Simulation of Radiation Monitors for Future Space Missions

P. Gonçalves, M. Pimenta, B. Tomé

LIP - Laboratório de Instrumentação e Física Experimental de Partículas

Lisboa, Portugal
Space radiation environment
(see by a non-expert...)

**Earth’s trapped radiation belts**
- Electrons (<6 MeV) & Protons (<250 MeV)
- Relevant only for Low Earth Orbits (LEO)

**Galactic Cosmic Rays**
- Energy spectrum peaked at ~1 GeV/n
- < 1 GeV/n affected by 11-year solar cycle
- Flux modulated by solar cycle (inversely proportional to solar activity)

**Solar Energetic Particles (SPE)**
- Associated w/ impulsive solar flares and Coronal Mass Ejections
- Sudden and dramatic increase in flux – unpredictable & highly variable
- Mostly “low energy” electrons & protons; some heavy ions
- Frequency and Magnitude strongly correlated with solar cycle
**Gravitational waves**
- **Status**: in develop.
- **Launch**: 2011
- **ESA + NASA**

**Darwin**
- **Status**: in develop.
- **Launch**: after 2014
- **ESA +**

**Laser Interferometer Space Antenna (LISA)**
- **Status**: in develop.
- **Launch**: after 2014
- **ESA +**

**Earth-like planets**
- **Status**: in develop.
- **Launch**: after 2014
- **ESA +**

**X-ray Evolving Universe Spectroscopy (XEUS)**
- **Status**: in develop.

**BH, Galaxy clusters: ISM**
- **Status**: in develop.
- **Launch**: after 2014
- **ESA +**

**Very distant Universe**
- **Status**: in develop.
- **Launch**: 2010
- **ESA + NASA**

**Galactic Census**
- **Status**: in develop.
- **Launch**: after 2011
- **GSC**

**BepiColombo**
- **Status**: in develop.
- **Launch**: 2011-2012
- **ESA + Japan**

**Sun’s polar regions**
- **Status**: in develop.
- **Launch**: after 2010
- **ESA +**

**Solar Orbiter**
- **Status**: in develop.

**Gaia**
- **Status**: in develop.
- **Launch**: after 2011
- **GSC**

**Some future missions**

*Radiation monitors for future space missions, GEANT4 2005, Bordeaux*  
12 November, 2005
Radiation Monitors in Space Missions

Provide ancillary radiation environment information for the spacecraft
Trigger shielding actions

Data with scientific quality always welcome
Radiation Monitor might be the only non dormant instrument during the cruise phase
Data of scientific relevance can be acquired during the cruise phase (e.g. particle fluxes & spectral distributions vs distance to Sun)

Stringent limitations on mass and power budget:

New generation compact, lightweight space radiation monitor:
Measure electrons: \( \sim 0.5 \text{ MeV} - 20 \text{ MeV} \);
protons and ions: \( 0.5 \text{ MeV/n} - 150 \text{ MeV/n} \);
Weight < 1 Kg, Volume of \( \sim 5 \times 5 \times 5 \text{ cm}^3 \), Power consumption < 1 W
An end to end simulation is needed (1)

Simulation of particle transport from the source to the detector

- description of the radiation environment
- modelling injection and propagation of particles from the Sun
- scaling of SPE fluxes to other planets
An end to end simulation is needed (2)

**Detailed detector simulation**

- Interaction of incident particles with detector materials.
- Generation & propagation of secondary signals (Fluorescence photons, ionization charges, ...).
- Detection of secondaries by readout devices (photodetectors, ...).
- Integration of readout electronics, signal digitization, trigger, ...
- Generation of simulated raw data (real data like) for further data processing (pedestal subtraction, calibration, event reconstruction,...) & Data analysis.
**Geant 4 toolkit**

*Geant4* is a toolkit for the simulation of particle transport and interaction with matter, featuring:

- **Description of geometries of arbitrary complexity.**
- **Simulation of Hadronic, Electromagnetic and Optical physics processes.**
- **OO design, allowing the implementation of flexible simulation applications.**
- **New physics processes categories easily plugged-in (openness & extensibility of the code).**
Optical processes in Geant4 – an example:

- Cerenkov & Transition radiation, Rayleigh scattering
- Description of surface roughness (Unified Model)
**DIGITsim - Digitization Module**

**Set of abstract interfaces for:**
- Detector charge signal simulation
- A/D conversion
- Trigger implementation
- Pulse amplitude and time reconstruction

*(Re-use of ClearPEM DIGITsim module, based on CMS/ECAL approach)*

**The electronics configuration is stored in a macro file and can be changed interactively**

**Example of input data:**
- QE, bias voltage, gain, current dark noise
- Amplifier electronic noise
- Pulse shape and ADC parameters
- Trigger configuration

![Diagram](image.png)
A compact, general purpose, radiation monitor concept
(A. Owens et al. (ESA-SCI/A), private communication)

Main features:
• Particle tracking
• Particle id. through dE/dx in trackers
• Energy measurement in crystal
• Anticoincidence shielding via phoswitching

Similar concepts from, e.g.:
• G. Pasquali et. al, NIM A301 (1991)101
• Sensys MRM´s
• ???
Si PIN photodiode

- High quantum efficiency
- Low voltage
- Low power dissipation

Good sensitivity matching with CsI(Tl), BGO.
A 10 MeV proton

Time spectrum of signals in the photodetectors

Scintillation photons

Decay time spectrum for CsI (TI)
A 100 MeV proton

Time spectrum of signals in the photodetectors

- Direct ionization and scintillation signals can be disentangled by real time pulse height analysis.
- Veto events not fully contained -> energy resolution improved.

Fast direct ionization (e.g. in Si PIN diode)
Scintillation photons
Some illustrative results from simulation (1)

Energy deposition in trackers vs incident energy

Energy deposition in crystal vs incident energy

Radiation monitors for future space missions, GEANT4 2005, Bordeaux

12 November, 2005
Some illustrative results from simulation (2)

**Fractional energy deposition in crystal by protons**
Concept optimization & developments

**Scintillator:** decay time, specific mass, light yield, emission spectrum

<table>
<thead>
<tr>
<th>Properties</th>
<th>CsI(Tl)</th>
<th>NaI(Tl)</th>
<th>BGO</th>
<th>LSO</th>
<th>LaBr₃</th>
<th>LuYAP</th>
<th>LuAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decay time (ns)</td>
<td>680 (64%)</td>
<td>230</td>
<td>300</td>
<td>40</td>
<td>26</td>
<td>20</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>3340 (36%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spec mass</td>
<td>4.51</td>
<td>3.67</td>
<td>7.13</td>
<td>7.40</td>
<td>5.29</td>
<td>7.40</td>
<td>8.40</td>
</tr>
<tr>
<td>Light yield (MeV)</td>
<td>65000</td>
<td>38000</td>
<td>8200</td>
<td>25000</td>
<td>61000</td>
<td>12000</td>
<td>17000</td>
</tr>
<tr>
<td>λ&lt;sub&gt;max&lt;/sub&gt;emission (nm)</td>
<td>540</td>
<td>415</td>
<td>480</td>
<td>420</td>
<td>350</td>
<td></td>
<td>365</td>
</tr>
</tbody>
</table>

**Photodetector:** Si photodiode, hybrid photosensor,…

**Alternative geometries & readout schemes**

**Study of secondaries induced by external mechanical structure:**
Complex geometries.

**Exchange of geometrical information with CAD systems is crucial.**
Concluding:

A new generation of compact, lightweight, general purpose radiation monitors are needed for future Space Missions (e.g. BepiColombo).

A simple concept based on a scintillating crystal is under study.

LIP will be responsible for implementing the required Geant4 based detector simulations (contract with EFACEC/Portugal).
An end to end simulation is needed

Simulation of particle transport from the source to the detector

- description of the radiation environment
- modelling injection and propagation of particles from the Sun
- scaling of SPE fluxes to other planets

Detailed detector simulation

- Interaction of incident particles with detector materials.
- Generation & propagation of secondary signals (Fluorescence photons, ionization charges, ...).
- Detection of secondaries by readout devices (photodetectors, ...).
- Integration of readout electronics, signal digitization, trigger, ...
- Generation of simulated raw data (real data like) for further data processing (pedestal subtraction, calibration, event reconstruction,...) & Data analysis.
Large scale instability

CME

Solar flare

Active region
Sunspot group

Coronal Hole

Fast Solar Wind Flow

Interplanetary magnetic cloud
Interplanetary shock wave

Solar Energetic Particles
(proton etc.)

Geomagnetic storm

Ionospheric storm

RecurrentGeomagnetic Disturbance

Enhancement of relativistic electrons