Beyond the Standard Model

Lecture 8
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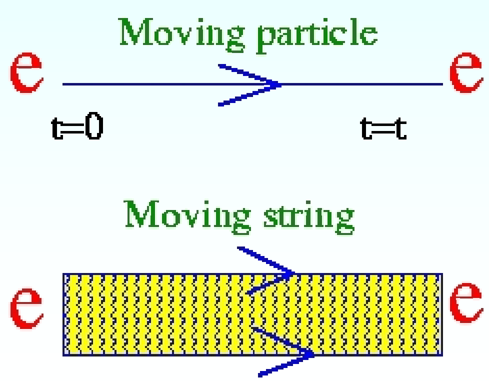
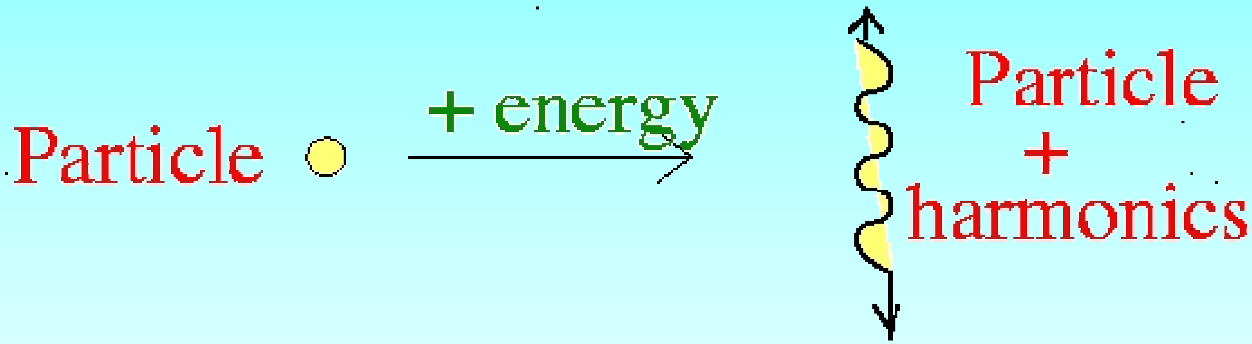
Strings

INTRODUCING STRINGS

- String theory constitutes an attempt to address (at least) two important issues:
  - The construction of a consistent theory of quantum gravity
  - Unification of all known interactions and particles
- Standard quantization of Einstein's gravity leads to inconsistencies. In particular the theory is not renormalizable.
- Many physicists think that in order to quantize gravity we have to give up the idea that the interactions among particles are strictly point-like.
- This is the fundamental idea underlying string theory: elementary particles are not point-like but have a 'stringy' structure:

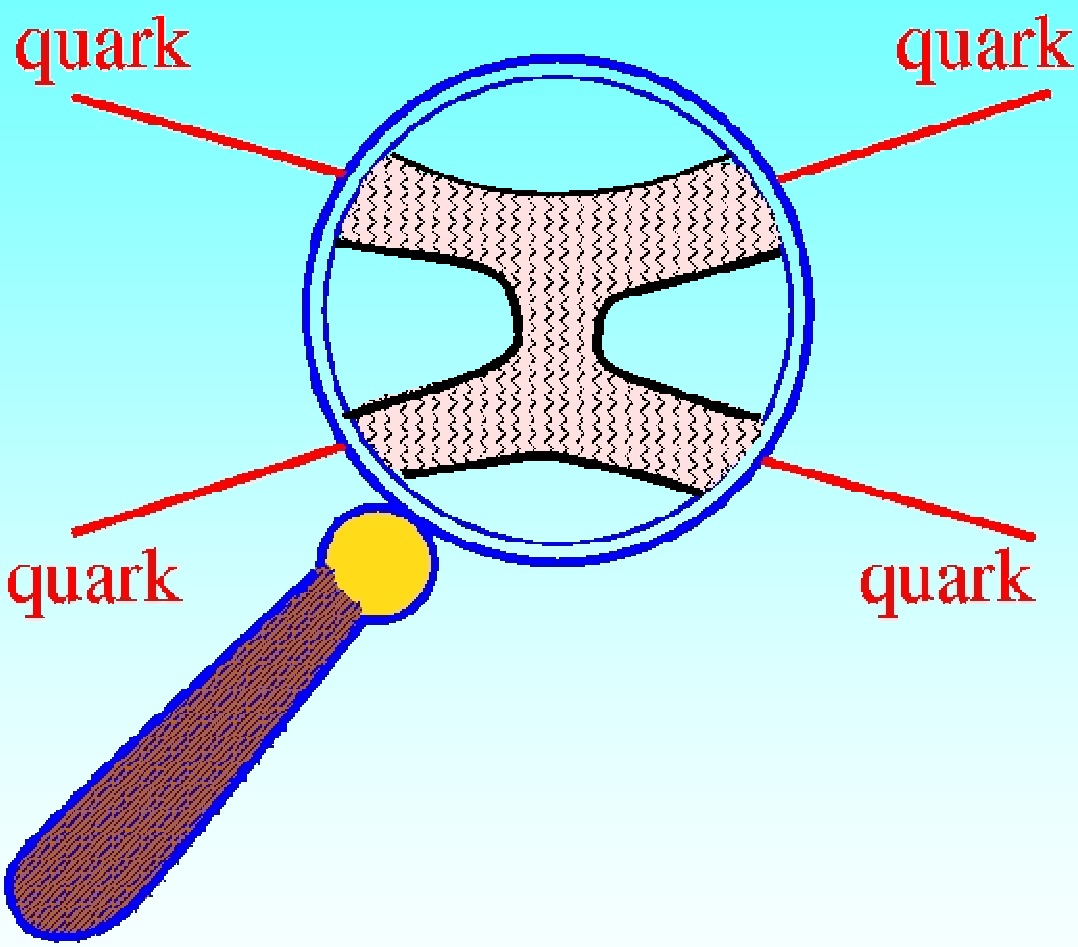


- In order to test this stringy structure we have to communicate a large amount of energy, to overcome the string tension $T_s = M_s^2$:



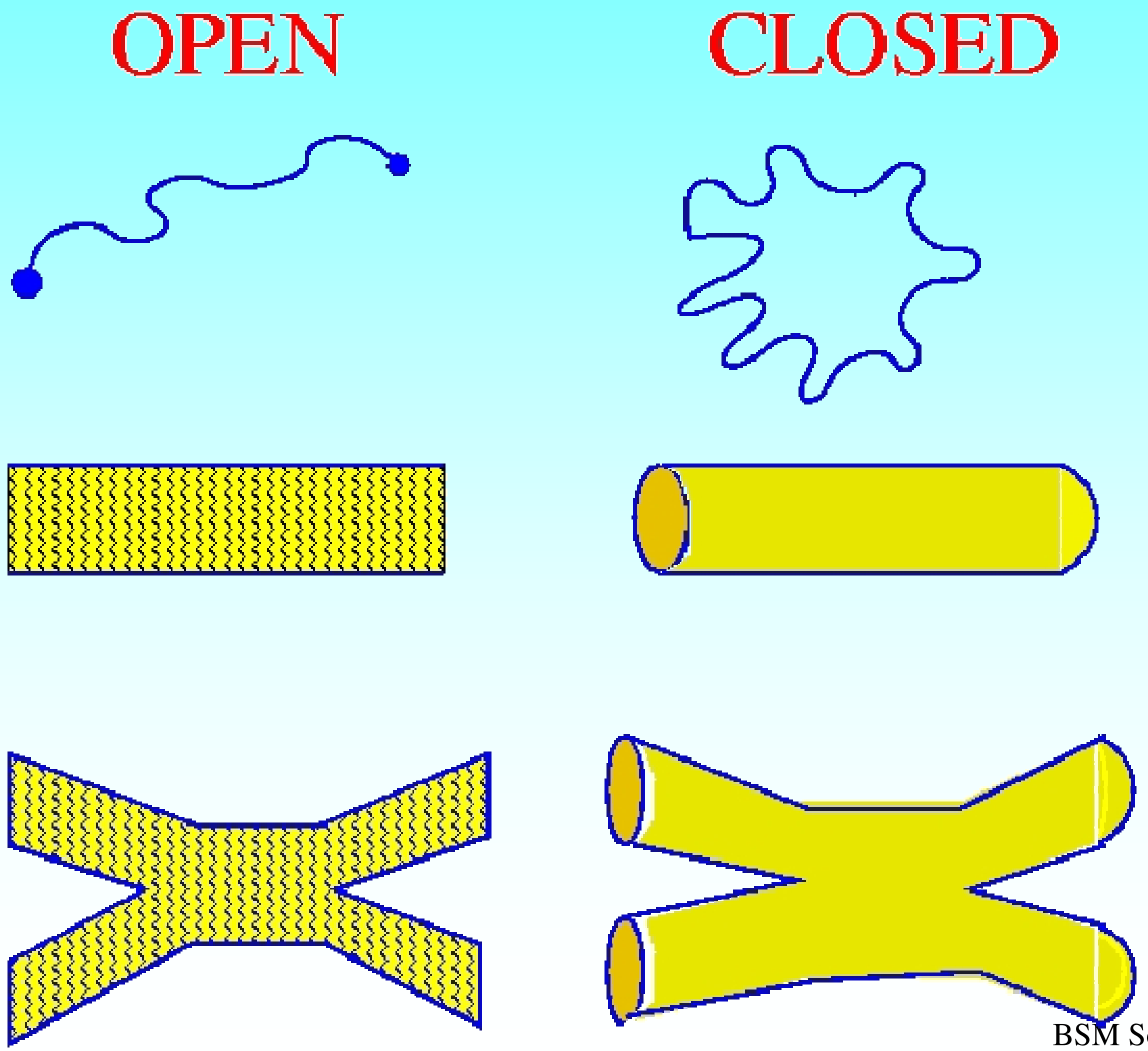
- The observed SM particles should correspond to the lightest vibrations of the string.
- There is complete unification: all particles are different 'notes' from a single 'instrument': the string.

- The interactions of strings are simply the joining and splitting:



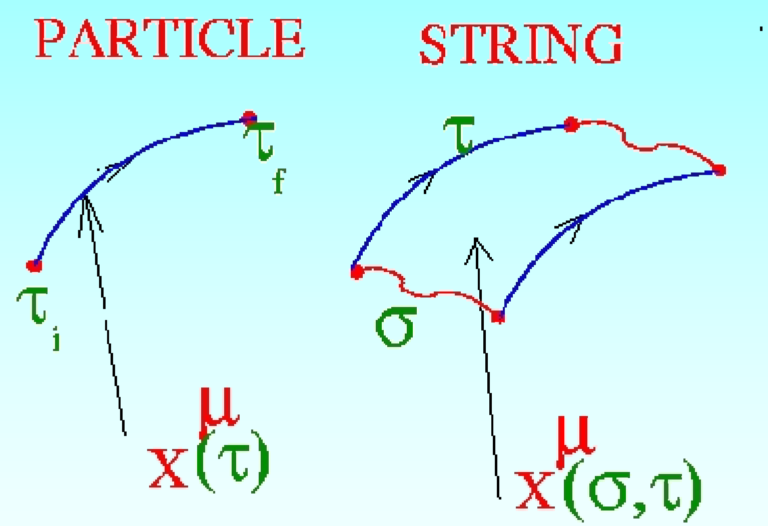
- The interactions are no longer point-like!
- This is the underlying reason for the FINITENESS of string theory loop corrections.

OPEN AND CLOSED STRINGS



THE STRING WORLDSHEET

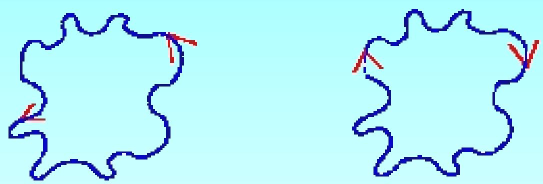
- Classically, one describes the motion of a particle by giving its position $X^\mu(\tau)$ as a function of proper time τ . The action is the length of the *world-line*
- The movement of a string is described by giving $X^\mu(\sigma,\tau)$:



- Strings sweep a *world-sheet* parametrized by σ and τ. the classical action is given by the area of the world-sheet.

PREDICTING THE EXISTENCE OF GRAVITY

- Intuitively, the quantization of a string $X^\mu(\sigma, \tau)$ is analogous to an infinite number of harmonic oscillators. For a closed string there are left- and right-moving oscillations:



- Correspondingly, there are two towers of creation/destruction operators contributing to the Number operators:

$$N_L = \sum_n a_n^\mu a_{-n}^\mu \; ; \; N_R = \sum_n \tilde{a}_n^\mu \tilde{a}_{-n}^\mu$$

- The spectrum of string oscillations is thus given by:

$$m^2 = M_s^2 (N_L + N_R - 2)$$

- For $N_L = N_R = 1$ there is a massless state:

$$a_1^\mu \tilde{a}_1^\nu |0> = g^{\mu\nu} = GRAVITON!!$$

- Thus one can claim that strings predict the existence of gravitation!. Indeed, graviton appeared as a consequence of the form of string spectrum, not as an input.

- In fact there is also an massless antisymmetric field $B^{\mu\nu}$ and massless scalar $\phi = a_1^\mu \tilde{a}_1^\mu |0>$, the DILATON.

- The vev of the dilaton $< \phi >$ turns out to correspond in the low energy effective action to the gauge coupling constant.

- Unfortunately, for $N_L = N_R = 0$ there is a scalar particle with mass$^2 = -2M_s^2$, a TACHYON.

- The tachyon disappears in supersymmetric strings : SUPERSTRINGS.

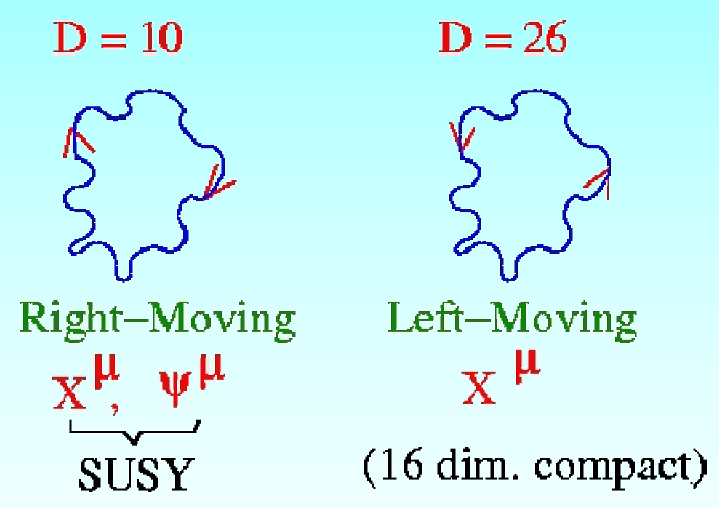
THE FIVE SUPERSTRINGS

- It turns out that in flat space there are five consistent string theories with the two following important properties:
  - *i) They are supersymmetric.*
  - *ii) They are defined in 10 dimensions*
- The first property is perhaps welcome: one can hope to make contact with low-energy SUSY
- The second property can be made consistent with observation if the extra 6 dimensions are compactified , very much as we did with extra dimension models.
- The 5 superstrings may be classified into two general groups:
  - The two heterotic strings [a]
  - Type IIA, IIB and I strings [b].
- Let us now briefly describe what they are.

[a] Gross et al. (1985)
[b] Green,Schwarz (1984)

THE HETERETIC STRINGS

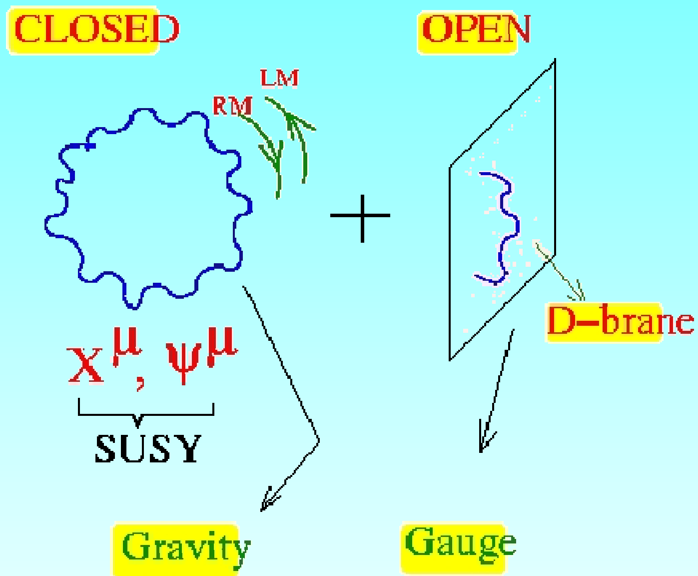
- They have CLOSED STRINGS ONLY.
- They have supersymmetry in D=10 for the right-moving string oscillations.
- They are purely bosonic, with $D = 26$, for the left-movers.
- The extra 16 dimensions for left-movers are forced by consistency to be compactified.



- There are only two allowed patterns of compactification leading to only two options for the gauge group : $SO(32)$ and $E_8 \times E_8$ coming from left-moving oscillations.

THE TYPE II, I SUPERSTRINGS

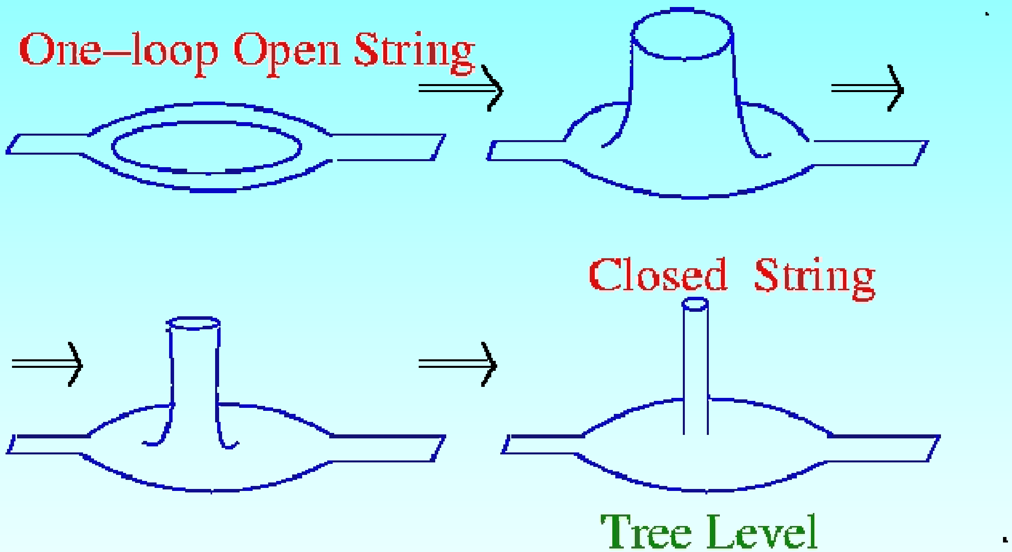
- Type IIA, Type IIB and Type I strings are close relatives They have both CLOSED AND OPEN strings .
- In fact they have only open strings in the presence of 'D-branes'



- D-branes are non-perturbative states of string theory, very much like monopoles in gauge field theory. For our purposes it is enough to know that D-branes are a sub-manifold of space-time on which open strings can start and end.
- Closed strings $\longrightarrow$ gravity , open strings $\longrightarrow$ gauge sector.

OPEN-CLOSED STRING DUALITY

- The system of closed+open strings has remarkable property: A one-loop open string computation is related to a closed string TREE computation:



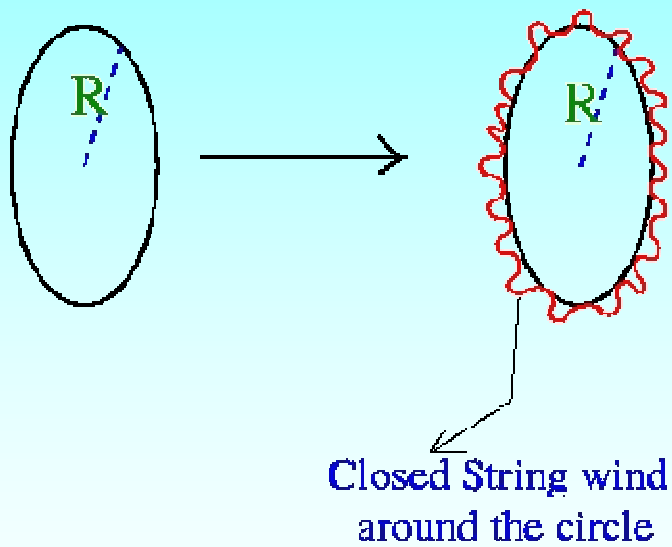
- Since open string =gauge and closed string=gravity this means there are dual descriptions of the same physics using either gauge or gravity variables.

ADS CFT duality

- This is at the root of the gauge-gravity correspondence of Juan Maldacena (1998). But there are further dualities...

T-DUALITY

- Consider a closed string theory and let us compactify one of the dimensions into a circle of radius R.
- As in standard extra dimensional field theory, there will be Kaluza-Klein replicas with masses $m_{KK}^2 = n^2/R^2$
- However in the case of strings there is an extra stringy type of massive replica:



- Closed strings may wind around the circle.

- These states have masses proportional to the compact radius, since the string has to stretch:

$$m^2 = \frac{n^2}{R^2} + k^2 M_s^4 R^2$$

- This formula has a remarkable symmetry under exchange of KK and winding particles [a]:

$$M_s R \longleftrightarrow \frac{1}{M_s R} \; ; \; n \longleftrightarrow k$$

- This means that in closed string theory there is an equivalence between large and small radius as long as one exchanges KK and winding particles.

- This symmetry and its generalizations is called T-duality.

- T-duality turns out to lead to the equivalence of some superstrings [b], as we will see soon.

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[a] Kikawa et al.(1984)

[b] Dine et al. (1989); Ginsparg (1987)

S-DUALITY

- There is an even more surprising symmetry [a] in certain string and field theories with extended $N > 2$ SUSY.
- This symmetry establishes an equivalence among particles interacting with strength g^2 and solitons (e.g. monopoles) interacting with strength $1/g^2$:

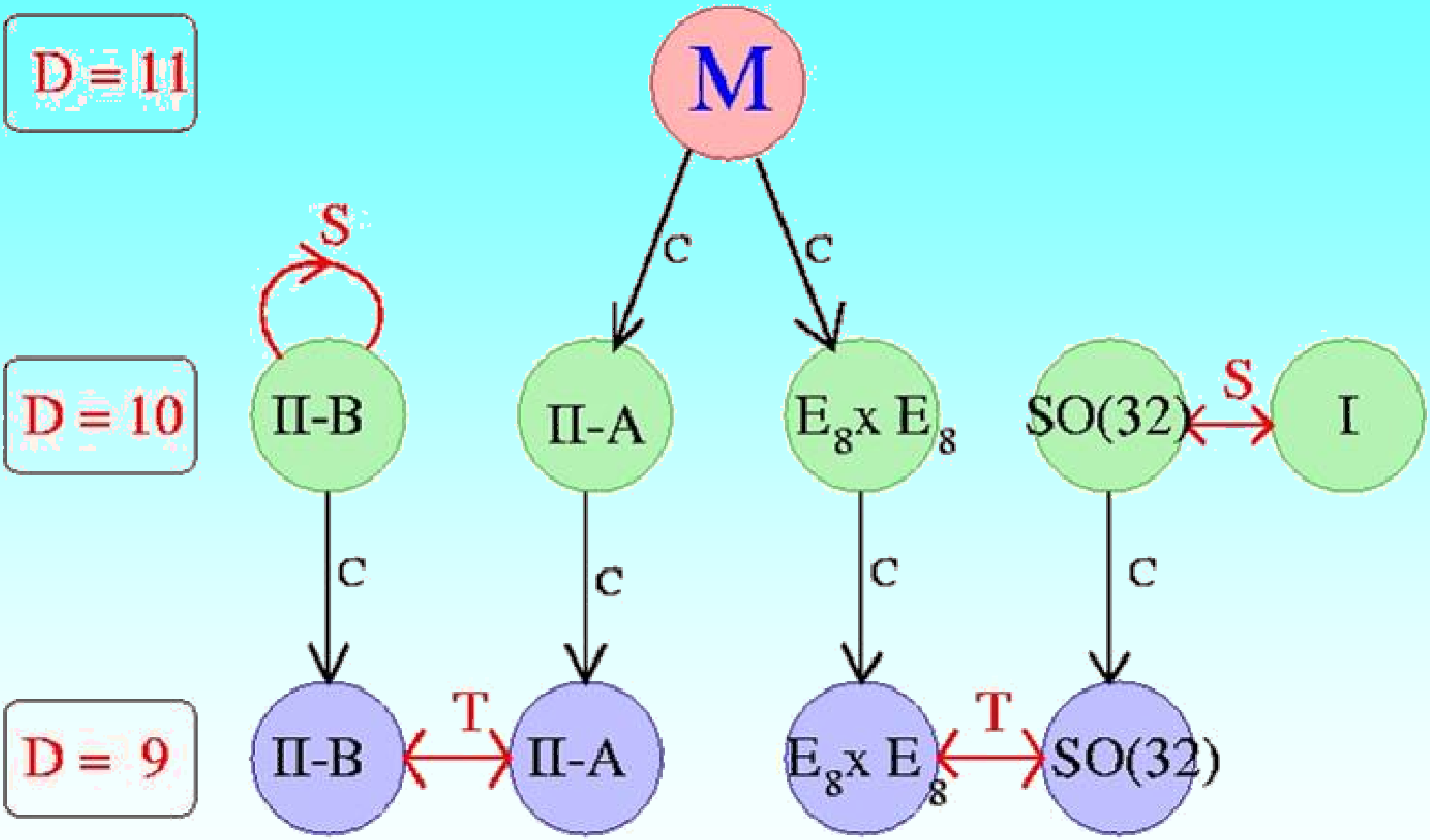
g =gauge coupling

$$g^2 \longleftrightarrow \frac{1}{g^2}$$

Charged particles — Solitons (e.g. monopole

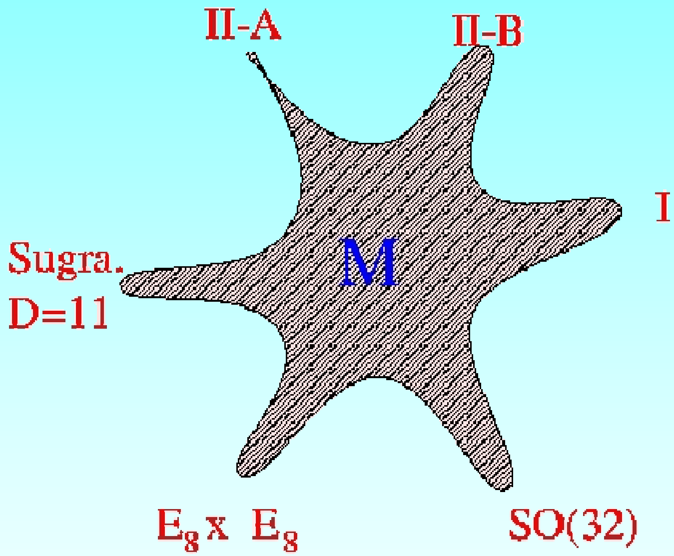
- This is a symmetry which relates small coupling g to large coupling $1/g$. It is clearly non-perturbative. It has allowed to compute certain non-perturbative quantities in field theory for the first time [b].
- In 1995 it was realized that all 5 superstrings are connected to each other by either T- or S-dualities!!

[a] Montonen, Olive (1974); Font et al. (1990)
[b] Seiberg,Witten (1994)


D = 11
M
C
C
S
D = 10
II-B
II-A
E8x E8
SO(32)
S
I
C
C
C
C
D = 9
II-B
T
II-A
E8x E8
T
SO(32)

M-THEORY

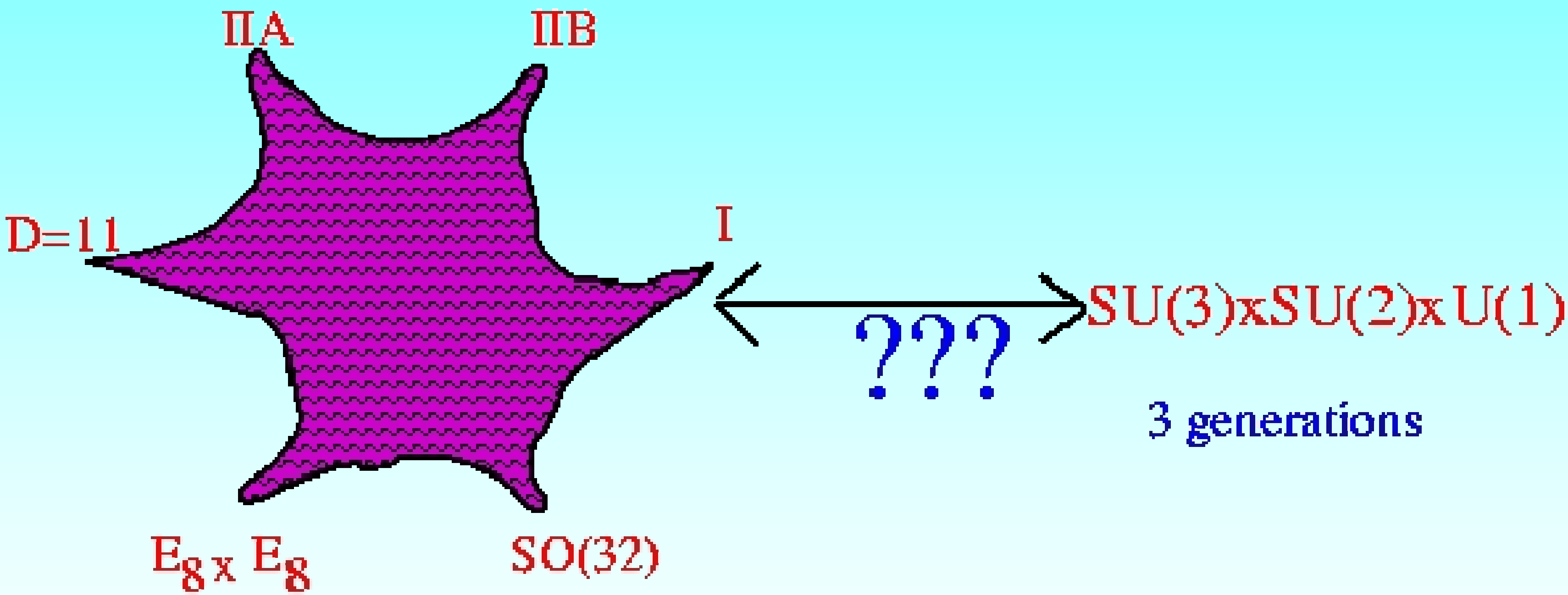
- In addition it was found that [a] Type IIA and heterotic $E_8 \times E_8$ are particular compactifications of an old theory: 11-dimensional supergravity [b].
- It is now believed that all 5 string theories and 11-dimensional supergravity are limits of a UNIQUE UNDERLYING THEORY:.



- Here M-theory is symbolically represented as an irregular surface with 6 cusps. Each point represents different geometries of the 10(11) dimensions.

[a] Hull,Townsend;Witten, (1995)
[b] Cremmer,Julia,Scherk (1978)

STRING PHENOMENOLOGY



M/String Theory

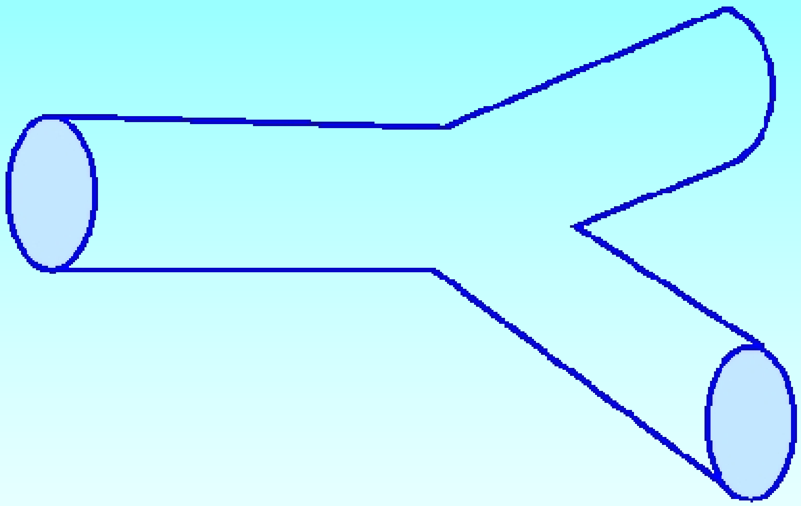
Low energy string models

STRING MODEL BUILDING

- String theories have as low-energy limits theories with 6(7) extra dimensions. Upon compactification of extra dimensions one obtains an effective field theory in $D = 4$.
- Thus the observed SM particles should correspond to the (almost) massless $D = 4$ string vibrations.
- Certain classes of compactifications lead to $N = 1$ SUSY at low energies. Others don't.
- A number of 3-generation compactifications have been obtained falling in general into two categories:
  - *i)Heterotic models (perturbative and non-pert.)*
  - *ii)D-brane models (Type IIA, IIB , I strings)*
- There are a couple of fundamental differences compared to usual gauge theory model building:
  - Once the compactification is specified, the particle spectrum is fixed, no room for changes
  - There are no free parameters in the game. Couplings and masses depend instead on undetermined vevs of scalar fields (e.g. *dilaton and moduli*).

1.-HETEROTIC MODEL BUILDING

- The heterotic string $E_8 \times E_8$ is simpler than the $SO(32)$ for model-building.
- Recall heterotic are closed string theories. There is a single coupling of closed strings:



- Thus Gravity and gauge interactions are unified with:

$$G_{Newton} - \frac{g^2}{M_{string}^2} \;;\; M_{string} - g\, M_{Planck}$$

HETEROTIC MODEL BUILDING

- The initial theory has $N = 1$ SUSY in $D = 10$ with gauge group $E_8 \times E_8$(you don't want to know what E_8 is).
- One compactifies the extra 6 dimensions. If the extra dimensions have certain properties (*Calabi-Yau manifold*) [a] one obtains a theory with $N = 1$ SUSY in four dimensions. This is welcome if we want to solve the hierarchy problem with SUSY.
- The gauge group obtained is normally a subgroup of E_8 plus an extra gauge factor which may act as SUSY-breaking hidden sector.
- $SU(5)$, $SO(10)$ and E_6 are subgroups of E_8 so GUT groups are natural in heterotic theory!
- However, at least in the simplest cases, there are no appropriate Higgs fields to break the GUT symmetry down to the SM! So it is not easy to get standard GUTs from strings.
- On the other hand there is a stringy method to break e.g. E_6 down to the standard model: vevs for the gauge fields in extra dimensions, *Wilson line backgrounds* [b].

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[a] Candelas et al. (1984)
[b] Witten, (1985)

EXPLICIT 3-GENERATION MODELS

- A number of 3-generation models (with N=1 SUSY)have been constructed, some of the most popular are
  - Tian-Yau 3-generation CY [a]
    $SU(3)_c \times SU(3)_L \times SU(3)_R \times G_H$
  - Z_3 orbifold [b] .
    $SU(3) \times SU(2)_L \times U(1)_Y \times G_H$
  - Fermionic string flipped $SU(5)$ [c]
    $SU(5)_F \times U(1) \times G_H$
  - $Z_2 \times Z_2$ orbifold [d]
    $SU(3) \times SU(2)_L \times U(1)_Y \times G_H$
  - GUT's from asymmetric Z_6 orbifold [e]
    $SO(10), SU(5)$ (massless adjoints).
- Some general properties:Extra light fermions beyond MSSM; extra $U(1)$'s. Gauge coupling unification not automatic.

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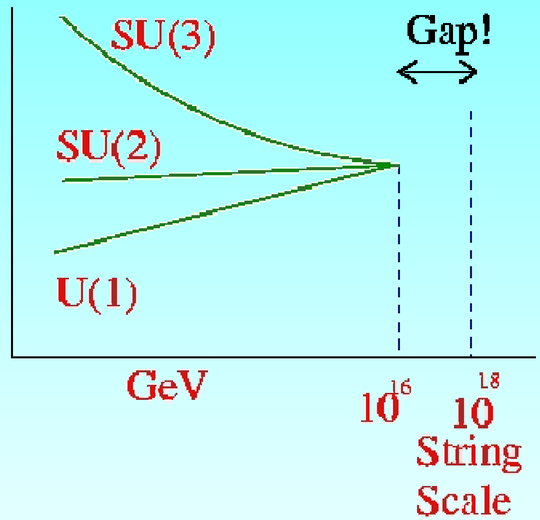
[a] Ross et al (1986)
[b] Ibanez et al.; Casas et al. (1987)
[c] Antoniadis et al (1988)
[d] Faraggi et al (1990)
[e] Kakushadze et al (1996)

GAUGE COUPLING UNIFICATION IN HETEROTIC

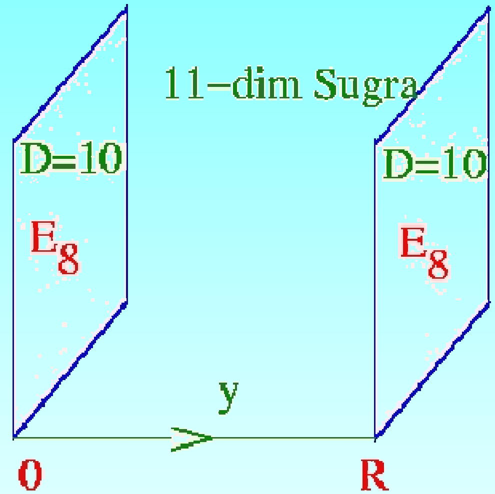
- We must emphasize that the search of realistic heterotic models has been far from complete.Still much to do.
- Assume for a moment that a compactification with just the MSSM spectrum was found: there is a slight problem with gauge coupling unification:



- Given the log dependence it does not look like a big problem. Contributions from heavy modes (e.g. threshold corrections) may be the cause.
- There is however an elegant solution in terms of M-theory version of heteroric.

HORAVA-WITTEN HETEROTIC

- In M-theory the $E_8 \times E_8$ heterotic appears as a S^1/Z_2 orbifold of 11-dimensional supergravity.
- The two E_8 gauge groups live in two different 9-branes separated by a distance R [a]:



- As in the extra dimension scenarios we discussed earlier, one can lower the fundamental M-theory scale M_* and identify it with the GUT-scale M_X: NO GAP!!
- This can be made compatible with $M_{Planck} = 10^{19}$ GeV by having R large enough [b].

[a] Horava, Witten (1996)
[b] Witten (1996)

2.-D-BRANE MODEL BUILDING

- Prior to 1995 only the Heterotic strings seemed to be good candidates to embed the SM. In particular, Type IIA , IIB strings did not have room enough for SM gauge fields.
- After the discovery of D-branes [a] it was realized that Type II strings do give rise to gauge fields in the presence of D-branes.
- Since then, D-brane model-building giving rise to realistic models has been vigorously pursued.
- Two main classes of models have been constructed:
  - D-branes at singularities
  - Intersecting brane models
- Let us first give a short qualitative introduction to D-branes.

[a] Polchinski (1995)

INTRODUCING D-BRANES

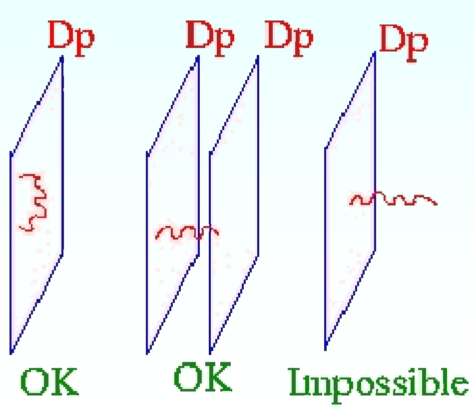
- Dp-branes are (p+1) dimensional non-perturbative states in Type II string theory. This is analogous to the magnetic monopole solutions which non-Abelian Higgs systems have.

- A Dp-brane has *tension* τ_p (analogue of mass) given by:

$$\tau_p = \frac{M_s^{(1+p)}}{(2\pi)^p g}$$

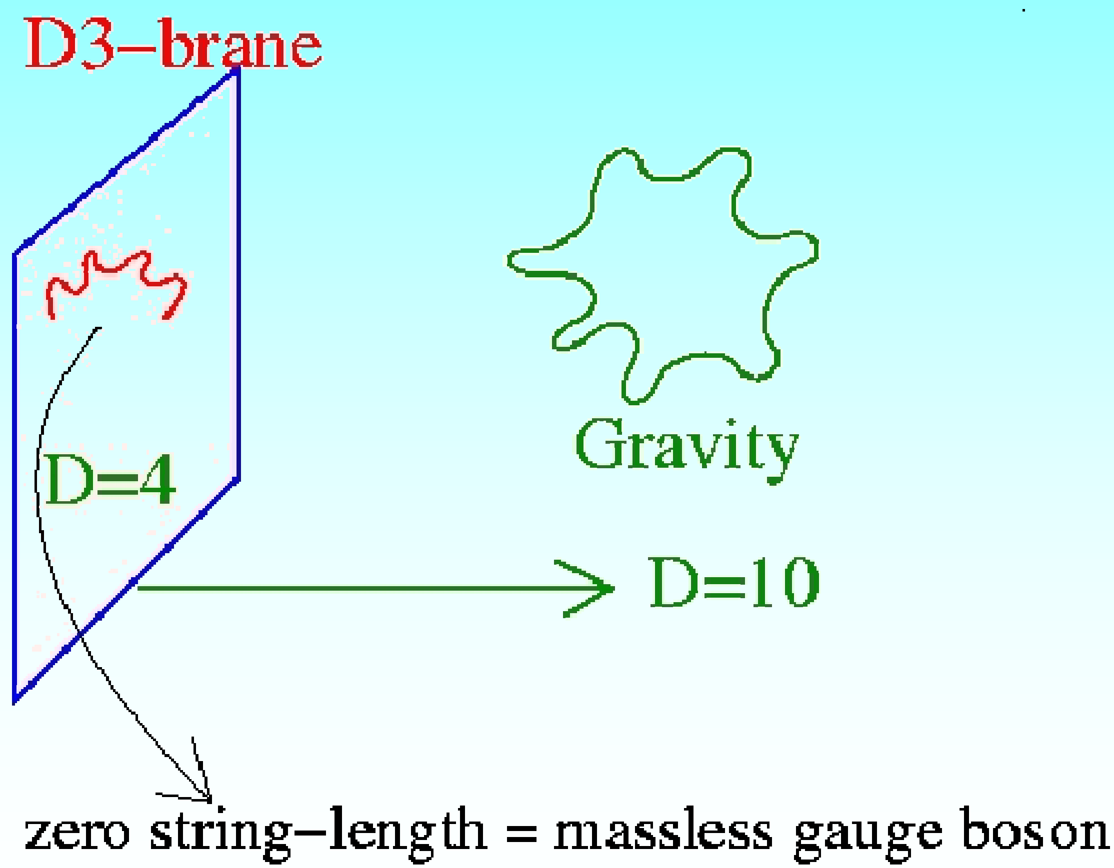
- They become very massive and static in the perturbative $g \to 0$ limit.

- The crucial issue is that they have the property that open strings are forced to start and end ON them:

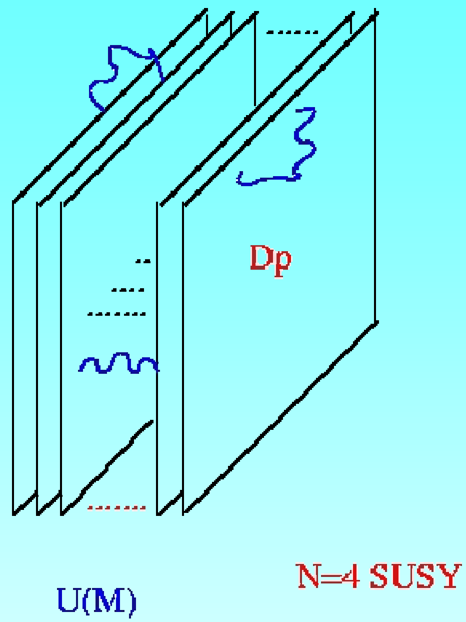


- Open strings starting and ending on SAME Dp-brane give rise to a $U(1)$ massless gauge boson living on (p+1) dimensional subspace of the full space.

- For example , for a D3-brane:



- A stack of M parallel $D3$ in smooth space gives rise to $U(M)$ gauge theory:

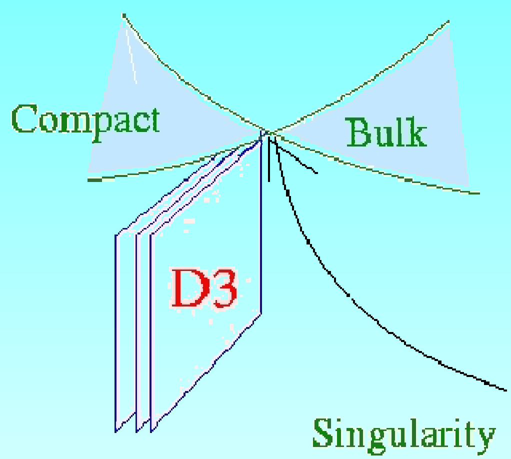


- However the massless fields have N=4 SUSY.
- This means that the fermions are in the adjoint of $SU(N)$ gauge theory, FERMIONS ARE NOT CHIRAL.
- To obtain chirality some of the simplest possibilities are
  - Locate e.g. $D3$-branes at an orbifold fixed point in extra dimensions
  - Consider intersecting Dp-branes, $p > 3$

2-a) D-BRANES AT SINGULARITIES

a

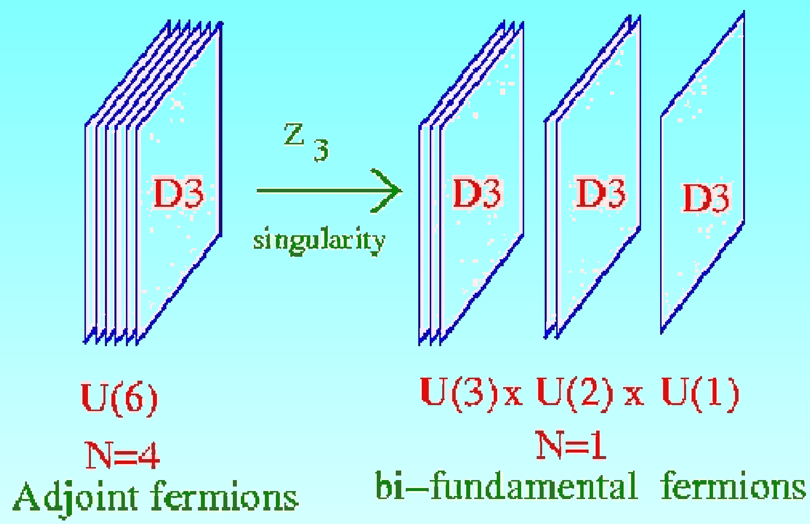
- Assume that a stack of parallel branes are sitting on e.g. an orbifold Z_N fixed point (singularity) in the extra dimensions:



- We already saw an example of a Z_2 orbifold and singularities before. We identified points in a 5-th dimension under an order-2 Z_2 reflection.
- In more than 5 dimensions we have simple generalizations involving identification of points under rotations θ of order N (i.e. $\theta^N = 1$). These lead to Z_N orbifolds.

[a] Douglas et al. (1996)

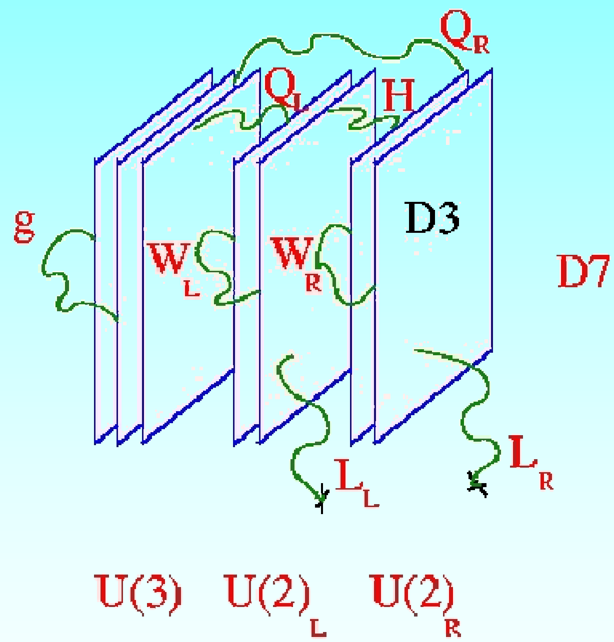
- A Z_N singularity breaks the $U(M)$ gauge group of a stack of M branes into N $U(n)$ factors.
- For example, 6 D3-branes on a Z_3 singularity break the symmetry and gives rise to chirality:



- The idea then is to construct specific configurations of D-branes such that the massless spectrum resembles the SM.
- The possibilities are strongly constrained by a property which we will not discuss here: D-branes are charged under certain antisymmetric fields (so called Ramond-Ramond fields) and a stable configuration of branes must have overall vanishing charge.

A LEFT-RIGHT SYMMETRIC EXAMPLE

- Consider a stack of 7 D3-branes sitting on a Z_3 singularity in some compact 6-dimensional space. The initial symmetry is broken: $U(7) \to U(3) \times U(2)_L \times U(2)_R$.
- Open strings among the different branes give rise to gauge bosons, and 3-GENERATIONS of quarks and Higgs fields [a]:

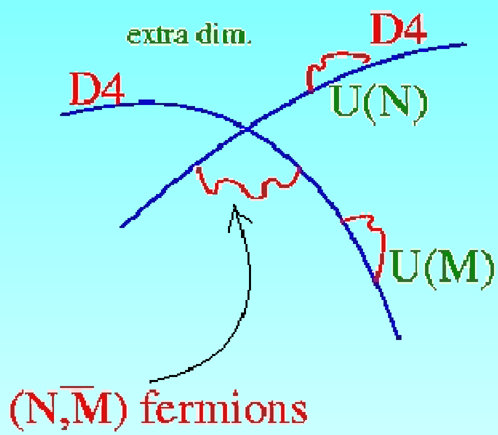


- If D3-branes inside additional D7-branes , leptons then arise from open strings in between D3 and D7-branes.

[a] Aldazabal et al. (2000);Antoniadis et al. (2000)

2-b) INTERSECTING D-BRANES

- Let us consider a stack of parallel D4-branes. It has 5 dimensions. Let us draw the 5-th dimension as a line. Consider now a second stack of D4-branes intersecting the other one:



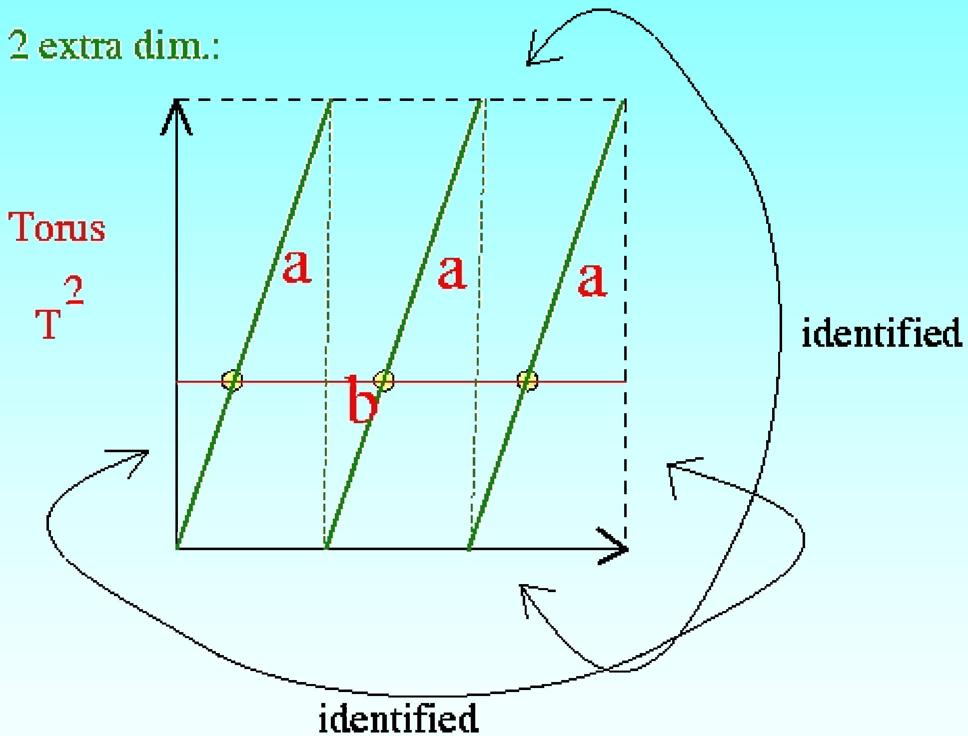
- The intersection is 4-dimensional. It may be seen that at that point there appear massless chiral fermions transforming as bi-fundamentals $(N, \bar{M})$[a].
- Those massless fermions are to be identified with quarks and leptons. The idea is to consider Dp-brane $(p > 3)$ configurations such that the SM fermions live at the intersections [b].

[a] Berkooz et al. (1997)

[b] Blumenhagen et al;Aldazabal et al.(2000)

ORIGIN OF TRIPLICATION OF GENERATIONS

- 2 stacks of D4-branes may intersect several times giving rise to several generations:
- Consider for example 2 stacks of D4-branes , a and b:

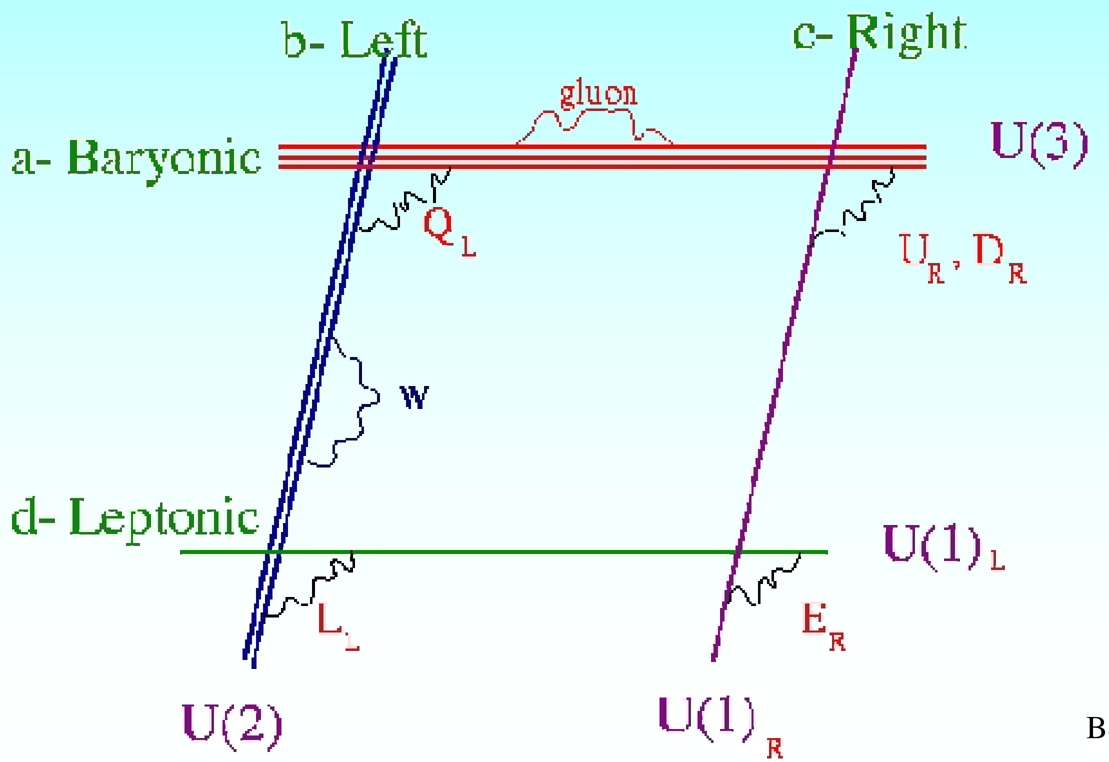


- Three copies of the same chiral fermion $(N_a, \bar{N}_b)$ will appear.

STANDARD MODEL AT INTERSECTING BRANES

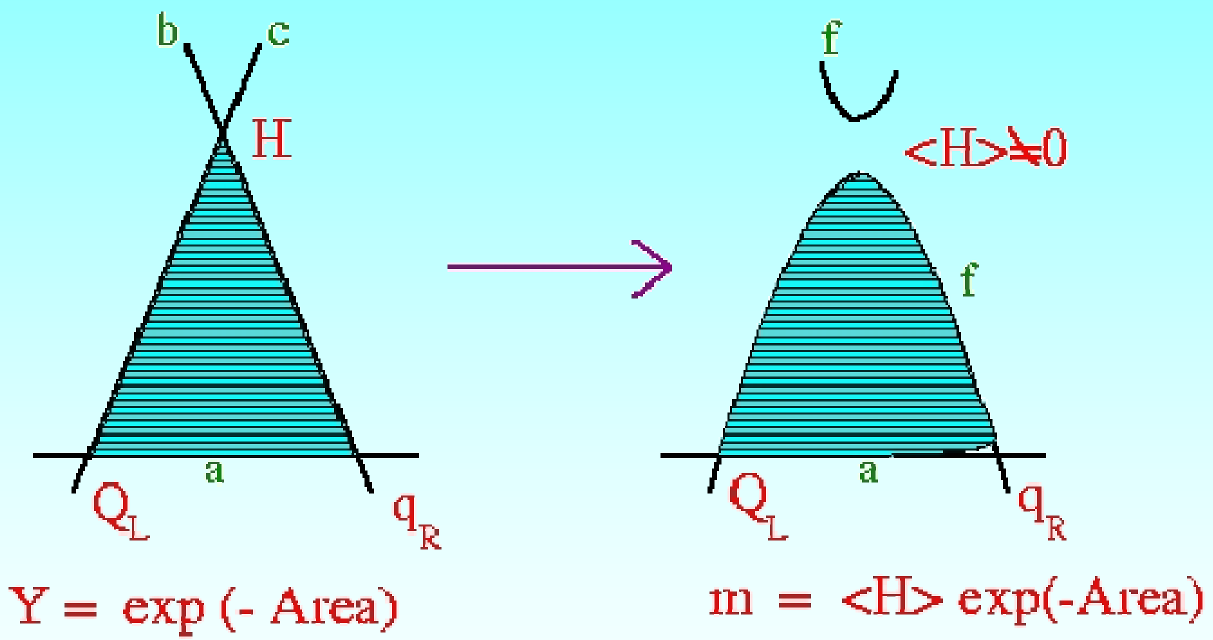
Configuration of 4 stacks of branes:

stack a	$N_a = 3$	$SU(3) \times U(1)_a$	Baryonic brane
stack b	$N_b = 2$	$SU(2) \times U(1)_b$	Left brane
stack c	$N_c = 1$	$U(1)_c$	Right brane
stack d	$N_d = 1$	$U(1)_d$	Leptonic brane



Hierarchical Yukawa couplings

- Yukawa couplings come from triangular world-sheets



- Different distance to Higgs field gives rise to hierarchical Yukawas [a]

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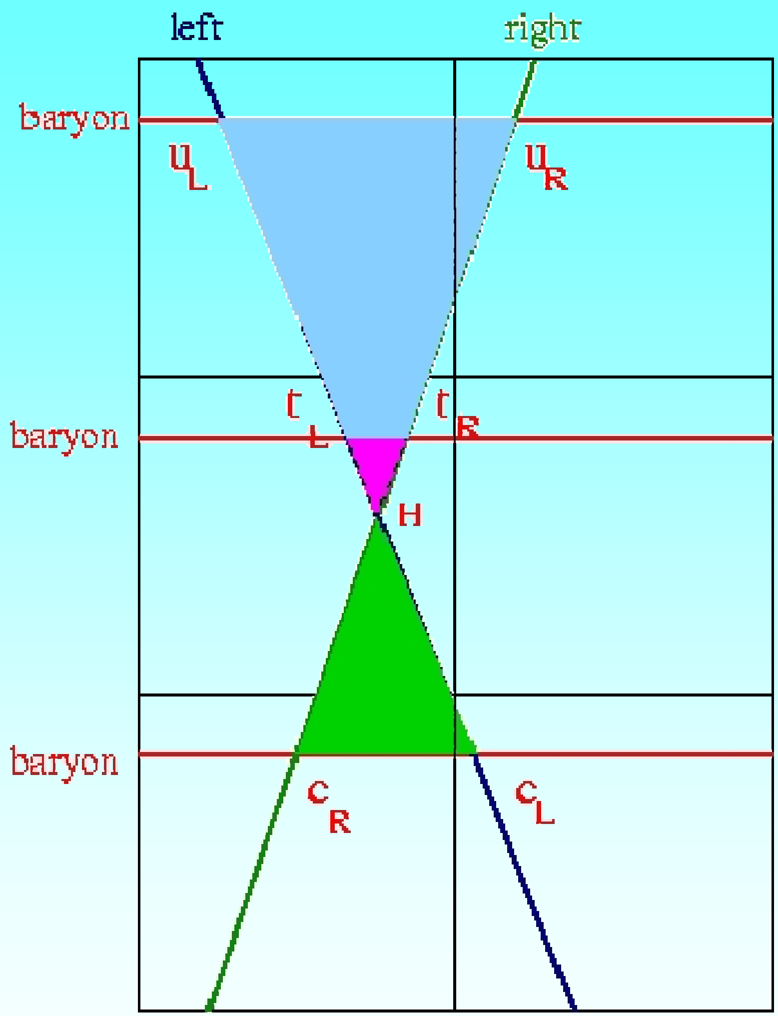
[a] Aldazabal et al. (2000); Cremades et al. (2003)

- Consider e.g. the case of D4-branes wrapping a T^2:



$m_t >> m_c >> m_u$

- Yukawas may be exponentially suppressed by the distance to the Higgs intersection.

STATUS OF D-BRANE MODEL-BUILDING

- This is a very young subject and there is much to explore. A brief summary of the situation is as follows:
- a) BRANES AT SINGULARITIES
  - 3-generation models based on Z_3 orbifolds with SM or LR group have been constructed
  - They may have $N = 1$ SUSY and present 3 copies of the Higgs multiplet
  - In these models gauge couplings tend to unify at an intermediate scale, $M_{string} = 10^{11}$ GeV.
  - Work needs to be done to study the Yukawa structure.
- b) INTERSECTING D-BRANES
  - Models with the fermion spectrum identical to that of (non-SUSY) SM have been obtained
  - $N = 1$ SUSY models with 3 generations have also been obtained, although with additional fermion exotics[a]
  - Structure of Yukawa couplings is at present being analyzed.

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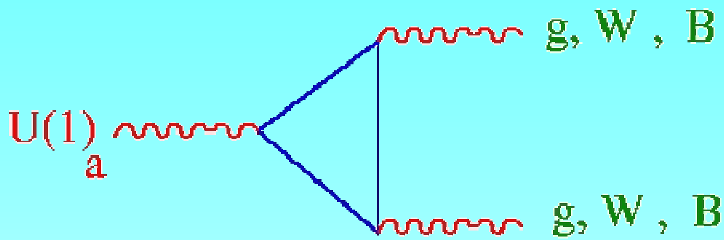
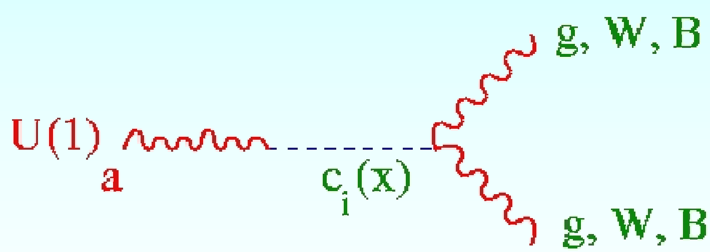
[a] Cvetic et al. (2001)

ANOMALOUS U(1)'s

- We have seen that in string models there are further $U(1)$'s beyond hypercharge. Some of them are anomalous:



- There is a stringy mechanism which cancels the anomaly by exchanging axion-like fields $c_i(x)$, which are present in string theories:



- The would-be anomalous $U(1)$'s become massive due to the $(\partial^\mu c_i(x))A_\mu$ Higgs-like couplings.

- In heterotic models there is only one anomalous $U(1)_a$ at most.
- In D-brane models there are generically several anomalous $U(1)$'s.
- An important property is that in D-brane models the anomalous $U(1)_a$ symmetries survive as *global* symmetries even after the $U(1)$'s become massive.
- There are a number of phenomenological applications of anomalous $U(1)$'s:
  - 1) In D-brane models the $U(1)_{baryon}$ is gauged. Thus proton is stable even with a low string scale $M_s = 1$ TeV.
  - 2) In models with $M_s = 1$ TeV there are up to 3 extra Z_0's which get mass of order 1 TeV through this mechanism and can mix with the physical SM Z_0. They could be produced at LHC[a].
  - In heterotic models there is a single $U(1)_a$ which may give rise to interesting flavor structure.

[a]Ghilencea et al., (2002)

DILATON-MODULI SECTOR

- In string compactifications there are certain massless scalars which couple only gravitationally :

Dilaton

- We already mentioned in $D = 10$ there is a massless scalar , ϕ, the dilaton. Its vev controls the strength of interactions g:

$$< \phi >= \frac{1}{g^2}$$

- In $D = 4$ compactifications the dilaton is part of a complex field S:

$$S = \frac{1}{g^2} + ia(x)$$

Moduli

- There are also scalar fields T_i, the moduli whose vev correspond to the size and shape of the 6 extra compact dimensions.

- One of them corresponds to the overall size R of extra dimensions:

$$T = R^2 + ib(x)$$

DILATON-MODULI SUSY BREAKING

- Dilaton and moduli constitute natural candidates for SUSY-breaking hidden sector, since they only have Planck-mass suppressed interactions.
- Assuming S and/or T fields are the origin of SUSY breaking (i.e. $F_S \neq 0$, $F_T \neq 0$), one can compute SUSY-breaking soft terms in specific compactifications [a].
- Thus for example for heterotic orbifold models one obtains soft masses ($tg\theta = |F_S|/|F_T|$):

$$M_a = \sqrt{3} m_{3/2} sin\theta \quad (1)$$

$$m_i^2 = m_{3/2}^2 (1 - n_i cos^2\theta) \quad (2)$$

$$A_{ijk} = -\sqrt{3} m_{3/2} (sin\theta + cos\theta (n_i + n_j - n_k)) \quad (3)$$

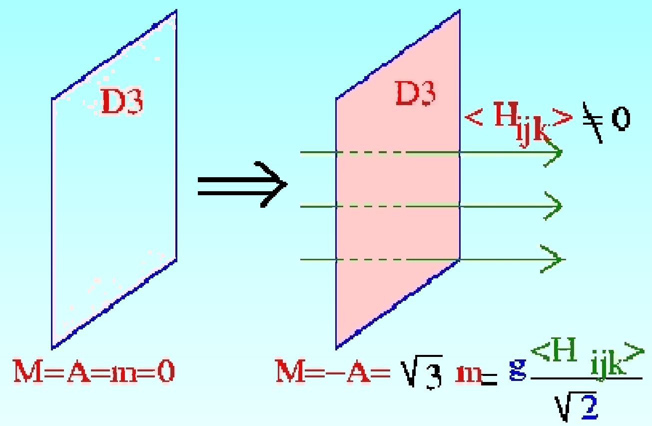
- where n_i are certain model-dependent negative integers.
- particularly interesting is the DILATON DOMINATION case $sin\theta = 1$,since then soft terms are universal and flavor independent:

$$M_a = -A = \sqrt{3} m$$

[a] Brignole et al.; Kaplunovsky et al.(1993)

DILATON SUSY BREAKING AND D3-BRANES

- It turns out that dilaton-dominated soft terms appear also in D-brane models from an apparently independent perspective.
- Type II-B string theory has certain antisymmetric B_{MN} fields. If there is a flux of the corresponding field strength H_{MNP} in 6 extra dimensions [a], i.e. $H_{ijk} \neq 0$, such type of soft terms is generated [b]:



- These H_{ijk} fluxes are quantized:

$$M_s^2 \int dx^3 H_{ijk} = n \longrightarrow H_{ijk} \simeq \frac{n}{M_s^2 R^3}$$

[a] Graña (2002)
[b] Camara et al. (2003)

- Thus one finds:

$$m_{soft} \simeq \frac{g}{M_s^2 R^3} \simeq \frac{M_s^2}{M_{Planck}}$$

- Thus in these scheme if we want to identify m_{soft} with the electroweak scale M_W , the natural value for the string scale should be:

$$M_{string} \simeq \sqrt{M_W M_{Planck}} \simeq 10^{11}\ GeV$$

Fluxes and dilaton/moduli fixing

- Another important effect of these fluxes is that the vevs of dilaton S and certain moduli (NOT T) are determined[a]

- This has opened the path to the possibility of solving the DILATON-MODULI PROBLEM of string theory, i.e., constructing string vacua with the vevs of all dilaton/moduli fixed.

- Toy models based on D3-D7 brane systems with a small (but non-vanishing) cosmological constant have been constructed [b]

[a] Gidcings et al.(2001); Kachru et al.(2002)
[b] Kachru et al.(2003)

WHAT IS THE STRING SCALE?

- There are three natural options:

i) $M_s = 1\ TeV$ [a]

- In this case the hierarchy is explained in terms of a large extra dimensions volume. Both KK and string excitations could be perhaps be produced at LHC!
- In principle SUSY is not needed. This possibility has the virtues and problems which we discussed when talking about extra dimension models.

ii) $M_s = \sqrt{M_W M_P} \simeq 10^{11}\ GeV$ [b]

- As we discussed , this is a natural scale if SUSY breaking comes from fluxes. $N = 1$ SUSY is needed to stabilize the hierarchy.
- Gauge coupling unification should take place at the intermediate scale, which is often the case in explicit D-brane constructions.

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[a] Antoniadis et al. (1998); Lykken (1996)
[b] Benakli;Burgess et al. (1999)

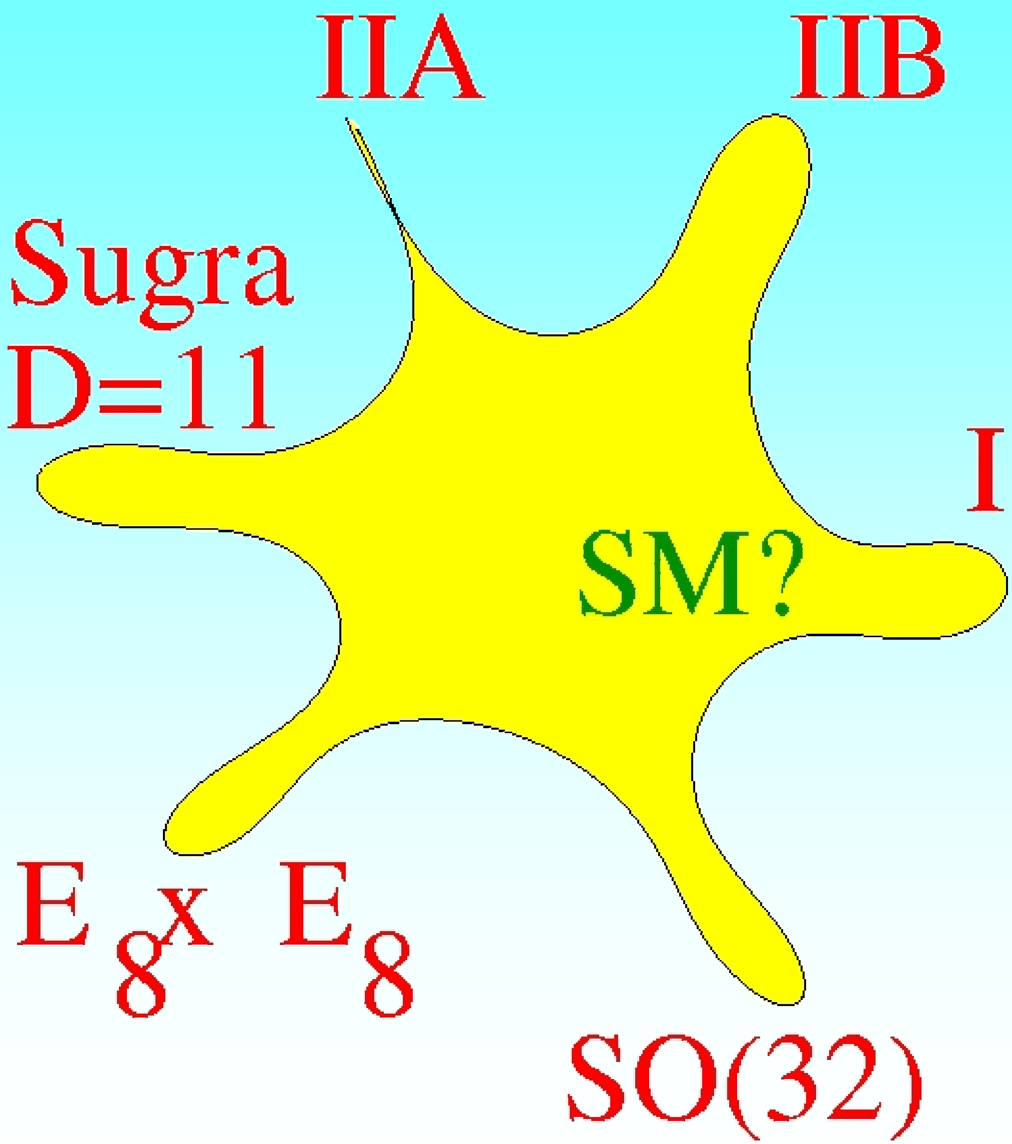
- The intermediate scale is in the range allowed by an axion solution of the strong-CP problem, and there are natural string candidates for the axions (partners of dilaton/moduli).

iii) $M_s = M_X \simeq 10^{16}\ GeV$

- This is the standard case with $N = 1$ SUSY and gauge coupling unification at $M_s = M_X$.
- $N = 1$ is needed. The hierarchy M_p / M_W should be explained by other mechanism, like gaugino condensation.
- If $M_s = 1\,TeV$ one could find direct evidence of string theory at LHC.
- Im $M_s = 10^{11}$ or $M_s = 10^{16}$ the trace of string theory should be captured by the low energy parameters like soft terms.

SUMMARY OF STRING PHENOMENOLOGY

- Explicit string compactifications have been built with particle content closer and closer to that of the SM or the MSSM.
- In string models one can understand the origin of three generations in terms of the geography of extra dimensions.
- The low-energy parameters like Yukawa couplings may be computed in terms of the dilaton/moduli vevs.
- Different origins for SUSY-breaking give rise to explicit predictions for SUSY-breaking soft terms which could perhaps be tested at LHC.
- Recent developments (fluxes) have shown a way in which all dilaton/moduli fields could be dynamically determined.
- In summary, string models offer us a general framework to understand the physics beyond the standard model, as well as a unification with gravity.
- This field is in its infancy and it will take some time until we figure at in a more complete way what is the space of solutions resembling the SM. And find out why the SM or MSSM structure was chosen among all possibilities.


IIA
IIB
Sugra
D=11
I
SM?
E8x E8
SO(32)

BSM Conclusions

- The SM should be considered as a low energy effective model with many unsolved problems
  - Values of couplings, masses and mixings
  - The origin of electroweak symmetry breaking
  - The fine-tuning problems
  - Unification with quantum gravity
- The goal is to build a (high energy) model (theory) which explains the SM peculiarities and leads to the SM as a low energy limit
  - GUT – unify strong and electro-weak interactions – many problems
  - Conclusion from GUT – we have to include also in the game the properties of the space – time (i.e. what we call gravity)
- Supersymmetry
  - Solves many of the problems of the SM
  - Makes possible unification of all known forces
  - MSSM – should be considered as an effective model (like SM)
  - Predicts many new particles
  - SUSY should be broken - the mechanism is not clear yet
  - If exists – it should be in the reach of the LHC experiments

BSM Conclusions

- Extra dimensions
  - KK – compactification – small R ~ M_{Pl}
  - LED – the mater fields are localized on 3+1 brane – Ms ~ 1 TeV
  - RS – model – warped extra dimensions - Ms ~ Mpl
- String models – pretend to build the true theory of everything ?
- Supersymmetric
  - The space time has more then 4 dimensions
  - Possible explanation of the SUSY breaking
  - Very limited number of parameters
  - To early to say, but I am not very big optimist

LHC – we are in front of very exciting new results – possibly we will be forced to change generally all our views about the Universe!!!

The Big Quest
for secrets of the Universe
ATLAS
PS
SPS
ALICE
From LEP to LHC
Superconducting
magnets
LHC-B
27 Km
CMS
Compact Muon Solenoid
Starts 2007

References

To prepare this slides I have used the excellent lectures by:

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