FIRST TRITIUM DECAY SPECTRA FROM THE MAINZ NEUTRINO MASS EXPERIMENT

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Abstract

After having tested the performance of the new solenoid retarding spectrometer by precision measurements on the electron conversion spectrum of ^{83m}Kr, first tritium decay spectra have been taken from a source of frozen T_2. The signal exceeds the background rate of 0.03 Hz for energies up to 30 eV below the endpoint. A preliminary analysis yields a Q-value of the tritium decay of (18589±3) eV. We expect from the final analysis of the present data set an upper limit for the electron antineutrino rest mass below 10 eV/c^2.

In preceding contributions to this workshop [1,2], we described the principle and the function of a new solenoid electron retarding spectrometer. It provides simultaneously high resolution and high transmission which are essential features for investigating the endpoint region of the β-decay of tritium in search for a finite electron antineutrino rest mass. The main components of the spectrometers are as follows: A film of 10 - 30 monolayers of molecular tritium is frozen onto a 1 cm^2 aluminum backing placed near the centre of a solenoidal field $B_0 \simeq 2.4$ T. The decay electrons emerging from the source expand adiabatically into a low field region of $B_1 \simeq 8 \times 10^{-4}$ T where they have to pass an electrostatic analyzing potential which is scanned in the vicinity of the endpoint of the β-spectrum $E_0 \simeq 18.6$ keV. Due to the adiabatic transformation of transverse cyclotron motion into longitudinal motion along the guiding magnetic field lines the whole forward solid angle of emission is analyzed within a filter width of

$$\Delta E = E\,(B_1/B_0) \qquad (1)$$

which amounts to $\Delta E \simeq 6$ eV for the settings given above. Electrons passing the filter are refocussed by two following solenoids onto a silicon detector which is separated into five concentric segments each of them having an area of 1 cm^2.

More detailed information on the source, the spectrometer and the detector may be found in references [3] - [5]. An instrument based on the same adiabatic principle has been built by a group at the Institute of Nuclear Research in Troitzk [6].

The performance of the instrument may be illustrated by the spectrum of the K-32 conversion line of ^{83m}Kr frozen onto an aluminum backing (Fig. 1). The instrument was set at a field ratio $B_0/B_1 = 3000$. In the region of steep transmission change data points were taken in steps of 2 V. The insert in Fig. 1 shows an expanded view of the spectrum close to the K-line. In this region the spectrum has been fitted with an elastic K-line component of Lorentzian shape. It is followed by a satellite spectrum of shake up and shake off events which is approximated by Gaussians convoluted with an exponential tail (see the dotted lines in the insert of Fig. 1). The fit uses the analytical transmission function given in ref. [7]. Below the shake off region the integral spectrum is rising further due to electrons backscattered

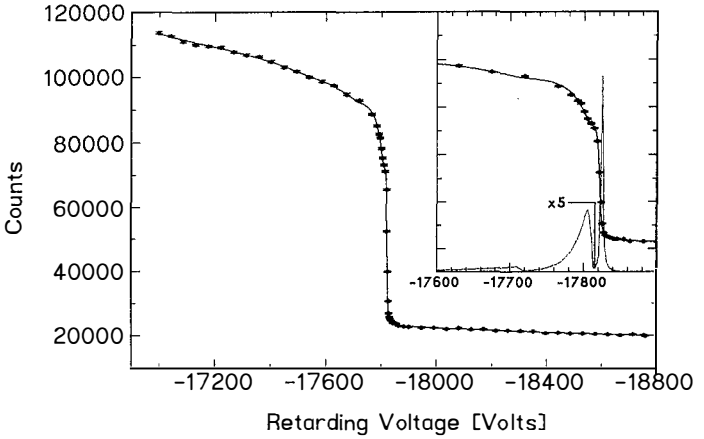

Fig. 1: Integral transmission spectrum measured in the region of the K-32 conversion line of ^{83m}Kr. Also shown is the fitted spectrum and its differential components in the insert.

from the aluminum substrate. Shape and height of the backscattered spectrum extracted from this measurement are in good agreement with a Monte-Carlo simulation. The K-32 line is sitting on a background which stems mainly from the backscattered tail of the L-32 components (compare also ref. [7]).

First tritium spectra were taken in two test runs and one production run in 1991. Fig. 2 shows the measured raw data obtained. The critical endpoint region is blown up in the insert. Plotted is the measured count rate as a function of the effective retarding potential which is the difference between the filter potential fixed to U_0 = 18877 V and the source potential U_S scanned in the respective interval. The plot represents 40 % of the data collected in the four weeks of running in November/December 1991. The signal rate equals the background rate of 0.030 Hz already 30 eV below the endpoint (the number of background counts collected in a single point above E_0 is about 550). The full line is a fit to the data with the neutrino mass m_ν fixed to zero. The preliminary fit yields an endpoint of the β-spectrum of T_2 imbedded in a matrix of frozen T_2 of

$$E_0 = 18572 \text{ eV} \qquad (2)$$

From this result we calculate a preliminary value for the mass difference

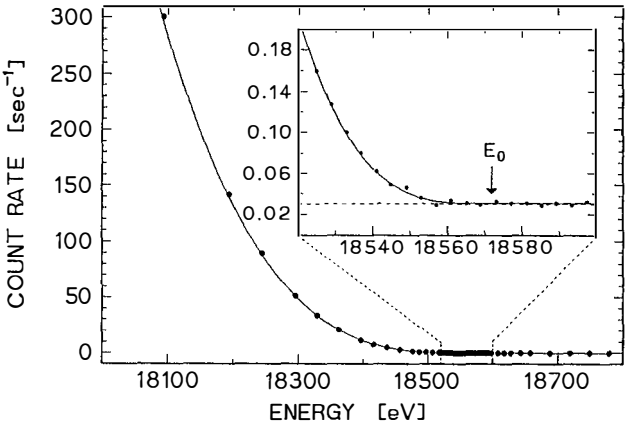

Fig. 2: Measured integral tritium decay spectrum in the endpoint region together with a fitted curve with m_ν fixed to 0. The insert shows an expanded view close to the endpoint E_0.

$$Q = m(^3H) - m(^3He) = 18589\ (\pm 3)\ eV \qquad (3)$$

The error bar on this result should be regarded as preliminary and conservative.

The source was prepared by evaporating 20 - 30 monolayers of T_2 onto the aluminum substrate under ellipsometric control. Although the source was kept at a temperature of 2.6 K, it diminished by a factor of 2 within one week of running with a slope somewhat inbetween linear and exponential. The source was refreshed after 7 to 10 days of running, depending on its actual thickness. Most of the evaporated T_2 was withheld by a tube mounted onto the source which was also cooled to 2.6 K. It limited the solid angle of free evaporation into the spectrometer to about $\Delta\Omega/4\pi \simeq 10^{-3}$. Although part of the tritium certainly evaporated into the spectrometer, it did not apparently contaminate the spectrometer: after removing the source the background rate dropped back to the value it had before the run. When the source was exposed to the spectrometer the background rate rose by about 50 % at maximum.

Fig. 3 shows the data points of Fig. 2 again but in a linearized plot. This is achieved to first approximation by taking the third root of the signal rate. However, the data bend up at about 50 eV below the endpoint. The fit

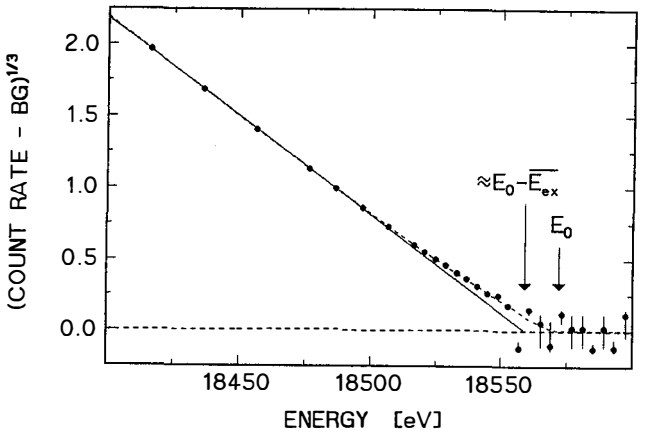

Fig. 3: Same data as in Fig. 2 but linearized by taking the third root of the signal rate. The linear extrapolation from data far below E_0 points to an endpoint shifted by the average excitation energy $\bar{E}_{ex}$ of the daughter molecule.

with $m_\nu = 0$ (broken line) indeed follows this bent and meets the abszissa at the endpoint quoted above. These events close to the endpoint correspond to an elastic emission of the electron where the daughter molecule $(^3He^3H)^+$ is left in its electronic ground state. The data at lower energies, on the other hand, point to an endpoint about 13 eV below that maximum decay energy. This shift agrees - as it should - reasonably well with the average excitation energy of the daughter molecule. As to our knowledge this is the first time that such fine details have ever been resolved in a β-spectrum.

A first impression of the sensitivity of the present data set to the neutrino mass may be gained from Fig. 4 which displays the linearized, measured spectrum again. The line indicated with $m_\nu = 0$ is a preliminary fit to the data with the neutrino mass fixed to zero. Taking the results of this fit as input parameters of a theoretical integral spectrum, but fixing the neutrino mass to 10 and 20 eV/c^2, instead, we calculate the other spectra shown in the plot. These plots show prima vista that a neutrino mass in the order of 20 eV/c^2 or more is certainly incompatible with the data. From a final evaluation of the present data set including detailed corrections for energy loss etc. we expect to be able to set a limit below 10 eV/c^2. A first result with respect to m_ν we hope to present at the Neutrino '92 conference at Granada.

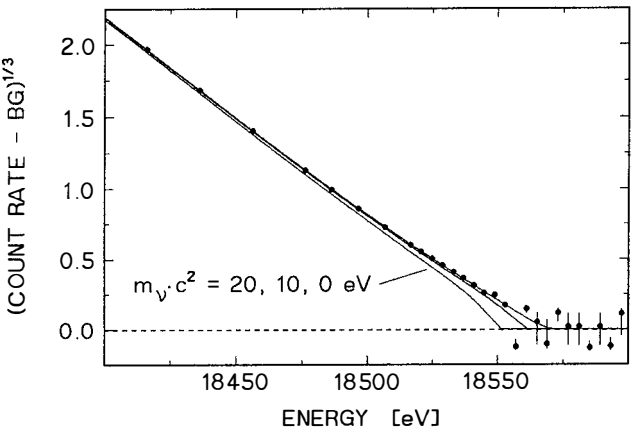

Fig. 4: Same data as in Fig. 3. The solid lines are fitted and calculated spectra, respectively (see text).

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