Physical Results by means of CompHEP

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Abstract

The CompHEP package was developed for calculations of decay and high energy collision processes with, correspondingly, up to 5 and 4 final particles in the lowest order (tree) approximation. The main idea put into CompHEP was to make available passing from the Lagrangian to final distributions efficiently with high level automation what is extremely needed in collider physics.

The present talk describes a general structure of the CompHEP facilities and reports some physical results obtained with its help. The main purpose of the talk is to attract the attention of high energy physicists to this user-friendly package which is completely aimed at making easier their routine and tedious calculations in the TeV region.

1. Introduction

CompHEP project was started in 1989 by group of physicists and programmers from the Institute of Nuclear Physics, Moscow State University. The first versions of the CompHEP package were written in Turbo Pascal for IBM compatible PC. In 1992 this package was rewritten in the C programming language and now the installation on UNIX workstations is available. At present time there are some versions for different platforms: HP Apollo 9000, IBM RS 6000, DECstation 3000, Sparc station, Silicon Graphics.

CompHEP is a menu-driven system with the mixed text/graphical output of information and the context HELP facility. The notations used in CompHEP are very similar to those used in particle physics. It contains several built-in theoretical models of particle interactions including the Standard Model in the unitary and 'tHooft-Feynman gauges. A creation of a new particle interaction model by the user is available. The user can change interaction vertices and model parameters. In the present version polarizations are not taken into account. Averaging over initial and summing over final polarizations are performed automatically.

The general structure of the CompHEP package is represented in Fig. 1. It consists of the symbolic part and the numerical one. The main facilities of the symbolical part allow the user to

- select process by specifying in- and out- particles for decays of $1 \to 2, \ldots, 1 \to 5$ types and collisions of $2 \to 2, \ldots, 2 \to 4$ types;
- generate and display tree-like Feynman diagrams in the lowest order;
- eliminate some number of diagrams from the further consideration;
- generate and display squared Feynman diagrams (corresponding to squared $S$-matrix elements);
- derive analytical expressions corresponding to squared diagrams with the help of the fast built-in symbolic calculator;
- carry out numerical calculations for $1 \to 2$, $1 \to 3$ and $2 \to 2$ processes and show plots of various distributions on the screen;
- generate LATEX files for graphical outputs;
- save analytical results in the REDUCE and MATHEMATICA codes for further symbolic manipulations;
- generate the optimized FORTRAN codes for the squared matrix elements in order to make further numerical calculations.

The numerical part of the CompHEP package is written in FORTRAN. It uses the CompHEP FORTRAN output and the BASES&SPRING package for Monte-Carlo integration and event generation. By means of the CompHEP numerical part the user is able to
• choose phase space kinematical variables;
• introduce kinematical cuts on momentum transfers and squared masses for any groups of outgoing particles;
• make regularization to remove sharp peaks from the integrand;
• change the BASES parameters of the Monte-Carlo integration;
• change numerical values of model parameters;
• calculate distributions, cross sections or particle widths by the Monte-Carlo method;
• carry out integration taking account of structure functions of incoming particles;
• generate events and obtain histograms simulating a signal in the real experiment.

2. Menu system of the CompHEP symbolic part

The user can select menu positions displayed on the screen with the help of the Arrow keys. The input of the selected position is performed by pressing the Enter key. One can press the F1 key for Help, i.e., in order to get information about the selected menu position. To return to the previous level menu one should click the Esc or Backspace keys.

The menu titles of the CompHEP symbolic part are shown in Fig.2.

Menu 1 (models)

This menu gives the user a possibility to select a model of elementary particle interaction. Fermi model includes QED and the four-fermion weak interaction. The interaction of fermion currents is implemented through the auxiliary intermediate bosons with constant propagators.

NEW MODEL is an option for creating a new physical model. The user will be asked about a new model name and a template for the model. To choose the template the list of the existing models appears. The Edit model option of Menu 2 can be used to insert changes.

Menu 2

Enter process is an option for entering the process from the keyboard with the CompHEP notations displayed on the top of the screen as a table:

| A(A)  | n1(N1) | e3(E3) | d(D)  | t(T)  | W+(W-) | -photon | -e-neutrino | -tau | -d-quark | t-quark | W-boson |
|-------|--------|--------|-------|-------|--------|----------|-------------|------|----------|--------|---------|
| G(G)  | e2(E2) | n3(N3) | c(C)  | b(B)  | Z(Z)   | -gluon   | -muon      | -tau-neutrino | c-quark | b-quark | Z-boson |
| e1(E1)| n2(N2)| e1(E1)| u(U)  | u(U)  | H(H)   | -electron| -nu-neutrino| u-quark | s-quark | -higgs |
|       |       |       |       |       |        |          |             |        |          |         |         |

If the input is correct CompHEP constructs the corresponding Feynman diagrams and the user gets to Menu 4.

The Edit model option leads the user to the Menu 3 to insert changes into model tables.

Menu 3 (edition of models)

A physical model in CompHEP consists of four tables: Parameters, Constraints, Particles and Lagrangian. For example, the latter looks like the following:

| A1 | A2 | A3 | A4 | Factor | Lorentz part |
|----|----|----|----|--------|--------------|
| W+ | W- | Z  |    | EE*CW/SW | m1.m2*(p1-p2).m3+m2.m3*(p2-p3).m1+m3.m1*(p3-p1).m2 |
| N1 | e1 | W+ |    | EE/(2*sqrt2*SW) | G(m3)*(1-G5) |
| E1 | n1 | W- |    | EE/(2*sqrt2*SW) | G(m3)*(1-G5) |
| U  | u  | G  |    | GG     | G(m3)       |
| ...| ...| ...|    | ...    | ...         |
After inserting the changes in the tables CompHEP checks the new version of the model. If the version is correct it is saved into the user’s directory models. Otherwise the message about an error appears on the screen.

Menu 4

View diagrams displays graphical presentation of the constructed Feynman diagrams (see Fig. 3). Here the user has a possibility to exclude some diagrams from further processing. The LATEX output of any diagram can be generated automatically.

Squaring generates diagrams for squared S-matrix elements.

Menu 5

Here the user can View squared diagrams and again has a possibility to exclude some diagrams from a further consideration.

In CompHEP the Symbolic calculations of the generated squared diagrams are performed by means of the built-in symbolic manipulation package. The user can Write results for squared diagrams on the hard disk in different formats (see Menu 6), the corresponding files are placed in the directory results.

REDUCE program generates source codes for the following calculation of the squared matrix element by means of the REDUCE package.

The built-in Numerical calculator fulfills calculations for the simplest 1 → 2 and 2 → 2 processes. Calculated numerical values of widths or cross sections for a given process are displayed on the screen. It can calculate various distributions as well (see Menu 7).

Interface gives a possibility to incorporate the CompHEP session with the work of other external packages. The menu of external packages appears. The first position of this menu is used to start the numerical part of the CompHEP package (see Section 3).

Menu 7

View/change data shows the table with parameter names and their numerical values on the screen. After inserting the changes the cross section (width) will be recalculated automatically.

The user can Set angular range putting in the min and max values of cosine of scattering angle in the center of mass reference frame. It is also available to Set precision of numerical calculations.

One can calculate the Angular dependence (differential cross section) of the scattering process in the center of mass system. Through the Menu 8 the user can urge CompHEP to Show plot, Save results in a file and generate the LATEX file of angular distribution. The files will be saved in user’s directory results.

The Parameter dependence option allows one using the Menu 9 to get distributions for cross section (width) and asymmetry in any range of parameters relevant to the process under consideration. The Menu 10 should be used to get tables and pictures for any distributions.

In the recent version of CompHEP the Dalitz plot facility has been implemented for decay processes of 1 → 3 type. It provides a possibility to investigate event distributions within phase space and to get vertical and horizontal slices of the Dalitz plot.

3. Numerical part of the CompHEP package

This facility allows the user to prepare the CompHEP FORTRAN output for a further numerical integration over phase space and to carry out this integration in a user-friendly manner. It provides also an interface with the Monte Carlo integration package BASES and the event generator SPRING. Thus the user has a possibility to calculate decay rates, collision cross sections and fill in histograms for various distributions. However the package is unable to make a summation over types of in- or out- particles.

There are available two run modes: the interactive and batch ones. In the interactive mode the package is a menu-driven system. The structure of the CompHEP numerical part is reproduced in Fig.4. It consists of the Main Menu and a set of submenus. To select the menu position the user should type its number and press the Enter key. To get HELP relevant to any menu the user should enter h# where # is a position number or h for general HELP.

The Calculation position of the Main Menu starts calculation of the collision cross section or the decay width by BASES. The program operation is organized as a sequence of working sessions with a displayed number automatically increasing after each sequential Monte Carlo calculation. Other Main Menu positions call the submenus for setting the environment of Monte Carlo integration. Below we give a brief description of the submenu titles.

The IN state submenu serves for preparing the initial state of collision processes and allows to:
• enter the CMS energy of in-particles;

• switch on structure function options.

The **Model parameters** submenu allows one to change any physical model parameters relevant to the studied process and save the new values in a file.

The **Invariant cuts** submenu is used to introduce kinematical cuts on any squared combinations of Lorentz momenta of in- and out-particles. These cuts are written down in a table like the following:

| N | MIN VALUE [GeV**2] | INVARIANT | MAX VALUE [GeV**2] | STATUS |
|---|------------------|-----------|------------------|--------|
| 1 | (-p1+p3)**2      | < -1.000  | HARD             |
| 2 | (-p2+p4)**2      | < -1.000  | HARD             |

One can use the **Kinematics** submenu for defining integration variables. This submenu allows the user to define kinematics in the most proper way for the further integration over phase space. An algorithm of this parametrisation is based on the idea that any process can be considered as subsequent kinematical decays of particle clusters into two other subclusters. The scheme of kinematical variable selection are fixed in a table which, for example, in the case of the \(2 \rightarrow 3\) process might take the following form:

| Cluster | In      | Out 1 | Out 2 | Pvect |
|---------|---------|-------|-------|-------|
| 1       | p1+p2   | p3    | p4+p5 | -p1   |
| 2       | p4+p5   | p4    | p5    | -p2   |

In the last column **Pvect** is chosen for fixing polar coordinates in such a way that the integration variables coincide with the variables in which the integrand is singular.

The **MC parameters** submenu allows the user to change some BASES parameters which are engaged in this package. There are two loops of the BASES calculation. The first one consists of iterations with grid adaptation from iteration to iteration. The second loop includes iterations with the fixed grid to accumulate necessary statistics. So the user should define:

• number of Monte-Carlo sample points for one iteration;

• maximal number of iterations with grid adaptation (1st loop);

• limit of the calculation accuracy in % (1st loop);

• maximal number of iterations with the fixed grid (2nd loop);

• limit of the calculation accuracy in % (2nd loop).

Also it is possible here to switch on the event generator SPRING. After completing the BASES calculation the **Event generator** submenu (the interface with the SPRING package) appears if the event generator has been switched on:

| Event generator menu | 1: Start generator | 2: Number of events = 10000 |
|----------------------|--------------------|-----------------------------|
| 3: View current ‘hst’ file |

The file hst.# contains the report of the SPRING run with histograms initialized by the user.

The **Regularization** submenu is used to transform integration variables for representing the integrand as a smooth function in the cases when the squared matrix element has singularities and the Monte Carlo integrators are not efficient enough. For a reliable evaluation of such singular integrals the package has special options which can be activated in the submenu. Certainly this option is available only if there is the correspondence between singularities and a set of the integration variables. So to make the regularization it could be necessary to change kinematics. The invariants over which the regularization
is made are written down in a table. For example, in the case of $t$-channel singularity it might look like this:

| N | INVARIANT | MASS [Gev] | WIDTH [Gev] | STATUS |
|---|-----------|------------|-------------|--------|
| 1 | $(p_1+p_3)^2$ | 0          |             | ON     |
| 2 | $(p_2+p_4)^2$ | 0          |             | ON     |

The Task formation submenu provides the following options:

- to collect results of the calculation in table(s) with any physical parameters as a table argument;
- to prepare a task for batch mode calculation;
- to set default session parameters.

The User’s menu serves for implementing some user’s routines allowing, for example, to:

- introduce cuts for any functions of kinematical variables;
- convolute squared matrix elements with any structure functions, for example, from the CERN PDF library.

The View results submenu allows the user to view any output files containing results of cross section (width) calculations, a report on the MC integration process, histograms. As a result of the calculations for each working session the program creates three output files (# denotes a session number):

- res.# contains a result of the calculation with a list of model parameters used.
- prt.# is a copy of the screen report of calculation with a list of all parameters (technical and physical ones).
- hst.# contains filled in histograms.

### 4. Brief review of physical results obtained by means of the CompHEP package

Ten three-body processes in the $e^+e^-$ collisions for a heavy particle production such as Higgs boson, $t$-quark, $W$- and $Z$-bosons are calculated in Ref.[3] by two independent computer codes (generated by CompHEP[1] and GRACE[2]). The results are in an excellent agreement within statistical errors of numerical integration (about 0.5%). This cross-check of numerical results demonstrates that the CompHEP and GRACE systems are quite reliable for a theoretical study of processes at future $e^+e^-$, $e\gamma$ and $\gamma\gamma$ colliders. Various $2 \rightarrow 3$ reactions for the Higgs production in association with a vector boson pair at future $e^+e^-$ colliders are calculated also in the paper[4] using the amplitude technique and the CompHEP package. A very good agreement of two independent calculations has been found. The paper demonstrates an important feature of CompHEP application as an additional test of results obtained by other methods or computer systems.

Cross sections of the Higgs boson associated production in $\gamma e$ collisions are calculated in Ref.[5] for the $\gamma e \rightarrow \nu WH$ and $\gamma e \rightarrow eZH$ processes. Event signatures for the Higgs boson production, event separation and background conditions are considered. It is shown that the Higgs boson production process $\gamma e \rightarrow \nu WH$ seems to be very promising for the investigation of gauge cancellations between different diagrams and search for anomalous phenomena (for instance, anomalous Higgs boson interaction vertices).

In the paper[6] the calculations of total cross sections for the $W$- and $Z$-bosons production in $\gamma e$ and $\gamma\gamma$ collisions are presented in the 3rd order in electroweak coupling constant at the tree level. They are compared with the estimations obtained by simple approximation methods to see their accuracy for this class of processes. The preliminary physical analysis of obtained results is given.

All tree level diagrams for the reaction $\gamma\gamma \rightarrow t\bar{t}H$ have been calculated by means of the CopmHEP package [7]. It was shown that the reaction is very sensitive to probing the Higgs-fermion coupling in the TeV energy range.
In the paper\textsuperscript{[8]} the complete tree level calculations for three particle final state production at future $e^+e^-$, $\gamma e$ and $\gamma\gamma$ colliders are presented (see Fig. 5). The results obtained with the help of the CompHEP package for total cross sections and other characteristics of processes in the energy range 0.1-2 TeV are summarized and their comparison with the results of other approaches is discussed. In particular the processes of $W^-$, $Z$- and $H$-bosons production are considered. These reactions are especially interesting in connection with probing new couplings, searching for new particle signals and estimating the most important backgrounds in various experiments.

The possibility of the single and pair excited neutrino production in high energy $e^+e^-$, $\gamma e$ and $\gamma\gamma$ collisions at linear colliders is studied in Ref.\textsuperscript{[10]}\textsuperscript{[10]}. The integrated cross sections of these subprocesses are calculated in a symbolical form. A special attention is paid to a search for excited neutrino in the $\gamma e \rightarrow WW e$ process (see Fig. 6). The lower limits for the compositeness parameter to be available in the experiments at Next Linear Colliders are estimated.

The possibility to detect the Higgs boson signal in the process $e^+e^- \rightarrow Z bb$ at LEP200 energies is considered in Ref.\textsuperscript{[10]}. The calculations are performed in the tree approximation for a complete set of diagrams. Tree level corrections to the Higgs signal are computed. If the highest possible LEPII energy considered in Ref.\textsuperscript{[10]}\textsuperscript{[10]} is investigated in Ref.\textsuperscript{[10]}\textsuperscript{[10]} the Higgs signal will be very clean for the masses of Higgs up to $\sqrt{s} - M_Z$ about 95 GeV.

In Ref.\textsuperscript{[11]}\textsuperscript{[11]} a possibility of Higgs boson signal observation at LEPII and Next Linear Colliders in the reactions $e^+e^- \rightarrow \mu^+\mu^- bb$, $e^+e^- \rightarrow \nu\bar{\nu} b\bar{b}$, $e^+e^- \rightarrow e^+e^- bb$ is investigated. Complete tree level calculations for these $2 \rightarrow 4$ processes are performed and compared with the various effective $2 \rightarrow 2$ body approximations. The accuracy of effective approximations near the thresholds and at different energies are calculated. In some situations it is necessary to introduce nontrivial kinematical cuts in order to separate the signal from a background.

A complete tree-level calculation of the reaction $e^+e^- \rightarrow e\nu tb$ in the electroweak standard theory in the LEPII energy range is presented in Ref.\textsuperscript{[12]}\textsuperscript{[12]}. For top quark masses in the range of 130 to 190 GeV the cross sections are found to be of the order of $10^{-5} - 10^{-6}$ pb (see Fig. 7). Therefore, the number of single top quark events is expected to be negligible even with an integrated luminosity of $L=500$ pb$^{-1}$. It is further demonstrated that the Weizsaecker-Williams approximation fits the accurate cross section reasonably well (see Fig. 8).

One needs to stress that all results for the reactions with 4 fermions production in the final state (Ref.\textsuperscript{[11]}, \textsuperscript{[12]}\textsuperscript{[12]}) have been obtained taking account of non-zero masses of all fermions. Such the complicated calculations have been carried out for the first time. Of course, in some cases one can neglect a mass effect using, for instance, cuts on variables like pair invariant mass or $p_t$. However, sometimes it is really necessary to keep nonvanishing masses. It is obvious for production of such a heavy particle as the top quark. But it happens that in order to calculate a total rate of some reactions one needs to keep even the electron mass because the cross section contains a large log($s/m_t^2$). As an example of such a situation one can demonstrate a calculation of the total rate of the reaction $e^+e^- \rightarrow e^+e^- bb$. You can see in Fig. 9 that contributions from multiipheral and single cascade diagrams including the above mentioned logarithmic terms are significantly greater than from other subsets of diagrams. In the case when the final electron and positron go to very forward-backward directions the reaction $e^+e^- \rightarrow e^+e^- bb$ turns out to be a very important background for the Higgs production with the signature $\nu\bar{\nu} b\bar{b}$.

Recently based on CompHEP the detail simulation of the production of light and intermediate Higgs bosons in association with $W$- and $Z$-bosons have been presented \textsuperscript{[13]}\textsuperscript{[13]} at TEVATRON collider energies. An optimal set of kinematical cuts to separate the Higgs signal from backgrounds have been found (see Fig. 10). It was shown that one can use such final states to detect the Higgs signal, however to reduce backgrounds strongly enough it would be necessary to increase the collider luminosity up to 500-1000 pb$^{-1}$ to have an effective $b$-tagging system.

In Ref.\textsuperscript{[14]}\textsuperscript{[14]} the possibilities of search for vector leptoquarks at high energy $ep$ and $\gamma p$ colliders are investigated. The exact analytical expressions are derived for cross sections with the help of CompHEP taking account of possible anomalous couplings of vector leptoquarks with gauge bosons. The vector leptoquark search potential of HERA and future $ep$ colliders is discussed in detail.

In Ref.\textsuperscript{[15]}\textsuperscript{[15]} leptoquark resonance production in electron-proton collisions associated with the emission of a hard photon is considered. Estimates of the sensitivity of the radiative amplitude zero (RAZ) effect (see Figs. 11,12) as a tool to identify the leptoquarks quantum numbers are carried out with the help
of CompHEP. Also the possibility of measuring the anomalous couplings of vector leptoquarks with the photon by means of the RAZ effect is discussed (see Fig. 13).
5. Concluding remarks

The main steps of the CompHEP development are published in Ref.[1]. Adaptations for various platforms were done during visits of the CompHEP group members to KEK (Japan), Seoul National University (Korea), University of London (UK), University "La Sapienza" (Italy), University of Sao Paulo (Brazil), DESY, MPI for physics, University of Karlsruhe (Germany).

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Figure captions

Fig. 1 The general structure of the CompHEP package.

Fig. 2 The menu system of the CompHEP symbolic part.

Fig. 3 Diagrams for the process $e^- u \rightarrow e^- uZ$ (the LATEX output of CompHEP).

Fig. 4 The menu system of the CompHEP numerical part.

Fig. 5 Complete tree level calculations for the cross sections of three particle final state production at future $\gamma e$ and $\gamma \gamma$ colliders in comparison with two particle production processes.

Fig. 6 Invariant mass of outgoing $e^-$ and $W^+$ distribution for $\gamma e^- \rightarrow W^- W^+ e^-$ process. Calculations without folding with the photon spectra: the dot-dashed line — invariant mass distribution according to the Standard Model; the dotted histogram — distribution when the excited neutrino is produced. The dashed line and solid line histograms represent corresponding distributions which are folded with photon spectra.

Fig. 7 Total cross section from the four photon exchange diagrams as a function of the electron angular cut for $m_{top} = 140$ GeV and $\sqrt{s} = 190$ GeV calculated. The dotted lines correspond to each of the diagrams squared, the solid line is the result for their coherent sum.

Fig. 8 Total cross sections for the process $e^+ e^- \rightarrow e^- \bar{\nu}_e t \bar{b}$ ($e^+ \nu_e \bar{t} \bar{b}$) as a function of top quark mass for $\sqrt{s} = 170, 190$ and $210$ GeV. The solid line — complete tree level calculations, the dashed line — the subset of photon exchange diagrams only, the dotted line — the Weizsacker-Williams approximation.

Fig. 9 Effective approximations (dashed lines) and exact calculations (solid lines) corresponding to various subsets of diagrams for the process $e^+ e^- \rightarrow e^+ e^- b \bar{b}$. Each subset includes subgraphs of a gauge invariant process.

Fig. 10 The effective $b \bar{b}$ invariant mass distribution at $M_H = 80$ GeV, $\sqrt{s} = 2$ TeV for the cases a) without any cuts and b) with cuts applied. All event numbers correspond to $L = 1000$ pb$^{-1}$.

Fig. 11 Characteristic angular CMS distributions of scalar leptoquarks in the processes 1) $e^- + d \rightarrow \gamma + S_3^{-1}$; 2) $e^+ + u \rightarrow \gamma + R_2$; 3) $e^- + u \rightarrow \gamma + S_1(S_0^2)$; 4) $e^+ + d \rightarrow \gamma + R_2$. The processes 1 and 2 show explicitly the RAZ effect. Here $M_{LQ} = 300$ GeV, $\sqrt{s} = 304$ GeV and fermion-leptoquark coupling $\lambda = 0.3$.

Fig. 12 Histograms of angular distribution for the scalar leptoquark with $M_{LQ} = 200$ GeV in the cases of HERA and future LEP II+LHC colliders.

Fig. 13 Histograms demonstrating a difference of the RAZ effects for the vector leptoquark $V_2^{-\frac{1}{2}}$ with $M_{LQ} = 300$ GeV in the cases of Yang-Mills photon-leptoquark coupling (left-hand picture) and minimal coupling (right-hand one).
CompHEP symbolic module

\[ \text{Lagrangian (SM and beyond)} \downarrow \text{ squared matrix element} \]

\[ \Rightarrow \text{Feynman diagrams} \]

\[ \Rightarrow \text{Symbolic answer} \]

\[ \Rightarrow \text{Numerical calculator (cross section, distributions) for } 1 \rightarrow 2, 2 \rightarrow 2 \]

\[ \Rightarrow \text{FORTRAN code for squared matrix element} \]

\[ \Rightarrow \text{CompHEP numerical module} \]

\[ \text{Kinematics} \quad \text{Cuts} \quad \text{Regularizations} \]

\[ \leftarrow \text{Structure functions} \]

\[ \leftarrow \text{Monte-Carlo} \]

\[ \begin{align*}
&\text{BASES (integration)} \\
&\text{SPRING (event generation)}
\end{align*} \]

\[ \leftarrow \text{Cross section} \quad \text{Event flow} \quad \text{Histograms} \]

Figure 1
Figure 2
Figure 3
Main menu

| 1. Calculation          | 2. IN state                     |
|-------------------------|---------------------------------|
| 3. Model parameters     | 4. Invariant cuts                |
| 5. Kinematics           | 6. MC parameters                 |
| 7. Regularization       | 8. Task formation                |
| 9. View results         | 10. User's menu                  |

In state

| 1. StructF(1) = OFF    | 2. SQRTS = 1000                  |
|------------------------|---------------------------------|
| 3. StructF(2) = OFF    |                                 |

Invariant cuts

| 1. Insert new cut      | 2. Delete cut                   |
|------------------------|---------------------------------|
| 3. Change cut          |                                 |

MC parameters

| 1. Ncall = 10000       | 2. Acc1 = 0.1                   |
|------------------------|---------------------------------|
| 3. Itmx1= 5            | 4. Acc2 = 0.1                   |
| 5. Itmx2=0             | 6. Event generator OFF          |
| 7. Number of events = 1000 |                                |

Regularization

| 1. Insert new regularization | 2. Delete regularization |
|-----------------------------|--------------------------|
| 3. Change regularization    |                          |

Task formation

| 1. Table parameters       | 2. Set default session     |
|----------------------------|----------------------------|
| 3. Add session to batch   |                            |

View results

| 1. session # to view - 3 | 2. View result file        |
|--------------------------|-----------------------------|
| 3. View protocol file    | 4. View histogram file      |

Figure 4
\( \gamma\gamma \) and \( \gamma e \) processes (\( \sigma_{\text{tot}} \), tree level)

\[ \begin{align*}
\sigma_{\text{tot}} & \quad (\text{pb}) \\
\end{align*} \]

\[ \begin{align*}
0 & \quad 200 & \quad 400 & \quad 600 & \quad 800 & \quad 1000 & \quad 1200 & \quad 1400 & \quad 1600 & \quad 1800 & \quad 2000 \\
\end{align*} \]

\( \sqrt{s} \) (GeV)

Figure 5

\[ \begin{align*}
\sqrt{s} = 1 \text{ TeV} \\
10^5 < \Theta < 170^\circ \\
\Lambda = 3 \text{ TeV} \\
m_{\nu^+} = 0.6 \text{ TeV} \\
\end{align*} \]

\[ \begin{align*}
\frac{d\sigma}{d\sqrt{s_2}} & \quad \text{[pb/GeV]} \\
\end{align*} \]

\[ \begin{align*}
10^{-a} & \quad 100 & \quad 200 & \quad 300 & \quad 400 & \quad 500 & \quad 600 & \quad 700 & \quad 800 & \quad 900 & \quad 1000 \\
\end{align*} \]

\( \sqrt{s_2} \) (GeV)

Figure 6
Figure 7

Figure 8
Figure 9

Background cross sections in 
\( e^+e^- \rightarrow e^+e^- b \bar{b} \)

![Graph showing background cross sections in various processes](image)

Figure 10

1. \( pp \rightarrow (l \bar{l} + l^+l^- + \nu \bar{\nu}) + b\bar{b} + X \)
2. \( M_{\tilde{t}} = 80 \text{ GeV} \)
3. all cuts absent

![Histogram showing number of events](image)

Figure 10 (continued)

![Histogram showing number of events](image)
Background cross sections in $e^+e^- \rightarrow e^+e^- b \bar{b}$