PROCEEDINGS OF SCIENCE

Cherenkov light detection by PPD

Tohru Takeshita[1]
Shinshu University
Asahi, 3-1-1, Matsumoto, Japan
E-mail: tohru@shinshu-u.ac.jp

Abstract

Particle Flow Algorithm (PFA) which combines detector components depending on their performances in order to get the best jet energy resolution, requires fine segmentations in longitudinal as well as lateral directions for the high energy particle calorimeters. The sampling calorimeter is the one which is able to meet those requirements, while the absorber gives no information for the energy measurement. There we introduce an active absorber with Cherenkov light detection in order to use absorber information to improve the energy measurements. The Cherenkov lights would be detected with novel semiconductor photo-detector which is called PPD. Pixelated Photon Detector. Measurements resulted muons passing 4cm lead glass yielded 10 p.e. which is rather small. Ideas to increase the Cherenkov photon detection efficiency are presented such as wave length shifting glue or sheet and Quantum Dots blended in lead glass.

International Conference on New Photo-detectors
PhotoDet2015
6-9 July 2015
Moscow, Troitsk, Russia

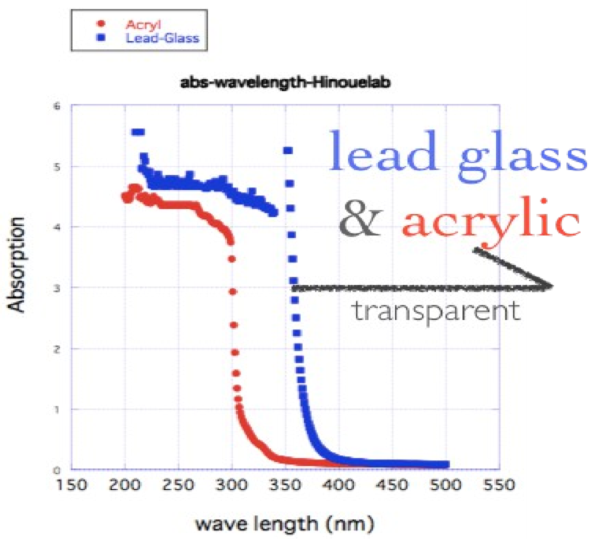
[1]Speaker

1.Introduction

Particle Flow Algorithm (PFA) which combines detector components depending on their performances in order to get the best jet energy resolution, requires fine segmentations in longitudinal as well as lateral directions for the high energy particle calorimeters [1]. Charged particles in a jet are precisely measured by the tracker, while photons mostly from the neutral pions are well measured by the ECAL through the electromagnetic showers, On the other hand, the neutral hadrons such as K0L are only detected and measured by the hadron calorimeter, where charged hadron-showers pollute the neutral hadron shower. To identify those neutral hadrons in other hadron showers, the fine segmentation of the hadron calorimeter is essential. The sampling calorimeter is the solution which is able to meet the requirements, while the absorber usually gives no information at all. Here we would present an active absorber case within the frame work of PFA which needs very small granularity in lateral directions. To fulfill PFA demands, the absorber should be also segmented as small as that of hadron calorimeter (HCAL) active sizes. Fine segmented absorber is quite relevant for the PFA which merge energy information around the tracks in HCAL, while the sizes of ECAL are even small, thus we concentrate on the HCAL case. The electromagnetic showers in the hadron interaction may arise though the neutral pion productions, which give large energy deposit in the Cherenkov absorber. As the number of Cherenkov lights are measuring total amount of energy in the absorber, this information will give precise information in the hadron interactions. As far as additional information from the absorber, we expect any improvement in the energy resolution for hadrons or jets. Throughout this work, we concentrate on the Cherenkov light information from the absorber. The Cherenkov lights are produced by any charged particles, which pass the absorber with certain velocity (v), when $v/c > 1/n$, where n is the refraction index of the absorber material, and c is the velocity of light in vacuum.

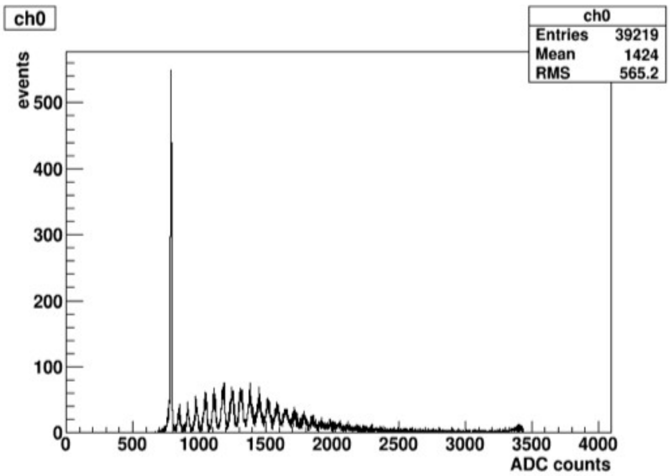
2. Active absorber with Cherenkov light

Though the PFA requires fine segmentation in 3D (two in lateral and one in longitudinal) directions, compactness is one of the issues for the hadron calorimeter at high energies, even for the hadron interaction length is rather long in order to merge the cluster correctly. The granularity in the longitudinal directions of shower would be as short as possible. Moreover, in order to reduce the shower leakage, enough length of heavy material can absorb whole shower energies, beside keeping the total length of the calorimeter as short as possible , in view of the cost and reality. To achieve such requirements the photo-detectors of the Cherenkov light from the absorber have to be thin. Otherwise we will lose the benefit of the PFA. This is only achieved by the recent developed semiconductor photon-detectors whose thicknesses are less than a mm. Furthermore to detect the Cherenkov light, the absorber must be transparent as possible at short wave length, since the emitted Cherenkov lights have $(1/\text{lamda})^2$ dependence, which is dominated in the UV light region, where lamda is the wave length of the Cherenkov lights. For this study,



we adopt the lead glass for the Cherenkov absorber, since it has high density (~5.3 g/cm^3) and heavy enough. Generally the heavier material has bigger refraction index, however, and strong absorption for the UV light. In case of lead glass of refraction index=1.8 [2] , absorption edge locates at 360 nm, while the acrylic has 300nm when the thickness is 30mm. This is shown in figure 1, where vertical axis is measured absorption which has not normalized as a function of wave length of the light in nm.

Furthermore, the generated number of Cherenkov photons is significantly small than that of the scintillation lights. It should be noted that the Cherenkov lights emitted by high energy charged particles passing though the Cherenkov radiator perpendicular to the detector have never extracted from the radiator to the air outside, as far as the refraction index of the absorber is smaller than square-root (2) ~1.41. Thus those Cherenkov lights have not detected by the photo-sensor as far as there is air gap between the absorber and the photo-detector. Therefore we have to take care of the light contact seriously. When there is no air gap in front of the photo-detector, namely MPPC of Hamamatsu 3x3mm^2, 100um pitch (S12572-100C) [4], we have measured about 10 p.e. / 4cm long lead glass. This is shown in figure 2 as an ADC histogram. There the first peak coincides the pedestal and the second broad peak is recognized due to the cosmic muons passing though. In the ADC histogram, one can find many small peaks due to good photo-electron separation of the sensor. The number of Cherenkov light detected is rather small, however, thinking the role of the absorber to be the detection of the electro-magnetic shower , the dynamic range of the received number of Cherenkov photons will be much larger than single passing. Taking into account of the limited range of the electronics, the detected photon yield for the single particle passing would be kept as small as possible. Never the less, the number of Cherenkov lights detected with above condition is not sufficient against the current noise level of the photo-sensors. On the contrary the new type MPPC with S13360 series will have less noises, thus the optimization for the Cherenkov light detection efficiency might change.



3.Cherenkov light detection improvement

There are some more ideas to increase the photon detection efficiency for the Cherenkov light with PPDs.

One is putting a special glue or sheet which contains the wave length shifting material inside, which is installed between the photo-detector and the lead glass. However the refraction index of this material must be bigger than 1.41 and smaller than 1.55 which corresponds to the covering material on the surface of the MPPC. In this case, the emitted Cherenkov lights must arrive at the absorber surface, pass the boarder between the radiator/absorber and glue/sheet material and converted to the different wave length and directions. Those photons could be easily detected by the photo-sensor.

The other idea is to blend the wave length shifting material to the lead glass. Immediately after generation of the Cherenkov lights, they will be absorbed and reemitted with longer wave length in every directions. The longer wave length photons can traverse the lead glass with small absorption possibility. Furthermore the redirected photons have no more suffer the total reflection problem on the surface of the lead glass and easily be able to get into the photo detector. However, the wave length shifting material has to be active after production procedure of the lead glass where it has to survive more than 1000 degrees centigrade. Thus the material would be inorganic and stable in the high temperature. Recently there are produced with named Quantum Dot (QD) technology, which is nano-crystals of nm order size of a semiconducting material. The QD's have apparent properties of fluorescence, where nano-crystals distinctive different wave length determined by the size of the particles. They have discrete quantized energy levels due to their small size in small space(quantum box), depending of their sizes the emitted wave length changes, namely if the size becomes smaller, the emitted wave length becomes shorter. The QD is quite recently found and developed, therefore we have less experience on the material to be mixed up with as glass or lead glass. More effort and experience are required to develop QD and its blending into glass or lead glass. However, since the QD is under developing rapidely, much applications will appear soon.

4. Summary and outlook

In the high energy physics experiment, PFA technology is delivering evolutional energy resolution. In addition to PFA alone, the active absorber technique is hoped to give more information for the hadron energy measurements. For a candidate of the absorber, we discussed primary interest on the lead glass. We found the number of Cherenkov light detected by a PPD is small enough to construct whole hadron calorimeter. In order to increase the Cherenkov light detection efficiency, some ideas are discussed and some are under study.

References

[1] M. Thomson, Nucl.Instrum.Meth.A611(2009) :25-40.

[2] T. Sumiyoshi et. al. , Performance of the VENUS lead glass calorimeter a t TRISTAN , Nucl.Instrum.Meth. A 271(1988) 432-441.

[3] http://www.hamamatsu.com/

[1] S.M. Reimann, and M. Manninen, Reviews of Modern Physics, 74(2002)1283.