PROTON DECAY, MAGNETIC MONOPOLES AND EXTRA DIMENSION(S)

Q. Shafi

- MOTIVATION
- p decay
- MONOPOLES / INFLATION
- 'LIGHT' MONOPOES / D-Branes
  EXOTIC STATES
- WARPED GEOMETRY &
  Phenomenology (p-decay, ν osc)

EXTRA DIMENSION(S)

(Caldwell
Altarelli
[illegible]
⋮

WHO NEEDS THEM?

- Unification of forces (Kaluza-Klein)

Consider 5 dimensional gravity

metric tensor $\rightarrow g_{AB}$, $A, B = 0, 1, \ldots, 4$

Dimensional reduction to $M_4 \times S^1$:

$$g_{\mu\nu} , \quad g_{\mu 4} \sim A_\mu , \quad g_{44}$$

graviton ($\mu, \nu = 0, \ldots, 3$) — EM field (!) — scalar

- Electric charge quantized
- Monopoles

MAGNETIC MONOPOLES

ALL UNIFIED THEORIES PREDICT MAGNETIC MONOPOLES

IF THEY ARE SUFFICIENTLY LIGHT, PRESUMABLY WE CAN PRODUCE THEM IN ACCELERATORS. OTHERWISE, WE SHOULD SEARCH FOR PRIMORDIAL ONES.

CAN THEY SURVIVE INFLATION

- M - Theory

  Presumably 11 dimensional ;

  Low energy limit may be 11-d supergravity ;

  (graviton, gravitino, A_{MNP})

  Contains all known superstring theories ;

  Unification of matter & gauge forces?

- Large extra dimension(s)

  (New way to approach hierarchy problem)

- Warped Geometry

  (May resolve hierarchy problem without SUSY)

- Proton decay limits impose (severe) constraints on many extensions of the SM (MSSM, GUTS, superstring, ...)

[Recall that in the SM p decay can occur via dim 6 operators such as

$$qqql$$

with $\tau_p \gtrsim 10^{46}$ yrs.]

- Discovery of p decay definitely means physics beyond SM. Lack of discovery leaves many options open. (p essentially stable in some unified theories)

BEYOND THE STANDARD MODEL (SM)

At least two good reasons:

(i) Neutrino Mass $\left(m_\nu \lesssim \ell\ell \langle M_W \rangle^2 / M_P \sim 10^{-6} - 10^{-5}\, eV \right)$
(Cf: Atmospheric ν)

(ii) Dark matter (SM has no viable non-baryonic DM needed for LSS) $\left. \begin{array}{l} \Omega_m \simeq 0.3\ (?) \\ \Omega_b \lesssim 0.1 \end{array} \right\}$

Other Reasons Include:

Origin of n_b/n_γ ? $\leftarrow$ SM almost succeeds!

Charge quantization? Family replication?

$M_W \ll M_P$; how?

Fermion mass hierarchies & mixings? θ_W? $\bar{\theta}_{QCD} < 10^{-9}$; how?

Unification with gravity? Inflation?

Λ?

PHYSICS BEYOND THE STANDARD MODEL

- SUPERSYMMETRY (MSSM)
  - Provides CDM (LSP);
  - Gauge hierarchy ameliorated;
  - May (barely?) explain n_b/s;

  - Proton Stability not guaranteed;
  - μ Problem;

- GRAND UNIFICATION (SU(5), SO(10))
  - $U(1)_{em} \subset SU(5) \Rightarrow$ charge quantization;
  - Unification of gauge couplings;
  - ν_R automatic in SO(10); (good for ν oscillations)
  - Unification of quantum numbers ($\underset{\sim}{16}$ of SO(10));
  - $m_b^{(0)} = m_\tau^{(0)}$;

MERGER OF SUSY & GUTS SEEMS

DESIRABLE

SUSY SO(10)

- Assuming Yukawa Unification (3rd family),

  $\tan\beta \simeq m_t/m_b$ ($\gg 1$);

  $m_b = m_\tau$ (asym) then yields

  $m_t \sim 170$ GeV

  With $m_A \gg m_{Z^0}$, we have a single 'light' higgs with tree level mass $\simeq M_{Z^0}$.

  After radiative corrections $m_{h^0} \simeq 110$-120 GeV.

  (This scenario also possible in models such as $SU(4) \times SU(2) \times SU(2)$).

- Additional higgs may not be too heavy (e.g. charged ones in MSSM).

- dim 5 p decay? monopoles?

• However, MSSM allows dim 5

operators $Q\,Q\,Q\,L \;\; (f/M_p)$

$\uparrow$ superfields

$\Rightarrow$ p decay rate unacceptably fast

unless $f \lesssim 10^{-8}$.

How to 'arrange' this ?

(R-sym / $\overset{\text{with}}{GL}$)

$\downarrow$

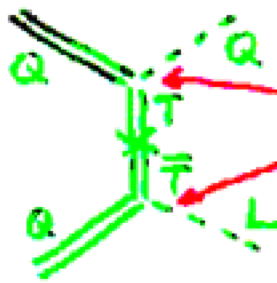
$\supset Z_2^m$

SUSY GUTS

In minimal susy SU(5) (& related models)

p decays as follows (dim 5 again!)

$\tau_p \sim 10^{30 \pm 2} \overset{\swarrow ?}{}$ yrs



vertices allowed by 'matter' parity

$p \to K\nu$

$p \to e^+\pi^0 \to$ gauge boson mediated }

STABLE PROTON ?

In models such as $SU(5)$ or $SO(10)$ the higgsino mediated dim 5 p decay can be suppressed by a variety of mechanisms. With $M_{GUT} \sim 10^{16}$ GeV, the gauge boson mediated proton decay yields $\tau_p \rightarrow 10^{34-36}$ yr (with $p \rightarrow e\pi$, etc.).

motivated by superstring.

In models such as $SU(3) \times SU(3) \times SU(3)$ you can suppress the proton decay rate to unobservable levels. For instance, in one example, the mechanism responsible for the solution of the μ problem $\left(\mu \sim M_{GUT} \rightarrow M_{GUT} \times \frac{M_W}{M_S} \right)$

also provides the same suppression for the proton decay amplitude.

(there is no gauge boson mediated decay)

BOTTOM Line :

Proton 'necessarily' decays according to $SU(5)/SO(10)$, but is essentially stable in a class of well motivated unified models.

They include $SU(4) \times SU(2) \times SU(2)$ and $SU(3) \times SU(3) \times SU(3)$. All such schemes require new physics. Origin? (cf: CY)

Proton Decay & Magnetic Monopoles in Susy Trinification

Gauge Group $G \equiv SU(3)_c \times SU(3)_L \times SU(3)_R$

Matter Superfields :

$SU(2)_L$ lepton doublet

$$\lambda_i \sim (1, \bar{3}, 3) = \begin{pmatrix} H^u & H^d & L \\ e^c & \nu^c & N \end{pmatrix}_i \updownarrow SU(3)_L$$

$$\xleftarrow{\quad SU(3)_R \quad}$$

$$Q_i \sim (3, 3, 1) = \begin{pmatrix} u \\ d \\ g \end{pmatrix}$$

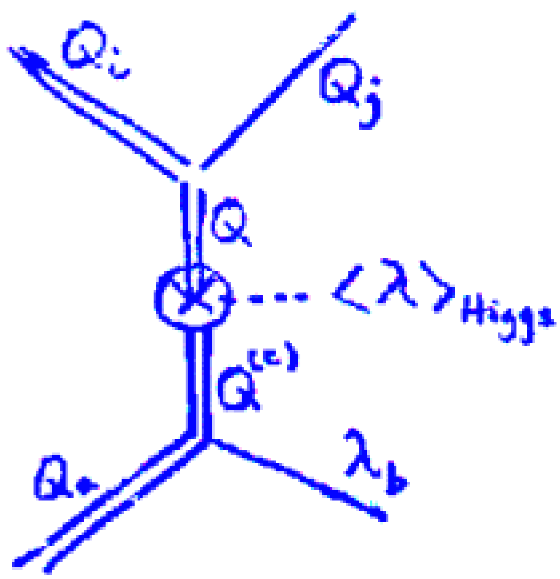
$$Q_i^{(c)} \sim (\bar{3}, 1, \bar{3}) = (u^c \;\; d^c \;\; g^c)$$

(Higgs fields transform like λ_i. Just as in MSSM, 'matter' parity is used)

Salient features:

1) Relatively easy to solve the μ-problem;

2) Dim 5 p decay suppressed (relative to SU(5)/SO(10)) by the gauge hierarchy factor M_W/M_{GUT}

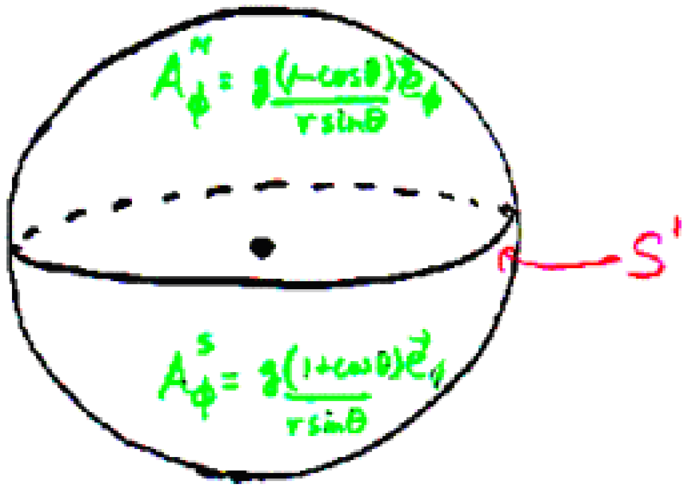


$\lambda^3_{Higgs} \xrightarrow{\mu\,\text{term}}$ suppressed by $\frac{M_W}{M_{GUT}}$

$\Rightarrow$ $QQ^{(c)}\lambda$ also suppressed by same factor!!

$\Rightarrow$ 'stable' proton

Monopoles & Topology



Require two vector potentials to avoid singularity. In the overlap region the two differ by a gauge transformation.

One essentially has a map from $S^1 \to U(1)$ which is classified by integers.

For instance, $A_\phi^N(\theta=\pi/2) - A_\phi^S(\theta=\pi/2) = \frac{1}{r}2g$

$$= \frac{1}{ier}(\partial_\phi \Omega)\,\Omega^{-1}$$

So $\quad \Omega(\phi) = \exp(i2eg\phi)$

$$\Rightarrow eg = n/2$$

Consider the symmetry breaking

$G \to H$. Monopoles arise

if $\pi_2(\underbrace{G/H}_{\text{vacuum manifold}})$ is non-trivial.

maps S^2 into G/H

($\pi_2(G/H) \sim \pi_1(H)$ if G is simply connected;) since $H \supset U(1)$, you get monopoles.

Examples

$SU(5)$ / $SO(10) \longrightarrow$ 3 - 2 - 1 (monopoles carry 1 unit of Dirac charge; mass $\sim 10^{17}$ GeV)

$SO(10) \longrightarrow SU(4) \times SU(2) \times SU(2) \longrightarrow$ 3 - 2 - 1

superheavy monopoles 1 Dirac unit

somewhat 'lighter' monopoles with 2 Dirac quanta (mass $\sim 10^{13}$ GeV)

('Lighter' monopoles with extra dim?)

In the old fashioned SUSY GUTs unified theories monopoles are expected to be superheavy $\sim 10^{17}$ GeV (or so). Consequently we must search for primordial monopoles, possibly produced during some GUT phase transition in the early universe.

The flux of such monopoles is expected to be $\lesssim 10^{-16}$ cm^{-2} sec^{-1} sr^{-1} (Parker bound)

(If monopoles catalyze nucleon decay we may get more stringent limits)

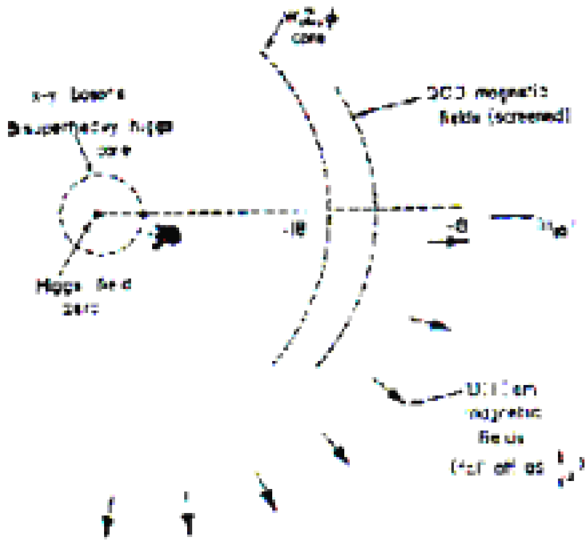
In higher dimensional theories it is conceivable that monopole masses $\ll 10^{17}$ GeV.

(esp. if the fundamental scale is low)

Core size $R \sim M_{GUT}^{-1}$ (In a class of SUSY GUTS, core size $\sim$ TeV^{-1})

Mass $M \sim M_{GUT}/\alpha_G$

$\Rightarrow$ $R \sim \alpha_G^{-1} M^{-1} \gg$ Compton Wavelength (almost classical object)



Parker pointed out that a background flux of magnetic monopoles could significantly reduce the magnetic fields associated with galaxies.

Assuming that the origin of these fields is unrelated to the monopole background, one estimates that the flux of monopoles should be smaller than

$$F_p \sim \frac{B}{8\pi g T} \sim 10^{-15} - 10^{-16}\ \mathrm{cm}^{-2}\ \mathrm{sr}^{-1}\ \mathrm{sec}^{-1}$$

where $B \sim 3\times10^{-6}$ gauss,

$T \sim 10^{8}$ years (regeneration time)

Flux Limits on very heavy ($\sim 10^{19}$ GeV) monopoles are somewhat weaker.

dynamo effect of the motions of interstellar gas

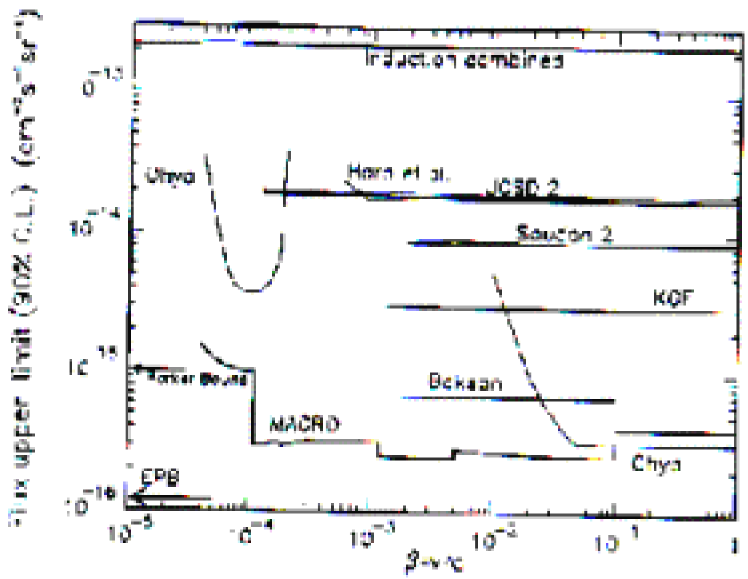
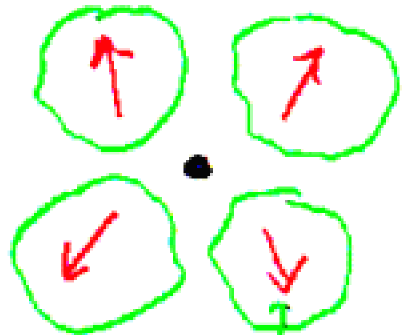


Figure 5: Compilation of 90% C.L. of direct experimental upper limits on an isotropic MM flux reaching detectors at the surface or underground [24].

G. Giacomelli & L. Patrizii

Monopoles & Inflation

In standard cosmology and with quartic higgs potential, a huge number density of monopoles arises during the GUT symmetry breaking phase transition.



order parameter

$$r_{in} \equiv n/T^3$$

$$\sim \frac{1}{\xi^3 T^3} \sim \mathcal{O}(10^{-2})$$

size of fluctuation region of higgs $\sim T^{-1}$

(Cf: $n_b/s \sim 10^{-11}$ with $m_M \sim 10^{17}$ GeV)

Due to the rapid expansion of the early universe there is no significant m-$\bar{m}$ annihilation

$\Rightarrow$ monopoles & standard cosmology is a disastrous combination.

During the last decade or so inflation has superceded standard cosmology, so the question is:

Can monopoles survive inflation?

Suppose monopoles are produced at/near the end of an inflationary epoch (after hybrid inflation, for instance). We now need some phase transition which can provide substantial dilution. Electroweak phase transition won't do (insufficient dilution, baryogenesis?, ...)

Consider, however, the phase transition associated with axion physics, the $U(1)$ symmetry breaking scale being $\sim 10^{12}$ GeV (with GL)

Consider the potential (common in SUSY models)

$$V(\phi) = -M_s^2\phi^2 + \frac{\phi^6}{M_{Planck}^2}$$

$$\Rightarrow \langle\phi\rangle \sim \sqrt{M_P M_S} \sim 10^{11} - 10^{12}\ \text{GeV}$$

axion symmetry breaking scale (Choi, Kim, Miller, ...)

In contrast to quartic potentials

$(\mathcal{U}(\phi) = -\mu^2\phi^2 + \phi^4,\ \langle\phi\rangle \sim \mu \sim 10^{11} - 10^{12}\ \text{GeV})$,

phase transitions associated with $V(\phi)$ occur after a certain amount of supercooling (inflation), and generate a significant amount of entropy.

It can be shown that this mechanism can dilute the primordial monopole number density to a level comparable to the Parker bound (or an order or two below). Challenge: n_b/s ? (Riotto et al)

- $V_T(\text{quartic}) \sim T^2\phi^2 - \mu^2\phi^2 + \lambda\phi^4$

  $\Rightarrow T_c \sim \mu \sim 10^{12}\ \text{GeV}$

- $V_T(\text{SUSY}) \sim T^2\phi^2 - M_S^2\phi^2 + \dfrac{\phi^6}{M_P^2}$

  $\Rightarrow T_c \sim M_S \sim \text{TeV} \ll \langle\phi\rangle \sim 10^{12}\ \text{GeV}$

  $\Rightarrow$ supercooling (thermal inflation)

  $\Rightarrow$ significant entropy production

There is one other amusing application of this scenario.

Just as EW phase transition in MSSM is driven by a heavy top quark, the axion phase transition also requires new fermions (and bosons) with masses $\sim 10^{12}$ GeV. The 'Lightest' ($\sim 10^{12}$ GeV!) guy is stable or quasi-stable, being protected by the analogue of 'matter' parity. Candidate for cold dark matter and may be useful for cosmic ray physics (Berezinsky et al, Kuzmin et al, ...)

MONOPOLES & INFLATION (non-SUSY)

Consider the breaking (Buccella)

$$
\begin{array}{ccc}
SO(10) & \xrightarrow[\sim 10^{16}\,\text{GeV}]{} & SU(4) \times SU(2) \times SU(2) \\
 & & \big\downarrow \sim 10^{12}\,\text{GeV} \\
 & & SU(3) \times SU(2) \times U(1)
\end{array}
$$

The first breaking produces monopoles that are inflated away.

Depending on the scheme, the second breaking produces monopoles (with mass $\sim 10^{13}$ GeV) that can survive inflation. These monopoles are stable, doubly 'charged', and do not catalyze nucleon decay (not possible in $SU(5)$).

(G. Lazarides, Q.S)

MAGNETIC MONOPOLES IN $SU(3) \times SU(3) \times SU(3)$

Monopoles carry three units of Dirac magnetic charge;

Not expected to catalyze nucleon decay;

Monopole number density can be suppressed to a level compatible with Parker bound;

Their presence predicts the existence of color singlet, charge $\pm e/3$ states, with an undetermined mass.

One should search for such states both at accelerators & elsewhere.

Magnetic Monopoles arise in a variety of unified gauge theories :

In theories such as SU(5) or SO(10), the lightest monopole carries one quantum of Dirac magnetic charge ($eg = n/2$, $n = \pm 1, \ldots$)

(topological)

In other examples such as $SU(4)_C \times SU(2)_L \times SU(2)_R$ or $SU(3)_C \times SU(3)_L \times SU(3)_R$ we have monopoles carrying two or three quanta of the Dirac charge. (Where are the corresponding fractionally charged singlets?)

Thus, discovery of a monopole will yield important information about the underlying theory (Cf: Proton decay)

LIGHT MAGNETIC MONOPOLES ?

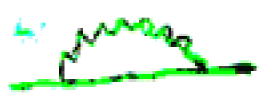
In principle, one could have monopoles as light as ~ 1 – 10 TeV. The question is :

Are there 'realistic' models that accomplish this ?

One possibility may be offered by type I string theory in which the string scale is lowered down to a few TeV (Antoniadis, Witten, Lykken, Arkani-Hamed et al., ...)

Gauge Interactions → described by open strings with ends confined on D-branes (solitons in string theory);

Gravity – mediated by closed strings that propagate in bulk;



Invoke two or more large transverse dimensions to account for the observed hierarchy $\mathrm{TeV}/M_P \sim 10^{-15} - 10^{-16}$.

In this case weak scale SUSY is not needed.

For instance, $SU(3) \times SU(2) \times U(1)$ can arise from a collection of stacks of D-branes associated with

$$\underbrace{U(3)}_{\text{stack of 3 coincident D-branes}} \times \underbrace{U(2)}_{\text{stack of 2 coincident D-branes}} \times \underbrace{U(1)}_{\text{single D-brane}}.$$

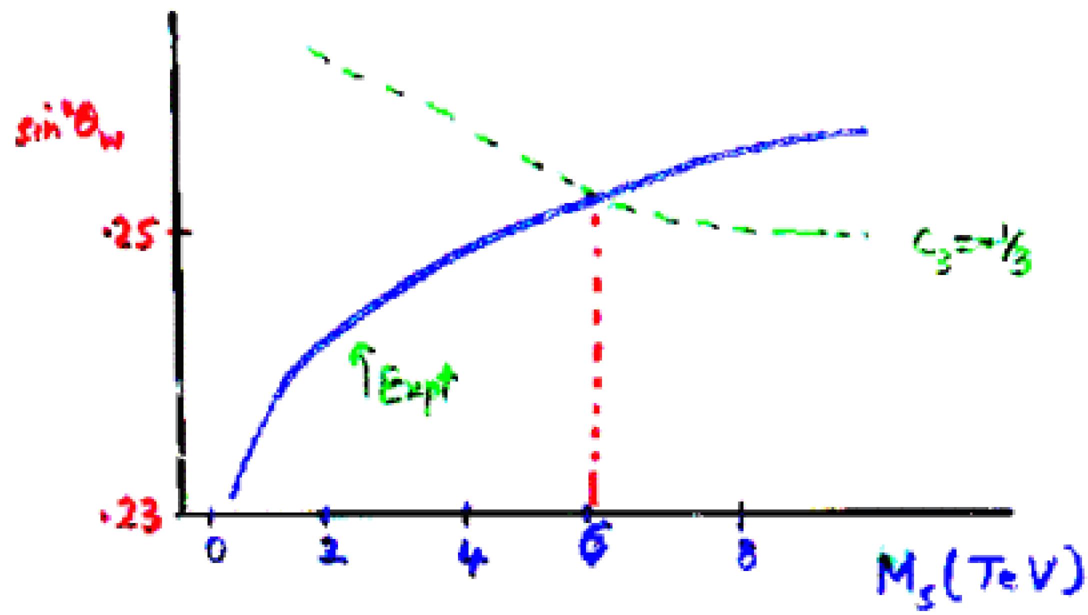
The weak hypercharge Y is:

$$Y = c_1 Q_1 + c_2 Q_2 + c_3 Q_3$$

(Q_i associated with the three $U(1)$'s)

With $g_1 = g_3$ at M_s (string scale)

$$\sin^2\theta_W(M_s) = \frac{1}{2 + 2(1+3c_3^2)\, g_2^2(M_s)/g_3^2(M_s)}$$



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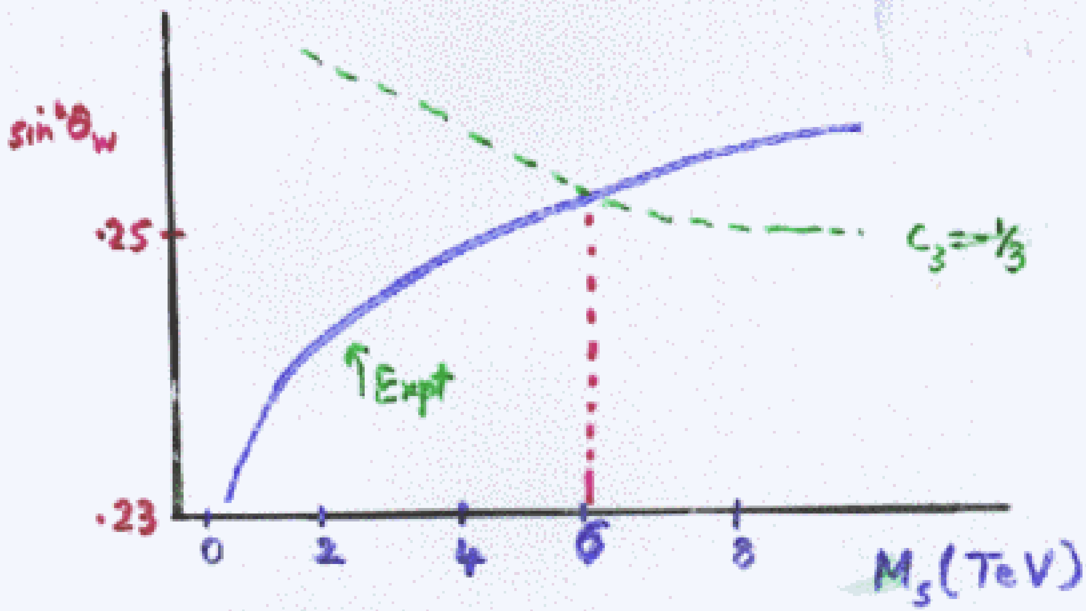


Discussion can be extended

to gauge groups such as

$SU(4)_c \times SU(2)_L \times SU(2)_R$ (Leontaris Rizos)

with $M_s \sim$ few $-$ 10 TeV.

(Proton stability assured by an unbroken $U(1)_B$ global symmetry)

In this model we expect monopoles with mass $\sim$ 10–100 TeV.

Is there a FIFTH dimension ?

MOTIVATION

- Superstrings / M-theory require extra dimensions.
- Gauge Hierarchy Problem

LARGE Extra Dimension(s)
(only felt by gravity)

Arkani-Hamed
Dimopoulos
Dvali
Antoniadis
⋮

$$\text{Spacetime} = M_4 \times I_n$$

$$M_{Planck}^2 = M_f^{n+2} \, V_n$$

$$n=2: \quad R \sim \text{mm}$$

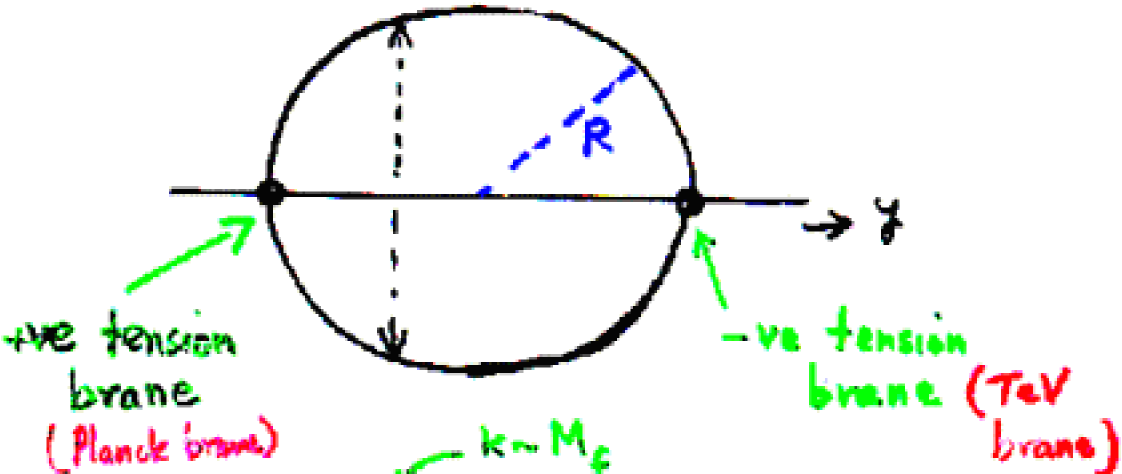
$$M_f \sim \text{TeV}$$

But : hierarchy between M_f and R^{-1} ??

WARPED GEOMETRY

Randall
Sundrum
[illegible]:
⋮

One extra dimension which corresponds to the orbifold S^1/Z_2



$k \sim M_5$

$$ds^2 = \underbrace{e^{-2k|y|}}_{\text{warp factor}} \eta_{\mu\nu}\, dx^\mu\, dx^\nu + dy^2$$

$$M^2_{Planck} = \frac{M_5^3}{k}\left(1 - e^{-2kR\pi}\right)$$

$$v = v_0\, e^{-kR\pi} \sim \text{TeV (!)}$$

v: vev in 4d effective theory

v_0: VEV in 5 dim

Original Proposal

All SM fields reside on the TeV brane ; only gravity feels the extra dimension.

$\Rightarrow$ hierarchy problem under control!
(scale on TeV-brane ~ TeV)

BUT

Difficulty with non-renormalizabe operators :

$$\frac{1}{M_{Pl}^2} \bar{\psi}\psi\bar{\psi}\psi \longrightarrow \frac{1}{(TeV)^2} \bar{\psi}\psi\bar{\psi}\psi$$

→ Rapid p decay

→ Large FCNC

→ Large neutrino masses

WAY OUT ?

- Symmetries ?

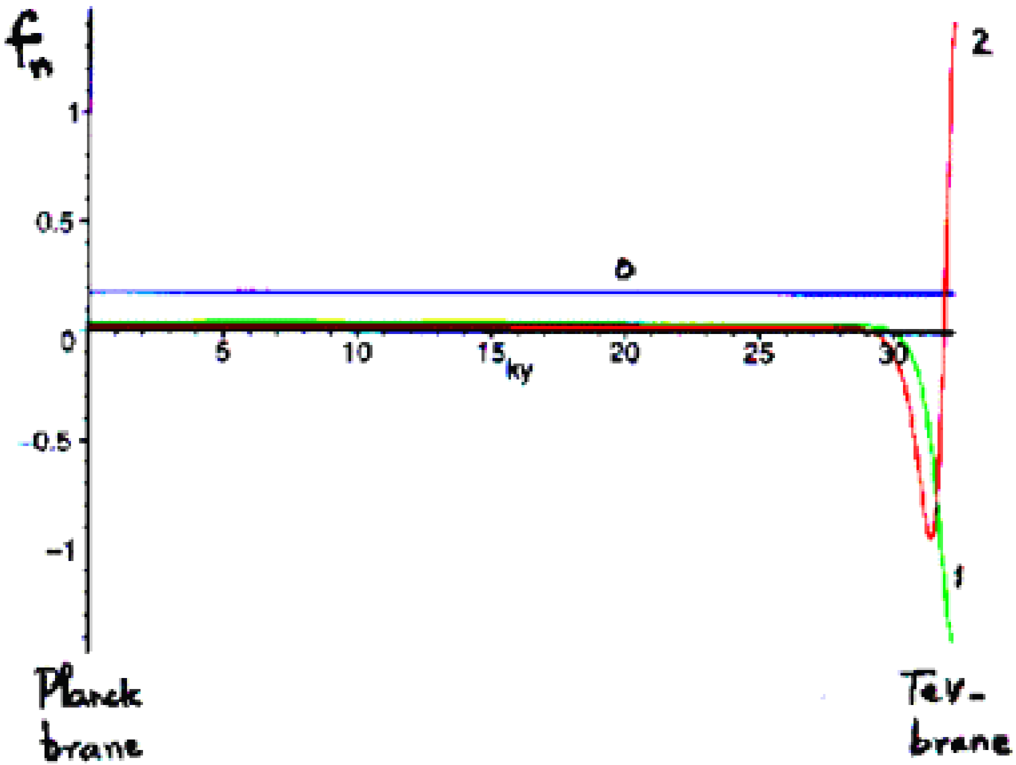
- Permit SM fields to leave the brane ? (Higgs stays on the TeV brane)

Gherghetta
Pomarol
Hewett et al
Huber + QS

5d Bulk field $\Longrightarrow$ Tower of 4d fields

KK ansatz: $\Phi(x^\mu, y) = \sum_{n=0}^{\infty} \Phi^n(x^\mu) f_n(y)$

wave fns
from field eq^{ns}



f_n
1
0.5
0
-0.5
-1
5
10
15
ky
20
25
30
0
1
2
Planck brane
Tev-brane

Bounds on KK Gauge Bosons

- Higgs on the TeV-brane

- Zero mode (gauge boson) becomes massive

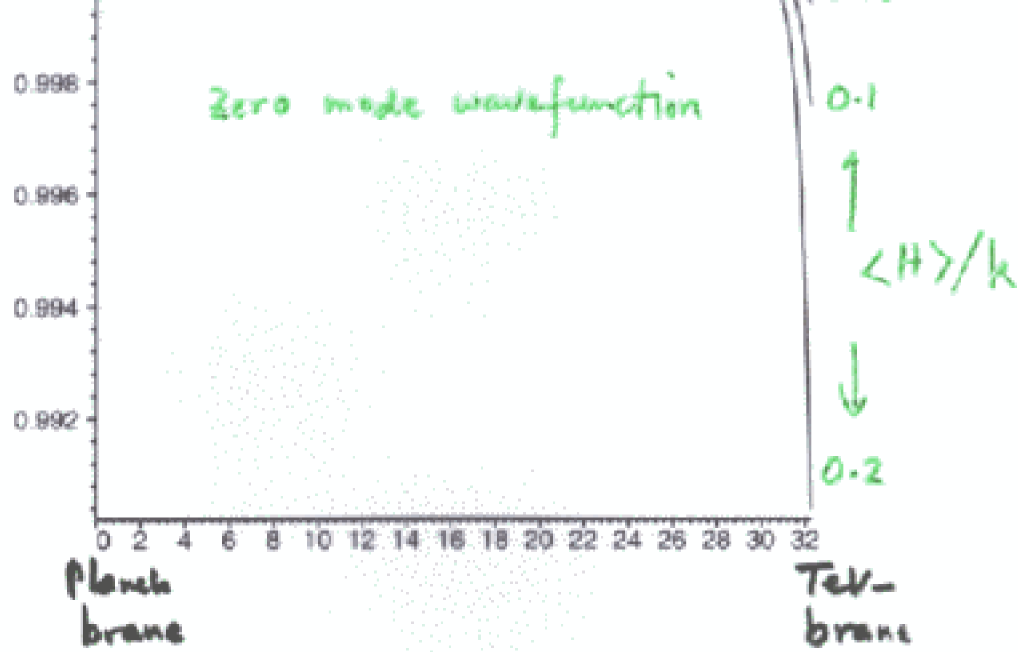
$\longrightarrow$ wavefunction f_0 becomes y dependent

In particular, f_0 reduced at the TeV-brane

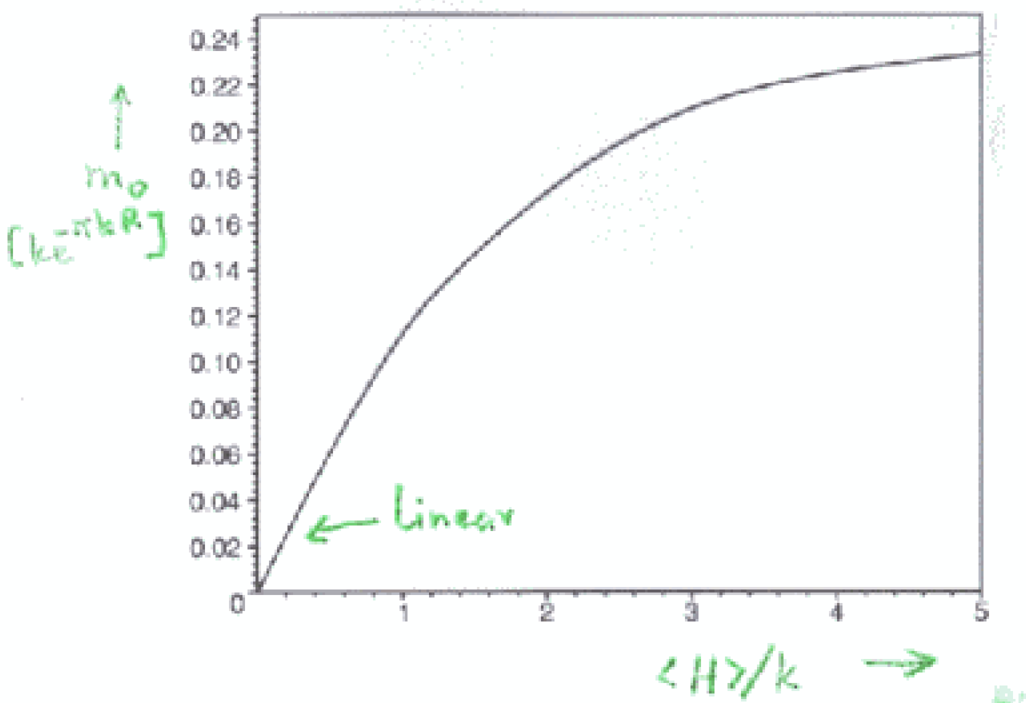
SM relationship between M_Z, M_W and coupling modified

$\Rightarrow$ bound on the TeV-brane KK scale

$$m_1 \sim k e^{-\pi k R} \gtrsim 10\,\text{TeV} \quad \left(\langle H\rangle/k \lesssim 10^{-2}\right)$$



0.998
0.996
0.994
0.992
Zero mode wavefunction
0.1
<H>/k
0.2
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32
Planck brane
TeV-brane



0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
m_0
$[ke^{-\pi kR}]$
linear
1 2 3 4 5
<H>/k

SM fermions arise as 'zero' modes of the KK decomposition.

Grossmann Neubert Huber + QS

5d Dirac mass $m_\psi = ck$

(Note: $\psi(-y) = \pm\gamma_5 \psi(y)$)

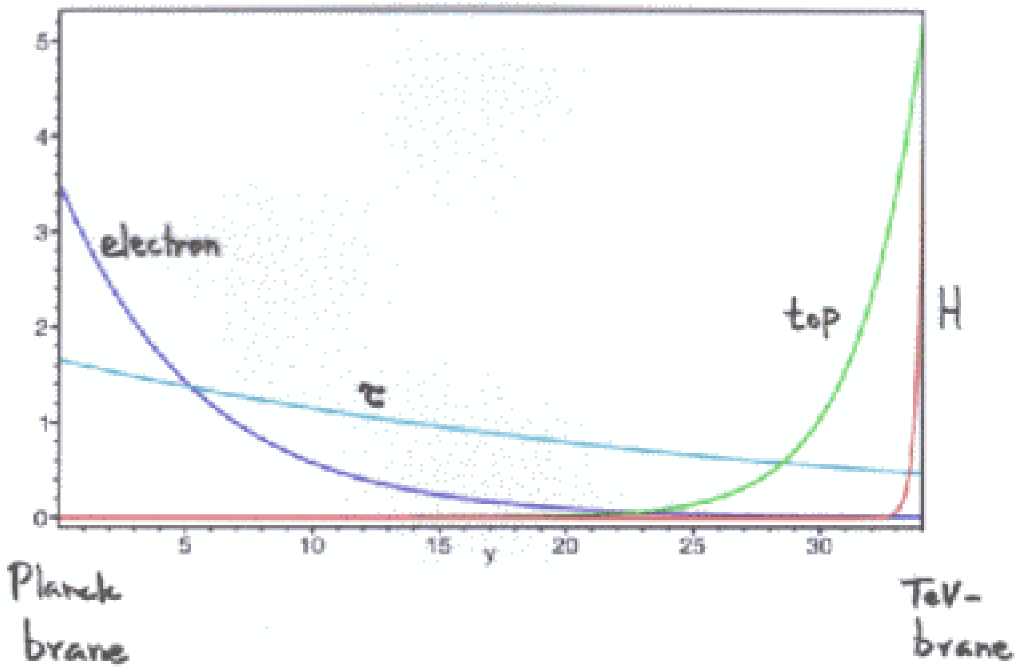
$m_n \sim n\pi k e^{-\pi kR}$ ← excited states

For $c > \frac{1}{2}$: zero mode localized (exponential) → Planck brane

$c < \frac{1}{2}$: zero mode → TeV-brane

Fermion mass hierarchy: Determined by the overlap between the fermion wave functions and Higgs (on TeV brane)

E.g: $c(e) = 0.68$, $c(\mu) = 0.59$, $c(\tau) = 0.54$



5
4
3
2
1
0
electron
τ
top
H
5
10
15
y
20
25
30
Planck
brane
TeV-
brane

Non-Renormalizable Operators

$$\int d^4x \int dy \sqrt{-g}\ \frac{1}{M_5^3}\ \bar{\psi}_i \psi_j \bar{\psi}_k \psi_\ell$$

$$\rightarrow \int d^4x\ \frac{1}{M^2}\ \bar{\psi}_i^{(0)} \psi_j^{(0)} \bar{\psi}_k^{(0)} \psi_\ell^{(0)}$$

EXAMPLES

	Expt	Model
• FCNC $\left(\frac{1}{M^2}(\bar{d}s)^2\right)$	$M \gtrsim 10^6$ GeV	✓
• $n-\bar{n}$ oscillations	$\gtrsim 10^5$ GeV	✓
• p decay	$\gtrsim 10^{15}$ GeV	$\sim 10^{11}$ GeV
• dim 5 ν masses	$\Delta m \lesssim 0.1$ eV	$m_{\nu_\tau} \sim$ keV

Need new ingredient

(e.g. $U(1)_L$?)

Neutrino Oscillations in RS

- 3 right-handed ν's in bulk
- Dirac mass from

$$\int d^4x \int dy \sqrt{-G}\; \frac{\lambda^{(5)}_{ij}}{\sqrt{k}}\, H\, \bar{L}^i\, \psi^j$$

TeV-brane

'Bulk'

RH-ν near Planck brane

!! (Dirac masses suppressed)

Spectrum (flavor index suppressed)

SM ν's : KK-tower
$$\begin{cases} \nu_L^{(0)}, & \nu_L^{(1)}, \quad \nu_L^{(2)}, \ldots \\ -, & \nu_R^{(1)}, \quad \nu_R^{(2)}, \ldots \end{cases}$$

Sterile ν's (Right-handed)
$$\begin{cases} -, & \psi_L^{(1)}, \quad \psi_L^{(2)}, \ldots \\ \psi_R^{(0)}, & \psi_R^{(1)}, \quad \psi_R^{(2)}, \ldots \end{cases}$$

Neutrino Mass Matrix

$$
\begin{array}{c|cccc}
 & \psi_R^{(0)} & \nu_R^{(1)} & \psi_R^{(1)} & \cdots \\
\hline
\nu_L^{(0)} & \langle H \rangle & 0 & \langle H \rangle & \cdots \\
\nu_L^{(1)} & \langle H \rangle & M & \langle H \rangle & \cdots \\
\psi_L^{(1)} & 0 & \langle H \rangle & \underset{\substack{\uparrow \\ \text{KK scale}}}{M} & \\
\vdots & \vdots & \vdots & & \ddots
\end{array}
$$

For solar ν both small and large mixing angle solutions can be realized, depending on how we choose the 'c' parameters.

Consider bimaximal mixing

ν_L: $c_{e_L} = c_{\mu_L} = c_{\tau_L} = 0.57$ } ← Explains $m_\tau \gg m_\mu \gg m_e$

$(c_{e_R} = 0.79,\ c_{\mu_R} = 0.62,\ c_{\tau_R} = 0.50)$

ψ_R: $c_{\psi_1} = 1.43$, $c_{\psi_2} = 1.36$, $c_{\psi_3} = 1.30$

Large MSW

5-d coupling → $$\lambda_{ij} = \begin{pmatrix} 2.0 & -1.5 & 0.5 \\ 1.8 & 1.1 & -1.9 \\ -0.5 & -1.9 & -1.7 \end{pmatrix}$$

$\Delta m_1^2 = 5 \cdot 10^{-2}\ eV^2 \rightarrow$ atm $(\sim m_{\nu_1})$

$\Delta m_2^2 = 9 \cdot 10^{-5}\ eV^2 \rightarrow$ solar $(\sim m_{\nu_2})$

$\sin^2 2\theta_{23} \simeq 0.98 \rightarrow$ atm

$\sin^2 2\theta_{12} \simeq 0.78 \rightarrow$ solar

KK contributions to $(g-2)_\mu$

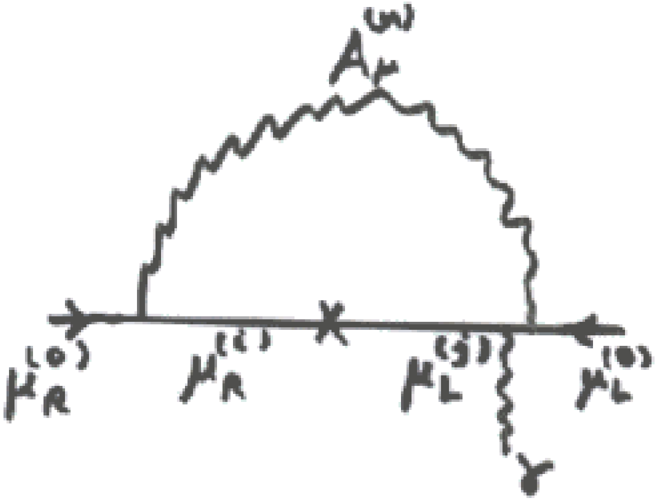
$$c_{\mu_L} = 0.57, \quad c_{\mu_R} = 0.61$$

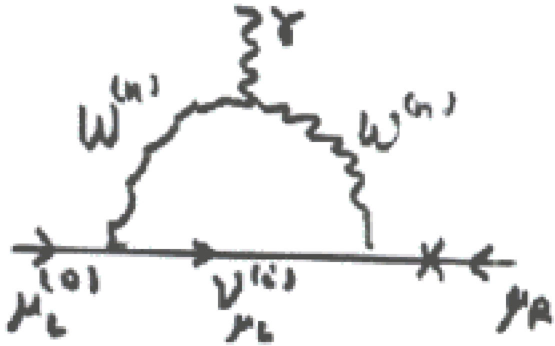
- Gauge boson

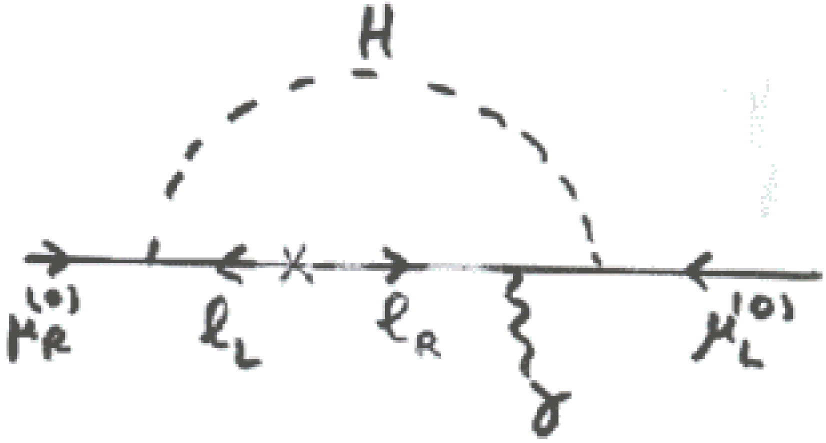
$$\Delta a_\mu^{(A)} = -5 \cdot 10^{-12} \left(\frac{10\,\text{TeV}}{m_{KK}}\right)^2$$

- Higgs

$$\Delta a_\mu^{(H)} = -3 \cdot 10^{-11} \left(\frac{10\,\text{TeV}}{m_{KK}}\right)^2$$


$A_\mu^{(n)}$
$\mu_R^{(0)}$
$\mu_R^{(i)}$
$\mu_L^{(j)}$
$\mu_L^{(0)}$
γ


γ
$W^{(n)}$
$W^{(n)}$
$\mu_L^{(0)}$
$\nu_{\mu_L}^{(i)}$
μ_R


H
$\mu_R^{(0)}$
ℓ_L
ℓ_R
γ
$\mu_L^{(0)}$

CONCLUSION

NEED ANSWERS TO THE FOLLOWING

- IS PROTON STABLE ?
- PRIMORDIAL SUPERHEAVY MONOPOLES ?

  'LIGHT' MONOPOLES?
- COLOR SINGLET FRACTIONAL CHARGES ?
- KALUZA-KLEIN TeV states?
  (5^{th} dim)
- REALISTIC HIGHER DIMENSIONAL MODELS ?