# - Sterile neutrinos (and μ-term phenomenology)

# from D-brane string models

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# OUTLINE

- Neutrino (s) mass **in** the Standard Model

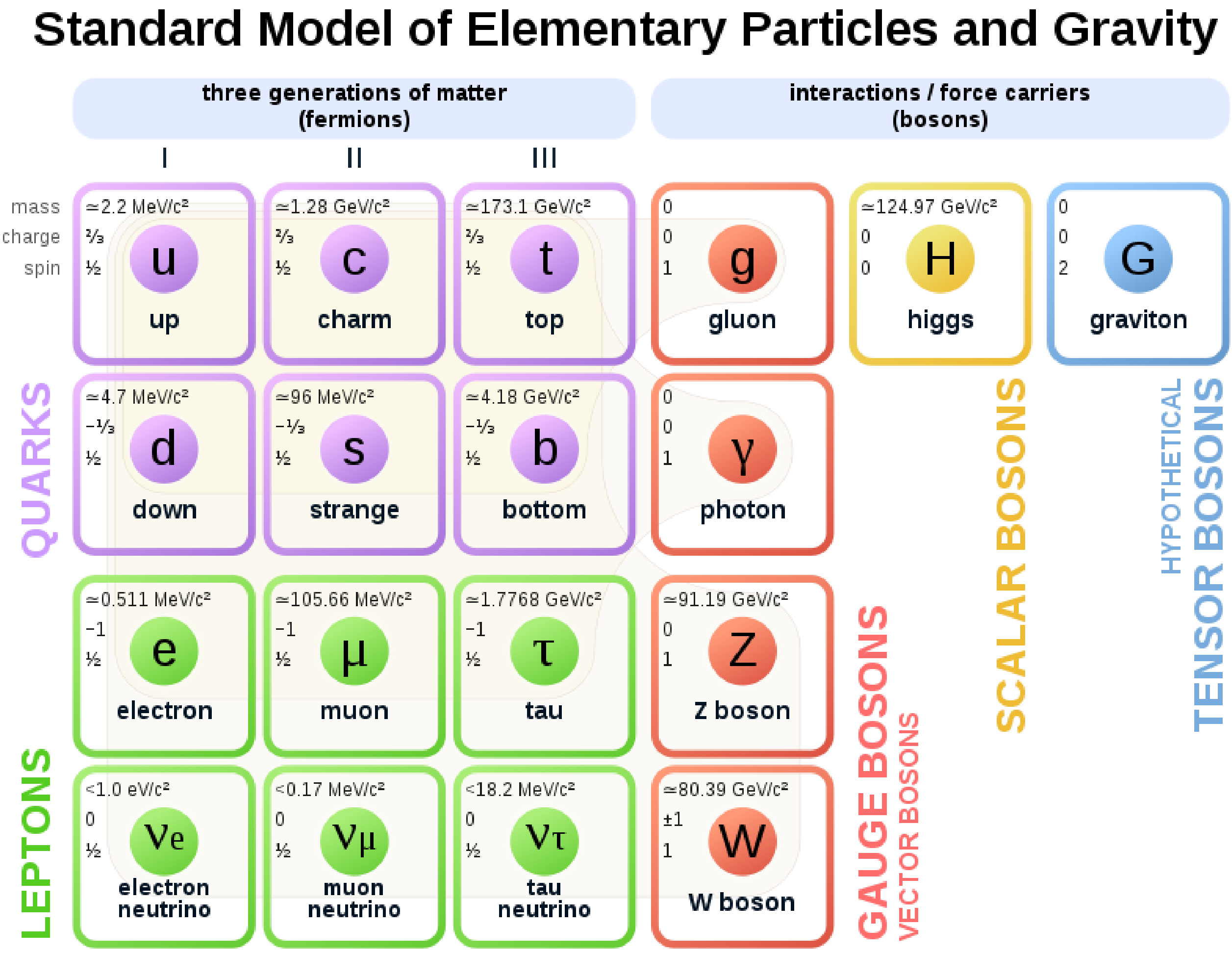
- Neutrino (s) mass **beyond** the Standard Model

- Neutrino (s) masses **in** (**non-SUSY intersecting brane**) models

- **Sterile Neutrinos** + **mass limits** in (non-SUSY intersecting brane) models

- • models with :
  **gauged baryon number** (stable proton)
  \+ **right handed neutrinos**
  \+ **sterile neutrinos**

# STANDARD MODEL neutrinos



- Accommodates 3 generations of neutrinos
- NO Mass term for neutrinos
- Baryon (B) &  
  Lepton (L) number → classically conserved (global abelian symmetries)
- B & L broken non-perturbatively

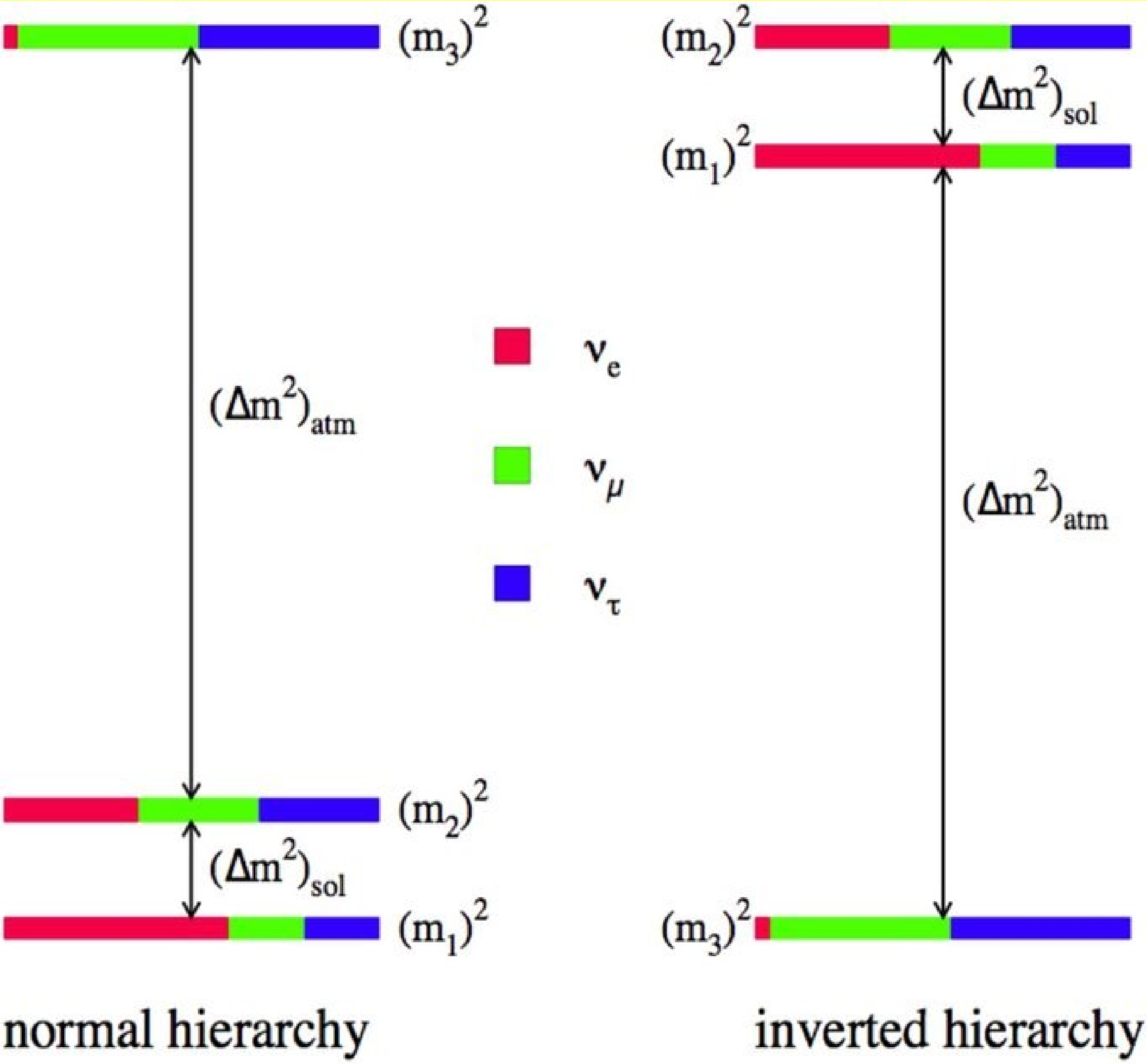
t'Hooft, Klinkhammer, & Manton

- B-L conserved

# NEUTRINOS beyond the SM

- No mass term for neutrinos in the SM
- A mass can only be introduced beyond the SM e.g. by adding a right handed neutrino(s)
    - Discovery of neutrino oscillations (Super-Kamiokande experiment /1998)

**Neutrinos have a non-zero mass => BEYOND SM**



http://www.hyper-k.org/en/physics/phys-hierarchy.html

- No DM candidate at SM- need to introduce new particles beyond the SM

More info

- Dark Matter (DM) contributes five times more to the energy of the Universe than ordinary matter.

- (Weakly interacting) dark matter candidates => sterile neutrinos of KeV masses + with small mixing with active neutrinos.

See e.g.
Miguel D. Campos1, and Werner Rodejohann
https://arxiv.org/pdf/1605.02918.pdf;

Light sterile neutrinos :
A white paper,
https://arxiv.org/pdf/1204.5379.pdf;

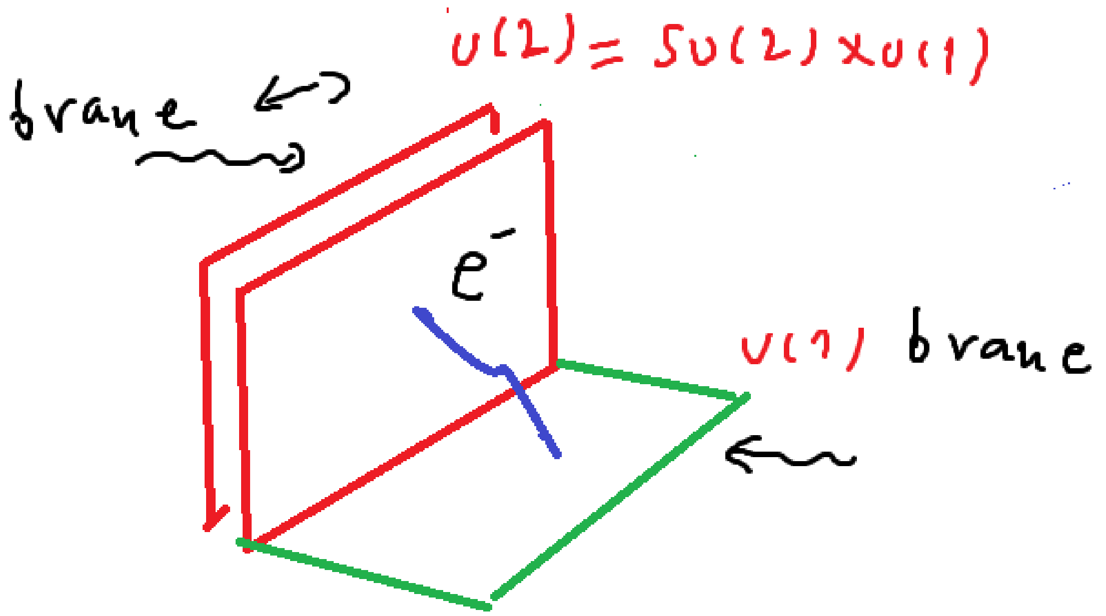
# STRING THEORY

- **Non-SUSY models with (gauged) B & L**

- Particles ➔ localized among intersecting branes

What is an intersecting brane ?
A higher dimensional hypersurface

Simplest representation:

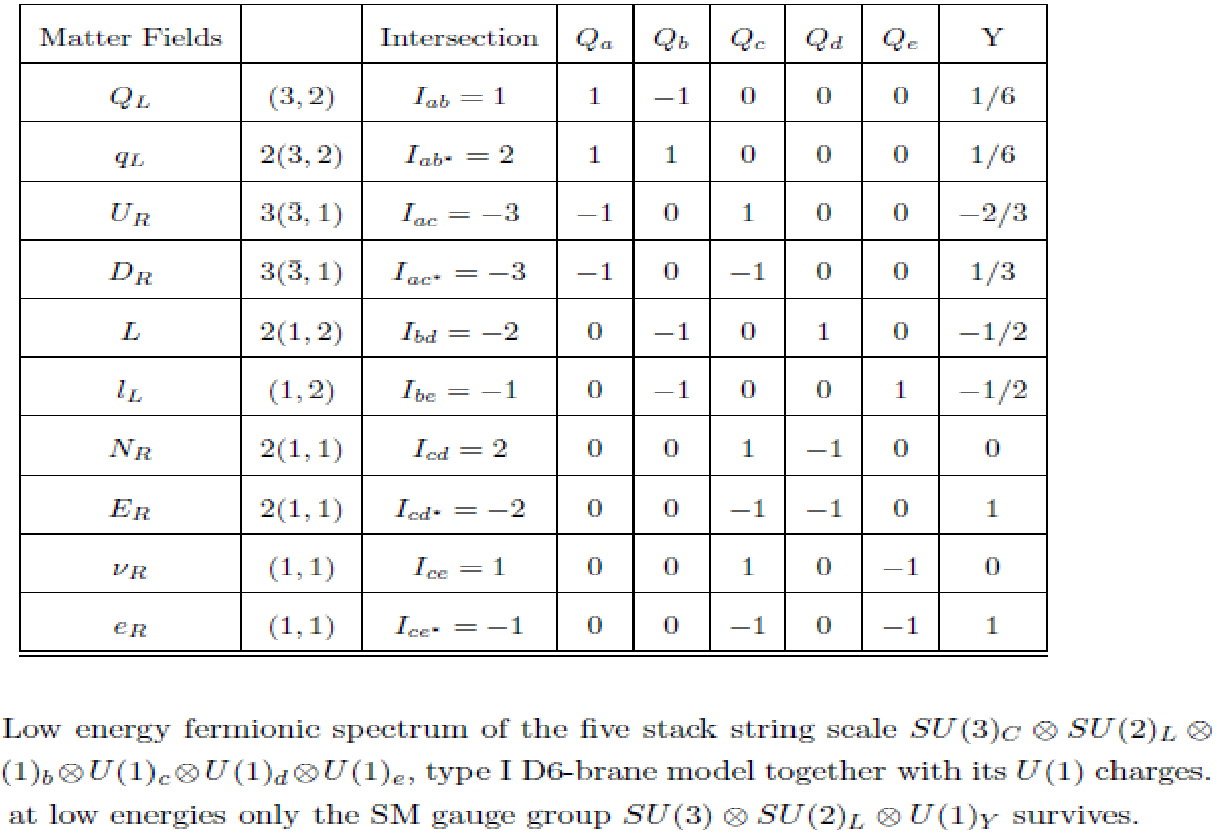


$e^-$ ➔ (2,1) representation ➔ and charges (1,-1) under U(2), U(1) branes resp.

Standard model at the string scale ➔ Gauge Group :

SU(3)a x SU(2)b x U(1)a x U(1) b x U(1)c x U(1) d x U(1)e

The models are NON-SUSY ==> BUT predict the existence of
1 or 2 SUSY particles ➔ sneutrino
C.K



| Matter Fields |  | Intersection | $Q_a$ | $Q_b$ | $Q_c$ | $Q_d$ | $Q_e$ | Y |
|---|---|---|---|---|---|---|---|---|
| $Q_L$ | $(3,2)$ | $I_{ab}=1$ | 1 | $-1$ | 0 | 0 | 0 | $1/6$ |
| $q_L$ | $2(3,2)$ | $I_{ab^\star}=2$ | 1 | 1 | 0 | 0 | 0 | $1/6$ |
| $U_R$ | $3(\bar{3},1)$ | $I_{ac}=-3$ | $-1$ | 0 | 1 | 0 | 0 | $-2/3$ |
| $D_R$ | $3(\bar{3},1)$ | $I_{ac^\star}=-3$ | $-1$ | 0 | $-1$ | 0 | 0 | $1/3$ |
| $L$ | $2(1,2)$ | $I_{bd}=-2$ | 0 | $-1$ | 0 | 1 | 0 | $-1/2$ |
| $l_L$ | $(1,2)$ | $I_{be}=-1$ | 0 | $-1$ | 0 | 0 | 1 | $-1/2$ |
| $N_R$ | $2(1,1)$ | $I_{cd}=2$ | 0 | 0 | 1 | $-1$ | 0 | 0 |
| $E_R$ | $2(1,1)$ | $I_{cd^\star}=-2$ | 0 | 0 | $-1$ | $-1$ | 0 | 1 |
| $\nu_R$ | $(1,1)$ | $I_{ce}=1$ | 0 | 0 | 1 | 0 | $-1$ | 0 |
| $e_R$ | $(1,1)$ | $I_{ce^\star}=-1$ | 0 | 0 | $-1$ | 0 | $-1$ | 1 |

Table 1: Low energy fermionic spectrum of the five stack string scale $SU(3)_C \otimes SU(2)_L \otimes U(1)_a \otimes U(1)_b \otimes U(1)_c \otimes U(1)_d \otimes U(1)_e$, type I D6-brane model together with its $U(1)$ charges. Note that at low energies only the SM gauge group $SU(3) \otimes SU(2)_L \otimes U(1)_Y$ survives.

- Number of fermions -> Intersection number

- Hypercharge

$$Y = \frac{1}{6}U(1)_a - \frac{1}{2}U(1)_c - \frac{1}{2}U(1)_d - \frac{1}{2}U(1)_e$$

●B is a gauged symmetry – All U1)–mixed gauge anomalies + cubic gauge anomalies cancel via a generalized Green-Schwarz mechanism

$$N_a m_a^1 m_a^2 m_a^3 \int_{M_4} B_2^o \wedge F_a \quad ; \quad n_b^1 n_b^2 n_b^3 \int_{M_4} C^o \wedge F_b \wedge F_b,$$
$$N_a n^J n^K m^I \int_{M_4} B_2^I \wedge F_a \quad ; \quad n_b^I m_b^J m_b^K \int_{M_4} C^I \wedge F_b \wedge F_b \,,$$

+ “PREDICTS”

- a Stringy explanation of

$b \to s\ell^+ \ell^-$ anomalies

A. Celis, W. Feng, D. Lust

↓↓

Stringy Z’ boson -> nonnegligible couplings to the first two quark generations

Z’ Mass➔ ~ [3.5, 5.5] TeV,

“possible to discover such a state” directly during the next LHC runs via Drell-Yan production in the di-electron or di-muon decay channels

$\mathrm{Br}(Z' \to \mu^+\mu^-)/\mathrm{Br}(Z' \to e^+e^-) \sim$ [0.5-0.9]

# NEUTRINO MASSES

$$Y_j^U Q_L U_R^j h_1 + Y_j^D Q_L D_R^j H_2 \quad +$$
$$Y_{ij}^u q_L^i U_R^j H_1 + Y_{ij}^d q_L^i D_R^j h_2 +$$
$$Y_h^l \, l_L^h \, \nu_R^h \, h_1 + \; Y_h^e l_L^h e_R^h H_2 \quad +$$

- $$Y_{ij}^N L^i N_R^j h_1 + Y_{ij}^E L_i E_R^j H_2 + \; h.c$$

  $i = 1, 2, \; j = 1, 2, 3, \; h = 1$

- can also originate via chiral symmetrybreaking

$$\alpha'(LN_R)\,(Q_L U_R)^\star, \;\; \alpha'(l\nu_R)(q_L U_R)$$

C.K

Ibanez, Marchesano, Rabadan

From u-quark chiral condensate

$$\frac{< u_R u_L >}{M_s^2} = \frac{(240MeV)^3}{M_s^2}$$

Mv's ~( 0.1-10) eV atmospheric neutrino data when $M^{\text{string}} \sim$ 1- few TeV

# STERILE NEUTRINOS

- Sterile neutrinos GAUGE THEORY → Inverse See Saw

$$\lambda_1 \nu_R \nu_L H + \lambda_2 \nu_R H N + \lambda_3 \frac{1}{M_{GUT}} \bar{K}^2 N N$$

$$m_D = \lambda_1 \langle H \rangle, \; V_R = \lambda_2 \langle H \rangle, \; \mu = \frac{\lambda_3}{M_{GUT}} \langle \tilde{\bar{K}} \rangle^2$$

- Sterile neutrinos in String theory

$$\begin{pmatrix} 0 & m_D^T & 0 \\ m_D & 0 & V_R \\ 0 & V_R & \mu \end{pmatrix}$$

Valle & Mohapatra,
Leontaris, Faraggi & Guzzi

# Intersecting Brane models sterile ν's

## Experimental constraints for sterile neutrino:

### 1) Oscillation experiments

The Daya Bay and Bugey-3 reactor experiments provide an upper limit

$\sin^2 2\theta_{14} \lesssim 0.06$ 90% C.L. $\Delta m_{41}^2 \approx 1.75\ \mathrm{eV}^2$

### 2) β-decay experiments

The β-decay of tritium can produce sterile neutrinos through mixing, which leads to a distortion in the electron energy spectrum. The current constraints on the mixing parameter, established by the non-detection of such distortion

$|U_{e4}|^2 \lesssim 10^{-2} - 10^{-3}$

10 eV < Sterile masses < 10 KeV

3) X-ray telescope

4) Phase space bound

5) Constraints from early Universe

## Experimental constraints for neutrinos:

**Katrin experiment** : $M\nu \leq 0.8$ eV

## ●For baryon number conserving intersecting D-brane models

⇨

eigenstate basis $(\nu_L, \nu_R, N_1)$

$$M_\nu \;=\; \begin{pmatrix} 0 & m_D & m_\Sigma \\ m_D & 0 & m_N \\ m_\Sigma & m_N & 0 \end{pmatrix}$$

$$\sqrt{m_D^2 + m_N^2 \;+\; m_\Sigma^2} \;+\; \frac{m_D m_N m_\Sigma}{m_D^2 + m_N^2 + m_\Sigma^2} - \frac{3(m_D m_N m_\Sigma)^2}{2(m_D^2 + m_N^2 + m_\Sigma^2)^{5/2}} + .$$

$M^{\mathrm{sterile}} = 1.75$ eV &

$m^{\nu L} = 0.8$ eV ➔

$m^{\nu R} > 9.6$ eV

Antoniadis, C.K