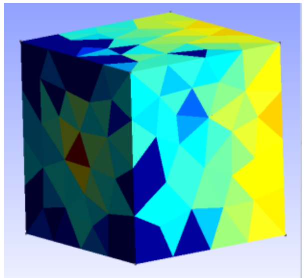
9th Geant4 Space User's Workshop

Barcelona, 4-6 March 2013



Geant4 tools and interfaces from ELSHIELD project

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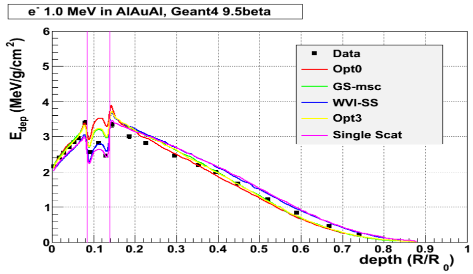
Introduction. ELSHIELD outcomes

ELSHIELD Project

Energetic Electron Shielding, Charging and Radiation Effects and Margins

An ESA funded activity (Galileo program) with the aim to improve the performance of deep/internal dielectric charging tools, review EM physics simulation for energetic electrons and develop interfaces and utilities to couple plasma and HEP tools.

- Review of EM physics in Geant4, focusing on energetic electrons (MeV).
  - Comparing models with existing electron data, other MC codes & tools.
  - Proposing improvements to current EM models and new I/F options
- Analysis of electron dose enhancement effects in multi-layer structures
  - New experimental datasets obtained and preliminary G4 simulations
- New EM and geometry biasing options
- Coupling Geant4/GRAS with ESA space charging tool (SPIS)
  - Internal dielectric (SPIS) + charge transport (G4)
- New interfaces
  - SPENVIS, FASTRAD, Geant4/GRAS, SPIS
- New generation look-up table tools for rapid effects calculations
- Automated tool to optimize payload arrangement



Review of EM physics.

Model improvements & new I/Fs

Review of EM physics. New models & I/Fs

- Analysis the existing Geant4 EM models
  - Simple 1-D, 3-D cases were built for benchmarking
  - The theoretical basis of the models was identified
  - Comparisons with EGS and Penelope2008 data
  - Geant4 results were validated vs. evaluated data and dedicated experimental benchmarks
  - Weak or missing models were identified
  - A set of improvements was proposed:
    - MSC and the single scattering models. Extension of exiting models
    - A new bremsstrahlung model
    - New interfaces to the atomic de-excitation models
    - Atomic de-excitation combined with photo-electric and Compton effects
    - PAI and Moller-Bhabha extended below 1 keV
- In addition, an e- irradiation campaign was performed to obtain dose profiles in multi-layer shieldings and compare to results from new EM Geant4 models

Review of EM physics. New models & I/Fs

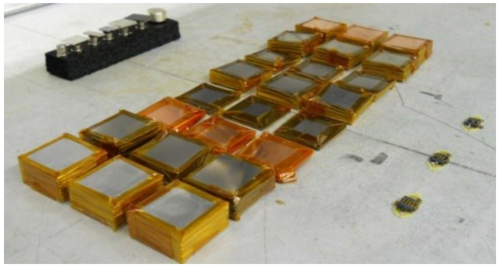
- Standard EM model improvements:
  - New bremsstrahlung model for G4SeltzerBergerModel
  - New version of L.Urban multiple scattering G4UrbanMscModel95
  - New model of photo-electric effect G4PEEffectFluoModel (Atomic de-excitation added)
  - New model of Compton scattering G4KleinNishinaModel (Atomic de-excitation and Doppler added)
  - New angular generator G4DipBustGenerator (Fast sampling of angular distribution for bremsstrahlung)
  - Extension of PAI and Moller-Bhabha ionisation models down in energy from 1 keV to 100 eV (Important for micrometer scale simulation)
- New EM interfaces:
  - Universal interface to angular generator (Interchange of angular generators between models)
  - New universal interface to atomic de-excitation (Standard EM package can use de-excitation module)
  - New EM biasing framework (Biasing options are available via UI commands)

All these available since Geant4 v.9.5

More details about models validation and UI commands in Vladimir's talk (Wednesday)

Conclusions

- As a result of ELSHIELD project Geant4 EM physics become uniform, more stable and more precise
- The default physics list (Opt0) is High Energy Physics oriented
- Standard Physics List Opt3 can be used for accurate study of shielding effects
- Livermore and Penelope Physics Lists are equivalent in CPU speed and physics capabilities to the Standard Opt3



Experimental electron dose enhancement

Comparison with G4 EM models

Experimental dose enhancement effects

New experimental data was obtained during ELSHIELD
(TRAD was in charge of experimental campaigns)

- Typical electron energies in GEO/MEO scenarios
  - 0.1 to 10 MeV range
- Common shielding materials in the space domain
  - Al, Ti, Cu, Ta
- Multilayer shielding combining high-Z / low-Z
  - Ta-Al, Cu-Al, Ti-Al
- Analyzing deposited dose under different shielding depths
- Comparing Data vs Geant4 and Penelope 2011

Experimental Test Samples

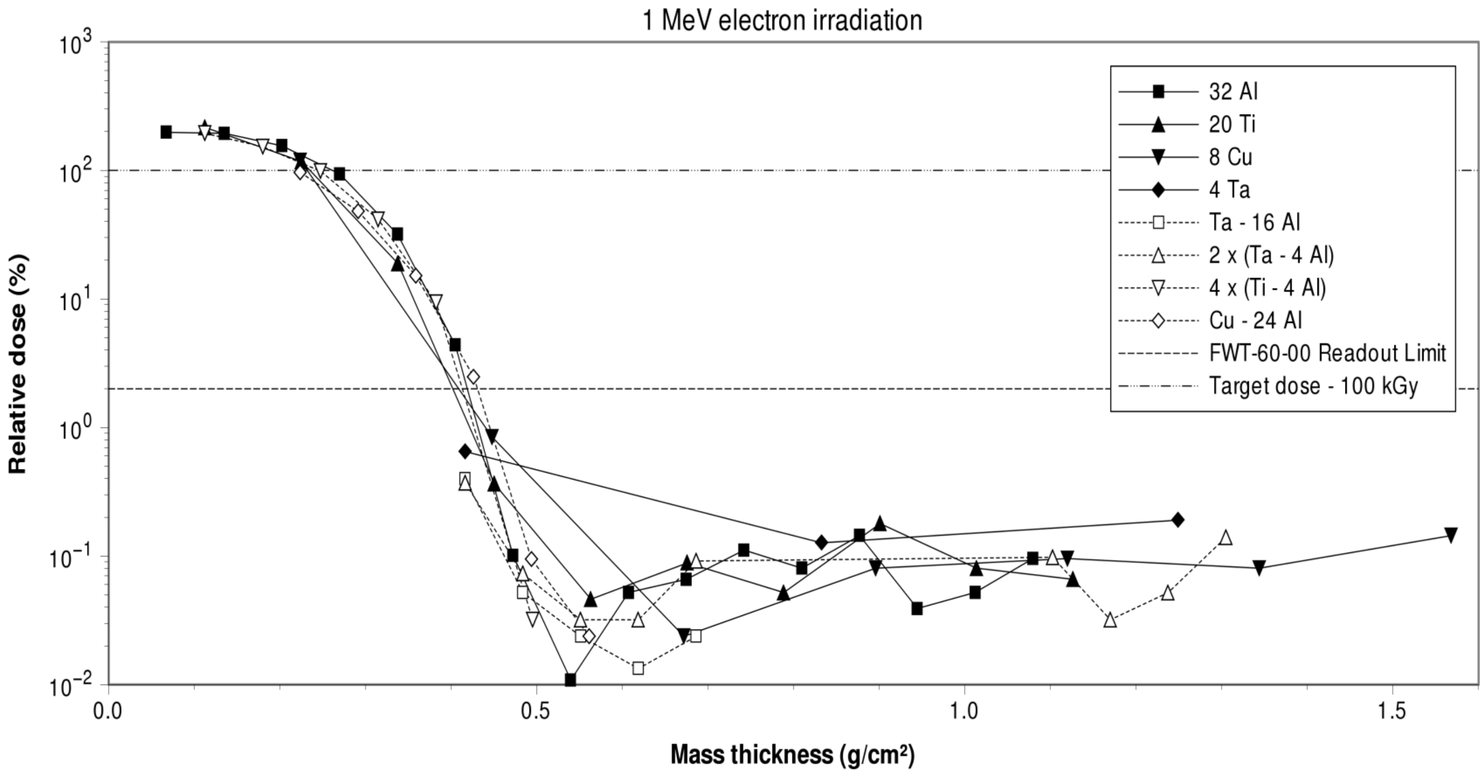
Ref	Name	Total Thickness (mm)	Description
1	32 Al	8	32 aluminium layers
2	20 Ti	5	20 titanium layers
3	8 Cu	2	8 copper layers
4	4 Ta	1	4 tantalum layers
5	Ta – 16 Al	4.25	Single tantalum layer followed by 16 aluminium layers
6	Ta - 4 Al (2x)	2.5	Single tantalum layer followed by 4 aluminium layers (2x)
7	Ti – 4 Al (4x)	5	Single titanium layer followed by 4 aluminium layers (4x)
8	Cu – 24 Al	6.25	Single copper layer followed by 24 aluminium layers

Experimental dose enhancement effects

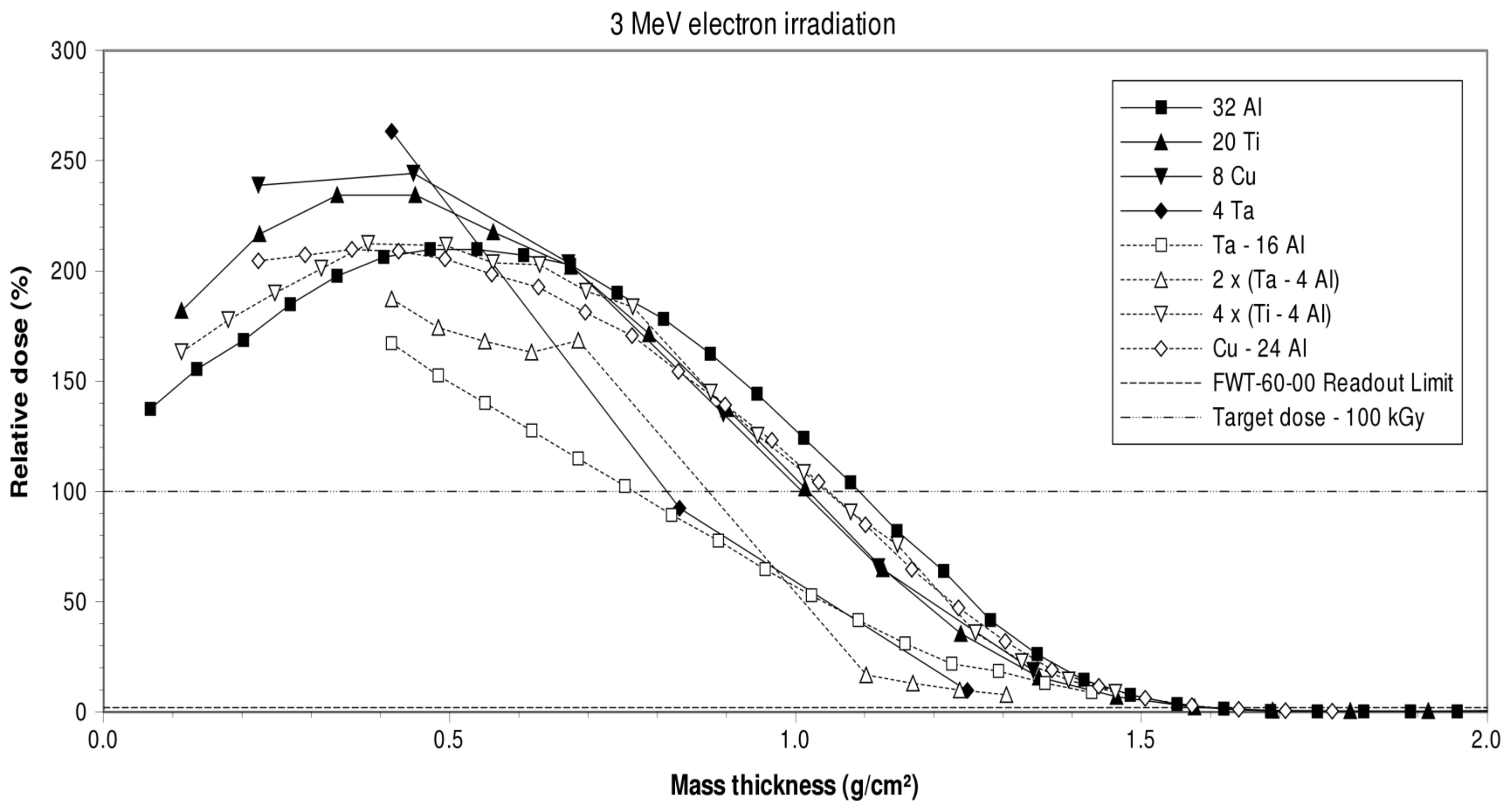
Experimental Irradiation Setup

Electron Energy	1 MeV	3 MeV	6 MeV	10 meV
Facility / Accelerator	TU Delft Van de Graaff		Elekta Synergy Linac	
Distance beam source to samples	15 cm		100 cm	
Beam irradiation area	300 x 500 mm^2		250 x 250 mm^2	
Beam spectral shape	Mono-Energetic FWHM < ±3%		Standard Elekta Synergy Beam	
Beam spatial profile	Gaussian ± 5%		Standard Elekta Synergy Beam	
Top plate	Aluminium 20 mm		Plastic Water WTe 12 mm	Plastic Water WTe 23 mm
Base plate	Aluminium 2 cm		Plastic Water WTe 10 cm	
Atmosphere	Air			
Expected total dose	100 kGy		2 kGy	
Measured total dose at control dosimeter	135.1	119.4	1.48	1.56

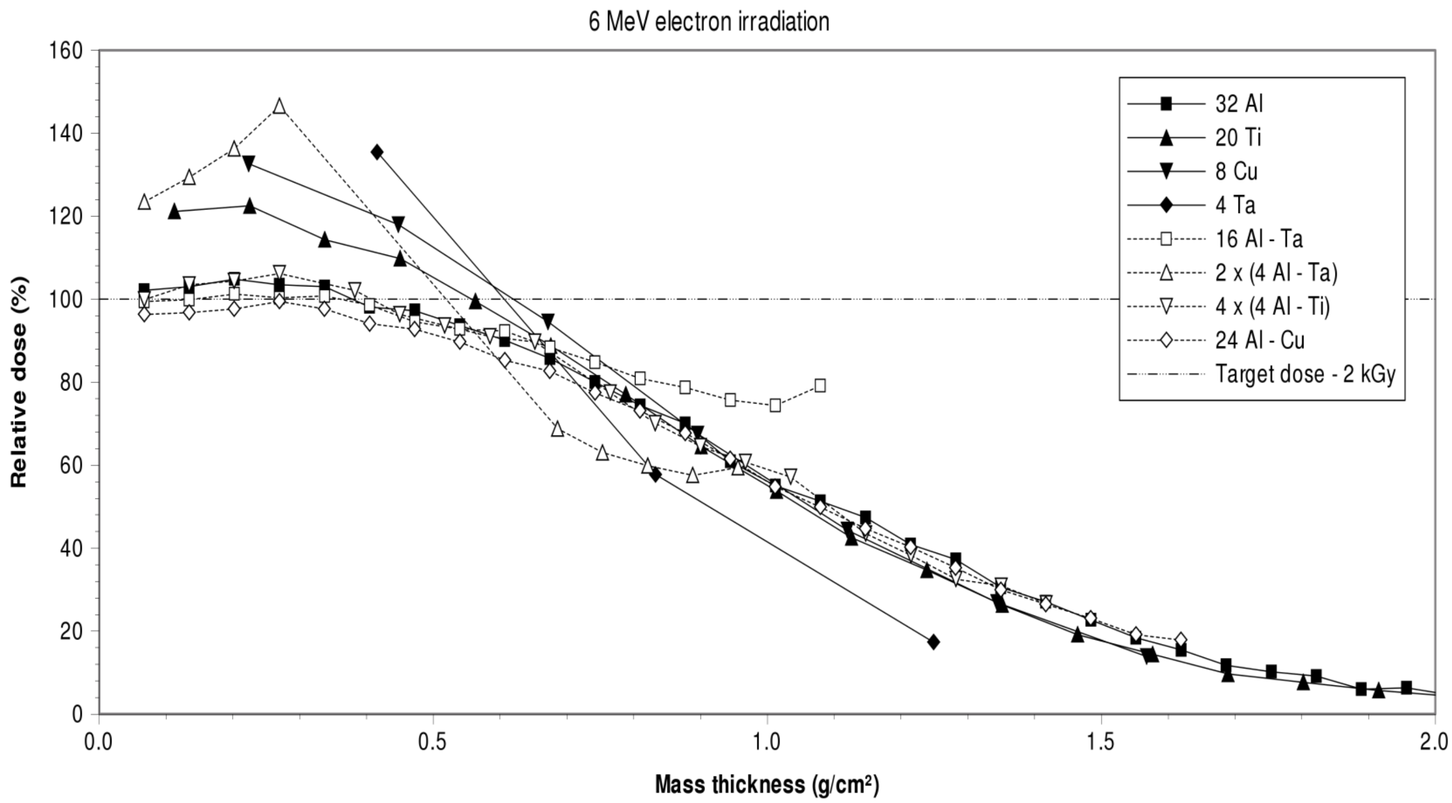
Experimental dose enhancement effects



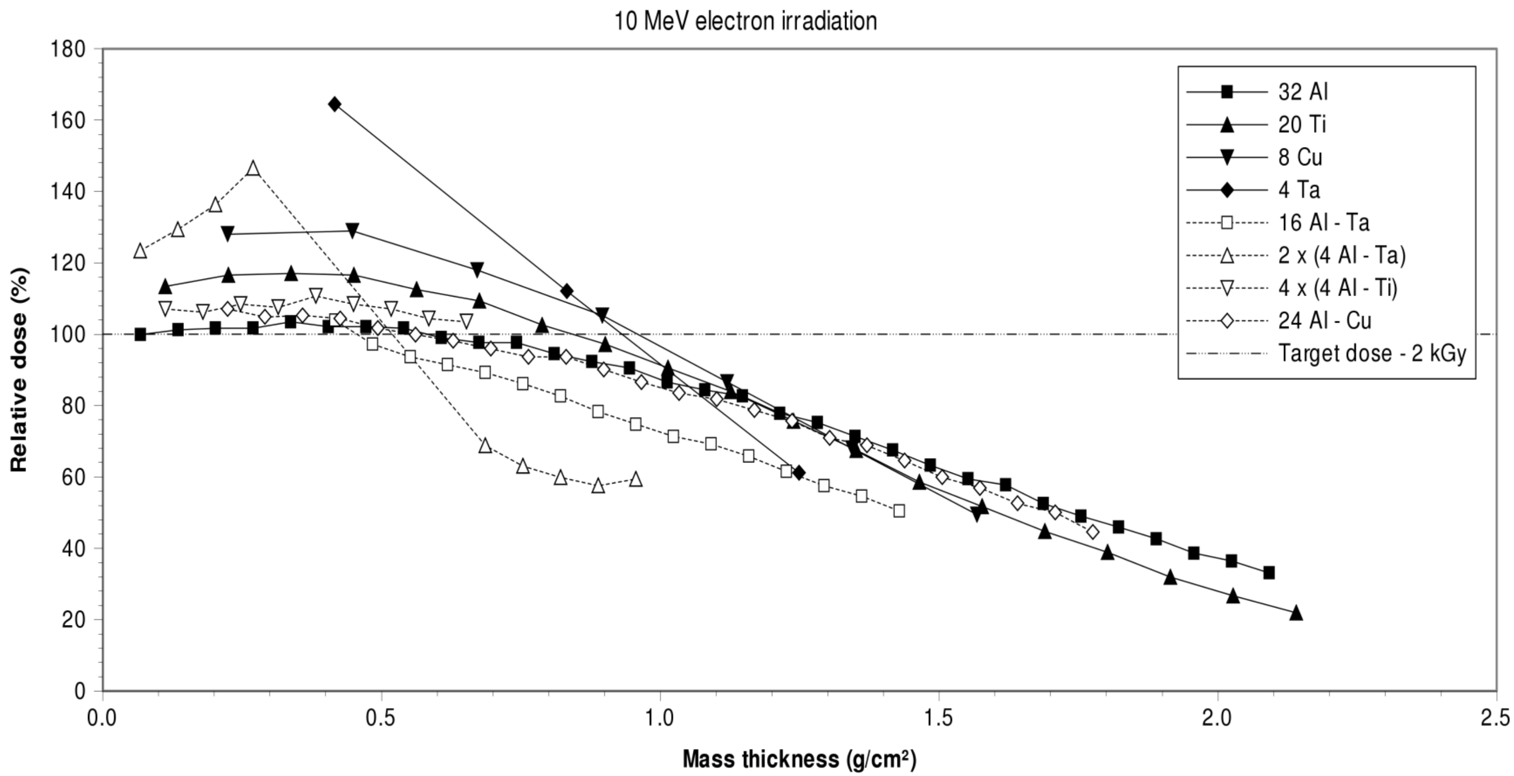
Experimental dose enhancement effects



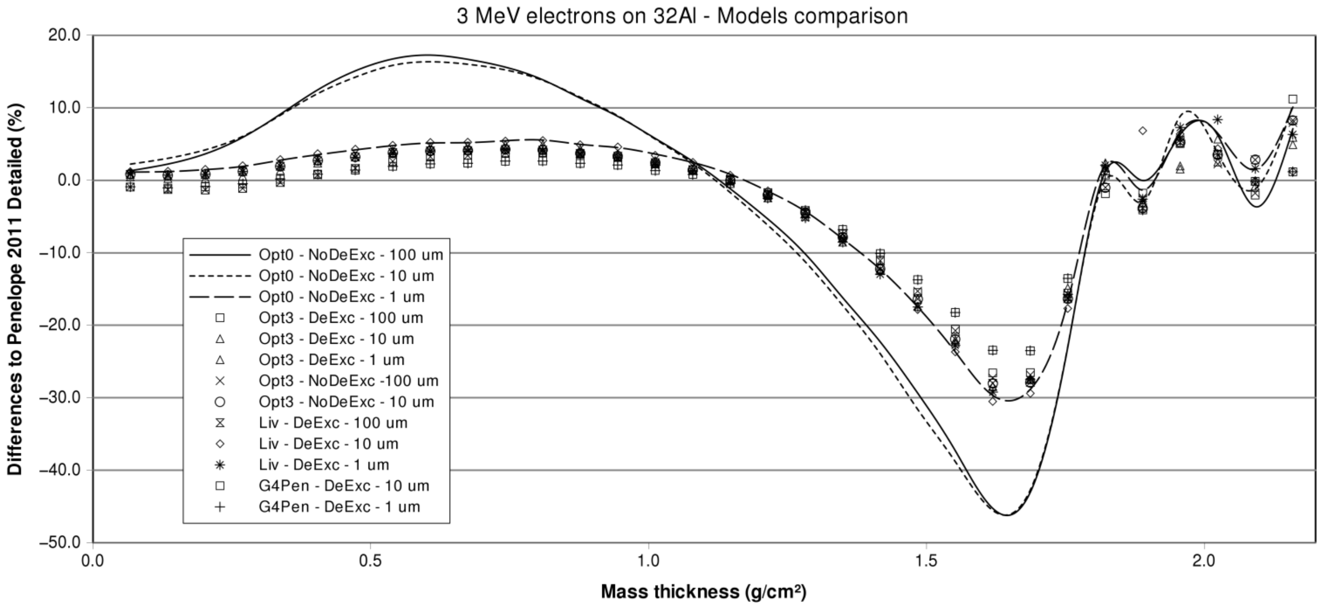
Experimental dose enhancement effects



Experimental dose enhancement effects



Geant4 modelling. Geant4 vs Penelope-2011



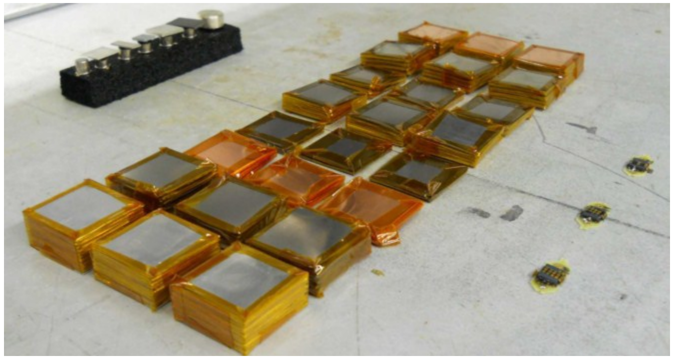
- Atomic de-excitation has no significant impact on dose profiles, but slight differences in the tail
- Opt0 and Opt3 provide similar results when production cut is set to 1.0 micron
- As expected , G4Penelope seems to provide a better agreement with Penelope-2011
- Similar results are obtained for other EM models (Opt4, Penelope, Livermore)

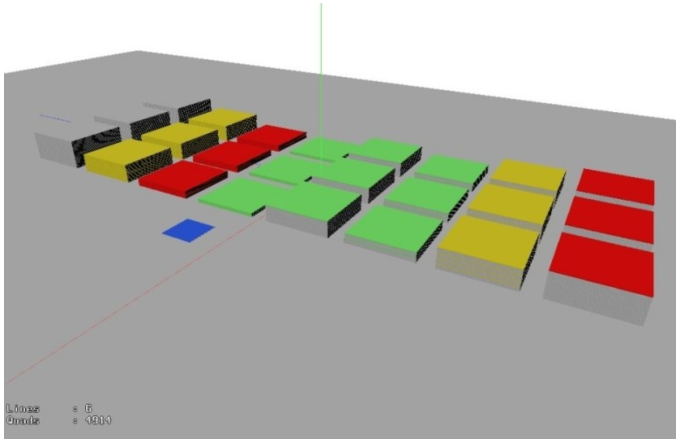
Experimental dose enhancement effects

Geant4 modelling

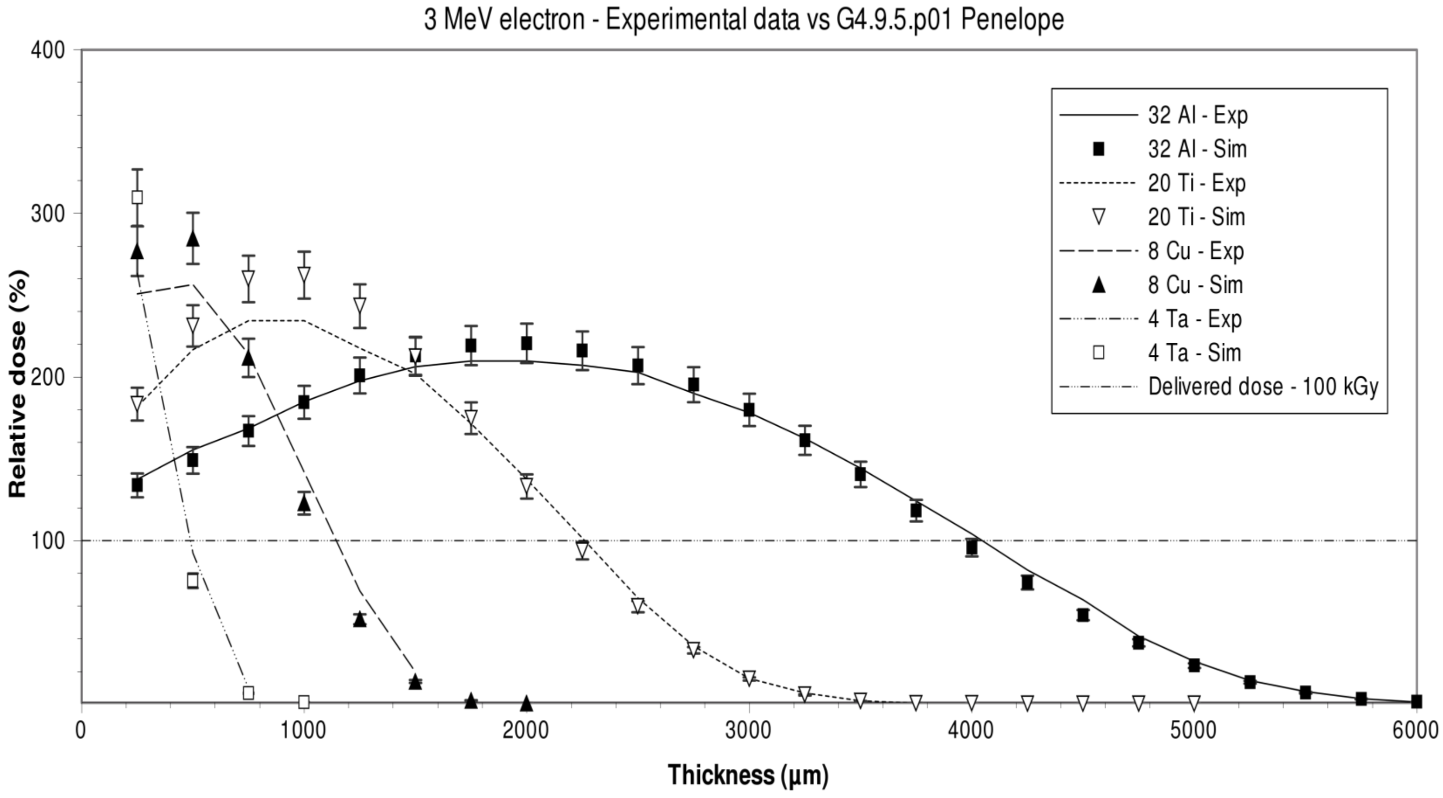
TU-Delft Setup

- Base plate20 mm Al
- Window 100 micron Al
- World filled of dry air
- Control Dosimeter (blue) next to 4th column (4Ta)
- Samples placed according Test Setup
- Primary electrons
  - 1.035 MeV (sigma 0.01)
  - 3.03 MeV (sigma 0.01)
- Simulated events: ~1E5/cm2



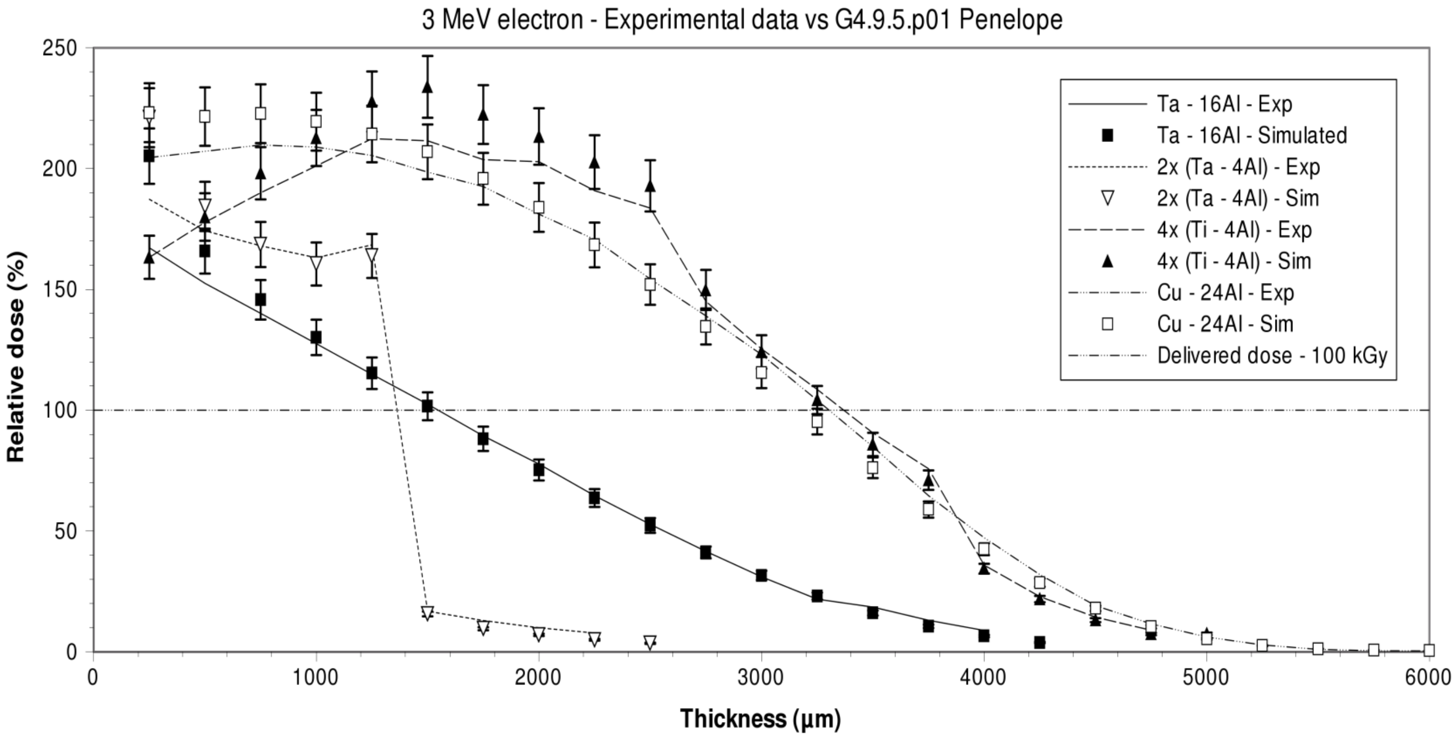


Geant4 modelling. Data vs G4Penelope



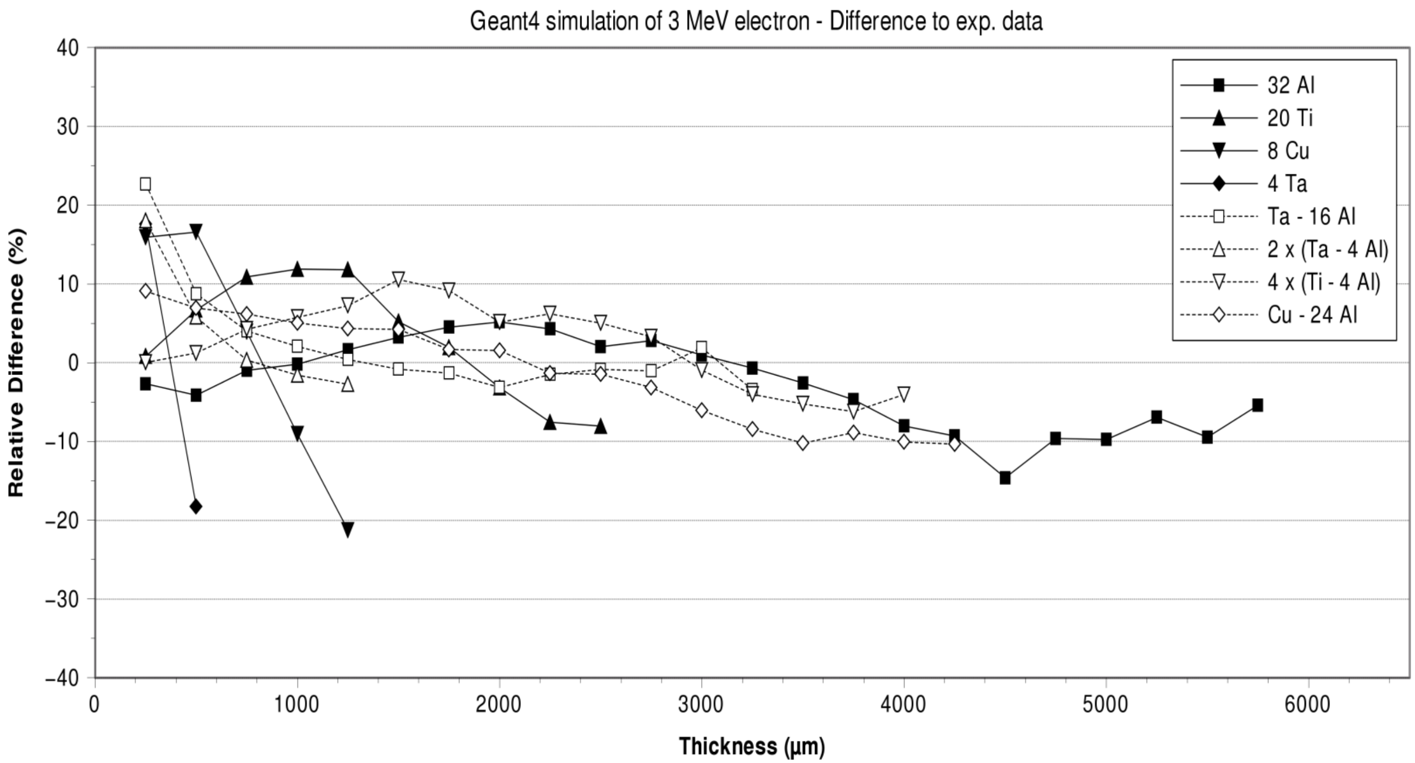
Experimental dose enhancement effects

Geant4 modelling. Data vs G4Penelope



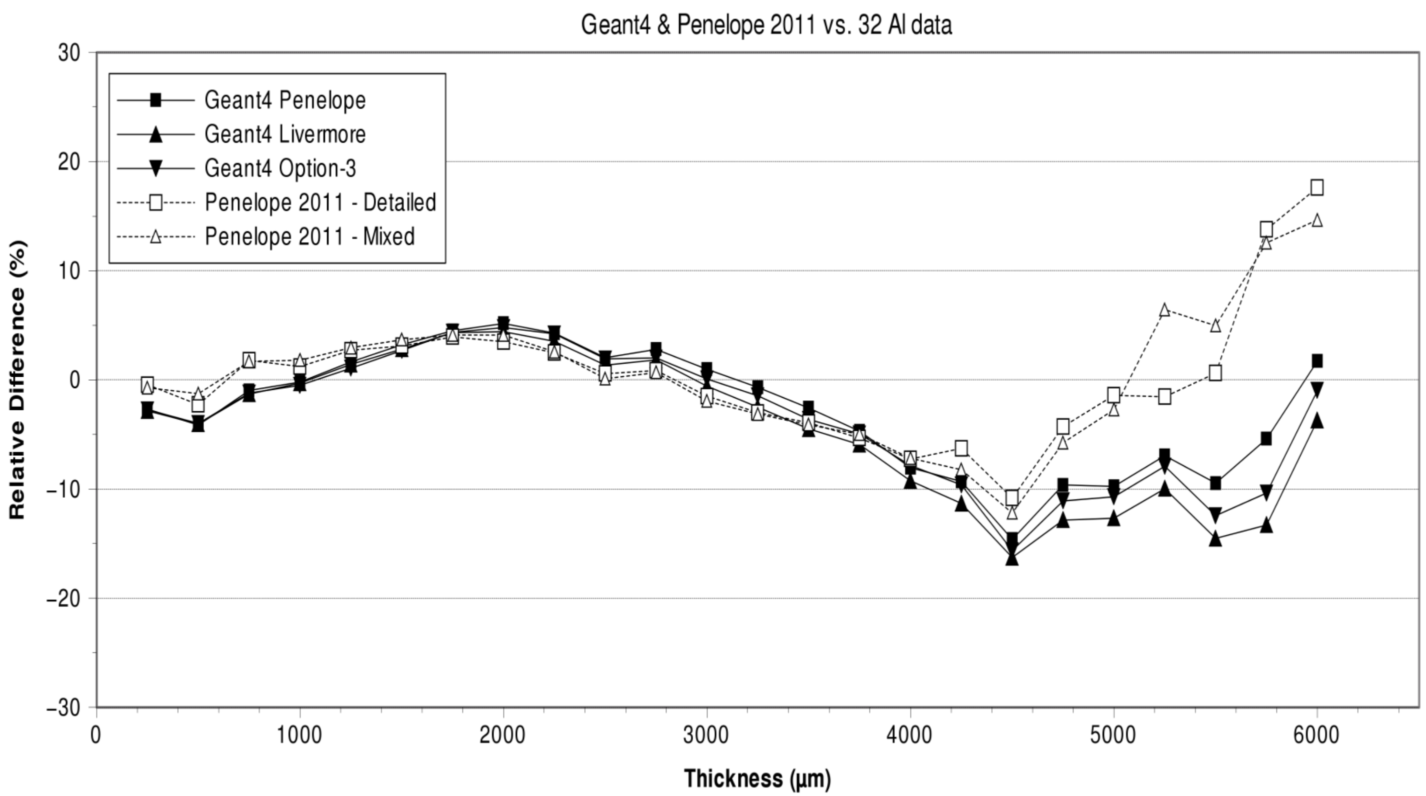
Experimental dose enhancement effects

Geant4 modelling. Data vs G4Penelope

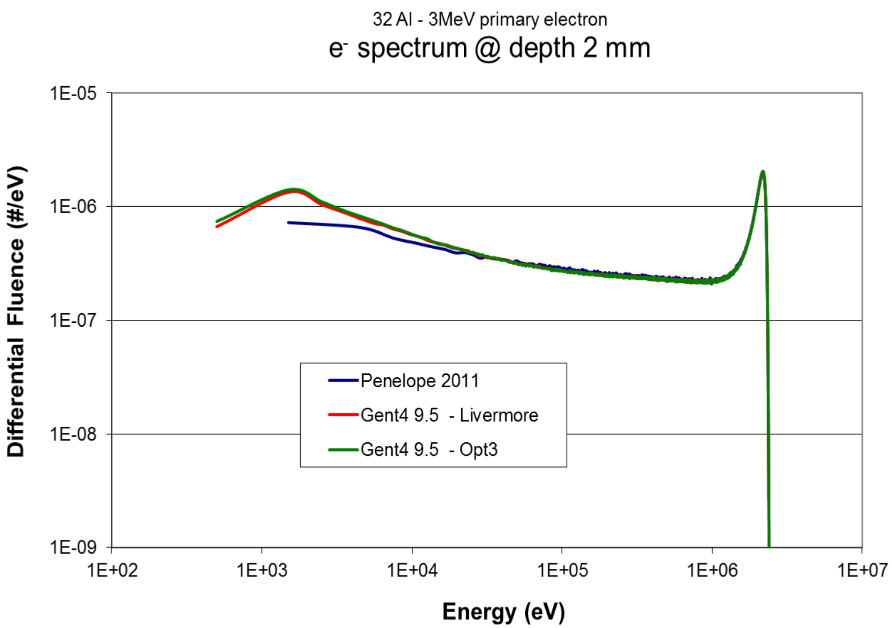


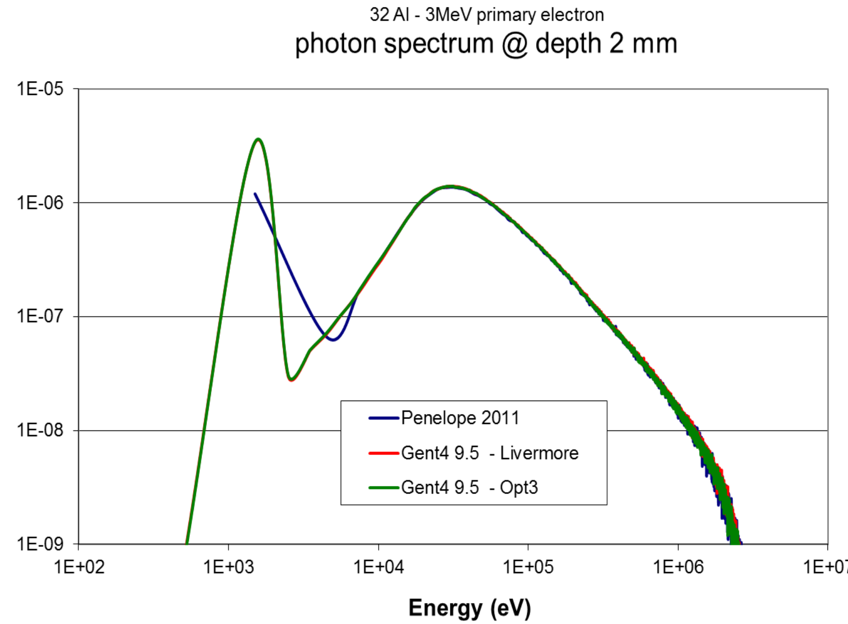
Experimental dose enhancement effects

Geant4 and Penelope-2011 vs Data



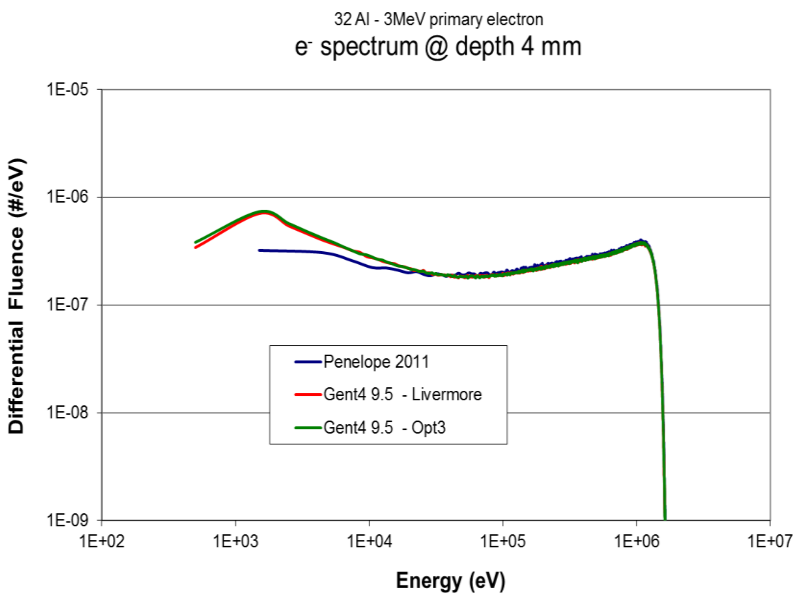
Where do the differences G4 – Penelope2011 come from?

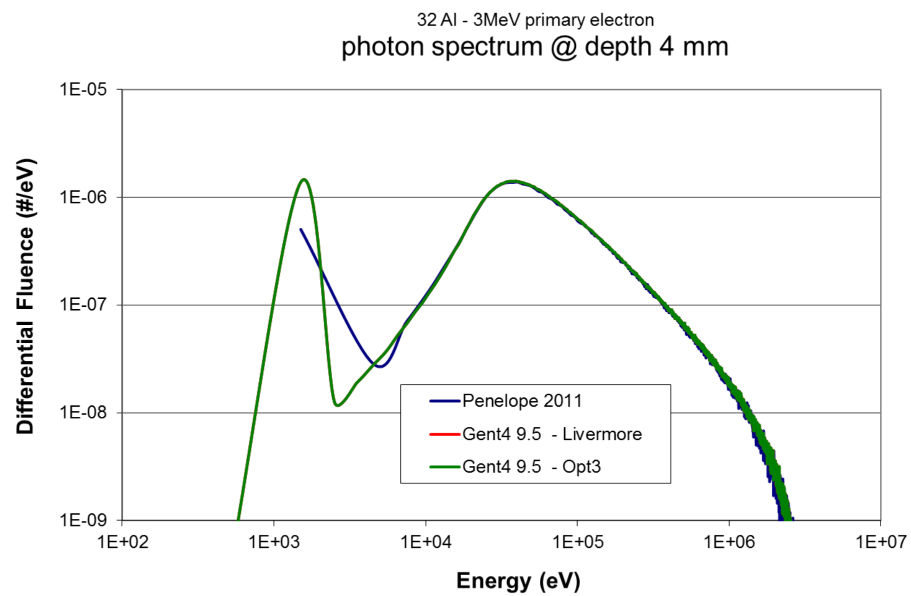




- Good agreement between both codes
- Electron and photon spectra are similar but for very low energies
  - Different mechanisms and values to simulate low energy particles producation: geometrical cuts (G4) and absorption energies (Penelope)

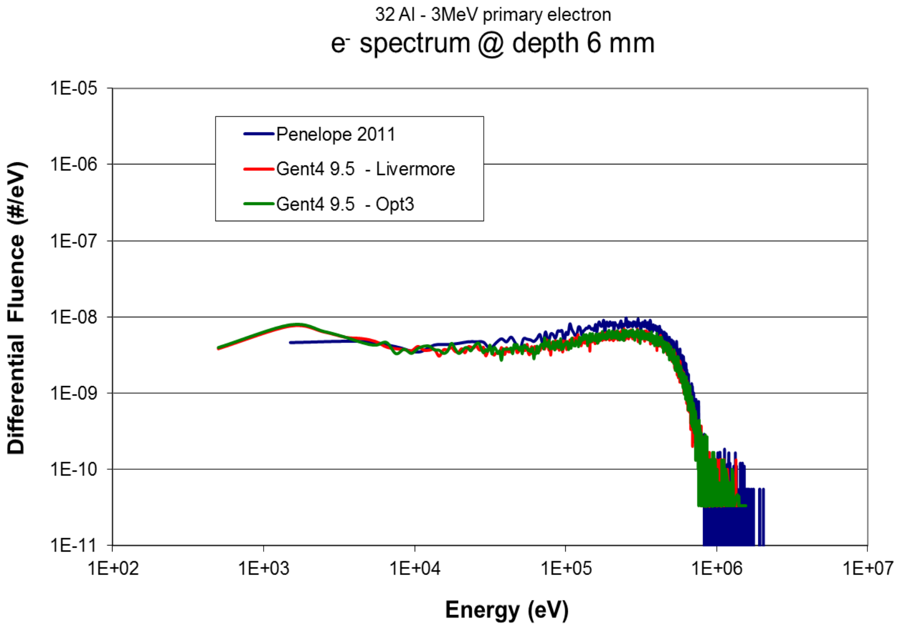
Experimental dose enhancement effects

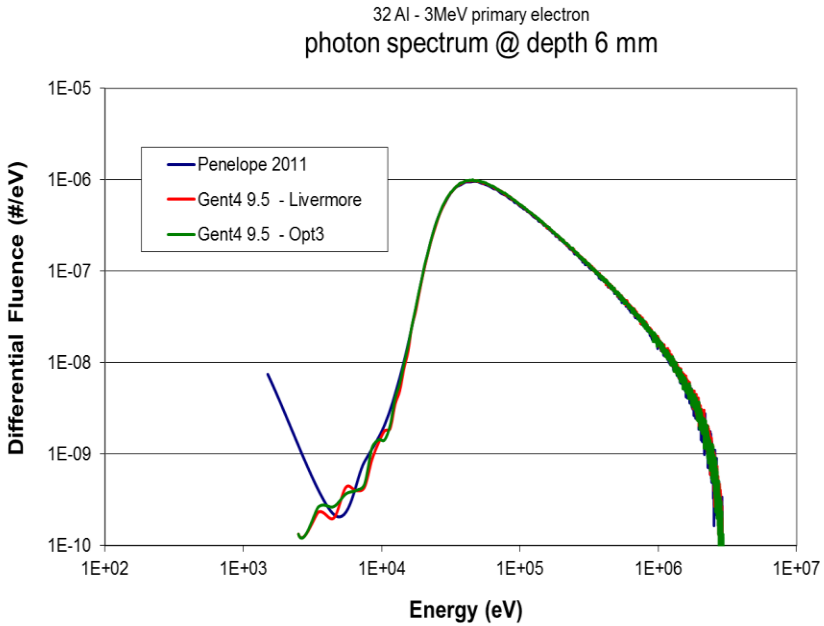




- Good agreement between both codes
- As in the 2 mm depth case, electron and photon spectra are still similar but for very low energies

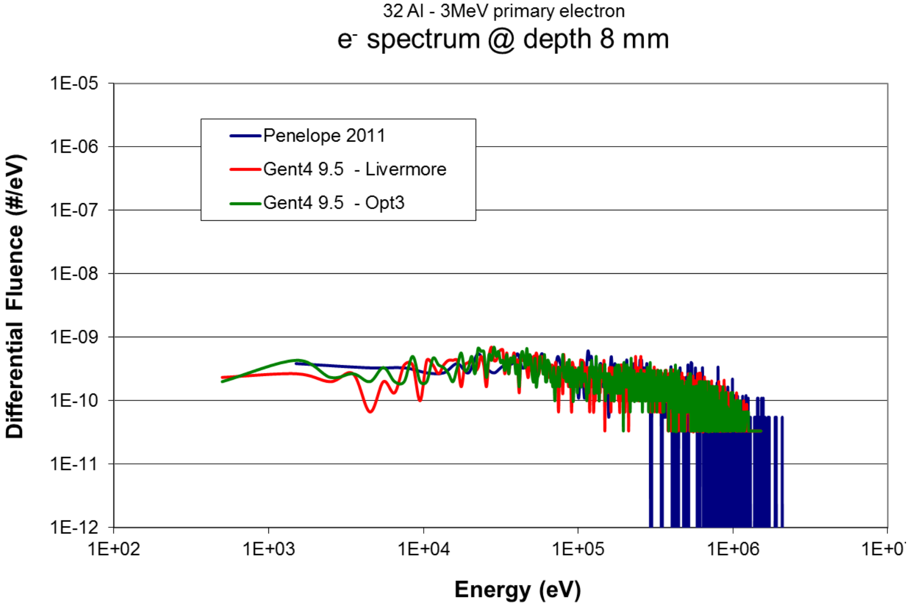
Experimental dose enhancement effects

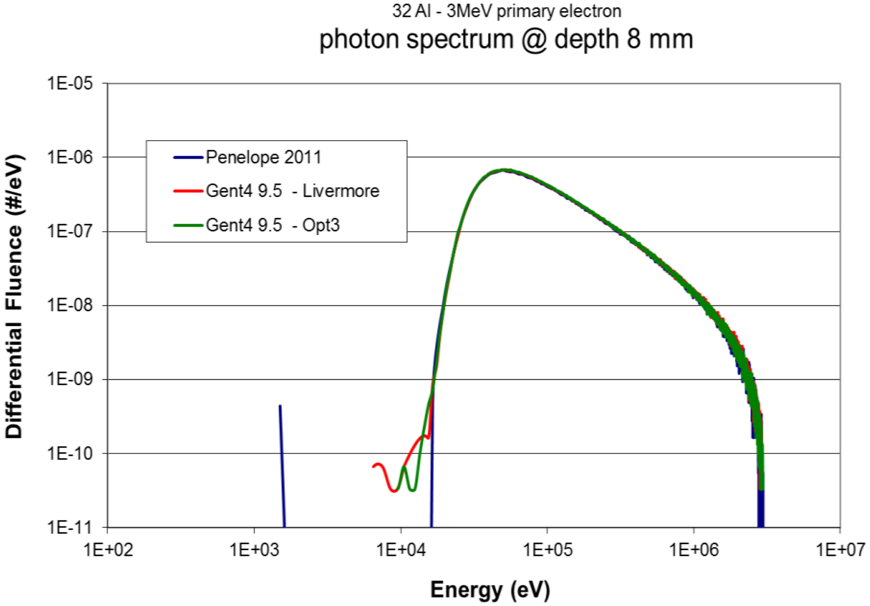




- Significant differences in the electron spectra (Geant4 spectra attenuated ~20-30%)
  - Electron spectra dominated by primaries
  - MSC modelling diferences becomes significant
- Photon spectra are still similar
  - Photon production almost similar for both codes

Experimental dose enhancement effects

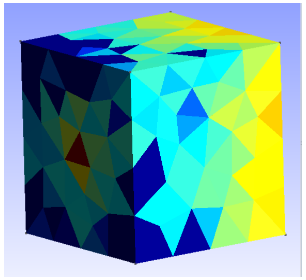




- Again, predicted electron spectra by both codes agree
  - No primary electron is present.
  - Spectra is dominated by secondary electrons
- Predicted photon spectra are still similar
  - Photon production is almost equivalent in both codes

Conclusions

- Total dose for high energy electrons is dominated by
  - primary particles in the e- range region, low shielded layers, and then it depends strongly on electron propagation modelling
  - Bremmstrahlung photons for high shielded layers showed low dependence on EM model.
- Major differences between EM Models comes from MSC modelling
- Atomic de-excitation has no significant impact on total dose predictions
- Optimum production cut, for total dose calculations, is found to be
  - 1 micron for Opt0 and Opt4
  - 1 to 100 micron for Opt3, Penelope and Livermore
- Best EM candidates for space radition shielding
  - Opt3 and Penelope
- Futher analysis of Geant4 MSC models should be done



Geant4 I/Fs to SPIS

Arbitrary geometry scoring

To develop a SPIS to Geant4 interface that:

- ⇨ Extends G4/GRAS to read SPIS mesh geometries
  - Converting SPIS meshes to Geant4 geometry
  - Fully command-line driven
  - and allowing G4 simulation on SPIS mesh ed volumes (using parallel scoring worlds)

Return Geant4 results to SPIS:

- ⇨ Providing radiation effects in terms of
  - Deposited dose (fconductivity)
  - Charge (transport, poisson eqs)
- ⇨ For each mesh cell of SPIS geometry
- ⇨ Output results in a SPIS compliant format

SPIS Mesh Reader & G4ScoringUserGeom

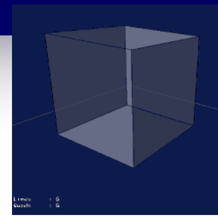
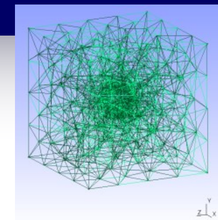
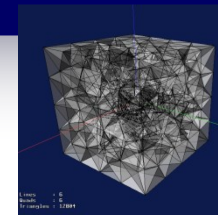
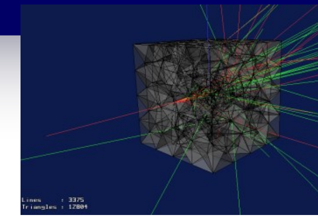
- New set of "Persistency" C++ classes → GmshGeometry family

  GmshGeometryReader, GmshElement, GmshNode, etc
- To read and parse GMSH ".msh" ASCII files.
- Compatible with GMSH 2.x series.
  - Based on Gmsh 2.5 specification. Tested with Gmsh 2.5 for Linux
- All GMSH sections are parsed and stored in a GmshGeometry object

  Mandatory: $MeshFormat, $Nodes, $Elements

  Optional: $ElementData, $NodeData
- Additional $Data sections can be added
- New GRAS geometry constructor → GRASGmshGeometry
- New G4 scoring mesh geometry → G4ScoringUserGeom

Geant4 I/F to SPIS

```
/gras/geometry/type gdml
/gdml/file/ test_geom.gdml
```

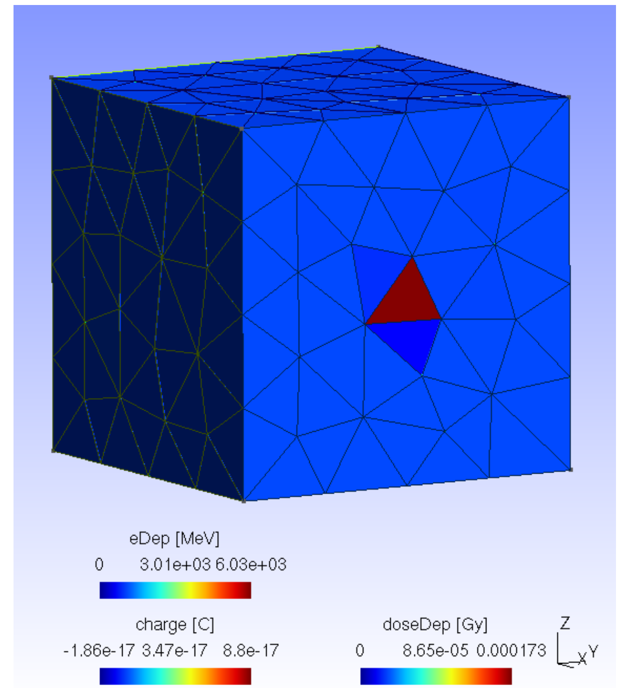
```
/gras/analysis/mesh/addModule MyMesh
/gras/analysis/mesh/MyMesh/geometryType gmsh
/gras/analysis/mesh/MyMesh/geometryFile test.msh
```

```
/gras/physics/setCuts 0.01 mm
/gras/physics/addPhysics em_lowenergy

/gps/position 25 0 0 mm
/gps/direction -1 0 0
/gps/particle e-
/gps/energy 20.00 MeV
```

```
/score/open MyMesh
/score/quantity/cellCharge charge C
/score/quantity/doseDeposit doseDep Gy
/score/quantity/energyDeposit eDep MeV
/score/verbose 0
/score/close
```

```
/run/beamOn 10000
```



Results

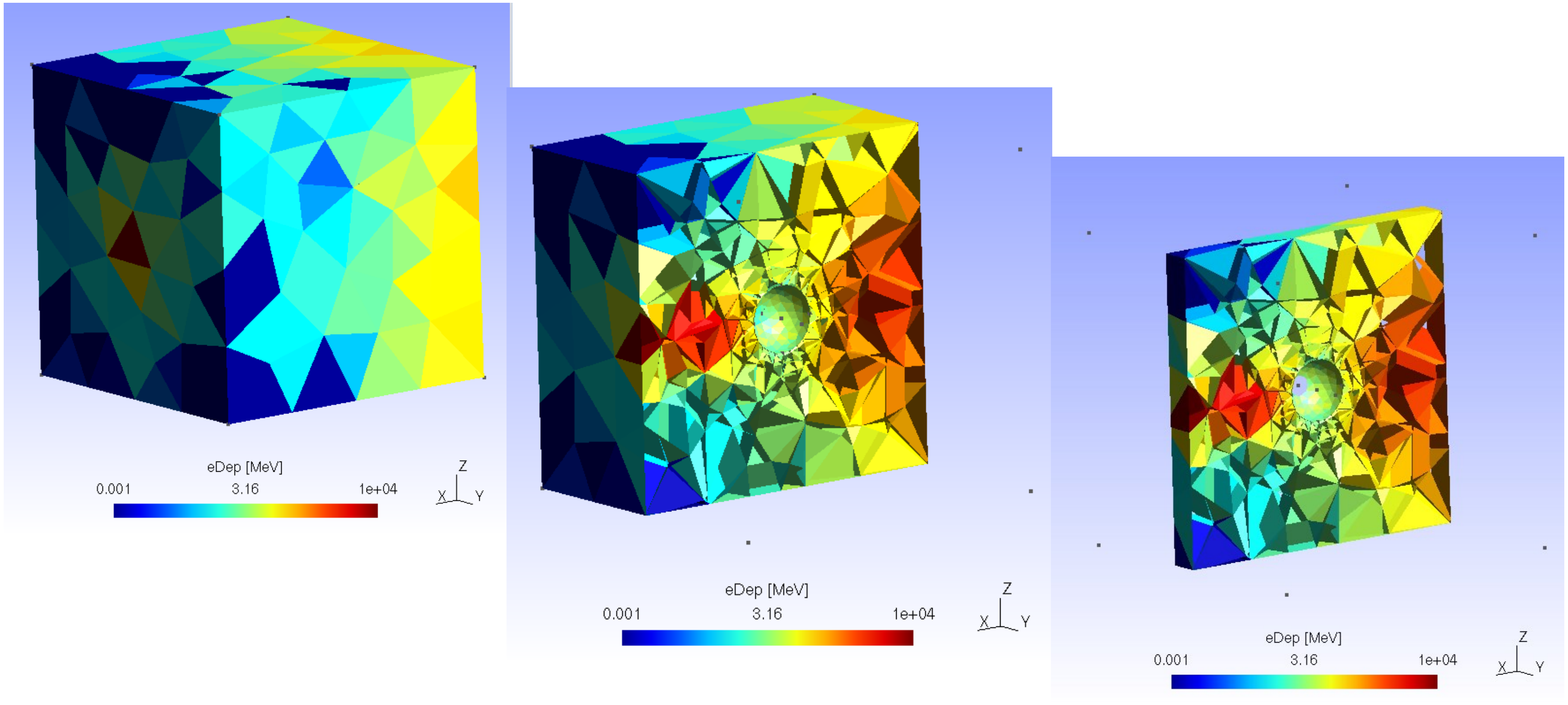
Dose, Charge and Energy deposited per mesh cell

Gmsh formatted

Visualized with GMSH Linux tool

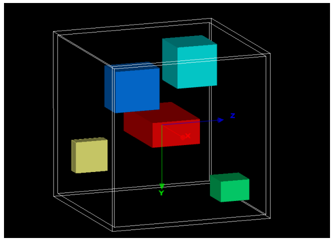
Deposited Energy

Visulaization with GMSH post-processing tool



GRAS-SPIS Charging Interface

- New GMSH ".msh" file reader classes available for Geant4 and GRAS
- New generic G4ScoringUserGeomFile to score quantities in arbitrary geometry volumes user-defined (GDML, GMSH, C++)
  - Other scoring geometry formats can be easily added is parsing classes are developed
- New GRASMeshAnalysisModule
  - Loads GMSH, GDML files as parallel scorers
  - Outputs analysis results in a SPIS-GMSH compliant format



New tools:

Automated payload arrangement inside a S/C

Automated Payload Arrangement

Objectives

- Analysis of the impact of different payload arrangement solutions in the total deposited dose in selected locations
- Using an automated optimization algorithm
  - Genetic Algorithms + Geant4 Reverse Monte Carlo
- Study case
  - Representative 5 boxed-payload inside a simple generic S/C
  - Usingas input typical MEO electron environment
  - And optimizing TID at a selected component inside one of the boxes

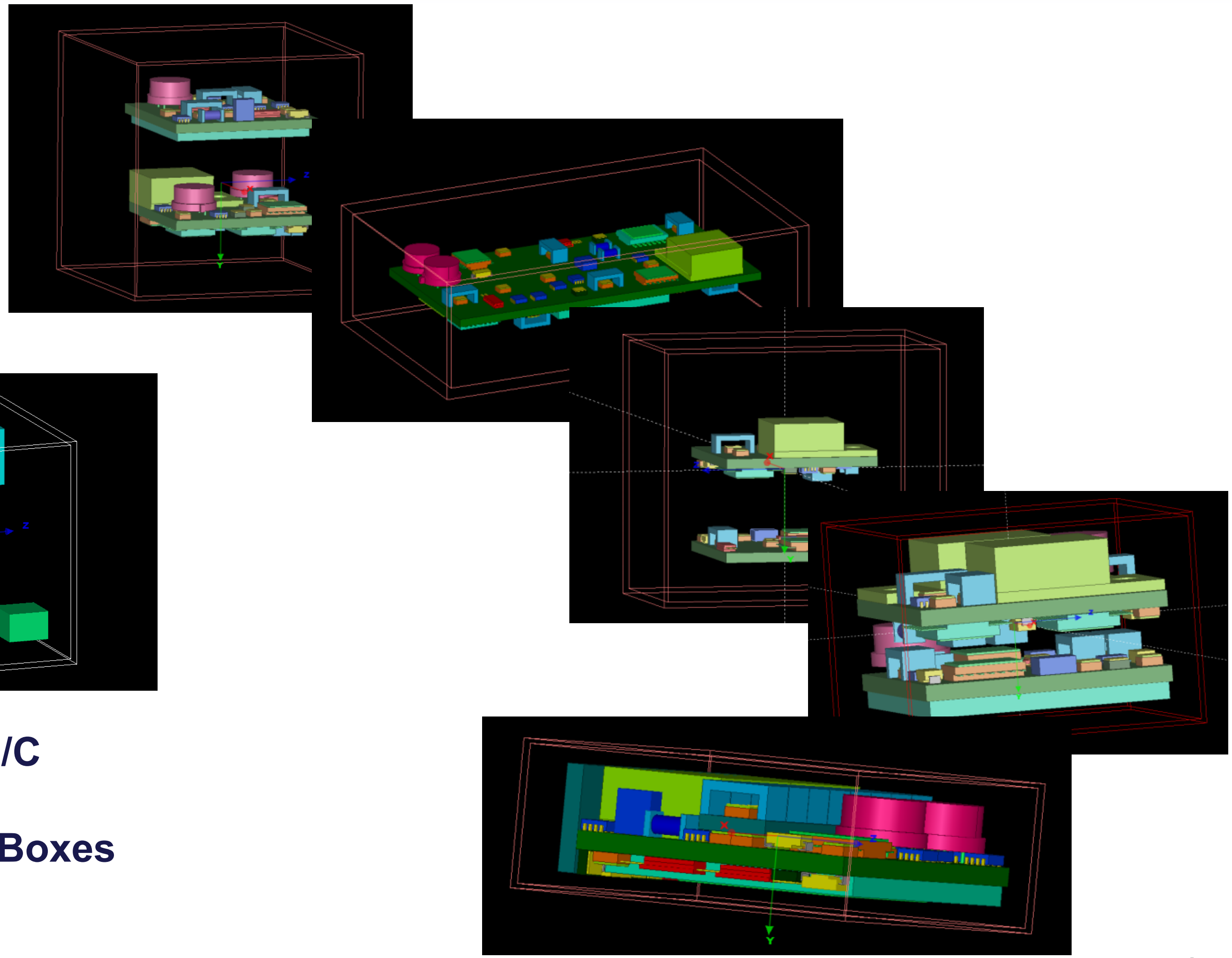
G4-GA algorithm basics

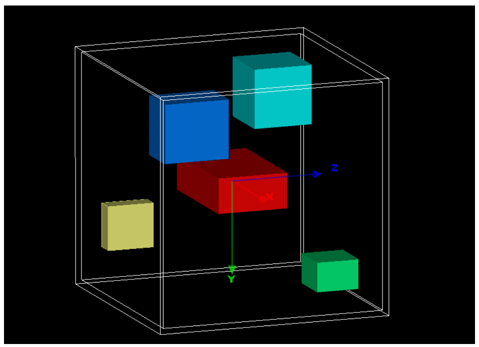
- GA chromosomes store information for XYZ coordinates of a box
- GA gens specifies the position of all boxes in 3D

Typical GA-G4 sequence:

- An initial population is generated: discrete XYZ sets
- Selection of a generation
  - A GDML geometry is generated using XYZ defined by genes/chromosomes
  - Impossible geometries are discarded (G4 Overlapping,etc)
  - Reverse MC is started
  - Fitness function: minimum dose ($f = 1 - TID/TID_{max\text{-}allowed}$)
- Apply GA common techniques to produce a new generation
  - Crossover, mutation, elitism

Automated Payload Arrangement





Simple S/C
+
5 Electronic Boxes

Automated Payload Arrangement

Main parameters

- Name of the initial GDML file
- List of boxes (volume names) to be included in the analysis
- Name of target volume
- (X,Y,Z) ranges for moving boxes
- Maximum allowed dose for normalising fitness function
- Name of the macro file with the environment spectrum
- GA specific parameters
- Geant4 specific parameters

```
&GAEES
  binpath='./runGRAS.sh'
  maxgen=20
  microga=1
  npopsiz=50
  DoseMax=1.0E13
  nXDivs=64
  nYDivs=64
  nZDivs=64
  nBoxes=5
  XMIN=-120.0
  XMAX=120.0
  YMIN=-120.0
  YMAX=120.0
  ZMIN=-120.0
  ZMAX=120.0
  outDir='.'
  outname='SIMPLE_01'
  gdml='Simple_SC.gdml'
  targetVolume='Box4_PCB1_DetectorSi_PV'
  adjointSurface='Box4_PCB1_DetectorSi_PV'
  extSurfRadius=499
  extSurfRadiusUnit='mm'
  primarySpectrum='primarySource.g4mac'
  dosePrecision=5
  saveNumEvents=10000
  adjointNumEvents=1000000
  grasEnvScript='./env_elshield.sh'
  grasBinary='./grasGA'
  grasMacDir='./macros'
  grasGeomDir='./geometry'
 /
```

Automated Payload Arrangement

- ##################### Generation 1 #######################
- # Box X Y Z Value
- 1 1 22.5000 151.8750 -151.8750 0.749
- 1 2 -168.7500 -78.7500 -126.5625 0.880
- 1 3 -104.0625 -16.8750 109.6875 0.170
- 1 4 -59.0625 112.5000 -28.1250 0.851
- 1 5 -30.9375 56.2500 16.8750 0.379
- Fitness: 0.8541
- Total Dose: 1.459E+11 MeV
- ==
- 2 1 16.8750 -154.6875 168.7500 0.721
- 2 2 160.3125 -126.5625 -137.8125 0.373
- 2 3 -73.1250 -16.8750 -112.5000 0.658
- 2 4 -104.0625 53.4375 78.7500 0.094
- 2 5 101.2500 -129.3750 135.0000 0.298
- Fitness: 0.0000
- Total Dose: -1.000E+33 MeV
- ==

Final output results

- ##
###

- Summary of Output

Generation	Evaluations	Avg. Fitness	Best Fitness
1	5	0.3616	0.9540
2	10	0.8766	0.9548
3	15	0.8779	0.9596
4	20	0.8778	0.9548
5	25	0.5617	0.9981
6	30	0.5685	0.9980
7	35	0.9683	0.9997
8	40	0.5973	0.9997
9	45	0.3680	0.9997
10	50	0.5382	0.9998

4.7 E10 MeV

2.05 E8 MeV

SUMMARY & CONCLUSIONS

- A review of electron EM physics models in Geant4 has been performed, providing new refinements and new interfaces to manage them
- New datasets for electron dose enhancement effects in multi-layer structures are available
  - Comparisons to Geant4 EM models aleady done.
- New geometry interfaces allow G4/GRAS to read complex Gmsh meshes and perform radiation calculations on them
- Parallel scoring is now possible for arbitrary geometries: Gmsh, GDML and C++ user-defined
- Preliminary assessment of 3D GA-based techniques seem to be a very promising approach to get automated shielding optimization tools.