Geometry II

Version 10.5

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Geant4 Tutorial Course

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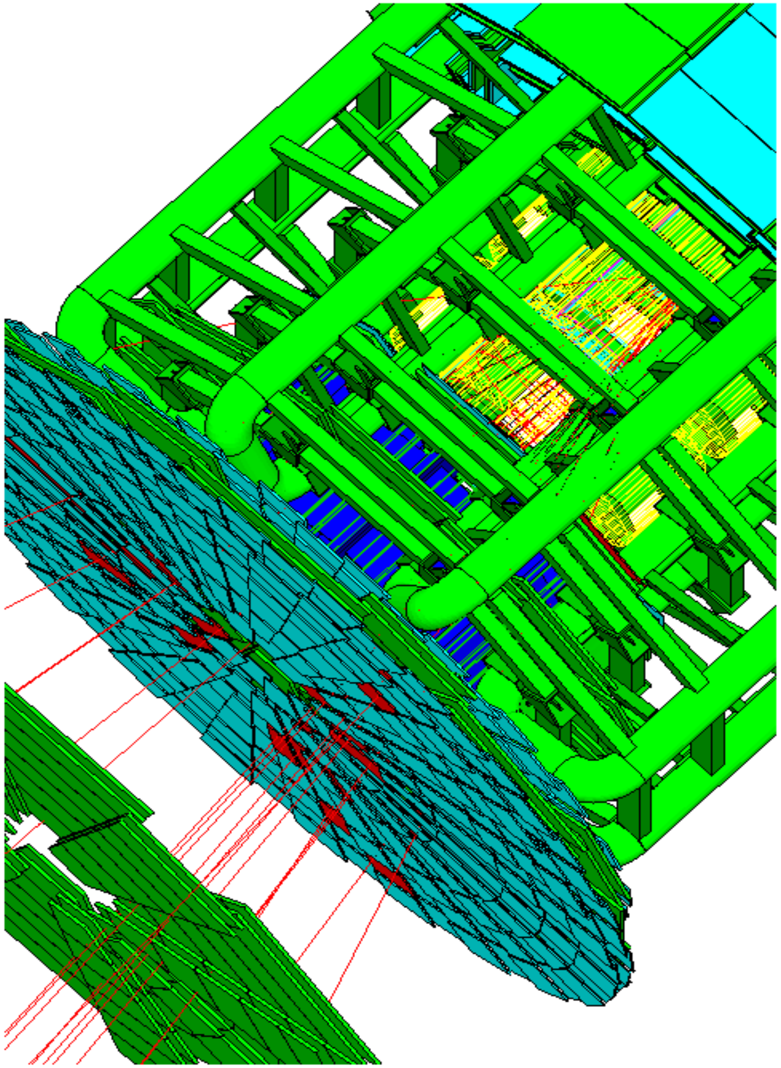
Contents

- Various ways of placing volumes
  - Simple placement volume
  - Parameterized volume
  - Replicated volume
  - Divided volume
  - Nested parameterization
  - Reflected volume
  - Assembly volume
- Touchable
- Parallel world and layered mass geometry



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Physical volume

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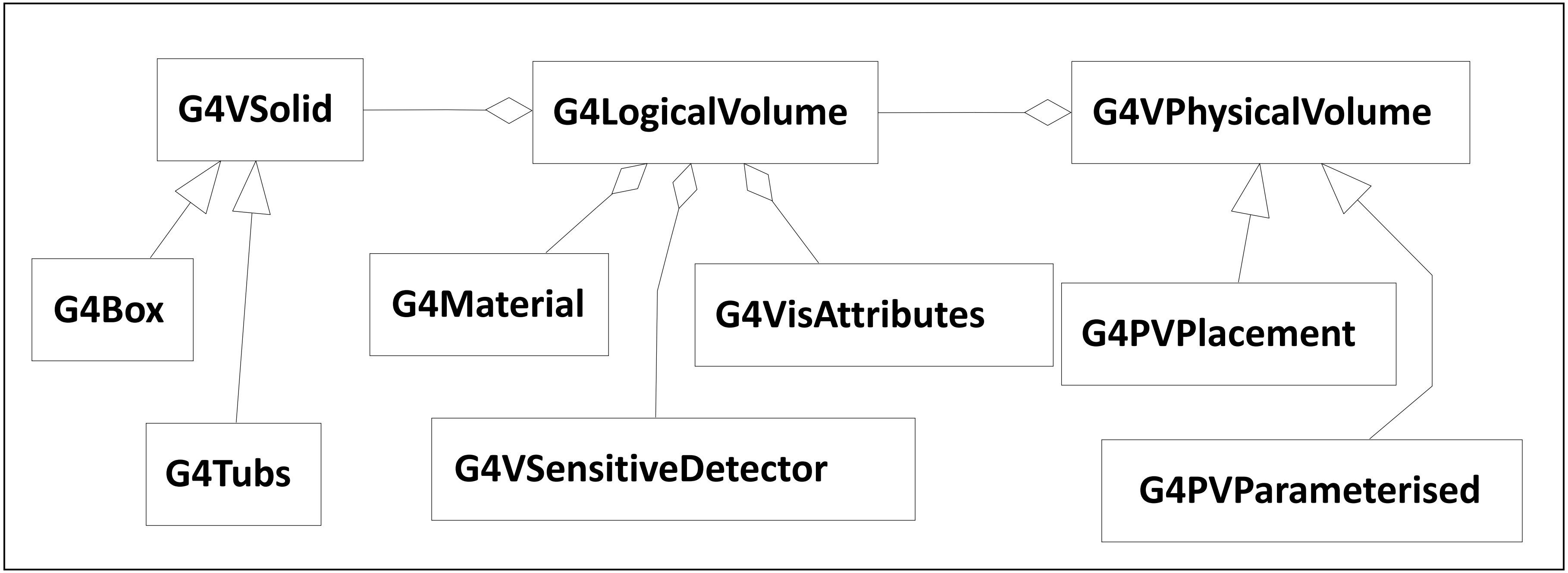
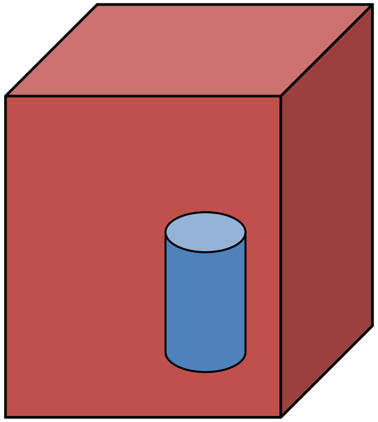
Detector geometry

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

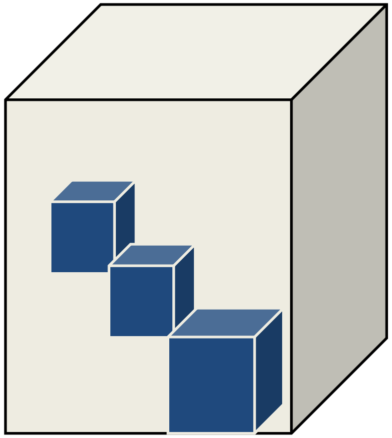


Physical Volumes

- 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 <u>represents</u> 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 G4VPVNestedParameterisation 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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Parameterized volume

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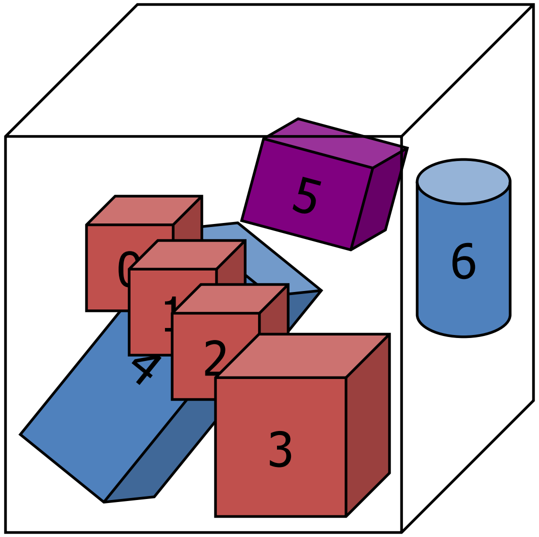
G4PVParameterised

```
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, visAtt
     (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;
    physVol->GetLogicalVolume()->SetVisAttributes( att1 );
  }
  …
  return mat;
}
```

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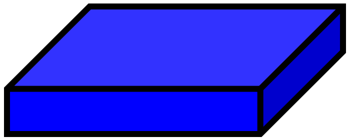
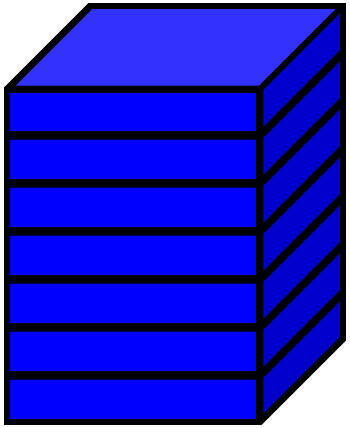
Replicated volume

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

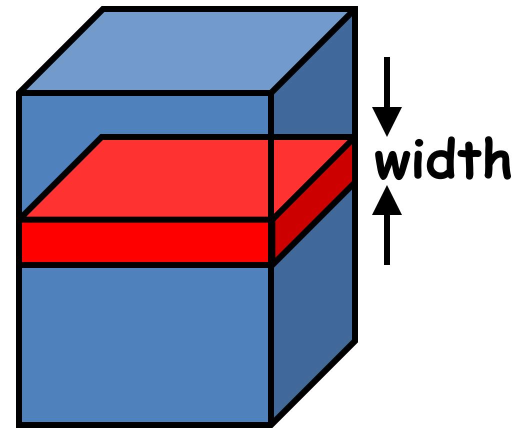
```
G4PVReplica(const G4String &pName,
            G4LogicalVolume *pLogical,
            G4LogicalVolume *pMother,
            const EAxis pAxis,
            const G4int nReplicas,
            const G4double width,
            const G4double offset=0.);
```

- `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

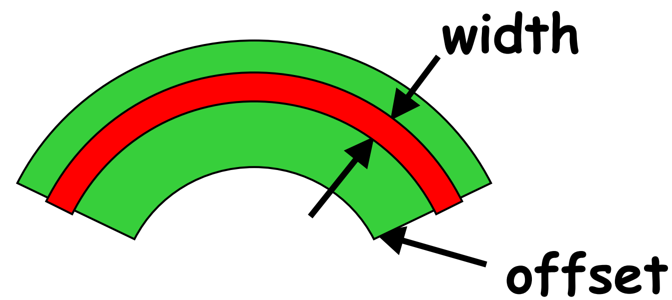
- Cartesian axes - **`kXaxis, kYaxis, kZaxis`**
  - Center of n-th daughter is given as

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



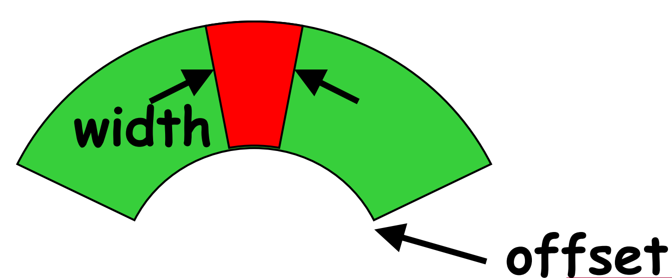
- Radial axis - **`kRaxis`**
  - Center of n-th daughter is given as

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



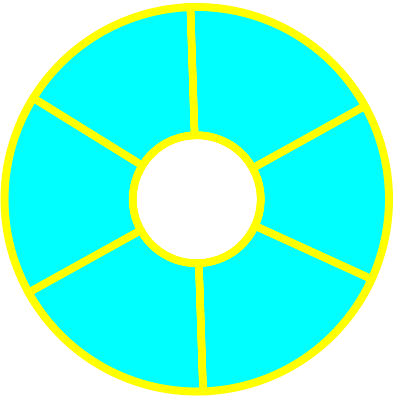
- Phi axis - **`kPhi`**
  - Center of n-th daughter is given as

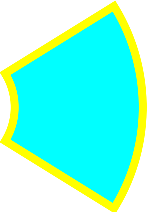
    `width*(n+0.5)+offset`
  - Offset must be the starting angle of the mother



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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Divided volume

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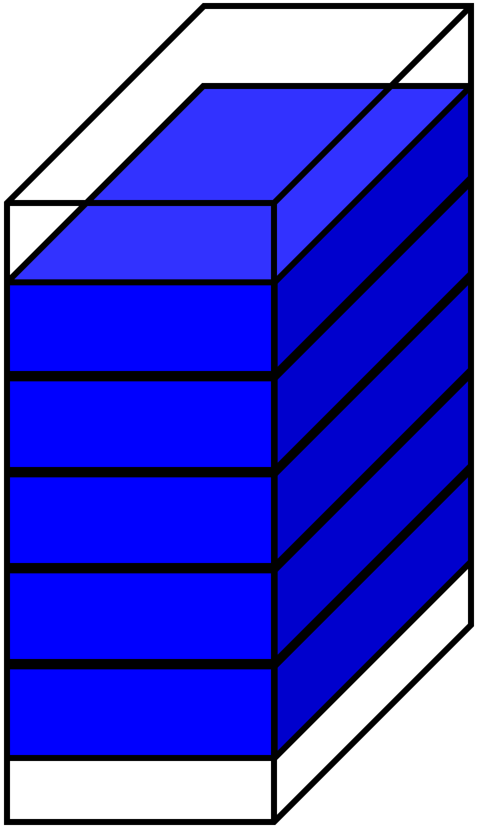
G4PVDivision

- 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 currently allows gaps in between mother and daughter volumes
  - We are extending G4PVDivision to allow gaps between daughters, and also gaps on side walls. We plan to release this extension in near future.
- 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.

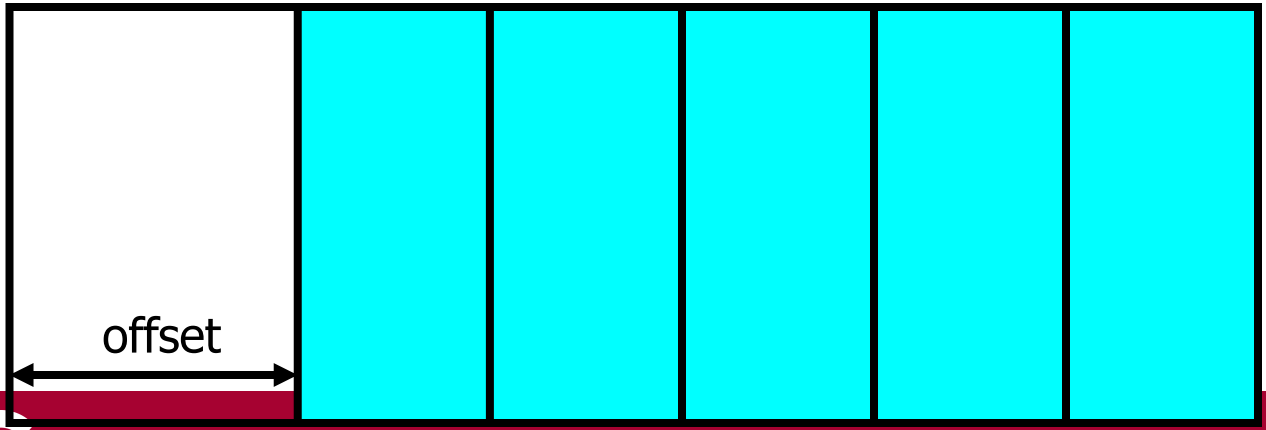


mother volume

G4PVDivision - 1

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

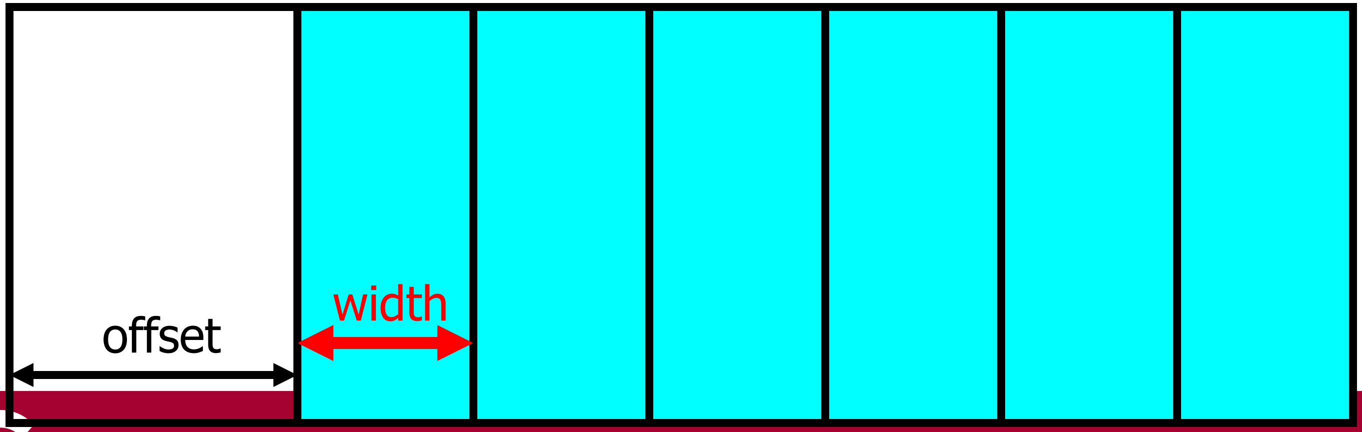
- The size (width) of the daughter volume is calculated as
  ((size of mother) - offset) / nDivisions



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);
```

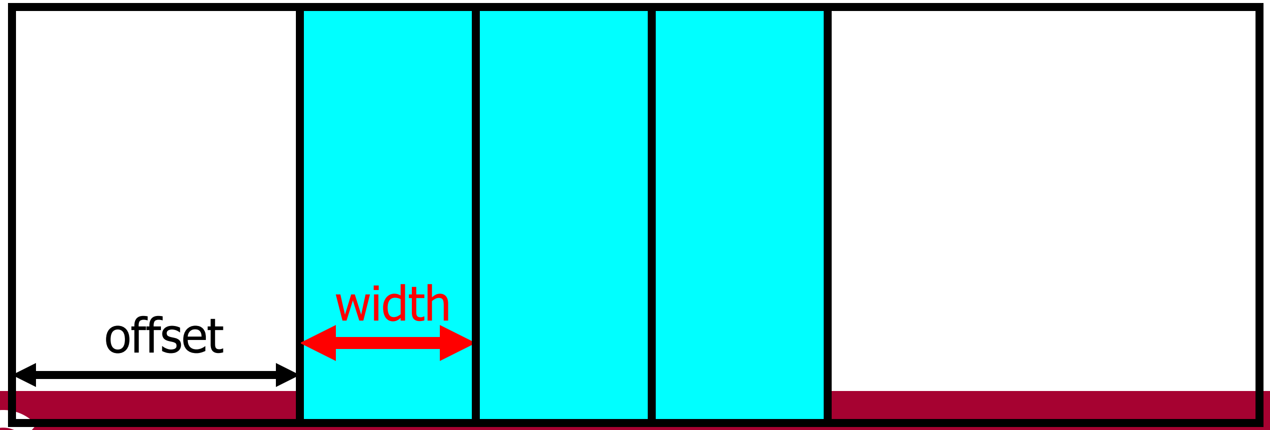
- The number of daughter volumes is calculated as
  `int( ( (size of mother) - offset ) / width )`
  - As many daughters as width and offset allow



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



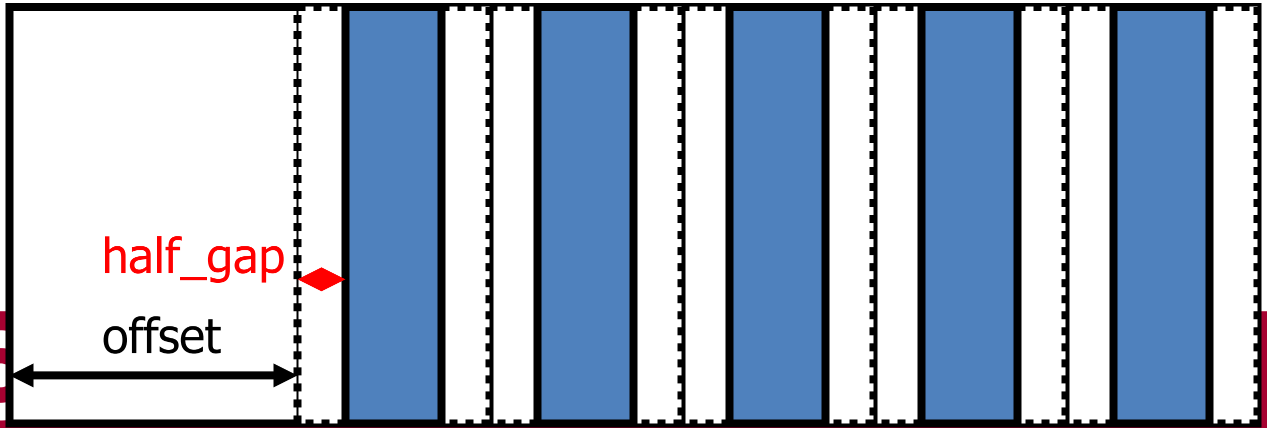
G4PVDivision

- 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

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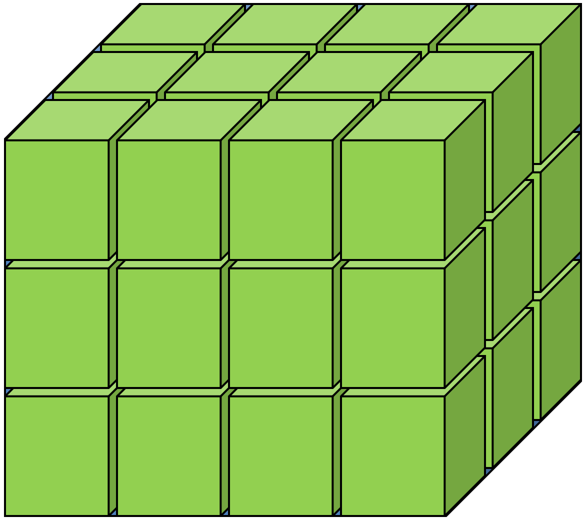
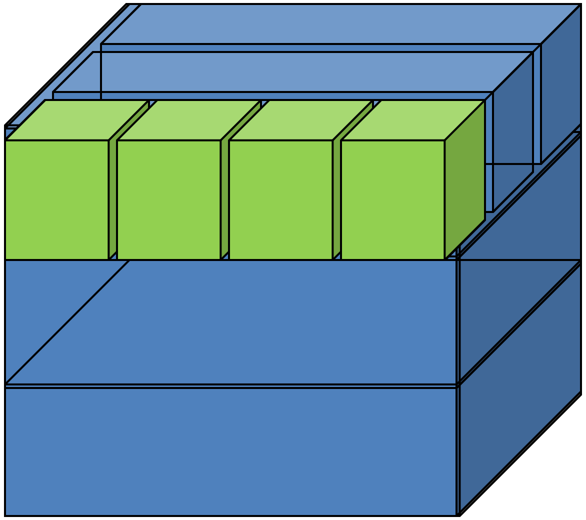
Nested parameterization

- 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,

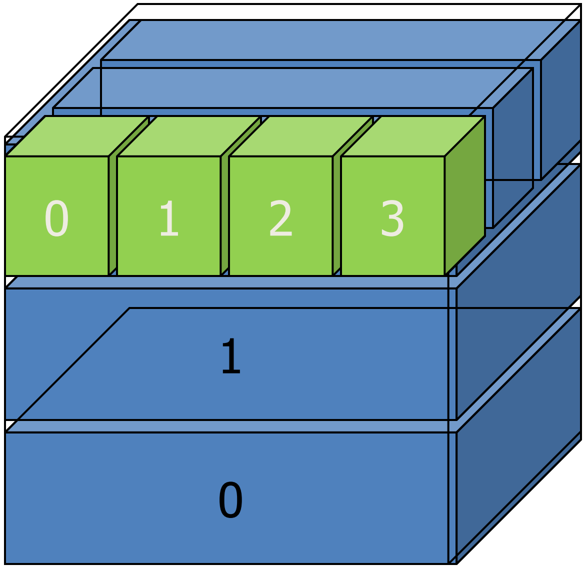
  use replicas for the first and second axes sequentially, and then use one-dimensional parameterization along the third axis.





- 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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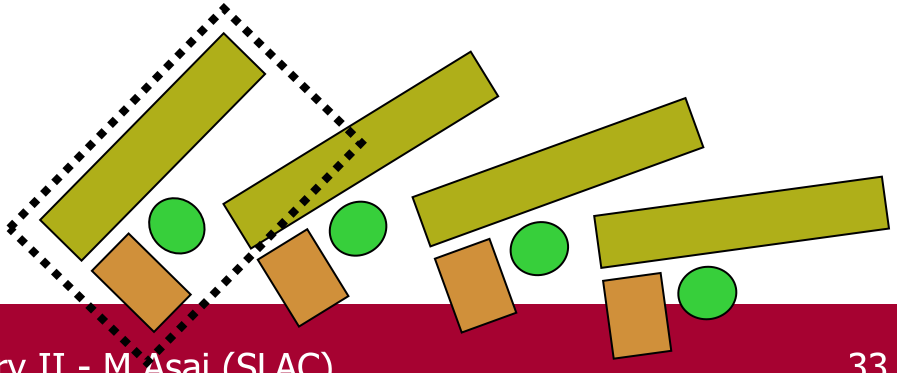
Assembly volume

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

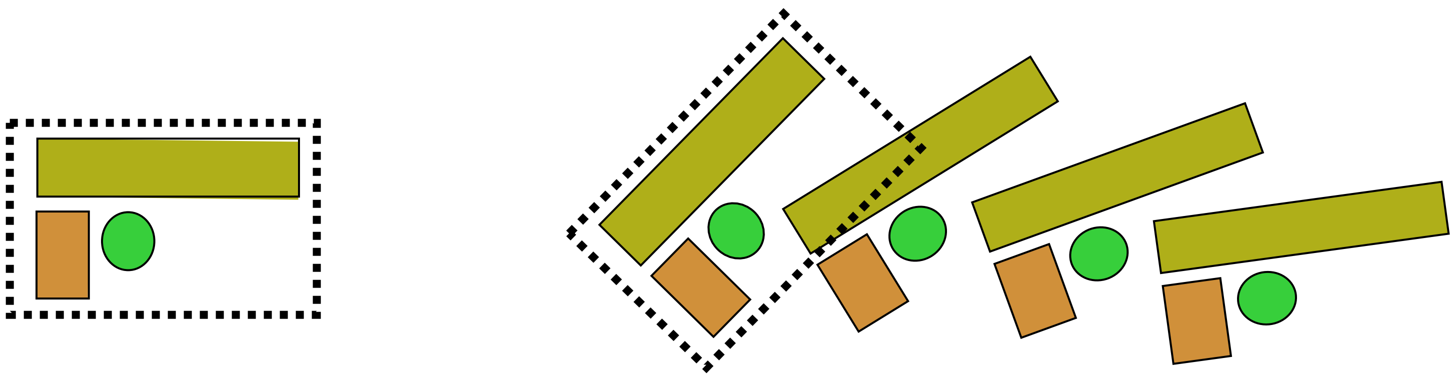
```
G4AssemblyVolume::AddPlacedVolume
                  ( G4LogicalVolume* volume,
                    G4ThreeVector& translation,
                    G4RotationMatrix* rotation );
```

- 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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Reflected volume

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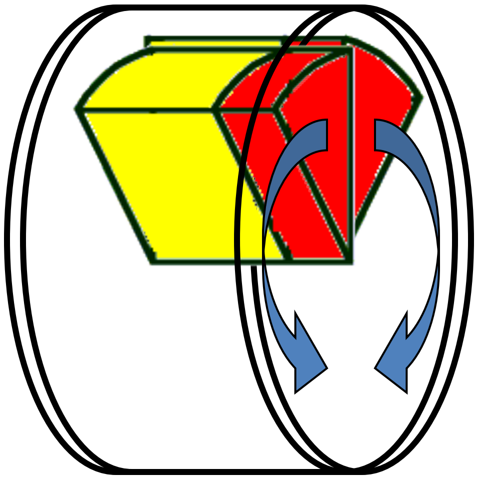
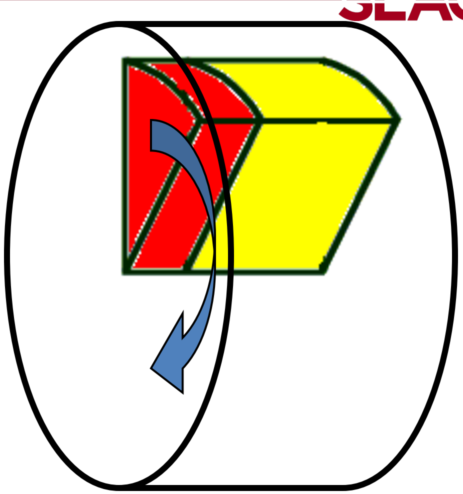
Reflecting solids



- 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

Version 10.5

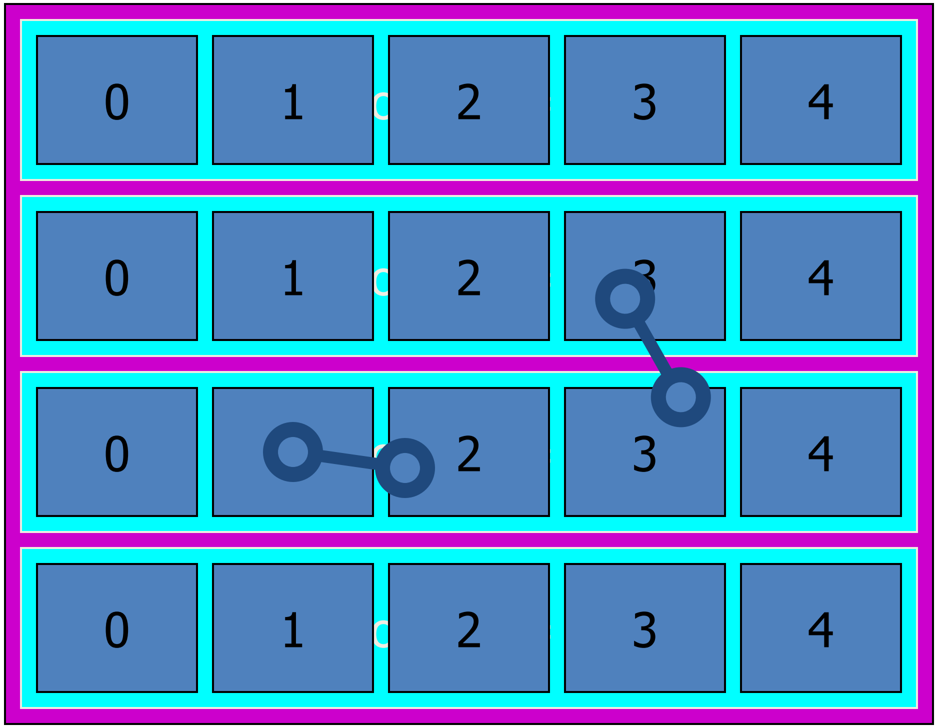
Touchable

Step point and touchable

- As mentioned already, 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
- Since release 4.0, *handles* (or *smart-pointers*) to touchables are intrinsically used. Touchables are reference counted.

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 =
    (G4TouchableHistory*)(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);
```

Geant4 A SIMULATION TOOLKIT

Version 10.5

Parallel geometry

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Parallel navigation

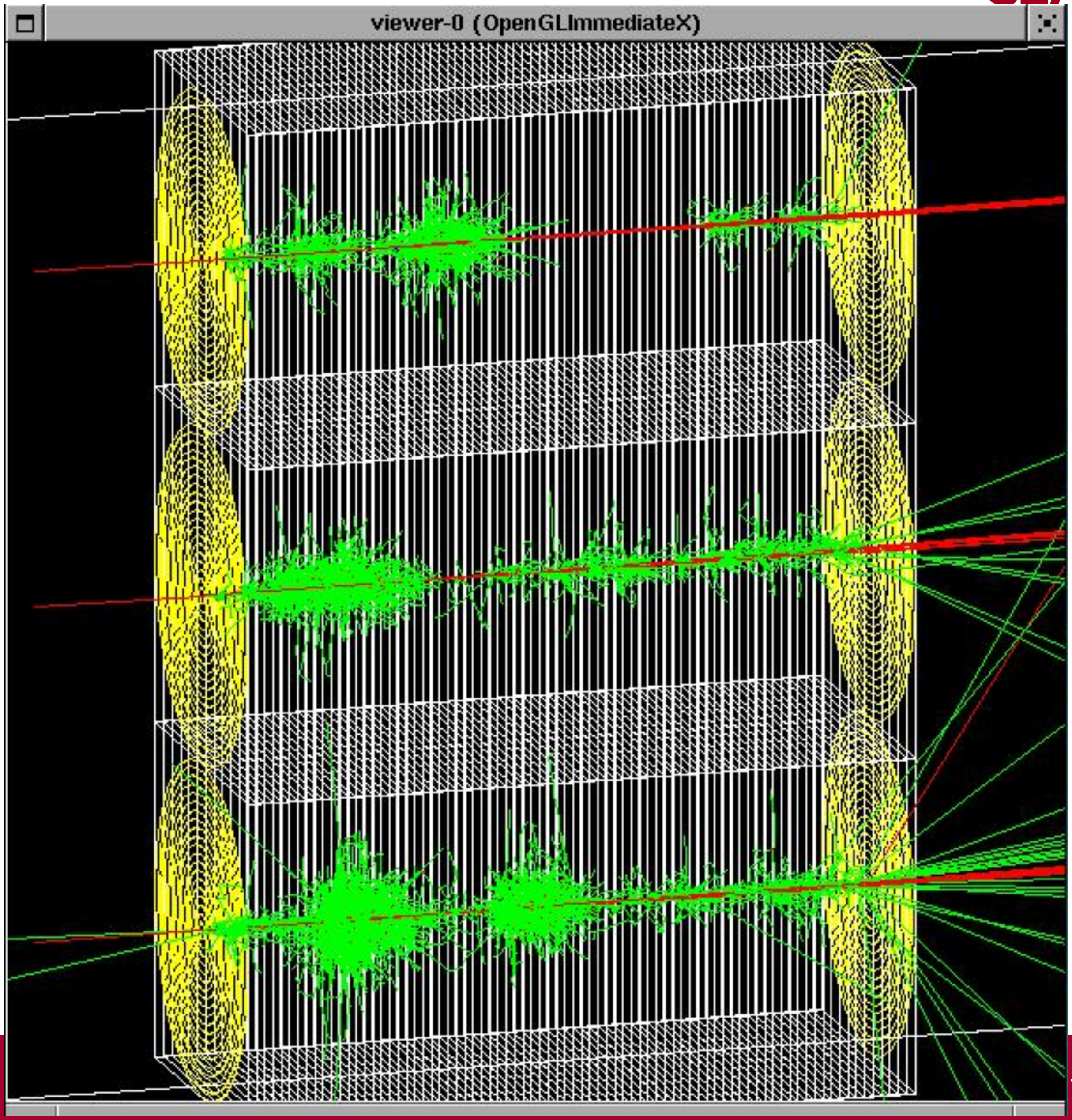
- Occasionally, it is not straightforward to define sensitivity, importance or envelope to be assigned to volumes in the mass geometry.
  – Typically a geometry built machinery by CAD, GDML, DICOM, etc. has this difficulty.
- The parallel navigation functionality allows the user to define more than one worlds in parallel.
  – G4CoupledTransportation 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.
  – 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 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.
  - All UserParallelWorlds must be registered to UserDetectorConstruction.
  - Each parallel world has its dedicated G4Navigator object, that is automatically assigned when it is constructed.
- Though all worlds will be comprehensively taken care by G4CoupledTransportation process for their navigations, each parallel world must have its own process to achieve its purpose.
  - For example, in case the user defines a sensitive detector to a parallel world, a process dedicated to this world is responsible to invoke this detector. G4SteppingManager sees only the detectors in the mass geometry. 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



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Layered mass geometry

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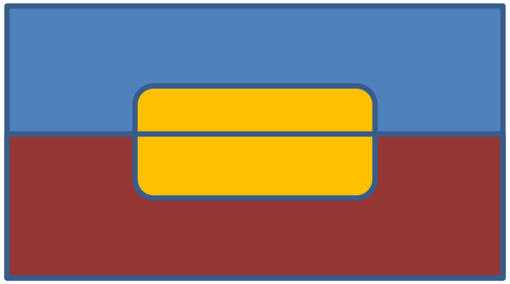
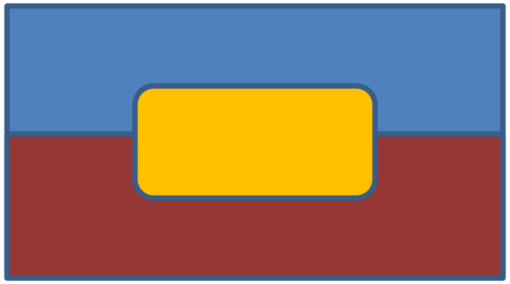
Layered mass geometries in parallel world

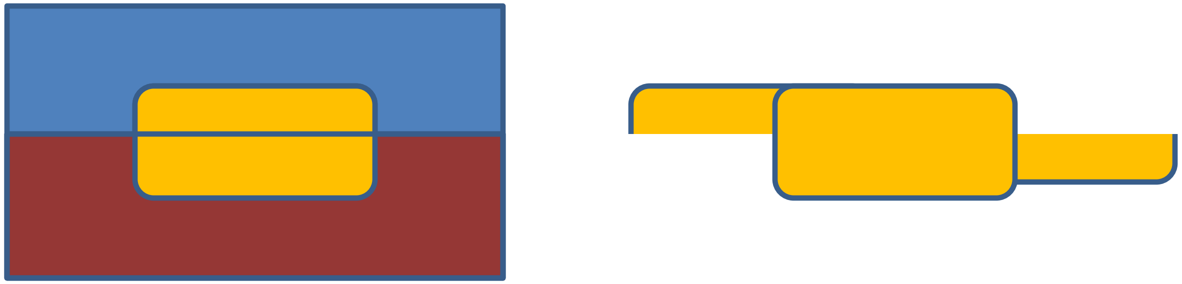
- Suppose you implement a wooden brick floating on the water.



- Dig a hole in water…

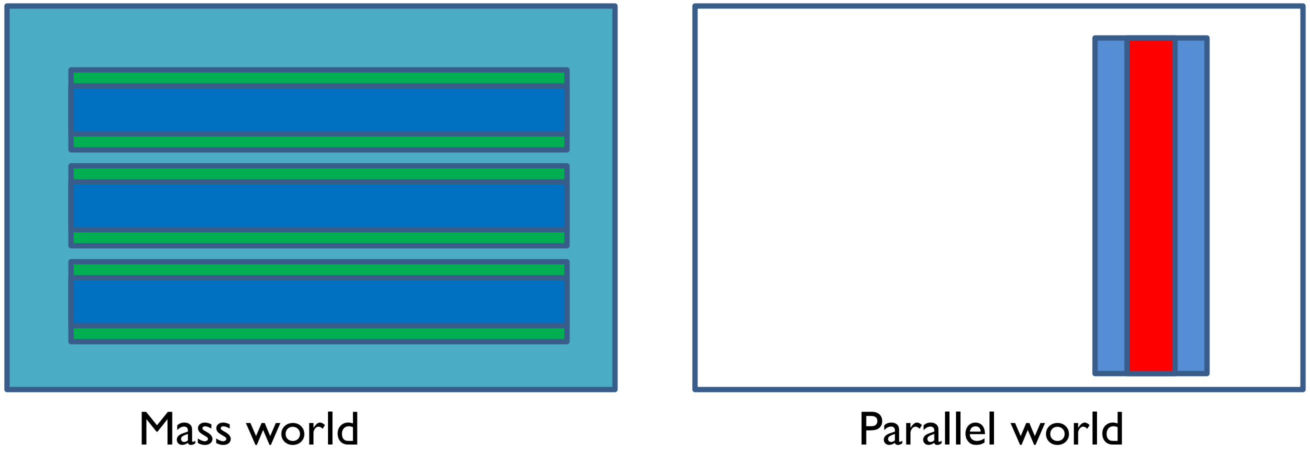


- Or, chop a brick into two and place them separately…



Layered mass geometries in parallel worlds

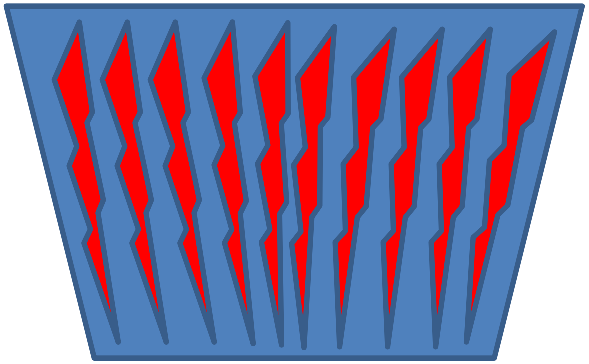
- Parallel geometry may be stacked on top of mass geometry or other parallel world geometry, allowing a user to define more than one worlds with materials (and region/cuts).
  - Track will see the material of top-layer, if it is null, then one layer beneath.
  - Alternative way of implementing a complicated geometry
    - Rapid prototyping
    - Safer, more flexible and powerful extension of the concept of "many" in Geant3



Layered mass geometries in parallel worlds - continued

- A parallel world may be associated only to some limited types of particles.
  - May define geometries of different levels of detail for different particle types
  - Example for sampling calorimeter: the mass world defines only the crude geometry with averaged material, while a parallel world with all the detailed geometry. Real materials in detailed parallel world geometry are associated with all particle types except e+, e- and gamma.
    - e+, e- and gamma do not see volume boundaries defined in the parallel world, i.e. their steps won't be limited
  - Shower parameterization such as GFLASH may have its own geometry

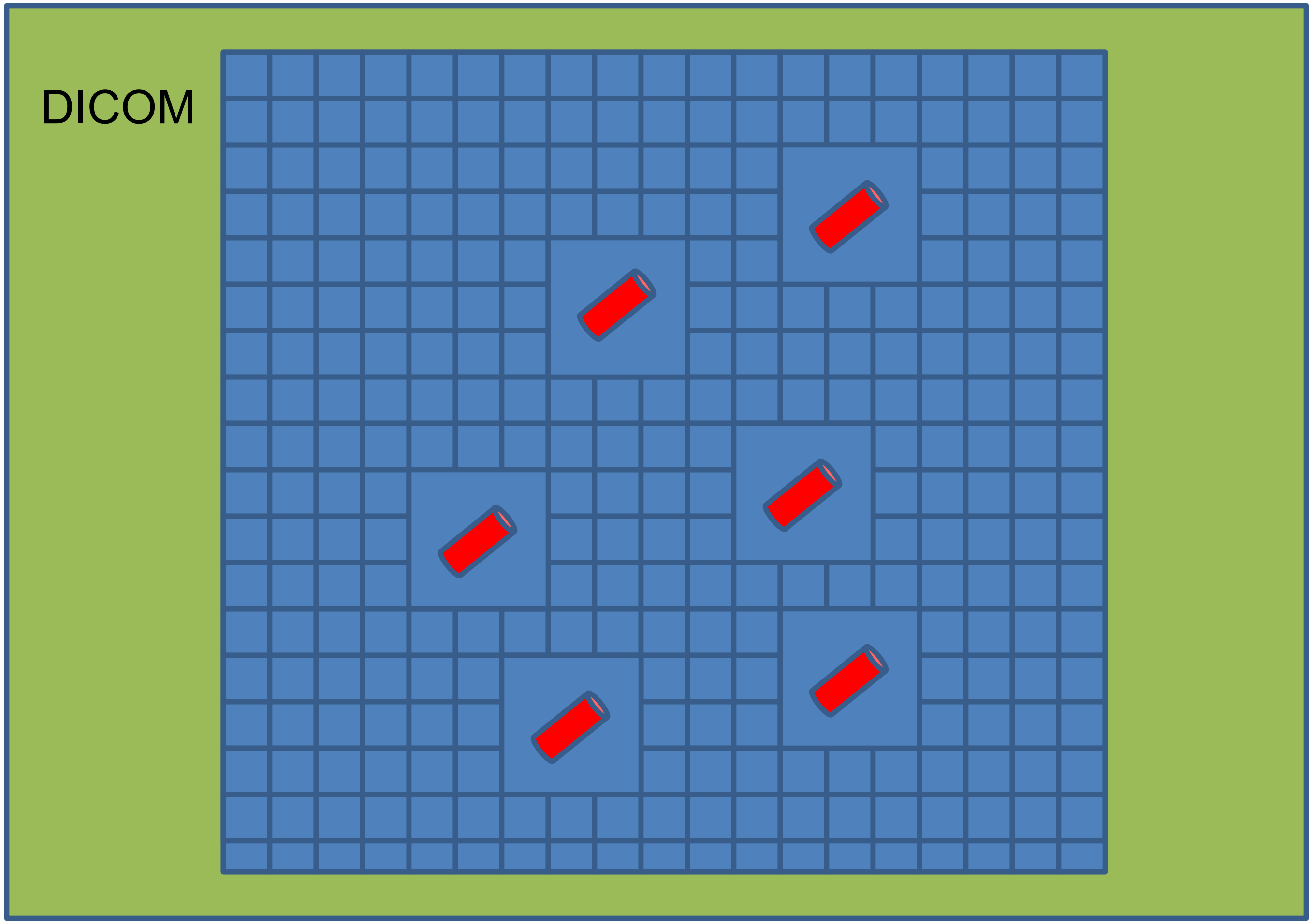
Geometry seen by e+, e-, γ



Geometry seen by other particles

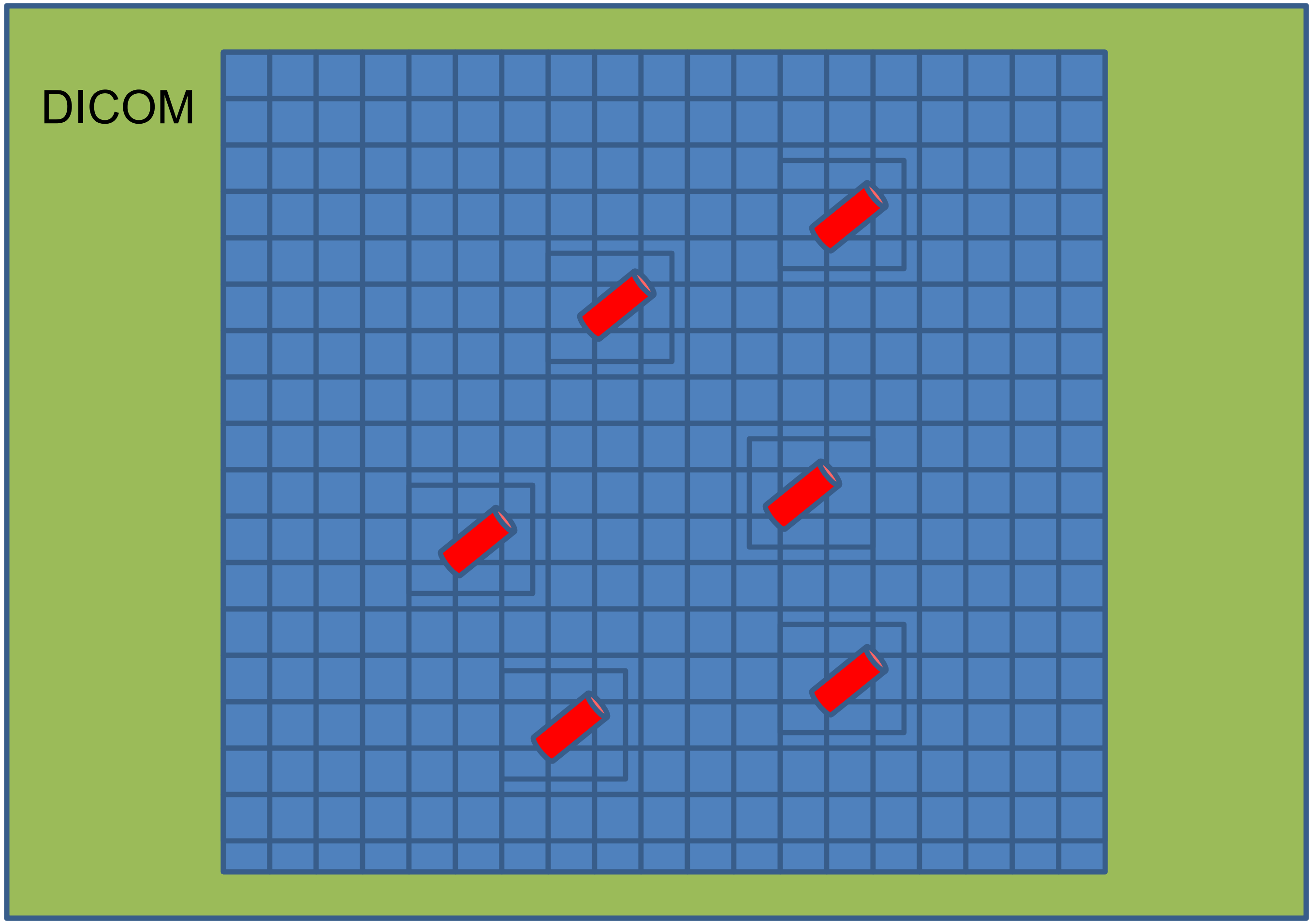
A medical use case

- Brachytherapy treatment for prostate cancer.



A medical use case

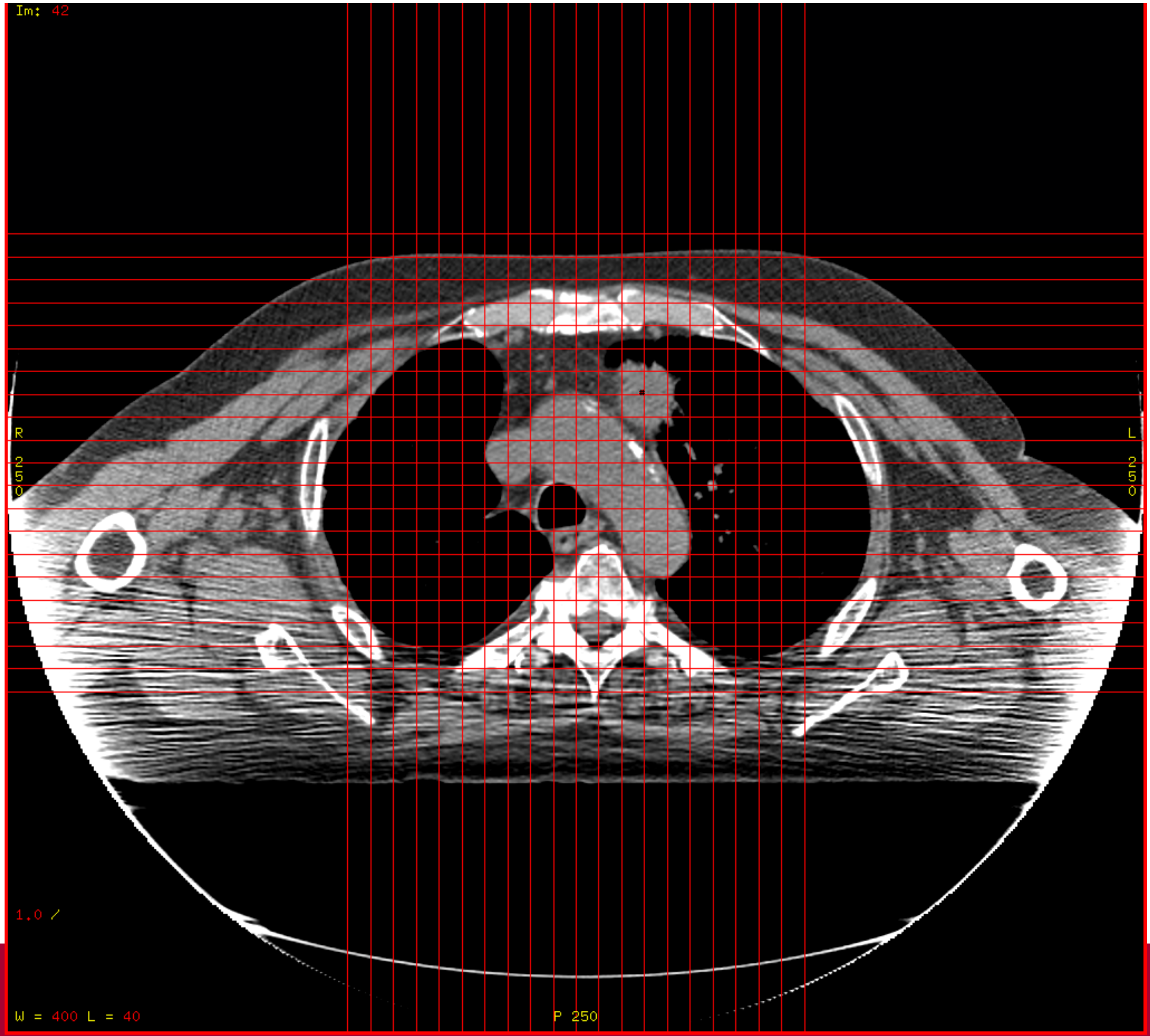
- Instead, seeds could be implemented in an empty parallel world.
  - Seeds in the parallel world would be encapsulated in empty boxes for faster navigation



Another important use case in medicine

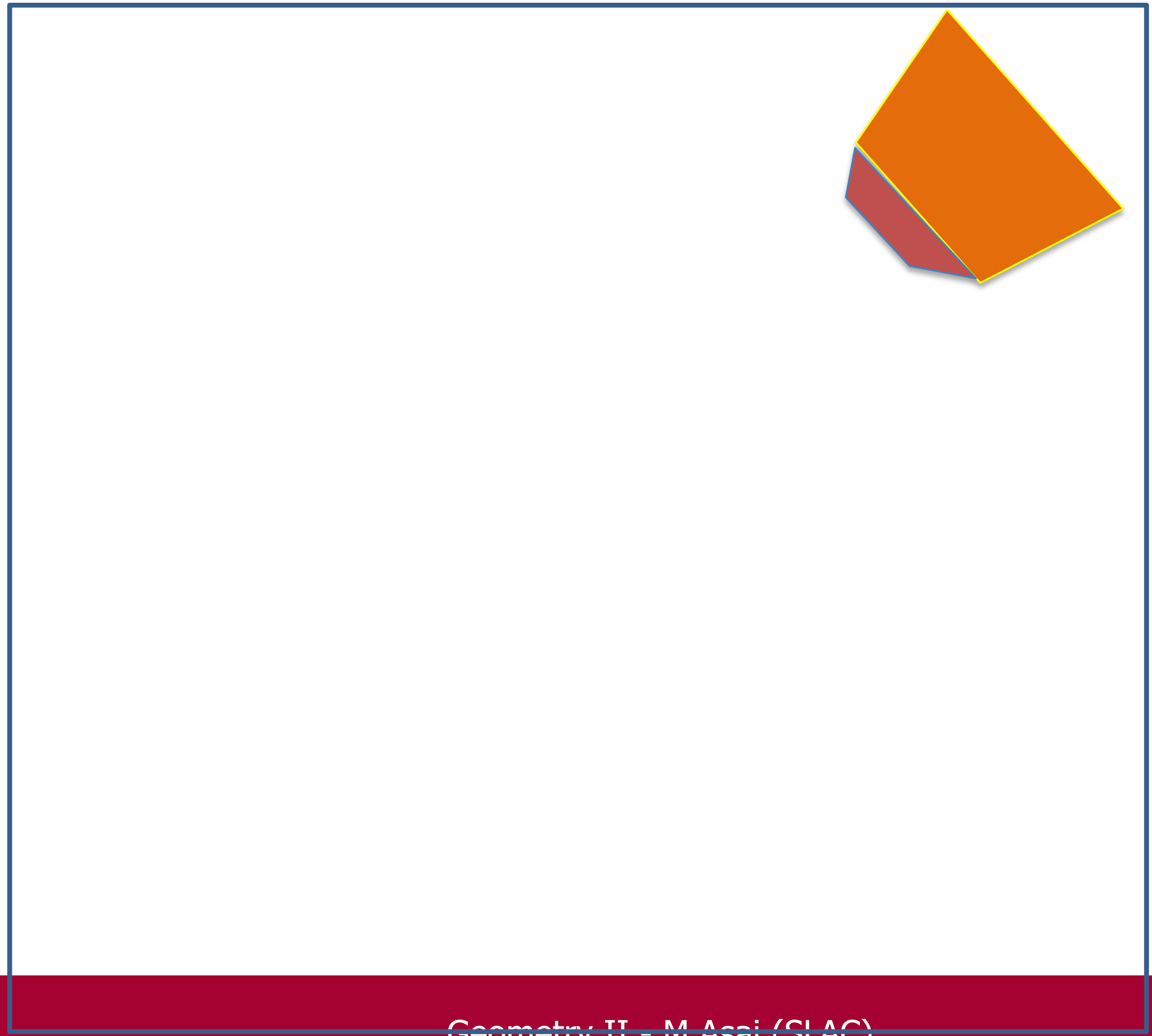
- DICOM data contain void air region outside of the patient, while the treatment head should be placed as close as patient’s body.

DICOM



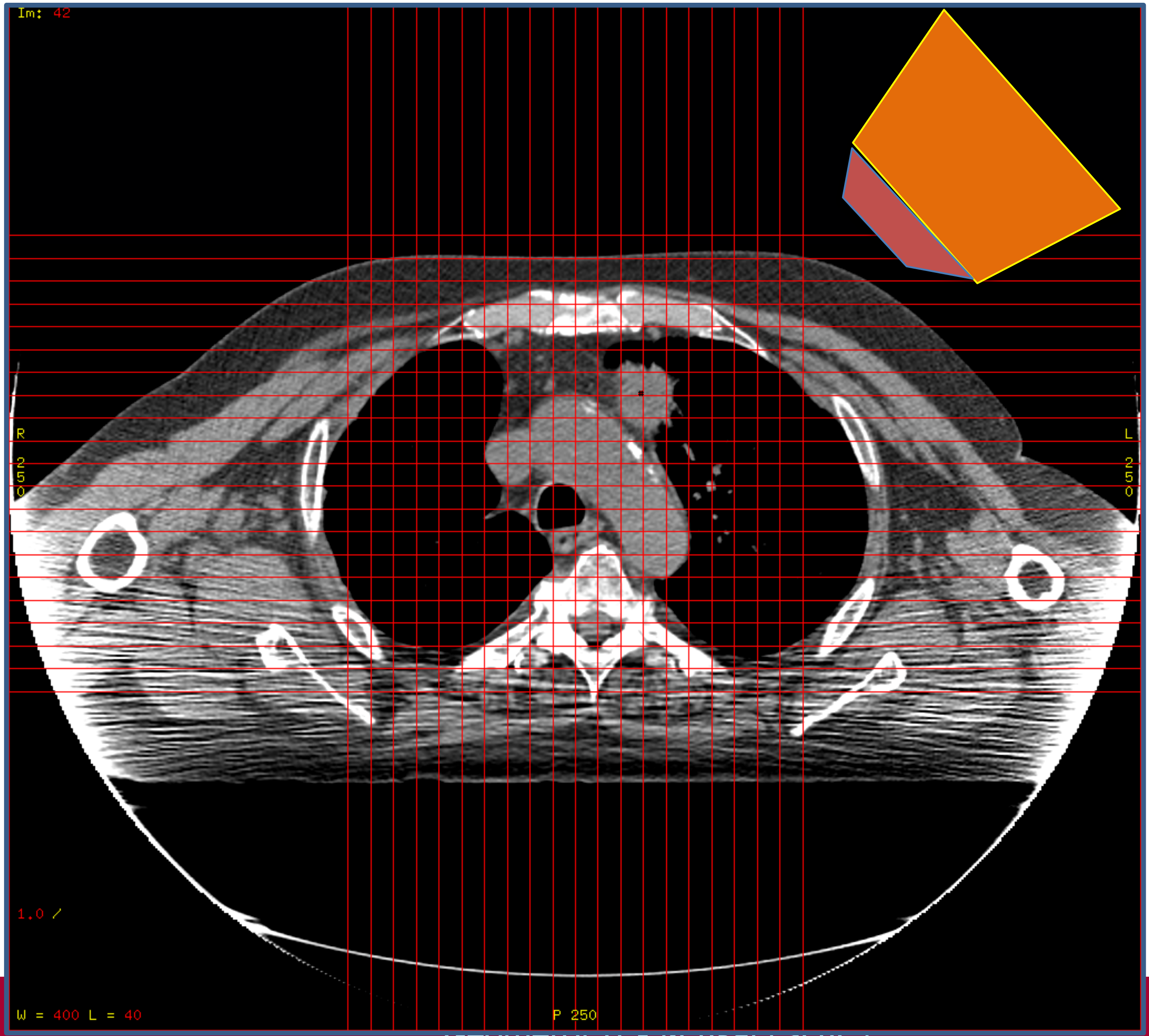
Another important use case in medicine

- Implement the treatment head in a parallel world.



Another important use case in medicine

- And overlay.



Defining a parallel world with layered mass geometry

main() (RE04.cc)

```
G4String paraWorldName = "ParallelWorld";
G4VUserDetectorConstruction* realWorld = new RE04DetectorConstruction;
G4VUserParallelWorldConstruction* parallelWorld
  = new RE04ParallelWorldConstruction(paraWorldName);
realWorld->RegisterParallelWorld(parallelWorld);
runManager->SetUserInitialization(realWorld);
//
G4VModularPhysicsList* physicsList = new FTFP_BERT;
physicsList->RegisterPhysics
      (new G4ParallelWorldPhysics(paraWorldName,true));
runManager->SetUserInitialization(physicsList);
```

Switch of layered mass geometry

– The name defined in the G4VUserParallelWorld constructor is used as the physical volume name of the parallel world, and must be given to G4ParallelWorldPhysics.

Defining a parallel world

```
void RE04ParallelWorldConstruction::Construct()
{
  //
  // World
  G4VPhysicalVolume* ghostWorld = GetWorld();
  G4LogicalVolume* worldLogical = ghostWorld->GetLogicalVolume();
  //
  // material defined in the mass world
  G4Material* water = G4Material::GetMaterial("G4_WATER");
  //
  // parallel world placement box
  G4VSolid* paraBox = new G4Box("paraBox",5.0*cm,30.0*cm,5.0*cm);
  G4LogicalVolume* paraBoxLogical
      = new G4LogicalVolume(paraBox, water, "paraBox");
  new G4PVPlacement(0,G4ThreeVector(-25.0*cm,0.,0.),paraBoxLogical,
                    "paraBox",worldLogical,false,0);
```

- The world physical volume of the parallel is provided as a clone of the world volume of the mass geometry. The user cannot create it.
- You can fill volumes regardless of the volumes in the mass geometry.
- Logical volumes in a parallel world may not have a material.