Comments on arXiv:1011.3046 "Muon Capture Constraints on Sterile Neutrino Properties"

S.N. Gninenko
Institute for Nuclear Research, Moscow 117312

(Dated: November 29, 2010)

It has been very recently reported (McKeen, Pospelov, arXive:1011.3046) that the parameter region suggested for an explanation of the neutrino oscillation results from the LSND, KARMEN and MiniBooNE experiments in terms of the production and radiative decay of a heavy neutrino (ν_h) can be ruled out based on the measurements of the radiative muon capture (RMC) on hydrogen. We calculate limits on mixing strength between the ν_h and ν_μ by using results of this experiment, and find out that they essentially disagree with the reported bounds. For the ν_h with mass 60 MeV our limit is worse by a factor of 5, while for 90 MeV it is worse by about two orders of magnitude. We also noticed the wrong behavior of the reported limit curve in the low mass region. The importance of accurate Monte Carlo simulations of the ν_h signal in the RMC experiment is stressed. Our conclusion is that the whole LSND-MiniBooNE parameter region cannot be ruled out by the RMC measurements.

PACS numbers:

In the recent work [1], see also [2], it has been shown that the neutrino oscillation results from the LSND, KARMEN and MiniBooNE experiments could be explained by the existence of a heavy sterile neutrino (ν_h), assuming that it is created by mixing in ν_μ neutral-current interactions and decays radiatively into a photon and a light neutrino. The ν_h's could be Dirac or Majorana type and decay dominantly into $\nu_h \to \gamma\nu$ in the detector target if, for example, there is a non-zero transition magnetic moment between the ν_h and the ν. Combined analysis of the energy and angular distributions of the LSND and MiniBooNe excess events suggests that the ν_h mass m_{ν_h}, the mixing strength $|U_{\mu h}|^2$ and the lifetime τ_{ν_h}, are in the ranges:

$$40 \lesssim m_{\nu_h} \lesssim 80 \text{ MeV},\ 10^{-3} \lesssim |U_{\mu h}|^2 \lesssim 10^{-2},$$
$$10^{-11} \lesssim \tau_{\nu_h} \lesssim 10^{-9}\ s, \qquad (1)$$

respectively.

The mixing $|U_{\mu h}|^2$ for the mass range of (1) would result in the ν_h emission in the ordinary muon capture (OMC) on nuclei $\mu^- A \to \nu_\mu A'$ [3]. The OMC rate of the heavy neutrino production can be estimated as

$$\Gamma_{\nu_h} = \Gamma_{OMC}|U_{\mu h}|^2 \rho(m_{\nu_h})/\rho(0) \qquad (2)$$

where Γ_{OMC} is the OMC rate and $\rho(m_{\nu_h})$, $\rho(0)$ are the phase space factors for emission of heavy neutrino and massless, unmixed neutrinos, respectively.

Recently, it has been noticed by McKeen and Pospelov [4] that the parameter space of (1) can be probed by using the results of the experiment on the radiative muon capture (RMC) rate on hydrogen [5]. In this experiment muons were stopped in a liquid hydrogen target. Photons from the reaction $\mu p \to \nu_\mu \gamma n$ were converted in a Pb layer surrounding the target into e^+e^- pairs , whose momenta were measured by a magnetic spectrometer. If the ν_h exists, it would be produced through mixing in the OMC process and after the prompt $\nu_h \to \gamma\nu$ decay in the target and subsequent decay photon conversion result in a final state identical to the one from the RMC reaction. The number of RMC photons observed in the experiment is calculated by using Eq.(38) from [5]:

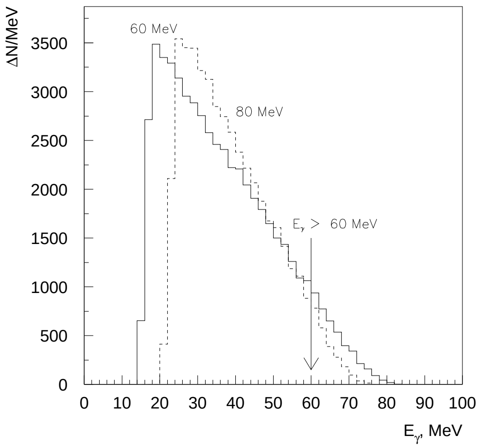

FIG. 1: Energy distributions of photons from the $\nu_h \to \gamma\nu$ decay of the Dirac heavy heutrino with $a = -1$ [1] with energy of 100 MeV created through the mixing in the muon capture $\mu_\nu p \to \nu_h n$ on proton and calculated for ν_h masses of 60 and 80 MeV. The arrow indicate the threshold of 60 MeV used in the analysis of RMC data [4].

$$n_\gamma = n_{stop} R_\gamma K A_a \qquad (3)$$

where $n_{stop}(\simeq 3.4 \cdot 10^{12})$ is the total number of muons stopped in the target, $R_\gamma = (2.1 \pm 0.21) \cdot 10^{-8}$ is the RMC branching fraction, K = 0.6 is an effciency factor, and A_a is the absolute photon spectrometer acceptance which include geometrical acceptance, conversion probability, e^+e^- reconstruction efficiency etc.. Using $n_\gamma = 279 \pm 26$ events found in the experiment, gives averaged over the

RMS photon spectrum value $A_a = 6.5 \cdot 10^{-3}$. We will use these numbers for the cross-check, but immediately note that the A_a value is about two times bigger than that estimated for the $\nu_h \to \gamma\nu$ spectrum. To be conservative we will keep this "safety" factor just in mind.

The energy distribution of photons from the $\nu_h \to \gamma\nu$ decay calculated for different masses of the ν_h with the total energy of 100 MeV, which is expected from the OMC on hydrogen, is shown in Fig.1 The upper limit on the excess number of photons from the $\nu_h \to \gamma\nu$ decay in the RMC experiment can be estimated at 2σ level for $E_\gamma > 60$ MeV as:

$$\Delta n_\gamma = n_\gamma - n_0 \lesssim 140 \text{ events} \tag{4}$$

where $n_0 \simeq 180$ is the number of events that are expected from the theory for the ratio of the pseudoscalar and axial-vector form factors $g_p/g_a = 0.69$ and ortho to para transition rate of the (μp) atom equal $\lambda = 4.1 \times 10^4$ s^{-1} [5].

The excess n_s of events from the $\nu_h \to \gamma\nu$ decays can be calculated as

$$n_s = n_{stop} R_{OMC} |U_{\mu h}|^2 f_{phs} B(\nu_h \to \gamma\nu) P_{\nu_h \to \gamma\nu} f_\gamma K A_a \tag{5}$$

where n_{stop}, K, A_a are as in (3), $R_{OMC}(1.5 \cdot 10^{-3})$ is the OMC branchning fraction, $B(\nu_h \to \gamma\nu)(\simeq 1)$ is the branching fraction of the $\nu_h \to \gamma\nu$ decay, $f_{phs} = \rho(m_{\nu_h})/\rho(0)$ is the ratio of phase space factors, $P_{\nu_h \to \gamma\nu}(0.15)$ is the probability to decay in the target for heavy neutrino lifetime $\tau = 10^{-9}$ s as in [4], f_γ is the fraction of photons with energy $E_\gamma > 60$ MeV (0.074 and 0.05 for 60 and 80 MeV ν_h, respectively) . Taking into account above values results in the 2σ limit $|U_{\mu h}|^2 < 1.4 \times 10^{-3}$ for the ν_h mass of 60 MeV, which is worse than the limit of [4] by a factor of 5, see Fig. 3 in [4]. For the mass of 80 MeV the limit is $|U_{\mu h}|^2 < 4 \times 10^{-3}$ and the disagreement is about factor 10, but for 90 MeV it is two orders of magnitude, $|U_{\mu h}|^2 < 5.1 \times 10^{-2}$ vs $|U_{\mu h}|^2 \lesssim 5 \times 10^{-4}$ reported in [4]. For the mass range $m_{\nu_h} \lesssim 20$ MeV the behavior of the limit curve shown in Fig.3 [4] and its extrapolation to zero mass is incorrect , because the probability $P_{\nu_h \to \gamma\nu} \to 0$ with $m_{\nu_h} \to 0$.

Let us note that work of Ref.[1] has been attempted to explain an excess of events observed by the LSND in the energy range $20 < E_\gamma < 60$ MeV. The idea is to introduce a new particle with such decay properties that would allow to keep the number of events with the energy deposition above 60 MeV close to zero, in agreement with the LSND observations. This is achieved by suggesting that the ν_h decays radiatively as a Dirac particle with the photon asymmetry parameter equal to $a = -1$. The emission of photons preferably backward with respect to the ν_h direction of move makes their energy spectrum much softer compare e.g. to the one form the isotropic distribution (probably used in the analysis of Ref.[4]). In contrary the limits of Ref.[4] are extracted from the data of the RMC experiment for the energy region $E_\gamma > 60$ MeV and even for the lower ν_h energy than in the LSND case. The fraction of expected $\nu_h \to \gamma\nu$ events in this energy range is small, and hence the limits obtained are quite sensitive to the details of the experimental analysis, in particular for the ν_h masses above 60 MeV. Let us give an example of such sensitivity related to the photon response function in the RMC experiment. It is determined by generating Monte Carlo photons sampled from the known $\pi^- p$ reaction spectrum, whose origins in the target are identical with the pion stopping distribution. The shape of this function is important to extract correct number of RMC events. The function is essentially asymmetric (see Fig. 10), and shifts the whole energy spectrum to the low energy region. The peak value of 129 MeV is shifted by 5-7 MeV but the low energy tail has energies up to 50% of the initial photon energy. If we shift spectra shown in Fig.1 just by, say 4 MeV, the decrease in the number of observed $\nu_h \to \gamma\nu$ events would result in limits $|U_{\mu h}|^2 < 2.1 \cdot 10^{-3}$ and $|U_{\mu h}|^2 < 0.01$ for the 60 and 80 MeV ν_h, respectively, instead of given above. Therefore, accurate Monte Carlo simulations of the ν_h production and decay sequence events in the experiment [5] and propagation of theses events through the spectrometer taking into account the response function is important to extract reliable limits on $|U_{\mu h}|^2$.

The Primakoff mechanism of the ν_h production $\nu A \to \nu_h A$ followed by the decay $\nu_h \to \gamma\nu$ through the transition magnetic moment μ_{tr} between the ν_h and light ν with the subsequent $\nu_h \to \gamma\nu$ decay has been originally considered in [6] and has been used to extract limits on μ_{tr} from the NOMAD data [7]. In order to use this mechanism for interpretation of the LSND ν_μ data [4], one has to make an additional assumption that the light ν is a component of the ν_μ. Although this is possible, it requires introduction of additional unknown parameters.

In summary, we do not find arguments of McKeen and Pospelov [4] convincing enough to exclude the whole LSND-MiniBooNE parameter region, at least for Dirac scenario of [1]. In contrary, their work enhances motivation for a more sensitive direct search for the $\nu_h \to \gamma\nu$ decay in a dedicated experiment.

I would like to thank D.S. Gorbunov for discussion and pointing out Ref. [4] to me.

---

[1] S.N. Gninenko, arXiv:1009.5536.

[2] S.N. Gninenko, Phys. Rev. Lett. **103**, 241802 (2009).

[3] J.P. Deutsch at el., Phys. Rev. **D 27**, 1644 (1983).

[4] D. McKeen and M. Pospelov, arXive:1011.3046.

[5] D.H. Wright at el., Phys. Rev. **C 57**, 373 (1998).

[6] S.N. Gninenko and N.V. Krasnikov, Phys. Lett. **B 450**, 165 (1999).

[7] J. Altegoer et al., Phys. Lett. **B 428**, 197 (1998).