第 28 卷 第 2 期
2004年2月

高 能 物 理 与 核 物 理
HIGH ENERGY PHYSICS AND NUCLEAR PHYSICS

Vol.28, No.2
Feb., 2004

Energy Reconstruction for Long Column CsI(Tl) Crystal Detector

LIU Da-Zhi[1;1)] LI Yuan-Jing[1] LI Jin[1,2;2)] YUE Qian[2]
Wong Henry Tsz-King[3] Chang Wen-Chen[3] Venktesh Singh[3]
1(Department of Engineering Physics, Tsinghua University, Beijing, 100084, China)
2(Institute of High Energy Physics, CAS, Beijing, 100039, China)
3(Institute of Physics, AS, Taipei, 11529)

Abstract Two methods of energy reconstruction for long column CsI(Tl) crystal detector in the TEXONO experiment, using concepts of "arithmetic mean" and "geometric mean", have been developed. Both the principle of two methods and data analysis are discussed.

Key words CsI(Tl) crystal, energy reconstruction, arithmetic mean, geometric mean

1 Introduction

TEXONO (Taiwan EXperiment On Neutrino) is an experiment which aims to study neutrino properties using reactor neutrino[1]. The array of CsI(Tl) crystal detectors is used in the experiment[2]. Each detector is a 40cm long column of CsI(Tl) crystal and coupled with two PMTs (PhotoMultiplier Tubes) at two ends. It is important to reconstruct the energy of the particle entering the detector using the outputs of the two PMTs. This paper discusses the energy reconstruction for one detector module. The methods we developed are also applicable in any energy reconstruction for long column detectors read out by PMTs at two ends.

2 Experiment

An array of CsI(Tl) crystal detectors, which has 11 layers and 8 or 9 detectors for each layer, is used in the experiment of TEXONO (Fig.1(a)). The CsI(Tl) crystal detector is made in Beijing Sensor Crystal Materials Co., Ltd. The length of each detector is 40 cm and its cross section is a hexagon with 2cm of each side. Each end of the detector is coupled with a PMT CR110 (made in Beijing Hamamatsu Photon Technology Co., Ltd).

A 20 MHz sampling rate FADC (Flash ADC)[3] is used to covert the electric current signal of PMT to digital signals for an entering particle. In the following discussions, we will process the data of the pulse shape and get the total charge of signal for one particle, and use this information to reconstruct the energy and the position of the particle in the detector.

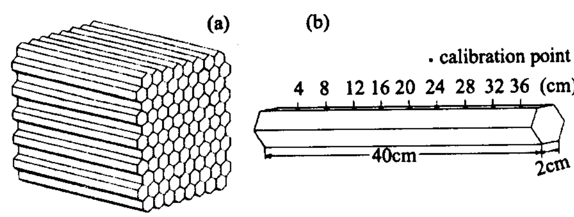

Fig.1. (a) detector array; (b) one detector.

The calibration has been performed before deta taking. The purpose of calibration is to obtain the energy response in different position for each detector. Total 9 different position points are selected along the length direction of a crystal. The interval between two points is 4cm (Fig.1(b)). The full energy peak of 662 KeV of γ ray source ^{137}Cs is used for calibration at each point. During

Received 9 May 2003, Revised 2 September 2003
1) Email: liudazhi@mail.tsinghua.org.cn
2) Email: lij@mail.ihep.ac.cn

data taking on site near the reactor core, the conditions are kept as the calibration's.

3 Method A: arithmetic mean energy reconstruction method

3.1 The relation between Q and the energy

The two PMTs provide the current pulse shape signals when γ rays hit the crystal. We can get the charges Q_{raw1} and Q_{raw2} gathered from each PMT by integrating the pulse shapes. Since the gains of PMTs and the electronics systems may not be equal, the normalization parameters N_1 and N_2, as discussed in details in Section 3.3, are used to normalize Q_{raw1} and Q_{raw2} to produce:

$$Q_1 = Q_{raw1}/N_1, Q_2 = Q_{raw2}/N_2. \quad (1)$$

We define:

$$Q_{total} = Q_1 + Q_2. \quad (2)$$

Q_{total} can be deemed as the energy response. But the Q_{total} for same energy will be different because of the difference of hit position along the length direction. Fig.2 shows the relation between the charges Q_{total} and the entering positions Z for same energy of γ ray ($E = 662$keV, selected from the full energy peak of ^{137}Cs). The curve of this relation can be fitted using quadratic function with parameters a_0, a_1, a_2:

$$Q_{t662}(Z) = a_0 + a_1 Z + a_2 Z^2. \quad (3)$$

For an arbitrary energy E_m, Q_{total} is in proportional to

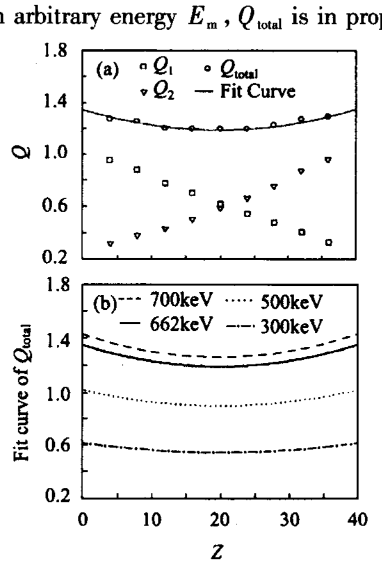

Fig.2. (a) relation between Q_1, Q_2, Q_{total} and Z; (b) the family of the quadratic curves for different energy.

E_m at the position Z_0:

$$E_m(Z_0) = 662 \frac{Q_{total}(Z_0)}{Q_{t662}(Z_0)} \text{keV}. \quad (4)$$

$Q_{t662}(Z_0)$ can be obtained from the calibration curve (made with ^{137}Cs) at the position Z_0. The curves of this relation between Q_{total} and Z for different energy particles are similar (shown in Fig.2). Therefore, the energy of a particle can be determined by the formulas (3) and (4) based on the parameters a_0, a_1, a_2 when the position of the particle in the detector is known.

3.2 The relation between Q and Z

In order to know the entering position Z of the particle from Q_1 and Q_2 we define:

$$R = \frac{Q_1 - Q_2}{Q_1 + Q_2}. \quad (5)$$

The relation between Z and R we have measured in the calibration test is shown in Fig.3. The function and the parameters b_0, b_1 can be obtained by fitting those points linearly:

$$Z = b_0 + b_1 R. \quad (6)$$

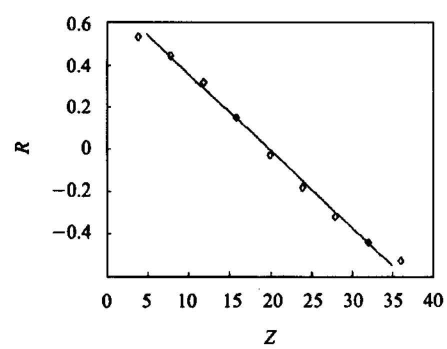

Fig.3. relation between R and Z.

Thus, the position of the particle can be determined from Q_1 and Q_2 by the formulas (5) and (6).

3.3 Normalization parameter N

For a crystal of 40cm long, the output of PMT at left end Q^L_{raw} (at the position of 4cm) and the output of PMT at right end Q^R_{raw} (at the position of 36cm) should be same if the gain of two PMTs and electronic are same (ignoring the effect of local defect and non-uniform of impurity of the crystal). The difference between Q^L_{raw} and Q^R_{raw} is mainly because of the difference of gains of two PMTs and electronic in two ends. So, Q^L_{raw} and Q^R_{raw} are selected to be the normalization parameter N_1 and N_2:

$$Q_{\mathrm{raw}}^{\mathrm{L}} = N_1$$

$$Q_{\mathrm{raw}}^{\mathrm{R}} = N_2$$

3.4 Energy reconstruction

Based on Q_1 and Q_2 we can measure the position Z by formulas (5) and (6) with the parameters b_0 and b_1 which was obtained in the calibration. Then we can obtain the energy by the formulas (3) and (4) with the parameters N_1, N_2, a_0, a_1, and a_2.

It should be noted that the parameters N_1, N_2, a_0, a_1, a_2, b_0 and b_1 are not only depend on individual crystal but also the measurement conditions (such as the high voltage of the PMT or the gain of the amplifier). If the conditions are different from those of calibrations, these parameters should be recalibrated.

4 Method B: geometric mean energy reconstruction method

The physics meaning of Q_1 and Q_2 are same as that in method A. We define:

$$Q_g = \sqrt{Q_1 Q_2}. \tag{7}$$

Q_g is a response of an energy. Fig.4 shows the relation between Q_g and Z. It can be observed in this figure that Q_g is almost a constant for different Z. According to formula (1), we can find Q_g still remains constant even if the Q_1 and Q_2 in formula (7) are replaced by Q_{raw1} and Q_{raw2}.

Therefore, using Q_g we can get the energy of entering particle without knowing hit position:

$$E_{\mathrm{m}} = 662\,\frac{Q_g}{Q_{g662}}\,\mathrm{keV}. \tag{8}$$

Q_{g662} is the calibration value of ^{137}Cs.

This reconstruction method is called geometric mean reconstruction method, because the geometric mean of Q_1 and Q_2 are used as the response of an energy in this method. Correspondingly, the method A, which is mentioned above, is called arithmetic mean reconstruction method because the sum of Q_1 and Q_2 or arithmetic mean of the sum is used in this method.

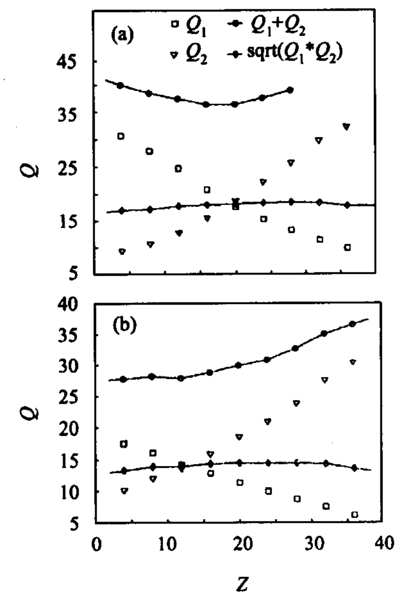

Fig.4. comparison of the two methods.

Without normalization of Q, (a) is from a detector which has good symmetry of the both sides PMTs and (b) is from a bad symmetry one. (a) Q_{total} approximates a quadratic curve and Q_g approximates a line. (b) Q_{total} does not approximate a quadratic curve and must normalize them before fitted. But Q_g still approximates a line. From the theoretic discussion (refers to 5.1 for the detail) we can draw a conclusion that Q_g is not affected by the normalization.

5 Comparison of the two methods

5.1 The principles of the two methods

For a long column shaped crystal detector with a length of $2S$, when a particle enters the crystal at the position Z (shown in Fig.5), the light intensities reaching

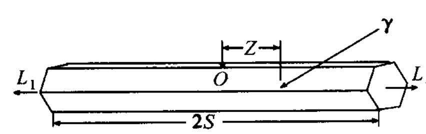

Fig.5. illustration of the principle of two methods.

the PMTs of each end are[4]:

$$L_1 = L_0 \mathrm{e}^{\frac{-(S+Z)}{l}}, \quad L_2 = L_0 \mathrm{e}^{\frac{-(S-Z)}{l}}. \tag{9}$$

l is the attenuation length of the crystal, L_0 is the original light intensity at position Z. According to the formula (9), we can get:

$$L_1 L_2 = L_0^2 \mathrm{e}^{\frac{-2S}{l}}. \tag{10}$$

and

$$L_g = \sqrt{L_1 L_2} = L_0 e^{\frac{-S}{l}}. \quad (11)$$

This means that the square root of the product of the light intensities at two ends is a constant independent of the position Z and proportional to the intensity of input light[5]. This is the principle of the method B.

Formula (9) is expanded as:

$$L_1 = L_0\left(1 - \frac{S+Z}{l} + \left(\frac{S+Z}{l}\right)^2 \frac{1}{2!} - \left(\frac{S+Z}{l}\right)^3 \frac{1}{3!} + \cdots\right), \quad (12)$$

$$L_2 = L_0\left(1 - \frac{S-Z}{l} + \left(\frac{S-Z}{l}\right)^2 \frac{1}{2!} - \left(\frac{S-Z}{l}\right)^3 \frac{1}{3!} + \cdots\right). \quad (13)$$

Adding up the formulas (12) and (13), we get the result without odd power of $\frac{Z}{l}$:

$$L_1 + L_2 = a_0 + a_2\left(\frac{Z}{l}\right)^2 + O\left(\left(\frac{Z}{l}\right)^4\right). \quad (14)$$

From Fig.2 and Fig.4, we can find that $l \approx 30$cm, while Z is less than 20cm (the half length of the crystal) and is often in the range of (-10cm, 10cm) in the experiment, because we are interested in the center event of the crystal. So ignoring the items of 4^{th} or higher power of $\frac{Z}{l}$ cannot bring a large error to the analysis. Then the approximate fit function curve as formula (3) can be obtained with parameters a_0, and a_2. This is the principle of the method A. The absence of the $\frac{Z}{l}$ term in formula (14) is due to the difference in the definitions of origin in the two formulas.

5.2 Energy reconstruction using the two methods

For the purpose of detecting neutrino, the detector array is well shielded to protect it from the background interference of neutron, γ and cosmic rays. Almost all of events obtained are the background from inside of detector (Crystal and PMT). The background spectrum is shown in Fig.6.

The peak in fig.6 clearly is a full energy peak of 662keV because of the radioactive impurity of ^{137}Cs in CsI (Tl) crystal. Fig.6(a) shows the scatter plot of Q_1 and Q_2. Fig.6(b) shows the reconstructed energy spectrum by the method A and the resolution of the 662keV peak is 12.7%. Fig.6(c) shows the reconstructed energy spectrum by the method B and the resolution of the 662keV peak is 12.0%. It seems that there is no much difference in the aspect of the resolution for the two methods.

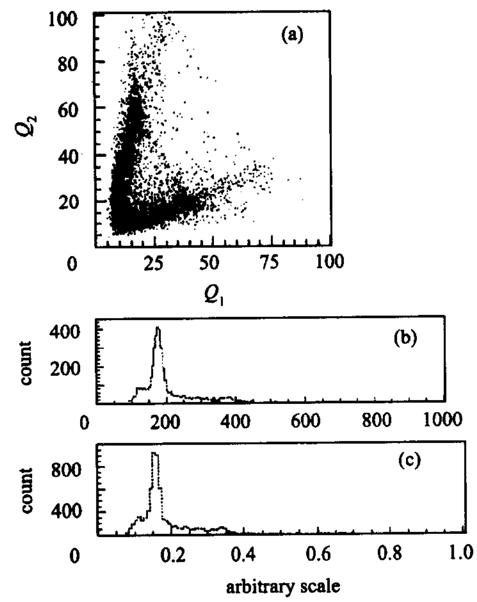

Fig.6. a background spectrum.
(a) scatter plot of Q_1 and Q_2; (b) reconstruction spectrum by method A; (c) reconstruction spectrum by method B There is a full energy peak of 662keV in the spectrum. That results from the self radioactivity of the detector. There is no more different of resolution between (b) and (c).

5.3 The advantages of arithmetic mean reconstruction method (method A)

Except the difference of the gain of PMTs and electronics systems of both sides, there are many other factors influencing output of the both sides, such as the local defect of the crystal or non-uniform impurity. The method A can correct the error made by these factors.

The method A can calculate the position of the entering particle. The position is important to do the discrimination of the background and the events.

5.4 The advantages of the geometric mean reconstruction method (method B)

From the view of the theoretical analysis, the method B is closer to the physical model than the method A.

In practice, although the effect of reconstruction are similar, the method B is much simpler in calculation and has no additional parameters such as N_1, N_2, a_0, a_1, a_2, b_0 and b_1. The high voltage of the PMT or the gain of the amplifier has no effect very much on the method B.

In general, the crystals used in a normal experiment have no local defects and have good uniformity. In TEXONO group, we used the selected crystal with high quality and non-uniform impurity. So the method B is suitable to do the energy reconstruction.

6 Conclusion

In this paper, we have discussed two methods of the particles energy reconstruction for long column shaped CsI(Tl) crystal detector which read out by two PMTs at two ends. The two methods have different application conditions. When we do the energy reconstruction, a proper method should be chosen according to the condition.

In TEXONO experiment, the crystals we selected have no local defect and non-uniform impurity, so the geometric mean reconstruction method is suitable to do the energy reconstruction.

References

1 Wong H T, LI J. Mod. Phys. Lett., 2000, **A15**:2011;
LI J et al. High Energy Physics and Nuclear Physics, 2002, **26**:393 (in Chinese)
(李金等. 高能物理与核物理,2002,**26**:393)

2 LI H B et al. Nucl. Instrum. Methods, 2001, **A459**:93;
LIU Y et al. Nucl. Instrum. Methods, 2002, **A482**:125;
LIU Yan, LI Jin et al. Nuclear Techniques, 2001, **24**:497—502 (in Chinese)
(刘延,李金等. 核技术,2001,**24**:497—502)

3 LAI W P et al. Nucl. Instrum. Methods, 2001, **A465**:550

4 Leo W R. Techniques for Nuclear and Particle Physics Experiments. Second Revised Edition. Springer-Verlag, 1994

5 WU Zhi-Hua et al. Nuclear Physics Experimental Methods. Third edition. Beijing: Atomic Energy Press, 1997 (in Chinese)
(吴治华等. 核物理实验方法. 第三版. 北京:原子能出版社, 1997)

长柱形CsI(Tl)闪烁晶体探测器的能量重建

刘大治[1;1)] 李元景[1] 李金[1,2;2)] 岳骞[2] 王子敬[3]
章文箴[3] Venktesh Singh[3]

1(清华大学工程物理系 北京 100084)
2(中国科学院高能物理研究所 北京 100039)
3(中研院物理研究所 台北 11529)

摘要 提出了用于TEXONO实验中双端读出的长柱形CsI(Tl)闪烁晶体探测器的两种粒子能量重建方法——“算术平均值能量重建法”和“几何平均值能量重建法”,讨论了两种算法的理论依据和计算方法,并对两种算法进行了比较.

关键词 CsI(Tl)晶体 能量重建 算术平均值 几何平均值

2003-05-09收稿,2003-09-02收修改稿

1) Email: liudazhi@mail.tsinghua.org.cn
2) Email: lij@mail.ihep.ac.cn