Spin-One Top Quark Superpartners

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SUSY Breaking in AdS

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work in progress

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Overview

- Motivation
- Review of AdS/CFT
- Unexpected SUSY Spectra
- SUSY Breaking

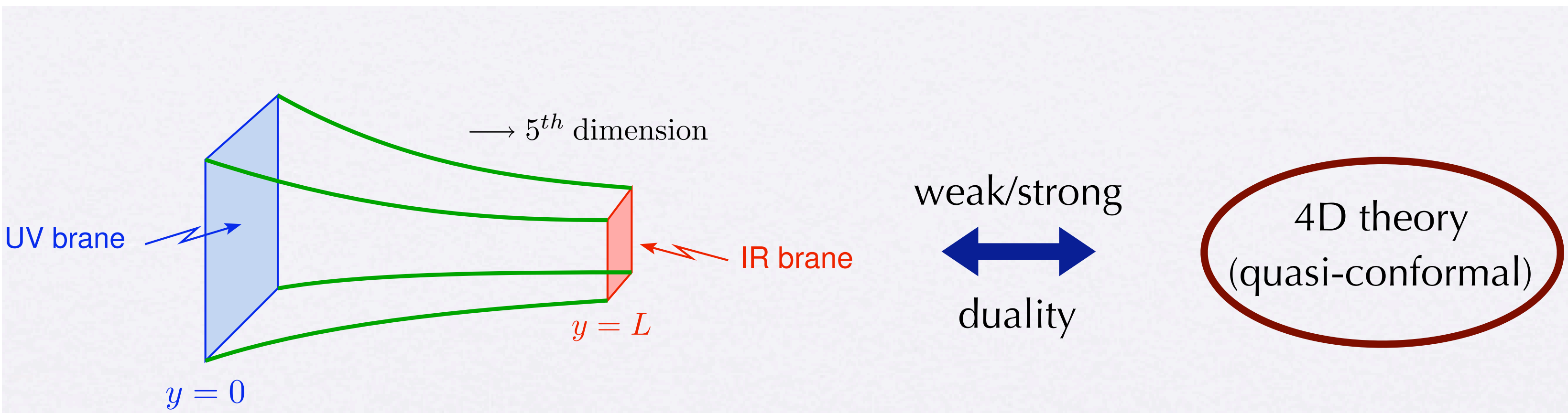
Motivation

The LHC is coming!

At a hadron collider, if you dont know precisely what you are looking for, you probably won't find it.

AdS/CFT

$$ds^2 = \frac{R^2}{z^2}\left(dx_\mu^2 - dz^2\right)$$



Maldacena

Randall, Sundrum

AdS/CFT

$$ds^2 = \frac{R^2}{z^2}\left(dx_\mu^2 - dz^2\right)$$

$$z > \epsilon$$

$$S_{bulk} = \frac{1}{2}\int d^4x\, dz \sqrt{g}(g^{\alpha\beta}\partial_\alpha\phi\partial_\beta\phi + m^2\phi^2)$$

$$\phi(p,z) = az^2 J_\nu(pz) + bz^2 J_{-\nu}(pz)$$

$$d[\mathcal{O}] = 2 \pm \nu = 2 \pm \sqrt{4 + m^2 R^2}$$

AdS/CFT

$$\phi(p,\epsilon) = \epsilon^{-\nu} R^{-3/2}\, \phi_0(p)$$

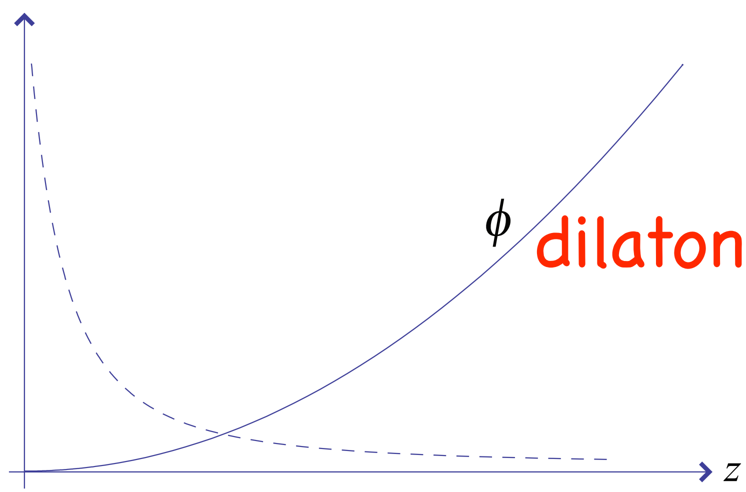
$$S = \frac{1}{2}\int d^4x\, dz\, \partial_z \left(\frac{R^3}{z^3} \phi \partial_z \phi \right)$$

$$S = \frac{1}{2}\int \frac{d^4p}{(2\pi)^4} \phi_0(-p)\phi_0(p) K(p)$$

$$K(p) = (2-\nu)\epsilon^{-2\nu} + b\, p^{2\nu} + c\, p^2 \epsilon^{2-2\nu} + \ldots$$

$$d = 2 \pm \nu$$

Soft-Wall



Karch, Katz, Son, Stephanov hep-ph/0602229
Gherghetta, Batell hep-th/0801.4383

AdS Gauge Fields

$$-\frac{1}{4g_5^2}\int_\epsilon^\infty d^4x\,dz\left(\frac{R}{z}\right)\Phi(z)F^{aMN}F^a_{MN}$$

dilaton: $\Phi(z) = e^{-mz}$

$$\frac{1}{g_4^2} = \frac{R}{g_5^2}\int_\epsilon^\infty \frac{e^{-mz}}{z} \approx \frac{R}{g_5^2}[-\gamma_E - \log(m\epsilon)]$$

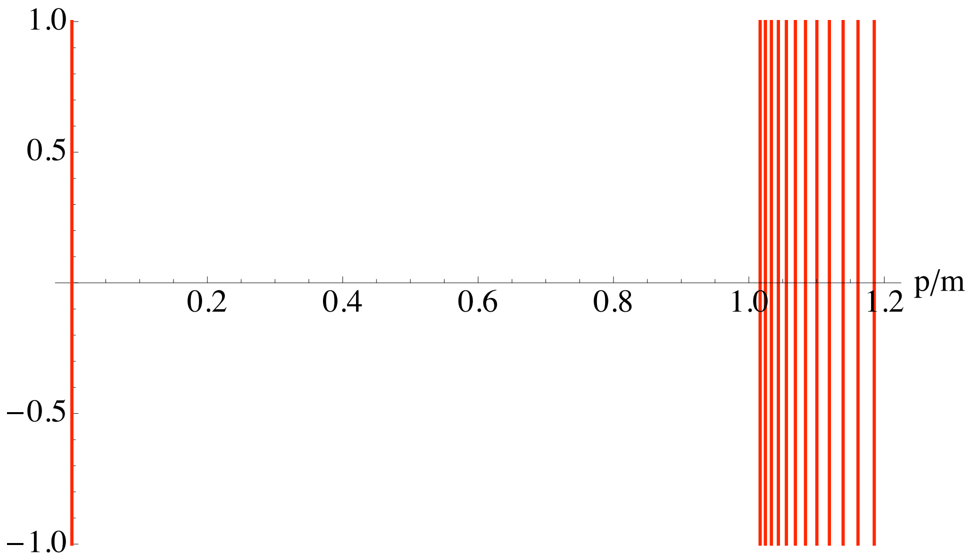
$$\frac{1}{g_4^2} \approx \frac{R}{g_5^2}\log\left(\frac{\Lambda_{UV}}{m}\right)$$

Cacciapaglia, Marandella, JT hep-ph/0804.0424

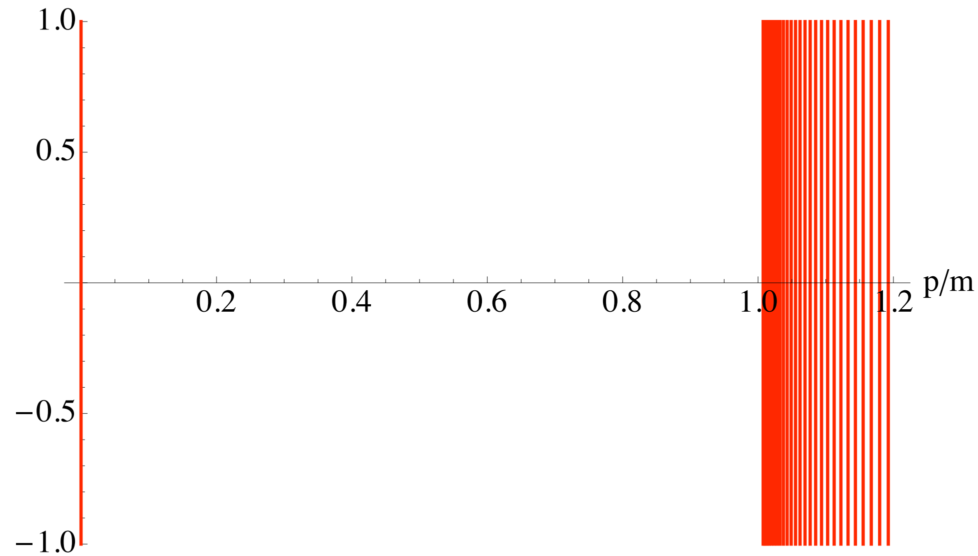
Gauge KK Modes

$$f''(z) - \left(m + \frac{1}{z}\right) f'(z) + p^2 f(z) = 0$$

spectrum



$z_{IR} = 100/m$



$z_{IR} = 200/m$

Cacciapaglia, Marandella, JT hep-ph/0804.0424

AdS/CFT Soft Wall

$$S_{int} = \frac{1}{2}\int d^4x\, dz\, \sqrt{g} H \phi\phi$$

$$H = \mu z^2$$

$$z^5 \partial_z \left(\frac{1}{z^3} \partial_z \phi \right) - z^2 (p^2 - \mu^2)\phi - m^2 R^2 \phi = 0$$

$$\langle \mathcal{O}(p')\mathcal{O}(p)\rangle \propto \frac{\delta^{(4)}(p+p')}{(2\pi)^4} (p^2 - \mu^2)^{d-2}$$

Massive Unparticle

$$\Delta(p,\mu,d) \equiv \int d^4x\, e^{ipx} \langle 0|T\mathcal{O}(x)\mathcal{O}^\dagger(0)|0\rangle|_\mu$$

$$= \frac{A_d}{2\pi}\int_{\mu^2}^{\infty} (M^2-\mu^2)^{d-2} \frac{i}{p^2-M^2+i\epsilon} dM^2$$

$$= i\frac{A_d}{2} \frac{\left(\mu^2-p^2-i\epsilon\right)^{d-2}}{\sin d\pi}$$

$$\Delta(p,\mu,1) = \frac{i}{p^2-\mu^2+i\epsilon}$$

Fox, Rajaraman, Shirman hep-ph/0705.3092

Unparticles

Georgi:

* a different way to calculate in CFT's

* phase space looks like a fractional number of particles

Georgi hep-ph/0703260, 0704.2457

unparticle phase space

$$d\Phi(p,d) = A_d\,\theta\left(p^0\right)\,\theta\left(p^2\right)\,\left(p^2\right)^{d-2}$$

$$d\Phi(p,1) = 2\pi\,\theta\left(p^0\right)\,\delta(p^2)$$

Quarks are Unparticles

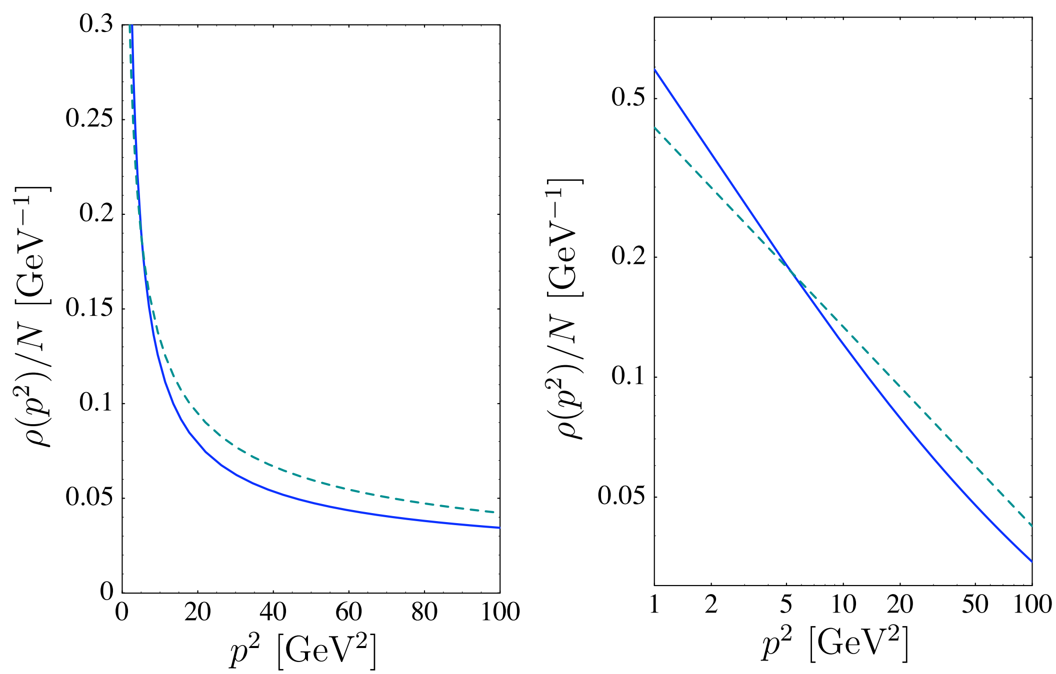


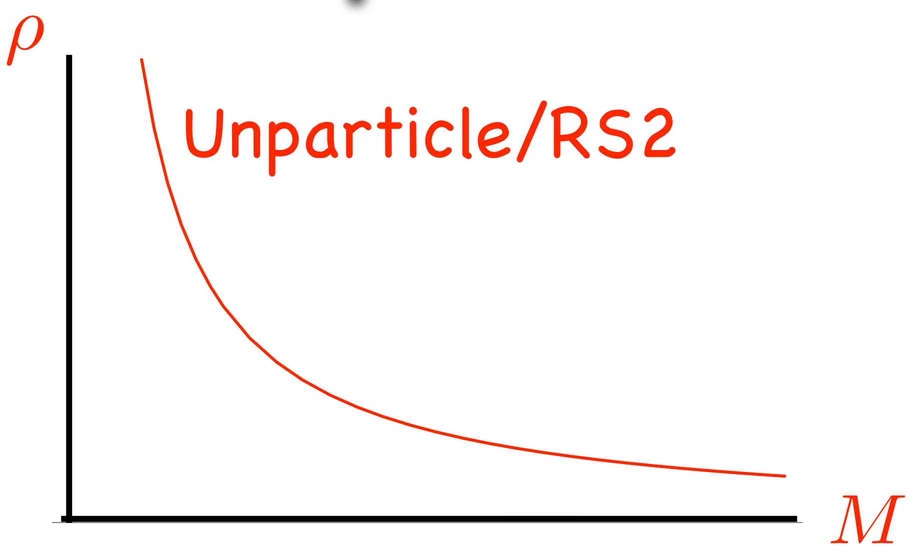
FIG. 1. Comparison of the unparticle spectral density (2) (dashed) and the spectral density (9) of a massless quark jet at next-to-leading order in QCD (solid). We use parameters $M = 10\,\text{GeV}$ and $\eta = 0.5$. The right plot shows the same results on logarithmic scales.

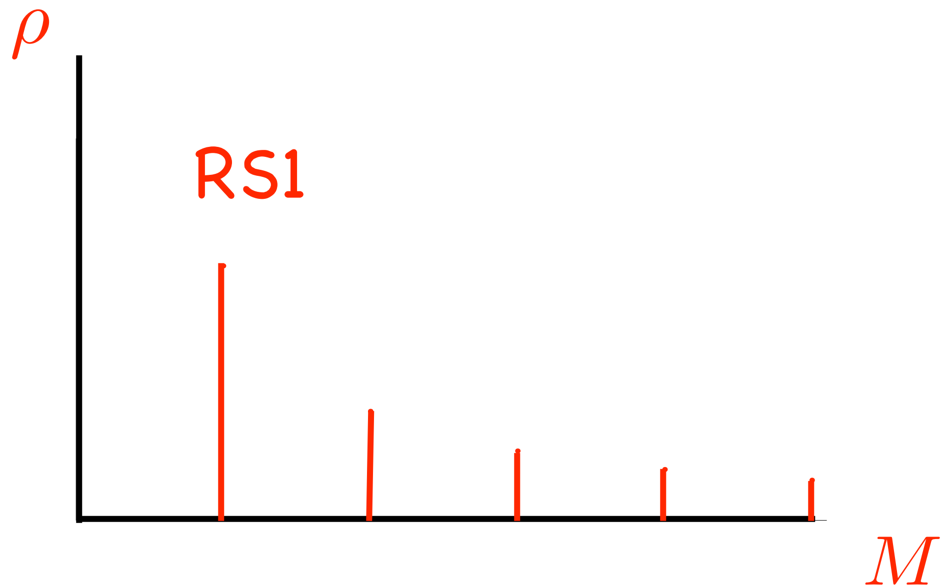
Neubert hep-ph/0708.0036

Why (broken) CFT's are Interesting

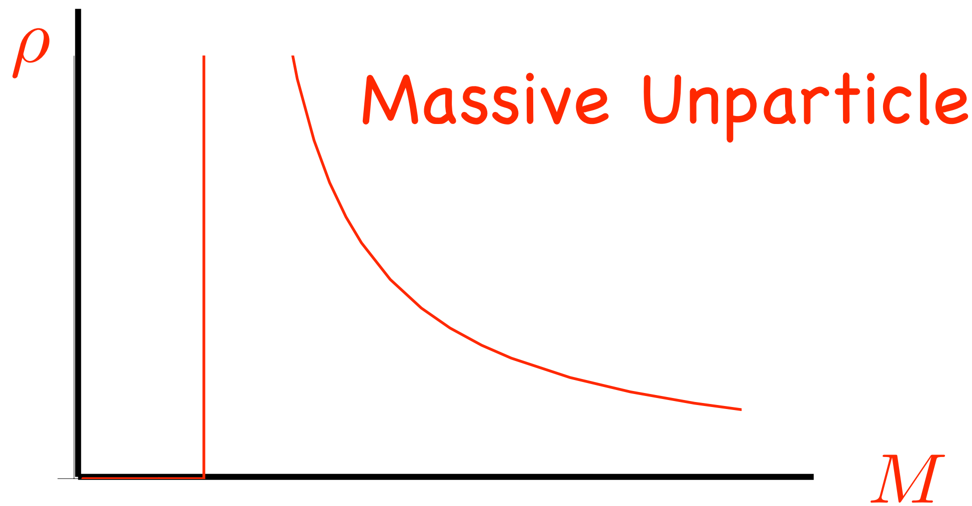
* unparticles are equivalent to RS2
* IR cutoff at TeV turns RS2 to RS1
* a new type of IR cutoff could lead to new phenomenology for LHC

Spectral Densities





$$\Delta(p) \sim (\mu^2 - p^2 - i\epsilon)^{d-2}$$



Bulk SUSY

$$S \;=\; \int d^4x\,dz \left\{ \int d^4\theta \left(\frac{R}{z}\right)^3 [\Phi^*\,\Phi + \Phi_{\,c}\,\Phi_c^*] + \right.$$

$$\left. + \int d^2\theta \left(\frac{R}{z}\right)^3 \left[\frac{1}{2}\,\Phi_c\,\partial_z\Phi - \frac{1}{2}\,\partial_z\Phi_c\,\Phi + m(z)\frac{R}{z}\,\Phi_c\,\Phi\right] + h.c.\right.$$

Marti, Pomarol hep-th/0106256

SUSY CFT

$$S = \int d^4x\, dz \left\{ \int d^4\theta \left(\frac{R}{z}\right)^3 [\Phi^* \Phi + \Phi_c \Phi_c^*] + \right.$$

$$\left. + \int d^2\theta \left(\frac{R}{z}\right)^3 \left[\frac{1}{2}\,\Phi_c\,\partial_z\Phi - \frac{1}{2}\,\partial_z\Phi_c\,\Phi + m(z)\frac{R}{z}\,\Phi_c\,\Phi\right] + h.c.\right.$$

$$m(z) = c$$

$$d_s = \frac{3}{2} - c$$

$$d_f = 2 - c$$

Cacciapaglia, Marandella, JT hep-th/0802.2946

Components

$$\Phi = \{\phi, \chi, F\}$$
$$\Phi_c = \{\phi_c, \psi, F_c\}$$

$$\partial_\mu \partial^\mu \phi + \partial_z F_c^* - \left(\frac{3}{2} + m(z)R\right) \frac{1}{z} F_c^* = 0$$

$$-i\bar{\sigma}^\mu \partial_\mu \bar{\psi} - \partial_z \chi + (m(z)R + 2)\frac{1}{z}\chi = 0$$

$$-i\sigma^\mu \partial_\mu \bar{\psi} + \partial_z \chi + (m(z)R - 2)\frac{1}{z}\chi = 0$$

$$F = \partial_z \phi_c^* - (\frac{3}{2} + m(z)R)\frac{1}{z}\phi_c^*$$

Components

$$\partial_\mu \partial^\mu \phi - \partial_z^2 \phi + \frac{3}{z}\, \partial_z \phi - (\partial_z m(z))\, \frac{R}{z} \phi$$

$$+ \left(m(z)^2 R^2 + m(z) R - \frac{15}{4} \right) \frac{1}{z^2}\, \phi = 0$$

Bulk Profiles

$$\chi(p,z) = \chi_4(p)\left(\frac{z}{z_{UV}}\right)^2 f_L(p,z) \qquad \phi(p,z) = \phi_4(p)\left(\frac{z}{z_{UV}}\right)^{3/2} f_L(p,z)$$

$$\psi(p,z) = \psi_4(p)\left(\frac{z}{z_{UV}}\right)^2 f_R(p,z) \qquad \phi_c(p,z) = \phi_{c4}(p)\left(\frac{z}{z_{UV}}\right)^{3/2} f_R(p,z)$$

Whittaker Functions

$$
\begin{aligned}
M_{k,j} &= z^{j+1/2} e^{-z/2} \sum_{n=0}^{\infty} \frac{\Gamma(j-k+1/2+n)\Gamma(2j+1)}{n!\Gamma(n-k+1/2)\Gamma(2j+1+n)} z^n \,, \\
W_{k,j} &= \frac{\Gamma(-2j)}{\Gamma(1/2-j-k)} M_{k,j} + \frac{\Gamma(2j)}{\Gamma(1/2+j-k)} M_{k,-j}
\end{aligned}
$$

In our case:

$$
k = -\frac{c\mu}{\sqrt{-p^2+\mu^2}} \qquad j = 1/2 \pm c
$$

Effective Potential

$$\mu > 0, \;\; c < 0$$

$$\frac{\partial^2}{\partial z^2} f_R + \left(p^2 - \mu^2 - 2\frac{\mu c}{z} - \frac{c(c-1)}{z^2} \right) f_R \quad = \quad 0$$

$$\frac{\partial^2}{\partial r^2} u + \left(2\mu E - 2\frac{\mu \alpha}{z} - \frac{\ell(\ell+1)}{z^2} \right) u \quad = \quad 0$$

$$\alpha = \ell = |c|$$

Two-Point Function

$$\Delta(p^2) = \left(\frac{R}{z_{UV}}\right)^3 \frac{f_L}{p f_R}$$

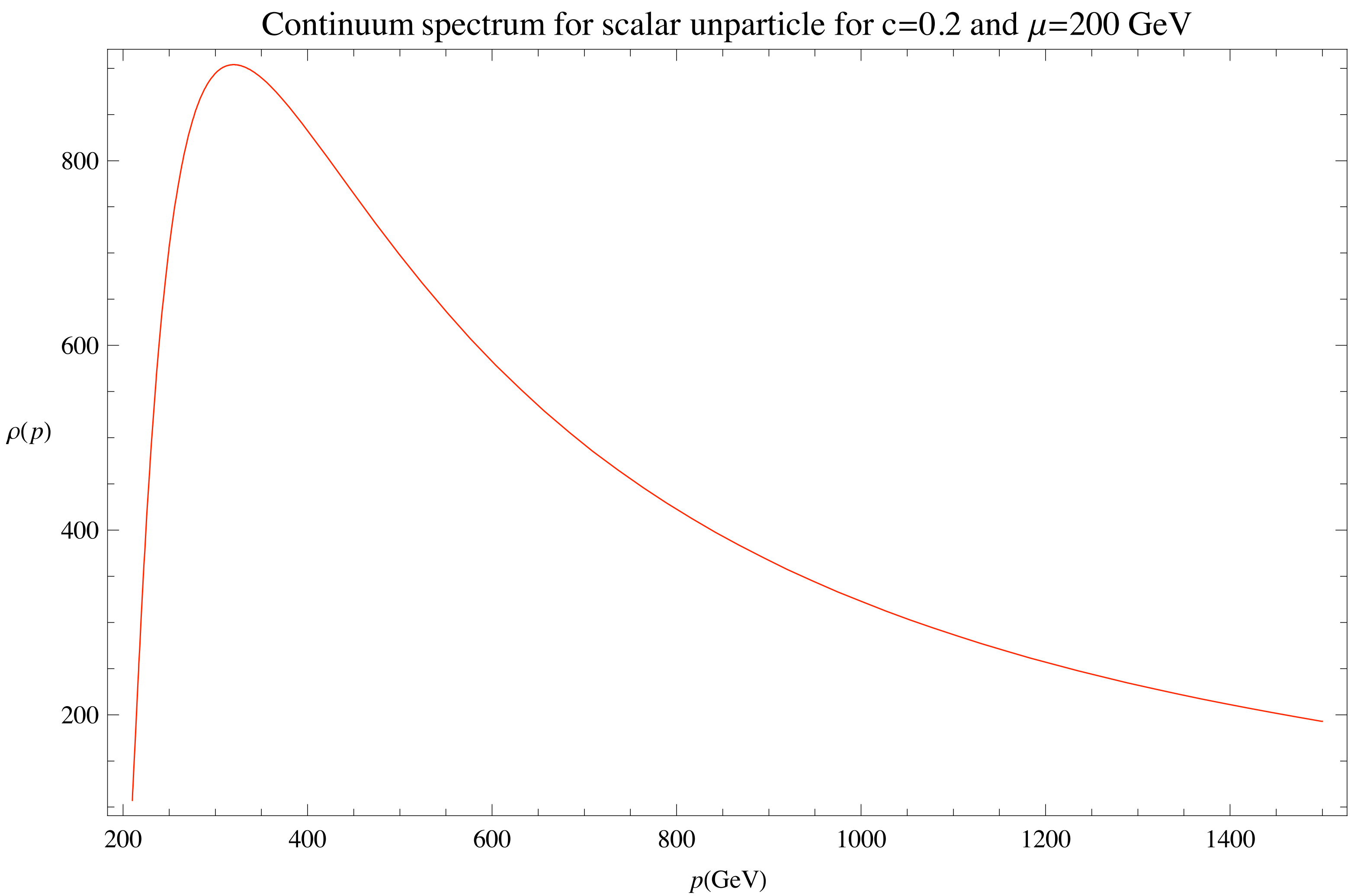
$$\Delta(p) = \frac{\epsilon(u + \sqrt{u^2 - p^2})}{p^2} \cdot \frac{W\left(-\frac{cu}{\sqrt{-p^2+u^2}}, \frac{1}{2} + c, 2\sqrt{-p^2 + u^2}\epsilon\right)}{W\left(-\frac{cu}{\sqrt{-p^2+u^2}}, \frac{1}{2} - c, 2\sqrt{-p^2 + u^2}\epsilon\right)}$$

Two-Point Function

$$\Delta(p) \approx -\frac{2^{1-2c}(-p^2+\mu^2)^{1/2-c}\epsilon^{1-2c}\Gamma(2c)\Gamma\left(1-c+\frac{c\mu}{\sqrt{-p^2+\mu^2}}\right)}{p^2\Gamma(1-2c)\Gamma\left(c+\frac{c\mu}{\sqrt{-p^2+\mu^2}}\right)}$$

discrete resonances below threshold
for c<0

Spectral Density



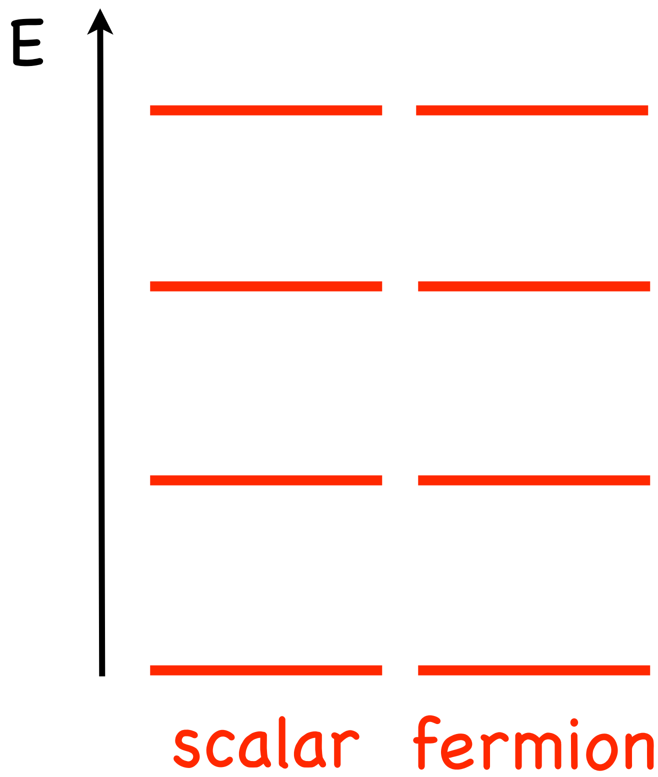
SUSY Breaking

$$\delta S = \frac{1}{2}\int d^4x \int dz \left(m^2/z_{UV} \cdot \phi^* \phi + h.c.\right)\delta(z - z_{UV})$$

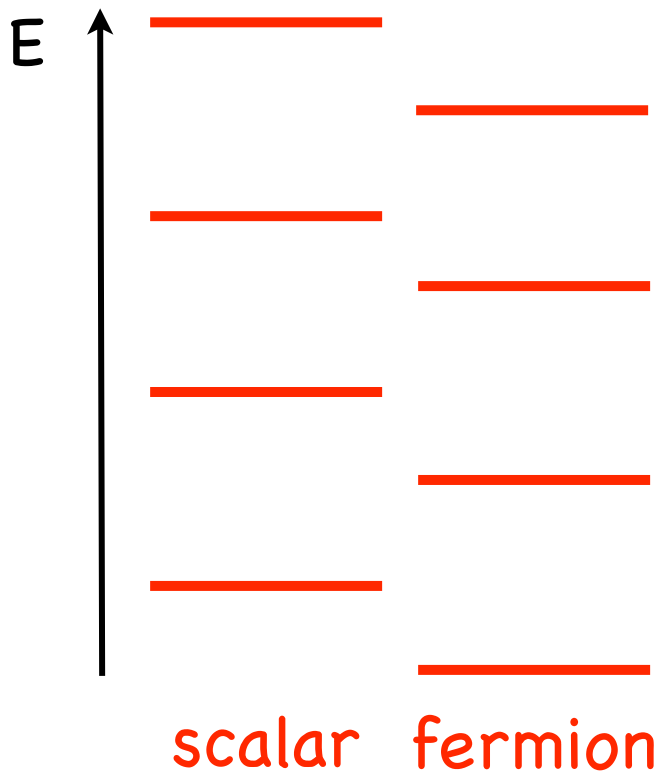
$$\Delta(p^2) = \left(\frac{R}{z_{UV}}\right)^3 \frac{f_L}{p f_R - (m^2/z_{UV}) f_L}$$

Scalar spectrum shifted up

KK Modes

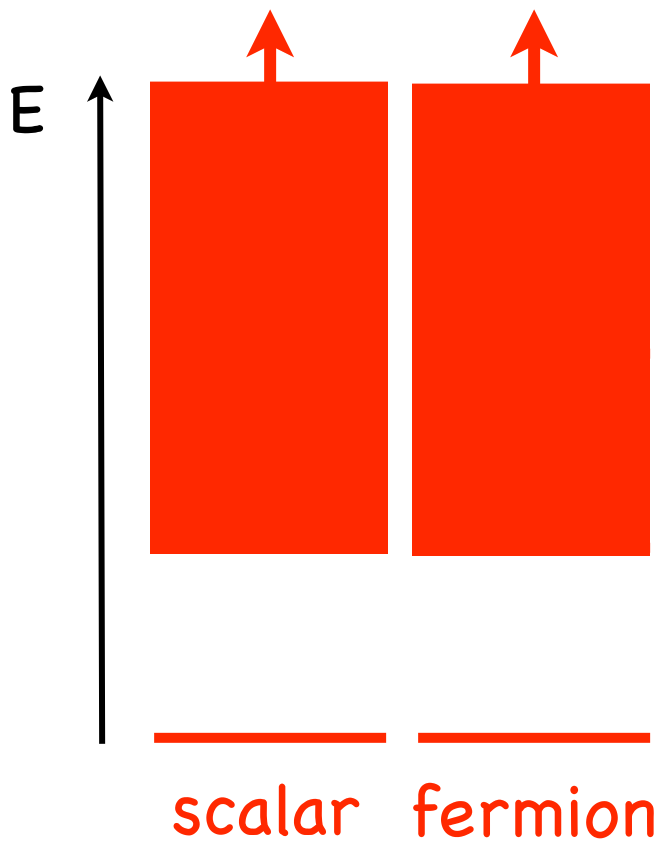


Scherk-Schwarz

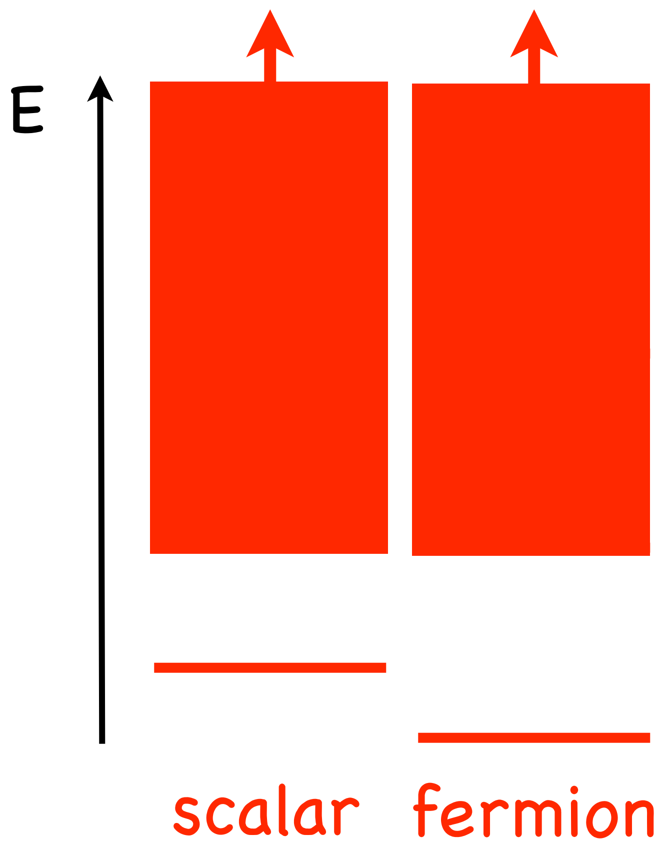


Phys. Lett. B82, 60 (1979)

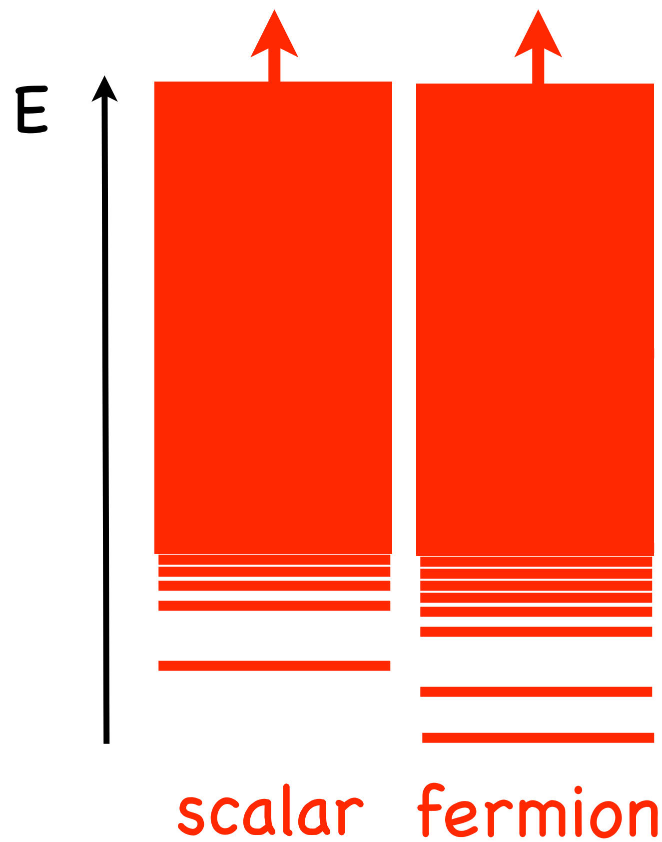
SUSY-CFT



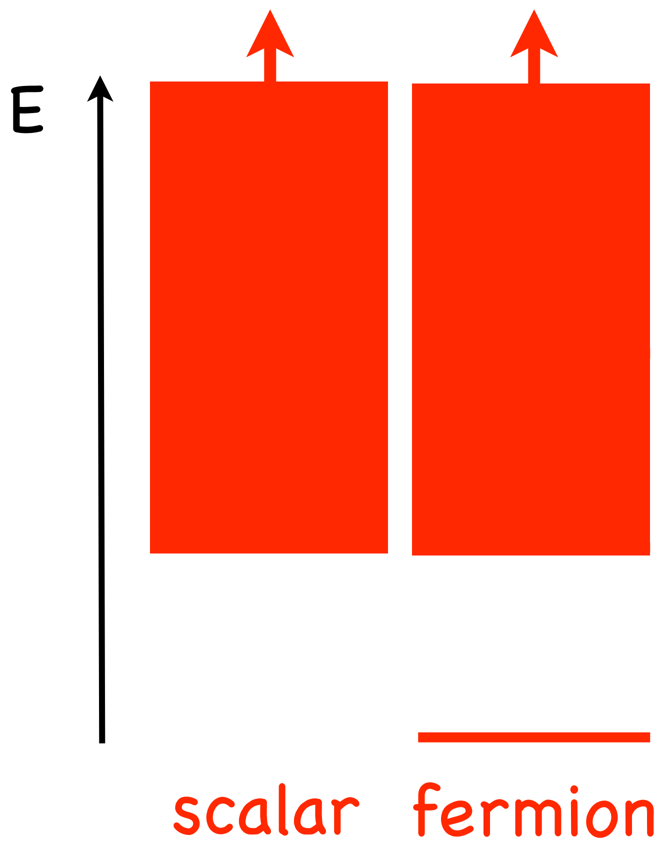
Broken SUSY-CFT



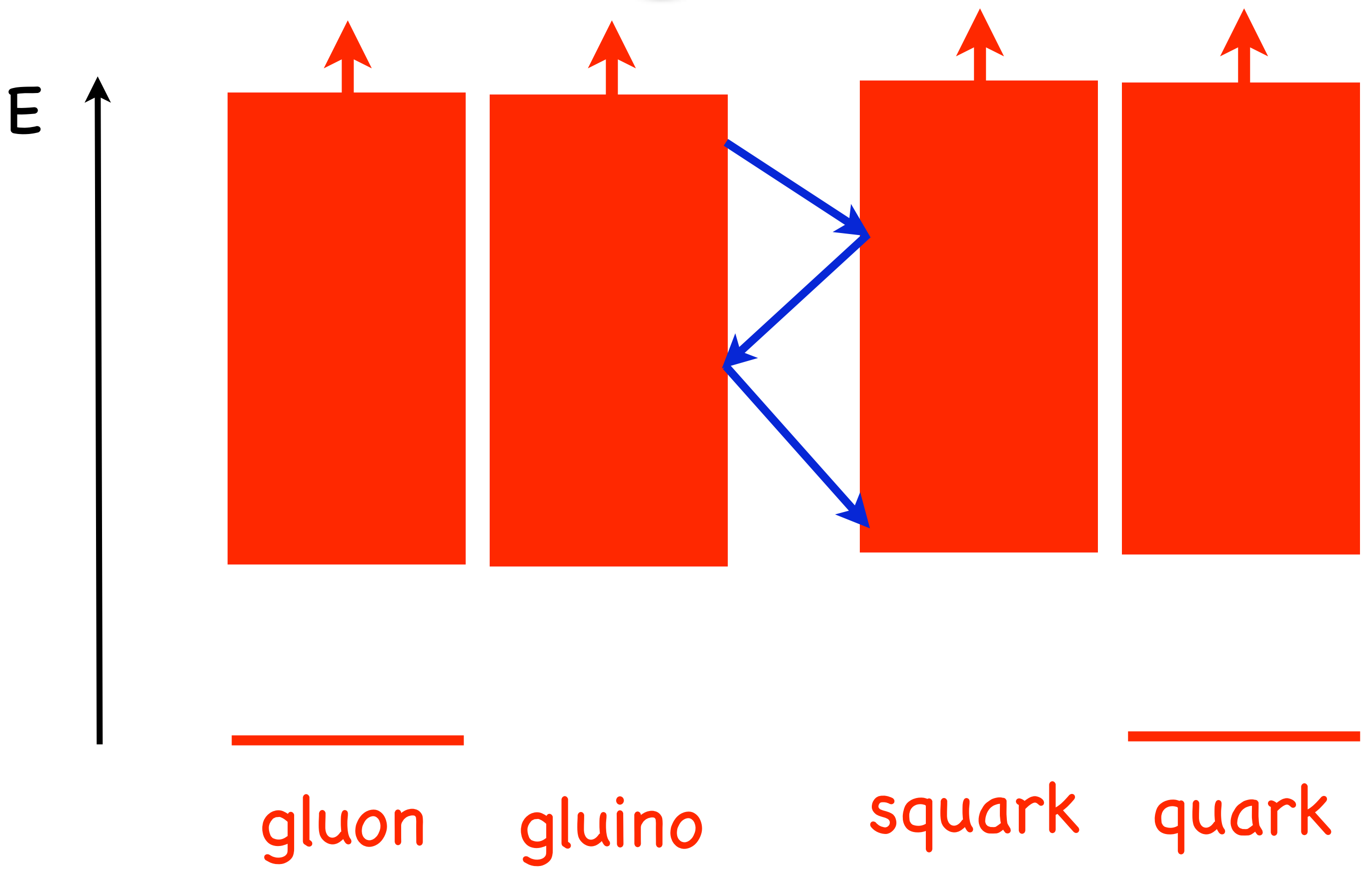
SUSY-Un-Partners



SUSY-Un-Partner



Decay Chains



Conclusions

There are new classes of SUSY spectra
that are entirely unexplored.

Are there models where SUSY breaking triggers
the gap and the splitting?