Aspects of string phenomenology

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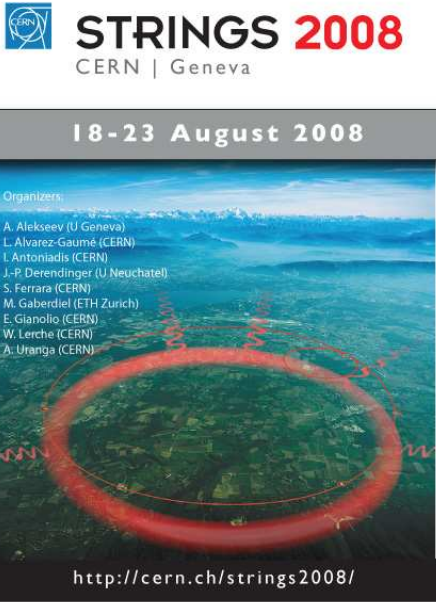
1. main questions and list of possibilities
2. phenomenology of low string scale
3. general issues of high string scale
4. framework of magnetized branes
   moduli stabilization, model building,
   SUSY breaking and D-term gauge mediation

- Are there low energy string predictions testable at LHC ?
- What can we hope to learn from LHC on string phenomenology ?



Very different answers depending mainly on the value of the string scale M_s

- arbitrary parameter : Planck mass $M_P \longrightarrow$ TeV
- physical motivations $\Rrightarrow$ favored energy regions:

- High : $\begin{cases} M_P^* \simeq 10^{18}\ \text{GeV} & \text{Heterotic scale} \\ M_{\rm GUT} \simeq 10^{16}\ \text{GeV} & \text{Unification scale} \end{cases}$
- Intermediate : around 10^{11} GeV ($M_s^2/M_P \sim$ TeV)

  SUSY breaking, strong CP axion, see-saw scale
- Low : TeV (hierarchy problem)

Low string scale ⇒ experimentally testable framework

- spectacular model independent predictions

perturbative type I string setup

- radical change of high energy physics at the TeV scale

explicit model building is not necessary at this moment

but unification has to be probably dropped

- particle accelerators

  TeV extra dimensions ⇒ KK resonances of SM gauge bosons I.A. '90

  Extra large submm dimensions ⇒ missing energy: gravity radiation

  string physics and possible strong gravity effects :

  · string Regge excitations [5]

  · production of micro-black holes ? [8]

- microgravity experiments

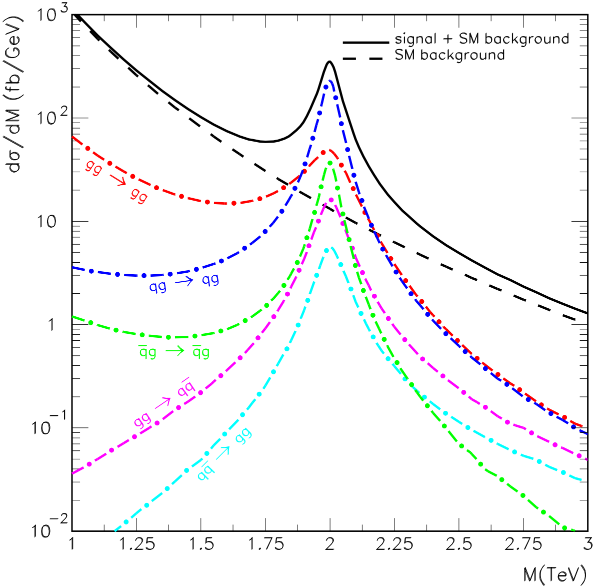
  change of Newton's law, new forces at short distances [10] [11]

Universal deviation from Standard Model in jet distribution

$M_s = 2$ TeV

Width = 15-150 GeV

Anchordoqui-Goldberg-Lüst-Nawata-Taylor-Stieberger '08 [4]



Tree N-point superstring amplitudes in 4 dims

involving at most 2 fermions and gluons:

completely model independent for any string compactification

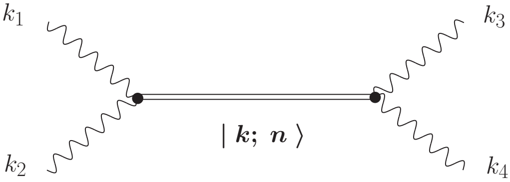
any number of supersymmetries, even none

No intermediate exchange of KK, windings or graviton emmission

Universal sum over infinite exchange of string Regge (SR) excitations:

masses: $M_n^2 = M_s^2\, n$

maximal spin: $n + 1$



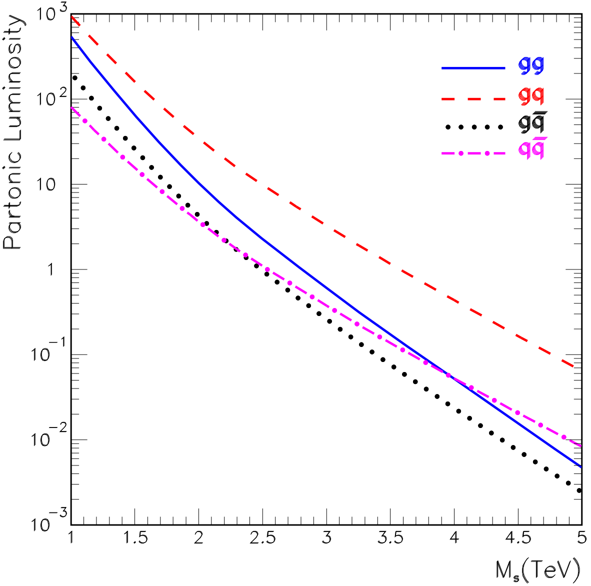
Parton luminosities in pp above TeV

are dominated by gq, gg

$\Rightarrow$ model independent [5]

$gq \rightarrow gq$

$gg \rightarrow gg$, $gg \rightarrow q\bar{q}$



Energy threshold for black hole production :

$$E_{\rm BH} \simeq M_s/g_s^2 \quad \leftarrow \text{ string coupling}$$

Horowitz-Polchinski '96, Meade-Randall '07

weakly coupled theory $\Rightarrow$

strong gravity effects occur much above M_s, $M_P^* \simeq M_s/g_s^{2/(2+d_\perp)}$

higher-dim Planck scale bulk dimensionality

$g_s \simeq \alpha_{\rm YM} \sim 0.1$; Regge excitations : $M_n^2 = M_s^2 n \;\Rightarrow$

gauge coupling

Energy threshold of n-th string excitation: $E_n \simeq M_s\sqrt{n} \;\Rightarrow$

production of $n \sim 1/g_s^4 \sim 10^4$ string states before reach $E_{\rm BH}$ [4]

- Newton constant: $G_N \sim g_s^2$ in string units $l_s = M_s = 1$

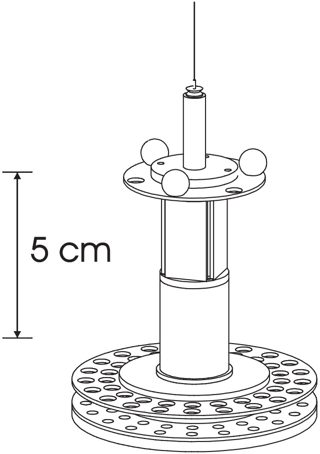
- string size black hole: $r_H \sim 1$

  $\Rightarrow$ black hole mass: $M_{\rm BH} \sim \underset{\substack{\uparrow \\ r_H^{d/2-1}}}{1/G_N} \simeq 1/g_s^2$

  valid in any dimension d:

- black hole entropy $S_{\rm BH} \sim 1/G_N \sim 1/g_s^2 \sim \sqrt{n}$: string entropy

Adelberger et al. '06



$R_\perp \lesssim 45\ \mu$m at 95% CL

- dark-energy length scale $\approx 85\mu$m [4]

Intermediate string scale :

not directly testable but interesting possibility with several implications

$\rightarrow$ 'large volume' compactifications

High string scale :

perturbative heterotic string : the most natural for SUSY and unification

prediction for GUT scale but off by almost 2 orders of magnitude

$M_s = g_H\, M_P \simeq 50\, M_{\rm GUT} \qquad g_H^2 \simeq \alpha_{\rm GUT} \simeq 1/25$

introduce large threshold corrections or strong coupling $\rightarrow$ $M_s \simeq M_{\rm GUT}$

but loose predictivity

High string scale: $M_s \sim M_{\rm GUT}$

Appropriate framework for SUSY + unification:

- intersecting branes in extra dimensions: IIA, IIB, F-theory
- Heterotic M-theory
- internal magnetic fields in type I

2 approaches: - Standard Model directly from strings
- 'orbifold' GUTs: matter in incomplete representations

Main problems: - gauge coupling unification is not automatic
different coupling for every brane stack
- extra states: vector like 'exotics' or worse
they also destroy unification in orbifold GUTs

Maximal predictive power if there is common framework for :

- moduli stabilization
- model building (spectrum and couplings)
- SUSY breaking (calculable soft terms)
- computable radiative corrections (crucial for comparing models)

Possible candidate of such a framework: **magnetized branes**

Type I string theory with magnetic fluxes on 2-cycles of the compactification manifold

- Dirac quantization: $H = \dfrac{m}{nA} \equiv \dfrac{p}{A}$ [17] $\Rightarrow$ moduli stabilization

  H: constant magnetic field m: units of magnetic flux

  n: brane wrapping A: area of the 2-cycle

- Spin-dependent mass shifts for charged states $\Rightarrow$ SUSY breaking

- Exact open string description: $\Rightarrow$ calculability

  $qH \to \theta = \arctan qH\alpha'$ weak field $\Rightarrow$ field theory

- T-dual representation: branes at angles $\Rightarrow$ model building

  (m, n): wrapping numbers around the 2-cycle directions

Magnetic fluxes can be used to stabilize moduli

I.A.-Maillard '04, I.A.-Kumar-Maillard '05, '06, Bianchi-Trevigne '05

e.g. T^6: 36 moduli (geometric deformations)

internal metric: $6\times 7/2 = 21 = 9 + 2\times 6$

type IIB RR 2-form: $6\times 5/2 = 15 = 9 + 2\times 3$

$$\text{complexification:}\begin{cases}\text{Kähler class} & J\\ \text{complex structure} & \tau\end{cases}\quad \text{9 complex moduli for each}$$

magnetic flux: 6×6 antisymmetric matrix F complexification $\Rightarrow$

$F_{(2,0)}$ on holomorphic 2-cycles: potential for τ

$F_{(1,1)}$ on mixed (1,1)-cycles: potential for J

$N=1$ SUSY conditions $\Rightarrow$ moduli stabilization

1. $F_{(2,0)} = 0 \;\; \Rightarrow \tau$ matrix equation for every magnetized $U(1)$

   need 'oblique' (non-commuting) magnetic fields to fix off-diagonal components of the metric $\leftarrow$ but can be made diagonal

2. $J \wedge J \wedge F_{(1,1)} = F_{(1,1)} \wedge F_{(1,1)} \wedge F_{(1,1)} \;\; \Rightarrow J$

   vanishing of a Fayet-Iliopoulos term: $\xi \sim F \wedge F \wedge F - J \wedge J \wedge F$

   magnetized $U(1) \rightarrow$ massive absorbs RR axion

   one condition $\Rightarrow$ need at least 9 brane stacks

3. Tadpole cancellation conditions : introduce an extra brane(s)

   $\Rightarrow$ dilaton potential from the FI D-term $\rightarrow$ two possibilities:

   - keep SUSY by turning on charged scalar VEVs
   - break SUSY in a dS or AdS vacuum $d = \xi / \sqrt{1+\xi^2}$ [20]

I.A.-Derendinger-Maillard '08

$F_{(2,0)} = 0 \Rightarrow \qquad \tau^{\mathrm{T}} p_{xx} \tau - (\tau^{\mathrm{T}} p_{xy} + p_{yx} \tau) + p_{yy} = 0$ [14]

T^6 parametrization: $(x^i, y^i) \quad i = 1, 2, 3 \qquad z^i = x^i + \tau^{ij} y^i$

Non-trivial VEVs v for charged brane scalars $\Rightarrow$

D-term condition is modified to:

$$q\, v^2 \,(J \wedge J \wedge J - J \wedge F \wedge F) = -(F \wedge F \wedge F - F \wedge J \wedge J)$$

charge

break SUSY in a dS or AdS vacuum

I.A.-Derendinger-Maillard '08

General form of the localized dilaton potential:

$$V(\phi, d) = \frac{e^{-\phi}}{g^2}\left\{\left(\sqrt{1-d^2}-1\right)+\xi d+\delta T\right\}$$

DBI action FI-term

d: D-auxiliary in $2\pi\alpha'$-units

δT: tension leftover RR tadpole cancellation $\Rightarrow \delta T = 1-\sqrt{1-\xi^2}$

d elimination $\Rightarrow$ $d = \frac{\xi}{\sqrt{1+\xi^2}}$

$V_{\min} = \delta\bar{T} e^{-\phi}$; $\delta\bar{T} = \sqrt{1+\xi^2}-\sqrt{1-\xi^2}$

Dilaton fixing:

1) by 3-form fluxes in a SUSY way $\Rightarrow$ dS vacuum with positive energy

D-term uplifting possible from flat space

2) add a 'non-critical' (bulk) dilaton potential

$\Rightarrow$ AdS vacuum with tunable string coupling

$$V_{\rm non-crit} = \delta c\, e^{-2\phi} \qquad \delta c\text{: central charge deficit}$$

minimization of $V = V_{\rm non-crit} + V_{\rm min} \Rightarrow \delta c < 0$

$$e^{\phi_0} = -\frac{2\delta c}{3\delta\bar{T}} \qquad V_0 = \frac{\delta c^3}{3\delta\bar{T}^2} \qquad R_0 = -\delta\bar{T}e^{3\phi_0}$$

curvature in Einstein frame

e.g. replace a free coordinate by a CFT minimal model

with central chage $1 + \delta c$

New gauge mediation mechanism

I.A.-Benakli-Delgado-Quiros '07

D-term SUSY breaking:

- problem with Majorana gaugino masses lowest order R-symmetry broken at higher orders but suppressed by the string scale

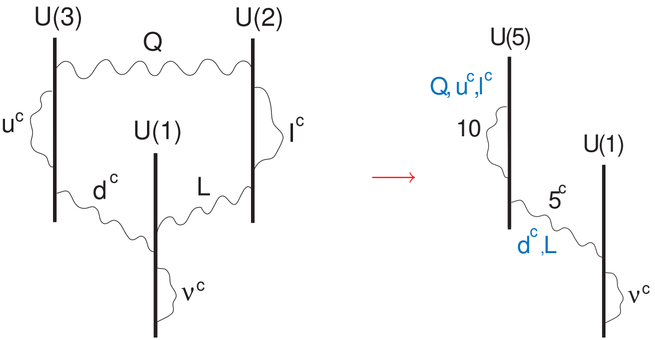
  I.A.-Taylor '04, I.A.-Narain-Taylor '05

- tachyonic squark masses

However in toroidal models gauge multiplets have extended SUSY $\Rightarrow$

Dirac gauginos without $\not{R}$ $\Rightarrow m_{1/2} \sim d/M$; $m_0^2 \sim d^2/M^2$ from gauginos

Also non-chiral intersections have $N = 2$ SUSY $\Rightarrow N = 2$ Higgs potential



Full string embedding with all geometric moduli stabilized:

- all extra $U(1)$'s broken $\Rightarrow$ gauge group just susy $SU(5)$
- gauge non-singlet chiral spectrum: 3 generations of quarks + leptons
- SUSY can be broken in an extra $U(1)$ factor by D-term [1]