# R&D Status of the GLD ECAL and Photon Sensors

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In the GLD detector, we consider using fine-segmented scintillator strips and tiles as the active media in both electromagnetic and hadron calorimeters in order to achieve excellent jet energy resolution with help from the particle flow algorithm. In this paper, we present performance of the scintillator ECAL in terms of shower profile measurement and R&D status of new photon sensors which could be used in combination with the scintillator-fiber system in the magnetic field.

## 1. INTRODUCTION

At the future linear collider experiment, precise jet energy measurement is one of the key issues for the detector, and many of us think that it can be achieved by the particle flow algorithm, in which fine granularity in both lateral and longitudinal directions of the calorimeter is more important than the energy resolution for single particle. In the GLD concept, scintillator strips and tiles sandwiched between absorbers are proposed as the primary candidate for both electromagnetic and hadron calorimeters (ECAL and HCAL) due to its inexpensive cost and design flexibility. In this case, absorber will be tungsten for ECAL and lead for HCAL, respectively. Light signal is read out through a wavelength shifting (WLS) fiber and is detected by a photon sensor, which is conceived to be Silicon Photomultiplier (SiPM) or its equivalent at the moment.

We report in this paper testbeam results of ECAL test module and R&D status on the new photon sensors.

## 2. LATERAL SHOWER PROFILE OF EM SHOWER

We have constructed ECAL test module (Figure 1) to investigate mainly the EM shower profile and capability of two cluster separation using testbeam [1]. The test module is a lead/scintillator sampling calorimeter with 24 layers, each of which consists of a 4 mm-thick lead plate and two orthogonal scintillator-strip arrays. The size of the strip is 20 cm $\times$ 1cm-width $\times$ 2 mm-think, and thus the effective granularity is 1 cm $\times$ 1cm. Light signal is read out by a 16-channel multi-anode PMT, through a WLS fiber and a clear fiber. A series of four layers are ganged to compose a superlayer. Effective Molière radius of this calorimeter is 27 mm. The detector configuration was not optimized in the test, but we could have a understanding of the behavior of the scintillator-strip calorimeter.

The beam test was carried out at KEK-PS with electron beam, however muon/pion beam was used for the calibration purpose. Four single-wire drift chambers were placed in front of the calorimeter for reconstructing a track of incident particle.

In order to examine the lateral shower spread, we introduce $I(x)$, which is defined as the energy deposit integrated between minus infinity and $x$, divided by the total energy deposit:

$$I(x) = \int_{-\infty}^{x} \rho(x')dx' \Big/ \int_{-\infty}^{\infty} \rho(x')dx'$$

where $\rho$ represents the shower density. The origin of $x$ is set, event by event, to the particle incident position determined by the extrapolation of the reconstructed track.

Figure 2(a) shows the $I(x)$ distributions of all superlayers for 4 GeV electron sample and that of the second superlayer for MIPs (in this figure we plot $I(x)$ as a sum of $I(-x)$ and $1 - I(x)$). The MIP spreads mainly originates

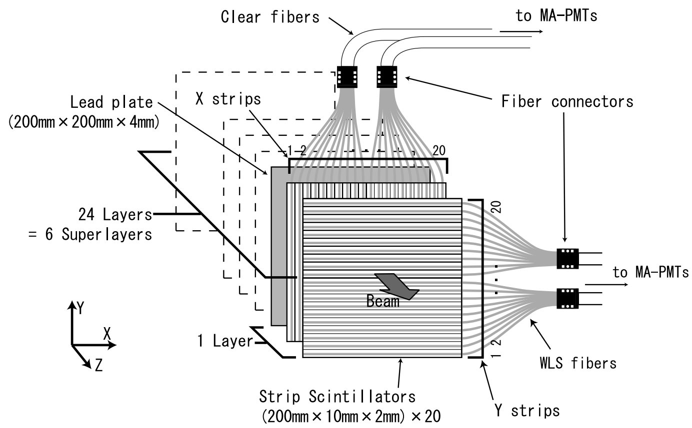



Figure 1: ECAL test module.

from light leakage between strips and cross-talks in the multi-anode PMT. On the other hand, the spreads for electrons mostly come from the EM shower spread in the calorimeter.

Figure 2(b) shows the shower spreads at the second superlayer for data and MC simulation. The simulation results do not include the detector effects mentioned above, and give smaller spread than the real data (filled circles). However, by calculating a convolution of the MC curve with MIP curve (which corresponds to the detector effects), dotted curve is obtained and it is consistent with the beam data.

## 3. PHOTON SENSOR R&D'S

As the GLD calorimeter is located within the solenoid, photon sensor should be operated in the magnetic field. It also should be compact to reduce dead space and cheap (per channel) to reduce the cost for the huge readout channels. The SiPM, recently developed in Russia, or similar product made by Hamamatsu (Multi-pixel Photon Counter: MPPC) is a good candidate for our photon sensor. It is, to be brief, multi-pixel avalanche photodiode (APD) operated in the limited Geiger mode, so its gain is as high as that of the conventional photomultiplier ($\sim 10^6$). The size of the detector surface is about 1 mm $\times$ 1 mm, which is suitable for direct coupling to WLS on

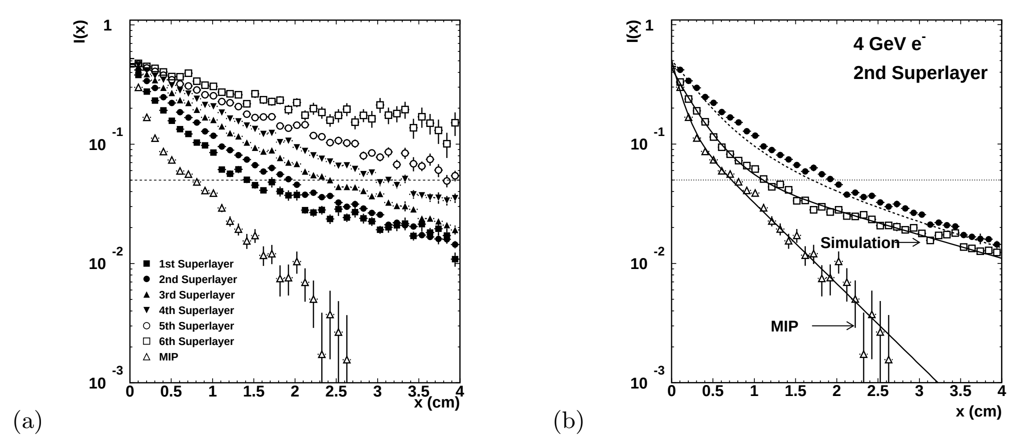



Figure 2: (a) Integral lateral shower profiles at each superlayer for 4 GeV electrons and at the second superlayer for MIPs. (b) Comparison with the simulation at the second superlayer. Filled circles are data and open squares are simulations. Dashed curve, which is a convolution of the MIP data and the simulation, is consistent with beam data.

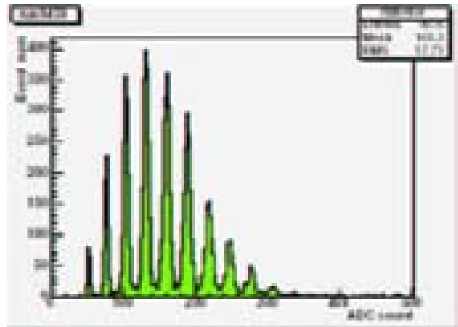


Figure 3: Photon counting by a Hamamatsu 100-pixel MPPC.

the scintillator. The surface is divided into hundreds or thousands of pixels, and we can measure incident number of photons by counting number of hit pixels (Figure 3). On the other hand, this fact means that saturation effect is expected if number of photons is similar to or greater than the number of pixels, in other words the number of pixels determine the dynamic range. Therefore, the number of pixels should be large enough for light signal around the shower maximum.

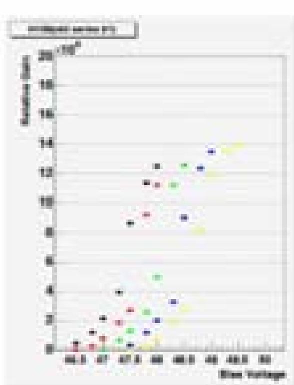
Gain and efficiency of the photon sensor ought to depend on bias voltage and temperature. Figure 4(a) shows measured gain of 100-pixel MPPC as a function of bias voltage at various temperatures. The gain is found to be very sensitive to bias voltage and modestly sensitive to temperature. Figure 4(b) shows noise rates of a 400-pixel MPPC, and obtained rates are around ∼0.1 MHz which seems be tolerable.

We also measured response uniformity and efficiency of 100-pixel MPPC by irradiating laser to the central region of the pixels. From RMS of the pulse height distribution at one photon equivalent, the uniformity was ∼10%. Relative inefficiency was checked by taking a ratio of number of events observing null photons to all events, and we observed that pixels at the sensor edges have lower efficiency than central ones.

There still remains many issues to be measured for the new devices, and further development with the makers will be needed for production use at the actual experiment.

## References


[1] A. Nagano *et al.*, "Fine-granularity electromagnetic calorimeter using plastic scintillator strip-array", Nucl. Instr. Meth. A. (in press).


(a) 

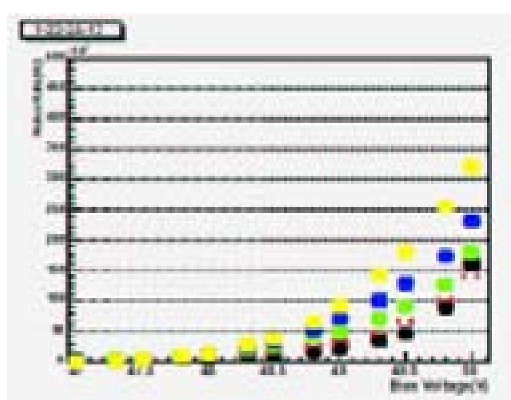
(b) 

Figure 4: Measurements of (a) 100-pixel MPPC gain and (b) 400-pixel MPPC noise rate as a function of bias voltage at 20, 10, 0, -10 and -20 °C (from right to left in (a); from top to bottom in (b)).