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A novel strip energy splitting algorithm for the fine granular readout of a scintillator strip electromagnetic calorimeter

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ABSTRACT

We describe an algorithm which has been developed to extract fine granularity information from an electromagnetic calorimeter (ECAL) with strip-based readout. Such a calorimeter, based on scintillator strips, is being developed to apply particle flow reconstruction to future experiments in high energy physics. The application of this algorithm to 100 GeV hadronic jets in an ECAL with $45 \times 5\ \text{mm}^2$ transverse segmentation improves the energy resolution from 3.6% to 3.0%, to be compared to the resolution of 2.9% achieved by an ECAL with $5 \times 5\ \text{mm}^2$ segmentation. The performance can be further improved by the use of $10 \times 10\ \text{mm}^2$ tile-shaped layers interspersed between strip layers.

1. Introduction

In the experiments being designed for next generation particle colliders, the particle flow approach (PFA) [1,2] is the leading candidate to achieve the excellent jet energy resolution required to fully exploit the information offered by the detector and the collider. In PFA, the energy of charged particles is measured by the tracking system, which has a much better momentum resolution than the energy resolution of calorimeters: typical resolutions are $\sigma_{1/p_T} \sim 2 \times 10^{-5}\ \text{GeV}^{-1}$ for the tracking system, and $\sigma_E/E \sim 46\%/\sqrt{E(\text{GeV})} \oplus 1.6\%$ for the HCAL response to single charged pions [3]. The calorimeters are used to estimate the energy only of neutral particles. In order to apply this approach, the calorimetric showers of each particle must be individually reconstructed. The granularity of calorimeter readout is therefore a key issue.

As an example, the sampling electromagnetic calorimeter (ECAL) with tungsten absorbers being designed for the International Large Detector (ILD, a detector being designed for use at the International Linear Collider (ILC) [3]) is optimized to have a transverse segmentation of 5 mm, corresponding to half of the Moliére radius of tungsten, and 20–30 longitudinal samplings in a total thickness of 23 X_0, giving a total of $\sim 10^8$ readout channels. The effective Molière radius of the ECAL is around 20 mm. A readout granularity finer than 5 mm does not result in significant performance gains for jet energies of 100 GeV and below, which correspond to the most relevant jet energies for the ILC physics program [1]. One technology being developed to effectively achieve this high calorimeter granularity is based on plastic scintillator strips individually read out by miniature photon detectors, for example, pixelated photon detectors (PPD, also commonly known as SiPM) [5].

The use of long scintillator strips rather than $5 \times 5\ \text{mm}^2$ tiles simplifies the design of such an ECAL, and also reduces its cost, due to the reduced number of readout channels. Successive ECAL layers have orthogonally aligned strips, giving an effective granularity close to the strip width. The CALICE collaboration has developed and constructed ECAL prototypes based on this technology, using scintillator strips of length 45 mm and width 5 or 10 mm, individually read out by PPDs [6,7].

This paper presents a reconstruction method which can be used to extract close to $5 \times 5\ \text{mm}^2$ effective granularity from such long scintillator strips, and reports on measurements of its performance using events fully simulated in ILD. Details of this detector are given in the next section, the reconstruction procedure is explained in Section 3, and Section 4 describes the calibration procedure. The performance of this method on the basic detector-related measures of position resolution and two-particle separation are discussed in Sections 5 and 6, while the jet energy resolution, which affects the physics

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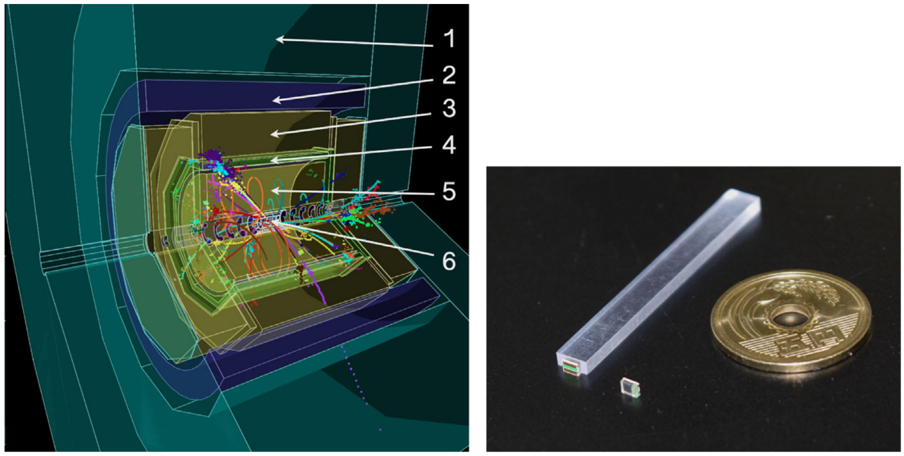

Fig. 1. *Left*: a view of ILD with a simulated multiple-jet event. The highlighted detector components are: 1. muon detector; 2. solenoid; 3. hadron calorimeter; 4. electromagnetic calorimeter; 5. TPC; and 6. vertex detector. *Right*: a 45 mm × 5 mm × 2 mm scintillator strip and a PPD.

performance of the detector, is discussed in Section 7. Finally we discuss the results in Section 8 and summarize this study in Section 9.

2. Detector model

Starting from the interaction point (IP), the ILD consists of a vertex detector, silicon tracking layers, a large time projection chamber (TPC) surrounded by additional silicon tracking detectors, a calorimeter system consisting of electromagnetic and hadronic sections, all placed within a solenoidal magnetic field of strength 3.5 T. The steel return yoke is instrumented to provide muon identification. The basic structure consists of a central, "barrel", region aligned with the beam axis, closed by two "endcaps" in the forward regions. The ECAL barrel detector has an octagonal cross-section, a length of around 5 m, and an inner radius of 1.85 m. A cylindrical coordinate system with its axis (z) aligned with the beam line is used in this paper. More details of the ILD design can be found in [3]. The ILD is simulated in MOKKA [8], a GEANT4-based simulation tool [9]. Fig. 1 *left* shows a multiple-jet event simulated in ILD.

The ILD strip-scintillator ECAL (strip-ScECAL) is a sampling calorimeter. In the simulation model used in this study, 30 sensitive layers are interleaved with tungsten plates of thickness 2.1 (4.2) mm in the inner 20 (outer nine) layers. The tungsten absorber layers correspond to a total thickness of 22 X_0, while layers of readout electronics, copper heat transfer plates, and scintillators contribute less than a single additional X_0. The total thickness of the ECAL is around 200 mm.

The sensitive layers are tiled with $45 \times 5\ \text{mm}^2$ scintillator strips of thickness 1 mm. Strips are aligned orthogonally in successive layers. A dead volume of size $2.5 \times 1.0 \times 0.91\ \text{mm}^3$ is implemented at the end of each scintillator strip to represent the volume occupied by the PPD, which leads to a constant term in the energy resolution. In the analyses presented in this paper, when scintillator tiles or strips with an area of less than $45 \times 5\ \text{mm}^2$ are used, this dead volume is scaled by the strip area.[1] This avoids penalizing smaller cell sizes with an additional constant term to the energy resolution. Each strip is enveloped by a reflective film of thickness 57 μm. Scintillator strips and PPDs are mounted on $180 \times 180\ \text{mm}^2$ "ECAL base units" (EBU), printed circuit boards which also host the front-end electronics and LEDs used for calibration.

The EBUs are arranged within mechanical structures in such a way as to avoid any projective cracks. Further technical details are available in [3]. Printed circuit boards and copper heat radiators are simulated in each detector layer. Four different scintillator tile configurations were used in this study:

1. $5 \times 5\ \text{mm}^2$ tiles ("5 × 5");
2. $45 \times 5\ \text{mm}^2$ strips ("45 × 5");
3. alternating layers of $5 \times 5\ \text{mm}^2$ tiles and $45 \times 5\ \text{mm}^2$ strips ("alt5"); and
4. alternating layers of $10 \times 10\ \text{mm}^2$ tiles and $45 \times 5\ \text{mm}^2$ strips ("alt10").

Successive strip layers were always orthogonally aligned. A hadronic calorimeter based on 40 layers of $30 \times 30 \times 3\ \text{mm}^3$ scintillator tiles interleaved with 20 mm iron absorbers was simulated in this study.

3. Strip splitting algorithm

A simple algorithm, the Strip Splitting Algorithm (SSA), has been developed to extract fine granularity information from the long strip geometry. Each strip is split into n virtual cells along its length; n is chosen to result in approximately square virtual cells; for example, a $45 \times 5\ \text{mm}^2$ strip is split into nine $5 \times 5\ \text{mm}^2$ cells. A simple procedure is used to distribute the total energy E_{strip} detected by the strip among its virtual cells. A weight w_k is assigned to each virtual cell k, defined as the sum of the energies E_i of all strips in immediately neighboring layers which intersect with virtual cell k, when seen from the IP:

$$w_k = \sum_{(i = \text{intersect})} E_i \tag{1}$$

where the sum runs over strips, i, in immediately neighboring layers which intersect with the virtual cell k. The energy E_k assigned to virtual cell k is then

$$E_k = E_{\text{strip}} \frac{w_k}{\sum_{(j = \text{all virtuals})} w_j} \tag{2}$$

where the sum j runs over all virtual cells of the strip being split. Fig. 2 shows a schematic of the SSA procedure.

In the case of the alt10 model, the $10 \times 10\ \text{mm}^2$ tile is first split into 2×2 virtual cells. The immediately neighboring strip layers are used to partition the tile's energy into these virtual cells using a very similar method to that defined above, making use of the strips' orthogonal orientation. In a second step, the virtual cells originating from the $10 \times 10\ \text{mm}^2$ tiles are used to partition strips' energy among their virtual cells, as described above.

[1] This scaling is of course not possible in practice, although we note that techniques for the readout of scintillation light from the lower surface, which therefore avoid dead space due to the PPD, are currently being studied.