D-brane neutrino phenomenology

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OUTLINE

- Standard model “weaknesses”
- Neutrino mass in the Standard Model
- Neutrino mass beyond Standard Model

- **Neutrino masses in string theory**
[Intersecting D-branes ~~open strings]

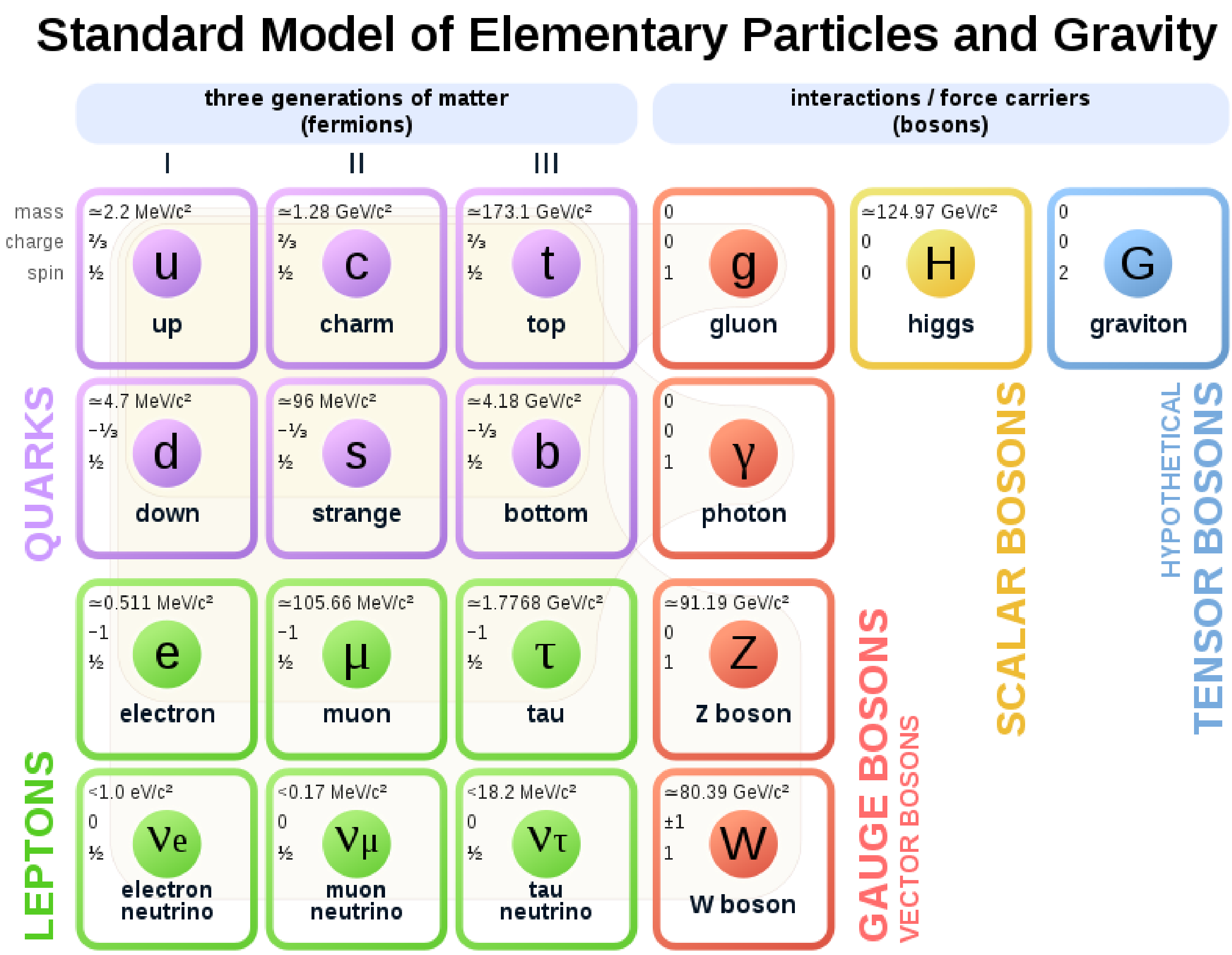
- **Non-SUSY** STANDARD MODEL **with SUSY** particles

➔ **gauged baryon number** ➔ **left handed neutrinos**	√ √
➔ **right handed neutrinos**	√
? sterile neutrinos ➔	????

[Interactions → coupling to left-handed neutrinos;

production mechanism →neutrino oscillations]

STANDARD MODEL



●+ accommodates 3 generations of neutrinos

BUT weaknesses

Baryon non-conservation (B-L conserved)

⇨ Proton decay

$$O^{(1)}_{abcd} = (\bar{d}^C_{\alpha a R} u_{\beta b R})(\bar{q}^C_{i \gamma c L} l_{j d L})\epsilon_{\alpha\beta\gamma}\epsilon_{ij},$$

$$O^{(2)}_{abcd} = (\bar{q}^C_{i \alpha a L} q_{j \beta b L})(\bar{u}^C_{\gamma c R} l_{d R})\epsilon_{\alpha\beta\gamma}\epsilon_{ij},$$

$$O^{(3)}_{abcd} = (\bar{q}^C_{i \alpha a L} q_{j \beta b L})(\bar{q}^C_{k \gamma c L} l_{l d L})\epsilon_{\alpha\beta\gamma}\epsilon_{ij}\epsilon_{kl},$$

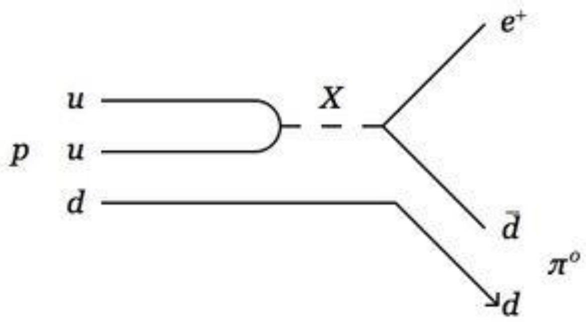
$$O^{(4)}_{abcd} = (\bar{q}^C_{i \alpha a L} q_{j \beta b L})(\bar{q}^C_{k \gamma c L} l_{l d L})\epsilon_{\alpha\beta\gamma} \times (\vec{\tau}\epsilon)_{ij}\cdot(\vec{\tau}\epsilon)_{kl},$$

$$O^{(5)}_{abcd} = (\bar{d}^C_{\alpha a R} u_{\beta b R})(\bar{u}^C_{\gamma c R} l_{d R})\epsilon_{\alpha\beta\gamma},$$

$$O^{(6)}_{abcd} = (\bar{u}^C_{\alpha a R} u_{\beta b R})(\bar{d}^C_{\gamma c R} l_{d R})\epsilon_{\alpha\beta\gamma}.$$

Weinberg (1979)
Wilczek and Zee (1979)

- $\tau_p > 8.2 \times 10^{33}$ years $\quad \Lambda \gtrsim 10^{16}$ GeV



BUT ➔➔➔➔➔➔➔➔➔➔➔

Hierarchy problem 100 GeV – 10^{16} GeV

- includes → **No Gravity**

- No Mass term for neutrinos in the SM

Motivation for introducing neutrino mass terms beyond the SM

- A mass can only be introduced beyond the SM e.g. by adding a right handed neutrino (s)

(see saw mechanism)

- **Neutrinos have a mass** - Discovery of **neutrino oscillations**

- Sterile → Explain (inconclusive) excess of low energy electronic recoil events, over known backgrounds, observed at XENON1T experiment ?

- Sterile ➔ as Dark Matter

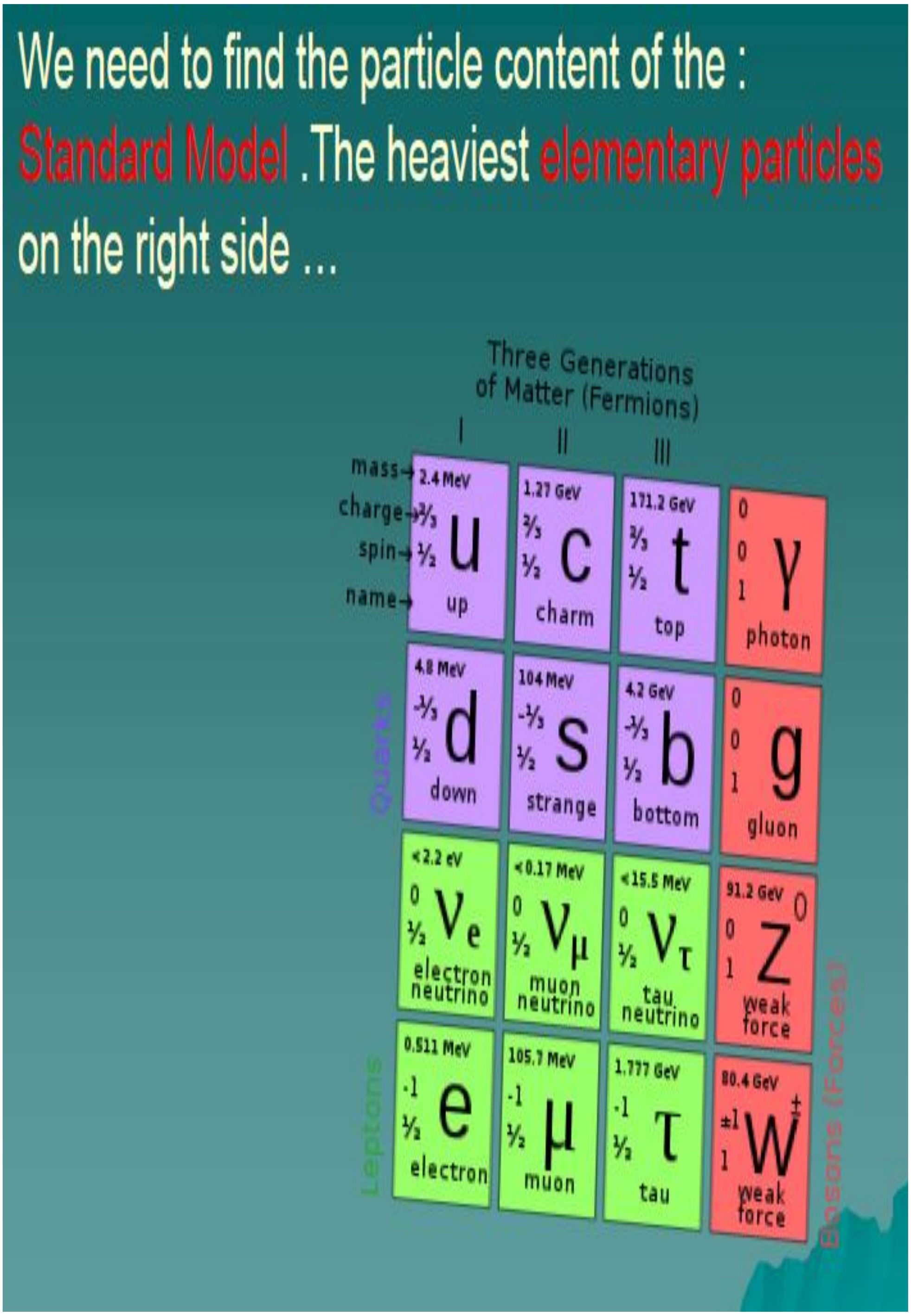
Contributes five times more to the energy of the Universe than ordinary matter → Weakly interacting) dark matter candidates => Sterile neutrinos of KeV masses + with small mixing with active neutrinos. Dodelson and Widrow (1993)

- Light sterile neutrinos :

T2K experiment ➔ STERILE NEUTRINOS < 1 eV

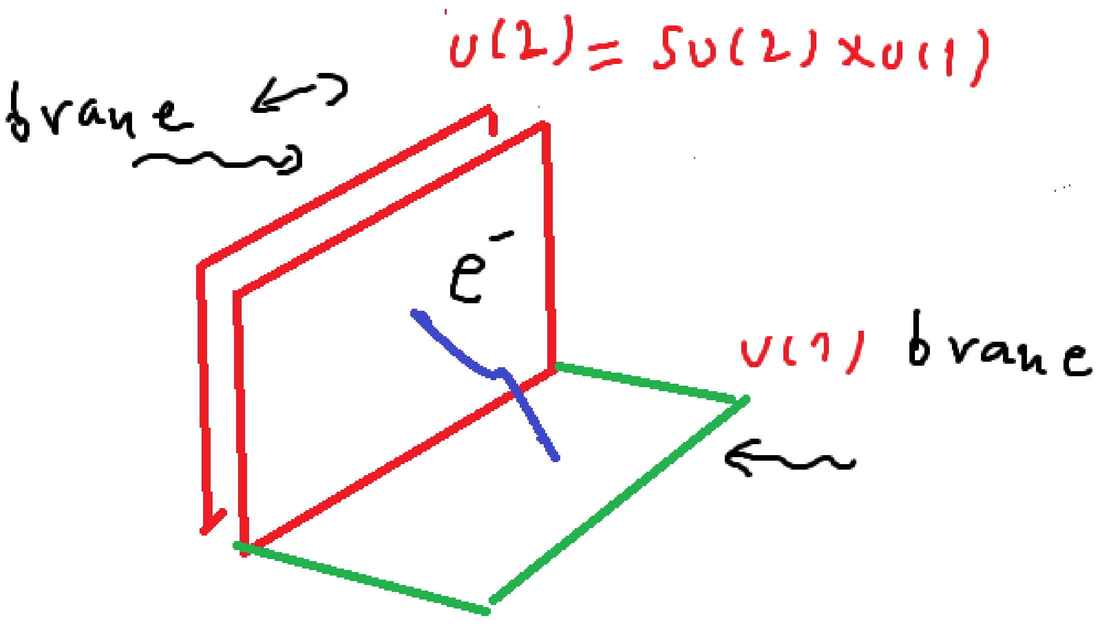
hep-ph/1204.5379.

? Solution – Building a model BEYOND the SM without Proton decay – UV completed



Build
Standard model**-like string** models **with**
particles ➔ localized among intersecting branes

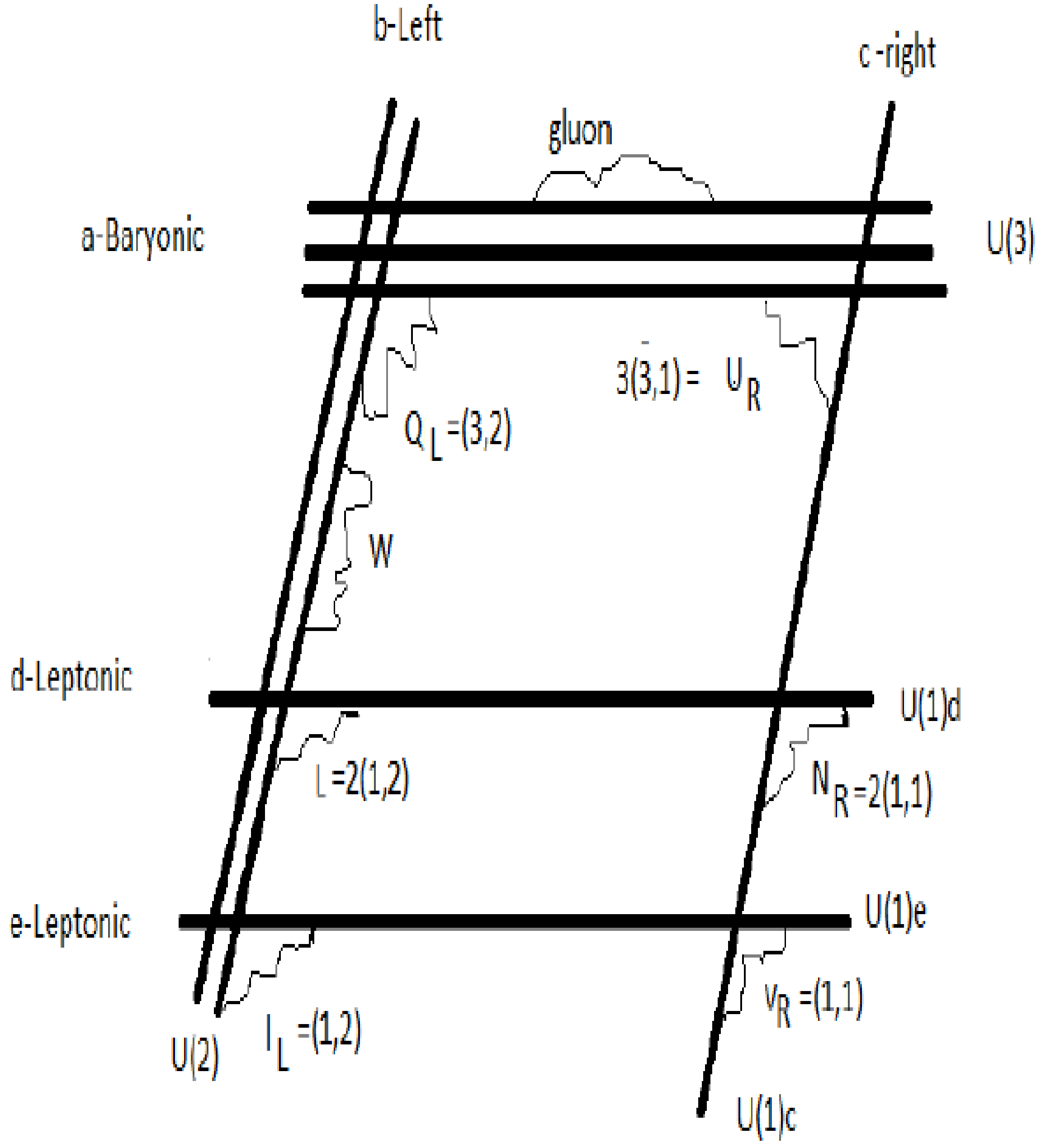
● Intersecting brane ?
"A higher dimensional hypersurface within 10D



→Simplest representation

e- ➔ (2,1) representation ➔ charge (1, -1) = (Qa, Qb)

5-stack String Standard Model



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

C.K (02)

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	$-2/3$
D_R	$3(\bar{3},1)$	$I_{ac^*}=-3$	-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

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.

Qa= 3B , L = Qd + Qe

"Predicts…"

- Existence of sneutrinos

>break the extra Z' with sν_R C.K (2002)

=>Used sν_R in MSSM to break $U(1)_{B-L}$
Barger, Perez, Spineer (2009)

- 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

$$\alpha'(LN_R)\,(Q_LU_R)^*,\;\; \alpha'(l\nu_R)(q_LU_R)$$

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

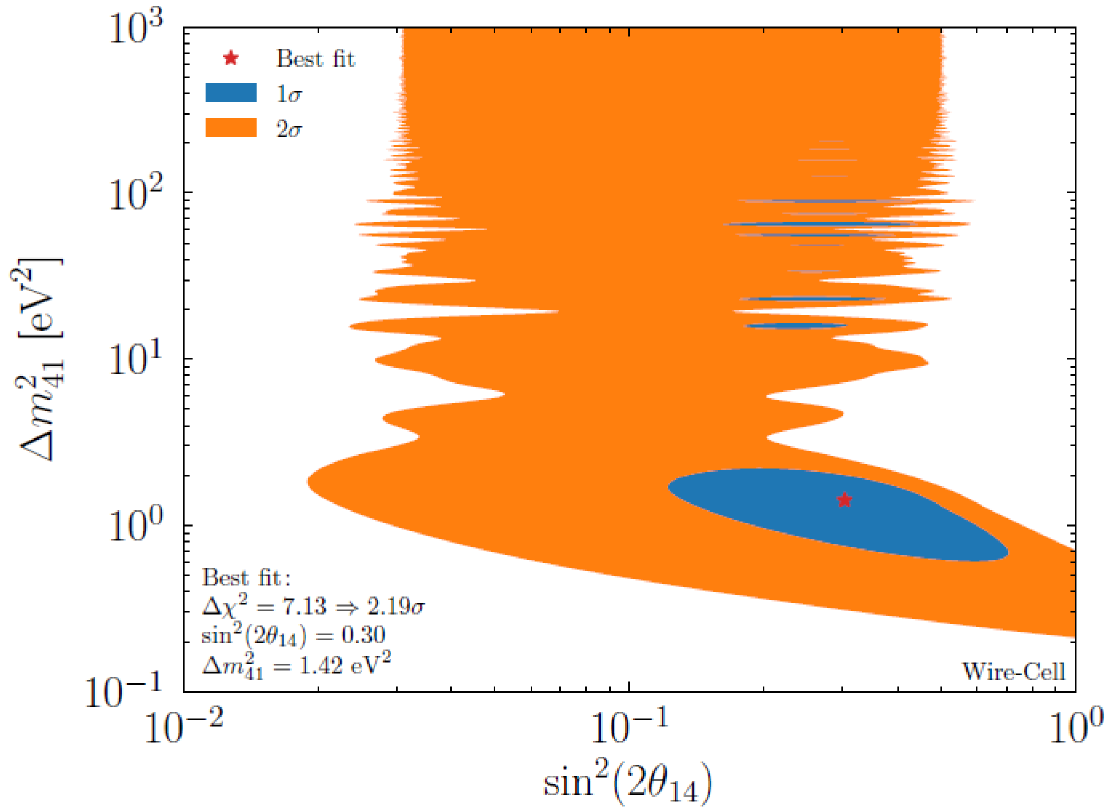


FIG. 2. The preferred regions in Δm^2_{41} - $\sin^2(2\theta_{14})$ parameter space using data from MicroBooNE's Wire-Cell analysis [41]. The blue (orange) region is the preferred region at 1σ (2σ) assuming Wilks' theorem. The red star is at the best fit point: $\Delta m^2_{41} = 1.42$ eV^2 and $\sin^2(2\theta_{14}) = 0.30$ which has a test statistic of $\Delta\chi^2 = 7.13$ to no oscillations which implies 2.19σ under Wilks' theorem.

2111.05793[hep-ph]

● 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 - (No Baryon # conservation) →

Sterile neutrinos → Calabi-Yau compactifications

Mohapatra and Valle

Faraggi; Leontaris, …

•• 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

$$10^{-54}\, e^{-A} < m_\Sigma < Ms\, e^{-A}$$
$$0 < m_N < Ms\, e^{-A}$$
$$0 < m_D < Ms\, e^{-A}$$