PROCEEDINGS OF SCIENCE

General performance of the IceCube detector and the calibration results

Mina Inaba for the IceCube collaboration*
Department of Physics, Faculty of Science, Chiba university
E-mail: mina@hepburn.s.chiba-u.ac.jp

IceCube is a huge neutrino telescope with 1 km^3 instrumented volume to aim for detecting astrophysical sources. A Digital Optical Module (DOM) is a module for IceCube which consists of a 10-inch diameter PMT supported by coupling gel, a signal processing electronics board, an LED flasher board and the photo-multiplier tubes (PMT) base with high-voltage supplier. The PMT is the HAMAMATSU R7081 with 10 dynodes, which has exhibited good charge resolution and low noise. The PMTs and DOMs are calibrated and characterized in a laboratory. We made several measurements of saturation behavior, photo-cathode uniformity mapping with an absolute quantum and collection efficiency and it's dependences on photon hit position on the cathode surface. We show that both PMT and DOM measurements are consistent over the wavelengths by comparing the DOM data and the simulation based on the PMT data.

International workshop on new photon-detectors PD07
June 27-29 2007
Kobe University, Kobe, Japan

*Speaker.

PoS(PD07)031

1. Introduction

IceCube is a very high energy cosmic neutrino Cherenkov detector at the South Pole. A fig. 1 shows a schematic view of the IceCube detector. The total size of the detector will be about a cubic-kilometer. It will consist of more than 4200 PMT. Each PMT is enclosed in a transparent pressure sphere. We call it DOM. Eighty strings are regulary spaced 125m over an area of approximately one square kilometer with DOMs at depths of 1.4 to 2.4 km below the ice surface. Each string, containing 60 DOMs spaced 17 m, will be deployed into a hole drilled with pressurized hot water. The construction started from 2004 and 22 strings have been deployed so far, which corresponds to about one-third of the full volume and taking data as the biggest neutrino detector.

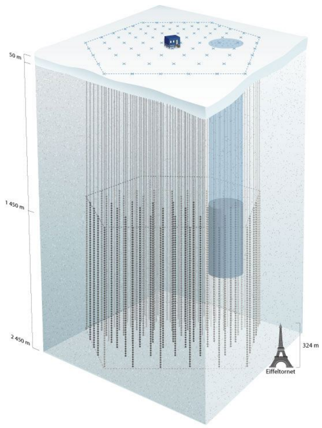

Figure 1: The Schematic view of the IceCube detector

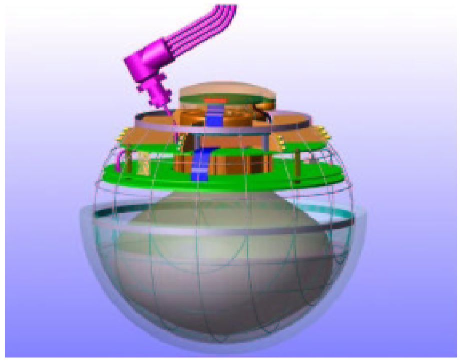

Figure 2: A DOM

2. IceCube detector

A DOM is the fundamental detector elememt of the IceCube. A fig. 2 shows the schematic illustration of the DOM. The DOM amplifies and digitizes the sample of the high-speed PMT pulses before trigger and build events from the entier array. Each DOM encloses a 10 inch diameter R7081-02 PMT made by Hamamatsu in a transparent pressure sphere along with subsystems for high voltage generation, digital readout and communication, and LED flasher for in-ice calibrations. A DOM has two digitizers, one is an ATWD which has three different gain channels for wide dynamic range effectively 14 bits and another one is FADC for long duration pulses of $\sim 6.4\mu$ sec.

Our PMT is the HAMAMATSU R7081 with 10 dynodes whose photo-cathode is a standard bialkali material. The peak quantum efficiency (QE) is approximately 25 % at 420 nm. It has a linear response up to approximately one thousand photo-electrons at the gain of 10^7. The operation gain is 1.0×10^7 with 1300 V. It has exhibited good charge resolution and low noise, the noise rate is about 300 Hz under $-40 \sim -20$ degree celcius, which is the usual temperature in the ice at the South Pole.

3. Single photo-electron (SPE) measurement

The basic performance of the PMTs under low temperature should be well understood. It is now over 4 years since we started the PMT calibration, and the present data is rich enough to picture average behavior of the IceCube PMT response. To imitate the same condition at the South Pole, we made a measurement in a freezer box which can cool down to -32 degree. An ultraviolet LED are used as the light source and a diffuser is attached on it to shed light uniformity on the photo-cathode. We derived a function to represent the single photo-electron distribution. In general, the charge of SPE pulse follows a gaussian distribution. However, a large PMT like those used for IceCube is occasionally observed to fail to stream secondary electrons out from the first to the second dynode. We show the measured SPE distribution of the IceCube PMT in fig. 3. The exponential term is due to an incomplete multiplication at the first dynode. Therefore, we fitted the SPE histogram with one exponential and one gaussian terms.

The averaged charge response of the IceCube PMT using 118 PMTs is shown in fig. 4. The line represents the average and the dotted lines are some indivisual PMT's charge responses to show these differences. The peak value of gaussian component corresponds to 1 p.e, however the mean of this function is 15 % less than 1 p.e because of the exponential term. The width of a single photo-electron charge response, namely the single photo-electron resolution, is 29 %.

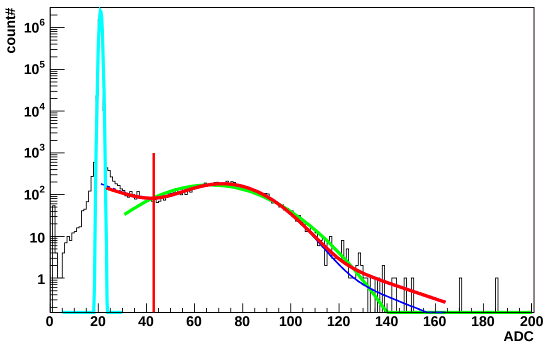

Figure 3: A measured charge histogram with the fitted SPE model function.

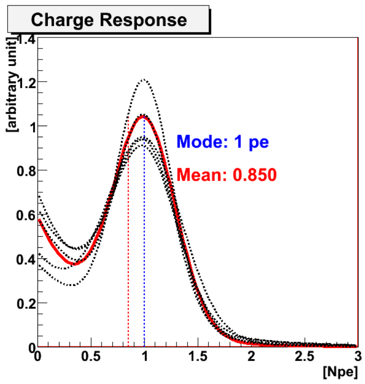

Figure 4: The average charge response. See the detail in text.

4. Absolute calibration of a PMT

Absolute calibration of a PMT is very important because IceCube uses the observed number of photo-electrons to estimate the energy for an event derived from a neutrino. A schematic view of the absolute calibration system is shown in fig. 5. We used 337 nm nitrogen laser for the light source. It is too strong to hit the laser light direct to a PMT, so to dump the light intensity we had photons scattered in the chamber filled with nitorogen. Only photons with scatter angles of ~90 degree will reach an IceCube PMT photocathode to generate an SPE signal. Cross section of the Rayleigh scattering is well known, so we can estimate the photon number at the cathode surface, monitoring the initial photons by a calibrated energy meter and numerical calculation for the Rayleigh scattering. By dividing measured photo-electrons by the initial photon numbers, we calcurated a QE of a PMT. The results are shown in fig. 6. The X-axis is the QE measured by Hamamatsu and the Y-axis is QExCE (collection efficiency) measured by us. Hamamatsu measurements are based on DC light source, while we use a pulse, and the CE at the center is to be about 100% by a simulation. Our results have a good correlation with Hamamatsu data within our 8% systematic error.

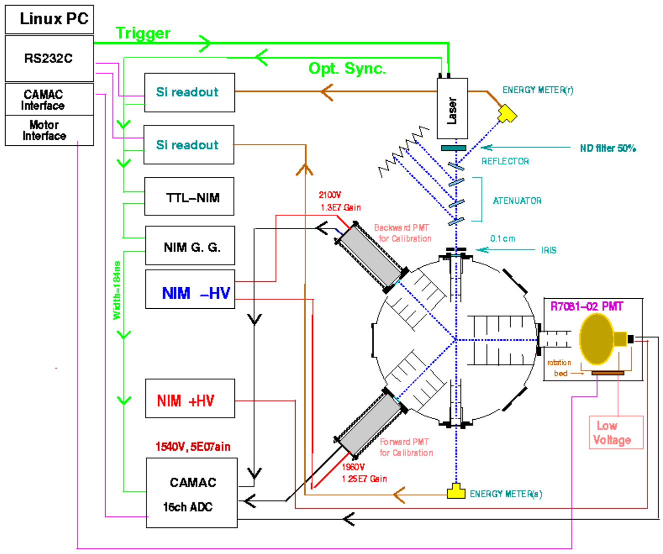

Figure 5: The schematic view of the absolute calibration system

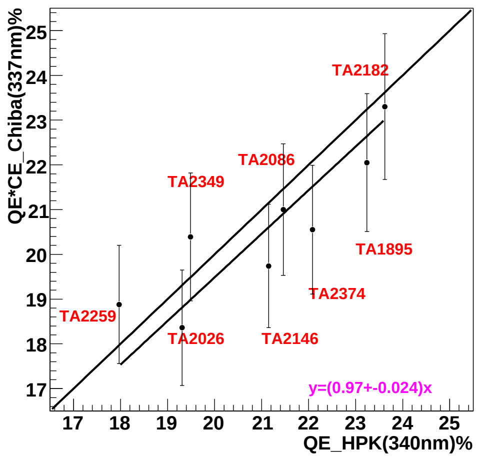

Figure 6: The correlation between our measurement and Hamamatsu.

5. PMT sensitivity surface uniformity

The IceCube PMT's photo-cathode surface is very large, so we have checked the uniformity. We have systematically measured the relative amplitude for each photo-cathode position, using a two dimensional scan system. A fig. 7 shows the averaged relative PMT efficiency map over 94 PMTs, where the X-Y coordinates represent distance along PMT surface. The efficiency falls down at the edge of the photo-cathode ($\sim$ 15 cm) and you can also see the effect of the first dynode direction (positive x direction).

A fig. 8 shows the measured detection efficiency as a function of distance on a PMT surface from the cathode center. Points are the absolute efficiencies and the histogram shows the relative efficiency which is fitted to the absolute efficiencies. It shows that the absolute efficiency measurements follow closely the shape measured by the 2D relative efficiency scan. By matching the relative efficiency to the absolute one which we only measured a several points, we can know the absolute efficiency for all the PMT surface.

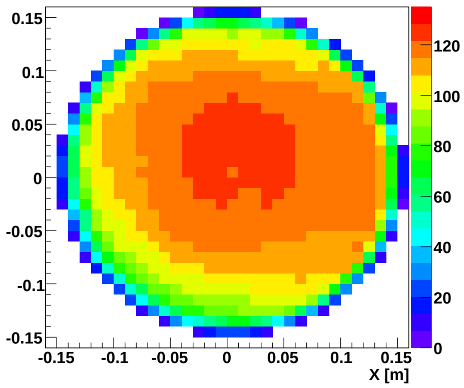

Figure 7: The averaged 2D CE Map over 94 PMTs

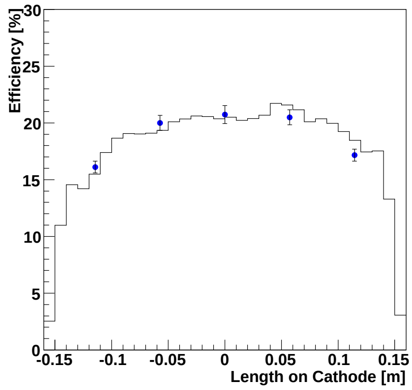

Figure 8: The detection efficiency for photons for one of the IceCube PMTs at 337 nm.

6. Absolute calibration of a DOM

It is fundamentally important to calibrate DOM absolutely because what we actually measure is the photo-electrons by a DOM not by a PMT. We used 4 different wavelength LEDs as the light source and used a ND filter to split the light for both an absolutely calibrated reference PMT and one which we measure. The transmission and the reflectivity of the ND filter and the gain of the reference PMT are calibrated within 7% precision. We also measured the 2 dimensional CE of DOMs by a scanning system such as for PMTs. The 2D Map which is converted absolute efficiency is shown in fig. 9. Unlike the case of the PMT 2D collection efficiency, we do not see the effect of first dynode direction well. The information is partly lost by a glass and gel.

7. Comparison between a PMT and the corresponding DOM

Finally I will show the consistency of the muasurement data by comparing the DOM data and the simulation based on the PMT data. The photon propagation in the glass and gel has been independently simulated by GEANT4, based on a measurement of the transmittance of a glass and a gel. A detector simulation reads the table generated by the GEANT simulation and simulates PMT response based on the PMT measurements. Since we have calibrated absolutely both for PMT and DOM, we can calibrate the photon propagation in a glass and a gel done by the Geant4. A fig.

10 shows the comparison between a DOM measurement and the corresponding PMT measurement with glass/gel simulation. The histogram is the expected efficiency by the simulation, while the points are the value of DOM measurements. This shows of the data and the simulation agree well over wavelengths.

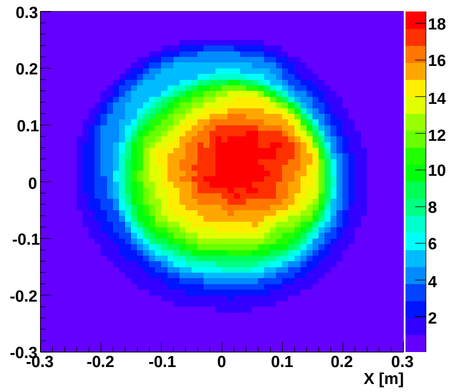

Figure 9: 2D QExCE Map of DOM

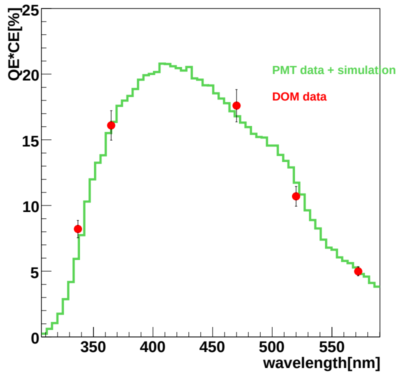

Figure 10: Comparison between a PMT and the corresponding DOM

8. Summary and the future work

The IceCube PMTs and DOMs are calibrated and characterized in a laboratory. Absolute efficiency of our measurement has a good correlation with Hamamatsu's one. We compared absolute efficiencies between a PMT with glass/gel simulation and the corresponding DOM. The results show good agreement over the wavelengths. For the future work, we will calibrate the photon propagation in ice in situ using an absolutely calibrated instruments, namely absolutely calibrated source and absolutely calibrated DOMs, that are both deployed already in ice. From the both measurements of the absolutely calibrated source and the photon receiver, we can analyze how photons propagate in ice. The study will reduce the systematic uncertainty of ice nature and improve our estimation of the target particle's energy.

References

[1] H. Miyamoto 29th ICRC, Pune (2005) 00,101-106

[2] S. Yoshida Nuclear Physics B (Proc. Suppl.) 138 (2005) 179-182

[3] IceCube collaboration Astroparticle Physics 26 (2006) 155-173

[4] http://www.ppl.phys.chiba-u.jp/research/IceCube/

[5] http://www.icecube/wisc.edu/

[6] http://geant4.web.cern.ch/geant4/