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EFFECTS OF THE SPIN-1 PARTNER OF THE GOLDSTINO (GRAVITINO) ON NEUTRAL CURRENT PHENOMENOLOGY

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ABSTRACT

Spontaneously broken supersymmetric theories involve, in addition to the standard neutral gauge boson, a second one which is, partly, the superpartner of the massless spin-$\frac{1}{2}$ goldstino (or massive spin-$\frac{3}{2}$ gravitino). The mass and the coupling strength of the new boson are not fixed but both might be very small. In the simplest example, the new boson is axially coupled to leptons and quarks, and neutrino scattering experiments restrict its mass to be less than 300 MeV/c^2, approximately.

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Neutral current phenomenology can be interpreted, presently, in terms of a single weak neutral current 1). Several of them may exist, but any extra contribution of order G_F to weak amplitudes is strongly constrained by experiments. To discuss them we have to compare the value of the momentum transfer q with the mass of the corresponding intermediate boson. This mass might be very small, so that extra contributions to weak neutral current amplitudes would be present at lower q^2 but negligible at higher q^2.

Our interest in this question originates in spontaneously broken supersymmetric theories 2)-4). (The reader uninterested in theoretical motivations and supersymmetry aspects can skip the following considerations, and go directly to the neutral current analysis.) These supersymmetric theories involve a new spin-1 boson related to the spin-2 graviton, the spin-$\frac{3}{2}$ gravitino, a pseudoscalar particle similar to the axion and a Higgs boson. The couplings of all these particles are intimately related to gravitation and to the structure of the mass spectrum *). The mass and coupling constant of the new spin-1 boson are unknown, but both might naturally be small.

The present paper aims essentially at illustrating the implications of the existence of such a particle for neutral current phenomenology. We leave several important questions for a future study :

i) a more detailed description of the structure of the masses and interactions of the above-mentioned particles ;

ii) the possible production of the new (light) boson as a (narrow) resonance in e^+e^- annihilation ;

iii) if the new boson is very light its 0-polarization state interacts more strongly than its ±1-polarization states ; in fact it is produced and interacts like a pseudoscalar axion 5) ; this does not mean, however, that its existence is forbidden experimentally ;

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*) In particular the Higgs coupling to a lepton or quark f can be expressed, not only as $\sim g(m_f/m_W)$, but also as $\sim \kappa m_f(\Delta m^2/m_{Z''} m_{3/2})$; Δm^2 is the boson-fermion mass^2- splitting in the lepton or quark multiplet, $m_{Z''}$ and $m_{3/2}$ the masses of the new spin-1 boson and of the gravitino, respectively. This gives the relation

$$\frac{G_{\text{Newton}}}{G_{\text{Fermi}}} \sim \left(\frac{m_{Z''}\, m_{3/2}}{\Delta m^2}\right)^2$$

The gauge coupling constant of the new boson is $\sim \kappa(\Delta m^2/m_{3/2})$. These formulas can be modified by the effects of mixing angles.

iv) depending on its mass and its couplings, the new boson may induce an extra contribution to the parity violating electron-nucleon potential ; this would modify the theoretical predictions for the results of experiments searching for parity violation in atomic physics 6) ; in particular the parity violation effect could be suppressed.

v) the new boson could also induce a long-distance force ; its strength and range would depend essentially on the mass of the boson *) ; this effect might appear as a deviation from Newton's universal law of gravitation, and an effective CPT violation for the K_o-$\bar{K}_o$ system in the field of the Earth 7).

THE NEW SPIN-1 BOSON, SUPERSYMMETRY AND GRAVITATION

In spontaneously broken globally supersymmetric theories there is a massless neutral spin-$\frac{1}{2}$ Goldstone fermion, the goldstino 8). It couples leptons and quarks to their bosonic partners proportionally to the boson-fermion mass^2- splittings, which we denote by Δm^2 3),4). These couplings are related by supersymmetry to the couplings of the bosonic partner of the goldstino. Relations between the latter give us constraints on the mass spectrum.

We assume that leptons and quarks have spin-0 partners (two of them for each Dirac fermion). If the bosonic partner of the goldstino is the photon, or any particle with vector couplings, or a combination of the photon and the neutral gauge boson of the standard SU(2)×U(1) model, we get unacceptable mass relations. To avoid them one needs to introduce a new neutral spin-1 boson with axial couplings of the same signs to light leptons and quarks ; there may be also vector parts in the couplings if they are smaller than the axial parts 2),9). The goldstino is a linear combination of the spin-$\frac{1}{2}$ partners of this new spin-1 boson and a spin-0 boson **). The spin-1 boson couples to leptons and quarks proportionally to the boson-fermion mass^2- splittings Δm^2. In the simplest situation there is a universal axial coupling of the new boson to leptons and quarks, and a universal mass^2- splitting Δm^2 between spin-0 and spin-$\frac{1}{2}$ leptons and quarks.

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*) The couplings of our boson are different from those considered in Ref. 7), but the effects it might induce are qualitatively similar.

**) We shall assume for simplicity that this spin-0 particle does not couple directly to leptons and quarks ; this is the case, in particular, if the theory admits a continuous R invariance, as in Ref. 2).

In a gauge theory the mass of the new spin-1 boson is proportional to its gauge coupling constant, itself related by supersymmetry to the goldstino Yukawa coupling constants, i.e., to the strength of the goldstino interactions (let us mention, for example, the scattering of goldstinos on matter 10) or the decay $\psi \to$ goldstino + antiphotino 10),11)).

When gravitation is introduced, supersymmetry is realized locally 12) and the massless spin-$\frac{1}{2}$ goldstino is eliminated in favour of the $\pm\frac{1}{2}$ polarization states of a massive spin-$\frac{3}{2}$ gravitino. The effective strength of the interactions of the gravitino are fixed (in terms of its mass $m_{\frac{3}{2}}$) by the ratio $G_{\text{Newton}}/m^2_{\frac{3}{2}}$. If $m_{\frac{3}{2}}$ is small the gravitino interacts essentially like a goldstino.

The mass of the gravitino is related to the one of the new boson (essentially one varies as the inverse of the other). At the present stage both the mass and gauge coupling of the new boson are unknown. They can be considered as having a gravitational origin so that they might naturally be very small.

From now on we can forget nearly everything about supersymmetry. We shall study the possible effects of the new spin-1 boson on neutral current phenomenology, using a simple example for illustration.

WEAK GAUGE BOSONS AND NEUTRAL CURRENTS

Let us consider first the simplest version of the SU(2)×U'(1)×U"(1) model of Ref. 2) (although in the real world the neutral boson mass matrix and neutral currents may have a more complicated structure). Both the standard gauge group SU(2)×U'(1) and the extra factor U"(1) are spontaneously broken. The latter is also responsible for the spontaneous breaking of the supersymmetry and the generation of large masses for spin-0 leptons and quarks. The model contains two Higgs doublets s and t. Their neutral components acquire equal non-vanishing vacuum expectation values of modulus $v_0/\sqrt{2}$. From the expression of the covariant derivative D_μ acting on the Higgs doublets s and t

$$i D_\mu = i \partial_\mu - \frac{1}{2}\left(g \vec{\tau} \vec{W}_\mu + g' W'_\mu \pm g'' W''_\mu \right) \qquad (1)$$

we get the mass spectrum of the gauge bosons. Let us denote the photon by γ, the standard charged and neutral gauge bosons by W_- and Z', and the new neutral gauge boson by Z''. Their masses are given by *)

$$m^2(W_-) = \frac{1}{2} g^2 v_0^2$$

$$m^2(Z') = \frac{1}{2}(g^2 + g'^2)\, v_0^2 \qquad (2)$$

$$m^2(Z'') = \frac{1}{2} g''^2 v_0^2 \qquad (3)$$

To make our phenomenological study more general we also consider the possible existence of an extra Higgs singlet transforming only under $U''(1)$. It would make the Z'' heavier without modifying the W_- and Z' masses, thereby reducing the effective strength of Z'' exchanges. To take this effect into account we replace formula (3) by

$$m^2(Z'') = \frac{1}{2} g''^2 v^2 = \frac{1}{2} \; \frac{g''^2 v_0^2}{r^2} \qquad (4)$$

The number $r = (v_0/v) \leqslant 1$ is a model-dependent parameter. It is important to note the proportionality between the mass and coupling constant of the new gauge boson **), and the relations :

$$\frac{g''^2}{m^2_{Z''}} = \frac{g^2 + g'^2}{m^2_{Z'}}\, r^2 = \frac{g^2}{m^2_{W_-}}\, r^2 = 4\, G_F \sqrt{2}\, r^2 \qquad (5)$$

For each lepton or quark field $\psi_{L(R)}$ of a given chirality the weak isospin $\vec{T}$ and the weak hypercharges F' and F'' are defined by the expression of the covariant derivative :

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*) It follows from the couplings of the goldstino that the gauge bosons W_- and Z' are, at lowest order, mass-degenerate with their spin-$\frac{1}{2}$ partners, the Dirac fermions L_-, ℓ_- and ℓ'_0. This is, however, model-dependent.

**) Incidentally, the existence of the new boson leads to an extra contribution

$$\sim g''^2 \frac{m_\mu^2}{m^2_{Z''}} \sim G_F\, m_\mu^2\, r^2$$

to the muon anomalous magnetic moment. In particular if Z'' is relatively heavy compared to the muon and axially coupled to it, its contribution to the anomaly reads

$$a_\mu^{(Z'')} \simeq -\frac{5}{3}\, r^2 \frac{G_F\, m_\mu^2}{8\pi^2\sqrt{2}} \simeq -2\, r^2\, 10^{-9}$$

$$i D_\mu = i \partial_\mu - \left(g \vec{T} \vec{W}_\mu + \frac{g'}{2} F' W'_\mu + \frac{g''}{2} F'' W''_\mu \right) \qquad (6)$$

The weak neutral current interactions of leptons and quarks are fixed by the following terms in the Lagrangian density :

$$\mathcal{L} = \left[\sqrt{g^2 + g'^2} \left(T_3 - \sin^2\theta \, Q \right) Z'_\mu + \frac{g''}{2} F'' Z''_\mu \right] \bar{\Psi}_{L(R)} \gamma^\mu \Psi_{L(R)} \qquad (7)$$

THE EFFECTIVE LAGRANGIAN DENSITY IN THE LOCAL LIMIT

In the limit of small momentum transfer compared to the Z' and Z" masses the exchanges of these gauge bosons between leptons and quarks can be described by the effective Lagrangian density

$$\begin{aligned} \mathcal{L}_{eff} &= \frac{g^2 + g'^2}{2 m_{Z'}^2} \left(J_3^\mu - \sin^2\theta \, J^\mu_{em} \right)^2 + \frac{g''^2}{8 m_{Z''}^2} \left(J''^\mu \right)^2 \\ &= 2 \, G_F \sqrt{2} \left[\left(J_3^\mu - \sin^2\theta \, J^\mu_{em} \right)^2 + \frac{r^2}{4} \left(J''^\mu \right)^2 \right] \end{aligned} \qquad (8)$$

In the simplest situation the new gauge boson is axially *) coupled to leptons and quarks so that a Z" exchange does not induce any parity violating effect in electron-nucleon scattering experiments, or in nuclear or atomic physics experiments. But the scattering of neutrinos and antineutrinos on matter is modified by the existence of the Z". It is given by **) :

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*) In order to cancel the anomalies (whether this is really necessary is not clear, especially since the U"(1) gauge coupling constant may be extremely small) one may have to introduce, next to ordinary leptons and quarks, heavy ones with opposite U"(1) transformation properties. The former are lighter than their spin-0 partners while the latter are heavier.

**) The sign convention used in Eq. (9) for the weak hypercharges F" is the opposite of the one used in Ref. 2). Here we have F" = +1 and -1 for the Higgs doublets s and t, $F'' = -\frac{1}{2}$ and $+\frac{1}{2}$ for the left-handed and right-handed parts of the lepton and quark fields, respectively. A left-handed neutrino field has $T_3 = \frac{1}{2}$, $F'' = -\frac{1}{2}$.

$$\mathcal{L}_{eff} = 2\, G_F \sqrt{2}\; \bar{\nu}_L \gamma_\mu \nu_L \left(J_3^\mu - \sin^2\theta\, J_{em}^\mu - \frac{r^2}{4} J''^\mu \right) \tag{9}$$

Both the exchanges of Z' and Z" in neutrino scattering experiments can be described, in the local limit, by a single effective neutral current. Its parts relative to the u and d quarks and the electron can be characterized by the six parameters [defined as in Ref. 1)] :

$$\left\{ \begin{array}{llll} u_L = & \frac{1}{2} & - \frac{2}{3} \sin^2\theta & + \frac{r^2}{8} \\ d_L = & -\frac{1}{2} & + \frac{1}{3} \sin^2\theta & + \frac{r^2}{8} \\ u_R = & & - \frac{2}{3} \sin^2\theta & - \frac{r^2}{8} \\ d_R = & & \frac{1}{3} \sin^2\theta & - \frac{r^2}{8} \end{array} \right. \tag{10}$$

$$\left\{ \begin{array}{llll} \varepsilon_L = & -\frac{1}{2} & + \sin^2\theta & + \frac{r^2}{8} \\ \varepsilon_R = & & \sin^2\theta & - \frac{r^2}{8} \end{array} \right. \tag{11}$$

The electronic effective neutral current can also be parametrized by

$$\left\{ \begin{array}{l} g_V = \varepsilon_L + \varepsilon_R = -\frac{1}{2} + 2 \sin^2\theta \\ g_A = \varepsilon_L - \varepsilon_R = -\frac{1}{2} + \frac{r^2}{4} \end{array} \right. \tag{12}$$

The quantity

$$u_L + 2\, d_L = -\frac{1}{2} + \frac{3r^2}{8} \tag{13}$$

like g_A, does not depend on the SU(2)xU'(1) mixing angle θ.

COMPARISON WITH EXPERIMENTAL RESULTS ON NEUTRINO SCATTERING, ASSUMING THE LOCAL LIMIT APPROXIMATION TO BE VALID

It is easy to compare Eqs. (10) to (13) with the experimental results 1), provided one is careful not to use the factorization hypothesis. For $r^2 \simeq 0$ the Z" exchanges are negligible and we recover the results of the standard model (i.e., $\sin^2\theta \simeq 0.23$). For $r^2 = 1$, expression (13) of $(u_L + 2d_L)$ is not compatible with the results of $\nu_\mu(\bar{\nu}_\mu)$ nucleon scattering experiments ; expression (12) of g_A is not compatible with the results of $\nu_\mu(\bar{\nu}_\mu)$ electron scattering experiments. As a result $r^2 = 1$ seems excluded, while $r^2 \lesssim \frac{1}{2}$ is phenomenologically acceptable.

Let us remind the reader under which assumptions formulas (9) to (12) have been derived :

i) the spontaneous breaking of the $SU(2) \times U'(1)$ gauge invariance is due to two Higgs doublets s and t acquiring equal vacuum expectation values ;

ii) the new neutral current is purely axial ;

iii) the local limit approximation is valid.

Under these hypotheses, neutrino scattering experiments imply that $r^2 \lesssim \frac{1}{2}$: an extra contribution to the Z" mass, due for example to a Higgs singlet, is needed.

This may not be necessary if one of the above hypotheses is relaxed : for example, if the new neutral current is not purely axial, the Z" coupling to the ν_μ field can be smaller, so that the Z" exchange contributions to ν_μ and $\bar{\nu}_\mu$ scatterings would be sufficiently small. We shall now concentrate on the possibility that both the Z" mass and gauge coupling constant are small ; this could happen naturally due to their relation with gravity. Then the local limit approximation is not necessarily valid.

WHY THE NEW GAUGE BOSON DOES NOT AFFECT HIGH MOMENTUM TRANSFER NEUTRINO SCATTERING NEUTRAL CURRENT PHENOMENOLOGY, IF IT IS LIGHT AND WEAKLY COUPLED

We now assume that both the Z" mass and gauge coupling constant are small, while still related by relation (5). Only for small momentum transfer compared to the Z" mass do Z" exchanges lead to an effective neutral current interaction with strength $\sim (g''^2/m_{Z''}^2) \sim G_F r^2$. For large momentum transfer compared to the Z" mass the amplitude for exchanging a Z" between leptons and quarks contains the factor

$$\frac{g''^2}{16\left(m_{Z''}^2+q^2\right)} \simeq \frac{g''^2}{16\, q^2} \left\{ \begin{array}{l} \ll \dfrac{g''^2}{16\, m_{Z''}^2} = \dfrac{G_F}{2\sqrt{2}}\, r^2 \\[2ex] \ll \dfrac{e^2}{q^2} \end{array} \right. \qquad (14)$$

As soon as q is larger than $\sim m_{Z''}$, the Z" exchange amplitudes in neutrino scatterings are negligible compared to ordinary weak neutral current amplitudes : the new gauge boson does not affect high momentum transfer neutrino phenomenology.

This result can be extended to Z" exchanges between leptons and quarks, but one has to be careful if the Z" mass is very small so that the masses of leptons and quarks cannot be neglected, even at very high energies. A very light longitudinally polarized Z" interacts more strongly than transversely polarized ones. Such a Z" would be produced and interact like a pseudoscalar axion *), as we shall discuss elsewhere.

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*) It is well known that the existence of an ordinary axion 5) seems in conflict with experiments. For similar reasons, this might also be the case for a very light Z". However, in the presence of a singlet Higgs field making the parameter r smaller than 1, the effective strength of the Z" interactions is reduced so that there is no incompatibility with experiments.

Even in the absence of supersymmetry, this remark shows that the existence of the axion introduced in Ref. 5) as a possible solution to the problem of CP conservation in strong interactions is indeed compatible with experiments. Such an axion will be, mostly, invariant under the standard gauge group SU(2)×U'(1), with a small contamination by the Higgs doublets responsible for the masses of the intermediate bosons $W_{\pm}$ and Z', as well as leptons and quarks.

NEUTRAL CURRENT PHENOMENOLOGY FOR A LIGHT Z"

Let us discuss again the results of neutrino scattering experiments, assuming now that the Z" mass is small. If $r^2 \lesssim \frac{1}{2}$ the existence of Z" is compatible with experiments, as before, whether the local limit approximation is valid or not.

But the constraint on r^2 becomes weaker or disappears if Z" is light enough so that the local limit approximation is not valid. We shall still keep hypotheses i) SU(2)×U'(1) is spontaneously broken by two Higgs doublets acquiring equal vacuum expectation values, and ii) the new neutral current is purely axial. If q^2 cannot be neglected with respect to $m^2_{Z''}$ the term $\pm r^2/8$ in formulas (10), (11) must be replaced by

$$\pm \frac{r^2}{8} \frac{m^2_{Z''}}{m^2_{Z''} + q^2} \tag{15}$$

Among $\nu_\mu(\bar{\nu}_\mu)$ nucleon scattering experiments the most important for the present analysis concern elastic scatterings on protons 13), with

$$.4\,(GeV/c)^2 < q^2 < .9\,(GeV/c)^2 \tag{16}$$

For $r = 1$ and $m_{Z''} \leq 600\ MeV/c^2$ the existence of the extra term (15) (smaller than 0.06 in magnitude) is compatible with the experimental results on neutrino-nucleon scatterings.

A stronger constraint comes from $\nu_\mu e$ scattering experiments. The effective electronic neutral current is parametrized by

$$\begin{cases} g_V = -\frac{1}{2} + 2\sin^2\theta \\ g_A(q^2) = -\frac{1}{2} + \frac{r^2}{4} \frac{m^2_{Z''}}{m^2_{Z''} + q^2} \end{cases} \tag{17}$$

The effect of Z" would be to make the $\nu_\mu e$ and $\bar{\nu}_\mu e$ cross-sections smaller at lower q^2 *). Let us find out how small $m_{Z''}$ should be if r is equal to 1. Only high energy $\nu_\mu e$ scattering experiments give us significant constraints [1]. In the experience of Ref. 14), the typical electron energy is ∿25 GeV, i.e., a momentum transfer of the order of 150 MeV/c. For $\sin^2\theta = 0.22$ and $q = \frac{3}{4} m_{Z''}$ we have

$$\begin{cases} g_V = -.06 \\ g_A(q^2) = -.34 \end{cases} \tag{18}$$

A careful analysis of the experimental results, involving the knowledge of the neutrino spectrum and the calculation of the expected electron spectrum in the present model, is necessary before one can give a precise limit on the Z" mass. Meanwhile we only conclude that if $r = 1$ this mass should be smaller than ∿ 300 MeV/c^2, approximately.

In summary, for the simplest model we have considered [in which the spontaneous breaking of SU(2)×U'(1)×U"(1) is due to two Higgs doublets acquiring equal vacuum expectation values, the new neutral current is purely axial, and there is no Higgs singlet giving an extra contribution to the Z" mass], neutrino scattering experiments **) imply that the Z" mass should be $\lesssim$300 MeV/c^2.

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*) For $q^2 \gg m^2_{Z''}$ these cross-sections have the same values as in the standard model. For $q^2 \ll m^2_{Z''}$ and $r = 1$ we have

$$\sigma_{\nu_\mu e} = \sigma_{\bar{\nu}_\mu e} = 0.35\ 10^{-42}\ \text{cm}^2\ E(\text{GeV}) \qquad \text{for } \sin^2\theta = 0.25$$

$$\left.\begin{array}{l} \sigma_{\nu_\mu e} = 0.55\ 10^{-42}\ \text{cm}^2\ E(\text{GeV}) \\ \sigma_{\bar{\nu}_\mu e} = 0.27\ 10^{-42}\ \text{cm}^2\ E(\text{GeV}) \end{array}\right\} \quad \text{for } \sin^2\theta = 0.20$$

Such a small value of $\sigma_{\nu_\mu e}$ does not seem compatible with present experimental results (but more experimental information would still be very useful).

**) One should also consider reactor experiments. A Z" lighter than one MeV/c^2 would have a negligible effect on the $\bar{\nu}_e e$ cross-section [15]. Otherwise this one would be modified according to Eqs. (12) or (17) ; this is acceptable for usual values of $\sin^2\theta$.

FINAL REMARKS

The new gauge boson could manifest in a variety of ways : neutral current phenomenology, including neutrino scattering, e^+e^- annihilation, parity violation effects in nuclear or atomic physics ; kaon decays, and searches for axion-like particles ; searches for deviations from Newton's law of gravitation.

What kind of experiment is the most appropriate to search for the new boson depends on its mass, the strength of its interaction, and whether it has a well-defined parity character. The variety of phenomena we have to consider reflects the very special rôle of the new boson. It appears as an ordinary gauge particle, like those mediating electroweak interactions. But it also appears as a particle mediating gravitational interactions, like the graviton and the gravitino to which it is related by supersymmetry.

REFERENCES

1) See, for example :

F. Dydak - Proceedings of the International Conference on High Energy Physics, Geneva (June 1979), p. 25 ;

P. Langacker et al. - Preprint COO-3071-243 (1979) ;

K. Winter - Proceedings of the Symposium on Lepton and Photon Interactions at High Energies, Fermilab (Aug. 1979), p. 258 ;

P. Musset - Proceedings of the Symposium on Lepton and Hadron Interactions, Visegrad (September 1979), p. 3.

2) P. Fayet - Phys.Letters 69B (1977) 489.

3) P. Fayet - Phys.Letters 70B (1977) 461.

4) For review articles, see :

P. Fayet - Proceedings Orbis Scientiae (Coral Gables, Florida, USA, January 1978), New Frontiers in High Energy Physics (Plenum, New York) p. 413 ; Talk given at the Europhysics Study Conference : "Unification of the Fundamental Interactions" (Erice, Italy, March 1980), CERN Preprint TH 2864.

5) R.D. Peccei and H.R. Quinn - Phys.Rev.Letters 38 (1977) 1440 ; Phys.Rev. D16 (1977) 1791 ;

S. Weinberg - Phys.Rev.Letters 40 (1978) 223 ;

F. Wilczek - Phys.Rev.Letters 40 (1978) 279.

6) M.A. Bouchiat and C. Bouchiat - Phys.Letters 48B (1974) 111 ;

C. Bouchiat - Summary talk given at the Workshop on Neutral Current Interactions in Atoms (Cargèse, France, September 1979) (University of Michigan Press, to be published), Preprint LPTENS 79/24.

7) J. Scherk - Proceedings of the Supergravity Workshop (State University of New York at Stony Brook, USA, September 1979), p. 43.

8) P. Fayet and J. Iliopoulos - Phys.Letters 51B (1974) 461.

9) P. Fayet - Phys.Letters 84B (1979) 416.

10) P. Fayet - Phys.Letters 86B (1979) 272.

11) P. Fayet - Phys.Letters 84B (1979) 421.

12) S. Ferrara, D.Z. Freedman and P. van Nieuwenhuizen - Phys.Rev. D13 (1976) 3214 ;

S. Deser and B. Zumino - Phys.Letters 62B (1976) 335.

13) A. Entenberg et al. - Phys.Rev.Letters 42 (1979) 1198.

14) R.H. Heisterberg et al. - Phys.Rev.Letters 44 (1980) 635.

15) F. Reines, H.S. Gurr and H.W. Sobel - Phys.Rev.Letters 37 (1976) 315.