KITP, Santa Barbara
Augst 29, 2006

Towards the Standard Model

and

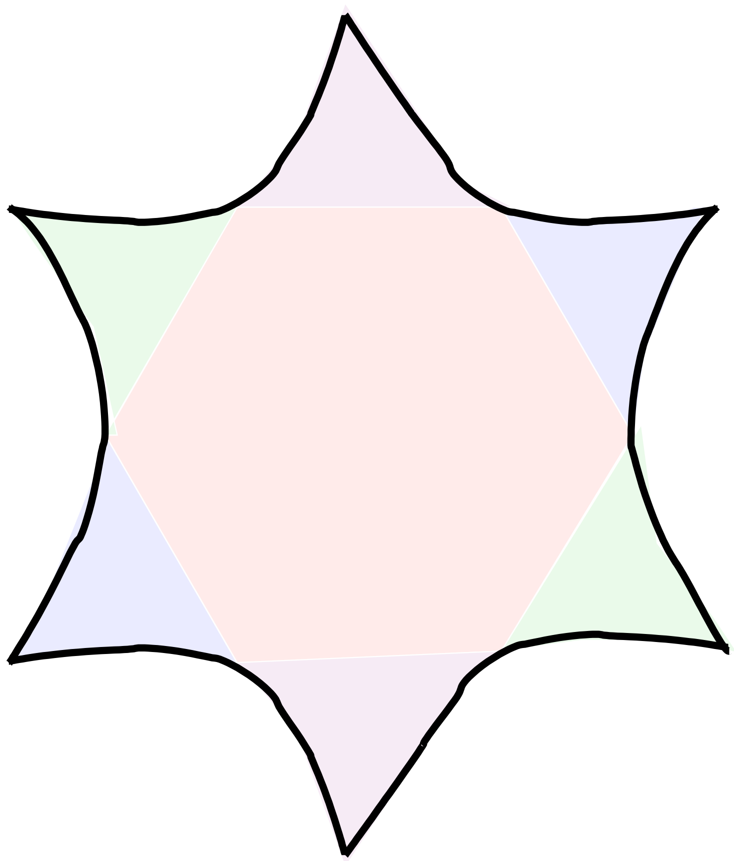
via D-branes at Singularities

Based on work with

Herman Verlinde

Martijn Wijnholt
Dima Malyshev
Matt Buican
Dave Morrison

The landscape of all possible string constructions of the SM:



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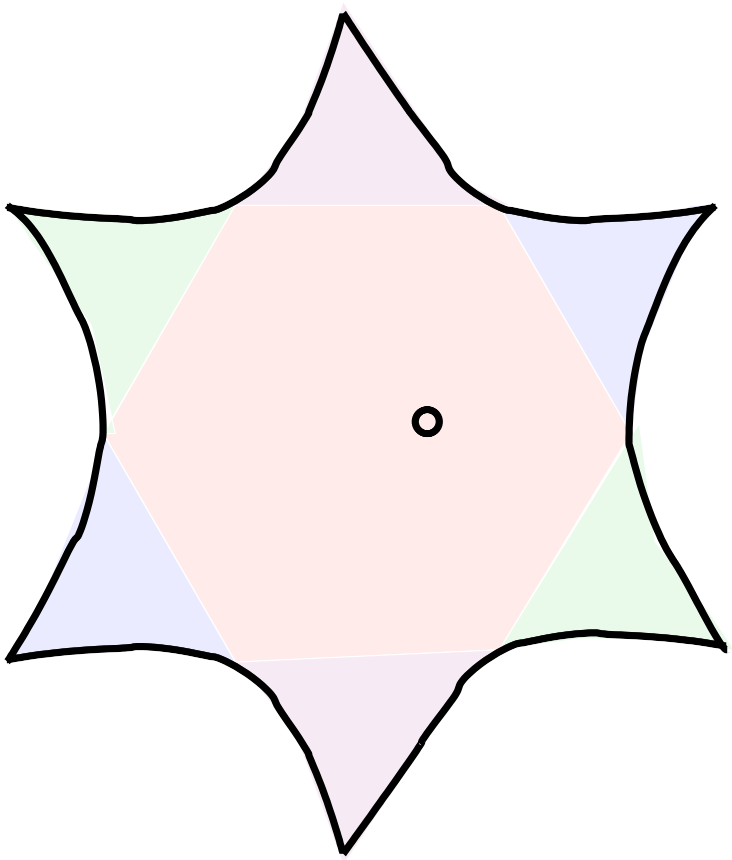


$\mathbf{o}$ = the right one!

The "correspondence principle"

"Occam's razor"

The "correspondence principle":

"a new theory should explain all phenomena for which the preceding theory is known to be valid"

"one of the tools available to physicists for selecting theories corresponding to reality"

"Occam's razor":

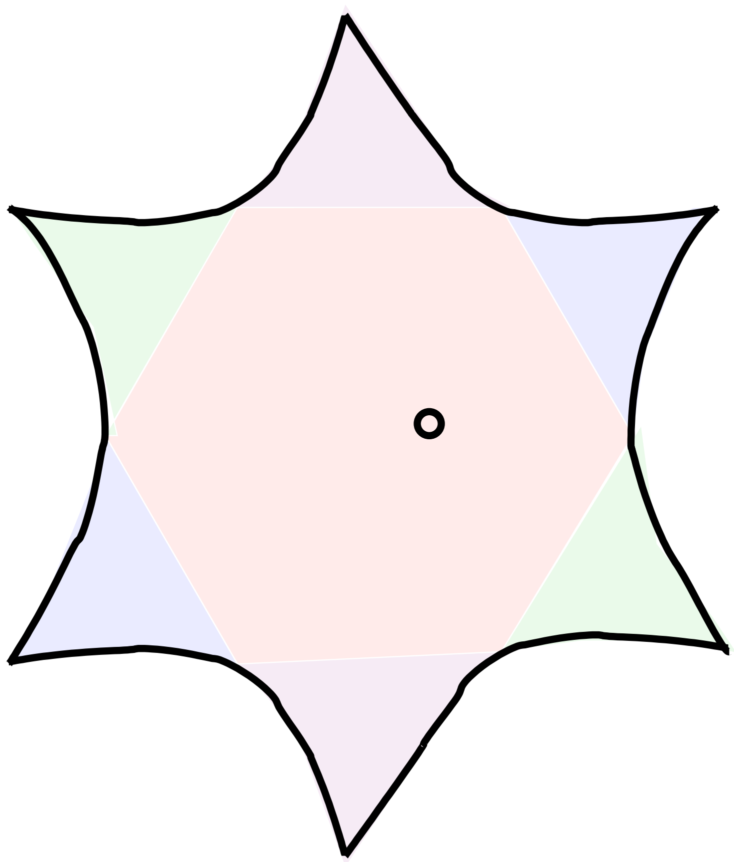
"entia non sunt multiplicanda praeter necessitatem"

"when competing theories have equal predictive power, pick the one that introduces the fewest assumptions and postulates the fewest hypothetical entities."

- Can one obtain the SM via a ‘decoupling limit’ of string theory?

- Look for a string construction of the SM in which all geometric data are in one-to-one correspondence with SM parameters.

The landscape of all possible string constructions of the SM



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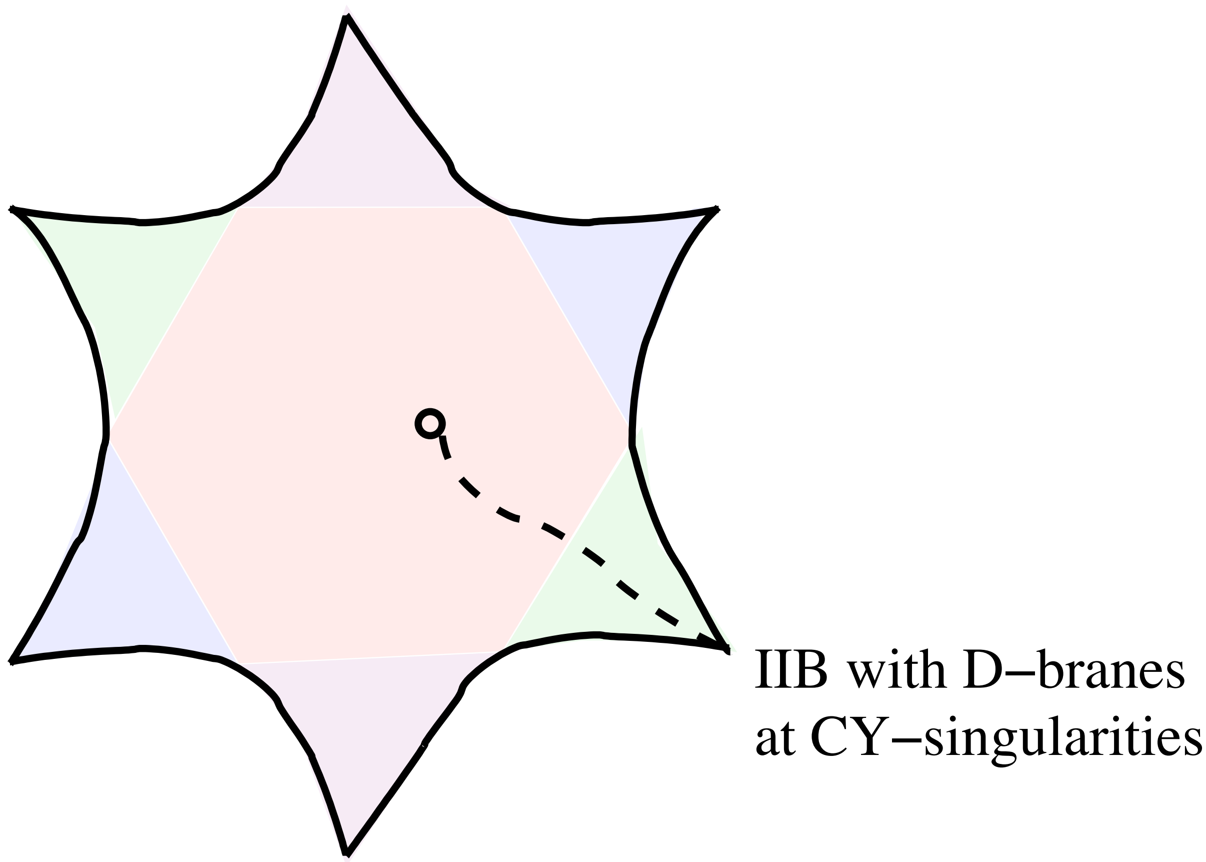

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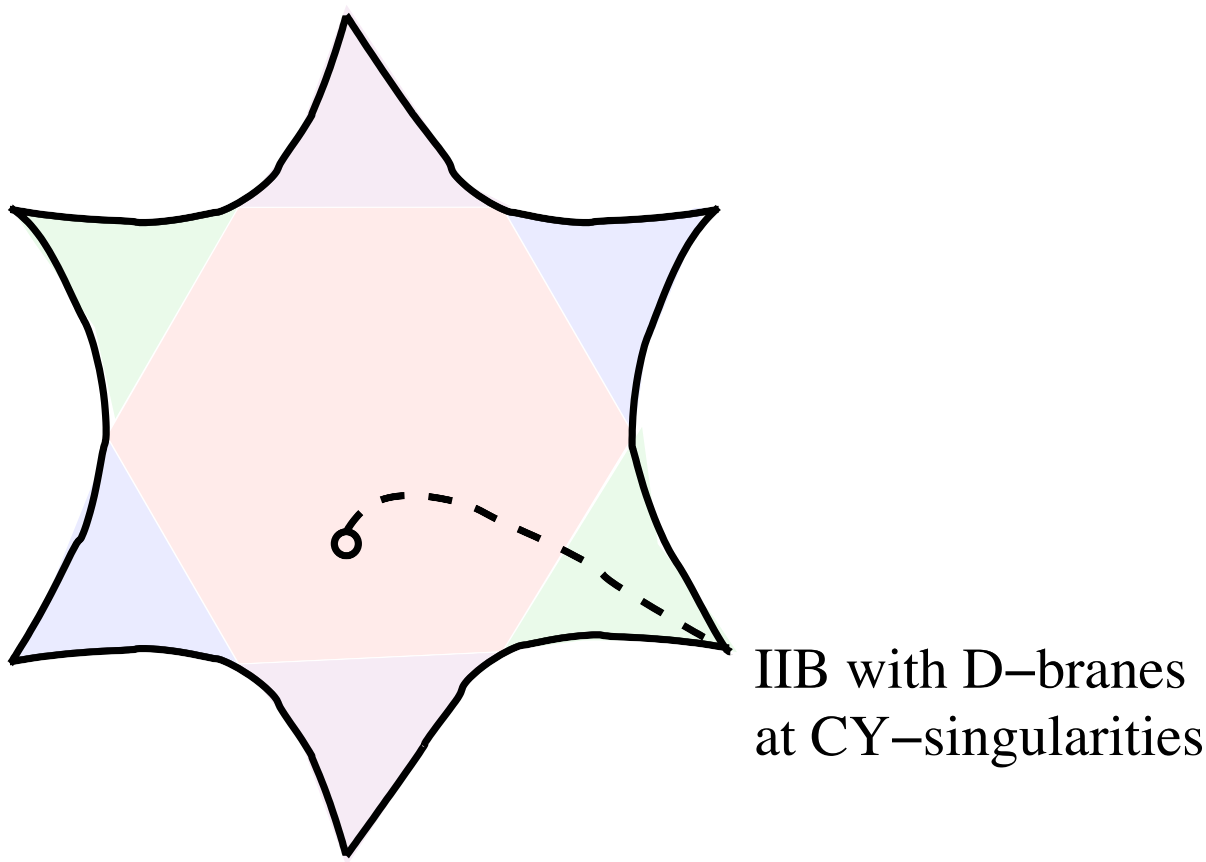

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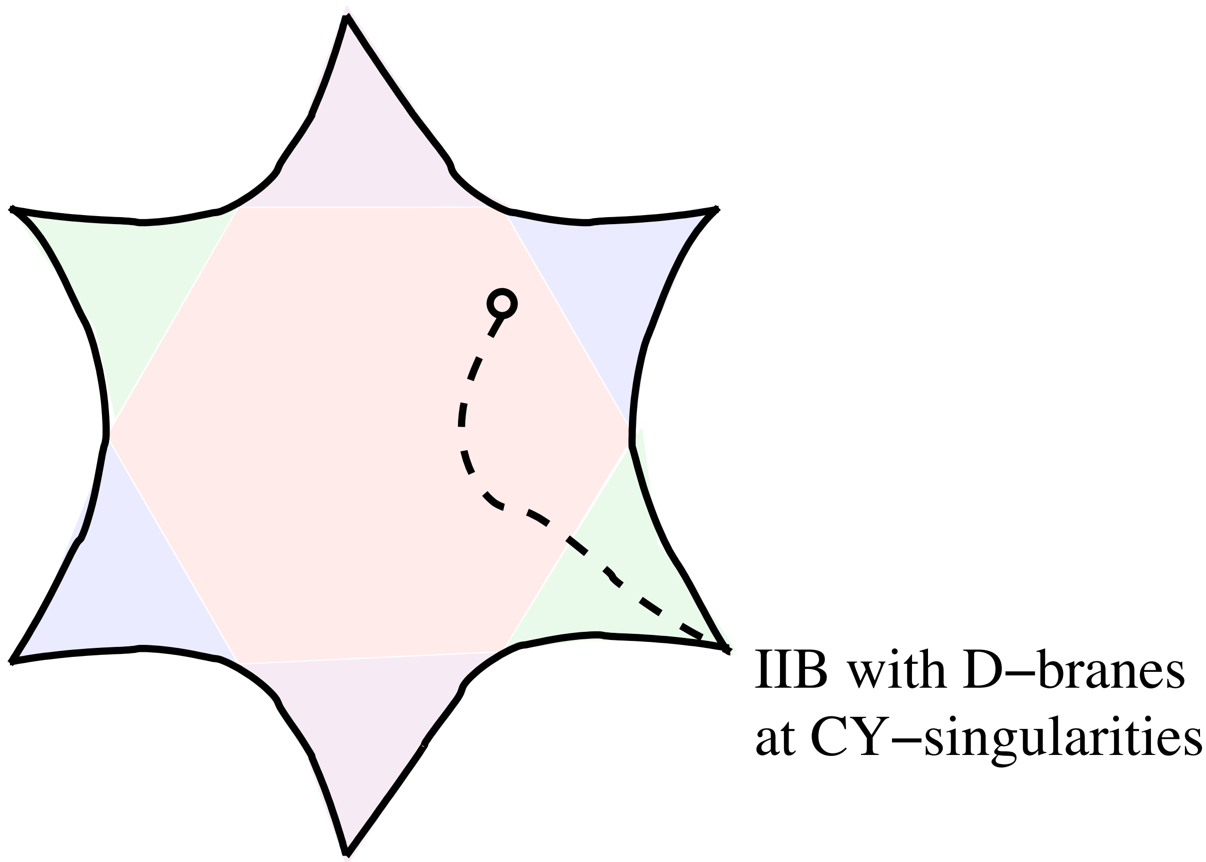
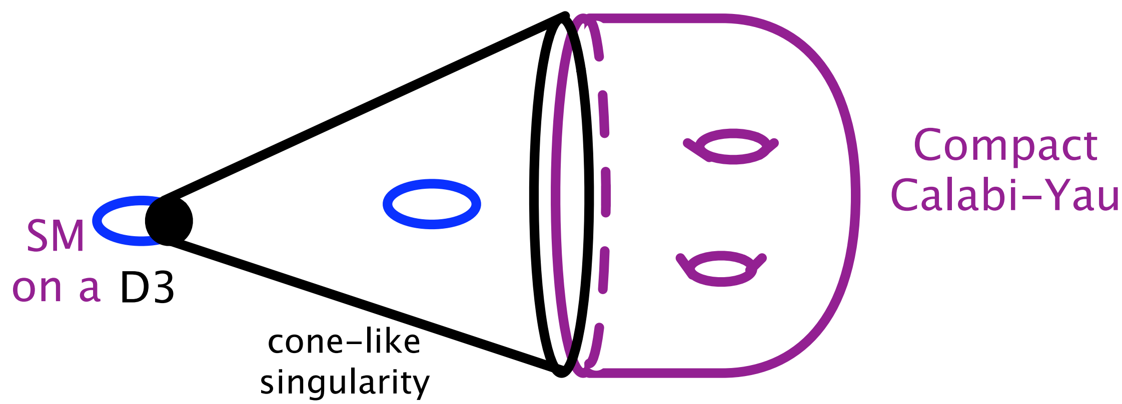


$\mathbf{o}$ = the right one!

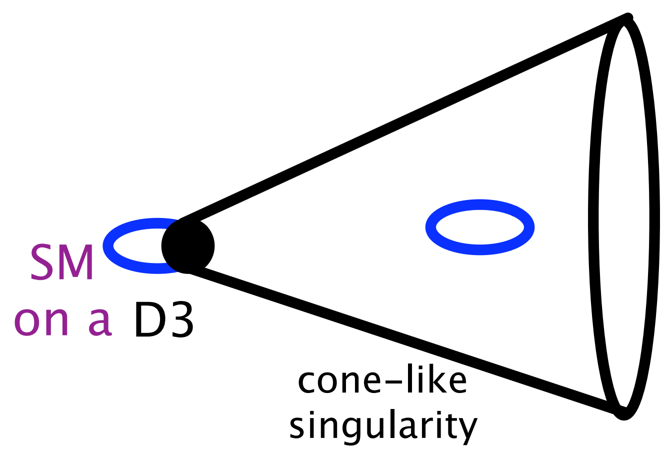
Conjecture: * every string model* that exhibits a gauge hierarchy admits a duality frame such that all gauge dynamics is described by open strings attached to D-branes near a CY singularity......



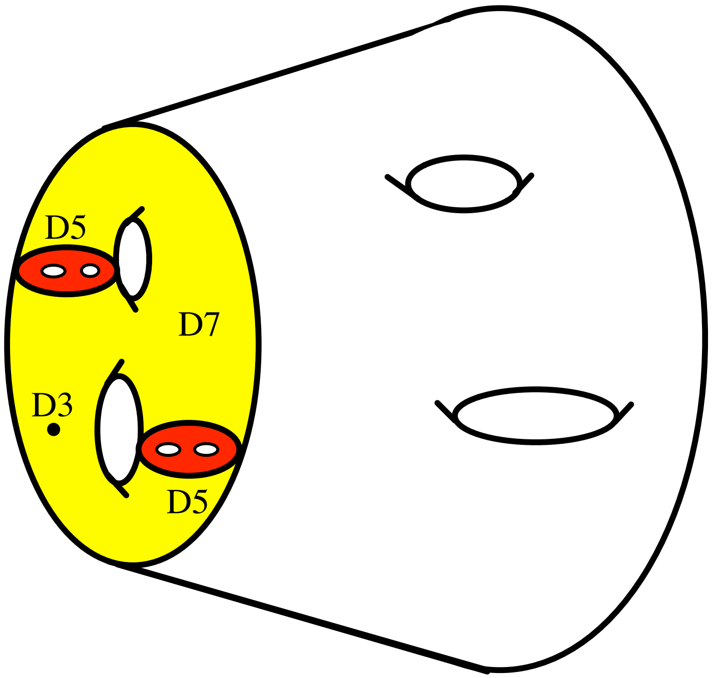
* almost

* with low energy susy

Motivation: can take a formal decoupling limit, in which all gauge invariant coupling constants are frozen, and tuned via (non-normalizable) deformations of the local geometry:



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



$$\mathrm{ch}(F) = (\, Q_7 \,,\, Q_5 \,,\, Q_3 \,)$$
$$= (\; \mathbf{r} \;,\; \mathbf{p}_{\mathrm{a}} \;,\; \mathbf{q} \;)$$

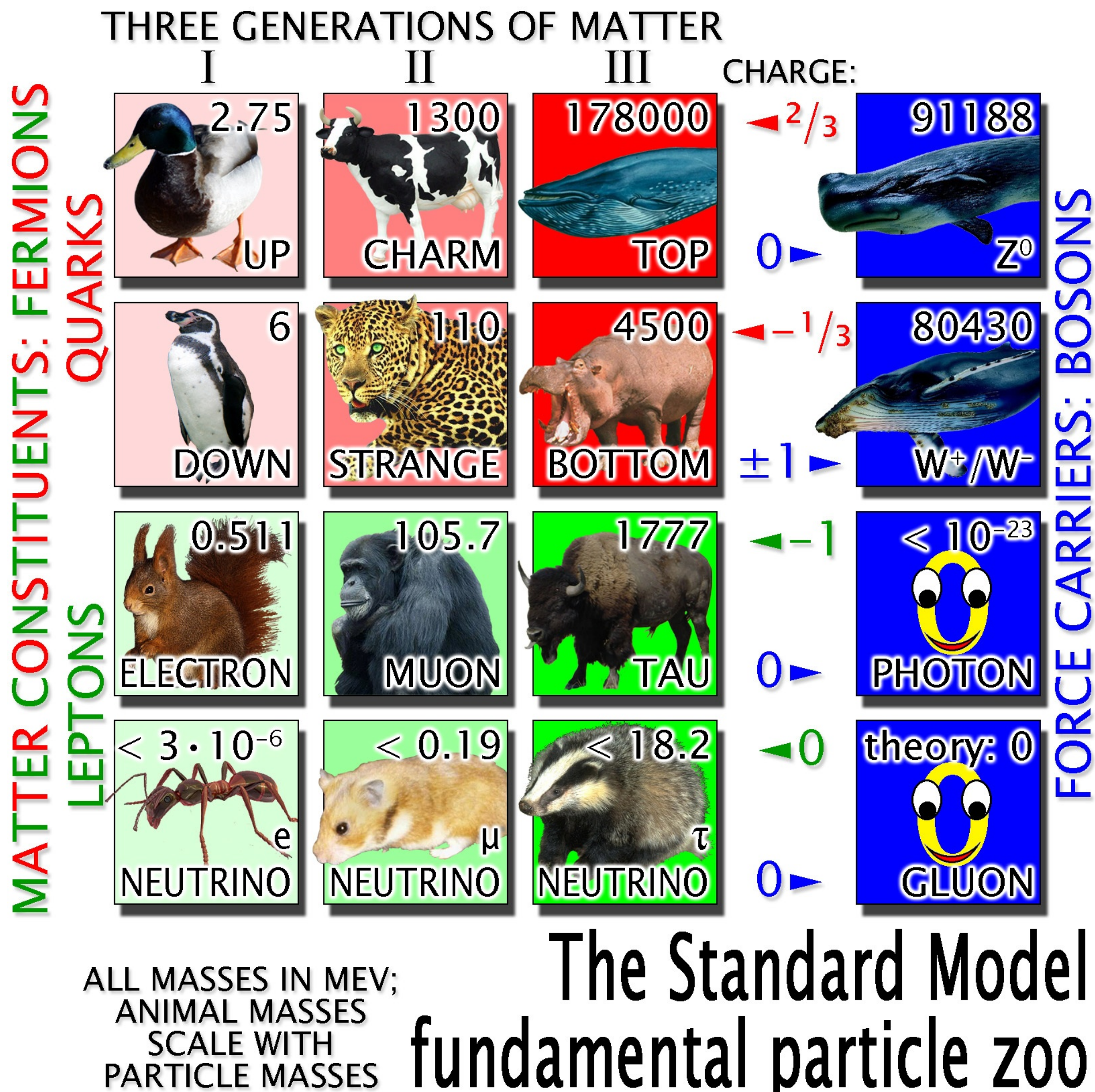
$$\mathbf{r} = \mathrm{rank}(F)$$
$$\mathbf{p}_{\mathrm{a}} = \int_{\alpha_{\mathrm{a}}} c_1(F)$$
$$\mathbf{q} = \mathrm{ch}_2(F).$$

$$\#(F_i, F_j) = \mathbf{r}_i \mathbf{d}_j - \mathbf{r}_j \mathbf{d}_i \qquad \mathbf{d} = c_1(F) \cdot k$$

Gauge theory/Geometry Dictionary

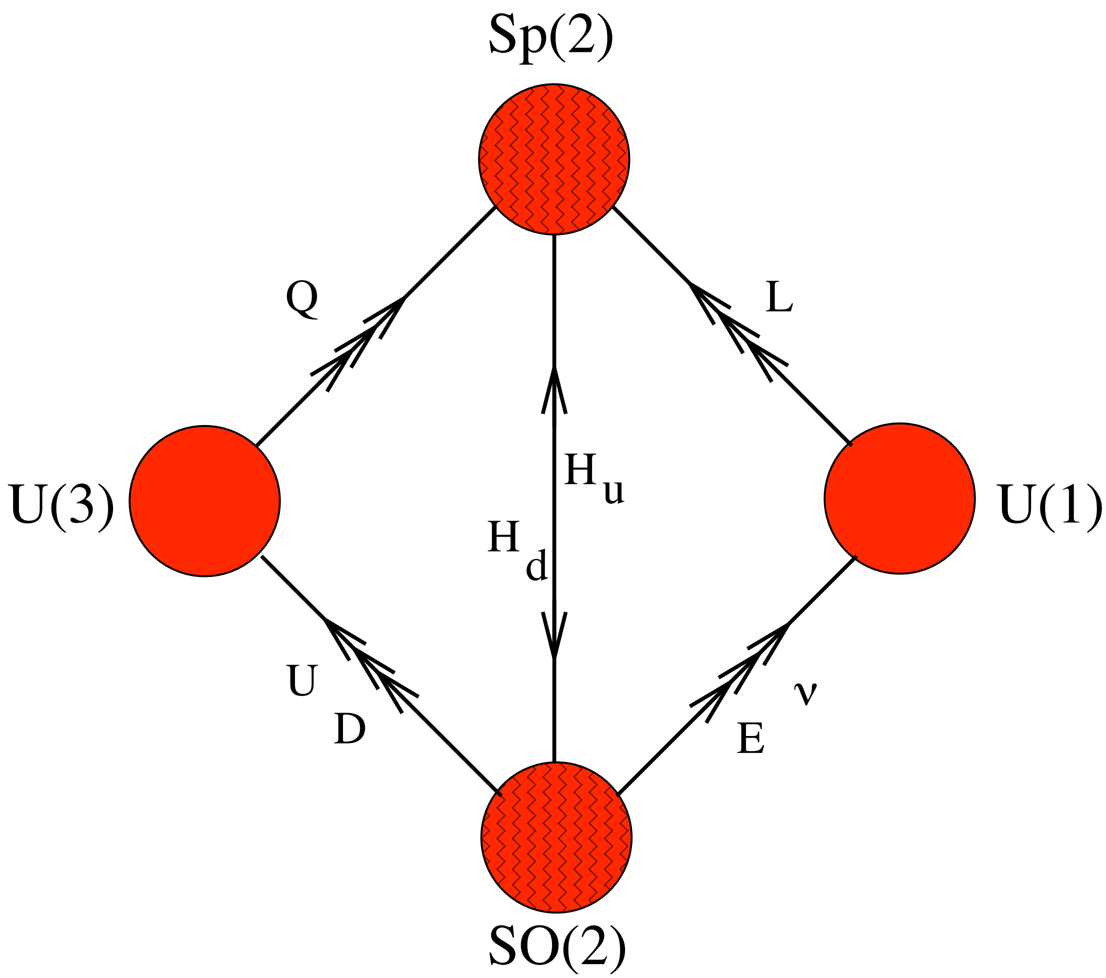
Superpotential	=	Complex Structure	
Gauge Couplings	=	periods of NS 2-form	B
FI-Parameters	=	periods of Kahler form	J
Symmetry breaking	=	bound state formation	

$\mathsf{Z}(F) = \int_X e^{-B+iJ}\mathsf{Tr}(e^F)\sqrt{Td}$ $\qquad \frac{4\pi}{g_{ym}^2} = e^{-\phi}|\mathsf{Z}(F)|$ $\qquad \zeta = \frac{1}{\pi}\log(\mathsf{Z}(F))$

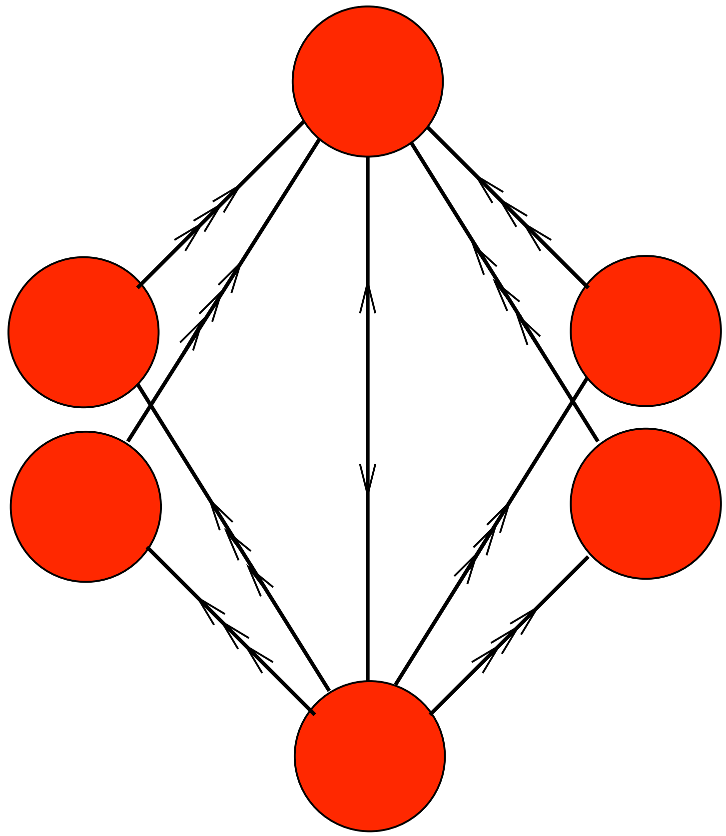


The Standard Model fundamental particle zoo

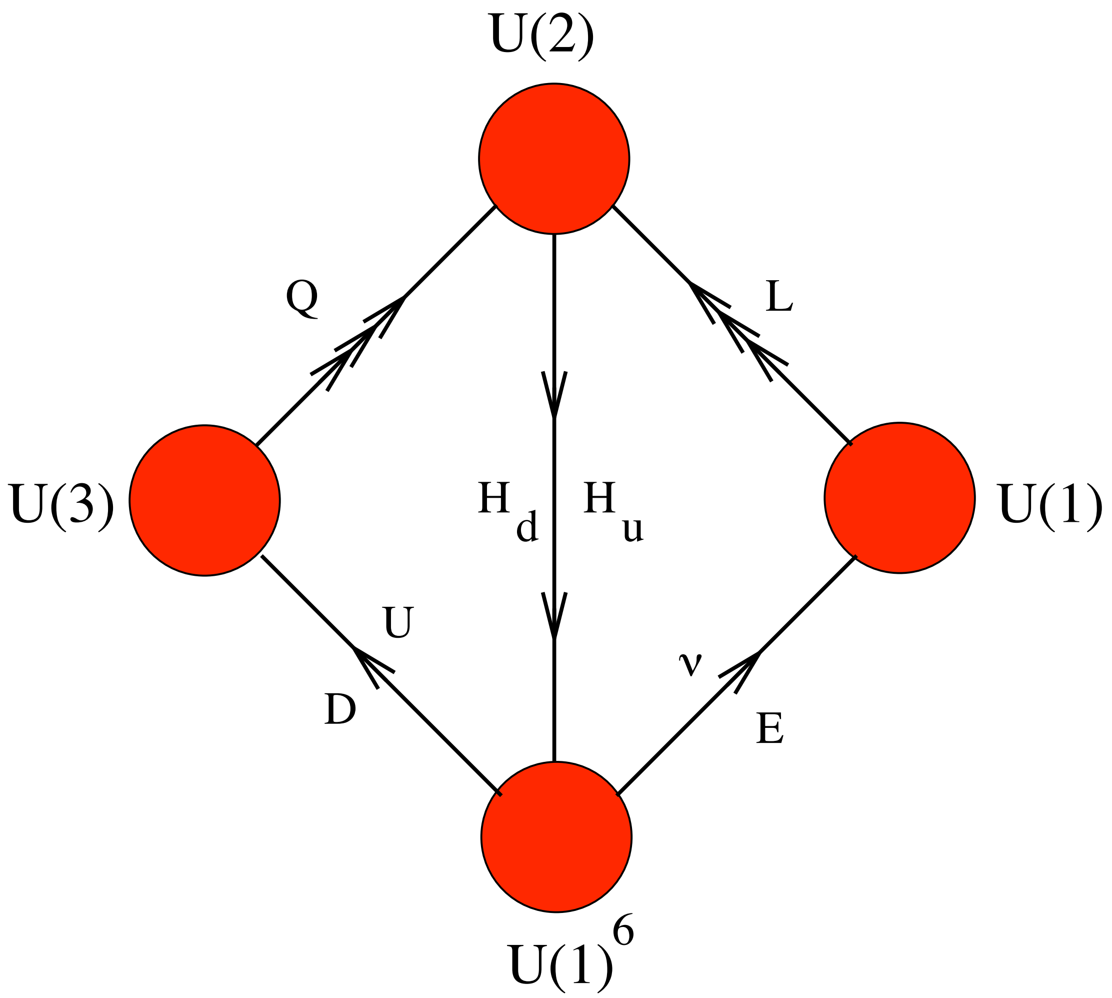
A minimal quiver realization of the SM-model: "Spanish Quiver"



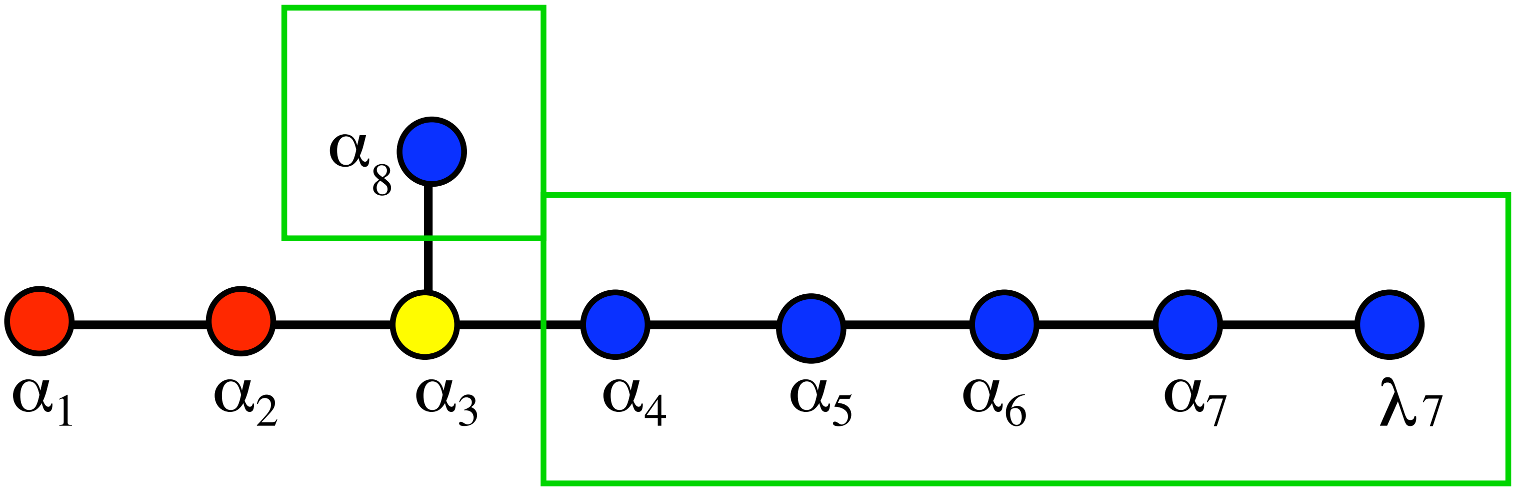
The "cover quiver":



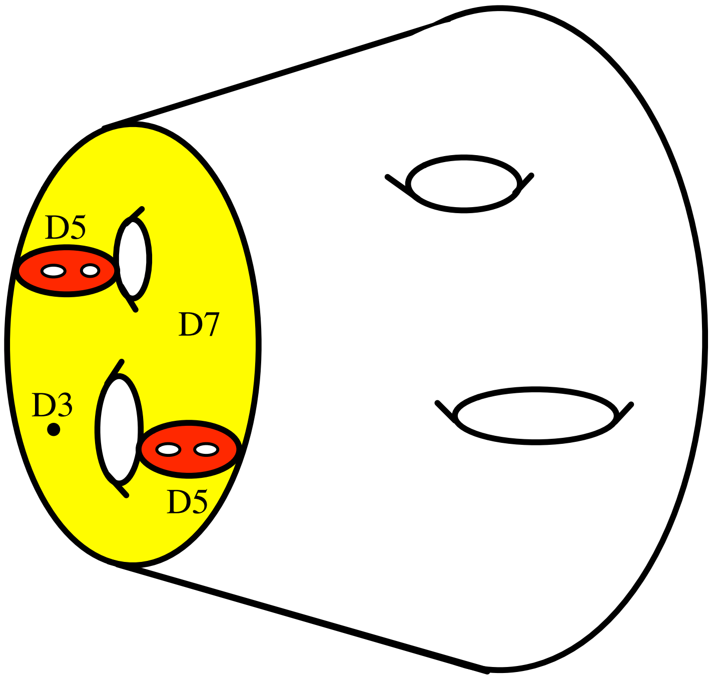
SM quiver, without orientifolding:



This quiver gauge theory can be obtained as the worldvolume gauge theory on a single D3-brane on a dP_8 singularity with an A_2 singularity associated with the two 2-cycles α_1 and α_2:



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



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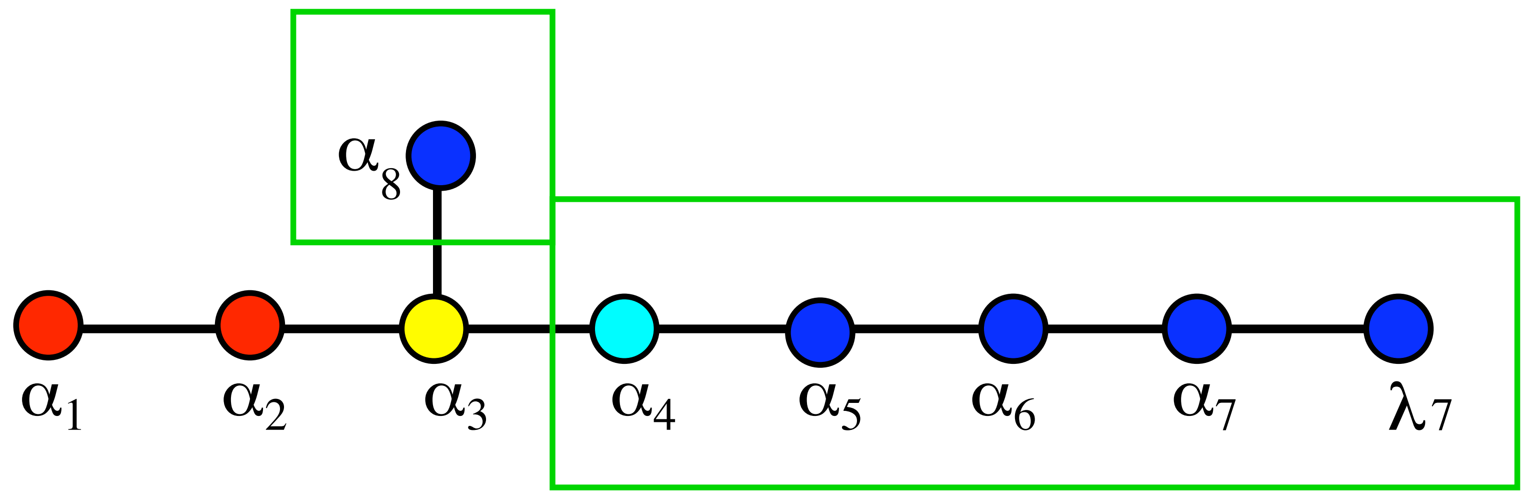
$$\#(F_i, F_j) = \mathbf{r}_i \mathbf{d}_j - \mathbf{r}_j \mathbf{d}_i \qquad \mathbf{d} = c_1(F) \cdot k$$

In remainder: will show how to eliminate all the extra $U(1)$ gauge symmetries, except for hypercharge.



How $U(1)$ symmetries get eliminated.....

- Non-anomalous $U(1)$'s $\leftrightarrow$ degree zero 2-cycles α_{a} in X.

- The D-brane action contains the linear coupling $\mathcal{C} \wedge F$ with

$$\mathcal{C} = \mathbf{r}\, c_X + \mathbf{p}_{\mathsf{a}}\, c^{\mathsf{a}} + \mathbf{q}\, C_2$$

$$c^{\mathsf{a}} = \int_{\alpha_{\mathsf{a}}} C_4 \qquad\qquad c_x = \int_x C_6$$

- Let ω_α denote a basis of normalizable harmonic 2-forms on Y:

$$G_{\alpha\beta} = \int_Y \omega_\alpha \wedge *\omega_\beta$$

- Every ω_α gives rise to a Stuckelberg field, via

$$C_4 = \sum_\alpha c^\alpha \omega_\alpha \qquad d\rho_\alpha = G_{\alpha\beta} * dc^\beta$$

- Introduce the matrix of periods

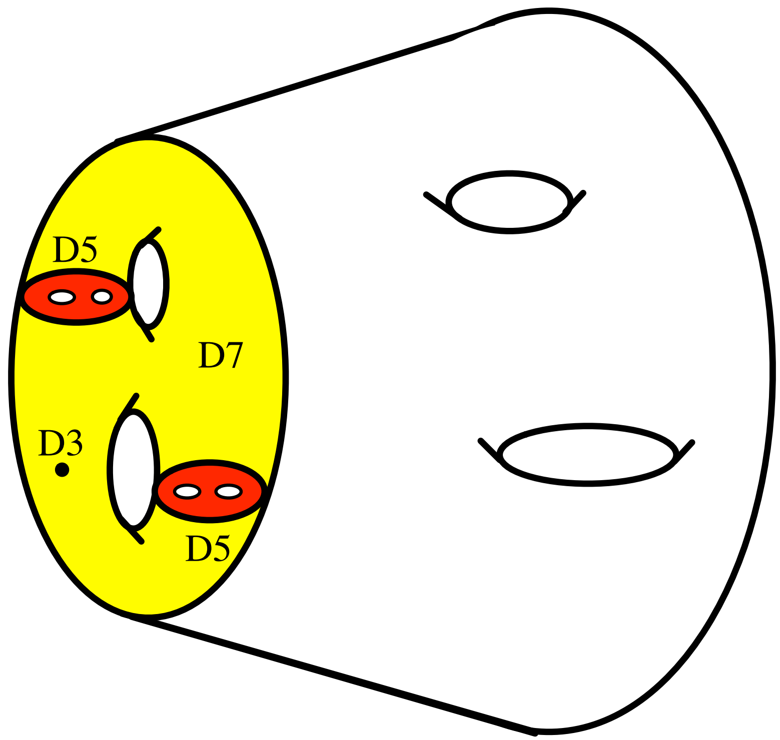
$$\Pi_\alpha^a = \int_{\alpha_a} \omega_\alpha$$

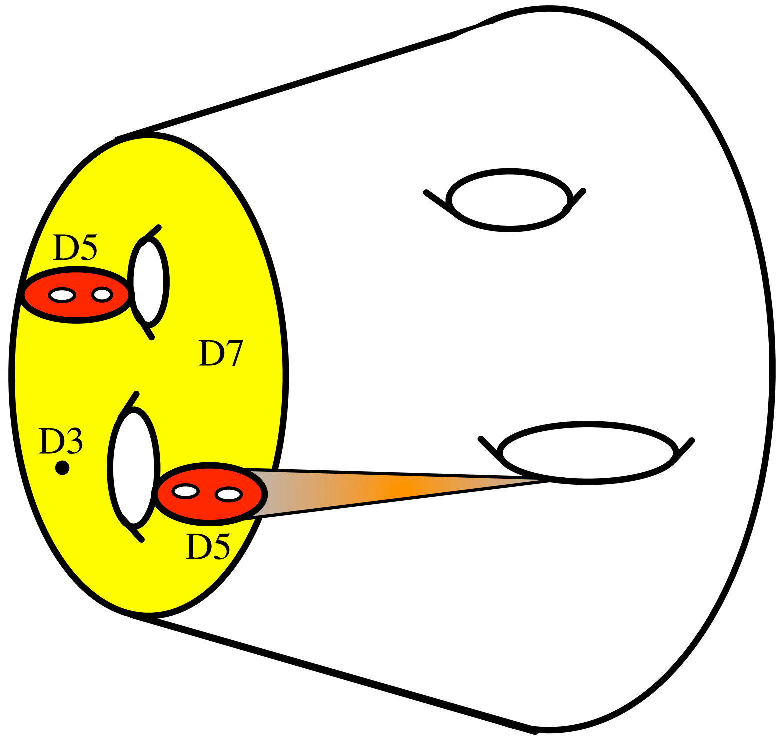
- The mass term for the $U(1)$ vector bosons reads:

$$m^2 = G_{XX}\,\mathbf{r}^2 + G^{\alpha\beta}\,\Pi_\alpha^{\mathsf{a}}\,\Pi_\beta^{\mathsf{b}}\,\mathbf{p}_{\mathsf{a}}\mathbf{p}_{\mathsf{b}}$$

For our specific SM construction via a dP_8 singularity, this result implies that hypercharge is a massless gauge symmetry, provided:

$$\Pi_\alpha^4 = \int_{\alpha_4} \omega_\alpha = 0 \qquad \forall \alpha$$


D5
D7
D3
D5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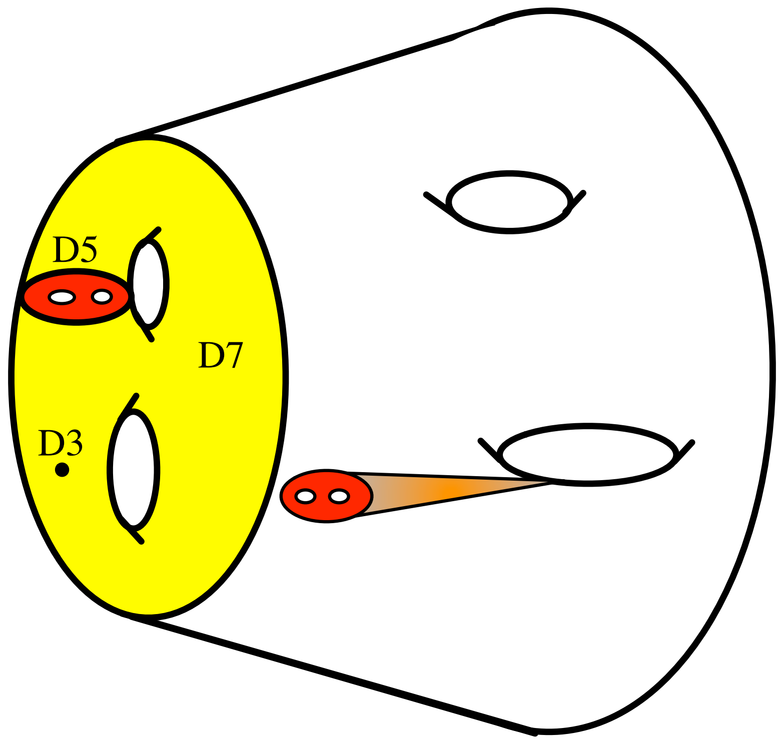
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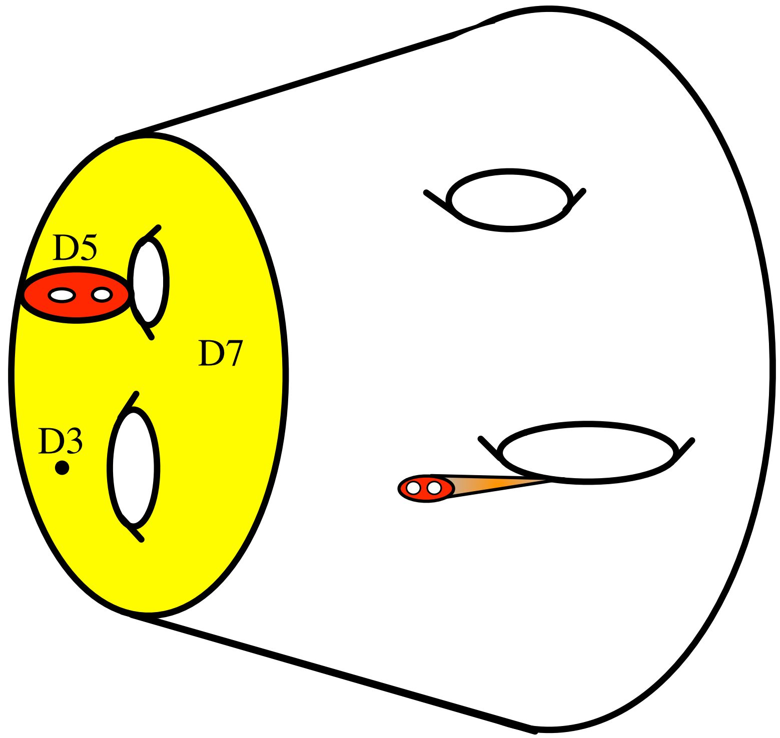
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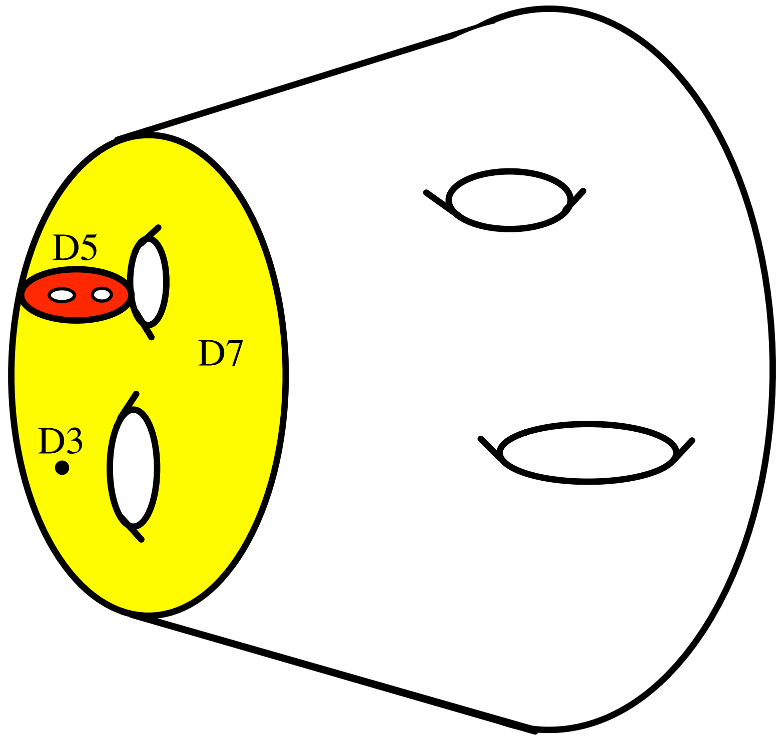

D5
D7
D3

	Q_i	u_i^c	d_i^c	ℓ_i	e_i^c	ν_i^c	H_i^u	H_i^d
$SU(3)_C$	$\mathbf{3}$	$\bar{\mathbf{3}}$	$\bar{\mathbf{3}}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$
$SU(2)_L$	$\mathbf{2}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{2}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{2}$	$\mathbf{2}$
$U(1)_Y$	$1/6$	$-2/3$	$1/3$	$-1/2$	1	0	$1/2$	$-1/2$

Some directions for near future:

- $U(1)$ breaking, via D-instantons $\rightarrow$ μ=terms.

$$\delta W = \mathcal{A}(\Phi)\, e^{-\mu_3 \mathsf{Vol}(\Sigma_\alpha) + i\rho_\alpha}$$

- SUSY breaking, via gauge mediation or otherwise

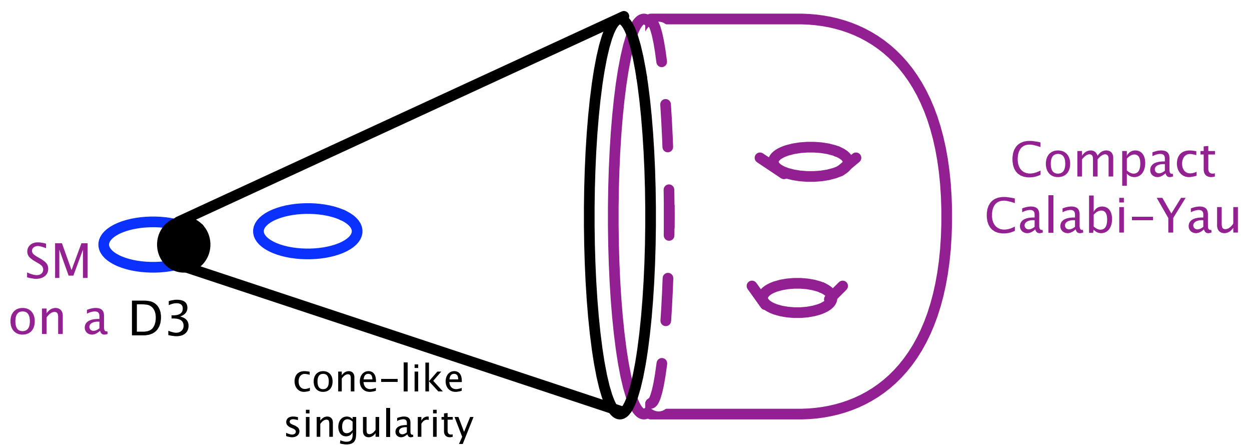
- Phenomenology!

- Monopoles, confinement

- Unification of coupling constants, GUTs

- "Swampland" of non-compact CY singularities:

  can not be embedded inside a compact CY.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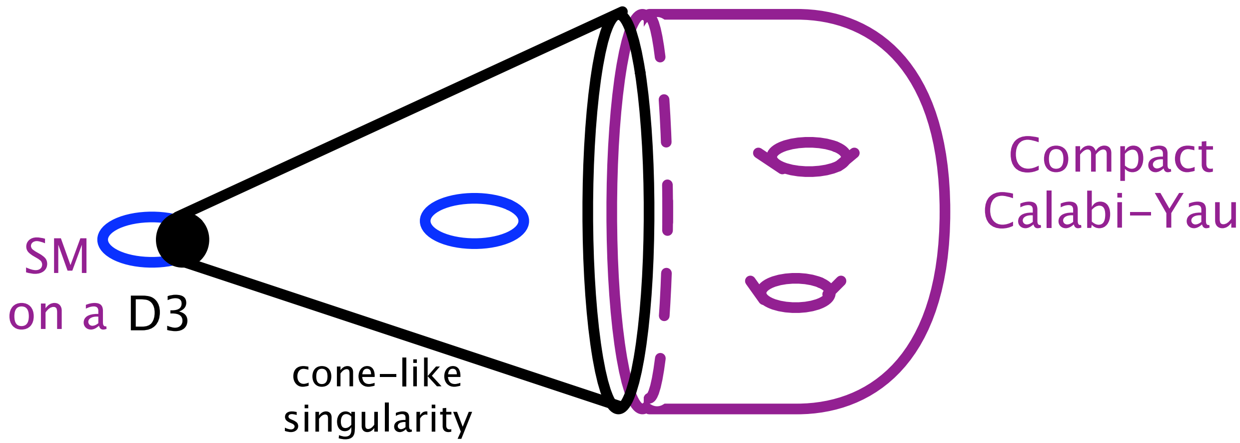
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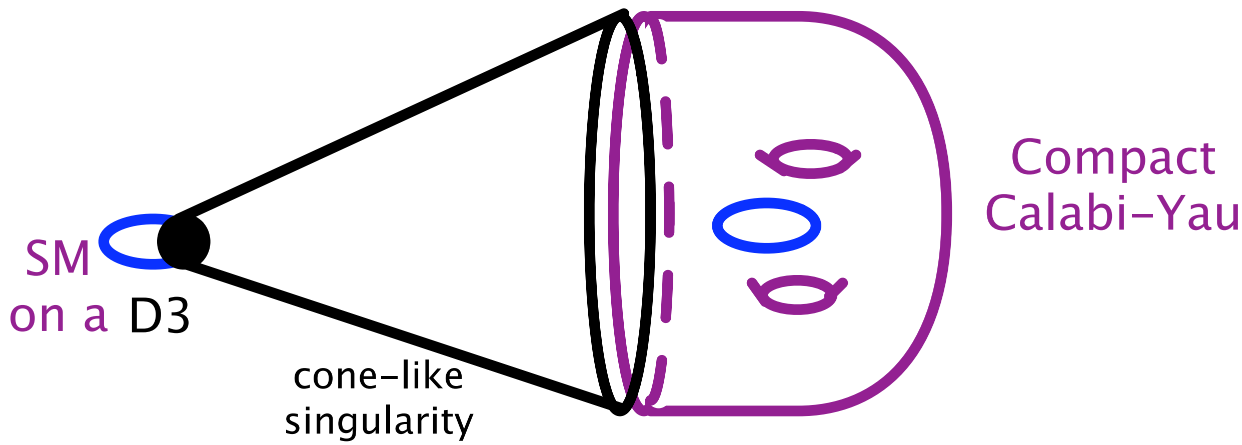
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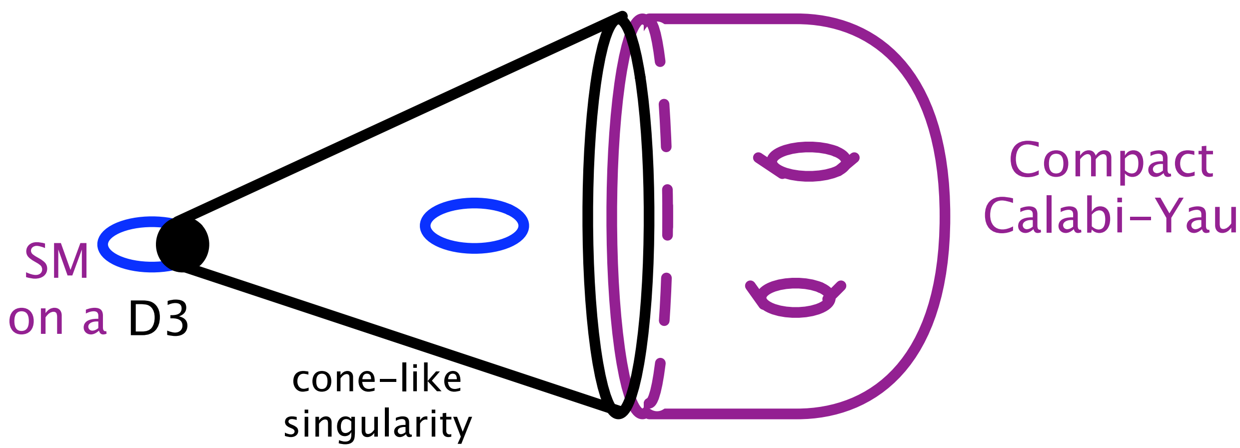
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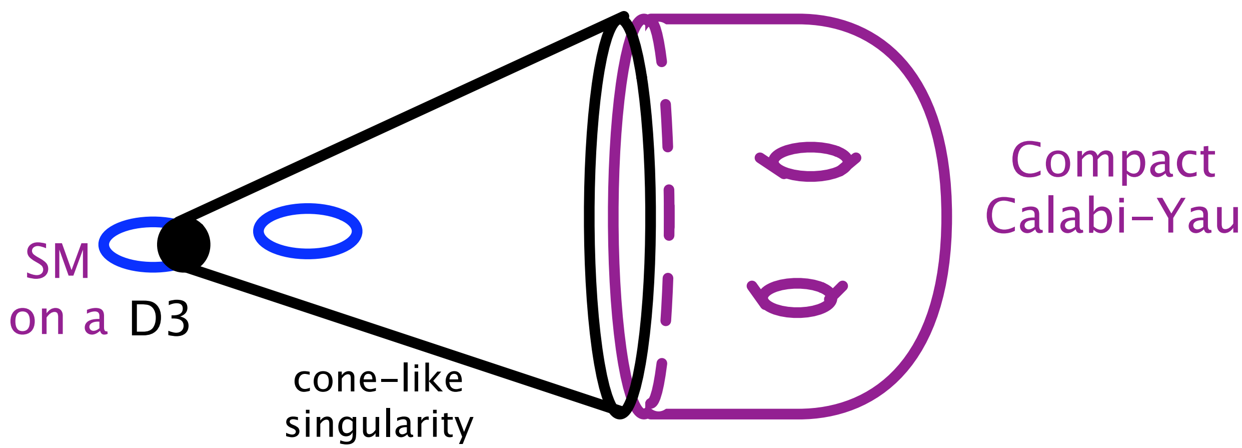
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