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SIMDET - Version 3
A Parametric Monte Carlo for a TESLA Detector

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Abstract

We describe the principles of operation and the usage of `SIMDET` version 3, a parametric Monte Carlo program to simulate the response of a detector for the TESLA linear collider. The detector components are implemented according to the TESLA Conceptual Design Report. Its performance characteristics can be varied within a wide range. The calorimetric response is 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. 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

The program SIMDET simulates the response of an LC detector for e^+e^- physics in a fast and flexible 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 LC.
- It is flexible, so that the consequences of different basic detector options for physics can be evaluated.
- It is fast and provides a simple output structure, so that physics studies can be done in a straight forward and decentralised way.

The detector implemented in all versions of SIMDET is based on the description of a conceptual detector for the TESLA Linear Collider as laid out in the TESLA Conceptual Design Report [1]. Some possible extensions of the CDR detector concept have been proposed since. A few of them were added optionally to SIMDET so that the general detector performance is improved in some respects or such that the program is prepared for improvements in the future. The basic components of the detector are assumed to be:

- a vertex detector,
- a tracker system with main tracker, forward tracker and forward muon tracker,
- an electromagnetic calorimeter,
- a hadronic calorimeter and
- a luminosity detector.

The program applies Gaussian smearing to charged particle momenta and directions. Impact informations for charged particles are also provided. In previous versions, Gaussian smearing was also applied to calorimeter energies and directions. Starting from version 3, a more accurate description of the calorimetric response has been derived from *ab initio* simulation using the GEANT3 [2] application program BRAHMS [3].

An additional major upgrade of the program is 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 as well as unresolved clusters using the Monte Carlo truth information. The output objects of 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 for the TESLA Linear Collider.

Tracker response simulation

The analysis of events at future e^+e^- linear colliders requires excellent tracking of charged particles. Within the CDR, this requirement is accounted for by assuming a large Time-Projection Chamber (TPC) as a main tracker which is supplemented by a tracker device positioned between the TPC and the vertex detector and forward trackers to measure tracks with low polar angles ($\theta < 15°$). Two options are considered for the vertex detector, Active Pixel Sensors (APS) and Charge-Coupled Devices (CCD), both with their first layer at a distance of 2.2 cm from the interaction point (IP). The tracking system has been studied in detail using an ab initio GEANT3 [2] simulation package. The resulting transverse momentum resolution values as functions of the particle momentum and the polar angle presented in Figs.7.2.6 and 7.2.7 of the CDR [1] are the input of the $p_\perp$ Gaussian smearing procedure. By means of simple parametrisations for interpolation between these data points and extrapolation into unexplored regions a reasonable description of the transverse momentum resolution in the whole (p, θ)-plane has been obtained. The directions of charged particles, θ and ϕ, are independently smeared using a Gaussian with $\sigma = 0.1$ mrad. Correlations between momenta and ϕ directions of tracks are neglected.

APS	Polar angle	A [μm]	B [μm]	C [μm]	D [μm]
$R = 20$mm	$0.000 < \lvert\cos\theta\rvert < 0.866$	8.0	22.0	8.8	22.0
	$0.866 < \lvert\cos\theta\rvert < 0.970$	9.0	24.0	11.0	25.0
	$0.970 < \lvert\cos\theta\rvert < 0.990$	18.0	32.0	18.0	32.0
$R = 10$mm	$0.000 < \lvert\cos\theta\rvert < 0.866$	8.0	13.0	8.4	14.0
	$0.866 < \lvert\cos\theta\rvert < 0.970$	9.0	14.0	11.0	14.0
	$0.970 < \lvert\cos\theta\rvert < 0.990$	18.0	32.0	18.0	32.0
CCD	Polar angle	A [μm]	B [μm]	C [μm]	D [μm]
$R = 20$mm	$0.000 < \lvert\cos\theta\rvert < 0.928$	5.8	15.9	5.8	15.9
		(3.0)	(0.9)	(3.0)	(0.9)
	$0.928 < \lvert\cos\theta\rvert < 0.961$	12.6	15.6	12.6	15.6
		(3.5)	(1.0)	(3.5)	(1.0)
$R = 10$mm	$0.000 < \lvert\cos\theta\rvert < 0.900$	3.8	6.3	3.8	6.3
		(2.8)	(0.9)	(2.8)	(0.9)
	$0.900 < \lvert\cos\theta\rvert < 0.928$	7.7	14.7	7.7	14.7
		(5.4)	(4.6)	(5.4)	(4.6)
	$0.928 < \lvert\cos\theta\rvert < 0.961$	12.6	16.0	12.6	16.0
		(7.9)	(7.4)	(7.9)	(7.4)

Table 1: Impact resolution parameters for the APS and CCD vertex detector options. The CCD values correspond to the resolutions extrapolated to $R = 0$; the numbers in parentheses correspond to the impact resolutions if the decay occurs at $R = 22$mm, resp. $R = 12$mm, i.e. the position of the first detector layer. The two values are interpolated linearly for vertex positions inside the first layer radius.

The measured values thus obtained for $p_\perp$, θ and ϕ can be transformed to p_x, p_y and p_z by means of the program package of ref. [4], including the errors of the measurements.

`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 given, both are however momentum and angular independent in the present version of the program. Also no attempt is made to take into account overlaps of closely spaced tracks.

For the vertex detector impact parameter informations in the $(r-\phi)$ and $(r-z)$ projections are provided by `SIMDET` so that efficient flavour identification capability is made possible. For both the APS and the CCD versions of the vertex detector, GEANT3 simulations provided the impact parameter precisions of

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

and

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

for a track with momentum p and polar angle θ. The symbol $\oplus$ denotes a quadratic sum. The values of the parameters A, B, C, and D are summarised in Tab. 1; we use $E = 5/2$ and $3/2$ for the APS respectively the CCD version.

To improve the CDR tracking system, the following suggestions were made, either by providing a detailed concept for an additional detector verbally mentioned in the CDR or by proposing new components:

An additional forward tracker (with a range in θ from 6° to 25° and a single point resolution of 50 μm) can optionally be included in `SIMDET`. If this option is enabled, $p_\perp$, θ and ϕ resolution parameters obtained from the ab initio simulation package `BRAHMS` [3] are parametrised and Gaussian smearing is applied in a similar way as above. This device improves significantly the accuracy for high-momentum tracks at low θ.

The measurement capability for muons in the forward direction can be improved by a muon toroid as proposed in ref. [5]. One of the versions discussed there can optionally be included into the program. Again, momentum and angular resolutions from GEANT3 simulations are parametrised so that Gaussian smearing is possible for any $p_\perp$, θ and ϕ in the restricted acceptance region of the muon toroid. For muons above a user selected energy cut-off value, muon reconstruction efficiency and charge mismeasurement can also be specified.

Recently, new CCD and APS vertex detector designs have been proposed [6, 7], starting with their first layers at a radius of 1.2cm from the IP. Because of the importance of permitting best possible flavour tagging performance this option of the vertex detector has also been included in `SIMDET`. The corresponding impact resolution parameters, again obtained from detailed simulations, are also presented in Tab. 1.

Luminosity detector and instrumented mask response

For the luminosity calorimeter within the mask only high-energy electron response is expected. Energy and directions of such particles are smeared according to a Gaussian with widths

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus b \tag{3}$$

$$\sigma_\theta = \sigma_\phi = \sqrt{\frac{c}{12}} \tag{4}$$

with $a = 10\%$, $b = 1\%$ and a cell size of $c = 35$mrad. These default values as well as the energy threshold above which electrons have a response in the luminosity detector can be overwritten by the user.

The mask, instrumented in some way not yet specified, is only formally included in SIMDET. When specifications exist the corresponding smearing code will be added.

Calorimeter response simulation

The calorimetric response of the CDR detector was studied using the *ab initio* simulation of BRAHMS in a test beam like set-up. Electrons and charged pions from the origin were generated in random direction inside the calorimeter barrel. Energies of 1, 2, 5, 10, 50 and 100 GeV were generated. An Ntuple with the energies deposited in $9 \times 9 \times 6$ calorimeter cells around the particle impact point was filled for further study. Complete compensation was assumed.

The energy distribution in the central cell, adjacent cells and three rings further away was used as a basis for parametrisation. As a first approximation for the longitudinal segmentation, only the electromagnetic and hadronic compartments were considered. An example for a typical electromagnetic shower profile is shown in Fig. 1.

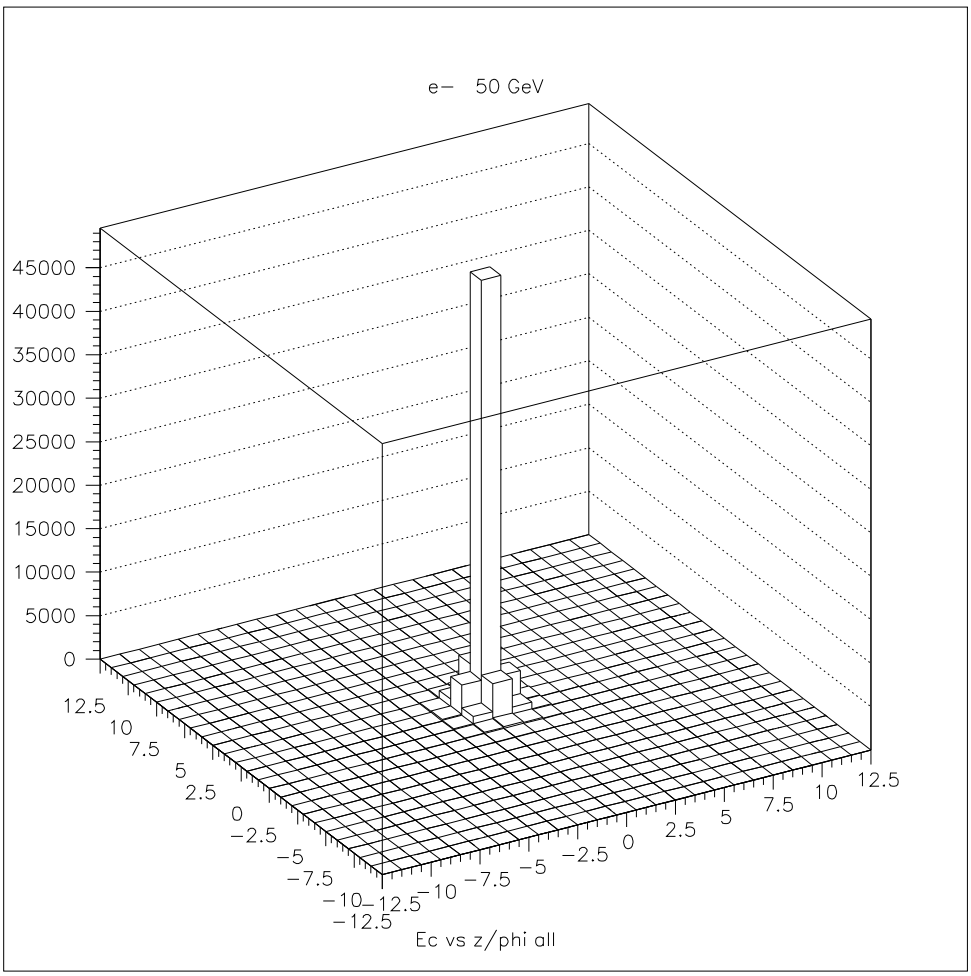

Figure 1: Lateral shower profile in the electromagnetic calorimeter barrel predicted by BRAHMS for electrons of 50 GeV from the origin with random impact points on the calorimeter towers.

For the energy distribution in the calorimeter cells we distinguish the central cell, adjacent one with or without common sides and cells in rings around this shower center. For electromag-

netic showers, one additional ring is sufficient, for hadronic showers three addition rings need to be considered. In each class of cells, a truncated Gaussian is used to parametrise the energy distribution in the electromagnetic case. Exponential tails are added for hadronic showers. Energy conservation is the main source of correlation among cell energy deposits. It is taken into account by using a binomial algorithm to distribute energies to cells in an ordered fashion, from the major to the minor components of the lateral and longitudinal profile.

The parameters of the distributions are determined for each of the above mentioned energies and histogrammed. They are then interpolated using a sigmoid function, characteristic for the asymptotic behaviour of the shower shape. As an example, Fig. 2 shows the mean and width of the energy distribution in the central cell of the electromagnetic calorimeter as a function of incident electron energy.

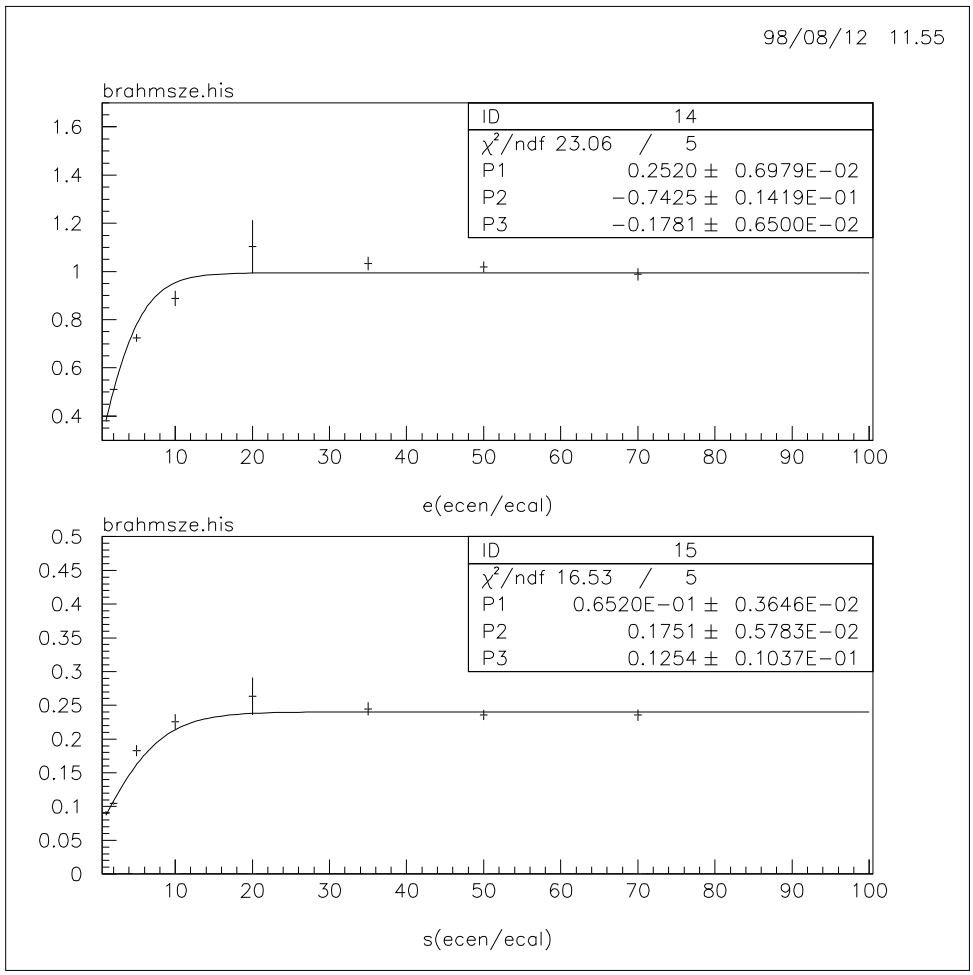

Figure 2: Mean and σ of the energy distribution in the central cell of the electromagnetic calorimeter as a function of the incident electron energy.

The description of the shower shape by this simple parametrisation is rather satisfactory. However, it has to be noted that the distributions are smoothed twice in this procedure, once at the level of the distributions themselves and second when the parameters are interpolated. Thus the resulting parametrisation is generally smoother than the result of the *ab initio* simulation itself.

Inside `SIMDET`, the results of this study are used as follows. Long-lived particles that hit

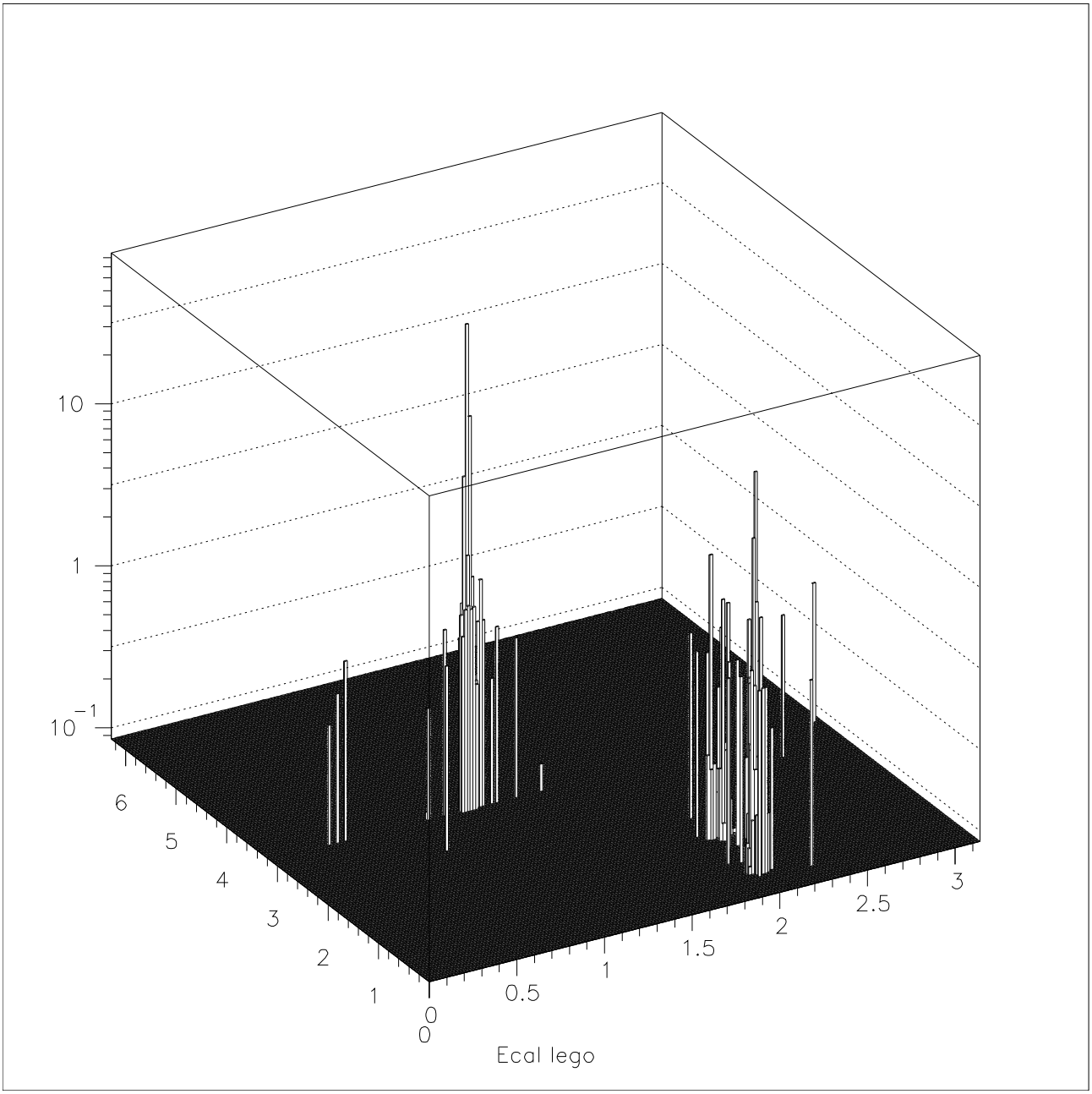

Figure 3: Lego plot of the energy deposits in the electromagnetic calorimeter for an event of the type $e^+e^- \rightarrow ZH \rightarrow e^+e^-b\bar{b}$ at 500 GeV simulated with SIMDET version 3.

the calorimeter are generically classified as $\mu^{\pm}$, $e^{\pm}$, γ, $h^{\pm}$ and h^0 and their impact onto the electromagnetic calorimeter is determined (subroutine `SILEGO`). Their energy deposits in the calorimeters are then simulated (subroutine `SIDEPO`). A lego array of 200×400 cells describes the electromagnetic compartment, 100×200 cells the hadronic compartment of the calorimeter. For reasons of simplicity and performance, the cell size is fixed to the typical size of a barrel cell for the whole solid angle. For each incident particle, energy is filled into the cells according to the relevant distribution. For muons, a fixed amount of energy is filled into the central cell only. The energy is recorded separately for each incident particle to provide a complete cross reference. The major result of this stage are two lego plots with the energy distribution in the electromagnetic and and hadronic calorimeter. Fig. 3 shows an example generated by the reaction $e^+e^- \rightarrow ZH \rightarrow e^+e^-b\bar{b}$ at 500 GeV center of mass energy. For each hit cell, the contributing particles and the energy they contribute is recorded. The contributors are ordered by energy, the particle contributing the most energy is called the major contributor in what follows.

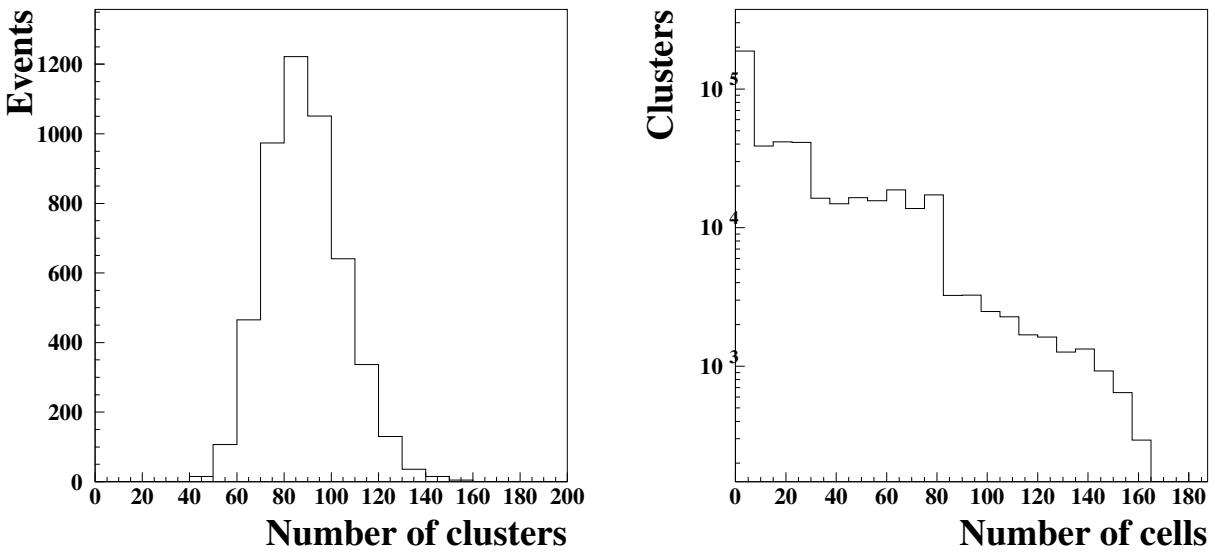

Figure 4: Number of clusters found (left) and number of hit cells per cluster (right) with default settings for W pair production at 800 GeV center of mass energy.

Cluster algorithm

The lego arrays filled as indicated above are used as input to a simple cluster finder based on local maxima. In the current version, awaiting more elaborate pattern recognition studies, an idealised version is implemented in subroutine `SICLUS_I`. It proceeds as follows:

- Seeds are formed from all local maxima with an energy above 1 GeV and an energy fraction from the particle with the major contribution to the cell above 90%.
- All ECAL cells are then added to the closest seed from the same particle, again based on the major contributor.

- If no existing seed is found, a new one is created.
- The same procedure is repeated for HCAL cells.

No attempt is made at the moment to join clusters belonging to the same primary particle. This algorithm thus results in many rather small clusters. For the typical reaction $e^+e^- \to W^+W^- \to 4$ jets at 800 GeV center of mass energy, Fig. 4 shows the number of clusters found and the number of cells per cluster.

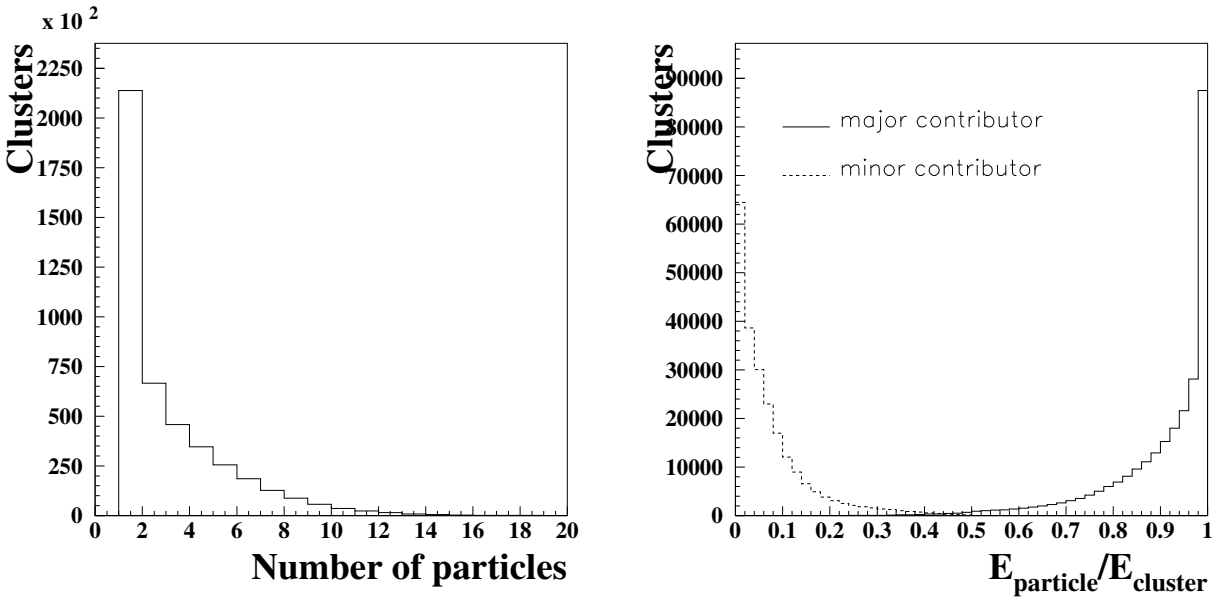

Figure 5: Left: Number of particles contributing to a cluster for W pair production at 800 GeV center of mass energy. Right: Energy fraction of the major contributor (solid line) and second contributor (dashed line).

From the cross reference table recording the particles contributing to cell energies, the contributors to the clusters and their fractional energies are derived. Typically three particles contribute to a single cluster, as shown in Fig. 5, but one particle always dominates the energy by a large margin. The clusters thus give a fair representation of their major contributor as shown in Fig. 6 both for the direction and for the energy.

Energy flow algorithm

The idea of the energy flow algorithm is to join tracker and calorimeter information such that as many single particles as possible are resolved. Particle identification, e.g. on the basis of shower shapes and matching between tracker and calorimeter information in space and momentum, then allows to apply optimum energy calibration to each particle type. Effects of imperfect compensation can thus be greatly reduced by distinguishing single showers of electromagnetic and hadronic nature. By optimising the single particle resolution, the resolution for energy and direction of jets as well as the total and missing energy and momentum can thus be optimised.

At the current stage, in the absence of true pattern recognition in either subsystem, an idealistic emulation has been put in place (subroutine `SIFLOW_I`). In a first stage, for each

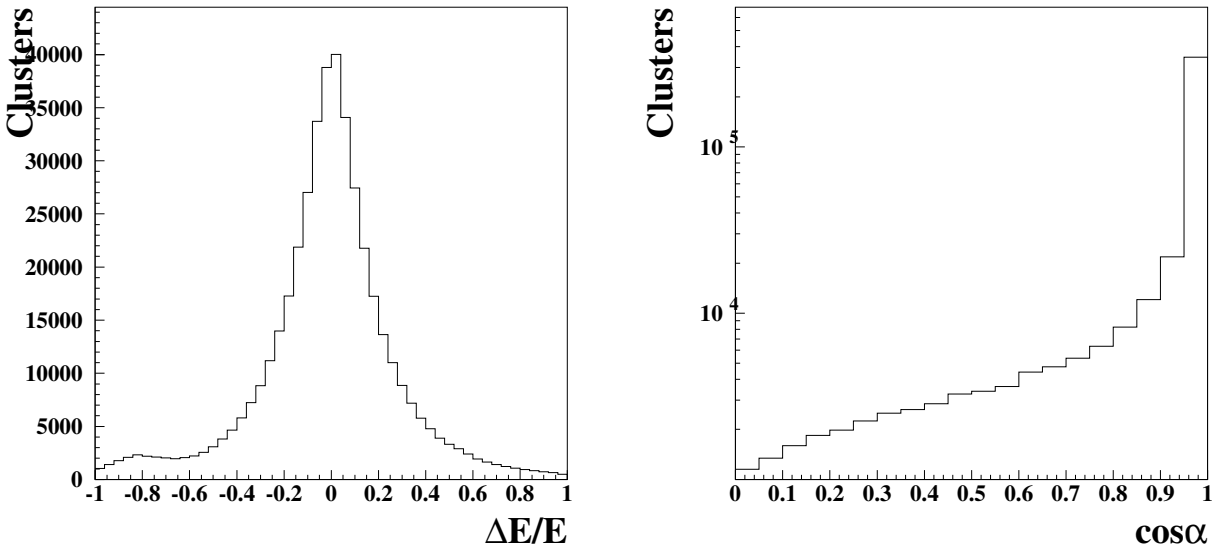

Figure 6: Left: Relative energy difference between a cluster and its major contributor. Right: Cosine of the angle between the cluster direction and the direction of the major contributor.

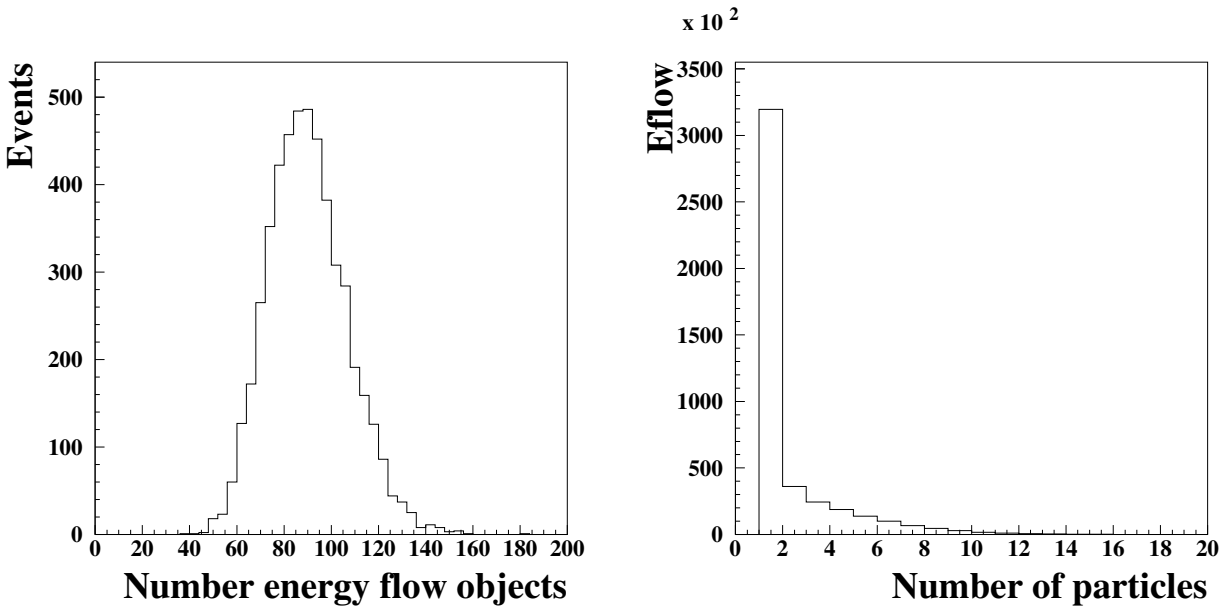

Figure 7: Left: Number of energy flow objects formed for W pair production at 800 GeV center of mass energy. Right: Number of particles contributing to an energy flow object.

track the closest cluster with the same major contributor is found and joint to form a charged energy flow object. Energy flow objects that share the same calorimetric cluster are then put together. Close by clusters with the same major contributors are then joined. Clusters not matched to a track at this stage are used to form neutral energy flow objects.

Particle identification is then emulated on the basis of the Monte Carlo information. For charged energy flow objects, the Monte Carlo particles type is used to classify the object as either electron, charged pion or muon. For neutral energy flow objects, the particle type of the major contributor to the calorimetric cluster is used to classify the object as photon or neutral hadron.

A best estimate of the direction and momentum of the object is then established. At this stage, this best estimate is simply taken from the tracker for charged objects, from the calorimeter for neutral objects. This will later be optimised using a proper weighting scheme for the two subsystems.

The energy flow objects found in this way indeed mostly represent single particles. This is shown in Fig. 7 where the number of energy flow objects per event and the number of particles contributing to each object are plotted. Fig. 8 demonstrates that the energy flow indeed, at least in this idealistic version, greatly improves the energy resolution. With respect to the total energy calculated from calorimetric clusters alone, the resolution of the total energy based on energy flow objects is reduced by essentially a factor of two, since the superb momentum resolution of the tracking system is properly used.

Program parameters and steering

In the appendices to this description, the main program parameters, user accessible COMMON blocks, data cards and the output data structure are described in detail. An up to date description together with advise for their usage is given in the `SIMDET` online documentation at

`http://www.ifh.de/linear_collider/users_guide_simdetv3.html`

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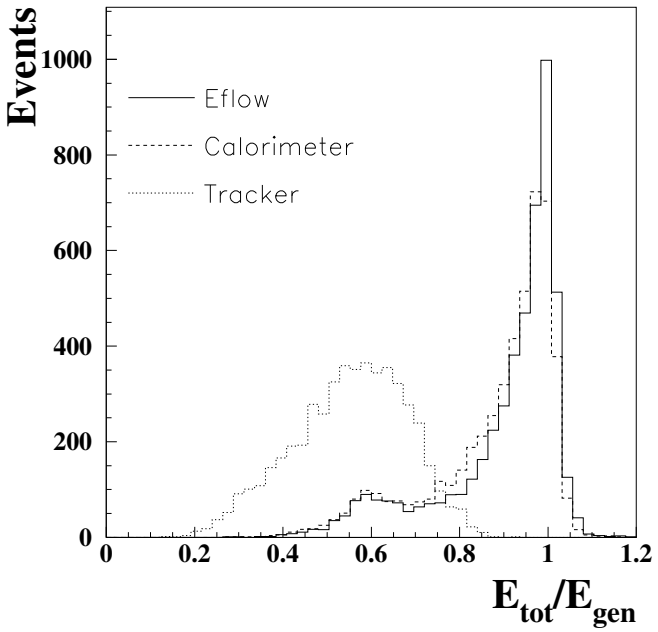

Figure 8: Resolution for the total event energy as determined from energy flow objects (solid line), calorimetric clusters (dashed line) and charged tracks (dotted line) for W pair production at 800 GeV.

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:

COSVXC	cos(theta) central polar angle acceptance value of the APS or CCD vertex detector
COSVXF	cos(theta) forward polar angle acceptance value of the APS or CCD vertex detector
COSVXVF	cos(theta) very forward polar angle acceptance value of the APS or CCD vertex detector
APSIMP	array of impact resolutions in the $(r-\phi)$ and the $(r-z)$ projections for the APS vertex detector
CCDIMP	array of impact resolutions in the $(r-\phi)$ and the $(r-z)$ projections for the CCD vertex detector
FIELD	field of the solenoid within the tracker volume [Tesla]
TPCLEN	total length of the TPC [m]
TPCRAD	outer radius of the TPC [m]

PTMINP	minimum transverse momentum of a track accepted for tracking
TRKEFF	track reconstruction efficiency
QTRKMIS	charge misinterpretation probability
COSTRK	cos(theta) polar angle acceptance value of the tracking system
COSTPC	cos(theta) central polar angle acceptance value of the TPC
DTHETPC	sigma for polar angle smearing in the TPC
DPHITPC	sigma for azimuth angle smearing in the TPC
EMINPH	minimum deposited energy required in the electromagnetic calorimeter
EPIMIS	electron misinterpretation probability
COSCAL	cos(theta) polar angle acceptance value of the electromagnetic calorimeter
SIZEMA	cell size of the electromagnetic calorimeter
AEMRES	stochastic parameter for the energy resolution
BEMRES	constant parameter for the energy resolution
EMINHA	minimum deposited energy required in the hadronic calorimeter
EMUDEP	average deposited energy of muons in the hadron calorimeter
COSCAL	cos(theta) polar angle acceptance value of the hadronic calorimeter
SIZHCA	cell size of the hadronic calorimeter
AHARES	stochastic parameter for the energy resolution
BHARES	constant parameter for the energy resolution
EMINLU	minimum deposited energy required in the luminosity calorimeter
ELEFLU	detection probability of electrons in the luminosity calorimeter
COSLML	min. cos(theta) polar angle acceptance value of the luminosity calorimeter
COSLMU	max. cos(theta) polar angle acceptance value of the luminosity calorimeter
ALURES	stochastic parameter for the energy resolution
BLURES	constant parameter for the energy resolution
CLURES	cell size of the luminosity calorimeter
PMINFTR	minimum transverse momentum of a track accepted in the forward tracker
COSLFTR	min. cos(theta) polar angle acceptance value of the forward tracker
COSUFTR	max. cos(theta) polar angle acceptance value of the forward tracker
DTHEFFT	sigma for polar angle smearing in the forward tracker
DPHIFFT	sigma for azimuth angle smearing in the forward tracker
EMINFWM	minimum energy of a muon accepted in the muon toroid
EFFFWMU	detection efficiency of a muon in the muon toroid
QMISFWM	charge misidentification of muons in the muon toroid
COSLFWM	min. cos(theta) polar angle acceptance value of the muon toroid
COSUFWM	max. cos(theta) polar angle acceptance value of the muon toroid
DTHEFWM	sigma for polar angle smearing in the muon toroid
DPHIFWM	sigma for azimuth angle smearing in the muon toroid

EMINMSK	minimum energy of a particle required for the instrumented mask
COSLMSK	min. cos(theta) polar angle acceptance value of the instrumented mask
COSUMSK	max. cos(theta) polar angle acceptance value of the instrumented mask

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
     +,               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 if non zero
 IEORUN    Flag to terminate run if non zero
 CMHEAD    Header of file (10 words, referenced in App. D end E)

+KEEP, SIUNIT.
      COMMON /SIUNIT/ LUNIN, LUNOUT, LUNDST, LUNHIS, LUNEVT, LUNDAT
*
 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

+KEEP, SICNTR.
      COMMON /SICNTR/ NPRTAC, NCHAPA, NACCLE, NPAMSK, NPALUM, NEFLOW
     +,               NPARSC
     +,               LOCPRT, LOCCPA, LOCMPO, LOCMSK, LOCLUM, LOCFIN
     +,               LOCRSC
*
 NPRTAC    Number of particles being accepted for simulation
 NCHAPA    Number of charged particles
 NACCLE    Number of particles in the lego plot
 NPAMSK    Number of particles in the instrumented mask
 NPALUM    Number of particles in the the 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
 LOCMSK    Start location of particles in the instrumented mask
 LOCLUM    Start location of particles in the luminosity calorimeter
```

```
 LOCFIN    Start location of particles for final storage
 LOCRSC    Start location of particles rescued

+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, SIFLAG.
      COMMON /SIFLAG/ IFPYTH, IFEVTI
     +,               IFBEST, IFVECS, IFWDST, IFCOMP, IFFORM, IFHIST
     +,               IFAPS,  IFCCD2, IFCCD1, IFFWMU, IFFWTR, IFMASK
*
Flags for enabling resp. disabling of detector components (see App. C)

+KEEP, SIPARA.
      COMMON /SIPARA/ COSCAL, EMINPH, EMINHA
     +,               EPIMIS, ELEFLU, XMUMIS
     +,               COSVXC, COSVXF, COSVXVF,
     +,               APSIMP(12), CCDIMP(24),
     +,               FIELD,  TPCRAD, TPCLEN, QTRKMIS
     +,               PTMINP, COSTRK, COSTPC, COSFTR, COSVFTR
     +,               TRRES1, TRRES2, DTHETPC, DPHITPC, TRKEFF
     +,               FTRKR1, FTRKR2
     +,               DTHEFTR, DPHIFTR
     +,               AEMRES, BEMRES, SIZEMA
     +,               AHARES, BHARES, SIZHCA
     +,               ALURES, BLURES, CLURES, SIZLUM
     +,               COSLMU, COSLML, EMINLU
     +,               ANGLUM
     +,               EMUDEP, EMUISO
     +,               COSLFWM, COSUFWM, EMINFWM, EFFFWMU
     +,               QMISFWM, DTHEFWM, DPHIFWM
     +,               COSLFTR, COSUFTR, PMINFTR, DTHEFFT, DPHIFFT
     +,               COSLMSK, COSUMSK, EMINMSK
*
 Detector parameters (see App. A)

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

```
*
 Working array for internal particle storage

+KEEP, PUCPPP.
      PARAMETER (MTRACK=500)
      COMMON /PUCPPP/PVECP
      DOUBLE PRECISION PVECP(5, 2*MTRACK)
      REAL             VECP(10, 2*MTRACK)
      DIMENSION        IVECP(10, 2*MTRACK)
      EQUIVALENCE ( VECP(1, 1), PVECP(1, 1))
      EQUIVALENCE (IVECP(1, 1),  VECP(1, 1))
*
 Working array for VECSUB package

+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=400)
      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=200)                          ! eflow objects
      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 for the results of the energy flow algorithm

+KEEP, SIBOUT.
      PARAMETER (NPLUND=500, 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 (see App. D)

+KEEP, SIENFL.
      PARAMETER (NMXEFL=200, NWENFL=700)
      COMMON /SIENFL/ NENFLO, CM(NMXEFL,NWENFL)
     +,               NGENNW(NMXEFL), NTRKNW(NMXEFL), NCALNW(NMXEFL)
     +,               NMUSNW(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 for best energy flow object information (see App. E)
*
```

Appendix C: Data cards

Key	Variable	Data type	Meaning
NEVT	NEVENT	INTEGER	total number of events to process (D=10)
PYTH	IFPYTH	INTEGER	1 = event generation by PYTHIA,
			0 = no PYTHIA generation (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)
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,
			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)
COMP	IFCOMP	INTEGER	1 = event reading from an external file,
			written by CompHEP, 0 = no event reading (D=0)
APS1	IFAPS1	INTEGER	1 = pixel detector (for 1 cm beam pipe) is enabled,
			0 = no pixel detector (D=0)
APS2	IFAPS2	INTEGER	1 = pixel detector (for 2 cm beam pipe) is enabled,
			0 = no pixel detector (D=1)
CCD2	IFCCD2	INTEGER	1 = CCD detector (for 2 cm beam pipe) is enabled,
			0 = no CCD (2cm) detector (D=0)
CCD1	IFCCD1	INTEGER	1 = CCD detector (for 1 cm beam pipe) is enabled,
			0 = no CCD (1cm) detector (D=0)
FWTR	IFFWTR	INTEGER	1 = additional forward tracker is enabled,
			0 = no additional forward tracker (D=0)
FWMU	IFFWMU	INTEGER	1 = forward muon detector is enabled,
			0 = no forward muon detector (D=0)
LUMI	IFLUMI	INTEGER	1 = luminosity detector is enabled,
			0 = no luminosity detector (D=0)
MASK	IFMASK	INTEGER	1 = instrumented mask is enabled,
			0 = no instrumented mask (D=0)

Key	Variable	Data type	Meaning
EFTR	TRKEFF	REAL	track measurement efficiency (D=0.99)
PTTR	PTMINP	REAL	minimum transverse momentum required [GeV] (D=0.050)
QMTR	QTRKMIS	REAL	charge misinterpretation probability (D=0.005)
EMPH	EMINPH	REAL	minimum energy required for photon detection [GeV] (D=0.100)
AEMR	AEMRES	REAL	first energy resolution parameter for ECAL (D=0.102)
BEMR	BEMRES	REAL	second (constant) energy resolution parameter for ECAL (D=0.006)
EMHA	EMINHAS	REAL	minimum energy required for hadron detection in HCAL [GeV] (D=0.200)
AHAR	AHARES	REAL	first energy resolution parameter for HCAL (D=0.405)
BHAR	BHARES	REAL	second (constant) energy resolution parameter for HCAL (D=0.042)
EMLU	EMINLU	REAL	minimum energy required for electron detection in LUMI detector [GeV] (D=30.0)
EFLU	ELEFLU	REAL	measurement efficiency for electrons in LUMI detector (D=0.999)
CSLU	SIZLUM	REAL	cell size of LUMI detector [degrees] (D=1.0)
ARLU	ALURESS	REAL	first energy resolution parameter for LUMI detector (D=0.10)
BRLU	BLURES	REAL	second (constant) energy resolution parameter for LUMI detector (D=0.01)
EMMU	EMINFWM	REAL	minimum energy required for muon detection in forward muon detector [GeV] (D=5.0)
EFMU	EFFFWMU	REAL	measurement efficiency for muons in forward muon detector (D=0.95)
QMMU	QMISFWM	REAL	charge misinterpretation probability for muons in forward muon detector (D=0.003)
PFWT	PMINFTR	REAL	minimum transverse momentum in forward tracker [GeV] (D=0.200)
EMSK	EMINMSK	REAL	minimum energy required for particle measurement in the mask [GeV] (D=10.0)

Appendix D: Full output data structure

This describes the `SIMDET V3.1` 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 or only the stable particles which might give a response in the detector are covered.

The number of the energy flow objects, `NENFLO`, then follows. For each object, blocks of records follow, describing status information, best estimates, generator information, charged particles, calorimetric 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]
4	IDCLASS	INTEGER	Reaction identifier, user defined
5	dummy	INTEGER	not used
6	dummy	REAL	not used
7	FIELD	REAL	Magnetic field [T]
8	dummy	INTEGER	not used
9	dummy	INTEGER	not used
10	dummy	INTEGER	not used

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 LUND convention
3	line	INTEGER	line number of mother in the LUND 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 LUND 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 `NENFLO` 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 LUND 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 [rad]
3	Phi	REAL	azimuthal angle [rad]
4	Q	REAL	charge of particle
5	Imp(R,phi)	REAL	transverse impact parameter, in units of sigma
6	Imp(R,z)	REAL	longitudinal impact parameter, in units of sigma
7	cov. matrix	REAL	element of the cov. matrix
8	cov. matrix	REAL	element of the cov. matrix
9	cov. matrix	REAL	element of the cov. matrix
10	cov. matrix	REAL	element of the cov. matrix
11	cov. matrix	REAL	element of the cov. matrix
12	cov. matrix	REAL	element of the cov. matrix
13	cov. matrix	REAL	element of the cov. matrix
14	cov. matrix	REAL	element of the cov. matrix
15	cov. matrix	REAL	element of the cov. matrix

This record is repeated `NTRK` times.

Energy flow record 5: calorimeter cluster (ECAL/HCAL) that are part of the object

Offset	Variable name	Data type	Meaning
1	E	REAL	energy [GeV]
2	Theta	REAL	polar angle [rad]
3	Phi	REAL	azimuth angle [rad]
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 [rad]
8	Phi	REAL	azimuthal angle [rad]
9	Time	REAL	timing information
10	C(mip)	REAL	probability of being consistent with a minimum ionising 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 [rad]
3	Phi	REAL	azimuthal angle [rad]
4	Q	REAL	charge of particle
5	Time	REAL	timing information
6	C(punch)	REAL	probability of being consistent with a punch-through object

This record is repeated `NMUS` times.

Appendix E: Restricted output structure

This describes the `SIMDET V3.0` 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, `NENFLO`. 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]
4	IDCLASS	INTEGER	Reaction identifier, user defined
5	dummy	INTEGER	not used
6	dummy	REAL	not used
7	FIELD	REAL	Magnetic field [T]
8	dummy	INTEGER	not used
9	dummy	INTEGER	not used
10	dummy	INTEGER	not used

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 LUND convention, 999 = cluster of unresolvable particles

In case of NTRK > 1, the largest impact parameters are recorded. This record is repeated `NENFLO` times.

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