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A RELATIVISTIC CONSTITUENT QUARK MODEL*

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ABSTRACT

We investigate the predictive power of a relativistic quark model formulated on the light-front. The nucleon electromagnetic form factors, the semileptonic weak decays of the hyperons and the magnetic moments of both baryon octet and decuplet are calculated and found to be in excellent agreement with experiment.

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We construct a relativistic constituent quark model consisting of a radial wave function which is spherically symmetric and invariant under permutations times a spin-isospin wave function which is uniquely determined by symmetry requirements [1]. We apply SU(6) symmetry to the rest frame spinors and boost them to the light-front with a Wigner (Melosh) rotation. The three-quark wave functions so constructed are eigenfunctions of mass and spin operators. Eigenfunctions of the four-momentum, which transform irreducibly under the Poincaré group, are obtained from the mass eigenfunctions using light-front symmetry. The current-density operator of the constituent quarks is assumed to be that of Dirac point particles. For the momentum-space wave function a simple function of the invariant mass M_0 is assumed. The invariant mass M_0 can be written as

$$M_0^2 = \sum_{i=1}^{3} \frac{\vec{k}_{\perp i}^2 + m_i^2}{x_i}, \tag{1}$$

where we used the longitudinal momentum fractions $x_i = p_i^+/P^+$ (P and p_i are the nucleon and quark momenta, respectively, with $P^+ = P_0 + P_z$). The internal momentum variables k_i are given by $k_i = p_i - x_i P$ with $\sum \vec{k}_{\perp i} = 0$ and $\sum x_i = 1$. We choose the following momentum wave functions

$$\phi_H \sim \exp(-M_0^2/2\beta^2), \tag{2}$$

$$\phi_P \sim (1 + M_0^2/\beta^2)^{-p}. \tag{3}$$

In Figure 1 the anomalous magnetic moment of the proton $F_2(0)$ is plotted against the radius $R_1^2 = -6F_1'(0)$. Figure 1 shows that the result for $Q^2 = 0$ is *independent* of the wave function chosen. The only parameters are:

- The constituent quark mass m_i.

- The scale parameter β.

For small values of Q^2, the two wave functions in Eqs. (2) and (3) still give the same results (Fig. 2). Only for very large momentum transfer Q^2 can we see a drastic difference between the different wave functions as shown in Figure 3.

The parameters of the model are fixed by fitting some of the experimental values [1]. The nucleon form factors can be calculated for low, medium and high momentum transfer in excellent agreement with experiment [2]. Figure 3 shows the proton form factor $G_M(Q^2)$ up to more than 30 GeV^2. The broken line gives the form factor calculated with a conventionally used wave function. That is the reason why it was believed that the relativistic constituent quark model breaks down at about 2 GeV^2. At intermediate energies, G_M and G_E for the neutron and G_M for the proton are in agreement with recent SLAC experiments [3]. A recent pion bremsstrahlung analysis [4] gives a ratio $\mu(\Delta^{++})/\mu(p) = 1.62 \pm 0.18$, much lower than the nonrelativistic quark model value 2, but in agreement with our value 1.69 [5]. The magnetic moments of the nucleons and hyperons and the semileptonic decays of the baryon octet are also described very well with the same parameters [1].

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FIGURES

FIG. 1. The anomalous magnetic moment $F_2(0)$ of the proton as a function of M_pR_1: continuous line, pole type wave function; broken line, gaussian wave function. The experimental value is given by the cross. Our model is independent of the wave function for $Q^2 = 0$.

FIG. 2. The proton form factor $F_{1p}(Q^2)$. The line code is the same as in the previous figure.

FIG. 3. The proton form factor $G_M(Q^2)$: continuous line is the present analysis; broken line gives form factor calculated with a conventionally used wave function. The relativistic constituent quark model does not break down at 2 GeV^2, it is even valid up to more than 30 GeV^2.

FIG. 4. The axial vector form factor $g_1(K^2 = -Q^2)$ for the neutron-proton weak decay.

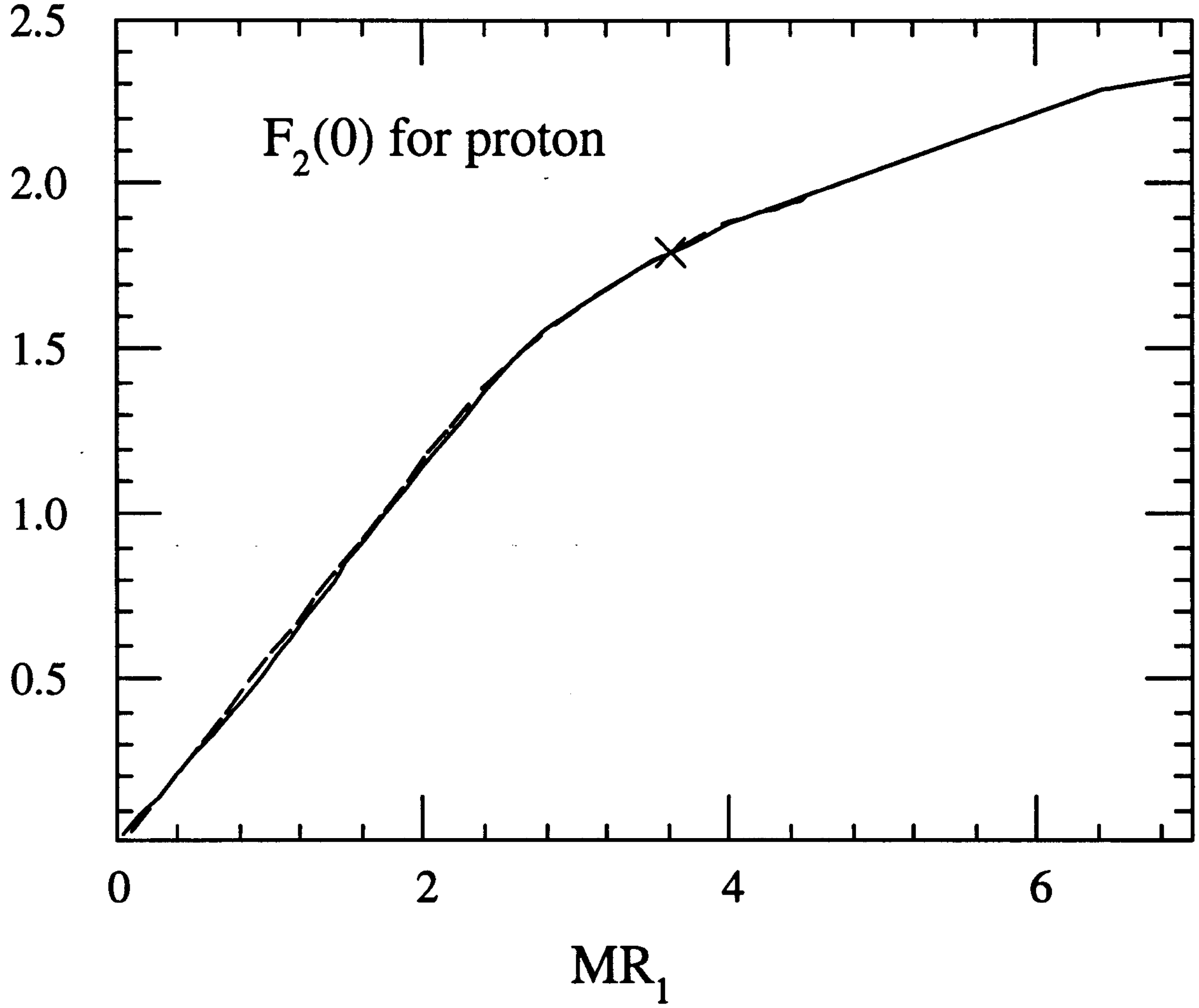

Fig. 1

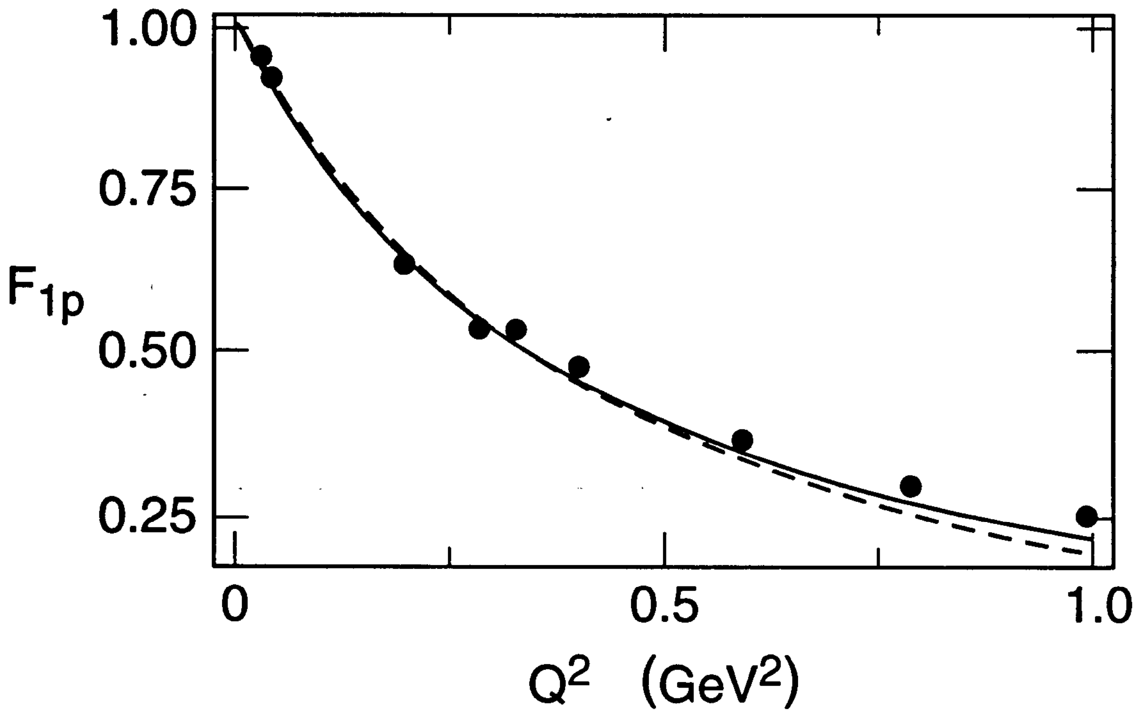

Fig. 2

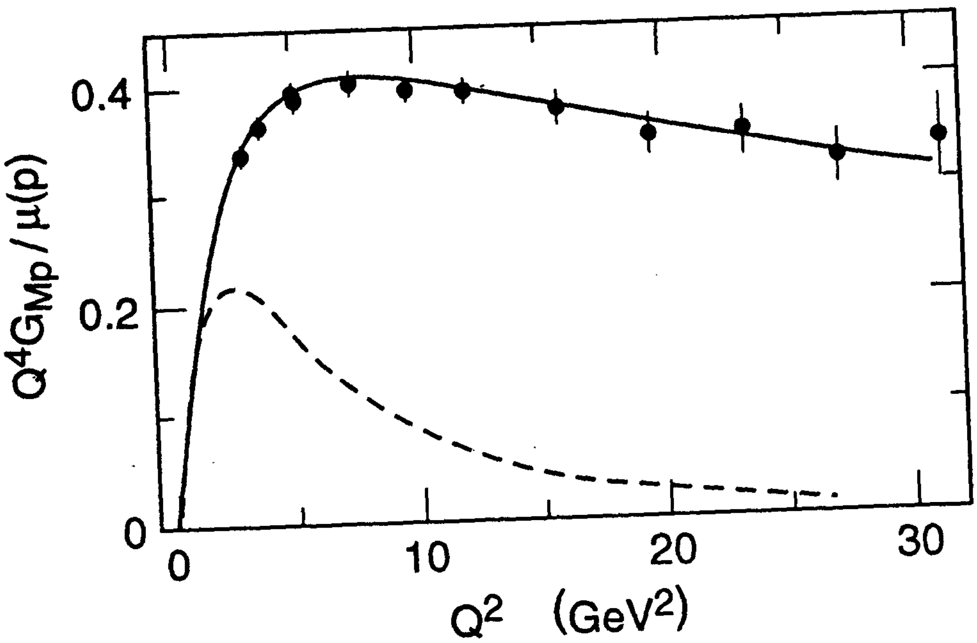

Fig. 3

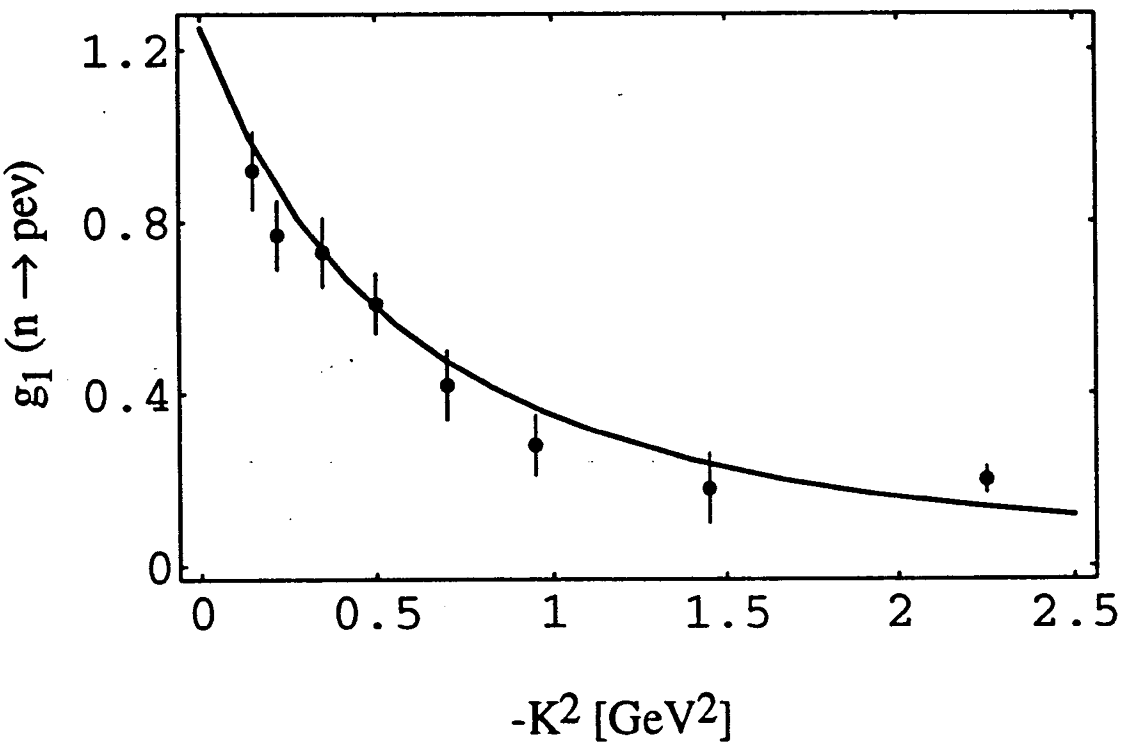

Fig. 4