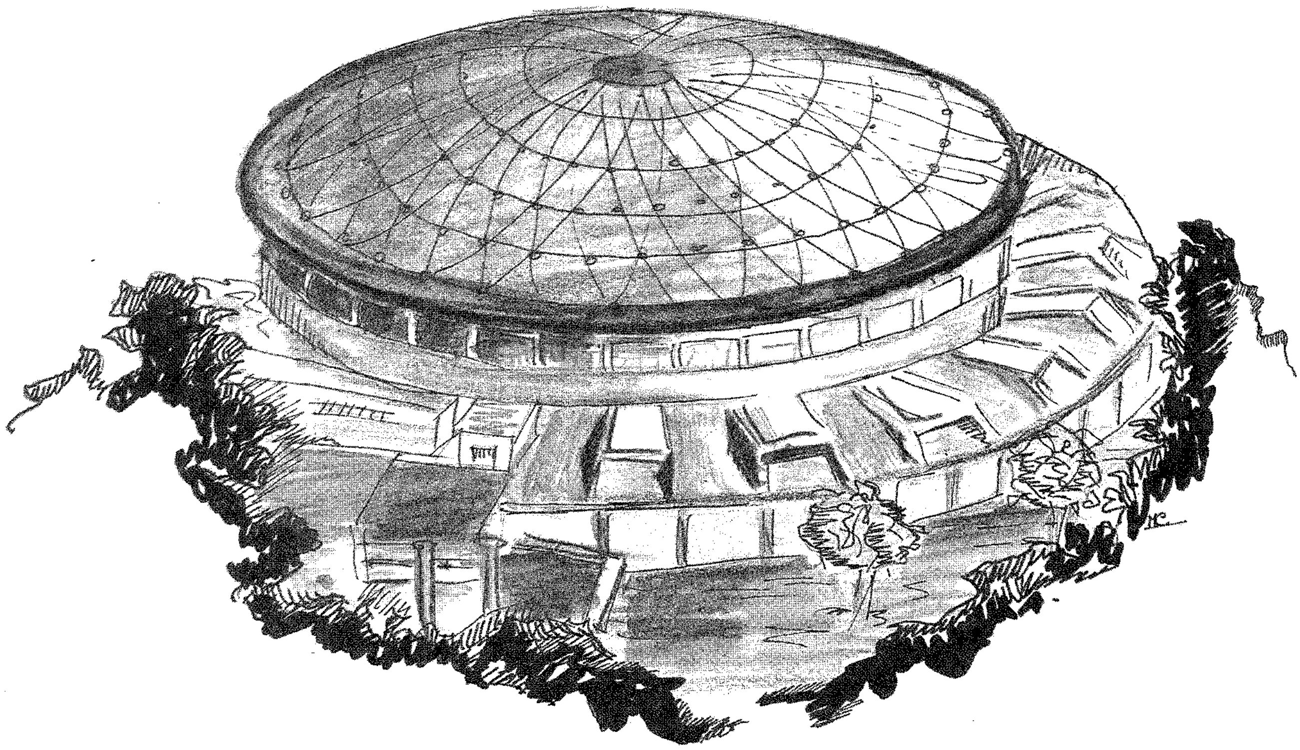
Laboratori Nazionali di Frascati

LNF-89/090(P)
19 Dicembre 1899

R. Baldini Ferroli, M.E. Biagini:

A CRUCIAL TEST FOR QCD: THE TIME-LIKE E.M. FORM FACTORS OF THE NEUTRON

Invited talk at
"International School of Subnuclear Physics"
27th Course: *The Challenging Questions*
26 July 3 August 1989



Servizio Documentazione
dei Laboratori Nazionali di Frascati
P.O. Box. 13 - 00044 Frascati (Italy)

INFN - Laboratori Nazionali di Frascati
Servizio Documentazione

LNF-89/090(P)
19 Dicembre 1989

A CRUCIAL TEST FOR QCD: THE TIME-LIKE E.M. FORM FACTORS OF THE NEUTRON

R. Baldini Ferroli, M. E Biagini
INFN - Laboratori Nazionali di Frascati, P.O. Box 13, I-00044 FRASCATI (Italy)

INTRODUCTION

The neutron e.m. time-like form factors (FF) have never been measured and the purpose of this paper is to demonstrate that this measurement is mandatory for understanding the nucleon structure. Actually the nucleon structure needs still to be investigated (as it has been proved by the recent, surprising, EMC results[1]), in spite of the overwhelming number of data collected in elastic and inelastic lepton-nucleon scattering. The current nucleon models, which reproduce either the proton FF and the neutron space-like FF, are in bad disagreement in providing the cross section for

$$e^+e^- \to n\bar{n} \qquad (1)$$

in the range experimentally accessible, with present storage rings: $4M_N^2 \leq Q^2 \leq 10\ GeV^2$.

To compare these predictions a suitable quantity is the ratio between the total cross sections $\sigma(e^+e^- \to n\bar{n})$ and $\sigma(e^+e^- \to$

$\bar{p}p$): for instance a value 0.25 is foreseen by PQCD, whereas EVMD predictions range from 1 up to 100.

This talk is organized as follows:

- a short summary of the main FF properties and present data is recalled.
- PQCD predictions are reviewed and tested in part in the time-like region, with emphasys on a puzzle in the J/Ψ decay.
- EVMD predictions are reviewed. A short status report on vector mesons is given together with some recent improvements upon simple EVMD.
- Hybrid models and the Skyrme model of the nucleon are reported. Unfortunately only suggestions are obtained by these fascinating models.
- A preliminary experimental evaluation of the neutron time-like FF is reported, based on U-spin invariance applied to available data on strange baryons.

Finally a new experiment, FENICE, is collecting data at the renewed storage ring ADONE, hence an experimental answer to this debate will come very soon.

MAIN PROPERTIES OF THE FF AND PRESENT EXPERIMENTAL SITUATION

In this paragraph the main properties of the FF are shortly recalled. In the following we shall use the convention $c = \hbar = 1$, with the exchanged 4-momentum squared Q^2 defined as $Q^2 = \left(E_{h_1}+E_{h_2}\right)^2 - \left|\vec{P}_{h_1}\vec{P}_{h_2}\right|^2$ and positive in the time-like region.

The one-photon exchange approximation is a standard assumption in lepton-hadron scattering and lepton-antilepton annihilation into hadron pairs (see Fig. 1). Many tests have been done for it in lepton-hadron scattering[2]: the angular behaviour for a given Q^2, the identity among e^- and e^+ scattering, the scattering on a polarized target. In e^+e^- annihilation the best check has been the absence of C=+1 final hadronic states.

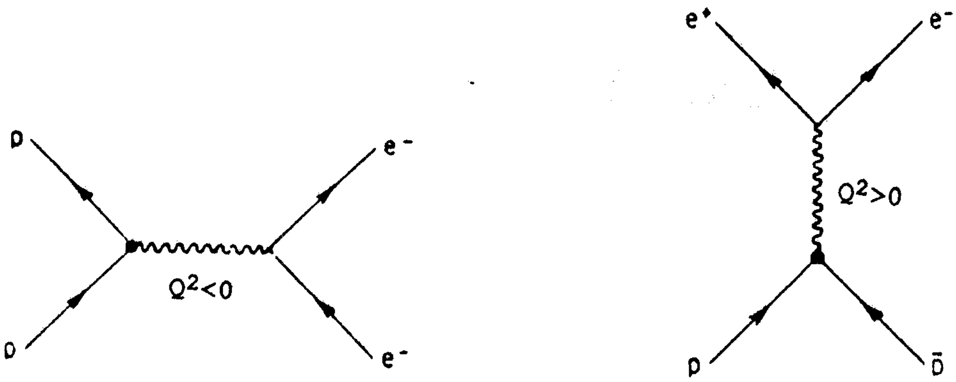


FIG. 1 - One-photon exchange approximation in ep scattering and e+e- annihilation into $p\bar{p}$.

FF must enter in the hadronic e.m. current because of the hadron structure. Parity and e.m. current conservation implies that these FF depend on Q^2 only[2]. In case of a 1/2 spin particle two FF exist, to take into account that the spin may flip or not. The Breit frame of a hadron of mass M is appropriate to define the spin states in lepton-hadron scattering. In this frame $J_z = 0$ and there are two orthogonal transition amplitudes: either the spin direction does not change along the ingoing-outgoing hadron direction z (that is an electric interaction takes place and $J_0 = 2MG_E(Q^2)$), or the spin direction changes (like in a magnetic interaction and $J_T = 2QG_M(Q^2)$)[3]. For a pointlike electron it is $G_E(Q^2) = G_M(Q^2) = 1$ and it is $J_0=0$ in the limit $m_e/Q \to 0$. For a baryon two other FF, the Dirac F_1 and the Pauli F_2, are also introduced: $F_1 = (G_E-\tau G_M)/(1-\tau)$, $F_2 = (G_E - G_M)/(1-\tau)$, where $\tau = Q^2/(4M^2)$.

In e^+e^- annihilation the center of mass frame has the role the Breit frame has in the scattering case and the virtual exchanged photon is polarized like a real one, along the beam direction, if the electron mass is neglected respect to Q. Projecting this virtual photon along the outgoing baryon direction θ, three orthogonal helicity states are available, with different transition amplitudes and different angular behaviour:

$$\mathbf{A} = \mathbf{A}_+ \ (1+\cos\theta)/2 - \mathbf{A}_0 \ \sin\theta/\sqrt{2} + \mathbf{A}_- \ (1-\cos\theta)/2 \ .$$

Invariance under parity transformations implies $A_+ = A_-$. An outgoing antibaryon with a given helicity corresponds to an ingoing baryon with the same helicity, therefore A_0 corresponds to the space-like non spin flip amplitude $2MG_E$ and A_+ corresponds to $2QG_M$. The differential cross section for unpolarized beams for reaction (1) is:

$$d\sigma/d\cos\theta = \pi\alpha^2\beta(3-\beta)/4Q^2\ ((1+\cos^2\theta)\ |G_M|^2-1/\tau \sin^2\theta\ |G_E|^2).$$

S and D waves are allowed, still at threshold the S wave is expected to be dominant, so that the cross section is isotropic, $G_E(4M^2) = G_M(4M^2)$, $F_1(Q^2)$ and $F_2(4M^2)$ are not singular.

Invariance under CPT transformations implies that time-like FF are the analytical continuation of the space-like FF. Unitarity implies that FF are real on the real axis up to the first inelastic threshold ($Q^2 = 4\ m_\pi^2$ for the isovector and 9 m_π^2 for the isoscalar part). An experimental proof of this continuity is reported in Fig. 2, concerning the pion ff[4]. Unfortunately a discontinuity is expected among baryon FF space-like and time-like above threshold, due to the presence of vector mesons poles in the unphysical region. In principle this region may be explored by looking at $B\bar{B} \to \pi^0 e^+e^-$.

Proton FF measurements are reported in Fig. 3. Space-like data, up to $Q^2 \approx 10\text{GeV}^2$, are well described by the classical dipole fit[3]: $G_M{}^p = \mu_p/(1-Q^2/m_0{}^2)^2$, with m_0=0.84 GeV, and $G_E{}^p = G_M{}^p/\mu_p$.

Time-like data disagree with a strightforward extrapolation of the dipole fit. The collected statistics begins to be relevant and other, more accurate, measurements from the APPLE experiment at LEAR will come very soon[5].

Neutron space-like FF measurements are reported in Fig.4. The magnetic FF is also well described by the dipole fit. New measurements of the electric ff are described by the fit[6] $G_E{}^n = a\ \mu_n\ \tau/(1+b\tau)$, where a = 1.1-1.5 and b = 8.4-5.6.

At small, non relativistic, Q^2 the electric ff is interpreted as the Fourier transform of the electric charge distribution[7]. Incidentally an extrapolation to imaginary Q would predict a very small neutron time-like electric FF.

Finally, only one poor measurement of strange baryon FF exists[8], namely: $\sigma(e^+e^-\to \Lambda\bar{\Lambda})$ = 110±50 pb at $Q^2 = 5.76\ \text{GeV}^2$, which implies $|G_M{}^\Lambda|$ = 0.12±0.03 assuming that $G_E \approx G_M$ is still valid.

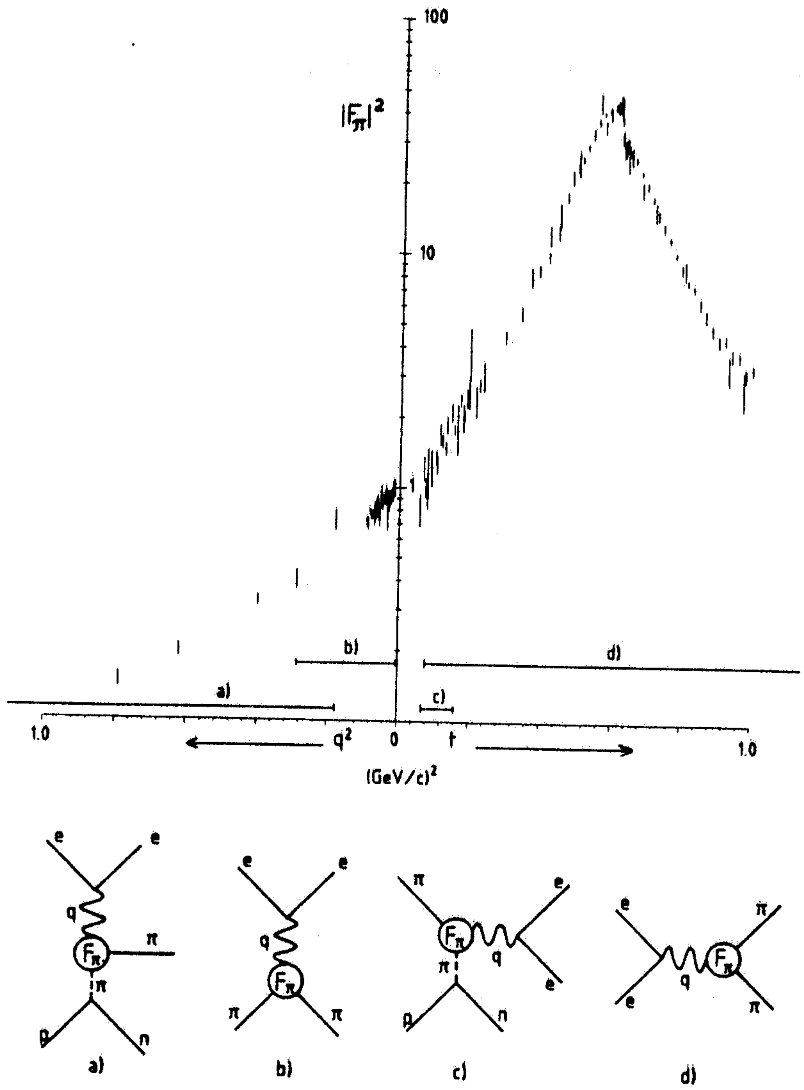


FIG. 2 - Pion space-like and time-like FF.

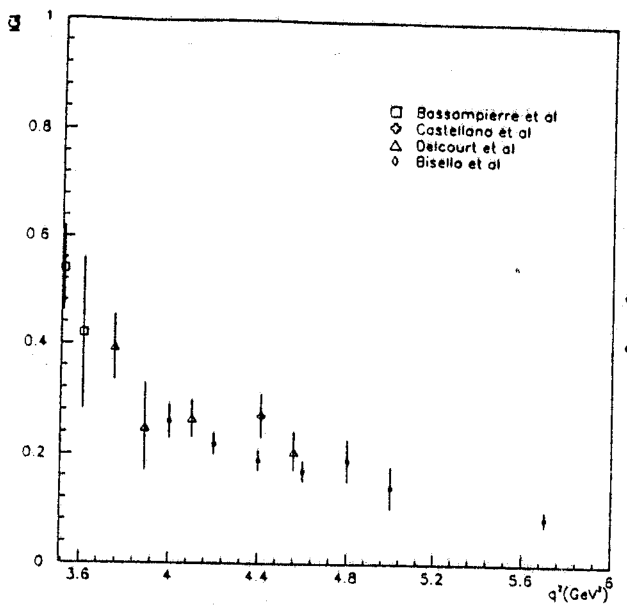


FIG. 3 - Proton time-like magnetic ff.

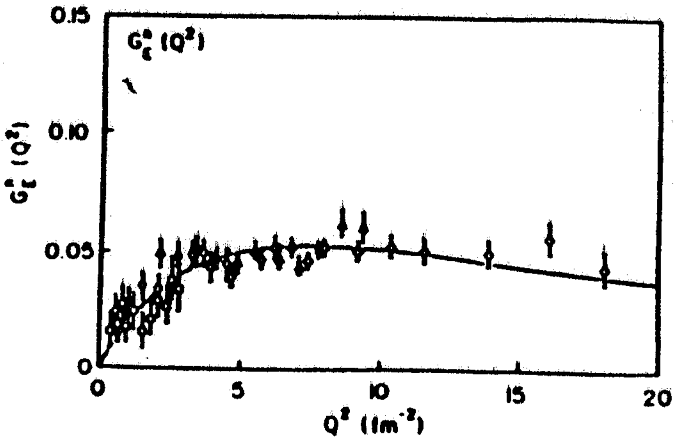


FIG. 4 - Neutron space-like electric ff.

MAIN QCD PREDICTIONS ON FORM FACTORS

At present the available QCD predictions on FF mainly concern their asymptotic behaviour and the quark wave functions probed at high Q^2 inside a hadron.

A still open question in QCD is at which Q^2 value an asymptotic prediction is achieved. This is the major lack to appreciate Perturbative QCD calculations. By the way asymptotic behaviours, like the Bjorken scaling, are fulfilled already at space-like Q^2 values of the order of few GeV^2 in the deep inelastic electron-nucleon scattering[3]. In the time-like region some - controversial - experimental tests about asymptotics are available and will be reported later.

Concerning the asymptotic behaviour of the FF for a hadron, made of n pointlike costituents, it is foreseen a Q^2 power law[9], modulo terms containing (log Q^2):

$$F \propto (1/Q^2)^{n-1}$$

For baryons this scaling rule concerns in practice the Dirac ff. As a check, a collection of space-like data is shown in Fig. 5[10], and the most recent results on pion and kaon time-like FF[8] are reported in Fig. 6.

The overall trend is in good agreement with the expected behaviour (even if not proven) expecially compared to the exponential drop expected in absence of pointlike costituents[11].

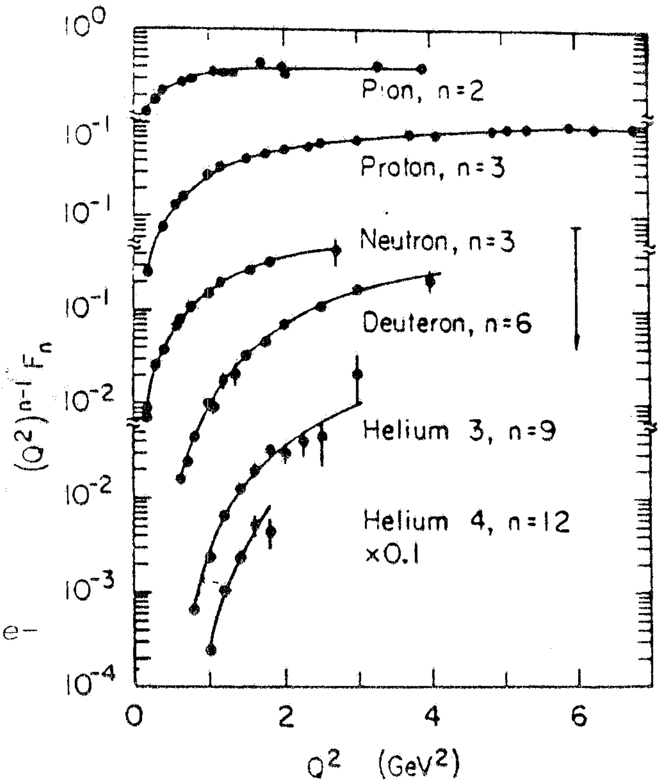


FIG. 5 - A collection of space-like Dirac FF.

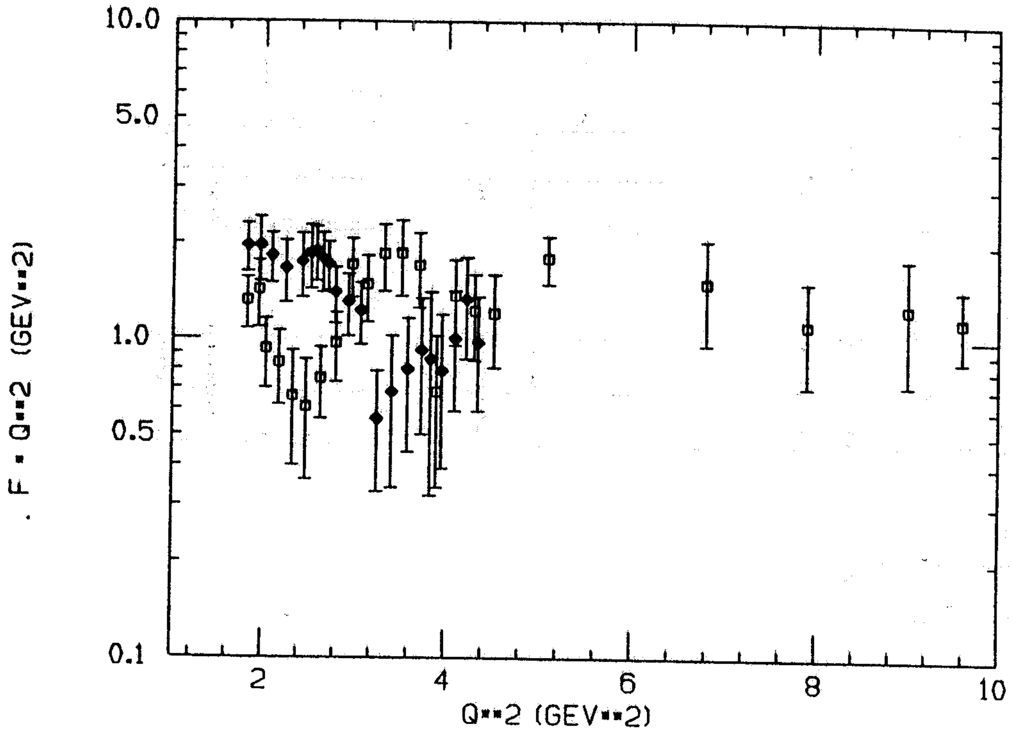


FIG. 6 - Pion (□), charged kaon (◆) time-like FF.

A power law rests on a more general ground than QCD[9,12]. In fact for every elementary field in the initial and final states, entering into the transition amplitude, a factor 1/Q must be introduced for dimensional reasons, if the coupling constant has no dimensions. A factor Q^2 must be factorized in the transition amplitude to get the FF, therefore in general $F \propto (1/Q)^{2n-2}$.

PQCD predicts for the leading terms in the no helicity flip amplitude T[9,13]:

$$T = \int dy\, dx\, \phi_B^{+}(y,Q)\, T_B(x,y,Q)\, \phi_B(x,Q)$$

where T_B is the scattering or annihilation amplitude between quarks, computed just replacing each baryon with its collinear valence quarks, and ϕ_B is the quark wave function inside the baryon, considering transverse momenta squared up to Q^2.

The power law is recovered taking into account the Q^2 dependence of the various propagators and wave functions according to Fig.7:

$$(n-1)\ \text{quark prop.} + (n-1)\ \text{gluon prop.} + n(u_q + u_q) \approx (u_B + u_B)\ F$$

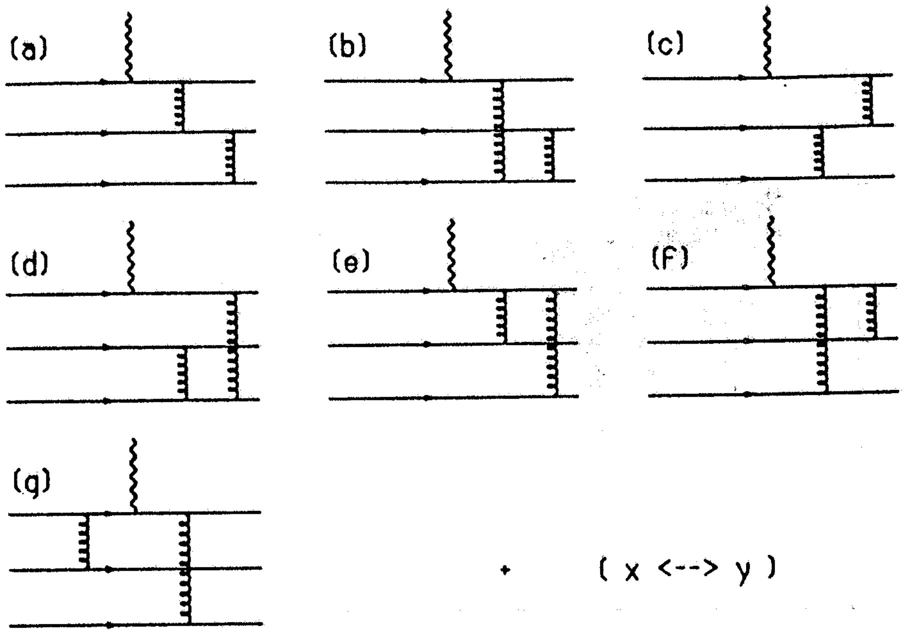


FIG. 7 - Leading contributions to the FF, according to PQCD.

Additional $\log(Q^2)$ dependence comes from $\sqrt{\alpha_s}(Q_i{}^2)$ factors at each quark-gluon vertex.

The no-helicity flip amplitude corresponds in practice to the Dirac ff, since the Pauli ff scales with an additional $1/Q^2$ factor and it is related to the quark dynamical mass, vanishing if u and d quarks are considered. Also this conclusion rests on a more general ground than QCD: G_E and G_M different structure constraints F_1 and F_2 to have different behaviours.

Critical ingredients in the PQCD calculation of the FF are the Q^2 dependence of α_s and the quark wave function. In the integration on the quark and gluon internal momenta there is a divergence using the asymptotic expression $\alpha_s\ (Q_i{}^2) \approx 1/\log\ (Q_i{}^2/\Lambda^2)$ (the only known at present). Nevertheless if $\langle\alpha_s\rangle \approx$ $\sqrt{\alpha_s\left(\frac{Q^2}{36}\right)\alpha_s\left(\frac{Q^2}{9}\right)}$ (coherent with the mean internal momenta) the correct order of magnitude is achieved for the space-like Dirac ff[13,14].

Better agreement has been obtained by Ji[14] if a fictitious gluon mass $m_g \approx 0.5$ GeV is introduced, as it is shown in Fig. 8.

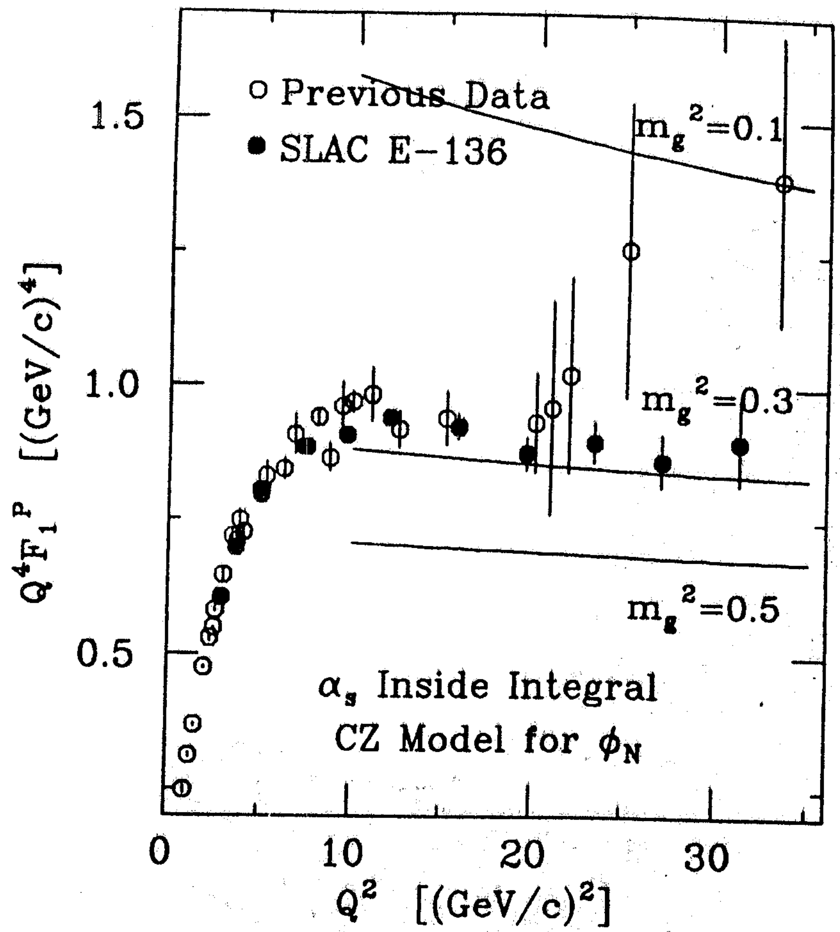


FIG. 8 - Proton Dirac ff, according to PQCD and $m_g \neq 0$.

The quark wave function is also critical because both a non-relativistic distribution $\Pi\delta(x_i-1/3)$ and an asymptotic one $n_1\, n_2\, n_3$ give unphysical space-like FF: $G_M^n > 0$, $G_M^p < 0$ or $G_M^p \ll G_M^n$.

Chernyak and Zhitnisky[13] have evaluated the wave function according to the S.V.Z. sum rules[15], which allow to know the quark momenta $x_1^{n_1}\, x_2^{n_2}\, x_3^{n_3}$ averaged on the nucleon wave function for every $n_1 n_2 n_3$ values. Very roughly these sum rules connect, according to the uncertainty principle, quantities averaged on the energy to short interaction times, related to perturbative and long range confining mechanism expectations. Chernyak and Zhitnisky have done an ansatz for the wave function, which agrees with sum rules for $n_1+n_2+n_3 \leq 2$. It is very relevant that in this wave function, see Fig. 9, there is a leading u(d) quark in a proton (neutron): $\langle x_{u(d)} \rangle \approx 2/3$. Such a result is in agreement with a baryon picture as a diquark-quark bound state.

The leading quark should be produced first in e^+e^- annihilation at high Q^2, therefore according to PQCD:

$$\sigma(e^+e^- \rightarrow n\bar{n}) / \sigma(e^+e^- \rightarrow p\bar{p}) = (q_u/q_d)^2 = 0.25$$

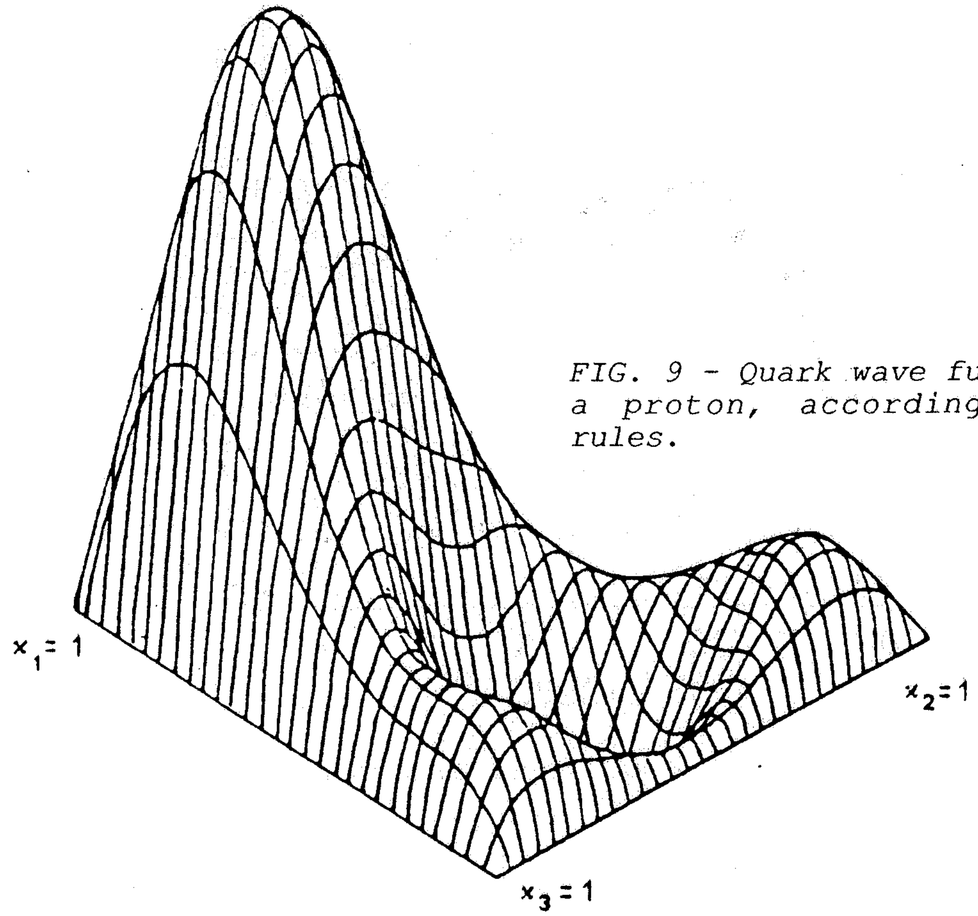


FIG. 9 - Quark wave functions in a proton, according SVZ sum rules.

A warning about S.V.Z. sum rules applied to heavy qq wave functions has been given by Bell and Bertlmann[16]. A $q\bar{q}$ confining potential has been derived, which gives the same quark momenta: $V(r) = -4/3\ \alpha_s/r + \pi/144 \langle\alpha_s GG\rangle m_q\ r^4$. The m_q dependence is in disagreement with the common opinion that this potential should be flavour independent.

It has already been pointed out that PQCD expectation (1) concerns the Dirac ff. The Pauli ff and higher twist terms have been evaluated by Ji and Sill[17], but only for heavy quark baryons using a non relativistic quark wave function. This calculation cannot be extrapolated to light quark baryons, even if the right magnetic momenta are provided. Nevertheless may be worthwhile that the quoted PQCD expectation is recovered by this calculation at $Q^2 \approx 4\ M_N^2$ regardless the light quark masses.

Finally, lattice calculations[18], done up to now in quenched approximation, do not predict a leading quark, but even the dipole fit is not predicted for G_E space-like, in clear disagreement with the data.

PQCD TIME-LIKE PREDICTIONS CHECKS

The strange quark mass is of the same order of magnitude of Λ_{QCD} and the aforementioned m_g, hence it could be meaningful to presume that asymptotics is reached when SU_3 flavour is also a good symmetry. In e^+e^- annihilation SU_3 flavour is related to the U-spin invariance, which predicts for meson's ff that:

$F_{K^+} \approx F_\pi$ and $F_{K^+} \ll F_{K^0}$.

In Fig. 6 these FF have been reported, normalized to the QCD's Q^2 asymptotic prediction: U-spin invariance is fulfilled, within large errors, at $N\bar{N}$ threshold.

A test of PQCD expectations is done looking at the branching ratios $B(J/\Psi \rightarrow B\bar{B})$ (even if related to Q^2 above the charm threshold, really). In this case the main decay of J/Ψ in three hard gluons well matches the three quarks of a baryon, as it is shown in Fig.10a.

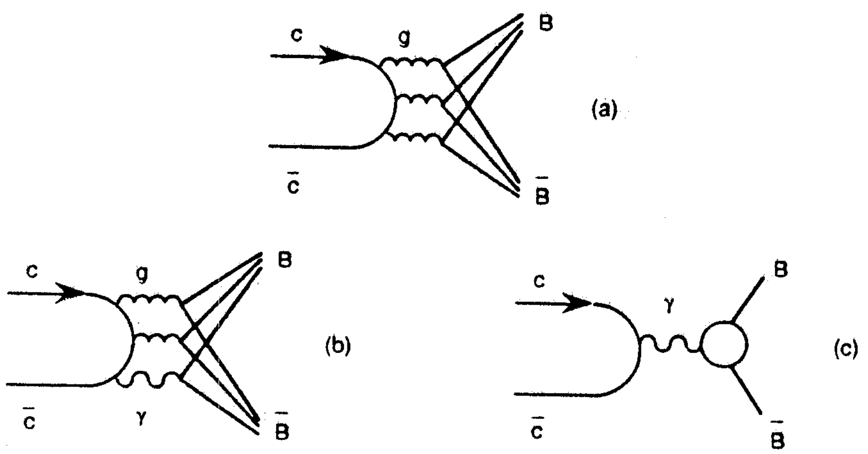


FIG. 10 - a) Leading contribution to $J/\Psi \rightarrow B\bar{B}$, according to PQCD. b,c) e.m. contributions to $J/\Psi \rightarrow B\bar{B}$.

This branching ratio is strongly dependent on α_s and ϕ_N [13], namely $B(J/\Psi \to B\bar{B}) \approx \alpha_s^3 \phi_N^4$. The experimental value, $B(J/\Psi \to B\bar{B}) = 0.22 \pm 0.01$[19], is just recovered if $\alpha_s(M_{J/\Psi}^2) \approx 0.2$ and the wave function is that derived according to sum rules. This expectation decreases by one or two order of magnitude if the asymptotic or non relativistic wave functions are introduced.

This impressive check conflicts with the helicity non conservation in the sizeable branching ratios $B(J/\Psi \to \rho\pi + K^*K) = 2.1 \pm 0.2$ %[19]. In fact in the gluon-quark spin matching and helicity conservation only two vector or pseudoscalar mesons should be produced.

The Ψ' agrees with this rule: $B(\Psi' \to \rho\pi + K^*K) = 0.009 + 0.005$%. Indeed the anomaly is the J/Ψ decay. It is expected that J/Ψ and Ψ' branching ratios into the same hadronic channel are in the same ratio as the relative branching ratios into e^+e^-[20]. In Table I many of these ratios are reported in good agreement with this prediction, only the decays into vector + pseudoscalar meson disagree by a factor as big as $(M_{J/\Psi}/M_{\Psi'})^{17}$.

TABLE I - Ψ/Ψ' decays anomaly.

CHANNEL X	$B(\Psi \to x)/B(\Psi' \to x)$
$e^+e^- + \mu^+\mu^-$	7.7
$3(\pi^+\pi^-)\pi^\circ$	8.3
$2(\pi^+\pi^-)\pi^\circ$	11.0
$\pi^+\pi^-\pi^\circ$	167.0
$\pi^+\pi^-K^+K^-$	4.5
$\pi^\circ K^+K^-$	>203.
$\pi^+\pi^- p\bar{p}$	7.5
$\pi^\circ p\bar{p}$	7.9
$\pi^+\pi^-$	1.9
K^+K^-	2.4
$p\bar{p}$	11.6
$3(\pi^+\pi^-)$	26.7
$2(\pi^+\pi^-)$	8.9

This anomalies have been pointed out many years ago[21]. Recently Brodsky, Lepage and Tuan [20] have proposed as explanation a small mixing between the J/Ψ and a "glueball" G nearby, with a difference in mass and width of the order of 100 MeV. In fact G would affect only the J/Ψ and a large effect is expected in channels forbidden to the J/Ψ, if the G width is large. On the other hand the interaction region for G is of the order of $1/m_{u,d,s}$, to be compared to $1/m_c$ for a $c\bar{c}$ pair, therefore also many soft gluons contributions are provided for the G decay.

The G detection in e^+e^- annihilation could be very hard if not impossible. If α is a small mixing angle, it is:

$$\psi = \psi_0 - \alpha G_0$$
$$G = \alpha \psi_0 + G_0$$

from which

$$A(\psi \to \rho\pi) = -\alpha A(G \to \rho\pi)$$
$$A(G \to e^+e^-) = \alpha A(\psi \to e^+e^-)$$

Hence the cross section $\sigma(e^+e^- \to \rho\pi)$ is independent of α, namely:

$$\sigma(e^+e^- \to \rho\pi) = (3\pi/Q^2)\ \Gamma(e^+e^- \to J/\Psi)\ \Gamma(J/\psi \to \rho\pi)$$
$$|1/(Q\ M_\psi + i\Gamma_\psi/2) - 1/(Q - M_G + i\Gamma_G/2)|^2$$

and at $Q \approx M_G$ it is expected $\sigma(e^+e^- \to \rho\pi) \approx 5 \times 10^{-4}$ nb !

VECTOR MESON DOMINANCE PREDICTIONS ON FORM FACTORS

Before QCD, the successful model to interpret the FF was the Vector Meson Dominance model. According to VMD[22] hadronic and e.m. interactions were mediated by vector mesons as ρ, ω and ϕ.

Proton and neutron different e.m. behaviour was explained in terms of different ρ, ω coupling constants. In fact $g_{\gamma\rho} \gg g_{\gamma\omega}$ (according to their quark contents $g_{\gamma\rho} : g_{\gamma\omega} = (Q_u - Q_d) : (Q_u + Q_d) = 9:1$), but $g_{NN\rho} \ll g_{NN\omega}$ (according to the repulsive core in the NN potential).

It is a curiosity that, just in the early days of the first nucleon FF measurements and of the first vector meson evidences, Cabibbo and Gatto[23] foresaw a very big neutron time-like FF:

$$\sigma(e^+e^-\to n\bar{n})/\sigma(e^+e^-\to p\bar{p}) = 14.$$

That was due to a cancellation between F_1 and F_2 in the proton time-like FF.

At the beginning VMD was a very ambitious model. If extrapolated at $Q^2 = 0$, VMD implies that the electric charge is related to $g_{\gamma V}$ times g_{HHV}, whence g_{HHV} is a hadronic universal constant. On these basis vector mesons could be identified as the gauge bosons of the conserved quantum numbers in the strong interactions[22]. The existence of ρ, ω and ϕ recurrences (in other words $R_\infty = \sigma(e^+e^-\to\text{hadrons})/\sigma(e^+e^-\to\mu\,\mu) \approx$ constant) destroyed this theoretical scheme. This approach has been recovered in a different context by the Skyrme model, which will be shortly reported later.

Anyhow at the moment the common opinion is that there is a transition from an Extended VMD to a direct photon-quark coupling, passing from low to high Q^2, from large to short interaction times. A duality relationship should exist between these two descriptions[24]. The uncertainty principle relates high Q^2 cross sections, described by PQCD, to integrated cross sections at low Q^2, described by EVMD. In turn, high Q^2 cross sections are achieved by the convolution of an infinite number of vector mesons.

Actually EVMD, which is the only available model at low Q^2, is a phenomenological model. In fact there is not yet a reliable prediction on the vector meson spectrum and on how to extrapolate their amplitudes out of the resonance. In spite of these uncertainties, most of the EVMD calculations on the time-like neutron FF expect:

$$\sigma(e^+e^-\to n\bar{n}) \gg \sigma(e^+e^-\to p\bar{p})$$

in the range $4M_N^2 \le Q^2 \le 10\ \text{GeV}^2$.

Besides, the determination of the various vector mesons contributions to the nucleon FF is an important result perse. For instance the size of the Φ contribution is the best measurement of the strange quark content in the nucleon wave function, which is very important[44] to interpret the aforementioned EMC results on the polarized nucleon structure functions.

According to the old Veneziano model[25] the masses of the ρ daugthers are given by $m_n^2 = m_\rho^2 + n/\alpha'$, where $\alpha' \approx 0.9 \div 1.0$ GeV^2 is the slope of the ρ trajectory, so that we have $m_{\rho'} \approx 1.25$ GeV, $m_{\rho''} \approx 1.6$ GeV and full degeneracy is expected between ρ and ω recurrences.

Korner and Kuroda [26] have reproduced the baryon space-like FF and predicted the time-like FF (see Fig. 11) with a remarkable formula, without free parameters:

$$F_{1,2} = \sum_{\rho,\omega,\phi} C_V \prod_{rec}^{N_{1,2}} \left(1 - \frac{Q^2}{m_{rec}^2}\right)^{-1}$$

The poles are those provided by the Veneziano model, their number $N_{1,2}$ is fixed by the asymptotic QCD power law requirements ($F_1 \propto 1/Q^4$ and $F_2 \propto 1/Q^6$) and the FF are normalized to $Q^2=0$. Demanding the asymptotic behaviour with a small number of poles should be coherent with the early scaling behaviours in the space-like region.

This formula agrees surprisingly well with the bulk of the proton time-like measurements, done many years later, and predicts, in the range $3.5 \leq Q^2 \leq 10$ GeV^2:

$$\sigma(e^+e^- \to n\bar{n}) / \sigma(e^+e^- \to p\bar{p}) \approx 2.$$

Yet a $\rho'(1.25)$ is demanded in this approach, and also in other EVMD space-like fits. On the contrary there is no experimental evidence of this vector meson in $\sigma(e^+e^- \to \text{hadrons})$ and in the pion FF[8].

If only even daugthers exist, like the $\rho(1.6)$, a good prediction for the asymptotic ratio $R_\infty = \sigma(e^+e^- \to \text{hadrons}) / \sigma(e^+e^- \to \mu\mu) \approx 2.5$ has been given by Etim and Greco[27], assuming simple rules for their widths and coupling constants. According to this by now standard scheme, which is in agreement with the bulk of the experimental data in e^+e^- annihilation around the $N\bar{N}$

threshold, it is provided [28] in the range $3.5 \le Q^2 \le 10$ GeV^2 (see Fig. 12):

$$\sigma(e^+e^- \to n\bar{n})/\sigma(e^+e^- \to p\bar{p}) \approx 100.$$

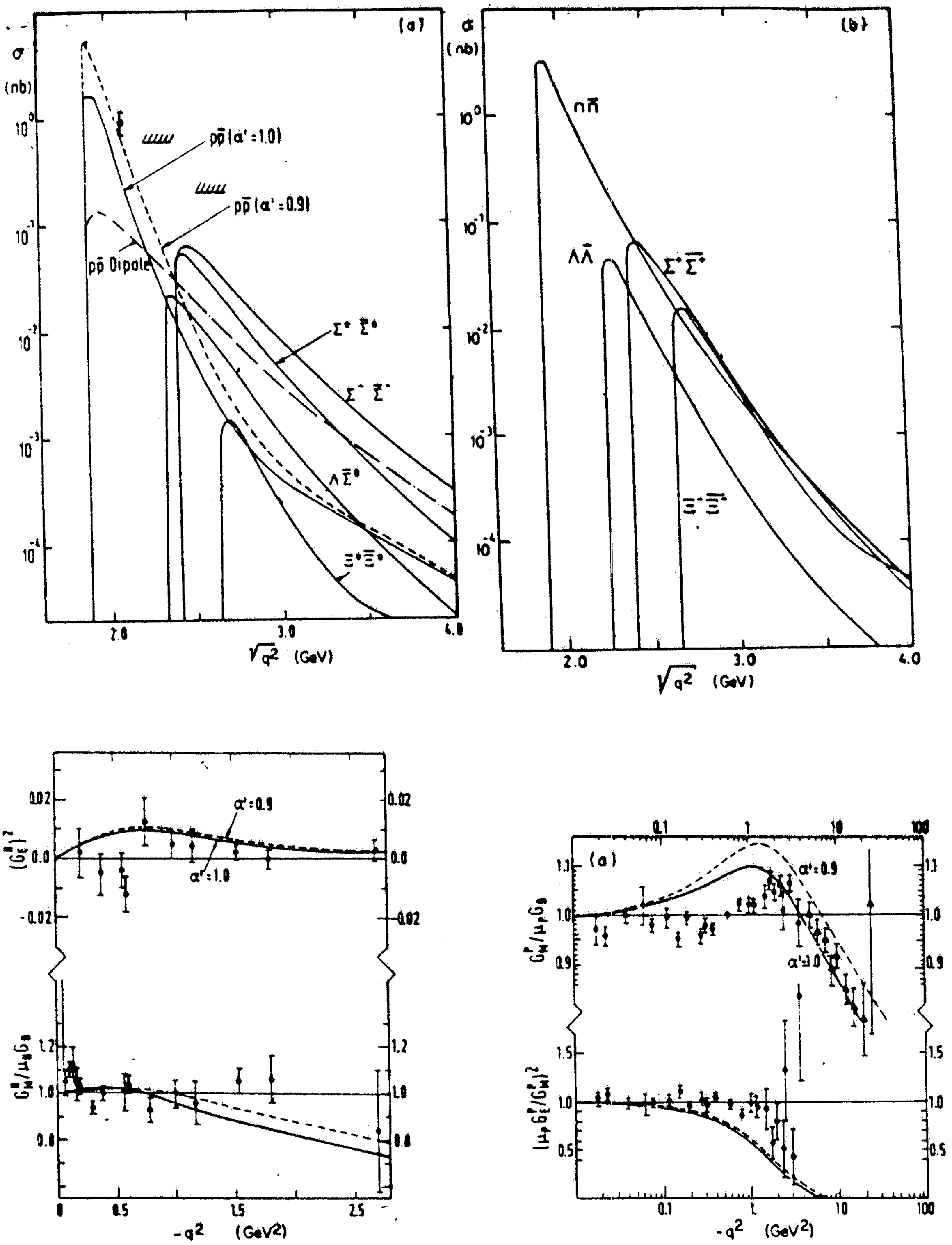


FIG. 11 - Baryon space like and time-like cross sections, according to EVMD, Veneziano daughters and SU_3 flavour symmetry.

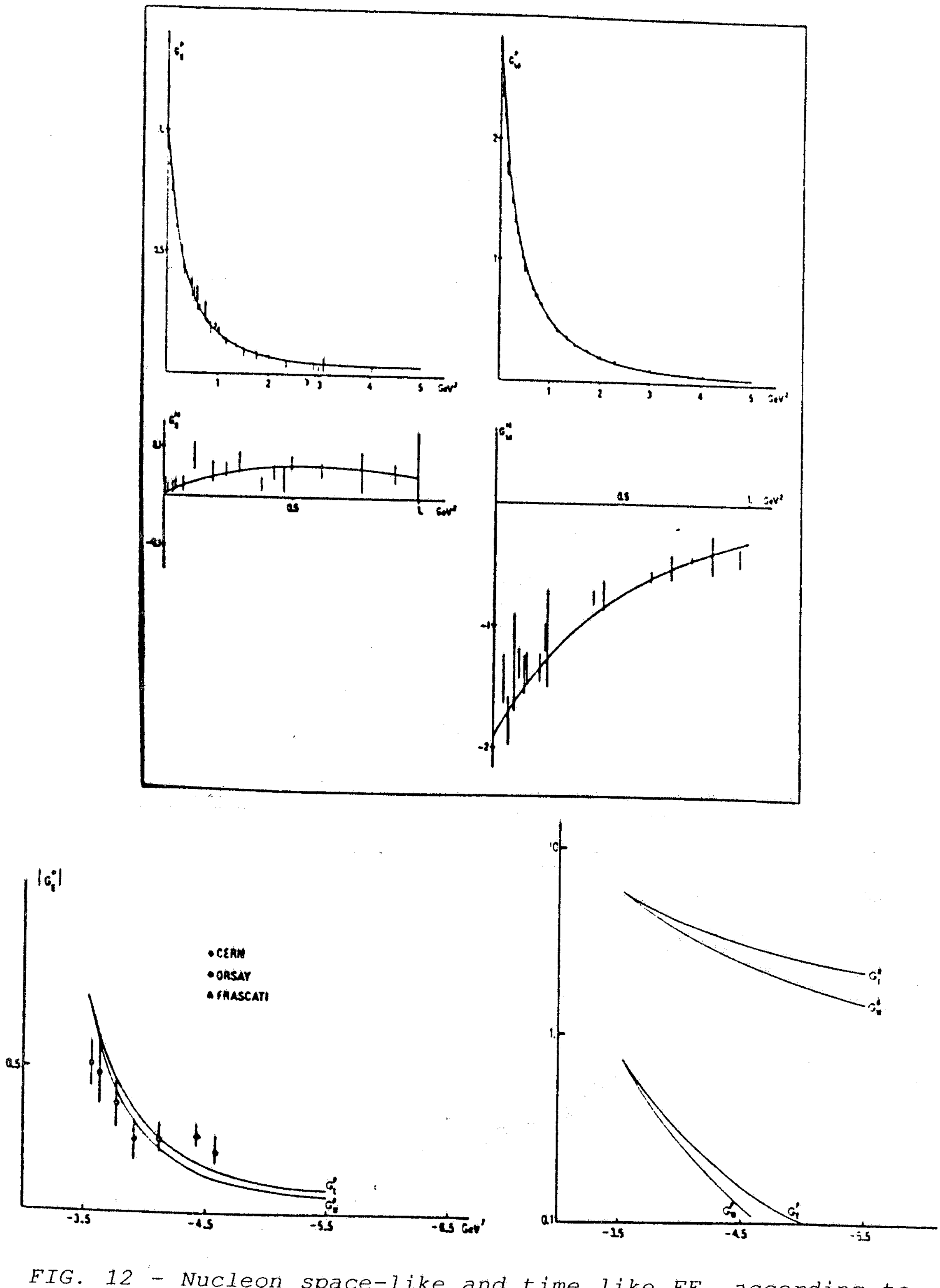


FIG. 12 - Nucleon space-like and time like FF, according to EVMD and even daughters only.

However there are hints that the spectrum of the ρ recurrences is much more complicated. The pion ff has a dip at 1.6 GeV and the comparison with the diffractive photoproduction of pion pairs, see Fig. 13, definitively shows that photoproduction cannot be related to e^+e^- annihilation according to the simplest version of EVMD[29]. The pion FF has been nicely fitted by Donnachie and his collaborators[29] with two interfering resonances $\rho'(1.4)$ and $\rho'(1.7)$.

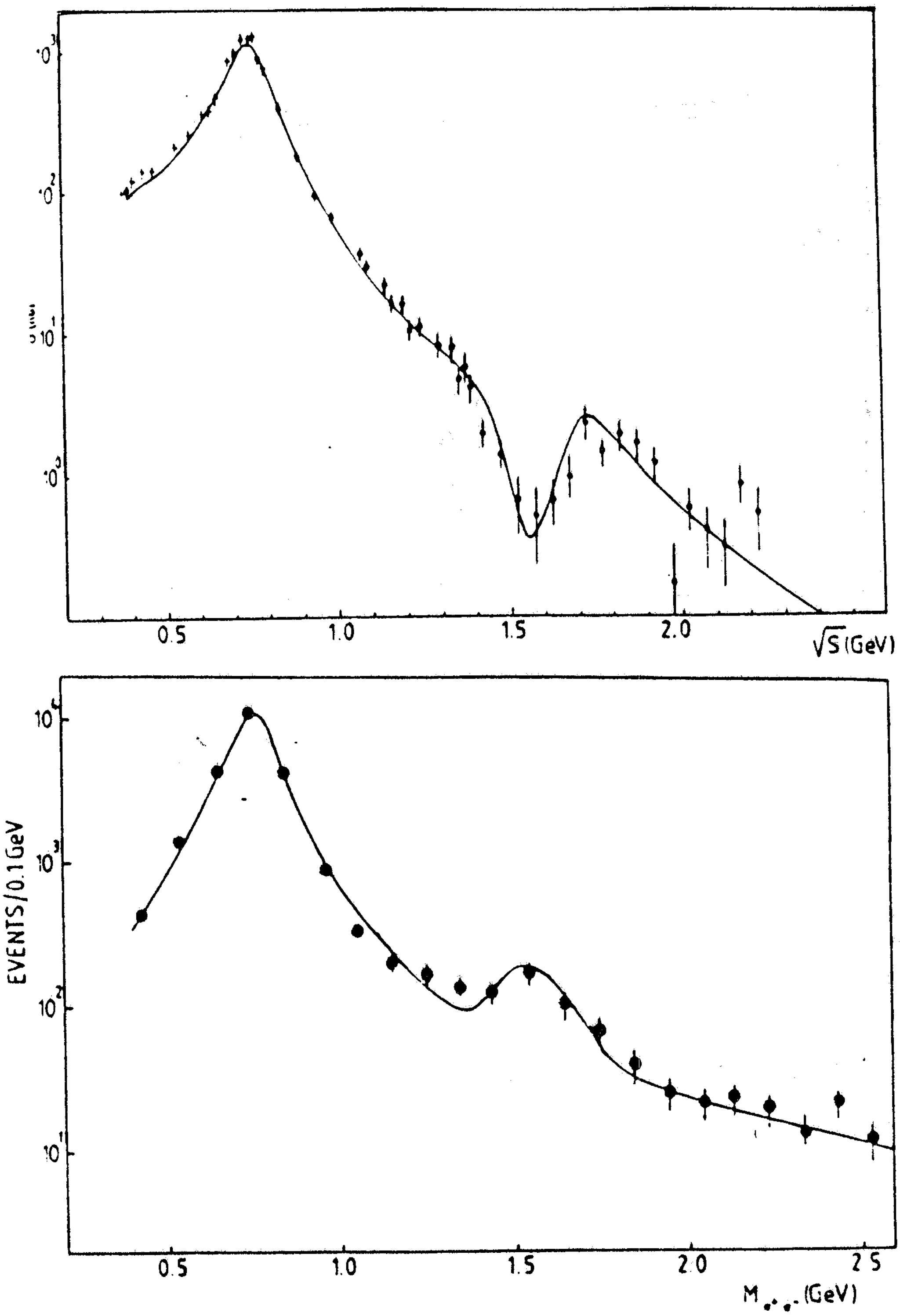


FIG. 13 - Pion ff and diffractive pion pairs photoproduction.

The smooth bump around 1.6 of $\sigma(e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-)$, the so called $\rho'(1.6)$ (see Fig. 14), does not show any interference pattern[30], but many channels may be superimposed in a many bodies process. Indeed in the two body channel $\rho\,\eta$ there are evidences for these two resonances, but the collected statistics is rather poor[31]. Results from data collected by the DM2 experiment at DCI about $e^+e^- \rightarrow \pi^+\pi^-\pi^0\pi^0$ will come very soon to add more informations.

These two resonances, if confirmed, will have very deep implications on the whole hadron spectroscopy.

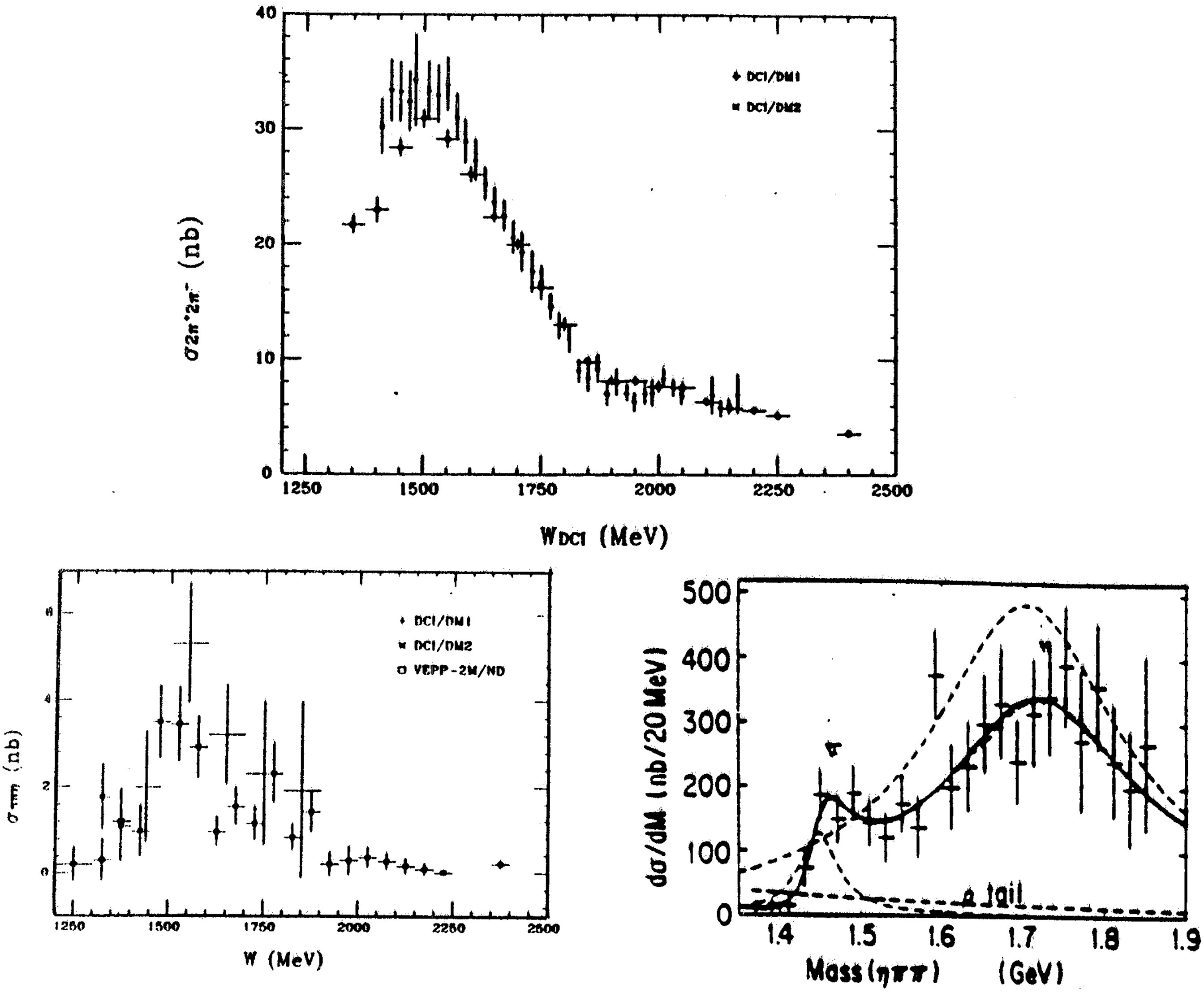


FIG. 14 – a) the $\rho'(1.6)$ bump in $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-$.
b) cross section $e^+e^- \rightarrow \rho'\eta$.
c) cross section $\pi^-p \rightarrow (\rho\eta)n$ as a function of $M_{\rho\eta}$ for $J^{P}_{\rho\eta} = 1^-$.

IMPROVEMENTS UPON VMD

All the aforementioned EVMD approaches extrapolate resonant amplitudes assuming that the vector meson-nucleon coupling constants remain real and do not vary with Q^2. Many years ago it was shown by Massam and Zichichi [32] that the space-like nucleon dipole fit is recovered by VMD if a further vector meson form factor $F = 1/(1-Q^2/\Lambda^2)$ with $\Lambda \approx 1.$ GeV, is introduced in the vector meson-nucleon coupling constants. Nowadays this procedure is embodied in the Skyrme model and the same cutoff is also used in practice in the One-Boson-Exchange model for the NN interaction [34].

A straightforward extrapolation of such a form factor in the time-like region is meaningless, introducing an unphysical pole, and it is in disagreement with the experimental data on the time-like proton FF. Incidentally a much lower neutron time-like FF is predicted by this extrapolation[35].

A not analytical, but trustworthy, extrapolation, which avoids unphysical poles, has been attempted by Etim and Malecki[36]: $F_V = 1/(1+|Q|^2/\Lambda^2)$. In this model Bloom-Gilman[37] duality is invoked to justify a form factor also for a vector meson, like for any hadron. Using standard even daughters and demanding the QCD asymptotic behaviour, a good fit is achieved for the space-like and time-like proton FF data, assuming $\Lambda \approx 0.7$ GeV (see Fig. 15). Then it is predicted in the range $3.5 \leq Q^2 \leq 10$ GeV^2:

$$\sigma(e^+e^- \to n\bar{n}) / \sigma(e^+e^- \to p\bar{p}) \approx 1$$

This prediction agree with the common opinion that ρ and its recurrences dominate e^+e^- annihilation into hadrons. In the nucleon case it is anyway very dependent on the high mass recurrences and it may change if the aforementioned doubts about $\rho'(1.6)$ are well- grounded.

Another improvement upon simple EVMD is the implementation in the FF of the cuts on the Q^2 real axis above inelastic thresholds, demanded by the unitarity.

Dubnicka [38] has conceived a formula which has almost all the required analytical properties and asymptotic behaviours.

Free parameters are pole positions, coupling constants on the poles, and an effective threshold for the unitarity cuts. In this formula again the effective coupling constants vary with Q^2 but the early asymptotic behaviour may be achieved without fixing the number of poles, as it has been required in simple EVMD. Leaving as parameters the still unknown masses, widths and coupling constants, a good fit is obtained for π^+, K^+, K°, p and n FF simultaneously (see Fig.16).

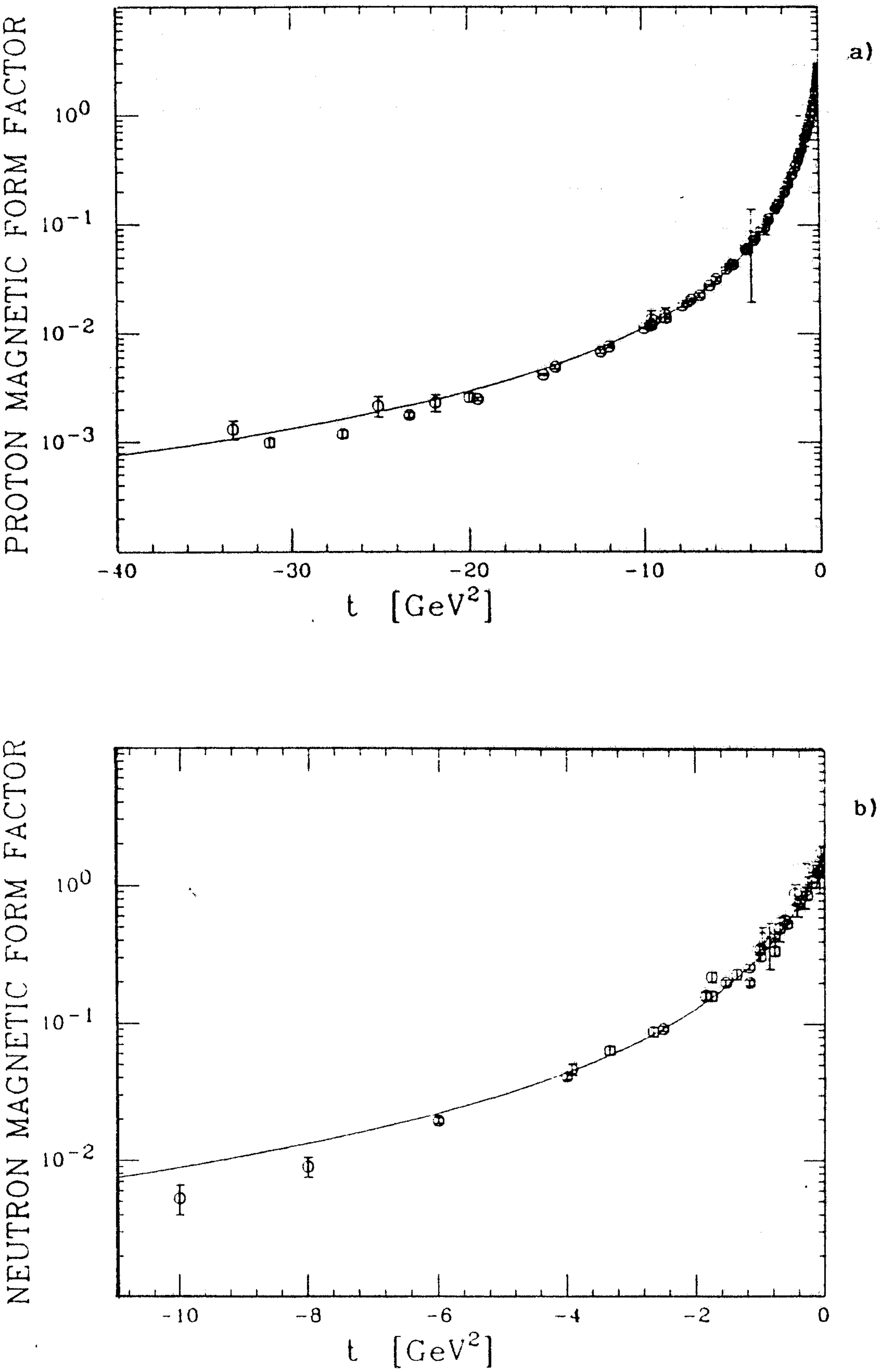


FIG. 15 - (a,b) nucleon space-like magnetic FF with EVMD fit, according to a vector meson ff and even daughters only.

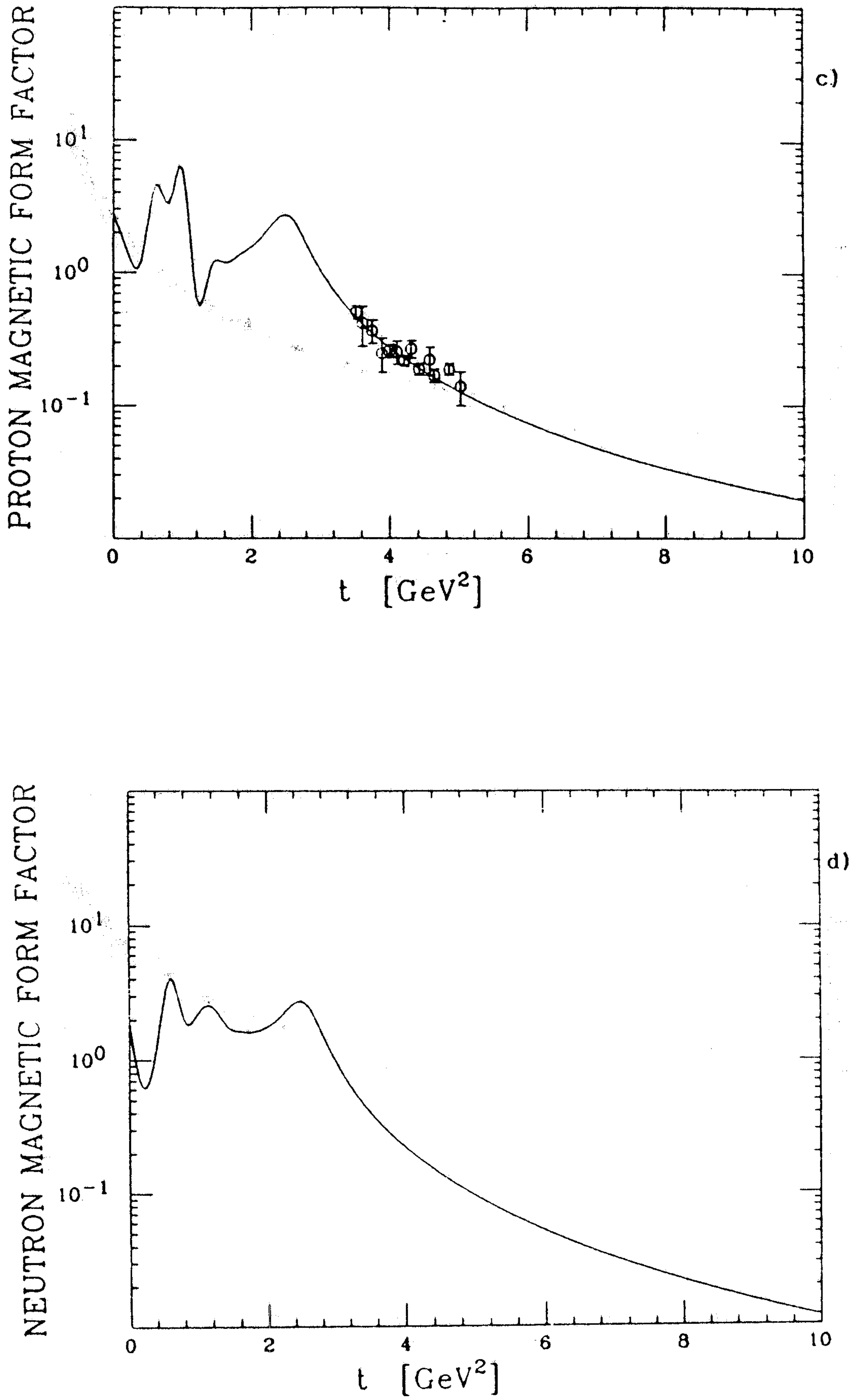
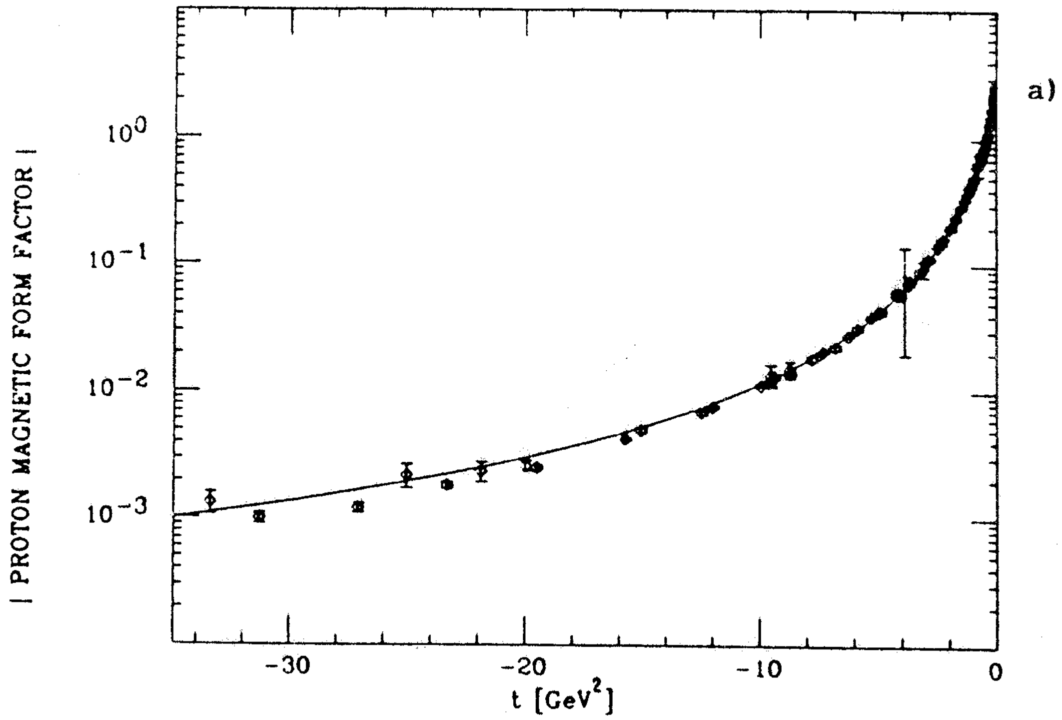


FIG. 15 - (c,d) nucleon time-like magnetic FF with EVMD fit, according to a vector meson ff and even daughters only.



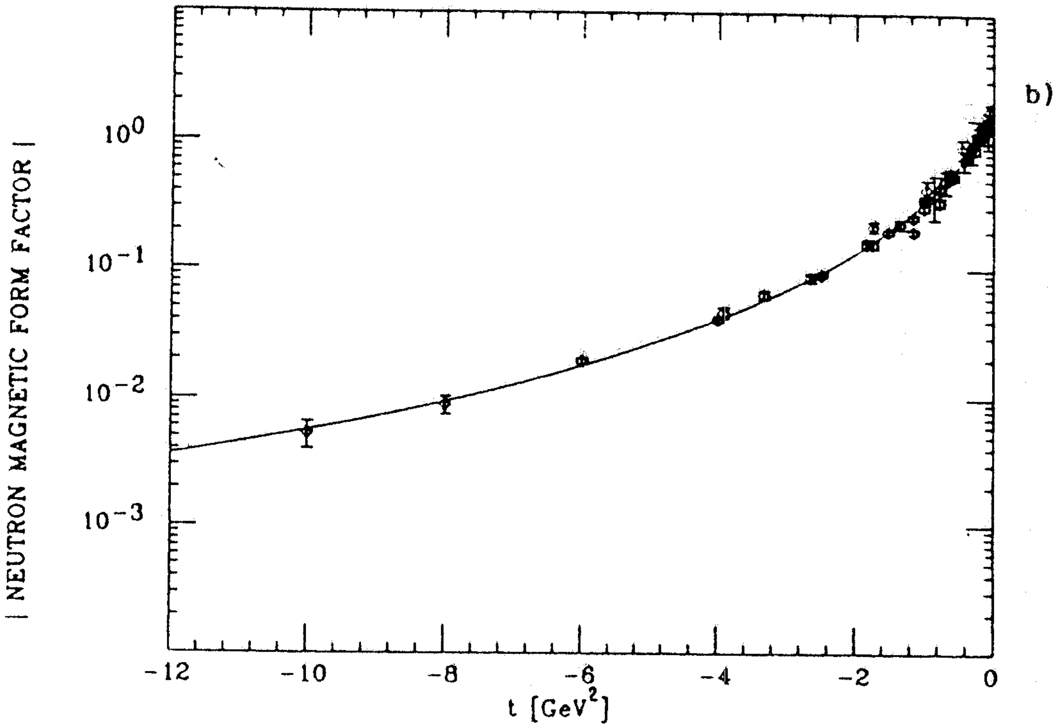


FIG. 16 - (a,b) nucleon space-like FF with EVMD fit according a unitarized amplitude.

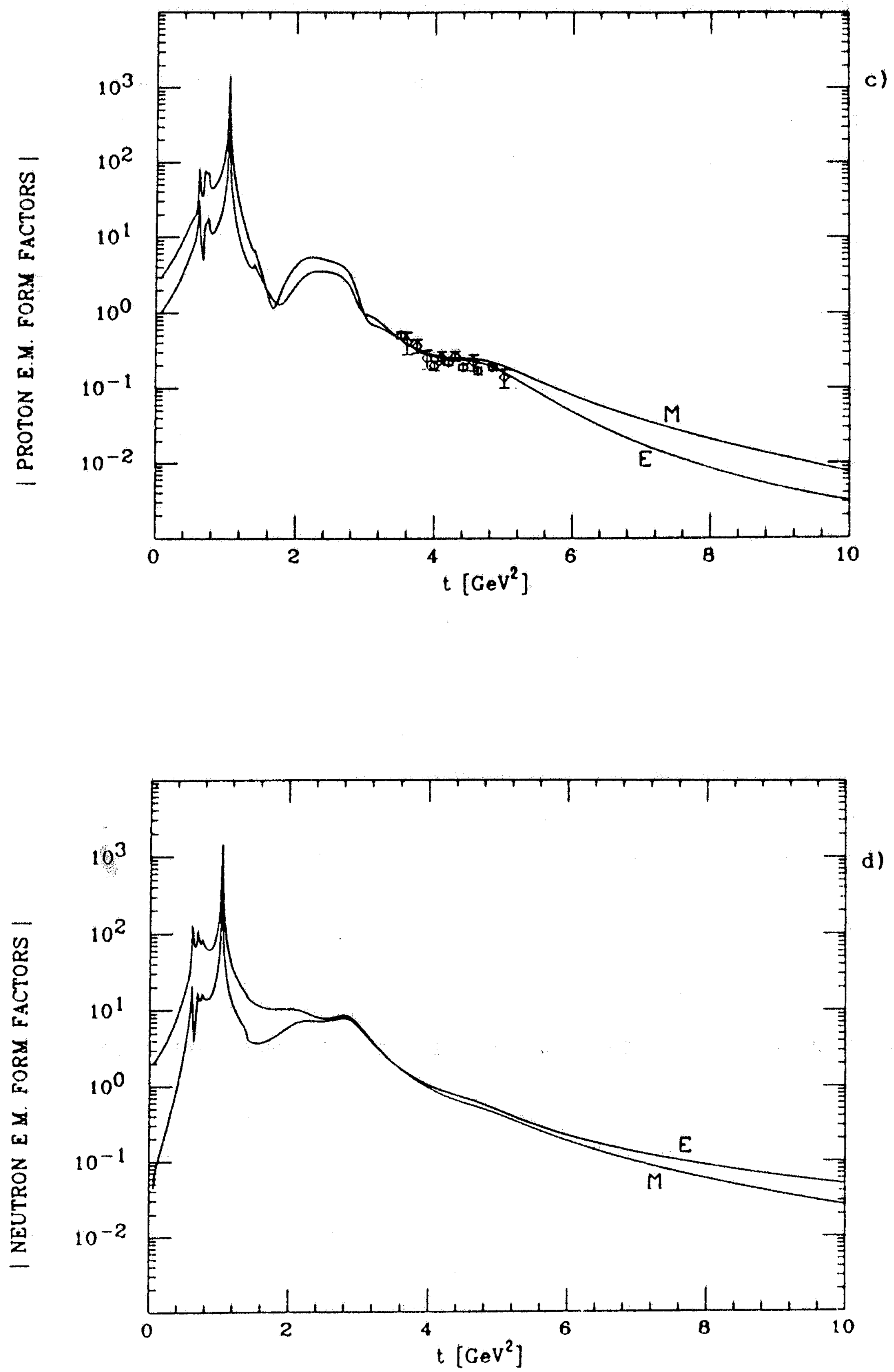


FIG. 16 - (c,d) nucleon time-like FF with EVMD fit according a unitarized amplitude.

A similar approach has been attempted for the pion ff by Terentiev[39].

It is worthwhile to note that Dubnicka's fit reproduces in part the double structure of the so called $\rho'(1.6)$ and another resonance, a $\rho'(2.2)$, which is above the $N\bar{N}$ threshold, is expected. This fit predicts on the whole range $3.5 \leq Q^2 \leq 10$ GeV^2 :

$$\sigma(e^+e^- \to n\bar{n}) / \sigma(e^+e^- \to p\bar{p}) \approx 25$$

There is another orthogonal approach, which provides poles peculiar to the baryon structure near $N\bar{N}$ threshold, namely a $B\bar{B}$ potential model[40]. Such a potential should be derived by the One Boson Exchange NN potential: repulsive terms become attractive if G = -1 for the exchanged meson, an imaginary part is added, related to the $N\bar{N}$ total annihilation cross section, and in principle no further parameter must be included. The non evidence of a long sought baryonium[41] has put this appealing model in the shade. However there are evidences for narrow structures in e^+e^- annihilation into hadrons just near the $N\bar{N}$ threshold[42]. Dalkarov[43] predicted these structures years ago. Polikarpov and Van der Velde[40] also gave a similar prediction together with a large neutron time-like FF near threshold:

$$\sigma(e^+e^- \to n\bar{n}) / \sigma(e^+e^- \to p\bar{p}) \approx 2.$$

HYBRYD MODELS AND THE SKYRME MODEL OF THE NUCLEON

A very interesting model has been worked out by Gari and his collaborators[45], attempting to merge VMD and PQCD in a suitable formula to have an overall fit of the nucleon FF.

When dual descriptions are merged together the main problem is to avoid double counting. For that only ρ and ω poles have been considered and the contributions coming from their recurrences or their quark structure have been lumped in a direct coupling term (see Fig. 1). Finally all these terms have been weighted by two universal vector meson form factors. This approach is a modern, refined, version of the old Massam-

Zichichi formula, as resumed by Iachello, Jackson and Lande[32]. To simplify the formulation ρ and ω contributions, isoscalar and isovector vector mesons form factors, have been retained similar, even if there is no fundamental reason for that. In detail:

$$F_1^{V,S} = (c\, m_\rho^2/(m_\rho^2 - Q^2) + 1-c)\ F_1(Q^2)$$
$$k_{\rho,\omega} F_2^{V,S} = (k_{\rho,\omega}\ c\ m_\rho^2/(\ m_\rho^2 - Q^2) + 1-c)\ F_2(Q^2)$$

Afterwards, in the limit of low Q^2 the vector mesons form factors must become $F_1 \approx F_2 \approx \Lambda^2/(\Lambda^2 - Q^2)$, whereas, in the limit of high Q^2, PQCD must be achieved, that is: $F_1 \propto 1/(Q^2 \log(Q^2))$ and $F_2 \propto F_1/Q^2$. An interpolating formula between these two extreme regimes is given by:

$$F_1 = \Lambda_1^2/(\Lambda_1^2 - q^2)\ \Lambda_2^2/(\Lambda_2^2 - q^2)$$
$$F_2 = \Lambda_1^2/\ (\Lambda_1^2 - q^2)\ (\Lambda_2^2/(\ \Lambda_2^2 - q^2))^2$$
$$q^2 = Q^2 \log(\ (\Lambda_2^2 - Q^2)/\Lambda_0^2/\log(\Lambda_2^2/\Lambda_0^2)$$

The new cutoff Λ_2 is a peculiar ingredient of the Gari formulation and it may be considered as a phenomenological estimation of the long sought energy scale beyond which PQCD predictions are achieved.

A fit of the space-like data gives (see Fig. 17): $\Lambda_0 = 0.3$ GeV, $\Lambda_1 = 0.8$ GeV and $\Lambda_2 = 2.2$ GeV. The authors have not quoted the errors on the estimated parameters. Anyhow the values obtained for Λ_0 and Λ_1 are well within the expectation [3,32] and the value of Λ_2 would mean, for our purposes, that $Q^2 \approx 4$ GeV^2 is almost asymptotic if there is asymptotic symmetry between space-like and time-like regions. Also peculiar to this model is that $F_1^n \approx 0$, hence for the neutron Pauli ff dominates, and it is expected at high Q^2:

$$\sigma(e^+e^- \rightarrow n\bar{n})\ /\ \sigma(e^+e^- \rightarrow p\bar{p}) \propto 1/Q^2$$

Unfortunately no time-like extrapolation has been done up to now for this model.

As it has been anticipated, FF varying with Q^2 are naturally embodied in the Skyrme model of the nucleon. This model of strongly interacting particles (whose basis have been conceived many years ago[46]) is the only one without quarks available on the market. In this and other related approaches there is an elementary but self-interacting pion field, instead of the quark field.

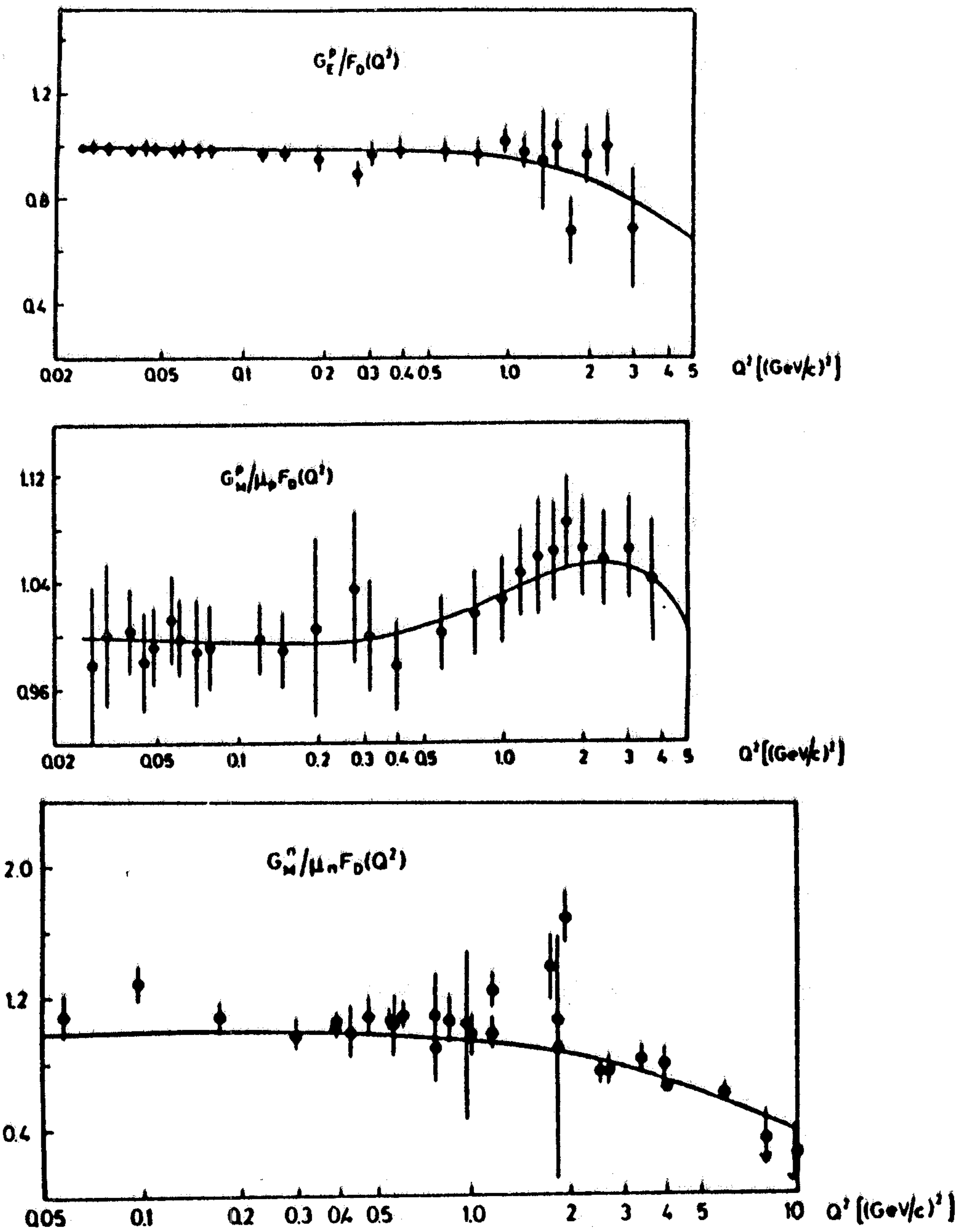
Very roughly the corresponding lagrangian may be derived considering at first massless quarks inside a bag, demanding chiral invariance and introducing another term,which contains a gauge pseudoscalar field ϕ for it: $L = L_{bag} + f_\pi^2/4\ Tr(D_\mu U D_\mu U^+)$, where $U = \exp(i\ \phi\tau)$. The added term may be regarded as a first order, S wave, in a $D_\mu U$ power expansion and the next order may be related to the introduction of vector mesons. Then the S wave coupling constant may be identified with the structure constant in the pion weak decay f_π and the D wave coupling constant with the $\pi\pi\rho$ coupling constant g_ρ. At this moment the quark field may be avoided and a theory without quark is achieved[33].

The motion equations have a solitonic solution, which may be identified as a baryon since it may behave like a fermion: that is the wave function changes sign under a 2π full rotation. This paradox can be understood taking into account that an half integer angular momentum is obtained adding up an infinite number of even and odd angular momenta.

The dipole fit of the proton FF is predicted by the Skyrme model (see Fig. 18) inasmuch as it corresponds to the vector meson propagator times the baryonic source, dimensions.

In the simplest version of this baryons achievement, vector meson parameters are not free[33], but $g_\rho = 2\pi$ and $m_\rho = \sqrt{2}\ f_\pi g_\rho$. Remarkably enough in this crude theory many meson and baryon properties are reproduced within a 50% accuracy (see Table II).

A spectacular confirmation of the Skyrme conjectures is just the quoted EMC result[1], according which the source of the proton spin is not the spin of the quarks! Such a model may be not so crazy taking into account it has been demonstrated that QCD becomes a local field theory of coupled mesons in the limit of an infinite number of colours[47]. Yet the philosophical implications of a strongly interacting particles theory without quarks are so relevant that it should pursued perse.



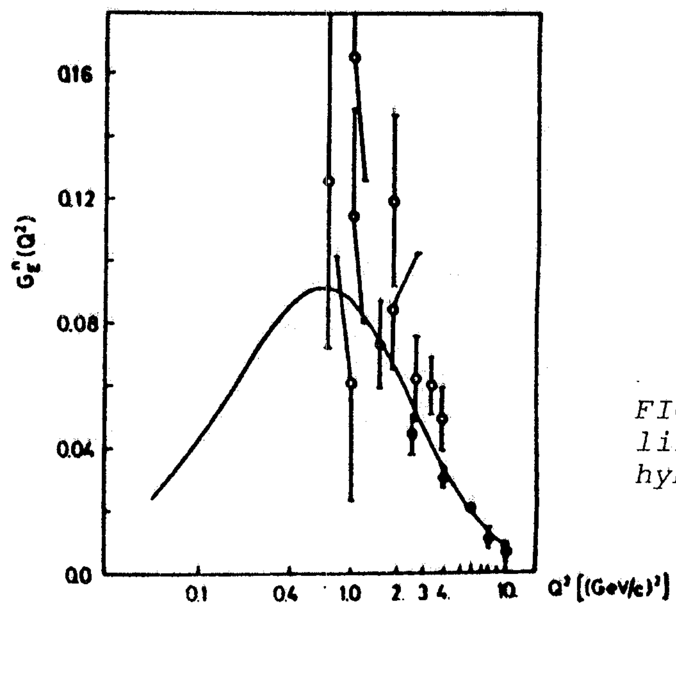


FIG. 17 - Nucleon space-like fit according to a hybrid model.

TABLE II - Nucleon properties as predicted by a minimal Skyrme model.

	MODEL	EXPERIMENT
$< M_E^2 >_p$ (fm^2)	0.85	0.74 ± 0.02
$< r_E^2 >_n$ (fm^2)	- 0.22	- 0.119 ± 0.004
$< r_M^2 >_p$ (fm^2)	0.71	0.74 ± 0.1
$< r_E^2 >_n$ (fm^2)	0.72	0.77 ± 0.14
μ_p	3.36	2.79
μ_n	- 2.57	- 1.91
g_A	0.88	1.25
$< r_A^2 >_n$ (fm^2)	0.41	0.39 ± 0.06
m_ρ (MeV)	826.	770.± 3.
g_ρ	6.28	≈ 6.1 ± 0.5

PREDICTIONS FROM DATA ON STRANGE BARYONS

A reader, so patient to follow this paper up to the end and so uneasy for the lack of any data on neutron time-like FF, will appreciate the following questionable considerations.

Indeed two measurements may be employed to infer two neutron time-like measurements, making use of the SU_3 flavour symmetry and U-spin relationships. Namely:

- the only available measurement of Λ FF[8],
- the available J/Ψ baryonic branching ratios[19].

The U-spin relationship[48] between Λ and neutron magnetic ff is $G_M{}^n = 2\ G_M{}^\Lambda$, if SU_3 flavour symmetry is attained, which is likely to be at these Q^2 values (see Fig.6). The difference in mass $m_\phi - m_\rho$, or $m_\Lambda - m_n$, may be employed as a correction in Q for small symmetry violation.

In short it is foreseen $|G_M{}^n| = 0.24\pm0.05$ at $Q^2 = 4.5$ GeV^2, to be compared to $G_M{}^p = 0.25\pm0.08$: the neutron ff is equal or greater than the proton ff, at threshold !

Concerning the J/Ψ baryonic decays three amplitudes must be taken into account[52]: an isoscalar direct decay amplitude (see Fig.10a) and two e.m. corrections (see Figg.10b,10c), where the amplitude in Fig.10b corresponds to the FF just before the J/Ψ, amplified exactly as the $\mu\mu$ amplitude. The direct decay is supposed to dominate and only projections on it are retained for e.m. amplitudes. This approximation should be irrelevant if PQCD holds, because e.m. and OZI amplitudes are expected to be mainly real. Furthermore, the amplitude in Fig.18c is expected to be proportional to the baryon electric charge and it does not contribute for the neutron.

The e.m. amplitude could be identified with the magnetic contribution, either because the J/Ψ is still not far from any $B\overline{B}$ threshold and the electric contribution is lowered by a $2M^2/Q^2$ factor or because the Pauli ff is small.

SU_3 flavour symmetry and U-spin relationships may be applied, once the baryon phase space $\sqrt{\beta_B}$ has been factorized. The direct decay is decomposed in a SU_3 flavour symmetric amplitude A and in SU_3 flavour symmetry breaking amplitudes B and C, related to the hypercharge as usual[49]. There are two U-spin invariant e.m. amplitudes, D and F, and U-spin violations are dealt as before. In short the relations expressed in Fig. 19 hold.

For the neutron it is deduced[50]: $G_M{}^n = -0.007+0.007$ at $Q^2 = 8.0$ GeV^2. For the proton an evaluation does not make sense because it takes a contribution from the very poorly measured branching ratio J/$\Psi\rightarrow n\overline{n}$[19]. Anyhow this neutron ff is definitively very small respect to any proton measurements extrapolation, which should be about 0.04! Such a steep behaviour with Q^2 would indicate that the Pauli ff dominates the neutron time-like FF as it does in the neutron space-like FF (see Fig. 20).

The smallness of an imaginary part among direct and e.m. amplitudes, assumed in the previous reasoning, has been questioned [51]. The only available test is done looking at the J/Ψ decays into pseudoscalar mesons [19]:

$$10^2\sqrt{B\left(J/\Psi\rightarrow\pi^+\pi^-\right)} = |F| = 1.2 \pm .1$$

$$10^2\sqrt{B\left(J/\Psi\rightarrow k_S k_L\right)} = |C| = 1.0 \pm .1$$

$$10^2\sqrt{B\left(J/\Psi\rightarrow k^+ k^-\right)} = |F+C| = 1.6 \pm .1$$

There is a fair disagreement but no definitive conclusion may be attained. A good measurement of $J/\Psi\rightarrow n\bar{n}, \Sigma^-\bar{\Sigma}$ will allow a good check.

Yet neutron time-like FF equal or higher than the proton FF at threshold and a steeper neutron slope with Q^2 would be a compromise in agreement with all the expectations.

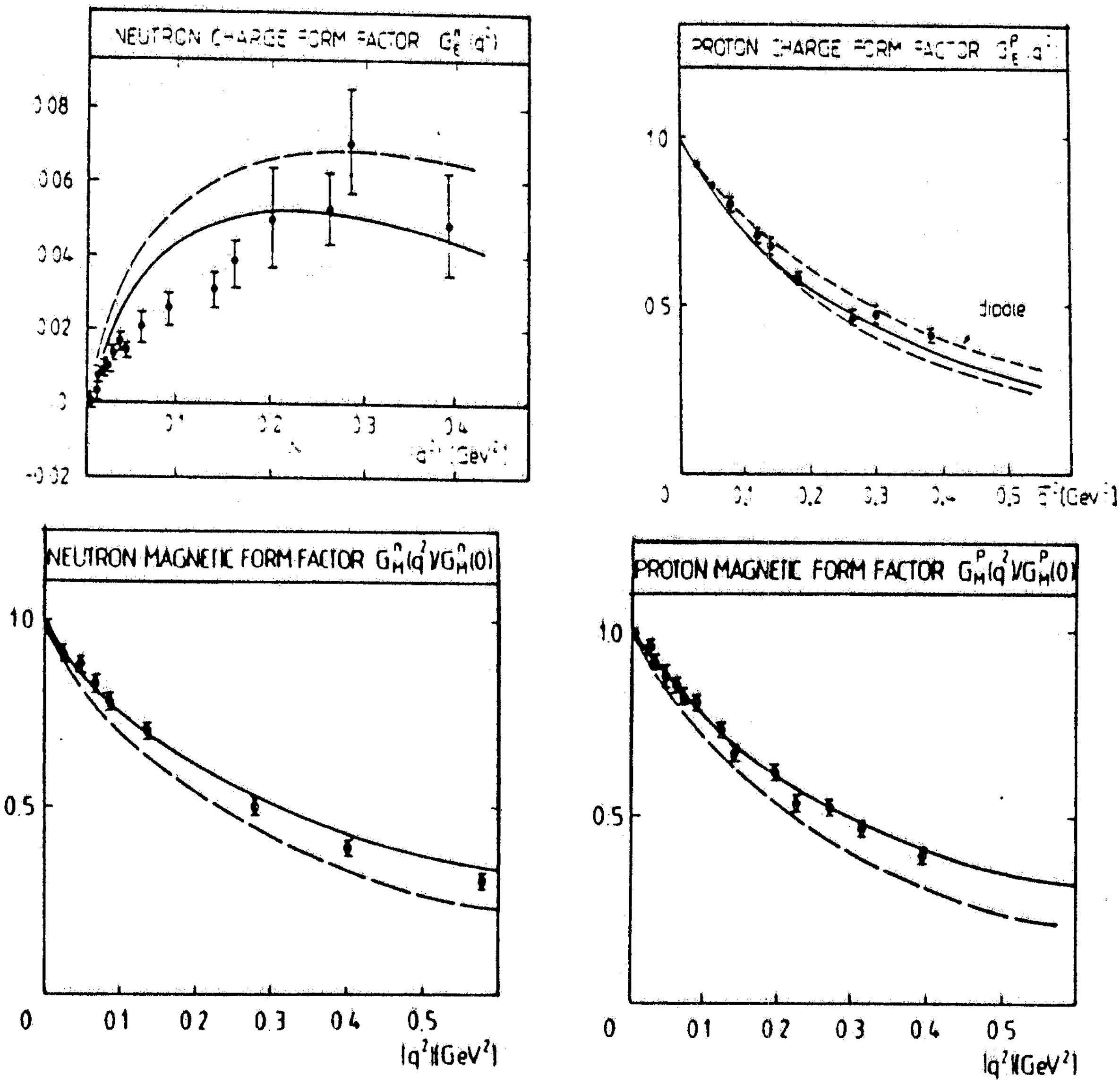


FIG. 18 - Skyrme model predictions.

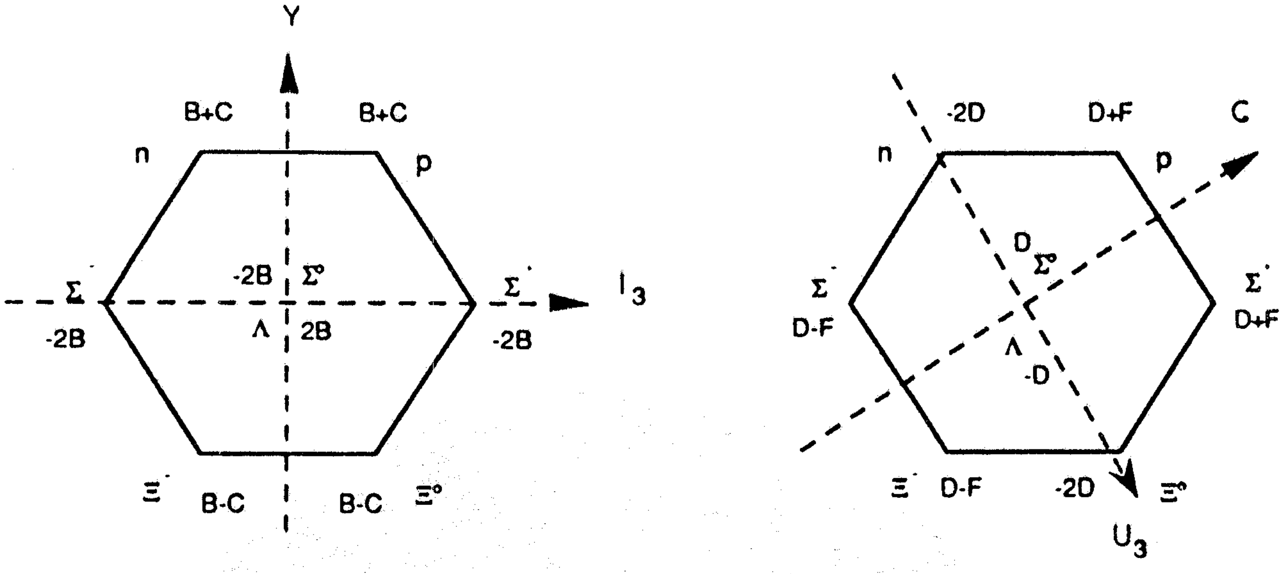


FIG. 19 - SU_3 flavour symmetry breaking and U-spin amplitudes.

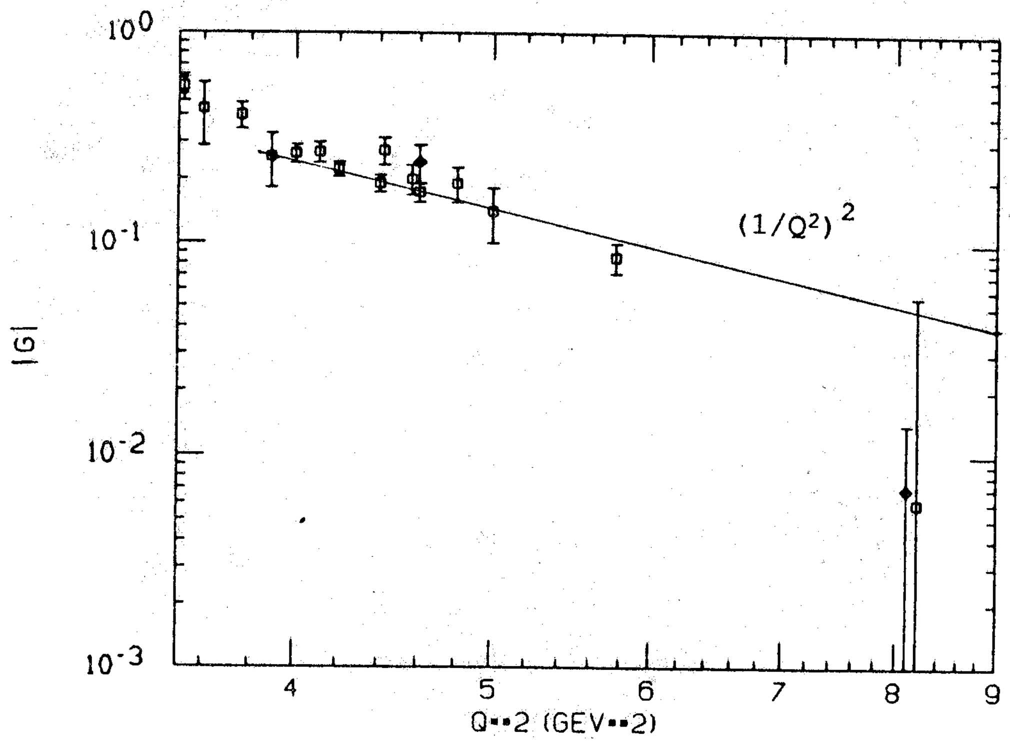


FIG. 20 - Neutron time-like FF (◆) as deduced by strange baryon FF measurements, compared to the proton FF (□).

THE FENICE EXPERIMENT

A new experiment[53], FENICE, is collecting data at the renewed storage ring ADONE. In fact a new radiofrequency cavity, a new optics and a wiggler have been installed: as a consequence shorter bunches and higher luminosities than in the past are available.

The detector is a 4π calorimeter made of iron, streamer tubes, scintillation counters and large area resistive plate counters (see Fig. 21).

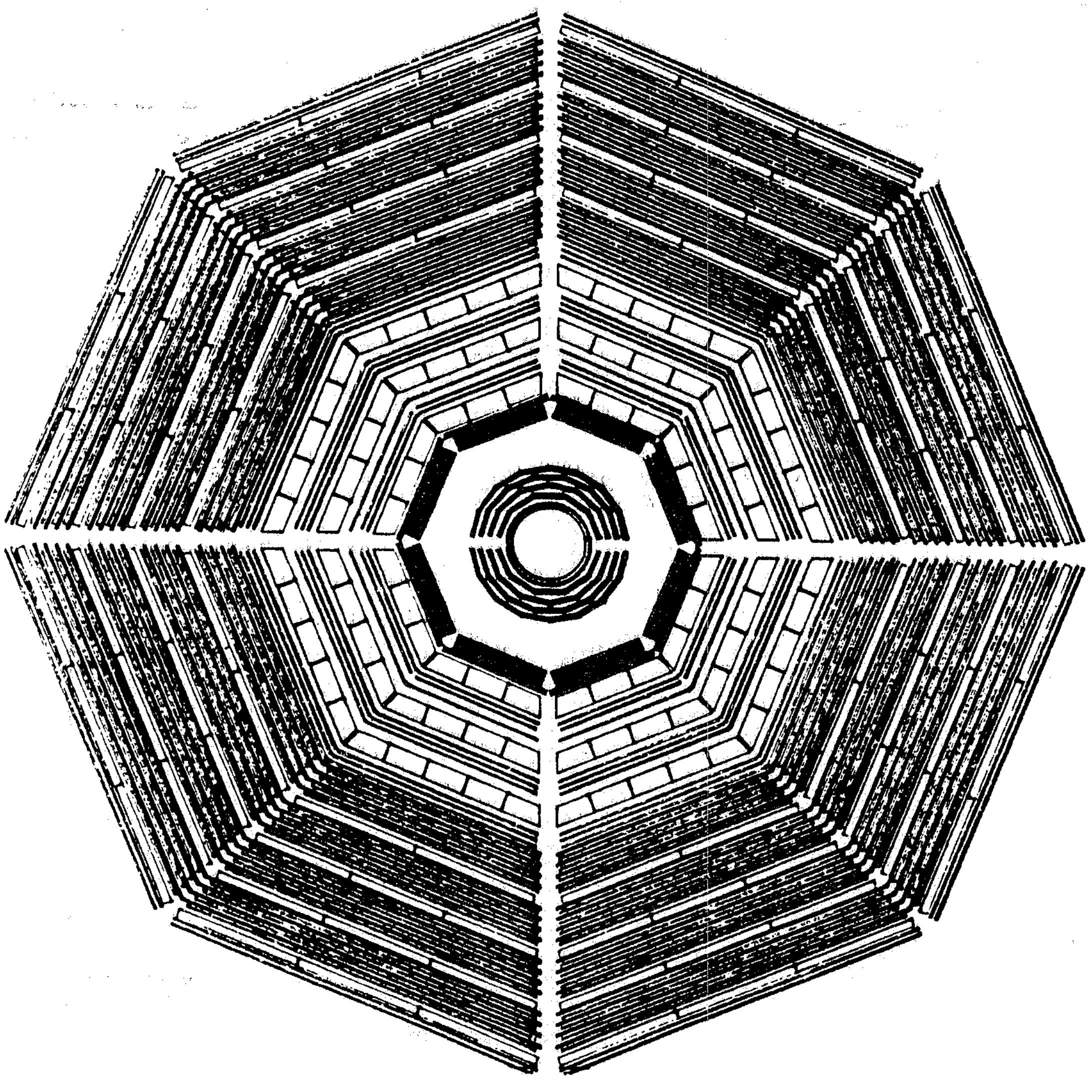


FIG. 21 - FENICE sketch, orthogonal to the beam axis.

At the trigger level only the antineutron is demanded. Actually the antineutron annihilation pattern and its time of flight should be enough to identify $e^+e^- \to n\bar{n}$, at least near threshold. However the neutron is detected in about 20% of the events.

The unknown FF of n, Λ and Σ should be measured with more than hundreds of events if the cross sections are higher than 10^{-34} cm^2. At the J/Ψ the unknown baryonic branching ratios will be measured with an overall relative error less than 10%. Furthermore the large solid angle and a second level, low threshold, trigger allow for a good measurement of the total cross section. In the detector capabilities are also processes kinematically constrained or with a large number of neutrals, like $e^+e^- \rightarrow \rho\eta$ (solving the $\rho(1.6)$ puzzle), or $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-\pi^0\pi^0$ (confirming or not structures in this process just at the $N\overline{N}$ threshold).

Indeed a Phoenix is raising again: a new life for an old physics and an old accelerator.

APPENDIX

Predictions from e^+e^- annihilation and J/Ψ decay into strange baryons are reported in details in the following, for future reference. SU_3 flavour symmetry, U-spin invariance and only a small breaking of these symmetries are supposed to hold.

Phenomenologically U-spin invariance stems from the existence of multiplets on the U axis with the same electric charge. Likey they should have similar e.m. interactions, the total U-spin should be conserved and the photon should be a U-spin singlet. For the pseudoscalar mesons, with c = +, that means: $F_{\pi^\pm} \simeq F_{K^\pm}$ and $F_{K^o} \simeq 0$. This last relation is related to $F_{\pi^o} = F_\eta = 0$. For electric an magnetic form factors of the baryon octet, U-spin invariance implies:

$$G_p \simeq G_{\Sigma^+}$$
$$G_{\Xi^-} \simeq G_{\Sigma^-}$$
$$G_n \simeq G_{\Xi^o}$$

$$G_n \simeq \left\langle \frac{\sqrt{3}}{2}\Lambda - \frac{1}{2}\Sigma^o \middle| H_{em} \middle| \frac{\sqrt{3}}{2}\Lambda - \frac{1}{2}\Sigma^o \right\rangle = \frac{3}{2}G_\Lambda - \frac{1}{2}G_{\Sigma^o} - \frac{\sqrt{3}}{2}G\left(\Sigma^o \to \Lambda\gamma\right)$$

$$O \simeq \left\langle \frac{\sqrt{3}}{2}\Lambda - \frac{1}{2}\Sigma^o \middle| H_{em} \middle| -\frac{\sqrt{3}}{2}\Sigma^o - \frac{1}{2}\Lambda \right\rangle =$$

$$= -3\,G\left(\Sigma^o \to \Lambda\gamma\right) - \frac{\sqrt{3}}{4}G_\Lambda + \frac{\sqrt{3}}{4}G_{\Sigma^o}$$

where $U_3 = 0$ eigenstates are taken into account and $G\left(\Sigma^o \to \Lambda\gamma\right)$ in the time-like region corresponds to $G\left(e^+e^- \to \Sigma^o\bar{\Lambda} + \bar{\Sigma}^o\Lambda\right)$. Moreover, due to isospin invariance it is: $G_{\Sigma^o} = \frac{1}{2}\left(G_{\Sigma^+} + G_{\Sigma^-}\right)$ and the smallness of SU_3 flavour breaking implies that the sum of the different elastic amplitudes is vanishing.

The nine baryon form factors are related to the amplitudes D and F, as in Fig. 19, according to these seven relations. In particular it is $G_\Lambda \cong \frac{1}{2}G_n$.

Coleman and Glashow[48] got the same results straight from a SU_3 symmetric lagrangian to first order in the e.m. interactions.

SU_3 breaking due to the strange quark mass should vanish at high Q^2 and all the baryon form factors should be described by the proton dipole fit $G_p \propto \left(Q^2 + m_o^2\right)^{-2}$. That is accomplished in the time-like, region for instance, if $G_\Lambda \propto \left[\left(Q-\Delta\right)^{-2} + m_o^2\right]^{-2}$ and $\Delta \approx 2\ (m_\Lambda - m_p) \approx m_\phi - m_e = 350 \div 250$ Mev. As a check the ratio μ_Λ/μ_n $= 0.320 \pm 0.002$ must be compared to $\frac{1}{2} m_o^4 / \left(\Delta^2 + m_o^2\right)^2 \simeq 0.37$.

Therefore the DM2 measurement $\left|G_\Lambda\right| = 0.12 \begin{smallmatrix} +0.03 \\ -0.02 \end{smallmatrix}$ at $Q^2 = 5.76$ Gev^2 implies $\left|G_n\right| = 0.24 \begin{smallmatrix} +0.06 \\ -0.04 \end{smallmatrix}$ at $Q^2 \simeq 4.4\ Gev^2$.

The decomposition of the decay $J/\Psi \to B\overline{B}$, according to the amplitudes reported in Fig. 10, allows to measure in principle the baryon form factors at $Q^2 \simeq M^2_\psi$, once the amplitude of Fig. 10c is isolated. Actually, with the present luminosities, this is the only possibility to determine the neutron form factor at $Q^2 \simeq 9\ Gev^2$. SU_3 flavour relationships should be even more reliable at $Q^2 \simeq M^2_\psi$. The direct J/Ψ decay can be decomposed into a SU_3 flavour symmetric term A and SU_3 flavour symmetry breaking amplitudes. These amplitudes, B and C, can be evaluated just according to the same arguments as before exchanging the electric charge and the hypercharge axis, the Uspin and the Isopin axis. These rotated amplitudes are reported in Fig. 19, the only difference being that now Σ^o and Λ are the $I_3 = 0$ eigenstates.

The e.m. amplitudes D and F and the J/Ψ direct decay amplitudes A, B and C are supposed to be mainly real, at high Q^2. In this case the following relations hold, taking into account the measured branching ratios[54] normalized at the same phase space:

$$\sqrt{\frac{B(\psi \to p\bar{p})}{\beta_p}} = 5.07 \pm 0.12 = A + B + C + D + F$$

$$\sqrt{\frac{B(\psi \to n\bar{n})}{\beta_n}} = 4.70 \pm 1.2 = A + B + C - 2D$$

$$\sqrt{\frac{B(\psi \to \Lambda\bar{\Lambda})}{\beta_\Lambda}} = 4.5 \pm 0.2 = A + 2B + D$$

$$\sqrt{\frac{B\left(\psi \to \Sigma\bar{\Sigma}^{o}\right)}{\beta_\Sigma}} = 4.4 \pm 0.3 = A - 2B + D$$

$$\sqrt{\frac{B\left(\psi \to \Xi\bar{\Xi}^{-}\right)}{\beta_\Xi}} = 4.2 \pm 0.2 = A + B - C + D - F.$$

At present these relations cannot be tested because there is the same number of unknown amplitudes and available branching ratios. Nevertheless a meaning ful result follows:

$A = (4.45 \pm 0.18) \times 10^{-2}$
$D = (0.1 \pm 0.1) \times 10^{-2}$

$G_n = -2D/\sqrt{B(\psi \to \mu\mu)\left(1 + 2\, M_n^2/M_\psi^2\right)} = -\, 0.008 \pm 0.008$ at $Q^2 \simeq 8$ Gev^2.

The neutron form factor is lower than any expected proton extrapolation.

The amplitude H, reported in Fig. 10b, being proportional to the baryon electric charge, contributes only to the antisymmetric part of the form factors F and it is negative for the proton.

According to pertubative QCD it is[13,52]

$$H \simeq -\frac{4}{5}\frac{\alpha Q_B}{\alpha_S\left(M_\psi^2\right)} A$$

Therefore

$$G_p = 0.01 \pm 0.05 \quad \text{at } Q^2 \simeq 8 \text{ GeV}^2.$$

Of course this last evaluation is irrelevant due to the large error from the $J/\Psi \to n\bar{n}$ measurement and the theoretical uncertainties on H evaluation. However it is consistent with the ISR[55] quoted upper limit $|G_p| \leq 0.05$ at $Q^2 = 8.9$ GeV^2.

There are theoretical arguments which foresee the J/Ψ direct decay amplitudes, as in Fig. 10a and b, to be mainly imaginary while certainly the e.m. form factor at $Q^2 \simeq M_\psi^2$ is mainly real. By the way a comparison at few percent level between $J/\Psi \to p\bar{p}$ and $J/\Psi \to n\bar{n}$ branching ratios would allow to check this point. In case of real direct decay amplitudes the form factor contribution to $J/\Psi \to p\bar{p}$, being proportional to the magnetic moment, should be positive while the same contribution to $J/\Psi \to n\bar{n}$ should be negative. Therefore it is expected $B(J/\Psi \to p\bar{p}) > B(J/\Psi \to n\bar{n})$ at $5 \div 10\%$ level at least. On the contrary, in case of imaginary decay amplitudes, the real form factor contributions should be negligible, being added in quadrature. Hence it is expected $B(J/\Psi \to p\bar{p}) < B(J/\Psi \to n\bar{n})$, again at $5 \div 10\%$ level at least. In fact the only difference is the amplitude H in the proton case, which brings a negative contribution. Moreover the hypothesis has been done there is only one form factor, identified with G_M, either as at the threshold and or that the Pauli form factor is small. The result found for the neutron contradicts this hypothesis: at least in D the Pauli form factor should be dominant. As extreme consequence there would be an even lower neutron magnetic form factor, namely:

$$G_M^n = \frac{-D}{\sqrt{B\left(\psi \to \mu\mu\right)\left(1 + \frac{Q^2}{8M^2}\right)}} = -\ 0.006 \pm 0.006$$

still $Q^2 \simeq 8$ Gev^2.

The Q^2 behaviour of G^n will settle this point. A further check can also be done measuring other baryonic J/Ψ decays, like for instance J/$\Psi \to \Sigma^- \overline{\Sigma}$.

ACKNOWLEDGEMENTS

We wish to acknowledge the Ettore Majorana Centre for the warm hospitality, S. Dubnicka, E. Etim, A. Kaydalov and M. Terentiev for many suggestions, Mrs. L. Invidia for her skilful decoding of the manuscript.

REFERENCES

[1] European Muon Collaboration, Phys.Lett. B206:364 (1988).
[2] M.Gourdin, Phys. Rep. 11:29 (1974).
[3] F.Halzen, A.D.Martin, 'Quarks and Leptons', Wiley (1984)
[4] S.R.Amendolia, B.Badelek, G.Batignani, G.A.Beck, E.H.Bellamy, E.Bertolucci, D.Bettoni, H.Bilokon, A.Bizzeti, G.Bologna, L.Bosisio, C.Bradaschia, M.Budinich, M.Dell'Orso, B.D'Ettore Piazzoli, M.Enorini, F.L.Fabbri, F.Fidecaro, L.Foà, E.Focardi, S.G.F.Frank, P.Giannetti, A.Giazzotto, M.A.Giorgi, J.Harvey, G.P.Heath, M.P.J. Landon, P.Laurelli, F.Liello, G.Mannocchi, P.V.March, P.S.Marrocchesi, D.Menasci, A.Menzione, E.Meroni, E.Milotti, L.Moroni, P.Picchi, F.Ragusa, L.Ristori, L.Rolandi, C.Saltmarsh, A.Saoucha, L.Satta, A.Scribano, A.Stefanini, J.A.Strong, R.Tenchini, G.Tonelli, G.Triggiani, A.Zallo, Phys. Lett. 138B:454 (1984).
[5] P.Dal Piaz, private communication.
[6] S.Platchkov, A.Amroun, S.Auffret, J.M.Cavedon, P.Dreux, J.Duclos, B.Frois, D.Goutte, H.Hachemi, J.Martino, X.H.Phan, I.Sick, Proc. XII Conf. on Few Body problems in Physics Vancouver (1989).
[7] G.F.Walters, Internal Note NIKHEF-H/84-5 (1984).
[8] D.Bisello, G.Busetto, A.Castro, M.Nigro, L.Pescara, M.Posocco, P.Sartori, L.Stanco, Z.Ajaltouni, A.Falvard, J.Jousset, B.Michel, J.C.Montret, A.Antonelli, R.Baldini, S.Calcaterra, M.Schioppa, J.E.Augustin, G.Cosme, F.Couchot, B.Dudelzak, F.Fulda, G.Grosdidier, B.Jean-Marie, S.Jullian, D.Lalanne, V.Lepeltier, F.Mane, C.Paulot, R.Riskalla, Ph.Roy, G.Szklarz, Internal Note LAL 88-58 (1988).
[9] S.J.Brodsky, G.R.Farrar, Phys. Rev. D 11:1309 (1975).
[10] S.J.Brodsky, B.T.Chertok, Phys. Rev. D 14:3003 (1976).
[11] J.D.Stack, Phys. Rev. 164:1904 (1967).
[12] V.A.Matveev, R.M.Muradyan, A.N.Tavkhelidze, Lett. Nuovo Cimento 7:719 (1973).
[13] V.L.Chernyak, I.R.Zhitnitsky, Nucl. Phys. B 246:52 (1984).
[14] Chueng-Ryong Ji, Proc. Summer School of Computational Atomic and Nucl. Phys. (1989). Chueng-Ryong Ji, A.F.Sill, R.M.Lombard-Nelsen, Internal Note SLAC-PUB-4068 (1986).
[15] M.A;Shifman, A.I.Vainshtain, V.I.Zakharov, Nucl. Phys. B 147:385 (1979).
[16] J.S.Bell, R.A.Bertlmann, Internal Note TH 2880-CERN (1980). J.S.Bell, R.A.Bertlmann, Nucl. Phys. B 187:285 (1981). J.S.Bell, R.A.Bertlmann, Internal Note TH 3540-CERN (1983).
[17] Chueng-Ryong Ji, A.F.Sill, Phys. Rev. D 34:3350 (1986).

[18] G.Martinelli, C.T.Sachrajda, Internal Note CERN TH 5042/88 (1988).
[19] Particle Data Group, Rewiev of Particle Properties, Phys. Lett. B 204 (1988)
[20] S.J.Brodsky, G.P.Lepage, San Fu Tuan, Phys.Rev. Lett. 59:621 (1987).
[21] P.G.O.Freund, Y.Nambu, Phys. Rev. Lett. 34:1645 (1975).
[22] J.J.Sakurai, Ann. of Phys. 11:1 (1960).
[23] R.Gatto, N.Cabibbo, Phys. Rev. 124:1577 (1961).
[24] A.Bramon, E.Etim, M.Greco, Phys. Lett. B 41:609 (1972).
J.J.Sakurai, Phys. Lett. B 46:207 (1973).
[25] G.Veneziano, Nuovo Cim. 57A:190 (1986).
G.Veneziano, Phys. Rep. 9 (1974).
[26] J.G.Korner, M.Kuroda, Phys. Rev. D 16:2165 (1977).
[27] M.Greco, Nucl. Phys.B 63:398 (1973).
[28] P.Cesselli, M.Nigro, C.Voci, Proc. of Workshop on Physics at LEAR Erice (1982).
[29] A.Donnachie, Internal Note CERN TH 5246/88 (1988).
[30] D.Bisello, G.Busetto, M.Nigro, L.Pescara, M.Posocco, P.Sartori, L.Stanco, Z.Ajaltouni, A.Falvard, J.Jousset, B.Michel, J.C.Montret, R.Baldini, G. Capon, S.Calcaterra, J.E.Augustin, G.Cosme, F.Couchot, B.Dudelzak, F.Fulda, B.Grelaud, G.Grosdidier, B.Jean-Marie, S.Jullian, D.Lalanne, V.Lepeltier, F.Mane, C.Paulot, R.Riskalla, Ph.Roy, G.Szklarz, Internal Note LAL 83-21 (1983).
[31] D.Bisello, G.Busetto, M.Nigro, L.Pescara, M.Posocco, P.Sartori, L.Stanco, Z.Ajaltouni, A.Falvard, J.Jousset, B.Michel, J.C.Montret,A.Antonelli, R.Baldini, S.Calcaterra, G. Capon, M.schioppa,J.E.Augustin, G.Cosme, F.Couchot, B.Dudelzak, F.Fulda, B.Grelaud, G.Grosdidier, B.Jean-Marie, S.Jullian, D.Lalanne, V.Lepeltier, F.Mane, C.Paulot, R.Riskalla, Ph.Roy, G.Szklarz, Phys.Lett.B 212:133 (1988).
S.Fukui et al., Phys.Lett.B 202:441 (1988).
[32] T.Massam, A.Zichichi, Nuovo Cim. 43:1137 (1966).
F.Iachello, A.D.Jackson, A.Lande, Phys. Lett. 43B:191 (1973).
[33] R.K.Bhaduri, 'Model of Nucleon', Addison-Wesley (1988).
[34] R.Machleidt,K.Holinde,Ch.Elster, Phys.Rep. 149 (1987).
[35] R.Felst, Internal Note DESY 73/56 (1973).
[36] E.Etim,A.Malecki, Internal Note LNF-89-023 (1989).
[37] E.D.Bloom, F.J.Gilman, Phys. Rev. Lett. 25:1140 (1970).
[38] S.Dubnicka, E.Etim, Internal Note LNF-89/013(PT) (1989).
[39] B.V.Geshkenbein, M.V.Terentyev, Internal Note ITEP-3 (1984).
[40] M.Van Der Velde, M.I.Polikarpov, Jour. Nucl. Phys. 35:180 (1982).
[41] B.O.Kerbikov, I.S.Shapiro, Internal Note ITEP-159 (1978).
[42] R.Baldini Ferroli Celio, Nucleon Structure Workshop Frascati (October 1988) in press.
[43] O.D.Dalkarov, V.G.Ksenzov, Pis'ma v ZhETF 30:74 (1979).
O.D.Dalkarov, K.V.Protasov, Mod. Phys. Lett.A 4:1203 (1989).
[44] H.Fritzsch, Internal Note CERN TH 5569/89 (1989).
G.Hohler, E.Pietarinen, I.Sabba-Stefanescu, F.Borkowski, G.G.Simon, V.H.Walther, R.D.Wendling, H.Genz, G.Hohler, Phys. Lett. B 61:389 (1976).
R.L.Jaffe, Phys. Lett. B 229:275 (1989).
[45] M.Gari, W.Krumpelmann, Internal Note SLAC-PUB-3398 (1984).

[46] T.H.R.Skyrme, Proc. Royal Soc.A 260:127 (1961).
[47] E.Witten, Nucl. Phys.B 223:422 (1983).
[48] S.Coleman, S.L.Glashow, Phys. Rev. Lett. 6:423 (1961).
[49] M.Gell-Mann, Y.Ne'eman, 'The Eightfold Way', Benjamin (1964).
[50] M.E.Biagini, E.Pasqualucci, to be published.
[51] M.Fukugita,J.Kwiecinski, Internal Note RL-79-045 (1979).
[52] M.Claudson,S.L.Glashow,M.B.Wise, Phys.Rev.25:1345 (1982).
[53] FENICE Collaboration, Internal Note LNF-87/18(R)(1987).
[54] L.Kopte, N. Wermes Phys. Rep. 174, 67 (1989).
[55] LAPP - CERN - Genova - IPN - Oslo - Roma - Strasbourg - Torino Coll. Phys. Lett. 163B, 400 (1985).