Extensive atmospheric cosmic-ray-shower simulations in the South Atlantic Magnetic Anomaly for aeronautical applications

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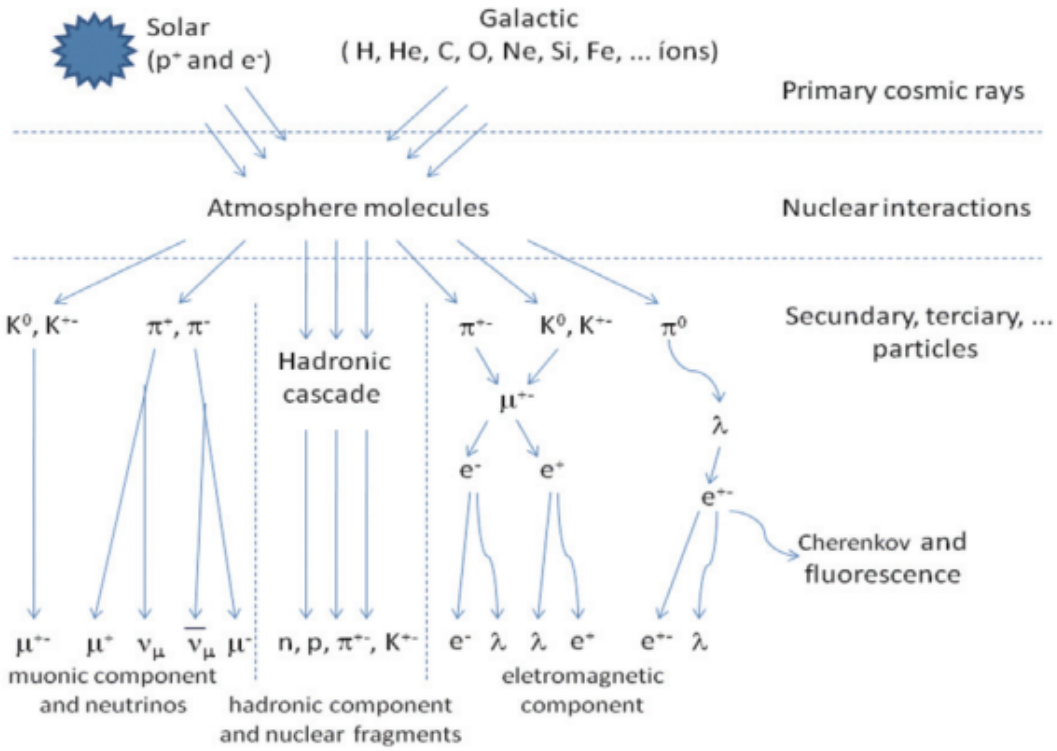
Introduction

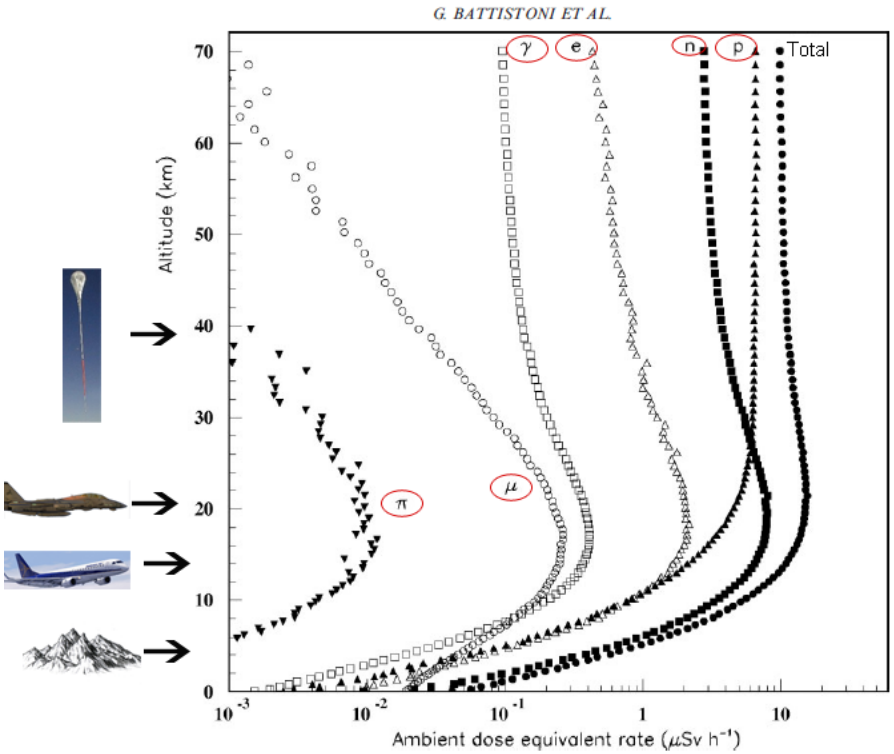
- The interaction of primary cosmic rays with atmospheric atoms produces many particles throught Spallation process;

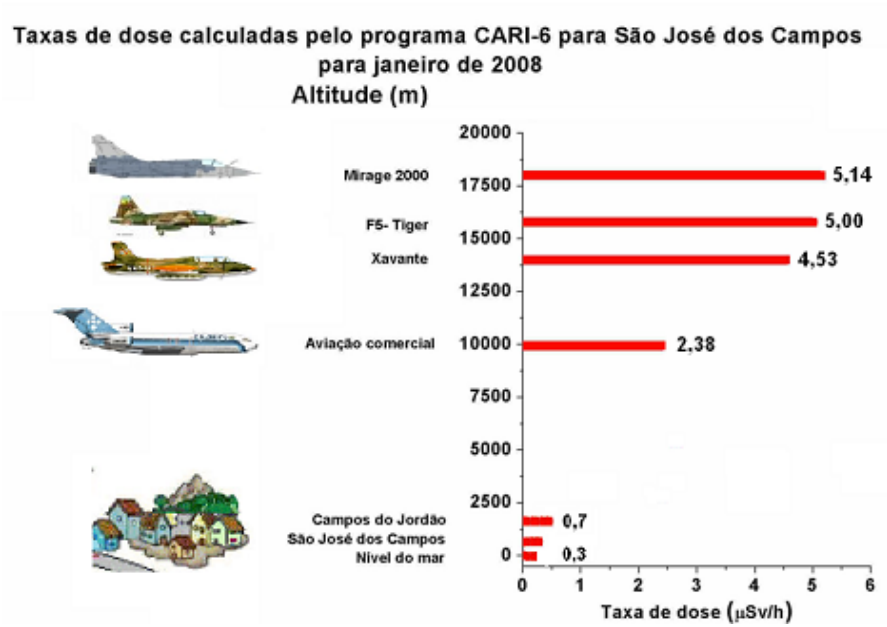


- This interaction can be divided: intranuclear cascade, pre-equilibrium and evaporation.

Motivation

- Aeronautics environment
  - Both the human being and onboard devices are inserted in this environment

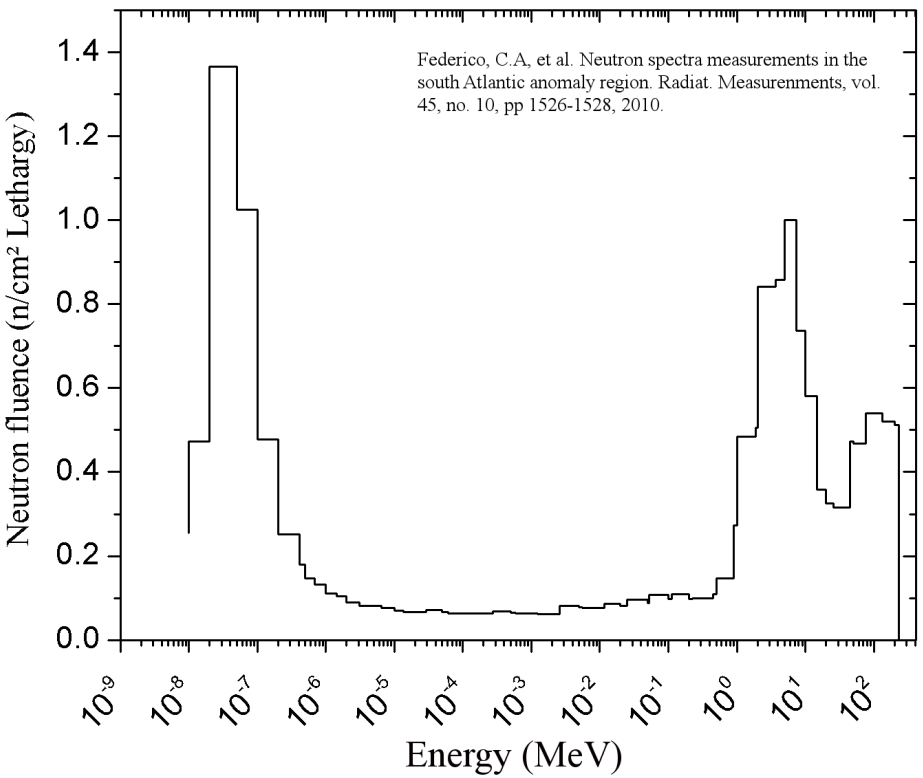


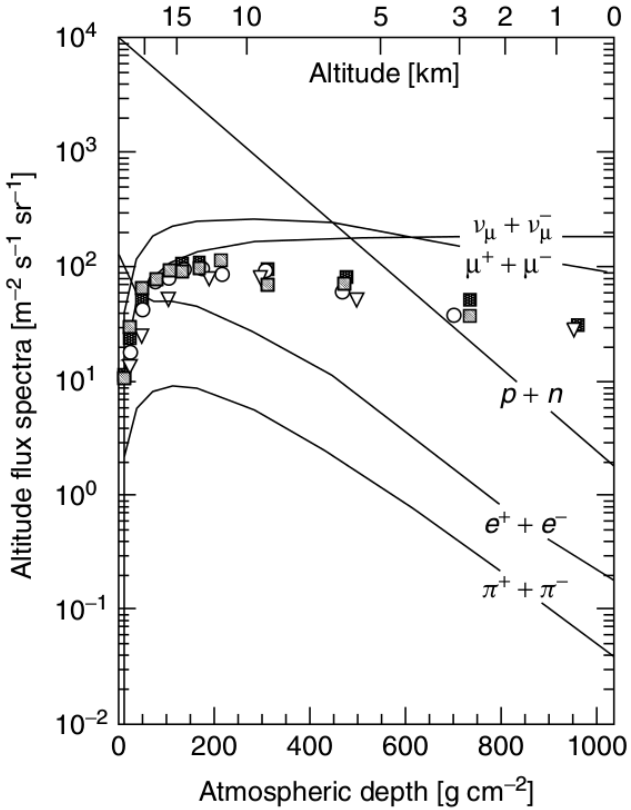


Neutrons are an important particle in dose levels received by aircraft crews and sensitive equipment

Motivation

- The interaction of primary cosmic rays with atmospheric atoms produces high energy neutrons;
- Secondary neutrons produced are moderated by the atmosphere;
- The result is a wide spectrum of neutron energy.





Motivation

ELSEVIER

Mutation Research 513 (2002) 11–15

Genetic Toxicology and Environmental Mutagenesis

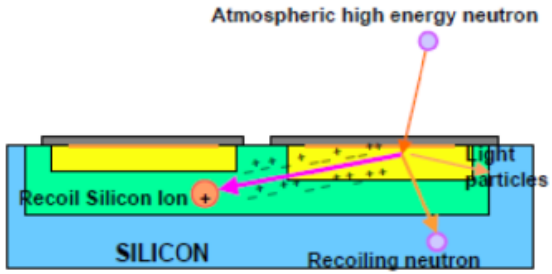
www.elsevier.com/locate/gentox
Community address: www.elsevier.com/locate/mutres

Chromosomal aberrations in long-haul air crew members

Delia Cavallo [a], Alessandro Marinaccio [a], Barbara Perniconi [a], Paola Tomao [a], Vittorio Pecoriello [a], Roberto Moccaldi [b], Sergio Iavicoli [a,*]

Incidence of cancer among Nordic airline pilots over five decades: occupational cohort study

Radiation effects on embedded electronic devices (Upsets, Burnouts, Latchaps, etc)



Charge generation in the Sensitive volume

Motivation

Great part of Brazil is subjected to the South Atlantic Magnetic Anomaly (SAMA).

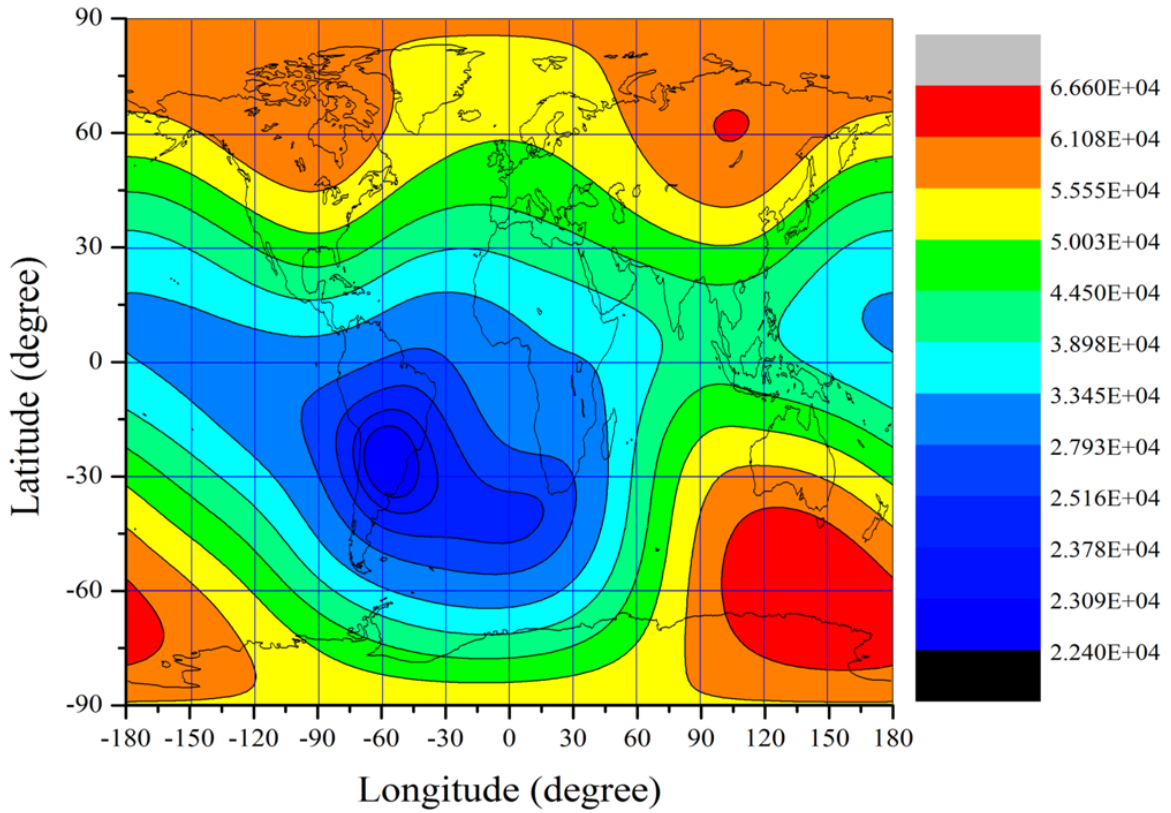
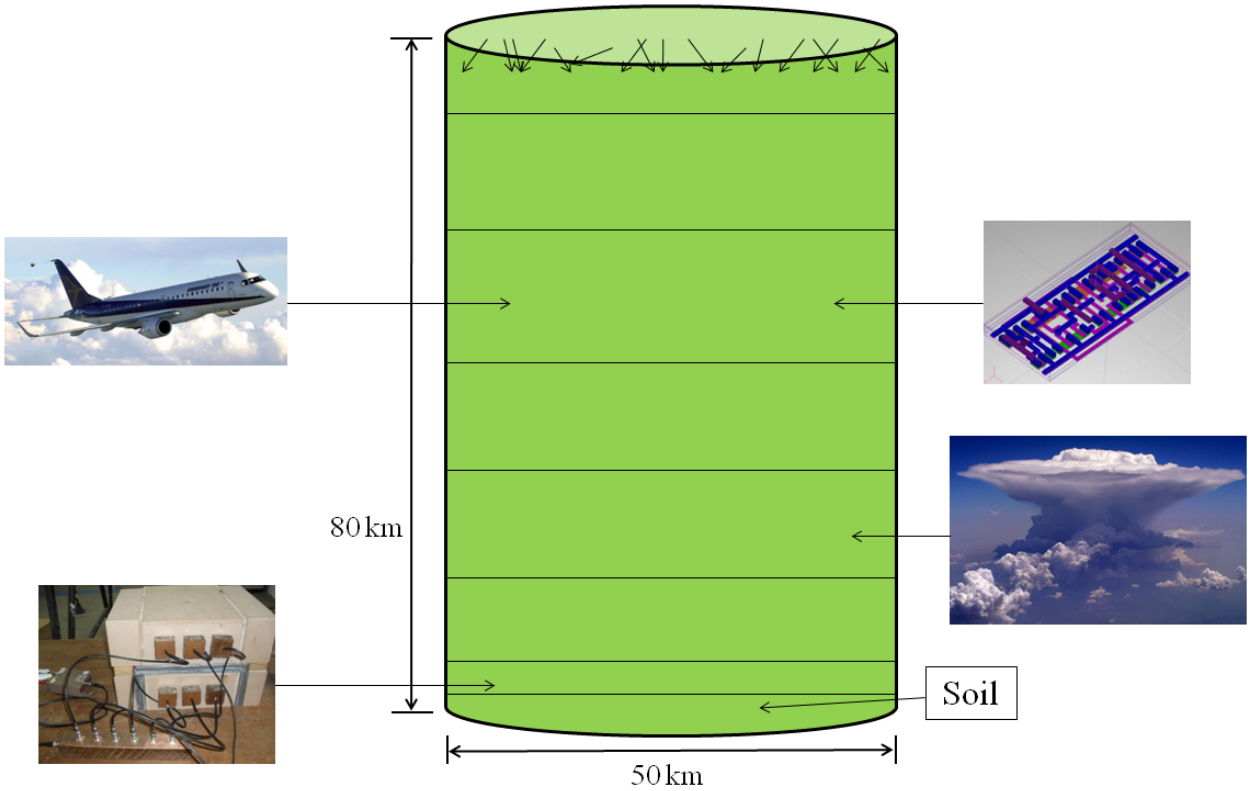


Figura: Earth's magnetic field (nT) map at 12 km altitude, for 10/01/2010 taken from IGRF2011.

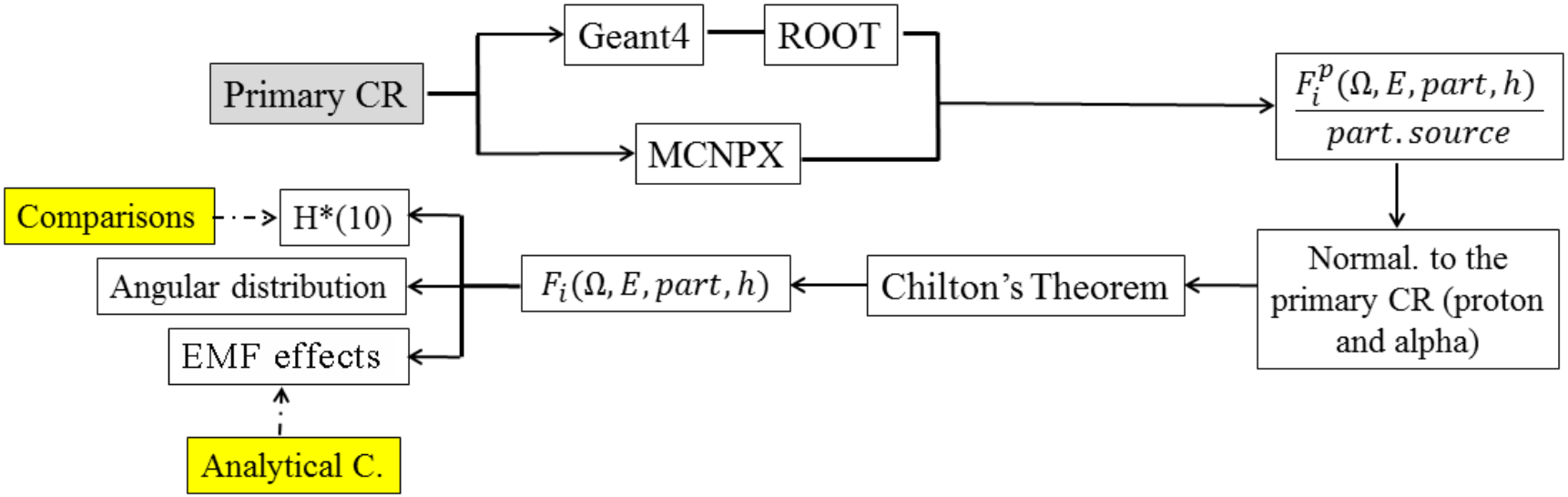
Atmospheric modeling

There is interest in modeling the atmosphere in the South Atlantic Magnetic Anomaly with MCNPX and GEANT4 in order to obtain the cosmic-ray-induced spectra as a function of altitude and develop further applications.

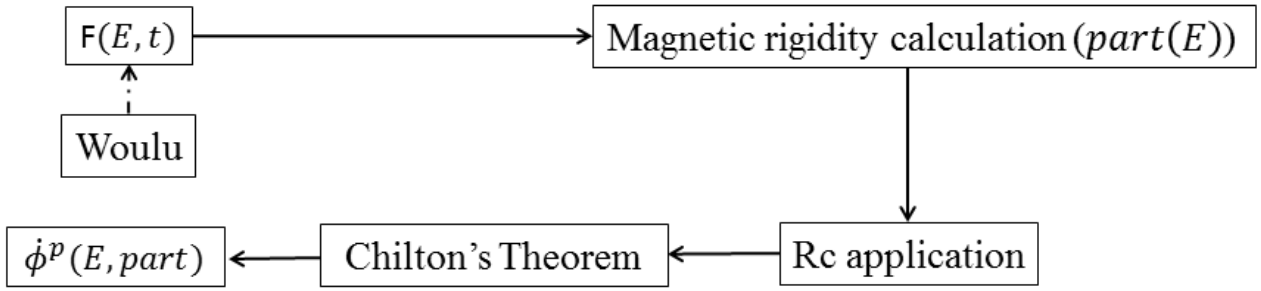


Computacional modeling

The main aspects of the methodology developed for the computational modeling using Monte Carlo codes:

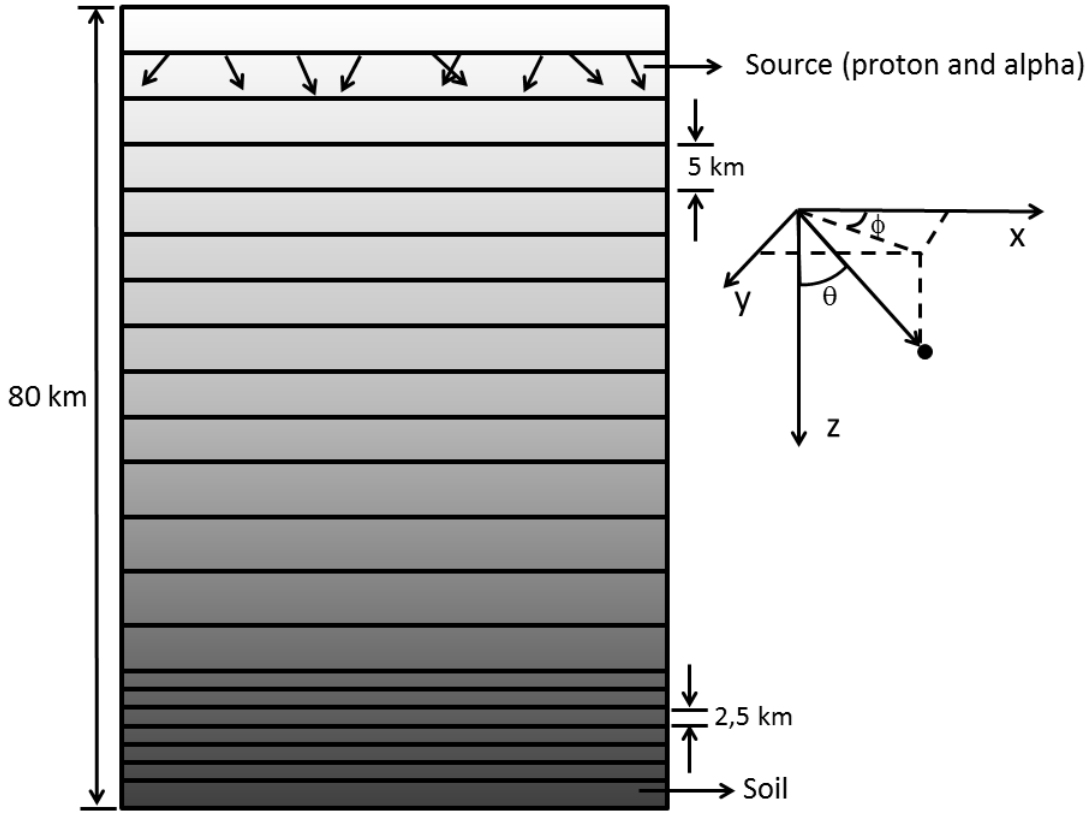


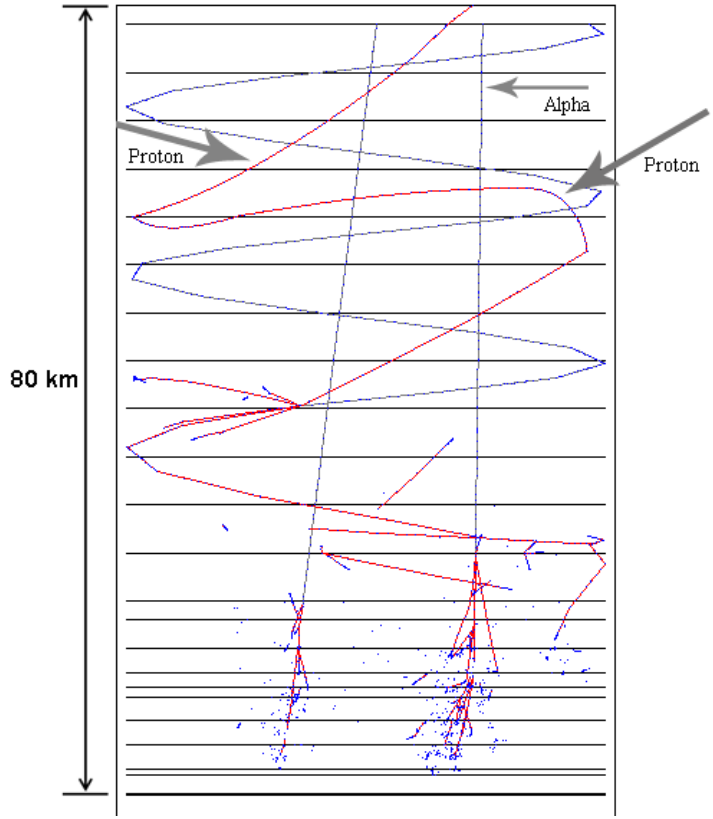
Generation of the primary cosmic radiation:



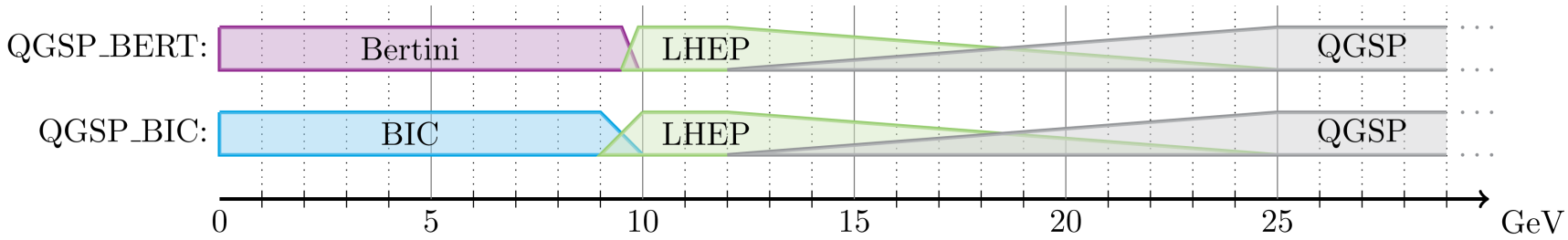
Modeling of the cosmic radiation propagation and the atmosphere

- Planar source (reproduce the isotropic radiation field (protons + alphas));
- Atmosphere modeling;
- **Reflective sides;**
- The Earth's magnetic field were considered.





Geant4.9.6 parameterization



- ENDF/VII nuclear data libraries were used for energies under 20 MeV (neutron transport)
- The scattering matrices S(α,β) were alse considered (thermal neutron treatment)
- Bertini: Bertini model for Spallation reaction
- BIC: Binary Cascade model for Spallation reaction
- QGSP: Quark-Gluon String Precompound model

Geant4 - Classes

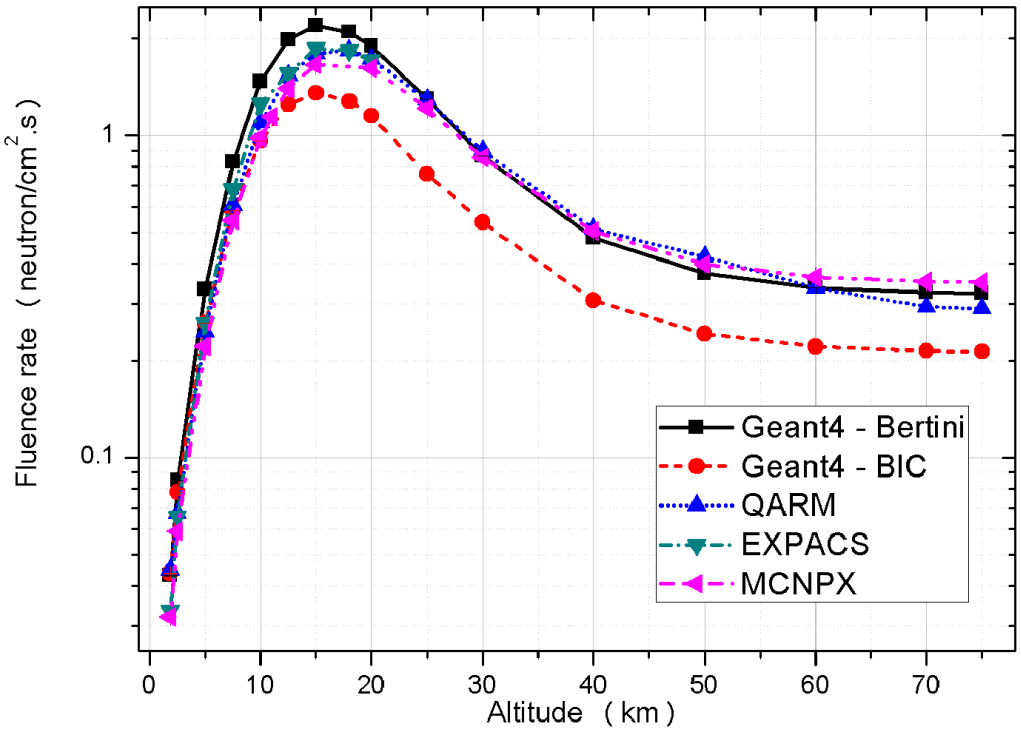
- Some classes used: "G4WallReflection.cc", "GNeutAtMagneticField.cc", "GNeutAtMagneticFieldMessenger.cc", "StackingMessenger.cc";
- Storage data in ROOT files.

MCNPX parameterization

MCNPX

- The ENDF/VI nuclear data library was used for all materials;
- Scattering matrices S(α,β);
- Nuclear data libraries were used for energies under 20 MeV. Physical models were used above this energy;
- Neutron and proton elastic scattering;
- Preequilibrium model after intranuclear cascade;
- Bertini for nucleons and pions;
- Coulomb barrier for incident charged particles;
- Experimental branching ratios were used.

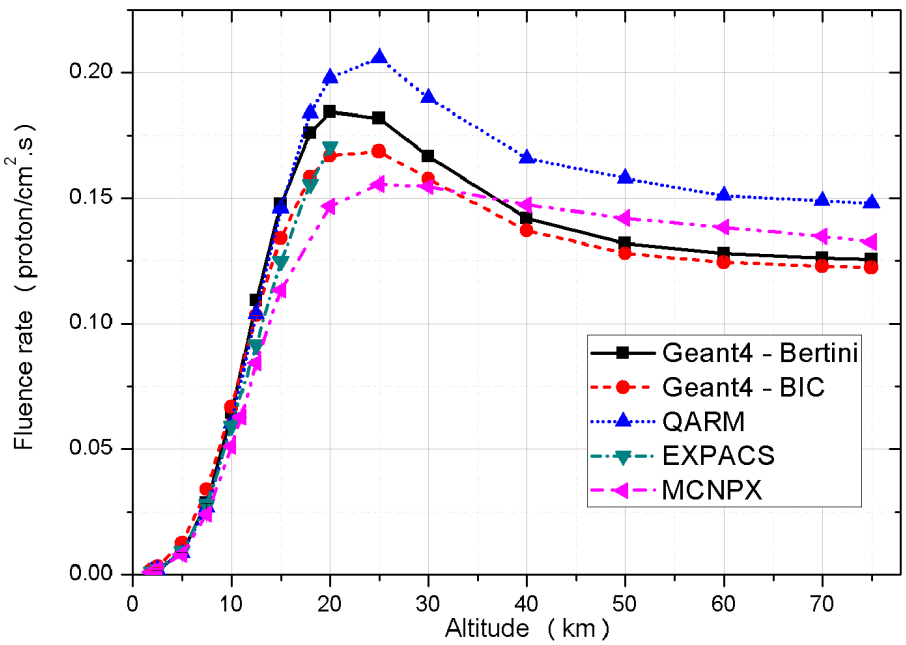
Neutron fluence rate in the atmosphere



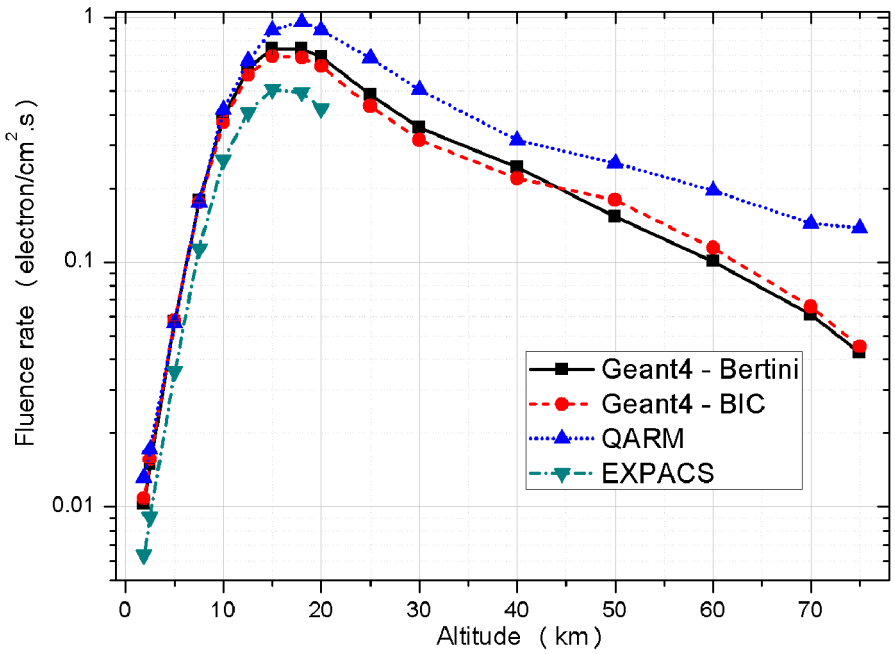
Conditions for the particle fluence simulation - OPD

- Date: (3-4)/8/2015
- Cutoff rigidity: 9.7 GV
- Solar potential: 683 MV; W_{OULU}: 6003 count/min
- Primary proton fluence rate: 1.02×10^{-1} prot/cm^2.s; alphas: 1.84×10^{-2} alpha/cm^2.s

Proton and electron fluence rate in the atmosphere



(a) Proton fluence rate as function of altitude.

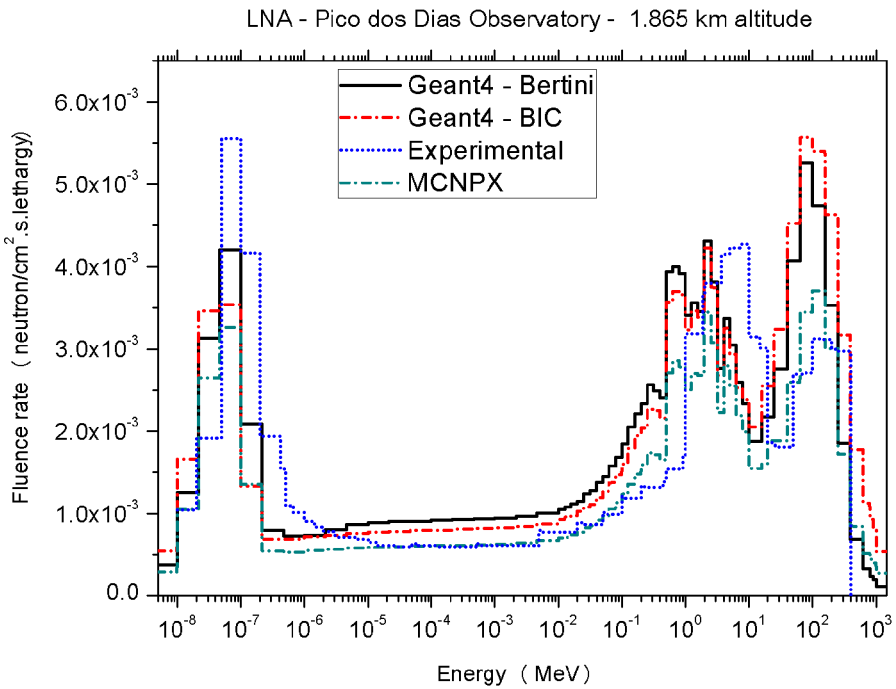


(b) Electron fluence rate as function of altitude.

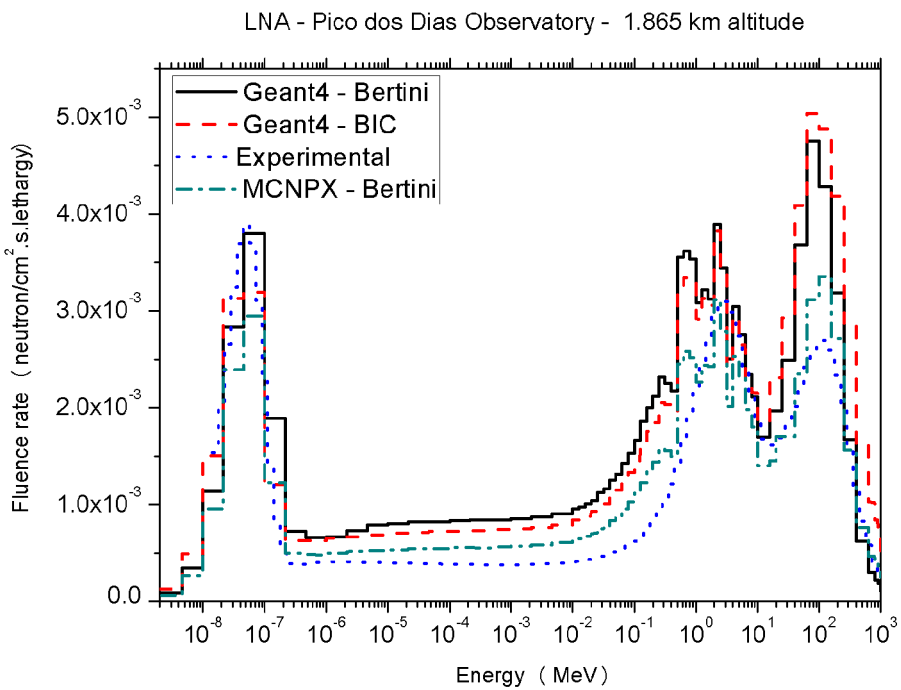
Conditions for the particle fluence simulation - OPD

- Date: (3-4)/8/2015
- Cutoff rigidity: 9.7 GV
- Solar potential: 683 MV; W_{OULU}: 6003 count/min
- Primary proton fluence rate: 1.02×10^{-1} prot/cm^2.s; alphas: 1.84×10^{-2} alpha/cm^2.s

Simulations and measurement at ground level - OPD (LNA)



(c) 2009



(d) 2015

Lethargic interval: $lnE_{i+1} - lnE_i$

H*(10) comparison with flight measurement

Comparison of the ambient dose equivalent rate calculated from simulations, EXPACS and QARM codes, and experimental measurement at flight altitude in the Foz do Iguaçu region.

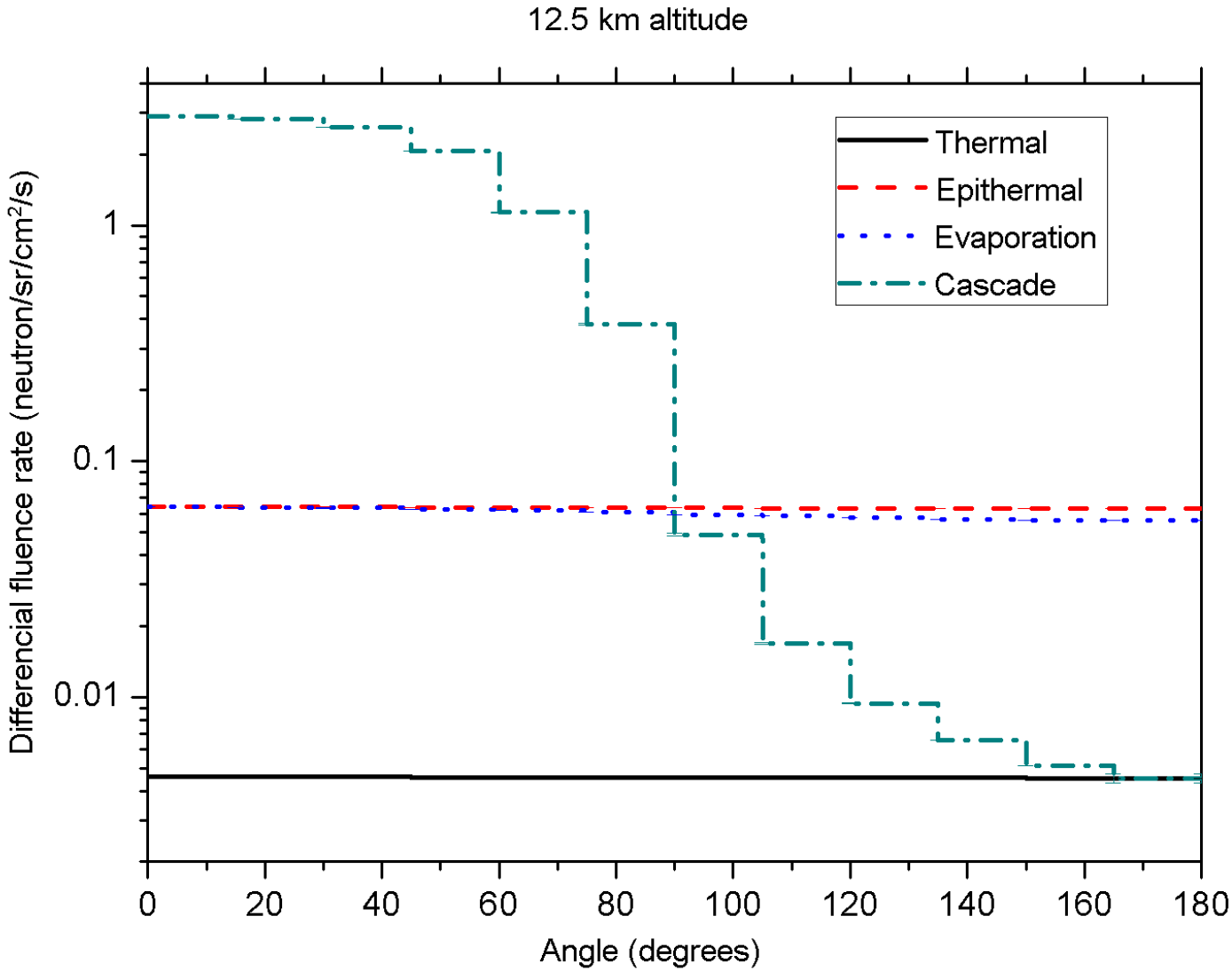
	H*(10) (μSv/hr)	Erro
Experimental	**1.57E+00**	**4.00E–02**
Geant4 - Bertini	**1.53E+00**	-
Geant4 - BIC	1.04E+01	-
MCNPX	1.03E+00	-
EXPACS	**1.48E+00**	-
QARM	1.10E+00	-

Conditions during the flight - Foz do Iguaçú

- Date: 29/06/2011
- Cutoff rigidity: 9.6 GV
- Solar potential: 517 MV; W_{OULU}: 6324 count/min
- Primary proton fluence rate (calculated): 1.08×10^{-1} prot/cm^2.s; alphas: 1.93×10^{-2} alpha/cm^2.s

Angular distribution analyses

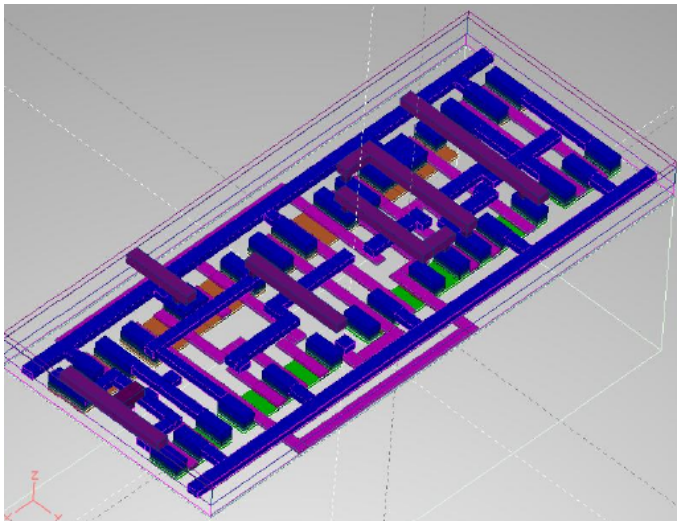
Neutron angular distribution for different energy ranges at 12.5 km altitude.

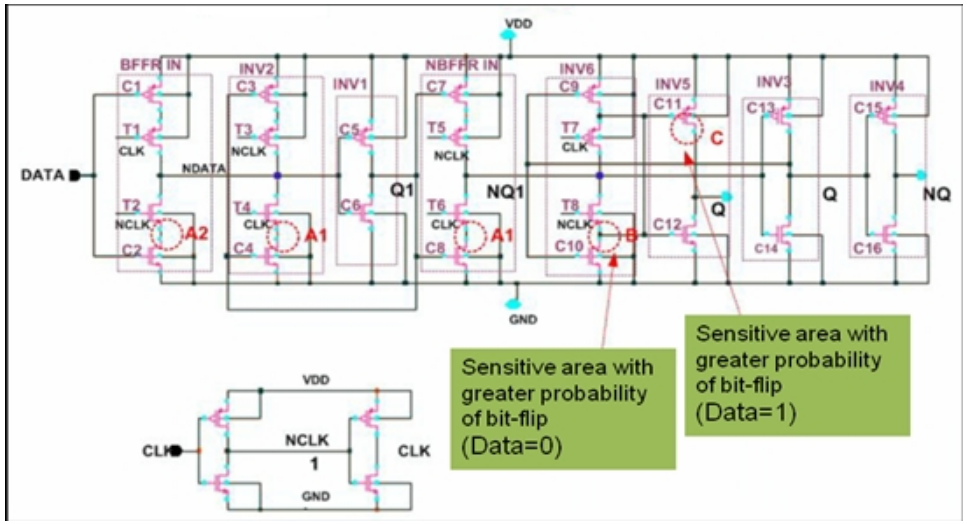


Embedded electronic

Irradiation application (CMOS flip-flop)

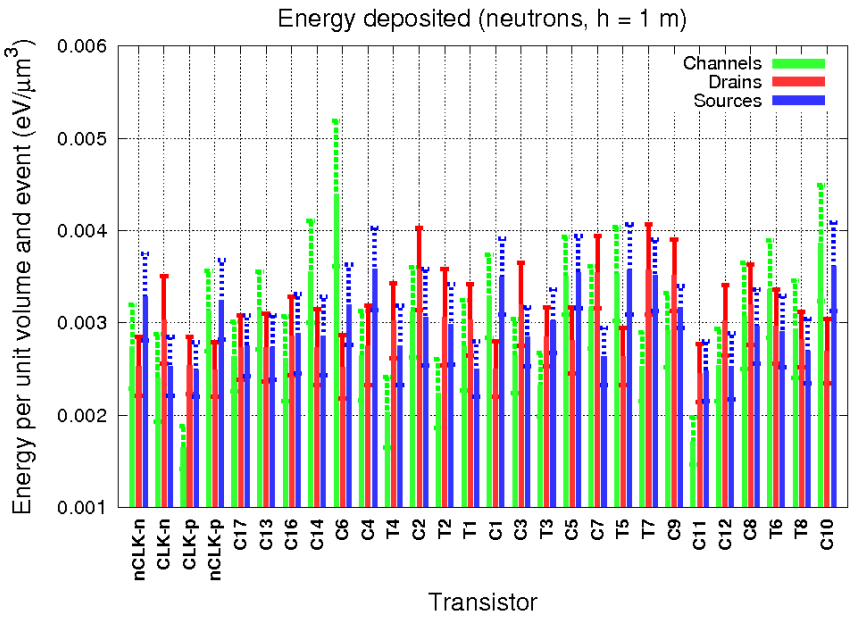
- The flip-flop target has been implemented as a CAD model using the FASTRAD tool;
- It was imported to Geant4 by means of the GDML interface;
- Spectra of neutrons were used to irradiate the flip-flop transistors;
- Determination of the energy deposition per unit volume in the channel, drain, source and gate oxide of all transistors present in the flip-flop structure.

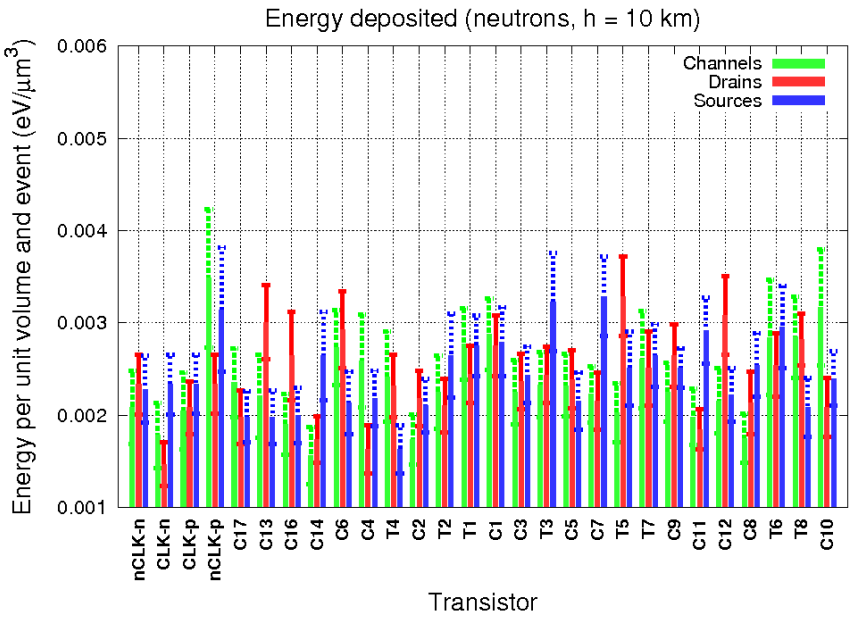




Embedded electronic

Energy Deposited per unit volume and event in the flip-flop elements at 1 m and 10 km altitude.



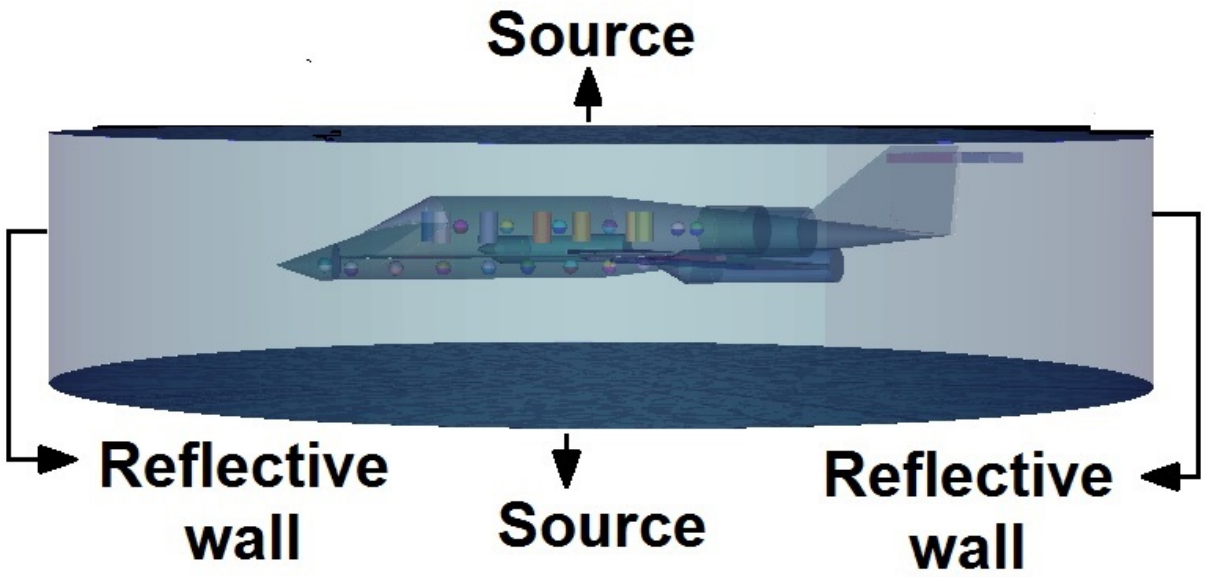


The histograms show values for channels, drains and sources.

Data from our simulations + MUSCA SEP3 platform (ONERA) $\Longrightarrow$ SEE estimations.

Radiation field inside aircrafts

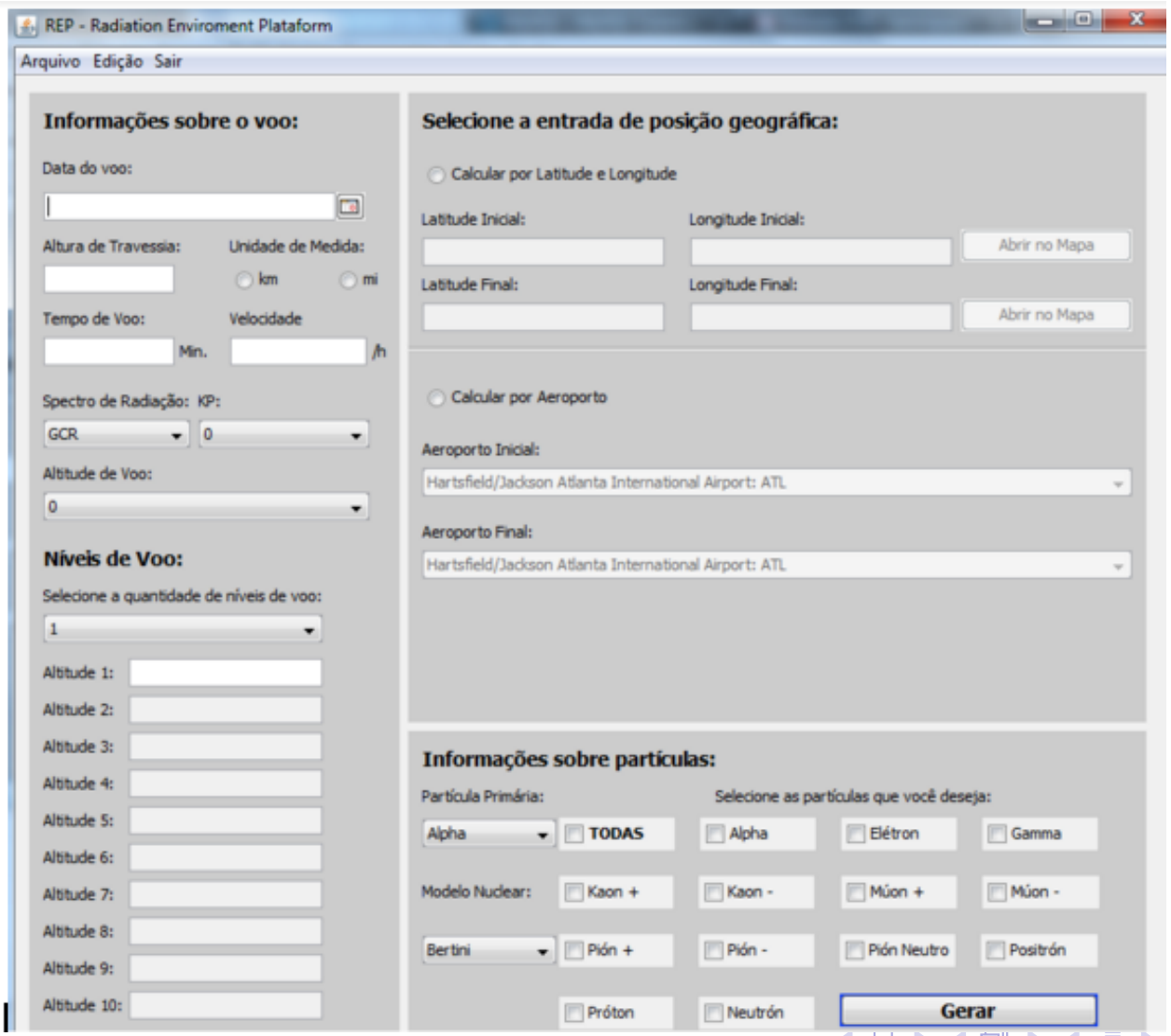
Investigation of the influence of the position inside a small aircraft on the cosmic-radiation-induced dose.



A. C. Prado, et al. Investigation of the influence of the position inside a small aircraft on the cosmic-radiation-induced dose. Rad. Prot. Dosimetry, v. 173, pp. 1-9, 2017.

REP - (*Radiation Environment Platform*)

Web interface:



REP - (*Radiation Environment Platform*)

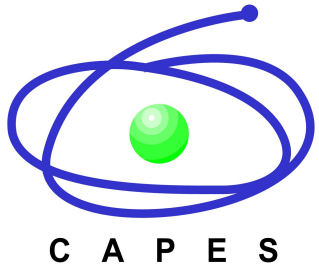
Primary particles parameterization

- Neutrons data measured at the ground level ⇒ primary cosmic radiation fluence rate ⇒ determine the cosmic-ray-induced particles data;
- These neutron data are collected at different locations around the world:
- stations located at Pico dos Dias (Brazil), Concórdia Station (Antarctica) and Pic-du-Midi (France).



IEAv and ONERA cosmic ray stations

Financial sponsors:



Collaborators: