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Energy Calibration of CsI(Tl) Crystal for Quenching Factor Measurement in Dark Matter Search*

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Abstract It is important to measure the quenching factor of recoiled nuclei of detector for direct detection of WIMP. Energy calibration of CsI(Tl) crystal detector for measuring quenching factor of recoiled nuclei induced by incident neutron beam has been done with low-energy X-ray sources such as ^{109}Cd and ^{133}Ba and the linearity of energy response of experimental system is obtained. The equivalent energy deposited in CsI(Tl) crystal of a single photoelectron of PMT has been measured. The time of integration of current signals is optimized for different X-ray source energys.

Key words dark matter, CsI(Tl) crystal, single photoelectron, energy calibration

1 Introduction

There are more and more evidences for the presence of large quantities of dark matter surrounding normal galaxies, but the nature of it is still unknown[1]. So detection of dark matter has been an important challenge in the development of modern astrophysics, cosmology and particle physics. Among several candidates of dark matter, the most prominent one is weakly-interacting massive particle (WIMP). The direct detection of WIMPs is dependent on the measurement of the energy of recoiled nuclei scattering off by WIMPs, and usually this energy is up to tens of keV[1]. Scintillating crystal detector has been paid much more attention for experiments searching for dark matter. The TEXONO collaboration sponsored jointly by Institute of high energy physics of Chinese Academy of Science and Academia Sinica in Taiwan will use up to several hundred of kilograms of CsI (Tl) crystal to measure and research reactor neutrino, at the same time a feasible study of CsI (Tl) crystal for WIMP search has been proposed[2]. Due to the presence of quenching mechanism of recoiled nuclei in the crystal, the measured energy for recoiled nuclei is lower than energy for gamma ray of the same kinetic energy (the quenching factor is the ratio of those two values of energy). One experiment is to measure the quenching factor of energy of recoiled nuclei scattering off elastically by incident neutron beam[3]. Energy calibration has been done for this neutron beam experiment, and linearity of energy response, the equivalent energy of single photoelectron have been obtained.

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2 Energy Calibration of CsI (Tl) Crystal Detector

The energy calibration from 0 to 100keV has been done for measuring the quenching factor of recoiling nuclei induced by incident neutron beam. We use source ^{109}Cd (22.1keV) and source ^{133}Ba (30.9keV and 81.0keV) to calibrate the measurement system.

2.1 Experimental Setup

Fig.1(a) shows the block diagram of the experimental setup. We use a ϕ3cm × 3cm cylindrical CsI (Tl) crystal (product of Beijing Sensor Company) with all surface wrapped with Teflon and Al foil except for one end. This unwrapped end is polished and coupled to PMT (Beijing Hamamtsu CR110) with silicon grease directly and the cathode window of PMT covers all area of this crystal surface.

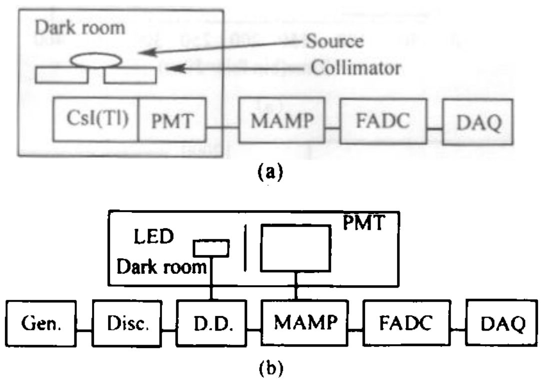


Fig.1.(a) Block diagram of energy calibration setup
(b) Block diagram of single photoelectron experiment

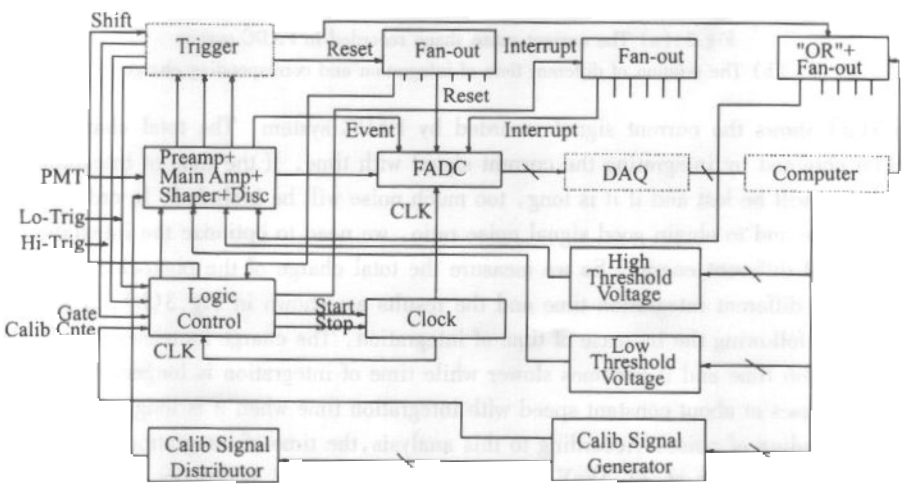
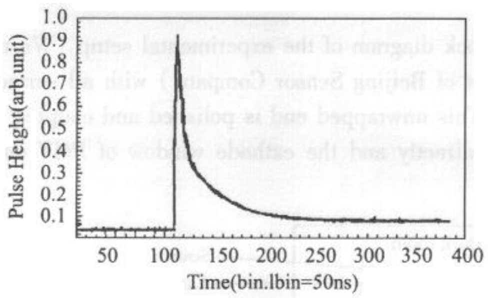


Fig.2. Schematic diagram of electronics system

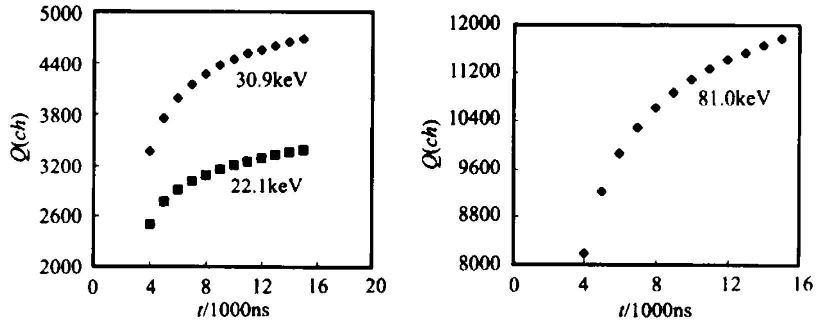
The voltage supplied to PMT is 1080V. The photons in CsI (Tl) crystal induced by incident X-ray are detected and converted into signals of current by PMT. The PMT signals pass through the main amplifier module (MAMP) for amplifying and shaping. Then the signals are continuously digitized by FADC module and recorded in buffers of FADC before being transferred into DAQ system. The block diagram of the electronics system[4] is shown in Fig. 2. Different energy of X-ray (22.1keV, 30.9keV and 81.0keV) have been used to calibrate the CsI(Tl) detector system.

2.2 Experimental Procedure and Data Analysis

We measure the different energy spectra of ^{109}Cd and ^{133}Ba sources and record the experimental data for offline analysis.



(a)



(b)

Fig.3. (a) The current pulse shape recorded in FADC system
(b) The relation of different time of integration and corresponding charge

Fig.3(a) shows the current signal recorded by FADC system. The total charge of output of PMT can be obtained by integrating the current signal with time. If the time of integration is short, a part of charge will be lost and if it is long, too much noise will be included. In order to reduce the influence of noise and to obtain good signal noise ratio, we need to optimize the integration times for current signals of different energy. So we measure the total charge of the photoelectron peak of different energy for different integration time and the results are shown in Fig.3(b). It shows that the charge increases following the increase of time of integration. The charge increases very fast at region of small integration time and it becomes slower while time of integration is longer. We can find that the charge increases at about constant speed with integration time when it is long enough, and this is evidence of including of noise. According to this analysis, the time of integration that we adopted to analyze the current signals of 22.1keV, 30.9keV and 81.0keV of energy of X-ray is 8000ns, 9000ns and 12000ns respectively.

The spectra of charge of different energy are shown in Figs.4(a), (b) and (c). We can find a peak of 22.1keV from the spectrum of ^{109}Cd clearly. There are 2 clear peaks of 30.9keV, 81.0keV and multi-peaks of about 350keV in the spectrum of ^{133}Ba. We only use first two peaks for the calibration. The energy and corresponding peak of charge are shown in Table 1, and the FWHMs of different photoelectron peaks are also given in this table.

Table 1. The charge of photoelectron peak and resolution of corresponding peak of charge

Energy/keV	22.1	30.9	81.0
Q(ch)	3104 ± 5.985	4367 ± 7.512	11430 ± 18.45
FWHM	452.9 ± 7.109	558.0 ± 8.100	693.0 ± 24.91

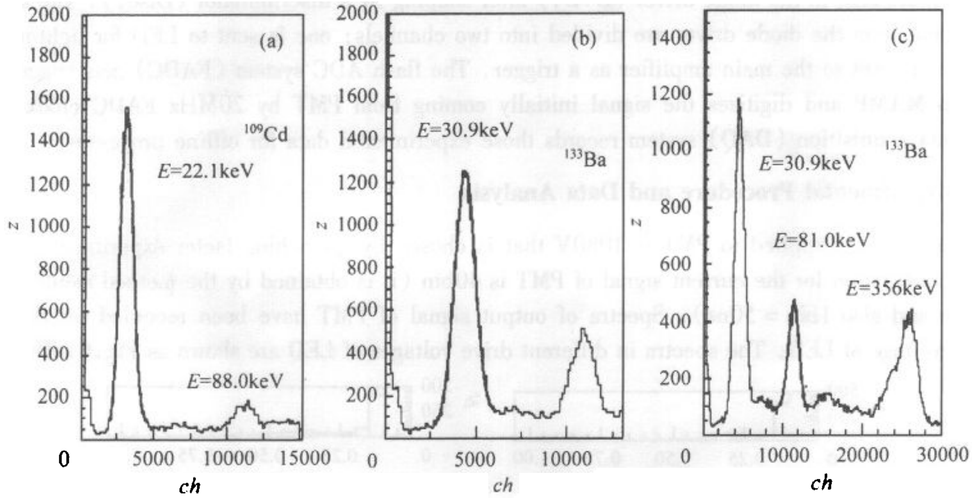


Fig.4. The spectra of charge of different energy of ^{109}Cd and ^{133}Ba sources

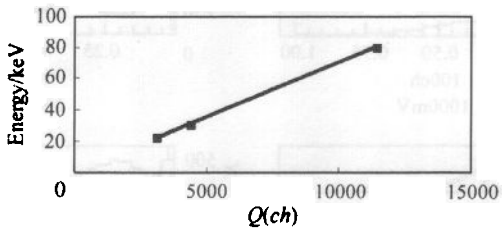


Fig.5. The linearity of energy response of CsI(Tl) detector system

The results are fitted and we get the equation of energy response between incident energy and charge of output of PMT and it is drawn in Fig.5. The equation is

$$y(\text{keV}) = 0.0071x(\text{ch}) + 0.0559,$$

where x is the position of photoelectron peak in FADC channel and y is the energy corresponding to the channel in keV.

It will provide the parameters of energy calibration for quenching factor experiment.

3 Single Photoelectron Measurement

3.1 Experimental Setup

A PMT can be treated as an instrument consisting of two independent parts: the first one is a photon detector that can convert photons into electrons and the second part is an amplifier that amplifies the initial charge emitted by photocathode of PMT[5]. So the photoelectron emitting is independent on the voltage supplied to the PMT, and it is just a property of photocathode of PMT. The experimental setup is shown as Fig.1(b).

The light-emitting diode (LED) used in this experiment is a kind of high-frequency and low-intensity LED. Several Teflon wrapping layers have been set to reduce the numbers of photon arriving to photocathode of PMT from LED. The signals generated by the pulse signal generator (Gen., 1000Hz) are sent to the diode driver (D.D.) after shaping by a discriminator (Disc.). The signals coming out from the diode driver are divided into two channels: one is sent to LED for lighting and the other is sent to the main amplifier as a trigger. The flash ADC system (FADC) gets trigger signal from MAMP and digitizes the signal initially coming from PMT by 20MHz FADC clock rate. Then data acquisition (DAQ) system records those experimental data for offline processing.

3.2 Experimental Procedure and Data Analysis

The voltage supplied to PMT is 1080V that is chosen by quenching factor experiment and the time of integration for the current signal of PMT is 40bin (it is obtained by the method mentioned at part two and also 1bin = 50ns). Spectra of output signal of PMT have been recorded for different driving voltage of LED. The spectra in different drive voltages of LED are shown as Fig.6. The volt-

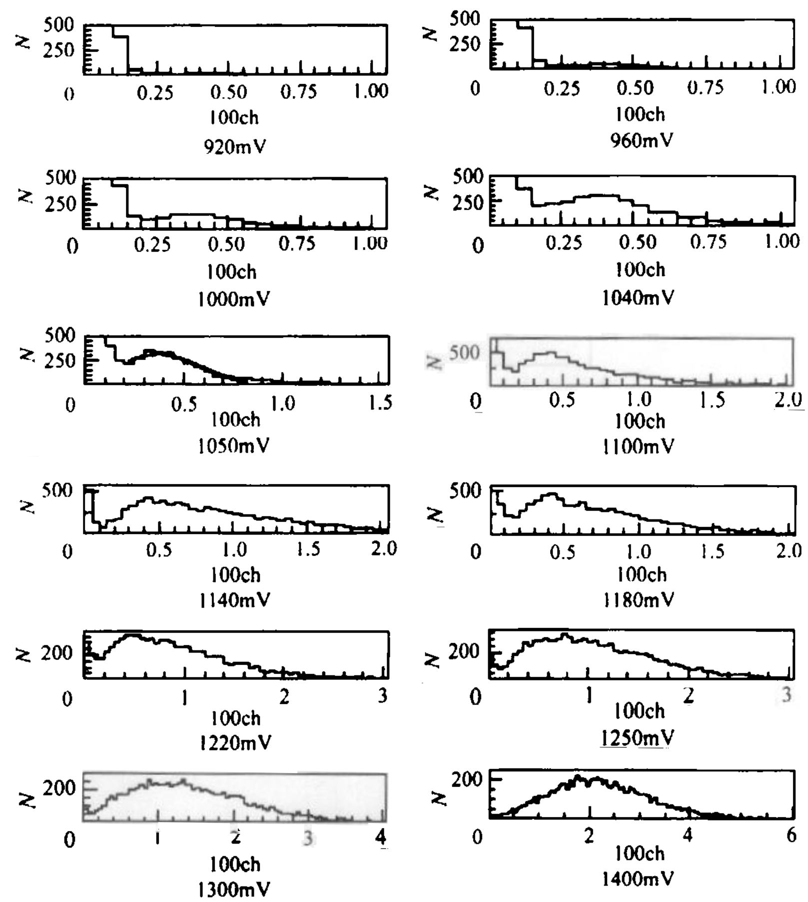


Fig.6. PMT signal spectra of different driving voltages of LED

age of LED is changed from 920mV to 1400mV. The spectra show that there are large quantities of noises and just a small part of signals when the voltages are 920mV, 960mV and 1000mV respectively. This is because lights emitted by LED seldom arrive at the surface of photocathode of PMT to induce electron-emitting. Following the increase of voltage, number of photons hitting to photocathode of PMT increases and the possibility of electron-emitting from the photocathode of PMT increases too, so a peak at about 37th channel has been observed gradually. The fact that the positions of the corresponding peaks do not change in wide range of voltage of LED shows those peaks are related to emitting of one photoelectron from PMT. The second peak can be seen on those spectra from 1100mV on and this is due to the emitting of two photoelectrons from photocathode of PMT. The second peak is about at 75th channel. At last, the lighting of LED are strong enough to make PMT emit multi-photoelectron and it cannot discriminate the different peaks as show in the spectra of 1260mV、1300mV and 1400mV. So we fit the spectrum which voltage is 1060mV (as shown in Fig. 6) and get the position of photoelectron peak at 37.0 ± 1.0ch. This is the position of photoelectron corresponding to single photoelectron emitting of PMT[6].

According to the linearity of energy response of the experimental system shown in Fig. 5, we can obtain the equivalent energy of single photoelectron emitting of PMT is 0.32keV.

4 Summary

The time of integration of current signal from PMT in those experiments has been studied and the time of integration is optimized for different energies. We also obtain the linearity of energy response of experimental system measuring quenching factor. The equivalent energy deposited in CsI (Tl) crystal of a single photoelectron of PMT is about 0.32keV. The parameters of energy calibration have been achieved for experimental system of measuring quenching factor of recoiled nuclei.

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用于暗物质探测实验的CsI(Tl)晶体探测器性能的实验研究*

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摘要 在直接测量暗物质的实验中,反冲核能量的Quenching Factor是一个重要参数.用低能X射线源对一套测量入射中子引起的反冲核能量Quenching Factor的系统进行了能量刻度,得到了这套系统的能量响应关系.PMT单光电子的发射对应于晶体中的能量沉积约为0.32keV.同时研究了不同能量的X射线引起的PMT输出电流信号的积分时间宽度与积分电荷的关系,得到最佳的PMT输出电荷收集条件.

关键词 暗物质 CsI(Tl)晶体 单光电子 能量刻度

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