SIMDET - Version 4
A Parametric Monte Carlo for a TESLA Detector

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Abstract

A new release of the parametric detector Monte Carlo program SIMDET (version 4.01) is now available. We describe the principles of operation and the usage of this program to simulate the response of a detector for the TESLA linear collider. The detector components are implemented according to the TESLA Technical Design Report. All detector component responses are treated in a realistic way using a parametrisation of results from the ab initio Monte Carlo program BRAHMS. Pattern recognition is emulated using a complete cross reference between generated particles and detector response. Also, for charged particles, the covariance matrix and \(dE/dx\) information are made available. An idealised energy flow algorithm defines the output of the program, consisting of particles generically classified as electrons, photons, muons, charged and neutral hadrons as well as unresolved clusters. The program parameters adjustable by the user are described in detail. User hooks inside the program and the output data structure are documented.
**Introduction**

Recently the Technical Design Report (TDR) for the superconducting linear collider TESLA has been completed. A possible detector as laid out in the TDR will have to deal with a large dynamic range in energy, complexity of final states and signal-to-background ratio. In particular, the detector should be able to cover the following important physics goals:

- very good momentum resolution ($\delta p_T / p_T \sim 4 \cdot 10^{-5}$/GeV in the central region) to measure e.g. the Z recoil mass in the Higgsstrahlung process $e^+e^- \rightarrow ZH/Z \rightarrow \ell^+\ell^-$ with optimal precision;
- high resolution of hadronic jet energies ($\Delta E/E \approx 30\%/\sqrt{E}$) to reconstruct multi-jet events;
- excellent b- and c-tagging capabilities to identify multi-b final states like $ZHH$ or $t\bar{t}H$ and to separate $H \rightarrow b\bar{b}$, $H \rightarrow c\bar{c}$ and $H \rightarrow gg$;
- good hermiticity to reduce background in missing energy channels; and
- measurement capabilities in the forward direction.

The detector version implemented in **SIMDET** is based on the description of the detector for the TESLA linear collider as presented in Part IV of the TDR. It has been optimised for the physics requirements mentioned above. Its basic components are:

- a multi-layer micro-vertex detector;
- a tracker system with the main tracker as a large Time Projection Chamber (TPC), a silicon tracking subsystem between the vertex detector and the TPC and a set of forward chambers behind the TPC endplates;
- a tracking electromagnetic calorimeter with very fine three dimensional granularity;
- a hadronic calorimeter;
- and an instrumented mask with a small-angle luminosity detector.

**Fig. 1** shows the principal layout of the TESLA detector and its dimensions. The tracking system and the calorimeters are situated inside a 4 T superconducting solenoid.

At TESLA a bunch train of $\sim 2800$ bunches with more than 300 ns spacing makes bunch identification easy and no special detectors are needed for this purpose. Background expected is mostly due to $e^+e^-$ pairs created in beam-beam interactions produced at the interaction point (IP). These pairs are concentrated at low polar angle and low transverse momentum. In order to absorb background related to low-angle pairs a mask in the forward direction is required which is also used for calorimetry. The pairs at large angles can be kept at low radius by a strong magnetic field. It limits the radius of the innermost vertex detector layer to 1.5 cm which ensures an acceptable background level.

The program **SIMDET** simulates the response of this detector for linear collider physics in a fast and user-friendly manner. The main objectives of the program are threefold:
• it provides physics studies groups with a tool for evaluation of the physics potential of a linear collider;

• it treats the detector responds in a realistic manner using a parametrisation of results from the *ab initio* Monte Carlo program **BRAHMS**;

• it is fast and provides a simple output structure, so that physics studies can be done in a straightforward and decentralised way.

Only the *ab initio* GEANT3 application program **BRAHMS** provides detailed and realistic information for charged particle momenta and directions, impact parameters and calorimeter energies and directions. Simple parametrisations of their resolution functions are used as input for **SIMDET**. Gaussian smearing procedures then generate the detector response. Starting from version 3 of the program, a more accurate description of the calorimeter response has been derived from **BRAHMS** and a major upgrade of the program was the implementation of an energy flow algorithm to link tracker and calorimeter information. For this purpose, a simple and idealistic cluster algorithm is applied to the energy deposits in the calorimeters. Clusters and tracks are then linked to form energy flow objects. The ultimate pattern recognition is emulated using a complete cross reference between the calorimeter deposits and the particles originally generated. Energy flow objects are then classified as electrons, photons, muons, charged and neutral hadrons and clusters of unresolved particles using the Monte Carlo truth information. Also, if enabled, the covariance matrix for charged particles and $dE/dx$ information are made available to the user. A new design of the instrumented mask and a low-angle luminosity calorimeter have been included into the default option of the detector, so that the program is
significantly enhanced as far as flavour and particle identification capabilities and large angle coverage are concerned. The identification of a technology for the muon system has yet to be explored in a comprehensive way. The program SIMDET has been prepared for muon response simulation. At present, however, muons are assumed to be measured by the tracking device and identified applying a general misidentification probability.

The objects produced by the energy flow algorithm provide a consistent data structure at the output of the program. This data structure, as well as defined user hooks inside the program itself, can be used to perform physics studies either within SIMDET or by means of an analysis program after writing the energy flow objects to a file.

Furthermore, beamstrahlung based on parametrizations of Ref.\[4\] can be included, $\gamma\gamma$ hadronic background events can be overlayed to physical events \[5\] and an event display for reconstructed objects has been prepared \[6\]. Recently, a CLIC version of the program was initiated \[7\] to study the physics potential of an $e^+e^-$ linear collider in the center-of-mass energy region of 3 TeV and beyond.

**Detector response simulation**

The anticipated particle physics program at TESLA, presented in detail in Part III of the TDR \[1\], represents a very demanding task for the detector. With such a detector the sensitivity for discovery and very high precision measurements over energies from the Z peak up to $\sim 1$ TeV should be as large as possible, withstanding at the same time the background expected. In this section we describe the response of the individual TESLA detector components as implemented in the present version of SIMDET.

Ongoing and planned R&D activities for possible improvements or redesigns of detector components are not considered in this note and have to be accounted for in forthcoming SIMDET versions.

**The tracker system**

The concept of the tracking system is shown in Fig. 2. Excellent tracking of charged particles is achieved by a large Time Projection Chamber (TPC) as a main tracker, supplemented by a silicon tracking detector between the vertex detector (VTX) and the TPC, by discs in the forward region and by a forward chamber located behind the TPC endplate (FCH). The TPC design is similar to existing ones, as implemented in the ALEPH or STAR detectors. So as to not compromise the momentum resolution and the calorimetric energy measurement, field cage and endplates will be designed as thin as possible. A TPC error of $\delta(1/p_T) \leq 2 \cdot 10^{-4}/$GeV for large polar angle tracks and $\sigma(dE/dx) \leq 5\%$ are anticipated. The intermediate tracker consists of two layers of silicon strip detectors (SIT) in the barrel region down to $\theta = 25^\circ$ and three silicon pixel and four silicon strip layers (FTD) on either side in the forward region of the detector. Single point resolutions of 10 $\mu$m respectively 50 $\mu$m are assumed in the simulations for these detectors. The FCH, SIT and FTD improve significantly the momentum resolution for all polar angles and, in particular, the angle measurement capability in the very forward region below $\theta = 12^\circ$.

For the microvertex detector several technologies were proposed: CCDs, active pixel sensors
(APS) and CMOS sensors. With the CCDs a point resolution of 3.5 µm and a layer thickness of 0.12 % of a radiation length can be reached. At present, the CCD detector version has been implemented in detail in the simulation program BRAHMS. Consequently, the same information is represented in SIMDET.

Using the overall tracking system, resolution functions for the inverse of the transverse momentum, polar and azimuthal angles as well as impact parameters as functions of momentum and polar angle θ are input to Gaussian smearing procedures. Interpolating between data points and extrapolation to not yet simulated regions, reasonable descriptions in the whole \((p, \theta)\)-plane have been obtained. Attention has been paid to ensure that the parametrised resolutions are in agreement within a few percent with the BRAHMS predictions. The inverse transverse momentum, the directions θ and φ and the impact parameter resolution parameters are smeared independently. Correlations between momenta and φ directions of tracks are neglected. An example of the BRAHMS simulated resolution functions for 20 GeV momentum tracks are shown in Fig. 3 as a function of polar angle.

The measured values thus obtained for \(1/p_T\), θ and φ can be transformed to \(p_x\), \(p_y\) and \(p_z\) by means of the program package described in Ref. 8, including proper propagation of the measurement errors.

SIMDET offers to set a minimum transverse momentum for tracks, so that below that value charged particles are removed from the event. Tracking efficiency and charge misinterpretation probability can also be specified. The track reconstruction efficiency is momentum dependent: it equals the (default) data card value for tracks with momentum above 2 GeV and becomes continuously smaller with decreasing track momentum. Charge misinterpretation according to the (default) data card value is only applied to large \(p_T\) tracks; this value is increased by a factor of three for badly measured particles. No attempt is currently made to take into account overlaps of closely spaced tracks.
The main element entering in the lifetime tagging is the impact parameter. The impact parameter in the \((r - \phi)\) plane is defined as the minimal distance between the primary vertex (PV) and the track trajectory projected onto the plane perpendicular to the beam direction. The point of closest approach \(P_C\) of the track trajectory to the primary vertex in the \((r - \phi)\) plane is also used to define the \((r - z)\) projection of the impact parameter. Then the \((r - z)\) projection of the track impact parameter is the difference between the \(z\)-coordinates of the primary vertex and the point \(P_C\).

Both impact parameters have a sign defined as follows. The point of closest approach of
the track to the simulated flight direction is computed and the negative (positive) sign is set if this point is upstream (downstream) with respect to the primary vertex position. With this definition, tracks from decays of long-lived particles have predominantly positive signs while tracks coming directly from the PV are equally likely to be positive or negative due to the limited precision of track reconstruction.

For the CCD version of the vertex detector, all necessary input for sophisticated flavour identification exists in the form of a parametrised covariance matrix.

For the APS version of the vertex detector, GEANT3 simulations provide the impact parameter errors as follows:

\[
\begin{align*}
\sigma_{r\phi} &= A \oplus \frac{B}{p \sin^{2} \theta} \\
\sigma_{rz} &= C \oplus \frac{D}{p \sin^{2} \theta}
\end{align*}
\] (1)

for a track with momentum \( p \) and polar angle \( \theta \) in the \((r - \phi)\) and the \((r - z)\) projections. The values of the parameters \( A, B, C, \) and \( D \) were obtained from BRAHMS simulations and transmitted to SIMDET.

**Calorimetric response and energy flow**

The physics programme at a linear collider calls for calorimetry with unprecedented performance which can be translated into the following requirements:

- hermeticity down to very small angles,
- excellent energy resolution for jets respectively partons,
- excellent angular resolution,
- capability to reconstruct non-pointing photons as a stand-alone device,
- good time resolution, to avoid event pile-up.

Dense and hermetic sampling calorimeters with very high granularity realise at best these demands. In the TDR, two options are presented both for the electromagnetic (ECAL) and the hadronic (HCAL) calorimeter components. For the ECAL, the two options are a very high granularity 3D calorimeter based on tungsten and silicon diode pads and a shashlik (scintillator/lead) calorimeter as presented in the CDR \[9\]. Both versions have undergone a successful R&D program, detailed layout studies and careful implementations into the simulation program BRAHMS.

For the HCAL, the two suggestios are an Fe/scintillating tile calorimeter with fine transverse and longitudinal segmentations and a fully digital calorimeter, which represents a novel approach to hadronic calorimetry. It consists of fine pixels \((1 \times 1 cm^{2})\) for an iron/gas sandwhich that is read-out digitally (yes/no) for each cell.
In Version 4 of SIMDET, the tungsten/silicon option for the electromagnetic component and the Fe/scintillating tile option for the HCAL are implemented.

The simulation of the calorimetric response to hadrons and leptons has been updated to correspond more closely to the expected performance of the TESLA calorimeters as described in the Technical Design Report. The excellent energy resolutions for single electrons and photons at high energies are shown in Fig. 4, the energy resolution for hadrons in Fig. 5. Both resolution curves have been determined using \textit{ab initio} simulations of the baseline electromagnetic and hadronic calorimeters as implemented in BRAHMS. They agree well with the resolutions quoted in the TESLA Technical Design Report\cite{1}. These resolution curves are implemented in the current version of SIMDET.

![Figure 4: Relative energy resolution as a function of energy for single high energy electrons as simulated with BRAHMS.](image)

On the other hand, no attempt has been made to simulate the benefits expected from the extremely fine three-dimensional granularity of the silicon tungsten calorimeter. Consequently, also the subsequent cluster algorithm sticks to the simple two-dimensional tower geometry used in the previous version of the program. Users who require a more accurate simulation of the spatial energy deposit or more sophisticated pattern recognition in the calorimeters should directly use BRAHMS for their study.

The energy flow output implemented in the present version of SIMDET which was left unchanged with respect to Version 3 \cite{10}, thus does not fully benefit from the superb pattern recognition capabilities of the tracking calorimeter. Nevertheless, as demonstrated in Fig. 3, usage of the energy flow concept leads to a vast improvement in the reconstruction of the visible and missing energy.
Figure 5: Relative energy resolution as a function of energy for single pions as simulated with BRAHMS.

Figure 6: Energy resolution, using different estimators, for the process $e^+e^- \rightarrow HZ$ at 500 GeV center of mass energy, where the Z boson decays hadronically, while the Higgs boson decays into two W bosons which in turn decay leptonically. The histograms represent the relative difference between true and measured energy using tracks alone (dotted line), calorimetric clusters alone (dashed line) and the energy flow (full line).
**Instrumented mask and forward luminosity calorimeter**

The standard calorimeters ECAL and HCAL are completed by forward calorimeters, which cover polar angles down to 4.6 mrad. These calorimeters, despite their small size, have a large impact on the overall detector performance, since they enhance missing energy resolution, provide electron/photon identification and measure single bunch luminosity.

The Low Angle Tagger (LAT) is designed at the tips of the tungsten mask with a coverage down to $\sim$30 mrad and serves as an additional shield to protect the tracking detectors from backscattered particles. Its design foresees a tungsten sampling calorimeter. It is supported by an inactive tungsten structure. BRAHMS simulations assume radial and azimuthal segmentations for this device. The background expected from $e^+e^-$ beamstrahlung pairs is comparatively small, so that the LAT can probably be used for (electron, photon) and muon identification and measurement.

The Low Angle Calorimeter (LCAL) serves both as a fast luminosity monitor and as a low angle calorimeter. The current design foresees a sampling calorimeter with segmentation in the $z$ direction and azimuthal subdivision. It has to withstand a high level of electromagnetic radiation, yet render accurate energy and angular resolutions. In Fig. 7 the placement of the two calorimeters in the mask structure is shown.

![Figure 7: Design of the forward angle calorimeters, LAT and LCAL.](image)

The expected performance of the LAT has been studied using BRAHMS responses for high energy electrons and muons. Energy and $\theta$ resolution functions for these particles were parametrised and the parameters obtained are implemented in SIMDET. Also, detection efficiencies as functions of energy and polar angle are taken into account. Since no charge information exists, electrons and positrons are interpreted as objects with unknown charge and treated as photons. Closely
spaced $e^+$, $e^-$ and photons are merged to a new energy flow object, while muons with sufficient energy are considered to be isolated and are given a random charge. SIMDET allows to overwrite the default energy and angular resolution parameters as well as the minimum energy needed for particle detection.

For the LCAL we expect from existing BRAHMS simulations that only $e^\pm$ and photons will be measurable with energy and polar angle dependent probabilities. The resolutions expected for energetic particles in light of intense backgrounds are taken into account in SIMDET. All measured LCAL objects are interpreted as photons, since charge information is missing. Accounting for some minimum energy deposits it seems possible that the detector allows electron measurements with more than 50 GeV down to polar angles of 5 mrad.

Since the LCAL is at present only in a stage of preliminary design, the current SIMDET response simulation is simple and accounts only for relative restricted information from the full Monte Carlo program BRAHMS.

**Particle identification with $dE/dx$**

The $dE/dx$ simulation is based on the Bethe-Bloch equation which is a universal function of $\beta\gamma$ for all particle species. The expected $dE/dx$ for a track is generated according to its mass and momentum using the Bethe-Bloch equation with parameters derived from the OPAL jet chamber. Then, the expected mean is smeared by an error that depends on the number of isolated samples, on the sampling length and on the error of the sampling length that results from the uncertainty of the track polar angle $\theta$. Parameters of the $dE/dx$ error description are based on a study with a dedicated Monte Carlo simulation [11] where individual electrons and clusters have been generated and tracked to the TPC endplate including diffusion, gas gain fluctuations and crosstalk.

The $dE/dx$ code provides for the electron, muon, pion, kaon and proton hypothesis five signed weights of range -1 to +1. The five weights are the signed $\chi^2$ probabilities of a track being consistent with a certain particle species. The sign of the weight corresponds to the sign of the difference $dE/dx_{\text{meas}} - dE/dx_{\text{exp}}$, where $dE/dx_{\text{exp}}$ is the $dE/dx$ value according to the Bethe-Bloch equation and $dE/dx_{\text{meas}}$ is the expected $dE/dx$ smeared with the appropriate error.

The $\chi^2$ probabilities also include the track momentum error and are calculated by minimising the following two-dimensional variable:

$$\chi^2 = \{(dE/dx_{\text{meas}} - dE/dx_{\text{exp}})/\sigma(dE/dx)\}^2 + \{(p_{\text{meas}} - p_{\text{exp}})/\sigma(p)\}^2$$

The signed weights also allow the conversion into equivalent normalised $dE/dx$ pull values. For particle identification purposes either the ”probability frame” might be used where cuts on $dE/dx$ weights are placed or the ”normalised $dE/dx$ frame” could be used where cuts on some standard deviations are placed. However, there is no general preference for one or the other framework as both are fully equivalent.

Please note that the five $dE/dx$ weights in general do not necessarily add up to one. For two different particle species, at a certain momentum, the expected $dE/dx$ values from the Bethe-Bloch equation are identical and indistinguishable. At this cross-over point, the probabilities for both particle hypotheses are exactly equal to one.
The expected particle separation power depends on the amount of the isolated samples available per track. Usually tracks are imbedded in dense track environments (multi-hadronic jets), which reduce the number of samples significantly due to the limited double track resolution of the TPC. The program SIMDET allows to estimate the amount of overlap regions for each track by means of two-particle separation distances in the \((r - \phi)\) and \((r - z)\) projections. Since each track is compared with all others, speed of computation can be governed by a step size parameter and the possibility to cut-off the comparison of tracks after a certain number of consecutive space points taking into account the spread-out of charged particles within the magnetic field.

**Usage notes**

SIMDET has a built in an interface to PYTHIA for internal event generation via subroutine SIPYTH. Alternatively, events generated by other programs can be used for detector simulation; subroutine SIEVTI provides an input interface to events written by subroutine LCWRITE. If the structure of the generated events does not coincide with common /PYJETS/ of PYTHIA, subroutine SIPREP should fill the arrays K_PY(I,...), P_PY(I,...) and V_PY(I,...).

To allow for initial state radiation and beamstrahlung during event generation is in the responsibility of the event generator. Subroutine SIPYTH accounts for both radiations if wanted.

In all cases, NEVENT specifies the number of events to be processed.

The detector parameters used are defined in subroutine SIDETR. The naming convention is self explanatory.

After selection of all particles which might give a response in the detector (subroutine SIPART), charged particle tracking, impact parameter estimations and the covariance matrix are obtained from the subroutine SITRAK, subroutine SICDAS and subroutine SICOVM, respectively.

Detector resolution parameters for tracks are provided by the ab initio Monte Carlo program BRAHMS taking into account the complete tracking system.

Two options exist for the vertex detector (subroutine SIDCAS):

1. the APS version, based on 1.5 cm beam pipe radius
2. the CCD version, based on 1.5 cm beam pipe radius

and only the CCD version allows for the covariance matrix at present.

The calorimetric response is also based on detector studies using the *ab initio* Monte Carlo simulation package BRAHMS. The energy distributions of electrons and charged pions in adjacent cells were fitted and the parameters obtained are used for appropriate energy deposite simulations in the electromagnetic and hadronic calorimeters (subroutine SILEGO and subroutine SIDEPO). Afterwards, a cluster search algorithm (with some idealised assumptions) provides clusters (subroutine SICLUS) in the ECAL as well as the HCAL. Finally, an energy flow algorithm (subroutine SIFLOW) joins tracker and calorimeter informations such that as many single particles as possible are resolved. At this stage, the best estimate for charged particles is simply taken from the tracker, except for high energy electrons and positrons. Here, a proper weighting scheme of their tracker and calorimeter energies is applied (subroutine SIWGHT). Particle identification on the basis of shower shapes and matching between tracker
and calorimeter information in space and momentum is emulated. Finally, best estimates of the energy flow objects are established.

In the very forward direction an instrumented mask, the low-angle tagger (subroutine SILOWT), and a low-angle luminosity calorimeter (subroutine SILCAL) are included as default devices. Their preliminary responses from BRAHMS simulation are included in SIMDET.

Particles not entering the calorimeters, e.g. low-pt tracks, are rescued in subroutine SIRSCU and added to the list of energy flow objects in subroutine SISTOR.

In addition, SIMDET allows for particle identification from specific energy losses $dE/dx$ within the TPC (steered by subroutine SIDEXD).

Background events of the type $\gamma\gamma \rightarrow$ hadrons (and later also of other sources) can be overlaid to each physical event using the package hades [3]. The data card IBKG enables this option provided the name of the background file (data card BKGF) and the average number of background events to be overlaid (data card NBKG) are given by the user. Also the study of only background events is possible. Formatted background files resulting from the package GUINEA_PIG exist for the TESLA collider at cms energies 170, 360, 500 and 800 GeV as well as for two CLIC options: the nominal CLIC parameter option with a luminosity $1.05 \times 10^{35}$ cm$^{-2}$sec$^{-1}$ at 3 TeV and an optimised version with lower beamstrahlung and a luminosity of $0.4 \times 10^{35}$ cm$^{-2}$sec$^{-1}$. It is the responsibility of the user to transform these files to a local binary file using the program hades_import.

The CLIC option of SIMDET can be enabled by the data card CLIC. If it equals 1, the process selected in subroutine SIPYTH is simulated at the predetermined cms energy, while CLIC 2 allows for beamstrahlung effects if a luminosity spectrum file is provided on the data card CLCF. This option reads the electron and positron energies as obtained from GUINEA_PIG for a nominal beam energy of 1500 GeV. If a different energy is desired, the simulated $e^+e^-$ energies are rescaled. In the case of invoking a luminosity spectrum file, note that the file name extension '.info' respectively '.ep' should not be given on the data card CLCF. For more details we refer to [4].

The history of the events can be monitored either completely or in a restricted form. If the data card HISTORY is enabled, the complete event history is stored as described in the generated particle record, otherwise input quantities of only stable particles are kept, with a flag of being accepted by the detector or not.

Booking of histograms is provided in subroutine SIBOOK. A few standard histograms allow to monitor the detector response. They can be optionally filled and switched off or on by the data card PLOT.

The simulation finishes by providing all measured objects in the proposed common output structure in subroutine SISTOR.

If requested, the program allows to write (unformatted/formatted) all objects in either the standard structure or in a restricted structure (best estimates only) to an external file in subroutine SIWDST so that analysis can follow externally. It also offers to produce zipped output files (patchy use selection GZIO and data card GZIO) in order to save disk space. If this option is chosen, the extension .gz is added by the program to the file name. The required package is provided with the SIMDET code.

If no external file should be written, the array VECP(I,K) is optionally filled in subroutine SIVECS which allows to use directly the physics analysis package VECSUB (a product from SLAC/DELPHI). In this case, the components 1 to 7 of the array VECP involve the quantities as described in the VECSUB-DELPHI note [12], while the originally free locations 8, 9 and 10 of this array contain now the transverse and the longitudinal impact parameters, in units of
sigma, and a simple numbering of the energy flow objects accepted.

Subroutine SIFFRE reads the set of data cards with the FFREAD package. Default settings in subroutine SIINIT and/or in subroutine SIDETR might be overwritten.

A user subroutine SIUSER (IFLAG) has been added. It is called during initialization (IFLAG=1), for each event before writing to output file (IFLAG=2) and during termination of the job (IFLAG=3).

The package exists as a CVS repository as well as PATCHY/CMZ CAR files. If the PATCHY distribution is chosen, the desired code generation is steered by 'use' selections. For the CVS repository the selections are given as arguments to the configure script.

SIMDET selects the standard simulation code, and with NOSIMU only all stable particles without any detector response are treated. This enables physics studies at the parton or generator level.

Further PATCHY 'use' options are:

CIRCE to allow for the beamstrahlung code,

COVMTX for the covariance matrix material,

GZIO to produce zipped output files,

IBKG to invoke additional code for background events and

CLIC for the CLIC linear collider option.

Please note that for HP platforms error handling routines are included (forced by the 'use' selection HPUX).

Please link the CERNLIB libraries, the PYTHIA 6.1 library and, if selected, the enclosed GZIO library, as transparently illustrated by the installation script which can be used for different platforms (Linux, HP-UX, SunOS, OSF1).

A small utility package SIANAL has been added which can serve as a template for further analyses. It contains routines to open and read the SIMDET output file of the energy flow objects written formatted or unformatted. For both types also zipped files can be read. A zipped file is assumed if the file name has the extension '.gz'. The file name is given in the command line to run SIANAL, eg. './sianal.bin simmdet_v4.evt.gz'.
**Input/Output units:**

| Logical unit number | Default file name | Contents |
|---------------------|-------------------|----------|
| 6                   | simdetv\_4.res   | debugging information like the history of a few events and histograms |
| 7                   | user-defined     | input events generated by an external program |
| 8                   | simdetv\_4.dat   | free format data card file |
| 9                   | user-defined     | input γγ background events generated by an external program |
| 10                  | user-defined     | CLIC luminosity spectrum file generated by an external program |
| 11                  | user-defined     | simulated and reconstructed objects for further analysis (for zipped output the extension '.gz' is added automatically) |
| 12                  | simdetv\_4.hist  | PAW histogram file |

Note that the names of input and reconstructed event files as well as γγ background event and the CLIC luminosity spectrum files should be enclosed in single quotes, start with a point and end with a blank when specified. The length of all file names is restricted to 80 characters.

**Program parameters and steering**

In the appendices to this description, the main program parameters, user accessible COMMON blocks, data cards and the output structure are described in detail. An up-date description together with advice for their usage is also given in the SIMDET online documentation at [http://www.ifh.de/linearCollider/users_guide_simdetv4.html](http://www.ifh.de/linearCollider/users_guide_simdetv4.html)

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## Appendix A: detector parameters

The parameters of the detector are specified in subroutine `SIDETR` and subroutine `SIFFRE`. They are printed in subroutine `SIPRNT` for user control. Their meaning is described in the following:

| Parameter  | Description                                                                 |
|------------|-----------------------------------------------------------------------------|
| FIELD      | field of the solenoid [Tesla]                                               |
| COSCCD     | cos(theta) polar angle acceptance value of the CCD vertex detector          |
| COSAPS     | cos(theta) polar angle acceptance value of the APS vertex detector          |
| TPCIRAD    | inner radius of the TPC [m]                                                 |
| TPCORAD    | outer radius of the TPC [m]                                                 |
| TPCLEN     | total length of the TPC [m]                                                 |
| COSTPC     | cos(theta) polar angle acceptance value of the TPC                          |
| COSTRK     | cos(theta) polar angle acceptance value of the total tracking system       |
| PTMINP     | minimum transverse momentum of a track accepted for tracking [GeV]          |
| TRKEFF     | track reconstruction efficiency                                             |
| QTRKMIS    | charge misinterpretation probability                                       |
| COSECAL    | cos(theta) polar angle acceptance value of the electromagnetic calorimeter  |
| EMECAL     | minimum deposited energy required in the electromagnetic calorimeter [GeV]   |
| AEMRES     | stochastic parameter for the energy resolution in the electromagnetic calorimeter |
| BEMRES     | constant parameter for the energy resolution in the electromagnetic calorimeter |
| EPIMIS     | electron misinterpretation probability                                     |
| COSHCAL    | cos(theta) polar angle acceptance value of the hadronic calorimeter         |
| EMINHA     | minimum deposited energy required in the hadronic calorimeter [GeV]         |
| AHARES     | stochastic parameter for the energy resolution in the hadronic calorimeter  |
| BHARES     | constant parameter for the energy resolution in the hadronic calorimeter    |
| COSCAL     | cos(theta) polar angle acceptance value of the total calorimeter            |
| COSLLAT    | min cos(theta) polar angle acceptance value of the low angle tagger         |
| COSLAT     | max cos(theta) polar angle acceptance value of the low angle tagger         |
| EMINLAT    | minimum deposited energy required in the low angle tagger [GeV]             |
| ALATRES    | stochastic parameter for the energy resolution in the low angle tagger      |
| BLATRES    | constant parameter for the energy resolution in the low angle tagger        |
| CLATRES    | cell size in theta of the low angle tagger [rad]                            |
| DLATRES    | cell size in phi of the low angle tagger [rad]                              |
| COSLLAC    | min cos(theta) polar angle acceptance value of the low angle calorimeter    |
| COSULAC    | max cos(theta) polar angle acceptance value of the low angle calorimeter    |
| EMUDEP     | averaged deposited energy of muons in the ECAL and HCAL [GeV]              |
| EMUISO     | min energy of muons considered of being isolated [GeV]                     |
| XMUMIS     | muon misidentification probability                                         |
Appendix B: User accessible COMMON blocks

The most important user accessible COMMON blocks are shortly described in the following:

+KEEP, SIEVNT.

    COMMON /SIEVNT/ NEVENT, IEVENT, IEOTRI, IEORUN, IDCHAN, ECMS
    +,                   BKGEVT, XSECTION, CMHEAD(10)
    INTEGER            ICMHEAD(10)
    EQUIVALENCE        (ICMHEAD(1), CMHEAD(1))

*     NEVENT  Number of events to be processed
IEVENT  Current event sequence number
IEOTRI  Flag to abort current event of non zero
IEORUN  Flag to terminate run of non zero
IDCHAN  Reaction channel identifier
ECMS    c.m.s. energy [GeV]
BKGEVT  average number of background events to be overlayed to a physical event
XSECTION cross section [fb]
CMHEAD  Header of files (10 words, referenced in App. D and E)

+KEEP, SIUNIT.

    COMMON /SIUNIT/ LUNIN, LUNOUT, LUNDST, LUNHIS, LUNEVT, LUNDAT
    +,                 LUNBKG

*     LUNIN   Standard input unit
LUNOUT  Standard output unit
LUNDST  Unit to write reconstructed event information
LUNHIS  Unit for histograms
LUNEVT  Unit to read generated events
LUNDAT  Unit for free format data cards
LUNBKG  Unit to read γγ → hadrons background events

+KEEP, SICONS.

    COMMON /SICONS/ PI, TWOPI, PIBY2, SMALL, RADDEG, DEGRAD

*     PI      Number PI (ACOS(-1.))
TWOPI   2*PI
PIBY2   PI/2.
SMALL   Arbitrary small number (1.E-10)
RADDEG  Radian to degree conversion factor
DEGRAD  Degree to radian conversion factor

+KEEP, SICNTR.

    COMMON /SICNTR/ NPRTAC, NCHAPA, NACCLE, NPLOWT, NPLCAL
    +,                NPARSC, NEFLOW, NGENPA
    +,               LOCPRT, LOCCPA, LOCMPO, LOCLOWT, LOCLCAL
    +,               LOCRSC, LOCEFL, LOCFIN

*
NGENPA  Number of all particles in the event history (if IFHIST = 1) 
or number of only stable particles (if IFHIST = 0)
NPRTAC  Number of particles being accepted for simulation
NCHAPA  Number of charged particles
NACCLE  Number of particles in the lego plot
NPLOWT  Number of particles in the low angle tagger
NPLCAL  Number of particles in the low angle luminosity calorimeter
NPARSC  Number of particles being rescued
NEFLOW  Number of energy flow objects
LOCPRT  Start location of particles being accepted for simulation
LOCCPA  Start location of charged particles
LOCMPO  Start location of particles in the lego plot
LOCLOWT Start location of particles in the low angle tagger
LOCLCAL Start location of particles in the low angle luminosity calorimeter
LOCRSC  Start location of particles rescued
LOCEFL  Start location of energy flow objects
LOCFIN  Start location of particles for final storage

+KEEP, SIFLAG.
   COMMON /SICONS/ IFPYTH, IFEVTI, IFPLOT, IFGZIO
   +, IFBEST, IFVECS, IFWDST, IFFORM, IFHIST
   +, IFAPS, IFCCD, IFCOVM, IFIPCT, IFBKGR
   +, IFLCAL, IFLAT, IFEDDX
*
Flags for enabling resp. disabling of detector components or program options (see App. C)

+KEEP, SIPARA.
   COMMON /SIPARA/ COSCAL, COSECAL, COSHCAL
   +, EMECAL, EMINHA
   +, EPIMIS, XMUMIS
   +, COSCCD, COSAPS, COSVTX
   +, FIELD, TPCIRAD, TPCORAD, TPCLEN, QTRKMIS
   +, TRKEFF, PTMINP, COSTRK, COSTPC
   +, AEMRES, BEMRES, AHARES, BHARES
   +, COSLLAC, COSULAC
   +, EMUDEP, EMUISO
   +, COSLLAT, COSULAT, EMINLAT
   +, ALATRES, BLATRES, CLATRES, DLATRES
*
Detector parameters (see App. A)

+KEEP, PUCPPP.
   PARAMETER (MAXOBJ=500)  ! max. # of e_flow objects (=LOCFIN-LOCEFL)
   COMMON /PUCPPP/PVECP
   DOUBLE PRECISION PVECP(5, 2*MAXOBJ)
   REAL \hspace{29mm} VECP(10, 2*MAXOBJ)
DIMENSION $h_{space}{17mm}$ IVECP(10, 2*MAXOBJ)
EQUIVALENCE (VECP(1, 1), PVECP(1, 1))
EQUIVALENCE (IVECP(1, 1), VECP(1, 1))

* Working array for VECSUB package

+KEEP, PWCPPP.
PARAMETER (NRAWS = 2000) ! working array (=LOCFIN)
PARAMETER (NLOC = 10)
COMMON /PWCPPP/ PP(NLOC, NRAWS)
DIMENSION IPP(NLOC, NRAWS)
EQUIVALENCE (IPP(1,1), PP(1,1))

* Working array for internal particle storage

+KEEP, SILATC.
parameter (maxlat=100) ! max. # of particles (=LOCLCAL-LOCLOWT)
parameter (mxplat=20) ! max. # of particles/cluster
common /silatc/ numblat(maxlat), linklat(mxplat, maxlat)
+,
    efrclat(mxplat, maxlat)

* Arrays for particle information in the LAT

+KEEP, SILEGC.
parameter (nte=200,npe=400) ! number of theta/phi cells in em calo
parameter (nth=100,nph=200) ! number of theta/phi cells in had calo
common /silegc/ ecal(nte,npe),hcal(nth,nph),ical(nte,npe)

* Lego arrays for em and hadronic calorimeter

+KEEP, SIXREF.
parameter (mxcel=4000,mxpar=20)
common /sixref/ ncell,idcel(mxcel),npart(mxcel)
+,
    epart(mxcel,mxpar),idpar(mxcel,mxpar)
+,
    iadre(nte,npe),iadrh(nth,nph)

* Cross reference between calorimeter cell contents and generator particles

+KEEP, SICLUC.
parameter (maxclu=500), maxcel=8000)
common /sicluc/ nclu(maxclu),eclu(maxclu),tclu(maxclu)
+,
    pclu(maxclu),eecl(maxclu),ehcl(maxclu)
+,
    listc(maxcel,maxclu),ntclu)

*
Storage for the output of the cluster algorithm

+KEEP, SICLAC.

    common /siclac/ npar(maxclu), listp(mxpar, maxclu)
    +, ppar(3, maxclu), epar(mxpar, maxclu)

* Cross reference between clusters and generator particles

+KEEP, SIFLOC.

    parameter (maxflo=500) ! max. # of e_flow objects (=LOCFIN-LOCEF)
    common /sifloc/ nflo ! number of objects
    +, ista(maxflo), ityp(maxflo) ! status and type
    +, lgen(mxpar, maxflo), ngen(maxflo) ! mothers
    +, frac(mxpar, maxflo) ! fraction per mother
    +, pbst(6, maxflo) ! best estimate
    +, ptrk(15, maxflo) ! tracker
    +, peca(5, maxflo) ! ecal
    +, phca(5, maxflo) ! hcal
    +, pmus(6, maxflo) ! muon system
    +, ltrk(mxpar, maxflo), ntrk(maxflo) ! track list
    +, lcal(mxpar, maxflo), ncal(maxflo) ! cluster list
    +, lmus(mxpar, maxflo), nmus(maxflo) ! muon list

* Storage of the results of the energy flow algorithm

+KEEP, SIBOUT.

    PARAMETER (NPLUND=1000, NWLUND=13)
    COMMON /SIBOUT/ NGENPA, BOUT(NPLUND, NWLUND)
    DIMENSION IBOUT(NPLUND, NWLUND)
    EQUIVALENCE (BOUT(1,1), IBOUT(1,1))

* Storage array of generator particle information

+KEEP, SIENFL.

    PARAMETER (NMXEFL=500) ! max. # of e_flows
    PARAMETER (NWENFL=1000) ! max. # of words/e_flow
    COMMON /SIENFL/ NENFLO, CM(NMXEFL, NWENFL)
    +, NGENNW(NMXEFL), NTRKNW(NMXEFL)
    +, NCALNW(NMXEFL)
    +, NMUSNW(NMXEFL), NLATNW(NMXEFL)
    +, NLCANW(NMXEFL)
    DIMENSION ICM(NMXEFL, NWENFL)
    EQUIVALENCE (CM(1,1), ICM(1,1))

* Storage array of energy flow objects (see App.D)
+KEEP, SIBSTC.
PARAMETER (NMXBST=2010)
COMMON /SIBSTC/ BEST(NMXBST)
DIMENSION IBEST(NMXBST)
EQUIVALENCE (BEST(1), IBEST(1))
*
Storage array of best energy flow object information (see App. E)

+KEEP, SIERRTRK.
parameter (maxtrk=300) ! max. # of tracks (= LOCMPO-LOCCPA)
common /sierrtrk/ rphitrk(maxtrk), rthetrk(maxtrk), rptitrk(maxtrk)
 +,
   dphitrk(maxtrk), dthetrk(maxtrk), dptotrk(maxtrk)
*
Track resolution and error for 1/pT, θ and φ

+KEEP, SIMXEL.
parameter (maxcpa=300) ! max. # of tracks (= LOCMPO-LOCCPA)
common /simxel/ covxel(15,maxcpa), icovmtx(maxcpa)
*
Elements of the covariance matrix

+KEEP, IDEDXPAR.
COMMON /IDEDXPAR/ DEDXPAR(5)
DIMENSION IDEDXPAR(5)
EQUIVALENCE (DEDXPAR(1), IDEDXPAR(1))
*
Data card parameters for dE/dx estimation

+KEEP, SIDEDXC.
parameter (maxtpc=300) ! max. # of tracks (= LOCMPO-LOCCPA)
parameter (maxpnt=1000) ! max. # of space points per track
common /sidedxc/ RATIO(maxtpc)
 +,
   TRK_P(maxtpc,maxpnt,3), STEP, INDCUT
 +,
   RLENGTH(maxtpc), N_POINTS(maxtpc), P_IMP(maxtpc)
 +,
   P_TTT(maxtpc), ICHRG(maxtpc)
 +,
   RCLOSE(maxtpc), ICLOSE(maxtpc), IDEDX(maxtpc)
 +,
   DEDXWGT(5,maxtpc), DEDXNORM(5,maxtpc)
*
Parameters for dE/dx estimates

+KEEP, DEDXPAR.
REAL XI, AKAPPA, XA, AA, PFAC, EXPB, PRES
PARAMETER (XI = 0.4720818 ,
+  AKAPPA = 11.862274 ,
+  XA = 2.2334855 ,
Bethe-Bloch, resolution and protection parameters for \( dE/dx \) estimates

\[ \begin{align*}
+ & \text{ REAL } RESOL, RESEX, SPLLEXP \\
+ & \text{ PARAMETER (RESOL = 0.52 , } \\
+ & \text{ RESEX = -0.47 , } \\
+ & \text{ SPLLEXP = 0.32 ) } \\
+ & \text{ REAL } RSPLMN, DEMX \\
+ & \text{ PARAMETER (RSPLMN = 0.20 , } \\
+ & \text{ DEMX = 250. ) }
\end{align*} \]

\* 

\[ \text{Bethe-Bloch, resolution and protection parameters for } dE/dx \text{ estimates} \]

\* 

\[ \begin{align*}
+ & \text{KEEP, DXPROB. } \\
+ & \text{ REAL } DEDXE, DDEDXE, DEDXM, DDEDXM, \\
+ & \text{ INTEGER } \text{METHOD} \\
+ & \text{ COMMON /DXPROB/ } DEDXE, DDEDXE, DEDXM, DDEDXM, \\
+ & \text{ PE, PM, DPM, XM, Q, WEIGHT, METHOD }
\end{align*} \]

\* 

\[ dE/dx \text{ weight and probability values} \]

\* 

\[ \begin{align*}
+ & \text{KEEP, SILINK. } \\
+ & \text{ COMMON /SILINK/ LVECP(NMXEFL) }
\end{align*} \]

\* 

\[ \text{Link to line number of particle in PYTHIA record if the VECSUB package is enabled} \]

For the CVS structure the common blocks are given in the simdet/include subdirectories with the replacement of e.g. +KEEP, SIEVNT by sievnt.inc.
Appendix C: Data cards

This describes the SIMDET V4.01 free format data cards.

The initialized default values are given in parentheses. Note that file names should be enclosed in single quotes, start with a point and end with a blank. The length of all file names is restricted to 80 characters.

Certain obvious logical restrictions apply to the proper combination of options. For example, option ‘PYTH 1’ does not allow for event reading from an external file.

| Key | Variable | Data type | Meaning |
|-----|----------|-----------|---------|
| NEVT | NEVENT | INTEGER | total number of events to process (D=10) |
| PYTH | IFPYTH | INTEGER | 0 = no PYTHIA event generation  
1 = event generation by PYTHIA without beamstrahlung  
2 = event generation by PYTHIA with beamstrahlung  
-1 = only $\gamma\gamma$ background events (D=1) |
| EVTI | IFEVTI | INTEGER | 1 = event reading from an external file, written by sr LCWRITE, 0 = no event reading (D=0) |
| GENF | LUNGENF | INTEGER | input file name of generated events, user defined |
| WDST | IFWDST | INTEGER | 1 = event writing to an external file, 0 = no event writing (D=1) |
| RECF | LUNRECF | INTEGER | output file name of processed events, user defined |
| FORM | IFFORM | INTEGER | 1 = formatted output structure, 0 = unformatted output structure (D=0) |
| GZIO | IFGZIO | INTEGER | 1 = zipped output is enabled, 0 = no zipped output (D=0) |
| IBKG | IFBKGR | INTEGER | 1 = background event reading from an external file, 0 = no background event reading (D=0) |
| NBKG | BKGEVT | REAL | average number of background events to be overlayed to each physical event (D=0.) |
| BKGF | LUNBKG | INTEGER | input file name of background events, user defined |
| CLIC | IFCLIC | INTEGER | 0 = CLIC option disabled  
1 = CLIC option enabled without lumi spectrum file  
2 = CLIC option enabled with lumi spectrum file (D=0) |
| CLCF | LUNCLCF | INTEGER | input file name of CLIC lumi spectrum file, user defined |
| BEST | IFBEST | INTEGER | 1 = best estimates are enabled, 0 = no best estimates (D=0) |
| VECS | IFVECS | INTEGER | 1 = filling of the array VECP(I,K) for VECSUB only if IFBEST = 1  
0 = no filling of this array (D=0) |
| HIST | IFHIST | INTEGER | 1 = history of the generated event to output file, 0 = only stable generated particles to output file (D=0) |
| COVM | IFCOVM | INTEGER | 1 = covariance matrix is enabled, 0 = no covariance matrix (D=0) |
| IPCT | IFIPCT | INTEGER | 1 = IP beam constraint enabled, 0 = no IP beam constraint (D=0) |
| Key  | Variable | Data type | Meaning                                                                 |
|------|----------|-----------|-------------------------------------------------------------------------|
| PLOT | IFPLOT   | INTEGER   | 1 = detector response plots are enabled, 0 = no detector response plots (D=0) |
| APS  | IFAPS    | INTEGER   | 1 = pixel detector is enabled, 0 = no pixel detector (D=0)              |
| CCD  | IFCCD    | INTEGER   | 1 = CCD detector is enabled, 0 = no CCD detector (D=1)                   |
| LCAL | IFLCAL   | INTEGER   | 1 = low-angle calorimeter is enabled, 0 = no low-angle calorimeter (D=1) |
| LAT  | IFLAT    | INTEGER   | 1 = low-angle tagger (instrumented mask) is enabled, 0 = no low-angle tagger (D=1) |
| DEDX | IFDEDX   | INTEGER   | 1 = dEdx information enabled, 0 = no dEdx information (D=0)               |
|      |          |           | 2. parameter (real): step size [cm] (D=3.0)                              |
|      |          |           | 3. parameter (real): two-particle separation distance in the \( r - z \) projection [cm] (D=1.0) |
|      |          |           | 4. parameter (real): two-particle separation distance in the \( r - \phi \) projection [cm] (D=0.22) |
|      |          |           | 5. parameter (integer): cut-off parameter                                |
|      |          |           | 0 = track comparison is stopped after 5 consecutive steps               |
|      |          |           | 1 = complete track comparison (D=0)                                     |
| EFTR | TRKEFF   | REAL      | measurement track efficiency (D=0.99)                                    |
| PTTR | PTMINP   | REAL      | min transverse momentum required [GeV] (D=0.10)                          |
| QMTR | QTRKMIS  | REAL      | charge misinterpretation probability (D=0.005)                            |
| EMPH | EMECAL   | REAL      | min energy required for photon detection [GeV] (D=0.200)                 |
|      |          |           | electron misidentification probability (D=0.002)                         |
|      |          |           | first energy resolution parameter for ECAL (D=0.145)                     |
| AEMR | AEMRES   | REAL      | second (constant) energy resolution parameter for ECAL (D=0.015)         |
| BEMR | BEMRES   | REAL      | min energy required for hadron detection in HCAL, [GeV] (D=0.500)        |
|      |          |           | first energy resolution parameter for HCAL (D=0.554)                     |
|      |          |           | second (constant) energy resolution parameter for HCAL (D=0.166)         |
| ELAT | EMINLAT  | REAL      | min energy required for particle detection in LAT [GeV] (D=5.0)          |
| ALAT | ALATRES  | REAL      | first energy resolution parameter for LAT (D=0.10)                       |
| BLAT | BLATRES  | REAL      | second (constant) energy resolution parameter for LAT (D=0.01)           |
| CLAT | CLATRES  | REAL      | theta angular resolution in LAT [rad] (D=0.04)                           |
| DLAT | DLATRES  | REAL      | phi angular resolution in LAT [rad] (D=0.262)                            |
| EMMU | EMUDEP   | REAL      | deposited muon energy in calorimeters [GeV] (D=3.8)                      |
| EMIS | EMUISO   | REAL      | min energy for isolated muons [GeV] (D=5.0)                              |
| XMUM | XMUMIS   | REAL      | muon misidentification probability (D=0.005)                             |
Appendix D: Full output structure

This describes the SIMDET V4.01 standard output structure.

The output file starts with a single file header of 10 words. Each event starts with the number of generated particles **NGENPA**, which is followed by a record of 13 words for each particle. According to the user’s choice, the whole event history (**HIST 1**) or only the stable particles which might give a response in the detector are covered.

The number of energy flow objects, **NEFLOW**, then follows. For each object, blocks of records follow, describing status information, best estimates, generator information, charged particles, calorimeter clusters and muons from the muon system, in this order.

**File header record:**

| Offset | Variable name | Data type | Meaning |
|--------|---------------|-----------|---------|
| 1      | INSTATE       | INTEGER   | ISR flag, PYTHIA default: 0 = no radiation, 1 = ISR & Beamstrahlung, 2 = ISR only, 3 = Beamstrahlung |
| 2      | SQRTS         | REAL      | nominal collider cms energy [GeV] |
| 3      | SIGMA         | REAL      | Cross section [fb], if provided |
| 4      | IDCLASS       | INTEGER   | Reaction identifier, user defined |
| 5      | NEVENT        | INTEGER   | Number of events to be processed |
| 6      | IFBEST        | INTEGER   | Flag for best estimates |
| 7      | IFFORM        | INTEGER   | Flag for formatted output |
| 8      | IFDEDX        | INTEGER   | Flag for dEdx |
| 9      | IFHIST        | INTEGER   | Flag for complete (restricted) event history |
| 10     | IFBKGR        | INTEGER   | Flag for background events |

This record is written once per file.

**Generated particle record:**

| Offset | Variable name | Data type | Meaning |
|--------|---------------|-----------|---------|
| 1      | STATUS        | INTEGER   | 0 = no detector response, 1 = detector response |
| 2      | ID            | INTEGER   | particle code according to PYTHIA convention |
| 3      | line          | INTEGER   | line number of particle in the PYTHIA record |
| 4      | Px            | REAL      | x-component of momentum [GeV] |
| 5      | Py            | REAL      | y-component of momentum [GeV] |
| 6      | Pz            | REAL      | z-component of momentum [GeV] |
| 7      | E             | REAL      | Energy [GeV] |
| 8      | m             | REAL      | mass of particle [GeV] |
| 9      | Q             | REAL      | charge of particle |
| 10     | x             | REAL      | x-component of vertex [mm] |
| 11     | y             | REAL      | y-component of vertex [mm] |
| 12     | z             | REAL      | z-component of vertex [mm] |
| 13     | Time          | REAL      | time of production [mm/c] |

This record is repeated **NGENPA** times.
Energy flow record 1: status of energy flow object

| Offset | Variable name | Data type | Meaning |
|--------|---------------|-----------|---------|
| 1      | STATUS        | INTEGER   | < 0: invalid object,   |
|        |               |           | 1=charged object,      |
|        |               |           | 2=neutral object,      |
|        |               |           | 3=composite object     |
| 2      | Type          | INTEGER   | particle code according to PYTHIA convention, |
|        |               |           | 999 = cluster of unresolvable particles |
| 3      | NGEN          | INTEGER   | number of generator particles contributing |
|        |               |           | to the energy flow object |
| 4      | NTRK          | INTEGER   | number of charged particles contributing |
|        |               |           | to the energy flow object |
| 5      | NCAL          | INTEGER   | number of clusters contributing to the energy flow object |
| 6      | NMUS          | INTEGER   | number of muons contributing to the energy flow object |

This record and the following blocks are repeated NEFLOW times.

Energy flow record 2: best estimate for object’s energy and direction

| Offset | Variable name | Data type | Meaning |
|--------|---------------|-----------|---------|
| 1      | Px            | REAL      | x-component of momentum [GeV] |
| 2      | Py            | REAL      | y-component of momentum [GeV] |
| 3      | Pz            | REAL      | z-component of momentum [GeV] |
| 4      | E             | REAL      | Energy [GeV] |
| 5      | m             | REAL      | mass of particle [GeV] |
| 6      | Q             | REAL      | charge of particle |

This record is written once per energy flow object.

Energy flow record 3: generator particle contributing to energy flow object

| Offset | Variable name | Data type | Meaning |
|--------|---------------|-----------|---------|
| 1      | link          | INTEGER   | line number of particle in the PYTHIA record |
| 2      | Efrac         | REAL      | energy fraction |

This record is repeated NGEN times.
Energy flow record 4: charged particle tracks that are part of the object

| Offset | Variable name | Data type | Meaning |
|--------|---------------|-----------|---------|
| 1      | P             | REAL      | absolute value of momentum [GeV] |
| 2      | Theta         | REAL      | polar angle [radian] |
| 3      | Phi           | REAL      | azimuth angle [radian] |
| 4      | Q             | REAL      | charge of particle |
| 5      | Imp(R,phi)    | REAL      | transverse impact parameter [cm] |
| 6      | Imp(R,z)      | REAL      | longitudinal impact parameter [cm] |
| 7      | cov. matrix   | REAL      | xy-xy element |
| 8      | cov. matrix   | REAL      | xy-z element |
| 9      | cov. matrix   | REAL      | z-z element |
| 10     | cov. matrix   | REAL      | xy-theta element |
| 11     | cov. matrix   | REAL      | z-theta element |
| 12     | cov. matrix   | REAL      | theta-theta element |
| 13     | cov. matrix   | REAL      | xy-phi element |
| 14     | cov. matrix   | REAL      | z-phi element |
| 15     | cov. matrix   | REAL      | phi-theta element |
| 16     | cov. matrix   | REAL      | phi-phi element |
| 17     | cov. matrix   | REAL      | xy-1/p element |
| 18     | cov. matrix   | REAL      | z-1/p element |
| 19     | cov. matrix   | REAL      | theta-1/p element |
| 20     | cov. matrix   | REAL      | phi-1/p element |
| 21     | cov. matrix   | REAL      | 1/p-1/p element |
| 22     | dEdx          | REAL      | signed electron probability |
| 23     | dEdx          | REAL      | signed muon probability |
| 24     | dEdx          | REAL      | signed pion probability |
| 25     | dEdx          | REAL      | signed kaon probability |
| 26     | dEdx          | REAL      | signed proton probability |
| 27     | dEdx          | REAL      | normalised electron dEdx value |
| 28     | dEdx          | REAL      | normalised muon dEdx value |
| 29     | dEdx          | REAL      | normalised pion dEdx value |
| 30     | dEdx          | REAL      | normalised kaon dEdx value |
| 31     | dEdx          | REAL      | normalised proton dEdx value |

This record is repeated \textbf{NTRK} times.
Energy flow record 5: calorimeter cluster (ECAL/HCAL/LAT/LCAL) that are part of the object

| Offset | Variable name | Data type | Meaning                                         |
|--------|---------------|-----------|------------------------------------------------|
| 1      | E             | REAL      | energy [GeV]                                    |
| 2      | Theta         | REAL      | polar angle [radian]                            |
| 3      | Phi           | REAL      | azimuth angle [radian]                          |
| 4      | Time          | REAL      | timing information                              |
| 5      | C(em)         | REAL      | probability of being consistent with an electromagnetic particle |
| 6      | E             | REAL      | energy [GeV]                                    |
| 7      | Theta         | REAL      | polar angle [radian]                            |
| 8      | Phi           | REAL      | azimuth angle [radian]                          |
| 9      | Time          | REAL      | timing information                              |
| 10     | C(mip)        | REAL      | probability of being consistent with a minimum ionizing particle |

This record is repeated \( NCAL \) times.

Energy flow record 6: muons from the muon system that are part of the object

| Offset | Variable name | Data type | Meaning                                         |
|--------|---------------|-----------|------------------------------------------------|
| 1      | E             | REAL      | energy [GeV]                                    |
| 2      | Theta         | REAL      | polar angle [radian]                            |
| 3      | Phi           | REAL      | azimuth angle [radian]                          |
| 4      | Q             | REAL      | charge of particle                              |
| 5      | Time          | REAL      | timing information                              |
| 6      | C(punch)      | REAL      | probability of being consistent with an punch-through object |

This record is repeated \( NMUS \) times.
Appendix E: Restricted output structure

This describes the SIMDET V4.01 restricted output structure, mainly intended to save disc space for reconstructed events. The output file starts with a single file header of 10 words. Each event starts with the number of energy flow objects, NEFLOW. This is followed by a series of records for each energy flow object, which describe only the best estimate of the object’s energy and direction, in analogy to energy flow record 2 from the full data format, supplemented by impact parameter information.

**File header record:**

| Offset | Variable name | Data type | Meaning |
|--------|---------------|-----------|---------|
| 1      | INSTATE       | INTEGER   | ISR flag, PYTHIA default: 0 = no radiation, 1 = ISR & Beamstrahlung, 2 = ISR only, 3 = Beamstrahlung |
| 2      | SQRTS         | REAL      | nominal collider cms energy [GeV] |
| 3      | SIGMA         | REAL      | Cross section [fb], if provided |
| 4      | IDCLASS       | INTEGER   | Reaction identifier, user defined |
| 5      | NEVENT        | INTEGER   | Number of events to be processed |
| 6      | IFBEST        | INTEGER   | Flag for best estimates |
| 7      | IFFORM        | INTEGER   | Flag for formatted output |
| 8      | IFDEDX        | INTEGER   | Flag for dEdx information |
| 9      | IFHIST        | INTEGER   | Flag for complete (restricted) event history |
| 10     | IFBKGR        | INTEGER   | Flag for background events |

This record is written once per file.

**Energy flow record:**

| Offset | Variable name | Data type | Meaning |
|--------|---------------|-----------|---------|
| 1      | Px            | REAL      | best estimate for x-component of momentum [GeV] |
| 2      | Py            | REAL      | best estimate for y-component of momentum [GeV] |
| 3      | Pz            | REAL      | best estimate for z-component of momentum [GeV] |
| 4      | E             | REAL      | best estimate for energy [GeV] |
| 5      | m             | REAL      | mass of particle [GeV] |
| 6      | Q             | REAL      | charge of particle |
| 7      | Imp(R,phi)    | REAL      | transverse impact parameter, in units of sigma |
| 8      | Imp(R,z)      | REAL      | longitudinal impact parameter, in units of sigma |
| 9      | NTRK          | INTEGER   | number of charged particles contributing to the energy flow object |
| 10     | type          | INTEGER   | particle code according to PYTHIA convention, 999 = cluster of unresolvable particles |

In cases of NTRK > 1, the largest impact parameters are recorded. This record is repeated NEFLOW times.
References

[1] F. Richard, J.R. Schneider, D. Trines and A. Wagner Edts., TESLA: The Superconducting Electron-Positron linear Collider with an Integrated X-Ray Laser Laboratory. Technical Design Report, Part IV A Detector for TESLA, DESY 2001-011 and ECFA 2001-209 (2001)

[2] GEANT, Detector Description and Simulation Tool, CERN Program Library Long Write-up W5013 (1994)

[3] T. Behnke, G. Blair, K. Mönig and M. Pohl, BRAHMS - Version 1.00, a Monte Carlo Program for a Detector at a 800 GeV Linear Collider, November 6, 1998, http://www.hep.ph.rhbn.ac.uk/~blair/detsim/brahms.html

[4] T. Ohl, IKDA 96/13-rev., July 1996 and hep-ph/9607454-rev.

[5] D. Schulte and /afs/cern.ch/eng/tev\_phys/user1/hades/src

[6] H. Vogt, Proceedings of the Linear Collider Workshop 2000, LCWS 2000, Fermilab, October 24-28, 2000

[7] M. Battaglia and /afs/cern.ch/eng/tev\_phys/public/simdet/v2.0

[8] V. Blobel, Package for constraint least squares and error propagation, private communication

[9] R. Brinkmann, G. Materlik, J. Rossbach and A. Wagner Edts., Conceptual Design of a 500 GeV $e^+e^-$ Linear Collider with Integrated X-ray Laser Facility, DESY 1997-048 and ECFA 1997-182 (1997)

[10] M. Pohl and H.J. Schreiber, DESY 99-030, March 1999

[11] M. Gruwe, Studies of $dE/dx$ Capabilities of a TPC for the Future Linear Collider TESLA, LC-DET-2001-043, 2001; M. Hauschild, Proceedings of the Linear Collider Workshop 2000, LCWS 2000, Fermilab, October 24-28, 2000

[12] G. Wormser, DELPHI note, November 16, 1988; revised by P. Roudeau, September 11, 1989