Geant4 Package in SPENVIS

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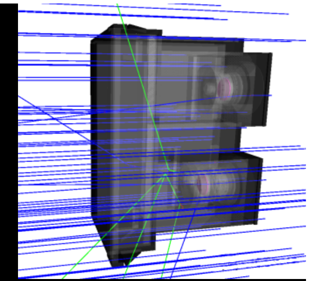

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- Material definition
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- Particle source
- GDML source geometry for GRAS
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- Selecting analysis parameters
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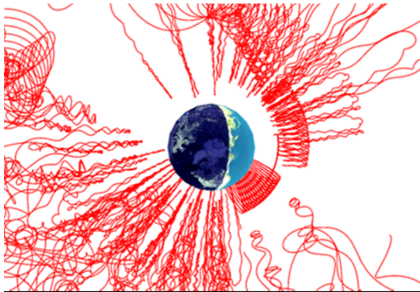
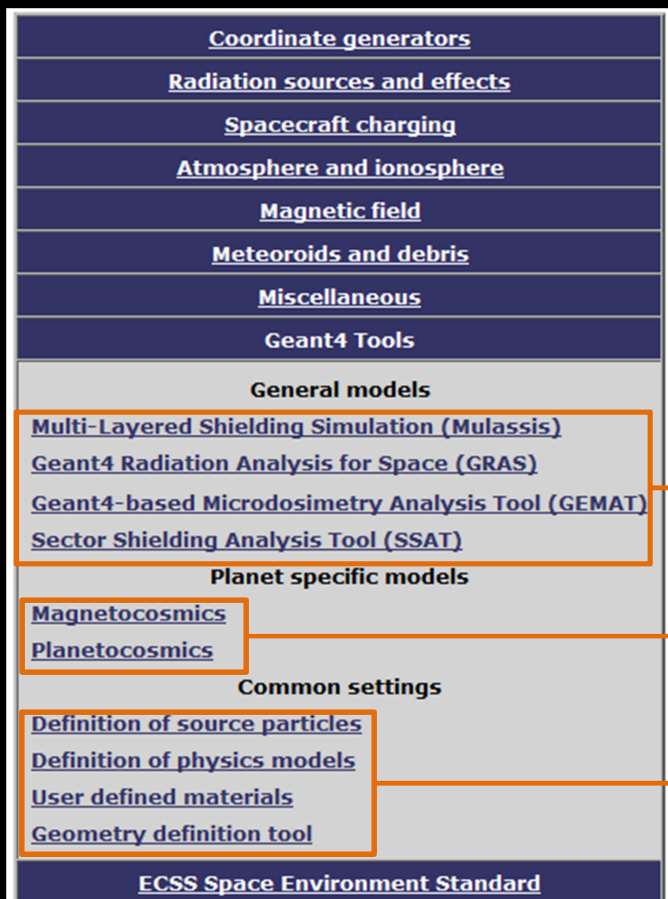


Introduction

- User friendly interface
- No prior knowledge of Geant4
- Generated macro file can be used directly by local Geant4 application
- Interaction with other SPENVIS models & tools

Introduction

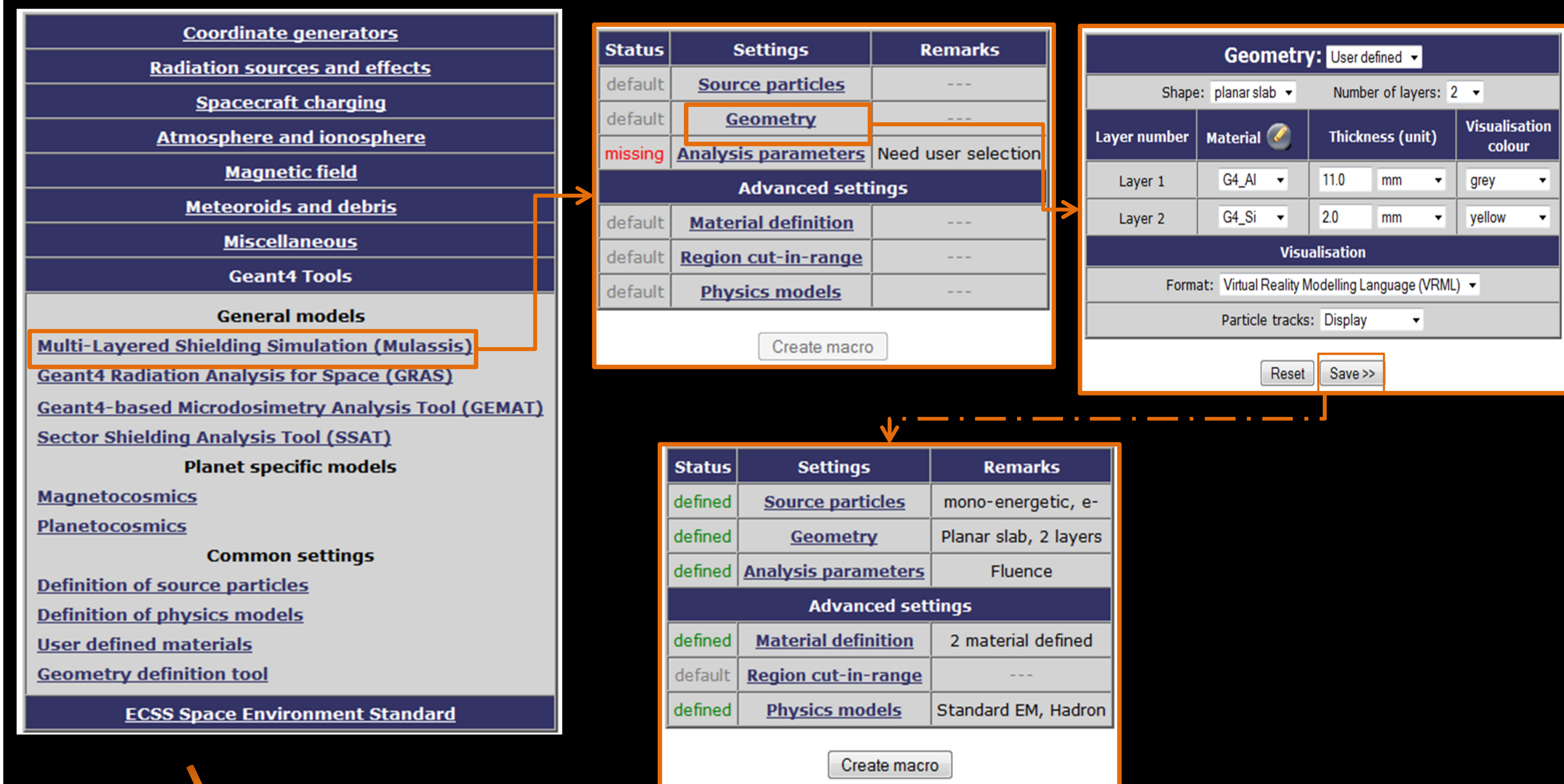


Models available for all planets

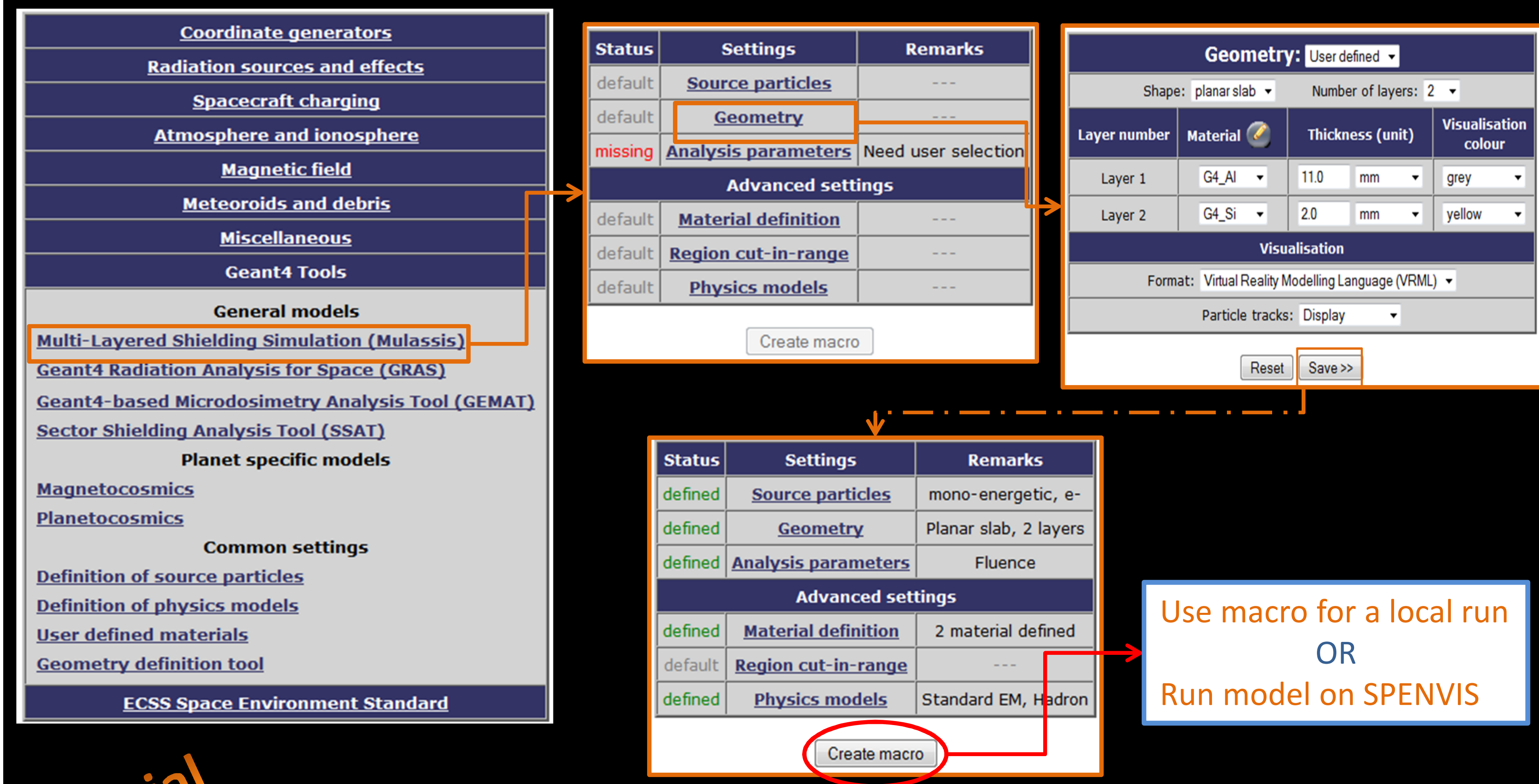
Model availability depends on planet selection

Tools providing inputs for multiple models

Introduction



Introduction



Overview of the Geant4 models in SPENVIS

- Geant4 Radiation Analysis for Space (GRAS v2.3, v3.1)
  - General space radiation analysis for 3D geometry models
- Multi-Layered Shielding Simulation (MULASSIS v1.19, v1.23)
  - Radiation analysis for a multi-layered, one-dimensional shield
- Geant4-based Microdosimetry Analysis Tool (GEMAT v2.4, v2.8)
  - Microdosimetry effects of space radiation on micro-electronics and micro-sensors
- Sector Shielding Analysis Tool (SSAT v2.1)
  - Performs ray tracing from a user defined point within the geometry to determine shielding levels and shielding distributions

Overview of the Geant4 models in SPENVIS

- MAGNETOCOSMICS (v2.0)
  - Charged particle trajectories & magnetic field lines
  - Cut-off rigidities as a function of position

- PLANETOCOSMICS (v2.0)
  - Definition of a planetary magnetic field, atmosphere & soil
  - Interactions of cosmic rays with planetary environment

- Supporting Tools
  - Geometry definition tools
  - GDML analysis tool
  - Material definition tool

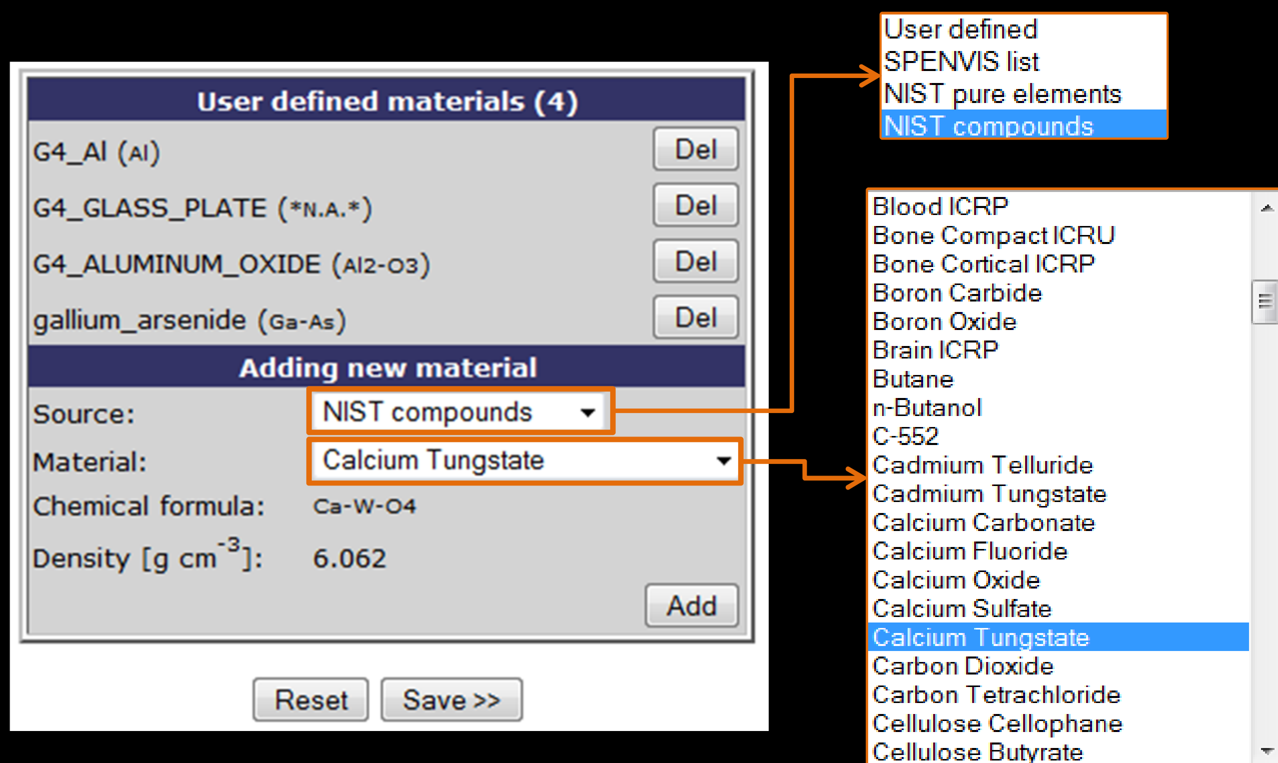
Overview of the Geant4 models in SPENVIS

Other:

- Mars Energetic Radiation Environment Models (MEREM)
- Jupiter Radiation Environment and Effects Models and Mitigation (JOREM)
  - PLANETOCOSMICS-J
  - Genetic Algorithm Radiation Shield Optimiser (GARSO) for MULASSIS
- MC-SCREAM
  - NIEL based damage equivalent fluences for solar cells

Material definition

Used by:
MULASSIS, GRAS, GEMAT & PLANETOCOSMICS



Material definition: User defined

Used by:
MULASSIS, GRAS, GEMAT & PLANETOCOSMICS

No user materials have been defined

Adding new material

Source:	User defined
Name(*):	
Chemical formula:	
Density [g cm^{-3}]:	1

Add

(*) should include only letters, digits or underscores and start with a letter

Reset Save >>

Unique name chosen by user

Special syntax required:
- chemical symbol & stoichiometric proportion
- hyphen to separate elements
- isotope and stoichiometry defined by integers

www.spenvis.oma.be/help/models/g4_material.html
http://www.spenvis.oma.be/forum/viewtopic.php?f=5&t=116

GDML geometry definition

Available for GRAS & SSAT

GRAS execution mode: GDML

Status	Settings	Remarks
default	Source particles	---
default	Source geometry	no visualisation
error	Analysis parameters	Load GDML first
Advanced settings		
missing	GDML definition	Need user selection
default	Region cuts-in-range	---
default	Physics models	---

Create macro

Status	Settings	Remarks
default	Shielding distribution	---
default	Ray tracing	---
missing	GDML definition	Need user selection

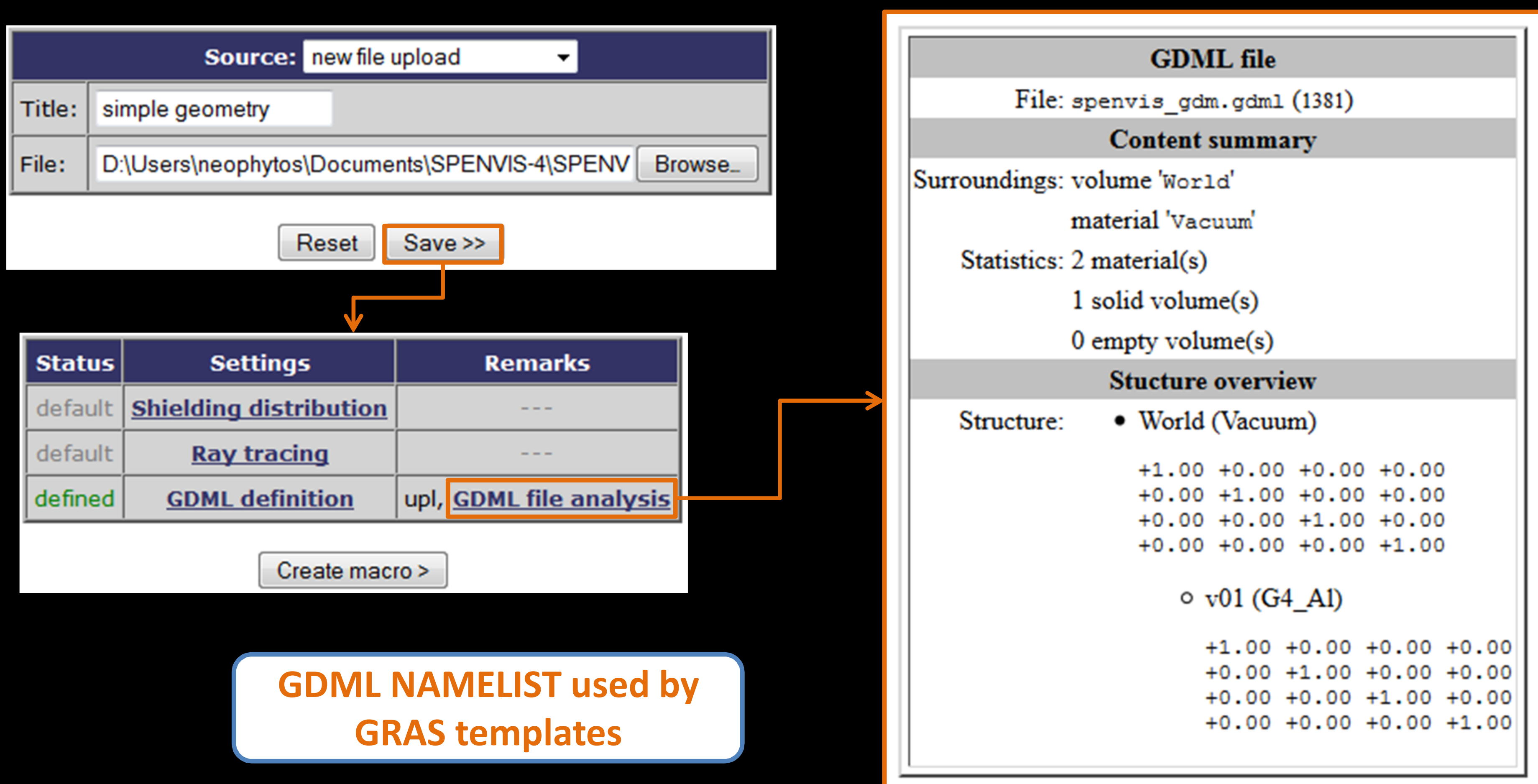
last geometry definition
uploaded GDML file
new file upload

Source: new file upload

Title:	simple geometry
File:	D:\Users\neophytos\Documents\SPENVIS-4\SPENV Browse...

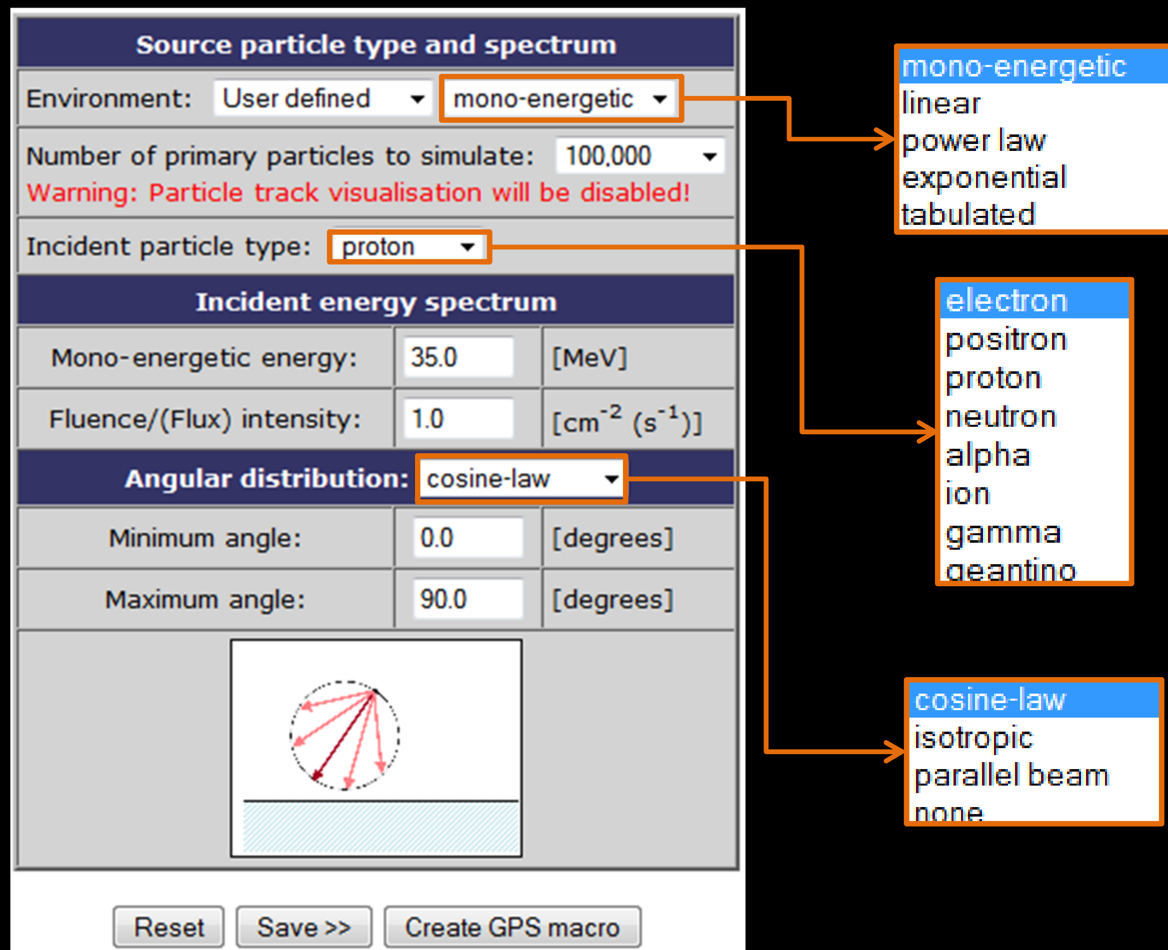
Reset Save >>

GDML geometry definition



Incident particle source: User defined

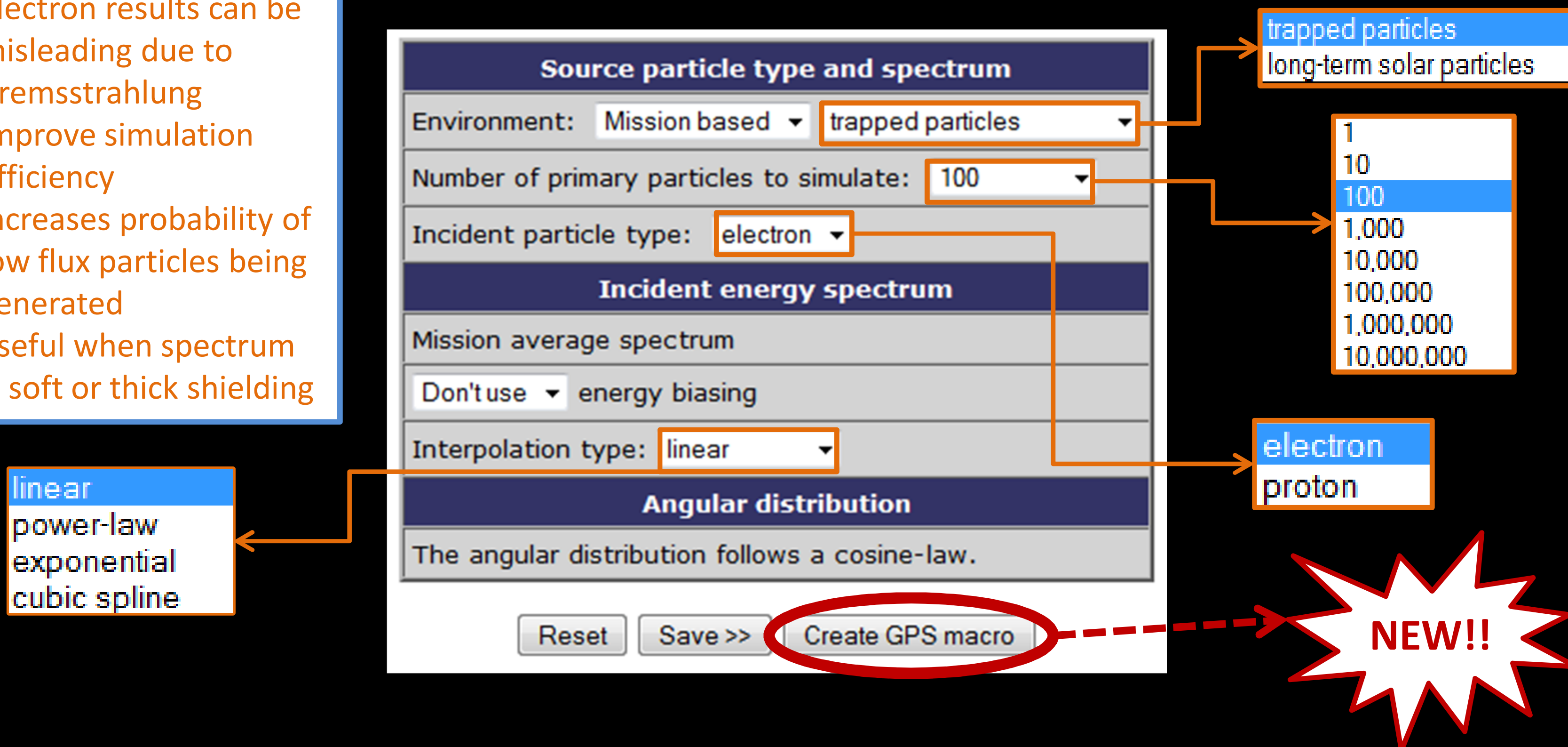
Used by:
MULASSIS, GRAS, GEMAT & PLANETOCOSMICS



Incident particle source: Mission based

energy biasing:

- electron results can be misleading due to Bremsstrahlung
- improve simulation efficiency
- increases probability of low flux particles being generated
- useful when spectrum is soft or thick shielding



Incident particle source: Mission based

```
#
#Source definition
#
# ==============================
# SPENVIS particle source
# Project: SPENVIS_USER_WORKSHOP_2013
# title:
# Particle: proton
# Mission Segment:   1   365.0 Days
# ==============================
/gps/particle  proton
/gps/ene/type Arb
/gps/hist/type arb
/gps/hist/point  1.000000E-01   3.050200E+08
/gps/hist/point  1.500000E-01   2.332000E+08
/gps/hist/point  2.000000E-01   1.721000E+08
/gps/hist/point  3.000000E-01   1.010300E+08
/gps/hist/point  4.000000E-01   6.609200E+07
/gps/hist/point  5.000000E-01   4.435900E+07
/gps/hist/point  6.000000E-01   3.142400E+07
/gps/hist/point  7.000000E-01   2.321700E+07
/gps/hist/point  1.000000E+00   1.149900E+07
/gps/hist/point  1.500000E+00   3.794100E+06
/gps/hist/point  2.000000E+00   1.468200E+06
/gps/hist/point  3.000000E+00   3.320500E+05
/gps/hist/point  4.000000E+00   1.170500E+05
/gps/hist/point  5.000000E+00   5.038100E+04
/gps/hist/point  6.000000E+00   2.845300E+04
/gps/hist/point  7.000000E+00   1.763900E+04
/gps/hist/point  1.000000E+01   6.878600E+03
/gps/hist/point  1.500000E+01   1.599500E+03
/gps/hist/point  2.000000E+01   4.542900E+02
/gps/hist/point  3.000000E+01   9.340400E+01
/gps/hist/point  4.000000E+01   3.077900E+01
/gps/hist/point  5.000000E+01   1.892200E+01
/gps/hist/point  6.000000E+01   1.089000E+01
/gps/hist/point  7.000000E+01   8.466200E+00
/gps/hist/point  1.000000E+02   5.486300E+00
/gps/hist/point  1.500000E+02   2.841100E+00
/gps/hist/point  2.000000E+02   1.604200E+00
/gps/hist/point  3.000000E+02   5.475100E-01
/gps/hist/point  4.000000E+02   3.646600E-02
/gps/hist/inter  Lin
/gps/ang/type cos

#
#Normalisation
#
/control/alias  NORM_FACTOR_ENERGY "   2.022277E+15 "
```

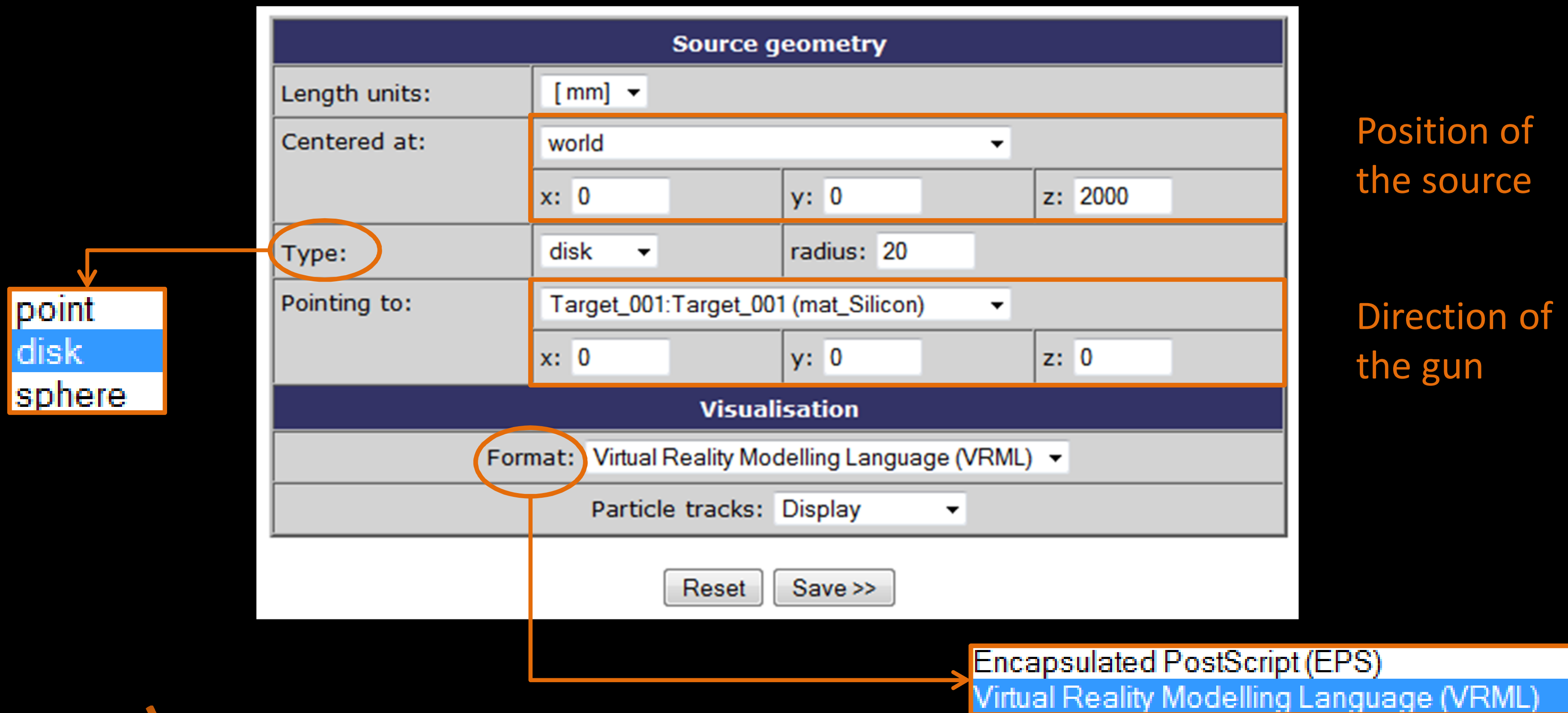
```
'Trapped proton model: AP-8 MAX'
 0.05, 2.00, 0.00
'Energy','MeV', 1,'Energy'
'IFlux','cm!u-2!n s!u-1!n', 1,'Integral Flux'
'DFlux','cm!u-2!n s!u-1!n MeV!u-1!n', 1,'Differential Flux'
  1.0000E-01,  6.4126E+07,  3.0502E+08
  1.5000E-01,  5.0671E+07,  2.3320E+08
  2.0000E-01,  4.0806E+07,  1.7210E+08
  3.0000E-01,  2.8636E+07,  1.0103E+08
  4.0000E-01,  2.0599E+07,  6.6092E+07
  5.0000E-01,  1.5417E+07,  4.4359E+07
  6.0000E-01,  1.1727E+07,  3.1424E+07
  7.0000E-01,  9.1324E+06,  2.3217E+07
  1.0000E+00,  4.6266E+06,  1.1499E+07
  1.5000E+00,  1.8101E+06,  3.7941E+06
  2.0000E+00,  8.3252E+05,  1.4682E+06
  3.0000E+00,  3.3829E+05,  3.3205E+05
  4.0000E+00,  1.6842E+05,  1.1705E+05
  5.0000E+00,  1.0420E+05,  5.0381E+04
  6.0000E+00,  6.7660E+04,  2.8453E+04
  7.0000E+00,  4.7290E+04,  1.7639E+04
  1.0000E+01,  1.8940E+04,  6.8786E+03
  1.5000E+01,  5.9764E+03,  1.5995E+03
  2.0000E+01,  2.9453E+03,  4.5429E+02
  3.0000E+01,  1.4412E+03,  9.3404E+01
  4.0000E+01,  1.0772E+03,  3.0779E+01
  5.0000E+01,  8.2559E+02,  1.8922E+01
  6.0000E+01,  6.9876E+02,  1.0890E+01
  7.0000E+01,  6.0778E+02,  8.4662E+00
  1.0000E+02,  4.1063E+02,  5.4863E+00
  1.5000E+02,  2.2676E+02,  2.8411E+00
  2.0000E+02,  1.2652E+02,  1.6042E+00
  3.0000E+02,  4.6217E+01,  5.4751E-01
  4.0000E+02,  1.7018E+01,  3.6466E-02
'End of Block'
```

SPENVIS mission average spectrum e.g. from AP-8

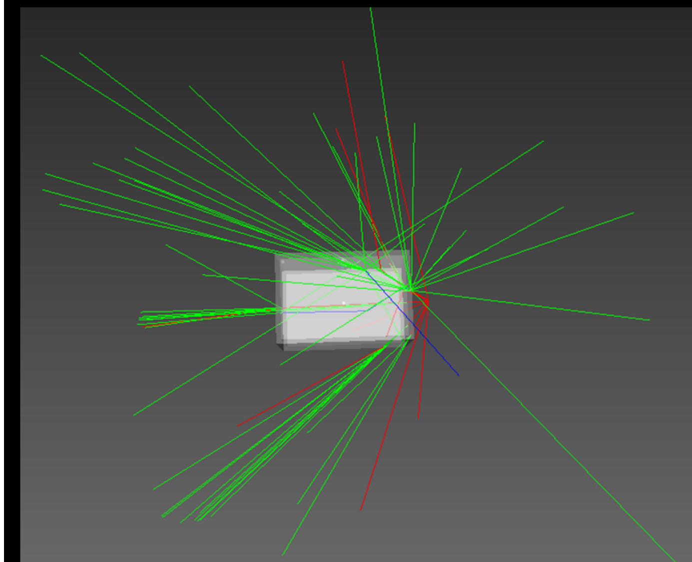
Calculated by integrating the differential particle spectrum over the energy limits of the simulation

$$\int_{T_1}^{T_0} f(T)dT = F(T_0) - F(T_1)$$

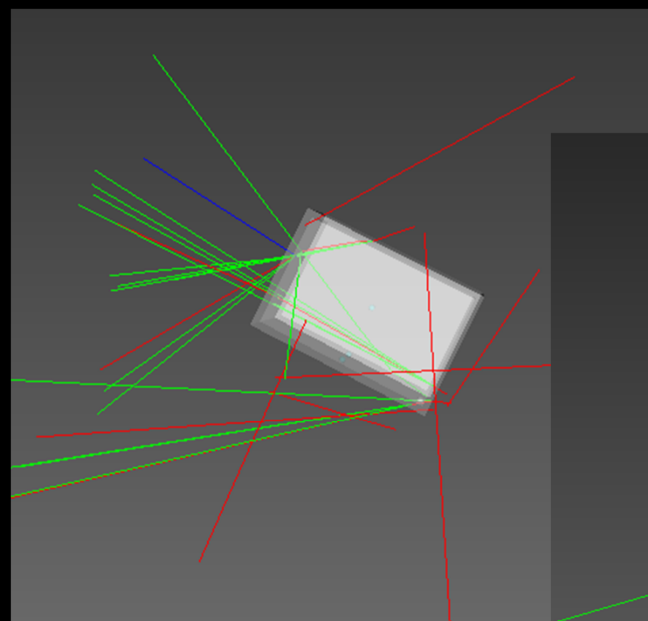
GDML source geometry for GRAS



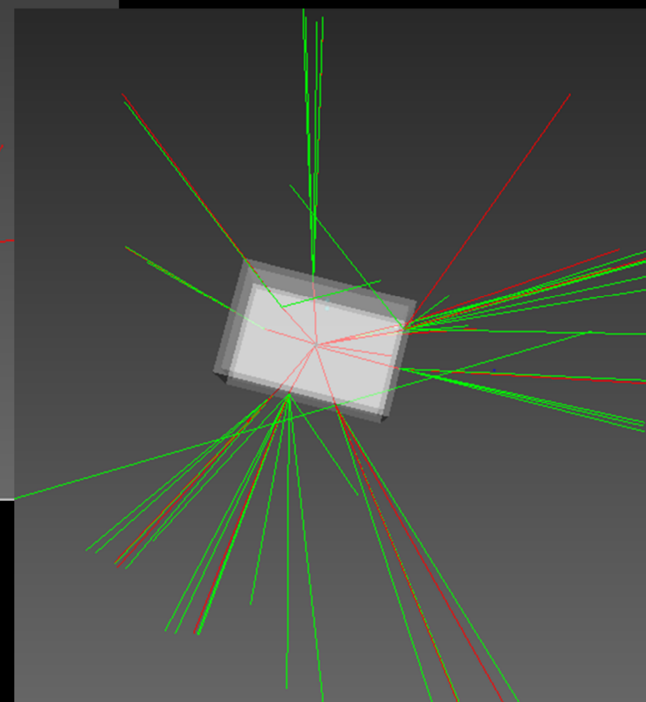
GDML source geometry for GRAS



Disk source of 20 mm radius



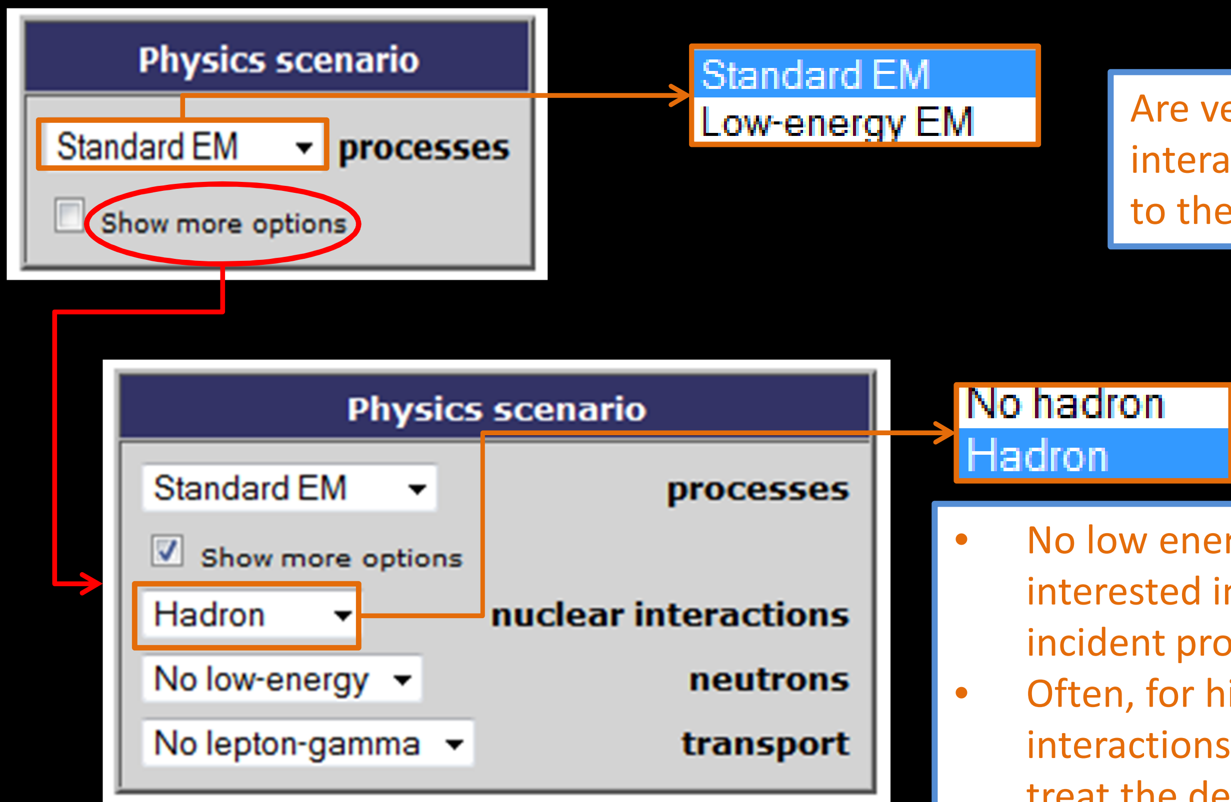
Spherical source of 2 m radius



Spherical source of 20 mm radius

All positioned w.r.t world

Physics scenario



Are very low energy EM interactions are important to the simulation or not?

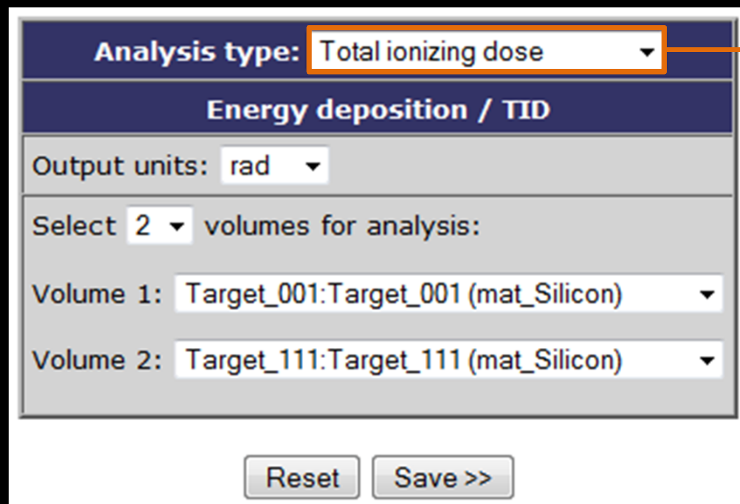
- No low energy neutrons if only interested in attenuation of incident protons by shielding layers
- Often, for high energy proton interactions it is unnecessary to treat the detailed electron-positron-gamma transport

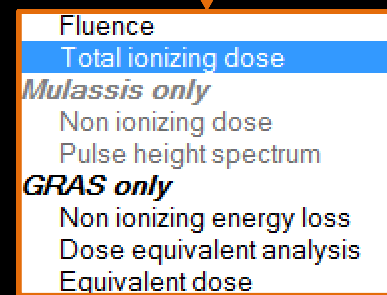
Cut-in-range

- General principles in Geant4 regarding secondary particle production cuts:
  1. Each process has its intrinsic limit(s) to produce secondary particles
  2. All particles produced (and accepted) will be tracked up to zero range
  3. Production cuts-in-range are assigned to regions
- A region is a collection of geometry volumes.
- Default region covering the whole geometry with global cut-in-range for gamma, electron and positron productions.
- User can change the global production cuts-in-range. The default values for the global cuts-in-range length is 1 µm.
- A cut of for example 1. mm for photons means that no photon will be produced if the expected range in the current material is less than 1. mm.

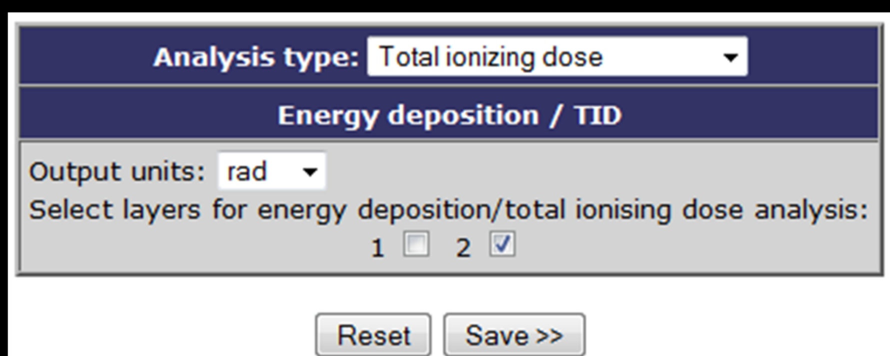
Selecting analysis parameters

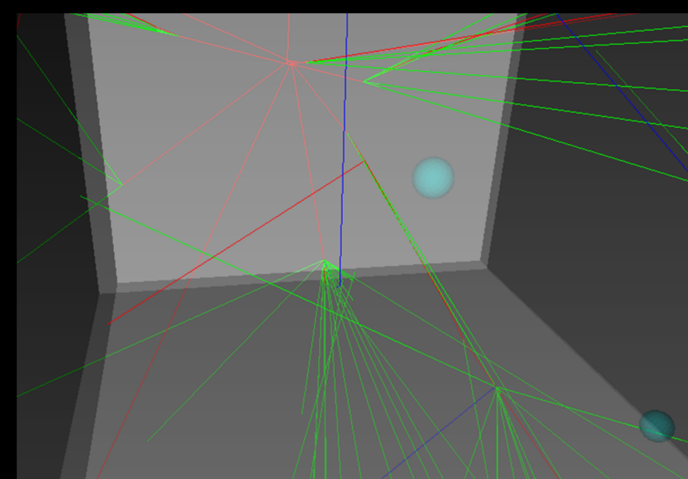
GRAS



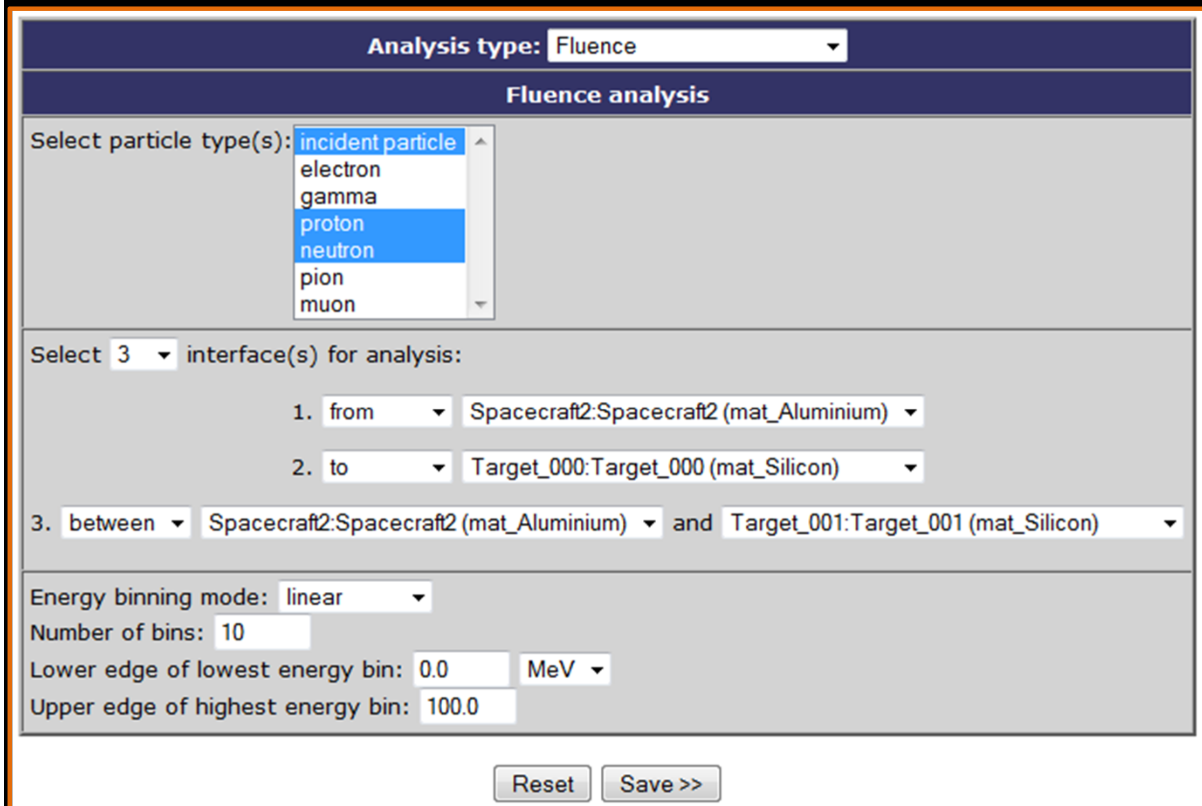


MULASSIS





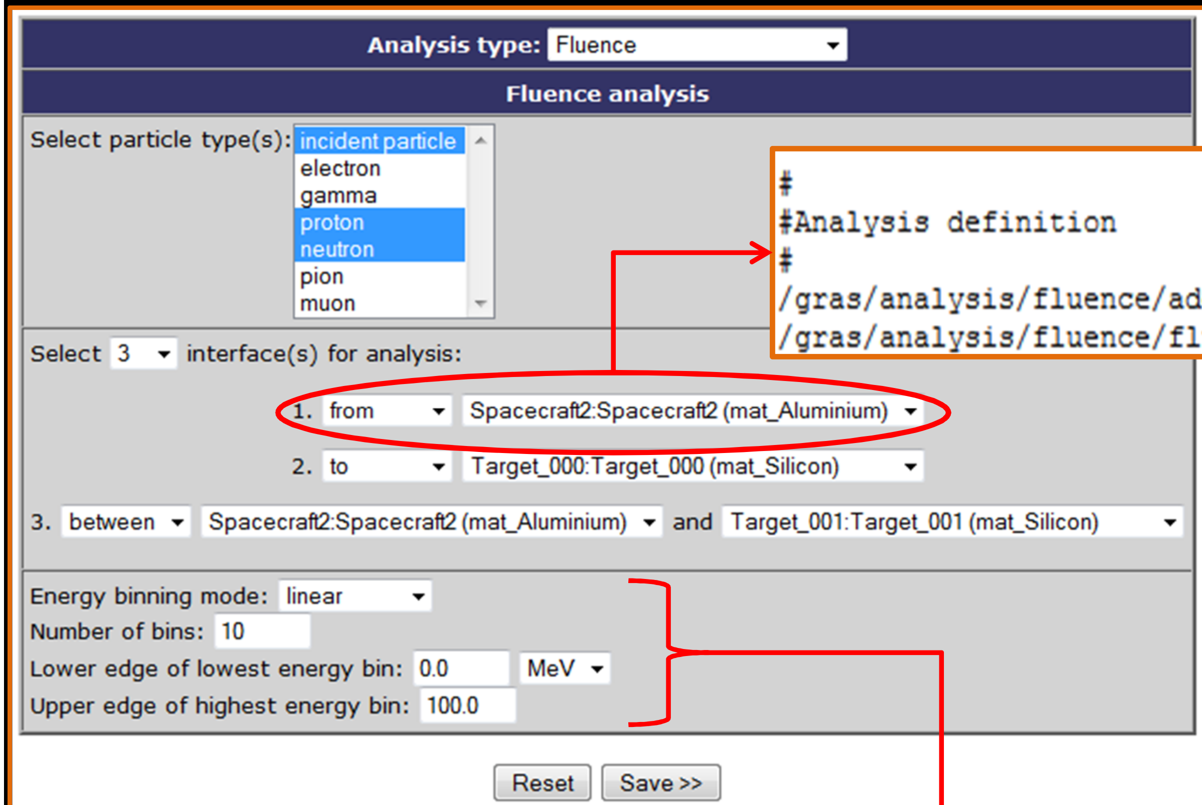
GRAS fluence analysis: GDML mode



Note that:

- **The order of the volume names is important!!**
- **Volumes must share a boundary otherwise output fluence is zero**

GRAS fluence analysis: GDML mode




```
#
#Analysis definition
#
/gras/analysis/fluence/addModule   fluence1
/gras/analysis/fluence/fluence1/addVolumeInterface {Spacecraft2} *
```

```
/gras/histo/setHistoByName fluence1_fluence_e-  10      0.000E+00      0.100E+03 MeV lin
/gras/histo/setHistoByName fluence1_fluence_proton  10      0.000E+00      0.100E+03 MeV lin
/gras/histo/setHistoByName fluence1_fluence_neutron  10      0.000E+00      0.100E+03 MeV lin
```

Future work

- Separate macro file for the source + GCRs as source
- Revisit physics scenario definition
- New functionalities in GRAS v3.1. e.g. reverse MC, normalisation, new analysis types (LET analysis, charging etc.)
- Geant4 models will continue being an important element in the new SPENVIS-NG
- New models will be more easily integrated (plug-in models, machine-machine interface etc.)

Bibliography

- Agostinelli S. et al, *GEANT4 a simulation toolkit*, Nuclear Instruments and Methods A, 506, 250–303, 2003
- Desorgher L., Flückiger E. O. & Gurtner M., *The PLANETOCOSMICS Geant4 application*, 36th COSPAR Scientific Assembly, Beijing, 16 - 23 July 2006
- Gonçalves P. et al, *The Martian Energetic Radiation Environment Models,* 38th COSPAR Scientific Assembly, Bremen 18-15 July, p.10, 2010
- Heynderickx D., *The JOREM Project: Jupiter Environment, Effects and Shielding Prediction Models for SPENVIS*, European Planetary Science Congress, Rome 20-24 September, p.628, 2010
- Santin G. et al, *GRAS: A general-purpose 3-D modular simulation tool for space environment effects analysis*, IEEE Trans. Nucl. Sc., vol **52**, 6, 2294-2299, 2005.
- Santin G. et al, *Particle radiation transport and effects models from research to space weather operations*, 38th COSPAR Scientific Assembly, Bremen 18-15 July, p.11, 2010
- Truscott P. et al, *MULASSIS: A Geant4 Based Multi-Layered Shielding Simulation Tool*, IEEE Trans. Nucl. Sci. **49**, 2788, 2002
- Truscott P. et al, *Simulation of the Radiation Environment Near Europa Using the Geant4-Based PLANETOCOSMICS-J Model*, IEEE Trans. Nucl. Sc, vol. 58, 6, 2776-2784, 2011
- ECSS-E-HB-10-12A, Calculation of radiation and its effects and margin policy handbook

Useful links

- Geant4 General Particle Source Users Manual: http://reat.space.qinetiq.com/gps/new_gps_sum_files/gps_sum.htm
- Geant4 home: http://geant4.web.cern.ch/geant4/
- Geant4 Space Users: http://geant4.esa.int/index.php/home.html
- GEMAT home: http://reat.space.qinetiq.com/gemat/
- GRAS home: http://space-env.esa.int/index.php/geant4-radiation-analysis-for-space.html
- MAGNETOCOSMICS home: http://cosray.unibe.ch/~laurent/magnetocosmics/
- MULASSIS home: http://reat.space.qinetiq.com/mulassis/
- PLANETOCOSMICS home: http://cosray.unibe.ch/~laurent/planetocosmics/
- SSAT home: http://reat.space.qinetiq.com/ssat/