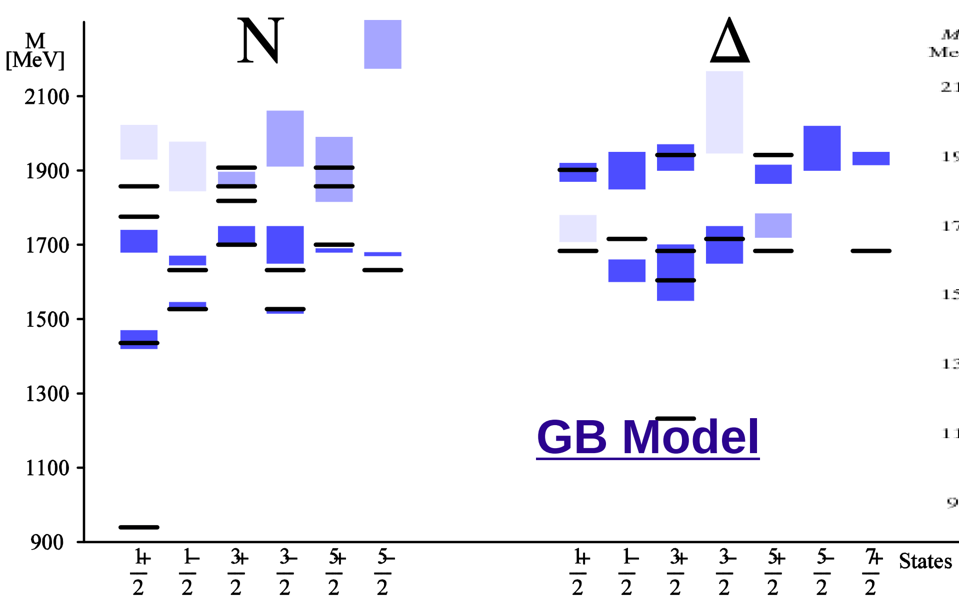
Non strange spectrum



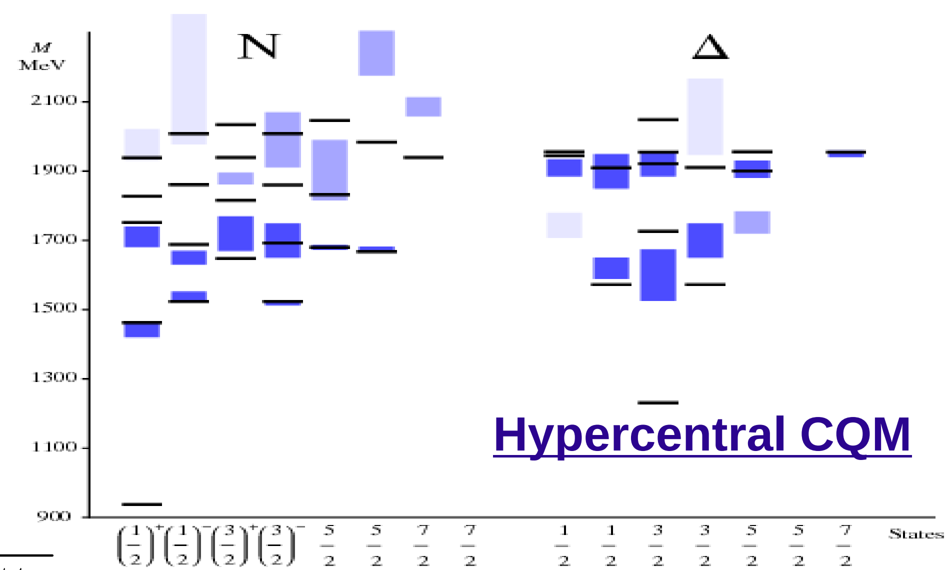
Capstick and Isgur, *Phys. Rev. D34, 2809.*



Bijker, Iachello, Leviatan, Ann. Phys. 236, 69 (1994)



Glozman & Riska, *Phys. Rept. 268, 263 (1996)*



Giannini, E. S, A.Vassallo, *Eur. Phys. J .A12:447*

The missing resonance problem is a long standing problem, linked also with our understanding of the confinement mechanisms.

Long standing, since the extraction of the resonance parameters is a difficult task

Two possible explanations:

1) Strongly coupled to channels other then the pion-N
2) Simply do not exist

Only dedicated experiments and sophysticated analysis methods can answer

One of the goals of the experimental program at Jlab12GeV,BES,MAMI

Many versions of CQMs have been developed

(IK, CI, GBE, U(7), hCQM,Bonn, etc.)

non relativistic and relativistic

While these models display peculiar features,

they share the following main features :

the effective degrees of freedom of 3q and a confining potential

the underling O(3) SU(3) symmetry

All of them are able to give a good description of the 3 and 4 stars spectrum

CQMs:

S

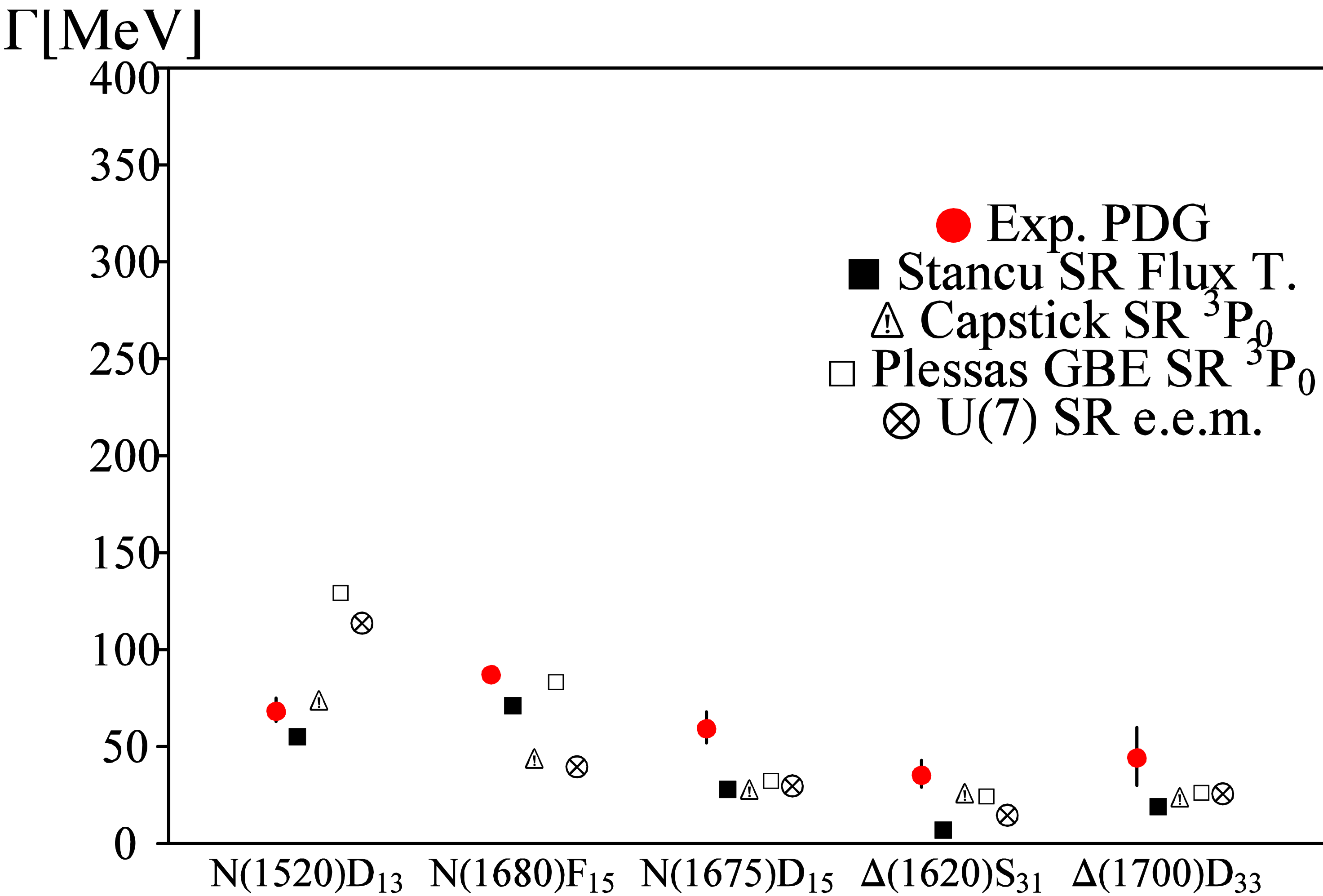
Good description of the spectrum and magnetic moments

Predictions of many quantities:

strong couplins
photocouplings
helicity amplitudes
elastic form factors
structure functions

Based on the effective degrees of freedom of 3 constituent quarks

$\Gamma_{N\pi}$ width – Rel. Models

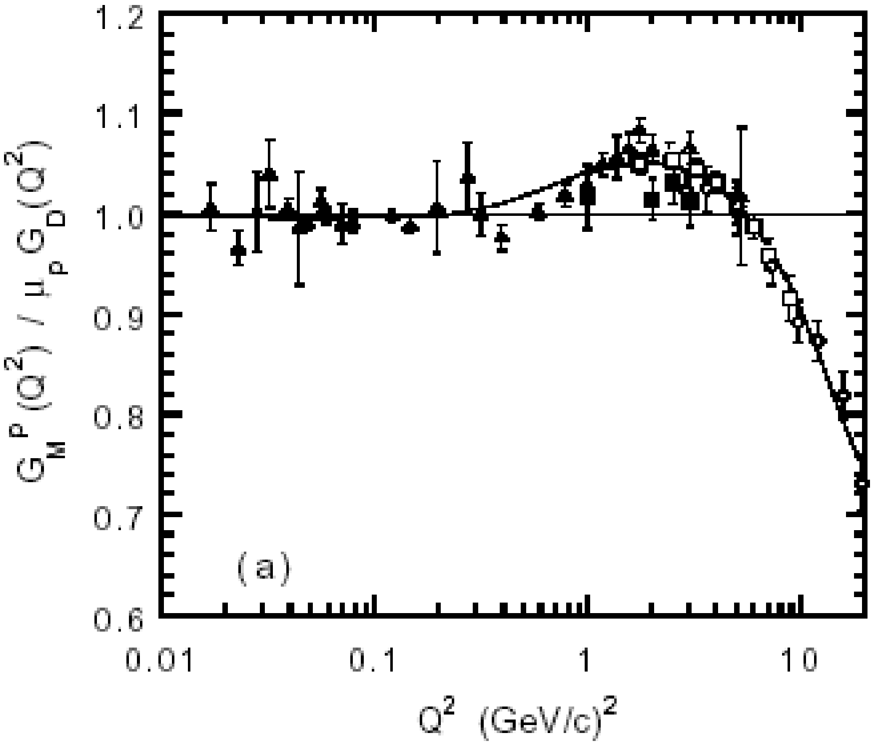


Elastic e.m. F.F.

Salme et al.

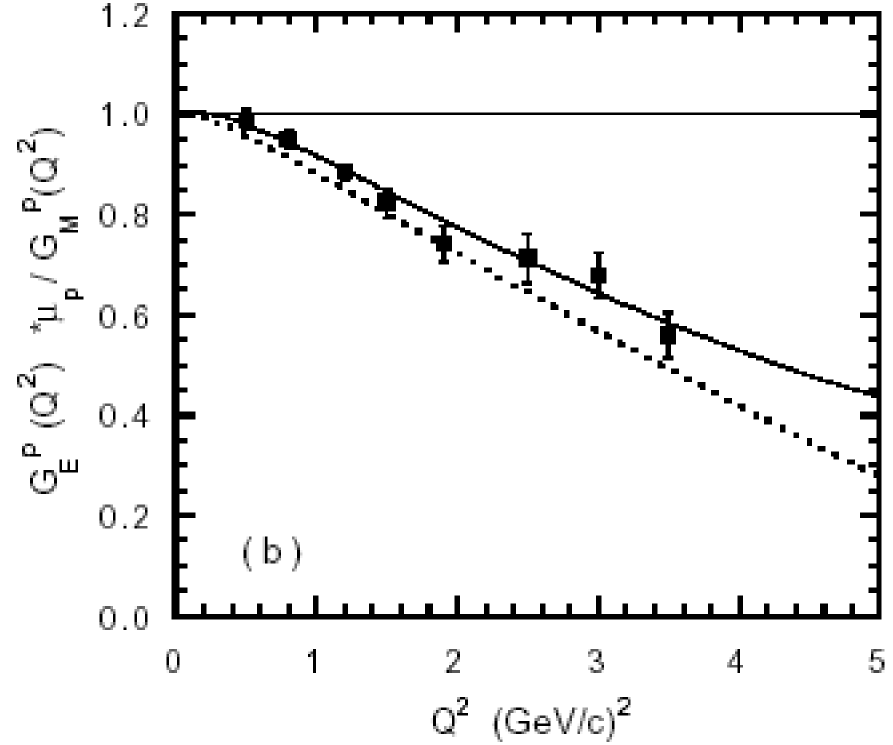
CQM: Capstick Isgur

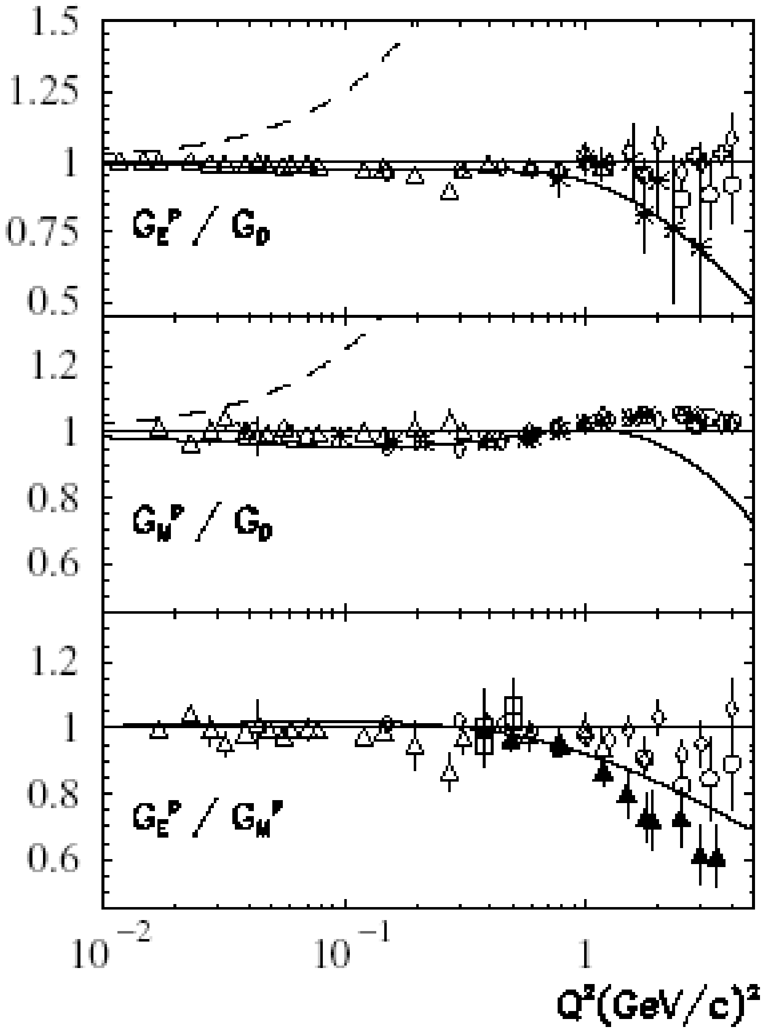
LF WF



full curve: with quark ff

dotted curve: without quark ff

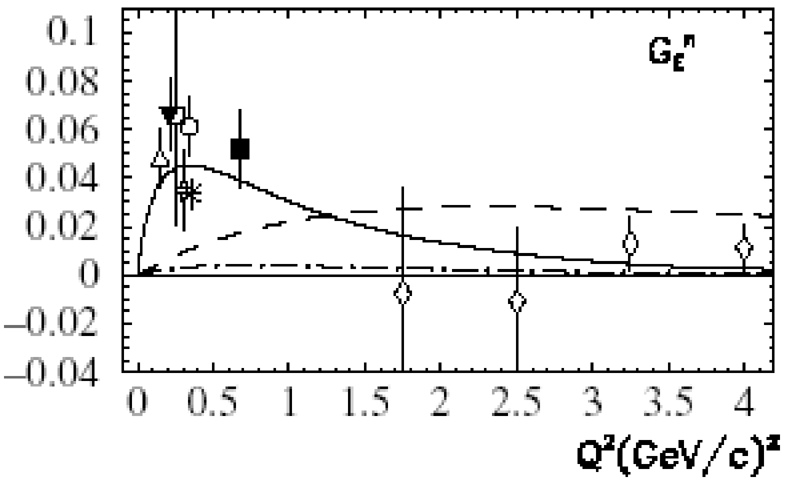




Point Form Spectator Approximation
(PFSA)

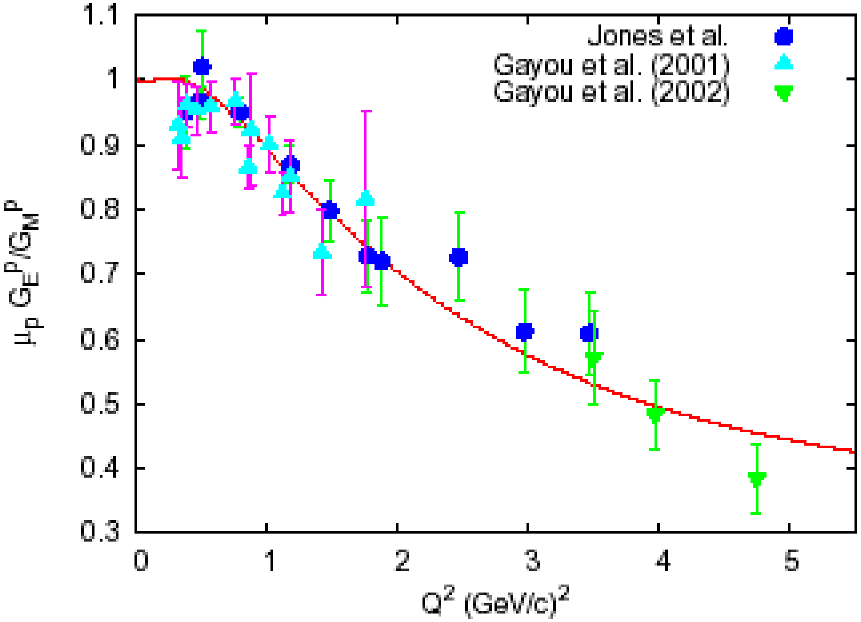
CQM: GBE

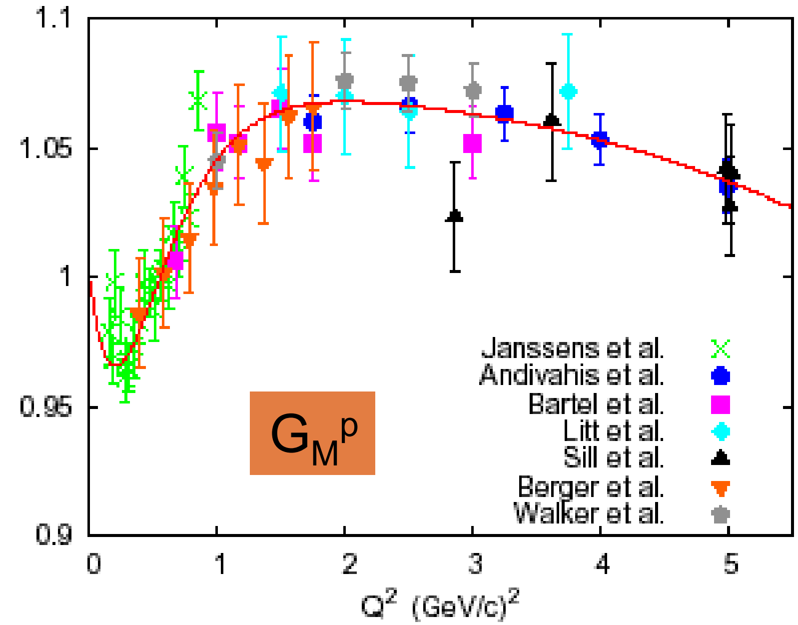
Dashed curve: NRIA
(Non relativistic impulse approximation)



Neutron electric ff: SU(6) violation
Dash-dotted confinement only

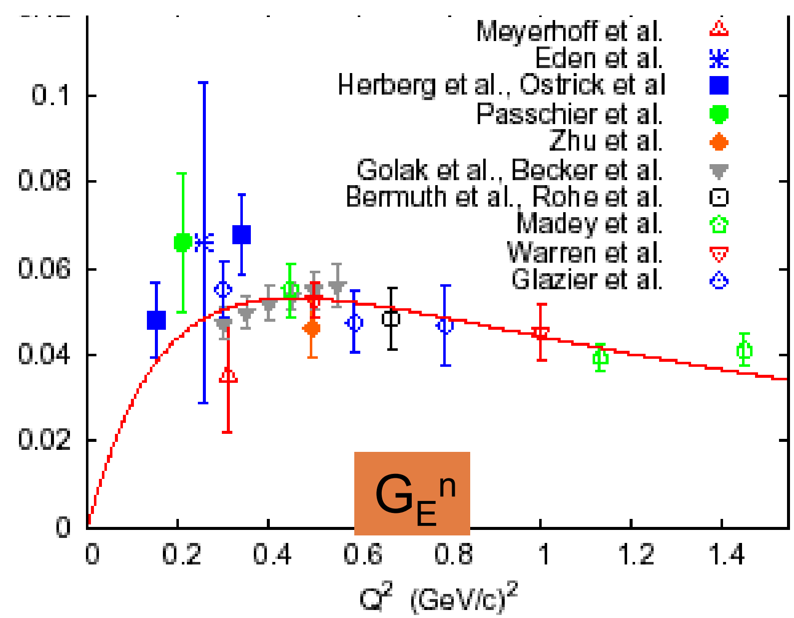
Boffi et al., EPJ **A14**, 17 (2002)





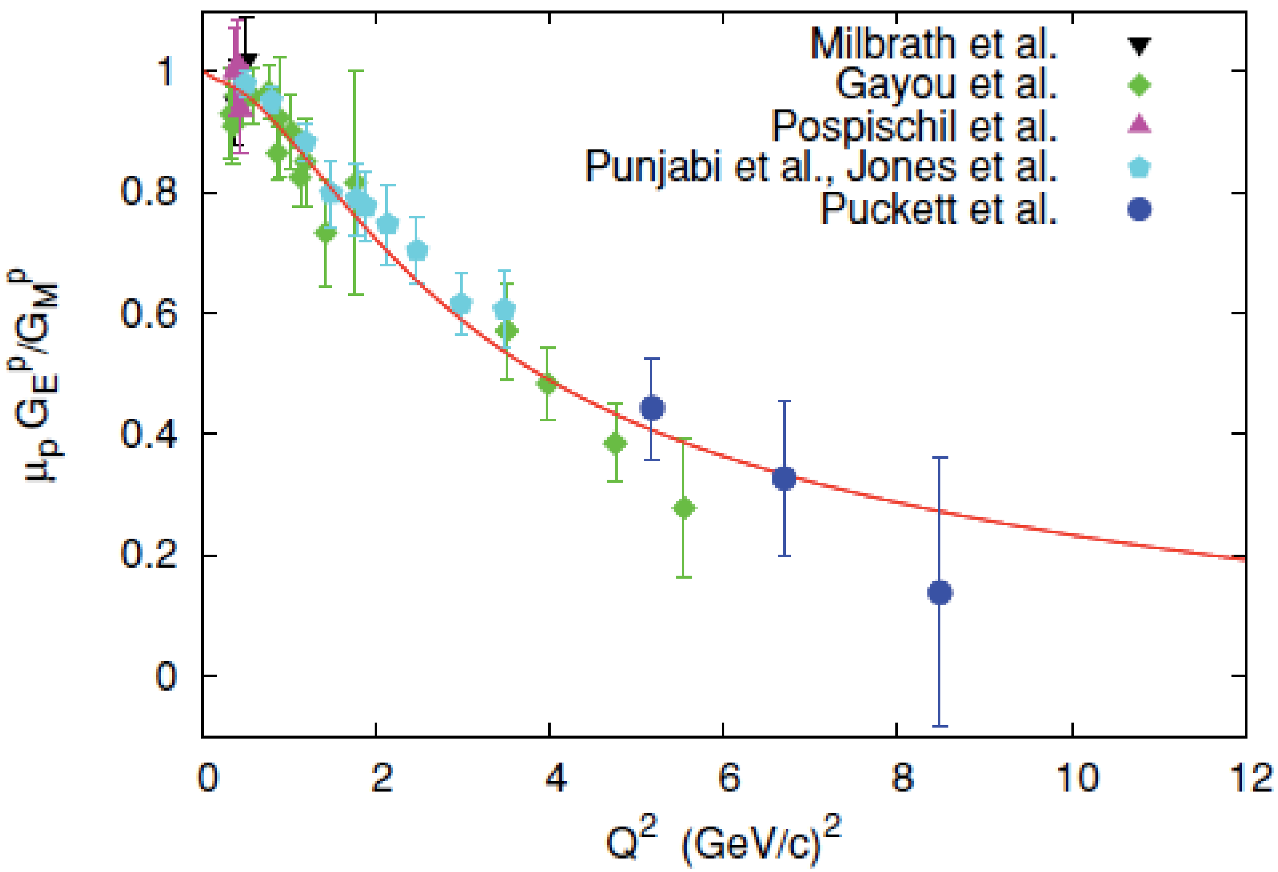
Hyper. Model

quark form factors



M. De Sanctis, M. Giannini, E. S., A. Vassallo, Phys. Rev. C 76, 062201(R)(2007)

Santopinto,DeSanctis,Giannini,Vassallo, PR C **82**, 065204 (2010)



HELICITY AMPLITUDES

Definition

$A_{1/2} = \langle R\ J_z = 1/2 \mid H^T{}_{em} \mid N\ J_z = -1/2 \rangle * \zeta$

$A_{3/2} = \langle R\ J_z = 3/2 \mid H^T{}_{em} \mid N\ J_z = 1/2 \rangle * \zeta$

$S_{1/2} = \langle R\ J_z = 1/2 \mid H^L{}_{em} \mid N\ J_z = 1/2 \rangle * \zeta$

N nucleon and R resonance as 3q states

$H^T{}_{em}$ $H^l{}_{em}$ e.m. transition operator

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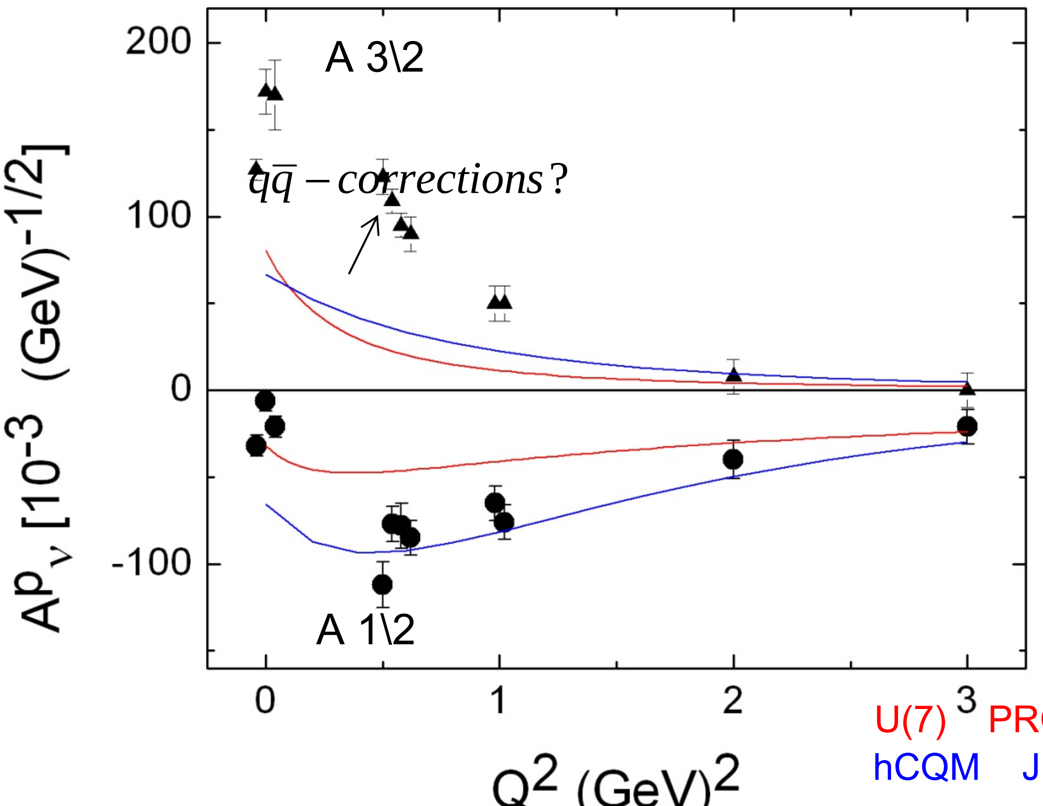
Is it a degrees of freedom problem?

$q\bar{q}$ corrections ? important in the outer region

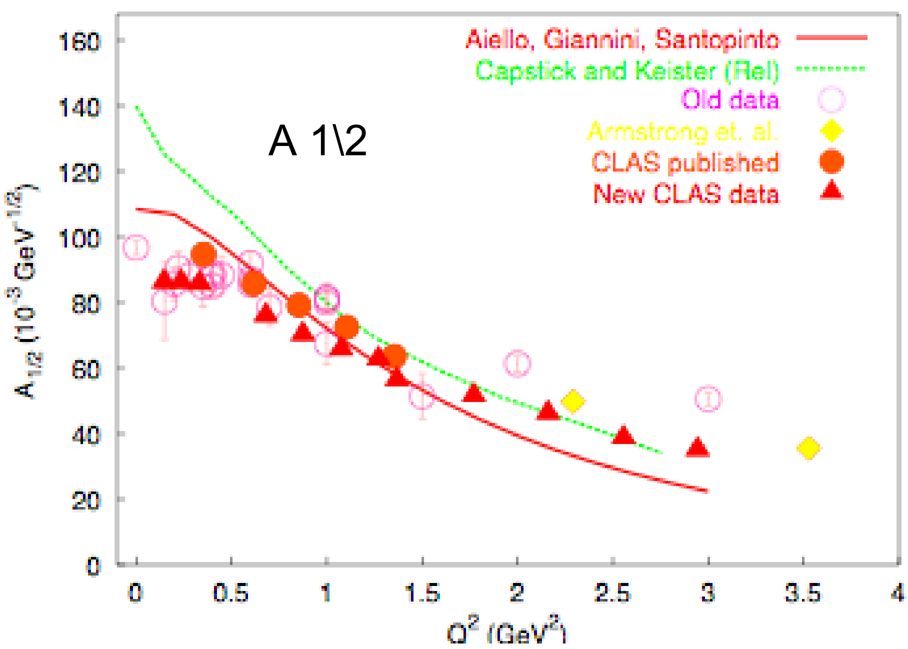


D13 transition amplitudes

U(7) PRC 54, 1935 (1996)

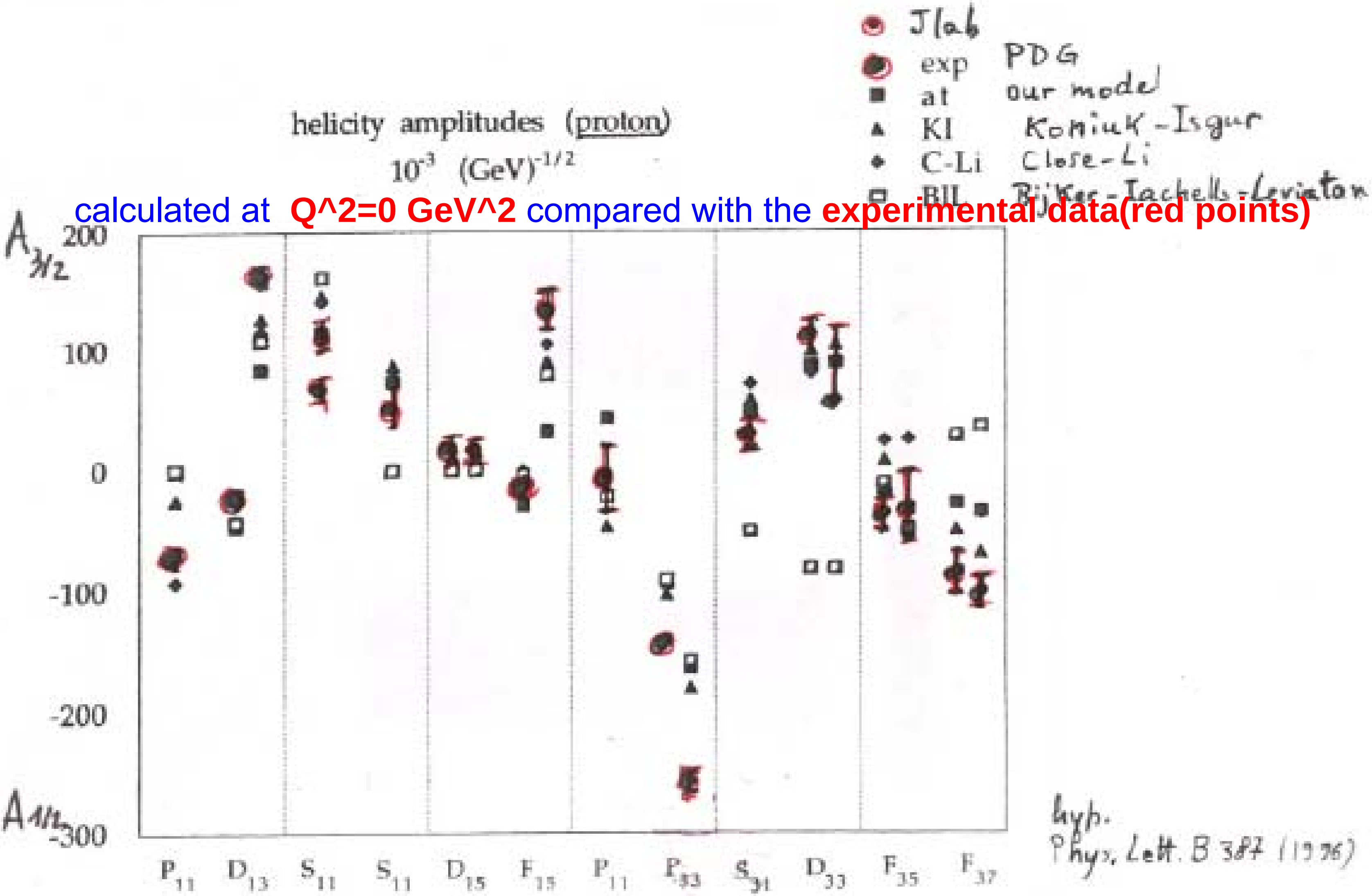
hCQM JPG 24, 753 (1998)

A_1/2 for the S11



hCQM JPG 24, 753 (1998)

calculated at **Q^2=0 GeV^2** compared with the **experimental data(red points)**



Aiello , Santopinto,Giannini, Phys.Lett. B 387 (1996)

Considering also CQMs for mesons, CQMs able to reproduce the **overall trend of hundred of data**

- … but they show very similar deviations for observables such as

- photocouplings

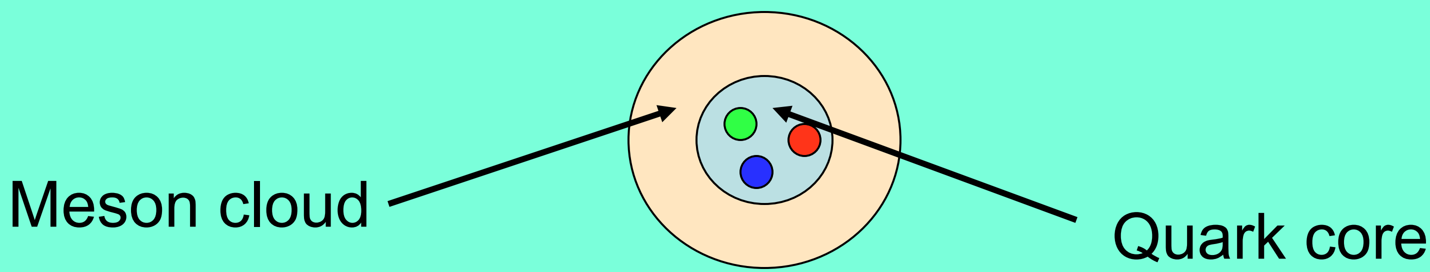
- helicity amplitudes,

please note

- 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

- emerging picture:

  quark core plus (meson or sea-quark) **cloud**



There are two possibilities:

phenomenological parametrization

microscopic explicit quark description

CQM problems -----> degrees of freedom problem

Key degrees of freedom----->q antiq pairs

Problems

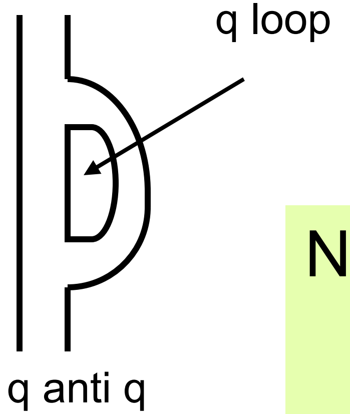
1) find a quark pair creation mechanism QCD inspired

2) implementation of this mechanism at the quark level
but in such a way to

do not destroy the good CQMs results

Unquenching the quark model

Mesons P. Geiger, N. Isgur, Phys. Rev. D41, 1595 (1990)
D44, 799 (1991)

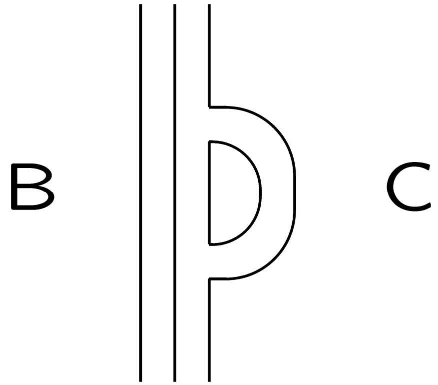


Pair-creation operator with 3P0 quantum number

Note:

- sum over intermediate states necessary for preserving the OZI rule
- linear interaction is preserved after renormalization of the string constant

Unquenched Quark Model for the baryons

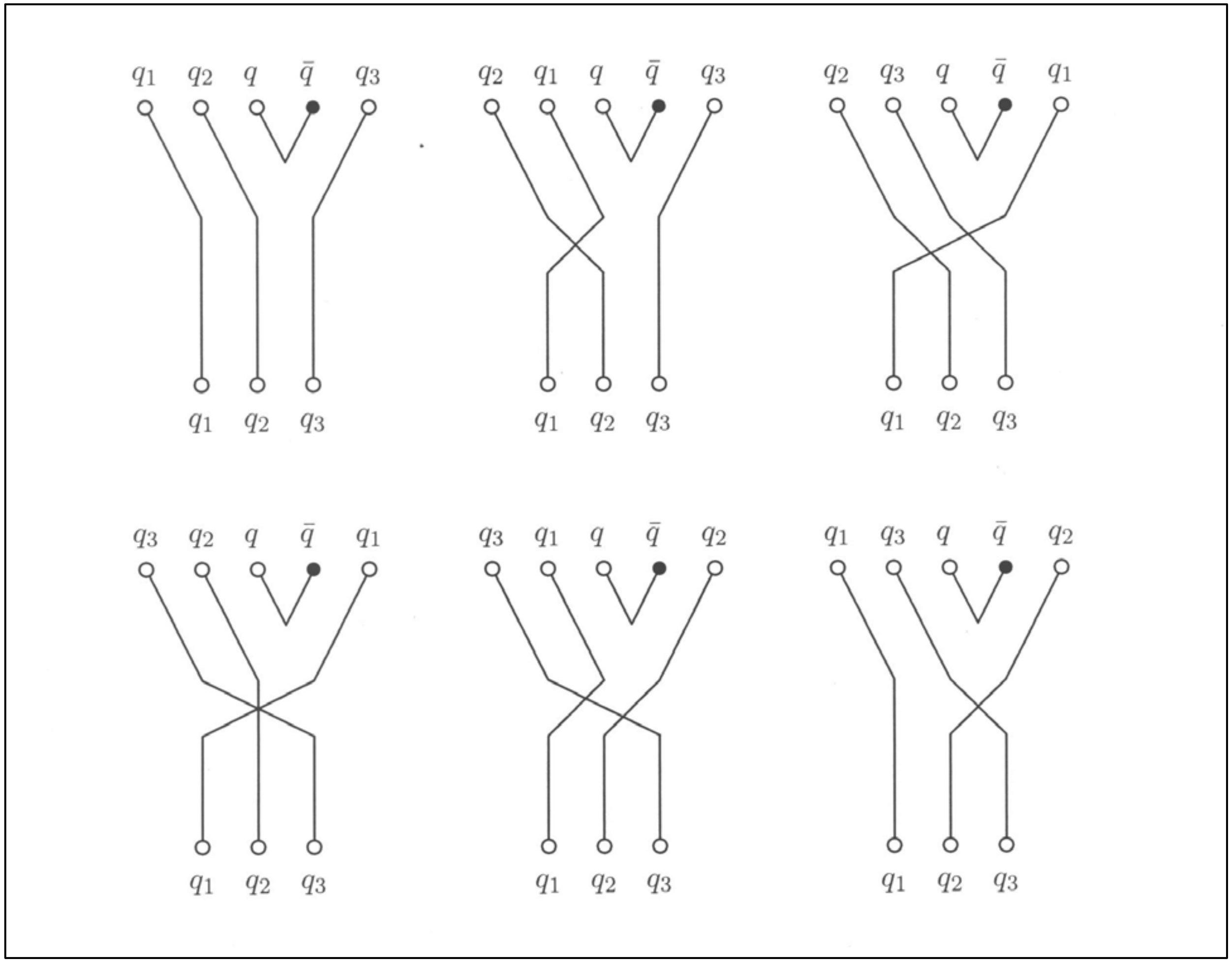


Strange quark-antiquark pairs in the proton with **h.o. wave functions**

Geiger & Isgur, PRD 55, 299 (1997)

- Pair-creation operator with $^3P_0$ quantum numbers
- Sum over a large tower of intermediate states to preserve the phenomenological success of CQM's

Diagrams



q1 q2 q q̄ q3
q1 q2 q3
q2 q1 q q̄ q3
q1 q2 q3
q2 q3 q q̄ q1
q1 q2 q3
q3 q2 q q̄ q1
q1 q2 q3
q3 q1 q q̄ q2
q1 q2 q3
q1 q3 q q̄ q2
q1 q2 q3

It would be desirable to devise tests of the mechanisms underlying the delicate cancellations which conspire to hide the effects of the sea in the picture presented here. It also seems very worthwhile to extend this calculation to $u\bar{u}$ and $d\bar{d}$ loops. Such an extension could reveal the origin of the observed violations [38] of the Gottfried sum rule [39] and also complete our understanding of the origin of the spin crisis. From our previous calculations [4], the effects of ‘‘un-

Geiger & Isgur, PRD 55, 299 (1997)

Extensions

- To any initial baryon or baryon resonance
- To any flavor of the quark-antiquark pair
- To any model of baryons and mesons

Problems for the baryons---->

- **towers of states** authomatically generated by means of group theoretical methods

- problems linked with **permutational symmetry(many different diagrams)**-> solved with group theoretical methods

$$| \psi_A \rangle = \mathcal{N} \left\{ | A \rangle + \sum_{qBClJ} \int d\vec{k} \; | BC\vec{k}\, lJ \rangle \frac{\langle BC\vec{k}\, lJ \,|\, h^{\dagger}_{q\bar{q}} \,|\, A \rangle}{M_A - E_B - E_C} \right\}$$

$$\mathcal{O} = \langle \psi_A \,|\, \hat{\mathcal{O}} \,|\, \psi_A \rangle = \mathcal{O}_{\text{valence}} + \mathcal{O}_{\text{sea}}$$

$$\mathcal{O}_{\text{valence}} = \mathcal{N}^2 \langle A \,|\, \hat{\mathcal{O}} \,|\, A \rangle$$

$$\mathcal{O}_{\text{sea}} = \mathcal{N}^2 \sum_{qBClJ} \int d\vec{k} \sum_{q'B'C'l'J'} \int d\vec{k}\,' \frac{\langle A \,|\, h_{q'\bar{q}'} \,|\, B'C'\vec{k}\,' \,l' J' \rangle}{M_A - E_{B'} - E_{C'}} \langle B'C'\vec{k}\,' \,l' J' \,|\, \mathcal{O} \,|\, BC\vec{k}\, lJ \rangle \frac{\langle BC\vec{k}\, lJ \,|\, h^{\dagger}_{q\bar{q}} \,|\, A \rangle}{M_A - E_B - E_C}$$

The good magnetic moment results of the CQM are preserved by the UCQM

Bijker, Santopinto,Phys.Rev.C80:065210,2009.

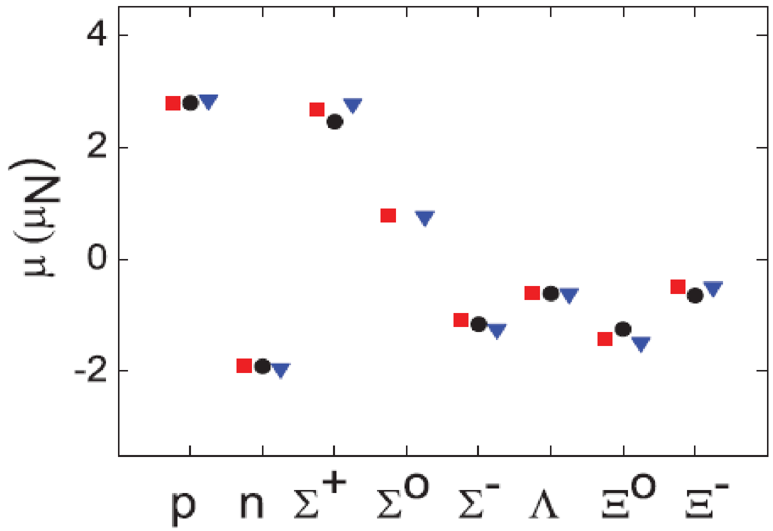


FIG. 3. (Color online) Magnetic moments of octet baryons: experimental values from the Particle Data Group [34] (circles), CQM (squares), and unquenched quark model (triangles).

PROTON SPIN in the UCQM

Bijker, Santopinto,Phys.Rev.C80:065210,2009.

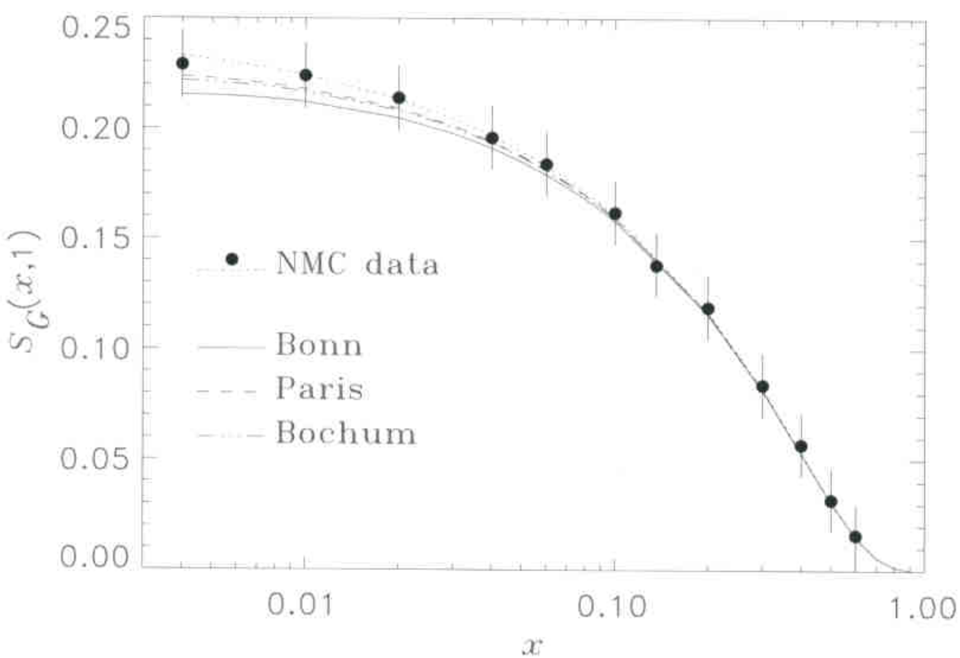
p	CQM	EJS	DIS	UCQM		
				Val	Sea	Total
Δu	4/3	0.928	0.842	0.504	0.594	1.098
Δd	−1/3	−0.342	−0.427	−0.126	−0.291	−0.417
Δs	0	0.000	−0.085	0.000	−0.005	−0.005
$\Delta\Sigma$	1	0.586	0.330	0.378	0.298	0.676
$2\Delta L$	0	0.414		0.000	0.324	0.324
$2J$	1	1.000		0.378	0.622	1.000

Contributions due to the sea quark spins and the orbital angular momentum, are comparable in size and equal to approximately 30 and 32 % respectively, of the total. The importance of the orbital angular momentum comes out in a natural way.

Flavor Asymmetry

Gottfried sum rule

$$S_G = \int_0^1 dx \frac{F_{2p}(x) - F_{2n}(x)}{x} = \frac{1}{3} - \frac{2}{3}\int_0^1 dx \left[\bar{d}(x) - \bar{u}(x)\right]$$



$$S_G(x,1) = \int_x^1 dx' \frac{F_{2p}(x') - F_{2n}(x')}{x'}$$

$$S_G \neq \frac{1}{3} \Rightarrow N_{\bar{d}} \neq N_{\bar{u}}$$

$$S_G = 0.2281 \pm 0.0065$$

$$\int_0^1 dx \left[\bar{d}(x) - \bar{u}(x)\right] = 0.16 \pm 0.01$$

Flavor asymmetry of the octect baryons in the UCQM

Santopinto, Bijker, PRC 82,062202(R) (2010)

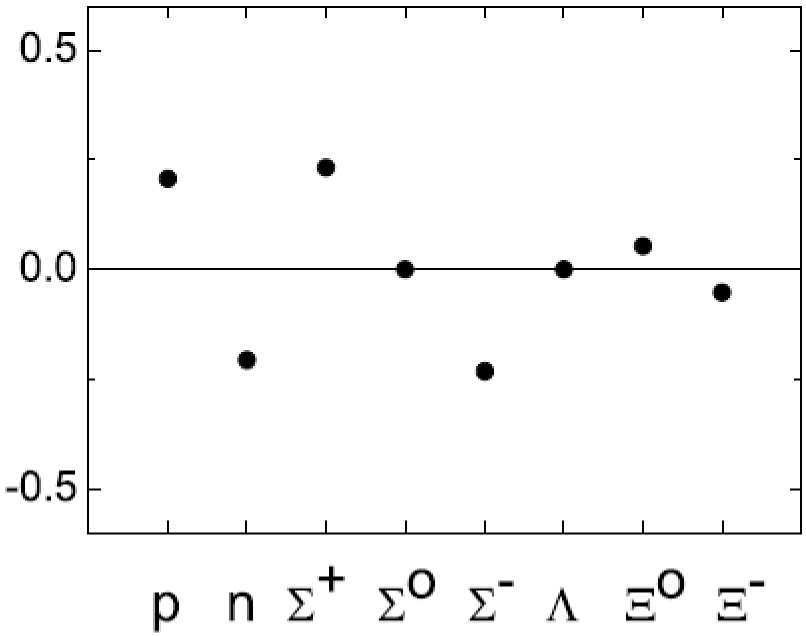


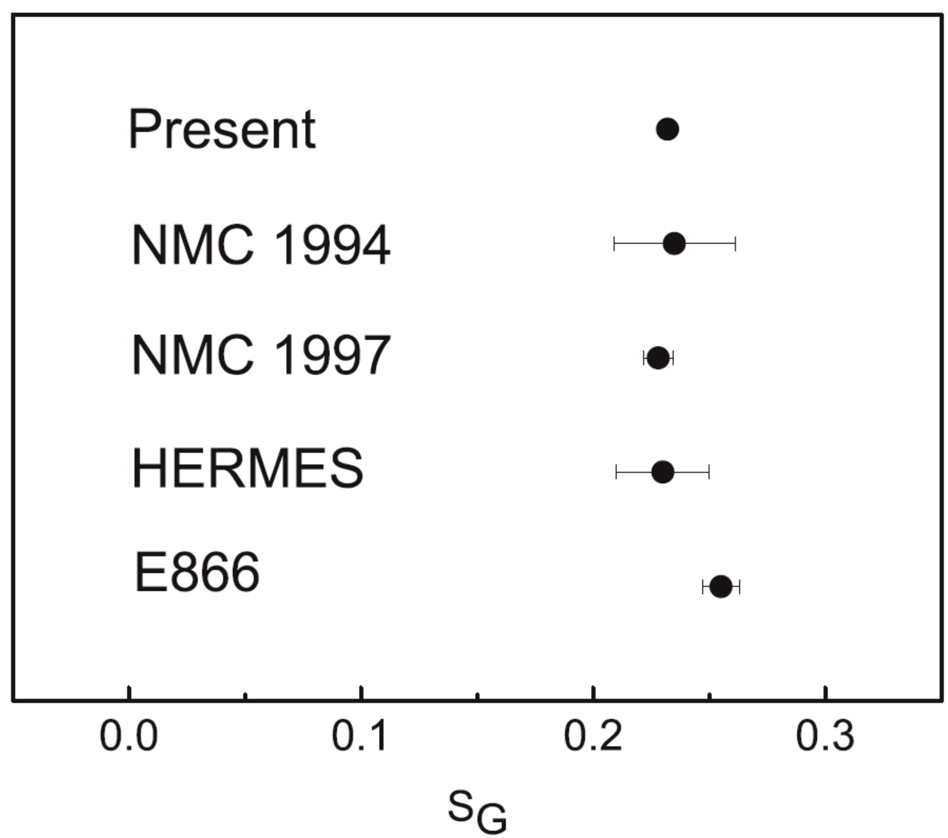
Figure 1. Flavor asymmetry of octet baryons

Flavor asymmetry
Nonperturbative QCD

Pauli blocking (Field & Feynman, 1977) too small
Pion dressing of the nucleon (Thomas et al., 1983)
Meson cloud models

Proton Flavor asymmetry

Santopinto, Bijker, PRC 82,062202(R) (2010)



Flavor asymmetries of octect baryons

Santopinto, Bijker, PRC 82,062202(R) (2010)

TABLE III. Relative flavor asymmetries of octet baryons.

Model	$\mathcal{A}(\Sigma^+)/\mathcal{A}(p)$	$\mathcal{A}(\Xi^0)/\mathcal{A}(p)$	Ref.
Unquenched CQM	0.833	−0.005	present
Chiral QM	2	1	Eichen
Balance model	3.083	2.075	Y.-J Zhang
Octet couplings	0.353	−0.647	Alberg

$$\Sigma^{\pm} p \rightarrow \ell^+ \ell^- + X \text{ (e.g., at CERN).}$$

Conclusions

- Unquenching quark model:we have constructed the formalism in an explicit way, also thanks to group theory tecniques. Now, it can be applied to any quark model.

- Results for magnetic moments, spin of the baryons, flavor asymmetry

- Study of symmetry limits and relations that can be usefull for the experimentalists

- Future: application to open problems in hadron structure and spectroscopy

The missing resonance problem is a long standing problem, linked also with our understanding of the confinement mechanisms.

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Two possible explanations:

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2) Simply do not exist

Only dedicated experiments and sophysticated analysis methods can answer

One of the goals of the experimental program at Jlab12GeV,BES,MAMI

Pion Form Factor

De Melo J P B C, Frederico T, Pace E and Salmé G 2006 *Phys. Rev.* D **73** 074013