New Geant4 based simulation tools for space radiation shielding and effects analysis.

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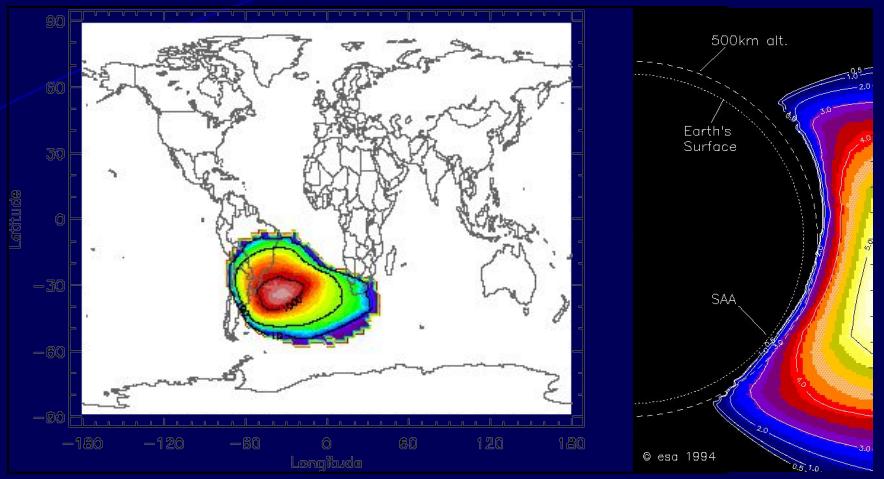
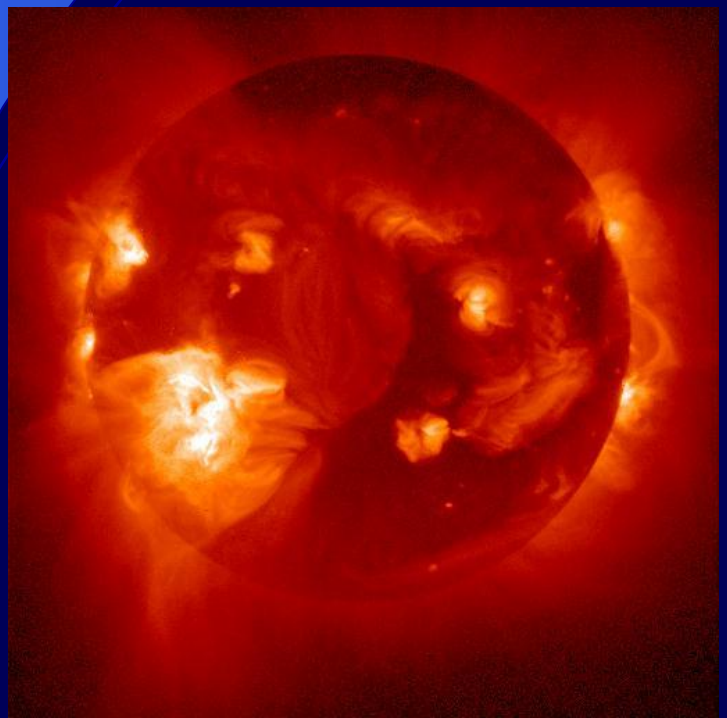
8th Topical Seminar on Innovative
Particle and Radiation Detectors
21 - 24 October 2002
Siena, Italy

Space radiation environment

- Trapped radiation
  - Electrons ~< 10 MeV
  - Protons ~< 10^2 MeV
- Solar radiation
  - Protons, heavy ions, electrons, neutrons, gamma rays, X-rays…
- Cosmic rays
  - Lower intensity
  - Heavy ions



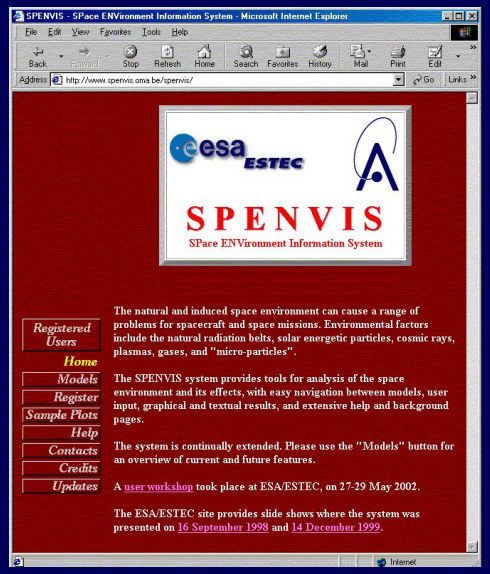


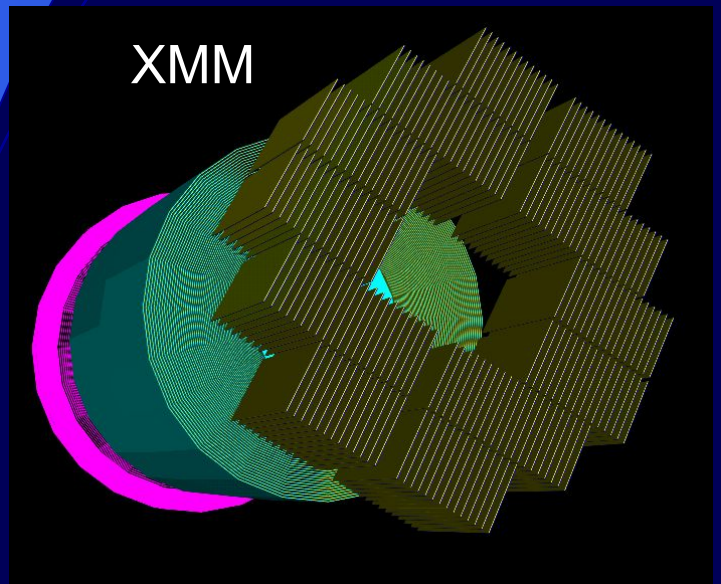
- Environment particles cause radiation damage to electronic components, solar cells and materials
- Effects include:
  - Surface charging
  - Single Event Upset / Latch Up
  - Increased background
  - Degradation, dose, solar cell, NIEL
  - DNA (biological) damage

- Other environment components (energetic and low-energy plasma, Oxygen atoms, debris) here neglected

Radiation effects and analysis tools

- Current tools include:
  - SPENVIS – models of space environment & basic effects analysis (ESA/BIRA)
  - CREME96 – Cosmic Ray/SEU analysis (NRL)
  - SIREST – space environment analysis for Shuttle missions (NASA/LaRC)
  - SEDAT (Space Environment Data Analysis Tool) – databases of space environment data & tools for analysis. (ESA/RAL)
  - ESABASE/Radiation Space Systems Analyser
  - …

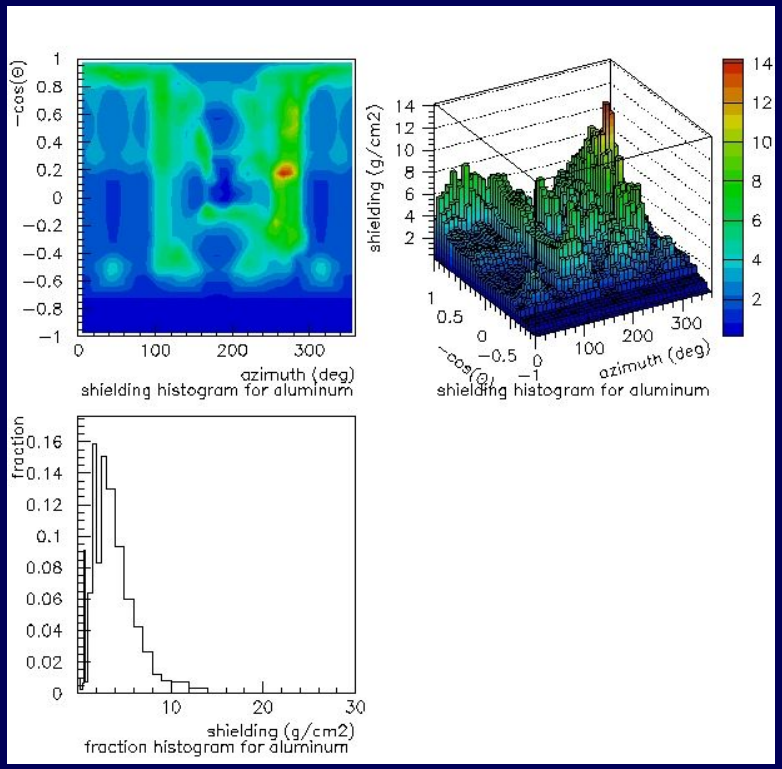




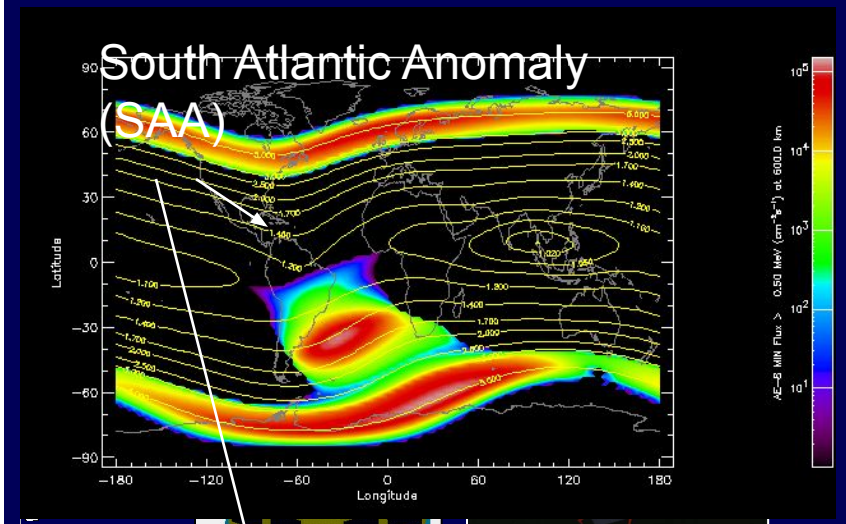
- The role of Geant 4
  - Specific applications developed to address particular items
    - Trapped/solar radiation, cosmic rays, spacecraft charging
  - SSAT, CAD Front-End, REAT/MULASSIS
    - "Generic engineering tool" approach
    - More detailed analysis tools (ESA/Qinetiq/BIRA)

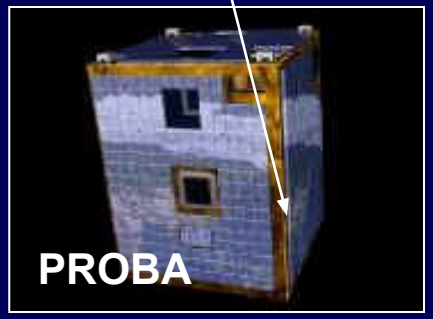
SSAT
Sector Shielding Analysis Tool

- Geant4 based application
- Ray-tracing analysis of a user-defined geometrical configuration
- Produces:
  - distributions of shielding material and thickness as viewed
    - from a given point within the configuration
    - as a function of direction from that location.
- This approach is highly useful for calculating the absorbed radiation dose, and for finding optimal shielding geometries.



Geant4 CAD Front-End tool

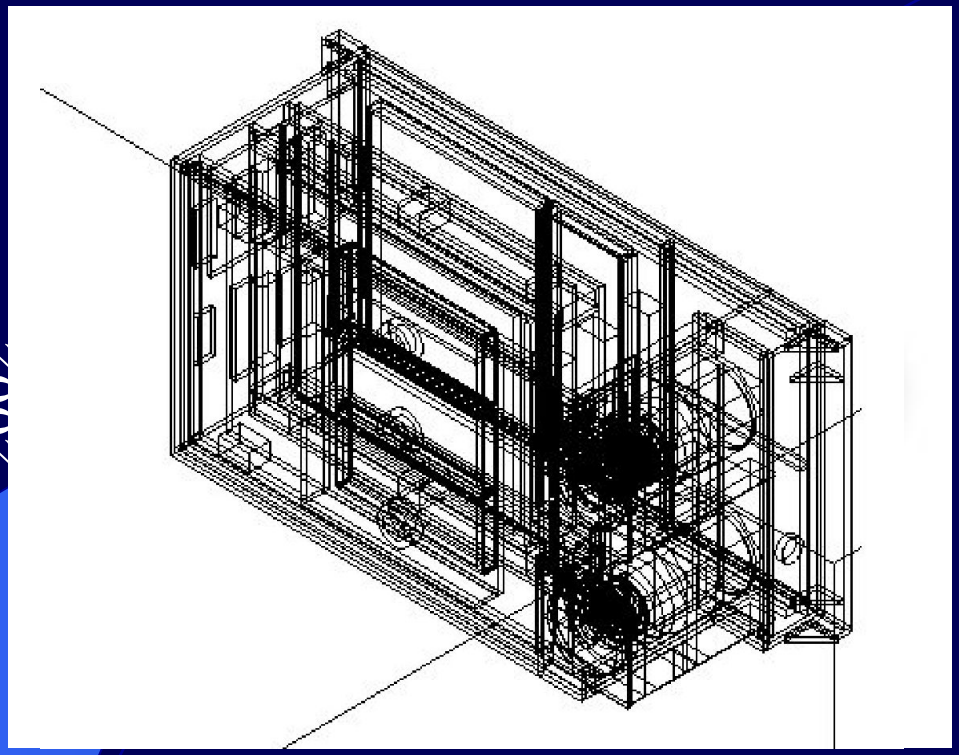


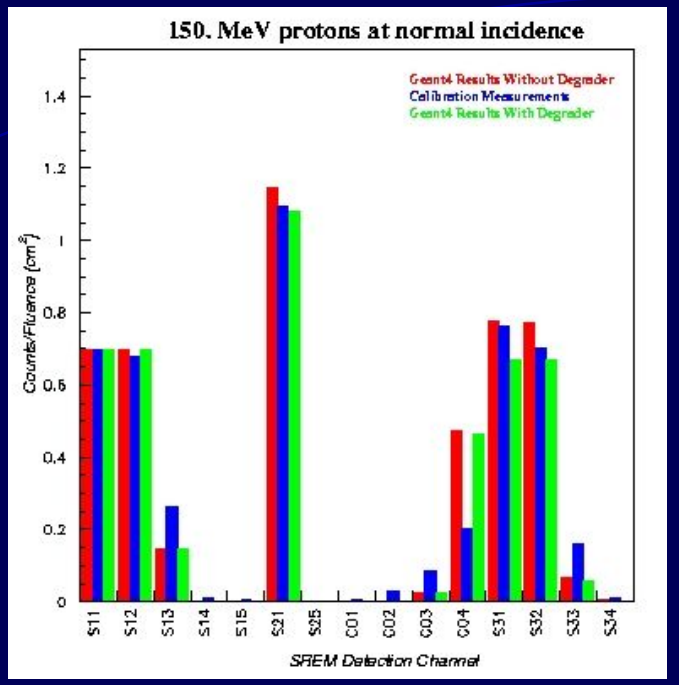


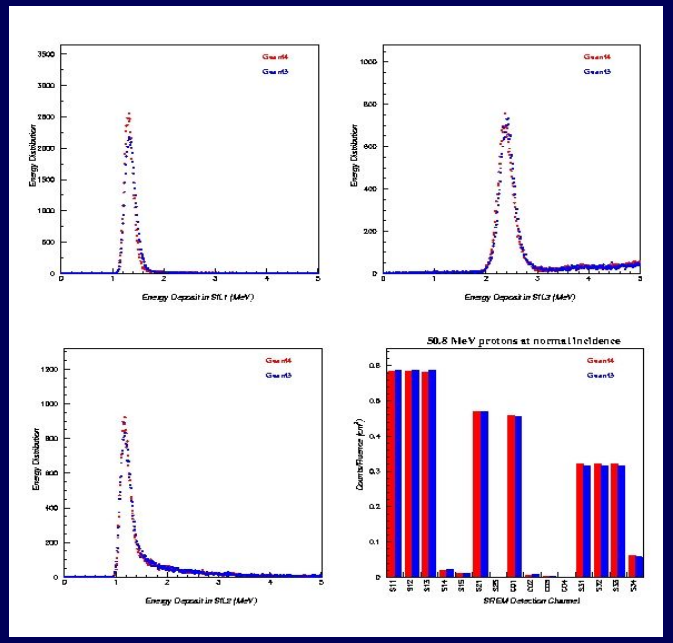
Used to import the SREM geometry
(Standard Radiation Environment Monitor)

SREM is flying on PROBA and INTEGRAL
(+ ROSETTA,…)

CAD Front-End Tool: the SREM case







- SREM geometry imported from STEP files
- Comparisons to
  - Geant3
  - Calibration data

Reat project
Radiation Effects Analysis Tools

- Develop a new generation of radiation shielding and effect tools for civil space applications

- Based on Geant4
  - Complete treatment of secondary particles
  - Completeness of physics list

- List of sub-projects
  - MULASSIS (MULti-LAyer Shielding Simulation S/W):
    - Geant4 application for dose and particle fluence analysis associated with the use of radiation shields (more advanced than SHIELDOSE).

  - GeMAT (Geant4-based Microdosimetry Analysis Tool):
    - Geant4 application for detailed study of radiation on microelectronic devices.

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MULASSIS
MUlti-LAyer Shielding Simulation Software

- Need for better description of the impact of space environment on the spacecrafts
  - Detailed radiation effects analysis in a multi-layer geometry
- Increasing mass □ secondaries more and more important
  - Difficult to take into account with analytical models or look-up table approach (SHIELDOSE)
- User-friendly (to non C++ programmers)
- Basic Space-Environment options included
  - Integrated into SPENVIS with a WWW interface

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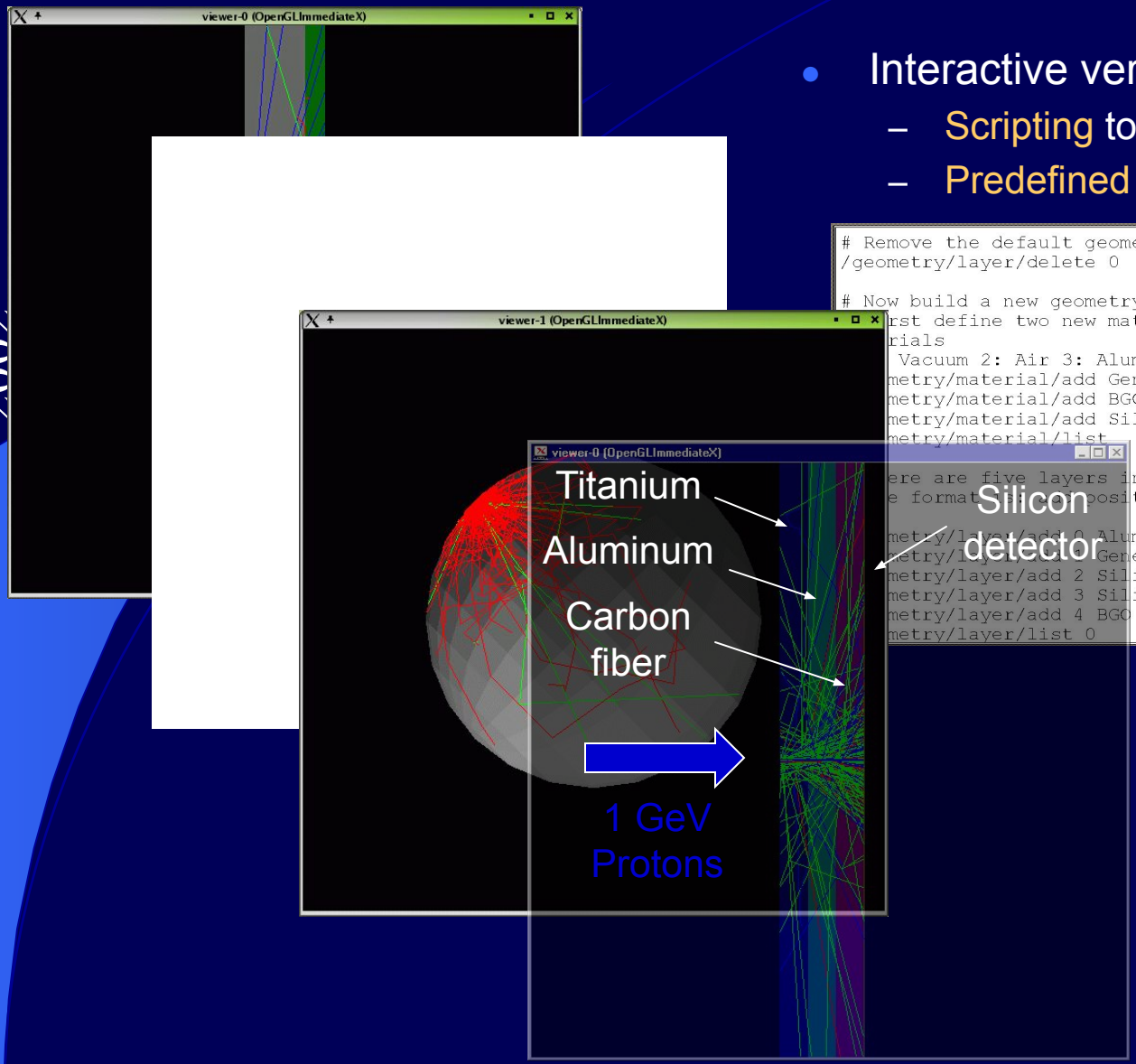
MULASSIS: Physics lists

- Physics description includes
  - EM (std or LowEnergy extension)
  - hadron/nuclear interaction (parameterised, precompound)
  - neutron transport

Application Scenario	Simulation conditions				Source								Models used									Particles									
	Hadron-nuclear interactions	Low-energy neutron	γ-e$^{\pm}$,$\mu^{\pm}$	LowE electromagnetics	Trapped protons	Solar protons and light ions	Cosmic ray protons	Mono-energetic protons	Reactor, fission, D-T, D-D neutron	Spallation neutron	Trapped electrons	Mono-energetic electrons	X-ray spectra	Parameterised "low-energy" hadron-nuclear	Precompound	Neutron_hp	Evaporation	Fermi break up	Fission	Photo-evaporation	Std EM interactions for hadrons/ions	Std EM interactions for leptons/photons	LowE EM interactions for hadrons/ions	LowE EM interactions for leptons/photons	Protons	Anti-protons	Neutrons	Anti-neutrons	K^+, K^-, K^0	π^+, π^-, π^0	Light ions	General ions/nuclei	γ, X-rays	e^+, e^-	μ^+, μ^-
1	✓				✓	✓	✓	✓	✓	✓				✓	✓		✓	✓	✓	✓	✓				✓	✓	✓	✓	✓	✓	✓	✓			
2	✓	✓			✓	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓	✓	✓	✓			
3	✓		✓		✓	✓	✓	✓	✓	✓				✓	✓		✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
4	✓	✓		✓	✓	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
5	✓				✓	✓	✓	✓	✓	✓				✓	✓		✓	✓	✓	✓	✓			✓		✓	✓	✓	✓	✓	✓	✓			
6	✓	✓			✓	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓	✓	✓			✓		✓	✓	✓	✓	✓	✓	✓				
7	✓		✓	✓	✓	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
8	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
9			✓		✓	✓	✓	✓			✓	✓	✓									✓			✓	✓			✓	✓	✓	✓	✓	✓	✓
10			✓	✓	✓	✓	✓	✓			✓	✓	✓											✓	✓	✓	✓			✓	✓	✓	✓	✓	✓

- Kinetic and HETC models coming
  - for energies ~< 10 GeV/nucleon

MULASSIS: geometry scripting, primaries and visualization

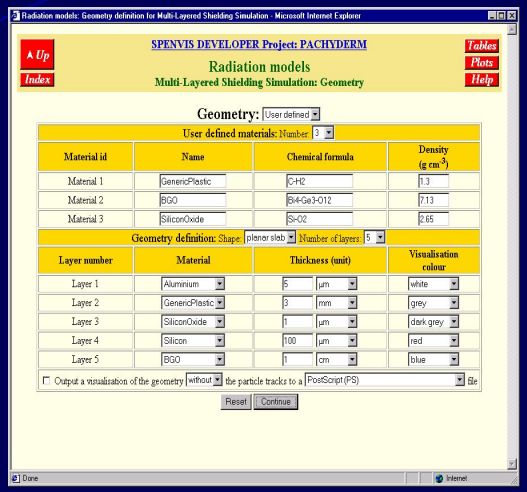


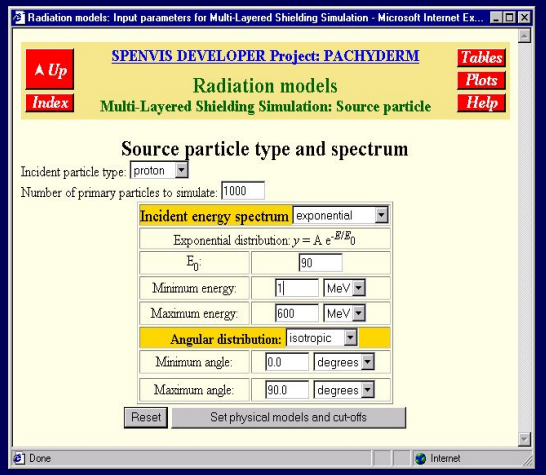
- Interactive version
  - Scripting to build the geometry layers
  - Predefined or user defined materials

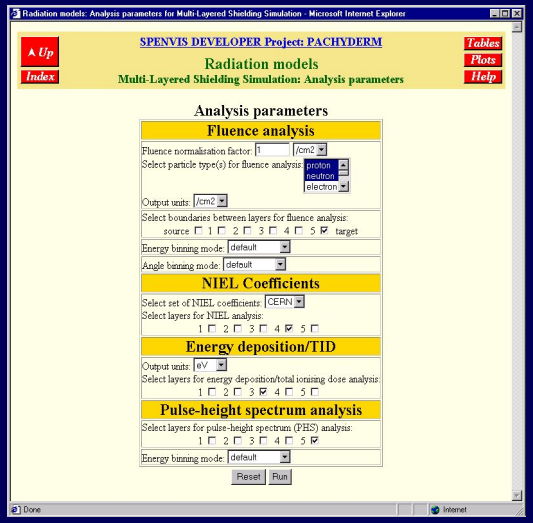
```
# Remove the default geometry
/geometry/layer/delete 0

# Now build a new geometry
rst define two new materials. There are 4 predefined
rials
 Vacuum 2: Air 3: Aluminium 4: Silicon
metry/material/add GenericPlastic C-H2 1.3
metry/material/add BGO Bi4-Ge3-O12 7.13
metry/material/add SiliconOxide Si-O2 2.65
metry/material/list

ere are five layers in geometry
e format is position materialName colourIndex thickness

metry/layer/add 0 Aluminium 1 5. mum
metry/layer/add 1 GenericPlastic 2 3. mm
metry/layer/add 2 SiliconOxide 3 1. mum
metry/layer/add 3 Silicon 4 0.1 mm
metry/layer/add 4 BGO 4 1.0 cm
metry/layer/list 0
```

MULASSIS: integration in SPENVIS

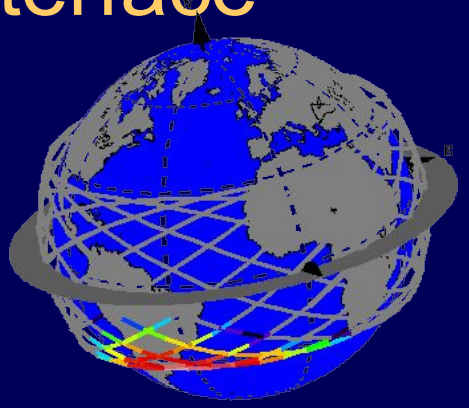
- First web interface to Geant4!
- Geometry definition
  - Layer number, depth and material
- Physics list choice
- Primary particle spectrum and fluences from SPENVIS
  - Trapped protons
  - Solar protons
  - Trapped electrons
- Analysis options
  - Pulse Height Spectrum
  - Ion. dose
  - NIEL





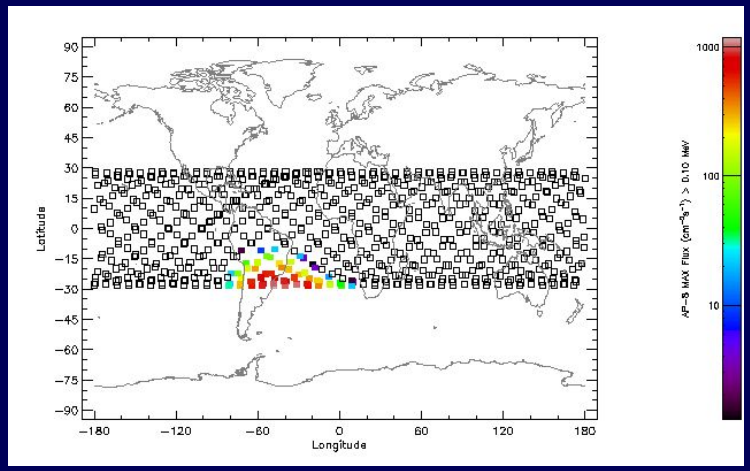


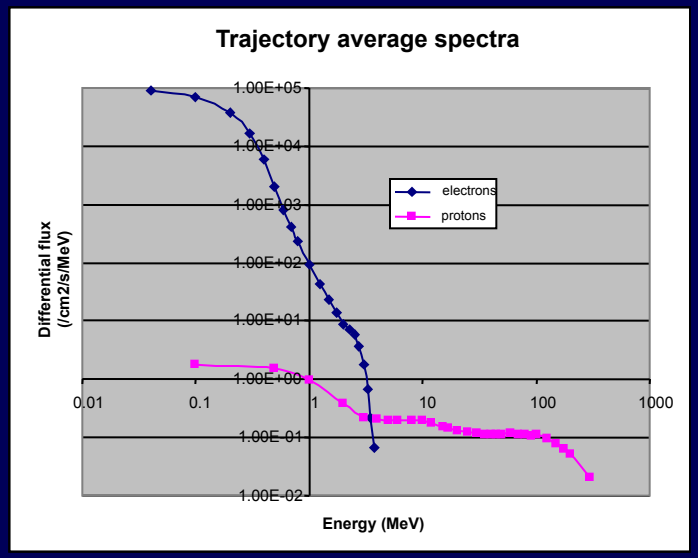
MULASSIS: an example inside the SPENVIS interface



- SPENVIS orbit input parameters
  - LEO circular orbit
    - altitude 500 km
    - inclination 28 deg

- SPENVIS output
  - Trapped proton and electron fluxes
  - Solar proton fluence





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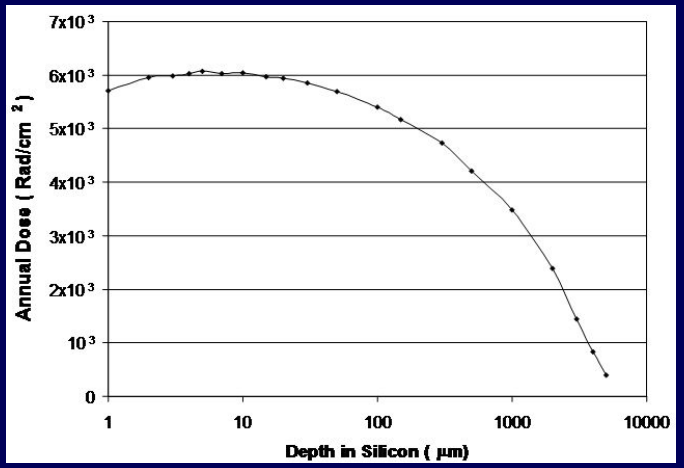
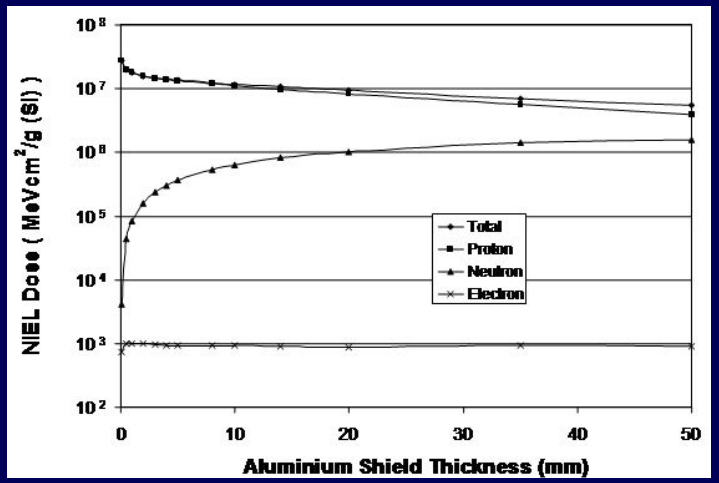
MULASSIS: output

- Particle fluence
  - as a function of particle species, energy, angle and boundary between the layers.
- Non-ionising energy loss (NIEL)
  - based on the fluence and CERN NIEL coefficients.
- Energy deposition in the layer or ionising dose in the layer.
- Pulse-height energy deposition in the layer.



- Doses: ionization
  - Dose-depth curve
- Displacement damage (NIEL)
  - Si (or Si equivalent)



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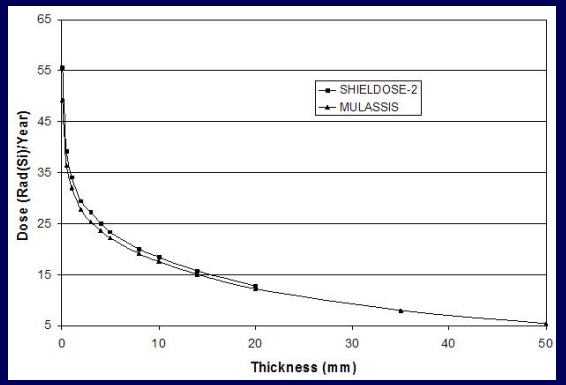
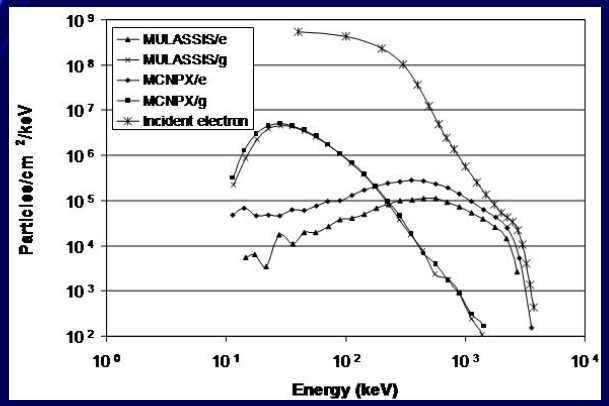
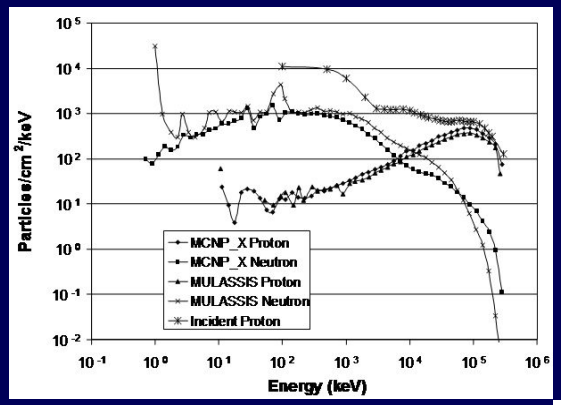
MULASSIS: comparisons

- Comparison with SHIELDOSE-2
  - Total ionising doses for the Si detector behind Al shield of various thicknesses
  - trapped proton from SPENVIS



- Comparison with MCNPX
  - Good agreement in secondary radiation spectra
  - Introduction of kinetic ant HETC models in the next release will eliminate the disagreement in the neutrons





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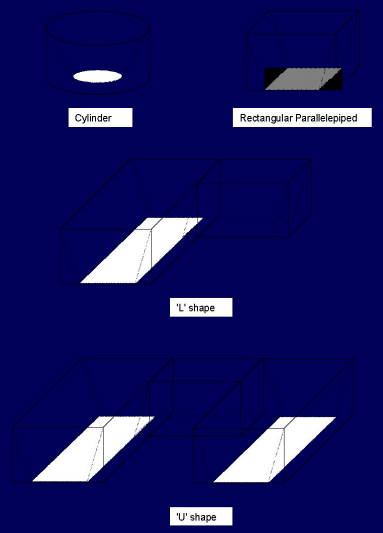
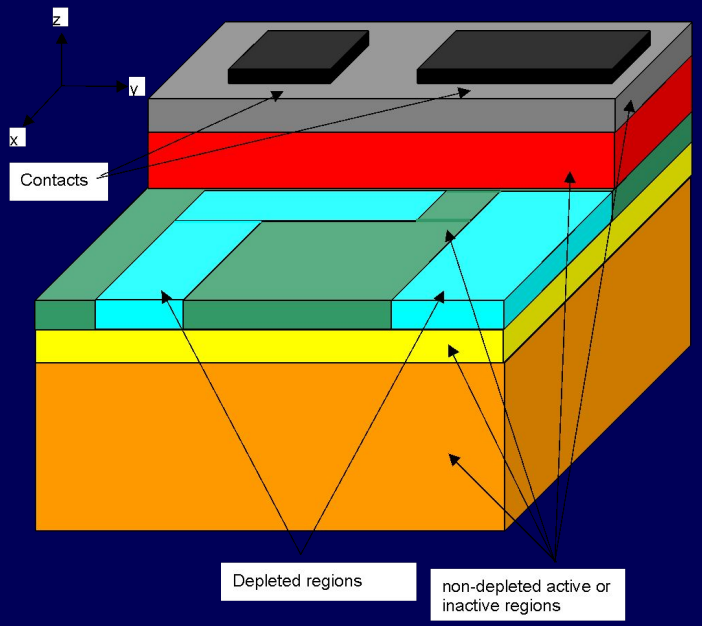
GeMAT

Geant4-based Microdosimetry Analysis Tool



- Simulate microdosimetry in geometries representing features of a semiconductor device (transistor/junction geometries)
- Proton (nuclear and electromagnetic), and electron interactions in the energy range applicable to microdosimetry effects induced by the space radiation environment

- Analysis includes
  - single event effects in semiconductor devices
  - simultaneous energy deposition in several sensitive regions



- Prototype ready
- Will be integrated into the ESA SPENVIS web-based space environment simulation tool-set

Future developments

- SpaceGRID
  - Space science, Earth observation, Space weather and Spacecraft engineering
  - MULASSIS is being ported to the GRID
    - Prototype ready
- New ESA contract: Energetic Particle Shielding and Interactions Software, major R&D item.
  - 5 ESA Science missions
  - 5 other activities for Geant4 *development* and *applications*

Summary

- Role of Geant4 in the space domain
- SSAT, CAD Front-End tool, MULASSIS, GeMAT
- Future developments (SpaceGRID, …)

- Geant4 Space Users' Forum 20-22 January 2003 at ESTEC:
  - http://www.estec.esa.nl/conferences/03C05/index.html