Geant 4

Detector Description – basic concepts

http://cern.ch/geant4

Detector Description

Part I *The Basics*

Part II *Logical and physical volumes*

Part III *Solids, touchables*

Part IV *Optimisation technique & Advanced features*

PART 1

Detector Description: the Basics

Describe your detector

- Derive your own concrete class from `G4VUserDetectorConstruction` abstract base class.
- Implementing the method `Construct()`:
  - Modularize it according to each detector component or sub-detector:
    - Construct all necessary materials
    - Define shapes/solids required to describe the geometry
    - Construct and place volumes of your detector geometry
    - Define sensitive detectors and identify detector volumes which to associate them
    - Associate magnetic field to detector regions
    - Define visualization attributes for the detector elements

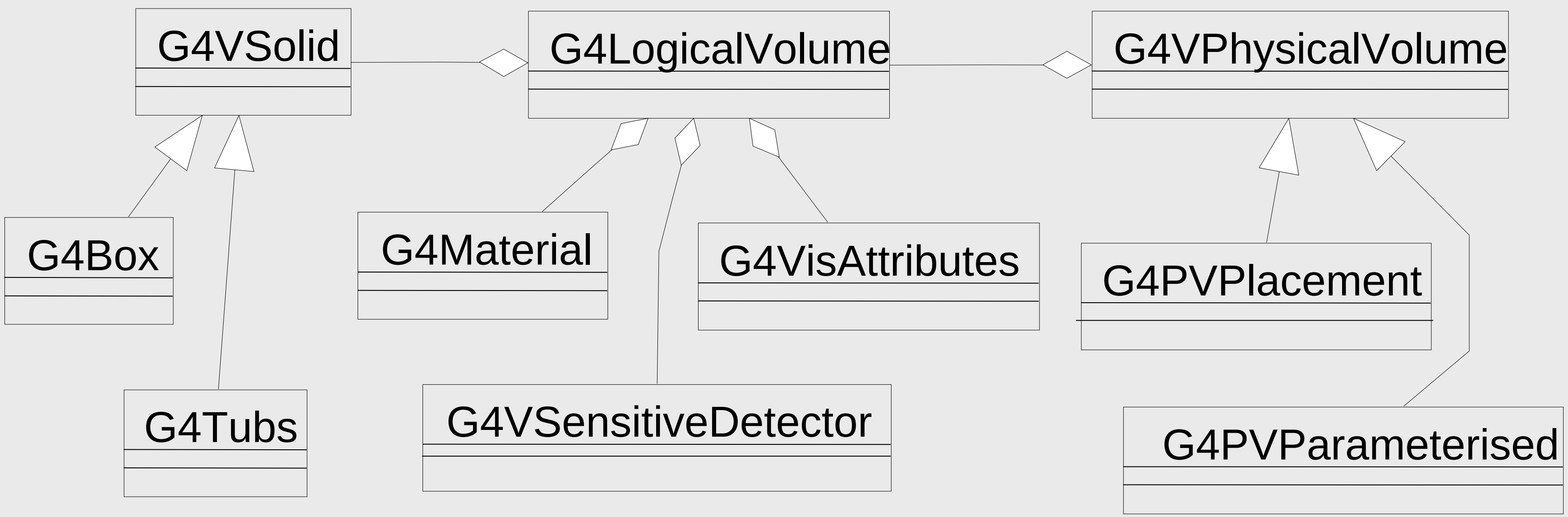
Creating a Detector Volume

- Start with its Shape & Size
  - Box 3x5x7 cm, sphere R=8m
- Add properties:
  - material, B/E field,
  - make it sensitive
- Place it in another volume
  - in one place
  - repeatedly using a function

- *Solid*
- *Logical-Volume*
- *Physical-Volume*

Define detector geometry

- Three conceptual layers
  - **G4VSolid** -- *shape, size*
  - **G4LogicalVolume** -- *daughter physical volumes,*
    material, sensitivity, user limits, etc.
  - **G4VPhysicalVolume** -- *position, rotation*



Define detector geometry

- Basic strategy

```
G4VSolid* pBoxSolid =
  new G4Box(“aBoxSolid”, 1.*m, 2.*m, 3.*m);
G4LogicalVolume* pBoxLog =
  new G4LogicalVolume( pBoxSolid, pBoxMaterial,
                       “aBoxLog”, 0, 0, 0);
G4VPhysicalVolume* aBoxPhys =
  new G4PVPlacement( pRotation,
                     G4ThreeVector(posX, posY, posZ),
                     pBoxLog, “aBoxPhys”, pMotherLog,
                     0, copyNo);
```

- A unique physical volume which represents the experimental area must exist and fully contains all other components
  - The world volume

PART II

Detector Description:

Logical and Physical Volumes

G4LogicalVolume

```
G4LogicalVolume(G4VSolid* pSolid, G4Material* pMaterial,
                const G4String& name, G4FieldManager* pFieldMgr=0,
                G4VSensitiveDetector* pSDetector=0,
                G4UserLimits* pULimits=0,
                G4bool optimise=true);
```

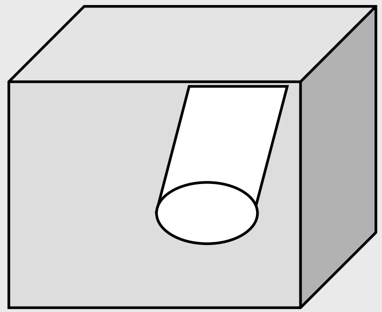
- Contains all information of volume except position:
  - Shape and dimension (G4VSolid)
  - Material, sensitivity, visualization attributes
  - Position of daughter volumes
  - Magnetic field, User limits
  - Shower parameterisation
- Physical volumes of same type can share a logical volume.
- The pointers to solid and material must be NOT null
- Once created it is automatically entered in the LV store
- It is not meant to act as a base class

G4VPhysicalVolume

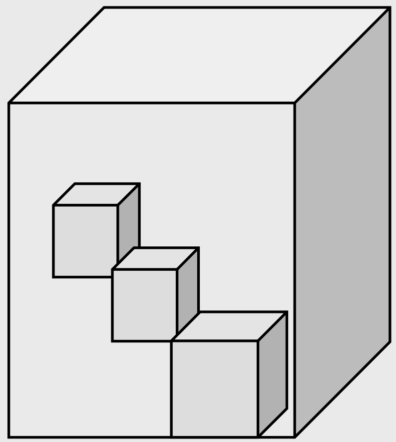
- G4PVPlacement 1 Placement = One Volume
  - A volume instance positioned once in a mother volume
- G4PVParameterised 1 Parameterised = Many Volumes
  - Parameterised by the copy number
    - Shape, size, material, position and rotation can be parameterised, by implementing a concrete class of `G4VPVParameterisation`.
  - Reduction of memory consumption
    - Currently: parameterisation can be used only for volumes that either a) have no further daughters <u>or</u> b) are identical in size & shape.
- G4PVReplica 1 Replica = Many Volumes
  - Slicing a volume into smaller pieces (if it has a symmetry)

Physical Volumes

- Placement: it is one positioned volume
- Repeated: a volume placed many times
  - can represent any number of volumes
  - reduces use of memory.
  - Replica
    - simple repetition, similar to G3 divisions
  - Parameterised
- A **mother** volume can contain **either**
  - **many placement** volumes **OR**
  - **one repeated** volume



placement



repeated

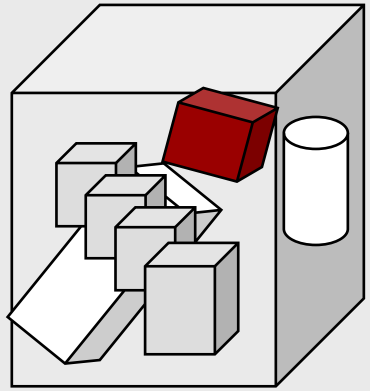
G4PVPlacement

```
G4PVPlacement(G4RotationMatrix* pRot,
              const G4ThreeVector& tlate,
              G4LogicalVolume* pCurrentLogical,
              const G4String& pName,
              G4LogicalVolume* pMotherLogical,
              G4bool pMany,
              G4int pCopyNo);
```

- Single volume positioned relatively to the mother volume
  - In a frame rotated and translated relative to the coordinate system of the mother volume
- Three additional constructors:
  - A simple variation: specifying the mother volume as a pointer to its physical volume instead of its logical volume.
  - Using `G4Transform3D` to represent the direct rotation and translation of the solid instead of the frame
  - The combination of the two variants above

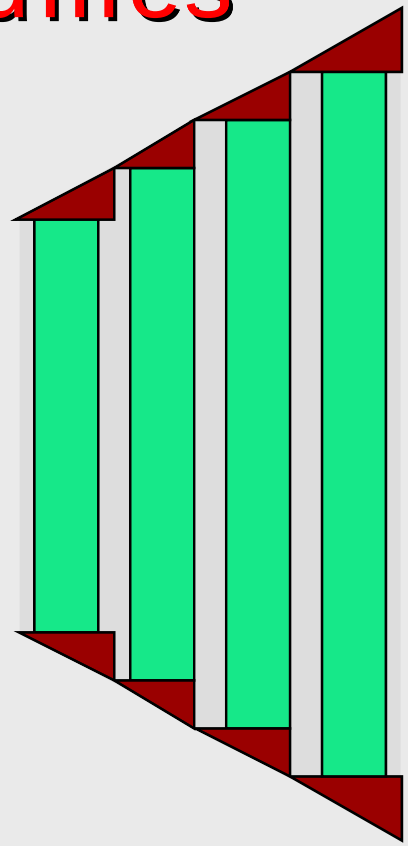
Parameterised Physical Volumes

- User written functions define:
  - the size of the solid (dimensions)
    - Function `ComputeDimensions(…)`
  - where it is positioned (transformation)
    - Function `ComputeTransformations(…)`
- Optional:
  - the type of the solid
    - Function `ComputeSolid(…)`
  - the material
    - Function `ComputeMaterial(…)`
- Limitations:
  - Applies to simple CSG solids only
  - Daughter volumes allowed only for special cases
- Very powerful
  - Consider parameterised volumes as "leaf" volumes



Uses of Parameterised Volumes

- Complex detectors
  - with large repetition of volumes
    - regular or irregular
- Medical applications
  - the material in animal tissue is measured
    - cubes with varying material



G4PVParameterised

```
G4PVParameterised(const G4String& pName,
                  G4LogicalVolume* pCurrentLogical,
                  G4LogicalVolume* pMotherLogical,
                  const EAxis pAxis,
                  const G4int nReplicas,
                  G4VPVParameterisation* pParam);
```

- Replicates the volume `nReplicas` times using the parameterisation `pParam`, within the mother volume
- The positioning of the replicas is dominant along the specified Cartesian axis
  - If `kUndefined` is specified as axis, 3D voxelisation for optimisation of the geometry is adopted
- Represents many touchable detector elements differing in their positioning and dimensions. Both are calculated by means of a `G4VPVParameterisation` object
- Alternative constructor using pointer to physical volume for the mother

Parameterisation

example - 1

```
G4VSolid* solidChamber = new G4Box("chamber", 100*cm, 100*cm, 10*cm);
G4LogicalVolume* logicChamber =
   new G4LogicalVolume(solidChamber, ChamberMater, "Chamber", 0, 0, 0);
G4double firstPosition = -trackerSize + 0.5*ChamberWidth;
G4double firstLength = fTrackerLength/10;
G4double lastLength  = fTrackerLength;
G4VPVParameterisation* chamberParam =
   new ChamberParameterisation( NbOfChambers, firstPosition,
                                ChamberSpacing, ChamberWidth,
                                firstLength, lastLength);
G4VPhysicalVolume* physChamber =
   new G4PVParameterised( "Chamber", logicChamber, logicTracker,
                          kZAxis, NbOfChambers, chamberParam);
```

Use **kUndefined** for activating 3D voxelisation for optimisation

Parameterisation

example - 2

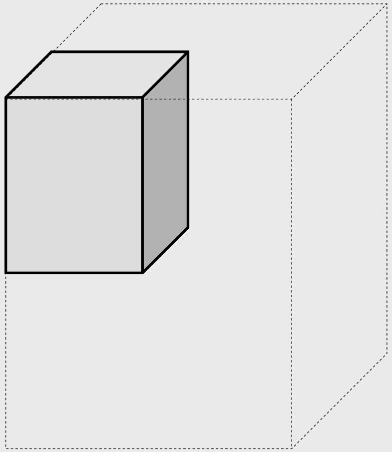
```
class ChamberParameterisation : public G4VPVParameterisation
{
  public:
    ChamberParameterisation( G4int NoChambers, G4double startZ,
                             G4double spacing, G4double widthChamber,
                             G4double lenInitial, G4double lenFinal );
   ~ChamberParameterisation();
   void ComputeTransformation (const G4int copyNo,
                               G4VPhysicalVolume* physVol) const;
   void ComputeDimensions (G4Box& trackerLayer, const G4int copyNo,
                           const G4VPhysicalVolume* physVol) const;
}
```

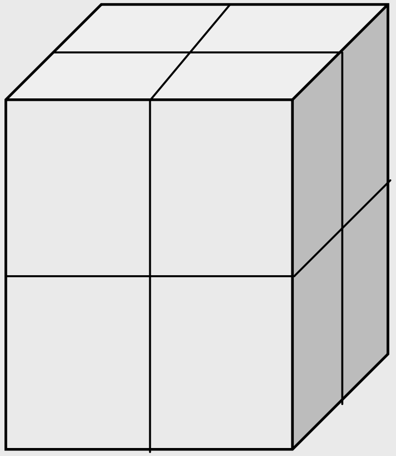
Parameterisation
example - 3

```
void ChamberParameterisation::ComputeTransformation
(const G4int copyNo, G4VPhysicalVolume* physVol) const
{
  G4double Zposition= fStartZ + (copyNo+1) * fSpacing;
  G4ThreeVector origin(0, 0, Zposition);
  physVol->SetTranslation(origin);
  physVol->SetRotation(0);
}
void ChamberParameterisation::ComputeDimensions
(G4Box& trackerChamber, const G4int copyNo,
 const G4VPhysicalVolume* physVol) const
{
  G4double  halfLength= fHalfLengthFirst + copyNo * fHalfLengthIncr;
  trackerChamber.SetXHalfLength(halfLength);
  trackerChamber.SetYHalfLength(halfLength);
  trackerChamber.SetZHalfLength(fHalfWidth);
}
```

Replicated Physical Volumes

- The mother volume is sliced into replicas, all of the same size and dimensions.
- Represents many touchable detector elements differing only in their positioning.
- Replication may occur along:
  - Cartesian axes (X, Y, Z) – slices are considered perpendicular to the axis of replication
    - Coordinate system at the center of each replica
  - Radial axis (Rho) – cons/tubs sections centered on the origin and un-rotated
    - Coordinate system same as the mother
  - Phi axis (Phi) – phi sections or wedges, of cons/tubs form
    - Coordinate system rotated such as that the X axis bisects the angle made by each wedge

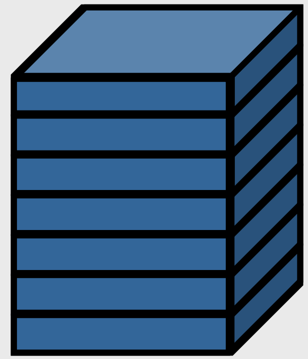




repeated

G4PVReplica

a daughter volume
to be replicated



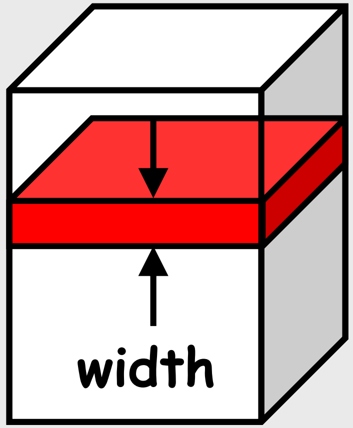
mother volume

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

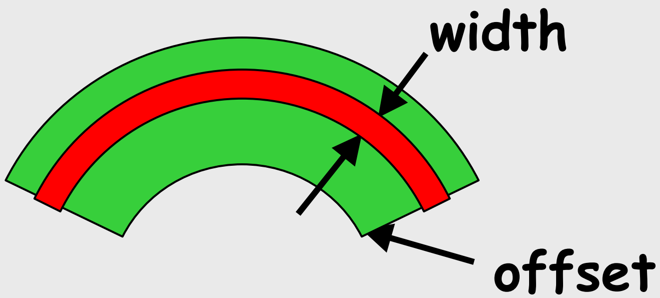
- Alternative constructor: using pointer to physical volume for the mother
- An `offset` can only be associated to a mother offset along the axis of replication
- Features and restrictions:
  - Replicas can be placed inside other replicas
  - Normal placement volumes can be placed inside replicas, assuming no intersection/overlaps with the mother volume or with other replicas
  - No volume can be placed inside a *radial* replication
  - Parameterised volumes cannot be placed inside a replica

Replica – axis, width, offset

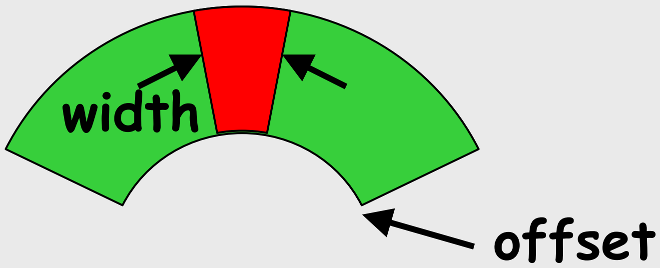
- Cartesian axes - **kXaxis, kYaxis, kZaxis**
  - offset shall not be used
  - Center of n-th daughter is given as
    -width*(nReplicas-1)*0.5+n*width



- Radial axis - **kRaxis**
  - Center of n-th daughter is given as
    width*(n+0.5)+offset



- Phi axis - **kPhi**
  - Center of n-th daughter is given as
    width*(n+0.5)+offset



Replication

example

```
G4double tube_dPhi = 2.* M_PI;
 G4VSolid* tube =
   new G4Tubs("tube", 20*cm, 50*cm, 30*cm, 0., tube_dPhi*rad);
 G4LogicalVolume * tube_log =
   new G4LogicalVolume(tube, Ar, "tubeL", 0, 0, 0);
 G4VPhysicalVolume* tube_phys =
   new G4PVPlacement(0,G4ThreeVector(-200.*cm, 0., 0.*cm),
                     "tubeP", tube_log, world_phys, false, 0);
 G4double divided_tube_dPhi = tube_dPhi/6.;
 G4VSolid* divided_tube =
   new G4Tubs("divided_tube", 20*cm, 50*cm, 30*cm,
             -divided_tube_dPhi/2.*rad, divided_tube_dPhi*rad);
 G4LogicalVolume* divided_tube_log =
   new G4LogicalVolume(divided_tube, Ar, "div_tubeL", 0, 0, 0);
 G4VPhysicalVolume* divided_tube_phys =
   new G4PVReplica("divided_tube_phys", divided_tube_log, tube_log,
                   kPhi, 6, divided_tube_dPhi);
```

Divided Physical Volumes

- Implemented as "special" kind of parameterised volumes
  - Applies to CSG-like solids only (box, tubs, cons, para, trd, polycone, polyhedra)
  - Divides a volume in identical copies along one of its axis (copies are not strictly identical)
    - e.g. - a tube divided along its radial axis
    - Offsets can be specified
- The possible axes of division vary according to the supported solid type
- Represents many touchable detector elements differing only in their positioning
- **`G4PVDivision`** is the class defining the division
  - The parameterisation is calculated automatically using the values provided in input

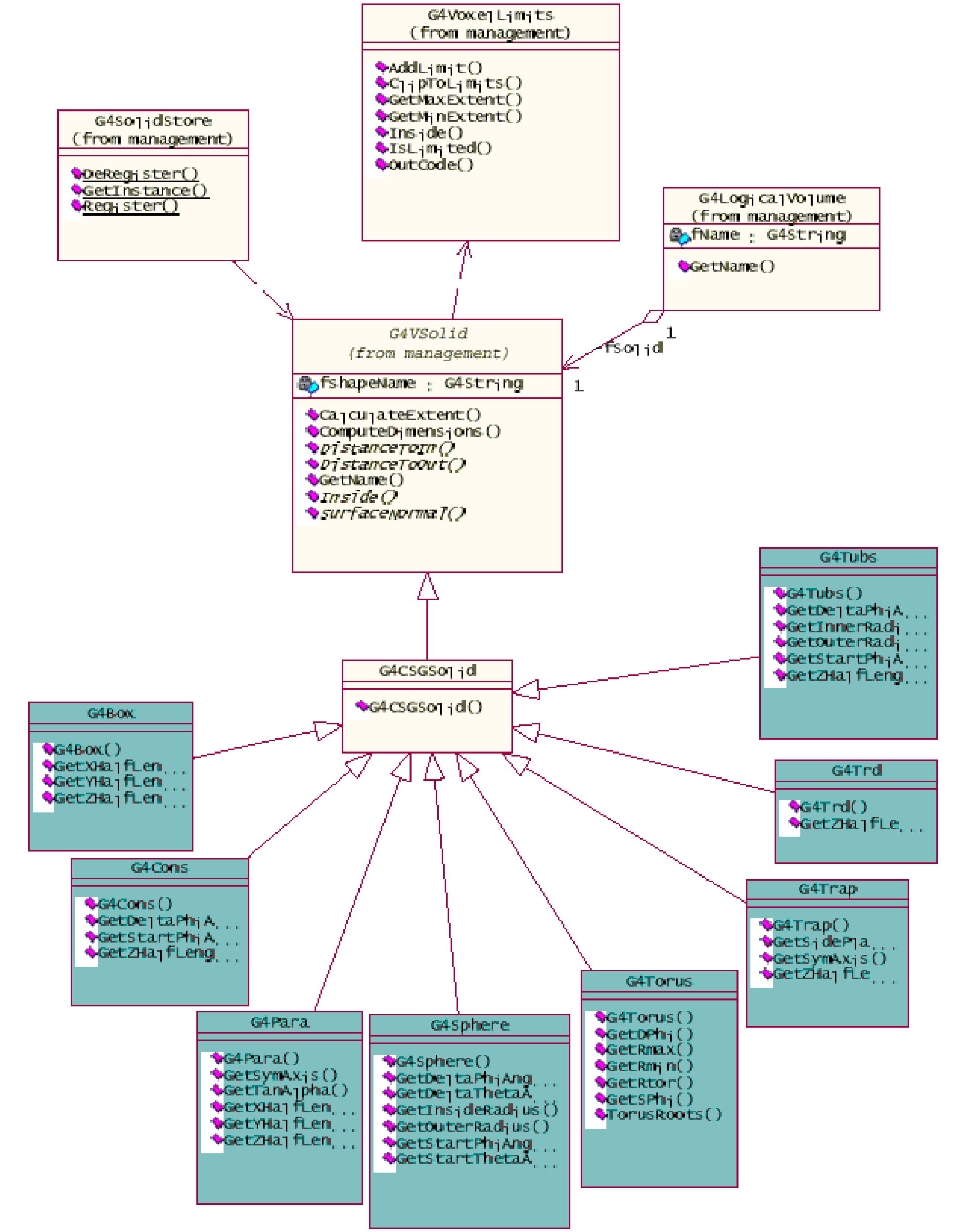
PART III

Detector Description:

Solids & Touchables

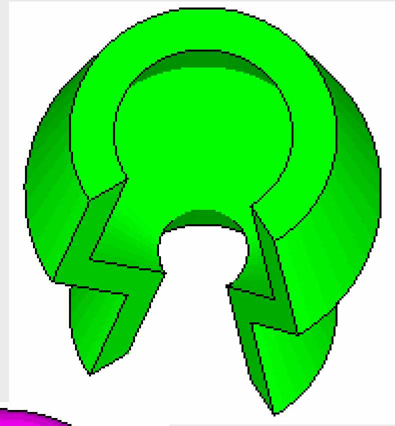
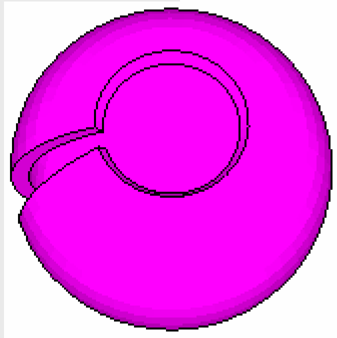
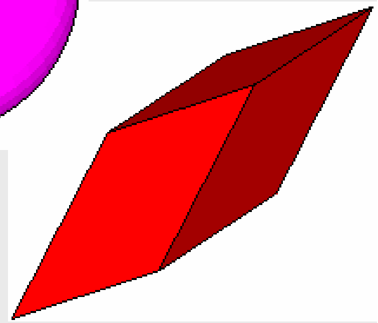
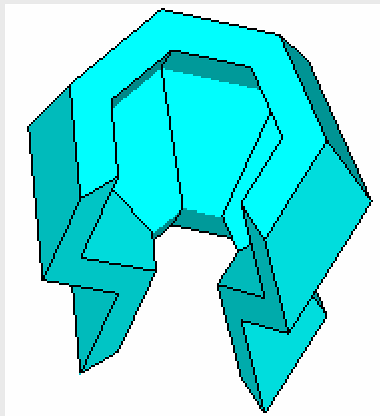
G4VSolid

- Abstract class. All solids in Geant4 derive from it
  - Defines but does not implement all functions required to:
    - compute distances to/from the shape
    - check whether a point is inside the shape
    - compute the extent of the shape
    - compute the surface normal to the shape at a given point
- Once constructed, each solid is automatically registered in a specific solid store



Solids

- Solids defined in Geant4:
  - CSG (Constructed Solid Geometry) solids
    - G4Box, G4Tubs, G4Cons, G4Trd, ...
    - Analogous to simple GEANT3 CSG solids
  - Specific solids (CSG like)
    - G4Polycone, G4Polyhedra, G4Hype, ...
  - BREP (Boundary REPresented) solids
    - G4BREPSolidPolycone, G4BSplineSurface, ...
    - Any order surface
  - Boolean solids
    - G4UnionSolid, G4SubtractionSolid, ...

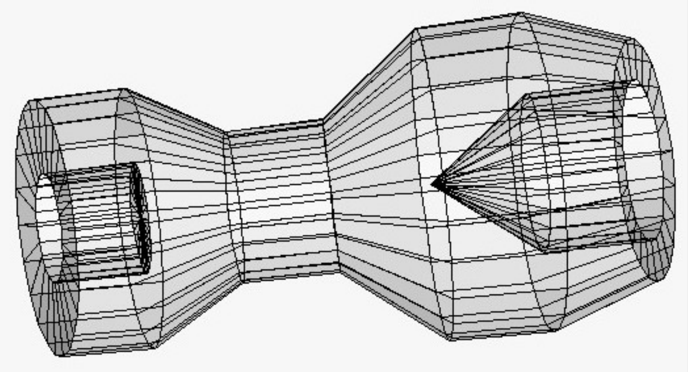
CSG: G4Tubs, G4Cons

```
G4Tubs(const G4String& pname,   // name
             G4double  pRmin,   // inner radius
             G4double  pRmax,   // outer radius
             G4double  pDz,     // Z half length
             G4double  pSphi,   // starting Phi
             G4double  pDphi);  // segment angle

G4Cons(const G4String& pname,   // name
             G4double  pRmin1,  // inner radius -pDz
             G4double  pRmax1,  // outer radius -pDz
             G4double  pRmin2,  // inner radius +pDz
             G4double  pRmax2,  // outer radius +pDz
             G4double  pDz,     // Z half length
             G4double  pSphi,   // starting Phi
             G4double  pDphi);  // segment angle
```

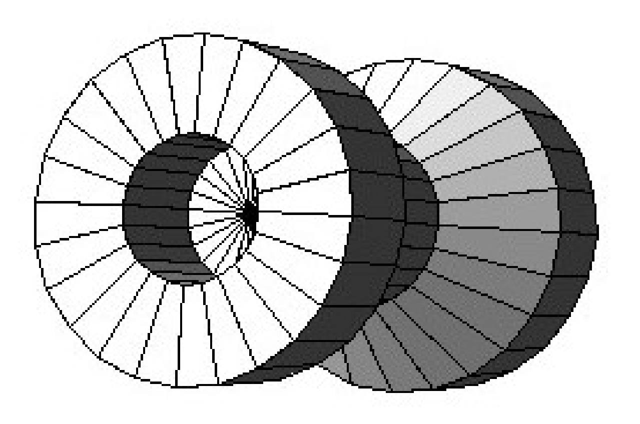
Specific CSG Solids: G4Polycone

```
G4Polycone(const G4String& pName,
                G4double phiStart,
                G4double phiTotal,
                G4int numRZ,
          const G4double r[],
          const G4double z[]);
```



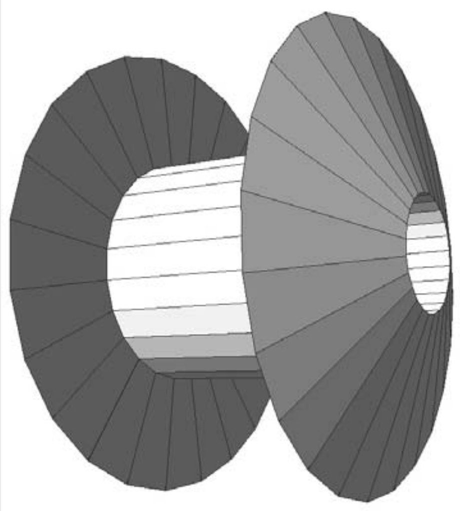
- numRZ - numbers of corners in the r,z space
- r, z - coordinates of corners

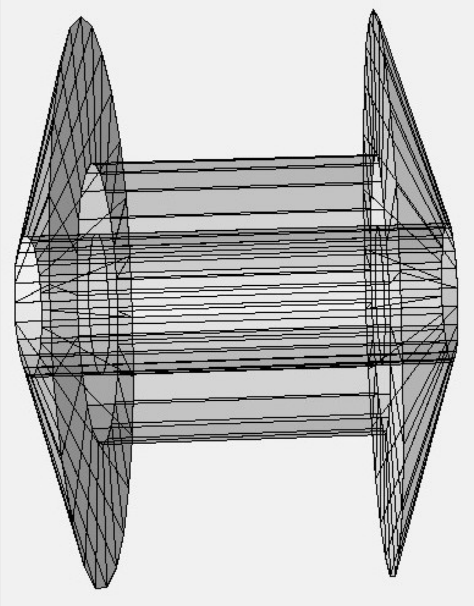
- Additional constructor using planes



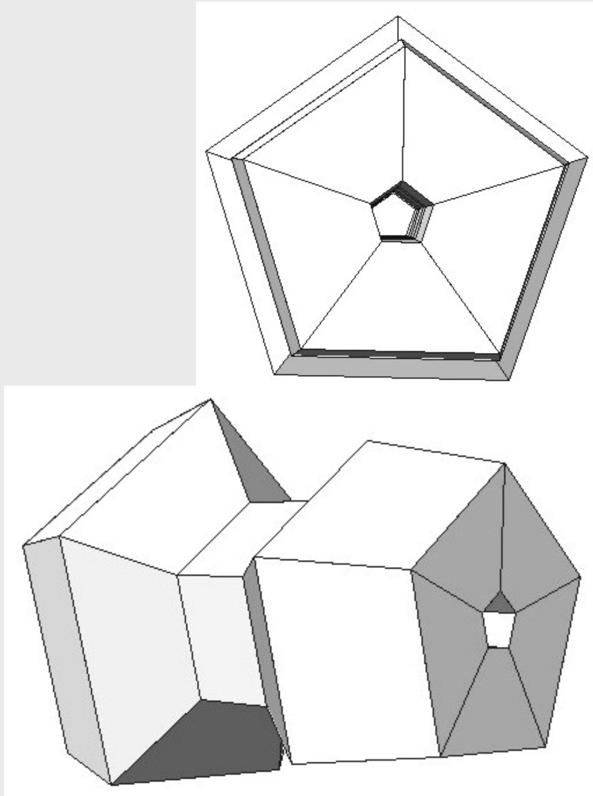
BREP Solids

- *BREP = Boundary REPresented Solid*
- Listing all its surfaces specifies a solid
  - e.g. 6 squares for a cube
- Surfaces can be
  - planar, 2^{nd} or higher order
    - elementary BREPS
  - Splines, B-Splines, *NURBS (Non-Uniform B-Splines)*
    - advanced BREPS
- Few elementary BREPS pre-defined
  - box, cons, tubs, sphere, torus, polycone, polyhedra
- Advanced BREPS built through CAD systems





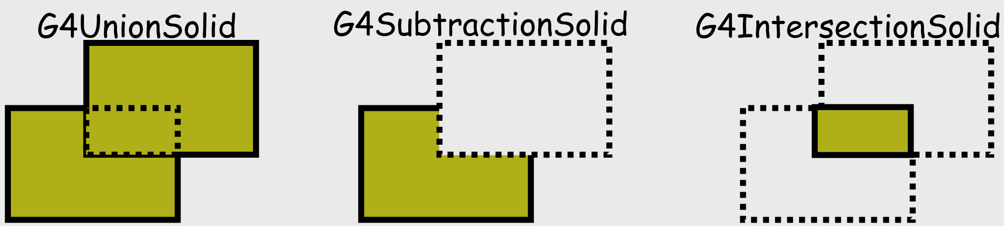
BREPS:
G4BREPSolidPolyhedra



```
G4BREPSolidPolyhedra(const G4String& pName,
                           G4double phiStart,
                           G4double phiTotal,
                           G4int sides,
                           G4int nZplanes,
                           G4double zStart,
                     const G4double zval[],
                     const G4double rmin[],
                     const G4double rmax[]);
```

- `sides` - numbers of sides of each polygon in the `x-y` plane
- `nZplanes` - numbers of planes perpendicular to the `z` axis
- `zval[]` - `z` coordinates of each plane
- `rmin[]`, `rmax[]` - Radii of inner and outer polygon at each plane

Boolean Solids



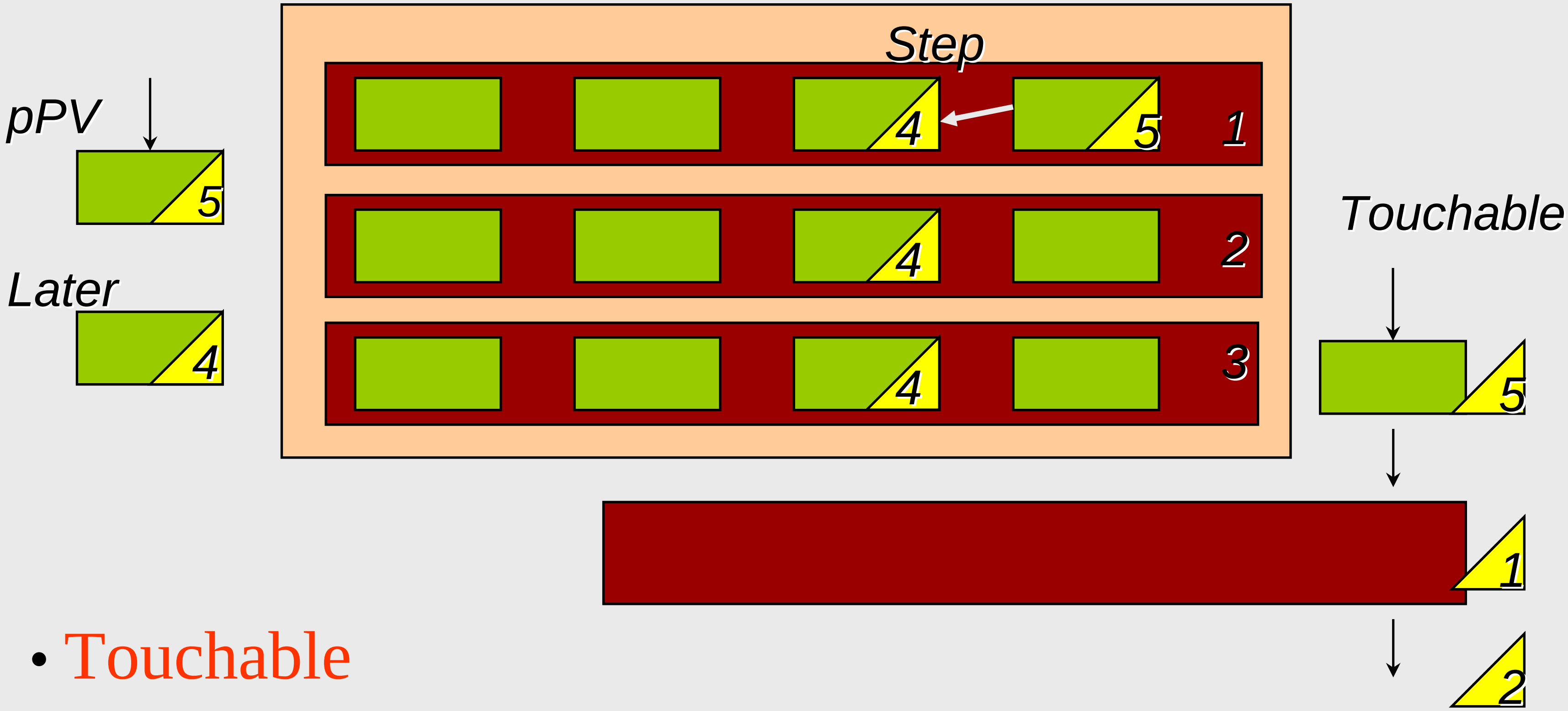
- Solids can be combined using boolean operations:
  - `G4UnionSolid, G4SubtractionSolid, G4IntersectionSolid`
  - Requires: 2 solids, 1 boolean operation, and an (optional) transformation for the 2nd solid
    - 2nd solid is positioned relative to the coordinate system of the 1st solid
- Example:

```
G4Box box("Box", 20, 30, 40);
G4Tubs cylinder("Cylinder", 0, 50, 50, 0, 2*M_PI);  // r:     0 -> 50
                                                    // z:   -50 -> 50
                                                    // phi:   0 ->  2 pi
G4UnionSolid union("Box+Cylinder", &box, &cylinder);
G4IntersectionSolid intersect("Box Intersect Cylinder", &box, &cylinder);
G4SubtractionSolid subtract("Box-Cylinder", &box, &cylinder);
```

- Solids can be either CSG or other Boolean solids
- Note: tracking cost for the navigation in a complex Boolean solid is proportional to the number of constituent solids

How to identify a volume uniquely?

- Need to identify a volume uniquely
- Is a physical volume pointer enough? NO!



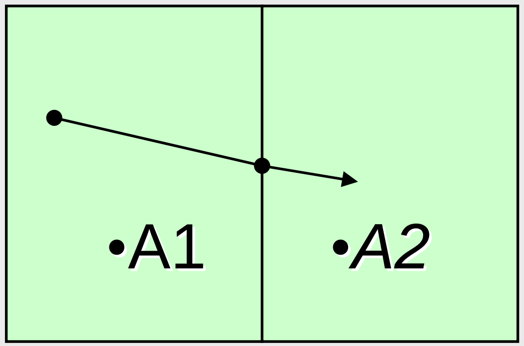
- Touchable

What can a touchable do ?

- All generic touchables can reply to these queries:
  - positioning information (rotation, position)
    - `GetTranslation()`, `GetRotation()`
- Specific types of touchable also know:
  - (solids) - their associated shape: `GetSolid()`
  - (volumes) - their physical volume: `GetVolume()`
  - (volumes) - their replication number: `GetReplicaNumber()`
  - (volumes hierarchy or touchable history):
    - info about its hierarchy of placements: `GetHistoryDepth()`
      - At the top of the history tree is the world volume
    - modify/update touchable: `MoveUpHistory()`, `UpdateYourself()`
      - take additional arguments

Benefits of Touchables in track

- Permanent information stored
  - to avoid implications with a “live” volume tree
- Full geometrical information available
  - to processes
  - to sensitive detectors
  - to hits



Touchable - 1

- G4Step has two G4StepPoint objects as its starting and ending points. All the geometrical information of the particular step should be got from “PreStepPoint”
  - Geometrical information associated with G4Track is basically same as “PostStepPoint”
- Each G4StepPoint object has:
  - position in world coordinate system
  - global and local time
  - material
  - G4TouchableHistory for geometrical information
    - Copy-number, transformations
- *Handles* (or *smart-pointers*) to touchables are intrinsically used. Touchables are reference counted

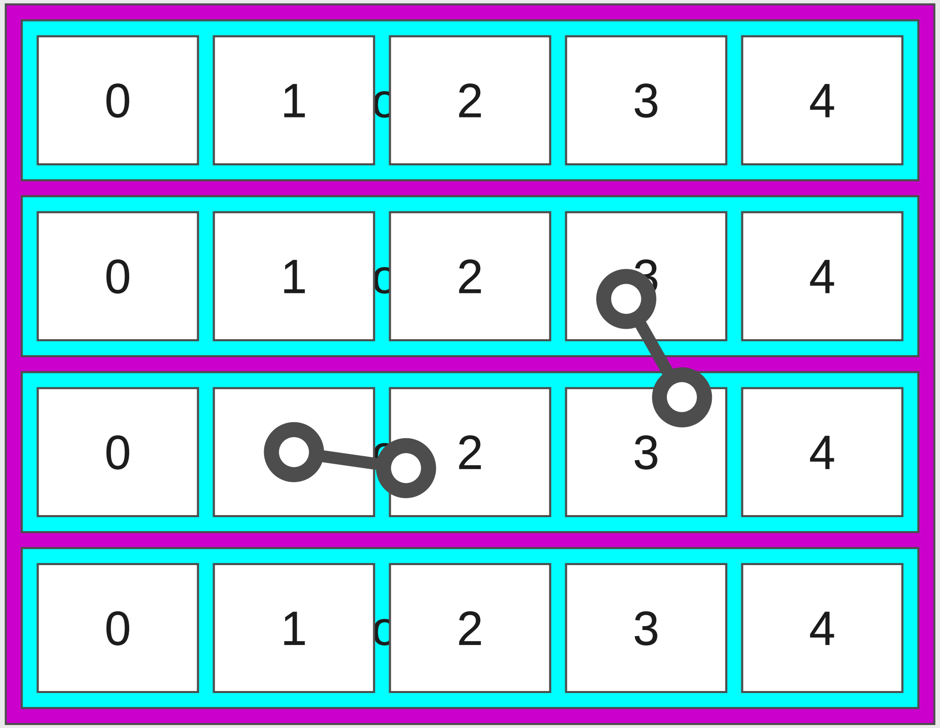
Touchable - 2

- G4TouchableHistory has information of geometrical hierarchy of the point

```
G4Step* aStep = ..;
G4StepPoint* preStepPoint = aStep->GetPreStepPoint();
G4TouchableHandle theTouchable =
               preStepPoint->GetTouchableHandle();
G4int copyNo = theTouchable->GetReplicaNumber();
G4int motherCopyNo = theTouchable->GetReplicaNumber(1);
G4ThreeVector worldPos = preStepPoint->GetPosition();
G4ThreeVector localPos = theTouchable->GetHistory()->
    GetTopTransform().TransformPoint(worldPos);
```

Copy numbers

- Suppose a calorimeter is made of 4x5 cells
  - and it is implemented by two levels of replica.
- In reality, there is only one physical volume object for each level. Its position is parameterized by its copy number
- To get the copy number of each level, suppose what happens if a step belongs to two cells



  - Remember geometrical information in G4Track is identical to "PostStepPoint". You cannot get the collect copy number for "PreStepPoint" if you directly access to the physical volume
- Use touchable to get the proper copy number, transform matrix,…