Ionizing collisions of solar neutrinos with helium

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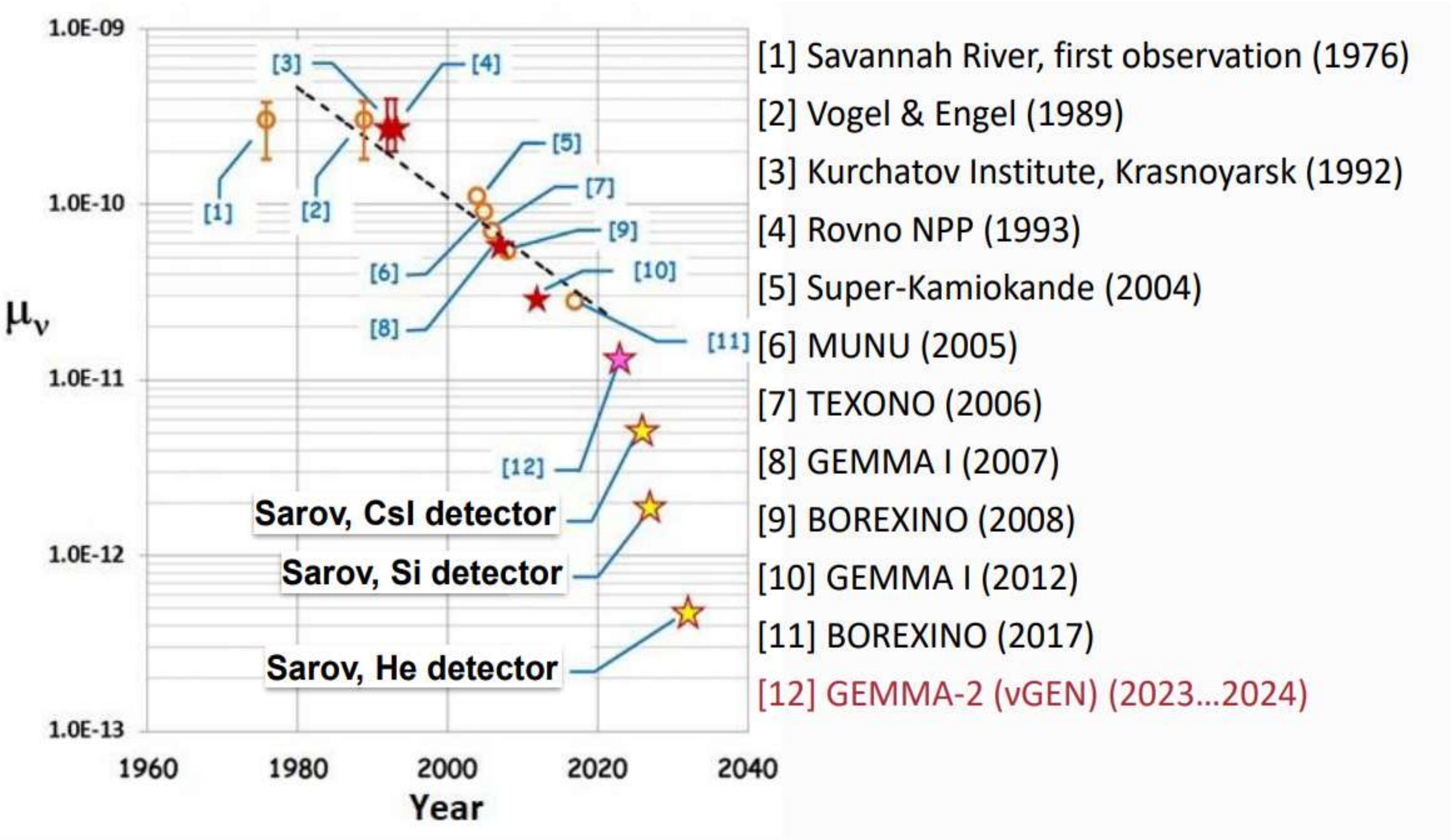
Motivation

1. Estimation of solar neutrino background in the SATURNE experiment
2. Estimation of solar neutrino background in dark matter experiments with a He detector (for instance, HeRALD)
3. Searching the neutrino magnetic moment in the SATURNE experiment

Progress of experimental sensitivity to the neutrino magnetic moment μ_ν

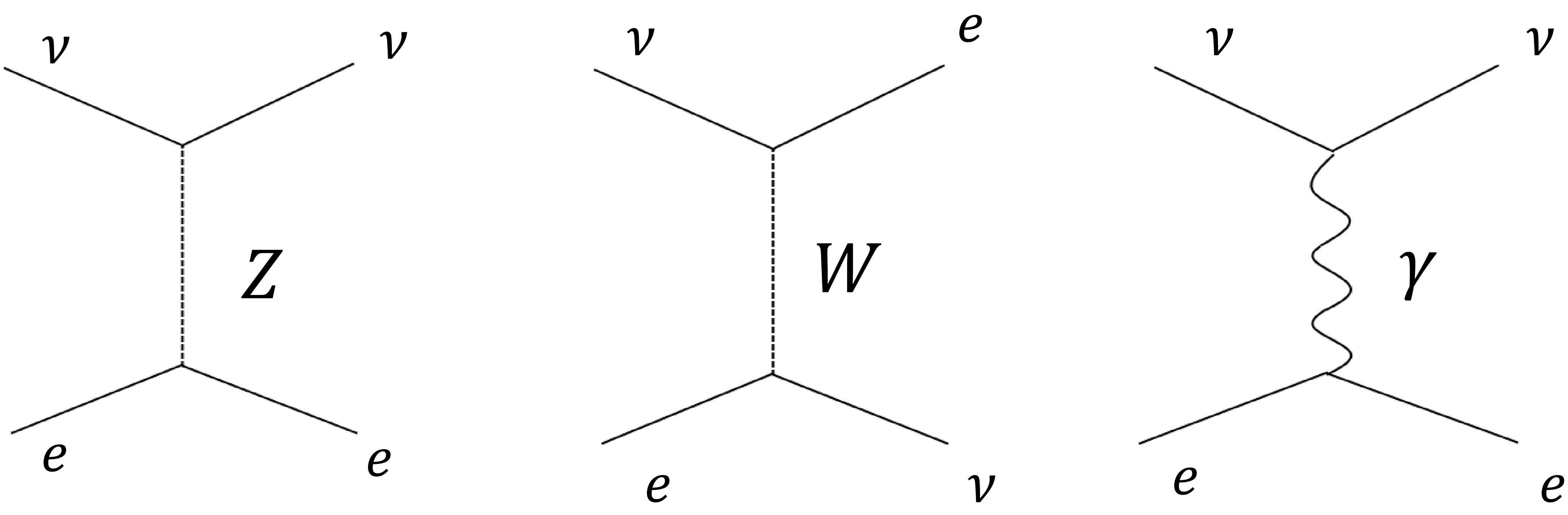


$$\chi^2(\mu_\nu) = \left(\frac{N_{SM} - N(\mu_\nu)}{\sqrt{N_{SM}}}\right)^2$$

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

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

Neutrino-electron interactions



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.

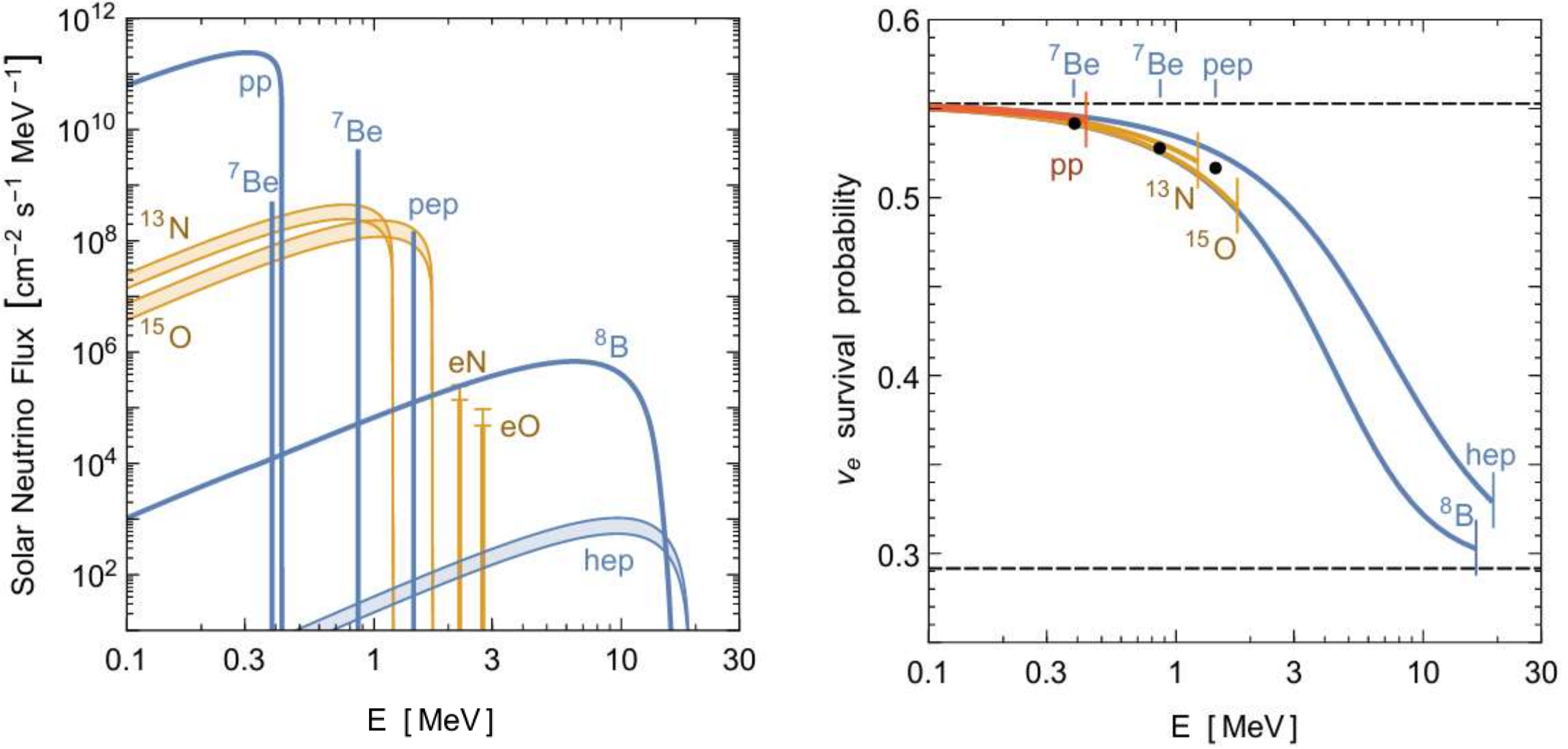
Electromagnetic interaction (due to μ_ν):

$$\frac{d\sigma_l^{EM}}{dT_e} = \mu_\nu{}^2\,\frac{\pi\alpha^2}{m_e^2}\left(\frac{1}{T_e} - \frac{1}{E_{\nu_l}}\right)$$

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



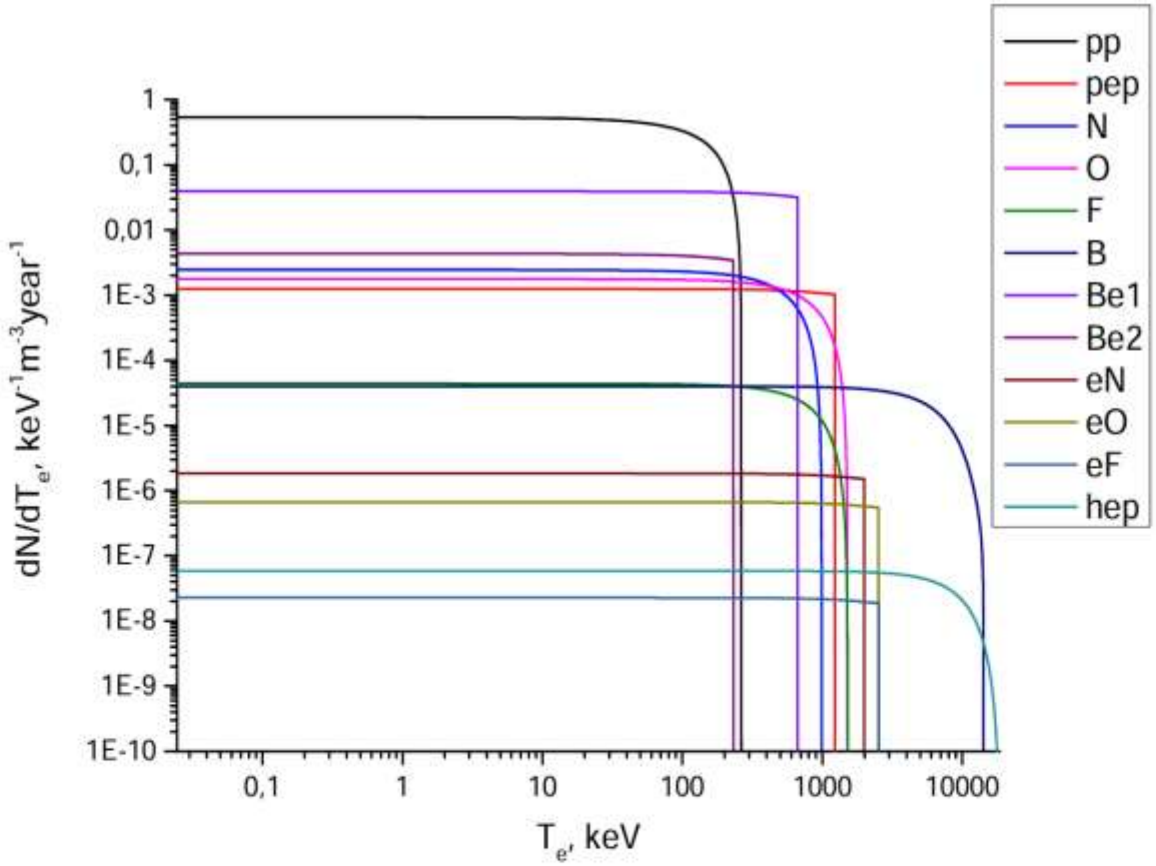
E. Vitagliano et al. Rev. Mod. Phys. 92, 45006 (2020)

The number of scattering events in the detector volume

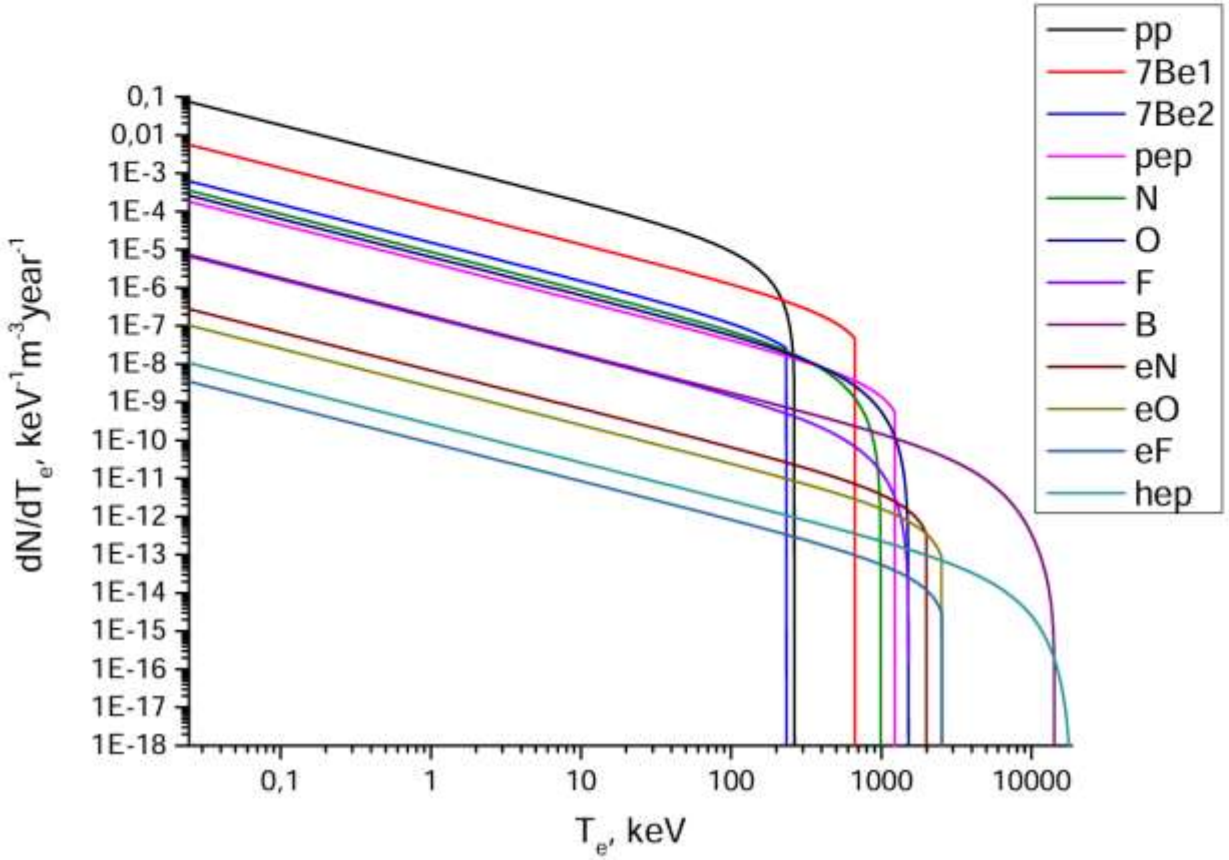
$$\frac{dN}{dT_e} = 2tA\sum_{l=e,\mu,\tau} \int_0^{E_{\nu_l}^{max}} dE_{\nu_l} \frac{d\sigma_l}{dT_e}\frac{d\phi_l}{dE_{\nu_l}}\theta(T_e - T_0)\theta(T_e^{max} - T_e).$$

Here $E_{\nu_l}, \sigma_l, \phi_l$ 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.

Dependence of the event number $\frac{dN}{dT_e}$ on T_e

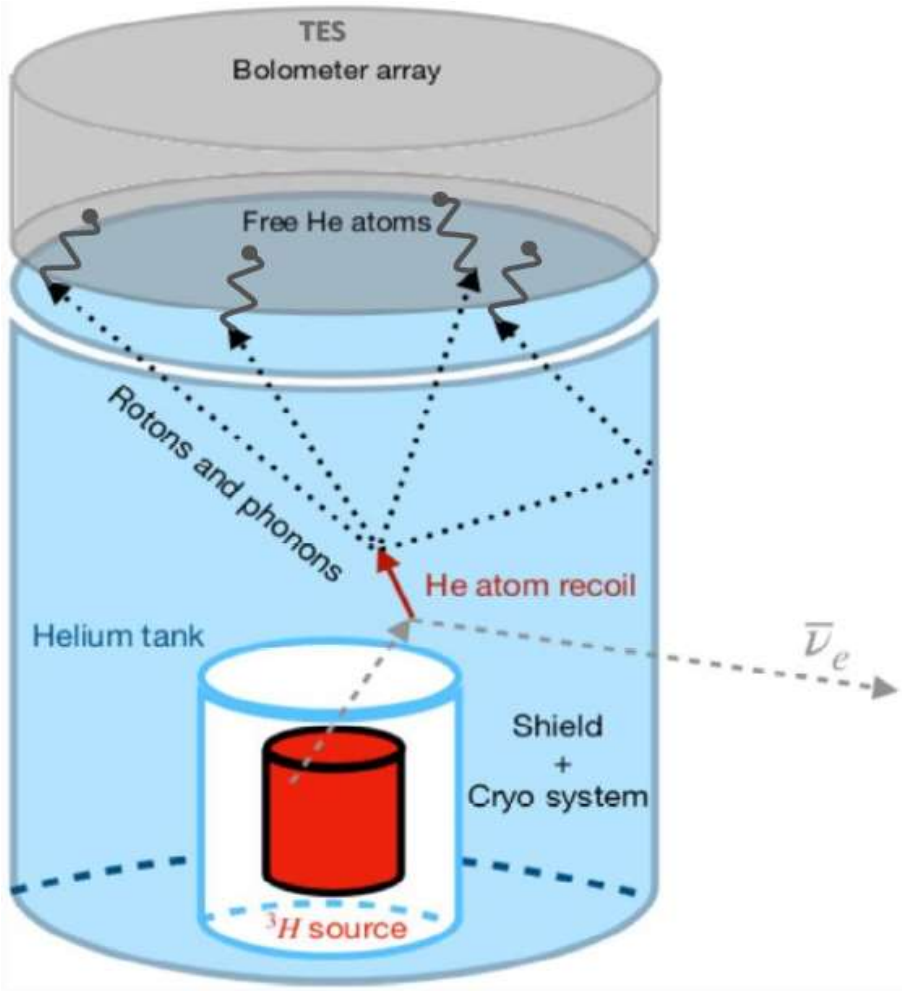


Weak interaction, the event number is $N = 96{,}3$



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

Helium detector that will be used within the SATURNE experiment



The detector working volume is 1 m^3

Quantum evaporation effect and TES (transition edge sensor) bolometers are used

Konstantin Kouzakov on behalf of SATURNE collaboration, «The Sarov experiment for probing coherent elastic neutrino-atom scattering and neutrino electromagnetic interactions», the first edition of the ACHEP (2023)

Conclusion

The reaction of ionization of helium by solar neutrinos and its possible impact on studying experimental data of helium detectors were considered.

The obtained results could be useful for analyzing the 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 and also for the first detection of neutrino elastic scattering with atoms.

Thank you for your attention!

Additional information: the solar nuclear reactions considered

Channel	Flux	Reaction	$E_{\rm av}$ MeV	$E_{\rm max}$ MeV	Flux at Earth GS98	AGSS09	Observed	Units
pp Chains (β^+)	$\Phi_{\rm pp}$	$p+p\to d+e^++\nu_e$	0.267	0.423	5.98 $\pm0.6\%$	6.03 $\pm0.5\%$	$5.971^{+0.62\%}_{-0.55\%}$	10^{10} cm^{-2} s^{-1}
	$\Phi_{\rm B}$	$^8{\rm B}\to{}^8{\rm Be}^*+e^++\nu_e$	6.735 ± 0.036	~15	5.46 $\pm12\%$	4.50 $\pm12\%$	$5.16^{+2.5\%}_{-1.7\%}$	10^6 cm^{-2} s^{-1}
	$\Phi_{\rm hep}$	$^3{\rm He}+p\to{}^4{\rm He}+e^++\nu_e$	9.628	18.778	0.80 $\pm30\%$	0.83 $\pm30\%$	$1.9^{+63\%}_{-47\%}$	10^4 cm^{-2} s^{-1}
pp Chains (EC)	$\Phi_{\rm Be}$	$e^-+{}^7{\rm Be}\to{}^7{\rm Li}+\nu_e$ $e^-+{}^7{\rm Be}\to{}^7{\rm Li}^*+\nu_e$	0.863 (89.7%) 0.386 (10.3%)		4.93 $\pm6\%$	4.50 $\pm6\%$	$4.80^{+5.9\%}_{-4.6\%}$	10^9 cm^{-2} s^{-1}
	$\Phi_{\rm pep}$	$p+e^-+p\to d+\nu_e$	1.445		1.44 $\pm1\%$	1.46 $\pm0.9\%$	$1.448^{+0.90\%}_{-0.90\%}$	10^8 cm^{-2} s^{-1}
CNO Cycle (β^+)	$\Phi_{\rm N}$	$^{13}{\rm N}\to{}^{13}{\rm C}+e^++\nu_e$	0.706	1.198	2.78 $\pm15\%$	2.04 $\pm14\%$	<13.7	10^8 cm^{-2} s^{-1}
	$\Phi_{\rm O}$	$^{15}{\rm O}\to{}^{15}{\rm N}+e^++\nu_e$	0.996	1.732	2.05 $\pm17\%$	1.44 $\pm16\%$	<2.8	10^8 cm^{-2} s^{-1}
	$\Phi_{\rm F}$	$^{17}{\rm F}\to{}^{17}{\rm O}+e^++\nu_e$	0.998	1.736	5.29 $\pm20\%$	3.26 $\pm18\%$	<8.5	10^6 cm^{-2} s^{-1}
CNO Cycle (EC)	$\Phi_{\rm eN}$	$^{13}{\rm N}+e^-\to{}^{13}{\rm C}+\nu_e$	2.220		2.20 $\pm15\%$	1.61 $\pm14\%$	—	10^5 cm^{-2} s^{-1}
	$\Phi_{\rm eO}$	$^{15}{\rm O}+e^-\to{}^{15}{\rm N}+\nu_e$	2.754		0.81 $\pm17\%$	0.57 $\pm16\%$	—	10^5 cm^{-2} s^{-1}
	$\Phi_{\rm eF}$	$^{17}{\rm F}+e^-\to{}^{17}{\rm O}+\nu_e$	2.758		3.11 $\pm20\%$	1.91 $\pm18\%$	—	10^3 cm^{-2} s^{-1}