The Emergence Proposal in String Theory and the Species Scale

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Based on [arXiv:2209.xxxxx]
with A. Castellano and L. E. Ibáñez

Instituto de Física Teórica presents:

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Madrid, 26-28 September 2022

The Emergence Proposal

In a theory of QG all light particles in a perturbative regime have no kinetic terms in the UV. The required kinetic terms appear as an IR effect after integrating out a tower of light states up to the species scale

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- Emergent infinite distances in moduli space $\longrightarrow$ **Infinite distances** appear as a consequence of an **infinite tower** of particles **becoming light** (related to the SDC)

$$S_{\text{kin}} = \int g_{\phi\phi}\, d\phi \wedge \star d\phi \qquad\qquad g^{IR}_{\phi\phi} \sim g^{UV}_{\phi\phi} + g^{\text{tower}}_{\phi\phi}$$

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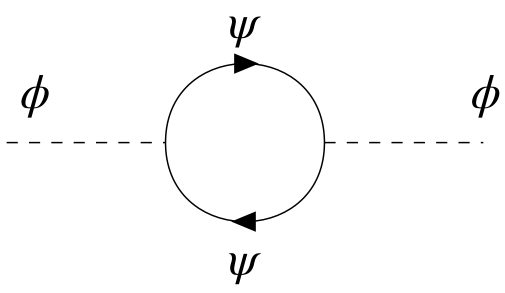

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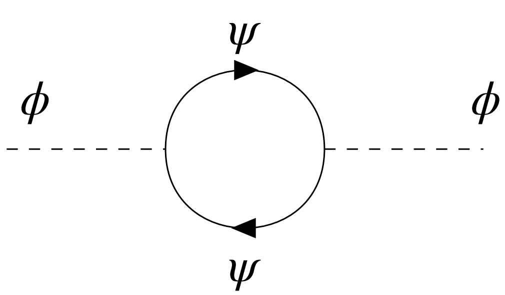

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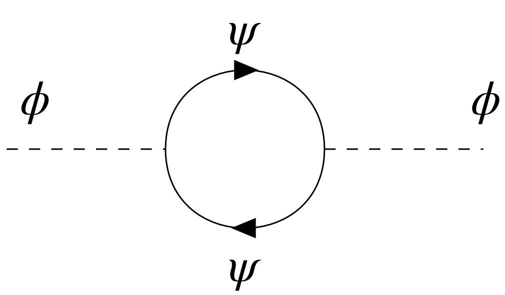

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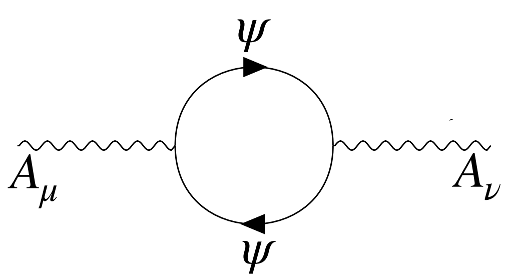

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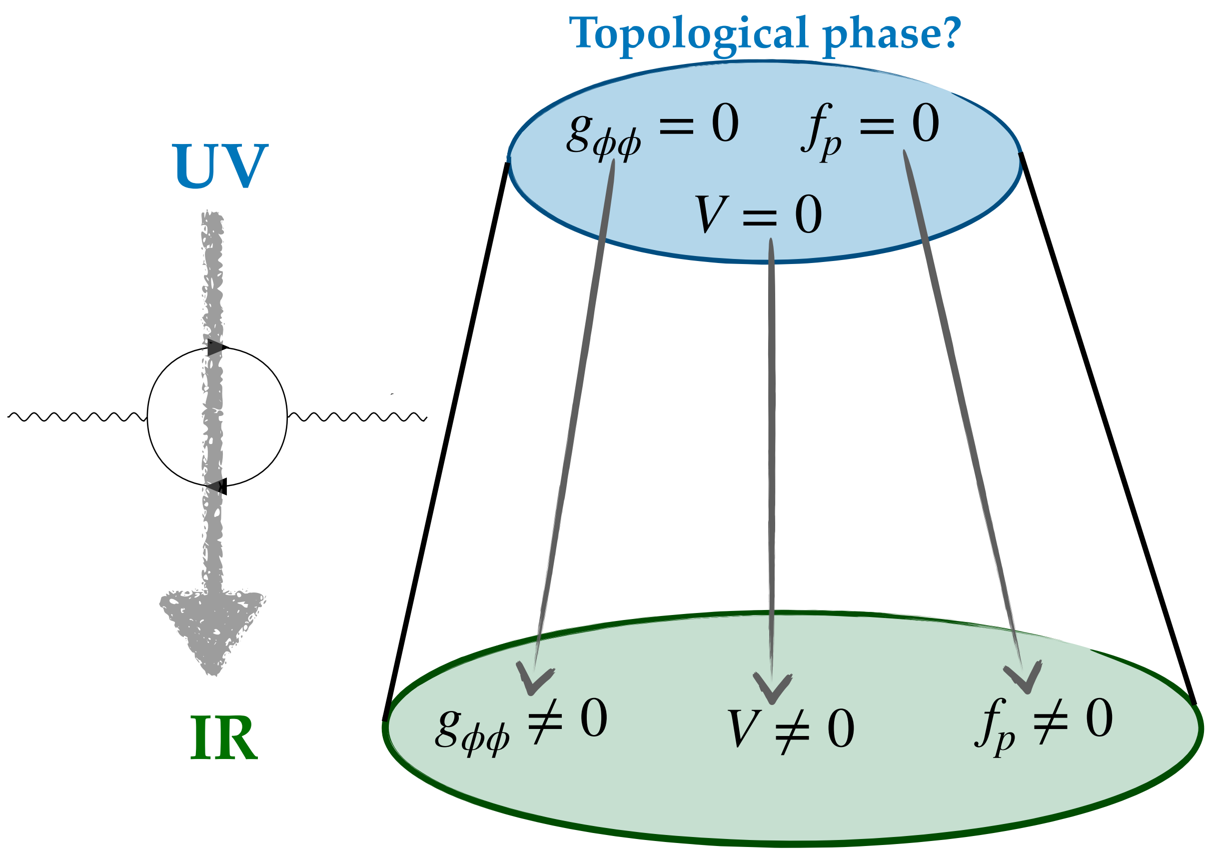

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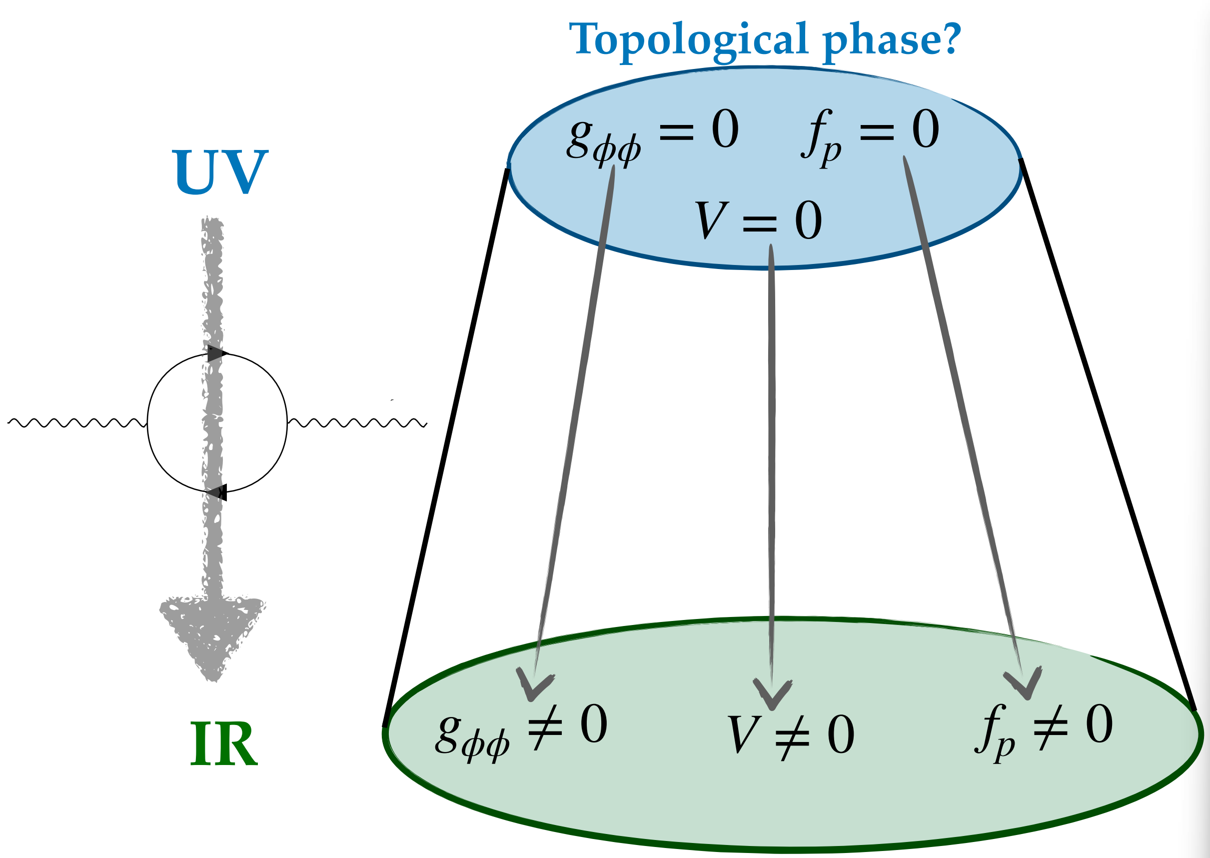

Recipe to obtain your own Emergent Kinetic Term

1. Identify the states of the tower(s) that becomes massless.
2. Compute the cut-off $\Lambda_{\rm QG}$ and the # of light species.
3. Find their coupling(s) to the scalars/p-forms with emergent kinetic terms.
4. Sum the contribution of the full tower to the propagator.

Outline

1. The Emergence Proposal
2. The Species Scale
3. Loop calculations recap
4. Emergence in 10d (type IIA at weak and strong coupling)
5. Emergence in 4d (type IIB / type IIA on a CY_3)
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- Quantum Gravity cut-off in the presence of N light species

$$M_{\mathrm{Pl,d}} \longrightarrow \Lambda_{\mathrm{QG}} = \frac{M_{\mathrm{Pl,d}}}{N^{\frac{1}{d-2}}}$$

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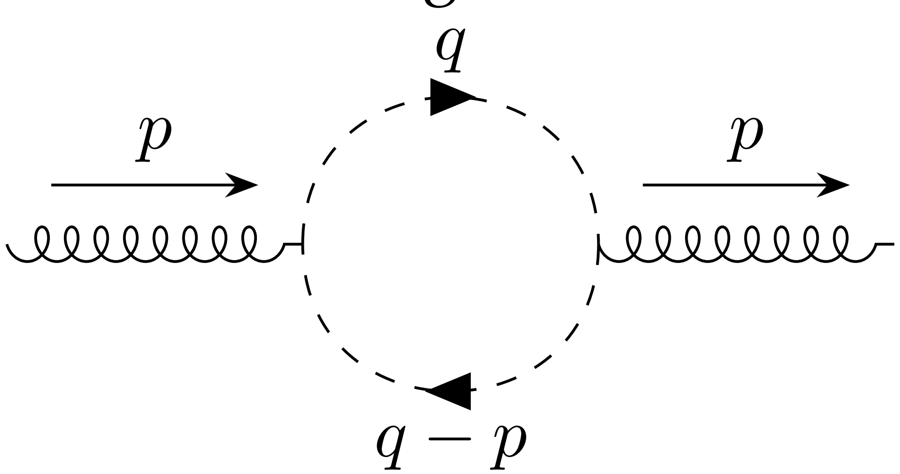

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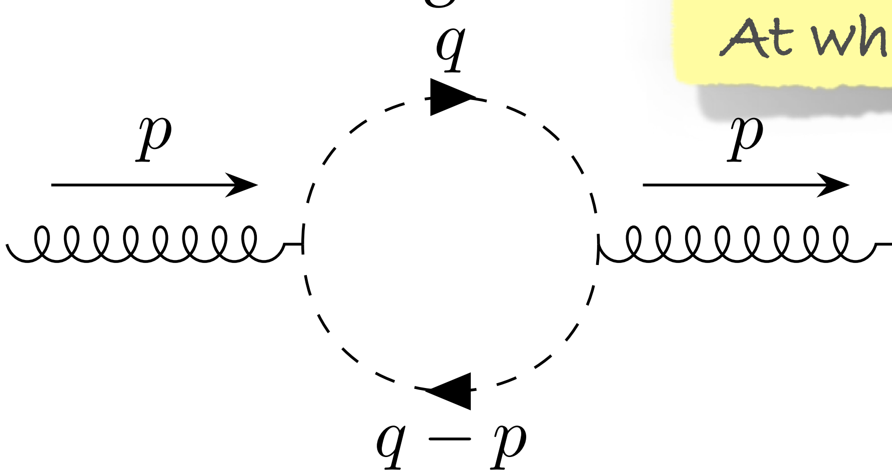

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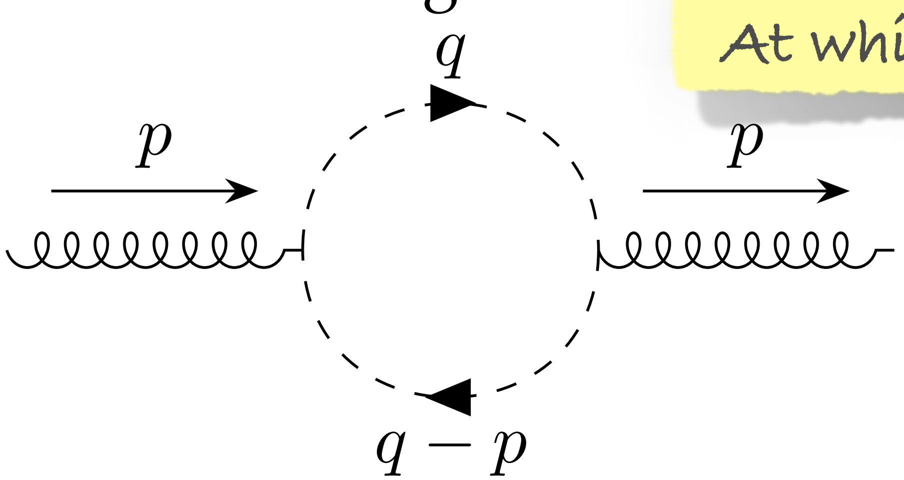

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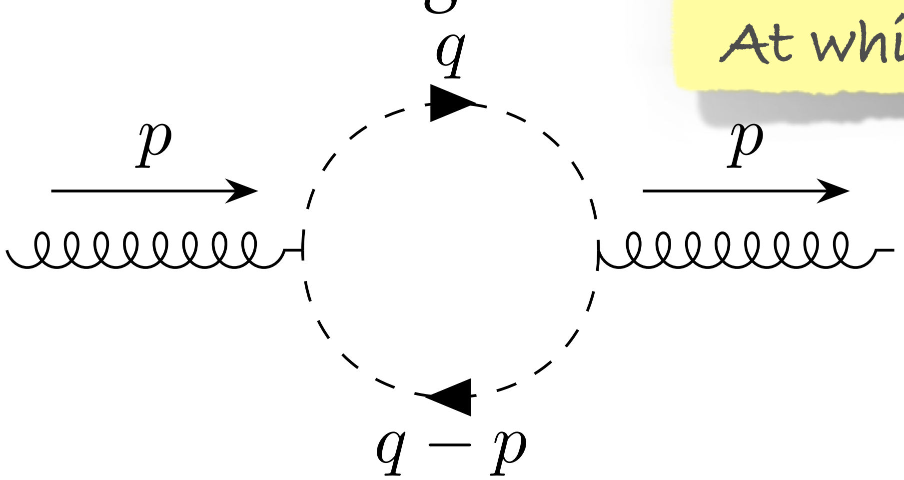

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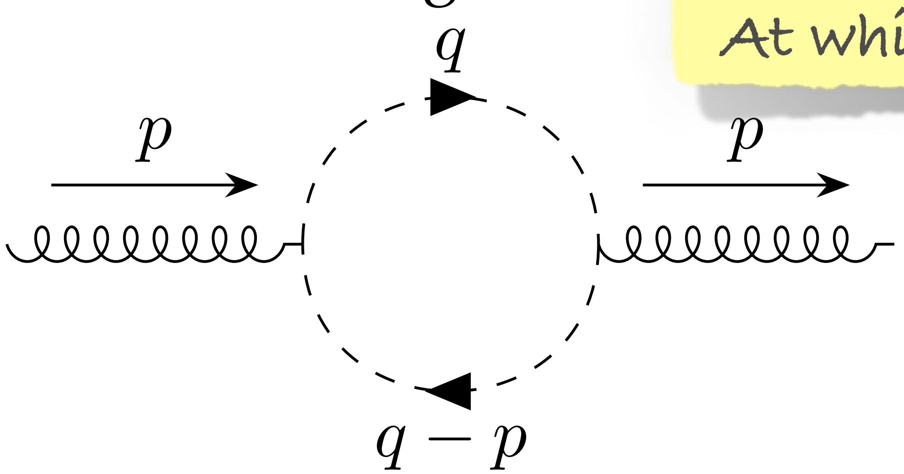

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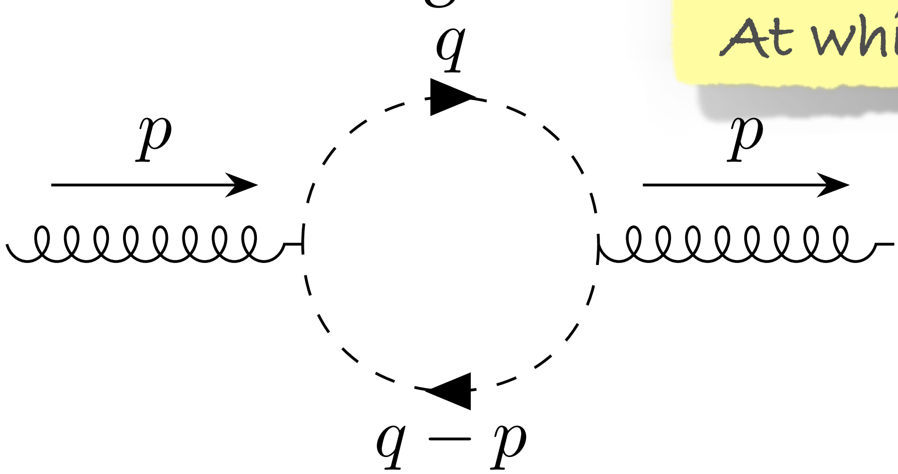

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(log corrections roughly amount to $N \rightarrow N \log N$)

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-Dimensional Reduction-

- Quantum Gravity cut-off in the presence of N light species $\Lambda_{\mathrm{QG}} = \frac{M_{\mathrm{Pl,d}}}{N^{\frac{1}{d-2}}}$
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$$\Lambda_{\rm QG}^{d+k-2} \simeq M_{{\rm pl},(d+k)}^{d+k-2}/N_0 \simeq \Lambda_{{\rm QG},\,(d+k)}^{d+k-2}$$

The Species Scale of the d-dim EFT = Λ_{QG} of the full theory

(including the zero modes N_0)

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- d-dimensional theory with the excitation modes of the string

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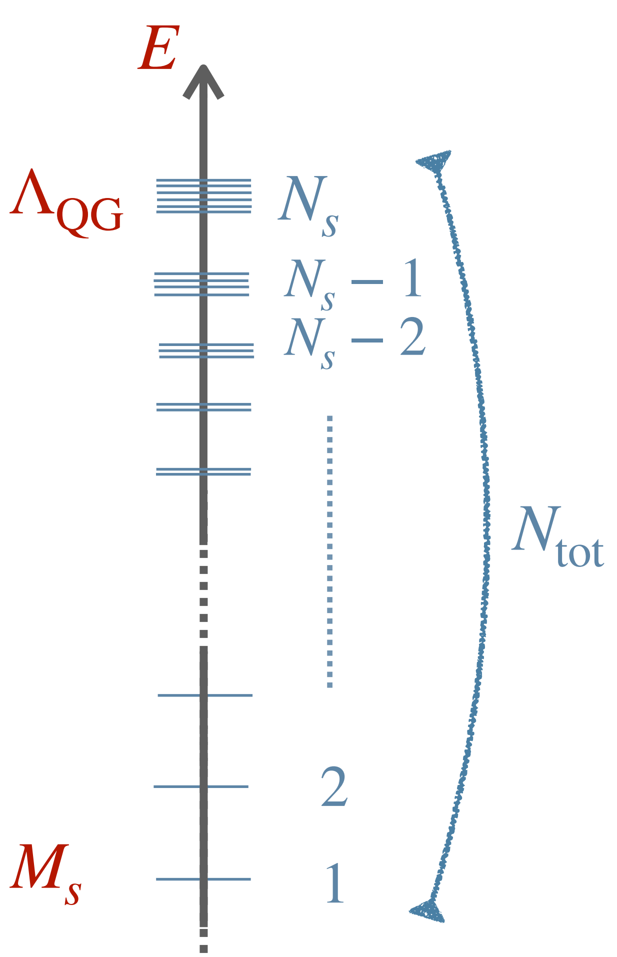

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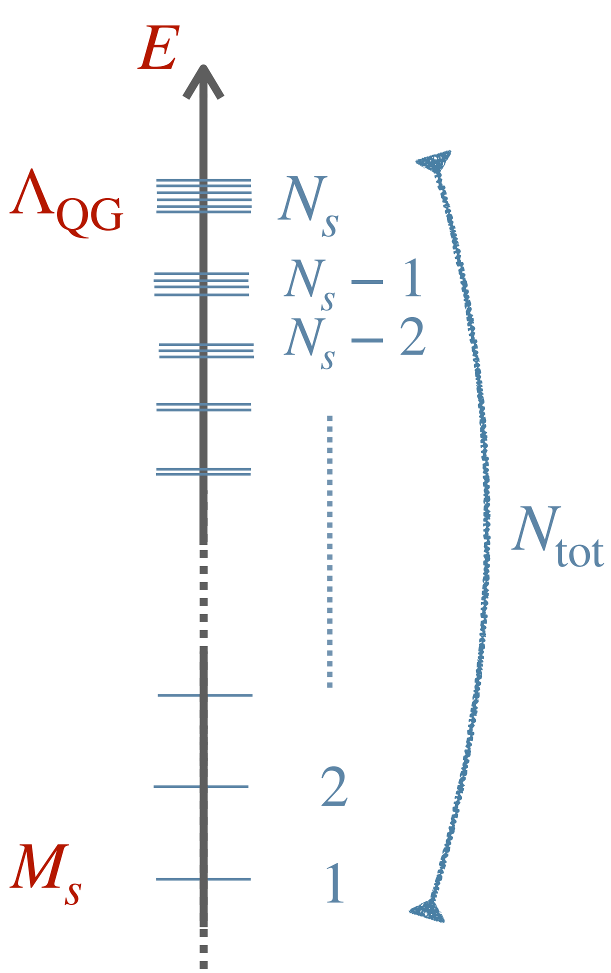

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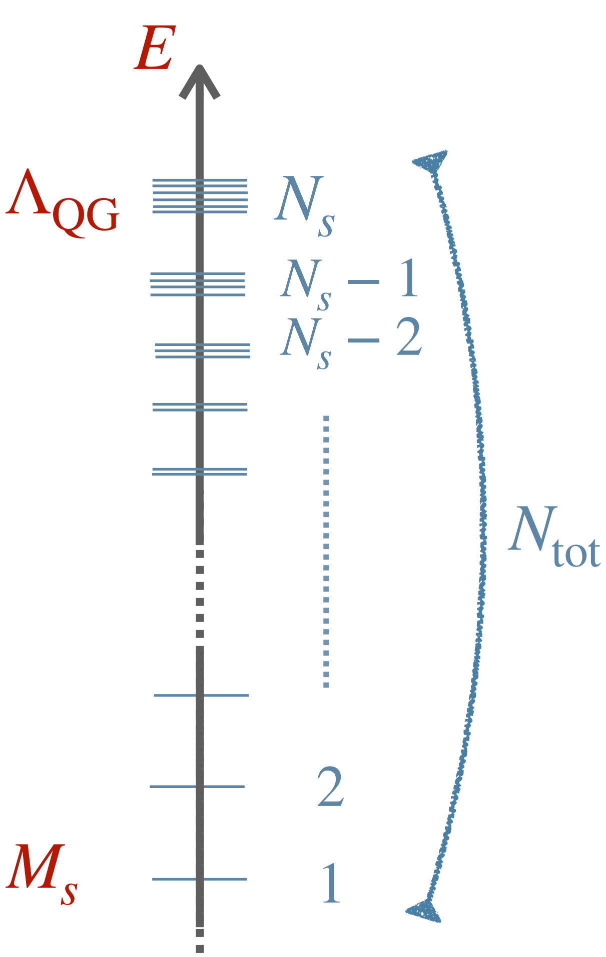

$$\frac{\Lambda_{\rm QG}}{M_s} = \sqrt{N_s}$$

$$\sqrt{N_s} \sim W_0\left(\frac{1}{(d-1)2^{\frac{1}{d-1}}}\left[\frac{M_{{\rm pl},d}}{M_s}\right]^{\frac{d-2}{d-1}}\right) \sim \log\left(\frac{M_{{\rm Pl},\,d}}{M_s}\right)$$

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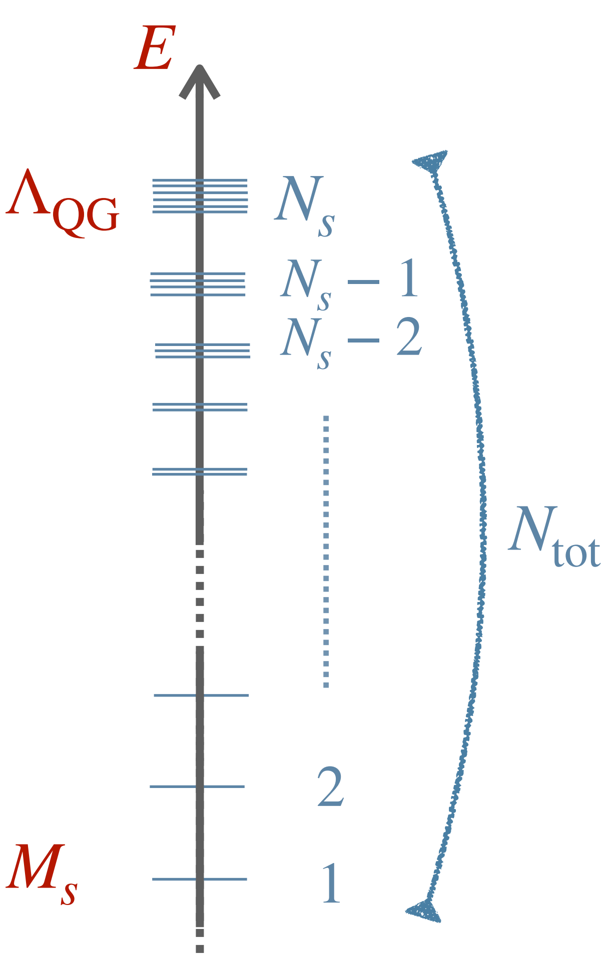

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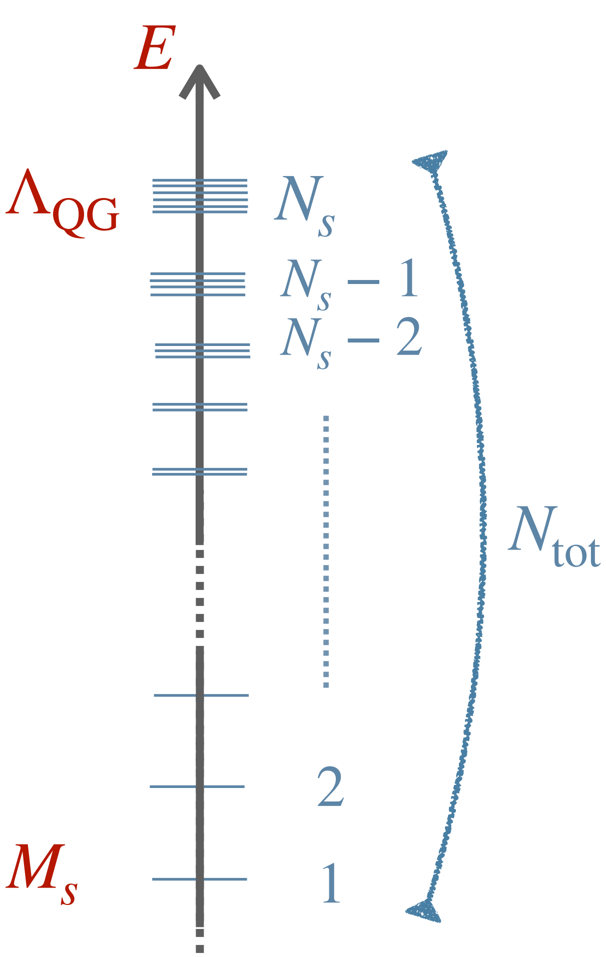

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Species Scale = M_s (up to log corrections)
Log corrections are key for the state counting

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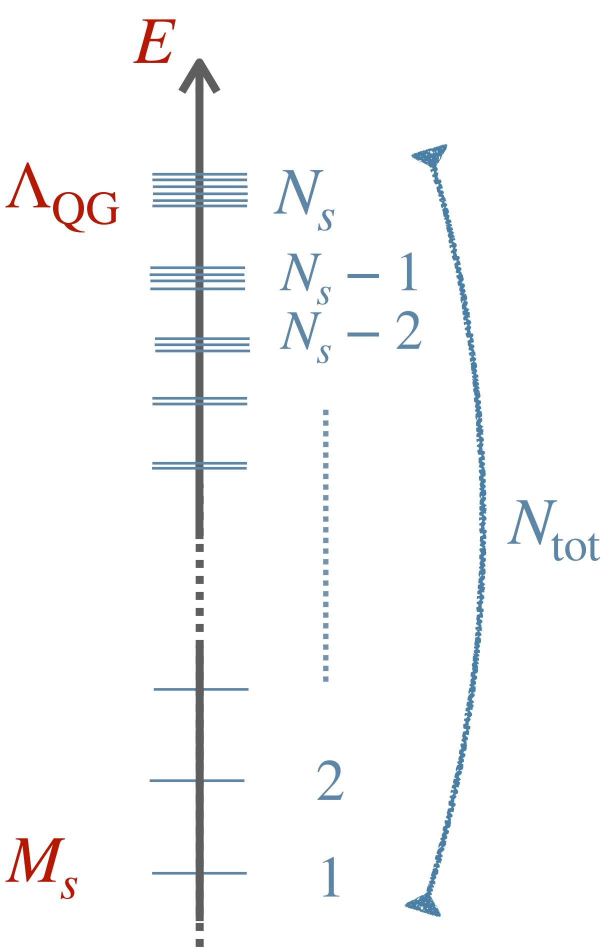

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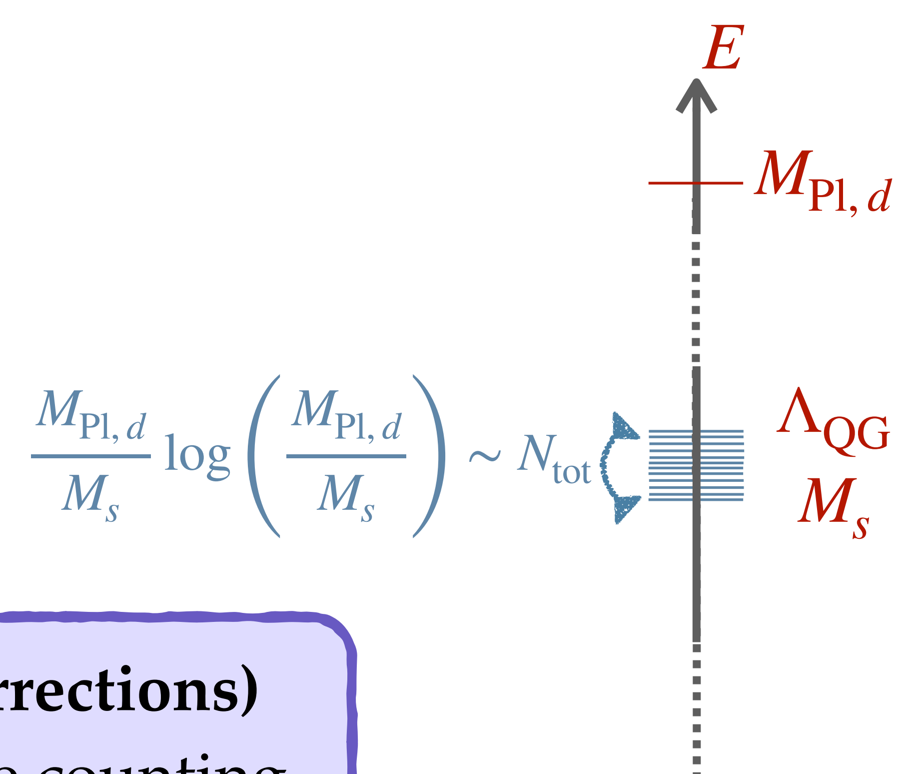

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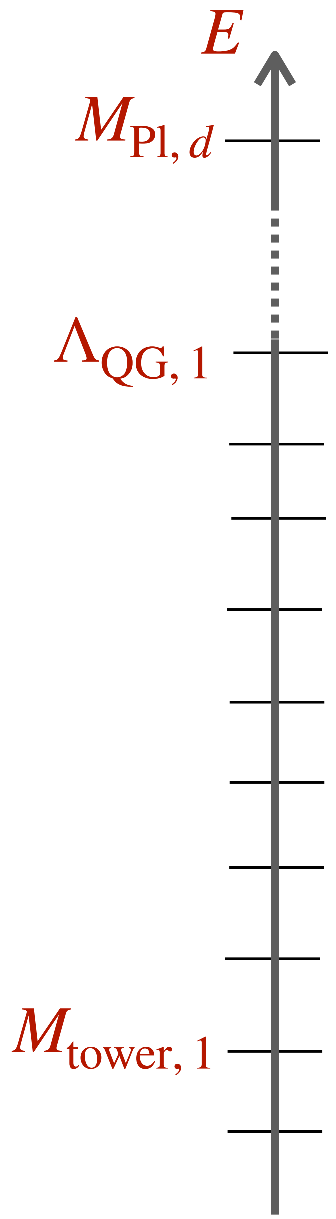
The species Scale

-Multiple towers-

- Quantum Gravity cut-off in the presence of N light species $$\Lambda_{\text{QG}} = \frac{M_{\text{Pl,d}}}{N^{\frac{1}{d-2}}}$$
- Typically, **not only** the tower with the lightest mass scale contributes to the Species Scale (i.e. more towers can be below the QG cutoff) [Castellano, AH, Ibáñez '21]



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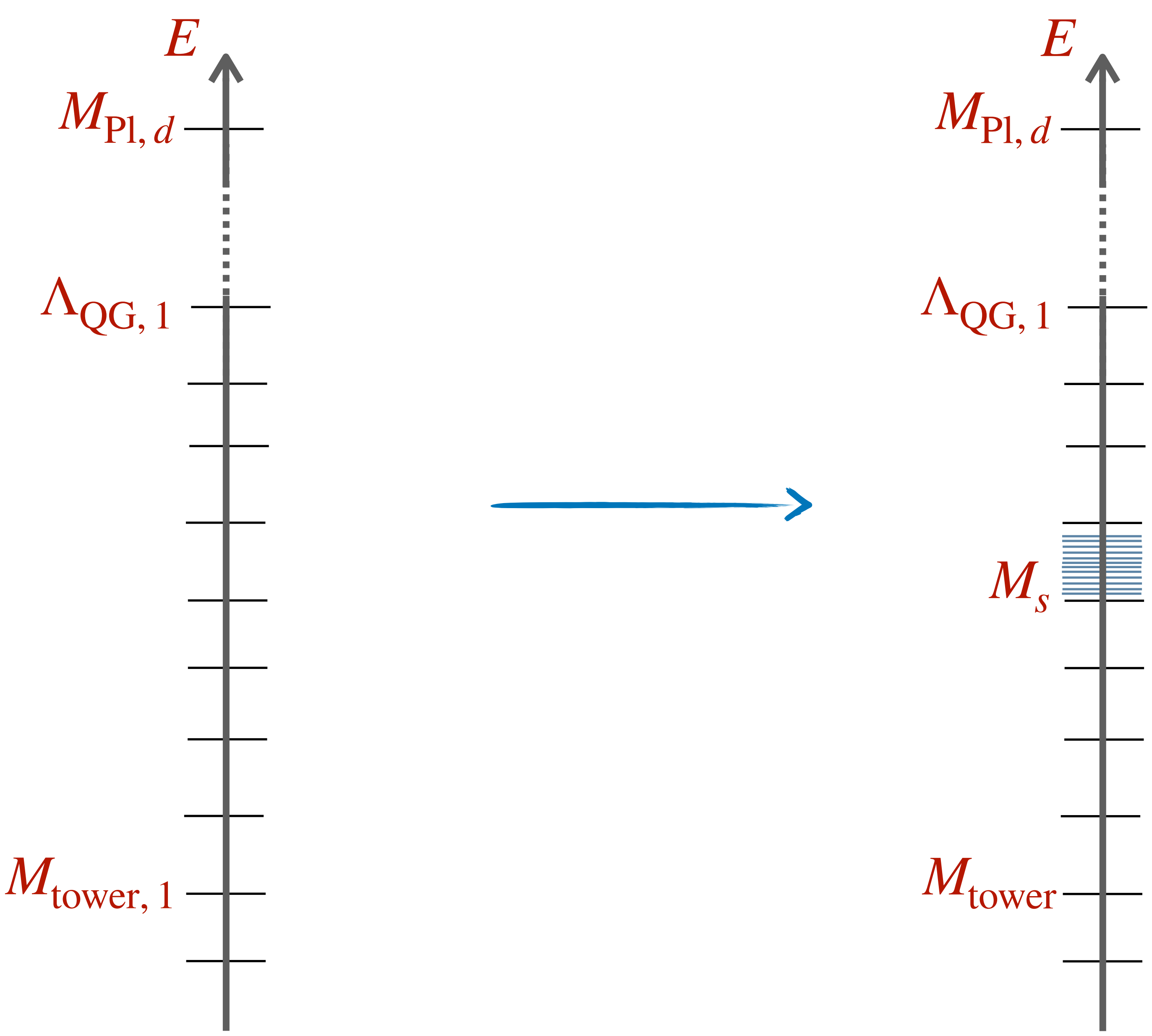

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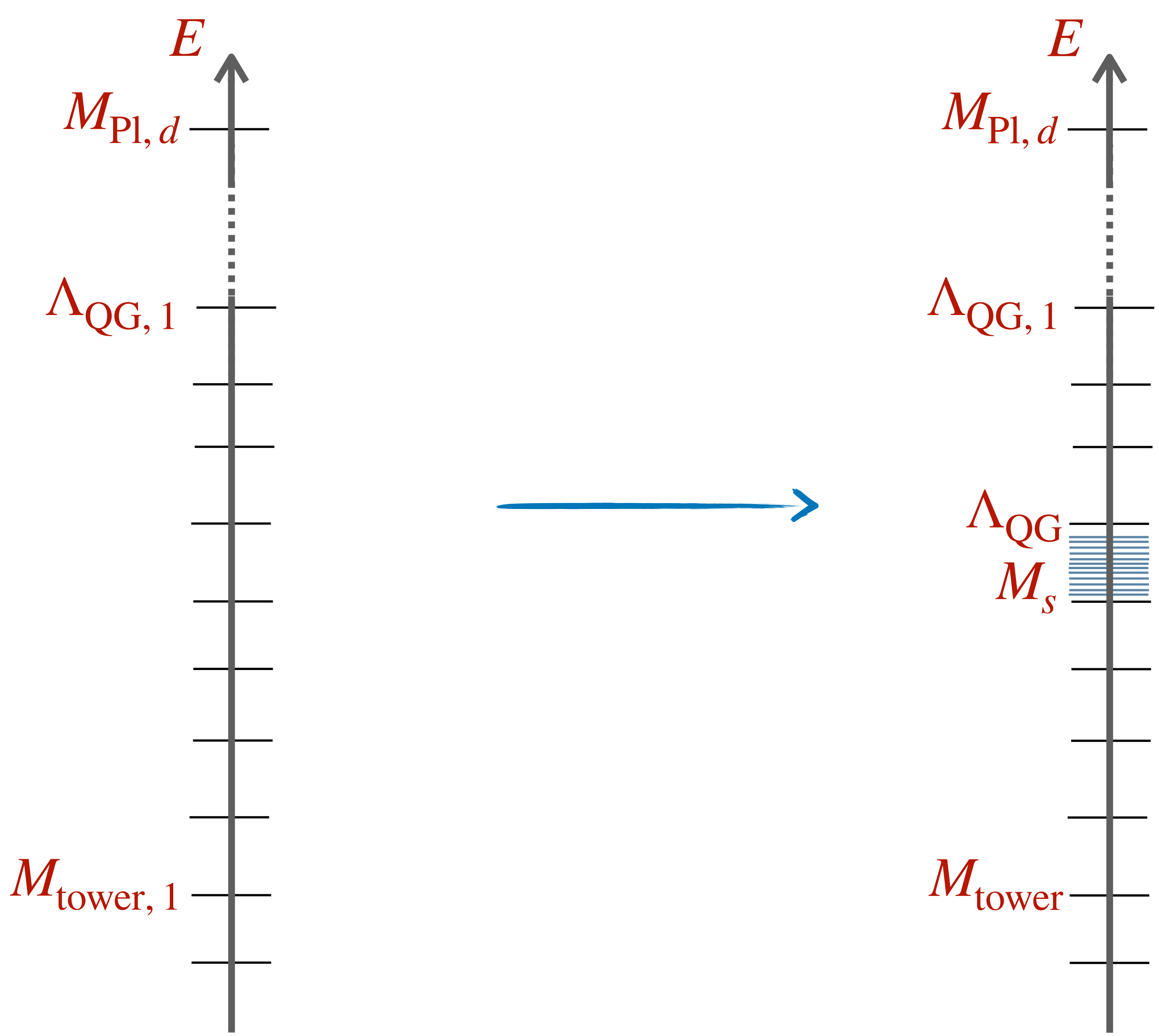

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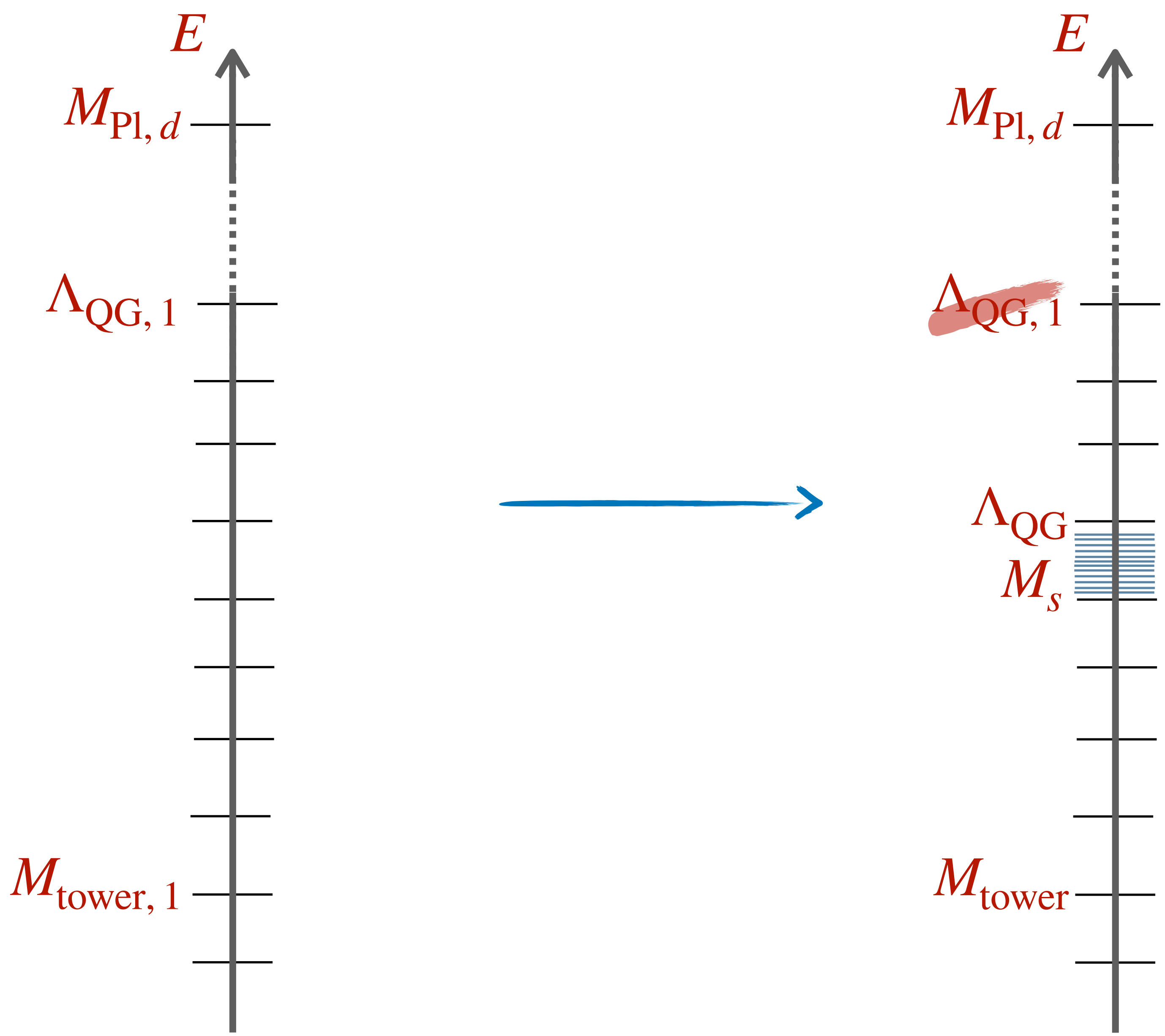


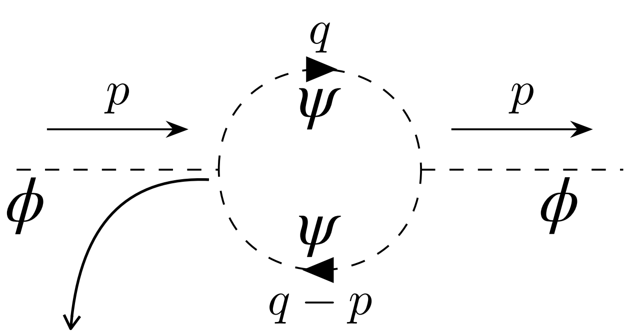
Outline

1. The Emergence Proposal
2. The Species Scale
3. Loop calculations recap
4. Emergence in 10d (type IIA at weak and strong coupling)
5. Emergence in 4d (type IIB / type IIA on a CY_3)
6. Emergent Potentials (M-theory in 5d and type IIA in 4d)
7. Other Results and Summary

Emergence

-Loop corrections-

$$g_{\phi\phi}^{IR} \sim \cancel{g_{\phi\phi}^{UV}} + g_{\phi\phi}^{\text{tower}}$$



$$g_{\phi\phi}^{n} \sim -\frac{\lambda_n^2}{2}\int \frac{\mathrm{d}^d\ell}{(2\pi)^d}\frac{1}{(\ell^2 + m_n^2)^3}$$

$$\lambda_n = 2m_n(\partial_\phi m_n)$$

Emergence

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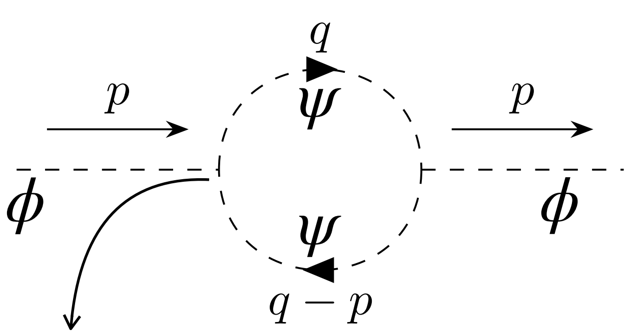

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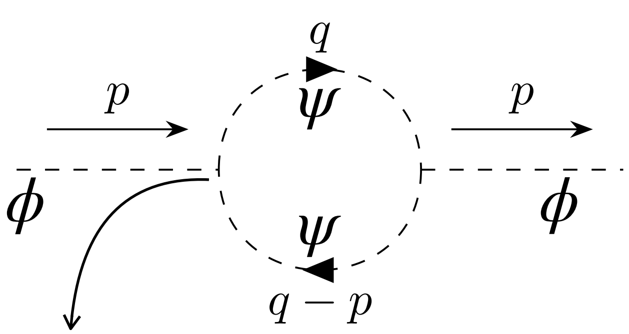

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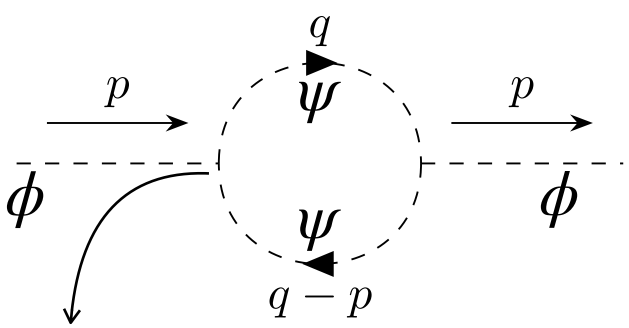

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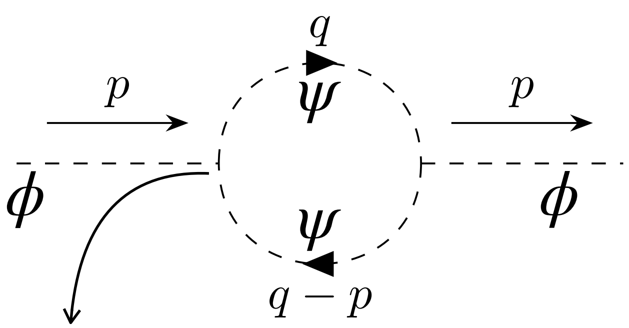

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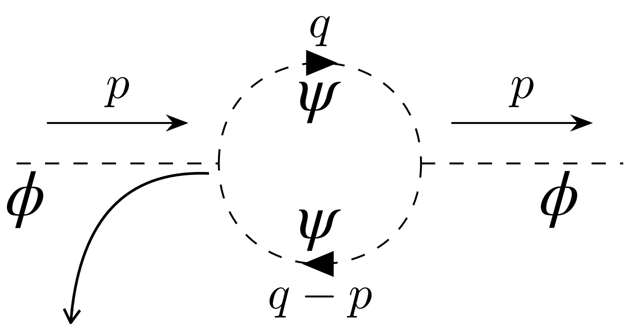

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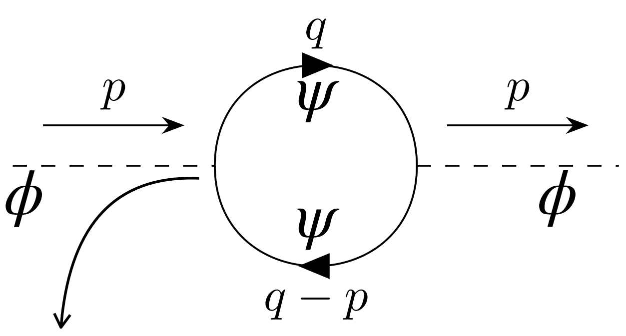

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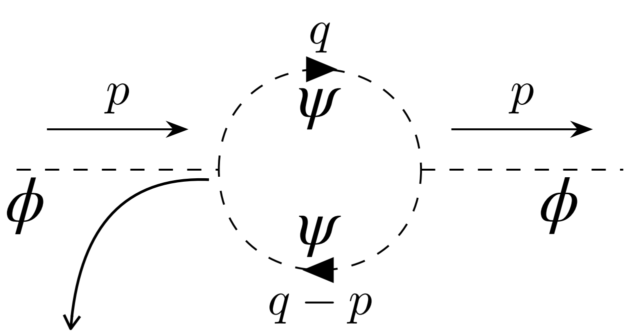

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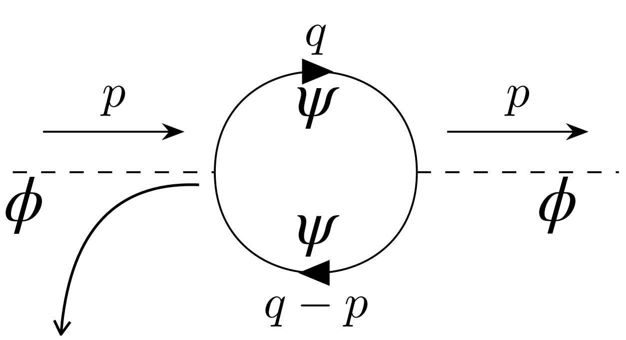

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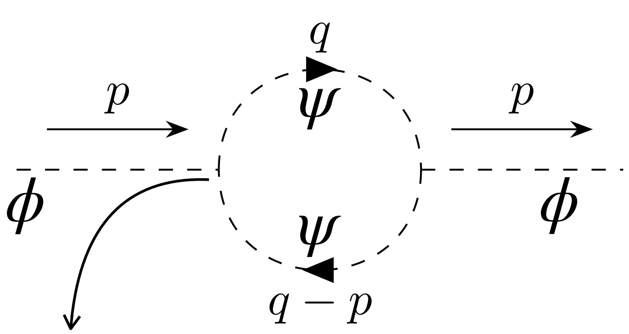

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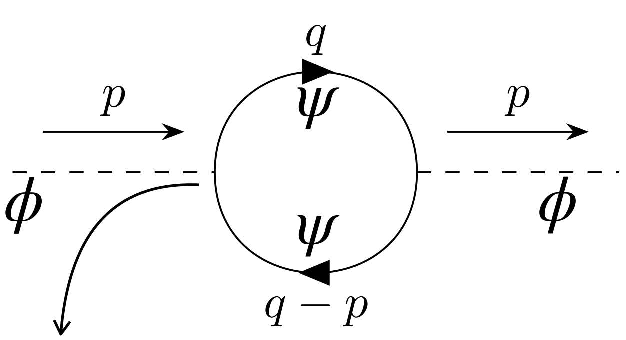

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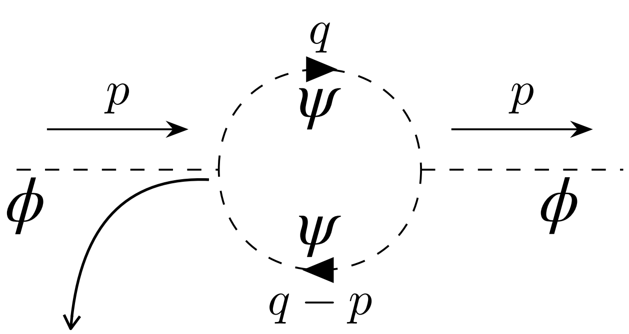

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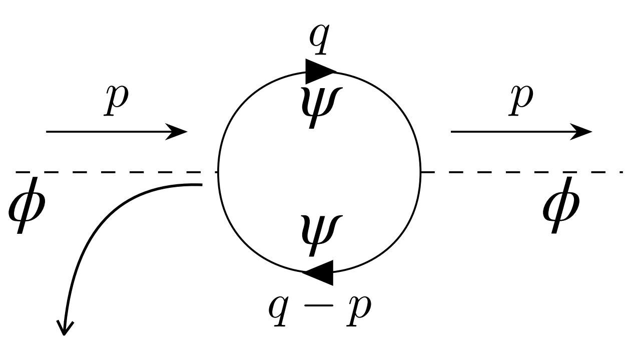

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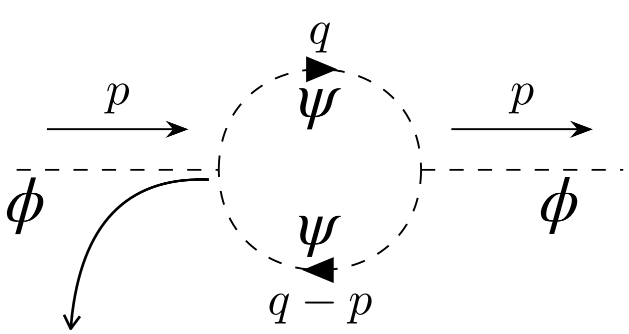

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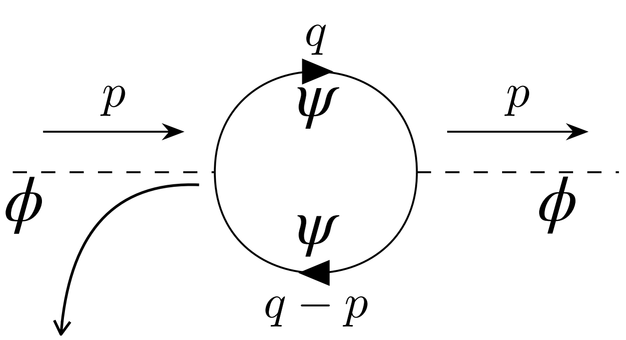

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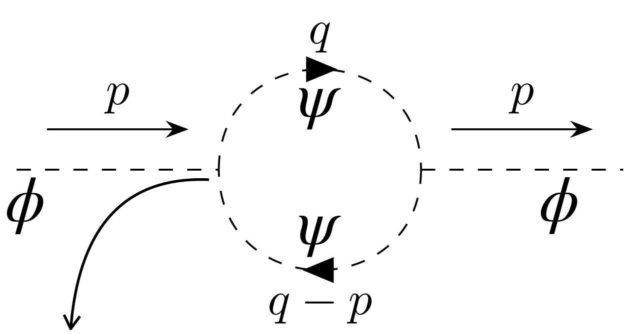

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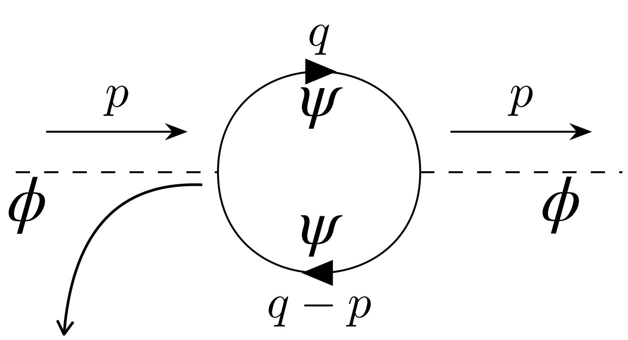

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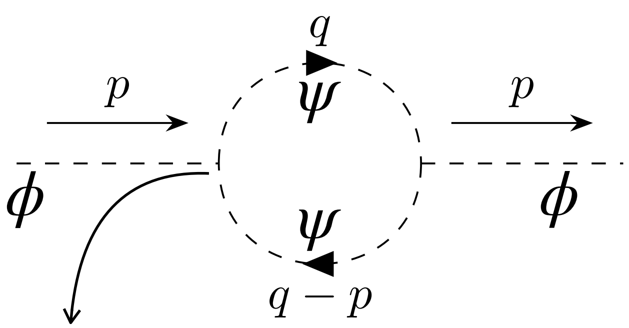

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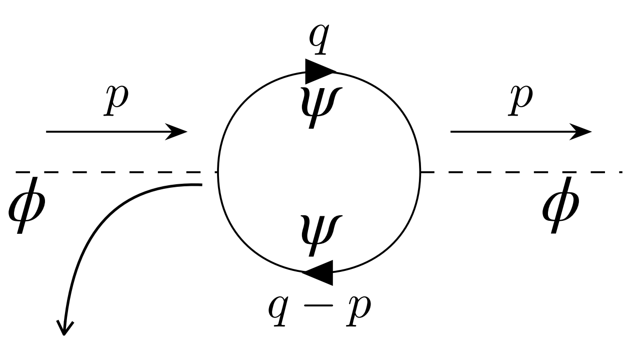

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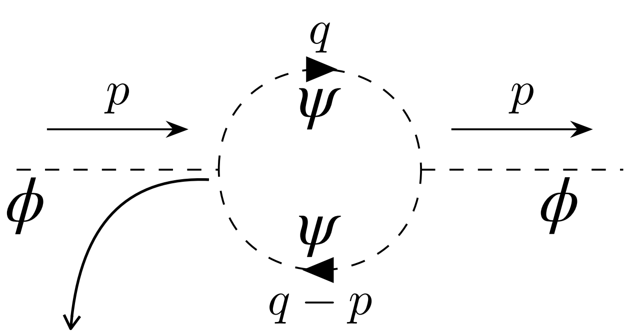

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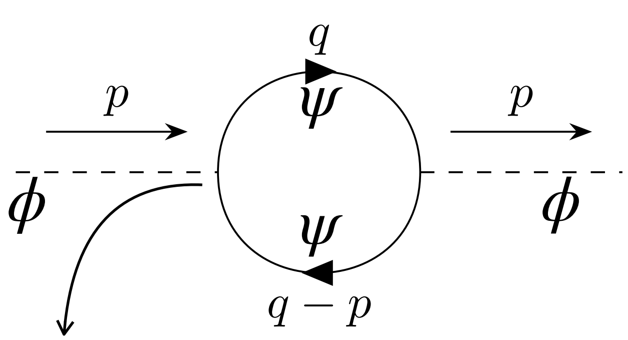

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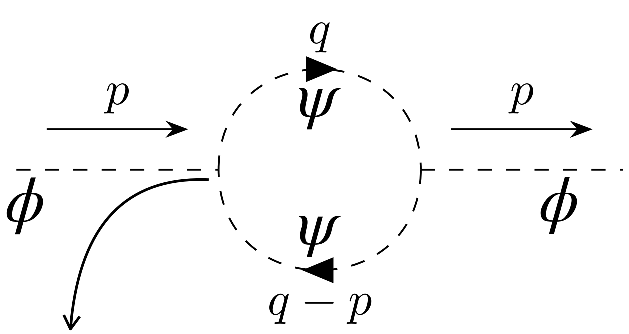

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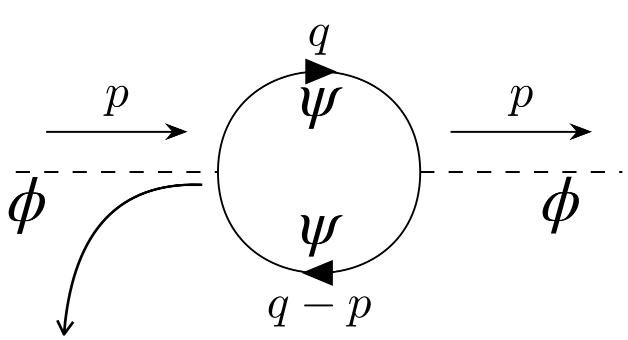

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- Universal behavior for field-space metric:

[Hamada, Montero, Vafa, Valenzuela '21]

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$$g_{\phi\phi} \simeq \Lambda_{\text{QG}}^{d-4} \sum_n (\partial_\phi m_n)^2 = \Lambda_{\text{QG}}^{d-4} (\partial_\phi \Delta m)^2 \sum_n n^{2/p} \simeq \Lambda_{\text{QG}}^{d-4} (\partial_\phi \Delta m)^2 N^{\frac{2+p}{p}} \simeq M_{\text{pl,d}}^{d-2} \left(\frac{\partial_\phi \Delta m}{\Delta m}\right)^2$$

[Hamada, Montero, Vafa, Valenzuela '21]

Emergence

-Loop corrections-

$$g_{\phi\phi}^{IR} \sim \cancel{g_{\phi\phi}^{UV}} + g_{\phi\phi}^{\text{tower}}$$

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$$\boxed{m_n = n^{1/2}\, M_s \qquad d_n \sim e^{\sqrt{n}}}$$

[Hamada, Montero, Vafa, Valenzuela '21]

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$$g_{\phi\phi} \simeq \Lambda_{\text{QG}}^{d-6} \sum_n m_n^2 (\partial_\phi m_n)^2\, d_n \simeq \Lambda_{\text{QG}}^{d-6} M_s^2 (\partial_\phi M_s)^2 \sum_n n^2 \exp(\sqrt{n}) \simeq$$

$$\simeq 2\, M_s^{d-4} (\partial_\phi M_s)^2\, N_s^{\frac{d-1}{2}}\, e^{\sqrt{N_s}} \simeq M_{\text{pl,d}}^{d-2} \left(\frac{\partial_\phi M_s}{M_s}\right)^2$$

[Hamada, Montero, Vafa, Valenzuela ’21]

Emergence

-Loop corrections-

$$g^{IR}_{\phi\phi} \sim \cancel{g^{UV}_{\phi\phi}} + g^{\text{tower}}_{\phi\phi} \qquad \frac{1}{g^2_{A_1}} \sim m^{1/\alpha} \qquad \alpha = \frac{D-2+p}{2p(D-1)} \qquad |q_n| = m_n = n^{1/p} m$$

[Castellano, AH, Ibáñez '21]

- Universal behavior for field-space metric:

$$m_n = n^{1/p} \Delta m$$

$$g_{\phi\phi} \simeq \Lambda_{\text{QG}}^{d-4} \sum_n (\partial_\phi m_n)^2 = \Lambda_{\text{QG}}^{d-4} (\partial_\phi \Delta m)^2 \sum_n n^{2/p} \simeq \Lambda_{\text{QG}}^{d-4} (\partial_\phi \Delta m)^2 N^{\frac{2+p}{p}} \simeq M_{\text{pl,d}}^{d-2} \left(\frac{\partial_\phi \Delta m}{\Delta m} \right)^2$$

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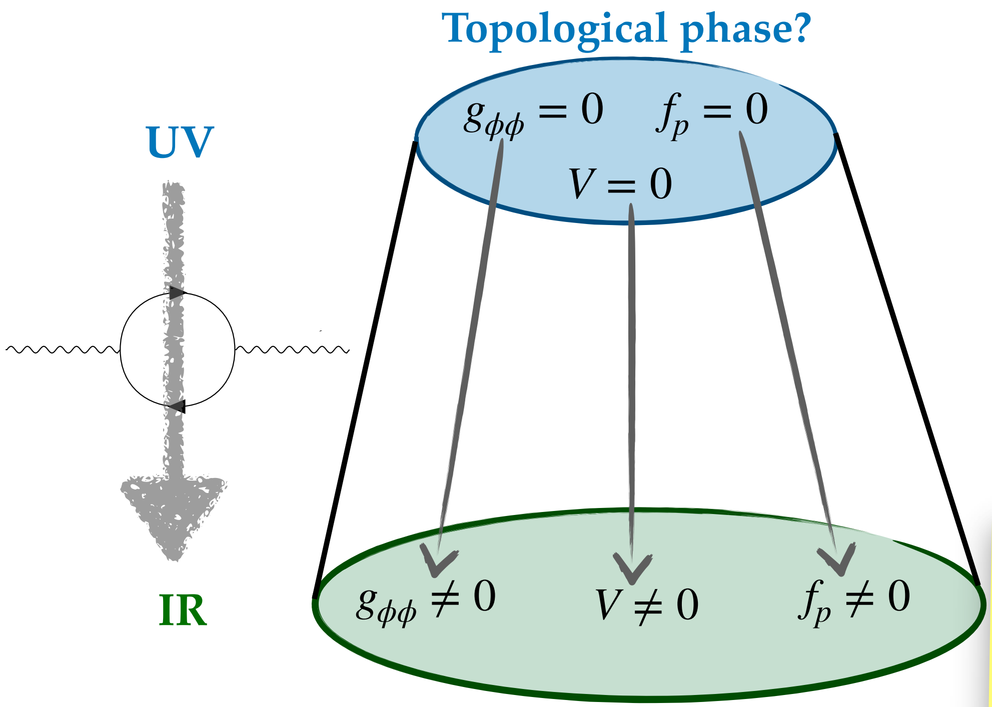
[Hamada, Montero, Vafa, Valenzuela '21]

Outline

1. The Emergence Proposal
2. The Species Scale
3. Loop calculations recap
4. Emergence in 10d (type IIA at weak and strong coupling)
5. Emergence in 4d (type IIB / type IIA on a CY_3)
6. Emergent Potentials (M-theory in 5d and type IIA in 4d)
7. Other Results and Summary

Emergence



Recipe to obtain your own Emergent Kinetic Term

1. Identify the states of the tower(s) that becomes massless.
2. Compute the cut-off $\Lambda_{\rm QG}$ and the # of light species.
3. Find their coupling(s) to the scalars/p-forms with emergent kinetic terms.
4. Sum the contribution of the full tower to the propagator.

Emergence

-Type IIA in 10d-

- 1 dimensional moduli space $\longrightarrow \phi \quad (g_s = e^{\phi})$

Infinite distance points

$$S^{10}_{\rm IIA} = \frac{1}{2\kappa_{10}^2}\int \mathrm{d}^{10}x\sqrt{-G}\left(R - \frac{1}{2}(\partial\phi)^2\right) - \frac{1}{4\kappa_{10}^2}\int e^{-\tilde{\phi}} H_3 \wedge \star H_3$$

$$- \frac{e^{2\phi_0}}{4\kappa_{10}^2}\int \left[e^{\frac{3}{2}\tilde{\phi}} F_2 \wedge \star F_2 + e^{\frac{1}{2}\tilde{\phi}} \tilde{F}_4 \wedge \star \tilde{F}_4 + B_2 \wedge F_4 \wedge F_4\right]$$

$\phi \to -\infty$

$\phi \to +\infty$

Emergence

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Infinite distance points

$$S^{10}_{\mathrm{IIA}} = \frac{1}{2\kappa_{10}^2}\int \mathrm{d}^{10}x\sqrt{-G}\left(R - \frac{1}{2}(\partial\phi)^2\right) - \frac{1}{4\kappa_{10}^2}\int e^{-\tilde{\phi}} H_3 \wedge \star H_3$$
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$$S_{\text{IIA}}^{10} = \frac{1}{2\kappa_{10}^2}\int \mathrm{d}^{10}x\sqrt{-G}\left(R - \frac{1}{2}(\partial\phi)^2\right) - \frac{1}{4\kappa_{10}^2}\int e^{-\tilde{\phi}}H_3 \wedge \star H_3$$
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$$S^{10}_{\text{IIA}} = \frac{1}{2\kappa^2_{10}} \int \mathrm{d}^{10}x\sqrt{-G}\left(R - \frac{1}{2}(\partial\phi)^2\right) - \frac{1}{4\kappa^2_{10}}\int e^{-\tilde{\phi}} H_3 \wedge \star H_3$$

$$-\frac{e^{2\phi_0}}{4\kappa^2_{10}}\int\left[e^{\frac{3}{2}\tilde{\phi}} F_2 \wedge \star F_2 + e^{\frac{1}{2}\tilde{\phi}} \tilde{F}_4 \wedge \star \tilde{F}_4 + B_2 \wedge F_4 \wedge F_4\right]$$

Infinite distance points

$\phi \to -\infty$

$\phi \to +\infty$

(1) Emergent string limit $\longrightarrow$ Stringy tower $\longrightarrow m_n^2 \simeq n M_s^2$ with $M_s^2 = \dfrac{e^{\frac{\phi_0}{2}}}{(4\pi)^{1/4}} M^2_{\text{Pl},\,10}$

Emergence
-Type IIA in 10d-

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<u>Infinite distance points</u>

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(2) $\Lambda_{\mathrm{QG}} \simeq M_s$ and $\sqrt{N_s}$

Emergence

-Type IIA in 10d-

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Infinite distance points

$$S_{\text{IIA}}^{10} = \frac{1}{2\kappa_{10}^2}\int d^{10}x\sqrt{-G}\left(R - \frac{1}{2}(\partial\phi)^2\right) - \frac{1}{4\kappa_{10}^2}\int e^{-\tilde{\phi}} H_3 \wedge \star H_3$$
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- $\mu_n = \partial_\phi m_n(\phi)$ (fermions)
- $\lambda_n = m_n(\phi)\partial_\phi m_n(\phi)$ (bosons)

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(1) Strong coupling point (Dual to decompactification limit of M-theory on S^1) $\longrightarrow$

Tower of D0s $\longrightarrow m_{\mathrm{D0}} = \dfrac{M_s}{2\pi e^{\phi}}$

Emergence

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Field content of a D0 brane

KK replicas of the gravity multiplet in 11d SUGRA reduced on the circle

$$\begin{array}{ll}
 & \quad\ \ \phi \qquad C_1 \qquad G_{MN} \quad B_2 \qquad C_3 \qquad\qquad \lambda_{1/2} \quad \lambda_{1/2} \qquad \psi_{3/2} \quad \psi_{3/2} \\
\text{IIA:} & (\mathbf{1}\oplus\mathbf{35}\oplus\mathbf{8}_v\oplus\mathbf{28}\oplus\mathbf{56}_t)_{\text{bos}}\oplus(\mathbf{8}_s\oplus\mathbf{8}_c\oplus\mathbf{56}_c\oplus\mathbf{56}_s)_{\text{ferm}} \\
\text{D0:} & (\mathbf{44}\oplus\mathbf{84})_{\text{bos}}\oplus(\mathbf{64}_s\oplus\mathbf{64}_c)_{\text{ferm}} \\
\text{M-th:} & (\underset{G_{MN}}{\mathbf{44}}\oplus\underset{C_3}{\mathbf{84}})_{\text{bos}}\oplus(\underset{\psi_{3/2}}{\mathbf{128}})_{\text{ferm}}
\end{array}$$

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$\phi \to -\infty$

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(3) Couplings of the tower from reducing the M-theory on S^1 and keeping track of massive modes

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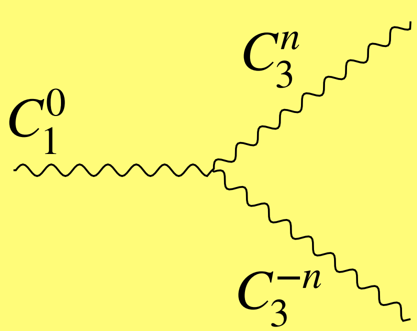
(2) N

(3) C ... modes

$$S_{11\mathrm{d}} \supset -\frac{1}{8\kappa^2_{11}} \int dC_3 \wedge \star dC_3$$

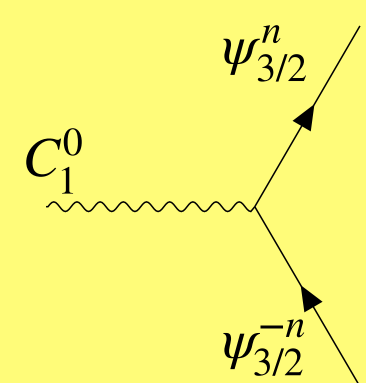
$$\Big\downarrow S^1 \qquad \begin{aligned} \hat{e}^a &= e^a \\ \hat{e}^z &= e^{3\phi/2}\,(dz - C^0_1) \end{aligned}$$



$$\sim \frac{n}{2\kappa^2_{10}} m_{\mathrm{D0}}\, e^{\phi_0}$$

$$S_{11\mathrm{d}} \supset -\frac{1}{2\kappa^2_{11}} \int \mathrm{d}^{11}x\ e\ (-i)\bar{\psi}_M \Gamma^{MNP} \mathscr{D}_N \psi_P$$

$$\Big\downarrow S^1$$



$$\sim \frac{n}{2\kappa^2_{10}} m_{\mathrm{D0}}\, e^{\phi_0}$$

Emergence

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(3) Couplings of the tower from reducing the M-theory on S^1 and keeping track of massive modes

(4) $$\frac{1}{g_{C_1}^2} \sim -\, e^{2\phi_0}\, m_{\rm D0}^2\, \Lambda_{\rm QG}^6 \sum_n n^2 \sim -\, e^{2\phi_0}\, m_{\rm D0}^2\, \Lambda_{\rm QG}^6\, N^3 \sim \frac{e^{2\phi_0}}{\kappa_{10}^2}$$

Emergence

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$\phi \to -\infty$

$\phi \to +\infty$

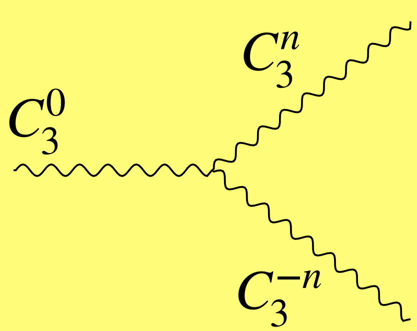
(1) Strong coupling point (Dual to decompactification limit of M-theory on S^1) $\longrightarrow$

Tower of D0s $\longrightarrow m_{\mathrm{D0}} = \dfrac{M_s}{2\pi e^{\phi}} \longrightarrow m_n = n\ m_{\mathrm{D0}}$

(2) N

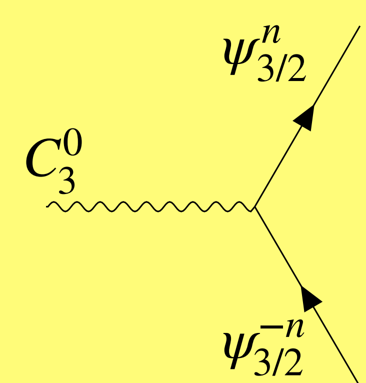
(3) C ... modes

$$S_{11\mathrm{d}} \supset -\frac{1}{12\kappa_{11}^2}\int C_3\wedge dC_3\wedge dC_3 \quad \Big\downarrow S^1$$



$$\sim \frac{n}{2\kappa_{10}^2} m_{\mathrm{D0}}\, e^{\phi_0}$$

$$S_{11\mathrm{d}} \supset -\frac{1}{384\kappa_{11}^2}\int \mathrm{d}^{11}x\ e\ \bar{\psi}_R\Gamma^{[R}\Gamma_{MNPQ}\Gamma^{S]}\psi_S F_4^{MNPQ} \quad \Big\downarrow S^1$$



$$\sim \frac{n}{2\kappa_{10}^2} m_{\mathrm{D0}}\, e^{\phi_0}$$

Emergence

-Type IIA in 10d-

- 1 dimensional moduli space $\longrightarrow \phi \quad (g_s = e^{\phi})$

<u>Infinite distance points</u>

$$S^{10}_{\rm IIA} = \frac{1}{2\kappa^2_{10}} \int \mathrm{d}^{10}x\sqrt{-G}\left(R - \frac{1}{2}(\partial\phi)^2\right) - \frac{1}{4\kappa^2_{10}}\int e^{-\tilde{\phi}} H_3 \wedge \star H_3$$

$$-\frac{e^{2\phi_0}}{4\kappa^2_{10}}\int\left[e^{\frac{3}{2}\tilde{\phi}} F_2 \wedge \star F_2 + e^{\frac{1}{2}\tilde{\phi}} \tilde{F}_4 \wedge \star \tilde{F}_4 + B_2 \wedge F_4 \wedge F_4\right]$$

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(3) Couplings of the tower from reducing the M-theory on S^1 and keeping track of massive modes

(4) $\dfrac{1}{g^2_{C_3}} \sim -\, e^{2\phi_0}\ m^2_{\rm D0}\ \Lambda^6_{\rm QG} \displaystyle\sum_n n^2 \sim -\, e^{2\phi_0}\ m^2_{\rm D0}\ \Lambda^6_{\rm QG}\ N^3 \sim \frac{e^{2\phi_0}}{\kappa^2_{10}}$

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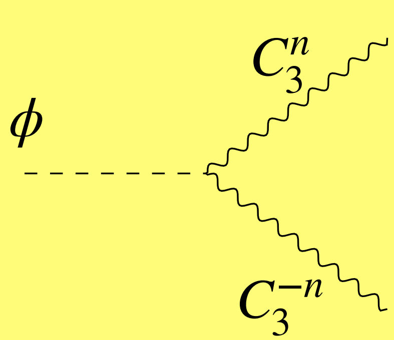
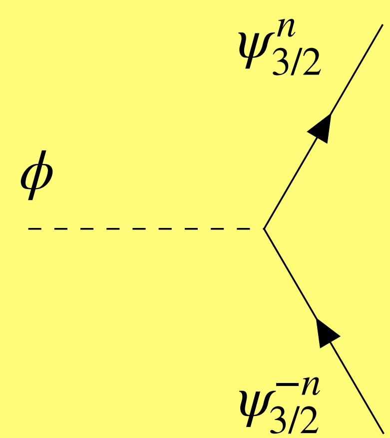


$$\sim \frac{n}{2\kappa_{10}^2}\underbrace{(2\, m_{\rm D0}\, \partial_\phi m_{\rm D0})}_{\lambda_n}$$



$$\sim \frac{n}{2\kappa_{10}^2}\underbrace{(\,\partial_\phi m_{\rm D0})}_{\mu_n}$$

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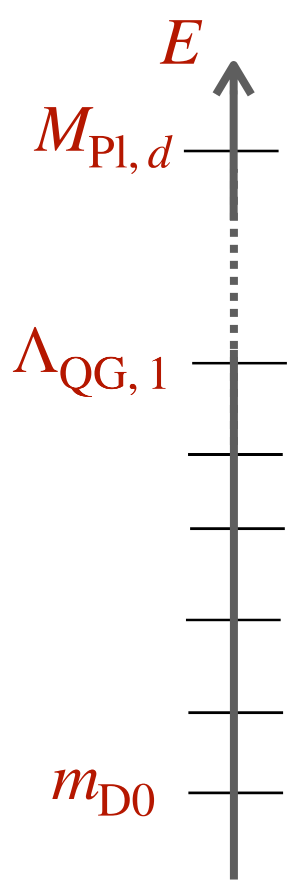

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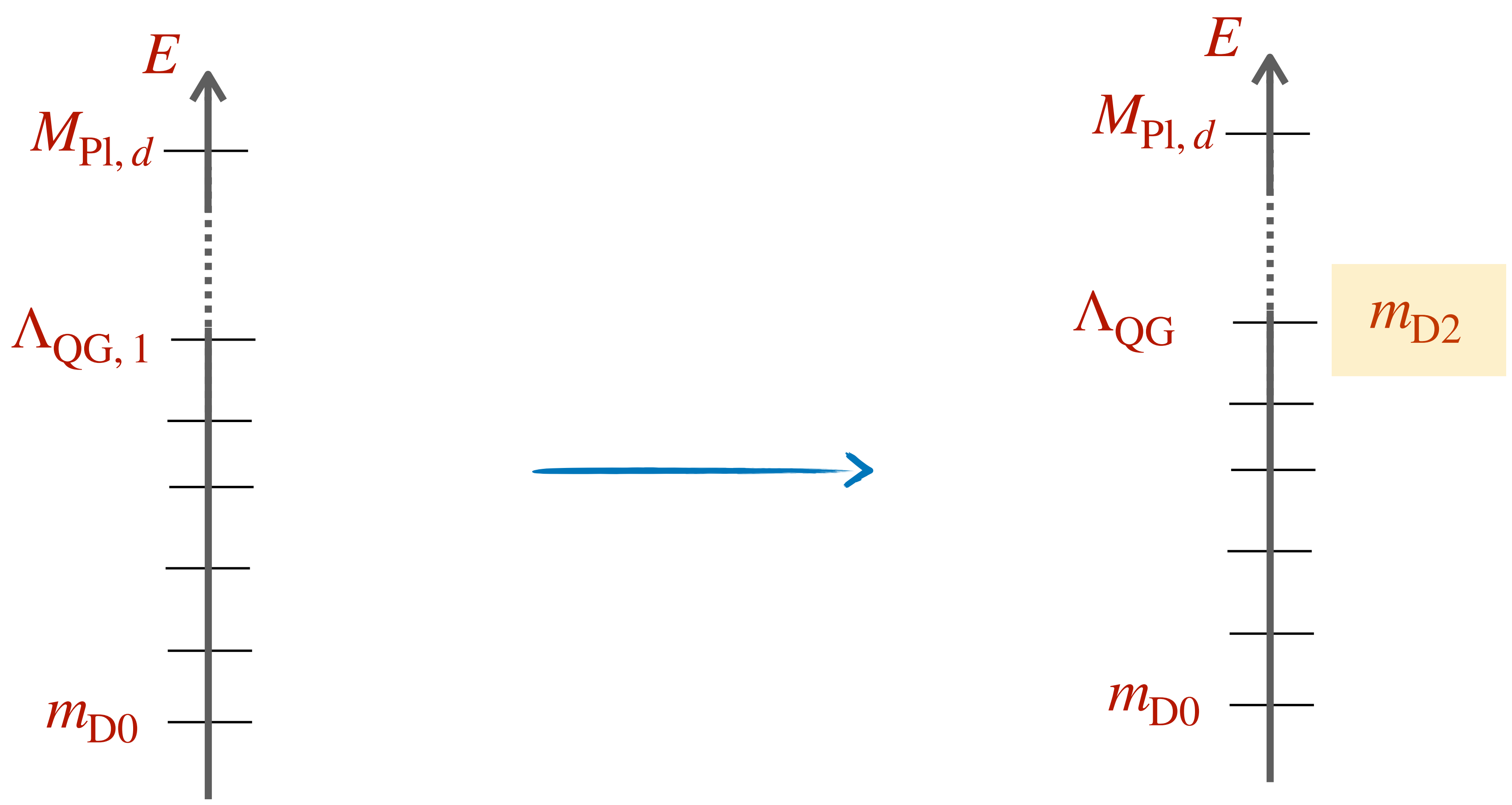

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4d type IIA

C_3^0

C_3^a

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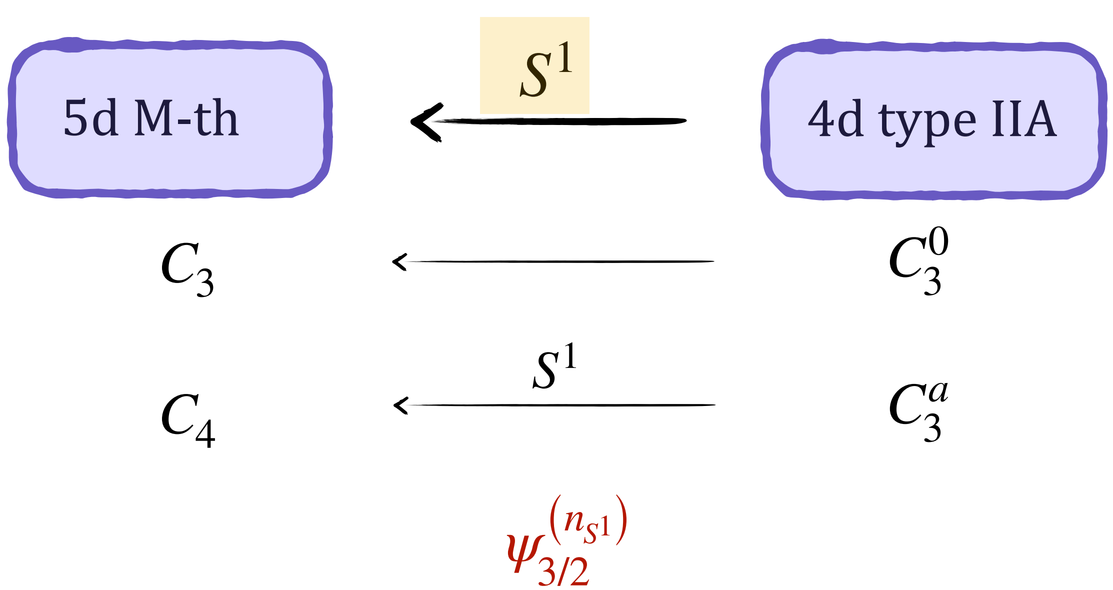

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$$\begin{array}{ccccc} \boxed{\text{11d M-th}} & \xleftarrow{\;X_3\;} & \boxed{\text{5d M-th}} & \xleftarrow{\;S^1\;} & \boxed{\text{4d type IIA}} \\ C_3 & \longleftarrow & C_3 & \longleftarrow & C_3^0 \\ C_6 & \xleftarrow{\;[\omega_a]\;} & C_4 & \xleftarrow{\;S^1\;} & C_3^a \\ \text{Tower:} & \psi_{3/2}^{(n_{X_3})} & & \psi_{3/2}^{(n_{S^1})} & \end{array}$$

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$$S_{5d} \supset \frac{1}{4\kappa_4^2}\int \mathscr{V}_5^{2}\left(F_4^0\wedge\star F_4^0 + G_{ab}\,F_5^a\wedge\star F_5^b\right) \qquad G_{ab} \neq G_{ab}(\mathscr{V})$$

$$\begin{tikzcd}
\boxed{\text{11d M-th}} \arrow[r, "X_3"] & \boxed{\text{5d M-th}} \\
C_3 \arrow[r] & C_3 \\
C_6 \arrow[r, "{[\omega_a]}"] & C_4
\end{tikzcd}$$

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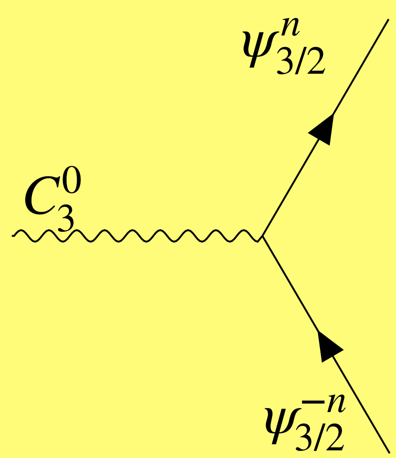
$$\boxed{\text{11d M-th}} \xrightarrow{X_3} \boxed{\text{5d M-th}}$$

$$S_{11d} \supset \frac{1}{2\kappa_{11}^2}\int \mathrm{d}^{11}x\; e\, \frac{1}{192} F_{4,\,MNPQ}\; \bar{\psi}_R\, \Gamma^{[R|}\, \Gamma^{MNPQ}\, \Gamma^{|S]}\, \psi_S$$

$$\Big\downarrow X_3$$

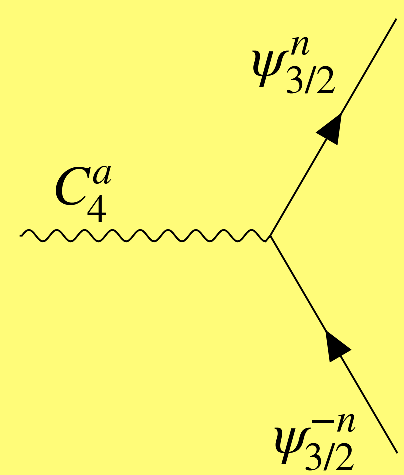


$\sim \mathcal{V}_5$

(Independent of n)

$$S_{11d} \supset \frac{1}{2\kappa_{11}^2}\int \mathrm{d}^{11}x\; e\, \frac{1}{960} F_{5,\,MNPQR}\; \bar{\psi}_S\, \Gamma^{[S|}\, \Gamma^{MNPQ}\, \Gamma^{|T]}\, \psi_T$$

$$\Big\downarrow X_3$$



$\sim \mathcal{V}_5$

(Independent of n)

Emergent Potentials

-Type II on a CY threefold-

- 4d EFT: $S_{4d} \supset \frac{1}{4\kappa_4^2} \int e^{-4\phi_4}\, \mathcal{V} \left(F_4^0 \wedge \star F_4^0 + 4\, g_{ab}\, F_4^a \wedge \star F_4^b \right)$ $\qquad e^{\phi_4} = \frac{e^{\phi}}{\sqrt{\mathcal{V}}}$

$$S_{5d} \supset \frac{1}{4\kappa_5^2} \int \mathcal{V}_5^2 \left(F_4^0 \wedge \star F_4^0 + F_5^a \wedge \star F_5^a \right)$$

$$\begin{array}{ccc}
\boxed{\text{11d M-th}} & \xrightarrow{X_3} & \boxed{\text{5d M-th}} \\
C_3 & \longrightarrow & C_3 \\
C_6 & \xrightarrow{[\omega_a]} & C_4
\end{array}$$

Tower: $\psi_{3/2}^{(n_{X_3})}$

$$\frac{1}{g_{C_{3,4}}^2} \sim -\mathcal{V}_5^2 \Lambda_{\text{QG}}^3 \sum_{i=1}^{N} 1 \sim -\mathcal{V}_5^2\, N \Lambda_{\text{QG}}^3 \sim -\frac{1}{\kappa_5^2} \mathcal{V}_5^2$$

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$$S_{5d} \supset \frac{1}{4\kappa_5^2}\int \mathscr{V}_5^2 \left(F_4^0 \wedge \star F_4^0 + F_5^a \wedge \star F_5^a\right)$$

$$\text{11d M-th} \xrightarrow{X_3} \text{5d M-th}$$

$$C_3 \longrightarrow C_3$$

$$C_6 \xrightarrow{[\omega_a]} C_4$$

Tower: $\psi_{3/2}^{(n_{X_3})}$

$$\frac{1}{g_{C_{3,4}}^2} \sim -\, \mathscr{V}_5^2 \Lambda_{\rm QG}^3 \sum_{i=1}^{N} 1 \sim -\, \mathscr{V}_5^2\, N \Lambda_{\rm QG}^3 \sim -\, \frac{1}{\kappa_5^2}\mathscr{V}_5^2$$

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Emergent Potentials

-Type II on a CY threefold-

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$$\begin{array}{ccccc}
\boxed{\text{11d M-th}} & \xrightarrow{X_3} & \boxed{\text{5d M-th}} & \xrightarrow{S^1} & \boxed{\text{4d type IIA}} \\
C_3 & \longrightarrow & C_3 & \longrightarrow & C_3^0 \\
C_6 & \xrightarrow{[\omega_a]} & C_4 & \xrightarrow{S^1} & C_3^a \\
\color{red}{\text{Tower:}} & \color{red}{\psi_{3/2}^{(n_{X_3})}} & & \color{red}{\psi_{3/2}^{(n_{S^1})}} &
\end{array}$$

Emergent Potentials

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$$\begin{array}{ccccc}
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C_3 & \longrightarrow & C_3 & \longrightarrow & C_3^0 \\
C_6 & \xrightarrow{[\omega_a]} & C_4 & \xrightarrow{S^1} & C_3^a
\end{array}$$

Tower: $\psi_{3/2}^{(n_{X_3})}$ $\qquad$ $\psi_{3/2}^{(n_{S^1})}$

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$$S_{5d} \supset \frac{1}{4\kappa_5^2}\int \mathscr{V}_5^2\left(F_4^0\wedge\star F_4^0+\,F_5^a\wedge\star F_5^a\right) \qquad R_5=\mathscr{V}^{1/3}$$

11d M-th $\xrightarrow{\;X_3\;}$ 5d M-th $\xrightarrow{\;S^1\;}$ 4d type IIA

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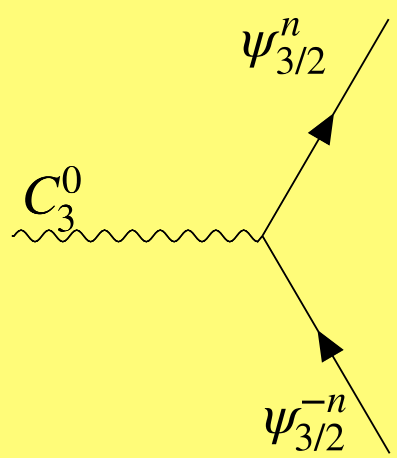
$$\Big\downarrow S^1$$

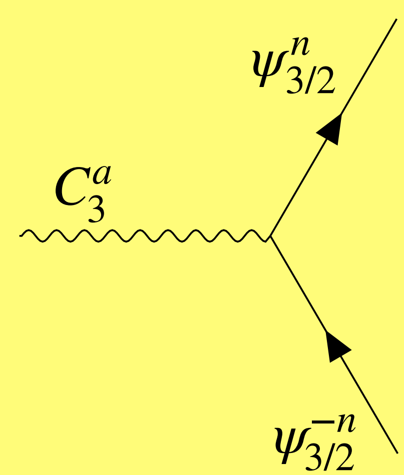


$\sim \mathscr{V}^{1/2}$

(Independent of n)

$$S_{11d}\supset\frac{1}{2\kappa_{11}^2}\int \mathrm{d}^{11}x\; e\,\frac{1}{960}F_{5,\,MNPQR}\,\bar\psi_S\,\Gamma^{[S|}\,\Gamma^{MNPQ}\,\Gamma^{|T]}\,\psi_T$$

$$\Big\downarrow S^1$$



$\sim \mathscr{V}^{1/6}$

(Independent of n)

Emergent Potentials

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$$S_{5d} \supset \frac{1}{4\kappa_5^2}\int \mathcal{V}_5^2\left(F_4^0\wedge\star F_4^0 + F_5^a\wedge\star F_5^a\right) \qquad R_5 = \mathcal{V}^{1/3}$$

$$\begin{array}{ccccc}
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C_6 & \xrightarrow{[\omega_a]} & C_4 & \xrightarrow{S^1} & C_3^a
\end{array}$$

Tower: $\psi_{3/2}^{(n_{X_3})}$ $\qquad \psi_{3/2}^{(n_{S^1})}$

$$\frac{1}{g^2_{C_3^0}} \sim -\mathcal{V}\Lambda_{\rm QG}^2\sum_{i=1}^{N}1 \sim -\mathcal{V}\,N\Lambda_{\rm QG}^2 \sim -\frac{1}{\kappa_4^2}\mathcal{V}$$

Emergent Potentials

-Type II on a CY threefold-

- 4d EFT: $S_{4d} \supset \frac{1}{4\kappa_4^2}\int e^{-4\phi_4}\,\mathcal{V}\left(F_4^0\wedge\star F_4^0 + \frac{1}{\mathcal{V}^{2/3}}\,F_4^a\wedge\star F_4^b\right)$ $\qquad e^{\phi_4} = \frac{e^{\phi}}{\sqrt{\mathcal{V}}}$

$$S_{5d} \supset \frac{1}{4\kappa_5^2}\int \mathcal{V}_5^2\left(F_4^0\wedge\star F_4^0 + F_5^a\wedge\star F_5^a\right) \qquad R_5 = \mathcal{V}^{1/3}$$

$$\begin{tikzcd}
\boxed{\text{11d M-th}} \arrow[r, "X_3"] & \boxed{\text{5d M-th}} \arrow[r, "S^1"] & \boxed{\text{4d type IIA}} \\
C_3 \arrow[r] & C_3 \arrow[r] & C_3^0 \\
C_6 \arrow[r, "{[\omega_a]}"] & C_4 \arrow[r, "S^1"] & C_3^a
\end{tikzcd}$$

Tower: $\quad \psi_{3/2}^{(n_{X_3})} \qquad \psi_{3/2}^{(n_{S^1})}$

$$\frac{1}{g_{C_3^0}^2} \sim -\mathcal{V}\Lambda_{\rm QG}^2\sum_{i=1}^{N} 1 \sim -\mathcal{V}\,N\Lambda_{\rm QG}^2 \sim -\frac{1}{\kappa_4^2}\mathcal{V}$$

$$\frac{1}{g_{C_3^a}^2} \sim -\mathcal{V}^{1/3}\Lambda_{\rm QG}^2\sum_{i=1}^{N} 1 \sim -\mathcal{V}^{1/3}\,N\Lambda_{\rm QG}^2 \sim -\frac{1}{\kappa_4^2}\mathcal{V}^{1/3}$$

Other Results

- Computations of species scale in all other 10d string theories $\longrightarrow$ Emergent dilaton metrics for stringy tower

- 6d F-theory on elliptically fibered CY_3 $\longrightarrow$ Emergent gauge kinetic function from emergent string limit (D3 on 2-cycle dual to weakly coupled heterotic string)

  [Lee, Lerche, Weigand '18]

Other Results

- Computations of species scale in all other 10d string theories ⟶ Emergent dilaton metrics for stringy tower

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  [Lee, Lerche, Weigand '18]

Summary

- Species scale as QG cutoff ⟶ Need to characterize **all the towers** in the EFT

- Careful analysis of light objects and their corresponding **field content**

- **Emergent kinetic terms** obtained for scalars and also p-forms (including (d-1)-forms ⟶ Potentials)

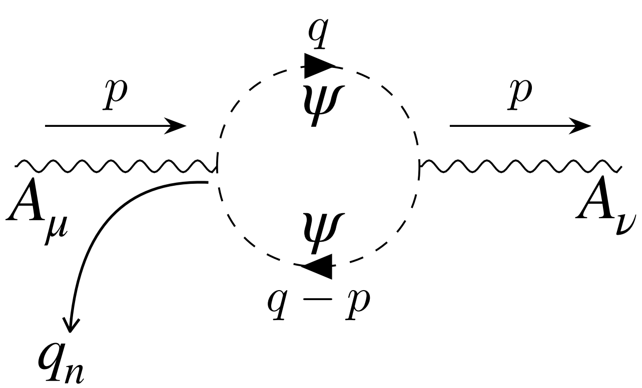
شكراً جزيلاً
ngiyabonga
рахмат
danke
謝謝
Баярлалаа
teşekkür ederim
spas
mersi
kia ora
barka
welalin
tack
спасибо
faafetai lava
vinaka
спасибі
blagodaram
dank je
misaotra
matondo
paldies
grazzi
mahalo
tapadh leat
kiitos
dankie
nandri
nanni
dhanyavad
thank you
gracias
хвала
asante
manana
obrigada
tenki
bedankt
bayarlalaa
gràcie
hvala
mauruuru
köszönöm
akun
dankon
aciū
djiere dieuf
tau
mochchakkeram
murakoze
enkosi
dziękuję
дякую
mamnun
chokrane
chnorakaloutioun
gratias ago
gràcies
sulpáy
go raibh maith agat
sobodi
dėkuji
sagolun
sukriya
kop khun krap
taiku
obrigado
mèsi
didi madloba
arigatô
takk
dakujem
trugarez
najis tuke
ありがとう
tanemirt
grazie
rahmet
kam sah hamnida
rahmat
terima kasih
ευχαριστώ
diolch
dhanyavadagalu
shukriya
mercé
мерси
xièxie
তোমাকে ধন্যবাদ
감사합니다
merci

Backup slides

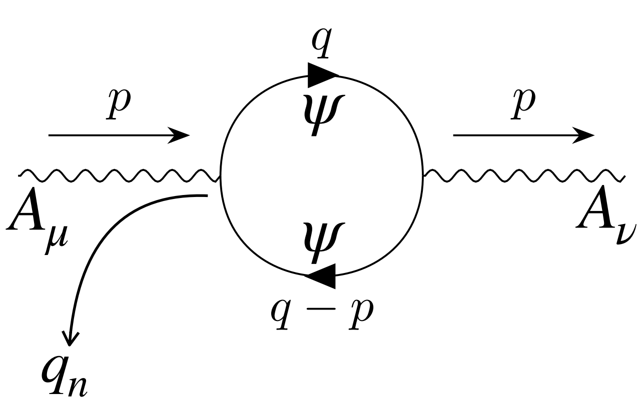
Emergence

-Loop corrections-

$$\frac{1}{g_{IR}^2} \sim \cancel{\frac{1}{g_{UV}^2}} + \frac{1}{g_{\text{tower}}^2}$$



$$\left.\frac{1}{g}\right|_n \sim -\frac{2q_n^2\delta^{\mu\nu}}{6}\int \frac{d^d\ell}{(2\pi)^d}\frac{4}{d}\frac{\ell^2}{\left(\ell^2+m_n^2\right)^3}$$



$$\left.\frac{1}{g}\right|_n \sim --\frac{2^{d/2}q_n^2\,\delta^{\mu\nu}}{6}\int d^d\ell\left(\frac{3}{\left(\ell^2+m_n^2\right)^2} - \frac{4}{d}\frac{\ell^2}{\left(\ell^2+m_n^2\right)^3}\right) \rightarrow \begin{cases} \sim -2q_n^2\,\delta_{\mu\nu}\,\Lambda^{d-4} & d>4 \\ \sim -q_n^2\,\delta_{\mu\nu}\,\log\left(1+\frac{\Lambda^2}{m_n^2}\right) & d=4 \\ \sim -2^{\frac{d-2}{2}}\mu_n^2\;m_n^{d-4} & d<4 \end{cases}$$