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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 [1] 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 ($\delta 1/p_T \sim 4 \cdot 10^{-5}$/GeV in the central region) to measure e.g. the Z recoil mass in the Higgsstrahlung process $e^+e^- \to \mathrm{ZH/Z} \to \ell^+\ell^-$ 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 $\mathrm{t\bar{t}H}$ and to separate $\mathrm{H} \to \mathrm{b\bar{b}}$, $\mathrm{H} \to \mathrm{c\bar{c}}$ and $\mathrm{H} \to gg$;
- good hermiticy 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 [1]. 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:

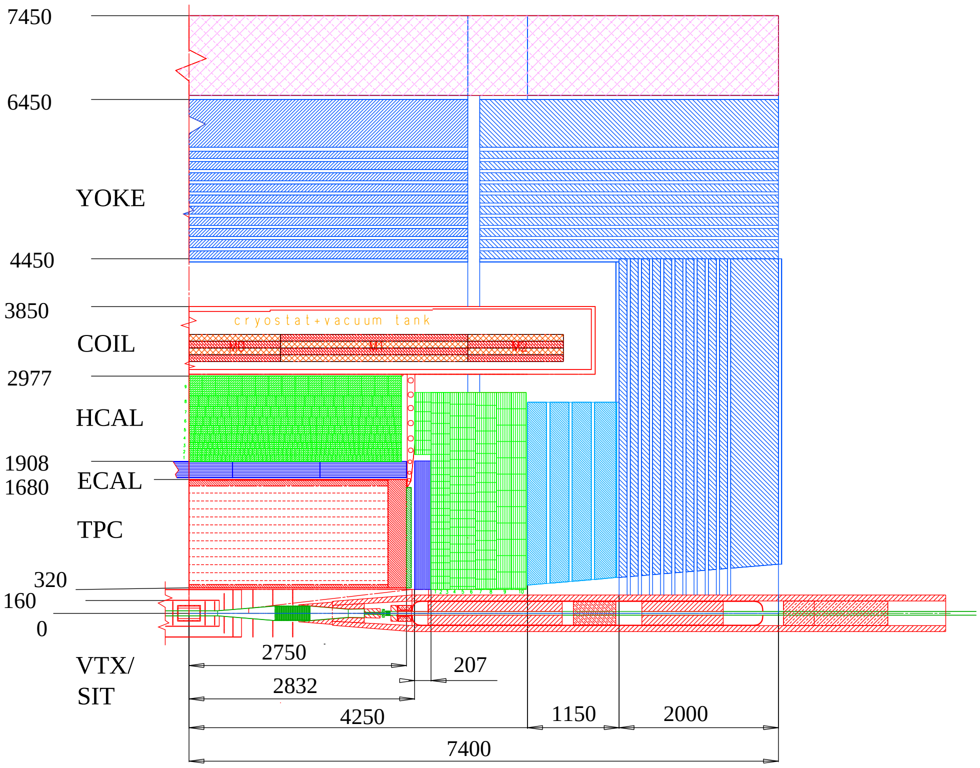

Figure 1: View of one quadrant of the TESLA detector. Dimensions are in mm.

- 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 straight forward and decentralised way.

Only the *ab initio* GEANT3 [2] application program `BRAHMS` [3] 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 parametrisations 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 ~ 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 to 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 $\theta = 25°$ 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 μm respectively 50 μm 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 $\theta = 12°$.

For the microvertex detector several technologies were proposed: CCDs, active pixel sensors

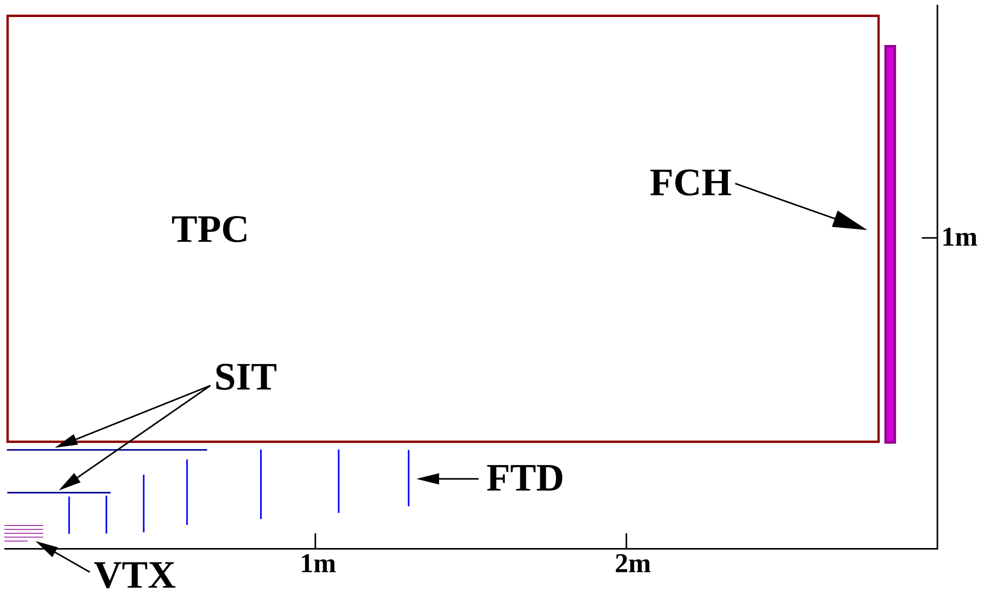

Figure 2: The tracking system of the TESLA detector.

(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, θ)-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 $1/p_T, \theta$ 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.

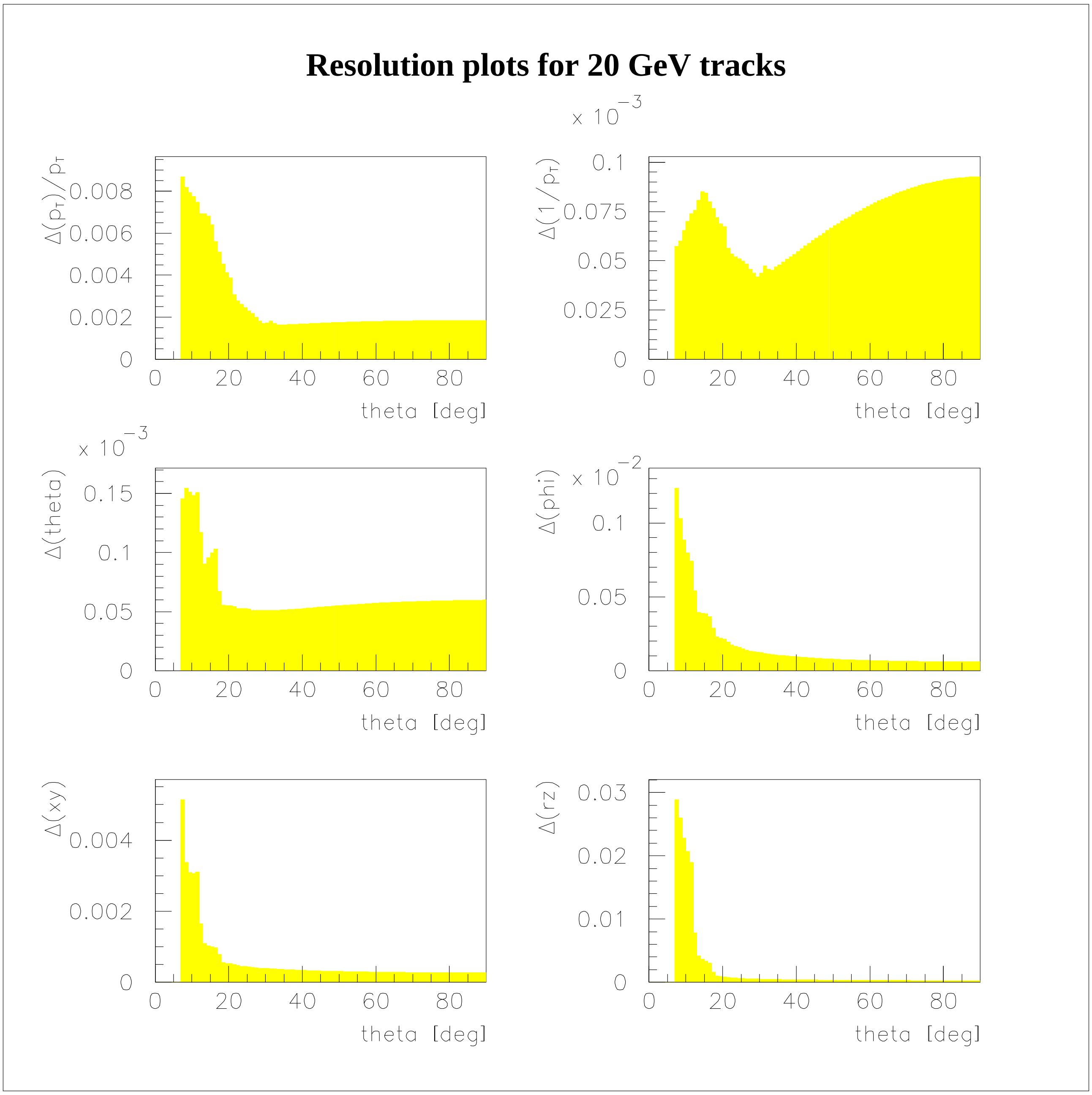

Figure 3: *Resolution plots for 20 GeV momentum tracks as simulated with BRAHMS.*

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:

$$\sigma_{r\phi} = A \oplus \frac{B}{p \sin^{\frac{3}{2}} \theta} \tag{1}$$

$$\sigma_{rz} = C \oplus \frac{D}{p \sin^{\frac{5}{2}} \theta} \tag{2}$$

for a track with momentum p and polar angle θ 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 ($1{\times}1cm^2$) 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 have been determined using *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[1]. These resolution curves are implemented in the current version of SIMDET.

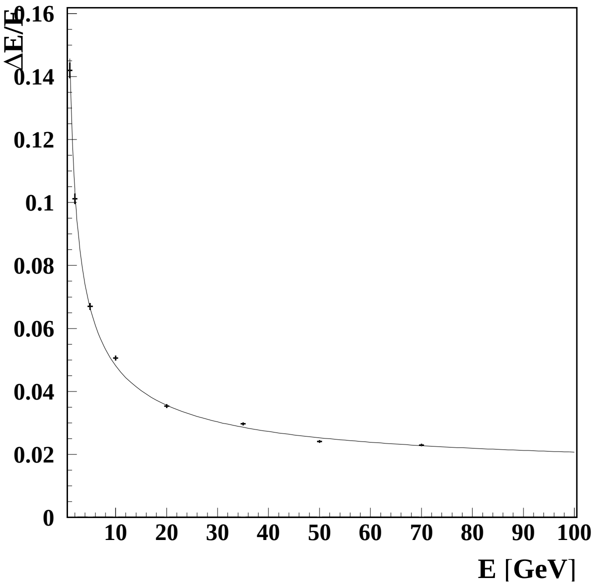

Figure 4: *Relative energy resolution as a function of energy for single high energy electrons as simulated with BRAHMS.*

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 [10], thus does not fully benefit from the superb pattern recognition capabilities of the tracking calorimeter. Nevertheless, as demonstrated in Fig. 6, usage of the energy flow concept leads to a vast improvement in the reconstruction of the visible and missing energy.

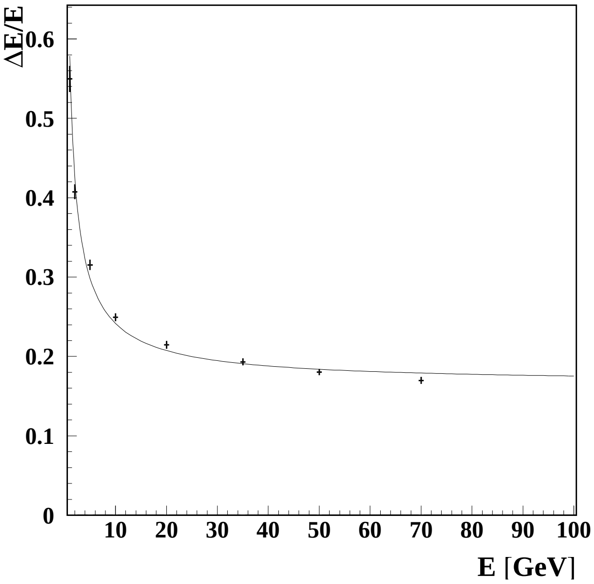

Figure 5: *Relative energy resolution as a function of energy for single pions as simulated with BRAHMS.*

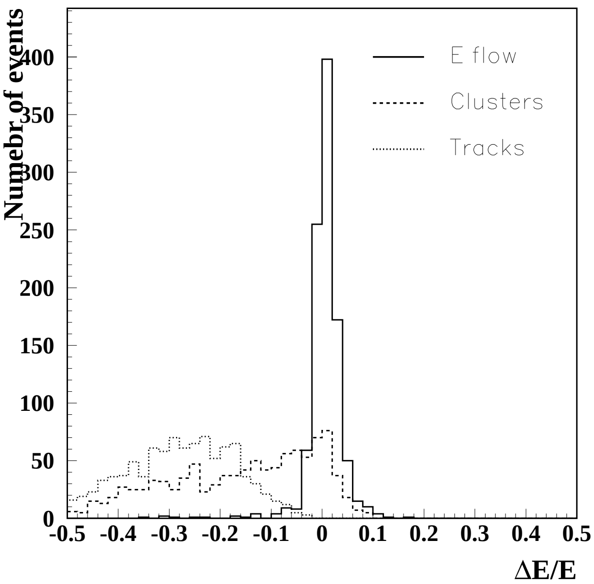

Figure 6: *Energy resolution, using different estimators, for the process* $e^+e^- \rightarrow HZ$ *at 500 GeV center of mass energy, where the Z boson decays hadronically, while the Higgs boson decays into two W bosons which in turn decay leptonically. The histograms represent the relative difference 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 θ 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.

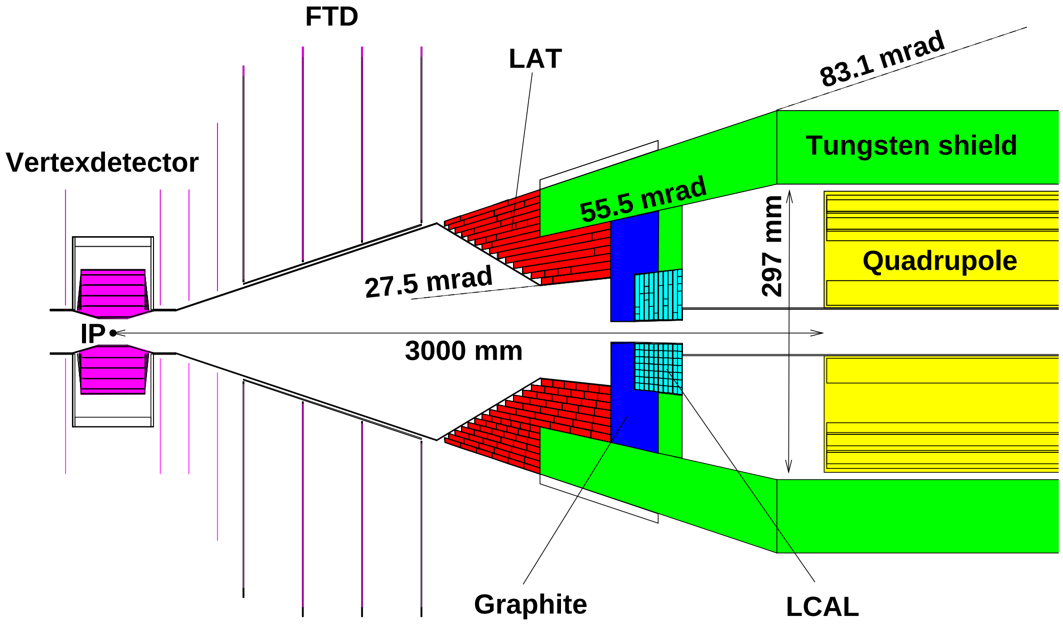

Figure 7: *Design of the forward angle calorimeters, LAT and LCAL.*

The expected performance of the LAT has been studied using `BRAHMS` responses for high energy electrons and muons. Energy and θ 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 θ. 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 χ^2 probabilities of a track being consistent with a certain particle species. The sign of the weight corresponds to the sign of the difference $dE/dx_{\mathrm{meas}} - dE/dx_{\mathrm{exp}}$, where dE/dx_{exp} is the dE/dx value according to the Bethe-Bloch equation and dE/dx_{meas} is the expected dE/dx smeared with the appropriate error.

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

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

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_I**) in the ECAL as well as the HCAL. Finally, an energy flow algorithm (subroutine **SIFLOW_I**) 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 **SIDEDX**).

Background events of the type $\gamma\gamma \rightarrow$ hadrons (and later also of other sources) can be overlayed to each physical event using the package **hades** [5]. 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 overlayed (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 $\dot{1}0^{35}$ cm^{-2}sec^{-1} at 3 TeV and an optimised version with lower beamstrahlung and a luminosity of 0.4 $\dot{1}0^{35}$ 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 [7].

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 inititialization (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	simdet$v$_4.res	debugging information like the history of a few events and histograms
7	user-defined	input events generated by an external program
8	simdet$v$_4.dat	free format data card file
9	user-defined	input $\gamma\gamma$ 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 $\gamma\gamma$ 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/linear_collider/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:

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 lenght 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
COSULAT	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 identificator
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 $\gamma\gamma \rightarrow$ 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 od particles in the lego plot
NPLOWT	Number of particles in the low angle tagger
NPLCAL	Number of particles in the 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,  IFDEDX
*
```

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 \hspace{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 contens 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 algorythm

```
+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 $1/p_T$, 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 ,
```

```
      +           AA     =  0.1717262 ,
      +           PFAC   =  1.1292883 ,
      +           EXPB   =  2.3909695 ,
      +           PRES   =  1.0000000 )
       REAL       RESOL,RESEXP,SPLEXP
       PARAMETER (RESOL  =  0.52 ,
      +           RESEXP = -0.47 ,
      +           SPLEXP =  0.32 )
       REAL       RSPLMN,DEMX
       PARAMETER (RSPLMN = 0.20 ,
      +           DEMX   = 250. )
*
```

Bethe-Bloch, resolution and protection parameters for dE/dx estimates

```
+KEEP, DXPROB.
       REAL            DEDXE,DDEDXE,DEDXM,DDEDXM,
      +                PE,PM,DPM,XM,Q,WEIGHT
       INTEGER         METHOD
       COMMON /DXPROB/ DEDXE,DDEDXE,DEDXM,DDEDXM,
      +                PE,PM,DPM,XM,Q,WEIGHT,METHOD
*
```

dE/dx weight and probability values

```
+KEEP, SILINK.
       COMMON /SILINK/ LVECP(NMXEFL)
*
```

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 restriced 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 otput (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	LUNBKGF	INTEGER	input file name of background events, user defined
CLIC	IFCLIC	INTEGER	0 = CLIC otion 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. paramter (real): step size [cm] (D=3.0)
			3. paramter (real): two-particle seperation
			distance in the $(r-z)$ projection [cm] (D=1.0)
			4. paramter (real): two-particle seperation
			distance in the $(r-\phi)$ projection [cm] (D=0.22)
			5. paramter (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)
EPIM	EPIMIS	REAL	electron misidentification probability (D=0.002)
AEMR	AEMRES	REAL	first energy resolution parameter for ECAL (D=0.145)
BEMR	BEMRES	REAL	second (constant) energy resolution
			parameter for ECAL (D=0.015)
EMHA	EMINHA	REAL	min energy required for hadron detection
			in HCAL, [GeV] (D=0.500)
AHAR	AHARES	REAL	first energy resolution parameter for HCAL (D=0.554)
BHAR	BHARES	REAL	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 **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, supplementerd 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.

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