Sensitivity of the νGeN experiment to the antineutrino magnetic moment and millicharge

Georgii Ignatov [1] [2] for the νGeN collaboration

[1]Moscow Institute of Physics and Technology [2]Lebedev Physical Institute

Neutrino magnetic moment (NMM) and millicharge

In minimal extensions of Standard Model which include massive neutrinos, neutrino has non-zero magnetic moment given by

$$\mu_{ii} = \frac{3eG_F m_i}{8\sqrt{2}\pi^2} \approx 3.2 \times 10^{-19}(\frac{m_i}{1eV})\mu_B. \quad (1)$$

This value is many orders of magnitude lower than sensitivity of modern experiments. Nevertheless there are extensions to Standard Model which allow NMM to be up to $10^{-14}\mu_B$ for Dirac neutrinos and $10^{-11}\mu_B$ for Majorana neutrinos.

In Standard Model neutrinos have exactly zero electric charge. However some models allow neutrinos to have very small electric charge, usually referred to as millicharge.

Neutrino-electron elastic scattering

Neutrino electromagnetic properties may be investigated using elastic scattering of neutrinos off electrons. This process is known from the Standard Model, its cross section equals to

$$\frac{d\sigma_W}{dT} = \frac{G_F^2 m_e}{2\pi}[(g_V + g_A)^2 + (g_A^2 - g_V^2)\frac{m_e T}{E_\nu^2} + (g_V - g_A)^2(1 - \frac{T}{E_\nu})^2]. \quad (2)$$

To take into account non-zero NMM one should add to the differential cross section an extra term

$$\frac{d\sigma_{EM}}{dT} = \pi\frac{\alpha^2}{m_e^2}(\frac{\mu_\nu}{\mu_B})^2(\frac{1}{T} - \frac{1}{E_\nu}). \quad (3)$$

If neutrinos have electric charges, the neutrino-electron elastic scattering cross section becomes

$$\frac{d\sigma_{SM+Q}}{dT} = \frac{d\sigma_{SM+Q_{ll}}}{dT} + \frac{d\sigma_{SM+Q_{ll'}}}{dT}. \quad (4)$$

$$\frac{d\sigma_{SM+Q_{ll}}}{dT} = \frac{d\sigma_{SM}}{dT}, \quad (5)$$

$$g_V \to g_V - \frac{\sqrt{2}\pi\alpha}{G_F m_e T}\frac{q_{ll}}{e}. \quad (6)$$

$$\frac{d\sigma_{SM+Q_{ll'}}}{dT} = \frac{\pi\alpha^2}{m_e T^2}[1 + (1 - \frac{T}{E_\nu})^2 - \frac{m_e T}{E_\nu^2}]|\frac{q_{ll'}}{e}|^2. \quad (7)$$

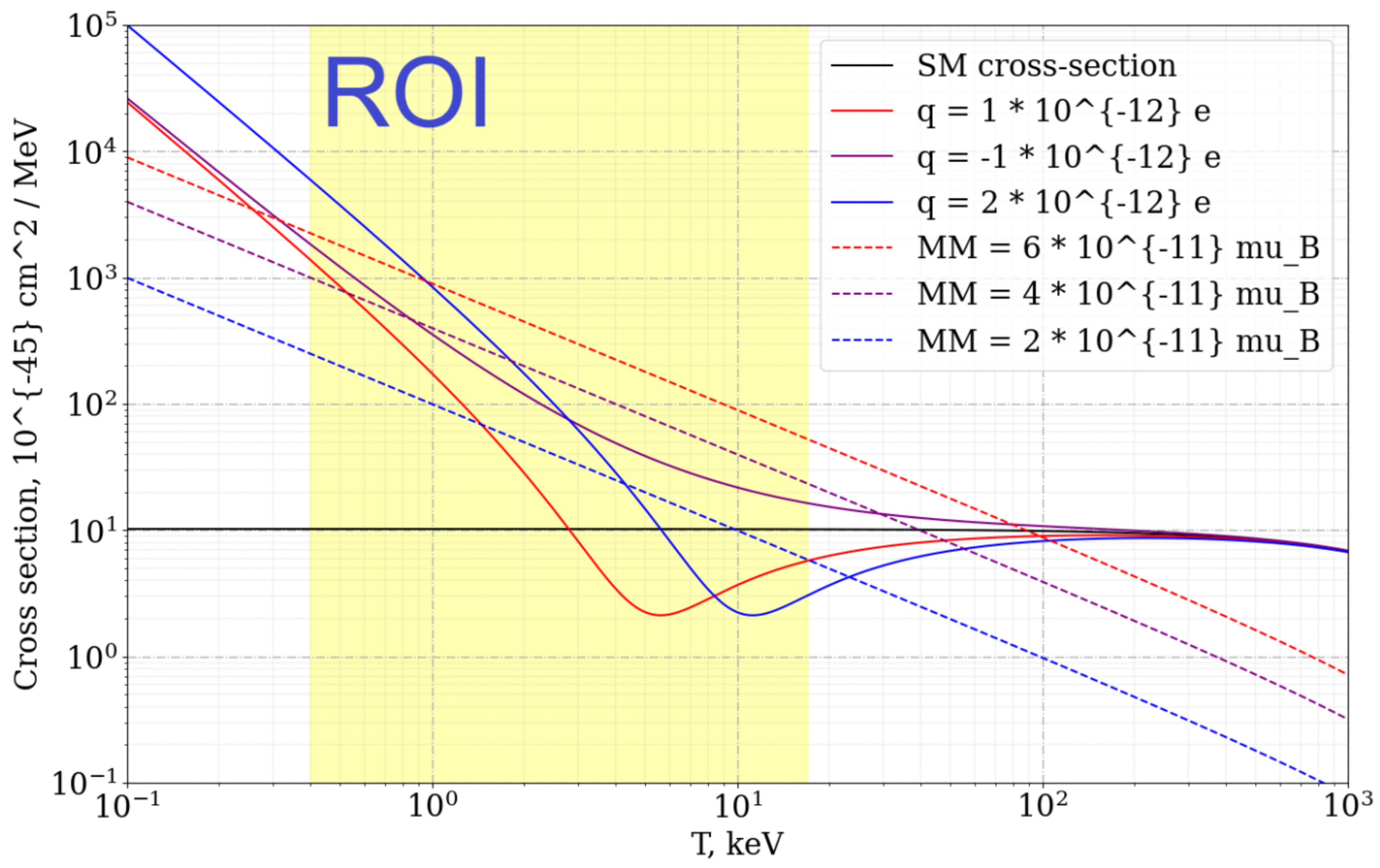

Figure 1. Neutrino-electron elastic scattering differential cross sections for different values of NMM and millicharge, calculated for $E_\nu = 5\ MeV$.

In the experiment the effective values of electromagnetic properties are measured – μ_{ν_l} for the NMM and $q_{\nu_{ll'}}, q_{\nu_{ll}}$ for neutrino millicharges.

The νGeN experiment

The νGeN experimental setup is deployed at the Kalinin Nuclear Power Plant. The data is collected with the help of a 1.4 kg high purity germanium detector located at a distance of 11 meters from the reactor core. The anti-neutrino flux is about $4 \times 10^{13} s^{-1} \times cm^{-2}$.

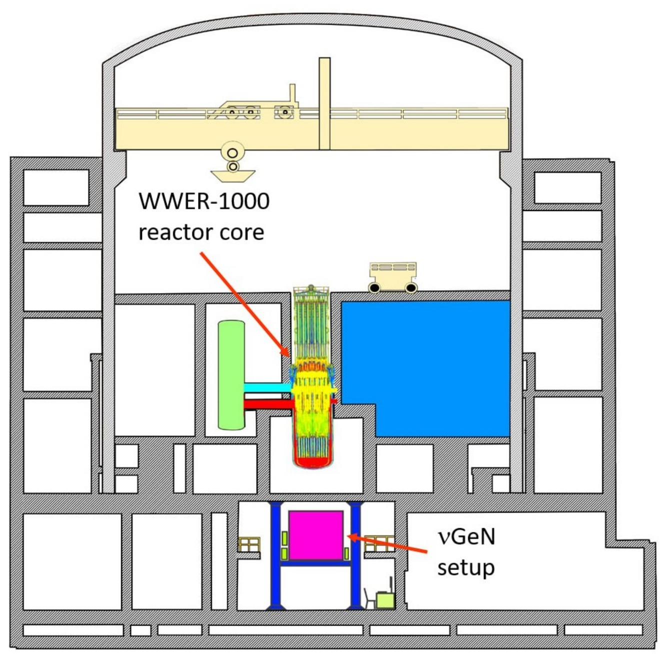

Figure 2. Reactor block shielding

Figure 3. P-type HPGe detector

The νGeN experiment aims to:

- Study of coherent elastic neutrino-nucleous scattering
- Study of neutrino electromagnetic properties

Experimental data

- The estimate is performed based on the energy deposition spectrum corresponding to 69.2 days exposition time in the reactor OFF regime. The exposition time in the reactor ON regime is assumed to be 140.2 days.

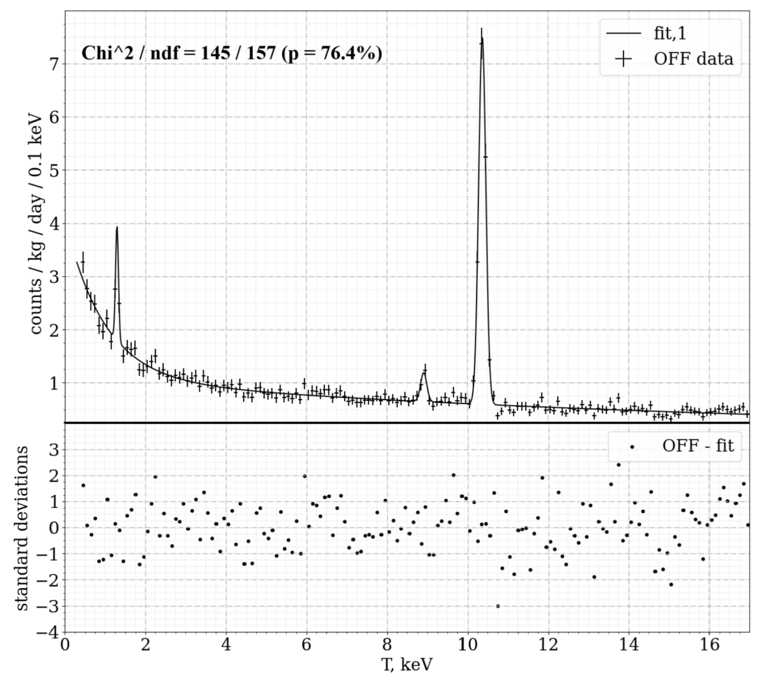

Figure 4. OFF energy deposition spectrum.

The typical reactor regime is 18 months ON and 45 days OFF. Because of that statistical errors of the ON spectrum are significantly lower than statistical errors of the OFF spectrum, so the powerful method to improve sensitivity is to make an approximation of the OFF spectrum.

- We fit OFF spectrum with function $f_{fit}(T) = exp + exp + 3Gauss$. Some of the parameters are fixed by table values or are related to each other.

Sensitivity estimation

To estimate sensitivity we calculate confidence belts for the studied parameters: value of amplitude of a signal, corresponding to NMM; values of amplitude of a signal, corresponding to off-diagonal millicharges; a value of diagonal millicharge.

With the νGeN data we can probe $|\mu_{\nu_e}|$, $|q_{\nu_{e\mu}}|$, $|q_{\nu_{e\tau}}|$ and $q_{\nu_{ee}}$.

NMM

The amplitude on the graphs below equals to $|\mu_{\nu_e}|^2 \times 10^{22}\mu_B$.

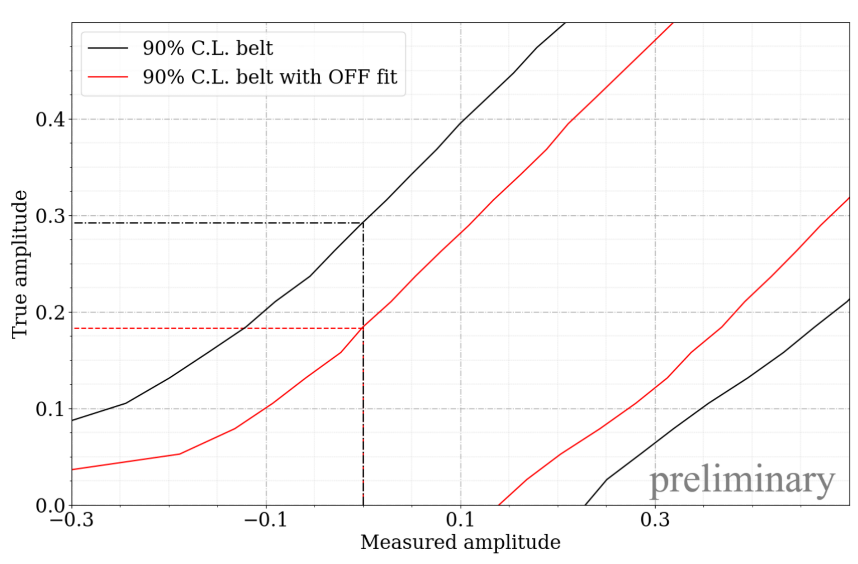

Figure 5. NMM signal amplitude 90 % C.L. belts with and without background fit.

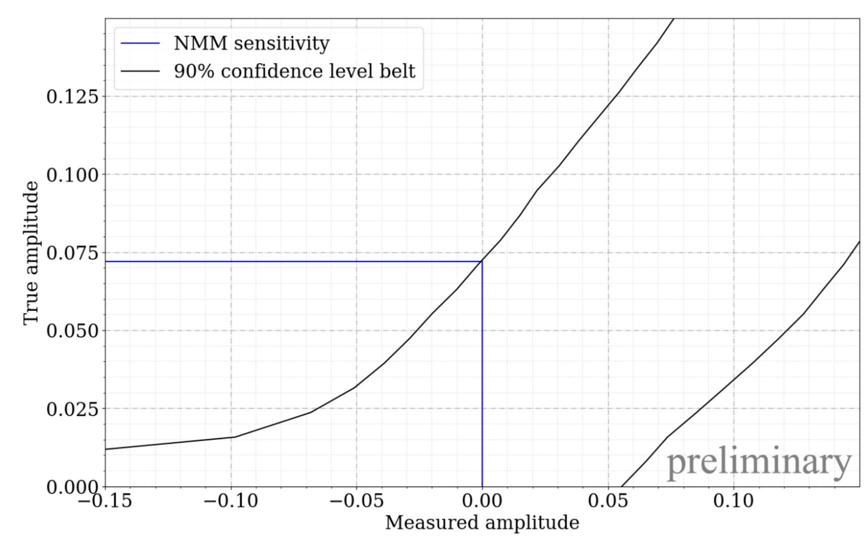

Figure 6. NMM signal amplitude 90 % C.L. belt for 755 days ON (equal to GEMMA experiment ON exposition time) and ideal background model.

Neutrino millicharge

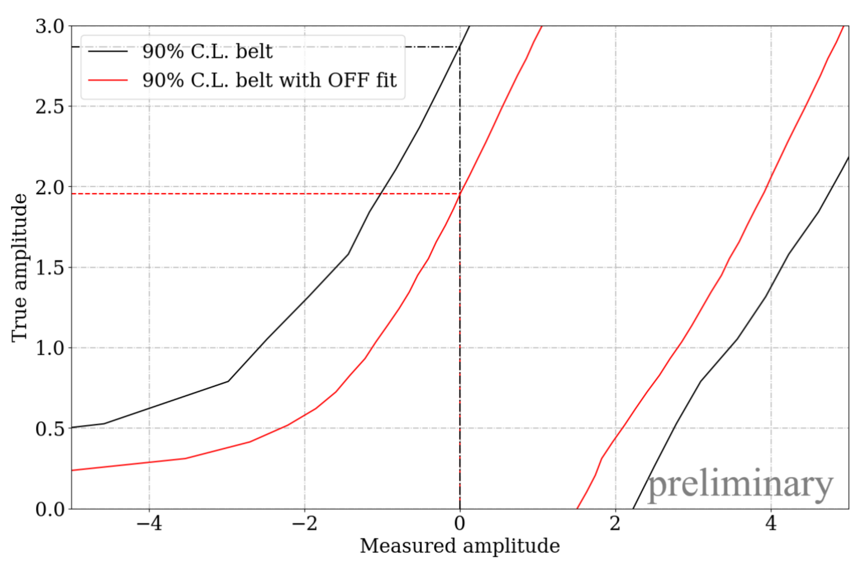

Figure 7. Off-diagonal millicharges signal amplitude 90 % C.L. belts with and without background fit. The amplitude equals to $|q_{\nu_{ll'}}|^2 \times 10^{24}e$.

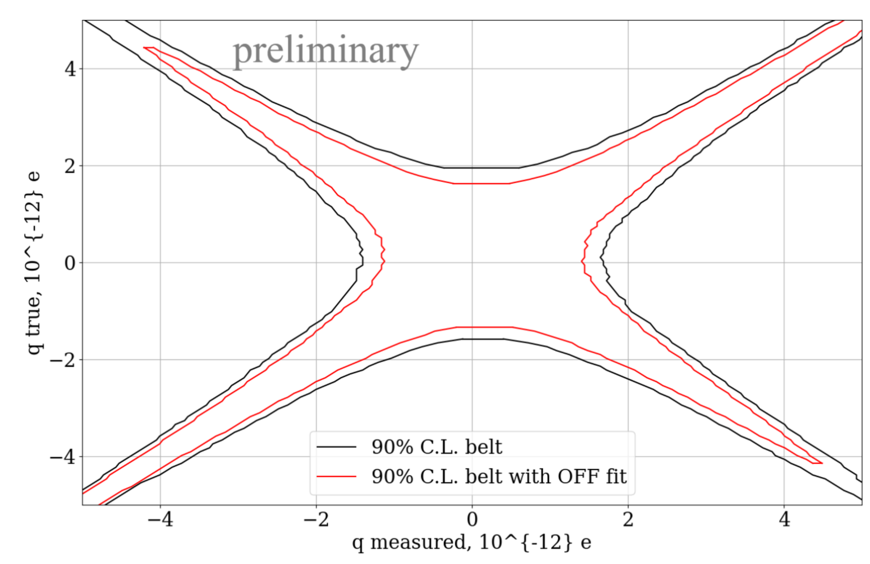

Figure 8. Diagonal millicharges signal amplitude 90 % C.L. belts with and without background fit.

Results and discussion

- Estimated sensitivities are presented in the table below:

	$q_{\nu_{ee}} \times 10^{-12}$ e	$\lvert q_{\nu_{e\mu}}\rvert, \lvert q_{\nu_{e\tau}}\rvert \times 10^{-12}$ e	$\lvert\mu_{\nu_e}\rvert \times 10^{-11}\mu_B$
Without OFF fit	(-1.6, 1.9)	<1.7	<5.4
With OFF fit	(-1.3, 1.6)	<1.3	<4.3

- Increasing the exposure time allows to achieve the value of sensitivity to the NMM: $|\mu_{\nu_e}| < 2.7 \times 10^{-11}\mu_B$
- Some of the experimental constraints on the studied values are presented below:

Limit, $10^{-11}\mu_B$	C.L.	Experiment
7.4	90%	TEXONO
2.9	90%	GEMMA
0.64	90%	XENONnT

Limit, 10^{-12} e	C.L.	Experiment
0.224	90%	LZ
2.1	90%	TEXONO
2.7	90%	GEMMA

- The νGeN experiment has been operating since 2020 and the total exposure now is more than 1500 kg×days. The usage of all available data will allow to improve sensitivity.

Acknowladgments

This work is supported by the Russian Scientific Fund under Contract №24-72-10089.