Splitting Extended SUSY

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Work in progress with
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Plan of the talk

- Introduction: naturalness and landscape
- Model-building with intersecting branes
- SUSY breaking
- The models

Naturaleness:

$$M_W << M_{Planck}$$

- SUSY
- Extra-dimensions
- ….

$$\Lambda^{1/4} << M_W$$

- ????

The Landscape of string vacuua

- A tentative definition: The effective field theory X is more natural than Y in string theory if the number of phenomenologically acceptable vacua leading to X is larger than the number leading to Y.

This justifies to look for " phenomenologically acceptable vacua " ? But, first, one has to define what is " phenomenologically acceptable vacuum "

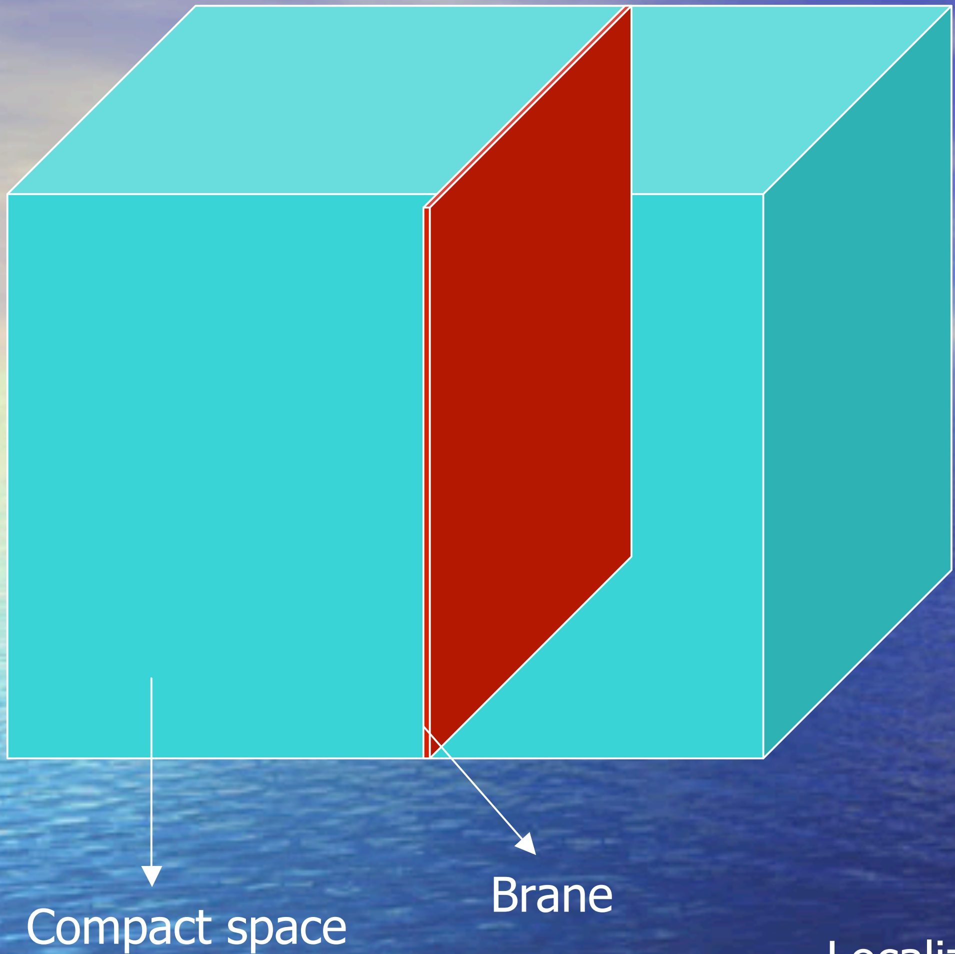
Intersecting brane models

Or

Introduction to the art of “perturbative string models for phenomenology”?

Compactification on a six torus from 10 to 4d

- 10d theory has N=8 SUSY



Localization implies :

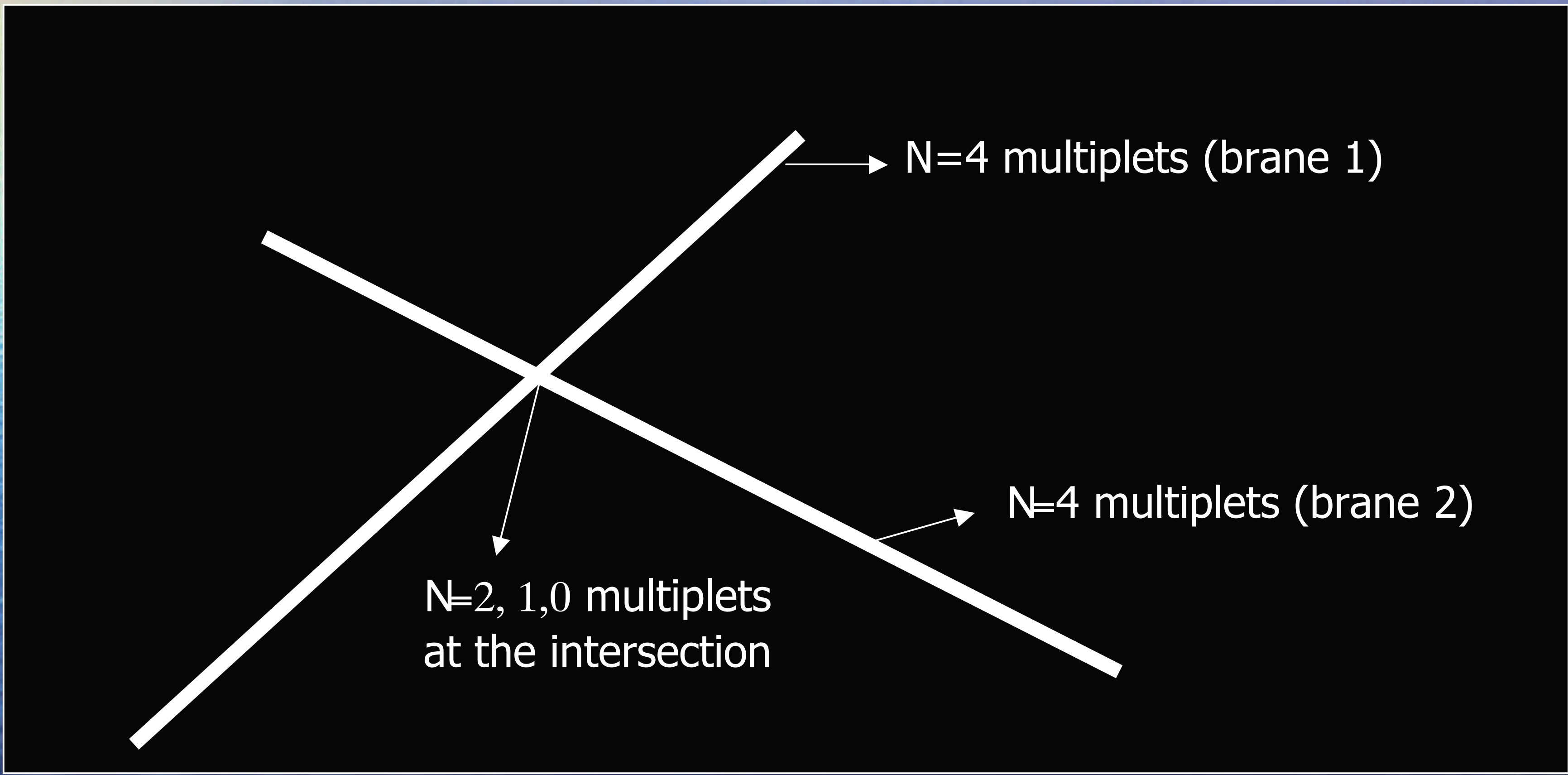
• breaking of translation invariance

Goldstone bosons = scalars on the brane

Compactification on a six torus

- 10d theory has N=8 SUSY
- Localization of a brane in 6 internal dimensions breaks translation invariance $\Rightarrow$ 6 scalars on the brane =Goldstone bosons
- Space is supersymmetric $\Rightarrow$ SUSY spontaneously broken $\Rightarrow$ 4 Weyl fermions on the brane = Goldstinos
- On the brane:
  - N=4 SUSY linearly realized
  - N=4 SUSY non linearely realized: overall U(1) (goldstones and goldstinos).
- Non parallel branes break different parts of the N=8 SUSY
- $\Rightarrow$ N=0 (or N=1) SUSY from intersecting branes

SUSY breaking by branes



Stability of intersecting branes: no tachyons

- 2d: no tachyon at the intersection ⇒parallel branes only ⇒ SUSY

Stability of intersecting branes: no tachyons

- 2d: no tachyon at the intersection $\Rightarrow$parallel branes only $\Rightarrow$ SUSY
- 4d: no tachyon at the intersection $\Rightarrow$parallel or orthogonal branes only $\Rightarrow$ all or half SUSY

Stability of intersecting branes: no tachyons

- 2d: no tachyon at the intersection ⇒parallel branes only ⇒ SUSY
- 4d: no tachyon at the intersection ⇒parallel or orthogonal branes only ⇒ all or half SUSY
- 6d: arbitrary angles !!! ⇒ SUSY or no SUSY possible!!!

Gauge bosons: SUSY multiplets on the brane

- N=2 multiplets

  1 vector

  2 Weyl fermions

  1 complex scalar

⇒two N=1 multiplets:

W^a vector

A_a chiral

- N=4 multiplets

  1 vector

  4 Weyl fermions

  3 complex scalars

⇒four N=1 multiplets:

W^a vector

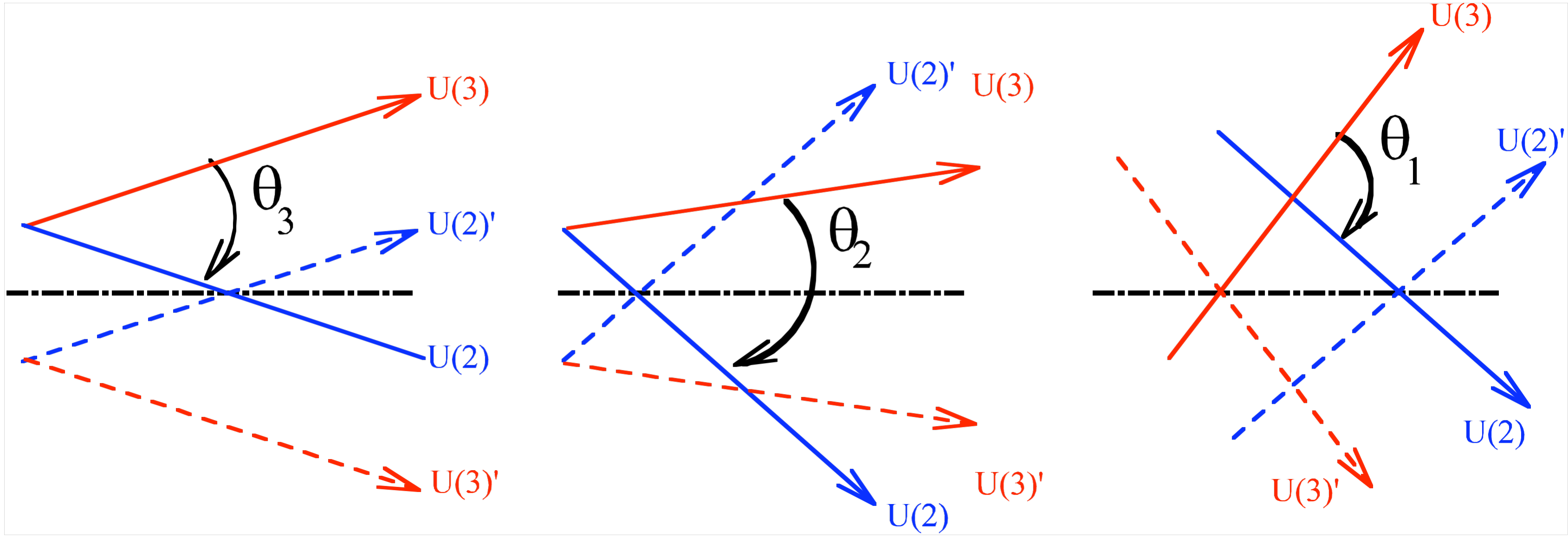
3 A_a chiral

Squarks and sleptons: SUSY breaking at the intersection

- Take the angles $\theta 1,\theta 2$ and $\theta 3$ in the three tori such that there is an N=1 SUSY preserved at the intersection (ex $\theta 1+\theta 2-\theta 3 =0$). Quarks and leptons are then in N=1 multiplets.

- Change now $\theta 3$ by very little such that $\theta 1+\theta 2-\theta 3 =D$. Then SUSY is broken spontaneously by a D-term.

- Squarks and leptons get masses (up to charges): $m_0^2 = D$



U(3)
θ3
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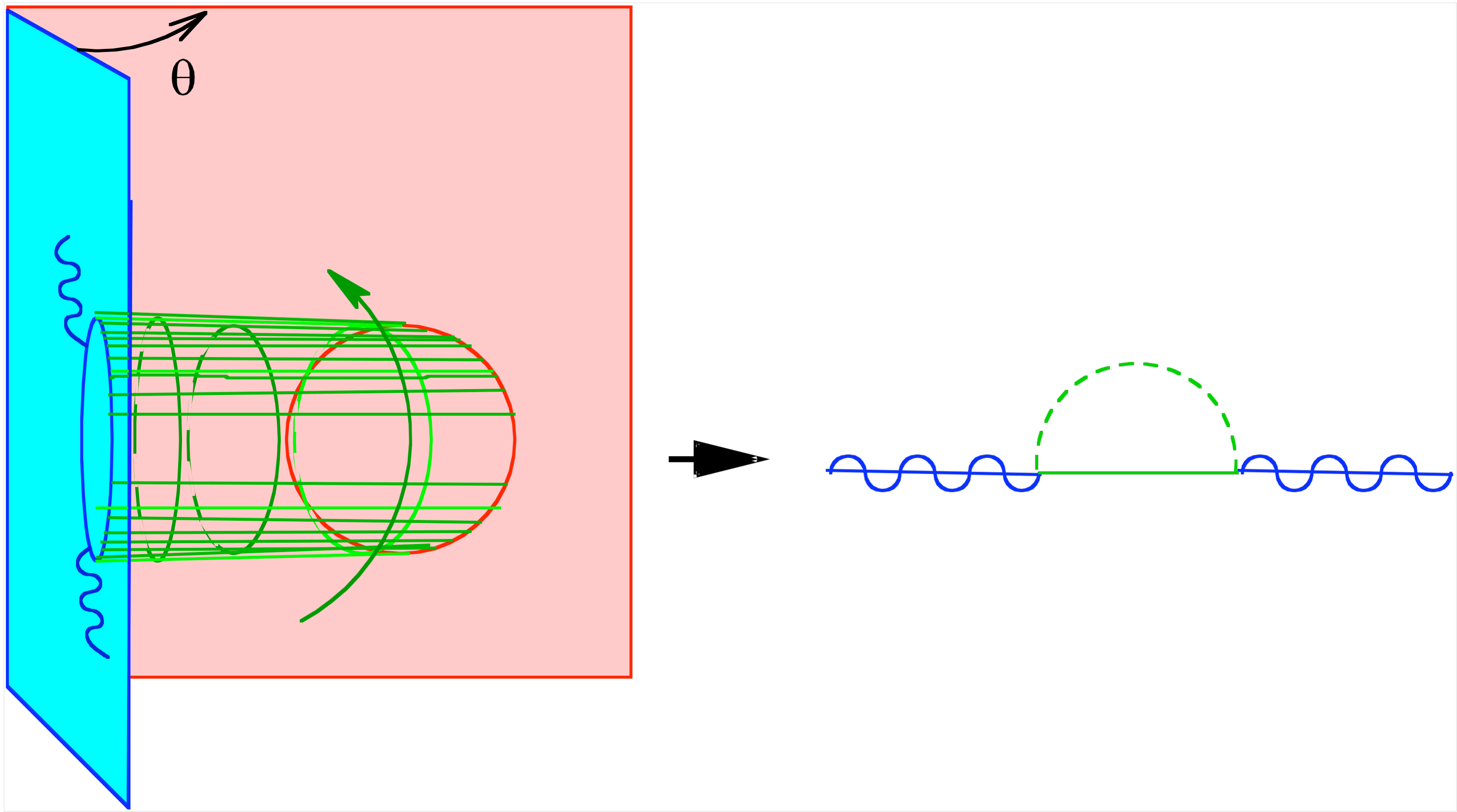
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Loop generated SUSY breaking masses for "bulk" states

Dirac masses for N=2 gauginos $M_{1/2}^{D} = \int d^2\vartheta \frac{1}{M_s} W' W_a A^a \approx \varepsilon \frac{m_0^2}{M_s}$

Dirac masses for N=4 gauginos $M_{1/2}^{D} = \int d^2\vartheta \frac{1}{M_s} W' \bar{D} A_a A^a \approx \varepsilon \frac{m_0^2}{M_s}$

Majorana masses for gauginos $M_{1/2}^{M} \approx \int d^2\vartheta \frac{1}{M_s^3} W'^2 \, tr W_a W^a \approx \varepsilon^2 \frac{m_0^2}{M_s^3}$

Scalar partners of gauginos $\varepsilon . m_0^2$

What about the Higgs sector?

- The Higgs multiplets come as N=2 hyper-multiplet
- The mparameter is either:
  - A free parameter (branes separation)
  - One-loop induced:

$$\frac{1}{M_s^3}\int d\theta^2 W'^2\,\overline{D}^2\,\overline{H}_1\,\overline{H}_2 \rightarrow \mu\,H_1\,H_2$$

- The Higgs scalars are fine tuned to get the right electroweak scale.

Unification of couplings?

- Yes for N=4 with one Higgs scalar light

$$M_{GUT} \approx 9.7 \times 10^{18}\, GeV$$

$$m_0 \approx 8.5 \times 10^{15}\, GeV$$

$$M^D_{1/2} \approx 7.4 \times 10^{12}\, GeV$$

Unification of couplings?

- Yes for N=2 with one Higgs doublet light

$$M_{GUT} \approx 2.8 \times 10^{18}\, GeV$$
$$m_0 \approx 4.5 \times 10^{12}\, GeV$$
$$M_{1/2}^{D} \approx 7.2 \times 10^{6}\, GeV$$

Unification of couplings?

- Yes for N=2 with two Higgs doublets light

$$M_{GUT} \approx 4.5 \times 10^{16}\, GeV$$

$$m_0 \approx 1.1 \times 10^{13}\, GeV$$

$$M_{1/2}^{D} \approx 2.7 \times 10^{9}\, GeV$$

What about binos?

- The binos do not enter in the RGE for unification
- The binos are important for getting a Dark Matter candidate.
- Could the lightest neutralino be the dark matter candidate?

The lightest neutralino be the dark matter candidate?

- No light winos but two or more binos
- Higgsinos alone can not be the DM because of the vector coupling.
- Mixing with light binos is necessary.
- The mixing must induce a mass splitting between the two Higgsinos at least of order 100 KeV.
- $\Rightarrow$ the lightest bino has a mass of at most order 100 TeV.
- $\Rightarrow$ the lightest bino has just a Majorana mass.

The lightest neutralino be the dark matter candidate?

- ⇒ the lightest bino has just a Majorana mass Mb at most ~100 TeV:
- This excludes the N=2 model with one Higgs: too light of order 10 KeV.
- N=4 and one Higgs is border line

- DarkSUSY⇒ m~1.1 TeV :
- OK for N=2 with two Higgs doublets
- Extra parameter (brane separation) to make N=4 work.

Neutralino dark matter candidate for N=2?

- lightest bino: a Majorana mass Mb at most ~100 TeV and m~1.1 TeV .
- Mb and m given by similar expressions can be compared:
- Mb<<m binos overclose the universe
- Mb~m OK
- Mb>>m OK
- N=4 work as for the last case above

Life time of extra states (N=2 case)

- Scalars decay into gauginos, Dirac gluinos decay through loop, Dirac winos decay into Higgses and Higgsinos.
- At low energies, both binos couple to Higgs and Higgsinos
- Only stable particle is the LSP

Life time of extra states (N=4 case)

- Half of the fermions will decay as before (the N=2 part).
- The other half will have to decay through massive string states.
  - No problem for gluinos and winos
  - Life-time of order 1/10 of the age of universe for binos.

Collider effects

Charginos are produced and decay to LSP neutralinos.

CONCLUSION

- The Salt Merchant And His Donkey

A PEDDLER drove his Donkey to the seashore to buy salt. His road home lay across a stream into which his Donkey, making a false step, fell by accident and rose up again with his load considerably lighter, as the water melted the sack.

The Peddler retraced his steps and refilled his panniers with a larger quantity of salt than before. When he came again to the stream, The Donkey fell down on purpose in the same spot, and, regaining his feet with the weight of his load much diminished, brayed triumphantly as if he had obtained what he desired.

The Peddler saw through his trick and drove him for the third time to the coast, where he bought a cargo of sponges instead of salt. The Donkey, again playing the fool, fell down on purpose when he reached the stream, but the sponges became swollen with water, greatly increasing his load. And thus his trick recoiled on him, for he now carried on his back a double burden.