Track-Based Particle Flow[*]

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Abstract

One of the most important aspects of detector development for the ILC is a good jet energy resolution σ_E/E. To achieve the goal of high precision measurements $\sigma_E/E = 0.30/\sqrt{E(\text{GeV})}$ is proposed. The particle flow approach together with highly granular calorimeters is able to reach this goal. This paper presents a new particle flow algorithm, called Track-Based particle flow, and shows first performance results for 45 GeV jets based on full detector simulation of the Tesla TDR detector model.

1 Introduction

The International Linear Collider (ILC) will provide the potential for high precision measurements at center-of-mass energies between several hundred GeV and one TeV. Many interesting physics processes in this regime will be composed of multi-jet final states originating from hadronic decays of heavy gauge bosons. To reach the goal of high precision measurements it is suggested to achieve a mass resolution for $W \rightarrow q'\overline{q}$ and $Z \rightarrow q\overline{q}$ decays which is comparable to their widths. This leads to a jet energy resolution of $\sigma_E/E = 0.30/\sqrt{E(\text{GeV})}$ considering the typical di-jet energies ranging from 100 to 400 GeV. Studies based on full detector simulation have shown that particle flow algorithms (PFA) are able to reach this goal [1, 2]. The basic concept of any PFA is to reconstruct the four-momenta of all visible particles in an event. The four-momenta of charged particles are measured in the tracking detectors, while the energy of photons and neutral hadrons is obtained from the calorimeters. The accuracy of momentum measurement in the tracking systems is by orders of magnitude better than the accuracy of energy measurement in the calorimeters. This leads to a theoretical limit on the jet energy resolution of approx. $\sigma_E/E = 0.20/\sqrt{E(\text{GeV})}$, considering the characteristic ratio of charged and neutral particles in a jet. The given limit is obtained if the PFA is able to disentangle all charged from close-by neutral showers. Since this is not possible in a realistic PFA the performance degrades due to this *confusion*. Any PFA relies strongly on pattern recognition

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[*]to appear in Proceedings of LCWS07, Hamburg, Germany, June 2007

in the highly granular calorimeters and it is not possible to distinguish between pure detector and algorithmic effects on the reconstructed jet energy. Hence, for reliable detector optimisation studies using a PFA it is necessary to study different PFA and compare their results.

2   The Track-Based Particle Flow Algorithm

The Track-Based PFA is a new proposal of a PFA at the ILC. Basis of this PFA is a collection of tracks. Sequentially, the tracks are extrapolated into the calorimeter and correlated energy depositions are assigned to the track. Related MIP-like track segments are identified as well. Additionally, a collection of photon candidates can be used as an input to improve the performance of the reconstruction. As soon as all tracks have been extrapolated their assigned hits are removed from the collection of calorimeter hits. Afterwards, a clustering procedure is applied on the remaining hits to reconstruct neutral particles. A simple particle identification (PID) is done for charged and neutral particles. The Track-Based PFA is implemented in C++ within the `Marlin` [3, 4] framework. Events for the reconstruction are created with `Mokka` [3], a `GEANT4` [5] simulation of the Large Detector Concept (LDC) [6]. `LCIO` [7] serves as persistent data format. The Track-Based PFA consists of six main stages:

i) Photon Finding: Photon finding is done with the "PhotonFinderKit" proposed by [8]. Only ECAL hits are taken into account. The output of this stage is a collection of clusters labeled as photon candidates.

ii) Tracking and Track-Extrapolation: Tracks, either provided by Monte Carlo information or by realistic tracking [9], are the basis of the Track-Based PFA. The tracks are sequentially extrapolated into the calorimeter using a trajectory interface. The trajectory is given by a simple helix model at the moment, not taking into account energy loss. If such an extrapolation traverses one of the photon candidates it is removed from the collection of photon candidates, since it could be the electro-magnetic core of a hadron shower or an electron.

iii) MIP-Stub Finding: The collection of MIP-like energy depositions along a track extrapolation is done by a simple geometrical procedure. A system of two cylindrical tubes are assigned to the track extrapolation, surrounding it concentrically. Calorimeter hits in the vicinity of the track extrapolation are sorted with respect to their path lengths on the extrapolated trajectory. Starting from hits with small path lengths those hits are assigned to the MIP-stub which are located within the inner cylindrical tube. Hits beyond the outer cylindrical tube are not taken into account. As soon as a hit located in-between both tubes is found the procedure is stopped. The position of the last hit collected and its direction given by the tangent on the trajectory at this point are stored as initial parameters for the clustering procedure performed in the next step.

iv) Clustering and Cluster-Assignment: The Trackwise Clustering, proposed in [10], has been modified to take the start point and direction given by the MIP-stub finding into account. Additionally, it is adapted to produce more but smaller clusters. The center of gravity and orientation is calculated by the inertia tensor of each cluster. The clusters are assigned to the track by proximity and direction criteria. The track momentum is taken into account to prevent from assigning clusters with too much energy.
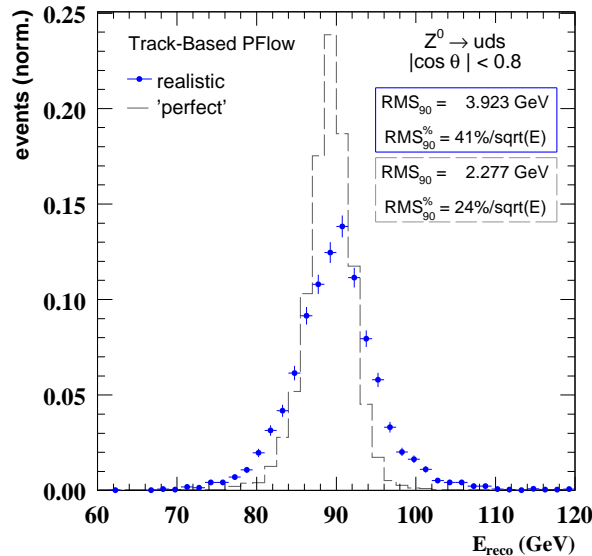
Figure 1: Total reconstructed energy for $Z^0 \rightarrow$ uds at $\sqrt{s} = 91.2\,\text{GeV}$, realistic Track-Based PFA (circles) and assignment of calorimeter hits to tracks by Monte Carlo information (dashed lines).

v) Particle Identification and Removal of "Charged" Calorimeter Hits: The PID of charged particles is done by a cut on the fraction of energy deposited in ECAL compared to the HCAL. It distinguishes only between electrons and charged pions. Additionally, muons are identified if a MIP-stub has been assigned to the track only. Afterwards, all calorimeter hits assigned to tracks are removed from the collection of calorimeter hits.

vi) Clustering and Particle Identification on "Neutral" Calorimeter Hits: The Trackwise Clustering is applied on the remaining calorimeter hits using the direction to the interaction point as a start direction. The PID is done in the same way as for the charged particles assigning a PID of photons or neutral kaons.

All reconstructed particles are filled into a collection assigned to the event. The Track-Based PFA described in this note is included in the `MarlinReco` package [3].

3 Performance

Figure 1 shows an example of a reconstruction of 45 GeV jets from a of Z^0 decaying in light-quarks (uds) at $\sqrt{s} = 91.2\,\text{GeV}$ using the Track-Based PFA (circles). The detector simulation has been done with `Mokka`, using the TESLA TDR detector model [1, 3]. The initial direction of the quarks is restricted to a polar acceptance of $|\cos\theta| < 0.8$. The tracks as described in stage ii) of Section 2 are reconstructed by Monte Carlo information. Additionally, a histogram is shown which indicates the same reconstruction using a perfect assignment of hits to

tracks by Monte Carlo information (dashed lines). It is getting close to the theoretical limit of approx. $0.20/\sqrt{E(\text{GeV})}$. The performance of the reconstruction is measured by the root-mean-square of the smallest range of reconstructed energies containing 90% of the events (RMS$_{90}$) [11]. The Track-Based PFA reaches a jet energy resolution of $0.41/\sqrt{E(\text{GeV})}$ for a polar acceptance of $|\cos\theta| < 0.8$. There are two other PFA available within the `Marlin` framework. The first one (Wolf) reaches approx. $0.52/\sqrt{E(\text{GeV})}$ [12] for the same detector model and physics process, whereas the second one (PANDORAPFA) already reaches the goal of $0.30/\sqrt{E(\text{GeV})}$ [2].

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