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► To cite this version:

M. Green. SUPERSTRING THEORIES AND THEIR FIELD THEORY LIMITS. Journal de Physique Colloques, 1982, 43 (C3), pp.C3-319-C3-320. 10.1051/jphyscol:1982362 . jpa-00221917

HAL Id: jpa-00221917

<https://hal.science/jpa-00221917>

Submitted on 4 Feb 2008

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SUPERSTRING THEORIES AND THEIR FIELD THEORY LIMITS

M.B. Green

Department of Physics, Queen Mary College, University of London, U.K.

In this talk I will describe the construction and properties of a relativistic string (or dual resonance) theory with extended supersymmetry in Minkowski space.* An intriguing feature of this theory is the connection in the limit of infinite string tension ($1/\alpha'$) with fashionable field theories: $N=4$ supersymmetric (SS) Yang-Mills comes from the open-string theory and $N=8$ (or $N=4$) supergravity from the closed-string theory.

The variables: The theory has not yet been formulated in a reparametrization-invariant manifestly Lorentz-covariant manner analogous to previous dual models. It is defined directly in the light-cone gauge and in $D=10$ space-time dimensions. The physical variables are the transverse coordinates $X^i(\sigma, \tau)$ ($i=1, 2, \dots, 8$) with $X^\pm \equiv (X^0 \pm X^9)/\sqrt{2} = x^\pm + 2\alpha' p^\pm \tau$ as well as Majorana spinors $S^A_a(\sigma, \tau)$ ($A=1, 2$; $a=1, 2, \dots, 32$) which satisfy a Weyl projection condition and $(\gamma_\pm \gamma_-)^{ac} S^a S^c = 0$ (where γ^μ are ten-dimensional Dirac matrices and (σ, τ) are the parameters of the string world-sheet). The action is

$$\int d\tau \int_0^\pi d\sigma \left(-\frac{1}{4\pi\alpha'} \partial_\alpha X^i \partial^\alpha X^i + \frac{i}{4\pi} \bar{S} \gamma^\mu \rho^\alpha \partial_\alpha S \right)$$

where $\alpha=1, 2$ and ρ^α are two dimensional Dirac matrices. Combined global supersymmetry transformations in (σ, τ) and Minkowski space leave the action invariant. The open-string boundary conditions lead to a $N=1$ SS theory whereas the closed-string theory has $N=2$ SS (which can be truncated to $N=1$). The states: The open-string ground states are a massless vector $|i\rangle$ and a spinor $|a\rangle$ where $|a\rangle = (i/8) \gamma^i S_0 |i\rangle$ and S_0 is the zero mode of S . For closed strings the periodic boundary conditions lead to a doubling of the normal modes of X and S . In this doubled Fock space the massless ground states are $|i, j\rangle$, $|a, i\rangle$, $|i, a\rangle$, $|a, b\rangle$ - a total of 256 states. Two $N=2$ theories are possible depending on whether the "gravitini" in $|a, i\rangle$ and $|i, a\rangle$ have the same or opposite chirality. The $N=1$ SS closed-string theory is obtained by symmetrizing between the Fock spaces. Excited states are generated by applying the higher mode operators to these ground states, generating an infinite spectrum of massive supermultiplets. The existence of a non-trivial representation of the super-Poincaré algebra guarantees the on-shell covariance of the formalism. Tree diagrams are constructed as matrix elements of products of string propagators Δ and vertices $V(\zeta, k)$ built from the mode operators (ζ is the polarization (or spinor) of an external massless boson (or fermion) with momentum k). For example, the open-string four-

* This work was carried out in collaboration with John Schwarz and partly with Lars Brink. Further details and references can be found in an expanded version of this talk:- M.B. Green, QMC preprint QMC-82-12 (to be published in *Surveys in High Energy Physics*). See also J.H. Schwarz, Caltech preprint CALT-69-911 (to be published in *Physics Reports*).

particle tree amplitudes can be reduced to the form

$$(\text{The } N=1 \text{ SS Yang-Mills Field-Theory Tree}) \times \Gamma(1-\alpha's)\Gamma(1-\alpha't)/\Gamma(1-\alpha's-\alpha't)$$

Loop amplitudes are constructed by sewing trees together. The one-loop four-particle closed string amplitude is finite (unlike previous dual theories) while the one divergence in the corresponding open-string amplitude can be absorbed into a renormalization of α' . Higher-loop diagrams have not yet been explicitly constructed but they are simple to enumerate. For closed strings, for example, there is only one diagram at each order in perturbation theory. Dimensional reduction is carried out naively by wrapping (10-D) dimensions onto a hypertorus of radius R . In the limit $R \rightarrow 0$ with $\alpha'/R \rightarrow 0$ D-dimensional field theory results are obtained. In this way we have obtained the one-loop S-matrices for $N=4$ SS Yang-Mills and $N=8$ supergravity with $D=4$. Hand-waving dimensional analysis suggests that the Yang-Mills theory converges at n loops when $D < 4 + 4/n$ whereas the supergravity theory converges when $D < 2 + 6/n$ and may thus diverge at three loops.

To summarize: (i) The SS dual string theory does not have the disastrous tachyon states of previous string theories and has less divergent loop amplitudes with the possibility of a finite closed-string theory. (ii) Loop calculations maintain the full supersymmetry at all stages (unlike most superfield approaches) and the classification of multiloop diagrams is much simplified compared to conventional superfield theories. (iii) If $N=8$ supergravity is divergent it may be that the SS closed-string theory provides a consistent well-defined alternative theory. (iv) The open-string theory contains closed-string bound states. This motivates the suggestion that $N=4$ supergravity may arise in the bound-state sector of $N=4$ SS Yang-Mills theory.