Neutrino decay: the role of new interactions

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Brookhaven Neutrino Theory Virtual Seminar March/23

Neutrino oscillations are the first signal of Beyond Standard Model (BSM)

The Nobel Prize in Physics 2015

Photo: A. Mahmoud

Takaaki Kajita

Prize share: 1/2

Photo: A. Mahmoud

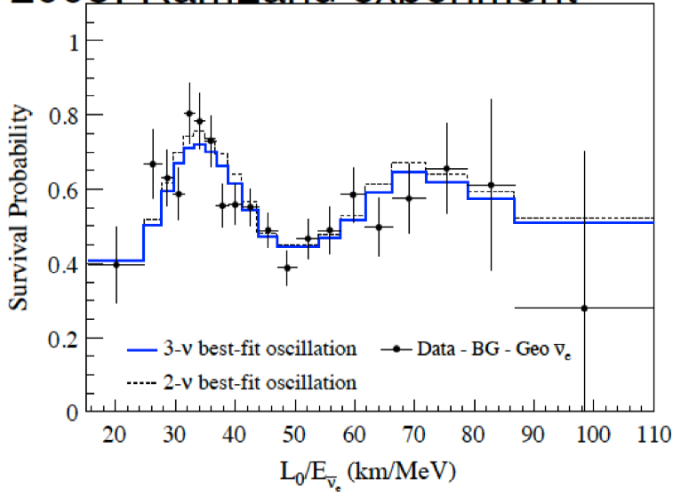
Arthur B. McDonald

Prize share: 1/2

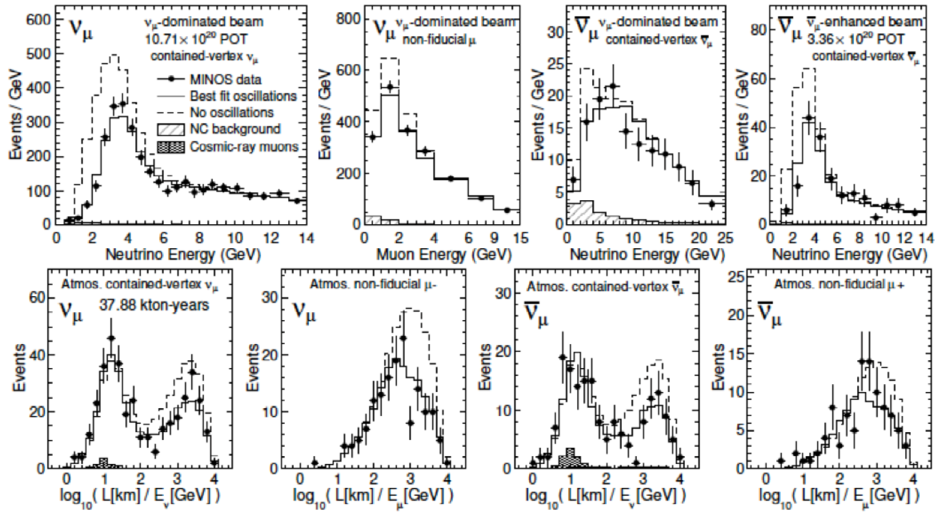
The Nobel Prize in Physics 2015 was awarded jointly to Takaaki Kajita and Arthur B. McDonald *"for the discovery of neutrino oscillations, which shows that neutrinos have mass"*

Neutrino oscillations are the first signal of Beyond Standard Model (BSM)

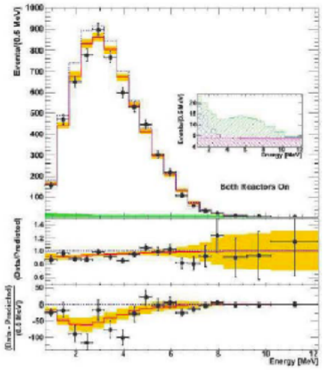
2008: KamLand experiment

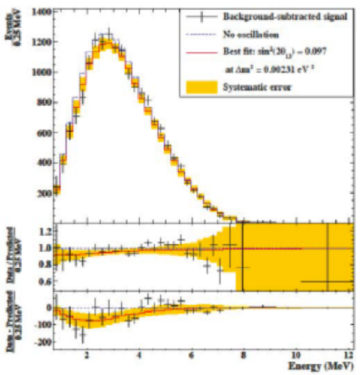


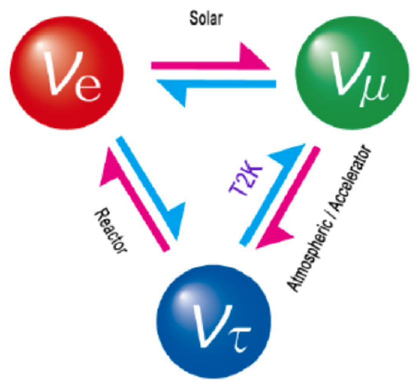
MINOS experiment 2010: UFG/USP/UNICAMP



2013: UNICAMP/UFABC/CBPF


Gd-capture


H-capture



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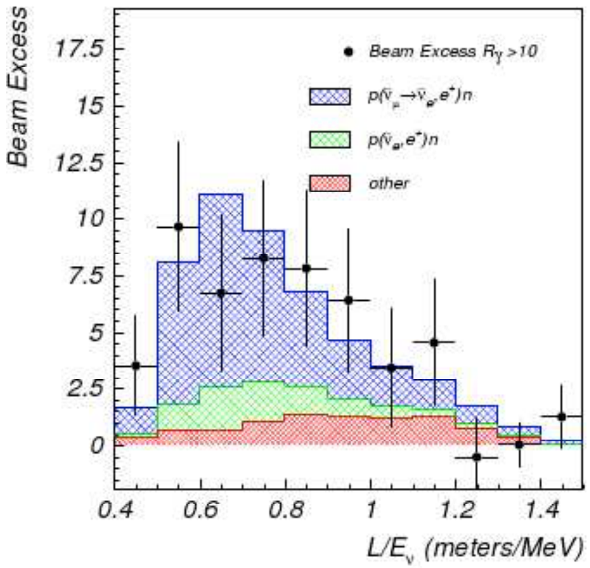
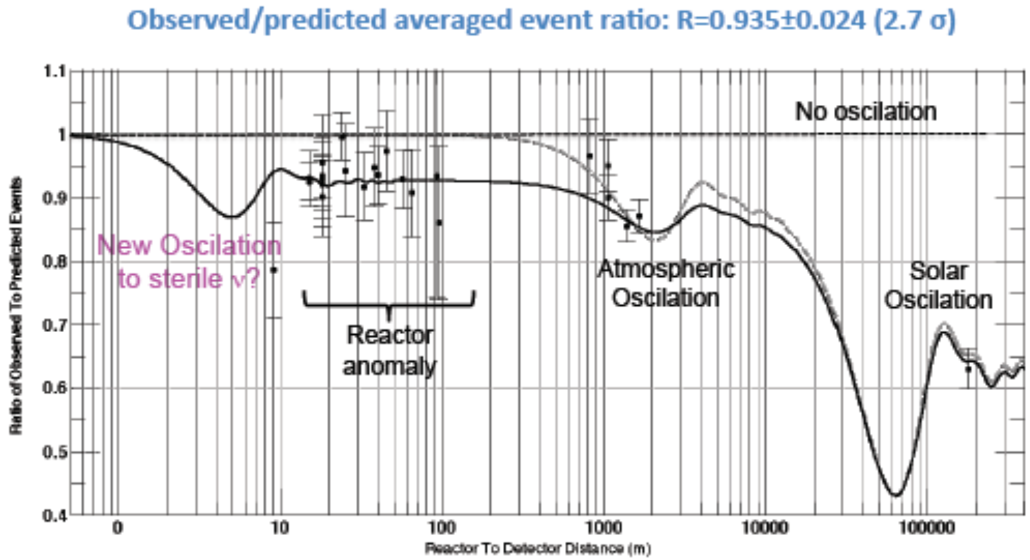
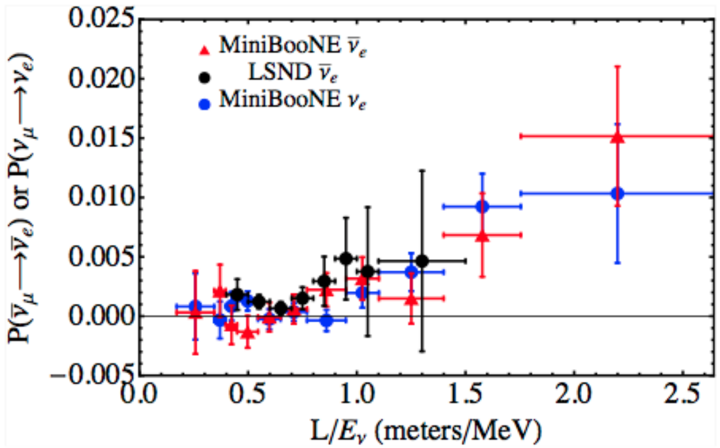
There are other signal of BSM ?

Not yet, search for sterile neutrinos, NSI (Non-standard neutrino interactions), Non-unitary scenarios, open quantum systems….

Hints from LSND,MINI-BOONE, Reactor Anomalyl







Neutrino decay

Old idea: Neutrino Decay in Gauge Theories , **G.T. Zatsepin, A.Yu. Smirnov**,Yad.Fiz. 28 (1978) 1569-1579
The Processes mu --> e Gamma, mu --> e e anti-e, Neutrino' --> Neutrino gamma in the Weinberg-Salam Model with Neutrino Mixing, **S.T. Petcov,** Sov. J. Nucl.Phys. 25 (1977) 340

Renewed interest: A Combined treatment of neutrino decay and neutrino oscillations,
Manfred Lindner, Tommy Ohlsson, Walter Winter, Nucl.Phys. B607 (2001) 326-354,
DOI: 10.1016/S0550-3213(01)00237-1, e-Print: hep-ph/0103170 | PDF

First point: which states the neutrino can decay?

Common scenario: $\nu' \rightarrow \nu + \gamma$

Scenario discussed here:

$$\nu' \rightarrow \nu + \phi$$

ϕ **Massless scalar**

$$\mathcal{L} = -\sum_{i,j} g_{ij} \overline{\nu_i^C} \nu_j \phi$$

Neutrino decay, what are the possible ways?

In the literature it was studied two possibilities

(I) Heavy neutrino(“sterile”) decaying into lighter neutrinos+scalar
(II) Lighter neutrino(“active”) decaying into the lightest neutrinos+scalar

Also we can have two scenarios (Dirac/Majorana)

(I) No Daughter neutrino(“sterile” or “right-handed neutrino”)
(II) Daughter neutrino(“active”)

And depending our choice (Dirac/Majorana)

Neutrino decay, recent activity?

In the literature, it was studied

(I) Long-Baseline experiments, T2K,MINOS, DUNE, T2K,
(II) Atmospheric neutrinos SK,ICECUBE
(III) Reactor Neutrinos KamLand, JUNO
(IV) Short-baseline experiments, LSND, MINI-BOONE, SBND
(V) Solar neutrino experiments,
(VI) Cosmology

(I) Gomes^2, OLGP, de Salas and Tortola,Ascencio-Sosa and Gago and Jones-Peres, Ghosal and Meloni, Choubey and Pramanick, Choubey and Goswami, Coloma and OLGP, Gago and Gomes^2 and OLGP and Jones-Perez

(II) Beacom and Bell, Meloni and Ohlsson, Dorame and Valle, Choubey, Denton and Tombora

(III) Minakata and Nunokawa, Porto-Silva, Prakash and O.L.G.P.

(IV) Palomares-Ruiz, Pascoli, Dentler and Esteban and Machado, Schwetz, Gouvea and Stenico and Prakash and OLGP

(V) Joshipura and Mohanty, Beacom, Choubey and Goswami, Picoreti, Guzzo and OLGP

(VI) Hannestad, Escudero

Neutrino decay phenomenology

Can neutrino decay to be the solution of short-baseline electron appearance?

Main Idea

$$\pi^+ \to \mu^+ + \nu_\mu$$

$$\mu^+ \to e^+ + \nu_e + \bar{\nu}_\mu$$

Assumption:

MeVish neutrino state

$$\nu_\mu = ... + U_{\mu 4}\nu_4$$

$$\nu_\mu \to \nu_{1,2,3} + \phi$$

$$\nu_\mu \to \bar{\nu}_{1,2,3} + \phi$$

$$\nu_e / \bar{\nu}_e$$

electron neutrino appearance

Oscillation scenario:

$$\bar{\nu}_\mu \to \bar{\nu}_e$$

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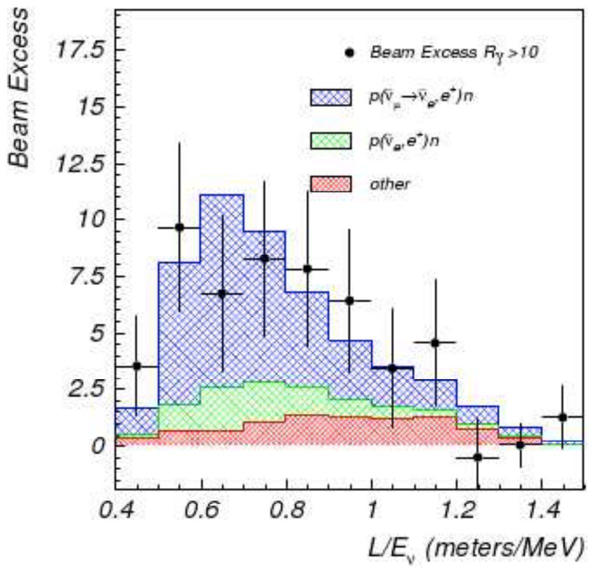
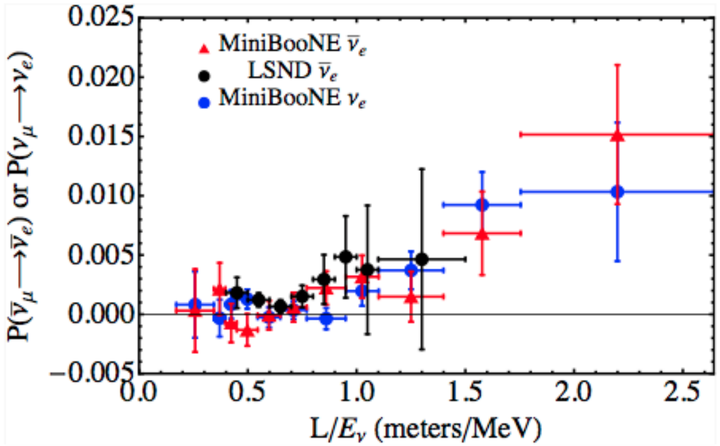
On The Decaying-Sterile Neutrino Solution to the Electron (Anti)Neutrino Appearance Anomalies

André de Gouvêa, O.L.G. Peres, Suprabh Prakash, G.V. Stenico. : arXiv:1911.01447

LSND experiment



MINI-BOONE experiment



pion decay at rest: MeVish energies

pion decay in flight: GeVish energies

For the analysis of the data: Daughter neutrinos were included.

$$\Gamma_{4e} = \Bigg[\frac{(g_M m_4)^2}{16\pi E_4} \qquad \frac{(g_D m_4)^2}{32\pi E_4}$$

Helicity conserving

Helicity conserving/flipping

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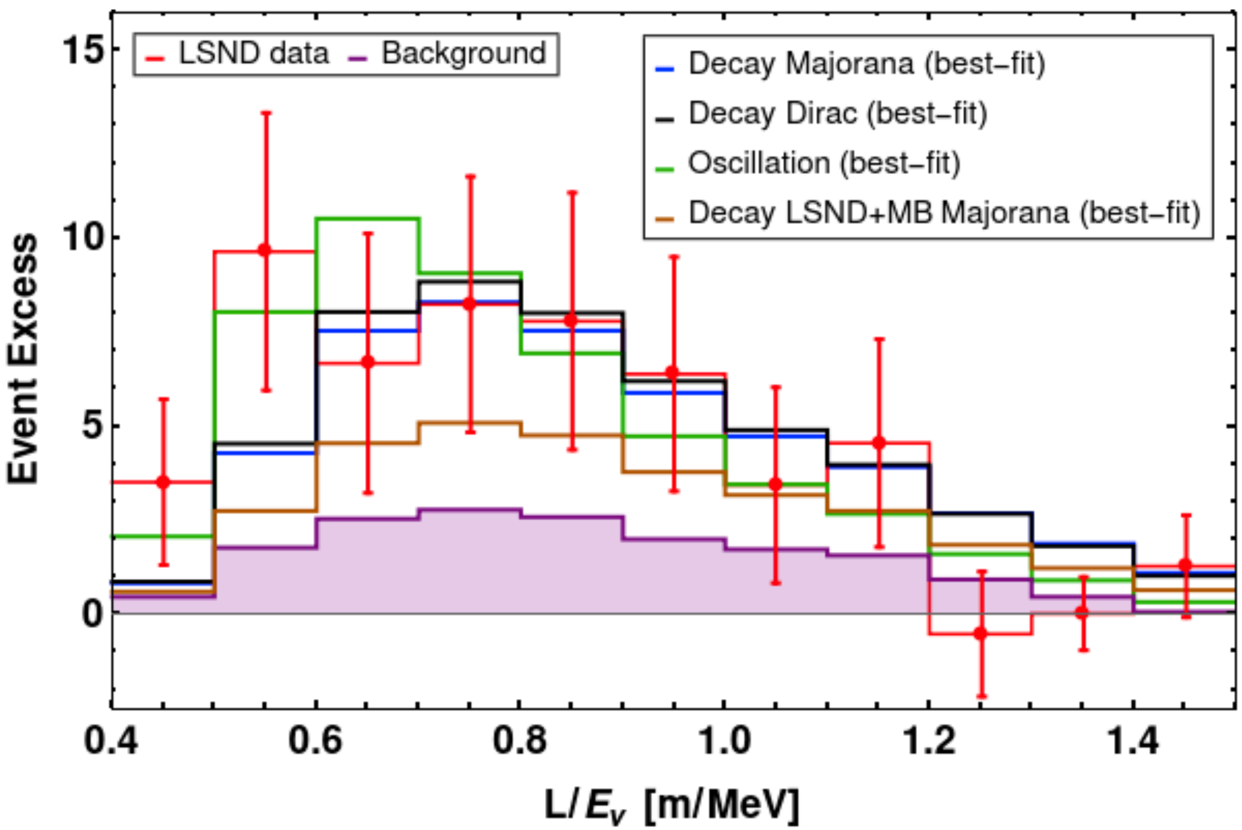
Spectrum of Daughters neutrino: Helicity conserving/Helicity flipping

$$|\mathcal{M}_{rs}|^2 = |g_{\mathrm{M}}|^2 \, m_4^2 \times \begin{cases} E_e/E_4 & r = s \\ (1 - E_e/E_4) & r \neq s \end{cases} .$$

LSND experiment



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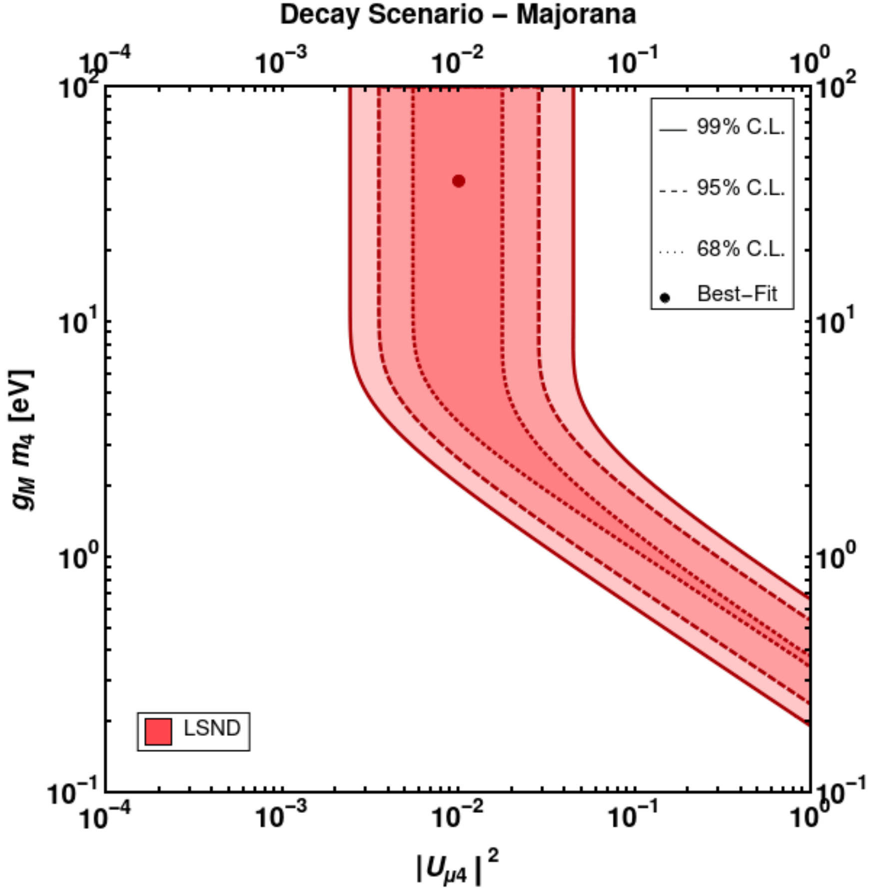
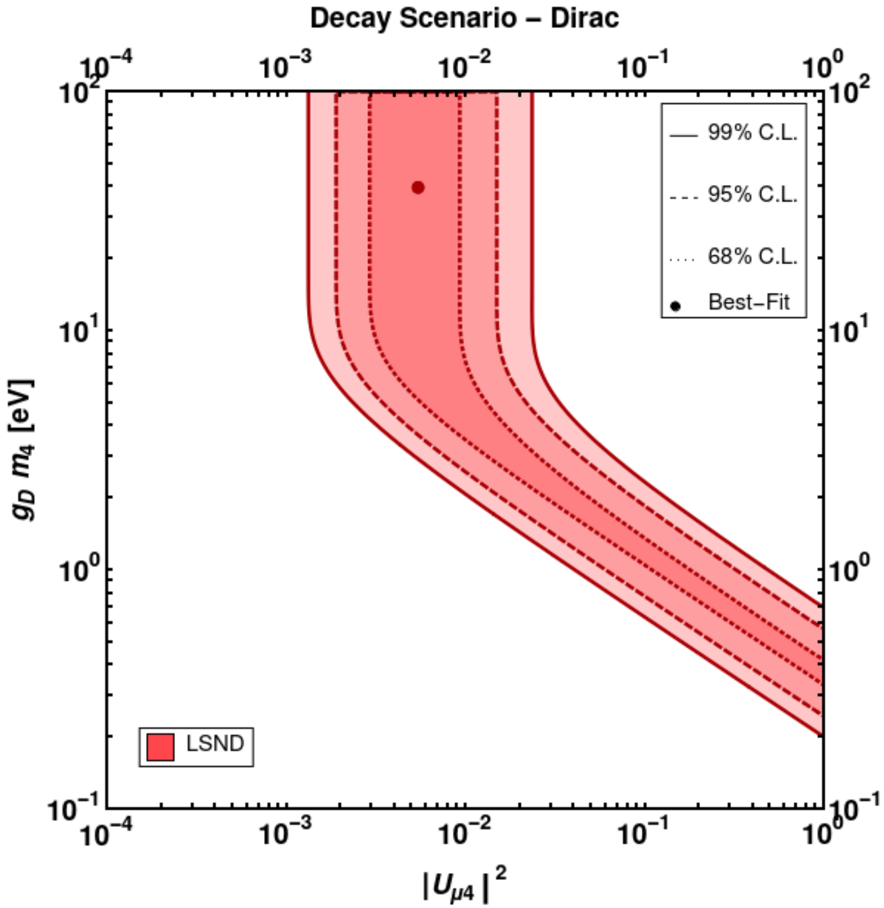




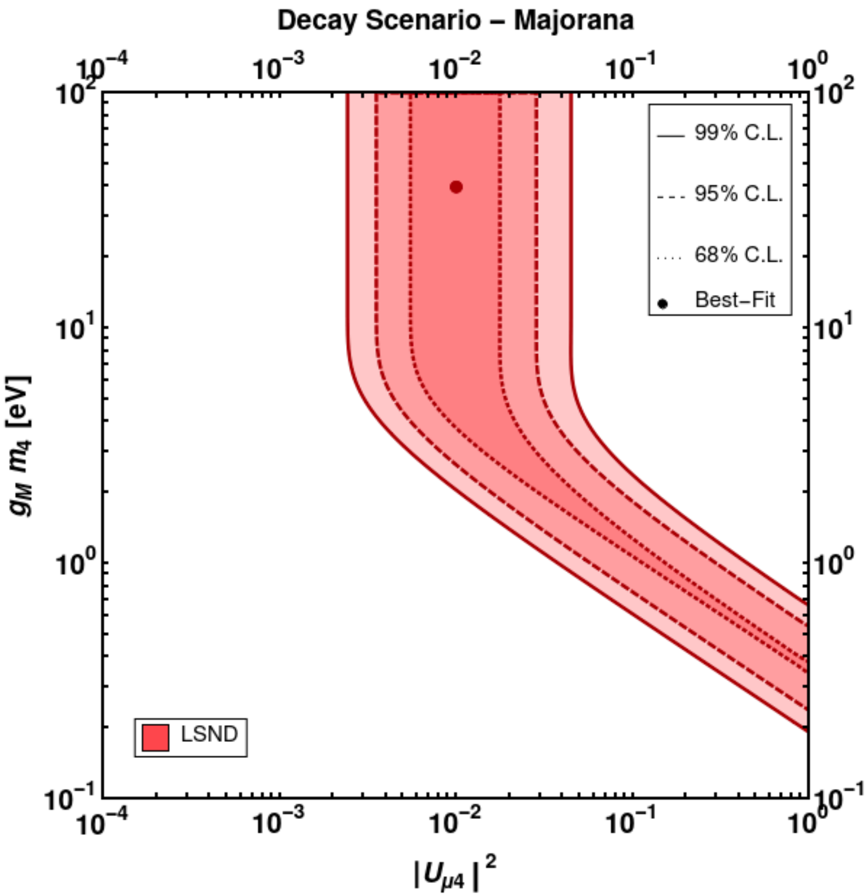
$$\Gamma_{4e} = \left[\frac{(g_M m_4)^2}{16\pi E_4} \right.$$

$$\frac{(g_D m_4)^2}{32\pi E_4}$$

$$\nu_\mu = ... + U_{\mu 4}\nu_4$$

How to understand the allowed region plot?

Assume the initial flux it ia power-law



For smaller lifetimes

$$\frac{\phi_{\nu_e}(E_{\nu_e})}{\phi_{\nu_\mu}(E_{\nu_e})} = \Gamma_{4e} L \left(\frac{2|U_{\mu 4}|^2 B_e}{1+\alpha}\right)$$

For larger lifetimes

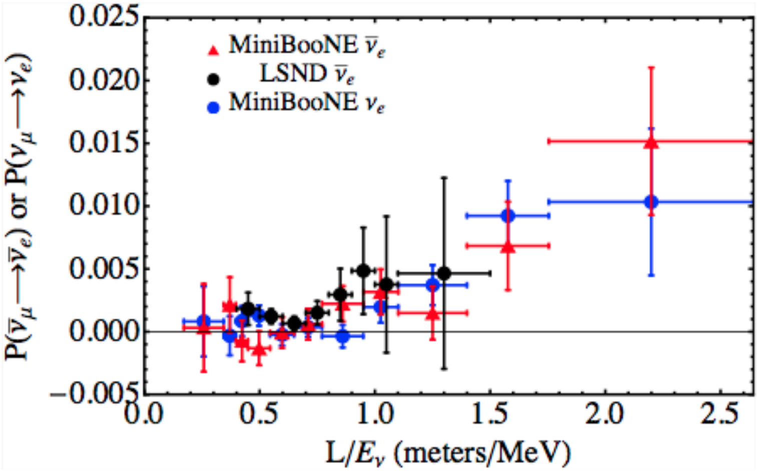
$$\frac{\phi_{\nu_e}(E_{\nu_e})}{\phi_{\nu_\mu}(E_{\nu_e})} = \left(\frac{|U_{\mu 4}|^2 2B_e}{1+\alpha}\right)$$

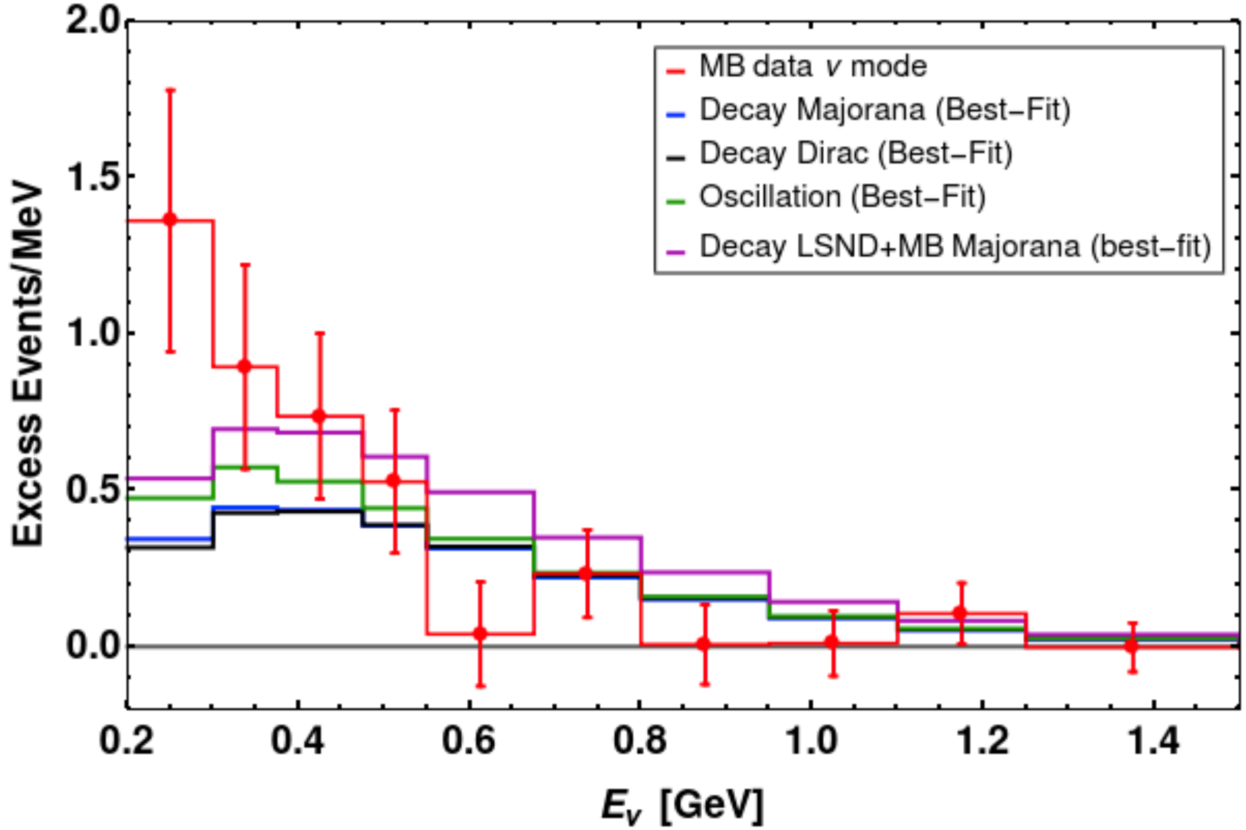
$$\Gamma_{4e} = \Big[\frac{(g_M m_4)^2}{16\pi E_4}$$

$$\frac{(g_D m_4)^2}{32\pi E_4}$$

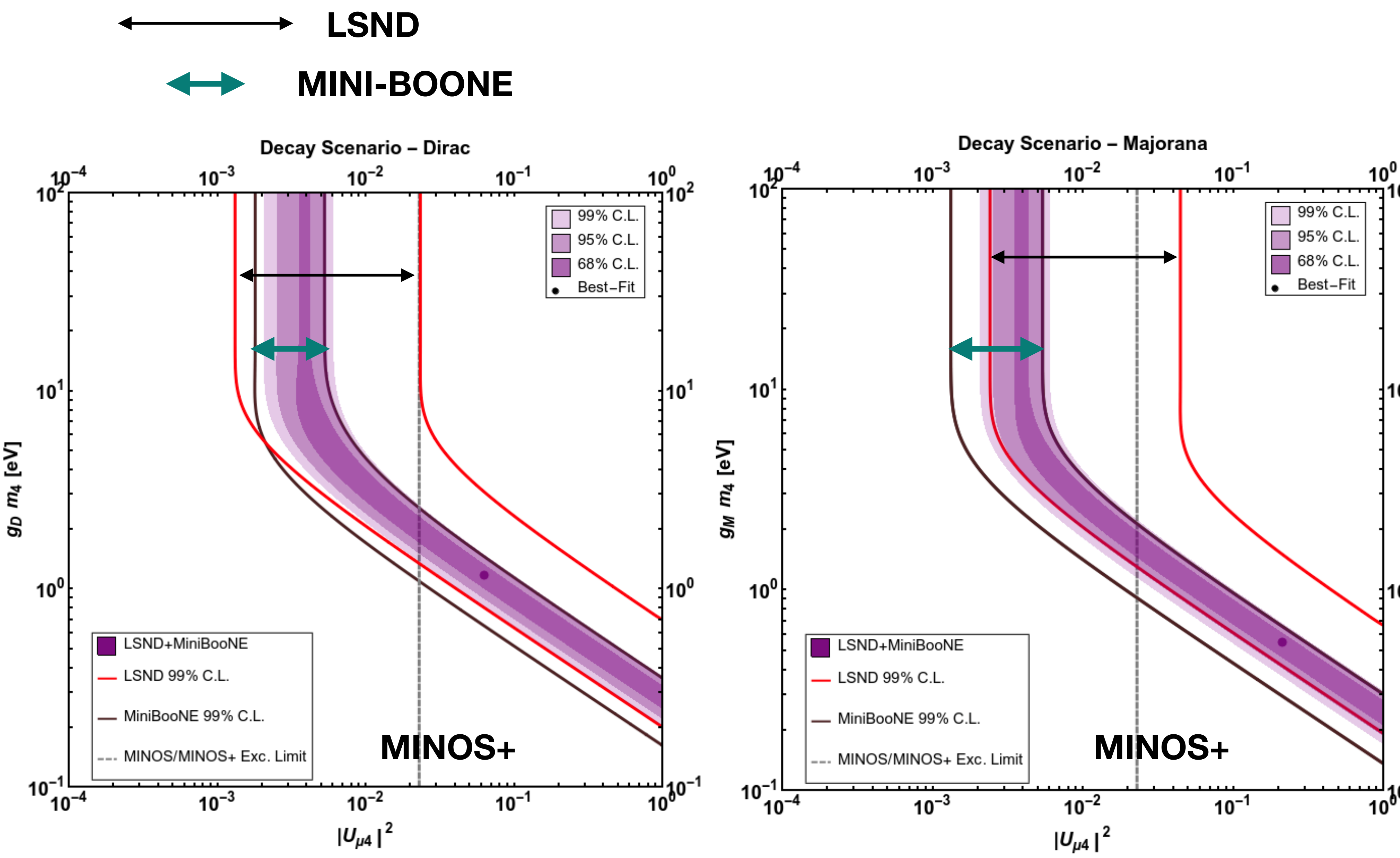
The devil it is in details

There is slight difference of L/Enu of LSND/MINI-BOONE

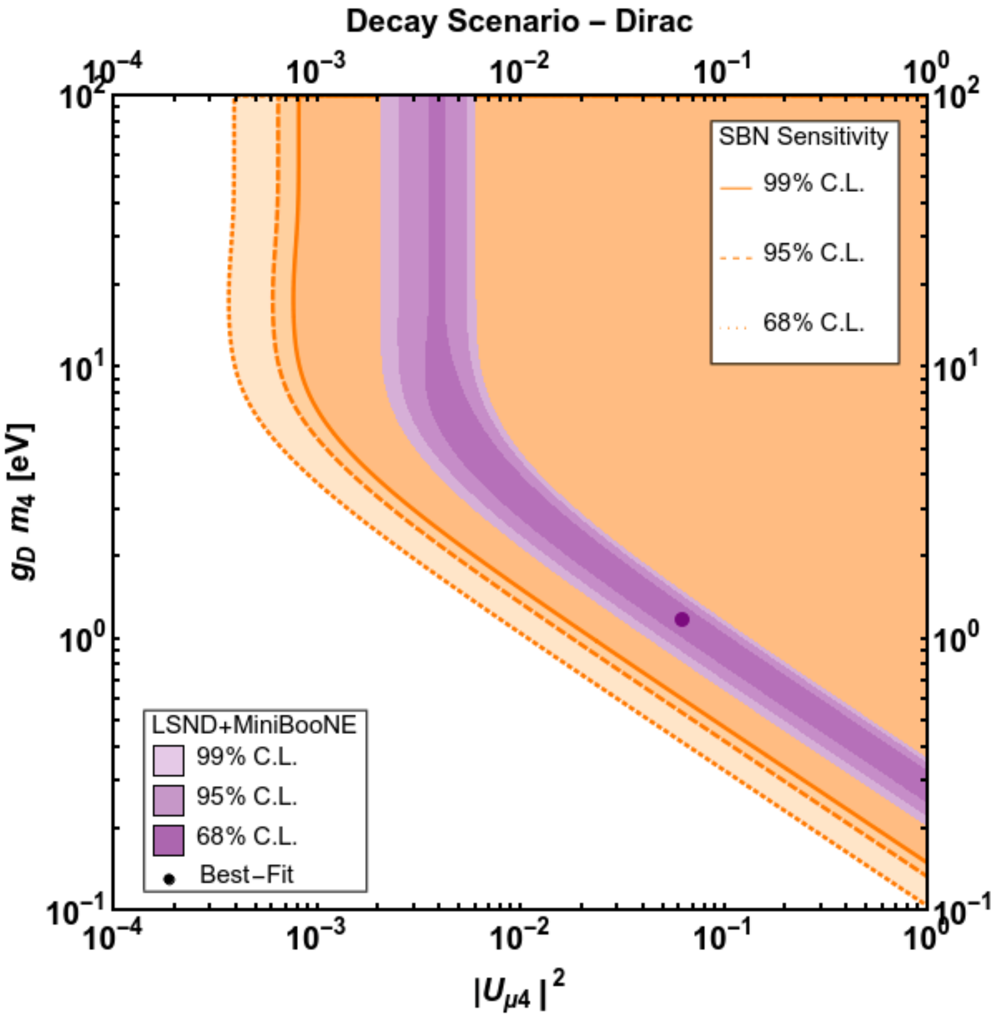


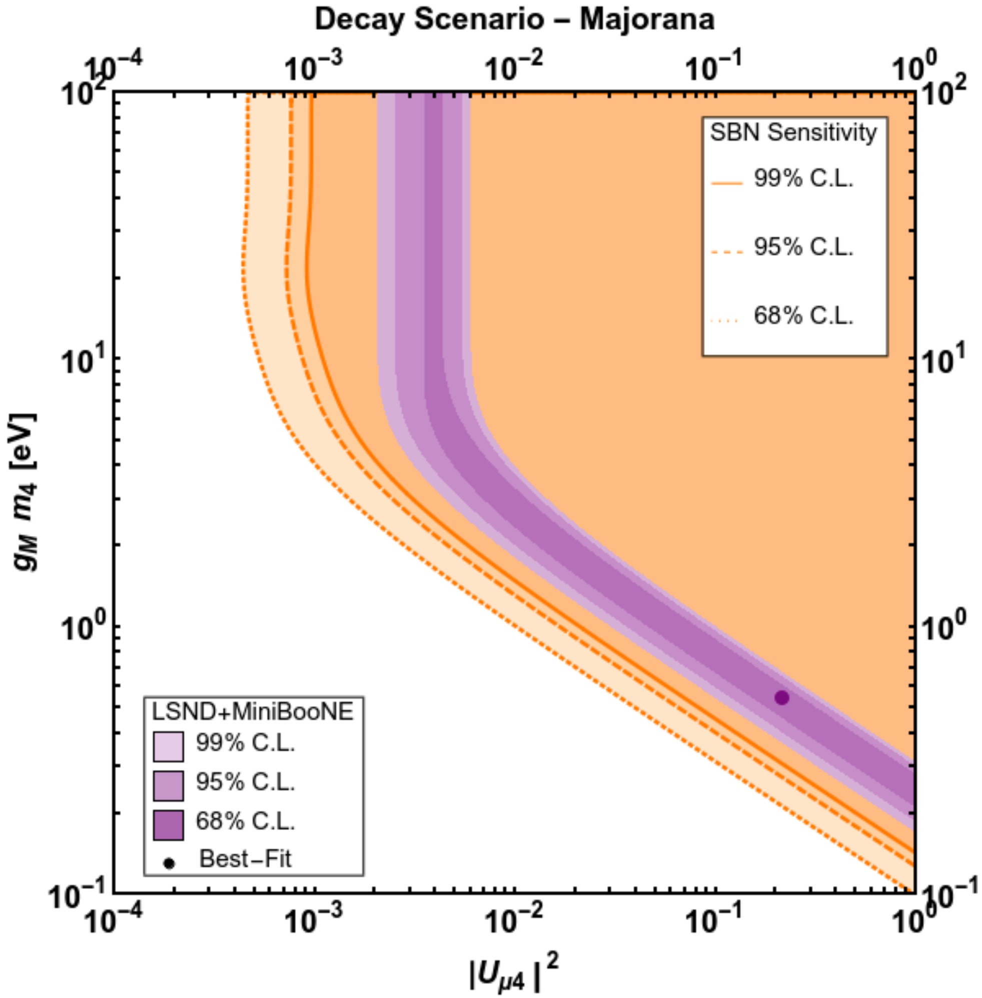


The devil it is in details



SBND experiment





SBND can test both cases : Dirac/Majorana

The SBND sensitivity was made using Gabriela Stenico's GLOBES input files.

Conclusions

Neutrino decay is now a topic of interest in neutrino phenomenology

Neutrino decay can be possibly another explanation for LSND/MINI-BOONE

Constrains from LSND/MINI-BOONE in neutrino/anti-neutrino mode were made.

Joint analysis show an allowed region for lifetime X mixing angle

Dirac/Majorana scenarios can be tested in SBND experiment