Calorimeter for JLC Experiment

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R & D's of the JLC calorimetry system is being done extensively on both hardware and software sides. In this article we describe physics requirement on performance, design criteria and results from beam tests and bench tests.

I. DETECTOR DESIGN

In order to carry out precision physics studies at linear collider, it is important to have good mass resolution for multi-jet final states. For example, good separation of W^+W^-, Z^0Z^0 and Z^0H is required for precision study of Higgs boson. We therefore set design criterion of the JLC calorimeter, in combination with the central tracker, such that 2-jet mass resolution be as good as the natural width of weak bosons. Simulation study indicates that the energy resolution for calorimeter to be

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

with reasonably fine granularity (where E is energy in GeV)[1]. To achieve the required energy resolution, we adopt a hardware compensation with tile/fiber sampling technique as a baseline design. This type of calorimeter has good features such as linearity, hermeticity, low production cost and design flexibility, with only one drawback of low photon yield, and is suitable for hadron calorimeter (HCAL). For the EM calorimeter (EMC), however, very fine granularity might be required for the event topology reconstruction, and software compensation would be another option.

We also need preshower (PreSH) and shower-maximum (SHmax) detectors for $e/\gamma/\pi^\pm/\pi^0$ separation, two-cluster identification, and track-cluster association. As a SHmax detector scheme, 1 cm-wide scintillator-strip array is considered.

All the calorimeter system, including photon detectors, are designed to be located in the 3 Tesla (or 2 Tesla) magnetic field. Table I summarizes basic parameters for the baseline design of the JLC calorimeter [1].

TABLE I: Basic parameters of the baseline JLC calorimeter.

Magnetic field option	2 Tesla	3 Tesla
Barrel Inner Radius	250 cm	160 cm
Barrel Outer Radius	400 cm	340 cm
Angular Coverage (full)	$\lvert\cos\theta\rvert < 0.985$	$\lvert\cos\theta\rvert < 0.966$
(partial)	$\lvert\cos\theta\rvert < 0.994$	$\lvert\cos\theta\rvert < 0.991$
SHmax scheme	scintillator strip (1 cm-wide)	scintillator strip (1 cm-wide)
Thickness		
PreSH	$4X_0$	$4X_0$
EMC	$23X_0$	$23X_0$
HCAL	$6.5\lambda_0$	$6.5\lambda_0$
Granularity		
PreSH/EMC transverse	6 cm × 6 cm (24 mrad)	4 cm × 4 cm (24 mrad)
longitudinal	3 sections (6+12+20 layers)	3 sections (6+12+20 layers)
HCAL transverse	18 cm × 18 cm (72 mrad)	12 cm × 12 cm (72 mrad)
longitudinal	4 sections (25+30+35+40 layers)	4 sections (25+30+35+40 layers)

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II. PERFORMANCE

In order to confirm that a tile/fiber calorimeter with hardware compensation has a required performance, beam tests were carried out with test modules. Purposes of the tests are to check 1) hardware compensation, 2) energy resolution, 3) linearity, and 4) tower-boundary response. e/π separation capability was also studied with preSH/SHmax test module. On the other hand, granularity is related to the component design and must be optimized with full simulation, which is still under study.

A. Beam Tests

Beam tests were carried out at KEK (1–4 GeV, T411) and at FNAL (10–200 GeV, T912) with the hadron calorimeter test module [2]. The test module is composed of 8 mm-thick lead plates and 2 mm-thick plastic scintillator plates with a transverse size of 1 m $\times$ 1 m. Each scintillator is divided into 20 cm $\times$ 20 cm cells, and 5 $\times$ 5 tower structure is created. Along the longitudinal direction, a tower is further divided into four blocks, each of which contains 20 layers of lead plates, scintillator plates and acryl plates for fiber-routing. One block corresponds to one photomultiplier (PMT) for readout.

Energy resolutions for pions and electrons are shown in Fig. 1. The obtained results from fitting are:

$$\sigma_E/E = (46.7 \pm 0.6)\%/\sqrt{E} \oplus (0.9 \pm 0.9)\% \quad \text{for pions, and}$$
$$\sigma_E/E = (23.9 \pm 0.3)\%/\sqrt{E} \oplus (0.8 \pm 0.3)\% \quad \text{for electrons.}$$

The pion energy resolution is worse than the design value. From another beam test result [3], this is concluded to be caused by the 1 mm-thick acryl plates for fiber-routing. Fig. 2 shows the linearity for the energy measurement. In most energy region deviations are at a level of 1 %. At 200 GeV/c, we observed a large deviation of 2 % which could be caused by the saturation effect of magnet current for momentum analysis. For the tower boundary response, we observed no significant anomaly for pions. However, there was small anomaly (deviation of $\sim$ 10 %) for electrons at the boundary. EM calorimeter must be designed with more uniform response. The response ratios for electrons and pions (e/π ratios) are also determined as a function of momentum, as shown in Fig. 3. At low energies, the e/π ratios are slightly greater than 1. This is consistent with results from the previous

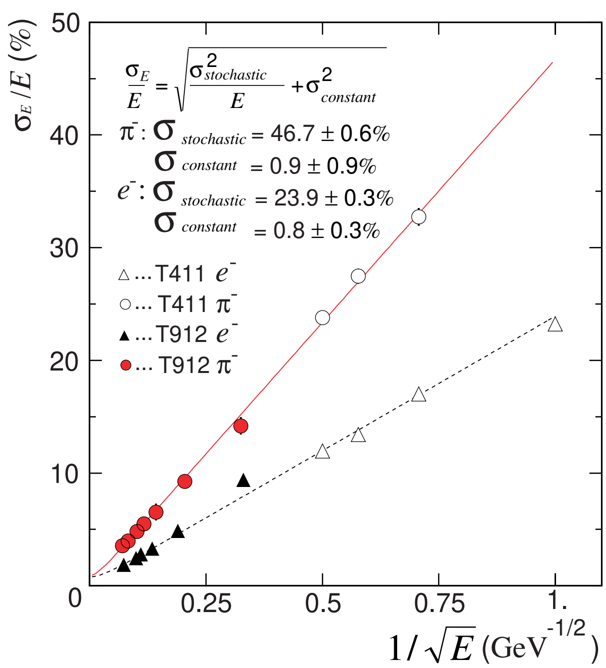

FIG. 1: Energy resolution of tile/fiber hadron calorimeter test module.

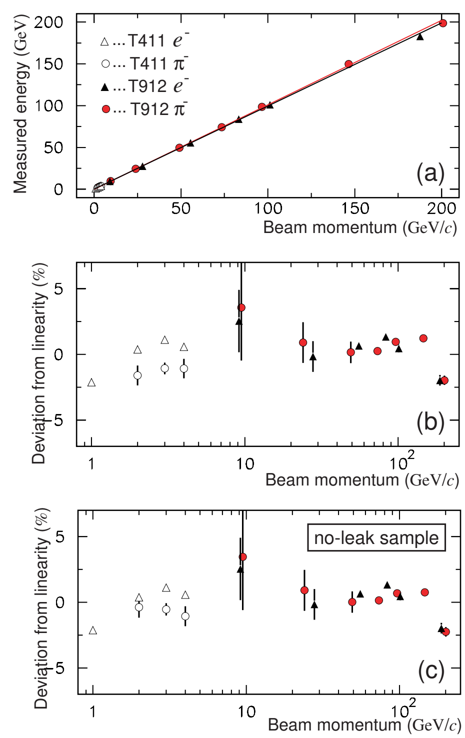

FIG. 2: Linearity and its deviation for the energy measurement. (a) and (b) are for full sample; (c) is for no-leak sample.

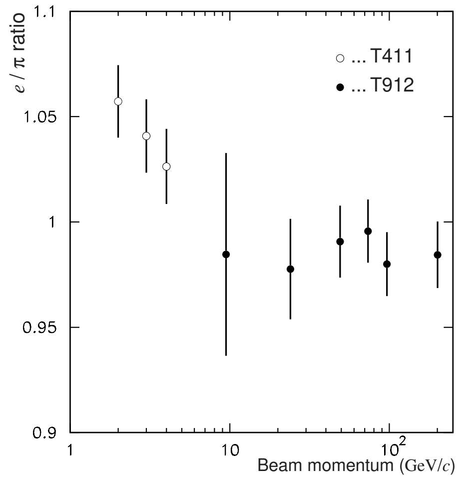

FIG. 3: e/π response ratio of the calorimeter vs. beam momentum.

beam test [3]. At higher energies average e/π ratio approaches to 1 because more fraction of energy is spent on π^0 production.

Performance of the preSH/SHmax test module was tested with beam as well [4]. Pion rejection of 1/1400 is achieved with electron efficiency of 98 % by using preSH, SHmax and HCAL. The position resolution is measured to be about 2∼3 mm due to noise and/or cross-talk effects of multi-anode PMT.

B. Other R&D's

As another option for fine granurality EMC, we are studying on stacks of scintillator strip arrays. Bench tests have been performed with various width of strips of 2 mm-thick. Non-uniformity of photo-electron (p.e.) yield over a strip was measured to be less than 4.8 % for 1 cm-wide strips. Average yield of 4.6 p.e./MIP, which corresponds to 260 p.e./GeV in EMC case, still needs further improvement.

Since we need multi-channel high-gain photon detectors operational in the magnetic field, R & D's on photon detectors have been made extensively. Multi-channel Hybrid Photodiode has nearly one hundred channels and is most promising for EMC and HCAL as well as SHmax, but cost down is needed for EMC/HCAL use. Recently developed Electron-Bombarded CCD (EBCCD) could be the best candidate for SHmax because of its large number of pixels and high sensitivity. We have started performance study on proximity-focused EBCCD which can be used in the magnetic field. The measured sensitivity is yet unable to detect single photon, and further studies are in progress.

III. SUMMARY

Study on calorimeter for JLC experiment is going on from the viewpoint of physics capability. A series of beam tests was done with a tile/fiber type test module. The obtained energy resolution almost satisfies the requirement for the detector. Granularity optimization, which should be optimized with a full simulation, is now in progress. Photon detectors operational in the magnetic field are also under study.

[1] K. Abe *et al.*, ACFA Linear Collider Working Group Report, hep-ph/0109166.
[2] S. Uozumi *et al.*, Submitted to Nucl. Instr. Meth. A.
[3] T. Suzuki *et al.*, Nucl. Instr. Meth. A **432** 48 (1999).
[4] K. Kawagoe *et al.*, Submitted to Nucl. Instr. Meth. A.