The Unhiggs

hep-ph/0708.0005, 0804.0424,
0807.3961

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Outline

* Unmotivation
* AdS/CFT/unparticle correspondence
* gauge interactions
* LEP & LHC

Hierarchy Problem Now

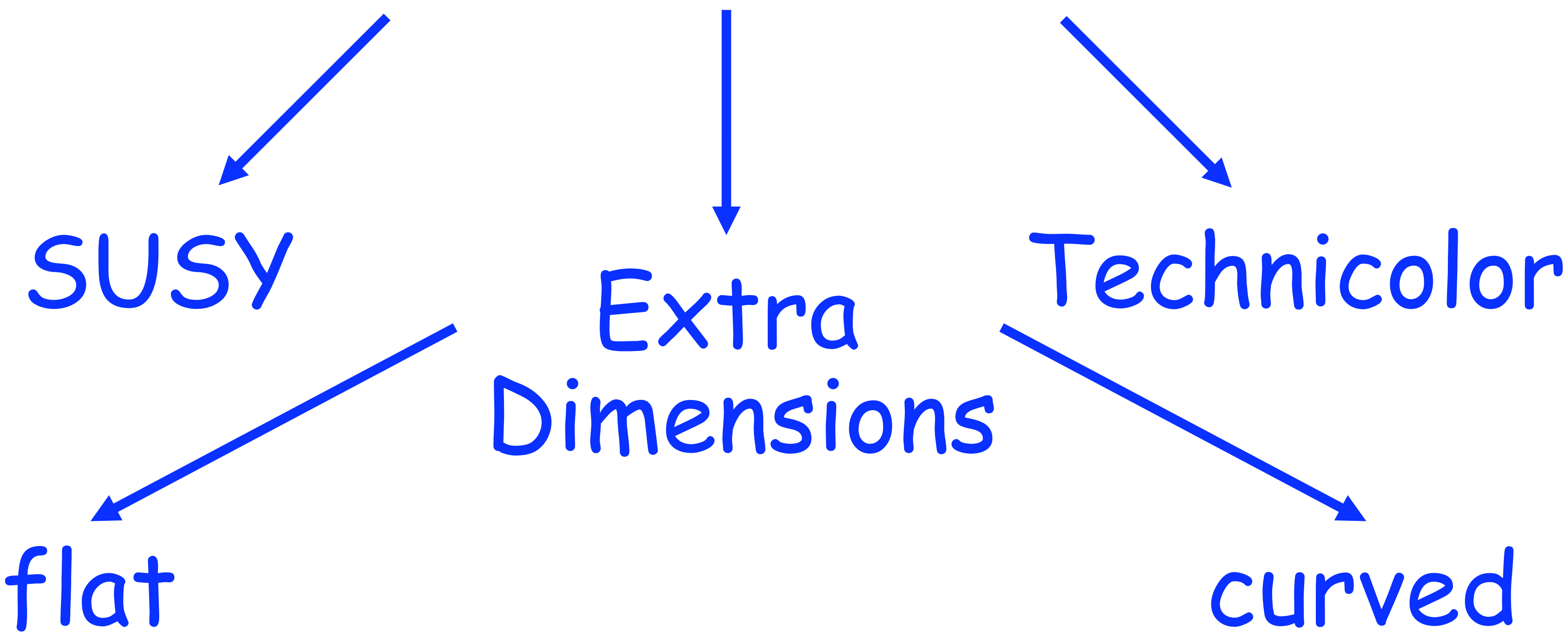
SUSY

Technicolor

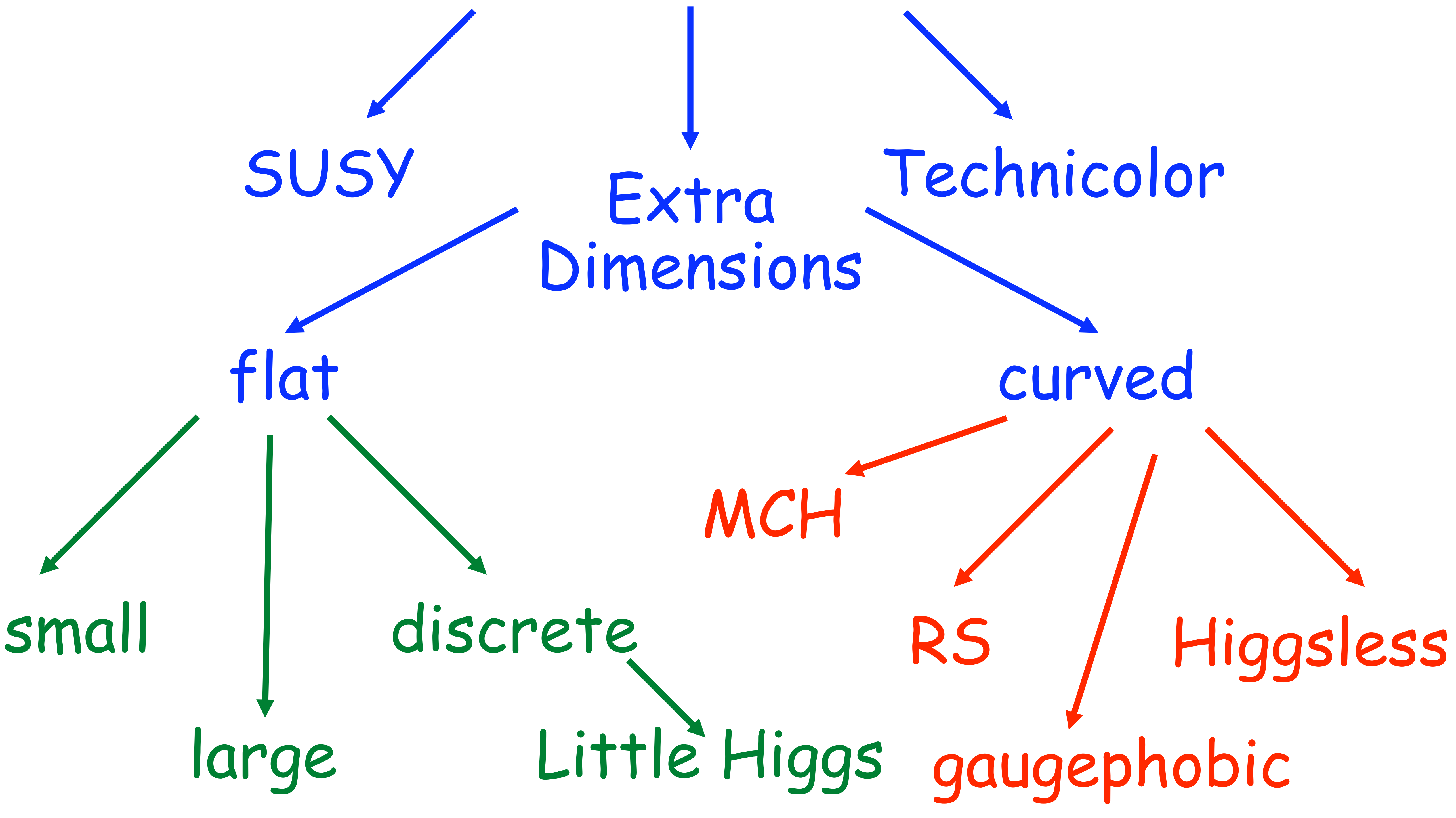
Hierarchy Problem Now

- SUSY
- Extra Dimensions
- Technicolor

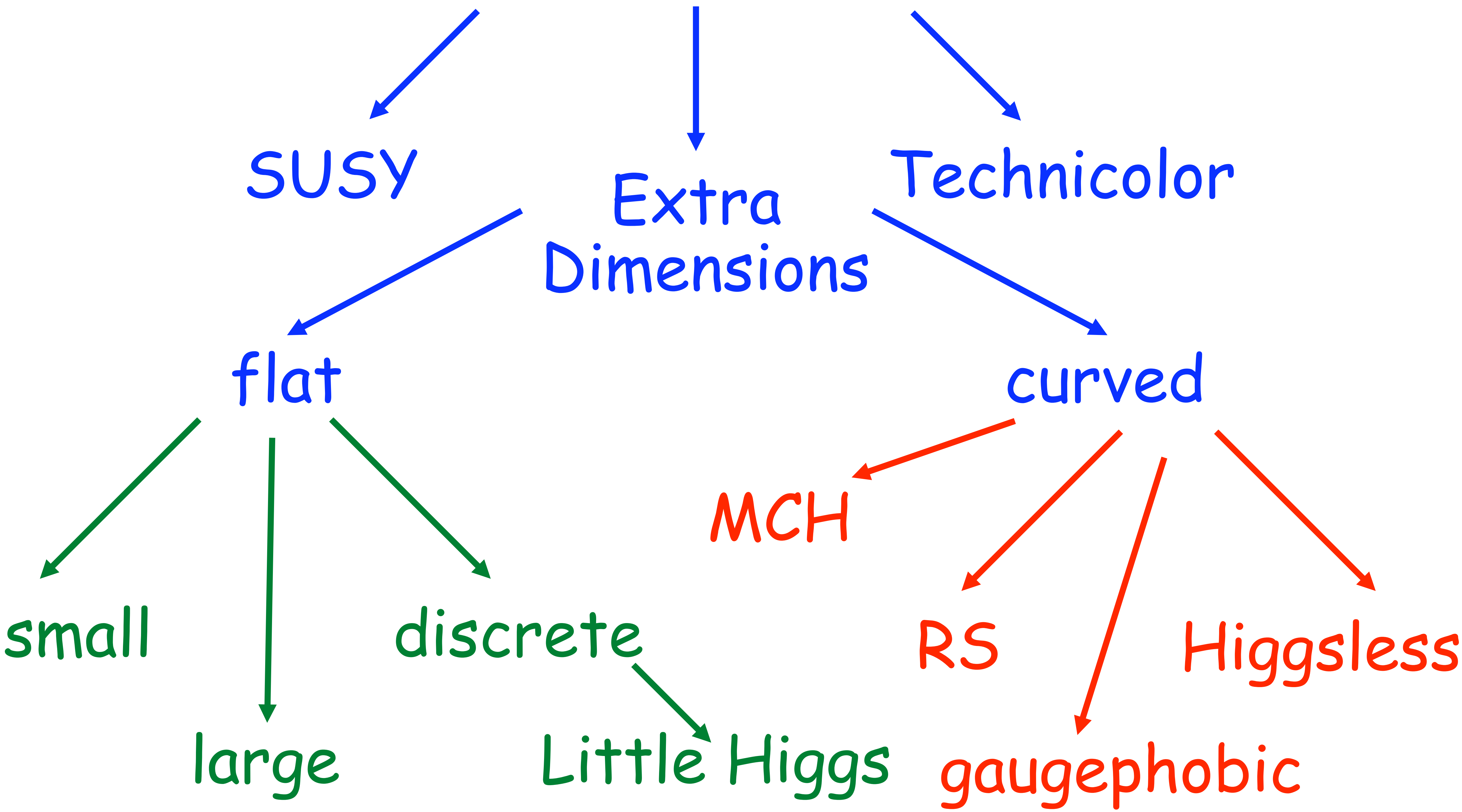
Hierarchy Problem Now



Hierarchy Problem Now

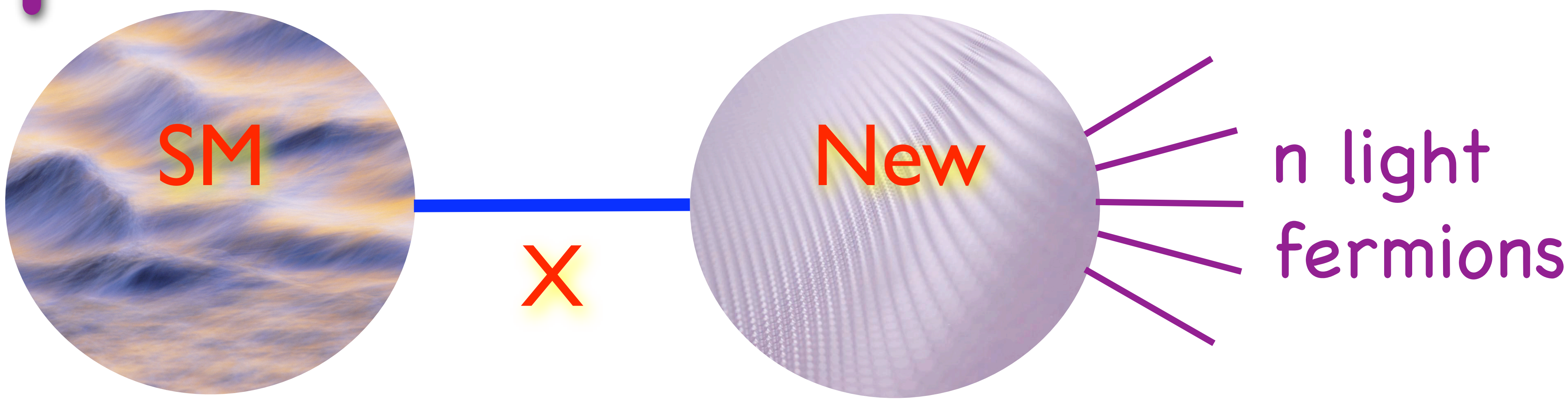


Hierarchy Problem Now



All of these are fine-tuned!

Quirk/Hidden Valley/ Unparticle Model



X is a heavy fermion with both SM and New gauge couplings

stringy confinement → quirks n=0

QCD-like confinement → hidden valley n=few

CFT, no confinement → unparticles n=many

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 propagator

$$\begin{aligned}
\Delta(p,d) &\equiv \int d^4x\, e^{ipx}\langle 0|T\mathcal{O}(x)\mathcal{O}^\dagger(0)|0\rangle \\
&= \frac{A_d}{2\pi}\int_0^\infty (M^2)^{d-2}\frac{i}{p^2-M^2+i\epsilon}dM^2 \\
&= i\frac{A_d}{2}\frac{\left(-p^2-i\epsilon\right)^{d-2}}{\sin d\pi}
\end{aligned}$$

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

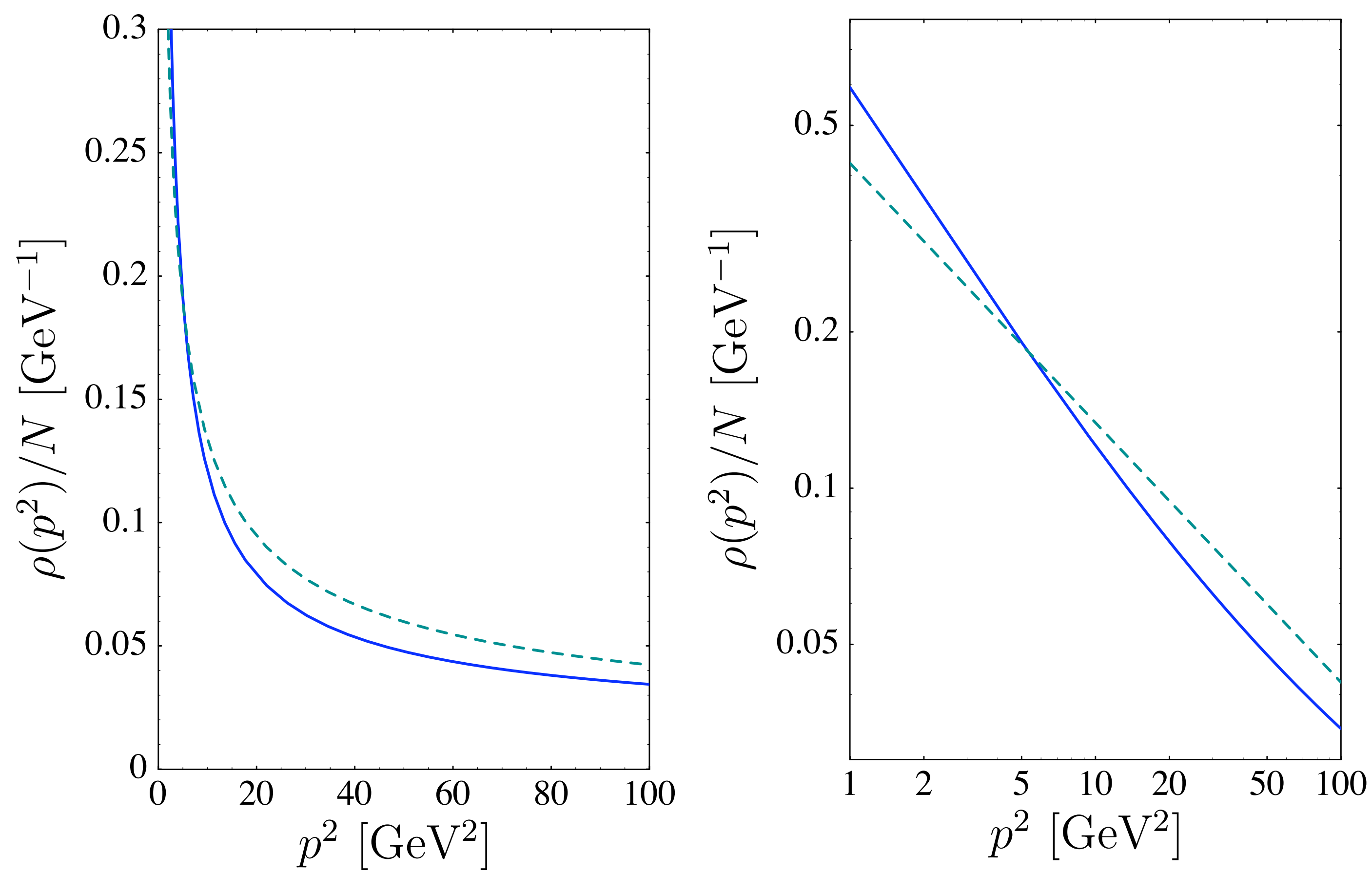
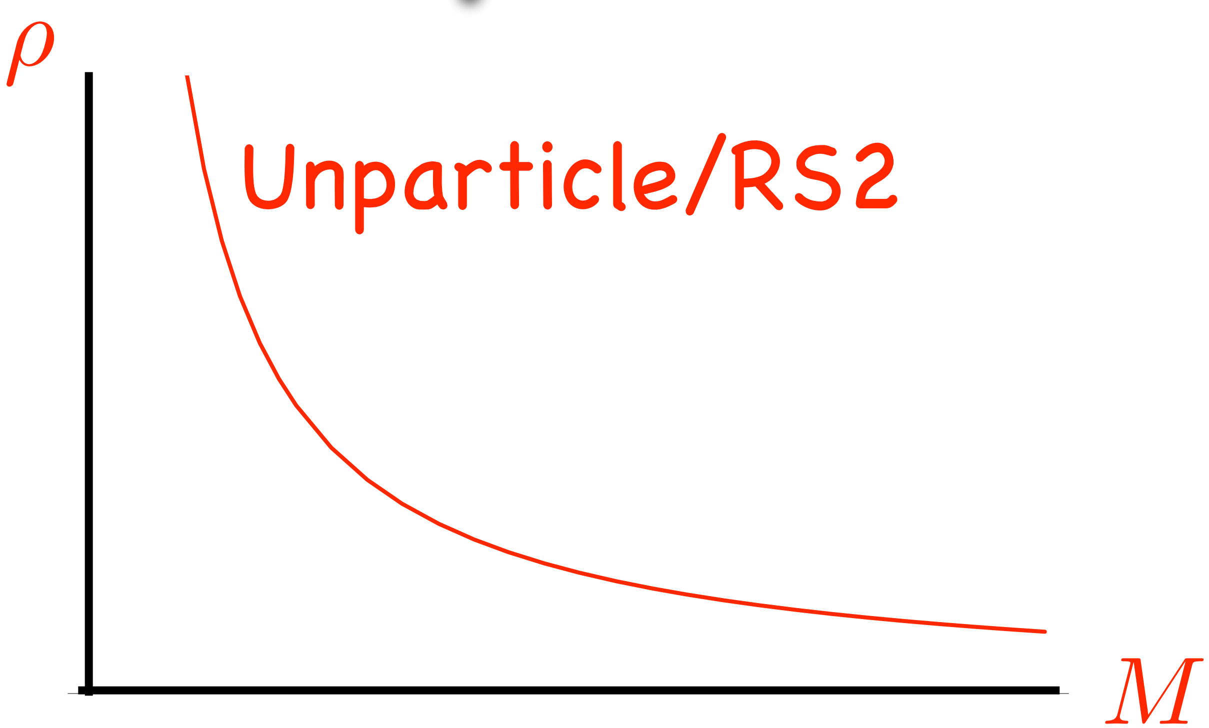
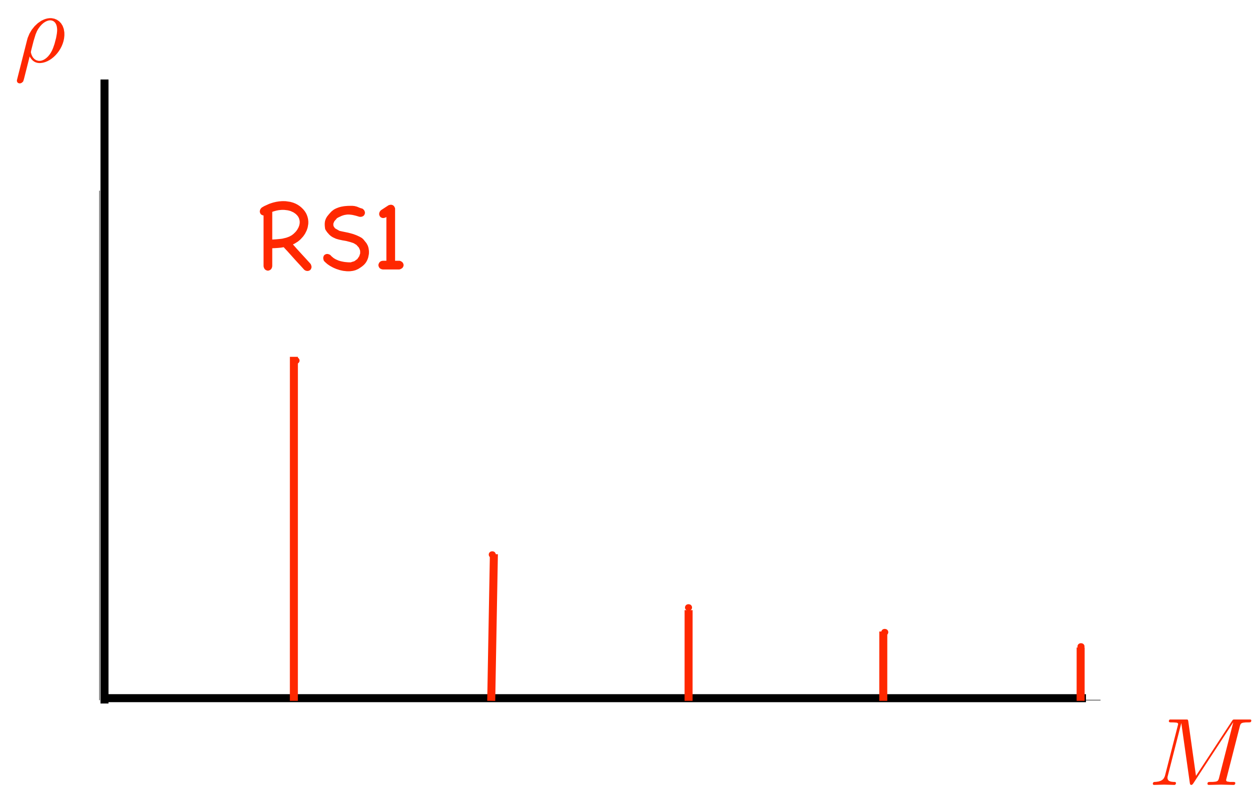


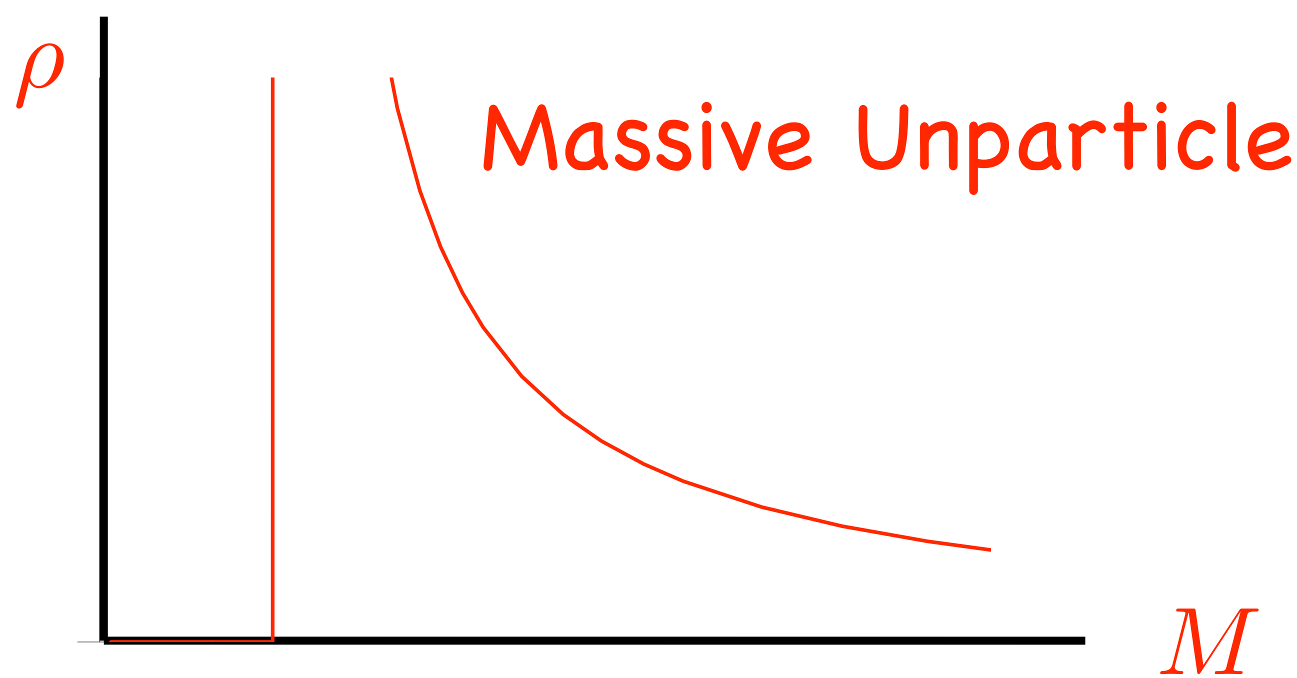
FIG. 1. Comparison of the unparticle spectral density (2) (dashed) and the spectral density (9) of a massless quark jet at next-to-leading order in QCD (solid). We use parameters $M = 10\,\text{GeV}$ and $\eta = 0.5$. The right plot shows the same results on logarithmic scales.

Neubert hep-ph/0708.0036

Spectral Densities







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

AdS/CFT/Unparticles

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

$$H = \mu z^2$$

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

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

Cacciapaglia, Marandella JT, hep-ph/0804.0424

Effective Action

$$S = \int \frac{d^4p}{(2\pi)^4}\, \phi^\dagger(p)\, \left[\mu^2 - p^2\right]^{2-d} \phi(p)$$

$$S = \int d^4x d^4y\, \phi^\dagger(x) F(x-y)\phi(y)$$

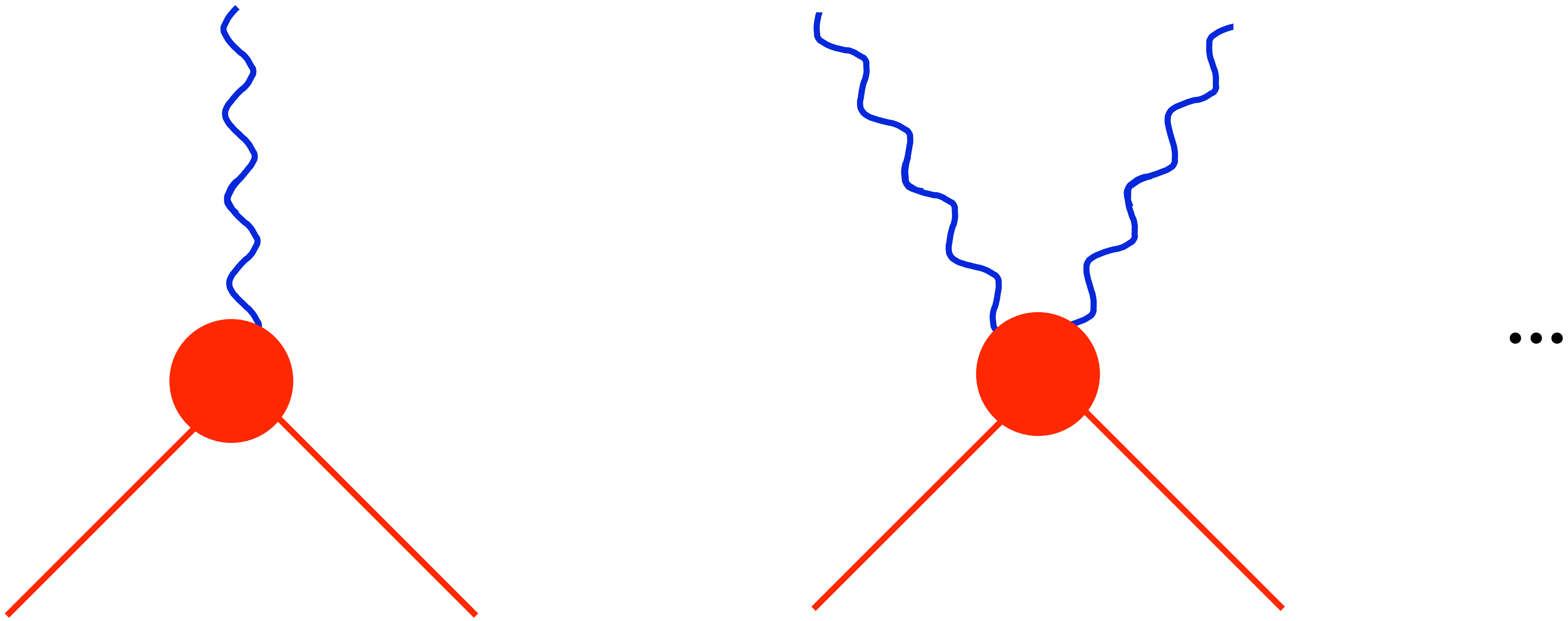
$$F(x-y) = \left[\partial^2 - \mu^2\right]^{2-d} \delta(x-y)$$

nonlocal

Minimal Gauge Coupling

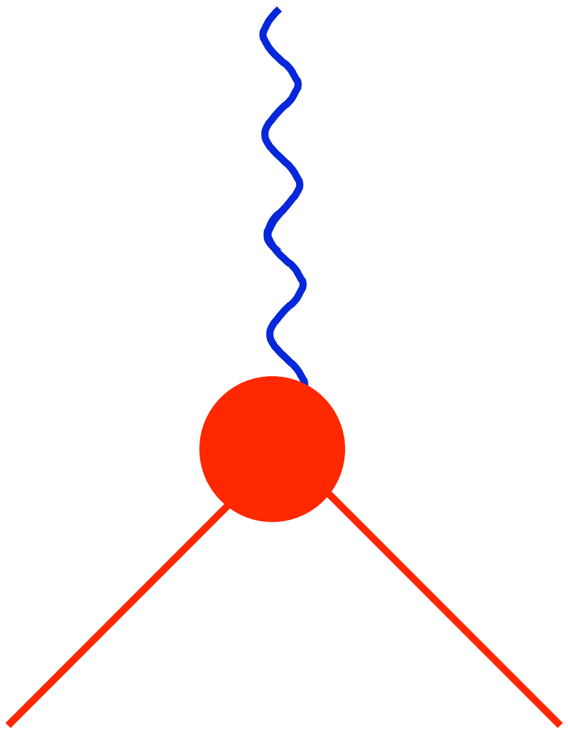
$$F(x-y) \to F(x-y)W(x,y)$$

$$W(x,y) = P\exp\left[-igT^a \int_x^y A_\mu^a dw^\mu\right]$$



cf Mandelstam Ann Phys **19** (1962) 1

Gauge Vertex



$$= -igT^a \frac{2p^\alpha + q^\alpha}{2p \cdot q + q^2} \left[\left(\mu^2 - (p+q)^2\right)^{2-d} - \left(\mu^2 - p^2\right)^{2-d} \right]$$

Ward-Takahashi Identity

$$ig\Gamma^{a\alpha}(p,q) = \quad igT^a \frac{2p^\alpha + q^\alpha}{2p\cdot q + q^2}\left[\left(\mu^2 - (p+q)^2\right)^{2-d} - \left(\mu^2 - p^2\right)^{2-d}\right]$$

$$iq_\mu \Gamma^{a\mu} = \Delta^{-1}(p+q,m,d)T^a - T^a\Delta^{-1}(p,m,d)$$

Unhiggs Model

$$S = -\int d^4x \, H^\dagger (\partial^2 + \mu^2)^{2-d} H$$

Unhiggs Model

$$S = -\int d^4x\, H^\dagger (D^2 + \mu^2)^{2-d} H + \lambda_t \bar{t}_R \frac{H}{\Lambda^{d-1}} \left(\begin{array}{c} t \\ b \end{array} \right)_L + h.c.$$

Unhiggs Model

$$S = -\int d^4x \, H^\dagger (D^2 + \mu^2)^{2-d} H + \lambda_t \bar{t}_R \frac{H}{\Lambda^{d-1}} \begin{pmatrix} t \\ b \end{pmatrix}_L + h.c.$$

$$- \int d^4x \, \lambda \left(\frac{H^\dagger H}{\Lambda^{2d-2}} - \frac{V^2}{2} \right)^2$$

$$H = \frac{1}{\sqrt{2}} e^{iT^a \pi^a / v^d} \begin{pmatrix} 0 \\ v^d + h \end{pmatrix}$$

Stancato JT, hep-ph/0807.3961

Mass Divergence

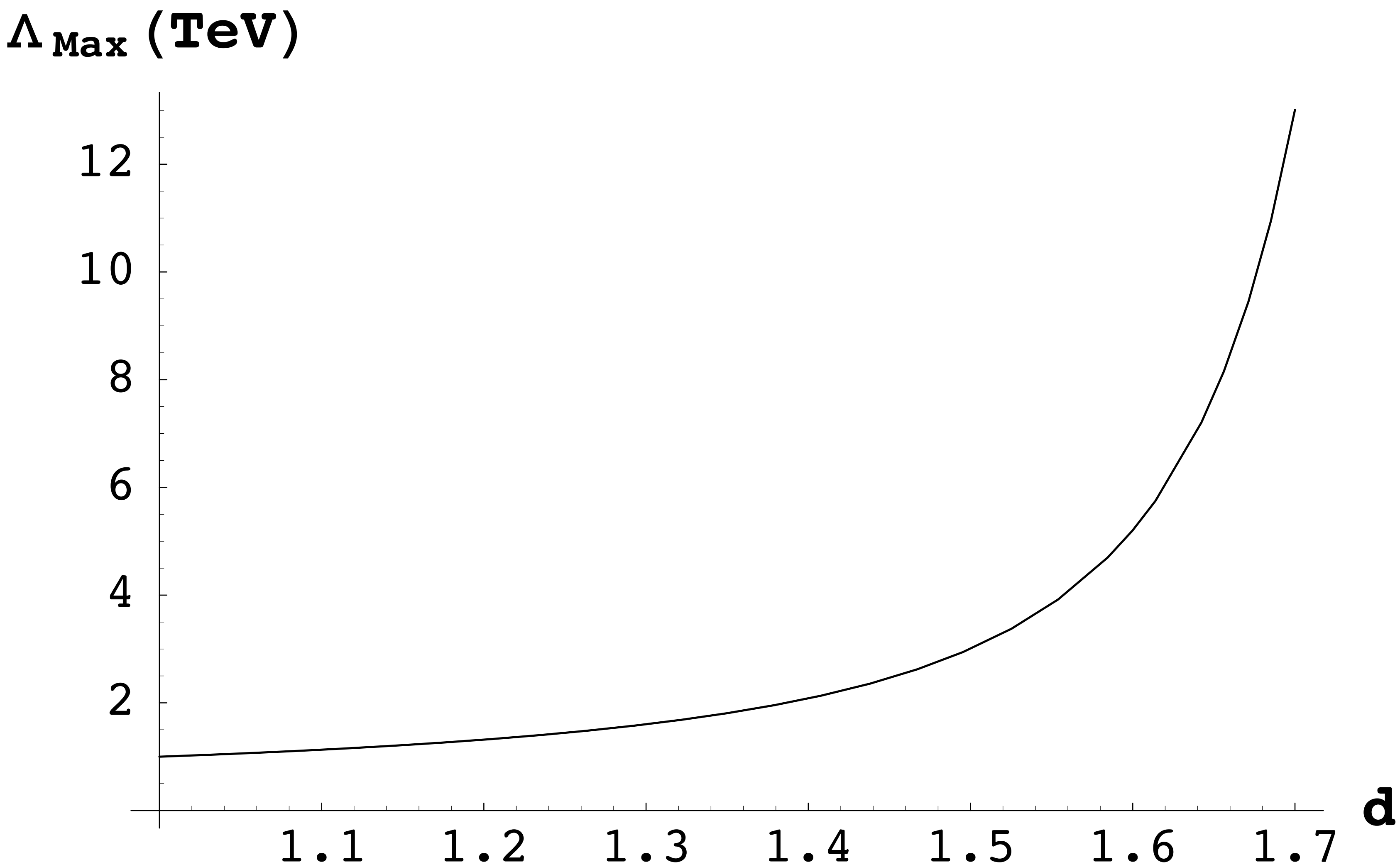
$$m_h^2 \sim \frac{\Lambda^{4-2d}}{16\pi^2}$$

$$\mathcal{L}_Y = \lambda_t \, \bar{t}_R \frac{H}{\Lambda^{d-1}} \left(\begin{array}{c} t \\ b \end{array} \right)_L$$

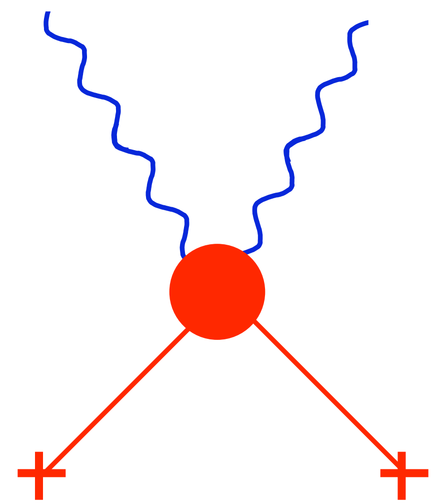
$$m_h^2 = 3 \left(\frac{\lambda_t}{\Lambda^{d-1}} \right)^2 \frac{\Lambda^2}{16\pi^2} = 3 \left(\frac{m_t}{V} \right)^2 \frac{\Lambda^{4-2d}}{16\pi^2}$$

Solve the little hierarchy problem?

loop < tree



Unhiggs and M_W

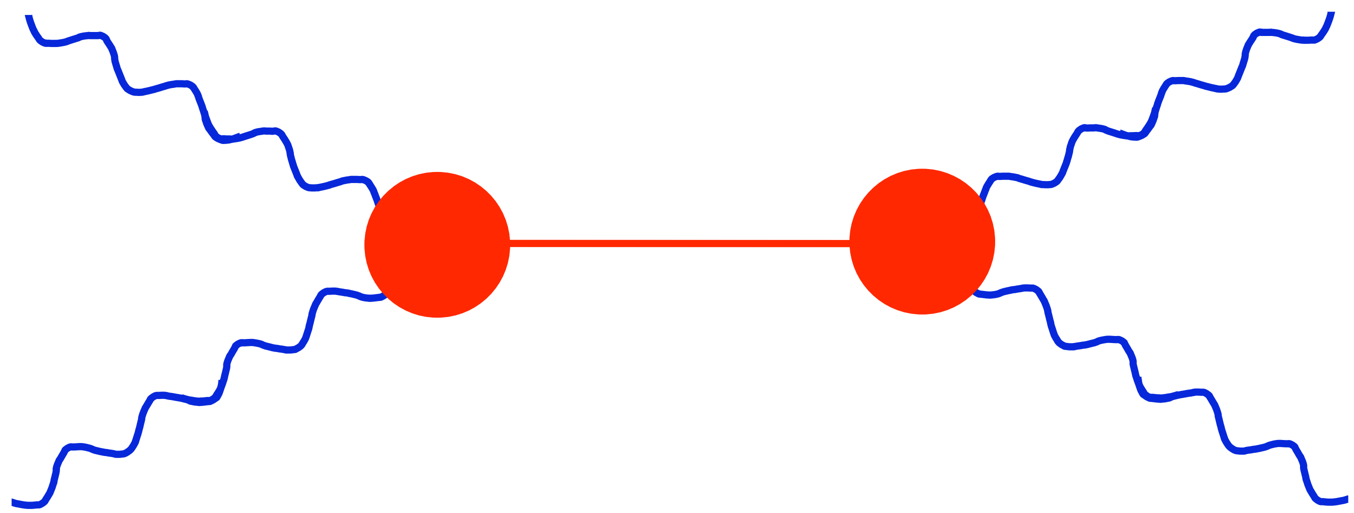


$$-g^2 A^a_\alpha A^b_\beta \langle H^\dagger \rangle T^a T^b \langle H \rangle \left\{ \quad g^{\alpha\beta}(d-2)\mu^{2-2d} \right.$$

$$\left. - \frac{q^\alpha q^\beta}{q^2} \left[(d-2)\mu^{2-2d} - \frac{\left(\mu^2 - q^2\right)^{2-d} - \left(\mu^2\right)^{2-d}}{q^2} \right] \right\}$$

$$M_W^2 \quad = \quad \frac{g^2(2-d)\mu^{2-2d}v^{2d}}{4}$$

WW Scattering

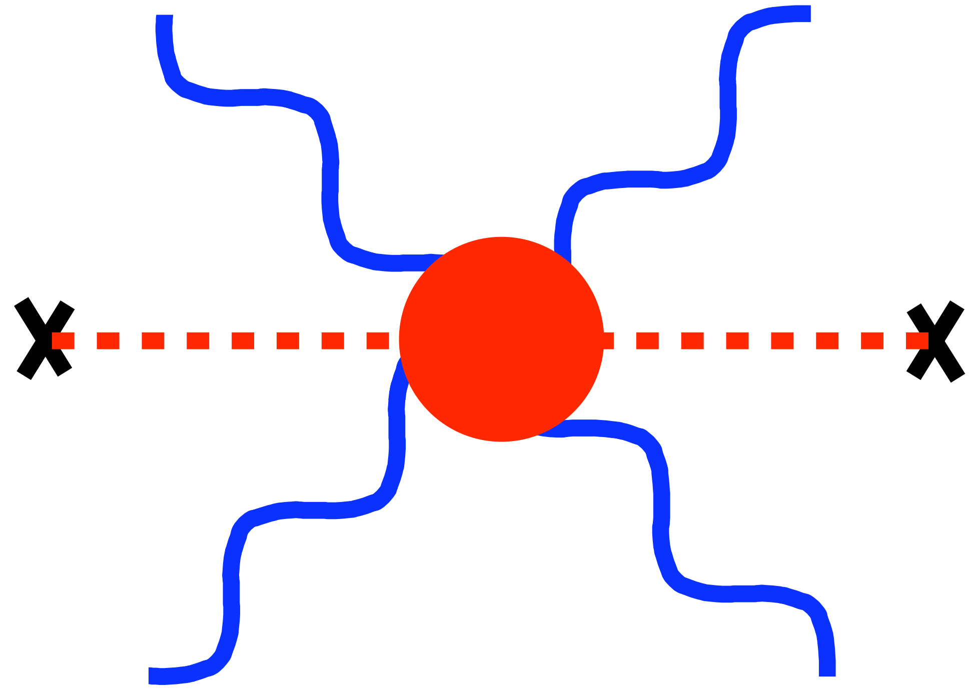


at large s

$$\mathcal{M}_h \to -i\frac{g^4}{4M_W^2(2-d)\mu^{2-2d}}(-s)^{2-d}$$

unHiggs exchange is insufficient to unitarize WW scattering

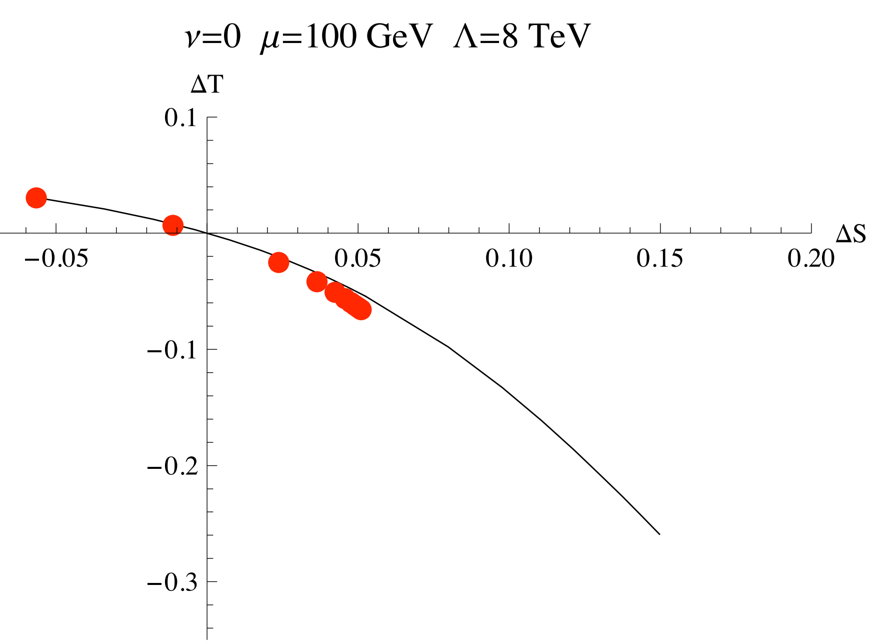
WW Scattering



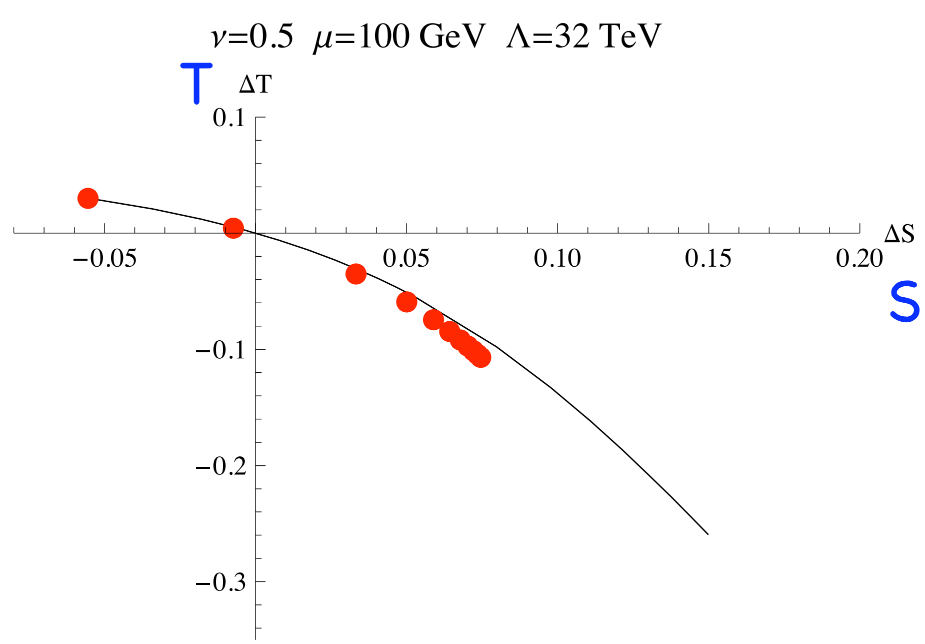
$$\mathcal{M}_{hh} = -i\frac{g^2}{4M_W^2}\left[s + \frac{(-s)^{2-d}}{(2-d)\mu^{2-2d}}\right]$$

unHiggs 6 point vertex does unitarize WW scattering

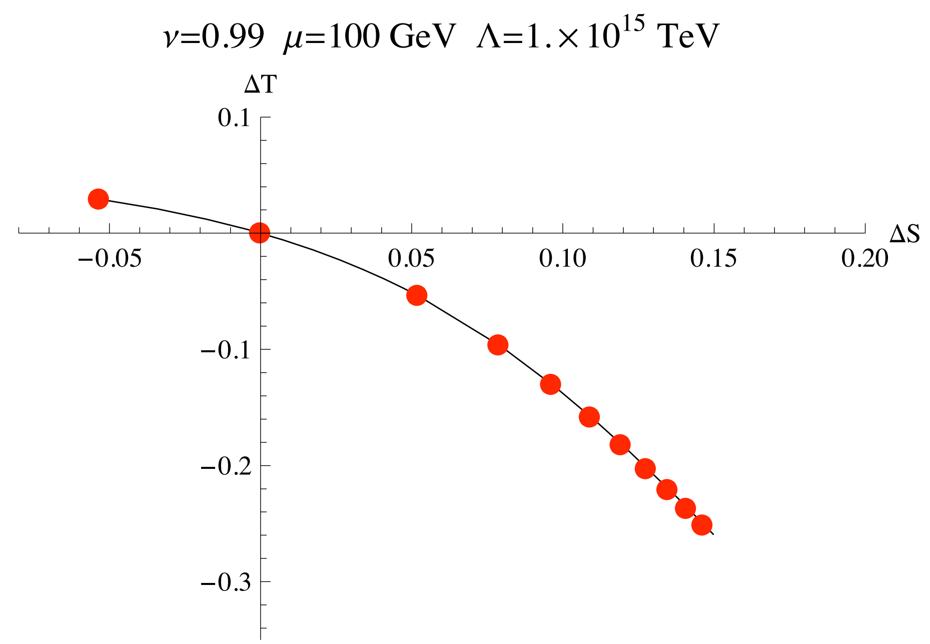
Precision Measurements



d=2



d=1.5

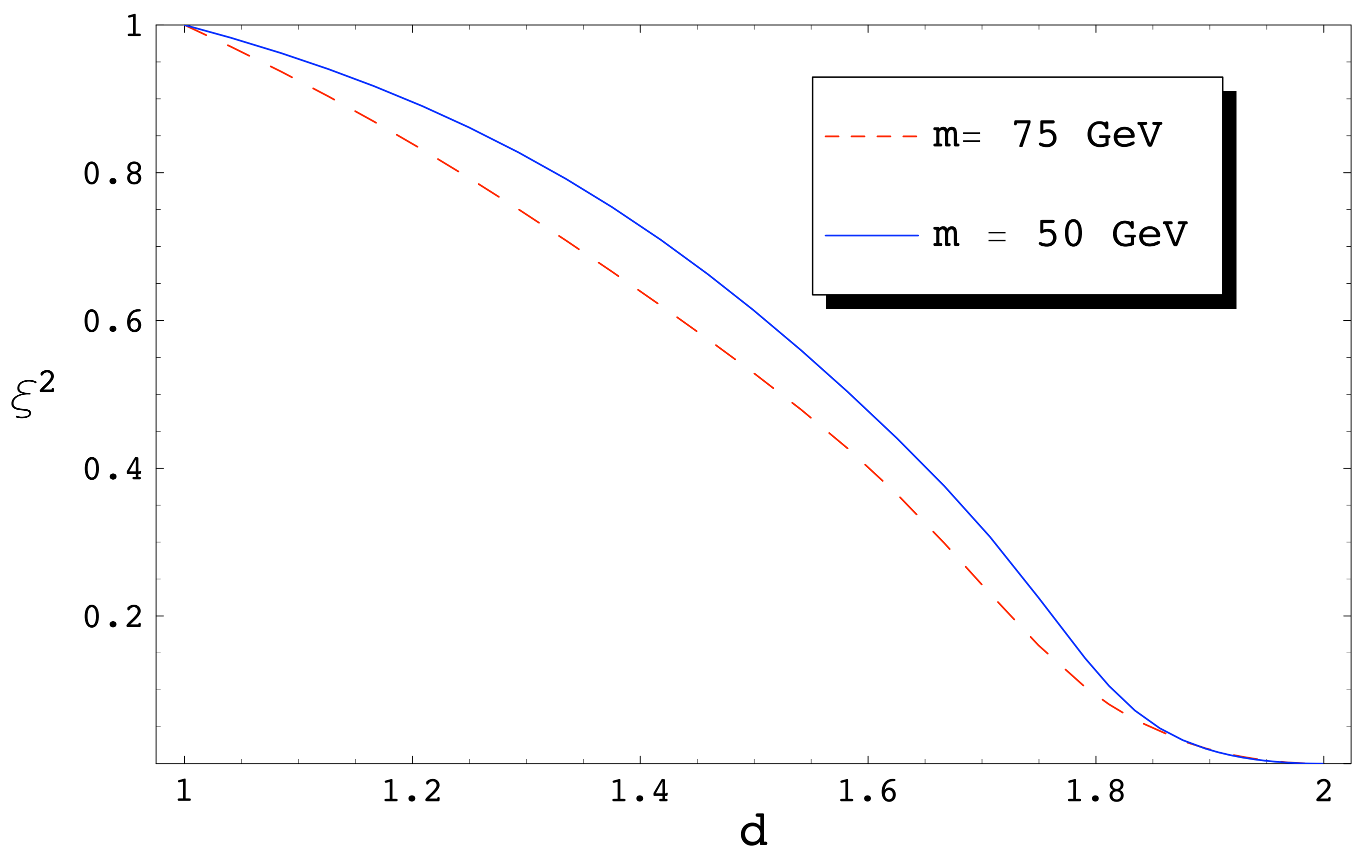


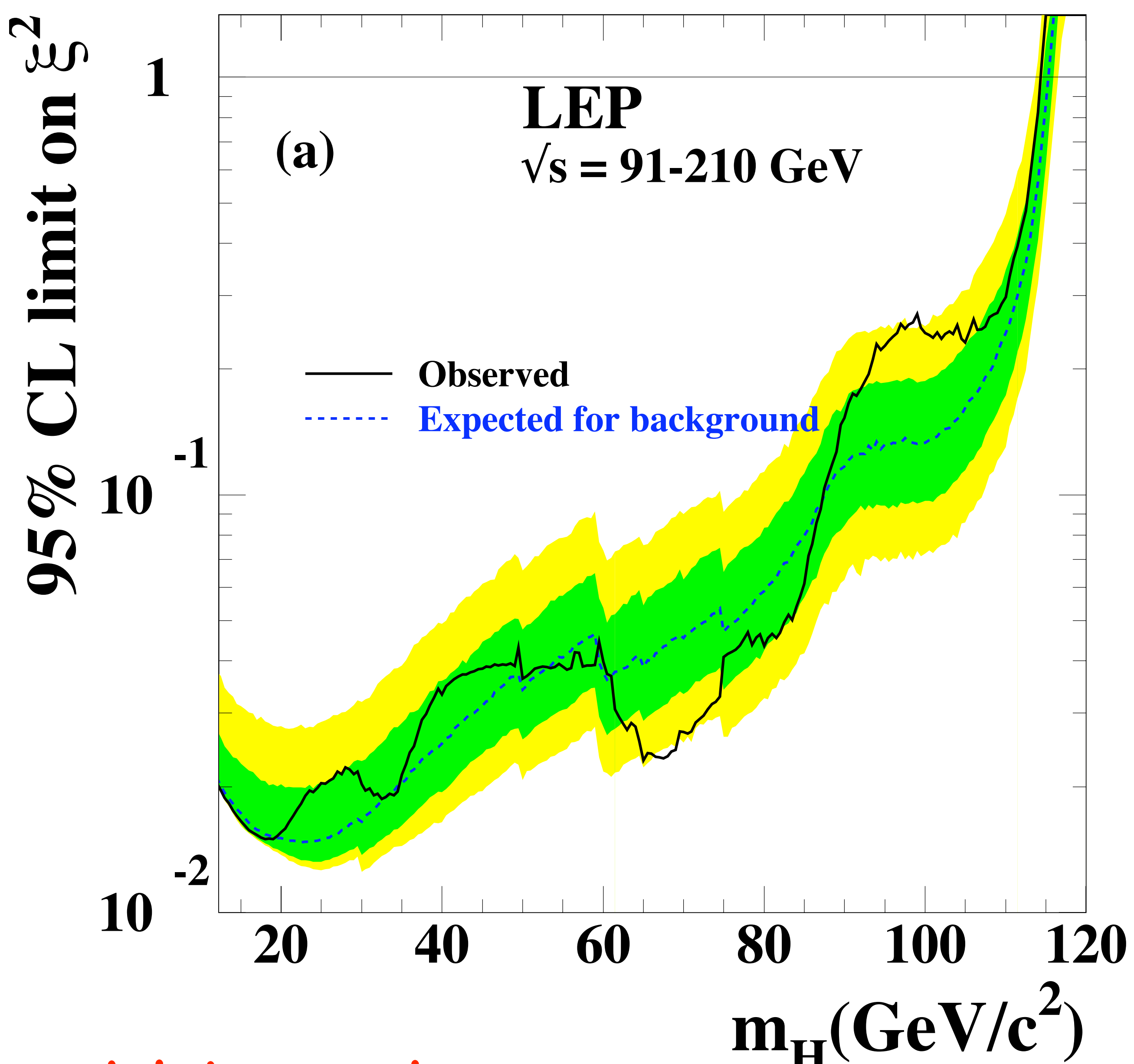
d=1.01

Falkowski & Perez-Victoria, hep-ph/0901.3777

Unhiggs at LEP

$$\xi^2 \equiv \frac{\sigma(e^+e^- \to HZ)}{\sigma_{SM}}$$





a light Unhiggs could have been missed at LEP

Unhiggs at LHC

generically a light Unhiggs would be missed at the LHC using current search strategies

Conclusions

massive unparticles with gauge interactions
are a new type of BSM physics

the Unhiggs is a new way to
break electroweak symmetry

we need to identify the new LHC signals

Backup

AdS/CFT

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

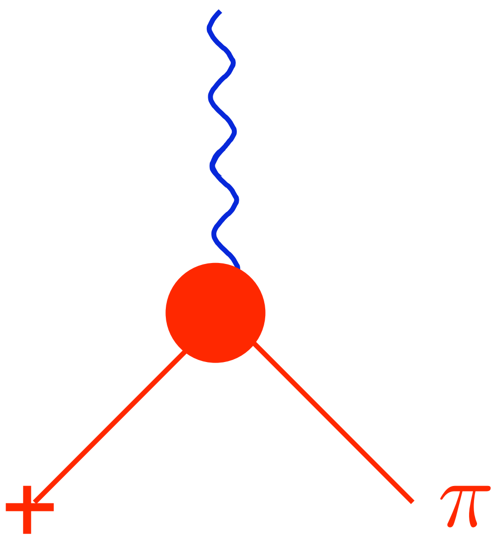
$$z > \epsilon$$

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

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

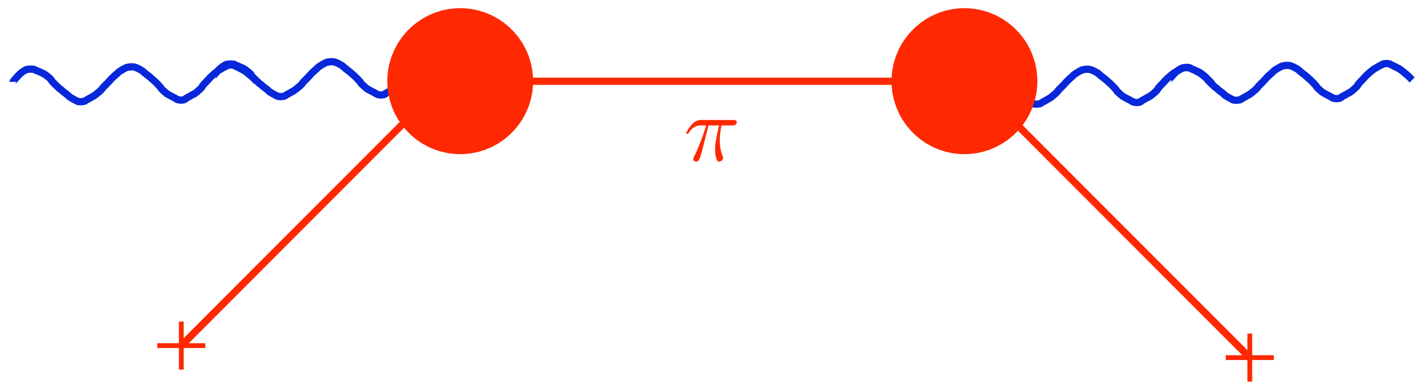
$$d[\mathcal{O}] = 2 \pm \nu = 2 \pm \sqrt{4 + m^2 R^2}$$

Unhiggs



$$g\left(\langle H^\dagger\rangle A^a_\alpha T^a \Pi - \Pi^\dagger A^a_\alpha T^a \langle H\rangle\right)$$
$$\times\left[\left(\mu^2 - q^2\right)^{2-d} - \left(\mu^2\right)^{2-d}\right] q^\alpha / q^2$$

Unhiggs



$$\Pi^{ab\alpha\beta}(q) = -g^2\langle H^\dagger\rangle T^a T^b \langle H\rangle \frac{q^\alpha q^\beta}{q^4} \times \left[\left(\mu^2 - q^2\right)^{2-d} - \left(\mu^2\right)^{2-d}\right]^2 \Delta_{GB}(q)$$

$$\Delta_{GB}(q) = -\frac{i}{\left(\mu^2 - q^2 - i\epsilon\right)^{2-d} - \mu^{4-2d}}$$

gauge invariance maintained