The neutrino problem in models from String theory

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OUTLINE

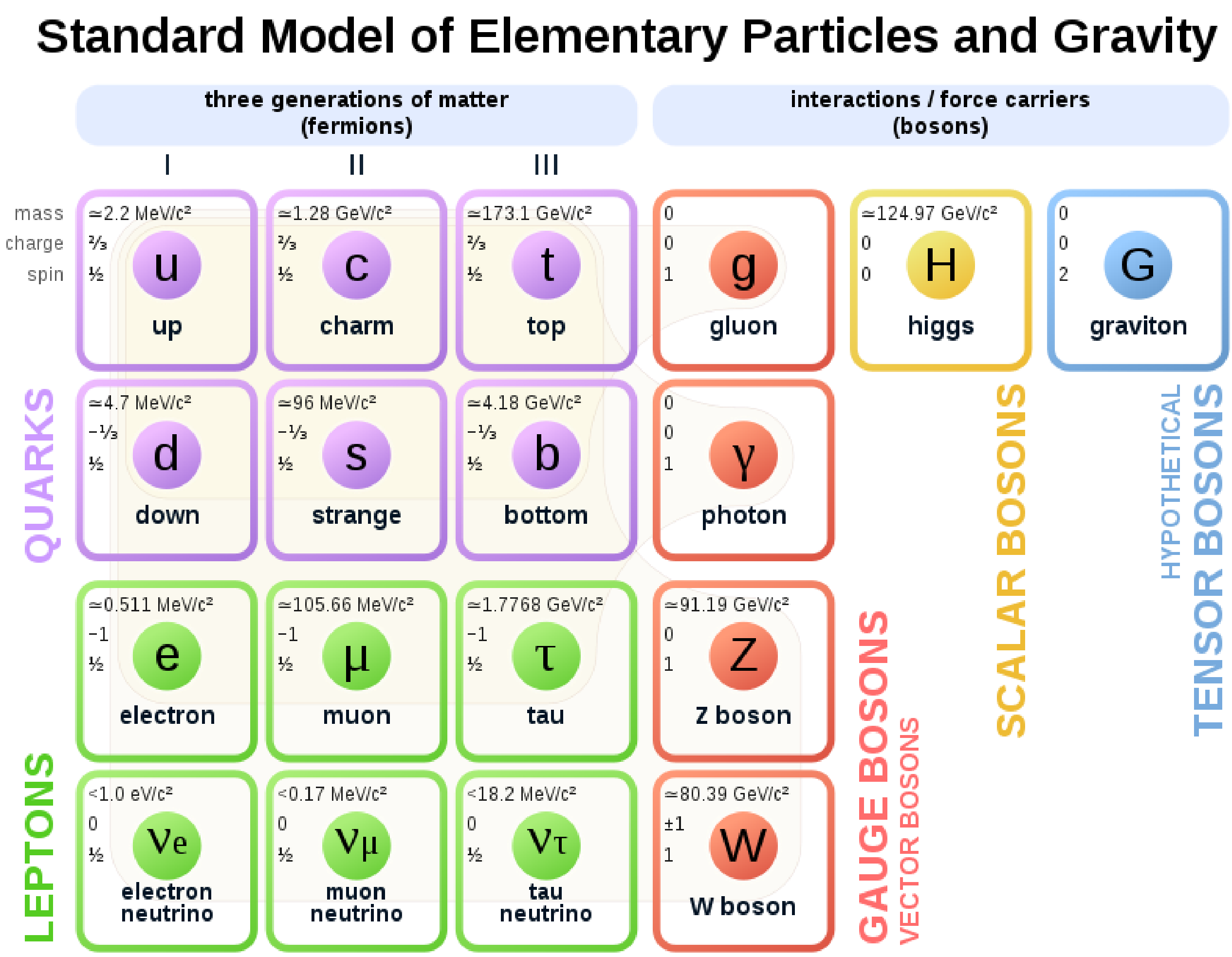
- Neutrino (s) mass in the Standard Model

- Neutrino (s) mass beyond Standard Model

• 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 ?

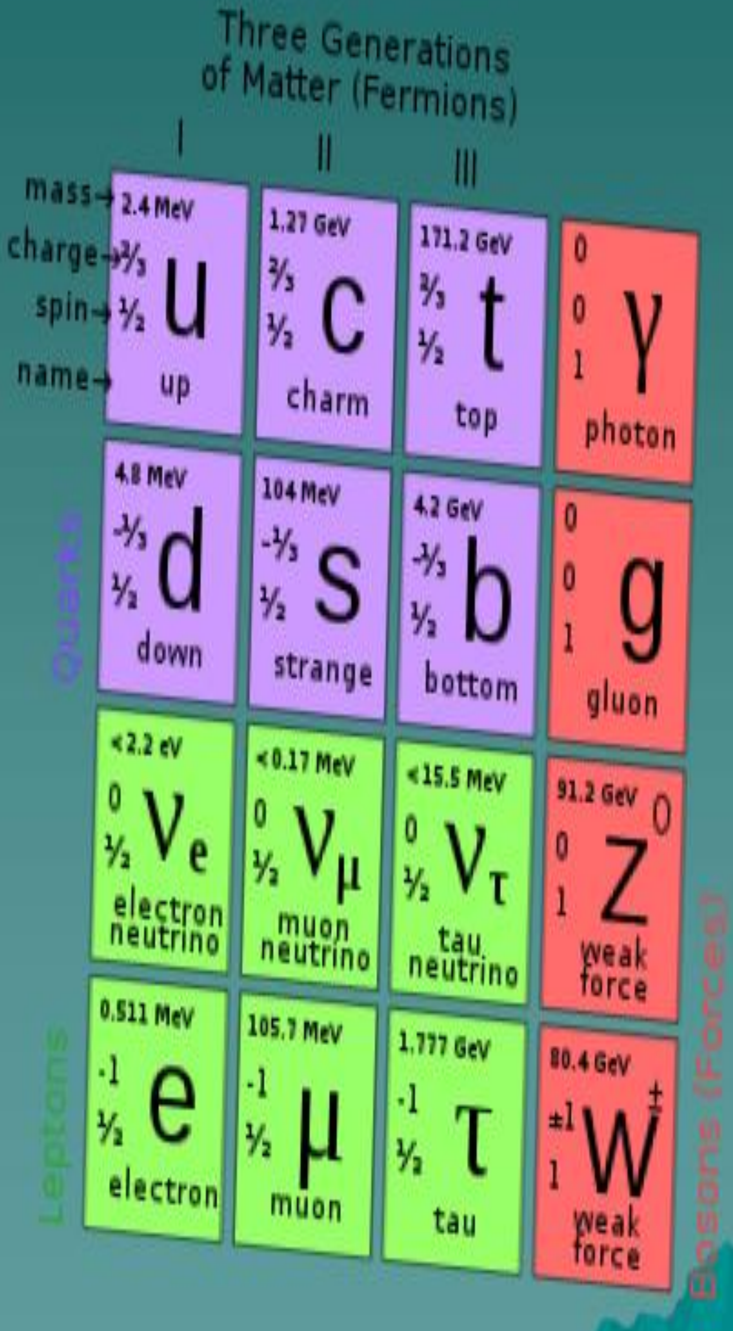
STANDARD MODEL



●Accommodates 3 generations of neutrinos

NO Mass term for neutrinos

We need to find the particle content of the : Standard Model .The heaviest elementary particles on the right side ...



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)

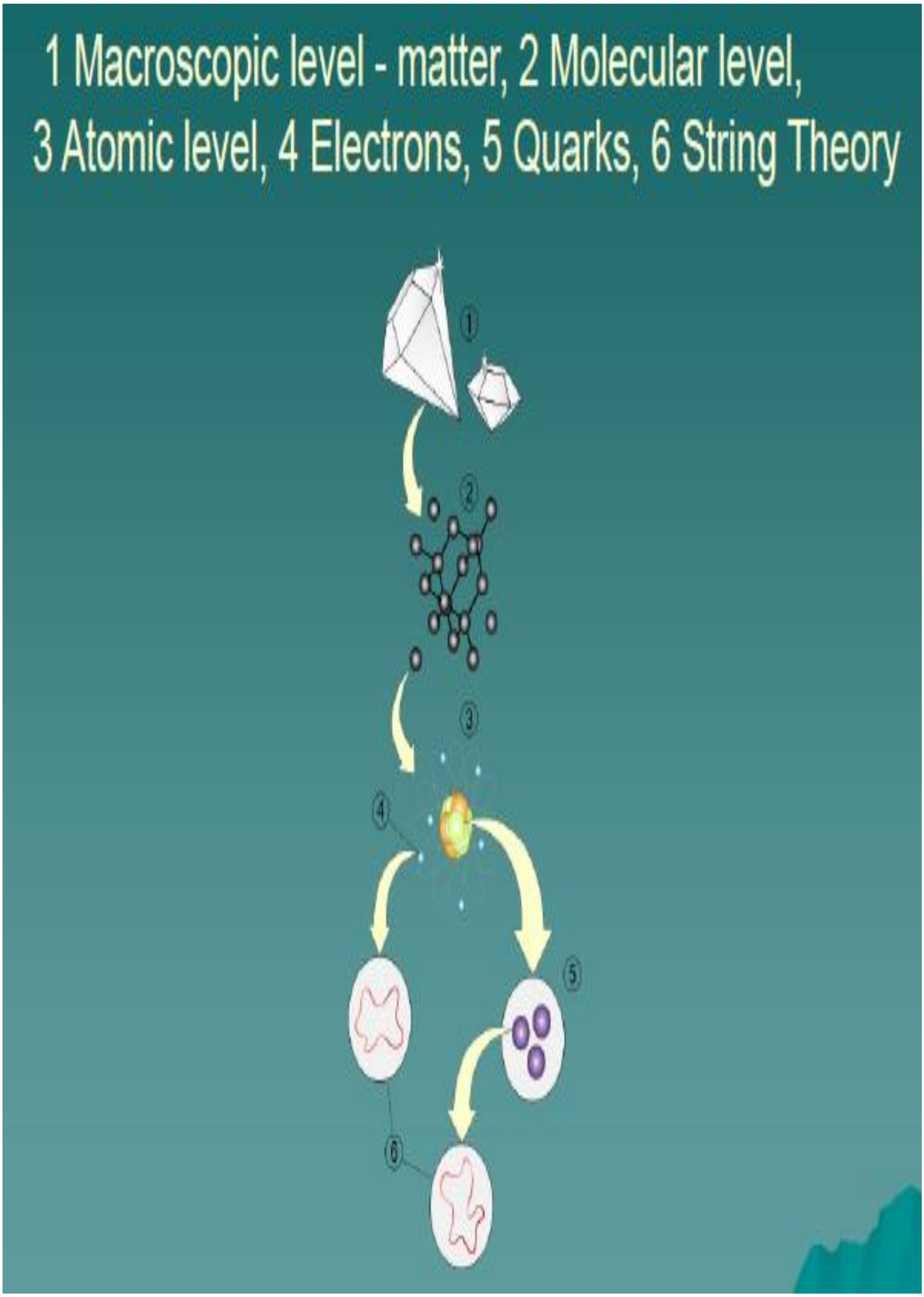
• Discovery of neutrino oscillations
(Super-Kamiokande experiment /1998)
Neutrinos have a non-zero mass => BEYOND SM

• 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.
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

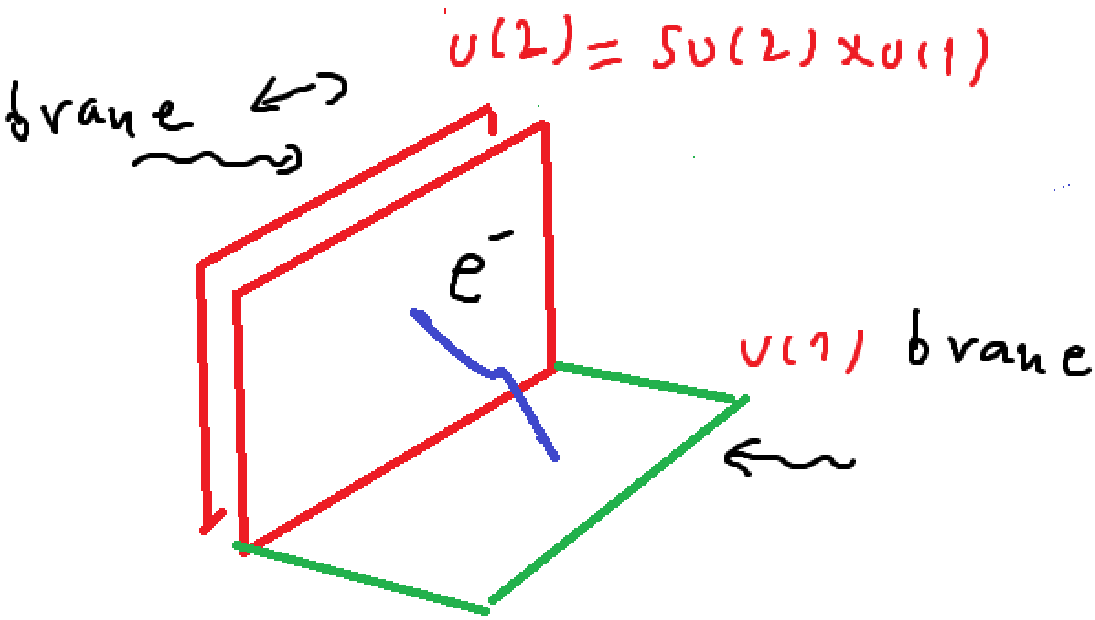


Particles ➔ localized among intersecting branes

What is an intersecting brane ?

A higher dimensional hypersurface

Simplest representation

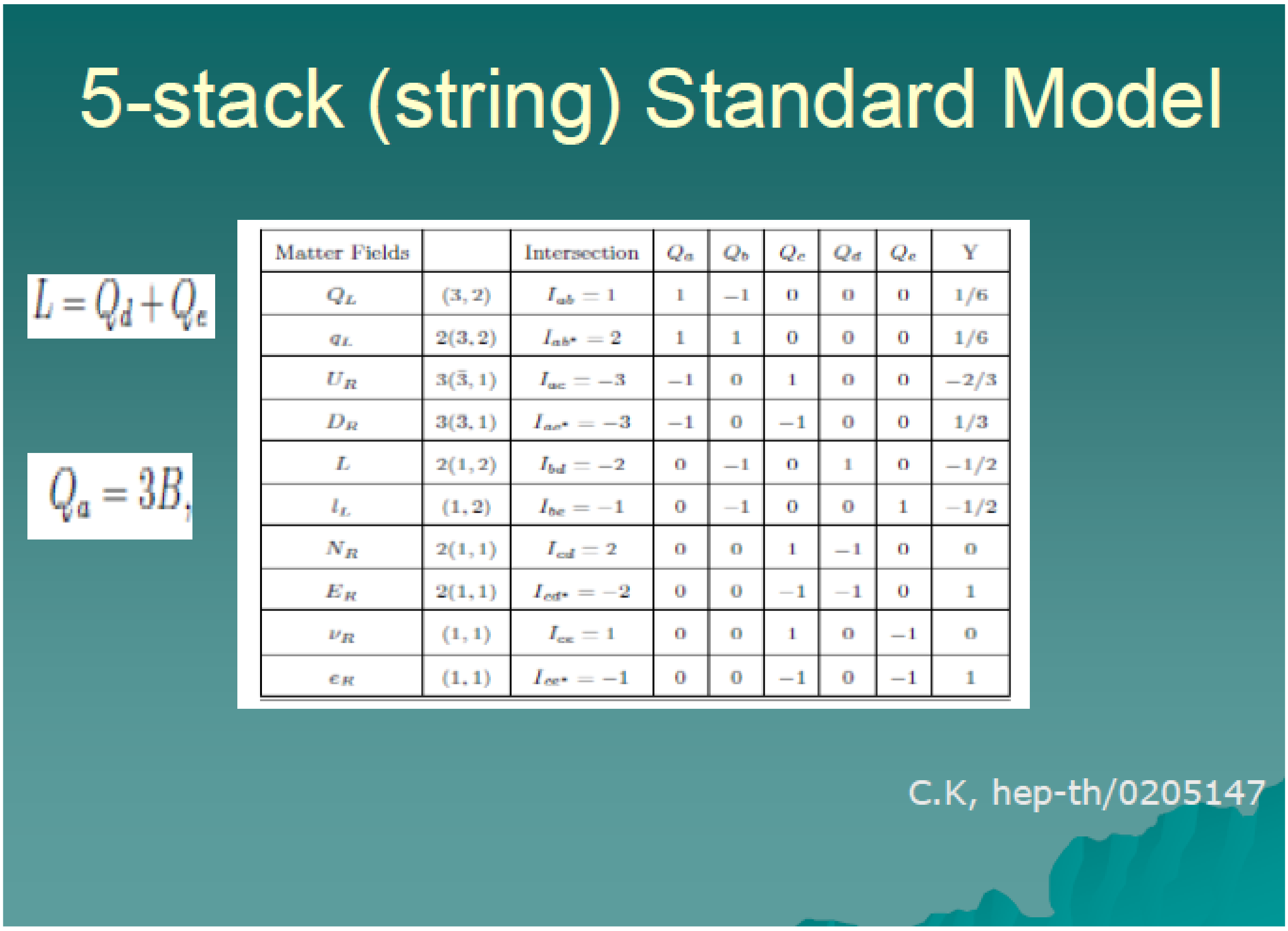


e- ➔ (2,1) reprentation ➔ and charges (1,-1)

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



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

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
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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.

$$Q_{qa} - 3Q_{qd} - 3Q_{e} = 3(B - L)$$

Neutrinos in the right magnitude from chiral condensate

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

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

AND

- EXPLAINS b-ANOMALIES

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,

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

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

From u-quark chiral condensate

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

Mv ~ (0.1-10 eV)

STERILE NEUTRINOS

● Sterile neutrinos in GAUGE THEORY➔

Inverse See Saw mechanism

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

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

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

● Sterile neutrinos in INTERSECTING D-BRANE models

- Sterile neutrinos in eigenstate basis

(ν_L , ν_R , N_1)

- the mass matrix becomes

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

~similar results on Calabi-Yau compactifications > Mohapatra and Valle