DESPERATELY SEEKING THE STANDARD MODEL

Carlos Muñoz
Madrid Autónoma University & Institute for Theoretical Physics

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OUTLINE

- Optimistic View about String Theory and Phenomenology

- Realistic (Pessimistic?) View about String Phenomenology

Optimistic View

19th-century chemistry described the properties of the chemical elements and their interactions

HOW the elements behave

It did NOT try to explain WHY a particular set of elements, each with its particular properties, exists

To answer the question ‘WHY’ new sciences were needed:

atomic and nuclear physics

‘Quantum Field Theory treats elementary particles just as 19th-century chemists treated the elements

The theory is in its nature descriptive and not explanatory

All the data (list of elementary particles, masses, spins, charges and interactions with one another) are put into the theory at the beginning

The purpose of the theory is simply to deduce from this information what will happen if particle A is fired at particle B with a given velocity

We are not yet sure whether the theory will be able to fulfil even this modest purpose completely

One of the difficulties is that we do not yet have the complete list of elementary particles

Nevertheless it seems likely that the theory in something like its present form will describe accurately a very wide range of possible experiments’

CHART of the fundamental particles (1953)
listed in the order of their mass

photon
graviton
neutrino
electron
positron
positive mu meson
negative mu meson
neutral pi meson
positive pi meson
negative pi meson
zeta meson ?
neutral V-particle
tau meson
kappa meson
positive chi meson
negative chi meson
proton
neutron
neutral V-particle
positive V-particle ?

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quarks
gluons
$W^{\pm}$, Z^0

Dyson, 1953

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is the standard model

20 standard model

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elementary particles

HOW the elements behave

elementary particles

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elementary particles

theory is

To answer the question 'WHY' new sciences were needed:

atomic and nuclear physics

string theory

point-like particles $\rightarrow$ one-dimensional objects

the WHY's

- Why is the gauge group $SU(3) \times SU(2) \times U(1)$?
- Why are there three families of particles ?
- Why $m_e = 0.5$ MeV ?
- Why $\alpha = 1/137$?
- ...
- ...

can be answered

'Looking backward, it is now clear that 19th-century chemists were right to concentrate on the HOW and to ignore the WHY

They did not have the tools to begin to discuss intelligently the reasons for the individualities of the elements

They had to spend a hundred years building up a good quantitative descriptive theory before they could go further

and the results of their labors the classical science of chemistry was not destroyed or superseded by the later insight that atomic physics gave'

Somebody in the future ← Dyson, 1953

Looking backward, it is now clear that

20-21 physicists

19th-century chemists were right to concentrate on the 'HOW' and to ignore the 'WHY'

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standard model

and the results of their labors the classical science of chemistry was not destroyed or superseded by the later insight that atomic physics gave

string theory

Realistic (pessimistic?) View

What is String Phenomenology ?

The Search of the Standard Model in String Theory

18 years have gone by
since String Phenomenology started
and the Standard Model has not been found yet !

- The compactification of the $E_8 \times E_8$ heterotic superstring on six-dimensional spaces was the starting point for this race

  Calabi-Yau, orbifold, fermionic, ..., 85-86

- It was shown that these compactifications can give rise to four-dimensional standard-like models,

  86-87-88

$$\downarrow$$

This is interesting: at least we know that something close to the real world can arise from strings

It was possible to obtain models, e.g. using orbifolds, with

$$SU(3) \times SU(2) \times U(1)^5 \times G_{hidden}$$

and three generations of particles

(plus extra particles)

And with the following properties:

- One of the $U(1)$'s is usually anomalous
- Combinations of the non-anomalous $U(1)$'s give rise to the physical hypercharge
- The Fayet–Iliopoulos D-term can give rise to the breaking of the extra $U(1)$'s through $< \phi >$

In this way it was possible to construct supersymmetric vacuum states with

- $SU(3) \times SU(2) \times U(1)_Y \times SO(10)_{hidden}$
- with three generations of particles

But...

Is a model with the gauge group of the Standard Model and three families of quark and leptons, the sought-after Standard Model ?

By no means !

The correct model must reproduce also the correct mass hierarchy for quarks and leptons.

$$\frac{m_t}{m_u} \sim 10^5, \qquad \frac{m_\tau}{m_e} \sim 10^3$$

Orbifold spaces have a beautiful mechanism to generate a mass hierarchy: Yukawa couplings can be computed and they get suppression factors

$$\lambda \sim e^{-\sum_i c_\lambda^i T_i} \,, \qquad Re\ T_i \sim R_i^2$$

which depend on the distance between the fixed points to which the relevant fields are attached

$$\Downarrow$$

one can span five orders of magnitude the Yukawa couplings

Unfortunately, this is not the end of the story

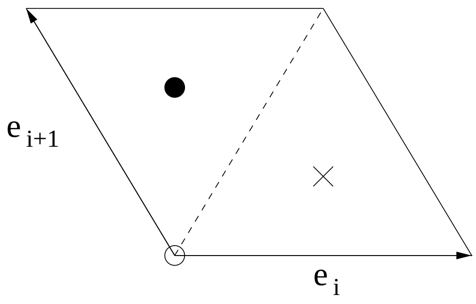
Nature is even more cruel with string phenomenologists:

$$\mathcal{M}_{\text{CKM}} = \begin{pmatrix} 0.9745 - 0.9760 & 0.217 - 0.224 & 0.0018 - 0.0045 \\ 0.217 - 0.224 & 0.9737 - 0.9753 & 0.036 - 0.042 \\ 0.004 - 0.013 & 0.035 - 0.042 & 0.9991 - 0.9994 \end{pmatrix}$$

$$\Downarrow$$

$$H_2^0 \; \bar{u}_{L\alpha} {\lambda_u}^{\beta\gamma} u_{R\gamma} + H_1^0 \; \bar{d}_{L\alpha} {\lambda_d}^{\beta\gamma} d_{R\gamma}$$

one can get in principle this kind of structure, e.g. in orbifolds



Two dimensional sublattices ($i = 1, 3, 5$) of the Z_3 orbifold, and fixed points

H_2^0	o o o	
	o	Q_t
Q	o o x	Q_c
	·	Q_u
	o	t_R
u_R	o o o	c_R
	·	u_R

This implies

H_2^0	o o o	H_2^0	o o o	H_2^0	o o o
Q_t	o o o	Q_c	o o x	Q_u	o o ·
t_R	o o o	u_R	o o ·	c_R	o o x

at the renormalizable level

with $\lambda_{tt} \sim 1, \quad \lambda_{cu} = \lambda_{uc} \sim e^{-R_5^2}$

Unfortunately, it is extremely difficult to implement this type of mechanisms in a particular model.

Given a model, everything is fixed, and it is not possible to play around

As far as I know, there is no model in the market with all the necessary Yukawa couplings

The main difficulty in string model building resides in how to obtain the weird structure of fermion masses and mixing angles

The experimental fact that neutrinos are massive makes this task even more involved:

$$\frac{m_t}{m_u} \sim 10^5, \qquad \frac{m_\tau}{m_e} \sim 10^3, \qquad \frac{m_e}{m_\nu} \gtrsim 10^6$$

$$\mathcal{M}_{\text{CKM}} = \begin{pmatrix} 0.9745 - 0.9760 & 0.217 - 0.224 & 0.0018 - 0.0045 \\ 0.217 - 0.224 & 0.9737 - 0.9753 & 0.036 - 0.042 \\ 0.004 - 0.013 & 0.035 - 0.042 & 0.9991 - 0.9994 \end{pmatrix}$$

$$\mathcal{M}_{\text{MNS}} = \begin{pmatrix} 0.73 - 0.89 & 0.45 - 0.66 & < 0.24 \\ 0.23 - 0.66 & 0.24 - 0.75 & 0.52 - 0.87 \\ 0.06 - 0.57 & 0.40 - 0.82 & 0.48 - 0.85 \end{pmatrix}$$

Again, as usual in string theory, one can find interesting mechanisms to try to explain these experimental results.

For example, if the Yukawa coupling for the neutrino is of order m_e and the see saw scale is 1 TeV, then the expected neutrino mass is

$$\frac{m_e^2}{1\ TeV} = 0.25 \text{ eV}$$

This suggests that a natural situation is one in which a see-saw mass of order a few TeV is generated by the electroweak symmetry breaking.

$$W_\nu \sim \lambda_\nu \langle H_2^0 \rangle \bar{\nu}_L \nu_R + \langle N \rangle \nu_R \nu_R + \langle N \rangle H_2^0 H_1^0$$

with $\lambda_\nu \sim e^{-R^2}$ and therefore very small,

and $\langle N \rangle \sim 1$ TeV

But recall:
to implement any mechanism in a particular model
is highly non-trivial

However, since we are optimistic people, we can argue that if the Standard Model arises from strings, there must exist at least one model with

the correct structure for Yukawas

This means:

1) with the necessary Yukawa couplings

$$H_2^0\ \bar{u}_L \lambda_{uu} u_R + H_2^0\ \bar{u}_L \lambda_{uc} c_R + \ldots + H_1^0\ \bar{d}_L \lambda_{db} b_R + \ldots$$

2) with the correct order of magnitude

i.e. one is able to put by hand the values of T_i such that

$$\lambda_t(T_i) \sim 1, \ \ \lambda_u(T_i) \sim 10^{-5}, \ldots$$

If, at the end of the day, such a model exists,
this would be a great success

But, in order to be sure that this is really the superstring standard model on should be able to compute explicitly the values of the Yukawas, $\lambda(T_i)$, and for this we need to know the $< T_i >$

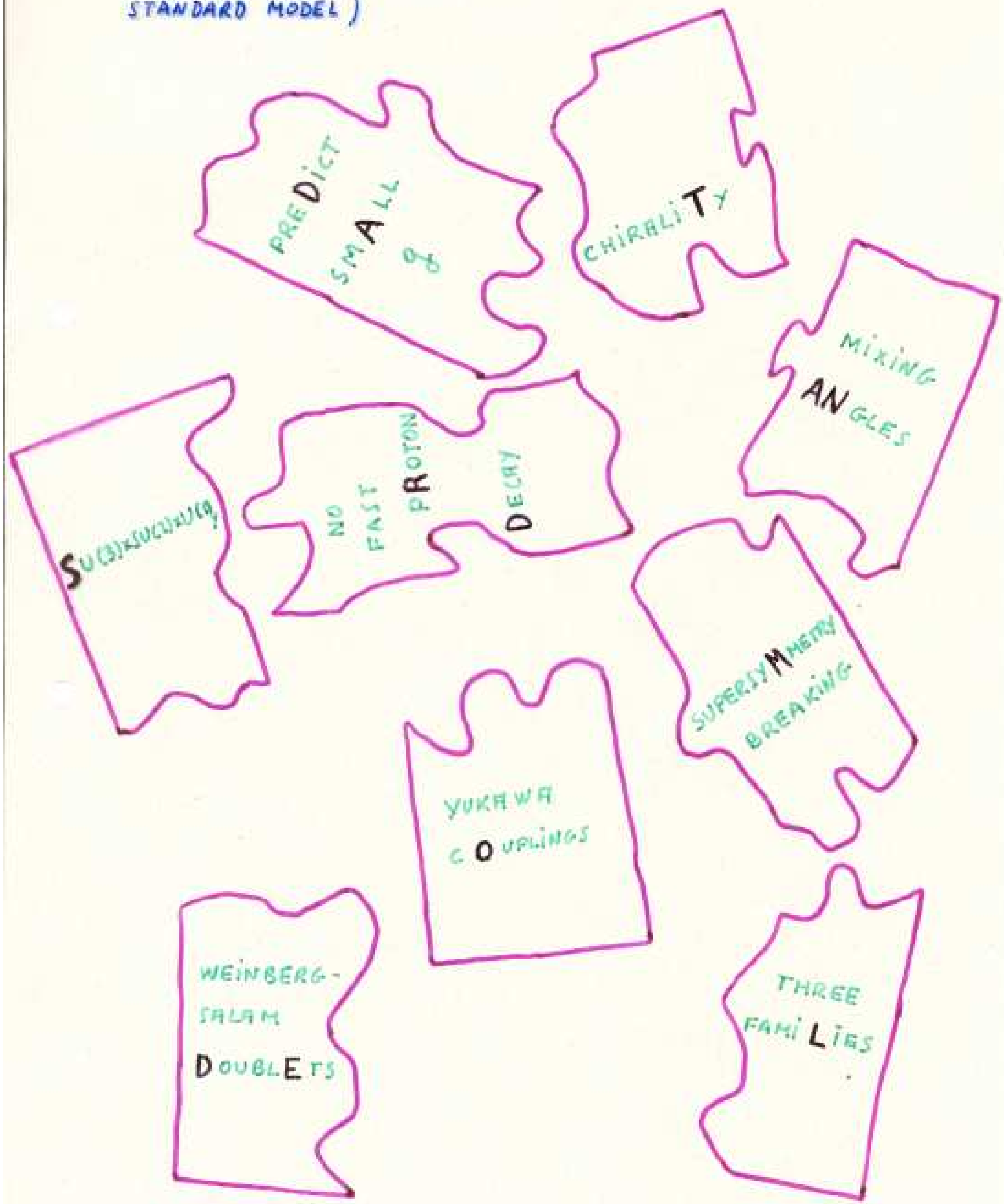
Unfortunately, these are related to the breaking of SUSY, and...

this is one of the biggest problems in strings

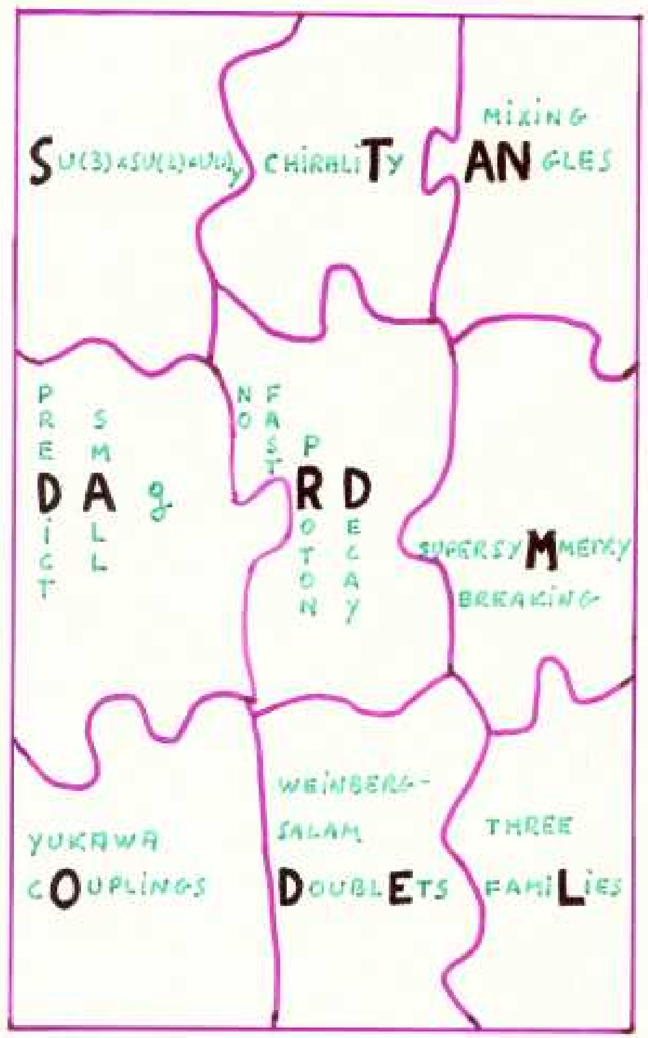
It is true that there are candidates for this task, such as gaugino condensation in a hidden sector $W(S, T_i)$, and that we have hidden-sector gauge groups that could condensate

But, again, implementing this mechanism in a particular model is not easy

WE HAVE GENERAL MECHANISMS FROM STRING THEORIES TO EXPLAIN "ALMOST EVERYTHING" (THE PROPERTIES OF THE STANDARD MODEL)



THE "ONLY" TASK WE HAVE TO DO IS TO ASSEMBLE ALL THE PIECES IN A SINGLE MODEL



In a sense, the problem of string theory is that it is too ambitious: the correct model must reproduce:

- Gauge group
- Three families
- Gauge couplings
- Masses of quarks and leptons
- CKM matrix
- ...

The more than 20 parameters fixed by the experiment in the standard model

In addition, there are thousands of models (vacua)

Some of them with

- the standard-model gauge group or GUT groups
- three families
- ...

but others with

- number of families $\neq 3$
- no appropriate gauge groups
- no appropriate matter
- ...

A nice way of solving this problem would be

to use a dynamical mechanism to select the correct model

$$DM$$

$$\downarrow$$

A point in the parameter space of the heterotic string determining the correct compactification with

$$SU(3) \times SU(2) \times U(1)_Y$$

$$3 \times \{(3,2) + 2(\bar{3},1) + (1,2) + 1 + 1\} + \text{Higgses}$$

and such that

$< S, T_i >$ generate the correct values for

$$g_3, g_2, g_1,$$
$$m_u, m_d, m_c, m_s, m_t, m_b,$$
$$m_\tau, m_\mu, m_e, m_{\nu_e}, m_{\nu_\mu}, m_{\nu_\tau},$$
$$\delta, \theta_c, \ldots$$

Unfortunately,
this marvellous (top-bottom) mechanism is

UNKNOWN

So, for the moment, the best we can do is ...

KEEP TRYING !

i.e. to use the experimental results available (such as $SU(3) \times SU(2)_L \times U(1)_Y$, 3 families, fermion masses, mixing angles, etc.), to discard models

But remember, the model space is huge

Fortunately, it can be reduced

e.g. Z_3 orbifold with two Wilson lines

$\sim$ 50000 models with $SU(3) \times SU(2) \times U(1)^5$ and 3 families

but the number of inequivalent models is

$$192$$

Still, to analyze each one of these models is painful

Summarizing: to obtain a connection between (string) theory and present (standard-model) experiments is possible in principle but difficult in practice

What about future experiments (such as LHC) ?

If Nature is SUSY at the weak scale, as many string phenomenologists believe(d), eventually the spectrum of SUSY particles will be measured providing us with a possible connection with the high-energy world of superstrings

This is because in superstring constructions:

- There is a natural hidden sector built in, S, T_i
- $K(S, S^*, T_i, T_i^*)$, $f(S, T_i)$ are known

$$\Downarrow$$

The soft terms, m_α, M_a, ..., can be computed and compared with the experimentally observed SUSY spectrum: 'SOFT' PHENOMENOLOGY

This will not be sufficient to select the (superstring) standard model, but probably will allow us to discard many constructions

[In addition, if experimentalists find some extra particles, this may also help]

But then another problem arises:
the soft terms get a contribution from the cosmological constant, $m_\alpha^2 \sim m_{3/2}^2 + \frac{V_0}{M_P^2}$,
and...

$V_0 \neq 0$ is one of the biggest problems in particle physics

If we use a specific mechanism for the breaking of SUSY, this may be specially disturbing,
e.g. in gaugino condensation $V_0 \sim -m_{3/2}^2 M_P^2$

In the late nineties, it was discovered that explicit $SU(3) \times SU(2) \times U(1)_Y$ models with interesting properties can also be constructed using D-brane configurations from type I string vacua

[or heterotic M-theory]

$\Downarrow$

More models to analyze

but also...

The Pandora's box opened

Large extra dimensions

no SUSY

$M_{string} << M_{Planck}$

...

Unfortunately, we still have a hierarchy problem

For instance, embedding the Standard Model inside D3-branes in type I strings

$$\frac{M_{string}^4}{M_c^3} = \frac{\alpha M_{Planck}}{\sqrt{2}} = 3.5 \times 10^{17} \text{ GeV}$$

E.g. one gets $M_{string} \approx 10^{11}$ GeV with $M_c \approx 10^9$ GeV

However, those values would imply

$$S = 1/\alpha \simeq 24 \ , \quad T = \frac{1}{\alpha}\left(\frac{M_{string}}{M_c}\right)^4 \simeq 10^9$$

Of course, if we want to have $M_{string} \approx 1$ TeV the hierarchy is even worse

E.g., using $M_{string}^4 = M_1 M_2^2$ $(3.5 \times 10^{17}$ GeV), $M_1 \sim 10^{-13}$ GeV and $M_2 = M_3 \sim 10^4$ GeV produce,

$$M_{string} \sim 1 \text{ TeV}$$

But then, $S = 1/\alpha \simeq 24$

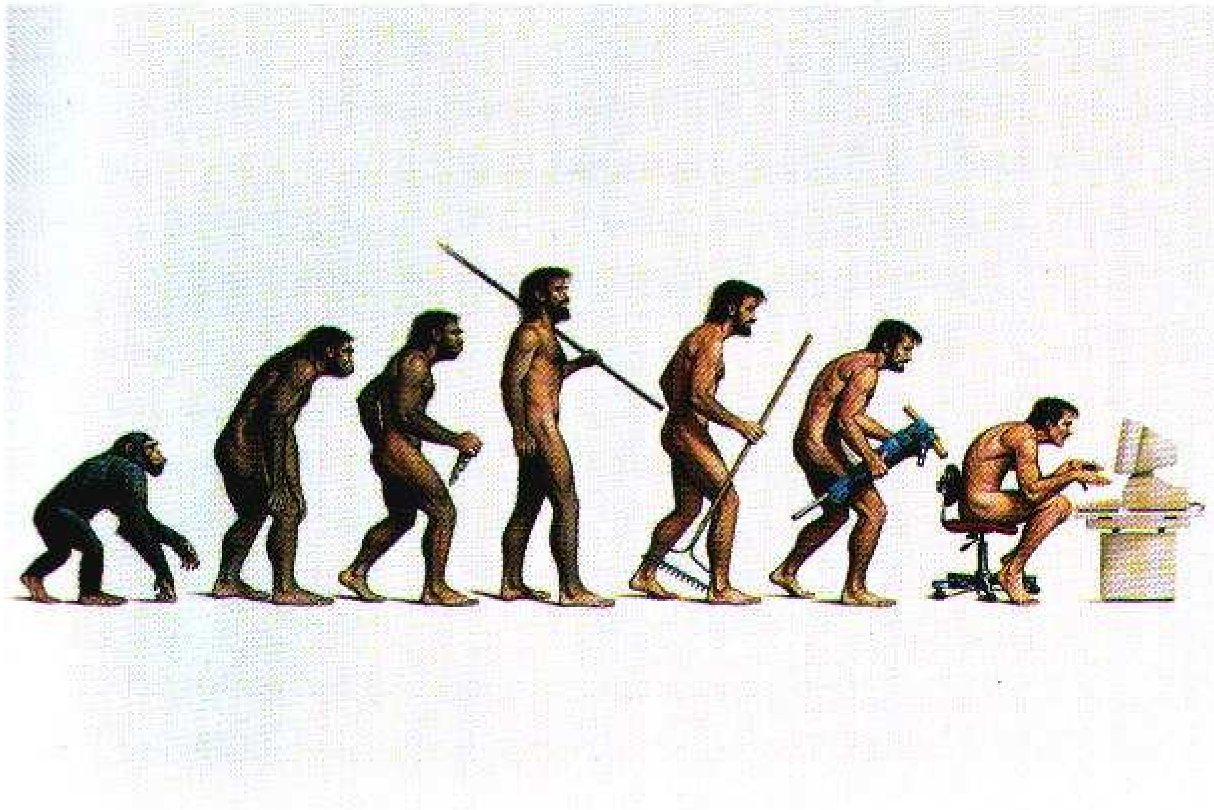
and $T_2 = \frac{1}{\alpha}\left(\frac{M_{string}^4}{M_1^2 M_3^2}\right) \simeq 10^{31}$, $T_1 = \frac{1}{\alpha}\left(\frac{M_{string}^4}{M_2^2 M_3^2}\right) \simeq 10^{-3}$

In any case, these are the new superstars, and ...

SUSY, Planck scale physics, small extra dimensions,..., or anything not involving D-branes is out of fashion

Statistics of this meeting:

Subjects of the talks	**Number**
Branes	17
Heterotic string	8
M-theory	7
Supersymmetry	7
Cosmology	5
D=5 constructions	3
Accelerators	2
Quantum gravity	1
AdS	1
Non-commutative	1
Electroweak	1
Neutrinos	1
...	...



Evolution: from the monkey to the string phenomenologist (year 1985).

A PHOTOGRAPH EXPLAINING WHAT IS GOING ON, CONCERNING THE SEARCH OF THE STANDARD MODEL FROM STRINGS, IN 1988, WILL BE READY SOON HERE

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A kind of prediction from superstring model building

C. Muñoz

Theory Division, CERN, CH-1211 Geneva 23, Switzerland.

Departamento de Física Teórica C-XI, Universidad Autónoma de Madrid, Cantoblanco, 28049 Madrid, Spain.

Instituto de Física Teórica C-XVI, Universidad Autónoma de Madrid, Cantoblanco, 28049 Madrid, Spain.

Abstract

Assuming that the Standard Model of particle physics arises from Type IIB compactified on an orientifold with D5-branes intersecting at angles on T^4, we predict that David Beckham will play in Real Madrid in 2003. As a by-product our analysis implies that David and Victoria Beckham live at the intersections.