Strings, D-branes and gauge theories

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Plan of the talk

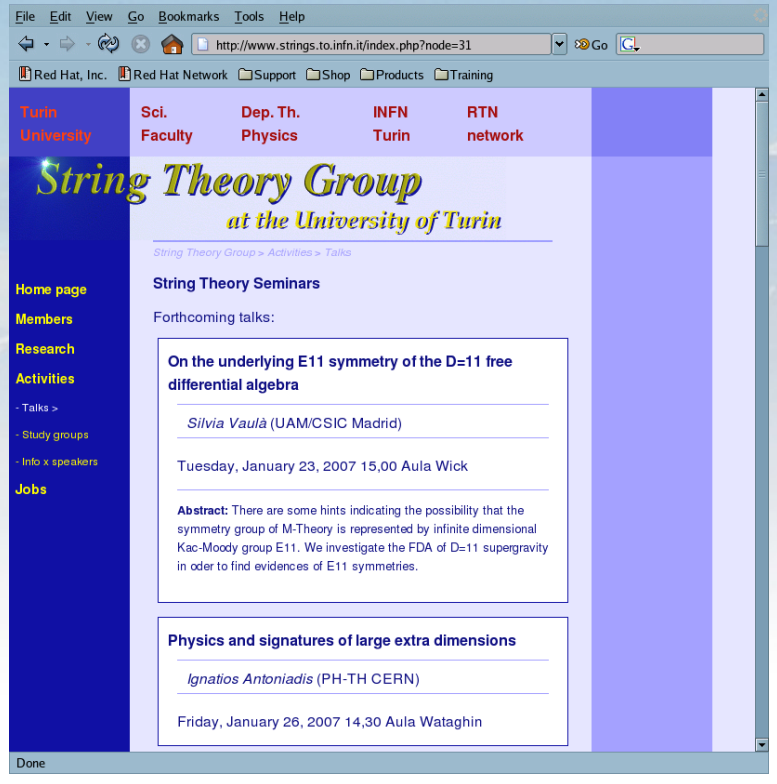
The string group at INFN-TO

String/supergravity people in our section

- INFN
  - Staff: A. Ceresole [A. D'Adda]
- UniTO
  - Staff: C. Angelantonj, M. Billò, M. Frau, P. Frè, I. Pesando, S. Sciuto [M. Caselle, F. Gliozzi, L. Magnea, J. Nelson]
  - Post-docs: A. Fotopoulos, M. P. Garcia del Moral [P. Giudice, P. Grinza]
  - Ph. D: L. Ferro, A. Mazur [S. Lottini]
- PoliTO
  - Staff: R. D'Auria
  - Post-docs: M. Trigiante
- UniPMN
  - Staff: L. Castellani, P. A. Grassi, A. Lerda
  - Post-docs: M. Marescotti, E. Scheidegger, [P. Aschieri]

About the group

- See our WEB page http://www.strings.to.infn.it for all informations, including specialistic seminars and study groups, ...
- We participate to the European project
  - RTN Network "Constituents, Fundamental Forces and Symmetries of the Universe" [MRTN-CT-2004-005104]



- ... and to the following Italian projects:
  - PRIN "Superstringhe, brane e interazioni fondamentali" [PRIN-2005023102]
  - PRIN "Simmetrie dell'Universo e delle Interazioni Fondamentali", [PRIN-2005024045]

Why strings?

Not just a theory of everything :-)

- String Theory is often emphatically presented as the T.O.E., i.e. the only way to unify the Standard Model of particle theory with a consistent quantum theory of gravity.
- Of course, this is a very intriguing but also very ambitious standpoint
  - Despite advances, we are still far from deriving (and explaining) the physics of “our world” from string first principles.
  - Concerns about the predictive power (problem of the “landscape”: huge degeneracy of vacua)
- String theory however is also a very fertile arena of ideas, models, techniques and suggestions for tackling hard problems in Quantum Field Theory and in Gauge Theories in particular.

Where strings (do, can or should) help

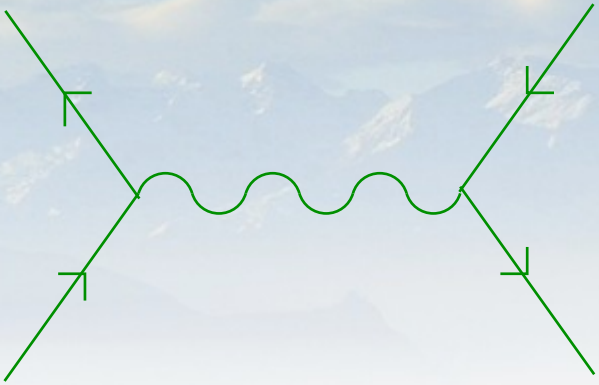
A certainly not exhaustive list

- Natural frame for proposing "new physics" effects at very high, but possible also in the LHC range, energies:
  - extra dimensions (superstrings live in $d = 10$)
  - extra $U(1)$'s $\Rightarrow$ Z' signatures
  - extra couplings in the effective actions from stringy effects
- Natural frame to investigate supersymmetry breaking (susy was discovered first in the string context)
- Tools and ideas to describe the strong coupling regime of gauge theories
  - Holography and gauge/gravity a.k.a. AdS/CFT correspondence (applications even to QGP)
  - Confining string for the QCD flux tube
- Physics of Black holes (microscopic d.o.f. of extremal B.H)
- Cosmology (models for inflation, acceleration etc)

What are strings?

From Feynman diagrams to world-sheets

Scatterings are described in QFT by Feynman diagrams



F.d.: “world-lines” of the particles involved.

From Feynman diagrams to world-sheets

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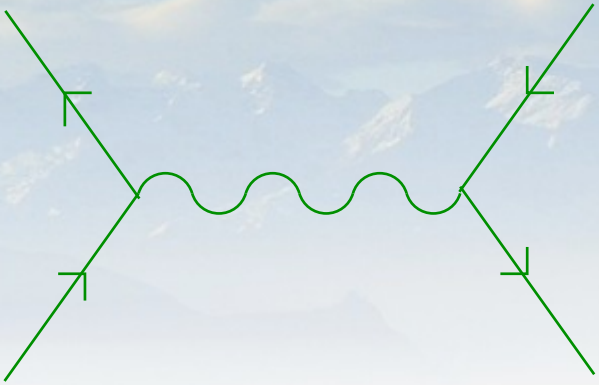

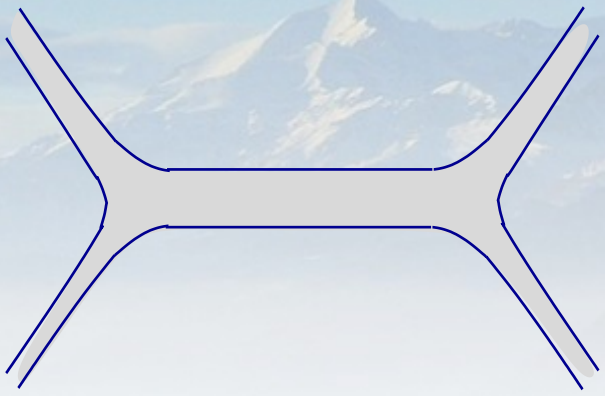

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String theory: promoted to "world-sheets"

From Feynman diagrams to world-sheets

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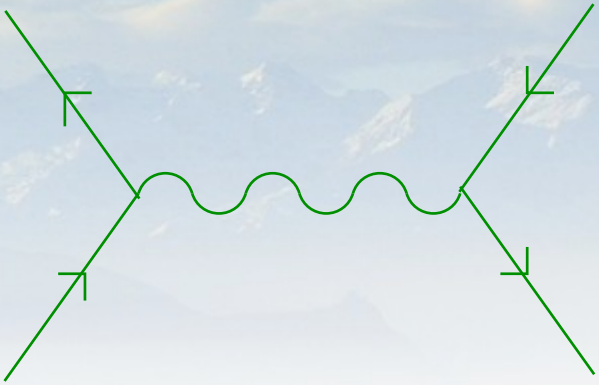

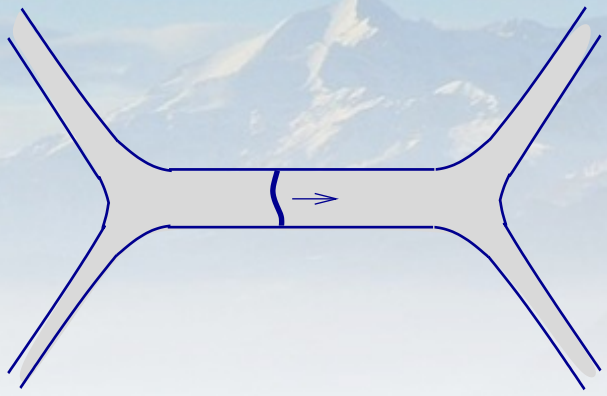

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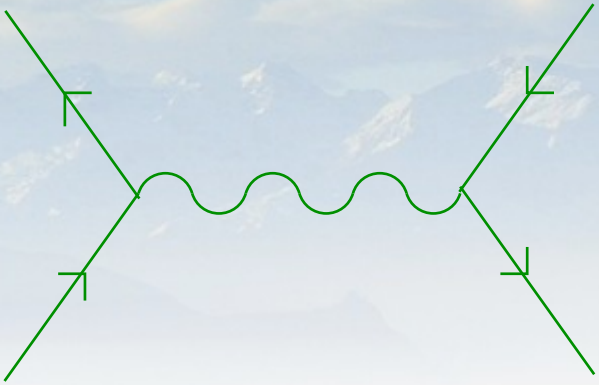
String theory: promoted to "world-sheets"

- The propagating object is one-dimensional: a string, with a tension ($\sim 1/\alpha'$)

From Feynman diagrams to world-sheets

Scatterings are described in QFT by Feynman diagrams



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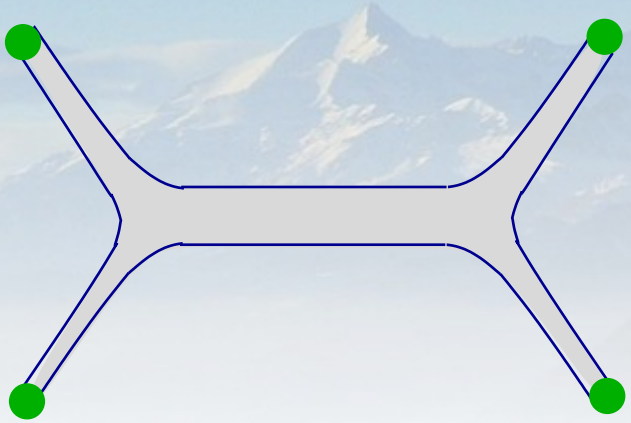


String theory: promoted to "world-sheets"

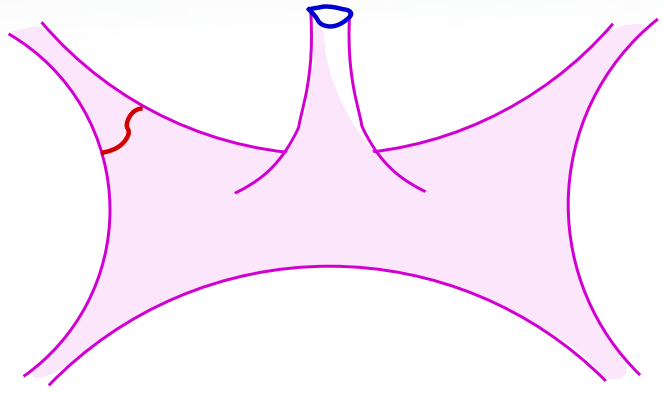
- External particles: states in the spectrum obtained quantizing the string.
  - This spectrum contains a tower of states of mass $M^2 \sim n/\alpha'$

Open vs closed strings

Strings can be open or closed

- The open string massless spectrum contains gauge fields. Open string amplitudes $\longrightarrow$ gauge theory eff. action
- The closed string massless spectrum contains the graviton. Closed amplitudes $\longrightarrow$ eff. action for gravity

- Open and closed strings unavoidably interact



What are D-branes?

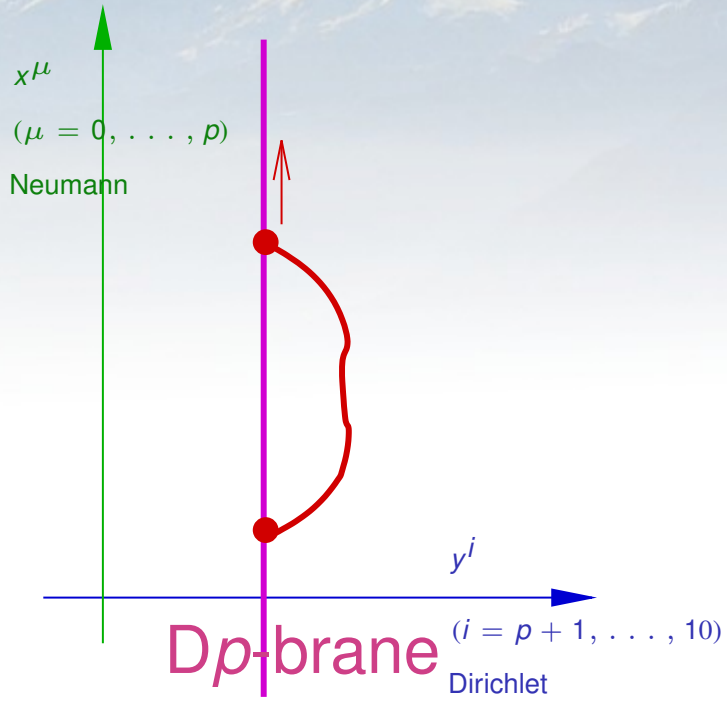
Open string boundary conditions and branes

For open strings one must specify boundary conditions at the endpoints. Along each direction of propagation we can have

- Neumann b.c.: no momentum flows out, the endpoint moves freely at the speed of light
- Dirichlet b.c.: the endpoint position is fixed

With $p+1$ Neumann, $10-(p+1)$ Dirichlet directions

- the open string endpoints are attached to a D(irichlet)p-brane

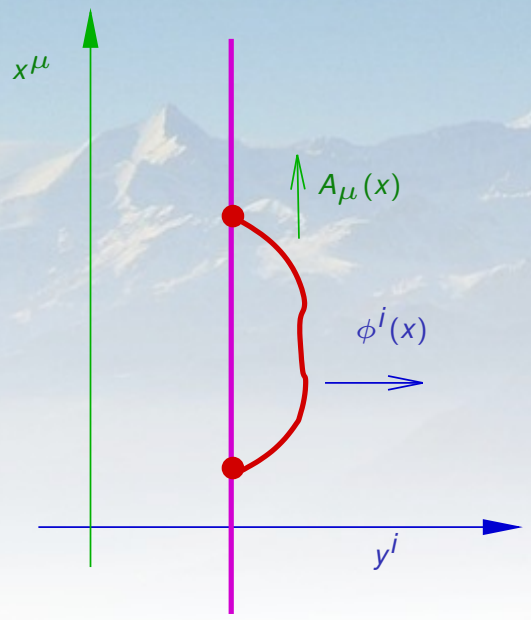


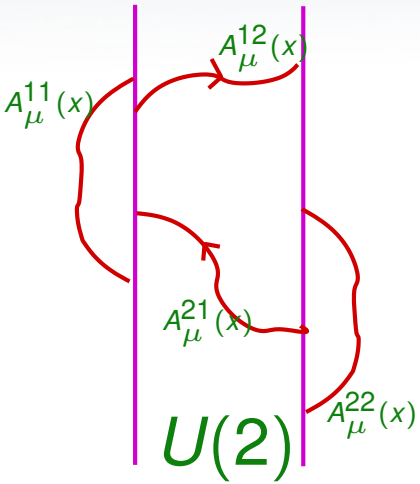
Gauge theory on the D-branes

Massless d.o.f. of open strings attached to a Dp-brane:

- Gauge field A_μ
- Scalars ϕ^i
- supersymmetric partners

Momentum flows only along the "worldvolume" (Neumann) direction





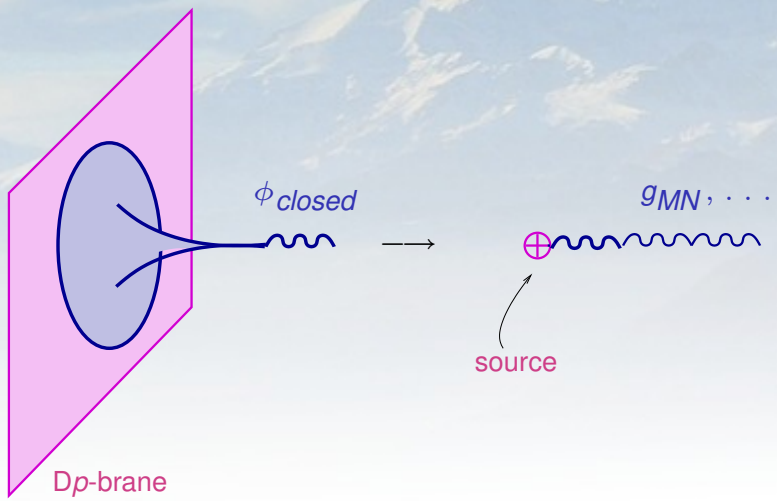
We have a gauge theory (with adoint matter) in the $p+1$-dimensional world-volume

- With N D-branes we get a non-Abelian $U(N)$ gauge theory

D-branes as solitonic membranes

Interplay between open and closed strings.

- A Dp-brane can emit closed strings
- It acts as a source for the gravitational field (and for "RR form fields") $\longrightarrow$ it has tension and charge



The Dp-brane curves the 10-d space-time into a "black membrane"

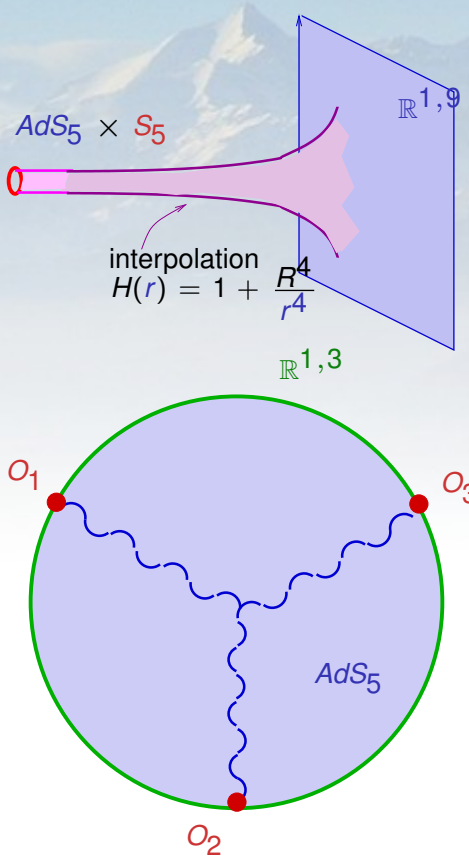
$$ds^2 = H^{-\frac{1}{2}}(r)dx_{||}^2 + H^{\frac{1}{2}}(r)dy_{\perp}^2$$

$H(r) = 1 + (R/r)^{7-p}$: harmonic function in the transverse radius r.

AdS/CFT

In the simplest case, the gauge theory on N D3-branes is $SU(N)$ super Yang-Mills with $\mathcal{N} = 4$ susy.

- Near the D3-branes ("near-horizon") the space-time looks like $AdS_5 \times S_5$
- $\mathcal{N} = 4$ SYM is equivalent to closed string theory on $AdS_5 \times S_5$
- This is an "holographic" relation: our 4d Minkowski space-time is the boundary of $AdS_5 \times S_5$.
- Hard quantum problems (correlators, Wilson loops, ...) $\rightarrow$ classical SUGRA computations

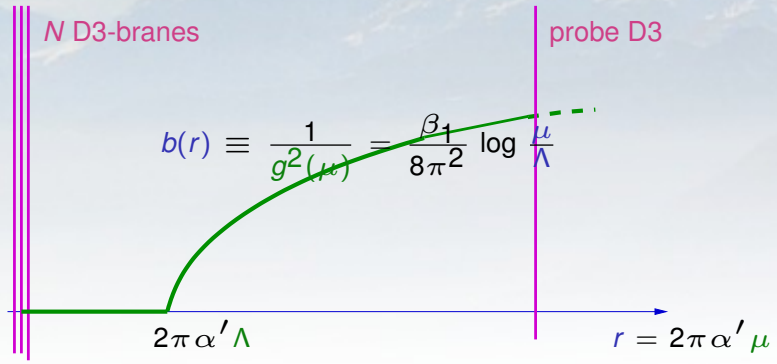


- Appears to be useful also in cases without susy, e.g. in QGP (shear viscosity, ...)

Gauge/gravity relations

On systems of D3-branes with less susy live confining gauge theories: running with the energy scale

- gauge theory parameters $\leftrightarrow$ closed string fields
- energy scale $\leftrightarrow$ transverse direction
- R.G.E $\leftrightarrow$ classical e.o.m.



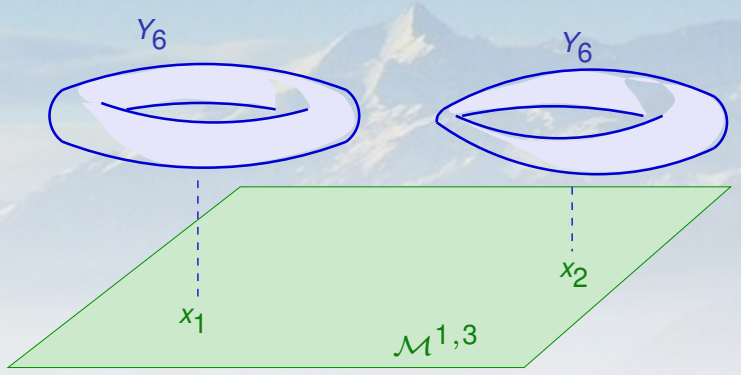
Many results for $\mathcal{N} = 2, 1$ (and even $\mathcal{N} = 0$) theories realized via orbifolds, conifolds, ...: β-function, anomaly, vacua structure, ...

Towards realistic constructions

SM-like constructions of branes at angles

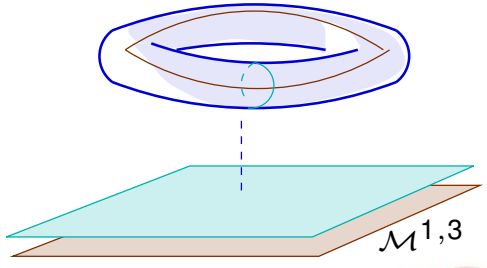
Consistent superstrings live in 10 dimensions.

- 6 dimensions must be "compactified" on some internal space
- This is a welcome feature which allows the construction of (semi)-realistic models



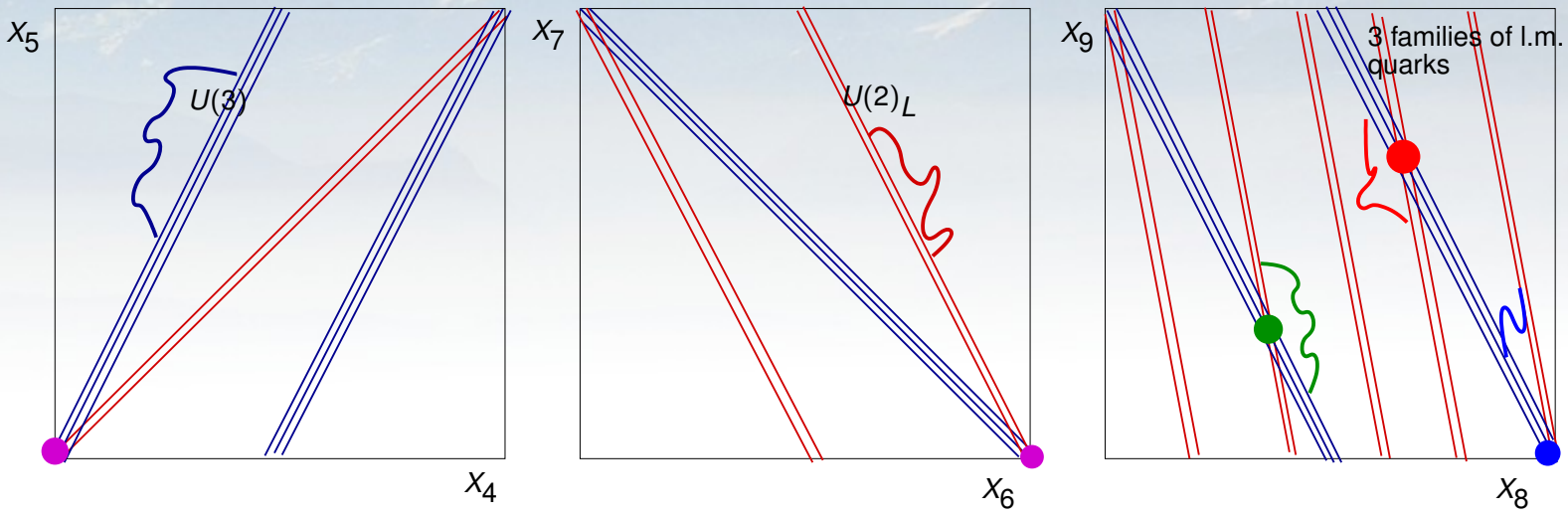
  - Combining compactification and D-branes $\rightarrow$ models where the energy scale of string effects $<<$ Planck scale

- Simple yet very interesting models already from compactifications on tori T_6, with stacks of D-branes which intersect in T_6 (or with magnetic fields along it)



Gauge groups and chiral matter from branes

- Gauge groups from multiple branes, bifundamental chiral matter from "twisted" strings, families from multiple intersections



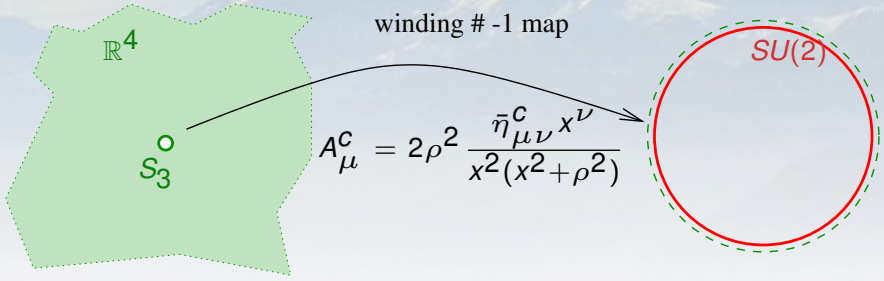
- I've been/am working on the determination of the eff. Lagrangian for the "twisted" fields in dependence of closed string moduli with A. Lerda, L. Ferro and others

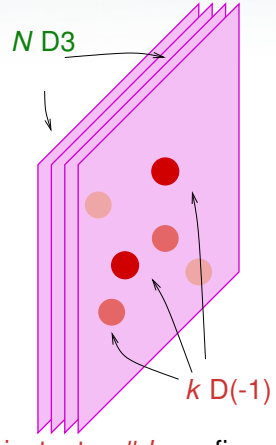
Non-perturbative effects

Instantons and D(-1)-branes

Usual QFT perturbation theory is around a vacuum where $\langle \phi(x) \rangle = 0$ Non-trivial classical solutions for the fields $\phi(x)$ may contribute to amplitudes: non-perturbative constributions

- For Yang-Mills theories, instantons (topol. stable sol.s with finite action and self-dual $F^{+}_{\mu\nu}$) play a prominent rôle





- In string realizations of gauge theories, the rôle of instantons is played by branes with Dirichlet conditions in all directions (time included), called D(-1)-branes or D-instantons
- With M. Frau, A.Lerda, I. Pesando, S. Sciuto and others I've been working on several aspects of D-instanton calculus