DARK MATTER FROM EXTRA DIMENSIONS

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with

-

• INTRODUCTION

Dark matter (DM) density $\sim 20\%$

Stable WIMPs: weak scale (few 100 GeV) mass + weak

scale $\sigma_{annihilation}$

Hierarchy problem of SM $\rightarrow$ new physics at weak scale:

DM?

SUSY: R-parity for proton stability $\rightarrow$ LSP stable,

gravitino/neutralino DM

OUTLINE

1. *Non*-SUSY solution: strong dynamics/composite Higgs

2. SM fermions *partially* composite: t_R purely composite

3. Grand Unified Theory (GUT): suppression of proton decay → stable particle (∼ SUSY)

   Exotic RH-neutrino (GUT partner of t_R)

4. Dual description with *warped* 5th dimension!

5. Exotic RH-neutrino is WIMP (good for detection)

6. Universal flat extra dimension (KK parity)
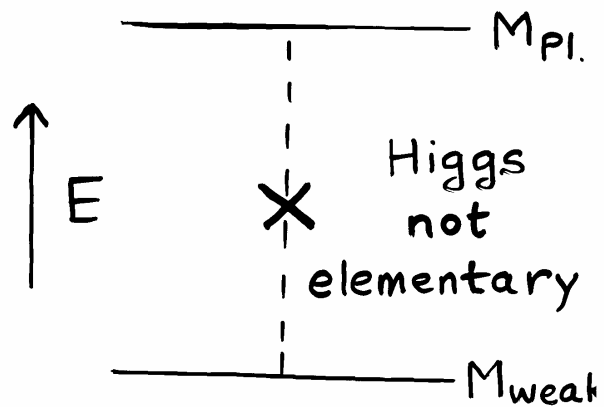
COMPOSITE HIGGS

HIGGS IS COMPOSITE ABOVE TeV

(a la quarks bound into proton by QCD/strong force)
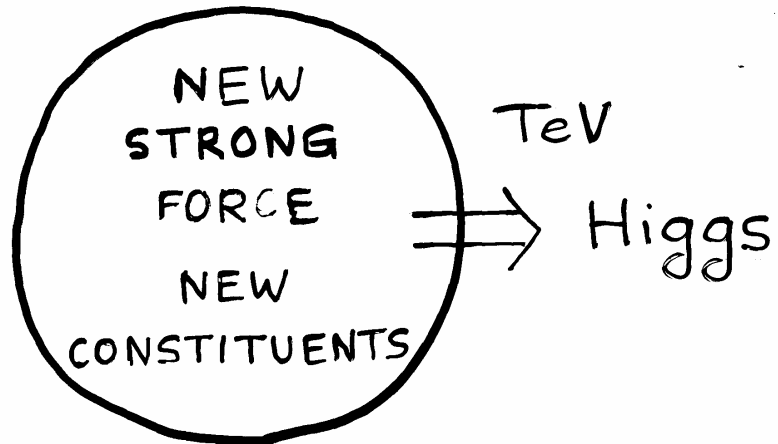
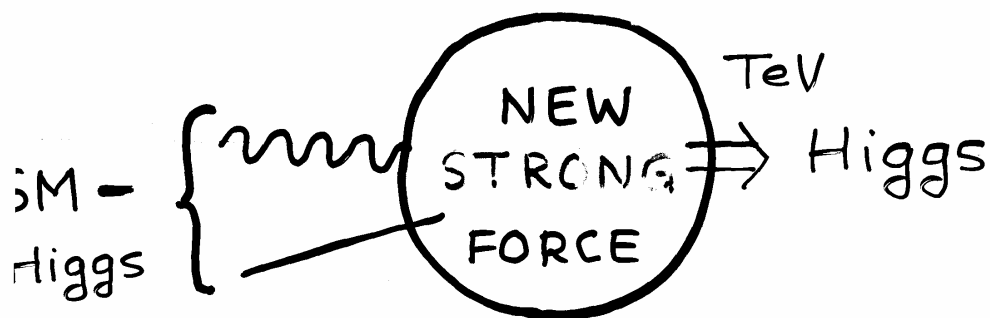Dynamical suppression of quantum corrections →

$M_{weak} \ll M_{Pl}$ natural

(a la $\Lambda_{QCD} \ll M_{Pl}$)

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SM FERMIONS
PARTIALLY
COMPOSITE

MIXING OF ELEMENTARY FERMIONS
WITH COMPOSITES

(a la $\gamma - \rho$ mixing)

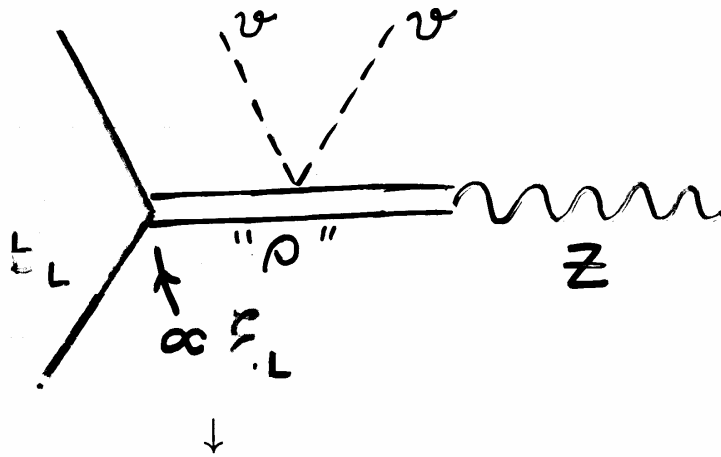SM fermion $\sim \sqrt{1 - \xi^2}$ elementary $+ \boxed{\xi}$ composite

$$(D.B. Kaplan) \qquad (1)$$

$$\boxed{m_f \propto \xi_L \xi_R} \qquad (2)$$

TOP HEAVY + $Z \to b\bar{b} \Rightarrow t_R$ COMPOSITE

$\underline{m_t} \sim v \Rightarrow \xi_{\underline{t_R}}$ or $\xi_{(t,b)_{\underline{L}}} \sim 1$

shift in $Z \to b_L b_{\underline{L}} \lesssim \underline{0.5\%} \Rightarrow \boxed{\xi_{(t,b)_{\underline{L}}} < 1}$

$\downarrow$

• $\boxed{\xi_{t_{\underline{R}}} \sim 1 : \ t_{\underline{R}} \text{ composite}}$
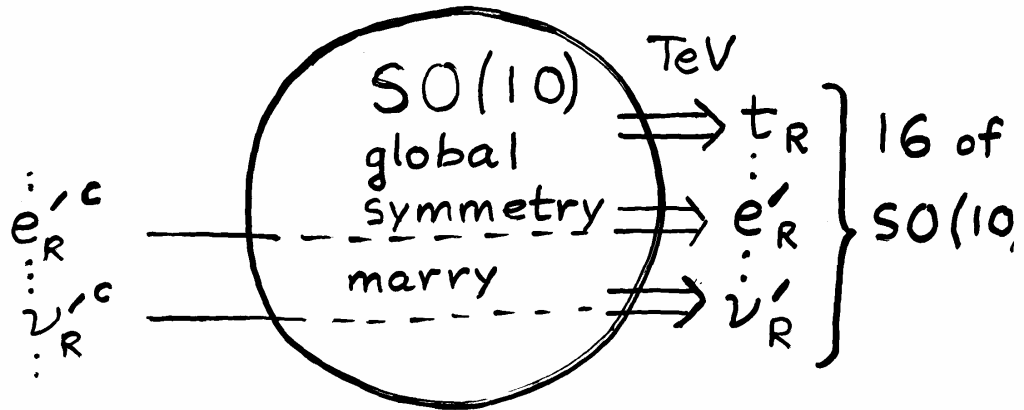
Light fermions $\sim$ elementary

GRAND UNIFIED THEORY (GUT)
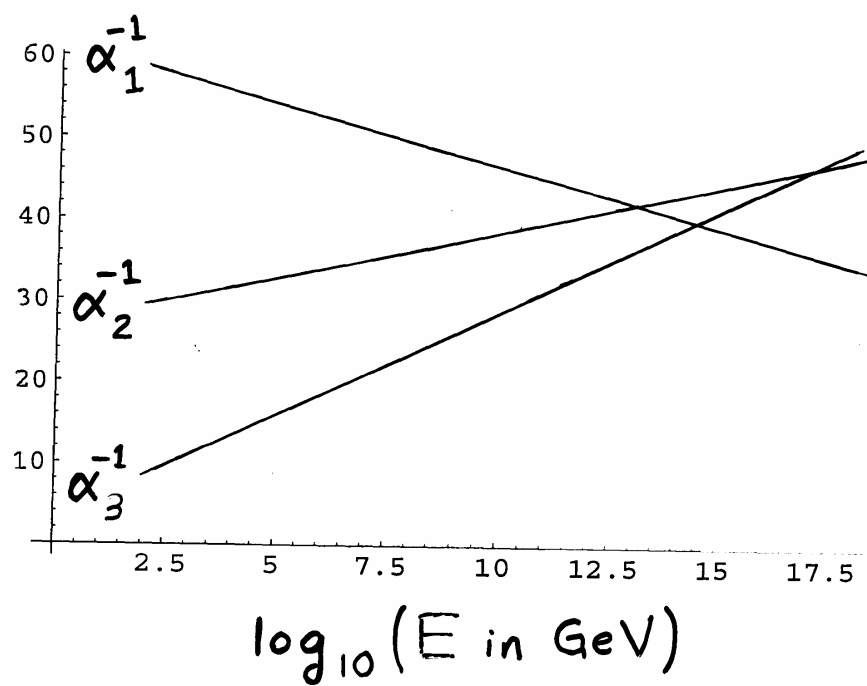
GUT PARTNERS OF t_R

Whole **16** of $SO(10)$ (containing t_R) composite

Elementary $e_R'^{\,c}$, $\nu_R'^{\,c}$... (**anti-generation**) marry

composite partners of t_R (can**not** be **SM** lepton)

$$\text{Running of SM gauge couplings}$$

$$\text{modified} : \text{SM} - t_R - \text{Higgs} + \underbrace{e_R'^{\,c}, \nu_R'^{\,c} \dots}_{\equiv\, -t_R}$$

SM

α_1^{-1}

α_2^{-1}

α_3^{-1}

$\log_{10}\left(E \text{ in GeV}\right)$

IN
WARPED EXTRA DIMENSION
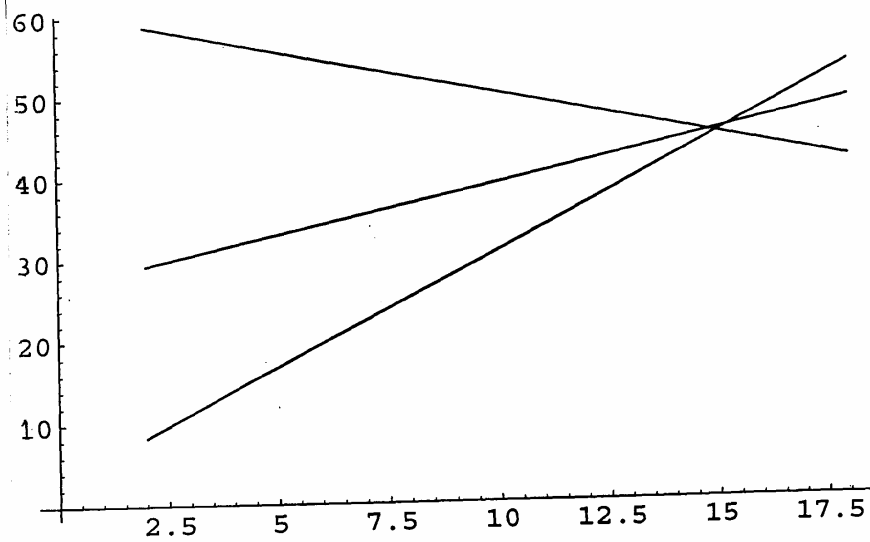
PROTON STABILITY
IN GUT
LEADS TO
DARK MATTER
(~ SUSY)

(KA, SERVANT)

EXOTIC PARTICLES WITH $\boxed{Z_3}$ CHARGE:

$$\Phi \rightarrow \Phi e^{i2\pi\left[\underline{B}-\underline{(\alpha-\bar{\alpha})}/3\right]}$$

Proton decay forbidden by **baryon-number** symmetry

of strong dynamics

$$B \begin{cases} e'^c_R \\ -\tfrac{1}{3} \end{cases} \begin{cases} e'^c_R \\ \nu'^c_R \end{cases}$$

$$\text{SO}(10) \Longrightarrow t_R \\ U(1)_B \Longrightarrow e'_R \\ marry \Longrightarrow \nu'_R$$

$$\left.\begin{matrix} 16 \text{ of} \\ \text{SO}(10) \\ B = +\tfrac{1}{3} \end{matrix}\right\}$$
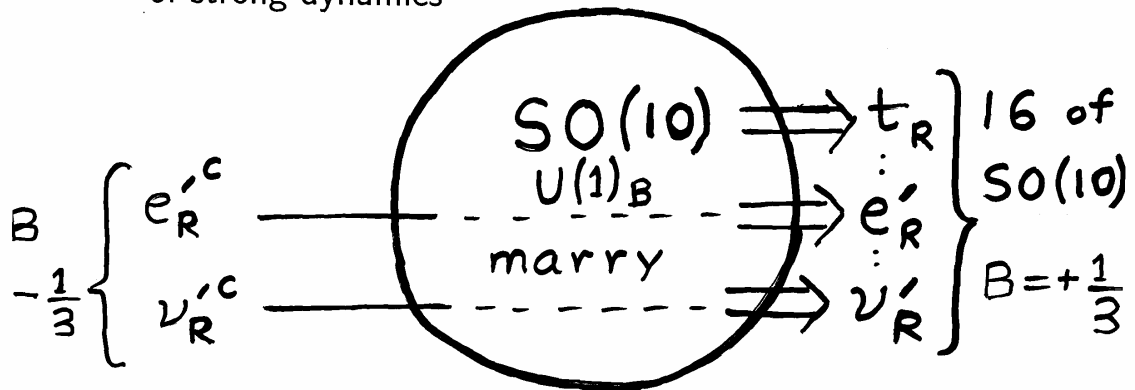
- "Wrong" combination of color and baryon-number:

  no color, $B = 1/3 \rightarrow$

  $$\boxed{\text{Lightest } Z_3\text{-charged particle } (\underline{\text{LZP}}) \text{ stable!}}$$

Moderate coupling $\rightarrow$ light GUT partners of t_R $\left(\begin{matrix}\textbf{compositeness} \\ \textbf{scale} \sim \\ \textbf{few TeV}\end{matrix}\right.$

(a few 100 GeV)

$\downarrow$

$\boxed{\nu^0_R \text{ is stable!}}$ (due to **heavy** top)

DUAL
DESCRIPTION

DUAL TO EXTRA DIMENSION!

Difficult to calculate ($\sim$ QCD):

constituents of Higgs strongly coupled

at best, incomplete models (Georgi, Kaplan)

AdS/CFT duality in String Theory

(Maldacena; Witten; Gubser, Klebanov, Polyakov):

Strong interactions dual to extra spatial dimension!

Weakly coupled $\to$ calculable (convert "$\sim$" to "$=$")!

MOTIVATION FOR DUALITY

Tower of bound states in $4D$ picture (with strong dynamics)

$$\updownarrow$$

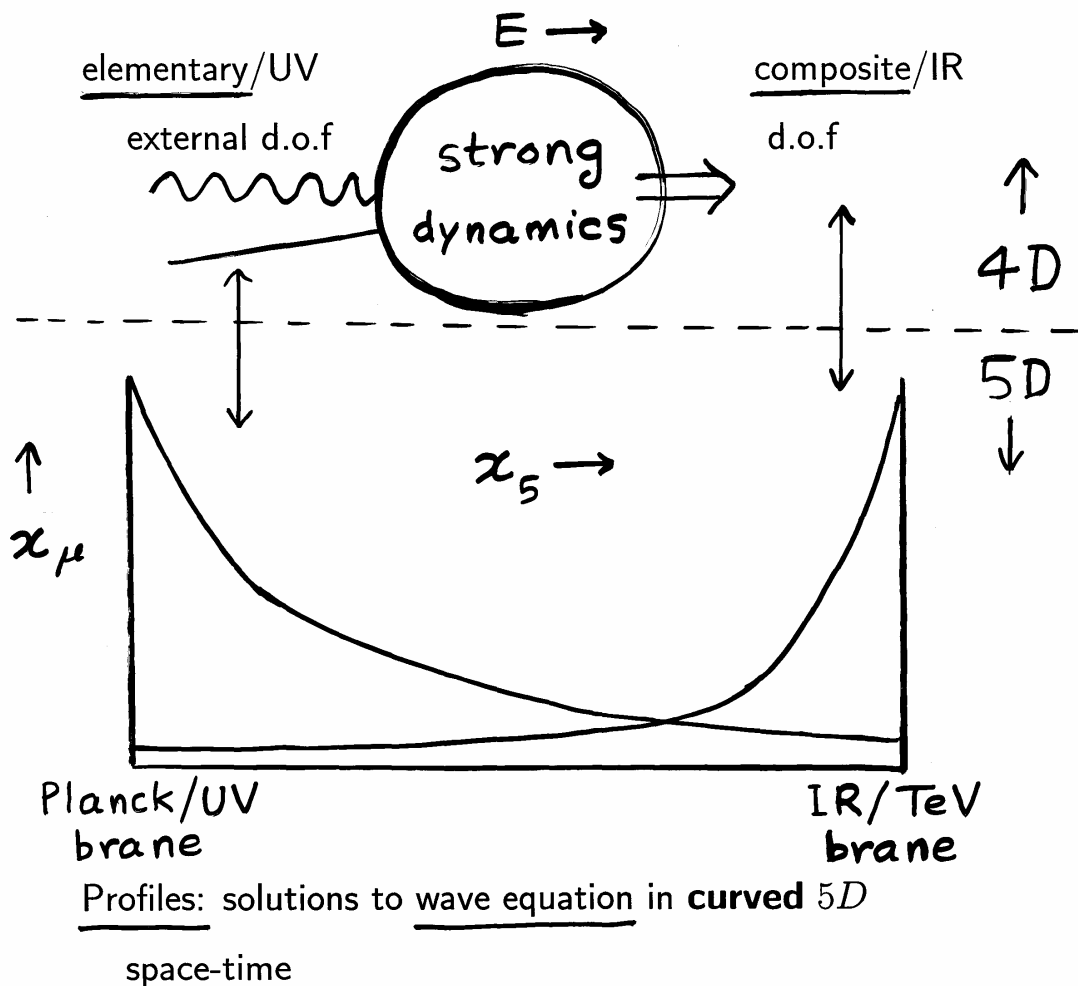Particle in $5D$ (a la particle in $1D$ box)

$\downarrow$ $4D$ point of view

- Lightest mode (SM) + heavier (Kaluza-Klein or KK) modes $\left(eigenmodes \ with \ p_5 = n/_L \right)$
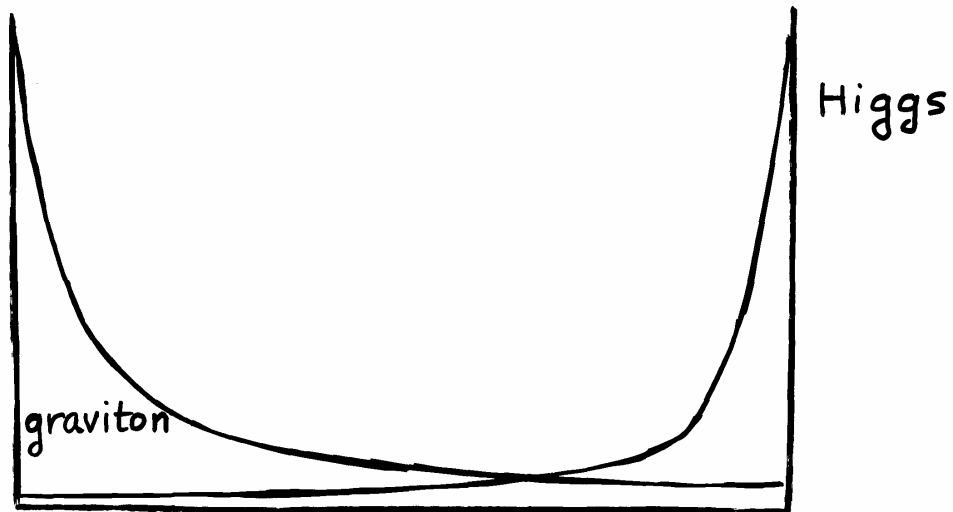
with profiles in 5th dimension

| KK mass scale $\gtrsim$ TeV $\rightarrow$ not yet seen! |

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DEGREE OF COMPOSITENESS ↔
LOCATION IN _{WARPED} EXTRA DIMENSION

elementary/UV

external d.o.f

$E \longrightarrow$

strong dynamics

composite/IR

d.o.f

$4D$

$5D$

$x_5 \longrightarrow$

x_μ

Planck/UV brane

IR/TeV brane

Profiles: solutions to wave equation in **curved** $5D$ space-time

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Coupling of particles ∝ wavefunction overlap

- Small overlap of <u>Higgs</u> with <u>gravitational</u> field →

  small Higgs mass/condensate ⇒

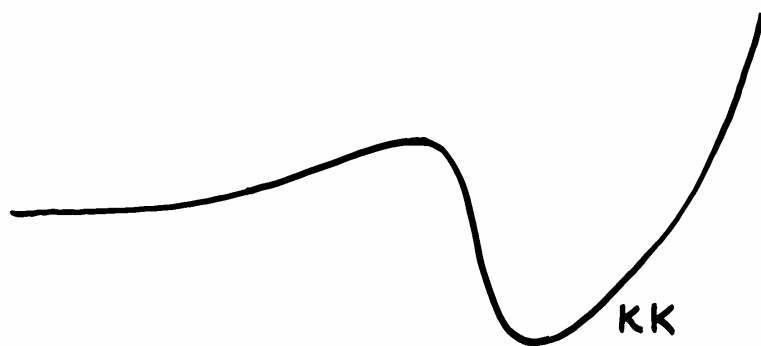 | Planck-weak hierarchy problem solved! |

  $\left(\begin{array}{l} \text{Randall \&} \\ \text{Sundrum} \end{array}\right)$

geometrical origin for hierarchies
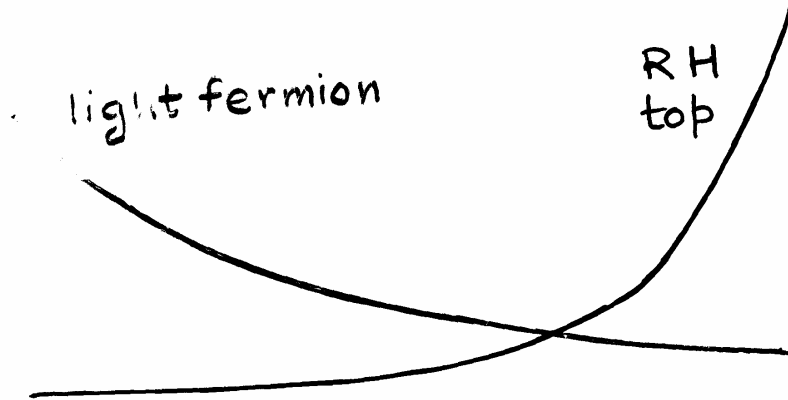
- Hierarchy of fermion masses from overlap of Higgs
  with lightest fermion mode $\left(\begin{array}{l} \text{Grossman, Neubert} \\ \text{Gherghetta, Pomarol} \end{array} \right)$

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$$\text{gauge}, (t, b)_L$$

KK

EXOTIC ν_R (LZP)

AS

WIMP DM

(KA, SERVANT)

• ANNIHILATION OF ν'_R

Exchange of <u>strongly</u> coupled $\sim$ few $(\sim \underline{3})$ $\underline{TeV}$ X, Z'

(<u>non</u>-SM gauge bosons)...

$$\downarrow$$

| Correct relic density |
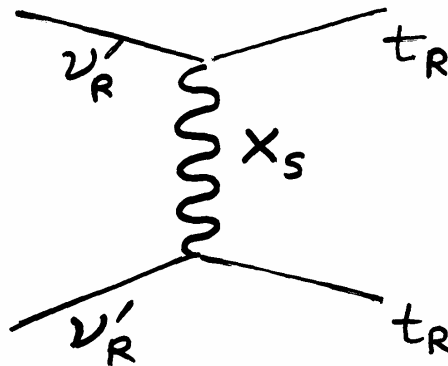
• DIRECT DETECTION

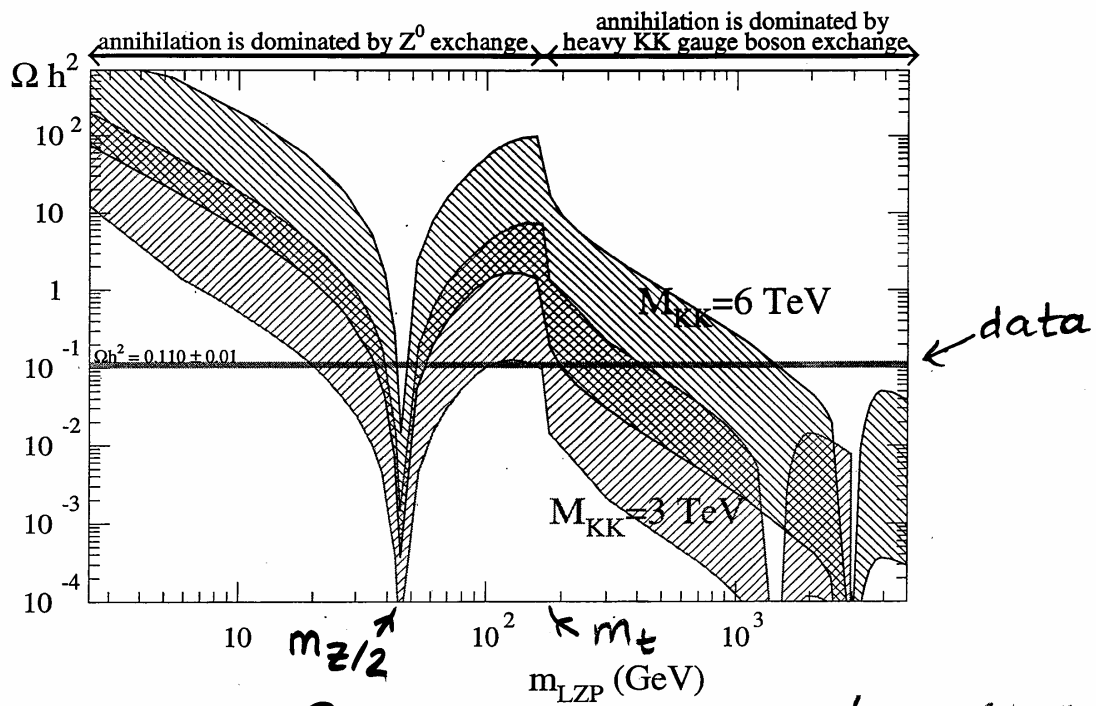<u>Small induced</u> coupling to Z

$$\downarrow$$

| Good prospects for direct detection |

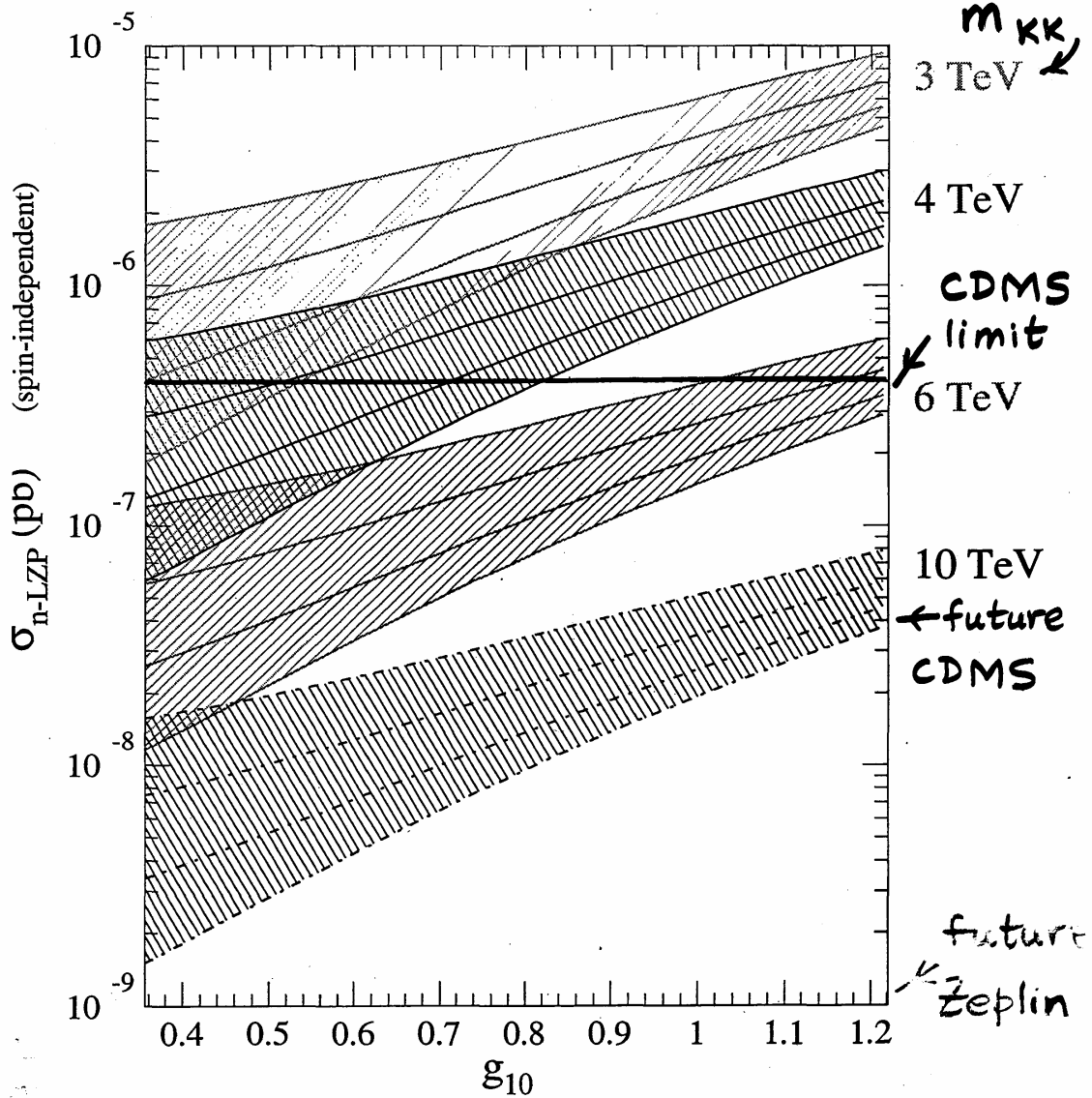$\big($ Dirac $\rightarrow$ spin-independent

cf. Majorana LSP $\big)$

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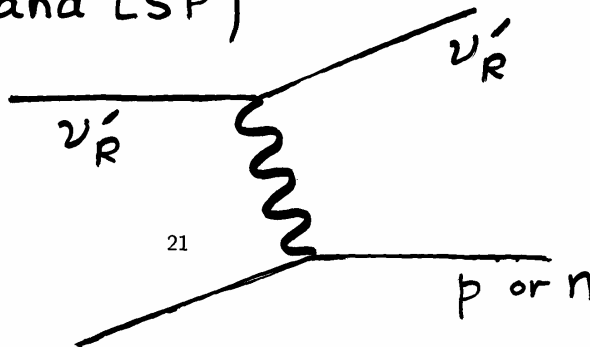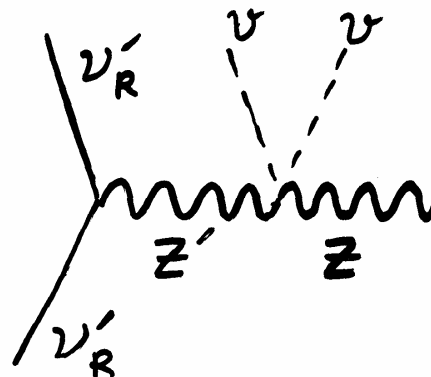
RELIC DENSITY
PREDICTION

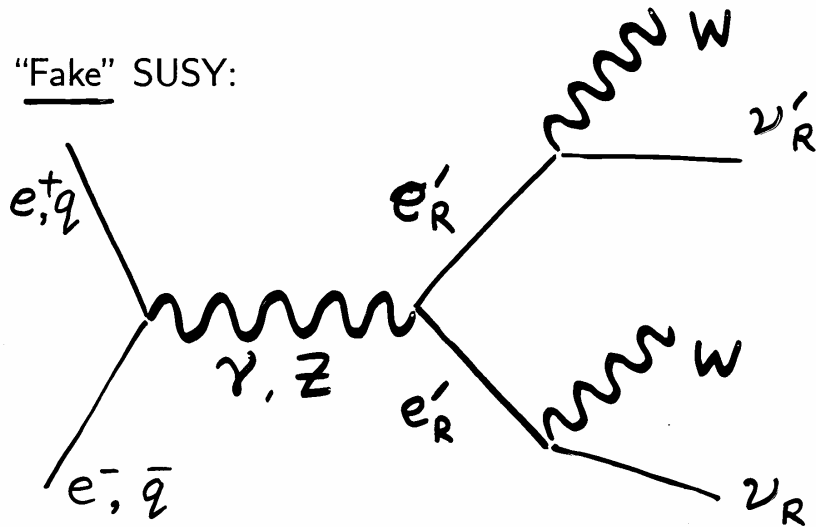Range of Ω due to c_{tR}, g_{5D} (loop effects

PREDICTIONS FOR DIRECT DETECTION

(RANGE OF σ due to $c_{\nu'_R}$, c_{t_R})
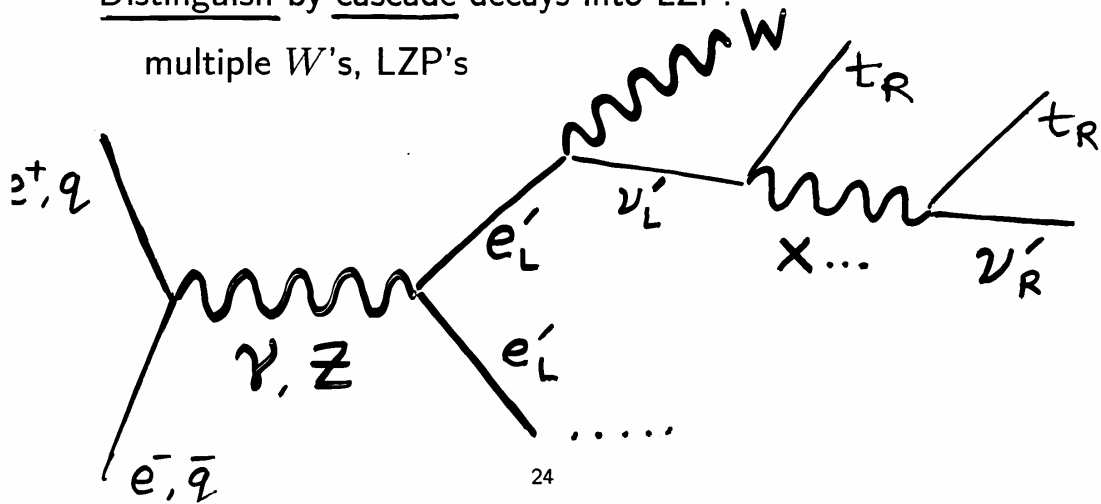
- **<u>OTHER</u> LIGHT ($\lesssim 1$ TeV) KK FERMIONS**
  FROM $\underline{t_R}$ MULTIPLET AT COLLIDERS:
  RUN II, LHC, ILC

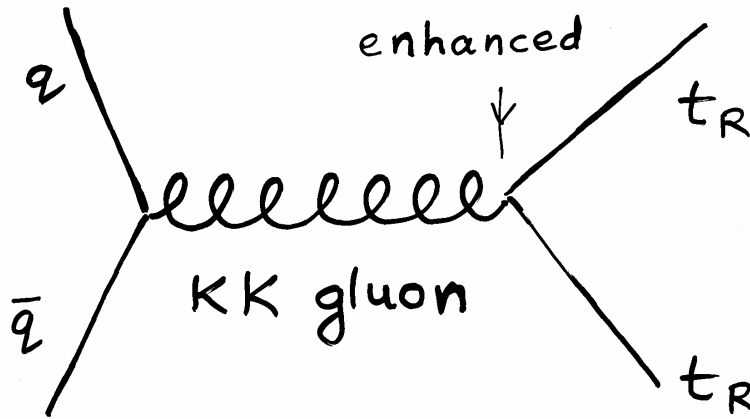<u>"Fake"</u> SUSY:

<u>Distinguish</u> by <u>cascade</u> decays into LZP:
  multiple W's, LZP's

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- *Single* **production of heavy (few TeV)** *SM*

  gauge KK modes at LHC

- **INDIRECT DETECTION**

Annihilation in Sun, galactic halo/center

(Hooper and Servant, hep-ph/0502247)

COUPLINGS
IN
COMPHEP
(G. SERVANT)

CONCLUSIONS:

DM from heavier excitations of SM in extra dimensions

.

Warped extra dimension:

    Suppression of proton decay $\rightarrow$ stable particle

    ($\sim$ SUSY)

(COMPOSITE WIMP!)

Dual to Higgs compositeness solving Planck-weak

hierarchy

Exotic RH ν as WIMP: good prospects for

direct/indirect detection