Heavy Sterile Neutrino Decay at Short-Baseline Experiments

Based on: JHEP 07 (2020) 141

André de Gouvêa

Orlando Peres

Suprabh Prakash

Gabriela Vitti Stenico

COMHEP

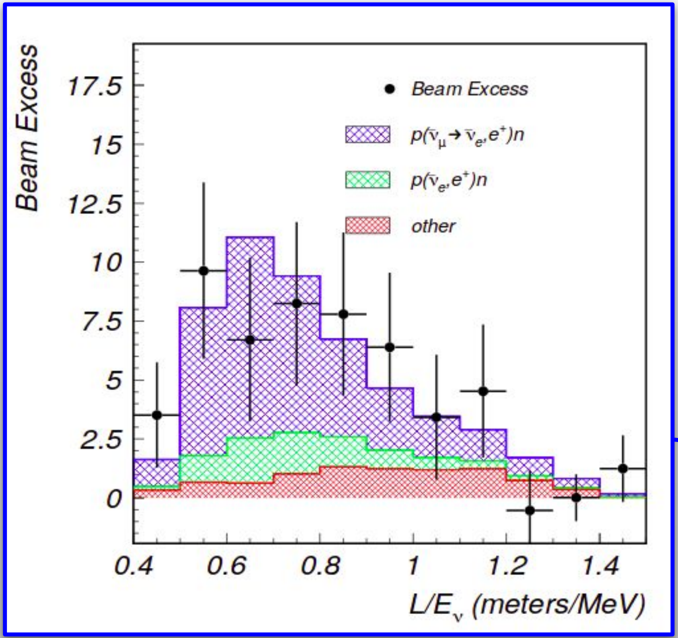
UNICAMP

GEFAN
Grupo de Estudos em Física e Astrofísica de Neutrinos

December 3rd, 2020

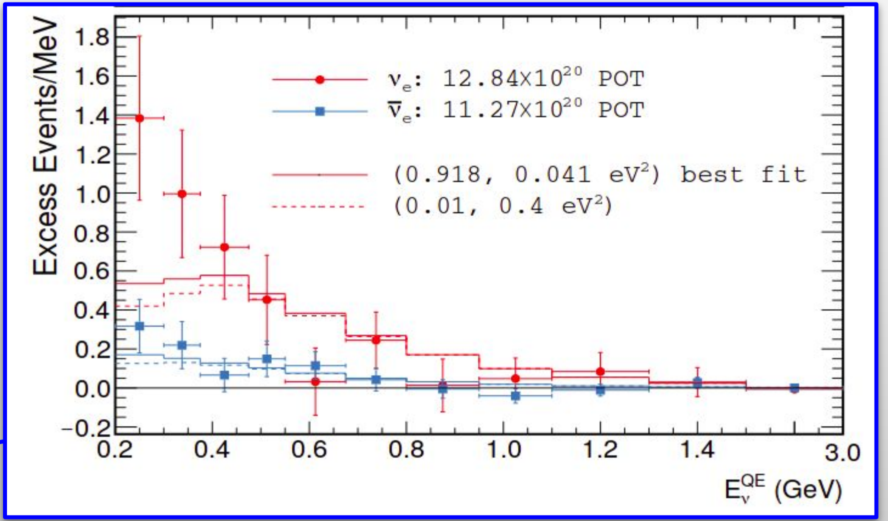
Short-Baseline Anomalies

Positive signal of electron (anti)neutrino candidates in the LSND and MiniBooNE experiments;



LSND

PhysRevD.64.112007

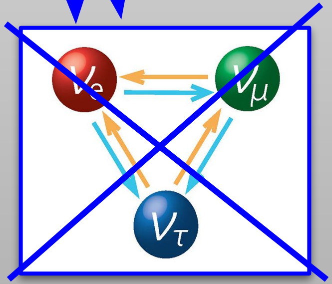


MiniBooNE

PhysRevLett.121.221801

$$|\Delta m^2_{31}| \simeq 2.5 \times 10^{-3}\ \mathrm{eV}^2$$

$$\Delta m^2_{21} \simeq 7.5 \times 10^{-5}\ \mathrm{eV}^2$$



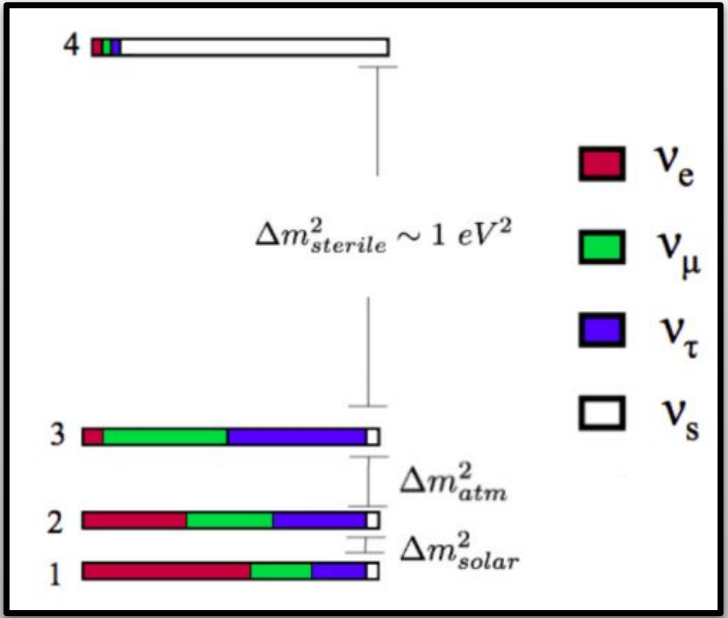
Oscillation Phase: ~ 1

$$1.27 \frac{(\Delta m^2_{ij}/\mathrm{eV}^2)(L/\mathrm{m})}{(E/\mathrm{MeV})} \sim \mathcal{O}(1)$$

~ 1 m/MeV for LSND and MiniBooNE

3+1 Oscillation Model

$$\nu_\alpha = \sum_{i=1}^{3} U_{\alpha i}\nu_i + U_{\alpha 4}\nu_4$$



$$U_{3+1} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} \\ \vdots & & \vdots & U_{\mu 4} \\ \vdots & & \vdots & U_{\tau 4} \\ U_{s1} & U_{s2} & U_{s3} & U_{s4} \end{bmatrix}$$

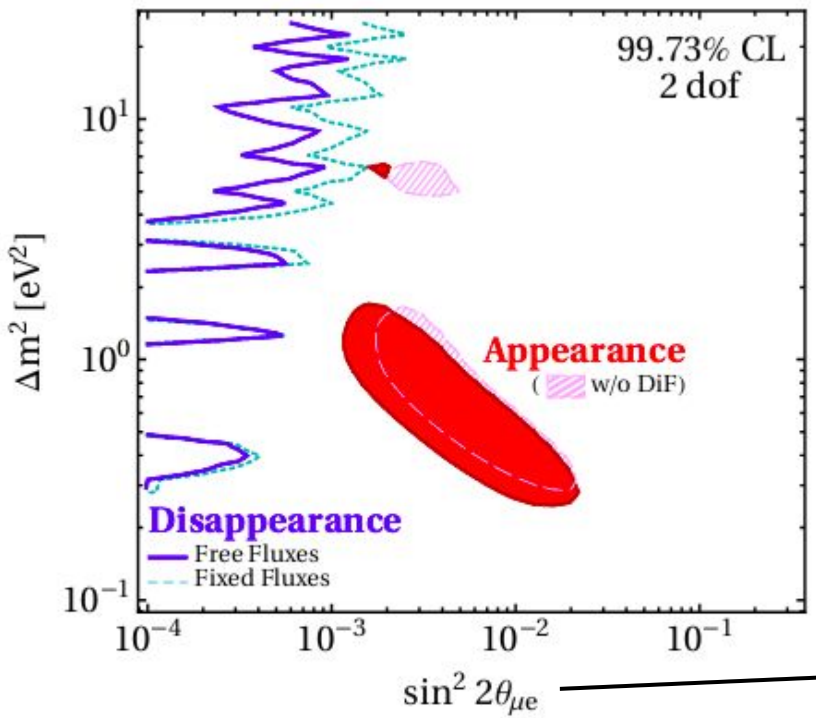
At short-baseline:

$$P_{\nu_e \to \nu_e} = 1 - 4(1 - |U_{e4}|^2)|U_{e4}|^2 \sin^2(1.27\Delta m^2_{41} L/E)$$
$$P_{\nu_\mu \to \nu_\mu} = 1 - 4(1 - |U_{\mu 4}|^2)|U_{\mu 4}|^2 \sin^2(1.27\Delta m^2_{41} L/E)$$

$$P_{\nu_\mu \to \nu_e} = 4|U_{e4}|^2|U_{\mu 4}|^2 \sin^2(1.27\Delta m^2_{41} L/E)$$

Why neutrino decay?

3+1 scenario!



JHEP 1808 (2018) 010

Disappearance searches:

$$P_{\nu_e\to\nu_e} = 1 - 4(1-|U_{e4}|^2)|U_{e4}|^2 \sin^2(1.27\Delta m^2_{41} L/E)$$
$$P_{\nu_\mu\to\nu_\mu} = 1 - 4(1-|U_{\mu4}|^2)|U_{\mu4}|^2 \sin^2(1.27\Delta m^2_{41} L/E)$$

Gallium and Reactor Anomalies OK!

Null results: MINOS/MINOS+
IceCube
Super-Kamiokande

Appearance searches:

$$P_{\nu_\mu\to\nu_e} = 4|U_{e4}|^2|U_{\mu4}|^2 \sin^2(1.27\Delta m^2_{41} L/E)$$

LSND and MiniBoonE OK!

$$\sin^2 2\theta_{e\mu} = 4|U_{e4}|^2|U_{\mu4}|^2$$

Why neutrino decay?

Alternative solution to the Short-Baseline Anomalies!

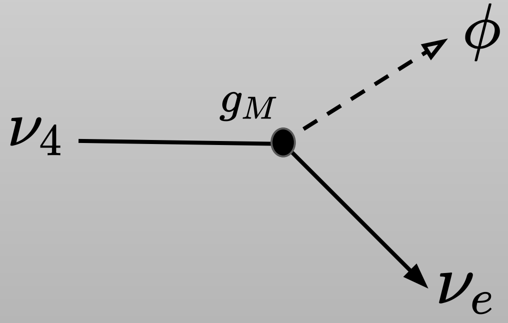
$$\nu_\alpha = \sum_{i=1}^{3} U_{\alpha i}\nu_i + U_{\alpha 4}\nu_4$$

Change neutrino mixing!

decays!

How?

$$\mathcal{L} = -g_M \bar{\nu}_e \nu_4 \phi + \mathrm{h.\,c.}$$

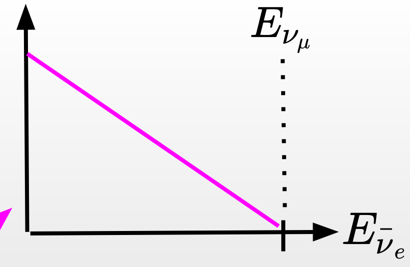


$$\Gamma_{4e} = \frac{|g_M|^2 m_4^2}{32\pi E_4}$$

Transition Probability

In practice:

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

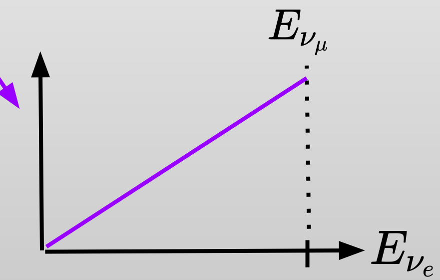


In Short-Baseline: Δm^2_{31} and Δm^2_{21} -> 0

$$\frac{dP_{\nu_\mu \to \overset{(-)}{\nu}_e}(E_{\nu_\mu})}{dE_{\overset{(-)}{\nu}_e}} = W(E_{\nu_\mu}, E_{\overset{(-)}{\nu}_e}) \frac{1}{2} |U_{\mu 4}|^2 (1 - e^{-\Gamma_4 L})$$

Appearance searches!

$\nu_\mu \to \nu_e$



$$P_{\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_\mu}(E_{\nu_\mu}) = \left(1 - |U_{\mu 4}|^2\right)^2 + \left(|U_{\mu 4}|^2\right)^2 e^{-\Gamma_4 L}$$

$$P_{\overset{(-)}{\nu}_e \to \overset{(-)}{\nu}_e} = 1$$

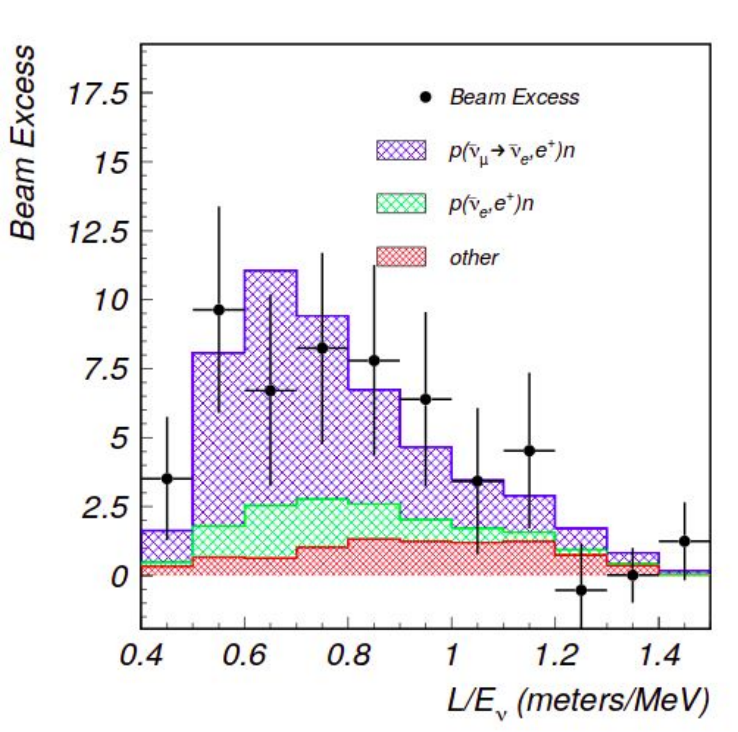
$$|U_{e4}|^2 = 0$$

Disappearance searches!

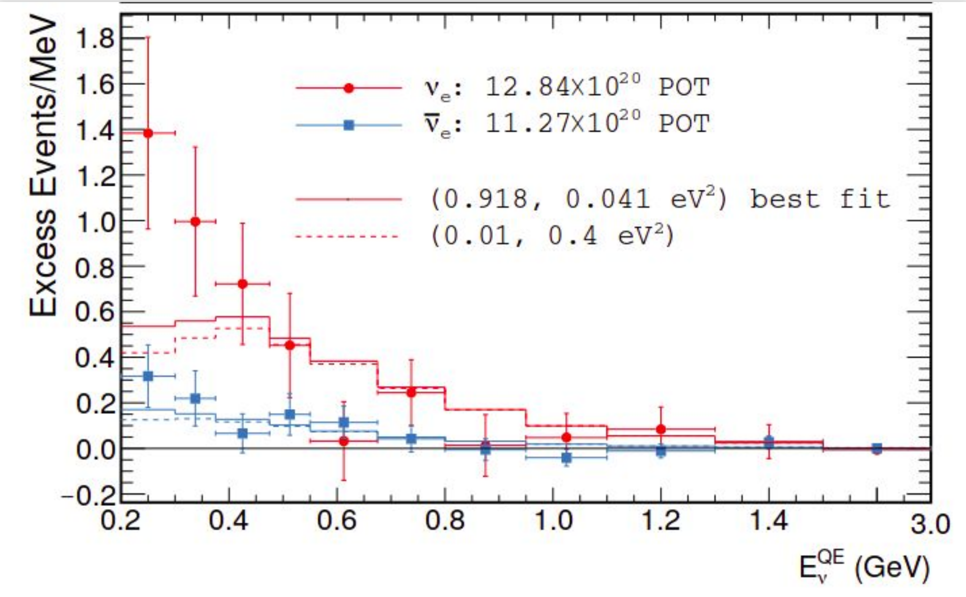
LSND and MiniBooNE

$$\overset{(-)}{\nu}_{\mu} \rightarrow \overset{(-)}{\nu}_{e}$$

Can decay model fit these data?



PhysRevD.64.112007

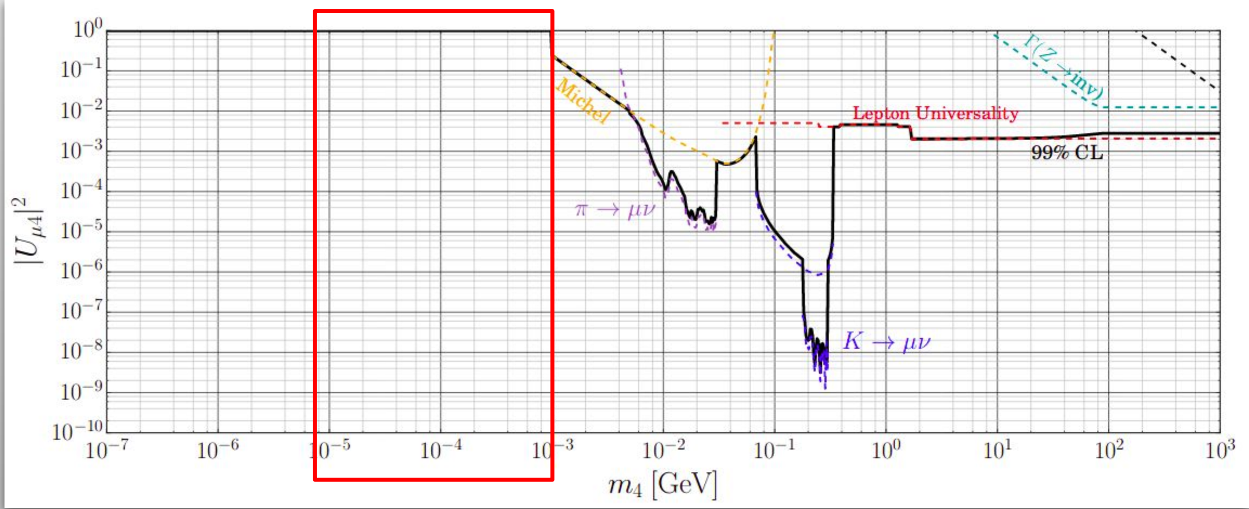


PhysRevLett.121.221801

Global Constraints

$$\left(|U_{\mu 4}|^2, g_M m_4\right)$$

Bounds from: PhysRevD.93.053007 → $|U_{\mu 4}|^2 g_M^2 < 1.9 \times 10^{-7}$



PhysRevD.93.033005

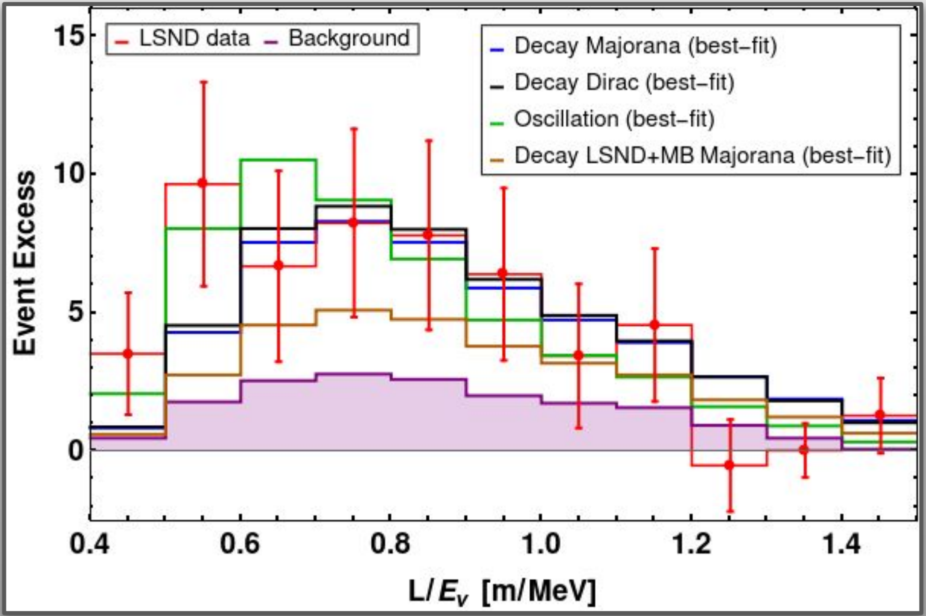
$$10\ \mathrm{keV} \leq \mathrm{m}_4 \leq 1\ \mathrm{MeV}$$

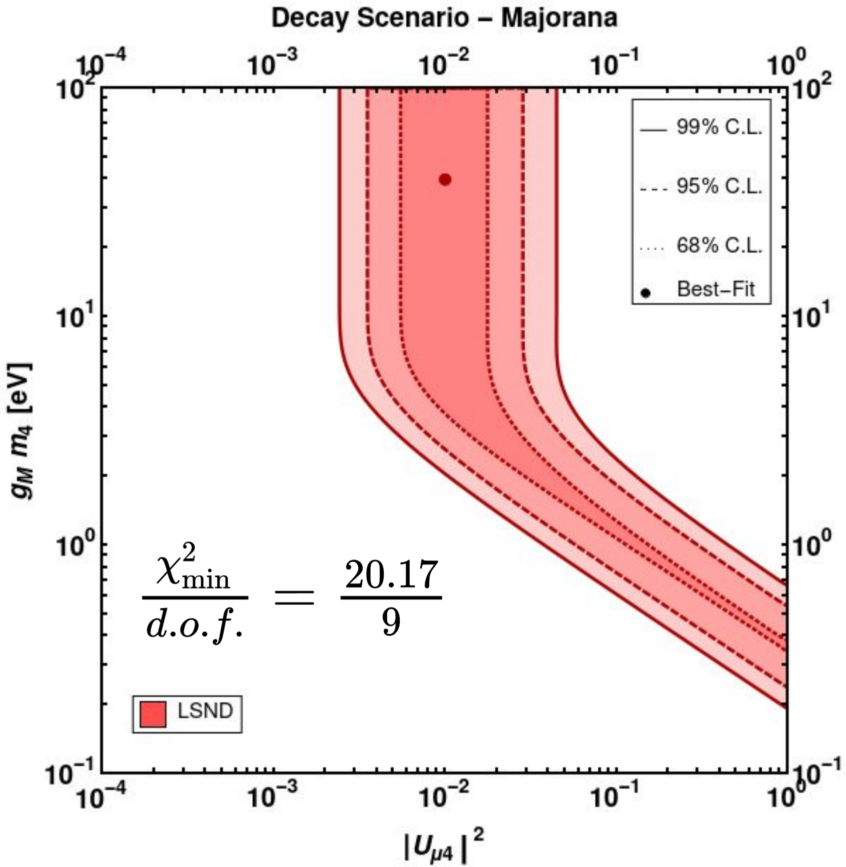
Decay Scenario for LSND

$$\frac{dP_{\nu_\mu \to \overset{(-)}{\nu_e}}(E_{\nu_\mu})}{dE_{\overset{(-)}{\nu_e}}} = W(E_{\nu_\mu}, E_{\overset{(-)}{\nu_e}}) \frac{1}{2} |U_{\mu 4}|^2 (1 - e^{-\Gamma_4 L})$$

Event Rates:

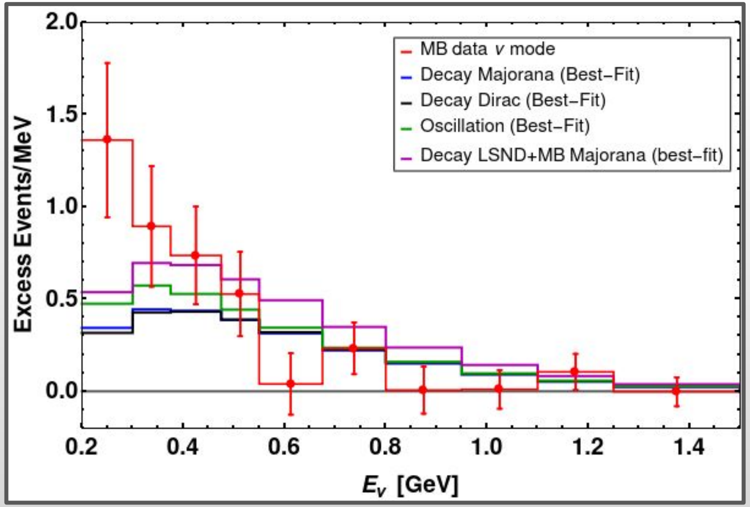
$$\frac{dN}{dE_{\bar{\nu}_e}} = C\,\sigma(E_{\bar{\nu}_e}) \left[\phi_0 \frac{dP_{\nu_\mu \to \bar{\nu}_e}(E_{\nu_\mu}^{(\pi)})}{dE_{\bar{\nu}_e}} + \int_{E_{\bar{\nu}_e}}^{E_{\bar{\nu}_\mu}^{\max}} dE_{\bar{\nu}_\mu}\, \phi_\mu(E_{\bar{\nu}_\mu}) \frac{dP_{\bar{\nu}_\mu \to \bar{\nu}_e}(E_{\bar{\nu}_\mu})}{dE_{\bar{\nu}_e}} \right]$$

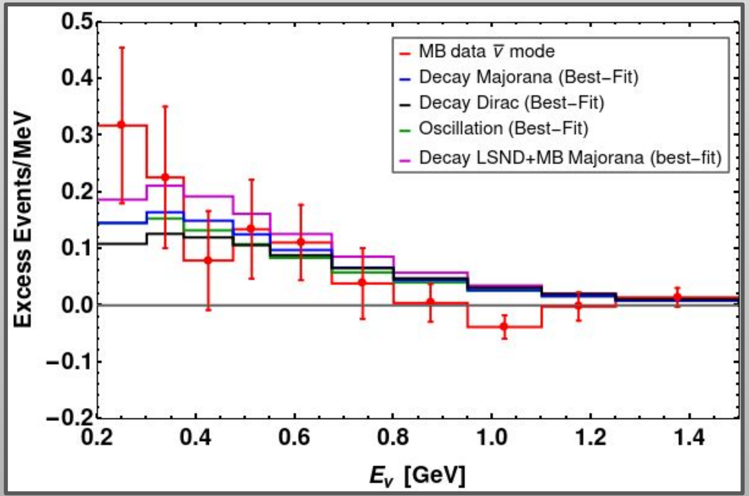


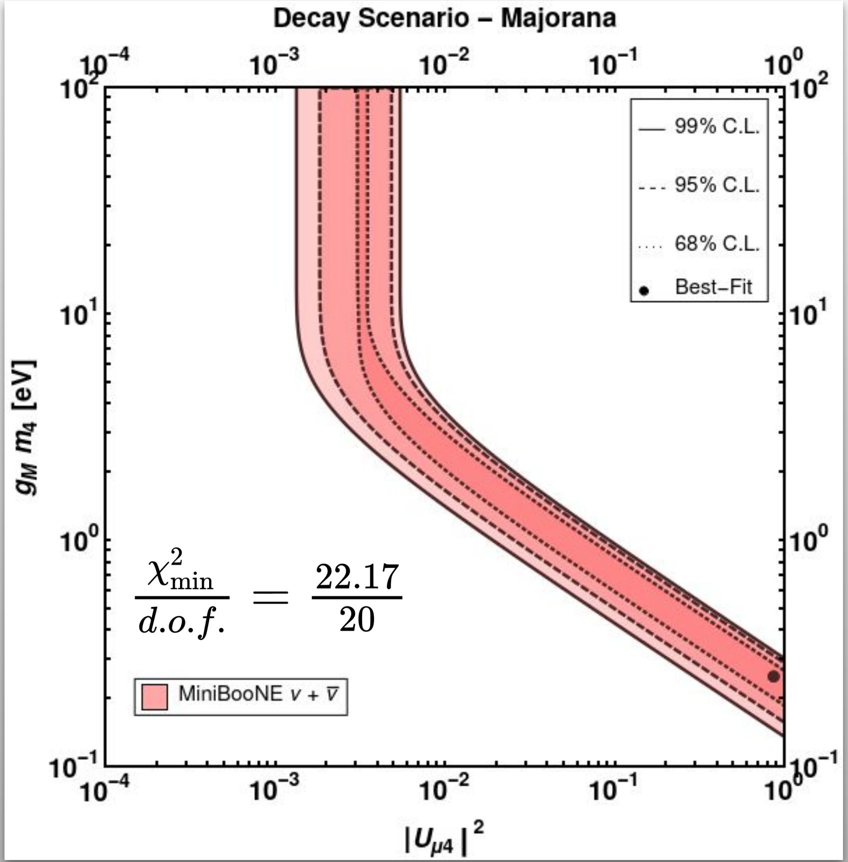


$$\frac{\chi^2_{\min}}{d.o.f.} = \frac{20.17}{9}$$

Decay Scenario for MiniBooNE

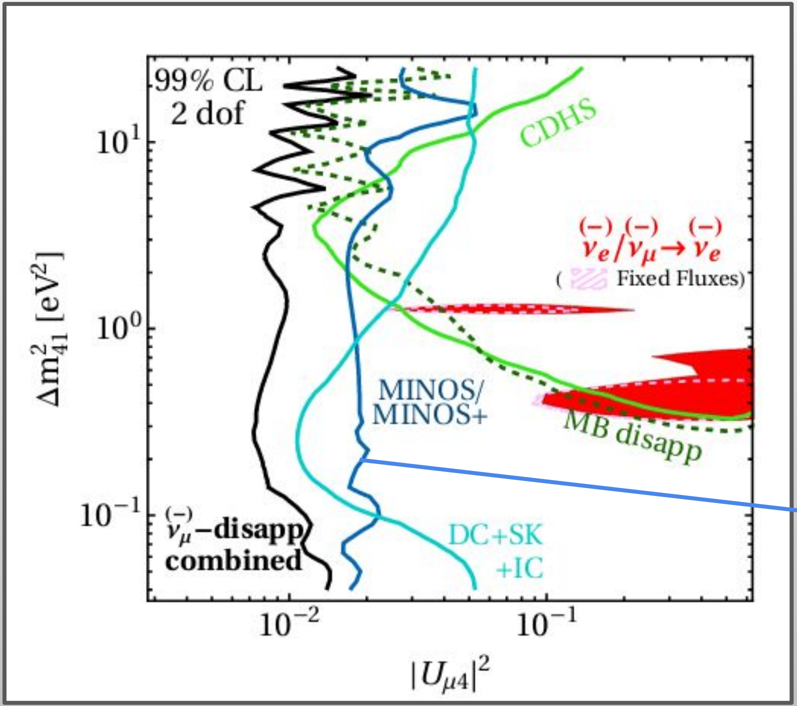




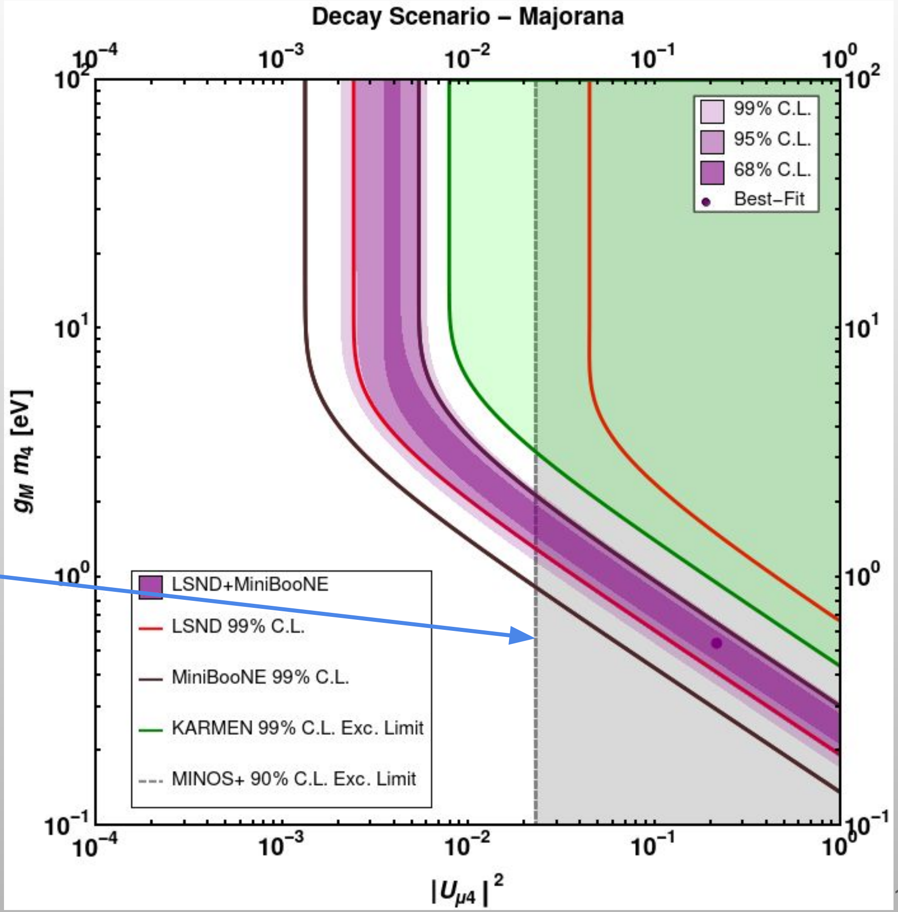


What about disappearance searches?

$$P_{\nu_\mu \to \nu_\mu}(E_{\nu_\mu}) = \left(1 - |U_{\mu 4}|^2\right)^2 + \left(|U_{\mu 4}|^2\right)^2 e^{-\Gamma_4 L}$$



JHEP 1808 (2018) 010

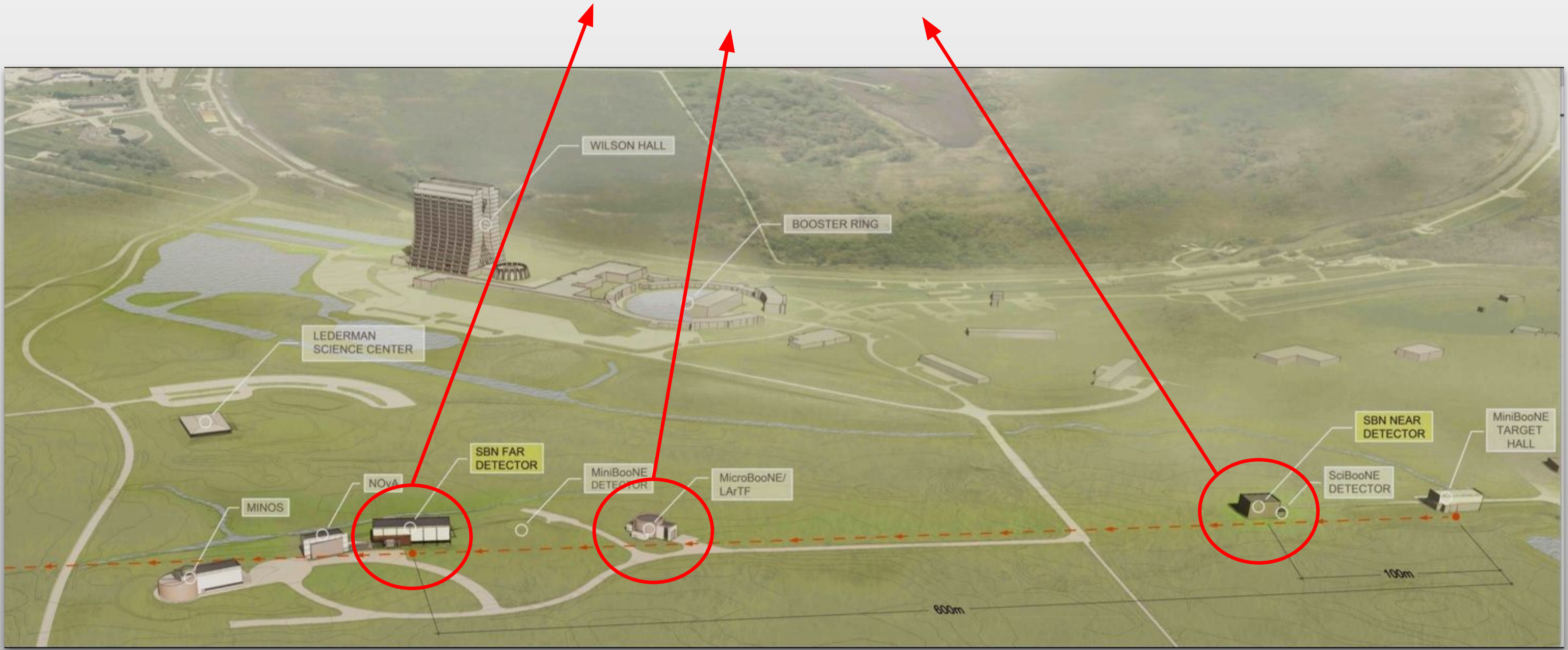


Summary of the Analysis

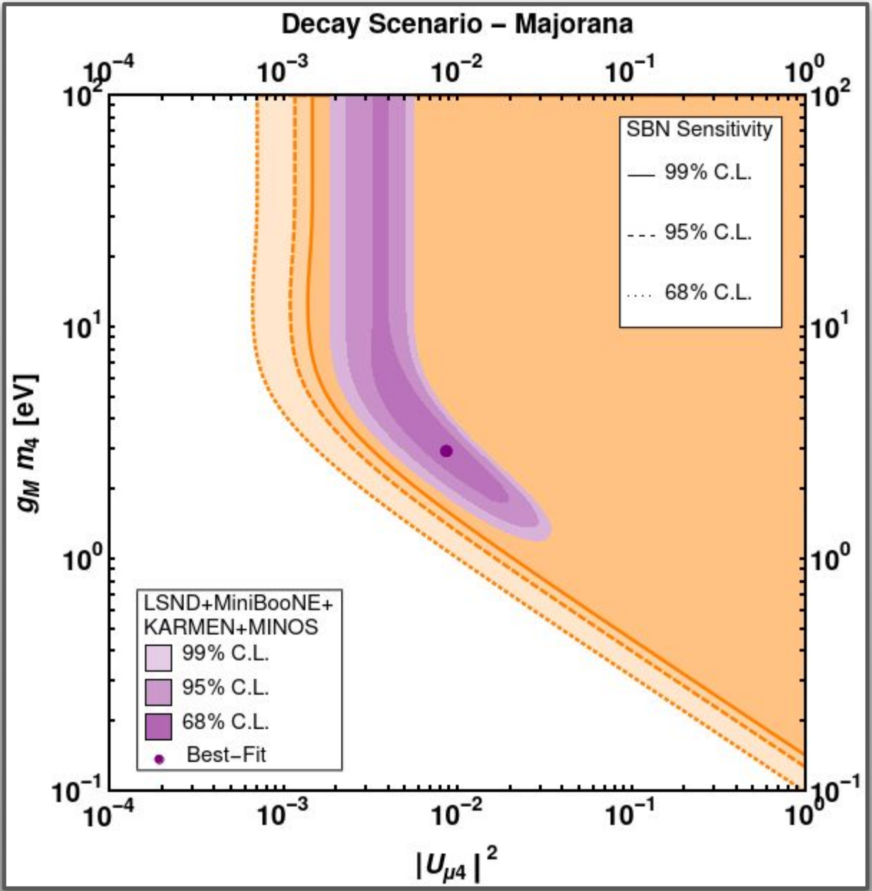
Experiment (app/disapp)	$\chi^2_{\text{min}}/\text{dof}$	Best-fit $(\lvert U_{\mu 4}\rvert^2, g m_4)$
LSND+MiniBooNE (app)	48.34/31	(0.21, 0.54 eV)
KARMEN (app)	6.47/7	No positive signal
All+MINOS (app+disapp)	58.45/40	(0.0086, 2.93 eV)

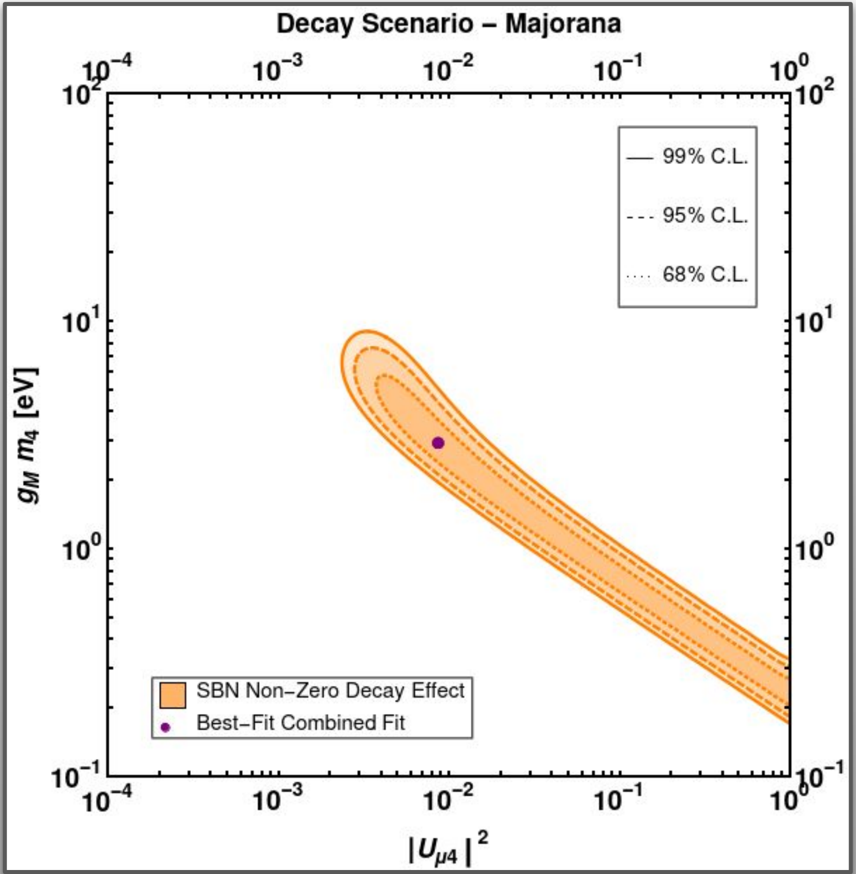
SBN Sensitivity

What is the SBN potential to exclude decay scenario from null-flavour transitions?



SBN Sensitivity





Conclusions

1. Decay Scenario is a potential physical model to deal with Short-Baseline anomaly data sets;

2. SBN has potential to explore the parameter region of this model!

Thank you!