

The DCBA experiment for studying neutrinoless double beta-decay

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Abstract. In order to search for neutrinoless double beta-decay, the DCBA (Drift Chamber Beta-ray Analyzer) experiment uses a momentum analyzer, which mainly consists of drift chamber and a uniform magnetic field. A beta ray from a source plate make helical trajectory in the drift chamber owing to the magnetic field. Momentum of each beta ray is obtained by three-dimensional track reconstruction. A test prototype called DCBA-T2 has been constructed and operated at KEK. Another prototype DCBA-T3 is also under construction to improve the energy resolution. The results of DCBA-T2 engineering run are described together with the status of DCBA-T3.

1. Introduction

Searching for neutrinoless double beta-decay ($0\nu\beta\beta$) is one of the most exciting issues of the present neutrino physics. The observation of $0\nu\beta\beta$ means the strong support of the so-called leptogenesis [1], which is the scenario of the advantage of matter over anti-matter in the early universe. In the leptogenesis, heavy Majorana neutrinos play important roles. According to the so-called seesaw mechanism, both heavy and light Majorana neutrinos must exist, and light Majorana neutrinos produce $0\nu\beta\beta$. If $0\nu\beta\beta$ events are accumulated, the half-life of decay nucleus is measurable, and then the absolute mass scale of light Majorana neutrino is obtained with the help of the calculation of nuclear matrix element.

In order to measure the momentum and kinetic energy of each beta-ray from double beta-decay, momentum analyzers called DCBA (Drift Chamber Beta-ray Analyzer) have been developed at KEK

[2][3]. DCBA is sensitive to only charged particles, thus gamma-rays are automatically eliminated. Electrons and positrons are easily separated because of the opposite directions of their curves in a uniform magnetic field. A background alpha particle is also easily distinguished because of its high momentum and its high pulse signals. The excellent particle identification ability and good spatial resolution of DCBA make it easy to find $0\nu\beta\beta$ events against many particle backgrounds. Only two-neutrino double beta-decay ($2\nu\beta\beta$) events will become backgrounds at the Q-value of decay nucleus. Therefore, the required energy resolution is as less than 5% at Q-value in order to search for $0\nu\beta\beta$ down to about 50 meV, which is predicted in the so-called inverted hierarchy mass spectrum model.

2. DCBA-T2

In order to study the spatial and energy resolutions and to seek operation problems, a test prototype called DCBA-T2 has been constructed and operated. Detection principle and the configuration of DCBA-T2 are described elsewhere [4][5].

2.1. Spatial and energy resolutions

Spatial resolution has been studied with the straight tracks using high-energy cosmic rays. Experimental results in X, Y and Z directions have been obtained as shown in figure 1, where σ_X stands for the resolution in X, which is obtained from the moving time information of drift electrons, taken by Flash Analogue-to-Digital Converter (FADC). Resolutions σ_Y and σ_Z are obtained from the information of anode and pickup wires, respectively. For the study of energy resolution, a point source of ^{207}Bi was installed in the middle point of source plate. The source of ^{207}Bi emitted internal conversion electrons (ICE's) of mainly 4 kinds of monochromatic energies. The obtained energy spectra of ICE's including backgrounds are shown in figure 2. One can see a clear peak with about 0.15 MeV (FWHM) around 1 MeV. This peak consists of 0.98 MeV and 1.05 MeV electrons and backgrounds. The electron of 0.98 MeV is the most intensive with the emission rate of 7% of disintegration, while 1.05 MeV electron has the rate of 2.4%. From figure 2, it seems that DCBA-T2 has the energy resolution of about 0.15 MeV (FWHM), which is in good agreement with simulation studies.

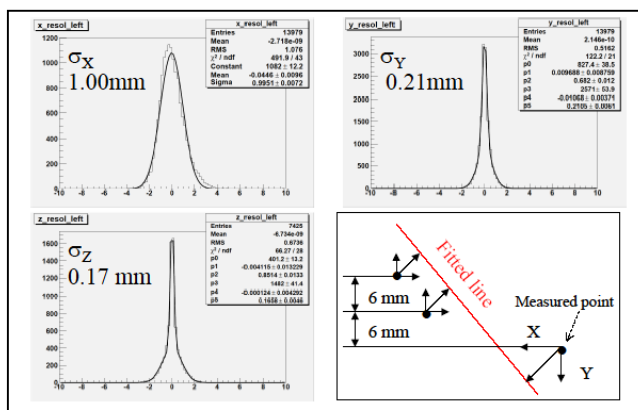


Figure 1. Spatial resolution of DCBA-T2.

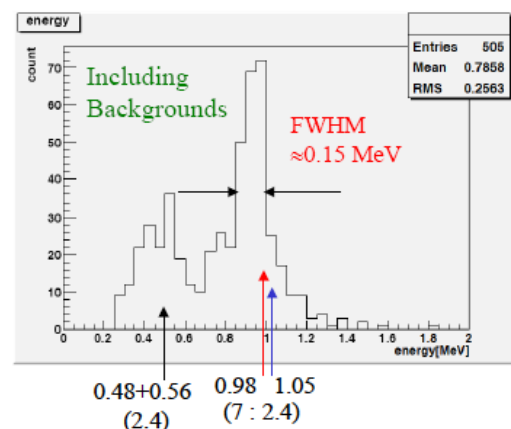


Figure 2. Energy spectra of ICE's from ^{207}Bi in DCBA-T2.

2.2. Half-life measurement of $2\nu\beta\beta$ for ^{100}Mo

Operation problems have been studied through the engineering run of half-life measurement using natural Mo thin plates, which includes ^{100}Mo with the abundance of 9.6%. Since the source area is 728 cm^2 and its thickness is 45 mg/cm^2 , the number of ^{100}Mo is 0.03 mol. An example of a $2\nu\beta\beta$ event candidate is as in figure 3. In the figure, upper part is X-Y projection plane and lower part is the X-Z plane. Decay vertex points are shown with LY (RY) and LZ (RZ) in X-Y and X-Z, respectively.

Though LY and RY look like different points in time-count space, they are actually the same point in the actual space. The absolute time count difference $245-239=6$ corresponds to 0.3 mm in the actual space, and it is within the spatial resolution in X direction. Of course, source plate is located at the vertex point. From the information in figure 3, three-dimensional reconstruction gives us the momentum and the pitch angle (λ) of each electron. And then we can calculate the kinetic energies of both electrons (T's) and the angular correlation ($\cos\theta$).

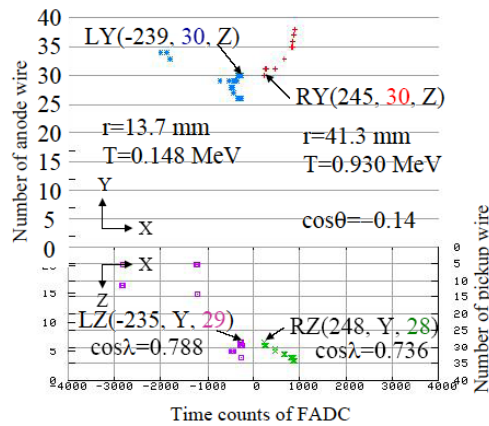


Figure 3. Example of a $2\nu\beta\beta$ event candidate from natural Mo plate.

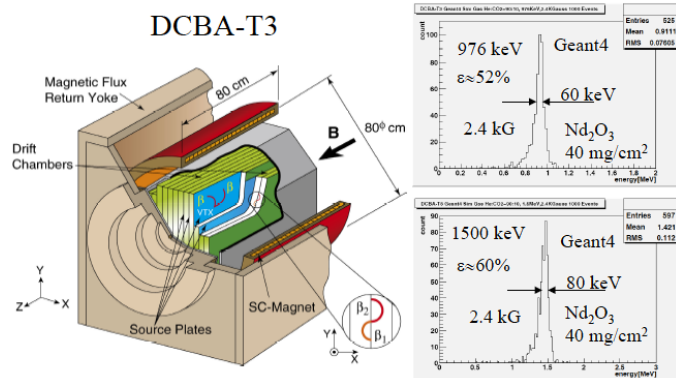


Figure 4. Illustration of DCBA-T3 and the energy resolutions simulated by Geant4.

3. DCBA-T3

The energy resolution obtained in DCBA-T2 is not enough to search for $0\nu\beta\beta$ down to about 50 meV. Since the energy resolution becomes worse due to the multiple scattering of beta ray in the chamber gas, it is useful to reduce the track length required in the momentum measurement. Figure 4 shows DCBA-T3, which is now under construction at KEK. It has 2 kG magnetic flux density, which is more than twice of that in T2: thus the track length produced in T3 is about half of T2. The sampling pitch is 3 mm for T3, being half of T2: thus the number of sampling points for one track in T3 is the almost same as T2. The energy resolutions obtained by simulation studies are better than those of T2 as shown in figure 4.

4. Conclusions

The background rejection ability of DCBA is excellent especially for gamma rays and alpha particles. According to the simulation studies, the energy resolution is also reasonable for investigating effective neutrino mass down to about 50 meV. DCBA-T3 is under construction at KEK in order to confirm the energy resolution. It will be able to measure the half-life of $2\nu\beta\beta$ for ^{150}Nd using natural Nd source in T3, while ^{100}Mo has been used in T2 for engineering run.

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