Vol. B19 (1988) ACTA PHYSICA POLONICA No 7

PHOTINO AND SEARCH FOR SUPERSYMMETRIC PARTICLES

BY P. MUKHOPADHYAY

Jadavpur University, Calcutta*

(Received September 16, 1987)

We point out that photino is one of the very few supersymmetric particles which may be freely produced. This, along with the fact that of all such particles photino is expected to be the least massive one, imparts on it the status of the best candidate for experimental search of supersymmetric particles.

PACS numbers: 11.30.Pb

It is well known that all supersymmetric grand unified theories [1–8] predict the existence of a set of particles corresponding to all known particles which have spins differing by one-half from those of the partner particles. The former particles are generally referred to as supersymmetric particles or as s-particles for the sake of brevity and the latter ones as normal particles. It is worth mentioning in this context that a s-particle and its partner particle share the same internal quantum numbers in simple supersymmetric theories [9]. On the other hand, the internal quantum numbers may not be identical for a s-particle and its partner particle in extended supersymmetric theories [10]. In this paper we shall be concerned with the s-particles as discussed by Fayet and Farrar in connection with their work [2, 11] on supersymmetry phenomenology. This work is based on a simple supersymmetry and assigns a new discrete quantum number R associated with R-symmetry [2, 11]. In passing we may note that $R = 0$ for normal (i.e. conventional) particles and $R = \pm 1$ for their supersymmetric partners (with $R = +1$ for a s-particle and $R = -1$ for its antiparticle). One important point regarding s-particles is that none of them has been seen to date. In this connection it may be recalled that the supersymmetric partners of electron [12], muon [13] and $W^{\pm}$, Z^0 [14] have been searched for but not observed. These experimental facts have prompted us to investigate in this paper the criteria for selection of a s-particle for experimental search. This paper concludes that photino is the best candidate for this purpose. This conclusion does not simply rest on the fact that photino is the least massive [15] of all s-particles. This point is discussed below.

* Address: Department of Physics, Jadavpur University, Calcutta 700032, India.

This paper highlights the role of production behaviour of a s-particle, apart from its mass, on the feasibility of its experimental detection. The important point to be recognized in this context is that a s-particle, if it undergoes suppressed production, will be more difficult to detect than what is expected if it could be freely produced. This point has been elaborated at the final stage of this paper. In fact, in this paper we have stressed that the two important criteria for the selection of a s-particle as a candidate for experimental search of such particles are (*i*) its mass and (*ii*) its production behaviour. Unfortunately, the crucial role played by production behaviour of a s-particle in the matter relating to its experimental detection remains underappreciated in the literature.

For the reason underlined above, we have investigated production behaviours of the supersymmetric partners of some familiar particles (which include hadrons and non--hadrons as well). For this purpose the most straightforward approach is to exploit suitable constraints. In order to select appropriate constraints it is important to remain aware of the fact that in the literature there is not a single constraint which is exclusively meant for particle production. Needless to mention, the conventional constraints which are applicable in particle production also find their use in particle decays. On the other hand, there are some constraints which cover particle decays only (such as, for example, $\Delta I = 1/2$ rule in weak decays). This fact prompted us to suggest in our earlier papers [16–19] two constraints for hadron production and their analogs for production of non-hadrons. As these constraints are exclusively meant for particle production, they are expected to deliver some vital information as regards production behaviour of particles. This is really the case as evident from our previous papers [16–19]. In the present paper we have generalized the constraints concerned to invoke the quantum number R within their expressions in order they can be employed for investigating production behaviours of s-particles. The predictions of these generalized constraints on the overall nature of production of some normal particles (for which $R = 0$) and their supersymmetric partners have been displayed in the last columns of Tables I and II. A look into these tables reveals that out of all the s-particles exhibited there only two i.e. $\tilde{\Lambda}$ (in Table I) and photino $\tilde{\gamma}$ (in Table II) may be freely produced and the rest are liable to suffer inhibited production. Implications of production behaviour of s-particles have been discussed by considering relatively light particles which include photino as well as scalar electrons and scalar muons. Finally, we have exploited the facts that photino is the least massive [15] of all s-particles and that it may be freely produced in order to justify its claim as the best candidate for experimental search of s-particles.

We now proceed to discuss the generalized versions of the two constraints [16, 19] for hadron production. One of them is of restricted validity whereas the other one is of general validity. For convenience of discussions, we first consider the former constraint which is applicable for production of a hadron having odd-half integral isospin or(and) actual spin. To formulate this constraint, we assume flavor symmetry [20] of hadrons to be $SU_f(4)$ for the sake of simplicity. Now, we consider a hadron specified by its actual spin J, $SU_f(4)$ quantum numbers I (isospin), S (strangeness), C (charm) and the quantum number R; its I or(and) J being odd-half integral. With this hadron we associate the quantity $(-1)^{K_1 I}$ which is a rotational invariant in isospace where K_1 is a c-number. With

TABLE I

The predictions on the nature of production of some normal particles and their supersymmetric partners by the constraints given by relations (9) and (10). The relation (9) is applicable for particles having odd-half integral isospin I or (and) actual spin J

Normal particle and its supersymmetric partner	J	Nature of production according to relation (9)	Nature of production according to relation (10)	Overall nature of production
π	0		free	free
$\tilde{\pi}$	1/2	suppressed	suppressed	suppressed
K	0	free	free	free
$\tilde{K}$	1/2	suppressed	suppressed	suppressed
(charmed D	0	free	free	free
mesons) $\tilde{D}$	1/2	suppressed	suppressed	suppressed
(charmed F	0		suppressed	suppressed
mesons) $\tilde{F}$	1/2	free	suppressed	suppressed
(nucleons) N	1/2	free	free	free
$\tilde{N}$	0	suppressed	suppressed	suppressed
(strange Λ	1/2	free	free	free
baryons) $\tilde{\Lambda}$	0		free	free
(charmed Λ_c	1/2	free	free	free
baryons) $\tilde{\Lambda}_c$	0		suppressed	suppressed
(charmed Σ_c	1/2	suppressed	suppressed	suppressed
baryons) $\tilde{\Sigma}_c$	0		suppressed	suppressed

TABLE II

The predictions on the nature of production of some non-hadrons and their supersymmetric partners by the constraints given by relations (9a) and (10a). The relation (9a) is applicable for a particle having odd-half I_w (weak isospin) or(and) J (actual spin)

Normal particle and its supersymmetric partner	J	Nature of production according to relation (9a)	Nature of production according to relation (10a)	Overall nature of production
(lepton) l	1/2	free	free	free
(scalar lepton) $\tilde{l}$	0	suppressed	free	suppressed
(photon) γ	1		free	free
(photino) $\tilde{\gamma}$	1/2	free	free	free
$W^{+,-}$, Z^0	1		free	free
$\tilde{W}^{+,-}$, $\tilde{Z}^0$	1/2	suppressed	suppressed	suppressed
(Higgs boson) H	0	suppressed	suppressed	suppressed
(Higgs fermion) $\tilde{H}$	1/2	free	suppressed	suppressed

the same particle we can also associate the quantity $(-1)^{K_2 J}$ which is a rotational invariant in actual spin space, where K_2 is a c-number. If, further, K_1 and K_2 are so chosen that both of them are c-number in isospace and actual spin space as well, then, the following conclusions can be drawn regarding the combination $(-1)^{K_1 I}+(-1)^{K_2 J}$. Obviously, the first term of this combination is an invariant under rotational transformations in isospace to which the second term does not respond and as such the latter may be treated as a constant quantity. On the other hand, under rotational transformations in actual spin space the first term of the above mentioned combination behaves as a constant quantity whereas the second term is an invariant. It is worth recalling in this context that invariance property of a quantity is not affected if we add to it a constant term. This in turn implies that

$$(-1)^{K_1 I}+(-1)^{K_2 J} \equiv \text{invariant} \tag{1}$$

under rotations in isospace or actual spin space.

In order that the invariant, defined by relation (1), may be physical it has to possess a real value. This in turn means that both K_1 and K_2 occurring in relation (1) can admit non-zero even integral values as we are considering a hadron having odd-half integral I or(and) J. Obviously, the minimum value admissible for both K_1 and K_2 is 2. If, however, we set $K_1 = K_2 = 2$, then, the invariant concerned remains real as desired. For this choice of the values for K_1 and K_2 the invariant concerned involves I and J which are not sufficient for specifying a non-ordinary hadron. Therefore, in order that the invariant may be useful for an ordinary as well as a non-ordinary hadron and their supersymmetric partners, one of the quantities K_1 and K_2 should be expressed in terms of the scalar quantum numbers indicated below

$$K_1 = |(B+S+C+R+X)| \text{ and } K_2 = 2 \tag{2}$$

where B denotes baryon number, S strangeness, C charm and R the quantum number relating to R-symmetry. The quantity X is necessary for the reality of the invariant as well as to ensure a non-zero value of K_1. The admissible values of X may be obtained by exploiting these conditions along with the more explicit form of the invariant shown below.

$$(-1)^{|(B+S+C+R+X)|(I)}+(-1)^{2J} \equiv \text{invariant.} \tag{3}$$

Now, taking into account the quantum numbers of the well known normal hadrons (for which $R = 0$) which are spinors in isospace or(and) actual spin space, it is easy to check that the allowed values of X are given by [16–18]

$$\begin{aligned} X &= \pm 2, \pm 4, \pm 6, \ldots \text{ for isobosons} \\ &= \pm 1, \pm 3, \pm 5, \ldots \text{ for isofermions,} \end{aligned} \tag{4}$$

where + sign refers to a particle and — sign to an antiparticle.

To proceed further we may note that the numerical value of the invariant can be either 0 or 2. Now, we demand that a hadron, which is a spinor in isospace or(and) actual spin space, to be freely produced it is essential (but not sufficient) that the invariant must have the value 0 i.e.

$$(-1)^{|(B+S+C+R+X)|(I)}+(-1)^{2J} = 0. \tag{5}$$

Obviously, relation (5) can be recast as

$$(-1)^{|(B+S+C+R+X)|(I)} = (-1)^{(2J\pm 1)} \tag{6}$$

by writing $(-1) = (-1)^{\pm 1}$ where both + and − signs have been used in the index for the sake of generality. As the quantity $(2J\pm 1)$ does not possess a unique sign when $J = 0$, we consider its magnitude and accordingly modify relation (6) as

$$(-1)^{|(B+S+C+R+X)|(I)} = (-1)^{|(2J\pm 1)|}. \tag{7}$$

This relation clearly indicates that as the bases are unity we cannot in general demand the equality of the powers of the same. However, with a proper choice for the value of X from its spectrum of allowed values given by relation (4), we can equate the powers of both sides of relation (7) to obtain the following constraint.

$$|(B+S+C+R+X)|(I) = |(2J\pm 1)|, \tag{8}$$

where + sign holds for a hadron having $I \neq 0$ and − sign for a hadron having $I = 0$. For convenience of future use, we rewrite relation (8) as

$$|(B+S+C+R+X)|(I) = \begin{cases} |(2J+1)|, & I \neq 0 \\ |(2J-1)|, & I = 0, \end{cases} \tag{9}$$

where, as mentioned earlier, the value of X should be chosen from its admissible values indicated by relation (4). We repeat to emphasize that relation (9) is applicable for a hadron having odd-half integral I or(and) J. For such a hadron relation (9) must hold true in order that it may be freely produced. Otherwise production of the hadron concerned is forbidden and, consequently, suppressed. It is easy to check that relation (9) is satisfied for the charmed meson D (for which $B = 0$, $S = 0$, $C = 1$, $R = 0$, $I = 1/2$, $J = 0$) with $X = +1$. This hadron, therefore, should be freely produced according to the constraint described by relation (9). The same constraint, however, is not satisfied for its supersymmetric partner $\tilde{\mathrm{D}}$ (with $B = 0$, $S = 0$, $C = +1$, $R = +1$, $I = 1/2$, $J = 1/2$) for any one of the values of X for an isospinor given by relation (4). Consequently, this s-particle must undergo suppressed production. Also, the same constraint is not satisfied for the charmed baryon Σ_c (for which $B = 1$, $S = 0$, $C = 1$, $R = 0$, $I = 1$, $J = 1/2$). This is because for this baryon, which is an isoboson, we cannot find any value of X from its allowed values for isobosons indicated by relation (4) for which the constraint i.e. relation (9) may be satisfied. As a necessary consequence of this, production of Σ_c should be forbidden. This in turn means that Σ_c should undergo inhibited production as claimed by the constraint described by relation (9). This claim, needless to mention, is justified by experiments [21, 22]. As can be easily checked, the same constraint also predicts that production of $\tilde{\Sigma}_c$ (having $B = +1$, $S = 0$, $C = +1$, $R = +1$, $I = 1$, $J = 0$), the supersymmetric partner of Σ_c, must suffer inhibited production.

As the constraint discussed above is of restricted validity, we require a constraint which should be applicable in production of all hadrons. To formulate such a constraint we consider, as before, flavor symmetry of hadrons to be $SU_f(4)$ for the sake of simplicity. For the moment, we confine our attention to the hadrons belonging to the 0^- and $\frac{1}{2}^+$ $SU_f(3)$ multiplets. For these particles (for which the quantum number $R = 0$) we consider the linear combination $|(2I \pm S \pm R)|$ where + sign refers to a particle and − sign to an antiparticle; I denotes isospin and S strangeness. This combination exhibits the following interesting property for the hadrons referred to above. Its value is odd integral for all the particles belonging to the $\frac{1}{2}^+$ multiplet and the same is even integral for all the particles of the 0^- multiplet. To be more specific,

$$\begin{aligned} |(2I \pm S \pm R)| &= 1 \text{ for an actual fermion} \\ &= 2 \text{ for an actual boson having } I \neq 0 \\ &= 0 \text{ for an actual boson having } I = 0. \end{aligned}$$

Further, all the hadrons mentioned above are conspicuous for their free production. From these considerations, we demand that a hadron, be it a particle or a s-particle, may be freely produced if its $SU_f(4)$ and R quantum numbers satisfy the following constraint.

$$\begin{aligned} |(2I \pm S \pm C \pm R)| &= 1 \text{ for an actual fermion} \\ &= 2 \text{ for an actual boson having } I \neq 0 \\ &= 0 \text{ for an actual boson having } I = 0, \end{aligned} \tag{10}$$

where C denotes charm; + sign refers to a particle and − sign to an antiparticle. This constraint is of general validity as it is applicable for all hadrons.

One interesting feature shared by both the constraints discussed above is that they are of non-dynamical origin. This is because they involve the internal quantum numbers (I, S, C, R) but not their variations (i.e. ΔI, ΔS, etc.). Needless to mention, dynamical constraints concern themselves with the variations of the internal quantum numbers (like $\Delta I = 0$, $\Delta S = \Delta C = 0$, etc. in strong interaction, for example). As is well known, non--dynamical constraints have a special advantage over dynamical ones as the former are applicable in all interactions. Therefore, the constraints of our interest are valid in all possible production mechanisms of a hadron.

In Table I have been shown individual predictions of the two constraints on the nature of production of some well known hadrons and their supersymmetric partners. The internal quantum numbers of the s-particles exhibited in this table have been assumed to be identical to the same for the corresponding normal particles as in simple supersymmetric theories. The last column of the same table shows the overall nature of production of the particles under considerations. In passing we may note that if production of a particle is forbidden (and as such suppressed) by any one of a set of constraints operative in its production, then, the overall status of its production turns out to be that of a suppressed particle even if its production is allowed by the rest of the constraints.

We now turn our attention to non-hadrons which are specified by the quantum numbers I_w (weak isospin), J (actual spin), L (lepton number) and R (which is the quantum number associated with R-symmetry) with $R = 0$ for a conventional particle. To investigate production behavior of the particles now under considerations we require the analogs of the constraints given by relations (9) and (10). The desired analog of relation (9) is easily obtained by the replacement $B \to L$, $I \to I_w$ and setting $S = C = 0$ in relation (9). Clearly, the analog of relation (9) reads

$$\begin{aligned} |(L+R+X)|\,(I_w) &= |(2J+1)|, \quad I_w \neq 0 \\ &= |(2J-1)|, \quad I_w = 0, \end{aligned} \tag{9a}$$

where the value of X should be chosen from its spectrum of allowed values [18] indicated below.

$$\begin{aligned} X &= \pm 2, \pm 4, \pm 6, \ldots \text{ for weak isobosons} \\ &= \pm 1, \pm 3, \pm 5, \ldots \text{ for weak isofermions,} \end{aligned}$$

where + sign refers to a particle and − sign to an antiparticle. It may be stressed that the constraint given by relation (9a) is applicable to a particle having odd-half integral I_w or(and) J as this relation is obtained from relation (9) which is valid for a particle having odd-half integral I or(and) J. Finally, the analog of the constraint given by relation (10) may be obtained by the replacement $I \to I_w$ and setting $S = C = 0$ in relation (10). This analog reads [18]

$$\begin{aligned} |(2I_w \pm R)| &= 1 \text{ for an actual fermion} \\ &= 2 \text{ for an actual boson having } I_w \neq 0 \\ &= 0 \text{ for an actual boson having } I_w = 0. \end{aligned} \tag{10a}$$

This constraint is of general validity as it is applicable to all non-hadrons. In passing we may also note that the constraints given by relations (9a) and (10a) are non-dynamical ones as they happen to be the analogs of the constraints, described by relations (9) and (10), which are so.

The individual predictions of the constraints given by relations (9a) and (10a) on the nature of production of some familiar non-hadrons and their supersymmetric partners have been shown in Table II. The internal quantum numbers of the s-particles exhibited in this table have been assumed to be identical to the same for the corresponding normal particles as in simple supersymmetric theories. The last column of the same table displays the overall nature of production of the particles concerned.

A close inspection of Tables I and II reveals that out of those s-particles displayed in these tables only one hadron i.e. $\tilde{\Lambda}$ (in Table I) and only one non-hadron i.e. photino $\tilde{\gamma}$ (in Table II) may be freely produced and the rest of such particles must undergo suppressed production. In sharp contrast to this, most of the normal particles exhibited in these tables may be freely produced. From these considerations one can conclude that free production should be a rare phenomenon for s-particles whereas the same should be witnessed in majority of the normal particles. This conclusion remains valid for all other normal particles and their supersymmetric partners not shown in Tables I and II. This point can be easily checked.

We now examine the implications of production behaviours of s-particles on their observability. To discuss this point we confine our attention to the relatively light s-particles which include photino as well as scalar electrons and scalar muons. As reflected in Table II, photino is predicted to be freely produced by both the constraints given by relations (9a) and (10a). However, as evident from the same table, scalar electron and scalar muon must suffer suppressed production as their production is forbidden by the constraint given by relation (9a). As is well known, suppressed production of a particle has the implication that its production cross section should be appreciably less than what is expected for the same if this particle could be freely produced. Stated differently, production cross section of a suppressed particle should be significantly less than its theoretical value (estimated on the assumption that the particle concerned may be freely produced). This in turn means that the number of events in which a suppressed particle may be detected will be less than that if it could be freely produced. Needless to mention, the number of events in which a particle may be seen is related to its effective production cross section. From what have been discussed above it is clear that the feasibility of experimental detections of scalar electrons and scalar muons is reduced appreciably due to their suppressed production. The situation, however, is different for photino as its production is not inhibited at all. This apart, as already mentioned, photino is expected to be the least massive [15] of all s-particles. Therefore, from the considerations of its mass as well as its production behaviour, we can conclude that photino enjoys the status of the best candidate for experimental search of s-particles.

To summarize, we have investigated production behaviours of the supersymmetric partners of some normal particles. This investigation reveals that photino is one of the few s-particles which may be freely produced. Furthermore, its mass as well as its production behaviour clearly indicate that photino is the best choice for experimental search of supersymmetric particles.

REFERENCES

[1] J. Wess, B. Zumino, *Nucl. Phys.* **B70**, 39 (1974); *Phys. Lett.* **B49**, 52 (1974); B. Zumino, *Supersymmetry and Supergravity*, Preprint UCB-PTH-83/2 and LBL-15819, March 1983.

[2] P. Fayet, Proc. Orbis Scientiae, Coral Gables, Florida, U.S.A., Jan. 1978; *New Frontiers in High Energy Physics*, Plenum, New York 1978; G. R. Farrar, Proc. Int. School of Subnuclear Physics, Erice, Italy, Aug. 1978; P. Fayet, S. Ferrara, *Phys. Rep.* **C32**, 249 (1977).

[3] S. Ferrara, B. Zumino, *Nucl. Phys.* **B79**, 413 (1974).

[4] A. Salam, J. Strathdee, *Phys. Lett.* **B51**, 353 (1974); A. Salam, B. Strathdee, *Phys. Rev.* **D11**, 1521 (1975).

[5] J. Ellis, M. K. Gaillard, D. V. Nanopoulos, *Nucl. Phys.* **B106**, 292 (1976).

[6] M. F. Sohnius, *Phys. Rep.* **C128**, 39 (1985).

[7] S. Dimopoulos, H. Georgi, *Nucl. Phys.* **B193**, 150 (1981); N. Sakai, *Z. Phys.* **C11**, 153 (1981); J. Ellis, *Supersymmetry and Grand Unified Theories*, CERN Preprint-TH3718, Sept. 1983.

[8] S. Ferrara, D. Z. Freedman, P. van Nieuwenhuizen, *Phys. Rev.* **D13**, 3214 (1976); J. Bragger, E. Witten, *Phys. Lett.* **B115**, 202 (1982); J. Bragger, *Nucl. Phys.* **B211**, 302 (1983); E. Cremmer et al., *Phys. Rev. Lett.* **49**, 970 (1982).

[9] R. Haag, J. T. Copuszansky, M. Sohnius, *Nucl. Phys.* **B88**, 257 (1975).

[10] J. Wess, B. Zumino, *Nucl. Phys.* **B70**, 39 (1974).

[11] P. Fayet, *Phys. Lett.* **B69**, 489 (1977); G. R. Farrar, P. Fayet, *Phys. Lett.* **B76**, 575 (1978); *Phys. Lett.* **B79**, 442 (1978).

[12] JADE collaboration: W. Bartel et al., *Phys. Lett.* **B152**, 385 (1985).
[13] JADE Collaboration: W. Bartel et al., *Phys. Lett.* **B152**, 392 (1985).
[14] B. Adeva et al., *Phys. Rev. Lett.* **53**, 1806 (1984).
[15] P. Fayet, *Phys. Lett.* **B84**, 416 (1979); *Phys. Lett.* **B86**, 272 (1979); G. R. Farrar, P. Fayet, *Phys. Lett.* **B89**, 191 (1980); L. E. Ibanez, G. G. Ross, *Phys. Lett.* **B110**, 215 (1982); J. Ellis, L. E. Ibanez, G. G. Ross, *Phys. Lett.* **B113**, 283 (1982); G. Barbiellini et al., DESY-79/67 (October 1979).
[16] P. Mukhopadhyay, *Phys. Lett.* **B98**, 96 (1981).
[17] P. Mukhopadhyay, *Hadronic Journal* **7**, 867 (1984).
[18] P. Mukhopadhyay, *Hadronic Journal* **8**, 317 (1985).
[19] P. Mukhopadhyay, *Acta Phys. Pol.* **B10**, 237 (1979).
[20] M. K. Gaillard, B. W. Lee, J. L. Rosner, *Rev. Mod. Phys.* **47**, 277 (1975).
[21] C. A. Heusch, Proc. SLAC Summer Institute on Particle Physics 1982.
[22] Particle Data Group, Review of Particle Properties, 1986.