Four and Six Fermion Event Generators for $e^+e^-$ Collider Physics$^a$

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**Abstract:** The status of four and six fermion event generators for Standard Model processes at present and future $e^+e^-$ colliders is briefly reviewed.

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$^a$To appear in the Proceedings of the International Workshop on Linear Colliders, Sitges, Spain, April 28- May 5, 1999
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1 Introduction

The ongoing run at LEP2 has led in the last recent years to detailed analyses related to both SM and beyond the SM physics. The theoretical results achieved for LEP2 physics have been implemented in dedicated four fermion codes. $M_W$ measurements, studies of triple gauge couplings and Higgs searches in the low mass range require the analysis of four fermion final states, making therefore unavoidable the calculation of four fermion processes at LEP2 and future $e^+e^-$ colliders. Since the advent of LEP2, several codes with different features have been implemented and carefully cross-checked. The available four fermion tree level programs, most part now interfaced to QCD Generators (PYTHIA/JETSET and/or HERWIG), reviewed by Sjöstrand, to relate parton level predictions with experiments, are listed in Tab.[1].

The work done for four fermion physics at LEP2 can be extended to the NLC. This machine however would not only improve the sensitivity to trilinear gauge couplings and gauge boson properties, but it would be also ideal for precision studies of quartic gauge couplings, top properties and Higgs searches in the intermediate mass range. All these topics involve processes with six fermions in the final state, but despite of this only a few six fermion codes have been at present implemented. To our knowledge, only GRACE, SIXPHACT and WWGENPV/ALPHA can simulate six fermion processes.

In this talk we summarize some features of the above mentioned codes, even if this brief description can do no justice to the effort that has been done by the various groups.

2 Four fermion codes

On the side of four fermion codes, many improvements have been recently introduced into the existing programs (e.g. refer to contributions by Jadach and Perret-Gallix) and two new codes, presented by Denner and Peskin, have been implemented.
Table 1: Available four fermion programs. The included processes are written using the notation of Ref.\cite{1}. Y(N) indicates the code includes (does not) fermion masses ($m_f$) and anomalous couplings (AC). Y/N is for approximate treatment of $m_f$.

Due to the increasing statistics at LEP2, the interplay between theory and experiments is becoming more stringent. The attention is therefore focusing on the role of the radiative effects and on the estimate of the theoretical uncertainty on the predictions. An example is the treatment of the photons in the initial and final state, a particularly delicate issue. Neglecting the $p_T$ of the photon, as in the usual LL approximation of the ISR, can have sizeable effects, for example on the detection efficiency and on the differential distributions used for TGC studies and also for New Physics searches since the detection of new particles often rely upon missing $p_T$. Different prescriptions have been adopted. Some codes include models for the generation of IS multiphotons with finite $p_T$ (KORALW\cite{KORALW} and LL FSR, while others make use of QED parton showers with $p_T$ (EXCALIBUR, grc4f, LEPWW and PYTHIA). A more accurate approach, not affected by possible gauge invariance problems, could consist in merging the explicit emission of a single hard photon with collinear bremsstrahlung and radiative corrections. As a further step toward the full calculation of the radiative effects, complete matrix elements for the process $e^+e^- \rightarrow 4f + \gamma$ have been implemented by ALPHA and recently by Denner et al.\cite{6}. Matcher theory and experiments means also being able to produce reliable
results in a finite time. This question has focused the attention on the integration methods. Since a large number of diagrams with different topologies contribute to a given final state, the multichannel techniques (as in EXCALIBUR, KORALW and WWGENPV/ALPHA) seem to be the most promising.

At the higher NLC energies, not only the complexity of the processes will increase, but new difficulties could appear. In Fig. [1], it is shown the result of one of the latest tuned comparisons among four codes, concerning the gauge invariance issue for the single W production at small angle, reviewed by Boos. Events with one or two electrons in the forward direction (coming from $e\nu W$

![Figure 1: Comparison for single W production at small angle at 500 GeV with and without ISR. On the X-axis: 1=CompHEP, 2=grc4f, 3=KORALW, 4=WPHACT. Cuts: $M(ud) \geq 5$ GeV and $E(u, d) \geq 3$ GeV.](image)

$eeZ$ or $2\gamma$ processes) will be relevant at the NLC as signal, to disentangle the $WW\gamma$ coupling, and as background to New Physics searches. These processes, which contain t-channel photon diagrams with mass singularity in the very forward region, require massive matrix elements and phase space to cure these apparent divergencies. Moreover, they need a proper implementation of the boson width in the propagators, in order to preserve the large cancellations among the t-channel diagrams dictated by the gauge invariance. The comparison in Fig.[1] involves gauge preserving prescriptions, namely the overall prescription (CompHEP and WPHACT) and the $L_{\mu\nu}$ transform method (grc4f
and KORALW), and shows a rather satisfactory agreement. Recently, also a new scheme based on complex gauge boson masses and obeying the Ward identities has been introduced, as presented by Denner.

3 Six fermion codes

Six fermion final states receive contributions from a great amount of different Feynman diagrams. Some of them correspond to Higgs production and decay. Others may come from $t\bar{t}$ or $WWZ$, or from partial resonant processes (as for instance $\nu_e\bar{\nu}_e WW$) as well as non resonant ones. All these diagrams, which in general are of the order of several hundreds, correspond to the same final state and interfere among themselves. Different resonant contributions might be considered as signal or background depending on the process under study and their interplay can be consistently analyzed only by complete calculations. Moreover, all these channels might constitute a main source of background to New Physics searches.

Recently three groups have started computing full tree level cross sections for six fermion final states at the NLC. These computations have been applied to study the phenomenology of $t\bar{t}$, $WWZ$ and higgs production and have already shown the importance of finite width effects and irreducible background. In these analyses, the beamstrahlung effects have been simulated using the parametrization implemented in CIRCE. Recently, also a new method (PYBMS), based on the Pisin-Chen formalism, has been proposed.

4 Conclusions

Much effort has already been devoted in order to have reliable tools for four fermion physics, but much work has still to be done on the side of electroweak and QCD radiative effects. Whereas the four fermion area is well covered, so far few codes have been implemented for six fermion processes. Hopefully, the joint work of the various groups will lead to a better understanding of what is still missing in order to fully exploit the great and unique capability of the $e^+e^-$ colliders.

Acknowledgments

It is a real pleasure to thank the organizers for the nice and stimulating atmosphere of the workshop. We wish to acknowledge also A. Ballestrero, E. Boos, S. Jadach and D. Perret-Gallix for supplying us with Fig.1 and for useful discussions.
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