# NEUTRINO-NUCLEUS INTERACTIONS AT LOW AND INTERMEDIATE ENERGIES

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**The main goal is to construct a new generator simulating neutrino interaction within a detector**

The main inputs are the neutrino-nucleus cross sections in a wide energy region.

The rate of neutrino-nucleon scattering in a medium at low energies can be presented in the following form

$$W_{fi} = \frac{G_{\mathrm{F}}^2 n}{4V} \left[ C_V^2 (1 + \cos\theta) \mathcal{S}_V(\mathbf{q}, \omega) + C_A^2 (3 - \cos\theta) \mathcal{S}_A(\mathbf{q}, \omega) \right]$$

where $\theta$ is the scattering angle, $V$ is the normalized volume, $n$ is the nuclear density, $\mathcal{S}_V$ and $\mathcal{S}_A$ are the vector and axial vector dynamic form factors (FF), which depend on the transferred 3-momentum $\mathbf{q}$ and the energy transfer $\omega$.

The FF $\mathcal{S}_{V,A}$ are related to the corresponding response function $\chi_{V,A}$

$$\mathcal{S}_{V,A}(\omega,\mathbf{q}) = \frac{2}{n}\frac{\mathrm{Im}\chi_{V,A}(\omega,\mathbf{q})}{1-\exp(-\omega/T)}.$$

The Dyson type perturbation equations over the spin-independent $\mathcal{F}$ and spin dependent $\mathcal{G}$ interactions of quasiparticles presented in the matrix form.

$$\begin{aligned} \chi_V &= \chi^0 - \chi_V \mathcal{F} \chi^0, \\ \chi_A &= \chi^0 - \chi_A \mathcal{G} \chi^0, \end{aligned}$$

Here $\chi^0$ is the diagonal $2\times 2$ matrix consisting of $\chi^0_p$ and $\chi^0_n$ which being the zero approximations of the proton and neutron response functions over the interaction. For isospin-symmetric nuclear matter $\mathcal{F}$ and $\mathcal{G}$ become also $2\times 2$ matrices

$$\begin{aligned} \chi^p_V(1+f_{nn}\chi^0_n) \; + \; \chi^n_V f_{pn}\chi^0_p \; &= \; \chi^0_p \\ \chi^p_V f_{pn}\chi^0_n \; + \; \chi^n_V(1+f_{pp}\chi^0_n) \; &= \; \chi^0_n \end{aligned}$$

and

$$\begin{aligned} \chi^p_A(1+g_{nn}\chi^0_n) \; + \; \chi^n_A g_{pn}\chi^0_p \; &= \; \chi^0_p \\ \chi^p_A g_{pn}\chi^0_n \; + \; \chi^n_A(1+g_{pp}\chi^0_n) \; &= \; \chi^0_n \; , \end{aligned}$$

where $f_{pp}$, $f_{nn}$, $f_{pn}$ and $g_{pp}$, $g_{nn}$, $g_{pn}$ are the spin-independent and spin-dependent amplitudes of $pp$, $nn$ and $pn$ interactions, respectively.

Note, that the amplitude of interaction between two quasi-particles $q$ and $q'$ with three-momenta $\mathbf{p}$

and $\mathbf{p}'$ neglecting the tensor forces has the following form

$$f_{qq'}(\mathbf{p},\mathbf{p}') = f + f'(\tau\cdot\tau') + g(\sigma\cdot\sigma') + g'(\sigma\cdot\sigma')(\tau\cdot\tau')$$

where $q$ and $q'$ can denote $p, n$, and $f$, $f'$, $g$, $g'$ are the Landau parameters, $\sigma$ and $\tau$ are the spin and isospin Pauli matrices, respectively.

$$\begin{aligned} f_{pp} &= f_{nn} = f + f', \\ g_{pp} &= g_{nn} = g + g', \\ f_{pn} &= f_{np} = f - f', \\ g_{pn} &= g_{np} = g - g'. \end{aligned}$$

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$$1/l = V \int \frac{d^3q}{(2\pi)^3} W_{fi}.$$

With this quantity one can estimate the cross section of the elastic neutrino interaction with a heavy nucleus $\sigma_{el}$

$$\sigma_{el} = \frac{V_A}{l} \; = \; V_A \int \frac{d^3q}{(2\pi)^3} \tilde{W}_{fi}$$

where $\tilde{W}_{fi} = V_A \cdot W_{fi}$ and $V_A = A \cdot v_N$. Here $A$ is the number of nucleons in a nucleus and $v_N = 4\pi/3r_N^3$ is the nucleon volume, $r_N$ is the nucleon radius about 0.8 fm. To estimate the number of neutrino interactions $\mathcal{R}$ per 1 second within a target $T$ we use the simple formula

$$\mathcal{R} \; = \; P_{targ} N_A \sigma_{\nu A} f_\nu$$

Here $f_\nu$ denotes the initial neutrino flux.

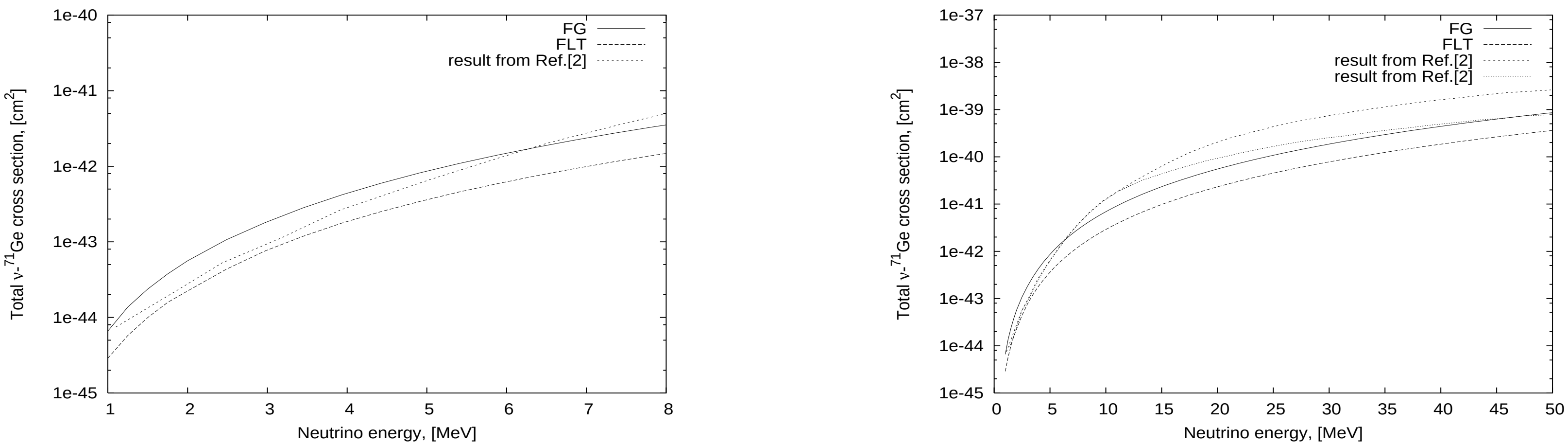


Figure 1: The total $\nu$-$^{71}$Ge cross section as a function of the neutrino energy $E_\nu$.

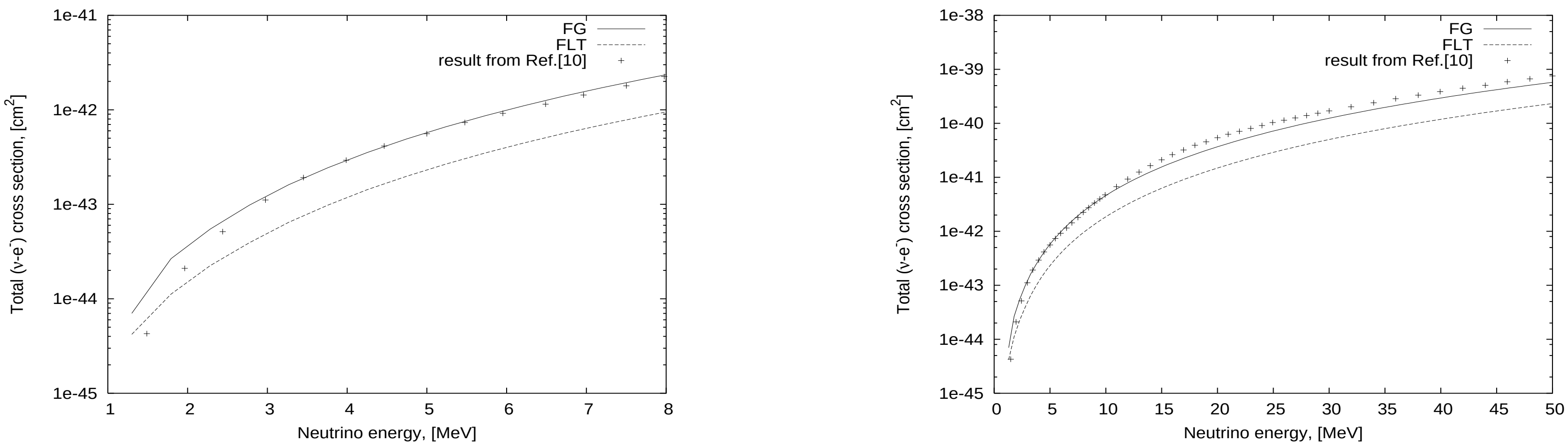


Figure 2: The total absorption $\nu$-$^{40}$Ar cross section as a function of the neutrino energy $E_\nu$.

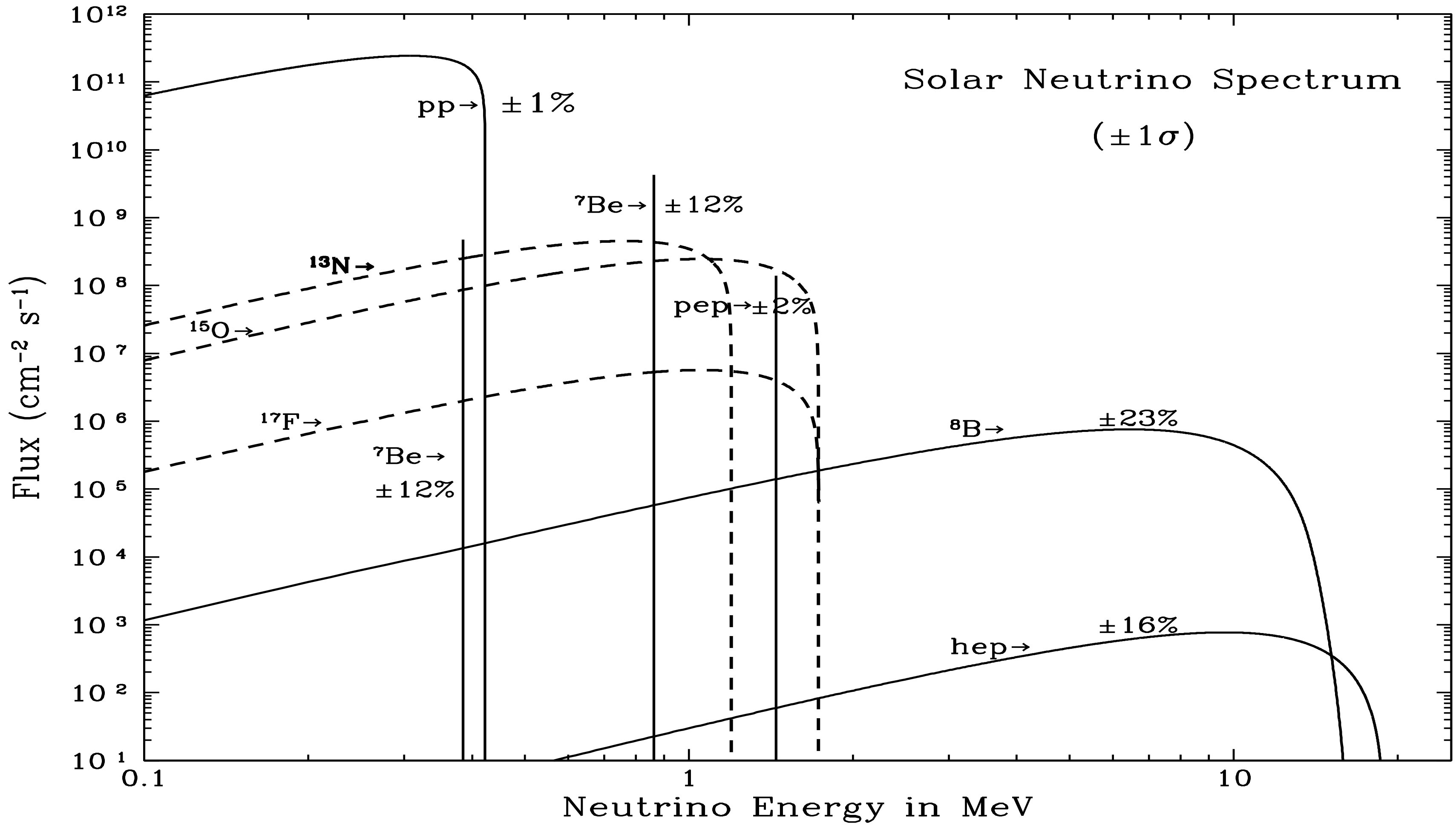


Figure 3: The flux continuum $[cm^{-2}sec^{-1}MeV^{-1}]$ as a function of the neutrino energy $E_\nu$.

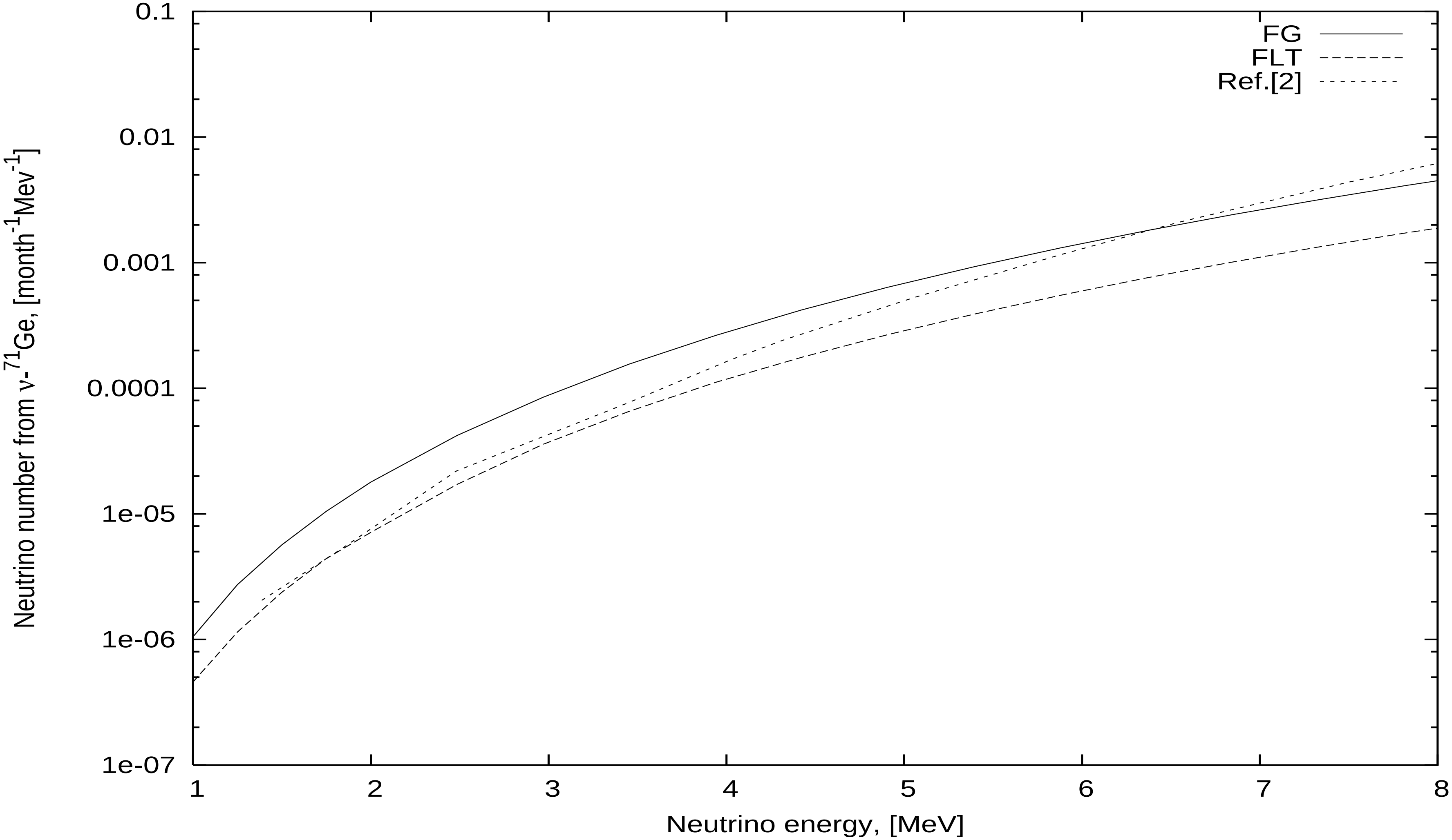


Figure 4: The total neutrino number per a month and MeV produced from $^8$B-$\nu$ flux interacting with 1.kg $^{71}$Ge target as a function of the neutrino energy $E_\nu$.

# CONCLUSION

I. The FLT can be applied to compute total cross sections for neutrino scattering off heavy nuclei at low neutrino energies.

II. The obtained cross sections do not contradict to other calculations within different nuclear models.

III. The suggested approach is much simple in comparing to other models.

IV. The cross sections obtained within the FLT are different from the results obtained within the Fermi gas approximation in a factor 2.5-3 at $E_\nu \leq 5 - 6 MeV$.

V. At higher energies such difference becomes smaller.

VI. The suggested approach can be applied to compute the background from solar neutrinos interacting within a detector.

VII. At intermediate energies about a few hundred of MeV the main *nuclear effect is a possible baryon isobar creation in a medium.*

*VIII. At high energies above 1 GeV a contribution of nuclear effects to total $\nu - A$ cross sections becomes small, it is less than 10$\%$.*