Goldstone-Boson-Exchange Dynamics for Constituent Quarks

Willibald Plessas

Institut für Theoretische Physik, Karl-Franzens-Universität Graz

Graz, Austria

Collaborations / Collaborators:

Pavia (Italy)
S. Boffi
M. Radici

Iowa City (USA)
W. Klink

Oak Ridge (USA)
K. Varga

Graz (Austria)
K. Berger
L. Glozman
T. Melde
R. Wagenbrunn

Pittsburgh, October 10th, 2002

OUTLINE

* Background & Characteristics of the Goldstone-Boson-Exchange Constituent Quark Model (GBE CQM)
* Baryon Spectroscopy
* Electroweak Nucleon Structure
* Baryon Resonance Decays
* Conclusions/Outlook

QUARK MODEL HAMILTONIAN

$$H_{CQM} = \sum_i \sqrt{\vec{p}_i^{\,2} + m_i^2}$$ kinetic energy (relativistic)

$$+ \sum_{i<j} V_{conf}(i,j)$$ confinement interaction

$$+ \sum_{i<j} V_{hyperf}(i,j)$$ hyperfine interaction

Requirements:

- Selfadjoint operator on a Hilbert space (theory with a finite # of particles)
- Meet the symmetries of low-energy QCD
- Fulfill the conditions of Poincaré invariance

ASSUMPTIONS GBE CQM

- Constituent Quarks : Q

  ⇝ Effective objects (quasiparticles) of low-energy QCD

  Dynamical mass $m_Q \gg m_q$

- Goldstone bosons : GB

  ⇝ $SU(3)_V$ remains after $SB\chi S$

  9 pseudoscalar GBs :

$$\underbrace{\pi^+, \pi^0, \pi^-, K^+, K^-, \bar{K}^0, \eta}_{\text{octet}} ; \underbrace{\eta'}_{\text{singlet}}$$

Nonperturbative Determination of Quark Masses in Quenched Lattice QCD with the Kogut-Susskind Fermion Action

S. Aoki,[1] M. Fukugita,[2] S. Hashimoto,[3] K-I. Ishikawa,[4] N. Ishizuka,[1,5] Y. Iwasaki,[1,5] K. Kanaya,[1,5] T. Kaneda,[1] S. Kaya,[3] Y. Kuramashi,[3] M. Okawa,[3] T. Onogi,[4] S. Tominaga,[3] N. Tsutsui,[4] A. Ukawa,[1,5] N. Yamada,[4] and T. Yoshié[1,5]

(JLQCD Collaboration)

[1]*Institute of Physics, University of Tsukuba, Tsukuba, Ibaraki 305-8571, Japan*
[2]*Institute for Cosmic Ray Research, University of Tokyo, Tanashi, Tokyo 188-8502, Japan*
[3]*High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki 305-0801, Japan*
[4]*Department of Physics, Hiroshima University, Higashi-Hiroshima, Hiroshima 739-8526, Japan*
[5]*Center for Computational Physics, University of Tsukuba, Tsukuba, Ibaraki 305-8577, Japan*
(Received 26 January 1999)

We report results of quark masses in quenched lattice QCD with the Kogut-Susskind fermion action, employing the regularization independent scheme of Martinelli *et al.* to nonperturbatively evaluate the renormalization factor relating the bare quark mass on the lattice to that in the continuum. Calculations are carried out at $\beta = 6.0$, 6.2, and 6.4, from which we find $m_{ud}^{\overline{\rm MS}}(2\ \mathrm{GeV}) = 4.23(29)$ MeV for the average up and down quark mass and, with the ϕ meson mass as input, $m_s^{\overline{\rm MS}}(2\ \mathrm{GeV}) = 129(12)$ MeV for the strange mass in the continuum limit. These values are about 20% larger than those obtained with the one-loop perturbative renormalization factor. [S0031-9007(99)09226-1]

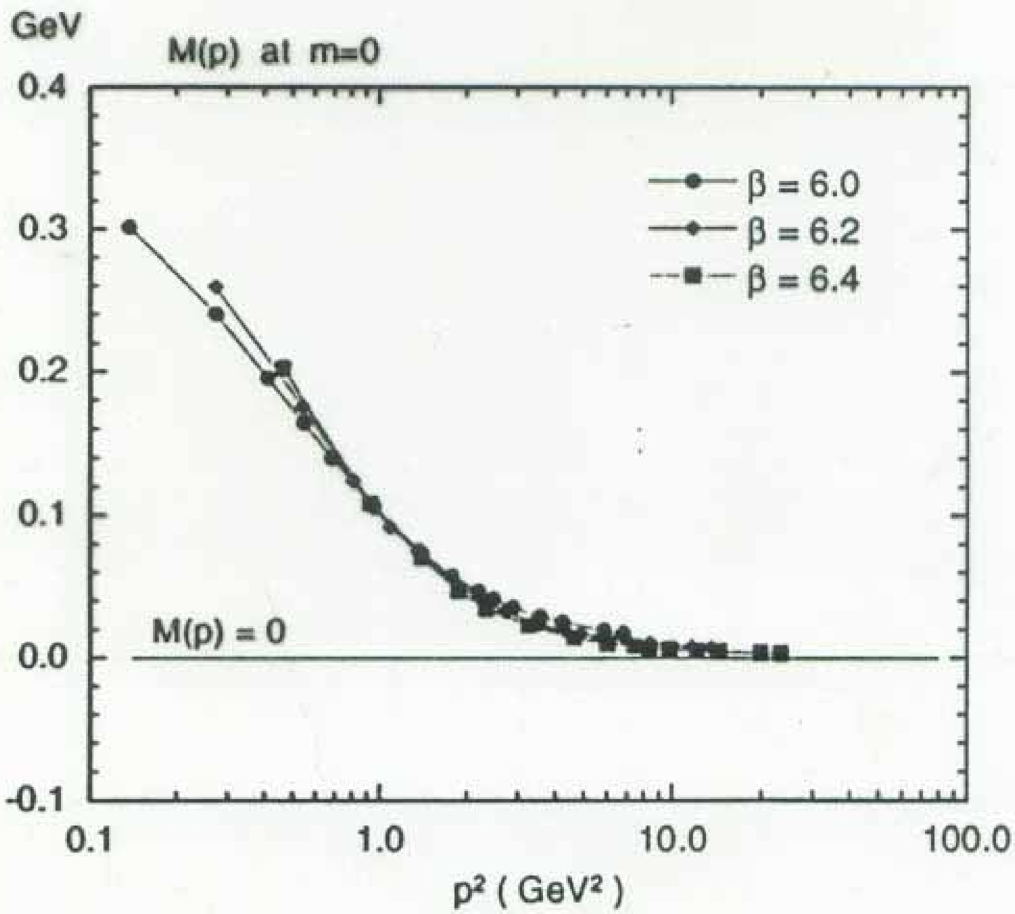


FIG. 2. $M(p)$ in the chiral limit.

GBE DYNAMICS

L. Ya. Glozman & D.O. Riska, Phys. Rep. 268 (1996) 263

Beyond the scale of SBχS:

Effective fields:

1. Constituent quark (fermion) fields: Ψ
2. Goldstone boson fields: ϕ

$SU(3)_F$: $\mathcal{L}_{int} \sim \bar{\Psi} i \gamma_5 \vec{\lambda}^F \cdot \vec{\phi}\, \Psi + \bar{\Psi} \sigma \Psi$

Gell-Mann flavor matrices

σ-field

(i.e. SU(3) analogue of SU(2) σ-model)

Instantaneous approx., nonrel. derivation:

$$\Rightarrow V_\chi(i,j) = \frac{g^2}{4\pi} \frac{1}{12 m_i m_j} \vec{\lambda}_i^F \cdot \vec{\lambda}_j^F \; \vec{\sigma}_i \cdot \vec{\sigma}_j \cdot$$

$$\cdot \left[\mu^2 \frac{e^{-\mu r_{ij}}}{r_{ij}} - 4\pi \delta(\vec{r}_{ij}) \right] +$$

GBE CQM

(Glozman, Plessas, Varga, Wagenbrunn:
PRD 58 (1998) 094030)

$$H_0 = \sum_{i=1}^{3} \sqrt{\vec{p}_i^{\,2} + m_i^2}$$

$$V_{conf}(i,j) = V_0 + C\, r_{ij}$$

$$V_{hyperf}(i,j) = \frac{g_\gamma^2}{4\pi} \frac{1}{12 m_i m_j} \vec{\lambda}_i^F \cdot \vec{\lambda}_j^F \; \vec{\sigma}_i \cdot \vec{\sigma}_j \times$$

$$\times \left[\mu_\gamma^2 \frac{e^{-\mu_\gamma r_{ij}}}{r_{ij}} - \Lambda_\gamma^2 \frac{e^{-\Lambda_\gamma r_{ij}}}{r_{ij}} \right]$$

$(\gamma = \pi, K, \eta, \eta')$

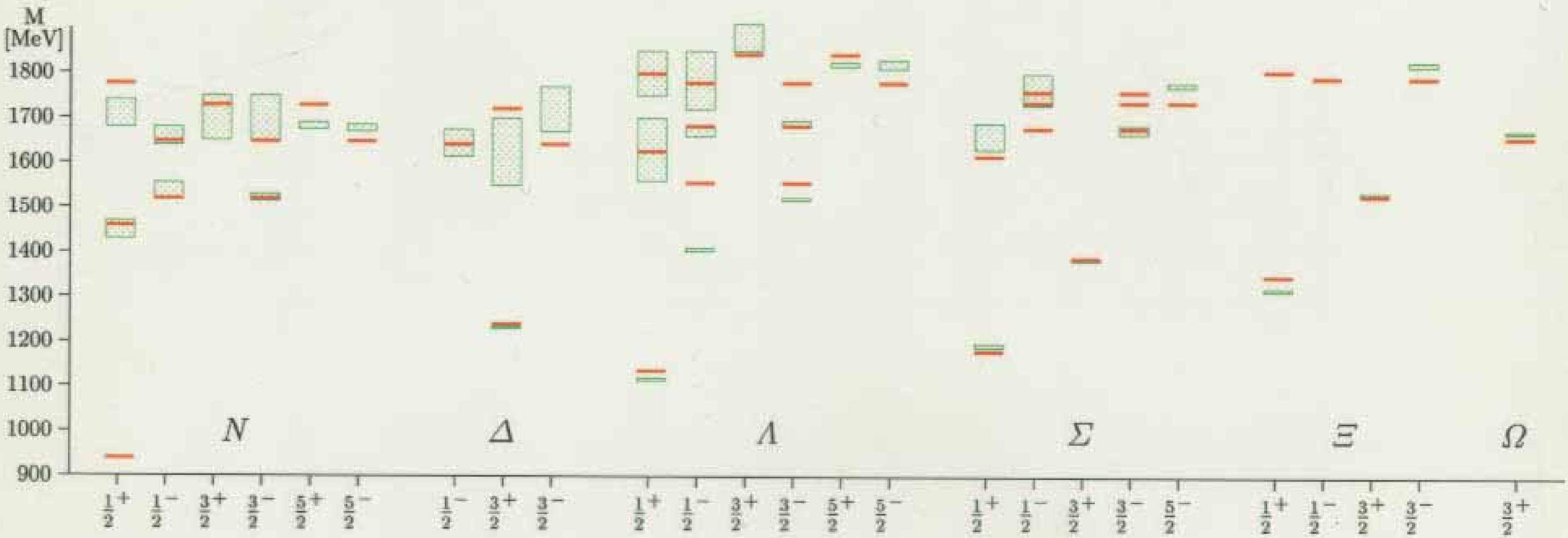
Parameters:

g_0/g_8	$\varkappa$	$\Lambda_0\,[\mathrm{fm}^{-1}]$	$C\,[\mathrm{fm}^{-2}]$	$V_0\,[\mathrm{MeV}]$
1.34	0.81	2.87	2.33	−416

$$\Lambda_\gamma = \Lambda_0 + \varkappa \mu$$

Light and strange baryon spectra

(ps. Goldstone-boson-exchange constituent-quark model)



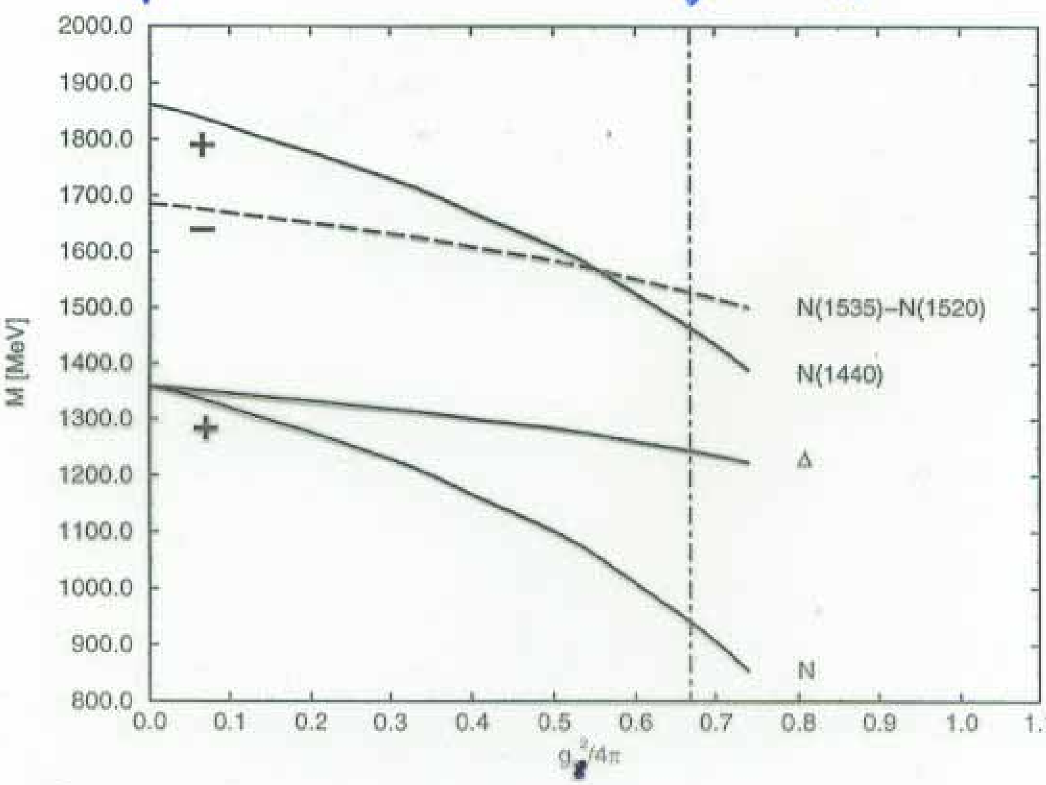
L. Ya. Glozman, W. Plessas, K. Varga, R. F. Wagenbrunn: PRD 58 (1998) 094030

EFFECT OF GBE Q-Q POTL.

only confinement

level crossing

final value of coupling constant $\frac{g_8^2}{4\pi} = 0.67$



$\longmapsto$ Increasing strength of V_χ^{GBE}

(semi-relativistic case)

Quenched lattice QCD (w. overlap fermions)

F. X. Lee et al.: hep-lat/0208070

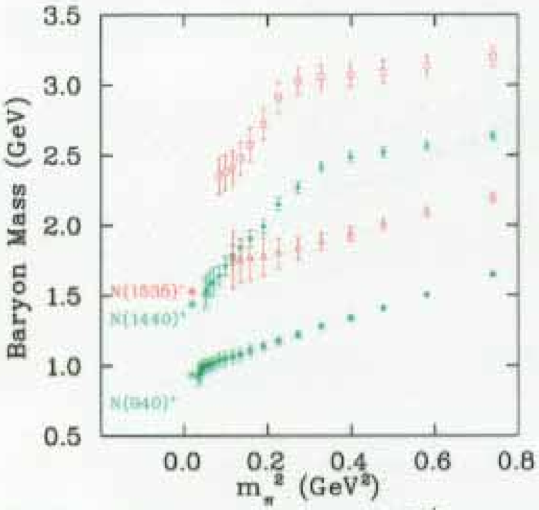


Figure 1. Solid symbols denote $N(\frac{1}{2}^+)$ states: ground (•) and 1st-excited (⋆). Empty symbols denote $N(\frac{1}{2}^-)$ states: lowest (△) and 2nd lowest (□). The experimental points (∗) are taken from PDG [1].

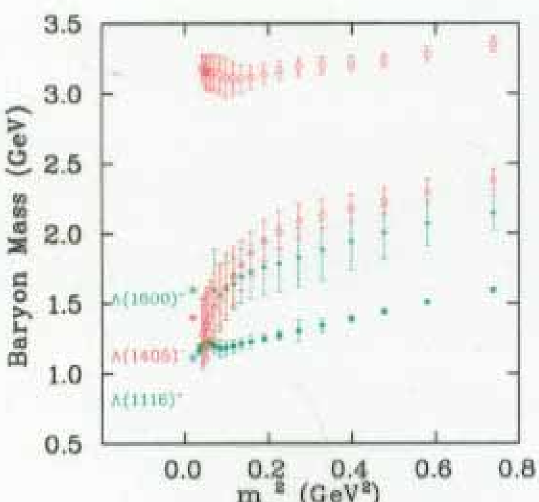


Figure 2. Similar to Fig. 1, but for $\Lambda(\frac{1}{2}^\pm)$ states.

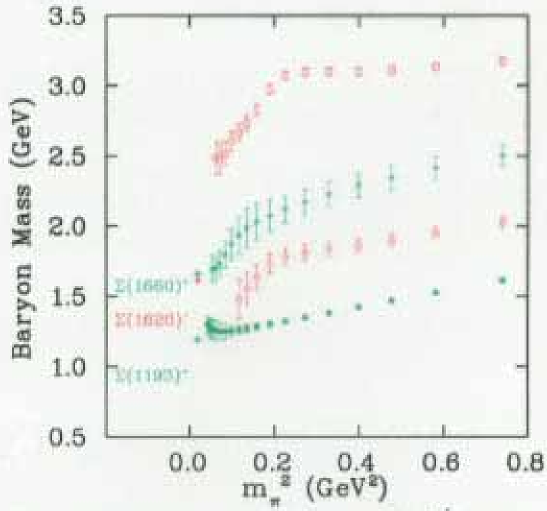


Figure 3. Similar to Fig. 1, but for $\Sigma(\frac{1}{2}^\pm)$ states.

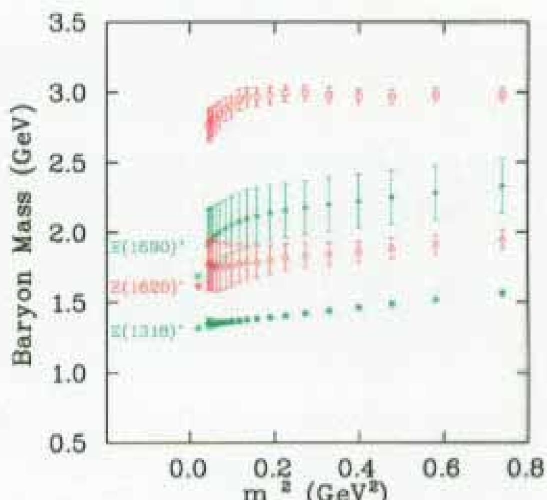
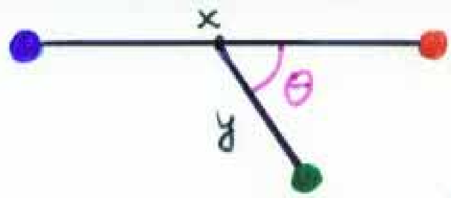


Figure 4. Similar to Fig. 1, but for $\Xi(\frac{1}{2}^\pm)$ states.

ANGLE-INTEGRATED 3-Q WAVE FCTS.

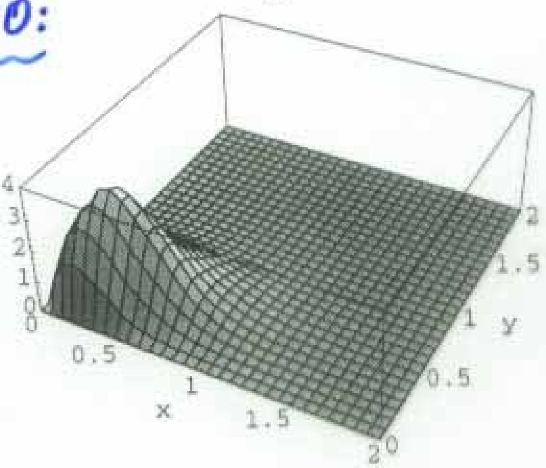
Jacobi coordinates:



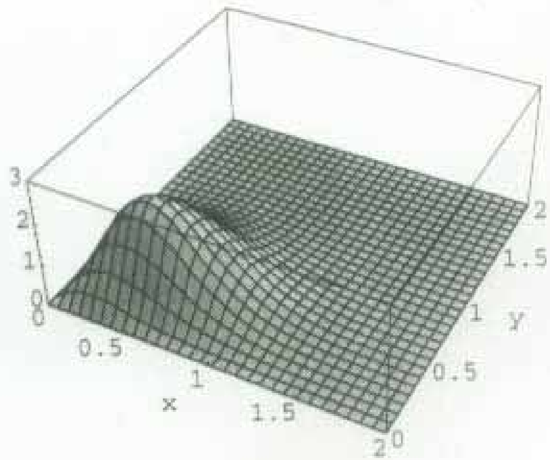
(distances in fm)

L=0:

N

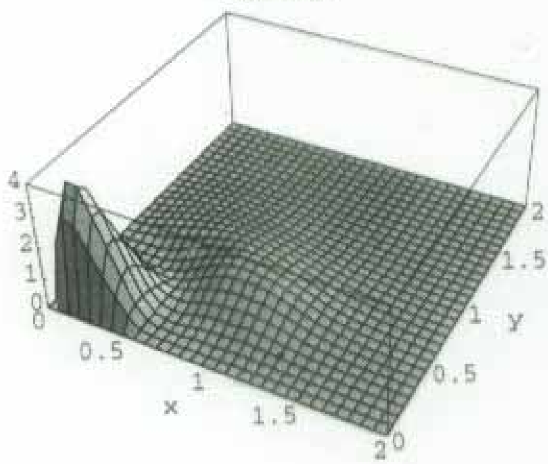


Delta(1232)

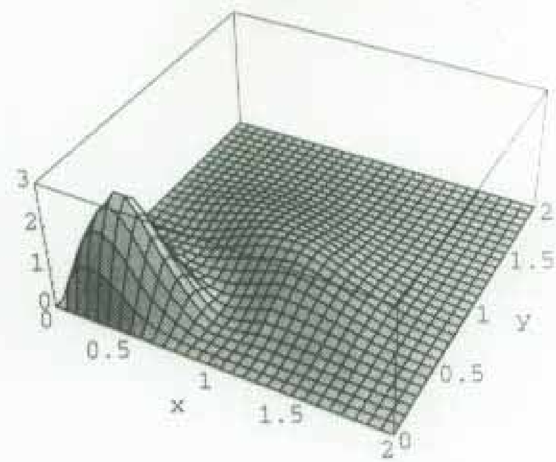


L=0:

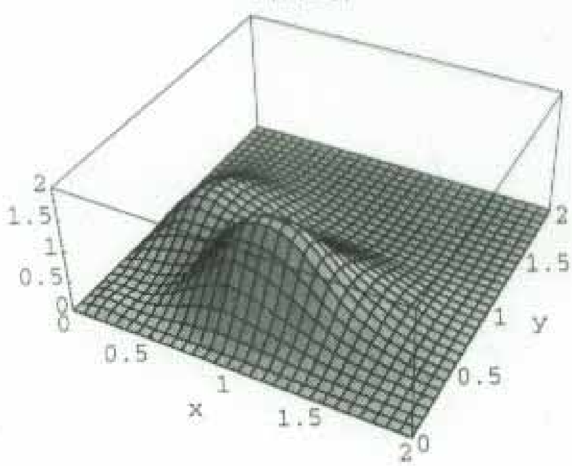
N(1440)



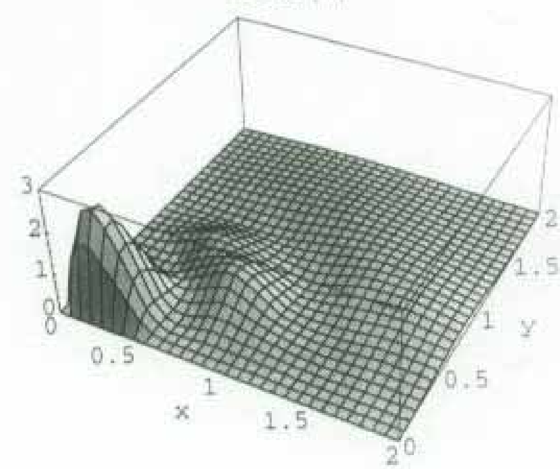
Delta(1600)



N(1710)

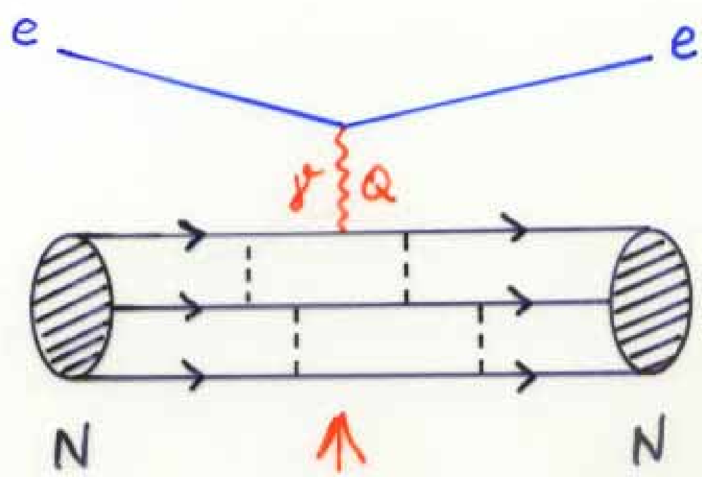


Delta(?)



ELASTIC e-N SCATTERING

(E.m. nucleon form factors)



$$p^{in}_{Breit} = \begin{pmatrix} E_N \\ 0 \\ 0 \\ -\frac{Q}{2} \end{pmatrix} \qquad \begin{pmatrix} E_N \\ 0 \\ 0 \\ +\frac{Q}{2} \end{pmatrix} = p^{out}_{Breit}$$

$$q_{Breit} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ Q \end{pmatrix} = p^{out}_{Breit} - p^{in}_{Breit}$$

Calculate this process in

Point-form relativistic QM

DIFFERENT FORMS OF REL. QM

P^μ ...... four-momentum
K^ℓ ..... Lorentz-boost
} operators

Poincaré group commutators, especially:

$[P^\mu, P^\nu] = 0$

$[P^i, K^\ell] = \delta_{i\ell} P^0 \rightsquigarrow$ linear momenta & Lorentz boosts give energy

$\Rightarrow$ Interactions either in $\vec{P}$ or in $\vec{K}$ (or in both)

Dirac, 1949:

Three sets of Poincaré group operators minimally affected by interactions:

$\left.\begin{array}{l}\text{instant form}\\ \text{front form}\\ \text{point form}\end{array}\right\}$ relativistic QM

POINT-FORM REL. QM

All interactions are put into the four-momentum operators P^μ.
Lorentz-boost operators remain interaction-free;

($\hat{=}$ Lorentz boosts are purely kinematical).

Free case: $$P^\mu_{fr} = M_{fr} V^\mu_{fr}$$

$$M^2_{fr} = P^\mu_{fr} P_{fr,\mu}$$

Interaction case: $$P^\mu = (M_{fr} + M_I) V^\mu_{fr} = M V^\mu_{fr}$$

$$M^2 = P^\mu P_\mu$$

(Bakamjian-Thomas constr.)

Equations of motion:

(*) $$i \frac{\partial}{\partial x_\mu} |\Psi(x)\rangle = P^\mu |\Psi(x)\rangle$$

$$|\Psi(x)\rangle \in \mathcal{H}$$

$$\left(\frac{\partial}{\partial x^\mu} \frac{\partial}{\partial x_\mu} - M^2\right) |\Psi(x)\rangle = 0$$

$|\Psi(x)\rangle$.... simultaneous eigenstates of

INVARIANT FORM FACTORS

The invariant nucleon/baryon FFs are defined as current matrix elements in the standard frame (Breit frame):

$$2M F^{\mu}_{\Sigma'\Sigma}(Q^2) =$$

$$= \langle v'(st), M, J, \Sigma' \,|\, J^{\mu}(0) \,|\, v(st), M, J, \Sigma \rangle$$

with

$$q^{\mu} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ Q \end{pmatrix} \quad ; \quad Q^2 = -q^{\mu} q_{\mu} \geq 0$$

SACHS FORM FACTORS

Electric form factor : $G_E(Q^2)$

Magnetic form factor : $G_M(Q^2)$

$$F^{\mu=0}_{\Sigma'\Sigma}(Q^2) = G_E(Q^2)\,\delta_{\Sigma'\Sigma}$$

$$F^{\mu=1,2}_{\Sigma'\Sigma}(Q^2) = \frac{Q}{M}\,G_M(Q^2)\,\delta_{\Sigma',\Sigma\pm1}$$

($F^{\mu=3}_{\Sigma'\Sigma}(Q^2)$ is not needed !)

Electric radius : r_E

Magnetic moment : μ

$$r_E^2 = -6\,\frac{dG_E(Q^2)}{dQ^2}\bigg|_{Q^2=0}$$

$$\mu = G_M(Q^2=0)$$

CURRENT MATRIX ELEMENTS

$$\langle v'(st), M, j, \Sigma' \,|\, J^\mu(0) \,|\, v(st), M, j, \Sigma \rangle \sim$$

$$\sim \sum_{\mu_i', \mu_i} \int d^3v' \, d^3k_2' \, d^3k_3' \, d^3v \, d^3k_2 \, d^3k_3 \, \delta(\vec{v}' - \vec{v}'(st)) \, \delta(\vec{v} - \vec{v}(st))$$

$$\Psi^*_{M, j, \Sigma'}(\vec{k}_i', \mu_i') \cdot \Psi_{M, j, \Sigma}(\vec{k}_i, \mu_i)$$

$$\langle v', \vec{k}_i', \mu_i' \,|\, J^\mu(0) \,|\, v, \vec{k}_i, \mu_i \rangle \sim$$

$$\sim \sum_{\substack{\mu_i', \mu_i \\ \sigma_i', \sigma_i}} \int d^3k_2' \, d^3k_3' \, d^3k_2 \, d^3k_3$$

$$\Psi^*_{M, j, \Sigma'}(\vec{k}_i', \mu_i') \cdot \Psi_{M, j, \Sigma}(\vec{k}_i, \mu_i)$$

$$\prod_{\sigma_i'} D^*_{\sigma_i' \mu_i'}[R_W(k_i, B(v'))] \cdot$$

$$\prod_{\sigma_i} D_{\sigma_i \mu_i}[R_W(k_i, B(v))] \cdot$$

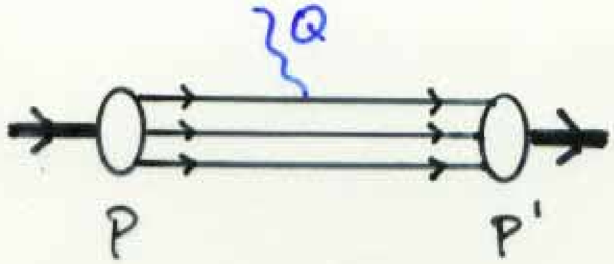
$$\langle p_1', \sigma_1'; p_2', \sigma_2'; p_3', \sigma_3' \,|\, J^\mu(0) \,|\, p_1, \sigma_1; p_2, \sigma_2; p_3, \sigma_3 \rangle$$

where

$$p_i' = B(v')\, k_i' \qquad p_i = B(v)\, k_i$$

PFSA

(Point-Form Spectator Approximation)



$$\langle p_1', \sigma_1'; p_2', \sigma_2'; p_3', \sigma_3' | J^\mu(0) | p_1, \sigma_1; p_2, \sigma_2; p_3, \sigma_3 \rangle \sim$$

$$\sim 2E_2 \, 2E_3 \, \delta(\vec{p}_2{}' - \vec{p}_2) \, \delta(\vec{p}_3{}' - \vec{p}_3) \cdot$$

$$\cdot \langle p_1', \sigma_1' | J^\mu_{[1]}(0) | p_1, \sigma_1 \rangle$$

Single-particle current:

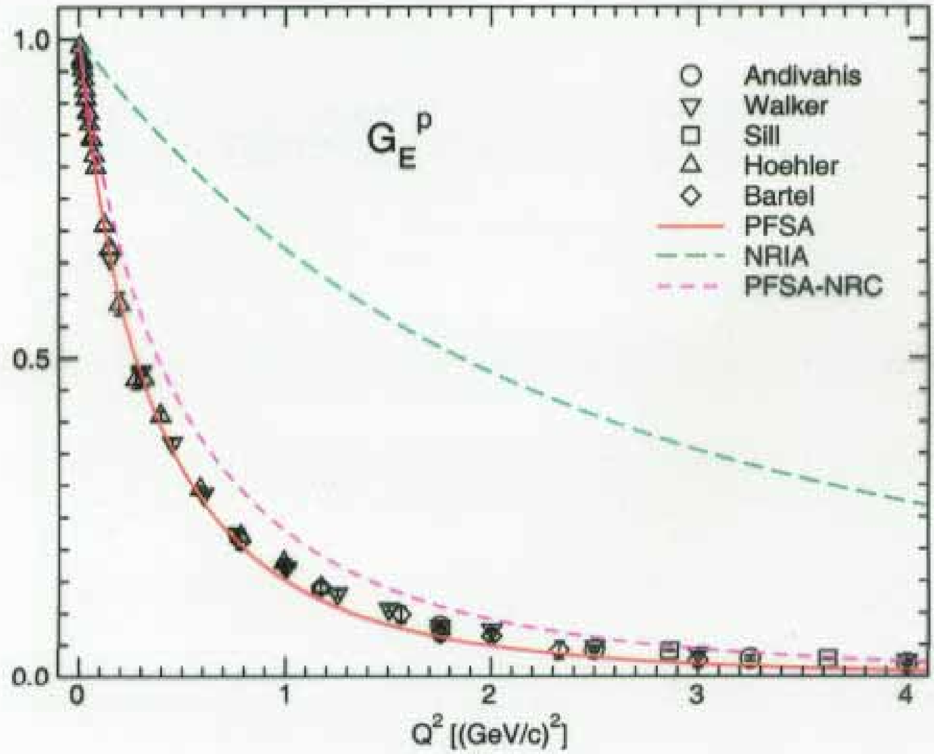
$$\langle p', \sigma' | J^\mu_{[1]}(0) | p, \sigma \rangle =$$

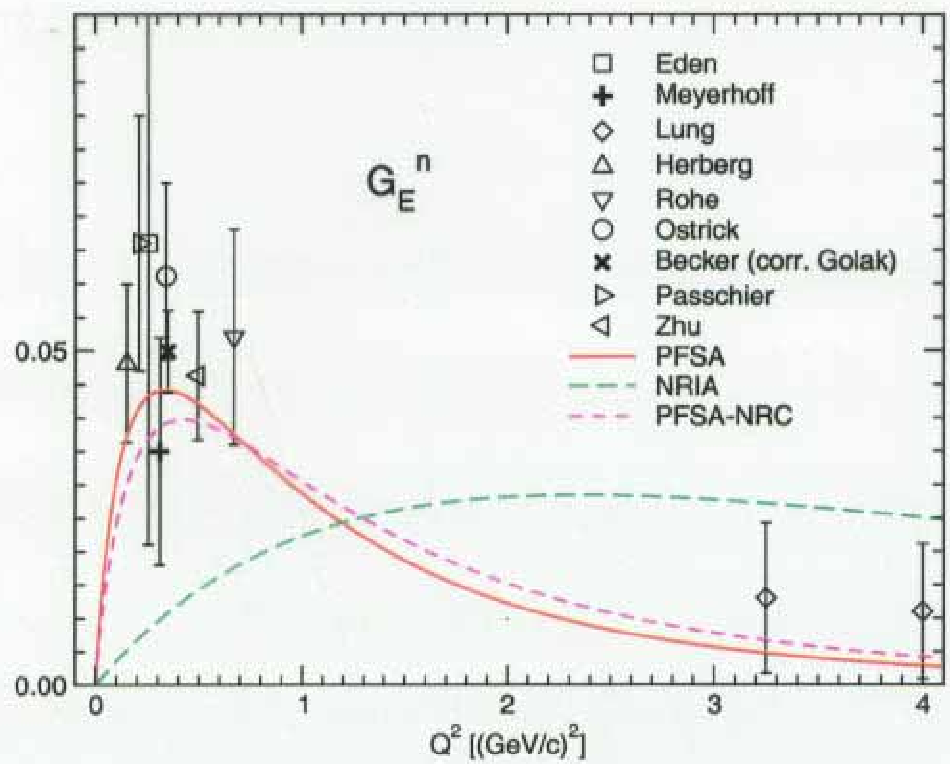
$$= \bar{u}(p', \sigma') \left[F_1(\tilde{Q}^2) \gamma^\mu + F_2(\tilde{Q}^2) \frac{i q_\nu \sigma^{\mu\nu}}{2m} \right] u(p, \sigma)$$

$$\tilde{Q}^2 = (p' - p)^2$$

Electromagnetic structure of the nucleons
Predictions of the GBE CQM

Electric form factors





Covariant nucleon electromagnetic form factors

For comparison:

Nonrelativistic impulse approximation (NRIA):

$$F^0_{\mu'\mu}(Q^2)=3e_1\prod_{i=1}^{3}\delta_{\mu_i'\mu_i}\ \int d^3pd^3qd^3p'd^3q'$$
$$\times\psi^*_{\mu'}(\vec{p}\,',\vec{q}\,';\mu_1',\mu_2',\mu_3')\psi_\mu(\vec{p},\vec{q};\mu_1,\mu_2,\mu_3)$$
$$\times\delta[\vec{k}_2'-(\vec{k}_2-\vec{q}_{\mathrm{st}}/3)]\delta[\vec{k}_3'-(\vec{k}_3-\vec{q}_{\mathrm{st}}/3)]$$

k_i and k_i' related by nonrelativistic kinematics; nonrelativistic current, and no Wigner rotations

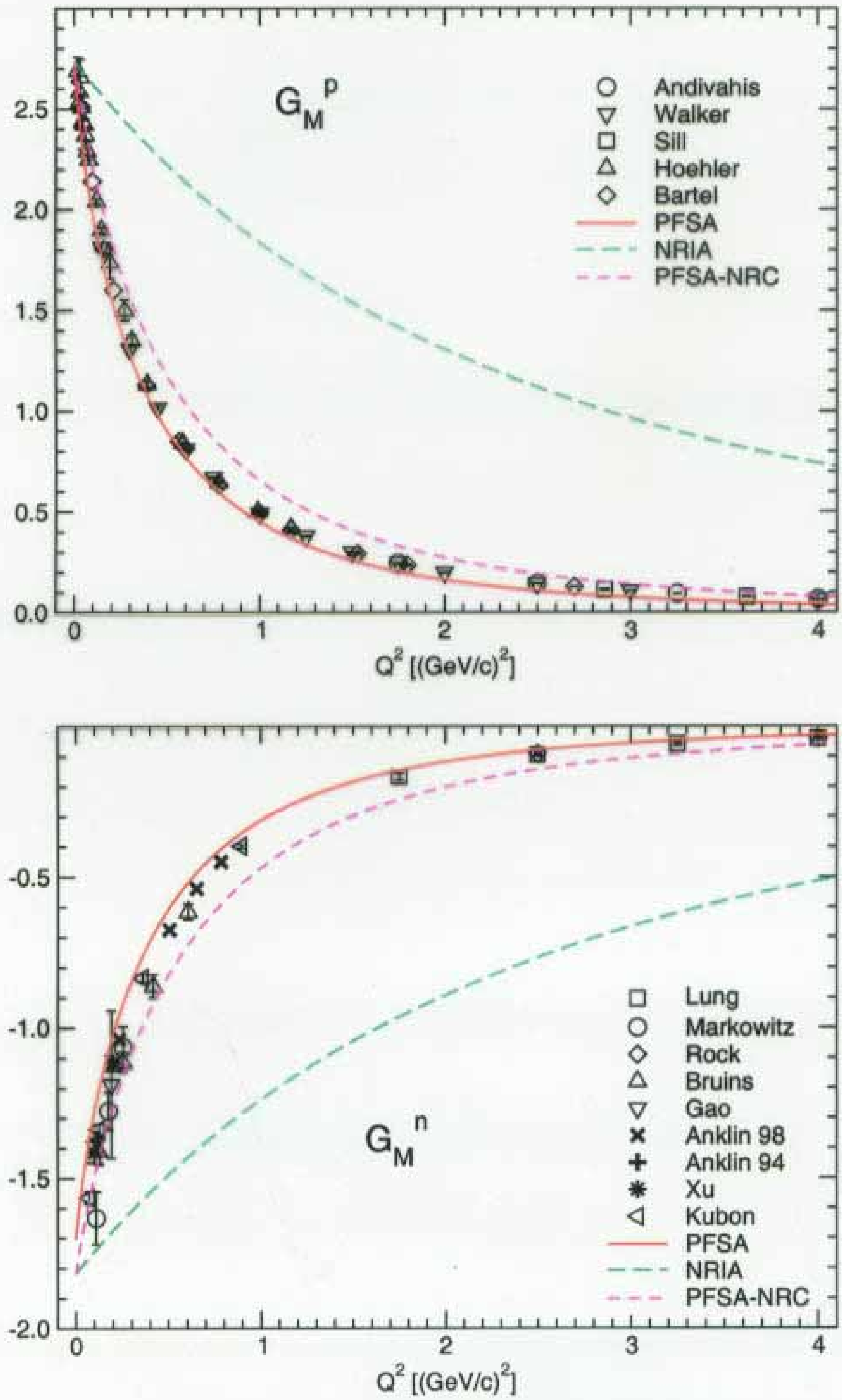
Intermediate step (PFSA-NRC):

$$F^0_{\mu'\mu}Q^2)=3e_1\prod_{i=1}^{3}\delta_{\mu_i'\mu_i}\ \int d^3pd^3qd^3p'd^3q'$$
$$\times\psi^*_{\mu'}(\vec{p}\,',\vec{q}\,';\mu_1',\mu_2',\mu_3')\psi_\mu(\vec{p},\vec{q};\mu_1,\mu_2,\mu_3)$$
$$\times\delta^3[k_2'-B^{-1}(v_{\mathrm{out}})B(v_{\mathrm{in}})k_2]\delta^3[k_3'-B^{-1}(v_{\mathrm{out}})B(v_{\mathrm{in}})k_3]$$

k_i and k_i' related by boost (as in PFSA); nonrelativistic current, and no Wigner rotations (as in NRIA)

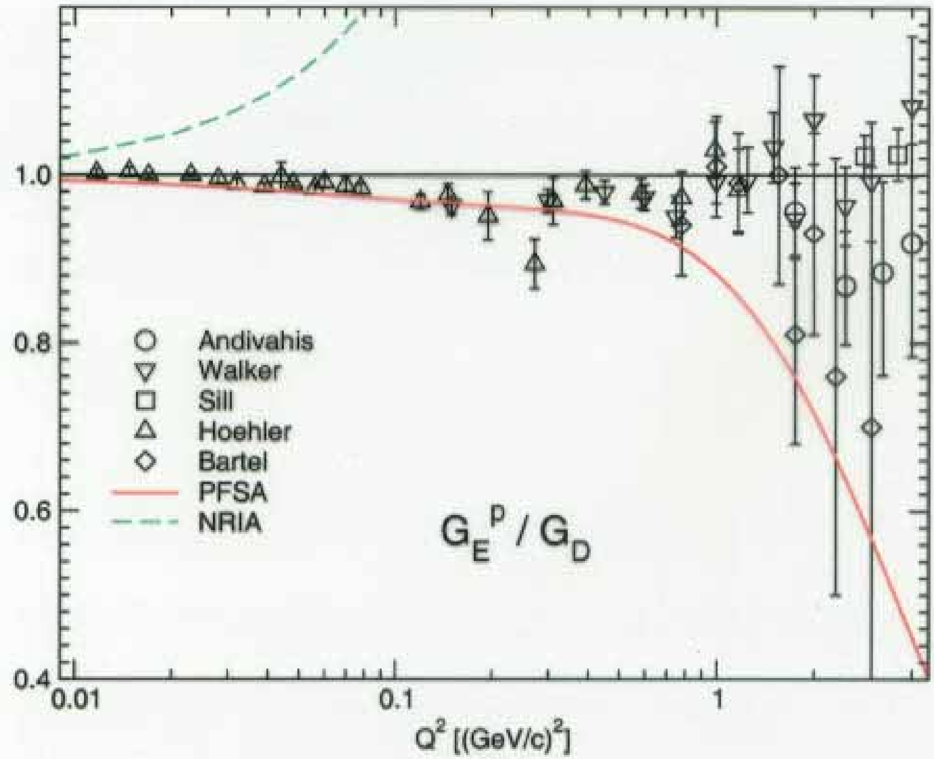
Electromagnetic structure of the nucleons
Predictions of the GBE CQM

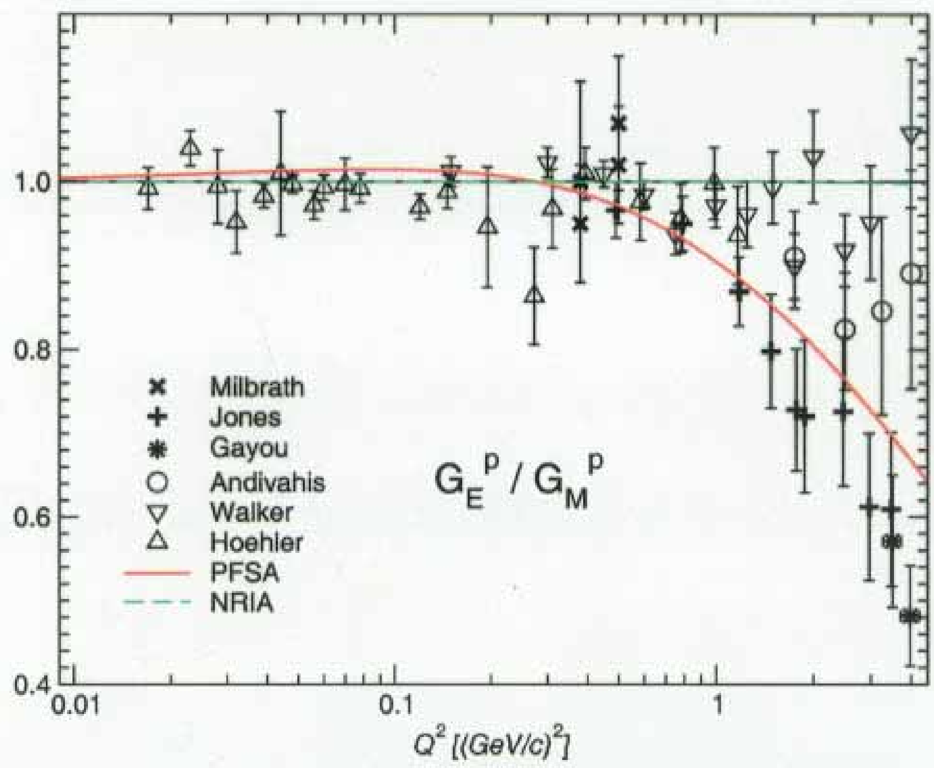
Magnetic form factors



Electromagnetic structure of the nucleons
Predictions of the GBE CQM

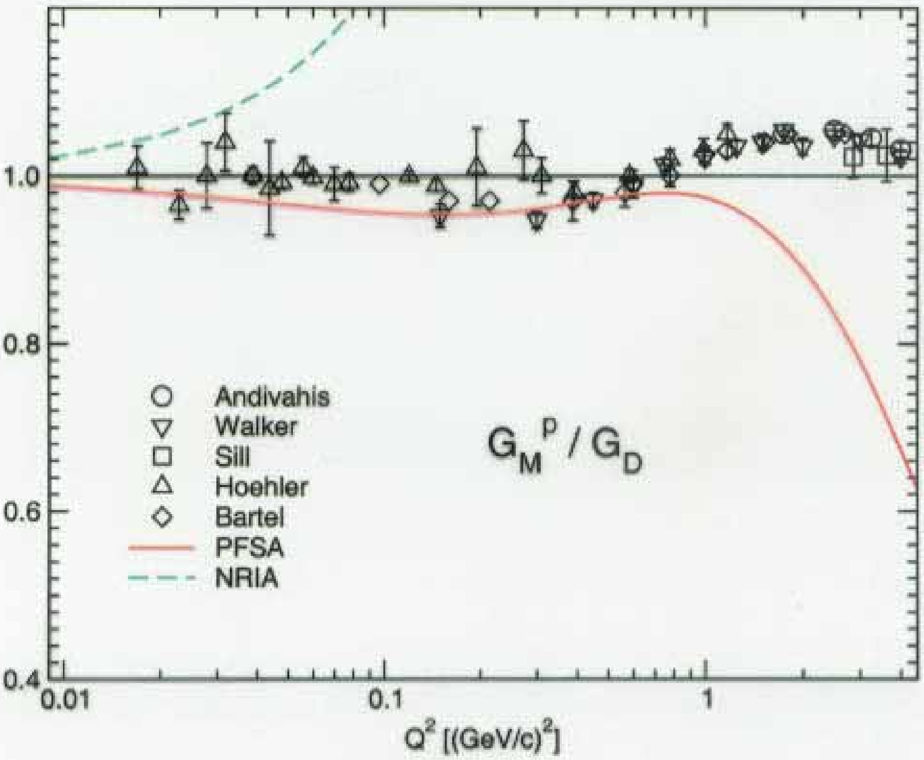
Ratios of G_E^p over G_D and over G_M^p

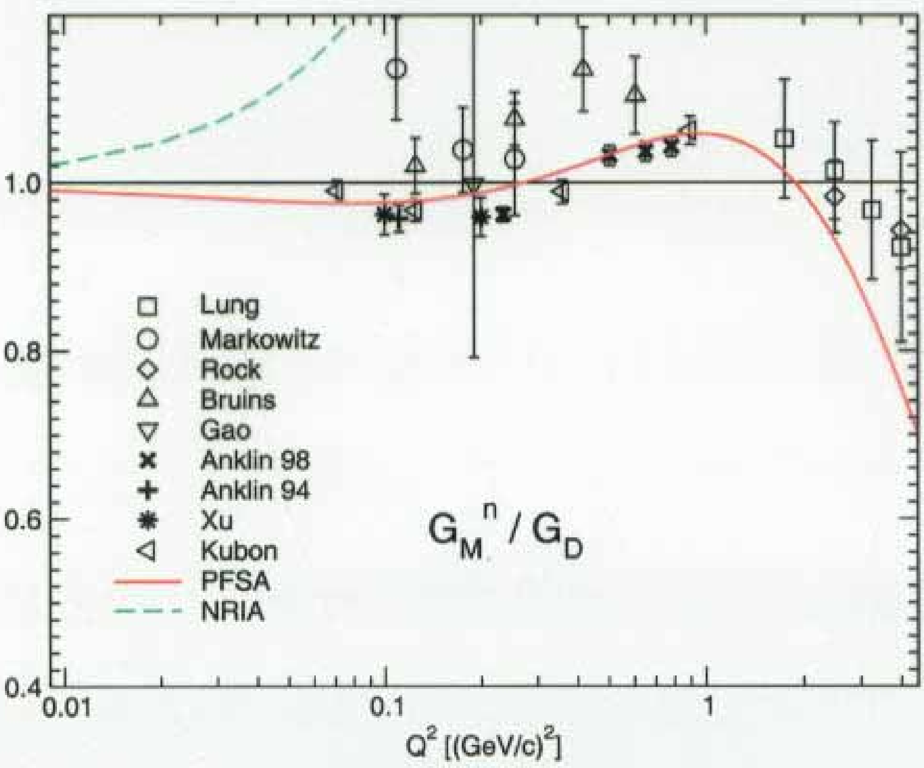




Electromagnetic structure of the nucleons
Predictions of the GBE CQM

Ratios of G_M^p and G_M^n over G_D





Electric radii and magnetic moments of the nucleons
Predictions of the GBE CQM

	PFSA	NRIA	Conf.	Experimental
r_p^2 [fm^2]	0.82	0.10	0.76	0.774(27), 0.780(25)
r_n^2 [fm^2]	−0.13	−0.01	−0.01	−0.113(7)
μ_p [n.m.]	2.70	2.74	2.65	2.792847337(29)
μ_n [n.m.]	−1.70	−1.82	−1.73	−1.91304270(5)

Point Form Spectator Approx.

Confinement Interaction only

NonRelativistic Impulse Approximation

Weak nucleon form factors

Axial current of spin 1/2 particle:

$$\langle p', s'| A_a^\mu(0) |p, s\rangle =$$
$$= \bar{u}(p's') \left[G_A(Q^2)\gamma^\mu + \frac{1}{2M}G_P(Q^2)q^\mu\right] \gamma_5 \frac{\tau^a}{2} u(ps)$$

$G_A(Q^2)$ axial form factor
$G_P(Q^2)$ induced pseudoscalar form factor

$q^\mu = p'^\mu - p^\mu$, $Q^2 = \vec{q}^{\,2} - \omega^2 \geq 0$

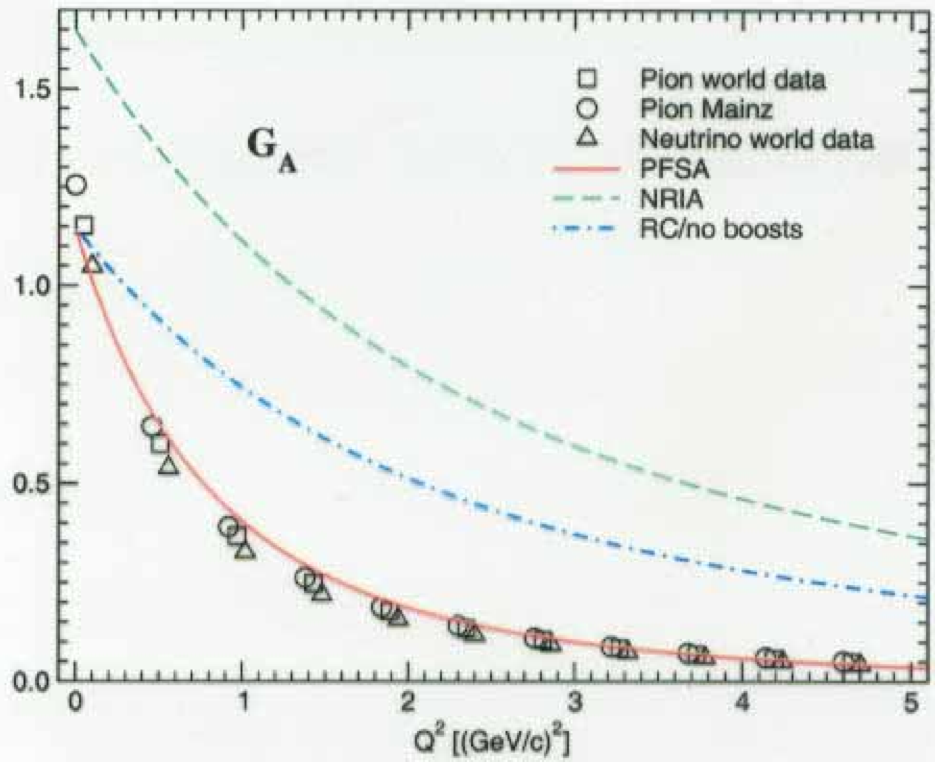
Spatial components in Breit frame

$$\langle p'_B s'|A^i(0)|p_B s\rangle = G^i_{s's}, \qquad i = 1, 2, 3$$

$$G^1_{s's} = \frac{E_B}{M} G_A(\delta_{s',s+1} + \delta_{s',s-1})$$
$$G^2_{s's} = -i\frac{E_B}{M} G_A(\delta_{s',s+1} - \delta_{s',s-1})$$
$$G^3_{ss'} = \left[G_A - \frac{\vec{q}_B^{\,2}}{4M^2} G_P\right] \delta_{ss'}$$

Weak nucleon form factors
Predictions of the GBE CQM

Axial form factor



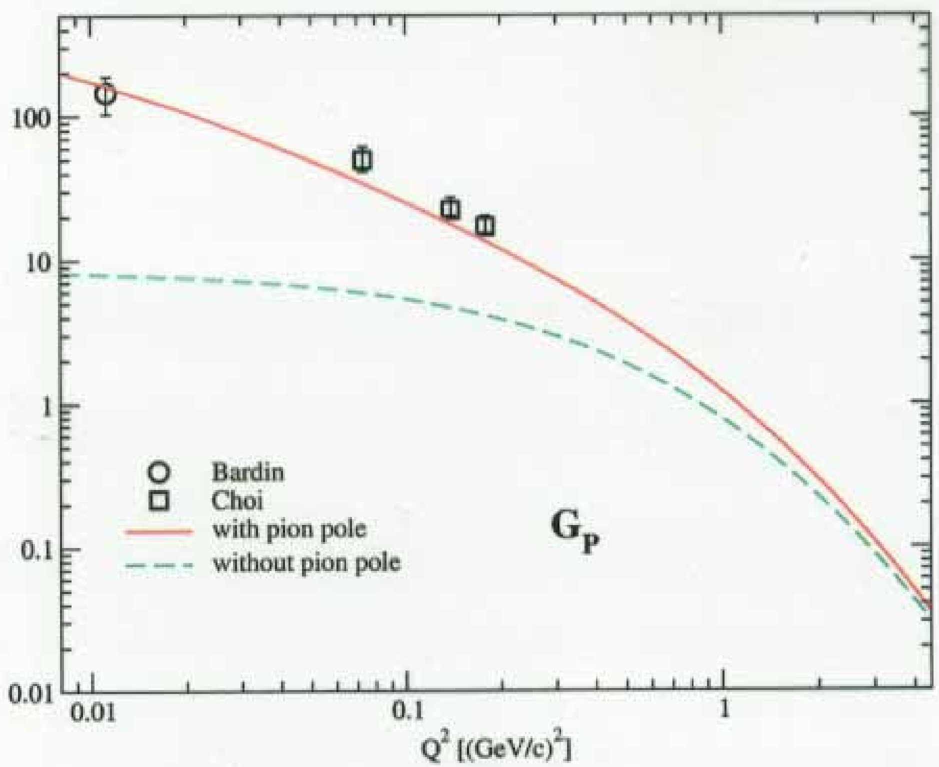
Axial coupling and radius :

	g_A	r_A [fm]
GBE PFSA	1.15	0.53
GBE NRIA	1.65	0.32
GBE RC/no boosts.	1.15	0.33
Experimental	1.2670(30)	0.635(23)

Weak nucleon form factors
Predictions of the GBE CQM

Induced pseudoscalar form factor

$$G_P = \frac{4M^2}{\vec{q}_B^2}\left[G_A - G_{ss}^3\right]$$



with $\frac{g_{\pi Q}^2}{4\pi} = 0.67$

Results for electric radii

Baryon	Theor. Mass	GBE CQM PFSA	GBE CQM NRIA	Confinement PFSA	Experiment
p	939	$0,8176$	$0,1016$	$0,7595$	$0,7744$ [Ros00] $0,7797$ [MvR00] $0,7174$ [MMD96] $0,69 \pm 0,12$ [E+01] $0,7921$ [UHG+97]
n	939	$-0,1332$	$-0,0086$	$-0,0088$	$-0,113$ [KRHH95] $-0,119 \pm 0,004$ [SSBW80] $-0,113$ [MMD96]
Σ^-	1180	$0,4946$	$0,0902$	$0,5329$	$0,61 \pm 0,21$ [E+01] $0,60 \pm 0,08 \pm 0,08$ [Pov99] $0,91 \pm 0,32 \pm 0,4$ [A+99]

Baryon	Theor. Mass GBE	Theor. Mass OGE	PFSA GBE	PFSA OGE
p	939	939	$0,8176$	$0,8859$
n	939	939	$-0,1332$	$-0,1958$
Σ^-	1180	1213	$0,4946$	$0,4440$

Results for magnetic moments

Baryon	Theor. Mass	GBE CQM PFSA	GBE CQM NRIA	Confinement PFSA	Experiment [G+00]
p	939	2,6980	2,7391	2,6478	2,793
n	939	−1,7004	−1,8185	−1,7287	−1,913
Λ	1136	−0,5894	−0,6103	−0,5802	−0,613
Σ^0	1180	0,7001	0,8059	0,6865	–
Σ^+	1180	2,3372	2,6261	2,2294	2,458
Σ^-	1180	−0,9371	−1,0143	−0,8564	−1,160
Ξ^0	1348	−1,2744	−1,4041	−1,2927	−1,250
Ξ^-	1348	−0,6663	−0,5331	−0,5490	−0,6507
Ω	1658	−1,5907	−1,8780	−1,5939	−2,0200

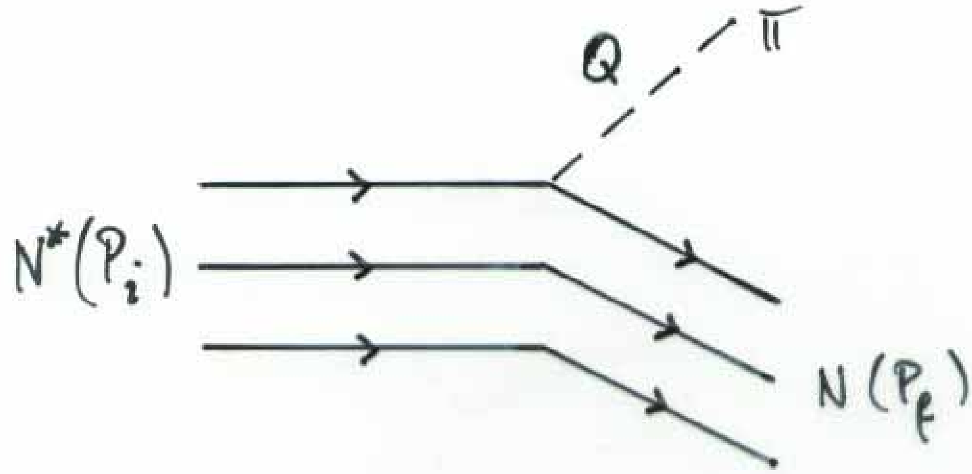
Magnetic Moments of Octet Baryons

Baryon	Theor. Mass [MeV]	μ (PFSA) [n.m.]	μ (NRIA)	Nonrel. Current with Boosts	Rel. Current w/o Boosts	Experiment [n.m.]
p	939	2,6980	2,7391	2,7390	1,3056	2,793
n	939	−1,7004	−1,8185	−1,8185	−0,8521	−1,913
Λ	1136	−0,5894	−0,6103	−0,6104	−0,3722	−0,613
Σ^0	1180	0,7001	0,8059	0,8054	0,3935	–
Σ^+	1180	2,3372	2,6261	2,6241	1,2457	2,458
Σ^-	1180	−0,9371	−1,0143	−1,0133	−0,4588	−1,160
Ξ^0	1348	−1,2744	−1,4041	−1,4035	−0,7871	−1,250
Ξ^-	1348	−0,6663	−0,5331	−0,5325	−0,3838	−0,6507

Prediction of the GBE CQM in Point-Form Spectator Approximation (PFSA).
Experiments taken from D. E. Groom et al., Eur. Phys. J. C **15**, 1 (2000)

Prediction of the GBE CQM in Non-Relativistic Impulse Approximation (NRIA).

POINT-FORM CALC. OF DECAY WIDTHS



- Spirit of Elementary Emission Model (EEM)

  ≈ One-particle decay operator

  ≈ Point-Form Spectator Approximation (PFSA)

- First covariant calculation of decay widths with full implementation of relativistic boost effects

UNI GRAZ

Pionic Decay Widths

Decays	Experiment	Rel. PFSA GBE CQM	Nonrel. EEM GBE CQM	
			dir	dir+rec
$N^\star_{1440} \to \pi N_{939}$	$(227 \pm 18)^{+70}_{-59}$	30.3	4.85	6.16
$N^\star_{1520} \to \pi N_{939}$	$(66 \pm 6)^{+9}_{-5}$	16.9	22.0	38.3
$N^\star_{1535} \to \pi N_{939}$	$(67 \pm 15)^{+55}_{-17}$	93.2	24.3	574.3
$N^\star_{1650} \to \pi N_{939}$	$(109 \pm 26)^{+36}_{-3}$	28.8	11.3	160.3
$N^\star_{1675} \to \pi N_{939}$	$(68 \pm 8)^{+14}_{-4}$	5.98	7.65	15.1
$N^\star_{1700} \to \pi N_{939}$	$(10 \pm 5)^{+3}_{-3}$	0.91	1.43	2.87
$N^\star_{1710} \to \pi N_{939}$	$(15 \pm 5)^{+30}_{-5}$	4.06	23.4	5.95

Pionic Decay Widths

Decays	Experiment	Rel. PFSA GBE CQM	Nonrel. EEM GBE CQM	
			dir	dir+rec
$\Delta_{1232} \to \pi N_{939}$	$(119 \pm 1)^{+5}_{-5}$	33.7	59.1	81.2
$\Delta_{1600} \to \pi N_{939}$	$(61 \pm 26)^{+26}_{-10}$	0.116	74.2	55.7
$\Delta_{1620} \to \pi N_{939}$	$(38 \pm 8)^{+8}_{-6}$	10.4	4.82	74.8
$\Delta_{1700} \to \pi N_{939}$	$(45 \pm 15)^{+20}_{-10}$	2.92	7.12	14.4

SUMMARY

I. Spectroscopy

- The specific spin-flavor symmetry in the GBE CQM is adequate to the phenomenological spectra
- Unified model for all light and strange baryons

II. Electroweak nucleon FFs

- Covariant predictions obtained in point-form rel. QM
- Simplest currents yield a very reasonable and consistent description
- Relativistic effects are most important

III. Charge Radii & Magnetic Moments

- Realistic predictions for all

CONCLUSIONS

- Constituent quark models ⇝ promising tool for low-energy QCD
- Relativistic framework is essential
- Attempts made so far: Spectroscopy, elastic form factors, ...
  appear promising
- More refined calculations:
  * two-(many-)body operators
  * transition reactions
  * more elaborate CQM wave functions

WANTED !!!!