Title: The Fuzzy Side of Decoupling Gravity

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Abstract: TBA

The Fuzzy Side of Decoupling Gravity

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hep-th/1005.3033 w/ H. Verlinde

Outline

- Motivation
- Particle Physics Ingredients
- The Fuzzy Limit
- 7-Brane Assembly

Motivation

There is a landscape of string vacua

Presumably some look like ours:

Standard Model...

Inflation...

But which ones?

Some Complications

Gravity + particles = complicated:

Particle data set by geometry

But geometry also dynamical

We live in 4D

More dimensions $\Rightarrow \infty$ of 4D modes

Summary: String compactifications are complicated

Simplifying Limit

But gravity is also very weak:

$$\frac{M_{weak}}{M_{pl}} \sim 10^{-17} \text{ and } \frac{M_{GUT}}{M_{pl}} \sim 10^{-3}$$

Strategy:

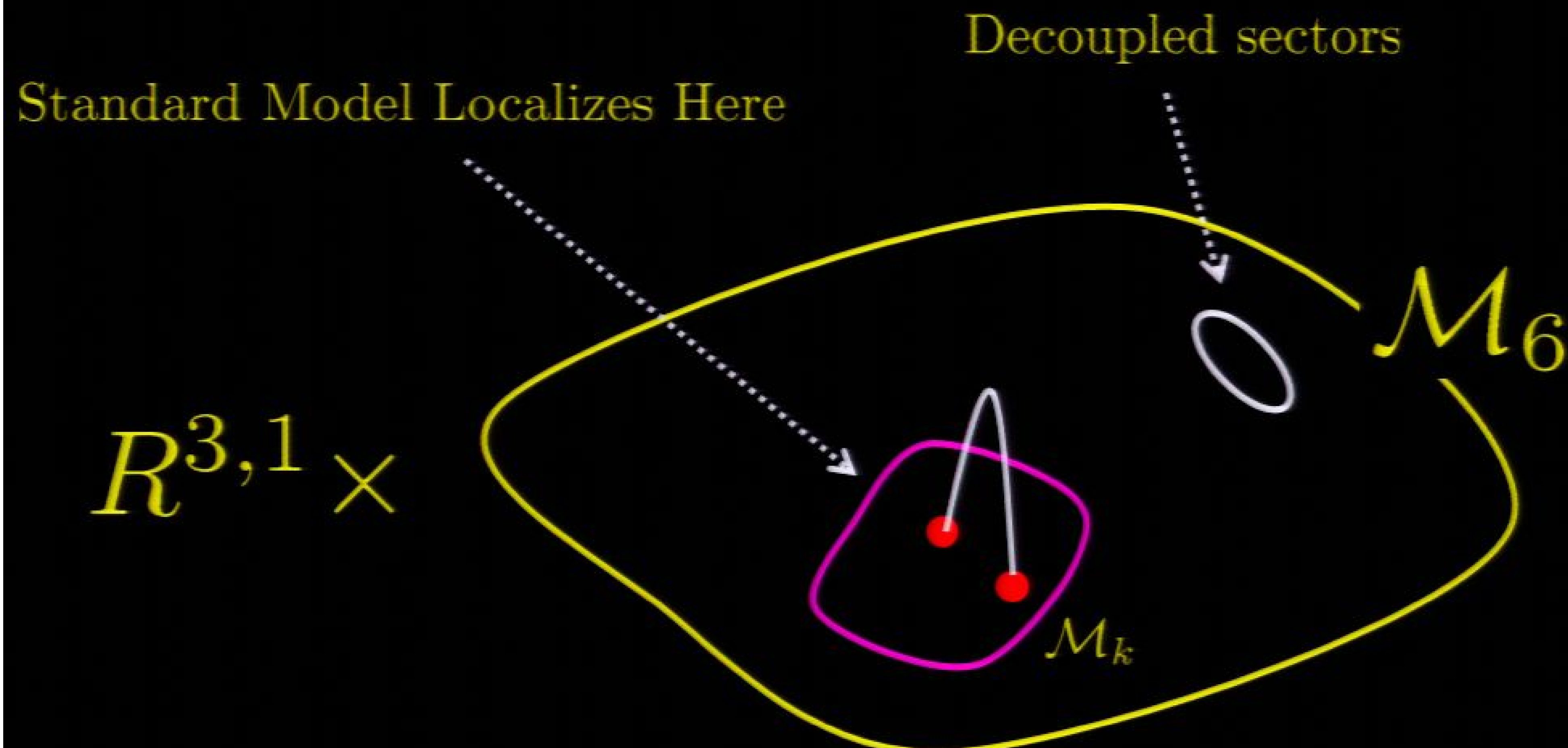
Antoniadis, Kiritsis, Tomaras '00
Aldazabel, Ibanez, Quevedo, Uranga '00
Verlinde Wijnholt '05,...

1) Decouple gravity from particle physics

2) Identify promising 4D vacua

3) Glue back on to rest of compactification

Geometric Picture



Flexibility?

Without gravity, can we do anything we want?

Lose some constraints from UV

Demanding its absence is also a constraint

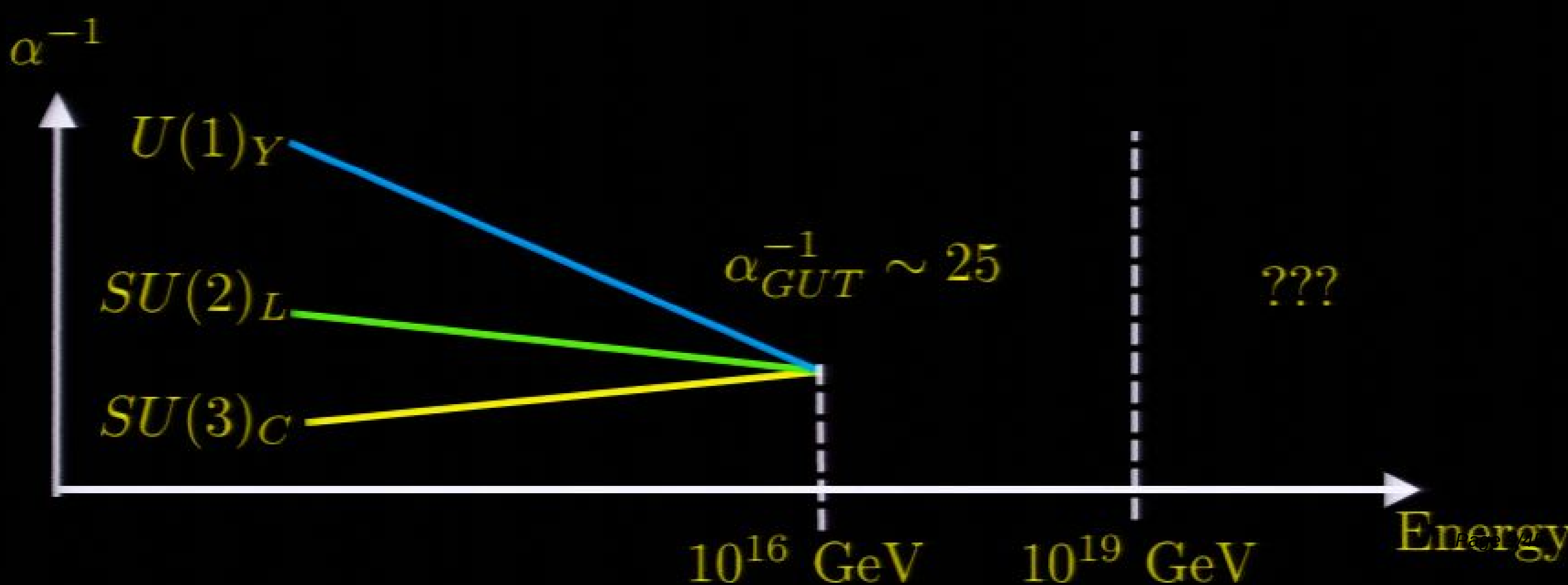
Still quite flexible, though

Less flexible: No gravity + GUTs   Beasley, JJH, Vafa '08

Main Assumptions

i) 4D Theory decoupled from gravity

ii) Some notion of unification (e.g. $SU(5)$ GUT structures)



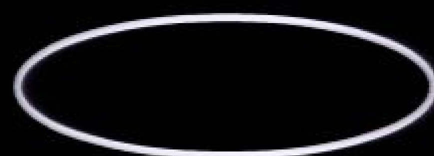
Roadmap

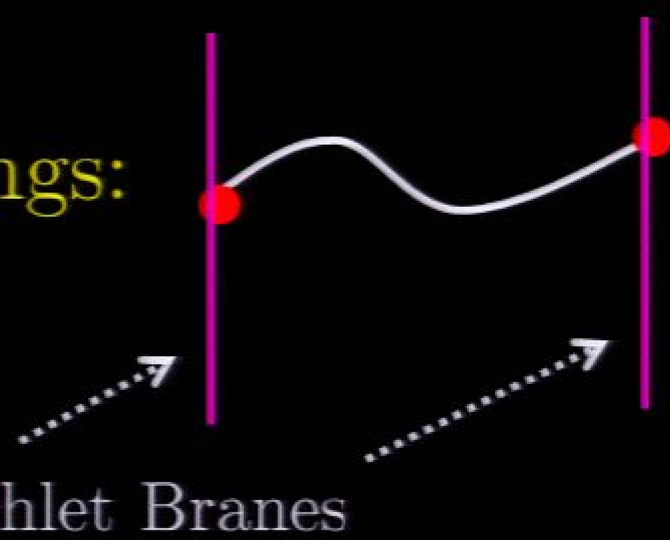
- Motivation

- Particle Physics Ingredients

Focussing on Particle Physics I

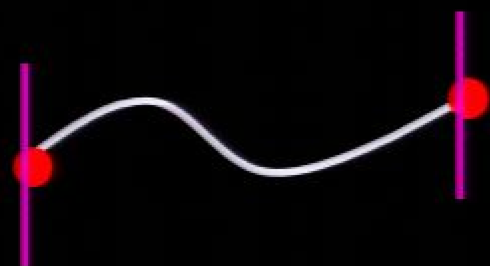
Gravity and Matter from Different Strings:

Closed Strings:  Spin 2 (gravity)

Open Strings: 

Spin $0, \frac{1}{2}, 1$ (matter)

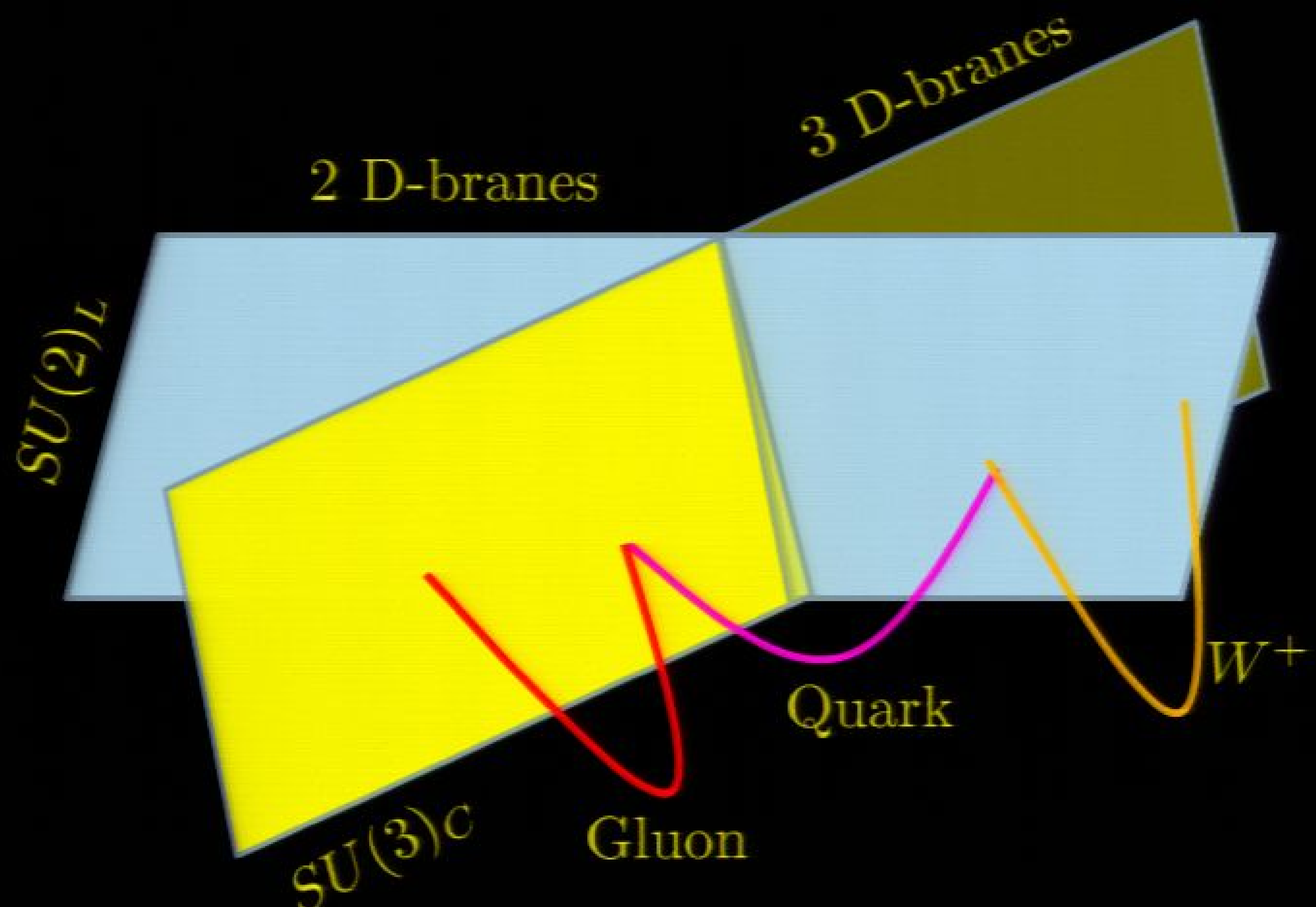
Focussing on Particle Physics II

Main Idea: Use  for particle physics

Defer complications from 

Qualitative Features

Particles = Strings ending on $R^{3,1}$ filling Dirichlet Branes:

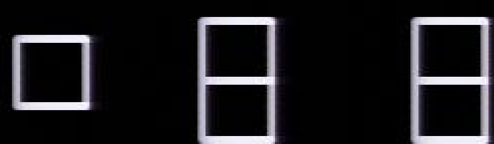


What about GUTs?

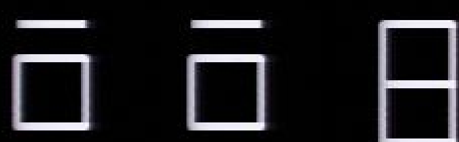
GUTs and Open Strings

$g_s \ll 1 \Rightarrow$ Problems with GUTs:

No $5_H \times 10_M \times 10_M \Rightarrow$ pert. massless t quark



But $\bar{5}_H \times \bar{5}_M \times 10_M \Rightarrow$ massive b quark



Wrong Prediction: $m_b > m_t$

$$g_s \rightarrow O(1)$$

Perturbative open strings somewhat limited

Increasing $g_s \rightarrow O(1)$ allows new bound states/interactions

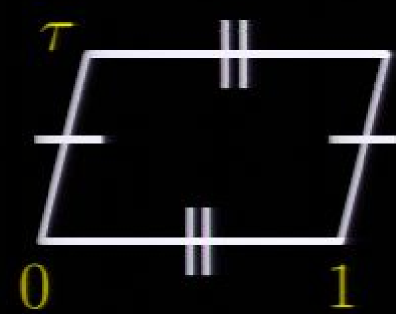
Top quark can now get a mass

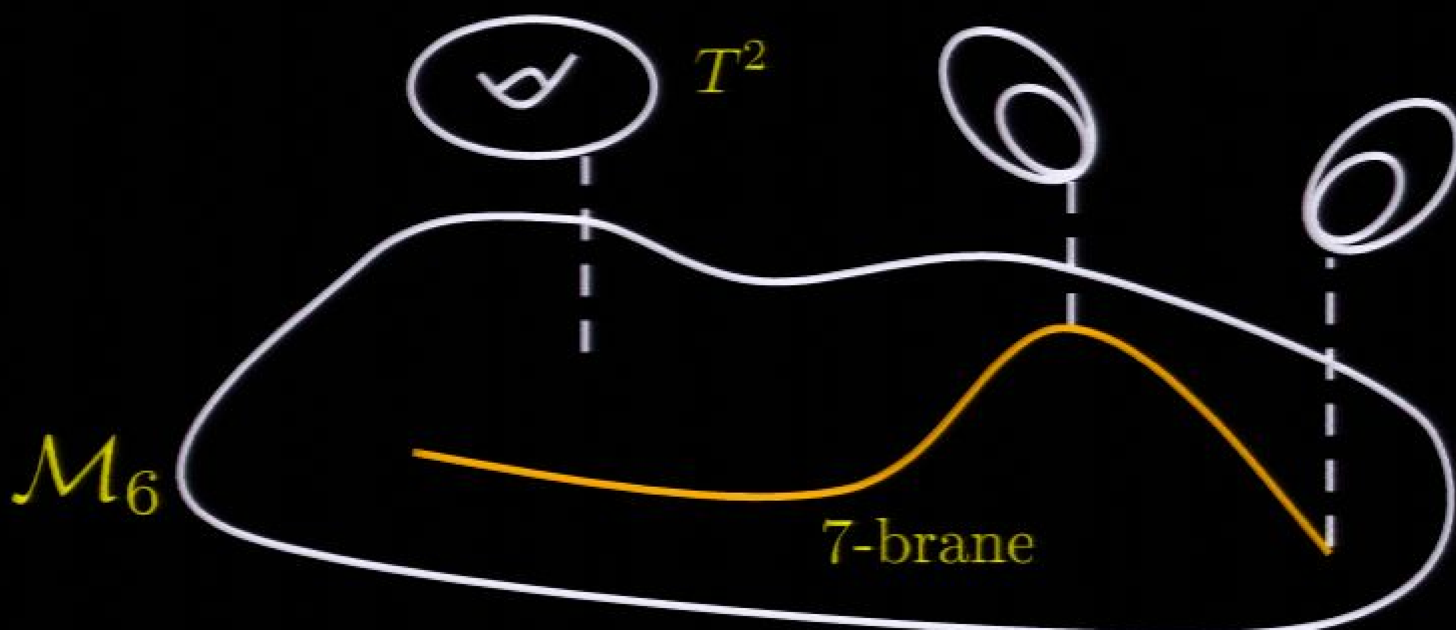
$g_s \to O(1)$ and F-theory

Vafa '96

F-theory = Strongly Coupled Formulation of IIB in 12d

$\tau(y_6) = C_0 + \frac{i}{g_s}$ is shape of a T^2:





SM Ingredients

	$R^{3,1}$				$\mathcal{M}_6$					
	0	1	2	3	4	5	6	7	8	9
7_{GUT}	×	×	×	×	×	×	×	×		
$7'$	×	×	×	×	×	×			×	×
$7''$	×	×	×	×			×	×	×	×

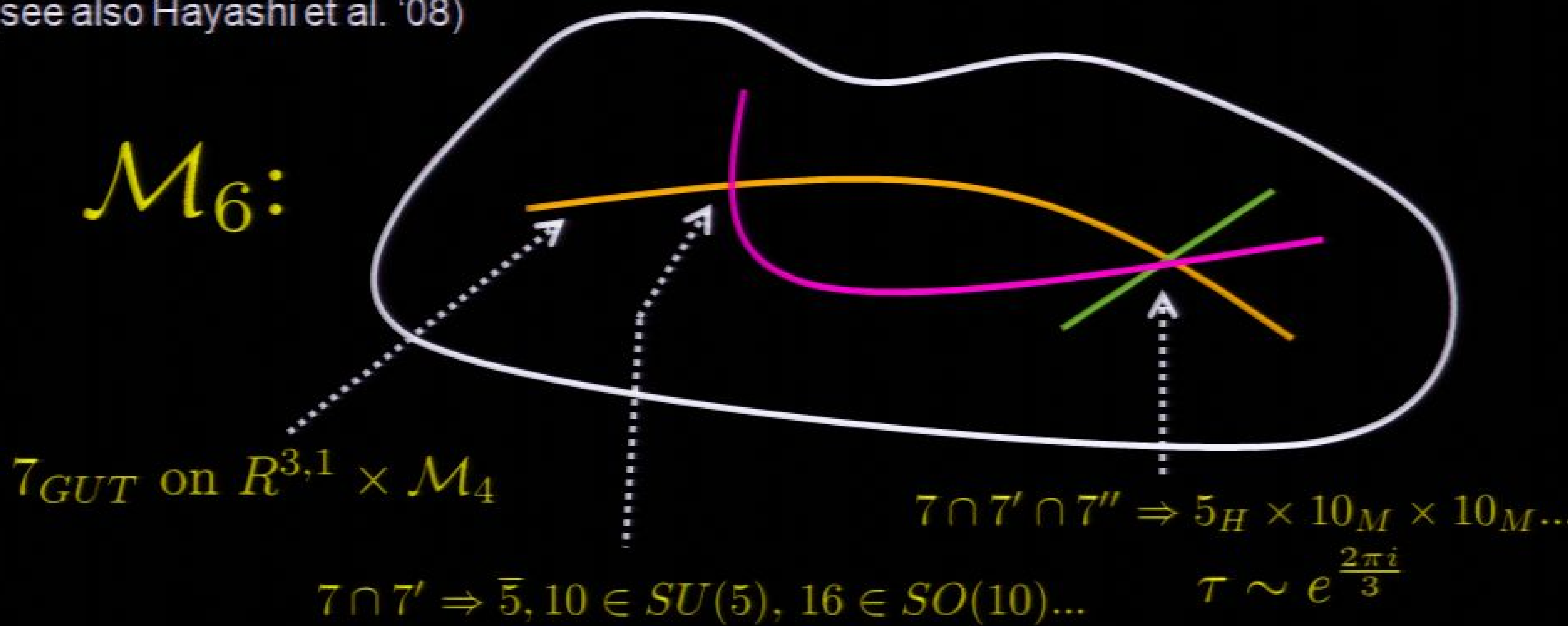
$8D$: Gauge Group (7)

$6D$: Matter $(7 \cap 7')$

$4D$: Yukawas $(7 \cap 7' \cap 7'')$

F-theory GUTs

Beasley JJH Vafa I II '08,
Donagi Wijnholt I II '08
(see also Hayashi et al. '08)



All of these intersections described by *holomorphic* equations

$$f_I(z_1, z_2, z_3) = 0$$

Roadmap

- Particle Physics Ingredients

- The Fuzzy Limit

Decoupling in $8D$

$8D$ fields: $\Phi(x_\mu, z, \bar{z}) = \sum a_I(z, \bar{z})\phi_I(x_\mu)$

$\nabla^2_{8D}\Phi(x_\mu, z, \bar{z}) = 0 \Rightarrow (\nabla^2_{4D} + M^2_I)\phi_I(x_\mu) = 0$

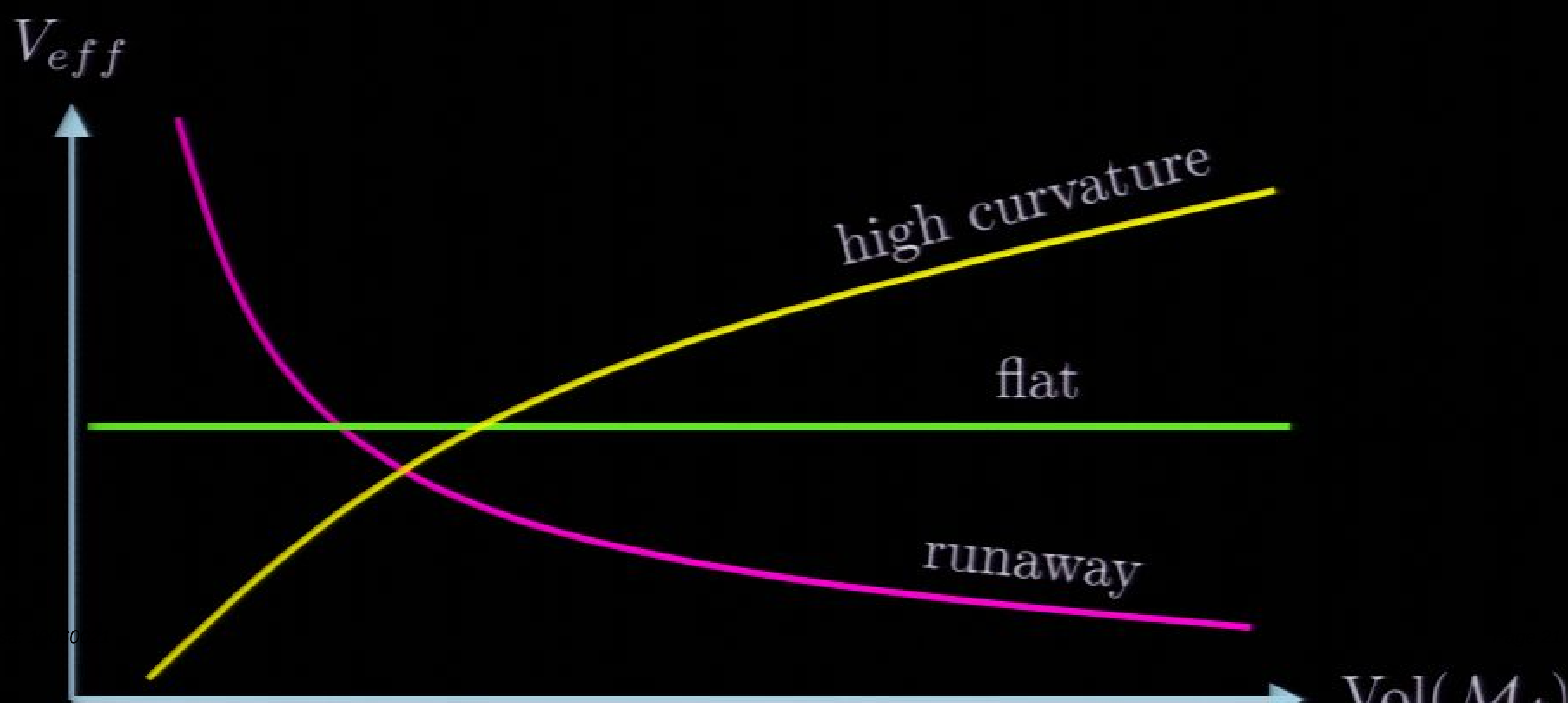
KK modes start to enter at energy $E = 1/R_4 \equiv \mathrm{Vol}(\mathcal{M}_4)^{-1/4}$

Decoupled at energies $E < 1/R_4 \Rightarrow$ send $R_4 \rightarrow 0$

Small Volume

Natural place to stabilize: At small volume — Dine Seiberg '85

Same argument also for $g_s \sim O(1)$

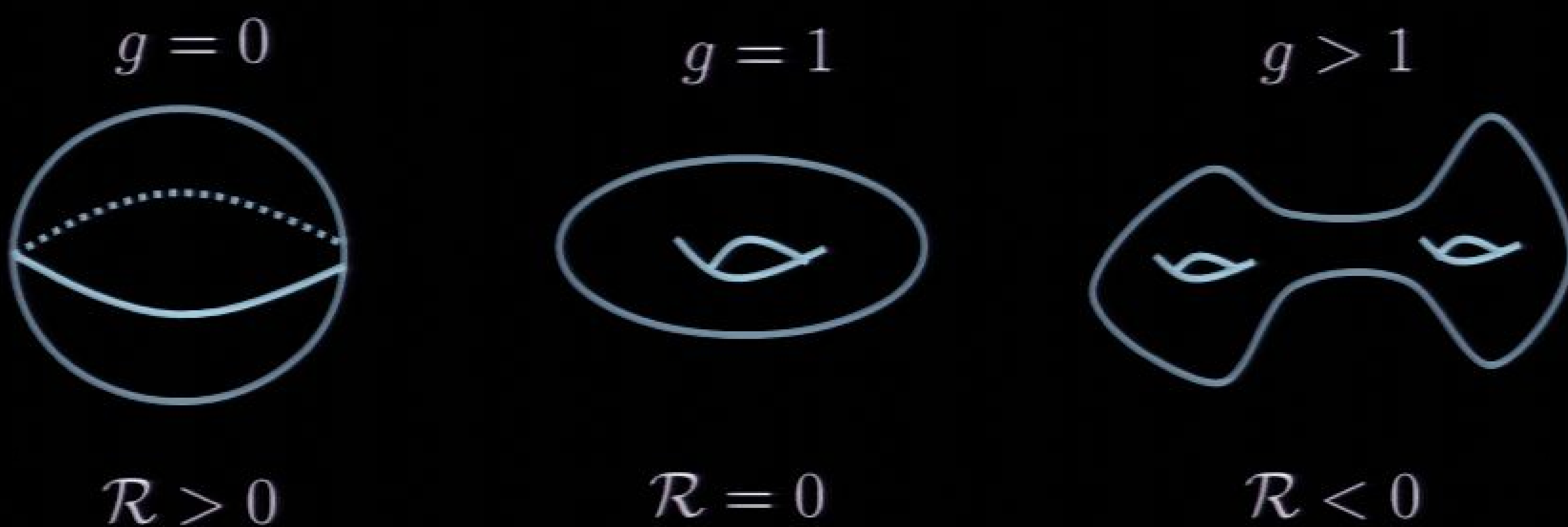


$\mathcal{M}_4 \to$ point

$\mathcal{M}_4 \to$ point is a non-trivial restriction:

Requires $\mathcal{M}_4$ have positive curvature $\Rightarrow$ only 10 choices

Example: 2D $\mathcal{M}_2$ classified by genus:



Volumes and Couplings

Start from $8D$ 7-brane gauge theory

$$L_{8D} = -\frac{1}{g_s \times l^4} Tr F^{(8D)}_{\mu\nu} F^{\mu\nu}_{(8D)}$$

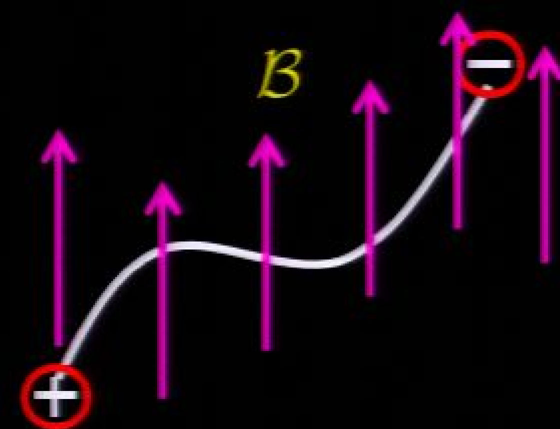
$$\Rightarrow L_{4D} = -\frac{\mathrm{Vol}(\mathcal{M}_4)}{g_s \times l^4} Tr F^{(4D)}_{\mu\nu} F^{\mu\nu}_{(4D)} = -\frac{1}{2g^2_{YM}} Tr F^{(4D)}_{\mu\nu} F^{\mu\nu}_{(4D)}$$

$$\Rightarrow g^2_{YM} \sim \mathrm{Vol}(\mathcal{M}_4)^{-1} \rightarrow \infty \text{ ???}$$

Couplings and Fluxes

$8D$ gauge theory has internal magnetic fluxes $\mathcal{B} = F + B$

Spreads out string ends:



In $\mathrm{Vol}_{\mathrm{closed}}(\mathcal{M}_4) \to 0$ Limit:

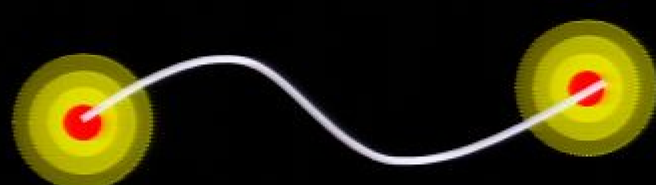
$$L_{eff} \sim -\left(\int_{\mathcal{M}_4} \mathcal{B}^2\right) \times F_{\mu\nu}F^{\mu\nu} \Rightarrow \boxed{\frac{4\pi}{g^2_{YM}} = \frac{N_{\mathrm{flux}}}{g_s}}$$

Two Geometries

Main Point: Open and Closed strings see *different* geometries

$$\text{Vol}_{\text{closed}} \to 0 \text{ BUT } \text{Vol}_{\text{open}} \not\to 0$$

String ends now attach to "fuzzy points" specified by fluxes



Non-Commutative Geometry

In flat space: $\mathcal{B} \neq 0 \Rightarrow [Z, Z^\dagger] = \hbar_{NC}$

Connes Douglas Schwarz '97
Seiberg Witten '99,....

Decoupling limit: keep Lowest Landau Level

$\Rightarrow$ Open strings see non-commutative (fuzzy) geometry

Need to extend to more general *compact* $4D$ spaces

Fuzzy Points

Classical $\rightarrow$ Non-Commutative:

Specified by deforming algebra of functions: $f \cdot g \rightarrow \widehat{f} * \widehat{g}$

Complementary View:

$\widehat{f}$ is an operator acting on a Hilbert space $\mathcal{H}$

$|\Psi\rangle$ = "fuzzy point" of $\mathcal{H}$

Fuzzy Geometry

Classical vacua of a Gauged Linear Sigma Model (GLSM)

$z_1, ..., z_r$ of C^r

Subspace: $\sum q_j |z_j|^2 = \xi \; (\text{mod } z_j \to e^{iq_j\theta} z_j)$

This generalizes to fuzzy theory

JJH, Verlinde '10

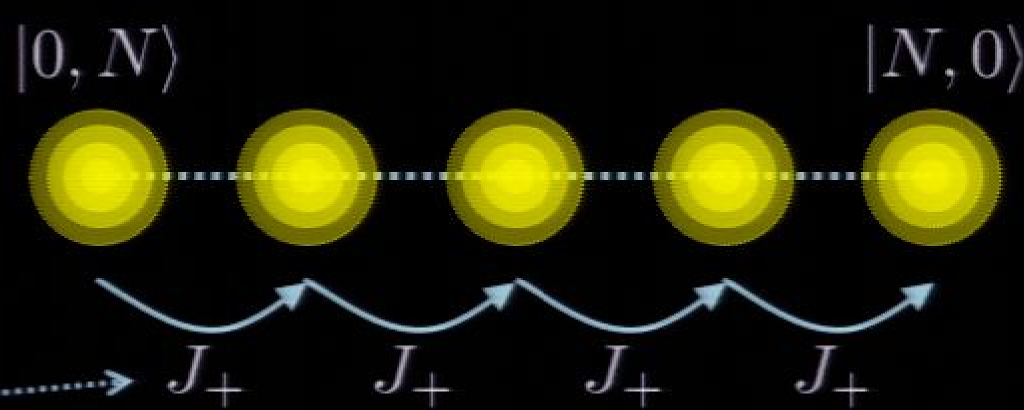
$[Z_i, Z_j^\dagger] = \delta_{ij}$ Fock space $\mathcal{F}(C^2) = \left\{ \prod \frac{Z_j^{\dagger n_j}}{\sqrt{n_j!}} |0\rangle \right\}$

Subspace: $\sum q_j Z_j^\dagger Z_j |\Psi\rangle = N |\Psi\rangle$

Example: Fuzzy S^2

Oscillators: Z_1, Z_2 such that: $[Z_i, Z_j^\dagger] = \delta_{ij}$

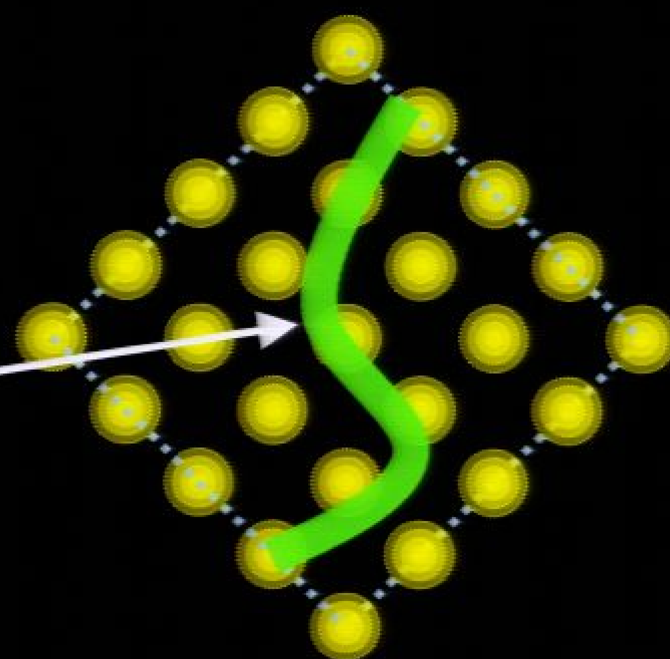
$\vec{J} = Z^\dagger \frac{\vec{\sigma}}{2} Z \Rightarrow SU(2)$ algebra: $[J_i, J_j] = i\epsilon_{ijk} J_k$



$J_+ = Z_1^\dagger Z_2$

Example: Fuzzy $S^2_I \times S^2_{II}$

7_{GUT} on $R^{3,1} \times$ Fuzzy $\mathrm{S}^2_{\mathrm{I}} \times \mathrm{S}^2_{\mathrm{II}}$:



Matter on $7_{GUT} \cap 7'$

Classically: $f(z_I, z_{II}) = 0$

Fuzzy: $\widehat{f}(Z_I, Z_{II})|\Psi\rangle = 0$

"Fuzz preserves holomorphy" $\Rightarrow$ preserves F-theory description

Fuzzy Geometry

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Subspace: $\sum q_j |z_j|^2 = \xi$ (mod $z_j \to e^{iq_j\theta} z_j$)

This generalizes to fuzzy theory

JJH, Verlinde '10

$[Z_i, Z_j^\dagger] = \delta_{ij}$ Fock space $\mathcal{F}(C^2) = \left\{ \prod \frac{Z_j^{\dagger n_j}}{\sqrt{n_j!}} |0\rangle \right\}$

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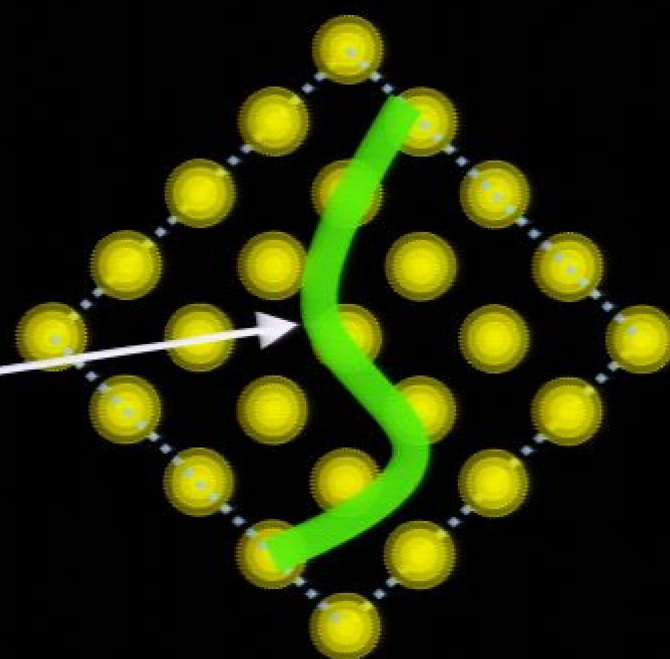

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4D Theory

$\phi(x_\mu, z, \overline{z}) \rightarrow \phi(x_\mu, Z^\dagger, Z)$

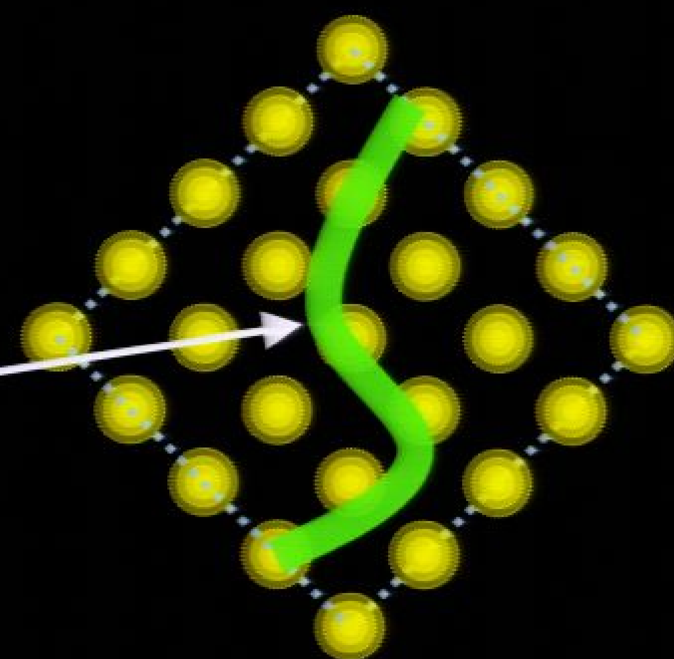
Theory with finite # 4D fields $\sim N_{\text{fuzz}} \times N_{\text{fuzz}}$ matrices

8D Lagrangian now an operator: $\mathcal{L}_{8D}(Z^\dagger, Z)$

$$\mathcal{L}_{4D} = \sum_{|\Psi\rangle} \langle\Psi|\mathcal{L}_{8D}(Z^\dagger, Z)|\Psi\rangle$$

Example: Fuzzy $S_I^2 \times S_{II}^2$

7_{GUT} on $R^{3,1} \times$ Fuzzy $\mathrm{S}^2_{\mathrm{I}} \times \mathrm{S}^2_{\mathrm{II}}$:



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Gauge Coupling

$$\frac{4\pi}{g_{4D}^2} = \frac{1}{\alpha_{GUT}} = \frac{\sum \langle \Psi | \Psi \rangle}{g_s} = \frac{N_{\text{fuzz}}}{g_s}$$

F-th input: $5_H \times 10_M \times 10_M \Rightarrow \tau \sim e^{\frac{2\pi i}{3}} \Rightarrow \frac{1}{g_s} \sim \frac{\sqrt{3}}{2}$

$\Rightarrow \alpha_{GUT}^{-1} \sim N_{\text{fuzz}}$

Realistic Value: $\alpha_{GUT}^{-1} \sim 25 \Rightarrow N_{\text{fuzz}} \sim 25$

Roadmap

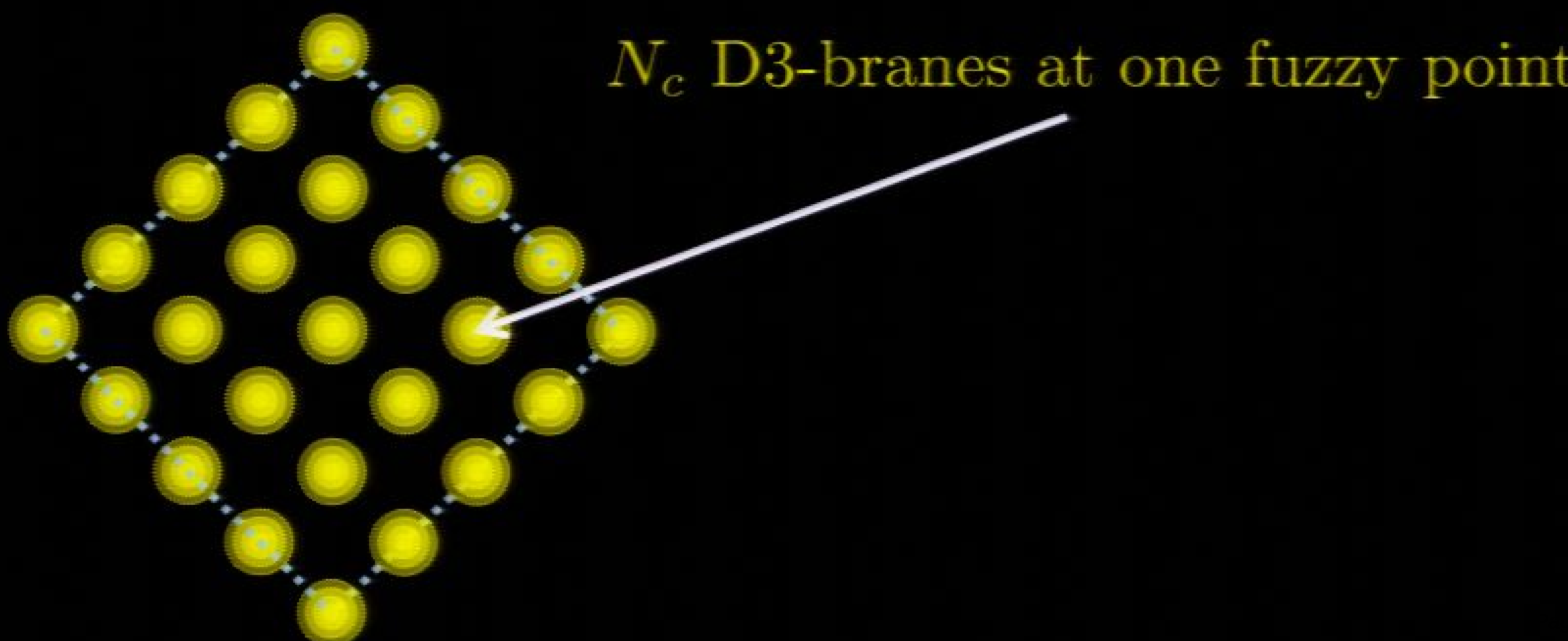
- Flux and Fuzz

- 7-Brane Assembly

From 7-Branes to D3-Branes

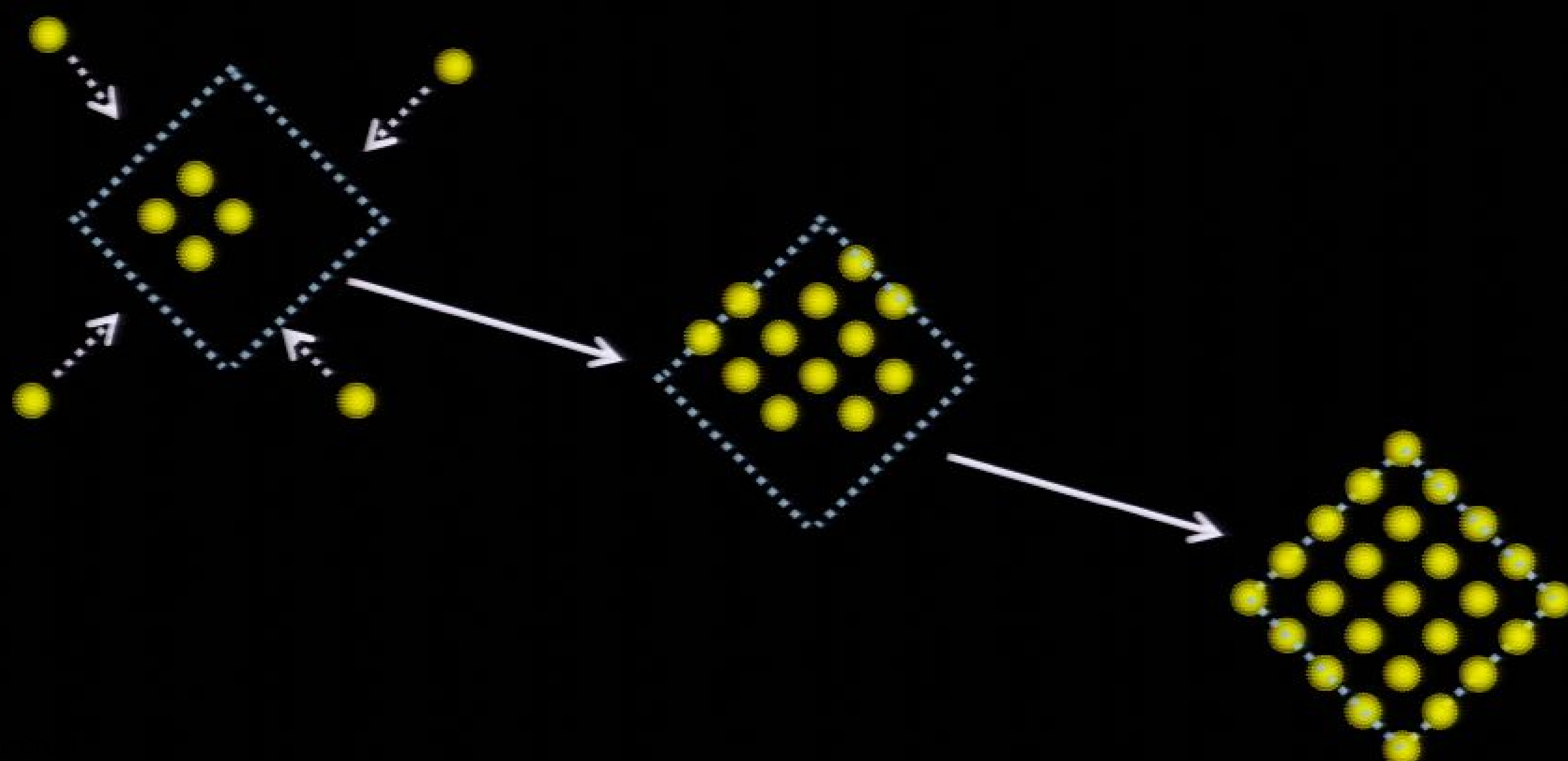
Fuzzy $SU(N_c)$ 7-brane is built from D3-branes:

Detect via: $L_{D7} = \int C_4 \wedge \mathcal{B} \wedge \mathcal{B} \Rightarrow N_{\text{fuzz}} = N_{D3}$



Assembling a 7-Brane

Suggests building up the brane:



Large N

Large # of D3-branes gravitationally backreact on geometry

N D3's on $R^{3,1} \times R^6 \rightarrow$ IIB supergravity on $AdS_5 \times S^5$

Maldacena '97

$$\left(\frac{\text{Radius}}{l_{\text{string}}}\right)^4 = g_{YM}^2 N \equiv \lambda \Rightarrow \text{weakly curved when } \lambda \rightarrow \infty$$

Large N_{fuzz}?

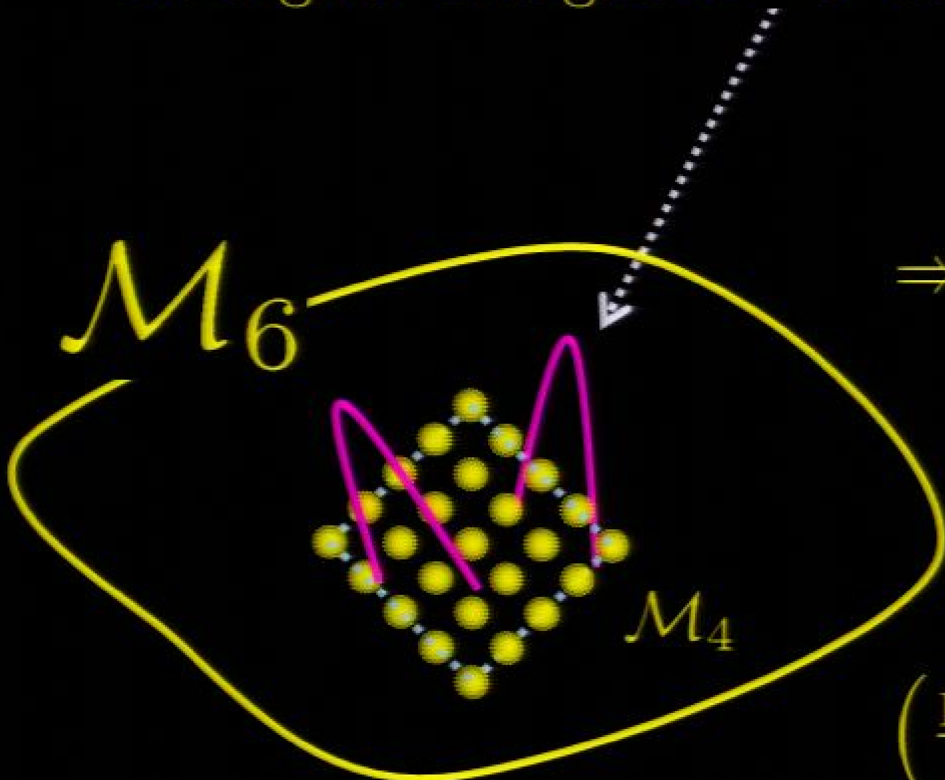
Candidate dual is strongly curved:

$$\left(\frac{\text{Radius}}{l_{\text{string}}}\right)^4 = g_{YM}^2 N_c \times N_{\text{fuzz}} = \frac{g_s}{N_{\text{fuzz}}} N_c \times N_{\text{fuzz}} \sim O(1-10)$$

Reason: geometry is fuzzy, D3's not at one point

Higher Energies

At higher energies $3 - 3'$ strings become dynamical



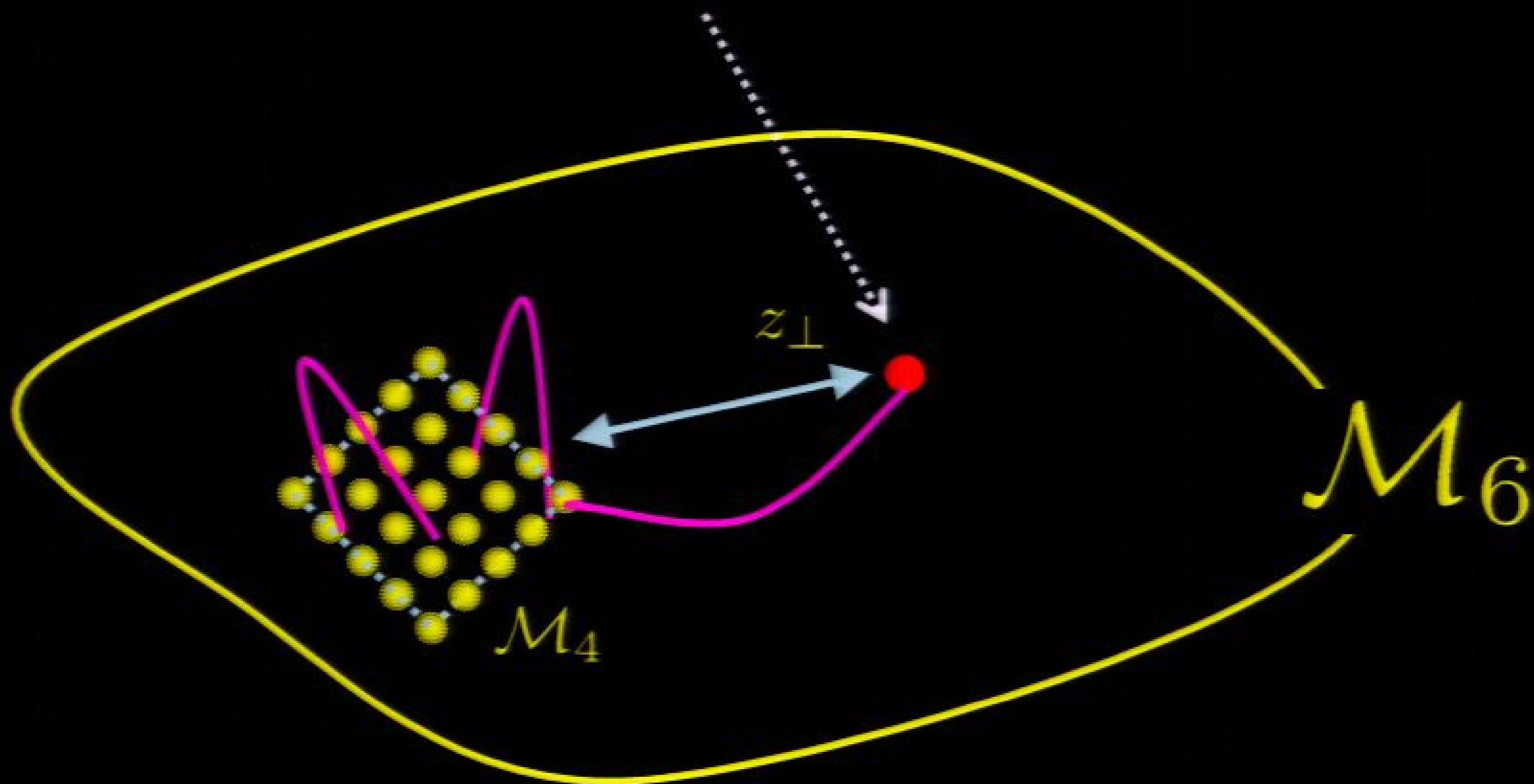
$\Rightarrow$ D3's free to move: $g_{YM}^2 \to g_s$

$$\left(\frac{\text{Radius}}{l_{\text{string}}}\right)^4 = g_{YM}^2 N_c \times N_{\text{fuzz}} \to \infty$$

Weakly coupled holographic dual opens up?

Probing The Fuzz

What does a nearby D3-brane see?



What is $V_{eff}(z_\perp)$?

Conclusions

- Decoupling and Fuzz
- $\alpha_{GUT}^{-1} \sim N_{\text{fuzz}}$
- Collective D3-branes
- ¿Probe Theory?

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