GDML USER'S GUIDE

Version 2.9

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1. Introduction

The Geometry Description Markup Language (GDML) is a specialized XML-based language designed as an application-independent persistent format for describing the geometries of detectors (or parts of them) for physics experiments. It serves to implement “geometry trees” which correspond to the hierarchy of volumes a detector geometry can be composed of, and to allow to identify the position of individual solids, as well as to describe the materials they are made of. Being pure XML, GDML can be universally used and in particular, it can be considered as the format for interchanging geometries among different applications.

GDML consists of two elements, an XML definition part containing the set of rules and the list of the legal elements to be used in constructing any GDML document, and the GDML generating and processing code implemented in the client tools. The structure of the GDML document is defined through a set of XML Schema Definition (XSD) files, which we call the GDMLSchema. Any GDML geometry file must be valid with respect to the GDMLSchema. The GDML file itself, can be either written by hand (in case GDML is used as the primary geometry source) or generated automatically (in case GDML is used as an exchange or persistency format) out of the application specific “in-memory” geometry tree using one of the GDML “writers” called by the user application. The GDML reader is responsible for parsing the GDML file and creating the in-memory representation of the geometry tree specific for the user application.

This manual will focus on the Geant4 binding to GDML, which, starting from release 9.2 of the simulation toolkit, it is now integrated in Geant4. The Root binding for GDML is integrated within the Root framework; the user should refer to the general Root manual for any information on importing and/or exporting GDML files to/from the Root geometry model. The description of the GDMLSchema in Section 3, however, is application-independent and therefore is relevant for both Geant4 and Root users.
GDML Schema is distributed with GDML Geant4 binding.

2. Getting started

2.1 *Installation of GDML in Geant4*

Building the GDML module in Geant4 is *optional*; by default, the GDML plug-in is not built along with the rest of the Geant4 libraries. In order to build the Geant4 module for GDML, one needs to have:

- The XercesC parser pre-installed
- The GEANT4_USE_GDML variable set to ON at the CMake configuration stage

With this setting, the GDML module in Geant4 will be built using the standard build procedure applicable for Geant4.

2.2 *Running simple examples*

The Geant4 binding for GDML comes with three examples, which demonstrate the reading and writing out of different geometry configurations from/to GDML files. The examples also show how user can extend GDML and how to export ST-Viewer CAD Geometry. The directories containing these examples can be found in the Geant4 distribution in the $G4INSTALL/examples/extended/persistency/gdml directory. NOTE: in case of using dynamic libraries, one needs to set the LD_LIBRARY_PATH variable to point to all the necessary libraries (CLHEP, Geant4, and XercesC) before running the examples. Please refer to the examples README files for more information.

3. GDMLSchema

3.1 *General structure*

The GDML schema is a set of XSD files which define the structure of the GDML document and its legal elements. The general structure of the GDML file can be seen below (with some parts replaced by '...' for brevity).

```
<?xml version="1.0" encoding="UTF-8"?>
<gdml xsi:noNamespaceSchemaLocation="schema/gdml.xsd">
       <define>
              …
              <position name="TrackerinWorldpos" unit="mm" x="0" y="0" z="100"/>
       </define>
       <materials>
              …
              <element name="Nitrogen" formula="N"  Z="7.">
              <atom value="14.01"/>
              </element>
              <material formula=" " name="Air" >
                     <D value="1.290" unit="mg/cm3"/>
                     <fraction n="0.7" ref="Nitrogen" />
                     <fraction n="0.3" ref="Oxygen" />
              </material>
       </materials>
       <solids>
              …
              <box lunit="mm" name="Tracker" x="50" y="50" z="50"/>
       </solids>
       <structure>
              …
              <volume name="World" >
                     <materialref ref="Air" />
                     <solidref ref="world" />
                     <physvol>
                     <volumeref ref="Tracker" />
                     <positionref ref="TrackerinWorldpos"/>
                     <rotationref ref="TrackerinWorldrot"/>
                     </physvol>
              </volume>
       </structure>
       <setup name="Default" version="1.0" >
              <world ref="World" />
       </setup>
</gdml>
```

One can distinguish there five parts, each holding specific type of data.

The <`define> ... </define>` block contains numerical values of different constants, positions, rotations and scales that will be used later on in the geometry construction.

The `<materials> ...</materials>` block contains definitions of all the materials used in the given geometry. The supported forms are simple materials, which are made from one element as well as mixtures. Mixtures can be composed on the basis of fraction of mass or atom count.

The `<solids> ... </solids>` block is the collection of all solid definitions which are used in the given geometry description. The presently supported solids are described in Section 3.4. Composite solids made using Boolean operation (union, subtraction, intersection) are also supported.

The `<structure> ... </structure>` block contains the actual implementation of the geometry tree together with the assignment of solids and materials. The hierarchy of volumes is defined by specifying the daughter volumes (`physvol`) positioned inside a volume; placed volumes can be provided of a copy-number through the `copynumber` attribute tag. Constructions like assembly volumes, reflections, replicas and divisions are possible. A more detailed discussion of the 'structure' block can be found in Section 3.5.

Finally, the `<setup> ... </setup>` block serves to specify the top volume of the geometry tree. It is possible to define several "setups" within one file, allowing testing different subparts (or different configurations included in the same file) of the geometry tree without changing the GDML file.

3.1.1 Splitting GDML file using ENTITY

Any GDML file can be split into several files, which are combined together during the parsing by using the `ENTITY` statement. The files included in such a way are not standalone GDML files, they simply contain parts of the GDML description and in general are meaningful only when put all together.

In order to use such a mechanism, one has to first declare the given `ENTITY` (just after the <xml ... > tag)

```
<!DOCTYPE gdml [
<!ENTITY materials SYSTEM "materials.xml">
]>
```

where `materials.xml` is the name of the file to be included and `materials` is the `ENTITY` name that we have assigned to it. The entity can be then used anywhere inside the GDML description.

```
<gdml ....>
....
&materials;
....
<gdml>
```

The `&materials` line is then replaced during parsing by the contents of `materials.xml` file.

3.1.2 Multiple GDML files

It is also possible to define the geometry in the form of several standalone GDML files, each one representing a module of the setup we want to describe. Each GDML file would contain only the materials, the solids and the volumes the module is made of. For example, if one wants to describe a detector, instead of creating a single `detector.gdml` file with thousands of volumes and materials, one could create smaller modules called `tracker.gdml`, `calorimeter.gdml`, `beampipe.gdml`, etc, and a small main `detector.gdml` file combining those modules. This approach makes it easier to read and write the geometries and to apply changes. Explanations and details on how GDML modules are defined and put together are given in the Section 3.5.

3.2 *Definitions*

3.2.1 Constants

Constants are defined in the beginning of the GDML file (in the define section). Once defined, they can be used anywhere inside the file. A constant can be defined as in the following example:

```
<constant name="length" value="6.25"/>
```

3.2.2 Quantities

Quantities are constants with units, they are defined in the beginning of the GDML file (in the define section). Once defined, they can be referenced where quantity is expected with the same type. Example:

```
<quantity name="W_Density" type="density" value="1" unit="g/cm3"
/>
```

3.2.3 Variables

Variables are defined in the beginning of the GDML file (in the define section). Once defined, they can be used anywhere inside the file. Their value will be evaluated each time they are used and it can change if they are used as loop variables (see section 3.5.1). A variable can be defined as in the following example:

```
<variable name="x" value="6"/>
```

This simple code defines a variable with an initial value of 6. Of course previously defined variables may be used in variable definitions, as in the following example:

```
<variable name="x" value="6"/>
<variable name="y" value="x/2"/>
```

In this case variable y is set with an initial value of 3. You can now use your variable wherever you like, for example in a box definition:

```
<box name="my_box" x="x" y="y" z="x+y"/>
```

3.2.4 Positions

Positions are usually defined in the beginning of the GDML file (in the define section). Once defined, they can be referenced in place where positions are expected. A position can be defined as in the following examples:

```
<position name="box_position" x="25.0" y="50.0" z="75.0"
unit="cm"/>
```

```
<constant name="size" value="25.0"/>
<position    name="position"    x="2.0*size"    y="size"    z="75.0"
unit="m"/>
```

3.2.5 Rotations

Rotations are usually defined in the beginning of the GDML file (in the define section). Once defined, they can be referenced in place where rotations are expected. Positive rotations are expected to be right-handed. A rotation can be defined as in the following example:

```
<rotation name="RotateZ" z=="30" unit="deg"/>
```

3.2.6 Scales

Scales are usually defined in the beginning of the GDML file (in the define section). Once defined, they can be referenced in place where scales are expected. Scale can be used to implement reflection and has no units. A scale can be defined as in the following example:

```
<scale name="my_reflection" x="-1" y="-1" z="1"/>
```

3.2.7 Matrices

A matrix definition allows you to store values in matrix format. The definition of a matrix is very simple: `<matrix name="name" coldim="number of columns" values="space-separated values" />`. A simple example follows:

```
<matrix name="m" coldim="3" values="0.4 9 126 8.5 7 21 34.6 7 9"
/>
```

Or you could also write it like this (visually clearer):

```
<matrix name="m" coldim="3" values=" 0.4  9  126
                                     8.5  7   21
                                    34.6  7    9" />
```

The elements of a matrix can be accessed anywhere after the definition of the matrix itself, just variables. To access them you have to use the following syntax:

```
matrix_name[row_number, column_number]
```

For example:

```
m[3,1]
```

will be evaluated to 34.6. You can also put variables inside the square brackets, like this:

```
m[y,y]
```

So if y=3 this will be evaluated to 9. Just be sure that the values of the variables don't exceed the matrix dimensions, otherwise you will get an error when processing the file. A matrix with coldim="1" is a vector and its elements may be accessed using only one index as in the following example:

```
<matrix name="m" coldim="1" values="4 9 12 6 7 9" />
```

So,

```
m[4]
```

will be evaluated to 6. Matrices can of course be used inside loops (there is where they are actually most useful). We will see how to do this in section 3.5.1.

3.3 *Materials*

3.3.1 Isotopes

Isotopes can be defined using the construct

`<isotope name=its_name Z=atomic_number N=num_of_nucleons>.`

The following shows an example:

```
<isotope name="U235" Z="92" N="235">
        <atom type="A" value="235.01">
</isotope>
<isotope name="U238" Z="92" N="238">
        <atom type="A" value="235.03">
</isotope>
```

3.3.2 Elements

Elements can be defined using fractions of isotopes as follows:

```
<element name="enriched_uranium" >
   <fraction ref="U235" n="0.9" />
   <fraction ref="U238" n="0.1" />
 </element>
```

3.3.3 Materials

Materials can be defined in three ways. The material can be defined directly from an element, created from previously defined elements or materials on number of atoms, and finally created as a fractional mixture of previously defined elements or materials. Optionally, you can specify the pressure (P) and the temperature (T). If you intend to utilise your GDML file with Geant4 only, you can also use directly the predefined Geant4 NIST database materials (see Section 3.5).

```
<material name="Al" Z="13.0" >
   <D value="2.70" />
   <atom value="26.98" />
  </material>
```

```
<material name="Water" formula="H2O">
   <D value="1.0" />
   <composite n="2" ref="Hydrogen" />
   <composite n="1" ref="Oxygen" />
  </material>
```

```
<material formula="air" name="Air" >
   <D value="0.0012899999999999999" />
   <fraction n="0.7" ref="Nitrogen" />
   <fraction n="0.3" ref="Oxygen" />
  </material>
```

3.4 *Solids*

3.4.1 Box

The GDML box is formed using the three standard dimensions: `x`, `y` and `z`. The box therefore has 4 attributes, the other being name which is standard for any `SolidType` element and corresponds to the name the solid can be referenced by.

The following example illustrates the construction of a box made from the above dimensions:

```
<box name = "thebox" x= "30" y= "30" z= "30" lunit= "mm" />
```

3.4.2 Cone Segment

The GDML Cone Segment is formed using 7 dimensions.

rmin1	inner radius at base of cone
rmax1	outer radius at base of cone
rmin2	inner radius at top of cone
rmax2	outer radius at top of cone
z	height of cone segment
startphi	start angle of the segment
deltaphi	angle of the segment

The cone segment therefore has 8 attributes, the other being name which is standard for any `SolidType` element and corresponds to the name the solid can be referenced by.

The following example illustrates the construction of a cone segment made from the above dimensions:

```
<cone name = "thecone" rmin1="10" rmax1="15" rmin2="15" rmax2="25" z="30"
startphi="1" deltaphi="4" aunit="rad" lunit= "mm" />
```

3.4.3 Ellipsoid

The GDML Ellipsoid is formed using 3 dimensions.

ax	x semi axis
by	y semi axis
cz	z semi axis

There are 2 optional dimensions that can cut the ellipsoid. *zcut1* will remove the specified value from the lower z axis effectively cutting a part of the bottom of the shape off. *zcut2* performs the same action but acts on the upper part of the z axis.

The ellipsoid therefore has 4 attributes, the other being name which is standard for any SolidType element and corresponds to the name the solid can be referenced by.

The following example illustrates the construction of a ellipsoid made from the above dimensions:

```
<ellipsoid name = "theellipsoid" ax="10" by="15" cz="20" zcut2="4" lunit= "mm"/>
```

3.4.4 Elliptical Tube

The GDML Elliptical Tube is formed using 3 dimensions:

dx x semi axis
dy y semi axis
dz z semi axis

The elliptical tube therefore has 4 attributes, the other being name which is standard for any `SolidType` element and corresponds to the name the solid can be referenced by.

The following example illustrates the construction of an elliptical tube made from the above dimensions:

```
<eltube name = "theeltube" dx="10" dy="15" dz="20"  lunit= "mm" />
```

3.4.5 Elliptical Cone

NB: supported only by Geant4

The GDML Elliptical Cone is formed using 3 dimensions and one possible upper cut in Z:

dx ratio of the X semi axis of the elliptical section at Z=0 to *zmax*
dy ratio of the Y semi axis of the elliptical section at Z=0 to *zmax*
zmax Z coordinate of the apex
zcut upper cut in Z

The elliptical cone therefore has 5 attributes, the other being name which is standard for any `SolidType` element and corresponds to the name the solid can be referenced by.

The following example illustrates the construction of an elliptical cone made from the above dimensions:

```
<elcone name = "theelcone" dx="1" dy="1.5" zmax="2" zcut="1.5"  lunit= "mm" />
```

3.4.6 Orb

The GDML Orb is formed using only 1 dimension:

r radius

The orb is a simplified GDML Sphere with only the radius specified. The orb therefore has 2 attributes, the other being name which is standard for any `SolidType` element and corresponds to the name the solid can be referenced by.

The following example illustrates the construction of an orb made from the above dimensions:

```
<orb name = "theorb" r="10"  lunit= "mm"/>
```

3.4.7 Paraboloid

The GDML Paraboloid is formed using 3 dimensions:

rlo radius at -z
rhi radius at +z
dz z length

The paraboloid therefore has 4 attributes, the other being name which is standard for any `SolidType` element and corresponds to the name the solid can be referenced by.

The following example illustrates the construction of a paraboloid made from the above dimensions:

```
<paraboloid name = "theparab" rlo="10" rhi="15" dz="20" aunit="rad"  lunit= "mm" />
```

3.4.8 Parallelepiped

The GDML Parallelepiped is formed using 6 dimensions:

x length of x
y length of y
z length of z
alpha angle between x and z planes
theta polar angle of the line joining the centres of the faces at –z & +z in z
phi azimuthal angle of the line joining the centres of faces at –z & +z in z

The Parallelepiped therefore has 7 attributes, the other being name which is standard for any `SolidType` element and corresponds to the name the solid can be referenced by.

The following example illustrates the construction of a parallelepiped made from the above dimensions:

```
<para name = "thepara" x="10" y="10" z="10" alpha="1" theta="1" phi="1" aunit="rad"
lunit= "mm"/>
```

3.4.9 Polycone

The GDML Polycone can be described in two ways :
as **Polycone** using *zplanes* with *rmin* and *rmax and*
as **Generic Polycone** using vertices with (r,z) coordinates.

The GDML Polycone is described using the following information:

startphi start angle of the segment – if not given 0.0 is defaulted

deltaphi angle of the segment
zplane *see below*

The `zplane` element is required to be used at least once. You can use it as many times as you like. The `zplane` is formed using the 3 attributes shown above:

rmin inner radius of cone at this point – if not given 0.0 is defaulted.
rmax outer radius of cone at this point
z z coordinate of the plane

The Polycone therefore has a minimum of 7 attributes, the other being name which is standard for any `SolidType` element and corresponds to the name the solid can be referenced by.

The following example illustrates the construction of a polycone made from the above dimensions:

```
<polycone name = "thepolycone" startphi="1" deltaphi="4" aunit="rad"  lunit= "mm">
      <zplane rmin="1" rmax="9" z="10" />
      <zplane rmin="3" rmax="5" z="12" />
</polycone>
```

3.4.10 Generic Polycone

The GDML Generic Polycone is described using the following information:

startphi start angle of the segment – if not given 0.0 is defaulted
deltaphi angle of the segment
rzpoint *see below*

The `rzpoint` element is required to be used at least three times. You can use it as many times as you like. The `rzpoint` is formed using the 2 attributes shown above:

r r- coordinate of this point
z z-coordinate of this point

The Generic Polycone therefore has a minimum of 7 attributes, the other being name which is standard for any `SolidType` element and corresponds to the name the solid can be referenced by.

The following example illustrates the construction of a generic polycone made from the above dimensions:

```
<genericPolycone name = "thepolycone" startphi="1" deltaphi="4" aunit="rad"
 lunit= "mm">
      <rzpoint r="1" z="5" />
      <rzpoint r="3" z="10" />
      <rzpoint r="1" z="12" />
</genericPolycone>
```

3.4.11 Polyhedron

The GDML Polychedron (Polyhedra) can be described in two ways :
as **Polyhedra** using *zplanes* with *rmin* and *rmax and*
as **Generic Polyhedra** using vertices with (r,z) coordinates.

The GDML Polyhedron (Polyhedra) is described using the following information:

startphi	start angle of the segment
deltaphi	angle of the segment
numsides	number of sides
zplane	*see below*

The `zplane` element is required to be used at least once. You can use it as many times as you like. The `zplane` is formed using the 3 attributes shown above:

rmin	inner radius of cone at this point – if not given 0.0 is defaulted.
rmax	outer radius of cone at this point
z	z coordinate of the plane

The Polyhedra therefore has a minimum of 6 attributes, the other being name which is standard for any `SolidType` element and corresponds to the name the solid can be referenced by.

The following example illustrates the construction of a polyhedra made from the above dimensions:

```
<polyhedra name= "thepolyhedra" startphi="1" deltaphi="4" numsides="10" aunit="rad"
 lunit= "mm">
      <zplane rmin="1" rmax="9" z="10" />
      <zplane rmin="3" rmax="5" z="12" />
</polyhedra>
```

3.4.12 Generic Polyhedron

The GDML Generic Polyhedra is described using the following information:

startphi	start angle of the segment
deltaphi	angle of the segment
numsides	number of sides
rzpoint	*see below*

The `rzpoint` element is required to be used at least three times. You can use it as many times as you like. The `rzpoint` is formed using the 2 attributes shown above:

r	r- coordinate of this point
z	z-coordinate of this point

The Generic Polyhedra therefore has a minimum of 6 attributes, the other being name which is standard for any `SolidType` element and corresponds to the name the solid can be referenced by.

The following example illustrates the construction of a polyhedra made from the above dimensions:

```
<genericPolyhedra name= "thepolyhedra" startphi="1" deltaphi="4" numsides="10"
 aunit="rad"  lunit= "mm">
      <rzpoint r="1" z="10" />
      <rzpoint r="3" z="12" />
      <rzpoint r="1" z="12" />
</genericPolyhedra>
```

3.4.13 Sphere

The GDML Sphere is formed using 6 dimensions:

rmin	inner radius – if not given 0.0 is defaulted
rmax	outer radius
startphi	starting angle of the segment – if not given 0.0 is defaulted
deltaphi	delta angle of the segment
starttheta	starting angle of the segment – if not given 0.0 is defaulted
deltatheta	delta angle of the segment

The Sphere therefore has a minimum of 7 attributes, the other being name which is standard for any `SolidType` element and corresponds to the name the solid can be referenced by.

The following example illustrates the construction of a sphere made from the above dimensions:

```
<sphere name = "thesphere" rmin="1" rmax="4" deltaphi="1" deltatheta="1" aunit="rad"
lunit= "mm"/>
```

3.4.14 Torus Segment

The GDML Torus Segment is formed using 5 dimensions:

rmin	inside radius of segment
rmax	outside radius of segment
rtor	swept radius of torus
startphi	starting phi position angle of segment
deltaphi	delta angle of segment

The Torus segment therefore has a minimum of 6 attributes, the other being name which is standard for any `SolidType` element and corresponds to the name the solid can be referenced by.

The following example illustrates the construction of a torus segment made from the above dimensions:

```
<torus name = "thetorus" rmin="1" rmax="4"  rtor="2" deltaphi="3" startphi="1" aunit="rad"
lunit= "mm"/>
```

3.4.15 Trapezoid – x & y varying along z

The GDML Trapezoid is formed using 5 dimensions:

x1	x length at -z
x2	x length at +z
y1	y length at -z
y2	y length at +z
z	z length

The Trapezoid therefore has a minimum of 6 attributes, the other being name which is standard for any `SolidType` element and corresponds to the name the solid can be referenced by.

The following example illustrates the construction of a Trapezoid made from the above dimensions:

```
<trd name = "thetrd" x1="9" x2="8"  y1="6" y2="5" z="10"  lunit= "mm"/>
```

3.4.16 General Trapezoid

The GDML General Trapezoid is formed using 11 dimensions:

z	length along z axis
theta	polar angle to faces joining at -/+z
phi	azimuthal angle of line joining centre of –z face to centre of +z face
y1	length along y at the face -z
x1	length along x at side y = -y1 of the face at -z
x2	length along x at side y = +y1 of the face at -z
alpha1	angle with respect to the y axis from the centre of side at y = -y1 to centre of y = +y1 of the face at -z
y2	length along y at the face +z
x3	length along x at side y = -y1 of the face at +z
x4	length along x at side y = +y1 of the face at +z
alpha2	angle with respect to the y axis from the centre of side at y = -y2 to centre of y = +y2 of the face at +z

The General Trapezoid therefore has a minimum of 12 attributes, the other being name which is standard for any `SolidType` element and corresponds to the name the solid can be referenced by.

The following example illustrates the construction of a General Trapezoid made from the above dimensions:

```
<trap name = "thetrap" z="10" theta="1"  phi="2" y1="15" x1="10"  x2="10" alpha1="1"
y2="15" x3="10" x4="10"  alpha2="1" aunit="rad"  lunit= "mm"/>
```

3.4.17 Tube with Hyperbolic Profile

The GDML Tube with Hyperbolic Profile is formed using 5 dimensions:

rmin	inside radius of tube
rmax	outside radius of tube
inst	inner stereo
outst	outer stereo
z	z length

The Hyperbolic Tube therefore has a minimum of 6 attributes, the other being name which is standard for any `SolidType` element and corresponds to the name the solid can be referenced by.

The following example illustrates the construction of a hyperbolic tube made from the above dimensions:

```
<hype name = "thehype" rmin="1" rmax="2"  z="20" inst="3" outst="4"  lunit= "mm"/>
```

3.4.18 Cut Tube

The GDML Cut Tube is formed using 11 dimensions:

z	length along z axis
rmin	inner radius – if not given 0.0 is defaulted
rmax	outer radius
startphi	starting phi angle of segment – if not given 0.0 is defaulted
deltaphi	delta phi of angle
lowX	normal at lower z plane
lowY	normal at lower z plane
lowZ	normal at lower z plane
highX	normal at upper z plane
highY	normal at upper z plane
highZ	normal at upper z plane

The cut Tube therefore has a minimum of 12 attributes, the other being name which is standard for any `SolidType` element and corresponds to the name the solid can be referenced by.

The following example illustrates the construction of a cut Tube made from the above dimensions:

```
<cutTube name = "thecuttube" z="20" rmin="1"  rmax="5" startphi="1" deltaphi="4"  lowX="15"
lowY="15"  lowZ="15" highX="10" highY="10"  highZ="10"  aunit="rad"  lunit= "mm"/>
```

3.4.19 Tube Segment

The GDML Tube Segment is formed using 5 dimensions:

rmin	inside radius of segment - if not given 0.0 is defaulted
rmax	outside radius of segment
z	z length of tube segment
startphi	starting phi position angle of segment - if not given 0.0 is defaulted
deltaphi	delta angle of segment

The Tube segment therefore has a minimum of 6 attributes, the other being name which is standard for any `SolidType` element and corresponds to the name the solid can be referenced by.

The following example illustrates the construction of a tube segment made from the above dimensions:

```
<tube name = "thetube" rmin="1" rmax="4" z="20" deltaphi="3" startphi="1"
aunit="rad" lunit= "mm"/>
```

3.4.20 Twisted Box

NB: supported only by Geant4

The GDML Twisted box is formed using the three standard dimensions: *x*, *y and z* and one added dimension: *PhiTwist.* The box therefore has 5 attributes, the other being name which is standard for any `SolidType` element and corresponds to the name the solid can be referenced by.

The following example illustrates the construction of a box made from the above dimensions:

```
<twistedbox name = "twistbox"  PhiTwist= "1" x= "30" y= "30" z= "30" aunit="rad"
lunit= "mm"/>
```

3.4.21 Twisted Trapezoid

NB: supported only by Geant4

The GDML Twisted Trapezoid is formed using 6 dimensions:

PhiTwist	Twist Angle
x1	x length at -z
x2	x length at +z
y1	y length at -z
y2	y length at +z
z	z length

The Twisted Trapezoid therefore has a minimum of 7 attributes, the other being name which is standard for any `SolidType` element and corresponds to the name the solid can be referenced by.

The following example illustrates the construction of a Twisted Trapezoid made from the above dimensions:

```
<twistedtrd name = "twisttrd"  PhiTwist="1" x1="9" x2="8"  y1="6" y2="5" z="10"  aunit="rad"
lunit= "mm"/>
```

3.4.22 Twisted General Trapezoid

NB: supported only by Geant4

The GDML Twisted General Trapezoid is formed using 11 dimensions:

PhiTwist	twist angle
z	length along z axis
Theta	polar angle to faces joining at -/+z
Phi	azimuthal angle of line joining centre of –z face to centre of +z face
y1	length along y at the face -z
x1	length along x at side y = -y1 of the face at -z

x2	length along x at side y = +y1 of the face at -z
y2	length along y at the face +z
x3	length along x at side y = -y1 of the face at +z
x4	length along x at side y = +y1 of the face at +z
Alph	angle with respect to the y-axis from the centre of the side

The Twisted General Trapezoid therefore has a minimum of 12 attributes, the other being name which is standard for any `SolidType` element and corresponds to the name the solid can be referenced by.

The following example illustrates the construction of a General Twisted Trapezoid made from the above dimensions:

```
<twistedtrap name = "twisttrap"  PhiTwist="1" z="10" Theta="1"  Phi="2" y1="15"
x1="10"  x2="10" y2="15" x3="10" x4="10"  Alph="1" aunit="rad"  lunit= "mm"/>
```

3.4.23 Twisted Tube Segment

NB: supported only by Geant4

The GDML Twisted Tube Segment is formed using at least 4 dimensions, depending on the kind of construction chosen:

endinnerrad	inside radius at end of segment (constructors 1,2)
endouterrad	outside radius at end of segment (constructors 1,2)
zlen	z length of tube segment (constructors 1,2)
twistedangle	twist angle (constructors 1,2,3,4)
phi	phi angle of segment (constructors 1,3)
midinnerrad	inner radius at z=0 (constructors 3,4)
midouterrad	outer radius at z=0 (constructors 3,4)
nseg	number of segments in totalPhi (constructors 2,4)
totphi	total angle of all segments (constructors 2,4)

The Twisted Tube segment therefore has a minimum of 4 attributes, the other being name which is standard for any `SolidType` element and corresponds to the name the solid can be referenced by.

The following example illustrates the construction of a twisted tube segment made from the above dimensions:

```
<twistedtubs name = "twisttube" endinnerrad="1" endouterrad="4"  zlen="20" phi="3"
twistedangle="1" aunit="rad"  lunit= "mm"/>
```

3.4.24 Extruded Solid

The GDML Extruded Solid (Xtru) is formed using 2 attributes:

twoDimVertex	vertices of an unbound blueprint polygon
section	z sections

The *twoDimVertex* element is required to be used at least 3 times and the *section* element is required to be used at least twice. You can use both as many times as you like. The *twoDimVertex* is formed using the 2 attributes shown below:

x	x coordinate of the vertex
y	y coordinate of the vertex

The *section* is formed using the 5 attributes shown below:

zOrder	index of the section, must be between 0 and n-1 where n is the number of sections
zPosition	distance from the plane z=0
xOffset	x offset from centre point of original plane
yOffset	y offset from centre point of original plane
scalingFactor	proportion to original blueprint

The Xtru therefore has a minimum of 17 attributes, the other being name which is standard for any `SolidType` element and corresponds to the name the solid can be referenced by.

The following example illustrates the construction of an Xtru made from the above dimensions:

```
<xtru name = "theXtru"  lunit= "mm" >
      <twoDimVertex x="3" y="9" />
      <twoDimVertex x="1" y="5" />
      <twoDimVertex x="2" y="4" />
      <section zOrder="1" zPosition="2" xOffset="5" yOffset="3" scalingFactor="3" />
      <section zOrder="2" zPosition="5" xOffset="3" yOffset="5" scalingFactor="1" />
</xtru>
```

3.4.25 Arbitrary Trapezoid (Arb8)

The GDML Arb8 (arbitrary trapezoid with less than 8 vertices) is formed using 17 dimensions. It's made up of two quadrilaterals sitting on parallel planes. V1 to V4 define the vertices for the quadrilateral base situated at -dz, V5 to V8 define the vertices for the other quadrilateral situated at -dx.

v1x	vertex 1 x position
v1y	vertex 1 y position
v2x	vertex 2 x position
v2y	vertex 2 y position
v3x	vertex 3 x position
v3y	vertex 3 y position
v4x	vertex 4 x position
v4y	vertex 4 y position
---	---
v5x	vertex 5 x position
v5y	vertex 5 y position
v6x	vertex 6 x position
v6y	vertex 6 y position
v7x	vertex 7 x position
v7y	vertex 7 y position
v8x	vertex 8 x position
v8y	vertex 8 y position

dz	half z length

The Arb8 therefore has a minimum of 18 attributes, the other being name which is standard for any `SolidType` element and corresponds to the name the solid can be referenced by.

The following example illustrates the construction of an Arb8 made from the above dimensions:

```
<arb8 name = "thearb8"  v1x="1" v1y="1" v2x="2"  v2y="2" v3x="3" v3y="3"  v4x="4"
v4y="4" v5x="10" v5y="10"  v6x="11" v6y="11"  v7x="12" v7y="12"  v8x="13" v8y="13"
dz="20"  lunit= "mm"/>
```

3.4.26 Tessellated solid

NB: supported only by Geant4

The GDML tessellated solid can be made of any number of triangular and/or quadrangular facets forming a closed space. Each facet is defined by specifying references to (names of) three (for the triangular one) or four (for the quadrangular one) vertices. The vertices are standard `position` elements and should be declared beforehand within the define section. If a referenced vertex is not defined, an error message is displayed. By looking from the outside of the tessellated solid, vertices are listed in the anti-clockwise order for each of the facets. There are two ways of defining vertices: `ABSOLUTE` (default), and `RELATIVE`. In the first case each vertex coordinates are considered to be absolute coordinates in the reference system of the solid. In the second case, only the first listed vertex has absolute coordinates, while the remaining ones are considered to be translations from the first one.
The tessellated solid has only one attribute `name`, which is standard for any `SolidType` element and corresponds to the name the solid can be referenced by. The sub-elements of tessellated solid element are all of `FacetType`, in other words they are the triangular and/or quadrangular facets the solid is made of.
The `triangular (quadrangular)` facet element contains three (four) attributes `vertex1, vertex2, vertex3, (vertex4)`, being references to the vertices (defined beforehand) of the facet and an optional attribute `type` indicated whether the coordinates of the vertices are `ABSOLUTE` (default) or `RELATIVE`.

The following example illustrates the construction of a simple tessellated solid made from a square base and six triangular walls. We first define the vertices

```
<define>
  <position name="v1" x="10" y="10" z="0" unit="m"/>
  <position name="v2" x="-10" y="10" z="0" unit="m"/>
  <position name="v3" x="-10" y="-10" z="0" unit="m"/>
  <position name="v4" x="10" y="-10" z="0" unit="m"/>
  <position name="v5" x="7" y="3" z="20" unit="m"/>
  <position name="v6" x="-3" y="7" z="5" unit="m"/>
</define>
```

and then we build the tessellated solid out of them

```
<tessellated name="pyramid">
     <triangular vertex1="v1" vertex2="v2" vertex3="v6" type="ABSOLUTE"/>
     <triangular vertex1="v2" vertex2="v3" vertex3="v6" type="ABSOLUTE"/>
     <triangular vertex1="v3" vertex2="v4" vertex3="v5" type="ABSOLUTE"/>
     <triangular vertex1="v4" vertex2="v1" vertex3="v5" type="ABSOLUTE"/>
     <triangular vertex1="v1" vertex2="v6" vertex3="v5" type="ABSOLUTE"/>
```

```
    <triangular vertex1="v6" vertex2="v3" vertex3="v5" type="ABSOLUTE"/>
    <quadrangular vertex1="v4" vertex2="v3" vertex3="v2" vertex4="v1" type="ABSOLUTE"/>
</tessellated>
```

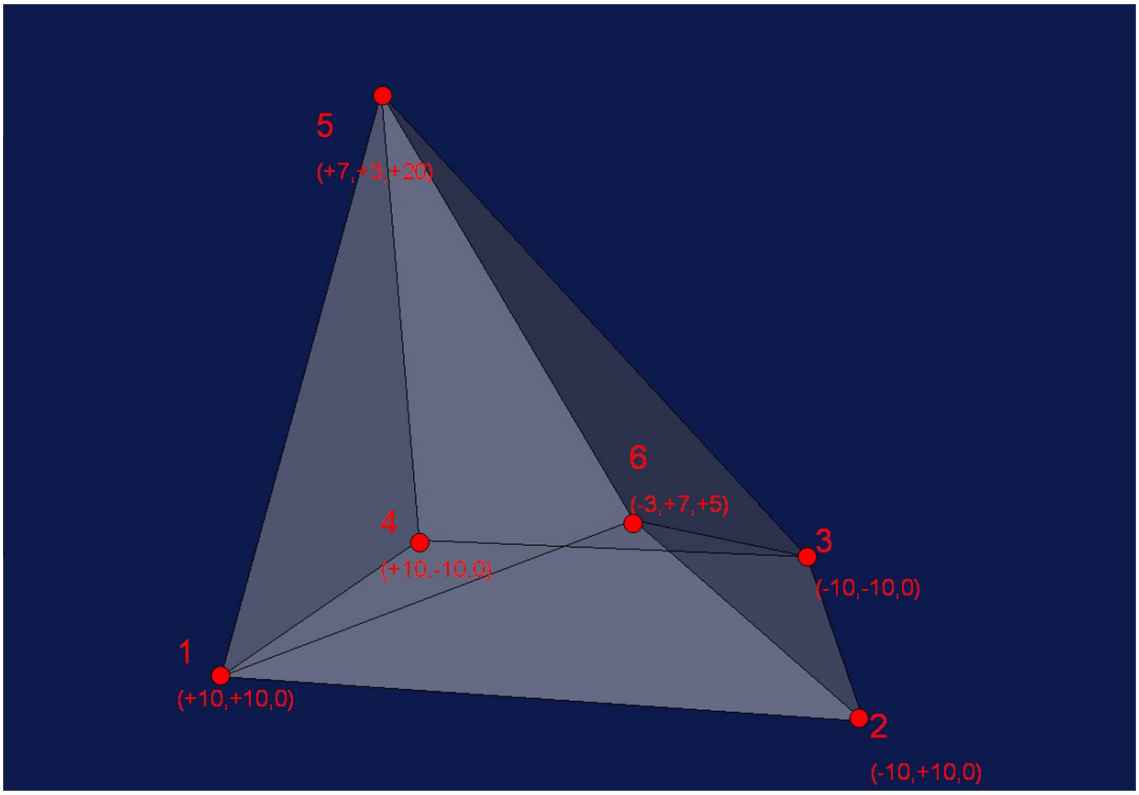


Figure: graphical representation of the tessellated solid as described in the example.

3.4.27 Tetrahedron

NB: supported only by Geant4

The tetrahedron solid in GDML is defined by specifying the coordinates of the four vertices. In order for the solid not to be degenerated, the four points must not lie on the same surface.
The `tet` solid element contains the standard name attribute and four attributes being references to the vertices namely `vertex1, vertex2, vertex3 and vertex4`. These vertices are standard position elements which must be defined beforehand within the `define` part.
The following example illustrates the construction of the tetrahedron.

```
<define>
 <position name="v1" x="10" y="10" z="0"/>
 <position name="v2" x="-10" y="10" z="0"/>
 <position name="v3" x="-10" y="-10" z="0"/>
 <position name="v4" x="0" y="0" z="10"/>
</define>
```

```
<tet name="halfpyramid" vertex1="v1" vertex2="v2" vertex3="v3" vertex4="v4"/>
```

3.4.28 Using loops for solids

Suppose you want to define a set of solids with the same shape but with dimensions varying according to a particular function. In this case loops are very useful, because the avoid repetition of solids definitions. For a more detailed discussion on loops please refer to Section 3.5.1. The following example shows you how to use a loop to define a set (10) of boxes with different dimensions. Without a loop you would write the following code:

```
<box name="box0" x="1"  y="5"   z="20" />
<box name="box1" x="4"  y="4.5" z="18" />
<box name="box2" x="7"  y="4"   z="16" />
<box name="box3" x="10" y="3.5" z="14" />
<box name="box4" x="13" y="3"   z="12" />
<box name="box5" x="16" y="2.5" z="10" />
<box name="box6" x="19" y="2"   z="8" />
<box name="box7" x="22" y="1.5" z="6" />
<box name="box8" x="25" y="1"   z="4" />
<box name="box9" x="28" y="0.5" z="2" />
```

Using a loop you would only need four lines

```
<variable name="x" value="0"/>
```

declared in the "define" section and

```
<loop for="x" to="9" step="1">
 <box name="box" x="1+(x*3)" y="5-(x/2)" z="20-(2*x)" />
</loop>
```

3.4.29 Boolean Solids

The GDML Boolean Solids can be described using following Boolean operations: union, subtraction and intersection. As for Geant4 Boolean operations, the second solid is placed with given position and rotation in the system coordinates of the first solid. The following example illustrates the construction of Boolean solid using union operation:

```
<box name="box_first"  x="1"  y="5"   z="20" />
<box name="box_second" x="4"  y="4.5" z="18" />

<union name= ="union" >
<first  ref="box_first" />
<second ref="box_second"/>
<positionref ref="union_position" />
<rotationref ref="union_rotation" />
</union>
```

Another way to describe Union Solid is by using the MultiUnion construct, which offers possibility to make union of many solids. The following example illustrates the construction of a MultiUnion structure:

```
<box name="box_first"  x="1"  y="5"   z="20" />
<box name="box_second" x="4"  y="4.5" z="18" />
```

```
<multiUnion name= =“multiUnion” >
  <multiUnionNode name-“node-1”>
    <solid ref=“box_first” />
  </multiUnionNode>
  <multiUnionNode name=”node-2”>
    <solid ref=“box_second” />
    <positionref ref=“union_position” />
    <rotationref ref=“union_rotation” />
  </multiUnionNode>
</multiUnion>
```

3.4.30 Scaled Solids

Any solid can be scaled along Cartesian axes by specifying a scale transformation where positive values for X, Y or Z should be specified, together with the shape, or reference to a shape to be scaled:

```
<tube name=“my_tube” z=“100.0” rmax=“10.0” deltaphi=“360”/>

<scaledSolid name=“ScaledTube” >
  <solidref ref=“my_tube” />
  <scale name=“tube_scale” x=“1” y=“2” z=“1”/>
</scaledSolid>
```

3.5 Structure

The structure section is where volumes in the geometry are defined. Volumes are referenced to solids and materials defined earlier to form the shape and composition of that volume. This volume is then a logical volume. Volumes can be placed within this logical volume; these volumes are called physical volumes. The physical volumes are required to have the reference to the logical volume which they are a placement of. They can be positioned and rotated how you wish within the logical volume. This can be done using explicit position and rotation defined within the physical volume block or using reference to position and rotation defined in the <defined> section. An example of the GDML code for this is below:

```
<volume name="World">
   <materialref ref="Air"/>
   <solidref ref="WorldBox"/>

   <physvol>
     <volumeref ref="vol0"/>
     <positionref ref="center"/>
     <rotationref ref="identity"/>
   </physvol>
</volume>
```

If you intend to utilize your GDML file with Geant4 only, you can also use the predefined Geant4 NIST database materials to construct your physical volumes. In that case, the name of the referenced material has to correspond to the name in the Geant4 NIST database, like for instance “G4_Al” or “G4_WATER” (see Geant4 manual). That material should not be then defined in the <materials> section, it will be directly taken from the Geant4 NIST database during the initialization of the geometry in memory.

In addition to the standard logical volumes, one can also define assemblies, which are made of several physical volumes and do not include a ‘mother volume’ being an envelop for its physical volumes. An example of an assembly volume can be seen below:

```
<assembly name="AssemblyVol">
  <physvol>
    <volumeref ref="TubeVol"/>
    <position name="pos1" unit="m" x="0" y="0" z="0.5"/>
    <rotationref ref="alignSurfX"/>
  </physvol>
  <physvol>
    <volumeref ref="TubeVol"/>
    <position name="pos2" unit="m" x="0" y="0" z="-0.5"/>
    <rotationref ref="alignSurfY"/>
  </physvol>
</assembly>
```

3.5.1 Loops

Loops can be used to avoid tedious repetitions of definitions. To use a loop you need to define a variable first (section 3.2.1). Suppose you defined a variable x with `0` initial value:

```
<variable name="x" value="0"/>
```

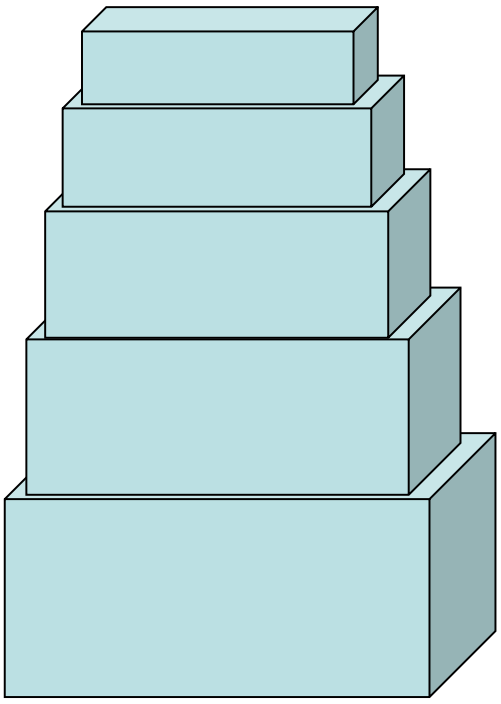
then, you can use it inside a loop statement:

```
<loop for="x" to="8" step="2">
…
</loop>
```

The code within the loop tags will we executed 5 times in this case, because the variable x starting from the initial value of `0` (as in its definition) will be increased by 2 (according to the step value) for each loop until it reaches the value of 8 (as stated in the `to` attribute).
Loops are very useful to access elements of matrices (see section 3.2.2); for example:

```
<variable name="i" value="1"/>
<matrix name="m" coldim="3" values=" 0.4  9  126
                                    8.5  7   21
                                   34.6  7    9" />
<loop for="i" to="3" step="1">
 … m[1,i] …
</loop>
```

We are able to access the three elements of the first row of the matrix, i.e. `0.4, 9` and `126`. Loops can be used when defining solids, logical volumes and physical volumes; let's see how this is done in practice. Suppose we want to create the following structure:



We need to write the code for 5 boxes, 5 logical volumes that refer to the boxes and 5 physical volumes that refer to the 5 logical volumes! The code would be the following:

```
<solids>
 <box name="box1" x="10" y="5" z="5" />
 <box name="box2" x="9" y="4.5" z="4" />
 <box name="box3" x="8" y="4" z="3.2" />
 <box name="box4" x="7" y="3.5" z="2.56" />
 <box name="box5" x="6" y="3" z="2.048" />
</solids>
<structure>
 <volume name="volbox1">
  <solidref ref="box1" />
  <materialref ref="iron" />
 </volume>
 <volume name="volbox2">
  <solidref ref="box2" />
  <materialref ref="iron" />
 </volume>
 <volume name="volbox3">
  <solidref ref="box3" />
  <materialref ref="iron" />
 </volume>
 <volume name="volbox4">
  <solidref ref="box4" />
  <materialref ref="iron" />
 </volume>
 <volume name="volbox5">
  <solidref ref="box5" />
  <materialref ref="iron" />
 </volume>
 <volume name="world">
  ...
  <physvol>
   <volumeref ref="volbox1" />
   <position x="5" y="0" z="0" />
  </physvol>
  <physvol>
   <volumeref ref="volbox2" />
   <position x="5" y="4.25" z="0" />
  </physvol>
  <physvol>
   <volumeref ref="volbox3" />
   <position x="5" y="8.0" z="0" />
  </physvol>
  <physvol>
   <volumeref ref="volbox4" />
   <position x="5" y="11.25" z="0" />
  </physvol>
  <physvol>
   <volumeref ref="volbox5" />
   <position x="5" y="14" z="0" />
  </physvol>
 </volume>
</structure>
```

Of course this is always possible; but using the `loop` tags (and combining them properly with matrices), you would have the same result with fewer code lines and less complexity. Here's the equivalent code using the `loop` and `matrix` tags:

```
<define>
 <matrix name="m" coldim="5" values="0 4.25 8.0 11.25 14
                                    5 4 3.2 2.56 2.048" />
 <variable name="i" value="0" />
 <variable name="num" value="5" />
</define>
<solids>
 ...
 <loop for="i" from="1" to="num" step="1">
  <box name="box[i+1]" x="10-i" y="5-i/2" z="m[2,i]" />
 </loop>
</solids>
<structure>
 <loop for="i" from="1" to="num" step="1">
  <volume name="volbox[i+1]">
   <materialref ref="iron" />
   <solidref ref="box[i+1]" />
  </volume>
 </loop>
 <volume name="world">
  ...
  <loop for="i" from="1" to="num" step="1">
   <physvol>
    <volumeref ref="volbox[i+1]" />
    <position name="pos" x="5" y="m[1,i]" z="0"/>
   </physvol>
  </loop>
 </volume>
</structure>
```

In this example we only "looped" 5 times, but just think if we needed to loop 100 times or more, the difference (in terms of code lines) between the two approaches would be enormous.
Now two important rules you need to follow when using loops:

1) Always use a properly initialized variable for each loop tag (in our example *i* and *num* for the three loops).
2) When you use linked loop triples (*loop triple* = 3 loop tags, as we did in our example; *linked* in the sense that we looped over a solid, then we looped over a logical volume that referred to that solid, and finally we looped over a physical volume that referred to that logical volume) you always have to be sure that the number of steps is the same for every loop tag of that particular triple. In our example that number was 5: from 1 to 5.

3.5.2 Replicated Volumes

NB: supported only by Geant4

Replicated volumes in GDML correspond to Geant4 Replicas. Replica volumes are created along the specific direction of one of Cartesian or Cylindrical Axis. The first replica is placed at the given position and rotated according to given rotation and others are placed using given distance. This repeated Volumes technique is available for volumes described by Geant4 CSG Solids. The following example illustrates the construction of replica volumes along X Axis. An example 'replicated.gdml' can be found in the $G4INSTALL/examples/extended/persistency/gdml/G01 girectory.

```
<solids >
  …
  <box name="Mother_Cube" x="800" y="100" z="100"/>
  <box name="Cube" x="100" y="100" z="100".>
</solids>

<structure>
  …
 <volume name="lvCube">
  <solidref ref="Cube" />
  <materialref ref="ALU" />
 </volume>

 <volume name="lvReplica">
  <solidref ref="Mother_Cube" />
  <materialref ref="AIR" />
  <replicavol number="8">
      <volumeref ref="lvCube" />
      <replicate_along_axis>
        <direction x="1" />
        <width  value="100"  unit="mm" />
        <offset value="0"    unit="mm" />
      </replicate_along_axis>
  </replicavol>
 </volume>
</structure>
…
```

3.5.3 Parameterised Volumes

NB: supported only by Geant4

Parameterised volumes in GDML correspond to the parameterised physical volumes in Geant4 with the difference that in GDML only parameterisation of dimension and placement is supported.
Parameterisation of type of solid or its material is not supported by current implementation; however it can be implemented as possible extension to the GDML schema.
Parameterised volumes are repeated volumes in the case in which the multiple copies of a volume can be different in size and position.
Examples of GDML files describing parameterised volumes are `parameterized.gdml` and `pTube.gdml` located in the example `G01` distributed with Geant4.
The following example illustrates the construction of parameterised volumes:

```
<solids >
  …
  <box name="tracker" x="4800" y="4800" z="4800"/>
  <box name="chamber" x="2000" y="2000" z="2000".>
</solids>

<structure>
  …
<volume name="Chamber">
  <solidref ref="chamber" />
  <materialref ref="XenonGas" />
 </volume>

<volume name="Tracker">
  <solidref ref="tracker" />
  <materialref ref="Air" />

  <paramvol ncopies="2">
    <volumeref ref="Chamber"/>
       <parameterised_position_size>
       <parameters number="1">
         <position name="positionCopy1"  x="0" y="0" z="-1500"/>
```

```
        <box_dimensions x="240" y="240" z="100"/>
      </parameters>

      <parameters number="2">
        <position name="positionCopy2"  x="0" y="0" z="-700"/>
        <box_dimensions x="672" y="672" z="100"/>
      </parameters>

    </parameterised_position_size>
  </paramvol>
 </volume>
…
</structure>
…
```

For giving the dimensions of each parameterised solid in GDML a special syntax is used.

3.5.3.1. Dimensions of Parameterised Box

The GDML dimensions of a parameterised box have the following form with 3 standard dimensions: `x`, `y` and `z`. Example:

```
<box_dimensions x="30" y="30" z="30" lunit= "mm"/>
```

3.5.3.2. Dimensions of Parameterised Tube

The GDML dimensions of a parameterised tube are given using :

InR	inside radius of segment
OutR	outside radius of segment
hz	z length of tube segment
StartPhi	starting phi position angle of segment
DeltaPhi	delta angle of segment

The following example illustrates its construction:

```
<tube_dimensions InR="30" OutR="60" hz="30" lunit= "mm"
                 StartPhi="60" DeltaPhi="30" aunit= "deg"/>
```

3.5.3.3. Dimensions of Parameterised Cone

The GDML dimensions of a parameterised cone are given using:

rmin1	inside radius at base of cone
rmax1	outside radius at base of cone
rmin2	inside radius at top of cone
rmax2	outside radius at top of cone
z	z length of cone
startphi	starting phi position of segment
deltaphi	delta angle of segment

The following example illustrates its construction:

```
<cone_dimensions rmin1="30" rmax1="60"  rmin2="20" rmax2="60"  z="30" lunit= "mm"
                 startphi="60" deltaphi="30" aunit= "deg"/>
```

3.5.3.4. Dimensions of Parameterised Orb

The GDML dimensions of a parameterised orb have the following form with 1 standard dimension: `r` (radius). Example:

```
<orb_dimensions r="30" lunit= "mm"/>
```

3.5.3.5. Dimensions of Parameterised Sphere

The GDML dimensions of a parameterised sphere are given using:

rmin	inside radius
rmax	outside radius
startphi	starting phi position of segment
deltaphi	delta angle of segment
starttheta	starting theta position of segment
deltatheta	delta theta angle of segment

The following example illustrates its construction:

```
<sphere_dimensions rmin="30" rmax="60" lunit= "mm"   starttheta="0" deltatheta="40"
                 startphi="60" deltaphi="30" aunit= "deg"/>
```

3.5.3.6. Dimensions of Parameterised Torus

The GDML dimensions of a parameterised torus are given using:

rmin	inside radius
rmax	outside radius
rtor	swept radius of torus
startphi	starting phi position of segment
deltaphi	delta angle of segment

The following example illustrates its construction:

```
<torus_dimensions rmin="30" rmax="60"  rtor="160"  lunit= "mm"
                 startphi="60" deltaphi="30" aunit= "deg"/>
```

3.5.3.7. Dimensions of Parameterised Hype

The GDML dimensions of a parameterised hype are given using:

rmin	inside radius
rmax	outside radius
z	length
ihst	inner stereo
outst	outer stereo

The following example illustrates its construction:

```
<hype_dimensions rmin="30" rmax="60"  z="160"  lunit= "mm"
                 inst="3" outst="4" />
```

3.5.3.8. Dimensions of Parameterised Parallelepiped

The GDML dimensions of a parameterised parallelepiped are given using:

x	length of x
y	length of y
z	length of z
alpha	angle between x and z plane
theta	polar angle of the line joining the centre of the faces –z&+z in z
phi	azimuthal angle of the line joining the centre of the faces –z&+z in z

The following example illustrates its construction:

```
<para_dimensions x="30" y="60" z= "60"   alpha="1" theta="1"
                 phi="1" lunit="mm" aunit= "rad"/>
```

3.5.3.9. Dimensions of Parameterised Trapezoid

The GDML dimensions of a parameterised trapezoid are given using:

x1	x length at - z
x2	x length at +z
y1	y length at - z
y2	y length at +z
z	z length

The following example illustrates its construction:

```
<trd_dimensions x1="30" x2="60"  y1="20" y2="40"  z ="30" lunit= "mm"/>
```

3.5.3.10. Dimensions of Parameterised General Trapezoid

The GDML dimensions of a parameterised general trapezoid are given using:

x1	length along x at side y=-y1 of the face at - z
x2	length along x at side y=+y1 of the face at - z
x3	length along x at side y=-y1 of the face at + z
x4	length along x at side y=+y1 of the face at + z
alpha1	angle with respect to the y axis from the centre of side at y=-y1 to centre of y=+y1 of the face at -z
alpha2	angle with respect to the y axis from the centre of side at y=-y2 to centre of y=+y2 of the face at -z
theta	polar angle of the line joining the centre of the faces –z&+z in z
phi	azimuthal angle of the line joining the centre of the faces –z&+z in z
y1	y length at - z
y2	y length at +z
z	length along z axis

The following example illustrates its construction:

```
<trap_dimensions x1="30" x2="60"  y1="20" y2="40"  x3="30" x4="60" z ="30" lunit= "mm"
                 alpha1="30" alpha2="30"  phi="30" theta="60" aunit="deg" />
```

3.5.3.11. Dimensions of Parametrised Polycone

The GDML dimensions of a parameterised polycone are given using:

startPhi	start angle of the segment
openPhi	angle of the segment
numRZ	number of zplanes forming polycone
zplane	inner radius, outer radius and z coordinate of each plane

The following example illustrates its construction:

```
<polycone_dimensions startPhi="30" openPhi="60"  numRZ="2" lunit= "mm" aunit="deg"
 <zplane rmin="0"  rmax="2"  z="10"  />
 <zplane rmin="0"  rmax="4"  z="20"  />
 polycone_dimensions/>
```

3.5.3.12. Dimensions of Parametrised Polyhedron

The GDML dimensions of a parameterised polyhedron (polyhedra) are given using:

startPhi	start angle of the segment
openPhi	angle of the segment
numRZ	number of zplanes forming polycone
numSide	number of sides
zplane	inner radius, outer radius and z coordinate of each plane

The following example illustrates its construction:

```
<polycone_dimensions startPhi="30" openPhi="60"  numRZ="2" numSide="3"
 lunit= "mm" aunit="deg"
 <zplane rmin="0"  rmax="2"  z="10"  />
 <zplane rmin="0"  rmax="4"  z="20"  />
 polycone_dimensions/>
```

3.5.3.13. Dimensions of Parametrised Ellipsoid

The GDML dimensions of a parameterised general tellipsoid are given using:

ax	length of semi-axis in x direction
by	length of semi-axis in y direction
cz	length of semi-axis in z direction
zcut1	lower cut plane level at -z (solid lies above this plane)
zcut2	upper cut plane level at +z (solid lies below this plane)

The following example illustrates its construction:

```
<ellipsoid_dimensions ax="30" by="60"  cz="20" zcut1="-30"  zcut2="30"  lunit= "mm"/>
```

3.5.4 GDML Modules

GDML modules are GDML files used in the definition of (complex) geometries. They allow an easier to understand view of big geometries as they split it into smaller (and therefore more readable) pieces.
A GDML module is a normal GDML file and it is completely independent from all the other modules (also from its mother module): it contains all the information (definitions, materials, solids and volumes) it needs, to be fully defined. It defines a logical volume (which corresponds to its world volume), which can be referenced by physical volumes of other modules (which are called mother modules).
To include a GDML module (say *child.gdml*) in a mother module (say *mother.gdml*), in the structure section of the mother module you should add a physical volume which points to the child module, as in the following example:

- Instead of having one file:

```
// mother.gdml

<volume name="child">
   <materialref ref="Alluminium"/>
   <solidref ref="ChildBox"/>
</volume>
<volume name="mother">
```

```
   <materialref ref="Iron"/>
   <solidref ref="MotherBox"/>
   <physvol>
     <volumeref ref="child"/>
     <positionref ref="center"/>
     <rotationref ref="identity"/>
   </physvol>
</volume>
```

- You can define `child` logical volume in a different GDML file, so you will have two files:

```
// mother.gdml

<volume name="mother">
   <materialref ref="Iron"/>
   <solidref ref="MotherBox"/>
   <physvol>
     <file name="child.gdml"/>
     <positionref ref="center"/>
     <rotationref ref="identity"/>
   </physvol>
</volume>
```

```
// child.gdml

<volume name="child">
   <materialref ref="Alluminium"/>
   <solidref ref="ChildBox"/>
</volume>
```

So in the general case instead of writing:

```
<volumeref ref="_logical_volume_"/>
```

You will need to write:

```
<file name="_logical_volume_.gdml"/>
```

And then define `_logical_volume_` inside `_logical_volume_.gdml`.

In the example given above, the mother module will only contain the material `Iron` and the solid `MotherBox`, while the child module will contain only the material `Aluminium` and the solid `ChildBox`, thus enhancing readability and modularity.

Some advises:

- While it is not useful to have a module for every single volume of the geometry, it is good to have one for each group of volumes that you would consider as a module in the real world (see par. “Multiple GDML files”).

- Modules should have low coupling, i.e. they should be as independent as possible from other modules (this improves reusability dramatically).

- Modules should have high cohesion, i.e. they should contain all (and only) the volumes that contribute to the geometry of the corresponding real world modules (this improves readability).

3.5.5 Volume Auxiliary Information

Volumes can have auxiliary information attached to them through GDML.

The auxiliary tags look like this:

```
<auxiliary auxtype="SensDet" auxvalue="veloSD1"/>
```

They have two attributes, `auxtype` and `auxvalue`, which are meant to specify what kind of auxiliary information it is and what is its value. An additional, optional attribute `auxunit` is also possible since version 3.1.2 of the schema; the new schema also allows for inserting recursive auxiliary tags as part of a single auxiliary information block. It is important to stress here that the GDML parser does not interpret in any way the auxiliary attributes. The auxiliary attributes are stored in memory and available to the user once the parsing is done. The auxiliary tags are placed within a volume like this:

```
<volume name="main">
   <materialref ref="Iron"/>
   <solidref ref="Box"/>
   <physvol>
     <volumeref ref="world"/>
     <positionref ref="center"/>
     <rotationref ref="identity"/>
   </physvol>
<auxiliary auxtype="SensDet" auxvalue="veloSD1"/>
<auxiliary auxtype="Color" auxvalue="blue"/>
</volume>
```

In Geant4, an additional GDML file example is `auxiliary.gdml` located in example `G01` provided in the Geant4 distribution; the same example also provides a snippet of code in its `main()` program showing how to retrieve the auxiliary information. Example `G04` instead shows how to define a sensitive detector associated to a logical volume, using the Auxiliary Information field.

3.5.6 Auxiliary User Information

Since version 3.1.2 of the schema, it is possible to specify an -optional- auxiliary block `<userinfo> ... </userinfo>`, after the `<structure> ... </structure>` block, where a generic list of auxiliary tags can be included to describe specific features of a model, which are then properly treated by the client code. Here is an example on how to represent geometrical regions with energy cuts associated to logical volumes in Geant4:

```
<userinfo>
  <auxiliary auxtype="Region" auxvalue="DefaultRegionForTheWorld">
    <auxiliary auxtype="volume" auxvalue="World"/>
    <auxiliary auxtype="gamcut" auxunit="mm" auxvalue="0.7"/>
    <auxiliary auxtype="ecut" auxunit="mm" auxvalue="0.7"/>
    <auxiliary auxtype="poscut" auxunit="mm" auxvalue="0.7"/>
    <auxiliary auxtype="pcut" auxunit="mm" auxvalue="0.7"/>
  </auxiliary>
  <auxiliary auxtype="Region" auxvalue="CalorA">
    <auxiliary auxtype="volume" auxvalue="CalorA"/>
    <auxiliary auxtype="gamcut" auxunit="mm" auxvalue="0.2"/>
    <auxiliary auxtype="ecut" auxunit="mm" auxvalue="0.2"/>
    <auxiliary auxtype="poscut" auxunit="mm" auxvalue="0.2"/>
    <auxiliary auxtype="pcut" auxunit="mm" auxvalue="0.2"/>
  </auxiliary>
```

```
  <auxiliary auxtype="Region" auxvalue="CalorB">
      :
  </auxiliary>
      :
</userinfo>
```

3.6 Setup

The top volume of the geometry needs to be specified. This is done using the setup section. The following GDML is the generic and most common for the setup section.

```
<setup name="Test1" version="1.0">
  <world ref="World"/>
 </setup>
```

The only part you should need to change is the `world ref` name to the volume name of the top volume of your geometry. Only one setup is defined here, however it is possible define multiple geometry setups choosing different volumes as world volumes from all the already defined volumes.

GDML file example

4. Importing and exporting GDML files

4.1 *GDML Reading*

4.1.1 Importing GDML files into Geant4 Geometry

GDML files can be directly imported into Geant4 geometry, using the GDML plug-in facility in your Geant4 application. Generally, you will want to put the following lines into your `DetectorCostruction` class:
- In the class constructor (as far as the initializations are concerned – step 2)
- In the `Construct` method (steps 3 and 4)

This can be done in four steps:

1) Include the necessary header files

```
#include "G4GDMLParser.hh"
```

2) Declare and initialize properly the parser

```
G4GDMLParser parser;
```

`source_file.gdml` will be your GDML source file, in case of multiple GDML files (modules) you should put the main GDML file there (the main mother module).

3) Run the parser

```
parser.Read("source_file.gdml");
```

If solids or other entities with the same name are found in different modules, a warning message is generated. Usually this happens when different GDML modules define the same logical volume. This is not a problem, but it may suggest that the input GDML modules have a low cohesion, therefore it maybe useful to review the way you have organized your geometry. All names for solids, volumes and other entities are by default stripped of possible hexadecimal suffixes (see Section 4.2.1); it is possible to disable the name stripping by calling `SetStripFlag(false)` available from the parser, before reading.
By default, when the parser reads a GDML file, comparison with the GDML Schema (from GDML Schema Location) is made. It is possible to switch off this comparison by setting to 'false' second optional parameter in the Read:

```
parser.Read("source_file.gdml", false);
```

4) Get the World volume

```
G4VphysicalVolume* W = parser.GetWorldVolume(); //world volume
W->GetLogicalVolume()->SetVisAttributes(G4VisAttributes::Invisible);
```

The second line is optional, but commonly used, because you generally don't want to be able to see the World volume.

4.2 GDML Writing

4.2.1 Exporting Geant4 Geometry

Geant4 geometry can be exported into GDML files. To do so you should do the following:

1) Include the Geant4 header file of the parser

```
#include "G4GDMLParser.hh"
```

2) Get the world volume from the geometry

```
G4VphysicalVolume* W = G4TransportationManager::
GetTransportationManager()->GetNavigatorForTracking()
->GetWorldVolume();
```

3) Instantiate the parser and write to file

```
G4GDMLParser parser;
parser.Write("output.gdml", W, true, "path_to_GDML_schema");
```

The last parameter is optional and refers to the GDML Schema path, it is very important to set this right in order to allow for comparison with the Schema while reading the file back to Geant4; the path can either be an absolute directory path relative to the system (schema location local to that system) or an URL to the Schema. By default the schema location points to the latest version of the GDML schema located in the GDML web site.

There exists also an optional third parameter, which is a Boolean value set by default to TRUE. This parameter tells how you would like the names of volumes (as well as of solids, materials and all entities) to be formatted in your output GDML file:

***true (default)* –** The names will be concatenated with their logical address in hexadecimal format. This is to avoid name duplication in the GDML output; in fact Geant4 allows different volumes (as well as materials and solids) with the same name. When you will read the GDML output file back into Geant4 the address part will be stripped off and you will have the original names. This is almost always safe.

***false* –** The names will NOT be concatenated with anything. So the names in the output file will correspond exactly to the ones you have in Geant4. This is the prettiest format although you have to be REALLY sure that you don't have name duplication inside Geant4, otherwise this will generate a GDML output with duplicated names, which will be unreadable by any parser of course.

4) Methods for dumping the geometry

There are three ways of doing this:

a) `parser.Write("output.gdml", W);`
Dumps all the geometry in a single GDML output file.

b) `parser.AddModule(physvol);`

Dumps the geometry modularizing the output. The generated module will include the geometry tree starting from the physical-volume pointer `physvol`.

c) `parser.AddModule(depth);`

Dumps the geometry modularizing the output. The parameter in input is an integer indicating the depth in the geometry levels from where you wish to start modularization. Any new sub-tree at that depth level will become a module stored in a different GDML file; the main tree binding all modules will include the geometry from the world volume down to that specified level and will be stored in a separate GDML file.

4.2.2 Exporting ST-Viewer CAD Geometry

ST-Viewer is an interactive tool for viewing 3D CAD information. ST-Viewer includes functions to display and relate product identification information, assembly structure information and 3D geometry information. ST-Viewer implements the ISO STEP standard for product model data. ST-Viewer works with a very large range of CAD, CAM, CAE and PDM systems. A list of systems that have been tested with the ST-Viewer can be found at: http://www.steptools.com.

ST-Viewer uses intermediate files to store CAD geometry and structure information. These files (with .geom and .tree extensions respectively) use an internal format that can be parsed and translated into GDML format using the functionalities provided by the Geant4 GDML plug-in.

The geometry of the solids is defined by means of triangular facets, i.e. every solid in the .geom files is a tessellated solid made of *only* triangular facets. Therefore the GDML output will be a collection of tessellated solids where each solid has its own set of facets that are in turn defined by a set of three vertices. The vertices are named vectors of three values (x,y and z coordinates) and are defined in the beginning of the GDML file. The facets within a tessellated solid contain references to the names (*not the values*) of the three vertices they are made of (for more information on how a tessellated solid is defined in GDML please refer to the GDML Solids Schema : `solids.xsd`).

Of course multiple facets may share a common vertex, therefore in their definition there will be a reference to the same vertex name. Again, the actual values of the vertices' vectors are stored in the first part (the one enclosed by the `<define>` and `</define>` tags) of the GDML file.

In order to use the parser in your own application you need to

1) Include the Geant4 parser header:

```
#include "G4GDMLParser.hh"
```

2) Instantiate a Geant4 parser object:

```
G4GDMLParser parser;
```

3) Call the parse method:

```
G4LogicalVolume* STW = parser.ParseST("filename", med_mat,
geo_mat);
```

This method takes three parameters: the first one is a string which specifies the name without file extension for the .geom and .tree files (assumed to have the same names and be located in the current directory). It returns a pointer of a generated mother volume with 'med_mat' material pointer associated, including the imported tessellated geometry with 'geom_mat' material pointer associated.
Common vertices will not be repeated in the define section, i.e. facets sharing the same vertex will refer to the same vertex name defined at the beginning of the GDML file. In this case there will not be any two vertices with the same coordinates.

During a test, a input .geom file of 9.5 MB could be saved in a GDML output file of 10.5 MB; the same input file would have become a 33 MB GDML output file, with repetition of common vertices.

4) Call the dump method:

```
parser.Write("output.gdml", STW_phys);
```

The same method of the parser for writing the GDML output file can be used, by passing the placed physical volume pointer of such geometry.
The result is a GDML file corresponding to the .geom and .tree files previously taken as input.

5. User extensions to GDML using Geant4

The GDML syntax is defined in an XML schema. Inside the schema are all the definitions of the tags and the rules associated to those tags. The GDML schema can be extended, as XML is a fully extendable mark-up language. This section will discuss how to add custom elements to GDML. This could be useful if certain information is required to be contained in the GDML file for an application of GDML. The extension can be defined as such to contain a new tag and values within whichever chosen part of the GDML file. It may be the case that within the binding to GDML being used, there are methods already in place for information not supported by the GDML schema, in which case the user extension facility will help implementing that.

An example of a user extension is implemented in Geant4 and can be found in the directory `geant4/examples/persistency/gdml/G03`. This example will be used as a point of reference throughout this section.

The Schema

The first step in extending GDML is to redefine the GDML schema. It needs to include the custom elements of the extension. The extension is done in a separate schema file that imports the original schema as opposed to adding new parts to the old one. The schema for example `G03` is found in a subdirectory of the example:

```
SimpleExtensionSchema/SimpleExtension.xsd
```

The original main GDML schema is imported from its local, relative location within your GDML directory. The new schema file normally will need to contain two main parts:

5.1 *A 'redefine' element*

This element uses the extension schema to modify existing GDML elements by adding additional content. This is called by this line, which gives the location of the schema to redefine:

```
<xs:redefine schemaLocation="schema/gdml.xsd">
```

In most cases, the extension will consist in defining new objects (like color) to a volume etc. In such case, the redefine needs to add a `ReferenceType` to the base it needs to be added to:

```
    <xs:extension base="VolumeType">
        <xs:sequence>
            <xs:element minOccurs="0" maxOccurs="1" name="colourref"
type="ReferenceType"/>
        </xs:sequence>
    </xs:extension>
```

5.2 *New Elements*

The new schema will need to define the new 'element' that the `ReferenceType` will be referencing to. In the example of adding a 'color' reference to a volume, the element `color` will need to be defined.

When elements are defined, attributes of that element are defined within it, but if tags within the element contain more than one attribute, a type needs to be defined, and then referenced to. This is implemented in the `G03` schema file.

All the new elements can't be contained inside the `<gdml>` tag as they are not part of the original schema, there needs to be a new container defined that contains the new elements AND replaces the original `<gdml>` tag; we call it here, `<gdml_simple_extension>`.
A new special tag, `<extension>`, is used to include all new tags to be considered as extension to the original GDML schema; in our example, we have only one tag, `<color>`, which is part of the extension. This is shown below:

```
<xs:element name="gdml_simple_extension">
  <xs:annotation>
    <xs:documentation>
       New container for new element and gdml.
    </xs:documentation>
  </xs:annotation>
  <xs:complexType>
    <xs:sequence>
       <xs:element ref="extension" minOccurs="0" maxOccurs="1"/>
       <xs:element ref="gdml" minOccurs="1"/>
    </xs:sequence>
  </xs:complexType>
</xs:element>
```

This then means that a GDML file now takes the following structure based on the above:

```
    <gdml_simple_extension xmlns:gdml_simple_extension= "http://www.example.org"
              xmlns:xs="http://www.w3.org/2001/XMLSchema-instance"
              xs:noNamespaceSchemaLocation="./SimpleExtensionSchema/SimpleExtension.xsd">

        <extension>
            <color name="aColor" R="1.0" G="0.0" B="0.0" A="1.0" />
        </extension>

        <structure>
           <volume>
                <materialref ref="someMaterial"/>
```

```
            <solidref ref="someSolid"/>
            <colorref ref="aColor"/>  <!-- new reference type -->
          </volume>
        </structure>

</gdml_simple_extension>
```

In any GDML file you wish to use your 'extended schema' in, you will need to change the Namespace GDML Schema Location to your extended schema file and replace the original schema. The new schema location must be relative to the location of the GDML file in question. This will then import your new additions as well as the original GDML schema, as shown above.

Customised Reader

Once the GDML schema has been extended as wished, the application making use of the extended GDML, needs to provide the necessary instruments in order to properly handle the extensions. This is done by implementing a specialized 'reader' class, whose instance will replace the standard reader inside the `G4GDMLParser` class in Geant4. The new class must inherit from `G4GDMLStructureRead` and override in this case two methods:

```
void ExtensionRead(const xercesc::DOMElement* const element);
void VolumeRead(const xercesc::DOMElement* const element);
```

The former will have to handle the top level parsing of the new tags (in our case, `<color>`), while the latter will have to properly bound the new reference-type (`<colorref>`) to the volume, such that the new tag can be assigned as attribute to the volume entity.
In our example, the class `ColorReader` implements such required functionality.
An instance of the reader must be dynamically created in the `DetectorConstruction` class and provided through pointer argument to the `G4GDMLParser` instance to be created as usual for importing GDML files in Geant4.

Try it...

To run the example application you simply need to build it, using the standard procedure as for any Geant4 application. Then from the `G03` directory, you can run the example using this command:

```
read_ext [filename.gdml]
```

The default file is `color_extension.gdml`, which defines a single colored box in the world volume.