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# Calculation and measurement of $^{144}\text{Ce}$ - $^{144}\text{Pr}$ $\beta$ -spectrum

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**Abstract.** We calculate beta spectrum of Ce-Pr-144 taking into account several types of corrections. The result is compared with the experimental data obtained at NRC Kurchatov Institute. Using this comparison we estimate the reliability of theoretical calculations for electron and antineutrino spectra from beta decay.

## 1. Introduction

Prospective neutrino experiments with intense radioactive sources (such as SOX [1]) require a precise knowledge of the emitted neutrino spectrum. One of the most promising antineutrino sources for such experiments is  $^{144}\text{Ce}$ - $^{144}\text{Pr}$  [2]. Antineutrinos are usually detected via inverse beta decay (IBD) process

$$\bar{\nu}_e + p \rightarrow n + e^+ \quad (1)$$

with a threshold  $E_{thr} = 1806$  keV. In case of  $^{144}\text{Ce}$ - $^{144}\text{Pr}$ , the actual antineutrino source is  $^{144}\text{Pr}$ , because it has two decay branches with endpoint energies greater than the IBD threshold  $E_{thr}$ . The first (dominant) branch is a non-unique first-forbidden Gamow–Teller transition  $0^- \rightarrow 0^+$  with endpoint energy 2997.5 keV and 97.9% branching. The second one is a unique first-forbidden Gamow–Teller transition  $0^- \rightarrow 2^+$  with endpoint energy 2301.0 keV and 1.04% branching.

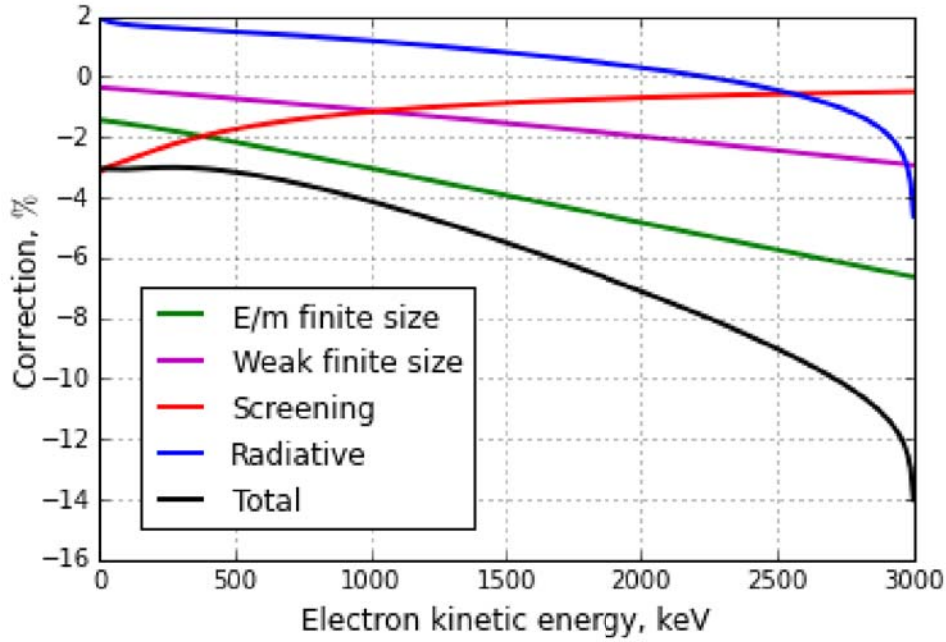
The electron and antineutrino  $\beta$ -spectra are described basically by the same formula. So, to verify the reliability of antineutrino spectrum calculation one can compare theoretical electron spectrum with experimental data. We provide such a comparison using the experimental data on  $^{144}\text{Ce}$ - $^{144}\text{Pr}$  electron spectrum obtained at NRC Kurchatov Institute. In our calculation, only the main decay branch (with the branching  $I = 97.9\%$ ) of  $^{144}\text{Pr}$  is considered.

## 2. Beta spectrum calculation

The formula for the electron spectrum is

$$N(W_e) = K p_e W_e (W_e - W_0)^2 F(Z, W_e) H(W_e) \times \\ \times L(Z, W_e) C(Z, W_e) S(Z, W_e) G_\beta(Z, W_e) B(W_e). \quad (2)$$





**Figure 1.** Corrections to electron spectrum for  $^{144}\text{Pr}$  branch with endpoint energy 2.998 MeV.

Here  $W_e$  and  $W_0$  are the total electron energy and the endpoint energy in units of  $m_e c^2$ ,  $p_e$  is the electron momentum,  $K$  is a normalization constant. The antineutrino spectrum is obtained by replacing  $W$  with  $W_0 - W$ .

The Fermi function  $F(Z, W)$  describes the effect of nuclear Coulomb field on the outgoing electrons [3]. In case of forbidden decays one has to take into account the shape factor  $H(W)$ . For the main decay branch of  $^{144}\text{Pr}$  we take the shape factor in the following form [4] :

$$H(W_e, W_0) = p_e^2 + (W_e - W_0)^2 + 2p_e^2(W_e - W_0)/W_e.$$

Electromagnetic and weak finite-size corrections  $L(Z, W)$  and  $C(Z, W)$  are due to the distributions of electric and weak isovector charges in the nucleus [5]. The effect of atomic electrons on the spectrum is given by the screening correction  $S(Z, W)$  [6]. The first order QED radiative corrections are included in  $G_\beta(Z, W)$  [7, 8]. Note that this is the only type of corrections that is different for electron and neutrino spectra. Finally, the weak magnetism correction  $B(W)$  describes the interaction of the emitted electrons with the magnetic moment of the daughter nucleus. For the main decay branch of  $^{144}\text{Pr}$ , which is a first-forbidden non-unique transition it equals zero [4, 9].

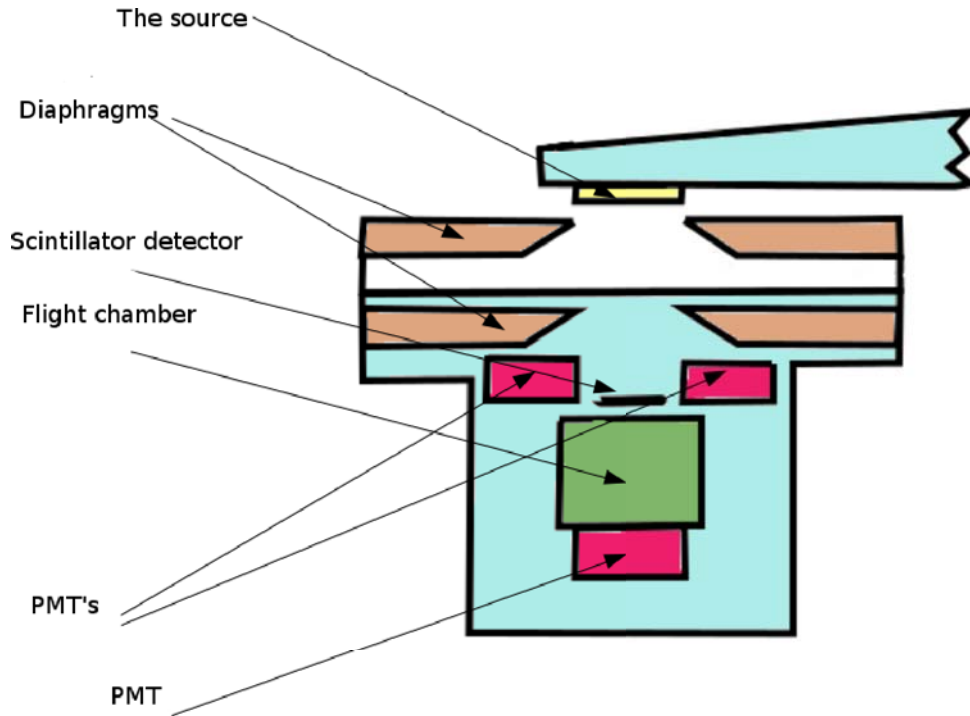
Figure 1 shows the correction values for the electron spectrum of the main  $^{144}\text{Pr}$  decay branch. Only the energy dependent parts affecting the spectrum shape are presented.

### 3. Comparing theory with experiment

An experiment on  $^{144}\text{Ce}$ - $^{144}\text{Pr}$  beta spectrum measurement was conducted at NRC "Kurchatov Institute" with a beta-spectrometer. The experimental setup is shown on figure 2. The detector was calibrated using  $^{207}\text{Bi}$  conversion spectrum. The detector resolution is  $\sigma/E = 5\%$  at 1 MeV. To make a proper comparison between the theoretical calculations and the experimental data we introduced the response function  $R(E, E')$ . The measured spectrum is given by

$$M(E) = \int_0^\infty R(W_e, W'_e) N(W'_e) dW'_e, \quad (3)$$

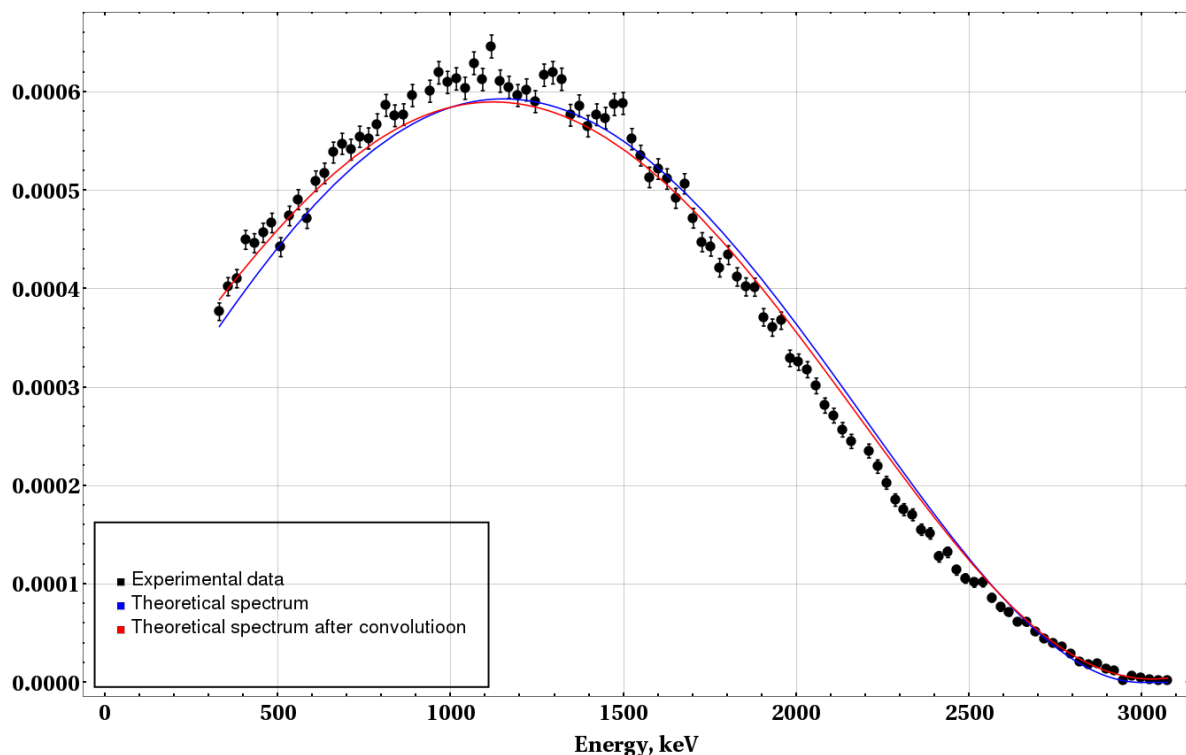
where  $N(W'_e)$  is the theoretical spectrum (2).



**Figure 2.** Beta-spectrometer scheme.

The response function  $R(E, E')$  should take into account the detector resolution given by a Gaussian function and electron backscattering given by a step function (see [10]). According to our Monte-Carlo simulations, the step function accounts for about 3% of total area under the response curve. Note that usually one expects a stronger (about 10%) influence of electron backscattering [10], so further improvement of the Monte-Carlo calculations should be done.

Figure 3 shows the theoretical calculation and the experimental data compared (unconvoluted theoretical spectrum is also given to show the effect of the response function). The spectra are normalized; the total number of experimental events is  $1.86 \cdot 10^5$ . The theoretical and the experimental spectra are in general agreement with each other. In particular, the spectra match at low electron energies. These energies correspond to high antineutrino energies and are of interest for neutrino experiments.



**Figure 3.** Comparison between calculated electron spectra for  $^{144}\text{Pr}$  and experimental data. Total number of experimental events is  $1.86 \cdot 10^5$ .

#### 4. Conclusion

We calculated the electron spectrum from the main branch of  $^{144}\text{Pr}$   $\beta$ -decay. The calculations are in general agreement with the experimental data. However, there is an uncertainty in the detector response function, so further data analysis is needed. A comparison with the data from other experiments is also desirable.

#### Acknowledgments

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