ISAJET 7.48
A Monte Carlo Event Generator
for $pp$, $\bar{p}p$, and $e^+e^-$ Reactions

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Abstract

ISAJET is a Monte Carlo program which simulates $pp$, $\bar{p}p$ and $e^+e^-$ interactions at high energies. This document summarizes the physics underlying the program and describes how to use it. Version 7.48 includes several new features. Anomaly Mediated SUSY Breaking (AMSB) models and right-handed sneutrinos have been added; the latter play a role, e.g., in inverted hierarchy models. A new process generating $Z + 2$ jets based on the Helas library and MadGraph has been added. Another new process generating Kaluza-Klein gravitons in models with extra dimensions has been added.
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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 $\sigma_0$ 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 $\sigma_0$ 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 $\alpha_s^2$ QCD processes, which give rise in lowest order to two high-$p_t$ jets. Included are, e.g.

$$g + g \rightarrow g + g$$
$$g + q \rightarrow g + q$$
$$g + g \rightarrow q + \bar{q}$$

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, Hinchcliffe, Lane and Quigg (EHLQ),

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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 \( \gamma \), 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

\[ q + \bar{q} \to W \to q + \bar{q} \to \ell + \bar{\ell} \]

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

\[ q + \bar{q} \to W + g \]
\[ g + q \to W + q \]

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

\[ 1/q_t^2 \to 1/\sqrt{q_t^4 + q_{t_0}^4} \quad q_{t_0} = (.2 \text{GeV})M \]

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 $g + b \rightarrow W + t$ and $g + t \rightarrow Z + t$, 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 $g + t \rightarrow W + b$ is not included. Both $g + b \rightarrow W^- + t$ and $g + \bar{t} \rightarrow W^- + \bar{b}$ 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 $t \rightarrow W + b$ 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

\[
g + q \rightarrow \gamma + q \\
quark + \bar{quark} \rightarrow \gamma + g \\
quark + \bar{quark} \rightarrow \gamma + \gamma
\]

Higher order corrections are not included. But $\gamma$’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,

\[
q + \bar{q} \rightarrow W^+ + W^- \\
\quad \rightarrow Z^0 + Z^0 \\
\quad \rightarrow W^+ + Z^0, W^- + Z^0 \\
\quad \rightarrow W^+ + \gamma, W^- + \gamma
\]

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

\[
g + g \rightarrow g + g + W^+ + W^-
\]

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

\[ g + g \rightarrow H \] (through a quark loop)
\[ q + \bar{q} \rightarrow H \] (with \( t + \bar{t} \) dominant)
\[ W^+ + W^- \rightarrow H \] (with longitudinally polarized \( W \))
\[ Z^0 + Z^0 \rightarrow H \] (with longitudinally polarized \( Z \))

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

\[
\Gamma(H \rightarrow W^+W^-) = \frac{G_FM_H^3}{8\pi\sqrt{2}}
\]
\[
\Gamma(H \rightarrow Z^0Z^0) = \frac{G_FM_H^3}{16\pi\sqrt{2}}
\]

Numerically these give approximately

\[
\Gamma_H = 0.5 \text{ TeV} \left( \frac{M_H}{1 \text{ TeV}} \right)^3
\]

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

\[ W^+W^- \rightarrow W^+W^- \]
\[ W^+W^- \rightarrow Z^0Z^0 \]
\[ Z^0Z^0 \rightarrow W^+W^- \]
\[ Z^0Z^0 \rightarrow Z^0Z^0 \]

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

\[ q \rightarrow W^+ + q' \]
\[ q \rightarrow W^- + q' \]
\[ q \rightarrow Z^0 + q \]

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 $Z^0Z^0$ 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 virtual $Z^0$ 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

$$q + \bar{q} \rightarrow W^+W^-$$

$$q + \bar{q} \rightarrow Z^0Z^0$$

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

If the MSSM1 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 $WW \rightarrow WW$ scattering are not included in the SUSY case. ($WW \rightarrow WW$ 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.,

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

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:

$$g + g \rightarrow \tilde{g} + \tilde{g}$$
\[ q + \bar{q} \rightarrow \tilde{g} + \tilde{g} \]
\[ g + q \rightarrow \tilde{g} + \tilde{q} \]
\[ g + g \rightarrow \tilde{q} + \tilde{q} \]
\[ q + \bar{q} \rightarrow \tilde{q} + \tilde{\bar{q}} \]
\[ q + q \rightarrow \tilde{q} + \tilde{\bar{q}} \]

Left and right squarks are distinguished but assumed to be degenerate. Masses can be specified using the \texttt{GAUGINO}, \texttt{SQUARK}, and \texttt{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 \texttt{FORCE} or \texttt{FORCE1} commands (see Section 6).

If \texttt{MSSMA}, \texttt{MSSMB}, and \texttt{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 \texttt{MSSMi}, so that the physical masses will be somewhat different due to \textit{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 \texttt{MSSMi} parameters are specified, then the following additional processes are included using the MSSM couplings for the production cross sections:

\[ g + q \rightarrow \tilde{Z}_i + \tilde{\bar{q}} \]
\[ q + \bar{q} \rightarrow \tilde{Z}_i + \tilde{q} \]
\[ q + \bar{q} \rightarrow \tilde{W}_i + \tilde{\bar{q}} \]
\[ q + \bar{q} \rightarrow \tilde{W}_i^+ + \tilde{W}_j^- \]
\[ q + \bar{q} \rightarrow \tilde{Z}_i + \tilde{Z}_j \]
\[ q + \bar{q} \rightarrow \tilde{\ell}^+ + \tilde{\ell}^- \]

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 \( A \rightarrow \tilde{B} f f \), 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 \texttt{FORCE} use the appropriate matrix elements.

An optional keyword \texttt{MSSMD} can be used to specify the second generation masses, which otherwise are assumed degenerate with the first generation. An optional keyword \texttt{MSSME} can be used to specify values of the \textit{U}(1) and \textit{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 \texttt{MSSMi} parameters, one can use the \texttt{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 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;
- $\text{sgn} \mu = \pm 1$: 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.

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 $\Lambda_m$. 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;
- $\text{sgn} \mu = \pm 1$: 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 $C_{\text{grav}}$ 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

- $R$, an extra factor multiplying the gaugino masses at the messenger scale. (Models with multiple spurions generally have $R < 1$.)
• \( \delta M_{H^u}^2, \delta M_{H^d}^2 \), Higgs mass-squared shifts relative to the minimal model at the messenger scale. (These might be expected in models which generate \( \mu \) realistically.)

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

• \( N_{51}, N_{52}, \) and \( N_{53} \), 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 \( M_{GVTNO} \). 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 \( m_0, m_{3/2}, \tan \beta, \text{sign}(\mu) \), 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 seesaw 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 \( \gamma \) 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 FORCED or FORCED1, not WMODEi. See Section [6] below.) Other Standard Model processes, including \( e^+e^- \rightarrow e^+e^- \) (t-channel graph) and \( e^+e^- \rightarrow \gamma\gamma \), 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 EEKREM command while stipulating the minimal and maximal subprocess energy. Beamstrahlung is implemented by invoking the EEKBEAM keyword. In this case, in addition the beamstrahlung parameter \( \Upsilon \) and longitudinal beam size \( \sigma_z \) (in mm) must be given. The definition for \( \Upsilon \) 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

\[
\begin{align*}
e^+e^- & \rightarrow \bar{q}q \\
e^+e^- & \rightarrow \bar{\ell}\ell \\
e^+e^- & \rightarrow \bar{W}_i\bar{W}_j \\
e^+e^- & \rightarrow \bar{Z}_i\bar{Z}_j \\
e^+e^- & \rightarrow H^0_L + Z^0, H^0_H + Z^0, H^0_A + H^0_L, H^0_A + H^0_R, H^+ + H^- 
\end{align*}
\]

Note that SUSY Higgs production via \( WW \) and \( ZZ \) fusion, which can dominate Higgs production processes at \( \sqrt{s} > 500 \) 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 \(-1 \leq P_L \leq +1\). 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 $G_{1/2}N$ has recently attracted interest. In these theories,

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

where $\delta$ is the number of extra dimensions and $M_D$ is the $4+\delta$ Planck scale. Gravity deviates from the standard theory at a distance $R \sim 10^{22/\delta-19}$ m, so $\delta \geq 2$ is required. If $M_D$ is of order 1 TeV, then the usual hierarchy problem is solved, although there is then a new hierarchy 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 $\delta$ 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-collinear 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 \( \text{MTOT} \) keyword. Limits on the \( p_T \) and rapidity of each final parton can be set via the \( \text{PT} \) and \( Y \) keywords, while limits on the mass of any pair of final partons can be set via the \( \text{MIJTOT} \) 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,

\[
g(p) \to g(p_1) + g(p_2)
\]

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,

\[
g(p) \to g(p_1) + g(p_2) \quad \text{and} \quad q(p) \to q(p_1) + \bar{q}(p_2)
\]

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, \((6 \text{ GeV})^2\), 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,

\[
P(t_0, t_1) = \left(\frac{\alpha_s(t_0)}{\alpha_s(t_1)}\right)^{2\gamma(z_c)/b_0}
\]

where

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

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

\[
\langle p_t^2 \rangle = (.1 \text{ GeV})\sqrt{Q^2}
\]

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 \texttt{WPMODE}, \texttt{WMMODE}, and \texttt{ZOMODE} 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 $q_i$, a new quark-antiquark pair $q_i\bar{q}_i$ is generated with

$$u : d : s = 0.43 : 0.43 : 0.14$$

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

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

and having a transverse momentum $p_t$ with $\langle p_t \rangle = 0.35$ 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

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

while for heavy quarks the Peterson form

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

is used with $\epsilon = 0.80/m_c^2$ for $c$ and $\epsilon = 0.50/m_q^2$ for $q = b, t, y, x$. These values of $\epsilon$ 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 $q_i$ 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 an 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

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

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 $K$:

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

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
$dN/dy$:

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

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 $K/\pi$ 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
See Section [8] 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

```bash
@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,

```fortran
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

```bash
23
```
Create an input file JOBNAME.PAR following the examples above or the instructions in Section 3. 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

```fortran
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 3. 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 Solaris, 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 postended to all external names; you must choose the appropriate compiler option if you intend to link with it. Then type

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

```fortran
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')
  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.
&USE,DOUBLE.
&USE,STDIO.
&USE,MOVEFTN.
&USE,RANFFTN,IF=-CERN.
&USE,RANFCALL.
&USE,NOCERN,IF=-CERN.
&EOD

&PATCH,APOLLO.
&DECK,BLANKDEK.
&USE,DOUBLE.
&USE,STDIO.
&USE,MOVEFTN.
&USE,RANFFTN,IF=-CERN.
&USE,RANFCALL.
&USE,NOCERN,IF=-CERN.
&USE,IMPNONE.
&EOD

&PATCH,CDC.
&USE,SINGLE.
&USE,LEVEL2.
&USE,CDCPACK.
&USE,RANFCALL.
&USE,NOCERN,IF=-CERN.
&EOD
```

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&PATCH, CRAY.
&USE, SINGLE.
&USE, STDIO.
&USE, MOVEFTN.
&USE, NOCERN, IF=-CERN.
&EOD

CRAY XMP OR 2.
SINGLE PRECISION.
STANDARD FORTRAN 77 TAPE INPUT/OUTPUT.
FORTRAN REPLACEMENT FOR MOVLEV.
NO CERN LIBRARY.

&PATCH, DECS.
&USE, SUN.
&EOD

DEC STATION (ULTRIX)

&PATCH, ETA.
&USE, SINGLE.
&USE, STDIO.
&USE, MOVEFTN.
&USE, RANFCALL.
&USE, NOCERN, IF=-CERN.
&EOD

ETA-10.
SINGLE PRECISION.
STANDARD FORTRAN 77 TAPE INPUT/OUTPUT.
FORTRAN REPLACEMENT FOR MOVLEV.
FORTRAN RANF.
STANDARD RANSET AND RANGET CALLS.
NO CERN LIBRARY.
IMPLICIT NONE

&PATCH, HPUX.
&USE, DOUBLE.
&USE, STDIO.
&USE, MOVEFTN.
&USE, RANFFTN, IF=-CERN.
&USE, RANFCALL.
&USE, NOCERN, IF=-CERN.
&USE, IMPNONE.
&EOD

HP/9000 7XX RUNNING UNIX.
DOUBLE PRECISION.
STANDARD FORTRAN 77 TAPE INPUT/OUTPUT.
FORTRAN REPLACEMENT FOR MOVLEV.
FORTRAN RANF.
STANDARD RANSET AND RANGET CALLS.
NO CERN LIBRARY.
IMPLICIT NONE

&PATCH, IBM.
&USE, DOUBLE.
&USE, STDIO.
&USE, MOVEFTN.
&USE, RANFFTN, IF=-CERN.
&USE, RANFCALL.
&USE, NOCERN, IF=-CERN.
&EOD

IBM 370 OR 30XX.
DOUBLE PRECISION.
STANDARD FORTRAN 77 TAPE INPUT/OUTPUT.
FORTRAN REPLACEMENT FOR MOVLEV.
FORTRAN RANF.
STANDARD RANSET AND RANGET CALLS.
NO CERN LIBRARY.

&PATCH, IBMRT.
&USE, DOUBLE.
&USE, STDIO.
&USE, MOVEFTN.
&USE, RANFFTN, IF=-CERN.
&EOD

IBM RS/6000 WITH AIX 3.1
DOUBLE PRECISION.
STANDARD FORTRAN 77 TAPE INPUT/OUTPUT.
FORTRAN REPLACEMENT FOR MOVLEV.
FORTRAN RANF.
&USE,RANFCALL. STANDARD RANSET AND RANGET CALLS.
&USE,NOCERN,IF=-CERN. NO CERN LIBRARY.
&USE,IMPNONE. IMPLICIT NONE &EOD

&PATCH,LINUX.
&USE,DOUBLE. IBM PC WITH LINUX 1.X
&USE,STDX. 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,STDX. 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,STDX. 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,STDX. 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

&PATCHY.

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

&PATCHY.

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.]
&[USE,HBOOK3.]
&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:

```fortran
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)

```fortran
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:

```fortran
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
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
- **ISAVEV** 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 accommodate 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):

```plaintext
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---------------------------------------------------------------------
C
C Initialize ISAJET
C
  CALL ISAINI(-i,0,m,n)
  1 IFL=0
```
CALL ISABEG(IFL)
IF(IFL.NE.0) STOP

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
Example of generating two kinds of events.

CHARACTER*60 FNAME
REAL VC1(20000),VC2(20000)
LOGICAL OK1,DONE1,OK2,DONE2
INTEGER NC1,NC2,IFL,ILOOP,I2,ILOOP2

Open decay table
READ 1000, FNAME
1000 FORMAT(A)
OPEN(1,FILE=FNAME,STATUS='OLD',FORM='FORMATTED')

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')

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

IFL=0
CALL CTXIN(NC1,VC1,20000)
CALL ISABEG(IFL)
CALL CTXOUT(NC1,VC1,20000)
IF(IFL.NE.0) GO TO 999
ILOOP=0

Main event
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 \( E_{cm} = 800 \, \text{GeV} \) and prints 10 events. The events printed are: 1,100,200,\ldots. 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           |             |         | HMASSSES   | STRUC  |
| Y           |             |         | LAMBDA     | WFUDGE |
| WMODE1      |             |         | MGVTNO     | WMMODE |
| WMODE2      |             |         | MSSMA      | WPMODE |
|             |             |         | MSSMB      | Z0MODE |
|             |             |         | MSSMC      |        |
|             |             |         | MSSMD      |        |
|             |             |         | MSSME      |        |
|             |             |         | NUSUG1     |        |
|             |             |         | NUSUG2     |        |
|             |             |         | NUSUG3     |        |
|             |             |         | NUSUG4     |        |
|             |             |         | NUSUG5     |        |
|             |             |         | SIGQT      |        |
|             |             |         | SIN2W      |        |
|             |             |         | SLEPTON    |        |
|             |             |         | SQUARK     |        |
|             |             |         | SUGRA      |        |
|             |             |         | SUGRHNN    |        |
|             |             |         | 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        | $m_0, m_3/2, \tan \beta, \text{sgn} \mu$ | none           | Anomaly-mediated SUSY breaking scalar mass, gravitino mass, VEV ratio, sign  |
| BEAMS       | type1, type2                  | 'P', 'P'       | Initial beams. Allowed are 'P', 'AP', 'N', 'AN'.                            |
| CUTJET      | $\mu_c$                       | 6.             | Cutoff mass for QCD jet evolution.                                          |
| CUTOFF      | $\mu^2, \nu$                  | .200, 1.0      | Cutoff $q^2 = \mu^2 Q^\nu$ for DRELLYAN events.                            |
| EEBEAM      | $\sqrt{s_{\text{min}}}, \sqrt{s_{\text{max}}}, \Upsilon, \sigma_z$ | none          | impose brems/beamstrahlung min and max subprocess energy, beamstrahlung parameter $\Upsilon$ longitudinal beam size $\sigma_z$ in mm |
| EEBREM      | $\sqrt{s_{\text{min}}}, \sqrt{s_{\text{max}}}$ | 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 $-1 \leq P_L \leq 1$ |
| EXTRAD      | $\delta, M_D, \text{UVCUT}$   | None           | Parameters for EXTRADIM process UVCUT is logical flag                      |
| FORCE       | $i, i_1, ..., i_5$            | None           | Force decay of particles, $\pm i \to \pm (i_1 + ... + i_5)$. Can call 20 times. See note for $i = \text{quark}$. |
| FORCE1      | $i, i_1, ..., i_5$            | None           | Force decay $i \to i_1 + ... + i_5$. Can call 40 times. See note for $i = \text{quark}$. |
| FRAGMENT    | $P_{ud, \ldots}$              | .4, \ldots    | 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 $\tilde{Z}^0$ |
| Parameter       | Symbol | Description                                      |
|-----------------|--------|--------------------------------------------------|
| GMSB            |        | GMSB messenger SUSY breaking, mass, number of $5 + 5$, VEV |
|                 | $\Lambda_m, M_m, N_5$ | none |
|                 | $\tan \beta, \text{sgn } \mu, C_{gr}$ | gravitino scale |
| GMSB2           |        | non-minimal GMSB parameters gaugino mass multiplier |
|                 | $\delta M^2_{Hd}, \delta M^2_{Hu}, D_Y(M)$ | $1,0,0,0$ |
|                 | $N_{51}, N_{52}, N_{53}$ | $N_5$ |
|                 | $N_5$, $N_5^1$, $N_5^2$, $N_5^3$ | Higgs mass shifts, D-term mass |
|                 | $D_Y(M)$ | $1,0,0,0$ gaugino mass multiplier |
| HMASS           |        | Mass for standard Higgs. |
|                 | $m$    | |
| HMASSSES        |        | Higgs meson masses for |
|                 | $m_1, \ldots, m_9$ | $0,\ldots,0$ |
| HTYPE           |        | One MSSM Higgs type ('HL0', 'HL0'/ or... none 'HH0', or 'HA0') |
| JETTYPE1        |        | Select types for jets: |
|                 | 'GL', 'UP', ... | 'ALL' |
| JETTYPE2        |        | )'ALL'; 'GL'; 'QUARKS'='UP', |
|                 | 'GL', 'UP', ... | 'ALL' |
| JETTYPE3        |        | )'LEPTONS'='E-', 'E+', 'MU-', |
| MSSSMA          |        | MSSM parameters – |
|                 | $m(\tilde{g}), \mu, m(A), \tan \beta$ | Required |
| MSSSMB          |        | MSSM 1st generation – |
|                 | $m(q_1), m(d_r), m(u_r), m(l_1), m(e_r)$ | Required |
| MGVTNNO         |        | Gravitino mass – ignored for GMSB model |
| $M_{\text{gravitino}}$ | $10^{30}$ GeV | |
| MIJLIM          | $i,j,M_{\text{min}}, M_{\text{max}}$ | $0,0,1$ GeV, $1$ GeV |
| MSSSMA          |        | MSSM parameters – |
| $m(\tilde{g}), \mu, m(A), \tan \beta$ | Required |
| MSSSMB          |        | MSSM 1st generation – |
| $m(q_1), m(d_r), m(u_r), m(l_1), m(e_r)$ | Required |

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| MSSMC | m(q_3), m(b_r), m(t_r), A_t, A_b, A_r | MSSM 3rd generation – Soft squark masses, slepton masses, and squark and slepton mixings |
|-------|-------------------------------------|-------------------------------------------------------------------------------------|
| MSSMD | m(q_2), m(s_r), m(c_r), m(l_2), m(mu_r) | MSSM 2nd generation – Left and right soft squark and slepton masses |
| MSSME | M_1, M_2 | MSSM gaugino masses – Default is to scale from gluino |
| MTOT | M_{min}, M_{max} | Mass range for multiparton processes |
| NODECAY | TRUE or FALSE | FALSE | Suppress all decays. |
| NOETA | TRUE or FALSE | FALSE | Suppress eta decays. |
| NOEVOLVE | TRUE or FALSE | FALSE | Suppress QCD evolution and hadronization. |
| NOGRAV | TRUE or FALSE | FALSE | Suppress gravitino decays in GMSB model |
| NOHADRON | TRUE or FALSE | FALSE | Suppress hadronization of jets and beam jets. |
| NONUNU | TRUE or FALSE | FALSE | Suppress Z^0 neutrino decays. |
| NOPI0 | TRUE or FALSE | FALSE | Suppress \( \pi^0 \) decays. |
| NPOMERON | n_1, n_2 | 1,20 | Allow \( n_1 < n < n_2 \) cut pomerons. Controls beam jet mult. |
| NSIGMA | n | 20 | Generate n unevolved events for SIGF calculation. |
| NTRIES | n | 1000 | Stop if after n tries cannot find a good event. |
| NUSUG1 | Optional non-universal SUGRA |
|--------|-----------------------------|
| $M_1, M_2, M_3$ | none | gaugino masses |

| NUSUG2 | Optional non-universal SUGRA |
|--------|-----------------------------|
| $A_t, A_b, A_\tau$ | none | $A$ terms |

| NUSUG3 | Optional non-universal SUGRA |
|--------|-----------------------------|
| $M_{H_d}, M_{H_u}$ | none | Higgs masses |

| NUSUG4 | Optional non-universal SUGRA |
|--------|-----------------------------|
| $M_{u_L}, M_{d_R}, M_{u_R}$, $M_{e_L}, M_{e_R}$ | none | 1st/2nd generation masses |

| NUSUG5 | Optional non-universal SUGRA |
|--------|-----------------------------|
| $M_{t_L}, M_{b_R}, M_{t_R}$, $M_{\tau_L}, M_{\tau_R}$ | none | 3rd generation masses |

| P | Momentum limits for jets. |
|---|---------------------------|
| $p_{\text{min}}(1), \ldots, p_{\text{max}}(3)$ | $1.5E_{\text{cm}}$ |

| PDFLIB | CERN PDFLIB parton distribution parameters. See PDFLIB manual. |
|-------|-------------------------------------------------------------|
| 'name1', 'val1', \ldots | None |

| PHI | Phi limits for jets. |
|-----|----------------------|
| $\phi_{\text{min}}(1), \ldots, \phi_{\text{max}}(3)$ | $0.2\pi$ |

| PHIW | Phi limits for W. |
|-----|-------------------|
| $\phi_{\text{min}}, \phi_{\text{max}}$ | $0.2\pi$ |

| PT or PPERP | $p_t$ limits for jets. |
|-------------|------------------------|
| $p_{t,\text{min}}(1), \ldots, p_{t,\text{max}}(3)$ | $0.05E_{\text{cm}}, 2E_{\text{cm}}$ |

| QMH | Mass limits for Higgs. |
|-----|-----------------------|
| $q_{\text{min}}, q_{\text{max}}$ | $0.05E_{\text{cm}}, 2E_{\text{cm}}$ |

| QMW | Mass limits for W. |
|-----|-------------------|
| $q_{\text{min}}, q_{\text{max}}$ | $0.05E_{\text{cm}}, 2E_{\text{cm}}$ |

| QTW | $q_t$ limits for W. Fix $q_t = 0$ for standard Drell-Yan. |
|-----|-----------------------------------------------------------|
| $q_{t,\text{min}}, q_{t,\text{max}}$ | $1.025E_{\text{cm}}$ |

| SEED | Random number seed (double precision if 32 bit). |
|-----|------------------------------------------------|
| real | 0 |
| Parameter   | Value                | Description                                                                 |
|-------------|----------------------|-----------------------------------------------------------------------------|
| SIGQT $\sigma$ | .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 $\tilde{\nu}_e, \tilde{\nu}_c, \tilde{\nu}_\mu$             |
| SQUARK $m_1,\ldots,m_6$ | 100.3,...,240.      | Masses for $\tilde{u}, \tilde{d}, \tilde{s}$, $\tilde{c}, \tilde{b}, \tilde{t}$ |
| STRUC name    | 'CTEQ3L'             | Structure functions. CTEQ3L, CTEQ2L, EHLQ, OR DO                           |
| SUGRA $m_0,m_{1/2},A_0$, $\tan\beta,\text{sgn}\mu$ | none, none          | Minimal supergravity parameters                                            |
| SUGRHN $m_{\nu},M_N,A_n,m_{\tilde{\nu}_R}$ | 0,1E20,0,0           | SUGRA see-saw $\nu$-effect                                                |
| THW $\theta_{\text{min}},\theta_{\text{max}}$ | 0,\pi               | Theta limits for jets. Do not also set $Y$.                                |
| TCMASS $m,\Gamma$ | 1000,100            | Technicolor mass and width.                                                |
| TMASS $m_t,m_y,m_x$ | 180.,-1.,-1.        | $t, y,$ and $x$ quark masses.                                             |
| WFUDGJE 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 'UP',..., 'TAU+', 'ALL' |            | Decay modes for $W^-$ in parton cascade. See JETTYPE.                      |
| **WMODE1** | 'UP', 'UB', ... 'ALL' |
|-------------|-----------------------|
| **WMODE2** | 'UP', 'UB', ... 'ALL' |
| **WPmode** | Decay modes for $W^+$ in parton cascade. See JETTYPE. |
| **WTYPE**  | Select W type: $W^+$, $W^-$, GM, Z0. |
| **type1, type2** | 'GM','Z0' |
| **X**      | Feynman x limits for jets. |
| $x_{\text{min}}(1), \ldots, x_{\text{max}}(3)$ | $-1,1$ |
| **XGEN**   | Jet fragmentation, Peterson with $\epsilon = a(n)/m^2$, $n = 4-8$. |
| a(1), ... ,a(8) | .96, 3, 0, 8, 5, ... |
| **XGENSS** | Fragmentation of GLSS, UPSS, etc. with $\epsilon = a(n)/m \ast \ast 2$ |
| a(1), ... ,a(7) | .5, 5, ... |
| **XW**     | Feynman x limits for W. |
| $x_{\text{min}}$, $x_{\text{max}}$ | $-1,1$ |
| **Y**      | Y limits for each jet. |
| $y_{\text{min}}(1), \ldots, y_{\text{max}}(3)$ | from PT |
| **YW**     | Y limits for W. |
| $y_{\text{min}}$, $y_{\text{max}}$ | from QTW, QMW |
| **Z0MODE** | Decay modes for $Z^0$ in parton cascade. See JETTYPE. |
| 'UP', ... , 'TAU+' | 'ALL' |
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 $E_{cm}$. 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 MJLIM. 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 $e^+e^- \rightarrow W^+W^-$, $Z^0Z^0$, 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 $2 \rightarrow 4$ 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',
'BTS1', 'BBTS1', 'TPSS1', 'TBTS1',
'UPSSR', 'UBSSR', 'DNSSR', 'DBSSR', 'STSSR', 'SBSSR', 'CHSSR', 'CBSSR',
'BTS2', 'BBTS2', 'TPSS2', 'TBTS2',
'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, $\mu$ 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 $\text{sgn}\mu = \pm 1$ 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 parameter of an optional right-handed neutrino. Similarly, the GMSB keyword is used to specify the $\Lambda, M_m, N_5, \tan\beta$, $\text{sgn}\mu = \pm 1$, and $C_{\text{grav}}$ 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 $\text{sgn}\mu$ 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 $D^0 \rightarrow K^+\pi^-$ and $\bar{D}^0 \rightarrow K^-\pi^+$. If only a specific decay is wanted one should use the FORCE1 command; e.g.

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

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

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 $t \rightarrow W^+b$ and $W^+ \rightarrow e^+\nu_e$ 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 usual 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 minimum $p_T$ 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
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:

\[
\begin{align*}
\text{COMMON/DYLIM/QMIN, QMAX, QTMIN, QTMAX, YWMIN, YWMAX, XWMIN, XWMAX, THWMIN,} \\
2 \quad \text{THWMAX, PHWMIN, PHWMAX} \\
3 \quad \text{SAVE /DYLIM/} \\
\text{LOGICAL SETLMQ} \\
\text{EQUIVALENCE(BLIM1(1), QMIN)} \\
\text{REAL QMIN, QMAX, QTMIN, QTMAX, YWMIN, YWMAX, XWMIN, XWMAX, THWMIN,} \\
+ \quad \text{THWMAX, PHWMIN, PHWMAX, BLIM1(12)}
\end{align*}
\]

\[
\begin{align*}
\text{QMIN, QMAX} & = W \text{ mass limits} \\
\text{QTMIN, QTMAX} & = W q_t \text{ limits} \\
\text{YWMIN, YWMAX} & = W \eta \text{ rapidity limits} \\
\text{XWMIN, XWMAX} & = W x_F \text{ limits} \\
\text{THWMIN, THWMAX} & = W \theta \text{ limits} \\
\text{PHWMIN, PHWMAX} & = W \phi \text{ limits}
\end{align*}
\]

\[
\begin{align*}
\text{COMMON/IDRUN/IDVER, IDG(2), IEVT, IEVGEN} \\
\text{SAVE /IDRUN/} \\
\text{INTEGER IDVER, IDG, IEVT, IEVGEN}
\end{align*}
\]

\[
\begin{align*}
\text{IDVER} & = \text{ program version} \\
\text{IDG(1)} & = \text{ run date (10000} \times \text{month+100} \times \text{day+year)} \\
\text{IDG(2)} & = \text{ run time (10000} \times \text{hour+100} \times \text{minute+second)} \\
\text{IEVT} & = \text{ event number}
\end{align*}
\]
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 $\eta$ rapidity limits
PHIMIN,PHIMAX = jet $\phi$ limits
THMIN,THMAX = jet $\theta$ 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/QOQ(MXGOQ,MXGOJ),GOALL(MXGOJ),GODY(4),STDDY,
$GOWW(25,2),ALLWW(2),GOWM(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
       ⇒ g u ě d ě s ě c ě b ě t ě ě
   I = 14 15 16 17 18 19 20 21 22 23 24 25
       ⇒ νe ë e e+ νμ ë μ μ+ ντ ë τ τ- τ+
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, QOW
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, QOW, PBEAMS

55
\[ P = \text{jet momentum} \quad |\vec{p}| \]
\[ PT = \text{jet } p_t \]
\[ YJ = \text{jet } \eta \text{ rapidity} \]
\[ PHI = \text{jet } \phi \]
\[ XJ = \text{jet } x_F \]
\[ TH = \text{jet } \theta \]
\[ CTH = \text{jet } \cos(\theta) \]
\[ STH = \text{jet } \sin(\theta) \]
\[ \text{JETTYP} = \text{jet type. The code is listed under } /Q1Q2/ \text{ above} \]

Continued...

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

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
JDCAI(I) = JPACK*K1+K2 if K1 and K2 are decay products of I.
  If JDCAI(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,IDCAI(MXPTCL)
SAVE /PARTCL/
INTEGER NPTCL,IORIG,IDENT,IDCAI
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

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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 x 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 ISAWN D 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, ISAVEV, 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

```fortran
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

\[
\begin{align*}
\text{IFL} = 0 & \quad \text{for a good read}, \\
\text{IFL} = -1 & \quad \text{for an end of file}.
\end{align*}
\]

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

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

\[
\begin{align*}
\text{IRECTP} & = 100 \quad \text{for an event record} \\
\text{IRECTP} & = 200 \quad \text{for a beginning record} \\
\text{IRECTP} & = 300 \quad \text{for an end record} \\
\text{IREC} & = \text{no. of physical records in event record, 0 otherwise}
\end{align*}
\]

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     | $\omega/\phi$ decay                       |
| 3     | $V - A$ decay                              |
| 4     | top decay: $V - A$ plus $W$ propagator     |
| 5     | $\tau \rightarrow \ell \nu \bar{\nu}$    |
| 6     | $\tau \rightarrow \nu \pi, \nu K$        |
| 7     | $\tau \rightarrow \nu \rho, \nu a_1$     |

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:

\[
\begin{align*}
UP & = 1 & \text{NUE} & = 11 \\
DN & = 2 & \text{E}^- & = 12 \\
ST & = 3 & \text{NUM} & = 13 \\
CH & = 4 & \text{MU}^- & = 14 \\
BT & = 5 & \text{NUT} & = 15 \\
TP & = 6 & \text{TAU}^- & = 16
\end{align*}
\]

with a negative sign for antiparticles. Arbitrary conventions are:

\[
\begin{align*}
\text{GL} & = 9 \\
\text{GM} & = 10 \\
\text{KS} & = 20 \\
\text{KL} & = -20 \\
\text{W}^+ & = 80 \\
\text{Z}^0 & = 90
\end{align*}
\]

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:

\[
\begin{align*}
\text{UPSSL} & \ldots \text{TPSS1} = 21 \ldots 26 \\
\text{NUEL} & \ldots \text{TAU1}^- = 31 \ldots 36 \\
\text{UPSSR} & \ldots \text{TPSS2} = 41 \ldots 46 \\
\text{NUER} & \ldots \text{TAU2}^- = 51 \ldots 56 \\
\text{GLSS} & = 29 \\
\text{Z1SS} & = 30 & \text{Z2SS} & = 40 \\
\text{Z3SS} & = 50 & \text{Z4SS} & = 60 \\
\text{W1SS}^+ & = 39 & \text{W2SS}^+ & = 49
\end{align*}
\]

Finally, the gravitino and graviton are

\[
\begin{align*}
\text{GVSS} & = 91 & \text{GRAV} & = 92
\end{align*}
\]

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,

\[
\begin{align*}
\text{PIO} & = 110 \\
\text{ETA} & = 220 \\
\text{ETAP} & = 330 \\
\text{ETAC} & = 440
\end{align*}
\]
which is natural for the heavy quarks. Similarly, the code for a baryon is a compound integer
+\text{-IJKL} formed from the three quarks I,J,K and a spin label L=0,1. The code for a diquark
is +\text{-IJ}00. Additional states are distinguished by a fifth integer, e.g.,

\begin{align*}
\text{A1+} & = 10121
\end{align*}

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 | HHO | 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 | PIO | .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 | AKO | .49767E+00 | 0.00 |
| 330 | ETAP | .95760E+00 | 0.00 |
| 140 | ADO | .18645E+01 | 0.00 |
-140  DO  .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

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|   | Symbol  | Value         | Charge |
|---|---------|---------------|--------|
| -132 | K2--    | 1.4254E+01    | -1.00  |
| 232  | K2*0    | 1.4324E+01    | 0.00   |
| -232 | AK2*0   | 1.4324E+01    | 0.00   |
| 10110 | F0     | 9.8000E+00    | 0.00   |
| 10111 | A10    | 1.2300E+01    | 0.00   |
| -10121 | A1-    | 1.2300E+01    | 0.00   |
| 10131 | K1+    | 1.2730E+01    | 1.00   |
| -10131 | K1-    | 1.2730E+01    | 1.00   |
| 10231 | K10    | 1.2730E+01    | 1.00   |
| -10231 | AK10   | 1.2730E+01    | 1.00   |
| 30131 | K1**    | 1.4120E+01    | 1.00   |
| -30131 | K1*+    | 1.4120E+01    | 1.00   |
| 30231 | K1*0    | 1.4120E+01    | 1.00   |
| -30231 | AK1*0   | 1.4120E+01    | 1.00   |
| 10441 | PSI(2S) | 3.6860E+01    | 0.00   |
| 20440 | CHI0    | 3.4151E+01    | 0.00   |
| 20441 | CHI1    | 3.5105E+01    | 0.00   |
| 20442 | CHI2    | 3.5662E+01    | 0.00   |
| 1120  | P       | 9.3828E+00    | 1.00   |
| -1120 | AP      | 9.3828E+00    | -1.00  |
| 1220  | N       | 9.3957E+00    | 0.00   |
| -1220 | AN      | 9.3957E+00    | 0.00   |
| 1130  | S+      | 1.1894E+01    | 1.00   |
| -1130 | AS-     | 1.1894E+01    | 1.00   |
| 1230  | S0      | 1.1925E+01    | 0.00   |
| -1230 | AS0     | 1.1925E+01    | 0.00   |
| 2130  | L       | 1.1156E+01    | 0.00   |
| -2130 | AL      | 1.1156E+01    | 0.00   |
| 2230  | S-      | 1.1974E+01    | 1.00   |
| -2230 | AS+     | 1.1974E+01    | 1.00   |
| 1330  | XIO     | 1.3149E+01    | 0.00   |
| -1330 | AXI0    | 1.3149E+01    | 0.00   |
| 2330  | XI-     | 1.3213E+01    | 1.00   |
| -2330 | AXI+    | 1.3213E+01    | 1.00   |
| 1140  | SC++    | 2.4527E+01    | 2.00   |
| -1140 | ASC--   | 2.4527E+01    | 2.00   |
| 1240  | SC+     | 2.4529E+01    | 1.00   |

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-1240  ASC-  .24529E+01  -1.00
2140  LC+  .22849E+01  1.00
-2140  ALC-  .22849E+01  -1.00
2240  SCO  .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.  .36700E+01  1.00
-3440  ASCC.  .36700E+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  0.00
-2250  ADDB.  .54700E+01  0.00
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  0.00
-2350  ADSB.  .56700E+01  0.00
3250  SDB.  .56700E+01  0.00
-3250  ASDB.  .56700E+01  0.00
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
|     | Code    | Value    | Charge |
|-----|---------|----------|--------|
| -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  | DLO     | 12320E+01 | 0.00   |
| -1221 | ADLO    | 12320E+01 | 0.00   |
| 2221  | DL-     | 12320E+01 | -1.00  |
| -2221 | ADL+    | 12320E+01 | 1.00   |
| 131   | S**     | 13823E+01 | 1.00   |
| -131  | 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   |
| 141   | UUC*    | 26300E+01 | 2.00   |
| -141  | 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*  0.27000E+01  1.00  
-1341 AUSC*  0.27000E+01  -1.00  
2341  DSC*  0.27000E+01  0.00  
-2341 ADSC*  0.27000E+01  0.00  
3341  SSC*  0.28000E+01  0.00  
-3341 ASSC*  0.28000E+01  0.00  
1441  UCC*  0.37500E+01  2.00  
-1441 AUCC*  0.37500E+01  -2.00  
2441  DCC*  0.37500E+01  1.00  
-2441 ADCC*  0.37500E+01  -1.00  
3441  SCC*  0.39000E+01  0.00  
-3441 ASCC*  0.39000E+01  0.00  
4441  CCC*  0.48000E+01  2.00  
-4441 ACCC*  0.48000E+01  -2.00  
1151  UUB*  0.55100E+01  1.00  
-1151 AUUB*  0.55100E+01  -1.00  
1251  UDB*  0.55100E+01  0.00  
-1251 AUDB*  0.55100E+01  0.00  
2251  DDB*  0.55100E+01  -1.00  
-2251 ADDB*  0.55100E+01  1.00  
1351  USB*  0.57100E+01  0.00  
-1351 AUSB*  0.57100E+01  0.00  
2351  DSB*  0.57100E+01  -1.00  
-2351 ADSB*  0.57100E+01  1.00  
3351  SSB*  0.59100E+01  0.00  
-3351 ASSB*  0.59100E+01  0.00  
1451  UCB*  0.68100E+01  1.00  
-1451 AUCB*  0.68100E+01  -1.00  
2451  DCB*  0.68100E+01  0.00  
-2451 ADCB*  0.68100E+01  0.00  
3451  SCB*  0.70100E+01  0.00  
-3451 ASCB*  0.70100E+01  0.00  
4451  CCB*  0.81100E+01  1.00  
-4451 ACCB*  0.81100E+01  -1.00  
1551  UBB*  0.10110E+02  0.00  
-1551 AUBB*  0.10110E+02  0.00  
2551  DBB*  0.10110E+02  -1.00  
-2551 ADBB*  0.10110E+02  1.00  
3551  SBB*  0.10310E+02  0.00  
-3551 ASBB*  0.10310E+02  1.00  
4551  CBB*  0.11410E+02  0.00  
-4551 ACBB*  0.11410E+02  0.00  
5551  BBB*  0.14710E+02  -1.00  
-5551 ABBB*  0.14710E+02  1.00
| Time  | Symbol | Value        | Phase |
|-------|--------|--------------|-------|
| 1100  | UU0    | 0.600E+00    | 0.67  |
| -1100 | AUU0   | 0.600E+00    | -0.67 |
| 1200  | UDO    | 0.600E+00    | 0.33  |
| -1200 | AUDO   | 0.600E+00    | -0.33 |
| 2200  | DDO    | 0.600E+00    | -0.67 |
| -2200 | ADDO   | 0.600E+00    | 0.67  |
| 1300  | USO    | 0.800E+00    | 0.33  |
| -1300 | AUSO   | 0.800E+00    | -0.33 |
| 2300  | DSO    | 0.800E+00    | -0.67 |
| -2300 | ADSO   | 0.800E+00    | 0.67  |
| 3300  | SS0    | 0.100E+01    | -0.67 |
| -3300 | ASS0   | 0.100E+01    | 0.67  |
| 1400  | UCO    | 0.190E+01    | 1.33  |
| -1400 | AUCO   | 0.190E+01    | -1.33 |
| 2400  | DCO    | 0.190E+01    | 0.33  |
| -2400 | ADCO   | 0.190E+01    | -0.33 |
| 3400  | SCO    | 0.210E+01    | 0.33  |
| -3400 | ASCO   | 0.210E+01    | -0.33 |
| 4400  | CCO    | 0.320E+01    | 1.33  |
| -4400 | ACCO   | 0.320E+01    | -1.33 |
| 1500  | UBO    | 0.490E+01    | 0.33  |
| -1500 | AUBO   | 0.490E+01    | -0.33 |
| 2500  | DBO    | 0.490E+01    | -0.67 |
| -2500 | ADBO   | 0.490E+01    | 0.67  |
| 3500  | SBO    | 0.510E+01    | -0.67 |
| -3500 | ASB0   | 0.510E+01    | 0.67  |
| 4500  | CBO    | 0.650E+01    | 0.33  |
| -4500 | ACBO   | 0.650E+01    | -0.33 |
| 5500  | BBO    | 0.980E+01    | -0.67 |
| -5500 | ABB0   | 0.980E+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., \( g \rightarrow b + \bar{b} \));
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

\[
g + g \rightarrow Q + \bar{Q}
\]

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

\[
g + g \rightarrow g + g, \quad g \rightarrow Q + \bar{Q}
\]

produces collinear pairs. Such collinear pairs are essential to obtain agreement with experimental data on \( bb \) 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 \( n_1n_2 \) events for each hard scattering, so the cross section must be divided by \( n_1n_2 \). This algorithm can speed up the generation of \( g \rightarrow b + \bar{b} \) splitting by a factor of ten for \( n_1 = n_2 = 10 \).

Since the evolution and fragmentation steps are executed \( n_1n_2 \) 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 \( \text{SIGF/NEVENT} \), 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 NOHADRONE.

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

\[ \text{SIGF/NEVENT} \]

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

\[
\begin{align*}
\text{NEVOLVE} & \quad 10/ \\
\text{NHADRON} & \quad 10/
\end{align*}
\]

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:

\[
\begin{align*}
\text{ILOOP} = 0 \\
101 \quad \text{CONTINUE} \\
\text{ILOOP} = \text{ILOOP} + 1
\end{align*}
\]
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 $R = \sqrt{\varphi^2 + \eta^2}$, and some $E_t$ cutoff. Given that information ISAJET will generate initial state radiation partons only below the $E_t$ 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

\begin{verbatim}
CALL INISAP(CMSE,REACTION,BEAMS,WZ,NDCAYS,DCAYS,ETMIN,RCONE,OK)
\end{verbatim}

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

\begin{verbatim}
CALL IPARTNS(NPRTNS,IDS,PRTNS,IDQ,WEIGHT,WZDK)
\end{verbatim}

where the inputs are

- NPRTNS = number of partons, $\leq 10$
- 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 $\mu$, $\tan \beta$, 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 $A_\tau$. 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, $H \rightarrow \gamma\gamma$ and $H \rightarrow gg$, loop corrections to the Higgs mass spectrum and couplings, and leading-log QCD corrections to $H \rightarrow q\bar{q}$ 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:

| Symbol  | Description                      |
|---------|----------------------------------|
| XMG     | gluino mass                      |
| XMU     | $\mu =$ SUSY Higgs mass          |
|         | $=-2 \times m_1$ of Baer et al.  |
| XMHA    | pseudo-scalar Higgs mass         |
| XTANB   | $\tan \beta$, ratio of vev’s     |
|         | $=1/R$ (of old Baer-Tata notation).|
The variable IALLOW is returned:

\[ IALLOW = 1 \text{ if } Z1SS \text{ is not LSP, } 0 \text{ otherwise} \]

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

\[ 50 < M(\tilde{g}) < 2000 \text{ GeV} \]
\[ 50 < M(\tilde{q}) < 2000 \text{ GeV} \]
\[ 50 < M(\tilde{\ell}) < 2000 \text{ GeV} \]
\[ -1000 < \mu < 1000 \text{ GeV} \]
\[ 1 < \tan \beta < m_t/m_b \]
\[ M(t) \approx 175 \text{ GeV} \]
\[ 50 < M(A) < 2000 \text{ GeV} \]
\[ M(\tilde{\ell}_t), M(\tilde{\tau}_r) < M(\tilde{q}) \]
\[ M(\tilde{b}_t) \sim M(\tilde{q}) \]

\[-1000 < A_t < 1000 \text{ GeV} \]

\[-1000 < A_b < 1000 \text{ GeV} \]

It is assumed that the lightest supersymmetric particle is the lightest neutralino \( \tilde{\chi}_1 \), 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 \( \tilde{\chi}_1 \). 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 \(/SSPAR/\):

| Variable | Description |
|----------|-------------|
| AMGLSS   | gluino mass |
| AMULSS   | up-left squark mass |
| AMELSS   | left-selectron mass |
| AMERSSS  | right-slepton mass |
| AMNiSS   | sneutrino mass for generation i |
| TWOM1    | Higgsino mass = - m \mu |
| RV2V1    | ratio v2/v1 of vev’s |
| AMTLSS,AMTRSS | left,right stop masses |
| AM1SS,AM2SS | light,heavy stop masses |
| AMBLSS,AMBSS | left,right sbottom masses |
| AM1SS,AMLSS | signed mass of Zi |
| ZMIXSS   | Zi mixing matrix |
| AM1iSS   | signed Wi mass |
| GAMMAL,GAMMAR | Wi left, right mixing angles |
| AMHL,AMHH,AMHA | neutral Higgs h0, H0, A0 masses |
| AMHC     | charged Higgs H+ mass |
| ALFAH    | Higgs mixing angle |
| AAT      | stop trilinear term |
| THETAT   | stop mixing angle |
| AAB      | sbottom trilinear term |
| THETAB   | sbottom mixing angle |
| AAL      | stau trilinear term |
| THETAL   | stau mixing angle |
| AMGVSS   | gravitino mass |

COMMON/SSPAR/AMGLSS,AMULSS,AMURSS,AMLNSS,AMDSS,AMLSS

$ ,AMRSS ,AMLSS ,AMCRSS,AMLSS,AMBSS,AMB1SS,AMB2SS

$ ,AMTLSS,AMTRSS,AM1SS,AM2SS,AMELSS,AMERSSS,AMLSS,AMMRSS

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It then calculates the widths and branching ratios and puts them in the common block /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 $H \rightarrow Z + Z^* \rightarrow Z + f + \bar{f}$ 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:

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 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 $\text{sgn} \mu$, the sign of the Higgsino mass term. The NUSUG1 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 renormalization group 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.

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

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-tau 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 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 $\alpha_i$; sfermions get squared-masses from two-loop graphs proportional to $\Lambda_m$ times the square of the appropriate $\alpha_i$. 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;
- $\text{sgn} \mu = \pm 1$: 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 $C_{\text{grav}}$ 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 7.47, 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 \( \text{sgn} \mu \). These are set by the \texttt{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 \texttt{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 \( \tilde{W}_i \rightarrow \tilde{Z}_j \tau \nu \).

13.2 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.

13.3 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 \( \tilde{A} \rightarrow \tilde{B}f\bar{f} \), 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 \texttt{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 \texttt{MELEM} that specifies
the matrix element to be used for all processes. This is also used for \textsc{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 \textsc{eebrem} keyword is selected, an electron structure function will be used. For a convolution of both bremsstrahlung and beamstrahlung, the keyword \textsc{eebeam} must be used, with appropriate inputs (see documentation).

### 13.4 Version 7.40, October 1998

A new process \textsc{wigg} 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 \textsc{jett}ype and \textsc{wmode} as for \textsc{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 \textsc{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 \textsc{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 \textsc{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 \textsc{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.

### 13.5 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 $\text{sgn} \mu$; and $C_{\text{grav}} \geq 1$, 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 $\tilde{\tau}_1$, 

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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 MGVTINO 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.

### 13.6 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 $\tilde{\chi}_1^0\tilde{b}\tilde{b}$ 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.

### 13.7 Version 7.31, August 1997

Version 7.31 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.

### 13.8 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.

\begin{verbatim}
FORCE
6,11,-12,5/
\end{verbatim}

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 x 11 inch) or A4 size paper can be used.

13.9 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 $\tilde{g} \rightarrow tb \tilde{W}_i$, $\tilde{Z}_i \rightarrow b\bar{b}\tilde{Z}_j$, and $\tilde{W}_i \rightarrow \tau\nu\tilde{Z}_j$. 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 $\tau$'s and $b$'s are often enhanced, while decays into $e$'s and $\mu$'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.

13.10 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, $Q = \sqrt{M(t_L)M(t_R)}$. Running $t$, $b$ and $\tau$ 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.

13.11 Version 7.22, July 1996

The new version fixes errors in $\tilde{b} \rightarrow \tilde{W}t$ and in some $\tilde{t}$ decays and Higgs decays. It also contains a new decay table with updated $\tau$, $c$, 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.

13.12 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 $gb \rightarrow Wt$ and $gt \rightarrow Zt$. When the $t$ mass is taken into account, the process $gt \rightarrow Wb$ 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 $q \rightarrow qg$ 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 $g \rightarrow q\bar{q}$ 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 $g \rightarrow Q\bar{Q}$ have been overestimated.

The new version also allows the user to set arbitrary masses for the $U(1)$ and $SU(2)$ gaugino masses 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 $ee\gamma\gamma E_T$ 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 $\tilde{Z}_1 \rightarrow \tilde{G}\gamma$ of the lightest zino into a gravitino or goldstino and a photon has been made, but forcing the decay $\tilde{Z}_1 \rightarrow \nu\gamma$ has the same effect for any collider detector.

A number of other minor bugs have also been corrected.
13.13  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.

13.14  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 $\tilde{g} \rightarrow \tilde{q}\bar{q}$. 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.,

```plaintext
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 $e^+e^- \rightarrow \tilde{W}_1^+\tilde{W}_1^-$, are not included.

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

13.15  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.,

```plaintext
SAMPLE E+E- JOB
300.,50000,10,100/
E+E-
SUGRA
100,100,0,2,-1/
```
The effects of spin correlations in the production and decay, e.g., in $e^+e^- \rightarrow \tilde{W}_1^+\tilde{W}_1^-$, are not included.

It should be noted that the Standard Model $e^+e^-$ generator in ISAJET does not include Bhabha 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 7.10, 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 $\mu$ 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

\[
\text{SUGRA} \quad m_0, m_{1/2}, A_0, \tan \beta, \text{sgn} \mu
\]

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