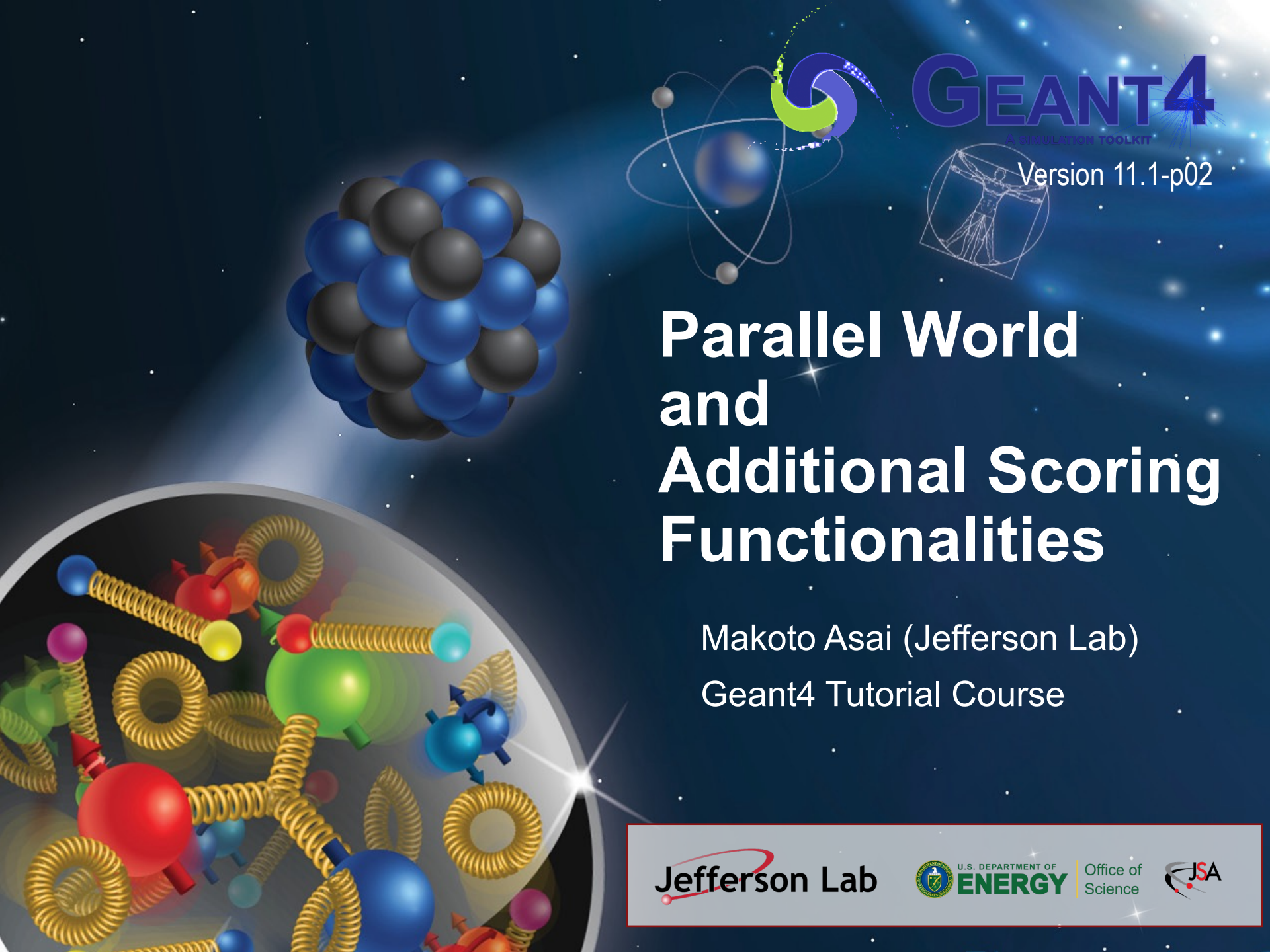


Parallel World and Additional Scoring Functionalities

Makoto Asai (Jefferson Lab)

Geant4 Tutorial Course

Jefferson Lab
U.S. DEPARTMENT OF ENERGY | Office of Science
JSA

Contents

Jefferson Lab
Thomas Jefferson National Accelerator Facility

- Parallel world
- Layered mass geometry
- Real-world scoring and scoring probe
- Histogram filling through a scorer

GEANT4
A SIMULATION TOOLKIT

U.S. DEPARTMENT OF ENERGY | Office of Science
JSA

Contents

Jefferson Lab
Thomas Jefferson National Accelerator Facility

- Parallel world
- Layered mass geometry
- Real-world scoring and scoring probe
- Histogram filling through a scorer

GEANT4
A SIMULATION TOOLKIT

U.S. DEPARTMENT OF ENERGY | Office of Science
JSA

Parallel world

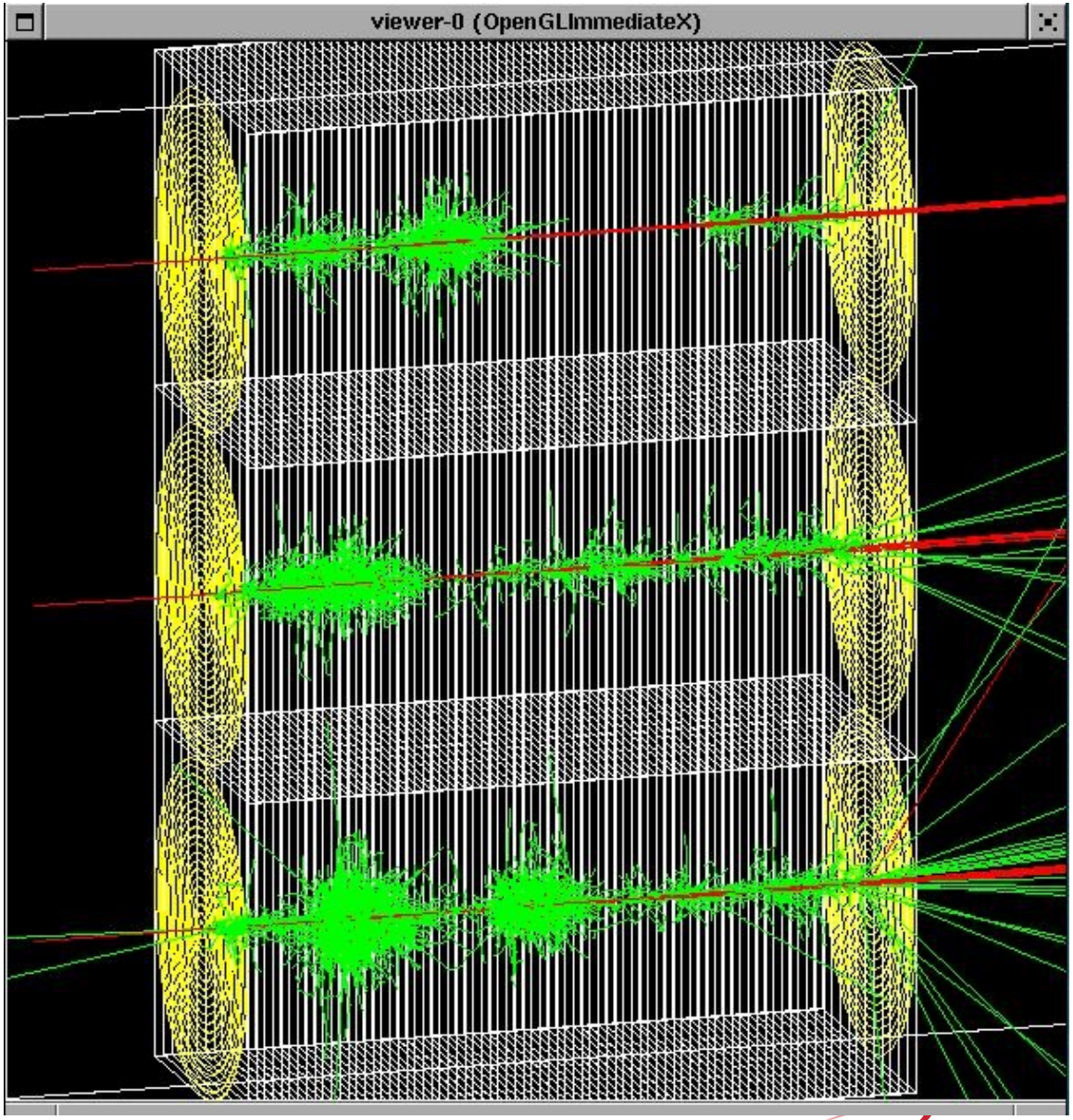
- Occasionally, it is not straightforward to define sensitivity, importance or envelope to volumes in the mass geometry.
  - Typically, a geometry that is built machinal by CAD, GDML, DICOM, etc. has this difficulty.
- Parallel world functionality allows the user to define more than one worlds simultaneously.
  - 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.
  - Materials, production thresholds and EM field should be defined in the mass geometry.
    - Exception for materials in “layered mass geometry”
  - A parallel world is a virtual and artificial world.
    - Volumes in different worlds may overlap.
  - In a parallel world, the user can define volumes in arbitrary manner with sensitivity, regions with shower parameterization, and/or importance field for biasing.

Parallel navigation

- G4VUserParrallelWorld is the 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.
  - If you need two parallel worlds, you must implement two concrete classes individually representing each worlds.
  - 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 G4ParallelWorldProcess 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 must have G4ParallelWorldProcess in his physics list.

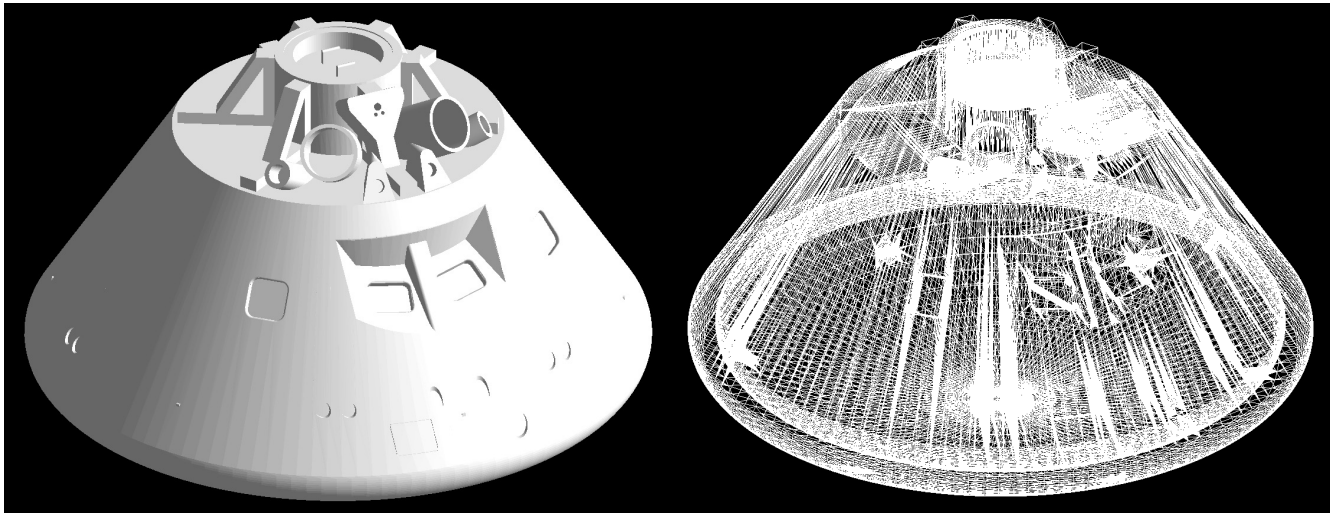
examples/extended/runAndEvent/RE06

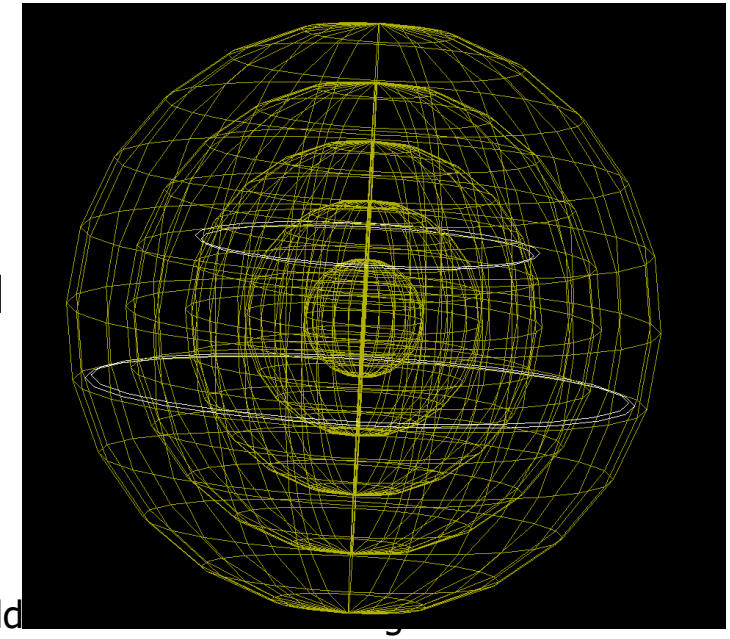
- Mass geometry (white)
  - sandwich of rectangular absorbers and scintillators
- Parallel scoring geometry (yellow)
  - Cylindrical layers for measuring lateral energy distribution

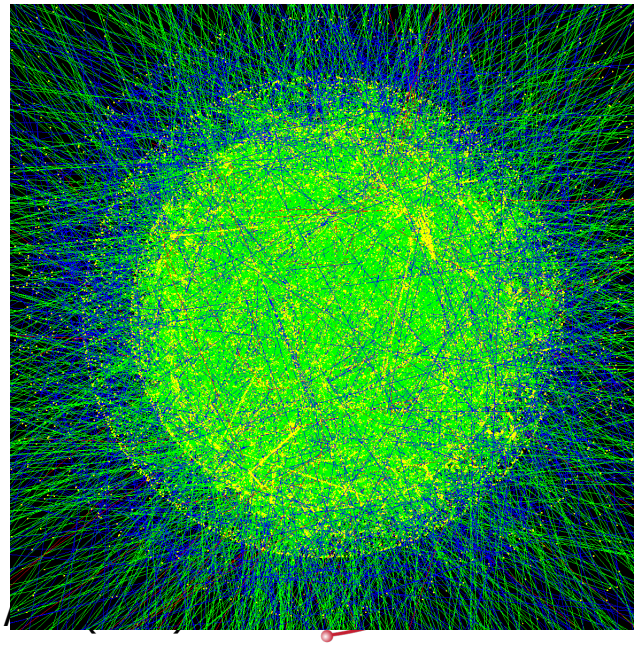


examples/advanced/gorad

- Geometry in mass world
  - Simplified Orion spacecraft
- Parallel world
  - Concentric spheres for geometry importance weight
  - Enhancing (biasing) tracks toward the center







Contents

Jefferson Lab
Thomas Jefferson National Accelerator Facility

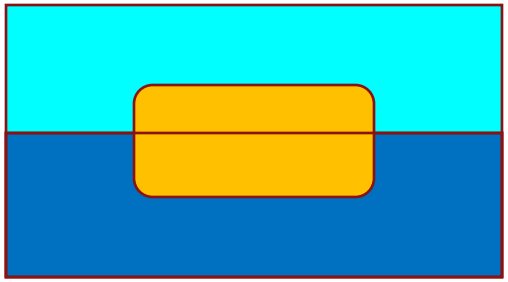
- Parallel world
- Layered mass geometry
- Real-world scoring and scoring probe
- Histogram filling through a scorer

GEANT4
A SIMULATION TOOLKIT

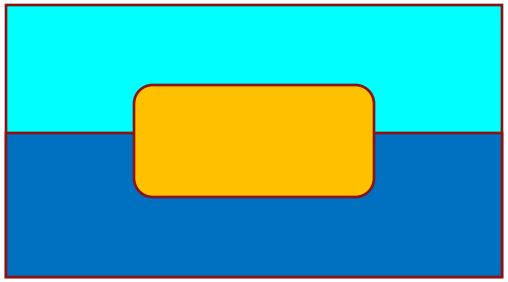
U.S. DEPARTMENT OF ENERGY | Office of Science
JSA

Layered mass geometries in parallel world

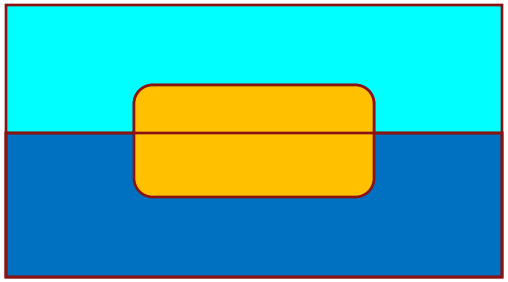
- Suppose you implement a wooden brick floating on the water.



- Dig a hole in water by a Boolean operation…

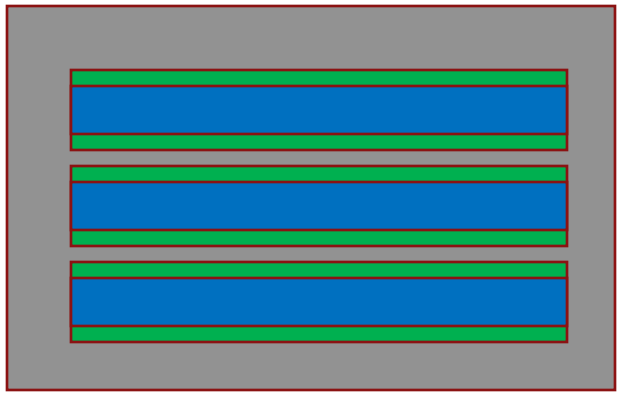


- Or, chop a brick into two and place them separately…

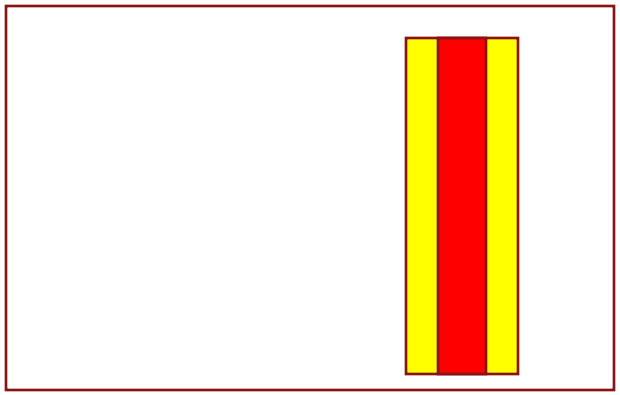


Layered mass geometries in parallel world

- 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



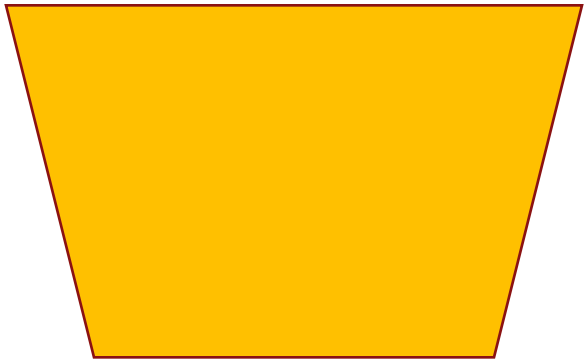
Mass world



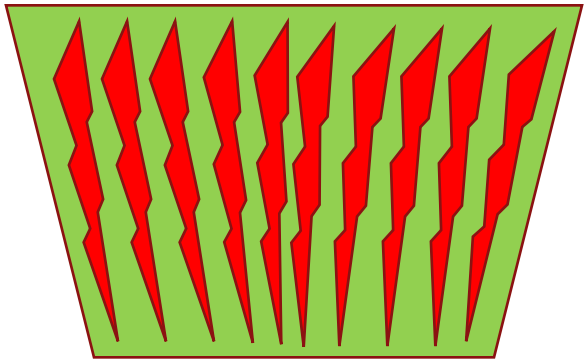
Parallel world

Layered mass geometries in parallel world - continued

- A parallel world may be associated only to some limited types of particle.
  - 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 by detailed volumes.
  - Shower parameterization such as GFLASH may have its own geometry



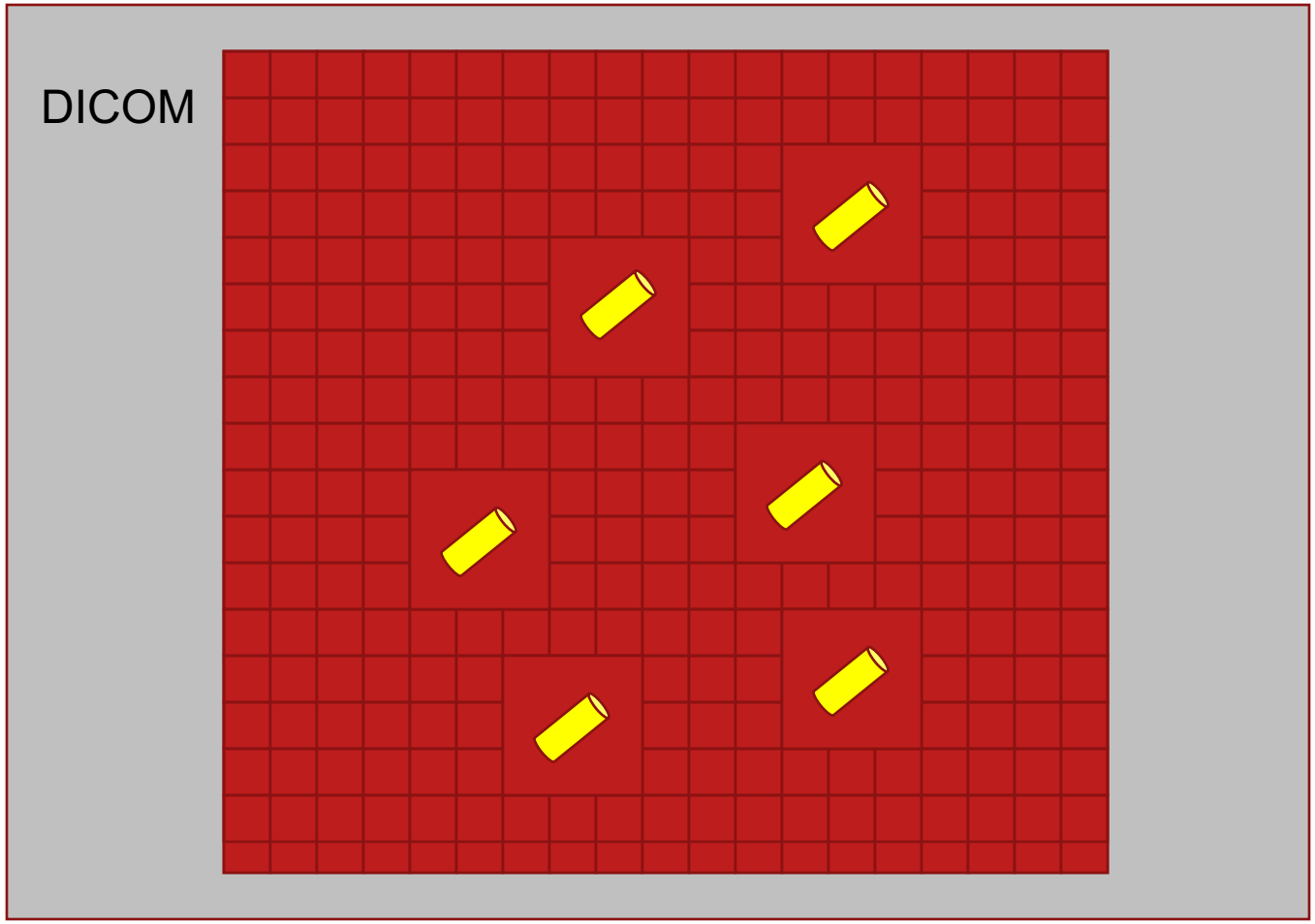
Geometry seen by e+, e-, γ



Geometry seen by other particles

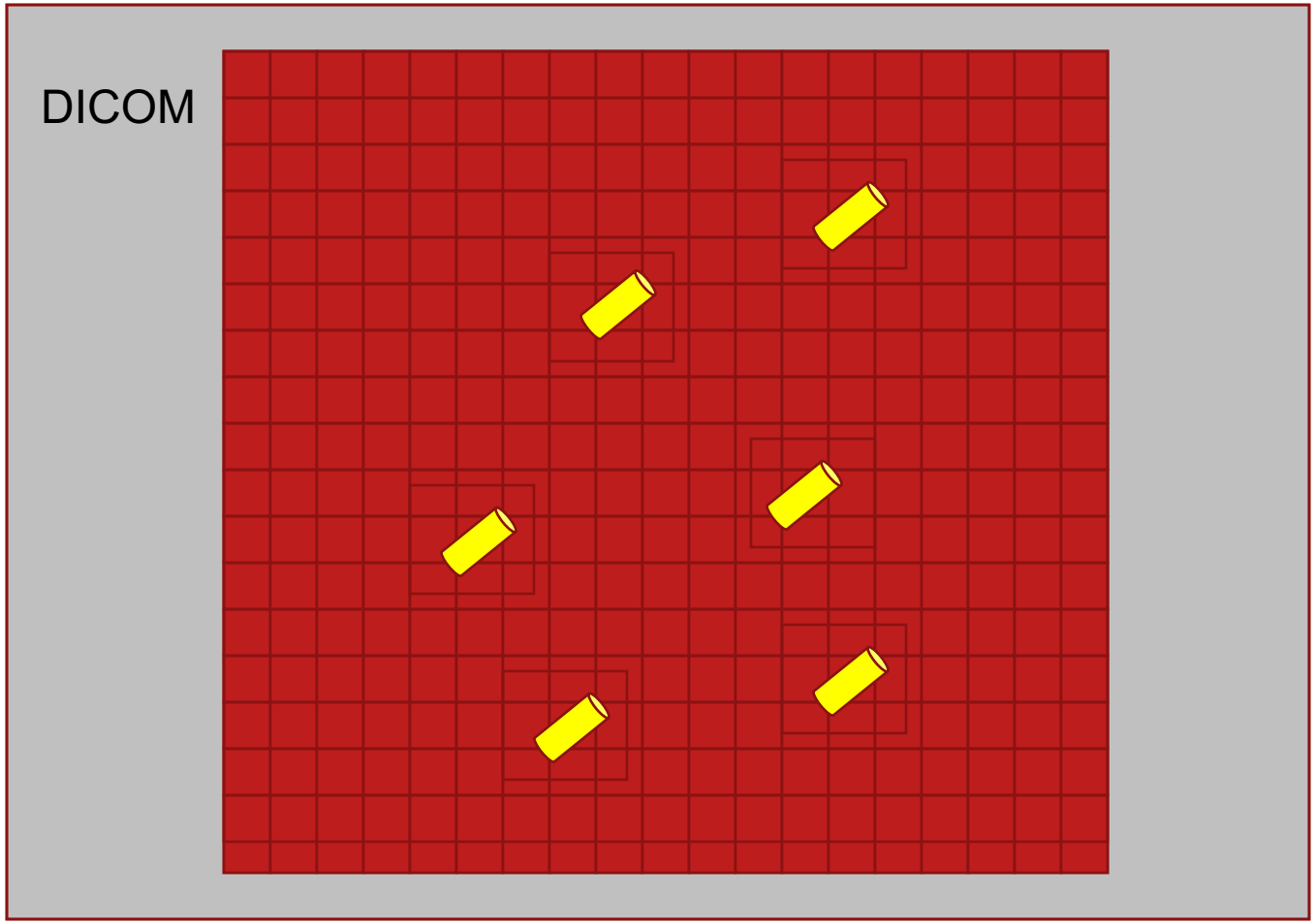
A medical use case

- Brachytherapy treatment for prostate cancer.



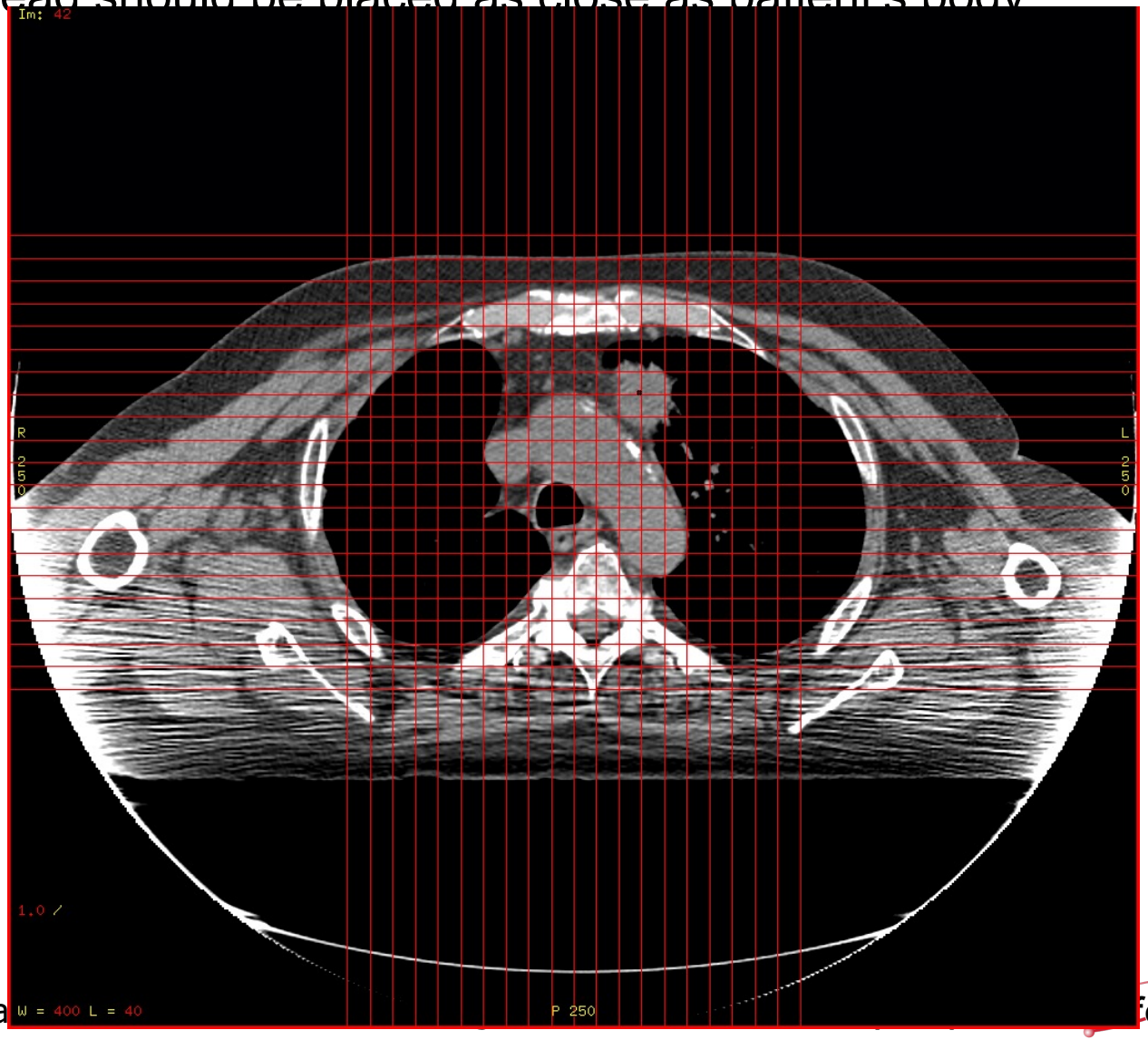
A medical use case

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



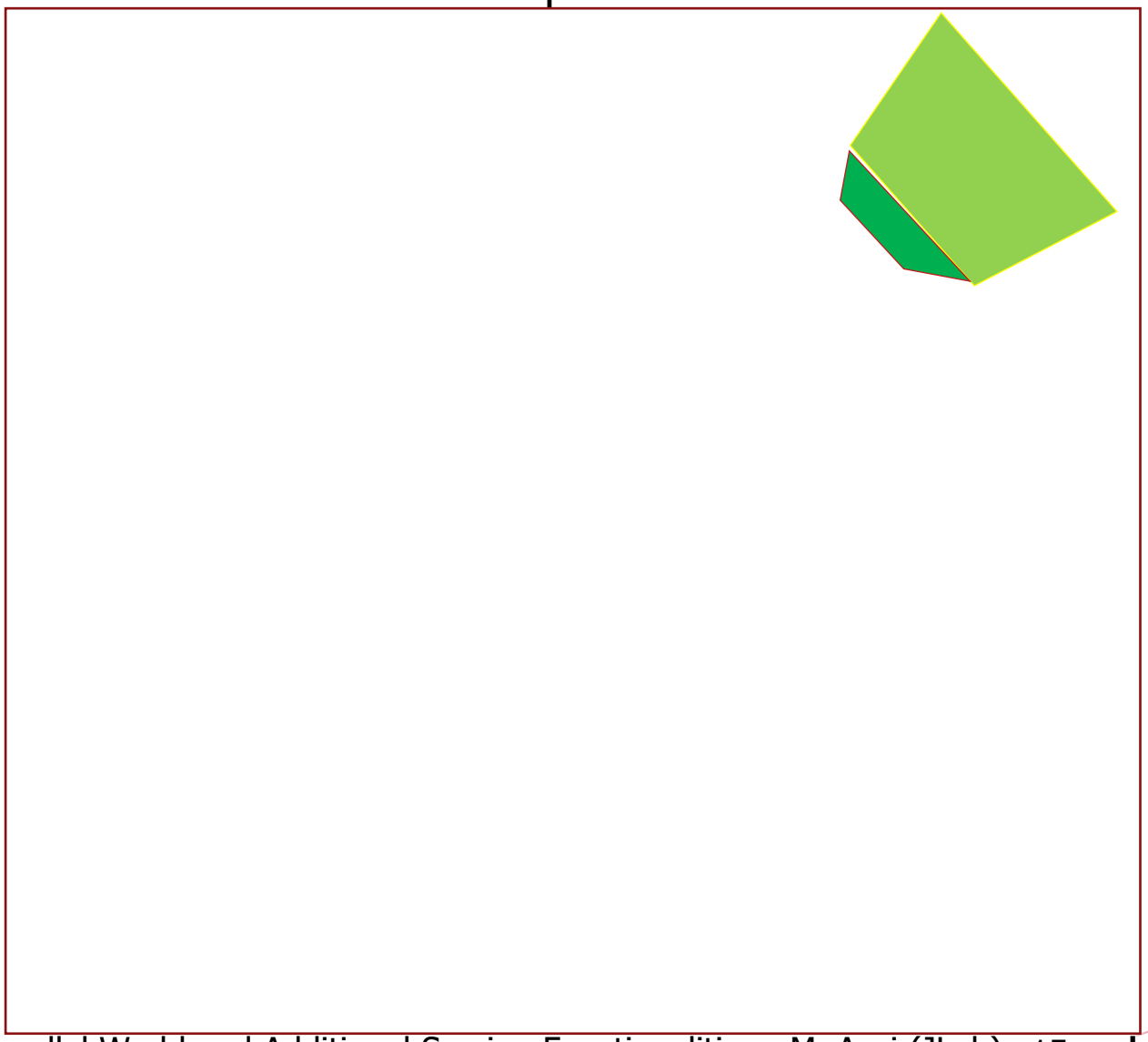
Another important use case in medicine

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



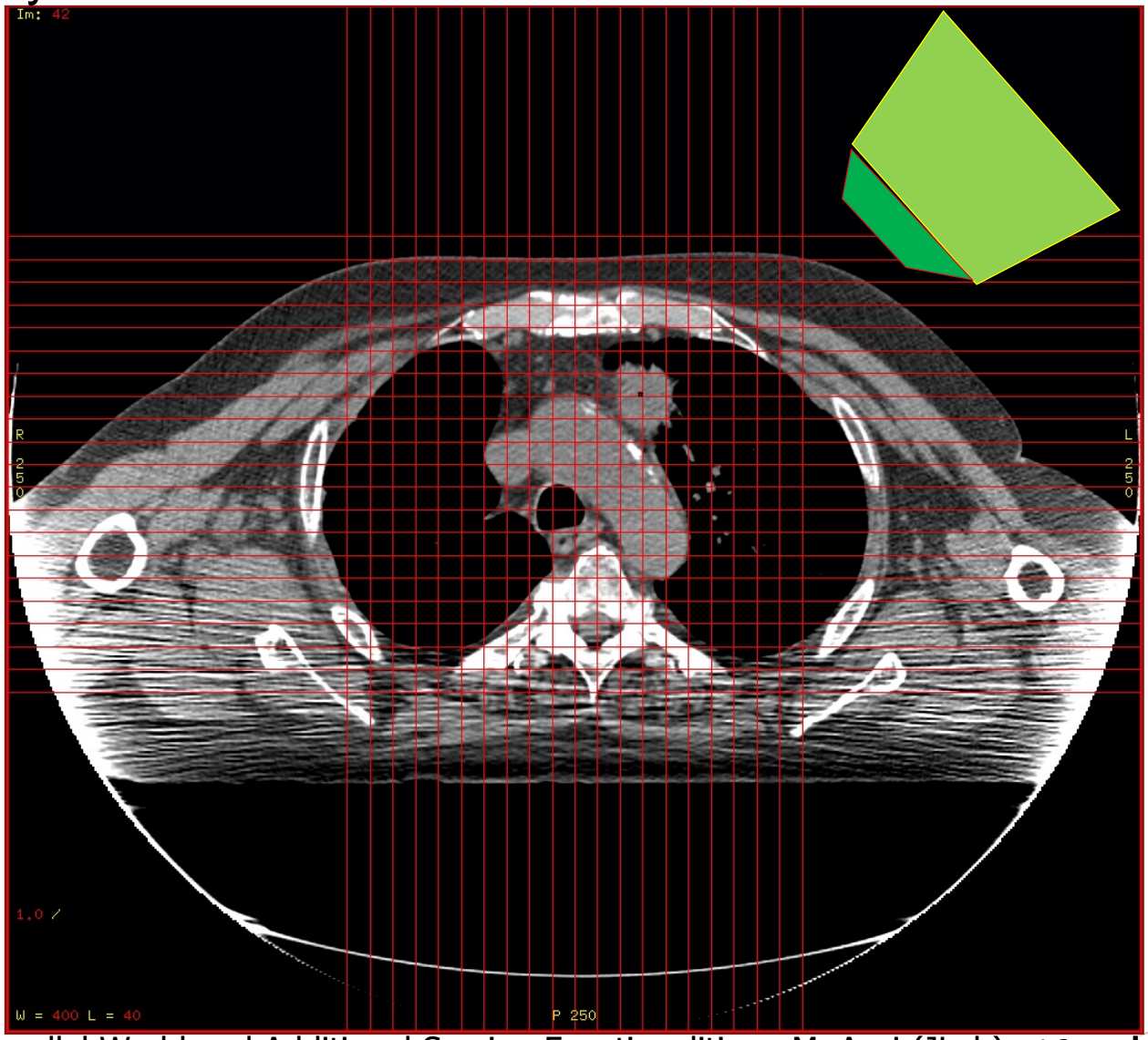
Another important use case in medicine

- Implement the treatment head in a parallel world.



Another important use case in medicine

- And overlay.

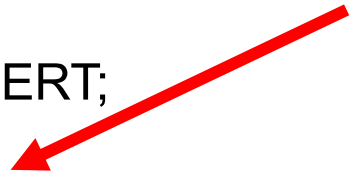


Defining a parallel world

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 it 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);
```

Should be *nullptr* if you don't want the volume to overwrite the material

- The world physical volume of the parallel world is provided as a clone of the world volume of the mass geometry. The user cannot create it.
- You can fill contents regardless of the volumes in the mass geometry.
- Logical volumes in a parallel world that do not overlay materials should have null material pointer.

Contents

Jefferson Lab
Thomas Jefferson National Accelerator Facility

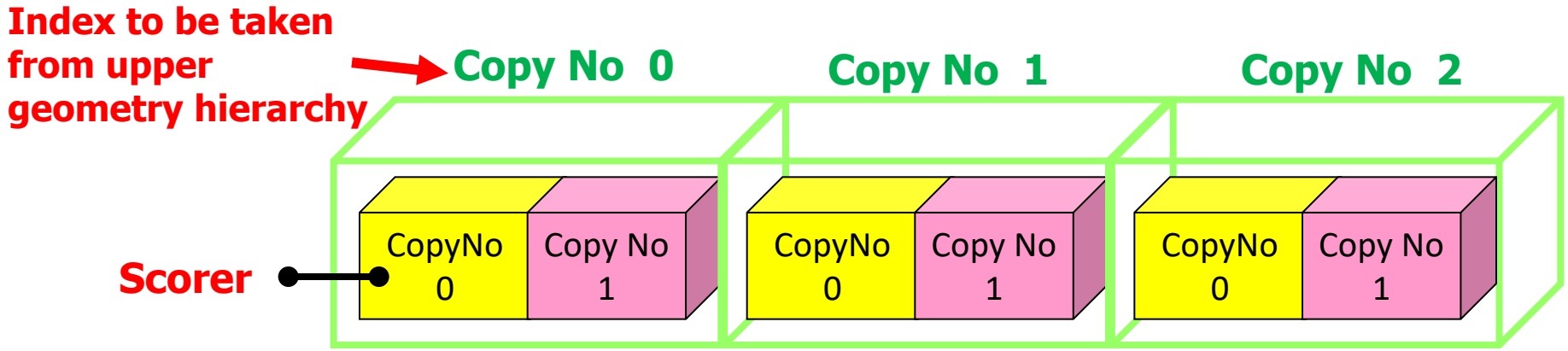
- Parallel world
- Layered mass geometry
- Real-world scoring and scoring probe
- Histogram filling through a scorer

GEANT4
A SIMULATION TOOLKIT

U.S. DEPARTMENT OF ENERGY | Office of Science
JSA

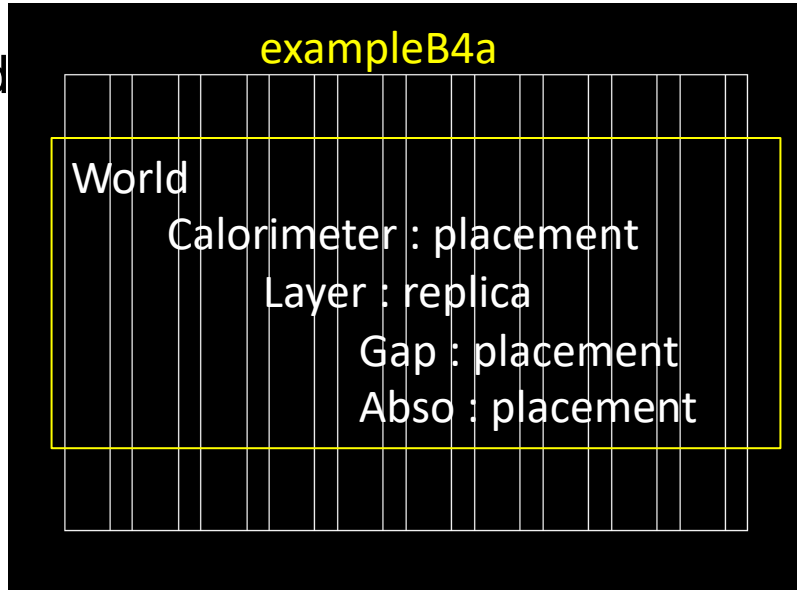
Define scorer to a tracking volume

- Define a scorer to a logical volume.
  `/score/create/realWorldLogVol <LV_name> <anc_lvl>`
- One can define arbitrary scoring quantities and filters.
  - Same recipe as scoring mesh.
  - Scores are automatically merged over worker threads.
  - Drawing is not yet supported.
- All physical volumes that share the same *<LV_name>* have the same primitive scorers but score separately.
  - Copy number of the physical volume is the index.
  - If the physical volume is placed only once, but its (grand-)mother volume is replicated, use the *<anc_lvl>* parameter to indicate the ancestor level where the copy number should be taken.



Command-based real-world scorer

- Do not use this /score/create/realWorldLogVol command to a mother logical volume.
  - For example of this exampleB4, “Layer” is fully filled with ”Gap” and “Abso” daughter volumes. You won’t see any energy deposition in “Layer” volume.

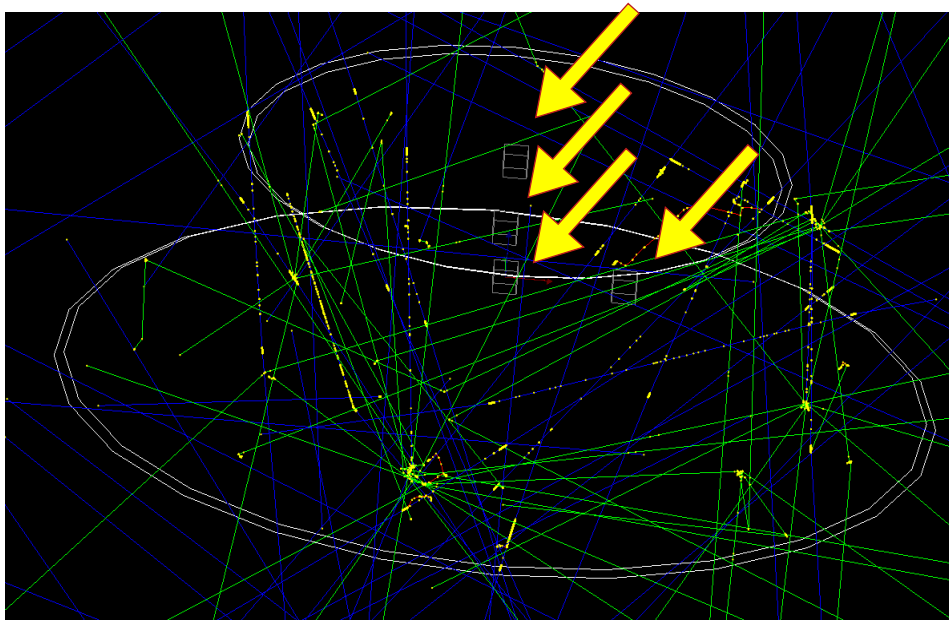



```
/score/create/realWorldLogVol Gap 1
/score/quantity/energyDeposit eDep MeV
/score/quantity/trackLength sLen mm
/score/filter/charged cFilter
/score/create/realWorldLogVol Abso 1
/score/quantity/energyDeposit eDep MeV
/score/quantity/trackLength sLen mm
/score/filter/charged cFilter
/score/close
```

If this is not set, given “Gap” and “Abso” are placed with copy number 0, energy deposition and track length are accumulated for all layers.

Command-based probe scorer

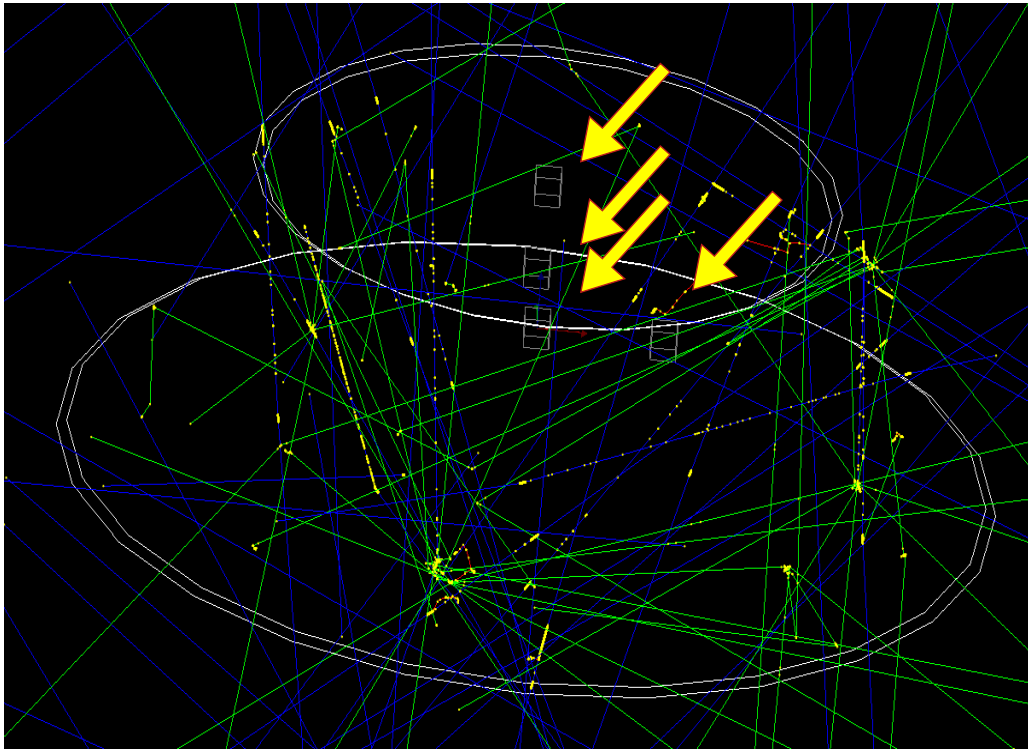
- User may locate scoring “probes” at arbitrary locations. A “probe” is a virtual cube, to which any Geant4 primitive scorers could be assigned.
- Given these probes are located in an artificial “parallel world”, probes may overlap to the volumes defined in the mass geometry.
- If probes are located more than once, all probes have the same scorers but score individually.



- In addition, the user may optionally set a material to the probe. Once a material is set to the probe, it overwrites the material(s) defined in the mass geometry when a track enters the probe cube.
  - Because of this overwriting, physics quantities that depend on material or density, e.g. energy deposition, would be measured accord to the specified material
  - You are alternating material, i.e. simulation results are affected. Make probes small and as few as needed.

Scoring probe

```
/score/create/probe Probes 5. cm
/score/probe/material G4_WATER
/score/probe/locate 0. 0. 0. cm
/score/probe/locate 25. 0. 0. cm
/score/probe/locate 0. 25. 0. cm
/score/probe/locate 0. 0. 25. cm
/score/quantity/energyDeposit eDep MeV
/score/quantity/doseDeposit dose mGy
/score/quantity/volumeFlux volFlx
/score/quantity/volumeFlux protonFlux
/score/filter/particle protonFilter proton
/score/close
```



Note: To visualize the probes defined in a parallel world, the following command is required.

/vis/drawVolume worlds

Contents

Jefferson Lab
Thomas Jefferson National Accelerator Facility

- Parallel world
- Layered mass geometry
- Real-world scoring and scoring probe
- Histogram filling through a scorer

GEANT4
A SIMULATION TOOLKIT

U.S. DEPARTMENT OF ENERGY | Office of Science
JSA

1-D histogram directly filled by a primitive scorer

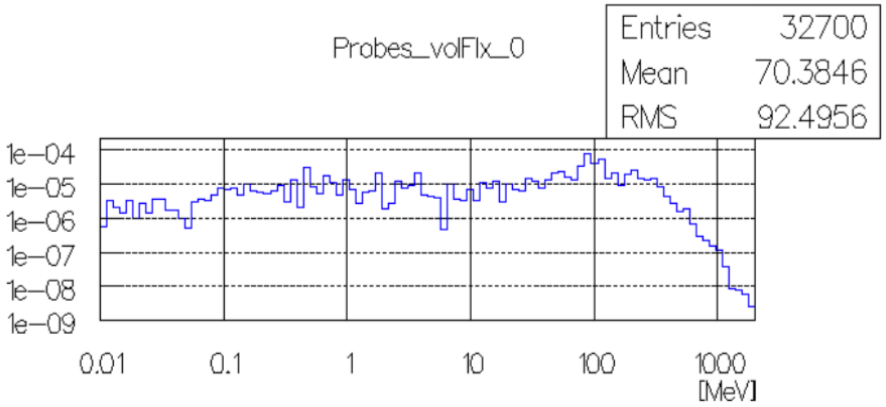
- Through a newly introduced interface class (G4TScoreHistFiller) a primitive scorer can directly fill a 1-D histogram defined by G4Analysis.
  - Track-by-track or step-by-step filling allows command-based histogram such as energy spectrum.
- G4TScoreHistFiller template class must be instantiated in the user's code with his/her choice of analysis data format.

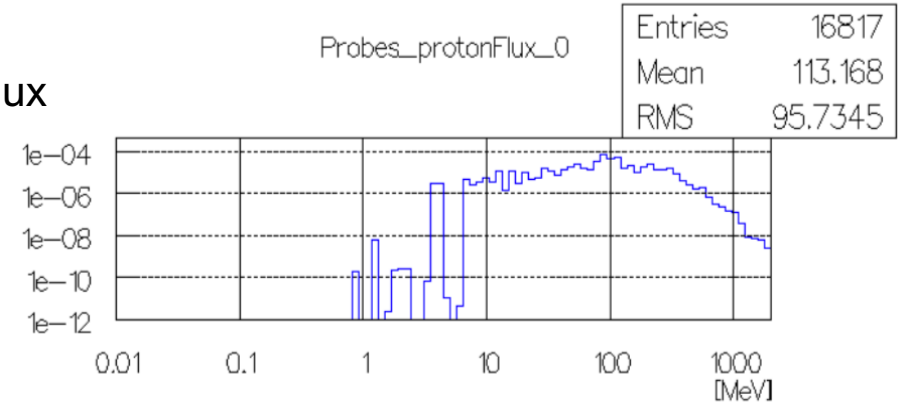
```
#include "G4AnalysisManager.hh"
#include "G4TScoreHistFiller.hh"
auto analysisManager = G4AnalysisManager::Instance();
analysisManager->SetDefaultFileType("root");
auto histFiller = new G4TScoreHistFiller<G4AnalysisManager>;
```

- Primitive scorer must be defined in advance to setting a histogram.
- Histogram must be defined through /analysis/h1/create command in advance to setting it to a primitive scorer.
- This functionality is available only for primitive scorers defined in real-world scorer or probe scorer.
  - Not available for box or cylindrical mesh scorer due to memory consumption concern.

1-D histogram directly filled by a primitive scorer

```
/score/create/probe Probes 5. cm
/score/probe/locate 0. 0. 0. cm
/score/quantity/volumeFlux volFlux
/score/quantity/volumeFlux protonFlux
/score/filter/particle protonFilter proton
/score/close
/analysis/h1/create volFlux Probes_volFlux
                    100 0.01 2000. MeV ! log
/score/fill1D 1 Probes volFlux
/analysis/h1/create protonFlux Probes_protonFlux
                    100 0.01 2000. MeV ! log
/score/fill1D 2 Probes protonFlux
```





N.B. If probe is placed more than once, *fill1D* command should be called to each *copyNo.*

```
/score/fill1D 1 Probes volFlux 0
```