Performance of compensated tile-fiber hadron calorimeter

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Abstract
Extensive R&Ds of a tile-fiber hadron calorimeter with hardware-compensation are going on as a primary candidate for a calorimeter of the JLC linear collider detector. Physics requirement on performance, design criteria, and beam test results of test modules are reported.

keywords: calorimeter; compensation; linear collider

1 Design Concept of JLC Calorimeter

Basic concept of the JLC detctor is a large-volume medium-field general purpose detector. A cut-view of the detector is shown in Fig.1. Whole of the calorimeter system is designed to be located inside a large superconducting solenoid to achieve the best performance.

The most important design criterium on the JLC detector is two-jet mass resolution better than the natural width of the weak bosons. This criterium is very important for precision study of weak couplings as well as of Higgs boson which mass could be quite close to Z boson. Simulation study indecates that, in combination with other JLC detector components, a calorimeter system of following energy resolutions with reasonable granularity can achieve two-jet mass resolution of about 1.3GeV ;

$\sigma_E/E = 15\%/\sqrt{E} \oplus 1\%$ for EM shower, and
$\sigma_E/E = 40\%/\sqrt{E} \oplus 2\%$ for Hadron shower.

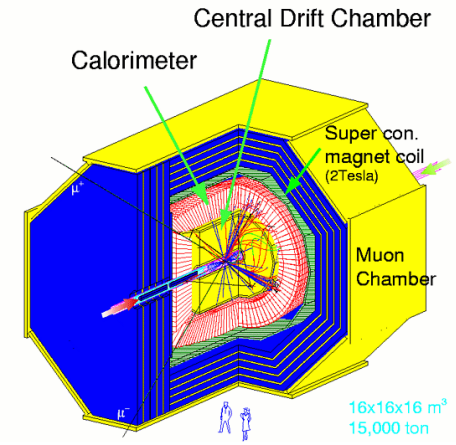

Fig. 1. Cut-view of the JLC detector with an event overlapped.

In order to achieve such excellent hadron energy resolution, compensation is indispensable ; either hardware compensation or software compensation. We adopted hardware compensation because software compensation costs much higher due to its very fine granularity. For EM calorimeter, on the other hand, software compensation could also be a good choice because it needs fine granularity anyway.

As a structural option, we selected a CDF-style tile-fiber design. This design has very nice feartures such as hermeticity, potential for very fine longitudinal segmentation and for excellent hadron energy resolution, and low cost.

2 Test Module Performance Study

In order to establish that a tile-fiber calorimeter with hardware compensation can achieve the required performance, a hanging-file hadron calorimeter test module was constructed. What to be established were as follows.

- e/π ratio and hardware compensation
- Energy resolution
- Linearity
- Tower-boundary response

A series of low-energy beam test was done at KEK to measure the stochastic term of energy resolution and e/π ratio with the best accuracy, and a high-energy beam test was done at FNAL to measure the constant term of energy resolution and linearity precisely. It should be noted that e/π ratio, an important parameter of calorimeters to predict resolution, linearity, and non-Gaussian behaviour, is best determined at low energy since it approaches to 1 at high energy regardless calorimeter structures.

The test module was constructed in two steps. First, a reconfigurable hanging-file module similar to the SDC test module[1] was made. This module had no transverse segmentation but had very fine longitudinal segmentation of 42

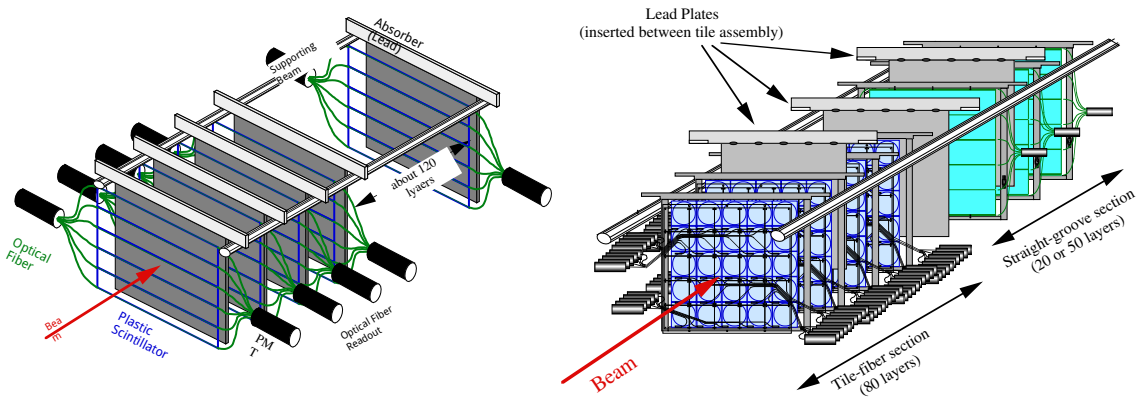

Fig. 2. Schematic drawings of the hanging-file (left) and the tile-fiber (right) test modules.

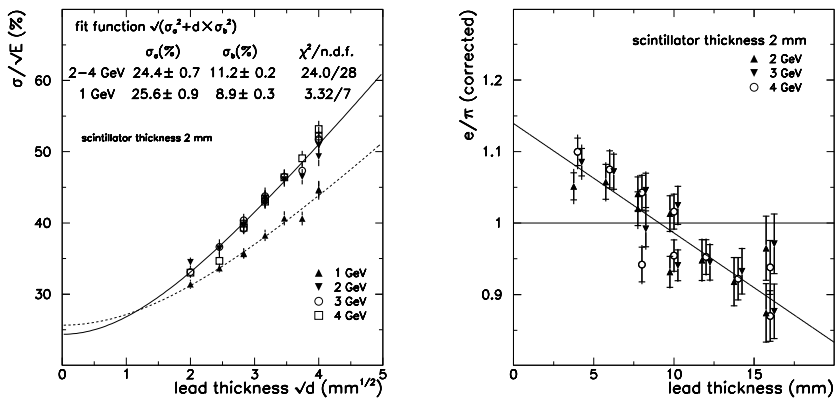

Fig. 3. Energy resolution (left) and e/π ratio (right) for pions as a function of lead thickness. Horizontal axis is a square-root of lead thickness for the left figure.

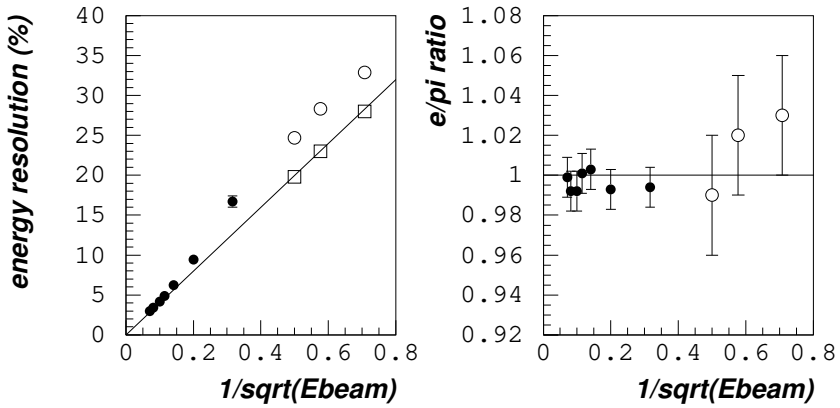

Fig. 4. Energy resolution (left) and e/π ratio (right) measured at KEK and at FNAL. Open marks are KEK data, and solid circles are FNAL data.

sampling over 6 λ at the maximum. This module was tested at KEK to establish hardware compensation and to study basic characteristics of hadron shower itself with variety of configuration. Afterwards, the 1st 4λ of the hanging-file module was modified to a tile-fiber structure, while the rear part remained unchanged. This tile-fiber section has 5×5 tower structure and four longitudinal segmentations, each having 1λ-thickness. This module was first tested at KEK to investigate realistic performance of tile-fiber structure. Afterwards, this module was brought to FNAL to investigate performance at high energy. Schematic drawings of the test modules are shown in Fig.2. For both design, transverse size was 1m×1m, and the scintillator thickness was 2mm.

Energy resolution for pions measured at KEK[2] with the hanging-file module is shown in Fig.3. In this measurement, lead thickness was varied from 4mm to 16mm by 2mm-step. Energy resolutions of $\sigma_E/E = 15.2\%/\sqrt{E} \oplus 0.0\%$ for electrons and $\sigma_E/E = 39.6\%/\sqrt{E} \oplus 1.0\%$ for pions were achieved for lead thickness of 4mm and 8mm, respectively. Here the constant terms have almost

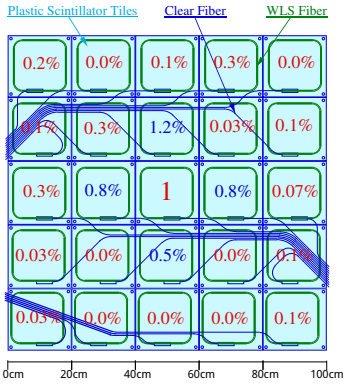

Fig. 5. Cross talk between towers when electron was injected at the center of the central tower. Curves in the figure indicate route of optical fibers.

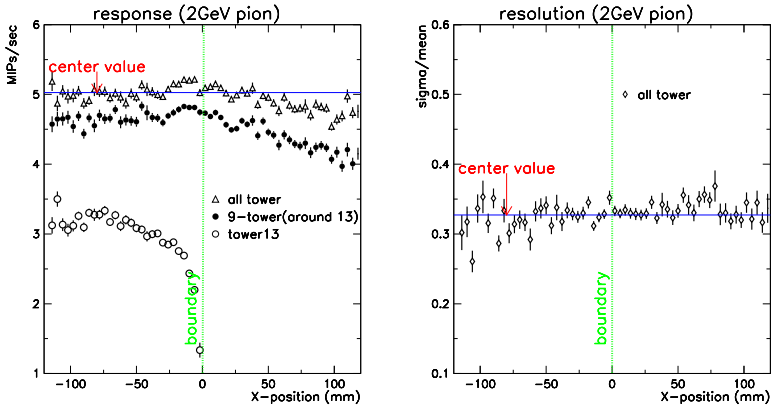

Fig. 6. Measured energy (left) and energy resolution (right) for pions at the tower boundary. Open triangles in the left figure are the total energy.

no significance. We further achieved $\sigma_E/E = 33.6\%/\sqrt{E} \oplus 0.0\%$ for pions with 4mm-thick lead plates, which is one of the best results achieved so far. e/π ratio was also measured for various lead thickness as shown in Fig. 3. It is seen that the hardware compensation was achieved for lead thickness of 9.1mm in the case of 2mm-thick plastic scintillator.

In the case of the tile-fiber design, a plastic plate is stuck on each scintillator plane in order to accomodate optical fibers running from tiles to photodetectors. Beam tests at KEK showed that acryl plates slightly worsened energy resolutions, while e/π ratio did not change when acryl plates were positioned downstream-side of the scintillator planes. Based on these results, design of the tile-fiber module was determined.

Combined plots of energy resolution for pions and of e/π ratio measured at KEK and at FNAL are shown in Fig.4. It seems there could be a systematic difference between low-energy response and high-energy response in energy resolutions. However analysis is yet very preliminary, and it is too early to make any definite conclusion now.

Fig.5 shows cross-talk between towers for the tile-fiber test module. It shows relative energy deposit to each tower when electron was injected to the central tower. This cross-talk is consistent to light cross-talk measured at a bench test with an RI source. Fig.6 shows boundary response of the tile-fiber module for pions. No anomaly was observed at tower boundaries for pion responses.

3 Summary

Requirement on the JLC calorimeter from the physics capability was studied. Based on this study, a hanging-file type and a CDF-type tile-fiber calorimeter test modules were made, and a series of beam tests were carried out. We achieved following energy resolutions ;

$\sigma_E/E = 15.2\%/\sqrt{E} \oplus 0.0\%$ for EM shower

$\sigma_E/E = 39.6\%/\sqrt{E} \oplus 1.0\%$ for pion shower

This satisfies requirement from the physics capability. The test module also showed uniform tower boundary responses for pions.

References

[1] A.Beretvas *et al.*, Nucl. Instrum. Meth. **A329**, 50 (1993).
[2] T.Suzuki *et al.*, Nucl. Instrum. Meth. **A432**, 48 (1999).