A DIRECT MEASUREMENT OF
\[ \tan \beta: e^+e^- \rightarrow b\bar{b} \rightarrow b\bar{b}A \] AT A
FUTURE \( e^+e^- \) LINEAR COLLIDER

M. Berggren\(^a\), R. Keränen\(^b\), A. Sopczak\(^b\)

\(^a\) LPNHE, Université de Paris VI & VII
\(^b\) Karlsruhe University

Abstract

The experimental sensitivity of the reaction \( e^+e^- \rightarrow b\bar{b} \rightarrow b\bar{b}A \) has been studied with a full-statistics background simulation for \( \sqrt{s} = 500 \) GeV and \( \mathcal{L} = 500 \) fb\(^{-1}\). The simulation is based on a fast and realistic simulation of a TESLA detector. For the first time this reaction has been analysed for a future linear collider and we show that a signal could be observed. A significant signal over background is achieved by the application of an Iterative Discriminant Analysis (IDA). For a signal production cross section of only 2 fb, which is expected for a Higgs boson mass of 100 GeV and \( \tan \beta = 50 \), we achieve 100 signal over 100 background events, and obtain for a \( \tan \beta \) measurement: \( \Delta \tan \beta / \tan \beta = 0.07 \). This measurement requires a high-luminosity future collider as proposed in the TESLA project.

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R. KERANEN, A. SOPCZAK
Karlsruhe University

M. BERGGREN
LPNHE, Université de Paris VI & VII

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1 Introduction

A future linear collider has a great potential for discovering new particles and measuring their properties. While many parameters of theories beyond the Standard Model can be measured with high precision, the determination of the important \( \tan \beta \) parameter, the ratio of the vacuum expectation values of two Higgs boson doublets, is difficult, in particular when \( \tan \beta \) is large. This study uses the fact that the Yukawa coupling \( b\bar{b}A \) is proportional to \( \tan \beta \). Therefore, the value of \( \tan \beta \) can be directly derived from the measurement of the \( e^+e^- \rightarrow b\bar{b} \rightarrow b\bar{b}A \rightarrow b\bar{b}b\bar{b} \) production cross section. The challenge of this study is the low expected production rate and the large irreducible background for a four-jet final state. The signal production process and the expected event rate are shown in Fig. 1. Searches for this four-jet channel were performed at LEP with data taken at the Z resonance.

2 Event Simulation

The simulated production process is \( e^+e^- \rightarrow b\bar{b} \rightarrow b\bar{b}A \rightarrow b\bar{b}b\bar{b} \), leading to four b-quark jets in the final state. The signal and background event generators include initial state radiation and beamstrahlung. We simulated a 100 GeV pseudoscalar Higgs boson. The generated events are passed through the fast detector simulation SGV. This program follows the helical paths of charged particles through

\(^\text{a}\)speaker
the detector in order to estimate their track-parameter covariance matrices. The track-parameters are then smeared according to these matrices. Calorimeters are simulated by parametrization of the detector response function. A probability-based b-tagging method is implemented using the simulated track-parameters (measured mainly with the micro-vertex detector). Particle identification and track-finding efficiencies are also simulated. The detector properties closely follow the TESLA detector CDR.

3 Event Preselection

First, an event preselection is applied using the hadronic character and expected b-quark characteristics of the simulated signal. The following preselection cuts are applied: 3rd significant jet b-tag > 2, $N_{\text{cluster}} > 17$, $E_{\text{vis}}/\sqrt{s} > 0.6$, $E_{\text{neutral}}/\sqrt{s} < 0.5$, $E_{\gamma} < 30 \text{ GeV}$, thrust < 0.92. The number of simulated events for the signal and for each background channel, as well as the remaining events after the preselection are given in Table 1.

| Channel  | bbA | qg | WW | eWν | tt | ZZ | eeZ | hA |
|----------|-----|----|-----|-----|----|----|-----|----|
| (in 1000)| 50  | 6250 | 3500 | 2500 | 350 | 300 | 3000 | 50 |
| After presel. | 73% | 20991 | 7481 | 0 | 89983 | 10278 | 145 | 12665 |

4 Iterative Discriminant Analysis

In order to separate the signal from the background, the following selection variables are defined: highest and third significant jet b-tagging, thrust value, second Fox-Wolfram moment, $y$-cut value to form four jets, minimum and maximum jet energy, isolation angle of the most energetic jet, minimum angle and invariant mass between any jet pair, minimum jet and event charge multiplicity, charged and neutral event energy. Figure 2 shows the simulated b-tagging variable for the third significant jet.
and the second Fox-Wolfram moment after the preselection for 141544 remaining background events. The thrust value and the IDA output variable are shown in Fig. 3. Half of these events and half of the signal events are used to train the IDA. In a first step, a cut on the IDA output variable is applied such that the efficiency is reduced by 30%. The remaining signal and 6745 background events are again passed through the IDA. Figure 4 shows the IDA output variable and the resulting number of background events as a function of the signal efficiency.

Figure 2: b-tagging variable and Fox-Wolfram moment after the preselection.

Figure 3: Thrust value and first step IDA output.

5 Results

We have determined the expected background rate for a given signal efficiency and evaluated that the sensitivity for a 100 GeV pseudoscalar Higgs boson in the process $e^+e^- \rightarrow b\bar{b} \rightarrow b\bar{b}A$ suffices to determine the value of $\tan \beta$. The sensitivity $N_{\text{signal}}/\sqrt{N_{\text{background}}}$ is almost independent of the working point signal efficiency.
in the range 5% to 50%. For a working point of 10% efficiency, the total simulated background of about 16 million events is reduced to 100 background events. The resulting error on \( \tan \beta = 50 \) is 7%:

\[
\Delta \tan^2 \beta / \tan^2 \beta = \Delta N_{\text{signal}} / N_{\text{signal}} = \sqrt{N_{\text{signal}} + N_{\text{background}}} / N_{\text{signal}} = 0.14.
\]

For smaller values of \( \tan \beta \) the sensitivity reduces quickly. A 5\( \sigma \) signal detection is possible for \( \tan \beta = 35 \).

In conclusion, an IDA analysis based on experience at LEP2 was applied and gave sufficient sensitivity to detect the signal process. A high-luminosity linear collider is essential and unique for this channel and allows the value of \( \tan \beta \) to be measured with precision.

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