Higgs Boson Branching Ratios at the Linear Collider

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Snowmass 2001 Results

- The Pandora v2.1 generator [1] 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 [2].
- Since the $h_{SM} \rightarrow b\bar{b}$ and $h_{SM} \rightarrow c\bar{c}$ measurements rely on a precise vertex detector, we have taken great care to simulate vertex reconstruction with the tools developed for SLD. Track assignment to jets and to primary and secondary vertices within each jet is done on every event for use in flavor tagging.
- The jet p_t corrected mass (m_{p_t}) and number of vertices ($n_{vertices}$), calculated using the ZVTOP algorithm[3] (based on 3D topological vertex finding) then serve to separate the two-jet events by flavor. For one-prong decays, the two-jet events are separated by the number of tracks (N_{sig}) with 3D impact parameter significance greater than 3.
- In order to optimize tagging, these parameters and their discriminating values were used in constructing a neural network implemented on the Stuttgart Neural Network Simulator v4.2

p	p_{disc}	p	p_{disc}
$p_{l^\pm max}$	10 GeV	N_{sig}	10
E_{cone}	10 GeV	$n_{vertices}$ (jet 1)	2
m_{jj}	m_W	$n_{vertices}$ (jet 2)	2
$thrust_{Higgs}$	0.88	m_{p_t} (jet 1)	2 GeV
y_{32}	0.04	m_{p_t} (jet 2)	2 GeV
n_{tracks}	6	p_{jet}/p_{kin} (jet 1)	0.45
$m_{h_{recon}}$	110 GeV	p_{jet}/p_{kin} (jet 2)	0.45

Event parameters and their discriminating values.

Mode	115 GeV	120 GeV	140 GeV
$h_{SM} \rightarrow WW^\star$	0.16	0.10	0.03
$h_{SM} \rightarrow b\bar{b}$	0.027	0.029	0.038
$h_{SM} \rightarrow \tau^+\tau^-$	0.07	0.08	0.10
$h_{SM} \rightarrow c\bar{c}$	0.31	0.39	0.44
$h_{SM} \rightarrow gg$	0.16	0.18	0.23
$h_{SM} \rightarrow c\bar{c} + gg$	0.15	0.16	0.20

Relative branching ratio errors δ_{BR}/BR.

Mode	160 GeV	180 GeV	200 GeV
$h_{SM} \rightarrow WW^\star$	0.02	0.03	0.04
$h_{SM} \rightarrow b\bar{b}$	0.13	0.59	-
$h_{SM} \rightarrow \tau^+\tau^-$	0.36	-	-
$h_{SM} \rightarrow c\bar{c}$	—	-	-
$h_{SM} \rightarrow gg$	-	-	-
$h_{SM} \rightarrow c\bar{c} + gg$	-	-	-

Relative branching ratio errors δ_{BR}/BR.

[1] M. Peskin, *Pandora: An object oriented event generator for linear collider physics*, 1999, `hep-ph/9910519`
[2] M. Iwasaki and T. Abe, *LCD Root simulation and analysis tools*, 2001, `hep-ex/0102015`
[3] D. Jackson, Nuc. Instrum. Methods A, **388**, 247, 1997

Comparison to Other Studies

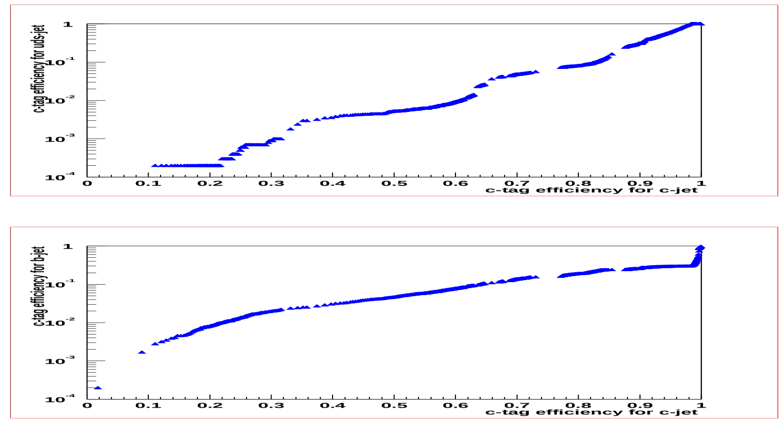
- Three studies are compared. All assume a 120 GeV Standard Model Higgs.
- The TESLA TDR study[4] assumed a 350 GeV linear collider with both WW-fusion and Higgstrahlung production modes. The TESLA results have been scaled to the assumptions of the Oregon study.
- The ACFA study[5] assumed the same parameters as the Oregon study.
- The greatest discrepancy is in the $h_{SM} \to c\bar{c}$ result. In the Oregon study, the predominant background came from b-jets mistagged as c-jets.
- An Oregon c-tag efficiency study compares well with a similar TESLA study. At right are plots from the Oregon 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

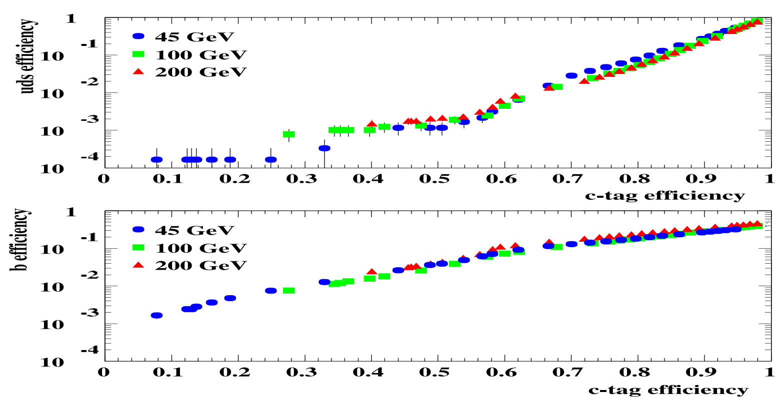
Relative branching ratio errors δ_{BR}/BR.

[4]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

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



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).



TESLA TDR[6] 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).

[6]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.

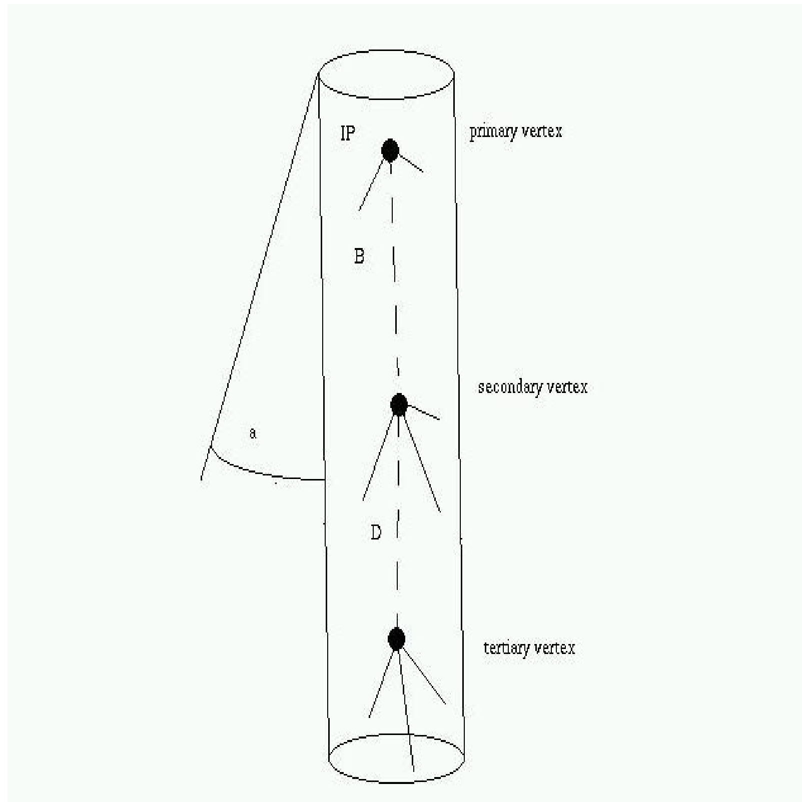
The SLD ZVTOP Algorithm for Vertex Finding

Vertex Finding[7]

- 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.

Tuning Parameters

- R_0: maxima resolution parameter
- χ_0^2: maximal vertexing χ^2 of track in vertex
- K_{IP}: interaction point weighting function ($f_{IP} \to K_{IP} f_{IP}$)
- K_α: weighting function for angle with respect to jet axis ($V(\mathbf{r}) \to V(\mathbf{r}) \exp(-K_\alpha \alpha^2)$))
- cylinder dimensions



The B decay chain and cylinder.

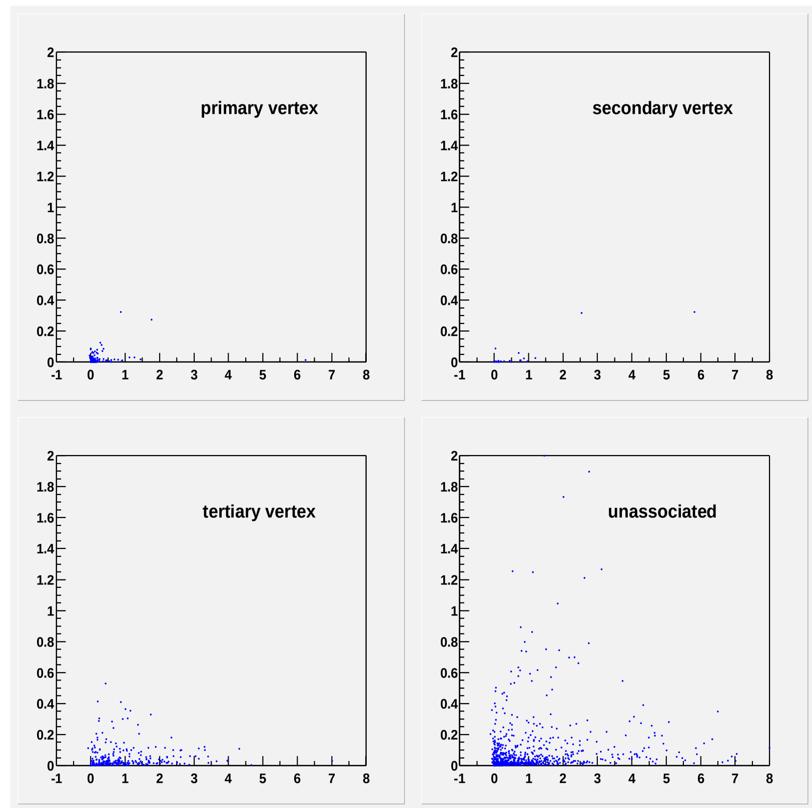
[7]D. Jackson, op cit

ZVTOP Performance in the NLD500 Environment

- ZVTOP tuning parameters values for the SLD environment and as set in the Oregon NLC500 Higgs boson branching ratio analysis.

Parameter	SLD	NLD500
R_0	0.6	0.6
χ_0^2	10.0	10.0
K_{IP}	1.0	1.0
K_α	5.0	5.0

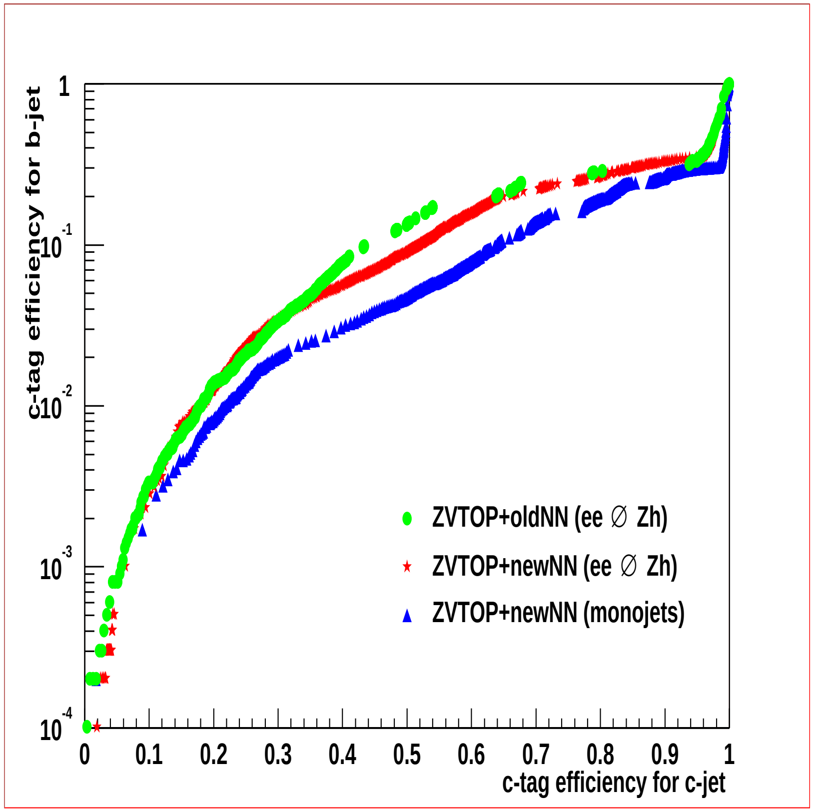
- No optimization of tuning parameters was performed for the NLD500 environment. It is not known how sensitive performance is to these tune parameters, though a jet momentum dependence is probable. The TESLA TDR study[8] suggested only a weak dependence, though here ZVTOP was used in combination with other algorithms.



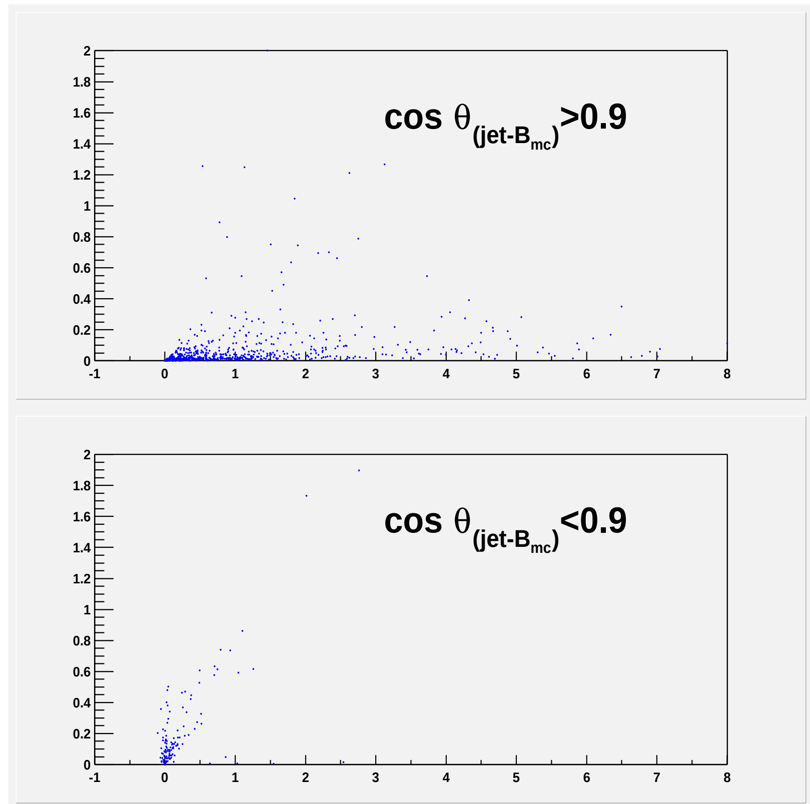
Spatial distribution of track origins verified as coming directly from B and D decays associated by ZVTOP to vertices (primary, secondary and tertiary) and those left unassociated in the rz-plane in $h_{SM} \to b\bar{b}$ events. The z-axis is aligned with the jet axis. The relative abundances are not normalized.

[8] S.M.X Hansen, D.J. Jackson, R. Hawkings, and C.J.S. Damerell, op. cit.

Tagging Impact of Unassociated Vertices



The c-tag efficiency for b-jet vs c-tag efficiency for c-jet for monojets and $h_{SM} \to q\bar{q}$. The monojets were generated by Pythia at 45 GeV. The h_{SM} decays were generated with Pandora-Pythia in the NLD500 environment.



Spatial distribution of track origins verified as coming directly from B and D decays but left unassociated to vertices in the rz-plane in $h_{SM} \to b\bar{b}$ events. The z-axis is aligned with the jet axis. The Monte Carlo B or D parent momentum is closely aligned with the jet axis in the top plot and is not in the bottom plot.

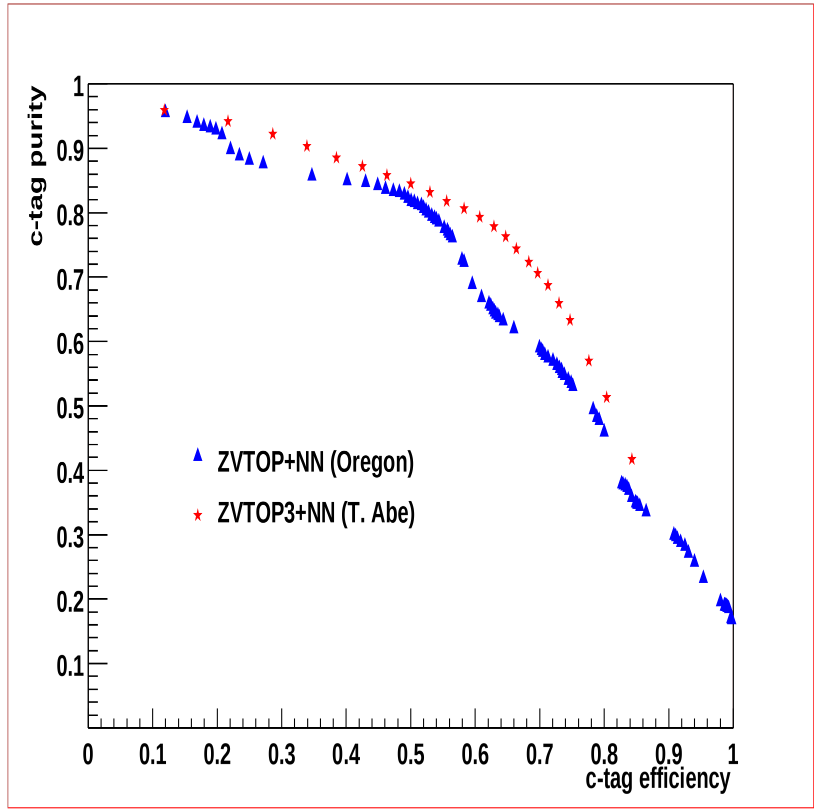
The SLD Ghost Track Algorithm for Vertex Finding

Vertex Finding[9]

- 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.

Improvement in the SLD Environment

- When used together with ZVTOP, the Ghost Track Algorithm improves reconstruction purity and efficiency at short decay lengths in the SLD environment.
- At right is a comparison of the performance of the tagging used in the Higgs branching ratio analysis, in which ZVTOP was used, to that of ZVTOP together with the Ghost Track Algorithm. The environment is that of SLD.



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).

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

Conclusions and Plans

- The North American, Asian and European Higgs boson branching ratio studies are largely in agreement. The $h_{SM} \to c\bar{c}$ error is the exception.
- The $h_{SM} \to c\bar{c}$ branching ratio error is dominated by mistagged $h \to b\bar{b}$ events in which B decay tracks are unassociated to vertices.
- ZVTOP should be tuned to the NLD500 environment in order to maximize B reconstruction efficiency.
- B decay tracks are left unassigned to vertices partly because they have been assigned to the wrong jet.
- B decay tracks assigned to the correct jet may still be left unassigned to vertices if they come from 1-prong decays.
- The Ghost Track Algorithm will improve the b tagging.
- New Higgs boson branching ratio error results incorporating a tuned ZVTOP and the Ghost Track Algorithm should be finished by the Santa Cruz Conference, Summer 2002.