Performance Report on the Mainz Tritium β-Decay Experiment

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Abstract:

At Mainz University a solenoid-retarding-spectrometer (SRS) for the investigation of the tritium β-spectrum close to the endpoint has been constructed. The performance of the apparatus has been tested with conversion electrons of ^{83m}Kr. The mesurements show that it reaches its design parameters of a resolution of $E/E_0 = 5000$ at an accepted solid angle of 40% of 4π. First tests with a tritium source showed an excellent signal to background ratio. The improvement of the present m_ν limit should be possible in near future.

We have built a solenoid-retarding-spectrometer (SRS) combining high resolution with large luminosity. It is designed for the measurement of the endpoint region of the tritium β-spectrum, in order to improve substantially the current limit on the neutrino rest mass /1/. The instrument consist essentially of two superconducting solenoids that are separated by a system of ring electrodes 4m in length which provides the energy analyzing electrostatic potential /2/,/3/.

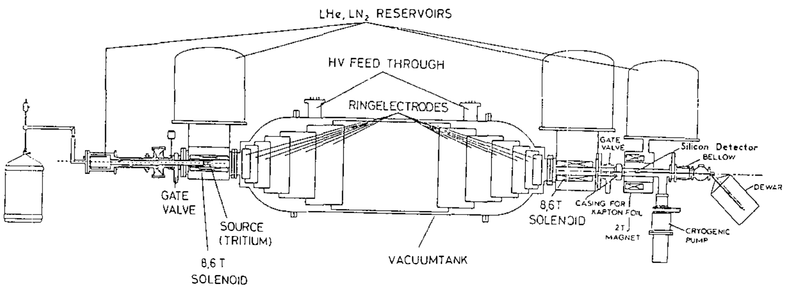


Fig.1: The experimental setup

The source is placed close to the maximum field in the left spectrometer solenoid, the silicon detector is placed in a third solenoid behind the right spectrometer solenoid. It is operated at about $B_o/4$ to limit the angle at which electrons impinch onto the detector to about 25° to minimize backscattering. The maximum of the analyzing potential is reached in the symmetry plane between the two solenoids, where the magnetic field has a minimum of about 10^{-3} T. Decay electrons spiraling adiabatically into the low field region, transform their transverse cyclotron energy into longitudinal energy, in proportion to the decrease of the magnetic field. Simultaniously, their longitudinal motion is decelerated by the electric field, which shaping designed in a way to be parallel to the magnetic field lines. Electrons with energy above the potential barrier are transmitted into the second half of the spectrometer, where they are re-accelerated by the electric field, and where they are refocussed onto PIN-photodiode detector by the magnetic field of the solenoid. The electronic resolution of the PIN-diode is 1keV, with about 1.6keV FWHM at 20keV. The transmission function of the SRS was investigated with conversion electrons from a frozen ^{83m}Kr-source. Fig. 2 shows a scan around the N32.147 keV transition.

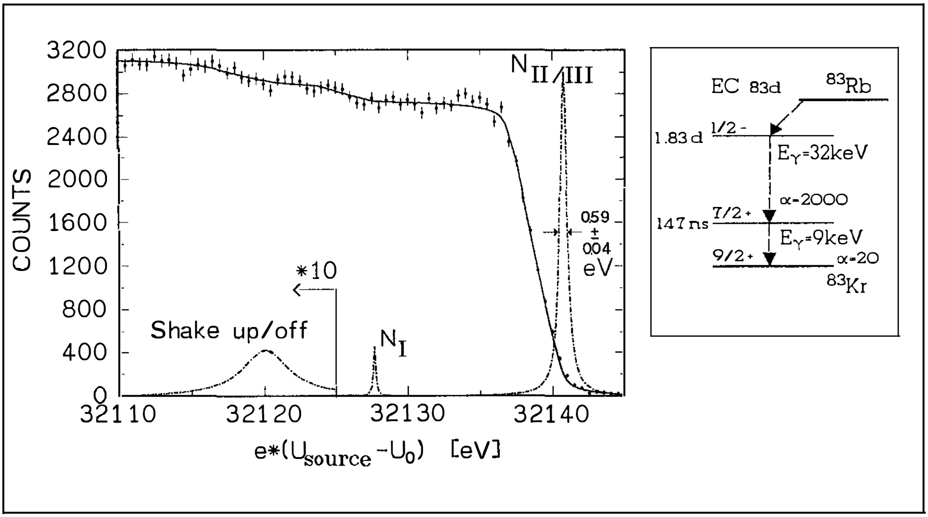


Fig.2: Test measurements with electrons for ^{83m}Kr.

The sharp rise in the count rate originates from $N_{II/III}$ conversion electrons, followed by the weaker N_I component and a small tail of electrons, having lost energy by shakeup/off and backscattering (dash-dotted lines). The full curve is a fit of the conversion lines and energy loss spectrum convoluted with the analytically known transmission function of the spectrometer, to the data. The spectrometer was operated at ≈ 18kV and the Krypton source was put at 14kV. The resolution of the spectrometer is 20keV/3.9eV ≈ 10^4 (10%-90% value). The accepted solid angle is reduced to 16.3% of 4π due to the bias of the source. In the course of the test measurements with ^{83m}Kr all conversion electron lines have been examined. The energy of the γ-transition was determinated to 32.151(3)keV, in good agreement with the value given by Robertson et al. /4/.

First test measurement with a $^3H_2$ source frozen on an aluminium backing.

The source, combining maximum specific activity and acceptable stability, consists of $^3H_2$-molecules frozen on a backing of low Z to minimize backscattering. In off line tests we have found that these $^3H_2$-films are sufficiently stable at the temperature of liquid Helium /6/. $^3H_2$ forms a van der Waals crystal with a binding energy of ≈ 15meV. It is evident that the recoiling decay products with an energy $E_R \leq 3$eV and the decay electrons will sputter off the source material. The $^3H_2$ released from the source itself is to a very large fraction 99% condensed on a 10 cm tube placed as a thermal shield in front of the source. The tube does not touch the imaged flux tube, so decay electrons starting from this shield are not accepted by the detector. The small fraction of $^3H_2$ released into the spectrometer will also be adsorbed on surfaces which are not imaged into the detector.

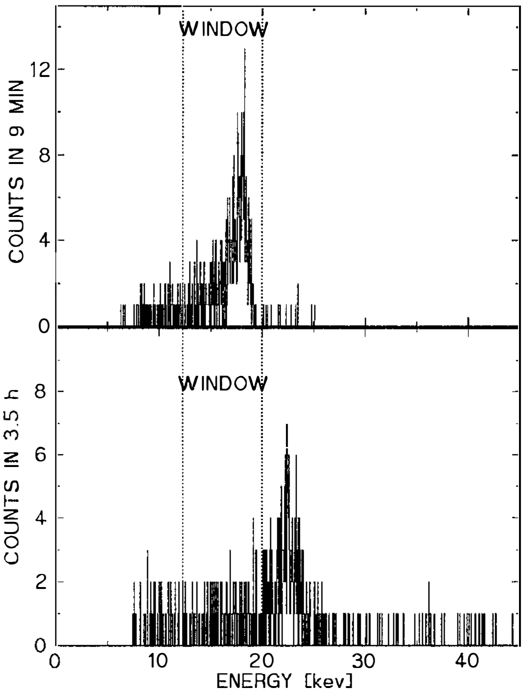
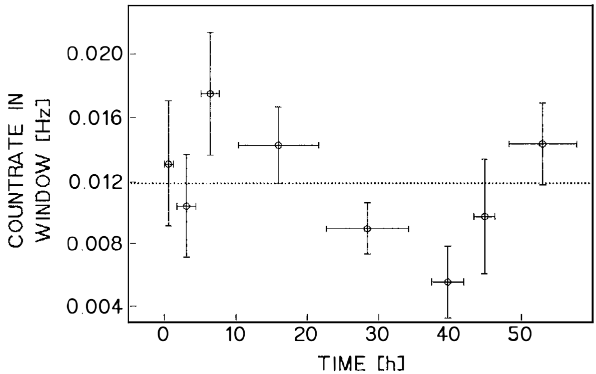


Fig.3: Spectrum of electrons from $^3H_2$ taken ~ 200V below the endpoint. In comparison with the background spectrum the excellent signal to background ratio close to the endpoint is clearly shown.



The temporale development of the background shows no hint of an increase due to $^3H_2$ contamination.

In the first test measurement with $^3H_2$ the evaluation of the background count value as shown in Fig. 3 gives indeed no evidence for a visible $^3H_2$ contamination of the spectrometer. The background level was constant at ~ 12mHz in the true event window. The dominant part of the background electrons is shifted to energies higher than the energy window of interest. Their energy is given by the sum of their kinetic energy with which they are created plus the potential of the emitting surface. With the field configuration used, only electrons with high energies can be imaged onto the detector. Low energy electrons have no overlay with the imaged flux tube.

The quality of the $^3H_2$ data is rather limited as the fraction shown here containes about one day of effective measuring time with a 100µCi source. A 1mCi source and a measuring time of several weeks are planned. A first preliminary analysis gives a statistical 1σ error of $\Delta m_\nu = 200eV^2$ with a value for m_ν^2 compatible with zero. This value, however, should not be taken as a final result, because backscatter and energy loss have to be investigated to more details.

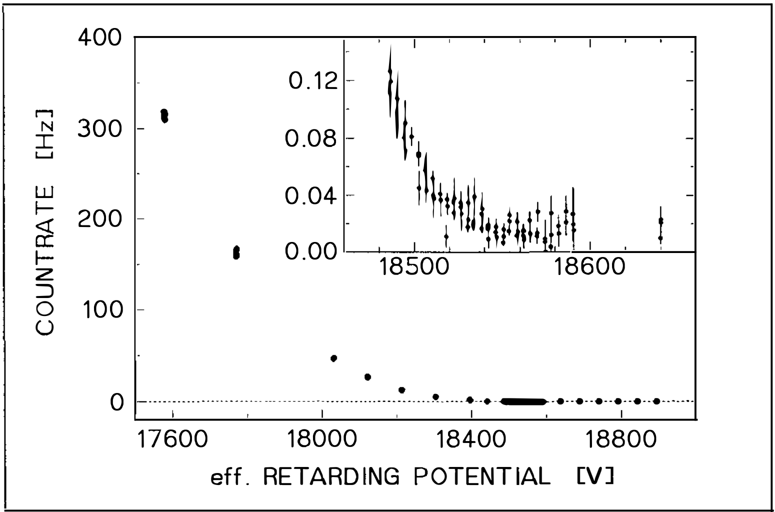


Fig.4: First $^3H_2$ spectrum taken with the Mainz SRS-spectrometer. The data represent about one day of effective measurement time.

In summary we claim to have shown that we can achieve a high statistical accuracy due to the high resolution and transmission of our spectrometer. The background did not increase during our measuring time. Systematic uncertanies have to be investigated. We therefore hope to be able to improve the present limit on m_ν by taking more data with a stronger source.

References

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