Precision measurement of ^{210}Bi β-spectrum

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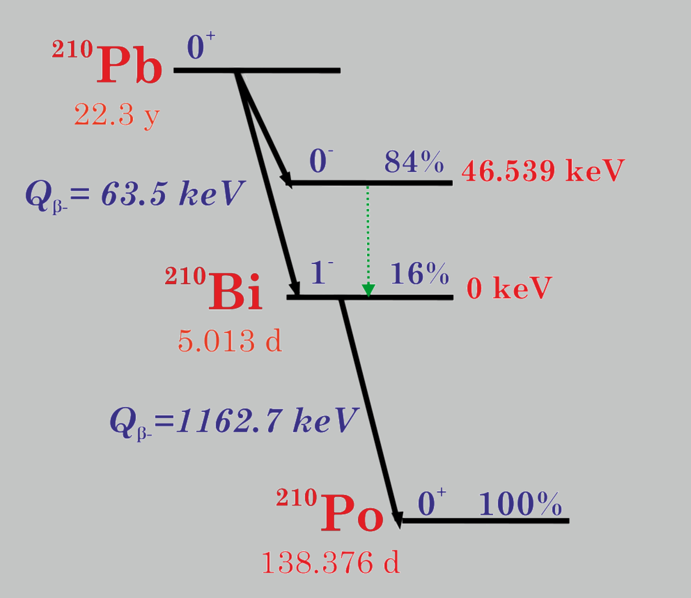
Abstract

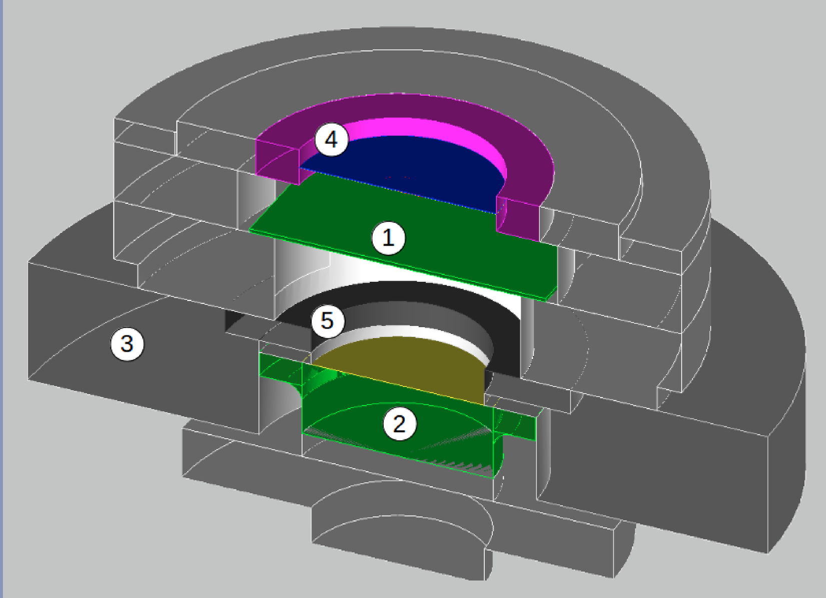
In this work we present a precision measurement of the beta-spectrum shape for ^{210}Bi (historically RaE) performed with spectrometers based on semiconductor Si(Li) detectors. The studies were performed with spectrometers in target-detector and 4-π geometries. The measured transition form-factor could be approximated as $C(W) = 1 + (-0.436 \pm 0.004)W + (0.0523 \pm 0.0010)W^2$ and $C(W) = 1 + (-0.436 \pm 0.008)W + (0.0532 \pm 0.0023)W^2$ for the target-detector and 4-π spectrometer respectively that is in good agreement between the two experiments as well as with the previous studies. The form-factor parameter precision has been substantially increased with respect to the previous experimental results.

^{210}Pb decay scheme

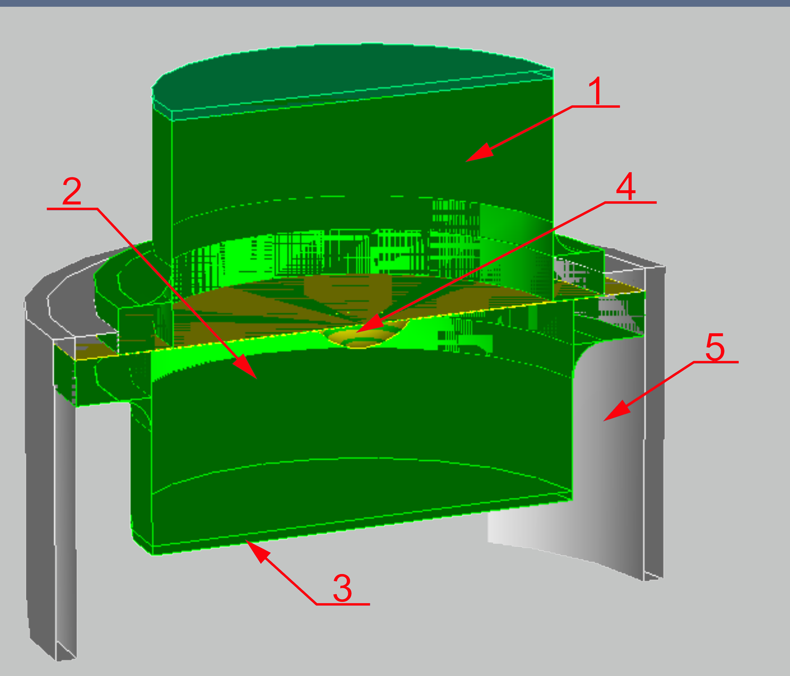
^{210}Pb decays to ^{210}Bi and, consequently, to ^{210}Po with two first forbidden beta-transitions. Thus, the transition of interest could be measured only above ^{210}Pb beta-spectrum endpoint of 63.5 keV and is not accompanied with any other spectra in this energy range. The only complications could come from ^{210}Po α-radiation with partial energy deposit.



Semiconductor-based beta-spectrometers



"Target-detector" spectrometer: 1 - removable transition detector, 2 - Si(Li) detector with thin entrance window, 3 - Teflon detector holder, 4 - radioactive source produced with thermal sublimation on steel substrate, 5 - tungsten collimator



4π spectrometer: 1 - upper Si(Li) detector with thin entrance window, 2 - lower Si(Li) detector with thin entrance window 3 - diffusive lithium insensitive layer, 4 - radioactive source in form of dried drop located in a special cavity, 5 - detectors support structure

Beta-spectrum models

Beta-spectrum could be expressed as

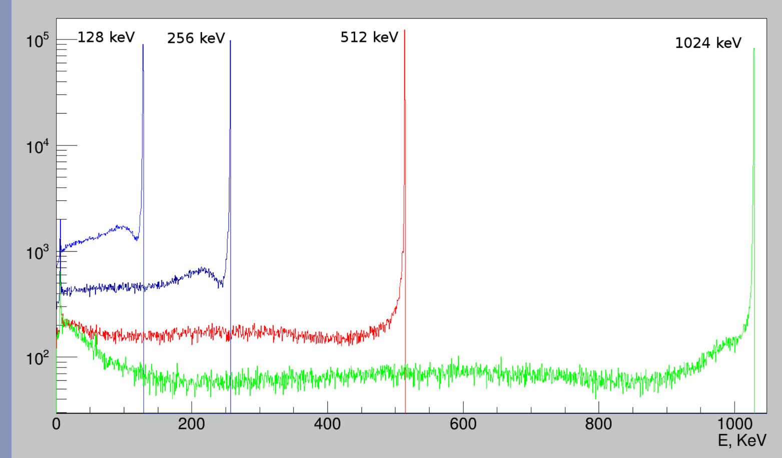
$$S(W) = F(E,Z)C(W,Z)PW(W-W_0)^2,$$

Where F(E,Z) is the Fermi function and C(W,Z) is the nuclear form-factor which is the subject of the measurement. Form-factor was modeled as in [7]

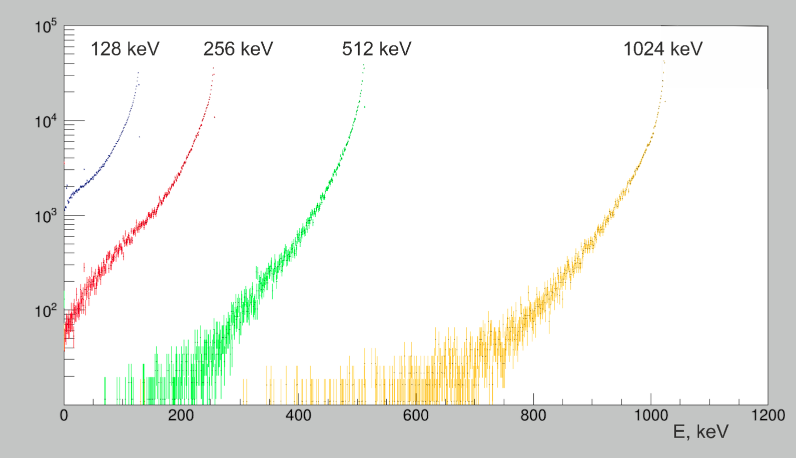
$$C(W) = 1 + C_1 \times W + C_2 \times W^2$$

The final Fermi function F(E,Z) was calculated according to the formalism described in [5] with application of various corrections for atomic effects.

Semiconductor spectrometer response



The "target-detector" spectrometer response was modeled with Geant4[4] package with "Option_4" standard electromagnetic interactions. Perfectly thin source allowed to model the response with high precision. An extra analytical freedom at "peak over tail" ratio was added for MC-related systematics evaluation.

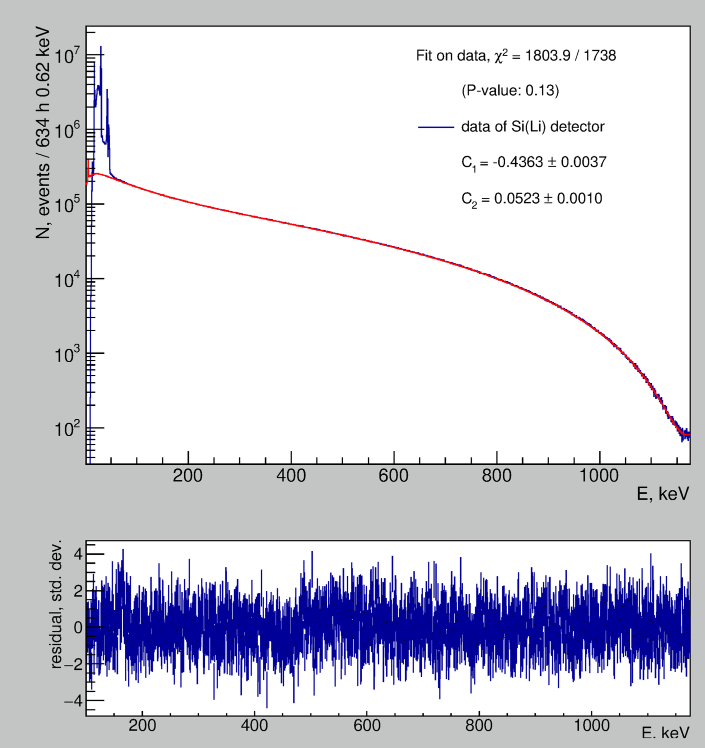


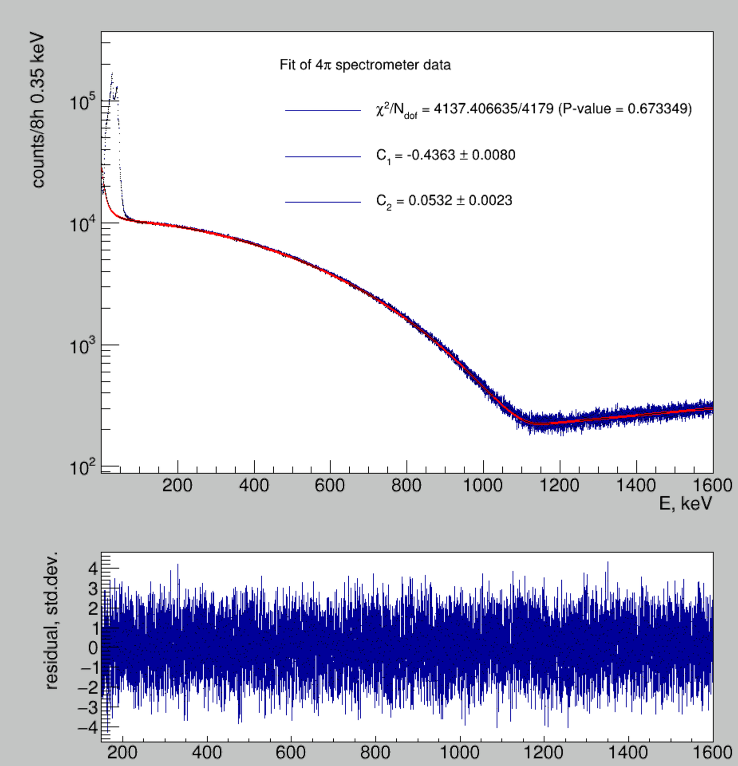
The source in form of dried drop did not allow to perform satisfactory precise MC modeling, so a the response was described analytically as

$$R(E,T_e) = e^{A(T_e)E + B(T_e)} \times \theta(E - T_e)$$

Parameters $A(T_e)$ and $B(T_e)$ were chosen through equalization of the variance with MC simulation and were given an extra parabolic freedom.

Fit of the final spectrum



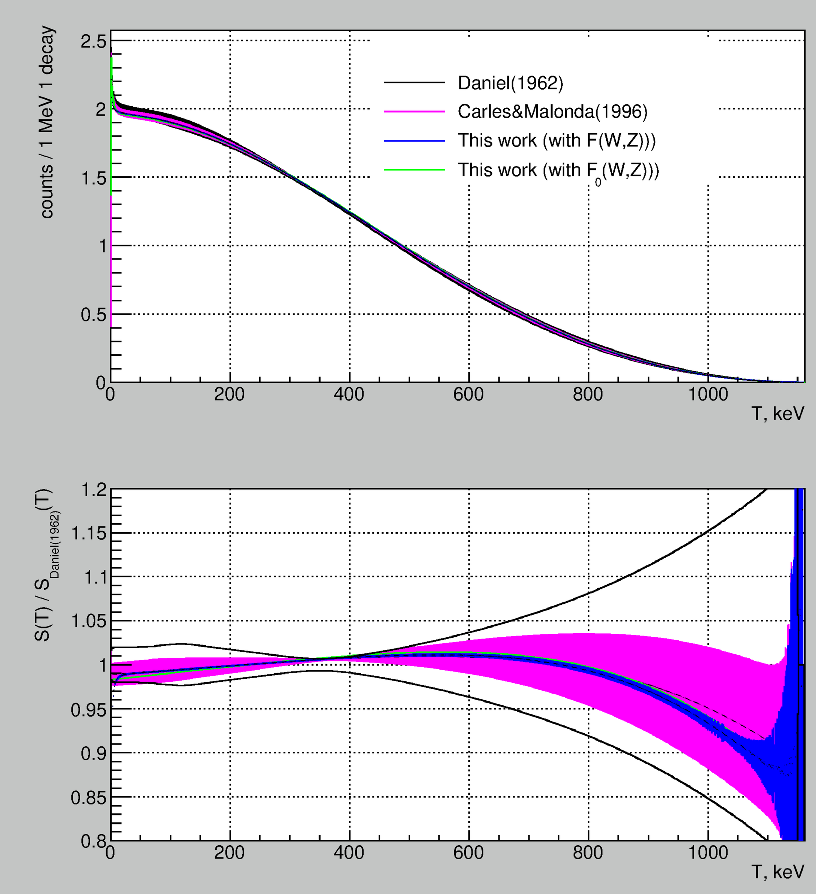


The fit was performed with maximum likelihood method with χ^2 likelihood and beta-spectra expressed as

$$N(E) = \int_E^{E_0} S(W = \frac{T_e}{m^0 c^2} + 1) R(E, T_e) dT_e$$

with exponential background model for 4π spectrometer and flat background model for "target-detector" spectrometer. The fit models demonstrate good statistical agreement with experimental data. Results of these measurements agree.

Discussion of the results



The resulting form-factors were compared with measurements performed by Daniel [6] and Carles and Malonda [7]. The uncertainties on the spectrum were evaluated through toy Monte-Carlo over 2D Gauss distribution with uncertainties and correlation coefficient taken from the fit with "target-detector" spectrometer. The figures, demonstrating obtained spectra and their ratios show good agreement among all measurements within uncertainties.

More information on the study could be found in [1, 2, 3]. The beta-spectrum measurement is being applied for the CNO neutrino program of the Borexino collaboration.

References

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