

The LCFIVertex Package: vertex detector-based Reconstruction at the ILC

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The contribution gives an overview of the LCFIVertex package, providing software tools for high-level event reconstruction at the International Linear Collider using vertex-detector information. The package was validated using a fast Monte Carlo simulation. Performance obtained with a more realistic GEANT4-based detector simulation and realistic tracking code is presented. The influence of hadronic interactions on flavour tagging is discussed.

1 Introduction

At the International Linear Collider (ILC), the vertex detector is expected to provide high-precision measurements with a point resolution of $\sim 3\,\mu\text{m}$ or below over an unprecedented acceptance region of $|\cos\theta| < 0.98$, where θ is the track polar angle. The ambitious detector design will result in excellent vertexing and flavour tagging performance. This contribution [1] describes scope, validation and resulting performance of the LCFIVertex package, a software package for vertex detector-based event reconstruction at the ILC.

The LCFIVertex package provides tools for vertexing, flavour tagging and the determination of the heavy quark charge sign of the leading hadron in heavy flavour jets. For vertexing, the ZVTOP topological vertex finding algorithm developed by D. Jackson for SLD is implemented [2]. For the first time within an ILC software environment, the more specific ZVKIN branch of the algorithm is provided in addition to the widely used ZVRES branch.

The ZVRES approach uses a vertex function calculated from “probability tubes” representing the tracks in a jet. Maxima of the vertex function in three-dimensional space are sought and the χ^2 of the vertex fit is minimised by an iterative procedure. In contrast, ZVKIN initially determines the best approximation to the direction of flight of the B -hadron in candidate b -jets and uses the additional kinematic information provided by this “ghost track” to find 1-prong decay vertices and short-lived B -hadron decays not resolved from the interaction point.

Flavour tagging is accomplished using a neural net approach. The software includes a full neural network package written by D. Bailey. By default, the flavour tag is obtained from the algorithm developed by R. Hawkins [3], however it should be noted that the implementation is highly flexible, allowing the user to change the input variables for the network, its architecture and training method.

Determination of the quark charge is initially limited to cases in which the leading hadron is charged using an approach developed at SLD and modified as described at a previous LCWS workshop [4]. With ZVKIN, the basis is provided for extending the functionality to cover also neutral hadrons, using the SLD charge dipole technique [5].

The C++-based package uses the LCIO data format [6] for input and output and is interfaced to the analysis and reconstruction framework MarlinReco [7]. An interface to the

JAS3-based US software framework `org.lcsim` [8] is planned to be written in the near future. The code is available at the ILC software portal [9] and the Zeuthen CVS repository [10]. To facilitate comparisons of results from ILC physics studies performed by different groups, in addition a new CVS repository called “tagnet” has been set up in Zeuthen for providing trained neural networks in the format used by this package. Users training their own neural networks, e.g. for specific physics processes, are encouraged to make them available to the community in this way.

2 Code validation

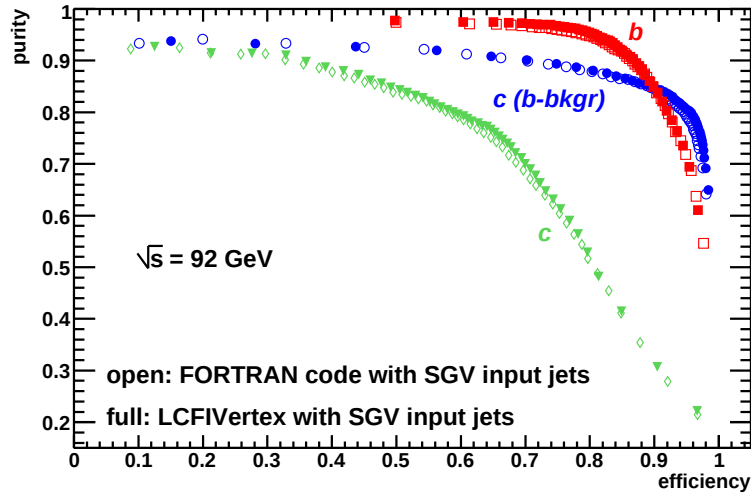


Figure 1: Comparison of tagging performance achieved with the LCFIVertex package and the previous FORTRAN code, using identical input events at the Z -resonance. Tagging purity is shown as function of efficiency for b -jets and c -jets. Performance for c -jets assuming only b -background is also shown. All tagging results are in excellent agreement.

Prior to development of the LCFIVertex package, part of its functionality was available in the form of FORTRAN routines which had been used in conjunction with the BRAHMS Monte Carlo (MC) simulation and reconstruction [11] used for the TESLA-TDR [12]. The fast MC program Simulation a Grande Vitesse, SGV, developed by M. Berggren [13] and interfaced to this FORTRAN flavour tag [14], allowed detailed cross checks to be performed during the development phase. Results from tests of various separate parts of the package were presented at the 2006 ECFA ILC workshop [15].

As final step of the code validation, the resulting flavour tagging performance achieved with the FORTRAN/SGV code and with our package was compared, using identical $e^+e^- \rightarrow q\bar{q}$ events ($q = u, d, s, c, b$) at the Z -resonance and at a centre of mass energy of $\sqrt{s} = 500$ GeV, generated with the PYTHIA MC program [16]. The SGV MC simulation was extended to write out the relevant information in LCIO format as input to our code using the FORTRAN interface provided within LCIO.

Figure 1 shows the resulting tagging performance from the LCFIVertex package compared to that of the FORTRAN code in terms of tagging purity vs efficiency, for events at the Z-resonance. Excellent agreement is seen for the b - and the c -tag as well as for the c -tag when considering b -background only, as is relevant for some physics processes. Agreement at the higher energy is equally good.

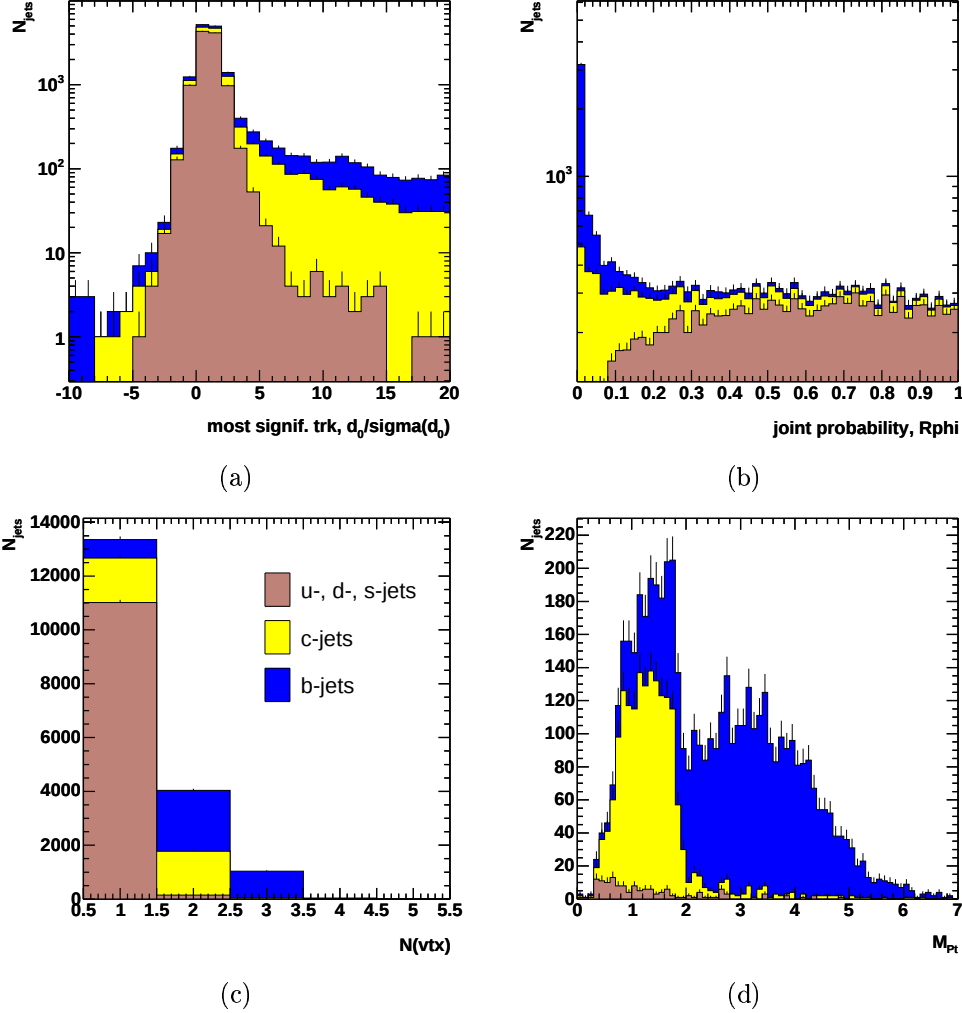


Figure 2: Some of the variables used to distinguish the different jet flavours. Shown are (a) the impact parameter significance of the most significant track in the jet, (b) the “joint probability” for all tracks in the jet to originate at the event vertex, (c) the vertex multiplicity in the jet and (d) the P_t -corrected vertex mass.

3 Performance obtained with full MC

Following the successful code validation, performance of the LCFIVertex package with more realistic input was studied. For this purpose, the same PYTHIA events used for the validation were passed through the GEANT4-based full MC simulation MOKKA, version 06-03 [17], assuming the detector model LDC01Sc, in which the vertex detector layers are approximated by cylinders.

Photon conversions were switched off in GEANT, as these can easily be suppressed later. Tracks stemming from hadronic interactions in the beam pipe and in the vertex detector layers were suppressed at the track selection stage using MC information.

The LDCTracking package by A. Raspereza [18] was used to simulate tracker hit digitization assuming simple Gaussian smearing of the hits, and for track reconstruction. Resulting tracks were fed into the Wolf particle flow algorithm [19] to obtain ReconstructedParticle objects, which were passed on to the Satoru jet finder [20] to perform jet finding using the Durham kT -cluster algorithm with a y -cut value of 0.04.

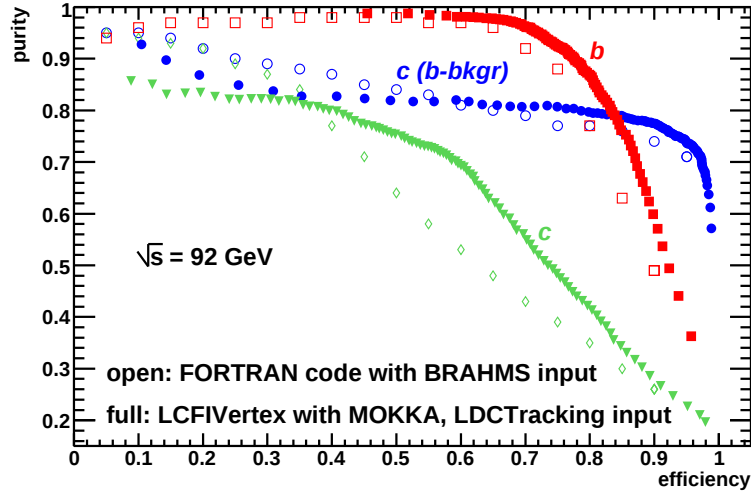


Figure 3: Comparison of tagging performance achieved with the LCFIVertex package and the previous FORTRAN code, using identical input events at the Z -resonance. For the FORTRAN case, events were passed through the BRAHMS simulation and reconstruction, for the LCFIVertex package the detector response was simulated using MOKKA and event reconstruction performed using MarlinReco. The new code, run with this input, yields better tagging performance, see text.

The default track selection used in the LCFIVertex package is based on a previous study [21] using the BRAHMS MC and reconstruction, with the modification that tracks stemming from the decays of K -shorts and Lambdas are suppressed using MC information.

Figure 2 shows the most sensitive input variables for the flavour tag as used in the Hawkings approach. Compared to the previous BRAHMS result [21], these variables provide somewhat better separation power. The resulting flavour tagging performance, presented in Figure 3, is hence improved. Reasons for the difference seen may include a better detector

resolution of $2\text{ }\mu\text{m}$ being assumed for the new result, compared to the former value of $3.5\text{ }\mu\text{m}$, as well as the suppression of K-short and Lambda-decays, photon conversions and hadronic interactions, all of which will need to be taken into account properly in a future version of the software.

The LDCTracking code can be run in different modes. The results shown in Figure 2 and Figure 3 correspond to the “track cheater”, which uses MC information to assign tracker hits to the different tracks, run with only the Silicon-based detectors, i.e. vertex detector, Silicon intermediate tracker (SIT) and forward tracker (FTD). It was shown that when including the hits in the TPC and replacing the track cheater with an algorithm including realistic pattern recognition, the resulting tagging performance does not change significantly.

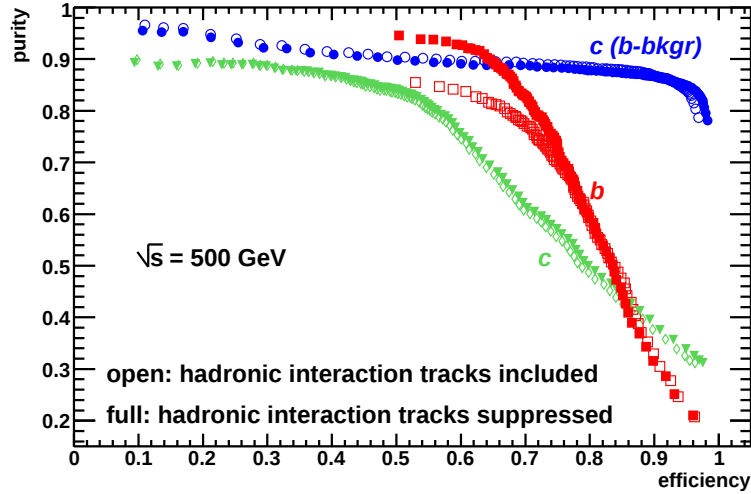


Figure 4: Effect of including tracks arising from hadronic interactions in the detector material and the beam pipe in the reconstruction, compared to the case, in which these tracks are suppressed using MC information. At a centre of mass energy of $\sqrt{s} = 500\text{ GeV}$, b -tagging performance clearly degrades.

The effect of including tracks arising from hadronic interactions in detector material and beam pipe is shown in Figure 4, compared to the current default settings of the package that suppress these tracks using MC information. At a centre of mass energy of 500 GeV , the b -tag degrades significantly when tracks from hadronic interactions are included. At the Z -resonance this effect is negligible. Note that the current implementation of the suppression of the effect is based on MC information and only works for the specific detector model used for the initial full MC study (LDC01Sc).

4 Summary

The LCFIVertex package provides the topological vertex finder ZVTOP, a flexible flavour tag with the Hawkings approach as default and determination of quark charge in heavy flavour jets. Validation of this C++ based code using the fast MC program SGV to simulate detector

response and event reconstruction has shown it to be in good agreement with results from an earlier FORTRAN implementation, in comparison to which the new code has extended functionality, a higher degree of flexibility and improved documentation.

With input from the GEANT4-based detector simulation MOKKA and the event reconstruction package MarlinReco, the LCFIVertex package yields results comparable to those previously obtained from BRAHMS, with the differences being likely to be accounted for by a number of unrealistic simplifications made in the current first release version of the new code. One of these is the suppression of hadronic interaction effects using MC information, giving a clear improvement at high centre of mass energies.

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