Geant4 Simulation of a Packaging for Solid-State Radiation Monitoring Sensors

R. Capra[1], M. Glaser[2], M. Moll[2], M. G. Pia[1], F. Ravotti[3]

[1] INFN Sezione di Genova; I-16146 Genova, Italy
[2] CERN PH; CH 1211, Geneva 23, Switzerland
[3] CERN TS; CH 1211, Geneva 23, Switzerland

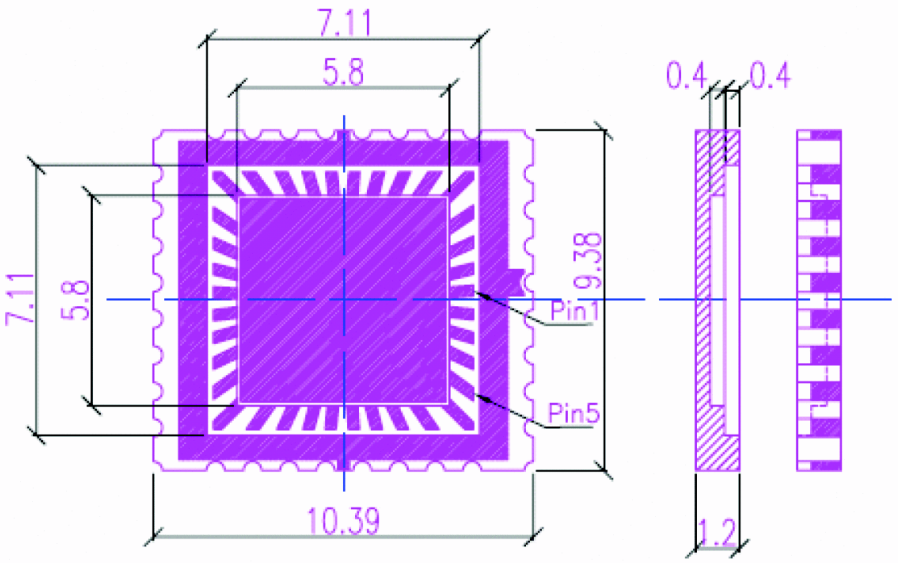
Spenvis & Geant4 Workshop – 3-7 October 2005

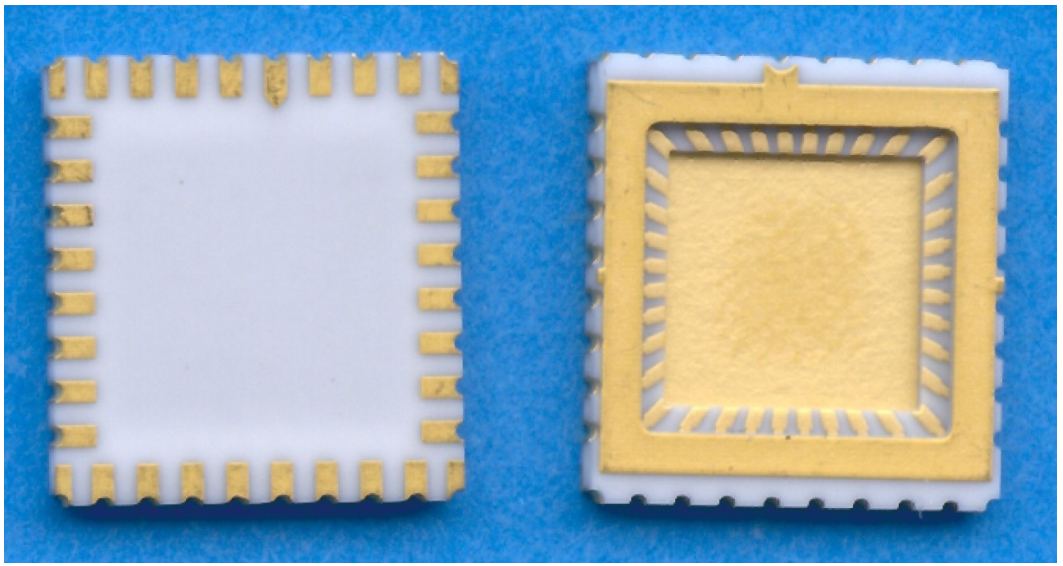
Project vision

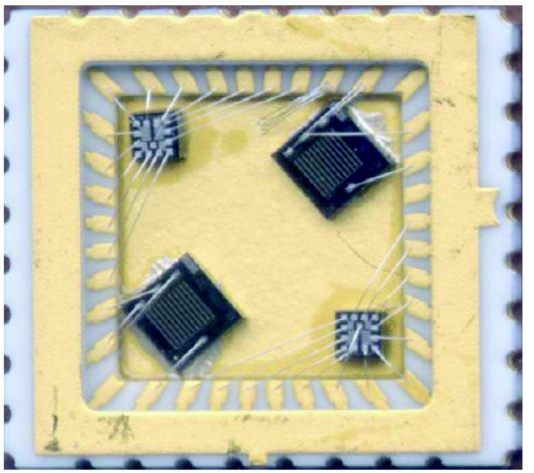
- The CERN RADMON group has selected and cataloged semi-conductor sensors to be used for radiation monitoring purposes
  - These sensors will be used in the LHC environment as radiation monitoring devices
- However the use of inappropriate materials around the sensors can modify the chips response
  - This can induce errors in the measurement
- They are interested to have a study of the effect of the packaging on the sensor response as a function of materials and thicknesses

Primary candidate

- Chip packaging is done in house at CERN
  - CERN has already available 2000 parts of a packaging with the following features
    - ~ 1 cm × ~ 1 cm × ~ 1.5 mm
    - 36 pins
    - Al_2O_3 carrier
    - Tungsten metalization
    - Gold-plated







Main objectives

- The main objectives are
  - A quantitative analysis of the energy cut-off introduced by the packaging as a function of the particle type
  - A quantitative analysis on how the materials and thicknesses affect the cut-off thresholds
  - A quantitative analysis of the spectrum of particles (primaries and secondaries) arriving on the dosimeter volume as a function of the incoming spectrum
- For physics validation purposes I will use experimental data taken in the past years by the RADMON group
  - This validation process is essential to provide sound results

Software process

- The project is developed as a Geant4 advanced example
- A rigorous software process based on the RUP
  - Requirements
    - Vision document
    - User requirements document
      - Both available in the Geant4 documentation CVS repository
  - Analysis and Design
    - Design model (Available in the Geant4 documentation CVS repository)
  - Implementation
    - Developed code is available in the Geant4 CVS repository
  - Testing
    - Validation against experimental data (planned)
  - Traceability
    - In progress
- The project is documented in
  - http://www.ge.infn.it/geant4/hep/radmon

Requirements 1/2

- Geometry
  - Define objects made up of several layers with different geometries
  - Define thicknesses, materials and other geometrical parameters of each layer
  - Define more than one multi-layer object and place them in a environment
  - Define a realistic environment like the CERN facility they use for their tests/measurements
- Event generation
  - Isotropic flux of monochromatic particles
  - Isotropic flux of particles according to tabulated spectra
  - Directional monochromatic beam

Requirements 2/2

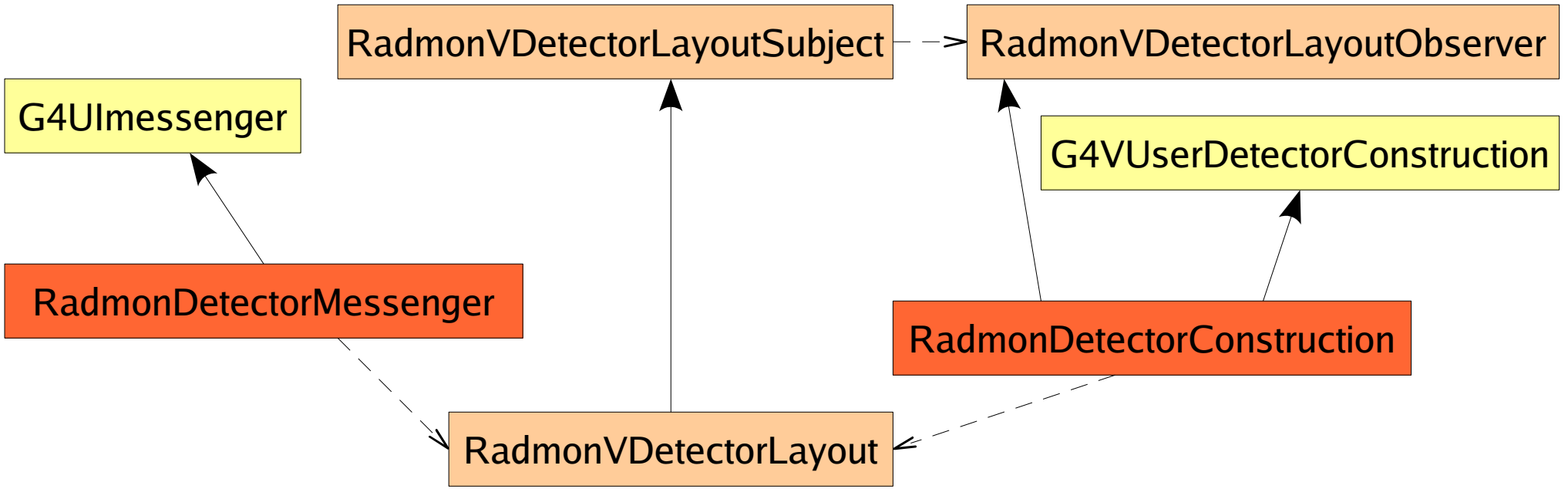
- Physics
  - Handle protons, neutrons, electrons, gammas, and pions
  - Electromagnetic and hadronic processes for primaries and secondaries particles
- Event
  - Be able to obtain
    - The particles flux into the sensor volume
    - The energy deposited into the sensor volume
    - Attenuation effect of the packaging on the particle flux
    - Spectra of the particles arriving to the sensor volume
- User interface
  - Be able to interactively change the geometrical parameters and the materials of the multi-layers objects and of the environment (test-beam setup)

Development schedule

- The project started on the 1st of August and will be completed in January
  - The Geometry & User interface design, implementation and testing was completed in September
  - Next phase will be the development of the event generators, the physics list and the sensible volumes
    - In the next months the RADMON group will take some experimental data
    - It is possible to directly compare the measures taken from the RADMON group with the simulation
  - This will allow validating the physics processes involved
- It is expected to have the example fully functional for the December release

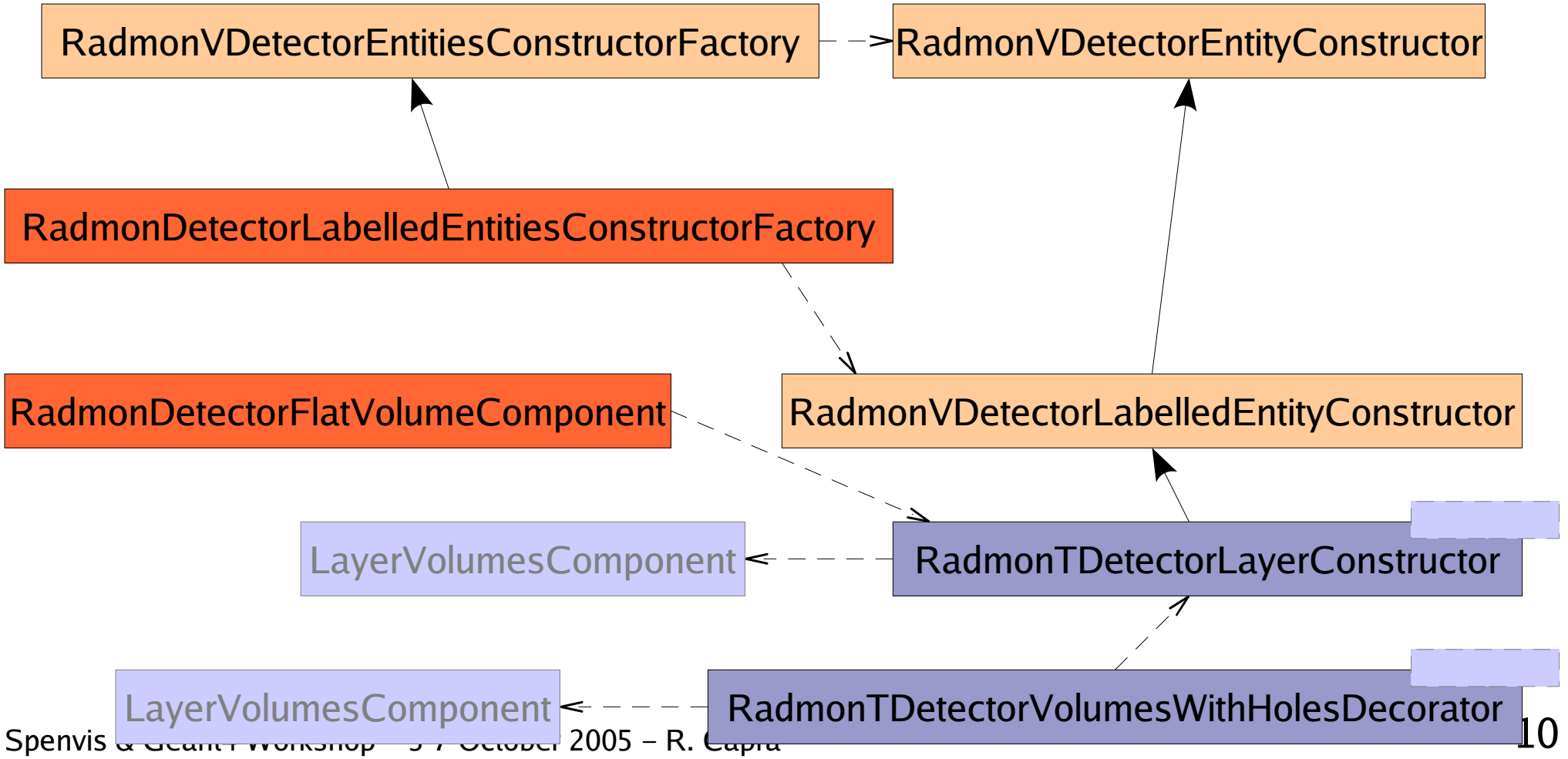
Geometry design key features[1/3]

- The geometry & user interface design and implementation is almost completed
- Key features are
  - Document-view for geometrical data management
  - Observer pattern for geometrical changes notification to the detector constructor



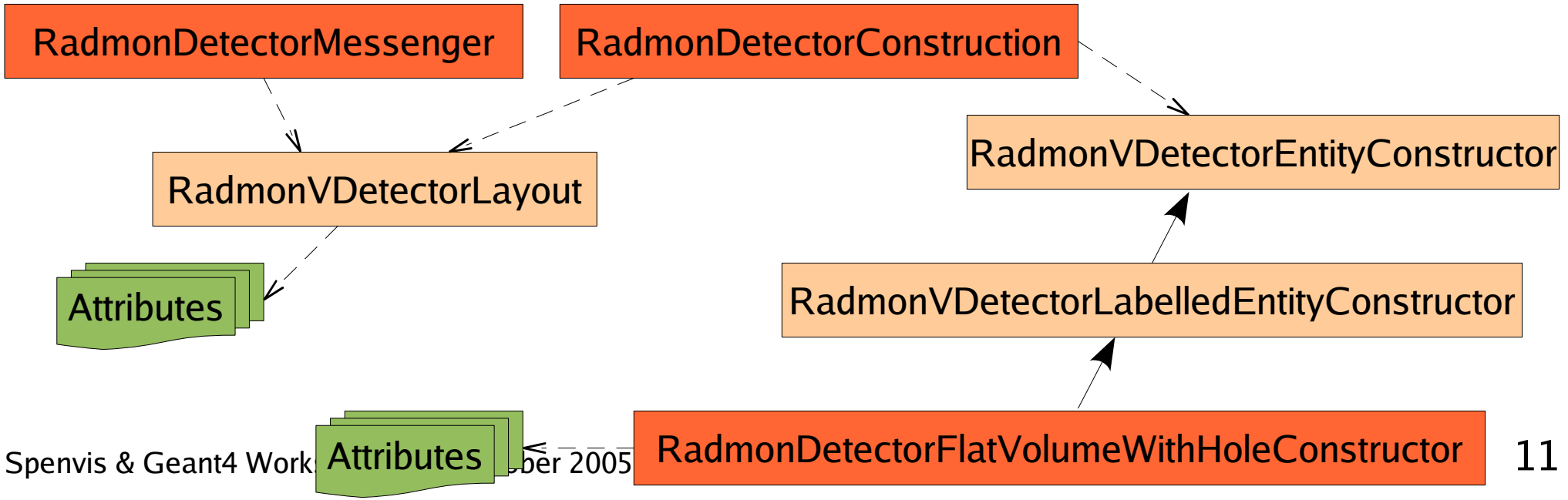
Geometry design key features 2/3

- Solids, physical volumes and logical volumes created using an Abstract Factory pattern
- As layers have partial similar features, layer creator classes use a Decorator pattern (template = compile bound)



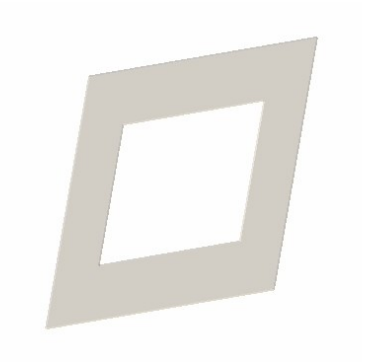
Geometry design key features 3/3

- At construction time, according to the layer type, several parameters must provided in order to define the geometrical features of the layer and its materials
  - To have a common and extensible way to manage these features, a list of attributes can be attached to each layer
    - Attribute means a pair of strings (the attribute name and the attribute value)
- In that way the definition of the layer type features through user interface commands comes for free

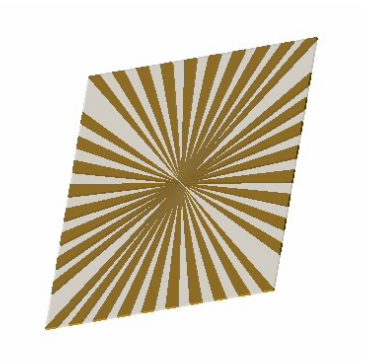


Layer types[1/2]

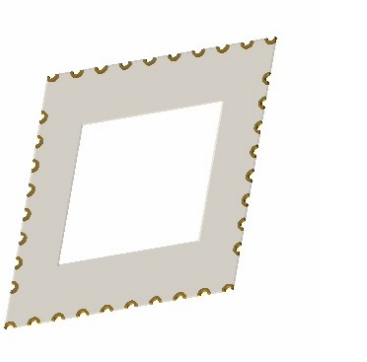
- A simple box with a hole



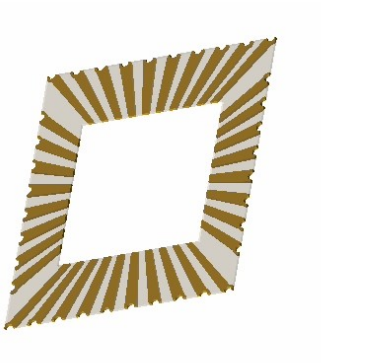
- A simple box with tracks



- A simple box with a hole and carved borders

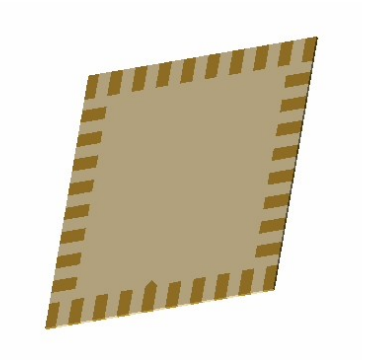


- A simple box with tracks, a hole and carved borders

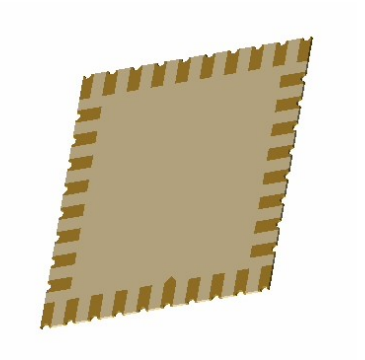


Layer types[2/2]

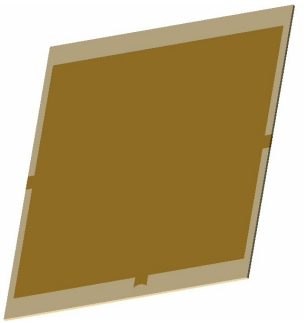
- A simple box with pins



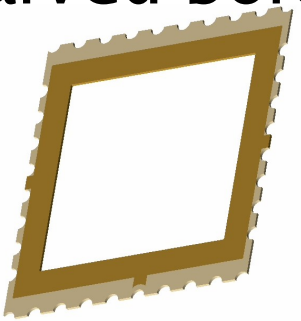
- A simple box with pins and carved borders



- A simple box with ground plane and marks

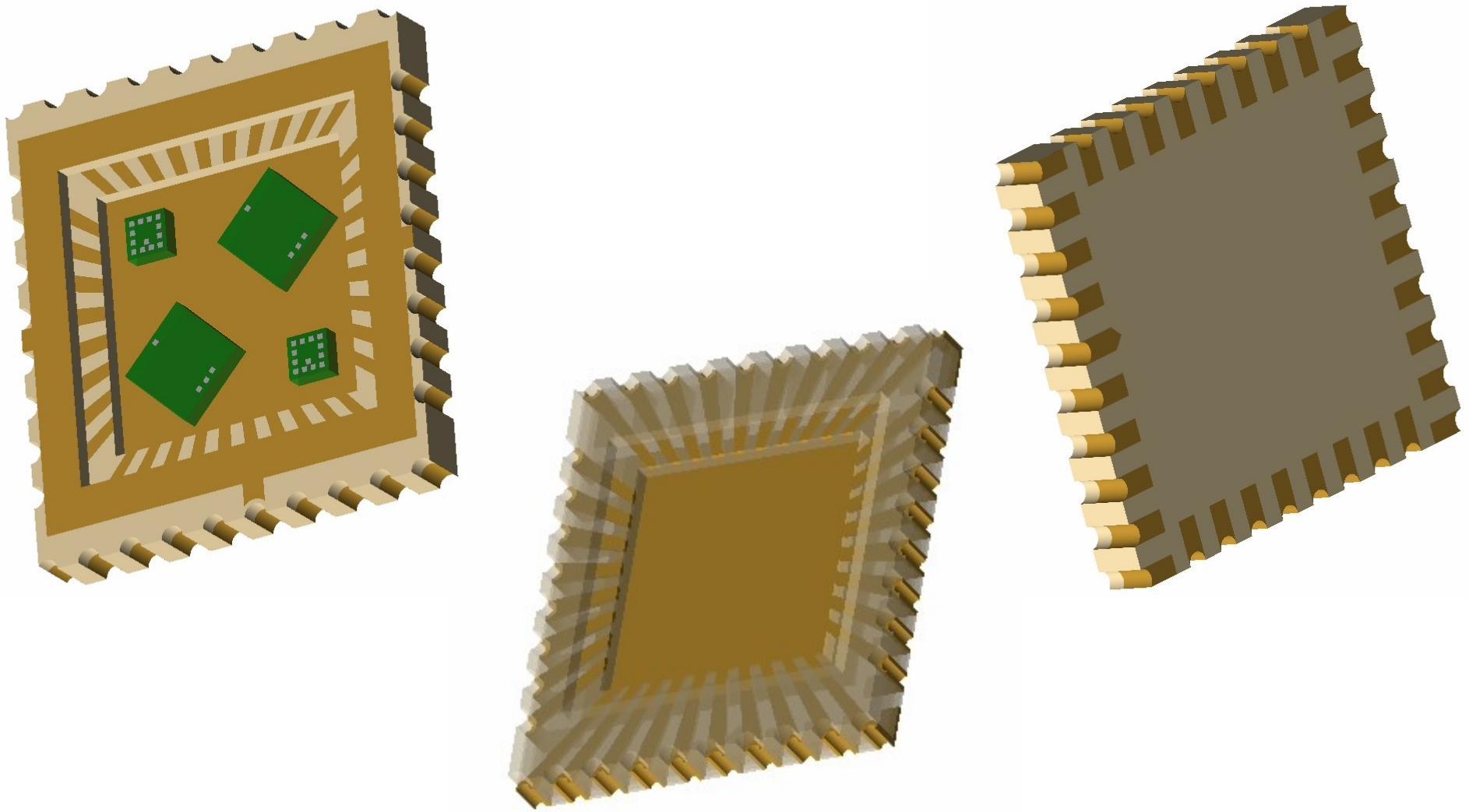


- A simple box with ground plane and marks, a hole and carved borders



Final packaging and sensors geometry

- Packaging has been tested against volumes overlapping



Interactivity

- The user can interactively
  - Select/change the type of environment
    - Set the attributes of the environment
  - Create one or more types of multi-layer object
    - Define the multi-layer dimension
    - Define each layer type and its thickness
    - Define the parameters of the layer type (attributes)
  - Position the multilayer object
    - There can be more than one instance of the same multilayer object
  - Define the materials
  - A non exhaustive list of parameters is
    - Plating thickness and material
    - Number of holes carved on the border
    - Radius of the holes
    - Spacing between holes
    - Dimensions of the central hole
    - Dimensions of the ground plane
    - Visual attributes

Macro example

- Materials

```
/radmon/materials/CreateElement  Nitrogen N  7.  14.01  g/mole
/radmon/materials/CreateElement  Oxygen   O  8.  16.00  g/mole
/radmon/materials/CreateElement  Aluminum Al 13. 26.98  g/mole
/radmon/materials/CreateElement  Copper   Cu 29  63.55  g/mole

/radmon/materials/CreateMaterial Aluminum 2.700 g/cm3 1
/radmon/materials/AddComponentByFraction Aluminum Aluminum 1
/radmon/materials/SetMaterialColor Aluminum .7 .7 .7
/radmon/materials/SetMaterialTrasparency Aluminum 1.
/radmon/materials/SetMaterialVisibility Aluminum visible
/radmon/materials/SetMaterialStyle Aluminum solid

/radmon/materials/CreateMaterial Copper 8.960 g/cm3 1
/radmon/materials/AddComponentByFraction Copper Copper 1
/radmon/materials/SetMaterialColor Copper .8 .6 .2
/radmon/materials/SetMaterialTrasparency Copper 1.
/radmon/materials/SetMaterialVisibility Copper visible
/radmon/materials/SetMaterialStyle Copper solid

/radmon/materials/CreateMaterial Air 1.290 mg/cm3 2
/radmon/materials/AddComponentByFraction Air Nitrogen 0.7
/radmon/materials/AddComponentByFraction Air Oxygen 0.3
/radmon/materials/SetMaterialColor Air .3 .9 1.
/radmon/materials/SetMaterialTrasparency Air 1.
/radmon/materials/SetMaterialVisibility Air visible
/radmon/materials/SetMaterialStyle Air wireframe
```

- Geometry definition

```
/radmon/detector/SetEnvironmentType FlatVolume
/radmon/detector/SetEnvironmentAttribute Width '.5 cm'
/radmon/detector/SetEnvironmentAttribute Height '.5 cm'
/radmon/detector/SetEnvironmentAttribute Thickness '.5 cm'
/radmon/detector/SetEnvironmentAttribute Material Air
/radmon/detector/EnableEnvironment

/radmon/detector/CreateMultilayer mly1
/radmon/detector/SetMultilayerWidth mly1 .95 mm
/radmon/detector/SetMultilayerHeight mly1 .95 mm

/radmon/detector/AppendLayerToMultilayer mly1 ly1
/radmon/detector/SetLayerType mly1 ly1 FlatVolume
/radmon/detector/SetLayerThickness mly1 ly1 0.5 mm
/radmon/detector/SetLayerAttribute mly1 ly1 Material Ceramics

/radmon/detector/AppendLayerToMultilayer mly1 ly2
/radmon/detector/SetLayerType mly1 ly2 FlatVolumeWithHole
/radmon/detector/SetLayerThickness mly1 ly2 0.2 mm
/radmon/detector/SetLayerAttribute mly1 ly2 Material Ceramics
/radmon/detector/SetLayerAttribute mly1 ly2 HoleWidth '.3 mm'
/radmon/detector/SetLayerAttribute mly1 ly2 HoleHeight '.2 mm'

/radmon/detector/CreatePlacement pl1 mly1
/radmon/detector/SetPlacementRotation pl1 90 45 45 deg
/radmon/detector/DumpLayout
```

Documentation

- Documentation on the web page and on CVS will be provided for
  - Custom user interface commands
  - List of layer types and their features
  - Attributes of each layer type

Summary

- A new advanced example is in progress
  - The aim of this example is to study the effects of a packaging on the sensor response to radiation
  - The packaging has been described in great detail adopting a rigorous software process and taking advantage of the Decorator pattern
- Next steps are:
  - Develop the primary generators and the physics list
  - Compare the results obtained from the simulation with the data that will be taken by the RADMON group
  - Validate the physics and deliver the studies needed by the RADMON group
- The example will be released in December, probably fully functional