8 Neutrino Masses and Mixing

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One of the important questions in today's physics is whether neutrinos have non-zero masses and whether there is neutrino mixing. In our experiment we use β–spectroscopy to search for heavy neutrinos which could be produced with small probability in nuclear β–decay. Mixing would manifest itself as an incoherent superposition of two (or more) decay branches. The signature would be a characteristic 'kink' at an energy $E_0 - m_i c^2$, where E_0 is the endpoint energy of the spectrum for zero neutrino mass.

The objective of the experiment is a systematic search with very high sensitivity for neutrino masses in the range 0.5 to 100 keV/c^2. The radioactive sources we are using are ^{63}Ni and ^{35}S with endpoint energies $E_0 = 67$ keV and 167 keV, respectively.

Figure 8.1: Simplified view of the spectrometer.

8.1 Experimental setup

Our β–spectrometer is of the Tret'yakov type with two 180° bends. The toroidal magnetic field is produced by 72 water-cooled current loops. The mean focal length between source and detector is 1355 mm. A simplified view of the spectrometer (without vacuum tank, etc.) is shown in figure 8.1. With a maximal current of 150 A the spectrometer can analyse electrons up to an energy of 190 keV. The spectrometer is located in an 'iron free' hut at PSI and is in operation since spring 1996 without significant problems.

Electrons arriving at the focus of the spectrometer are detected by a large Si strip detector. The detector has a total area of 80×130 mm^2 and consists of four Si plates with 24 strips each. The strips function as (nearly) independent detectors and are read out by independent electronic channels. In that way we can take data with very high rates without dead-time or pile-up problems. The complete detector assembly and the electronics was described in last year's report. In the mean time we have replaced the original Si plates with new ones. These have less leakage current and thus produce less noise.

The source activity is supported by a very thin foil of Kapton with a typical thickness of 20μg/cm^2 as measured by α–spectroscopy. The foils have an area of 20×40 mm^2. To compensate for the source size, 1 mm wide strips of aluminum are evaporated onto the foils and suitable electric potentials are applied to the strips. In that way, it is possible to focus a 20 mm wide source on an about 2 mm wide band on the detector. We have tested this by accelerating photo electrons with a high voltage (up to 60 keV) with results as expected.

During measurements the source assembly is put on negative high voltage. To obtain a well-shaped electric field, there is a large ($10 \times 21 \times 22$ cm^3), box-like grid around the source. The grid was made with 17.5μm thick aluminum wire, with 1 mm pitch. Hence the transmission probability through the grid is better than 98%.

8.2 Source preparation

A source of ^{63}Ni was prepared in the following way. The activity was obtained as $NiCl_2$ in hydrochloric acid. The acid was evaporated at room temperature and then the $NiCl_2$ was dissolved in a solution of ammonia. This solution was brought into a tungsten boat and the Ni was electro-chemically reduced to the metal. The remaining solution was removed. Then the Ni was vacuum-evaporated onto a Kapton foil (see above) forming a metallic layer with a thickness of 80 Å. The activity of the source was measured with an ion chamber and found to be 0.5 mCi. The source was (chemically, etc.) very stable and did not cause any detectable contamination.

Our original plan for making a ^{35}S source was vacuum-evaporation of ^{35}S labeled methionin (an amino acid). This compound is commercially available with very high specific activity (about 1000 Ci per mMol) and should have given a very thin source (at the 1 Å level). Seemingly this method was used previously by an other group (Apalikov *et al.*, JEPT Lett. 42, 289, 1985). Also our own tests with non-active methionin showed that this compound can be evaporated at about 250° C without significant decomposition. Unfortunately it turned out that this is not true for the active material. It did not evaporate but decomposed to a brown residue. Presently we are investigating alternatives. One very simple method is to expose a thin layer of vacuum-evaporated copper to H_2S gas forming copper sulfide. We found that this is highly efficient. Starting with a few ppm of H_2S in air more than 50 % react with the copper within several hours. After one day no H_2S can be detected in the reaction vessel at the 0.1 to 0.2 ppm level. Suitable compounds for making active H_2S are commercially available with the required high specific activity. So this should be a practical method for making a ^{35}S source of good quality. We are considering other methods. One possibility could be ion implantation of ^{35}S. An ion implanter for radioactive isotopes exists at K. U. Leuven, Belgium, which we might use. However, no tests could be done so far.

8.3 Measurements

Figure 8.2: Measured β–spectrum of ^{63}Ni and a best fit. Inset shows ten data points around 45 keV with error bars still smaller than the points.

The measurements with the ^{63}Ni source have been performed during last year. The data were taken in the following way. The spectrometer current was set to a fixed value, corresponding to an analysing energy of 71.5 keV. A negative high voltage in the range 0 to 40 kV was applied on the source and varied in 50 V steps. The energy resolution was about 87 eV (FWHM, slightly energy dependent). With this method the recorded spectrum shape is independent of any energy dependent detection efficiency because electrons arriving at a certain detector position have constant energy. A histogram of the data is shown in figure 8.2. It is likely to be by far the most precise β–spectrum ever measured with this quality (resolution, source thickness, etc.). So far we see nothing unusual in the data. Because of the very high statistical precision many small effects have to be included in the analysis which is not yet completed.

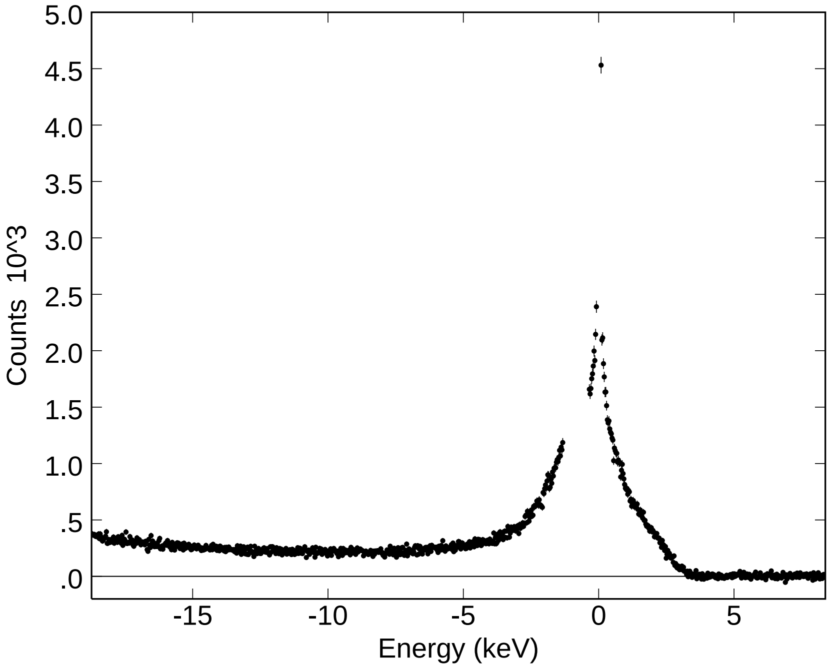

Figure 8.3: Measured energy distribution of electrons scattered in the spectrometer. See main text for explanations.

One effect important for the analysis is due to electrons which are scattered from baffles, current conductors etc. and detected. We have been careful in the design of the spectrometer to keep the scattering probability small but it could not completely be avoided and had to be measured. We have done this in the following way: A gold-plated sphere with 20 mm diameter was placed at the source position and illuminated by UV light. The sphere was put on negative high voltage (up to 60 kV) and the photo electrons were accelerated towards the grid (see figure 8.1). The method worked well simulating an almost monoenergetic source with an apparent diameter of about 2 mm. Measurements were performed in two mode: Stepping the accelerating voltage at fixed current and stepping the spectrometer current at fixed voltage. Figure 8.3 shows some data taken with the first mode. The central line of unscattered electrons at zero energy (effectively at 40 keV) is a delta–like spike containing 2×10^8 counts. It has been suppressed by a factor 10^4 to make the energy distribution of the scattered electrons visible. A small fraction, about 10^{-3}, of the accelerated electrons originated from the support bar of the sphere and were detected at -1.2 keV to -0.5 keV making the data in this range useless. These points have been removed from the plot. The remaining distribution can be characterized by a wide bump from -3.5 keV to +3.5 keV and a flat tail toward lower energies. The width of the bump corresponds to the size of the detector when scaled with the spectrometer dispersion. Above the bump no scattered electrons were detected. The integrated intensity of the distribution is 1.3×10^{-3} relative to the line of unscattered electrons. This is about as small as we could hope. We intend to make a Monte Carlo simulation in order to better understand the shape of the distribution.

In conclusion, the measurements with ^{63}Ni have been completed. The measurements with ^{35}S will be started as soon as we have a suitable source.