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AN APPLICATION OF THE GEANT3 GEOMETRY PACKAGE
TO THE DESCRIPTION OF THE OPAL DETECTOR

J. Allison¹, R. Brun², F. Bruyant², F.W. Bullock³, C.Y. Chang⁴, J.-J. Dumont^{5*},
P. Hattersley⁶, R.J. Hemingway⁵, P.R. Hobson^{3**}, D. Hochman⁷, T. Kawamoto⁸,
B. Lorazo⁹, J. Mallet¹⁰, A.C. McPherson⁵, S.W. O'Neale⁶, G. Patrick¹¹,
A. Possoz¹², A. Rossi¹³, D.R. Ward¹⁴, C.P. Ward¹⁴ and P. Zanarini².

- 1 Dept. of Physics, Manchester University, Manchester, UK
- 2 CERN, European Organisation for Nuclear Research, Geneva, Switzerland
- 3 Physics Dept., University College, London, UK
- 4 Physics Dept., University of Maryland, College Park, Maryland, USA
- 5 Dept. of Physics, Carleton University, Ottawa, Canada
- 6 Dept. of physics, University of Birmingham, Birmingham
- 7 Dept. of Nuclear Physics, Weizmann Inst. of Science, Rehovot, Israel
- 8 ICEPP, University of Tokyo, Tokyo, Japan
- 9 Lab. de Physique Nucléaire, Univ. de Montréal, Montréal, Quebec, Canada
- 10 Dept. de Physique des Particules Élémentaires, CEN Saclay, France
- 11 Rutherford Appleton Laboratory, Chilton, Didcot, UK
- 12 Enrico Fermi Institute, University of Chicago, Chicago, Illinois, USA
- 13 Institut di Fisica, Università di Bologna, Bologna, Italy
- 14 Dept. of Physics, Cambridge University, Cambridge, UK
- * Now at Ecole Polytechnique Féd., Lausanne
- ** Now at Dept. of Physics, Brunel University, Uxbridge, U.K.

ABSTRACT

We present the general features of the GEANT3 package for coding the geometrical structure of a large and complex detector in the computer programs used for their design and analysis. This package has been developed in the context of Monte Carlo studies of detector performance but should be well matched to the problem of analysis. As a specific example, we illustrate the description of the OPAL detector for the Large Electron Positron collider at CERN and show the results of a sample study using this description.

This paper is dedicated to the memory of Wolfgang Gebel. Wolfgang wrote the code for the Jet chamber of the OPAL detector and contributed to several utility routines of the GEANT3 package.

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1. INTRODUCTION

The apparatus used in High Energy Physics experiments has evolved steadily over the last twenty years from the relatively simple detectors containing few modules to the sophisticated and complex detectors now being constructed for the new generation of colliding beam machines.

Although Monte Carlo techniques have been widely used in the conceptual design of such detectors, the ability of the physicist to describe the geometrical structure of a detector in the computer program has been somewhat limited. In most cases the material, the shape, and the position data needed to describe a particular detector element have been 'hard-coded' into the program. For detectors employing hundreds, if not thousands, of detector elements this task has been daunting. Often one is forced into an 'averaging' mode wherein an effective supervolume is used to represent the behaviour of the many sub-elements it contains.

As the new detectors start operation, and as the data recorded by these detectors increase in statistical weight, we need to predict and understand the behaviour of even the smallest detector element. We describe here a new method which has been developed to simplify the task of coding a complex detector geometry.

The remainder of this paper is as follows. In section 2 the overall Monte Carlo environment (GEANT) is described and the details of the new geometry package are given in section 3. As an example of the utilisation of this new method, we discuss in section 4 the OPAL detector now being built for the LEP collider at CERN, and show in section 5 how the geometrical computer model for OPAL has been constructed. Finally, in section 6, this model is used to generate a computer 'X-ray' of the detector and distribution maps of the material within OPAL.

2. THE GEANT MONTE CARLO

As the scale and complexity of High Energy Physics experiments increase, simulation studies require more and more care and become essential

- to design and optimize the detector
- to develop and test the reconstruction and analysis programs, and
- to interpret the experimental data.

GEANT is a system of detector description and simulation tools which has been developed for such studies [1]. It has been continuously developed over the past 10 years. Initially designed for the first SPS experiments, versions 1 and 2 have been used by more than 30 experiments in many laboratories. In 1983 the system was rewritten in view of the complexity of the new large detectors. This new system, known as GEANT3, puts more emphasis on the description of complicated geometrical set-ups and on the calorimetry. It is now being used by many experiments at LEP, SPS, LEAR, HERA and SLC and has benefited greatly from the extensive tests and contributions of such a large community of users.

The GEANT3 system allows one to

- describe an experimental set-up in an efficient and simple way [the GEOMETRY package],
- generate simulated data from standard physics event generators [the KINEMATICS package],
- control the transport of particles through the various devices of the set-up taking into account the boundaries of geometrical volumes and all physical mechanisms [the TRACKING package],
- record the elements of the particle trajectories and the response from the sensitive detectors [the HIT-DIGITISATION package],
- draw the detectors, the particle trajectories and the hits [the GRAPHICS package],
- save (or read) the results of each event on disk or tape in a machine independent format [the I/O package].

GEANT3 is a collection of Fortran 77 routines grouped into several modules as above. It uses the CERN Library routines extensively and therefore is easily portable on most of the computers available in the particle physics community. The program segments contain 'dummy' and 'default' user subroutines called whenever application dependent actions are expected. It is the responsibility of the user to assemble the appropriate program segments and tools into an executable program, to code the relevant user subroutines, to provide the data describing the experimental environment, and to submit the data cards which control the execution of the program.

The following section describes in detail the GEOMETRY package of GEANT3 and uses some features of the GRAPHICS package to illustrate the software tools available. This graphical representation of the GEOMETRY package is very important. The geometrical elements of the package are, essentially, only elementary exercises in coordinate geometry. The important aspect is that the coordinate geometry must actually represent the physical construction of the detector - and the GRAPHICS package allows one to check this. The graphics system can display the whole and/or any part of the detector from any angle and it can display sections through the detector. The TREE structure of the detector as well as any part of the detector can be viewed, thus providing the user with information and fast debugging facilities. Software zooming is available to achieve a high resolution.

The interactive version of the package is a very powerful tool. It works under control of the ZCEDEX package [2] which enables editing and executive commands. For example, the user may store and modify the parameters defining a volume, the position of the volume, the material filling the volume and the parameters used by the tracking package for that volume, and other attributes (color, line style, visibility in the graphics package, activation in the tracking package) without recompiling the whole or part of the program : this last feature is of considerable interest in terms of time saving and debugging possibilities. Another important feature is the facility for defining and saving MACROs which are collections of (interactive) commands. The interactive version has proved to be an essential tool for assistance in simulating large detectors.

3. THE GEOMETRY PACKAGE OF GEANT3

The geometrical description package in GEANT3 has been used extensively to describe the OPAL experimental layout. Indeed, it was the need to describe a sophisticated detector like OPAL which originally motivated the development of the package. Most of it has been written by members of the OPAL collaboration, and, until recently, OPAL has been the dominant test-bed for the system.

3.1 General Structure

It is important that the development of a computer description can follow the development of the design and construction of an experiment without major rewrites. For this reason great emphasis has been placed on the correspondence between the conceptual structure of the detector and the structure of the computer description. Further, the modularity of this description must be such that each section can be coded independently by the group responsible for the design and construction of that section of the detector. This is particularly important when it is necessary to describe the small details of complex structures, as only the designers and constructors can reasonably be expected to have such information at their finger tips.

The essential structure of the geometrical package is a nested tree form. An overall super volume is designated to contain the entire detector; within this, various subvolumes are defined each containing some section of the detector; within each of these, further subvolumes are defined and so on till the appropriate level of detail is reached in each branch. A particular volume can be repeated (with all its contents) several times in a manner which reduces the information storage in the, frequently occurring, case where several identical (or similar) modules appear in the total experiment. This kind of structure has several advantages. It naturally generates a description with a multilevel structure which is well matched to the conceptual structure of an experiment in terms of large sections containing groups of modules each containing modules with deeper substructures, down, if necessary, to nuts and bolts and structural members. The tree structure provides a good environment for fast search techniques since each volume will, in general, have only a few contents at the level immediately below. The list of name and number of each volume in the branch of the tree above a given volume provides a natural, precise and mnemonical identification of every part of the detector. It is far easier to identify the 10th wire in the 5th chamber of the forward tracking module of the small angle electron tagging system, than the 13250th wire in the detector. The system of multiple copies of identical, or even merely similar, volumes minimises the repetition of information. This is extremely important when trying to access a reasonably detailed description of any of the LEP detectors.

Simple volumes are defined in an unlocated fashion, giving name, shape and the parameters needed to define the volume (dimensions, angles etc.). Then volumes are placed within other volumes, giving copy number, position and rotation matrix relative to the volume within which it is placed. Multiple copies can be placed in the same or different volumes. When copies are placed, the entire volume with all its contents (whether defined before or after the placement) is replicated. If the copies are not identical but similar (same shape), the parameters can be specified at the placement stage instead of at the volume definition stage. Some parameters which are naturally positive definite (dimensions) can be specified to be negative, in which case the system will assume them to be as large as will fit in the particular volume in which the object is placed. An alternative procedure is to divide a volume into uniform slices along a coordinate axis (the precise definition of these axes depends on the shape being divided, e.g. shapes with cylindrical symmetry use cylindrical coordinate systems for divisions). This procedure simultaneously creates the new volume and effectively places multiple copies of it in a volume, all in a single action.

3.2 The Volume Definition

Experimental set-ups can be described accurately through the definition of a set of simple VOLUMES.

Each VOLUME is given a NAME and is characterized by :

- a SHAPE identifier, specifying one of the basic geometrical shapes available,
- the shape parameters, giving the dimensions of the volume,
- a local reference system, whose origin and axes are the ones defined for the given shape (cartesian, cylindrical or spherical coord.),
- its physical properties, given by a set of constants for the material which fills the volume,
- additional properties, known as tracking constants, which depend on the characteristics of the volume itself and on its geometrical and physical environment (properties of the neighbouring media, magnetic field, etc.)
- a set of attributes, in connection with the drawing package and the detector response package.

As long as it is not 'positioned' in a given reference frame, a VOLUME is an entity which has no spatial relation with the set-up. By convention, a unique initial volume has to be defined which should match (or surround) the outside boundaries of the entire set-up. The reference frame attached to this volume is considered to be the master reference frame.

3.3 The System Shapes

The system shapes supported at present are as follows :

- 'BOX ' is a rectangular box.
- 'TRD1' is a trapezoid with only the x length varying with z.
- 'TRD2' is a trapezoid with both x and y lengths varying with z.
- 'TRAP' is a trapezoid for which the faces perpendicular to z are trapezia and their centers are not at the same x, y.
- 'TUBE' is a tube.
- 'TUBS' is a phi segment of a tube.
- 'CONE' is a conical tube.
- 'CONS' is a phi segment of a conical tube.
- 'SPHE' is a segment of a spherical shell.
- 'PARA' is a parallelepiped.
- 'PGON' is a solid formed by joining concentric regular polygons, or a number of equal chords to two arcs, defined in two or more planes perpendicular to the z axis.
- 'PCON' is a solid formed by joining concentric circles, or arcs, defined in two or more planes perpendicular to the z axis.

Examples of all these shapes are shown, using the GEANT3 drawing package, in Fig. 1 - 3.

3.4 Volumes with Contents

A VOLUME can be declared to have 'contents' and become a 'mother' volume. The contents are either predefined volumes which are explicitly positioned inside the mother, or new volumes which are implicitly defined by a division mechanism applied to the mother.

Positioning a volume with given shape and dimensions inside a mother volume is achieved by specifying its translation and rotation with respect to the mother reference frame. The user should make sure that no volume overlaps the boundaries of its mother. When a volume is positioned, the user gives it a NUMBER. Multiple copies of a given volume, with different numbers, can be positioned inside a mother or inside different mothers and the contents of the volume are reproduced implicitly in all copies.

Divisions can be performed along any of the three axes of the mother volume. The definition of the axes (X, Y, Z or R_{xy} , ϕ , Z or R, θ , ϕ) depends on the shape. Examples of division for each of the system shapes are shown in Fig. 4 - 6. The mother volume can be partially or totally divided. The division generates a cell, which is considered as a new volume with (usually) the same shape as the mother. Its dimensions are computed according to the declared division number and/or step size. This cell, as any volume, can again be divided along any of its proper axes, or have other volumes positioned into it. Volumes positioned within a cell are reproduced implicitly in all cells.

These operations permit a tree of volumes to be defined at deeper and deeper levels. It is assumed that the material and tracking constants of the contents replace the ones of the mother within the space they occupy. A VOLUME is therefore defined not only by its intrinsic characteristics but also by the definition of its 'daughters', namely its contents, the contents of its contents, etc.

The user may define volumes which have nothing to do with the real physical structure. It is sometimes convenient to make use of such volumes to artificially delimit regions with simple shapes. As a consequence, it may happen that volumes overlap each other (a volume positioned inside a mother is obviously not regarded as overlapping the mother) and a special mechanism has been introduced to handle such cases.

3.5 The Basic User Tools

The set of subroutines for the definition, positioning and division of volumes is as follows.

[A] The user can DEFINE a volume through a call to the subroutine :

GSVOLU : Input arguments specify the NAME, SHAPE and parameters of the volume. An output argument returns the position of the volume inside the data structure bank.

[B] The user can POSITION a volume through a call to either one of the following subroutines :

GSPOS : Input arguments specify the NAME and copy NUMBER of the volume to be positioned, the NAME of the mother, the translation and the rotation matrix.

GSPOSP : In case the user has to position, inside the mother, a large number of volumes with the same shape but different dimensions an alternative is provided which consists of defining the generic volume once, with the number of shape parameters set to zero, and to call GSPOSP for each volume in turn, with the same arguments as GSPOS plus the shape parameters. The volumes will be identified by their NAME and NUMBER as for the multiple copies.

[C] The user can DIVIDE a volume through a call to any one of the following subroutines :

GSDVN : Input arguments specify the NAME of the cell volume, the name of the MOTHER being divided, the number of divisions NDIV and the axis along which the division is performed. In this simple case, the cell tracking medium is assumed to be the same as for the mother.

GSDVS : The division STEP is given instead of NDIV and the cell tracking medium is specified.

GSDVX : In addition to both STEP and NDIV (with at least one of them positive to be effectively used), the origin of the first cell and the cell tracking medium are specified.

3.6 The Optimisation Tools

When a track enters a volume with contents, the search time to identify whether the current point is in the mother, or in any of the contents, is very short when the contents are division cells (straightforward computation along the relevant axis). When the contents have been positioned, the search time can be quite large. In order to save time the user can make use of either of the following facilities :

[A] GSORD

From the known position of the contents inside a given volume the subroutine GSORD computes fictitious boundaries along the specified coordinate, simulating a division with non regular step size. A binary search technique is used to identify within which pseudo-cell the current point is. The slow process of computing whether the point is inside or outside the contents is therefore limited to the few (if any) volumes sitting in that pseudo-cell.

[B] GSNEXT

When a particle enters a mother volume, the contents are scanned initially in the order they have been positioned, and the user should take care deciding on the best sequence of GSPOS calls. However, when the particle comes back inside the mother from any one of the contents, it is usually possible to limit the search to the neighbouring contents. The subroutine GSNEXT permits the user to inject at initialisation time, for each content in turn, the list of neighbours to search for. A proper use of this facility can reduce the search time significantly.

[C] GSSEAR/GOSEAR

The order in which the contents of a given volume are scanned, as well as the order within the lists of neighbours (if any), can be updated according to the statistics observed during the execution of the program provided the user has explicitly called the subroutine GSSEAR for this volume. The reordering takes place, with control print-out, every time the user calls the subroutine GOSEAR.

4. THE OPAL DETECTOR AT LEP

CERN is constructing a large electron-positron collider (LEP) to study the production and decay properties of the Intermediate Vector Bosons, the Z^0 and the $W^\pm$. One of the four detectors being constructed is OPAL - an Omni Purpose Apparatus for LEP - costing some 75 million Swiss francs and involving some 130 physicists from 22 institutes in nine countries.

A schematic diagram of the OPAL detector is shown in Fig. 7 in which the major components are labelled.

OPAL's design features a central detector consisting of a slim VERTEX detector around the beam pipe, the main JET chamber for recording particle tracks and measuring particle momenta, and the outer ZED chambers. The central detector is surrounded by a solenoidal COIL, and outside the magnet is the calorimetry for measuring the deposition of electromagnetic and hadronic energy, and finally the outer muon chambers.

The major component of the central detector is the 3.85 m diameter JET chamber containing 24 sectors each of 159 stretched sense wires separated by potential wires. The 3816 sense wires and 19800 field wires of the JET chamber are mounted between two conical aluminium end-plates which carry a load of some 15000 kg. Embedded in the JET chamber is the VERTEX detector (23.5 cm outer radius, 8.5 cm inner radius and 1 m in length) wrapped around a thin beam pipe. This detector is built up from drift chamber cells. Another feature of the central detector design is the series of ZED chambers, providing mechanical support for the jet chamber and carrying out additional precise measurements of the (z) direction parallel to the beams.

Surrounding the central detector is the aluminium COIL of the solenoid carrying a current of 7000 A to provide a field of 0.4 T. Outside the coil, 2500 tons of iron return yoke will also function as part of the outer HADRON CALORIMETER.

The barrel electromagnetic calorimeter around the solenoid consists of a layer of 9440 blocks, each pointing towards the interaction point. The electromagnetic calorimetry is completed by two endcaps either side of the central detector, containing a total of 2264 additional blocks.

Fitted between the electromagnetic calorimeter and the solenoid are the electromagnetic PRESAMPLER, a double layer of streamer tubes to pick up electromagnetic showers originating in the magnet coil and a TIME OF FLIGHT system, based on a shell of scintillation counters.

The HADRON CALORIMETER consists of three main sections – the cylindrical barrel plus outer and inner endcaps. Except for the inner endcaps (magnet pole tips) instrumented with thin multiwire proportional chambers, the calorimetry will use plastic streamer-tubes. The barrel will consist of 24 wedge-shaped elements, each subtending 15° and over 10 m long.

Outside the hadron calorimeter there are four planes of drift chambers in the outer barrel (MUON BARREL) and four planes of streamer tubes in the endcaps (MUON END CAP).

Finally, a pair of FORWARD detectors are located close to the beam pipe and consist of lead/scintillator sandwich calorimeters and a set of radial drift chambers and scintillator luminosity monitors.

5. THE GEOMETRICAL DESCRIPTION OF THE OPAL DETECTOR

Referring back to the schematic diagram of the OPAL detector (Fig. 7) and armed with the detailed engineering diagrams of the separate components, we have been able to construct a geometry data structure using the tools described in section 3.

Fig. 8 shows an overview of the OPAL geometry tree structure in which the majority of labels correspond to the notation of Fig. 7, and the three volumes VOLA, VOLB and VOLC represent 'super-volumes'. Each box in Fig. 8 represents a branch of the tree and in detail contains the sub-volume members of that particular detector or mechanical structure. We give here two specific examples to show a) the ease of use of the GEANT3 Geometry package and b) the complexity that can be achieved.

5.1 The Vertex Chamber

As a detailed illustration of the use of the geometry package, Appendix I lists the 70 lines of code needed to completely specify the geometrical layout for an early design of the OPAL vertex chamber. The design comprises a segmented r-phi drift region, bounded on the inside by a gas tight skin and on the outside by a support tube. Outside this is a z drift path which is segmented in both z and phi. The whole includes end caps and an outside gas tight skin.

An explanation of this code follows. The data statements establish the parameter values which define the volume dimensions. The calls to GSTMED define materials and tracking parameters which are various criteria for the choice of tracking step size. For instance, one is the maximum angular change due to magnetic field allowed in a single step. The calls to GSVOLU establish the volume, including parameters, for the inner skin, the r-phi drift volume, the support tube, the z measurement region, the outer skin, end plates, anode and cathode planes and the z drift volume. The calls to GSPOS locate the first five of these and two copies of the end plates in the supervolume CV (defined elsewhere). The r-phi drift volume is divided into 36 phi sectors by the first call to GSDVN. The second call divides the z measurement region into 6 z sections. The next calls to GSPOS position the anode, two cathodes and two z drift volumes in (each of) the z sections. The last call to GSDVN divides each of these (2 x 6) drift regions into 18 phi segments.

Fig. 9 shows the detailed tree structure of this vertex chamber geometry together with a picture of each element, the name of the volume, and the number of times a volume has been divided or replicated.

5.2 The Barrel Electromagnetic Calorimeter

The OPAL EM barrel calorimeter illustrated in Fig. 10 consists of ten-ring structures (five on each side of the beam axis). The geometrical arrangement of the lead glass blocks is made especially complicated by the physics decision to have their orientation so that they do not point exactly at the centre, whilst still minimising the gaps between them.

The dimension of the EM barrel is 7.52 m in the beam (z) direction, and the radius of the inner surface is 245.5 cm. In the r-phi plane it is segmented equally into 160 blocks each covering 2.25° in azimuth. The blocks are tilted by 0.574° by a mounting mechanism to avoid the r-phi gap pointing directly toward the intersection point ($Z = 0$, $r = 0$). In the r-z plane it is segmented in 59 blocks arranged in a nearly pointing geometry, the boundaries of the blocks pointing towards positions slightly different from $z = 0$. The shape of each block is a trapezoid 'TRD1' and 16 different block sizes are needed to construct the entire calorimeter. The length of the blocks is 370 mm except for those at the end of the barrel in the overlap region with the Electromagnetic End Cap Calorimeter, whose length is 250 mm.

The geometry of the EM barrel is fully modelled in the GEANT3 geometry definition. The composition of the material is correctly introduced for the calculation of the physical processes which occur in the lead glass. The other materials such as the support mechanism, light guides, and magnetic shield are expressed as three coaxial tubes which have the average thickness of these materials. Fig. 11 shows the resulting tree structure from the coded geometry.

5.3 The Complete Detector

The entire tree for the OPAL geometry contains 307 individual volumes. With the tree structure extending to eight levels of depth and with the division/replication facility, these 307 volumes actually describe the geometry of some 63487 components of the OPAL detector. Thus the 11704 lead glass blocks, the 192 Zed chambers, the 112 muon barrel chambers, the 160 time-of-flight counters, the 3072 streamer tubes of the presampler and 9152 streamer tubes of the muon endcap are all incorporated. Not only have all the detector elements been coded but also the passive material - the massive structural supports, the coil, the beam pipe, the calorimeter steel plates, the pressure vessel, etc. - has been included.

Two cross sectional views of the OPAL geometry are shown in Fig. 12 - 13. These figures have been prepared using the drawing package of GEANT3 which enables 'attributes' to be set for each volume thus allowing specific detectors to be 'seen' or 'not-seen'. Comparison with Fig. 7 shows the remarkable detail already included in the geometry model.

6. THE DISTRIBUTION OF MATERIAL IN OPAL

Having assembled the complete geometrical description of the OPAL detector we are able to map the material of OPAL encountered by a relativistic particle originating at the centre by accumulating the number of radiation lengths and number of absorption lengths in each step of the tracking of the particle through the detector. Multiple scattering has been suppressed and the magnetic field set to zero. The results of this mapping are displayed in Figs. 14 - 17.

OPAL is symmetrical about the coordinate planes - at least out to the muon detector - so only the positive octant is shown. 9000 particles were tracked in straight lines from the origin, one in each of 100 bins of $\cos\theta$ for each of 90 bins of ϕ , the direction of the particle within the bin being random. The fluctuations seen in the figures are real - they are the result of chance coincidence of the trajectory with e.g. small gaps between lead glass blocks (1 mm) or between hadron calorimeter modules (4 mm) or with iron spacers and flux bars in the magnet.

The first important parameter of a general purpose 4π detector, as far as calorimetry is concerned, is the number of radiation lengths of material in front of the sensitive volume of the Electromagnetic Calorimeter. This is shown as a function of $\cos\theta$ and ϕ in the 3-D plot of Fig. 14. The slight structure in ϕ is the effect of structural material between segments of the Z chamber. The peaks near $\cos\theta = 0.80$ and 0.96 are due to traversal of the pressure vessel endcap and flanges and supports.

Fig. 15 displays a fine scan of the number of radiation lengths to the end of the sensitive volume of the Electromagnetic Calorimeter as a function of $\cos\theta$ at $\phi = 13^\circ$. The dips and peaks in the region $0 < \cos\theta < 0.82$ are due to particles crossing the boundaries between blocks. Near $\cos\theta \approx 0$ this results in a slight decrease in the number of radiation lengths, but at larger $\cos\theta$ to an increase because the particle is sure to cross two blocks. The bottom curve is the number of radiation lengths before the calorimeter, i.e. the projection of Fig. 14. We calculate that averaging over the solid angle there is a mean of 25.7 radiation lengths of material to the end of the sensitive volume of the electromagnetic calorimeter. There is a mean of 23.4 radiation lengths of sensitive material. 99.9% of the solid angle is covered by an electromagnetic detector and 99.1% of the solid angle has more than 10 radiation lengths of sensitive material.

The Hadron Calorimeter is not as uniform as the Electromagnetic Calorimeter so we have chosen to present its material in 6 different regions. Fig. 16 shows the $\cos\theta$ projection for two different ϕ ranges, $0 < \phi < 74^\circ$ and $74^\circ < \phi < 90^\circ$. The latter (18% of the solid angle) includes the large gaps (4% of the solid angle) for the cables of the central detector, magnet etc. Fig. 17 shows the ϕ projection in 4 $\cos\theta$ ranges. The ordinate is in units of absorption length and the material is divided into 5 zones :

- a) before the sensitive volume of the Electromagnetic Calorimeter,
- b) in the sensitive volume of the Electromagnetic Calorimeter,
- c) between the sensitive volumes of the Electromagnetic and Hadron Calorimeters,
- d) in the sensitive volume of the Hadron Calorimeter and
- e) between the sensitive volume of the Hadron Calorimeter and the Muon Detector.

We calculate that 95.0% of the solid angle is covered by a sensitive volume of the Hadron Calorimeter and that 87.3% of the solid angle has more than 3.2 absorption lengths instrumented. The mean number of absorption lengths in the above 5 zones are 0.58, 1.37, 0.64, 5.23 and 1.09 respectively.

7. SUMMARY

We have described a method to code in a flexible and simple manner the complex geometrical structure of present day High Energy Physics apparatus. Such a method is not restricted to High Energy Physics and could be used for any ensemble of physical objects. The resulting geometry data structure may be used as an essential component of either a Monte Carlo simulation program or an Analysis program.

REFERENCES

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APPENDIX I

SUBROUTINE GEVERT

Routine to set up geometry of the Vertex Detector

```
DIMENSION PSKN(3),PRPI(3),PSUP(3),PZCH(3),POUT(3)
PEND(3),PZAN(3),PZCA(3),PZDR(3)
DIMENSION NAMHV(4),NBITJU(4),ORIG(4),FACT(4)
DATA PSKN/8.5,8.51,50.0/
DATA PRPI/8.51,20.0,50.0/
DATA PZCH/20.1,23.2,50.0/
DATA POUT/23.2,23.5,50.0/
DATA PEND/8.5,20.1,1.2/
DATA PZAN/20.1,23.2,0.22/
DATA PZAN/20.1,23.2,0.01/
DATA PZDR/20.1,23.2,4.045/
```

```
CALL GSTMED(20,'VERT SKIN$',20,0,3,4.0,0.01,0.01,0.01,0.001,0.005,0.,0)
CALL GSTMED(21,'VERT SUP$',20,0,3,4.0,0.01,0.01,0.01,0.001,0.005,0.,0)
CALL GSTMED(22,'VERT OUTSIDE$',20,0,3,4.0,0.01,0.01,0.01,0.001,0.005,0.,0)
CALL GSTMED(23,'VERT END$',20,0,3,4.0,0.01,0.01,0.01,0.001,0.005,0.,0)
CALL GSTMED(24,'VERT Z ANODE$',20,0,3,4.0,0.01,0.01,0.01,0.001,0.005,0.,0)
CALL GSTMED(25,'VERT Z CATH$',20,0,3,4.0,0.01,0.01,0.01,0.001,0.005,0.,0)
```

```
CALL GSVOLU('CVI+', 'TUBE',20,PSKN,3,IVOL)
CALL GSVOLU('CVT ', 'TUBE',2,PRPI,3,IVOL)
CALL GSVOLU('CVS+', 'TUBE',21,PSUP,3,IVOL)
CALL GSVOLU('CVZ ', 'TUBE',2,PZCH,3,IVOL)
CALL GSVOLU('CVO+', 'TUBE',22,POUT,3,IVOL)
CALL GSVOLU('CVE+', 'TUBE',23,PEND,3,IVOL)
CALL GSVOLU('CVA+', 'TUBE',24,PZAN,3,IVOL)
CALL GSVOLU('CVC+', 'TUBE',25,PZCA,3,IVOL)
CALL GSVOLU('CVZD', 'TUBE',2,PZDR,3,IVOL)
```

```
CALL GSPOS('CVI+',1,'CV ',0.,0.,0.,0,'ONLY')
CALL GSPOS('CVT ',1,'CV ',0.,0.,0.,0,'ONLY')
CALL GSPOS('CVS+',1,'CV ',0.,0.,0.,0,'ONLY')
CALL GSPOS('CVZ ',1,'CV ',0.,0.,0.,0,'ONLY')
CALL GSPOS('CVO+',1,'CV ',0.,0.,0.,0,'ONLY')
CALL GSPOS('CVE+',1,'CV ',0.,0.,51.2,0,'ONLY')
CALL GSPOS('CVE+',2,'CV ',0.,0.,-51.2,0,'ONLY')
```

```
CALL GSDVN('CVTP','CUT ',36,2)
CALL GSDVN('CVZZ','CUZ ',6,3)
```

```
CALL GSPOS('CVA+',1,'CUZZ',0.,0.,0.,0,'ONLY')
CALL GSPOS('CVC+',1,'CUZZ',0.,0.,8.32,0,'ONLY')
CALL GSPOS('CVC+',2,'CUZZ',0.,0.,-8.32,0,'ONLY')
CALL GSPOS('CVZD',1,'CUZZ',0.,0.,4.265,0,'ONLY')
CALL GSPOS('CVZD',2,'CUZZ',0.,0.,-4.265,0,'ONLY')
```

```
CALL GSDVN('CVZP','CVZD',18,2)
```

```
RETURN
END
```

FIGURE CAPTIONS

- Fig. 1 Specification examples for the shapes 'BOX', 'TRD1', 'TRD2', and 'TRAP'.
- Fig. 2 Specification examples for the shapes 'TUBE', 'TUBS', 'CONE', and 'CONS'.
- Fig. 3 Specification examples for the shapes 'SPHE', 'PARA', 'PGON', and 'PCON'.
- Fig. 4 Example divisions for the shapes 'BOX', 'TRD1', 'TRD2', and 'TRAP'.
- Fig. 5 Example divisions for the shapes 'TUBE', 'TUBS', 'CONE', and 'CONS'.
- Fig. 6 Example divisions for the shapes 'PARA', 'PGON', and 'PCON'.
- Fig. 7 A schematic view of the OPAL detector.
- Fig. 8 An overview of the OPAL geometry tree structure.
- Fig. 9 The detailed tree structure of the Vertex chamber geometry.
- Fig. 10 A schematic view of the Lead Glass barrel.
- Fig. 11 The detailed tree structure of the Lead Glass barrel geometry.
- Fig. 12 An x-y slice through the OPAL geometry description at $z = 0$.
- Fig. 13 An x-z slice through the OPAL geometry description at $y = 5$ cm.
- Fig. 14 The number of radiation lengths of material in OPAL between the centre and the start of the Lead Glass calorimeter as a function of the spherical angles ϕ and $\cos\theta$.
- Fig. 15 The number of radiation lengths of material in OPAL between the centre and the end of the lead glass calorimeter as a function of $\cos\theta$ for $\phi = 13^\circ$. The lower curve is the projection of Fig. 14.
- Fig. 16 The number of absorption lengths in OPAL for the two ranges of ϕ [$0 < \phi < 74^\circ$, $74^\circ < \phi < 90^\circ$] as a function of $\cos\theta$ for material
(a) before the lead glass calorimeter,
(b) within the lead glass calorimeter,
(c) between the lead glass calorimeter and the hadron calorimeter,
(d) within the hadron calorimeter,
(e) between the hadron calorimeter and the muon chambers.
- Fig. 17 The number of absorption lengths in OPAL for the four ranges of $\cos\theta$ [$0 < \cos\theta < 0.74$, $0.74 < \cos\theta < 0.82$, $0.82 < \cos\theta < 0.88$, $0.88 < \cos\theta < 0.98$] as a function of ϕ for material
(a) before the lead glass calorimeter,
(b) within the lead glass calorimeter,
(c) between the lead glass calorimeter and the hadron calorimeter,
(d) within the hadron calorimeter,
(e) between the hadron calorimeter and the muon chambers.

FIG. 1

FIG. 2

FIG. 3

SHAPE \ IAXIS	1	2	3
BOX
TRD1
TRD2
TRAP

FIG. 4

SHAPE \ IAXIS	1	2	3
TUBE
TUBS
CONE
CONS

FIG. 5

SHAPE \ IAXIS	1	2	3
SPHE			
PARA
PGON
PCON

FIG. 6

- 1 μ barrel
- 2 hadron calorimeter
- 3 lead glass
- 4 presampler + TOF
- 5 ZED
- 6 forward
- 7 coil
- 8 vertex
- 9 jet
- 10 μ -end cap

FIG. 7

FIG. 8

FIG. 9

FIG. 10

FIG. 11

OPAL

Cross - Section ($z = 0$)

12/02/85

FIG. 12

OPAL

Horizontal Section ($y = 5$)

12/02/85

FIG. 13

No. of Radiation Lengths Before Electromagnetic Calorimeter

FIG. 14

Number of Radiation Lengths in Electromagnetic Calorimeter

A fine scan at $\varphi = 13^\circ$.
Bottom curve is material before calorimeter.

FIG. 15

FIG. 16

Number of Absorption Lengths in OPAL

FIG. 17