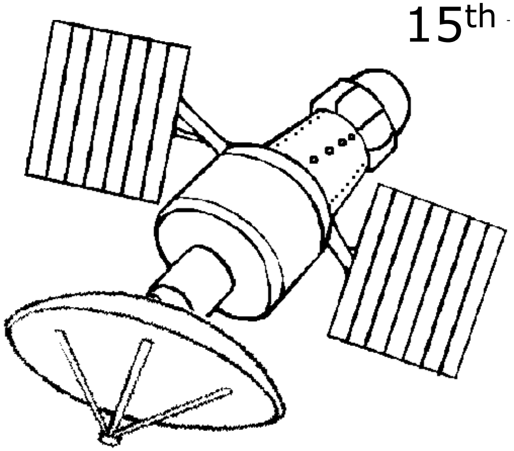


15th Geant4 Collaboration Workshop

ESTEC, 4-8 Oct 2010

Report from user domains: space

Giovanni Santin*, Petteri Nieminen

Space Environments and Effects Analysis Section

European Space Agency

ESTEC

** on loan from RHEA Tech Ltd*

- Selection from latest Geant4 space users' workshop, Seattle, 18-20 August 2010
- Although not all users could be present in Seattle, it gives a good flavour of wide range of use cases

- Interesting traditional and new fields of application
- Space-specific topics, requirements

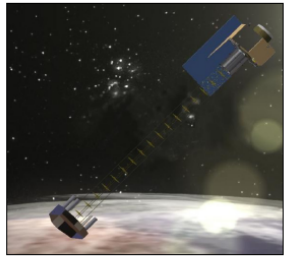
- Slightly more technical presentation on space this afternoon at EM parallel session

- For more information from the event, see http://active.boeing.com/events/GEANT4/

Science and exploration missions: performance and engineering feasibility

The New Hard X-ray Mission (NHXM)

- Angular resolution < 20 arcsec HEW
- Focal length = 10 m (extendible bench)
- Four coaligned grazing incidence telescopes:
  - Three spectral-imaging cameras (0.5 – 80 keV)
  - One imaging polarimeter (2 – 35 keV)
- FOV ≥ 12´
- Effective area = 1000 cm^2 @ 5 keV, 350 cm^2 @ 30 keV
- Planned orbit = Low Earth Orbit (mean altitude = 550 km, low inclination)
- Launch date = 2016?



The X-ray spectral-imaging focal plane is hybrid:

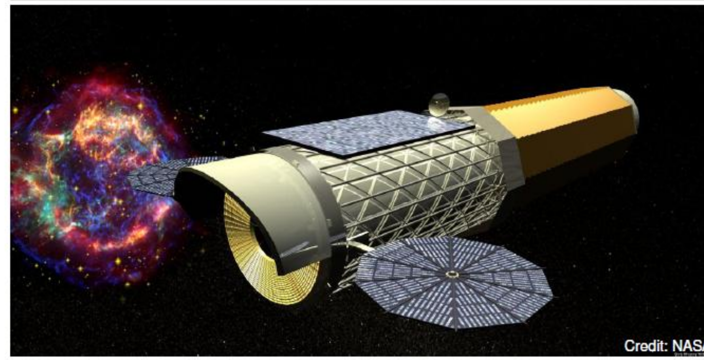
- Silicon Low Energy Detector (LED) = 0.5 – 20 keV
- CdTe High Energy Detector (HED) = 5 – 100 keV

Sensitivity < 1 μCrab (10 – 40 keV) → Background flux < 2 × 10^{-4} cts cm^{-2} s^{-1} keV^{-1}

Background Simulations for the IXO Wide Field Imager

TECHNISCHE UNIVERSITÄT DARMSTADT

Steffen Hauf, Markus Kuster, Dieter H.H. Hoffmann, Maria Grazia Pia, Eckhard Kendziorra, Philipp Lang, Alexander Stephanescu, Lothar Strüder, Chris Tenzer and Georg Weidenspointner



MPE

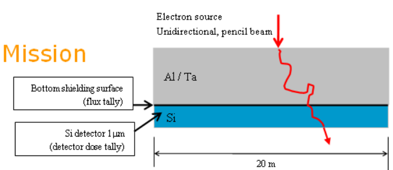
MAX-PLANCK-GESELLSCHAFT

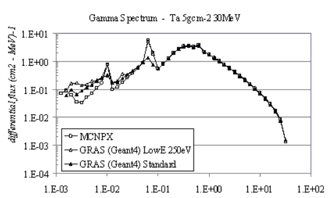
18.(

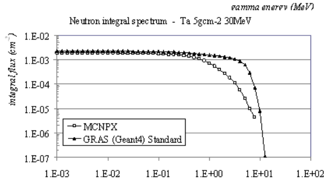
G4

EJSM
Europa Jupiter System Mission

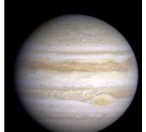
- Combined missions
  - JEO – NASA-led
  - JGO – ESA-led
- Harsh e- dominated environment
- Prediction capabilities of Geant4 and MCNPX
  - From single materials to multi-layered shielding options
  - Mono-energetic e- and realistic spectra
  - TID, electron, gamma and also neutron fluxes
- Selection of input parameters and models for Geant4 non-trivial
- Agreement generally good, with some notable differences
- Providing benchmarks for potential instrument providers to validate their own choice of transport tools







esa



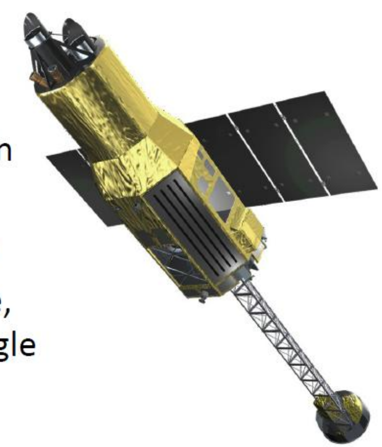
See talk by S.Kang (JPL)

2010, l

JAXA Japan Aerospace Exploration Agency

ASTRO-H

- 6th Japanese X-ray astronomy satellite
- Scheduled for launch in 2014
- 1.7t mass, 14m length
- LEO of 550 km altitude, ~30 deg inclination angle



Detector design and performance

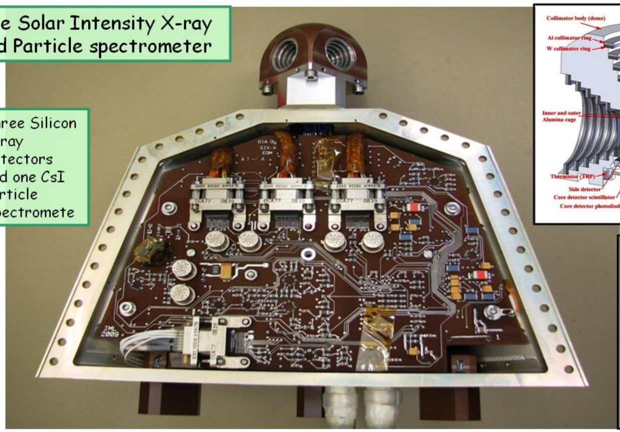
SIXS Sensor Unit Dose Mapping and X-ray detector – BepiColombo Mission

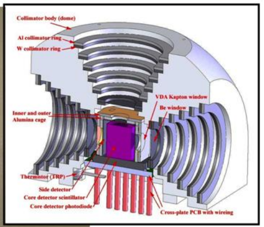
SIXS Sensor Unit

The Solar Intensity X-ray and Particle spectrometer

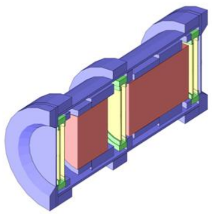
Particle Spectrometer

Three Silicon X-ray detectors and one CsI Particle Spectrometer





CRaTER Aboard LRO



- Six silicon solid-state detectors
- D1-D6 from zenith to nadir
- Odd numbers 140μ, evens 1mm
- Above is simplified Geant4 model

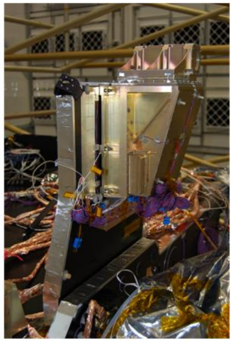


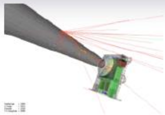
Photo courtesy of NASA

GEANT4 @ INTA

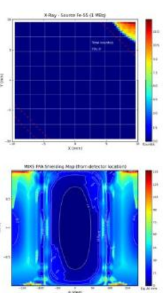
Supported missions: ESA programmes

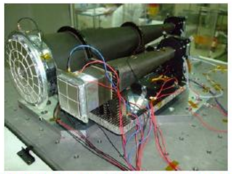
BepiColombo / MIXS

- Launch: ~2014
- Mercury Imager X-ray Spectrometer (MIXS)
- Geant4 activities
  - Shielding analysis of MIXS instrum
  - X-Ray sources simulation
  - Environment propagation
  - Particle focusing / Deflecting

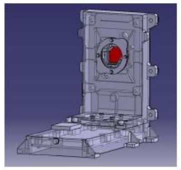


Radiation studies MIXS FPA Design





BepiColombo MIXS Instrument

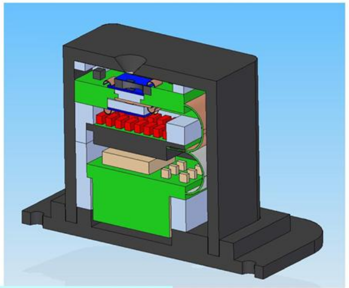


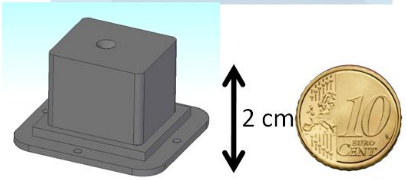
FPA G4 Model

010, E

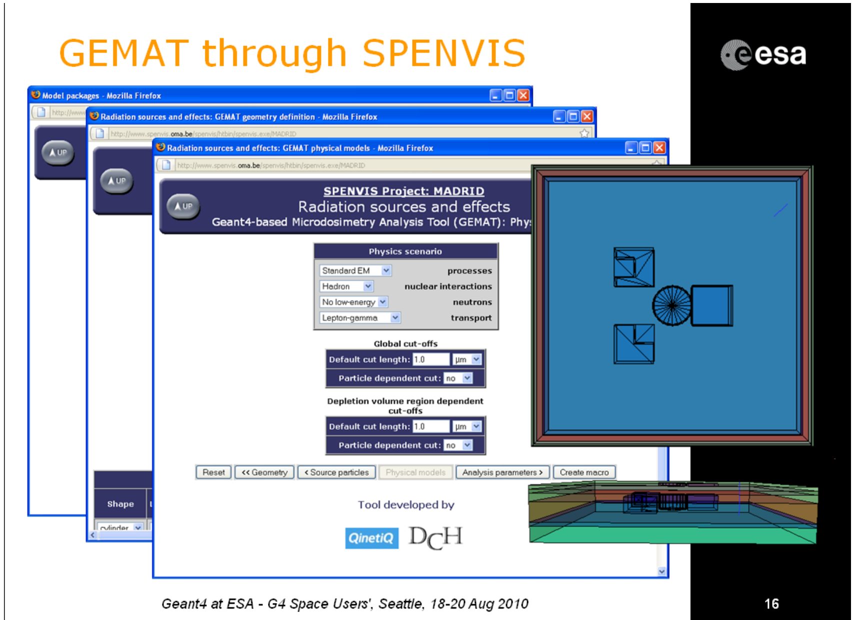
HMRM architecture

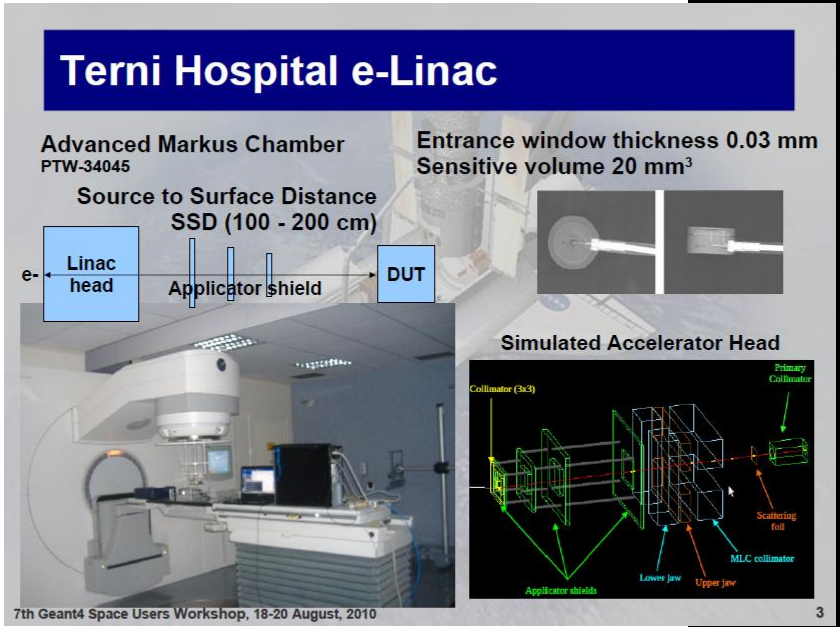
- Telescopic configuration of four sensors
- Inter-sensor shielding to aid particle discrimination
- Casing and aperture designed to restrict exposure to particles
- Field-programmable gate array (FPGA) for data processing

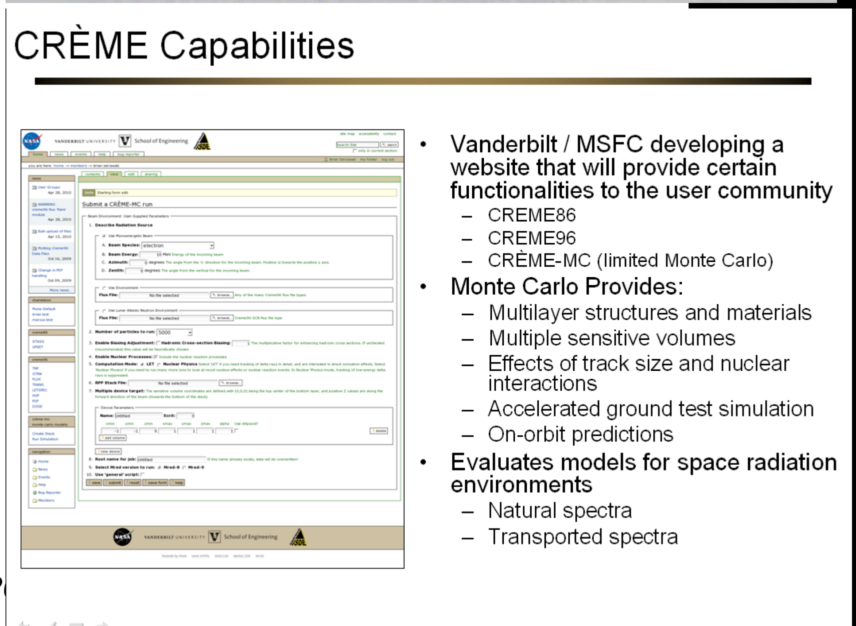




Engineering applications

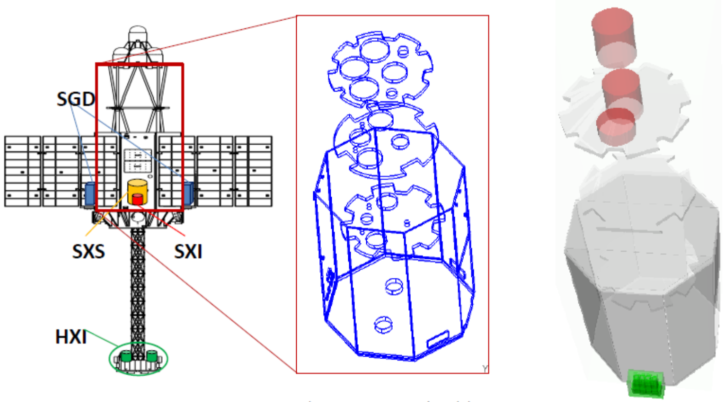






CAD interfaces GDML "standard"

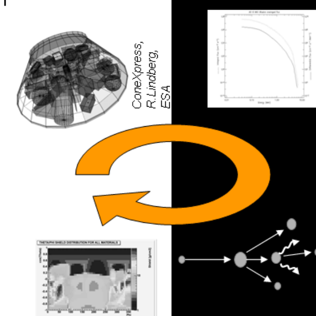
From the original design to G4 model



REST-SIM
Geant4 for ESA Cosmic Vision

esa

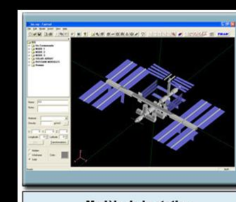
- Development of specific tools and capabilities for radiation effects analysis based on Geant4
- Enable quantitative analyses of the susceptibility of the proposed Cosmic Vision payloads to HEP radiation
- Greatly improved efficiency for integrated use through all project phases
  - for radiation effects tools
  - for geometry generation and exchange
  - for analysis case definition
- Continuous and smooth improvement of radiation analyses over entire mission design lifetime



Modelling speed in 3-D realistic S/C

esa

http://www.trad.fr
http://www.etamax.de



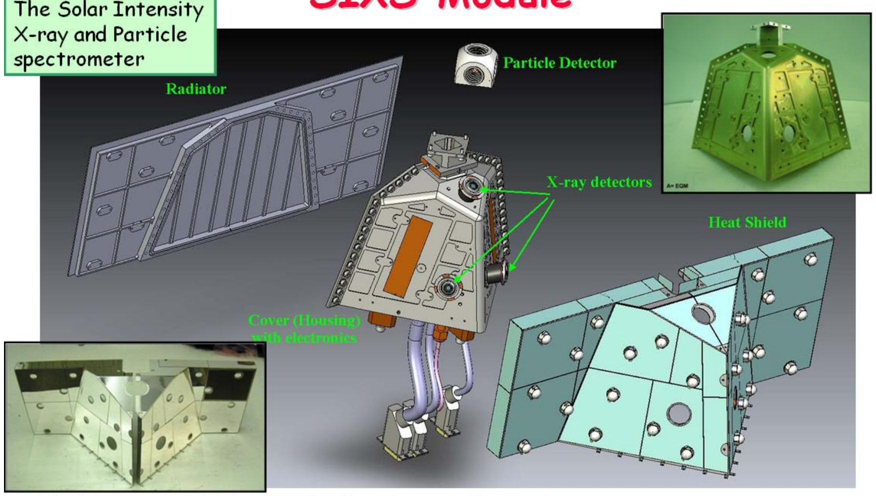
CAD geometry interface

- CAD STEP and IGES interface (and normal 3D models)
  - via external 3D modelling tools tools
  - Direct GDML output for Geant4

SIXS Sensor Unit Dose Mapping and X-ray detector – BepiColombo Mission

SIXS Module

The Solar Intensity X-ray and Particle spectrometer



SIXS Sensor Unit Dose Mapping and X-ray detector – BepiColombo Mission

X-ray detector, cont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Free STL to GDML Conversion Software

Born from our STL2STEP conversion software, we have developed, with the support of Dr. Francisco García (Helsinki Institute of Physics - University of Helsinki), this app. The main use of this application is to convert a stereolithography STL file (binary or ascii format) into a Generic and Geometric Model (GDML) file for use in the GEANT4 application.

Though both the STL and GDML formats use facets to represent geometry, their implementation is slightly different in that the STL file explicitly uses three vertices per facet to define the location and implicitly its normal. The GDML format uses a library of vertices and all facets are defined relative to these vertices.

Since the uniqueness of each vertex needs to be guaranteed, a sorting algorithm was introduced that removes any vertex information that is duplicate. Unlike the STL2STEP application, a faster method was chosen (this newer algorithm is scheduled for implementation in the STL2STEP application at a later point should its development continue).

Additionally, a simple definition of materials and world volume is provided in the application's interface. This feature is still under development but provided as-is for the time being.

Loading of multiple STL files is currently provided with little testing. Outputs need to be reviewed for accuracy.

Also see our STL-to-STEP converter useful for more generic work and with binary-ascii and ascii-binary export options.

DICOM Import & Conversion (DCM to STL)

New with Version 1.1.0 it is possible to load DICOM layers (with the file extension .dcm) into solid bodies. This feature required substantial changes and we therefore decided to exclude this from the "free" version by means of a serial number registration process. If you donate (see below) any amount over $25, you will receive a serial number that will unlock the import features (for one user).

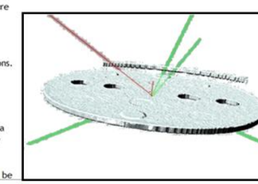
The idea is that rastered images (DCM files by default but converting others such as JPEG or BMP to this format can be

This work has been done by the unconditional effort of Ben Masefield

From the DICOM images the isosurfaces were extracted and then exported to STL format.

STL file was processed with the STL2GDML program and parsed into GEANT4.

Here we observe the incident electron in red and the secondary photons in green



http://www.solveering.com/products/products_stl2gdml.html

GDML-based
3-D radiation analyses in SPENVIS

SPENVIS DEVELOPER Project: PROBA1_SREM
Geant4 tools
Geant4 Radiation Analysis for Space (Gras)

UP | Output | Help

Gras is a Geant4-based tool that provides a general space radiation analysis for 3D geometry models. Gras is a complex tool, so please consult the help page before using it.

Status	Settings	Remarks
defined	Source particles	Trapped, proton
defined	Geometry	GDML
defined	Analysis parameters	Fluence
Advanced settings		
not required	Material definition	----
default	Region cuts-in-range	---
defined	Physical models	Standard EM, Hadron
defined	GDML definition	upl, GDML file analysis

Create macro

Model developed by

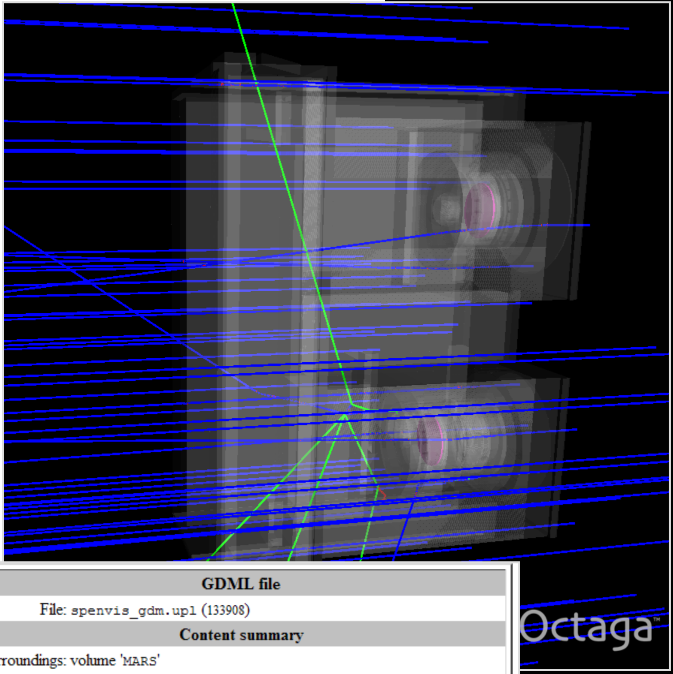
SPENVIS DEVELOPER Project: PROBA1_SREM
Geant4 tools
GDML definition

UP | Output | Help

GDML files are used by Geant4 applications to describe the user geometry. Inside SPENVIS, GDML files can either be uploaded or generated by the Geometry definition tool

Source:	new file upload
Title:	SREM
File:	C:\Documents and Settings\neophytos\Desktop\srem_ [Browse...]

Reset | Save >>



GDML file	
File:	spenvis_gdm.upl (133908)
Content summary	
Surroundings:	volume 'MARS'
	material 'vacuum'
Statistics:	8 material(s)
	125 unique volume(s)
	24 empty volume(s)
Stucture overview	

Structure:

- MARS (VACUUM)

```
+1.00 +0.00 +0.00 +0.00
+0.00 +1.00 +0.00 +0.00
+0.00 +0.00 +1.00 +0.00
+0.00 +0.00 +0.00 +1.00
```

  - SBAL (VACUUM)

```
+1.00 +0.00 +0.00 +33.00
+0.00 +1.00 +0.00 -30.00
+0.00 +0.00 +1.00 -70.60
+0.00 +0.00 +0.00 +1.00
```

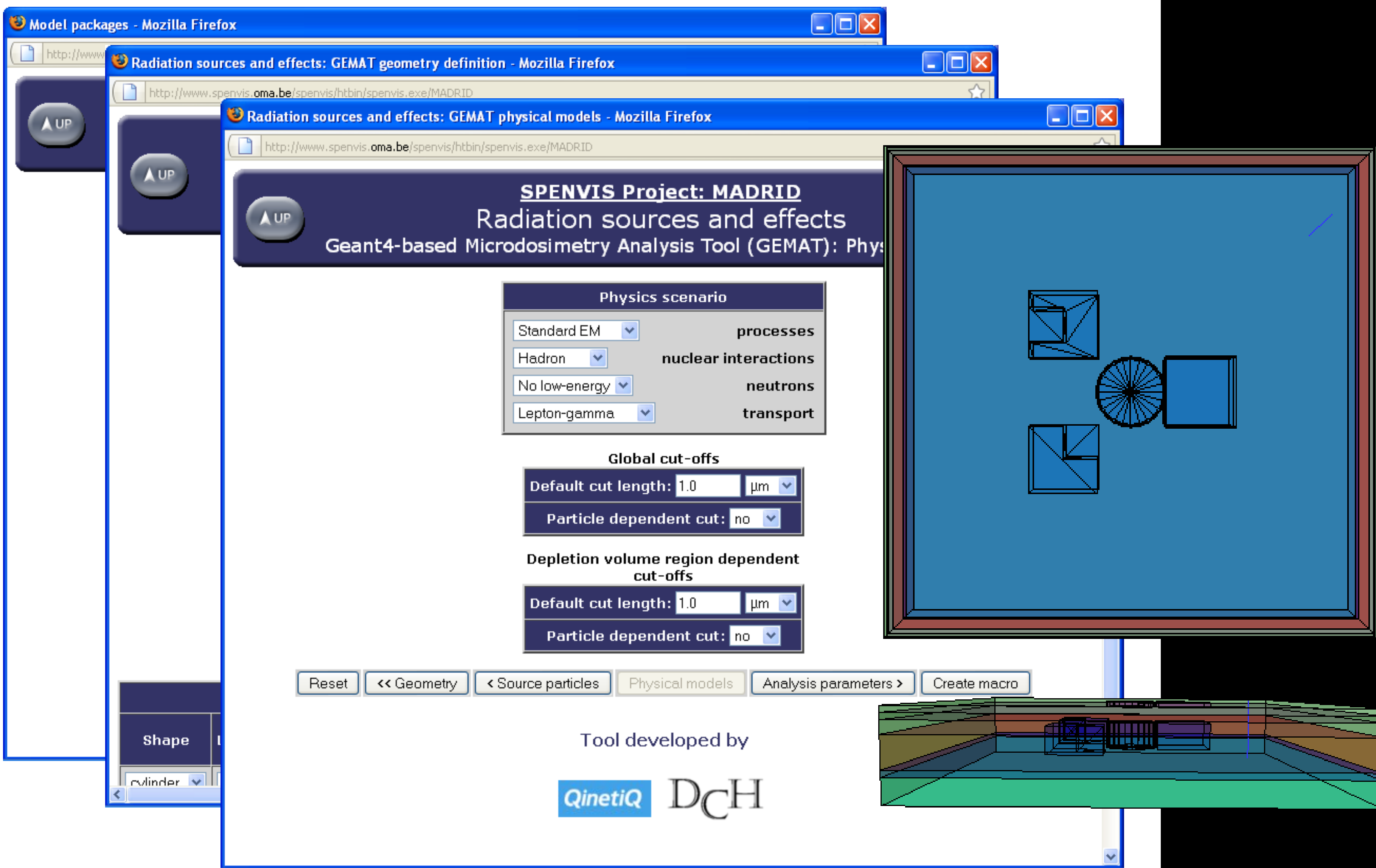
    - C2W1 (ALUMINUM)

```
+1.00 +0.00 +0.00 -1.00
+0.00 +1.00 +0.00 +0.00
+0.00 +0.00 +1.00 +17.10
+0.00 +0.00 +0.00 +1.00
```

    - C2V1 (ALUMINUM)

```
+1.00 +0.00 +0.00 -1.00
+0.00 +1.00 +0.00 -60.00
+0.00 +0.00 +1.00 +17.10
+0.00 +0.00 +0.00 +1.00
```

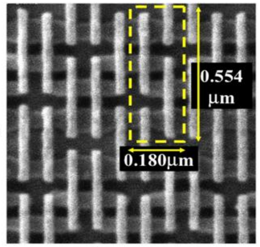
Advanced 3D radiation effects analysis GEMAT through SPENVIS



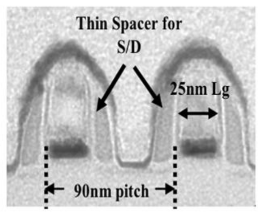
Trends for radiation effects in modern technologies – Vanderbilt group

Trends in Advanced Technology Nodes

- Decreasing feature sizes are leading to an overall reduction in critical charge
  - IBM 65 nm SOI critical charge around 0.14 fC – 0.24 fC (1500 electrons) [1]
- Recent publication from IBM details a 22 nm SOI technology node [2]
  - SRAM cell area of 0.1 µm^2
  - Estimated critical charge of 0.08 fC, approximately 1.8 keV (500 electrons)

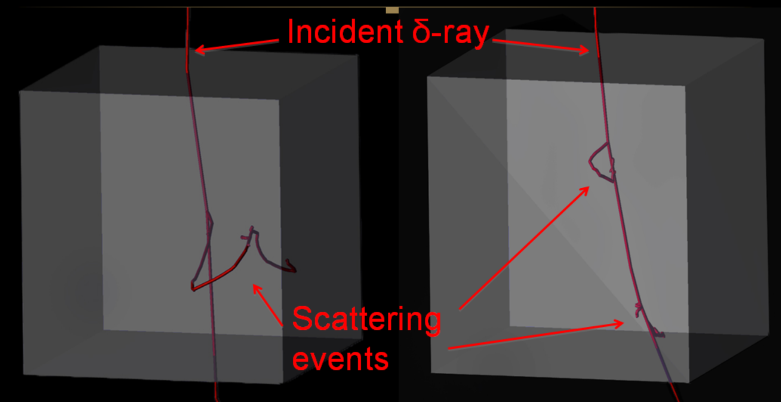


0.1 µm^2 SRAM after [2].



[1] Rodbell, K.P., et al, "Low-Energy Proton-Induced Single-Event-Upsets in 65 nm Node, Silicon-on-Insulator, Latches and Memory Cells," IEEE Trans. Nucl. Sci. Dec. 2007.
[2] Haran, B.S. et al, "22 nm technology compatible fully functional 0.1 µm2 6T-SRAM cell," IEDM Dec. 2008.

Electron Events in 50 × 50 ×50 nm^3 Si Cube



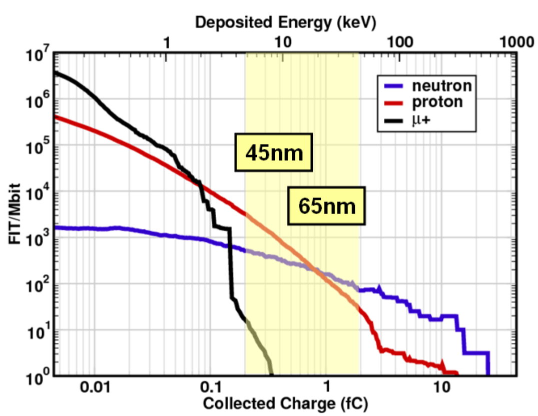
Energy Deposited = 2.1 keV   E.D. = 2.6 keV

Both Events Deposit Sufficient Energy to Upset 22 nm SRAM !

King, TNS 2010

Preliminary Simulations

- MRED Monte Carlo simulations indicated potential for upset from muon direct ionization
- Technology scaling (assuming same sensitive volume dimensions) will increase susceptibility to terrestrial protons, muons
- Spectra will be moderated by concrete, buildings, etc.



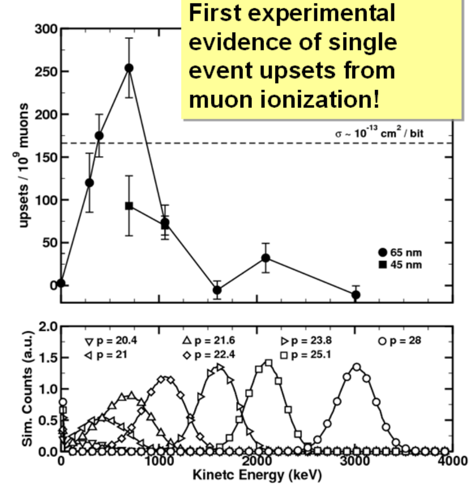
Technology scaling

201

Single Event Upsets

- Trend in upsets is indicative of direct ionization
  - –Peak occurs when beam is tuned to stop in device active region
  - –At higher energies, stopping power is too low for upset
  - –At lower energies particles range out
- Kinetic energy distributions were determined by simulation and related to the abscissa for SEU probability
- Two other SRAMs from a different vendor showed similar response

First experimental evidence of single event upsets from muon ionization!



Sierawski, TNS 2010

DESMICREX
Radiation effects in deep sub-micron technologies

- Usage of technologies below 100 nm in space for European missions is actively pursued with combined efforts of Space Agencies
- Circuit designers challenged with evolving susceptibility to SEEs and possibly other effects traditionally not observed with larger size CMOS technologies

Objectives

- Develop simulation framework enabling IC designers to characterize the impact of radiation effects on integrated circuits using DSM technologies

  → TCAD / SPICE interfaces, novel algorithms, etc
- Identify new effects and trends, and design countermeasures

- Geant4-based radiation transport core (GEMAT2)

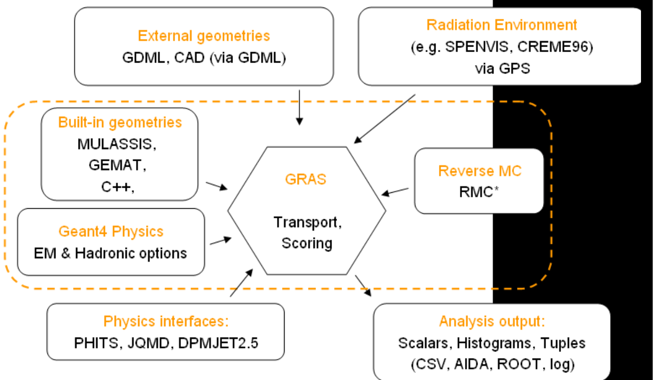
- Consortium

Ready to use tools
Engineering requirements
Reverse Monte Carlo

Geant4 tool integration: GRAS

Requirements:

- Ready-To-Use tool
  Multi-mission approach
- Quick assessments
  Ray-tracing ↔ MC
  1D ↔ 3D
  EM ↔ Hadronics
  LET ↔ SV details
- Modular progress
  Open to collaborations and contributions



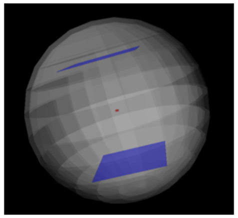
G Santin, V Ivantchenko et al, IEEE Trans. Nucl. Sci. 52, 2005

http://space-env.esa.int/index.php/geant4-radiation-analysis-for-space.html

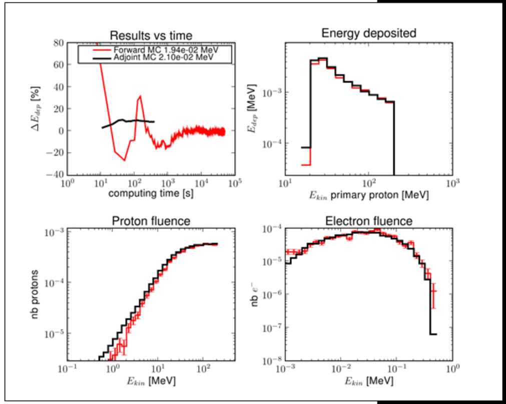
** in progress*

Reverse MC: comparison VS forward
Protons, simple geometry

See talks by L.Desorgher (Space IT)



- Proton source
  - [0.1keV, 200MeV]
  - E^{-1} spectrum



- Difference in total computed dose <~5%
- Reverse MC method more rapid than forward by orders of magnitude

Physics developments

esa

esa galileo navigation European Space Agency

ELSHIELD

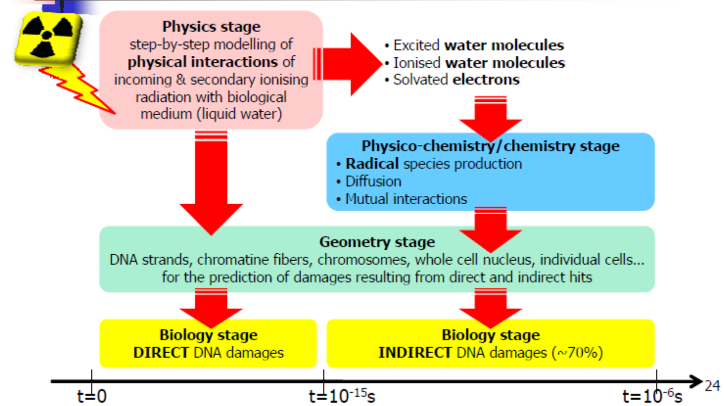
Energetic Electron Shielding, Charging and Radiation Effects and Margins

- Analysis of problem areas in energetic electron penetration and interactions in S/C and P/L
- Tools: improve usability and physics modelling
- Validation of developments (also dedicated testing campaigns)
- Relationships with pre-flight testing and design margins
  Benchmarking and analyses to identify systematic deviations between simulation tools and engineering analysis processes performed as part of radiation hardness assurance and EMC assurance

esa

TAS-E led consortium
G4AI,
TRAD,
INTA,
DHC,
ONERA,
Artenum,
TAS France

How can Geant4-DNA model radiation biology ?



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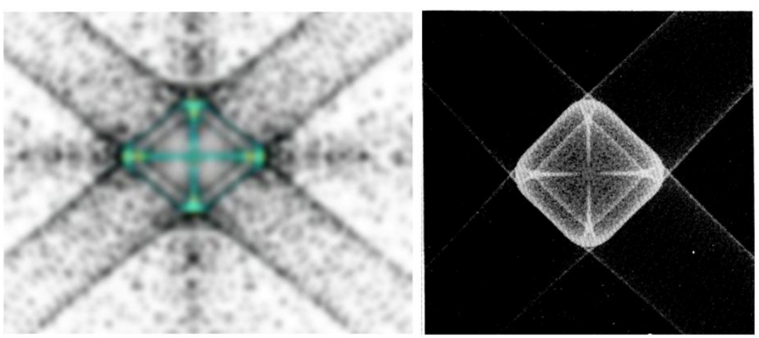
Validating phonon focusing

Simulated phonon focusing patterns for Slow Transverse (ST) polarized phonons scattering at the center of a Ge crystal are a good qualitative match for experimental results.



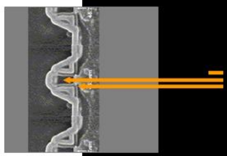
Simulated Ge caustic   Experimentally recorded Ge caustic[2]

[2] Hurley and Wolfe, *Phys. Rev. B* **32** (1985)

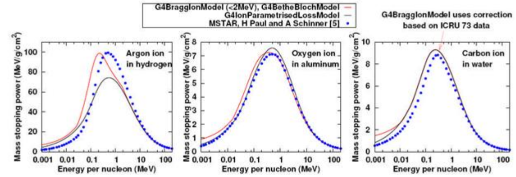
12

Physics development examples: Ions

esa

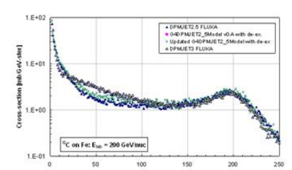


- Impact e.g. on
  - SEE ground testing of EEE components
  - Shielding, recoil and fragment ion contribution to SEE, dose
- ICRU-73 tabulated stopping powers (PASS code results)



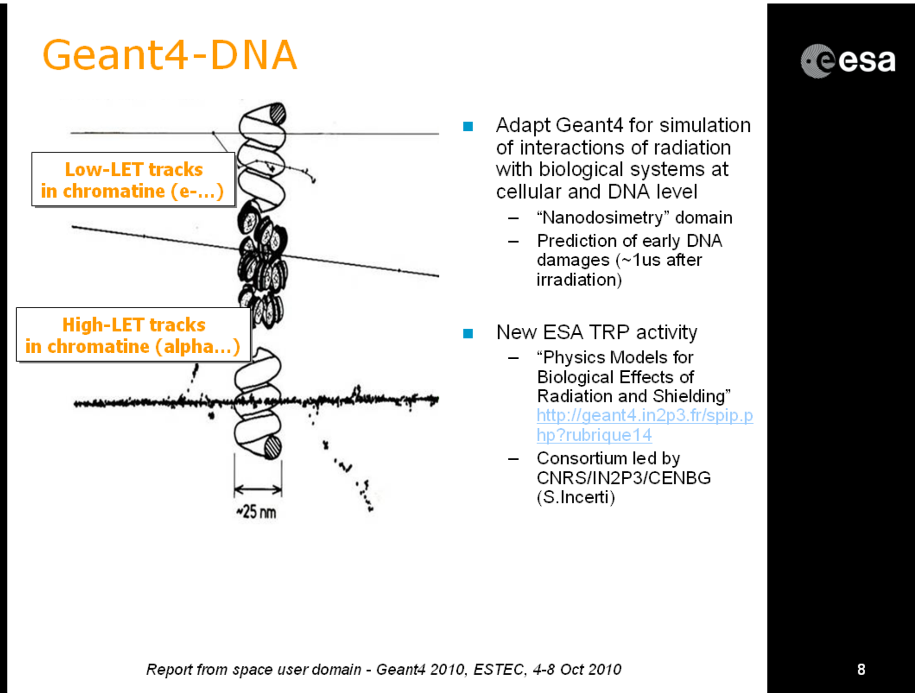
V. Ivantchenko
A.Lechner

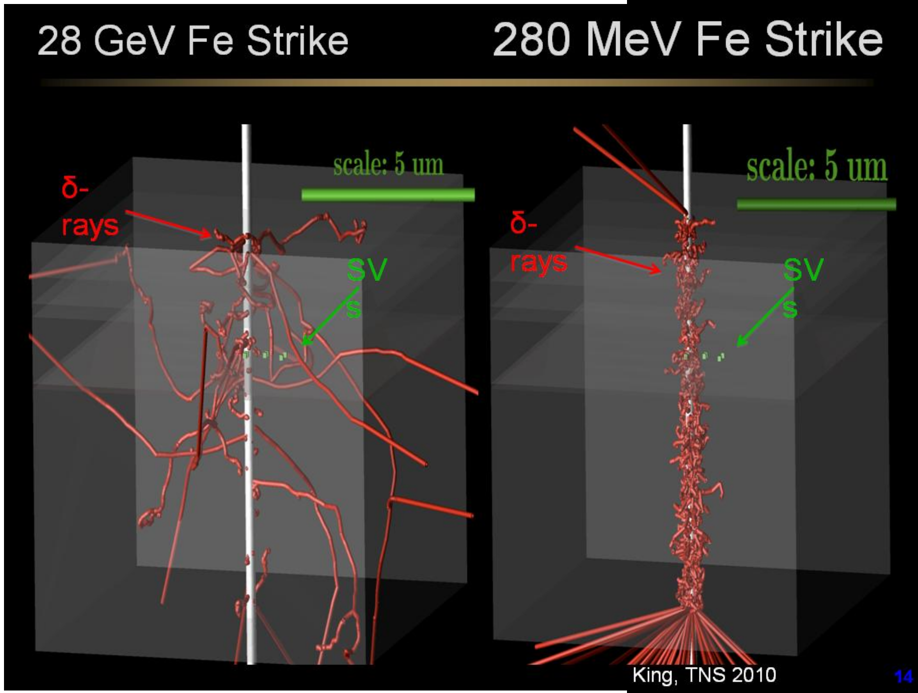
- DPMJET-II.5 model in Geant4
  - Interface to DPMJET-II.5 event generator
  - Cross sections



P.Truscott (QinetiQ)

Nano-dosimetry in radio-biological and semiconductor effects





- More synergies space – medical user domains

Development of physics interfaces

Forward Angle Spallation

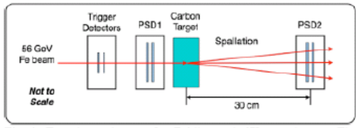


Fig. 1. Experimental setup for Zeitlin et al. [7] experiment. The trigger and PSD1 detectors are for measuring the energy and timing of the Fe ions, and the PSD2 detectors measure the energy deposition from the nuclear fragments.

M.A. Clemens et al.,
IEEE TRANS, VOL. 56, 3158 (2009)

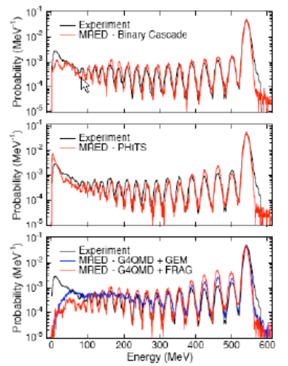


Fig. 2. Histogram of Zeitlin et al. experiment [12] and MRED simulations using the binary light-ion cascade model (top), The PHITS model (middle), and the G4QMD (bottom) with the GEM and Frag models. The rightmost peak corresponds to Fe ions, and each lower energy peak corresponds to lower Z fragments.

MarsREM – DPMJET interface

ESA contract (QinetiQ, LIP, BIRA, DHC, SpaceIT)

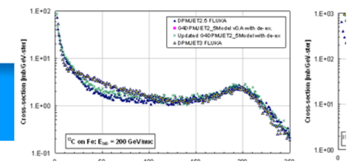
See talk by Pete Truscott

Implementation of DPMJET-II.5 model in Geant4

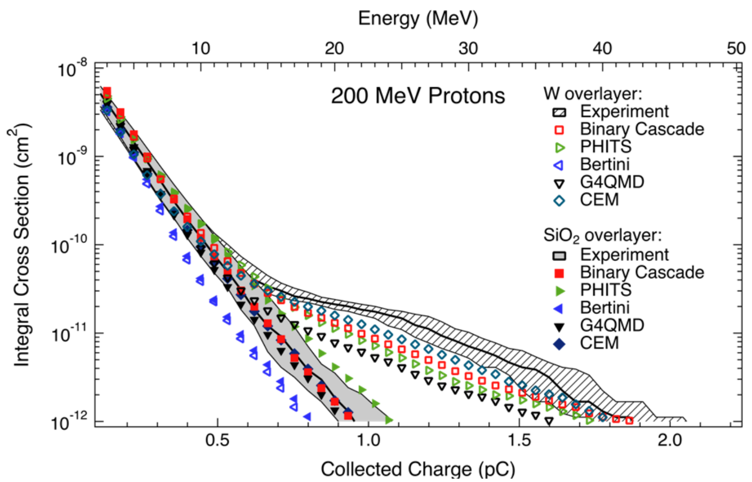
- Priority to extend the high-energy regime of Geant4 to ultra-relativistic energies
- Existing FORTRAN code DPMJET-II.5 to act as an event generator: 5GeV/nuc to 1E+11 GeV/nuc
- Geant4 DPMJET-II.5 interface: G4DPMJET2_5Model class now developed and tested, covers projectiles from A=2 to A=58 on targets from A=2 to A=58

  Currently extending this to projectiles from A=2 to A=240 on targets from A=2 to A=240
- After prompt nuclear-nuclear collisions, nuclear de-excitation treated using other Geant4 models (precompound, evaporation, Fermi break-up)
- Total inelastic cross-section class G4DPMJET2_5CrossSection also created to estimate mean-free-path between nuclear-nuclear collisions, and also covers projectiles from A=2 to A=58 on targets from A=2 to A=58

  (similarly being extended to A=240)
- Models used on Detailed Mars Energetic Radiation Environment Model (dMEREM) to be presented

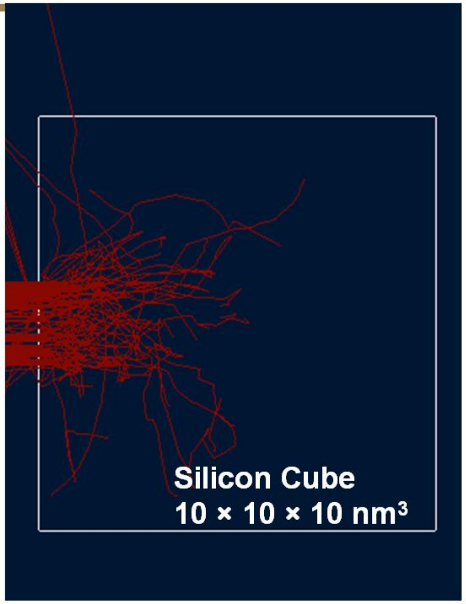


Hadronic Physics Model Comparison



MRED+PENELOPE2008: Electrons in Silicon

- Penelope2008 extension
  - State-of-the-art electron, positron and gamma transport code
  - Gold-standard for low energy ionizing electromagnetic interactions with atoms and solids.
- Simulate 250 eV electrons
  - 100 particle raster



Tentative summary

Radiation effects

- Head-to-head of Geant4-based solutions VS technology evolution
- Increasing overlap between space and aeronautics / eventually ground-based applications, especially regarding SEE phenomena

Physics model developments / improvements driven by requirements often not shared with HEP domain (nanodosimetry, electron transport, secondaries from inelastic, ion interactions)

- Internal Geant4 models
- Interfaces to external MC physics models

Usability & speed

- User experience (tool availability, scripting, GUI, web access, Windows)
- Physics: guidance needed, many pitfalls make all nervous
- Exchange formats: Geometry (GDML, CAD/TCAD), data I/O
- Speed / scoring in nano-volumes in macroscopic S/C (reverse MC)

- For more information see
  - Latest space users WS: http://active.boeing.com/events/GEANT4/
  - Geant4 Space Users site: http://geant4.esa.int/