Ionization of helium atoms by solar neutrinos

Stepantsov Ivan

Physics Faculty, Lomonosov Moscow State University, Moscow, Russia

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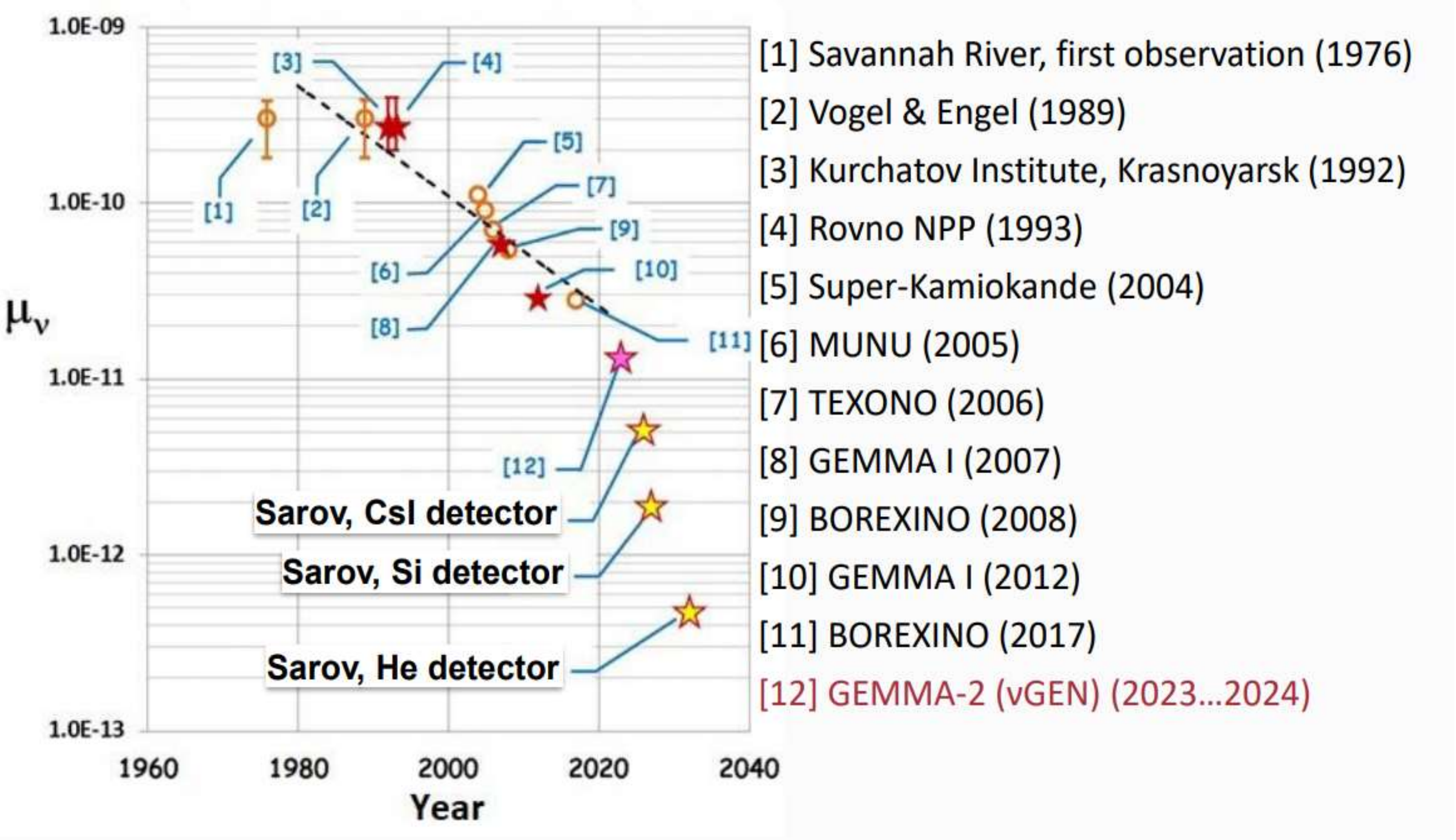
Motivation:

1. Estimation of solar neutrino background within the SATURNE experiment
2. Estimation of solar neutrino background within dark matter experiments (for instance, HeRALD)
3. Measuring the neutrino magnetic moment within the SATURNE experiment

The main quantities needed:

1. Differential cross section of solar neutrino scattering reaction
2. Recoil-electron spectrum $\frac{dN}{dT_e}$ as a function of recoil electron energy T_e for two kinds of neutrino-electron interactions (week and electromagnetic)
3. Number of background events for a given observation time

Progress of experimental sensitivity to the neutrino magnetic moment μ_ν

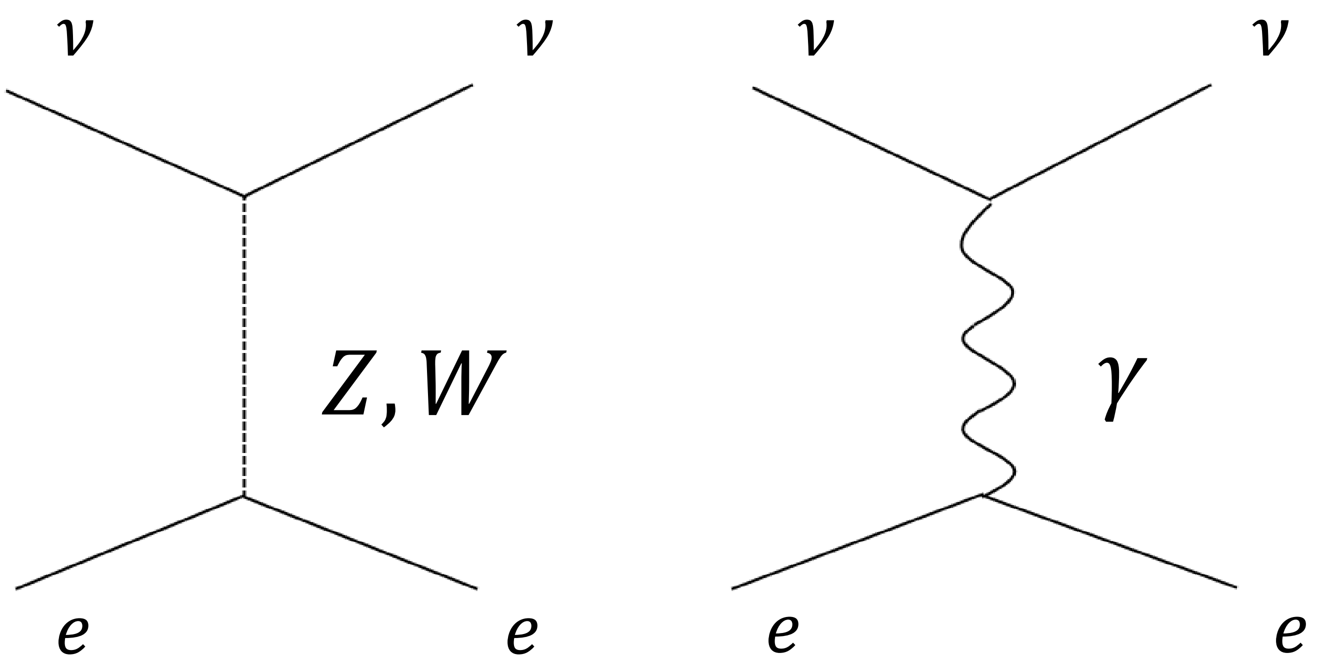


$$\chi^2(\mu_\nu) = \left(\frac{N_{SM} - N(\mu_\nu)}{\sqrt{N_{SM}}} \right)^2$$

$$\Delta\chi^2 = \chi^2(\mu_\nu) - \chi^2_{min}$$

A. A. Yukhimchuk, A. N. Golubkov, I. P. Maximkin, et al., Fizmat 1, 5 (2023).

Neutrino interactions in scattering by an electron



The process of neutrino scattering by an atomic electron can take place either due to weak interaction, with a neutral Z boson or a charged W boson as a mediator, or due to electromagnetic interaction, with a photon as a mediator.

Differential cross section

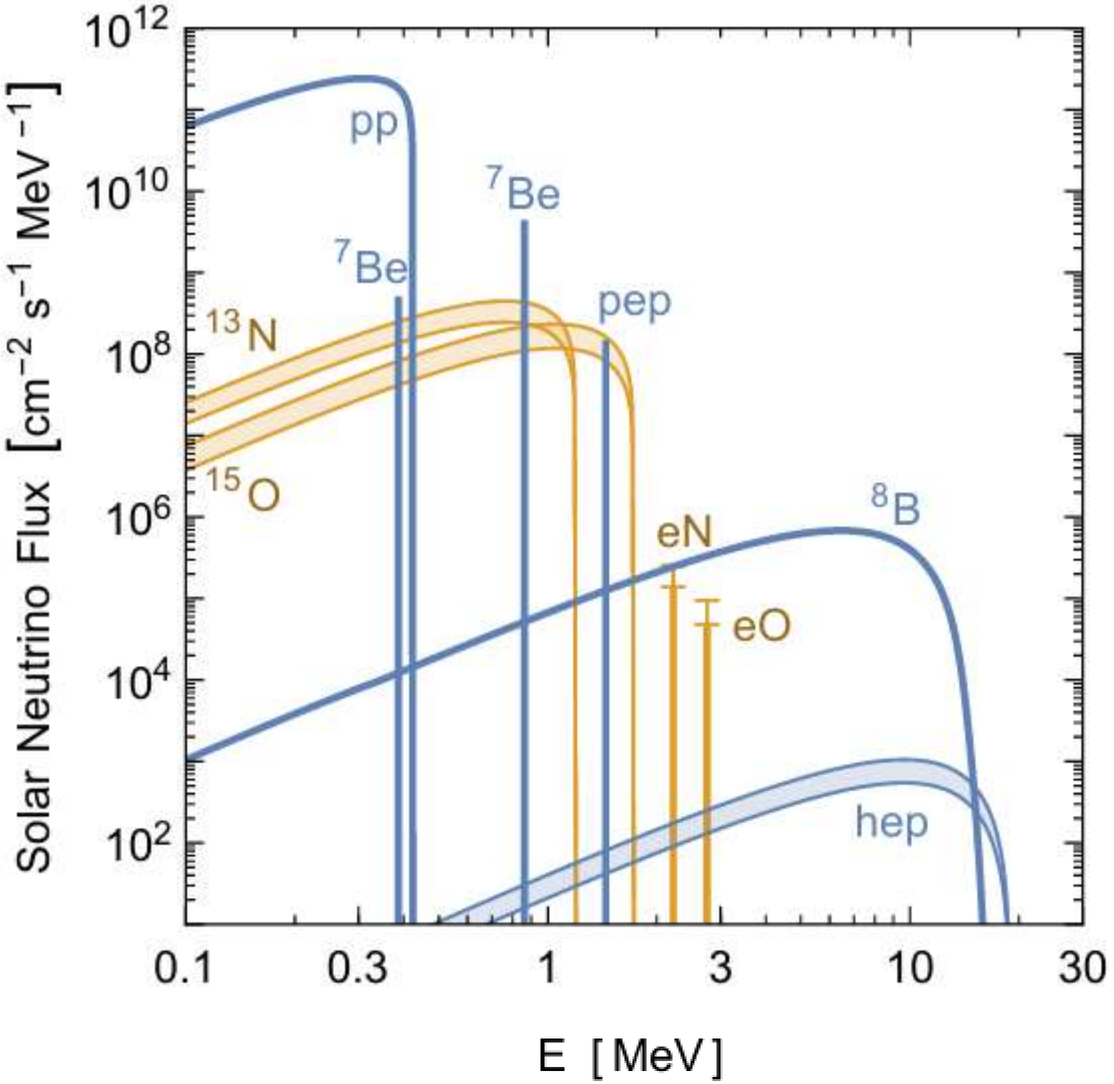
Weak interaction: $$\frac{d\sigma_l^{SM}}{dT_e} = \frac{\sigma_0}{m_e}\left[g_{1l}^2 + g_{2l}^2\left(1 - \frac{T_e}{E_{\nu_l}}\right)^2 - g_{1l}g_{2l}\frac{m_e T_e}{E_{\nu_l}^2}\right].$$

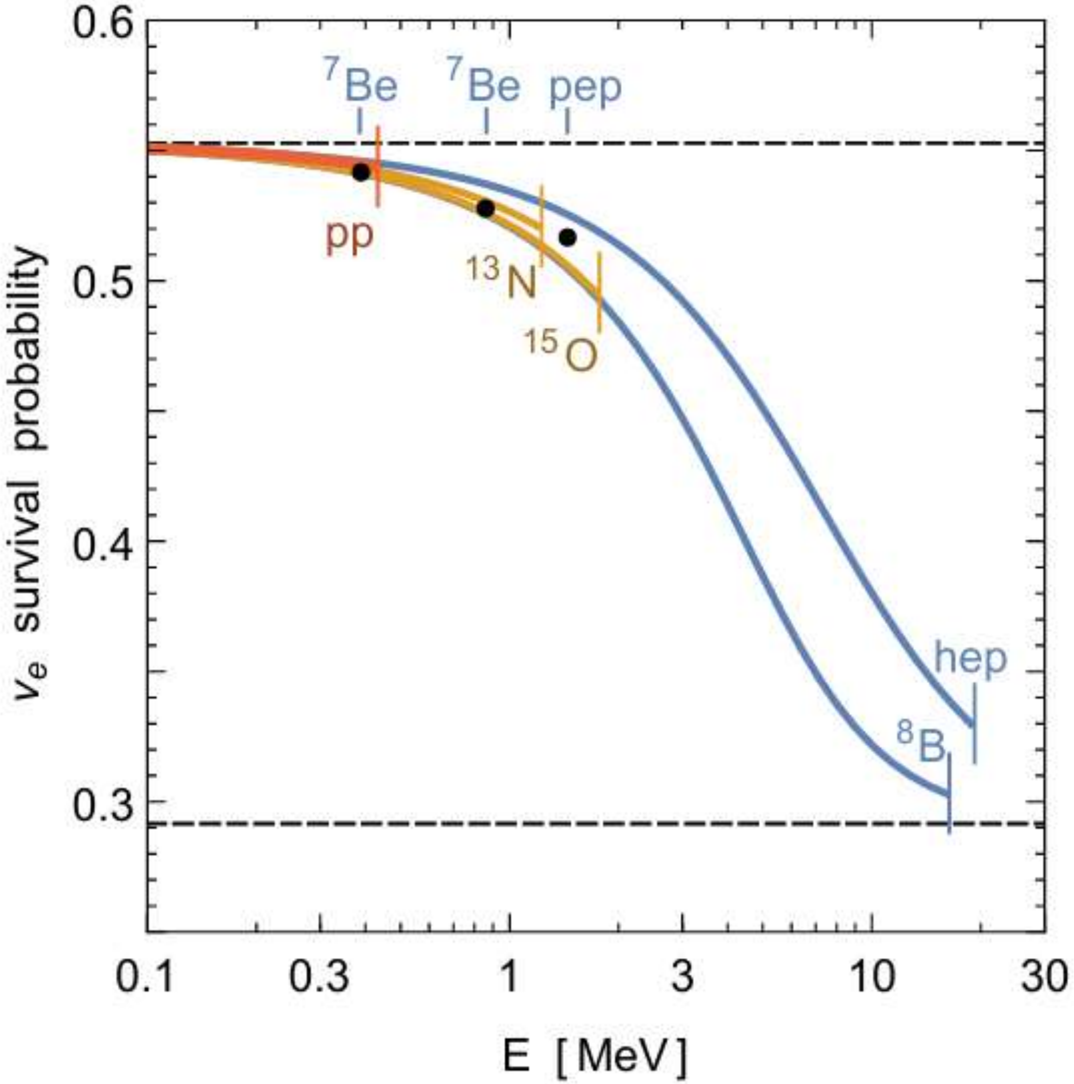
Here T_e is the recoil electron energy, E_{ν_l} is the energy of neutrino with flavor l. g_{1l} and g_{2l} are constants which values depend on neutrino flavor.

Electromagnetic interaction (due to μ_ν): $$\frac{d\sigma_l^{EM}}{dT_e} = {\mu_\nu}^2\frac{\pi\alpha^2}{m_e^2}\left(\frac{1}{T_e} - \frac{1}{E_{\nu_l}}\right)$$

The full cross section can be written as a sum of the Standard Model (SM) weak component and the EM one: $$\frac{d\sigma_l}{dT_e} = \frac{d\sigma_l^{SM}}{dT_e} + \frac{d\sigma_l^{EM}}{dT_e}.$$

Solar neutrino flux and survival probability





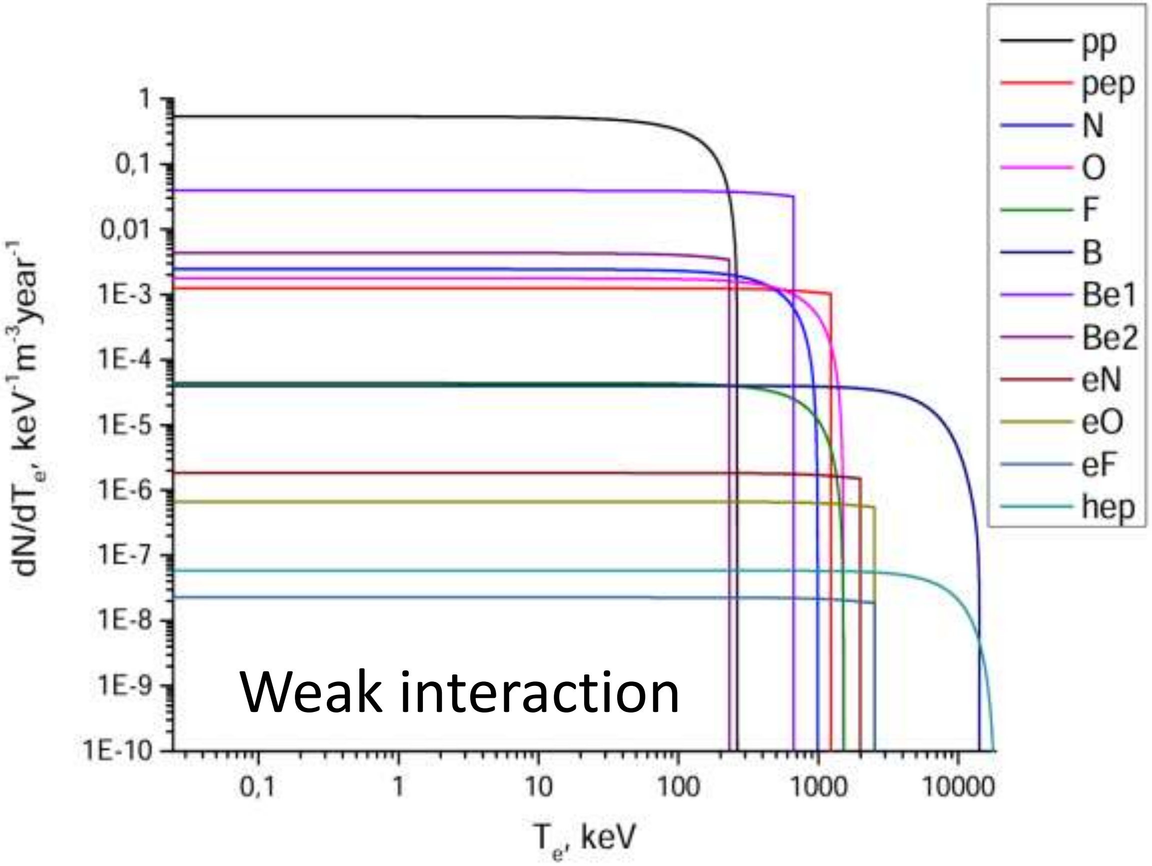
E. Vitagliano et al. Rev. Mod. Phys. 92, 45006 (2020)

The number of scattering events in the detector volume:

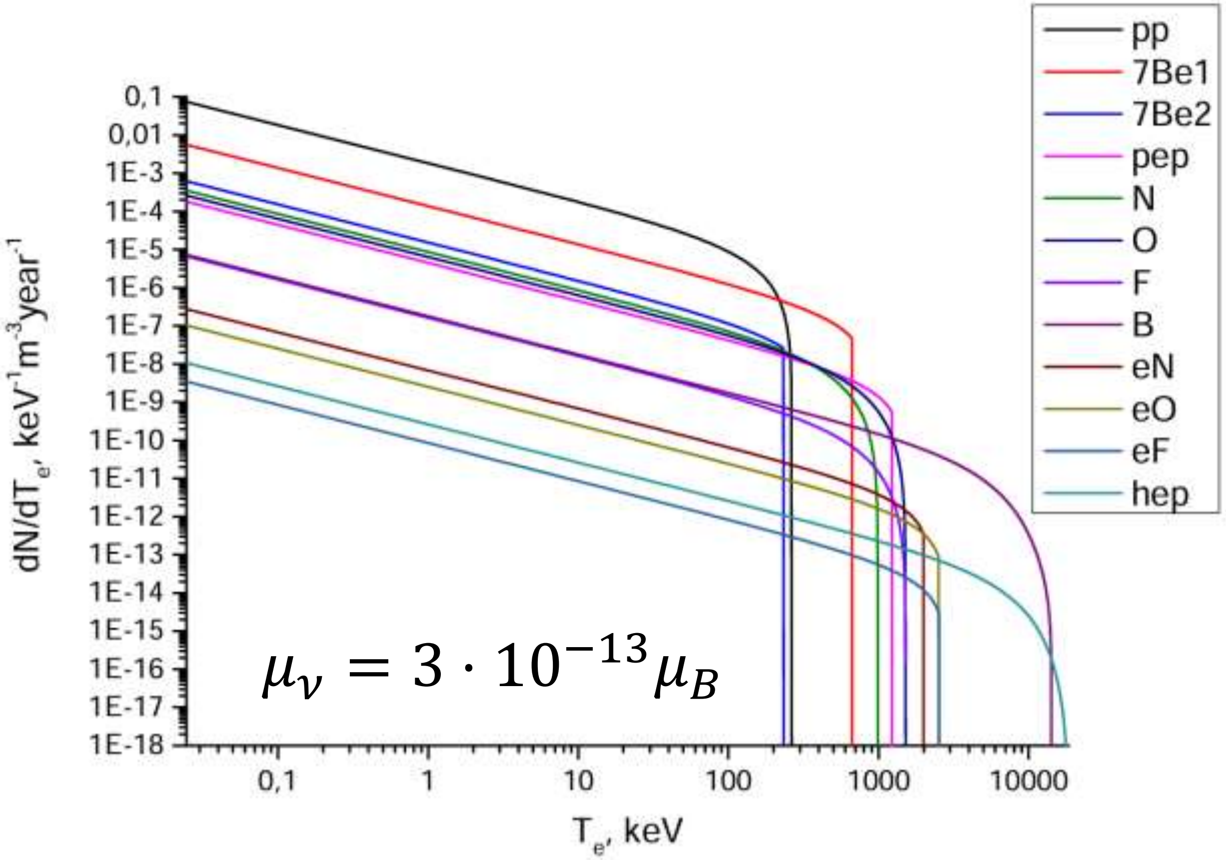
$$\frac{dN}{dT_e} = 2tA \sum_{l=e,\mu,\tau} \int_0^{E_{\nu_l}^{max}} dE_{\nu_l} \frac{d\sigma_l}{dT_e} \frac{d\phi_l}{dE_{\nu_l}} \theta(T_e - T_0)\theta(T_e^{max} - T_e).$$

Here E_{ν_l}, σ_l, ϕ_l are respectively the energy, cross section and flux of solar neutrinos with flavor l. A is the number of particles in the detector volume, t is the time of observation, $T_0 = 24.5$ eV is the binding energy of an electron in an atom, T_e^{max}=2 $E_{\nu_l}^2/(m_e + 2E_{\nu_l})$ is the maximal recoil electron energy.

Recoil-electron spectrum $\frac{dN}{dT_e}$



Weak interaction, the event number is
$N = 96{,}3$ per year



Electromagnetic interaction
(due to μ_ν), the event number is
$N = 5{,}0 \cdot 10^{-2}$ per year

Conclusion

We have considered ionization of helium atoms by solar neutrinos and its possible impact on studying experimental data with helium detectors.

The obtained results can be important for analyzing the future data of the Sarov tritium neutrino experiment (SATURNE), which will search for the neutrino magnetic moment of tritium antineutrinos with a liquid He-4 detector.

Thank you for your attention!