Results of ion simulations

Geant4 EM meeting
CERN, 7 Feb 2008

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Motivation

- Simulation of radiation induced effects in electronic devices for space missions
- Space radiation environment induces a wide range of effects that can affect the operation of space missions

  Effects include
  - Degradation from cumulative doses (TID, NIEL, …)
  - Single Event Effects (SEE) ←
- Ions are present as primaries (e.g. cosmic rays) or as secondaries (e.g. as recoil and from inelastic interactions)
- SEE ground testing of electronic components and memories increasingly difficult
  - Limited ion species and energies at irradiation facilities
  - Geometry constraints → irradiation from rear face of thinned components
- Modelling (simulation) plays an important role in interpretation of tests
  - Transients are induced by local energy deposit in active volumes

    → nominal LET at chip surface (i.e. dE/dx) has to be corrected

Facilities, simulation tools, data harmonisation

- *A. Javanainen et al., IEEE TNS 54, 2007, p.1158*

  LET values are determined differently at different irradiation facilities

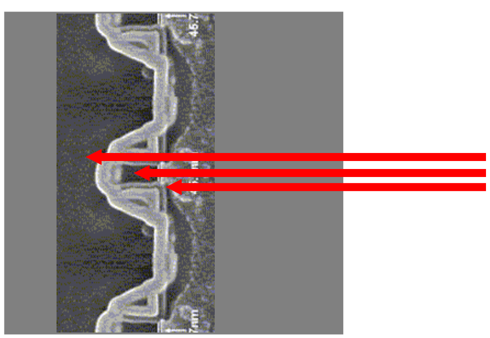
  Some use “SRIM”, some “LET Calculator”

  No common guidelines

  → inconsistent characterization of tested electronics.

- Radiation Effects Facility (RADEF)
  - JYFL Accelerator Laboratory, Jyväskylä, Finland

    One of the ESA’s European Component Irradiation Facilities (ECIF)
  - Heavy ion cocktail (7 ion species from N to Xe)
  - Energy of < 9.3 MeV/nuc
  - LET in Si from ~2 to 60 MeV/(mg/cm^2)



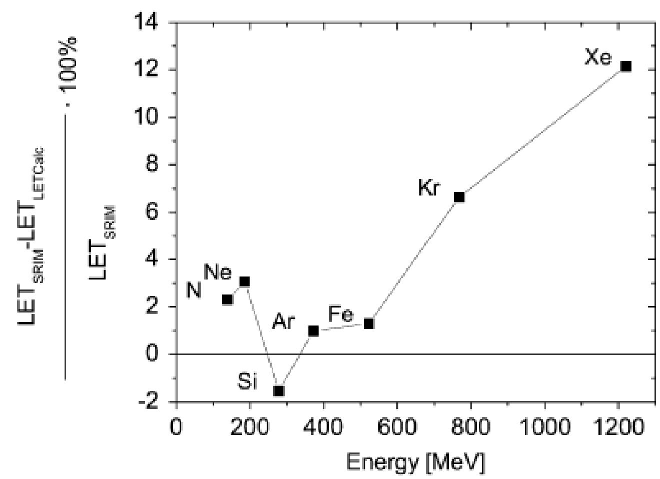
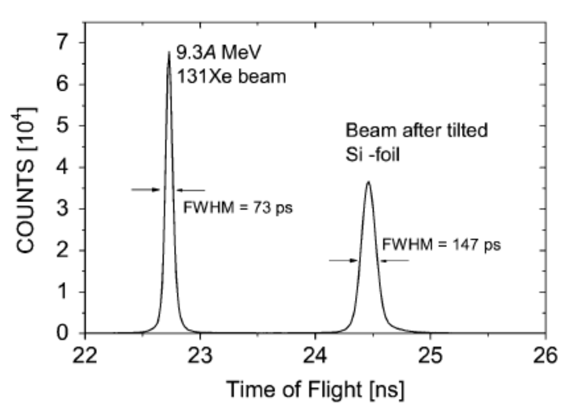
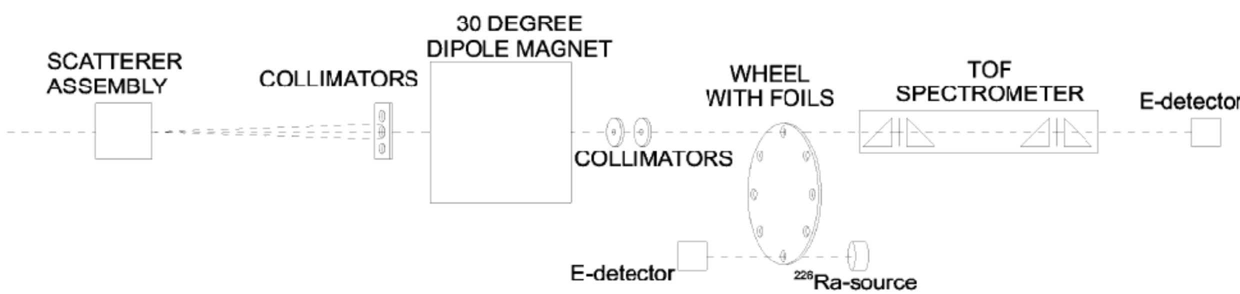


Fig. 1. Percentage difference in LET values in Si calculated with SRIM and LET Calculator for different ions as a function of energy.

Ion LET data taking campaign

- Working group (from RADECS thematic workshop)
- First measurements
  - ^{82}Kr, ^{131}Xe
- High precision TOF spectrometer
  - Base length ~1m
  - Intrinsic resolution FWHM < 70 ps

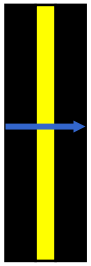




A. Javanainen et al., IEEE TNS 54, 2007, p.1158

Simulation setup

- Geant4 9.1
- GRAS v2.3
- Geometry
  - MULASSIS type
    Vacuum – Silicon (1µm, 10µm) – Vacuum
- Source
  - ^{131}Xe, ^{82}Kr (^{84}Kr)
- Physics
  - Standard EM
  - G4ionIonisation
  - Cuts: 1µm / 10µm

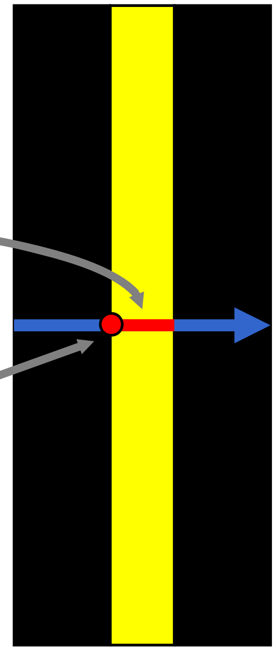


Vacuum – Silicon – Vacuum

```
# geometry
/gras/geometry/type mulassis
/geometry/layer/delete  0
/geometry/layer/shape slab
/geometry/layer/add  0 Vacuum   2    10.0 mm
/geometry/layer/add  1 Silicon  8    0.001 mm
/geometry/layer/add  2 Vacuum   2    10.0 mm
/geometry/update

# source
/gps/particle ion
/gps/ion 54 131

# flat spectrum
/gps/ene/type Arb
/gps/hist/type arb
/gps/ene/min    0.    MeV
/gps/ene/max    1310. MeV
/gps/hist/point    0.      1.
/gps/hist/point    1310.   1.
/gps/hist/inter Lin

# physics
/gras/physics/addPhysics  em_standard
/gras/physics/setCuts    0.001 mm
```

GRAS analysis

- Dose analysis
  - Energy deposit in the volume
- LET analysis
  - dE/dx table at boundary
  - From G4EMcalculator

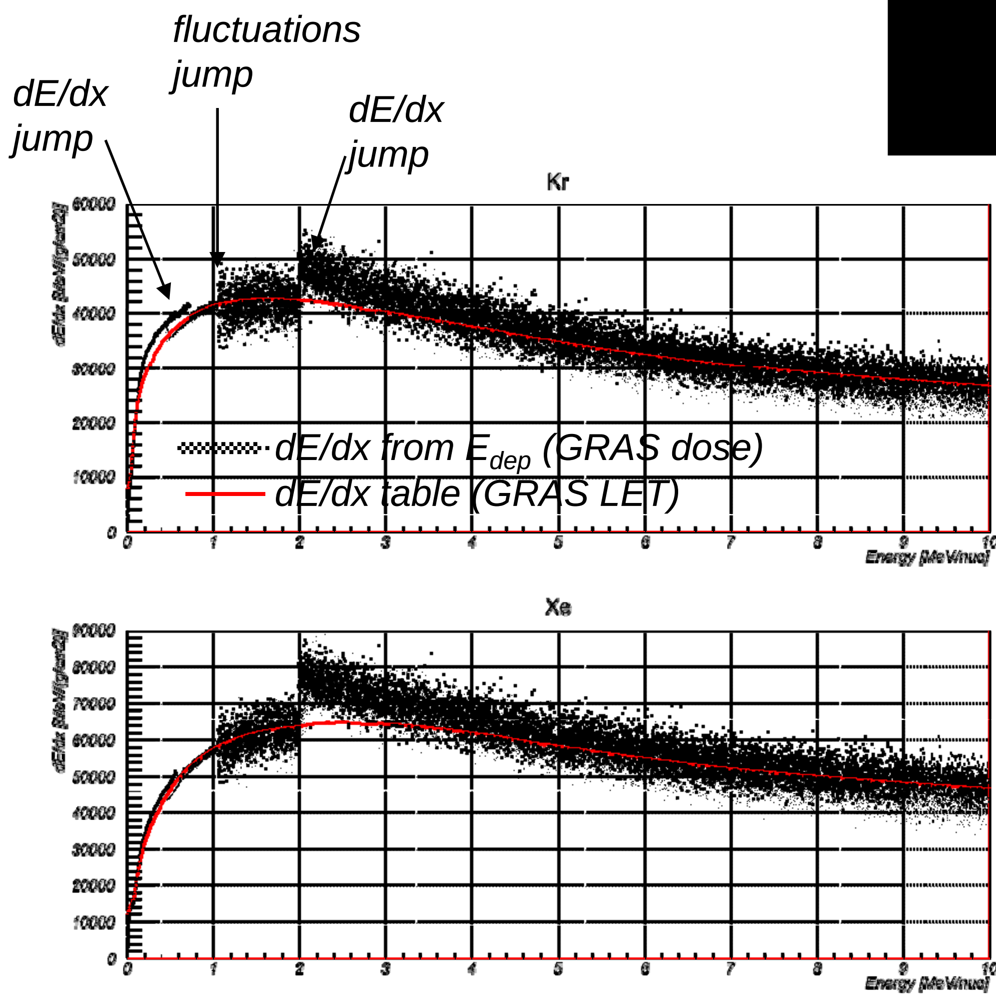


^{82}Kr, ^{131}Xe

```
/gras/analysis/dose/addModule dose2
/gras/analysis/dose/dose2/addVolume Layer-2
/gras/analysis/dose/dose2/setUnit MeV
/gras/analysis/dose/dose2/initialise
/gras/histo/setHistoByName dose2_dose 100 0.000000001 100. none log

/gras/analysis/LET/addModule let2
/gras/analysis/LET/let2/addVolumeInterface Layer-1 Layer-2
/gras/analysis/LET/let2/setUnit MeV/cm
/gras/analysis/LET/let2/initialise
/gras/histo/setHistoByName let2_LET 60 0.001 1000. none log
```

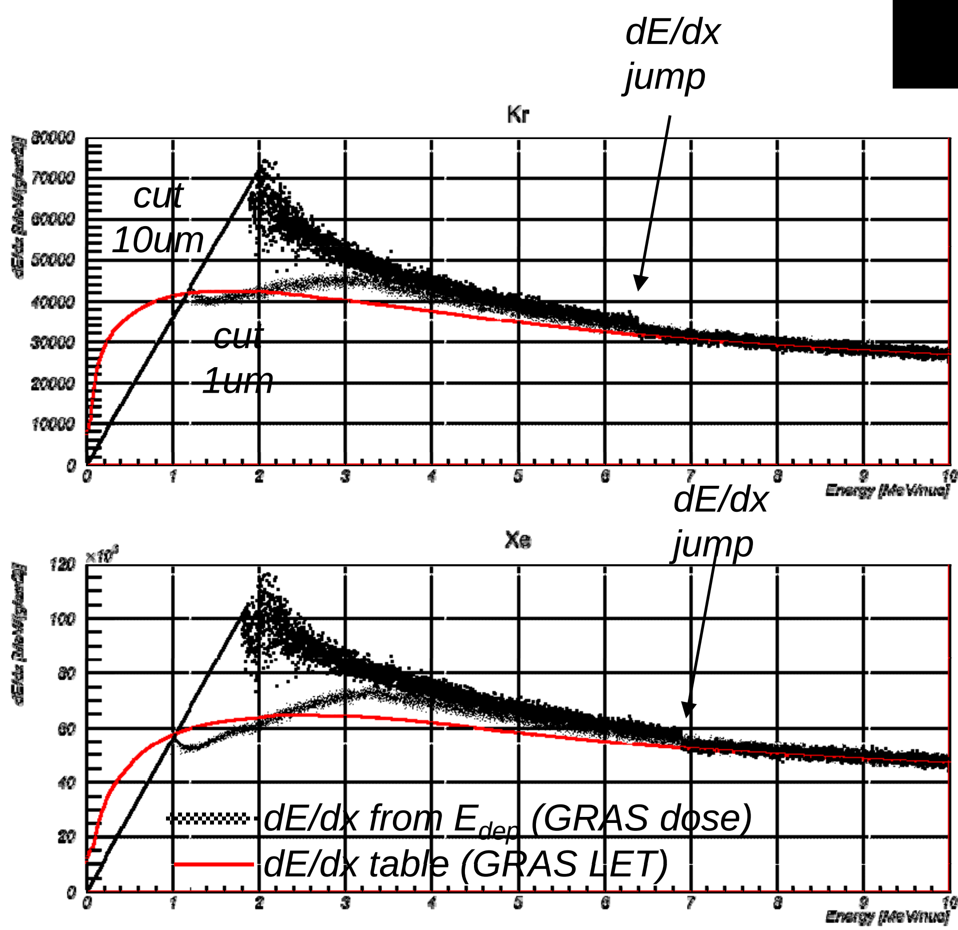
Simulation results: 1 μm target

- Thickness: 1 μm
- Cuts: 1 μm, 10 μm



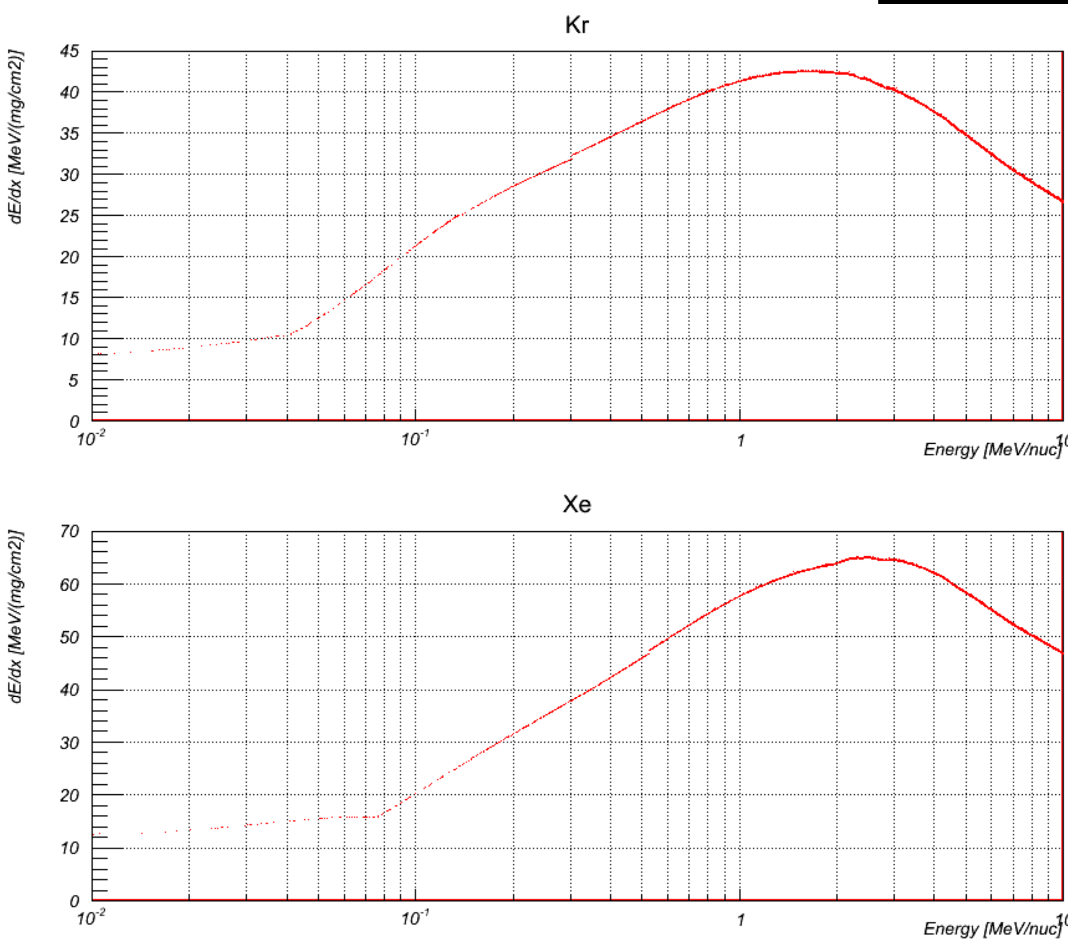
Simulation results: 10 um target

- Thickness 10 μm
- Cuts: 1 μm, 10 μm



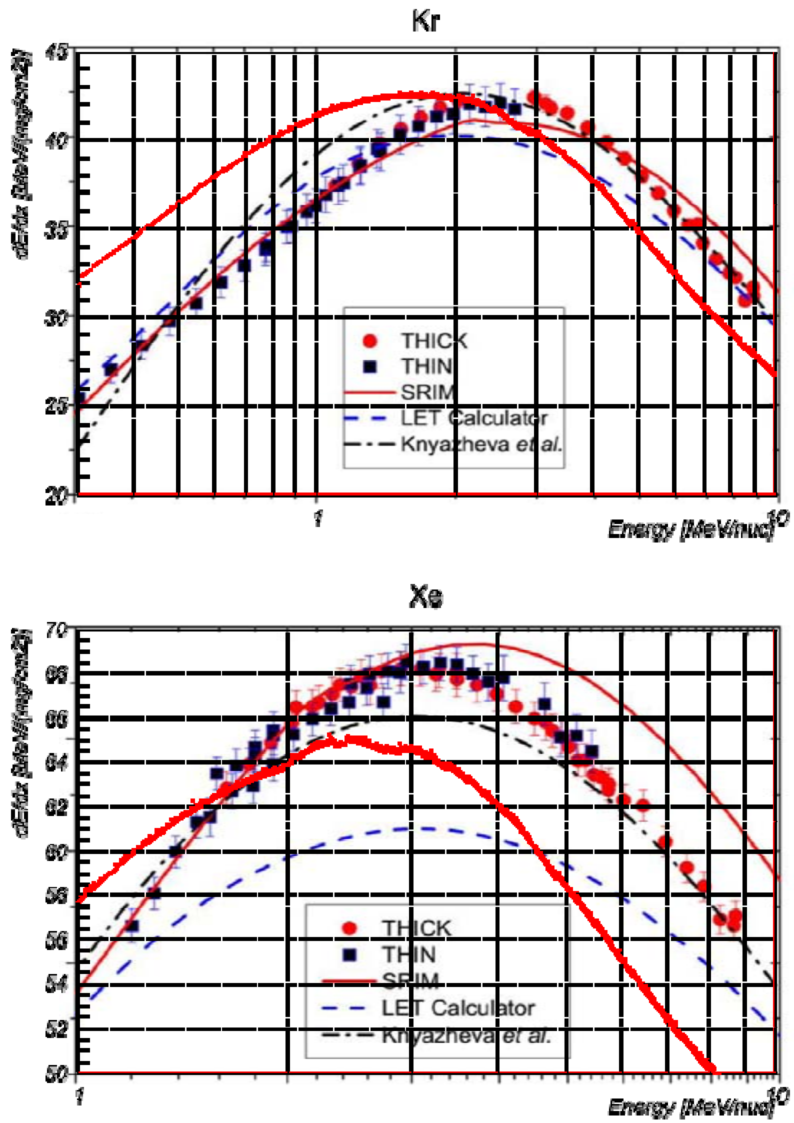
Geant4 dE/dx tables

- Much smoother than final ionisation values
- Some minor jumps
- Comparison to data
  → next slide



Comparison of dE/dx tables

- ^{82}Kr, ^{131}Xe
- E < 10 MeV/nuc
- Comparison to
  - SRIM 2003
  - LET calculator
  - Exp data



- Data:

  A. Javanainen et al.,

  IEEE TNS 54, 2007

Summary, perspectives

- Some problems detected in the G4ionIonisation process.

  2 separate sources:
  - Stopping power tables
  - The way Geant4 uses the tables (including fluctuations)

- Stopping power tables: comparison to other ion simulation tools and exp data show significant disagreement
  - Need for Geant4 to include better tables (e.g. ICRU73)

- Additional note:

  The new data taking campaign on LET will be completed in 2008.

  Direct inclusion of these dE/dx data would enable systematic use of Geant4–based tools (e.g. MULASSIS, GEMAT, GRAS) in the ESA standard component SEE testing procedure

Spare

GRAS tool description

Geometry
GDML,
C++,
CAD (GDML)

Physics
EM,
Hadronics,
Ions

Radiation environment
SPENVIS,
CREME96,…

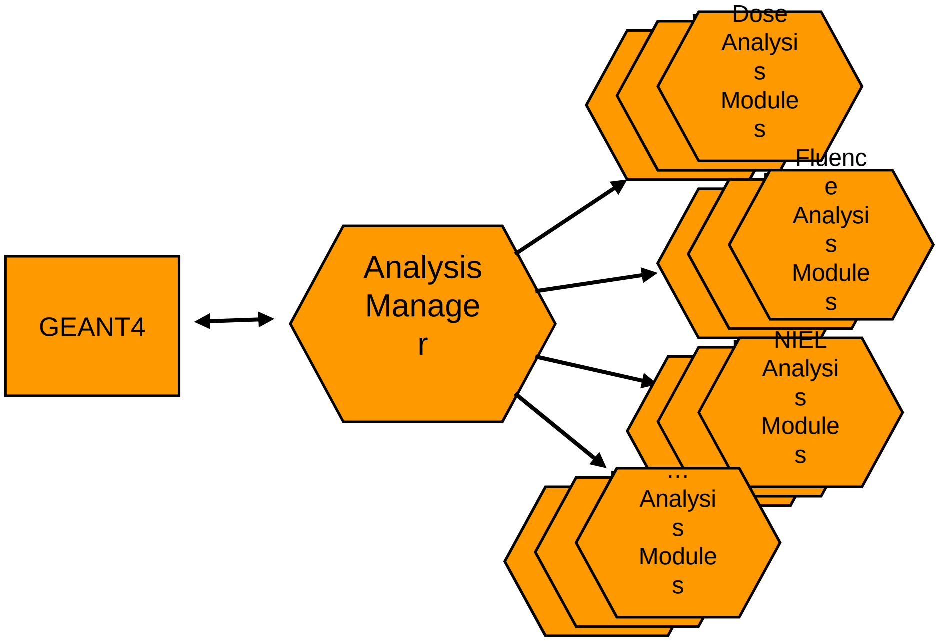
- Analysis types
  - 3D
  - Dose, Fluence, NIEL, charge deposit… for support to engineering and scientific design
  - Dose Equivalent, Equivalent Dose,… for ESA exploration initiative
  - SEE: PHS, LET, path length, GEMAT (QQ)
  - Open to new analysis models
- Analysis independent from geometry input format
  - GDML (& CAD), or existing C++ class, …
- Pluggable physics lists
- All text UI (macro) driven!
  Different analyses without re-compilation
- Modular / extendable design
- Publicly accessible

Histogramming
AIDA,
ROOT,
CSV

GRAS components

Analysis

RADIATION EFFECTS




```
/gras/analysis/dose/addModule doseB12
/gras/analysis/dose/doseB12/addVolume b1
/gras/analysis/dose/doseB12/addVolume b2
/gras/analysis/dose/doseB12/setUnit rad
```

- At present:
  - Dose
  - Fluence / Current
  - NIEL
  - Deposited charge
  - Detector

  Component degradation, background, detectors

  - Dose equivalent
  - Equivalent dose

  Human exploration

  - Path length
  - LET
  - Pulse Spectrum
  - GEMAT (QinetiQ)

  Component SEE

  - Common
  - Source monitoring

  Simulation monitoring

- Analysis independent from geometry input mode
  - GDML, or existing C++ class, …
  - Open to CAD geometry interface

Simulations of the Space Radiation Environment

esa

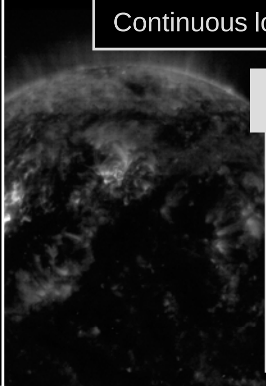
Sources

(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…

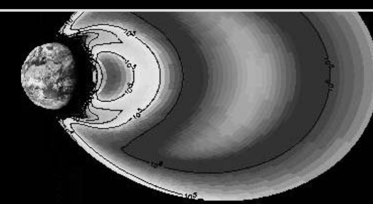
Softer spectrum

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

Signal, Background

(Spurious signals, Detector overload,…)

Charging

(internal, interferences, …)

Threats to life

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

Radiobiological effects