From CAD geometries to Geant4 via CADMesh

M. Pinto, L.Arruda and P. Gonçalves

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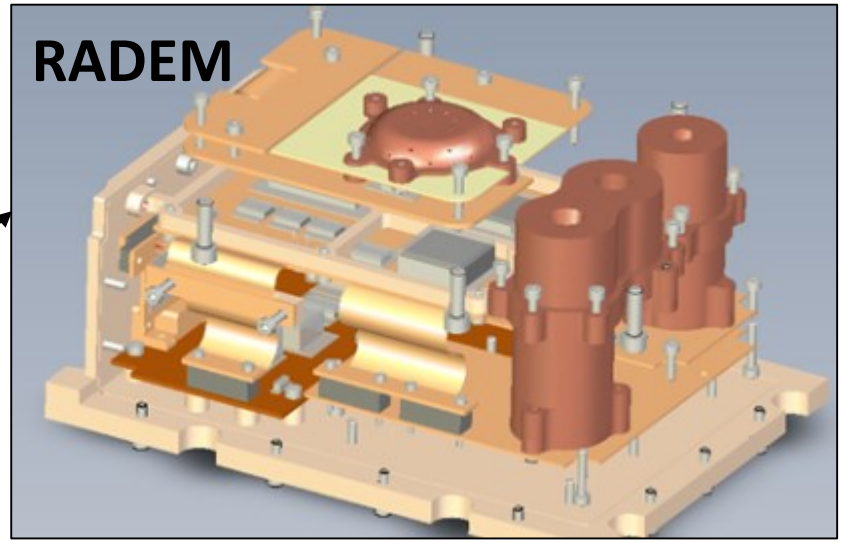
Contents

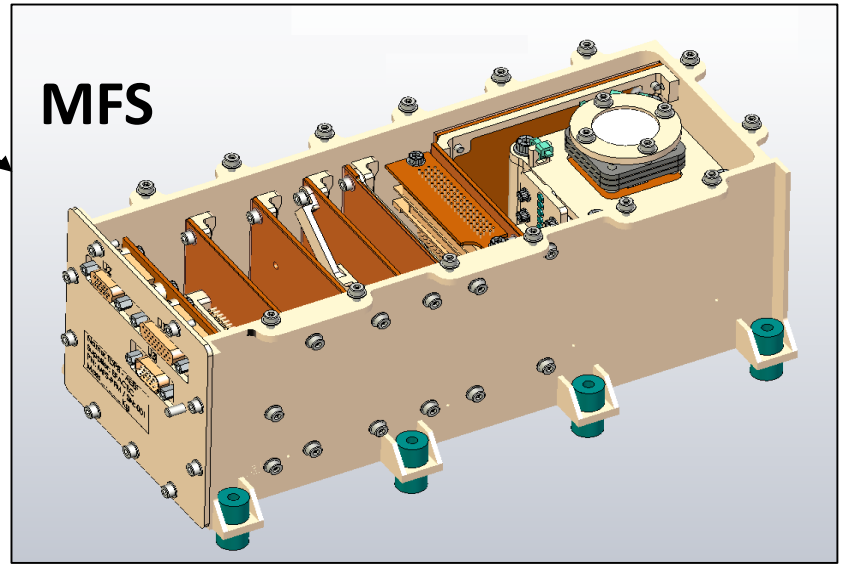
- Motivation
- CAD-to-GDML (Step-by-Step conversion)
  - STEP-to-STL (FreeCAD)
  - STL-to-GDML (CADMesh)
  - GDML manipulation
- Volume Integration in Geant4
  - Materials
  - Issues
- Case Study
  - RADEM
  - MFS
- Future Developments

Motivation



Space radiation detectors can be rather complex:

- Complicated geometries
- Several materials
- CAD format



Difficult to implement via Geant4 C++ geometry classes:

- Great number of volumes
- Volumes with different complexities

Very Time Consuming

Subject to Human Error

CADMesh:

- CAD model interface to Geant4
- Imports STL and PLY files (Mesh formats)
- Exports to GDML
- Requires additional steps
- Open-Source

Motivation – RADEM

RADEM – Radiation Hard Electron Monitor for the JUICE Mission

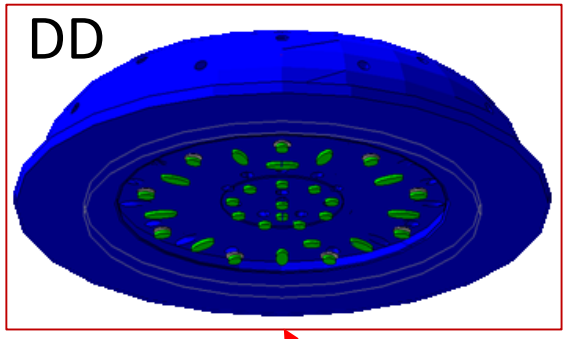
ESA contract

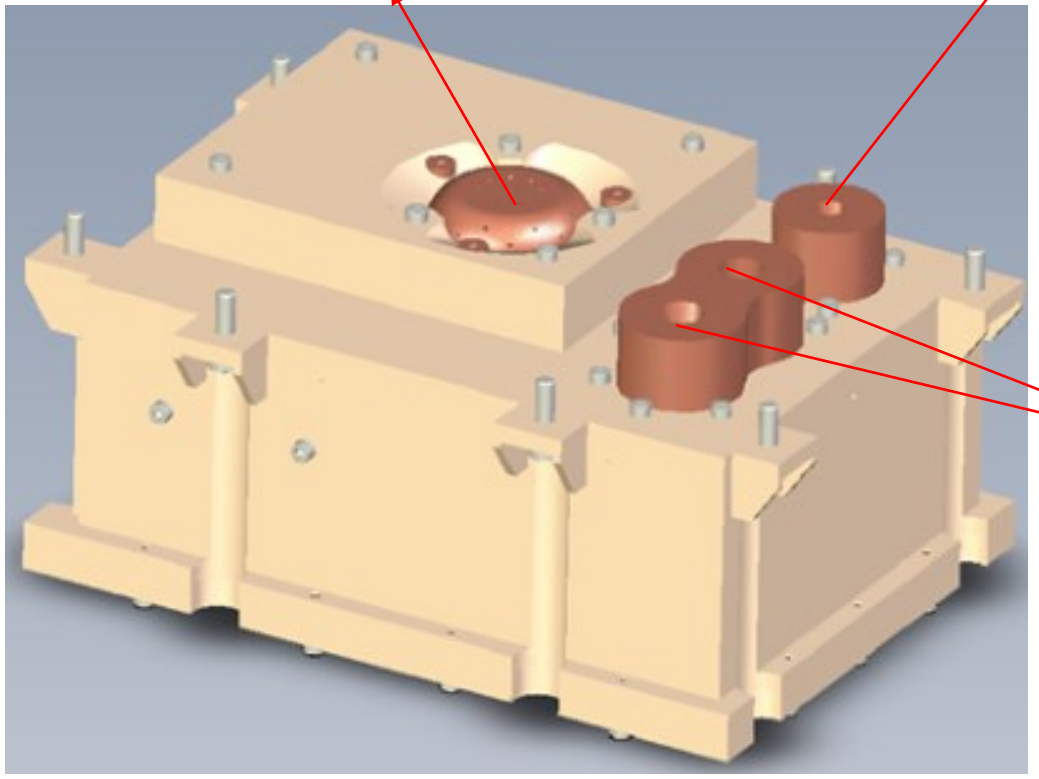
Main Objectives

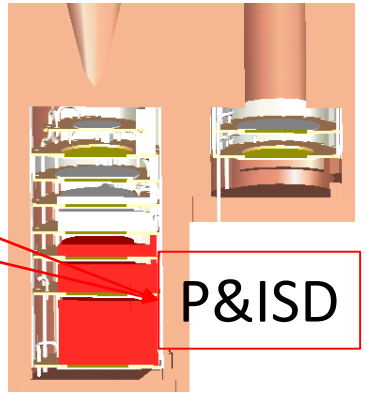
- Ensure mission safety
- Provide valuable scientific data

Requirements:

- Electron detector
  - Spectral range 300 keV – 40 MeV
  - Peak Flux 10^9 e/cm^2/s
- Proton Detector
  - Spectral range 5 MeV– 250 MeV
  - Peak Flux 10^9 e/cm^2/s
- Particle Separation
  - From Helium to Oxygen
- Dose determination
- Weight: 1kg
- Power: 1W







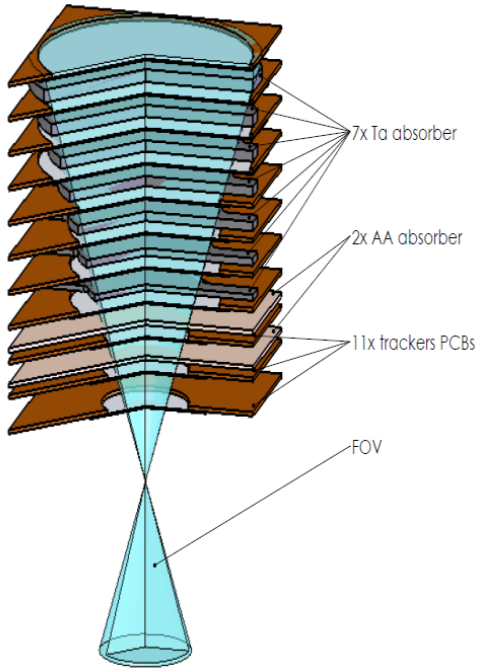
Motivation – MFS

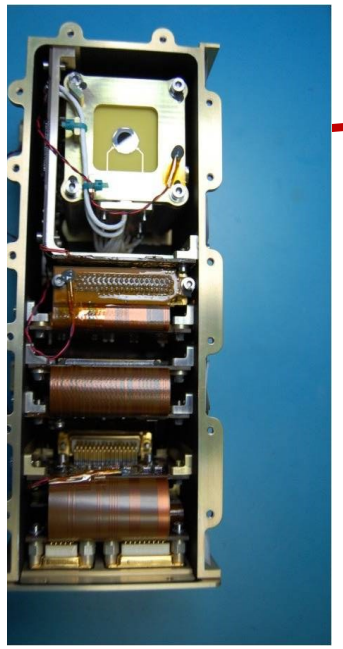
MFS - MultiFunctional Spectrometer aboard AlphaSat in GEO

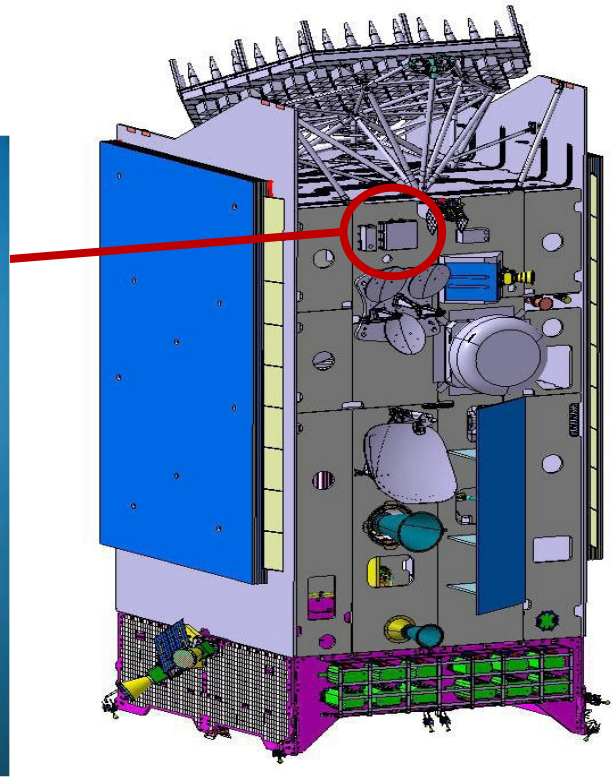
ESA contract efacec LIP

Requirements:

- Electron energies
  - Spectral range 350 keV – 7 MeV
  - 20% resolution
- Proton energies
  - Spectral range 1 MeV – 200 MeV
  - 10% resolution
- Alpha particle energies
  - Spectral range 5 MeV – 100 MeV
  - 20% resolution
- Weight: <3kg
- Power: <5W



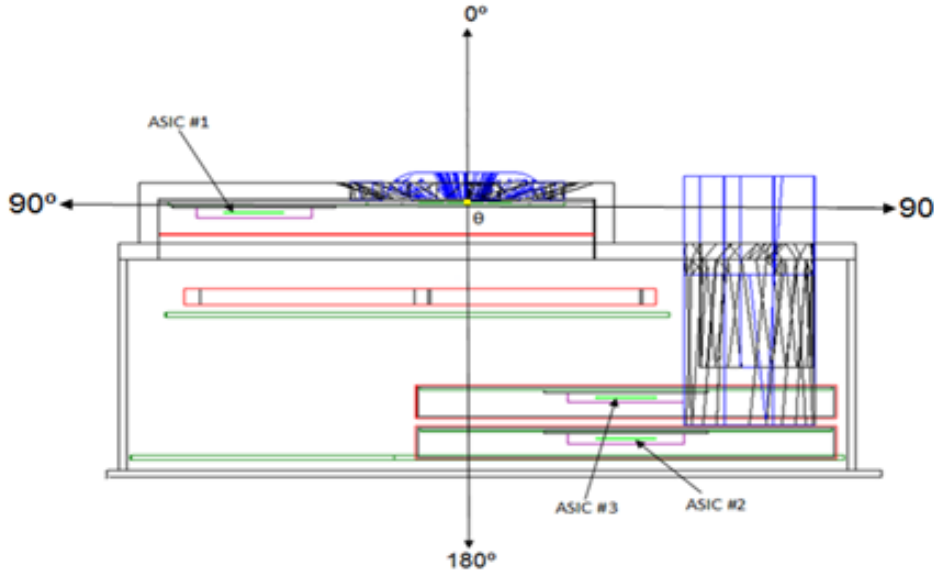


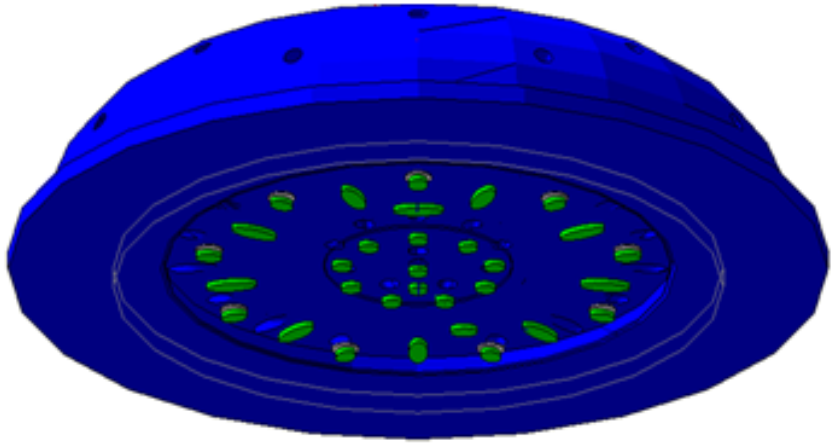


Motivation

Radiation Analysis for TID, TNID and SEE in EEE components requires a more detailed model

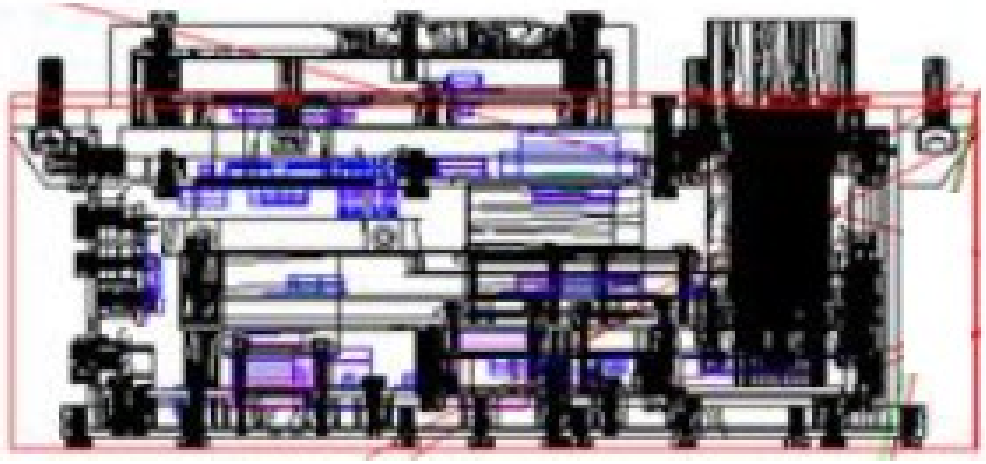
RADEM G4
Preliminary Model

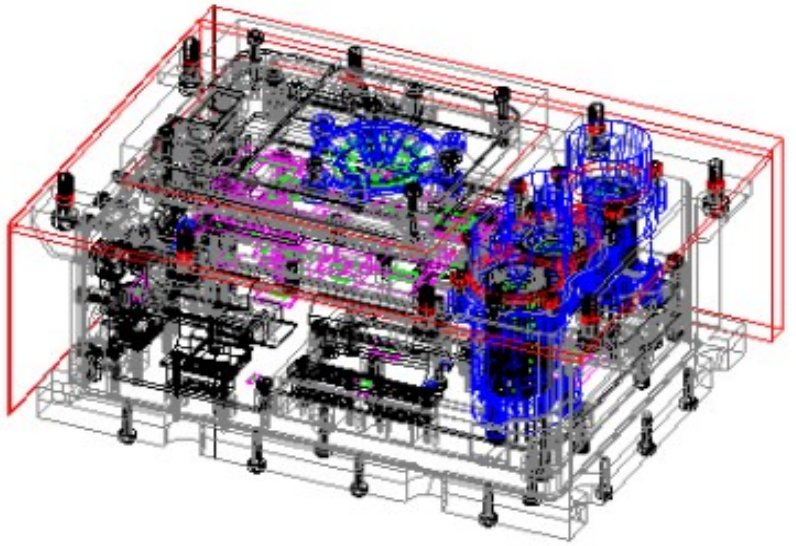




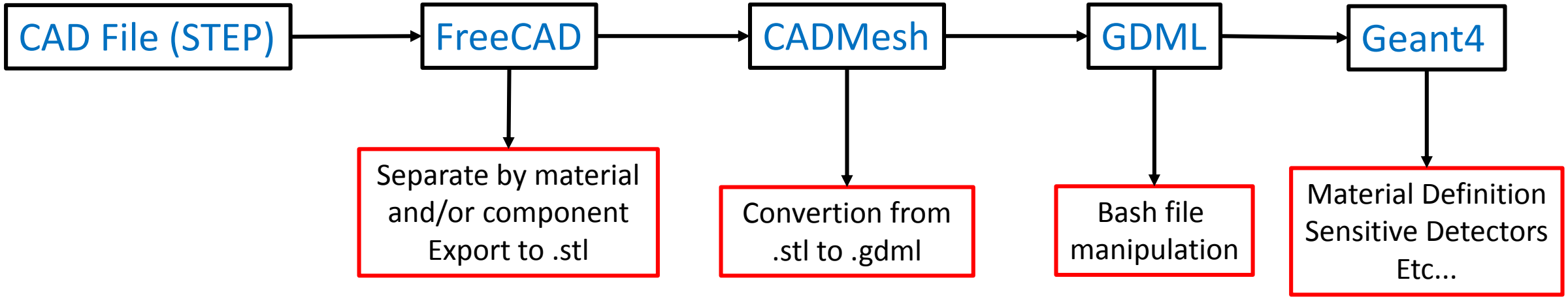
CSG Solids

RADEM
GDML Model





CAD-to-GDML



https://github.com/christopherpoole/CADMesh
http://assimp.sourceforge.net/

Conversion Summary:

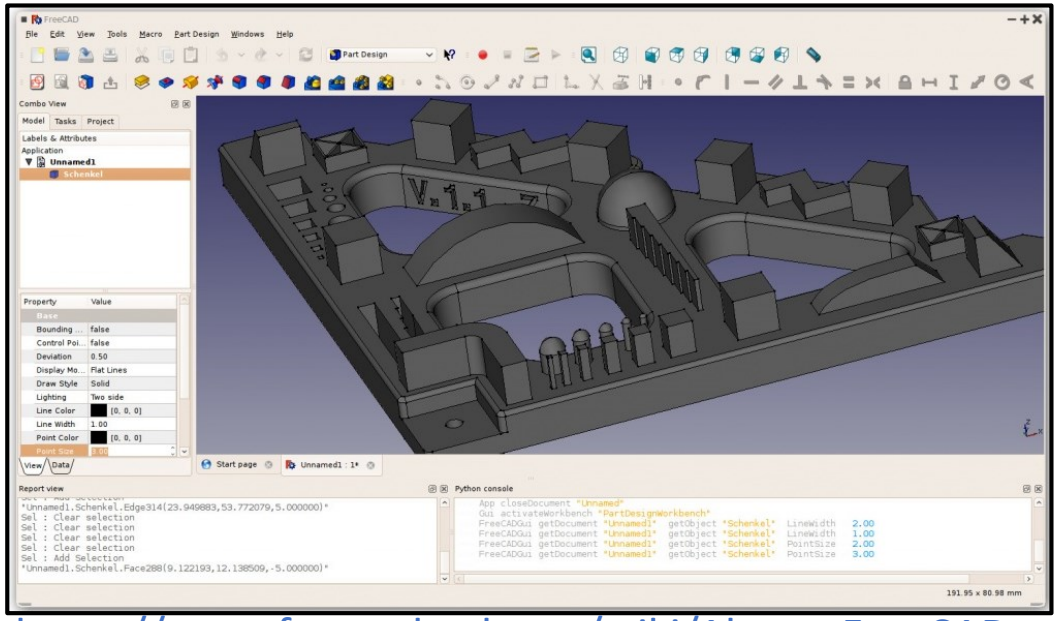
- ❑ 4 stages
  - STEP to STL
  - STL to GDML
  - GDML Manipulation
  - Geant4 Implementation
- ❑ 3 plataforms
  - FreeCAD
  - CADMesh
  - Geant4
- ❑ Apparent unlimited complexity
  - Memory limitations

Open Source

STEP-to-STL (1)

FreeCAD© v0.13 r.1828:

- ❑ General purpose 3D CAD modeler
- ❑ Open-source
- ❑ Imports CAD formats (STEP)
- ❑ Exports Mesh formats (STL, PLY)
- ❑ **Supports Python**



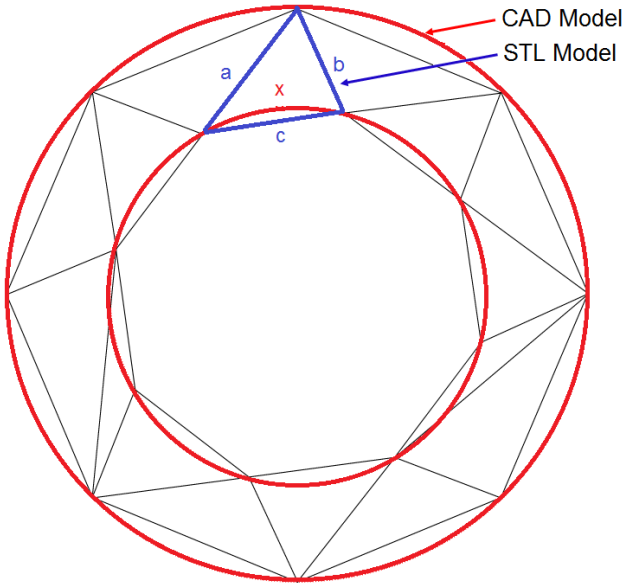
https://www.freecadweb.org/wiki/About_FreeCAD

Loop through volumes and manage them individually

Separate by Material:
Bigger Structures
Less Overlaps
Less Flexibility

Separate by Component:
Smaller Structures
More Overlaps
Larger Flexibility

STL (STereoLithography) – Mesh format

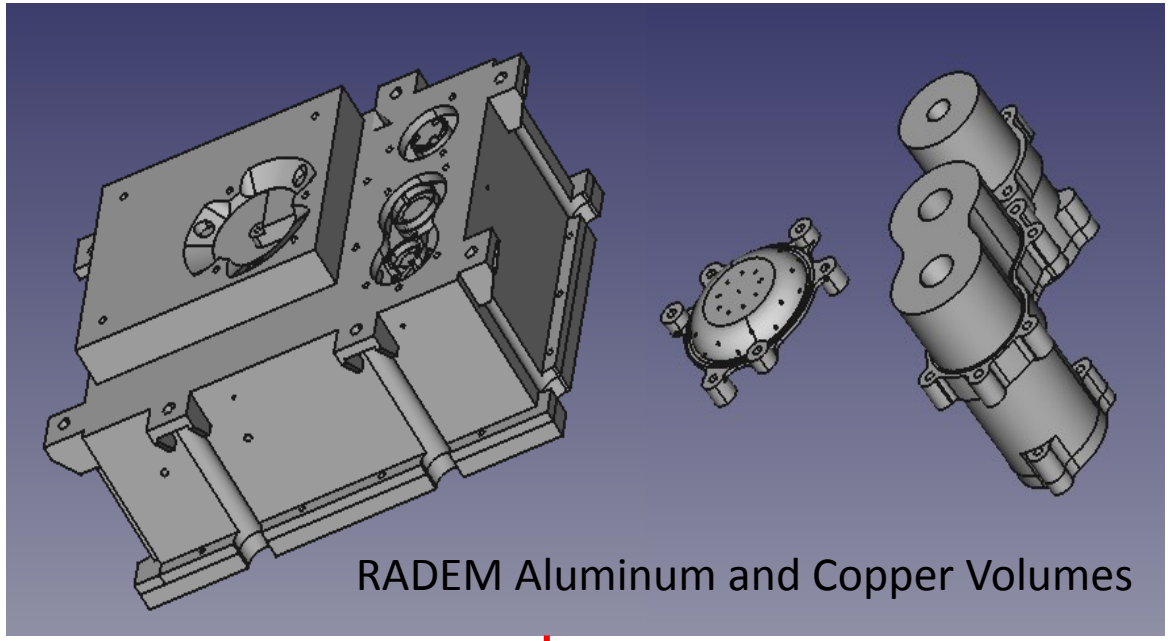


Describes solids as series of triangles adjacent to each other enclosing the full volume

Meshing Parameters:
Tolerance = 0.10

STEP-to-STL (2)

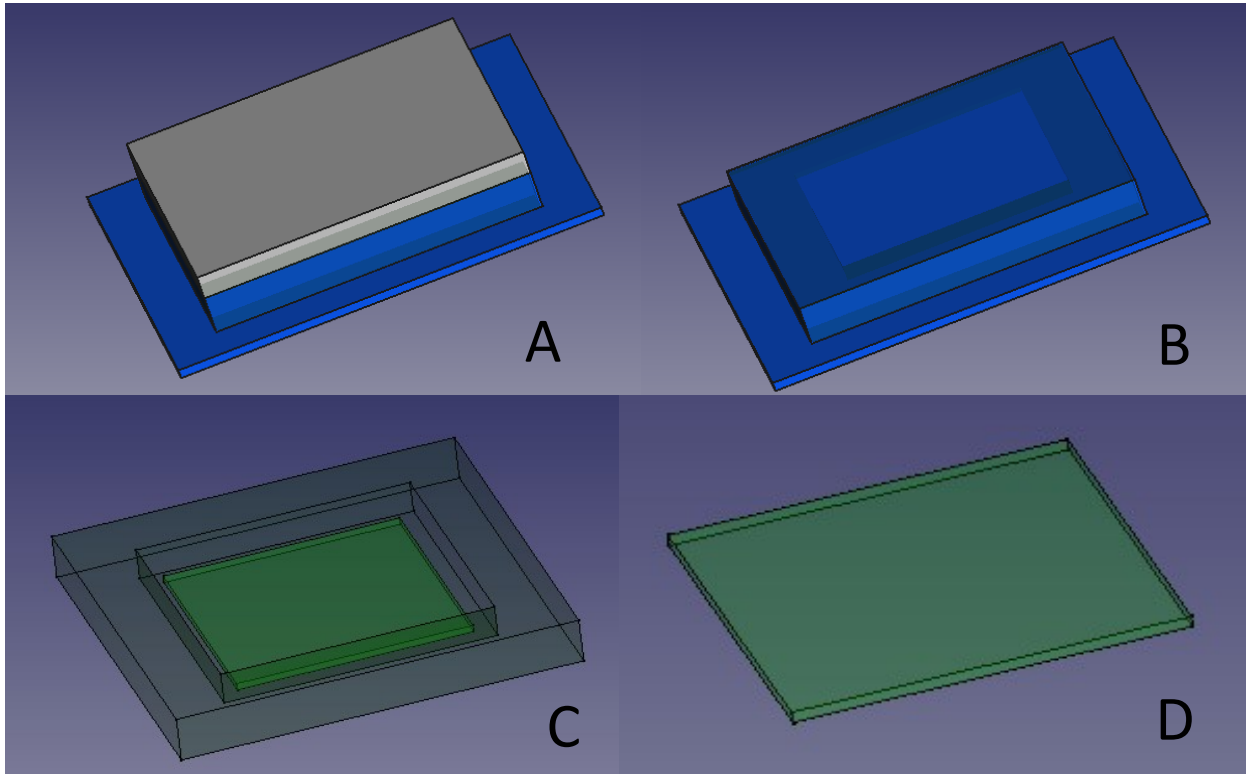
Separation by Material - not intended for analysis



Lookup Table
Solid name - Material

Diferent materials/densities and purposes

Separation by Component- TID Analysis



A – Full component with vibration space
B – Component Box
C – Component Body + Dye
D – Component Dye (Sensitive Detector)

STL-to-GDML (1)

CADMesh v1.0:

- ❑ A CAD interface for Geant4
- ❑ Open-source
- ❑ Imports Mesh formats (STL, PLY)
  - ASSIMP
- ❑ Exports to GDML
  - Example available*

*https://github.com/christopherpoole/CADMesh
http://assimp.sourceforge.net/

```
<?xml version="1.0" encoding="UTF-8" standalone="no" ?>
<gdml xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSchemaLocation="http://service-spi.w
/gdml.xsd">

  <define>
    <position name="Sil1.stl_v0" unit="mm" x="-132.65535736084" y="64.4899978637695" z="-33.5724563598633"/>
    <position name="Sil1.stl_v1" unit="mm" x="-132.557167053223" y="64.8099975585938" z="-33.5521926879883"/>
    <position name="Sil1.stl_v2" unit="mm" x="-132.65535736084" y="64.8099975585938" z="-33.5724563598633"/>
    <position name="Sil1.stl_v3" unit="mm" x="-132.557167053223" y="64.4899978637695" z="-33.5521926879883"/>
    <position name="Sil1.stl_v4" unit="mm" x="-132.752815246582" y="64.4899978637695" z="-33.5959892272949"/>
    <position name="Sil1.stl_v5" unit="mm" x="-132.752815246582" y="64.8099975585938" z="-33.5959892272949"/>
    <position name="Sil1.stl_v6" unit="mm" x="-132.849433898926" y="64.4899978637695" z="-33.6227684020996"/>
    .
    .
    .
  <materials>
    .
    .
    .
  </materials>

  <solids>
    <tessellated aunit="deg" lunit="mm" name="Sil1.stl0x12b20f0">
      <triangular vertex1="Sil1.stl_v0" vertex2="Sil1.stl_v1" vertex3="Sil1.stl_v2"/>
      <triangular vertex1="Sil1.stl_v0" vertex2="Sil1.stl_v3" vertex3="Sil1.stl_v1"/>
      <triangular vertex1="Sil1.stl_v4" vertex2="Sil1.stl_v2" vertex3="Sil1.stl_v5"/>
      .
      .
      .
      <triangular vertex1="Sil1.stl_v2050" vertex2="Sil1.stl_v2051" vertex3="Sil1.stl_v1029"/>
      <triangular vertex1="Sil1.stl_v2052" vertex2="Sil1.stl_v1029" vertex3="Sil1.stl_v1031"/>
      <triangular vertex1="Sil1.stl_v1" vertex2="Sil1.stl_v2053" vertex3="Sil1.stl_v1031"/>
      <triangular vertex1="Sil1.stl_v3" vertex2="Sil1.stl_v2054" vertex3="Sil1.stl_v1"/>
    </tessellated>
    <box lunit="mm" name="world_solid0x12a5760" x="1000" y="1000" z="1000"/>
  </solids>

  <structure>
    <volume name="cad_logical0x12b1fb0">
      <materialref ref="G4_WATER0x12a0f70"/>
      <solidref ref="Sil1.stl0x12b20f0"/>
    </volume>
    <volume name="world_logical0x12a5b20">
      <materialref ref="G4_AIR0x1298e70"/>
      <solidref ref="world_solid0x12a5760"/>
      <physvol name="cad_physical0x12b1730">
        <volumeref ref="cad_logical0x12b1fb0"/>
        <rotation name="cad_physical0x12b1730_rot" unit="deg" x="0" y="0" z="90"/>
      </physvol>
    </volume>
  </structure>

  <setup name="Default" version="1.0">
    <world ref="world_logical0x12a5b20"/>
  </setup>

</gdml>
```

Vertex position definition

Materials (optional

Triangles Definition (Vertex)

Structure

STL-to-GDML (2)

CADMesh v1.0:

- ❑ A CAD interface for Geant4
- ❑ Open-source
- ❑ Imports Mesh formats (STL, PLY)
- ❑ Exports to GDML

Still needs some internal change

```
<?xml version="1.0" encoding="UTF-8" standalone="no" ?>
<gdml xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSchemaLocation="http://service-spi.w
/gdml.xsd">

  <define>
    <position name="Sil1.stl_v0" unit="mm" x="-132.65535736084" y="64.4899978637695" z="-33.5724563598633"/>
    <position name="Sil1.stl_v1" unit="mm" x="-132.557167053223" y="64.8099975585938" z="-33.5521926879883"/>
    <position name="Sil1.stl_v2" unit="mm" x="-132.65535736084" y="64.8099975585938" z="-33.5724563598633"/>
    <position name="Sil1.stl_v3" unit="mm" x="-132.557167053223" y="64.4899978637695" z="-33.5521926879883"/>
    <position name="Sil1.stl_v4" unit="mm" x="-132.752815246582" y="64.4899978637695" z="-33.5959892272949"/>
    <position name="Sil1.stl_v5" unit="mm" x="-132.752815246582" y="64.8099975585938" z="-33.5959892272949"/>
    <position name="Sil1.stl_v6" unit="mm" x="-132.849433898926" y="64.4899978637695" z="-33.6227684020996"/>
    .
    .
    .
  </define>
  <materials>
    .
    .
    .
  </materials>
  <solids>
    <tessellated aunit="deg" lunit="mm" name="Sil1.stl0x12b20f0">
      <triangular vertex1="Sil1.stl_v0" vertex2="Sil1.stl_v1" vertex3="Sil1.stl_v2"/>
      <triangular vertex1="Sil1.stl_v0" vertex2="Sil1.stl_v3" vertex3="Sil1.stl_v1"/>
      <triangular vertex1="Sil1.stl_v4" vertex2="Sil1.stl_v2" vertex3="Sil1.stl_v5"/>
      .
      .
      .
      <triangular vertex1="Sil1.stl_v2050" vertex2="Sil1.stl_v2051" vertex3="Sil1.stl_v1029"/>
      <triangular vertex1="Sil1.stl_v2052" vertex2="Sil1.stl_v1029" vertex3="Sil1.stl_v1031"/>
      <triangular vertex1="Sil1.stl_v1" vertex2="Sil1.stl_v2053" vertex3="Sil1.stl_v1031"/>
      <triangular vertex1="Sil1.stl_v3" vertex2="Sil1.stl_v2054" vertex3="Sil1.stl_v1"/>
    </tessellated>
    <box lunit="mm" name="world_solid0x12a5760" x="1000" y="1000" z="1000"/>
  </solids>

  <structure>
    <volume name="cad_logical0x12b1fb0">
      <materialref ref="G4_WATER0x12a0f70"/>
      <solidref ref="Sil1.stl0x12b20f0"/>
    </volume>
    <volume name="world_logical0x12a5b20">
      <materialref ref="G4_AIR0x1298a70"/>
      <solidref ref="world_solid0x12a5760"/>
      <physvol name="cad_physical0x12b1730">
        <volumeref ref="cad_logical0x12b1fb0"/>
        <rotation name="cad_physical0x12b1730_rot" unit="deg" x="0" y="0" z="90"/>
      </physvol>
    </volume>
  </structure>

  <setup name="Default" version="1.0">
    <world ref="world_logical0x12a5b20"/>
  </setup>

</gdml>
```

Vertex position definition

Materials (optional

Triangles Definition (Vertex)

Structure

GDML manipulation

Bash script

```
<?xml version="1.0" encoding="UTF-8" standalone="no" ?>
<gdml xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSchemaLocation="http://service-s
/gdml.xsd">

  <define>
    <position name="Sil1_v0" unit="mm" x="-132.65535736084" y="64.4899978637695" z="-33.5724563598633"/>
    <position name="Sil1_v1" unit="mm" x="-132.557167053223" y="64.8099975585938" z="-33.5521926879883"/>
    <position name="Sil1_v2" unit="mm" x="-132.65535736084" y="64.8099975585938" z="-33.5724563598633"/>
    <position name="Sil1_v3" unit="mm" x="-132.557167053223" y="64.4899978637695" z="-33.5521926879883"/>
    <position name="Sil1_v4" unit="mm" x="-132.752815246582" y="64.4899978637695" z="-33.5959892272949"/>
    <position name="Sil1_v5" unit="mm" x="-132.752815246582" y="64.8099975585938" z="-33.5959892272949"/>
      .
      .
      .
  <materials>
      .
      .
      .
  </materials>

  <solids>
    <tessellated aunit="deg" lunit="mm" name="Sil10x13c00f0">
      <triangular vertex1="Sil1_v0" vertex2="Sil1_v1" vertex3="Sil1_v2"/>
      <triangular vertex1="Sil1_v0" vertex2="Sil1_v3" vertex3="Sil1_v1"/>
      <triangular vertex1="Sil1_v4" vertex2="Sil1_v2" vertex3="Sil1_v5"/>
      <triangular vertex1="Sil1_v4" vertex2="Sil1_v0" vertex3="Sil1_v2"/>
      <triangular vertex1="Sil1_v6" vertex2="Sil1_v7" vertex3="Sil1_v8"/>
      <triangular vertex1="Sil1_v6" vertex2="Sil1_v4" vertex3="Sil1_v9"/>
        .
        .
        .
      <triangular vertex1="Sil1_v2045" vertex2="Sil1_v2046" vertex3="Sil1_v1026"/>
      <triangular vertex1="Sil1_v2047" vertex2="Sil1_v2048" vertex3="Sil1_v1026"/>
      <triangular vertex1="Sil1_v2049" vertex2="Sil1_v1026" vertex3="Sil1_v1029"/>
      <triangular vertex1="Sil1_v2050" vertex2="Sil1_v2051" vertex3="Sil1_v1029"/>
      <triangular vertex1="Sil1_v2052" vertex2="Sil1_v1029" vertex3="Sil1_v1031"/>
      <triangular vertex1="Sil1_v1" vertex2="Sil1_v2053" vertex3="Sil1_v1031"/>
      <triangular vertex1="Sil1_v3" vertex2="Sil1_v2054" vertex3="Sil1_v1"/>
    </tessellated>
    <box lunit="mm" name="world_solid0x13b3760" x="1000" y="1000" z="1000"/>
  </solids>

  <structure>
    <volume name="Sil1">
      <materialref ref="G4_WATER0x13aef70"/>
      <solidref ref="Sil10x13c00f0"/>
    </volume>
  </structure>

  <setup name="Default" version="1.0">
    <world ref="Sil1"/>
  </setup>

</gdml>
```

```
<structure>
  <volume name="Sil1">
    <materialref ref="G4_WATER0x13aef70"/>
    <solidref ref="Sil10x13c00f0"/>
  </volume>
</structure>

<setup name="Default" version="1.0">
  <world ref="Sil1"/>
</setup>
```

One file per material/component

Geant4 Integration (1)

Requirements:

- ❑ Geant4 compilation with gdml option (4.10.01-p02)
- ❑ Multiple gdml files
- ❑ mother.gdml

Provides World Volume and all .gdml volumes

```
<?xml version="1.0" encoding="UTF-8" ?>

<gdml xmlns:gdml="../schema" xmlns:xsi="http://www.w3.org/20

<define>
  <constant name="HALFPI" value="pi/2."/>
  <constant name="PI" value="1.*pi"/>
  <constant name="TWOPI" value="2.*pi"/>
  <position name="center" x="0" y="0" z="0"/>
  <rotation name="identity" x="0" y="0" z="0"/>
  <rotation name="alignSurfX" y="HALFPI" />
  <rotation name="alignSurfY" x="HALFPI" />
</define>

<materials>
    ...
</materials>

<solids>
  <box  name="WorldBox" x="1.0" y="1.0" z="1.0" lunit="m"/>

</solids>


<structure>

<volume name="World">
<materialref ref="Air"/>
<solidref ref="WorldBox"/>

<physvol>
<file name="gdml/Si1.gdml"/>
<positionref ref="center"/>
<rotationref ref="identity"/>
</physvol>
    ...

</volume>


</structure>
<setup name="Default" version="1.0">
  <world ref="World"/>
</setup>

</gdml>
```

Optional

World Solid

World Volume

Physical Volumes

Geant4 Integration (2)

DetectorConstruction.cc

```
#include “G4GDMLParser.hh”
.
.
.
Parser.Read(“mother.gdml”, false);
G4VPhysicalVolume* W = parser.GetWorldVolume();
G4LogicalVolume* W_log = W->GetLogicalVolume();
W_log->SetMaterial(Vacuum);
```

World

```
Cycle through W_log daughters:
        G4VPhysicalVolume* daughter = W_log->GetDaughter[i];
        G4LogicalVolume* daughter_log = daughter->GetLogicalVolume;
        daughter->CheckOverlaps();
        string daughter_name = daughter->GetName;
        daughter_log->SetMaterial(daughter_material)
        daughter_log->SetSensitiveDetector(SD);
```

Material
Sensitive Detector
CopyNumber
Etc...

Geant4 Integration (3)

DetectorConstruction.cc

```
#include “G4GDMLParser.hh”
.
.
.
Parser.Read(“mother.gdml”, false);
G4VPhysicalVolume* W = parser.GetWorldVolume();
G4LogicalVolume* W_log = W->GetLogicalVolume();
W_log->SetMaterial(Vacuum);

Cycle through W_log daughters:
        G4VPhysicalVolume* daughter = W_log->GetDaughter[i];
        G4LogicalVolume* daughter_log = daughter->GetLogicalVolume;
        daughter->CheckOverlaps();
        string daughter_name = daughter->GetName;
        daughter_log->SetMaterial(daughter_material)
        daughter_log->SetSensitiveDetector(SD);
```

Small

There are overlaps!

Low Probability

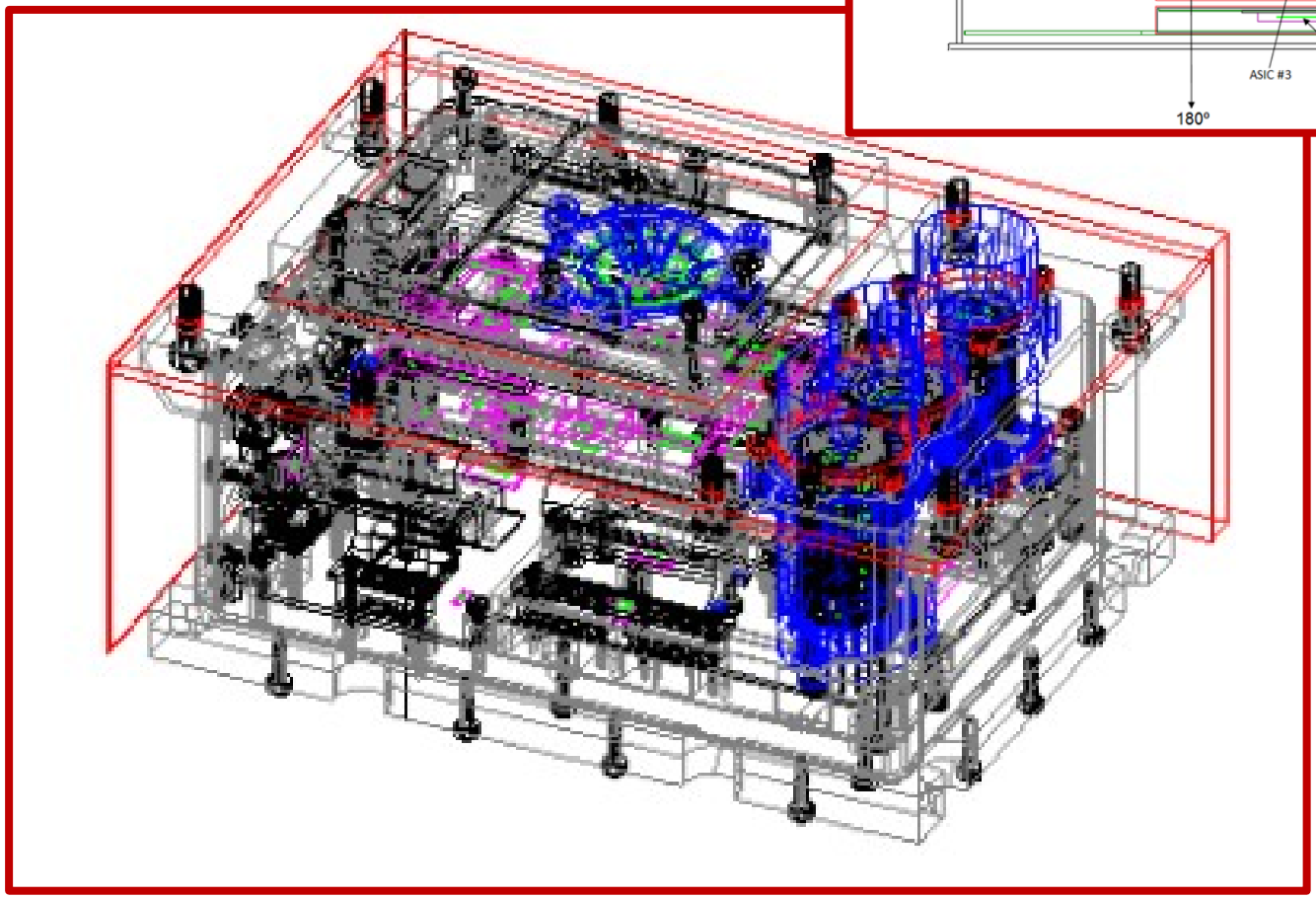
Managable by G4Navigator

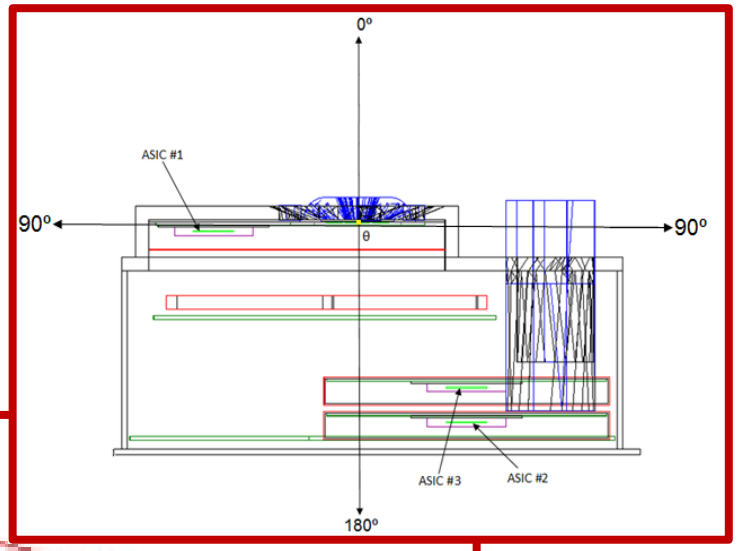
Material
Sensitive Detector
CopyNumber
Etc...

Case Study 1 – RADEM (1)

RADEM GDML Model

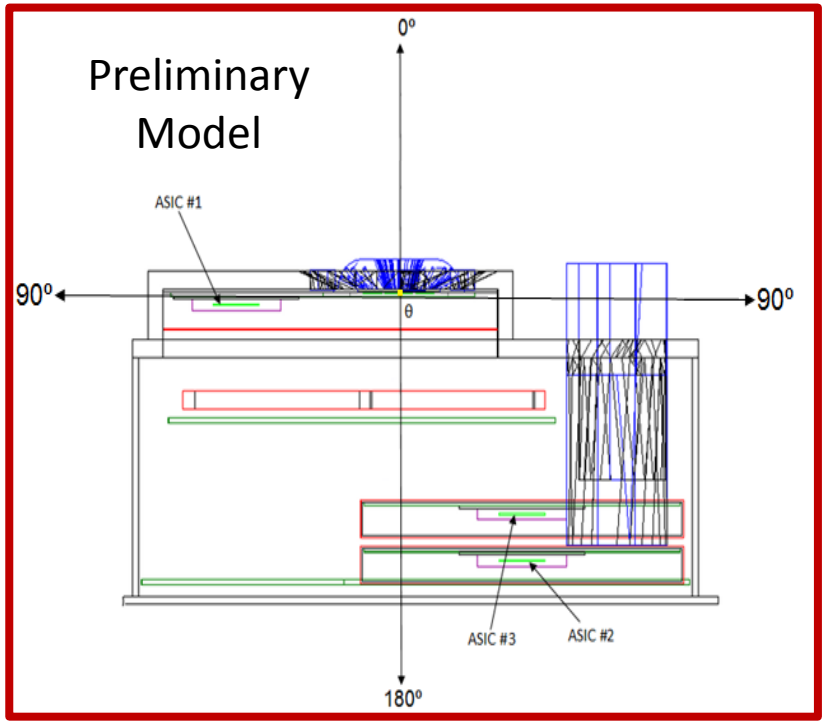
- 152 independent volumes
  - >20 materials/densities
- 137 sensitive volumes
  - 2x44 EEE components
  - 49 Silicon detectors
- Radiation Analysis:
  - Total Ionizing Dose (TID)
  - Iterations with additional mass
  - Displacement Damage (DD)
  - Single Event Effects (SEE)
- Detector response:
  - On-going





Case Study 1 – RADEM (2)

Component	Electron TID for the entire JUICE mission (kRad)		
	Preliminary Model	STEP to GDML	STEP-to-GDML+Additional Shielding
ASIC #1	683±13	185±11	111±1
ASIC #2	787±15	726±33	144±1
ASIC #3	734±11	182±10	136±1

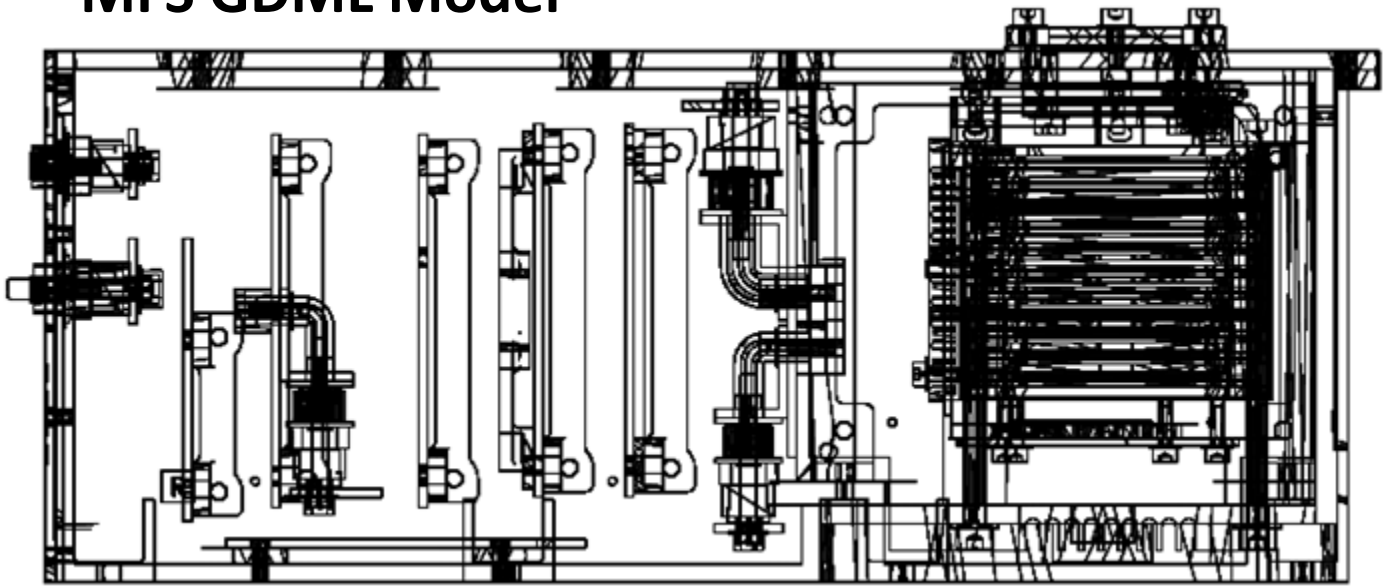


- Preliminary Model: CSG Volumes, naive EEE component modeling
- First iterations allowed to improve the CAD model
  - Increased wall and bottom thickness
- Subsequent results aimed at local shielding
  - To be implemented in the CAD model

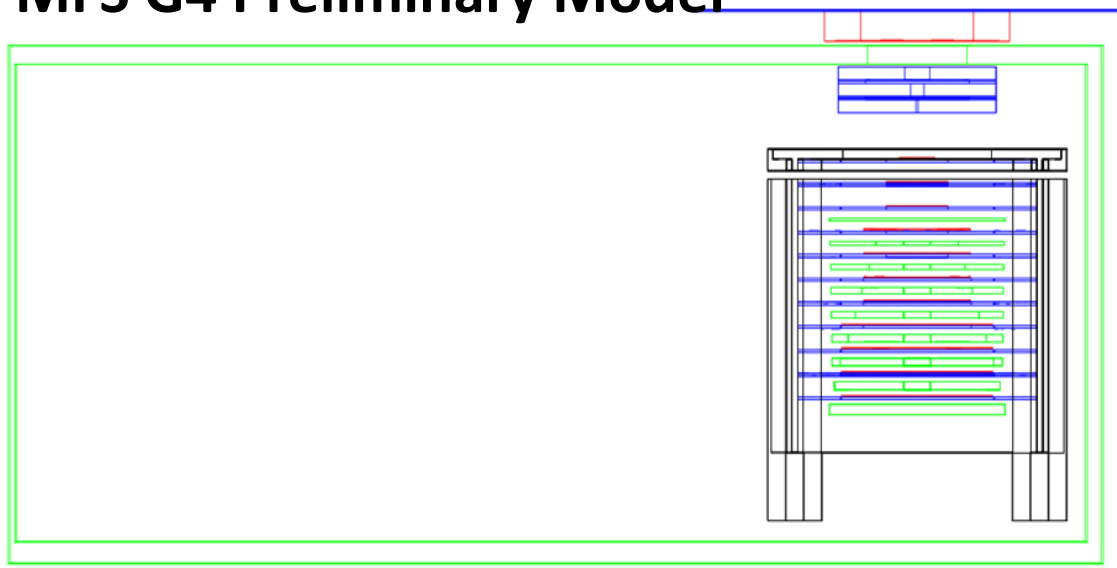
CAD and Geant4 complement each other

Case Study 2 – MFS

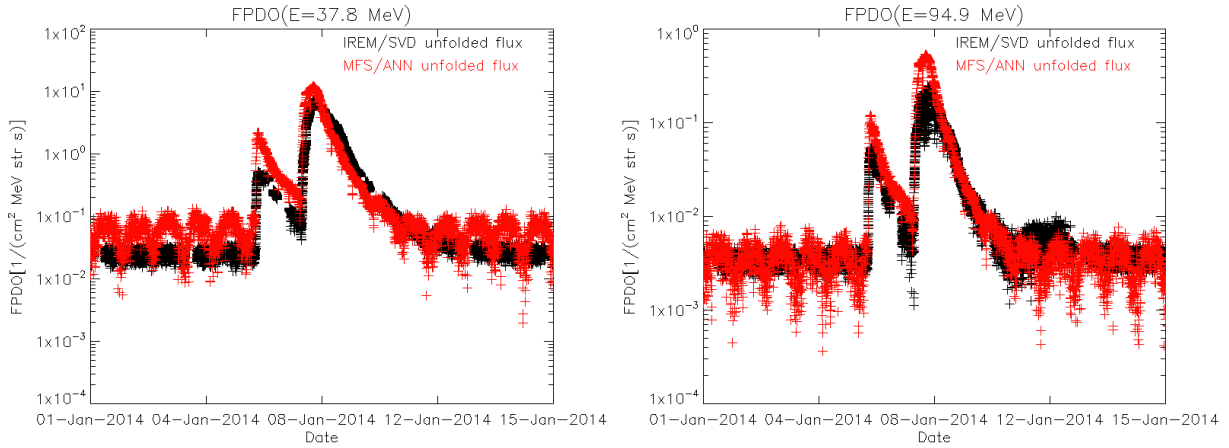
MFS GDML Model



MFS G4 Preliminary Model



- 21 independent volumes
  - >11 Material/densities
- 11 sensitive volumes
  - Silicon detectors
- Response Functions



SEP Protons in GEO measured with ESA MultiFunctional Spectrometer, L. Arruda et al, RADECS 2016

Conclusions/Future Developments

- ✓ A procedure to convert CAD files into GDML was successfuly developed
- ✓ Two different radiation monitors are already simulated with G4 this process: RADEM and MFS
- ✓ Works well together with G4 classes

- ➢ Additional control over the tessellation process is under study in order to improve the overlap issues
- ➢ Further comparison between CAD converted solids and equivalent G4 coded solids is also under way
- ➢ Development of an open-source tool to convert CAD/STEP files with minimal user interaction

Thank you !!!

LIP