Electromagnetic Shower Reconstruction for the Silicon Detector

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This report presents a two–pass reconstruction algorithm for electromagnetic showers, based on studies with simulated photons in the highly segmented Silicon Tungsten calorimeter of the Silicon Detector concept for the International Linear Collider. It is shown that the initial reconstruction and identification of the dense shower cores allows shower separation down to 3 cm distance between two photons on the calorimeter surface.
First results are shown for the subsequent collection of unassociated hits around the shower cores necessary to reconstruct complete energy deposits by individual particles.

1. INTRODUCTION

The Silicon Detector concept (SiD) has highly granulated calorimeters [1] to allow the use of Particle Flow techniques for optimal energy resolution, which can only be achieved if individual showers can be reconstructed with high efficiency and purity. For electromagnetic showers, this task can be accomplished by a two–pass algorithm. The first pass aims at shower purity (all energy deposits within one cluster should originate from the same particle) by locating dense shower cores. A second pass of assigning further hits to the cores is neccessary to enhance the energy collection efficiency, i.e. the fraction of reconstructed energy from each particle. The algorithm is tuned and tested with Monte Carlo (MC) samples of isolated photons and of photons from $K_s^0 \to \pi^0\pi^0$ decays. In both samples, the energy range of the photons is $E_\gamma = 1 - 10\,\mathrm{GeV}$.

In the following the reconstruction and identification of shower cores using a Minimum Spanning Tree (MST) algorithm is described, followed by a study of the prospects to resolve nearby showers as a function of the spatial separation of two photons on the calorimeter surface. The general concept of assigning fragmented hits to the cores is then outlined, and preliminary studies are summarized.

2. SHOWER CORES AND PHOTON SEPARATION

The dense cores of electromagnetic showers are reconstructed using an MST algorithm, which already has been used for global clustering of hadronic Z–pole events at the SiD [2]. The algorithm merges two hits into the same cluster if the three–dimensional distance between the centers of the corresponding calorimeter cells is below a threshold, which is set to 0.75 cm in this study. With this value, only hits from neighboring cells get clustered together, which is the finest reasonable step size unless further information such as energy density is used in addition.

Each simulated photon results in several clusters, one of which usually contains the bulk of the deposited energy. This shower core is identified by basic requirements on the number of hits, the distance to track–like patterns expected from minimum ionising particles, the cluster shape, and the innermost hit. The criteria are tuned to accept one shower core per photon, and the difference $N = N(core) - N(MC)$ between the number of accepted shower cores and simulated MC photons is used to estimate the selection efficiency. It is shown in Fig. 1a) that the error probability for negative (positive) N is only 2 % (0.3 %) for isolated photons.

Clusters which contain major energy deposits from two different showers have different parameters with respect to pure clusters from only one photon, especially for the cluster shape. As a consequence, the number of accepted shower

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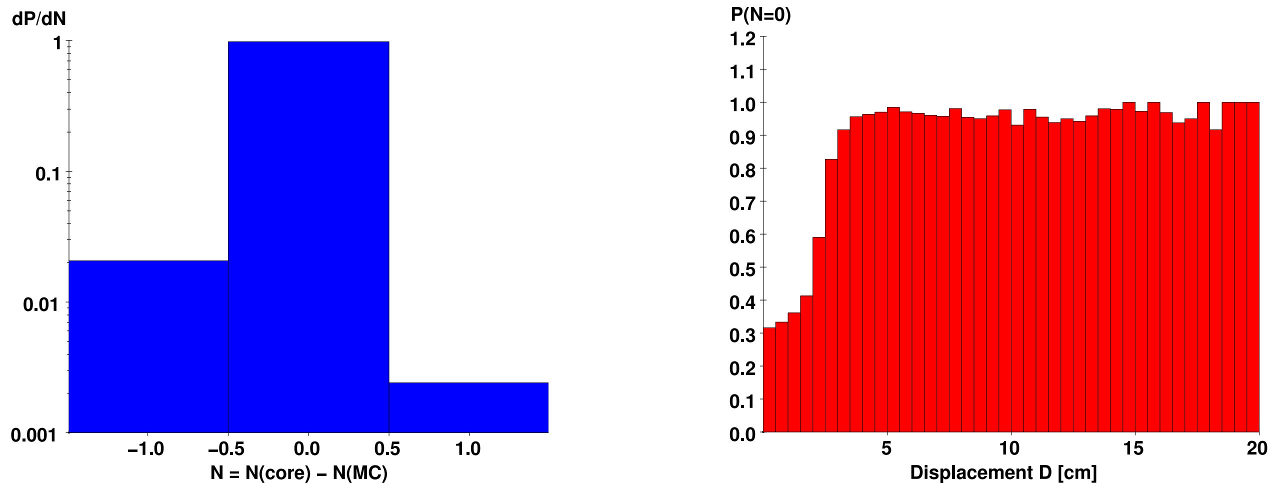


a) b)

Figure 1: Part a) shows the probability for the number difference N of identified shower cores $N(core)$ and MC particles $N(MC)$ for isolated photons, note the logarithmic scale. One shower core per photon, equivalent to $N = 0$, is found with about 98 % probability. Part b) shows this probability for photons from $K_s^0 \to \pi^0\pi^0$ decays as a function of the photon displacement D on the calorimeter surface. Significant amounts of merged shower cores are only observed for $D < 3$ cm.

cores $N(core)$ is reduced in the presence of overlapping showers. A high probability for $N(core) - N(MC) = 0$ thus means good shower separation, while a value significantly below one indicates that shower cores cannot be resolved. This probability is shown in Fig. 1b) for photons in $K_s^0 \to \pi^0\pi^0$ decays as a function of the displacement D, defined as the distance between two simulated photons on the calorimeter surface. It can be seen that separate shower cores are reconstructed if the two photons are displaced by at least 3 cm, which corresponds to an angular resolution of approximately $1.5°$ for the SiD calorimeter dimensions..

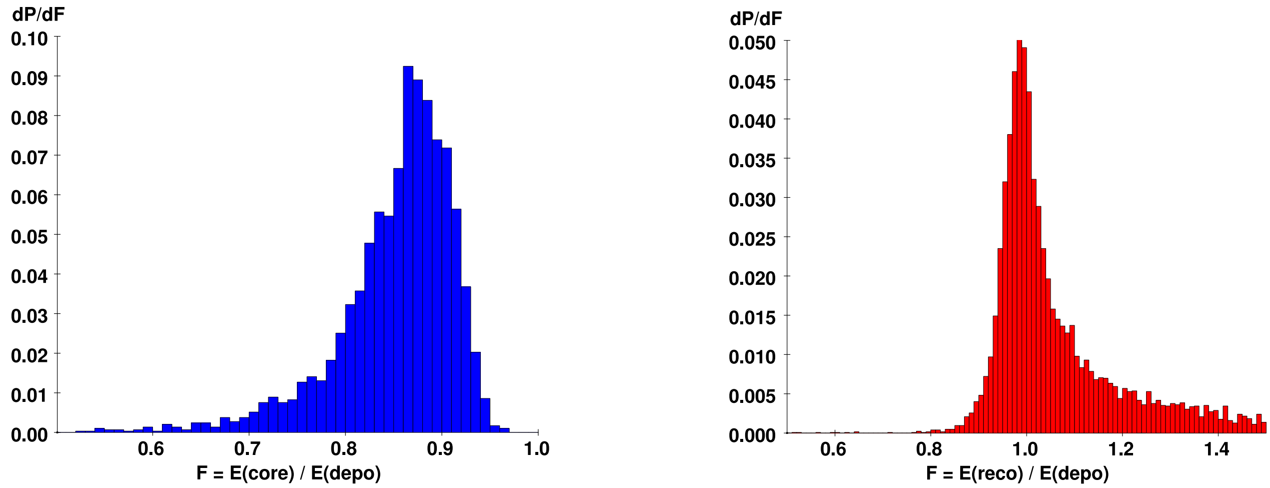
It should be noted that the MST threshold is a free parameter of the algorithm. Using a larger threshold significantly deteriorates the separation of nearby shower cores. For example, two photons with 8 cm displacement on the calorimeter surface cannot be resolved if the threshold parameter is set to 3 cm.

3. SHOWER FRAGMENTS AND ENERGY COLLECTION

The good separation of showers described above is achieved at the expense of energy efficiency, i.e. the shower cores contain only part of the total shower energy. The distribution is shown in Fig. 2a) for isolated photons. Both the mean of 85 % and the long tail towards lower values indicate that further collection of fragmented hits around the cluster cores is neccessary.

The general ansatz is to approximate the shower direction by the principle axis of the shower core already reconstructed. Hits are clustered with the core if they lie within a cylinder of 7.5 cm around this axis, where the parameter is tuned on isolated photons for high energy collection efficiency. The best treatment of hits in the overlap region of two such cylinders in more complex cases with nearby showers is still to be optimized.

The first attempt is simply to assign these hits to the closest cluster core. Then, energy deposits within the overlap region of two showers get distributed about evenly among the shower cores. For low–energy photons with nearby high–energy showers, this results in a value well above one for the fraction of energy reconstructed in the associated shower core, as can be seen from the strongly populated upper tail in Fig. 2b).



a) b)

Figure 2: Part a) shows the fraction of energy from isolated photons reconstructed in the identified shower core. Part b) shows the fraction of energy reconstructed in refined showers for photons from $K_s^0 \to \pi^0\pi^0$ decays.

4. CONCLUSIONS AND OUTLOOK

So far, electromagnetic showers have been studied only in events containing exclusively photons. It still needs to be explored whether the reconstruction method presented is also robust in the case of nearby or overlapping hadronic showers. Also, the assignment of hits to shower cores is still non optimal and exhibits the tendency to overestimate the energy of low–energy photons. More sophisticated methods are still under investigation.

In the long term, the efforts of electromagnetic shower reconstruction will be merged with strategies for hadronic shower reconstruction, also presented at this workshop [3], towards an universal cluster algorithm. Since the cut–based identification of shower cores presented here is not intended for separation of dense energy deposits from electromagnetic and hadronic showers, it might be neccessary to replace it with more advanced algorithms. Possible alternatives such as neural network techniques for cluster classification [4] or cluster shape fits using the H–Matrix approach [5] as photon idenifier have been developed with slightly different objectives, and further studies are needed to explore their use for this specific task.

Acknowledgments

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