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A Search for Neutrinoless Double Beta Decay of ^{48}Ca*

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Abstract

A search for neutrinoless double beta decay of ^{48}Ca is being carried out in a coal mine near Beijing. Large scintillation crystals of natural CaF_2 are used as both the detector and the beta source. Results obtained after the first 1700 hours of data taking give 3.6×10^{21} years as the lower limit of the half-life of the neutrinoless double beta decay of ^{48}Ca. The experiment is still in progressing.

1. Introduction

The nuclear double beta decay without emission of neutrino has attracted

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since long time considerable attention as a test of the lepton number cons-ervation and a crucial experiment for the study of neutrino properties. Recently much interest on this problem has been re-aroused and there are several groups carrying out double beta decay experiments, the nuclei used in most of these experiments are ^{76}Ge, ^{82}Se, ^{100}Mo, ^{136}Xe, and ^{150}Nd.

^{48}Ca as a potential double beta decay nuclei, the decay energy released of $^{48}Ca \rightarrow {}^{48}Ti + 2e^-$ is 4.27 MeV, it is much higher than that of other potential double beta decay nuclei. The phase space is larger, it may compensate the disadvantage of smaller matrix element for ^{48}Ca, while the higher decay energy will help to avoid low energy background. Mateoslan and Goldhaber used ^{48}Ca enriched CaF_2(Eu) crystal as scintillator which contained 11.4g of ^{48}Ca in 1966, a lower limit of $2x10^{20}$ years for the half-life of neutrinoless double beta decay of ^{48}Ca was obtained [1]. The crystals were grown by the Harshaw Chemical Company, as to the energy resolution of the CaF_2(Eu) crystal, the Harshaw Chemical Company reported that no full energy photo-electron peak was observed for the 662 KeV γ-ray of ^{137}Cs[2].

Recently, in the course of studying the scintillation properties of several kinds of crystals, we found that the unactivated CaF_2 crystals grown by the Institute of Optics and Fine Mechanics have fairly good energy resolution, if quartz window photo-multiplier was used, full energy photo-electron peak of the 662 KeV γ-ray of ^{137}Cs was clearly seen with energy resolution about $7\%\cdot E^{-\frac{1}{2}}$(MeV) for small CaF_2 crystal[3]. It is evident to us that there is possibility to get a more lower limit of half-life for ^{48}Ca neutrinoless double beta decay by using large natural unactivated CaF_2 crystals as both the beta source and the detector. Obviously, there is the advantage of the equivalent of a "thin source" of large quantity of source nuclei. Though the energy resolution of CaF_2 crystal is much worse than that of Ge crystal, large volume can compensate somewhat this disadvantage.

A laboratory in a coal mine near Beijing has been set up, the height of rock above is 512 m, equivalernt to about 1300 m of water. We have started to collect data in the coal mine cave to measure the neutrinoless double beta decay of ^{48}Ca and have already run the experiment more than 1700 hours until now.

2. Detector

Two cylindrical CaF_2 crystals are stacked together. Each crystal has a cylindrical part of about 12.0 cm long and 17.8 cm in diameter and a conical part of 3.8 cm long and 10.0 cm in diameter at the smaller end. Total weight of two crystals is 19.9 kg which contains 22.0 g of ^{48}Ca. Each crystal is separately canned in an oxygen-free high conductivity copper can . Specially purified MgO powder (K<27 ppm, U<0.013 ppm) is used as the reflective layer between crystal and can. To reduce the adsorption of natural radioactive gas inside the can, we sealed the crystal in an atmosphere of pure argon. Photo-multiplier XP 2041Q with quartz window are used to collect the ultra-violet scintillation light while the natural radioactivity in glass is avoided. One photo-multiplier is coupled to each crystal.

The energy response of CaF_2 crystals had been calibrated with beta and gamma radioactive sources and electron beams of a microtron to 10MeV [4]. The CaF_2 crystals have identical linear energy response to both electron and γ-ray from 0.5 MeV to 10 MeV. For our large CaF_2 crystal. the energy resolution

$$R=18.7\%\ E^{-\frac{1}{2}}(\mathrm{MeV}),$$

and

R=9.1% at E=4.27 MeV.

Fig.1 is the schematic drawing of the detector assembly. The crystals are surrounded by plastic scintillator of NE110 as the anti-coincidence veto. Limited by the fund, we had to use the existing plastic scintillator in our laboratory, the thickness of scintillatior used for veto is 2.5 cm for the sides and bottom and 5.0 cm for the top, the efficiency for the detection of minimum ionization particle is 100%.

Steel plates of 2 cm thick and lead bricks of 8 ∿ 10 cm thick are used as the hard shielding material.

Fig. 2 is the schematic diagram of on-line data taking system, an IBM PC/XT computer is used and data are registered on disk. LED light source is used for the routine calibrations of the detector . Besides, the background spectrum with anti-coincidence veto off is recorded at regular interval, the ^{40}K peak is used also for calibration.

3. Experimental Results

Initial testing of the detector system had been carried out in the ground laboratory of the Institute of High Energy Physics, then the detector was moved into the coal mine cave.

Fig. 3 is the background spectra observed inside the cave. Spectrum (1) is without hard shielding and anti-coincidence veto, the ^{40}K and ^{208}Tl peak of natural radioactivity are prominent.

The counts per channel around 4.27 MeV for 1700 hours are shown in Fig. 4. No peak is present near 4.27 MeV. The total counts for 1700 hours within an energy interval 4.271±. 194 MeV are 52.

To evaluate the lower limit of half-life of ^{48}Ca neutrinoless double beta decay, we adopt the "sensitive formula" introduced by Fiorini [5],

$$T_{\frac{1}{2}} \geq A\left(\frac{MT}{\Delta E.B}\right)^{\frac{1}{2}} \text{ years,}$$

where A is a constant, $A=(0.76\times\ln 2\times 6.023\times 10^{23}\times a)/m\times 8760)$, a is the abundance of ^{48}Ca, m is the molecular weight of CaF_2, M is the effective mass of detector in gram; T is the total counting time in hours; ΔE is the FWHM energy resolution of detector in KeV; B is the counting rate in the energy region of interest in counts/hr/KeV/g, we have

$A=8.35\times 10^{14}$, $B=4.28\times 10^{-9}$ counts/hr/KeV/g, M=18,400g, ΔE=388 KeV, T=1700 hrs; then

$$T_{\frac{1}{2}} \geq 3.6\times 10^{21} \text{ years.}$$

The value of $T_{\frac{1}{2}}$ is the lower limit of half-life of ^{48}Ca neutrinoless double beta decay for which a real peak (assuming Gauss distribution) could be detected at 68% confidence level. Table 1 shows the results of ^{48}Ca neutrinoless double beta decay experiments. Our result is compatible to that of C.S. Wu in regards to the quantities of ^{48}Ca and the time of data taking.

Table 1

Authors	Goldhaber[1]	C.S. Wu[6]	We
quantity of ^{48}Ca	11.4g	10.6g	20.0g
hours of experiment data taking	689 hrs	1150 hrs	1700 hrs
detector	CaF_2(Eu)	streamer chamber	CaF_2
$T_{\frac{1}{2}}$	2×10^{20}y	2×10^{21}y	3.6×10^{21}y

This experiment is in progressing for more statistics. Two more same size CaF_2 crystals will be added and futher improvement on the lowering of bockground is in trying.

4. Acknowledge

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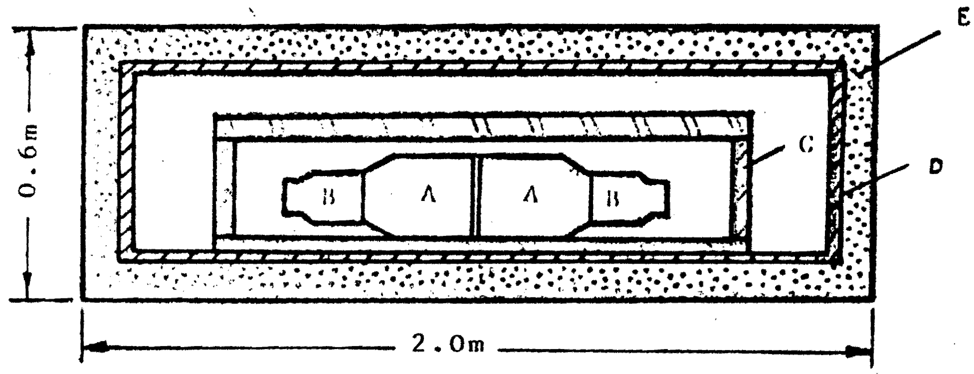

Fig.1 A:CaF2 crystal, B:XP2041Q PMT.
C:plastic scintillator, D:Fe shielding,
E:Pb shielding.

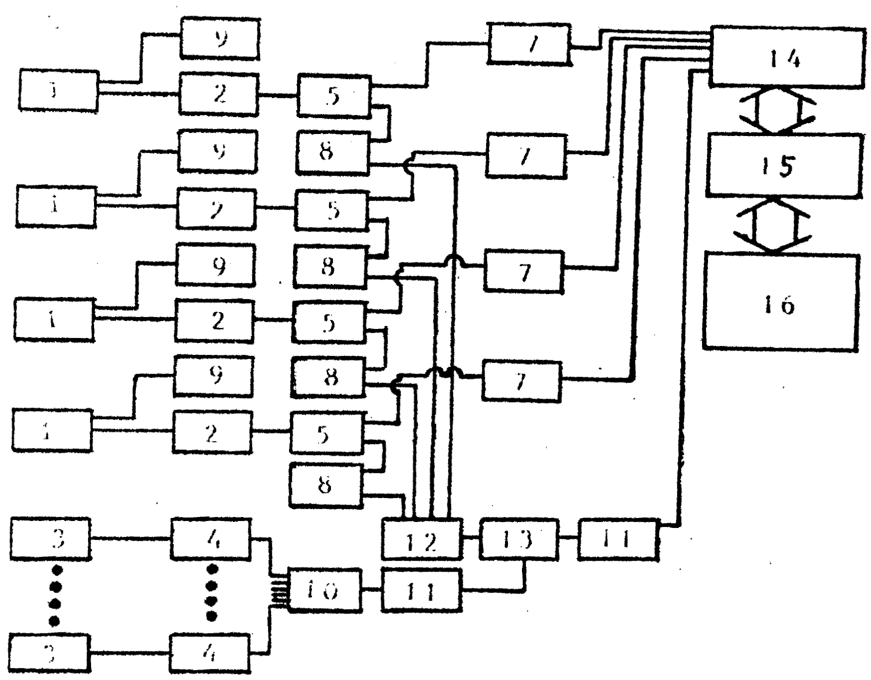

Fig.2 1:CaF_2 detector, 2:FET source follower,
3:plastic scintillator, 4:discriminator,
5:fan out, 7:amplifier, 8:Amp. discriminator,
9:-HV. 10:OR logic unit, 11:gate generator,
12: OR logic unit, 13:logic unit, 14:2259B ADC.
15:CCU-2-80 CAMAC controllor, 16:IBM PC/XT.

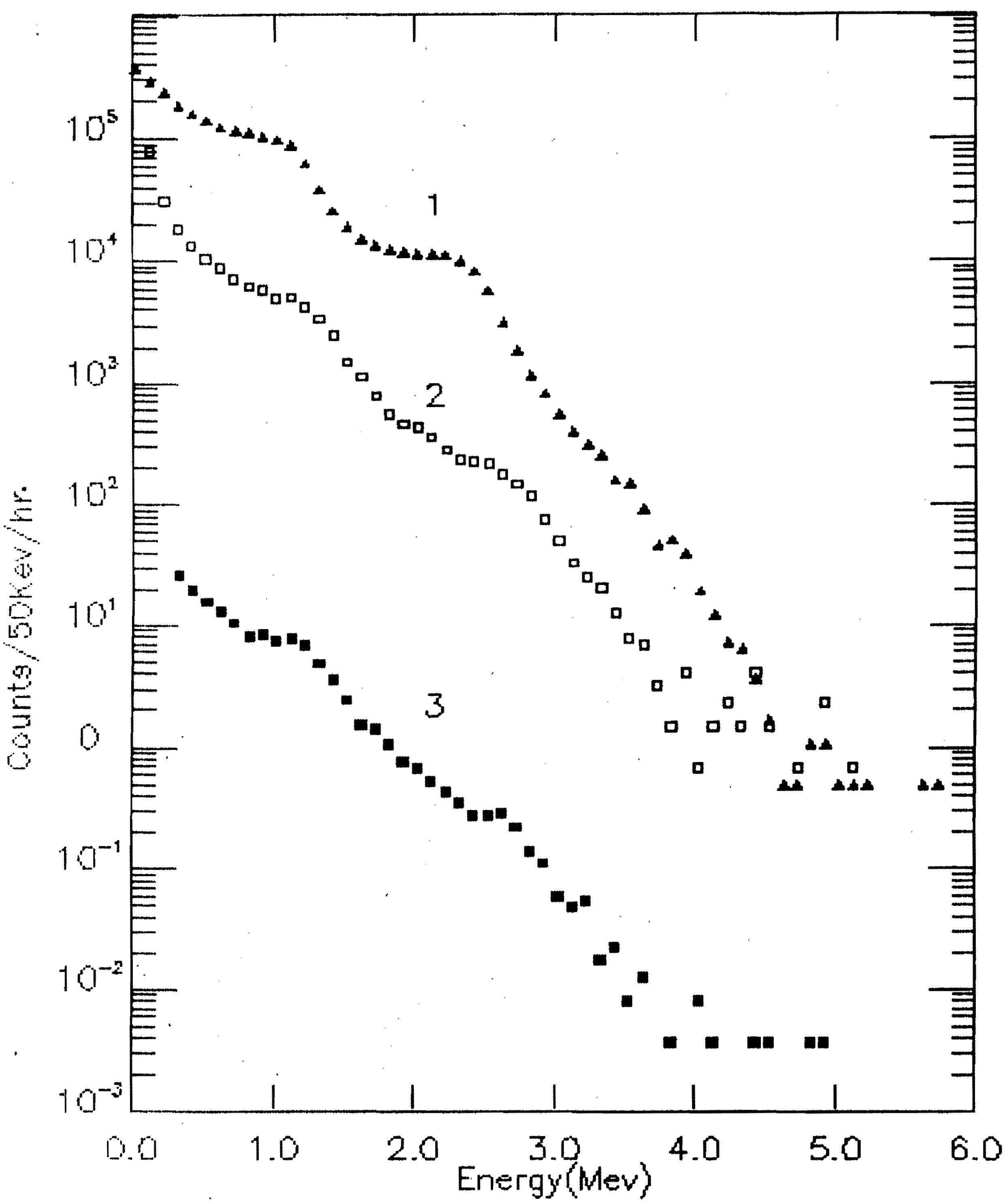

Fig3. The Energy Spectrum Underground

1. without hard shielding and anti-coincidence veto,
2. with hard shielding,
3. with hard shielding and anti-coincidence veto

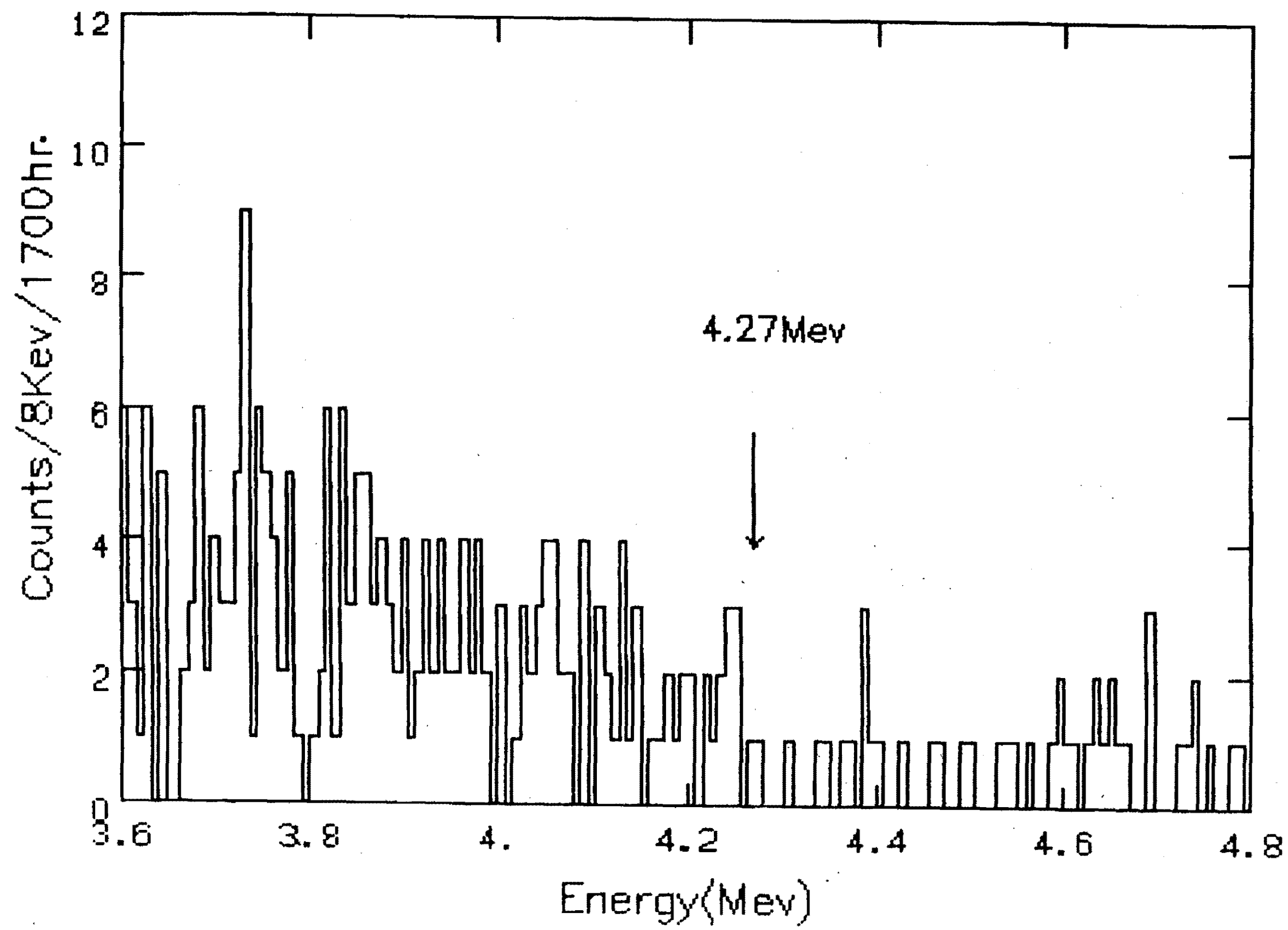

Fig4. The Energy Spectrum near 4.27Mev Underground