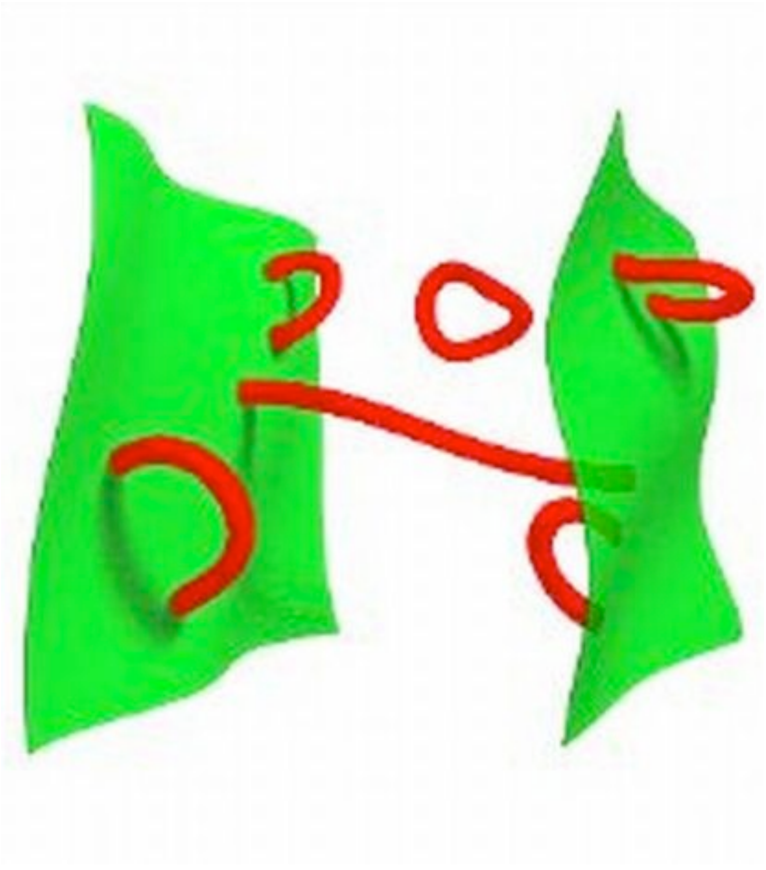
D-branes and Model Building

Fernando Marchesano



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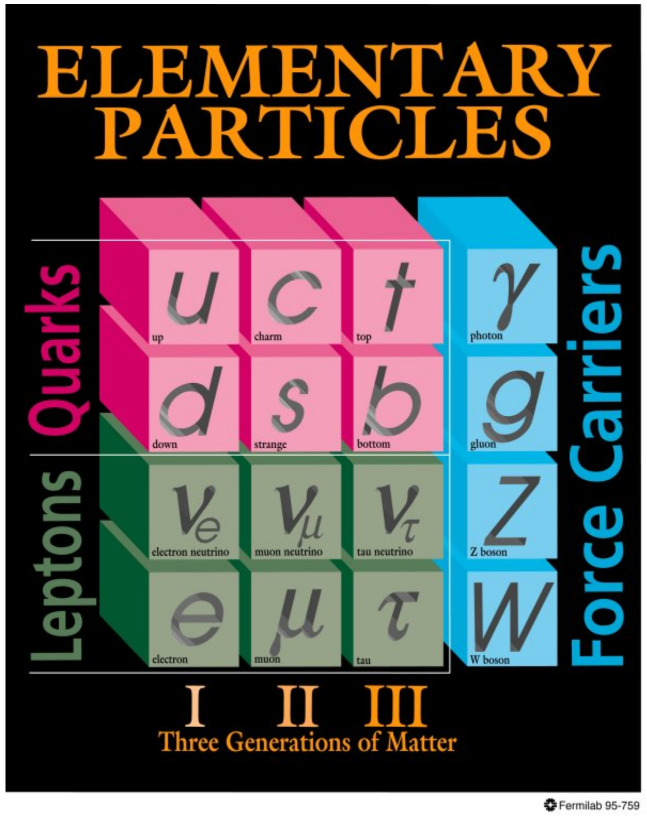


The quest for the Standard Model

Question: Can we reproduce the Standard Model from D-branes?

- Many "ingredients" are needed...

Four observable dimensions

Gauge group SU(3) x SU(2) x U(1)$_Y$

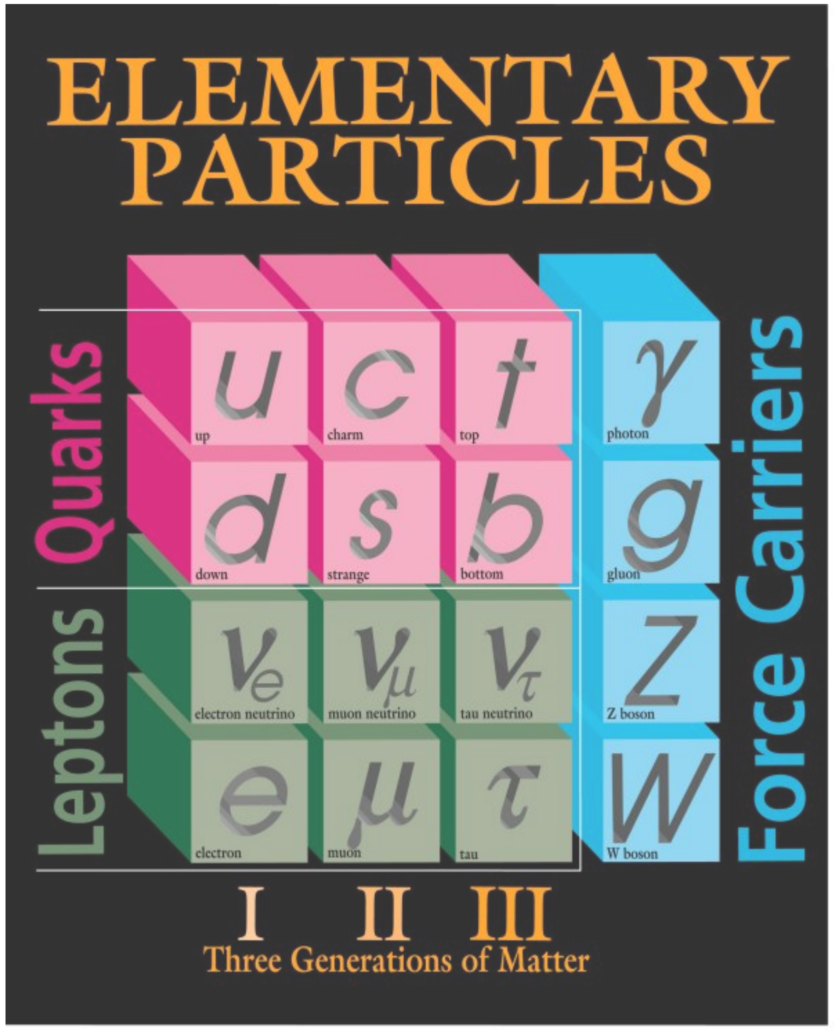
Chiral fermions

3 Quarks & Leptons generations

Gauge coupling constants

Yukawa couplings

...



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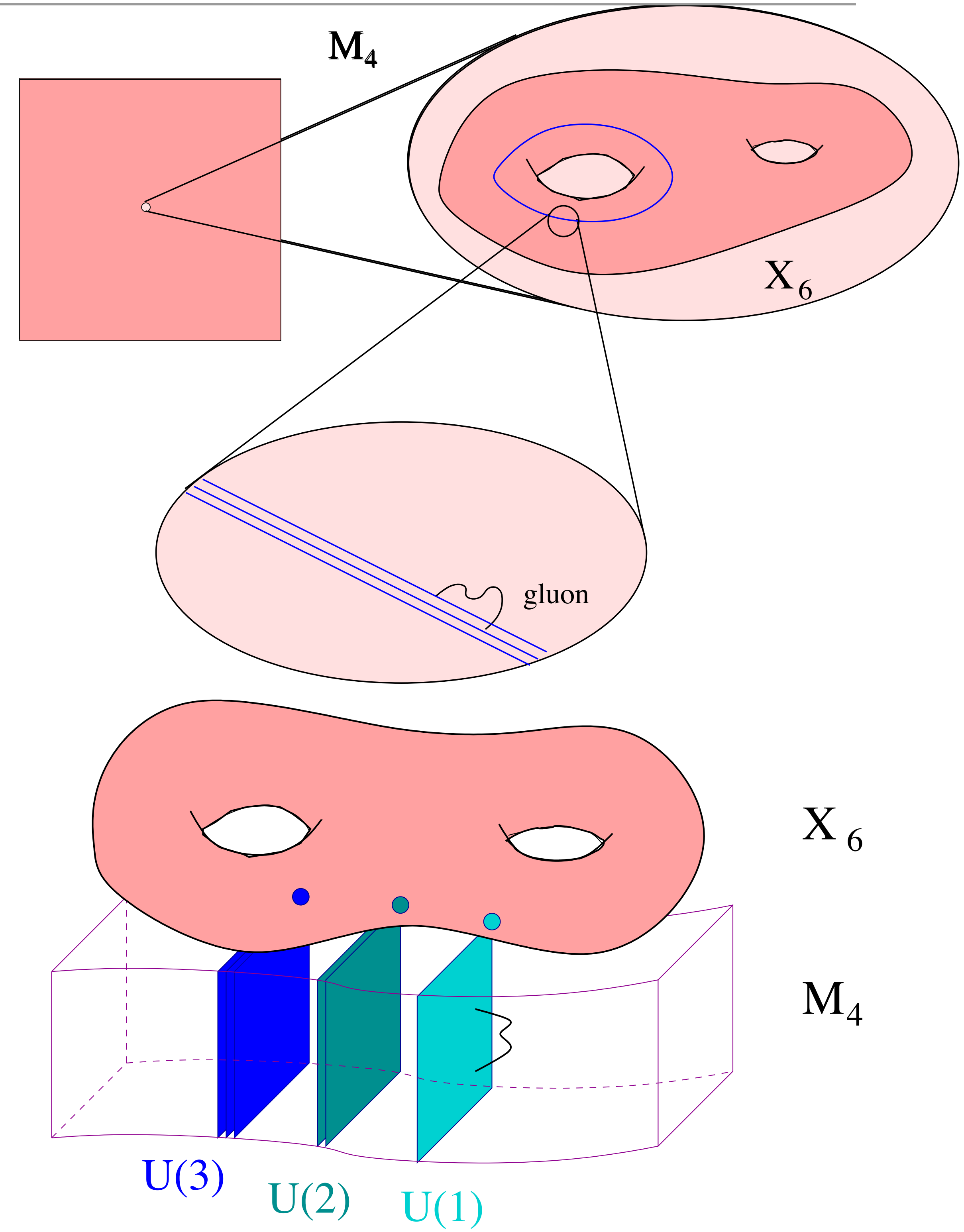
Strings vs. Particles

- String theories live in 10d
- Kaluza-Klein idea: 6d are very small
- Gauge interactions are localized on D*p*-branes which have
    - 3+1 observable dim.
    - p-3 internal dim.
- Simplest example: 3 + 2 + 1 D3-branes

➡ 4d U(3) x U(2) x U(1) gauge theory

SM gauge theory!!



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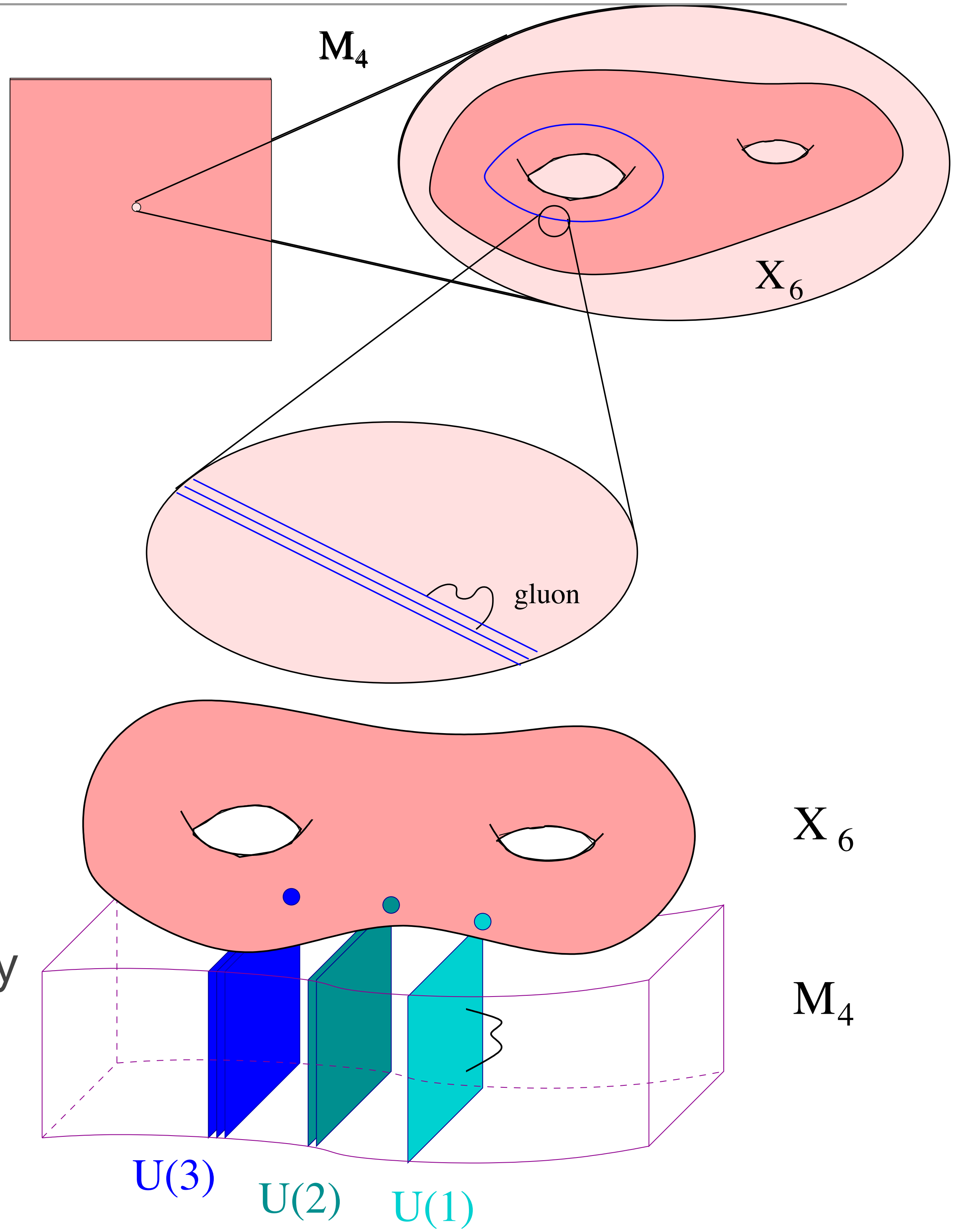
  ➡ 4d U(3) x U(2) x U(1) gauge theory
- However, this example lacks of a key property of the Standard Model: Chiral Fermions



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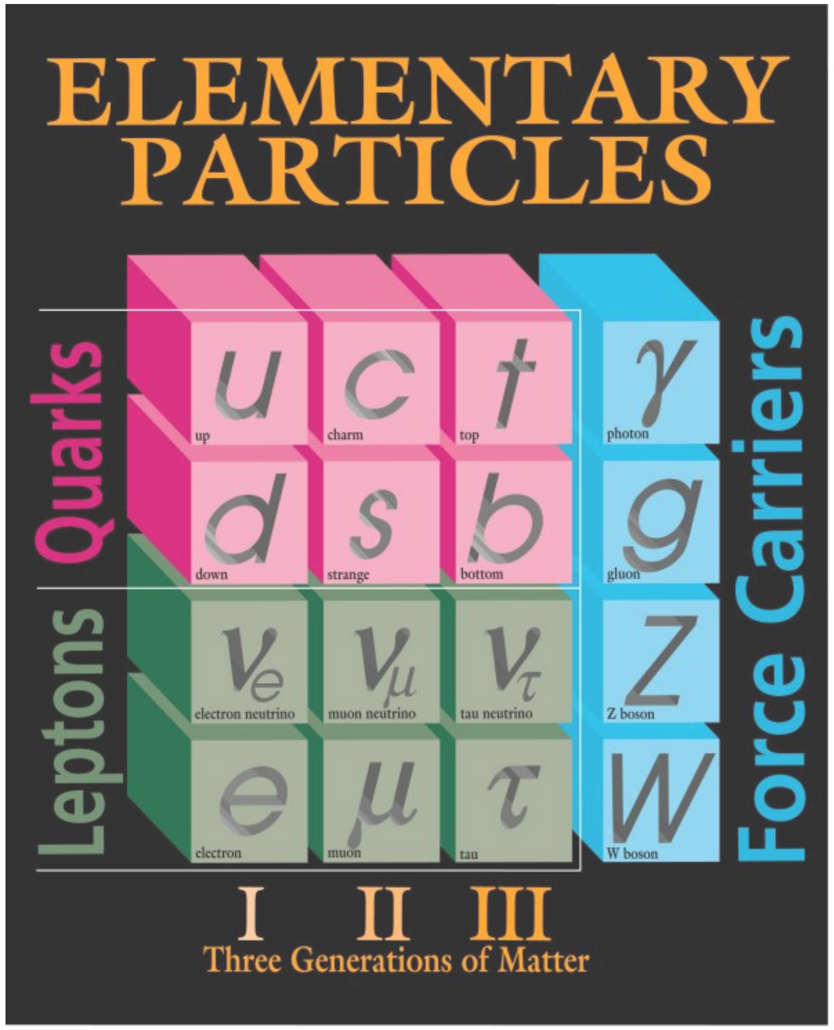

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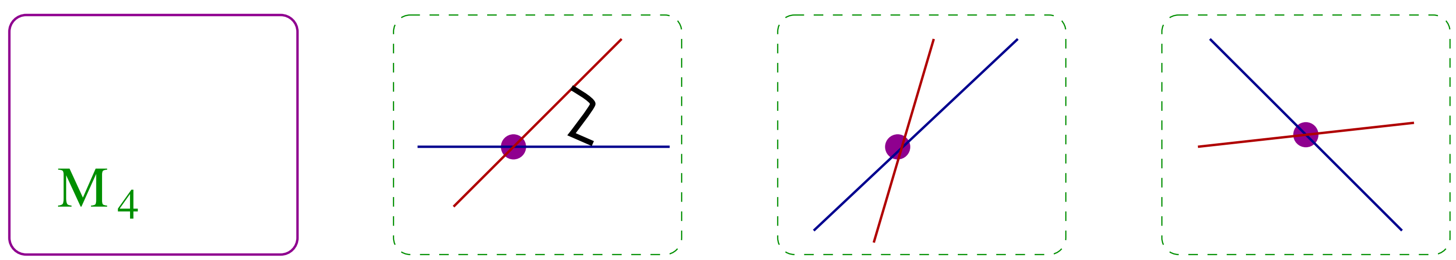
D-branes and Chirality

Strategy I: Intersecting D-branes

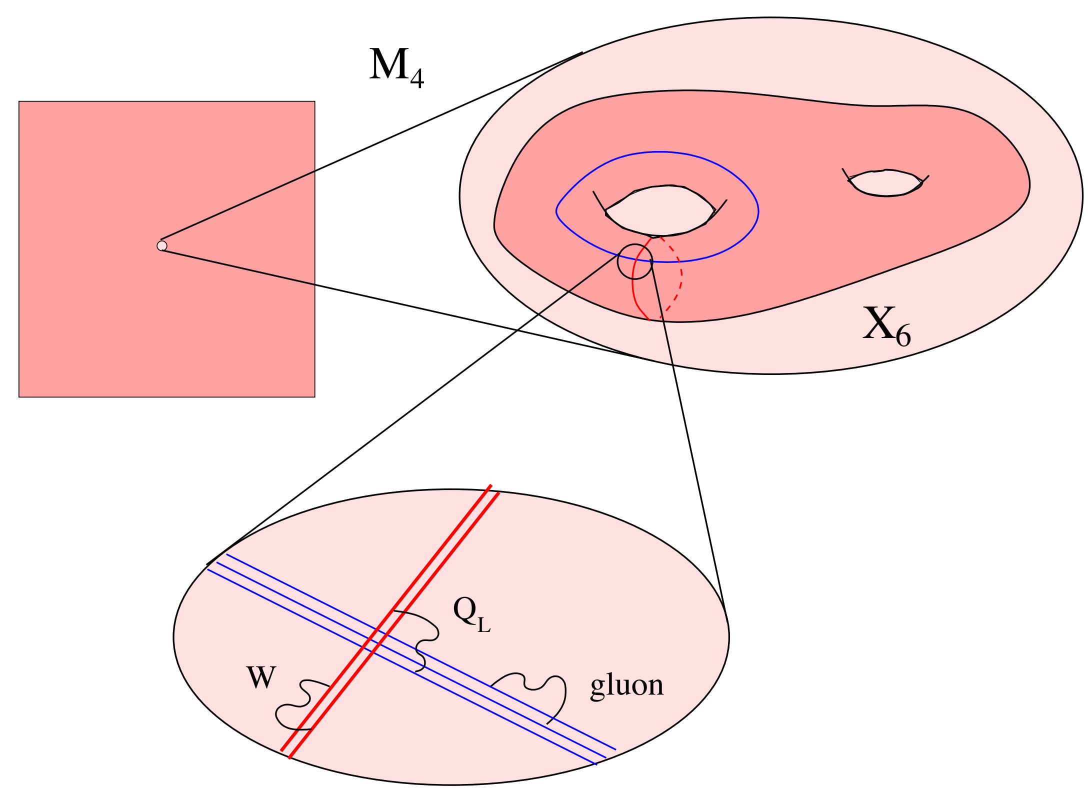
- If two D-branes **intersect** in **d dimensions** there is a **d-dim chiral fermion** localized at the intersection



- In particular, two D6-branes in $R^{1,9}$ intersect in 4d $\Rightarrow$ 4d chiral fermion

Idea:

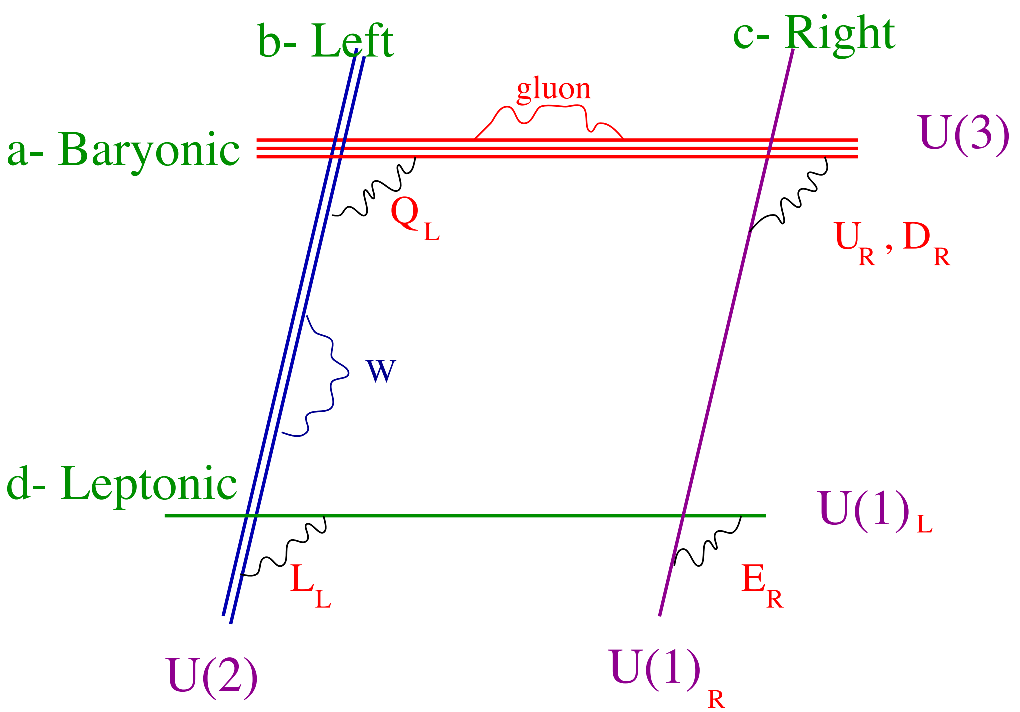
Obtain a realistic model via intersecting D6-branes



Getting the Standard Model

- One can indeed accommodate the full SM particle content via the following general scheme:
    - Four sets of D-branes

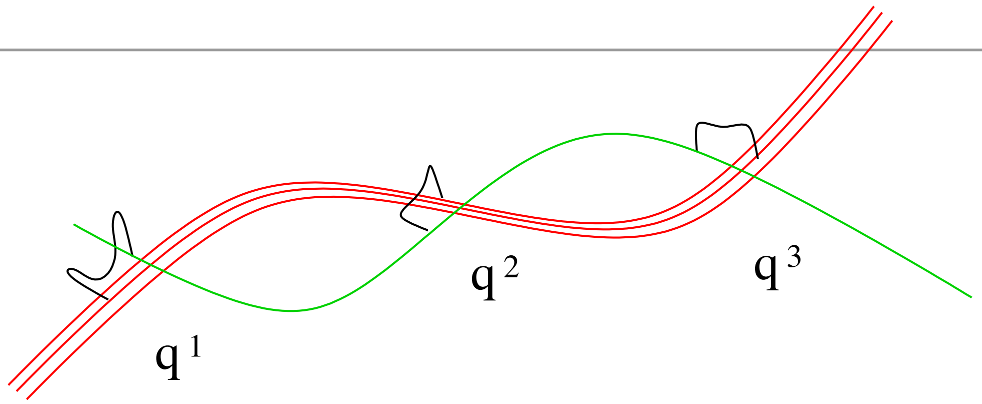
# D-branes	Gauge Group	Name
$N_a = 3$	$SU(3) \times U(1)_a$	Baryonic Brane
$N_b = 2$	$SU(2)$ [$\times U(1)_b$]	Left Brane
$N_c = 1$	$U(1)_c$	Right Brane
$N_d = 1$	$U(1)_d$	Leptonic Brane



... + appropriate topological properties

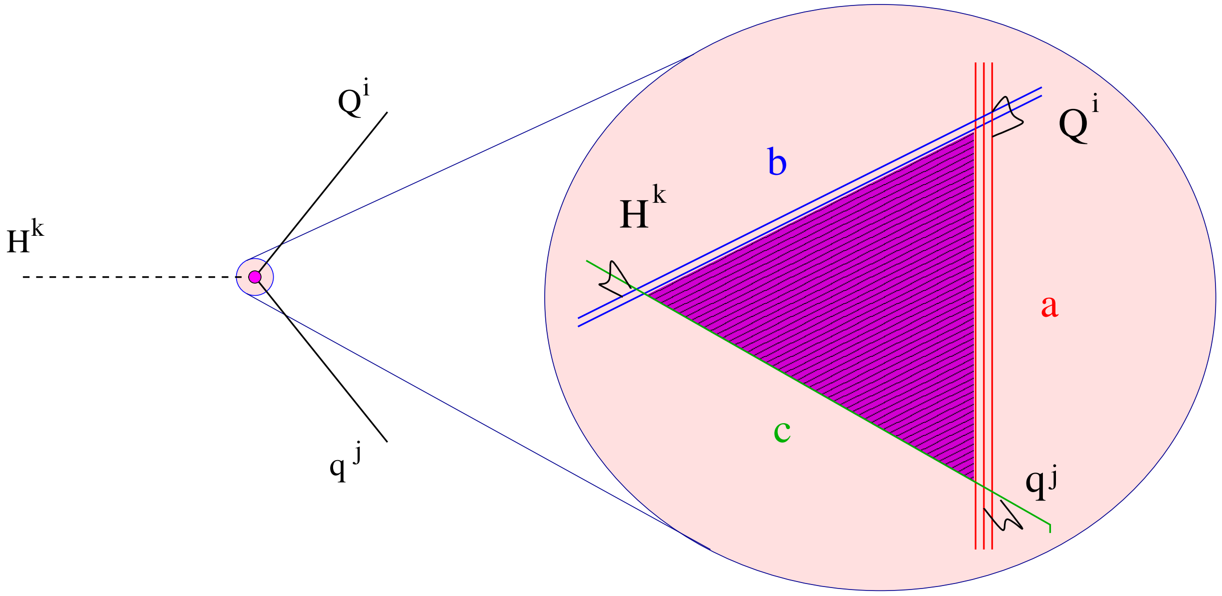
SM features from Geometry

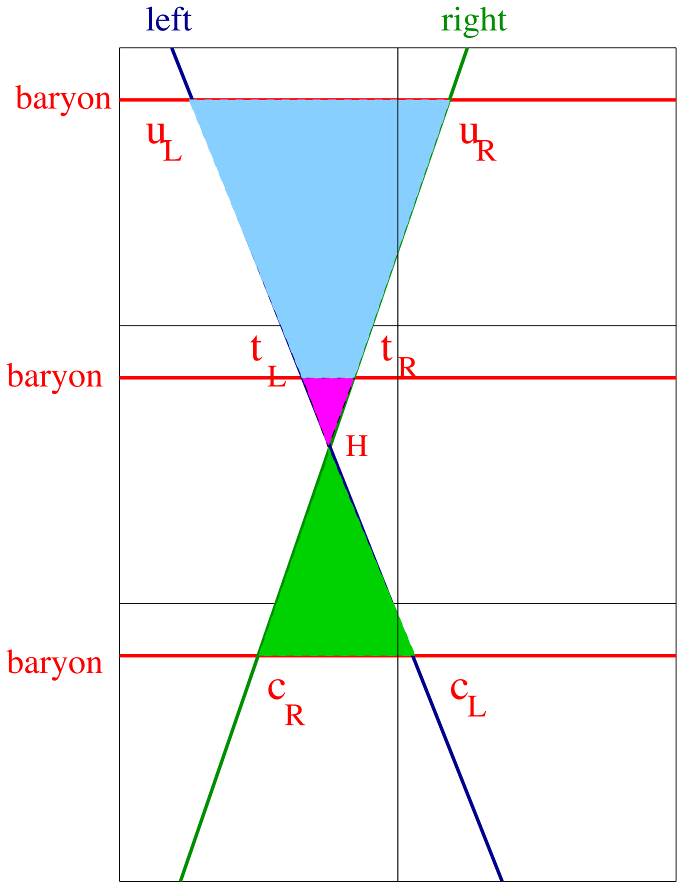
- Matter replication



- Gauge coupling constants $\alpha_i \sim \frac{1}{\mathrm{Vol}(D_i)}$

- Yukawa couplings $Y_{ijk} = e^{-A_{ijk}}$



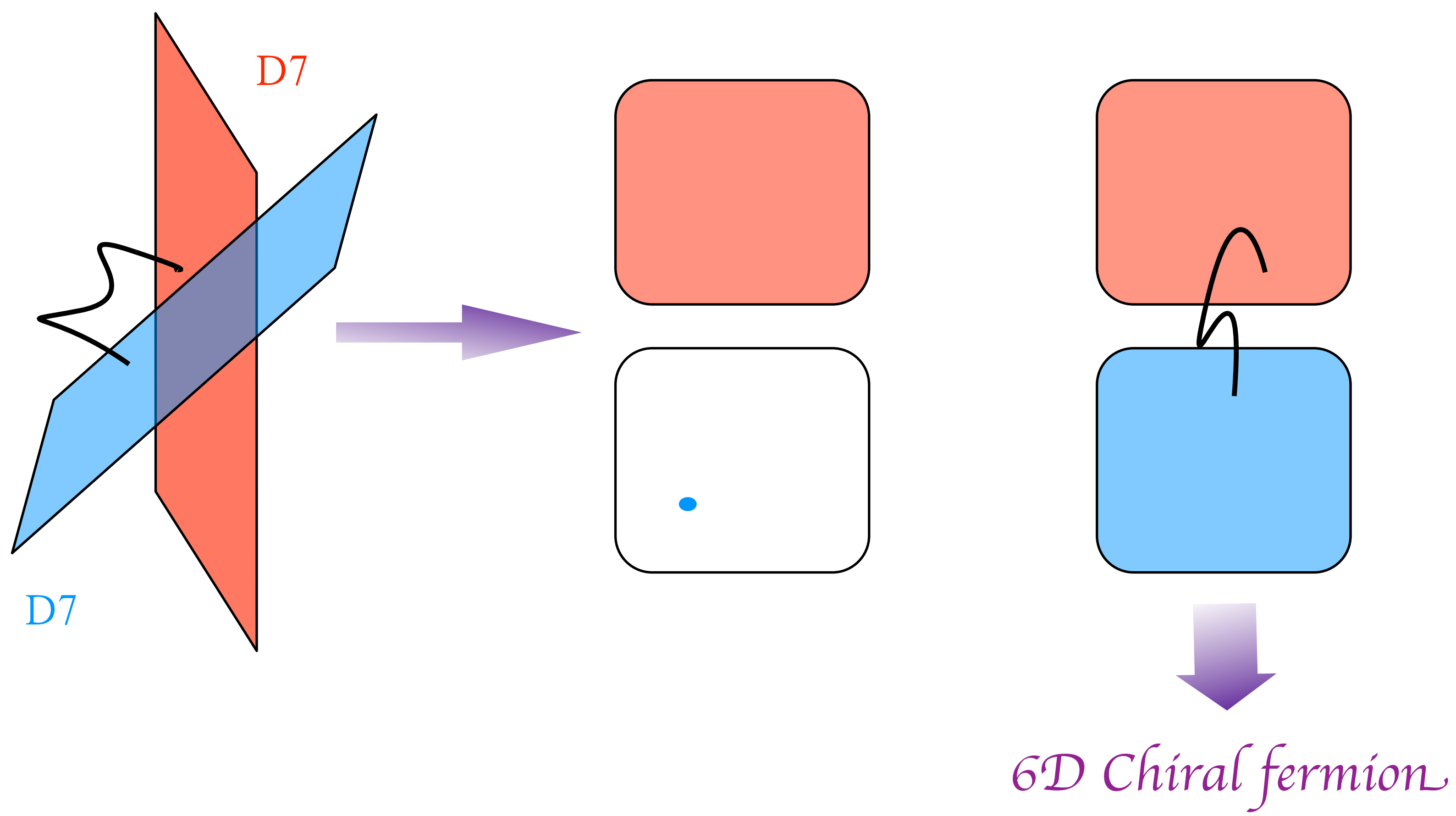


$m_t \gg m_c \gg m_u$

D-branes and Chirality II

Strategy II: Magnetized D-branes

- If the intersection is larger than 4d, then in principle we do not have 4d chirality



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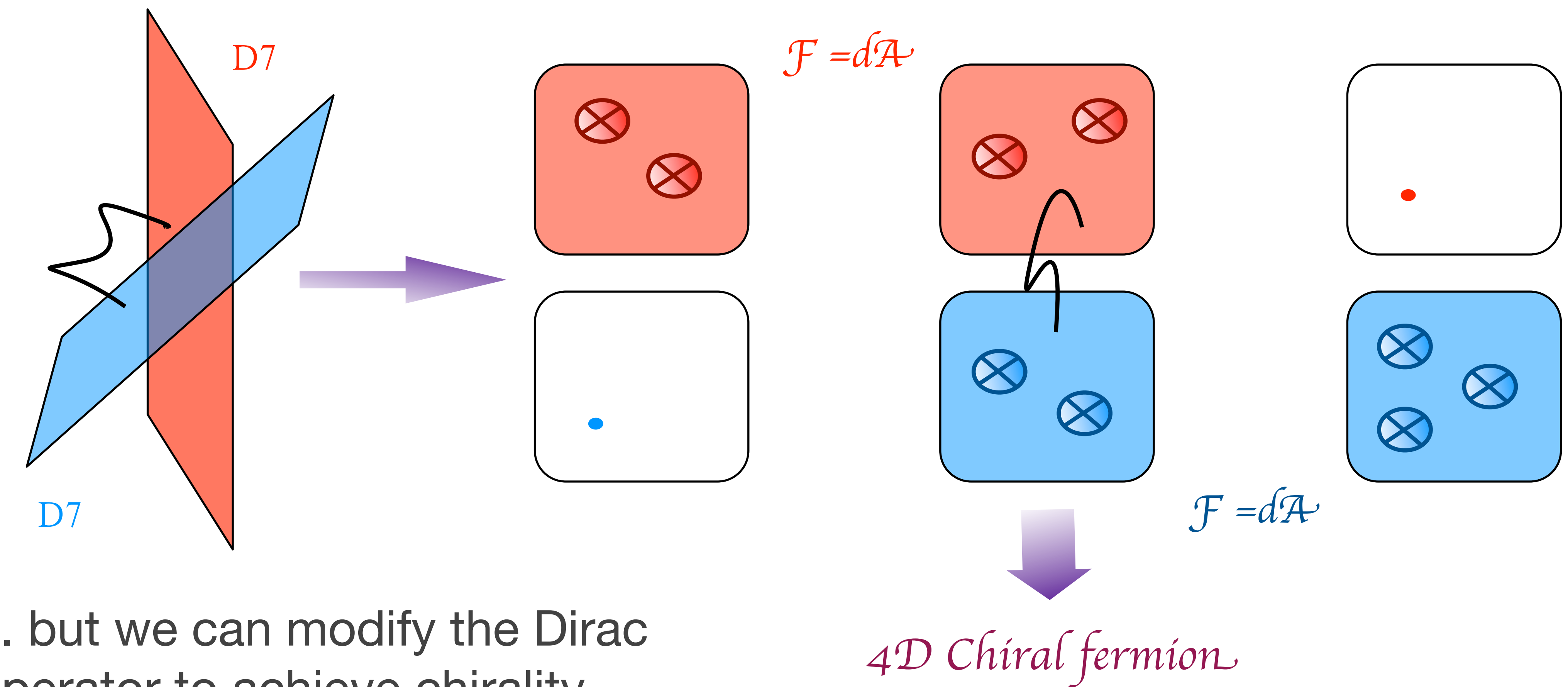


... but we can modify the Dirac operator to achieve chirality

$$D = \nabla + i\,(qA + qA)$$

SM and Geometry II

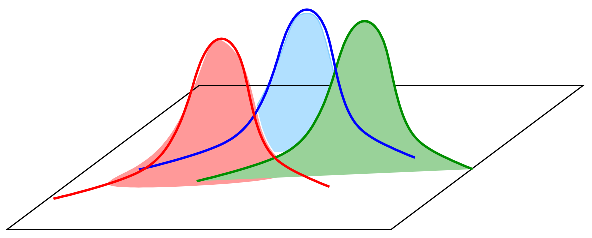
- Matter replication

  Combination of Dirac index and intersection number (still a topological quantity)

- Gauge coupling constants

  $$\alpha_i^{-1} \sim \mathrm{Vol}(D_i) + \int_{D_i} F^2$$

- Yukawa couplings

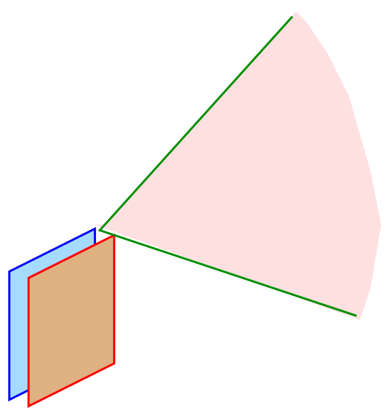


Overlap of wavefunctions

D-branes and Chirality III

Strategy III: D-branes at singularities

- We may also consider D3-branes placed at an orbifold singularity



$\Rightarrow$ Orbifold of the gauge theory

U(6)	→	U(3) x U(2) x U(1)
N=4 SUSY	→	N=1 SUSY
N=4 fields Φ^i	→	chiral matter
$\mathrm{Tr}\{[\Phi^i, \Phi^j]\Phi^k\}$	→	Y_{ijk}

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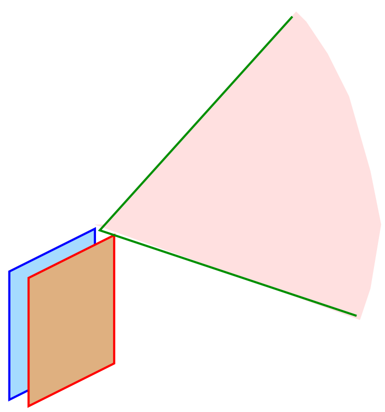

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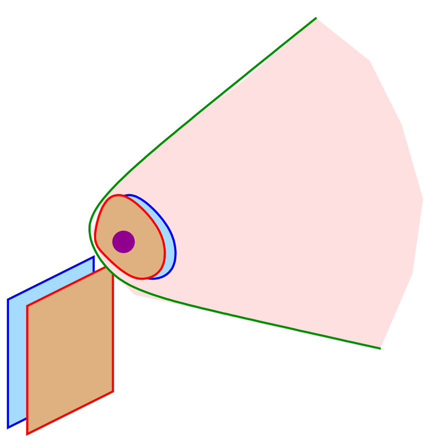


In fact, this strategy is secretly the previous one...

Local models

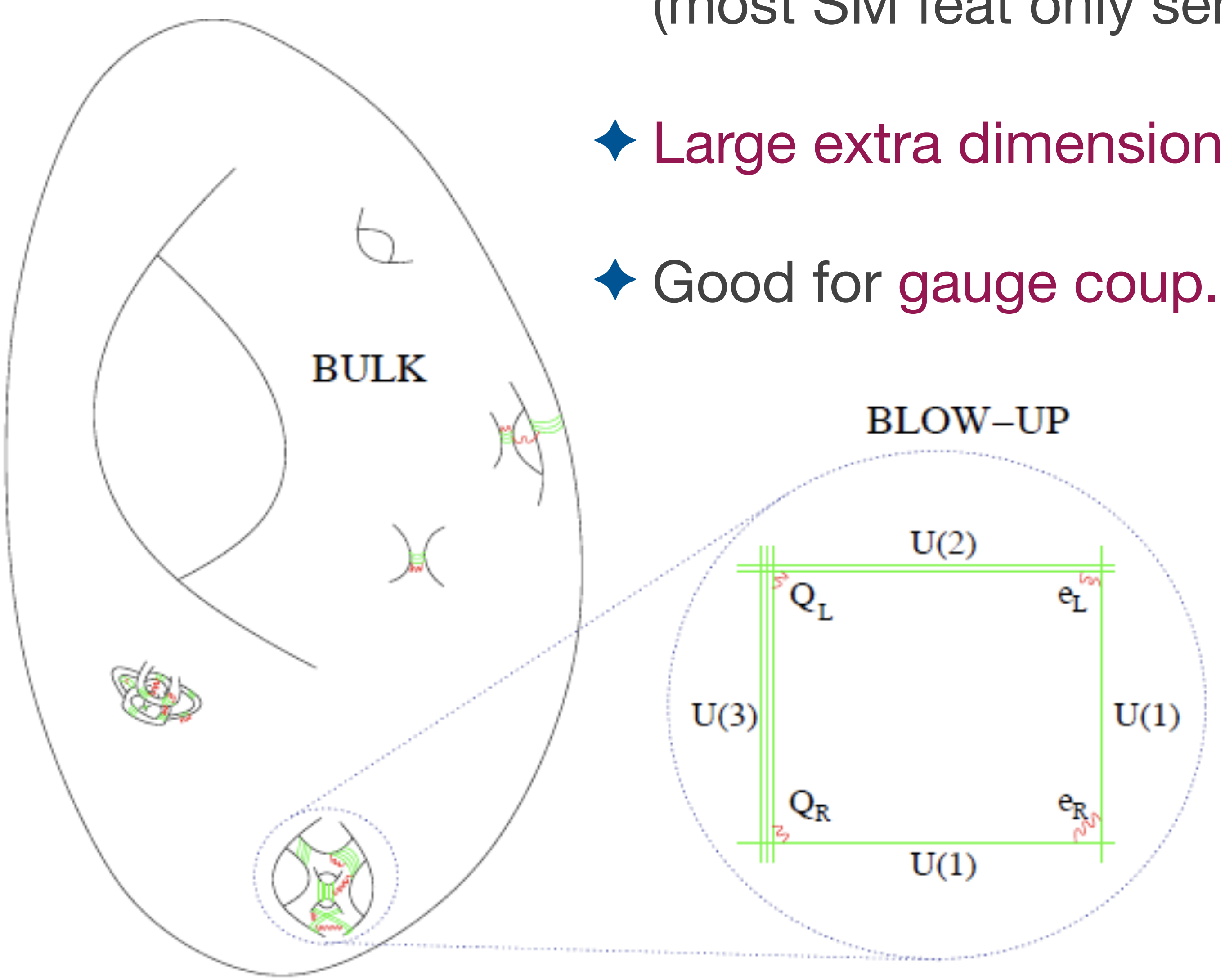
- The latter models and their relatives make up the subclass of local models

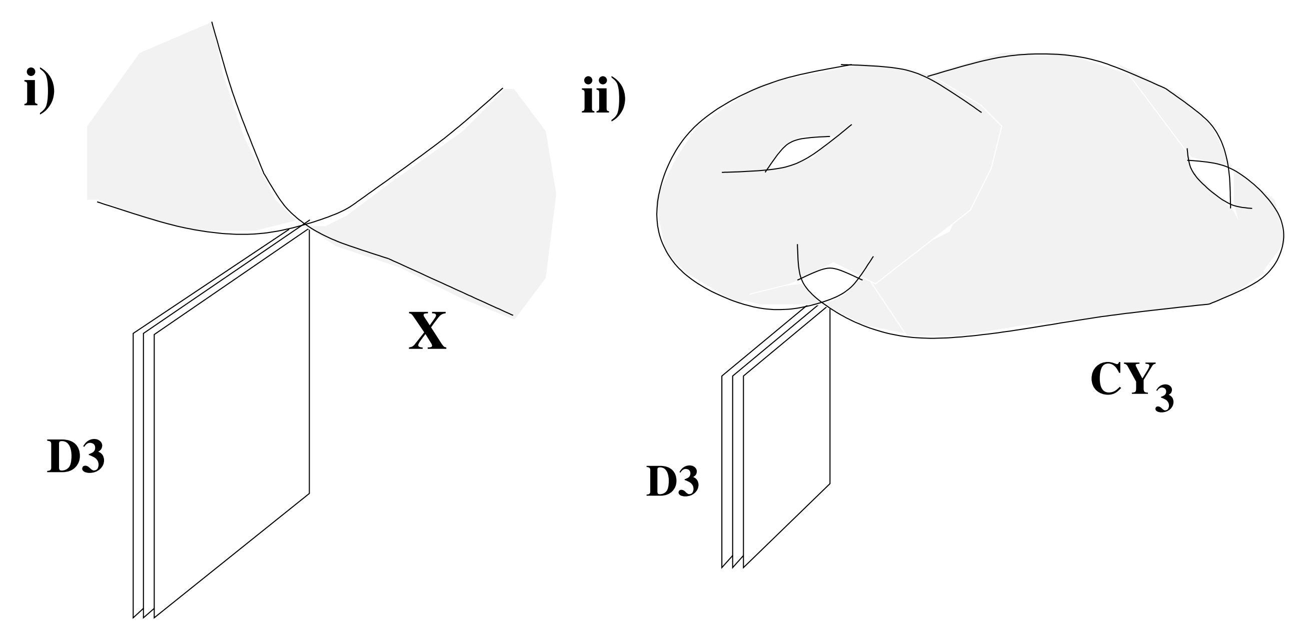
Features:

✦ Bottom-up model building approach
(most SM feat only sensitive to local data)

✦ Large extra dimensions / brane-world idea

✦ Good for gauge coup. unification / GUT models (F-theory, etc.)





Conclusions

- To build a string model, we need to reproduce a “wish list” of SM features
- The first items of the list are more universal, as well as more robust with respect to corrections. Further items are usually more model-dependent
- A key feature is chirality. One can classify models by how chiral fermions arise
- We have focused on D-brane models, which allow to make contact with many recent ideas in BSM physics
  - ✦ Brane worlds/Large extra dim.
  - ✦ Brane inflation

... as well as other string theory ideas

- ✦ AdS/CFT
- ✦ Fluxes