LETTERS TO THE EDITOR

DYNAMICAL SYMMETRY BREAKING IN SUPERSTRING SCENARIO*

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The possibility of dynamical symmetry breaking in the field theory limit of superstring theories is discussed. The proposed scenario should lead to a natural solution to the hierarchy problem.

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Superstring theories [1, 2] are nowadays the only hope for a consistent framework to unify the all known interactions. Especially, the ten-dimensional heterotic superstring with the $E_8' \times E_8$ gauge group seems to be very promising. In the orthodox approach it leads to a four-dimensional theory with $N = 1$ supersymmetry [3]. This approach generalizes the Grand Unification program. In such a theory most of the important physical parameters are calculable at least in principle [4]. Nevertheless this program has some difficult problems to solve. We should find an appriopriate manifold to compactify the theory in a realistic way (for a discussion see e.g. [3–9]). The low energy $N = 1$ supersymmetry needed to solve the hierarchy problem seems to be difficult to achieve [10, 11].

We propose another approach to the superstring scenario. It is based on the dynamical symmetry breaking [12–13]. We think that superstrings offer the opportunity to give masses to elementary particles without Higgs particles or at least without low energy Higgses [14]. The strategy is simple [12]. One has to find a finite solution of the Schwinger-Dysons equation for the fermion proper selfenergy Σ. In the classical approach [13] this could not be achieved because the appropriate integral equations have no finite solution. But, as was recently noticed by Hošek [12, 15], the situation changes dramatically if we introduce an additional (massive!) U(1) gauge field. The integral equations are now

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of Fredholm type. Although the exact solutions are still not known the approximate fermion masses ($\sim \Sigma(0)$) are known with a promissing accuracy [12]:

$$m_t = M(\mu_t) \exp [8\pi^2/3y(f_L)y(f_R)h^2(\mu_f)], \tag{1}$$

where μ_f is some physically distinguished renormalization point and $y(f_L)$ and $y(f_R)$ denote the charges of left-handed and right-handed fermions with respect to the additional U(1) group. $M(\mu_f)$ is of order 10^{14} GeV. The gauge boson masses are generated via "dynamical would-be" Nambu-Goldstone bosons built up from some fermion fields. The residue in polarization tensor is related to a non-vanishing vacuum expectation values of some bilinear combinations of those fermion-fields [12].

Superstrings give a natural way to incorporate this program. If superstrings are the true story they are compactified on some Calabi-Yau manifold (orbifold and coset space compactification lead to analogous conclusions). If this manifold is not simply connected (and this seems to be demanded by both mathematics and phenomenology [3, 4], there is a possibility of breaking one of the two E_8 factors to a subgroup of the E_6 group via Wilson loops [3, 4]. These produce some (very) massive vector fields and this is the most important fact. If some of them interact both with left- and right-handed fermions, the dynamical symmetry breaking occurs. The Schwinger-Dyson equations lead to integral equations with Fredholm kernel. Although the exact solution would be difficult to find, the "toy model" consideration [12] suggests the following approximate fermion mass formulae

$$m_i = M \exp [f(Y_i^1, \ldots, Y_i^n)], \tag{2}$$

where M is the mass scale of the symmetry breaking [12, 14] and f is a function of fermions' charges with respect to the massive gauge fields. This could be seen in the following way. The massive gauge bosons part of the Lagrange function has the form

$$L = \tfrac{1}{4} F^r_{\mu\nu}F^{r\mu\nu} + \tfrac{1}{2} M_r^2 A^r_\mu A^{r\mu} + \text{ self interaction term } + \bar{\psi}\hat{D}\psi, \tag{3}$$

where

$$F^r_{\mu\nu} = \partial_\mu A^r_\nu - \partial_\nu A^r_\mu, \qquad D_\mu = \partial_\mu - igA^r_\mu T^r.$$

The Feynman rules for this "effective" Lagrange function (in the ladder approximation) lead to (2) in a way analogous to that of Hoŝek [12].

Let us concentrate on the fenomenological consequences of this scenario. Due to the exponential factor fermion masses can vary within several orders of magnitude. What is important, is the fact that neutrinos stay masselss as far as mixing is neglected (when the unification group is of the form SU(2) × U(1) × simple factors) as was explained in [12]. As far as low energy physics is considered the fermion charges with respect to the massive gauges are restricted only by fermion masses. The mass scale M is at least of order 10^{14} GeV [12, 14]. Dynamical symmetry breaking demands the existence of additional fermions when gravitional interactions are included into consideration [15] and superstring theories provide them in a very natural way. The dynamically generated fermion masses break (spontaneously) the gauge symmetry. Consequently, the $W^\pm$ and Z particles (and the additional gauge bosons if they exist) obtain masses. Numerical results given by Hoŝek in the simplest model [12] seem to be very promissing.

If the Wilson loops mechanism is rejected as a symmetry breaking tool the dynamical mass generation is also possible. In this case very massive ($\sim 10^{14}$ GeV) Higgs particles are necessary to obtain massive vector fields as in [14] where the "effective" GSW model has been obtained from the superstring inspired $SU(2) \times U(1)^n$ model via dynamical symmetry breaking.

Let as conclude by saying that the dynamical symmetry breaking in superstring scenario offers a possibility of giving masses to all particles without a Higgs sector. Neutrinos stay massless in a natural way. The model offers also possibilities of generalization of the standard model. The low energy physics could be described by effective Lagrangians [14, 16, 17].

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