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Elastic neutrino-atom scattering as a probe of neutrino millicharge and magnetic moment

LOMONOSOV MOSCOW STATE UNIVERSITY

Georgy Donchenko[1], Konstantin Kouzakov[1,2], and Alexander Studenikin[1,2]

[1]Faculty of Physics, Lomonosov Moscow State University, Russia

[2]National Centre for Physics and Mathematics, 607328 Satis, Nizhny Novgorod region, Russia

National Center FOR PHYSICS AND MATHEMATICS

Introduction

- The detectors for searching light particles of dark matter are actively discussed in the literature. To achieve the sensitivity to low-energy signals at a level of $\lesssim$100 meV, condensed matter targets are proposed [1].
- Such detectors can also be used to study the low-energy neutrino scattering, in particular to observe for the first time the coherent elastic neutrino-atom scattering (CEνAS) [2].
- We inspect the sensitivity of the CEνAS processes in the case of light atomic systems to such neutrino electromagnetic properties as millicharge e_ν and magnetic moment μ_ν [3].

Background

Kinematical regime

$$E_\nu \ll m, \qquad T \leq \frac{2E_\nu^2}{m} \ll E_\nu, \qquad E_\nu \ll \frac{1}{R_{\text{nuc}}},$$

where T is the energy transfer, m is the atomic mass, and R_{nuc} is the nuclear radius.

The CEνAS differential cross section

According to [2, 4, 5, 6]:

$$\frac{d\sigma}{dT} = \frac{d\sigma^{(w,e_\nu)}}{dT} + \frac{d\sigma^{(\mu_\nu)}}{dT}.$$

The weak interaction and millicharge contribution:

$$\frac{d\sigma^{(w,e_\nu)}}{dT} = \frac{G_F^2 m}{\pi}\left[C_V^2\left(1 - \frac{mT}{2E_\nu^2}\right) + C_A^2\left(1 + \frac{mT}{2E_\nu^2}\right)\right],$$

$$C_V = Z\left(\tfrac{1}{2} - 2\sin^2\theta_W\right) - \tfrac{1}{2}N + Z\left(\mp\tfrac{1}{2} + 2\sin^2\theta_W\right)F_{\text{el}}(q^2) + \frac{\sqrt{2}\pi\alpha Z e_\nu}{G_F m T}[1 - F_{\text{el}}(q^2)],$$

$$C_A^2 = (C_A^{nuc})^2 + \frac{1}{4}\sum_{n,l}\left[\left(L_+^{nl} - L_-^{nl}\right)F_{\text{el}}^{nl}(q^2)\right]^2,$$

$$(C_A^{nuc})^2 = \frac{g_A^2}{4}\left[(Z_+ - Z_-) - (N_+ - N_-)\right]^2,$$

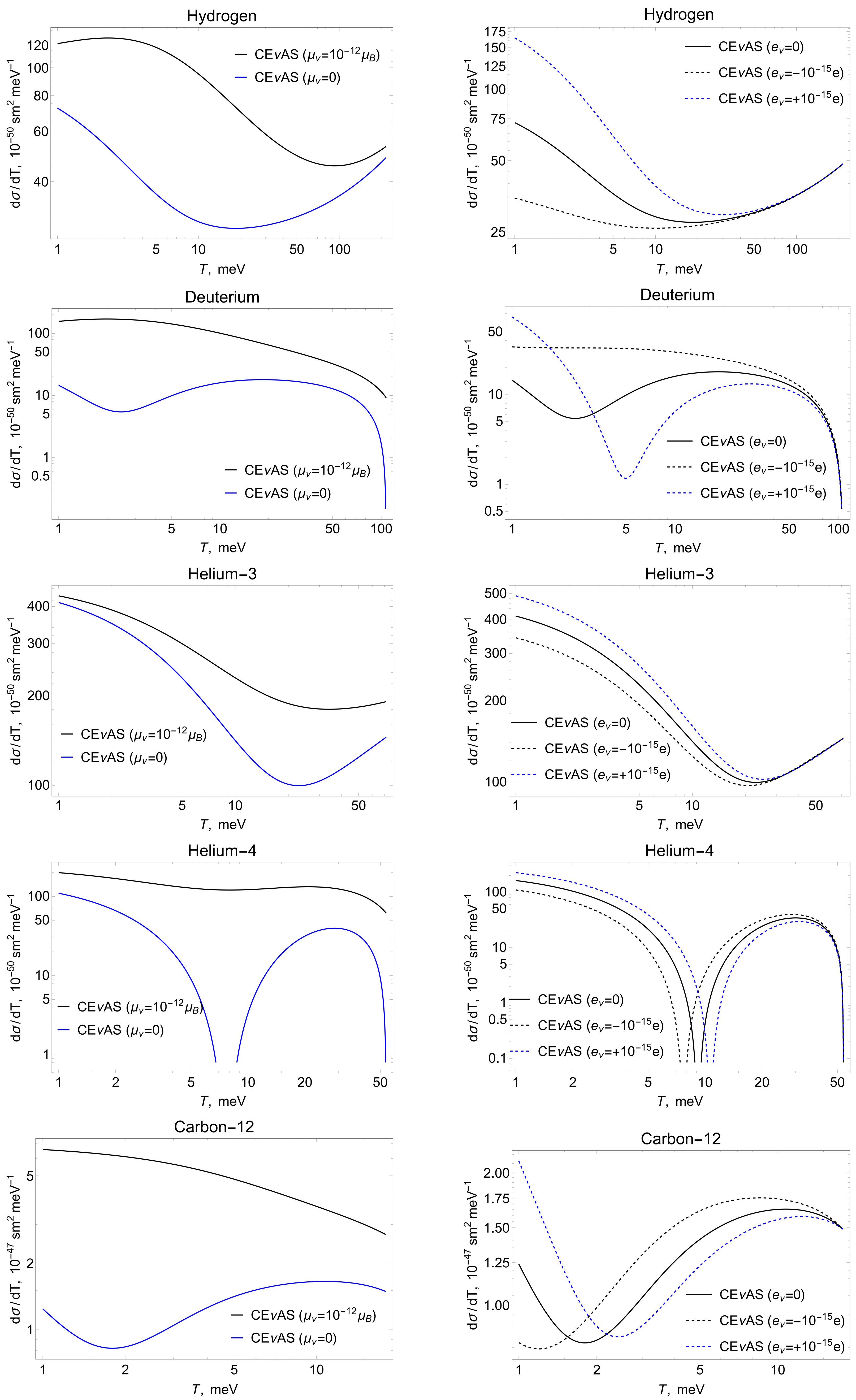
where q is the momentum transfer, with $q^2 = 2mT$, the plus (minus) stands for $\nu = \nu_e$ ($\nu = \nu_{\mu,\tau}$), and Z (N) is the number of protons (neutrons). $F_{\text{el}}(q^2)$ is the Fourier transform of the electron density, $g_A = 1.25$, $Z_\pm$ and $N_\pm$ ($L_\pm^{nl}$) are the numbers of protons and neutrons (electrons) with spin parallel (+) or antiparallel (−) to the nucleus spin (the total electron spin), and the neutrino millicahrge e_ν is in units of e.

The magnetic moment contribution:

$$\frac{d\sigma^{(\mu_\nu)}}{dT} = \frac{\pi\alpha^2 Z^2}{m_e^2}|\mu_\nu|^2\left(\frac{1}{T} - \frac{1}{E_\nu}\right)[1 - F_{\text{el}}(q^2)]^2,$$

where the neutrino magnetic moment μ_ν is in units of μ_B.

Results for $E_\nu = 10$ keV



Conclusions

- We accounted for the neutrino millicharge and magnetic moment in the theory of CEνAS.
- It is shown that the atomic recoil spectra in CEνAS processes on the H, ^{2}H, ^{3}He, ^{4}He and ^{12}C atomic systems are very sensitive to the neutrino millicharge and magnetic moment. Measuring these spectra may allow us to test the e_ν and μ_ν values at a level of $10^{-15}e$ and $10^{-12}\mu_B$, respectively, or even below that level.
- The obtained results will be used in the search for the electromagnetic properties of neutrinos in the experiment involving an intense tritium neutrino source and a superfluid ^{4}He target. This experiment is currently being prepared in the framework of the research program of the National Center for Physics and Mathematics in Sarov, Russia (parallel talk, presentation #775).

References

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Contacts

- Konstantin Kouzakov: kouzakov@gmail.com