ISAJET 7.51

A Monte Carlo Event Generator for pp, $\bar{p}p$, and e^+e^- Reactions

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Contents

1 Introduction

ISAJET is a Monte Carlo program which simulates pp, $\bar{p}p$ and e^+e^- interactions at high energies. ISAJET is based on perturbative QCD plus phenomenological models for parton and beam jet fragmentation. Events are generated in four distinct steps:

- A primary hard scattering is generated according to the appropriate QCD cross section.
- QCD radiative corrections are added for both the initial and the final state.
- Partons are fragmented into hadrons independently, and particles with lifetimes less than about 10^{-12} seconds are decayed.
- Beam jets are added assuming that these are identical to a minimum bias event at the remaining energy.

ISAJET incorporates ISASUSY, which evaluates branching ratios for the minimal supersymmetric extension of the standard model. H. Baer and X. Tata are coauthors of this package, and they have done the original calculations with various collaborators. See the ISASUSY documentation in the patch Section 12.

ISAJET is supported for ANSI Fortran and for Cray, DEC Ultrix, DEC VMS, HP/9000 7xx, IBM VM/CMS 370 and 30xx, IBM AIX RS/6000, Linux, Silicon Graphics 4D, and Sun computers. The CDC 7600 and ETA 10 versions are obsolete and are no longer supported. It is written mainly in ANSI standard FORTRAN 77, but it does contain some extensions except in the ANSI version. The code is maintained with a combination of RCS, the Revision Control System, and the Patchy code management system, which is part of the CERN Library. The original sources are kept on physgi01.phy.bnl.gov in `~isajet/isalibrary/RCS`; decks revised in release `n.nn` are kept in `~isajet/isalibrary/nnn`. ISAJET is supplied to BNL, CERN, Fermilab, and SLAC; it is also available by anonymous ftp from

`ftp://penguin.phy.bnl.gov/pub/isajet`

or by request from the authors.

Patch ISAPLT contains the skeleton of an HBOOK histogramming job, a trivial calorimeter simulation, and a jet-finding algorithm. (The default is HBOOK4; HBOOK3 can be selected with a Patchy switch.) These are provided for convenience only and are not supported.

2 Physics

ISAJET is a Monte Carlo program which simulates pp, $\bar{p}p$ and e^+e^- interactions at high energy. The program incorporates perturbative QCD cross sections, initial state and final state QCD radiative corrections in the leading log approximation, independent fragmentation of quarks and gluons into hadrons, and a phenomenological model tuned to minimum bias and hard scattering data for the beam jets.

2.1 Hard Scattering

The first step in simulating an event is to generate a primary hard scattering according to some QCD cross section. This has the general form

$$\sigma = \sigma_0 F(x_1, Q^2) F(x_2, Q^2)$$

where σ_0 is a cross section calculated in QCD perturbation theory, $F(x, Q^2)$ is a structure function incorporating QCD scaling violations, x_1 and x_2 are the usual parton model momentum fractions, and Q^2 is an appropriate momentum transfer scale.

For each of the processes included in ISAJET, the basic cross section σ_0 is a two-body one, and the user can set limits on the kinematic variables and type for each of the two primary jets. For DRELLYAN and WPAIR events the full matrix element for the decay of the W's into leptons or quarks is also included.

The following processes are available:

2.1.1 Minbias

No hard scattering at all, so that the event consists only of beam jets. Note that at high energy the jet cross sections become large. To represent the total cross section it is better to use a sample of TWOJET events with the lower limit on pt chosen to give a cross section equal to the inelastic cross section or to use a mixture of MINBIAS and TWOJET events.

2.1.2 Twojet

All order α_s^2 QCD processes, which give rise in lowest order to two high-p_t jets. Included are, e.g.

$$\begin{aligned} g + g &\rightarrow g + g \\ g + q &\rightarrow g + q \\ g + g &\rightarrow q + \bar{q} \end{aligned}$$

Masses are neglected for c and lighter quarks but are taken into account for b and t quarks. The Q^2 scale is taken to be

$$Q^2 = 2stu/(s^2 + t^2 + u^2)$$

The default parton distributions are those of the CTEQ Collaboration, fit CTEQ3L, using lowest order QCD evolution. Two older fits, Eichten, Hinchliffe, Lane and Quigg (EHLQ), Set 1, and Duke and Owens, Set 1, are also included. There is also an interface to the CERN PDFLIB compilation of parton distributions. Note that structure functions for heavy quarks are included, so that processes like

$$g + t \to g + t$$

can be generated. The Duke-Owens parton distributions do not contain b or t quarks.

Since the t is so heavy, it decays before it can hadronize, so instead of t hadrons a t quark appears in the particle list. It is decayed using the $V - A$ matrix element including the W propagator with a nonzero width, so the same decays should be used for $m_t < m_W$ and $m_t > m_W$; the W should *not* be listed as part of the decay mode. The partons are then evolved and fragmented as usual; see below. The real or virtual W and the final partons from the decay, including any radiated gluons, are listed in the particle table, followed by their fragmentation products. Note that for semileptonic decays the leptons appear twice: the lepton parton decays into a single particle of the same type but in general somewhat different momentum. In all cases only particles with `IDCAY` = 0 should be included in the final state.

A fourth generation x, y is also allowed. Fourth generation quarks are produced only by gluon fusion. Decay modes are not included in the decay table; for a sequential fourth generation they would be very similar to the t decays. In decays involving quarks, it is essential that the quarks appear last.

2.1.3 Drellyan

Production of a W in the standard model, including a virtual γ, a W^+, a W^-, or a Z^0, and its decay into quarks or leptons. If the transverse momentum QTW of the W is fixed equal to zero then the process simulated is

$$\begin{aligned} q + \bar{q} \to W &\to q + \bar{q} \\ &\to \ell + \bar{\ell} \end{aligned}$$

Thus the W has zero transverse momentum until initial state QCD corrections are taken into account. If non-zero limits on the transverse momentum q_t for the W are set, then instead the processes

$$\begin{aligned} q + \bar{q} &\to W + g \\ g + q &\to W + q \end{aligned}$$

are simulated, including the full matrix element for the W decay. These are the dominant processes at high q_t, but they are of course singular at $q_t = 0$. A cutoff of the $1/q_t^2$ singularity is made by the replacement

$$1/q_t^2 \to 1/\sqrt{q_t^4 + q_{t0}^4} \quad q_{t0}^2 = (.2\,\mathrm{GeV})M$$

This cutoff is chosen to reproduce approximately the q_t dependence calculated by the summation of soft gluons and to give about the right integrated cross section. Thus this option can be used for low as well as high transverse momenta.

The scale for QCD evolution is taken to be proportional to the mass for lowest order Drell-Yan and to the transverse momentum for high-p_t Drell-Yan. The constant is adjusted to get reasonable agreement with the $W + n$ jet cross sections calculated from the full QCD matrix elements by F.A. Berends, et al., Phys. Lett. B224, 237 (1989).

For the processes $g + b \to W + t$ and $g + t \to Z + t$, cross sections with a non-zero top mass are used for the production and the W/Z decay. These were calculated using FORM 1.1 by J. Vermaseren. The process $g + t \to W + b$ is *not* included. Both $g + b \to W^- + t$ and $g + \bar{t} \to W^- + \bar{b}$ of course give the same $W^- + t + \bar{b}$ final state after QCD evolution. While the latter process is needed to describe the $m_t = 0(!)$ mass singularity for $q_t \gg m_t$, it has a pole in the physical region at low q_t from on-shell $t \to W + b$ decays. There is no obvious way to avoid this without introducing an arbitrary cutoff. Hence, selecting only $W + b$ will produce a zero cross section. The Q^2 scale for the parton distributions in these processes is replaced by $Q^2 + m_t^2$; this seems physically sensible and prevents the cross sections from vanishing at small q_t.

2.1.4 Photon

Single and double photon production through the lowest order QCD processes

$$\begin{aligned} g + q &\to \gamma + q \\ q + \bar{q} &\to \gamma + g \\ q + \bar{q} &\to \gamma + \gamma \end{aligned}$$

Higher order corrections are not included. But γ's, W's, and Z's are radiated from final state quarks in all processes, allowing study of the bremsstrahlung contributions.

2.1.5 Wpair

Production of pairs of W bosons in the standard model through quark-antiquark annihilation,

$$\begin{aligned} q + \bar{q} &\to W^+ + W^- \\ &\to Z^0 + Z^0 \\ &\to W^+ + Z^0, W^- + Z^0 \\ &\to W^+ + \gamma, W^- + \gamma \\ &\to Z^0 + \gamma \end{aligned}$$

The full matrix element for the W decays, calculated in the narrow resonance approximation, is included. However, the higher order processes, e.g.

$$q + q \to q + q + W^+ + W^-$$

are ignored, although they in fact dominate at high enough mass. Specific decay modes can be selected using the WMODEi keywords.

2.1.6 Higgs

Production and decay of the standard model Higgs boson. The production processes are

$$
\begin{aligned}
g+g &\rightarrow H \quad \text{(through a quark loop)} \\
q+\bar{q} &\rightarrow H \quad \text{(with } t+\bar{t} \text{ dominant)} \\
W^{+}+W^{-} &\rightarrow H \quad \text{(with longitudinally polarized } W\text{)} \\
Z^{0}+Z^{0} &\rightarrow H \quad \text{(with longitudinally polarized } Z\text{)}
\end{aligned}
$$

If the (Standard Model) Higgs is lighter than $2M_W$, then it will decay into pairs of fermions with branching ratios proportional to m_f^2. If it is heavier than $2M_W$, then it will decay primarily into W^+W^- and Z^0Z^0 pairs with widths given approximately by

$$
\begin{aligned}
\Gamma(H \rightarrow W^{+}W^{-}) &= \frac{G_F M_H^3}{8\pi\sqrt{2}} \\
\Gamma(H \rightarrow Z^{0}Z^{0}) &= \frac{G_F M_H^3}{16\pi\sqrt{2}}
\end{aligned}
$$

Numerically these give approximately

$$
\Gamma_H = 0.5\,\mathrm{TeV}\left(\frac{M_H}{1\,\mathrm{TeV}}\right)^3
$$

The width proportional to M_H^3 arises from decays into longitudinal gauge bosons, which like Higgs bosons have couplings proportional to mass.

Since a heavy Higgs is wide, the narrow resonance approximation is not valid. To obtain a cross section with good high energy behavior, it is necessary to include a complete gauge-invariant set of graphs for the processes

$$
\begin{aligned}
W^{+}W^{-} &\rightarrow W^{+}W^{-} \\
W^{+}W^{-} &\rightarrow Z^{0}Z^{0} \\
Z^{0}Z^{0} &\rightarrow W^{+}W^{-} \\
Z^{0}Z^{0} &\rightarrow Z^{0}Z^{0}
\end{aligned}
$$

with longitudinally polarized W^+, W^-, and Z^0 bosons in the initial state. This set of graphs and the corresponding angular distributions for the W^+, W^-, and Z^0 decays have been calculated in the effective W approximation and included in HIGGS. The W structure functions are obtained by integrating the EHLQ parameterization of the quark ones term by term. The Cabibbo-allowed branchings

$$
\begin{aligned}
q &\rightarrow W^{+}+q' \\
q &\rightarrow W^{-}+q' \\
q &\rightarrow Z^{0}+q
\end{aligned}
$$

are generated by backwards evolution, and the standard QCD evolution is performed. This correctly describes the W collinear singularity and so contains the same physics as the effective W approximation.

If the Higgs is lighter than $2M_W$, then its decay to $\gamma\gamma$ through W and t loops may be important. This is also included in the HIGGS process and may be selected by choosing `GM` as the jet type for the decay.

If the Higgs has $M_Z < M_H < 2M_Z$, then decays into one real and one virtual Z^0 are generated if the `Z0 Z0` decay mode is selected, using the calculation of Keung and Marciano, Phys. Rev. D30, 248 (1984). Since the calculation assumes that one Z^0 is exactly on shell, it is not reliable within of order the Z^0 width of $M_H = 2M_Z$; Higgs and and $Z^0 Z^0$ masses in this region should be avoided. The analogous Higgs decays into one real and one virtual charged W are not included.

Note that while HIGGS contains the dominant graphs for Higgs production and graphs for W pair production related by gauge invariance, it does not contain the processes

$$\begin{aligned} q + \bar{q} &\to W^+W^- \\ q + \bar{q} &\to Z^0 Z^0 \end{aligned}$$

which give primarily transverse gauge bosons. These must be generated with WPAIR.

If the `MSSMi` or `SUGRA` keywords are used with HIGGS, then one of the three MSSM neutral Higgs is generated instead using gluon-gluon and quark-antiquark fusion with the appropriate SUSY couplings. Since heavy CP even SUSY Higgs are weakly coupled to W pairs and CP odd ones are completely decoupled, WW fusion and $WW \to WW$ scattering are not included in the SUSY case. ($WW \to WW$ can be generated using the Standard Model process with a light Higgs mass, say 100 GeV.) The MSSM Higgs decays into both Standard Model and SUSY modes as calculated by ISASUSY are included. For more discussion see the SUSY subsection below and the writeup for ISASUSY. The user must select which Higgs to generate using HTYPE; see Section 6 below. If a mass range is not specified, then the range mass $M_H \pm 5\Gamma_H$ is used by default. (This cannot be done for the Standard Model Higgs because it is so wide for large masses.) Decay modes may be selected in the usual way.

2.1.7 WHiggs

Generates associated production of gauge and Higgs bosons, i.e.,

$$q + \bar{q} \to H + W, H + Z\,,$$

in the narrow resonance approximation. The desired subprocesses can be selected with JETTYPEi, and specific decay modes of the W and/or Z can be selected using the WMODEi keywords. Standard Model couplings are assumed unless SUSY parameters are specified, in which case the SUSY couplings are used.

2.1.8 SUSY

Generates pairs of supersymmetric particles from gluon-quark or quark-antiquark fusion. If the MSSMi or SUGRA parameters defined in Section 6 below are not specified, then only gluinos and squarks are generated:

$$g + g \to \tilde{g} + \tilde{g}$$

$$
\begin{aligned}
q + \bar{q} &\to \tilde{g} + \tilde{g} \\
g + q &\to \tilde{g} + \tilde{q} \\
g + g &\to \tilde{q} + \bar{\tilde{q}} \\
q + \bar{q} &\to \tilde{q} + \bar{\tilde{q}} \\
q + q &\to \tilde{q} + \tilde{q}
\end{aligned}
$$

Left and right squarks are distinguished but assumed to be degenerate. Masses can be specified using the `GAUGINO`, `SQUARK`, and `SLEPTON` parameters described in Section 6. No decay modes are specified, since these depend strongly on the masses. The user can either add new modes to the decay table (see Section 9) or use the `FORCE` or `FORCE1` commands (see Section 6).

If `MSSMA`, `MSSMB`, and `MSSMC` are specified, then the ISASUSY package is used to calculate the masses and decay modes in the minimal supersymmetric extension of the standard model (MSSM), assuming SUSY grand unification constraints in the neutralino and chargino mass matrix but allowing some additional flexibility in the masses. The scalar particle soft masses are input via `MSSMi`, so that the physical masses will be somewhat different due to D-term contributions and mixings for 3rd generation sparticles. $\tilde{t}_1$ and $\tilde{t}_2$ production and decays are now included. The lightest SUSY particle is assumed to be the lightest neutralino $\tilde{Z}_1$. If the `MSSMi` parameters are specified, then the following additional processes are included using the MSSM couplings for the production cross sections:

$$
\begin{aligned}
g + q &\to \tilde{Z}_i + \tilde{q}, \quad \tilde{W}_i + \tilde{q} \\
q + \bar{q} &\to \tilde{Z}_i + \tilde{g}, \quad \tilde{W}_i + \tilde{g} \\
q + \bar{q} &\to \tilde{W}_i + \tilde{Z}_j \\
q + \bar{q} &\to \tilde{W}_i^+ + \tilde{W}_j^- \\
q + \bar{q} &\to \tilde{Z}_i + \tilde{Z}_j \\
q + \bar{q} &\to \tilde{\ell}^+ + \tilde{\ell}^-, \quad \tilde{\nu} + \tilde{\nu}
\end{aligned}
$$

Processes can be selected using the optional parameters described in Section 6 below.

Beginning with Version 7.42, matrix elements are taken into account in the event generator as well as in the calculation of decay widths for MSSM three-body decays of the form $\tilde{A} \to \tilde{B} f \bar{f}$, where $\tilde{A}$ and $\tilde{B}$ are gluinos, charginos, or neutralinos. This is implemented by having ISASUSY save the poles and their couplings when calculating the decay width and then using these to reconstruct the matrix element. Other three-body decays may be included in the future. Decays selected with `FORCE` use the appropriate matrix elements.

An optional keyword `MSSMD` can be used to specify the second generation masses, which otherwise are assumed degenerate with the first generation. An optional keyword `MSSME` can be used to specify values of the $U(1)$ and $SU(2)$ gaugino masses at the weak scale rather than using the default grand unification values. The chargino and neutralino masses and mixings are then computed using these values.

Instead of using the `MSSMi` parameters, one can use the `SUGRA` parameter to specify in the minimal supergravity framework. This assumes that the gauge couplings unify at a GUT scale and that SUSY breaking occurs at that scale with universal soft breaking terms, which are related to the weak scale using the renormalization group. The renormalization group equations now include all the two-loop terms for both gauge and Yukawa couplings and the possible contributions from right-handed neutrinos. The parameters of the model are

- m_0: the common scalar mass at the GUT scale;
- $m_{1/2}$: the common gaugino mass at the GUT scale;
- A_0: the common soft trilinear SUSY breaking parameter at the GUT scale;
- $\tan\beta$: the ratio of Higgs vacuum expectation values at the electroweak scale;
- $\operatorname{sgn}\mu = \pm 1$: the sign of the Higgsino mass term.

The renormalization group equations are solved iteratively to determine all the electroweak SUSY parameters from these data assuming radiative electroweak symmetry breaking but not other possible constraints such as b-tau unification or limits on proton decay.

The assumption of universality at the GUT scale is rather restrictive and may not be valid. A variety of non-universal SUGRA (NUSUGRA) models can be generated using the `NUSUG1`, ..., `NUSUG5` keywords. These might be used to study how well one could test the minimal SUGRA model. The keyword `SSBCSC` can be used to specify an alternative scale (i.e., not the coupling constant unification scale) for the RGE boundary conditions.

An alternative to the SUGRA model is the Gauge Mediated SUSY Breaking (GMSB) model of Dine, Nelson, and collaborators. In this model SUSY breaking is communicated through gauge interactions with messenger fields at a scale M_m small compared to the Planck scale and are proportional to gauge couplings times Λ_m. The messenger fields should form complete $SU(5)$ representations to preserve the unification of the coupling constants. The parameters of the GMSB model, which are specified by the `GMSB` keyword, are

- $\Lambda_m = F_m/M_m$: the scale of SUSY breaking, typically 10–100 TeV;
- $M_m > \Lambda_m$: the messenger mass scale;
- N_5: the equivalent number of $5 + \bar{5}$ messenger fields.
- $\tan\beta$: the ratio of Higgs vacuum expectation values at the electroweak scale;
- $\operatorname{sgn}\mu = \pm 1$: the sign of the Higgsino mass term;
- $C_{\text{grav}} \geq 1$: the ratio of the gravitino mass to the value it would have had if the only SUSY breaking scale were F_m.

In GMSB models the lightest SUSY particle is always the nearly massless gravitino $\tilde{G}$. The parameter C_{grav} scales the gravitino mass and hence the lifetime of the next lightest SUSY particle to decay into it. The `NOGRAV` keyword can be used to turn off gravitino decays.

A variety of non-minimal GMSB models can be generated using additional parameters set with the GMSB2 keyword. These additional parameters are

- $\not{R}$, an extra factor multiplying the gaugino masses at the messenger scale. (Models with multiple spurions generally have $\not{R} < 1$.)

- $\delta M^2_{H_d}$, $\delta M^2_{H_u}$, Higgs mass-squared shifts relative to the minimal model at the messenger scale. (These might be expected in models which generate μ realistically.)

- $D_Y(M)$, a $U(1)_Y$ messenger scale mass-squared term (D-term) proportional to the hypercharge Y.

- N_{5_1}, N_{5_2}, and N_{5_3}, independent numbers of gauge group messengers. They can be non-integer in general.

For discussions of these additional parameters, see S. Dimopoulos, S. Thomas, and J.D. Wells, hep-ph/9609434, Nucl. Phys. **B488**, 39 (1997), and S.P. Martin, hep-ph/9608224, Phys. Rev. **D55**, 3177 (1997).

Gravitino decays can be included in the general MSSM framework by specifying a gravitino mass with `MGVTNO`. The default is that such decays do not occur.

Another alternative SUSY model choice allowed is anomaly-mediated SUSY breaking, developed by Randall and Sundrum. In this model, it is assumed that SUSY breaking takes place in other dimensions, and SUSY breaking is communicated to the visible sector via the superconformal anomaly. In this model, the lightest SUSY particle is usually the neutralino which is nearly pure wino-like. The chargino is nearly mass degenerate with the lightest neutralino. It can be very long lived, or decay into a very soft pion plus missing energy. The model incorporated in ISAJET, based on work by Ghergetta, Giudice and Wells (hep-ph/9904378), and by Feng and Moroi (hep-ph/9907319) adds a universal contribution m_0^2 to all scalar masses to avoid problems with tachyonic scalars. The parameter set is m_0, $m_{3/2}$, $\tan\beta$, $sign(\mu)$, and can be input via the $AMSB$ keyword. Care should be taken with the chargino decay, since it may have macroscopic decay lengths, or even decay outside the detector.

Since neutrinos seem to have mass, the effect of a massive right-handed neutrino has been included in ISAJET, when calculating the sparticle mass spectrum. If the keyword $SUGRHN$ is used, then the user must input the 3rd generation neutrino mass (at scale M_Z) in units of GeV, and the intermediate scale right handed neutrino Majorana mass M_N, also in GeV. In addition, one must specify the soft SUSY-breaking masses A_n and $m_{\tilde{\nu}_R}$ valid at the GUT scale. Then the neutrino Yukawa coupling is computed in the simple see-saw model, and renormalization group evolution includes these effects between M_{GUT} and M_N. Finally, to facilitate modeling of $SO(10)$ SUSY-GUT models, loop corrections to 3rd generation fermion masses have been included in the ISAJET SUSY models.

The ISASUSY program can also be used independently of the rest of ISAJET, either to produce a listing of decays or in conjunction with another event generator. Its physics assumptions are described in more detail in Section 12. The ISASUGRA program can also be used independently to solve the renormalization group equations with SUGRA, GMSB, or NUSUGRA boundary conditions and then to call ISASUSY to calculate the decay modes.

Generally the MSSM, SUGRA, or GMSB option should be used to study supersymmetry signatures; the SUGRA or GMSB parameter space is clearly more manageable. The more general option may be useful to study alternative SUSY models. It can also be used, e.g., to generate pointlike color-3 leptoquarks in technicolor models by selecting squark production and setting the gluino mass to be very large. The MSSM or SUGRA option may also be used with top pair production to simulate top decays to SUSY particles.

2.1.9 e^+e^-

An e^+e^- event generator is also included in ISAJET. The Standard Model processes included are e^+e^- annihilation through γ and Z to quarks and leptons, and production of W^+W^- and Z^0Z^0 pairs. In contrast to WPAIR and HIGGS for the hadronic processes, the produced W's and Z's are treated as particles, so their spins are not properly taken into account in their decays. (Because the W's and Z's are treated as particles, their decay modes can be selected using `FORCE` or `FORCE1`, not `WMODEi`. See Section [6] below.) Other Standard Model processes, including $e^+e^- \to e^+e^-$ (t-channel graph) and $e^+e^- \to \gamma\gamma$, are not included. Once the primary reaction has been generated, QCD radiation and hadronization are done as for hadronic processes.

The e^+e^- generator can be run assuming no initial state radiation (the default), or an initial state electron structure function can be used for bremsstrahlung or the combination bremsstrahlung/beamstrahlung effect. Bremsstrahlung is implemented using the Fadin-Kuraev e^- distribution function, and can be turned on using the `EEBREM` command while stipulating the minimal and maximal subprocess energy. Beamstrahlung is implemented by invoking the `EEBEAM` keyword. In this case, in addition the beamstrahlung parameter Υ and longitudinal beam size σ_z (in mm) must be given. The definition for Υ in terms of other beam parameters can be found in the article Phys. Rev. D49, 3209 (1994) by Chen, Barklow and Peskin. The bremsstrahlung structure function is then convoluted with the beamstrahlung distribution (as calculated by P. Chen) and a spline fit is created. Since the cross section can contain large spikes, event generation can be slow if a huge range of subprocess energy is selected for light particles; in these scenarios, `NTRIES` must be increased well beyond the default value.

e^+e^- annihilation to SUSY particles is included as well with complete lowest order diagrams, and cascade decays. The processes include

$$\begin{aligned} e^+e^- &\to \tilde{q}\tilde{q} \\ e^+e^- &\to \tilde{\ell}\tilde{\ell} \\ e^+e^- &\to \tilde{W}_i\tilde{W}_j \\ e^+e^- &\to \tilde{Z}_i\tilde{Z}_j \\ e^+e^- &\to H_L^0 + Z^0, H_H^0 + Z^0, H_A^0 + H_L^0, H_A^0 + H_H^0, H^+ + H^- \end{aligned}$$

Note that SUSY Higgs production via WW and ZZ fusion, which can dominate Higgs production processes at $\sqrt{s} > 500\,\mathrm{GeV}$, is not included. Spin correlations are neglected, although 3-body sparticle decay matrix elements are included.

e^+e^- cross sections with polarized beams are included for both Standard Model and SUSY processes. The keyword `EPOL` is used to set $P_L(e^-)$ and $P_L(e^+)$, where

$$P_L(e) = (n_L - n_R)/(n_L + n_R)$$

so that $-1 \le P_L \le +1$. Thus, setting `EPOL` to $-.9, 0$ will yield a 95% right polarized electron beam scattering on an unpolarized positron beam.

2.1.10 Technicolor

Production of a technirho of arbitrary mass and width decaying into $W^\pm Z^0$ or W^+W^- pairs. The cross section is based on an elastic resonance in the WW cross section with the effective W approximation plus a W mixing term taken from EHLQ. Additional technicolor processes may be added in the future.

2.1.11 Extra Dimensions

The possibility that there might be more than four space-time dimensions at a distance scale R much larger than $G_N^{1/2}$ has recently attracted interest. In these theories,

$$G_N = \frac{1}{8\pi R^\delta M_D^{2+\delta}} \,,$$

where δ is the number of extra dimensions and M_D is the $4+\delta$ Planck scale. Gravity deviates from the standard theory at a distance $R \sim 10^{22/\delta-19}\,\mathrm{m}$, so $\delta \ge 2$ is required. If M_D is of order 1 TeV, then the usual heirarchy problem is solved, although there is then a new heirarchy problem of why R is so large.

In such models the graviton will have many Kaluza-Klein excitations with a mass splitting of order $1/R$. While any individual mode is suppressed by the four-dimensional Planck mass, the large number of modes produces a cross section suppressed only by $1/M_D^2$. The signature is an invisible massive graviton plus a jet, photon, or other Standard Model particle. The `EXTRADIM` process implements this reaction using the cross sections of Giudice, Rattazzi, and Wells, hep-ph/9811291. The number δ of extra dimensions, the mass scale M_D, and the logical flag `UVCUT` are specified using the keyword `EXTRAD`. If `UVCUT` is `TRUE`, the cross section is cut off above the scale M_D; the model is not valid if the results depend on this flag.

2.2 Multiparton Hard Scattering

All the processes listed in Section 2.1 are either $2 \to 2$ processes like `TWOJET` or $2 \to 1$ s-channel resonance processes followed by a 2-body decay like `DRELLYAN`. The QCD parton shower described in Section 2.3 below generates multi-parton final states starting from these, but it relies on an approximation which is valid only if the additional partons are collinear either with the initial or with the final primary ones. Since the QCD shower uses exact non-colliear kinematics, it in fact works pretty well in a larger region of phase space, but it is not exact.

Non-collinear multiparton final states are interesting both in their own right and as backgrounds for other signatures. Both the matrix elements and the phase space for multiparton processes are complicated; they have been incorporated into ISAJET for the first time in Version 7.45. To calculate the matrix elements we have used the MadGraph package by Stelzer and Long, Comput. Phys. Commun. **81**, 357 (1994), hep-ph/9401258. This automatically generates the amplitude using `HELAS`, a formalism by Murayama, Watanabe, and Hagiwarak KEK-91-11, that calculates the amplitude for any Feynman diagram in terms of spinors, vertices, and propagators. The MadGraph code has been edited to incorporate summations over quark flavors. To do the phase space integration, we have used a simple recursive algorithm to generate n-body phase space. We have included limits on the total mass of the final state using the `MTOT` keyword. Limits on the p_T and rapidity of each final parton can be set via the `PT` and `Y` keyworks, while limits on the mass of any pair of final partons can be set via the `MIJTOT` keyword. These limits are sufficient to shield the infrared and collinear singularities and to render the result finite. However, the parton shower populates all regions of phase space, so careful thought is needed to combine the parton-shower based and multiparton based results.

While the multiparton formalism is rather general, it still takes a substantial amount of effort to implement any particular process. So far only one process has been implemented.

2.2.1 $Z + 2$ jets

The `ZJJ` process generates a Z boson plus two jets, including the $q\bar{q} \to Zq\bar{q}$, $gg \to Zq\bar{q}$, $q\bar{q} \to Zgg$, $qq \to Zqq$, and $gq \to Zgq$ processes. The Z is defined to be jet 1; it is treated in the narrow resonance approximation and is decayed isotropically. The quarks, antiquarks, and gluons are defined to be jets 2 and 3 and are symmetrized in the usual way.

2.3 QCD Radiative Corrections

After the primary hard scattering is generated, QCD radiative corrections are added to allow the possibility of many jets. This is essential to get the correct event structure, especially at high energy.

Consider the emission of one extra gluon from an initial or a final quark line,

$$q(p) \to q(p_1) + g(p_2)$$

From QCD perturbation theory, for small p^2 the cross section is given by the lowest order cross section multiplied by a factor

$$\sigma = \sigma_0 \alpha_s(p^2)/(2\pi p^2)P(z)$$

where $z = p_1/p$ and $P(z)$ is an Altarelli-Parisi function. The same form holds for the other allowed branchings,

$$\begin{aligned} g(p) &\to g(p_1) + g(p_2) \\ g(p) &\to q(p_1) + \bar{q}(p_2) \end{aligned}$$

These factors represent the collinear singularities of perturbation theory, and they produce the leading log QCD scaling violations for the structure functions and the jet fragmentation functions. They also determine the shape of a QCD jet, since the jet M^2 is of order $\alpha_s p_t^2$ and hence small.

The branching approximation consists of keeping just these factors which dominate in the collinear limit but using exact, non-collinear kinematics. Thus higher order QCD is reduced to a classical cascade process, which is easy to implement in a Monte Carlo program. To avoid infrared and collinear singularities, each parton in the cascade is required to have a mass (spacelike or timelike) greater than some cutoff t_c. The assumption is that all physics at lower scales is incorporated in the nonperturbative model for hadronization. In ISAJET the cutoff is taken to be a rather large value, $(6\,\mathrm{GeV})^2$, because independent fragmentation is used for the jet fragmentation; a low cutoff would give too many hadrons from overlapping partons. It turns out that the branching approximation not only incorporates the correct scaling violations and jet structure but also reproduces the exact three-jet cross section within factors of order 2 over all of phase space.

This approximation was introduced for final state radiation by Fox and Wolfram. The QCD cascade is determined by the probability for going from mass t_0 to mass t_1 emitting no resolvable radiation. For a resolution cutoff $z_c < z < 1 - z_c$, this is given by a simple expression,

$$P(t_0, t_1) = (\alpha_s(t_0)/\alpha_s(t_1))^{2\gamma(z_c)/b_0}$$

where

$$\gamma(z_c) = \int_{z_c}^{1-z_c} dz\, P(z), \qquad b_0 = (33 - 2n_f)/(12\pi)$$

Clearly if $P(t_0, t_1)$ is the integral probability, then dP/dt_1 is the probability for the first radiation to occur at t_1. It is straightforward to generate this distribution and then iteratively to correct it to get a cutoff at fixed t_c rather than at fixed z_c.

For the initial state it is necessary to take account of the spacelike kinematics and of the structure functions. Sjostrand has shown how to do this by starting at the hard scattering and evolving backwards, forcing the ordering of the spacelike masses t. The probability that a given step does not radiate can be derived from the Altarelli-Parisi equations for the structure functions. It has a form somewhat similar to $P(t_0, t_1)$ but involving a ratio of the structure functions for the new and old partons. It is possible to find a bound for this ratio in each case and so to generate a new t and z as for the final state. Then branchings for which the ratio is small are rejected in the usual Monte Carlo fashion. This ratio suppresses the radiation of very energetic partons. It also forces the branching $g \to t + \bar{t}$ for a t quark if the t structure function vanishes at small momentum transfer.

At low energies, the branching of an initial heavy quark into a gluon sometimes fails; these events are discarded and a warning is printed.

Since t_c is quite large, the radiation of soft gluons is cut off. To compensate for this, equal and opposite transverse boosts are made to the jet system and to the beam jets after fragmentation with a mean value

$$\langle p_t^2 \rangle = (.1\,\mathrm{GeV})\sqrt{Q^2}$$

The dependence on Q^2 is the same as the cutoff used for DRELLYAN and the coefficient is adjusted to fit the p_t distribution for the W.

Radiation of gluons from gluinos and scalar quarks is also included in the same approximation, but the production of gluino or scalar quark pairs from gluons is ignored. Very little radiation is expected for heavy particles produced near threshold.

Radiation of photons, W's, and Z's from final state quarks is treated in the same approximation as QCD radiation except that the coupling constant is fixed. Initial state electroweak radiation is not included; it seems rather unimportant. The W^+'s, W^-'s and Z's are decayed into the modes allowed by the `WPMODE`, `WMMODE`, and `Z0MODE` commands respectively.

Warning: The branching ratios implied by these commands are not included in the cross section because an arbitrary number of W's and Z's can in principle be radiated.

2.4 Jet Fragmentation:

Quarks and gluons are fragmented into hadrons using the independent fragmentation ansatz of Field and Feynman. For a quark q, a new quark-antiquark pair $q_1\bar{q}_1$ is generated with

$$u : d : s = .43 : .43 : .14$$

A meson $q\bar{q}_1$ is formed carrying a fraction z of the momentum,

$$E' + p'_z = z(E + p_z)$$

and having a transverse momentum p_t with $\langle p_t \rangle = 0.35\,\mathrm{GeV}$. Baryons are included by generating a diquark with probability 0.10 instead of a quark; adjacent diquarks are not allowed, so no exotic mesons are formed. For light quarks z is generated with the splitting function

$$f(z) = 1 - a + a(b+1)(1-z)^b, \qquad a = 0.96, b = 3$$

while for heavy quarks the Peterson form

$$f(z) = x(1-x)^2/((1-x)^2 + \epsilon x)^2$$

is used with $\epsilon = .80/m_c^2$ for c and $\epsilon = .50/m_q^2$ for $q = b, t, y, x$. These values of ϵ have been determined by fitting PEP, PETRA, and LEP data with ISAJET and should not be compared with values from other fits. Hadrons with longitudinal momentum less than zero are discarded. The procedure is then iterated for the new quark q_1 until all the momentum is used. A gluon is fragmented like a randomly selected u, d, or s quark or antiquark.

In the fragmentation of gluinos and scalar quarks, supersymmetric hadrons are not distinguished from partons. This should not matter except possibly for very light masses. The Peterson form for $f(x)$ is used with the same value of epsilon as for heavy quarks, $\epsilon = 0.5/m^2$.

Independent fragmentation correctly describes the fast hadrons in a jet, but it fails to conserve energy or flavor exactly. Energy conservation is imposed after the event is generated by boosting the hadrons to the appropriate rest frame, rescaling all of the three-momenta, and recalculating the energies.

2.5 Beam Jets

There is now experimental evidence that beam jets are different in minimum bias events and in hard scattering events. ISAJET therefore uses similar a algorithm but different parameters in the two cases.

The standard models of particle production are based on pulling pairs of particles out of the vacuum by the QCD confining field, leading naturally to only short-range rapidity correlations and to essentially Poisson multiplicity fluctuations. The minimum bias data exhibit KNO scaling and long-range correlations. A natural explanation of this was given by the model of Abramovskii, Kanchelli and Gribov. In their model the basic amplitude is a single cut Pomeron with Poisson fluctuations around an average multiplicity $\langle n\rangle$, but unitarity then produces graphs giving K cut Pomerons with multiplicity $K\langle n\rangle$.

A simplified version of the AKG model is used in ISAJET. The number of cut Pomerons is chosen with a distribution adjusted to fit the data. For a minimum bias event this distribution is

$$P(K) = (1 + 4K^2)\exp -1.8K$$

while for hard scattering

$$P(1) \to 0.1P(1), \quad P(2) \to 0.2P(2), \quad P(3) \to 0.5P(3)$$

For each side of each event an x_0 for the leading baryon is selected with a distribution varying from flat for $K = 1$ to like that for mesons for large K:

$$f(x) = N(K)(1 - x_0)^c(K), \qquad c(K) = 1/K + (1 - 1/K)b(s)$$

The x_i for the cut Pomerons are generated uniformly and then rescaled to $1 - x_0$. Each cut Pomeron is then hadronized in its own center of mass using a modified independent fragmentation model with an energy dependent splitting function to reproduce the rise in dN/dy:

$$f(x) = 1 - a + a(b(s) + 1)^b(s), \qquad b(s) = b_0 + b_1\log(s)$$

The energy dependence is put into $f(x)$ rather than $P(K)$ because in the AKG scheme the single particle distribution comes only from the single chain. The probabilities for different flavors are taken to be

$$u : d : s = .46 : .46 : .08$$

to reproduce the experimental K/π ratio.

3 Sample Jobs

The simplest ISAJET job reads a user-supplied parameter file and writes a data file and a listing file. The following is an example of a parameter file which generates each type of event:

```
SAMPLE TWOJET JOB
800.,100,2,50/
TWOJET
PT
50,100,50,100/
JETTYPE1
'GL'/
JETTYPE2
'UP','UB','DN','DB','ST','SB'/
END
SAMPLE DRELLYAN JOB
800.,100,2,50/
DRELLYAN
QMW
80,100/
WTYPE
'W+','W-'/
END
SAMPLE MINBIAS JOB
800.,100,2,50/
MINBIAS
END
SAMPLE WPAIR JOB
800.,100,2,50/
WPAIR
PT
50,100,50,100/
JETTYPE1
'W+','W-','Z0'/
JETTYPE2
'W+','W-','Z0'/
WMODE1
'E+','E-','NUS'/
WMODE2
'QUARKS'/
END
SAMPLE HIGGS JOB FOR SSC
40000,100,1,1/
HIGGS
```

```
QMH
400,1600/
HMASS
800/
JETTYPE1
'Z0'/
JETTYPE2
'Z0'/
WMODE1
'MU+','MU-'/
WMODE2
'E+','E-'/
PT
50,20000,50,20000/
END
SAMPLE SUSY JOB
1800,100,1,10/
SUPERSYM
PT
50,100,50,100/
JETTYPE1
'GLSS','SQUARKS'/
JETTYPE2
'GLSS','SQUARKS'/
GAUGINO
60,1,40,40/
SQUARK
80.3,80.3,80.5,81.6,85,110/
FORCE
29,30,1,-1/
FORCE
21,29,1/
FORCE
22,29,2/
FORCE
23,29,3/
FORCE
24,29,4/
FORCE
25,29,5/
FORCE
26,29,6/
END
SAMPLE MSSM JOB FOR TEVATRON
```

```
1800.,100,1,1/
SUPERSYM
BEAMS
'P','AP'/
MSSMA
200,-200,500,2/
MSSMB
200,200,200,200,200/
MSSMC
200,200,200,200,200,0,0,0/
JETTYPE1
'GLSS'/
JETTYPE2
'SQUARKS'/
PT
100,300,100,300/
END
SAMPLE MSSM SUGRA JOB FOR LHC
14000,100,1,10/
SUPERSYM
PT
50,500,50,500/
SUGRA
247,302,-617.5,10,-1/
TMASS
175/
END
SAMPLE SUGRA HIGGS JOB USING DEFAULT QMH RANGE
14000,100,20,50/
HIGGS
SUGRA
200,200,0,2,+1/
HTYPE
'HA0'/
JETTYPE1
'GAUGINOS','SLEPTONS'/
JETTYPE2
'GAUGINOS','SLEPTONS'/
END
SAMPLE E+E- TO SUGRA JOB WITH POLARIZED BEAMS AND BREM/BEAMSTRAHLUNG
500.,100,1,1/
E+E-
SUGRA
125,125,0,3,1/
```

```
TMASS
175,-1,1/
EPOL
-.9,0./
EEBEAM
200.,500.,.1072,.12/
JETTYPE1
'ALL'/
JETTYPE2
'ALL'/
NTRIES
10000/
END
SAMPLE WH JOB
2000,100,0,0/
WHIGGS
BEAMS
'P','AP'/
HMASS
100./
JETTYPE1
'W+','W-','HIGGS'/
JETTYPE2
'W+','W-','HIGGS'/
WMODE1
'ALL'/
WMODE2
'ALL'/
PT
10,300,10,300/
END
SAMPLE EXTRA DIMENSIONS JOB
14000,100,1,100/
EXTRADIM
QMW
5,1000/
QTW
500,1000/
EXTRAD
2,1000,.FALSE./
END
SAMPLE ZJJ JOB AT LHC
14000,100,1,100/
ZJJ
```

```
PT
20,7000,20,7000,20,7000/
MIJLIM
0,0,20,7000/
MTOT
100,500/
NSIGMA
200/
NTRIES
10000/
END
STOP
```

See Section 6 of this manual for a complete list of the possible commands in a parameter file. Note that all input to ISAJET must be in *UPPER* case only.

Subroutine RDTAPE is supplied to read events from an ISAJET data file, which is a machine-dependent binary file. It restores the event data to the FORTRAN common blocks described in Section 7. The skeleton of an analysis job using HBOOK and PAW from the CERN Program Library is provided in patch ISAPLT but is not otherwise supported. A Zebra output format based on code from the D0 Collaboration is also provided in patch ISAZEB; see the separate documentation in patch ISZTEXT.

3.1 DEC VMS

On a VAX or ALPHA running VMS, ISAJET can be compiled by executing the .COM file contained in P=ISAUTIL,D=MAKEVAX. Extract this deck as ISAMAKE.COM and type

```
@ISAMAKE
```

This will run YPATCHY with the pilot patches described in Section 4 and the VAX flag to extract the source code, decay table, and documentation. The source code is compiled and made into a library, which is linked with the following main program,

```
      PROGRAM ISARUN
C            MAIN PROGRAM FOR ISAJET
      OPEN(UNIT=1,STATUS='OLD',FORM='FORMATTED',READONLY)
      OPEN(UNIT=2,STATUS='NEW',FORM='UNFORMATTED')
      OPEN(UNIT=3,STATUS='OLD',FORM='FORMATTED')
      OPEN(UNIT=4,STATUS='NEW',FORM='FORMATTED')
      CALL ISAJET(-1,2,3,4)
      STOP
      END
```

to produce ISAJET.EXE. Two other executables, ISASUSY.EXE and ISASUGRA.EXE, will also be produced to calculate SUSY masses and decay modes without generating events. Temporary files can be removed by typing

```
@ISAMAKE CLEAN
```

Create an input file `JOBNAME.PAR` following the examples above or the instructions in Section 6 and run ISAJET with the command

```
@ISAJET JOBNAME
```

using the ISAJET.COM file contained P=ISAUTIL,D=RUNVAX. This will create a binary output file `JOBNAME.DAT` and a listing file `JOBNAME.LIS`. Analyze the output data using the commands described in Section 8.

There is also an simple interactive interface to ISAJET which will prompt the user for commands, write a parameter file, and optionally execute it.

3.2 IBM VM/CMS

On an IBM mainframe running VM/CMS, run YPATCHY with the pilot patches described in Section 4 and the IBM flag to extract the source code, decay table, and documentation. Compile the source code and link it with the main program

```
      PROGRAM ISARUN
C          MAIN PROGRAM FOR ISAJET
      OPEN(UNIT=1,STATUS='OLD',FORM='FORMATTED')
      OPEN(UNIT=2,STATUS='NEW',FORM='UNFORMATTED')
      OPEN(UNIT=3,STATUS='OLD',FORM='FORMATTED')
      OPEN(UNIT=4,STATUS='NEW',FORM='FORMATTED')
      CALL ISAJET(-1,2,3,4)
      STOP
      END
```

to make ISAJET MODULE.

Create a file called `JOBNAME INPUT` containing ISAJET input commands following the examples above or the instructions in Section 6. Then run ISAJET using ISAJET EXEC, which is contained in P=ISAUTIL,D=RUNIBM. The events will be produced on `JOBNAME DATA A` and the listing on `JOBNAME OUTPUT A`.

3.3 Unix

The Makefile contained in P=ISAUTIL,D=MAKEUNIX has been tested on DEC Ultrix, Hewlett Packard HP-UX, IBM RS/6000 AIX, Linux, Silicon Graphics IRIX, Sun SunOS, and Sun Solaris. It should work with minor modifications on almost any Unix system with /bin/csh, `ypatchy` or `nypatchy`, and a reasonable Fortran 77 compiler. Extract the Makefile and edit it, changing the installation parameters to reflect your system. Note in particular that CERNlib is usually compiled with underscores postpended to all external names; you must choose the appropriate compiler option if you intend to link with it. Then type

```
make
```

This should produce an executable `isajet.x` for the event generator, which links the code with the following main program:

```
      PROGRAM RUNJET
      CHARACTER*60 FNAME
      READ 1000, FNAME
1000  FORMAT(A)
      PRINT 1020, FNAME
1020  FORMAT(1X,'Data file      = ',A)
      OPEN(2,FILE=FNAME,STATUS='NEW',FORM='UNFORMATTED')
      READ 1000, FNAME
      PRINT 1030, FNAME
1030  FORMAT(1X,'Parameter file = ',A)
      OPEN(3,FILE=FNAME,STATUS='OLD',FORM='FORMATTED')
      READ 1000, FNAME
      PRINT 1040, FNAME
1040  FORMAT(1X,'Listing file   = ',A)
      OPEN(4,FILE=FNAME,STATUS='NEW',FORM='FORMATTED')
      READ 1000, FNAME
      OPEN(1,FILE=FNAME,STATUS='OLD',FORM='FORMATTED')
      CALL ISAJET(-1,2,3,4)
      STOP
      END
```

Two other executables, `isasusy.x` and `isasugra.x`, will also be produced to calculate SUSY masses and decay modes without generating events. Type

```
make clean
```

to delete the temporary files.

Most Unix systems do not allow two jobs to read the same decay table file at the same time. The shell script in P=ISAUTIL,D=RUNUNIX copies the decay table to a temporary file to avoid this problem. Extract this file as `isajet`. Create an input file `jobname.par` following the examples above or the instructions in Section 6 and run ISAJET with the command

```
isajet jobname
```

This will create a binary output file `jobname.dat` and a listing file `jobname.lis`. Analyze the output data using the commands described in Section 8.

This section only describes running ISAJET as a standalone program and generating output in machine-dependent binary form. The user may elect to analyze events as they are generated; this is discussed in Section 5 of this manual.

4 Patchy and PAM Organization

Patchy is a code management system developed at CERN and used to maintain the CERN Library. It is used to provide versions of ISAJET for a wide variety of computers. Instructions for using PATCHY are available from `http://wwwinfo.cern.ch/asdoc/Welcome.html`.

A master source file in Patchy is called a "PAM." The ISAJET PAM contains all the source code and documentation plus Patchy commands to include common blocks and to select the desired version. It is divided into the following patches:

`ISACDE`: contains all common blocks, etc. These are divided into decks based on their usage.

`ISADATA`: contains block data ALDATA. This must always be loaded when using ISAJET.

`ISAJET`: contains the code for generating events. Each subroutine is in a separate deck with the same name.

`ISASSRUN`: contains the main program for ISASUSY, which prompts for input parameters and prints out all the decay modes. It is selected by `*ISASUSY`.

`ISASUSY`: contains code to calculate all the decay widths and branching fractions in the minimal supersymmetric model.

`ISATAPE`: contains the code for reading and writing tapes, again with each subroutine on a separate deck.

`ISARUN`: contains a main program and a simple interactive interface. It is selected by `IF=INTERACT`.

`ISAZEB`: contains Zebra format output routines, an alternative to the ISATAPE routines.

`ISZRUN`: contains the analog of ISAPLT for the Zebra format.

`ISAPLT`: contains a simple calorimeter simulation and the skeleton of a histogramming job using HBOOK.

`ISATEXT`: contains the instructions for using ISAJET, i.e. the text of this document. It also includes the documentation for ISASUSY.

`ISZTEXT`: contains the instructions for the Zebra output routines and a description of the Zebra banks.

`ISADECAY`: contains the input decay table.

The code is actually maintained using RCS on a Silicon Graphics computer at BNL. Patchy is used primarily to handle common blocks and machine dependent code.

The input to YPATCHY must contain both `+USE` cards, which define the wanted program version, and `+EXE` cards, which determine which patches or decks are written to the ASM file. To facilitate this selection, the ISAJET PAM contains the following pilot patches:

`*ISADECAY`: USE selects ISADECAY and all corrections to it.

`*ISAJET`: USE selects ISACDE, ISADATA, ISAJET, ISATAPE, ISARUN and all corrections to them. Note that ISARUN is not actually selected without `+USE,INTERACT`.

`*ISAPLT`: USE selects ISACDE, ISAPLT, and all corrections to them.

`*ISASUSY`: USE selects CDESUSY, ISASUSY, and ISASSRUN to create a program to calculate all the MSSM decay modes.

`*ISATEXT`: USE selects ISACDE, ISATEXT, and all corrections to them.

`*ISAZEB`: USE selects ISAJET with a Zebra output format.

`*ISZRUN`: USE selects the Zebra analysis package.

Patches are provided to select the machine dependent features for specific computers or operating systems:

`ANSI`: ANSI standard Fortran (no time or date functions)
`APOLLO`: APOLLO – only tested by CERN
`CDC`: CDC 7600 and 60-bit CYBER (obsolete)
`CRAY`: CRAY with UNICOS
`DECS`: DEC Station with Ultrix
`ETA`: ETA 10 running Unix System V (obsolete)
`HPUX`: HP/9000 7xx running Unix System V
`IBM`: IBM 370 and 30xx running VM/CMS
`IBMRT`: IBM RS/6000 running AIX 3.x or 4.x
`LINUX`: PC running Linux with f2c/gcc or g77 compiler
`SGI`: Silicon Graphics running IRIX
`SUN`: Sun Sparcstation running SUNOS or Solaris
`VAX`: DEC VAX or Alpha running VMS

These patches in turn select a variety of patches and IF flags, allowing one to select more specific features, as indicated below. (Replace `&` by `+` everywhere.)

```
&PATCH,ANSI.                      GENERIC ANSI FORTRAN.
&USE,DOUBLE.                      DOUBLE PRECISION.
&USE,STDIO.                       STANDARD FORTRAN 77 TAPE INPUT/OUTPUT.
&USE,MOVEFTN.                     FORTRAN REPLACEMENT FOR MOVLEV.
&USE,RANFFTN,IF=-CERN.            FORTRAN RANF.
&USE,RANFCALL.                    STANDARD RANSET AND RANGET CALLS.
&USE,NOCERN,IF=-CERN.             NO CERN LIBRARY.
&EOD

&PATCH,APOLLO.
&DECK,BLANKDEK.
&USE,DOUBLE.                      DOUBLE PRECISION.
&USE,STDIO.                       STANDARD FORTRAN 77 TAPE INPUT/OUTPUT.
&USE,MOVEFTN.                     FORTRAN REPLACEMENT FOR MOVLEV.
&USE,RANFFTN,IF=-CERN.            FORTRAN RANF.
&USE,RANFCALL.                    STANDARD RANSET AND RANGET CALLS.
&USE,NOCERN,IF=-CERN.             NO CERN LIBRARY.
&USE,IMPNONE.                     IMPLICIT NONE
&EOD.

&PATCH,CDC.                       CDC 7600 OR CYBER 175.
&USE,SINGLE.                      SINGLE PRECISION.
&USE,LEVEL2.                      LEVEL 2 STORAGE.
&USE,CDCPACK.                     PACK 2 WORDS PER WORD FOR INPUT/OUTPUT.
&USE,RANFCALL.                    STANDARD RANSET AND RANGET CALLS.
&USE,NOCERN,IF=-CERN.             NO CERN LIBRARY.
&EOD
```

```
&PATCH,CRAY.                      CRAY XMP OR 2.
&USE,SINGLE.                      SINGLE PRECISION.
&USE,STDIO.                       STANDARD FORTRAN 77 TAPE INPUT/OUTPUT.
&USE,MOVEFTN.                     FORTRAN REPLACEMENT FOR MOVLEV.
&USE,NOCERN,IF=-CERN.             NO CERN LIBRARY.
&EOD

&PATCH,DECS.                      DEC STATION (ULTRIX)
&USE,SUN.
&EOD

&PATCH,ETA.                       ETA-10.
&USE,SINGLE.                      SINGLE PRECISION.
&USE,STDIO.                       STANDARD FORTRAN 77 TAPE INPUT/OUTPUT.
&USE,MOVEFTN.                     FORTRAN REPLACEMENT FOR MOVLEV.
&USE,RANFCALL.                    STANDARD RANSET AND RANGET CALLS.
&USE,NOCERN,IF=-CERN.             NO CERN LIBRARY.
&EOD

&PATCH,HPUX.                      HP/9000 7XX RUNNING UNIX.
&USE,DOUBLE.                      DOUBLE PRECISION.
&USE,STDIO.                       STANDARD FORTRAN 77 TAPE INPUT/OUTPUT.
&USE,MOVEFTN.                     FORTRAN REPLACEMENT FOR MOVLEV.
&USE,RANFFTN,IF=-CERN.            FORTRAN RANF.
&USE,RANFCALL.                    STANDARD RANSET AND RANGET CALLS.
&USE,NOCERN,IF=-CERN.             NO CERN LIBRARY.
&USE,IMPNONE.                     IMPLICIT NONE
&EOD

&PATCH,IBM.                       IBM 370 OR 30XX.
&USE,DOUBLE.                      DOUBLE PRECISION.
&USE,STDIO.                       STANDARD FORTRAN 77 TAPE INPUT/OUTPUT.
&USE,MOVEFTN.                     FORTRAN REPLACEMENT FOR MOVLEV.
&USE,RANFFTN,IF=-CERN.            FORTRAN RANF.
&USE,RANFCALL.                    STANDARD RANSET AND RANGET CALLS.
&USE,NOCERN,IF=-CERN.             NO CERN LIBRARY.
&EOD

&PATCH,IBMRT.                     IBM RS/6000 WITH AIX 3.1
&USE,DOUBLE.                      DOUBLE PRECISION.
&USE,STDIO.                       STANDARD FORTRAN 77 TAPE INPUT/OUTPUT.
&USE,MOVEFTN.                     FORTRAN REPLACEMENT FOR MOVLEV.
&USE,RANFFTN,IF=-CERN.            FORTRAN RANF.
```

```
&USE,RANFCALL.                     STANDARD RANSET AND RANGET CALLS.
&USE,NOCERN,IF=-CERN.              NO CERN LIBRARY.
&USE,IMPNONE.                      IMPLICIT NONE
&EOD

&PATCH,LINUX.                      IBM PC WITH LINUX 1.X
&USE,DOUBLE.                       DOUBLE PRECISION.
&USE,STDIO.  STANDARD FORTRAN 77 TAPE INPUT/OUTPUT.
&USE,MOVEFTN.                      FORTRAN REPLACEMENT FOR MOVLEV.
&USE,RANFFTN,IF=-CERN.             FORTRAN RANF.
&USE,RANFCALL.                     STANDARD RANSET AND RANGET CALLS.
&USE,NOCERN,IF=-CERN.              NO CERN LIBRARY.
&USE,IMPNONE.                      IMPLICIT NONE
&EOD

&PATCH,SGI.
SILICON GRAPHICS 4D/XX.
&USE,DOUBLE.                       DOUBLE PRECISION.
&USE,STDIO.                        STANDARD FORTRAN 77 TAPE INPUT/OUTPUT.
&USE,MOVEFTN.                      FORTRAN REPLACEMENT FOR MOVLEV.
&USE,RANFFTN,IF=-CERN.             FORTRAN RANF.
&USE,RANFCALL.                     STANDARD RANSET AND RANGET CALLS.
&USE,NOCERN,IF=-CERN.              NO CERN LIBRARY.
&EOD

&PATCH,SUN.                        SUN (SPARC)
&USE,DOUBLE.                       DOUBLE PRECISION.
&USE,STDIO.                        STANDARD FORTRAN 77 TAPE INPUT/OUTPUT.
&USE,MOVEFTN.                      FORTRAN REPLACEMENT FOR MOVLEV.
&USE,RANFFTN,IF=-CERN.             FORTRAN RANF.
&USE,RANFCALL.                     STANDARD RANSET AND RANGET CALLS.
&USE,NOCERN,IF=-CERN.              NO CERN LIBRARY.
&EOD

&PATCH,VAX.                        DEC VAX 11/780 OR 8600.
&USE,DOUBLE.                       DOUBLE PRECISION.
&USE,STDIO.                        STANDARD FORTRAN 77 TAPE INPUT/OUTPUT.
&USE,MOVEFTN.                      FORTRAN REPLACEMENT FOR MOVLEV.
&USE,RANFFTN,IF=-CERN.             FORTRAN RANF.
&USE,RANFCALL.                     STANDARD RANSET AND RANGET CALLS.
&USE,NOCERN,IF=-CERN.              NO CERN LIBRARY.
&USE,IMPNONE.                      IMPLICIT NONE
&EOD
```

An empty patch INTERACT selects a main program and an interactive interface which will prompt the user for parameters and do some error checking. A patch CERN allows ISAJET to take the random number generator RANF and several other routines from the CERN Library; to use this include the Patchy command

```
&USE,CERN.
```

Similarly, a patch PDFLIB enables the interface to the PDFLIB parton distribution compilation by H. Plothow-Besch:

```
&USE,PDFLIB
```

The only internal links with PDFLIB are calls to the routines PDFSET, PFTOPDG, and DXPDF, and the common blocks W50510 and W50517,

```
C          Copy of PDFLIB common block
      COMMON/W50510/IFLPRT
      INTEGER IFLPRT
      SAVE /W50510/
C          Copy of PDFLIB common block
      COMMON/W50517/N6
      INTEGER N6
      SAVE /W50517/
```

which are used to specify the level of output messages and the logical unit number for them.

In general it should be sufficient to run YPATCHY with the following cradle (replace & with + everywhere):

```
&USE,(*ISAJET,*ISATEXT,*ISADECAY,*ISAPLT).      CHOOSE ONE.
&USE,ANSI,DECS,HPUX,IBM,IBMRT,SGI,SUN,....      CHOOSE ONE.
&[USE,INTERACT].                                FOR INTERACTIVE MODE.
&[USE,CERN.]                                    FOR CERN LIBRARY.
&[USE,HBOOK3.]                                  HBOOK 3 FOR ISAPLT.
&EXE.
&PAM.
&QUIT.
```

The input to YPATCHY can also contain changes by the user. It is suggested that these not be made permanent parts of the PAM to avoid possible conflicts with later corrections.

5 Main Program

A main program is not supplied with ISAJET. To generate events and write them to disk, the user should provide a main program which opens the files and then calls subroutine ISAJET. In the following sample, i,j,m,n are arbitrary unit numbers.

Main program for VMS:

```
      PROGRAM RUNJET
C
C          MAIN PROGRAM FOR ISAJET ON BNL VAX CLUSTER.
C
      OPEN(UNIT=i,FILE='$2$DUA14:[ISAJET.ISALIBRARY]DECAY.DAT',
     $STATUS='OLD',FORM='FORMATTED',READONLY)
      OPEN(UNIT=j,FILE='myjob.dat',STATUS='NEW',FORM='UNFORMATTED')
      OPEN(UNIT=m,FILE='myjob.par',STATUS='OLD',FORM='FORMATTED')
      OPEN(UNIT=n,FILE='myjob.lis',STATUS='NEW',FORM='FORMATTED')
C
      CALL ISAJET(+-i,+-j,m,n)
C
      STOP
      END
```

Main program for IBM (VM/CMS)

```
      PROGRAM RUNJET
C
C          MAIN PROGRAM FOR ISAJET ON IBM ASSUMING FILES HAVE BEEN
C          OPENED WITH FILEDEF.
C
      CALL ISAJET(+-i,+-j,m,n)
C
      STOP
      END
```

Main program for Unix:

```
      PROGRAM RUNJET
C
C          Main program for ISAJET on Unix
C
      CHARACTER*60 FNAME
C
C          Open user files
      READ 1000, FNAME
1000  FORMAT(A)
      PRINT 1020, FNAME
```

```
1020  FORMAT(1X,'Data file      = ',A)
      OPEN(2,FILE=FNAME,STATUS='NEW',FORM='UNFORMATTED')
      READ 1000, FNAME
      PRINT 1030, FNAME
1030  FORMAT(1X,'Parameter file = ',A)
      OPEN(3,FILE=FNAME,STATUS='OLD',FORM='FORMATTED')
      READ 1000, FNAME
      PRINT 1040, FNAME
1040  FORMAT(1X,'Listing file   = ',A)
      OPEN(4,FILE=FNAME,STATUS='NEW',FORM='FORMATTED')
C          Open decay table
      READ 1000, FNAME
      OPEN(1,FILE=FNAME,STATUS='OLD',FORM='FORMATTED')
C
C          Run ISAJET
      CALL ISAJET(-1,2,3,4)
C
      STOP
      END
```

The arguments of ISAJET are tape numbers for files, all of which should be opened by the main program.

`TAPEi`: Decay table (formatted). A positive sign prints the decay table on the output listing. A negative sign suppress printing of the decay table.

`TAPEj`: Output file for events (unformatted). A positive sign writes out both resonances and stable particles. A negative sign writes out only stable particles.

`TAPEm`: Commands as defined in Section 6 (formatted).

`TAPEn`: Output listing (formatted).

In the sample jobs in Section 3, TAPEm is the default Fortran input, and TAPEn is the default Fortran output.

5.1 Interactive Interface

To use the interactive interface, replace the call to ISAJET in the above main program by

```
      CALL ISASET(+-i,+-j,m,n)
      CALL ISAJET(+-i,+-j,m,n)
```

ISASET calls DIALOG, which prompts the user for possible commands, does a limited amount of error checking, and writes a command file on TAPEm. This command file is rewound for execution by ISAJET. A main program is included in patch ISARUN to open the necessary files and to call ISASET and ISAJET.

5.2 User Control of Event Loop

If the user wishes to integrate ISAJET with another program and have control over the event generation, he can call the driving subroutines himself. The driving subroutines are:

`ISAINI(+-i,+-j,m,n)`: initialize ISAJET. The arguments are the same as for subroutine ISAJET.

`ISABEG(IFL)`: begin a run. IFL is a return flag: IFL=0 for a good set of commands; IFL=1001 for a STOP; any other value means an error.

`ISAEVT(I,OK,DONE)` generate event I. Logical flag OK signifies a good event (almost always .TRUE.); logical flag DONE signifies the end of a run.

`ISAEND`: end a run.

There are also subroutines provided to write standard ISAJET records, or Zebra records if the Zebra option is selected:

`ISAWBG` to write a begin-of-run record, should be called immediately after ISABEG

`ISAWEV` to write an event record, should be called immediately after ISAEVT

`ISAWND` to write an end-of-run record, should be called immediately after ISAEND

The control of the event loop is somewhat complicated to accomodate multiple evolution and fragmentation as described in Section 11. Note in particular that after calling ISAEVT one should process or write out the event only if OK=.TRUE. The check on the DONE flag is essential if one is doing multiple evolution and fragmentation. The following example indicates how events might be generated, analyzed, and discarded (replace `&` by `+` everywhere):

```
      PROGRAM SAMPLE
C
&SELF,IF=IMPNONE
      IMPLICIT NONE
&SELF
&CDE,ITAPES
&CDE,IDRUN
&CDE,PRIMAR
&CDE,ISLOOP
C
      INTEGER JTDKY,JTEVT,JTCOM,JTLIS,IFL,ILOOP
      LOGICAL OK,DONE
      SAVE ILOOP
C----------------------------------------------------------------------
C>         Open files as above
C>         Call user initialization
C----------------------------------------------------------------------
C
C          Initialize ISAJET
C
      CALL ISAINI(-i,0,m,n)
    1 IFL=0
```

```
      CALL ISABEG(IFL)
      IF(IFL.NE.0) STOP
C
C          Event loop
C
      ILOOP=0
  101 CONTINUE
        ILOOP=ILOOP+1
C          Generate one event - discard if .NOT.OK
        CALL ISAEVT(ILOOP,OK,DONE)
        IF(OK) THEN
C-----------------------------------------------------------------------
C>         Call user analysis for event
C-----------------------------------------------------------------------
        ENDIF
      IF(.NOT.DONE) GO TO 101
C
C          Calculate cross section and luminosity
C
      CALL ISAEND
C-----------------------------------------------------------------------
C>         Call user summary
C-----------------------------------------------------------------------
      GO TO 1
      END
```

5.3 Multiple Event Streams

It may be desirable to generate several different kinds of events simultaneously to study pileup effects. While normally one would want to superimpose minimum bias or low-pt jet events on a signal of interest, other combinations might also be interesting. It would be very inefficient to reinitialize ISAJET for each event. Therefore, a pair of subroutines is provided to save and restore the context, i.e. all of the initialization information, in an array. The syntax is

```
      CALL CTXOUT(NC,VC,MC)
      CALL CTXIN(NC,VC,MC)
```

where VC is a real array of dimension MC and NC is the number of words used, about 20000 in the standard case. If NC exceeds MC, a warning is printed and the job is terminated. The use of these routines is illustrated in the following example, which opens the files with names read from the standard input and then superimposes on each event of the signal sample three events of a pileup sample. It is assumed that a large number of events is specified in the parameter file for the pileup sample so that it does not terminate.

```
      PROGRAM SAMPLE
```

```
C
C          Example of generating two kinds of events.
C
      CHARACTER*60 FNAME
      REAL VC1(20000),VC2(20000)
      LOGICAL OK1,DONE1,OK2,DONE2
      INTEGER NC1,NC2,IFL,ILOOP,I2,ILOOP2
C
C          Open decay table
      READ 1000, FNAME
1000  FORMAT(A)
      OPEN(1,FILE=FNAME,STATUS='OLD',FORM='FORMATTED')
C          Open user files
      READ 1000, FNAME
      OPEN(3,FILE=FNAME,STATUS='OLD',FORM='FORMATTED')
      READ 1000, FNAME
      OPEN(4,FILE=FNAME,STATUS='NEW',FORM='FORMATTED')
      READ 1000,FNAME
      OPEN(13,FILE=FNAME,STATUS='OLD',FORM='FORMATTED')
      READ 1000,FNAME
      OPEN(14,FILE=FNAME,STATUS='NEW',FORM='FORMATTED')
C
C          Initialize ISAJET
      CALL ISAINI(-1,0,3,4)
      CALL CTXOUT(NC1,VC1,20000)
      CALL ISAINI(-1,0,13,14)
      IFL=0
      CALL ISABEG(IFL)
      IF(IFL.NE.0) STOP1
      CALL CTXOUT(NC2,VC2,20000)
      ILOOP2=0
      CALL user_initialization_routine
C
1     IFL=0
      CALL CTXIN(NC1,VC1,20000)
      CALL ISABEG(IFL)
      CALL CTXOUT(NC1,VC1,20000)
      IF(IFL.NE.0) GO TO 999
      ILOOP=0
C
C          Main event
C
101   CONTINUE
        ILOOP=ILOOP+1
```

```
        CALL CTXIN(NC1,VC1,20000)
        CALL ISAEVT(ILOOP,OK1,DONE1)
        CALL CTXOUT(NC1,VC1,20000)
        IF(.NOT.OK1) GO TO 101
        CALL user_analysis_routine
C
C          Pileup
C
        CALL CTXIN(NC2,VC2,20000)
        I2=0
201     CONTINUE
          ILOOP2=ILOOP2+1
          CALL ISAEVT(ILOOP2,OK2,DONE2)
          IF(OK2) I2=I2+1
          IF(DONE2) STOP2
          CALL user_analysis_routine
        IF(I2.LT.3) GO TO 201
        CALL CTXOUT(NC2,VC2,20000)
C
      IF(.NOT.DONE1) GO TO 101
C
C          Calculate cross section and luminosity
C
      CALL CTXIN(NC1,VC1,20000)
      CALL ISAEND
      GO TO 1
C
999   CALL CTXIN(NC2,VC2,20000)
      CALL ISAEND
      CALL user_termination_routine
      STOP
      END
```

It is possible to superimpose arbitrary combinations of events, including events of the same reaction type with different parameters. In general the number of events would be selected randomly based on the cross sections and the luminosity.

At this time CTXOUT and CTXIN cannot be used with the Zebra output routines.

6 Input

6.1 Input Format

ISAJET is controlled by commands read from the specified input file by subroutine READIN. (In the interactive version, this file is first created by subroutine DIALOG.) Syntax errors will generate a message and stop execution. Based on these commands, subroutine LOGIC will setup limits for all variables and check for inconsistencies. Several runs with different parameters can be combined into one job. The required input format is:

```
Title
Ecm,Nevent,Nprint,Njump/
Reaction
(Optional parameters)
END
(Optional additional runs)
STOP
```

with all lines starting in column 1 and typed in *upper* case. These lines are explained below.

Title line: Up to 80 characters long. If the first four letters are STOP, control is returned to main program. If the first four letters are SAME, the parameters from previous run are used excepting those which are explicitly changed.

Ecm line: This line must always be given even if the title is SAME. It must give the center of mass energy (Ecm) and the number of events (Nevent) to be generated. One may also specify the number of events to be printed (Nprint) and the increment (Njump) for printing. The first event is always printed if Nprint > 0. For example:

```
800.,1000,10,100/
```

generates 1000 events at $E_{\rm cm} = 800\,{\rm GeV}$ and prints 10 events. The events printed are: 1,100,200,.... Note that an event typically takes several pages of output. This line is read with a list directed format (READ*).

After Nprint events have been printed, a single line containing the run number, the event number, and the random number seed is printed every Njump events (if Njump is nonzero). This seed can be used to start a new job with the given event if in the new run NSIGMA is set equal to zero:

```
SEED
value/
NSIGMA
0/
```

In general the same events will only be generated on the same type of computer.

Reaction line: This line must be given unless title is SAME, when it must be omitted. It selects the type of events to be generated. The present version can generate TWOJET, E+E-, DRELLYAN, MINBIAS, WPAIR, SUPERSYM, HIGGS, PHOTON, TCOLOR, or WHIGGS events. This line is read with an A8 format.

6.2 Optional Parameters

Each optional parameter requires two lines. The first line is a keyword specifying the parameter and the second line gives the values for the parameter. The parameters can be given in any order. Numerical values are read with a list directed format (READ*), jet and particle types are read with a character format and must be enclosed in quotes, and logical flags with an L1 format. All momenta are in GeV and all angles are in radians.

The parameters can be classified in several groups:

Jet Limits:	W/H Limits:	Decays:	Constants:	Other:
JETTYPE1	HTYPE	FORCE	AMSB	BEAMS
JETTYPE2	PHIW	FORCE1	CUTJET	EPOL
JETTYPE3	QMH	NODECAY	CUTOFF	EEBEAM
MIJLIM	QMW	NOETA	EXTRAD	EEBREM
MTOT	QTW	NOEVOLVE	FRAGMENT	NPOMERON
P	THW	NOFRGMNT	GAUGINO	NSIGMA
PHI	WTYPE	NOGRAV	GMSB	NTRIES
PT	XW	NOPI0	GMSB2	PDFLIB
TH	YW		HMASS	SEED
X			HMASSES	STRUC
Y			LAMBDA	WFUDGE
WMODE1			MGVTNO	WMMODE
WMODE2			MSSMA	WPMODE
			MSSMB	Z0MODE
			MSSMC	
			MSSMD	
			MSSME	
			NUSUG1	
			NUSUG2	
			NUSUG3	
			NUSUG4	
			NUSUG5	
			SIGQT	
			SIN2W	
			SLEPTON	
			SQUARK	
			SSBCSC	
			SUGRA	
			SUGRHN	
			TCMASS	
			TMASS	
			WMASS	

It may be helpful to know that the TWOJET, WPAIR, PHOTON, SUPERSYM, and WHIGGS processes use the same controlling routines and so share many of the same variables. In particular, PT limits should normally be set for these processes, and JETTYPE1 and JETTYPE2 are used to select the reactions. Similarly, the DRELLYAN, HIGGS, and TCOLOR processes use the same controlling routines since they all generate s-channel resonances. The mass limits for these processes are set by QMW. Normally the QMW limits will surround the $W^{\pm}$, Z^0, or Higgs mass, but this is not required. (QMH acts like QMW for the Higgs process.) For historical reasons, JETTYPE1 and JETTYPE2 are used to select the W decay modes in DRELLYAN, while WMODE1 and WMODE2 select the W decay modes for WPAIR, HIGGS, and WHIGGS. Also, QTW can be used to generate DRELLYAN events with non-zero transverse momentum, whereas HIGGS automatically fixes QTW to be zero. (Of course, non-zero transverse momentum will be generated by gluon radiation.)

For example the lines

```
P
40.,50.,10.,100./
```

would set limits for the momentum of jet 1 between 40 and 50 GeV, and for jet 2 between 10 and 100 GeV. As another example the lines

```
WTYPE
'W+'/
```

would specify that for DRELLYAN events only W+ events will be generated. If for a kinematic variable only the lower limit is specified then that parameter is fixed to the given value. Thus the lines

```
P
40.,,10./
```

will fix the momentum for jet 1 to be 40 GeV and for jet 2 to be 10 GeV. If only the upper limit is specified then the default value is used for the lower limit. Jet 1 or jet 2 parameters for DRELLYAN events refer to the W decay products and cannot be fixed. If QTW is fixed to 0, then standard Drell-Yan events are generated.

A complete list of keywords and their default values follows.

Keyword Values	Default values	Explanation
AMSB m_0,$m_{3/2}$,$\tan\beta$,sgn μ	none	Anomaly-mediated SUSY breaking scalar mass, gravitino mass, VEV ratio, sign
BEAMS type$_1$,type$_2$	'P','P'	Initial beams. Allowed are 'P','AP','N','AN'.
CUTJET μ_c	6.	Cutoff mass for QCD jet evolution.
CUTOFF μ^2, ν	.200,1.0	Cutoff $qt^2 = \mu^2 Q^\nu$ for DRELLYAN events.
EEBEAM $\sqrt{\hat{s}}_{min}$, $\sqrt{\hat{s}}_{max}$, Υ, σ_z	none	impose brem/beamstrahlung min and max subprocess energy, beamstrahlung parameter Υ longitudinal beam size σ_z in mm
EEBREM $\sqrt{\hat{s}}_{min}$, $\sqrt{\hat{s}}_{max}$	none	impose bremsstrahlung for e^+e^- min and max subprocess energy
EPOL $P_L(e^-), P_L(e^+)$	0,0	Polarization of e^- (e^+) beam, $P_L(e) = (n_L - n_R)/(n_L - n_R)$, so that $-1 \le P_L \le 1$
EXTRAD δ,M_D,UVCUT	None	Parameters for EXTRADIM process UVCUT is logical flag
FORCE $i, i_1, ..., i_5/$	None	Force decay of particles, $\pm i \to \pm(i1 + ... + i5)$. Can call 20 times. See note for i = quark.
FORCE1 $i, i_1, ..., i_5/$	None	Force decay $i \to i1 + ... + i5$. Can call 40 times. See note for i = quark.
FRAGMENT P_{ud},. . .	.4,. . .	Fragmentation parameters. See also SIGQT, etc.
GAUGINO m_1,m_2,m_3, m_4	50,0,100,100	Masses for $\tilde{g}$, $\tilde{\gamma}$, $\tilde{W}^+$, and $\tilde{Z}^0$

GMSB		GMSB messenger SUSY breaking,
Λ_m,M_m,N_5	none	mass, number of $5+\bar{5}$, VEV
$\tan\beta$,sgn μ,$C_{\rm gr}$		ratio, sign, gravitino scale
GMSB2		non-minimal GMSB parameters
$\not{R}$,$\delta M^2_{H_d}$,$\delta M^2_{H_u}$,$D_Y(M)$	1,0,0,0	gaugino mass multiplier
N_{5_1},N_{5_2},N_{5_3}	N_5	Higgs mass shifts, D-term mass^2
		indep. gauge group messengers
HMASS	0	Mass for standard Higgs.
m		
HMASSES		Higgs meson masses for
m_1,...,m_9	0,...,0	charges 0,0,0,0,0,1,1,2,2.
HTYPE		One MSSM Higgs type ('HL0',
'HL0'/ or...	none	'HH0', or 'HA0')
JETTYPE1		)Select types for jets:
'GL','UP',...	'ALL'	)'ALL'; 'GL'; 'QUARKS'='UP',
		)'UB','DN','DB','ST','SB',
JETTYPE2		)'CH','CB','BT','BB','TP',
'GL','UP',...	'ALL'	)'TB','X','XB','Y','YB';
		)'LEPTONS'='E-','E+','MU-',
JETTYPE3		)'MU+','TAU-','TAU+'; 'NUS';
'GL','UP',...	'ALL'	)'GM','W+','W-','Z0'
		) See note for SUSY types.
LAMBDA		QCD scale
Λ	.2	
MGVTNO		Gravitino mass – ignored for
$M_{\rm gravitino}$	10^{20} GeV	GMSB model
MIJLIM		Multimet mass limits
i,j,$M_{\rm min}$,$M_{\rm max}$	0,0,1 GeV,1 GeV	
MSSMA		MSSM parameters –
$m(\tilde{g})$,μ,	Required	Gluino mass, μ, A mass,
$m(A)$,$\tan\beta$		$\tan\beta$
MSSMB		MSSM 1st generation –
$m(q_1)$,$m(d_r)$,$m(u_r)$,	Required	Left and right soft squark and
$m(l_1)$,$m(e_r)$		slepton masses

MSSMC		MSSM 3rd generation –
$m(q_3)$,$m(b_r)$,$m(t_r)$,	Required	Soft squark masses, slepton
$m(l_3)$,$m(\tau_r)$,		masses, and squark and slepton
A_t,A_b,A_τ		mixings
MSSMD		MSSM 2nd generation –
$m(q_2)$,$m(s_r)$,$m(c_r)$,	from MSSMB	Left and right soft squark and
$m(l_2)$,$m(mu_r)$		slepton masses
MSSME		MSSM gaugino masses –
M_1,M_2	MSSMA + GUT	Default is to scale from gluino
MTOT		Mass range for multiparton
$M_{\min}$,$M_{\max}$	None	processes
NODECAY		Suppress all decays.
TRUE or FALSE	FALSE	
NOETA		Suppress eta decays.
TRUE or FALSE	FALSE	
NOEVOLVE		Suppress QCD evolution and
TRUE or FALSE	FALSE	hadronization.
NOGRAV		Suppress gravitino decays in
TRUE or FALSE	FALSE	GMSB model
NOHADRON		Suppress hadronization of
TRUE or FALSE	FALSE	jets and beam jets.
NONUNU		Suppress Z^0 neutrino decays.
TRUE or FALSE	FALSE	
NOPI0		Suppress π^0 decays.
TRUE or FALSE	FALSE	
NPOMERON		Allow $n_1 < n < n_2$ cut pomerons.
n_1,n_2	1,20	Controls beam jet mult.
NSIGMA		Generate n unevolved events
n	20	for SIGF calculation.
NTRIES		Stop if after n tries
n	1000	cannot find a good event.

NUSUG1 M_1,M_2,M_3	none	Optional non-universal SUGRA gaugino masses
NUSUG2 A_t,A_b,A_τ	none	Optional non-universal SUGRA A terms
NUSUG3 M_{H_d},M_{H_u}	none	Optional non-universal SUGRA Higgs masses
NUSUG4 M_{u_L},M_{d_R},M_{u_R}, M_{e_L},M_{e_R}	none	Optional non-universal SUGRA 1st/2nd generation masses
NUSUG5 M_{t_L},M_{b_R},M_{t_R}, M_{τ_L},M_{τ_R}	none	Optional non-universal SUGRA 3rd generation masses
P $p_{\rm min}(1)$,...,$p_{\rm max}(3)$	1.,$0.5E_{\rm cm}$	Momentum limits for jets.
PDFLIB 'name$_1$',val$_1$,...	None	CERN PDFLIB parton distribution parameters. See PDFLIB manual.
PHI $\phi_{\rm min}(1)$,...,$\phi_{\rm max}(3)$	0,2π	Phi limits for jets.
PHIW $\phi_{\rm min}$,$\phi_{\rm max}$	0,2π	Phi limits for W.
PT or PPERP $p_{t,\rm min}(1)$,...,$p_{t,\rm max}(3)$	$.05E_{\rm cm}$,$.2E_{\rm cm}$	p_t limits for jets. Default for TWOJET only.
QMH $q_{\rm min}$,$q_{\rm max}$	$.05E_{\rm cm}$,$.2E_{\rm cm}$	Mass limits for Higgs. Equivalent to QMW.
QMW $q_{\rm min}$,$q_{\rm max}$	$.05E_{\rm cm}$,$.2E_{\rm cm}$	Mass limits for W.
QTW $q_{t,\rm min}$,$q_{t,\rm max}$	.1,$.025E_{\rm cm}$	q_t limits for W. Fix $q_t = 0$ for standard Drell-Yan.
SEED real	0	Random number seed (double precision if 32 bit).

SIGQT σ	 .35	Internal k_t parameter for jet fragmentation.
SIN2W $\sin^2(\theta_W)$	 .232	Weinberg angle. See WMASS.
SLEPTON $m_1,\ldots,m_6$	 100,...,101.8	Masses for $\tilde{\nu}_e$, $\tilde{e}$, $\tilde{\nu}_\mu$, $\tilde{\mu}$, $\tilde{\nu}_\tau$, $\tilde{\tau}$
SQUARK $m_1,\ldots,m_6$	 100.3,...,240.	Masses for $\tilde{u}$, $\tilde{d}$, $\tilde{s}$, $\tilde{c}$, $\tilde{b}$, $\tilde{t}$
SSBCSC M	 M_{GUT}	Alternate mass scale for RGE boundary conditions.
STRUC name	 'CTEQ3L'	Structure functions. CTEQ3L, CTEQ2L, EHLQ, OR DO
SUGRA m_0,$m_{1/2}$,A_0, $\tan\beta$,sgn μ	 none	Minimal supergravity parameters scalar M, gaugino M, trilinear breaking term, vev ratio, +-1
TH or THETA $\theta_{\min}(1),\ldots,\theta_{\max}(3)$	 0,π	Theta limits for jets. Do not also set Y.
SUGRHN m_{ν_τ},M_N,A_n,$m_{\tilde{\nu}_R}$	 $0, 1E20, 0, 0$	SUGRA see-saw ν-effect nu-mass, int. scale, GUT scale nu SSB terms
THW $\theta_{\min}$,$\theta_{\max}$	 0,π	Theta limits for W. Do not also set YW.
TCMASS m,Γ	 1000,100	Technicolor mass and width.
TMASS m_t,m_y,m_x	 180.,-1.,-1.	t, y, and x quark masses.
WFUDGE factor	 1.85	Fudge factor for DRELLYAN evolution scale.
WMASS M_W,M_Z	 80.2, 91.19	W and Z masses. See SIN2W.

WMMODE		Decay modes for W^- in parton
'UP',...,'TAU+'	'ALL'	cascade. See JETTYPE.
WMODE1		)
'UP','UB',...	'ALL'	)Decay modes for WPAIR.
		)Same code for quarks and
WMODE2		)leptons as JETTYPE.
'UP','UB',...	'ALL'	)
WPMODE		Decay modes for W^+ in parton
'UP',...,'TAU+'	'ALL'	cascade. See JETTYPE.
WTYPE		Select W type: W+,W-,GM,Z0.
type_1,type_2	'GM','Z0'	Do not mix W+,W- and GM,Z0.
X		Feynman x limits for jets.
$x_{\min}(1),\ldots,x_{\max}(3)$	-1,1	
XGEN		Jet fragmentation, Peterson
a(1),...,a(8)	.96,3,0,.8,.5,...	with $\epsilon = a(n)/m^2$, $n =$ 4-8.
XGENSS		Fragmentation of GLSS, UPSS,
a(1),...,a(7)	.5,.5,...	etc. with $\epsilon = a(n)/m**2$
XW		Feynman x limits for W.
$x_{\min}$,$x_{\max}$	-1,1	
Y		Y limits for each jet.
$y_{\min}(1),\ldots,y_{\max}(3)$	from PT	Do not also set TH.
YW		Y limits for W.
$y_{\min}$,$y_{\max}$	from QTW,QMW	Do not set both YW and THW.
Z0MODE		Decay modes for Z^0 in parton
'UP',...,'TAU+'	'ALL'	cascade. See JETTYPE.

6.3 Kinematic and Parton-type Parameters

While the TWOJET PT limits and the DRELLYAN QMW limits are formally optional parameters, they are set by default to be fractions of $\sqrt{s}$. Thus, for example, the parameter file

```
DEFAULT TWOJET JOB
14000,100,1,100/
TWOJET
END
STOP
```

will execute, but it will generate jets between 5% and 20% of $\sqrt{s}$, which is probably not what is wanted. Similarly, the parameter file

```
DEFAULT DRELLYAN JOB
14000,100,1,100/
DRELLYAN
END
STOP
```

will generate $\gamma + Z$ events with masses between 5% and 20% of $\sqrt{s}$, not masses around the Z mass, and transverse momenta between 1 GeV and 2.5% of $\sqrt{s}$.

Normally the user should set PT limits for TWOJET, PHOTON, WPAIR, SUPERSYM, and WHIGGS events and QMW and QTW limits for DRELLYAN, HIGGS, and TCOLOR events. If these limits are not set, they will be selected as fractions of $E_{\rm cm}$. This can give nonsense. For TWOJET the p_t range should usually be less than about a factor of two except for b and t jets at low p_t to produce uniform statistics. For W^+, W^-, or Z^0 events or for Higgs events the QMW (QMH) range should usually include the mass. But one can select different limits to study, e.g., virtual W production or the effect of a lighter or heavier Higgs on WW scattering. If only t decays are selected, then the lower QMW limit must be above the t threshold. For standard Drell-Yan events QTW should be fixed to zero,

```
QTW
0/
```

Transverse momenta will then be generated by initial state gluon radiation. A range of QTW can also be given. For SUPERSYM either the masses and decay modes should be specified, or the MSSM, SUGRA, GMSB, or AMSB parameters should be given. For fourth generation quarks it is necessary to specify the quark masses.

Note that if the limits given cover too large a kinematic range, the program can become very inefficient, since it makes a fit to the cross section over the specified range. NTRIES has to be increased if narrow limits are set for X, XW or for jet 1 and jet 2 parameters in DRELLYAN events. For larger ranges several runs can be combined together using the integrated cross section per event SIGF/NEVENT as the weight. This cross section is calculated for each run by Monte Carlo integration over the specified kinematic limits and is printed at the end of the run. It is corrected for JETTYPEi, WTYPE, and WMODEi selections; it cannot be corrected for branching ratios of forced decays or for WPMODE, WMMODE, or Z0MODE selections, since these can affect an arbitrary number of particles.

To generate events over a large range, it is much more efficient to combine several runs. This is facilitated by using the special job title SAME as described above. Note that SAME cannot be used to combine standard DRELLYAN events (QTW fixed equal to 0) and DRELLYAN events with nonzero QTW.

The cross sections for multiparton final states in general have infrared and collinear singularities. To obtain sensible results, it is in general essential to set limits both on the p_T of each final parton using PT and on the mass of each pair of partons using MIJLIM. The default lower limits are all 1 GeV. Using these default limits without thought will likely give absurd results.

For TWOJET, DRELLYAN, and most other processes, the JETTYPEi and WTYPEi keywords should be used to select the subprocesses to be included. For $e^+e^- \to W^+W^-$, Z^0Z^0, use FORCE and FORCE1 instead of WMODEi to select the W decay modes. Note that these *do not* change the calculated cross section. (In the E+E- process, the W and Z decays are currently treated as particle decays, whereas in the WPAIR and HIGGS processes they are treated as $2 \to 4$ parton processes.)

For HIGGS with W^+W^- or Z^0Z^0 decays allowed it is generally necessary to set PT limits for the W's, e.g.

```
PT
50,20000,50,20000/
```

If this is not done, then the default lower limit of 1 GeV is used, and the t-channel exchanges will dominate, as they should in the effective W approximation. Depending on the other parameters, the program may fail to generate an event in NTRIES tries.

6.4 SUSY Parameters

SUPERSYM (SUSY) by default generates just gluinos and squarks in pairs. There are no default masses or decay modes. Masses can be set using GAUGINO, SQUARK, SLEPTON, and HMASSES. Decay modes can be specified with FORCE or by modifying the decay table. Left and right squarks are distinguished but assumed to be degenerate, except for stops. Since version 7.11, types must be selected with JETTYPEi using the supersymmetric names, e.g.

```
JETTYPE1
'GLSS','UPSSL','UPSSR'/
```

Use of the corresponding standard model names, e.g.

```
JETTYPE1
'GL','UP'/
```

and generation of pure photinos, winos, and zinos are no longer supported.

If MSSMA, MSSMB and MSSMC are given, then the specified parameters are used to calculate all the masses and decay modes with the ISASUSY package assuming the minimal supersymmetric extension of the standard model (MSSM). There are no default values, so you must specify values for each MSSMi, i=A-C. MSSMD can optionally be used to set the second generation squark and slepton parameters; if it is omitted, then the first generation ones are used. MSSME can optionally be used to set the U(1) and SU(2) gaugino masses; if it is omitted, then the grand unification values are used. The parameters and the use of the MSSM is preserved if the title is SAME. FORCE can be used to override the calculated branching ratios.

The MSSM option also generates charginos and neutralinos with cross sections based on the MSSM mixing angles in addition to squarks and sleptons. These can be selected with JETTYPEi; the complete list of supersymmetric options is:

```
'GLSS',
'UPSSL','UBSSL','DNSSL','DBSSL','STSSL','SBSSL','CHSSL','CBSSL',
'BTSS1','BBSS1','TPSS1','TBSS1',
'UPSSR','UBSSR','DNSSR','DBSSR','STSSR','SBSSR','CHSSR','CBSSR',
'BTSS2','BBSS2','TPSS2','TBSS2',
'W1SS+','W1SS-','W2SS+','W2SS-','Z1SS','Z2SS','Z3SS','Z4SS',
'NUEL','ANUEL','EL-','EL+','NUML','ANUML',MUL-','MUL+','NUTL',
'ANUTL','TAU1-','TAU1+','ER-','ER+','MUR-','MUR+','TAU2-','TAU2+',
'Z0','HL0','HH0','HA0','H+','H-',
'SQUARKS','GAUGINOS','SLEPTONS','ALL'.
```

Note that mixing between L and R stop states results in 1 (light) and 2 (heavy) stop, sbottom and stau eigenstates, which depend on the input parameters of left- and right- scalar masses, plus A terms, μ and $\tan\beta$. The last four JETTYPE's generate respectively all allowed combinations of squarks and antisquarks, all combinations of charginos and neutralinos, all combinations of sleptons and sneutrinos, and all SUSY particles.

For SUSY Higgs pair production or associated production in E+E-, select the appropriate JETTYPE's, e.g.

```
JETTYPE1
'Z0'/
JETTYPE2
'HL0'/
```

As usual, this gives only half the cross section. For single production of neutral SUSY Higgs in pp and $\bar{p}p$ reactions, use the HIGGS process together with the MSSMi, SUGRA, GMSB, or AMSB keywords. You must specify one and only one Higgs type using

```
HTYPE
'HL0' or 'HH0' or 'HA0'/      <<<<< One only!
```

If no QMH range is given, one is calculated using $M \pm 5\Gamma$ for the selected Higgs. Decays into quarks, leptons, gauge bosons, lighter Higgs bosons, and SUSY particles are generated using the on-shell branching ratios from ISASUSY. You can use JETTYPEi to select the allowed Higgs modes and WMODEi to select the allowed decays of W and Z bosons. Since heavy SUSY Higgs bosons couple weakly to W pairs, WW fusion and WW scattering are not included.

SUGRA can be used instead of MSSMi to generate MSSM decays with parameters determined from m_0, $m_{1/2}$, A_0, $\tan\beta$, and $\operatorname{sgn}\mu = \pm 1$ in the minimal supergravity framework. The NUSUGi keywords can optionally be used to specify additional parameters for non-universal SUGRA models, while SUGRHN is used to specify the parameterf of an optional right-handed neutrino. Similarly, the GMSB keyword is used to specify the Λ, M_m, N_5, $\tan\beta$, $\operatorname{sgn}\mu = \pm 1$, and C_{grav} parameters of the minimal Gauge Mediated SUSY Breaking model. GMSB2 can optionally be used to specify additional parameters of non-minimal GMSB models. The AMSB keyword is used to specify m_0, $m_{3/2}$, $\tan\beta$, and $\operatorname{sgn}\mu$ for the minimal Anomaly Mediated SUSY Breaking model. Note that $m_{3/2}$ is much larger than the weak scale, typically 50 TeV.

WHIGGS is used to generate W plus neutral Higgs events. For the Standard Model the JETTYPE is `HIGGS`. If any of the SUSY models is specified, then the appropriate SUSY Higgs type should be used, most likely `HL0`. In either case WMODEi is used to specify the W decay modes. The Higgs is treated as a particle; its decay modes can be set using FORCE.

6.5 Forced Decay Modes

The FORCE keyword requires special care. Its list must contain the numerical particle IDENT codes, e.g.

```
FORCE
140,130,-120/
```

The charge-conjugate mode is also forced for its antiparticle. Thus the above example forces both $\bar{D}^0 \to K^+\pi^-$ and $D^0 \to K^-\pi^+$. If only a specific decay is wanted one should use the FORCE1 command; e.g.

```
FORCE1
140,130,-120/
```

only forces $\bar{D}^0 \to K^+\pi^-$.

To force a heavy quark decay one must generally separately force each hadron containing it. If the decay is into three leptons or quarks, then the real or virtual W propagator is inserted automatically. Since Version 7.30, top and fourth generation quarks are treated as particles and decayed directly rather than first being made into hadrons. Thus for example

```
FORCE1
6,-12,11,5/
```

forces all top quarks to decay into an positron, neutrino and a b-quark (which will be hadronized). For the physical top mass, the positron and neutrino will come from a real W. Note that forcing $t \to W^+ b$ and $W^+ \to e^+\nu_e$ does *not* give the same result; the first uses the correct $V - A$ matrix element, while the second decays the W according to phase space.

Forced modes included in the decay table or generated by ISASUSY will automatically be put into the correct order and will use the correct matrix element. Modes not listed in the decay table are allowed, but caution is advised because a wrong decay mode can cause an infinite loop or other unexpected effects.

FORCE (FORCE1) can be called at most 20 (40) times in any run plus all subsequent 'SAME' runs. If it is called more than once for a given parent, all calls are listed, and the last call is used. Note that FORCE applies to particles only, but that for gamma, W+, W-, Z0 and supersymmetric particles the same IDENT codes are used both as jet types and as particles.

6.6 Parton Distributions

The default parton distributions are fit CTEQ3L from the CTEQ Collaboration using lowest order QCD. The CTEQ and the older EHLQ and Duke-Owens distributions can be selected using the STRUC keyword.

If PDFLIB support is enabled (see Section 4), then any of the distributions in the PDFLIB compilation by H. Plothow-Besch can be selected using the PDFLIB keyword and giving the proper parameters, which are identical to those described in the PDFLIB manual and are simply passed to the routine PDFSET. For example, to select fit 29 (CTEQ3L) by the CTEQ group, leaving all other parameters with their default values, use

```
PDFLIB
'CTEQ',29D0/
```

Note that the fit-number and the other parameters are of type DOUBLE PRECISION (REAL on 64-bit machines). There is no internal passing of parameters except for those which control the printing of messages.

6.7 Multiparton Processes

For multiparton final states one should in general set limits on the total mass `MTOT` of the final state, on the minimum `PT` of each light parton, and on the minimum mass `MIMLIM` of each pair of light partons. Limits for `PT` are set in the ususal way. Limits for the mass M_{ij} of partons i, j are set using

```
MIJLIM
i,j,Mmin,Mmax
```

If $i = j = 0$, the limit is applied to all jet pairs. For example the following parameter file generates `ZJJ` events at the LHC with a mimimum p_T of 20 GeV and a minimum mass of 20 GeV for all jet pairs:

```
GENERATE ZJJ with PTMIN = 20 GEV AND MMIN = 20 GEV
14000,100,1,100/
ZJJ
PT
20,7000,20,7000,20,7000/
MIJLIM
```

```
0,0,20,7000/
MTOT
100,500/
NSIGMA
200/
NTRIES
10000/
END
STOP
```

The default lower limits for PT and MIJLIM are 1 GeV. While these limits are sufficient to make the cross sections finite, they will in general not give physically sensible results. Thus, *the user must think carefully about what limits should be set.*

7 Output

The output tape or file contains three types of records. A beginning record is written by a call to ISAWBG before generating a set of events; an event record is written by a call to ISAWEV for each event; and an end record is written for each run by a call to ISAWND. These subroutines load the common blocks described below into a single

```
COMMON/ZEVEL/ZEVEL(1024)
```

and write it out when it is full. A subroutine RDTAPE, described in the next section, inverts this process so that the user can analyze the event.

ZEVEL is written out to TAPEj by a call to BUFOUT. For the CDC version IF = PAIRPAK is selected; BUFOUT first packs two words from ZEVEL into one word in

```
COMMON/ZVOUT/ZVOUT(512)
```

using subroutine PAIRPAK and then does a buffer out of ZVOUT to TAPEj. Typically at least two records are written per event. For all other computers IF=STDIO is selected, and ZEVEL is written out with a standard FORTRAN unformatted write.

7.1 Beginning Record

At the start of each run ISAWBG is called. It writes out the following common blocks:

```
      COMMON/DYLIM/QMIN,QMAX,QTMIN,QTMAX,YWMIN,YWMAX,XWMIN,XWMAX,THWMIN,
     2  THWMAX,PHWMIN,PHWMAX
     3  ,SETLMQ(12)
      SAVE /DYLIM/
      LOGICAL SETLMQ
      EQUIVALENCE(BLIM1(1),QMIN)
      REAL      QMIN,QMAX,QTMIN,QTMAX,YWMIN,YWMAX,XWMIN,XWMAX,THWMIN,
     +          THWMAX,PHWMIN,PHWMAX,BLIM1(12)
```

QMIN,QMAX	=	W mass limits
QTMIN,QTMAX	=	W q_t limits
YWMIN,YWMAX	=	W η rapidity limits
XWMIN,XWMAX	=	W x_F limits
THWMIN,THWMAX	=	W θ limits
PHWMIN,PHWMAX	=	W ϕ limits

```
      COMMON/IDRUN/IDVER,IDG(2),IEVT,IEVGEN
      SAVE /IDRUN/
      INTEGER   IDVER,IDG,IEVT,IEVGEN
```

IDVER	=	program version
IDG(1)	=	run date (10000×month+100×day+year)
IDG(2)	=	run time (10000×hour+100×minute+second)
IEVT	=	event number

```
C          Jet limits
      INTEGER MXLIM
      PARAMETER (MXLIM=8)
      INTEGER MXLX12
      PARAMETER (MXLX12=12*MXLIM)
      COMMON/JETLIM/PMIN(MXLIM),PMAX(MXLIM),PTMIN(MXLIM),PTMAX(MXLIM),
     $YJMIN(MXLIM),YJMAX(MXLIM),PHIMIN(MXLIM),PHIMAX(MXLIM),
     $XJMIN(MXLIM),XJMAX(MXLIM),THMIN(MXLIM),THMAX(MXLIM),
     $SETLMJ(12*MXLIM)
      SAVE /JETLIM/
      COMMON/FIXPAR/FIXP(MXLIM),FIXPT(MXLIM),FIXYJ(MXLIM),
     $FIXPHI(MXLIM),FIXXJ(MXLIM),FIXQM,FIXQT,FIXYW,FIXXW,FIXPHW
      SAVE /FIXPAR/
      COMMON/SGNPAR/CTHS(2,MXLIM),THS(2,MXLIM),YJS(2,MXLIM),XJS(2,MXLIM)
      SAVE /SGNPAR/
      REAL      PMIN,PMAX,PTMIN,PTMAX,YJMIN,YJMAX,PHIMIN,PHIMAX,XJMIN,
     +          XJMAX,THMIN,THMAX,BLIMS(12*MXLIM),CTHS,THS,YJS,XJS
      LOGICAL SETLMJ
      LOGICAL FIXQM,FIXQT,FIXYW,FIXXW,FIXPHW
      LOGICAL FIXP,FIXPT,FIXYJ,FIXPHI,FIXXJ
      EQUIVALENCE(BLIMS(1),PMIN(1))
```

PMIN,PMAX	=	jet momentum limits
PTMIN,PTMAX	=	jet p_t limits
YJMIN,YJMAX	=	jet η rapidity limits
PHIMIN,PHIMAX	=	jet ϕ limits
THMIN,THMAX	=	jet θ limits

```
      INTEGER MXKEYS
      PARAMETER (MXKEYS=20)
      COMMON/KEYS/IKEYS,KEYON,KEYS(MXKEYS)
      COMMON/XKEYS/REAC
      SAVE /KEYS/,/XKEYS/
      LOGICAL KEYS
      LOGICAL KEYON
      CHARACTER*8 REAC
      INTEGER   IKEYS
```

KEYON	=	normally TRUE, FALSE if no good reaction
KEYS	=	TRUE if reaction I is chosen
		1 for TWOJET
		2 for E+E-
		3 for DRELLYAN
		4 for MINBIAS
		5 for SUPERSYM
		6 for WPAIR
REAC	=	character reaction code

```
      COMMON/PRIMAR/NJET,SCM,HALFE,ECM,IDIN(2),NEVENT,NTRIES,NSIGMA
      SAVE /PRIMAR/
      INTEGER   NJET,IDIN,NEVENT,NTRIES,NSIGMA
      REAL      SCM,HALFE,ECM
```

NJET	=	number of jets per event
SCM	=	square of com energy
HALFE	=	beam energy
ECM	=	com energy
IDIN	=	ident code for initial beams
NEVENT	=	number of events to be generated
NTRIES	=	maximum number of tries for good jet parameters
NSIGMA	=	number of extra events to determine SIGF

```
      INTEGER MXGOQ,MXGOJ
      PARAMETER (MXGOQ=85,MXGOJ=8)
      COMMON/Q1Q2/GOQ(MXGOQ,MXGOJ),GOALL(MXGOJ),GODY(4),STDDY,
     $GOWW(25,2),ALLWW(2),GOWMOD(25,MXGOJ)
      SAVE /Q1Q2/
      LOGICAL GOQ,GOALL,GODY,STDDY,GOWW,ALLWW,GOWMOD
```

GOQ(I,K)	=	TRUE if quark type I allowed for jet k
		I = 1 2 3 4 5 6 7 8 9 10 11 12 13
		$\Rightarrow g\ u\ \bar{u}\ d\ \bar{d}\ s\ \bar{s}\ c\ \bar{c}\ b\ \bar{b}\ t\ \bar{t}$
		I = 14 15 16 17 18 19 20 21 22 23 24 25
		$\Rightarrow \nu_e\ \bar{\nu}_e\ e^-\ e^+\ \nu_\mu\ \bar{\nu}_\mu\ \mu^-\ \mu^+\ \nu_\tau\ \bar{\nu}_\tau\ \tau^-\ \tau^+$
GOALL(K)	=	TRUE if all jet types allowed
GODY(I)	=	TRUE if W type I is allowed.
I= 1 2 3 4		
GM W+ W- Z0		
STDDY	=	TRUE if standard DRELLYAN
GOWW(I,K)	=	TRUE if I is allowed in the decay of K for WPAIR.
ALLWW(K)	=	TRUE if all allowed in the decay of K for WPAIR.

```
      COMMON/QCDPAR/ALAM,ALAM2,CUTJET,ISTRUC
      SAVE /QCDPAR/
```

```
      INTEGER   ISTRUC
      REAL      ALAM,ALAM2,CUTJET
```

ALAM	=	QCD scale Λ
ALAM2	=	QCD scale Λ^2
CUTJET	=	cutoff for generating secondary partons
ISTRUC	=	3 for Eichten (EHLQ),
	=	4 for Duke (DO)
	=	5 for CTEQ 2L
	=	6 for CTEQ 3L
	=	-999 for PDFLIB

```
      COMMON/QLMASS/AMLEP(100),NQLEP,NMES,NBARY
      SAVE /QLMASS/
      INTEGER   NQLEP,NMES,NBARY
      REAL      AMLEP
```

AMLEP(6:8) = t,y,x masses, only elements written

7.2 Event Record

For each event ISAWEV is called. It writes out the following common blocks:

```
      COMMON/FINAL/NKINF,SIGF,ALUM,ACCEPT,NRECS
      SAVE /FINAL/
      INTEGER   NKINF,NRECS
      REAL      SIGF,ALUM,ACCEPT
```

SIGF = integrated cross section, only element written

```
      COMMON/IDRUN/IDVER,IDG(2),IEVT,IEVGEN
      SAVE /IDRUN/
      INTEGER   IDVER,IDG,IEVT,IEVGEN
```

IDVER	=	program version
IDG	=	run identification
IEVT	=	event number

```
      COMMON/JETPAR/P(3),PT(3),YJ(3),PHI(3),XJ(3),TH(3),CTH(3),STH(3)
     1 ,JETTYP(3),SHAT,THAT,UHAT,QSQ,X1,X2,PBEAM(2)
     2 ,QMW,QW,QTW,YW,XW,THW,QTMW,PHIW,SHAT1,THAT1,UHAT1,JWTYP
     3 ,ALFQSQ,CTHW,STHW,Q0W
     4 ,INITYP(2),ISIGS,PBEAMS(5)
      SAVE /JETPAR/
      INTEGER   JETTYP,JWTYP,INITYP,ISIGS
      REAL      P,PT,YJ,PHI,XJ,TH,CTH,STH,SHAT,THAT,UHAT,QSQ,X1,X2,
     +          PBEAM,QMW,QW,QTW,YW,XW,THW,QTMW,PHIW,SHAT1,THAT1,UHAT1,
     +          ALFQSQ,CTHW,STHW,Q0W,PBEAMS
```

P	=	jet momentum $\|\vec{p}\|$
PT	=	jet p_t
YJ	=	jet η rapidity
PHI	=	jet ϕ
XJ	=	jet x_F
TH	=	jet θ
CTH	=	jet $\cos(\theta)$
STH	=	jet $\sin(\theta)$
JETTYP	=	jet type. The code is listed under /Q1Q2/ above

continued...

SHAT,THAT,UHAT	=	hard scattering $\hat{s}$, $\hat{t}$, $\hat{u}$
QSQ	=	effective Q^2
X1,X2	=	initial parton x_F
PBEAM	=	remaining beam momentum
QMW	=	W mass
QW	=	W momentum
QTW	=	W transverse momentum
YW	=	W rapidity
XW	=	W x_F
THW	=	W θ
QTMW	=	$\sqrt{q_{t,W}^2 + Q^2}$
PHIW	=	W ϕ
SHAT1,THAT1,UHAT1	=	invariants for W decay
JWTYP	=	W type. The code is listed under /Q1Q2/ above.
ALFQSQ	=	QCD coupling $\alpha_s(Q^2)$
CTHW	=	W $\cos(\theta)$
STHW	=	W $\sin(\theta)$
Q0W	=	W energy

```
      INTEGER   MXJSET,JPACK
      PARAMETER (MXJSET=400,JPACK=1000)
      COMMON/JETSET/NJSET,PJSET(5,MXJSET),JORIG(MXJSET),JTYPE(MXJSET),
     $JDCAY(MXJSET)
      SAVE /JETSET/
      INTEGER   NJSET,JORIG,JTYPE,JDCAY
      REAL      PJSET
```

NJSET = number of partons
PJSET(1,I) = p_x of parton I
PJSET(2,I) = p_y of parton I
PJSET(3,I) = p_z of parton I
PJSET(4,I) = p_0 of parton I
PJSET(5,I) = mass of parton I
JORIG(I) = JPACK*JET+K if I is a decay product of K.
IF K=0 then I is a primary parton.
(JET = 1,2,3 for final jets.)
(JET = 11,12 for initial jets.)
JTYPE(I) = IDENT code for parton I
JDCAY(I) = JPACK*K1+K2 if K1 and K2 are decay products of I.
If JDCAY(I)=0 then I is a final parton
MXJSET = dimension for /JETSET/ arrays.
JPACK = packing integer for /JETSET/ arrays.

```
      INTEGER   MXSIGS,IOPAK
      PARAMETER (MXSIGS=3000,IOPAK=100)
      COMMON/JETSIG/SIGMA,SIGS(MXSIGS),NSIGS,INOUT(MXSIGS),SIGEVT
      SAVE /JETSIG/
      INTEGER   NSIGS,INOUT
      REAL      SIGMA,SIGS,SIGEVT
```

SIGMA = cross section summed over types
SIGS(I) = cross section for reaction I (not written)
NSIGS = number of nonzero cross sections (not written)
INOUT(I) = packed partons for process I (not written)
MXSIGS = dimension for JETSIG arrays (not written)
SIGEVT = partial cross section for selected channel

```
      INTEGER   MXPTCL,IPACK
      PARAMETER (MXPTCL=4000,IPACK=10000)
      COMMON/PARTCL/NPTCL,PPTCL(5,MXPTCL),IORIG(MXPTCL),IDENT(MXPTCL)
     1,IDCAY(MXPTCL)
      SAVE /PARTCL/
      INTEGER   NPTCL,IORIG,IDENT,IDCAY
      REAL      PPTCL
```

NPTCL	=	number of particles
PPTCL(1,I)	=	p_x for particle I
PPTCL(2,I)	=	p_y for particle I
PPTCL(3,I)	=	p_z for particle I
PPTCL(4,I)	=	p_0 for particle I
PPTCL(5,I)	=	mass for particle I
IORIG(I)	=	IPACK*JET+K if I is a decay product of K.
	=	-(IPACK*JET+K) if I is a primary particle from parton K in /JETSET/.
	=	0 if I is a primary beam particle. (JET = 1,2,3 for final jets.) (JET = 11,12 for initial jets.)
IDENT(I)	=	IDENT code for particle I
IDCAY(I)	=	IPACK*K1+K2 if decay products are K1-K2 inclusive. If IDCAY(I)=0 then particle I is stable.
MXPTCL	=	dimension for /PARTCL/ arrays.
IPACK	=	packing integer for /PARTCL/ arrays.

```
      COMMON/PINITS/PINITS(5,2),IDINIT(2)
      SAVE /PINITS/
      INTEGER   IDINIT
      REAL      PINITS
```

PINITS(1,I)	=	p_x for initial parton I
PINITS(2,I)	=	p_y for initial parton I
PINITS(3,I)	=	p_z for initial parton I
PINITS(4,I)	=	p_0 for initial parton I
PINITS(5,I)	=	mass for initial parton I
IDINIT(I)	=	IDENT for initial parton I

```
      INTEGER MXJETS
      PARAMETER (MXJETS=10)
      COMMON/PJETS/PJETS(5,MXJETS),IDJETS(MXJETS),QWJET(5),IDENTW
     $,PPAIR(5,4),IDPAIR(4),JPAIR(4),NPAIR,IFRAME(MXJETS)
      SAVE /PJETS/
      INTEGER   IDJETS,IDENTW,IDPAIR,JPAIR,NPAIR,IFRAME
      REAL      PJETS,QWJET,PPAIR
```

PJETS(1,I) = p_x for jet I
PJETS(2,I) = p_y for jet I
PJETS(3,I) = p_z for jet I
PJETS(4,I) = p_0 for jet I
PJETS(5,I) = mass for jet I
IDJETS(I) = IDENT code for jet I
QWJET(1) = p_x for W
QWJET(2) = p_y for W
QWJET(3) = p_z for W
QWJET(4) = p_0 for W
QWJET(5) = mass for W
IDENTW = IDENT CODE for W
PPAIR(1,I) = p_x for WPAIR decay product I
PPAIR(2,I) = p_y for WPAIR decay product I
PPAIR(3,I) = p_z for WPAIR decay product I
PPAIR(4,I) = p_0 for WPAIR decay product I
PPAIR(5,I) = mass for WPAIR decay product I
IDPAIR(I) = IDENT code for WPAIR product I
JPAIR(I) = JETTYPE code for WPAIR product I
NPAIR = 2 for $W^{\pm}\gamma$ events, 4 for WW events

```
      COMMON/TOTALS/NKINPT,NWGEN,NKEEP,SUMWT,WT
      SAVE /TOTALS/
      INTEGER   NKINPT,NWGEN,NKEEP
      REAL      SUMWT,WT
```

NKINPT = number of kinematic points generated.
NWGEN = number of W+jet events accepted.
NKEEP = number of events kept.
SUMWT = sum of weighted cross sections.
WT = current weight. (SIGMA×WT = event weight.)

```
      COMMON/WSIG/SIGLLQ
      SAVE /WSIG/
      REAL      SIGLLQ
```

SIGLLQ = cross section for W decay.

Of course irrelevant common blocks such as /WSIG/ for TWOJET events are not written out.

7.3 End Record

At the end of a set ISAWND is called. It writes out the following common block:

```
      COMMON/FINAL/NKINF,SIGF,ALUM,ACCEPT,NRECS
      SAVE /FINAL/
```

```
      INTEGER   NKINF,NRECS
      REAL      SIGF,ALUM,ACCEPT
```

NKINF	=	number of points generated to calculate SIGF
SIGF	=	integrated cross section for this run
ALUM	=	equivalent luminosity for this run
ACCEPT	=	ratio of events kept over events generated
NRECS	=	number of physical records for this run

Events within a given run have uniform weight. Separate runs can be combined together using SIGF/NEVENT as the weight per event. This gives a true cross section in mb units.

The user can replace subroutines ISAWBG, ISAWEV, and ISAWND to write out the events in a different format or to update histograms using HBOOK or any similar package.

8 File Reading

The FORTRAN instruction

```
CALL RDTAPE(IDEV,IFL)
```

will read a beginning record, an end record or an event (which can be more than one record). IDEV is the tape number and

```
IFL=0  for a good read,
IFL=-1 for an end of file.
```

The information is restored to the common blocks described above. The type of record is contained in

```
COMMON/RECTP/IRECTP,IREC
SAVE /RECTP/
INTEGER   IRECTP,IREC
```

IRECTP	=	100 for an event record
IRECTP	=	200 for a beginning record
IRECTP	=	300 for an end record
IREC	=	no. of physical records in event record, 0 otherwise

The parton momenta from the primary hard scattering are contained in /PJETS/. The parton momenta generated by the QCD cascade are contained in /JETSET/. The hadron momenta both from the QCD jets and from the beam jets are contained in /PARTCL/. The final hadron momenta and the associated pointers should be used to calculate the jet momenta, since they are changed both by the QCD cascade and by hadronization. Particles with IDCAY=0 are stable, while the others are resonances.

The weight per event needed to produce a weighted histogram in millibarn units is SIGF/NEVENT. The integrated cross section SIGF is calculated by Monte Carlo integration during the run for the given kinematic limits and JETTYPE, WTYPE, and WMODE selections. Any of three methods can be used to find the value of SIGF:

(1) The current value, which is written out with each event, can be used. To prevent enormous fluctuations at the beginning of a run, NSIGMA extra primary parton events are generated first. The default value, NSIGMA = 20, gives negligible overhead but may not be large enough for good accuracy.

(2) The value SIGF calculated with the full statistics of the run can be obtained by reading through the tape until an end record (IRECTP=300) is found. After SIGF is saved with a different name, the first event record for the run can be found by backspacing the tape NRECS times.

(3) Unweighted histograms can be made for the run and the weight added after the end record is found. An implementation of this using special features of HBOOK is contained in ISAPLT.

The functions AMASS(IDENT), CHARGE(IDENT), and LABEL(IDENT) are available to determine the mass, charge, and character label in A8 format. Subroutine FLAVOR returns the quark content of any hadron and may be useful to convert IDENT codes to other schemes. CALL PRTEVT(0) prints an event.

9 Decay Table

ISAJET uses an external table of decay modes. Particles can be put into the table in arbitrary order, but all modes for each particle must be grouped together. The table is rewound and read in before each run with a READ* format. Beginning with Version 7.41, the decay table must begin with a comment of the form

```
' ISAJET     V7.41   11-JAN-1999 20:41:57'
```

If this does not match the internal version number, a warning is printed. After this initial line, each entry must have the form

```
IDENT,MELEM,CBR,ID1,ID2,ID3,ID4,ID5/
```

where IDENT is the code for the parent particle, MELEM specifies the decay matrix element, CBR is the cumulative branching ratio, and ID1,...,ID5 are the IDENT codes for the decay products. The currently defined values of MELEM are:

MELEM	Matrix Element
0	Phase Space
1	Dalitz decay
2	ω/ϕ decay
3	$V-A$ decay
4	top decay: $V-A$ plus W propagator
5	$\tau \to \ell\nu\bar{\nu}$
6	$\tau \to \nu\pi$, νK
7	$\tau \to \nu\rho$, νa_1

The parent IDENT must be positive; the charge conjugate mode is used for the antiparticle. The values of CBR must of course be positive and monotonically increasing for each mode, with the last value being 1.00 for each parent IDENT. The last parent IDENT code must be zero. Care should be taken in adding new modes, since there is no checking for validity. In some cases order is important; note in particular that quarks and gluons must always appear last so that they can be removed and fragmented into hadrons.

The format of the decay table for Versions 7.41 and later is incompatible with that for Versions 7.40 and earlier. Using an obsolete decay table will produce incorrect results.

The decay table is contained in patch ISADECAY.

10 IDENT Codes

ISAJET uses a numerical ident code for particle types. Quarks and leptons are numbered in order of mass:

```
UP     = 1             NUE    = 11
DN     = 2             E-     = 12
ST     = 3             NUM    = 13
CH     = 4             MU-    = 14
BT     = 5             NUT    = 15
TP     = 6             TAU-   = 16
```

with a negative sign for antiparticles. Arbitrary conventions are:

```
GL     = 9
GM     = 10
KS     = 20
KL     =-20
W+     = 80
Z0     = 90
```

The supersymmetric particle IDENT codes distinguish between the partners of left and right handed fermions and include the Higgs sector of the minimal supersymmetric model:

```
UPSSL ... TPSS1 = 21 ... 26
NUEL ... TAU1-  = 31 ... 36
UPSSR ... TPSS2 = 41 ... 46
NUER ... TAU2-  = 51 ... 56
GLSS  = 29
Z1SS  = 30            Z2SS  = 40
Z3SS  = 50            Z4SS  = 60
W1SS+ = 39            W2SS+ = 49

HL0   = 82            HH0   = 83
HA0   = 84            H+    = 86
```

Finally, the gravitino and graviton are

```
GVSS  = 91            GRAV  = 92
```

The same symbol is used for the graviton and its (possible) Kaluza-Klein excitations.

The code for a meson is a compound integer +-JKL, where J.LE.K are the quarks and L is the spin. The sign is for the J quark. Glueball IDENT codes have not been selected, but the choice GL=9 clearly allows 990, 9990, etc. Flavor singlet mesons are ordered by mass,

```
PI0    = 110
ETA    = 220
ETAP   = 330
ETAC   = 440
```

which is natural for the heavy quarks. Similarly, the code for a baryon is a compound integer +-IJKL formed from the three quarks I,J,K and a spin label L=0,1. The code for a diquark is +-IJ00. Additional states are distinguished by a fifth integer, e.g.,

```
A1+    = 10121
```

These and a few J=2 mesons are used in some of the B decays.

A routine PRTLST is provided to print out a complete list of valid IDENT codes and associated information. The usage is CALL PRTLST(LUN, AMY, AMX) where LUN is the unit number and AMY and AMX are the masses of the Y and X quarks respectively. This routine should be linked with the ISAJET library and with ALDATA.

The complete list of ident codes follows. (Hadrons containing t quarks are defined but are no longer listed since the t quark is treated as a particle.)

IDENT	LABEL	MASS	CHARGE
1	UP	.30000E+00	.67
-1	UB	.30000E+00	-.67
2	DN	.30000E+00	-.33
-2	DB	.30000E+00	.33
3	ST	.50000E+00	-.33
-3	SB	.50000E+00	.33
4	CH	.16000E+01	.67
-4	CB	.16000E+01	-.67
5	BT	.49000E+01	-.33
-5	BB	.49000E+01	.33
6	TP	.17500E+03	.67
-6	TB	.17500E+03	-.67
9	GL	0.	0.00
10	GM	0.	0.00
11	NUE	0.	0.00
-11	ANUE	0.	0.00
12	E-	.51100E-03	-1.00
-12	E+	.51100E-03	1.00
13	NUM	0.	0.00
-13	ANUM	0.	0.00
14	MU-	.10566E+00	-1.00
-14	MU+	.10566E+00	1.00
15	NUT	0.	0.00
-15	ANUT	0.	0.00
16	TAU-	.18070E+01	-1.00
-16	TAU+	.18070E+01	1.00

20	KS	.49767E+00	0.00
-20	KL	.49767E+00	0.00
21	UPSSL	none	0.67
-21	UBSSL	none	-0.67
22	DNSSL	none	-0.33
-22	DBSSL	none	0.33
23	STSSL	none	-0.33
23	SBSSL	none	0.33
24	CHSSL	none	0.67
-24	CBSSL	none	-0.67
25	BTSS1	none	-0.33
-25	BBSS1	none	0.33
26	TPSS1	none	0.67
-26	TBSS1	none	-0.67
29	GLSS	none	0.00
30	Z1SS	none	0.00
31	NUEL	none	0.00
-31	ANUEL	none	0.00
32	EL-	none	-1.00
-32	EL+	none	+1.00
33	NUML	none	0.00
-33	ANUML	none	0.00
34	MUL-	none	-1.00
-34	MUL+	none	+1.00
35	NUTL	none	0.00
-35	ANUTL	none	0.00
36	TAU1-	none	-1.00
-36	TAU1+	none	-1.00
39	W1SS+	none	1.00
-39	W1SS-	none	-1.00
40	Z2SS	none	0.00
41	UPSSR	none	0.67
-41	UBSSR	none	-0.67
42	DNSSR	none	-0.33
-42	DBSSR	none	0.33
43	STSSR	none	-0.33
43	SBSSR	none	0.33
44	CHSSR	none	0.67
-44	CBSSR	none	-0.67

45	BTSS2	none	-0.33
-45	BBSS2	none	0.33
46	TPSS2	none	0.67
-46	TBSS2	none	-0.67
49	W2SS+	none	1.00
-49	W2SS-	none	-1.00
50	Z3SS	none	0.00
51	NUER	none	0.00
-51	ANUER	none	0.00
52	ER-	none	-1.00
-52	ER+	none	+1.00
53	NUMR	none	0.00
-53	ANUMR	none	0.00
54	MUR-	none	-1.00
-54	MUR+	none	+1.00
55	NUTR	none	0.00
-55	ANUTR	none	0.00
56	TAU2-	none	-1.00
-56	TAU2+	none	-1.00
60	Z4SS	none	0.00
80	W+	.80200E+02	1.00
81	HIGGS	.80200E+02	0.00
82	HL0	none	0.00
83	HH0	none	0.00
84	HA0	none	0.00
86	H+	none	1.00
90	Z0	.91190E+02	0.00
91	GVSS	0	0.00
92	GRAV	0	0.00
110	PI0	.13496E+00	0.00
120	PI+	.13957E+00	1.00
-120	PI-	.13957E+00	-1.00
220	ETA	.54745E+00	0.00
130	K+	.49367E+00	1.00
-130	K-	.49367E+00	-1.00
230	K0	.49767E+00	0.00
-230	AK0	.49767E+00	0.00
330	ETAP	.95760E+00	0.00
140	AD0	.18645E+01	0.00

-140	D0	.18645E+01	0.00
240	D-	.18693E+01	-1.00
-240	D+	.18693E+01	1.00
340	F-	.19688E+01	-1.00
-340	F+	.19688E+01	1.00
440	ETAC	.29788E+01	0.00
150	UB.	.51700E+01	1.00
-150	BU.	.51700E+01	-1.00
250	DB.	.51700E+01	0.00
-250	BD.	.51700E+01	0.00
350	SB.	.53700E+01	0.00
-350	BS.	.53700E+01	0.00
450	CB.	.64700E+01	1.00
-450	BC.	.64700E+01	-1.00
550	BB.	.97700E+01	0.00
111	RHO0	.76810E+00	0.00
121	RHO+	.76810E+00	1.00
-121	RHO-	.76810E+00	-1.00
221	OMEG	.78195E+00	0.00
131	K*+	.89159E+00	1.00
-131	K*-	.89159E+00	-1.00
231	K*0	.89610E+00	0.00
-231	AK*0	.89610E+00	0.00
331	PHI	.10194E+01	0.00
141	AD*0	.20071E+01	0.00
-141	D*0	.20071E+01	0.00
241	D*-	.20101E+01	-1.00
-241	D*+	.20101E+01	1.00
341	F*-	.21103E+01	-1.00
-341	F*+	.21103E+01	1.00
441	JPSI	.30969E+01	0.00
151	UB*	.52100E+01	1.00
-151	BU*	.52100E+01	-1.00
251	DB*	.52100E+01	0.00
-251	BD*	.52100E+01	0.00
351	SB*	.54100E+01	0.00
-351	BS*	.54100E+01	0.00
451	CB*	.65100E+01	1.00
-451	BC*	.65100E+01	-1.00
551	UPSL	.98100E+01	0.00
112	F2	.12750E+01	0.00
132	K2*+	.14254E+01	1.00

-132	K2*-	.14254E+01	-1.00
232	K2*0	.14324E+01	0.00
-232	AK2*0	.14324E+01	0.00
10110	F0	.98000E+00	0.00
10111	A10	.12300E+01	0.00
10121	A1+	.12300E+01	1.00
-10121	A1-	.12300E+01	-1.00
10131	K1+	.12730E+01	1.00
-10131	K1-	.12730E+01	-1.00
10231	K10	.12730E+01	0.00
-10231	AK10	.12730E+01	0.00
30131	K1*+	.14120E+01	1.00
-30131	K1*-	.14120E+01	-1.00
30231	K1*0	.14120E+01	0.00
-30231	AK1*0	.14120E+01	0.00
10441	PSI(2S)	.36860E+01	0.00
20440	CHI0	.34151E+01	0.00
20441	CHI1	.35105E+01	0.00
20442	CHI2	.35662E+01	0.00
1120	P	.93828E+00	1.00
-1120	AP	.93828E+00	-1.00
1220	N	.93957E+00	0.00
-1220	AN	.93957E+00	0.00
1130	S+	.11894E+01	1.00
-1130	AS-	.11894E+01	-1.00
1230	S0	.11925E+01	0.00
-1230	AS0	.11925E+01	0.00
2130	L	.11156E+01	0.00
-2130	AL	.11156E+01	0.00
2230	S-	.11974E+01	-1.00
-2230	AS+	.11974E+01	1.00
1330	XI0	.13149E+01	0.00
-1330	AXI0	.13149E+01	0.00
2330	XI-	.13213E+01	-1.00
-2330	AXI+	.13213E+01	1.00
1140	SC++	.24527E+01	2.00
-1140	ASC--	.24527E+01	-2.00
1240	SC+	.24529E+01	1.00

-1240	ASC-	.24529E+01	-1.00
2140	LC+	.22849E+01	1.00
-2140	ALC-	.22849E+01	-1.00
2240	SC0	.24525E+01	0.00
-2240	ASC0	.24525E+01	0.00
1340	USC.	.25000E+01	1.00
-1340	AUSC.	.25000E+01	-1.00
3140	SUC.	.24000E+01	1.00
-3140	ASUC.	.24000E+01	-1.00
2340	DSC.	.25000E+01	0.00
-2340	ADSC.	.25000E+01	0.00
3240	SDC.	.24000E+01	0.00
-3240	ASDC.	.24000E+01	0.00
3340	SSC.	.26000E+01	0.00
-3340	ASSC.	.26000E+01	0.00
1440	UCC.	.35500E+01	2.00
-1440	AUCC.	.35500E+01	-2.00
2440	DCC.	.35500E+01	1.00
-2440	ADCC.	.35500E+01	-1.00
3440	SCC.	.37000E+01	1.00
-3440	ASCC.	.37000E+01	-1.00
1150	UUB.	.54700E+01	1.00
-1150	AUUB.	.54700E+01	-1.00
1250	UDB.	.54700E+01	0.00
-1250	AUDB.	.54700E+01	0.00
2150	DUB.	.54700E+01	0.00
-2150	ADUB.	.54700E+01	0.00
2250	DDB.	.54700E+01	-1.00
-2250	ADDB.	.54700E+01	1.00
1350	USB.	.56700E+01	0.00
-1350	AUSB.	.56700E+01	0.00
3150	SUB.	.56700E+01	0.00
-3150	ASUB.	.56700E+01	0.00
2350	DSB.	.56700E+01	-1.00
-2350	ADSB.	.56700E+01	1.00
3250	SDB.	.56700E+01	-1.00
-3250	ASDB.	.56700E+01	1.00
3350	SSB.	.58700E+01	-1.00
-3350	ASSB.	.58700E+01	1.00
1450	UCB.	.67700E+01	1.00
-1450	AUCB.	.67700E+01	-1.00
4150	CUB.	.67700E+01	1.00
-4150	ACUB.	.67700E+01	-1.00
2450	DCB.	.67700E+01	0.00

-2450	ADCB.	.67700E+01	0.00
4250	CDB.	.67700E+01	0.00
-4250	ACDB.	.67700E+01	0.00
3450	SCB.	.69700E+01	0.00
-3450	ASCB.	.69700E+01	0.00
4350	CSB.	.69700E+01	0.00
-4350	ACSB.	.69700E+01	0.00
4450	CCB.	.80700E+01	1.00
-4450	ACCB.	.80700E+01	-1.00
1550	UBB.	.10070E+02	0.00
-1550	AUBB.	.10070E+02	0.00
2550	DBB.	.10070E+02	-1.00
-2550	ADBB.	.10070E+02	1.00
3550	SBB.	.10270E+02	-1.00
-3550	ASBB.	.10270E+02	1.00
4550	CBB.	.11370E+02	0.00
-4550	ACBB.	.11370E+02	0.00
1111	DL++	.12320E+01	2.00
-1111	ADL--	.12320E+01	-2.00
1121	DL+	.12320E+01	1.00
-1121	ADL-	.12320E+01	-1.00
1221	DL0	.12320E+01	0.00
-1221	ADL0	.12320E+01	0.00
2221	DL-	.12320E+01	-1.00
-2221	ADL+	.12320E+01	1.00
1131	S*+	.13823E+01	1.00
-1131	AS*-	.13823E+01	-1.00
1231	S*0	.13820E+01	0.00
-1231	AS*0	.13820E+01	0.00
2231	S*-	.13875E+01	-1.00
-2231	AS*+	.13875E+01	1.00
1331	XI*0	.15318E+01	0.00
-1331	AXI*0	.15318E+01	0.00
2331	XI*-	.15350E+01	-1.00
-2331	AXI*+	.15350E+01	1.00
3331	OM-	.16722E+01	-1.00
-3331	AOM+	.16722E+01	1.00
1141	UUC*	.26300E+01	2.00
-1141	AUUC*	.26300E+01	-2.00
1241	UDC*	.26300E+01	1.00
-1241	AUDC*	.26300E+01	-1.00
2241	DDC*	.26300E+01	0.00
-2241	ADDC*	.26300E+01	0.00

1341	USC*	.27000E+01	1.00
-1341	AUSC*	.27000E+01	-1.00
2341	DSC*	.27000E+01	0.00
-2341	ADSC*	.27000E+01	0.00
3341	SSC*	.28000E+01	0.00
-3341	ASSC*	.28000E+01	0.00
1441	UCC*	.37500E+01	2.00
-1441	AUCC*	.37500E+01	-2.00
2441	DCC*	.37500E+01	1.00
-2441	ADCC*	.37500E+01	-1.00
3441	SCC*	.39000E+01	1.00
-3441	ASCC*	.39000E+01	-1.00
4441	CCC*	.48000E+01	2.00
-4441	ACCC*	.48000E+01	-2.00
1151	UUB*	.55100E+01	1.00
-1151	AUUB*	.55100E+01	-1.00
1251	UDB*	.55100E+01	0.00
-1251	AUDB*	.55100E+01	0.00
2251	DDB*	.55100E+01	-1.00
-2251	ADDB*	.55100E+01	1.00
1351	USB*	.57100E+01	0.00
-1351	AUSB*	.57100E+01	0.00
2351	DSB*	.57100E+01	-1.00
-2351	ADSB*	.57100E+01	1.00
3351	SSB*	.59100E+01	-1.00
-3351	ASSB*	.59100E+01	1.00
1451	UCB*	.68100E+01	1.00
-1451	AUCB*	.68100E+01	-1.00
2451	DCB*	.68100E+01	0.00
-2451	ADCB*	.68100E+01	0.00
3451	SCB*	.70100E+01	0.00
-3451	ASCB*	.70100E+01	0.00
4451	CCB*	.81100E+01	1.00
-4451	ACCB*	.81100E+01	-1.00
1551	UBB*	.10110E+02	0.00
-1551	AUBB*	.10110E+02	0.00
2551	DBB*	.10110E+02	-1.00
-2551	ADBB*	.10110E+02	1.00
3551	SBB*	.10310E+02	-1.00
-3551	ASBB*	.10310E+02	1.00
4551	CBB*	.11410E+02	0.00
-4551	ACBB*	.11410E+02	0.00
5551	BBB*	.14710E+02	-1.00
-5551	ABBB*	.14710E+02	1.00

1100	UU0.	.60000E+00	0.67
-1100	AUU0.	.60000E+00	-0.67
1200	UD0.	.60000E+00	0.33
-1200	AUD0.	.60000E+00	-0.33
2200	DD0.	.60000E+00	-0.67
-2200	ADD0.	.60000E+00	0.67
1300	US0.	.80000E+00	0.33
-1300	AUS0.	.80000E+00	-0.33
2300	DS0.	.80000E+00	-0.67
-2300	ADS0.	.80000E+00	0.67
3300	SS0.	.10000E+01	-0.67
-3300	ASS0.	.10000E+01	0.67
1400	UC0.	.19000E+01	1.33
-1400	AUC0.	.19000E+01	-1.33
2400	DC0.	.19000E+01	0.33
-2400	ADC0.	.19000E+01	-0.33
3400	SC0.	.21000E+01	0.33
-3400	ASC0.	.21000E+01	-0.33
4400	CC0.	.32000E+01	1.33
-4400	ACC0.	.32000E+01	-1.33
1500	UB0.	.49000E+01	0.33
-1500	AUB0.	.49000E+01	-0.33
2500	DB0.	.49000E+01	-0.67
-2500	ADB0.	.49000E+01	0.67
3500	SB0.	.51000E+01	-0.67
-3500	ASB0.	.51000E+01	0.67
4500	CB0.	.65000E+01	0.33
-4500	ACB0.	.65000E+01	-0.33
5500	BB0.	.98000E+01	-0.67
-5500	ABB0.	.98000E+01	0.67

11 Higher Order Processes

Higher order processes can be generated either by the QCD evolution or by supplying partons from an external generator.

Frequently it is interesting to generate higher-order processes with a particular branching in the QCD evolution or with a particular particle or group of particles being produced from the fragmentation. Examples include

1. Branching of jets into heavy quarks (e.g., $g \to b + \bar{b}$);
2. Decay of such a heavy quark into a lepton or neutrino;
3. Radiation of a photon, W, or Z from a jet.

It is important to realize that all of the cross sections and the QCD evolution in ISAJET are based on leading-log QCD, so generating such processes does not give the correct higher order QCD cross sections or "K factors", even though it may produce better agreement with them in some cases.

ISAJET does produce events with particular topologies which in many cases are the most important effect of higher order processes. In the heavy quark example, the lowest order process

$$g + g \to Q + \bar{Q}$$

produces back-to-back heavy quark pairs, whereas the splitting process

$$g + g \to g + g, \quad g \to Q + \bar{Q}$$

produces collinear pairs. Such collinear pairs are essential to obtain agreement with experimental data on $b\bar{b}$ production, and they often are the dominant background for processes of interest.

Branchings such as the emission of a heavy quark pair, a photon, or a $W^{\pm}$ or Z^0 are rare, and since they may occur at any step in the evolution, one cannot force them to occur. Therefore, generation of such events is very slow. M. Della Negra (UA1) suggested first doing n_1 QCD evolutions for each hard scattering and rejecting events without the desired partons, then doing n_2 fragmentations for each successful evolution. This generates the equivalent of $n_1 n_2$ events for each hard scattering, so the cross section must be divided by $n_1 n_2$. This algorithm can speed up the generation of $g \to b + \bar{b}$ splitting by a factor of ten for $n_1 = n_2 = 10$.

Since the evolution and fragmentation steps are executed $n_1 n_2$ times even if good events are found, a single hard scattering can lead to multiple events. This does not change the inclusive cross sections, but it does mean that the fluctuations may be larger than expected. Hence it is important to choose the numbers n_1 and n_2 carefully.

The following entities are used in ISAJET for generating events with multiple evolution and fragmentation:

`NEVENT`: The number of primary hard scatterings to be generated. Set as usual on the input line with the energy.

`SIGF`: The cross section for the selected hard scatterings divided by $n_1 \times n_2$. Hence the correct weight is SIGF/NEVENT, just as for normal running. (The cross section printed at the end of a run does not contain this factor.)

`NEVOLVE`: The number n_1 of evolutions per hard scattering. This should never be set unless you supply a REJJET function. Do not confuse this with NOEVOLVE.

`NHADRON`: The number n_2 of fragmentations for a given evolution. This should never be set unless you supply a REJFRG function. Do not confuse this with NOHADRON.

`REJJET`: A logical function which if true causes the evolution to be rejected. The user must supply one to make the selections which he wants. The default always .FALSE. but includes an example as a comment.

`REJFRG`: A logical function which if true causes the fragmentation to be rejected. The user must supply one to make the selections which he wants. The default always .FALSE. but includes an example as a comment.

Note that one can also use function EDIT to make a final selection of the events. Of course ISAJET must be relinked if EDIT, REJJET or REJFRG is modified.

At the end of a run, the jet cross section, the cross section for the selected events, and the number and fraction of events selected are printed. The cross section SIGF stored internally is divided by $n_1 \times n_2$ so that if the events are used to make histograms, then the correct weight per event is

```
      SIGF/NEVENT
```

just as for normal events. Of course NEVENT now has a different meaning; it is in general larger than the number of events in the file but might be smaller if NEVOLVE and NHADRON are badly chosen.

NEVOLVE and NHADRON are set as parameters in the input. One wants to choose them to give better acceptance of the primary hard scatterings but not to give multiple events for one hard scattering. For lepton production from heavy quarks the values

```
NEVOLVE
10/
NHADRON
10/
```

seem appropriate, giving reasonable efficiency. For radiation of photons from jets, NEVOLVE can be somewhat larger but NHADRON should be one, and REJFRG should always return .FALSE., since the selection is just on the parton process, not on the hadronization.

The loops over evolutions and fragmentations are done inside of subroutine ISAEVT and are always executed the same number of times even though ISAEVT returns after each generated event. Logical flag OK signals a good event, and logical flag DONE signals that the run is finished. If you control the event generation loop yourself, you should make use of these flags as in the following extract from subroutine ISAJET:

```
      ILOOP=0
  101 CONTINUE
        ILOOP=ILOOP+1
```

```
    CALL ISAEVT(ILOOP,OK,DONE)
    IF(OK) CALL ISAWEV
  IF(.NOT.DONE) GO TO 101
```

Otherwise you may get the wrong weights.

It is possible to supply to ISAJET events with partons generated by some other program that may have more accurate matrix elements for higher order processes. Because any such calculation must involve cutoffs ISAJET assumes that the partons were generated imposing some R cutoff, where $R = \sqrt{\phi^2 + \eta^2}$, and some E_t cutoff. Given that information ISAJET will generate initial state radiation partons only below the Et cutoff and final state radiation inside the R cutoff. The external partons can be supplied to ISAJET by calls to 2 subroutines. To initialize ISAJET for externally supplied partons, use

```
  CALL INISAP(CMSE,REACTION,BEAMS,WZ,NDCAYS,DCAYS,ETMIN,RCONE,OK)
```

where the inputs are

CMSE	=	center of mass energy
REACTION	=	reaction (only TWOJET and DRELLYAN are implemented so far)
BEAMS(2)	=	chose 'P ' or 'AP'
ETMIN	=	minimum ET of supplied partons
RCONE	=	minimum cone (R) between supplied partons
WZ	=	option 'W', 'Z', or ' ' no W's or Z's
NDCAYS	=	number of decay options (if 0, assume decay has already been done)
DCAYS	=	list of particles W or Z can decay into

and the output is

OK	=	TRUE if initialization is possible

Then for each event use

```
  CALL IPARTNS(NPRTNS,IDS,PRTNS,IDQ,WEIGHT,WZDK)
```

where the inputs are

NPRTNS	=	number of partons, ≤ 10
IDS(NPRTNS)	=	ids of final partons
PRTNS(4,NPRTNS)	=	parton 4 vectors
IDQ(2)	=	ids of initial partons
WEIGHT	=	weight
WZDK	=	if true last 2 partons are from W,Z decay

Further QCD radiation is then generated consistent with ETMIN and RCONE, and the partons are fragmented into hadrons as usual. If RCONE is set to a value greater than 1.5 no cone restriction is applied during parton evolution.

12 ISASUSY: Decay Modes in the Minimal Supersymmetric Model

The code in patch ISASUSY of ISAJET calculates decay modes of supersymmetric particles based on the work of H. Baer, M. Bisset, M. Drees, D. Dzialo (Karatas), X. Tata, J. Woodside, and their collaborators. The calculations assume the minimal supersymmetric extension of the standard model. The user specifies the gluino mass, the pseudoscalar Higgs mass, the Higgsino mass parameter μ, $\tan\beta$, the soft breaking masses for the first and third generation left-handed squark and slepton doublets and right-handed singlets, and the third generation mixing parameters A_t, A_b, and A_τ. Supersymmetric grand unification is assumed by default in the chargino and neutralino mass matrices, although the user can optionally specify arbitrary $U(1)$ and $SU(2)$ gaugino masses at the weak scale. The first and second generations are assumed by default to be degenerate, but the user can optionally specify different values. These inputs are then used to calculate the mass eigenstates, mixings, and decay modes.

Most calculations are done at the tree level, but one-loop results for gluino loop decays, $H \to \gamma\gamma$ and $H \to gg$, loop corrections to the Higgs mass spectrum and couplings, and leading-log QCD corrections to $H \to q\bar{q}$ are included. The Higgs masses have been calculated using the effective potential approximation including both top and bottom Yukawa and mixing effects. Mike Bisset and Xerxes Tata have contributed the Higgs mass, couplings, and decay routines. Manuel Drees has calculated several of the three-body decays including the full Yukawa contribution, which is important for large tan(beta). Note that e+e- annihilation to SUSY particles and SUSY Higgs bosons have been included in ISAJET versions > 7.11. ISAJET versions > 7.22 include the large $\tan\beta$ solution as well as non-degenerate sfermion masses.

Other processes may be added in future versions as the physics interest warrants. Note that the details of the masses and the decay modes can be quite sensitive to choices of standard model parameters such as the QCD coupling ALFA3 and the quark masses. To change these, you must modify subroutine SSMSSM. By default, ALFA3=.12.

All the mass spectrum and branching ratio calculations in ISASUSY are performed by a call to subroutine SSMSSM. Effective with version 7.23, the calling sequence is

```
      SUBROUTINE SSMSSM(XMG,XMU,XMHA,XTANB,XMQ1,XMDR,XMUR,
     $XML1,XMER,XMQ2,XMSR,XMCR,XML2,XMMR,XMQ3,XMBR,XMTR,
     $XML3,XMLR,XAT,XAB,XAL,XM1,XM2,XMT,IALLOW)
```

where the following are taken to be independent parameters:

XMG	=	gluino mass
XMU	=	μ = SUSY Higgs mass
	=	$-2 * m_1$ of Baer et al.
XMHA	=	pseudo-scalar Higgs mass
XTANB	=	$\tan\beta$, ratio of vev's
	=	$1/R$ (of old Baer-Tata notation).

XMQ1	=	$\tilde{q}_l$ soft mass, 1st generation
XMDR	=	$\tilde{d}_r$ mass, 1st generation
XMUR	=	$\tilde{u}_r$ mass, 1st generation
XML1	=	$\tilde{\ell}_l$ mass, 1st generation
XMER	=	$\tilde{e}_r$ mass, 1st generation
XMQ2	=	$\tilde{q}_l$ soft mass, 2nd generation
XMSR	=	$\tilde{s}_r$ mass, 2nd generation
XMCR	=	$\tilde{c}_r$ mass, 2nd generation
XML2	=	$\tilde{\ell}_l$ mass, 2nd generation
XMMR	=	$\tilde{\mu}_r$ mass, 2nd generation
XMQ3	=	$\tilde{q}_l$ soft mass, 3rd generation
XMBR	=	$\tilde{b}_r$ mass, 3rd generation
XMTR	=	$\tilde{t}_r$ mass, 3rd generation
XML3	=	$\tilde{\ell}_l$ mass, 3rd generation
XMTR	=	$\tilde{\tau}_r$ mass, 3rd generation
XAT	=	stop trilinear term A_t
XAB	=	sbottom trilinear term A_b
XAL	=	stau trilinear term A_τ
XM1	=	U(1) gaugino mass
	=	computed from XMG if ¿ 1E19
XM2	=	SU(2) gaugino mass
	=	computed from XMG if ¿ 1E19
XMT	=	top quark mass

The variable IALLOW is returned:

IALLOW	=	1 if Z1SS is not LSP, 0 otherwise

All variables are of type REAL except IALLOW, which is INTEGER, and all masses are in GeV. The notation is taken to correspond to that of Haber and Kane, although the Tata Lagrangian is used internally. All other standard model parameters are hard wired in this subroutine; they are not obtained from the rest of ISAJET. The theoretically favored range of these parameters is

$$50 < M(\tilde{g}) < 2000\,\mathrm{GeV}$$
$$50 < M(\tilde{q}) < 2000\,\mathrm{GeV}$$
$$50 < M(\tilde{\ell}) < 2000\,\mathrm{GeV}$$
$$-1000 < \mu < 1000\,\mathrm{GeV}$$
$$1 < \tan\beta < m_t/m_b$$
$$M(t) \approx 175\,\mathrm{GeV}$$
$$50 < M(A) < 2000\,\mathrm{GeV}$$
$$M(\tilde{t}_l), M(t_r) < M(\tilde{q})$$

$$M(\tilde{b}_r) \sim M(\tilde{q})$$
$$-1000 < A_t < 1000\,\mathrm{GeV}$$
$$-1000 < A_b < 1000\,\mathrm{GeV}$$

It is assumed that the lightest supersymmetric particle is the lightest neutralino $\tilde{Z}_1$, the lighter stau $\tilde{\tau}_1$, or the gravitino $\tilde{G}$ in GMSB models. Some choices of the above parameters may violate this assumption, yielding a light chargino or light stop squark lighter than $\tilde{Z}_1$. In such cases SSMSSM does not compute any branching ratios and returns IALLOW = 1.

SSMSSM does not check the parameters or resulting masses against existing experimental data. SSTEST provides a minimal test. This routine is called after SSMSSM by ISAJET and ISASUSY and prints suitable warning messages.

SSMSSM first calculates the other SUSY masses and mixings and puts them in the common block /SSPAR/:

```
C          SUSY parameters
C          AMGLSS               = gluino mass
C          AMULSS               = up-left squark mass
C          AMELSS               = left-selectron mass
C          AMERSS               = right-slepton mass
C          AMNiSS               = sneutrino mass for generation i
C          TWOM1                = Higgsino mass = - mu
C          RV2V1                = ratio v2/v1 of vev's
C          AMTLSS,AMTRSS        = left,right stop masses
C          AMT1SS,AMT2SS        = light,heavy stop masses
C          AMBLSS,AMBRSS        = left,right sbottom masses
C          AMB1SS,AMB2SS        = light,heavy sbottom masses
C          AMLLSS,AMLRSS        = left,right stau masses
C          AML1SS,AML2SS        = light,heavy stau masses
C          AMZiSS               = signed mass of Zi
C          ZMIXSS               = Zi mixing matrix
C          AMWiSS               = signed Wi mass
C          GAMMAL,GAMMAR        = Wi left, right mixing angles
C          AMHL,AMHH,AMHA       = neutral Higgs h0, H0, A0 masses
C          AMHC                 = charged Higgs H+ mass
C          ALFAH                = Higgs mixing angle
C          AAT                  = stop trilinear term
C          THETAT               = stop mixing angle
C          AAB                  = sbottom trilinear term
C          THETAB               = sbottom mixing angle
C          AAL                  = stau trilinear term
C          THETAL               = stau mixing angle
C          AMGVSS               = gravitino mass
      COMMON/SSPAR/AMGLSS,AMULSS,AMURSS,AMDLSS,AMDRSS,AMSLSS
     $,AMSRSS,AMCLSS,AMCRSS,AMBLSS,AMBRSS,AMB1SS,AMB2SS
     $,AMTLSS,AMTRSS,AMT1SS,AMT2SS,AMELSS,AMERSS,AMMLSS,AMMRSS
```

```
     $,AMLLSS,AMLRSS,AML1SS,AML2SS,AMN1SS,AMN2SS,AMN3SS
     $,TWOM1,RV2V1,AMZ1SS,AMZ2SS,AMZ3SS,AMZ4SS,ZMIXSS(4,4)
     $,AMW1SS,AMW2SS
     $,GAMMAL,GAMMAR,AMHL,AMHH,AMHA,AMHC,ALFAH,AAT,THETAT
     $,AAB,THETAB,AAL,THETAL,AMGVSS
      REAL AMGLSS,AMULSS,AMURSS,AMDLSS,AMDRSS,AMSLSS
     $,AMSRSS,AMCLSS,AMCRSS,AMBLSS,AMBRSS,AMB1SS,AMB2SS
     $,AMTLSS,AMTRSS,AMT1SS,AMT2SS,AMELSS,AMERSS,AMMLSS,AMMRSS
     $,AMLLSS,AMLRSS,AML1SS,AML2SS,AMN1SS,AMN2SS,AMN3SS
     $,TWOM1,RV2V1,AMZ1SS,AMZ2SS,AMZ3SS,AMZ4SS,ZMIXSS
     $,AMW1SS,AMW2SS
     $,GAMMAL,GAMMAR,AMHL,AMHH,AMHA,AMHC,ALFAH,AAT,THETAT
     $,AAB,THETAB,AAL,THETAL,AMGVSS
      REAL AMZISS(4)
      EQUIVALENCE (AMZISS(1),AMZ1SS)
      SAVE /SSPAR/
```

It then calculates the widths and branching ratios and puts them in the common block /SSMODE/:

```
C          MXSS         =  maximum number of modes
C          NSSMOD       = number of modes
C          ISSMOD       = initial particle
C          JSSMOD       = final particles
C          GSSMOD       = width
C          BSSMOD       = branching ratio
C          MSSMOD       = decay matrix element pointer
C          LSSMOD       = logical flag used internally by SSME3
      INTEGER MXSS
      PARAMETER (MXSS=1000)
      COMMON/SSMODE/NSSMOD,ISSMOD(MXSS),JSSMOD(5,MXSS),GSSMOD(MXSS)
     $,BSSMOD(MXSS),MSSMOD(MXSS),LSSMOD
      INTEGER NSSMOD,ISSMOD,JSSMOD,MSSMOD
      REAL GSSMOD,BSSMOD
      LOGICAL LSSMOD
      SAVE /SSMODE/
```

Decay modes for a given particle are not necessarily adjacent in this common block. Note that the branching ratio calculations use the full matrix elements, which in general will give nonuniform distributions in phase space, but this information is not saved in /SSMODE/. In particular, the decays $H \to Z + Z^* \to Z + f + \bar{f}$ give no indication that the $f\bar{f}$ mass is strongly peaked near the upper limit.

All IDENT codes are defined by parameter statements in the PATCHY keep sequence SSTYPE:

```
C          SM ident code definitions. These are standard ISAJET but
```

```
C          can be changed.
      INTEGER IDUP,IDDN,IDST,IDCH,IDBT,IDTP
      INTEGER IDNE,IDE,IDNM,IDMU,IDNT,IDTAU
      INTEGER IDGL,IDGM,IDW,IDZ,IDH
      PARAMETER (IDUP=1,IDDN=2,IDST=3,IDCH=4,IDBT=5,IDTP=6)
      PARAMETER (IDNE=11,IDE=12,IDNM=13,IDMU=14,IDNT=15,IDTAU=16)
      PARAMETER (IDGL=9,IDGM=10,IDW=80,IDZ=90,IDH=81)
C          SUSY ident code definitions. They are chosen to be similar
C          to those in versions < 6.50 but may be changed.
      INTEGER ISUPL,ISDNL,ISSTL,ISCHL,ISBT1,ISTP1
      INTEGER ISNEL,ISEL,ISNML,ISMUL,ISNTL,ISTAU1
      INTEGER ISUPR,ISDNR,ISSTR,ISCHR,ISBT2,ISTP2
      INTEGER ISNER,ISER,ISNMR,ISMUR,ISNTR,ISTAU2
      INTEGER ISZ1,ISZ2,ISZ3,ISZ4,ISW1,ISW2,ISGL
      INTEGER ISHL,ISHH,ISHA,ISHC
      INTEGER ISGRAV
      PARAMETER (ISUPL=21,ISDNL=22,ISSTL=23,ISCHL=24,ISBT1=25,ISTP1=26)
      PARAMETER (ISNEL=31,ISEL=32,ISNML=33,ISMUL=34,ISNTL=35,ISTAU1=36)
      PARAMETER (ISUPR=41,ISDNR=42,ISSTR=43,ISCHR=44,ISBT2=45,ISTP2=46)
      PARAMETER (ISNER=51,ISER=52,ISNMR=53,ISMUR=54,ISNTR=55,ISTAU2=56)
      PARAMETER (ISGL=29)
      PARAMETER (ISZ1=30,ISZ2=40,ISZ3=50,ISZ4=60,ISW1=39,ISW2=49)
      PARAMETER (ISHL=82,ISHH=83,ISHA=84,ISHC=86)
      PARAMETER (ISGRAV=91)
```

These are based on standard ISAJET but can be changed to interface with other generators. Since masses except the t mass are hard wired, one should check the kinematics for any decay before using it with possibly different masses.

Instead of specifying all the SUSY parameters at the electroweak scale using the MSSMi commands, one can instead use the SUGRA parameter to specify in the minimal supergravity framework the common scalar mass m_0, the common gaugino mass $m_{1/2}$, and the soft trilinear SUSY breaking parameter A_0 at the GUT scale, the ratio $\tan\beta$ of Higgs vacuum expectation values at the electroweak scale, and $\operatorname{sgn}\mu$, the sign of the Higgsino mass term. The `NUSUGi` keywords allow one to break the assumption of universality in various ways. `NUSUG1` sets the gaugino masses; `NUSUG2` sets the A terms; `NUSUG3` sets the Higgs masses; `NUSUG4` sets the first generation squark and slepton masses; and `NUSUG5` sets the third generation masses. The keyword `SSBCSC` can be used to specify an alternative scale (i.e., not the coupling constant unification scale) for the RGE boundary conditions.

The renormalization group equations now include all the two-loop terms for both gauge and Yukawa couplings and the possible contributions from right-handed neutrinos. These equations are solved iteratively using Runge-Kutta numerical integration to determine the weak scale parameters from the GUT scale ones:

1. The RGE's are run from the weak scale M_Z up to the GUT scale, where $\alpha_1 = \alpha_2$, taking all thresholds into account. We use two loop RGE equations for the gauge

couplings only.

2. The GUT scale boundary conditions are imposed, and the RGE's are run back to M_Z, again taking thresholds into account.

3. The masses of the SUSY particles and the values of the soft breaking parameters B and mu needed for radiative symmetry are computed, e.g.

$$\mu^2(M_Z) = \frac{M_{H_1}^2 - M_{H_2}^2 \tan^2\beta}{\tan^2\beta - 1} - M_Z^2/2$$

   These couplings are frozen out at the scale $\sqrt{M(t_L)M(t_R)}$.

4. The 1-loop radiative corrections are computed.

5. The process is then iterated until stable results are obtained.

This is essentially identical to the procedure used by several other groups. Other possible constraints such as b-τ unification and limits on proton decay have not been included.

An alternative to the SUGRA model is the Gauge Mediated SUSY Breaking (GMSB) model of Dine and Nelson, Phys. Rev. **D48**, 1277 (1973); Dine, Nelson, Nir, and Shirman, Phys. Rev. **D53**, 2658 (1996). In this model SUSY is broken dynamically and communicated to the MSSM through messenger fields at a messenger mass scale M_m much less than the Planck scale. If the messenger fields are in complete representations of $SU(5)$, then the unification of couplings suggested by the LEP data is preserved. The simplest model has a single $5+\bar{5}$ messenger sector with a mass M_m and and a SUSY-breaking VEV F_m of its auxiliary field F. Gauginos get masses from one-loop graphs proportional to $\Lambda_m = F_m/M_m$ times the appropriate gauge coupling α_i; sfermions get squared-masses from two-loop graphs proportional to Λ_m times the square of the appropriate α_i. If there are N_5 messenger fields, the gaugino masses and sfermion masses-squared each contain a factor of N_5.

The parameters of the GMSB model implemented in ISAJET are

- $\Lambda_m = F_m/M_m$: the scale of SUSY breaking, typically 10–100 TeV;

- $M_m > \Lambda_m$: the messenger mass scale, at which the boundary conditions for the renormalization group equations are imposed;

- N_5: the equivalent number of $5+\bar{5}$ messenger fields.

- $\tan\beta$: the ratio of Higgs vacuum expectation values at the electroweak scale;

- $\operatorname{sgn}\mu = \pm 1$: the sign of the Higgsino mass term;

- $C_{\text{grav}} \geq 1$: the ratio of the gravitino mass to the value it would have had if the only SUSY breaking scale were F_m.

The solution of the renormalization group equations is essentially the same as for SUGRA; only the boundary conditions are changed. In particular it is assumed that electroweak symmetry is broken radiatively by the top Yukawa coupling.

In GMSB models the lightest SUSY particle is always the nearly massless gravitino $\tilde{G}$. The phenomenology depends on the nature of the next lightest SUSY particle (NLSP) and on its lifetime to decay to a gravitino. The NLSP can be either a neutralino $\tilde{\chi}_1^0$ or a slepton $\tilde{\tau}_1$. Its lifetime depends on the gravitino mass, which is determined by the scale of SUSY breaking not just in the messenger sector but also in any other hidden sector. If this is set by the messenger scale F_m, i.e., if $C_{\text{grav}} \approx 1$, then this lifetime is generally short. However, if the messenger SUSY breaking scale F_m is related by a small coupling constant to a much larger SUSY breaking scale F_b, then $C_{\text{grav}} \gg 1$ and the NLSP can be long-lived. The correct scale is not known, so C_{grav} should be treated as an arbitrary parameter. More complicated GMSB models may be run by using the GMSB2 keyword.

Patch ISASSRUN of ISAJET provides a main program SSRUN and some utility programs to produce human readable output. These utilities must be rewritten if the IDENT codes in /SSTYPE/ are modified. To create the stand-alone version of ISASUSY with SSRUN, run YPATCHY on isajet.car with the following cradle (with `&` replaced by `+`):

```
&USE,*ISASUSY.                          Select all code
&USE,NOCERN.                            No CERN Library
&USE,IMPNONE.                           Use IMPLICIT NONE
&EXE.                                   Write everything to ASM
&PAM,T=C.                               Read PAM file
&QUIT.                                  Quit
```

Compile, link, and run the resulting program, and follow the prompts for input. Patch ISASSRUN also contains a main program SUGRUN that reads the minimal SUGRA, non-universal SUGRA, or GMSB parameters, solves the renormalization group equations, and calculates the masses and branching ratios. To create the stand-alone version of ISASUGRA, run YPATCHY with the following cradle:

```
&USE,*ISASUGRA.                         Select all code
&USE,NOCERN.                            No CERN Library
&USE,IMPNONE.                           Use IMPLICIT NONE
&EXE.                                   Write everything to ASM
&PAM.                                   Read PAM file
&QUIT.                                  Quit
```

The documentation for ISASUSY and ISASUGRA is included with that for ISAJET.

ISASUSY is written in ANSI standard Fortran 77 except that IMPLICIT NONE is used if +USE,IMPNONE is selected in the Patchy cradle. All variables are explicitly typed, and variables starting with I,J,K,L,M,N are not necessarily integers. All external names such as the names of subroutines and common blocks start with the letters SS. Most calculations are done in double precision. If +USE,NOCERN is selected in the Patchy cradle, then the Cernlib routines EISRS1 and its auxiliaries to calculate the eigenvalues of a real symmetric matrix and DDILOG to calculate the dilogarithm function are included. Hence it is not necessary to link with Cernlib.

The physics assumptions and details of incorporating the Minimal Supersymmetric Model into ISAJET have appeared in a conference proceedings entitled "Simulating Supersymmetry with ISAJET 7.0/ISASUSY 1.0" by H. Baer, F. Paige, S. Protopopescu and X. Tata; this has appeared in the proceedings of the workshop on *Physics at Current Accelerators and Supercolliders*, ed. J. Hewett, A. White and D. Zeppenfeld, (Argonne National Laboratory, 1993). Detailed references may be found therein. Users wishing to cite an appropriate source may cite the above report.

13 Changes in Recent Versions

This section contains a record of changes in recently released versions of ISAJET, taken from the memoranda distributed to users. Note that the released version numbers are not necessarily consecutive.

13.1 Version 7.51, May 2000

Several improvements in the SUSY RGE's have been made. All two-loop terms including both gauge and Yukawa couplings and the contributions from right-handed neutrinos are now included. There is a new keyword `SSBCSC` to specify a scale other than the GUT scale for the RGE boundary conditions.

The process $Z+\gamma$ is now included in `WPAIR`. (This was omitted because it has no contribution from triple gauge boson couplings.)

An incorrect type declaration produced unphysical results for beamsstrahlung on some computers. This has been fixed. While the bug is serious for e^+e^- with the `EEBEAM` option, it has no effect on other processes. Some other minor bugs have also been fixed.

13.2 Version 7.47, December 1999

There are several improvements in the treatment of supersymmetry. The Anomaly Mediated SUSY Breaking model of of Randall and Sundrum and of Gherghetta, Giudice, and Wells (hep-ph/9904378) has been added. The parameters of the model are a universal scalar mass m_0 at the GUT scale, a gravitino mass $m_{3/2}$, and the usual $\tan\beta$ and $\operatorname{sgn}\mu$. These are set by the `AMSB` keyword. The renormalization group equations have been extended to include two-loop Yukawa terms and right-handed sneutrinos (with default masses above the Planck scale). The $\tilde{\nu}_R$ play a role in the evolution for the inverted hierarchy models of Bagger, Feng, and Polonsky, hep-ph/9905292. SUSY loop corrections to Yukawa couplings have been incorporated in the SUSY mass calculations.

The Helas library of Murayama, Watanabe, and Hagiwara has been incorporated together with a simple multi-body phase space generator. This makes it possible to use code generated by MadGraph to produce multi-body hard scattering processes. As a first example, a `ZJJ` process that generates $Z+2$ jets has been added, with the Z treated as a narrow resonance. Additional processes may be added in future releases.

A new `EXTRADIM` process has been added to generate Kaluza-Klein graviton production in association with a jet or photon in models with extra dimensions at the TeV scale. The cross sections are from G.F.Giudice et al., hep-ph/9811291. We thank I. Hinchliffe and L. Vacavant for providing this.

A number of bugs have been fixed, including in particular one in the decay $\widetilde{W}_i \to \widetilde{Z}_j \tau\nu$.

13.3 Version 7.44, April 1999

A serious bug introduced in Version 7.42 that could lead to matrix elements being stored for the wrong mode has been corrected. Some sign errors in the matrix elements for gaugino decays have also been corrected.

13.4 Version 7.42, January 1999

Beginning with this version, matrix elements are taken into account in the event generator as well as in the calculation of decay widths for MSSM three-body decays of the form $\tilde{A} \to \tilde{B} f \bar{f}$, where $\tilde{A}$ and $\tilde{B}$ are gluinos, charginos, or neutralinos. This is implemented by having ISASUSY save the poles and their couplings when calculating the decay width and then using these to reconstruct the matrix element. Other three-body decays may be included in the future. Decays selected with `FORCE` use the appropriate matrix elements.

As part of the changes to implement these matrix elements, the format of the decay table has changed. It now starts with a header line; if this does not match the internal version, then a warning is printed. The decay table now includes an index MELEM that specifies the matrix element to be used for all processes. This is also used for `FORCE` decays and is printed on the run listing for them. SUSY 3-body decays have internally generated negative values of MELEM.

This version also includes both initial state radiation and beamstrahlung for e^+e^- interactions. For initial state radiation (bremsstrahlung), if the `EEBREM` keyword is selected, an electron structure function will be used. For a convolution of both bremsstrahlung and beamstrahlung, the keyword `EEBEAM` must be used, with appropriate inputs (see documentation).

13.5 Version 7.40, October 1998

A new process WHIGGS generates $W^\pm + H$ and $Z + H$ events for both the Standard Model and SUSY models and also Higgs pair production for SUSY models. The types and W decay modes are selected with JETTYPE and WMODE as for WPAIR events. This process is of particular interest for producing fairly light Higgs bosons at the Tevatron. See the documentation for more details.

Some non-minimal GMSB models can be generated using a new keyword GMSB2. The optional parameters are an extra factor between the gaugino and scalar masses, shifts in the Higgs masses, a D-term proportional to hypercharge, and independent numbers of messenger fields for the three gauge groups. The documentation gives more details and references.

The default for SUGRA models has been changed to use $\alpha_s(M_Z) = 0.118$, the experimental value. This means that the couplings do not exactly unify at the GUT scale, presumably because of the effects of heavy particles. The keyword AL3UNI can be used to select exact unification, which produces too large a value for $\alpha_s(M_Z)$.

A number of three-body slepton decays that occur through left-right mixing are now included. These are obviously small but might compete with gravitino decays. In particular, a decay like $\tilde{\mu}_R \to \tilde{\tau}_1 \nu \bar{\nu}$ might lead to a wrong momentum measurement in the muon system. So far we have found no case in which this is probable.

The new release also includes a separate Unix tar file `mcpp.tar` containing C++ code to read a standard ISAJET output file and copy all the information into C++ classes. The tar file contains makefiles for Software Release Tools, documentation, and examples as well as the code.

13.6 Version 7.37, April 1998

Version 7.37 incorporates Gauge Mediated SUSY Breaking models for the first time. In these models, SUSY is broken in a hidden sector at a relatively low scale, and the masses of the MSSM fields are then produced through ordinary gauge interactions with messenger fields. The parameters of the GMSB model in ISAJET are M_m, the messenger mass scale; $\Lambda_m = F_m/M_m$, where F_m is the SUSY breaking scale in the messenger sector; N_5, the number of messenger fields; the usual $\tan\beta$ and $\mathrm{sgn}\,\mu$; and $C_{\mathrm{grav}} \geq 1$, a factor which scales the gravitino mass and hence the lifetime for the lightest MSSM particle to decay into it.

GMSB models have a light gravitino $\tilde{G}$ as the lightest SUSY particle. The phenomenology of the model depends mainly on the nature of the next lightest SUSY particle, a $\tilde{\chi}_1^0$ or a $\tilde{\tau}_1$, which changes with the number N_5 of messengers. The phenomenology also depends on the lifetime for the $\tilde{\chi}_1^0 \to \tilde{G}\gamma$ or $\tilde{\tau}_1 \to \tilde{G}\tau$ decay; this lifetime can be short or very long. All the relevant decays are included except for $\tilde{\mu} \to \nu\nu\tilde{\tau}_1$, which is very suppressed.

The keyword MGVTNO allows the user to independently input a gravitino gravitino mass for the MSSM option. This allows studies of SUGRA (or other types) of models where the gravitino is the LSP.

Version 7.37 also contains an extension of the SUGRA model with a variety of non-universal gaugino and sfermion masses and A terms at the GUT scale. This makes it possible to study, for example, how well the SUGRA assumptions can be tested.

Two significant bugs have also been corrected. The decay modes for B^* mesons were missing from the decay table since Version 7.29 and have been restored. A sign error in the interference term for chargino production has been corrected, leading to a larger chargino pair cross section at the Tevatron.

13.7 Version 7.32, November 1997

This version makes several corrections in various chargino and neutralino widths, thus changing the branching ratios for large $\tan\beta$. For $\tilde{\chi}_2^0$, for example, the $\tilde{\chi}_1^0 b\bar{b}$ branching ratio is decreased significantly, while the $\tilde{\chi}_1^0\tau^+\tau^-$ one is increased. Thus the SUGRA phenomenology for $\tan\beta \sim 30$ is modified substantially.

The new version also fixes a few bugs, including a possible numerical precision problem in the Drell-Yan process at high mass and q_T. It also includes a missing routine for the Zebra interface.

13.8 Version 7.31, August 1997

Version fixes a couple of bugs in Version 7.29. In particular, the JETTYPE selection did not work correctly for supersymmetric Higgs bosons, and there was an error in the interactive interface for MSSM input. Since these could lead to incorrect results, users should replace the old version. We thank Art Kreymer for finding these problems.

Since top quarks decay before they have time to hadronize, they are now put directly onto the particle list. Top hadrons ($t\bar{u}$, $t\bar{d}$, etc.) no longer appear, and FORCE should be used directly for the top quark, i.e.

```
FORCE
6,11,-12,5/
```

The documentation has been converted to LaTeX. Run either LaTeX 2.09 or LaTeX 2e three times to resolve all the forward references. Either US (8.5x11 inch) or A4 size paper can be used.

13.9 Version 7.30, July 1997

This version fixes a couple of bugs in the previous version. In particular, the JETTYPE selection did not work correctly for supersymmetric Higgs bosons, and there was an error in the interactive interface for MSSM input. Since these could lead to incorrect results, users should replace the old version. We thank Art Kreymer for finding these problems.

Since top quarks decay before they have time to hadronize, they are now put directly onto the particle list. Top hadrons ($t\bar{u}$, tud, etc.) no longer appear, and FORCE should be used directly for the top quark, i.e.

```
FORCE
6,11,-12,5/
```

The documentation has been converted to LaTeX. Run either LaTeX 2.09 or LaTeX 2e three times to resolve all the forward references. Either US (8.5×11 inch) or A4 size paper can be used.

13.10 Version 7.29, May 1997

While the previous version was applicable for large as well as small $\tan\beta$, it did contain approximations for the 3-body decays $\tilde{g} \to t\bar{b}\tilde{W}_i$, $\tilde{Z}_i \to b\bar{b}\tilde{Z}_j, \tau\tau\tilde{Z}_j$, and $\tilde{W}_i \to \tau\nu\tilde{Z}_j$. The complete tree-level calculations for three body decays of the gluino, chargino and neutralino, with all Yukawa couplings and mixings, have now been included (thanks mainly to M. Drees). We have compared our branching ratios with those calculated by A. Bartl and collaborators; the agreement is generally good.

The decay patterns of gluinos, charginos and neutralinos may differ from previous expectations if $\tan\beta$ is large. In particular, decays into τ's and b's are often enhanced, while decays into e's and μ's are reduced. It could be important for experiments to study new types of signatures, since the cross sections for conventional signatures may be considerably reduced.

We have also corrected several bugs, including a fairly serious one in the selection of jet types for SUSY Higgs. We thank A. Kreymer for pointing this out to us.

13.11 Version 7.27, January 1997

The new version contains substantial improvements in the treatment of the Minimal Supersymmetric Standard Model (MSSM) and the SUGRA model. The squarks of the first two generations are no longer assumed to be degenerate. The mass splittings and all the two-body decay modes are now correctly calculated for large $\tan\beta$. While there are still some approximations for three-body modes, ISAJET is now usable for the whole range $1 \lesssim \tan\beta \lesssim M_t/M_b$. The most interesting new feature for large $\tan\beta$ is that third generation modes can be strongly enhanced or even completely dominant.

To accomodate these changes it was necessary to change the MSSM input parameters. To avoid confusion, the MSSM keywords have been renamed MSSM[A-C] instead of MSSM[1-3], and the order of the parameters has been changed. See the input section of the manual for details.

Treatment of the MSSM Higgs sector has also been improved. In the renormalization group equations the Higgs couplings are frozen at a higher scale, $Q = \sqrt{M(\tilde{t}_L)M(\tilde{t}_R)}$. Running t, b and τ masses evaluated at that scale are used to reproduce the dominant 2-loop effects. There is some sensitivity to the choice of Q; our choice seems to give fairly stable results over a wide range of parameters and reasonable agreement with other calculations. In particular, the resulting light Higgs masses are significantly lower than those from Version 7.22.

The default parton distributions have been updated to CTEQ3L. A bug in the PDFLIB interface and other minor bugs have been fixed.

13.12 Version 7.22, July 1996

The new version fixes errors in $\tilde{b} \to \tilde{W}t$ and in some $\tilde{t}$ decays and Higgs decays. It also contains a new decay table with updated τ, c, and b decays, based loosely on the QQ decay package from CLEO. The updated decays are less detailed than the full CLEO QQ program but an improvement over what existed before. The new decays involve a number of additional resonances, including $f_0(980)$, $a_1(1260)$, $f_2(1270)$, $K_1(1270)$, $K_1^*(1400)$, $K_2^*(1430)$, $\chi_{c1,2,3}$, and $\psi(2S)$, so users may have to change their interface routines.

A number of other small bugs have been corrected.

13.13 Version 7.20, June 1996

The new version corrects both errors introduced in Version 7.19 and longstanding errors in the final state QCD shower algorithm. It also includes the top mass in the cross sections for $gb \to Wt$ and $gt \to Zt$. When the t mass is taken into account, the process $gt \to Wb$ can have a pole in the physical region, so it has been removed; see the documentation for more discussion.

Steve Tether recently pointed out to us that the anomalous dimension for the $q \to qg$ branching used in the final state QCD branching algorithm was incorrect. In investigating this we found an additional error, a missing factor of 1/3 in the $g \to q\bar{q}$ branching. The first error produces a small but non-negligible underestimate of gluon radiation from quarks. The second overestimates quark pair production from gluons by about a factor of 3. In particular, this means that backgrounds from heavy quarks Q coming from $g \to Q\bar{Q}$ have been overestimated.

The new version also allows the user to set arbitrary masses for the $U(1)$ and $SU(2)$ gaugino mases in the MSSM rather than deriving these from the gluino mass using grand unification. This could be useful in studying one of the SUSY interpretations of a CDF $ee\gamma\gamma\not{E}_T$ event recently suggested by Ambrosanio, Kane, Kribs, Martin and Mrenna. Note, however, that radiative decay are *not* included, although the user can force them and multiply by the appropriate branching ratios calculated by Haber and Wyler, Nucl. Phys. B323, 267 (1989). No explicit provision for the decay $\tilde{Z}_1 \to \tilde{G}\gamma$ of the lightest zino into a gravitino or goldstino and a photon has been made, but forcing the decay $\tilde{Z}_1 \to \nu\gamma$ has the same effect for any collider detector.

A number of other minor bugs have also been corrected.

13.14 Version 7.16, October 1995

The new version includes e^+e^- cross sections for both SUSY and Standard Model particles with polarized beams. The e^- and e^+ polarizations are specified with a new keyword EPOL. Polarization appears to be quite useful in studying SUSY particles at an e^+e^- collider.

The new release also includes some bug fixes for pp reactions, so you should upgrade even if you do not plan to use the polarized e^+e^- cross sections.

13.15 Version 7.13, September 1994

Version 7.13 of ISAJET fixes a bug that we introduced in the recently released 7.11 and another bug in $\tilde{g} \to \tilde{q}\bar{q}$. We felt it was essential to fix these bugs despite the proliferation of versions.

The new version includes the cross sections for the e^+e^- production of squarks, sleptons, gauginos, and Higgs bosons in Minimal Supersymmetric Standard Model (MSSM) or the minimal supergravity (SUGRA) model, including the effects of cascade decays. To generate such events, select the `E+E-` reaction type and either SUGRA or MSSM, e.g.,

```
SAMPLE E+E- JOB
300.,50000,10,100/
E+E-
SUGRA
100,100,0,2,-1/
TMASS
170,-1,1/
END
STOP
```

The effects of spin correlations in the production and decay, e.g., in $e^+e^- \to \widetilde{W}_1^+\widetilde{W}_1^-$, are not included.

It should be noted that the Standard Model e^+e^- generator in ISAJET does not include Bhabba scattering or W^+W^- and Z^0Z^0 production. Also, its hadronization model is cruder than that available in some other generators.

13.16 Version 7.11, September 1994

The new version includes the cross sections for the e^+e^- production of squarks, sleptons, gauginos, and Higgs bosons in Minimal Supersymmetric Standard Model (MSSM) or the minimal supergravity (SUGRA) model including the effects of cascade decays. To generate such events, select the `E+E-` reaction type and either SUGRA or MSSM, e.g.,

```
SAMPLE E+E- JOB
300.,50000,10,100/
E+E-
SUGRA
100,100,0,2,-1/
TMASS
170,-1,1/
END
STOP
```

The effects of spin correlations in the production and decay, e.g., in $e^+e^- \to \widetilde{W}_1^+\widetilde{W}_1^-$, are not included.

It should be noted that the Standard Model e^+e^- generator in ISAJET does not include Bhabba scattering or W^+W^- and Z^0Z^0 production. Also, its hadronization model is cruder than that available in some other generators.

13.17 Version 7.10, July 1994

This version adds a new option that solves the renormalization group equations to calculate the Minimal Supersymmetric Standard Model (MSSM) parameters in the minimal supergravity (SUGRA) model, assuming only that the low energy theory has the minimal particle content, that electroweak symmetry is radiatively broken, and that R-parity is conserved. The minimal SUGRA model has just four parameters, which are taken to be the common scalar mass m_0, the common gaugino mass $m_{1/2}$, the common trilinear SUSY breaking term A_0, all defined at the GUT scale, and $\tan\beta$; the sign of μ must also be given. The renormalization group equations are solved iteratively using Runge-Kutta integration including the correct thresholds. This program can be used either alone or as part of the event generator. In the latter case, the parameters are specified using

SUGRA
m_0, $m_{1/2}$, A_0, $\tan\beta$, $\operatorname{sgn}\mu$

While the SUGRA option is less general than the MSSM, it is theoretically attractive and provides a much more managable parameter space.

In addition there have been a number of improvements and bug fixes. An occasional infinite loop in the minimum bias generator has been fixed. A few SUSY cross sections and decay modes and the JETTYPE flags for SUSY particles have been corrected. The treatment of B baryons has been improved somewhat.