SPACE SUITE

Beyond the space horizon

Examples of applications cases of GEANT4 in space environment effects analysis with the SpaceSuite tools and feedbacks

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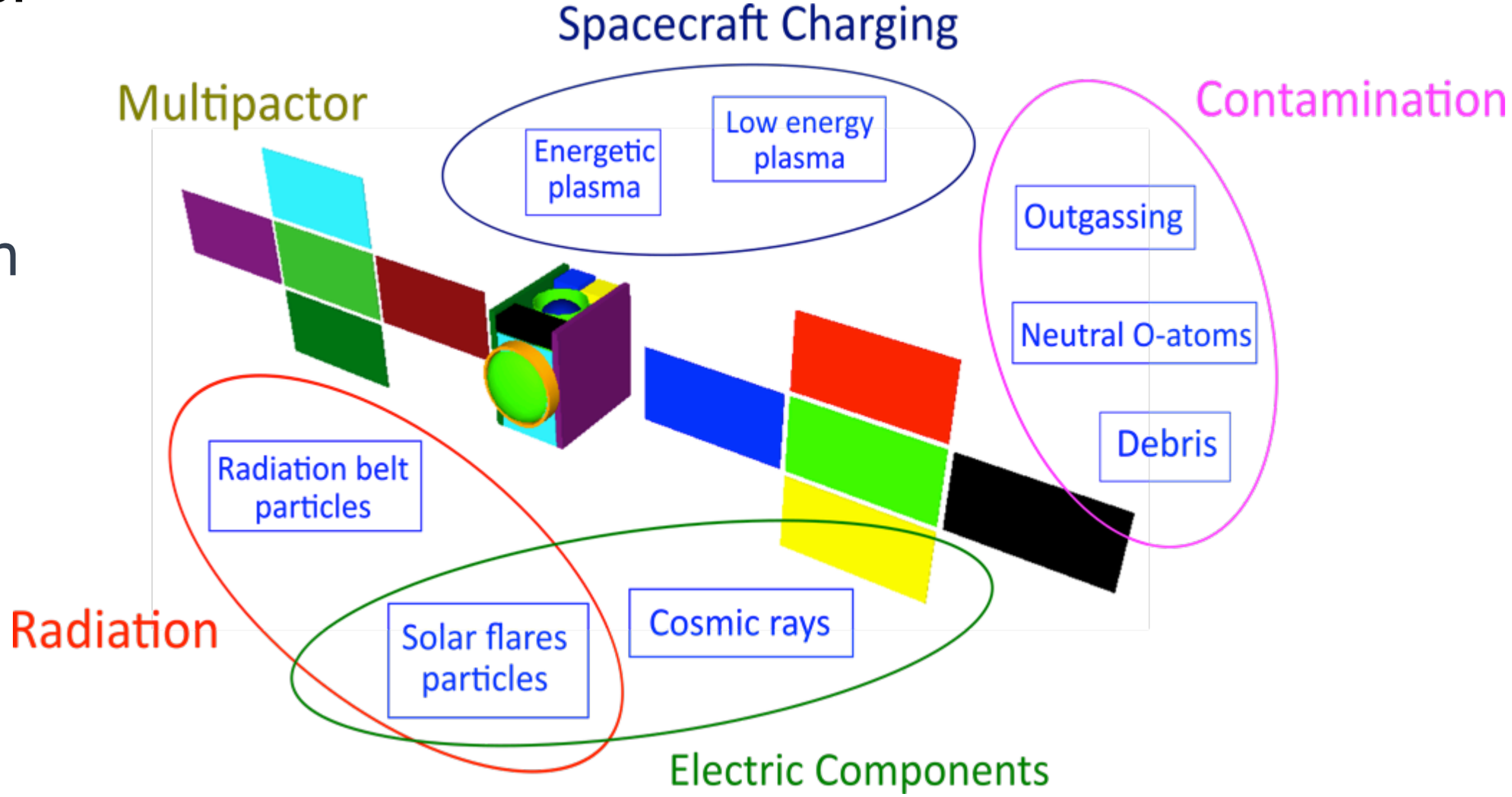
(1) Artenum Toulouse; (2) Artenum Paris; (3) ONERA-DPhy

14th Geant4 Space Users Workshop– October 2019

Impacts of the space environment

- Harmful effects of the spacecraft environment
- Consequences on equipment:
  - Losses of sensitive components, payload or even of the entire spacecraft;
  - Malfunctions.
- Space qualification
- Optimisation



New missions, New challenges

New constraints

- Use of COTS components
- New spacecraft designs
- New missions (EOR, constellations...)
- Optimisation
- New actors
- Risks reduction

Proposed solution

- Finer modelling of the impact of space environment

Single physic analysis

Multi-physics analysis

SpaceSuite, a new approach

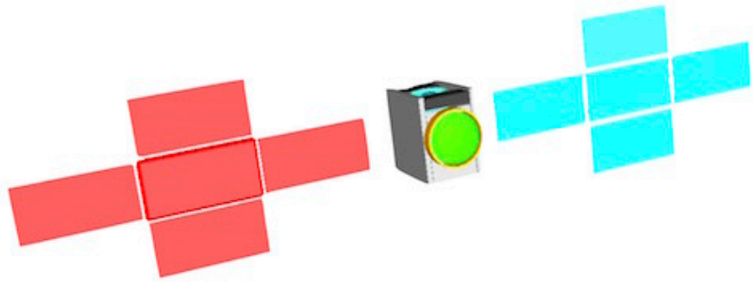
- **An Artenum / ONERA partnership**
- **To provide a structured software suite for the assessment of the impact of the space environment on space systems**
- **With**
  - A multi-physical approach to better assess the consequences on space systems
  - Integration of reference models and tools validated
- **Through some key axis**
  - Spacecraft charging and surface-plasma interactions
  - Electrical propulsion impact characterisation
  - Radiations analysis and single events in electronic devices
  - Internal charging
  - ...

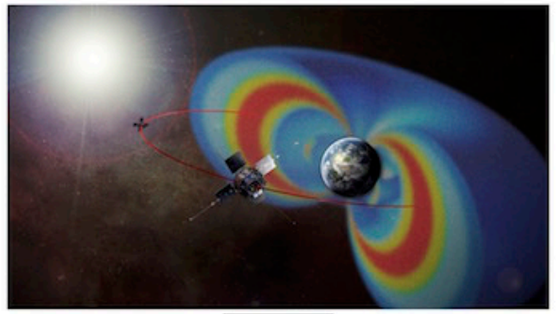
ARTENUM

ONERA

THE FRENCH AEROSPACE LAB

SPACE SUITE





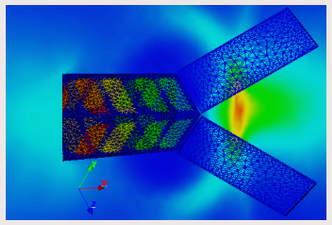
MISSION

ENVIRON-MENT

MULTI-PHYSICS ANALYSIS

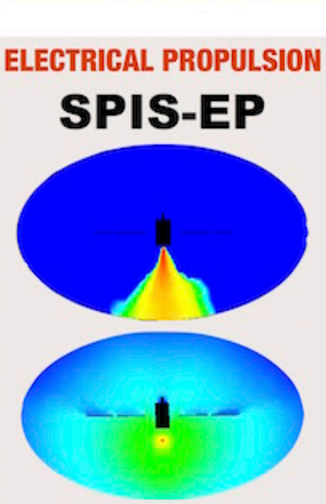
SPACECRAFT CHARGING

SPIS



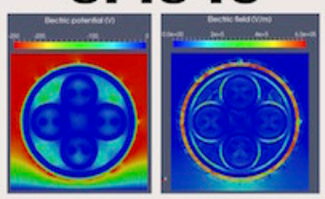
ELECTRICAL PROPULSION

SPIS-EP

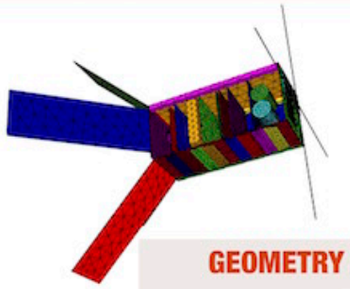


INTERNAL CHARGING

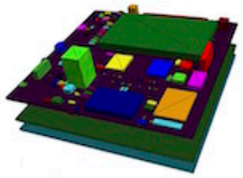
SPIS-IC



SCORING

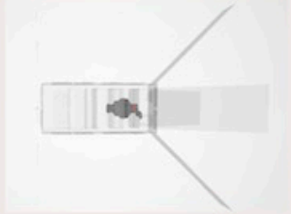


STEP-AP
GDML
MESH
MCNP
...
FILES



GEOMETRY & MATERIAL DEFINITION

EDGE
ExtendeD Gdml Editor
SECTOR SHIELDING ANALYSIS
+QUICK RADIATION ANALYSIS



GEOMETRY

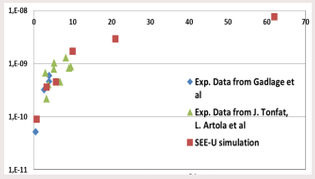
GEOMETRY & MATERIALS

GEOMETRY & MATERIALS

GDML

SINGLE EVENTS

SEE-U
SINGLE EVENT EFFECT - UPSET MODELLING



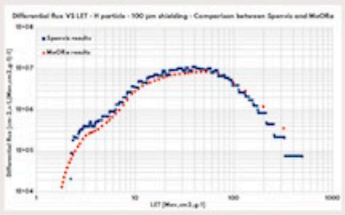
GEANT4
A SIMULATION TOOLKIT

ADVANCED RADIATION ANALYSIS

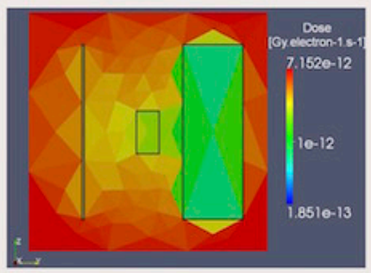
MONTECARLO PARTICLE TRANSPORT

MoDRA
Modelling Of Radiations
Geant4* based

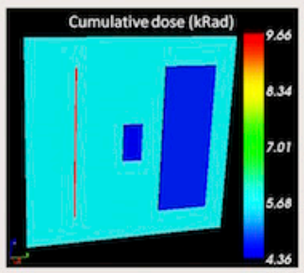
SPECTRUM AFTER SHIELDING



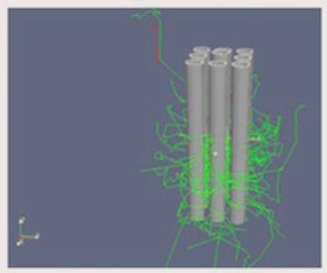
DOSE RATE / CHARGE RATE



TOTAL IONIZING DOSE (TID)



PARTICLE DEPOSITED ENERGY



*not part of the SpaceSuite offer

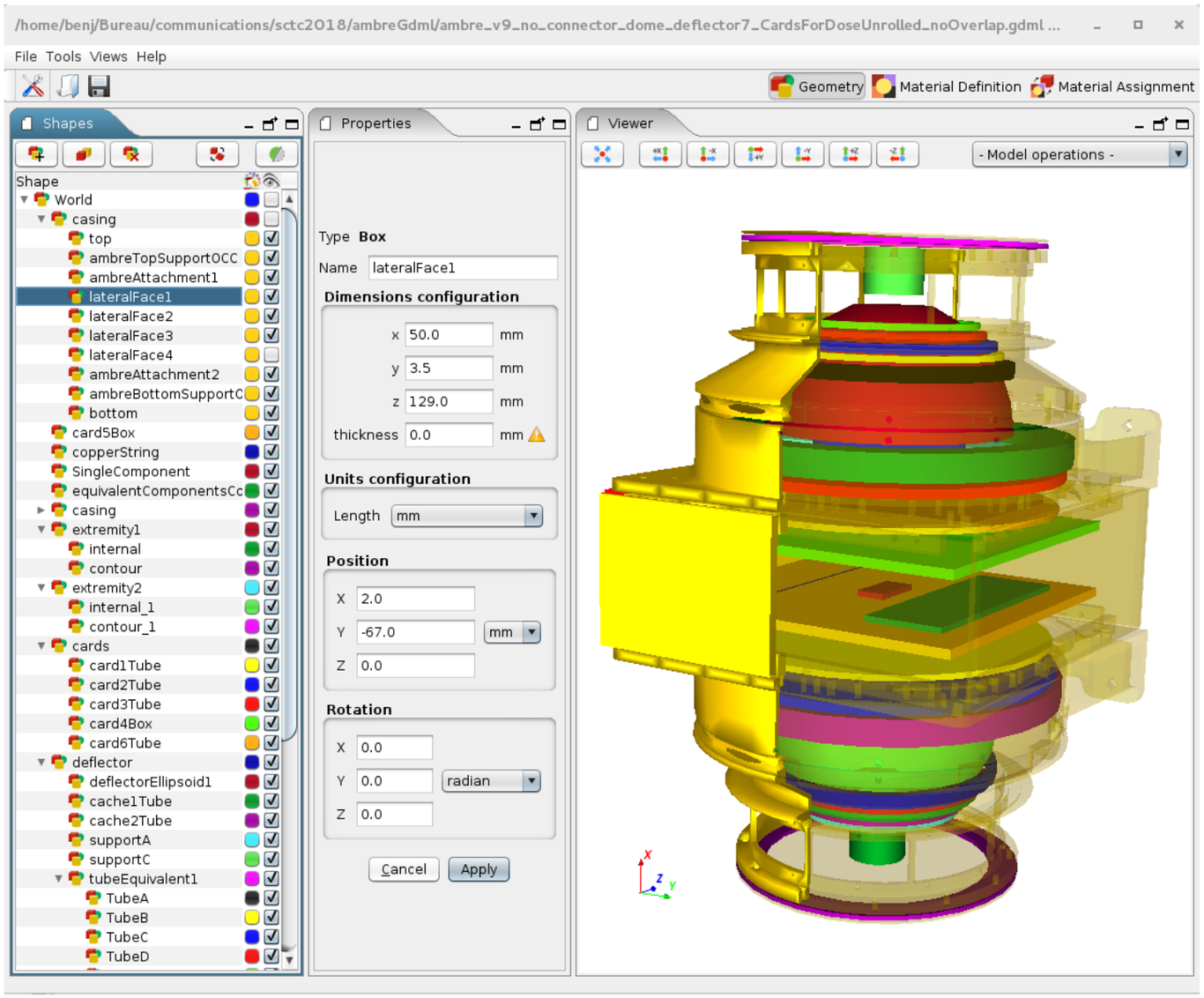
GEANT4
A SIMULATION TOOLKIT

Radiation transport analysis

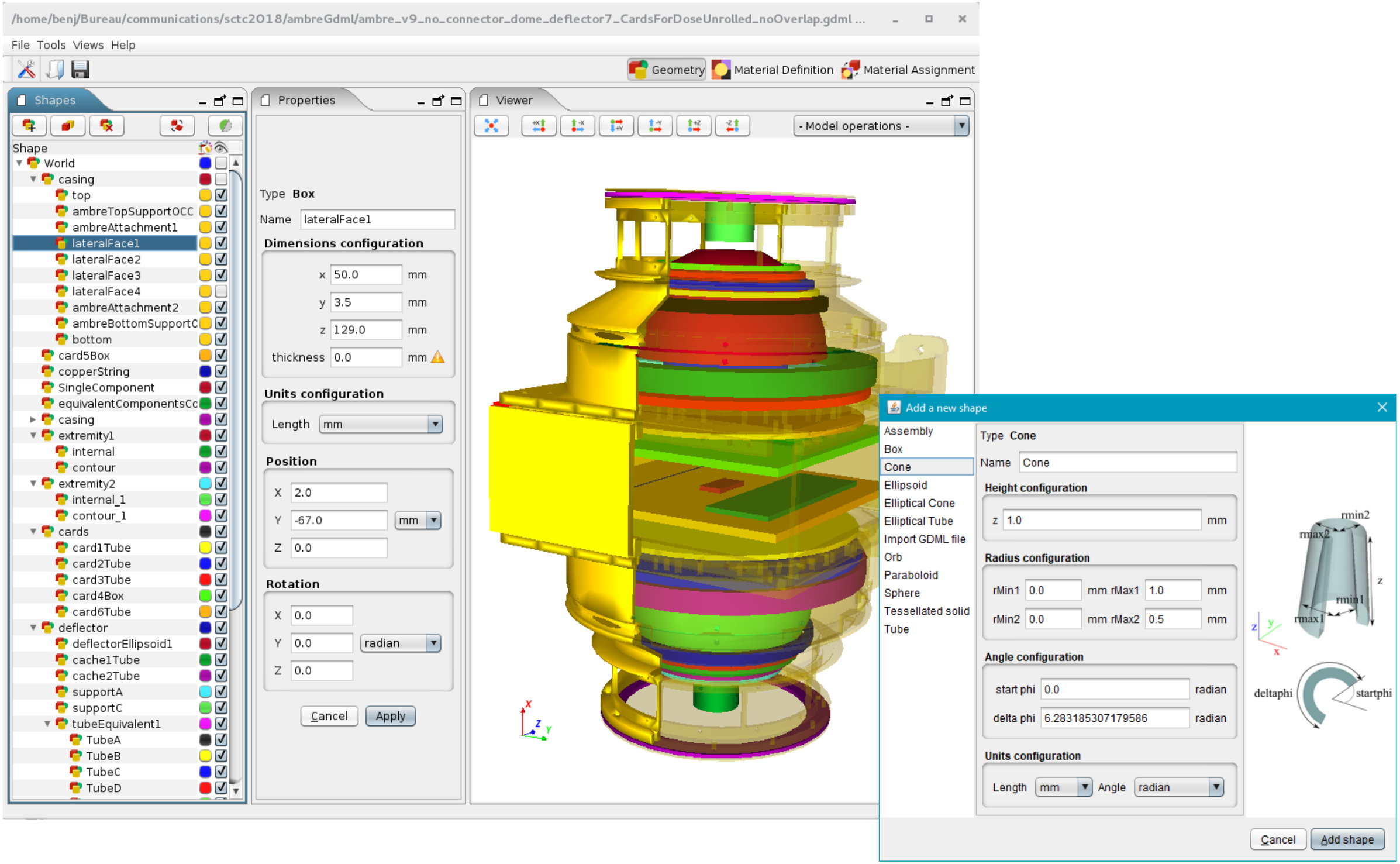
EDGE
ExtendeD Gdml Editor

- **Materials edition**
  - Edition and attribution
  - Import/export of materials
  - Multi-attribution
- **Easy to use**
- **Reach import/export capabilities**
  - STEP-AP 203/214
  - GMSH
  - MCNP (partialy)
  - …

- **Geometry creation/edition for GEANT4 based tools**
  - Native support of the GDML format
  - 3D visualization



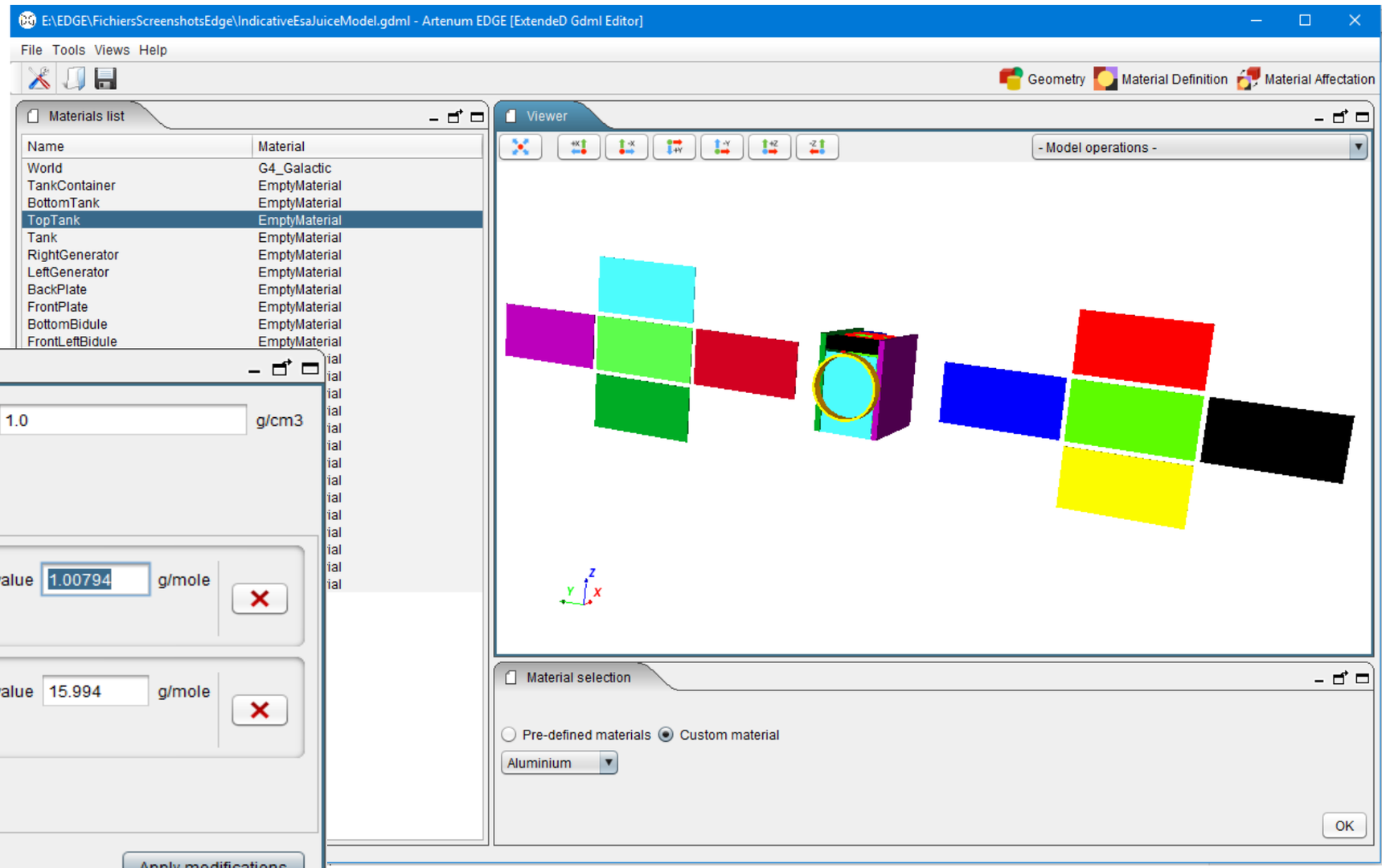
EDGE – Geometrical modelling



EDGE – Material properties edition

- **Edition**
- User-friendly material editor
- Duplicate user-defined materials
- Import/Export materials from another .gdml file
- Geant4 default materials

- **Assignment**
  - 3D view



EDGE – I/O capabilties

Import

.gdml

.geo

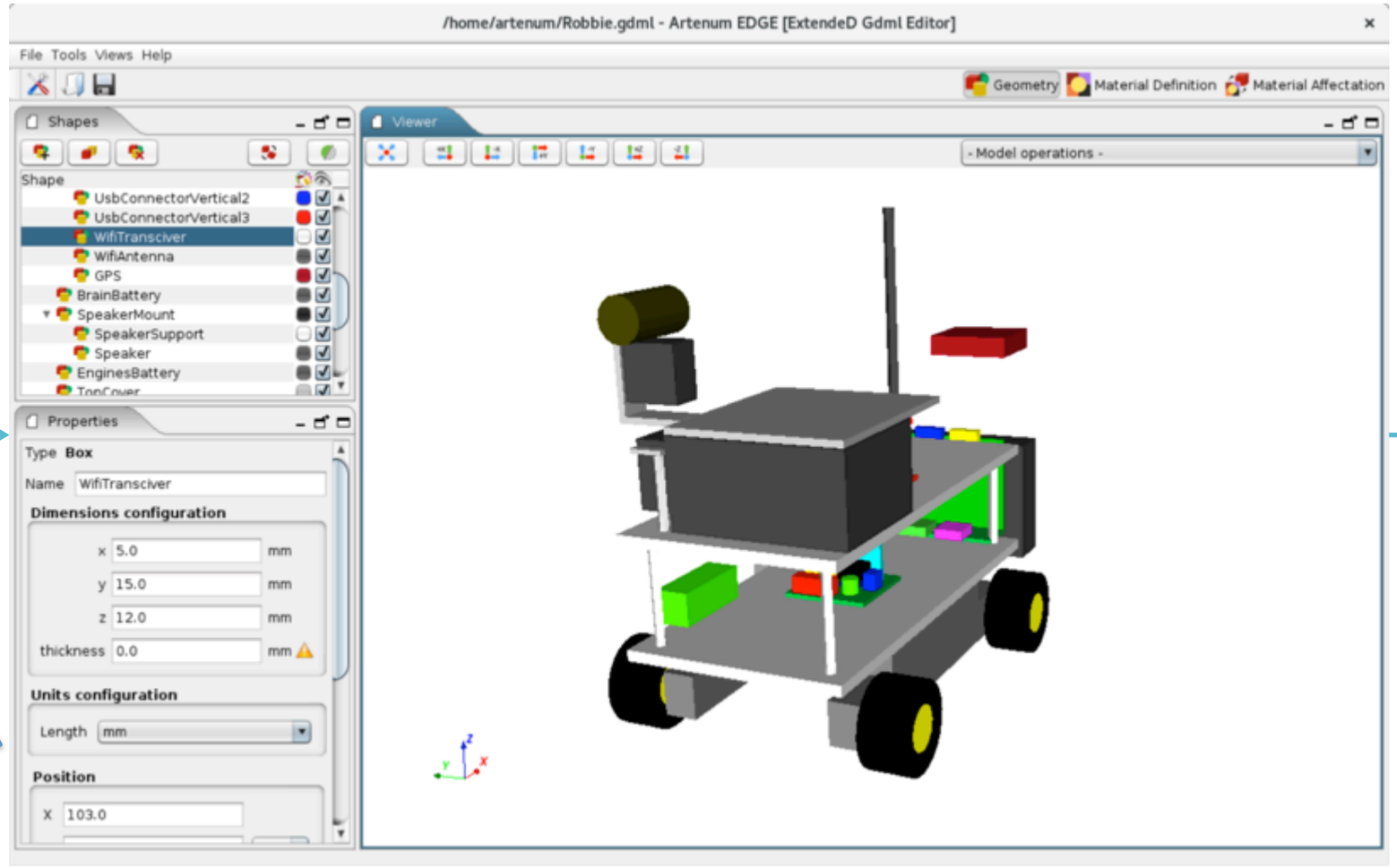
.stp

.stl

.msh

.unv

MCNP



Export

.gdml

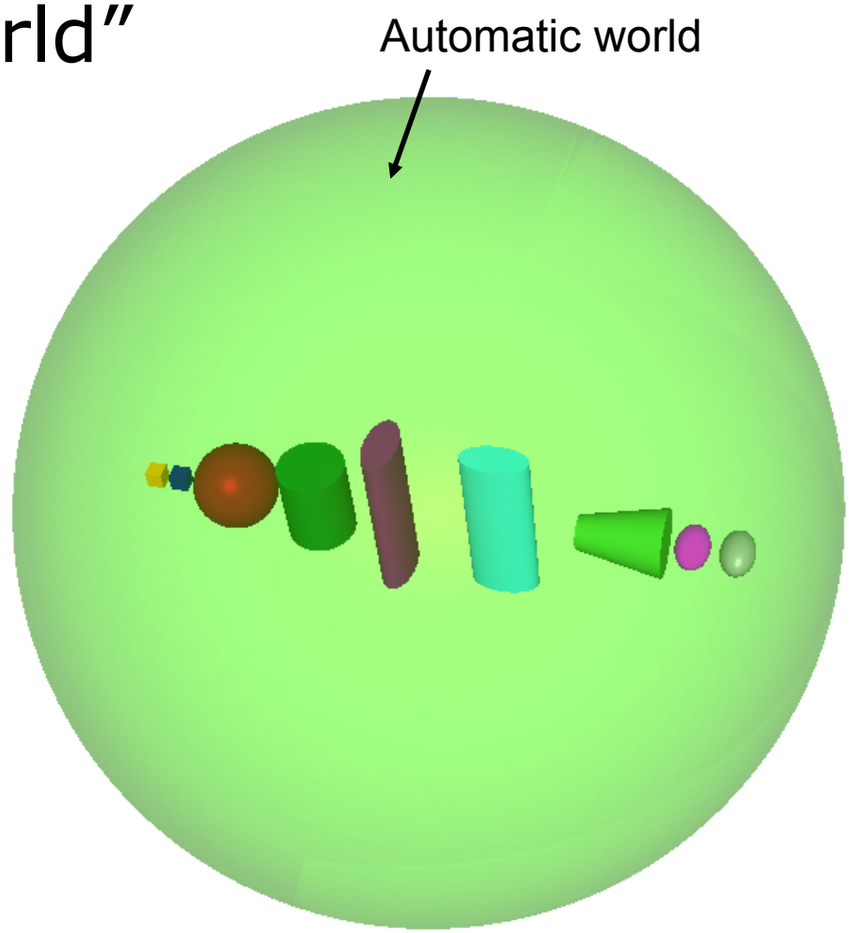
.geo

EDGE – MCNP import

- **Preliminary implementation (still under improvements)**
  - Currently macro-bodies geometric entities supported only
  - Surfaces (plans) not supported yet
  - Material definitions not supported yet
  - Automatic creation of the GDML "world"
  - Generation of hiearachies

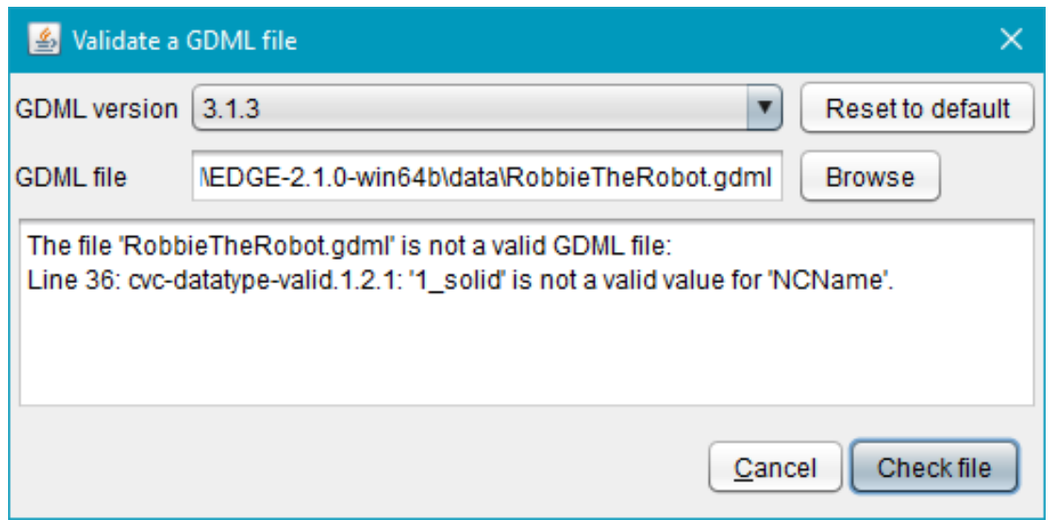
```
ALL SHAPES
c Start cell definition
1     0 -1
2     0 -2
3     0 -3
4     0 -4
5     0 -5
6     0 -6
7     0 -7
8     0 -8
9     0 -9
10    0 1 2 3 4 5 6 7 8 9
c End cell definition

c Start macrobodies definition
1     BOX -35 -1 -1   2 0 0   0 2 0   0 0 2
2     RPP -32 -30   -1 1   -1 1
3     SPH -24 0 0   5
4     RCC -14 -5 0   0 10 0   4
5     REC -05 -5 0   0 10 0   0 0 4   2
6     REC +08 -5 0   0 10 0   4 0 0   0 0 2
7     TRC +17 0 0   10 0 0   4   2
8…
```

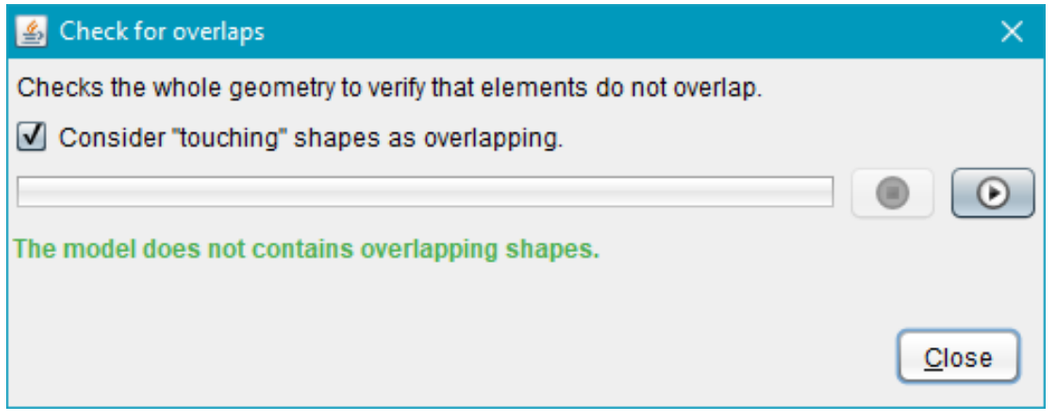


EDGE - Extra tools and operations

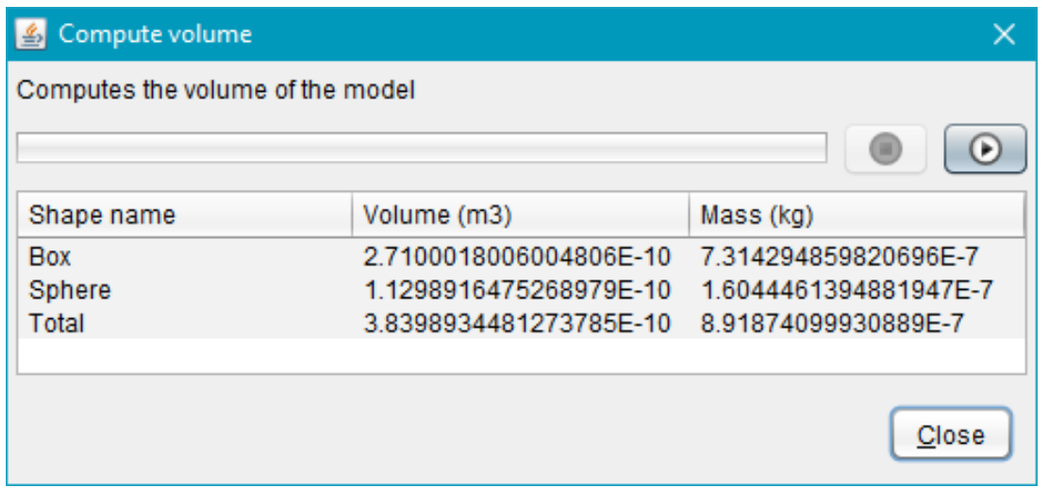
- **Checking of the GDML file validity (XSD scheme)**



- **Overlaps detection**

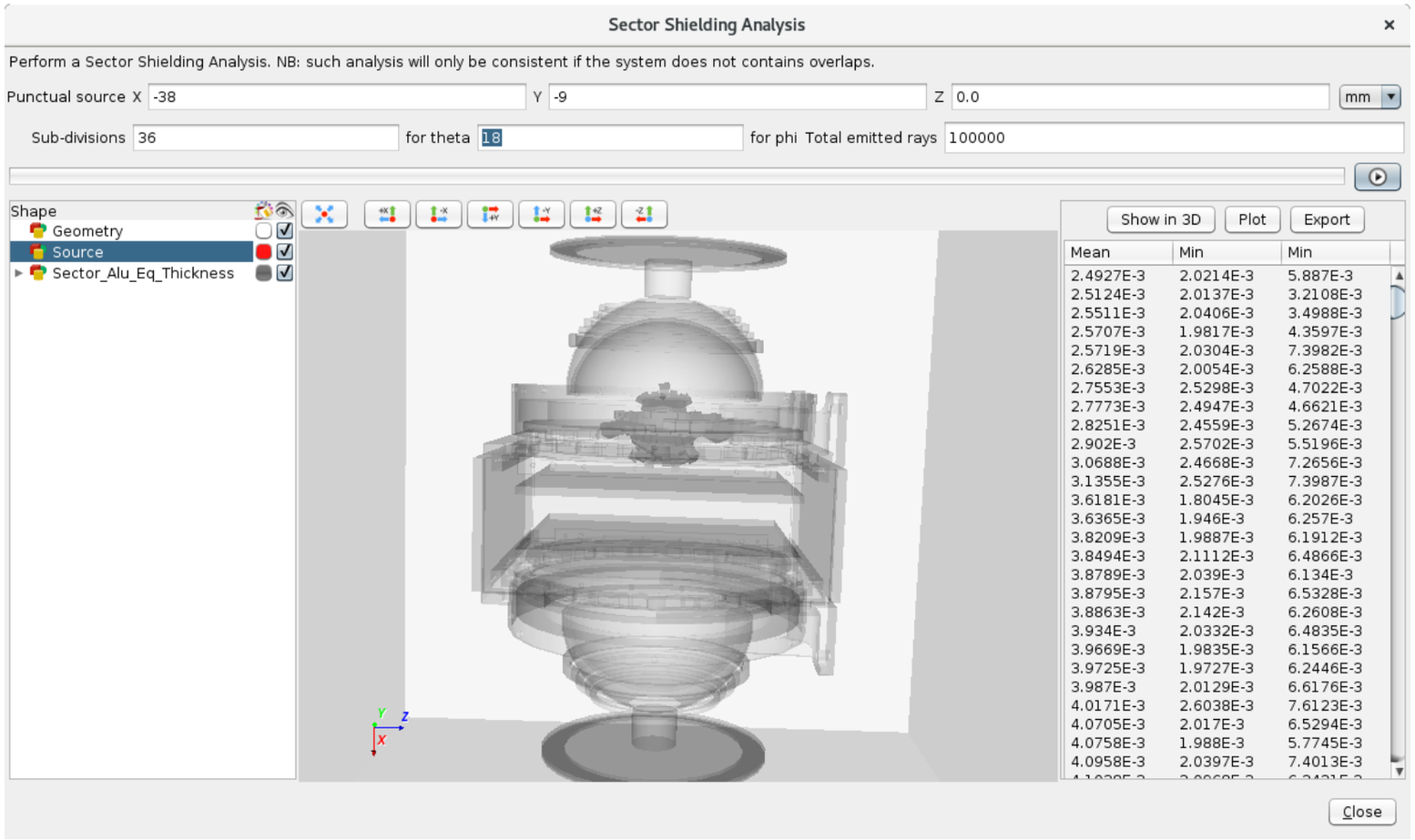


- **Volumes and mass computation**

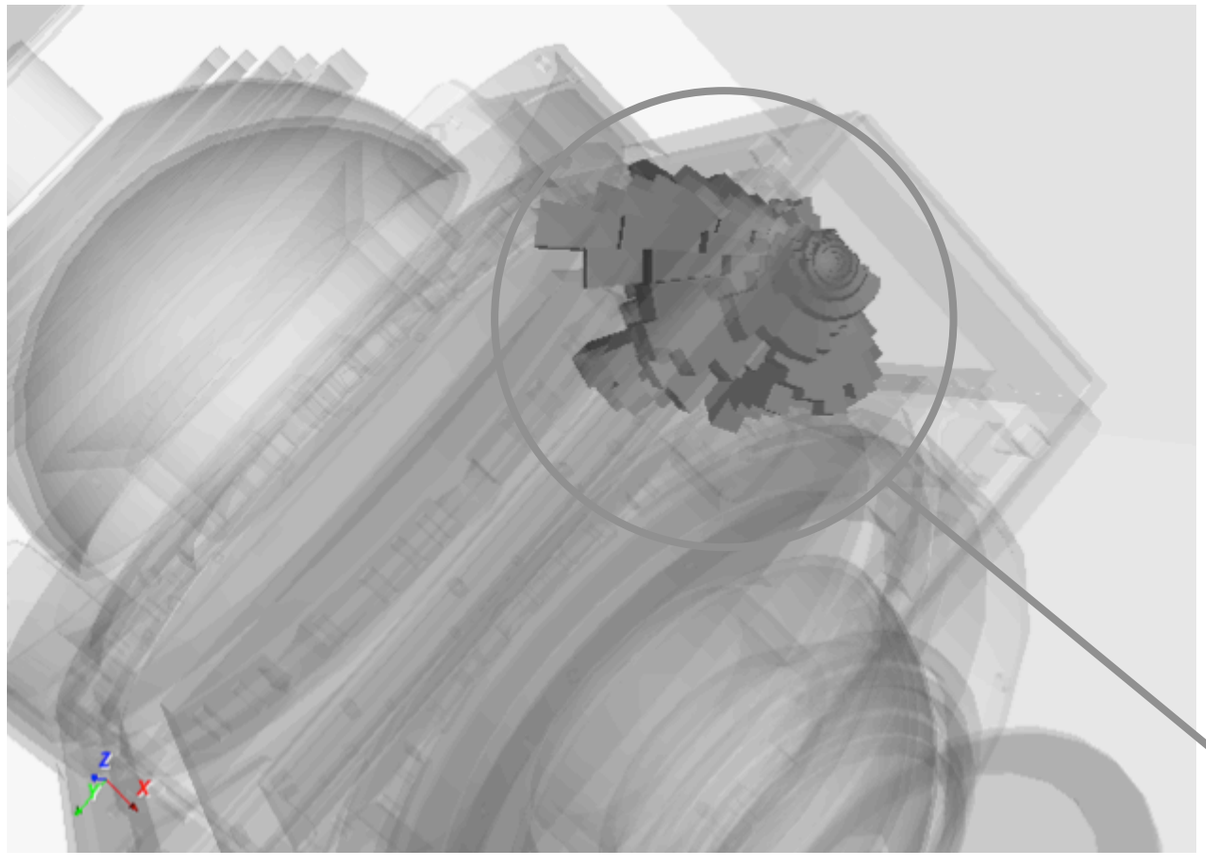


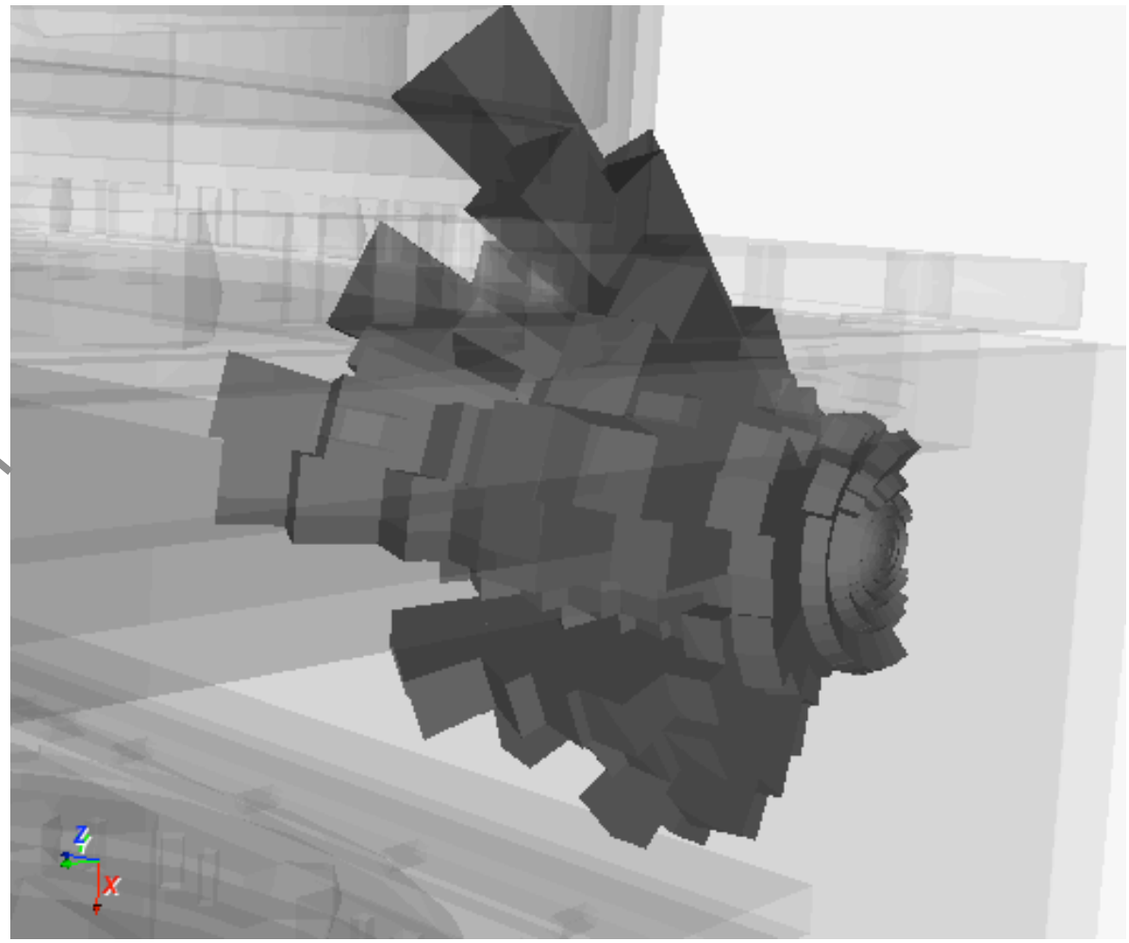
SSAM Sector Shielding Analysis

- Quick deposited dose computation
- Pre-condition tool for Geant4 analysis:
  - Sphere equation model
  - Thickness of each materials from a point
- Shielding optimisation
- Aluminium equivalent thickness computation
  - Considering on material densities
  - On all directions
  - Aluminium



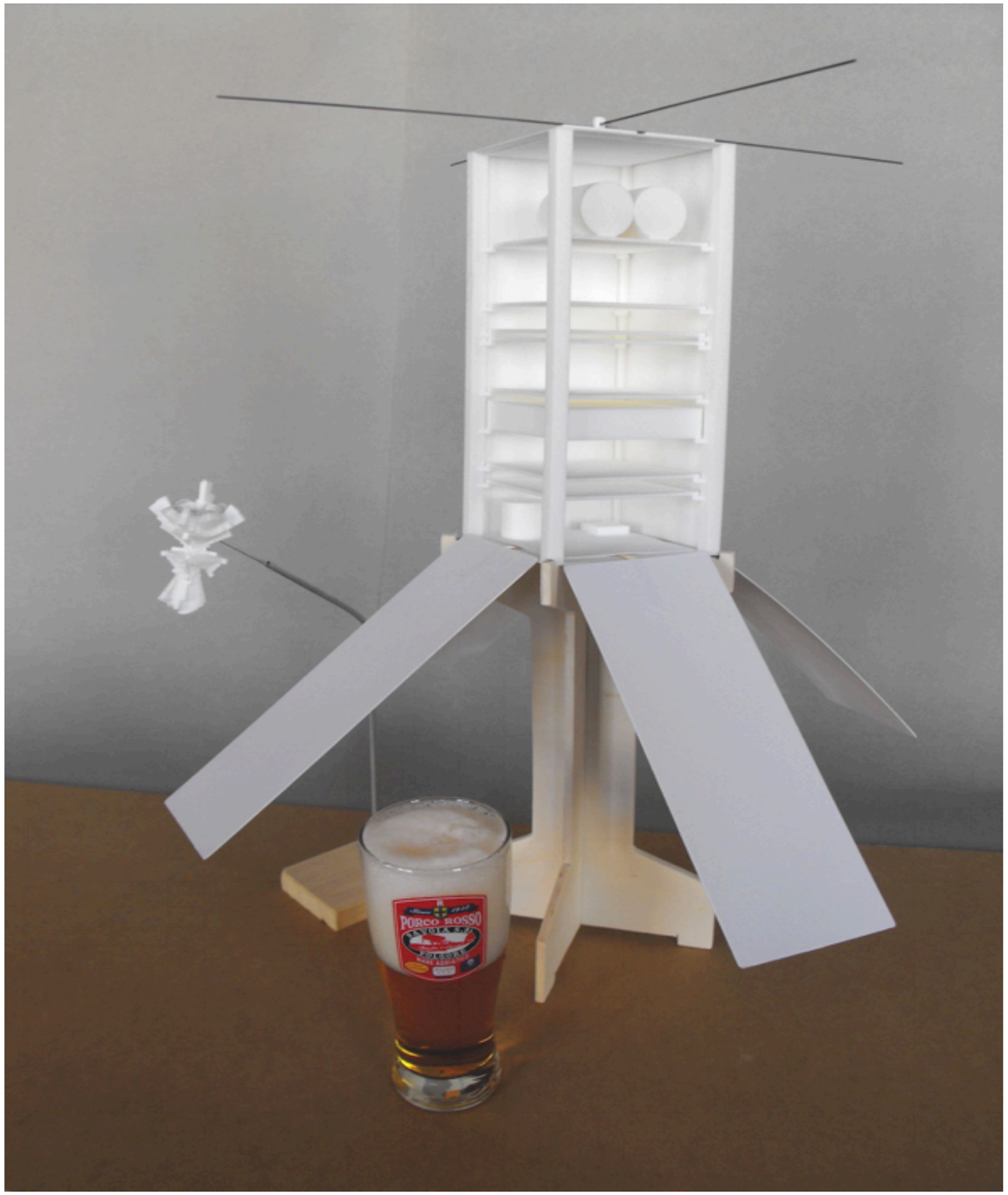
SSAM Sector Shielding Analysis





SSAM Sector Shielding Analysis

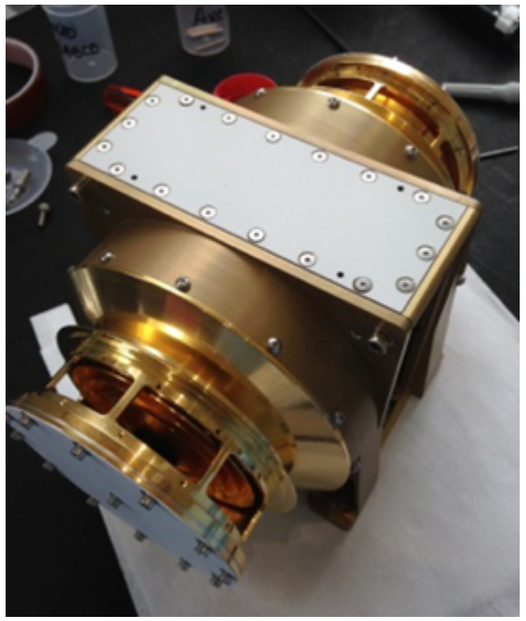
- A concrete example
- ONERA's project of plasma characterisation cubesat
- Shielding optimisation
  - Radiations analysis (dose)
  - Internal charging analysis
  - Surface charging analysis
- Sector shielding analysis done with SAAM
- 3D printing done from GDML model



With courtesy of ONERA-Dphy and J. – C. Mateo Velez

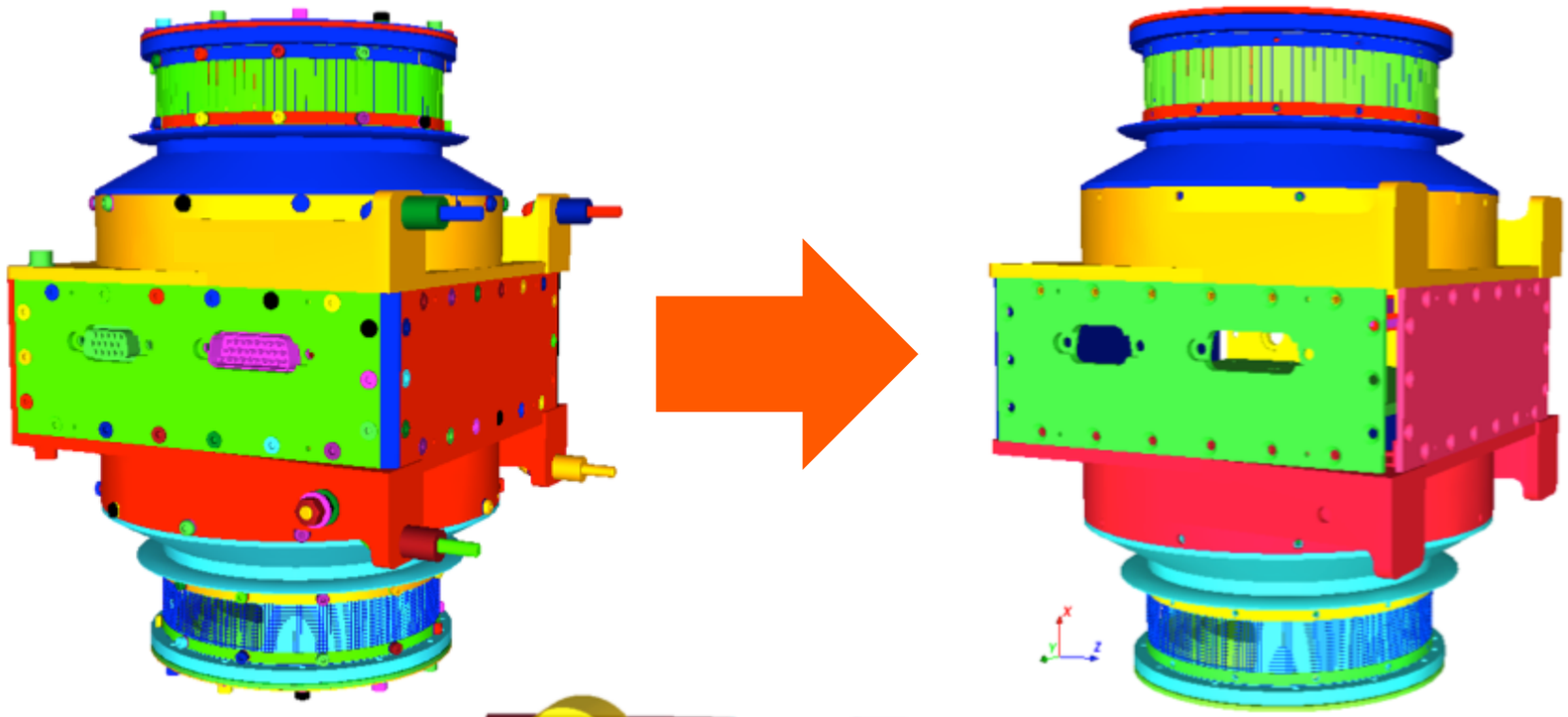
Photo (and beer) by Artenum

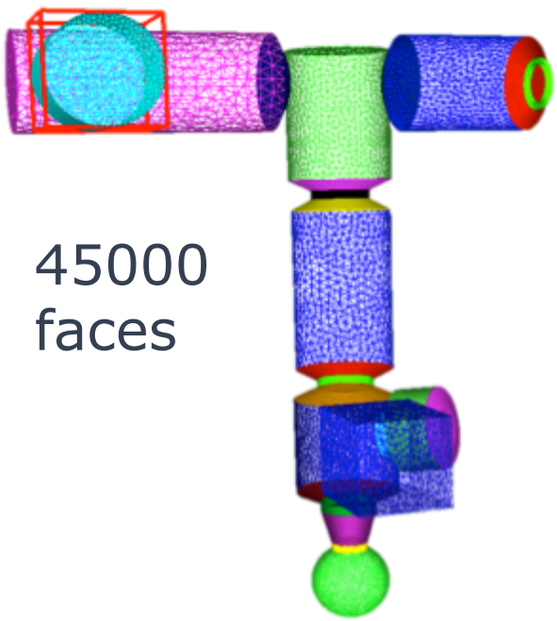
CAD processing with EDGE



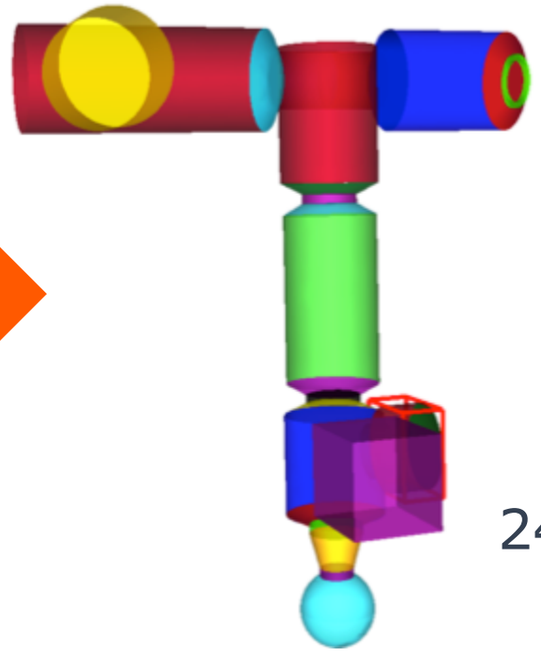
Ambre experiment, with courtesy of CNES

- Geometry simplification/cleaning





45000 faces



24 shapes

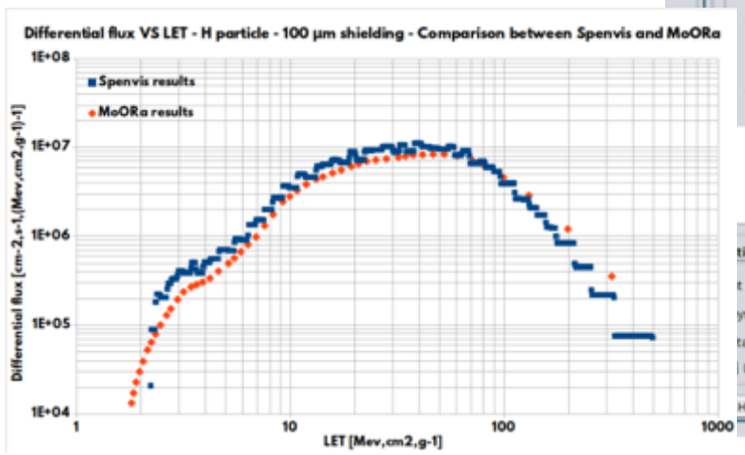
- Detessalation

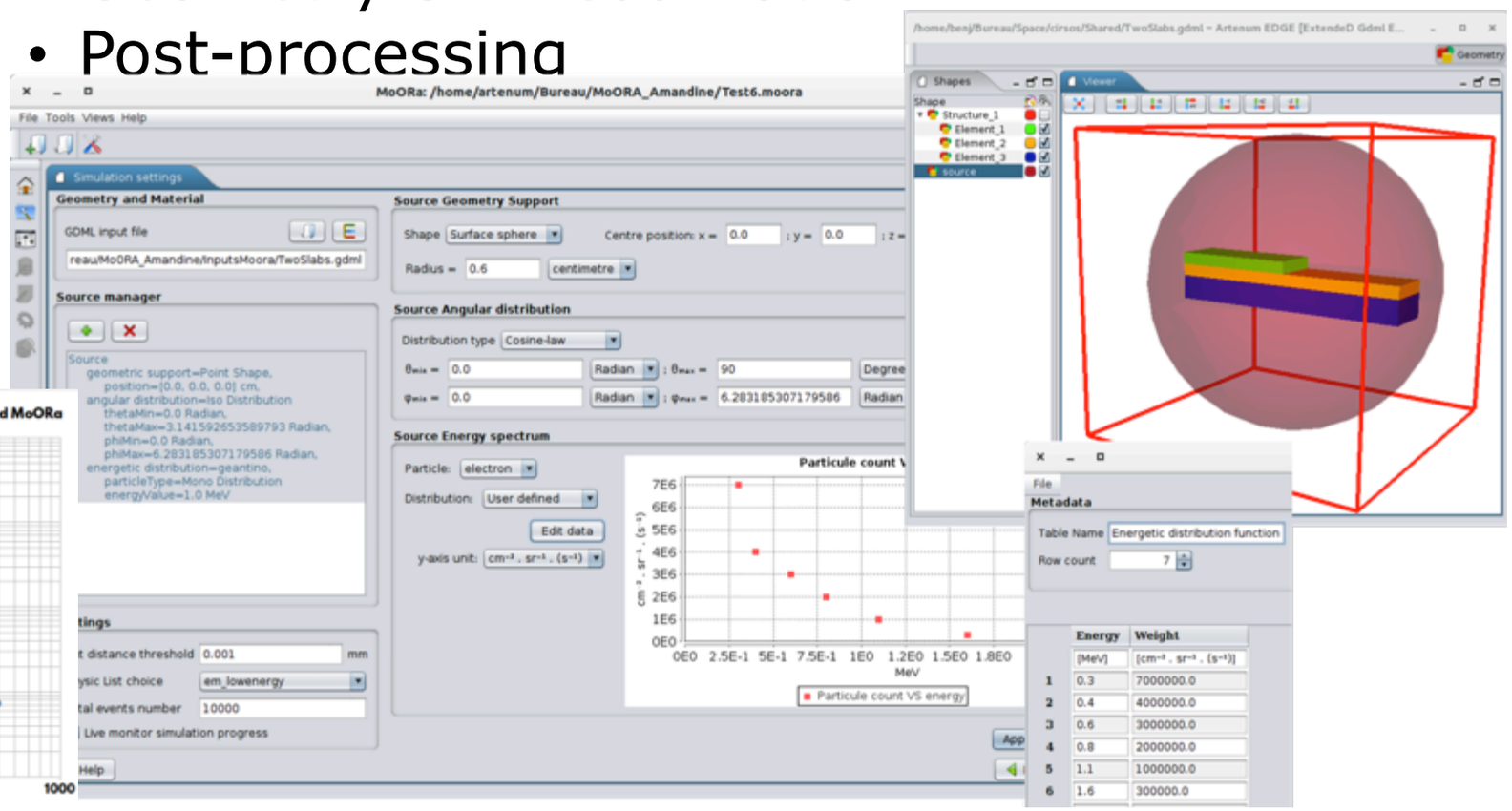
Radiation transport analysis

MoORA
Modelling Of Radiations

- Accurate physics
- Deposited dose, energy, charge…
- Fluence energy spectrum
- Fine scoring

- Facilitate the use of GRAS/GEANT4 models
  - Rich and user-friendly interface
  - 3D direct Monte-Carlo
  - Easy simulation configuration:
    - Sources definition;
    - Particles spectrum;
    - Events number…
  - Geometry 3D visualization
  - Post-processing

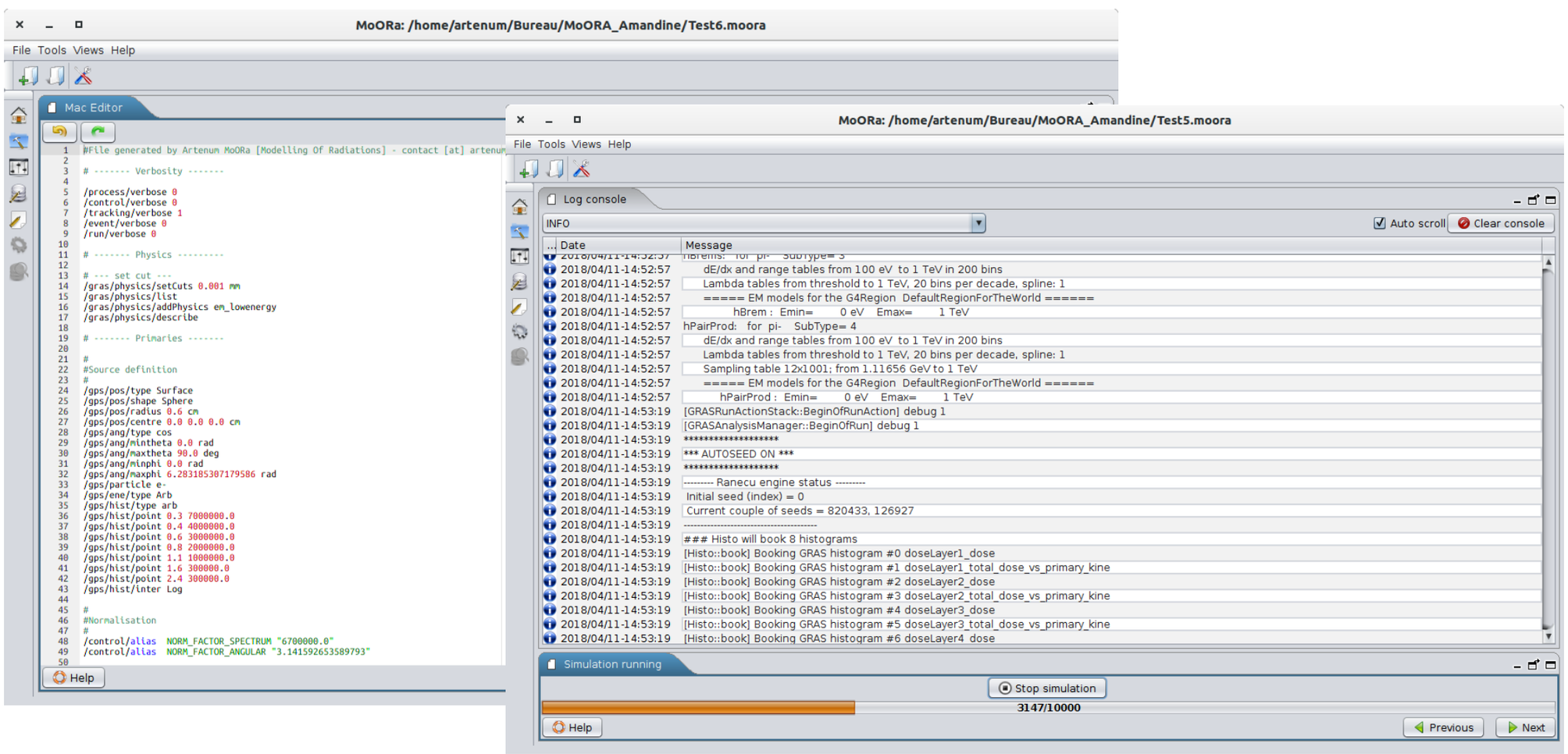




Radiation transport analysis

Modelling Of Radiations

- GEANT4 macro files generation and edition
- Simulation launch and monitoring
- Integrates the ESA/GRAS kernel
- Extensible / adaptable to all GEANT4 based kernels

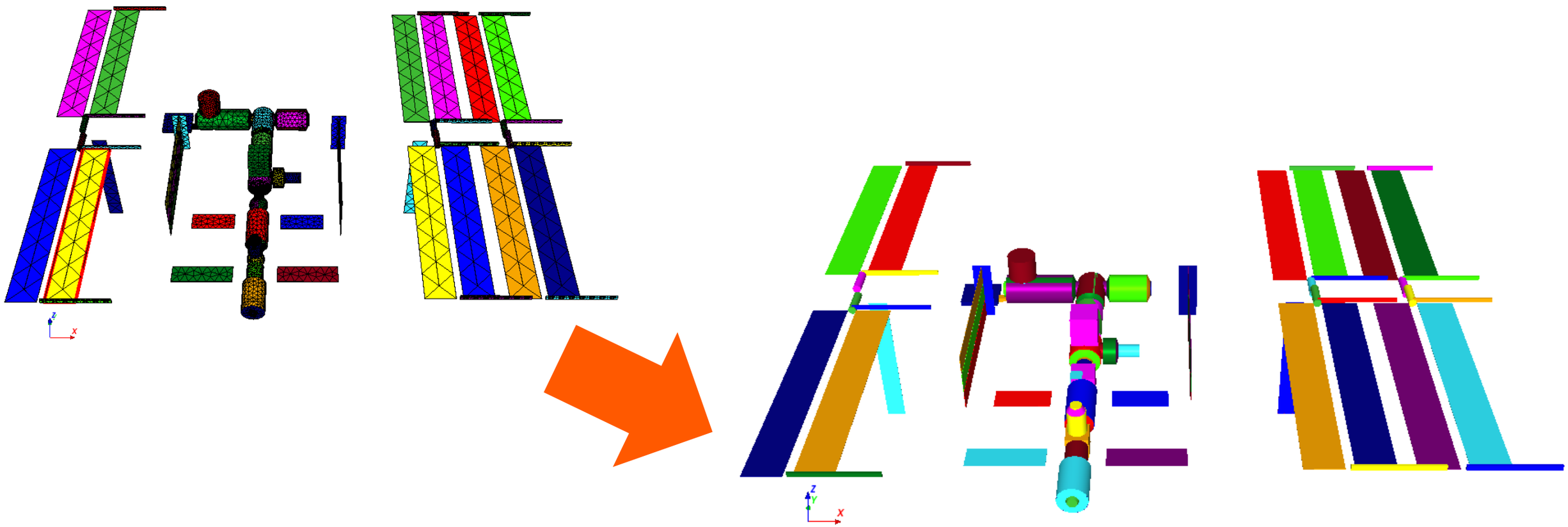


Back on the challenges of complex geometries importation

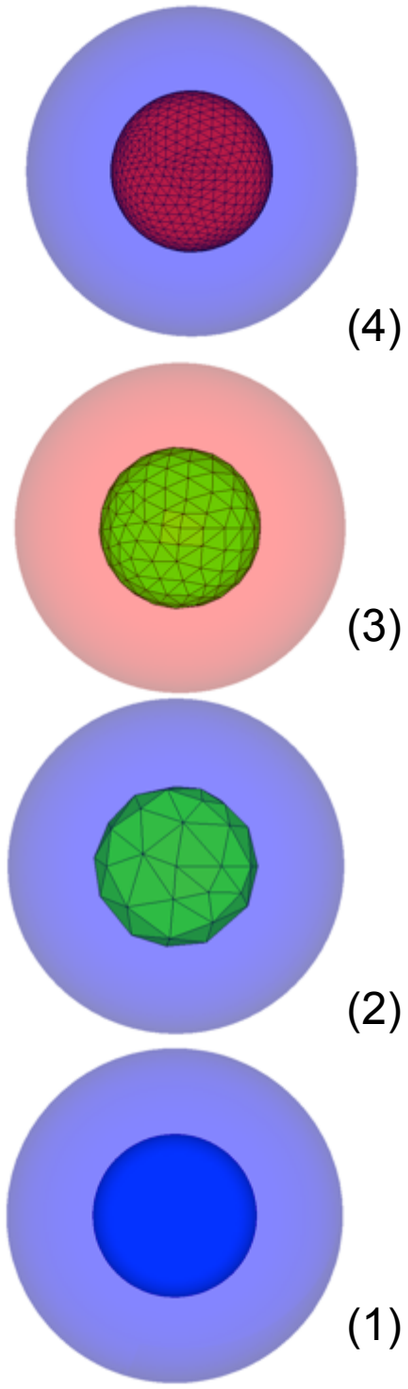
- Strong temptation to directly import complex geometries directly from other analysis via STEP-AP files
- Needs reinforced in case of multi-physics approach
- The B-Rep (e.g. STEP-AP) to CSG (GDML/G4) conversion can generally done by tesselation only.
- But may lead to:
  - Over detailed and too costly models
  - Models not adapted to radiations
  - With lack of information (e.g. materials definitions)
- Need of simplifications / adaption of model

Detessalation

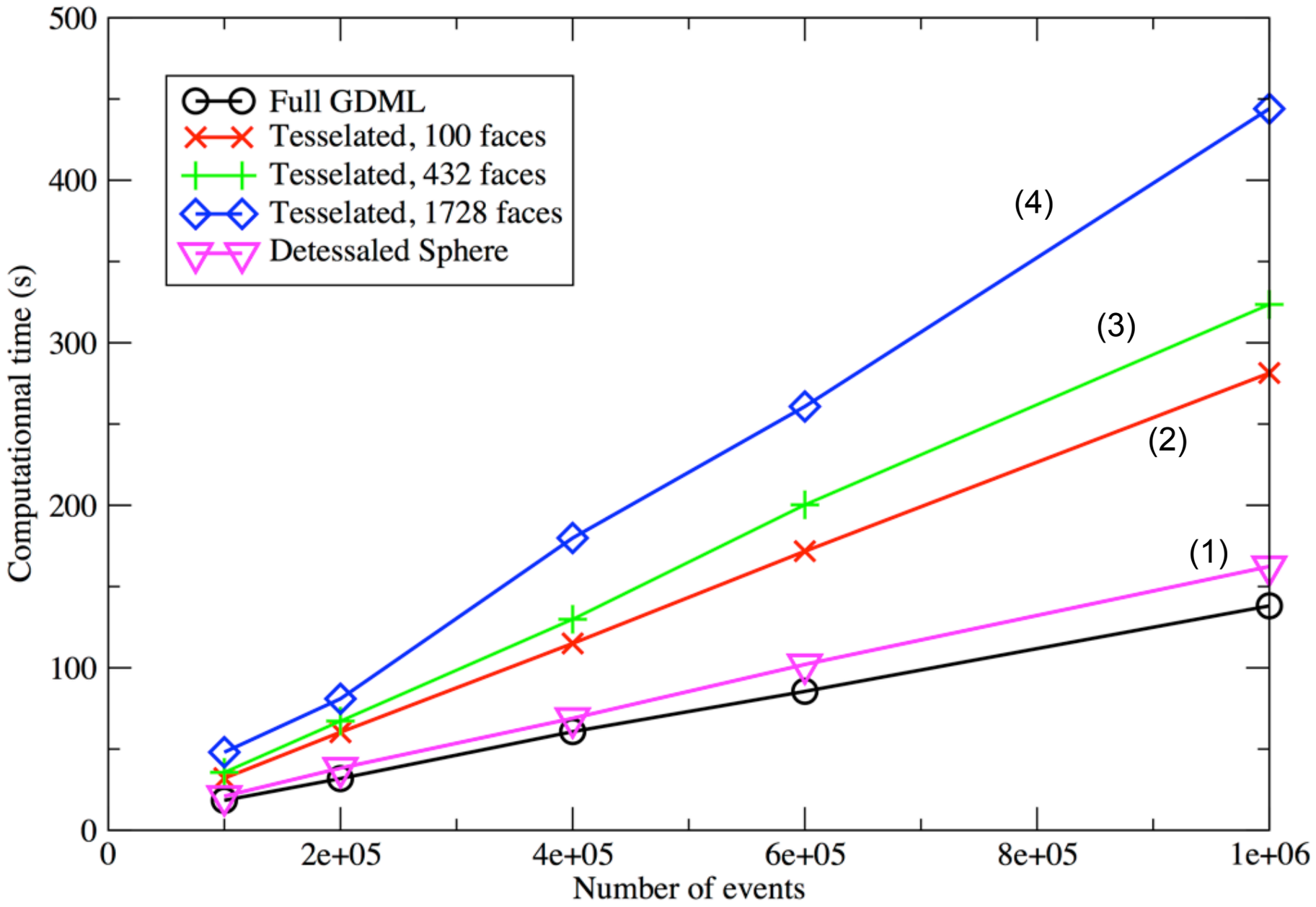
- From a “soup of triangle” try to identify canonical shapes and a simpler CSG model
- STEP-AP importer plug-in in EDGE
- Support characterisation of most of GDML chapes
- Automatic detection for boxes and spheres



Tesseleted / CSG / Detesselated



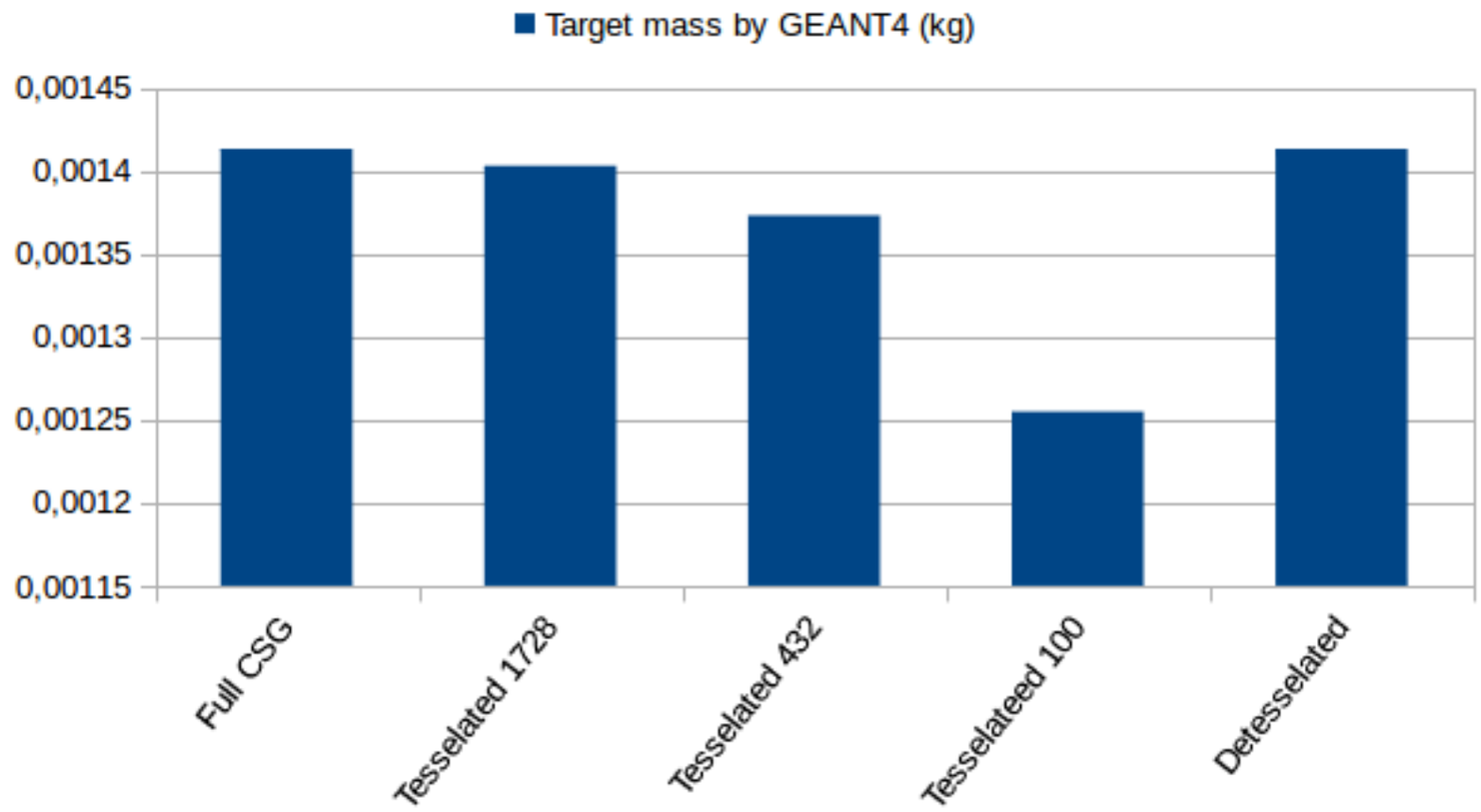
- Strongly impact the simulation cost

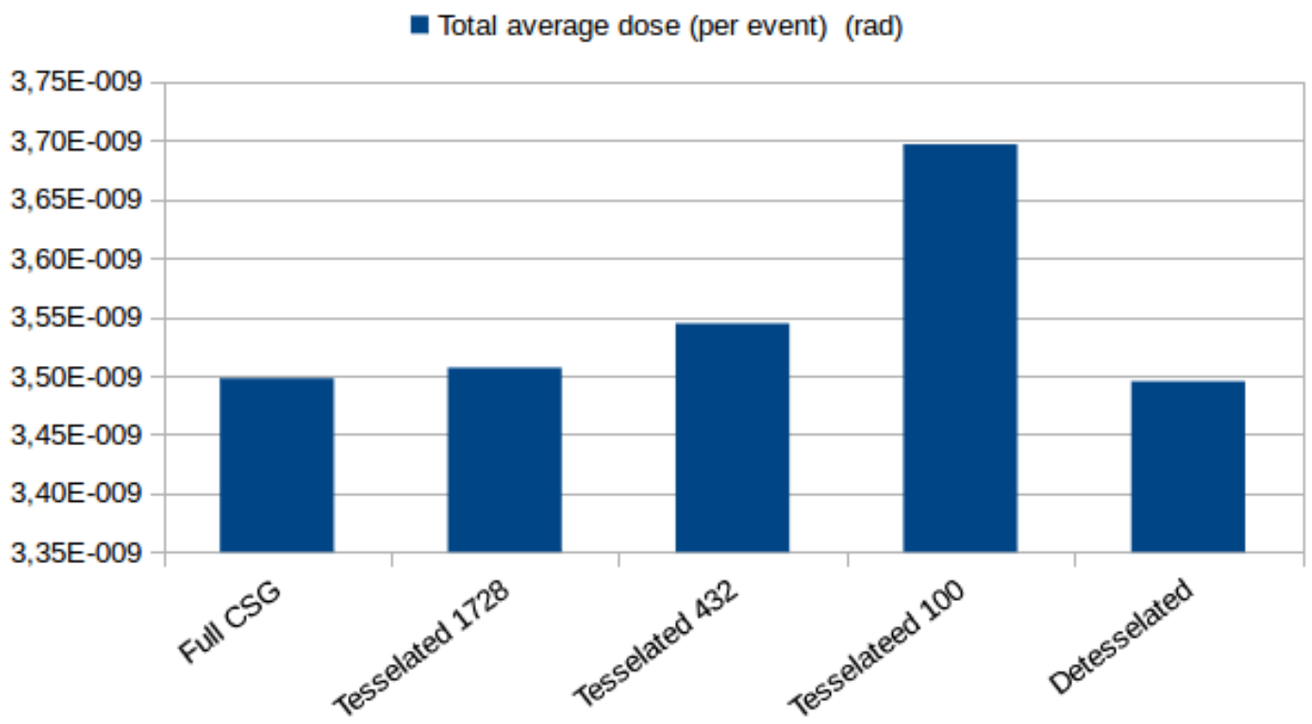


Done with geant4.10.03.p02

Tesseleted / CSG / Detesselated

- Impact the accuracy of the simulations as well

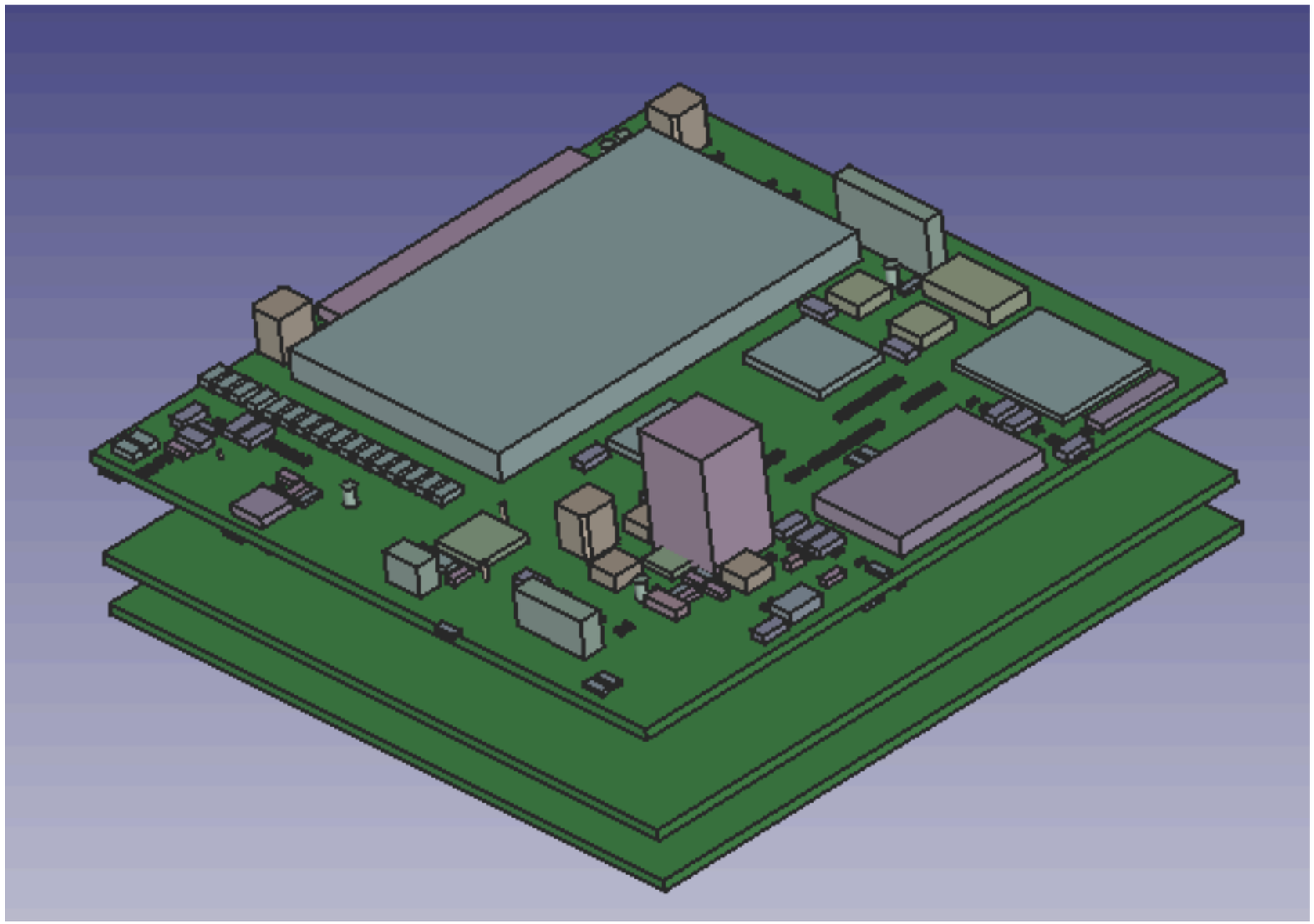




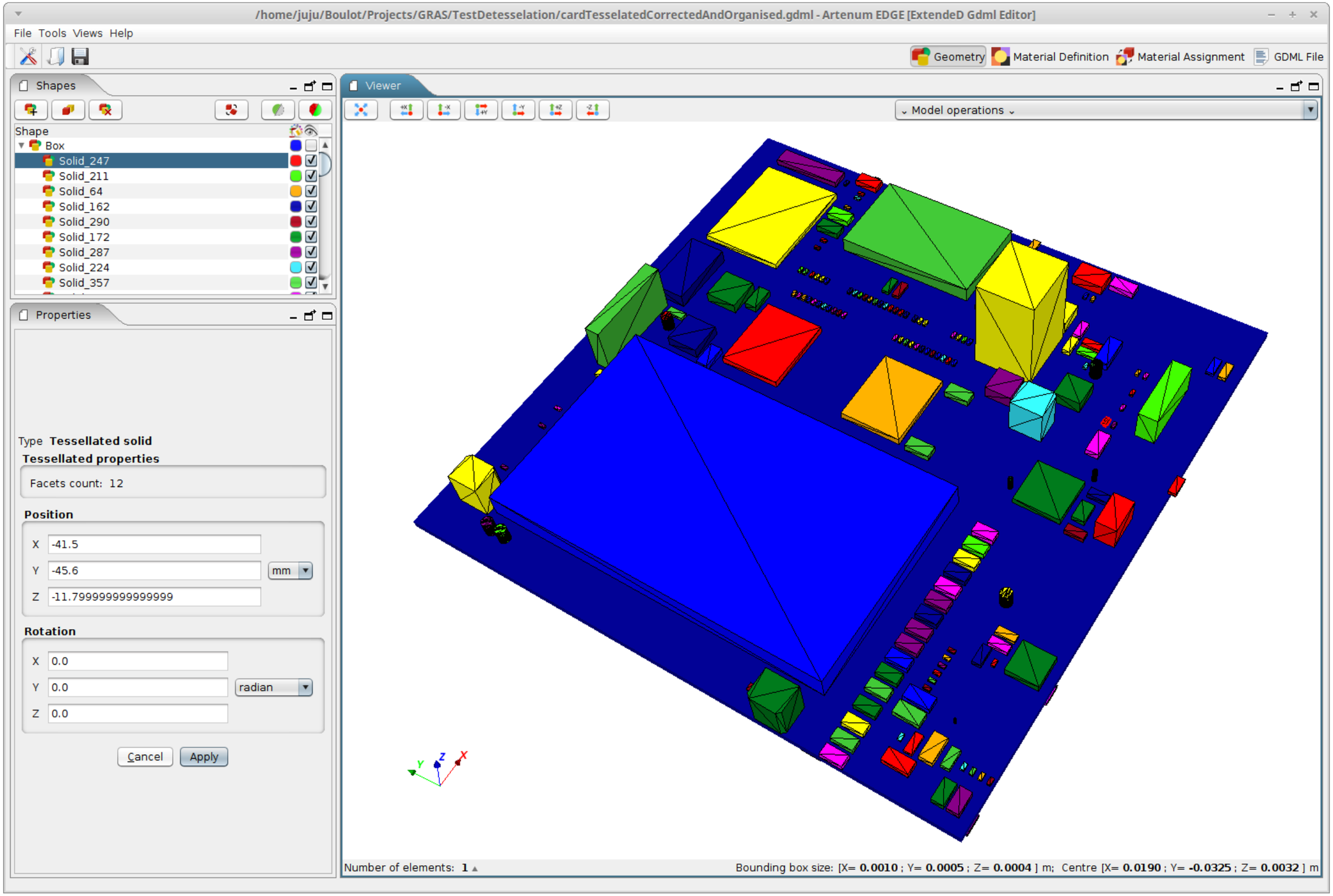
Done with geant4.10.03.p02

A more realistic example

- Cubsat computer board
- From STEP-AP

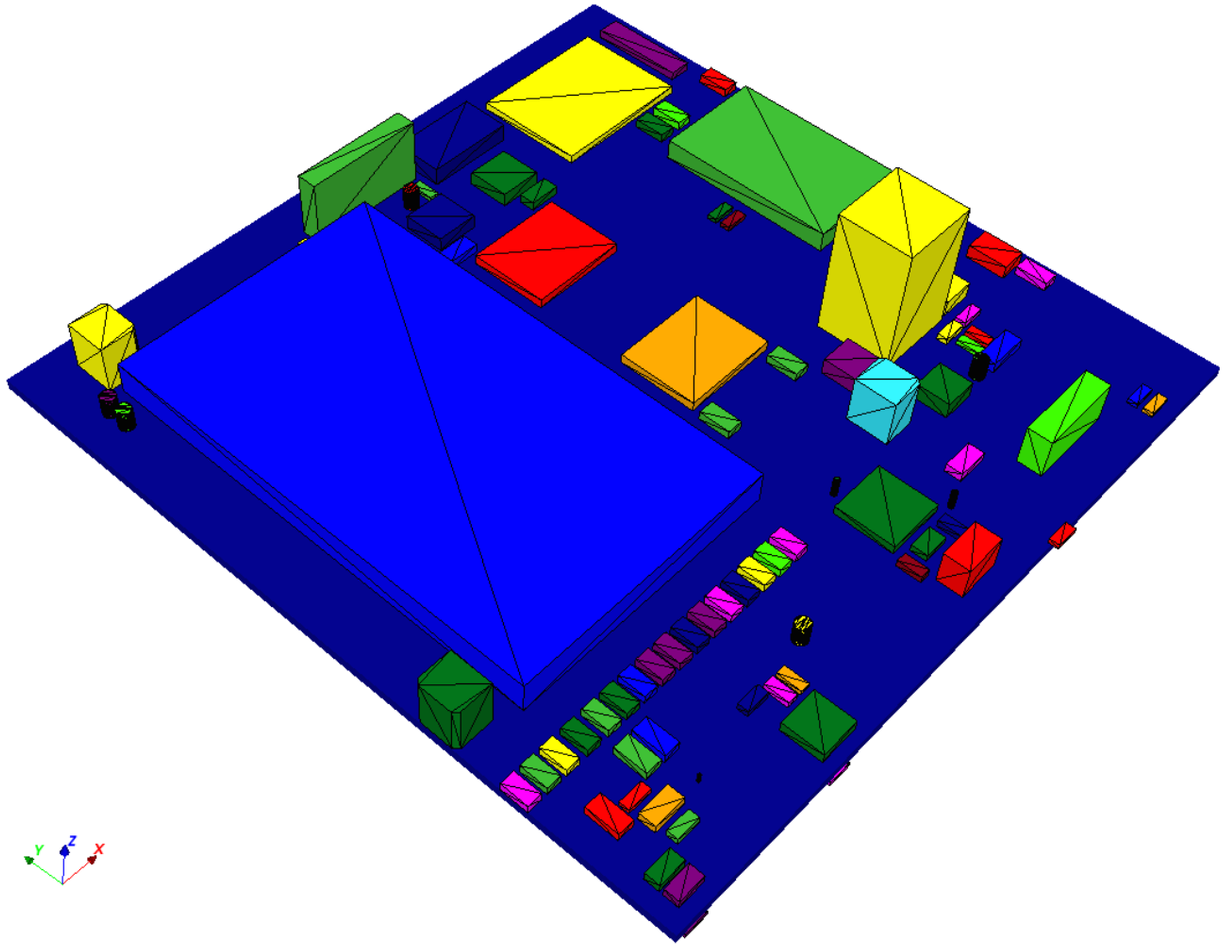


A more realistic example

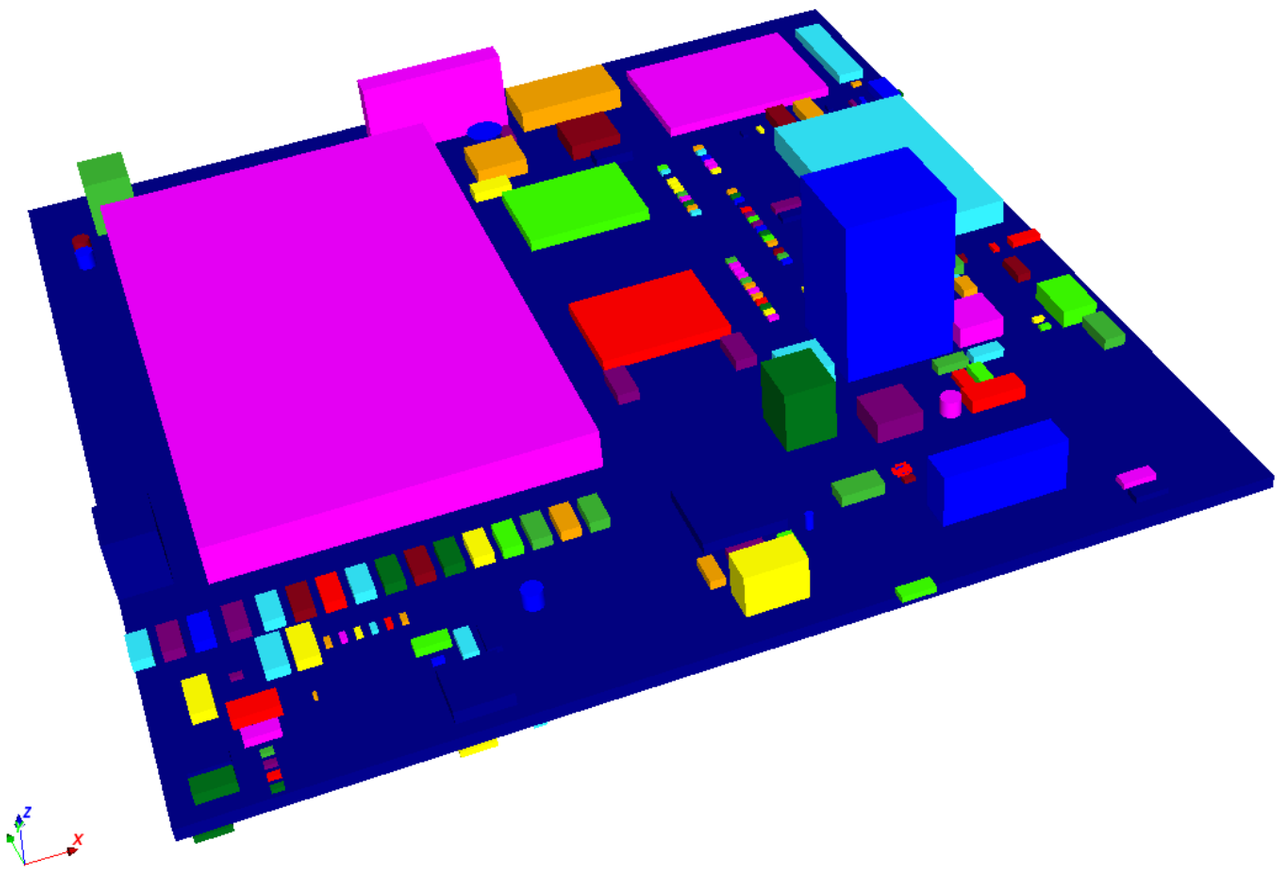


A more realistic example

Tesselated and simplified model

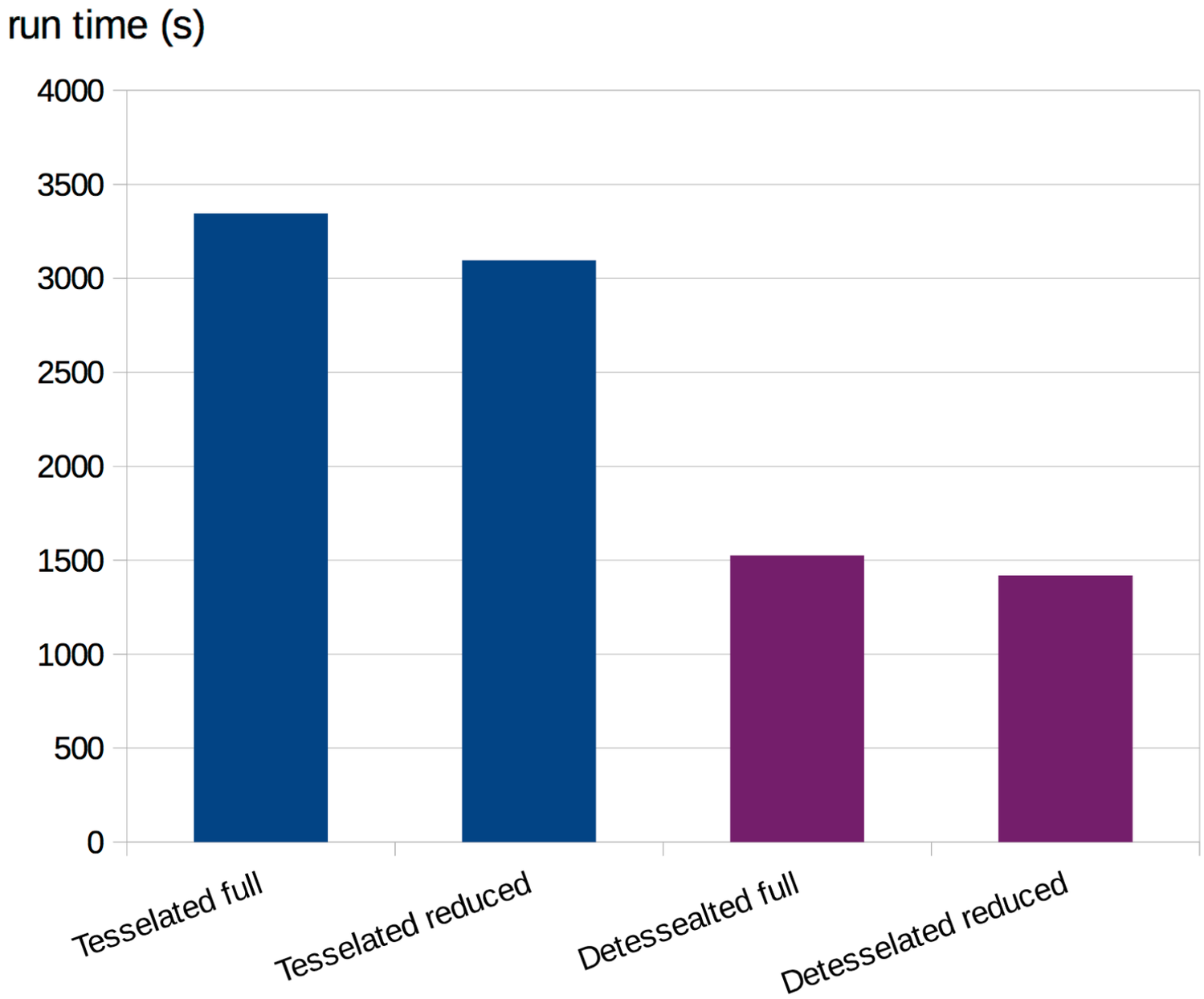


Detesselated model



Examples and feedbacks

- Detessalation more efficient than simplification
- Stuck particles observed for tesselated model
  - Effets of triangle shapes
  - Shapes anysotropy
  - Fine setting of G4 track step



Done with geant4.10.03.p02

Conclusion of CAD import

- Import realistic geometries possible with EDGE
- Simulation may remain costly
- Stuck particles remains an issue for improperly or too finely meshed surfaces
- The quality of the meshing / Geant4 settings is critical
- Detesselation is a promising way to:
  - Back closer to the geometry
  - Optimise simulation cost (both CPU time and memory)
- Geometry simplication / adaption remain needed -> human expertise will always be needed

Internal Charging

- **Example of multi physics approach**
- Radiations / plasma analysis bridge
- Initial charges & doses rates via particle transport Monte-Carlo codes (e.g MoOra/GRAS/GEANT4)
- Evolutions of charges in dielectrics using 3D plasma codes (e.g SPIS-IC)
- Require a 3D and dynamical approach
- Evaluation of radiations induces breakdown in dielectrics
- Evaluation of radiations induces current leakages
- **An increasing risk for space devices**
- e.g EOR mission profiles

Internal Charging analysis

CAD Import and modelling for radiations analysis

EDGE

Radiation analysis initial dose rate / charges rate computation

EDGE / SAAM

MoOra/GRAS

GEANT4

SPIS

Adaptation / edition of CAD model for charging analysis

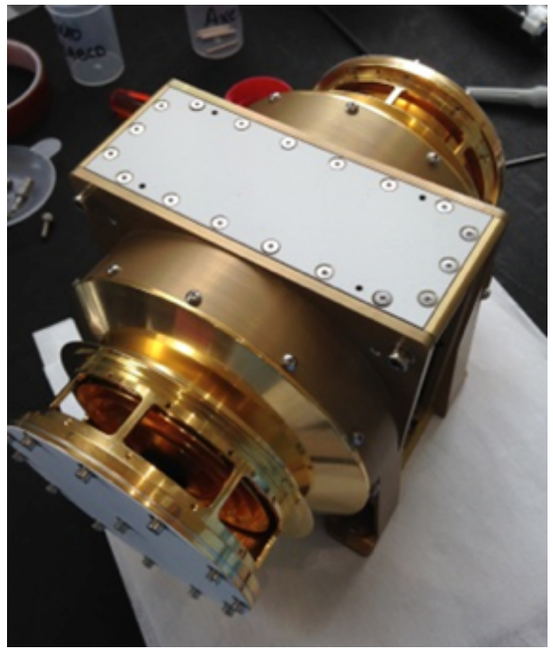
Scoring on unstrutured mesh

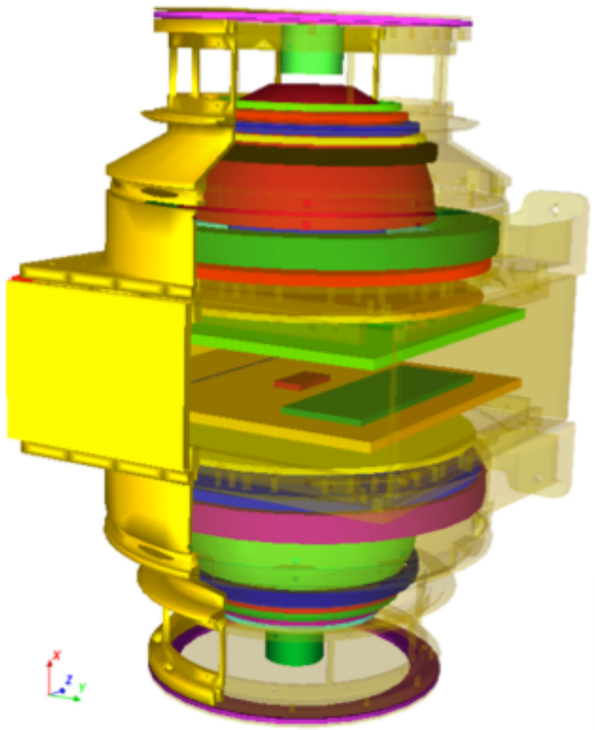
← Thanks to ESA/CIRSOS

Computation of chargies migration, internal E-field Leakage current

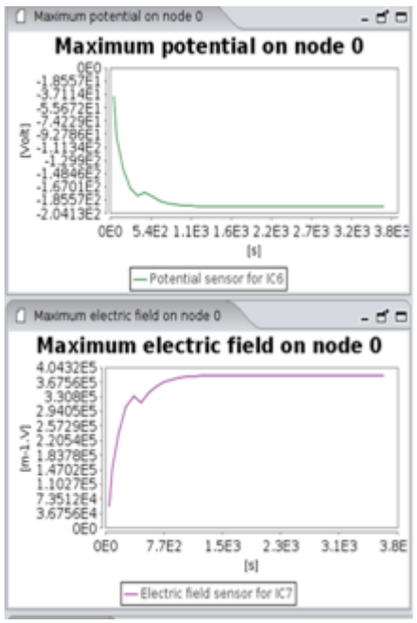
SPIS-IC

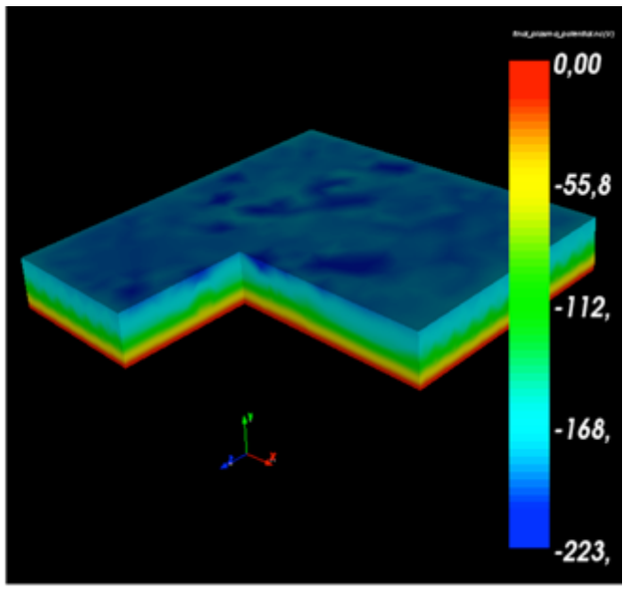
Internal charging analysis

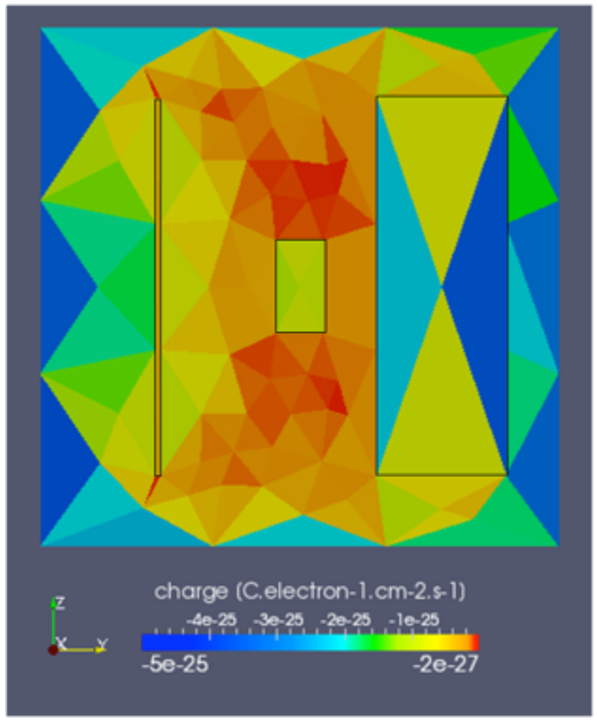


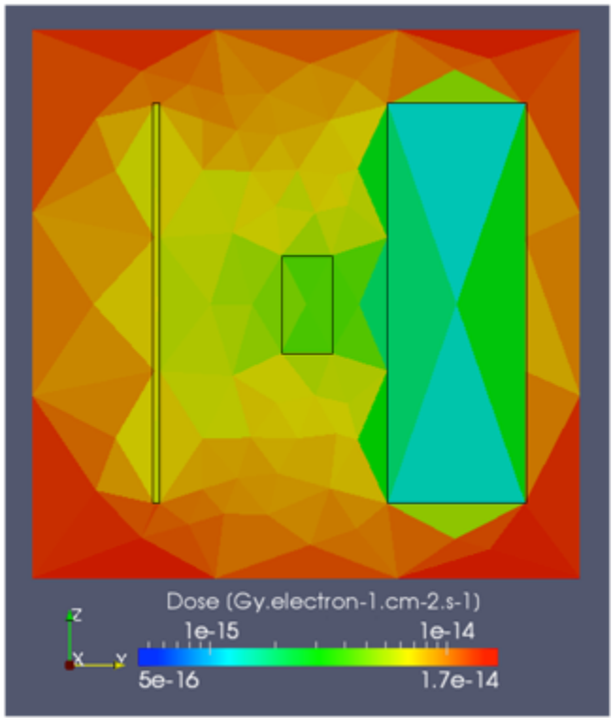


- Ambre experiment, with courtesy of CNES
- IEEE publication



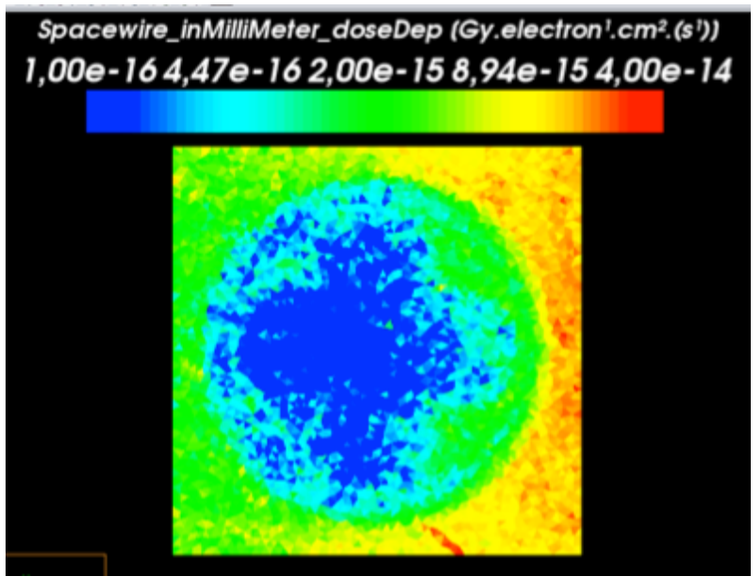


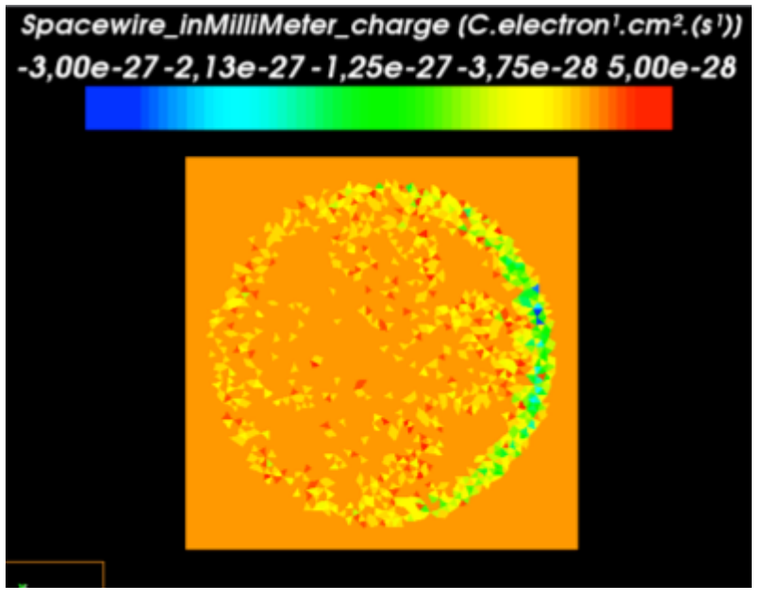


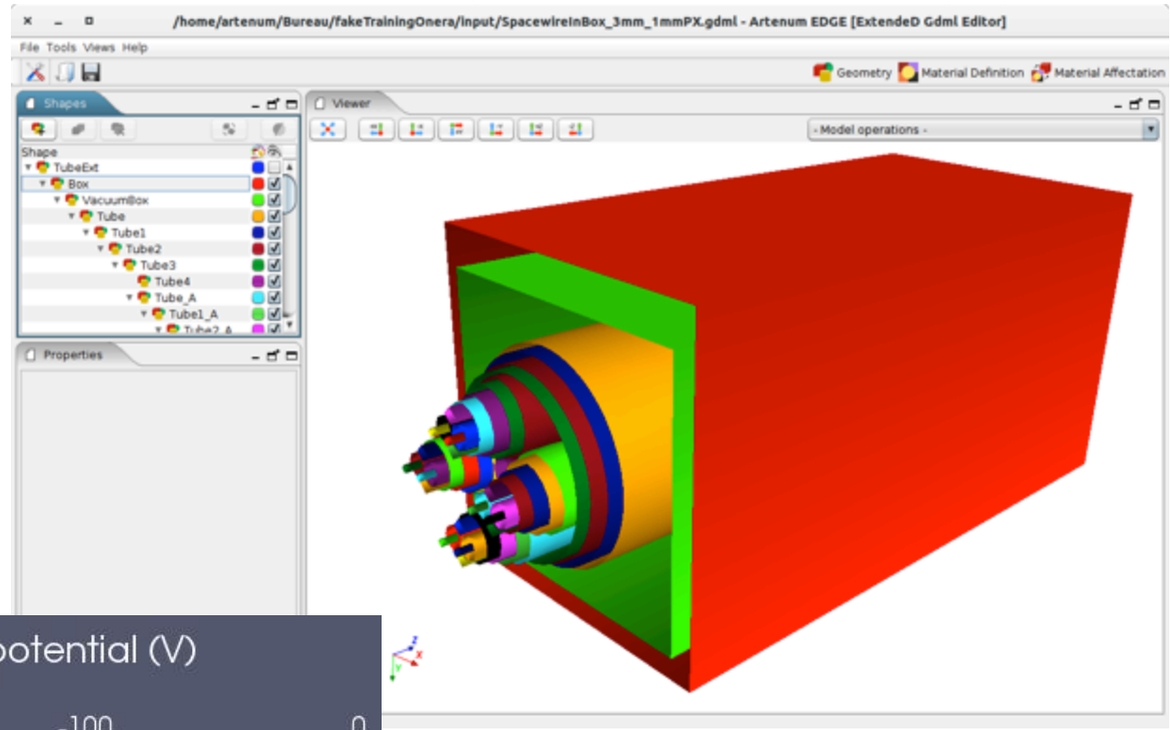


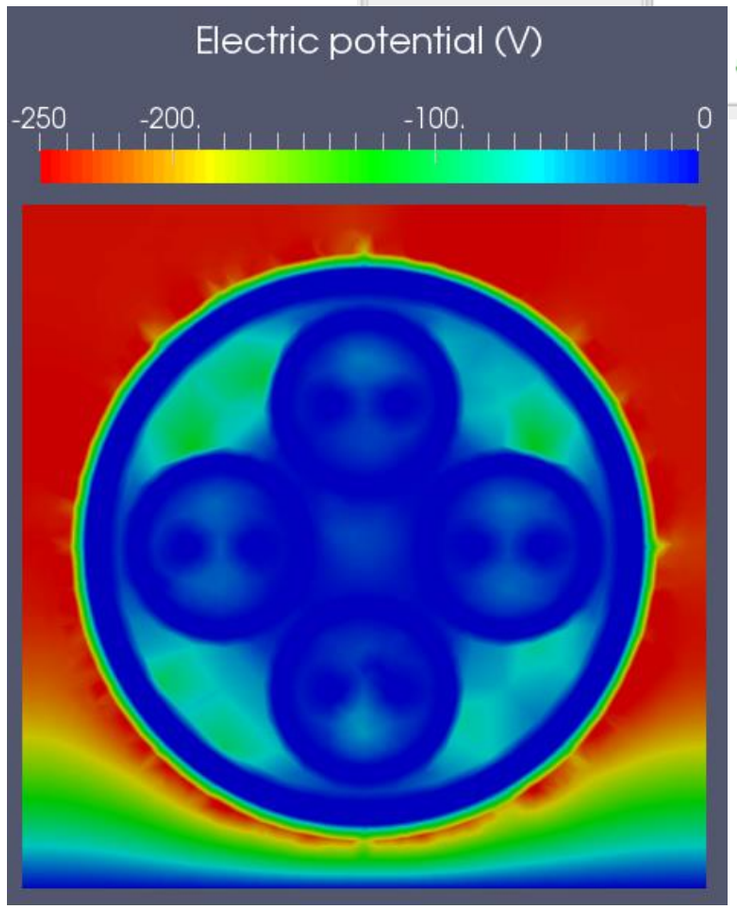
Internal charging

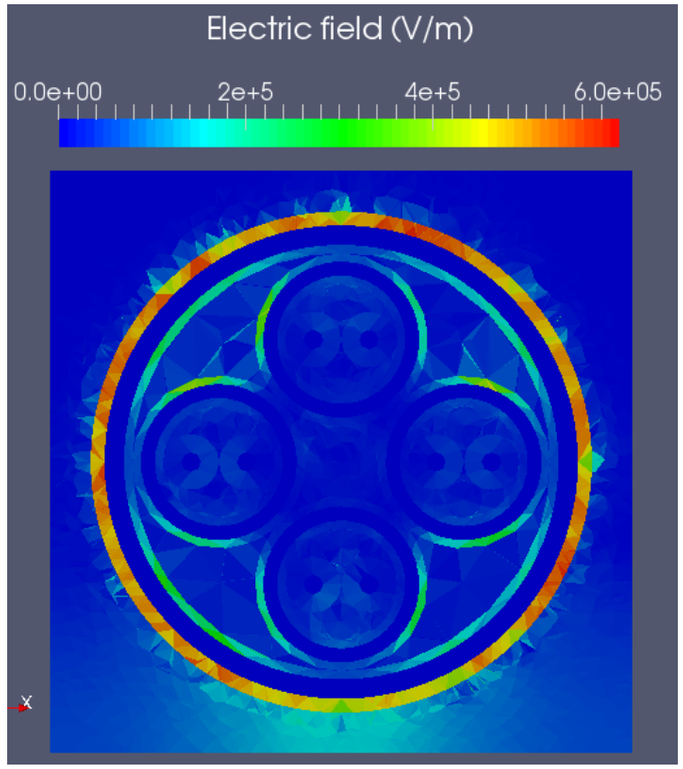
- Cable/wire











SPACE SITE | New Single Events (SEE/SEU) modelling tool

SEE-U
SINGLE EVENT EFFECT - UPSET MODELLING

- **Computation of SEU (Single Event Upset) cross section of electronic devices**
  - Protons, heavy ions
  - Various artificial environments (ground radiations testing facilities) and isotropic fluxes (in-flight)
- **Computation of in-site Software Events Rate (SER) taking into account the whole spacecraft structure in 3D and its shielding**
- Take into account a large spectrum of space environments from various external tools (e.g. SPENVIS, OMERE, user defined…)

An internal R&D initiative

- **Artenum/ONERA Partnership**
- **Internal developments and R&D**
- **Support of the French Occitannie region and Europe**

SEE-U: General overview

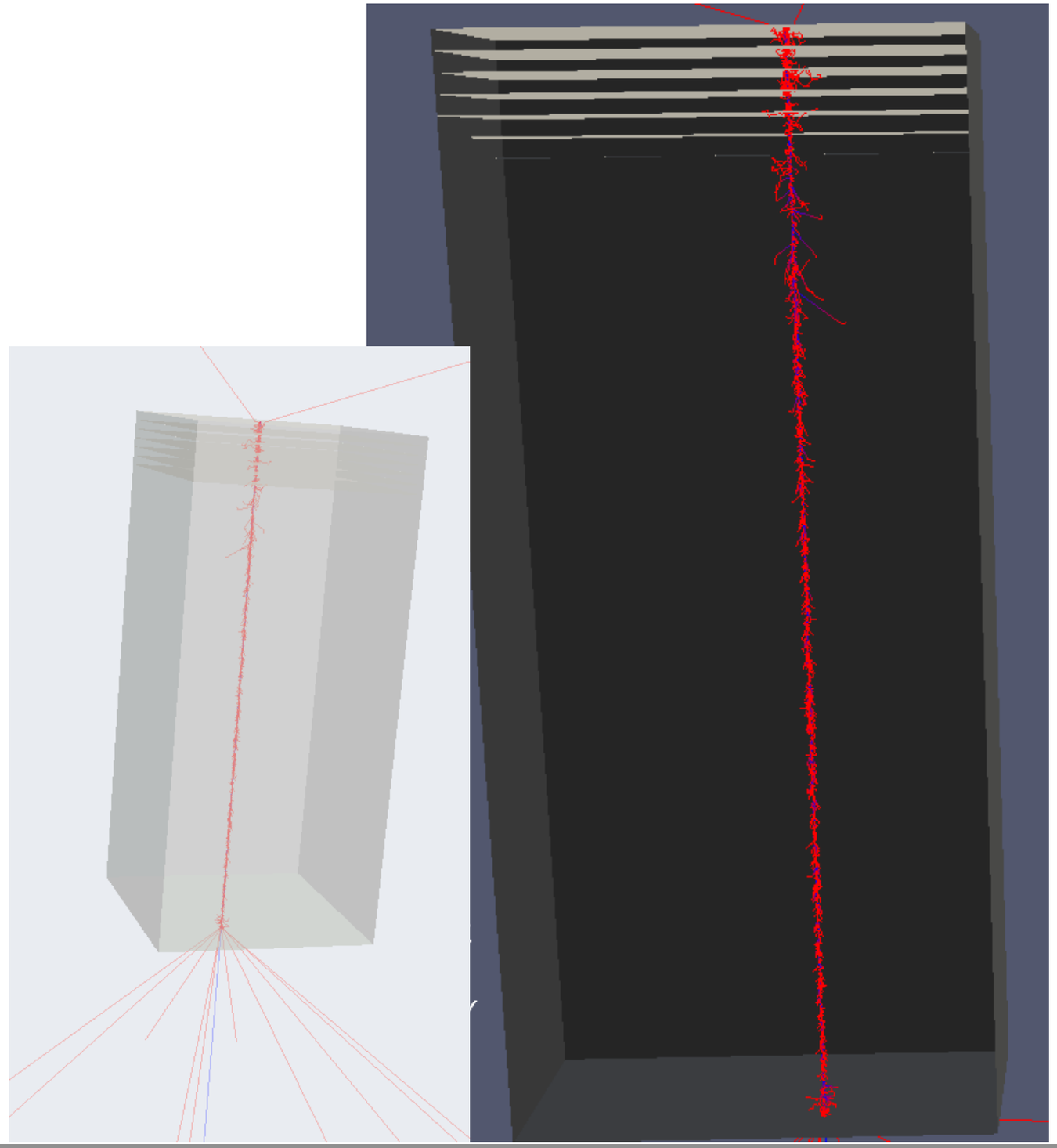
- Single Event Effect – Upset model
  - Transport
  - Collection
  - Diffusion
- Sensibility cross section characterized with MoOra/GRAS/ GEANT4
- Include a preloaded large catalogue of technologies :
  - CMOS (45-nm / 28nm / 20nm for the first release)
  - FF (FinFet) 28nm in 2020
- Representative of most current embedded FPGA and/or SoC SRAM based components
- Intensive SEE Experimental validations for heavy ions and protons

SEE-U: General overview

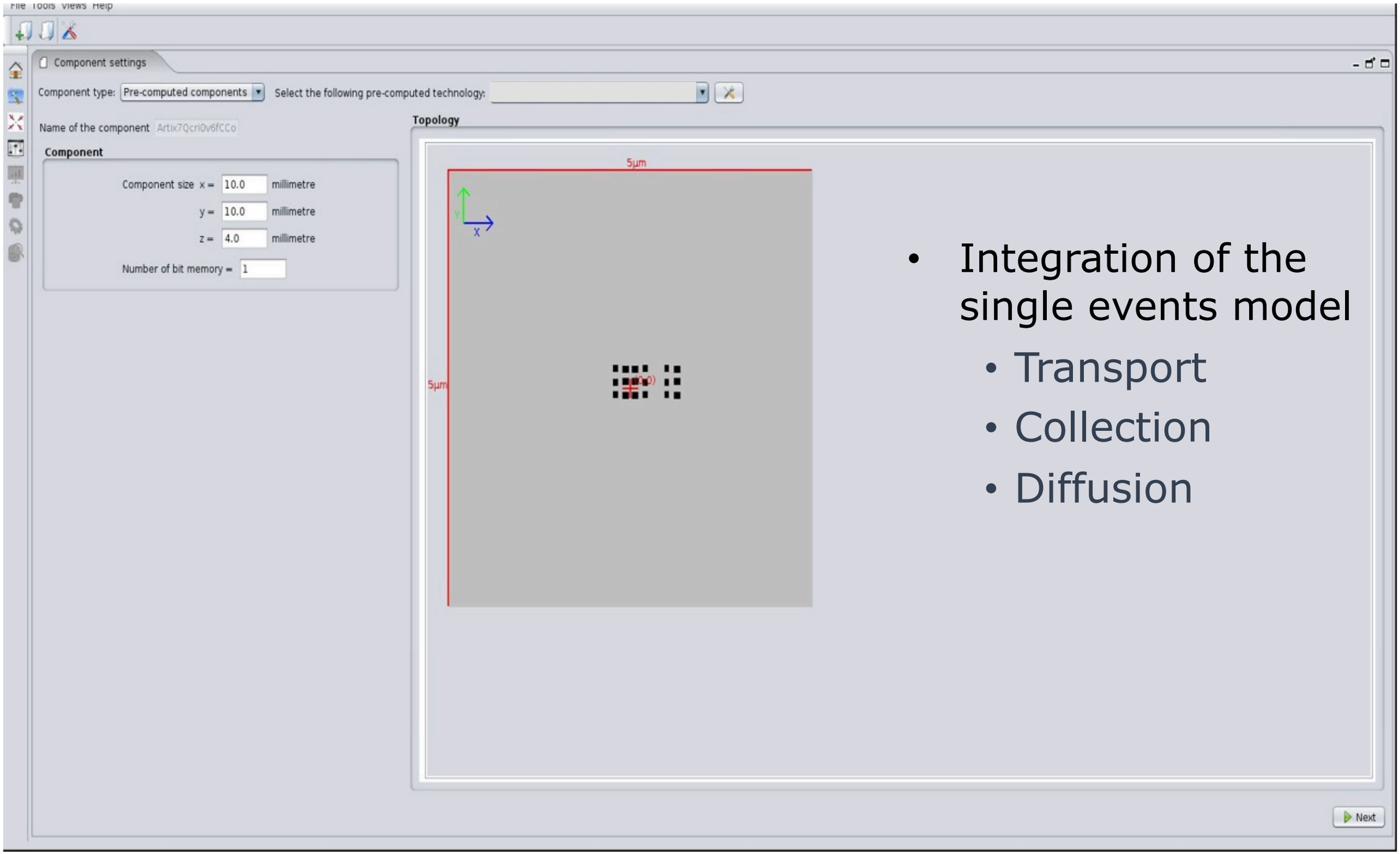
- Simple tool for an easy use in industrial context
- Friendly GUI
- Quite fast events rate computation
- Bridges with other SpaceSuite tools (MoOra, EDGE/SAAM)
- Multiplatform
- Help to the optimization of components positioning and PCB design
- Support to radiation hardness assurance

Sensitivity cross section characterisation

- Sensibility cross section characterized
  - By direct Monte-Carlo
  - MoOra/GRAS/GEANT4 chain
- Import of experimental data (expected for December 2019)

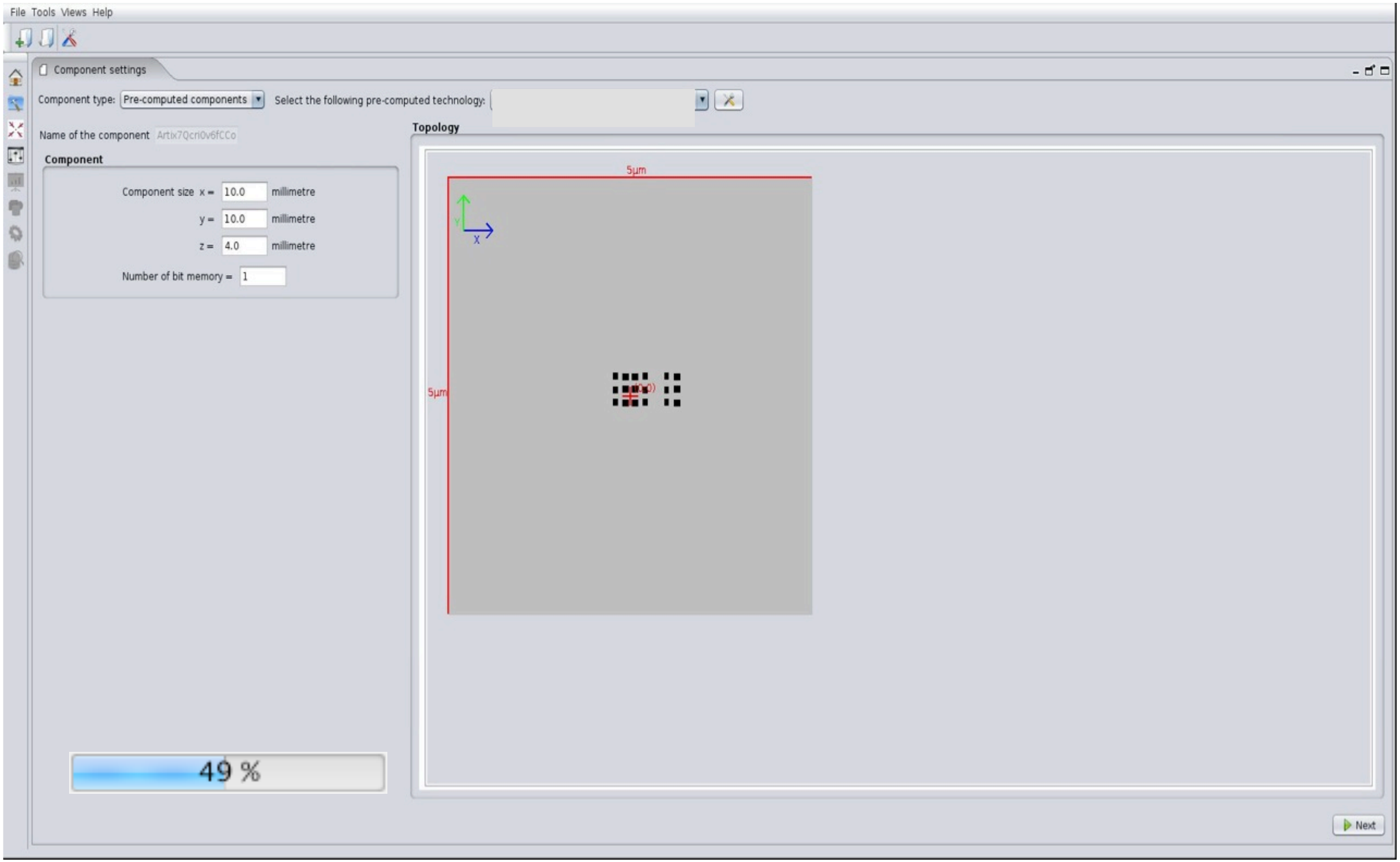


Technology design selection

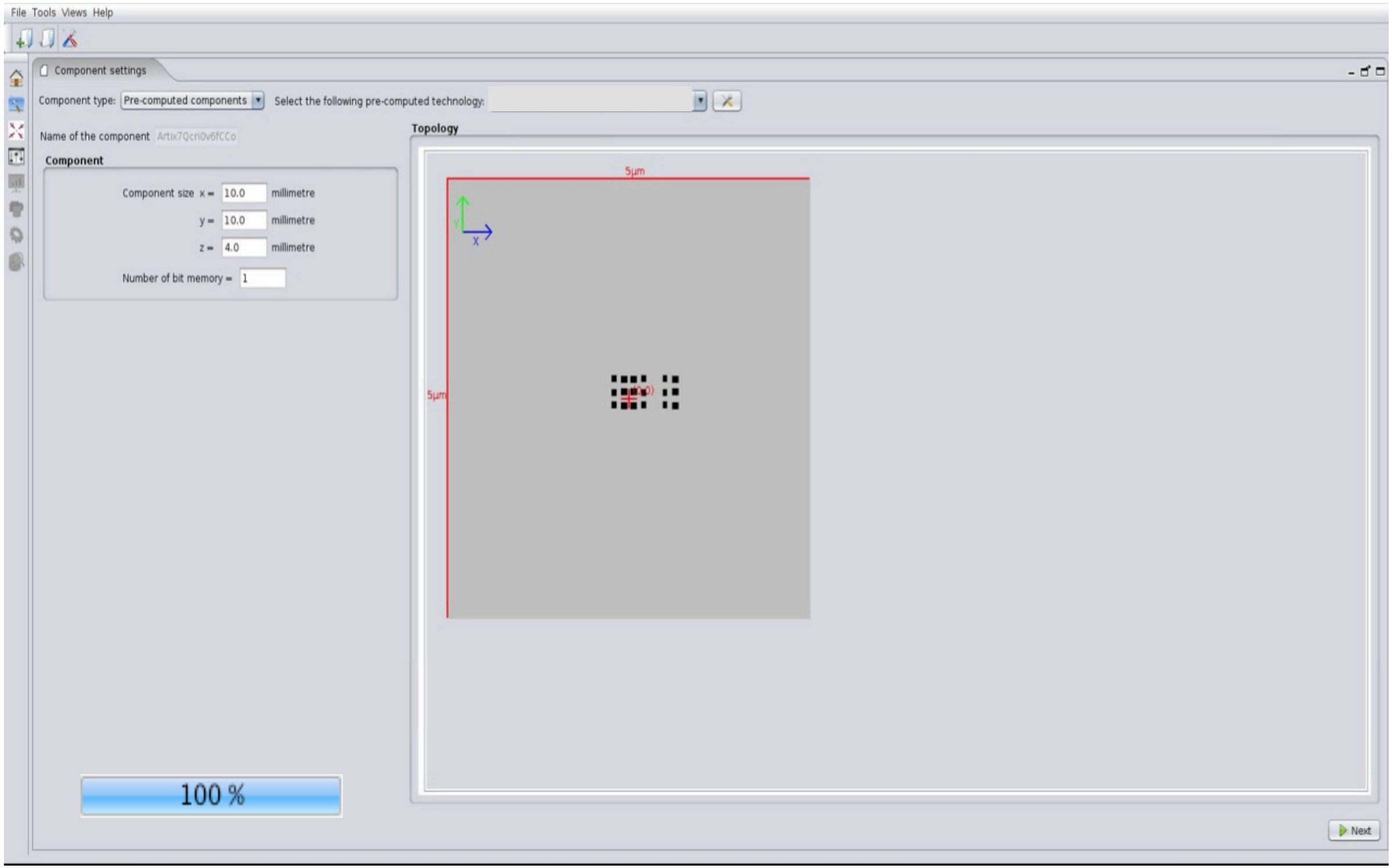


- Integration of the single events model
  - Transport
  - Collection
  - Diffusion

Technology design selection



Technology design selection



Sensibility cross section

File Tools Views Help

Component settings

Component type: Pre-computed components Select the following pre-computed technology:

Name of the component Artix7QcriOv6fCCo

Component

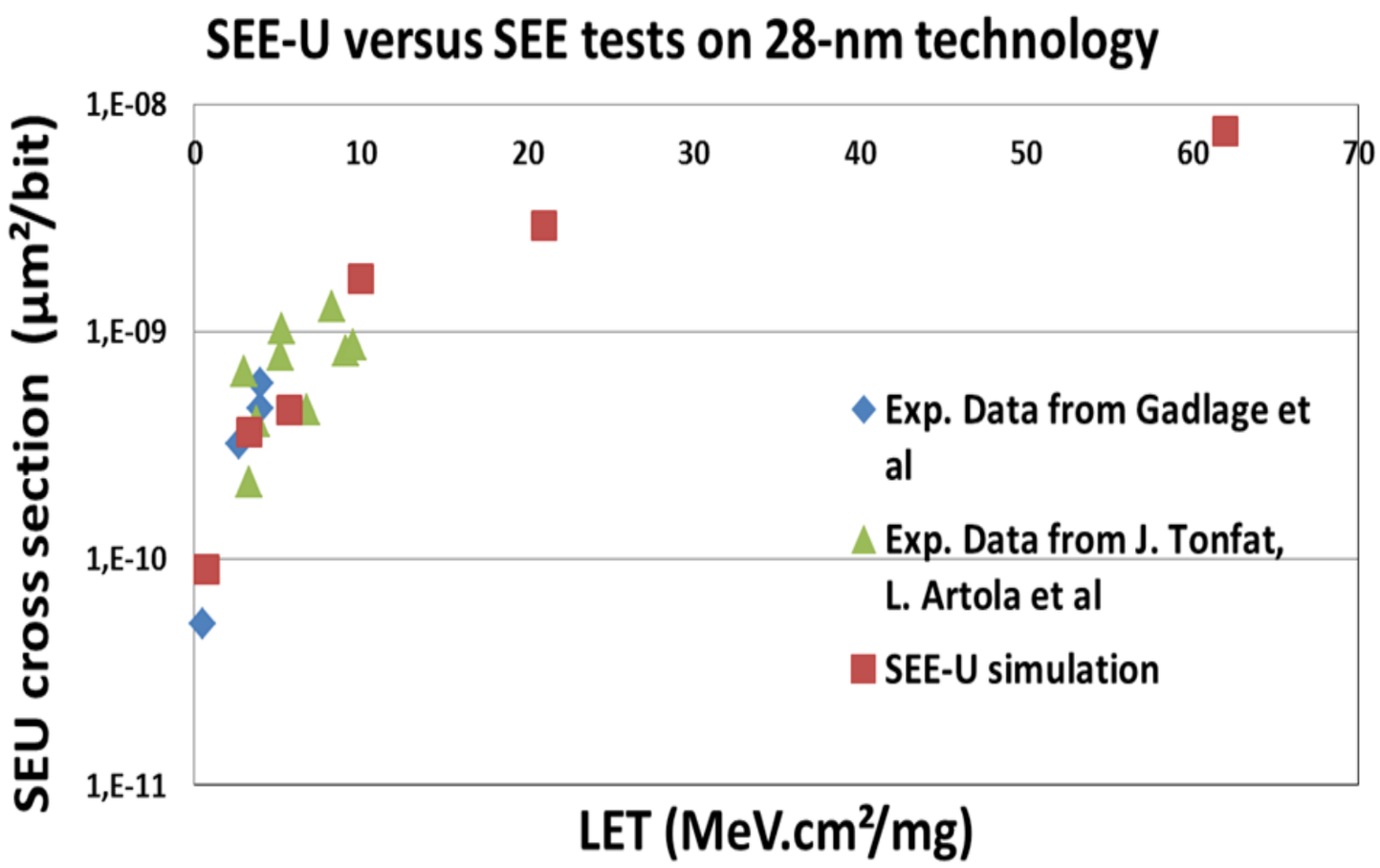
Component size x = 10.0 millimetre

y = 10.0 millimetre

z = 4.0 millimetre

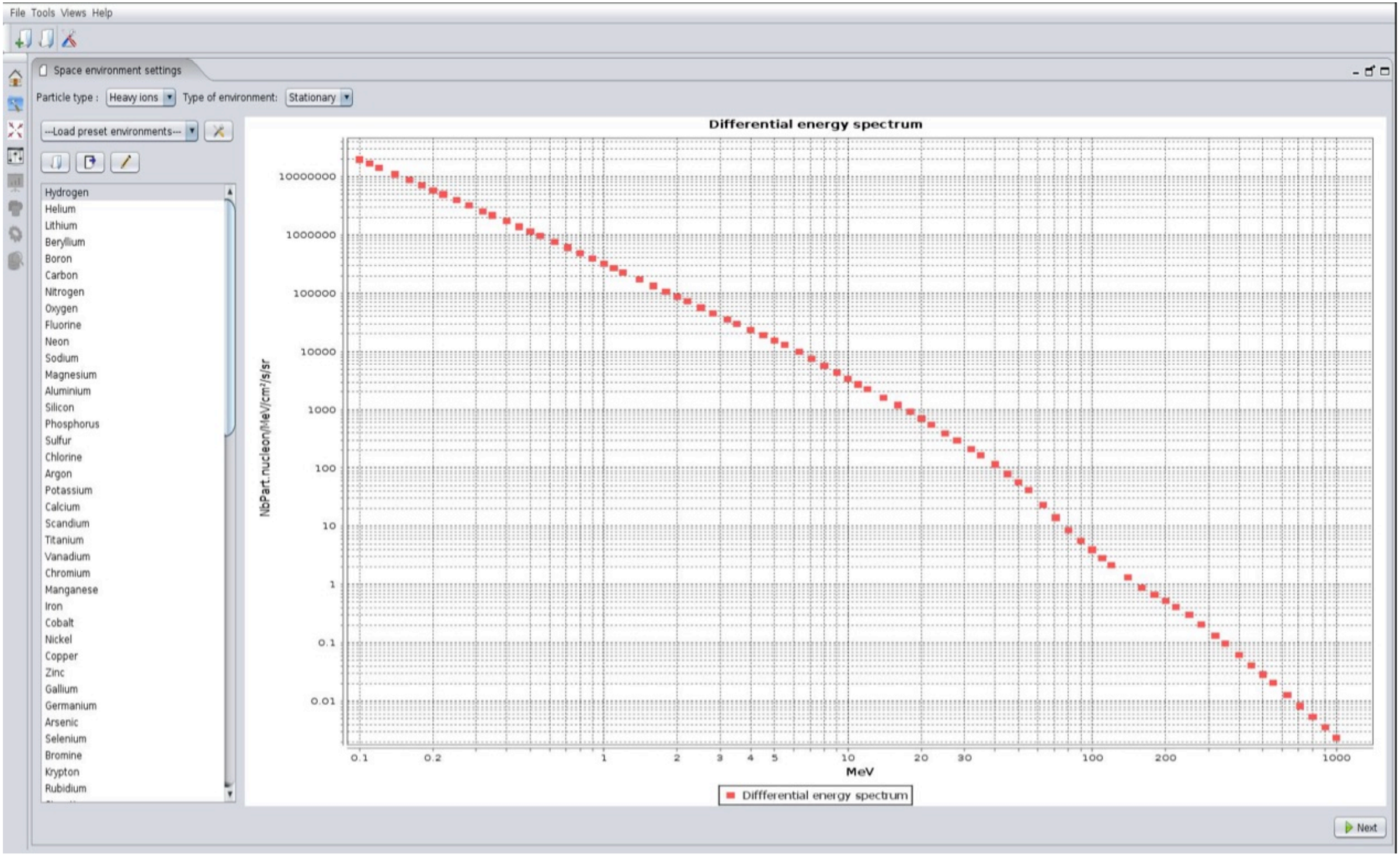
Number of bit memory = 1

Topology



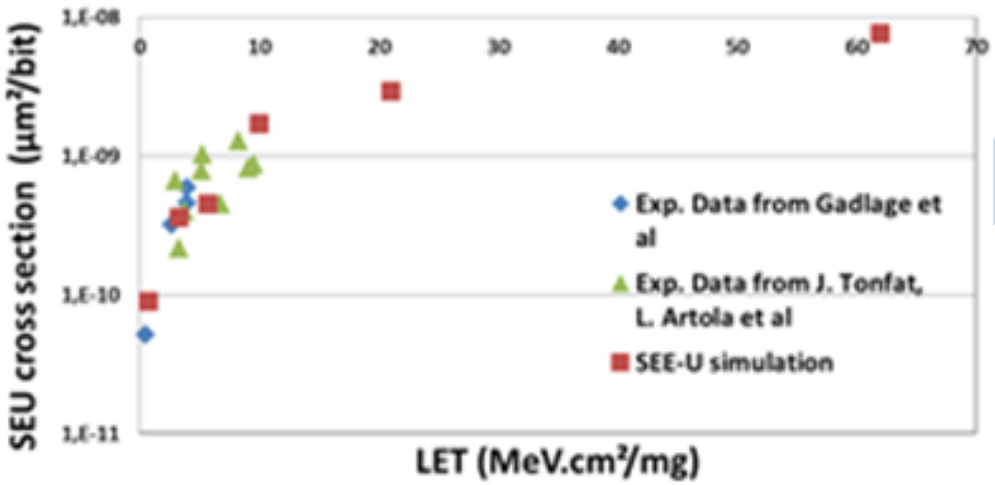
Next

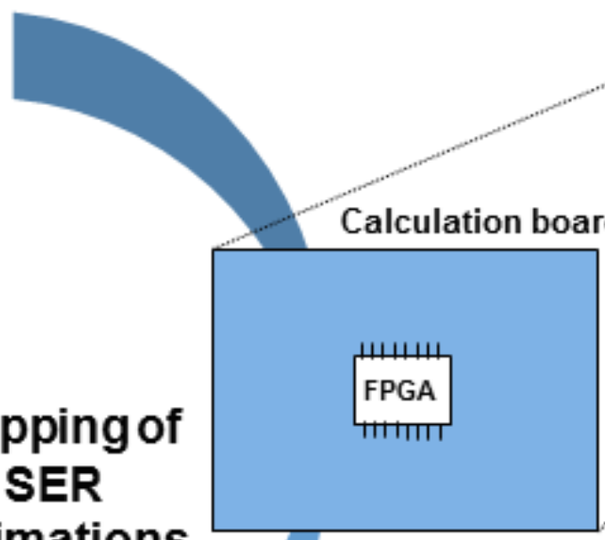
Application of input spectrum

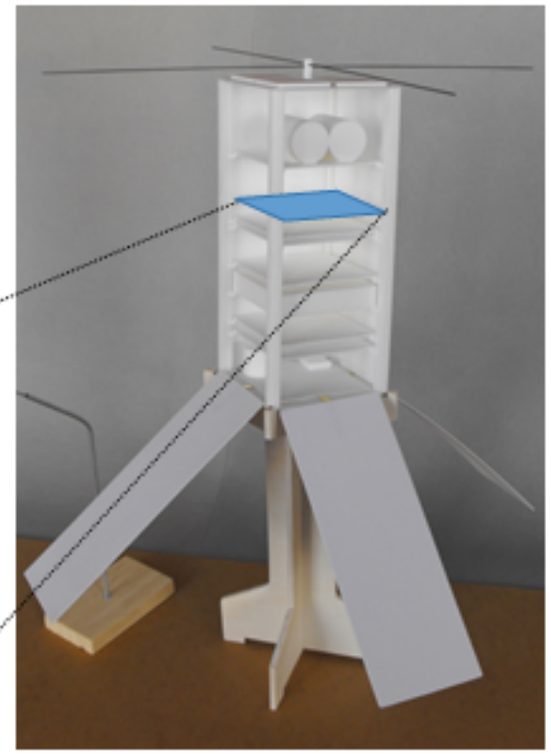


In situ SER estimation

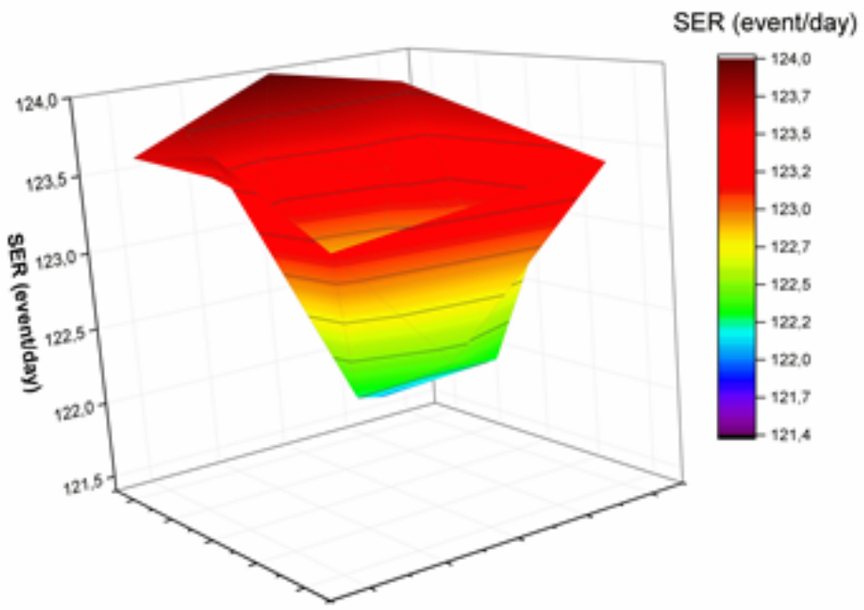
Intrinsic SEU sensitivity of the FPGA estimations versus ground SEE tests







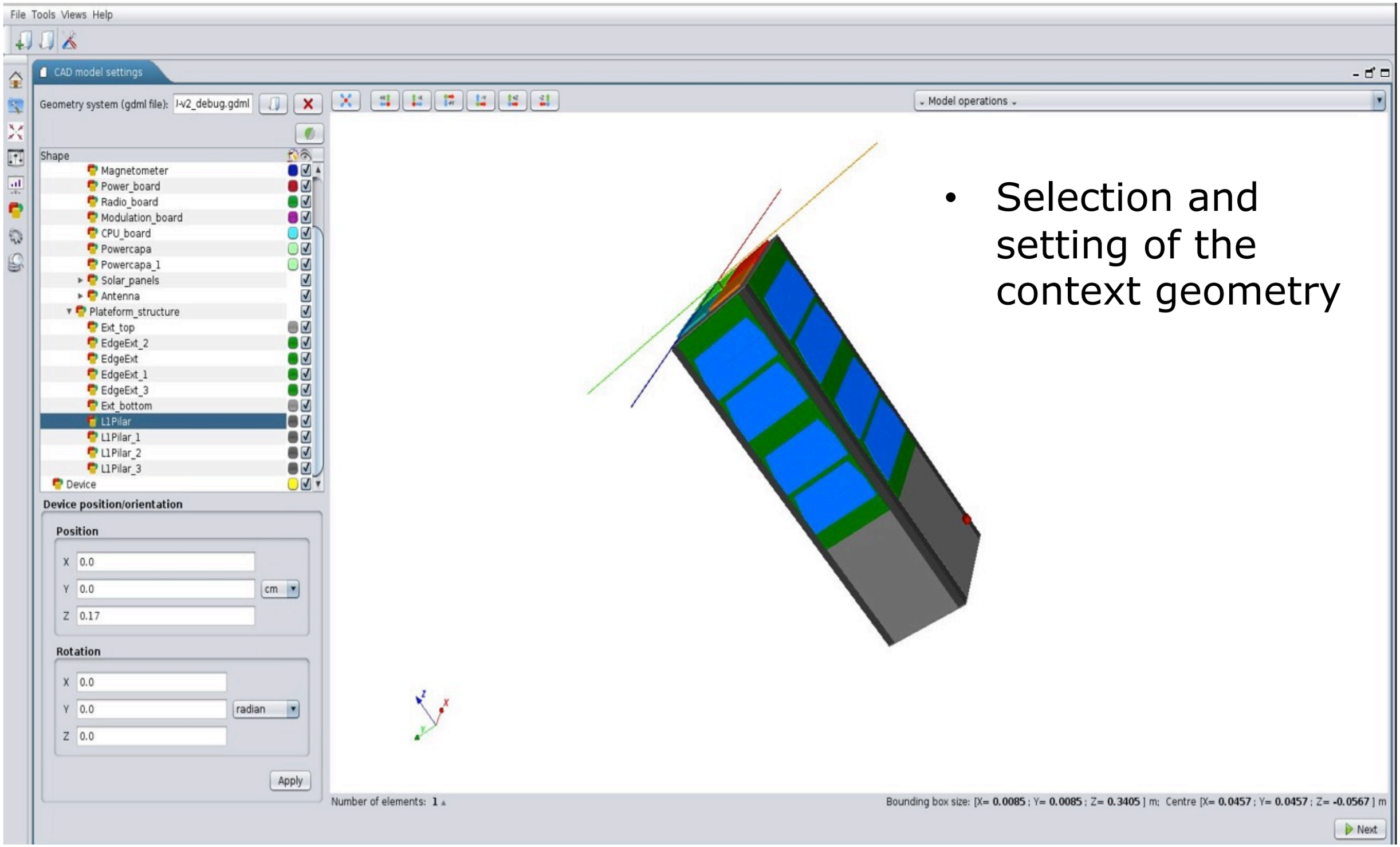
Mapping of SER estimations



→ SER Worst cases on the side of the calculation board

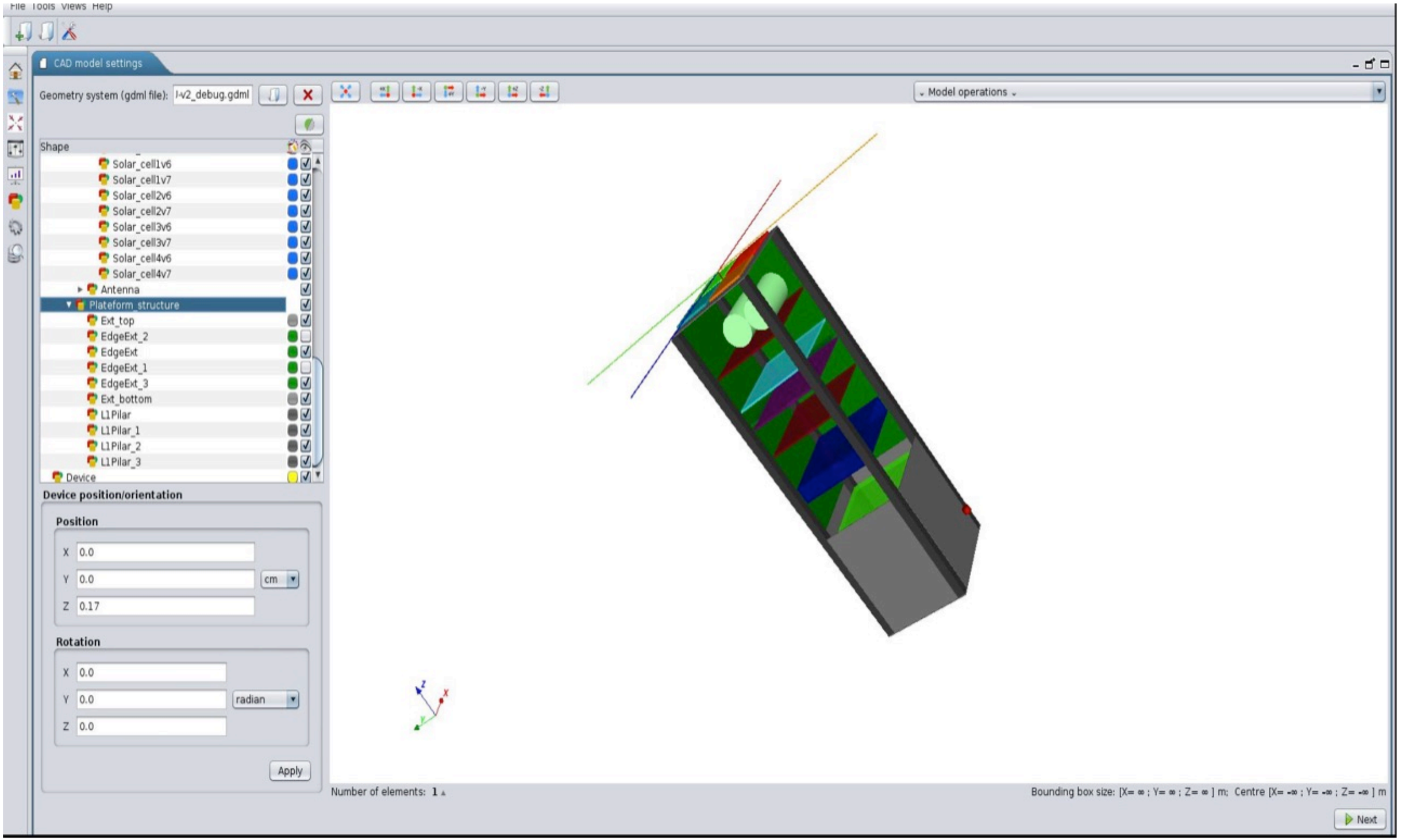
→ Main contribution from heavy ions

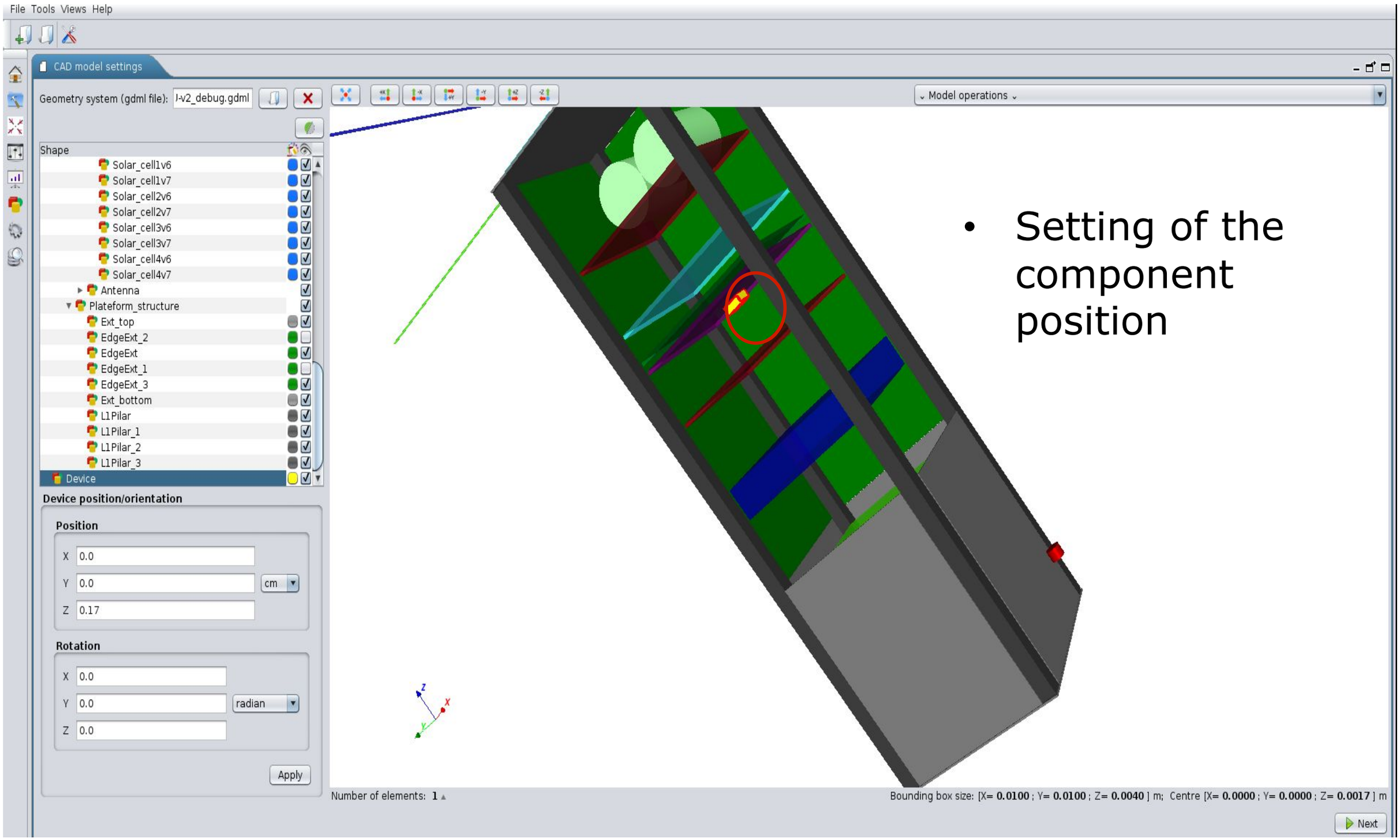
In situ SER estimation



- Selection and setting of the context geometry

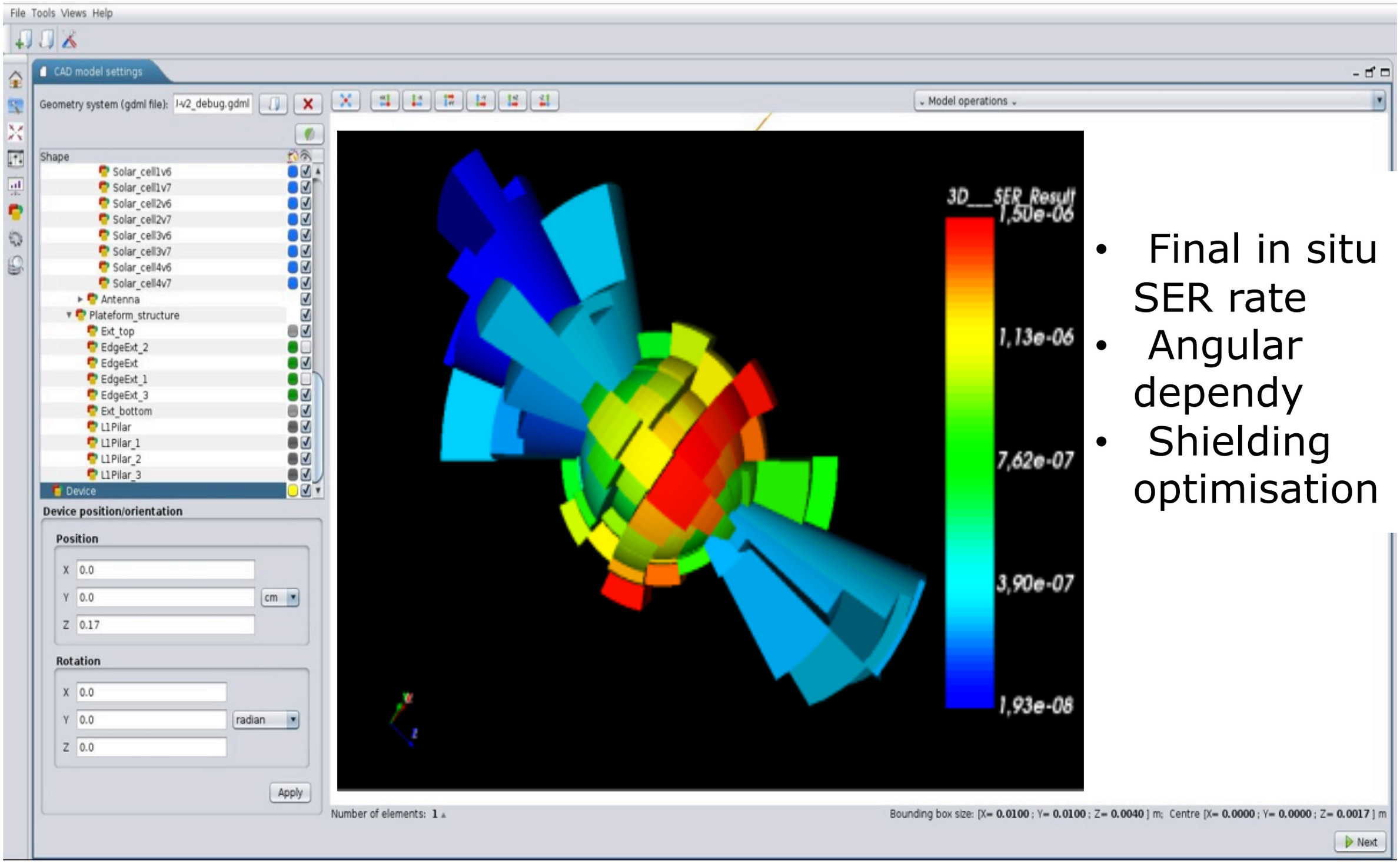
In situ SER estimation





- Setting of the component position

In situ SER



- Final in situ SER rate
- Angular dependy
- Shielding optimisation

Intensive validation campaign

- **Intensive test campaign currently done at ONERA**
  - Characterisation already done for 45nm, 28nm et 20nm technological nodes
  - SEE-U / GEANT4 results fit very well with experimental measurement done on ground

- **Not yet part of the commercial offer**
- **Expected availability end 2019**
- **But already good feedbacks of several early/beta users from the industry**

Conclusion

- **Several examples of GEANT4 applications in the SpaceSuite offer**
  - Rich CAD modelling with EDGE
  - Radiations analysis with MoOra/GRAS/GEANT4
  - Internal charging analysis with EDGE/MoOra/SPIS-IC
  - Single Events analysis with SEE-U
- **GEANT4 a very powerful basis**
- **Quid of improvement of support of meshed or B-Rep based geometries in future GEANT4 versions**

Thank you for your attention.

www.space-suite.com

ARTENUM

ONERA
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