

# NOVEL 3D CLUSTERING ALGORITHM AND TWO PARTICLE SEPARATION WITH TILE HCAL

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Based on a novel shower reconstruction algorithm, the study of two particle separation with tile hadron calorimeter (HCAL) is performed. The separability of two close-by particles is found to be strongly dependent on transverse and longitudinal segmentation of tile HCAL.

## 1 Introduction

Event reconstruction in a future linear  $e^+e^-$  collider experiment will be based on a particle flow concept<sup>1</sup> aiming at reconstruction of every single particle in an event. Clearly, performance of the particle flow algorithm will strongly depend on its capability to separate two and more close-by showers. In its turn particle separation capability will be influenced by transverse and longitudinal segmentation of calorimeters. In this note we investigate the impact of transverse and longitudinal segmentation of hadron calorimeter on two particle separation. The study is based on a novel shower reconstruction algorithm which makes use of finely granulated electromagnetic and hadron calorimeters foreseen for a linear collider detector.

## 2 Simulation

The detector setup used in our simulation closely follows the calorimeter design outlined in the TESLA Technical Design report<sup>2</sup>. The electromagnetic calorimeter consists of tungsten absorbers interspersed with silicon diode pads and is characterised by a very high granularity. The transverse size of the readout cell is  $1 \times 1 \text{ cm}^2$ . The hadron calorimeter represents an analog device, consisting of stainless steel absorber plates interspersed with scintillating tiles. Calorimeter parameters are given in Table 1. In our studies calorimeter response has been simulated using the GEANT3 package<sup>3</sup>. Hadronic interactions are simulated using FLUKA<sup>4</sup> complemented with low energy neutron transport code MICAP<sup>5</sup>.

Calorimeter	Type	Number of layers	Thickness of absorber layers	Thickness of active layer
ECAL	W/Si	40	1-30 : 1.4mm 31-40 : 4.2mm	0.5mm
HCAL	Fe/Sci	40	20mm	5mm

Table 1: Parameters of calorimeters.

Several options of transverse granularity of HCAL have been considered:  $1\times 1$ ,  $3\times 3$  and  $5\times 5$  cm<sup>2</sup>. For the  $3\times 3$  cm<sup>2</sup> tile size, the readout scheme with each two adjacent layers joined in depth is also considered. The influence of transverse tile size is studied using a recently developed shower reconstruction procedure which takes advantage of the fine granularity of calorimeters.

### 3 Clustering

Before describing clustering and the shower reconstruction procedure, some definitions need to be introduced. By clusters we mean internal structures inside shower, e.g. pieces of tracks produced by minimal ionising particles, electromagnetic subshowers originated from neutral pions or set of adjacent hits produced by several charged particles in the vicinity of nuclear interaction points. The shower is then viewed as a group of topologically connected clusters.

Clustering begins with the hit classification procedure based on the energy of each hit. Hits with energy deposit greater than half a MIP signal and less than 1.7 MIPs are assigned for the so called "track-like" category. Hits with an extremely dense energy deposit exceeding 3.5 times MIP expectation, are considered as relics of electromagnetic activity. Finally, hits with energy deposit ranging from 1.7 to 3.5 MIPs are assigned for "hadron-like" category. Hit classification is illustrated in Figure 1. At the next stage, the clustering procedure based on 3D pattern recognition is performed and clusters are classified into different categories taking into account hit categorisation, topological properties of clusters, their inter-relations and position in the calorimeter volume. The "track-like" clusters are classified as having small eccentricity and low hit density. The "hadron-like" clusters have relatively large eccentricity and low hit density. The "electromagnetic-like" clusters have high hit density and small eccentricity. An additional hit category is introduced by clustering. These are hits spatially disconnected from other clusters and presumably initiated by neutrons, hence the name for this category: "neutron-like" hits.

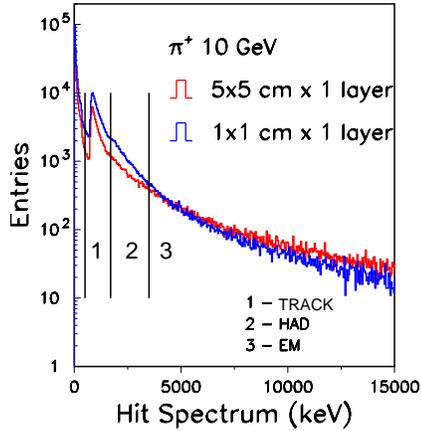


Figure 1: Hit classification based on hit energy.

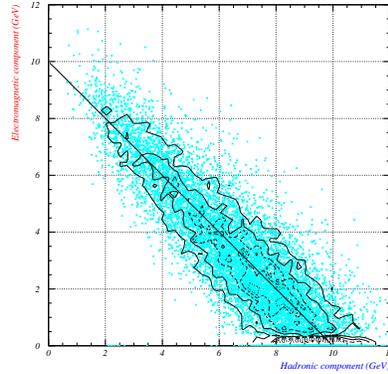


Figure 2: Correlation between electromagnetic and hadronic components of a 10 GeV  $K_S^0$  shower.

Such a clustering procedure results in separation of total energy into different components. Correlation between hadronic component, including energy contained in the "track-like", "hadron-like" clusters and "neutron-like" hits and electromagnetic component, including energy contained in the "electromagnetic-like" showers, is illustrated in Figure 2. The reconstructed energy distribution of a 10 GeV  $\pi^+$  shower after dedicated energy correction procedure similar to that used by DREAM collaboration<sup>6</sup> is presented in Figure 3. This energy correction procedure is based on individual weighting of hadronic and electromagnetic components of the shower energy and uses a priori knowledge of the  $\pi^+$  beam energy. Such an approach is obviously non-Bayesian and Figure 3 indicates only the degree of correlation between measured hadronic and electromagnetic components of the shower energy rather than realistically achievable energy resolution.

#### 4 Shower Reconstruction

Once clustering is performed, showers are reconstructed by building a "tree" of "electromagnetic-like" and "hadron-like" clusters connected by "track-like" clusters. "Neutron-like" hits and clusters disconnected from the main tree are added to shower if their distance to the shower axis is less than some cut parameter,  $D_{cut}$ . Shower axis is defined at each step of the shower building

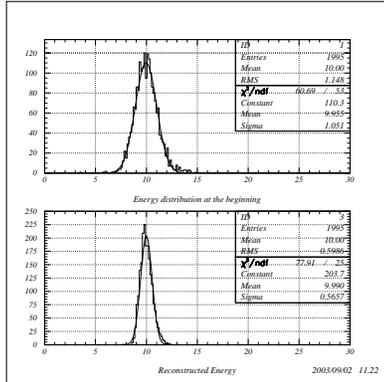


Figure 3: Hadron energy resolution without (upper plot) and with (lower plot) weighting procedure using a priori knowledge of hadron beam energy.

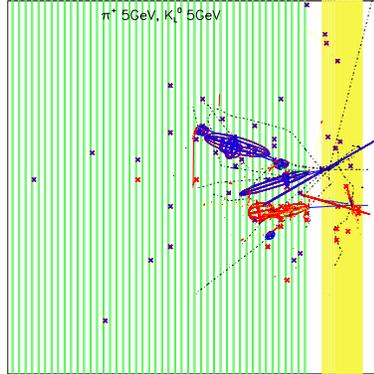


Figure 4: Two reconstructed showers from 5 GeV  $K_L^0$  and 5 GeV  $\pi^+$ . Showers are composed of clusters represented by inertia ellipsoids. Neutron hits are indicated as a cross-dots.

process as the main principle axis of inertia tensor associated with shower. For showers produced by charged particles, the cluster nearest to the track intersection point with the ECAL front plane seeds the shower. Furthermore, for showers initiated by charged particles, parameter  $D_{cut}$  is adjusted iteratively during the process of shower building until the energy contained in the reconstructed shower matches the best the momentum of the associated track. Typical value of  $D_{cut}$  ranges from 1 to 3 cm.

## 5 Two Particle Separation

To estimate shower separation performance we simulated the response of the electromagnetic and hadron calorimeters to two particles,  $K_S^0$  and  $\pi^+$ , which are normally incident at the ECAL front plane. Our preliminary study did not take into account the effect of a magnetic field. The momentum of  $\pi^+$  and its trajectory are assumed to be precisely measured with an inner tracking system. The particle separation performance is estimated as a function of distance between two particles. Figure 4 presents an example of two resolved showers initiated by  $K_S^0$  and  $\pi^+$  with an energy of 5 GeV each. Figure 5 shows the distribution of the reconstructed energy of the neutral shower produced by a 10 GeV  $K_L^0$  in the proximity of the shower produced by a 10 GeV  $\pi^+$ . The distance between the two particles is 7cm. Distributions are shown for two options of transverse segmentation of an analog HCAL,  $3 \times 3$  and  $5 \times 5$

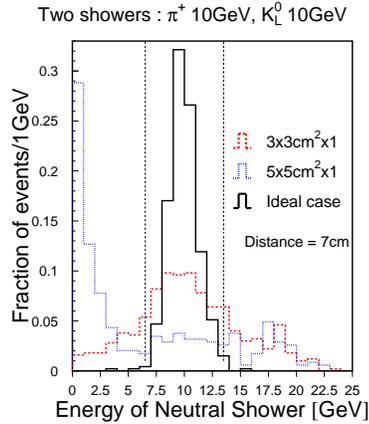


Figure 5: Distributions of the reconstructed energy of the neutral shower from  $K_S^0$  in the presence of nearby shower from  $\pi^+$  for two options of HCAL transverse segmentation,  $3 \times 3$  and  $5 \times 5$   $\text{cm}^2$  (dashed and dotted histograms, respectively). Solid histogram shows reference distribution obtained for a 10 GeV  $K_S^0$  shower in the absence of nearby shower.

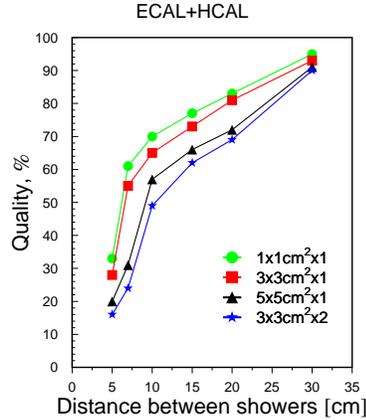


Figure 6: Separation quality as a function of distance between two particles, 10 GeV  $K_S^0$  and 10 GeV  $\pi^+$ , for different options of HCAL transverse and longitudinal segmentation.

$\text{cm}^2$ . The reference energy distribution obtained for a 10 GeV  $K_L^0$  shower in the absence of any nearby shower is also shown. Performance is quantified in terms of particle separation quality defined as a fraction of events in which the reconstructed energy of a neutral shower lies in the interval  $E_{true} \pm 3\sigma$ , where  $E_{true}$  is the true energy of  $K_L^0$  and  $\sigma$  is the nominal energy resolution. The separation quality is found to be highly sensitive to both transverse and longitudinal segmentation of the HCAL as demonstrated in Figure 6. An independent approach of shower separation based on an alternative clustering method with minimal spanning trees gives comparable results for a digital calorimeter with  $1 \times 1$   $\text{cm}^2$  RPC cell size<sup>7</sup>.

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