

JUNO GEANT4 SCHOOL

Beijing (北京)
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Detector description: materials and geometry

Geant4 tutorial



User classes (starting...)

At initialization

G4VUserDetectorConstruction

G4VUserPhysicsList

G4VUserActionInitialization

Global: only one instance exists in memory, shared by **all threads**.

At execution

G4VUserPrimaryGeneratorAction

G4UserRunAction

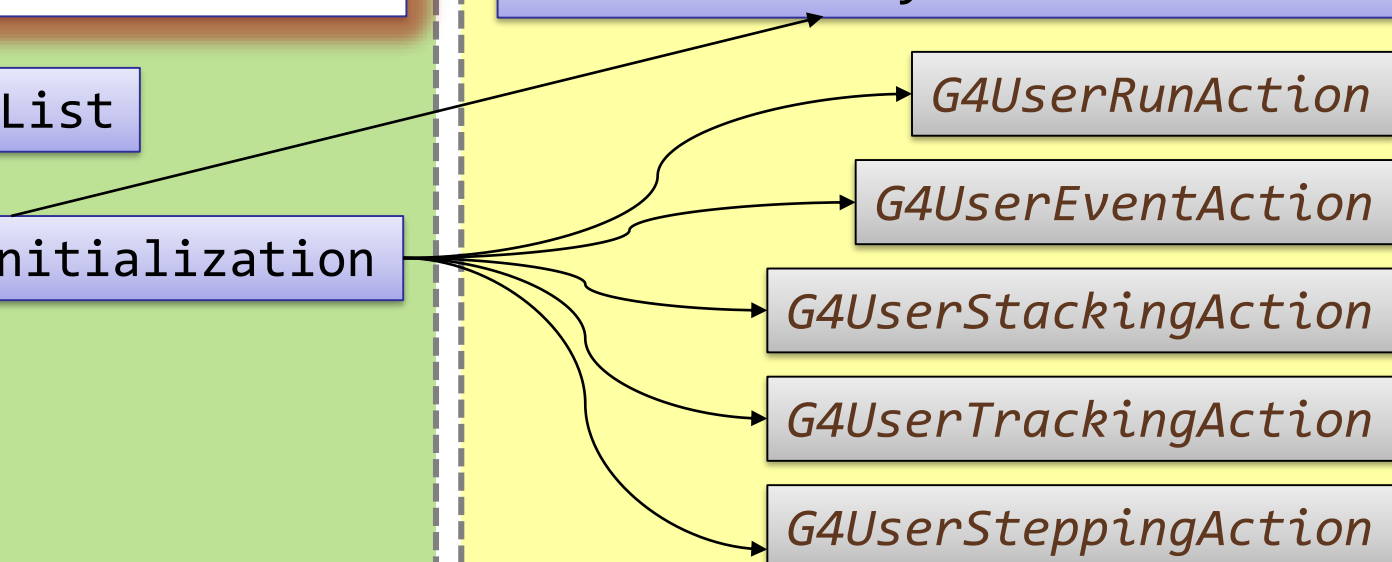
G4UserEventAction

G4UserStackingAction

G4UserTrackingAction

G4UserSteppingAction

Thread-local: an instance of each action class exists **for each thread**.



Contents

- Units and materials
- Geometry construction
- Parallel worlds

...Part 2 (advanced):

- Electromagnetic fields
- Repeated volumes
- GDML sharing & CAD import

Note: Geant4 basic types

- Aliases for the **primitive data types** to provide cross-platform compatibility:
 - `G4double`, `G4float`, `G4int`, `G4bool`, `G4long`
- Enhanced version of string called **G4String**
 - inherits from `std::string` ⇒ all methods and operators
 - several additional methods
- **G4ThreeVector** is a three-component class corresponding to a real physics vector (example later)

```
G4ThreeVector dimensions {1.0, 2.0, 3.0 };
```

Please, use these types for best compatibility (e.g. `G4int` instead of `int`, etc., `G4ThreeVector` when it makes sense etc.)

Part I:

Units & materials

- System of units & constants
- Definition of elements
- Materials and mixtures
- NIST database

Units in Geant4

- **Don't use default units!**

- When specifying dimensions, always* multiply by an appropriate unit:

```
G4double width = 12.5 * m;  
G4double density = 2.7 * g/cm3;
```

- Most common units are defined in **CLHEP** library (included in Geant4):

```
▶ G4SystemOfUnits.hh
```

```
▶ CLHEP/SystemOfUnits.hh
```

- You can define new units (**see backup slides**)

- Output data in terms of a specific unit:

- **divide** a value by the unit:

```
G4cout << dE / MeV << " (MeV)" << G4endl;
```

System of Units

Basic units:

nanosecond (**ns**)

unit charge (**eplus**)

megaelectronvolt (**MeV**)

radian

kelvin

millimetre (**mm**)

candela

steradian

- All other units derived from the basic ones.
- **Useful feature:** Geant4 can select the most appropriate unit to use
 - specify the *category* for the data (Length, Time, Energy, etc...):

```
G4cout << G4BestUnit(StepSize, "Length");
```

StepSize will be printed in km, m, mm or ... **fermi**, depending on its actual value

Materials

- Different levels of material description:
 - isotopes → **G4Isotope**
 - elements → **G4Element**
 - molecules → **G4Material**
 - compounds and mixtures → **G4Material**
- Attributes associated:
 - temperature, pressure, state, density
- **G4Isotope** and **G4Element** describe properties of the *atoms*:
 - Atomic number, number of nucleons, mass of a mole, shell energies, cross-sections per atoms, etc...
- **G4Material** describes the *macroscopic* properties of the matter:
 - temperature, pressure, state, density
 - Radiation length, absorption length, etc...
- **G4Material** is used by tracking, geometry and physics

Elements and isotopes

Isotopes...

```
G4Isotope(const G4String& name,  
          G4int      z,      // atomic number  
          G4int      n,      // number of nucleons  
          G4double   a );   // mass of mole
```

...can be assembled into elements as follows:

```
G4Element (const G4String& name,  
          const G4String& symbol, // element symbol  
          G4int      nIso );     // n. of isotopes
```

```
G4Element::AddIsotope(G4Isotope* iso, // isotope  
                     G4double reLAbund); // fraction of atoms
```

Elements & compounds

Single-element material:

```
G4double z, a, density;  
density = 1.390*g/cm3;  
a = 39.95*g/mole;  
G4Material* lAr = new G4Material("liquidAr", z=18, a, density);
```

Molecule material (composition by number of atoms):

```
a = 1.01*g/mole;  
G4Element* elH = new G4Element("Hydrogen", symbol="H", z=1., a);  
  
a = 16.00*g/mole;  
G4Element* elO = new G4Element("Oxygen", symbol="O", z=8., a);  
  
density = 1.000*g/cm3;  
G4Material* H2O = new G4Material("Water", density, ncomponents=2);  
H2O->AddElement(elH, natoms=2);  
H2O->AddElement(elO, natoms=1);
```

Mixtures

Composition by fraction of mass:

```
a = 14.01*g/mole;
G4Element* e1N = new G4Element(name="Nitrogen",symbol="N", z= 7., a);
a = 16.00*g/mole;
G4Element* e1O = new G4Element(name="Oxygen",symbol="O", z= 8., a);
density = 1.290*mg/cm3;
G4Material* Air = new G4Material(name="Air", density, ncomponents=2);
Air->AddElement(e1N, 70.0*perCent);
Air->AddElement(e1O, 30.0*perCent);
```

Composition of mixtures:

```
G4Element* e1C = ...; // define "carbon" element
G4Material* SiO2 = ...; // define "quartz" material
G4Material* H2O = ...; // define "water" material
density = 0.200*g/cm3;

G4Material* aerogel = new G4Material("Aerogel",
                                     density, ncomponents=3);
aerogel->AddMaterial(SiO2, fractionmass=62.5*perCent);
aerogel->AddMaterial(H2O, fractionmass=37.4*perCent);
aerogel->AddElement(e1C, fractionmass= 0.1*perCent);
```

Example: Gas

- It may be necessary to specify temperature and pressure
 - (dE/dx computation affected)

```
G4double density = 27. * mg/cm3;
G4double temperature = 325. * kelvin;
G4double pressure = 50. * atmosphere;

G4Material* CO2 = new G4Material("CO2Gas", density,
    ncomponents=2, kStateGas, temperature, pressure);
CO2->AddElement(C, natoms = 1);
CO2->AddElement(O, natoms = 2);
```

- Absolute vacuum does not exist: gas at very low density!
 - Cannot define materials composed of multiple elements through **Z** or **A**, or with $\rho=0$

```
G4double atomicNumber = 1.;
G4double massOfMole = 1.008*g/mole;
G4double density = 1.e-25*g/cm3;
G4double temperature = 2.73*kelvin;
G4double pressure = 3.e-18*pascal;
G4Material* Vacuum = new G4Material("interGalactic",
    atomicNumber, massOfMole, density,
    kStateGas, temperature, pressure);
```

NIST material database

- No need to predefine elements and materials
- Retrieve materials from NIST manager:

```
G4NistManager* manager = G4NistManager::Instance();  
G4Material* H2O = manager->FindOrBuildMaterial("G4_WATER");  
G4Material* air = manager->FindOrBuildMaterial("G4_AIR");  
G4Material* vacuum = manager->FindOrBuildMaterial("G4_Galactic");
```

- UI commands:

`/material/nist/printElement`

← print defined elements

`/material/nist/listMaterials`

← print defined materials

► `G4NistManager.hh`

NIST material database

- NIST database for materials is imported inside Geant4

<http://physics.nist.gov/PhysRefData>

- UI commands specific for handling materials
- The best accuracy for the most relevant parameters guaranteed:
 - Density
 - Mean excitation potential
 - Chemical bounds
 - Element composition
 - Isotope composition
 - Various corrections

Z	A	m	error (%)	A _{eff}	
14	Si	22	22.03453	(22)	
		28.0855	(3)		
		23	23.02552	(21)	
		24	24.011546	(21)	
		25	25.004107	(11)	
		26	25.992330	(3)	
		27	26.98670476	(17)	
		28	27.9769265327	(20)	92.2297 (7)
		29	28.97649472	(3)	4.6832 (5)
		30	29.97377022	(5)	3.0872 (5)
		31	30.97536327	(7)	
		32	31.9741481	(23)	
		33	32.978001	(17)	
		34	33.978576	(15)	
		35	34.984580	(40)	
		36	35.98669	(11)	
		37	36.99300	(13)	
		38	37.99598	(29)	
		39	39.00230	(43)	
		40	40.00580	(54)	
		41	41.01270	(64)	
		42	42.01610	(75)	

- *Natural isotope compositions*
- *More than 3000 isotope masses*

NIST materials

```

=====
### Elementary Materials from the NIST Data Base
=====
Z Name      ChFormula      density(g/cm^3)      I(eV)
=====
1  G4_H      H_2              8.3748e-05           19.2
2  G4_He     He              0.000166322         41.8
3  G4_Li     Li              0.534                40
4  G4_Be     Be              1.848                63.7
5  G4_B      B               2.37                 76
6  G4_C      C               2                    81
7  G4_N      N_2             0.0011652           82
8  G4_O      O_2             0.00133151          95
9  G4_F      F               0.00158029          115
10 G4_Ne     Ne              0.000838505         137
11 G4_Na     Na              0.971                149
12 G4_Mg     Mg              1.74                 156
13 G4_Al     Al              2.6989              166
14 G4_Si     Si              2.33                 173

```

```

=====
### Compound Materials from the NIST Data Base
=====
N Name      ChFormula      density(g/cm^3)      I(eV)
=====
13 G4_Adipose_Tissue 0.92             63.2
    1  0.119477
    6  0.63724
    7  0.00797
    8  0.232333
    11 0.0005
    12 2e-05
    15 0.00016
    16 0.00073
    17 0.00119
    19 0.00032
    20 2e-05
    26 2e-05
    30 2e-05
4  G4_Air          0.00120479       85.7
    6  0.000124
    7  0.755268
    8  0.231781
    18 0.012827
2  G4_CsI          4.51              553.1
    53 0.47692
    55 0.52308

```

- NIST Elements:

- **H -> Cf (Z = 1 -> 98)**

- NIST compounds:

- e.g. “**G4_ADIPOSE_TISSUE_IRCP**”

- HEP and Nuclear materials:

- e.g. **Liquid Ar, PbWO**

- It is possible to build mixtures of NIST and user-defined materials

Part II: Geometry

- Basic concepts
- Implementation
 - Solids
 - Logical volumes
 - Physical volumes
 - Regions
- Tools for geometry checking

Geometry – implementation basics

- Implement a class inheriting from the abstract base class

G4VUserDetectorConstruction:

```
class MyDetector : public G4VUserDetectorConstruction {
public:
    virtual G4VPhysicalVolume* Construct();           // required

    virtual void ConstructSDAndField();             // optional
    // ...
};
```

- Create an instance in the main program:

```
MyDetector* detector = new MyDetector();
runManager->SetUserInitialization(detector);
```

Note: Split the implementation into more classes & methods! (good programming practice)

- especially for complex geometries!

Note: you should not delete the **MyDetector** instance! Run manager does that automatically.

G4VUserDetectorConstruction

- Method **Construct()**
 - Define materials
 - Define solids and volumes of the geometry
 - Build the tree hierarchy of volumes
 - Define visualization attributes

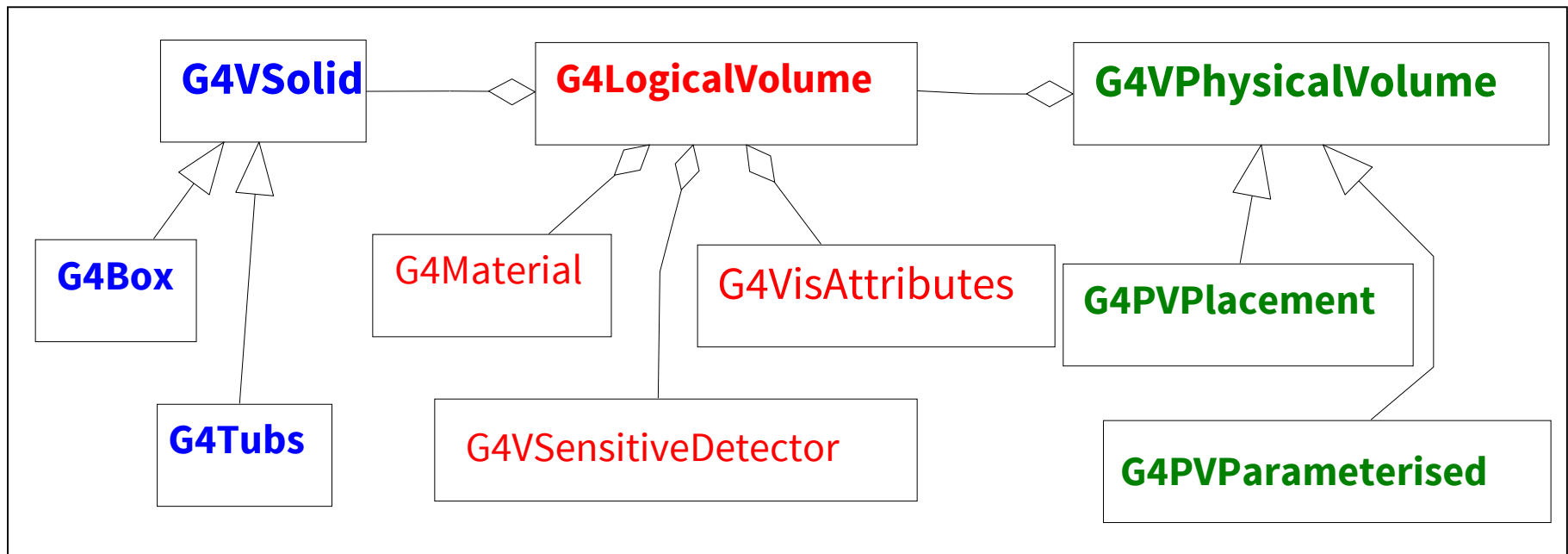
 - Return the world physical volume!

- Method **ConstructSDAndField()** MT
 - Assign magnetic field to volumes / regions
 - Define sensitive detectors and assing them to volumes

▶ G4VUserDetectorConstruction.hh

Detector geometry components

- Three conceptual layers
 - **G4VSolid**: *shape, size*
 - **G4LogicalVolume**: *material, sensitivity, magnetic field, etc.*
 - **G4VPhysicalVolume**: *position, rotation*

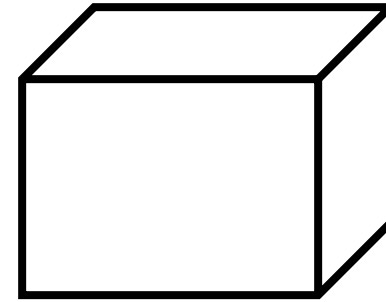


Define detector geometry

- Basic strategy

```
G4VSolid* pBoxSolid =  
  new G4Box("aBoxSolid",  
    1.*m, 2.*m, 3.*m);
```

Solid : shape and size



Step 1
Create the geom.
object : box

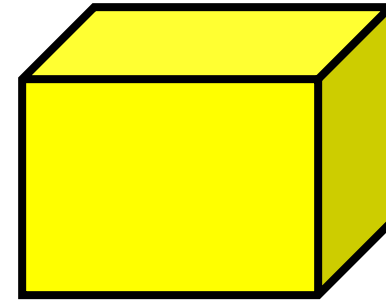
Define detector geometry

- Basic strategy

```
G4VSolid* pBoxSolid =  
  new G4Box("aBoxSolid",  
    1.*m, 2.*m, 3.*m);
```

```
G4LogicalVolume* pBoxLog =  
  new G4LogicalVolume( pBoxSolid,  
    pBoxMaterial, "aBoxLog", 0, 0, 0);
```

Logical volume :
+ material, sensitivity, etc.



Step 1
Create the geom.
object : box



Step 2
Assign properties
to object : material

Define detector geometry

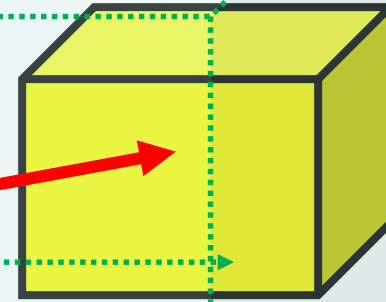
- Basic strategy

Physical volume :
+ rotation and position

```
G4VSolid* pBoxSolid =  
  new G4Box("aBoxSolid",  
    1.*m, 2.*m, 3.*m);
```

```
G4LogicalVolume* pBoxLog =  
  new G4LogicalVolume( pBoxSolid,  
    pBoxMaterial, "aBoxLog", 0, 0, 0);
```

```
G4VPhysicalVolume* aBoxPhys =  
  new G4PVPlacement(pRotation,  
    G4ThreeVector(posX, posY, posZ), pBoxLog,  
    "aBoxPhys", pMotherLog, 0, copyNo);
```



Step 1
Create the geom.
object : box

Step 2
Assign properties
to object : material

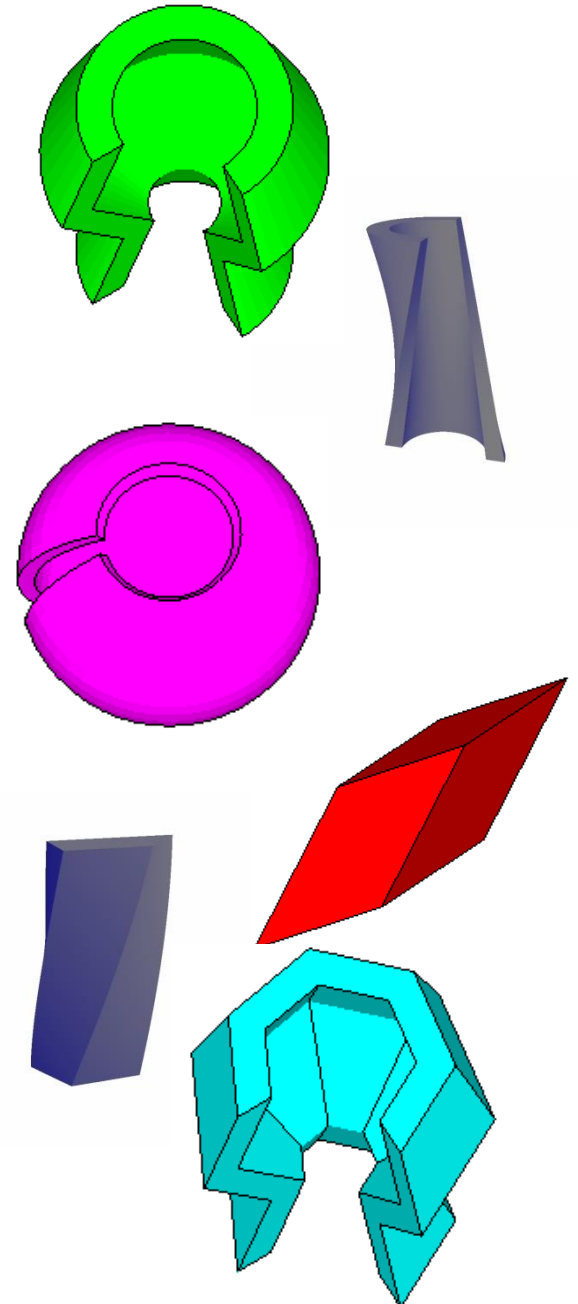
Step 3
Place it in the
coordinate system
of mother volume

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

➤ The world volume

Solids

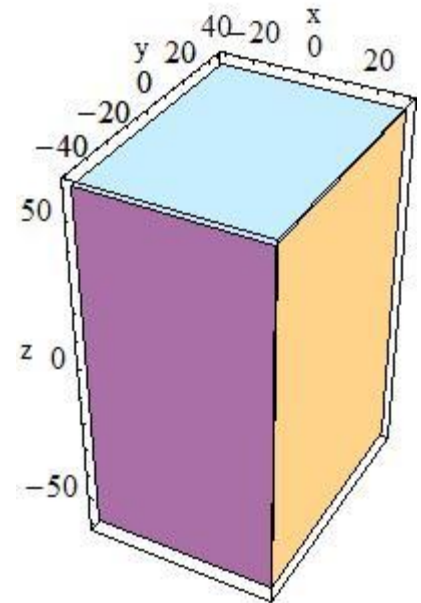
- Solids defined in Geant4:
 - CSG (Constructed Solid Geometry) solids
 - `G4Box`, `G4Tubs`, `G4Cons`, `G4Trd`, ...
 - Specific solids (CSG like)
 - `G4Polycone`, `G4Polyhedra`, `G4Hype`, ...
 - `G4TwistedTubs`, `G4TwistedTrap`, ...
 - BREP (Boundary REPresented) solids
 - `G4BREPSolidPolycone`, `G4BSplineSurface`
 - Any order surface
 - Boolean solids
 - `G4UnionSolid`, `G4SubtractionSolid`, ...



CSG: G4Box

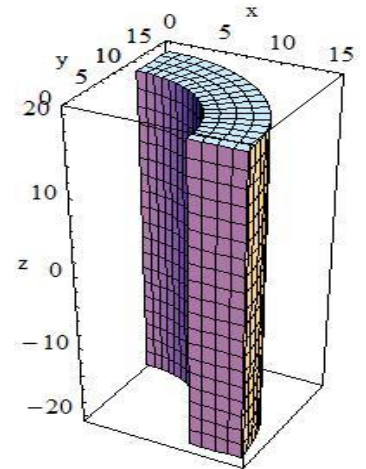
```
G4Box(const G4String& pname, // name
      G4double pX, // half-length in X
      G4double pY, // half-length in Y
      G4double pZ, // half-length in Z);
```

Note the half-length!

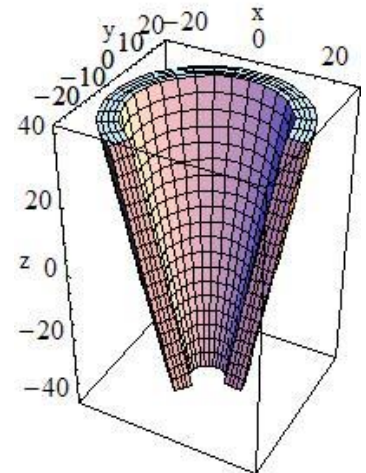


CSG: G4Tubs, G4Cons

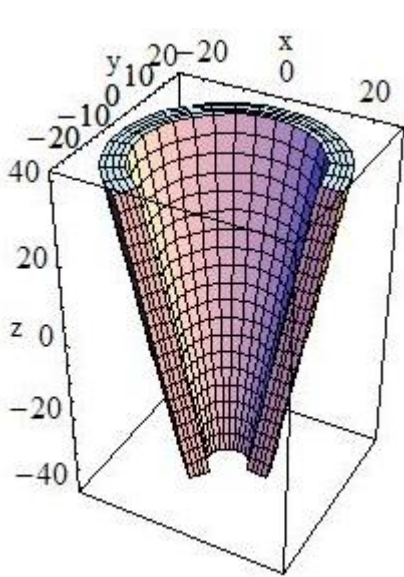
```
G4Tubs(const G4String& pname, // name
        G4double pRmin, // inner radius (0)
        G4double pRmax, // outer radius
        G4double pDz, // Z half! length
        G4double pSphi, // starting Phi (0)
        G4double pDphi); // segment angle (twopi)
```



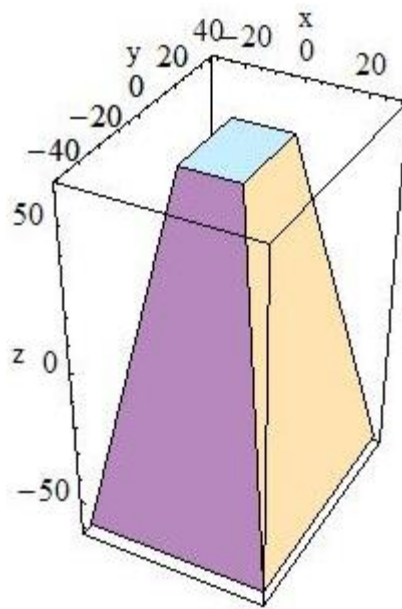
```
G4Cons(const G4String& pname, // name
        G4double pRmin1, // inner radius -pDz
        G4double pRmax1, // outer radius -pDz
        G4double pRmin2, // inner radius +pDz
        G4double pRmax2, // outer radius +pDz
        G4double pDz, // Z half length
        G4double pSphi, // starting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



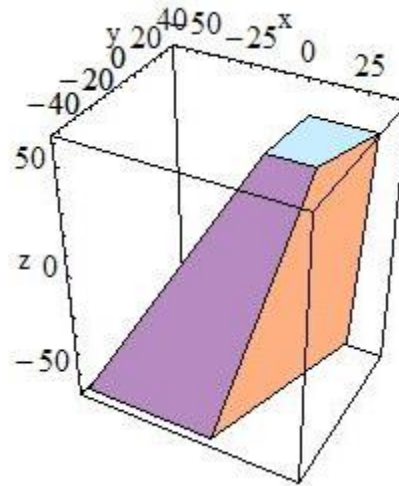
Other CSG solids



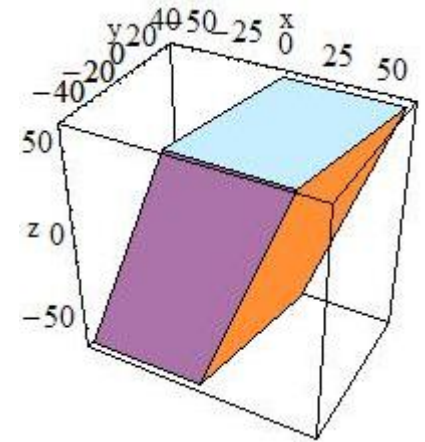
G4Cons



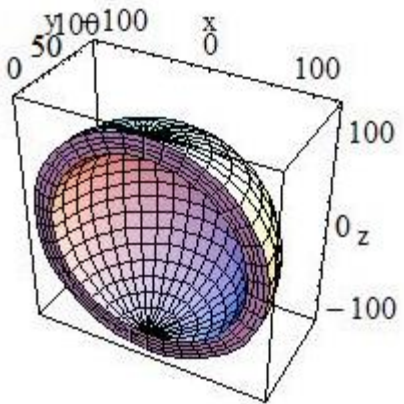
G4Trd



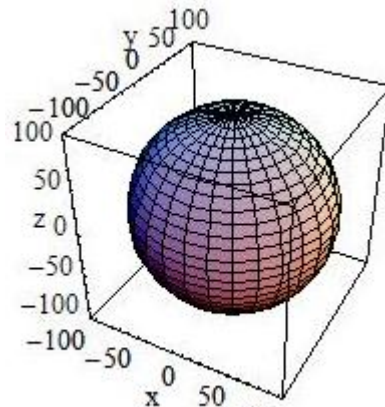
G4Trap



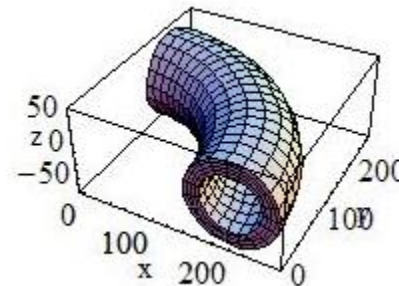
G4Para
(parallelepiped)



G4Sphere



G4Orb
(full solid sphere)



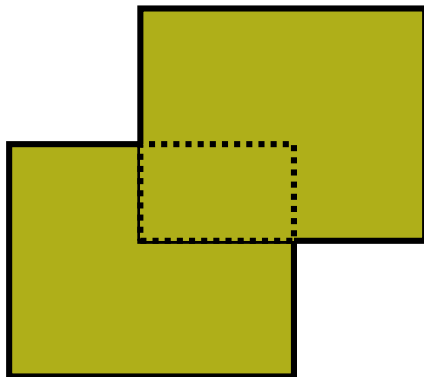
G4Torus

Consult [Section 4.1.2 of Geant4 Application Developers Guide](#) for all available shapes.

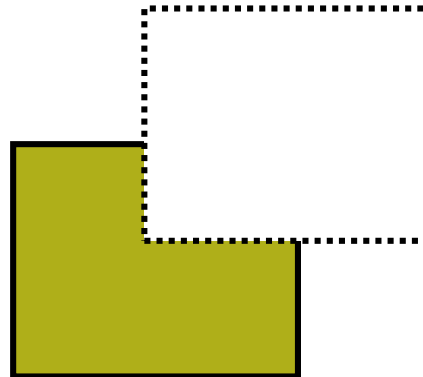
Boolean Solids

- ▶ 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 a third solid can be combined with 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

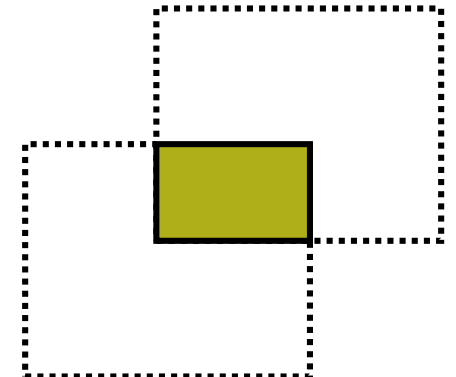
G4UnionSolid



G4SubtractionSolid



G4IntersectionSolid



Boolean Solids - example

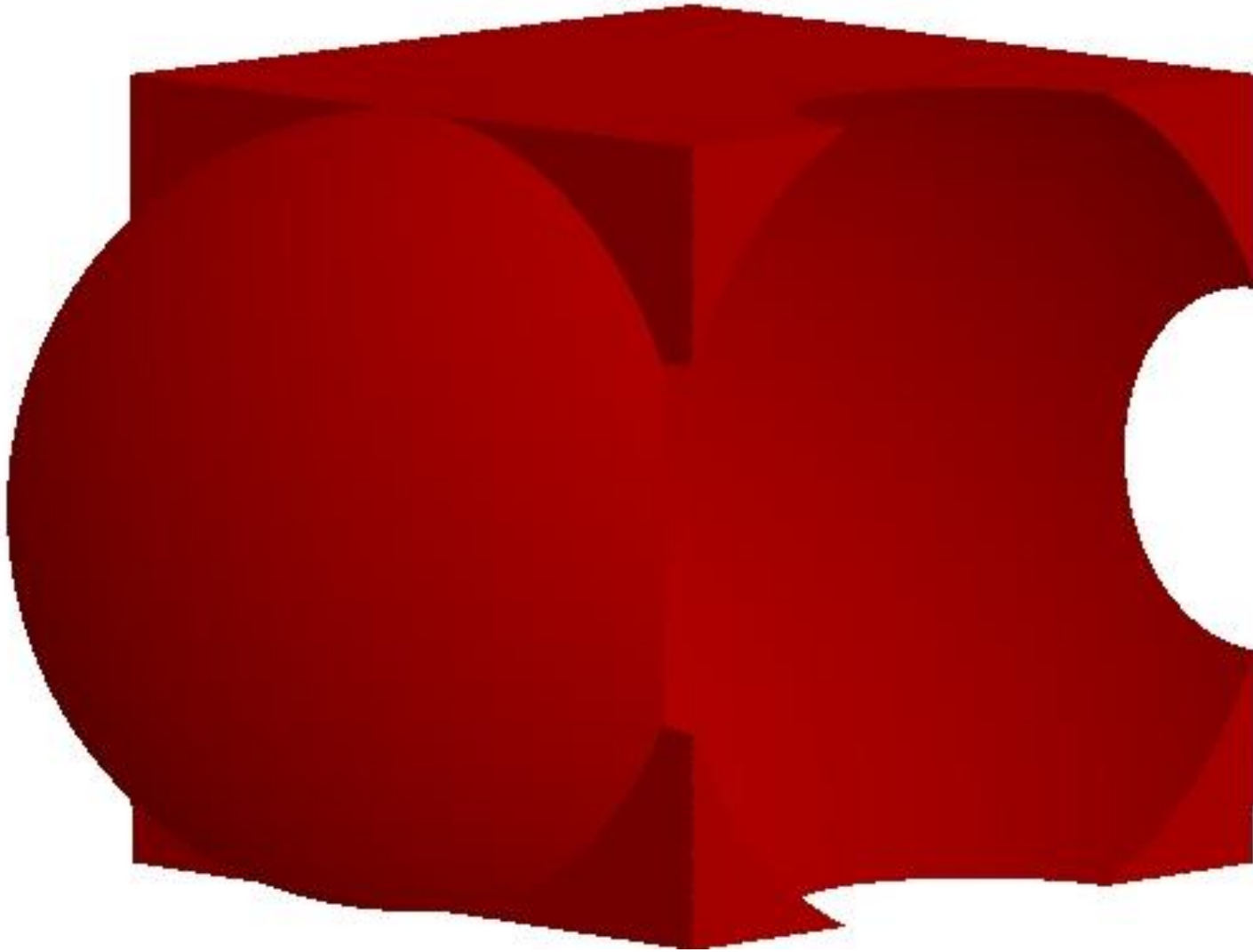
```
G4VSolid* box = new G4Box("Box",50*cm,60*cm,40*cm);
G4VSolid* cylinder =
    new G4Tubs("Cylinder",0.,50.*cm,50.*cm,0.,2*M_PI*rad);

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.));
```

Boolean Solids



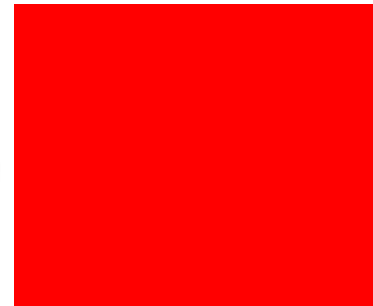
G4LogicalVolume

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

- Contains all information of volume except position:
 - Shape and dimension (G4VSolid, see *above*)
 - Material, sensitivity, visualization attributes
 - Position of daughter volumes
 - Magnetic field, User limits
- Physical volumes of same type can share a logical volume.
- The pointers to solid and material must not be null!

Visualization attributes

- Instance of **G4VisAttributes** class assigned to a logical volume
 - visible / invisible
 - colour as **G4Colour** instance
 - solid / wireframe



```
// ..
G4LogicalVolume* myLog = new G4LogicalVolume(...);
G4VisAttributes* red = new G4VisAttributes(G4Colour::Red());
red->SetVisibility(true);
red->SetForceSolid(true);
myLog->SetVisAttributes(red);
//...

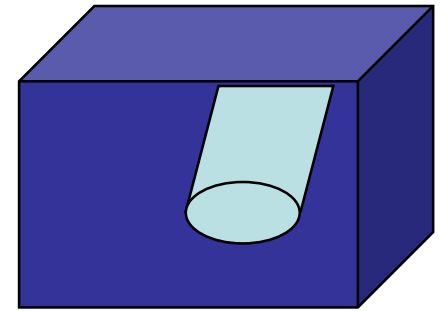
G4VisAttributes* blue = new G4VisAttributes(G4Colour::Blue());
blue->SetVisibility(true);
blue->SetForceWireframe(true);
myLog->SetVisAttributes(blue);
```



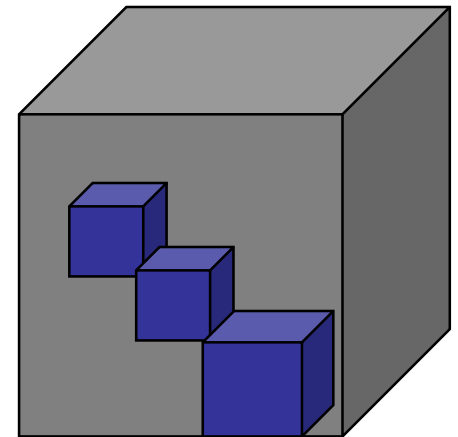
Physical Volumes

A physical volume is a positioned instance of a logical volume inside another logical volume (the mother volume).

- **G4PVPlacement**: a single **positioned volume**
Note that a Placement Volume can still represent multiple detector elements, if several copies exist of the mother logical volume
- **Repeated Volumes**: a **single physical volume represents multiple copies of a volume** within its mother volume
 - **G4PVReplica** (= simple repetition)
 - **G4PVParameterised** (= more complex)
 - **G4PVDivision**



G4PVPlacement



G4PVParameterised

G4PVPlacement

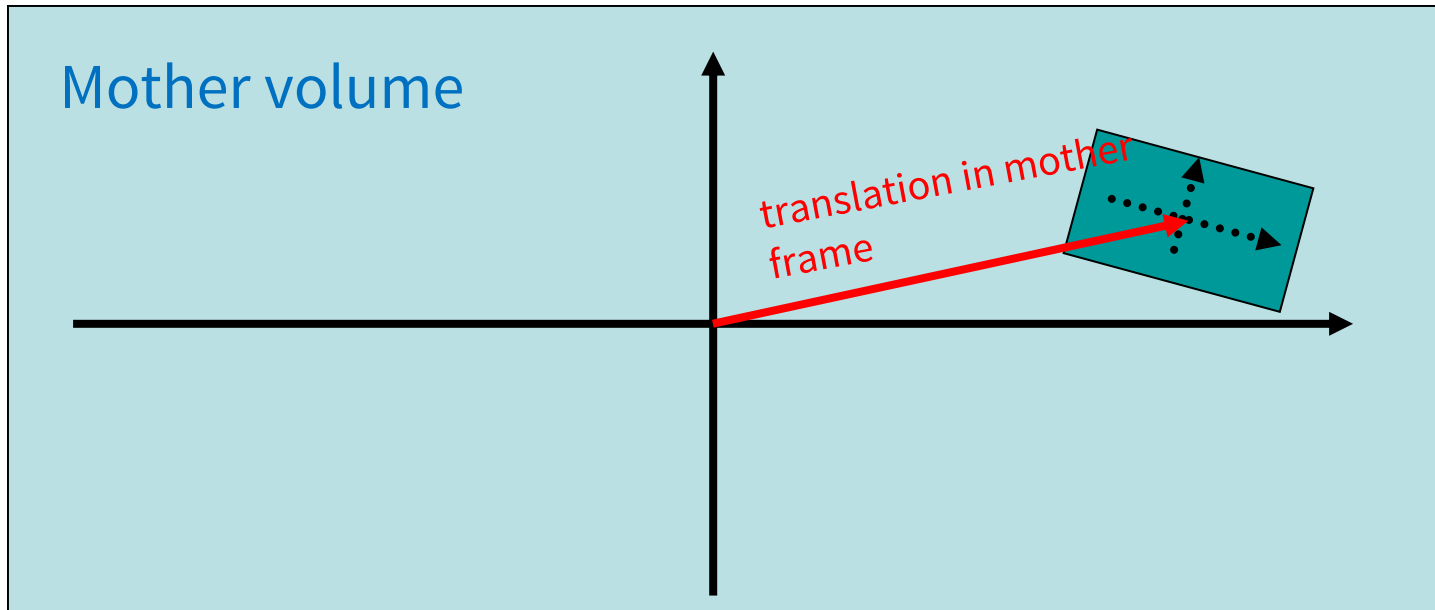
- Single volume positioned relatively to the mother volume
 - In a frame rotated and translated relative to the coordinate system of the mother volume
- Four constructors:
 - **logical** OR **physical** volume as mother
 - **active** OR **passive** transformation of the coordinate system

G4PVPlacement

Rotation of mother frame ...

```
G4PVPlacement(G4RotationMatrix* pRot,          // rotation of mother frame
              const G4ThreeVector& tlate,      // position in mother frame
              G4LogicalVolume* pCurrentLogical,
              const G4String& pName,
              G4LogicalVolume* pMotherLogical,
              G4bool pMany,                    // not used. Set it to false..
              G4int pCopyNo,                  // unique arbitrary index
              G4bool pSurfChk=false );       // optional overlap check
```

- Single volume positioned relatively to the mother volume (passive transformation)

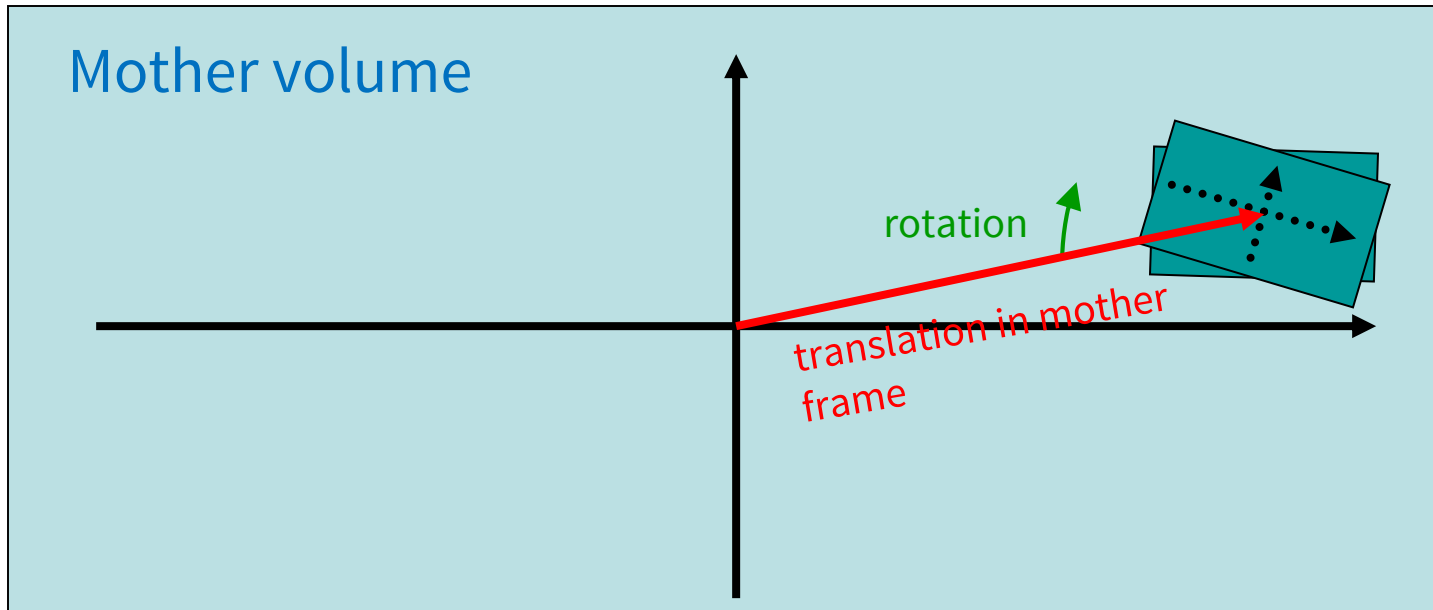


G4PVPlacement

Rotation in mother frame ...

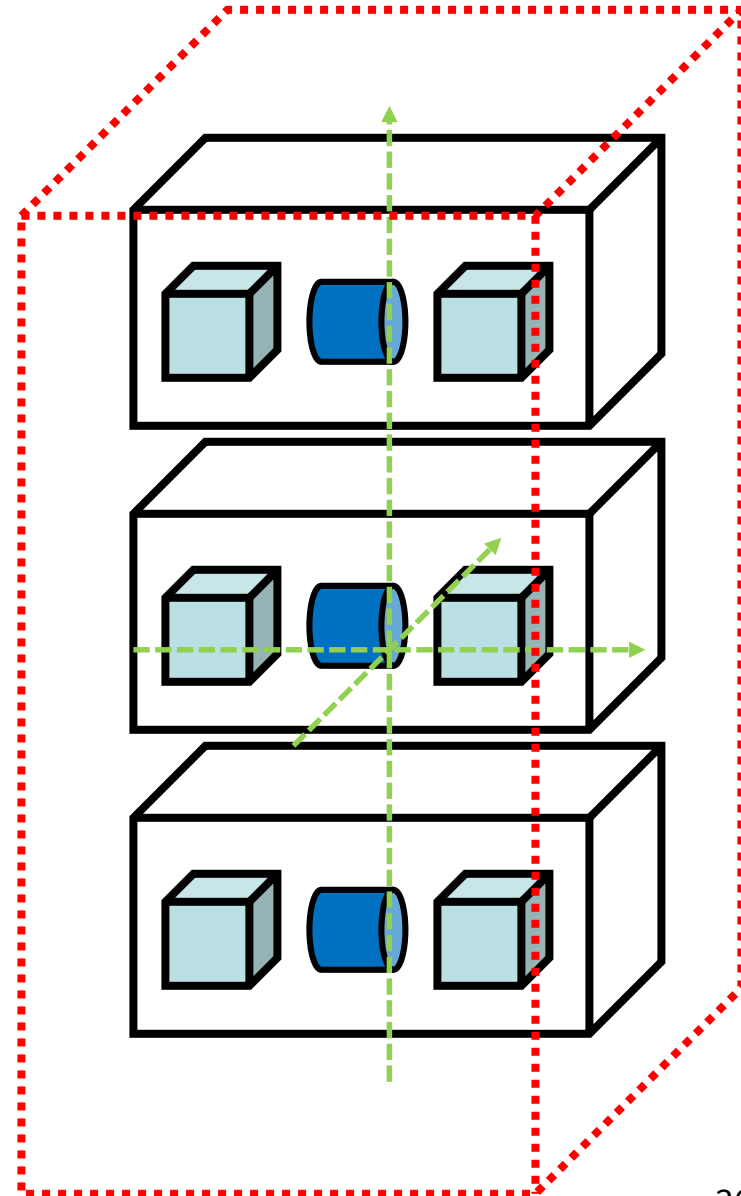
```
G4PVPlacement(G4Transform3D(  
    G4RotationMatrix &pRot,           // rotation in daughter frame  
    const G4ThreeVector &tlate),     // position in mother frame  
    G4LogicalVolume *pDaughterLogical,  
    const G4String &pName,  
    G4LogicalVolume *pMotherLogical,  
    G4bool pMany,                     // not used, set it to false..  
    G4int pCopyNo,                    // unique arbitrary integer  
    G4bool pSurfChk=false );         // optional overlap check
```

- Single volume positioned relatively to the mother volume (active transformation)



Geometrical hierarchy

- It forms a **tree**.
- There is just one physical **world volume** forming a root of the tree:
 - 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 this coordinate system
 - It contains all other volumes (with no protruding!)
- One logical volume can be placed more than once.
- One or more volumes can be placed in one mother volume.
- There must be no overlapping or protrusion.
- **G4LogicalVolume** carries the information about daughter volumes => if it is placed more than once, all daughters by definition appear in each physical instance



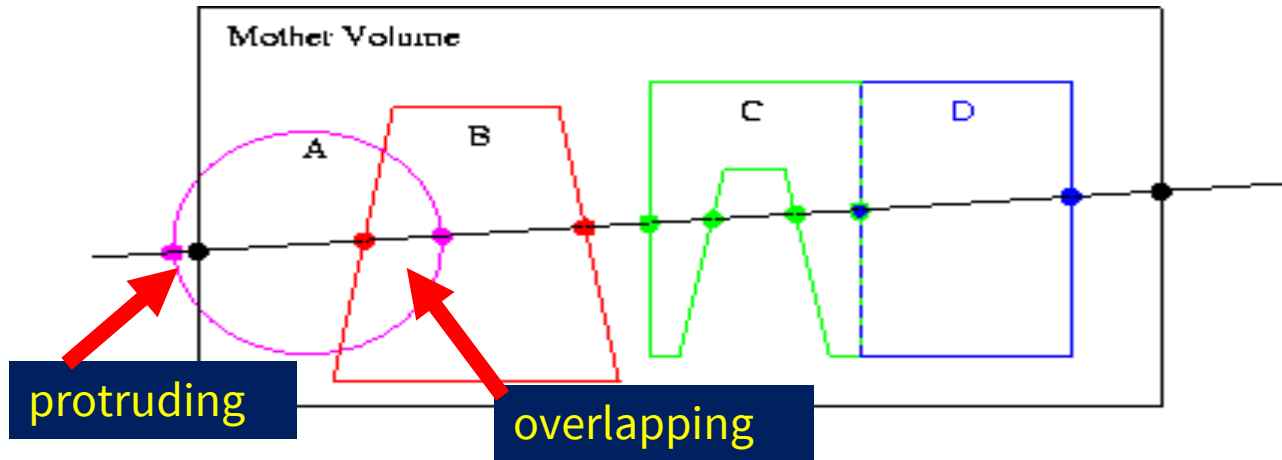
Regions

- A **region** is a collection of related logical volumes collected together independent of the geometry tree
- A **region** may have its unique
 - Production thresholds (cuts)
 - If a region in the mass geometry does not have its own production thresholds, those of the default region are used (i.e., may not be those of the parent region).
 - User limits
 - Artificial limits affecting to the tracking, e.g. max step length, max number of steps, min kinetic energy left, etc.
 - Limits assigned to logical volumes have higher priority
 - Fast simulation manager
 - Field manager

Please note :

- World logical volume is recognized as **the default region**. User is **not** allowed to define a region for the world logical volume.

Problems in geometry



- Geant4 **does not allow** malformed geometries, **neither protruding nor overlapping**.
 - The behavior of navigation is unpredictable for such cases!
- Overlaps become an important issue in complex geometries.
- There are tools for detecting wrong positioning:
 - Optional checks at construction
 - Kernel run-time commands
 - Graphical tools (DAVID, OLAP)

Tools for geometry checking

- 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.

This check requires lots of CPU time, but it is worth to try at least once.

- Built-in run-time commands to activate verification tests for the user geometry:

`/geometry/test/run` or `/geometry/test/grid_test`

to start verification of geometry for overlapping regions based on a standard grid setup, limited to the first depth level

`/geometry/test/recursive_test`

applies the grid test to all depth levels (may require lot of CPU time!)

`/geometry/test/line_test`

to shoot a line along a specified direction and position

Tools for geometry checking

Source

```
void MyDetectorConstruction::CheckOverlaps()
{
    G4PhysicalVolumeStore* thePVStore = G4PhysicalVolumeStore::GetInstance();
    G4cout << thePVStore->size() << " physical volumes are defined" << G4endl;
    G4bool overlapFlag = false;
    G4int res = 1000;
    G4double tol = 0.; // tolerance
    for (size_t i=0; i<thePVStore->size(); i++)
    {
        overlapFlag = (*thePVStore)[i]->CheckOverlaps(res,tol,fCheckOverlapsVerbosity)
            | overlapFlag;
    }
    if (overlapFlag)
        G4cout << "Check: there are overlapping volumes" << G4endl;
}
```

Output

```
Checking overlaps for volume BeamLineSupport ... OK!
Checking overlaps for volume BeamLineCover ... OK!
Checking overlaps for volume BeamLineCover2 ... OK!
Checking overlaps for volume VacuumZone ... OK!
Checking overlaps for volume FirstScatteringFoil ... OK!
```

```
.....
----- WWWWW ----- G4Exception-START ----- WWWWW -
*** G4Exception : GeomVol1002 issued by : G4PVPPlacement::CheckOverlaps()
Overlap with volume already placed !
    Overlap is detected for volume BrassTube2
    with HoleNozzleSupport volume's
    local point (12.6381,12.8171,-25.1867), overlapping by at least: 3.5 mm
```

```
*** This is just a warning message ***
```

```
----- WWWWW -----
```

This method can be called at any point after run->Initialize();

Part III:
Parallel worlds

Parallel worlds – why & what?

- Scoring & read-out
 - Different segmentation / resolution for sensitivity
- Shower parameterisation
 - Different level of detail for different particles
- Complicated overlapping geometries
 - Layered mass geometry
- Importance sampling

Parallel worlds form a layered hierarchy of independent volume descriptions spanning the same world volume.

Replaces <10.0 **readout geometries**

Parallel world transportation

- **G4Transportation** process sees all worlds simultaneously
 - the step is ended at **volume boundaries** in any parallel world
 - for each step, it is possible to get information about the volumes at all levels of hierarchy
 - no **fields** or **production cuts** in parallel worlds
 - **volumes** in parallel worlds don't need to have **materials** (and typically don't; they have only in the case of layered mass geometries)

Parallel world – implementation

- 1) Inherit from **G4VUserParallelWorld**.
 - assign a name (used to identify this world)
- 2) Construct the world (like the real world)
 - geometry in **Construct()**
 - sensitive detectors in **ConstructSD()** – no fields!

```
class MyParallelWorld : public G4VUserParallelWorld {
public:
    MyParallelWorld(G4String worldName) : G4VUserParallelWorld(worldName) { }
    virtual void Construct();
    virtual void ConstructSD();
};

void MyParallelWorld::Construct() {
    G4VPhysicalVolume* worldPhys = GetWorld(); ←
    // ...
}
```

Copy of real-world volume

...Parallel worlds - usage

3) Register the instance to the detector construction.

```
detector->RegisterParallelWorld(new MyParallelWorld(paraWorldName));
```

4) Register the physics to the physics list

- one **G4ParallelWorldProcess** per parallel world

```
physicsList->RegisterPhysics(new G4ParallelWorldPhysics(paraWorldName));
```

Layered mass geometry

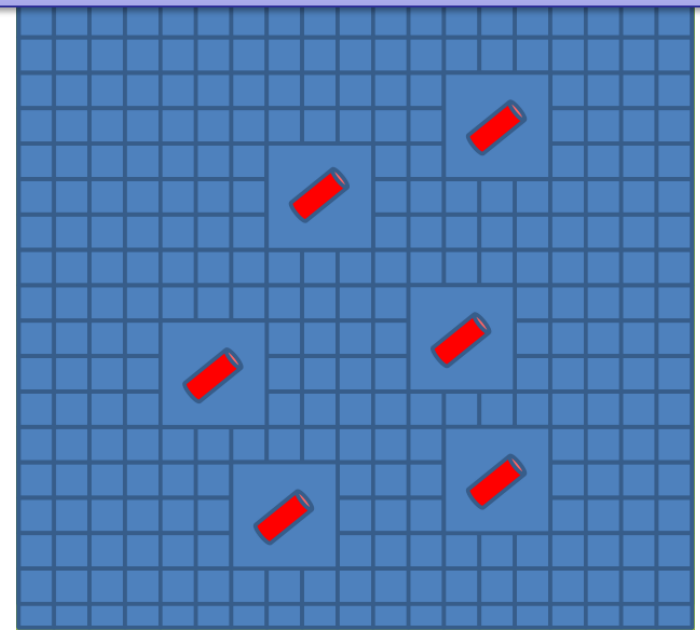
```
physicsList->RegisterPhysics(new G4ParallelWorldPhysics(paraWorldName), true);
```

- You may assign material to volumes
 - To all, to some or to no volume
 - The top-most layer wins
 - Different geometries for different particles*
 - Volumes at different levels can overlap

Brick floating on water surface



Brachytherapy:
= metal seeds in voxel geometry



**by adding `G4ParallelWorldProcess` to their process manager*

Conclusion

Geant4 has very broad range of capabilities for geometry description:

- extensible set of **units**
- complex hierarchy of **volumes**
- many types of **solids** and their combinations
- **material** description down to isotope level
- **parallel worlds** etc.

谢谢

Backup slides

How to define a new unit

- New units can be defined directly as constants, or (suggested way) as a **G4UnitDefinition**:

```
G4UnitDefinition(name, symbol, category, value);
```

- Example (speed):

```
new G4UnitDefinition("km/hour", "km/h", "Speed", km/(3600*s));
```

- The new category “**Speed**” will be registered in the kernel in **G4UnitsTable** (if not present)

```
▶ G4UnitsTable.hh/.cc
```

- **Define it in each thread!** => e.g. in run action
- To print the list of units:

- From the code:

```
G4UnitDefinition::PrintUnitsTable();
```

- At run-time, as UI command:

```
/units/list
```