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Modular Implementation of Particle Flow Algorithm with Minimized Dependence on the Detector Geometry

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A Particle Flow Algorithm (PFA) with the minimized dependence on the detector geometry is presented. Current PFA implementation includes procedures of the track reconstruction, calorimeter clustering, and individual particle reconstruction and is meant as a tool for the optimization of the International e^+e^- Linear Collider detector.

1. INTRODUCTION

The most promising strategy for event reconstruction at the future linear e^+e^- collider experiment is based on the particle flow concept, implying reconstruction of the four-vectors of all particle produced in an event. The particle flow algorithm works best at moderate energies of individual particles, below about 100 GeV. In this regime, the tracking system reconstructs the momentum of the charged particles with an accuracy superseding the energy and angle measurements with calorimeters. Hence, in order to attain a better reconstruction of events, the charged particle measurement must be solely based on the tracking information. The crucial step of the particle flow algorithm is correct assignment of calorimeter hits to the charged particles and efficient separation of close-by showers produced by charged and neutral particles. Monte Carlo studies have shown that an ideal reconstruction algorithm [1], which finds each particle and measures its energy and direction with the detector resolution expected for single particles, could reach a jet energy resolution of $14\%/\sqrt{E}$. Over the years a jet energy resolution of $30\%/\sqrt{E}$ has become accepted as a good compromise between the theoretically possible and practically achievable resolution.

In this paper modular implementation of the Particle Flow algorithm (PFA) with weak dependence on the detector geometry is presented. It is meant as a tool for the linear collider detector optimization.

2. PARTICLE FLOW ALGORITHM IN MARLIN

Particle Flow algorithm is implemented in a modular way within the framework of the MARLIN package [2]. Algorithm consists of the following steps:

- track finding and fitting in the main tracking device;
- cluster finding in calorimeters;
- track $-$ cluster matching and reconstruction of individual particles.

Each step is implemented as a separate module, MARLIN processor. All processors constitute MarlinReco package which can be downloaded from the web [3].

2.1. Track Finding and Fitting

Two separate track finding algorithms are available within the MarlinReco package. The first one is based on the existing LEP code and optimized for the Time-Projection-Chamber (TPC) as the main tracking device. The algorithm exploits Kalman filter approach for track finding and fitting, taking into account particle interaction with the detector material such as ionization losses and multiple scattering. The second algorithm is designed for silicon tracker, which has relatively small number of layers. Algorithm represents combinatorial search for set of hits compatible with the helix hypothesis.

2.2. Calorimeter Clustering

Cluster finding in calorimeters is based solely on the spatial information. Algorithm requires as an input the list of calorimeter hits with their coordinates. No amplitude information is used in the clustering procedure, making the algorithm applicable to both analogue and digital calorimeters. Clustering is applied on the unified array of hits in the electromagnetic and hadronic calorimeters and produces as an output the list of found clusters. Detailed description of the algorithm can be found in Reference [4]. Found clusters are classified into four-categories on the basis of the cluster shape analysis.

- The electro-magnetic clusters, whose longitudinal profile is compatible with an expectation from electrons or photons.
- The MIP (minimal ionizing particle) clusters, whose shape is compatible with the helix model. In addition an energy of such clusters is required to be compatible with an expectation from MIP.
- The hadronic clusters; these are clusters not classified as the MIP or electromagnetic clusters.

2.3. Track−Cluster Matching and Individual Particle Reconstruction

Once tracking and the calorimeter clustering is performed, an attempt is made to associate clusters with tracks. For each track, its intersection point with the front face of the electromagnetic calorimeter is determined. Cluster containing calorimeter hit closest to this intersection point is found. If the distance from the intersection point to the closest hit is less than certain predefined threshold, cluster is associated with the track.

Electromagnetic clusters with no associated track are identified as photons, whereas electromagnetic clusters with associated track are regarded as electrons/positrons. MIP clusters with associated track are identified as muons. Hadronic clusters with associated tracks are accepted as charged pion candidates. Finally, hadronic clusters with no associated track are identified as neutral hadrons. Four-momentum of charged objects are estimated using tracking information. Track parameters at the point of closest approach to the primary interaction point define momentum vector of charged objects (electrons, muons, charged hadrons). For neutral objects, cluster energy is used as an estimate of particle energy, while the line connecting interaction point with the cluster centroid is used as an estimate of the direction of particle momentum vector.

3. RESULTS

Performance of the algorithm has been tested with the sample of hadronic events at Z-pole. The algorithm is applied to the different detector models. Figures 1 and 2 present the reconstructed visible mass for the LDC (Large Detector Concept) detector with the TPC as the main tracking device. Detector simulation is performed with the program Mokka [5]. Figure 1 corresponds to the LDC detector with the analogue W-Si electromagnetic calorimeter (ECAL) and analogue hadron calorimeter consisting of steel absorber plates interleaved with scintillating tiles. Figure 2 corresponds to the LDC detector with the analogue W-Si ECAL and digital HCAL consisting of steel absorber plates interleaved with the resistive-plate chambers (RPC) as an active elements. Figure 3 presents the reconstructed visible mass for the small detector with the silicon tracker (SiD), W-Si ECAL and digital RPC HCAL. The detector response is simulated with the SLIC program [6]. The resolution achieved varies from 40 to 45%, depending on the detector model.

Additionally, PFA performance has been tested with the the selected signal processes at higher center-of-mass energies. As an example, Figure 4 presents reconstructed Higgs boson mass for the fusion process, $e^+e^- \to W^+W^-\nu\bar{\nu} \to H\nu\bar{\nu}$ with subsequent Higgs boson decays into b quarks. Process is simulated at center-of-mass energy of 800 GeV. The Higgs boson mass is 120 GeV. The detector response is simulated with Mokka for the LDC detector with the analogue tile HCAL.

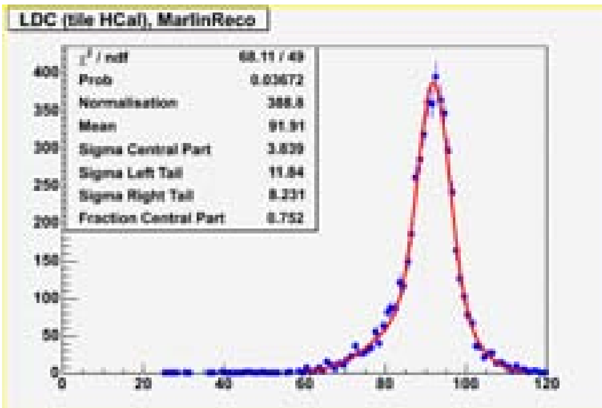

Figure 1: Reconstructed visible mass in the sample of $Z \to q\bar{q}(q = u, d, s)$ events at center-of-mass energy of 91.2 GeV for the LDC detector with the analogue tile HCAL.

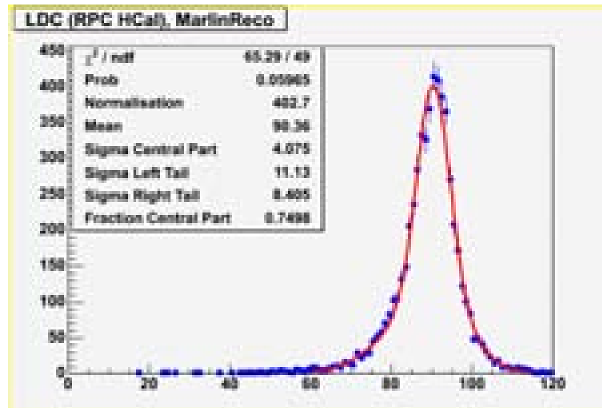

Figure 2: Reconstructed visible mass in the sample of $Z \to q\bar{q}(q = u, d, s)$ events at center-of-mass energy of 91.2 GeV for the LDC detector with the digital RPC HCAL.

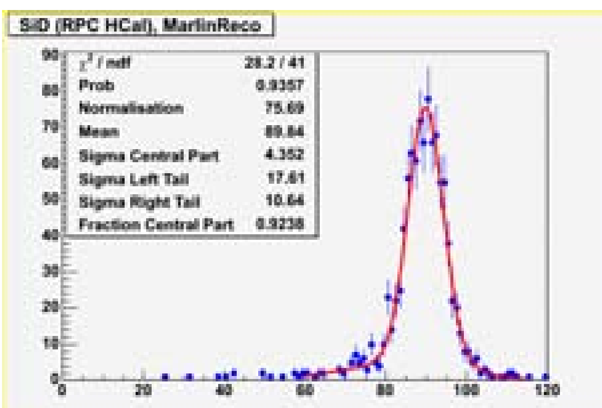

Figure 3: Reconstructed visible mass in the sample of $Z \to q\bar{q}(q = u, d, s)$ events at center-of-mass energy of 91.2 GeV for the SiD detector with the digital RPC HCAL.

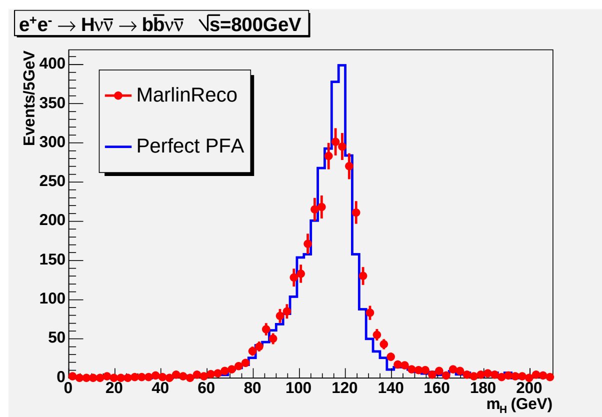

Figure 4: Reconstructed Higgs boson mass in the sample of $e^+e^- \to W^+W^-\nu\bar{\nu} \to H\nu\bar{\nu}$ events at center-of-mass energy of 800 GeV for the LDC detector with analogue tile HCAL. The simulated Higgs boson mass is 120 GeV. Result of realistic PFA (dots) is compared with the perfect reconstruction (histogram).

4. FUTURE DEVELOPMENTS

The algorithm described in this paper is incomplete and needs further development. We hope that PFA performance can be significantly improved by

- supplementing tracking in the main tracker with the dedicated pattern recognition in the vertex detector and forward tracking devices (this will increase track finding efficiency of low P_T tracks);
- inclusion of the dedicated neutral vertex and kink finding procedures in the chain of PFA;
- further optimization and refinement of the clustering algorithm.

References

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