Banff
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The Shape of the Standard Model

Based on work with

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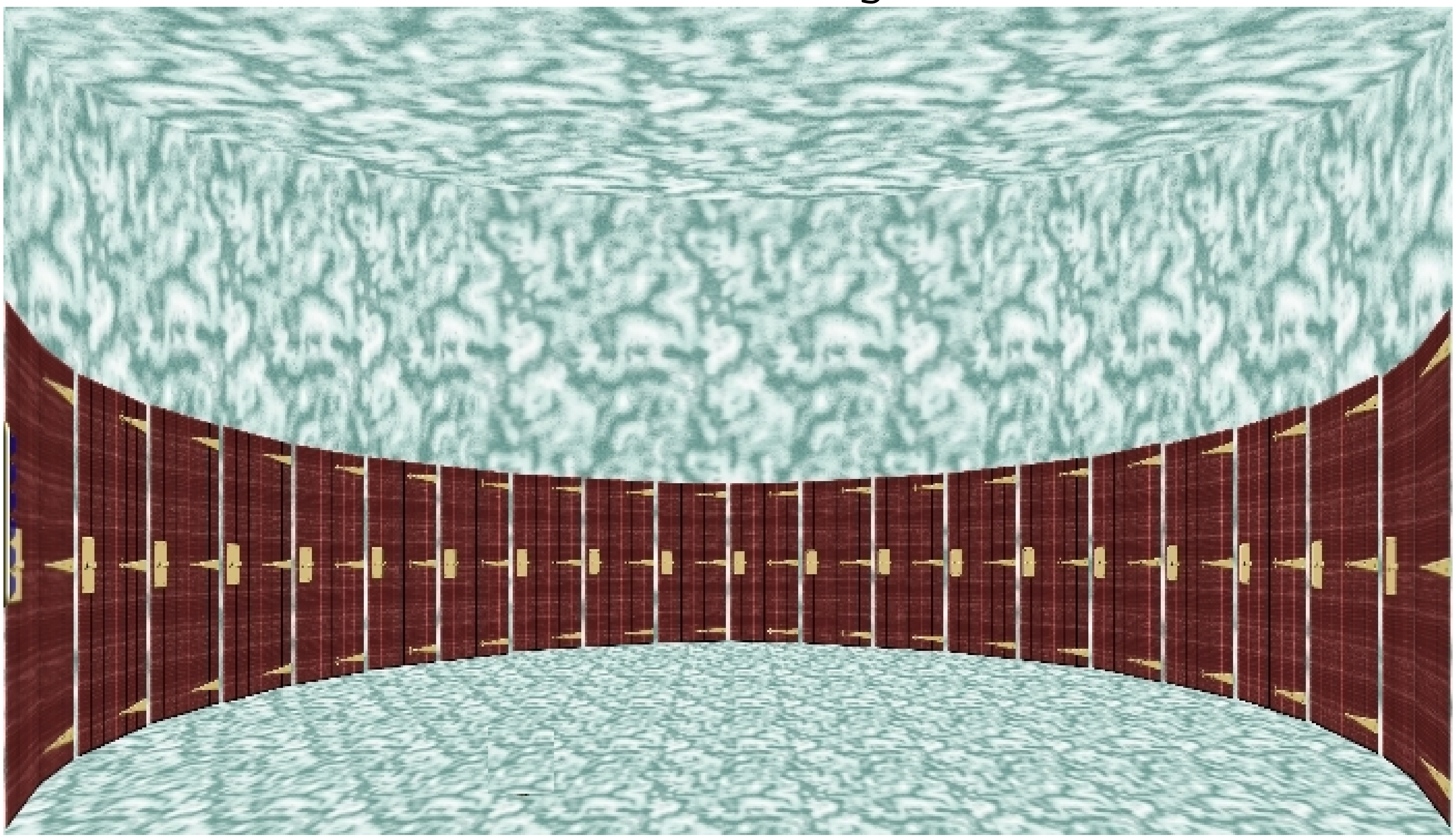
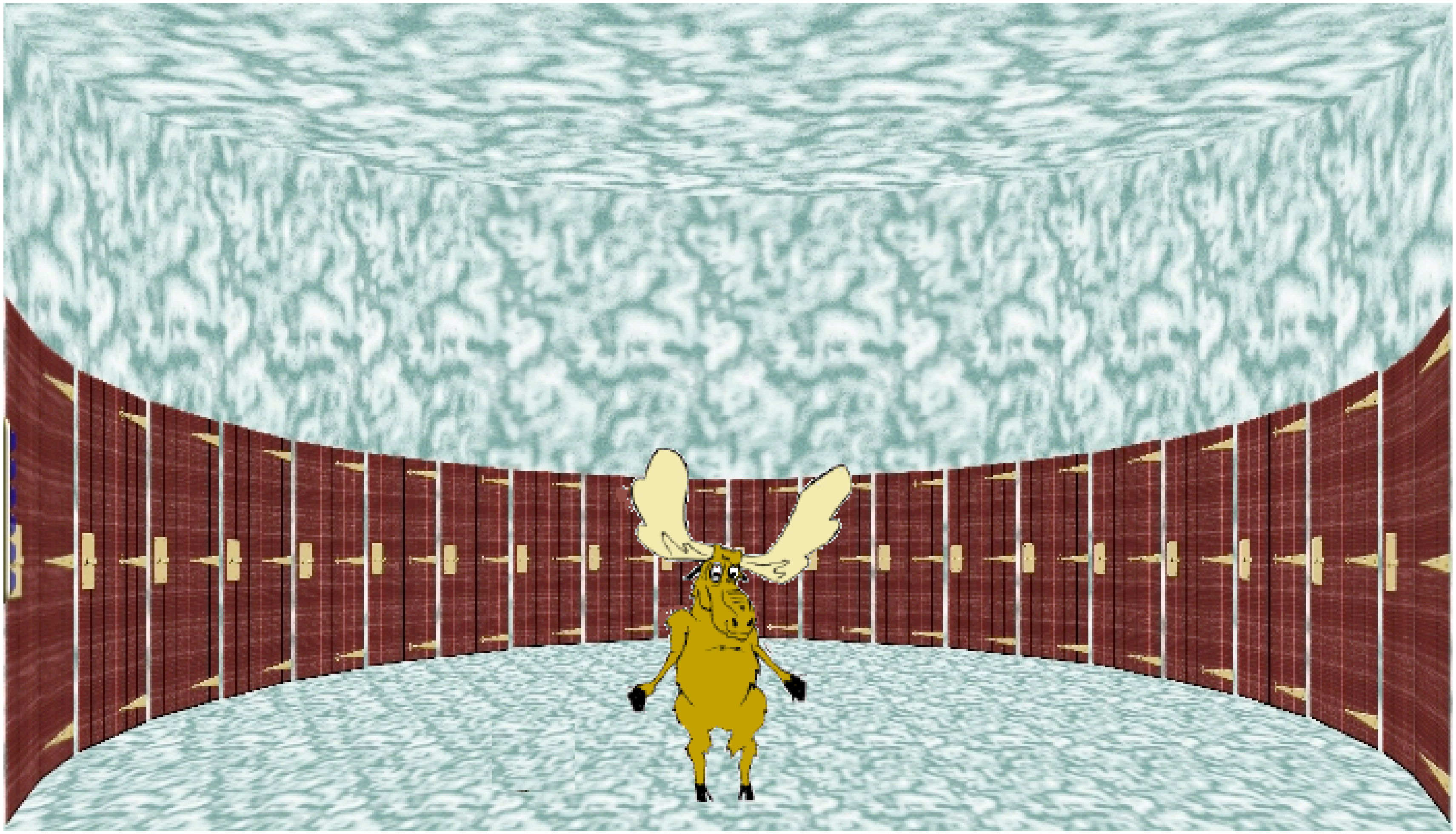
The traditional, optimistic point of view on string phenomenology has been that its dual unification program – tame the Planckian realm of physics and describe all elementary particle and forces – will require a highly constrained mathematical framework, from which we can extract specific predictions for particle physics. The landscape makes clear that this is probably not true!

So, to connect string theory with particle physics, it seems opportune to develop a framework in which we do not need to commit to any detailed assumptions about physics at the Planck scale.

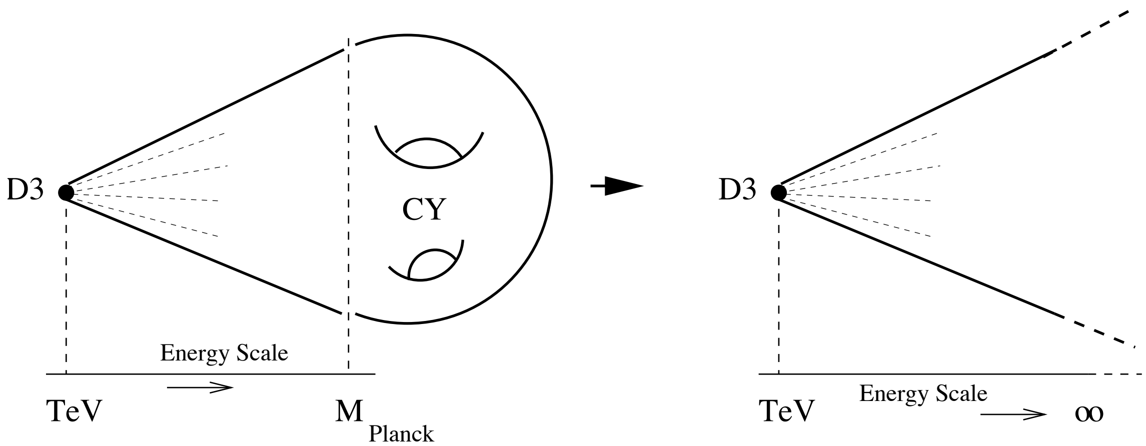
Which door is the right one?



Which door is the right one?



A bottom-up perspective on string phenomenology:



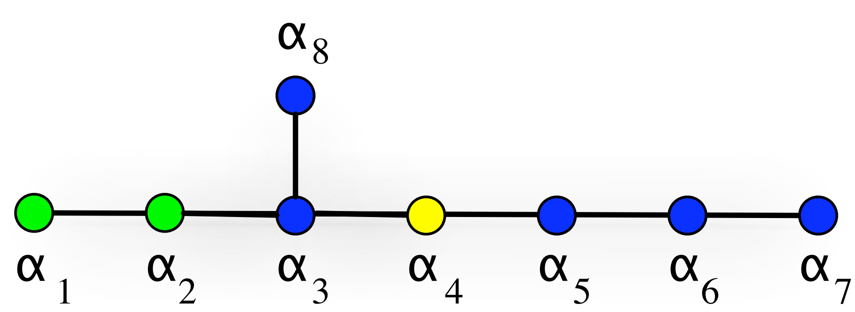
- Open strings only: D3-brane(s) at a CY Singularity
- Decoupling limit: Decouple the Landscape!

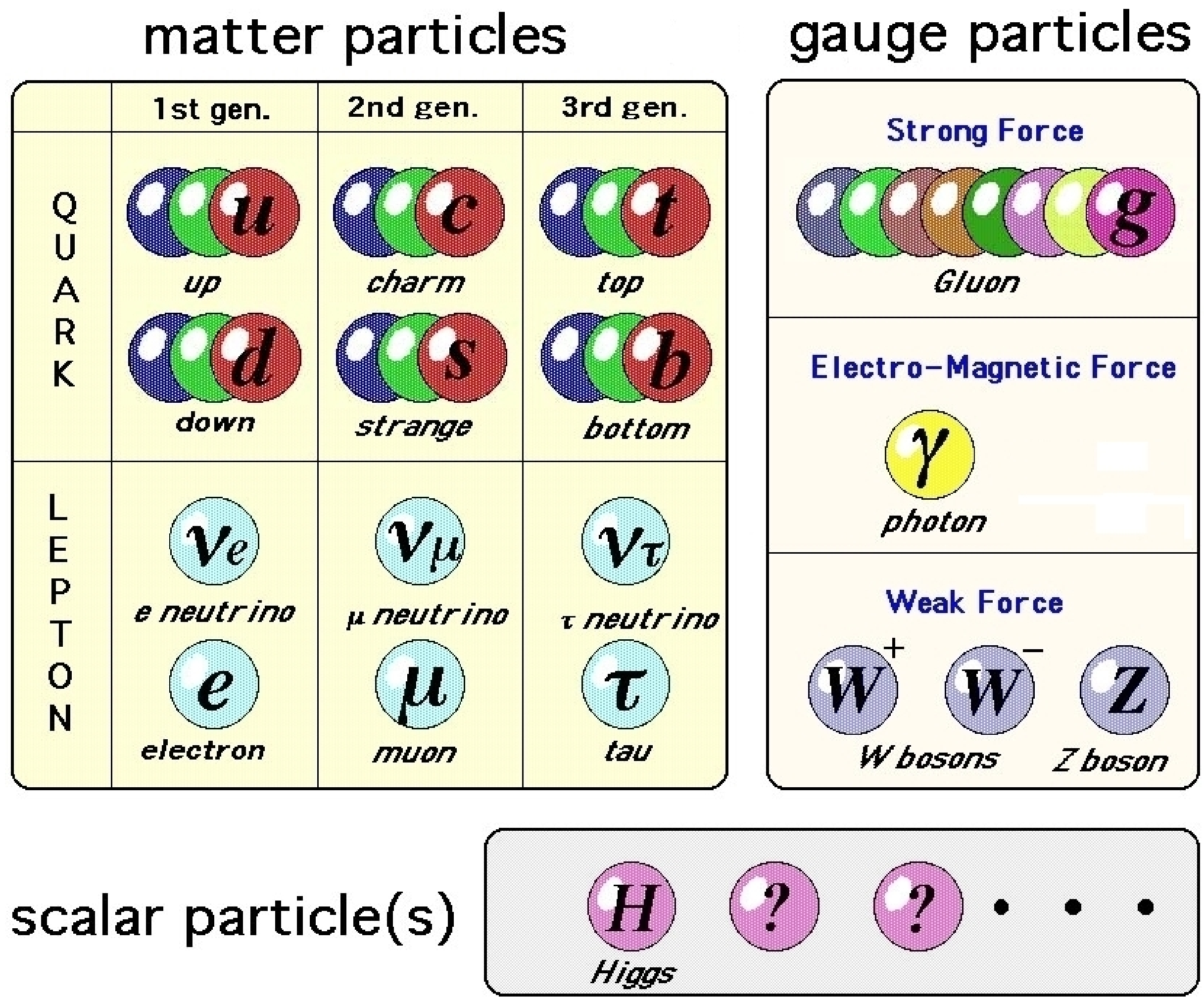
Our result:

(hep-th/0508089, M. Wijnholt, HV, and to appear)

A D3-brane on a partially resolved del Pezzo 8 singularity
has the particle content and interactions of the MSSM *

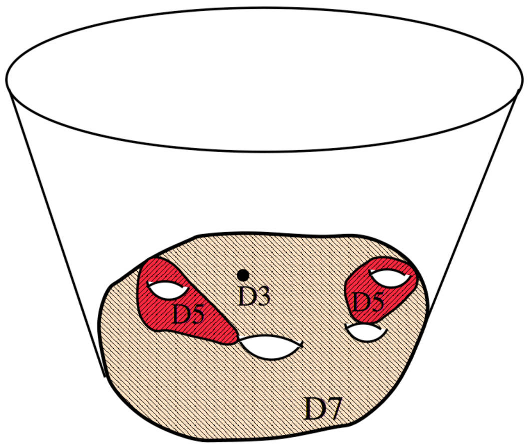
* except for some extra Higgs fields





Elements of the Standard Model + • •

Fractional brane = bound state of wrapped D7, D5 or D3-branes



$$\mathrm{ch}(F_i) = (\, Q_7 \,,\, Q_5 \,,\, Q_3 \,)$$

A D3-brane splits up as a sum of fractional branes $\{F_i\}$ with multiplicities n_i such that:

$$\sum_i n_i \, \mathrm{ch}(F_i) \;=\; (\, 0 \,,\, 0 \,,\, 1 \,)$$

With these ingredients, let's start to prepare our recipe:

$\Longrightarrow$ A Moose ! Quiver theory with gauge group:

$$\prod_i U(n_i)$$

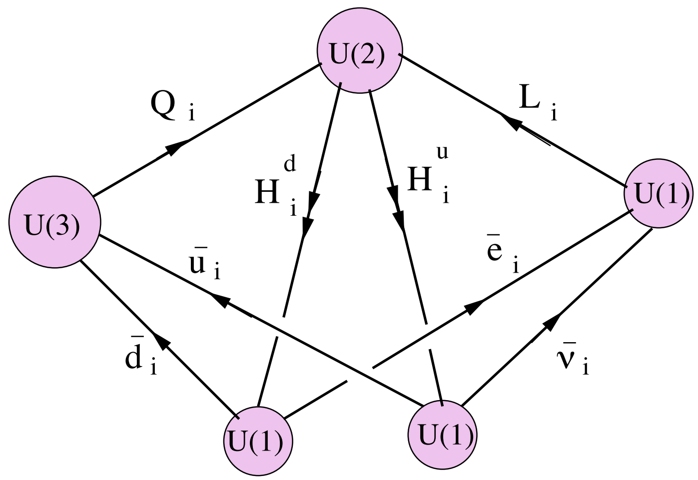
chiral fields in $(n_i, \bar{n}_j)$ = geometric intersection number.

How to draw a Moose:

- A node $= U(n_i)$ gauge multiplet
- Oriented line = chiral field in $(n_i, \bar{n}_j)$
- Equal number of incoming and outgoing lines

- No lines return to the same node $\Longrightarrow$ no adjoint matter
- One type of lines between nodes $\Longrightarrow$ only chiral matter

MMSM: Minimal Moosification of the Standard Model:



- Two non-anomalous $U(1)$'s:

$$Y = \frac{1}{3}Y_3 - Y_0 + \frac{1}{2}(Y_u - Y_d)$$
$$B-L = \frac{1}{3}Y_3 - Y_0$$

- Two pairs of Higgs doublets per generation. $\leftrightarrow$ rule c)

- Hypercharge should survive as only massless $U(1)$

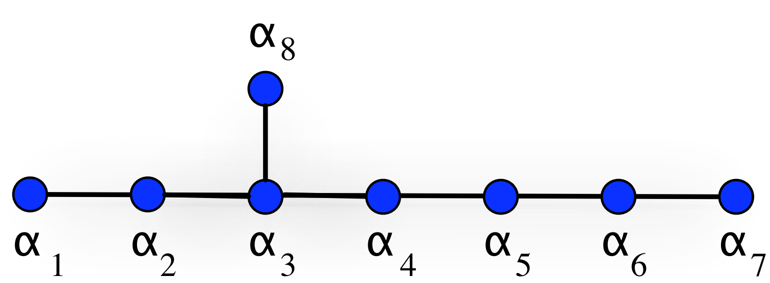
A del Pezzo 8 is a complex 4-manifold with nine 2-cycles:

$$h \cdot h = 1 \qquad e_i \cdot e_j = -\delta_{ij} \qquad h \cdot e_i = 0$$

$$k = -3h + \sum_i e_i \qquad \alpha_i = e_i - e_{i+1}, \quad i = 1,.,7 \qquad \alpha_8 = h - e_1 - e_2 - e_3\,,$$

The α_i span an E_8-root lattice:

$$\alpha_a \cdot \alpha_b = -A_{ab}; \qquad k \cdot k = 2; \qquad k \cdot \alpha_a = 0$$



A "three block exceptional collection" on dP_8:

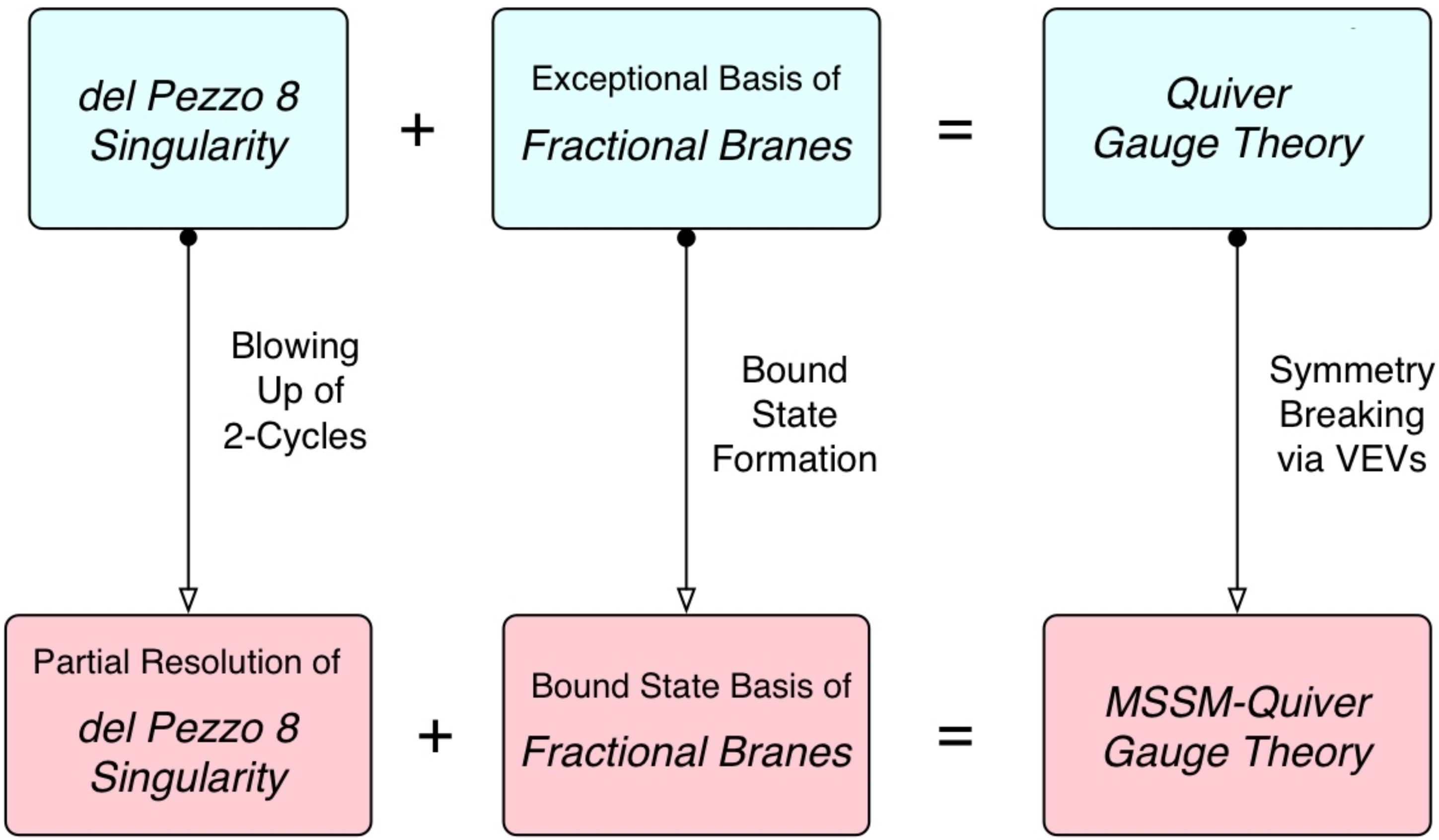
$$\mathrm{ch}(F_i) = (1, h - e_i, 0) \qquad i = 1, .., 4$$

$$\mathrm{ch}(F_i) = (1, -k + e_i, 1) \qquad i = 5, .., 8$$

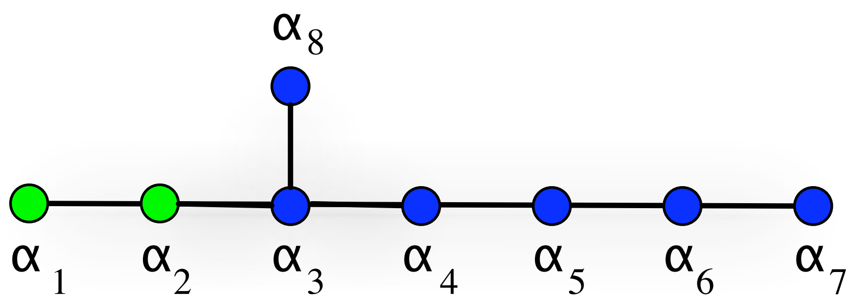
$$\mathrm{ch}(F_9) = (1, 2h - \sum_{i=1}^{4} e_i, 0)$$

$$\mathrm{ch}(F_{10}) = (3, -k + \sum_{i=5}^{8} e_i, -\tfrac{1}{2})$$

$$\mathrm{ch}(F_{11}) = (3, \sum_{i=5}^{8} e_i, -2)$$

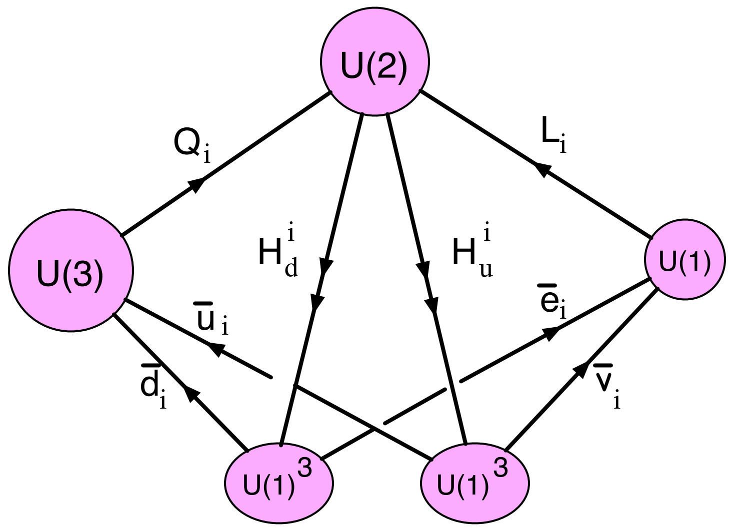

del Pezzo 8 Singularity
+
Exceptional Basis of Fractional Branes
=
Quiver Gauge Theory
Blowing Up of 2-Cycles
Bound State Formation
Symmetry Breaking via VEVs
Partial Resolution of del Pezzo 8 Singularity
+
Bound State Basis of Fractional Branes
=
MSSM-Quiver Gauge Theory

Partial resolution: we let the dP_8 surface develop a A_2 singularity, so that we can blow-up the 2-cycles α_1 and α_2. The new basis of fractional branes spans the full homology of dP_8, except for α_1 and α_2.



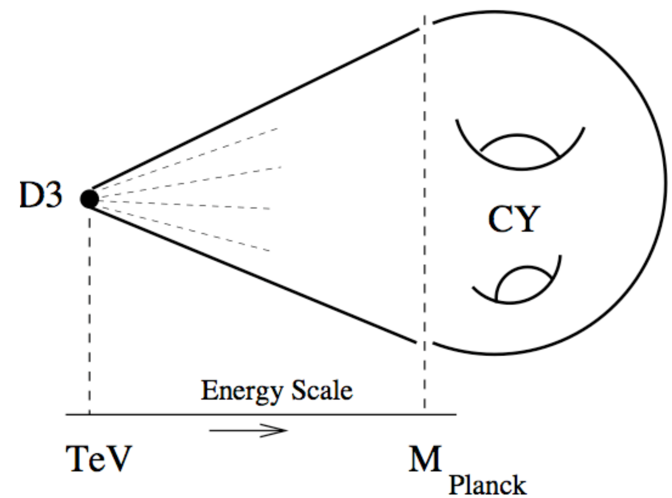
Symmetry breaking = Bound state formation:

$$\mathrm{ch}(F_0) \;=\; 3\,\mathrm{ch}(F_{10}) - \sum_{i=1,2,3} \mathrm{ch}(F_i) - \mathrm{ch}(F_{11})$$



MMSM $\quad + \text{ extra } U(1)$'s

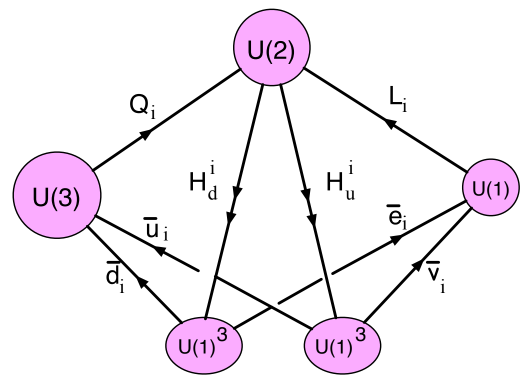
Embedding in full string compactification:



- Moduli stabilization

- Tadpole cancellation

- Decoupling of extra $U(1)$'s



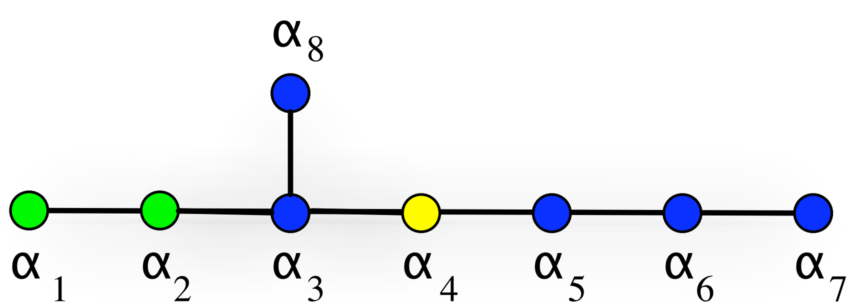
$$Y = \frac{1}{3}Y_3 - Y_0 + \frac{1}{2}(Y_u - Y_d)$$

	Y_0	Y_1^d	Y_1^u	Y_2	Y_3	Y
Q	0	0	0	-1	1	$\frac{1}{6}$
$\overline{u}$	0	0	1	0	-1	$-\frac{2}{3}$
$\overline{d}$	0	1	0	0	-1	$\frac{1}{3}$
L	1	0	0	-1	0	$-\frac{1}{2}$
$\overline{\nu}$	-1	0	1	0	0	0
$\overline{e}$	-1	1	0	0	0	1
H^u	0	0	-1	1	0	$\frac{1}{2}$
H^d	0	-1	0	1	0	$-\frac{1}{2}$

(1)

The hypercharge Y is associated with the D5-brane that wraps the 2-cycle α_4. We make sure that α_4 is contractible within the full CY, whereas all other 2-cycles are non-contractible. All other $U(1)$ bosons then acquire a longitudinal component from normalized RR-zero modes, and become massive via the Stückelberg mechanism.

Only hypercharge survives as a massless $U(1)$ symmetry!



Bottom-Up Philosophy: Open String Phenomenology

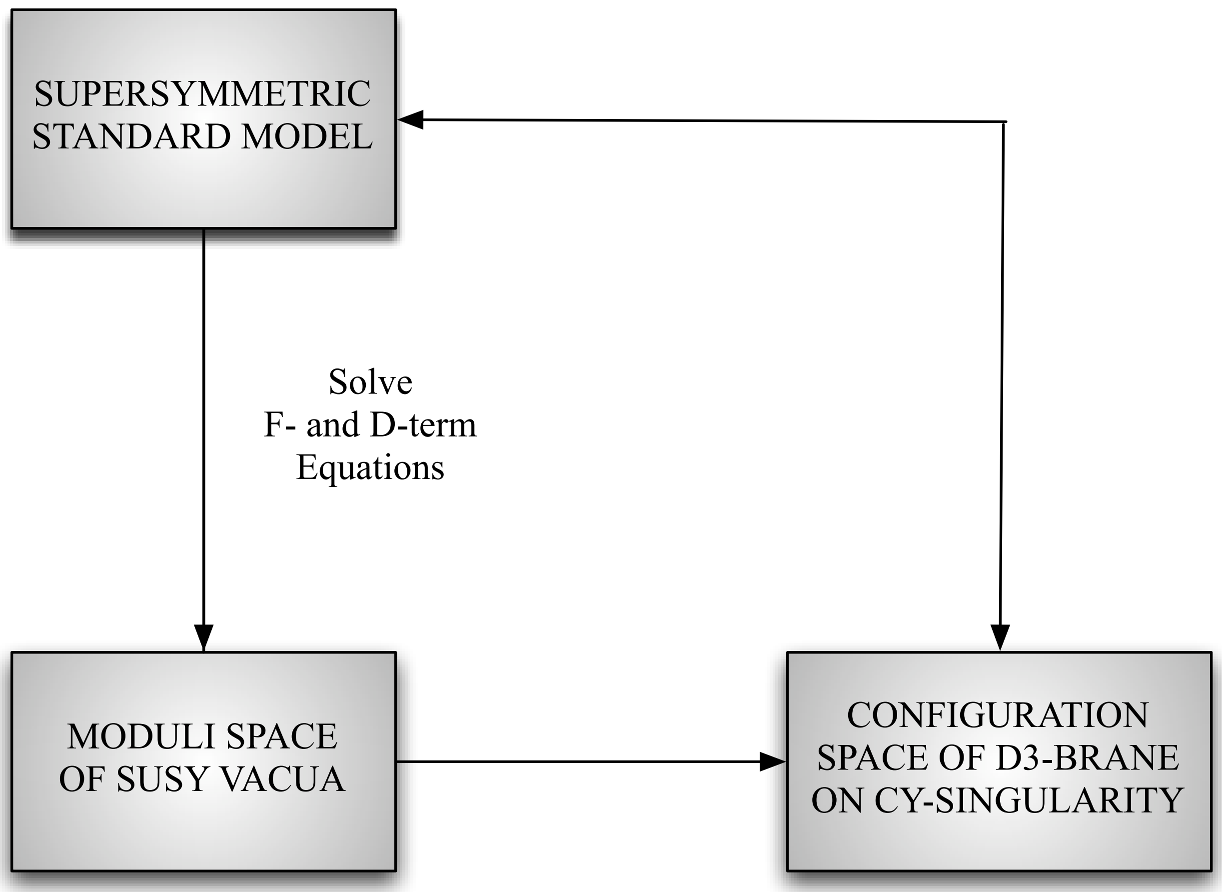
- Take decoupling limit from gravity and closed string moduli.

- Couplings and expectation values dialed by local geometry.

- Postpone issue of string compactification and the landscape.

- Geometric unification: one single D3-brane?

Uniqueness: "Shape of the Standard Model"



Partial dictionary:

Complex structure $\longleftrightarrow$ Superpotential W

Blow-up modes $\longleftrightarrow$ FI-parameters ζ

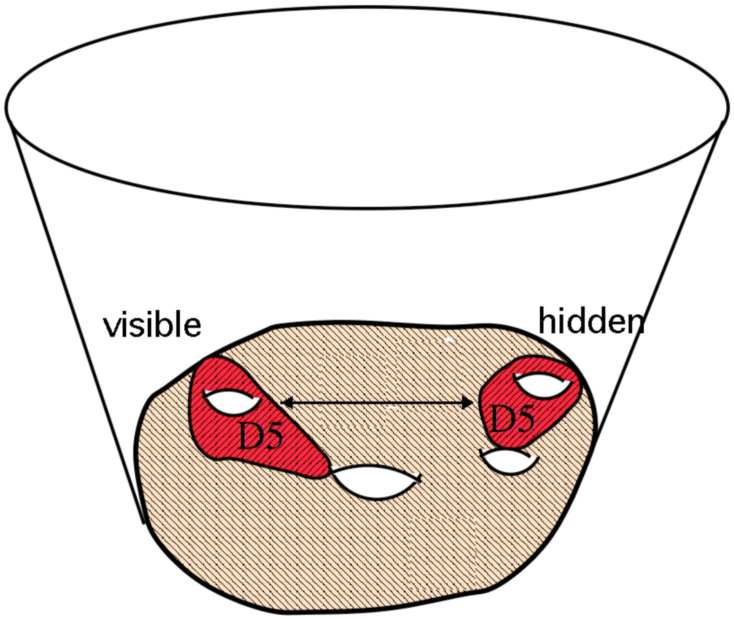
Govern moduli space of D3-brane vacua via F- and D-flatness conditions:

$$\frac{\partial W}{\partial \phi^a} = C_{abc}\,\phi^b\,\phi^c = 0 \qquad\qquad \sum_a |\phi^+_{ia}|^2 - \sum_b |\phi^-_{ib}|^2 = \zeta_i$$

Periods of 2-forms $\longleftrightarrow$ Gauge couplings

RR-field strengths $\longleftrightarrow$ Soft parameters

SUSY breaking:



Gauge or Gravity Mediation?

Depends on distance between branes, relative to string scale.

Provocative Question:

Is open string phenomenology useful?

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Provocative Answer:

Via open string phenomenology, we may identify:

$$\boxed{\begin{array}{c}\text{closed string}\\ \text{in the near-horizon}\\ \text{geometry of the D3-brane}\end{array}} = \boxed{\begin{array}{c}\text{QCD string}\\ \text{defined via the}\\ 1/N\text{ expansion}\end{array}}$$


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MATT GROENING