LCFI Vertex Package: Precision Physics Opportunities with Heavy Flavour

Ben Jeffery on behalf of the LCFI Collaboration

University Of Oxford - Department of Physics
Denys Wilkinson Building, Keble Road, Oxford OX1 3RH - UK

The LCFI collaboration has recently released LCFIVertex, a software package for reconstructing heavy quark flavour and charge using vertex detector information at the International Linear Collider. This contribution reviews the content of the package and some of the precision physics opportunities arising from its use. These include Higgs branching ratios and self coupling, anomalous top couplings and top polarisation, and asymmetry measurements.

1 Introduction

One of the key features of the International Linear Collider (ILC) will be the ability to reconstruct events at the parton level with unprecedented accuracy. Part of this accuracy comes from the ability to determine the quark flavour and charge of heavy flavour hadronic jets with excellent purity and efficiency. This results in exciting prospects in many interesting processes, such as: high precision unfolded asymmetry measurements giving access to physics beyond the centre of mass energy; Higgs branching ratios and self coupling; anomalous top couplings; top polarisation; and background rejection in other channels. The key questions under current research include what the best methods for this reconstruction are, what accuracy is acheviable with a given detector and what sensitivity this brings to key benchmark channels. LCFI are conducting a program of tool development and benchmark studies to answer these questions in a realistic full MC and reconstruction framework.

The key to flavour and charge identification of heavy quarks is information from the vertex detector. This is in the form of precise impact parameter measurements. An expected track point resolution of $\sim 3\mu$m gives an impact parameter of[2]:

$$\sigma_{rz} \approx \sigma_{r\phi} \approx 4.2\mu\text{m} \oplus \frac{4\mu\text{m}}{p\sin^{\frac{3}{2}}\theta}$$

(Where θ is the polar angle of the track) These precise impact parameters are used to locate particles produced a distance from the interaction point by the decay of short lived B or D hadrons. By intersection with other tracks the decay vertices and decay products are identified and the properties of the decaying hadron inferred.

To enable initial benchmark studies LCFI have implemented a reconstruction package in the C++ based MARLIN framework. The package is based on algorithms used in previous ILC studies (but not available in a flexible modern framework) thereby allowing effective comparison and providing a solid benchmark. The package consists of three distinct parts: vertexing, flavour and charge tagging, and utilities such as cuts and MC information.

2 Tracks To Flavour

The vertexing within the LCFI vertex package is performed by ZVTOP[3]. a vertexing algorithm initially developed by D. Jackson for use on the SLD experiment. ZVTOP consists of two complementary branches, ZVRES and ZVKIN

ZVRES employs a heuristic vertex function (based on track probability density) in the detector space to identify likely points of true vertices. Tracks are assigned by proximity to maxima in the vertex function and ambiguities resolved by χ^2 considerations and the magnitude of the vertex function. ZVRES serves as a good benchmark algorithm due to its performance and previous use both in SLD and ILC studies. During development detailed comparisons were conducted against the previous FORTRAN based SGV version.[4]

ZVKIN uses a kinematic approach to reconstruct the unseen decaying hadron. The sum of χ^2s of vertices of all possible pairs of input tracks and a line projecting outwards from the interaction point is minimised in the line's angular degrees of freedom. The vertices are then combined by considering the fit probability of the combined vertices until no combinations are probable. Note that this enables vertices with only one detected track to be reconstructed. This is particularly useful for neutral vertex charge as disscussed later. Although used at SLD, this branch has not been studied for use at the ILC and the implementation has had minimal testing. It is therefore the default and recommended behaviour that only the ZVRES branch is used in non-experimental studies. Once any secondary vertices in a given jet have been reconstructed, flavour tagging can be performed using the vertex information. The algorithm implemented follows that of R. Hawkins[5]. The method defines a set of discriminating variables calculated from the jet and from secondary vertices (if any are found). For classification of jet flavour from the set of discriminating variables, a simple linear perceptron neural net is used. The LCFI package uses a neural net toolkit developed by D. Bailey to perform this classification.

3 Vertex Charge

Vertex charge is performed by a method developed at SLD and improved in an ILC study by S. Hillert[6]. The charges of all secondary tracks found by vertexing and tracks passing a cut (based on distance from the jet axis) are summed to give a measure of charge of the decaying hadron. The charge of the initial parton can thus be inferred in most cases (see Figure 1). Neutral vertices require a further technique developed at SLD[7]. The charge

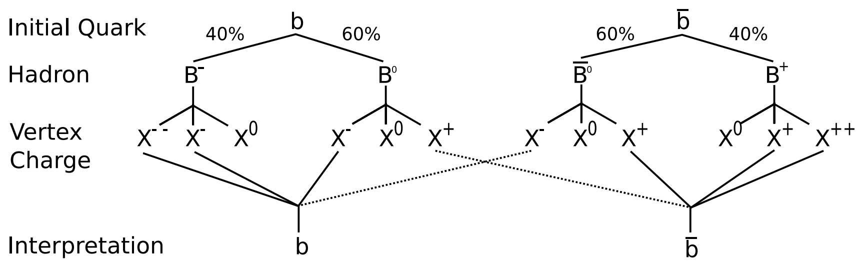

Figure 1: How quark charge is inferred from vertex charge - the dashed line are the only cases where assignment is incorrect.

dipole of a jet is the distance between B and D vertices multiplied by their charge difference: $\delta Q = L_{B \to D} \times SIGN\,(Q_D - Q_B)$ This gives good separation of b and $\bar{b}$ for neutral vertices: as shown in Figure 2, the mistag probability is $\sim 20\%$. A study into the usage of this technique at the ILC is planned, it requires the ZVKIN branch of ZVTOP as both B and D

vertices need to be identified - many of which have only one seen track and would therefore be missed by ZVRES.

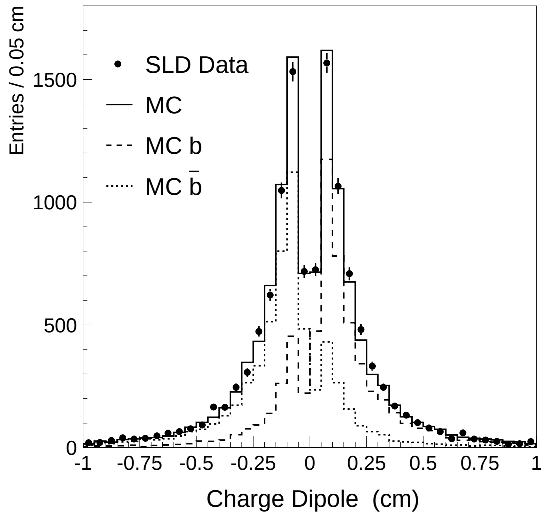

Figure 2: Charge dipole distribution and separation at SLD[7]

4 LCFIVertex Package

The software package LCFIVertex contains the above algorithms implemented in C++ and interfaced to the European software framework MARLIN. Input is in LCIO[8] format, by default from the MARLINReco[9] package. An interface to the US Java based org.lcsim [10] framework is also planned. During development, extensive testing and comparison with the previous SGV-based FORTRAN code was performed using identical input events[4]. Comparisons with previous full reconstruction studies[11] are favorable[12], as shown in Figure 3, However, there are technical differences between the two studies such as tracks produced by the decays of K_S or Λ particles are suppressed at the MC truth level in the LCFIVertex result. See [12] for details. The package is available for download at the ILC Software portal[13].

5 Applications

LCFI are currently starting to use the newly released package to study several processes where accurate flavour tagging is crucial to separate out decays to different quark flavours. Measurement of the hadronic branching ratios of the Higgs boson has been previously studied for the ILC, using a fast parametric simulation (SIMDET)[14]. In this case the use of realistic track-wise flavour tagging (as opposed to a parameterisation of well separated jets) resulted in a 50% increase in production rate error for $H \rightarrow c\bar{c}$ and $H \rightarrow gg$, highlighting the need for realistic flavour tagging. A full study considering the impact of detector options and material budget is planned.

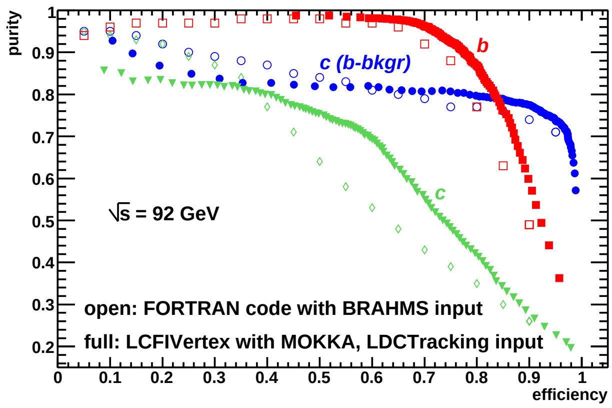

Figure 3: Purity vs. Efficiency for the newly released LCFIVertex code and a previous FORTRAN based study[11] The discrepancy is likely due to technical differences discussed in [12]

The reconstruction of vertex charge enables the measurement of top polarisation[15]. For the other heavy quarks, depolarisation effects during fragmentation wash out the quark helicities. However for the top, its short lifetime preserves its spin. In $t \rightarrow bW^+, W^+ \rightarrow c\bar{s}$ if the b and c jet are correctly tagged the $\bar{s}$ can be inferred by knowing the vertex charge of either the b or c jet. The $\bar{s}$ jet then has a $1 - \cos\theta$ angular dependence on the polarisation of the top (θ being the polar angle of the jet). Measurement of top polarization in scalar top and scalar bottom decays can be used to determine the fundamental SUSY parameters $\tan\beta$ and the trilinear couplings A_t, A_b[16].

Another interesting top measurement is that of the coupling W_{tb} which is sensitive to anomalous magnetic couplings[17]. Measurement of the coupling can be performed by the forward-backward asymmetry of b quarks in the process $e^+e^- \rightarrow t\bar{t} \rightarrow W^+bW^-\bar{b}$ If one wishes to use spin-spin correlations to boost the sensitivity, then a double b tag increases the need for high tagging efficiency. Currently, the t and W identification methods are being optimised in preparation for a full study.

An obvious application of accurate flavour and charge determination is the measurement of asymmetries in simple two-jet production. The measurement of A_{LR} in $e^+e^- \rightarrow q\bar{q}$ is sensitive to many phenomena beyond the standard model, including leptoquarks, Z' and extra spacial dimensions[18]. The possibility of polarised beams at the ILC, combined with high statistics and efficient flavour and charge tagging, allow a very precise measurement which is sensitive to effects far beyond the centre of mass energy. The analysis is expected to be sensitive to the material budget of the vertex detector, as the region of interest is at small θ (see Figure 4). It is therefore be a good benchmark for detector optimisation.

6 Summary

Flavour and charge tagging are essential to many of the benchmarking processes needed to optimise ILC detector design. LCFI are conducting studies of several physics channels

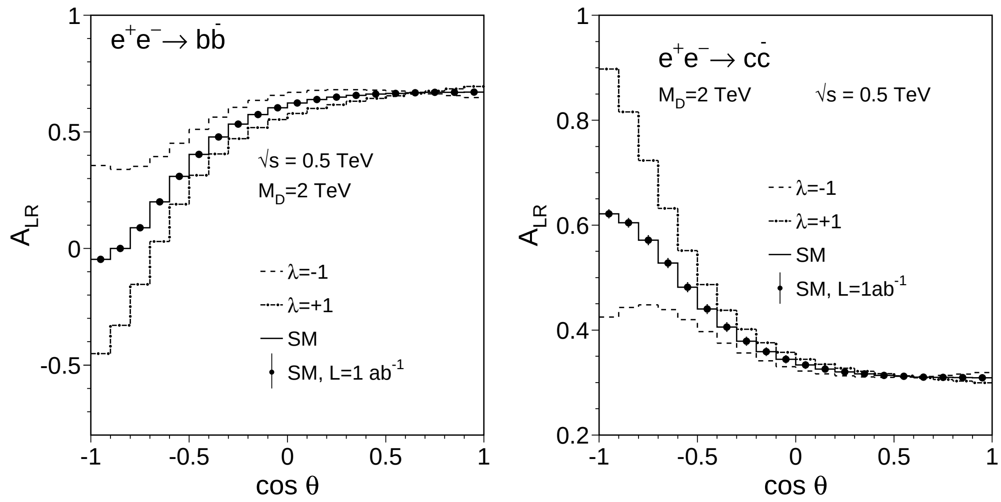

Figure 4: Expected signature in A_{LR} from extra spacial dimensions for both b and c pair production. Note that the sensitive region is at small θ (λ is a model parameter)[18]

using the newly developed LCFIVertex package. The package provides vertexing by two complementary algorithms, a flavour tag and a charge tag, all within a flexible framework. It is actively maintained and supported, and has a growing user base. Several comprehensive studies are already in progress.

References

[1] Slides:
`http://ilcagenda.linearcollider.org/contributionDisplay.py?contribId=242&sessionId=72&confId=1296`

[2] C. J. S. Damerell, LC-DET-2001-023;

[3] D. J. Jackson, Nucl. Instrum. Meth. A **388** (1997) 247;

[4] B. Jeffery, *Contribution to International Linear Collider Workshop (ILC-ECFA and GDE Joint Meeting), Valencia, 6-10 November 2006,* slides: `http://ilcagenda.linearcollider.org/contributionDisplay.py?contribId=72&sessionId=7&confId=1049`

[5] S. M. Xella Hansen, C. Damerell, D. J. Jackson and R. Hawkings, *Prepared for 5th International Linear Collider Workshop (LCWS 2000), Fermilab, Batavia, Illinois, 24-28 Oct 2000*, LC-PHSM-2001-024;

[6] S. Hillert [LCFI Collaboration], *In the Proceedings of 2005 International Linear Collider Workshop (LCWS 2005), Stanford, California, 18-22 Mar 2005, pp 0313*, ECONF,C050318,0313;

[7] K. Abe *et al.* [SLD Collaboration], Phys. Rev. D **67** (2003) 012006 [arXiv:hep-ex/0209002].

[8] F. Gaede, T. Behnke, N. Graf and T. Johnson, *In the Proceedings of 2003 Conference for Computing in High-Energy and Nuclear Physics (CHEP 03), La Jolla, California, 24-28 Mar 2003, pp TUKT001* [arXiv:physics/0306114];

[9] O. Wendt, F. Gaede and T. Kramer, LC-DET-2007-001;

[10] org.lcsim web page at `http://www.lcsim.org/software/lcsim/`;

[11] S. M. Xella Hansen, M. Wing, D. J. Jackson, N. De Groot and C. J. S. Damerell, "Update on flavour tagging studies for the future linear collider using the BRAHMS simulation", LC-PHSM-2003-061.

[12] S. Hillert [LCFI Collaboration], *In the Proceedings of 2007 International Linear Collider Workshop (LCWS 2007, DESY, Hamburg, Germany 30 May-03 June 2007)*, [arXiv:0708.2622v1];

[13] ILC software portal at `http://ilcsoft.desy.de/portal`;

[14] T. Kuhl, K. Desch, LC-PHSM-2007-002;

[15] E. Ruiz Morales and M. E. Peskin, [arXiv:hep-ph/9909383];

[16] E. Boos, H. U. Martyn, G. A. Moortgat-Pick, M. Sachwitz, A. Sherstnev and P. M. Zerwas, Eur. Phys. J. C **30** (2003) 395 [arXiv:hep-ph/0303110];

[17] E. Boos, M. Dubinin, M. Sachwitz and H. J. Schreiber, Eur. Phys. J. C **16** (2000) 269 [arXiv:hep-ph/0001048];

[18] S. Riemann, LC-TH-2001-007;