PROSPECTS AND PROBLEMS IN FERMION-PAIR PRODUCTION

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We discuss 2f production at LC energies ($f \neq t$). This type of reaction has a big event number and may give interesting hints to the existence and perhaps to details of New Physics like susy, LQ, Z', etc. For any search the radiative corrections have to be controlled carefully. An interesting challenge for theoreticians could also be the Giga-Z option of the TESLA project.

1 Introduction

Fermion-pair production,

$$e^+ + e^- \rightarrow f + \bar{f} + n\gamma,$$

is among the scattering processes with the biggest expected counting rates at a future Linear Collider (LC) running somewhere between 500 and 1000 GeV. This may be seen e.g. in Figure 1.(a) in\textsuperscript{1}. If the Giga–Z option\textsuperscript{2} of the TESLA–project\textsuperscript{3} will be realized, the $Z$–resonance region could be additionally studied with a rate of about $20 \times 10^9$ $Z$–bosons.

The physics potential was summarized in several of the plenary talks\textsuperscript{4–7} and quotations therein. The main interest is concentrated on indirect high-energy searches with reaction (1) for diverse phenomena beyond the Standard Model: $Z'$, $W'$, extra spatial dimensions, susy R-parity violation, leptoquarks, preons, etc.

There is also some discovery potential of direct searches with the Giga–Z option, e.g. for lepton number violation\textsuperscript{8–10}. But, the interest is focused here on precision studies of the Standard Model and its MSSM extension\textsuperscript{11}.

Whenever we have indirect searches, we have to control the known physics extremely well. Thus it might well be that we will have to face the challenge to provide high precision predictions in two largely different situations – at the $Z$–peak and far away from it. Aiming at theoretical errors of single cross-section contributions of one tenth of the experimental error, we need accuracies of 0.015% to 0.5%, depending on observables and rates; see Table 1 in\textsuperscript{12}.

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The success of indirect searches depends finally on the control of radiative corrections to the reactions studied. The cross-section for (1) is:

\[ \sigma(s) \sim \int \frac{ds'}{s} \sigma^0(s') \rho(s'/s). \]  

The radiative corrections may be roughly divided into two classes. There are the virtual corrections to the basic, two-to-two-particle scattering process \( \sigma^0(s') \). They are largely model-dependent and increase asymptotically at high energies due to several mechanisms. A nice example for this are the one-loop \( t \)-quark corrections to \( b \)-pair production shown in Figure 1 of 12; see also 13−15. For a quantitative discussion of higher-order corrections see e.g. 16, with the estimate that uncertainties from them at 1 TeV are not under 1%. Further, it has been stressed quite recently that virtual corrections of the Standard Model may get completely modified in enlarged scenarios so that they may lose their role as a reasonably estimated basis on which Born effects of New Physics could appear. The other class of corrections are the photonic (and QCD−) corrections \( \rho(s'/s) \), including real photon (and gluon) emission. They are basically understood but have to be controlled carefully and efficiently. A mini-review was given in 18. In the rest of this contribution, we will concentrate on a semi-analytical approach advocated by the ZFITTER team. We aim at a realization of (2) with one-dimensional numerical integrations only, thus allowing for a flexible, accurate, but also very fast Fortran program well suited for the multi-parameter fits typically applied to the \( Z \)-resonance.

There have been performed countless improvements of the Fortran packages for a description of the \( Z \)-lineshape, accompanied by a number of dedicated numerical comparisons between different programs, most recently e.g. in 19−20.

2 Photonic corrections at the \( Z \)-resonance

One of the open problems until recently was the accuracy of ZFITTER at the \( Z \)-resonance with application of an acollinearity cut, the so-called realistic cut situation. The agreement e.g. with TOPAZ021 was not considered to be satisfactory in 19. After a complete recalculation it is excellent now 20, 22. This we may demonstrate with Table 1.

3 Photonic corrections above the \( Z \)-peak

At higher energies, the situation is much more involved since radiative corrections generally will grow. Further, there was a specific suppression of hard photonic bremsstrahlung, and thus also of related classes of higher-order corrections, in the vicinity of the \( Z \)-resonance. At an LC, we will have to control hard photonic corrections with great care, especially if the so-called radiative return is not suppressed by dedicated cuts. One may get an impression of all this from Figures 1 and 2.
Table 1: A comparison of predictions for muonic cross-sections and forward-backward asymmetries around the $Z$-peak. First row is without initial-final state interference, second row with, third row the relative effect of that interference in per mil.

| $\theta_{acc} = 0^\circ$ | $M_z - 3$ | $M_z - 1.8$ | $M_z$ | $M_z + 1.8$ | $M_z + 3$ |
|--------------------------|------------|-------------|-------|-------------|-------------|
| **TOPAZO**               |            |             |       |             |             |
| $\sigma_\mu$ [nb] with $\theta_{acol} < 10^\circ$ | 0.21932    | 0.46287     | 1.44795 | 0.67725 | 0.39366 |
|                           | $-7.16$    | $-4.43$     | $-0.07$ | +2.49      | +3.17      |
| **ZFITTER**              |            |             |       |             |             |
| $A_{FB}^\mu$ with $\theta_{acol} < 10^\circ$ | 0.21928    | 0.46284     | 1.44780 | 0.67721 | 0.39360 |
|                           | $-7.16$    | $-4.40$     | $-0.03$ | +2.60      | +3.27      |

where we show cross-section ratios from **TOPAZO** or **ALIBABA** with **ZFITTER**, with $s'$-cut or with acollinearity cut. It may nicely be seen that for a sufficient suppression of the radiative return to the $Z$-peak the programs agree well within the expected errors, although it is also seen that higher order corrections are treated differently. For an acollinearity cut, allowing for more hard photonic corrections than a correspondingly chosen $s'$-cut, the deviations between the programs get bigger.

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