Gauge Unification from Split Supersymmetric String Models

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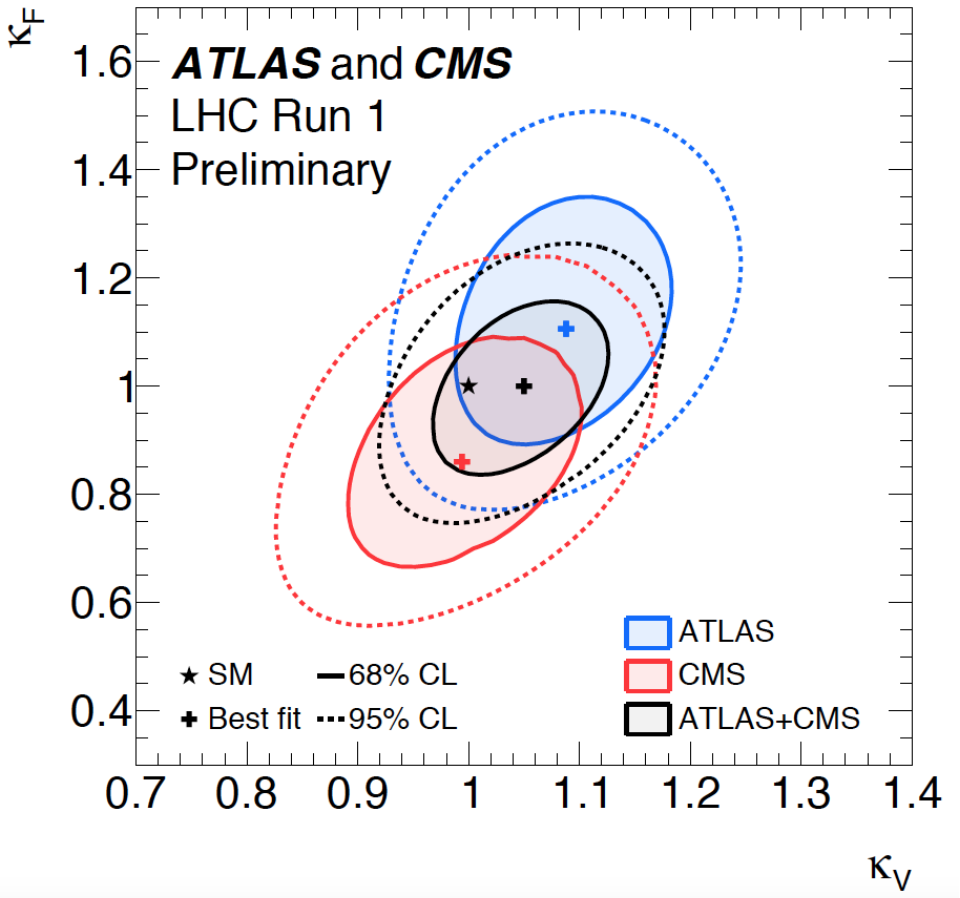
ATLAS and CMS experiments shed light on Higgs properties



combined 2011 & 2012 results-> May 2015-> clearly shows improvement in precision (also G.Tonelli in the school)

...all experinents consistent up to now...with the SM ...?..BUT ..!

Standard model is an incomplete theory

WHY ?

1) does not incorporate **GRAVITY**

2) *Dark matter and dark energy*

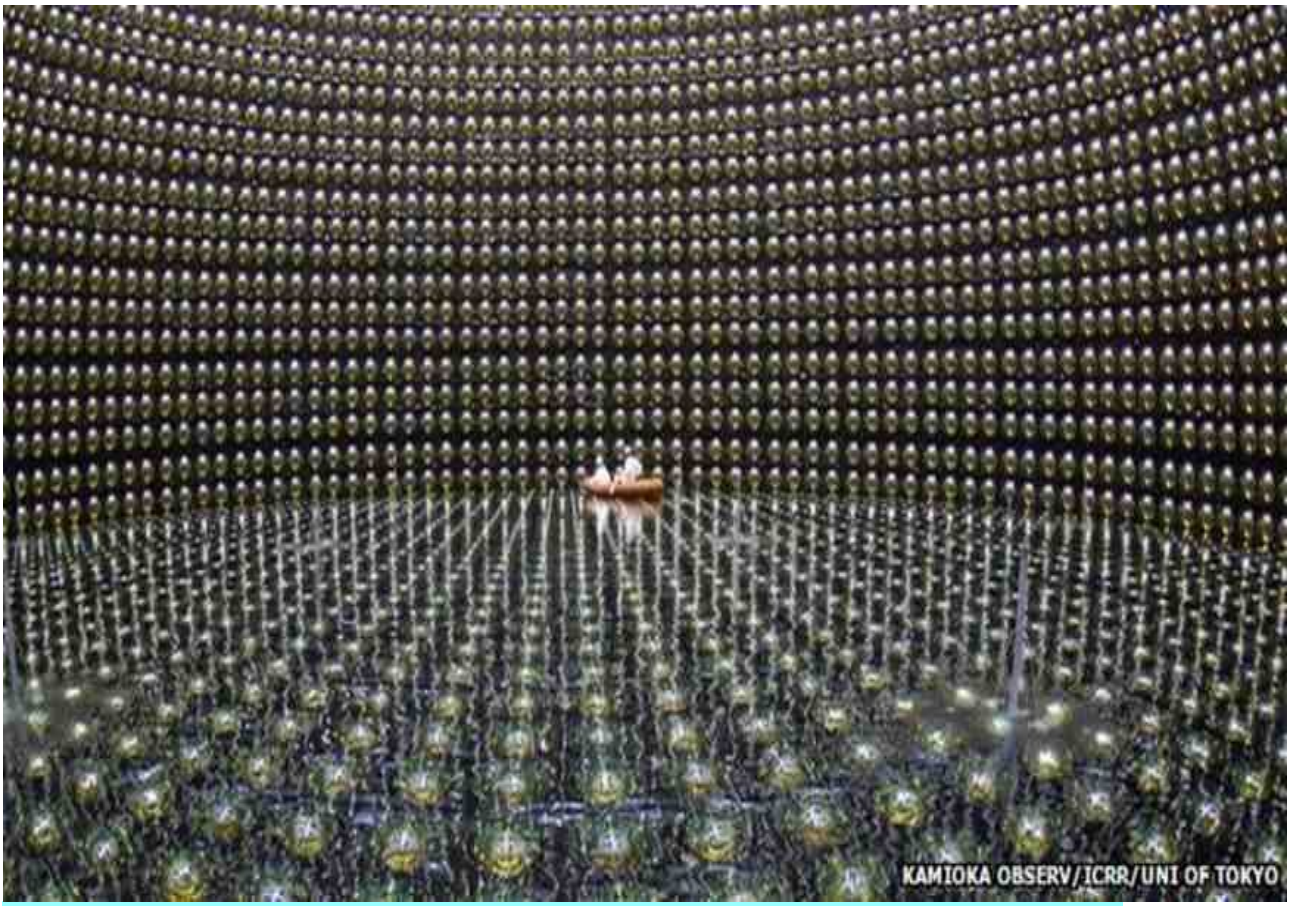
Cosmological observations tell us the standard model explains about 5% of the matter present in the universe --> About ~27% should be dark matter, which would behave just like other matter, but which only interacts weakly (if at all) with the Standard Model fields

3) *Neutrinos*

At the SM $m_\nu = 0$, but

measurements however indicated that neutrinos spontaneously change flavour, which implies that neutrinos have a mass.

This necessitates an extension of the standard model, which not only needs to explain how neutrinos get massive, but also why the mass is so small



Super-K looks for the faint flashes of light emitted when passing neutrinos interact with its water

●●●

SOLUTION>

The SM may be extended BEYOND..

1st possibility=>use

N=1 SUSY (Supersymmetry)

to promote

SM > SSM

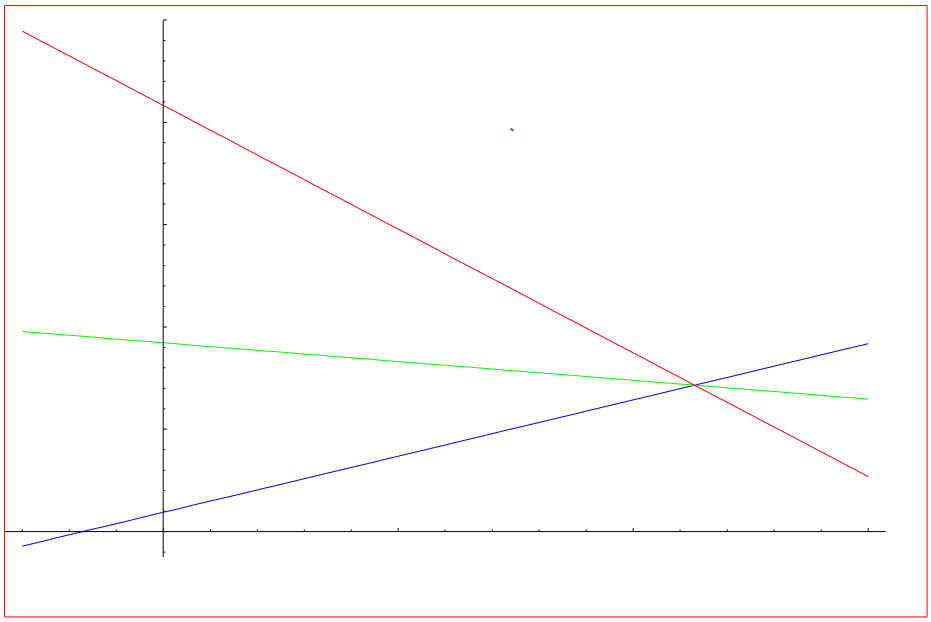
- For every Standard Model particle there exists its supersymmetric partner with the same charge but with different spin

- Solves the gauge hierarchy problem

- Gauge couplings unify at the unification scale/energy

$M_{GUT} \sim 2 \cdot 10^{16}$ GeV

SSM Gauge unification



SU(5) gauge unification :$1/\alpha$ vs log E (SU(3), SU(2), $U(1)_Y$ gauge couplings) :Running couplings in the SSM at one-loop/ from top to bottom, $\alpha 1^{-1}$, $\alpha 2^{-1}$, $\alpha 3^{-1}$

S.Dimopoulos, S.Raby and F.Wilczek
L. E. Ibanez and G. G. Ross
S. Dimopoulos and H. Georgi
N. Sakai

The SM RG equations for SU(3), SU(2), $U(1)_Y$

$$\frac{1}{\alpha_s(M_s)} = \frac{1}{a_s(M_s)} - \frac{b_3}{2\pi} \ln|\left(\frac{M_z}{M_s}\right)$$

$$\frac{1}{\alpha_w(M_s)} = \frac{1}{a_w(M_s)} - \frac{b_2}{2\pi} \ln|\left(\frac{M_z}{M_s}\right)$$

$$\frac{1}{\alpha_Y(M_s)} = \frac{1}{a_Y(M_s)} - \frac{b_1}{2\pi} \ln|\left(\frac{M_z}{M_s}\right)$$

Remark..!

In a gauge theory context, there is no fundamental reason from first principles why the unification scale should be so high, if not by accident..!

However

in the (perturbative) Heterotic String Theory >

▼

the string scale M^{STRING} is determined

$$M_{STRING} \stackrel{def}{=} \frac{2e^{(1-\gamma))}}{\sqrt{27\pi\alpha'}} \approx\approx 0.7\ g_{STRING}\ 10^{18}\ GeV$$

V. Kaplunovsky; J.P. Derendinger, S. Ferrara, C. Kounnas, F. Zwirner

BUT

(FORGETING PROTON DECAY PROBLEMS....!!)

it appears that M^{STRING} is 2 orders of magnitude LARGER than that of the SUSY gauge theory $M_{GUT} \sim 2\ 10^{16}$ GeV

Several explanations..were invoked to reconcile the apparent discrepancy...▲ threshold corrections,

► extra states etc.

INSTEAD..IN THE

FOLLOWING

WE PREFER TO STUDY..

A STRING THEORY

where

THE STRING UNIFICATION SCALE

is A FREE PARAMETER..

► .. COULD BE "ADJUSTED" (NATURALLY) TO COINCIDE

with the

SSM UNIFICATION SCALE

+ a conserved baryon ≠

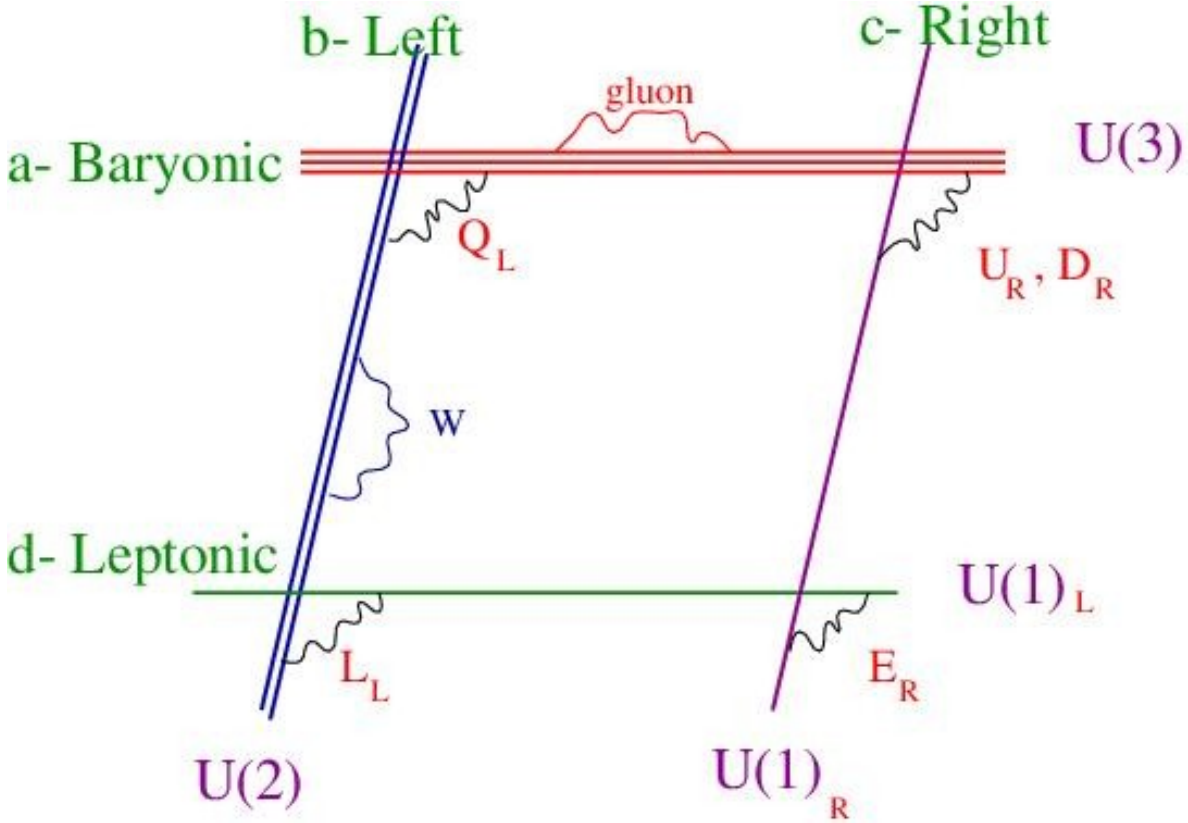
*****SPLIT SUPERSYMMETRIC MODELS _ DO NOT NEED SUPERSYMMETRY TO SUPPORT THEIR EXISTENCE...!!!!

******

Such > String Theories exist>

Four dimensional compactifications of 10D IIA orientifolds with D6 branes intersecting at angles

[R.Blumenhagen,L.Goerlich,B.Kors,D.Lust-Berlin Group], [L.Ibanez, F.Marchesano,R.Rabadan, D.Cremades,**C.K-**Madrid Group]



Fermions appear as open strings stretched at the intersections between the D6-branes

SPLIT SUSY as a Gauge Theory

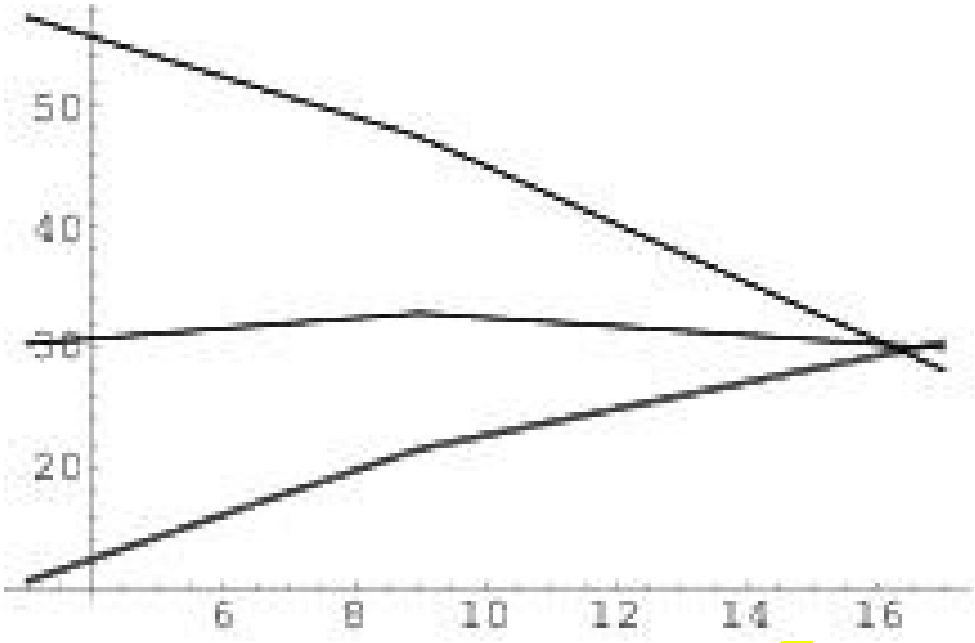
(N. Arkani-Hamed, S. Dimopoulos '04)

• does not solve the Gauge Hierarchy problem but keeps the unification and dark matter candidate

• Gauge couplings unify at a scale < 10^{16} GeV

•all superpartners become massive, & Higgsinos, gauginos remain at low energy

• (claim)there is a light and a heavy Higgs



Running couplings at one-loop, with the scalars at 10^9 GeV -table 1

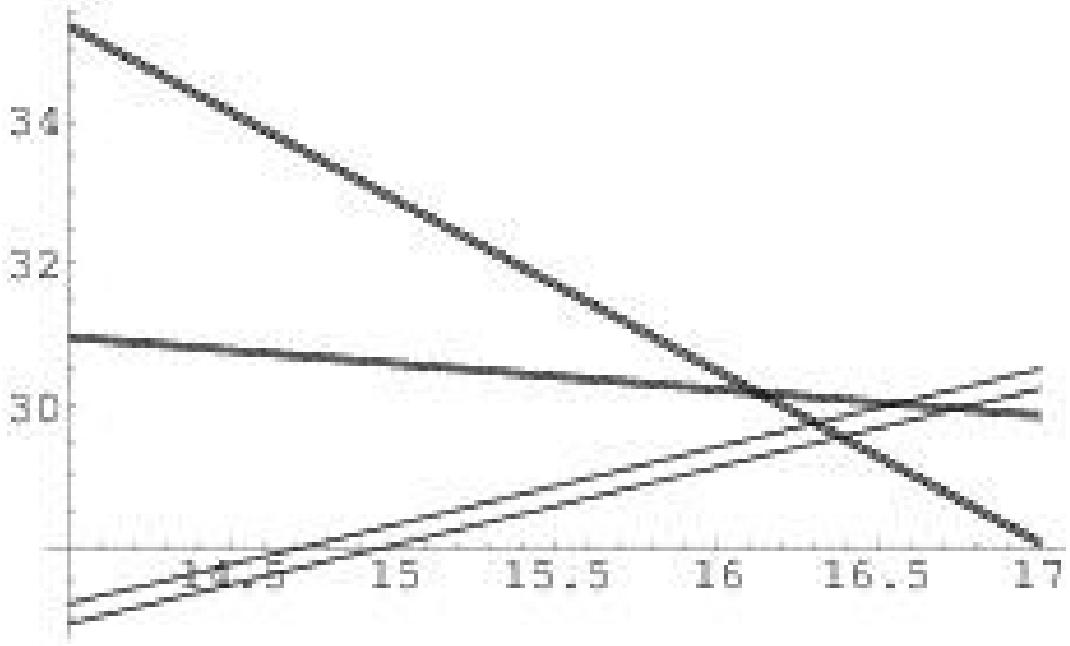


table 2 - Close-up of the one-loop couplings near the unification scale with the heavy scalars at 10^9 GeV. Note that the prediction for $\alpha_3(M_Z)$ is lower than in the SSM.

We observe partial unification of the gauge couplings...

With the SM + Higgsinos > Unification at ~10^{14} GeV

Split Susy in String Theory

(I.Antoniadis, S.Dimopoulos, C. K /'04)

String Theory can achieve SPLIT SUSY if a number of conditions are satisfied :

i) $\mathrm{Sin}^2 \Theta w = 3/8$ at the string/ unification scale even with partial unification of 2 of the 3 gauge couplings of the SM

ii) there are light gauginos in the presence of gravity

iii) there are light Higgsinos

(you don't need N=1SUSY)

I.Antoniadis and S.Dimopoulos(2004)

Explicit string realizations > C.K(2004)

1*Model	Particles	$(\mathbf{SU(3)} \times \mathbf{SU(2)})_{(\mathbf{Q_a},\mathbf{Q_b},\mathbf{Q_c})}$	$\mathbf{U(1)^Y}$
7* $MSSM$	$\{Q_L\}$	$3(3,2)_{(1,\ -1,\ 0)}$	$1/6$
	$\{u_L^c\}$	$\#\ = 3(3,1)_{(2,\ 0,\ 0)}$	$-2/3$
	$\{d_L^c\}$	$3(3,1)_{(-1,\ 0,\ -1)}$	$1/3$
	$\{L\ +\ H_d\}$	$6(1,2)_{(0,\ 1,\ -1)}$	$-1/2$
	$\{H_u\}$	$3(1,\bar{2})_{(0,\ -1,\ -1)}$	$1/2$
	$\{e_L^+\}$	$\#^- = 3(1,1)_{(0,\ -2,\ 0)}$	1
	$\{N_R\}$	$\#\ = 9(1,1)_{(0,\ 0,\ 2)}$	0
2*Extra Matter	$\{C_1\}$	$3(3,\ 1)_{(1,\ 0,\ -1)}$	$1/3$
	$\{C_2\}$	$3(\bar{3},1)_{(-1,\ 0,\ -1)}$	$-1/3$

3 - generation non-supersymmetric model with the fermion content of N=1 MSSM on top of the table + N_R's + 3 pairs of H_u, H_d Higgsinos >

> A four dimensional String model realization of Split supersymmetry : massless spectrum of IIA orientifolds with D6-branes intersecting at angles

The extra matter C_1 C_2 become massive, leaving at low energies the rest of the spectrum:

SM+ 3 pairs of Higgses + 3 pairs of Higgsinos-->partial unification as in table 1 at $M_{STRING} \sim 5.03 \times 10^{13}\ GeV$

Matter	$(SU(3) \times SU(2))_{(Q_a,Q_b,Q_c)}$	$U(1)^Y$
$\{Q_L\}$	$3(3,2)_{(1,\ 1,\ 0)}$	$1/6$
$u_L^c\}$	$3(\bar{3},1)_{(2,\ 0,\ 0)}$	$-2/3$
$\{d_L^c\}$	$3(3,1)_{(-1,\ 0,\ 1)}$	$1/3$
$\{L\}$	$3(1,2)_{(0,\ -1,\ -1)}$	$-1/2$
$\{e_L^+\}$	$3(1,1)_{(0,\ -2,\ 0)}$	1
$\{N_R\}$	$3(1,1)_{(0,\ 0,\ 2)}$	0

Table 1: A three generation chiral (open string) spectrum accommodating the split susy SM with no Higgsinos & $sin^2\theta = 3/8$. The value of $sin^2\theta$ comes from the "presence" of an SU(5)-like unification relation at the string scale that relates the gauge couplings of the SM gauge groups.

SM + 6 Higgses at low energy- *partially* unify as in table 1 at (gauginos receive loop corrections):

$$\mathrm{M}_{STRING} = 5.03 \times 10^{13}\ GeV$$

Because at the string scale> C.K 2014

$$\frac{1}{a_Y} = \frac{2}{3}\frac{1}{a_s} + \frac{1}{a_w}$$

or

$$\frac{2}{3}\frac{1}{\alpha_s(M_Z)} + \frac{2sin^2\theta_w(M_Z)-1}{\alpha_{em}(M_Z)} = \frac{B}{2\pi}\ \ln\frac{M_Z}{M_s}\ ,$$

$$B = -\frac{2}{3}b_3 + b_2 - b_Y$$

=>IF THE NUMBER OF HIGGSES IS 1, 3, 6 >String Theory Standard Model couplings partially unify at

$M_S \sim 5.03\ 10^{13}$ GeV

..Conclusions..

Split supersymmetry is a beautiful idea that originated in a gauge theory context and is accommodated naturally in the massless spectrum of a special class of non-supersymmetric string theories
(based on four dimensional compactications of IIA string theories on the orientifolded torus $\mathrm{T}^6/Z_3 \times Z_3$)