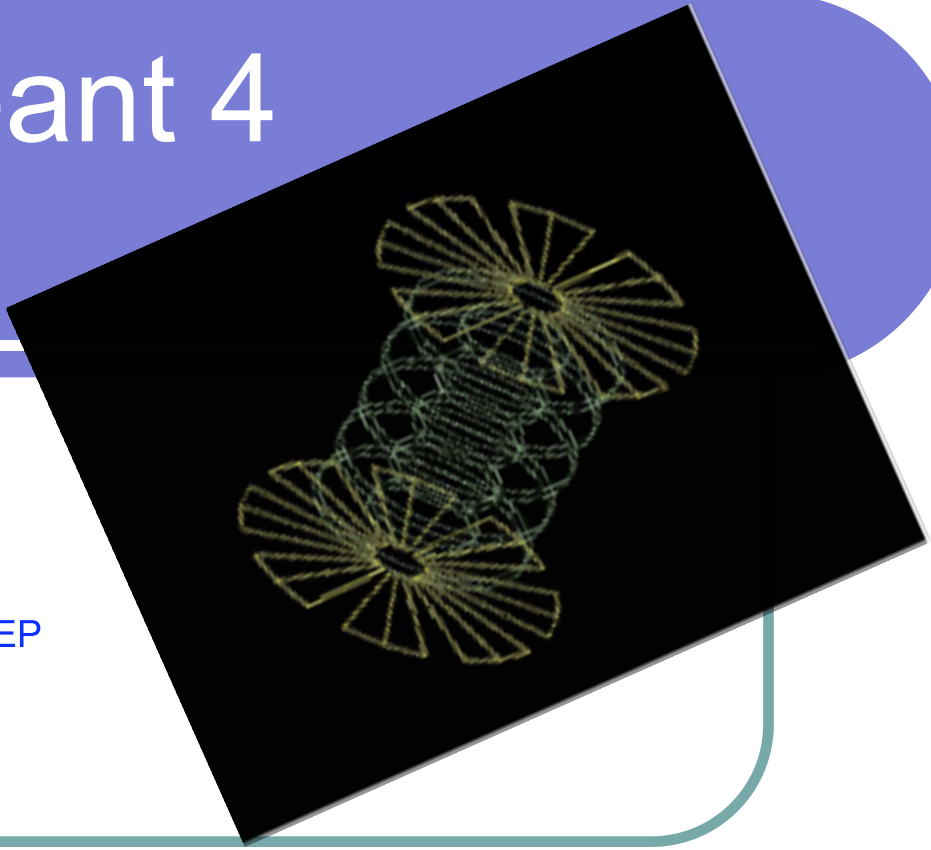
Quick Intro to

Geometry in Geant 4 - Basic concept



Karim Laihem

Geant4 Training event – Calorimetry in HEP

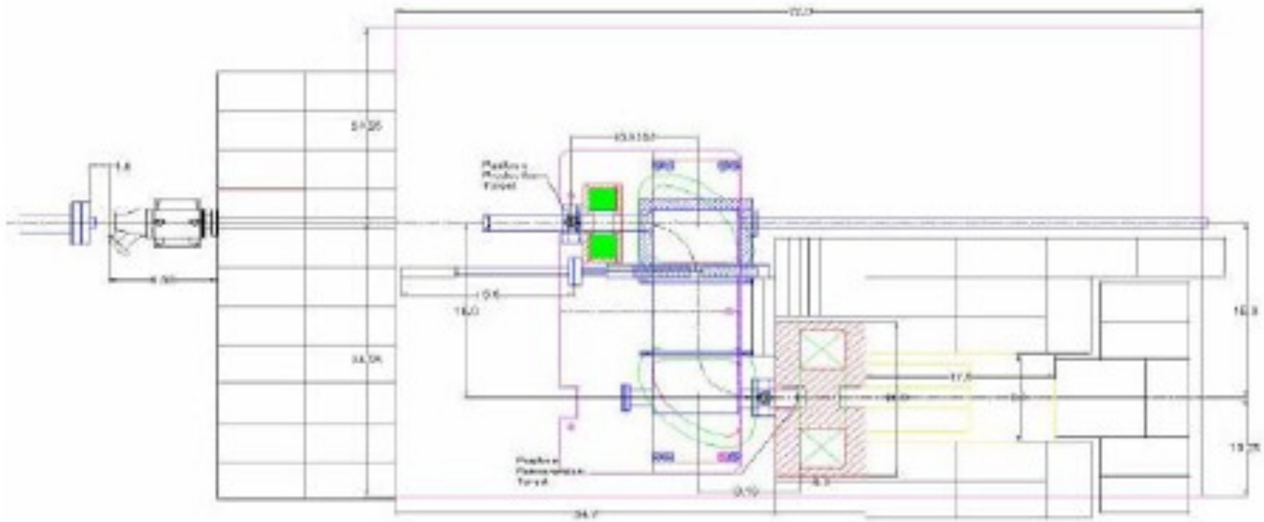
DESY Zeuthen 10 -13 May 2011

Contents

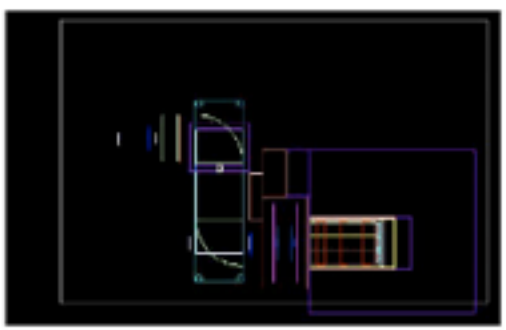
- Introduction
- Solid and shape
- Logical volume
- Physical volume and placement

Introduction: Example of an experimental setup

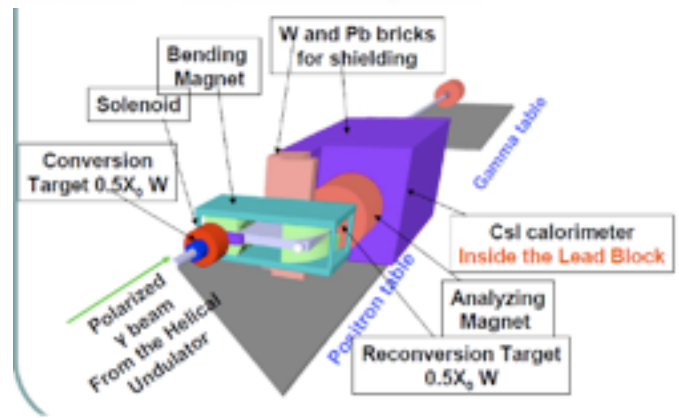
Technical design



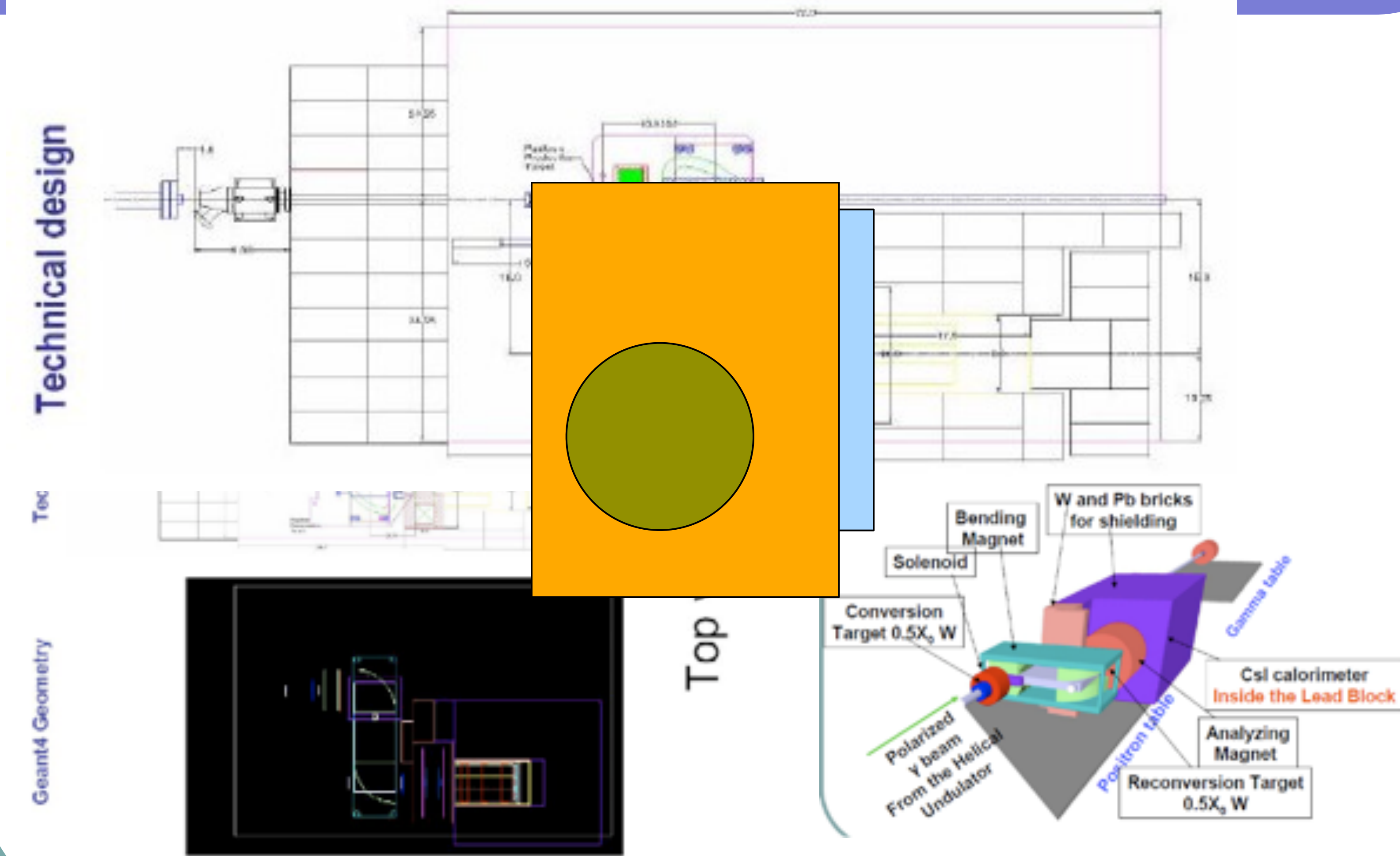
Geant4 Geometry



Top view



Introduction: Example of an experimental setup



Geometry – Basics.

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

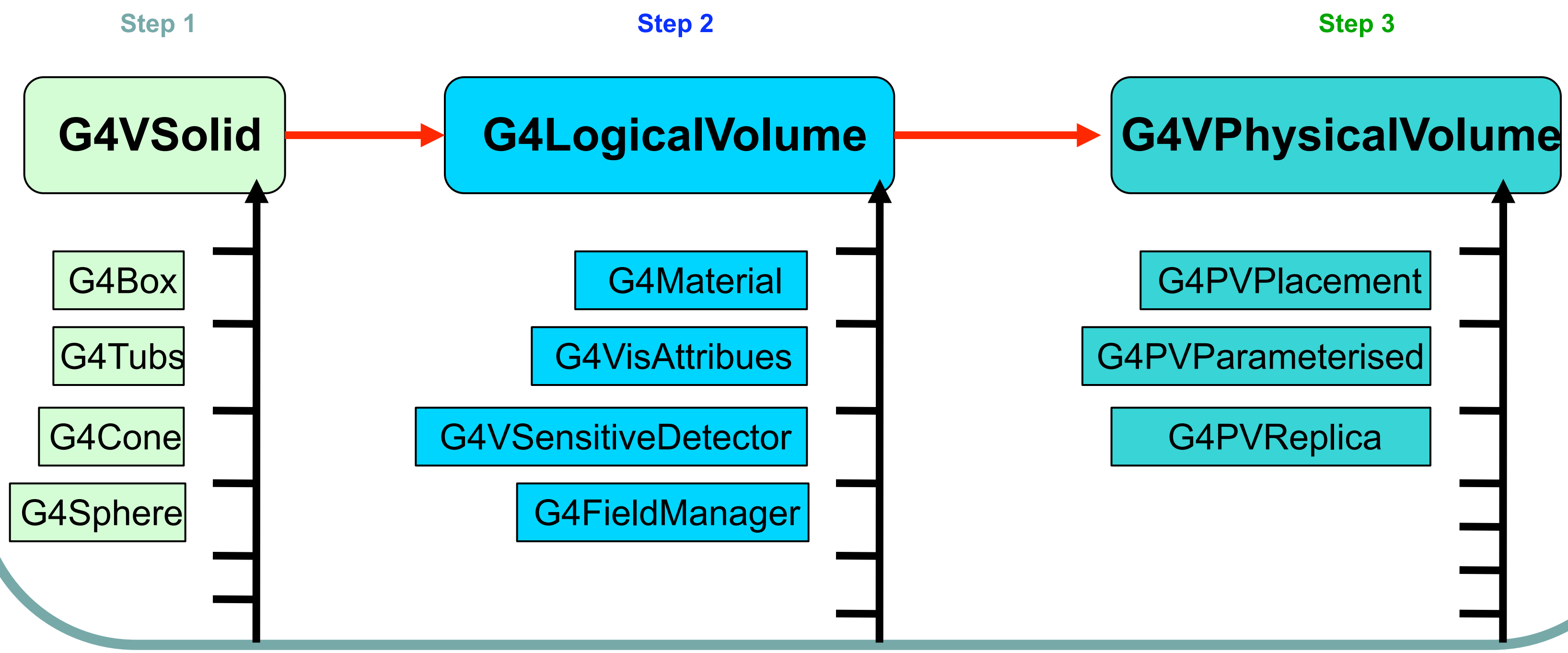
Basic concept

Three conceptual layers (Steps)

Step 1 **G4VSolid** -- *shape, size*

Step 2 **G4LogicalVolume** -- *material, sensitivity, Electric & Magnetic fields etc…*

Step 3 **G4VPhysicalVolume** -- *position, rotation*



Geometrical hierarchy

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- One logical volume can be placed more than once. One or more volumes can be placed to a mother volume.

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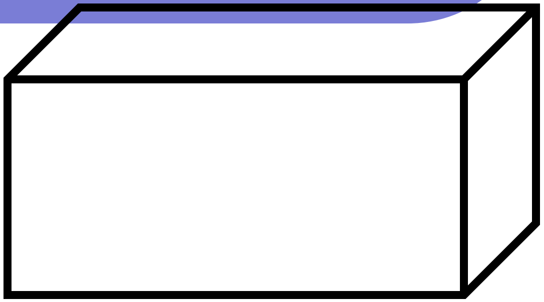

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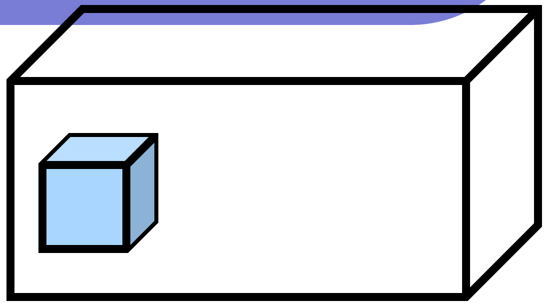

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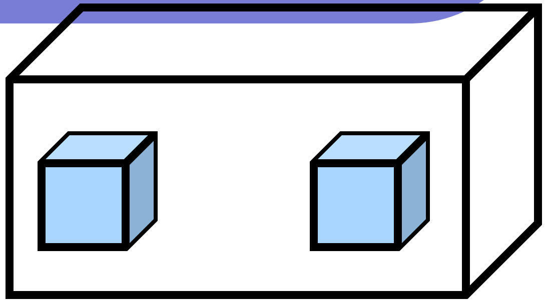

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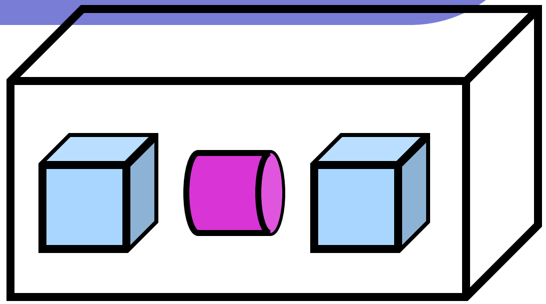

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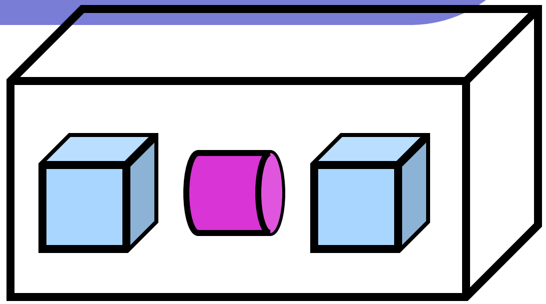

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  - If the mother volume is placed more than once, all daughters are by definition appear in all of mother physical volumes.

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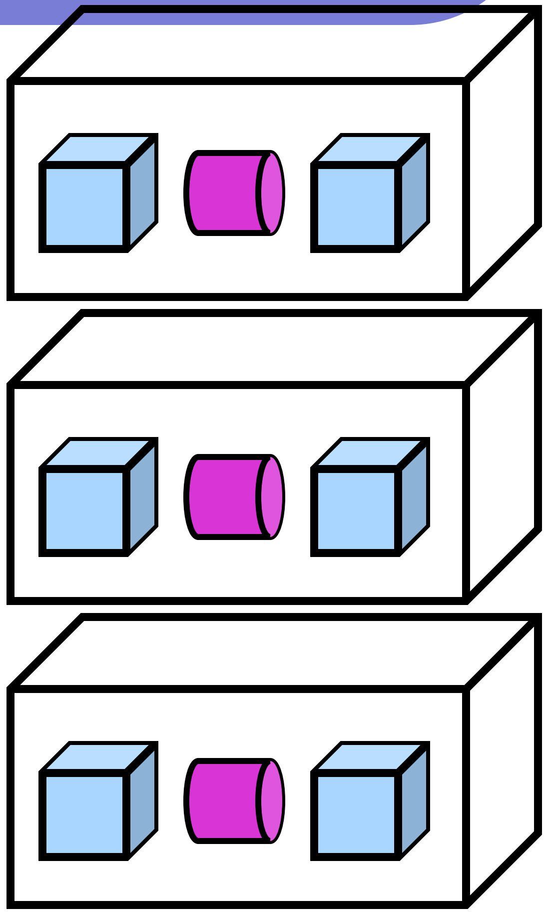

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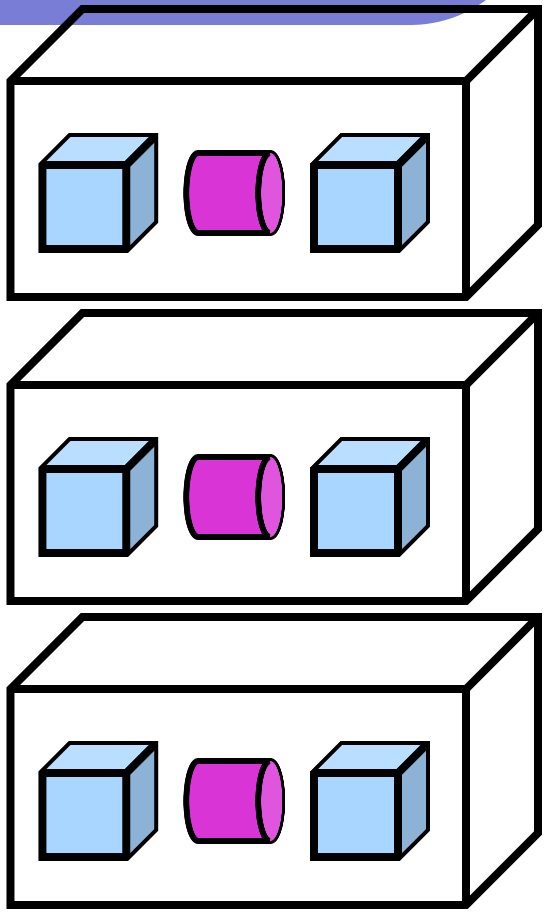
- The world volume must be a unique physical volume which fully contains all the other volumes.



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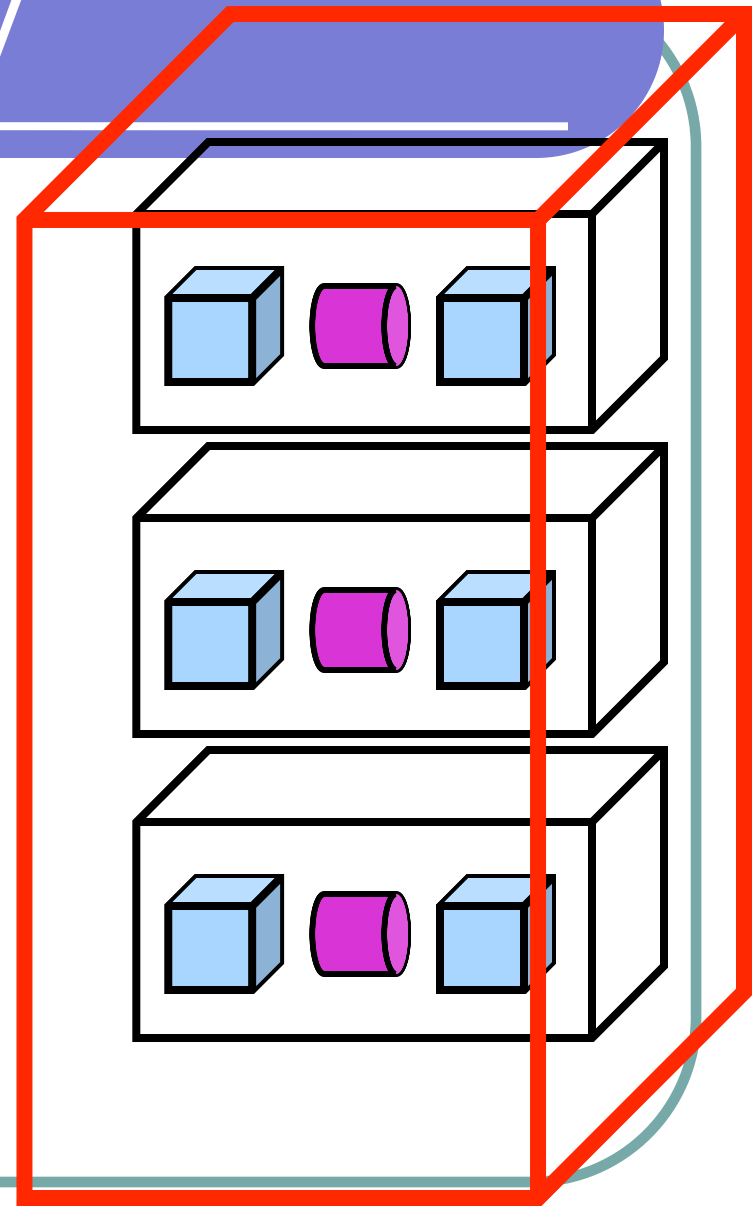

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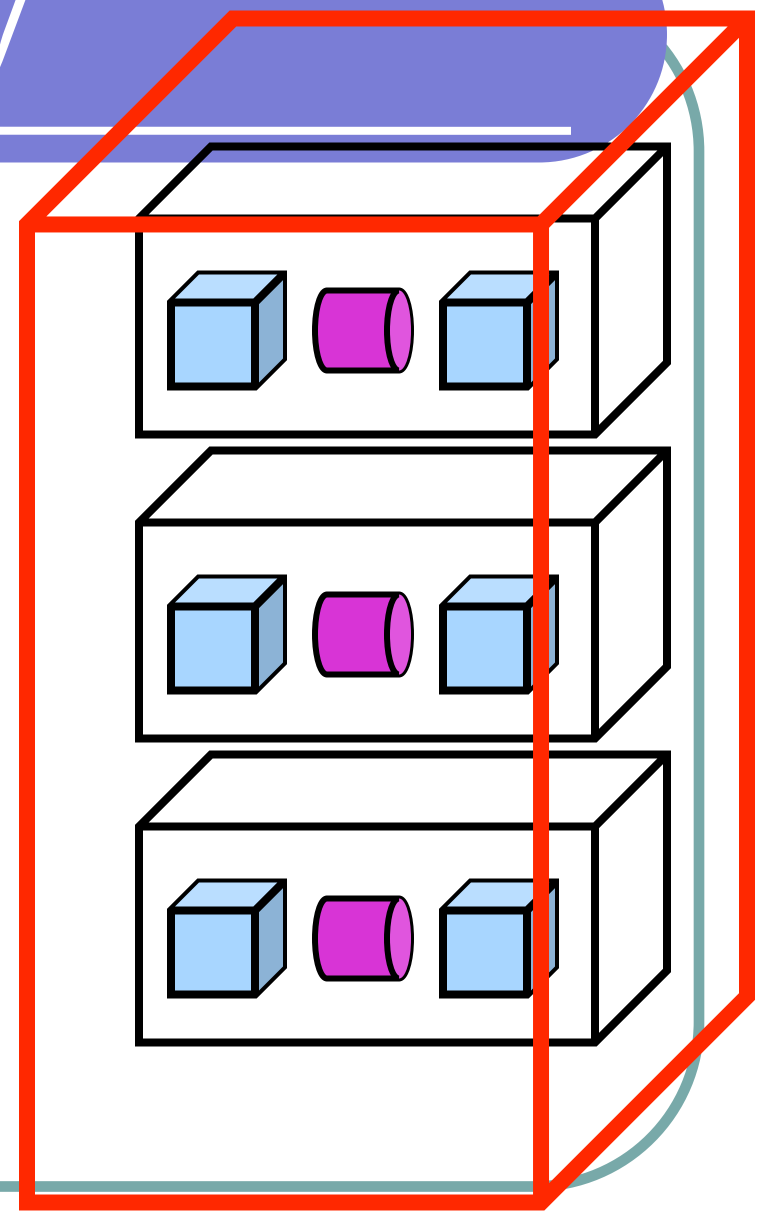

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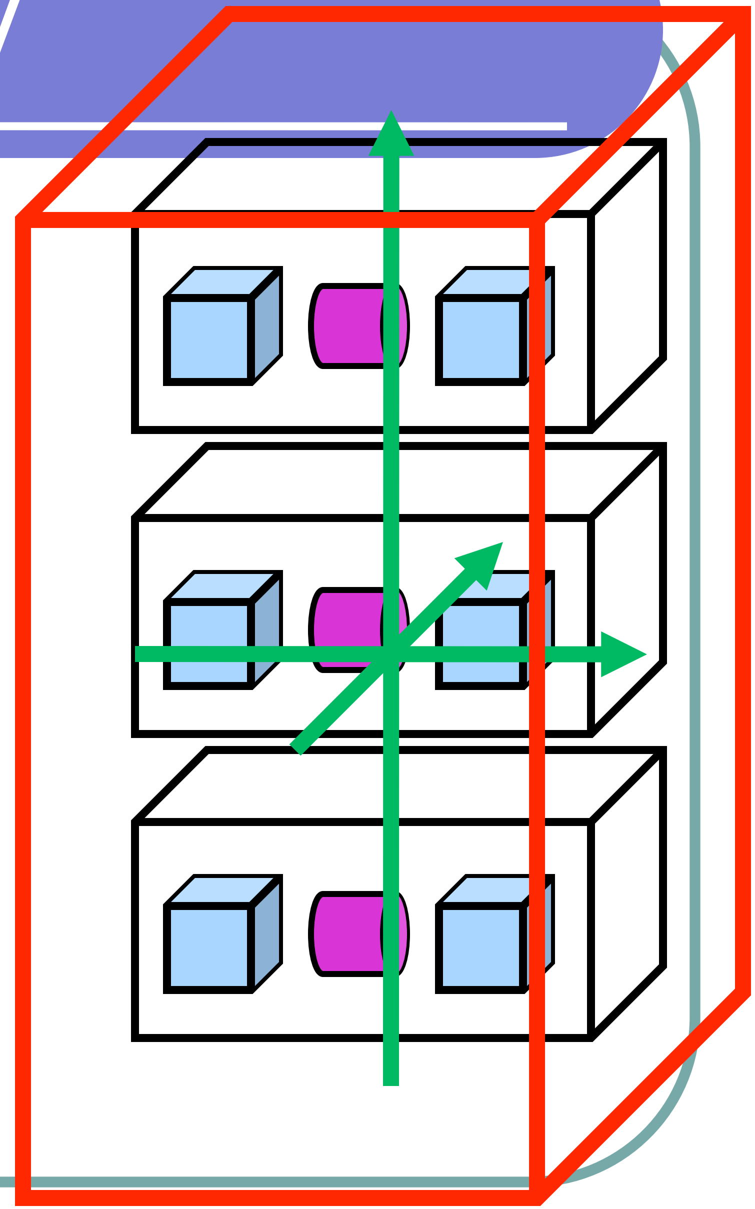

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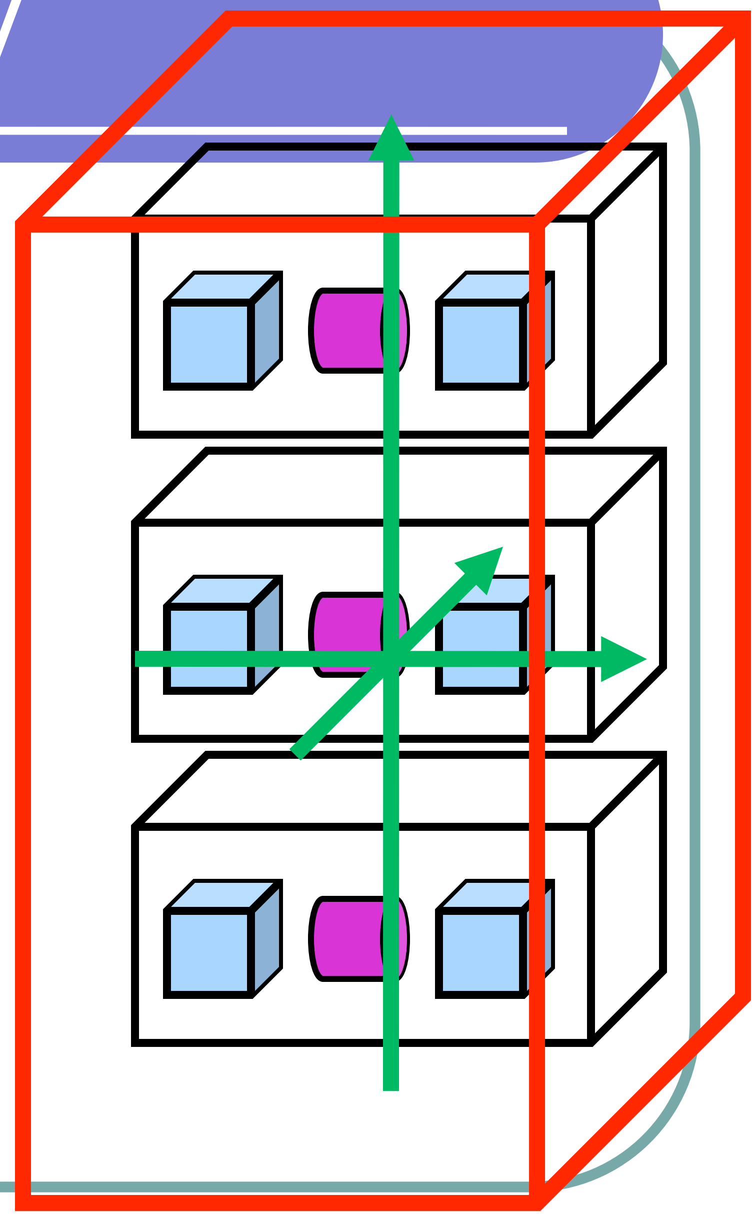
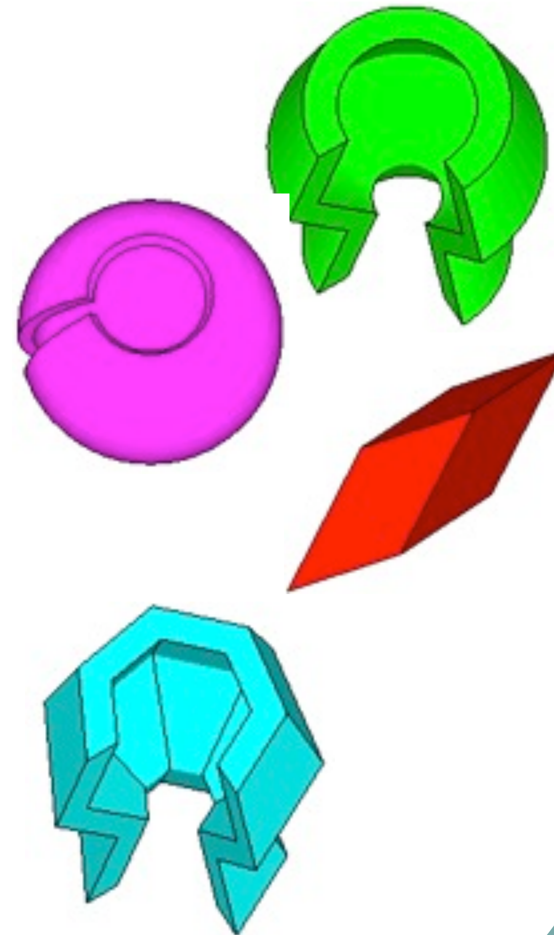
  - The world volume defines the global coordinate system. The origin of the global coordinate system is at the center of the world volume.
  - Position of a track is given with respect to the global coordinate system.



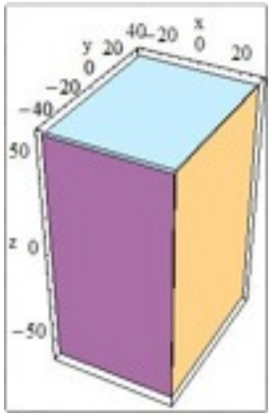
Solids and shapes

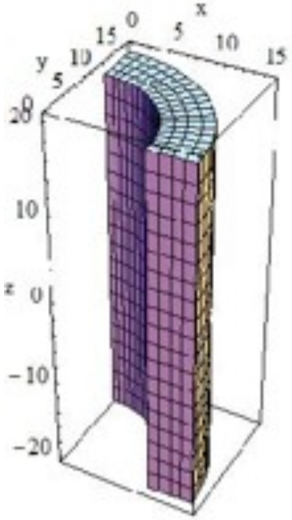
- **Solids defined in Geant4:**
  - **CSG (Constructed Solid Geometry) solids**
    - G4Box, G4Tubs, G4Cons, G4Trd, …
  - **Specific solids (CSG like)**
    - G4Polycone, G4Polyhedra, G4Hype, …
  - **BREP (Boundary REPresented) solids**
    - G4BREPSolidPolycone, G4BSplineSurface, …
    - Any order surface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



Box and Tubs

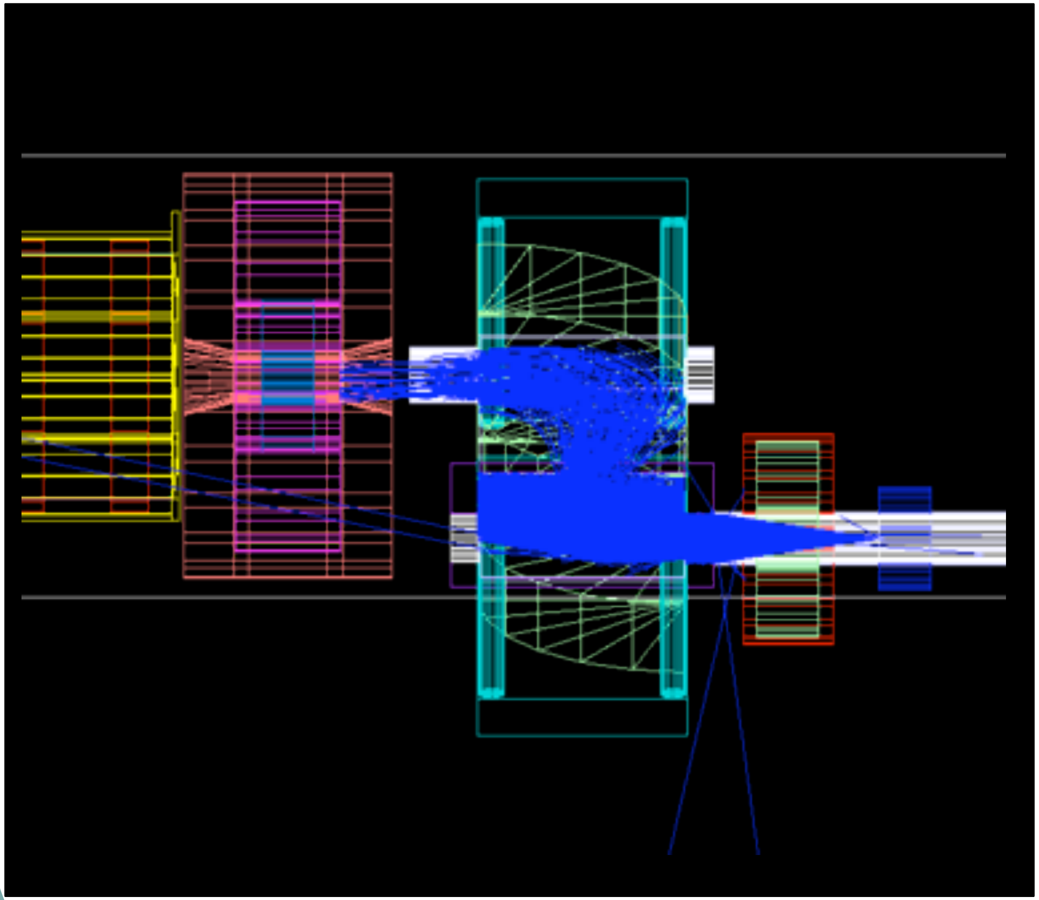
- G4Box(const G4String &pname, // name
- G4double half_x, // X half size
- G4double half_y, // Y half size
- G4double half_z); // Z half size

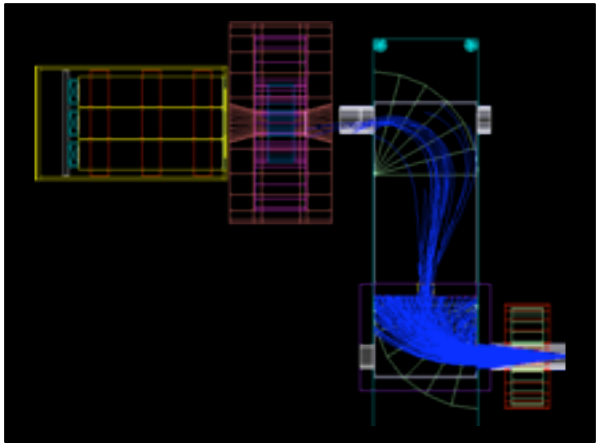




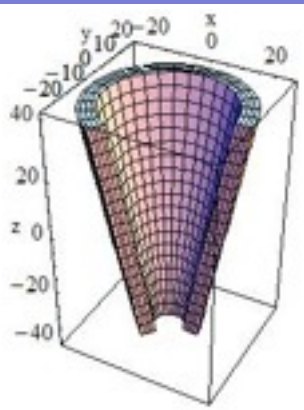
- G4Tubs(const G4String &pname, // name
- G4double pRmin, // inner radius
- G4double pRmax, // outer radius
- G4double pDz, // Z half length
- G4double pSphi, // starting Phi
- G4double pDphi); // segment angle

Example of an experimental setup. Spectrometer E166 experiment at SLAC

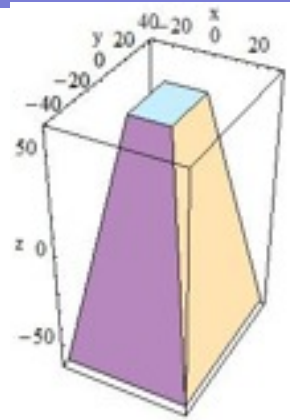




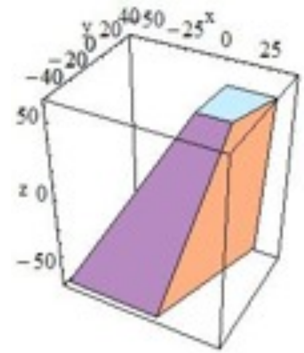
Other CSG solids



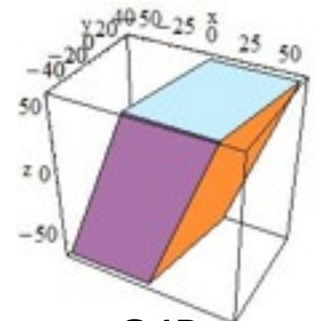
G4Cons



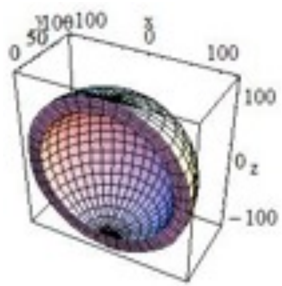
G4Trd



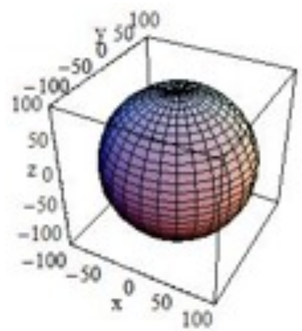
G4Trap



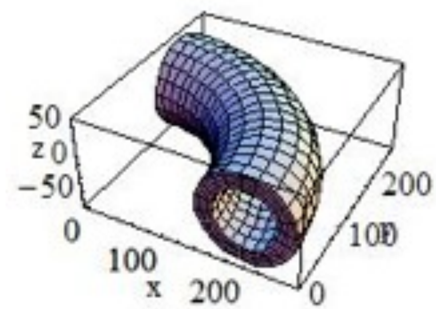
G4Para
(parallelepiped)



G4Sphere



G4Orb
(full solid sphere)



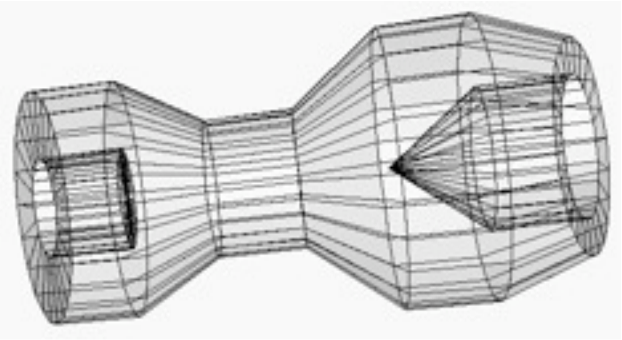
G4Torus

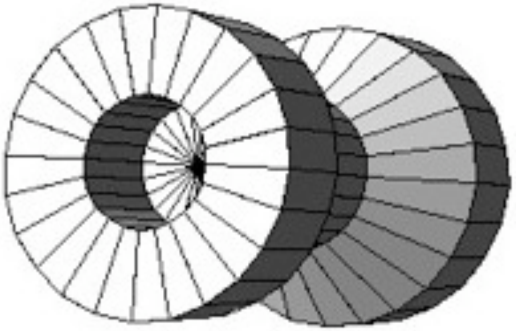
Consult to Section 4.1.2 of Geant4 Application Developers Guide for all available shapes.

Specific CSG Solids: G4Polycone

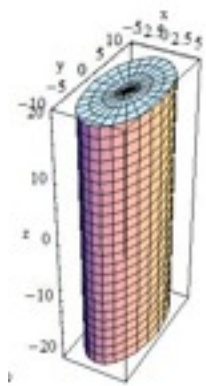
```
G4Polycone(const G4String& pName,
           G4double phiStart,
           G4double phiTotal,
           G4int numRZ,
           const G4double r[],
           const G4double z[]);
```

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

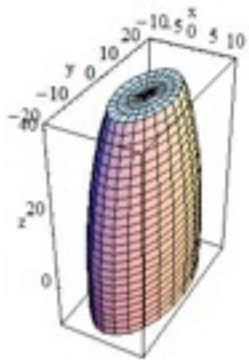




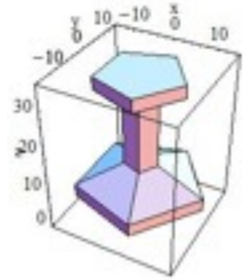
Other Specific CSG solids



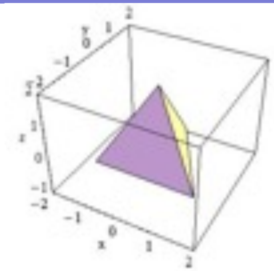
G4EllipticalTube



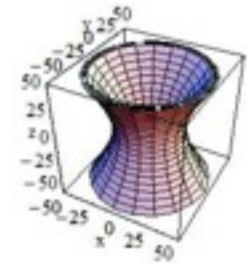
G4Ellipsoid



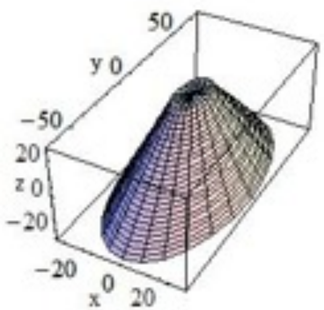
G4Polyhedra



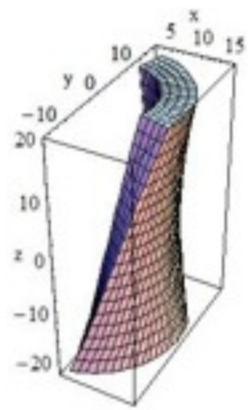
G4Tet (tetrahedra)



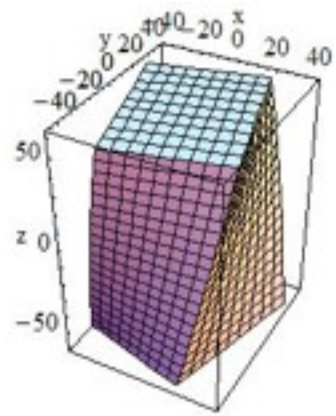
G4Hype



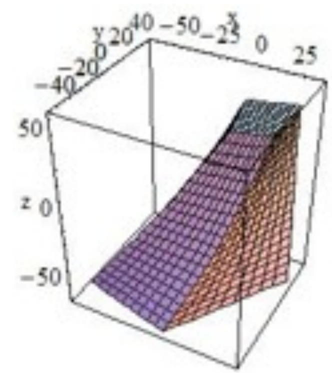
G4EllipticalCone



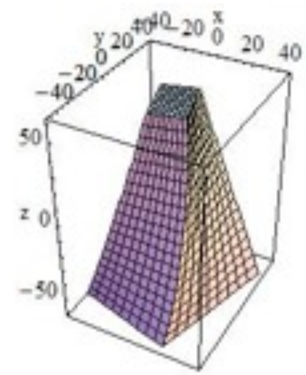
G4TwistedTubs



G4TwistedBox



G4TwistedTrap

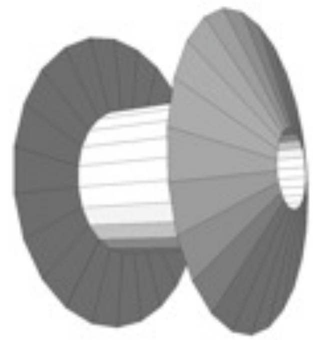


G4TwistedTrd

Consult to Section 4.1.2 of Geant4 Application Developers Guide for all available shapes.

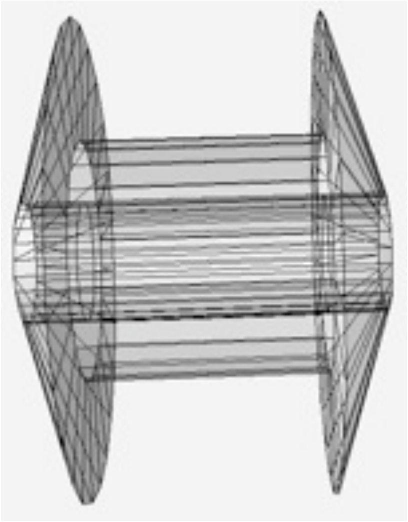
BREP Solids

BREP = Boundary REPresented Solid



- Listing all its surfaces specifies a solid
  - e.g. 6 planes for a cube
- Surfaces can be
  - planar, 2^{nd} or higher order
    - elementary BREPS
  - Splines, B-Splines,

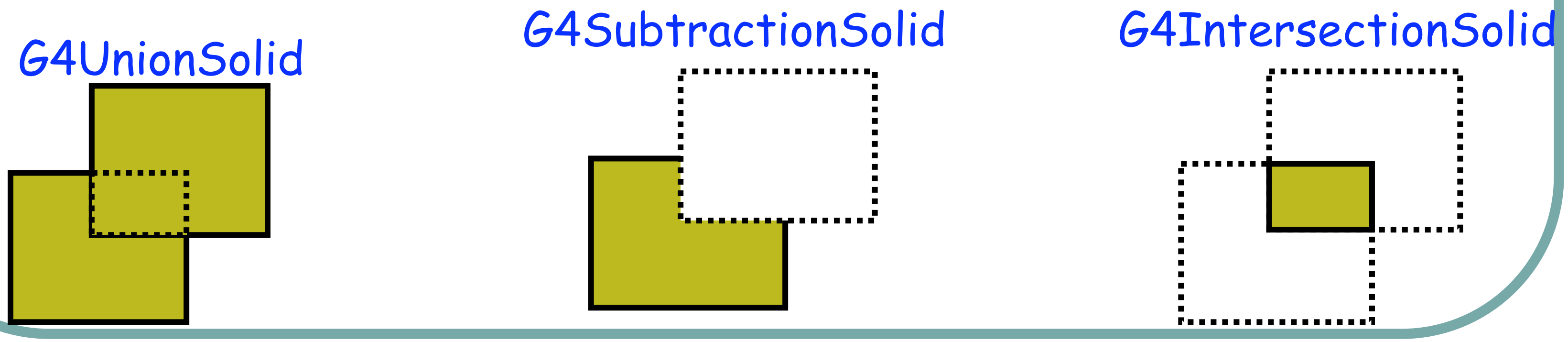
    NURBS (Non-Uniform B-Splines)
    - advanced BREPS
- Few elementary BREPS pre-defined
  - box, cons, tubs, sphere, torus, polycone, polyhedra
- Advanced BREPS built through CAD systems



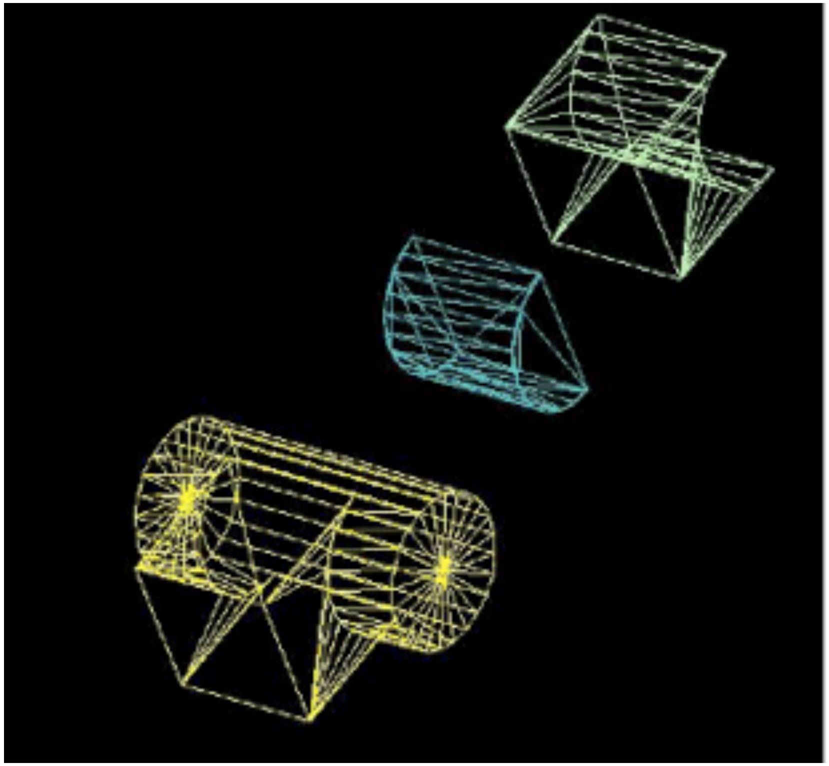
Boolean Solids

- 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
  - Result of boolean operation becomes a solid. Thus the third solid can be combined to the resulting solid of first operation.
- Solids to be combined 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 CSG solids



Boolean solid



Boolean Solids - example

```
G4VSolid* box = new G4Box("Box",50*cm,60*cm,40*cm);
G4VSolid* cylinder = new G4Tubs("Cylinder",0.,50.*cm,50.*cm,0.,2*M_PI*rad);

G4VSolid* union = new G4UnionSolid("Box+Cylinder", box, cylinder);

G4VSolid* subtract = new G4SubtractionSolid("Box-Cylinder", box, cylinder,
                                  0, G4ThreeVector(30.*cm,0.,0.));

G4RotationMatrix* rm = new G4RotationMatrix();
rm->RotateX(30.*deg);

G4VSolid* intersect = new G4IntersectionSolid("Box&&Cylinder",
                box, cylinder, rm, G4ThreeVector(0.,0.,0.));
```

- The origin and the coordinates of the combined solid are the same as those of the first solid.

Next step

We are done with solids and shapes

Logical Volume

G4LogicalVolume

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

- Contains all information of volume except position and rotation
  - Shape and dimension (G4VSolid)
  - Material, sensitivity, visualization attributes
  - Position of daughter volumes
  - Magnetic field, ……
- Physical volumes of same type can share the common logical volume object.
- The pointers to solid must NOT be null.
- The pointers to material must NOT be null for tracking geometry.

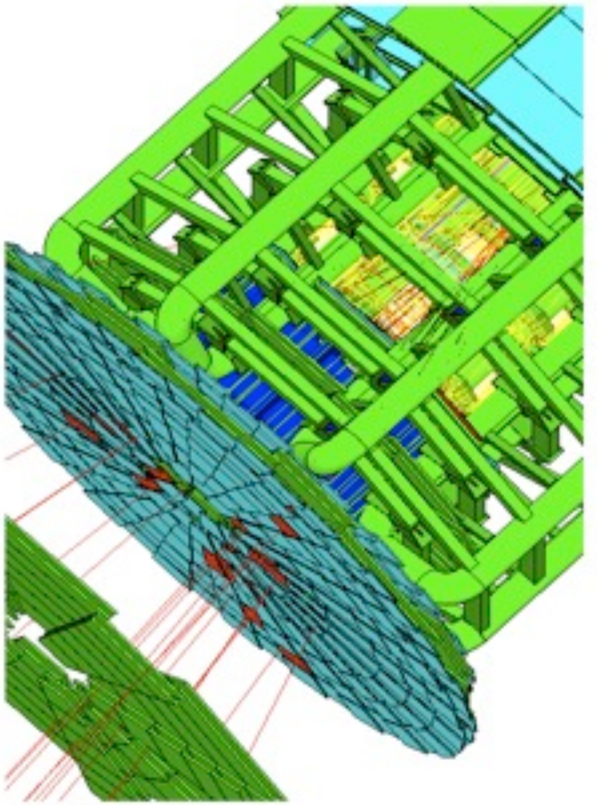
Next step

We are done with
Logical volume

Physical Volume

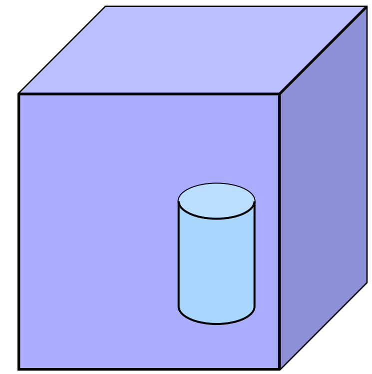
Physical Volume and placement

- Various ways of placement
  - Simple placement volume
  - Parameterized volume
  - Replicated volume
  - -
  - -
- Geometry checking tools

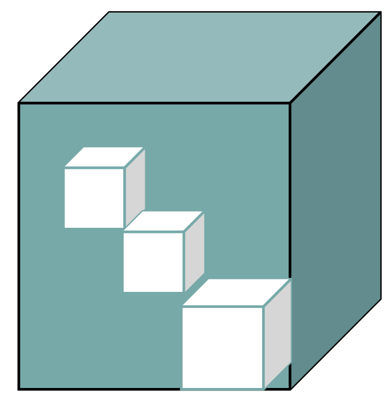


Physical Volumes

- Placement volume : it is one positioned volume
  - One physical volume object represents one “real” volume.
- Repeated volume : a volume placed many times
  - One physical volume object represents many “real” volumes.
  - reduces use of memory.
  - Parameterised
    - repetition w.r.t. copy number
  - Replica
    - simple repetition along one axis
- A mother volume can contain either
  - many placement volumes
  - or, one repeated volume



placement



repeated

Physical volume

- G4PVPlacement 1 Placement = One Placement Volume
  - A volume instance positioned once in its mother volume
- G4PVParameterised 1 Parameterized = Many Repeated Volumes
  - Parameterized by the copy number
    - Shape, size, material, sensitivity, vis attributes, position and rotation can be parameterized by the copy number.
    - You have to implement a concrete class of G4VPVParameterisation.
  - Reduction of memory consumption
  - Currently: parameterization can be used only for volumes that either

    a) have no further daughters, or

Physical volume

- G4PVReplica 1 Replica = Many Repeated Volumes
  - Daughters of same shape are aligned along one axis
  - Daughters fill the mother completely without gap in between.

G4PVPlacement

```
G4PVPlacement(
  G4Transform3D(G4RotationMatrix &pRot, // rotation of daughter volume
            const G4ThreeVector &tlate), // position in mother frame
            G4LogicalVolume *pDaughterLogical,
            const G4String &pName,
            G4LogicalVolume *pMotherLogical,
            G4bool pMany,              // 'true' is not supported yet…
            G4int pCopyNo,             // unique arbitrary integer
            G4bool pSurfChk=false);    // optional boundary check
```

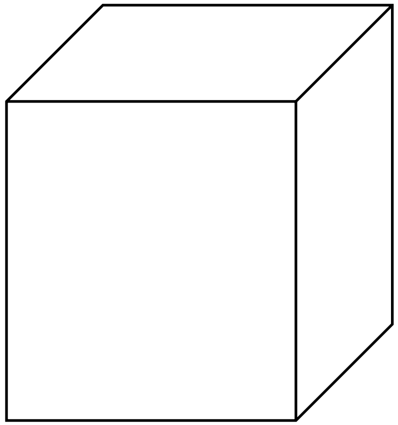
- Single volume positioned relatively to the mother volume.

G4PVParameterised

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

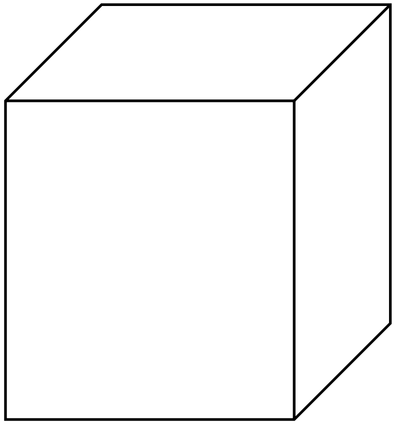
- Replicates the volume `nReplicas` times using the parameterization `pParam`, within the mother volume `pMother`
- `pAxis` is a "suggestion" to the navigator along which Cartesian axis replication of parameterized volumes dominates.
  - kXAxis, kYAxis, kZAxis : one-dimensional optimization
  - kUndefined : three-dimensional optimization

Parameterized Physical Volumes



Parameterized Physical Volumes

- User should implement a class derived from G4VPVParameterisation abstract base class and define following as a function of copy number
  - where it is positioned (transformation, rotation)



Parameterized Physical Volumes

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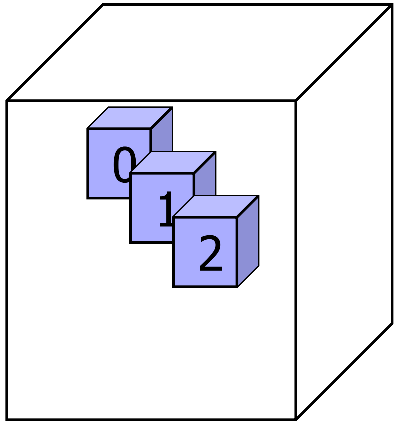
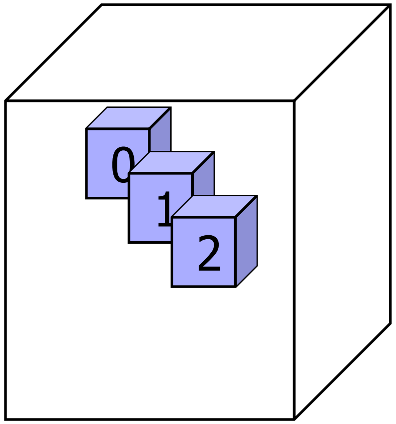


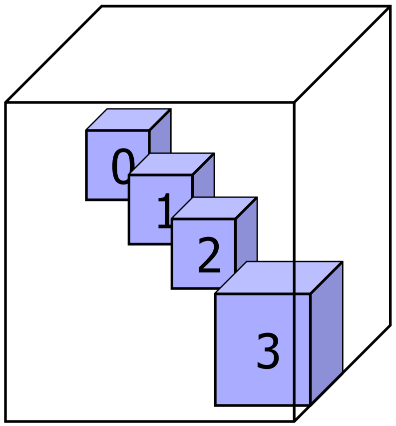
Parameterized Physical Volumes

- User should implement a class derived from G4VPVParameterisation abstract base class and define following as a function of copy number
  - where it is positioned (transformation, rotation)
- Optional:
  - the size of the solid (dimensions)



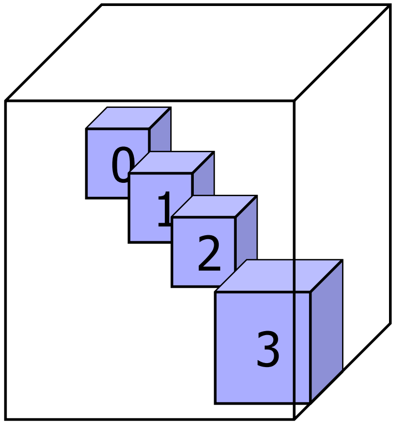
Parameterized Physical Volumes

- User should implement a class derived from G4VPVParameterisation abstract base class and define following as a function of copy number
  - where it is positioned (transformation, rotation)
- Optional:
  - the size of the solid (dimensions)



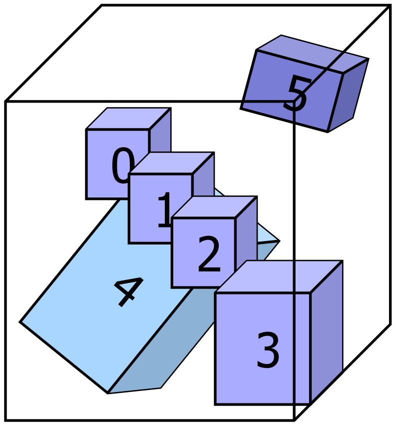
Parameterized Physical Volumes

- User should implement a class derived from G4VPVParameterisation abstract base class and define following as a function of copy number
  - where it is positioned (transformation, rotation)
- Optional:
  - the size of the solid (dimensions)
  - the type of the solid, material, sensitivity, vis attributes



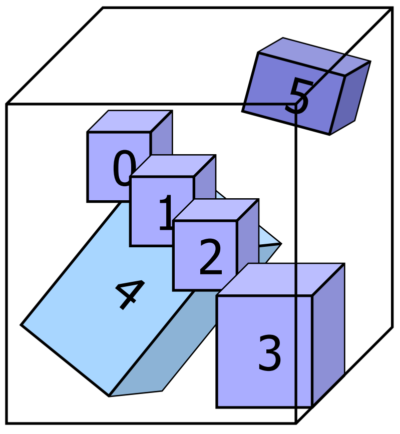
Parameterized Physical Volumes

- User should implement a class derived from G4VPVParameterisation abstract base class and define following as a function of copy number
  - where it is positioned (transformation, rotation)
- Optional:
  - the size of the solid (dimensions)
  - the type of the solid, material, sensitivity, vis attributes



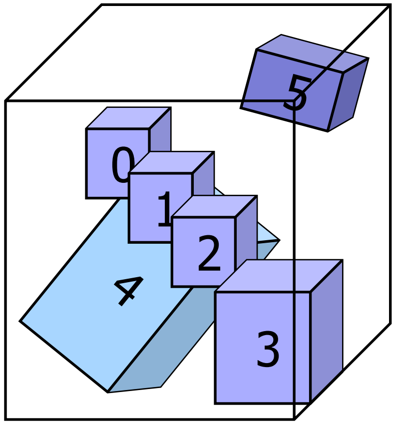
Parameterized Physical Volumes

- User should implement a class derived from G4VPVParameterisation abstract base class and define following as a function of copy number
  - where it is positioned (transformation, rotation)
- Optional:
  - the size of the solid (dimensions)
  - the type of the solid, material, sensitivity, vis attributes
- All daughters must be fully contained in the mother.
- Daughters should not overlap to each other.



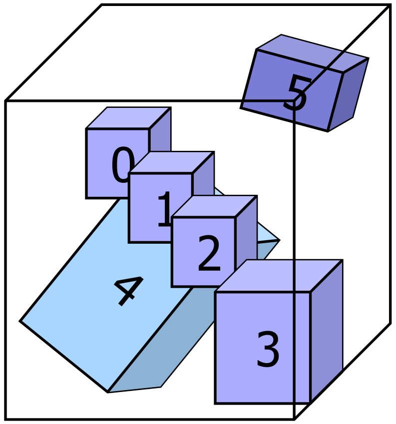
Parameterized Physical Volumes

- User should implement a class derived from G4VPVParameterisation abstract base class and define following as a function of copy number
  - where it is positioned (transformation, rotation)
- Optional:
  - the size of the solid (dimensions)
  - the type of the solid, material, sensitivity, vis attributes
- All daughters must be fully contained in the mother.
- Daughters should not overlap to each other.
- Limitations:
  - Applies to simple CSG solids only



Parameterized Physical Volumes

- User should implement a class derived from G4VPVParameterisation abstract base class and define following as a function of copy number
  - where it is positioned (transformation, rotation)
- Optional:
  - the size of the solid (dimensions)
  - the type of the solid, material, sensitivity, vis attributes
- All daughters must be fully contained in the mother.
- Daughters should not overlap to each other.
- Limitations:
  - Applies to simple CSG solids only
- Typical use-cases
  - Complex detectors
    - with large repetition of volumes, regular or irregular



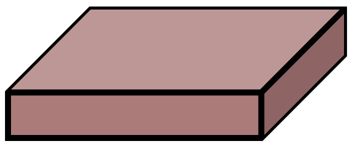
G4PVReplica

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

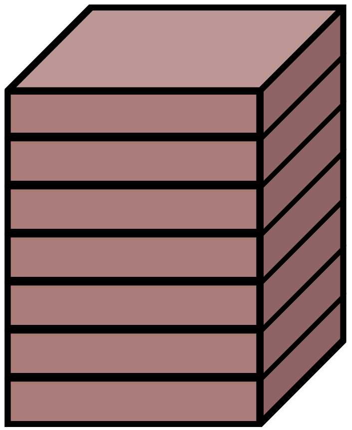
- `offset` may be used only for tube/cone segment
- Features and restrictions:
  - Replicas can be placed inside other replicas
  - Normal placement volumes can be placed inside replicas, assuming no intersection/overlaps with the mother volume or with other replicas
  - No volume can be placed inside a radial replication
  - Parameterised volumes cannot be placed inside a replica

Replicated Volumes

- The mother volume is completely filled with replicas, all of which are the same size (width) and shape.
- 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



a daughter logical volume to be replicated



mother volume

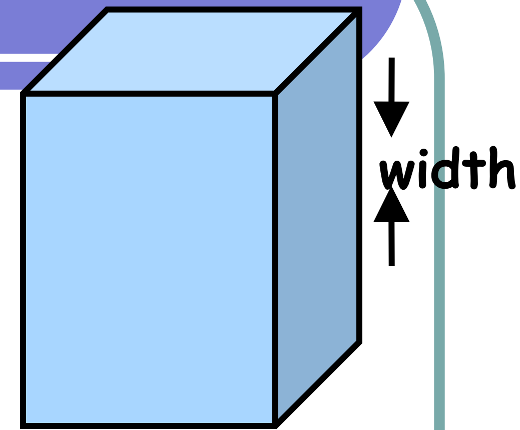
Replica - axis, width, offset

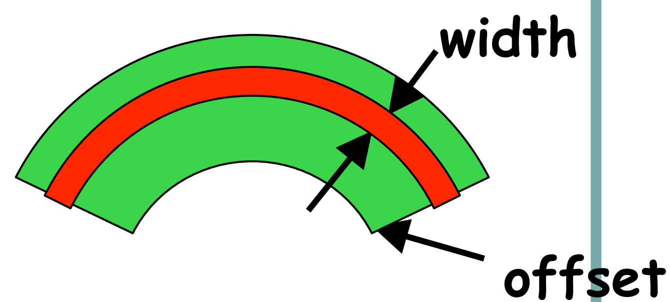
- Cartesian axes - **`kXaxis, kYaxis, kZaxis`**
  - Center of n-th daughter is given as

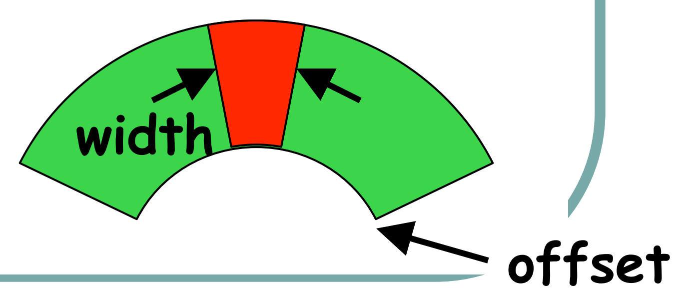
    `-width*(nReplicas-1)*0.5+n*width`
  - Offset shall not be used
- Radial axis - **`kRaxis`**
  - Center of n-th daughter is given as

    `width*(n+0.5)+offset`
  - Offset must be the inner radius of the mother
- Phi axis - **`kPhi`**
  - Center of n-th daughter is given as

    `width*(n+0.5)+offset`
  - Offset must be the starting angle of the mother

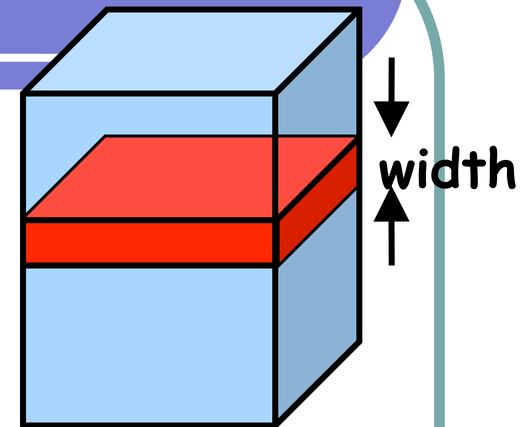




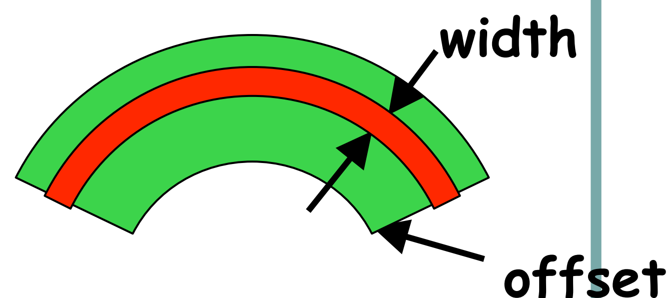


Replica - axis, width, offset

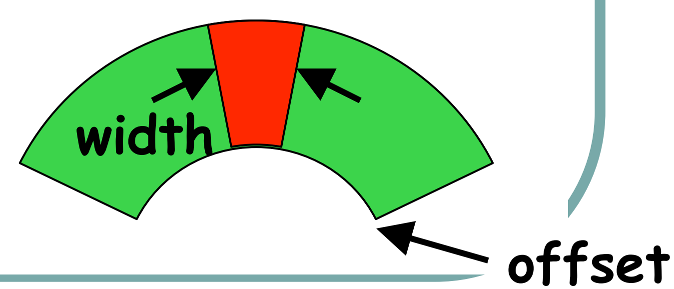
- Cartesian axes - **kXaxis, kYaxis, kZaxis**
  - Center of n-th daughter is given as
    `-width*(nReplicas-1)*0.5+n*width`
  - Offset shall not be used



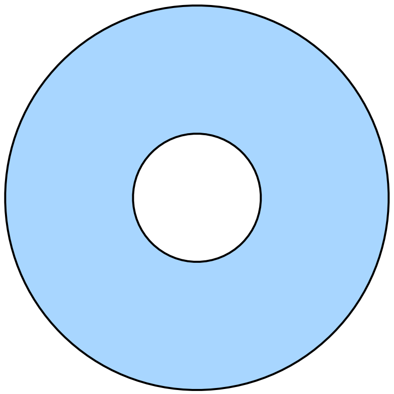
- Radial axis - **kRaxis**
  - Center of n-th daughter is given as
    `width*(n+0.5)+offset`
  - Offset must be the inner radius of the mother



- Phi axis - **kPhi**
  - Center of n-th daughter is given as
    `width*(n+0.5)+offset`
  - Offset must be the starting angle of the mother

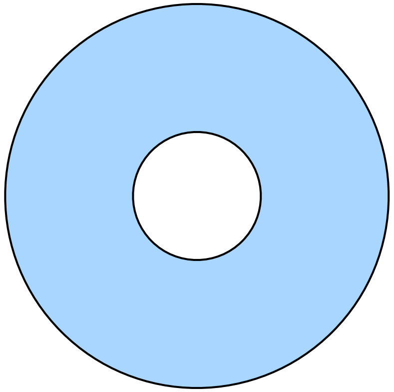


G4PVReplica : example



G4PVReplica : example

```
G4double tube_dPhi = 2.* M_PI * rad;
G4VSolid* tube =
   new G4Tubs("tube",20*cm,50*cm,30*cm,0.,tube_dPhi);
G4LogicalVolume * tube_log =
   new G4LogicalVolume(tube, Air, "tubeL", 0, 0, 0);
G4VPhysicalVolume* tube_phys =
   new G4PVPlacement(0,G4ThreeVector(-200.*cm,0.,0.),
         "tubeP", tube_log, world_phys, false, 0);
```



G4PVReplica : example

```
G4double tube_dPhi = 2.* M_PI * rad;
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G4VPhysicalVolume* tube_phys =
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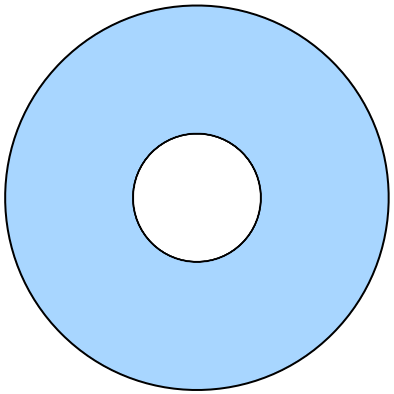
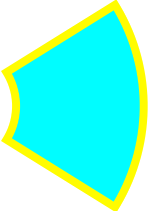
            "tubeP", tube_log, world_phys, false, 0);
G4double divided_tube_dPhi = tube_dPhi/6.;
G4VSolid* div_tube =
   new G4Tubs("div_tube", 20*cm, 50*cm, 30*cm,
        -divided_tube_dPhi/2., divided_tube_dPhi);
G4LogicalVolume* div_tube_log =
   new G4LogicalVolume(div_tube,Pb,"div_tubeL",0,0,0);
```





G4PVReplica : example

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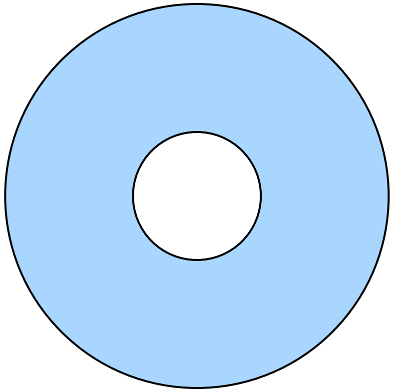
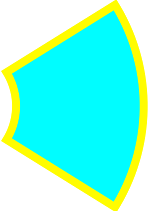
   new G4LogicalVolume(tube, Air, "tubeL", 0, 0, 0);
G4VPhysicalVolume* tube_phys =
   new G4PVPlacement(0,G4ThreeVector(-200.*cm,0.,0.),
            "tubeP", tube_log, world_phys, false, 0);
G4double divided_tube_dPhi = tube_dPhi/6.;
G4VSolid* div_tube =
   new G4Tubs("div_tube", 20*cm, 50*cm, 30*cm,
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





G4PVReplica : example

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G4double divided_tube_dPhi = tube_dPhi/6.;
G4VSolid* div_tube =
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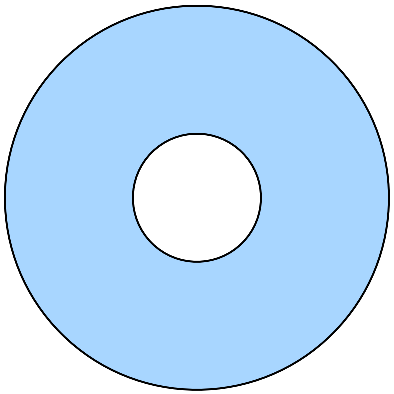
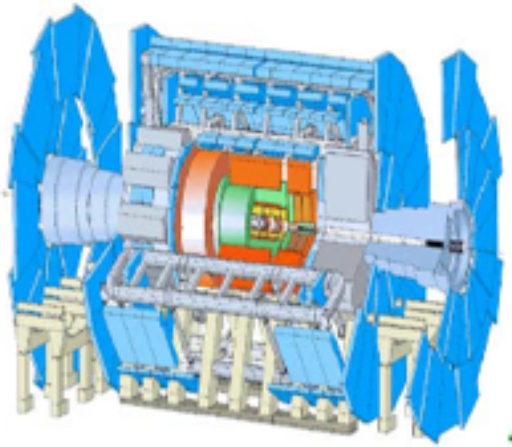
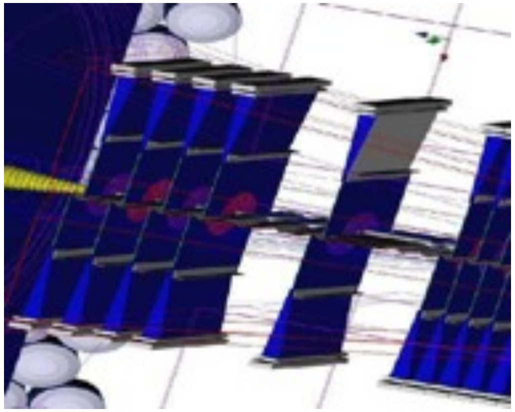
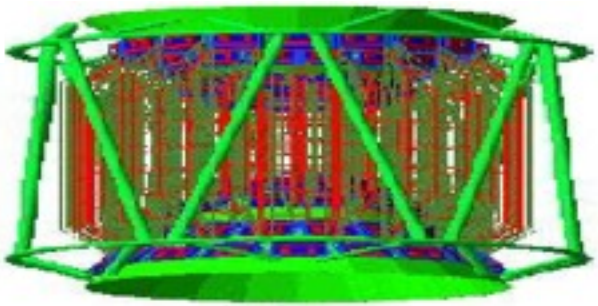
        -divided_tube_dPhi/2., divided_tube_dPhi);
G4LogicalVolume* div_tube_log =
   new G4LogicalVolume(div_tube,Pb,"div_tubeL",0,0,0);
G4VPhysicalVolume* div_tube_phys =
   new G4PVReplica("div_tube_phys", div_tube_log,
   tube_log, kPhi, 6, divided_tube_dPhi);
```

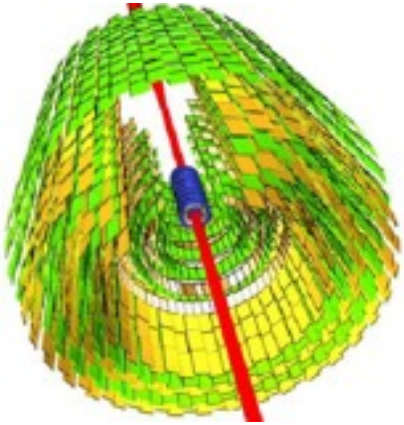


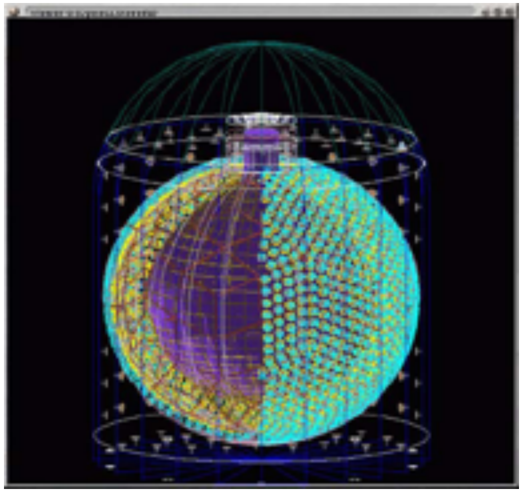
Geometry. Is it complicated ?





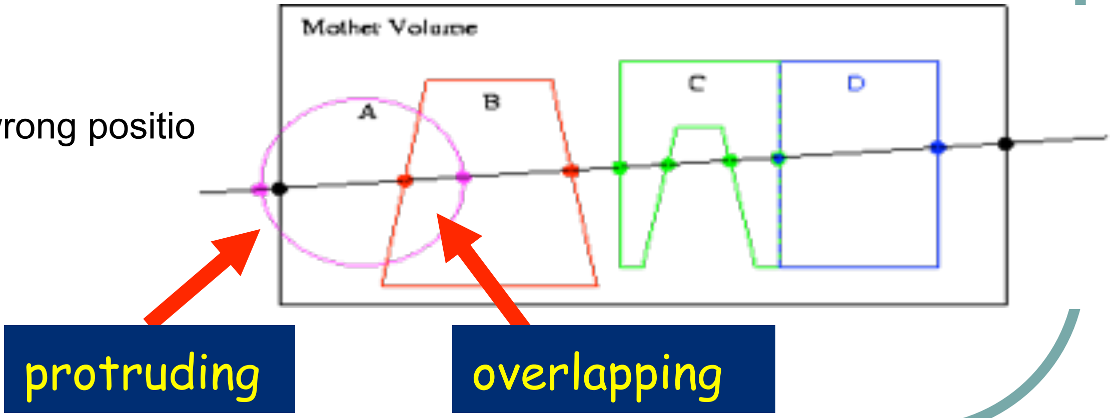






Debugging geometries

- An protruding volume is a contained daughter volume which actually protrudes from its mother volume.
- Volumes are also often positioned in a same volume with the intent of not provoking intersections between themselves. When volumes in a common mother actually intersect themselves are defined as overlapping.
- Geant4 does not allow for malformed geometries, neither protruding nor overlapping.
  - The behavior of navigation is unpredictable for such cases.
- The problem of detecting overlaps between volumes is bounded by the complexity of the solid models description.
- Utilities are provided for detecting wrong positio
  - Optional checks at construction
  - Kernel run-time commands
  - Graphical tools (DAVID, OLAP)



Optional checks at construction

- Constructors of G4PVPlacement and G4PVParameterised have an optional argument "pSurfChk".

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

- If this flag is true, overlap check is done at the construction.
  - Some number of points are randomly sampled on the surface of creating volume.
  - Each of these points are examined
    - If it is outside of the mother volume, or
    - If it is inside of already existing other volumes in the same mother volume.
- This check requires lots of CPU time, but it is worth to try at least once when you implement your geometry of some complexity.

Debugging run-time commands

- Built-in run-time commands to activate verification tests for the user geometry are defined
  - to start verification of geometry for overlapping regions based on a standard grid setup, limited to the first depth level

    `geometry/test/run` or **`geometry/test/grid_test`**
  - applies the grid test to all depth levels (may require lots of CPU time!)

    `geometry/test/recursive_test`
  - shoots lines according to a cylindrical pattern

    `geometry/test/cylinder_test`
  - to shoot a line along a specified direction and position

    `geometry/test/line_test`
  - to specify position for the **`line_test`**

    `geometry/test/position`
  - to specify direction for the **`line_test`**

    `geometry/test/direction`

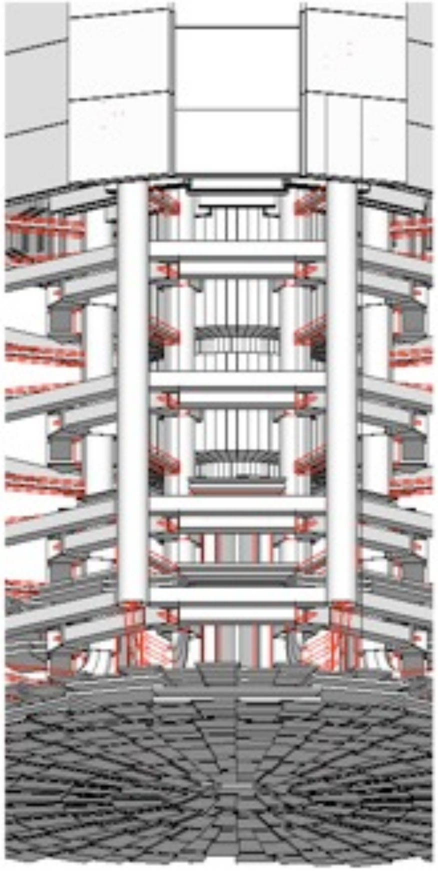
Debugging run-time commands

- Example layout:

```
GeomTest: no daughter volume extending outside mother detected.
GeomTest Error: Overlapping daughter volumes
    The volumes Tracker[0] and Overlap[0],
    both daughters of volume World[0],
    appear to overlap at the following points in global coordinates: (list truncated)
  length (cm)    ----- start position (cm) -----  ----- end position (cm) -----
    240            -240      -145.5      -145.5     0       -145.5      -145.5
Which in the mother coordinate system are:
  length (cm)    ----- start position (cm) -----  ----- end position (cm) -----
    . . .
Which in the coordinate system of Tracker[0] are:
  length (cm)    ----- start position (cm) -----  ----- end position (cm) -----
    . . .
Which in the coordinate system of Overlap[0] are:
  length (cm)    ----- start position (cm) -----  ----- end position (cm) -----
    . . .
```

Debugging tools: DAVID

- DAVID is a graphical debugging tool for detecting potential intersections of volumes
- Accuracy of the graphical representation can be tuned to the exact geometrical description.
  - physical-volume surfaces are automatically decomposed into 3D polygons
  - intersections of the generated polygons are parsed.
  - If a polygon intersects with another one, the physical volumes associated to these polygons are highlighted in color (red is the default).
- DAVID can be downloaded from the Web as external tool for Geant4
  - http://geant4.kek.jp/~tanaka/



Trainings

- Geometry – Basics

  Exercise

Lets start !!