Sterile neutrino from D-brane SM-like models

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OUTLINE

- Neutrino (s) mass in the Standard Model

- Neutrino (s) mass beyond Standard Model
  (D-branes)

• Neutrino mass in string theory
  e.g Intersecting D6-brane models
[open strings]

• • Examine models with :

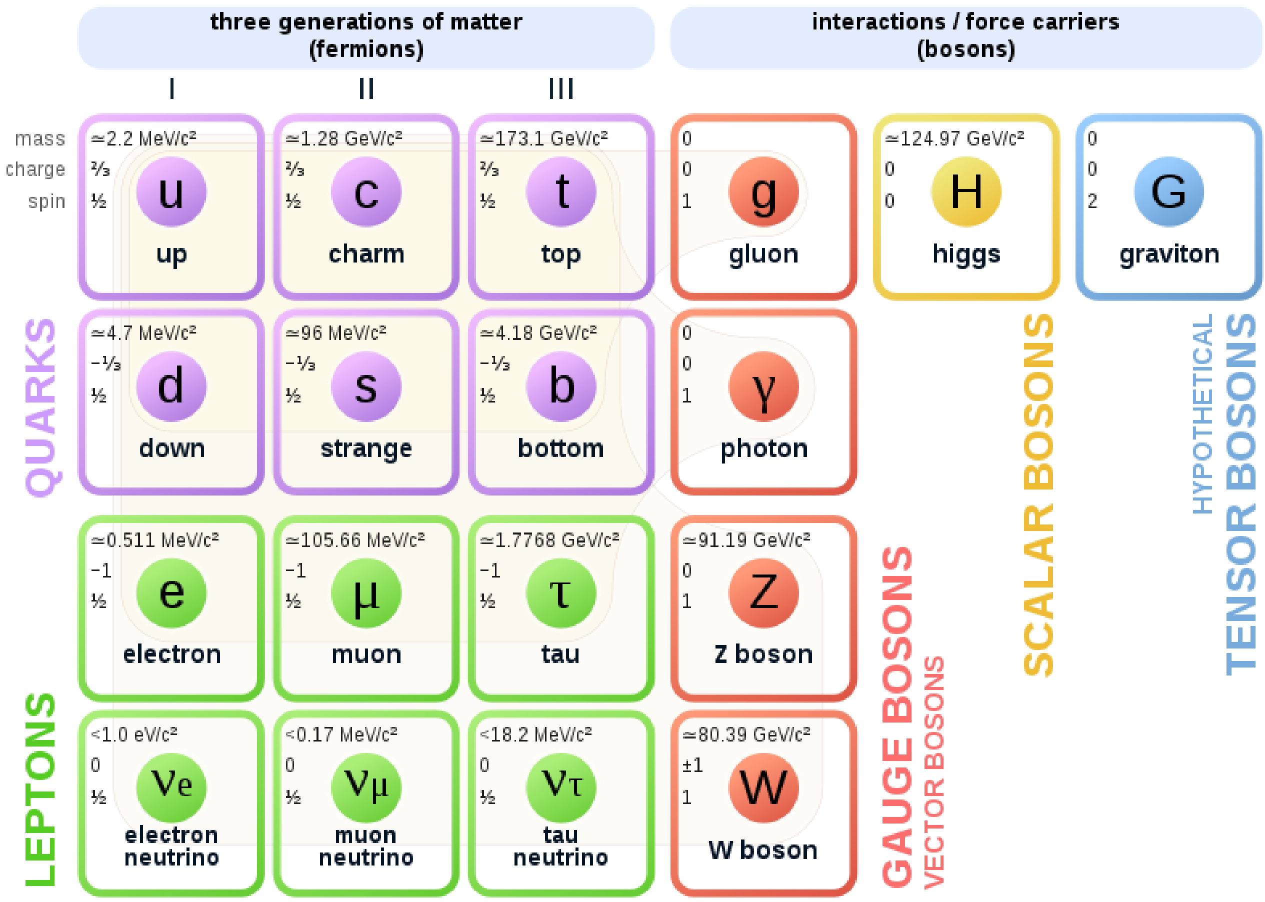
gauged baryon number (stable proton)	➔	√
right handed neutrinos	➔	√
sterile neutrinos	➔	?

\+ right handed neutrinos

\+

→ → STANDARD MODEL from D-Branes

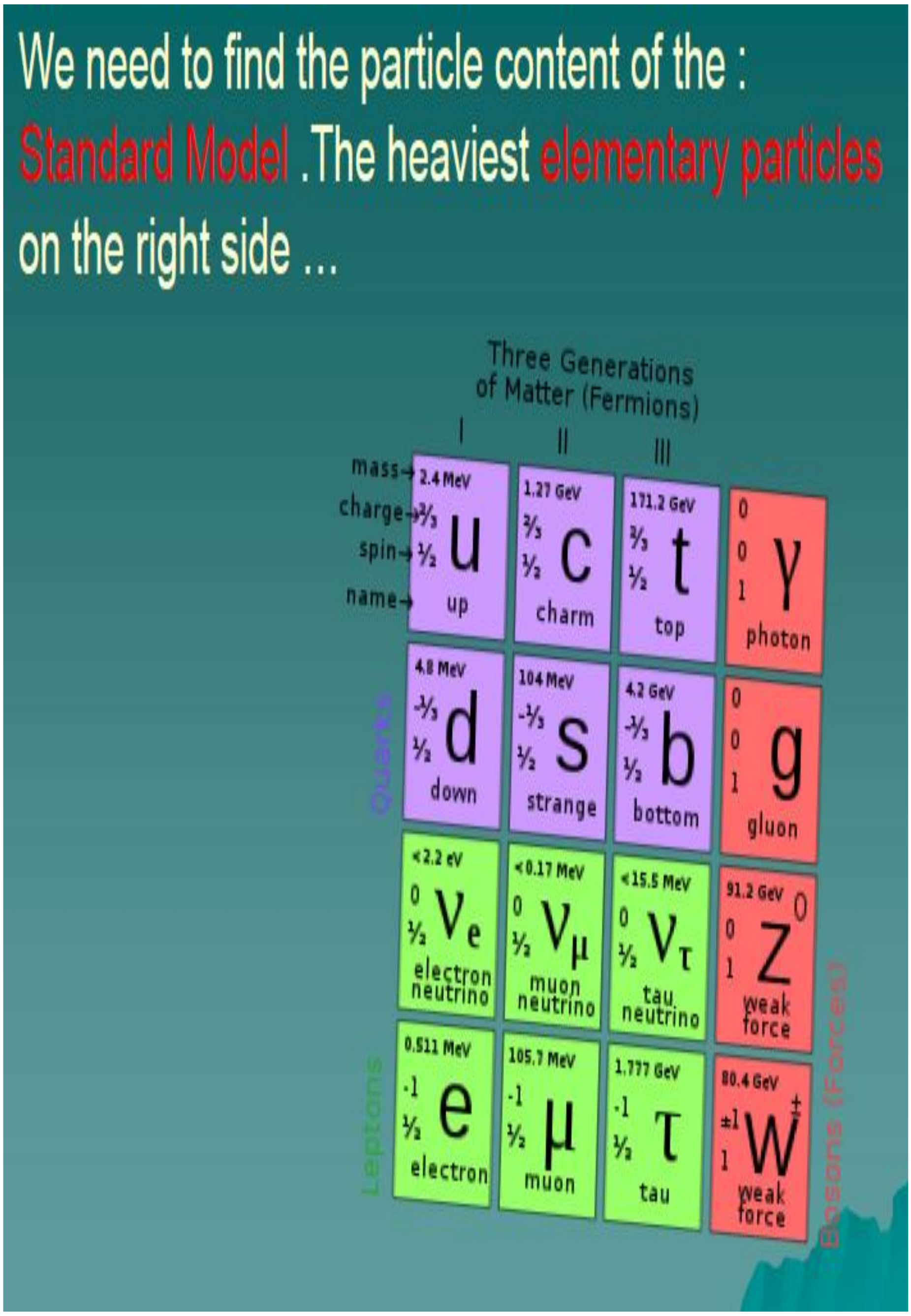
Standard Model of Elementary Particles and Gravity



- Accommodates 3 generations of neutrinos

BUT

- **No gravity**
- NO Mass term for neutrinos



For a model BEYOND the SM

Motivation for introducing mass term for 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

• Explain excess of low energy electronic recoil events, over known backgrounds, observed at XENON1T experiment

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

T2K experiment ➔ STERILE NEUTRINOS < 1 eV

STRING THEORY

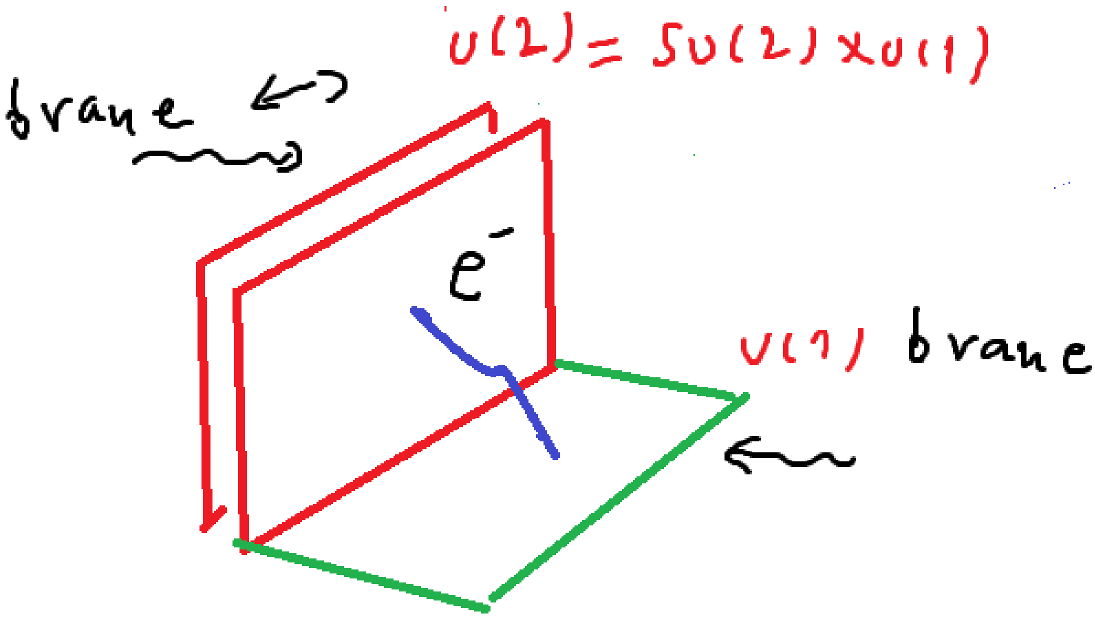
1 Macroscopic level - matter, 2 Molecular level,
3 Atomic level, 4 Electrons, 5 Quarks, 6 String Theory

Particles → localized among intersecting branes

What is an intersecting brane ?

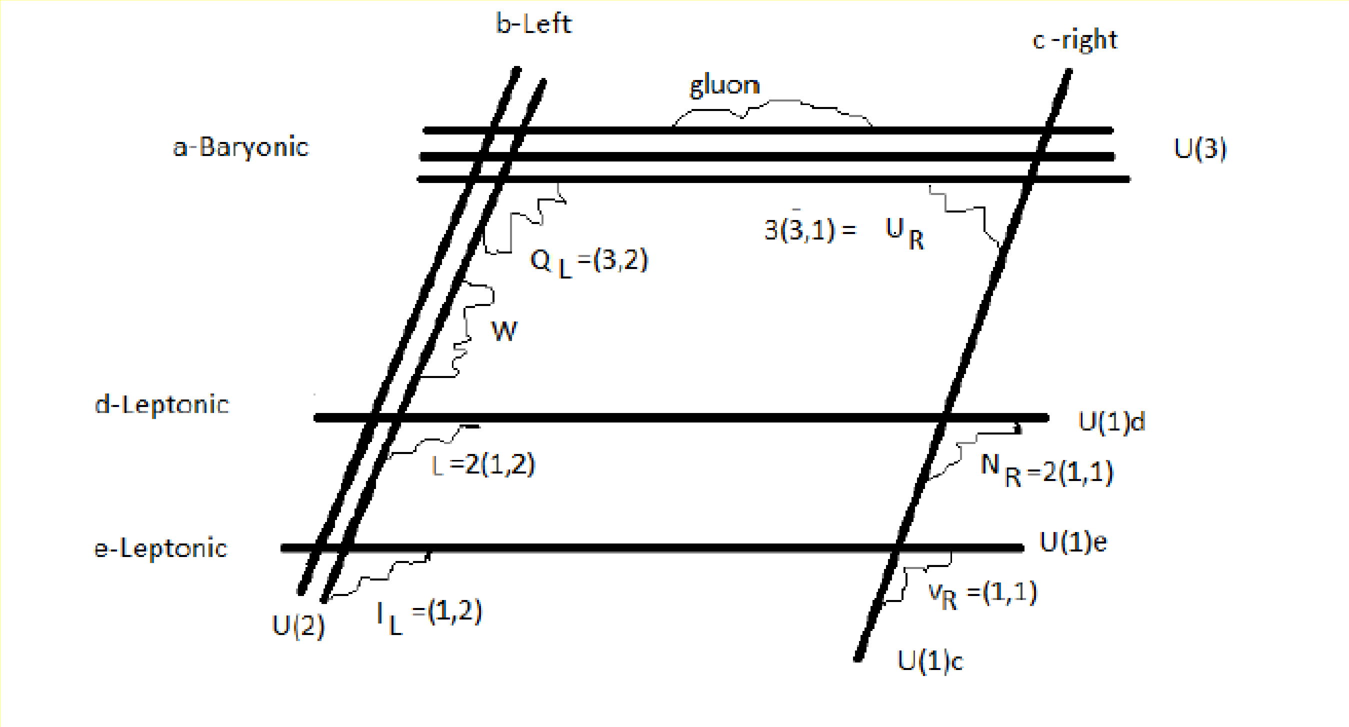
A higher dimensional hypersurface

Simplest representation



e- → (2,1) reprentation → and charges (1,-1)

Model → 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

C.K

5-stack (string) Standard Model

$$L = Q_d + Q_e$$

$$Q_a = 3B,$$

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	$2(3,2)$	$I_{ab^*} = 2$	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	$3(3,1)$	$I_{ac^*} = -3$	-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	$2(1,1)$	$I_{cd^*} = -2$	0	0	-1	-1	0	1
ν_R	$(1,1)$	$I_{ce} = 1$	0	0	1	0	-1	0
e_R	$(1,1)$	$I_{ce^*} = -1$	0	0	-1	0	-1	1

C.K, hep-th/0205147

MATTER SPECTRUM

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	$2(3,2)$	$I_{ab^*} = 2$	1	1	0	0	0	$1/6$
U_R	$3(\bar{3},1)$	$I_{ac} = -3$	-1	0	1	0	0	$-2/3$
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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	$2(1,1)$	$I_{cd^*} = -2$	0	0	-1	-1	0	1
ν_R	$(1,1)$	$I_{ce} = 1$	0	0	1	0	-1	0
e_R	$(1,1)$	$I_{ce^*} = -1$	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.

Predicts..

- The existence of only 1 or 2 supersymmetric particles : The spartners of the right handed neutrino, the sneutrino. The 2 sneutrinos come from the same intersection.

$$Q_{a} - 3Q_{d} - 3Q_{e} = 3(B - L)$$

Neutrinos in the right magnitude from chiral condensate

$$\alpha'(LN_R)\,(Q_L U_R)^*, \quad \alpha'(l\nu_R)(q_L U_R).$$

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

AND

- EXPLAINS LHCb b-ANOMALIES

A Stringy explanation of b → 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,

should be possible to discover such a state directly during the next LHC runs via Drell-Yan production in :

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

- can originate via chiral symmetry breaking

C.K;
Ibanez, Marchesano, Rabadan

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

From u-quark chiral condensate

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

Mv ~ (0.1-10 eV)

STERILE NEUTRINOS

- Sterile neutrinos in GAUGE THEORY ➔

Inverse See Saw mechanism

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

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

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

Valle; Leontaris and Shafi,…

• Sterile neutrinos in INTERSECTING D-BRANE models

$$\mathcal{L} = m_D \nu_L \nu_R + m_N \nu_R N_1 + m_\Sigma \nu_L N_1 + \cdots$$

• Sterile neutrinos in eigenstate basis

(ν_L , ν_R , N_1)

• → mass matrix

$$\begin{pmatrix} 0 & m_D & m_\Sigma \\ m_D & 0 & m_N \\ m_\Sigma & m_N & 0 \end{pmatrix}$$

BARYON # CONSERVED

I.Antoniadis and C.K

Sterile neutrinos → Calabi-Yau compactifications

Mohapatra and Valle

Faraggi; Leontaris, ..

(NO BARYON # conservation)