SUSY23 v2.0: an Event Generator for Supersymmetric Processes at e^+e^- Colliders

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Abstract

SUSY23 is a Monte-Carlo package for generating supersymmetric (SUSY) processes at e^+e^- colliders. Twenty-three types of SUSY processes with 2 or 3 final state particles at tree level are included in version 2.0. SUSY23 addresses event simulation requirements at e^+e^- colliders such as LEP. Matrix elements are generated by `GRACE` with the helicity amplitude method for processes involving massive fermions. The phase space integration of the matrix element gives the total and differential cross sections, then unweighted events are generated. Sparticle widths and decay branching ratios are calculated. Each final state particle may then decay according to these probabilities. Spin correlations are taken into account in the decays of sparticles. Corrections of initial state radiation (ISR) are implemented in two ways, one is based on the electron structure function formalism and the second uses the parton shower algorithm called `QEDPS`. Parton shower and hadronization of the final quarks are performed through an interface to `JETSET`.

PROGRAM SUMMARY

Title of program: SUSY23
Program obtainable from: CPC Program Library, Queen's University of Belfast, N.Ireland (see application form in this issue) and from ftp.kek.jp in directory kek/minami/susy23.
Computer for which the program is designed and others on which it is operable: HP9000 and most of the UNIX platforms with a FORTRAN77 compiler
Computer: HP9000 ;
Installation: High Energy Accelerator Research Organization(KEK), Tsukuba, Ibaraki, Japan
Operating system: UNIX ;
Programming language used: FORTRAN77
High speed storage required: 23 Mbyte ; *Card image code*: ASCII
Key words: supersymmetry, e^+e^- colliders, ISR, QEDPS, event generator, spin correlation, hadronization.
Nature of physical problem
Study of supersymmetric particle search at LEP2.
Method of solution
The automatic amplitude generator `GRACE` is used to get the necessary helicity amplitudes for twenty-three sparticle production processes. The specific corrections such as the initial state radiation or hadronization are implemented in the program. Sparticle widths and decay branching ratios for some modes are calculated. Each event of final state is then generated according to these probabilities.
Typical running time
The running time depends on the number of diagrams of the selected process, on the required cross-section accuracy and on the applied cuts. For instance, on a HP-755/99, the process $e^+e^- \to e^+\tilde{e}_R\chi_1^0$ takes 20 minutes to reach a 0.5% accuracy on the total cross section.

1. Introduction

The supersymmetric (SUSY) standard model [1] is the most promising extension of the standard model (SM) as it could naturally give a solution to the gauge hierarchy problem. In SUSY model, thanks to the symmetry between bosons and fermions, the quadratic divergences are genuinely cancelled out. The price to pay is the existence of a large number of new particles, SUSY particles (sparticles), yet to be discovered. The most impressive evidence in favor of SUSY may be the unification of gauge couplings in SUSY Grand Unified Theories (GUTs) [2]. The Lightest SUSY Particle (LSP) is often proposed as a candidate to the missing mass in the Universe for the cold component of the so-called dark matter [3]. Many peoples consider the "SUSY world" as a plausible scenario for future particle physics prompting the need of event generators.

Although the gauge hierarchy issue set a mass upper bound to SUSY particles of $O(1\mathrm{TeV})$, lighter sparticles are seen as giving more natural solution. So there is a possibility that the sparticles could be discovered at LEP2 in electron-positron collision. While the hadron colliders such as FNAL Tevatron and DESY HERA have already covered larger scattering energies, LEP2 could be the first machine to discover "light" sparticles (the chargino, the slepton or the stop) as the background conditions are far better in electron-positron than in hadron colliders.

SUSY23 is an event generator suitable for detector simulation and data analysis dedicated to SUSY processes in the LEP2 energy range.

It is based on the `GRACE` [4, 5] system which generates automatically the matrix element in terms of helicity amplitudes (supplied by the `CHANEL` [6] library) for any processes once the initial and the final states have been specified. In addition, a kinematics library has been developed for each process topology (weeding out multidimensional singularities) for a better convergence of the Monte-Carlo integration over the phase space.

The SUSY23 package is actually a collection of 23 types of SUSY processes at e^+e^- colliders, consisting of 18 final 2-body and 5 final 3-body processes, presented in a coherent and uniform environment. These processes are

$e^+e^- \to$

$\chi_1^+\chi_1^-$	$\chi_1^0\chi_2^0$	$\chi_2^0\chi_2^0$	$\tilde{\bar{\nu}}_e\tilde{\nu}_e$	$\tilde{\bar{\nu}}_\mu\tilde{\nu}_\mu$	$\tilde{\bar{\nu}}_\tau\tilde{\nu}_\tau$
$\tilde{\tau}_1^+\tilde{\tau}_1^-$	$\tilde{\tau}_2^+\tilde{\tau}_2^-$	$\tilde{\tau}_1^+\tilde{\tau}_2^-$	$\tilde{\tau}_2^+\tilde{\tau}_1^-$	$\tilde{e}_L^+\tilde{e}_L^-$	$\tilde{e}_R^+\tilde{e}_R^-$
$\tilde{e}_L^+\tilde{e}_R^-$	$\tilde{e}_R^+\tilde{e}_L^-$	$\tilde{\mu}_L^+\tilde{\mu}_L^-$	$\tilde{\mu}_R^+\tilde{\mu}_R^-$	$\tilde{\bar{t}}_1\tilde{t}_1$	$\tilde{\bar{b}}_1\tilde{b}_1$

and

$e^+\tilde{e}_R^-\chi_1^0 \qquad e^+\tilde{e}_L^-\chi_1^0 \qquad e^+\tilde{\nu}_e\chi_1^- \qquad \nu_e\tilde{e}_L^+\chi_1^- \qquad \gamma\chi_1^0\chi_1^0$

Once a process has been selected, the total and differential cross sections are computed with the Monte-Carlo integration package `BASES` [7]. Then `SPRING` [7], a general purpose event generator, provides unweighted events. Some physics results have already been presented in ref.[8].

The matrix element generated by `GRACE` corresponds to the genuine tree level process in the massive case. Initial state radiation corrections, unstable sparticle decays and hadronization must then be introduced to produce realistic event generation. All of them have been implemented in SUSY23.

For the initial state radiation (ISR) two techniques are provided in the program. [1] The first one uses the well-known analytic form of $e^\pm$ structure function [9] and the second is based on `QEDPS` [10], a radiative correction generator producing an indefinite numbers of photons according to the parton shower algorithm in the leading-logarithmic (LL) approximation. Originally this algorithm has been developed to simulate QCD parton shower. One important point here is that `QEDPS` reproduces the radiative photon transverse momentum distributions.

Sparticle widths and decay branching ratios are calculated (see Tables 3$\sim$8 in Appendix C). Each final state is then generated according to the branching ratios. In the present version, 2-body and 3-body direct decays as well as some possible cascade decays are included. Note that helicity informations of matrix elements of the direct decays of inos [2] are taken into account in evaluating their decays.

We assume that the hadronization of partons can be separated from the hard interaction studied here. Under this assumption, the calculation of cross sections is exact in SUSY23. Final state parton hadronization is performed, in SUSY23, through the mechanism implemented in `JETSET` [11].

This paper is organized as follows. MSSM basics is given in section 2. The structure of the program is discussed in section 3. In section 4, all details about running the program are presented. A summary of the paper can be found in section 5. Four appendices describe the parameters and options which can be changed by the user, the list of all processes and the program installation procedure.

2. Theoretical framework of MSSM

2.1 Particle content

[1] ISR is not available for the hard photon process, i.e., $e^-e^+ \to \gamma\chi_1^0\chi_1^0$.

[2] We use ino as a generic name to represent neutral (neutralinos) and charged (charginos) mixtures of gauginos and higgsinos.

The Minimal SUSY Standard Model (MSSM) includes the *minimal* particle content. That is, there should be at least one new particle (sparticle) for each known particle in the SM and the two Higgs doublets. The additional Higgs doublet must be included in order to give mass to the up- and down-type quarks and to allow for the chiral anomaly cancellation [1].

For quarks and charged leptons there exist two scalar partners per species, while for neutrinos there exists one scalar partner per species. These scalars are called squarks and sleptons, or, generically, sfermions. Before SU(2)×U(1) breaking, the left- and right-sfermions do not mix since they have different SU(2)×U(1) quantum numbers. After the breaking, however, they can mix with each other. In this case the mass eigenstates are parametrized by a mixing angle θ_f ;

$$\begin{pmatrix} \tilde{f}_1 \\ \tilde{f}_2 \end{pmatrix} = \begin{pmatrix} \tilde{f}_L \cos\theta_f + \tilde{f}_R \sin\theta_f \\ -\tilde{f}_L \sin\theta_f + \tilde{f}_R \cos\theta_f \end{pmatrix}. \tag{1}$$

Actually this mixing effect is substantial only for the third-generation sfermions, especially for the stops (superpartners of the top quark) owing to the large top mass [12].

The new fermions are either the superpartner of spin-1 gauge bosons (gauginos) or that of spin-0 bosons (higgsinos). They mix each other when SU(2)×U(1) symmetry is broken. The mass eigenstates (inos) are usually mixtures of gaugino and higgsino states. They are called neutralinos χ^0_k ($k = 1 \sim 4$) and charginos $\chi^\pm_i$ ($i = 1, 2$), respectively, according to their electric charges. Gluinos $\tilde{g}$ are free from mixing since the color SU(3) is not broken. As usual, we consider the lightest neutralino χ^0_1 as the lightest sparticle (LSP).

MSSM contains two Higgs doublets and five physical Higgs bosons are left after SU(2)×U(1) breaking [13]. They are two CP even (h^0, H^0), one CP odd (A^0) neutral scalars and two charged scalars ($H^\pm$).

The list of sparticles in the model is shown in Appendix A, where the abbreviated particle names used in the control card and the KF-codes assigned for each sparticles in SUSY23 are also shown.

2.2 Basic parameters of MSSM

The standard model has 18 fundamental parameters to be determined by experiments. The MSSM has a somewhat larger number of parameters. They are classified as (i) gauge couplings, (ii) superpotential parameters and (iii) soft-breaking parameters. In the following, we adopt the notation of the SUSY parameters described in ref.[14].

2.2.1 gauge couplings

The three gauge coupling parameters corresponding to SU(3), SU(2) and U(1) gauge groups are the same as in the SM. All gauge interactions are governed by these couplings. They determine the fermion-sfermion-gaugino interactions and four-point scalar interactions as well as ordinary fermion-fermion-gauge-boson interactions.

2.2.2 superpotential parameters and R-parity

In the MSSM, ordinary Yukawa interactions are generalized using the superpotential $W(\hat{\phi})$, where $\hat{\phi}$ denotes arbitrary chiral superfield [1]. Renormalizability restricts the functional form of the superpotential to

$$W(\hat{\phi}) = m_{ij}\hat{\phi}_i\hat{\phi}_j + \lambda_{ijk}\hat{\phi}_i\hat{\phi}_j\hat{\phi}_k. \tag{2}$$

The parameters m_{ij} and λ_{ijk} are further constrained by the gauge symmetry and some discrete symmetries.

Later, we use the notation μ which is a coefficient of the term quadratic in Higgs superfields and contributes to the mass terms of higgsinos and Higgs bosons [14].

A well-known discrete, multiplicative symmetry is the R-parity defined by

$$R = (-)^{3(B-L)+2S}, \tag{3}$$

where B, L and S stand for the baryon number, the lepton number and the spin, respectively. This formula implies that all ordinary SM particles have even R-parity, whereas the corresponding superpartners have odd R-parity. Usually we impose the $B-L$ conservation on the MSSM and then the MSSM possesses the R-parity invariance. In SUSY23 only R-parity conserving processes are considered.

2.2.3 soft-breaking parameters

SUSY is not an exact symmetry of nature since our world is not manifestly supersymmetric. In the MSSM the SUSY breaking is induced by the soft-SUSY breaking terms, which do not introduce quadratic divergences. Hence the solution of the naturalness problem remains intact. There are four types of soft breaking terms ; (1) gaugino masses M_i ($i = 1 \sim 3$), (2) masses for the sfermions $\widetilde{m}_f$, (3) trilinear term A_f and (4) three Higgs mass terms. The three mass parameters in the last item can be re-expressed in terms of two Higgs vacuum expectation values, v_1 and v_2, and one physical Higgs mass. Here v_1 and v_2 respectively denote the vacuum expectation values of the Higgs field coupled to d-type and u-type quarks. $v_1^2 + v_2^2 = (246 \text{ GeV})^2$ is determined from the experimentally measured W-boson mass, while the ratio

$$\tan\beta = \frac{v_2}{v_1} \tag{4}$$

is a free parameter of the model.

A generally accepted assumption is that all the three gaugino mass parameters M_i are equal at some grand unification scale M_X. Then the gaugino mass parameters can be expressed in terms of one of them, for instance, M_2. The other two gaugino mass parameters are given by

$$M_1 = \frac{5}{3}\tan^2\theta_W M_2 \tag{5}$$

$$M_3 = \frac{\alpha_3}{\alpha}\sin^2\theta_W M_2, \tag{6}$$

where α and α_3 ($= \alpha_s$) denote the QED and the QCD coupling constants, respectively.

The trilinear terms A_f appear in off-diagonal elements of the mass matrix for sfermions($\widetilde{f}_L$, $\widetilde{f}_R$). Consequently, it has direct relation to the mass eigenvalues ($m_{\widetilde{f}_1}$, $m_{\widetilde{f}_2}$) and the mixing angle θ_f. In our formulation, A_f's ($f = t, b, \tau$) are determined by those mixing parameters (see Eqs.(19), (20) and (21)).

2.3 MSSM parameters in SUSY23

In Appendix B, the input MSSM parameters in SUSY23 are listed. They are

i) gaugino parameters, ($\tan\beta$, M_2, μ),

ii) masses of scalar partners of charged leptons in the 1st and 2nd generations, ($m_{\widetilde{e}_L}$, $m_{\widetilde{e}_R}$), ($m_{\widetilde{\mu}_L}$, $m_{\widetilde{\mu}_R}$),

iii) masses of 1st and 2nd generation squarks, $(m_{\tilde{u}_L}, m_{\tilde{u}_R}, m_{\tilde{d}_R})$, $(m_{\tilde{c}_L}, m_{\tilde{c}_R}\ m_{\tilde{s}_R})$

iv) masses and mixing angles of charged sfermions in the 3rd generation, $(m_{\tilde{t}_1}, m_{\tilde{t}_2}, \theta_t)$, $(m_{\tilde{b}_1}, m_{\tilde{b}_2}, \theta_b)$, $(m_{\tilde{\tau}_1}, \theta_\tau)$ and $m_{\tilde{\nu}_\tau}$.

From the above inputs, the following physical parameters are calculated in SUSY23,

i) masses of χ_i^0 $(i = 1 \sim 4)$, the mixing matrix $\mathcal{O}_N$ and the sign factor η_i of neutralinos,

$$\chi_{iL}^0 = \eta_i(\mathcal{O}_N)_{ij}\mathcal{X}_{jL}^0, \tag{7}$$
$$\chi_{iR}^0 = \eta_i^*(\mathcal{O}_N)_{ij}\mathcal{X}_{jR}^0, \tag{8}$$

with $\mathcal{X}_{iL}^0 = (\tilde{B}_L, \widetilde{W}_L^0, \tilde{H}_{1L}^0, \tilde{H}_{2L}^0)$.

ii) masses of $\chi_i^\pm (i = 1 \sim 2)$, the mixing angles $\cos\phi_L$, $\cos\phi_R$, $\sin\phi_L$, $\sin\phi_R$, sign factor ϵ_R of charginos,

$$\chi_{1L}^- = \widetilde{W}_L^- \cos\phi_L + \tilde{H}_{1L}^- \sin\phi_L, \tag{9}$$
$$\chi_{2L}^- = -\widetilde{W}_L^- \sin\phi_L + \tilde{H}_{1L}^- \cos\phi_L, \tag{10}$$
$$\chi_{1R}^- = \widetilde{W}_R^- \cos\phi_R + \tilde{H}_{2L}^- \sin\phi_R, \tag{11}$$
$$\chi_{2R}^- = \epsilon_R(-\widetilde{W}_R^- \sin\phi_R + \tilde{H}_{2L}^- \cos\phi_R), \tag{12}$$

iii) the gluino mass $m_{\tilde{g}}$ $(= M_3)$ using Eq.(6),

iv) $m_{\tilde{\nu}_e}$ and $m_{\tilde{\nu}_\mu}$ are calculated by the following relations:

$$m_{\tilde{\nu}_e}^2 = m_{\tilde{e}_L}^2 - m_e^2 + m_W^2 \cos 2\beta, \tag{13}$$
$$m_{\tilde{\nu}_\mu}^2 = m_{\tilde{\mu}_L}^2 - m_\mu^2 + m_W^2 \cos 2\beta. \tag{14}$$

v) $m_{\tilde{d}_L}$ and $m_{\tilde{s}_L}$ are calculated by the following relations:

$$m_{\tilde{d}_L}^2 = m_{\tilde{u}_L}^2 - m_u^2 + m_d^2 - m_W^2 \cos 2\beta, \tag{15}$$
$$m_{\tilde{s}_L}^2 = m_{\tilde{c}_L}^2 - m_c^2 + m_s^2 - m_W^2 \cos 2\beta, \tag{16}$$

vi) $m_{\tilde{\tau}_2}$ is given by:

$$m_{\tilde{\nu}_\tau}^2 = \cos^2\theta_\tau m_{\tilde{\tau}_1}^2 + \sin^2\theta_\tau m_{\tilde{\tau}_2}^2 - m_\tau^2 + m_W^2 \cos 2\beta, \tag{17}$$

vii) $m_{\tilde{b}_2}$ is given by:

$$\cos^2\theta_t m_{\tilde{t}_1}^2 + \sin^2\theta_t m_{\tilde{t}_2}^2 - m_t^2 = \cos^2\theta_b m_{\tilde{b}_1}^2 + \sin^2\theta_b m_{\tilde{b}_2}^2 - m_b^2 + m_W^2 \cos 2\beta, \tag{18}$$

viii) the trilinear term A_f using formulae as follows

$$
\begin{aligned}
A_t &= -\frac{1}{2}\sin 2\theta_t \frac{m^2_{\tilde{t}_2} - m^2_{\tilde{t}_1}}{m_t} - \mu\cot\beta & (19)\\
A_b &= -\frac{1}{2}\sin 2\theta_b \frac{m^2_{\tilde{b}_2} - m^2_{\tilde{b}_1}}{m_b} - \mu\tan\beta, & (20)\\
A_\tau &= -\frac{1}{2}\sin 2\theta_\tau \frac{m^2_{\tilde{\tau}_2} - m^2_{\tilde{\tau}_1}}{m_\tau} - \mu\tan\beta, & (21)
\end{aligned}
$$

Here we briefly discuss the relation between our input parameters and those adopted in the **susygen** program [15]. As for the gaugino parameters, the sign convention of $\tan\beta$ and μ is different. We use the positive definite μ and $\tan\beta$ can have either positive or negative values. In **susygen**, on the other hand, positive definite $\tan\beta$ and positive or negative μ are adopted. As there exits a symmetry for the sign of $\tan\beta$ and μ in the MSSM, the negative μ in **susygen** corresponds to the negative $\tan\beta$ in SUSY23. The definition of gaugino mass M_2 is the same in both generators. As for the left-right mixing of sfermions in the 3rd generation, we take observable masses and mixing angles, $(m_{\tilde{f}_1}, m_{\tilde{f}_2}, \theta_f)$, as inputs. In **susygen**, on the other hand, more basic model parameters $(m_{\tilde{f}_L}, m_{\tilde{f}_R}, A_f)$ are adopted. The relation between them can be found from Eqs.(19) $\sim$ (21) and the following formula,

$$
m^2_{\substack{\tilde{f}_1\\ \tilde{f}_2}} = \frac{1}{2}\left[m^2_{\tilde{f}_L} + m^2_{\tilde{f}_R} \mp \left((m^2_{\tilde{f}_L} - m^2_{\tilde{f}_R})^2 + (2a_f m_f)^2\right)^{1/2}\right], \tag{22}
$$

where $a_t = -(A_t + \mu\cot\beta)$, $a_b = -(A_b + \mu\tan\beta)$ and $a_\tau = -(A_\tau + \mu\tan\beta)$. We did not impose low energy mass relations between masses of sfermions determined by the renormalization group equations in some SUSY GUTs because such mass relations sensitively depend on details of a model and boundary conditions for model parameters at the unification scale. In **susygen**, however, there is an option for the calculation in the framework of the minimal supergravity model [14]. In this model, masses of all sfermions in the 1st and 2nd generations are determined by an input parameter, m_∞ $(= m_0)$, which is the universal soft scalar mass at the unification scale. For convenience of the users, we present an example of relations between observable masses and the parameter m_∞ for the case of $\sin^2\theta_W = 0.230$,

$$
\begin{aligned}
m^2_{\tilde{u}_L} &= m^2_\infty + 7.26M^2_\infty + m^2_u + (\frac{1}{2} - \frac{2}{3}\sin^2\theta_W)m^2_Z\cos 2\beta, & (23)\\
m^2_{\tilde{u}_R} &= m^2_\infty + 6.83M^2_\infty + m^2_u + \frac{2}{3}\sin^2\theta_W m^2_Z\cos 2\beta, & (24)\\
m^2_{\tilde{d}_R} &= m^2_\infty + 6.78M^2_\infty + m^2_d - \frac{1}{3}\sin^2\theta_W m^2_Z\cos 2\beta, & (25)\\
m^2_{\tilde{e}_L} &= m^2_\infty + 0.530M^2_\infty + m^2_e - (\frac{1}{2} - \sin^2\theta_W)m^2_Z\cos 2\beta, & (26)\\
m^2_{\tilde{e}_R} &= m^2_\infty + 0.1515M^2_\infty + m^2_e - \sin^2\theta_W m^2_Z\cos 2\beta, & (27)
\end{aligned}
$$

where $M_\infty = 1.22M_2$ denotes the universal soft gaugino mass at the unification scale.

3. Features of the program

This section covers some important features of the program, the introduction of the initial state radiation, available decay modes of unstable sparticles and the spin correlation in the ino decays.

3.1 Initial state radiation

In the first approach, the simple electron structure function is used. The electron structure function at $O(\alpha^2)$ [9] which is to be convoluted with the cross section for a primary process is given by

$$\begin{aligned} D(x,s) &= \left[1+\frac{3}{8}\beta+\left(\frac{9}{128}-\frac{\zeta(2)}{8}\right)\beta^2\right]\frac{\beta}{2}(1-x)^{\beta/2-1} \\ &\quad -\frac{\beta}{4}(1+x)-\frac{\beta^2}{32}\left[4(1+x)\ln(1-x)+\frac{1+3x^2}{1-x}\ln x+(5+x)\right], \qquad (28) \\ \beta &= (2\alpha/\pi)(\ln(s/m_e^2)-1), \qquad (29) \end{aligned}$$

where s is the square of the total energy of the system and x is the momentum fraction of the electron. Compared with the exact $O(\alpha)$ calculation for s-channel annihilation, the corrected cross section obtained by this function does not contain the so-called K-factor:

$$1+\frac{\alpha}{\pi}\left(\frac{\pi^2}{3}-\frac{1}{2}\right)=1.006480\cdots. \qquad (30)$$

This factor is not included since it is sensible only when the s-channel e^+e^- annihilation takes place.

The basic assumption of the QED Parton Shower method, `QEDPS` [10], is primarily based on the fact that $D(x,Q^2)$ obeys the Altarelli-Parisi equation, which can be expressed by the integral equation in the leading-logarithmic(LL) approximation

$$D(x,Q^2)=\Pi(Q^2,Q_s^2)D(x,Q_s^2)+\frac{\alpha}{2\pi}\int_{Q_s^2}^{Q^2}\frac{dK^2}{K^2}\Pi(Q^2,K^2)\int_x^{1-\epsilon}\frac{dy}{y}P(y)D(x/y,K^2), \qquad (31)$$

where the small quantity ϵ is a cutoff related with the infrared singularity [16] and it will be defined later. In this equation $P(x)$ is the split function noted $P_+(x)$ when regularized at $x=1$. Q_s^2 is the initial value of Q^2 and a free parameter(of order m_e^2). For simplicity the fine structure constant α is assumed not running with Q^2. The Sudakov factor Π is given by:

$$\Pi(Q^2,Q'^2)=\exp\left(-\frac{\alpha}{2\pi}\int_{Q'^2}^{Q^2}\frac{dK^2}{K^2}\int_0^{1-\epsilon}dxP(x)\right). \qquad (32)$$

and denotes the probability that an electron evolves from Q'^2 to Q^2 without emitting hard photon.

The integral equation (31) can be solved by iteration. It is clear that the emission of n photons corresponds to n iterations. Hence it is possible to regard the process as a stochastic mechanism suggesting the shower algorithm in Ref. [10].

Once an exclusive process is fixed by the algorithm, each branching of a photon is a real process, that is, an electron with x, K^2 decays as: $e^-(x,-K^2)\to e^-(xy,-K'^2)+\gamma(x(1-y),Q_0^2)$. Here Q_0^2 is a cut-off to avoid the infrared divergence and ϵ is given by $\epsilon=Q_0^2/K'^2$. The momentum conservation at the branching gives: $-K^2 = -K'^2/y + Q_0^2/(1-y) + \mathbf{k}_T^2/(y(1-y))$ which in turn determines the photon transverse momentum relative to the parent, $\mathbf{k}_T^2$, from y, K^2, K'^2. This technique gives the $\mathbf{k}_T^2$ distribution as well as the shape of the x-distribution.

The above algorithm concerns the case where either e^- or e^+ radiates photons when the axial gauge vector is chosen along the momentum of the other electron, namely e^+ or e^-. In the program, however, we use the double cascade scheme to ensure the symmetry of the radiation between e^+ and e^- [17]. These two are mathematically equivalent in the LL approximation.

3.2 Sparticle decays

3.2.1 Decay modes

The decay modes shown below are implemented in SUSY23. They are also presented in Tables 3∼ 9 in Appendix C. The decay modes (1)∼(8) are applied iteratively as long as the mass relationship between the sparticle and their decay products allows. The spin correlation is considered as is discussed in the next subsection.

(1) lighter chargino (Table 3)

$$\begin{aligned}
\chi_1^- &\rightarrow f\bar{f}'\chi_1^0 \\
&\rightarrow \ell\bar{\tilde{\nu}}_\ell \rightarrow \ell \quad (\bar{\nu}_\ell\chi_1^0) \\
&\rightarrow \bar{\nu}_\ell\tilde{\ell} \rightarrow \bar{\nu}_\ell \quad (\ell\chi_1^0) \\
&\rightarrow b\bar{\tilde{t}}_1 \rightarrow b \quad (\bar{c}\chi_1^0)
\end{aligned}$$

(2) second lightest neutralino (Table 4)

$$\begin{aligned}
\chi_2^0 &\rightarrow f\bar{f}\chi_1^0 \\
&\rightarrow \ell\tilde{\ell} \rightarrow \ell \quad (\ell\chi_1^0) \\
&\rightarrow \nu\tilde{\nu} \rightarrow \nu \quad (\nu\chi_1^0)
\end{aligned}$$

(3) left-handed selectron and smuon (Table 5)

$$\begin{aligned}
\tilde{\ell}_L &\rightarrow \ell\chi_1^0 \\
&\rightarrow \ell\chi_2^0 \rightarrow \ell \quad (f\bar{f}\chi_1^0) \\
&\rightarrow \nu\chi_1^- \rightarrow \nu \quad (f\bar{f}'\chi_1^0)
\end{aligned}$$

(4) right-handed selectron and smuon (Table 6)

$$\begin{aligned}
\tilde{\ell}_R &\rightarrow \ell\chi_1^0 \\
&\rightarrow \ell\chi_2^0 \rightarrow \ell \quad (f\bar{f}\chi_1^0)
\end{aligned}$$

(5) lighter and heavier staus (Table 7)

$$\begin{aligned}
\tilde{\tau}_{1,2} &\rightarrow \tau\chi_1^0 \\
&\rightarrow \tau\chi_2^0 \rightarrow \tau \quad (f\bar{f}\chi_1^0) \\
&\rightarrow \nu_\tau\chi_1^- \rightarrow \nu_\tau \quad (f\bar{f}'\chi_1^0)
\end{aligned}$$

(6) sneutrinos (Table 8)

$$\begin{aligned}\tilde{\nu}_\ell &\to \nu_\ell \chi_1^0 \\ &\to \nu_\ell \chi_2^0 \to \nu_\ell \quad (f\bar{f}\chi_1^0) \\ &\to \ell^+ \chi_1^- \to \ell^+ \quad (f\bar{f}'\chi_1^0)\end{aligned}$$

(7) lighter stop (Table 9)

$$\begin{aligned}\tilde{t}_1 &\to c\chi_1^0 \\ &\to c\chi_2^0 \to c \quad (f\bar{f}\chi_1^0) \\ &\to b\chi_1^- \to b \quad (f\bar{f}'\chi_1^0)\end{aligned}$$

(8) lighter sbottom (Table 9)

$$\begin{aligned}\tilde{b}_1 &\to b\chi_1^0 \\ &\to b\chi_2^0 \to b \quad (f\bar{f}\chi_1^0)\end{aligned}$$

We assume that squarks in the first and second generations and the gluinos are sufficiently heavy to forbid the charginos, neutralinos, sleptons, stop and sbottom decays in these channels. These are natural assumptions as long as one deal with production processes of the sparticles with mass $\lesssim$100GeV in the LEP2 energy regions.

In SUSY23 system, the masses are inspected whether the decay is possible or not. [3] When the channel is open, the decay width is computed.

3.2.2 Spin correlations

The helicity informations of matrix elements in the fermionic 2-body and 3-body decays of the lighter chargino χ_1^- and the second lightest neutralino χ_2^0 are used in the event generation of their decay products. In other words kinematical distribution of the decay products is sensitive to spin correlations with the mother ino. All decay matrix elements are computed exactly with `GRACE` [4] in tree approximation.

In the event generation step, the helicity state of inos is selected by the Monte-Carlo method based on the relative cross sections of all possible helicity combinations. Four-momentum vectors of daughter-particle are determined by the decay matrix element of the ino with specified helicity.

4. Structure of the program

The SUSY23 provides event generation for twenty-three SUSY processes as listed in Table 2 in Appendix C, at e^+e^- colliders with or without radiative corrections. As is shown in Appendix B, there are many options covering theoretical and experimental requirements. Since all program components are distributed as source code, users can select all options by editing the relevant subprograms directly. However, an interface program `susy23` is prepared to lighten the user's burden. [4] It selects and/or corrects the program code which are affected by the various options

[3]Users must be careful in taking the input mass parameters so that the lightest neutralino χ_1^0 (LSP) should be lighter than charginos and sfermions.

[4]Please do not confuse the executable module named `susy23` with the SUSY23 system itself.

and it creates a "Makefile" according to the user requirements. This procedure is called the source generation phase.

In the integration step, the matrix element of a selected process is integrated over the phase space by the subprogram BASES, which gives the total and differential cross sections and the probability distribution used in the event generation phase [7]. There, the subprogram SPRING samples a point in the phase space and test if it can be accepted as a new event according to its probability. When an event is accepted, the program control returns to the main program, where sparticle decays are performed.

There are, therefore, three steps in the generator SUSY23, the first is the source generation, the second is the integration and the third is the event generation. In addition to the user interface program susy23, the following programs are available in the SUSY23 system:

i) Twenty-three function programs FUNCs for final 3-body or 2-body SUSY processes, each of which calculates the numerical value of the differential cross section for each process.

ii) The kinematics subprogram KINMOQ is called when initial state radiation (ISR) based on QEDPS, the QED parton shower model, is requested. Although KINEMO covers both the case where no ISR is produced and where at most 2 photons can be generated at zero angle following the electron structure function method.

iii) An extended version of the CHANEL [6] library to include MSSM couplings. The CHANEL library calculates the numerical values of Feynman diagrams based on the helicity amplitudes method.

iv) The numerical integration and event generation program package BASES/SPRING v5.1 [7].

v) The main programs, MAINBS and MAINSP, and all program components for the integration and event generation steps.

vi) The subprograms for branching ratios and sparticle decays.

v) The interface programs to JETSET (GR2LND, SP2LND and GRC2SH).

The function of these program components and relationship among them are presented in the next three subsections.

4.1 Source generation step

The user interface program susy23 reads the parameters from the control data file, which contains process selection, type of radiative corrections, SUSY parameters, etc. The complete list of parameters is found in Appendix B. Then susy23 generates the following program code:

i) Three initialization subprograms USRPRM, MODMAS KINIT, USERSP and

ii) A "Makefile".

4.2 Integration step

Before starting the numerical integration, the main program MAINBS invokes an initialization subprogram USERIN, in which the following subprograms are called in this order:

`USRPRM`	:	To define the set of input SUSY parameters and some optional parameters.
`SETMAS`	:	To set default values to particle masses and decay widths.
`MODMAS`	:	To alter the default values of all parameters defined in `SETMAS`.
`AMPARM`	:	To set the coupling constants and other parameters.
`KINIT`	:	To set the parameters for the integration, kinematics, cuts and to initialize the histogram package.

The subprograms `SETMAS` and `AMPARM` are generated by the `GRACE` system. By default ino and charged Higgs masses, as well as ino mixing angles (see Sec.2.3) and all branching ratios, are calculated in the framework of the MSSM. Users can selectively set the values of these parameters and some branching ratios. Only naive consistency checks are made, such as the normalization check of the branching ratios and the mass ordering check, so all modifications on these parameters or branching ratios in the subprograms `USRPRM`, `MODMAS` and `KINIT` are on the users' own responsibility.

The integration program `BASES` calculates the scattering cross section by sampling the function `FUNC` on the allowed phase space segmented by a self adapted grid where finer cells are clustered on the high gradient zones. This is an iterative procedure running until either the maximum number of allowed iteration is reached or the required accuracy is obtained. In the function program `FUNC`, the kinematics subroutine `KINEMO` or `KINMOQ` maps the integral variables into the four-momentum of the final state particles. `KINEMO` is called for reactions with no radiative corrections or those involving the initial state radiation treated with the structure function techniques. `KINMOQ` is called for processes in which radiative corrections are computed with the QED parton shower method. The subprograms `AMPTBL` and `AMPSUM` are further called for calculating the helicity amplitudes and the squared of their sum.

It is recommended to look at the integration result carefully, especially over the convergency behaviors both for the grid optimization and integration steps. When the accuracy of each iteration fluctuates from iteration to iteration or when it jumps up suddenly to a large value compared to the other iterations, the resultant estimate of the integral may not be reliable. There are two possible origins of this behavior; too few sampling points or/and an unsuitable choice of the kinematical variables.

After the numerical integration by `BASES`, the subprograms `BSINFO` and `BHPLOT` are called to print the result of integration and the histograms, respectively. Before terminating the integration procedure the probability distribution of the integrand can be saved in a file named `bases.data` by invoking `BSWRIT`, which is later used for the event generation by `SPRING`.

4.3 Event generation step

The main program, `MAINSP`, handles the event generation step. The subprogram `BSREAD` reads the data file `bases.data` to restore the probability distribution and then the subprogram `USERIN` is called. Each call to `SPRING` generates one event by sampling a point in the phase volume. It first calculates the differential cross section at that point using the same function `FUNC` in the integration step and returns the weight of this sampling point. A weight one event is finally produced using usual unweighting technique. Subsequently, `SUDCAY` handles the sparticle decay. By calling the subprogram `SP2LND`, the event information including the color connection to be used by `JETSET` is stored in the labelled common `LUJETS`.

Then hadronization of quarks and gluons can be performed by calling `LUEXEC`. At the end of the event generation, the routine `SPINFO` and `SHPLOT` are invoked successively for printing event generation information and histograms.

5. How to run the program

The user should first prepare the control data to define the process, the option flags, the MSSM parameters and the experimental cuts. The user interface program `susy23` takes this control data as an input. For example, let's call the following sequence of lines `control.data`.

```
process  =  SW1sw1
energy   =  200.0d0
type     =  tree
hadron   =  no
tanbe    =  -2.0d0
xm2      =  50.0d0
xmu      =  150.0d0
end
```

The first line specifies the process to be calculated and the second is the center of mass energy in GeV unit. The others are options, whose meanings are given in Appendix B. Then the user may type:

```
% susy23 < control.data
```

If the message "syntax error" is returned, the user must carefully examine the contents of the control data. No file is generated in this case. When the control data is accepted the following message appears:

```
Process is "SW1sw1"
Energy is "200.0d0"
HADRNZ <no>
bye-bye
directory name is SW1sw1
absolute directory name is /home/susy23/prc/SW1sw1
------------------------------------------
cd /home/susy23/prc/SW1sw1
make integ
integ
make spring
spring
------------------------------------------
```

According to the parameters given in the control data, the files, i.e. `usrprm.f`, `modmas.f`, `kinit.f`, `usersp.f` and `Makefile`, are generated in a specified subdirectory (`SW1sw1` in this case).
According to the last five lines in the message, users can proceed with the calculations as follows:

i) Change directory by typing:

```
% cd /home/susy23/prc/SW1sw1
```

ii) Create an executable `integ` for the integration by typing:

```
% make integ
```

iii) Numerical integration is actually performed by typing:

```
%  integ
```

The results of integration step are displayed on the console as well as written in an output file `bases.result`. The total cross section in *pb* and the estimated statistical error are shown on the last line, under `Cumulative Result`, in the table of the `Convergence Behavior for the Integration step`. The differential cross sections are also printed as a function of the energy, scattering angle of each particle and invariant masses of any two final particles. The probability distribution of the integrand is written in a file `bases.data` which will be used in the event generation step by `spring`.

iv) Before running the event generation, users may edit `mainsp.f` to set additional parameters if needed and call user's own analysis routines.

The following is the structure of the generated `mainsp.f`, where four-momentum of all particles are stored in the `common/lujets/` in the `JETSET` format when subprogram `sp2lnd` is called in the event-loop:

```
      Program  mainsp
      implicit real*8(a-h,o-z)
      external func
       ....................
      real*4  p,v
      common/lujets/n,k(4000,5),p(4000,5),v(4000,5)
       ....................
       ....................
      mxtry  =   50
      mxevnt = 1000
      do 100 nevnt = 1, mxevnt

         call spring( func, mxtry )
       ....................
*          -----------------
            call sp2lnd
*          -----------------
*
*        ==============================================
*        (  user_analysis based on the common lujets )
*        ==============================================
*
  100 continue
       ....................
      stop
      end
```

v) Create an executable `spring` for event generation by typing:

```
% make spring
```

vi) Start the event generation by typing:

```
% spring
```

Information on the event generation will be written in the `spring.result` file. Users should pay attention to the histograms generated in this step. The distributions of the generated events are superimposed with the character "`O`" on the histograms generated in the integration step. These two distributions should be consistent with each other within the statistical error of the generation. For the detail of the output files of `BASES` and `SPRING`, users can consult the Ref.[7].

6. Summary

The SUSY23 system calculates the effective cross section and generates events for one of the twenty-three SUSY processes at e^+e^- colliders listed in Appendix C. It is dedicated to the LEP2 studies. The numbers 2 and 3 in SUSY23 refer to the fact that processes with 2 and also 3 final particles are fully computed at tree level in the massive case. These particles are then allowed to decay producing multi-particle final states. Sparticle widths and decay branching ratios in accordance with this energy range are calculated. In particular, the helicity information for direct decays of spinor sparticles (the lighter chargino and the second lightest neutralino) is handled properly. The produced quarks can be hadronized according to `JETSET`. Processes with initial radiations can be generated in terms of the electron structure function or the QED parton shower method.

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Appendix A. List of sparticles in the MSSM

The list of sparticles in the MSSM is shown in Table 1, which includes abbreviated names used in the control cards and the KF-codes asigned for each particles. As is seen, the keywords in SUSY23 are case-sensitive.

particle	abbrev.	KF code	particle	abbrev.	KF code
χ_1^+	`SW1`	75	$\bar{\tilde{u}}_L$	`SUL`	-42
χ_1^-	`sw1`	-75	$\tilde{u}_R$	`sur`	48
χ_2^+	`SW2`	76	$\bar{\tilde{u}}_R$	`SUR`	-48
χ_2^-	`sw2`	-76	$\tilde{d}_L$	`sdl`	41
χ_1^0	`sz1`	71	$\bar{\tilde{d}}_L$	`SDL`	-41
χ_2^0	`sz2`	72	$\tilde{d}_R$	`sdr`	47
χ_3^0	`sz3`	73	$\bar{\tilde{d}}_R$	`SDR`	-47
χ_4^0	`sz4`	74	$\tilde{c}_L$	`scl`	44
$\tilde{g}$	`sgl`	70	$\bar{\tilde{c}}_L$	`SCL`	-44
$\tilde{e}_L^-$	`sel`	51	$\tilde{c}_R$	`scr`	50
$\tilde{e}_L^+$	`SEL`	-51	$\bar{\tilde{c}}_R$	`SCR`	-50
$\tilde{e}_R^-$	`ser`	57	$\tilde{s}_L$	`ssl`	43
$\tilde{e}_R^+$	`SER`	-57	$\bar{\tilde{s}}_L$	`SSL`	-43
$\tilde{\nu}_e$	`sne`	52	$\tilde{s}_R$	`ssr`	49
$\bar{\tilde{\nu}}_e$	`SNE`	-52	$\bar{\tilde{s}}_R$	`SSR`	-49
$\tilde{\mu}_L^-$	`sml`	53	$\tilde{t}_1$	`st1`	46
$\tilde{\mu}_L^+$	`SML`	-53	$\bar{\tilde{t}}_1$	`ST1`	-46
$\tilde{\mu}_R^-$	`smr`	58	$\tilde{t}_2$	`st2`	62
$\tilde{\mu}_R^+$	`SMR`	-58	$\bar{\tilde{t}}_2$	`ST2`	-62
$\tilde{\nu}_\mu$	`snm`	54	$\tilde{b}_1$	`sb1`	45
$\bar{\tilde{\nu}}_\mu$	`SNM`	-54	$\bar{\tilde{b}}_1$	`SB1`	-45
$\tilde{\tau}_1^-$	`sa1`	55	$\tilde{b}_2$	`sb2`	61
$\tilde{\tau}_1^+$	`SA1`	-55	$\bar{\tilde{b}}_2$	`SB2`	-61
$\tilde{\tau}_2^-$	`sa2`	59	h^0	`sh1`	25
$\tilde{\tau}_2^+$	`SA2`	-59	H^0	`sh2`	35
$\tilde{\nu}_\tau$	`sna`	56	A^0	`sh3`	36
$\bar{\tilde{\nu}}_\tau$	`SNA`	-56	H^+	`sh4`	37
$\tilde{u}_L$	`sul`	42	H^-	`SH4`	-37

Table 1 Sparticles in SUSY23.

Appendix B. Parameters in control data

In the table below, the default values are underlined and the relation between commands and variable/array in Fortran sources is also described. Variable names are written in bold letters and filenames in italic. All masses and energy parameters are given in GeV.

i) Process selection.

`Process`	=	<u>`SW1sw1`</u> abbreviation of process name

This specifies the subdirectory name, where subroutines for the process are stored. Table 1 in Appendix C shows the abbreviation of process names.

ii) Center of mass energy.

`energy`	=	<u>`200.D0`</u> CMS energy `w` in *kinit.f*

iii) Control parameters.

`helicity1`	=	<u>`average`</u>, `left`, `right` Helicity state for the initial electron.
`helicity2`	=	<u>`average`</u>, `left`, `right` Helicity state for the initial positron.

`type`	=	<u>`tree`</u>, `sf`, `qedpsi` (Not available for $\gamma\tilde{\chi}_1^0\tilde{\chi}_1^0$) Type of calculation: Without radiation(`tree`), ISR with structure function(`sf`) and ISR with QEDPS(`qedpsi`). `jqedps` in *usrprm.f*, `isr` in *kinit.f*. `jqedps = 0`, `isr = 0` without radiation(`tree`). `jqedps = 0`, `isr = 1` for `sf`. `jqedps = 1` for `qedpsi`.

`decay`	=	<u>`yes`</u>, `no` Unstable sparticle decays : `jdecay =` <u>`1`</u> or `0` in *usrprm.f*.
`spincr`	=	`yes`, <u>`no`</u> Include spin correlations for direct 3-body decays of gauginos : `jspncr = 1` or <u>`0`</u> in *usrprm.f*.
`qcdcr`	=	`yes`, <u>`no`</u> Include overall QCD correction factor in squark production : `jqcdcr = 1` or <u>`0`</u> in *usrprm.f*.
`susyp`	=	`yes`, <u>`no`</u> (yes) user can selectively set ino masses and mixing angles as well as charged Higgs mass in *modmas.f* (see next sections) (no) all parameters are calculated in the MSSM framework : `jsusyp = 1` or <u>`0`</u> in *usrprm.f*.

iv) Standard Model parameters.

amw	=	80.23D0 W mass : amw in *modmas.f*.
agw	=	2.08D0 W width : agw in *modmas.f*.
amz	=	91.19D0 Z mass : amz in *modmas.f*.
agz	=	2.491D0 Z width : agz in *modmas.f*.
amu	=	100.0D-3 u-quark mass : amu in *modmas.f*.
amd	=	100.0D-3 d-quark mass : amd in *modmas.f*.
amc	=	1.8645D0 c-quark mass : amc in *modmas.f*.
ams	=	300.0D-3 s-quark mass : ams in *modmas.f*.
amt	=	174.0D0 top mass : amt in *modmas.f*.
amb	=	5.0D0 b-quark mass : amb in *modmas.f*.

alphai	=	128.07D0 α^{-1} : alphai in *modmas.f*.
alpha_s	=	0.12D0 α_s : alphas in *modmas.f*.

v) Minimal SUSY Standard Model parameters.

tanbe	=	-2.0D0 $\tan\beta$: tanbe in *usrprm.f*.
xm2	=	50.0D0 SU(2) gaugino mass M_2 : xm2 in *usrprm.f*.
xmu	=	150.0D0 SUSY Higgs mixing mass μ : xmu in *usrprm.f*.

vi) Sfermion sector parameters.

`xmsel`	=	<u>`95.0D0`</u> left-handed selectron mass $m_{\tilde{e}^-_L}$: `xmsel` in *usrprm.f.*
`xmser`	=	<u>`90.0D0`</u> right-handed selectron mass $m_{\tilde{e}^-_R}$: `xmser` in *usrprm.f.*
`xmsml`	=	<u>`95.0D0`</u> left-handed smuon mass $m_{\tilde{\mu}^-_L}$: `xmsml` in *usrprm.f.*
`xmsmr`	=	<u>`90.0D0`</u> right-handed smuon mass $m_{\tilde{\mu}^-_R}$: `xmsmr` in *usrprm.f.*

`xmsa1`	=	<u>`90.0D0`</u> lighter stau mass $m_{\tilde{\tau}_1}$: `xmsa1` in *usrprm.f.*
`xmsa2`	=	<u>`95.0D0`</u> heavier stau mass $m_{\tilde{\tau}_2}$: `xmsa2` in *usrprm.f.* (this parameter is recalculated in case of `susyp = no`)
`xmsna`	=	<u>`100.0D0`</u> tau-sneutrino mass $m_{\tilde{\nu}_\tau}$: `xmsna` in *usrprm.f.*
`tha`	=	<u>`pi/2.0D0`</u> mixing angle θ_τ of staus : `tha` in *usrprm.f.*

`xmsul`	=	<u>`200.0D0`</u> left-handed s u-quark mass $m_{\tilde{u}_L}$: `xmsul` in *usrprm.f.*
`xmsur`	=	<u>`200.0D0`</u> right-handed s u-quark mass $m_{\tilde{u}_R}$: `xmsur` in *usrprm.f.*
`xmsdr`	=	<u>`200.0D0`</u> right-handed s d-quark mass $m_{\tilde{d}_R}$: `xmsdr` in *usrprm.f.*
`xmscl`	=	<u>`200.0D0`</u> left-handed s c-quark mass $m_{\tilde{c}_L}$: `xmscl` in *usrprm.f.*
`xmscr`	=	<u>`200.0D0`</u> right-handed s c-quark mass $m_{\tilde{c}_R}$: `xmscr` in *usrprm.f.*
`xmssr`	=	<u>`200.0D0`</u> right-handed s s-quark mass $m_{\tilde{s}_R}$: `xmssr` in *usrprm.f.*

`xmst1`	=	<u>`80.0D0`</u> lighter stop mass $m_{\tilde{t}_1}$: `xmst1` in *usrprm.f*.
`xmst2`	=	<u>`250.0D0`</u> heavier stop mass $m_{\tilde{t}_2}$: `xmst2` in *usrprm.f*.
`xmsb1`	=	<u>`90.0D0`</u> lighter sbottom mass $m_{\tilde{b}_1}$: `xmsb1` in *usrprm.f*.
`xmsb2`	=	<u>`210.0D0`</u> heavier sbottom mass $m_{\tilde{b}_2}$: `xmsb2` in *usrprm.f*. This parameter is calculated in case of `susyp = no`.
`tht`	=	<u>`1.5D0`</u> mixing angle θ_t of stops : `tht` in *usrprm.f*.
`thb`	=	<u>`0.3D0`</u> mixing angle θ_b of sbottoms : `thb` in *usrprm.f*.

`xaa`	=	<u>`0.0D0`</u> trilinear coupling A_τ in *modmas.f* in case of `susyp = yes`.
`xau`	=	<u>`250.0D0`</u> trilinear coupling A_t in *modmas.f* in case of `susyp = yes`.
`xad`	=	<u>`50.0D0`</u> trilinear coupling A_b in *modmas.f* in case of `susyp = yes`.

vii) Neutralino sector parameters.

For only `susyp = yes`, the following parameters can be given by users.

If `susyp = no` is specified, the input for the following parameters are neglected since these are calculated by Eqs.(7) and (8).

`amn1`	=	<u>`30.0D0`</u> neutralino mass χ_1^0.
`amn2`	=	<u>`70.0D0`</u> neutralino mass χ_2^0.
`amn3`	=	<u>`200.0D0`</u> neutralino mass χ_3^0.
`amn4`	=	<u>`400.0D0`</u> neutralino mass χ_4^0.
`on`	= =	`i,i`, <u>`1.0D0`</u> (for `i`$= 1 \sim 4$) `i,j`, <u>`0.0D0`</u> (for `i`$\neq$`j`, `i,j` $= 1 \sim 4$) neutralino mixing matrix $\mathcal{O}_N$ in *modmas.f*
`sgn`	=	`i`, <u>`1.0D0`</u>, <u>`0.0D0`</u> (for `i` $= 1 \sim 4$) neutralino sign factor $Re(\eta_i)$, $Im(\eta_i)$.

viii) Chargino sector parameters.

For only `susyp = yes`, the following parameters can be given by users.

If `susyp = no` is specified, the input for the following parameters are neglected since these are calculated by Eqs.(9) $\sim$ (12).

`amc1`	=	<u>`30.0D0`</u> chargino mass χ_1^-.
`amc2`	=	<u>`200.0D0`</u> chargino mass χ_2^-.
`cphl`	=	<u>`1.0D0`</u> chargino mixing matrix $\cos\phi_L$.
`sphl`	=	<u>`0.0D0`</u> chargino mixing matrix $\sin\phi_L$.
`cphr`	=	<u>`1.0D0`</u> chargino mixing matrix $\cos\phi_R$.
`sphr`	=	<u>`0.0D0`</u> chargino mixing matrix $\sin\phi_R$.
`eps`	=	<u>`1.0D0`</u> chargino sign factor ϵ_R.

ix) Experimental cuts.

The numbering convention of particles follows the `GRACE` scheme, where the initial electron and positron are 1st and 2nd, respectively, and the final particles are numbered 3, 4 and 5. In the process name of Table 2, the order of particles corresponds to this numbering convention. For instance, in the process, $e^+\tilde{e}_R^-\chi_1^0$, the 3rd is e^+, the 4th is $\tilde{e}_R^-$ and the 5th is χ_1^0.

`thecut3`	=	<u>`180.D0`</u>, <u>`0.0D0`</u> Polar angle cut for 3rd particle in degree (backward-angle, forward-angle). `coscut(1:2,1)=cos(thecut3)` in *kinit.f*.
`thecut4`	=	<u>`180.D0`</u>, <u>`0.0D0`</u> Polar angle cut for 4th particle in degree (backward-angle, forward-angle). `coscut(1:2,2)=cos(thecut4)` in *kinit.f*.
`thecut5`	=	<u>`180.D0`</u>, <u>`0.0D0`</u> Polar angle cut for 5th particle in degree (backward-angle, forward-angle). `coscut(1:2,3)=cos(thecut5)` in *kinit.f*.

Instead of giving a numerical value, the user can use the strings as below:

`amass1(i)` has the mass for i-th particle and `w` is the CM energy.

`engcut3`	=	<u>`amass1(3)`</u>, <u>`w`</u> Energy cut for 3rd particle (min.,max.) `engyct(1:2,1)` in *kinit.f*
`engcut4`	=	<u>`amass1(4)`</u>, <u>`w`</u> Energy cut for 4th particle (min.,max.) `engyct(1:2,2)` in *kinit.f*
`engcut5`	=	<u>`amass1(5)`</u>, <u>`w`</u> Energy cut for 5th particle (min.,max.) `engyct(1:2,3)` in *kinit.f*

x) Parameters for integration.

`itmx`	=	<u>5</u>, <u>10</u> Iteration numbers: `itmx1`, `itmx2` in *kinit.f*
`acc`	=	<u>`0.1`</u>, <u>`0.05`</u> Accuracies in %:`acc1`, `acc2` in *kinit.f*
`ncall`	=	<u>`10000`</u> Sampling points: `ncall` in *kinit.f*

xi) Parameters for event generation.

`mxtry`	=	<u>`50`</u> Maximum trial numbers: `mxtry` in *usersp.f*
`mxevnt`	=	<u>`10000`</u> Maximum event numbers: `mxevnt` in *usersp.f*
`hadron`	=	<u>`yes`</u>, `no` Hadronization with `JETSET`[11] for event generation: If `yes`, then a statement, `call luexec` is activate in *grc2sh.f*.

xii) End of description.

`end`

After the command `end` any command is neglected.

Appendix C. Process table

The 23 processes included in SUSY23 are listed in Table 2. In the heading, 'abbrev.' and 'dir.' stand for the abbreviated name used in the control card and directory name where the generated code is stored, respectively. In Tables 3 $\sim$ 9, decay modes taken into account in the unstable sparticle decays in SUSY23 are listed. By default, each branching ratio is automatically calculated in the framework of the MSSM. The abbreviated names are used in the control card or *kinit.f* when users want to set each branching ratio (`jbrnch = 1`).

process $e^+e^- \to$	abbrev.	dir.	process $e^+e^- \to$	abbrev.	dir.
$\chi_1^+\chi_1^-$	`SW1sw1`	`SW1sw1`	$\tilde{\tau}_2^+\tilde{\tau}_1^-$	`SA2sa1`	`SA2sa1`
$\chi_1^0\chi_2^0$	`sz1sz2`	`sz1sz2`	$\tilde{\tau}_2^+\tilde{\tau}_2^-$	`SA2sa2`	`SA2sa2`
$\chi_2^0\chi_2^0$	`sz2sz2`	`sz2sz2`	$\tilde{\bar{\nu}}_e\tilde{\nu}_e$	`SNEsne`	`SNEsne`
$\gamma\chi_1^0\chi_1^0$	`asz1sz1`	`sz1sz1a`	$\tilde{\bar{\nu}}_\mu\tilde{\nu}_\mu$	`SNMsnm`	`SNMsnm`
$\tilde{e}_R^+\tilde{e}_R^-$	`SERser`	`SERser`	$\tilde{\bar{\nu}}_\tau\tilde{\nu}_\tau$	`SNTsnt`	`SNTsnt`
$\tilde{e}_L^+\tilde{e}_L^-$	`SELsel`	`SELsel`	$e^+\tilde{e}_R^-\chi_1^0$	`Esersz1`	`Esersz1`
$\tilde{e}_L^+\tilde{e}_R^-$	`SELser`	`SELser`	$e^+\tilde{e}_L^-\chi_1^0$	`Eselsz1`	`Eselsz1`
$\tilde{e}_R^+\tilde{e}_L^-$	`SERsel`	`SERsel`	$e^+\tilde{\nu}_e\chi_1^-$	`Esnesw1`	`Esnesw1`
$\tilde{\mu}_R^+\tilde{\mu}_R^-$	`SMRsmr`	`SMRsmr`	$\nu_e\tilde{e}_L^+\chi_1^-$	`nSELsw1`	`nSELsw1`
$\tilde{\mu}_L^+\tilde{\mu}_L^-$	`SMLsml`	`SMLsml`	$\tilde{\bar{t}}_1\tilde{t}_1$	`ST1st1`	`ST1st1`
$\tilde{\tau}_1^+\tilde{\tau}_1^-$	`SA1sa1`	`SA1sa1`	$\tilde{\bar{b}}_1\tilde{b}_1$	`SB1sb1`	`SB1sb1`
$\tilde{\tau}_1^+\tilde{\tau}_2^-$	`SA1sa2`	`SA1sa2`			

Table 2 Available processes in SUSY23.

process	abbrev.	process	abbrev.
$\chi_1^- \to e^-\bar{\nu}_e\chi_1^0$	`sw1br(1)`	$\chi_1^- \to \tau^-\tilde{\bar{\nu}}_\tau$	`sw1br(8)`
$\chi_1^- \to \mu^-\bar{\nu}_\mu\chi_1^0$	`sw1br(2)`	$\chi_1^- \to \bar{\nu}_e\tilde{e}_L^-$	`sw1br(9)`
$\chi_1^- \to \tau^-\bar{\nu}_\tau\chi_1^0$	`sw1br(3)`	$\chi_1^- \to \bar{\nu}_\mu\tilde{\mu}_L^-$	`sw1br(10)`
$\chi_1^- \to \bar{u}d\chi_1^0$	`sw1br(4)`	$\chi_1^- \to \bar{\nu}_\tau\tilde{\tau}_1^-$	`sw1br(11)`
$\chi_1^- \to \bar{c}s\chi_1^0$	`sw1br(5)`	$\chi_1^- \to \bar{\nu}_\tau\tilde{\tau}_2^-$	`sw1br(12)`
$\chi_1^- \to e^-\tilde{\bar{\nu}}_e$	`sw1br(6)`	$\chi_1^- \to b\tilde{\bar{t}}_1$	`sw1br(13)`
$\chi_1^- \to \mu^-\tilde{\bar{\nu}}_\mu$	`sw1br(7)`		

Table 3 Decay processes of lighter chargino χ_1^- in SUSY23.

process	abbrev.	process	abbrev.
$\chi_2^0 \to e^- e^+ \chi_1^0$	`sn2br(1)`	$\chi_2^0 \to \tau^+ \tilde{\tau}_1^-$	`sn2br(16)`
$\chi_2^0 \to \mu^- \mu^+ \chi_1^0$	`sn2br(2)`	$\chi_2^0 \to \tau^- \tilde{\tau}_1^+$	`sn2br(17)`
$\chi_2^0 \to \tau^- \tau^+ \chi_1^0$	`sn2br(3)`	$\chi_2^0 \to e^+ \tilde{e}_L^-$	`sn2br(18)`
$\chi_2^0 \to \nu_e \bar{\nu}_e \chi_1^0$	`sn2br(4)`	$\chi_2^0 \to e^- \tilde{e}_L^+$	`sn2br(19)`
$\chi_2^0 \to \nu_\mu \bar{\nu}_\mu \chi_1^0$	`sn2br(5)`	$\chi_2^0 \to \mu^+ \tilde{\mu}_L^-$	`sn2br(20)`
$\chi_2^0 \to \nu_\tau \bar{\nu}_\tau \chi_1^0$	`sn2br(6)`	$\chi_2^0 \to \mu^- \tilde{\mu}_L^+$	`sn2br(21)`
$\chi_2^0 \to u \bar{u} \chi_1^0$	`sn2br(7)`	$\chi_2^0 \to \tau^+ \tilde{\tau}_2^-$	`sn2br(22)`
$\chi_2^0 \to d \bar{d} \chi_1^0$	`sn2br(8)`	$\chi_2^0 \to \tau^- \tilde{\tau}_2^+$	`sn2br(23)`
$\chi_2^0 \to c \bar{c} \chi_1^0$	`sn2br(9)`	$\chi_2^0 \to \nu_e \tilde{\bar{\nu}}_e$	`sn2br(24)`
$\chi_2^0 \to s \bar{s} \chi_1^0$	`sn2br(10)`	$\chi_2^0 \to \bar{\nu}_e \tilde{\nu}_e$	`sn2br(25)`
$\chi_2^0 \to b \bar{b} \chi_1^0$	`sn2br(11)`	$\chi_2^0 \to \nu_\mu \tilde{\bar{\nu}}_\mu$	`sn2br(26)`
$\chi_2^0 \to e^+ \tilde{e}_R^-$	`sn2br(12)`	$\chi_2^0 \to \bar{\nu}_\mu \tilde{\nu}_\mu$	`sn2br(27)`
$\chi_2^0 \to e^- \tilde{e}_R^+$	`sn2br(13)`	$\chi_2^0 \to \nu_\tau \tilde{\bar{\nu}}_\tau$	`sn2br(28)`
$\chi_2^0 \to \mu^+ \tilde{\mu}_R^-$	`sn2br(14)`	$\chi_2^0 \to \bar{\nu}_\tau \tilde{\nu}_\tau$	`sn2br(29)`
$\chi_2^0 \to \mu^- \tilde{\mu}_R^+$	`sn2br(15)`		

Table 4 Decay processes of second lightest neutralino χ_2^0 in SUSY23.

process	$\ell = e$	$\ell = \mu$
$\tilde{\ell}_L \to \ell \chi_1^0$	`selbr(1)`	`smlbr(1)`
$\tilde{\ell}_L \to \ell \chi_2^0$	`selbr(2)`	`smlbr(2)`
$\tilde{\ell}_L \to \nu_\ell \chi_1^-$	`selbr(3)`	`smlbr(3)`

Table 5 Decay processes of left-handed charged sleptons $\tilde{\ell}_L$ in SUSY23.

process	$\ell = e$	$\ell = \mu$
$\tilde{\ell}_R \to \ell \chi_1^0$	`serbr(1)`	`smrbr(1)`
$\tilde{\ell}_R \to \ell \chi_2^0$	`serbr(2)`	`smrbr(2)`

Table 6 Decay processes of right-handed charged sleptons $\tilde{\ell}_R$ in SUSY23.

process	abbrev.
$\tilde{\tau}_1^- \to \tau^-\chi_1^0$	`sa1br(1)`
$\tilde{\tau}_1^- \to \tau^-\chi_2^0$	`sa1br(2)`
$\tilde{\tau}_1^- \to \nu_\tau\chi_1^-$	`sa1br(3)`
$\tilde{\tau}_2^- \to \tau^-\chi_1^0$	`sa2br(1)`
$\tilde{\tau}_2^- \to \tau^-\chi_2^0$	`sa2br(2)`
$\tilde{\tau}_2^- \to \nu_\tau\chi_1^-$	`sa2br(3)`

Table 7 Decay processes of lighter and heavier staus $\tilde{\tau}$ in SUSY23.

process	$\ell = e$	$\ell = \mu$	$\ell = \tau$
$\tilde{\nu}_\ell \to \nu_\ell\chi_1^0$	`snebr(1)`	`snmbr(1)`	`snabr(1)`
$\tilde{\nu}_\ell \to \nu_\ell\chi_2^0$	`snebr(2)`	`snmbr(2)`	`snabr(2)`
$\tilde{\nu}_\ell \to \ell\chi_1^+$	`snebr(3)`	`snmbr(3)`	`snabr(3)`

Table 8 Decay processes of sneutrinos $\tilde{\nu}_\ell$ in SUSY23.

process	abbrev.
$\tilde{t}_1 \to c\chi_1^0$	`st1br(1)`
$\tilde{t}_1 \to c\chi_2^0$	`st1br(2)`
$\tilde{t}_1 \to b\chi_1^+$	`st1br(3)`
$\tilde{b}_1 \to b\chi_1^0$	`sb1br(1)`
$\tilde{b}_1 \to b\chi_2^0$	`sb1br(2)`

Table 9 Decay processes of 3rd generation squarks $\tilde{t}_1$ and $\tilde{b}_1$ in SUSY23.

Appendix D. Installation

The source code is available by `anonymous ftp` from `ftp.kek.jp` in the directory `kek/minami/susy23`. The SUSY23 system contains the complete set of Fortran sources for 23 processes, the three libraries, i.e., `BASES/SPRING`, `CHANEL` and utilities for kinematics. Those source codes are written in FORTRAN77. In addition, SUSY23 provides the interface program to generate a few Fortran source files according to the control data specified by the user. This program is written in C, YACC and LEX. SUSY23 has been developed on HP-UX, but should run on any UNIX platform with a fortran complier.

The procedure of installation is as follows:

1. Editing *Makefile*.

   The following macros in *Makefile* should be taken care of by users themselves. For example, `SU23DIR` defines the directory name where SUSY23 is installed. The values of `FC` and `FOPT` define the relevant compiler name and option for your system. The other macros can be left as they are.

`SU23DIR`	=	directory where SUSY23 are installed.
`PRCDIR`	=	directory where process files are installed. (default is `$(SU23DIR)/prc`.)
`LIBDIR`	=	directory where libraries are installed. (default is `$(SU23DIR)/lib`.)
`BINDIR`	=	directory where an executable is installed. (default is `$(SU23DIR)/bin`.)
`MACHINE`	=	`[hpux|hiux|sgi|dec|sun]`
`FC`	=	FORTRAN compiler command name.
`FOPT`	=	FORTRAN compiler options.
`CERNLIBS`	=	CERNLIB including the jetset library. For HP-UX, `-L/cern/pro/lib -ljetset74 -lpacklib -lkernlib -L/lib/pa1.1/ -lm`

2. Compilation.

   By executing command `make install` the executable of the interface program(`susy23`) is generated at `BINDIR`. Furthermore six libraries, `BASES/SPRING`, `CHANEL`, kinematics utility library and three susy libraries, are generated in `LIBDIR`.

The sample control data files will be found in the directory `sample`.

TEST RUN OUTPUT

`control data`

```
Process = Eselsz1
Energy  = 200.0d0
type    = tree
itmx    = 7, 15
ncall   = 10000
hadron = yes
mxevnt = 10000
end
```

Followings are the output files from `BASES` and `SPRING`. Only one histogram, the momentum distribution of the particle 3, is shown since the whole output is too lengthy to be included here.

```
************************************************************************
*----------------------------------------------------------------------*
*----------------------------------------------------------------------*
*------------------------------------------------222---------333-------*
*----------------------------------------------2222222-----3333333-----*
*----------------------------------------------22----22----3----33-----*
*----SSSS SS-UUU--UUUU-----####-##-YYYY---YYYY-------22---------33-----*
*--SSSSSSSS--UUU--UUUU---########--YYYY---YYYY-------22------3333------*
*--SS    SSS--UU----UU---##----###---YY---YY--------22-------3333------*
*--SSSSSSS----UU----UU---#######-----YY---YY------222-----------33-----*
*----SSSSSSS--UU----UU-----#######---YYY-YY------222------------33-----*
*--SS     SS--UU---UUU---##-----##----YYYYY-----22---22----3----33-----*
*--SSSSSSSS----UUUUUUUU--########-----YYYY-----22222222---3333333------*
*--SSSSSSS------UUU-UUU--#######-------YY------22222222-----333--------*
*-------------------------------------YYY------------------------------*
*----------------------------------YYYYYYY-----------------------------*
*----------------------------------YYYYYYY-----------------------------*
*----------------------------------------------------------------------*
*------------------ matrix element generated by GRACE -----------------*
*------------------ version 2.0 (07) --  1997 JUN. 17 -----------------*
************************************************************************
*---------------Copyright -- Minami Tateya Collaboration --------------*
*------------------- E-mail:susy23@minami.kek.jp ----------------------*
************************************************************************
*   Process      : e+e- --> (3)positron (4)selectronl (5)neutralino1
*                                                                      *
*   CM Energy(GeV):     200.00000                                      *
*                                                                      *
*   Mass (Width)                                                       *
*         W-boson:  80.230(  2.080)  Z-boson:  91.190(  2.491)         *
*         u-quark:    .100           d-quark:   .100                   *
*         c-quark:   1.865           s-quark:   .300                   *
*         t-quark: 174.000           b-quark:  5.000                   *
*                                                                      *
*         alpha  :  1/128.070                                          *
*         alpha_s:   .12000                                            *
*                                                                      *
*----------------------------------------------------------------------*
*    SUSY Parameters                                                   *
*----------------------------------------------------------------------*
*       tan(beta)                        =     -2.00                   *
*       SU(2) gaugino mass(Gev)          =     50.00                   *
*       SUSY Higgs parameter(Gev)        =    150.00                   *
*----------------------------------------------------------------------*
*----------------------------------------------------------------------*
*    SFermions Masses(GeV)                                             *
*----------------------------------------------------------------------*
*         s-electron(L):   95.000    s-electron(R):  90.000            *
*                              s-neutrino-electron:  95.000            *
*             s-muon(L):   95.000        s-muon(R):  90.000            *
*                                  s-neutrino-muon:  95.000            *
*              s-tau(1):   90.000         s-tau(2):  95.000            *
*                                   s-neutrino-tau: 100.000            *
*----------------------------------------------------------------------*
*          s-u-quark(L):  200.000     s-u-quark(R): 200.000            *
*          s-d-quark(L):  200.000     s-d-quark(R): 200.000            *
*          s-c-quark(L):  200.000     s-c-quark(R): 200.000            *
*          s-s-quark(L):  200.000     s-s-quark(R): 200.000            *
*          s-t-quark(1):   80.000     s-t-quark(2): 250.000            *
*          s-b-quark(1):   90.000     s-b-quark(2): 210.000            *
*----------------------------------------------------------------------*
*    SFermions Mixing Angles (rad.)                                    *
*----------------------------------------------------------------------*
*                 s-tau:     .000                                      *
*                 s-top:    1.500         s-bottom:    .300            *
```

```
*----------------------------------------------------------------------*

*----------------------------------------------------------------------*
*       trlinear couplings                                             *
*                A_tau:    .3000000E+03                                *
*                  A_u:    .5225048E+02                                *
*                  A_d:   -.1732713E+04                                *
*----------------------------------------------------------------------*
*----------------------------------------------------------------------*
*    Neutralino                                                        *
*----------------------------------------------------------------------*
*       neutralino masses(Gev)           =     27.89,     70.53        *
*                                             159.24,    183.34        *
*                                                                      *
*       neutralino mixing matrix (bino bases)                          *
*                  .952     .284     .104     .036                     *
*                 -.207     .864    -.459    -.018                     *
*                 -.122     .280     .611    -.731                     *
*                 -.187     .308     .637     .681                     *
*                                                                      *
*       Neutralino sign factor                                         *
*           1.00    .00 |  1.00    .00 |  1.00    .00 |    .00   1.00   *
*----------------------------------------------------------------------*
*    Chargino                                                          *
*----------------------------------------------------------------------*
*       chargino masses(GeV)             =     69.60,    181.74        *
*                                                                      *
*       chargino mixing matrix                                         *
*                                                .85,      -.53        *
*                                              1.00,        .09        *
*                                                                      *
*       chargino sign factor            =       1.00                   *
*                                                                      *
*----------------------------------------------------------------------*
*   Calculated Total Decay width(GeV)                                  *
*                                                                      *
*  chargino1  : .364E-04  chargino2  : .521E+01                        *
*  neutralino2: .149E-04  neutralino3: .322E+00  neutralino4: .662E+00 *
*  selectronR : .339E+00  selectronL : .392E+00                        *
*  smuonR     : .339E+00  smuonL     : .392E+00                        *
*  stau1      : .325E+00  stau2      : .367E+00                        *
*  sneu_e     : .272E+00  sneu_mu    : .272E+00  sneu_tau   : .351E+00 *
*  stop1      : .240E-03  sbottom1   : .469E-01                        *
*----------------------------------------------------------------------*
*   Experimental Cuts                                                  *
*        Angle Cuts                                                    *
*             Particle 3      -1.000  --->     1.000                   *
*             Particle 4      -1.000  --->     1.000                   *
*             Particle 5      -1.000  --->     1.000                   *
*        Energy CUT                                                    *
*             Particle 3        .001  --->    62.246                   *
*             Particle 4      95.000  --->   120.618                   *
*             Particle 5      27.888  --->    79.382                   *
*        Invariant mass CUT                                            *
*             Inv. Mass 4-5  122.888  --->   199.999                   *
*             Inv. Mass 3-4   95.001  --->   172.112                   *
*             Inv. Mass 3-5   27.889  --->   105.000                   *
*----------------------------------------------------------------------*
*                                                                      *
*   OPTIONS:                                                           *
*        Calculation:         TREE                                     *
*        Width      :         FIX                                      *
************************************************************************

************************************************************************
```

```
*   Branching Ratios of Sparticles                                     *
*----------------------------------------------------------------------*
*  chargino 1   (sw1)                                                  *
*----------------------------------------------------------------------*
*   (EL ne sz1): .1774   (MU nm sz1): .1774   (TA nt sz1): .2171       *
*   (uq DQ sz1): .2153   (cq SQ sz1): .2129                            *
*   (EL sne)   : .0000   (MU snm)   : .0000   (TA snt)   : .0000       *
*   (ne SEL)   : .0000   (nm SML)   : .0000                            *
*   (nt SA1)   : .0000   (nt SA2)   : .0000                            *
*   (BQ st1)   : .0000                                                 *
*----------------------------------------------------------------------*
*  neutralino 2 (sz2)                                                  *
*----------------------------------------------------------------------*
*   (EL el sz1): .2747   (MU mu sz1): .2747   (TA ta sz1): .3367       *
*   (NE ne sz1): .0200   (NM nm sz1): .0200   (NT nt sz1): .0136       *
*   (UQ uq sz1): .0198   (DQ dq sz1): .0017                            *
*   (CQ cq sz1): .0194   (SQ sq sz1): .0017   (BQ bq sz1): .0177       *
*   (el seR)   : .0000   (mu smR)   : .0000   (ta sa1)   : .0000       *
*   (el seL)   : .0000   (mu smL)   : .0000   (ta sa2)   : .0000       *
*   (ne sne)   : .0000   (nm snm)   : .0000   (na sna)   : .0000       *
*----------------------------------------------------------------------*
*  selectron L  (seL)                                                  *
*----------------------------------------------------------------------*
*   (el sz1)   : .5581   (el sz2)   : .1193   (ne sw1)   : .3226       *
*----------------------------------------------------------------------*
*  selectron R  (seR)                                                  *
*----------------------------------------------------------------------*
*   (el sz1)   : .9914   (el sz2)   : .0086                            *
*----------------------------------------------------------------------*
*  smuon L      (smL)                                                  *
*----------------------------------------------------------------------*
*   (mu sz1)   : .5581   (mu sz2)   : .1193   (nm sw1)   : .3226       *
*----------------------------------------------------------------------*
*  smuon R      (smR)                                                  *
*----------------------------------------------------------------------*
*   (mu sz1)   : .9914   (mu sz2)   : .0086                            *
*----------------------------------------------------------------------*
*  stau 1       (sa1)                                                  *
*----------------------------------------------------------------------*
*   (ta sz1)   : .6223   (ta sz2)   : .1007   (na sw1)   : .2770       *
*----------------------------------------------------------------------*
*  stau 2       (sa2)                                                  *
*----------------------------------------------------------------------*
*   (ta sz1)   : .9883   (ta sz2)   : .0115   (na sw1)   : .0002       *
*----------------------------------------------------------------------*
*  snu_e        (sne)                                                  *
*----------------------------------------------------------------------*
*   (ne sz1)   : .0669   (ne sz2)   : .2900   (el sw1)   : .6431       *
*----------------------------------------------------------------------*
*  snu_mu       (snm)                                                  *
*----------------------------------------------------------------------*
*   (nm sz1)   : .0669   (nm sz2)   : .2900   (mu sw1)   : .6431       *
*----------------------------------------------------------------------*
*  snu_tau      (sna)                                                  *
*----------------------------------------------------------------------*
*   (nt sz1)   : .0555   (nt sz2)   : .2960   (tu sw1)   : .6485       *
*----------------------------------------------------------------------*
*  stop 1       (st1)                                                  *
*----------------------------------------------------------------------*
*   (cq sz1)   : .0000   (cq sz2)   : .0000   (bq sw1)   :1.0000       *
*----------------------------------------------------------------------*
*  sbottom 1    (sb1)                                                  *
*----------------------------------------------------------------------*
*   (bq sz1)   : .1410   (bq sz2)   : .8590                            *
************************************************************************
```

```
                                                 Date: 97/ 7/ 1  11:49
  **********************************************************
  *                                                        *
  *     BBBBBBB     AAAA     SSSSSS   EEEEEE   SSSSSS      *
  *     BB    BB   AA  AA   SS    SS  EE      SS    SS     *
  *     BB    BB  AA    AA  SS        EE      SS           *
  *     BBBBBBB   AAAAAAAA   SSSSSS   EEEEEE   SSSSSS      *
  *     BB    BB  AA    AA        SS  EE            SS     *
  *     BB    BB  AA    AA  SS    SS  EE      SS    SS     *
  *     BBBB BB   AA    AA   SSSSSS   EEEEEE   SSSSSS      *
  *                                                        *
  *                   BASES Version 5.1                    *
  *           coded by S.Kawabata KEK, March 1994          *
  **********************************************************


<<   Parameters for BASES    >>

 (1) Dimensions of integration etc.
     # of dimensions :    Ndim    =        5   ( 50 at max.)
     # of Wilds      :    Nwild   =        5   ( 15 at max.)
     # of sample points : Ncall   =     9375(real)    10000(given)
     # of subregions    : Ng      =       50 / variable
     # of regions       : Nregion =        5 / variable
     # of Hypercubes    : Ncube   =     3125

 (2) About the integration variables
     ------+---------------+---------------+-------+-------
         i       XL(i)           XU(i)       IG(i)   Wild
     ------+---------------+---------------+-------+-------
         1     .000000E+00    1.000000E+00     1      yes
         2     .000000E+00    1.000000E+00     1      yes
         3     .000000E+00    1.000000E+00     1      yes
         4     .000000E+00    1.000000E+00     1      yes
         5     .000000E+00    1.000000E+00     1      yes
     ------+---------------+---------------+-------+-------

 (3) Parameters for the grid optimization step
     Max.# of iterations: ITMX1 =        7
     Expected accuracy  : Acc1  =    .1000 %

 (4) Parameters for the integration step
     Max.# of iterations: ITMX2 =       15
     Expected accuracy  : Acc2  =    .0500 %


<<   Computing Time Information   >>

          (1) For BASES              H: M:  Sec
              Overhead           :   0: 0: 7.46
              Grid Optim. Step   :   0:13:41.90
              Integration Step   :   0:29:13.41
              Go time for all    :   0:43: 2.77

          (2) Expected event generation time
              Expected time for 1000 events :     17.81 Sec
```

```
                                                         Date: 97/ 7/ 1  11:49
              Convergency Behavior for the Grid Optimization Step
------------------------------------------------------------------------------
<- Result of  each iteration ->  <-     Cumulative Result     -> < CPU  time >
 IT Eff R_Neg   Estimate  Acc %  Estimate(+- Error )order  Acc % ( H: M: Sec )
------------------------------------------------------------------------------
  1 100   .00  1.351E-01  5.295  1.351125(+- .071544)E-01  5.295   0: 1:57.29
  2 100   .00  1.456E-01  1.470  1.447336(+- .020502)E-01  1.417   0: 3:54.83
  3 100   .00  1.430E-01  1.211  1.437373(+- .013232)E-01   .921   0: 5:52.58
  4 100   .00  1.448E-01  1.130  1.441760(+- .010290)E-01   .714   0: 7:50.20
  5 100   .00  1.453E-01  1.205  1.444741(+- .008872)E-01   .614   0: 9:47.20
  6 100   .00  1.457E-01  1.171  1.447447(+- .007871)E-01   .544   0:11:44.74
  7 100   .00  1.452E-01  1.264  1.448097(+- .007233)E-01   .499   0:13:41.90
------------------------------------------------------------------------------
```

```
                                                         Date: 97/ 7/ 1  11:49
              Convergency Behavior for the Integration Step
------------------------------------------------------------------------------
<- Result of  each iteration ->  <-     Cumulative Result     -> < CPU  time >
 IT Eff R_Neg   Estimate  Acc %  Estimate(+- Error )order  Acc % ( H: M: Sec )
------------------------------------------------------------------------------
  1 100   .00  1.467E-01  1.159  1.467078(+- .017002)E-01  1.159   0:15:39.79
  2 100   .00  1.436E-01  1.111  1.450578(+- .011636)E-01   .802   0:17:37.65
  3 100   .00  1.469E-01  1.101  1.456866(+- .009447)E-01   .648   0:19:35.01
  4 100   .00  1.450E-01  1.119  1.455106(+- .008164)E-01   .561   0:21:31.73
  5 100   .00  1.453E-01  1.100  1.454677(+- .007271)E-01   .500   0:23:28.23
  6 100   .00  1.457E-01  1.158  1.454980(+- .006677)E-01   .459   0:25:24.70
  7 100   .00  1.450E-01  1.146  1.454232(+- .006195)E-01   .426   0:27:21.81
  8 100   .00  1.446E-01  1.091  1.453082(+- .005766)E-01   .397   0:29:18.61
  9 100   .00  1.484E-01  1.199  1.455997(+- .005485)E-01   .377   0:31:15.24
 10 100   .00  1.443E-01  1.202  1.454854(+- .005230)E-01   .359   0:33:12.25
 11 100   .00  1.453E-01  1.195  1.454674(+- .005008)E-01   .344   0:35: 8.71
 12 100   .00  1.481E-01  1.212  1.456559(+- .004824)E-01   .331   0:37: 5.18
 13 100   .00  1.457E-01  1.248  1.456616(+- .004662)E-01   .320   0:39: 2.19
 14 100   .00  1.462E-01  1.212  1.456987(+- .004509)E-01   .309   0:40:58.71
 15 100   .00  1.464E-01  1.360  1.457306(+- .004398)E-01   .302   0:42:55.31
------------------------------------------------------------------------------
```

```
Histogram (ID =  1 ) for Momentum of Particle 3
                             Linear Scale indicated by "*"
    x      d(Sigma)/dx       .0E+00      1.5E-03     3.0E-03     4.5E-03
+-------+------------------+------------+-----------+-----------+------------+
I  E  1 I  .000        E  0I                                                 I
I  .000 I 2.313+- .443 E -5I*000000                                          I
I  .150 I 5.546+-1.029 E -5I*0000000000000                                   I
I  .300 I 8.262+-1.265 E -5I*0000000000000000                                I
I  .450 I 7.249+-1.200 E -5I*000000000000000                                 I
I  .600 I 9.100+-1.624 E -5I*00000000000000000                               I
I  .750 I 8.764+-1.639 E -5I*00000000000000000                               I
I  .900 I 1.090+- .189 E -4I*0000000000000000000                             I
I 1.050 I 6.979+-1.197 E -5I*000000000000000                                 I
I 1.200 I 7.721+-1.723 E -5I*0000000000000000                                I
I 1.350 I 9.019+-1.836 E -5I*00000000000000000                               I
I 1.500 I 5.955+-1.129 E -5I*00000000000000                                  I
I 1.650 I 1.232+- .199 E -4I**0000000000000000000                            I
I 1.800 I 1.104+- .197 E -4I*0000000000000000000                             I
I 1.950 I 1.120+- .157 E -4I*0000000000000000000                             I
I 2.100 I 1.144+- .180 E -4I*0000000000000000000                             I
I 2.250 I 1.399+- .159 E -4I**00000000000000000000                           I
I 2.400 I 1.648+- .104 E -4I**000000000000000000000                          I
I 2.550 I 3.776+- .622 E -4I****00000000000000000000000000                   I
I 2.700 I 2.477+- .081 E -3I*********************000000000000000000000000    I
I 2.850 I 2.739+- .064 E -3I***********************00000000000000000000000   I
I 3.000 I 3.066+- .071 E -3I**************************000000000000000000000  I
I 3.150 I 4.264+- .083 E -3I************************************0000000000000I
I 3.300 I 4.362+- .080 E -3I*************************************000000000000I
I 3.450 I 4.349+- .079 E -3I*************************************000000000000I
I 3.600 I 4.384+- .070 E -3I*************************************000000000000I
I 3.750 I 4.491+- .074 E -3I**************************************000000000000
I 3.900 I 4.467+- .076 E -3I**************************************000000000000
I 4.050 I 4.410+- .071 E -3I*************************************000000000000I
I 4.200 I 4.453+- .069 E -3I**************************************000000000000
I 4.350 I 4.551+- .080 E -3I**************************************000000000000
I 4.500 I 4.469+- .080 E -3I**************************************000000000000
I 4.650 I 4.402+- .077 E -3I*************************************000000000000I
I 4.800 I 4.381+- .082 E -3I*************************************000000000000I
I 4.950 I 4.554+- .084 E -3I**************************************000000000000
I 5.100 I 4.503+- .076 E -3I**************************************000000000000
I 5.250 I 4.564+- .081 E -3I***************************************00000000000
I 5.400 I 4.536+- .075 E -3I**************************************000000000000
I 5.550 I 4.380+- .071 E -3I*************************************000000000000I
I 5.700 I 4.602+- .066 E -3I***************************************00000000000
I 5.850 I 4.264+- .071 E -3I************************************0000000000000I
I 6.000 I 2.521+- .062 E -3I**********************00000000000000000000000    I
I 6.150 I 5.346+- .292 E -5I*0000000000000                                   I
I 6.300 I  .000+- .000 E  0I                                                 I
I 6.450 I  .000+- .000 E  0I                                                 I
I 6.600 I  .000+- .000 E  0I                                                 I
I 6.750 I  .000+- .000 E  0I                                                 I
I 6.900 I  .000+- .000 E  0I                                                 I
I 7.050 I  .000+- .000 E  0I                                                 I
I 7.200 I  .000+- .000 E  0I                                                 I
I 7.350 I  .000+- .000 E  0I                                                 I
I  E  1 I  .000        E  0I                                                 I
+-------+------------------+------------------+-----------------+------------+
    x      d(Sigma)/dx      1.0E-05            1.0E-04           1.0E-03
                             Logarithmic Scale indicated by "O"
```

```
                                                     Date: 97/ 7/ 1  14:28
   **********************************************************
   *                                                        *
   *    SSSSS   PPPPPP   RRRRRR   IIIII  N    NN   GGGGG    *
   *   SS   SS  PP   PP  RR   RR   III   NN   NN  GG   GG   *
   *   SS       PP   PP  RR   RR   III   NNN  NN  GG        *
   *    SSSSS   PPPPPP   RRRRR     III   NNNN NN  GG  GGGG  *
   *        SS  PP       RR  RR    III   NN NNNN  GG   GG   *
   *   SS   SS  PP       RR   RR   III   NN  NNN  GG   GG   *
   *    SSSSS   PP       RR    RR IIIII  NN   NN   GGGGG    *
   *                                                        *
   *                  SPRING Version 5.1                    *
   *           coded by S.Kawabata KEK, March 1994          *
   **********************************************************

Number of generated events    =      10000
Generation efficiency         =     23.794 Percent
Computing time for generation =    443.281 Seconds
              for Overhead    =      8.240 Seconds
              for Others      =     10.349 Seconds
GO time for event generation  =    461.870 Seconds
Max. number of trials MXTRY   =         50 per event
Number of miss-generation     =         51 times
```

```
Original Histogram (ID =  1 ) for Momentum of Particle 3
Total =      10000 events   "*" : Orig. Dist. in Log Scale.
   x      d(Sig/dx)  dN/dx 1.0E-05            1.0E-04            1.0E-03
+-------+----------+-------+------------------+------------------+-----------+
I  E  1 I  .000E  0I      0I                                                 I
I  .000 I 2.313E -5I      7I*******    <   0  >                              I
I  .150 I 5.546E -5I      5I*******<****0* >                                 I
I  .300 I 8.262E -5I      7I***********<***0* >                              I
I  .450 I 7.249E -5I     13I**************** <  0 >                          I
I  .600 I 9.100E -5I      3I*<******0***>*****                               I
I  .750 I 8.764E -5I     10I***************<**0 >                            I
I  .900 I 1.090E -4I      6I*********<****0*>***                             I
I 1.050 I 6.979E -5I     10I***************<  0 >                            I
I 1.200 I 7.721E -5I     12I*****************< 0 >                           I
I 1.350 I 9.019E -5I     10I***************<**0 >                            I
I 1.500 I 5.955E -5I     17I***************     < 0 >                        I
I 1.650 I 1.232E -4I      8I************<***0*>**                            I
I 1.800 I 1.104E -4I      3I*<******0***>*******                             I
I 1.950 I 1.120E -4I      9I**************<**0*>                             I
I 2.100 I 1.144E -4I     16I*******************<  0>                         I
I 2.250 I 1.399E -4I     11I****************<**0*>                           I
I 2.400 I 1.648E -4I     18I********************<**0>                        I
I 2.550 I 3.776E -4I     33I**************************<0*>                   I
I 2.700 I 2.477E -3I    231I******************************************<0>    I
I 2.850 I 2.739E -3I    262I********************************************<>   I
I 3.000 I 3.066E -3I    292I********************************************<>*  I
I 3.150 I 4.264E -3I    416I***********************************************<>I
I 3.300 I 4.362E -3I    478I*************************************************0
I 3.450 I 4.349E -3I    472I************************************************<>
I 3.600 I 4.384E -3I    439I************************************************<>
I 3.750 I 4.491E -3I    445I************************************************<>
I 3.900 I 4.467E -3I    457I************************************************<>
I 4.050 I 4.410E -3I    480I*************************************************0
I 4.200 I 4.453E -3I    487I*************************************************0
I 4.350 I 4.551E -3I    451I************************************************<>
I 4.500 I 4.469E -3I    447I************************************************<>
I 4.650 I 4.402E -3I    448I************************************************<>
I 4.800 I 4.381E -3I    469I************************************************<>
I 4.950 I 4.554E -3I    458I************************************************<>
I 5.100 I 4.503E -3I    490I*************************************************0
I 5.250 I 4.564E -3I    471I************************************************<>
I 5.400 I 4.536E -3I    473I************************************************<>
I 5.550 I 4.380E -3I    501I*************************************************<
I 5.700 I 4.602E -3I    488I*************************************************0
I 5.850 I 4.264E -3I    413I***********************************************<>I
I 6.000 I 2.521E -3I    223I******************************************<>*    I
I 6.150 I 5.346E -5I     11I**************  <  0 >                           I
I 6.300 I  .000E  0I      0I                                                 I
I 6.450 I  .000E  0I      0I                                                 I
I 6.600 I  .000E  0I      0I                                                 I
I 6.750 I  .000E  0I      0I                                                 I
I 6.900 I  .000E  0I      0I                                                 I
I 7.050 I  .000E  0I      0I                                                 I
I 7.200 I  .000E  0I      0I                                                 I
I 7.350 I  .000E  0I      0I                                                 I
I  E  1 I  .000E  0I      0I                                                 I
+-------+----------+-------+------------------+------------------+-----------+
   x      d(Sig/dx)  dN/dx    "0" : Generated Events.( Arbitrary unit in Log )
```