Gravitinos, Modulinos & Neutrinos

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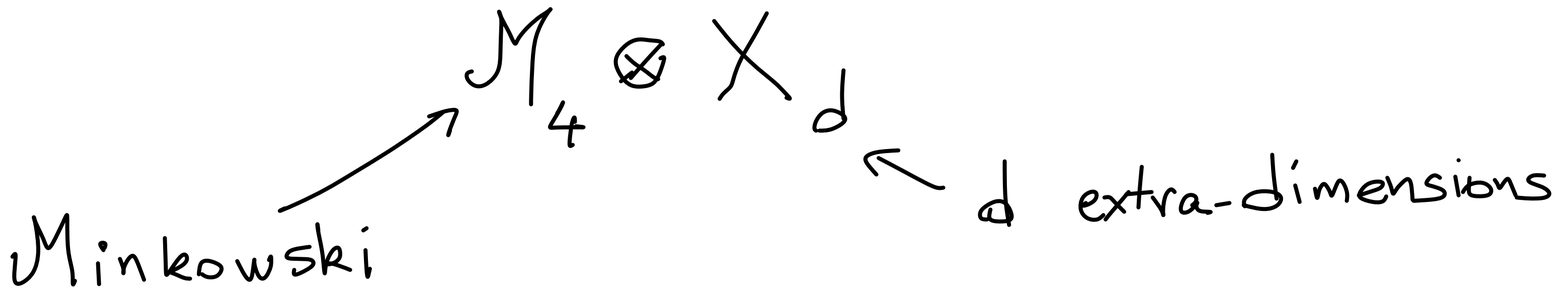
Part based on:

L. Anchordoqui, I. Antoniadis, K-B., J. Cunat, D. Lüst, JHEP 2024

Corfu, September 5th, 2024

Let's consider a space-time



SUGRA in $d+4$ $\longrightarrow$ $N=1$ in 4 dimensions

We will discuss: gravitino & fermion masses

Phenomenological relevance $\longrightarrow$ SUSY must be broken

Supergravity : gravitino $\xrightarrow[\text{SUSY}]{}$ mass $m_{3/2}$

We assume that the supersymmetric theory has

massless fields singlet under the gauge symmetry

$\rightarrow$ moduli

SUSY breaking $\longrightarrow$ masses for the scalar moduli

masses for the fermion **modulinos**

$$G = K + \ln |W|^2$$

Fermion masses

$$(M_f)_{\alpha\beta} = e^{G/2} \left[G_{\alpha\beta} - G_{\alpha\beta\bar{\gamma}} G^{\bar{\gamma}} + \frac{1}{3} G_\alpha G_\beta \right]$$

$$G_\alpha = \frac{\partial G}{\partial z^\alpha} \; ; \quad G_{\bar{\alpha}} = \frac{\partial G}{\partial \bar{z}^\alpha} \; ; \quad G^{\bar{\gamma}} = G_\alpha G^{\alpha\bar{\gamma}} \; ; \quad G^{\alpha\bar{\beta}} G_{\beta\bar{\gamma}} = \delta^\alpha_\gamma$$

$\langle e^{G/2} \rangle = m_{3/2}$ is the gravitino mass

Typically, we get $M_f \sim m_{3/2}$

...

Gravitino Swampland Conjecture

$\Rightarrow$ $m_{3/2}$ can NOT be arbitrarly small

$m_{3/2} \to 0$ $\Rightarrow$ tower of states have mass $\to 0$

$\Downarrow$

EFT no more valid

Gravitino Swampland Conjecture:

$m_{3/2}$ can NOT be arbitrarily small:

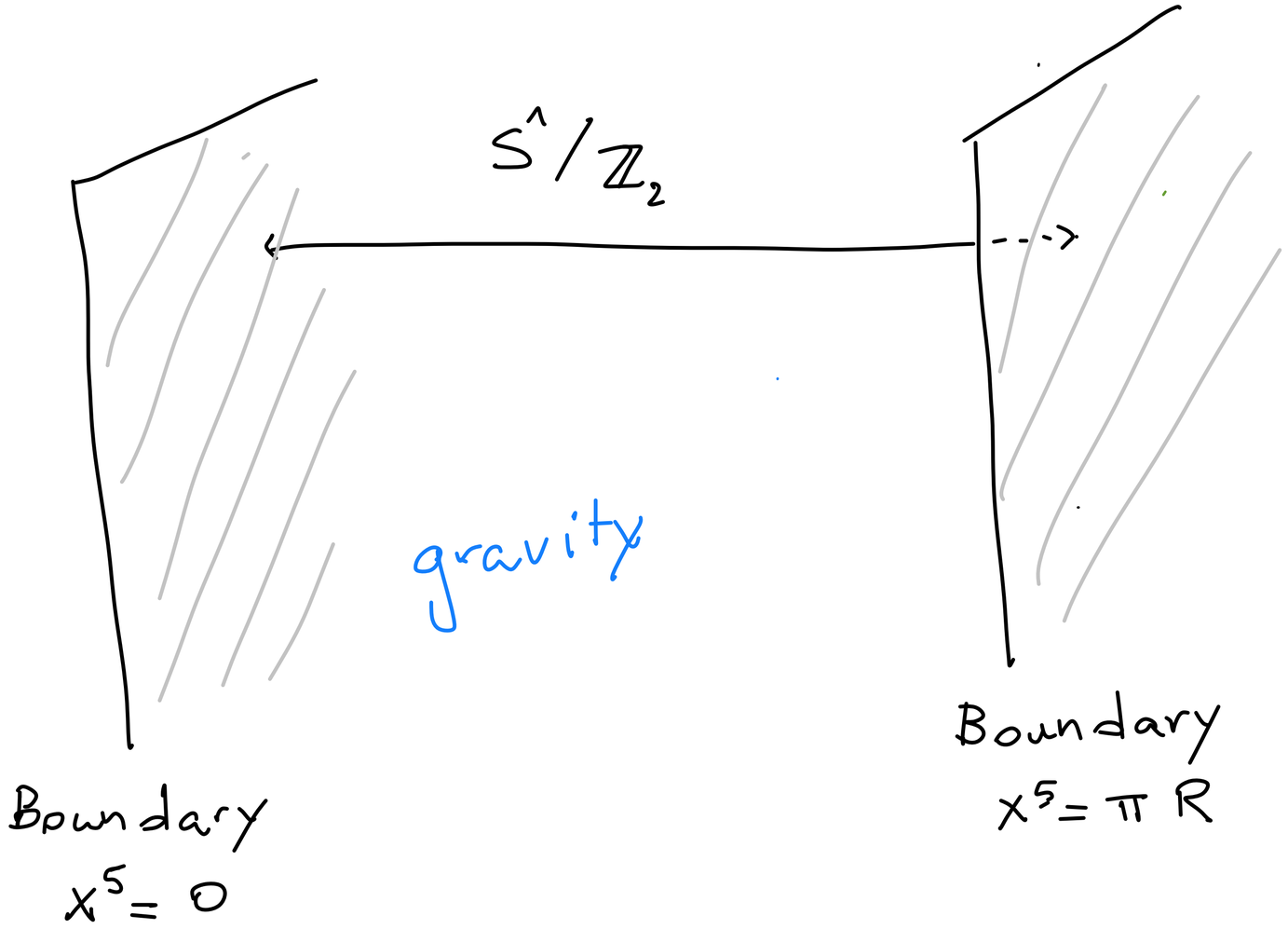
$m_{3/2} \to 0 \Rightarrow$ Infinite tower with masses $\to 0$

EFT no more valid

Antoniadis-Bachas-Lewellen-Tomaras

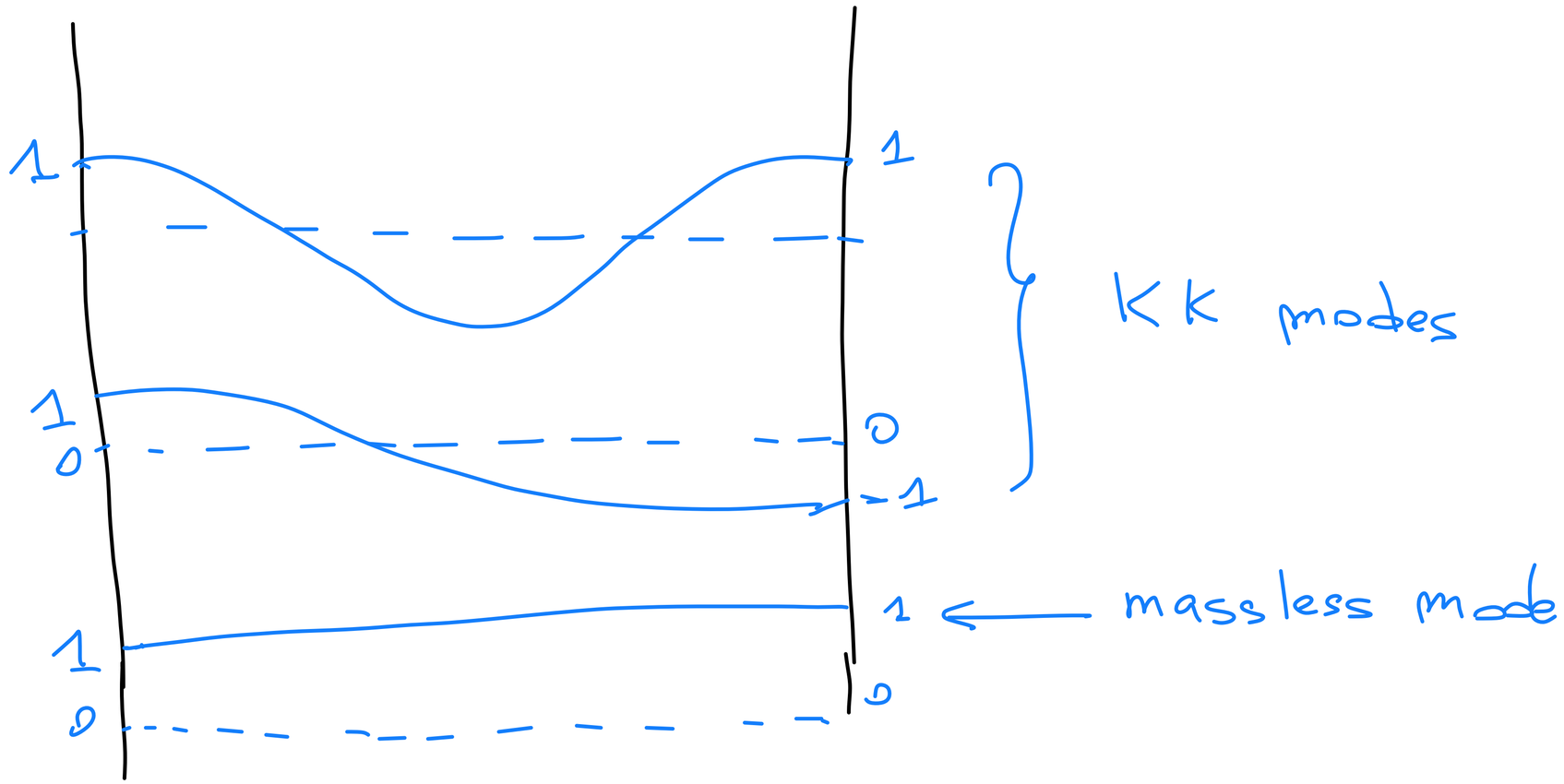
Cribiori-Lust-Scalisi

One extra-dimension



KK modes of the gravitino

SUSY



Let's break SUSY as a deformation of our previous set-up

two scenari:

① Non-periodic boundary conditions

② Some dynamics on the boundary

Two usual scenari to break SUSY:

① Non-trivial boundary conditions

② Dynamics on the brane

① Non-periodic condition for the gravitino

$$\rightarrow \quad m_{3/2} = \frac{\alpha}{R} \qquad 0 < \alpha \leq \frac{1}{2}$$

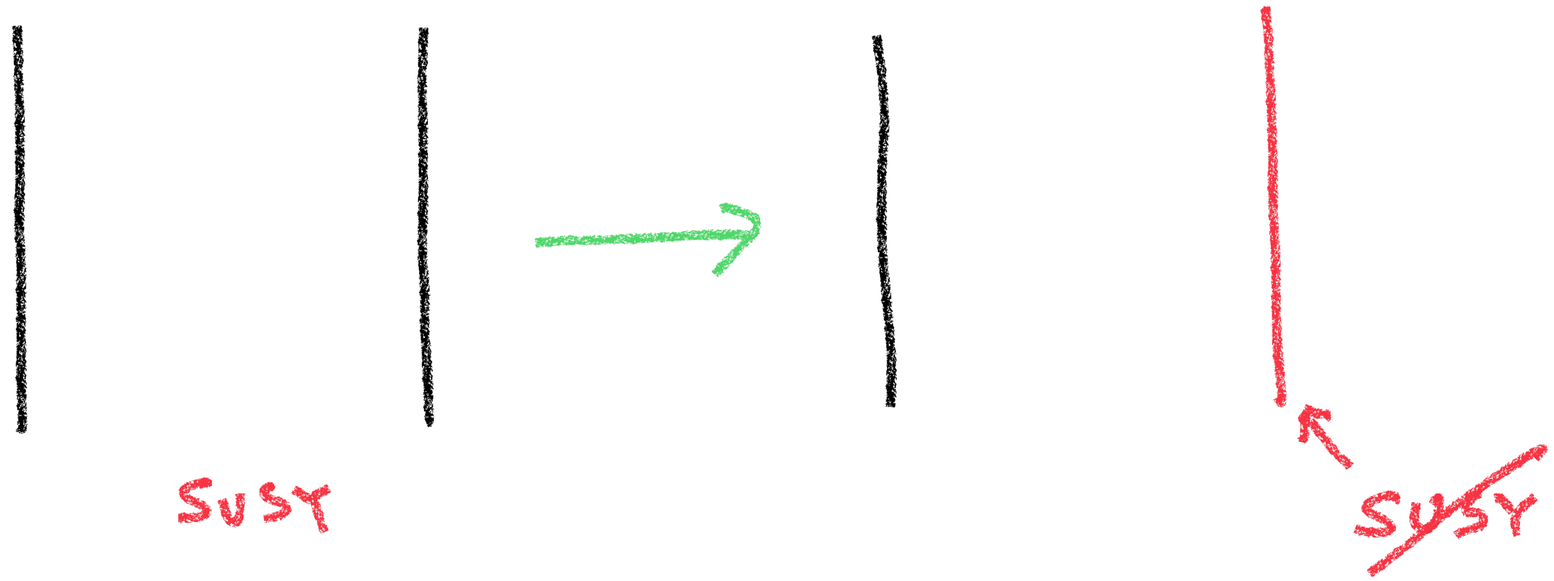
Scherk - Schwarz mechanism

Gravitino Swampland Conjecture $\Longrightarrow$ α not arbitrarily small

⊛ Note also that $m_{3/2}$ is of order of KK scale

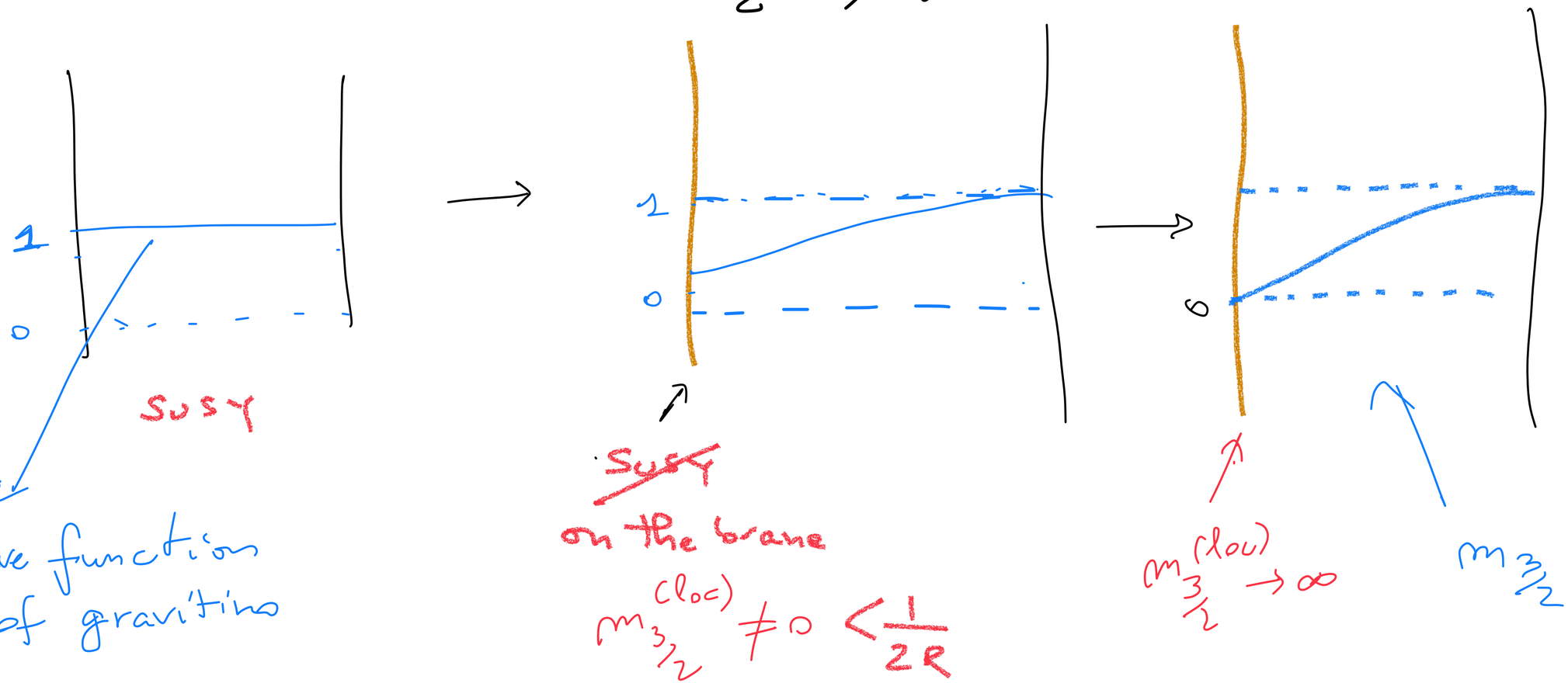
$$\left(m_{3/2} < \frac{1}{R} \right)$$

② Breaking SUSY on the boundary:



what is the mass of the gravitino?

$$\mathcal{L} \longrightarrow \mathcal{L} + \delta(x^5)\, m_{3/2}^{(loc)}\, \bar{\psi}_\mu \psi^\mu$$



Wave function of gravitino

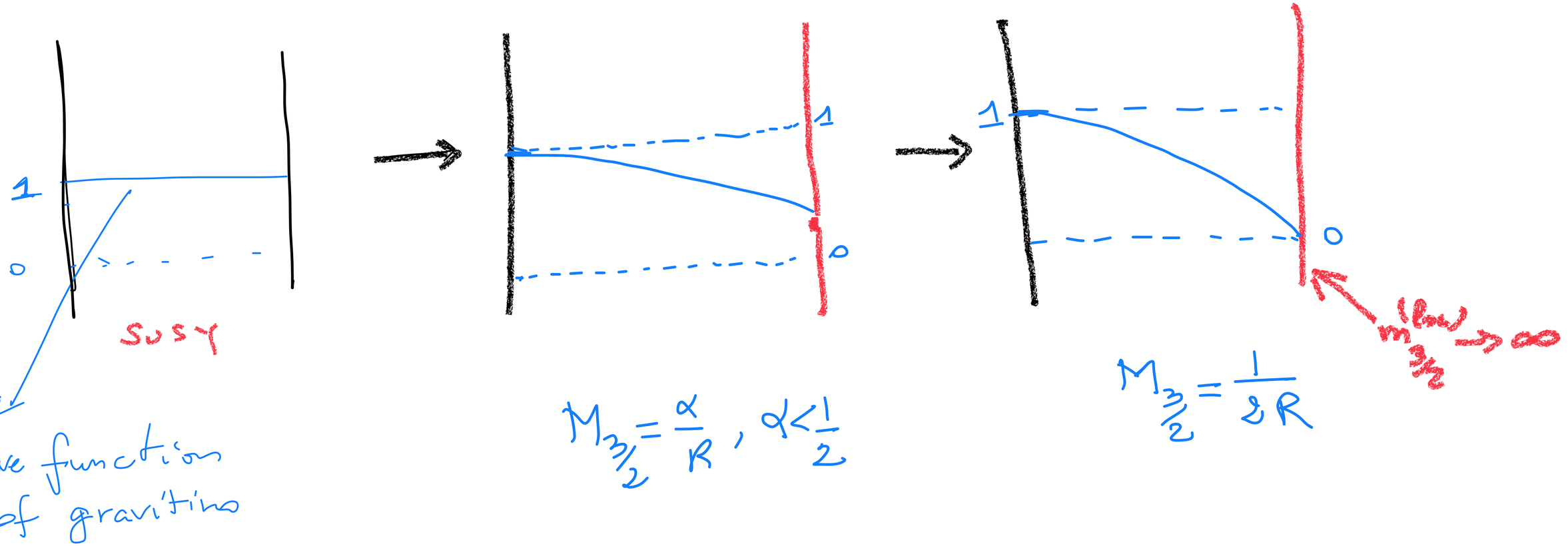
$m_{3/2}^{(loc)} \neq 0 < \frac{1}{2R}$

$m_{3/2}^{(loc)} \to \infty$

$m_{3/2} \to \frac{1}{2R}$

Note gravitino mass is bounded by m_{KK}

$$\mathcal{L} \longrightarrow \mathcal{L} + \delta(x^5 - \pi R)\, m_{3/2}^{(loc)}\, \bar{\psi}^{\mu}\psi_{\mu}$$



Note: The gravitino mass is of order of KK scale

The gravitino mass formula:

$$M_{3/2} = \left[n + \frac{1}{\pi} \arctan \left[\frac{4\pi R \, m_{3/2}^{(loc)}}{\pi^2 R^2 \, m_{3/2}^{(loc)\,2} + 4} \right] \right] \frac{1}{R}$$

Note: $M_{3/2}$ always smaller than the KK scale

For the case of many dimension, the generalization would be:

The gravitino wave-function spreads such that:

$$M_{3/2} < m_{KK}^{(1)}$$

$m_{KK}^{(1)}$ the lightest KK mode in the direction where SUSY is broken

Modulino mass

- Let's stay with the $S^1/\mathbb{Z}_2$ example
- We consider the case of Scherk-Schwarz breaking with $\alpha = \frac{1}{2}$
- This can be realized in superstrings

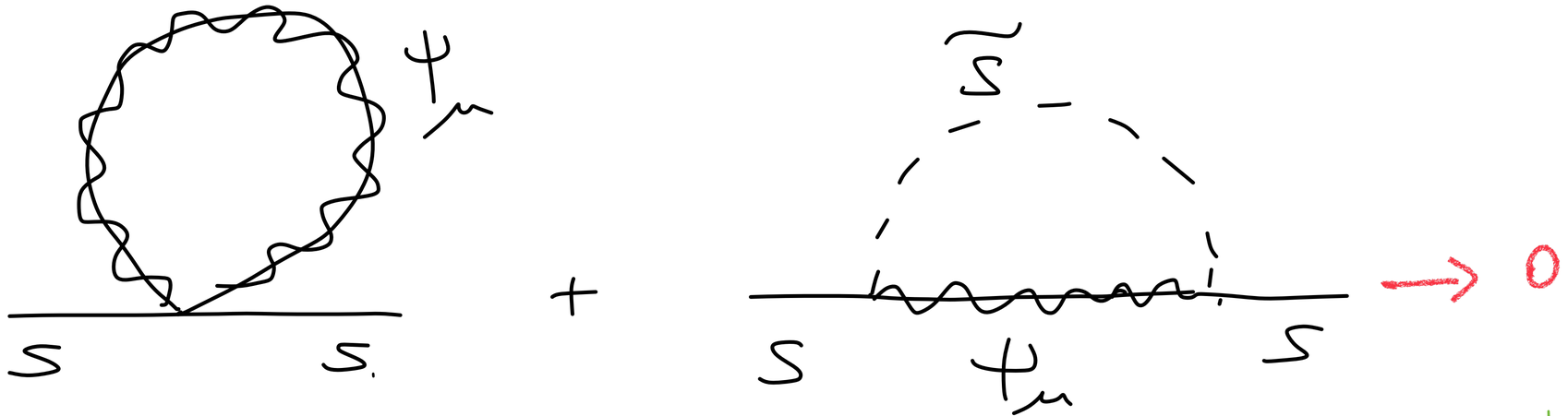
$$M_{3/2} = \frac{1}{2R}$$

Not described by 4D N=1 SUGRA

What is the expected size for fermion states localized on the boundary (modulino on boundary)

* Bulk: gravitino $M_{3/2} = \frac{1}{2R}$

* Boundary modulino $M_f = ?$



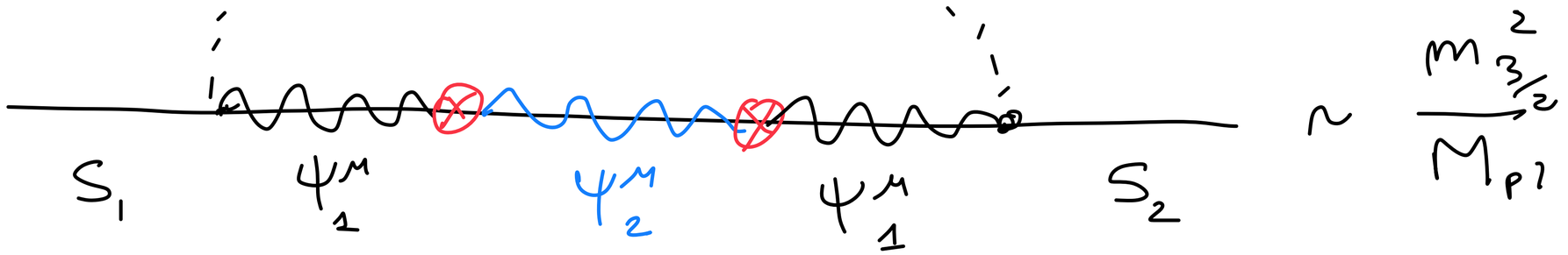
Gherghetta – Riotto
Antoniadis-KB-Quiros

Two issues:

① There is an R-symmetry restored @ $\alpha = \frac{1}{2}$

$\Rightarrow$ No Majorana masses

② There are two gravitini, so you can get a Dirac mass



$\sim \frac{m^2_{3/2}}{M_{Pl}}$

We can get a modulino of mass:

$$M_f \sim m_{3/2}$$

or

$$M_f \sim \frac{m_{3/2}}{M_p}$$

What about coupling to matter

Two possibilities:

$$M_f \sim m_{3/2}$$

or

$$M_f \sim \frac{m_{3/2}^2}{M_P}$$

Neutrino-modulino oscillations

K.B. Y. Smirnov

Anchordoqui – Antoniadis – K.B. – Cunat – List

Sterile neutrino of mass ~ 50 eV can be detected by FPF @ CERN

For $m_{3/2} = \frac{1}{2R} \sim 250$ TeV

$\rightarrow \frac{m_{3/2}^2}{M_{Pl}} \sim 50$ eV $\Longrightarrow$ Modulino = sterile neutrino?

$\rightarrow \propto m_{3/2} \rightarrow$ "MSSM" states @ few TeV

↑ "gauge coupling"

(gaugino mediation from $x^5 \rightarrow \mathcal{M}_4$)

Such a small $m_{3/2}$ mass might also be obtained as

$$\sim \left(\frac{1}{2R}\right)^3 \frac{1}{M_s^2}$$

$$M_s \sim 3 \quad 10^9 \text{ GeV} \qquad \frac{1}{R} \sim 3 \quad 10^8 \text{ GeV}$$

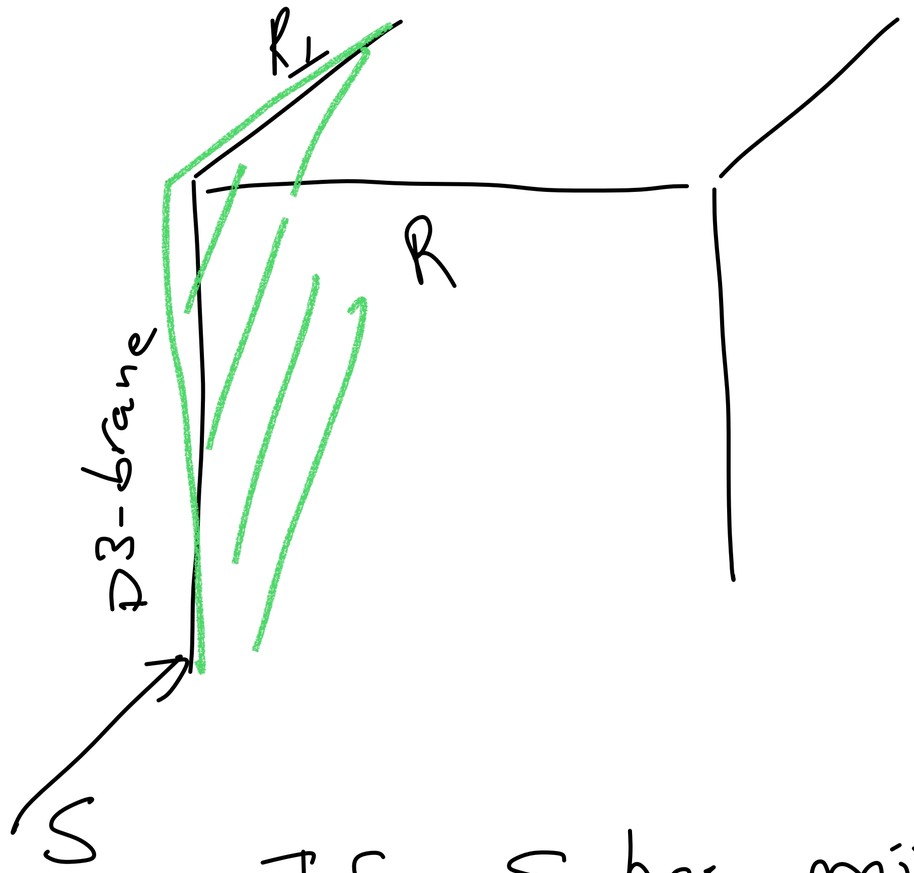
Modulino = sterile neutrino

IF

Modulino mixes with neutrino

Very model dependent

For sterile neutrino with mass < 10 keV
no strong constraints on mixing.



$\frac{1}{R_\perp} \sim eV$ Dark dimension

$\frac{1}{R} \sim 250\,TeV$

$M_s \sim 10^{10}\,GeV$

If S has mixing through

Yukawa coupling $\lambda S L H$?

1st possibility R-parity μ-term

$\mu L H$

$$\mu = m_{3/2} \frac{\langle S \rangle}{M_S} \alpha$$

- $m_{3/2}$: Giudice-Masiero mechanism
- $\frac{\langle S \rangle}{M_S}$: dependance on moduli
- α: coupling

Note that

$$\alpha \frac{m_{3/2}}{M_{Pl}} \sim \alpha \frac{1}{R} \frac{1}{R R_1 M_s^3}$$

$$\frac{1}{(R M_s)^2} \quad \frac{1}{R_1 M_s}$$

↖ Already there

Coupling to state in the x^5 dimension

$\Rightarrow$ ~~SUSY~~ not necessarily related to mixing

$$\propto \frac{m_{3/2}}{M_{Pl}} SLH \Rightarrow \propto \frac{m_{3/2}\langle H \rangle}{M_{Pl}} SL$$

$\Rightarrow$ mixing of order 0.1

$\Rightarrow$ The range of mass & mixing that FPF will probe

Conclusions

* Upper bound on gravitino masses ?
  → Large volume scenario

* Modulinos are not subject of a lot of interest
  " $M_f \sim m_{3/2} \gg$ masses of interest "

* But M_f can be light and lead to new phenomena