UNIFICATION OF GAUGE COUPLINGS IN PRESENCE OF LARGE EXTRA DIMENSIONS

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ICHEP-2000, PA-10 (e)
(work done in collaboration

: D. Dumitru + S. Nandi,
Phys. Rev. D (to appear)

: J. Lykken + S. Nandi
(Phys. Lett. B, to appear)

A3. D. A. Dicus, C. McMullen + S. Nandi (to appear)

: Unification of gauge couplings for

A) $\mu_{SUSY} < \mu_0$

↑ SUSY Breaking Scale

↑ compactification scale

B) $\mu_{SUSY} > \mu_0$ ⇐ new possibility

⇒ allow unification at a scale ~ few tens of a TeV.

: Asymmetric compactification scenario

⇒ phenomenological implications (new physics at LHC)

(2)

UNIFICATION OF SM COUPLINGS IN PRESENCE OF EXTRA DIMENSIONS

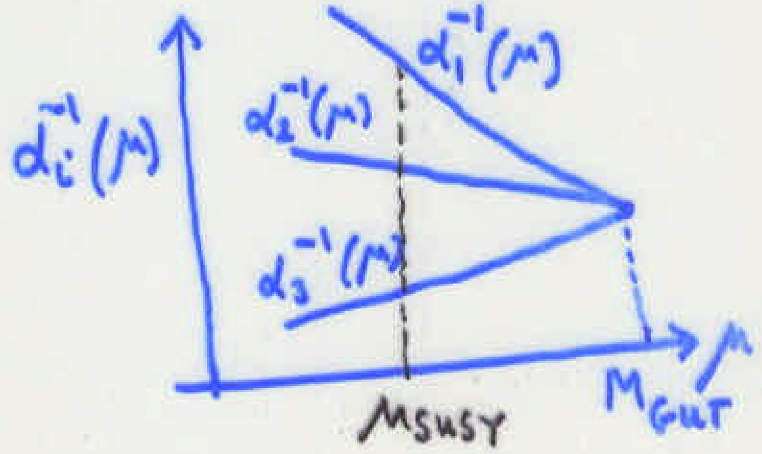
4-dim ⇒ Weak scale, M_W ; Planck Scale, M_{PL}

: There exist another scale, GUT scale, M_{GUT}

⇓

Scale at which three SM couplings $\alpha_1, \alpha_2, \alpha_3$ unify.

In MSSM, $M_{GUT} \sim 2 \times 10^{16}$ GeV



: In 4+n dim,

M_{GUT} can be drastically alterned.

: Evolution changes from logarithmic to power laws above decompactification threshold, μ_0 due to contribution of the KK excitations of SM particles.

Dienes, Dudas + Gherghetta (one loop)

For $\mu < \mu_0$: (2-loop)

$$\mu \frac{d\alpha_i(\mu)}{d\mu} = \frac{b_i}{2\pi}\alpha_i^2(\mu) + \sum_{j=1}^{3} \frac{b_{ij}}{8\pi^2} \alpha_i^2(\mu)\,\alpha_j(\mu) \qquad (1)$$

For $\mu > \mu_0$: (1-loop)

$$\alpha_i^{-1}(\mu) = \alpha_i^{-1}(\mu_0) - \frac{b_i - \tilde{b}_i}{2\pi} \ln\frac{\mu}{\mu_0} - \frac{\tilde{b}_i\, X_\delta}{(2\pi)\,\delta}\left[\left(\frac{\mu}{\mu_0}\right)^{\delta} - 1\right] \qquad (2)$$

here, δ = # of extra dim SM particles see.

$\tilde{b}_i \to \beta$-function coefficients including the contribution of the KK modes

$$X_\delta = \frac{2\pi^{\delta/2}}{\delta\,\Gamma(\frac{\delta}{2})}$$

Set $\mu_0 = M_Z$, $\mu = \Lambda$

Define $\alpha_3(M_Z) \equiv x$, $\frac{\Lambda}{\mu_0} \equiv y$, $\alpha_{GUT} \equiv z$

unification $\Rightarrow \alpha_1(\Lambda) = \alpha_2(\Lambda) = \alpha_3(\Lambda) = \alpha_{GUT}$ (3)

Solve (1) and (2) for (x, y, z) using matching conditions at μ_0, and constraints (3)

DEMAND $\Rightarrow \alpha_3(M_Z)$ lies in 0.1191 ± 0.0018 (1σ)

: need $\tilde{b}_i$

For $\mu_0 < \mu < M_{SUSY}$

$$\tilde{b}_i^{SM} = \left(\frac{1}{10}, -\frac{41}{6}, -\frac{21}{2}\right) + \eta\left(\frac{8}{3}, \frac{8}{3}, \frac{8}{3}\right)$$

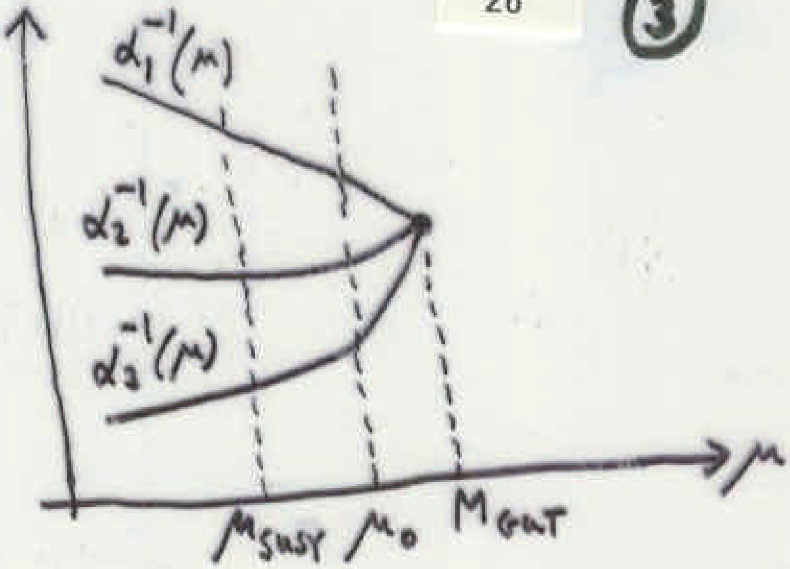
For $\mu > M_{SUSY}$,

$$\tilde{b}_i = \left(\frac{3}{5}, -3, -6\right) + \eta\,(4, 4, 4)$$

$\eta \to$ # of fermion families seeing extra dim.

(3)

In $n+4$ dim :



$M_{GUT} \sim 2\mu_0$ ($n=6$)
to $20\mu_0$ ($n=1$)

$\mu_0 \rightarrow$ decompactification scale

: M_{GUT} can be low $\Rightarrow$ eliminate gauge hierarchy problem

: Possibility of GUT physics at LHC !

However,

D. Ghilencea & G.G. Ross

(two loop below μ_0, one loop above μ_0)

$\Rightarrow$ Low scale unification fails.

Use $\alpha_1^{-1}(M_Z) = 58.995$, $\alpha_2^{-1}(M_Z) = 29.571$ } $M_Z = 91.187$ GeV, $m_t = 175$ GeV

: Evolve $\alpha_1(\mu)$ and $\alpha_2(\mu)$ to find M_{GUT}, then evolve back $\alpha_3(\mu)$ to get $\alpha_3(M_Z)$.

$\Rightarrow$ gives much higher value of $\alpha_3(M_Z)$

$$\alpha_3(M_Z)\big|_{EXPT} = 0.1191 \pm 0.0018$$

Dienes, Dudas & Gherghetta

: Many uncertainties due to various threshold corrections. A 6% threshold effect at the GUT scale can remedy the situation.

Procedure: choose μ_0 and search for M_{SUSY} that lead to Unification, and acceptable values for $\alpha_3(M_Z)$ within 1σ and 3σ.

Results:

case 1) $\mu_0 > M_{SUSY}$

⇒ no solution for M_{SUSY} and μ_0 in the 100 TeV range or less. } ignoring threshold corrections (Fig)

case 2) $\mu_0 < M_{SUSY}$

⇒ Solutions for μ_0 and M_{SUSY} in the few TeV range with M_{GUT} in few tens of TeV (Fig + table)

⇒ Possibility of producing KK excitations and observing String dynamics at LHC !!

4a

Dumitru + Nandi

$\mu_0 > M_{SUSY}$

$\delta = n$ = # of extra dim.

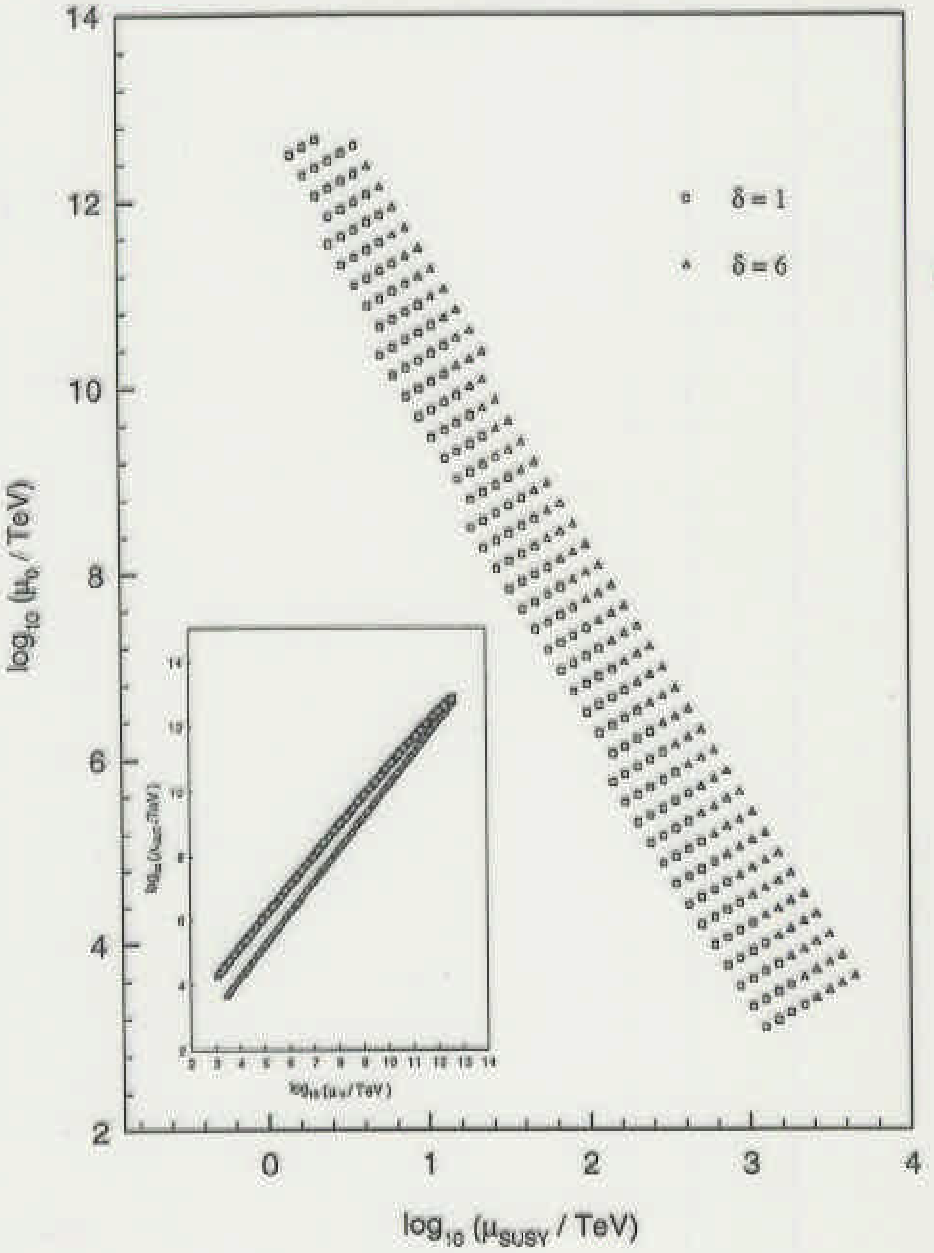


Figure 2: Scattered plot of the allowed compactification scales, μ_0, for various SUSY breaking scales, μ_{SUSY}. Only results within 1σ of $\alpha_3(M_Z)$ are presented. The same set of points as for the previous plot was used. Unification is spoiled for points lying outside the corresponding bands. The inset figure gives the unification scale against the compactification scale.

A NEW POSSIBILITY

: SUSY broken at higher dim.
(before decompactification)
$\mu_0 < M_{SUSY}$

Dumitru + Nandi

Plausible mechanisms:

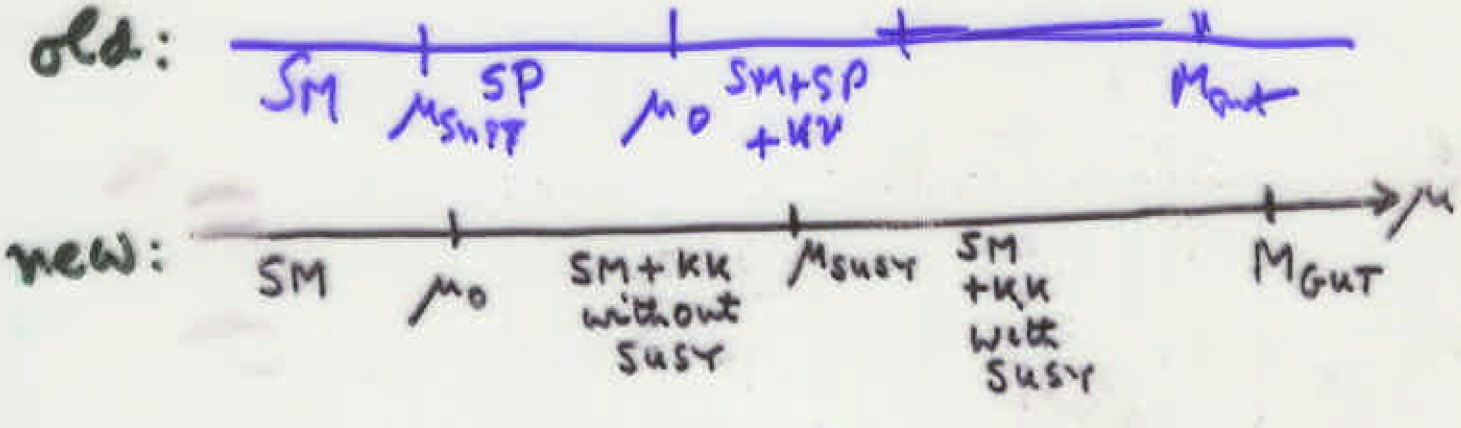
: SUSY broken at string level (non-SUSY string) ← Dienes

· gaugino condensation in 4+n dim.

: SM lives in non-BPS branes
does not preserve SUSY

Result ⇒ can achieve low scale unification, M_{GUT} ~ few tens of a TeV

⇒ GUT and string physics at LHC!



(5a)

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$\mu_0 < \mu_{SUSY}$

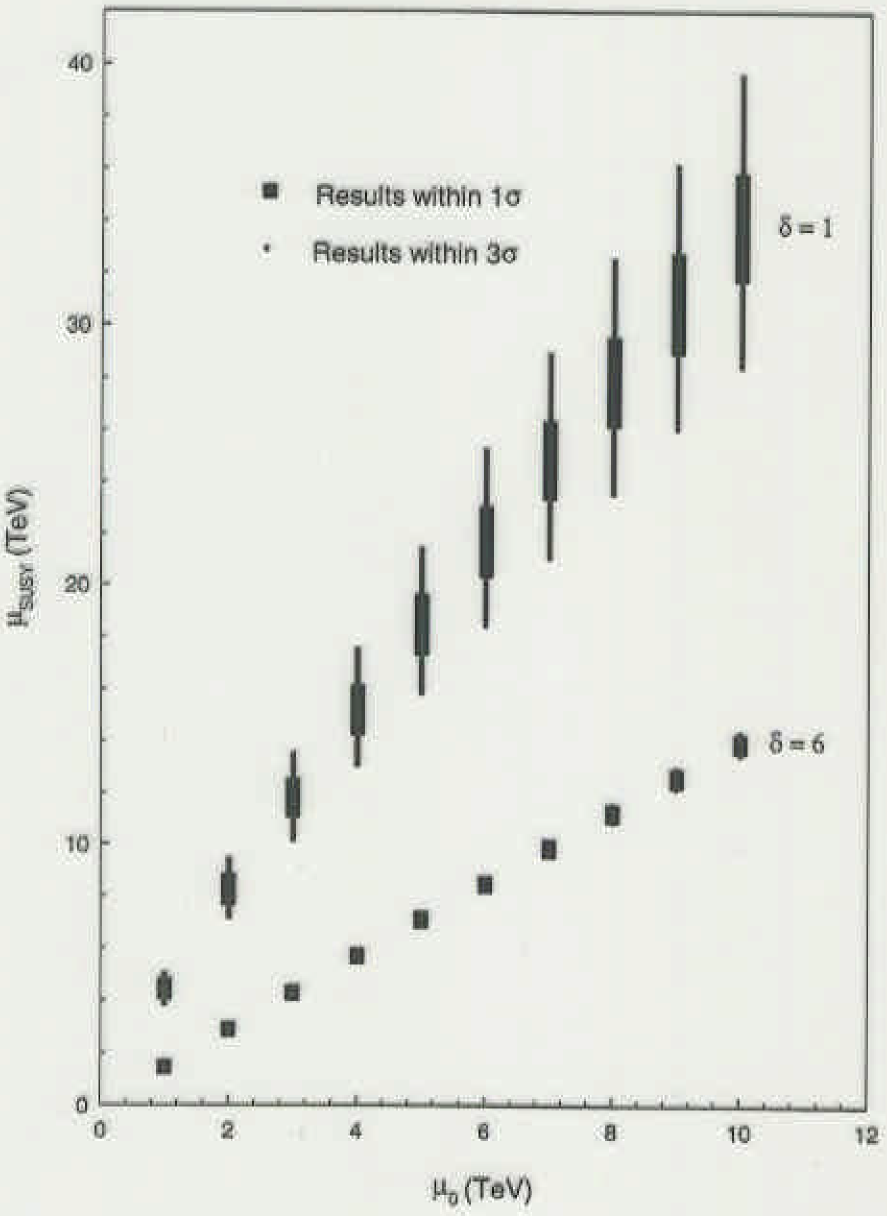


Figure 3: Allowed values of SUSY breaking scale, μ_{SUSY}, for various choices of μ_0 in a scenario with $\mu_0 < \mu_{SUSY}$. Results within 1σ and 3σ of $\alpha_3(M_Z)$ are presented, for $\delta = 1$ and $\delta = 6$. Unification is spoiled if μ_{SUSY} lies outside the corresponding vertical spreads shown in the plot.

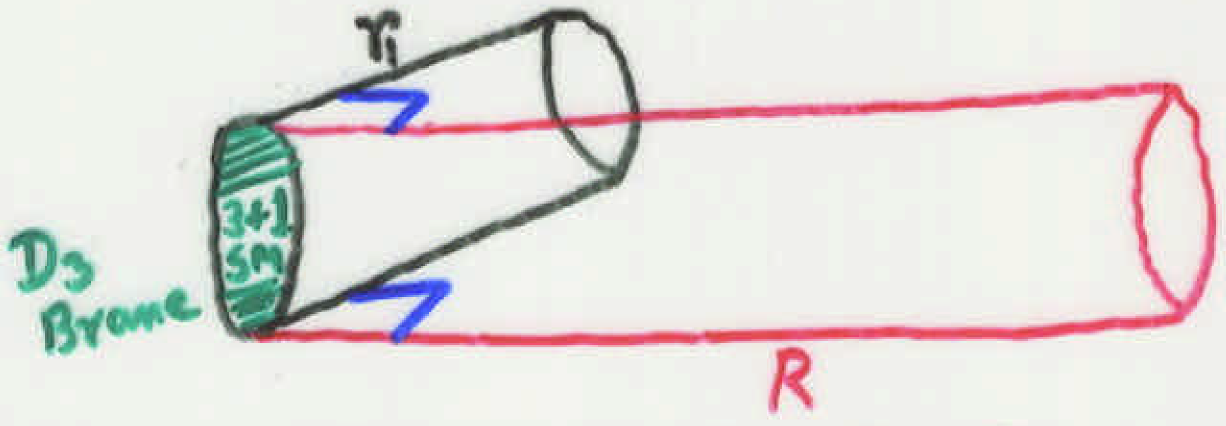
An asymmetric compactification scenario: (Lykken + Nandi)

: realizes gauge coupling unification with $\mu_{\text{compactification}} \sim$ few TeV

: has a single mm size extra dim. (R)

: five TeV^{-1} size extra dim. (r)

: SM gauge bosons see only <u>one</u> TeV^{-1} extra dim. $(r_1) \Rightarrow D_4$ brane



: only gravity propagate along R

: SM fermions confined to D_3 brane

: Gauge coupling unification $\sim \frac{20}{r} \sim 20\mu_0$

Scaling relation:

$$M_{PL}^2 = M^{n+m+2} \; R^n \; r^m$$

10^{19} GeV (→ M_{PL})

$n=1, \quad m=5$

works for: $\frac{1}{R} \sim 10^{-3}$ eV (→ mm size)

$\frac{1}{r} \sim 1$ TeV (→ collider observability)

$\Rightarrow M \sim 100$ TeV

$M \Rightarrow$ fundamental $n+4$ dim. Planck scale

$M_{PL} \Rightarrow$ effective 4 dim. Planck scale $\sim 10^{19}$ GeV.

COLLIDER IMPLICATIONS

: KK excitations of gauge bosons can be probed at LHC (NLC)

$$q\bar{q} \to g_1^* \to q\bar{q}$$
$$\to g_1^* g \to q\bar{q} g$$
$$\to g_1^* g_1^* \to q\bar{q}\; q\bar{q}$$

⇒ enhancement in dijet, trijet and 4-jet events at high p_T

: $q\bar{q} \to g_1^* \to t\bar{t}$ ⇒ altered top productions

: $e^+e^- \to ZH$, $\gamma\nu\bar{\nu}$ altered.

....

⇒ possibility of exploring string dynamics at LHC and NLC.

CONCLUSIONS

- For $\mu_0 > \mu_{SUSY}$, **no** solution for coupling unification with μ_0 in the 100 TeV range or less, (ignoring threshold corrections).
- For $\mu_0 < \mu_{SUSY}$, solution for coupling unification with μ_0 in the few TeV range
- assymetric compactification scenario with **one** mm size and **five** TeV^{-1} size dims. SM gauge bosons see only **one** TeV^{-1} extra dim.
- Possibility of producing KK excitations of the gauge bosons, and observing String dynamics at LHC.