Gas Cherenkov Detector Calibration Correction for Small Angle GDH Experiment in Hall-A *

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Abstract Due to the change of the hardware and high voltage during the small angle GDH experiment datatakeing, the CO_2 gas threshold Cherenkov detector on HRS at Hall-A in Jefferson Jlab(JLab) was calibrated for seven times. The ADC signals of the single photo-electron peak for all ten PMTs were scaled to two hundred. The electrons could be separated from π by the detector after the calibration correction.

Key words calibration, gas Cherenkov detector, single photo-electron peak

1 Introduction

A threshold Cherenkov detector is based on the Cherenkov effect[1, 2], which refers to that when a high energy charged particle travels through transparent materials with a velocity v higher than the velocity of light in the material c/n, a characteristic electromagnetic radiation is emitted. Here c is the speed of light in vacuum and n is the refractive index of the material. The Cherenkov light is emitted because the charged particle polarizes the atoms along its track so that they become electric dipoles. The dipoles are symmetrically arranged around the particle's path as long as $v < c/n$, so that the dipole field integrated over all dipoles vanishes and no radiation results. If, however, $v > c/n$, the symmetry is broken resulting in a non-vanishing dipole moment, which leads to the emission of radiation. By detecting whether a given particle emits Cherenkov light, one can know if its velocity is larger than the threshold velocity depending on the material used.

The standard Hall-A detector configuration included two high resolution spectrometers(HRS) in JLab[3]. The spectrometers were initially equipped for the $(\mathrm{ep} \rightarrow \mathrm{e'p})$ reaction. Hence they were known as 'hadron' and 'electron' arms. For the small angle GDH experiment (E97-110)[4], only the electron arm HRS was set and configured for electron detection. As such we will refer the HRS as electron arm HRS.

The separation of electrons from the background particles for the HRS was accomplished by a threshold gas Cherenkov detector and a calorimeter counter. The threshold gas Cherenkov detector for the GDH experiment was filled with CO_2 at atmospheric pressure whose refraction index is 1.00041. The threshold speed and momentum were

$$v = \frac{c}{n}, \quad p = \frac{mc}{\sqrt{n^2 - 1}}. \tag{1}$$

So the threshold momentums for electron and pion, which were the main background particles for this experiment, are about 18MeV/c and 4.9GeV/c, respectively. The acceptance momentum range for the HRS was from 0.3 to 4.0GeV. Thus the electrons could emit Cherenkov light and trigger an ADC signal but pions couldn't do that directly.

The Cherenkov detector is made of steel with thin

Received 16 October 2006, Revised 21 November 2006
* Supported by National Natural Science Foundation of China (10605022)
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entry and exit windows. Ten spherical mirrors configured as 2×5 are used to collect the Cherenkov light. Each mirror is coupled to a photo-multiplier tube(PMT). The light is converted to electronic signals by PMTs and fed to ADCs. Then one can distinguish electron from pion with the summed signal of all ten ADCs which provide the information about the total light emitted by the particle.

2 Calibration

2.1 Cherenkov detector calibration PMT by PMT

In the HRS momentum acceptance, pion should not produce any signal in the gas Cherenkov detector. But it can interact with the matter it passes through and generate δ electron. The δ electrons will emit Cherenkov light and trigger the ADCs. But the δ electrons in general do not move in the same direction as the scattered electrons, so the Cherenkov light emitted by δ electrons will not be efficiently collected by the mirrors. The ADC signals generated by δ electrons are mostly in single photo-electron peak[5].

The number of Cherenkov light emitted in a wavelength range from λ_1 to λ_2 by the electrons, which is called the number of photo-electron ($N_{\rm p.e.}$), is given by[5]

$$N_{\rm p.e.}=2\pi\alpha L\int_{\lambda_2}^{\lambda_1}{\rm QE}(\lambda)\eta(\lambda)\frac{1}{\lambda^2}\sin^2\theta_{\rm C}(\lambda){\rm d}\lambda \ , \quad (2)$$

where α is the fine-structure constant and L is the path length in the detector. η is the Cherenkov light collecting efficiency, QE is the PMT quantum efficiency, and $\theta_{\rm C}$ is the polar angle of the Cherenkov light.

When the average $N_{\rm p.e.}$ is less than 5, there is an obvious single photo-electron peak in the PM responce[5].

The summed ADC signals generated by the scattered electrons are mainly in multiple photo-electron peak. For the small angle GDH experiment, the mean $N_{\rm p.e.}$ in ten mirrors is about 9. So there is a high possibility of single photo-electron peak in one PTM response from electrons.

The ADC signal readout is converted from the Cherenkov light. It depends on the number of photo-electron. The ADC signals should be the same if there is only one photo-electron in every PMT. Due to the high voltage and readout problem, the ADC responses of single photo-electron are not the same in different PMTs. So one has to do the calibration PMT by PMT before summing up the ADC values, which is used to separate electrons from pions and to obtain the separation efficiency. The method of the calibration correction for the Cherenkov detector is to scale the ADC signals of single photo-electron peak in every mirror to a same value.

2.2 Event selection and constant determination in the calibration

Because Cherenkov lights from electrons and the δ electrons generated by pions all have a probability to locate in single photo-electron peak, all events can be used as the calibration sample except those pions which don't emit δ electrons.

The single photo-electron peak($X_{\rm S.P.E}$) of each PMT is fitted with a Gaussian function. Then the single photo-electron peaks are scaled to 200. So the calibration constants for 10 PMTs are determined as:

$$C_i=\frac{200}{X_{\rm S.P.E}} \ . \quad (3)$$

Two PMT responses for one run before calibration correction are shown in Fig. 1(a,b). The plots show that there are obviously single photo-electron peaks in two PMTs, but the responses are not the same.

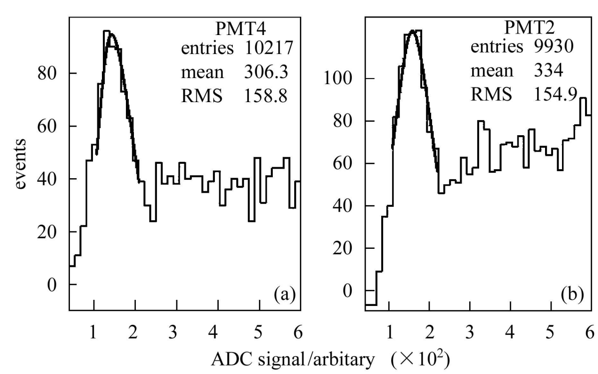

Fig. 1. The responses in the fourth (a) and second (b) PMT before calibration for one run.

The single photo-electron peaks and its corresponding calibration constants in ten PMTs from this run are listed in Table 1.

Table 1. $X_{\rm S.P.E}$ and C_i in different PMT.

PMT	$X_{\rm S.P.E}$	C_i	PMT	$X_{\rm S.P.E}$	C_i
PMT1	137	1.46	PMT6	170	1.18
PMT2	163	1.23	PMT7	139	1.44
PMT3	166	1.20	PMT8	153	1.31
PMT4	121	1.65	PMT9	146	1.37
PMT5	154	1.30	PMT10	168	1.19

3 Checking the calibration results

3.1 Check the ADC responses in different PMTs

The single photo-electron peaks in 10 PMTs are scaled to 200 for the calibration run after the calibration correction. We need to check if these constants are suitable for other runs or not. During the small angle GDH experiment, the constants are regarded as acceptable if those single photo-electron peaks are at 200±5 Otherwise the constants have to be re-obtained for those runs. Since the high voltage for the PMTs were changed during the data-taking, different calibrations for the Cherenkov detector are needed. In this experiment, 7 sets of constants for runs were obtained. The single photo-electron peaks in ten PMTs before or after calibration correction for another run are shown in Table 2.

Table 2. $X_{\rm S.P.E}$ in different PMT.

PMT	before	after	PMT	before	after
PMT1	138	201	PMT6	171	202
PMT2	165	203	PMT7	137	197
PMT3	164	197	PMT8	155	203
PMT4	123	203	PMT9	145	199
PMT5	154	200	PMT10	170	202

3.2 Check the summed ADC responses

The total ADC signals triggered by the particles were obtained from the summed ADC responses in 10 PMTs, which were shown in Fig. 2.

Fig. 2 shows many particles do not have signals in the Cherenkov, which mainly come from pions. A small peak around 200 is the single photo-electron peak, which comes from δ electrons generated by pions. The wide distribution is triggered by electrons. In this experiment, the average photo-electron count from the scattering electron in ten mirrors is about 9. The summed ADC signals in all PMTs for the electrons are in the multi-photo-electron peak, which is a convolution of Poisson and multi-Gaussian distribution.

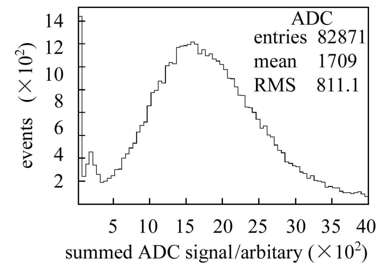

Fig. 2. The summed ADC signal after calibration for a run.

After the calibration correction, one can check what the advantage of the CO_2 gas Cherenkov detector is. A calorimeter counter can be used to identify electrons from pion on HRS. The E/p should be around 1 and 0.5 for electrons and pions, respectively, where E is the deposit energy in the calorimeter and p is the momentum of the particle. In Fig. 3, the points with error bars are the E/p distribution when the summed ADC signal is required to be higher than 500. The histogram without error bars is plotted when the summed ADC signal is less than 500. From Fig. 3 one can see that the pion is rejected effectively by the gas threshold Cherenkov detector with a E/p cut of , say, greater than 0.8. But it might drop a lot of electrons. So the gas Cherenkov detector is combined with the calorimeter detector on HRS to separate electrons from pions.

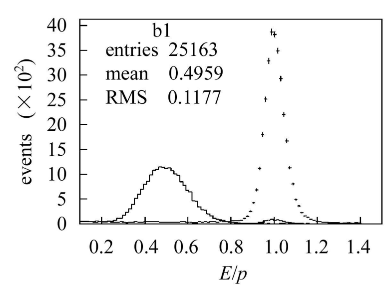

Fig. 3. The E/p in calorimeter counter for a run.

4 Conclusion

The Hall-A HRS CO_2 gas threshold Cherenkov detector had been calibrated throughout the small angle GDH experiment. Since the high voltage was changed many times, 7 different calibration constants were obtained. The single photo-electron peaks in different PMTs were reasonable for all runs with corresponding constants. The summed ADC signals show that there were many δ electrons generated by the pions. After applying the cut on the summed ADC signals, the pion contamination could be decreased effectively.

We would like to thank J.P. Chen for his suggestion and V.Sulkosky, X.C. Zhen for their advices.

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Hall-A 上小角度 GDH 实验中气体契仑柯夫探测器的刻度修正*

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摘要　在 JLab 的 A 大厅上的小角度 GDH 实验中, 因为实验过程中硬件条件的变化, 对位于高分辨谱仪上的 CO_2 阈契仑柯夫探测器进行了多次刻度修正, 并得到 7 套修正系数. 单光电峰在阈契仑柯夫探测器的 10 个 PMT 中的信号响应均被调整到两百. 通过对在该探测器中的信号响应的判断, 本底 π 粒子可以被有效的去除.

关键词　刻度　气体契仑柯夫探测器　单光电峰

2006 – 10 – 16 收稿,　2006 – 11 – 21 收修改稿
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