Recent developments in GEANT4-related activities at ESA: physics, tools, interfaces

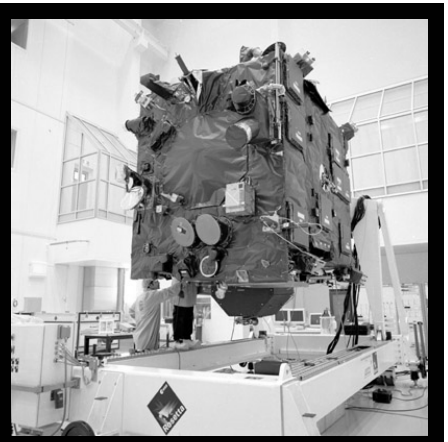
G.Santin*, P.Nieminen, A.Mohammadzadeh, R.Lindberg, H.Evans*, E.Daly

ESA / ESTEC

**Rhea System SA*

Giovanni.Santin@esa.int

Geant4 Simulations in the Space domain



- Simulations in Space domain are just one element in a big picture going from
  - Design, to Construction, Integration, Testing, Launch, Operation
  - In an environment in which commercial companies and not academia are the main players
- Geant4 has been a strategic choice for ESA
  - Advanced physics
  - Extendibility (OO design)
  - Interfaces (Geometry/CAD, visualization, post-processing, analysis)
  - Open source approach (plus code transparency)
  - Long term support in a collaborative world wide effort
- ESA is member of the Geant4 Collaboration since 1997
- Two communities of Geant4 Space Users
  - Science
  - Industry

Areas of attention
- Physics
- Interfaces
- Usability

Outline

1. Physics models
2. Interfaces
3. (Engineering) Tools

1. Physics models

1. Physics models
   - Scientific Exploration:
     Low En EM
   - Manned space flight:
     Even Lower En EM and physics for hadrons
2. Interfaces
3. (Engineering) Tools

Simulations of the Space Radiation Environment

Sources

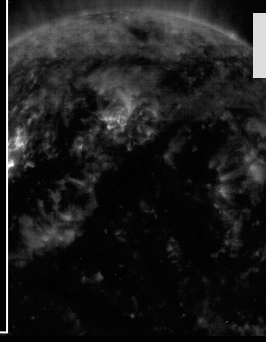
(Extra) Galactic and anomalous Cosmic Rays

Protons and Ions

<E> ~ 1 GeV, E_{max} > 10^{21} eV

Continuous low intensity

Solar radiation



Protons, some ions, electrons, neutrons, gamma rays, X-rays…

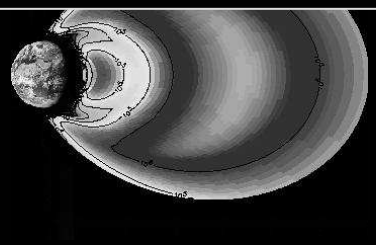
Softer spectrum

Event driven – occasional high fluxes over short periods.

Trapped radiation

Electrons ~< 10 MeV

Protons ~< 10^2 MeV



Goals

Mission design

Ground tests

Extrapolation to real life in space

Cheaper than accelerator tests

Science analyses

Particle signal extraction

Background

Degradation

Environment models

Simulation of the emission and the propagation of radiation in space

Effects

Effects in components

Single Event Effects

(SE Upset, SE Latchup, …)

Degradation

(Ionisation, displacement,…)

Effects to science detectors

Background

(Spurious signals, Detector overload,…)

Charging

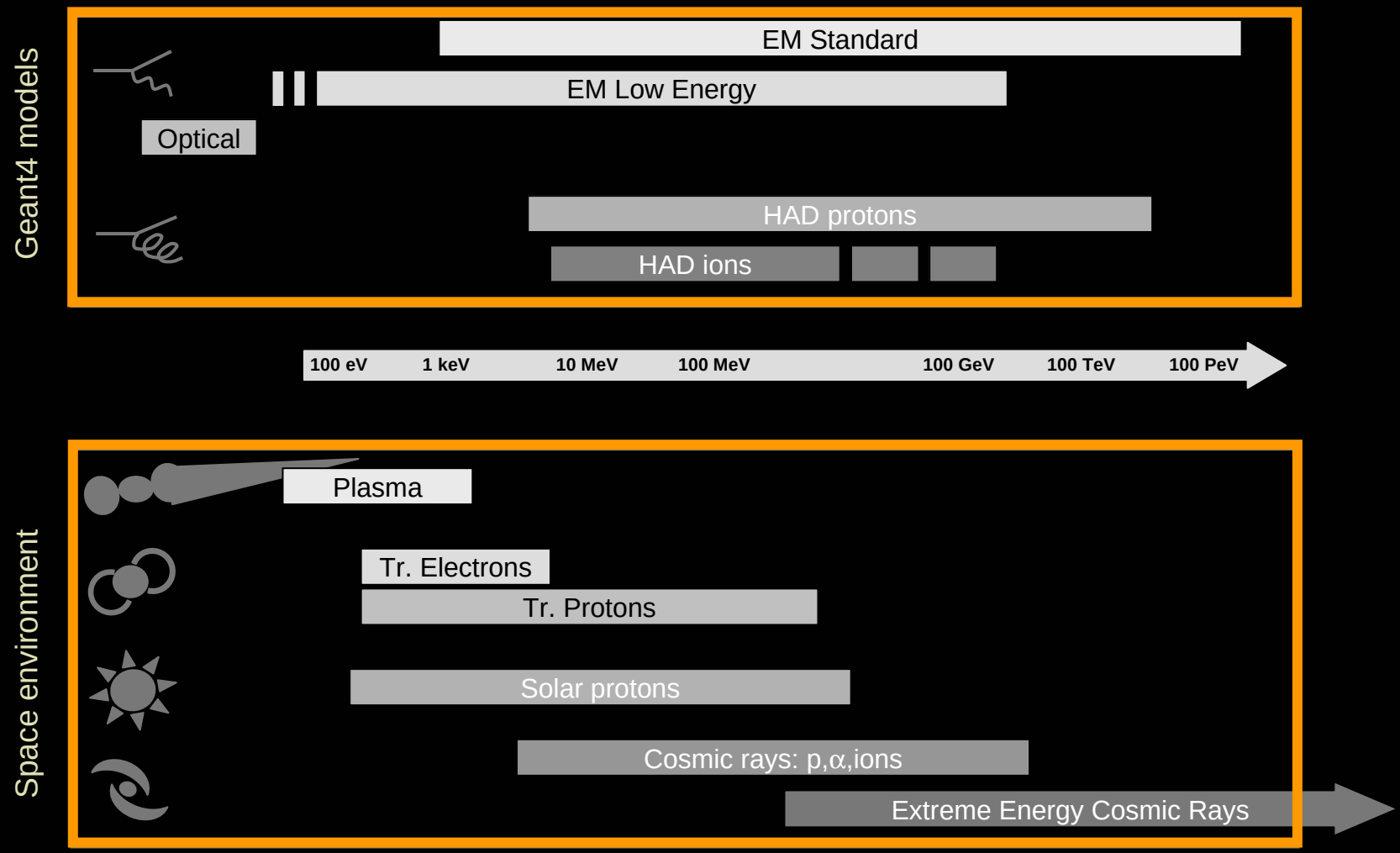
(internal, interferences, …)

Threats to life

Dose (dose equivalent) and dose rate in manned space flights

Radiobiological effects

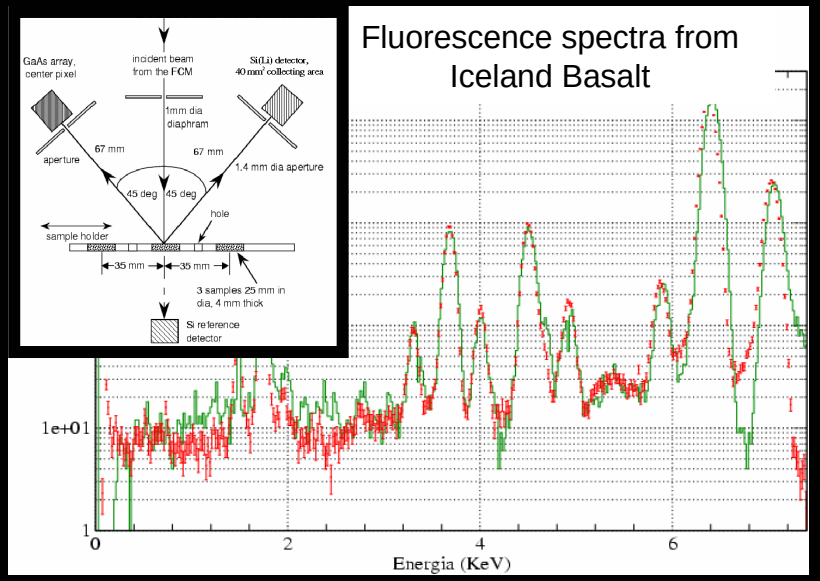
Space environment and Physics models

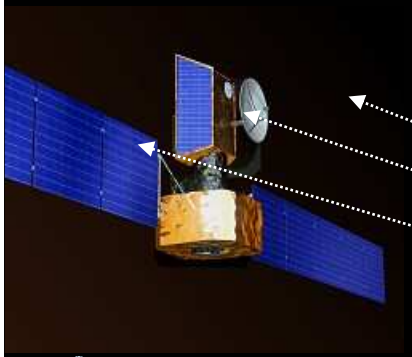


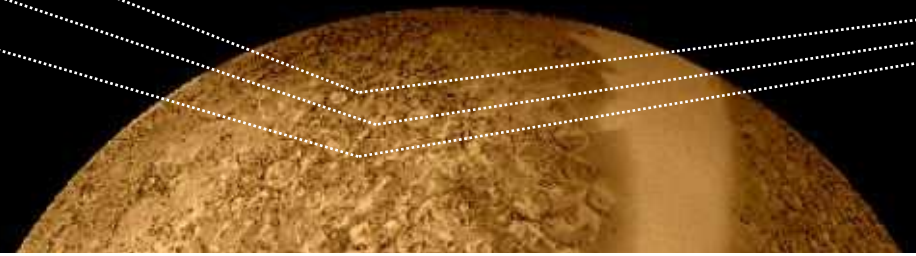
Mercury BepiColombo X-ray spectrometer

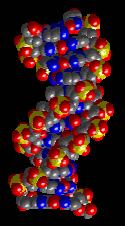
IEEE NSS Conf. Record, 2003 and 2004

- Rock samples irradiation and fluorescence emission measurement
  - Geant4 atomic deexcitation
  - Physics validation
  - Creation of a reference database
- The simulation reproduces:
  - Complex geological materials
  - Experimental Geometry
  - Response and efficiency of the detector



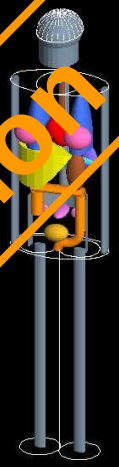






Geant4 DNA

- Damage mechanisms
- Interactions of Radiation with Biological Systems at the Cellular and DNA Level



Human phantom library

Applications in radiation protection, therapy protocol studies

Analytical model

G.Guerrieri

INFN Genova

Geant4-DNA collaboration (ESA funding)

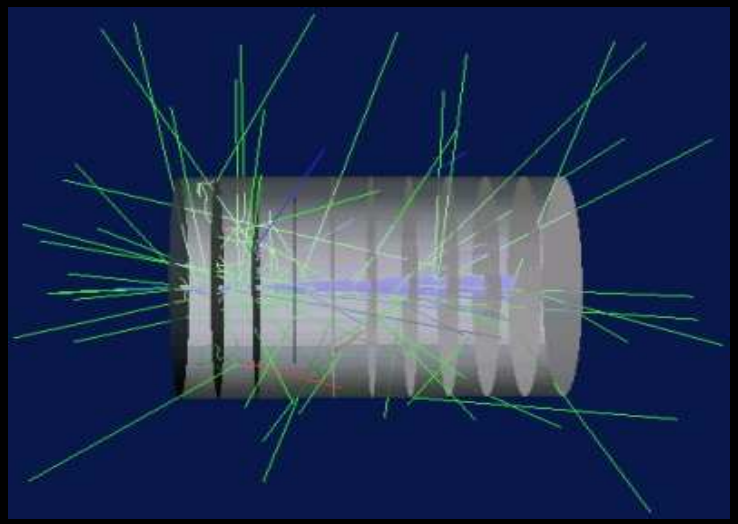
- Electromagnetic interactions in liquid water down to ~7.5 eV
  - e^-, p, H, He
- Validation : two independent computations by LPC Clermont & CENBG from literature

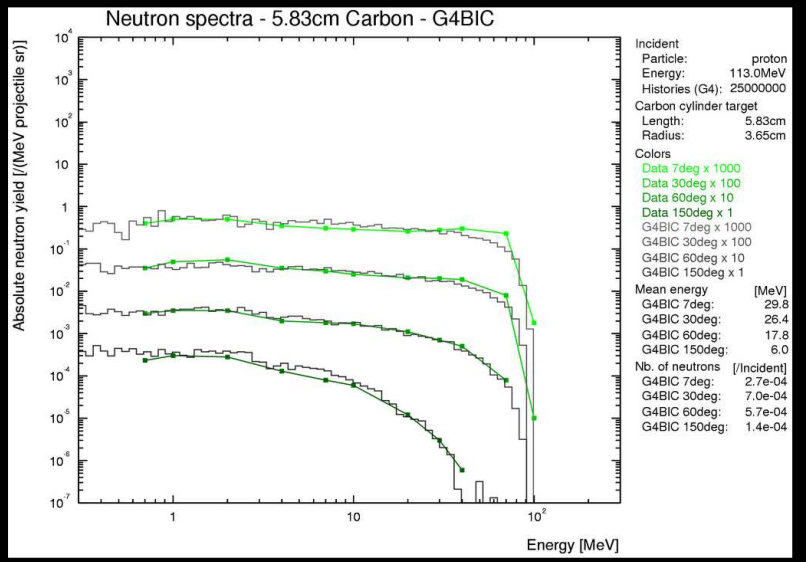
e^- Total cross section	Energy deposit	Rutherford + screening factor		No models
e^- Angular distribution		Brenner	Emfietzoglou	
p energy distribution	Analytical	Tabulated		
e^-, H, He^0, He^+, He^{++} energy distribution	Tabulated			

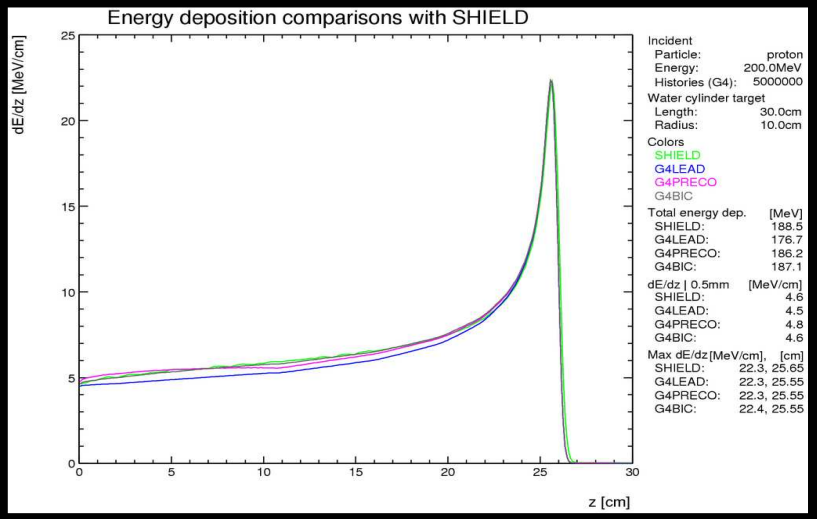
See related talks in this session

DESIRE
Physics validation

IEEE Trans. Nucl. Sci., 51, Issue: 4, 1378–1384 (2004).





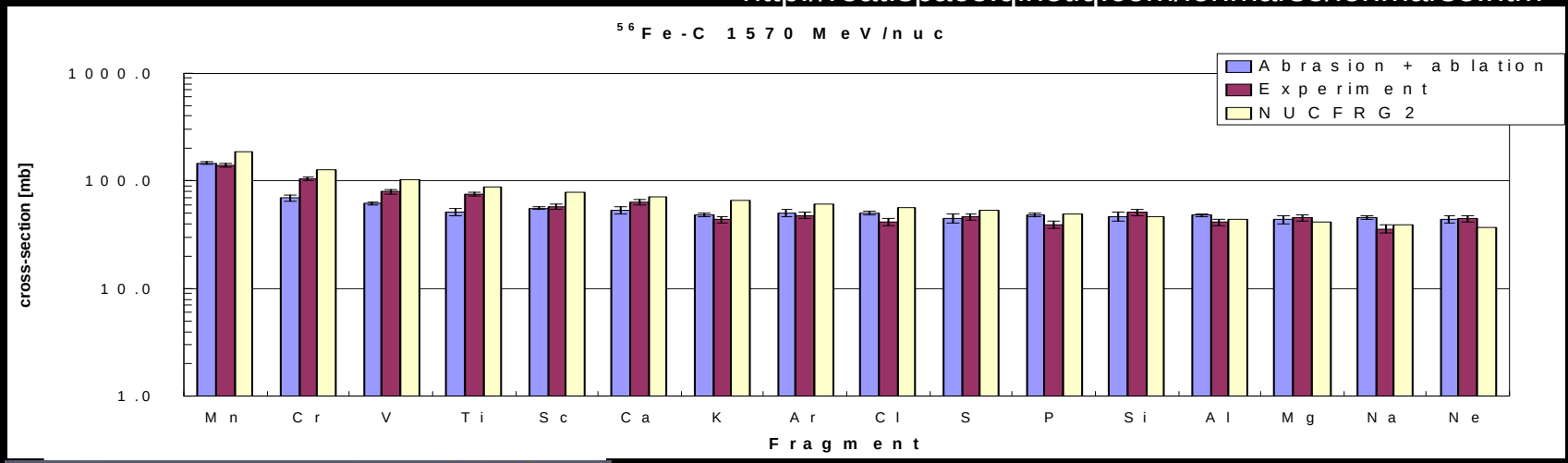


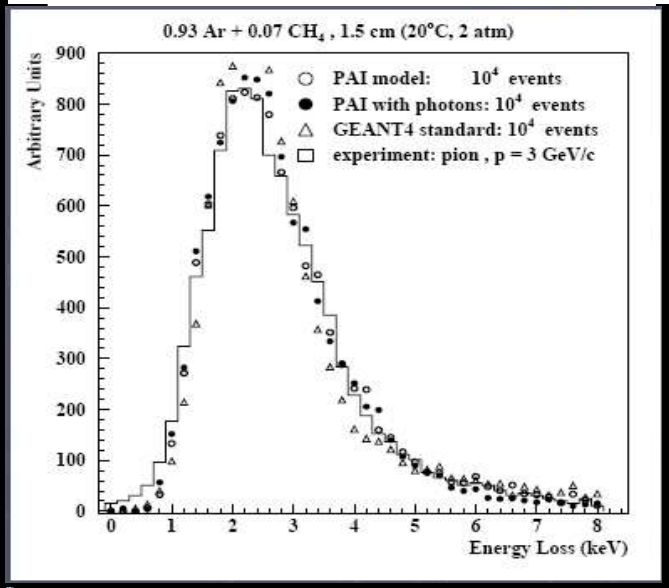
Courtesy: T. Ersmark, KTH Stockholm

DESIRE web page:
http://gluon.particle.kth.se/desire

Physics for hadrons (ions) in GEANT4

http://reat.space.qinetiq.com/ionmarse/ionmarse.htm





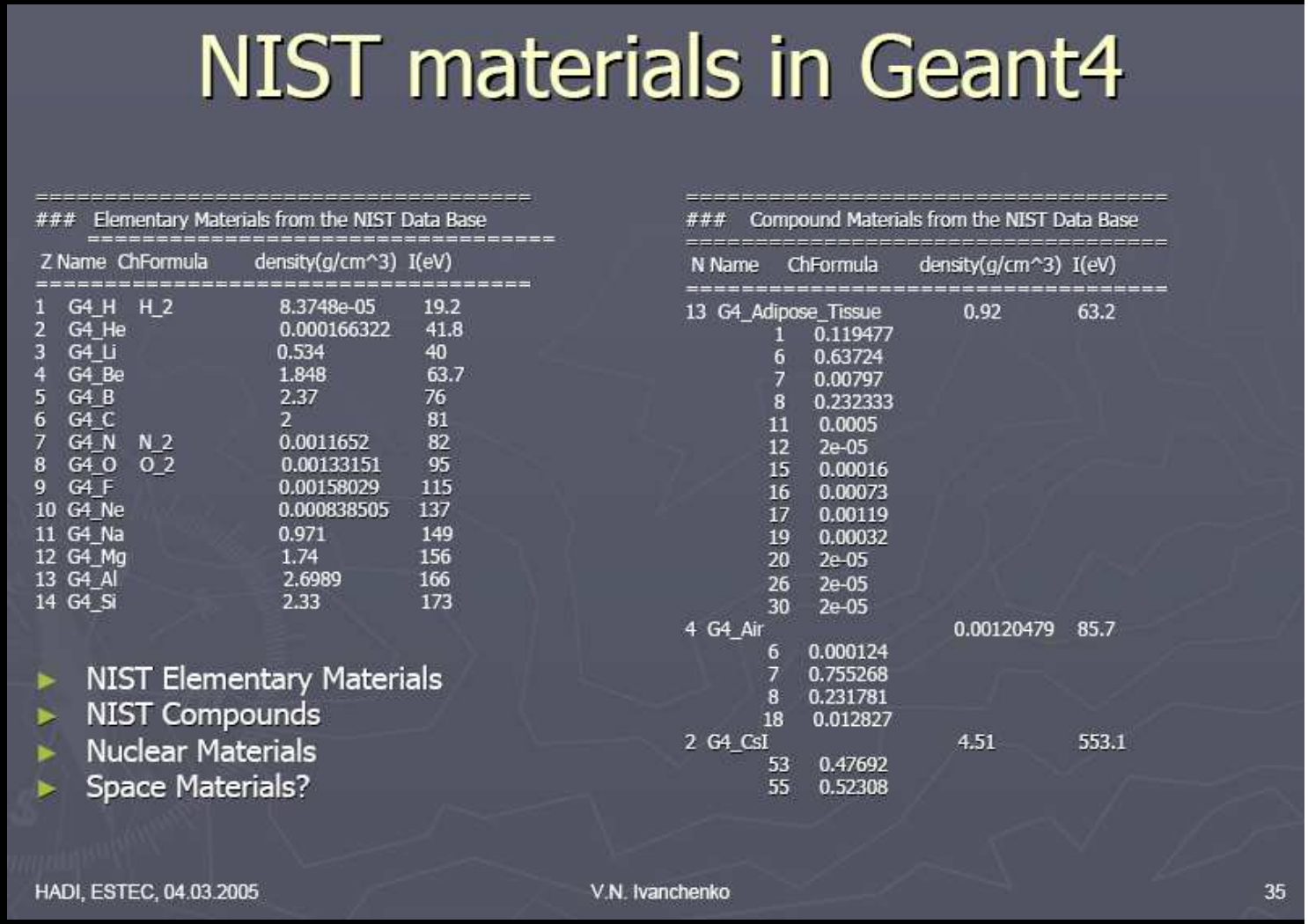
- ESA – IONMARSE (P.Truscott, Qinetiq)
  - New nuclear-nuclear cross sections
  - Abration/Ablation (Wilson) in Geant4
- HADI (V.Ivantchenko)
  - Hadron and Ion models
- Also important for SEE studies

2. Interfaces

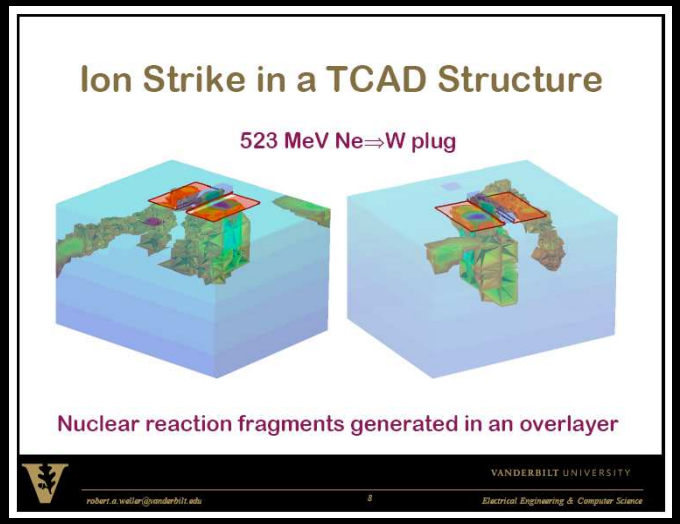
1. Physics models
2. Interfaces
   - Materials
   - CAD geometries
   - SPENVIS
3. (Engineering) tools

NIST Material Database

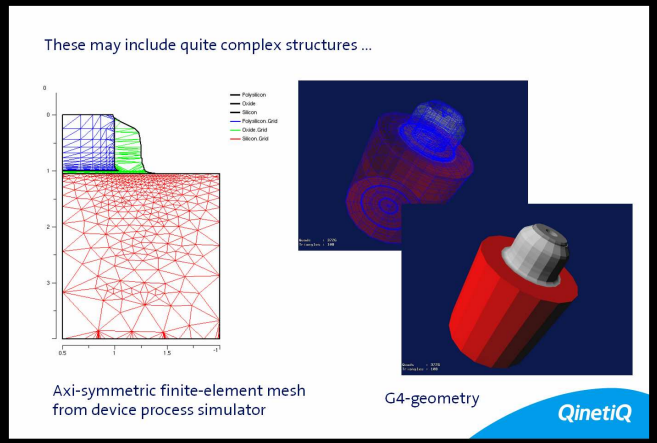
- V.Ivantchenko (ESA contract)



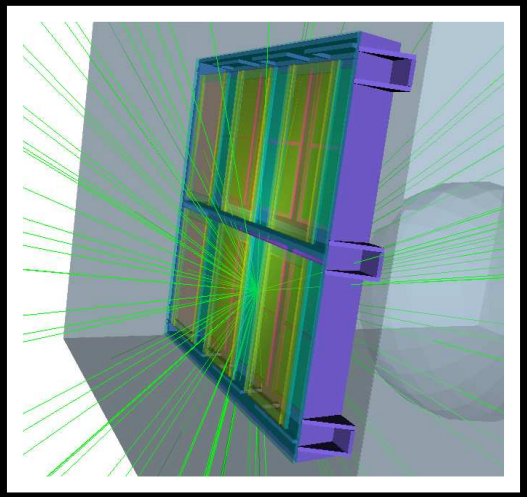
CAD Interface



Vanderbilt University (2005)



QinetiQ (2005)



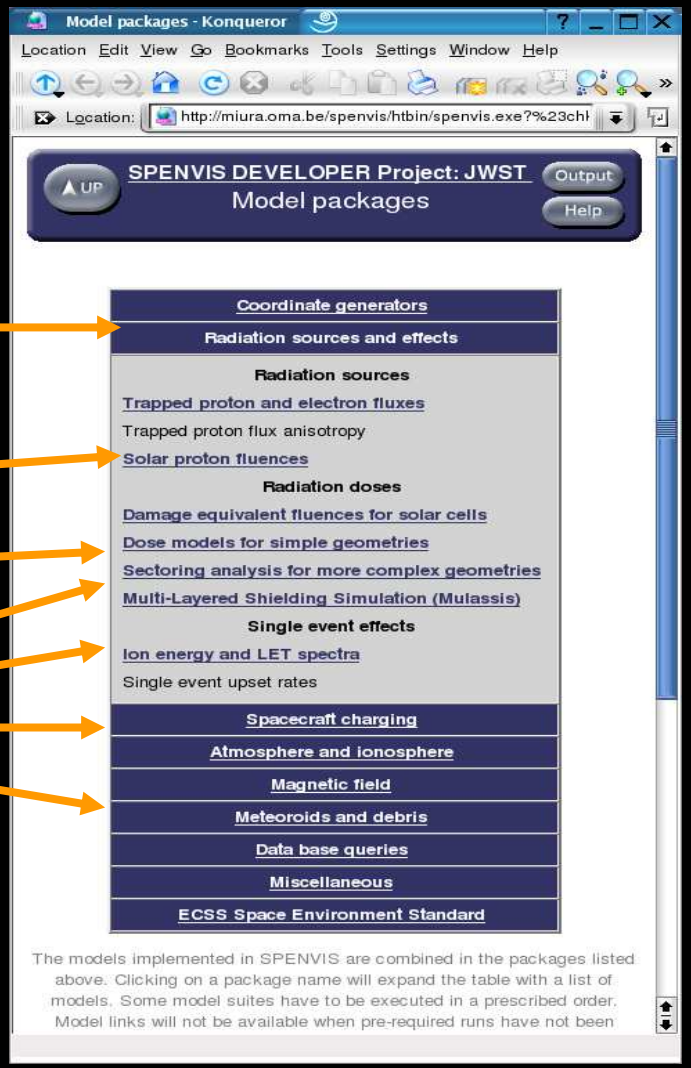
EFACEC (2005)

- Several examples of existing interfaces
- ESA ongoing contract (QinetiQ+sub.) to develop public prototype
- Future contract (2006) to integrate GEANT4 interface with GUI

SPENVIS
Space Environment Information System

- Space Environment Information System
  - Models and tools for the space environments effects analysis
  - Also GEANT4-based models
- Web Interface

- Mission model
  - Orbit, attitude
- Space environment models
- Radiation transport
  - Simulation engine
- Effects Analysis
  - Damage mechanisms
  - Charging
  - SEE
  - Effects to humans



SPENVIS / GEANT4 Space Users Workshop 3-7 Oct 2005

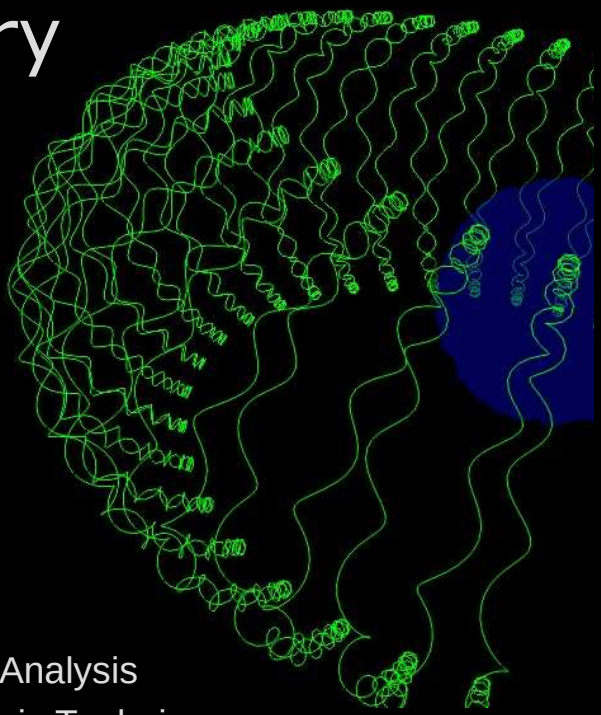
- Joint session: GEANT4 tools in SPENVIS (now or in the near future)
  - MULASSIS
  - MAGNETOCOSMICS
  - GRAS
  - GEMAT

Geant4 Space Users

- Gather and help the GEANT4 space user community
- New web page
  - User list
  - Related publications
  - Resources (codes…)
  - Related events
  - …
- Events
  - Tutorials
  - Space User Workshops
  - …

http://geant4.esa.int

GEANT4 Tutorial for Space Industry



3 March 2005
ESA / ESTEC

Organisation:
Giovanni Santin
Petteri Nieminen
Ali Mohammadzadeh

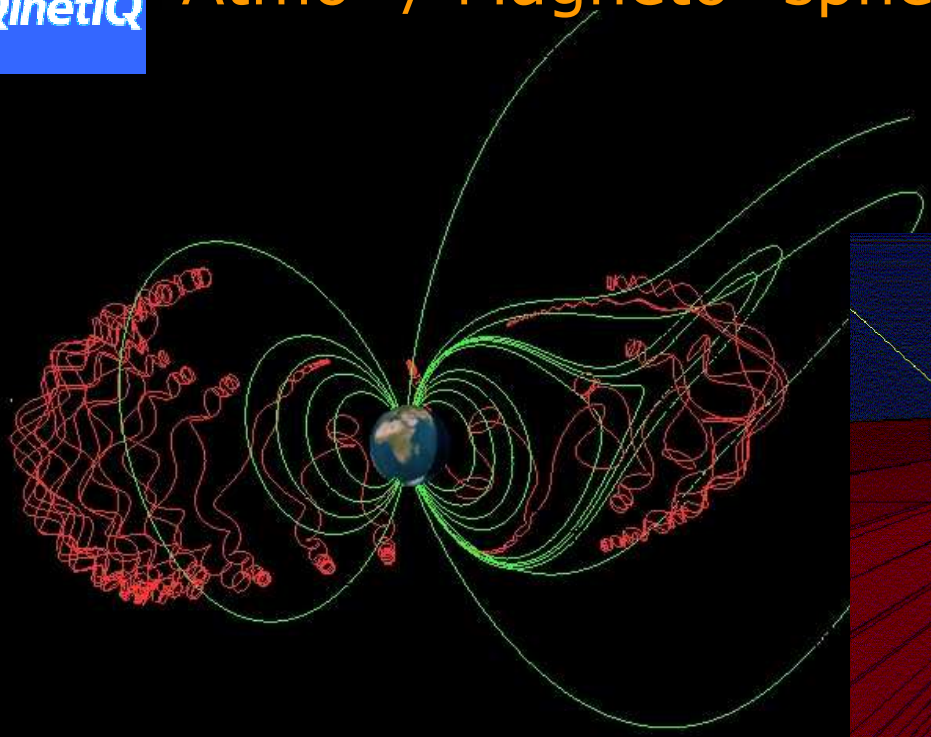
Space Environments and Effects Analysis
Radiation Effects and Component Analysis Techniques

- GEANT4-based tools for Space: **SSAT, QARM, MULASSIS, GRAS**
- ~30 people (despite heavy snowfall, block of Amsterdam airport,…)
- Attendees from industry (not only space) and research institutes

3. (Engineering) tools

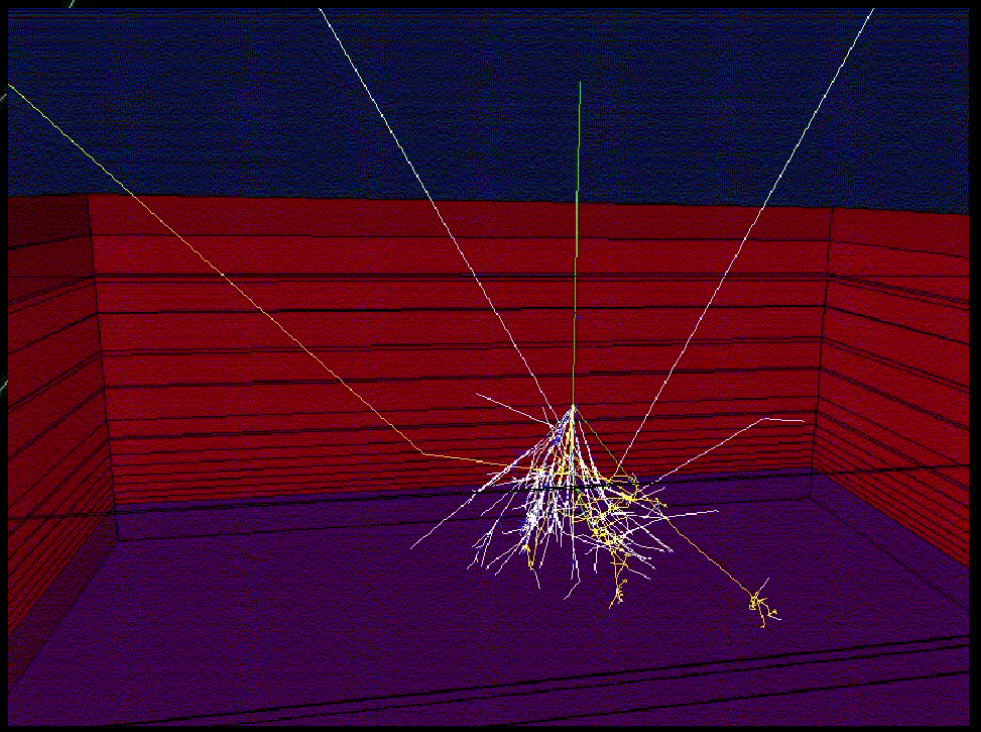
1. Physics models
2. Interfaces
3. (Engineering) tools
   - PlanetoCosmics
   - SSAT
   - MULASSIS
   - GEMAT
   - NIEL
   - GRAS

PlanetoCosmics
Cosmic Rays in planetary Atmo- / Magneto- spheres

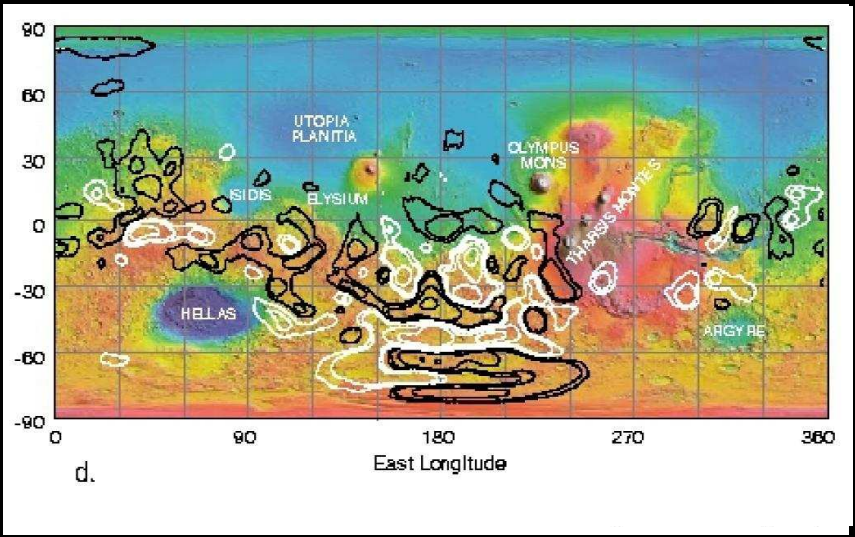


- Laurent Desorgher, University of Bern

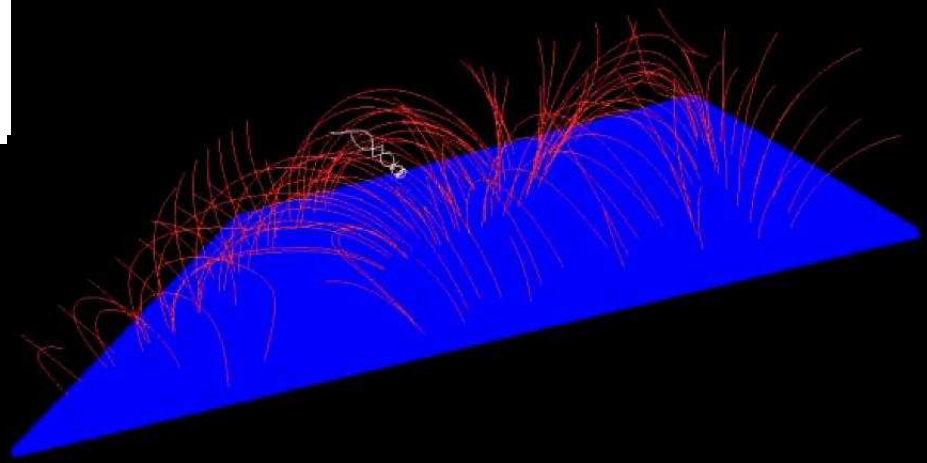
http://reat.space.qinetiq.com/septimess/magcos/



PlanetoCosmics
Mars field and atmosphere



- NASA Mars-GRAM2001 model



Geant4 implementation courtesy L. Desorgher, University of Bern

SSAT
Sector Shielding Analysis Tool

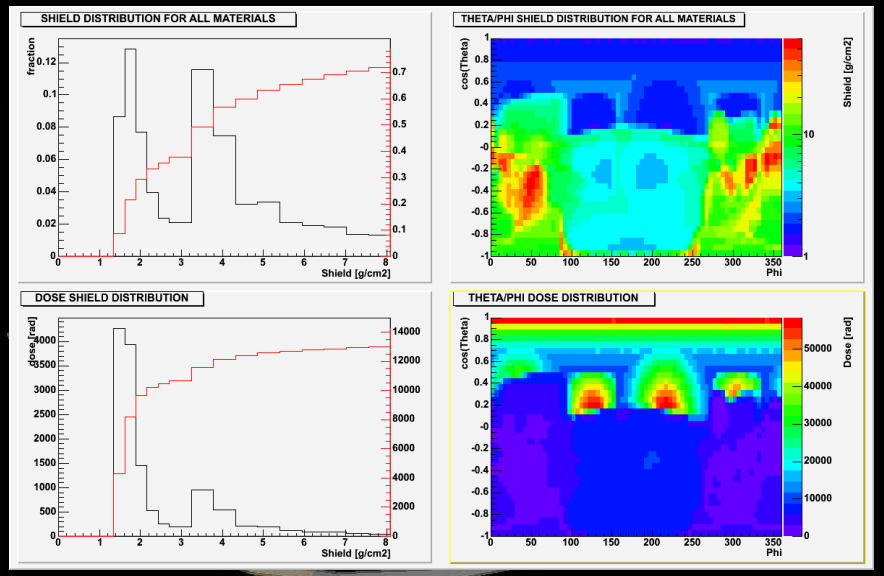
- Ray tracing: from a user-defined point within a Geant4 geometry

SHIELDING

- shielding levels
  - fraction of solid angle for which the shielding is within a defined interval
  - global and from single materials
- shielding distribution
  - the mean shielding level as a function of look direction
- It utilizes geantinos

DOSE

- Estimate of the dose at a point
  - Based on external Dose-Depth curve
    - E.g. SHIELDOSE-2 curve [rad VS g/cm^2]
  - Ray-by-ray dose calculation
- Results:
  - Total dose
  - Dose-Depth profile
  - Dose directionality

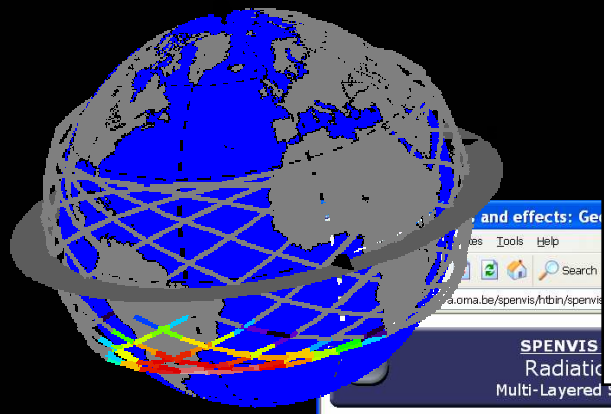


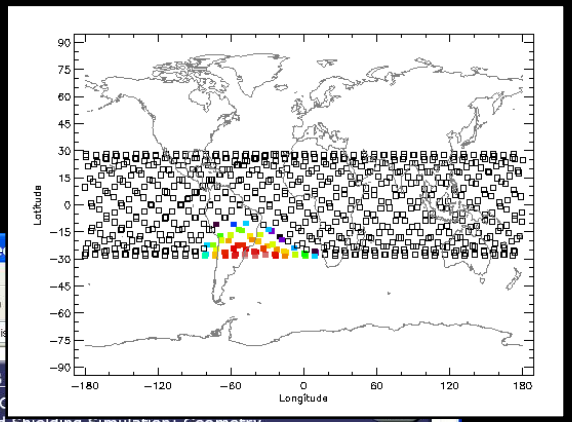
ConeXpress model: R.Lindberg, ESA

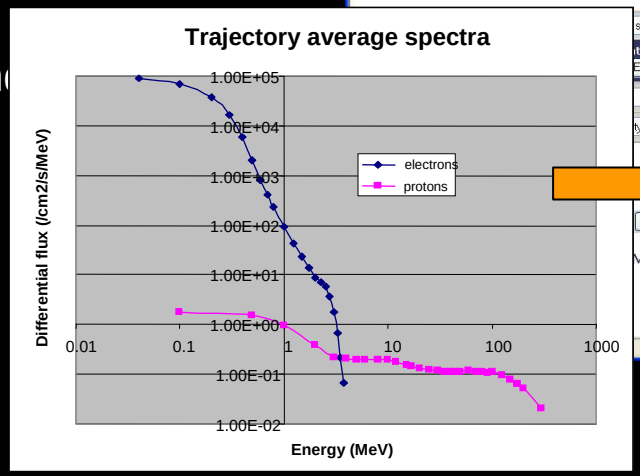
MULASSIS
Multi Layered Shielding Simulation

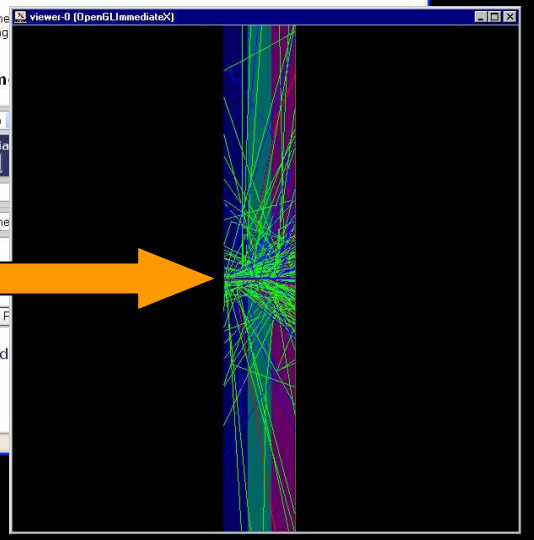
- Layer Geometry
- Physics list choice
- Analysis capabilities
  - Dose
  - Pulse Height Spectrum
  - Ion. dose
  - NIEL
  - Dose equivalent calculation

- Web interface
- Primary particle spectrum an
  from SPENVIS
  - Trapped protons
  - Solar protons
  - Trapped electrons
  - …

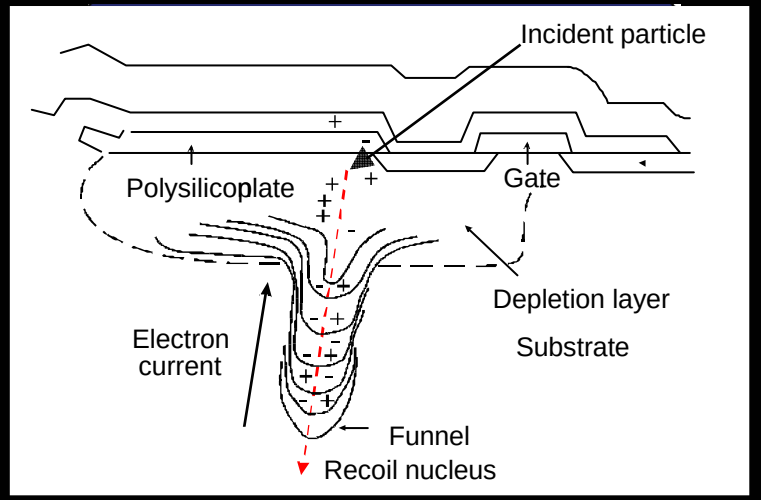






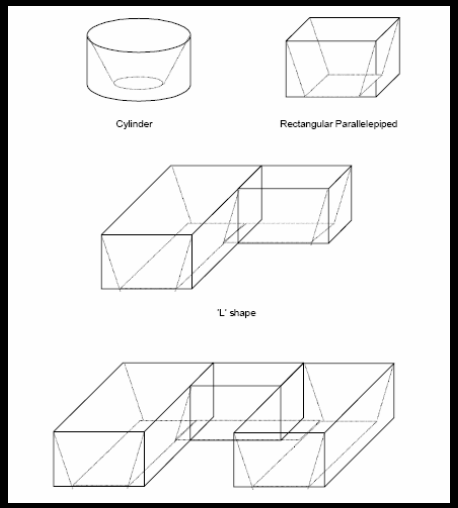


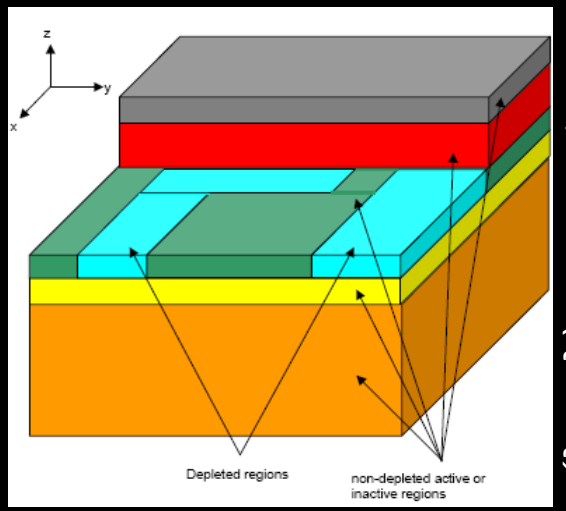
GEMAT
Geant4 Microdosimetry Analysis Tool



AIM
- Single Event Effects in microelectronics

- Dedicated geometry builder UI
- Dedicated physics list
- Built-in analysis modes
  - PHS: SEU rates
  - Path-length





F.Lei, P.Truscott (QinetiQ)

- Analogy with medical microdosimetry for physics models

QinetiQ

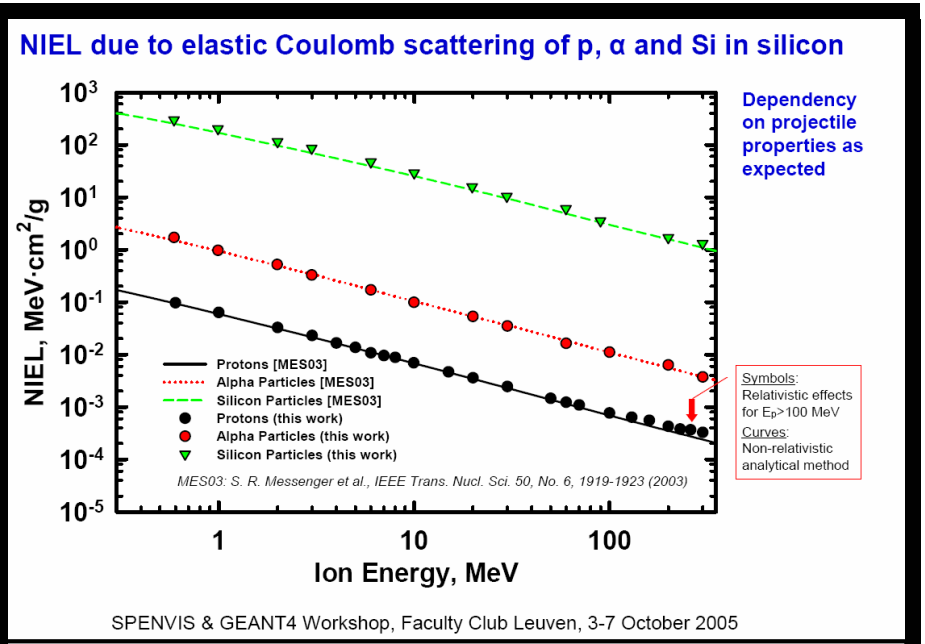
esa

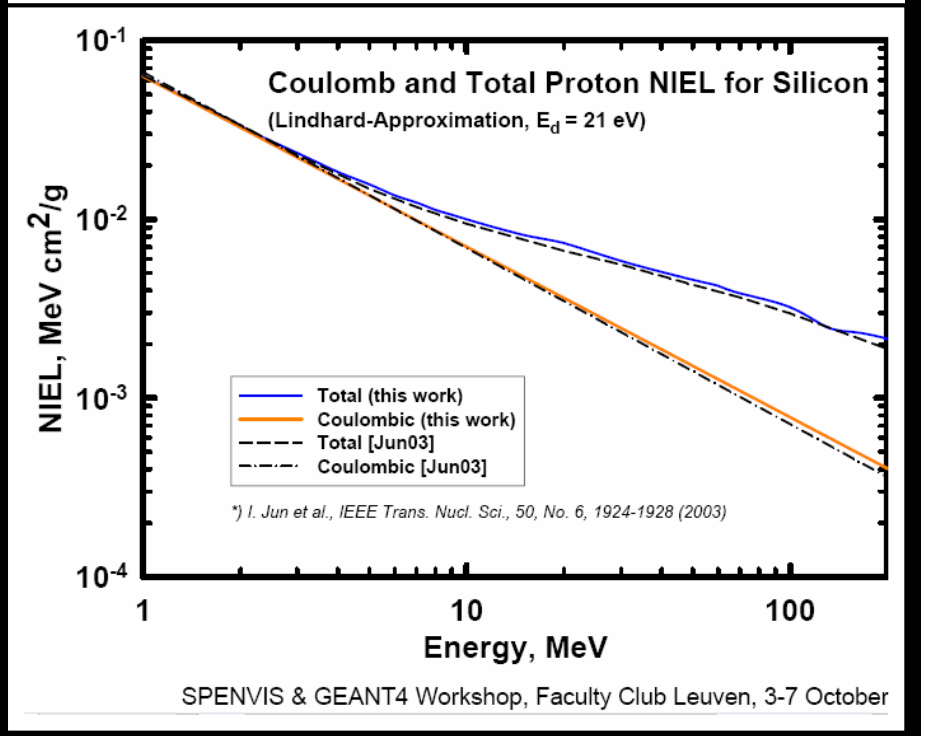
NIEL
Non Ionizing Dose and Damage

AIM

- Facilitate qualification procedure for new electronic devices used in space missions

- Displacement Damage (DD) in semiconductors induced by NIEL
- Performance degradation of electronics components
- Uses Screened Coulomb scattering
  - Implementation by Vanderbilt University
    Nucl Instr Meth B 227, Issue 3, 420-430 (2004)

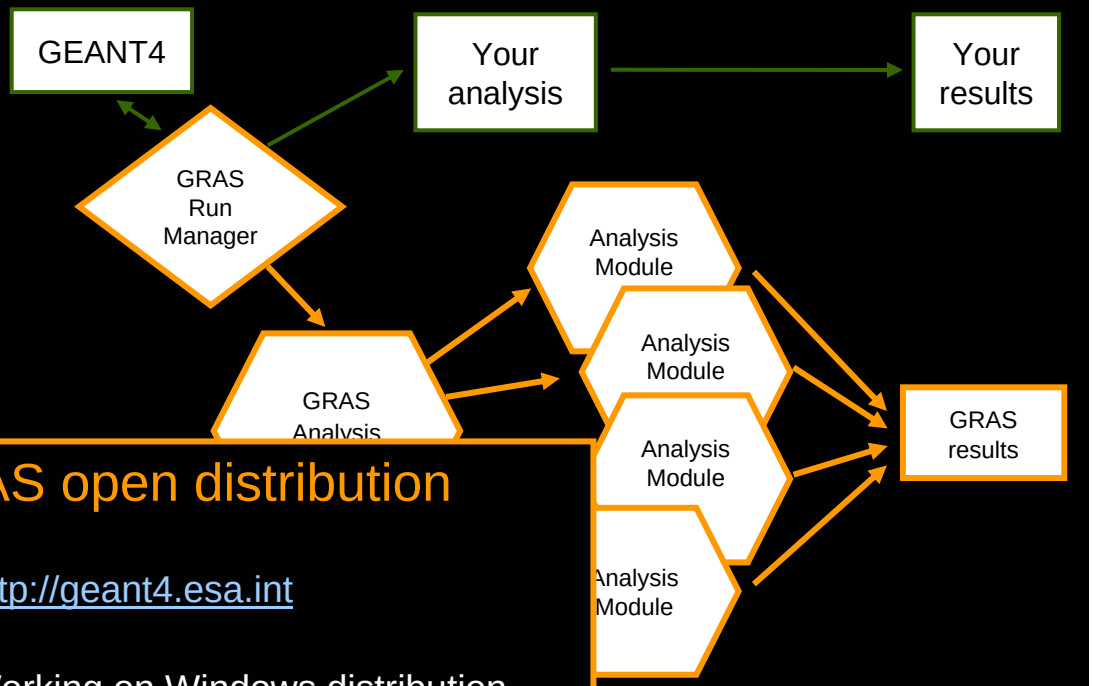




GRAS

GEANT4 Radiation Analysis for Space

IEEE Trans.Nuc.Sci. 2005 (accepted)

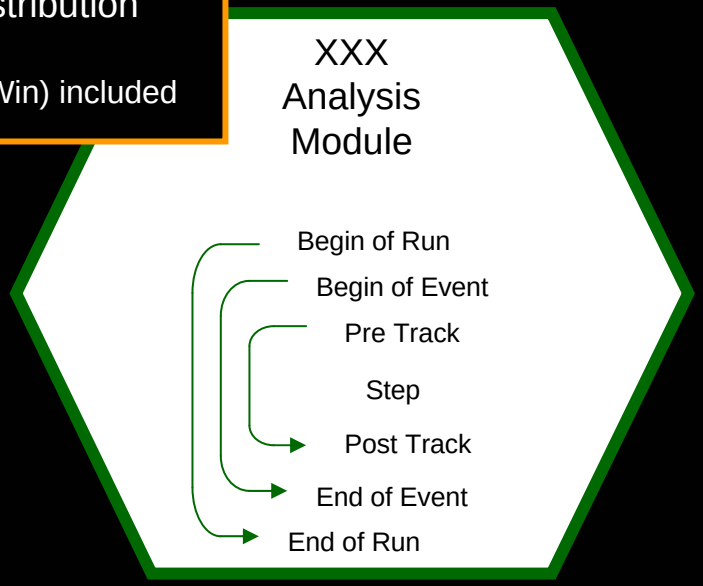


- Detector / Component effects
  - Dose, Fluence, NIEL, charging…
    for support to engineering and scientific design
- Human dosimetry
  - Dose Equivalent, Equivalent Dose
    for ESA exploration initiative
- 3D geometry
  - GDML format, or existing C++ cla

GRAS open distribution

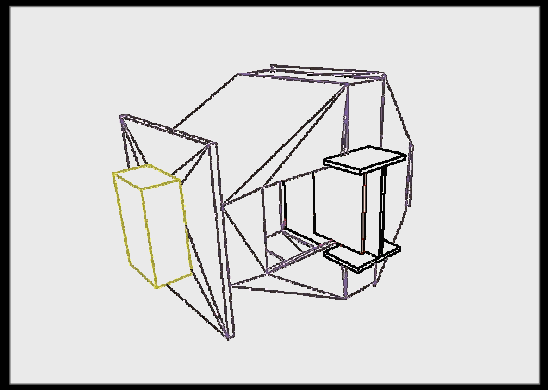
- http://geant4.esa.int
- Working on Windows distribution
  - InstallShield
  - AIDA/OpenScientist (Win) included

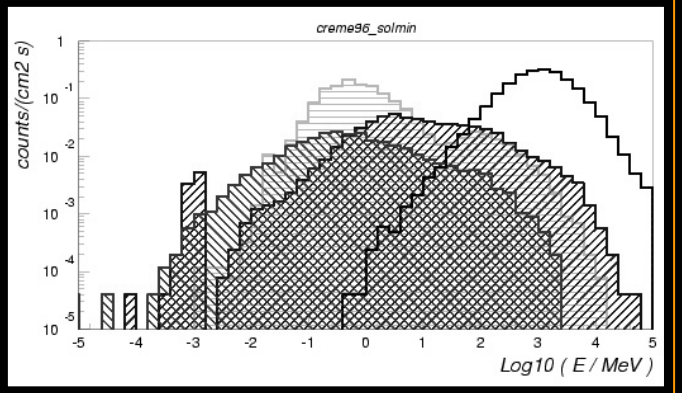
- Ready-To-Use tool
  - Different analyses set without re-compilation
- Modular / extendable design
- Integration with GATE under investigation
  - Many commonalities
- Is being integrated into SPENVIS

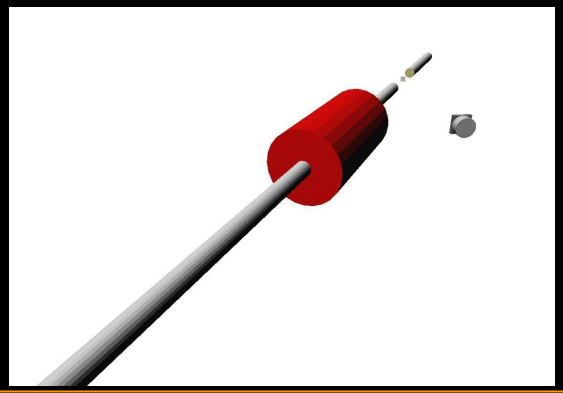


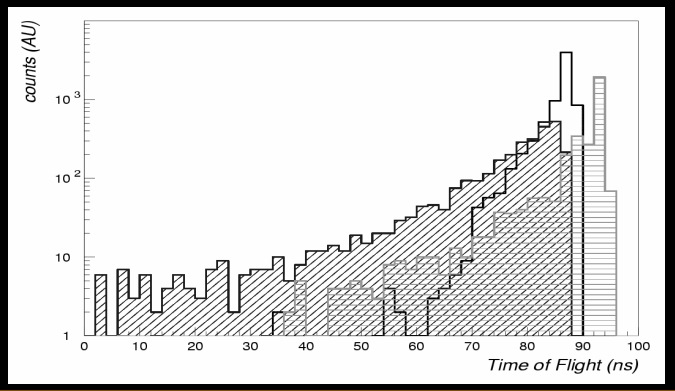
GRAS use cases

IEEE Trans.Nuc.Sci. 2005 (accepted)

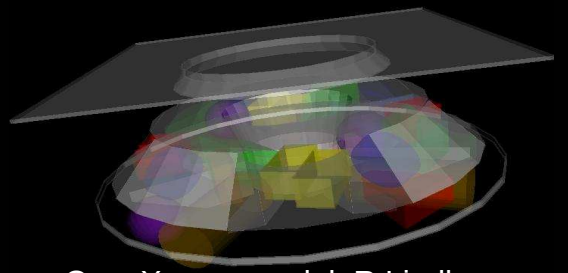






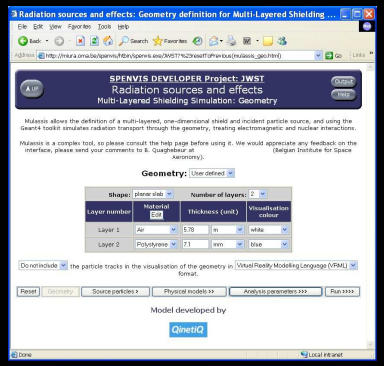


- JWST background
- TOF for neutron production exp.
- Total Dose in ConeXpress

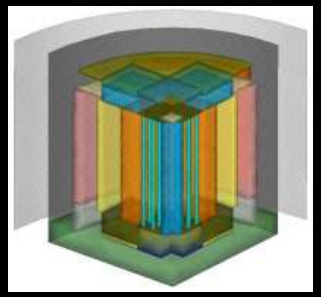


ConeXpress model: R.Lindberg, ESA

Interface GEANT4 to CAD GUI (or CAD GUI to GEANT$)



GUI tool

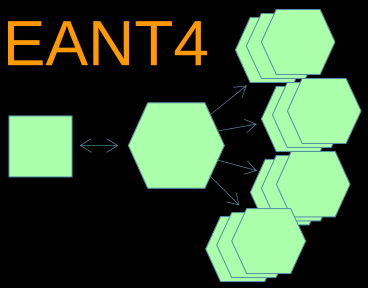


Geometry modeling

Script instructions:
- Physics
- Radiation Environment
- Analysis type

Geometry exchange format
- GDML
- CAD / STEP
- ...

GEANT4



Planned developments

- Radiation Effects on Advanced Technologies – Models and Software (Part II)
- MEO Electron Environment Models development (2006)
- Martian Radiation Environment Models; AO published in Oct 2005

  Extension of the developments presented in this Workshop + Geant4 heavy ion hadronic physics work + “active shield” concept analysis. Focus on ESA ExoMars mission.
- Preparatory Study of Investigations into Biological Effects on Radiation (AO now closed)
- Long-term R&D roadmap for the Exploration programme existing

Conclusions

- GEANT4 studies essential part of human space mission design and optimization
- Increased use of Geant4 in space thanks to tools and applications
- Extensions of present physics and interfaces required for manned and unmanned space missions
- Synergies with medical activities to address critical areas of improvement
  - Interfaces
  - Physics model extensions
- Fruitful collaboration in the past among ESA, GEANT4 collaboration, academia and external institutes

http://geant4.esa.int

Giovanni.Santin@esa.int