R^4 in type II superstrings

Dimitrios Tsimpis

Arnold Sommerfeld Center for Theoretical Physics
Department für Physik, Ludwig-Maximilians-Universität

Challenges Beyond the Standard Model
BW2007, Serbia

Outline

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Motivation

String/M-theory can be approximated by LEEA

String/M-theory predicts higher-derivative corrections

- String-theory ($10D$) implies l_{String} corrections
- M-theory ($11D$) receives l_{Planck} corrections
- κ-symmetric branes receive l_{String}, l_{Planck} corrections

Motivation

Important consequences

- Qualitative modifications to vacua
- Implications for no-go theorems
- Testing dualities beyond leading-order
- Black-hole precision measurements

Overview

Various approaches

- Corrections not fully under control
- Much recent progress

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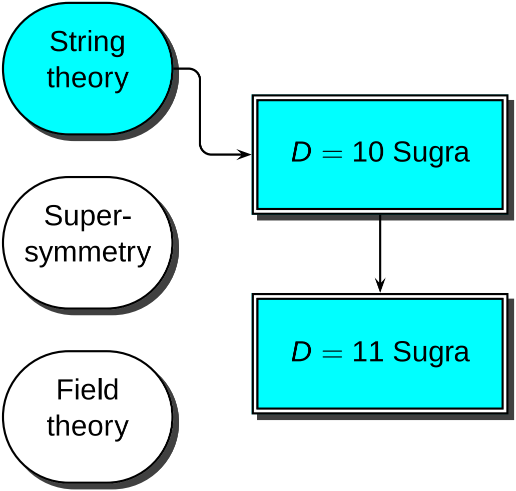
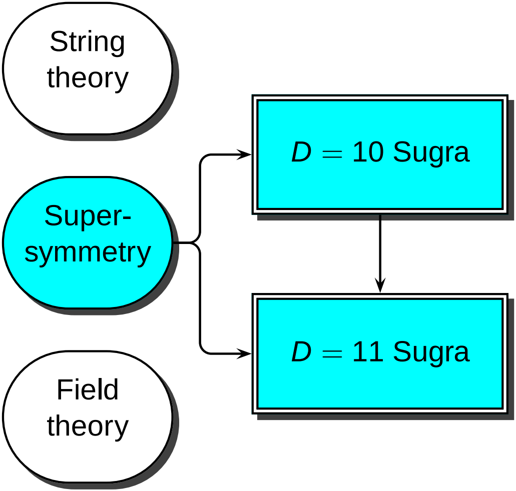


String perturbation

- Conformal invariance
- Scattering amplitudes

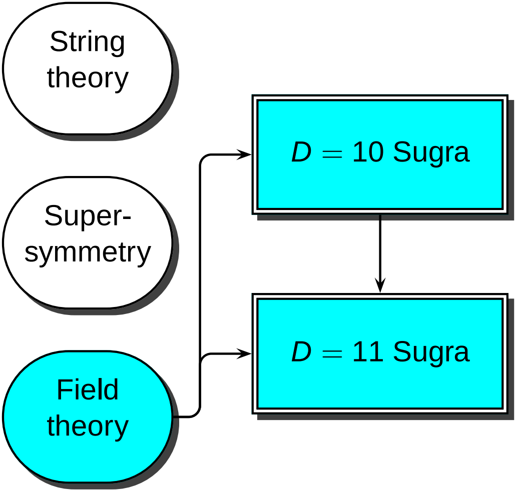
Overview



Supersymmetry

- Component approach
- Harmonic superspace
- Action principle
- Spinorial cohomology

Overview



Field theory

- Higher-loop counterterms
- New techniques

Outline

Scattering Amplitudes

RNS/GS

- Time-honored technique
- Expansions in α', g_s
- General N-point expressions
- Difficulty with RR fields

M.B. Green, J. Schwarz, PLB 109 (1982)

D. Gross, E. Witten, NPB 277 (1986)

N. Sakai, Y. Tanii, NPB 287 (1987)

D. Gross, J. Sloan, NPB 291 (1987)

K. Peeters, P. Vanhove, A. Westerberg, CQG 18 (2001); 19 (2002)

K. Peeters, A. Westerberg, CQG 21 (2004)

D. Oprisa, S. Stieberger, hep-th/0509042

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Scattering Amplitudes

Pure-spinor

- Bypasses difficulties with RNS/GS
- Easier to treat RR fields

- N. Berkovits, JHEP 0004; 0409; 0601
- N. Berkovits B.C. Vallilo, JHEP 0007
- N. Berkovits, CRP 6 (2005)
- C.R. Mafra, JHEP 0601
- G. Policastro, DT, CQG 23 (2006)
- N. Berkovits, C.R. Mafra, JHEP 0611
- C. Stahn, 0704.0015

Outline

Pure-spinor superstring

BRST operator

$Q = \oint dz \lambda^\alpha d_\alpha$

where

$\lambda \gamma^a \lambda = 0$

Massless vertex operators

$QU = 0, QV = \alpha' \partial U$

Tree Amplitudes

N-point amplitude

$$\mathcal{A} = \langle U_1(z_1)U_2(z_2)U_3(z_3)\int dz_4 V_4(z_4)\dots\int dz_N V_N(z_N)\rangle$$

Integrate out nonzero modes:

$$\mathcal{A} = \int dz_4\dots\int dz_N \langle\lambda^\alpha\lambda^\beta\lambda^\gamma f_{\alpha\beta\gamma}(z_r, k_r, \theta)\rangle$$

Zero-mode integration

$$\mathcal{A} = T^{\alpha\beta\gamma}\int dz_4\dots\int dz_N f_{\alpha\beta\gamma}(z_r, k_r, \theta)$$

where:

$$T^{\alpha\beta\gamma}(\gamma^i\theta)_\alpha(\gamma^j\theta)_\beta(\gamma^k\theta)_\gamma(\theta\gamma_{ijk}\theta) = 1$$

Outline

Vertices

Integrated vertex

$U = \lambda^{\alpha} A_{\alpha}(x, \theta)$

10D SYM in Superspace

- Field-strength: $F = DA$
- Bianchi identities: $DF = 0$
- $F_{\alpha\beta} = 0 \Longrightarrow$ ordinary SYM

B.E.W. Nilsson, Göteborg-ITP-81-6

The expansion of the vertices

Wess-Zumino gauge

$\theta^\alpha A_\alpha = 0$

so that:

$\theta^\alpha D_\alpha = \theta^\alpha \frac{\partial}{\partial \theta^\alpha}$

Integrate on-shell conditions

$$A_m = [cosh\sqrt{\mathcal{O}}]_m{}^q a_q + [\mathcal{O}^{-\frac{1}{2}} sinh\sqrt{\mathcal{O}}]_m{}^q (\theta\gamma_q\xi)$$

where:

$[\mathcal{O}]_m{}^q := \frac{1}{2}(\theta\gamma_m{}^{qp}\theta)\partial_p ; \qquad a_q := A_q| , \quad \xi^\alpha := W^\alpha|$

Solvability in linearized approximation is generic

DT, JHEP 0411

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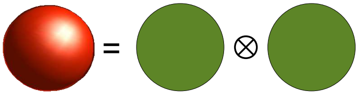
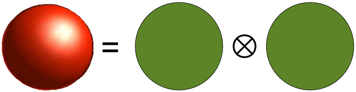
The Kawai-Lewellen-Tye Relations



$$\int d^2z = \int dz \otimes \int d\bar{z}$$

The Kawai-Lewellen-Tye Relations

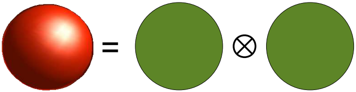


$$\int d^2z = \int dz \otimes \int d\bar{z}$$

Four-point amplitude factorizes

$$\mathcal{A}_4^{\rm cl} = -g^2 \sin(\pi\alpha' k_2 \cdot k_3)\mathcal{A}_4^{\rm op}\left(\frac{\alpha' s}{2}, \frac{\alpha' t}{2}\right) \otimes \tilde{\mathcal{A}}_4^{\rm op}\left(\frac{\alpha' t}{2}, \frac{\alpha' u}{2}\right)$$

The Kawai-Lewellen-Tye Relations



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Four-point Lagrangian factorizes

$$\mathcal{L}_4^{\mathrm{cl}} = \mathcal{L}_4^{\mathrm{op}} \otimes \tilde{\mathcal{L}}_4^{\mathrm{op}}$$

Pole Subtraction

Unitarity

Poles in N-pt amplitudes come from 1PRD's with N' vertices, where $N' < N$

Before taking the 1PRD's into account:

$$\mathcal{A} \sim f(s,t,u)\,\{\ldots\}$$

where:

$$f(s,t,u) = -\frac{8\pi}{\alpha'^3 stu} - 2\pi\zeta(3) + \mathcal{O}(\alpha'^2)$$

Taking 1PRD's into account:

$$f(s,t,u) \longrightarrow \widehat{\mathcal{G}}(s,t,u) := f(s,t,u) + \frac{8\pi}{\alpha'^3 stu}$$

Outline

Four-point Lagrangian: schematically

Four-point Lagrangian

$$\mathcal{L}_{4pt} \propto (\alpha')^3 \widehat{\mathcal{G}} \left\{ \widehat{R}^4 + (\partial F)^2 \widehat{R}^2 + (\partial F)^4 \right\}$$

where:

$$\widehat{R}_{mn}{}^{pq} := R_{mn}{}^{pq} + 2\kappa e^{-\frac{\kappa D}{\sqrt{2}}} \nabla_{[m} H_{n]}{}^{pq} - \sqrt{2}\kappa \delta_{[m}{}^{[p} \nabla_{n]} \nabla^{q]} D$$

G. Policastro, DT,
CQG 23 (2006)

Four-point Lagrangian: the gore and the glory

- NS-NS

$$\mathcal{L}_{NS} = \frac{(\alpha')^3}{4!} \widehat{\mathcal{G}}\, t_8 t_8 \widehat{R}^4$$

where:

$$\widehat{R}_{mn}{}^{pq} := R_{mn}{}^{pq} + 2\kappa e^{-\frac{\kappa D}{\sqrt{2}}} \nabla_{[m} H_{n]}{}^{pq} - \sqrt{2}\kappa \delta_{[m}{}^{[p} \nabla_{n]} \nabla^{q]} D$$

Four-point Lagrangian: the gore and the glory

- RR-NS

$$\mathcal{L}_{(\partial F)^2R^2} = -2^6\kappa(\alpha')^3\widehat{\mathcal{G}}\,\left(A_1 + \frac{1}{2}A_2 + \frac{1}{4}A_3\right)$$

where:

$$A_1 := \widehat{R}^i{}_n{}^j{}_{n'}\widehat{R}_{ipjp'} < \gamma^n\partial^p\not{F}\gamma^{(n'}\partial^{p')}\not{F}^{Tr} >$$

$$A_2 := \widehat{R}_{mn}{}^i{}_{n'}\widehat{R}_{pqip'}\Big(< \gamma^{mnp}\partial^q\not{F}\gamma^{(n'}\partial^{p')}\not{F}^{Tr} > + F \leftrightarrow F^{Tr}\Big)$$

$$A_3 := \widehat{R}_{mnm'n'}\widehat{R}_{pqp'q'} < \gamma^{[mnp}\partial^{q]}\not{F}\gamma^{m'n'p'}\partial^{q'}\not{F}^{Tr} >$$

Four-point Lagrangian: the gore and the glory

- RR-RR

$$\mathcal{L}_{(\partial F)^4} = \frac{32}{9}(\alpha')^3\kappa^2\widehat{\mathcal{G}}\left(B_1 - 5B_2 + B_3 + 4B_4 - B_5\right)$$

where:

$$B_1 := < \partial_m\partial_p \not{F}\gamma_q\partial^m\partial^p \not{F}^{Tr}\gamma_n \not{F}\gamma^q \not{F}^{Tr}\gamma^n >$$
$$B_2 := < \partial_m\partial_p \not{F}\gamma_q \not{F}^{Tr}\gamma_n\partial^m\partial^p \not{F}\gamma^q \not{F}^{Tr}\gamma^n >$$
$$B_3 := < \partial_m\partial_p \not{F}\gamma_q \not{F}^{Tr}\gamma_n \not{F}\gamma^q\partial^m\partial^p \not{F}^{Tr}\gamma^n >$$
$$B_4 := < \partial_m\partial_p \not{F}\gamma_q \not{F}^{Tr}\gamma_n >< \partial^m\partial^p \not{F}\gamma^q \not{F}^{Tr}\gamma^n >$$
$$B_5 := < \not{F}\gamma_q \not{F}^{Tr}\gamma_n >< \partial^m\partial^p \not{F}\gamma^q\partial_m\partial_p \not{F}^{Tr}\gamma^n >$$

Future Directions

- Physical applications
- Higher points
- Factorization
- IIB

Thank You