Precision measurements of ^{210}Bi β-spectrum for neutrino physics tasks.

A.V. Derbin, I.S. Drachnev, I.M. Kotina, I.S. Lomskaya, M.S. Mikulich, V.N. Muratova, N.V. Niyazova, D.A. Semenov, M.V. Trushin, E.V. Unzhakov, E.E. Chmel

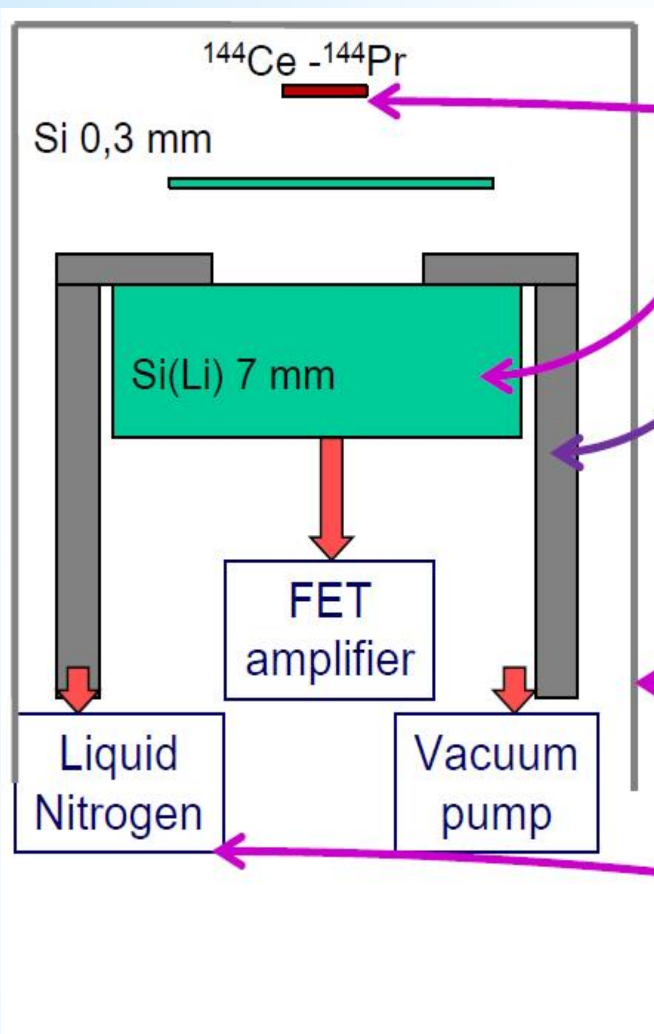
St. Petersburg Nuclear Physics Inst., NRC "Kurchatov Institute", Gatchina, Russia

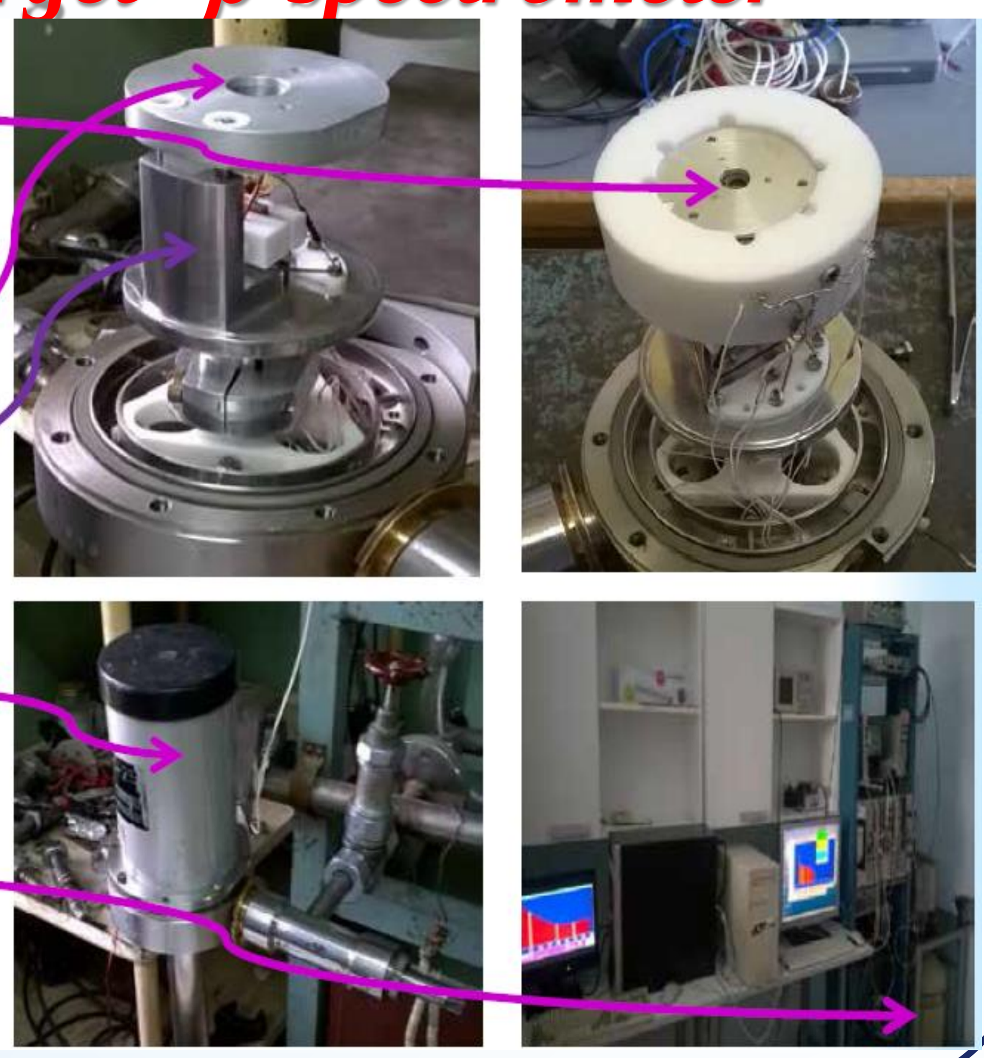
Abstract

The isotope ^{210}Bi is an element of ^{238}U natural decay chain. As decay product of ^{222}Rn gas and subsequent long-lived ^{210}Pb, the ^{210}Bi isotope is present inside and on the surface of all structural materials. At present, accurate measurement of 210Bi β-spectrum is necessary for background simulation of modern neutrino and dark matter detectors, as well as for other low-background experiments. In particular, the shape of ^{210}Bi β-spectrum is very similar to the spectrum of recoil electrons from the scattering of **solar CNO-neutrinos.**

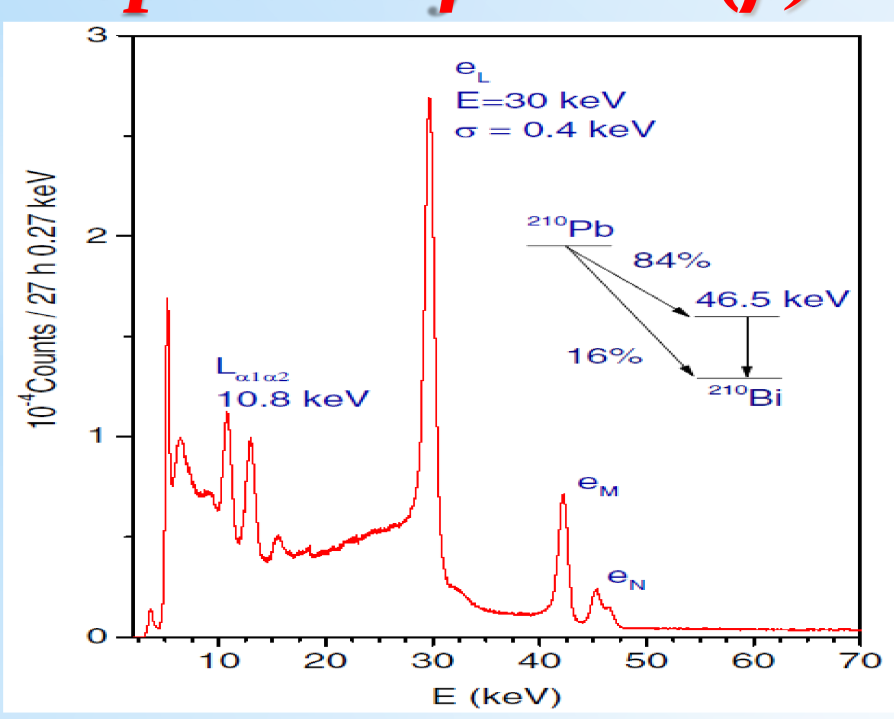
The β-spectrum was measured with two types of Si-spectrometers developed and manufactured at the PNPI. To register electrons in a spectrometer designed according to the classical "target-detector" scheme, a Si(Li) detector 15 mm in diameter and 7 mm thick was used [1]. The main difference of the new 4πβ-spectrometer is the response function, which is close to Gaussian, which does not require careful consideration of electron backscattering from the crystal surface [2,3]. As a result of two independent measurements, the values of the nuclear form factor parameters are determined with an accuracy better than a percent and are consistent with each other.

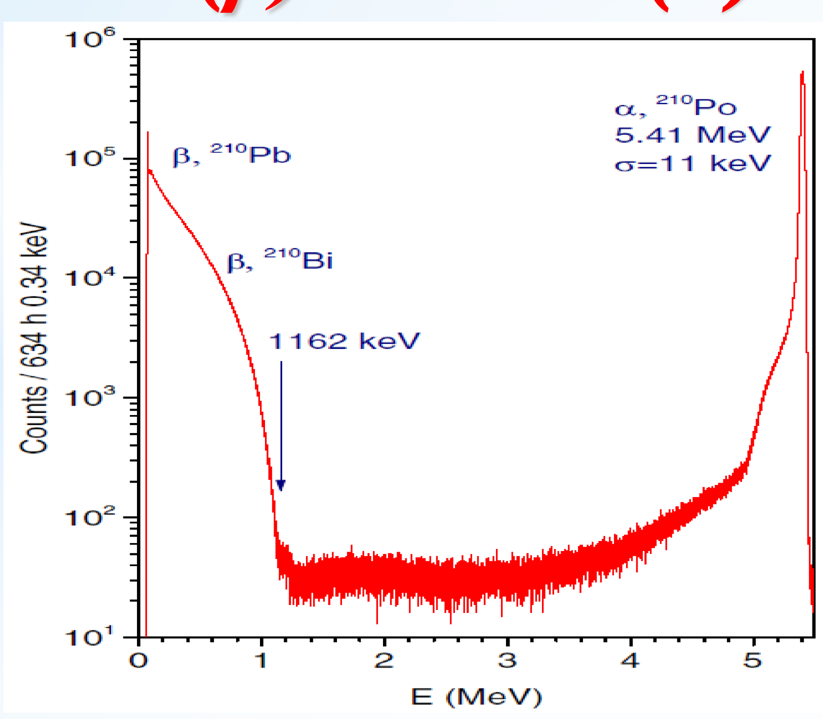
"Detector-Target" β-spectrometer





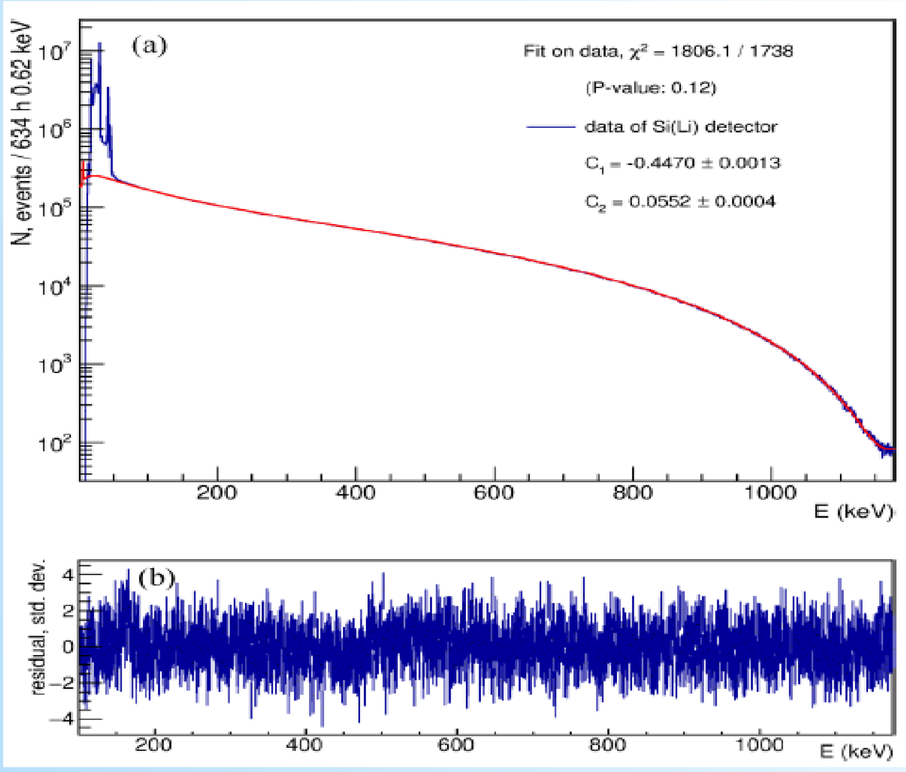
Spectra of ^{210}Pb (β)→^{210}Bi (β) →^{210}Po (α)

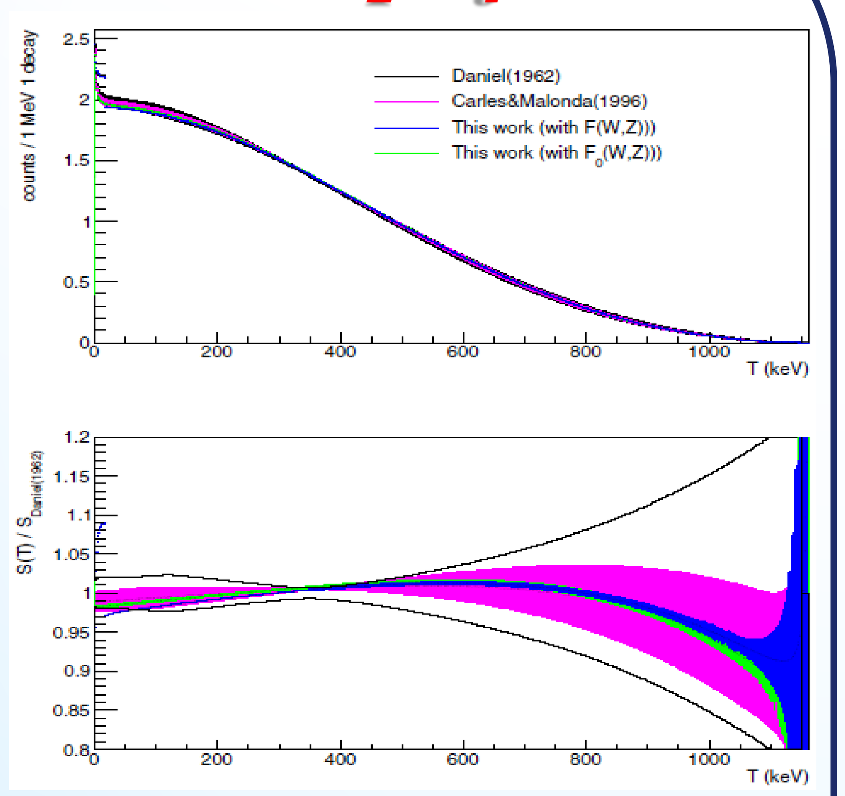




Left: Low energy part of ^{210}Pb → ^{210}Bi spectra measured with Si(Li) detector.
Right: The energy spectrum of ^{210}Pb → ^{210}Bi → ^{210}Po source measured with the Si(Li) detector in energy range of (0.05 –5.5) MeV.

Fit of ^{210}Bi β-spectrum and shape factor

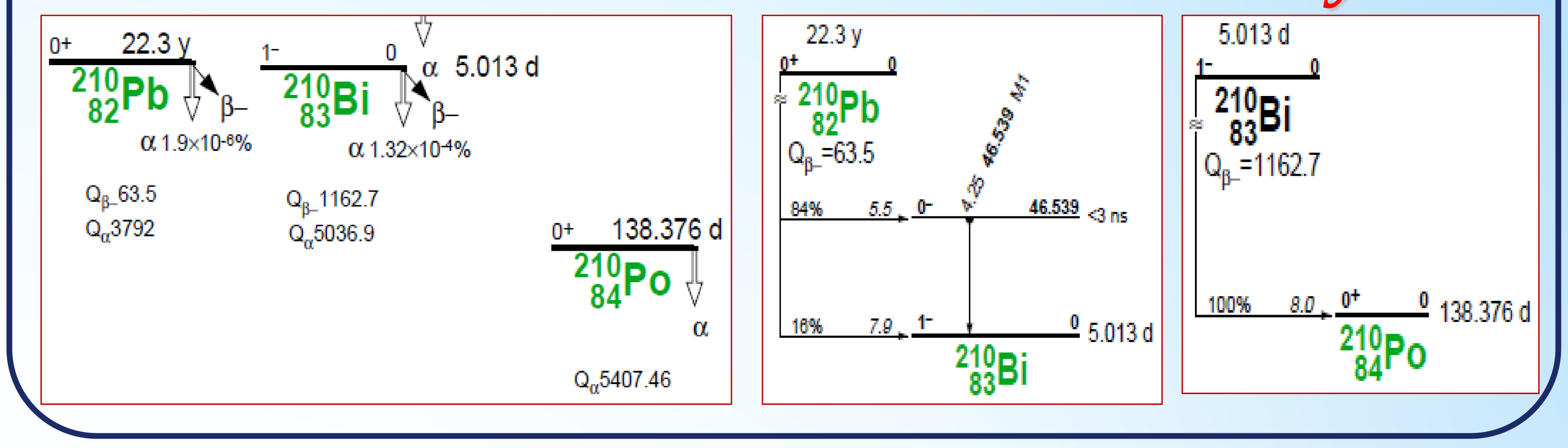




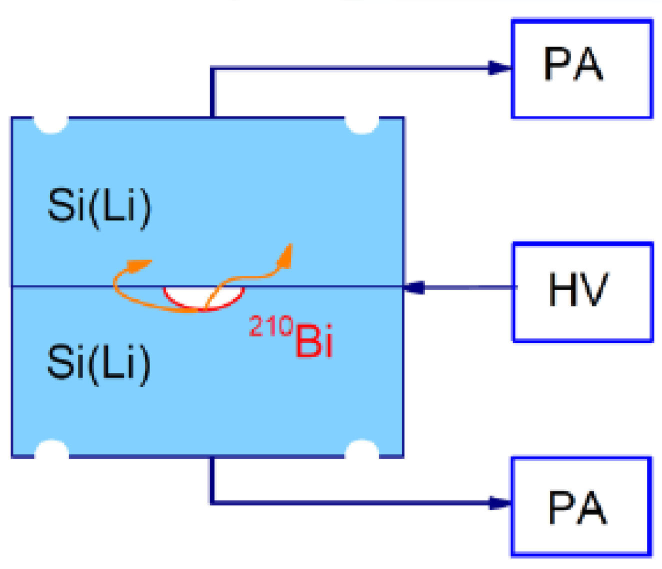
Left: Experimental spectrum fit with parabolic form-factor C(W) and Fermi function F(W, Z). The χ2 fit was performed in the energy range 100–1175 keV. **Right:** Comparison of the spectra measured by Daniel (1962) and Carles&Malonda (1996) with the present study (top). Ratio to Daniel (1962) spectrum (bottom). Daniel (1962) spectrum errors are shown by solid black lines.

1. Alekseev I.E., Bakhlanov S.V., Derbin A.V., Drachnev I.S., Kotina I.M., Lomskaya I.S., Muratova V.N., Niyazova N.V., Semenov D.A., Trushin M.V., Unzhakov E.V., Phys. Rev. C 102, 064329 (2020).
2 Alekseev I.E., Bakhlanov S.V., Derbin A.V., Drachnev I.S., Kotina I.M., Lomskaya I.S., Muratova V.N., Niyazova N.V., Semenov D.A., Trushin M.V., Unzhakov E.V. J. Phys.: Conf. Ser. 2103, 012144 (2021).
3. Bakhlanov S.V., Derbin A.V., Drachnev I.S., Kotina I.M., Lomskaya I.S., Muratova V.N., Niyazova N.V., Semenov D.A., Trushin M.V., Unzhakov E.V., Chmell E.A. Instrum. Exp. Tech., 64, 190 (2021).

^{210}Pb → ^{210}Bi→ ^{210}Po → ^{206}Pb decays

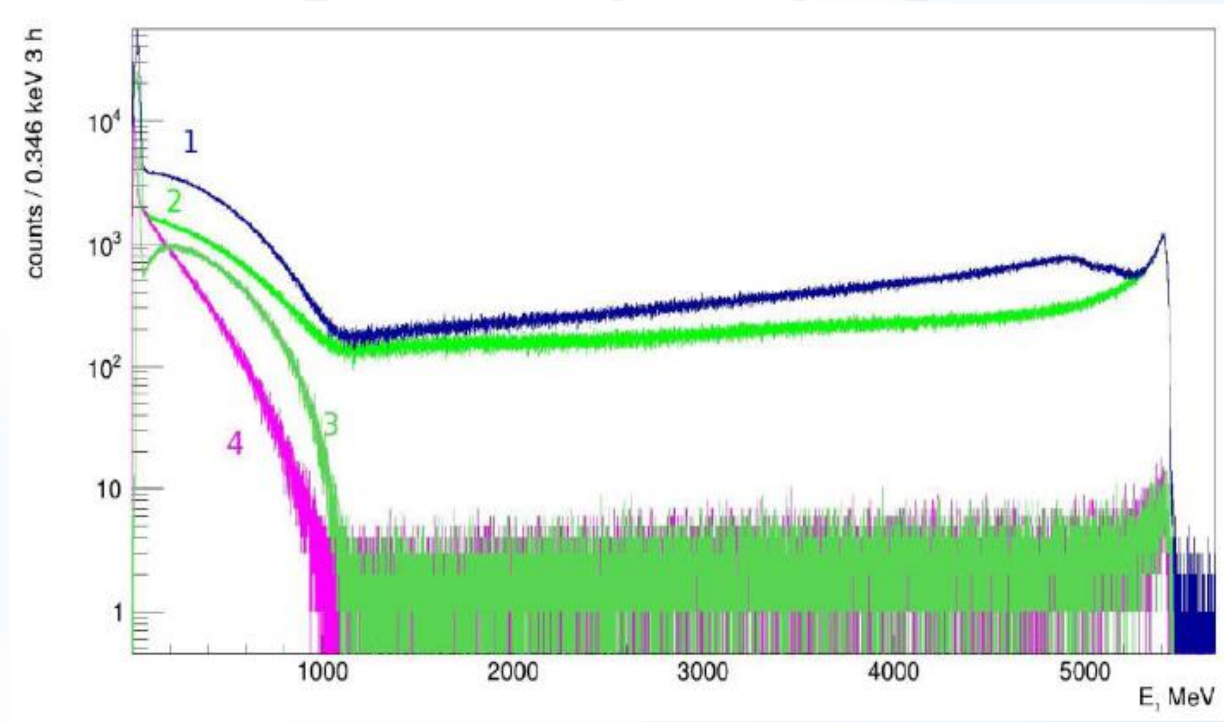


4π β-spectrometer with two Si-detectors



Si(Li) detectors produced in PNPI with 16 mm diameter, 9 mm thick. The low threshold of detected energy is 5 keV. The energy resolution with γ lines of ^{241}Am is FWHM= 1.1 keV. The response function of the spectrometer is close to Gaussian and does not contain a part associated with backscattering of electrons from the crystal surface,.

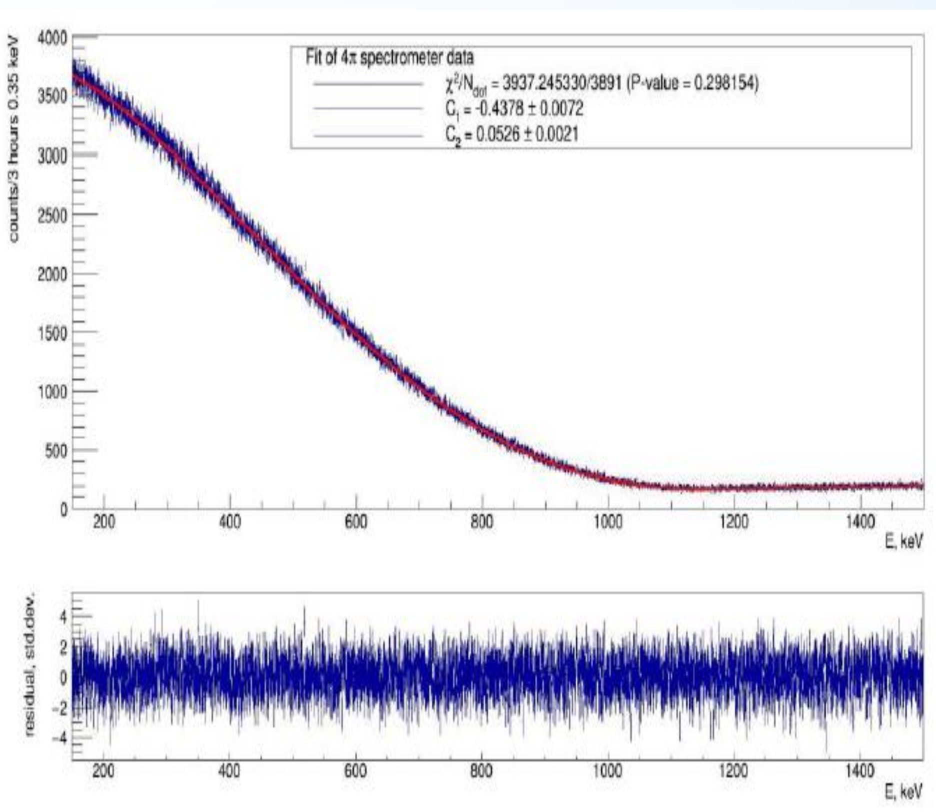
Spectra of 4π β-spectrometer



The experimental spectra measured by 4π β-spectrometer.
1 – total registered energy spectrum;
2 and **4** anti-coincidence and coincidence, respectively;
3 – spectrum of events recorded by two detectors.

Gaussian response function of 4π-spectrometer allows to directly measure the energy of electrons in β-decay. The figure shows the energy spectra of electrons and α-particles, produced by the decay chain of ^{210}Pb and registered by one and both Si(Li) detectors. The events recorded by both detectors in a 100 ns time window were considered coincident..

Fit of 4πβ-spectrometer ^{210}Bi β-spectrum



Shape of β-spectrum

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

Fermi function and corrections

$$F(E,Z) = F_0(E,Z) \times S(E,Z) \times L_0(E,Z) \times M(E,Z) \times G_\beta(E)$$

Nuclear formfactor

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

Convolution with response function

$$N(E) = \int_{E/mc^2+1}^{W_0} S(W) \times R(W,E) dW$$

The results of fitting the measured spectrum (blue curve) to the theoretical curve (red curve). The bottom graph shows the difference between the experimental spectrum and the theoretical curve in standard deviation units.

Conclusion

The spectrometer based on the Si(Li) detector was used to precisely measure the β spectrum of ^{210}Bi nuclei. As a result of the 634 h measurements with a total number of 1.0 ×10^8 of registered electrons it was established that the β spectrum is described by form-factor **C(W) = 1 + (−0.4523 ± 0.0031)W + (0.0560 ± 0.0008)W2** if the Fermi function is calculated for a point-like nucleus.

New 4π-spectrometer consisting of two Si(Li) detectors was used to measure an electron spectrum produced by β-decay of ^{210}Bi. The spectrometer response function is close to the Gaussian and does not contain a low-energy part associated with backscattering of electrons from the crystal surface. The determined values of the nuclear shape factor parameters **C1 = -0.4378 ± 0.0072** and **C2 = 0.0526 ±0.0021** are in agreement with the results of the previous measurements [1].

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