Geant 4 advanced geometry

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Based on presentations by M. Asai (SLAC) and M. Antonello (INFN-LNGS)

EM Fields

Tracking in EM fields

- Divide the trajectory of the particle in **"steps"**
  - Straight free-flight tracks between consecutive physics interactions
- In presence of EM fields, the free-flight part between interactions is **not straight**
  - Change of *direction* (B-field) or *energy* (E-field)
  - Effect of fields must be incorporated into the tracking algorithm → **CPU-demanding**
- Notice: most codes handle only **weak fields**
  - An e^- at rest will not accelerate, no syncrothron radiation, no avalanche

Tracking in fields

- In order to propagate a particle inside a field the equation of motion of the particle in the field is integrated numerically
- In general this is best done using a Runge-Kutta (RK) method for the integration of ordinary differential equations
  - Other methods are also available
- Once the curved path is calculated, Geant4 breaks it up into **linear chord segments**

- The chord segments are determined to closely approximate the curved path
  - In some cases, one step could be split in several helix-turns

Example: how to create a magnetic field: uniform

- Uniform field in the entire world volume: easy recipe

```
G4ThreeVector field(0,1.*tesla,0);
G4GlobalMagFieldMessenger* fMagFieldMessenger =
  new G4GlobalMagFieldMessenger(field)
```

- In general, one can customize the precision of the stepper and method used for the numerical integration of the equations

```
G4UniformMagField* magField = new G4UniformMagField(field);
G4FieldManager* fieldMgr =
G4TransportationManager::GetTransportationManager()
 ->GetFieldManager();
fieldMgr->SetDetectorField(magField);
fieldMgr->CreateChordFinder(magField);
```

register

Example: how to create a magnetic field: non-uniform

- Non-uniform field in the world volume
  - Create a class, derived from **`G4MagneticField`**, implementing $\vec{B} = f(\vec{x}, t)$

```
void MyField::GetFieldValue(const double
   Point[4], double *field) const
```

```
MyField* myField = new MyField();
G4FieldManager* fieldMgr =
G4TransportationManager::GetTransportationManager()
 ->GetFieldManager();
fieldMgr->SetDetectorField(myField);
fieldMgr->CreateChordFinder(myField);
```

Example: how to create a local magnetic field

- It is possible to define a field inside a logical volume (and its daughters)
  - This can be done creating a local **G4FieldManager** and attaching it to a logical volume

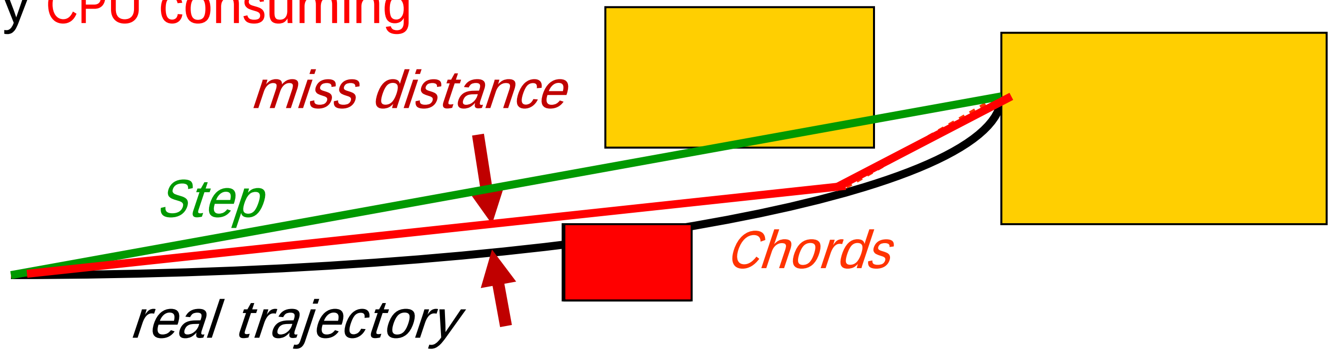
```
MyField* myField = new MyField();
G4FieldManager* localFieldMgr =
             new G4FieldManager(myField);
G4bool allLocal = true;
logicVolWithField
 ->SetFieldManager(localFieldMgr, allLocal);
```

If true, field assigned to all daughters

If false, field assigned only to daughters w/o their own field manager

Customization

- A few parameters to customize the precision of the tracking in EM fields. Most critical: "miss distance"
  - Upper bound for the value of the sagitta (default: 3 mm)
  - May be highly CPU consuming



- Integration calculated by 4th-order Runge-Kutta (**G4ClassicalRK4**), robust and general purpose
  - If the field is not smooth (e.g. field map), lower-order (and faster) integrators can be appropriate
  - 3rd order **G4SimpleHeum**, 2nd order **G4ImplicitEuler**, 1st order **G4ExplicitEuler**

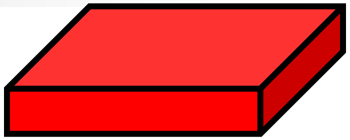
(Bird's eye view) Replicas and parametrized volumes

Physical volumes

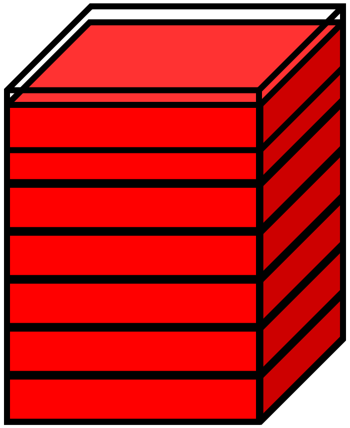
- Placement volume (**`G4PVPlacement`**): one positioned volume
  - One physical volume represents one "real" volume
- Repeated volume: a volume placed many times
  - One physical volume represents any number of "real" volumes
    - Reduced use of memory
    - Very convenient for large voxelized geometries
  - Parametrized (repetitions w.r.t. copy number)
  - Replicas and Divisions
- Notice: a repeated volume is **not equivalent** to a loop of placements
  - All placements of the loop exists individually in the memory

Replicated volumes (**`G4PVReplica`**)

- The mother volume is completely filled with replicas, all having same size and shape
  - If you need gaps, use **`G4PVDivision`** instead (less CPU-efficient)
- Replication may occur along:
  - Cartesian axes (kXAxis, kYAxis, kZAxis)
    - Coordinate system at the center of each replica
  - Radial axis (cilindrical polar) (kRho) - onion rings
    - Coordinate system same as the mother
  - Phi axis (cylindrical polar) (kPhi) – cheese wedges
    - Coordinate system rotated so that the X axis bisects the angle made by each wedge

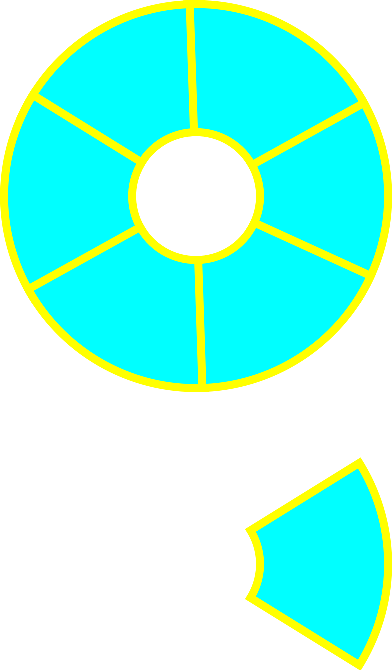


a daughter logical volume to be replicated



mother volume

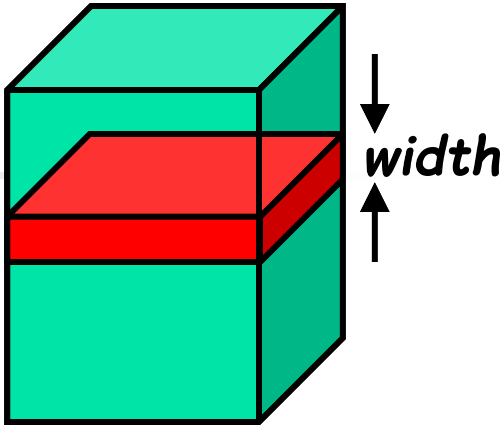
G4PVReplica



```
G4PVReplica(const G4String &pName,
            G4LogicalVolume* pLogical,
            G4LogicalVolume* pMother,
            const EAxis pAxis,
            const G4int nReplicas,
            const G4double width,
            const G4double offset=0.);
```

- Features and restrictions:
  - **CSG** solids only
  - **`G4PVReplica`** must be the **only** daughter
  - Replicas may be placed inside other replicas
  - Normal placement volumes may be placed inside replicas
  - No volume can be placed inside a radial replication
  - Parameterised volumes cannot be placed inside a replica

Replica: axes, width and offset

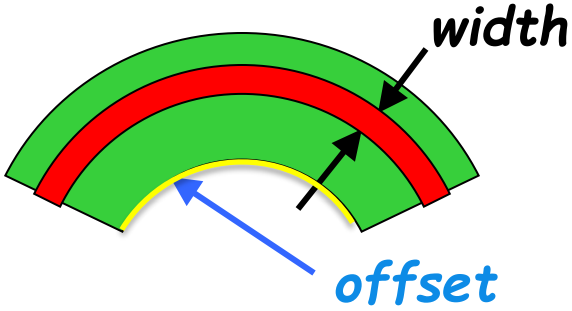


Center of n^th^ daughter is given as

- Cartesian axes - kXaxis, kYaxis, kZaxis

`-width*(nReplicas-1)*0.5+n*width`

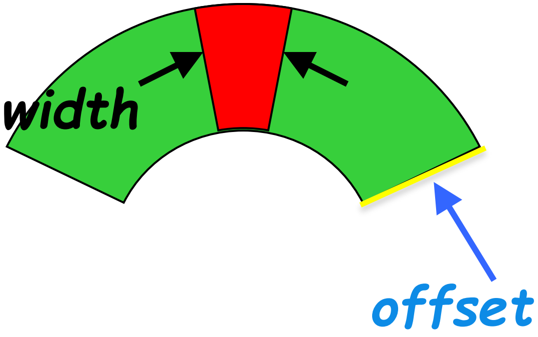
Offset shall not be used



- Radial axis – kRho

`width*(n+0.5)+offset`

Offset must be the inner radius of the mother



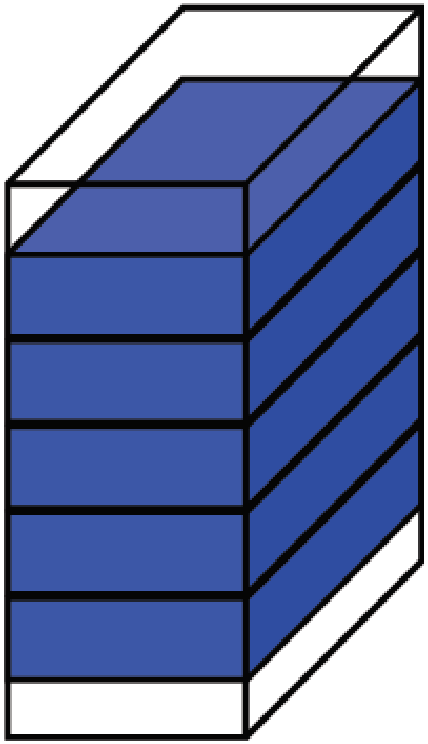
- Phi axis – kPhi

`width*(n+0.5)+offset`

Offset must be the starting angle of the mother

G4PVDivision

- The **`G4PVDivision`** is similar to the **`G4PVReplica`** **but**
  - Allows for gaps between mother and daughter volumes
  - Less CPU-effective than replica
- Shape of all daughter volumes **must be the same** as of the mother volume
- A number of shapes / axes patterns are supported, e.g.
  - G4Box : kXAxis, kYAxis, kZAxis
  - G4Tubs : kRho, kPhi, kZAxis
  - G4Cons : kRho, kPhi, kZAxis
  - ...



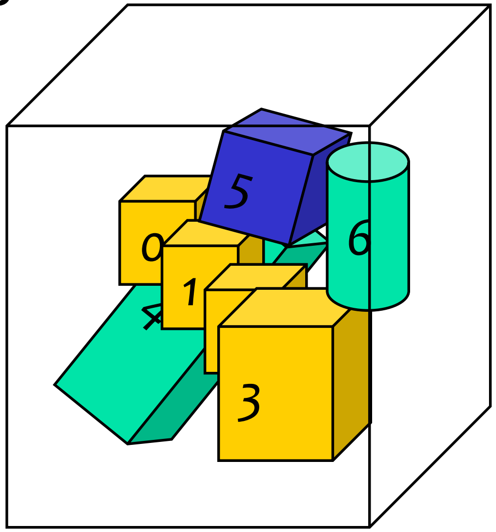
mother volume

Parametrized volumes (G4VPVParameterisation)

- Repeated volumes can differ by **size**, **shape**, **material** and **transformation matrix**, that can all be parameterised by the user as a function of the copy number

User is asked to derive her/his own parameterisation class from the G4VPVParameterisation class implementing the methods:

```
void ComputeTransformation(const G4int copyNo,
                           G4VPhysicalVolume
                           *physVol) const;
void ComputeDimensions(G4Tubs& trackerLayer,
       const G4int copyNo, const
       G4VPhysicalVolume *physVol)  const;
```



Optional methods:

```
       ComputeMaterial(…)
       ComputeSolid(…)
```

Parametrized volumes

- All daughters must be fully contained in the mother
  - Daughters should not overlap to each other
- Limitations:
  - Applies to simple CSG solids only
  - Grand-daughter volumes allowed only for special cases
- **Typical use-cases**
  - Complex detectors with large repetition of volumes, regular or irregular
  - Medical applications: the **material** in tissue is modeled as parametrixed voxels with variable density
  - Limited memory footprint

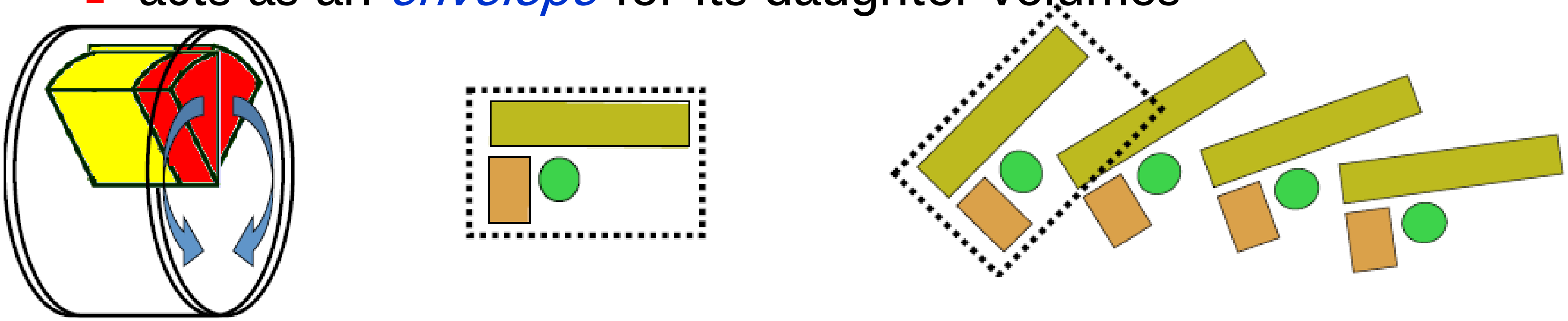
G4PVParametrized

```
G4PVParameterised(const G4String& pName,
                  G4LogicalVolume* pLogical,
                  G4LogicalVolume* pMother,
                  const EAxis pAxis,
                  const G4int nReplicas,
                  G4VPVParameterisation *pParam
                  G4bool pSurfChk=false);
```

- Replicates the volume nReplicas times using the parameterization pParam, within the mother volume pMother
- pAxis specifies the tracking optimisation algorithm to apply:
  - kXAxis, kYAxis, kzAxis → 1D voxelisation algorithm
  - kUndefined → 3-D voxelisation algorithm
- Each replicated volume is a **touchable** detector element

Assembly & reflections

- Possible to represent a regular pattern of positioned volumes, composing a more or less complex structure
  - structures which are hard to describe with simple replicas or parameterised volumes
- Assembly volume (**`G4AssemblyVolume`**)
  - acts as an *envelope* for its daughter volumes



- **`G4ReflectedSolid`** (derived from **`G4VSolid`**)
  - Utility class representing a solid shifted from its original reference frame to a new **mirror** symmetric one

GDML exchange format and CAD

GDML

Requires the **Xerces-C++** libraries

- **Geometry Description Markup Language**
  - application-indepedent geometry description format based on XML
  - Not limited to Geant4
- General geometry description
  - Implements "geometry trees" allowing for the description of hierarchical geometries
  - Contains material definitions and volume placements
- Profitably used for geometry exchange between:
  - Fluka and Geant4 → physics validation
  - Geant4 and ROOT → geometry visualization
  - CAD and Geant4 → geometry import (with care)
- Allows running the same application with different geometries

GDML document example

positions, rotations

materials

solids

geometry tree

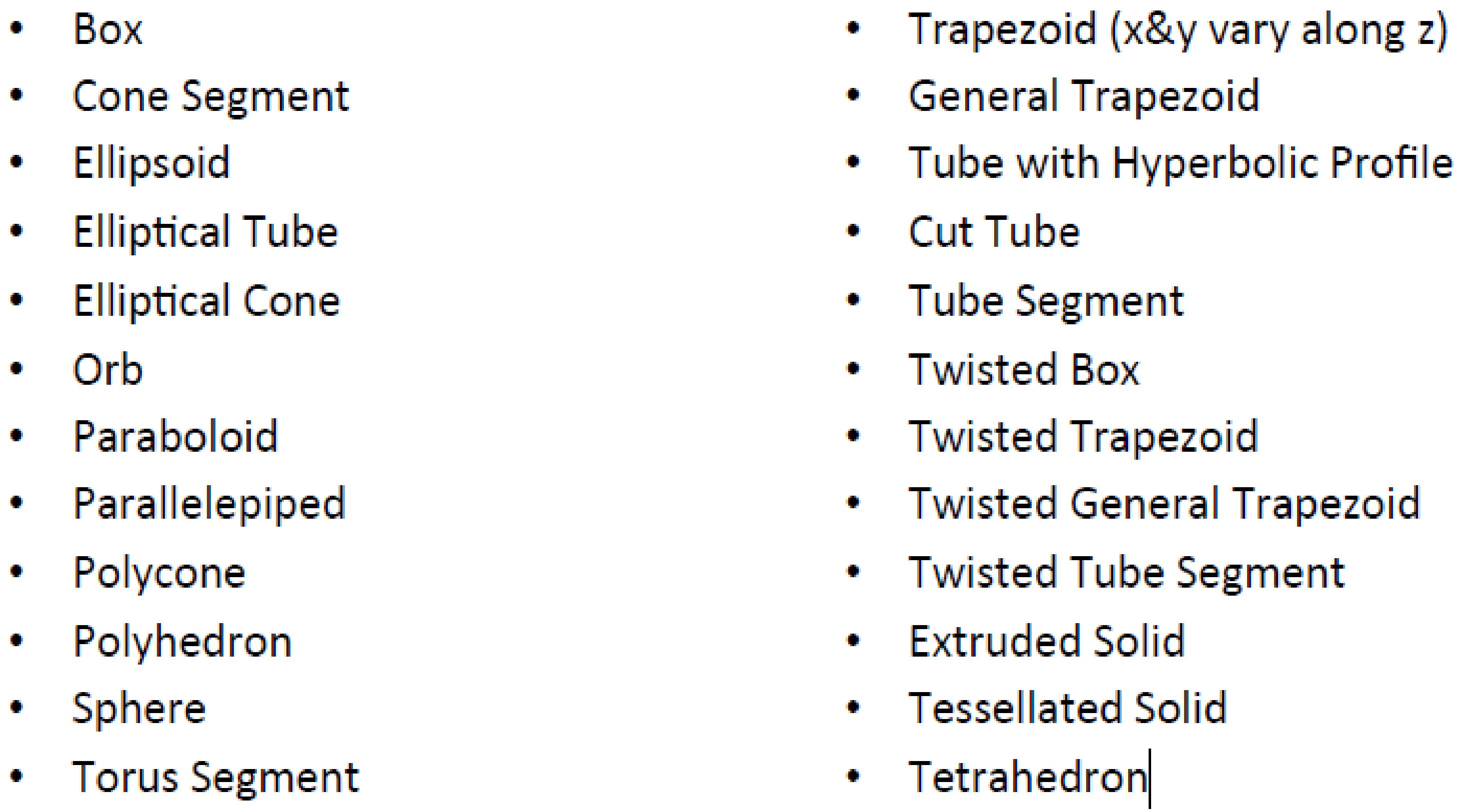
'world' volume

```
<?xml version="1.0" encoding="UTF-8"?>
<gdml xsi:noNamespaceSchemaLocation="GDMLSchema/gdml.xsd">
   <define>
         …
         <position name="TrackerinWorldpos" unit="mm" x="0" y="0" z="100"/>
   </define>
   <materials>
         …
         <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>
```

- *ASCII file: easy to create, read, debug, modify,…*

- *Similar to HTML, explicit tags for elements, …*

GDML solids



- Box
- Cone Segment
- Ellipsoid
- Elliptical Tube
- Elliptical Cone
- Orb
- Paraboloid
- Parallelepiped
- Polycone
- Polyhedron
- Sphere
- Torus Segment
- Trapezoid (x&y vary along z)
- General Trapezoid
- Tube with Hyperbolic Profile
- Cut Tube
- Tube Segment
- Twisted Box
- Twisted Trapezoid
- Twisted General Trapezoid
- Twisted Tube Segment
- Extruded Solid
- Tessellated Solid
- Tetrahedron

And booleans

GDML components

GDML Schema

- self-consistent definition of GDML syntax
- defines document structure and the list of legal elements

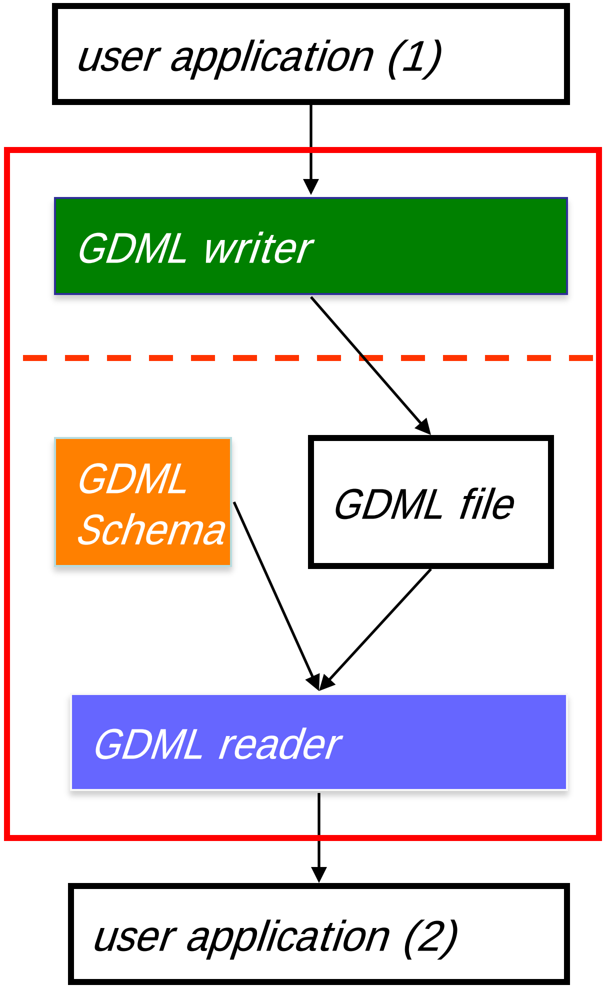
GDML Reader

- Creates 'in-memory' representation of the geometry description

GDML Writer

- Allows exporting geometry on a file
- Files can be also edited by hand

Reader and Writer are integrated in packages like Geant4 and ROOT providing GDML compliant interfaces



Reading GDML files in Geant4

- Importing a geometry from a GDML file, only requires

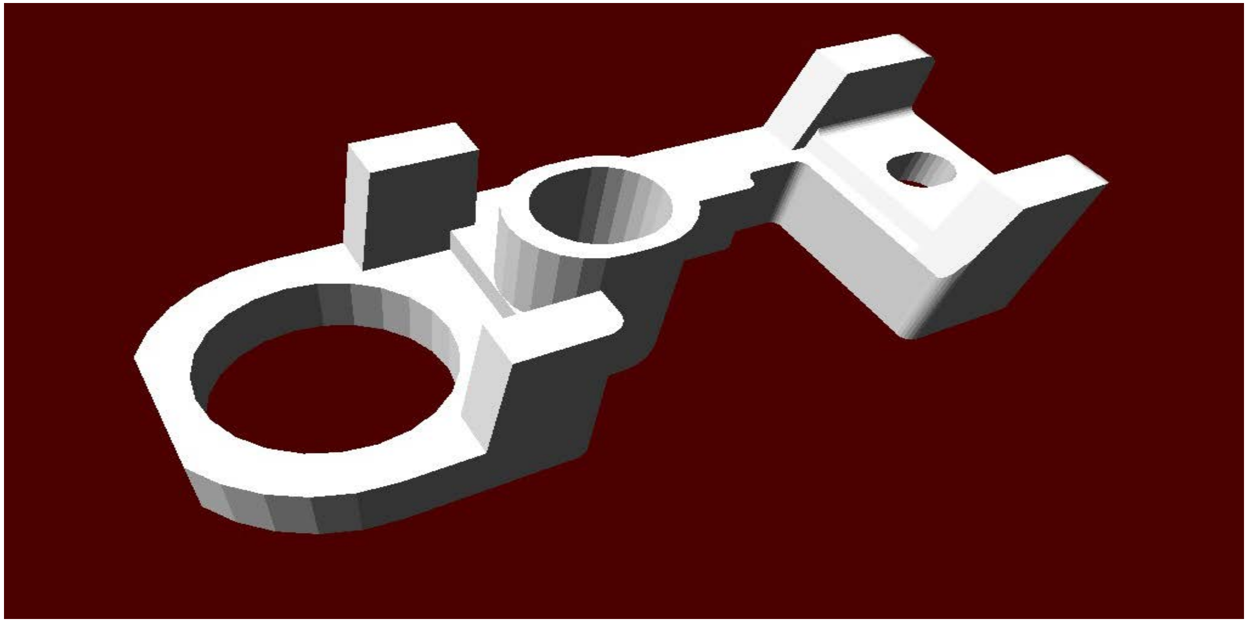
```
DetectorConstructor::Construct(){

// gdml parser
#include "G4GDMLParser.hh”
G4GDMLParser fParser;

// importing geometry

fParser.Read(“detectorgeometry.gdml”);    // reads and stores
                                          // in memory

G4VPhysicalVolume* fWorldPhysVol = fParser.GetWorldVolume();
// get world

}
```

Writing a GDML files from Geant4

- Converserly, one can export a Geant4 geometry (e.g. C++ coded) in a GDML file

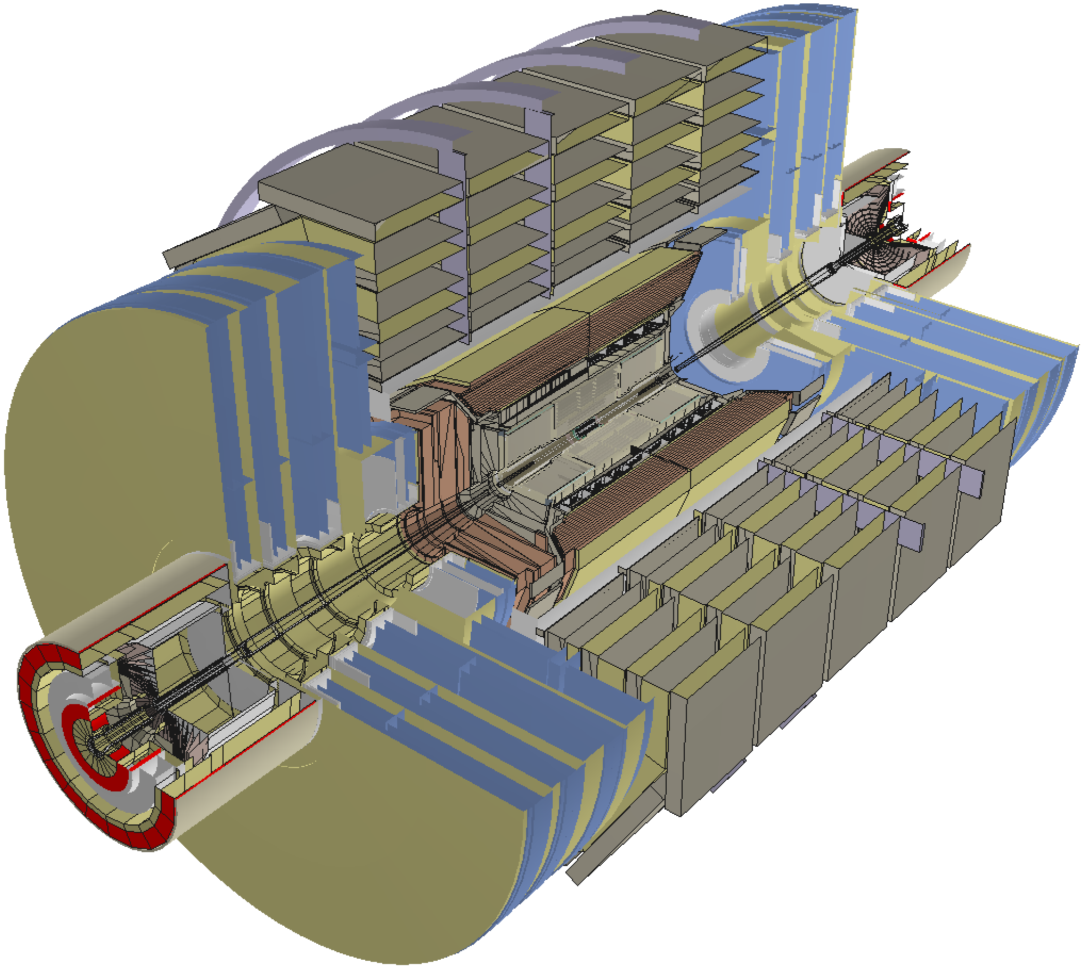
```
DetectorConstructor::Construct(){

// gdml parser
#include "G4GDMLParser.hh”
G4GDMLParser fParser;
G4VPhysicalVolume* fWorldPhysVol;

// exporting geometry
fParser.Write(“geometrydump.gdml”, fWorldPhysVol);


}
```

Tessellated solids



- The geometry imported from GDML will be made by tessellated solids **`G4TessellatedSolid`**
  - Generic solid defined by a number of facets (**`G4VFacet`**)
  - Facets can be triangular or quadrangular

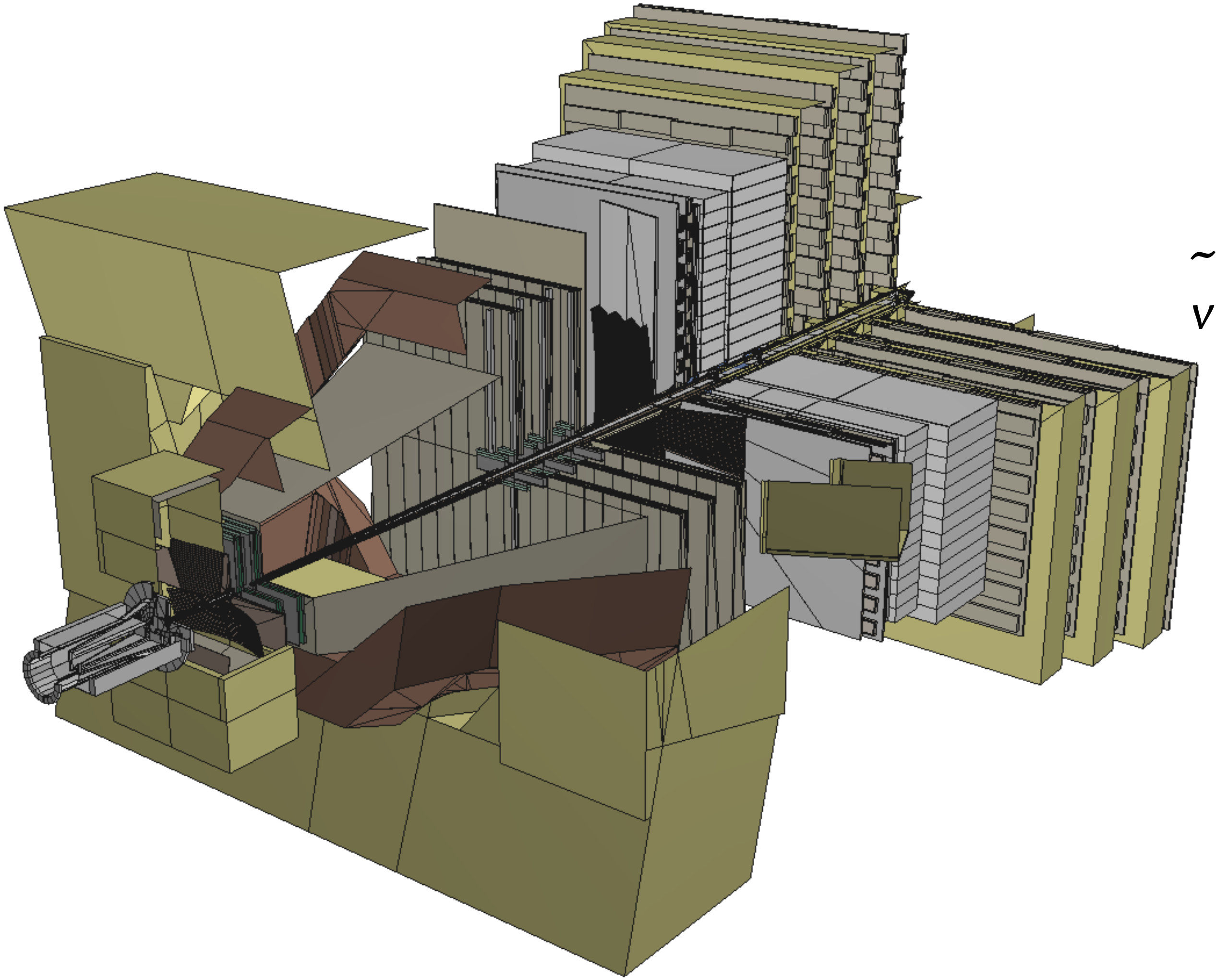
CMS detector: G4→ GDML→ ROOT



~19000 physical volumes

snapshot provided by R.Maunder

LHCb detector: G4→ GDML→ ROOT



~5000 physical volumes

snapshot provided by R.Maunder

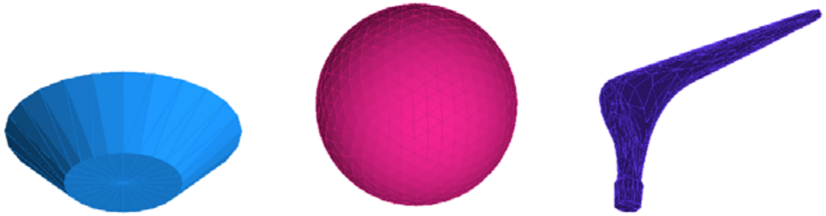
CAD import

- Typical request: import CAD technical drawings as Geant4 geometries
- Difficulties:
  - Proprietary, undocumented or changing CAD formats
  - Usually no connection between geometry and materials
  - CAD is never as easy as you might think
- Possible solution (a lot of work!)
  - Convert **CAD into STEP** (no material information)
  - Convert **STEP into GDML** and restore manually material information
    - Needs commercial software (ST-viewer, FastRAD)

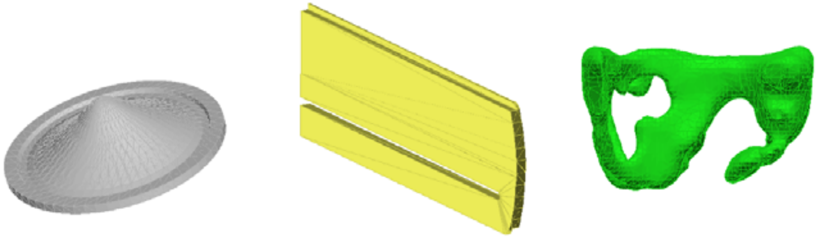
CADMesh

- **CADMesh** is a direct CAD model import interface for Geant4 optionally leveraging VCGLIB, and ASSIMP by default.
  - Currently it supports the import of triangular facet surface meshes defined in formats such as STL and PLY
  - A **`G4TessellatedSolid`** is returned and can be included in a standard user detector construction

https://code.google.com/p/cadmesh/
http://arxiv.org/pdf/1105.0963.pdf



(a) cone (b) sphere (c) hip prosthesis



(d) flattening filter (e) MLC leaf (f) pelvis model

Fig. 3 Six test geometries loaded directly into GEANT4 using the proposed CAD interface and visualised using the GEANT4 OpenGL viewer.

Hands-on session

- Task1c
  - Magnetic fields

- **`http://202.122.35.46/geant/task1`**

Backup

Parallel world

Parallel world

- The possibility to define a scoring volume different from the physical volumes available since the old times of Geant4 (**ROGeometry**)
- Occasionally, it is not straightforward to define sensitivity, importance or envelope to be assigned to volumes in the mass geometry.
  - Typically a geometry built machinery by CAD, GDML, DICOM, etc. has this difficulty. Mass geometry is composed by voxels or tessels (difficult to be treated individually for sensitivity)
- Other concurrent/similar requirements emerged since then
  - Ghost volume for shower parameterization
  - Importance field geometry for geometry importance biasing assigned to importance biasing process
  - Scoring geometry assigned to scoring process
- New design → everything merged into **`G4ParallelWorld`**

Parallel world

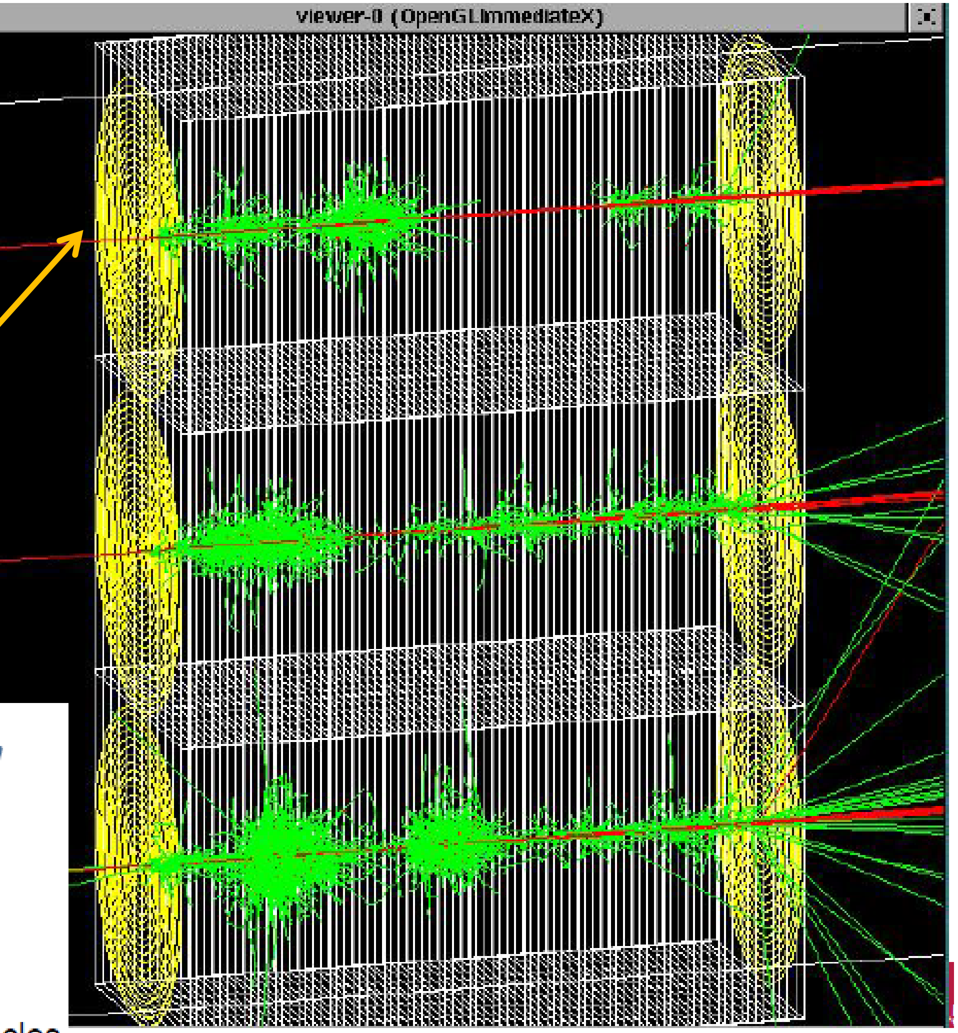
- New parallel navigation functionality allows the user to define **more than one worlds** simultaneously.
- New **`G4Transportation`** process sees all worlds simultaneously.
  - A step is limited not only by the boundary of the mass geometry but also by the boundaries of parallel geometries: a step will never cross a boundary of any volume in any parallel world
  - Materials, production thresholds and EM field are used only from the mass geometry
- In a parallel world, the user can define volumes in arbitrary manner with sensitivity, regions with shower parameterization, and/or importance field for biasing.
  - Volumes in different worlds *may overlap*.

Parallel world and navigation

- **`G4VUserParallelWorld`** is the new base class where the user implements a parallel world.
  - The world physical volume of the parallel world is provided by G4RunManager as a clone of the mass geometry
    - The same world volume applies to all parallel worlds
  - All UserParallelWorlds must be registered to UserDetectorConstruction.
  - Each parallel world has its dedicated **`G4Navigator`** object, that is automatically assigned
- The user has to have **`G4ParallelWorldProcess`** in his physics list.

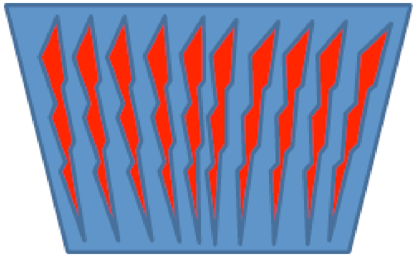
example/extended/runAndEvent/RE06

- Mass geometry
  - sandwich of rectangular absorbers and scintilators
- Parallel scoring geometry
  - Cylindrical layers



Shower parametrization

Geometry seen by e+, e-, γ



Geometry seen by other particles