LCCAL: a Hybrid Electromagnetic Calorimeter*

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An Electromagnetic Calorimeter prototype based on a hybrid technique is described. The prototype is an absorber-scintillator sandwich with lateral W.L.S. fiber read-out with the addition of three Si-pad planes. Results from test-beam runs are given.

1. INTRODUCTION

An excellent jet energy reconstruction is a very important requirement for a Linear Collider Detector[1]. The capability to separate the contribution due to charged particles measured by the tracking system from the one coming from neutral particles detected in the calorimeters is mandatory for jet measurements. Showers produced by photons and electrons must be distinguished from the ones generated by hadron interactions and consequently the calorimeters have to be designed with the highest granularity compatible with costs and a reasonable number of channels. The proposed technique consists of a sampling calorimeter made by absorber and scintillator layers with wavelength shifting fibers and by 3 planes of Si pads to obtain very precise information on the transversal shower profile at different depths in the shower development.

2. THE PROTOTYPE

The produced prototype has 45 layers of lead absorber $25 \times 25 \times 0.3$ cm^3 ($\sim 24\ X_0$ in total) coupled to 45 layers of scintillator subdivided in cells of $5 \times 5 \times 0.3$ cm^3 each with a green WLS fiber inserted in a circular groove. The WLS fibers are connected to clean fibers with long attenuation length in order to transport the light signal at large distance. In the region of the 3×3 central scintillator cells, the fibers corresponding to the cells placed at the same lateral position are grouped into 4 bundles each connected to a Photo-Multiplier (PM), thus obtaining a 4-fold longitudinal segmentation. All the longitudinal sectors of the 16 border cells are grouped into a single bundle since they are used to recover the lateral energy released by particles impinging in the central cells.

Three planes of 252 Silicon diode pads (0.9×0.9 cm^2) are inserted at a depth of 2, 6 and 12 X_0 from the calorimeter front face. The planes consist of 3×2 detectors of 6×7 pads each which are connected through a conductive glue to a pcb where the front-end ASIC VAHDR9c from Ideas is mounted.

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*Presented by P. Checchia

2.1. Prototype construction details: scintillator

The scintillator tiles (SCSN-61 from Kuraray and BC-408 from Bicron) were machined, with a vacuum plate as a holder, in order to produce circular grooves for the fiber insertion and linear grooves for cell light separation. The linear grooves were filled by Tyvec paper.

2.2. Prototype construction details: fibers

All the WLS fibers (Kuraray 1mm diameter Y11 300 ppm multicladding, 40 cm in length) were polished and aluminised on one face by sputtering. A middle temperature oven (about $60°C$) was used to curl the fibers before their insertion into the 2.25 cm radius groove. This procedure was followed to ensure light yield stability which could not be guaranteed when bending the fibers at room temperature.

2.3. Prototype construction details: Silicon pads

The Silicon pad production was accomplished in three batches with different technological characteristics; an optimisation was made possible by a close interaction with the Silicon foundry. The most relevant figures of merit of the production are summarized in Table I.

	1^{st} batch	2^{nd} batch	3^{rd} batch
AC Coupling	Integrated	Integrated	External
Wafer rejected	1/11	2/9	0/9
Depletion voltage	32 V	27 V	28 V
Current at depletion	2.1 μA	0.8 μA	0.6 μA
Not depleted pads	0/420	8/249	0/378

Table I: Production yield for the three different batches.

3. TEST BEAM RESULTS

After a test of a segment of the calorimeter (4 layers, 2 X_0) and of a single Si detector in summer 2002 at CERN [2] giving a first indication on the light yield (>5.1 ph.e./m.i.p./scintillator tile), the complete prototype (except for the third Si layer) was exposed twice to the Frascati Beam Test Facility (BTF)[3] in December 2002 and April 2003. BTF is a low energy electron beam (50 to 750 MeV) where the multiplicity of particles arriving almost at the same time can be tuned. A high-energy run with the fully equipped detector (including the third Si layer) was then done at the CERN SPS H6 test beam.

3.1. Energy resolution and linearity

The PM response calibration could be obtained by comparing the signals of non-interacting particles (muons or pions) in the four longitudinal segments. The signal amplitude is expected to scale with the number of scintillator layers of each segment. This procedure has shown a fair agreement with the MC expectations in the electromagnetic shower development.

After the calibration, the linearity is good below 30 GeV (unfortunately at very high energies the PMs with largest gain were showing clear evidence of saturation) and the energy resolution is as expected ($11.1\%/\sqrt{E}$ with a constant term compatible with the beam momentum spread) (Figure 1).

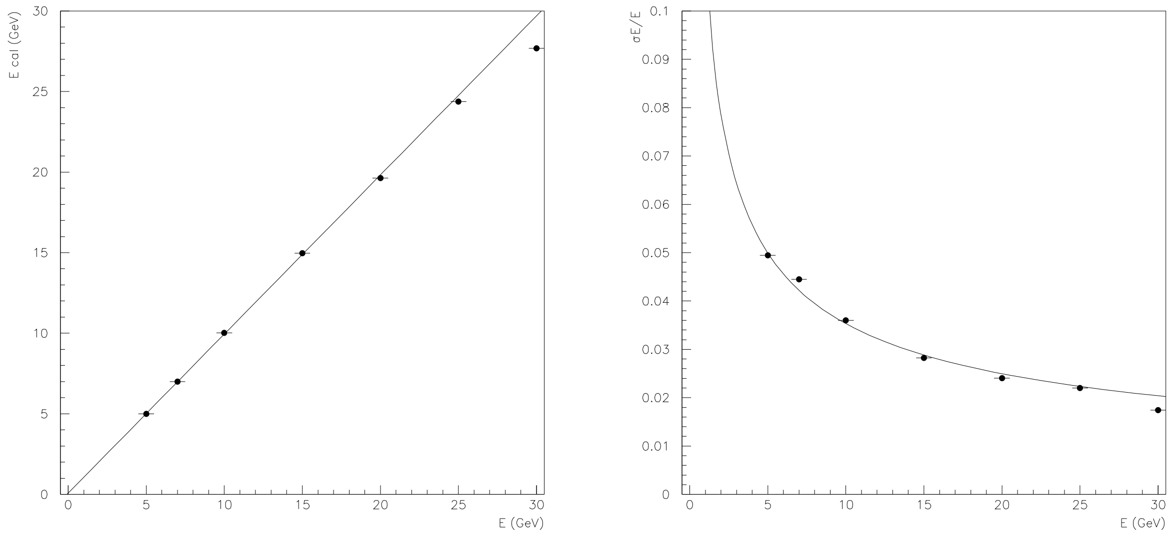

Figure 1: Left: detector energy response to electrons of different energy. Right: energy resolution as a function of the input energy in GeV. The full line corresponds to the fitted function $\sigma_E/E = 11.1\%/\sqrt{E}$. The point at 30 GeV was excluded from the fit.

3.2. Electron-hadron separation

The detector has a high redundancy in the measurements of the longitudinal and lateral shower development. This is given by the four calorimetric longitudinal samples and by the three planes of high granularity Si pads. Therefore the electron-hadron separation is excellent. Examples of the quantities used for the identification are shown in Figures 2. The evaluation of the overall rejection factor is limited by the contamination of electrons in the pion beams and is smaller than 10^{-3}.

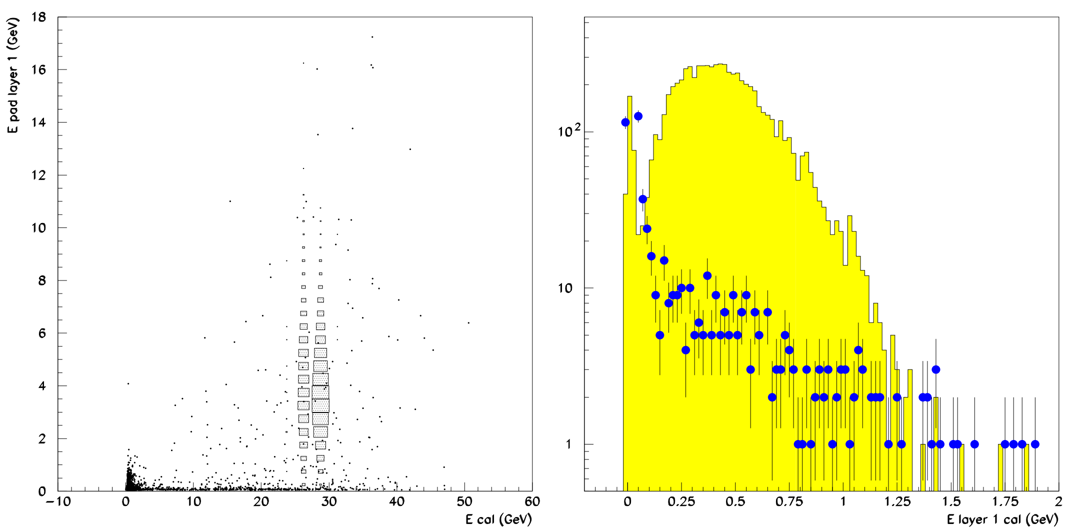

Figure 2: Left: the energy on the first Si pad plane vs. total energy on the calorimeter for electrons of 30 GeV (boxes) and pions of 75 GeV (dots). Right: energy response to 30 GeV electrons (histogram) and 30 GeV pions (dots) on the first longitudinal segmentation of the calorimeter. The peak at low energy on the histogram is due to a contamination of the electron beam.

3.3. Shower position reconstruction

The shower position is determined through the centre of gravity of the energy released on the pads. The position resolution is obtained by comparing the reconstructed position with the particle impact point as given by a microstrip telescope with a resolution of 50 μm located in front of the detector. A plot with the difference between the reconstructed and the predicted positions for 10 GeV electrons is shown in Figure 3.

Given the good position resolution, it is possible to compare the energy dependence on the impact point on the calorimeter as determined both by the external telescope and by the internal pad information. This is shown in Figure 3: the dependence is small ($< 2\%$) and there is almost no difference between the two position determinations. It is therefore possible to use the pads to apply a correction to the energy value depending on the reconstructed particle impact.

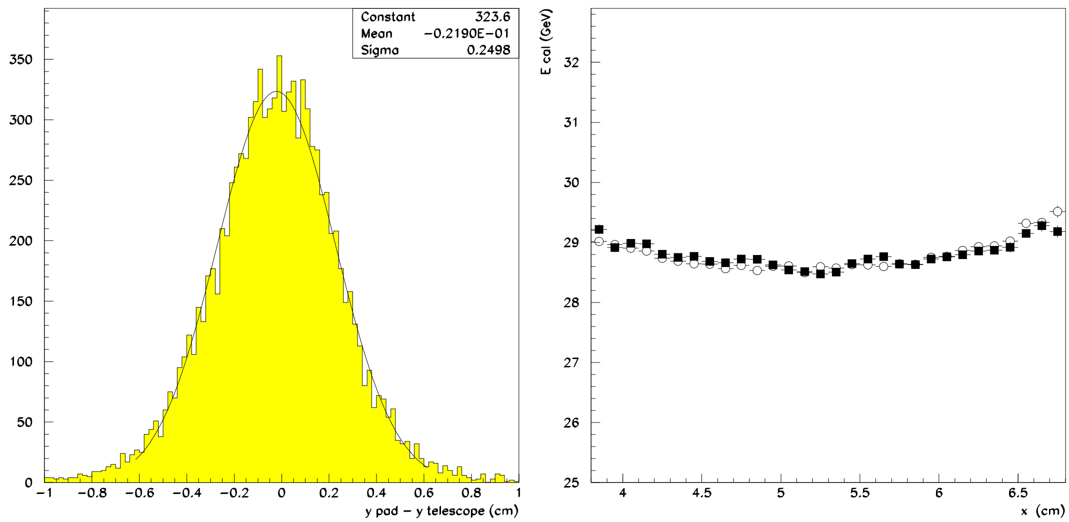

Figure 3: Left: the difference y reconstructed-y telescope for the vertical (y) coordinate on the first Si pad plane for 10 GeV electrons. Right: energy dependence on the horizontal (x) impact coordinate for 30 GeV electrons: predicted by the telescope (open circles), reconstructed by the first plane of Si pads (black dots).

4. Particle-particle separation

The capability of this detector to separate the contributions of two near particles is a complex pattern recognition problem. An example of two particle separation using the first two layers of Silicon pad is shown in Figure 4. In the present data a light leakage from consecutive scintillator cells of about 5% was observed. In addition, the Silicon pad signal was saturating at a rather low value (equivalent to about 15 single tracks) because of an erroneous setting of the amplification gain. These facts make difficult to exploit the ultimate potential of this kind of detector concerning particle-particle separation and require the implementation of different algorithms. Studies on this subject are still going on.

5. Conclusions

The preliminary results obtained with the calorimeter built following the proposed technique are in agreement with the expectations. In particular the energy resolution is in the range $11 \div 11.5\%/\sqrt{E}$ with a negligible constant term, the energy uniformity is at the level of few %, the position reconstruction is ~ 2 mm at 30 GeV and the electron hadron separation is better than per mille level. The analysis on the particle-particle separation is ongoing.

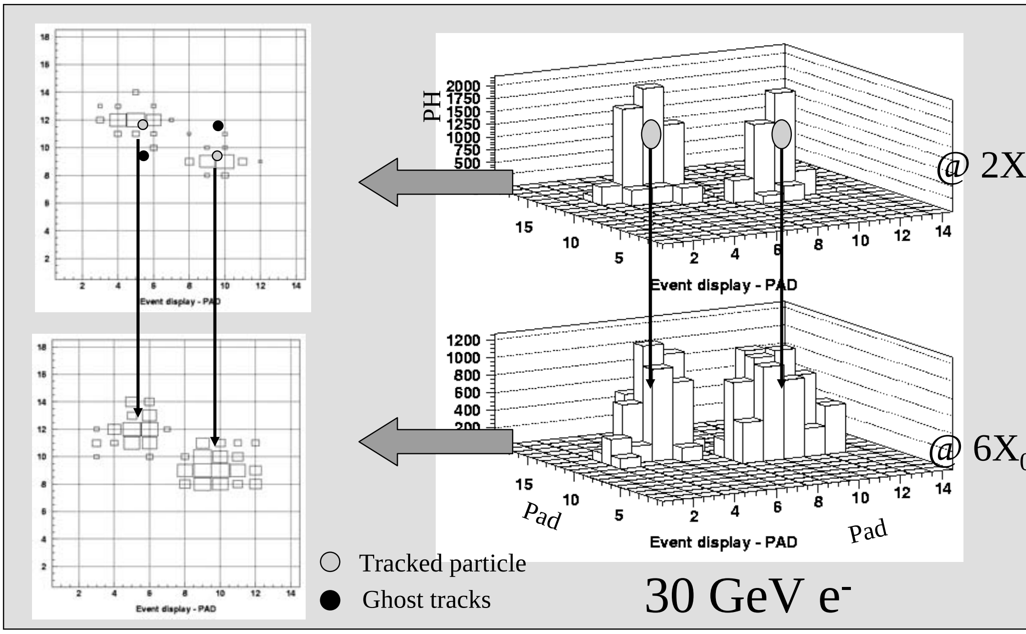

Figure 4: Example of particle separation on the silicon pads. The dots correspond to particle impact prediction using the external telescope. The physical particles are clearly recognised.

References

[1] TESLA Technical Design Report DESY 2001-011 ECFA 2001-209, Part IV.
[2] LC note LC-DET-2003-014 .
[3] G. Mazzitelli et al., Nucl. Instr. Meth. A 515 (2003) 524.