Unification of the fundamental interactions: new scenarios in superstring theory

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Outline

1.Why strings?

2. From 1st to 2nd string revolution – D branes

3. Brane-world scenario

4. Gauge/gravity correspondence.

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5. Towards more realistic extension of the
   gauge/gravity correspondence:
   orbifolds and fractional branes

6. Gauge/gravity correspondence
   versus open/closed string duality

7. Perspectives

More technical

5,6 based on

NA + TO + CPH collaboration

M.Frau, A. Liccardo and R. Musto ``The Geometry of Fractional Branes''

Nucl.Phys.B602 (2001) 39-60 ; hep-th/0012035

M. Billo', L. Gallot and A. Liccardo ``Classical geometry and gauge duals for fractional branes on ALE orbifolds''

Nucl.Phys. B614 (2001) 254-278 ; hep-th/0105258,

P. Di Vecchia, A. Liccardo, R. Marotta and F. Pezzella ``Gauge/Gravity Correspondence from Open/Closed String Duality''

JHEP 0306 (2003) 007 ; hep-th/0305061,

P. Di Vecchia and A. Liccardo ``Gauge Theories from D Branes'' hep-th/0307104,

Related papers:

R.Marotta et al.	JHEP 0209 (2002) 010 ; hep-th/0208153,
M.Bertolini et al.	Nucl.Phys.B621 (2002) 157 ; hep-th/0107057
	Nucl.Phys.B360 (2002) 222 ; hep-th/0112187
I.R. Klebanov et al.	Phys. Rev. D65 (2002) 105007; hep-th/0202056
M. Bianchi et al.	JHEP 03 (2000) 030 ; hep-th/0002149

Why strings?

Is the only known candidate for a unified description of all fundamental interactions and particles.

STRONG, WEAK, ELECTROMAGNETIC

↓

Quantum Field Theories (gauge theories)

SM: $SU(3)_c \times SU(2) \times U(1)$ $E \leq 250$ Gev

GRAVITY

↓

Macroscopic world — Einstein General Relativity (Classical field theory)

Microscopic world — Need of a quantum theory of gravitation!

But QG is not renormalizable!

$[G_N] = E^{2-d} \Longrightarrow d=4$ dimensionless coupl. $g \sim G_N E^2$

QG → effective theory for $E<250$ Gev. But gravitational coupling becomes relevant only at the Planck scale

$M_{pl} = (\hbar c/G_N)^{1/2} \sim 10^{19}$ GeV (g~E/Mpl)

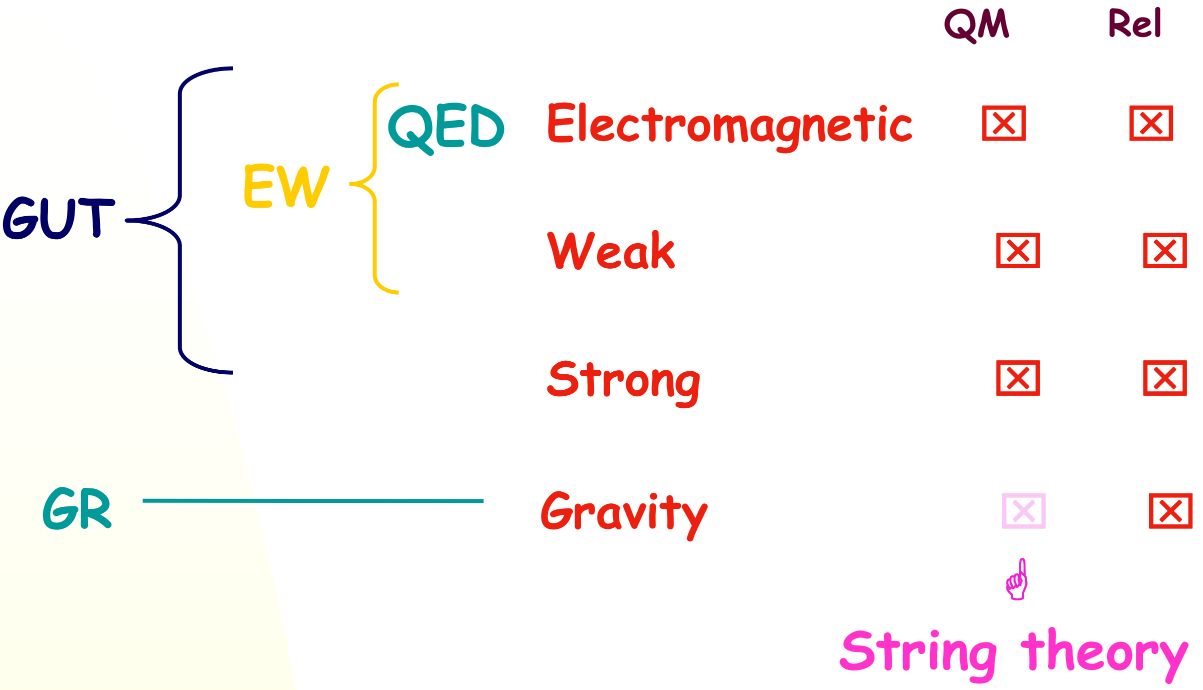
Electron-proton interaction

Electromagnetic $\alpha_e = e^2/\hbar c \sim 7.3 \times 10^{-3}$

Gravitational $\alpha_g \sim G_N m_p m_e/\hbar c \sim 3 \times 10^{-41}$

Hierarchy problem!

QFT cannot be the framework for the unification!



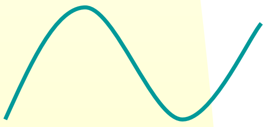
				QM	Rel
GUT	EW	QED	Electromagnetic	☒	☒
			Weak	☒	☒
			Strong	☒	☒
GR			Gravity	☒	☒

☝

String theory

BASIC IDEA

Fundamental object ⟶ STRING



L_s<<current accelerator length ~10^{-16}mm

L_s → only free parameter of the theory

tipically $L_s \sim L_p \sim 10^{-32}$mm

Particles ⟶ STRING VIBRATIONAL MODES

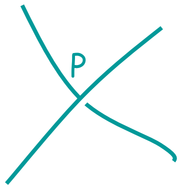
(bosons and fermions)

Why should strings solve the renormalization problems ?

Point particle

QFT divergences are UV divergences (l → 0 ; E→∞) due to the point-like structure of the interactions

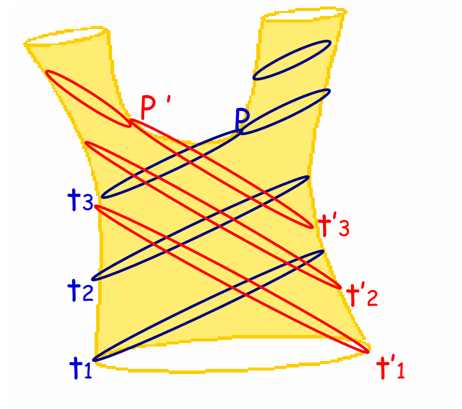
World line



interaction vertex

String : Ls → natural cut-off on short distances

World sheet

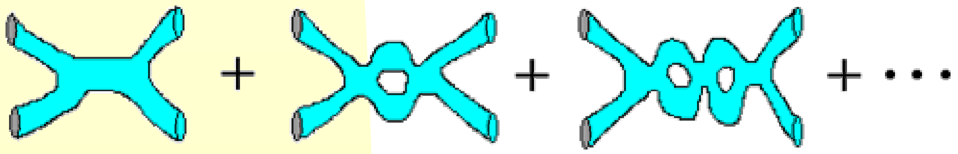


interaction vertex

No Lorentz invariant notion of interaction point!

No difference between free and interacting strings!

String scattering amplitudes Perturbative expansion sum over all the world-sheet string topologies with given number of external legs (E) and increasing number of handles (L).

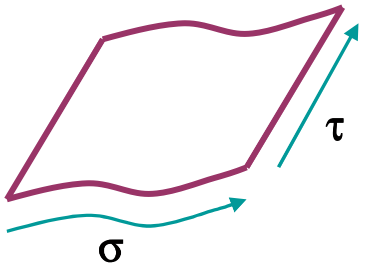


ST turns out to be UV divergence free!

Bosonic free string

$X^{\mu}\ (\tau,\sigma)$

$\sigma\in[0,\pi]$ $\tau\in[-\infty,+\infty]$



String action

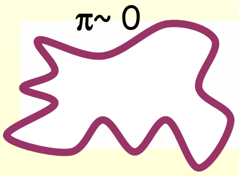
$$S_{\rm str} = T\int d\sigma d\tau \frac{1}{2}\left[\left(\frac{\partial X^{\mu}}{\partial\tau}\right)^{2} - \left(\frac{\partial X^{\mu}}{\partial\sigma}\right)^{2}\right]$$

$T = \frac{1}{2\pi\alpha'} \rightarrow$ **string tension** $\alpha' = L_s^2$

Equation of motion + Boundary conditions

$$(\partial_{\sigma}^{2} - \partial_{\tau}^{2})X^{\mu} = 0 \qquad , \qquad \partial_{\sigma}X_{\mu}\delta X^{\mu}|_{\sigma=\pi} - \partial_{\sigma}X_{\mu}\delta X^{\mu}|_{\sigma=0} = 0$$

Closed string



$$X^{\mu}(\tau,\sigma) = X^{\mu}(\tau,\sigma+\pi)$$

$$X^{\mu}(\tau,\sigma) = q^{\mu} + 2\alpha' p^{\mu}\tau + i\sqrt{\frac{\alpha'}{2}}\sum_{n\neq 0}\left(\frac{\alpha_n^{\mu}}{n}e^{-2in(\tau-\sigma)} + \frac{\tilde{\alpha}_n^{\mu}}{n}e^{-2in(\tau+\sigma)}\right) \quad .$$

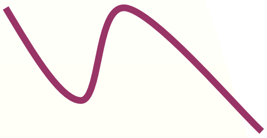
Quantization ⇒ promoted to creation and annhilation operators on Fock space

$[X^{\mu}\ (\tau,\sigma),\ \dot{X}^{\nu}(\tau,\sigma'),] = i\ \delta(\sigma-\sigma')\eta^{\mu\nu}$

Open string

$$\partial_\sigma X_\mu \delta X^\mu|_{0,\pi} = 0 \Rightarrow \begin{cases} \partial_\sigma X_\mu|_{0,\pi} = 0 \rightarrow \text{Neumann boundary conditions} \\ \delta X^\mu|_{0,\pi} = 0 \rightarrow \text{Dirichlet boundary conditions} \end{cases} .$$

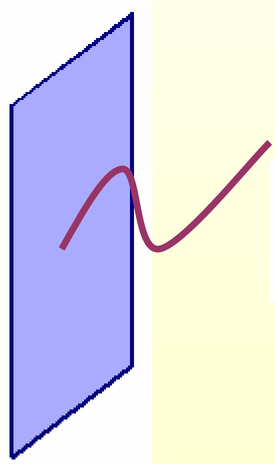
N boundary conditions → preserve Poincaré invariance



$$X^\mu(\tau,\sigma) = q^\mu + 2\alpha' p^\mu \tau + i\sqrt{2\alpha'} \sum_{n\neq 0} \left(\frac{\alpha_n^\mu}{n} e^{-in\tau} \cos n\sigma \right)$$

solution with NN boundary conditions

D boundary conditions→ strings attached to hyperplanes break translational invariance



$$X^\mu(\tau,\sigma) = \frac{c^\mu(\pi-\sigma) + d^\mu\sigma}{\pi} - \sqrt{2\alpha'} \sum_{n\neq 0} \left(\frac{\alpha_n^\mu}{n} e^{-in\tau} \sin n\sigma \right)$$

solution with DD boundary conditions

World-sheet supersimmetric extension → $\Psi_\mu(\tau,\sigma)$

$$S \longrightarrow S_{bos} + \frac{iT}{2} \int d\tau d\sigma \bar{\psi}^\mu \gamma^\alpha \partial_\alpha \psi_\mu$$

Consistency requirements:

- **ST is consistent only in (9+1) space-time dimensions!**
- **ST requires space-time SUSY!**

What is Susy?

Is a simmetry connecting bosons and fermions → **matter and interactions on the same ground!**

Main assumption: **for each elementary particle there exists a susy partner with same mass and with spin that differs of ½:**

Q|Bos>=|Ferm> ; Q → susy generators (fermionic operator with spin 1/2).

[H,Q]=0→ mass degeneration between susy partners.

$\mathcal{N}$= # **of Q.** $\mathcal{N}$>1 extended susy models $\mathcal{N}$=1 **chiral fermions**

5 different and consistent perturbative 10dims superstring models:

type IIA,
type IIB
Heterotic E8xE8,
Heterotic SO(32).

Closed strings

Type I → **Open and Closed strings**

Particle content

Open string spectrum $\supset$ **Gauge theories (SM)**

$$M^2 \sim \frac{1}{\alpha'}\left[N - a + \frac{y^2}{(2\pi)^2\alpha'}\right]$$

y→ string extension

Zero-point energy $a, \tilde{a}$ $\begin{cases} 1 & \text{bosonic string} \\ 0 \quad (1/2) & \text{R (NS) sectors} \end{cases}$

finite massless + infinite massive (+tachyon)

(Notice : for y ≠ 0 → no massless open string states!)

For L>>Ls (i.e. α' → 0) one sees only massless excitations!

Open string massless spectrum

Ns sector → Aμ (gauge boson → spin 1)

$$\epsilon_\mu(k)\psi^\mu_{-1/2}|0,k> \qquad k\cdot\epsilon = 0$$

R sector → Ψ (gaugino →spin 1/2)

$$u_A(k)|A,k> \quad ; \quad u_A(k\cdot\Gamma)^A{}_B = 0$$

Low energy limit of open string theory

is a gauge theory

SYM $\mathcal{N}$=1 U(1) in d=10

Closed string spectrum $\supset$ Gravity

$$M^2 = \frac{2}{\alpha'}\left[N + \tilde{N} - a - \tilde{a}\right]$$

finite massless + infinite massive (+tachyon)

In the low energy limit only massless excitations survive.

Closed string massless spectrum

NS - NS sector $\psi^{\mu}_{-1/2}\tilde{\psi}^{\nu}_{-1/2}|0, k>$

Gμν	$\epsilon^{(h)}_{\mu\nu} = \epsilon^{(h)}_{\nu\mu} \qquad \epsilon^{(h)}_{\mu\nu}\eta^{\mu\nu} = 0$	**GRAVITON !**
Φ	$\epsilon^{(\phi)}_{\mu\nu} = \frac{1}{\sqrt{8}}\left[\eta_{\mu\nu} - k_\mu \ell_\nu - k_\nu \ell_\mu\right]$	**dilaton**
Bμν	$\epsilon^{(A)}_{\mu\nu} = -\epsilon^{(A)}_{\nu\mu}$	**Kalb Ramond**

R-R sector **(n+1)-form potential**
with n={1,3} in type IIA
n={0,2,4} in IIB

$$u_A(k)\tilde{u}_B(k)|A, k/2\rangle|\widetilde{B, k/2}\rangle$$

NS-R R-NS **gravitinos + dilatino** $u_A(k)|A, k/2> \quad \epsilon_\mu(k)\psi^{\mu}_{-1/2}|\widetilde{0, k/2}>$

The low energy limit of closed string theory is SUGRA in d=10

How to make contact with particle physics?

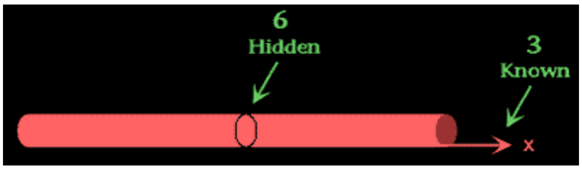
Top down approach : Start from ST and try to understand how to undress the theory from its exotic features (extra dims and susy) in order to reproduce the SM in the low-energy limit.

- 6 extra space dims → compactification
  (toroidal, Calabi-Yau, Orbifolds, etc.)

But ∞ compactifications

⇓

∞ vacua !



(compactification parameters → moduli)

- Susy → susy breaking mechanisms
  orbifold compactification,

…..and then try to answer the question:

"Why this vacuum?"

why 3+1 dims, why SU(3)c x SU(2) x U(1), why 3 families of quark-lepton generations, why charges and masses take the values found with experiments,

The hope is that all the fundamental parameters that characterize the physical universe should be derived from the theory instead of being given by experiments!

3. From 1st to 2nd string theory revolution

- **t < 1995**

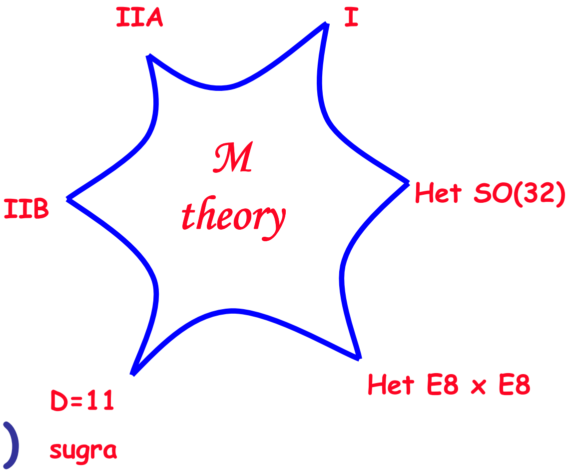
5 different consistent 10 dims
perturbative string models
+
Infinitly many vacua

↓

Too many candidates to be the unique theory of everything!

- **t=1995**

There is a web of dualities connecting the 5 different string models which corresponds to different corners of the moduli space of a more fundamental theory (S-duality, T-duality,etc.)



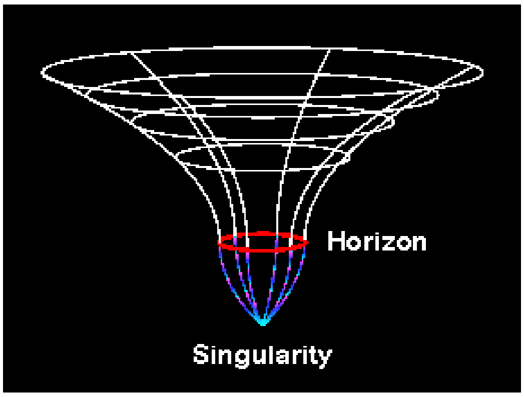
String theory does not contain just strings but also other extended (p+1)dims objects

Dp-branes

t=1995 : D-branes

two-fold description:

1. Closed string description:



Black-brane solutions of low energy closed string effective action (SUGRA)

$$\mathcal{S} = \frac{1}{2\kappa^2}\int d^{10}x\,\sqrt{-G}\,\left\{\mathcal{R} - \frac{1}{2}G_{\mu\nu}\,\partial_\mu\Phi\partial_\nu\Phi - \frac{1}{12}\mathrm{e}^{-\Phi}H_{\mu\nu\rho}H^{\mu\nu\rho} - \sum_p \frac{1}{2(p+2)!}\mathrm{e}^{\frac{3-p}{2}\Phi}\,F^2_{(p+2)} + \text{ferm.} + \mathcal{O}(\alpha')\right\}$$

With $\kappa = 8\pi^{7/2}\alpha'^2 g_s$ 10 dims gravitational coupling

Black p-brane solution

$$\begin{cases} ds^2 = H(r)^{-\frac{p-7}{8}}\,\eta_{\alpha\beta}dx^\alpha dx^\beta + H(r)^{\frac{p+1}{8}}\,\delta_{ij}dx^i dx^j \\ e^{-\Phi} = H(r)^{\frac{p-3}{4}} \\ F_{(p+2)} = d\left(H(r)^{-1}dx^0\wedge\ldots\wedge dx^p\right) \end{cases}$$

where $r^2 = (x_{p+1})^2+\ldots+(x_9)^2$, $F_{(p+2)} = dC_{(p+1)}$

and $H(r) = 1 + Q_p/r^{7-p}$ $(Q_p \sim \alpha'^{\frac{7-p}{2}}Ng_s)$

Supergravity approximation holds for small curvature

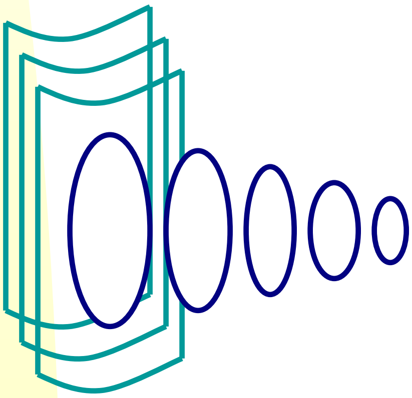
$\alpha'\mathcal{R} << 1$ $\mathcal{R} \sim 1/\alpha'(Ng_s)^{2/7-p} \Longrightarrow$ **Ngs >>1**

Main features:

- $M = T_p/\kappa \sim 1/g_s$ → Solitonic solution: heavy at weak coupling! Non perturbative string states! String theory is a pure theory of strings only in the perturbative regime!

$$T_p = \sqrt{\pi}(2\pi\sqrt{\alpha'})^{3-p}$$

- Charged under the (p+1)-form potential C(p+1) ($Q \sim \sqrt{2}\, T_p$).
- Mass/charge relation fixed by susy algebra! BPS states that breaks ½ of susy
- Balance between gravitational and 'electric' interaction → No force condition → Dp-branes can be piled up!
- Source for closed string that are emitted in the 10 dims space-time (BULK)

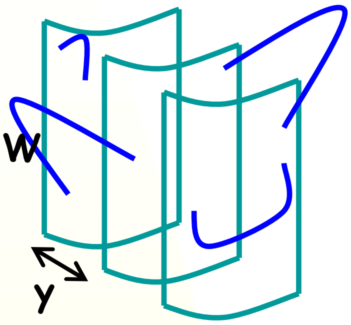


10 dims

BULK

2.<u>Open string description</u>: Dp-branes are (p+1)-dims hypersurfaces on which open string attach their end-points satisfying Dirichlet b.c.

One Dp-brane support a U(1) SYM in p+1 dims



<u>Chan Paton factors</u>: Labels on open strings end-points that distinguish which branes they are attached to.

$$M_W \sim y/L_s^2$$

$$y \longrightarrow 0 \Longrightarrow U(1)^N \sim U(N)$$

N coincident Dp-branes support (p+1)dims SYM with gauge group U(N)

p=3 → $\mathcal{N}$=4 SYM in d=4

$\mathcal{N}$=1 in d=10⇒$\mathcal{N}$=4 in d=4

2^d/2 x $\begin{cases} 1/4 \text{ (Majorana-Weyl→d=10)} \\ 1/2 \text{ (Weyl→ d=4)} \end{cases}$

D branes dynamics described in terms of open string amplitudes.

$$\Downarrow$$

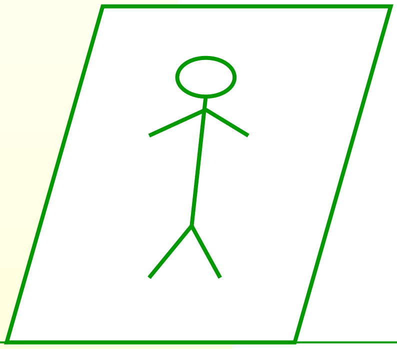
The description holds in the perturbative regime of string theory $g_s N << 1$

BRANE WORLD SCENARIO

To unify gauge and gravity we want both open and closed strings. But we have learned that closed string theories contains open strings as well, as Dp-branes excitations

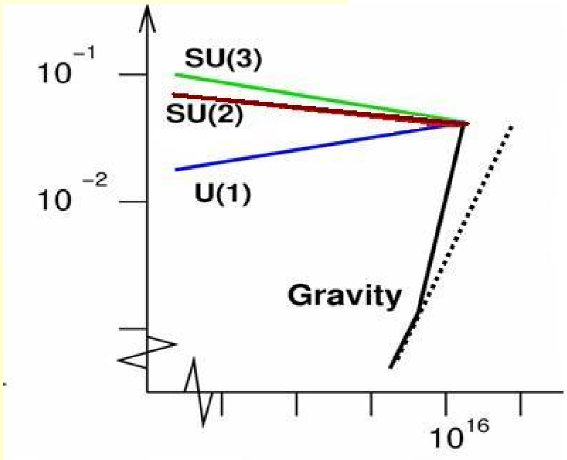
Type IIB contains D3-branes in which 4dims gauge theories are naturally located.

Type IIB unification scenario
SM fields confined on the world volume of a D3 brane, while gravity lives in d=10.



Do we live on a D3 brane?

Gauge theories and gravity do not 'feel' the same number of space-time dims.



$\alpha_{GUT} \sim 1/25$; $M_{GUT} \sim 10$ Gev

Opening of extra dims

⇓

$$g = G_N E^{D-2}$$

Deviation from 4dims
Newton law!

Bottom-up approach to embed SM in string theory:

- Find a brane configuration which lives in flat 10 dims space-time and support a gauge theory close to SM.
- Compactify 6 dims orthogonal to the branes in order to reproduce 4 dims gravity

Main phenomelogical consequence of brane-world scenario:

the string scale could be lower than the Planck scale

String effective action in d=4

$$S = -\frac{1}{2\pi}\int d^4x\sqrt{-g}\left[\frac{1}{L_s{}^8}r^6 e^{-2\phi}R + \frac{1}{4}e^{-\phi}F_{\mu\nu}^2\right]$$

Gravity and gauge couplings

$$M_P{}^2 = \frac{1}{L_P^2} \sim \frac{1}{L_s{}^8}e^{-2\phi}r^6 \qquad \frac{1}{g_{YM}^2} \sim e^{-\phi}$$

Only L_P depends on $r \Rightarrow$ relation between L_P and L_s fixed by r

$$r \sim 1 \text{ fm} \Longrightarrow L_s^{-1} \sim \text{Tev}$$

6. Gauge/gravity correspondence

Dp brane

Polchinski 1995

closed string description:
10 dims SUGRA solution
(classic)

open string description:
4dims gauge theory
(quantistic)

This twofold nature allows to derive **quantum properties** of the world volume gauge theory of N D branes from their **classical geometry** and viceversa.

1st example: Maldacena conjecture

type IIB on $AdS_5 \times S_5$ ⇔ **$\mathcal{N}=4$ U(N) SYM on $\partial(AdS_5)$**

Near horizon limit of the geometry of N D3-branes ⇔ **World-volume theory on N D3-branes**

To extend the gauge/gravity to more phenomenological scenario

1. **Reduce the ammount of susy → Orbifolds background**

2. **Break conformal invariance → Fractional branes**

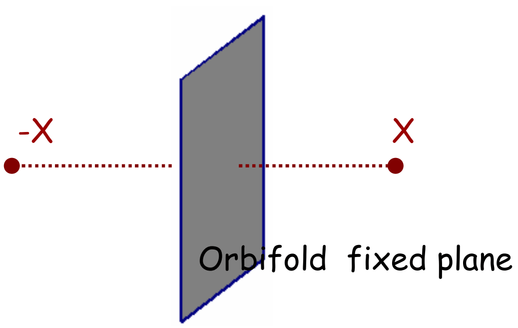
Orbifold backgrounds

Quotient spaces $\mathcal{M}/\mathcal{G}$ $\mathcal{G}$ → discret symmetry of $\mathcal{M}$

$\mathcal{M}$ → space – time

ex. $\mathcal{G}$ → reflection

g: X→-X X=0 → fixed point



Even if the orbifold is singular at the fixed points string theory can be consistently formulated on it!

String spectrum → all states (perturbative and non perturbative) must be $\mathcal{G}$-invariant

Some states are projected out → reduction of susy !

But other new states appear in the closed string spectrum as twisted states!

Untwisted sector $X(\tau,\sigma) = X(\tau,\sigma+\pi)$

Twisted sector $X(\tau,\sigma) = - X(\tau,\sigma+\pi)$

new states which can propagate only on the fixed plane

(p=0 in the orbifolded directions→ twisted states cannot propagate in orb. dirs).

Examples:

- type IIB on $\mathcal{R}_{(1,5)} \times \mathcal{R}_4 / \mathcal{Z}_2$

(more gen. $\mathcal{R}_{(1,5)} \times \mathcal{C}_2 / \Gamma$ with Γ discrete subgroup of SU(2))

$\mathcal{Z}_2 = \{1, g\}$

g: $X_a \to -X_a \quad a \in \{6,7,8,9\}$

This orbifold breaks ½ of type IIB supercharges (32) →
16 residual supercharges

- type IIB on $\mathcal{R}_{(1,3)} \times \mathcal{C}_3 / \mathcal{Z}_2 \times \mathcal{Z}_2$

$\mathcal{Z}_2 \times \mathcal{Z}_2 = \{1, g_1, g_2, g_3\}$

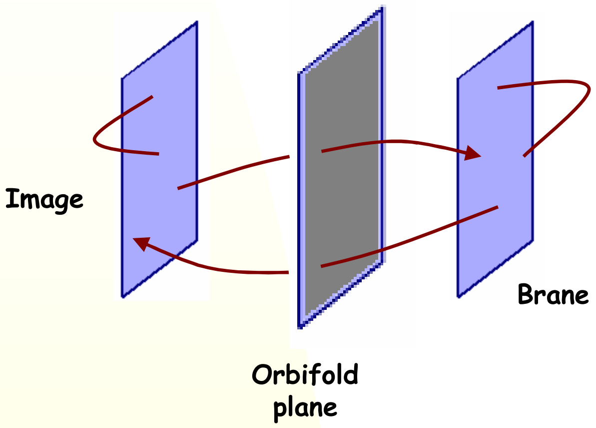
$$\begin{cases} g_1 : (z_1, z_2, z_3) \to (z_1, -z_2, -z_3) \\ g_2 : (z_1, z_2, z_3) \to (-z_1, z_2, -z_3) \\ g_3 : (z_1, z_2, z_3) \to (-z_1, -z_2, z_3) \end{cases}$$

This orbifold breaks 1/4 of type IIB supercharges (32) →
8 residual supercharges

ST on orbifolds contains two kind of branes:

bulk branes and fractional branes

D-brane system must be invariant under the orbifold projection→ each D-brane must be accompained by its image!



4 different kind of open strings. Chan Paton (i,j) factors specify to which brane they are attached to

$$\lambda = \begin{pmatrix} bb \,,\, bi \\ ib \,,\, ii \end{pmatrix}$$

Generic open string state λ|oscillators>

The reflection exchange b with i→ it acts also on λ which transform under the regular representation of $\mathcal{G}$ (dims 2):

$$\mathcal{Z}_2 : \quad \sigma_1 \begin{pmatrix} bb \,,\, bi \\ ib \,,\, i\,i \end{pmatrix} \sigma_1 = \begin{pmatrix} ii \,,\, ib \\ bi \,,\, bb \end{pmatrix}$$

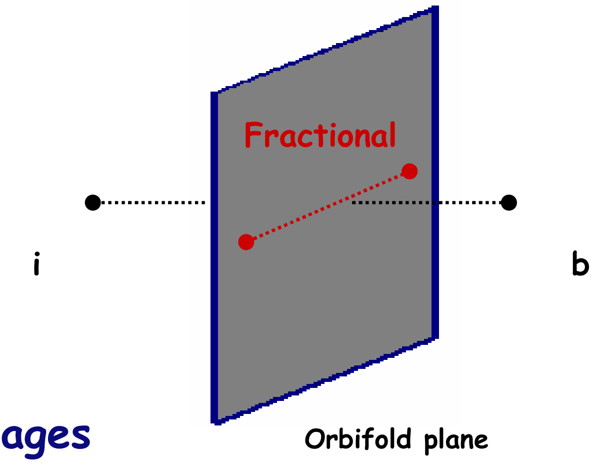
Regular rep of finite abelian group are not irreducible (dims 1)!

At the orbifold fixed point decompose rep in irrep → there are more elementary objects associated to C.P. factors which transform under irrep of $\mathcal{G}$ → FRACTIONAL BRANES

FRACTIONAL BRANES

C.P. indices in the irrep of $\mathcal{G}$. Most elementary objects!

When a brane and its image meet at the fixed point they can separate in their fractional brane consitutuents.



- Fractional branes do not have images
  →stuck at the fixed point
- Charged under twisted fields.
- Their charge under the R-R untwisted fields is a fraction of the bulk brane charge.
- The world-volume theory on fractional branes is

$\mathcal{N}$=2 SYM for $\mathcal{R}_{(1,5)} \times \mathcal{R}_4 / \mathcal{Z}_2$

$\mathcal{N}$=1 SYM for $\mathcal{R}_{(1,3)} \times \mathcal{C}_3 / \mathcal{Z}_2 \times \mathcal{Z}_2$

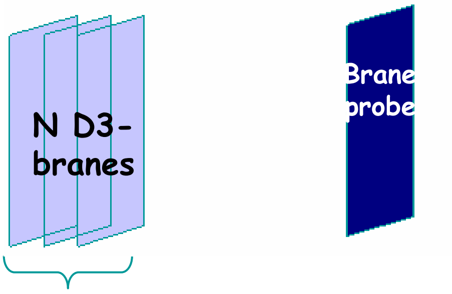
less susy, not conformal
⇓
running coupling constant!

Main result:

the classical supergravity solutions may be used to evaluate the β-function of the gauge theory living on the world volume of fractional branes!

Making Gauge/gravity correspondence to work:

(e.g. Type IIB on $\mathcal{R}_{(1,5)} \times \mathcal{R}_4 / \mathcal{Z}_2$)



1st step:

Find the SUGRA solution corresponding to N D3-fractional branes

Metric

$$ds^2 = H^{-1/2} dx^\mu dx_\mu + H^{1/2}\left[(d\rho)^2 + \rho^2 (d\theta)^2 + dx^a dx_a\right]$$

R-R field-strength

$$F_5 = d\left(H^{-1} dx^0 \wedge ... \wedge dx^3\right) + {}^*d\left(H^{-1} dx^0 \wedge ... \wedge dx^3\right)$$

Twisted scalar fields

$$b = \frac{1}{2} + \frac{N g_s}{\pi} \ln(\rho/\epsilon) \qquad A_0 = \frac{N}{\pi}\theta$$

where $x^4 + i x^5 = \rho e^{i\theta}$ →directions orthogonal to the brane and the orbifold

{6,7,8,9}→ orbifold
{0,1,2,3}→ D3-brane

2nd step:

Take the world-volume action of the brane probe →interactions between the closed string massless states and all the open string fluctuaction on the D3 branes

$$S_{wv} = -\frac{T_3}{\kappa} \int d^4x e^{-\varphi} \sqrt{-det(G + 2\pi\alpha' F)}\, b + \frac{T_3}{\kappa} \int \sum_n \left(C_{(p)} b + A_p\right) \wedge e^{2\pi\alpha' F}$$

3rd step: Take the field theory limit to select only open string massless fluctuaction

$$\alpha' \to 0$$

4th step: expand Swv up to 2nd order in F

Swv→ $\mathcal{N}$=2 SYM

$$S = -\frac{1}{g_{YM}^2}\int d^4x Tr\left\{\frac{1}{2}F^2 + D\bar{\phi}D\phi\right\} + \frac{\theta_{YM}}{16\pi^2}\int d^4x Tr\left\{F\tilde{F}\right\}$$

with the **holographic identifications** between the gauge theory parameter and the sugra fields

$$\boxed{\frac{1}{g_{YM}^2} = \frac{1}{4\pi}e^{-\varphi}b} \quad \text{and} \quad \boxed{\frac{\theta_{YM}}{2\pi} = C_0 b + A_0}$$

5th step: plug the classical solution into the holographic relations obtaining

$$\frac{1}{g_{YM}^2(\rho)} = \frac{1}{8\pi g_s} + \frac{N}{4\pi^2}\ln(\rho/\epsilon)$$

Correct logarithmic running for $\mathcal{N}$=2 SYM!

Introducing the gauge/gravity relations

$$\mu \equiv \frac{\rho}{(2\pi\alpha')} \qquad \Lambda_0 \equiv \frac{\epsilon}{(2\pi\alpha')} \qquad \Lambda = \Lambda_0 e^{-\frac{\pi}{2Ng_s}}$$

↑ Energy scale

↑ Dynamically generated scale

ρ (distance $\perp$ to branes and orbifold) ⟶ energy scale of gauge theory

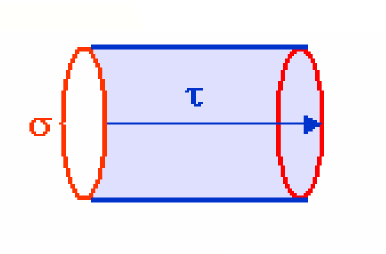
$$\boxed{\frac{1}{g_{YM}^2(\mu)} = \frac{N}{4\pi^2}\ln(\mu/\Lambda) \qquad \beta \equiv \mu\frac{\partial}{\partial\mu}g(\mu) = -\frac{g_{YM}^3 N}{8\pi^2}}$$

WHY DOES GAUGE/GRAVITY CORRESPONDENCE WORK?

IT IS A DIRECT CONSEQUENCE OF OPEN/CLOSED STRING DUALITY

P. Di Vecchia, A. L., R. Marotta and F. Pezzella ``Gauge/Gravity Correspondence from Open/Closed String Duality''   JHEP 0306 (2003) 007 ; hep-th/0305061,

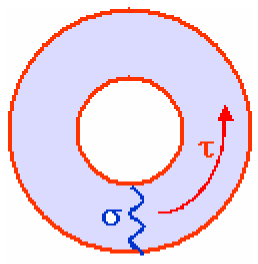
CLOSED STRING



$(\sigma,\tau) \rightarrow (\tau,\sigma)$

World Sheet duality

OPEN STRING



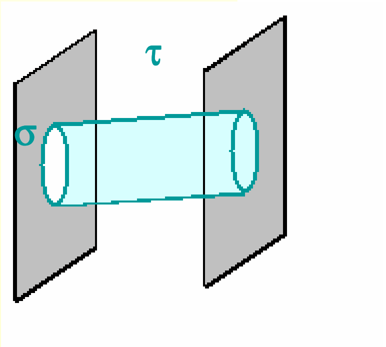
TREE LEVEL PROPOAGATOR

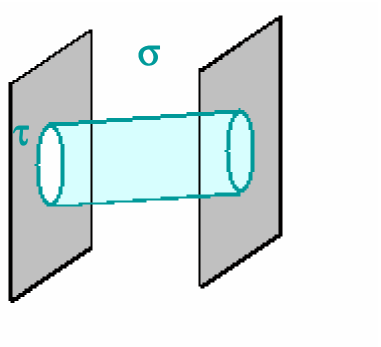
(classical)

1 LOOP ANNULUS DIAGRAM

(quantistic)

The interaction between 2 Dp-branes can be described in 2 ways





$\langle Bp \mid D \mid Bp \rangle$

Tree-level exchange diagram of closed string between the branes

Casimir Energy

1 loop vacuum energy of the open string streatched between the branes

Interaction between a stack of N D3 fractional branes with an external field and a further fractional D3 brane.

OPEN CHANNEL

Massless divergent contributions

$$Z_h^o(F) \to \left[-\frac{1}{4}\int d^4x F^a_{\alpha\beta}F^{a\,\alpha\beta}\right]\left\{-\frac{N}{8\pi^2}\int_{\frac{1}{\alpha'\Lambda^2}}^{\infty}\frac{d\tau}{\tau}e^{-\frac{y^2\tau}{2\pi\alpha'}}+\frac{N}{8\pi^2}\int_0^{\infty}\frac{d\tau}{\tau}e^{-\frac{y^2\tau}{2\pi\alpha'}}G(k)\right\}$$
$$+iN\left[\frac{1}{32\pi^2}\int d^4x F^a_{\alpha\beta}\tilde{F}^{a\,\alpha\beta}\right]\int_{\frac{1}{\alpha'\Lambda^2}}^{\infty}\frac{d\tau}{\tau}e^{-\frac{y^2\tau}{2\pi\alpha'}}$$

$$G(k) = -\left[\frac{f_3(k)f_4(k)}{f_1(k)f_2(k)}\right]^4 2k\frac{d}{dk}\log\left[\frac{f_3(k)}{f_4(k)}\right]+1$$

Massive state contributions

CLOSED CHANNEL

Massless divergent contributions

$$Z_h^c(F) \to \left[-\frac{1}{4}\int d^4x F^a_{\alpha\beta}F^{a\,\alpha\beta}\right]\left\{-\frac{N}{8\pi^2}\int_0^{\alpha'\Lambda^2}\frac{dt}{t}e^{-\frac{y^2}{2\pi\alpha' t}}+\frac{N}{8\pi^2}\int_0^{\infty}\frac{dt}{t}e^{-\frac{y^2}{2\pi\alpha' t}}F(q)\right\}$$
$$+iN\left[\frac{1}{32\pi^2}\int d^4x F^a_{\alpha\beta}\tilde{F}^{a\,\alpha\beta}\right]\int_0^{\alpha'\Lambda^2}\frac{dt}{t}e^{-\frac{y^2}{2\pi\alpha' t}}\quad ,$$

$$F(q) = \left[\frac{f_3(q)f_2(q)}{f_1(q)f_4(q)}\right]^4 2q\frac{d}{dq}\log\left[\frac{f_3(q)}{f_2(q)}\right]+1$$

both in the open and closed channel the interactionis logarithmically divergent

UV divergence due to open string massless

states propagating in the loop *ENCODED IN THE*

1 LOOP β-FUNCTION

IR divergence due to twisted closed string

massless states (b, A_0) propagating between the

branes *ENCODED IN THE SUGRA SOLUTION*

- Under open/closed duality

closed string massless states ←→ open string massless states

closed string massive states ←→ open string massive states

Thus there is a quantitative evidence of WHY THE *1 LOOP β-FUNCTION* CAN BE DERIVED FROM THE *CLASSICAL SUGRA SOLUTION !*

PERSPECTIVES:

How general is the gauge/gravity correspondence and its relation with open/closed string duality?

(OB, O'B string theory)

What is the role played by susy?

(it emerges that susy play an important role but is not a strictly necessary ingredient)

What is the role played by the stability of the brane configuration?

(stability seems to be a necessary requirement)

Work in progress