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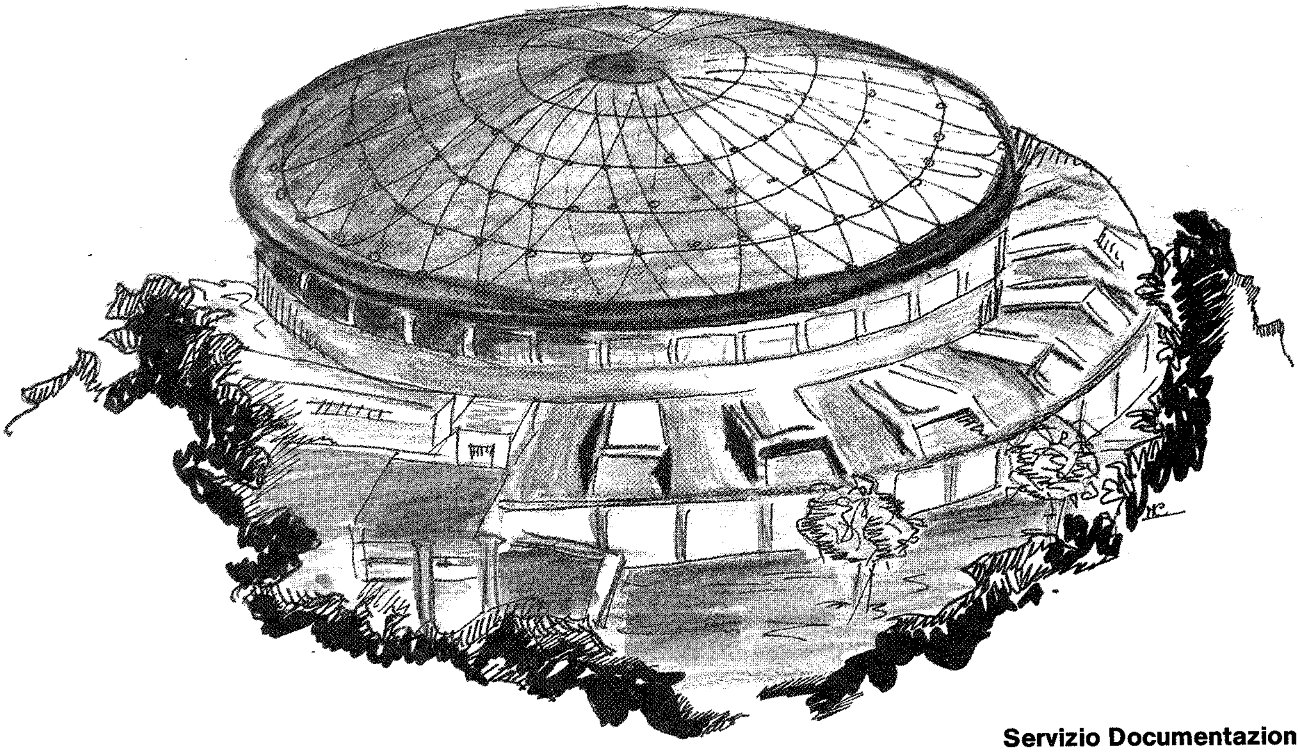

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U-SPIN CONSIDERATIONS TO GUESS THE UNKNOWN TIME-LIKE NEUTRON FORM FACTORS

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ABSTRACT

The neutron time-like form factors have never been measured. Perturbative QCD, Extended Vector Meson Dominance and other models give very different predictions. By using U-spin symmetry, the available data on the Λ form factor and on the decay $J/\Psi \rightarrow B\bar{B}$ allow the neutron time-like form factors to be estimated. This results in a neutron magnetic form factor, which is large at threshold and is then likely to fall more steeply, with increasing energy, than the proton one.

1. - INTRODUCTION

The electromagnetic structure of baryons still awaits investigation, in spite of the data collected for decades on space-like form factors and structure functions. The totally unexpected results on polarized deep inelastic scattering, obtained recently by the EMC collaboration(1), represent striking proof of that. The time-like form factors are poorly known, in particular the neutron time-like form factors have never been measured and only one scanty measurement of the Λ form factor exists(2).

A suitable quantity to compare the predictions for nucleon time-like form factors is the ratio:

$$\mathbf{R} = \frac{\sigma\left(e^+e^- \to n\bar{n}\right)}{\sigma\left(e^+e^- \to p\bar{p}\right)}$$

The most popular models (Perturbative QCD (PQCD), Extended Vector Meson Dominance (EVMD), Skyrme-like model), which fit the bulk of the data on the nucleon space-like form factors and static properties, give very different predictions for R.

At high Q^2, we expect $\mathbf{R} \approx 0.25$ on PQCD; namely R should be the square of the ratio between the electric charges of the leading quarks. This assumes, as implied by QCD sum rules, that there is a leading quark in the nucleon wave function(3), which also agrees with the picture of a baryon as a diquark-quark bound state. To be more precise, the PQCD predictions are for the Dirac form factors, which should dominate at high Q^2 because of their expected $1/Q^4$ behaviour, while the Pauli form factors(4) are expected to fall like $1/Q^6$. At present the Q^2 domain where PQCD expectations are valid is not well established theoretically(5). As a matter of fact data at $Q^2 > 4$ GeV^2, in the space-like region, are usually compared to PQCD calculations(6). In the following, we will only discuss theoretical calculations in the Q^2 range from threshold up to $Q^2 \approx 10$ GeV^2, which is the range accessible to measurement in the near future.

Fits, using EVMD, to space-like form factors and to the available proton time-like form factors, in contrast predict $\mathbf{R} \approx 2 \div 100$ (7). These depend on the location of the various vector meson recurrences, which are still not well established(8). Yet, in spite of these uncertainties, all these fits foresee a smooth ratio R in favour of the neutron.

A successful fit, which attempts to merge VMD and PQCD, has been performed by M. Gari and his collaborators(9). Peculiar to this model is the vanishing of the neutron Dirac form factor. Consequently, the Pauli form factor dominates, and so $\mathbf{R} \propto 1/Q^2$. Unfortunately no straight time-like extrapolation of this model is available. Actually in this approach the old idea(10) of introducing Q^2 dependent coupling constants in VMD has been resurrected. This is, incidentally, quite naturally embodied in the Skyrme model of the nucleon(11).

Similar coupling constants, Q^2 dependent yet not analytic, have been introduced by Etim and Malecki (12), achieving a smooth ratio $\mathbf{R} \approx 1$. Likewise, Dubnicka has given a fit(13) where the effective coupling constants vary with Q^2, while the form factors have almost all the required analytical properties, and yet a smooth ratio $\mathbf{R} \approx 25$ is predicted.

The spread among these various VDM predictions emphasizes the crucial role of the measurement of the time-like neutron form factors in differentiating between models. The determination of the contributions of the different vector mesons will be an important result per se. For instance, the size of the ϕ contribution is the best estimate of the strange quark content in the nucleon (14).

Finally $B\overline{B}$ potential models, which should be reliable near $B\overline{B}$ threshold, provide a smooth ratio **R** ≈ 2 (15). According to $B\overline{B}$ potential models, structures are also to be expected near threshold in the form factors and in the e+e- annihilation cross section into many hadrons (16). The present data (17) do suggest this hypothesis.

In conclusion, data on $e^+e^- \to n\bar{n}$ are strongly demanded.

Waiting for results from the FENICE experiment(18) (now running at the renewed storage ring ADONE), some experimental information on the neutron form factors may be extracted from the available data on the Λ form factor and from the J/Ψ baryonic decays.

2. - NEUTRON TIME-LIKE FORM FACTORS ACCORDING TO THE Λ FORM FACTOR AND THE J/Ψ BARYONIC DECAY MEASUREMENTS

At high Q^2, the e.m. interactions of strange hadrons are related to the e.m. interactions of non strange hadrons belonging to the same SU_3 flavour multiplet by U-spin symmetry (19), as illustrated in Fig.1a. For the baryon octet these relations are: $G_M{}^p \approx G_M{}^{\Sigma+}$, $G_M{}^{\Sigma-} \approx G_M{}^{\Xi-}$ $G_M{}^n \approx -2\, G_M{}^{\Sigma^\circ} \approx G_M{}^{\Xi^\circ}$, and in particular $G_M{}^n \approx 2\, G_M{}^\Lambda$.

For the pseudoscalar mesons it is expected: $F^{\pi+-} \approx F^{K+-}$ and $F^{K^\circ} \approx 0$.

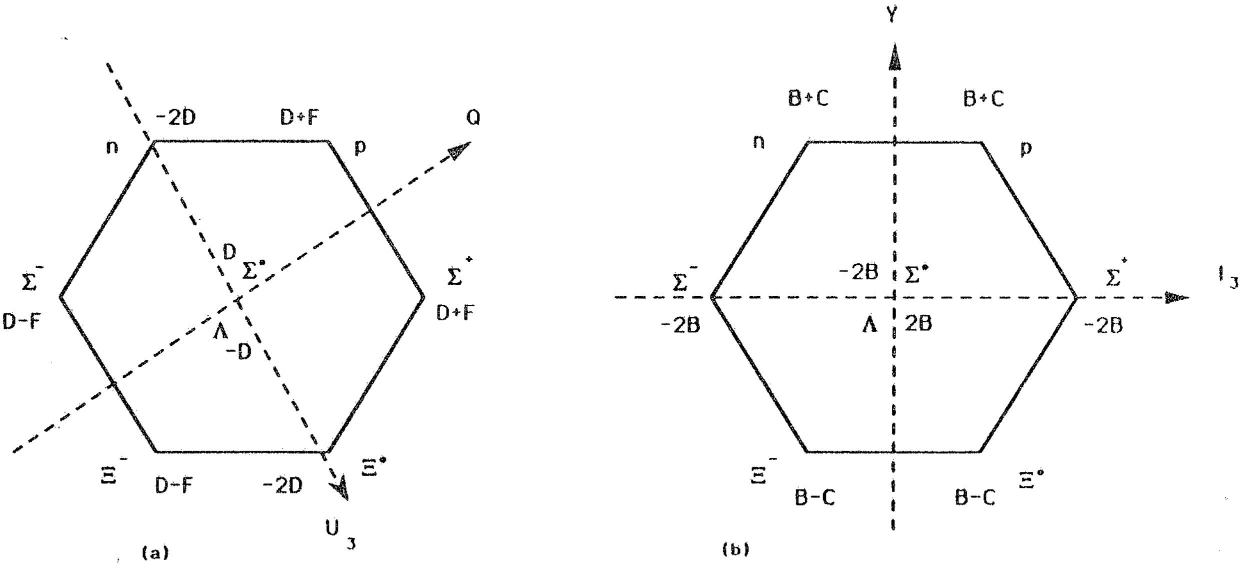

FIG. 1 - **a)** Magnetic form factors relationships according to U-spin symmetry; **b)** SU_3 flavour symmetry breaking amplitudes in $J/\Psi \to B\overline{B}$ direct decay.

U-spin symmetry is supposed to be valid at values of Q^2 at which the strange quark mass can be neglected. Nevertheless, even static properties, like the baryon magnetic moments, are in rough agreement with U-spin expectations. Charged pseudoscalar form factors (2,20) are shown in Fig. 2. They accord with U-spin expectations, though within large errors. Indeed if they are averaged in energy to smooth out the resonant behaviour, they agree with U-spin expectations even beyond $N\overline{N}$ threshold (20). As a first approximation for U-spin symmetry breaking, a correction $\Delta \approx m_\phi - m_p$ on the Q scale can be done, which does not change the expected asymptotic Q^2 behaviour. As a check, the ratio μ_Λ/μ_n=0.32 must be compared to $m_0{}^4/2(\Delta^2 + m_0{}^2)^2 \approx 0.37$, still assuming the standard space-like dipole fit (m_0 = 0.84 GeV) at small positive Q^2.

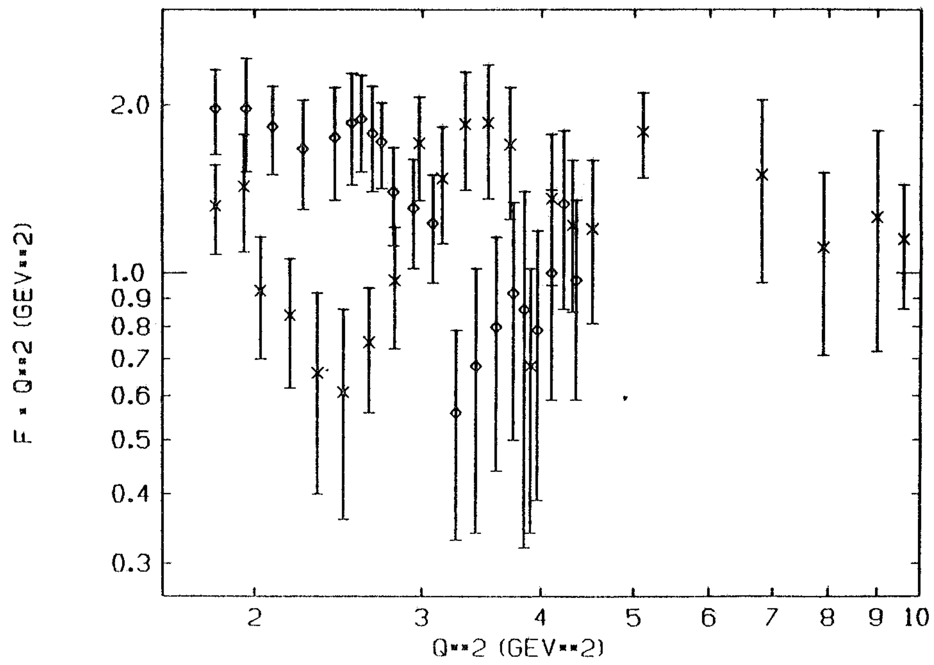

FIG. 2 - Charged pseudoscalar form factors near BB threshold: (x) pion, (◊) kaon.

A few events at Q^2 = 5.76 GeV^2 coming from $e^+e^- \rightarrow \Lambda\overline{\Lambda}$ have been observed by the DM2 experiment at the DCI storage ring(2). These events are very clean and the only experimental problem, a contamination from $e^+e^- \rightarrow \Sigma\overline{\Lambda}$, $\Lambda\overline{\Sigma}$ has been taken into account in the error evaluation. The quoted cross section corresponds to a Λ form factor $|G^\Lambda|$= $0.12^{+0.03}_{-0.02}$ in the standard hypothesis that $G_E = G_M$ is still valid near the threshold. The available proton form factor measurements have also been obtained from the total cross section using this hypothesis. Actually all these time-like form factors may be more properly identified with the magnetic form factor G_M, either because the G_M contribution to the total cross section becomes dominant with increasing Q^2 and because the Pauli form factor would decrease faster than the Dirac form factor. Therefore the DM2 measurement implies:

$$|G_M{}^n| = 0.24 \,{}^{+\,0.06}_{-\,0.04} \text{ at } Q^2 \approx 4.4 \text{ GeV}^2$$

Still at $Q^2 = 5.75$ GeV^2 two candidate events for $e^+e^- \to n\bar{n}$ have also been found(2), in spite of the low detection efficiency of DM2 for this process. The expected cosmic ray background is about one event, to be taken into account in the error evaluation and only an upper limit has been quoted. Anyway these events, taken at face value, correspond to a neutron form factor

$$|G_M{}^n| \approx 0.15 + 0.07 \qquad \text{at } Q^2 = 5.75 \text{ GeV}^2,$$

again with the hypothesis $G_E = G_M$.

A further point may be learnt by looking at $J/\Psi \to B\bar{B}$ decay. In fact a decomposition of this decay into the amplitudes shown in Fig.3 in principle allows the baryon form factors to be measured, once the amplitude of Fig.3c has been isolated. Actually, with the present storage rings, this is the only opportunity to determine the neutron form factor at $Q^2 \approx M_\Psi{}^2$.

SU_3 flavour relationships should be even more reliable at $Q^2 \approx M_\Psi{}^2$. The direct J/Ψ decay, see Fig.3a, can be decomposed into a SU_3 flavour symmetric amplitude A and SU_3 flavour breaking amplitudes, B and C, as shown in Fig.1b. These amplitudes are evaluated according to the same arguments quoted in the U-spin case(19,21), exchanging the electric charge and the hypercharge axis, the U-spin and the isospin axis.

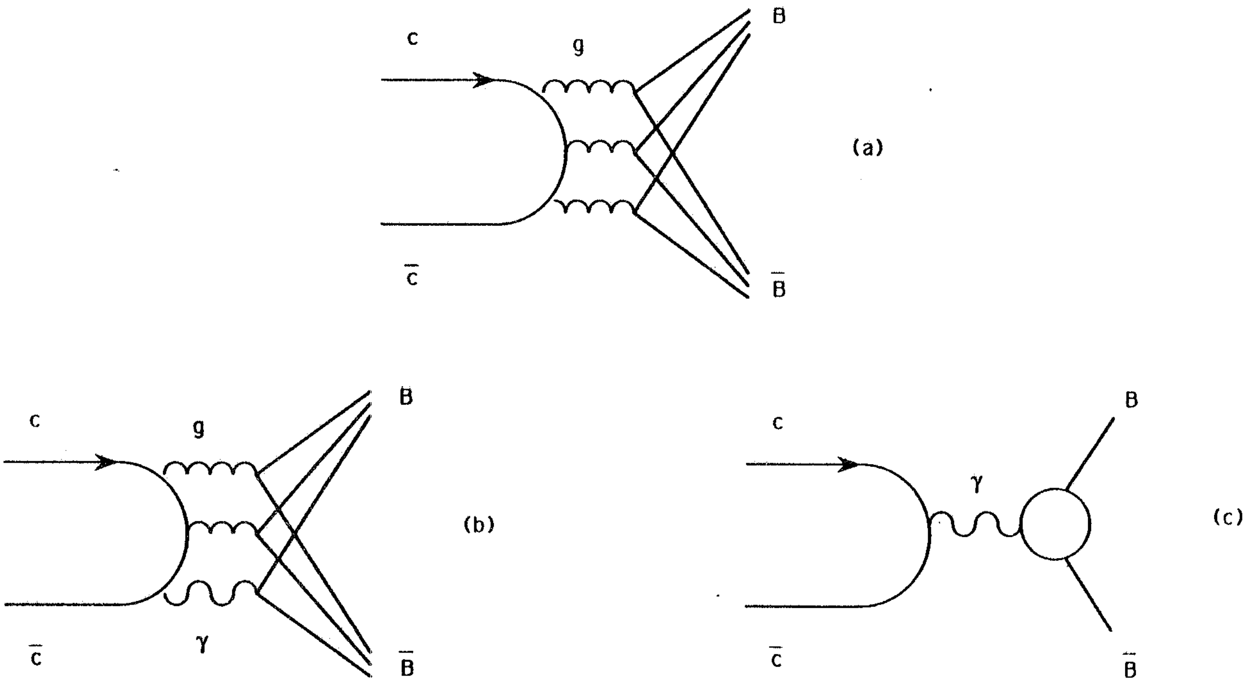

FIG. 3 - Expected main contributions to $J/\Psi \to B\bar{B}$: **a)** direct decay; **b)** e.m. correction to the direct decay; **c)** decay throught a virtual photon.

There is the same number of unknown amplitudes and available branching ratios(21). The e.m. amplitudes, D and F, and the direct decay amplitudes are supposed to be mainly real at high Q^2. Therefore the SU_3 relationships may be applied to the square root of the branching ratios, normalized at the same phase space. Numerical details are reported in Ref. 22. In spite of the large errors the following meaningful results can be drawn:

$$\begin{aligned} A &= (4.4 \pm 0.2) \times 10^{-2} \\ D &= (0.1 \pm 0.1) \times 10^{-2} \\ G_M{}^n &= -2D/\sqrt{}(B(\Psi \rightarrow \mu\mu)(1 + 2M_n{}^2 /M_\Psi{}^2) = -\ 0.008 \pm 0.008 \text{ at } Q^2 \approx 8 \text{ GeV}^2 \end{aligned}$$

Even within such a large range, this neutron magnetic form factor is lower than any plausible extrapolation of the proton magnetic form factor.

The amplitude H, corresponding to Fig.3b, only contributes to the antisymmetric part of the form factor F, being proportional to the baryon electric charge. According to PQCD (23) it is:

$$H = -\frac{4\alpha\ Q_B}{5\ \ \alpha_s} A$$

Therefore the H contribution in the proton case is negative and it is: $G_M{}^p = 0.01 \pm 0.05$ at $Q^2 \approx 8$ GeV^2. Of course this last evaluation is irrelevant, mainly because of the large error on the measurement of the branching ratio $B(J/\Psi \rightarrow n\bar{n})$. However, it is consistent with the upper limit at 90% confidence level: $|G_M{}^p| < 0.05$ at $Q^2 = 8.9$ GeV^2, quoted by the ISR group(24).

The steep fall with Q^2 of the neutron magnetic form factor, compared to the proton one, suggests that even in the time-like region the Pauli form factor is dominating. This is, of course, not in agreement with the hypothesis $G_E = G_M$. To be consistent the former form factors must be corrected by a factor:

$$\sqrt{\left(1+2\frac{M_n^2}{Q^2}\right) \Big/ 1+\left(\frac{Q^2}{8M_n^2}\right)}$$

The corrected values are reported in Fig.4, with the present proton form factor measurements(2).

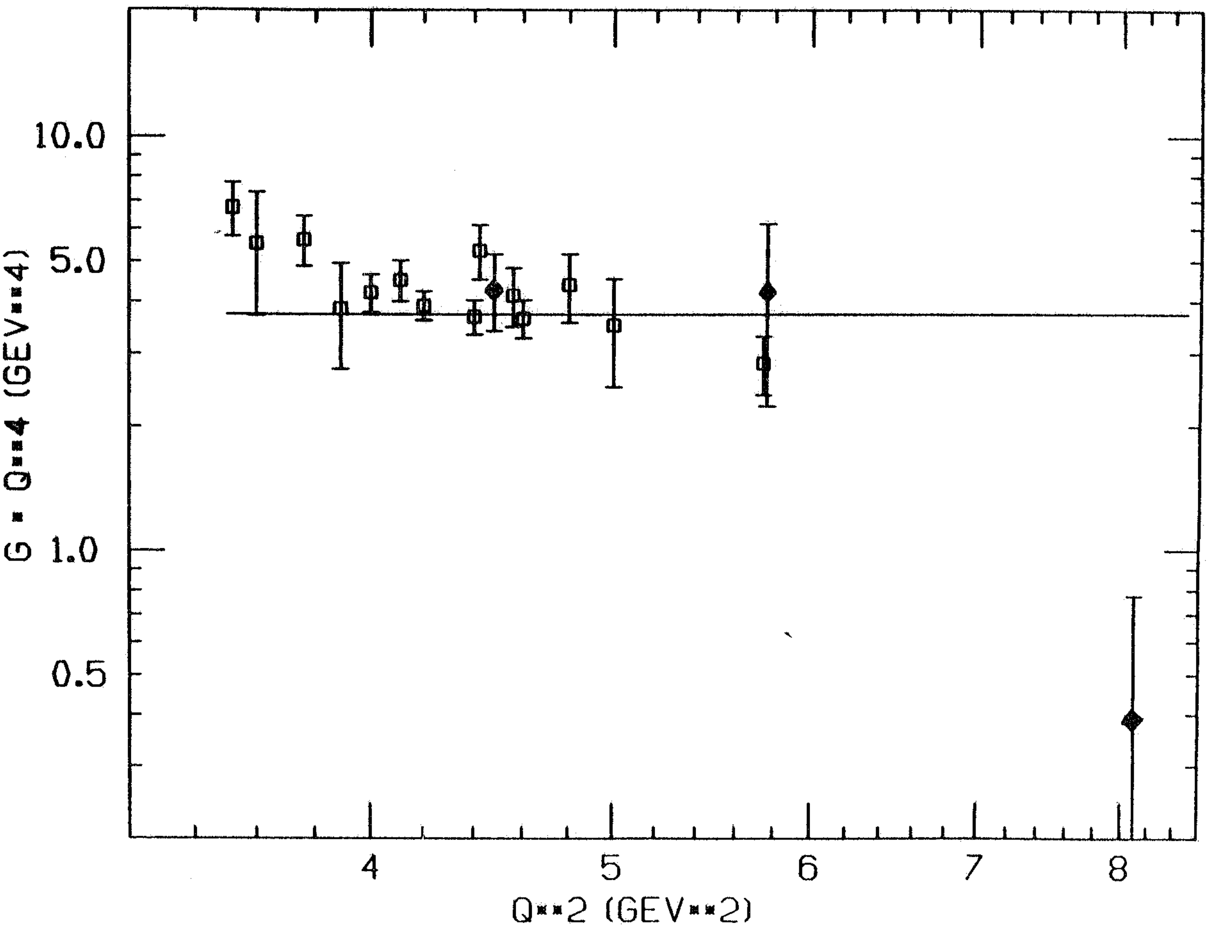

FIG. 4 - Present nucleon magnetic time-like form factor data: (□) proton, (◆) neutron. The continous line represents the expected proton extrapolation, according to PQCD.

CONCLUSION

As a consequence of the former picture a compromise in agreement with all the expectations is foreseen: the ratio R is large at the threshold, as predicted by EVDM, and small asymptotically, as predicted by PQCD.

Of course these conclusions rest on questionable hypotheses. In particular there are theoretical arguments(25), which imply that the J/Ψ direct decay amplitude should be predominantly imaginary, while certainly the e.m. form factor at $Q^2 \approx M_\Psi{}^2$ is mainly real. A test may be made by looking at the J/Ψ decay into pseudoscalar mesons(21), namely: $|F| = (1.2 \pm 0.1) \times 10^{-2}$, $|C| = (1.0 \pm 0.1) \times 10^{-2}$ and $|F+C| = (1.6 \pm 0.1) \times 10^{-2}$.

There is a fair disagreement but as yet no conclusion may be reached. By the way, a comparison (provided in the calibration runs at the J/Ψ of the FENICE experiment) at the few percent level between $B(J/\Psi \rightarrow p\bar{p})$ and $B(J/\Psi \rightarrow n\bar{n})$ will allow this point to be checked. In fact, in the case of real amplitudes the form factor contributions, being proportional to the magnetic moments, give rise to $B(J/\Psi \rightarrow p\bar{p}) > B(J/\Psi \rightarrow n\bar{n})$. If the direct decay amplitude is imaginary the form factors contributions are negligible, being added in quadrature, while the negative H contribution causes $B(J/\Psi \to p\bar{p}) < B(J/\Psi \to n\bar{n})$. In this last case the only conclusion is that the proton and the neutron have similar form factors at $Q^2 \approx 5$ GeV^2.

In summary, the structure of the nucleon has still to be fully investigated. A measurement, never performed up to now, of the neutron time-like form factors, would add valuable new information able to distinguish between models. There are hints, on the basis of the available data on strange baryons, that the neutron form factor may be even larger than the proton at threshold, with a steeper fall at higher Q^2.

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