Detecting High Mass H^0A^0 Pairs at a 1 TeV Linear Collider

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We report results from a study of simulated production of H^0A^0 pairs at a 1 TeV Collider. We assume the decoupling limit, and thus assume nearly degenerate masses of the H^0 and A^0. We find 5σ sensitivity in 50 fb^{-1} for masses up to roughly 460 GeV.

This note describes results from a study of H^0A^0 associated production at a linear e^+e^- collider with $\sqrt{s} = 1.0$ TeV. For the values of $\tan\beta$ as well as the H^0 and A^0 masses considered here, the dominant decay mode is $b\bar{b}$ pairs. This fully hadronic final state has limited backgrounds at an e^+e^- collider, but at the LHC or VLHC it suffers extremely high backgrounds from standard QCD jet production. At an e^+e^- collider, the dominant background is $t\bar{t}$ production with fully hadronic t-quark decay in which the c-quarks from $W^\pm$ decay are misidentified as b's. Other backgrounds such as four-fermion production are negligible because of the signal is dominated by a four b final state. The results of this study are quite encouraging. Good signal-to-background was observed using event rates alone, and reconstructed Higgs mass distributions showed high-efficiency, low background regions. This note has four sections. The first is a description of the Monte Carlo generation and simulation. The second describes the analysis, including mass reconstruction and jet-flavor identification. The third presents the results, and the fourth discusses additional work to be done.

1. Event Generation

Signal and background events were generated with the Pythia[1] Monte Carlo program version 6.158, using processes 165 and 300 at $\sqrt{s} = 1$ TeV. Initial state radiation was modelled using the default Pythia simulation. The H^0, A^0 decay modes were not constrained at generation, but instead all modes were produced, with the branching ratios as calculated by Pythia. The $t\bar{t}$ background was forced to decay as $t\bar{t} \to b\bar{b}c\bar{s}\bar{c}s$.[1] The Pythia four vectors were then input to the Root-based NLC fast simulation used during the Snowmass workshop.[2] The "silicon" detector geometry was used with the no-beam-constraint track smearing. The production cross-sections are shown in Table I. As a cross-check, the center-of-mass energy was changed to that used in an H^0A^0 study for Tesla.[3]. The generator cross-sections then agreed with those in the Tesla report.

2. Analysis

The detector simulation produced tracks and calorimeter cluster information. These were then used to find jets using the Durham algorithm with $y_{cut} = 0.004$. Both track-only and calorimeter-only jets were considered. As expected the calorimeter jets resulted in considerably better performance. Figure. 1 shows the number of reconstructed calorimeter jets/event for signal and background. The flavor of a jet was determined by looking at the flavor of the parton (quark or lepton) closest to the jet. A jet and parton were associated if $\cos\gamma > 0.97$, in which γ is the angle between the jet and quark three momenta. For cases in which more than one quark or charged lepton satisfied the $\cos\gamma$ requirement, quarks were preferred over leptons, and heavier quarks preferred to lighter. Each jet was then assigned a b-tag probability based on the flavor. The tag probabilities were assumed to be 80% for true b-jets, 10% for true c-jets and negligible for light

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[1]Events with leptonic W decays (from $t \to Wb$) can easily be rejected. The flavor mistag rate is dominated by c, so we ignore the $W \to u\bar{d}$ modes.

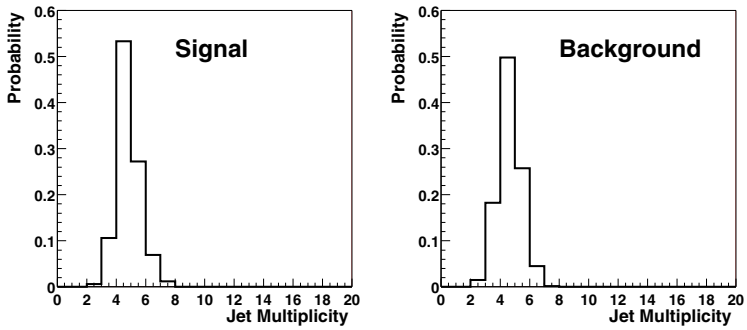

Figure 1: Jet multiplicity distributions for signal and background. The jets were reconstructed from calorimeter clusters using the Durham algorithm with $y_{cut} = 0.004$.

flavored jets.[4] These tag probabilities are used in the analysis to determine the overall probability for an event to have N_b b-tagged jets. The selection efficiency for a signal of $M = 450$ GeV was 0.16, and the background selection efficiency was 7×10^{-4}.

Events were selected for the analysis if they had exactly four calorimeter jets. The four jets were then used to compute dijet masses, M_1 and M_2. There are three possible combinations of jet pairs in a four jet event. The correct combination was defined to be that which gave the smallest mass difference, $|M_1 - M_2|$. Figure 2 shows the distribution for M_1 and M_2[2]. The histograms are normalized to 50 fb^{-1} of data, and dijet masses are weighted by the probability that the four jets in the event are tagged as b jets. The number of selected events and signal significance for 50 fb^{-1} of data are shown in Table I. Also shown is the number of events with $M_1 > 250$ GeV and $M_2 > 250$ GeV.

This analysis has not distinguished events with semi-leptonic b-decay from those with hadronic b-decay. Figure 3 shows the reconstructed masses for three categories: (1) dijet pair with hadronic b decay in both jets, (2) dijet pairs with one hadronic and one leptonic b decay and (3) pairs for which both jets have leptonic b decay. A jet is designated as being a leptonic jet if either a b-flavored particle or a c-flavored particle in the jet undergoes semi-leptonic decay. It is clear from this figure that the modes with all-hadronic final states have a significantly better mass resolution than the other two categories.

M_H^0	Production	BR($X \to b\bar{b}$)		Number of Events	
$= M_{A^0}$	σ (fb)	$X = A^0$	$X = H^0$	Counting	Min. Mass
400	2.4	0.80	0.88	20.	17.
425	1.5	0.78	0.86	12.	10.
450	0.85	0.77	0.84	7.	6.
460	0.59	0.77	0.84	4.6	3.8
475	0.28	0.76	0.83	2.1	1.6
$t\bar{t}$	$\sigma \times \mathrm{BR}(t\bar{t} \to b\bar{b}c\bar{s}s\bar{c}) = 19$			0.64	0.11

Table I The production cross-section, $b\bar{b}$ branching ratio and number of events selected. The data correspond to 50 fb^{-1} of integrated luminosity. There are two analysis cases shown. The first is a pure counting experiment, and the second places a requirement that the reconstructed masses in the event are above 250 GeV. The branching ratio to $b\bar{b}$ decreases as the $t\bar{t}$ decay modes of the A^0 and H^0 open.

[2] There are two entries/event in this figure.

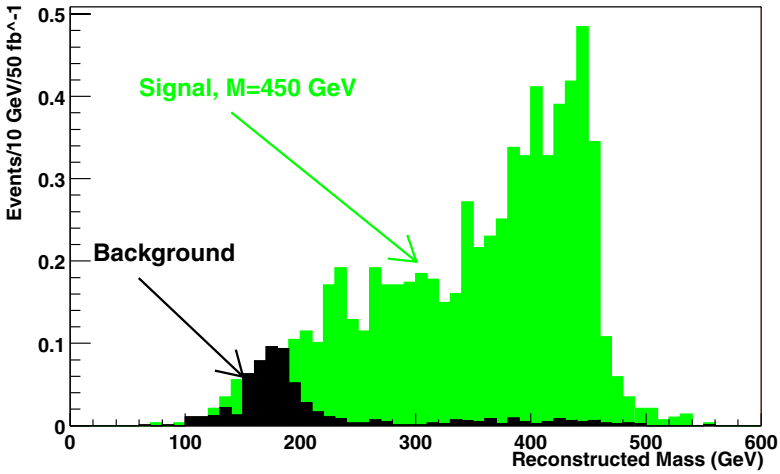

Figure 2: Reconstructed mass distribution. The signal is H^0A^0 with $M = 450$ GeV. The histogram has both masses for each event, but the plot is normalized to the expected number of events. The green(light gray) histogram is signal. The black histogram is background.

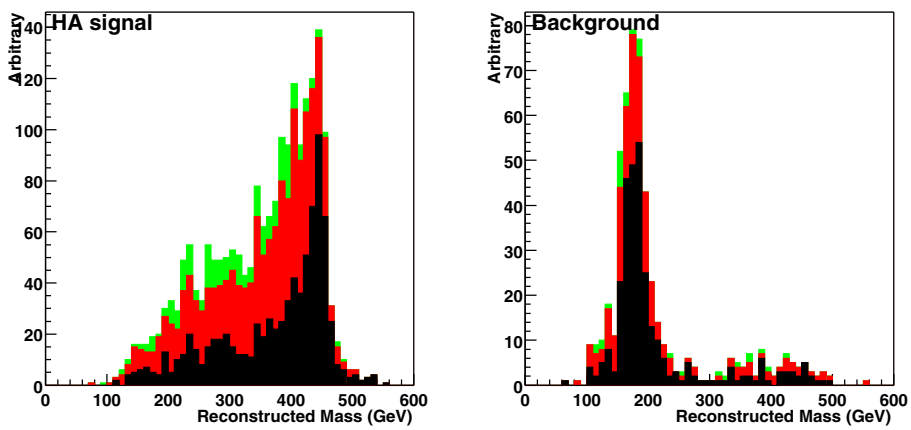

Figure 3: Decay-mode dependence of the reconstructed jet mass. The histograms from Fig. 2 are plotted for three decay modes. The black band has the reconstructed dijet masses for which both b's decay hadronically. The red(medium gray) band has masses for which one b had a semi-leptonic decay, and the green(light gray) band has masses for which both jets had undergone semi-leptonic b decays.

3. Summary and Future Work

The results of this analysis clearly demonstrate the feasibility of detecting H^0A^0 production at a 1 TeV e^+e^- collider. The sensitivity for 50 fb^{-1} extends, for the case of degenerate masses, to $M = 460$ GeV. This depends only on a counting experiment. The dominant background, $t\bar{t}$ peaks at 180 GeV, while the signal peaks at the Higgs mass.

There are additional issues that could be addressed by measurements of this final state. The first would be a measurement of the mass difference between the H^0 and the A^0. A second interesting possibility would be a measurement of the widths. The widths are proportional to $\tan^2\beta$, and for $\tan\beta = 10$, the width is 1.2 GeV. For both of these measurements, the mass resolution must be significantly improved beyond that in this analysis. A future study should attempt this. We see three steps toward this. The first is to have a high purity means of separating the events with only hadronic b-decays. This alone significantly improves the resolution. The second is forcing the events to have exactly four jets by varying the jet-finding combination

threshold, and the third is to use an energy–flow algorithm for the jet finding.

Acknowledgments

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References

[1] T. Sjostrand, Computer Physics Commun. 82 (1994) 74, and the Supersymmetric extensions in S. Mrenna, ANL-HEP-PR-96-63. See also T.Sjostrand it et. al., Computer Physics Commun. 135 (2001) 238.
[2] Available at `http://www-sldnt.slac.stanford.edu/nld/New/Docs/LCD_Root/root.htm`
[3] A. Andreazza, C. Troncon. *A Study of HA Production in* e^+e^- *Collisions at* $\sqrt{s}$ = 800 *GeV*, DESY-123-E, p. 417.
[4] *TESLA, Technical Design Report*, DESY 2001-011, See FIG. 9.3.1. See also S. M. Xella Hansen, D. J. Jackson, R. Hawkings, and C. J. S. Damerell, *Flavor Tagging Studies for the TESLA Linear Collider*. LC-PHSM-2001-024, 2001. `http://www.decay.de/~lcnotes`.