Measuring $h_{SM} \rightarrow c\bar{c}$ at the Linear Collider

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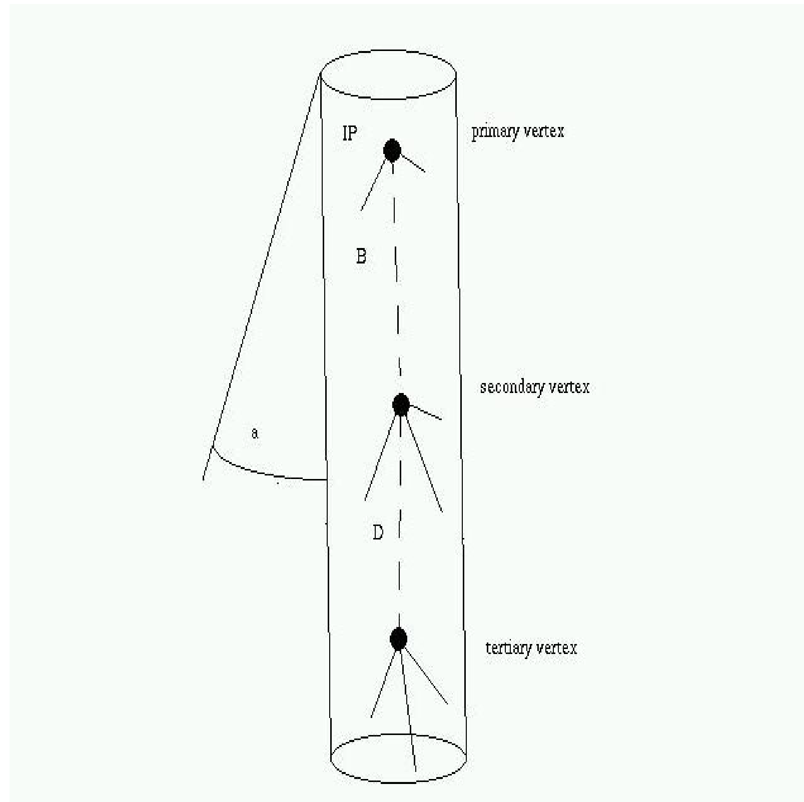
28 June 2002

The SLD ZVTOP Algorithm for Vertex Finding

Vertex Finding[1]

- Construct vertex significance function $V(\mathbf{r}) = \sum_i f_i(\mathbf{r}) - \sum_i f_i^2(\mathbf{r}) / \sum_i f_i(\mathbf{r})$ where each f_i is a Gaussian probability tube centered on each track.
- Include the interaction point as a Gaussian ellipsoid f_{IP} centered on the IP.
- Search for vertices in the spatially resolved maxima of $V(\mathbf{r})$ in which no contributing track exceeds a maximum vertexing χ^2.
- Each track is associated uniquely to the vertex with the maximal $V(\mathbf{r})$.
- Weight $V(\mathbf{r})$ low in regions outside a cylinder around the jet axis where fake vertices are likely.
- Order found vertices by distance from interaction point and label them primary, secondary and tertiary vertices.

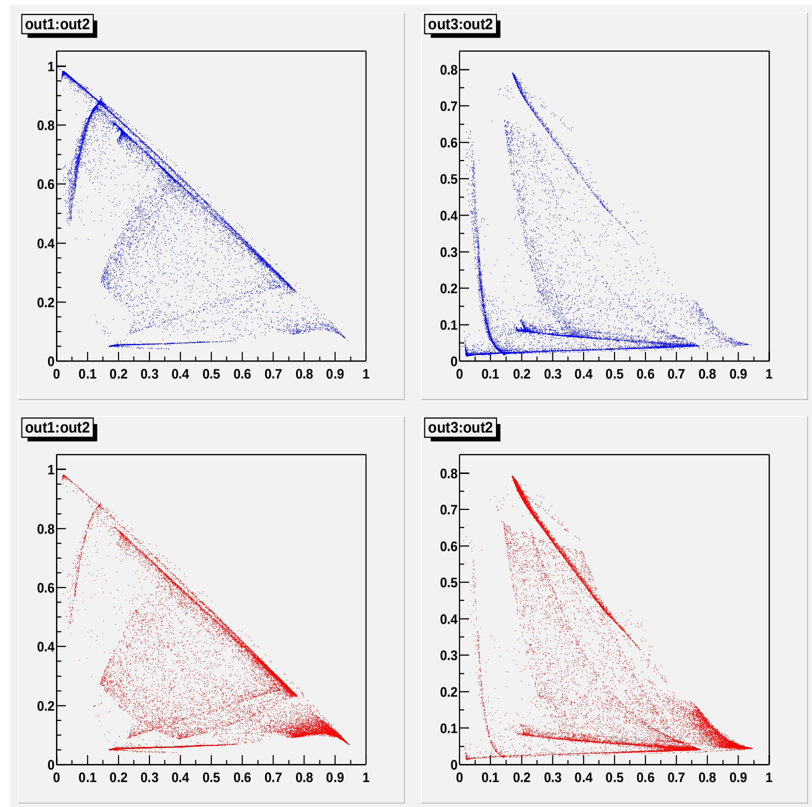


The B decay chain and cylinder.

[1] D. Jackson, op cit

The Two-Jet Flavor Tag Neural Network

- The Pandora v2.1 generator [2] with interface to Tauola for τ decay and Pythia v6.125 for parton shower and hadronization was used for both signal and background events. Beamstrahlung and initial state radiation were turned on.
- We assume a center of mass energy $\sqrt{s} = 500$ GeV and an integrated luminosity $\int dt\mathcal{L} = 500$ fb^{-1}. The NLD Large detector geometry was simulated using the LCD Fast Simulator [3].
- For multi-prong decays, the jet p_t corrected mass vertex momentum and number of vertices, found using the ZVTOP algorithm [4] (based on 3D topological vertex finding) serve to separate jets by flavor.
- For one-prong decays, jets are separated by the number of tracks with 3D impact parameter significance greater than 3 as well as the largest 3D impact parameter significance in the jet.
- In order to optimize tagging, these five parameters and their discriminating values were used in constructing a simple neural network implemented on the Stuttgart Neural Network Simulator v4.2. Three outputs (b-tag, c-tag, and g-tag) were trained.



Above, the two-jet neural network b-tag versus c-tag (left) and g-tag versus c-tag for 10^4 $h \to b\bar{b}$ events. Below, the b-tag versus c-tag (left) and g-tag versus c-tag for 10^4 $h \to c\bar{c}$ (bottom) events. Assumed is $m_h = 120$ GeV.

[2] M. Peskin, *Pandora: An object oriented event generator for linear collider physics*, 1999, hep-ph/9910519

[3] M. Iwasaki and T. Abe, *LCD Root simulation and analysis tools*, 2001, hep-ex/0102015

[4] D. Jackson, Nuc. Instrum. Methods A, **388**, 247, 1997

Comparison to Other Studies: Branching Ratio Errors

- Three studies are compared. All assume a 120 GeV Standard Model Higgs.
- The TESLA TDR study[5] assumed a 350 GeV linear collider with both WW-fusion and Higgstrahlung production modes. The TESLA results have been scaled to the assumptions of the Oregon study.
- The ACFA study[6] assumed the same parameters as the Oregon study.
- The greatest discrepancy is in the $h_{SM} \to c\bar{c}$ result. In the Oregon study, the dominant background came from b-jets mistagged as c-jets.
- An Oregon c-tag efficiency study compares well with a similar TESLA study.

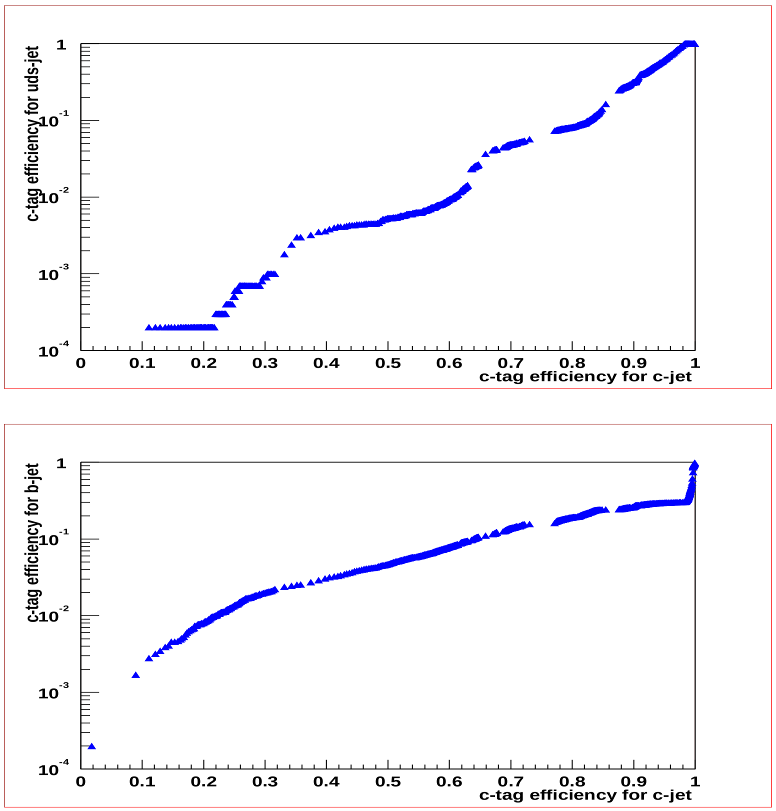
Mode	Oregon	TESLA TDR	ACFA
$h_{SM} \to WW^\star$	0.1	0.1	0.16
$h_{SM} \to b\bar{b}$	0.03	0.05	0.02
$h_{SM} \to \tau^+\tau^-$	0.08	0.1	–
$h_{SM} \to c\bar{c}$	0.39	0.17	0.27
$h_{SM} \to gg$	0.18	0.11	0.13

Relative branching ratio errors δ_{BR}/BR.

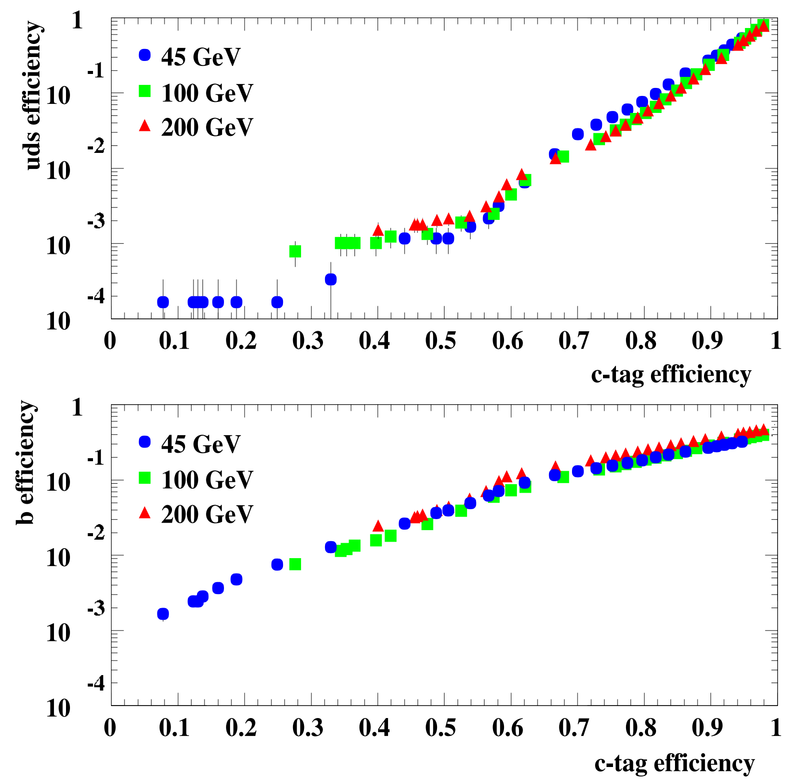
[5] M. Battaglia, in Proc. of the Worldwide Study on Physics and Experiments with Future e^+e^- Linear Colliders, E. Fernandez (editora), UAB, Barcelona 200, volI, 163

[6] Particle Physics Experiments at JLC, ACFA Linear Collider Working Group, `http://acfahep.kek.jp/acfareport/`

Comparison to Other Studies: Tagging Efficiency



Oregon study c-tag efficiency for uds-jet vs c-tag efficiency for c-jet (top) and c-tag efficiency for b-jet vs c-tag efficiency for c-jet (bottom) (45 GeV monojets). The IP resolution is $< 1.8, 1.8, 6.4) > \mu m$.



TESLA TDR[7] study c-tag efficiency for uds-jet vs c-tag efficiency for c-jet (top) and c-tag efficiency for b-jet vs c-tag efficiency for c-jet (bottom) for b-jet (45, 100 and 200 GeV monojets). The xy resolution is 1 μm.

[7] S.M.X Hansen, D.J. Jackson, R. Hawkings, and C.J.S. Damerell, Flavour Tagging Studies for the TESLA Linear Collider, LC-PHSM-2001-024, 2001.

Sources of Flavor Confusion in $ee \to Zh$

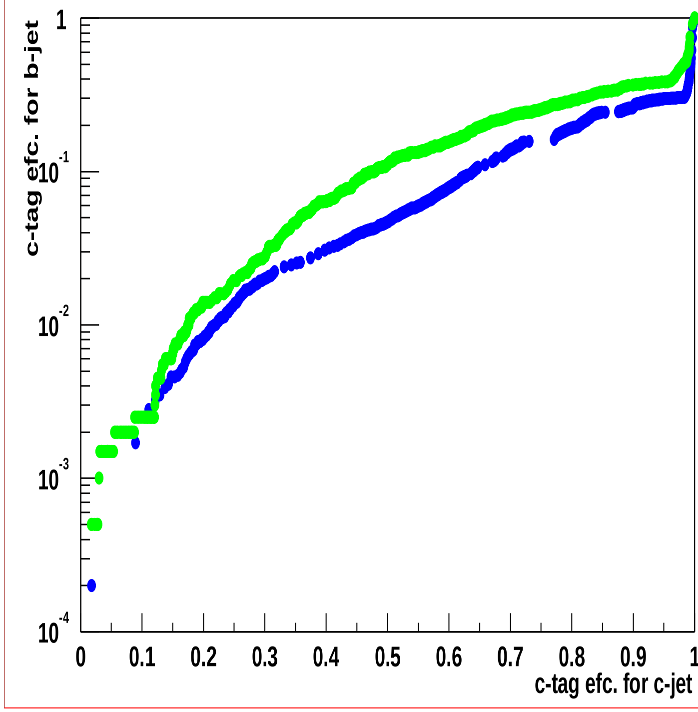
- Track migration between jets. If a track is asigned to the wrong jet, its parent's decay vertex is less likely to be found.

  (However, it is found that if all tracks in an event are assigned to both jets, the mean number of unassigned tracks per event does not decrease.)

- Monojets here plotted are monoenergetic. In Higgstrahlung the jets are boosted to a characteristic momentum distribution.

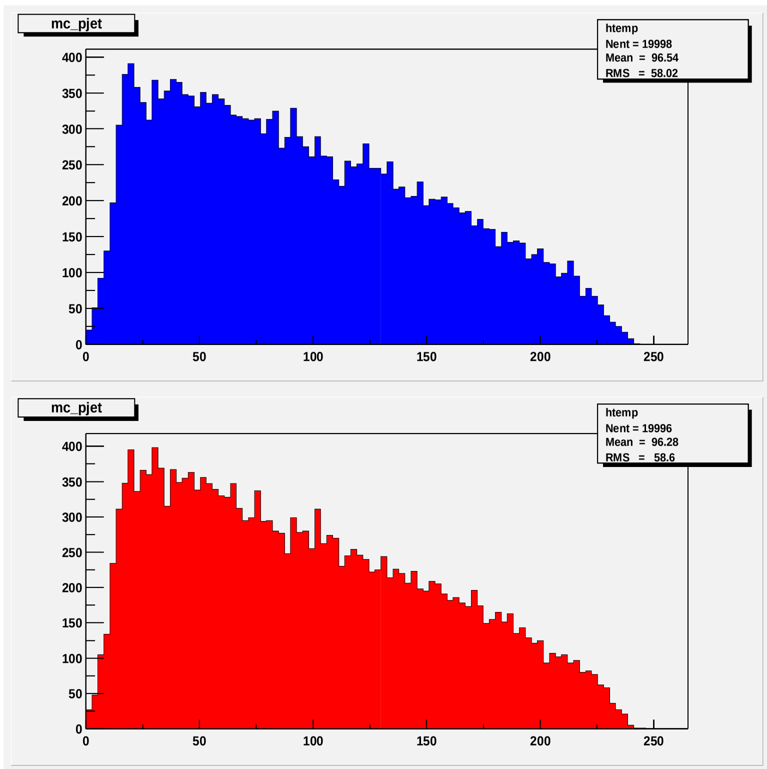
- One-prong decay vertices are not found by ZVTOP. A one-prong B decay followed by a multi-prong D decay looks simply like a D decay.

- Interactions between jets. Confusion caused by interactions betwen jets is unavoidable.

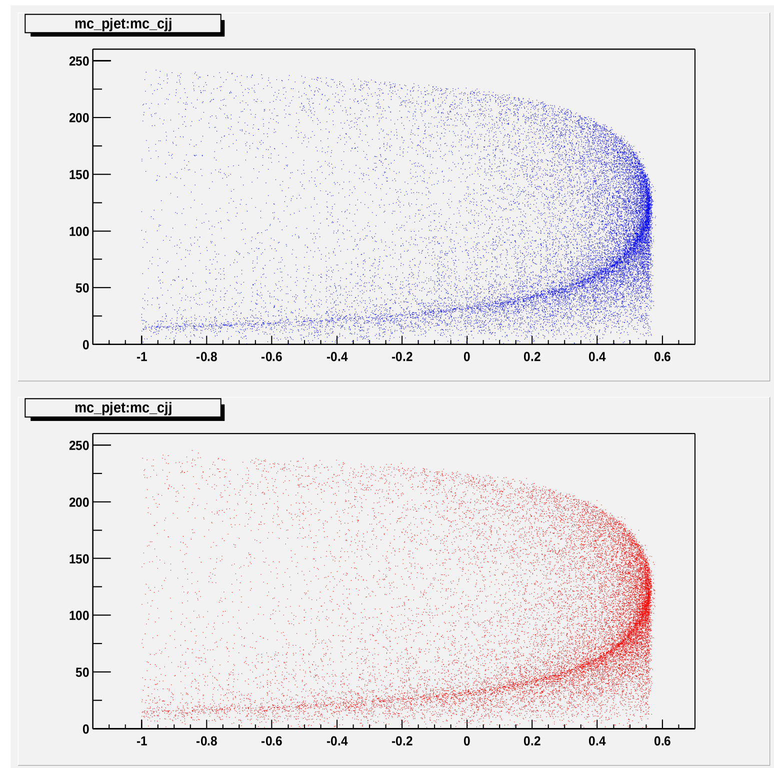


Oregon study c-tag efficiency for b-jet vs c-tag efficiency for c-jet for 45 GeV monojets (blue) and jets from $h \to j\bar{j}$ (green).

$h \to jj$ Momentum Spectrum in Higgstrahlung

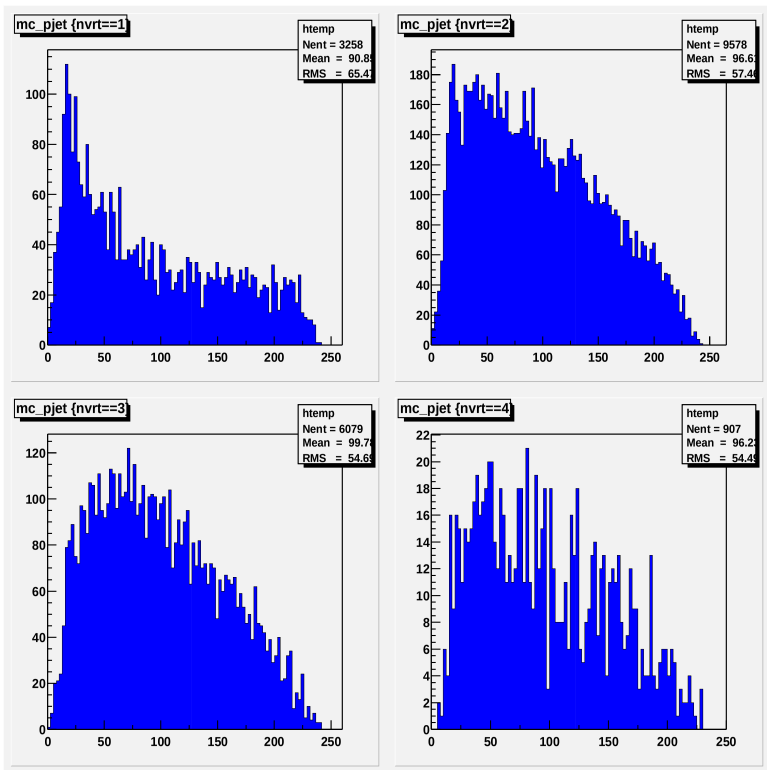


The momentum distribution for jets from $h \to jj$ in Higgstrahlung for $h \to b\bar{b}$ (top) and $h \to c\bar{c}$ (bottom).

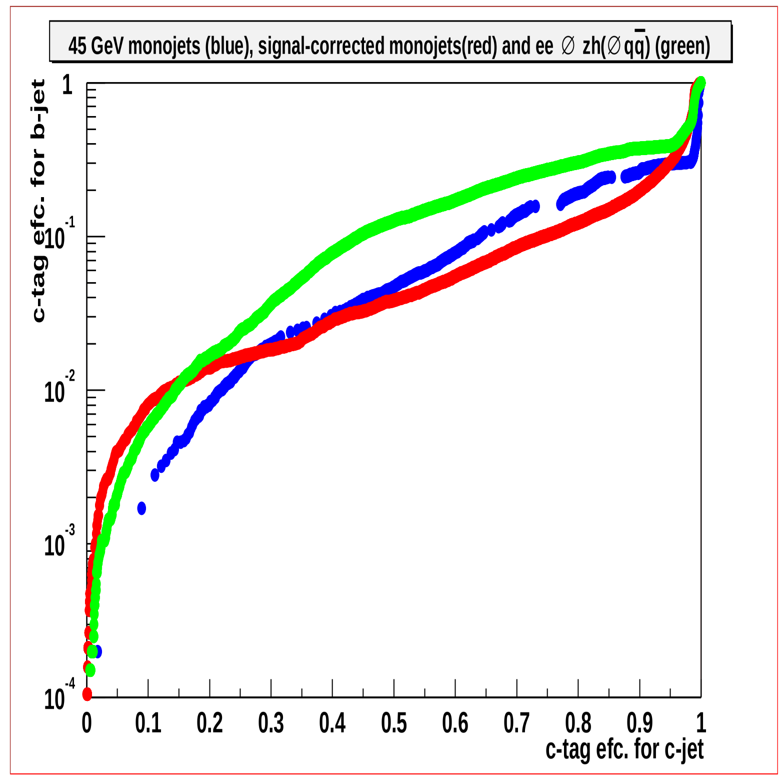


Momentum versus opening angle for jets from $h \to jj$ in Higgstrahlung for $h \to b\bar{b}$ (top) and $h \to c\bar{c}$ (bottom).

Found Vertex Multiplicity and Jet Momentum



The momentum distribution for jets from $h \to b\bar{b}$ in which ZVTOP found one, two, three, and four vertices. The means are $90.8, 96.6, 99.8$ and 96.2 GeV respectively.



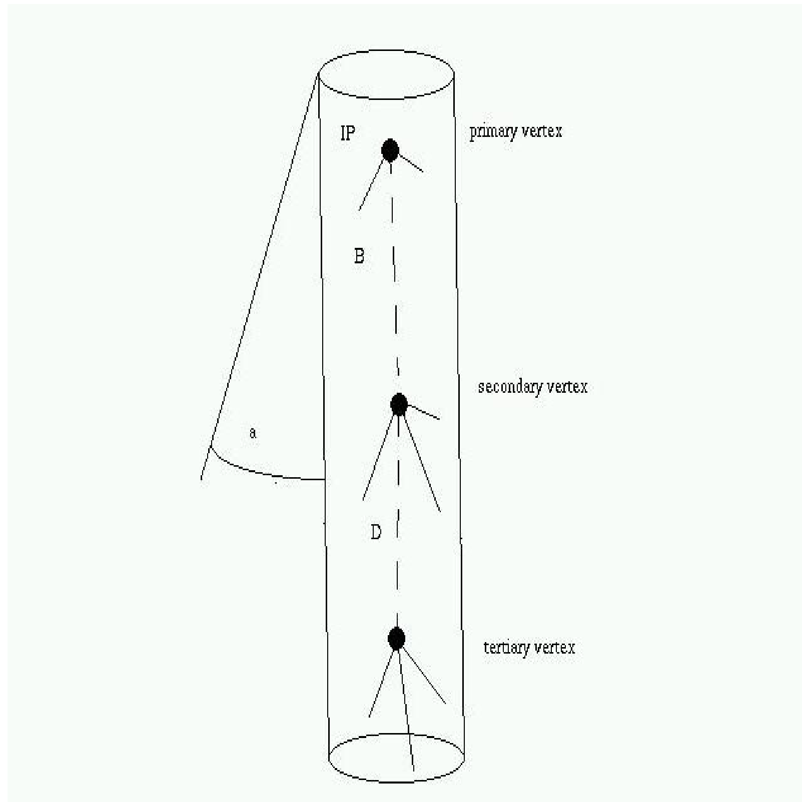
Oregon study c-tag efficiency for b-jet vs c-tag efficiency for c-jet for 45 GeV monojets (blue), monojets with the "corrected" momentum distribution (red) and jets from $h \to j\bar{j}$ (green).

Finding One-Prong Decays: the SLD Ghost Track Algorithm

Vertex Finding[8]

- Improve on ZVTOP by exploiting the straightness of the B decay chain.
- Identify the 'ghost' of the B track with the jet or thrust axis.
- Vertex each track with the ghost track and minimize

  $\sum_i \chi_i^2$ by varying the ghost track direction.
- Set the width of the ghost track so that the maximum $\chi^2_{track} = 1$ for all candidate B tracks.
- Assign tracks to vertices by iteratively merging cluster candidates with the highest fit probability until the maximum fit probability is less than 0.01.



The B decay chain and cylinder.

[8] T. Abe, Nuc. Instrum. Methods A, **447**, 90, 2000

The SLD Ghost Track Algorithm Performance

A Sample Jet

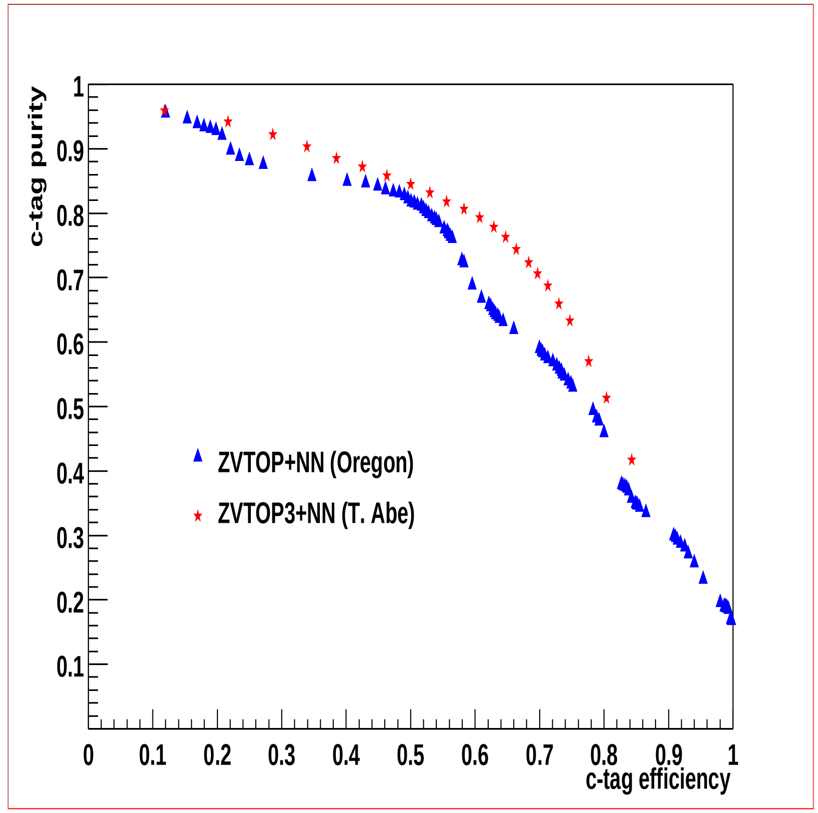
- In a sample jet ($B^+ \to e^+ \bar{D}^0 (\to K3\pi)$) in the 500 GeV LC environment, ZVTOP alone found, in addition to the primary vertex (IP):

```
=> Jet #1 ZVTOP
o Vertex #1 L=4
---> K+ from D0_bar L=4
---> pi+ from rho(770)0 L=4
---> pi- from a_1(1260)- L=4
---> pi- from rho(770)0 L=4
```

  while the GTA algorithm also found

```
o Vertex #1 L=3.3
---> e+ from B+ L=3.6
```

- Ghost Track Algorithm tuning parameters are now being optimized for the 500 GeV LC environment.



The c-tag purity vs efficiency in the SLD environment $\sqrt{s} = m_Z$ for ZVTOP3, which includes the ghost track algorithm to improve vertex fiding (T. Abe), compared to ZVTOP (Oregon study).