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Particle-Nucleus and Nucleus-Nucleus Scattering at Relativistic Energies

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Electromagnetic form factors in the relativized Hypercentral CQM

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Electromagnetic form factors in the relativized Hypercentral CQM

E. Santopinto

Trieste 22_26 May 2006

M. Ferraris, M.Giannini, M. Pizzo, E. Santopinto, L. Tiator**,**Phys. Lett. **B 364**, 231 (1995).

M. Aiello, M. Ferraris, M. Giannini, M.Pizzo, E. Santopinto, Phys. Lett. B 387, 215 (1996).

E. Santopinto, F. Iachello, M. Giannini, Eur. Phys. J. **A 1**, 307 (1998).

R. Bijker, E. Santopinto, F. Iachello, J. Phys. **A 31**, 9041 (1998).

M. De Sanctis, M.M. Giannini, L.Repetto, E. Santopinto, Phys. Rev. **C 62**, 025208 (2000).

De Sanctis, M.Giannini, E.Santopinto, A.Vassallo, Nucl. Phys. **A**.**755**,294(2005)

Introduction

The hypercentral Constituent Quark Model

The elastic nucleon form factors (relativistic effects)

Conclusion

Work done in collaboration with M. Giannini, A. Vassallo, M. De Santis

New Jlab data on nucleon f.f.

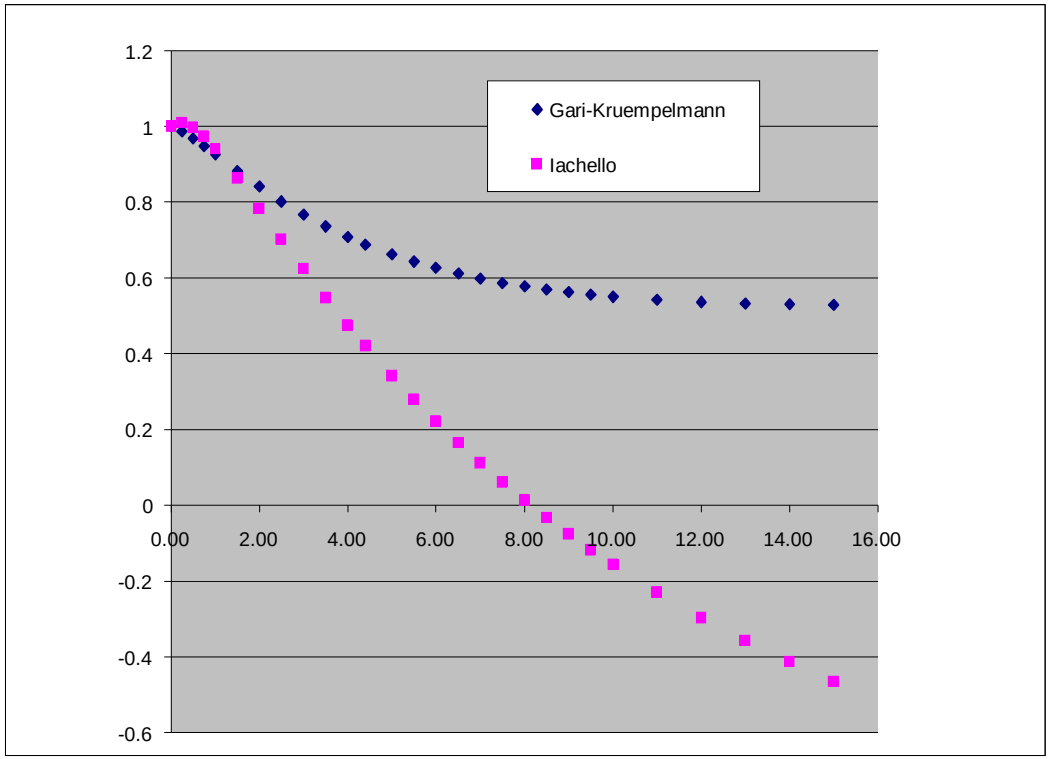
Give rise to problems:

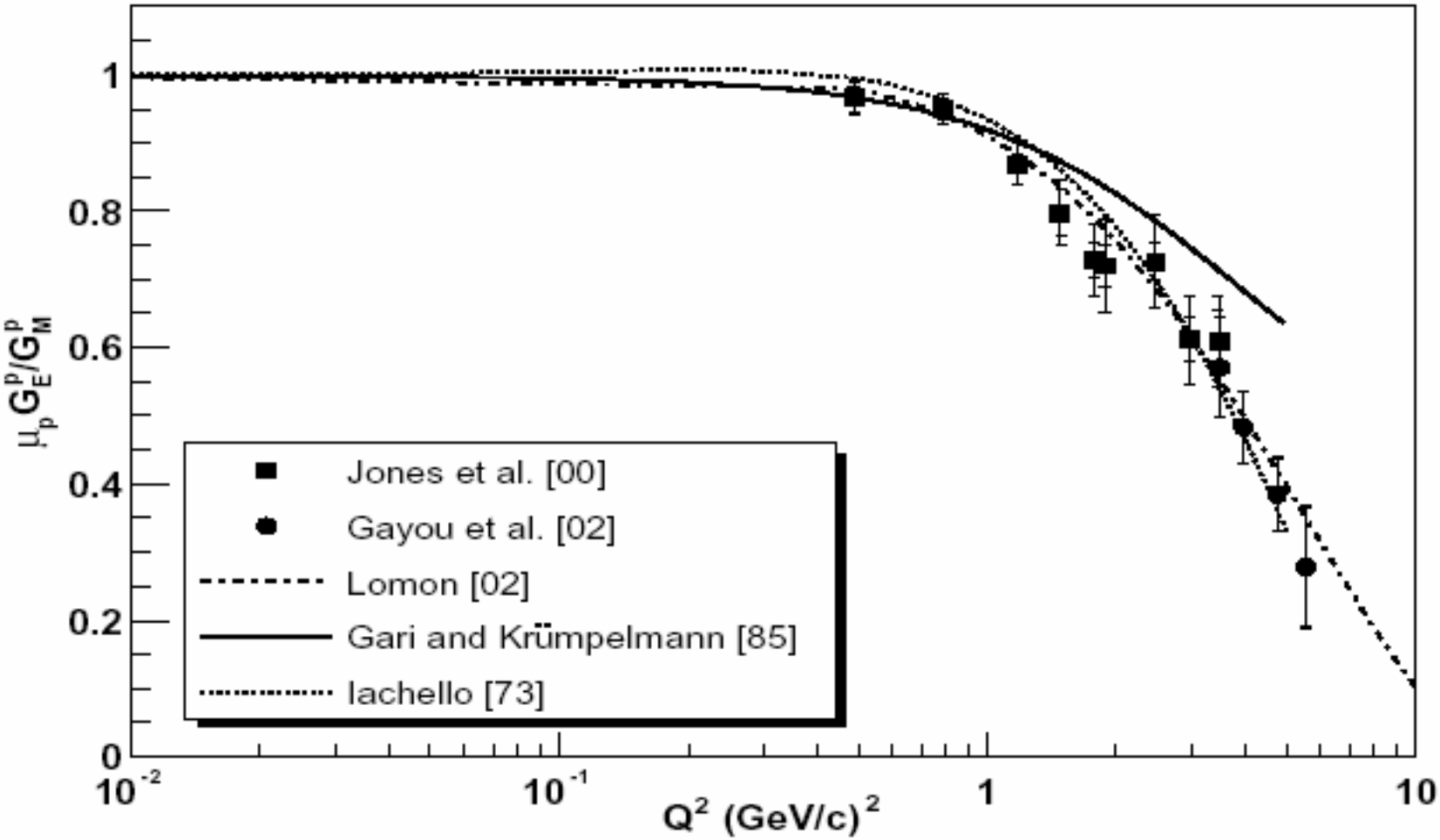
- compatibility with old (Rosenbluth plot) data
- why the ratio G_E/G_M decreases?
- is there any zero in the f.f. ?

VMD models (fits)

FF = F_{intr} * VMD propagators

	Mesons	F_{intr}
JIL	ρ ω ϕ	dipole
		monopole
G K	ρ ω ϕ	
		QCD-interpolation




1
0.8
0.6
0.4
0.2
0
$\mu_p G_E^p/G_M^p$
10^{-2}
10^{-1}
1
10
Q^2 (GeV/c)^2
Jones et al. [00]
Gayou et al. [02]
Lomon [02]
Gari and Krümpelmann [85]
Iachello [73]

Skyrme Model

Holzwarth 1996,2002

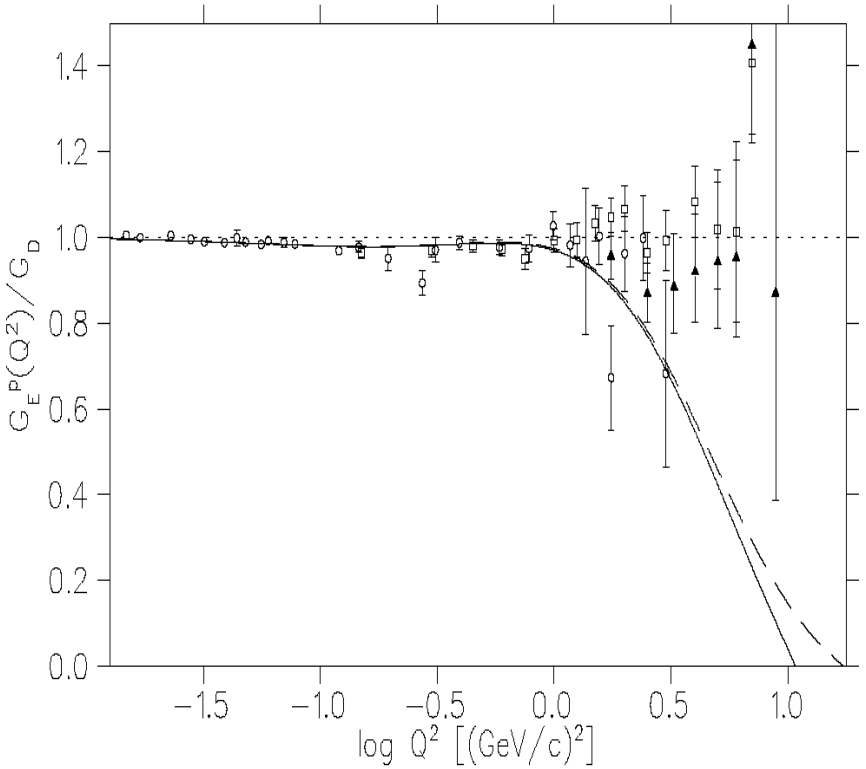
ff given by soliton + VMD

dip at Q^2 3 GeV^2

Boosting of the soliton

dip at Q^2 10 GeV^2

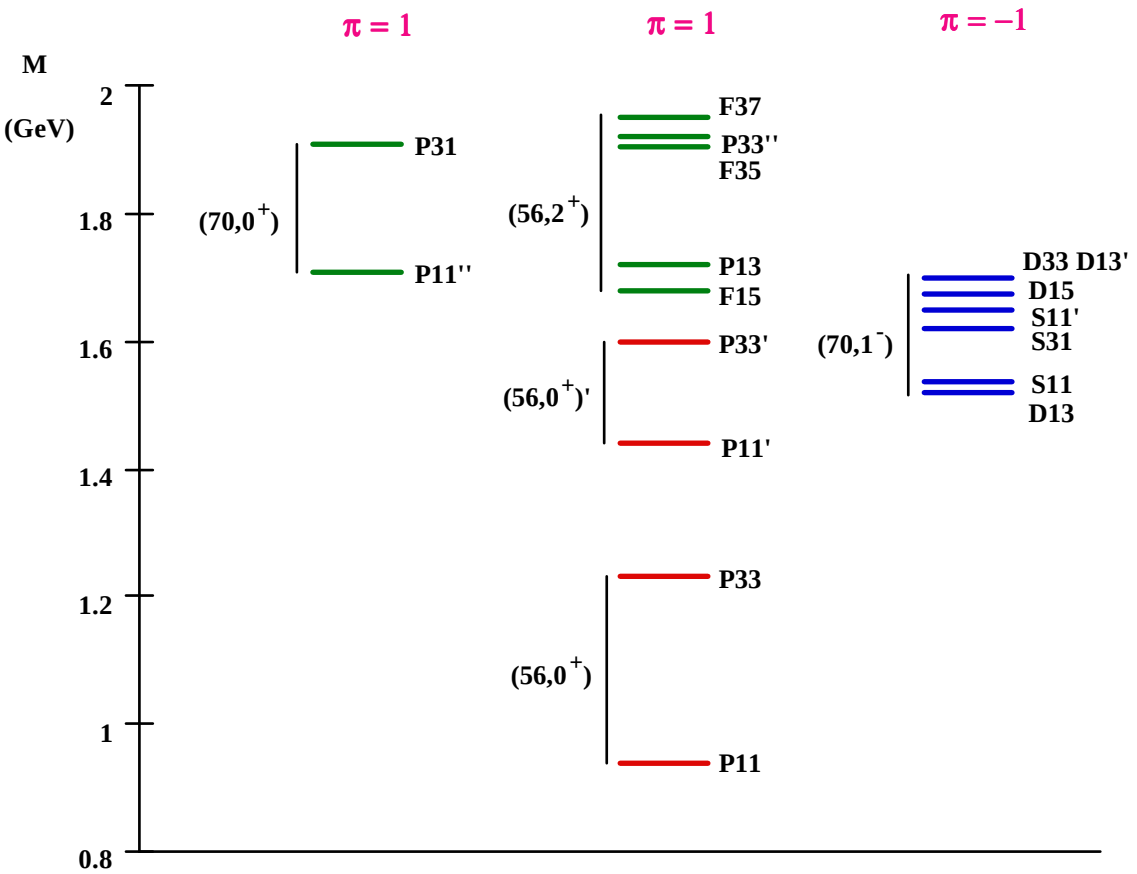
Skyrmion (nucleon) mass 1648 MeV



The Hypercentral Constituent Quark Model

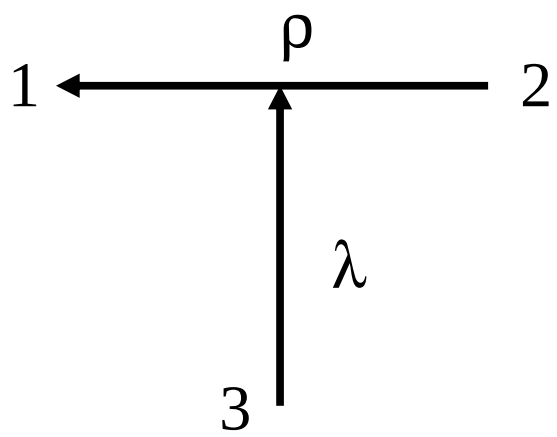
M. Ferraris et al., Phys. Lett. B364, 231 (1995)

PDG 4* & 3*


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

SPACE WAVE FUNCTION

Jacobi coordinates



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

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

Hyperspherical coordinates

$$(\rho, \lambda, \Omega_\rho, \Omega_\lambda) \longrightarrow (x, \xi, \Omega\rho, \Omega\lambda)$$

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

$$\xi = \text{arc tg}\,\frac{\rho}{\lambda} \qquad \text{(shape)}$$

Hypercentral Hypothesis

$$V = V(x)$$

- Factorization

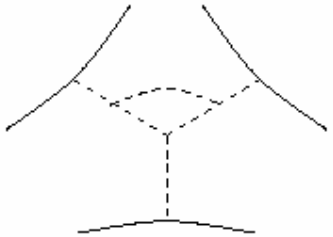
$$\psi(x, t, \Omega_\rho, \Omega_\lambda) = \underset{\text{(“dynamics”)}}{\psi_{\nu\gamma}(x)} \quad \underset{\text{(“geometry”)}}{Y_{[\gamma, l_\rho, l_\lambda]}}$$

ν hyperradial excitation γ grand angular quantum number

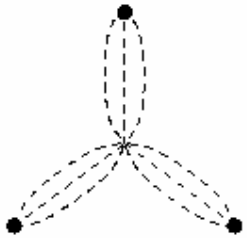
- 3 Body Forces

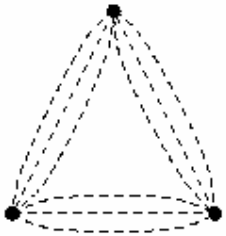
Motivations

- QCD fundamental mechanism



- Flux tube model





- Hypercentral approximation

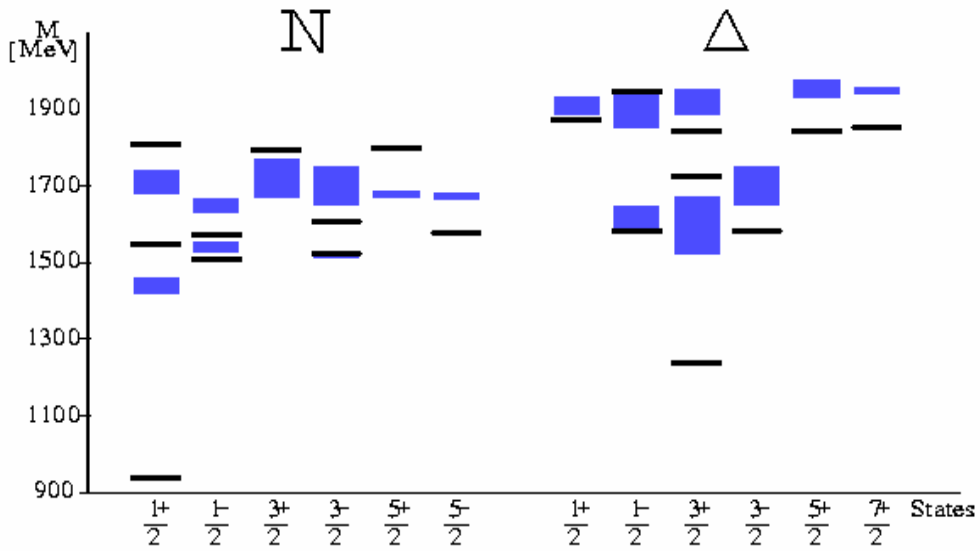
$$\sum_{i<j} V(\mathbf{r}_{ij}) \approx V(x) + \dots$$

Hypercentral Model

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

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

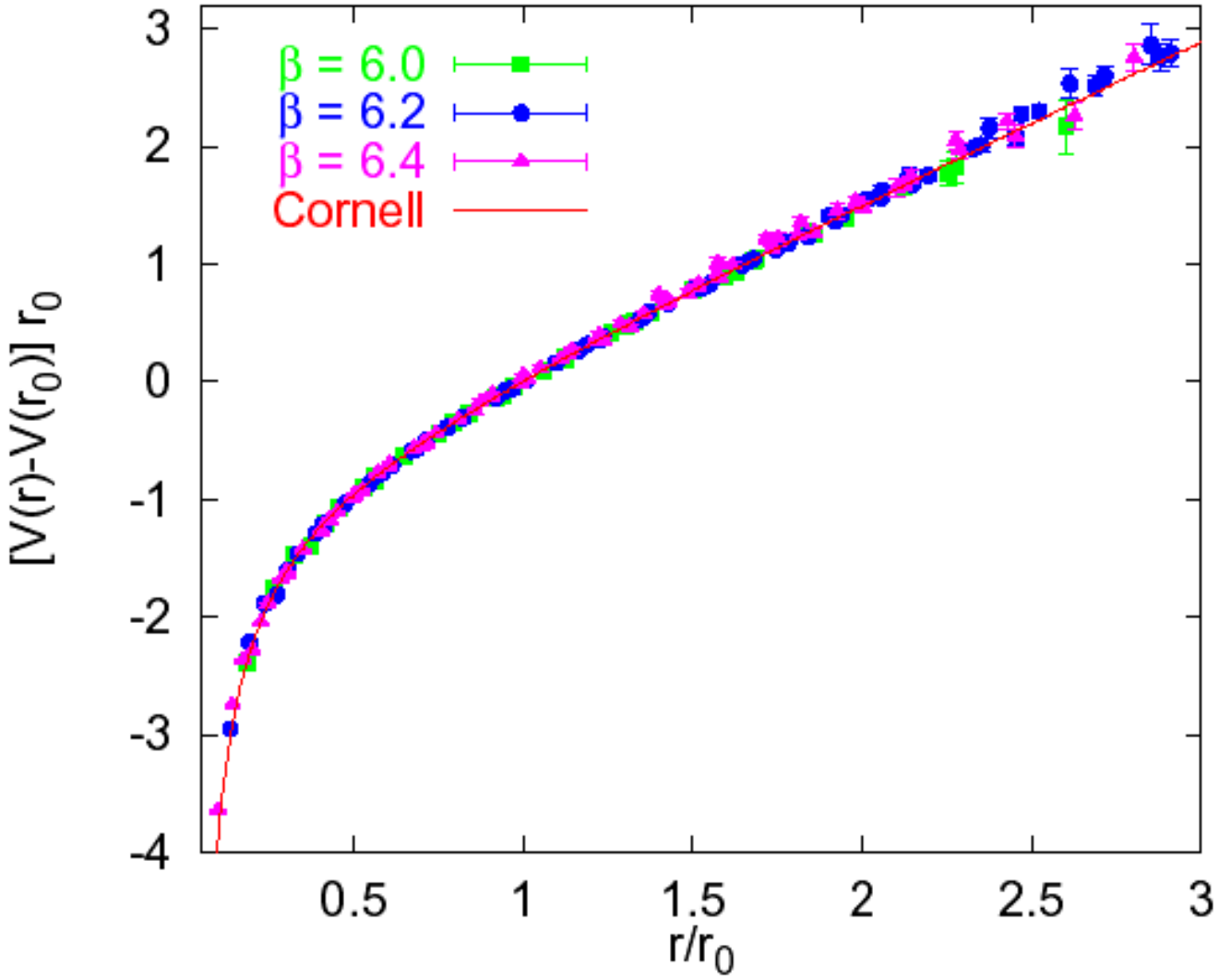


$\tau = 4.59$

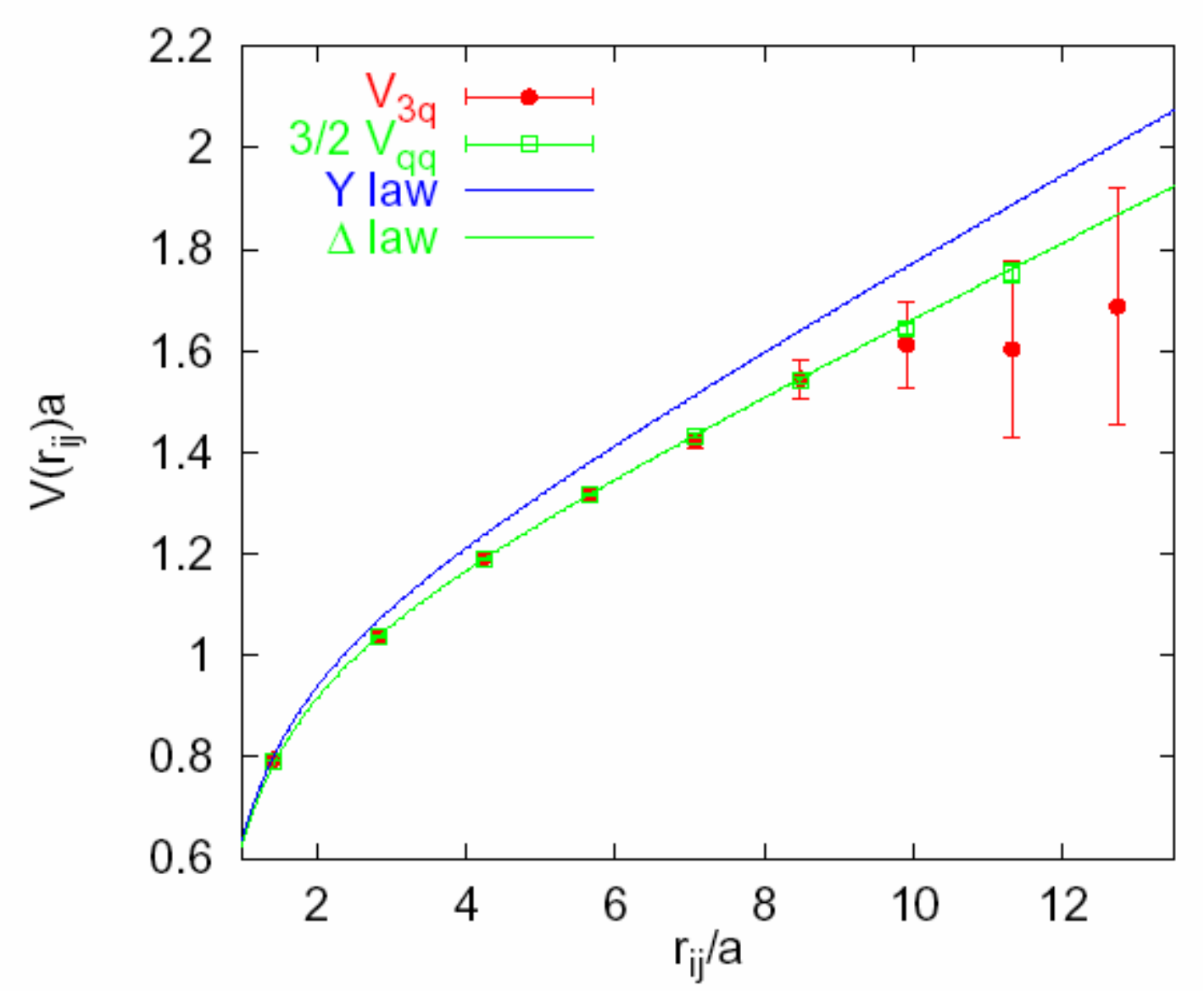
$\alpha = 1.61\ \text{fm}^{-1}$

$\text{A} \Leftarrow (N - \Delta)$

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



3-quark lattice potential G.S. Bali Phys. Rep. 343, 1 (2001)



Electromagnetic properties

- Photocouplings

  M. Aiello et al., PL B387, 215 (1996)

- Helicity amplitudes (transition f.f.)

  M. Aiello et al., J. of Phys. G24, 753 (1998)

- Elastic form factors of the nucleon

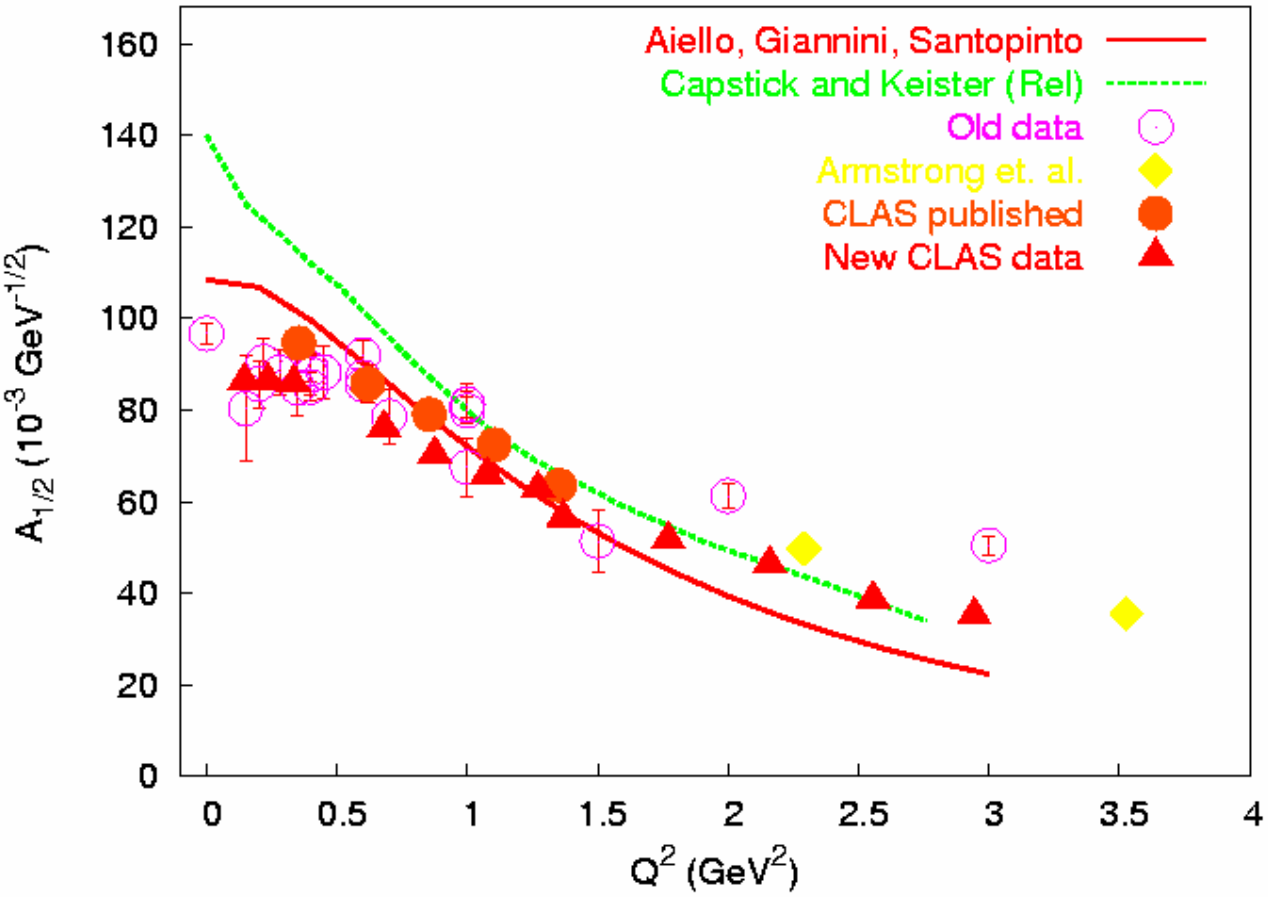
  M. De Sanctis et al., EPJ A1, 187 (1998)

- Structure functions

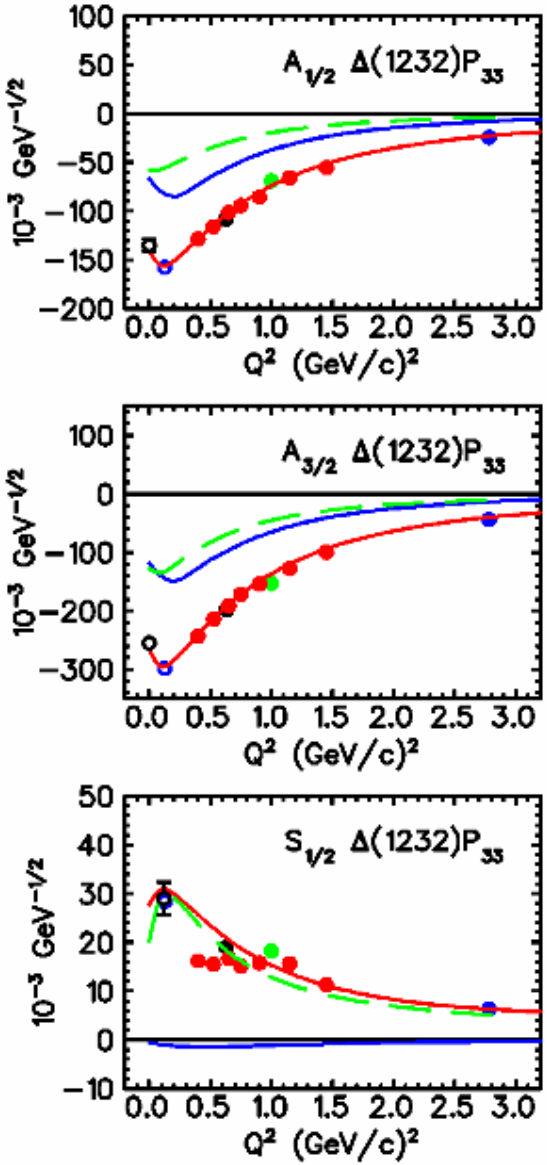
  to be published

Fixed parameters ⟶ predictions

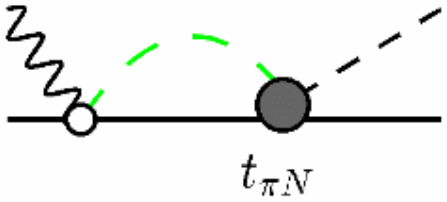
$A^p_{\frac{1}{2}}\ N(1535)S11$



Dynamical model (Mainz group)



— — — pion cloud contribution

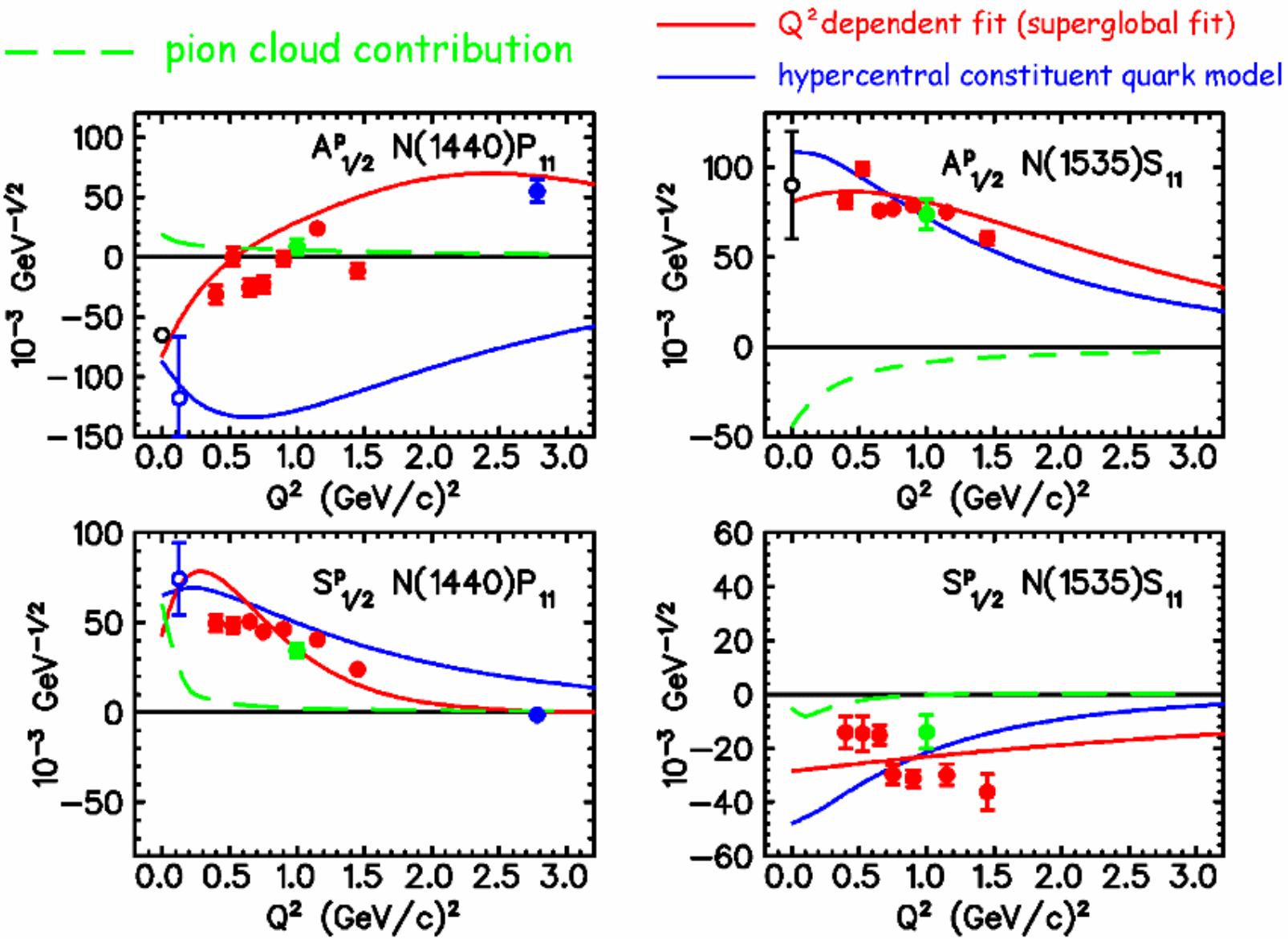


is included in phenomenlogical approach

but not in the constituent quark model

—— Q^2 dependent fit (superglobal fit)

—— hypercentral constituent quark model


pion cloud contribution
Q² dependent fit (superglobal fit)
hypercentral constituent quark model
A^p_1/2 N(1440)P11
A^p_1/2 N(1535)S11
S^p_1/2 N(1440)P11
S^p_1/2 N(1535)S11
10⁻³ GeV⁻¹/²
Q² (GeV/c)²

please note

- the calculated proton radius is about 0.5 fm

(value previously obtained by fitting the helicity amplitudes)

- not good for elastic form factors
- there is lack of strength at low Q^2 (outer region) in the e.m. transitions
- emerging picture: quark core (0.5 fm) plus (meson or sea-quark) cloud

ELASTIC FORM FACTORS

1. - Relativistic corrections to the elastic form factors

2. - Results with the semirelativistic CQM

3. - Introduction of Quark form factors

1.- 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

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

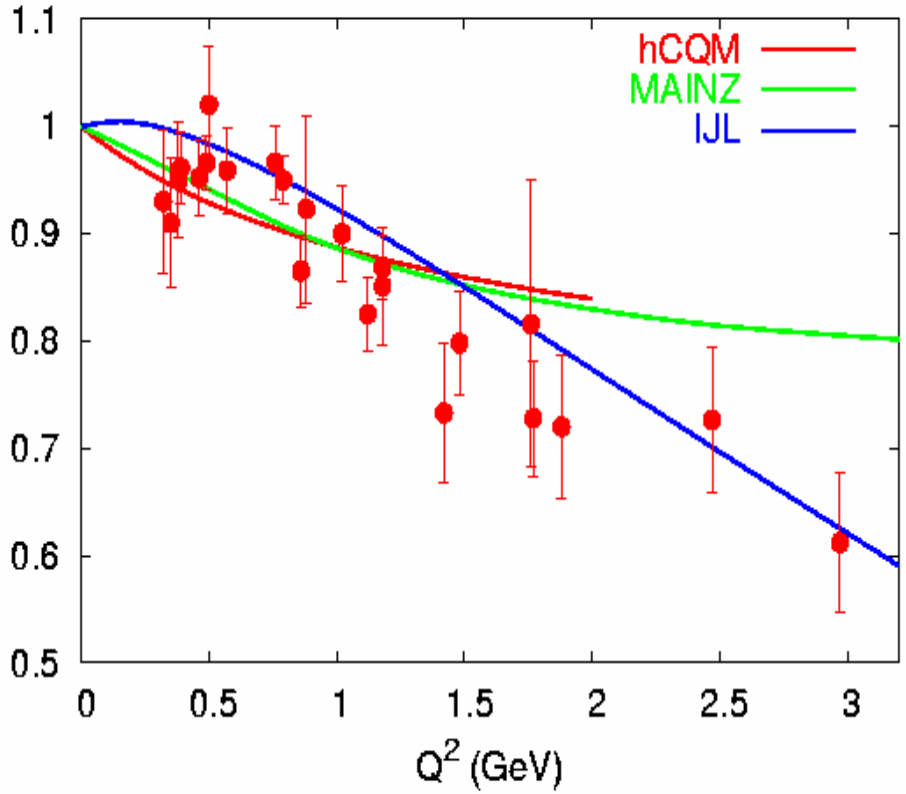
F = kin factor

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

Elastic Form Factors in the hCQM

M. De Sanctis, M.M. Giannini, L. Repetto, E. Santopinto, Phys. Rev. **C62**, (2000) 025208.

$\mu_p\, G_E^p(Q^2)/G_M^p(Q^2)$



calculated

NO QUARK
FORM FACTORS

T_{NR}, BOOSTS, CURRENT EXPANSION

2.- Results with the semirelativistic

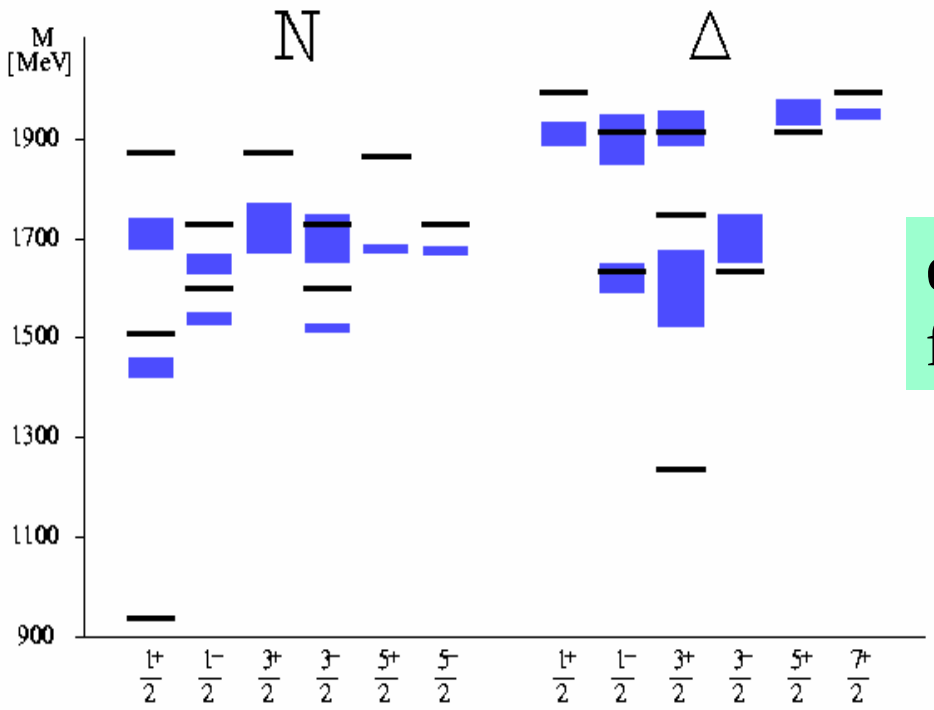
M. De Sanctis, M. Giannini., E. Santopinto, A. Vassallo,
Nucl. Phys. **A**.**755**,294(2005)

- Relativistic kinetic energy
- Boosts to initial and final states
- Expansion of current to any order
- Conserved current

Hypercentral Model

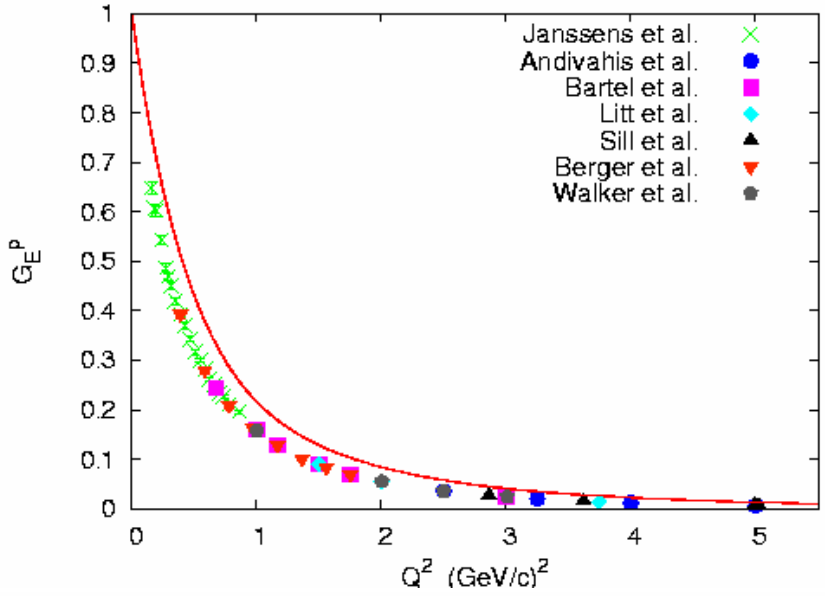
$$H_{3q} = \sum_{i=1}^{3} \sqrt{\mathbf{p}_i^2 + m^2} + V(x) + H_{hyp}$$

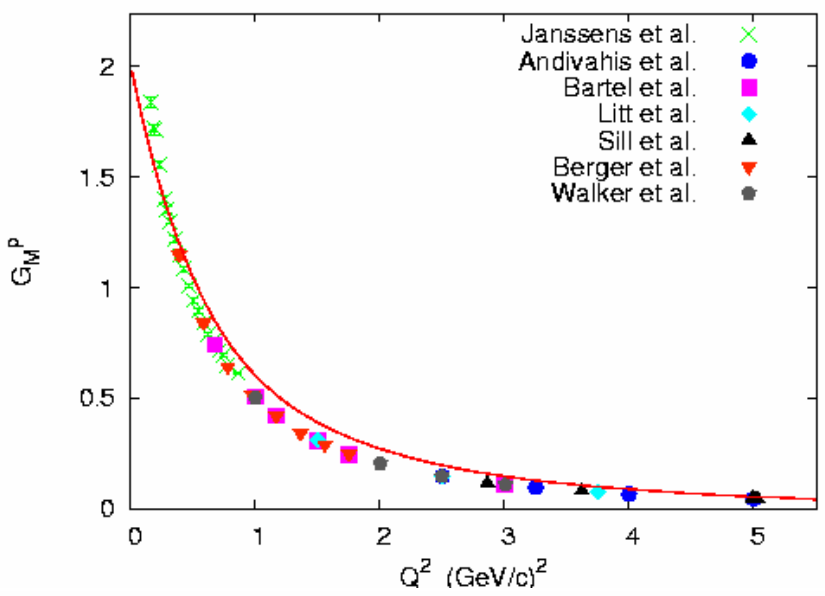
M. M. Giannini, E. Santopinto and A. Vassallo, To be published.

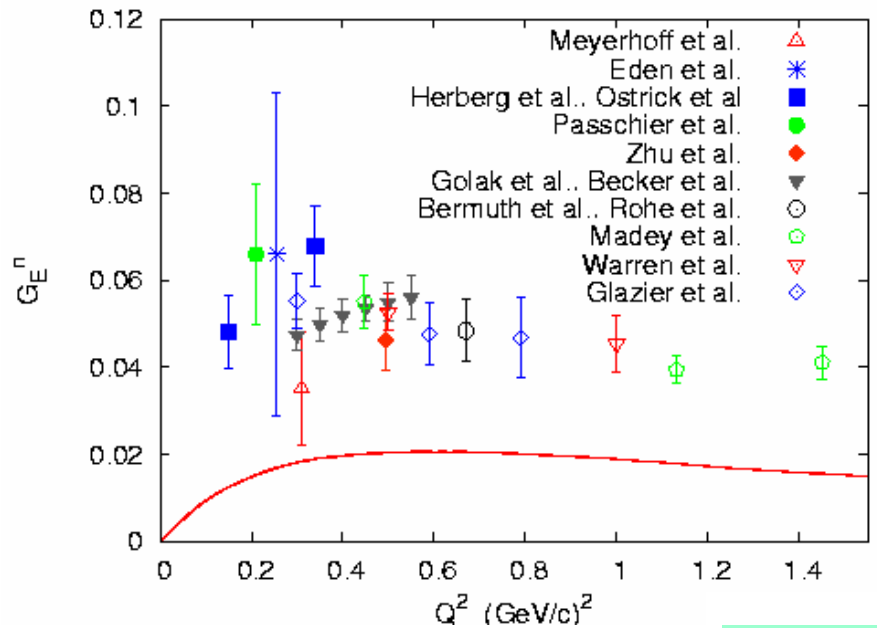


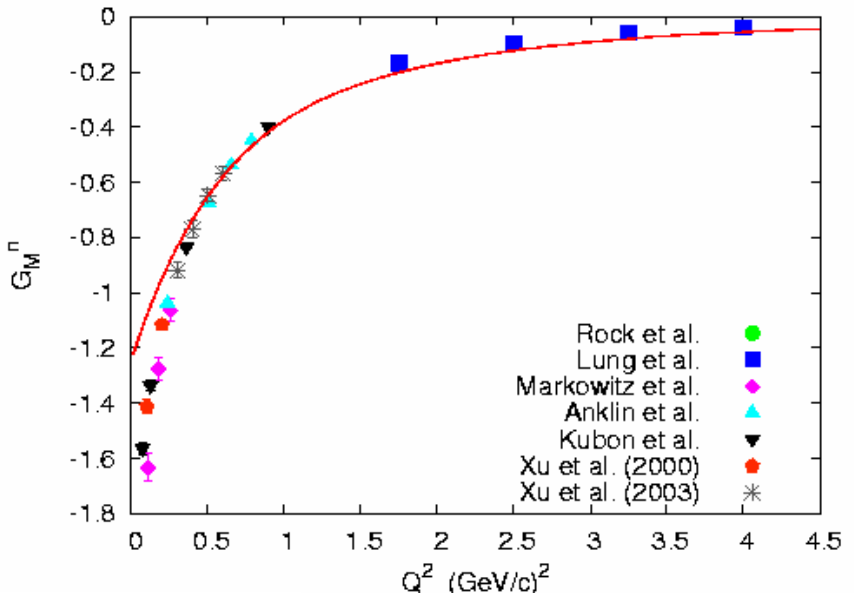
$V(x) = - \tau/x + \alpha\, x$

α and τ not much different from the NR case

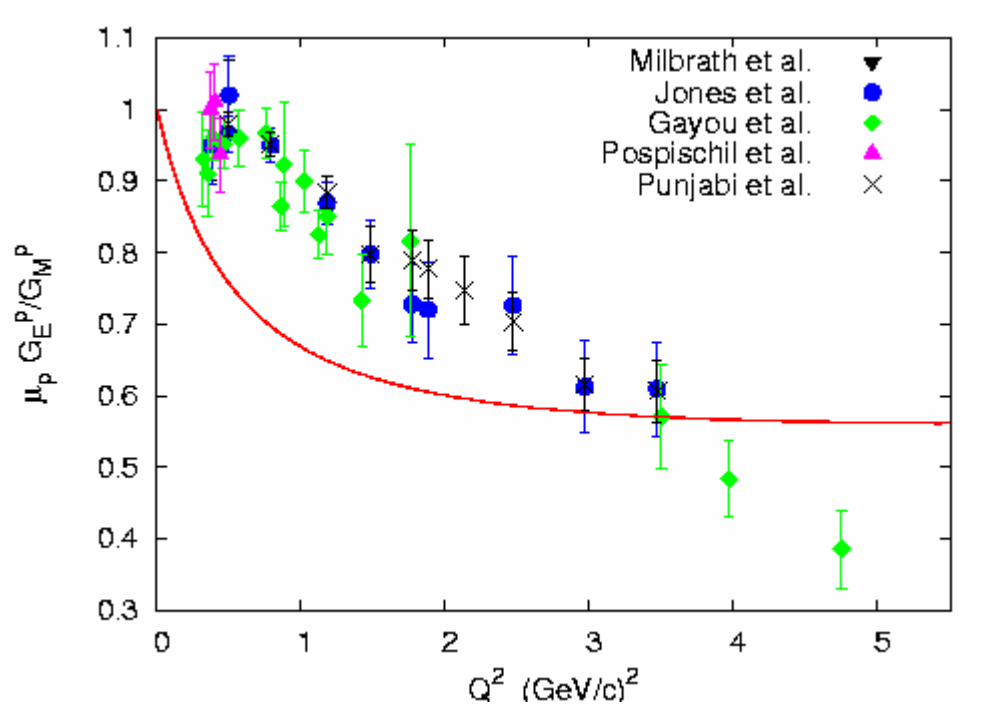


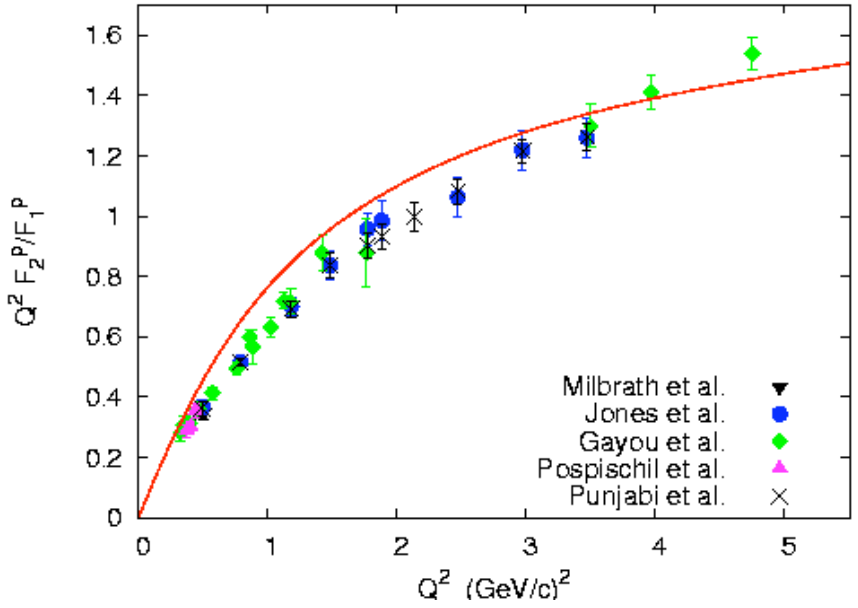






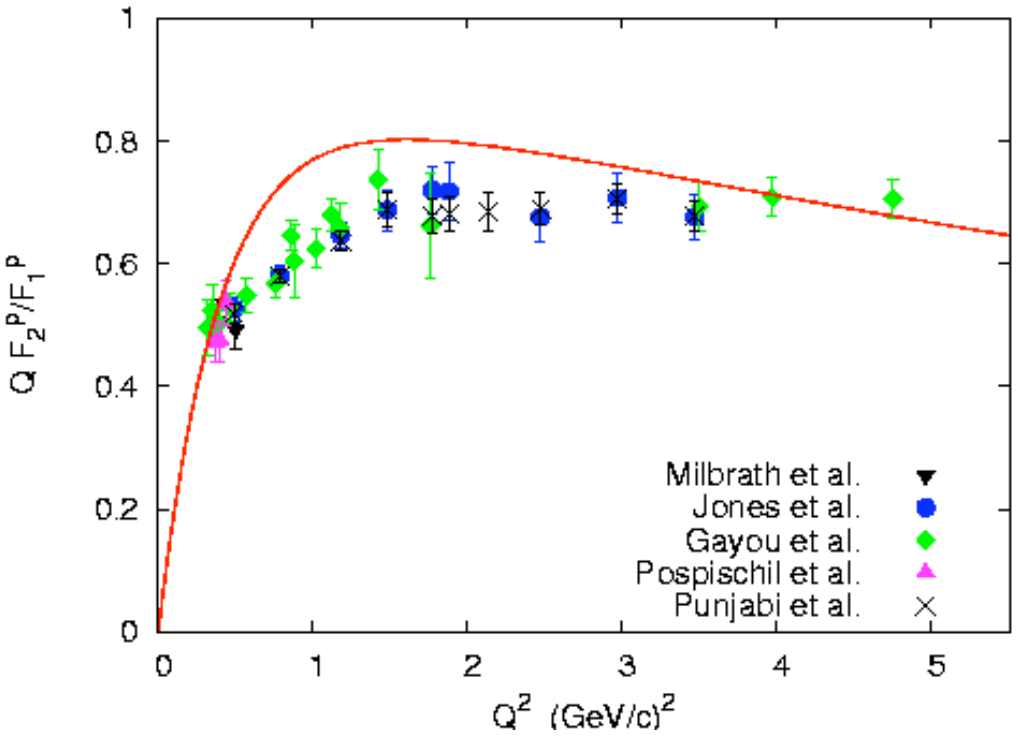
Calculated values!


Milbrath et al.
Jones et al.
Gayou et al.
Pospischil et al.
Punjabi et al.
$\mu_p G_E^p/G_M^p$
Q^2 (GeV/c)^2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0
1
2
3
4
5



$Q^2\ F_2^p/F_1^p$

$Q\ F_2^p/F_1^p$



3.- Quark form factors

M. De Sanctis, M. Giannini, E. Santopinto, A. Vassallo,
Nucl. Phys. **A**.**755**,294(2005)

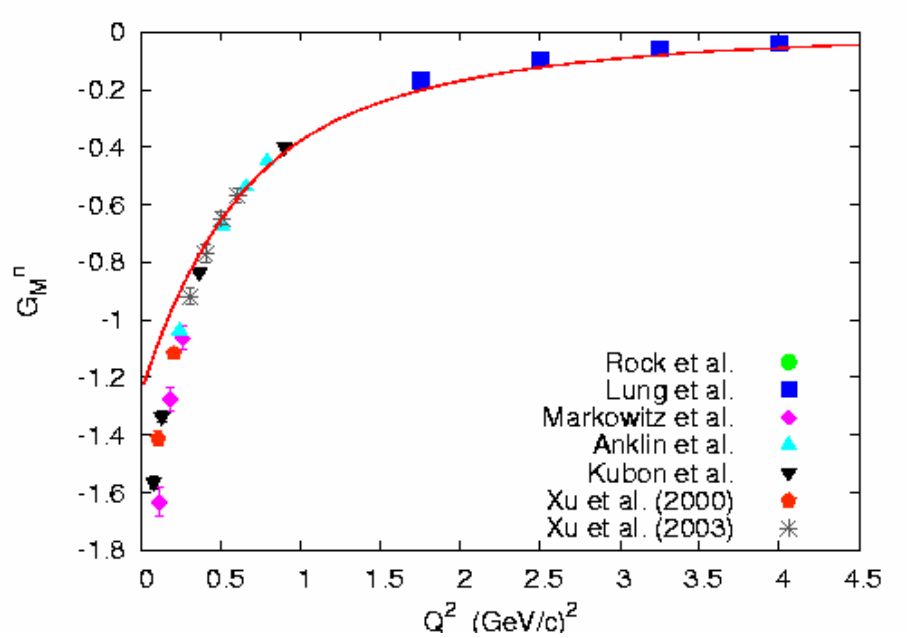
- Quark form factors are added into the current

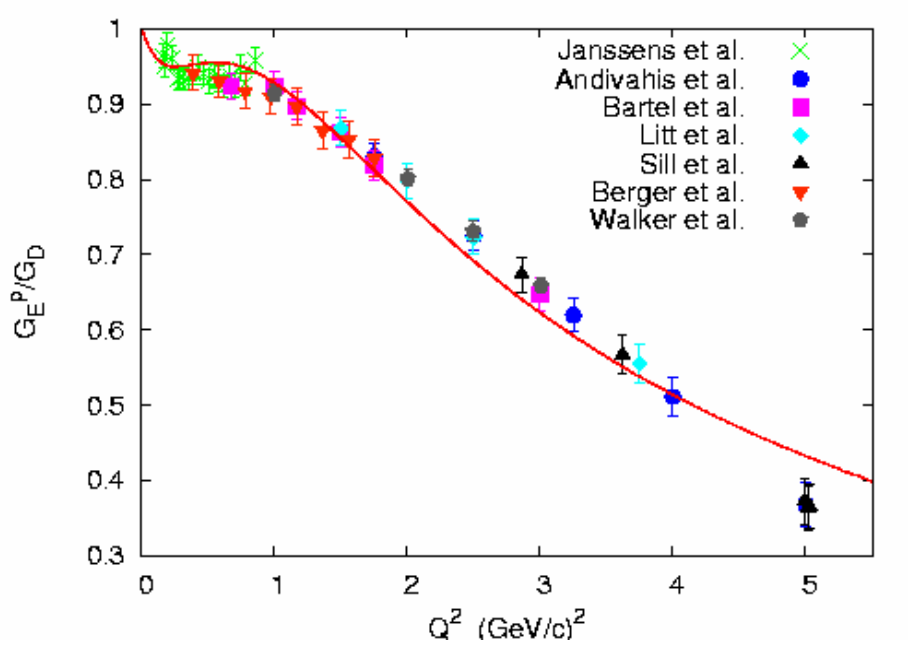
  ff = F_{intr} * quark form factors

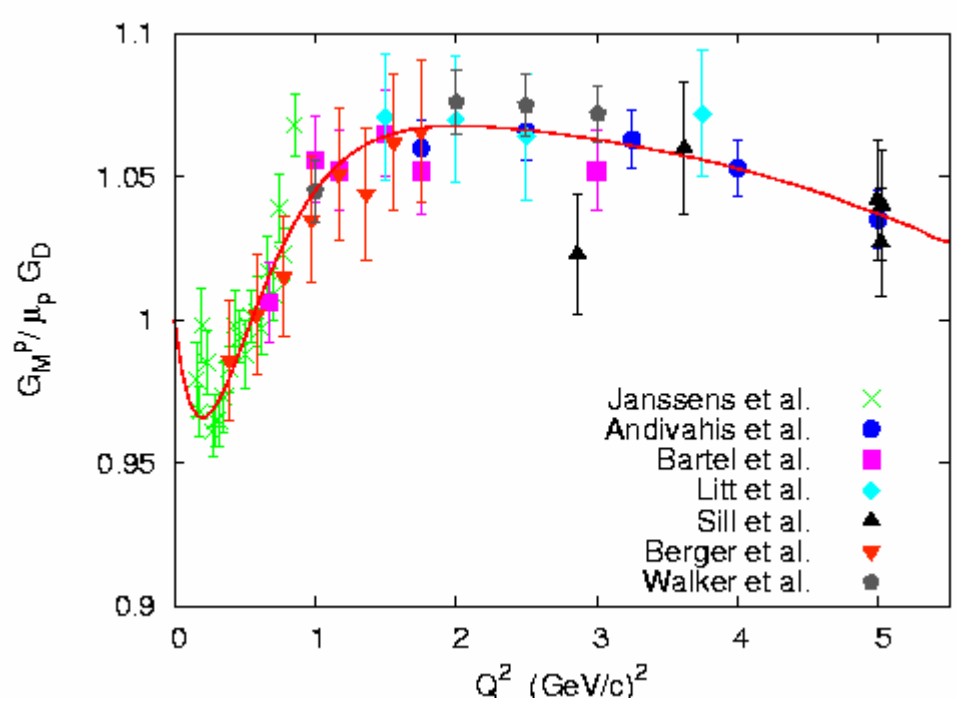
  ↑

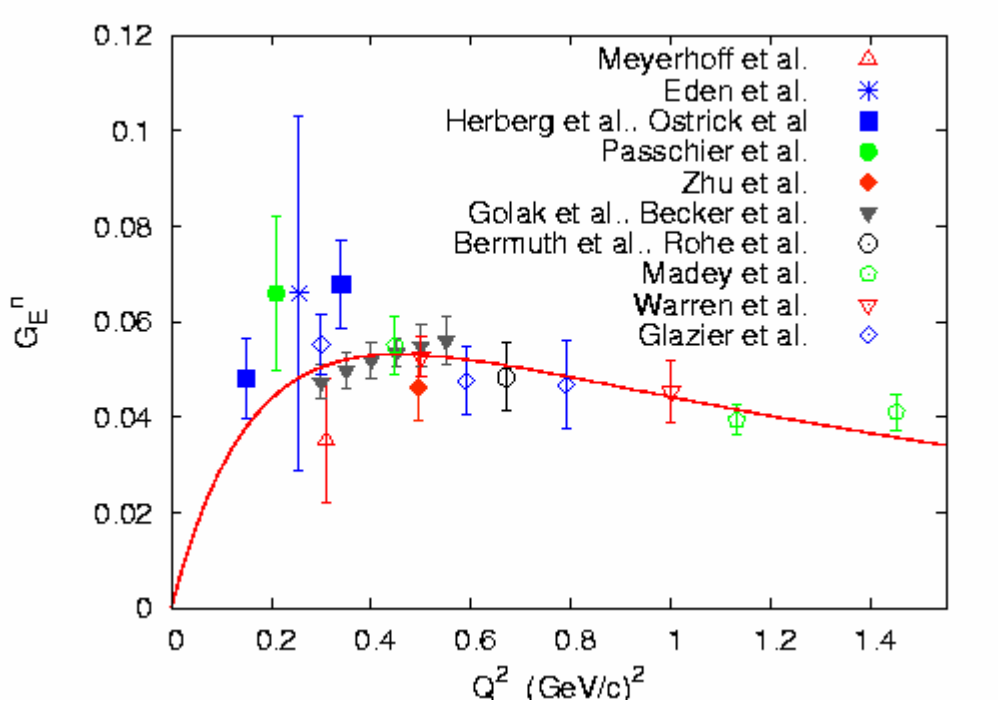
  semirelativistic hCQM input (calculated)

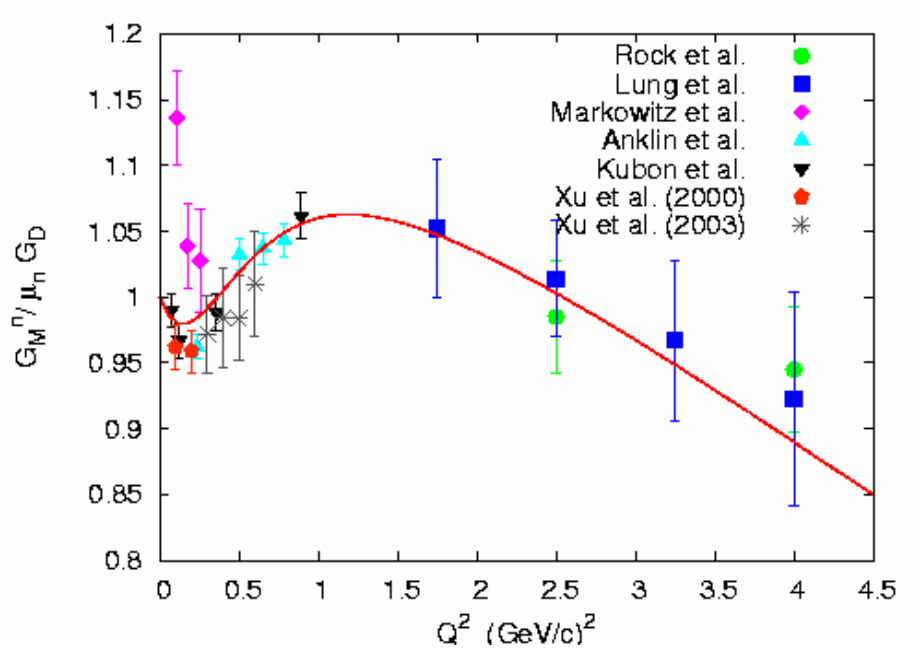
- Monopole + dipole form for qff
- Fit of:
  - G_E^p/G_M^p ratio (polarization data)
  - G_M^p; G_E^n ;G_M^n

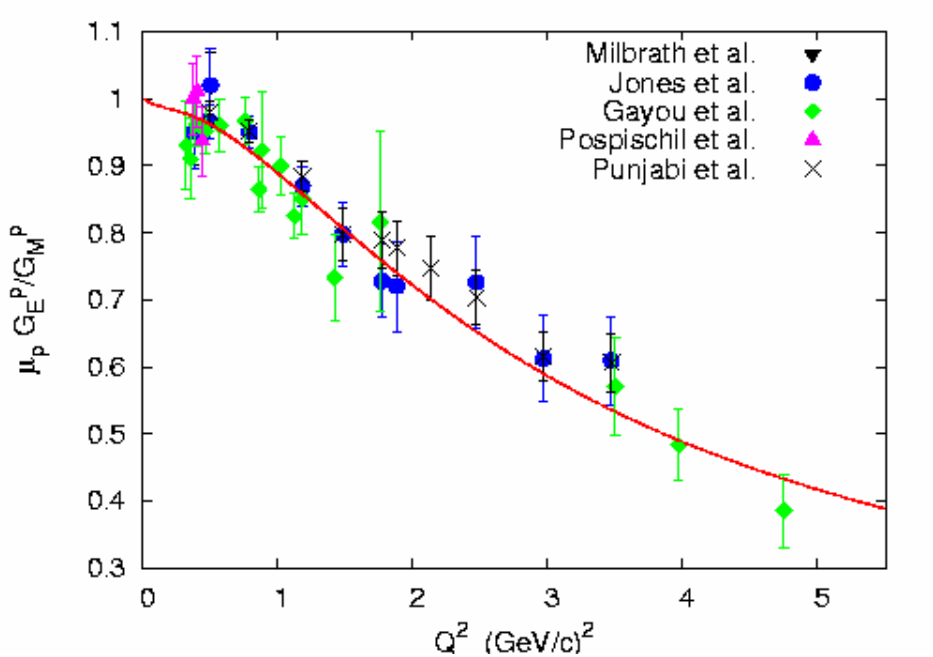

G_M^n
Q^2 (GeV/c)^2
Rock et al.
Lung et al.
Markowitz et al.
Anklin et al.
Kubon et al.
Xu et al. (2000)
Xu et al. (2003)

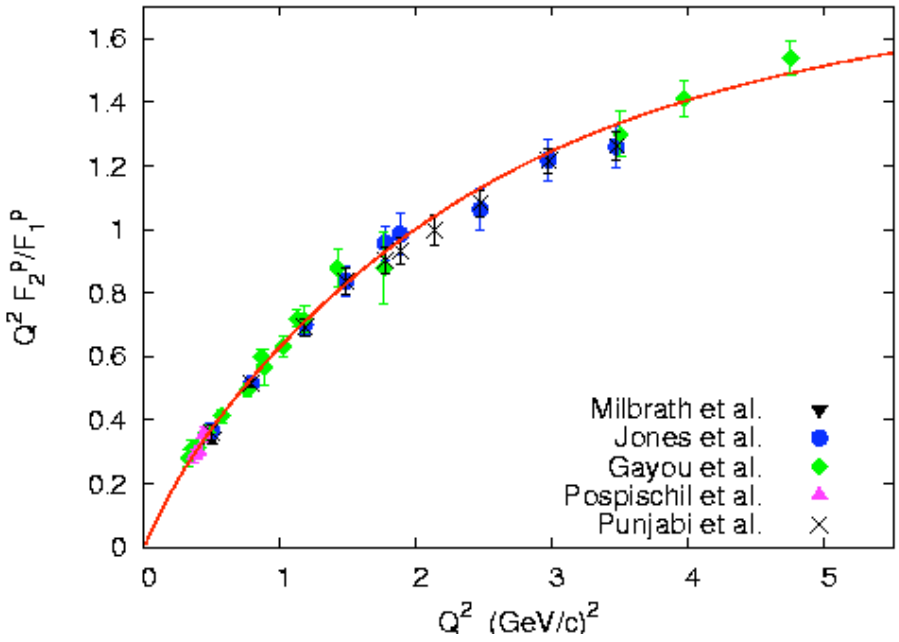

G_E^p/G_D
Q^2 (GeV/c)^2
Janssens et al.
Andivahis et al.
Bartel et al.
Litt et al.
Sill et al.
Berger et al.
Walker et al.


1.1
1.05
1
0.95
0.9
0
1
2
3
4
5
$G_M^p / \mu_p G_D$
Q^2 (GeV/c)^2
Janssens et al.
Andivahis et al.
Bartel et al.
Litt et al.
Sill et al.
Berger et al.
Walker et al.


0.12
0.1
0.08
0.06
0.04
0.02
0
G_E^n
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Q^2 (GeV/c)^2
Meyerhoff et al.
Eden et al.
Herberg et al.. Ostrick et al
Passchier et al.
Zhu et al.
Golak et al.. Becker et al.
Bermuth et al.. Rohe et al.
Madey et al.
Warren et al.
Glazier et al.

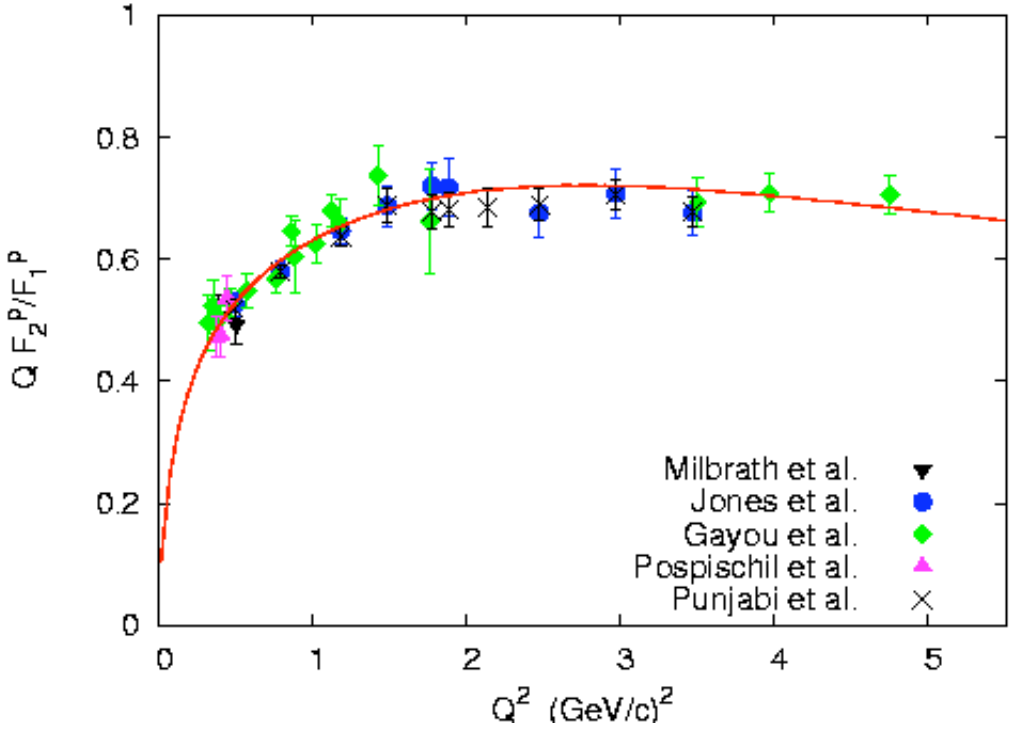

Rock et al.
Lung et al.
Markowitz et al.
Anklin et al.
Kubon et al.
Xu et al. (2000)
Xu et al. (2003)
$G_M^n / \mu_n G_D$
Q^2 (GeV/c)^2


Milbrath et al.
Jones et al.
Gayou et al.
Pospischil et al.
Punjabi et al.
$\mu_p G_E^p / G_M^p$
Q^2 (GeV/c)^2



$Q^2\ F_2^p/F_1^p$

$Q\ F_2^p/F_1^p$



Conclusion

- The hCQM provides a consistent framework for the description of all the 4 nucleon electromagnetic form factors
- Relativity is crucial in explaining the decrease of the ratio G_E/G_M
- Quark form factors are necessary in order to get a good reproduction of the Q^2 behaviour