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GAmma Reconstruction at a LInear Collider

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Detectors for a future linear electron-positron collider are being designed with the requirements of Particle Flow event reconstruction method in mind. A central aspect is the extremely high readout granularity of the calorimeters. New techniques to identify and measure photons are possible with such a caloriemter. The GARLIC algorithm has been designed to make use of this detailed measurement of the spatial distribution of energy deposits in such a calorimeter to identify photon clusters, a central task of Particle Flow reconstruction.

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1. Introduction

Several proposals have been made for electron-positron colliders at the high energy frontier, e.g. [1, 2]. The major role of such a machine and its associated detector(s) will be to make precision measurements of high energy phenomena in the Higgs, top and electro-weak sectors, as well as possible beyond-the-standard model processes.

To maximise the usefulness of the produced events, the full reconstruction of hadronic decay processes is desirable. To make accurate measurements of these final states, excellent jet energy resolution is required. The particle flow approach to jet energy measurement has been proposed and shown to work significantly better than traditional techniques, for example allowing the statistical separation of hadronic W and Z decay modes [3, 4]. This approach to event reconstruction, which relies on the separation of calorimetric energy deposits on a particle-by-particle basis, is best applied to a detector whose calorimeter has a highly segmented readout.

In this paper we discuss a photon reconstruction algorithm designed to be used in a highly granular electromagnetic calorimeter (ECAL), such as the silicon-tungsten ECAL being developed for the ILD concept [5].

2. Role of photon reconstruction in particle flow

On average, photons carry around 25% of a hadronic jet's energy, predominantly produced in the decays of neutral pions. A further $\sim 10\%$ is carried by neutral hadrons, and the remaining $\sim 65\%$ by charged particles, mostly hadrons. For the application of the Particle Flow approach, these components must be efficiently and cleanly identified, in order to allow a correct combination of measurements of charged particle momenta and neutral particle calorimeter deposits. Any confusion between neutral and charged energy deposits in the calorimeters leads to either an over- or under-estimation of energy. The identification of photons, and the estimation of their energy, is therefore a central aspect of Particle Flow reconstruction.

Photons leave a characteristic energy deposit in the ECAL, with a typical longitudinal and transverse profiles which vary little between showers. A specific clustering algorithm can be used to identify such clusters in the ECAL. Energy deposits not part of such photon clusters can then be treated by more general algorithms to cluster deposits from hadronic showers, whose shape has large variations from shower to shower. This initial removal of photon clusters can simplify the task of the general algorithms which follow it.

3. GARLIC algorithm

The aim of the GARLIC algorithm [6] is to efficiently and cleanly identify energy deposits due to photons in the ECAL. An important aspect is its ability to reject ECAL clusters which are not induced by photons, for example by charged or neutral hadrons. The clustering algorithm is informed by the knowledge of the form of electromagnetic showers, in terms of their longitudinal and transverse development. An outline of the algorithm is as follows:

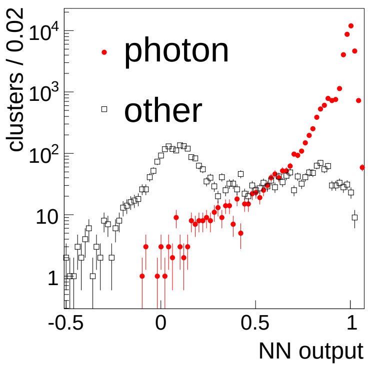

Figure 1: Neural Network output for clusters far from tracks, with an energy between 1 and 3 GeV.

- ECAL hits within some distance of the extrapolation of identified tracks are removed. This distance is typically the cell size of the ECAL. This removes many hits produced by charged particles.
- Hits in the first twelve layers of the ECAL are projected onto the ECAL front face, weighted by their energy. A simple two-dimensional clustering is performed in this projection. Two-dimensional clusters satisfying requirements on energy and number of hits are selected as cluster seeds.
- Cluster seeds are then projected into the ECAL, along the line between the interaction point and the seed position. Hits within some distance of this projection are added to the cluster, making a cluster core. This distance is typically the Molière radius of the ECAL. This procedure clusters the hits within the shower core.
- After all cluster cores have been identified, remaining hits within same distance (typically a few Molière radii) of a core are added to the nearest cluster core.
- Several artificial neural networks (ANN) are trained to distinguish between true photon clusters and those arising from other particles, based on a number of cluster observables. Different trainings are used according to energy and the presence of nearby tracks. The ANN output is used to reject non photon-like clusters. Figure 1 shows an example of an ANN output spectrum.

4. Performance in jet events

The performance of the algorithm has been measured in four-quark events produced in e^+e^- collisions at a centre-of-mass energy of 500 GeV, fully simulated in the ILD. Such events typically contain four high energy hadronic jets, with a mean energy of 125 GeV. The algorithm is considered to have successfully identified a photon if a cluster is found within 0.01 radians of the true photon direction. The efficiency depends most strongly on the photon energy and the distance between the photon and the nearest charged particle at the front face of the ECAL. For photons above 500 MeV,

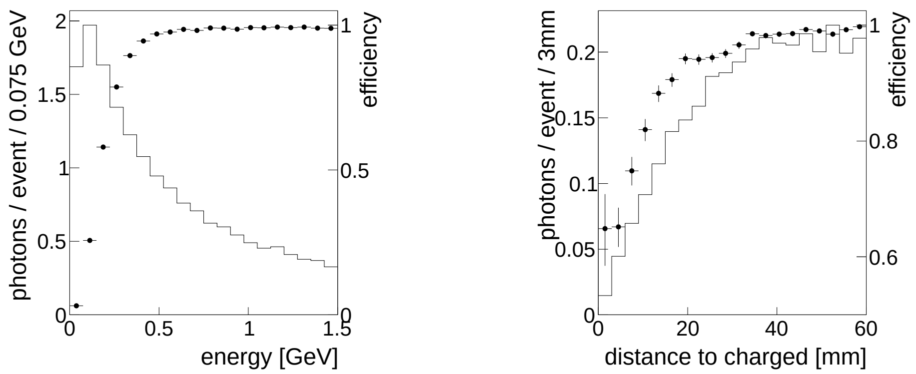

Figure 2: Efficiency (points with error bars) of the GARLIC algorithm as a function of energy (left) and distance to the nearest charged particle at the ECAL entrance (right). The solid histograms show the distributions of photons in these observables in the studied four-jet events at 500 GeV.

the efficiency is above 95% for distances greater than 30 mm, and falls to around 80% at a distance of 10 mm, and $\sim$ 60% at a distance of 0 mm. Well isolated photons, at a distance of at least 40 mm from the nearest track, have an efficiency of above 99% for energies of at least 500 MeV, while at 200 MeV the efficiency is around 55%. There is no strong dependence of the efficiency on the distance to the nearest photon in the ECAL, or on the polar angle of the photon.

To investigate the purity of the selected clusters, we consider what particle deposited the largest fraction of the clustered energy. The fraction of clusters produced by different particle types as a function of cluster energy is shown in Fig. 3. For identified clusters of at least 1 GeV, around 95% of identified clusters have their largest contribution from photons. The largest source of fake photon clusters is from neutral hadrons. Such mis-identification is not particularly damaging from the point of view of jet energy resolution, since no confusion between charged and neutral energy deposits (with its associated over- or under-counting of energy) has occurred. At lower energies, a larger number of fake clusters is identified, produced both by neutral and charged hadrons. At the lowest energies, below around 200 MeV, around 25% of identified clusters are not, in fact, produced by photons.

Figure 4 shows the comparison between the generated and reconstructed photon energy in the four-jet event sample. The distribution of the difference between the total photon energy reconstructed by GARLIC per event and the true generated photon energy has a sharp central peak, whose width is due to the intrinsic ECAL energy resolution, with additional non-Gaussian tails due to the loss or mis-reconstruction of photons. The RMS of the distribution is around 10.8 GeV, corresponding to around 2% of the total event energy, giving a rather small contribution to the overall jet energy resolution.

5. Conclusions

The GARLIC algorithm has been developed to cluster photon energy deposits in a highly granular ECAL, as proposed for linear collider experiments. The ability to identify such energy deposits is essential for the application of Particle Flow event reconstruction. The algorithm searches

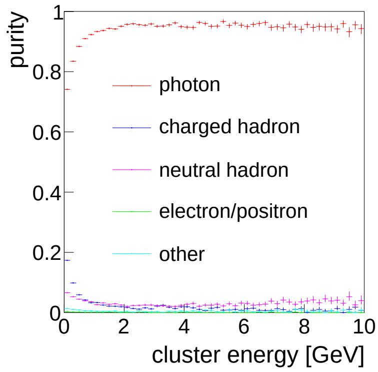

Figure 3: Fraction of selected GARLIC clusters in 500 GeV four-jet events which have their dominant energy content produced by different particle types, shown as a function of the cluster energy.

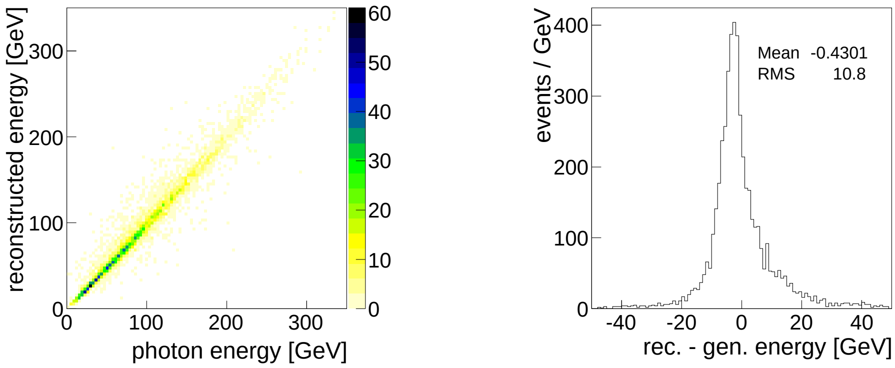

Figure 4: Comparison of the generated and reconstructed photon energy in 500 GeV four-jet events.

for energy deposits which have the form expected of electromagnetic showers. As a final step, a Neural Network-based selection is used to select photon-like clusters.

The performance of the algorithm has been measured in simulated four-jet events. The efficiency and purity of the photon selection is excellent (both above 95%) for photons with an energy of at least 500 MeV, and isolated by at least 3 cm from charged particles at the entrance to the ECAL. The selection of lower energy and less isolated photons has somewhat lower selection efficiencies and purities. The contribution from this level of mis-reconstruction by the GARLIC algorithm is not expected to give a significant contribution to the overall resolution of the jet energy measurement.

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