Production and radiative decay of heavy neutrinos at the Booster Neutrino Beam

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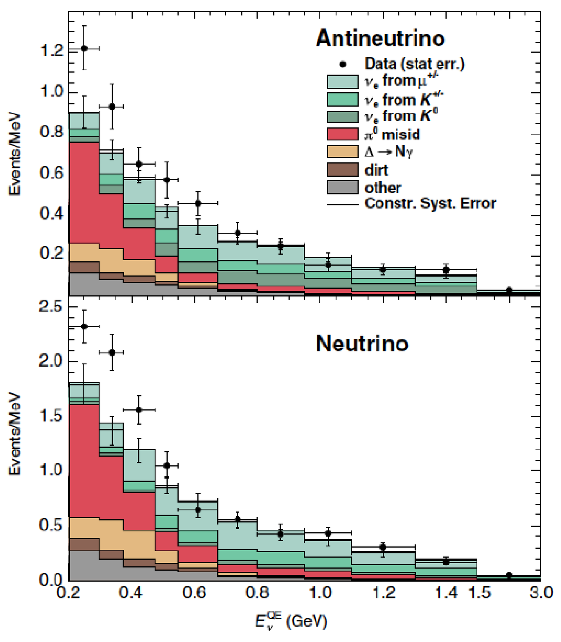
MiniBooNE anomaly

Excess of e-like events in $\nu_\mu \to \nu_e$ searches:

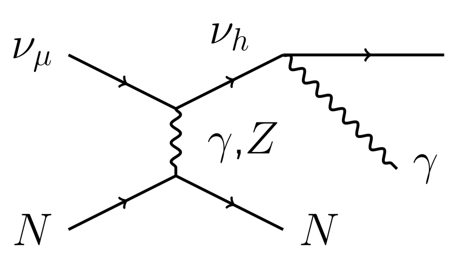


Aguilar-Arevalo et al. PRL110.161801 (2013)

No satisfactory explanation in terms of oscillations.

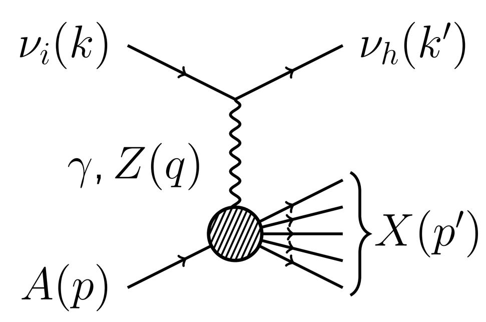
Heavy sterile neutrino model

Gninenko's proposal [1]. Masip et al. added electromagnetic production channel [2],



Heavy neutrino production

Inclusive process $\nu_i(k) + A(p) \to \nu_h(k') + X(p')$,



Neutral current interactions (NC):

$$\mathcal{L}_I = -\frac{g}{2\cos\theta_W} j^\mu Z_\mu; \qquad j^\alpha = \frac{1}{2}\overline{\nu}_\mu \gamma^\alpha (1-\gamma_5)\nu_\mu,$$

$$\nu'_h = \cos\theta\, \nu_h + \sin\theta\, \nu_\mu,$$
$$\nu'_\mu = -\sin\theta\, \nu_h + \cos\theta\, \nu_\mu,$$

with $\sin\theta = U_{\mu h}$,

$$\mathrm{i}\mathcal{M} = -\mathrm{i}\, U_{\mu h} \frac{G_F}{\sqrt{2}} \overline{u}(k')\gamma^\mu(1-\gamma_5)u(k)\langle X|J_\mu|N\rangle .$$

Electromagnetic interactions (EM):

$$\mathcal{L}_{eff} = \frac{1}{2}\mu^i_{tr}\left[\overline{\nu}_h \sigma_{\mu\nu}(1-\gamma_5)\nu_i + \overline{\nu}_i \sigma_{\mu\nu}(1+\gamma_5)\nu_h\right]\partial^\mu A^\nu ,$$

$$\mathrm{i}\mathcal{M} = \frac{\mathrm{i}\, e\, \mu^i_{tr}}{2(q^2+\mathrm{i}\epsilon)} \overline{u}(k')\, q_\alpha\, \sigma^{\alpha\mu}(1-\gamma_5)u(k)\langle X|J_\mu|N\rangle .$$

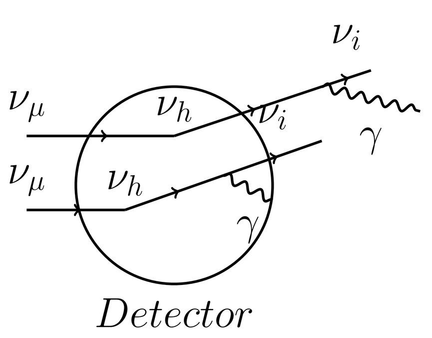
ν_h production and radiative decay at MiniBooNE (CH_2)

$\nu_\mu + \mathrm{p} \to \nu_h + \mathrm{p}$
$\nu_\mu + {}^{12}\mathrm{C} \to \nu_h + {}^{12}\mathrm{C}$ coherent
$\nu_\mu + {}^{12}\mathrm{C} \to \nu_h + \mathrm{X}$ incoherent

Decay $\nu_h \to \nu\gamma$:

$$\frac{d\Gamma}{d\cos\theta_\gamma} = \frac{(\mu^i_{tr})^2 m_h^3}{32\pi}(1 \pm \cos\theta_\gamma)$$

We can calculate the energy and the angular distributions of the photons inside the detector:

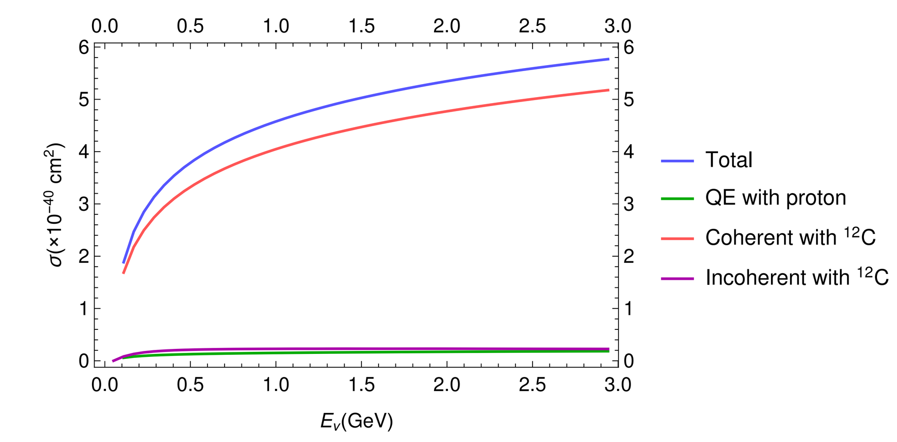


Parameters

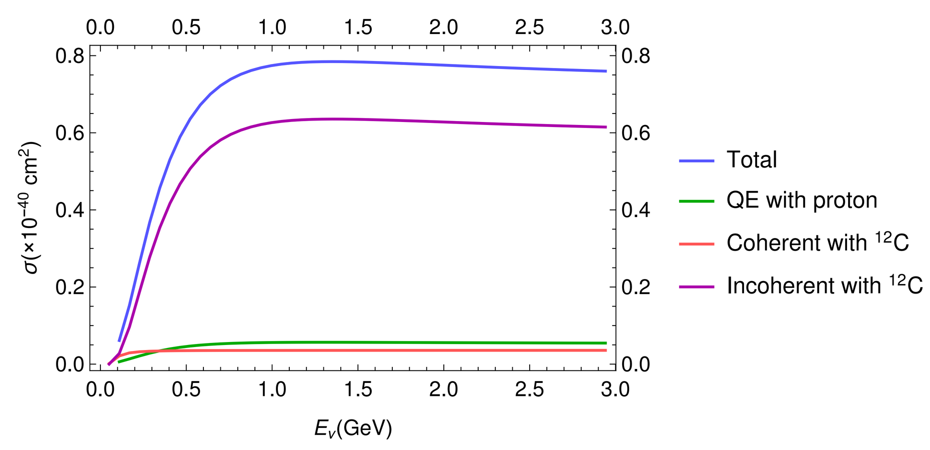
Values of Masip et al. [2]:

- Mass of the heavy neutrino, $m_h = 50$ MeV
- Mixing angle, $|U_{\mu h}|^2 = 3 \times 10^{-3}$
- Lifetime, $\tau_h = 5 \times 10^{-9}$s
- Branching ratio, $BR_i = \frac{(\mu^i_{tr})^2}{\sum_i (\mu^i_{tr})^2} \to BR_\mu = 10^{-2}$

ν_h production cross sections



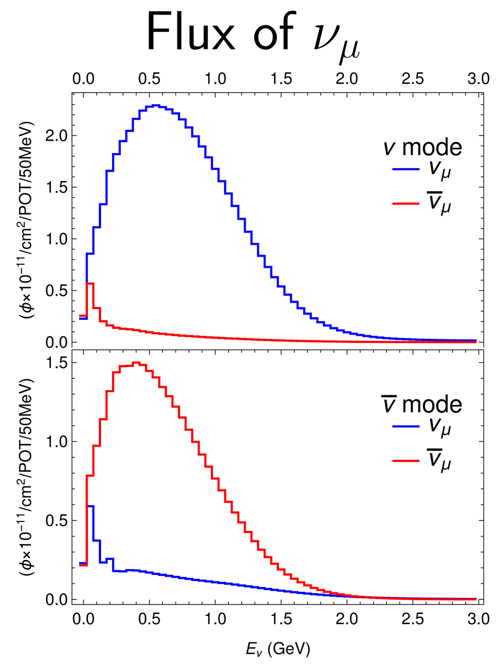
EM. Dominant coherent cross section.



NC. Dominant incoherent cross section.

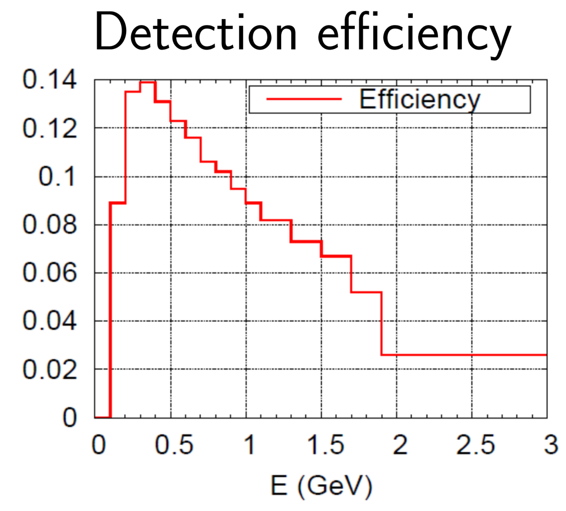
MiniBooNE flux and efficiency

Flux of ν_μ



Aguilar-Arevalo et al, PRD 79 (2009)

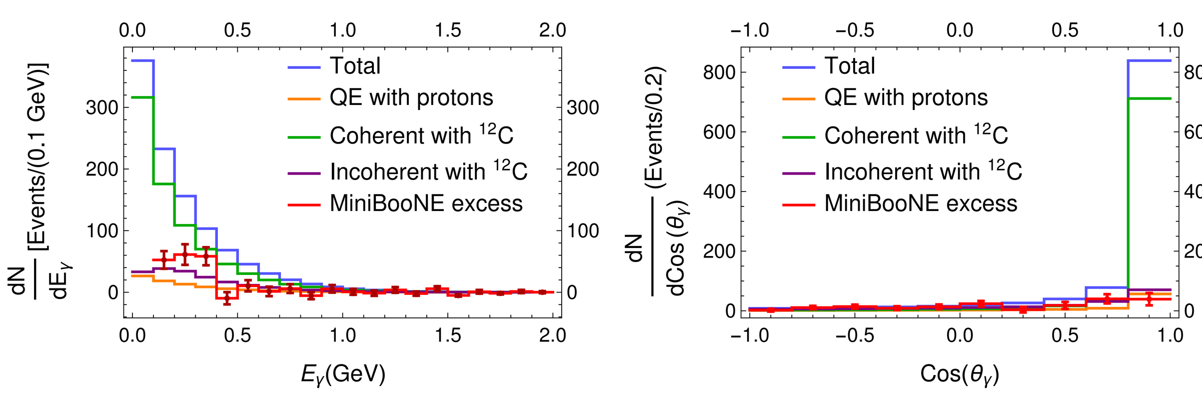
Detection efficiency



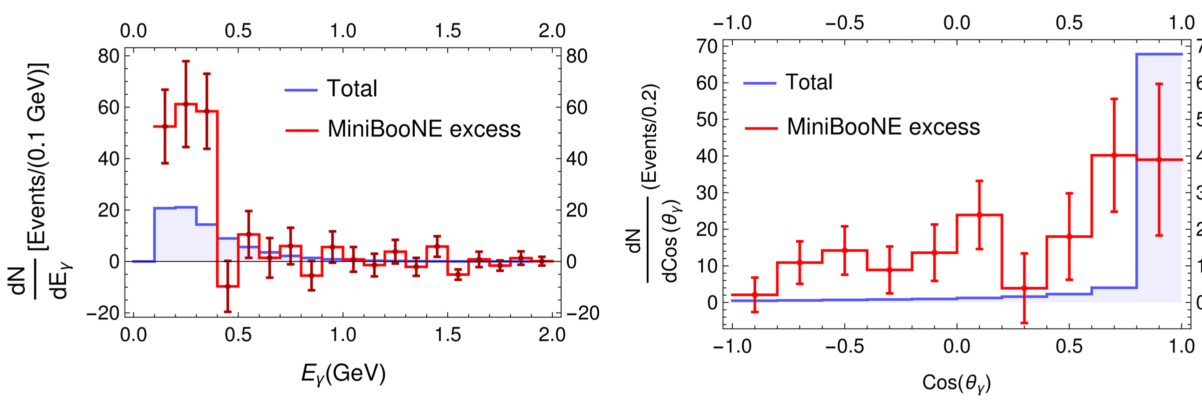
http://www-boone.fnal.gov/forphysicists/datarelease/nue_nuebar_2012

Photon event distributions

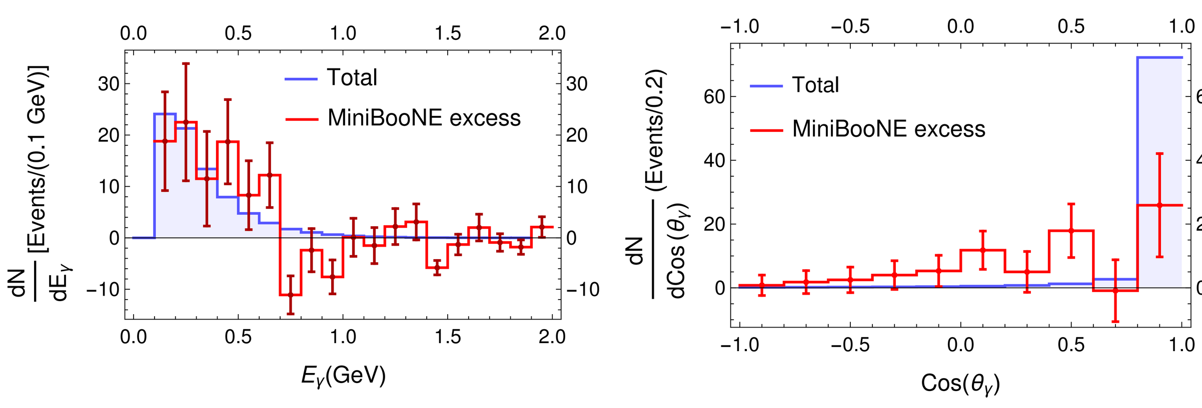
- Neutrino mode:



- Neutrino mode with efficiency:



- Antineutrino mode with efficiency:



Low efficiency reduces the number of events.
With the parameters of [2] data are not well described.

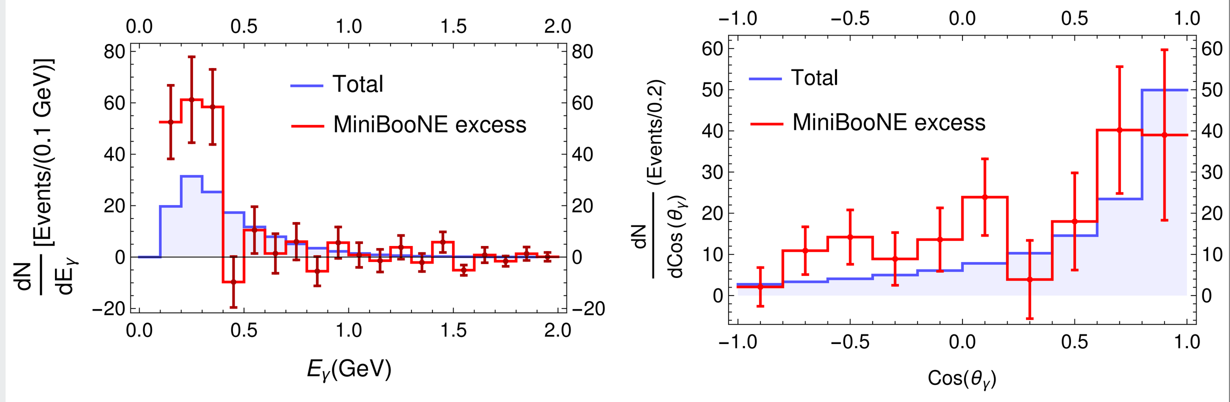
Fitted parameters

Within the LSND compatible limits by Gninenko [1]:

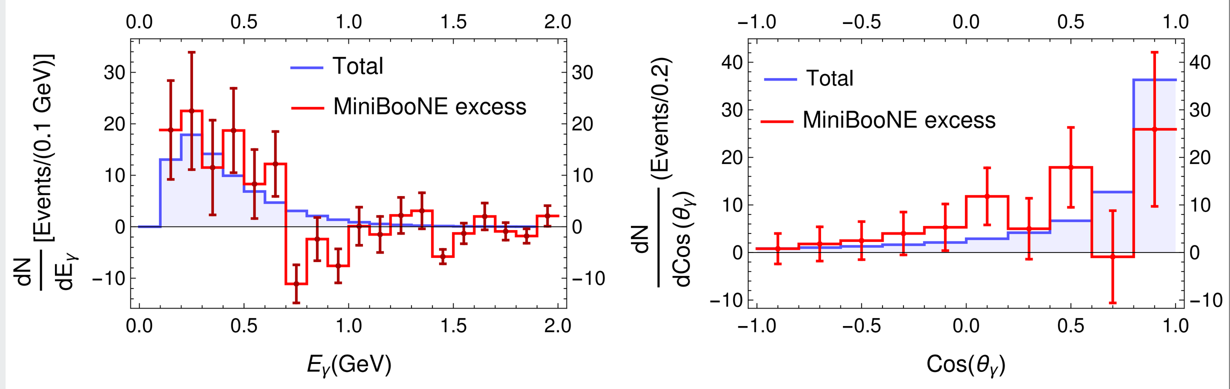
- $m_h = 68.6$ MeV
- $|U_{\mu h}|^2 = 10^{-2}$
- $\tau_h = 2.5 \times 10^{-9}$ s
- $BR_\mu = 8.9 \times 10^{-4}$

Photon event distributions

- Neutrino mode:

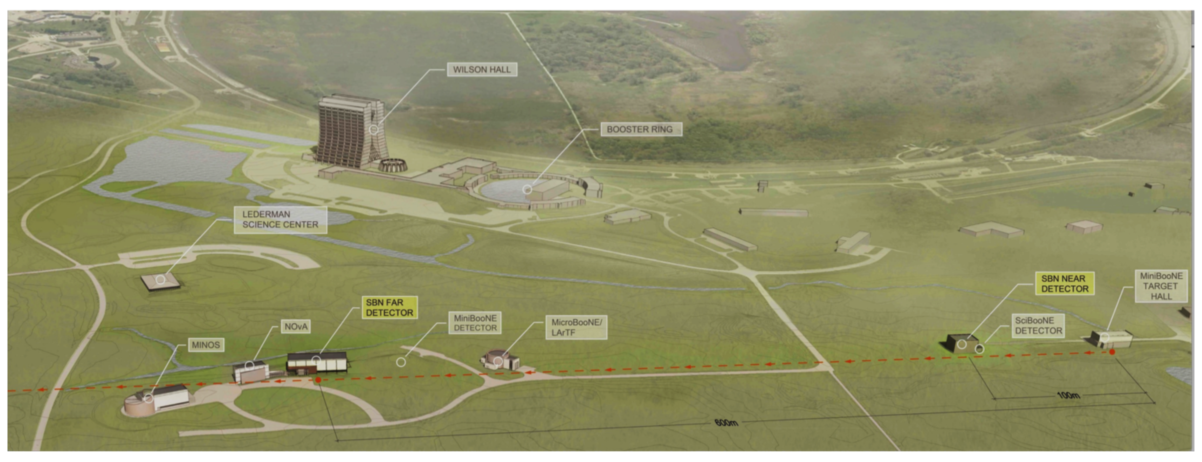


- Antineutrino mode:



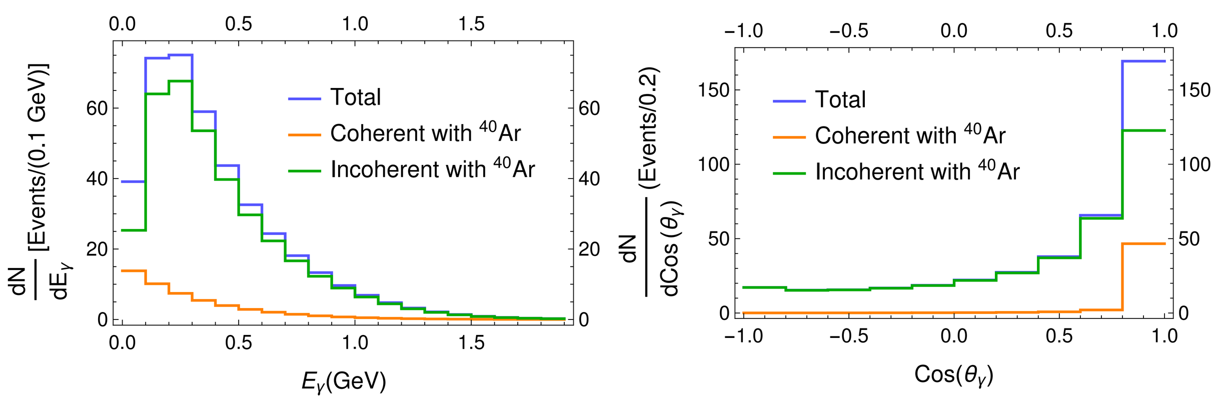
Better agreement with experimental data, particularly in antineutrino mode. But unlikely to be the full explanation for the anomaly, $\chi^2 = 101.1 > n_{\mathrm{DoF}} = 54$.

Short-Baseline Neutrino Oscillation Program, Fermilab

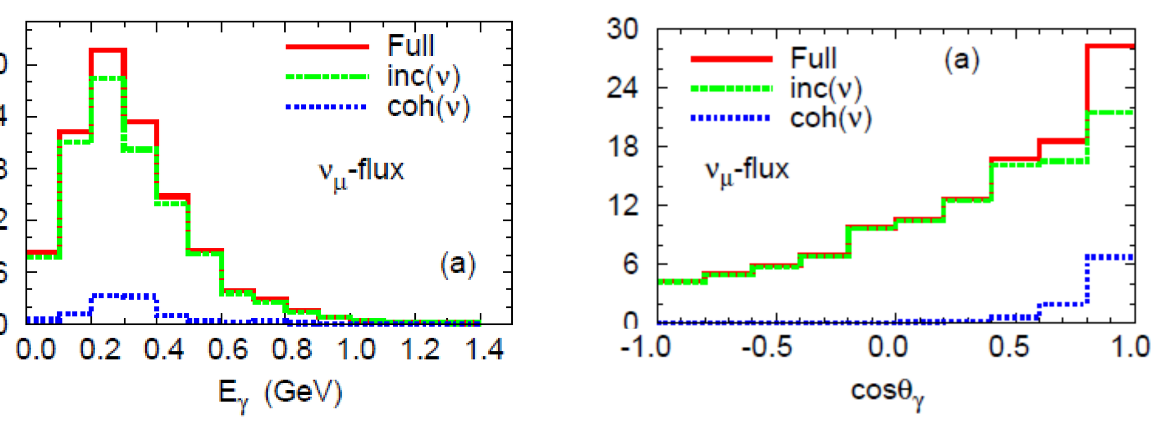


Photon distribution prediction for the **MicroBooNE** LArTPC detector.

- Neutrino mode:



- Prediction for SM predominant photon emission from $\Delta(1232) \to n\gamma$ [3]:



Shape and total number of events of the distributions in the two models are different. Therefore we can test the model and compare with other sources of signal.

We have analogous predictions for **SBND** and **ICARUS**.

References

[1] S. N. Gninenko, Phys. Rev. D **83** (2011) 015015
[2] M. Masip, P. Masjuan and D. Meloni, JHEP **1301** (2013) 106
[3] E. Wang, L. Alvarez-Ruso and J. Nieves, Phys. Rev. C **89** (2014) no.1, 015503