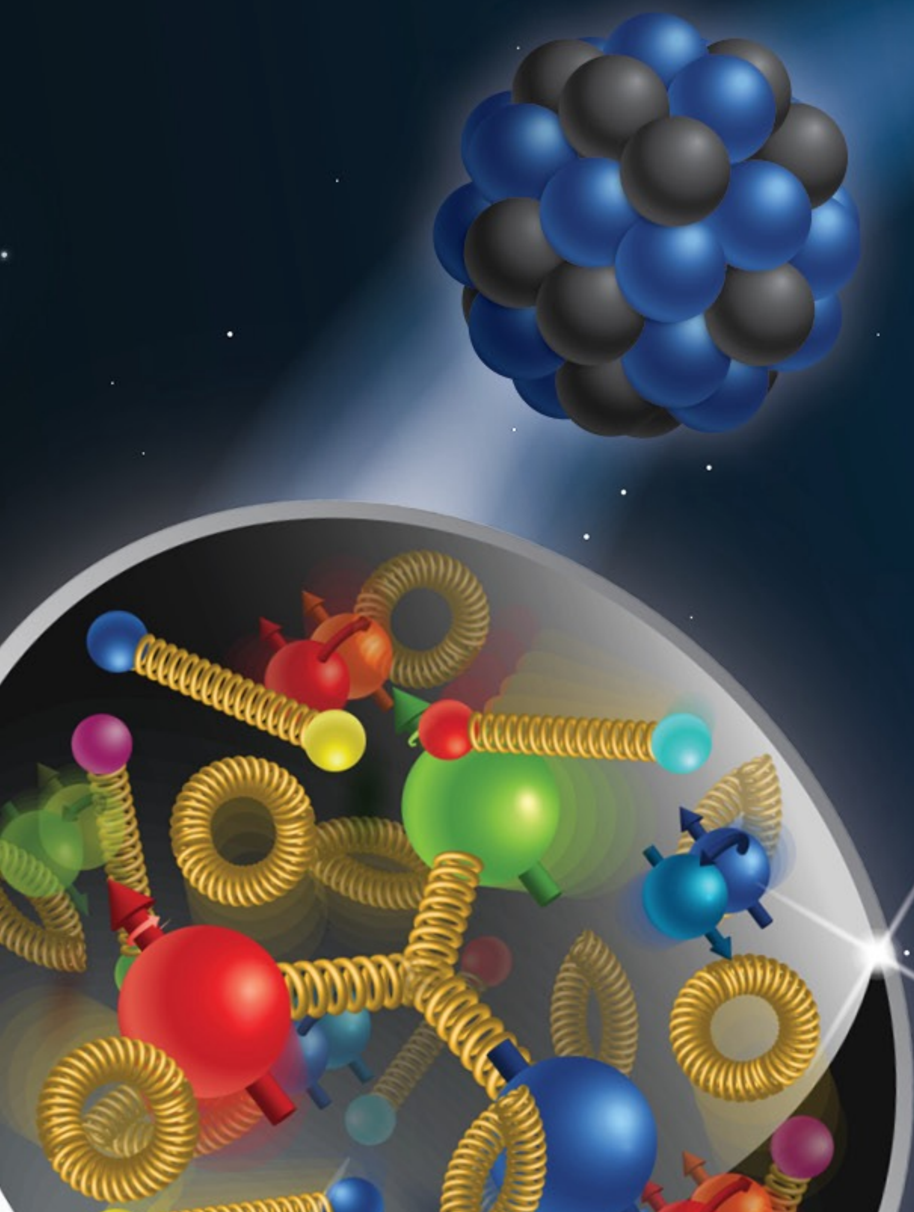

Version 11.2-p01

Geometry II

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Geant4 Tutorial Course

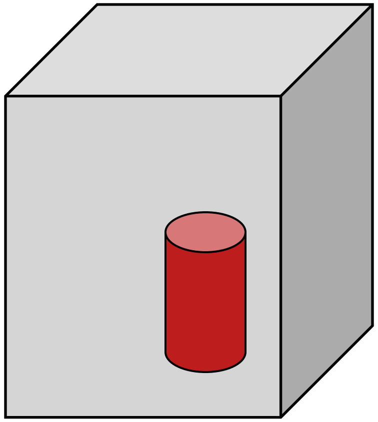
Jefferson Lab · U.S. Department of Energy · Office of Science · JSA

Contents

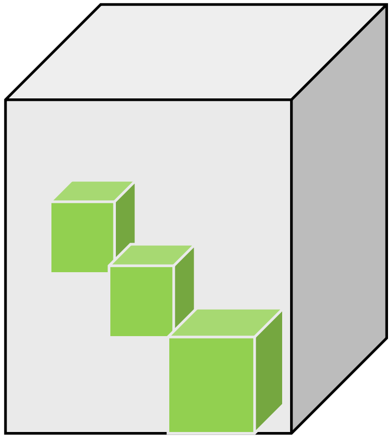
- Various ways of defining physical volume
  - Parameterized volume
  - Replicated volume
  - Divided volume
  - Nested parameterization
  - Assembly volume
  - Reflection volume
- Touchable

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 any number of "real" volumes.
  - reduces use of memory.
  - Parameterised
    - repetition w.r.t. copy number
  - Replica and Division
    - 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

    b) are identical in size & shape (so that grand-daughters are safely fit inside).
  - By implementing G4PVNestedParameterisation instead of G4VPVParameterisation, material, sensitivity and vis attributes can be parameterized by the copy numbers of ancestors.

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.
- G4PVDivision 1 Division = Many Repeated Volumes
  - Daughters of same shape are aligned along one axis and fill the mother.
  - There can be gaps between mother wall and outmost daughters.
  - No gap in between daughters.
- G4ReflectionFactory 1 Placement = a pair of Placement volumes
  - generating placements of a volume and its reflected volume
  - Useful typically for end-cap calorimeter
- G4AssemblyVolume 1 Placement = a set of Placement volumes
  - Position a group of volumes

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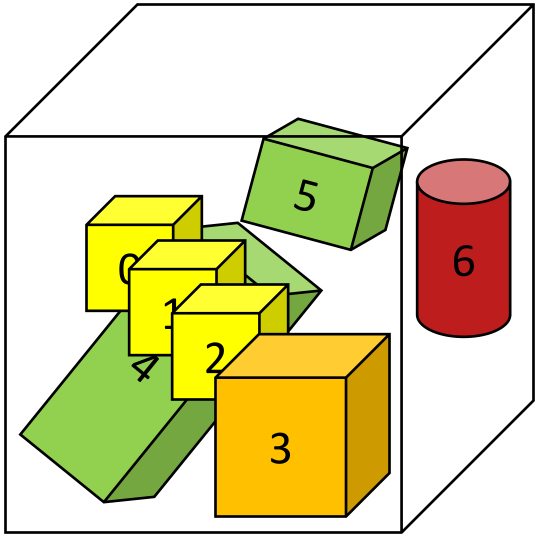
G4PVParameterised

```
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

- 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
  - Granddaughter volumes allowed only for special cases
  - Consider parameterised volumes as “leaf” volumes
- Typical use-cases
  - Complex detectors
    - with large repetition of volumes, regular or irregular
  - Medical applications
    - the material in animal tissue is measured as cubes with varying material



G4PVParameterized : example

```
G4VSolid* solidChamber =
   new G4Box("chamber", 100*cm, 100*cm, 10*cm);
G4LogicalVolume* logicChamber =
   new G4LogicalVolume
   (solidChamber, ChamberMater, "Chamber", 0, 0, 0);
G4VPVParameterisation* chamberParam =
   new ChamberParameterisation();
G4VPhysicalVolume* physChamber =
   new G4PVParameterised("Chamber", logicChamber,
        logicMother, kZAxis, NbOfChambers, chamberParam);
```

G4VPVParameterisation : example

```
class ChamberParameterisation : public G4VPVParameterisation
{
  public:
   ChamberParameterisation();
   virtual ~ChamberParameterisation();
   virtual void ComputeTransformation // position, rotation
     (const G4int copyNo, G4VPhysicalVolume* physVol) const;
   virtual void ComputeDimensions // size
     (G4Box& trackerLayer, const G4int copyNo,
         const G4VPhysicalVolume* physVol) const;
   virtual G4VSolid* ComputeSolid // shape
     (const G4int copyNo, G4VPhysicalVolume* physVol);
   virtual G4Material* ComputeMaterial // material, sensitivity, etc.
       (const G4int copyNo, G4VPhysicalVolume* physVol,
         const G4VTouchable *parentTouch=0);
       // G4VTouchable should not be used for ordinary
       // parameterization
};
```

G4VPVParameterisation : example

```
void ChamberParameterisation::ComputeTransformation
(const G4int copyNo, G4VPhysicalVolume* physVol) const
{
  G4double Xposition = … // w.r.t. copyNo
  G4ThreeVector origin(Xposition,Yposition,Zposition);
  physVol->SetTranslation(origin);
  physVol->SetRotation(0);
}

void ChamberParameterisation::ComputeDimensions
(G4Box& trackerChamber, const G4int copyNo,
 const G4VPhysicalVolume* physVol) const
{
  G4double XhalfLength = … // w.r.t. copyNo
  trackerChamber.SetXHalfLength(XhalfLength);
  trackerChamber.SetYHalfLength(YhalfLength);
  trackerChamber.SetZHalfLength(ZHalfLength);
}
```

G4VPVParameterisation : example

```
G4VSolid* ChamberParameterisation::ComputeSolid
      (const G4int copyNo, G4VPhysicalVolume* physVol)
{
  G4VSolid* solid;
  if(copyNo == …) solid = myBox;
  else if(copyNo == …) solid = myTubs;
  …
  return solid;
}

G4Material* ComputeMaterial // material, sensitivity, visAtt
      (const G4int copyNo, G4VPhysicalVolume* physVol,
          const G4VTouchable *parentTouch=0);
{
  G4Material* mat;
  if(copyNo == …) { mat = material1; }
  else if(copyNo == …) { mat = material2; }
  return mat;
}
```

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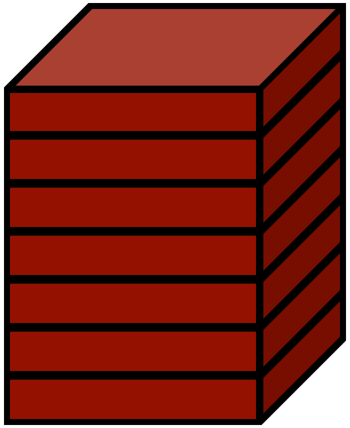
Replicated Volumes

- 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

G4PVReplica

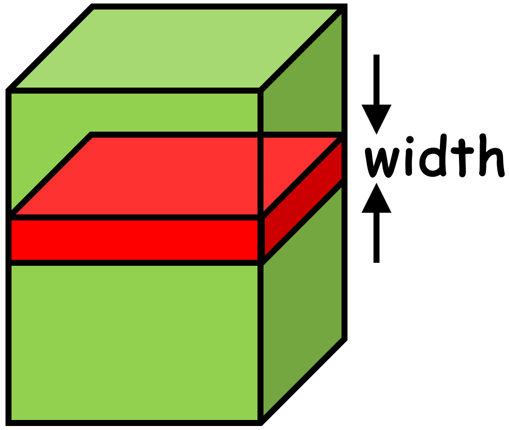
```
G4PVReplica(const G4String &pName,
            G4LogicalVolume *pLogical,
            G4LogicalVolume *pMother,
            const EAxis pAxis,
            const G4int nReplicas,
            const G4double width,
            const G4double offset=0.);
```

- `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

Replica - axis, width, offset

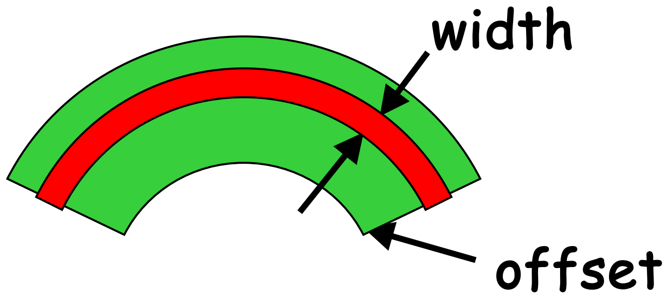
- Cartesian axes - **kXaxis, kYaxis, kZaxis**
  - Center of n-th daughter is given as

    -width*(nReplicas-1)*0.5+n*width
  - Offset shall not be used



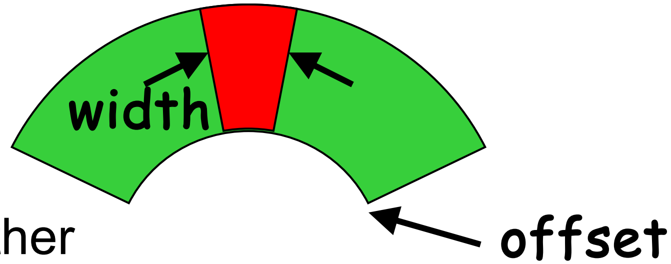
- Radial axis - **kRaxis**
  - Center of n-th daughter is given as

    width*(n+0.5)+offset
  - Offset must be the inner radius of the mother



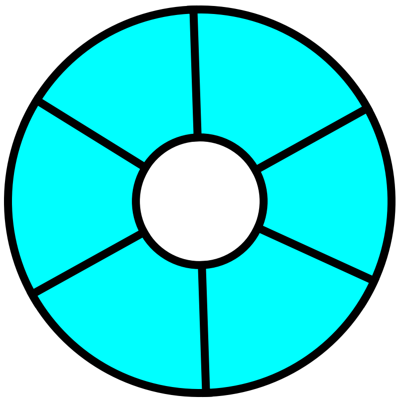
- Phi axis - **kPhi**
  - Center of n-th daughter is given as

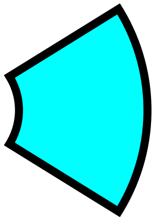
    width*(n+0.5)+offset
  - Offset must be the starting angle of the mother



G4PVReplica : example

```
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);
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);
```





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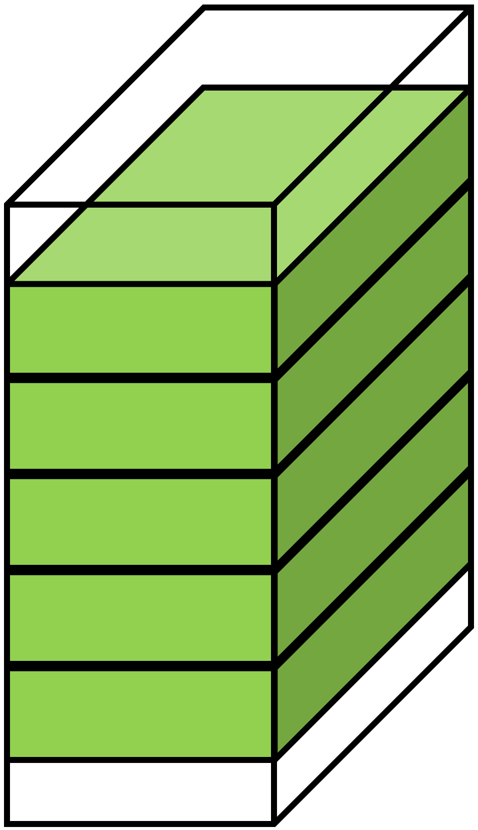
G4PVDivision

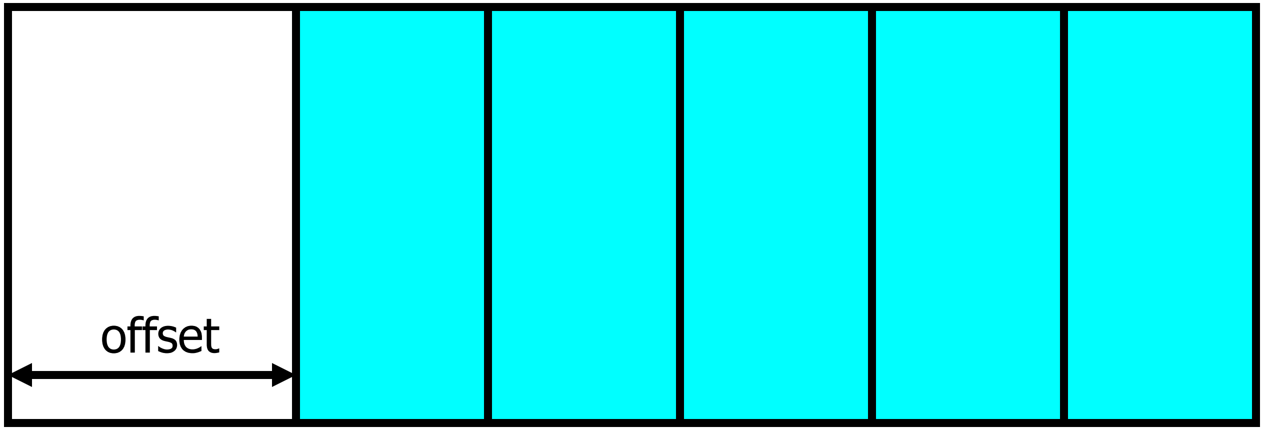
- G4PVDivision is a special kind of G4PVParameterised.
  - G4VPVParameterisation is automatically generated according to the parameters given in G4PVDivision.
- G4PVDivision is similar to G4PVReplica but
  - It allows gaps in between mother and daughter volumes
  - With G4ReplicatedSlice you can define gaps between daughters as well.
- Shape of all daughter volumes must be same shape as the mother volume.
  - G4VSolid (to be assigned to the daughter logical volume) must be the same type, but different object.
- Replication must be aligned along one axis.
- If your geometry does not have gaps, use G4Replica.
  - For identical geometry, navigation of G4Replica is faster.



G4PVDivision - 1

```
G4PVDivision(const G4String& pName,
    G4LogicalVolume* pDaughterLogical,
    G4LogicalVolume* pMotherLogical,
    const EAxis pAxis,
    const G4int nDivisions,    // number of division is given
    const G4double offset);
```

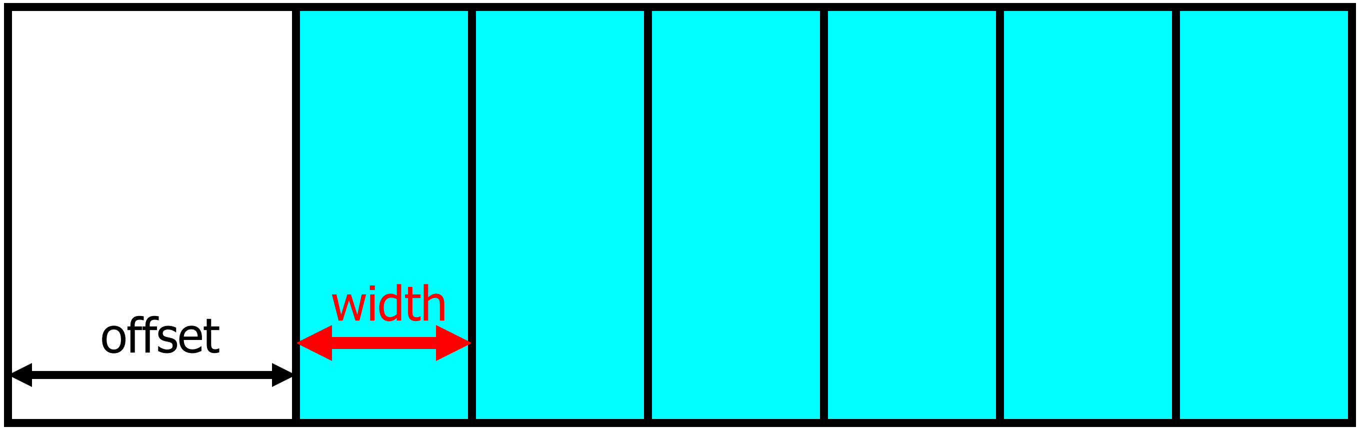
- The size (width) of the daughter volume is calculated as
  `( (size of mother) - offset ) / nDivisions`



G4PVDivision - 2

```
G4PVDivision(const G4String& pName,
    G4LogicalVolume* pDaughterLogical,
    G4LogicalVolume* pMotherLogical,
    const EAxis pAxis,
    const G4double width,   // width of daughter volume is given
    const G4double offset);
```

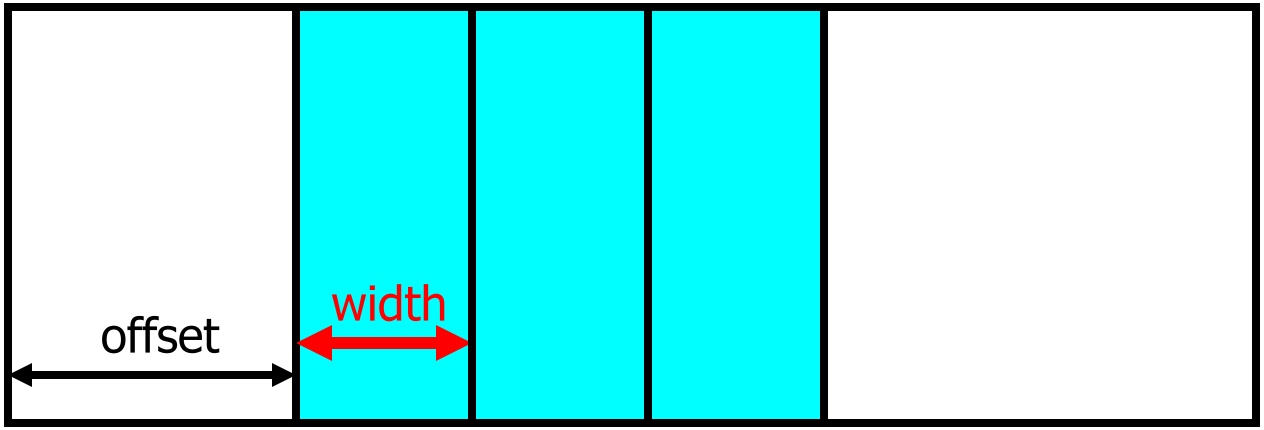
- The number of daughter volumes is calculated as
  `int( ( (size of mother) - offset ) / width )`
  - As many daughters as width and offset allow



G4PVDivision - 3

```
G4PVDivision(const G4String& pName,
     G4LogicalVolume* pDaughterLogical,
     G4LogicalVolume* pMotherLogical,
     const EAxis pAxis,
     const G4int nDivisions,
     const G4double width,    // both number of division and width are given
     const G4double offset);
```

- *nDivisions* daughters of *width* thickness



G4PVDivision

- G4PVDivision currently supports following shapes / axes.
  - G4Box : kXAxis, kYAxis, kZAxis
  - G4Tubs : kRho, kPhi, kZAxis
  - G4Cons : kRho, kPhi, kZAxis
  - G4Trd : kXAxis, kYAxis, kZAxis
  - G4Para : kXAxis, kYAxis, kZAxis
  - G4Polycone : kRho, kPhi, kZAxis
    - kZAxis - the number of divisions has to be the same as solid sections, (i.e. numZPlanes-1), the width will not be taken into account.
  - G4Polyhedra : kRho, kPhi, kZAxis
    - kPhi - the number of divisions has to be the same as solid sides, (i.e. numSides), the width will not be taken into account.
    - kZAxis - the number of divisions has to be the same as solid sections, (i.e. numZPlanes-1), the width will not be taken into account.
- In the case of division along kRho of G4Cons, G4Polycone, G4Polyhedra, if width is provided, it is taken as the width at the -Z radius; the width at other radii will be scaled to this one.

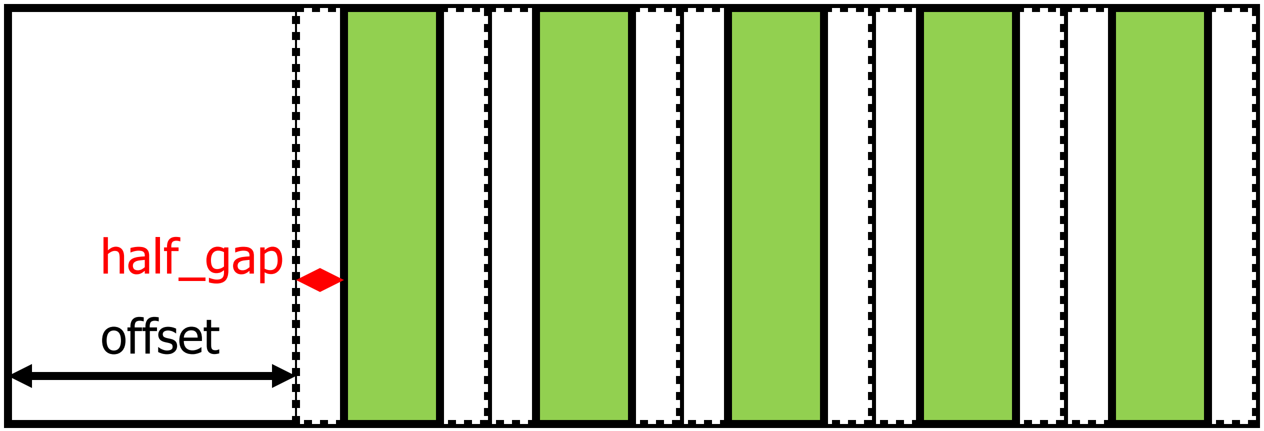
G4ReplicatedSlice

- New extension of G4Division introduced with version 9.4.
- It allows gaps in between divided volumes.

G4PVDivision(const G4String& pName, G4LogicalVolume* pDaughterLogical,
G4LogicalVolume* pMotherLogical, const EAxis pAxis,
const G4int nDivisions, const G4double half_gap, const G4double offset);

G4PVDivision(const G4String& pName, G4LogicalVolume* pDaughterLogical,
G4LogicalVolume* pMotherLogical, const EAxis pAxis,
const G4double width, const G4double half_gap, const G4double offset);

G4PVDivision(const G4String& pName, G4LogicalVolume* pDaughterLogical,
G4LogicalVolume* pMotherLogical, const EAxis pAxis,
const G4int nDivisions, const G4double width,
const G4double half_gap, const G4double offset);



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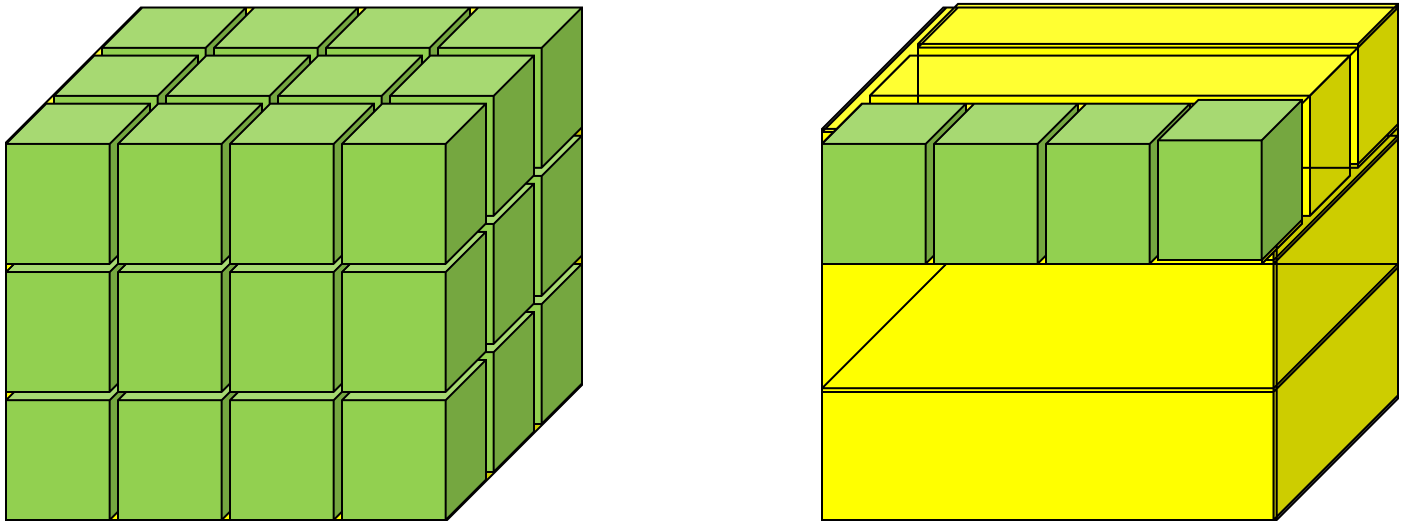
Nested parameterization

- Suppose your geometry has three-dimensional regular reputation of same shape and size of volumes without gap between volumes. And material of such volumes are changing according to the position.
  - E.g. voxels made by CT Scan data (DICOM)
- Instead of direct three-dimensional parameterized volume,

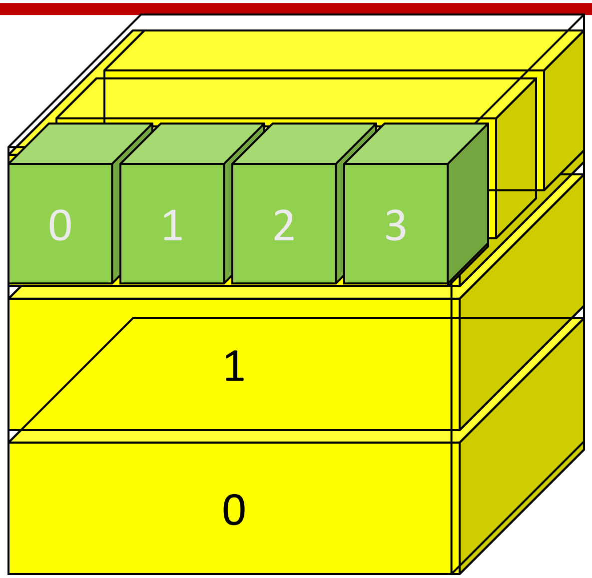
  use replicas for the first and second axes sequentially, and then use one-dimensional parameterization along the third axis.



- It requires much less memory for geometry optimization and gives much faster navigation for ultra-large number of voxels.

Nested parameterization

- Given geometry is defined as two sequential replicas and then one-dimensional parameterization,
  - Material of a voxel must be parameterized not only by the copy number of the voxel, but also by the copy numbers of ancestors.
  - Material is indexed by three indices.



- G4VNestedParameterisation is a special parameterization class derived from G4VPVParameterisation base class.
  - ComputeMaterial() method of G4VNestedParameterisation has a touchable object of the parent physical volume, in addition to the copy number of the voxel.
    - Index of first axis = theTouchable->GetCopyNumber(1);
    - Index of second axis = theTouchable->GetCopyNumber(0);
    - Index of third axis = copy number

G4VNestedParameterisation

- G4VNestedParameterisation is derived from G4VPVParameterization.
- G4VNestedParameterisation class has three pure virtual methods you have to implement,
  - in addition to ComputeTransformation() method, which is mandatory for all G4VPVParameterization classes.

virtual G4Material* ComputeMaterial(G4VPhysicalVolume *currentVol,
const G4int repNo, const G4VTouchable *parentTouch=0)=0;

- Return a material pointer w.r.t. copy numbers of itself and ancestors.
- Must cope with parentTouch=0 for navigator's sake. Typically, return a default material if parentTouch=0.

virtual G4int GetNumberOfMaterials() const=0;

- Return total number of materials which may appear as the return value of ComputeMaterial() method.

virtual G4Material* GetMaterial(G4int idx) const=0;

- Return idx-th material.
- “idx” is not a copy number. idx = [0, nMaterial-1]

G4VNestedParameterisation

- G4VNestedParameterisation is a kind of G4VPVParameterization.
  - It can be used as an argument of G4PVParameterised.
  - All other arguments of G4PVParameterised are unaffected.
- Nested parameterization of placement volume is not supported.
  - All levels used as indices of material must be repeated volume. There cannot be a level of placement volume in between.

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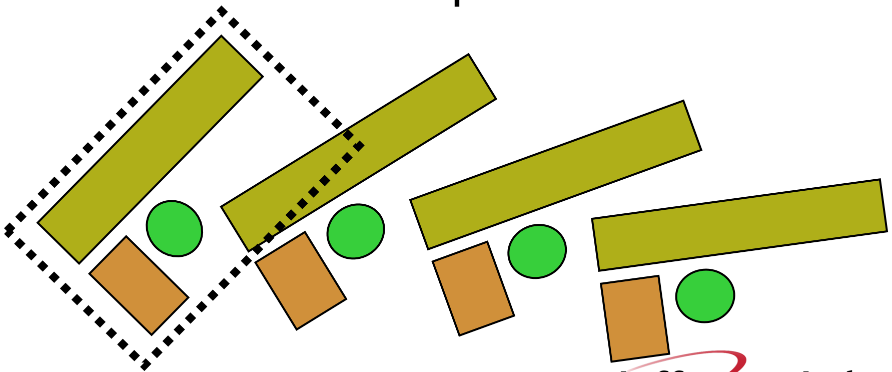
Grouping volumes

- 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
  - structures which may consist of different shapes
  - Too densely positioned to utilize a mother volume
- Assembly volume
  - acts as an *envelope* for its daughter volumes
  - its role is over once its logical volume has been placed
  - daughter physical volumes become independent copies in the final structure
- Participating daughter logical volumes are treated as triplets
  - logical volume
  - translation w.r.t. envelop
  - rotation w.r.t. envelop



G4AssemblyVolume

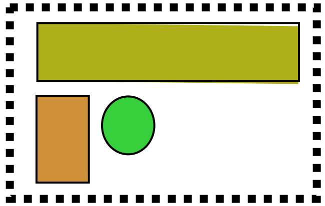
```
G4AssemblyVolume::AddPlacedVolume
                    ( G4LogicalVolume* volume,
                      G4ThreeVector& translation,
                      G4RotationMatrix* rotation );
```

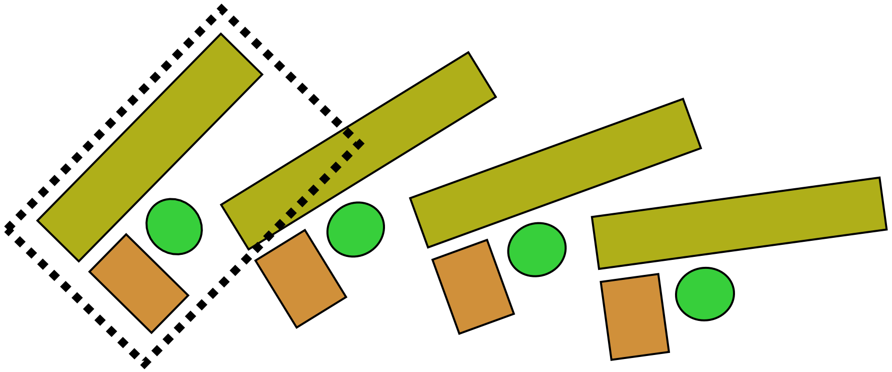
- Helper class to combine daughter logical volumes in arbitrary way
  - Imprints of the assembly volume are made inside a mother logical volume through `G4AssemblyVolume::MakeImprint(…)`
  - Each physical volume name is generated automatically
    - Format: **av**_WWW_**impr**_XXX_YYY_ZZZ
      - **WWW** – assembly volume instance number
      - **XXX** – assembly volume imprint number
      - **YYY** – name of the placed logical volume in the assembly
      - **ZZZ** – index of the associated logical volume
  - Generated physical volumes (and related transformations) are automatically managed (creation and destruction)

G4AssemblyVolume : example

```
G4AssemblyVolume* assembly = new G4AssemblyVolume();
G4RotationMatrix Ra;
G4ThreeVector Ta;
Ta.setX(…); Ta.setY(…); Ta.setZ(…);
assembly->AddPlacedVolume( plateLV, Ta, Ra );
  … // repeat placement for each daughter

for( unsigned int i = 0; i < layers; i++ ) {
  G4RotationMatrix Rm(…);
  G4ThreeVector Tm(…);
  assembly->MakeImprint( worldLV, Tm, Rm );
}
```





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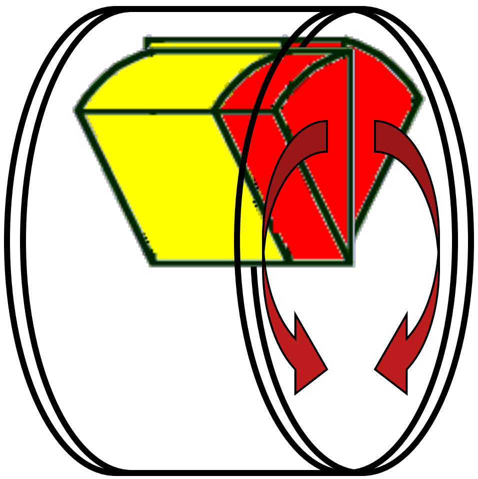
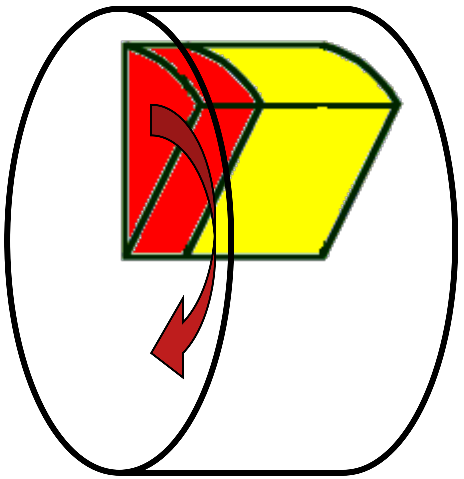
Reflecting solids



- Let's take an example of a pair of mirror symmetric volumes.
- Such geometry cannot be made by parallel transformation

or 180 degree rotation.



- G4ReflectedSolid (derived from G4VSolid)
  - Utility class representing a solid shifted from its original reference frame to a new mirror symmetric one
  - The reflection (G4Reflect[X/Y/Z]3D) is applied as a decomposition into rotation and translation
- G4ReflectionFactory
  - Singleton object using G4ReflectedSolid for generating placements of reflected volumes
- Reflections are currently limited to simple CSG solids.
  - will be extended soon to all solids

Reflecting hierarchies of volumes - 1

```
G4PhysicalVolumesPair G4ReflectionFactory::Place
  (const G4Transform3D& transform3D, // the transformation
   const G4String&  name,            // the name
   G4LogicalVolume* LV,              // the logical volume
   G4LogicalVolume* motherLV,        // the mother volume
   G4bool           noBool,          // currently unused
   G4int            copyNo)        // optional copy number
```

- Used for normal placements:
  i. Performs the transformation decomposition
  ii. Generates a new reflected solid and logical volume
     - Retrieves it from a map if the reflected object is already created
  iii. Transforms any daughter and places them in the given mother
  iv. Returns a pair of physical volumes, the second being a placement in the reflected mother
- `G4PhysicalVolumesPair` is `std::map<G4VPhysicalVolume*,G4VPhysicalVolume*>`

Reflecting hierarchies of volumes - 2

```
G4PhysicalVolumesPair G4ReflectionFactory::Replicate
   (const G4String&  name,       // the actual name
    G4LogicalVolume* LV,         // the logical volume
    G4LogicalVolume* motherLV,   // the mother volume
    Eaxis            axis        // axis of replication
    G4int            replicaNo   // number of replicas
    G4int            width,     // width of single replica
    G4int           offset=0)   // optional mother offset
```

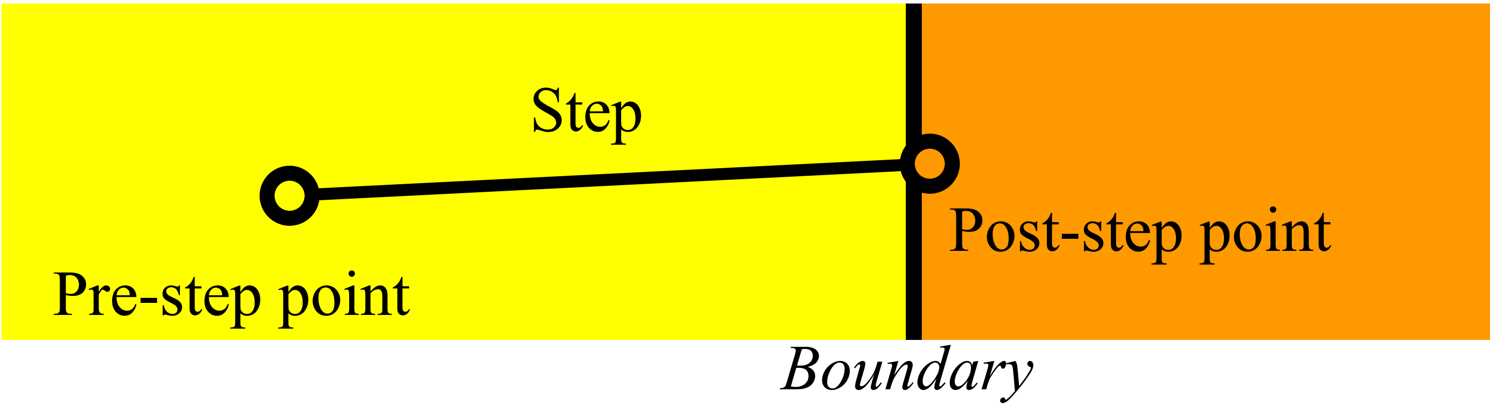
- Creates replicas in the given mother volume
- Returns a pair of physical volumes, the second being a replica in the reflected mother

Contents

- Various ways of defining physical volume
  - Parameterized volume
  - Replicated volume
  - Divided volume
  - Nested parameterization
  - Assembly volume
  - Reflection volume
- Touchable

Step in Geant4

- Step has two points and also “delta” information of a particle (energy loss on the step, time-of-flight spent by the step, etc.).
- Each point knows the volume (and material). In case a step is limited by a volume boundary, the end point physically stands on the boundary, and it logically belongs to the next volume.
  - Because one step knows materials of two volumes, boundary processes such as transition radiation or refraction could be simulated.

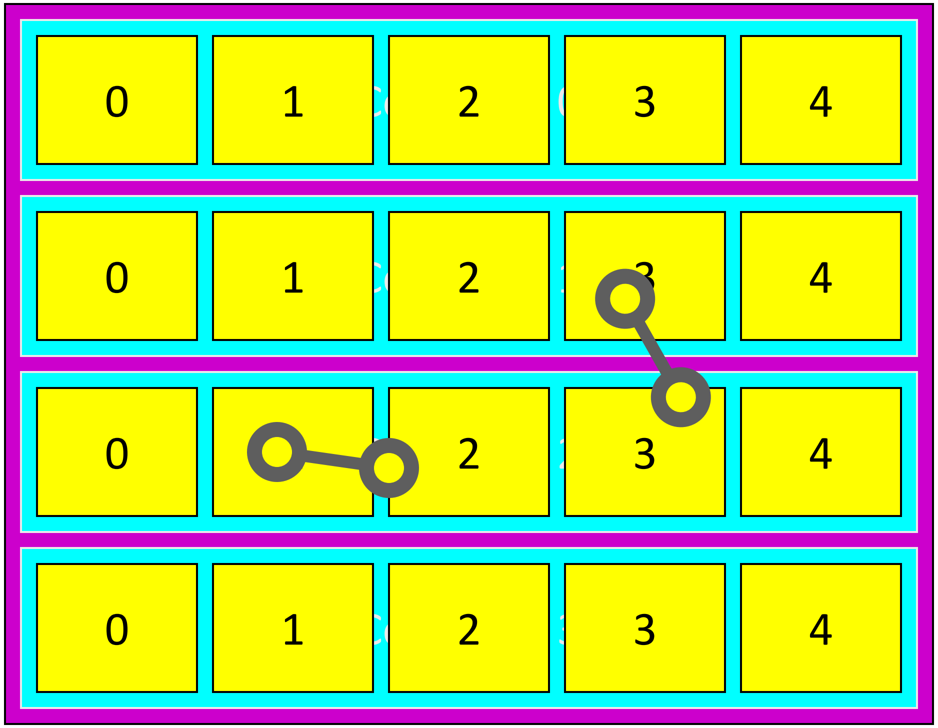


Step point and touchable

- As mentioned in the previous slide, G4Step has two G4StepPoint objects as its starting and ending points. All the geometrical information of the particular step should be taken from "PreStepPoint".
  - Geometrical information associated with G4Track is identical to "PostStepPoint".
- Each G4StepPoint object has
  - Position in world coordinate system
  - Global and local time
  - Material
  - G4TouchableHistory for geometrical information
- G4TouchableHistory object is a vector of information for each geometrical hierarchy.
  - copy number
  - transformation / rotation to its mother

Copy number

- 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 correct copy number for "PreStepPoint" if you directly access to the physical volume.
- Use touchable to get the proper copy number, transform matrix, etc.

Touchable

- G4TouchableHistory has information of geometrical hierarchy of the point.

```
G4Step* aStep;
G4StepPoint* preStepPoint = aStep->GetPreStepPoint();
G4TouchableHistory* theTouchable
            = preStepPoint->GetTouchable();
G4int copyNo = theTouchable->GetVolume()->GetCopyNo();
G4int motherCopyNo
            = theTouchable->GetVolume(1)->GetCopyNo();
G4int grandMotherCopyNo
            = theTouchable->GetVolume(2)->GetCopyNo();
G4ThreeVector worldPos = preStepPoint->GetPosition();
G4ThreeVector localPos = theTouchable->GetHistory()
    ->GetTopTransform().TransformPoint(worldPos);
```