Simulation of Radiation Monitors for Future Space Missions

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Space radiation environment

(seen 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

SOME FUTURE MISSIONS

X-ray Evolving Universe Spectroscopy

BH, Galaxy clusters; ISM
Status in develop.
Launch after 2014
ESA +

XEUS

Laser Interferometer Space Antenna

LISA

Gravitational waves

Status in develop.
Launch2011
ESA + NASA

James Webb Space Telescope

JWST

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

Darwin

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

Sun's polar regions
Status in develop.
Launch after 2010
ESA +

Solar Orbiter

BepiColombo

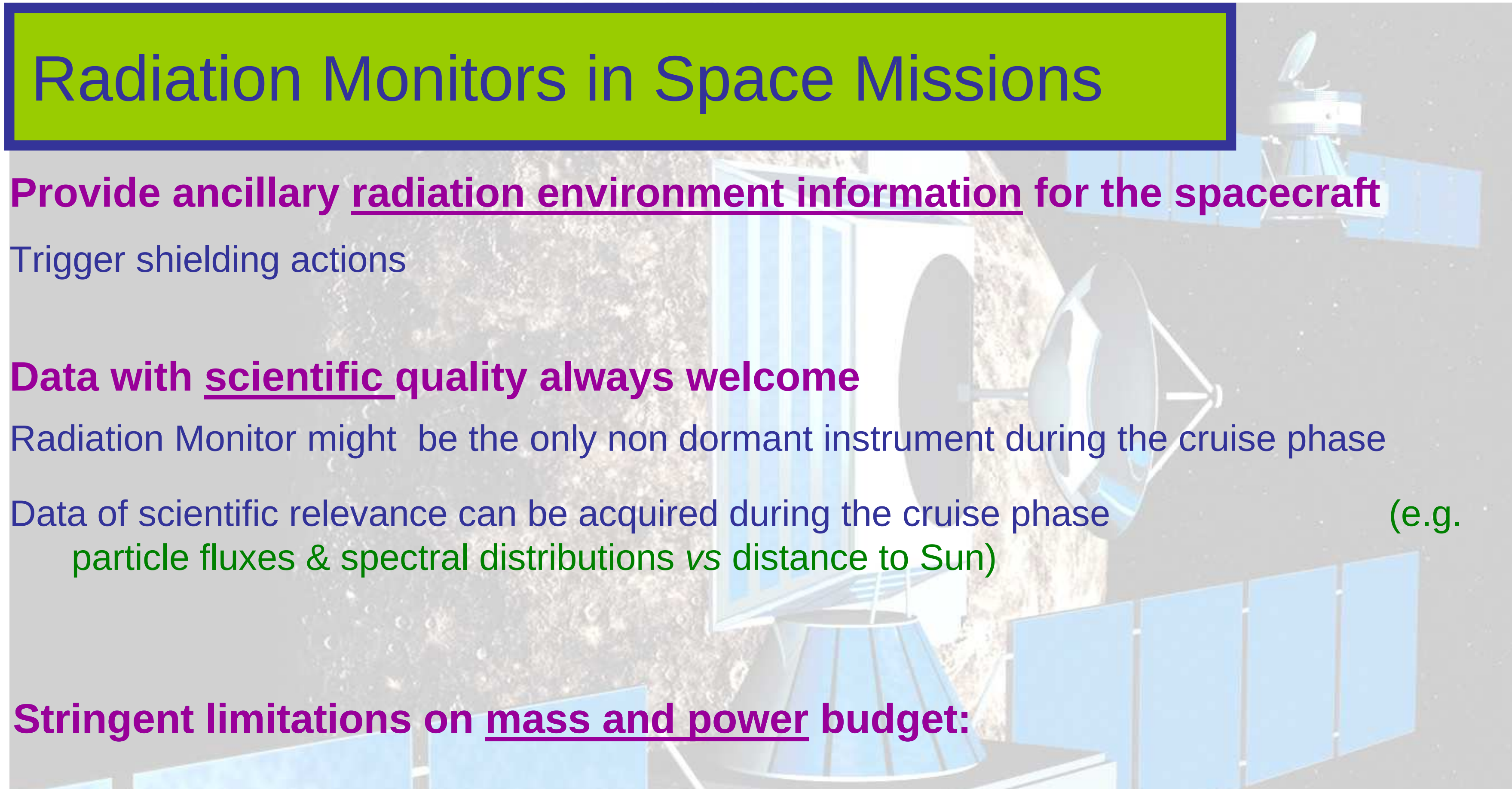
Mercury

Status in develop.
Launch 2011-2012
ESA +Japan

Gaia

Galactic Census
Status in develop.
Launch after 2011
GSC

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 : ~ 0.5 MeV – 20 MeV ;

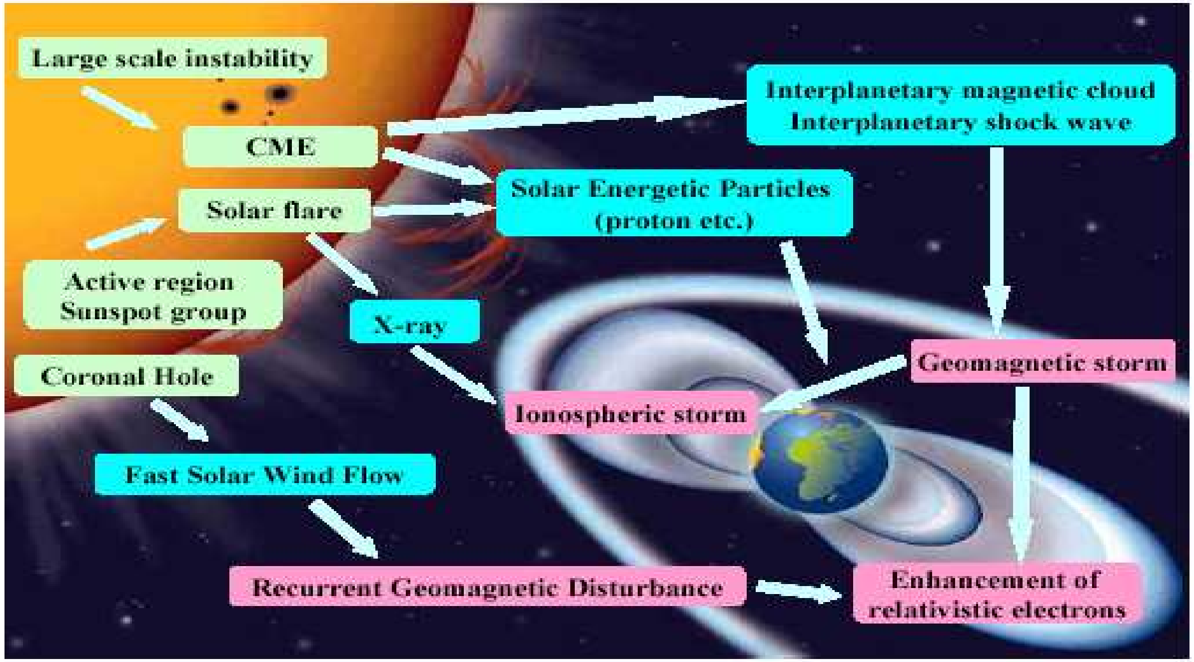
protons and ions : 0.5 MeV/n – 150 MeV/n ;

Weight < 1 Kg, Volume of ~ 5 x 5 x 5 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

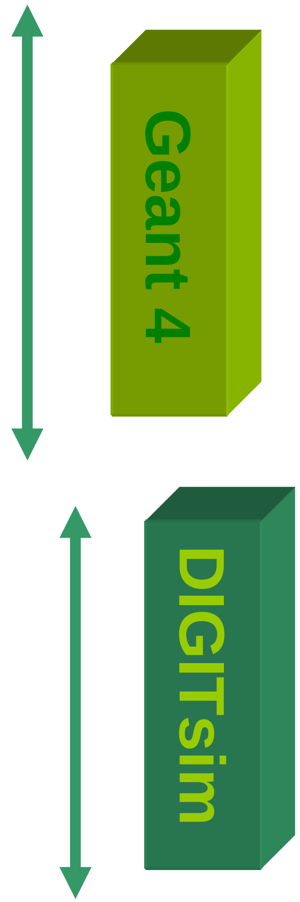


(Adam Szabo, Laboratory for Extraterrestrial Physics,NASA, Goddard Space Flight Center Greenbelt, Maryland,USA)

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.

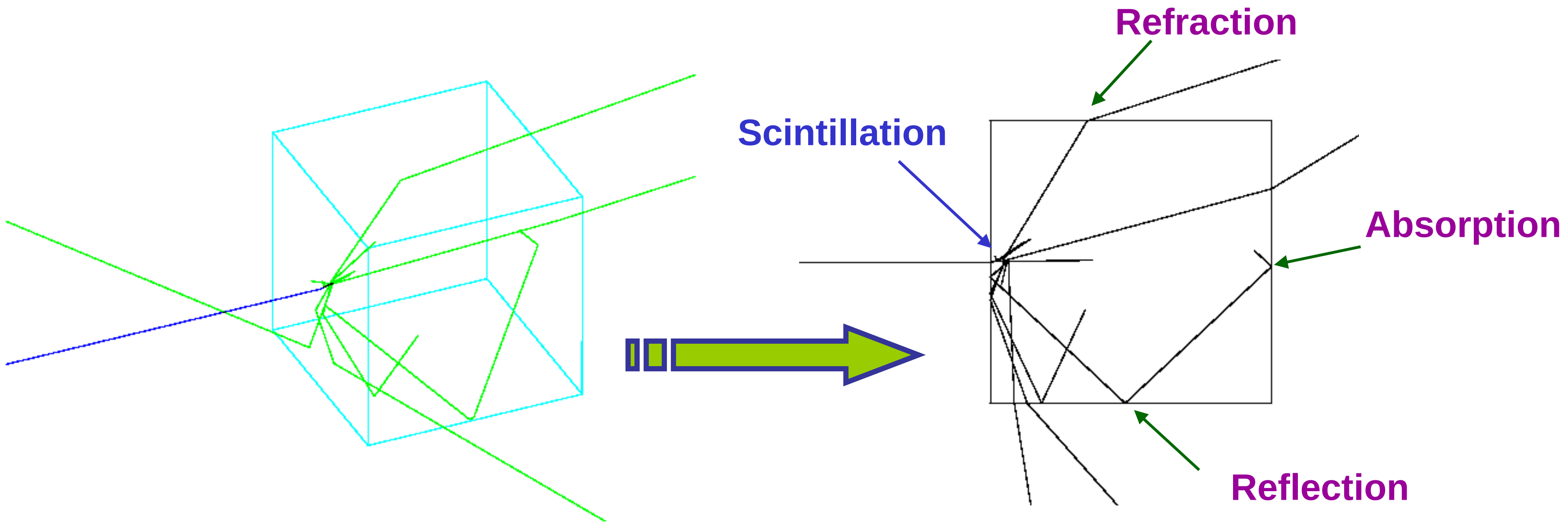


Geant 4 toolkit

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:

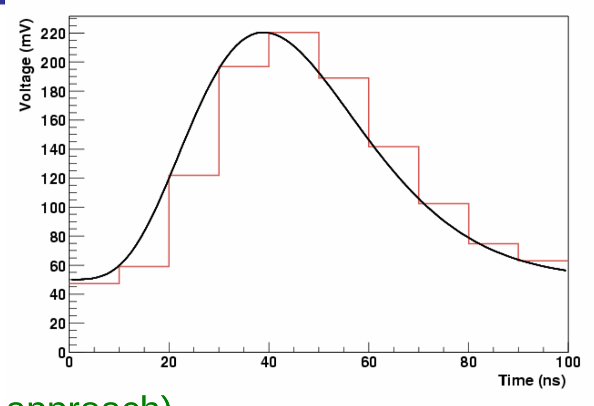


+ Cerenkov & Transition radiation, Rayleigh scattering
+ description of surface roughness (Unified Model)

DIGITsim - Digitization Module

Set of abstract interfaces for:

- Detector charge signal simulation
- A/D conversion
- Trigger implementation
- Pulse amplitude and time reconstruction

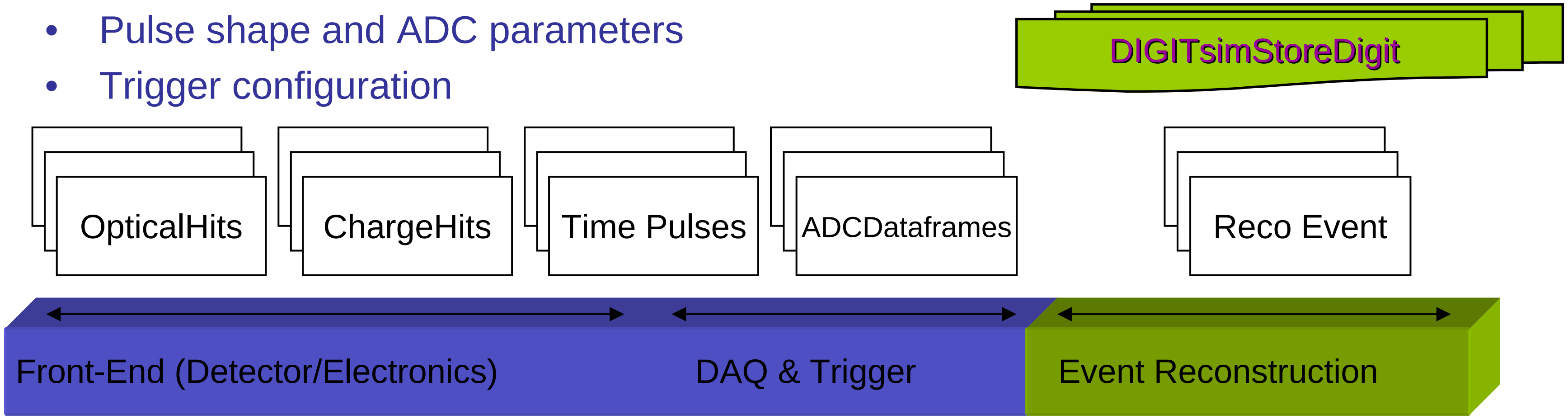


(Re-use of ClearPEM DIGITsim module, based on CMS/ECAL approach)

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

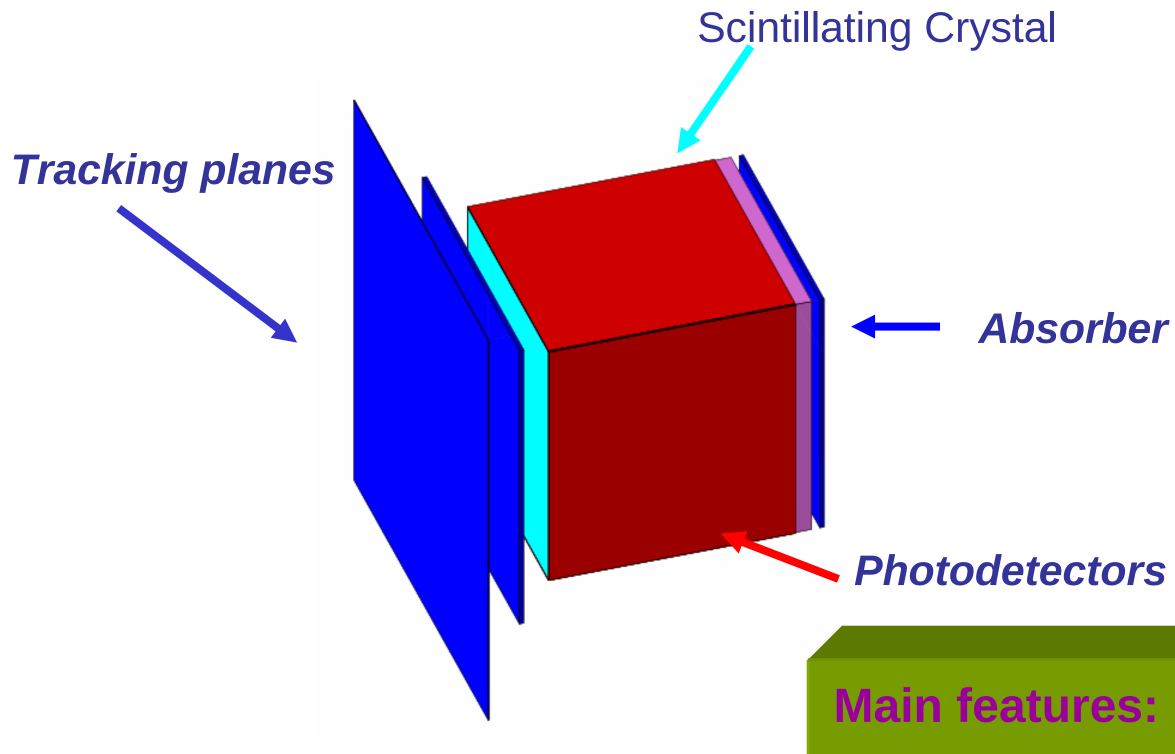
Example of input data:

- QE, bias voltage, gain, current dark noise
- Amplifier electronic noise
- Pulse shape and ADC parameters
- Trigger configuration



A compact, general purpose, radiation monitor concept

(A. Owens et al. (ESA-SCI/A), private communication



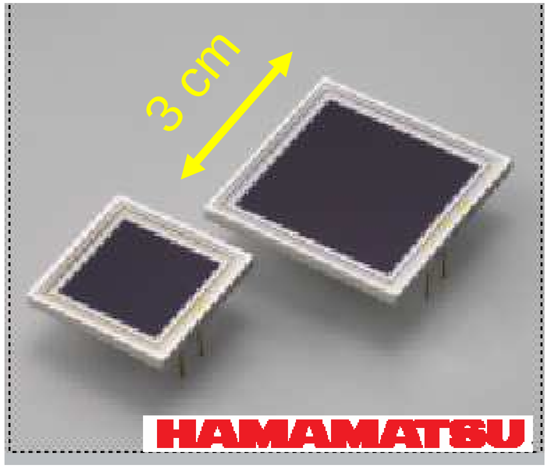
Main features:

- **Particle tracking**
- **Particle id. through dE/dx in trackers**
- **Energy measurement in crystal**
- **Anticoincidence shielding via phoswitching**

Similar concepts from, e.g.:

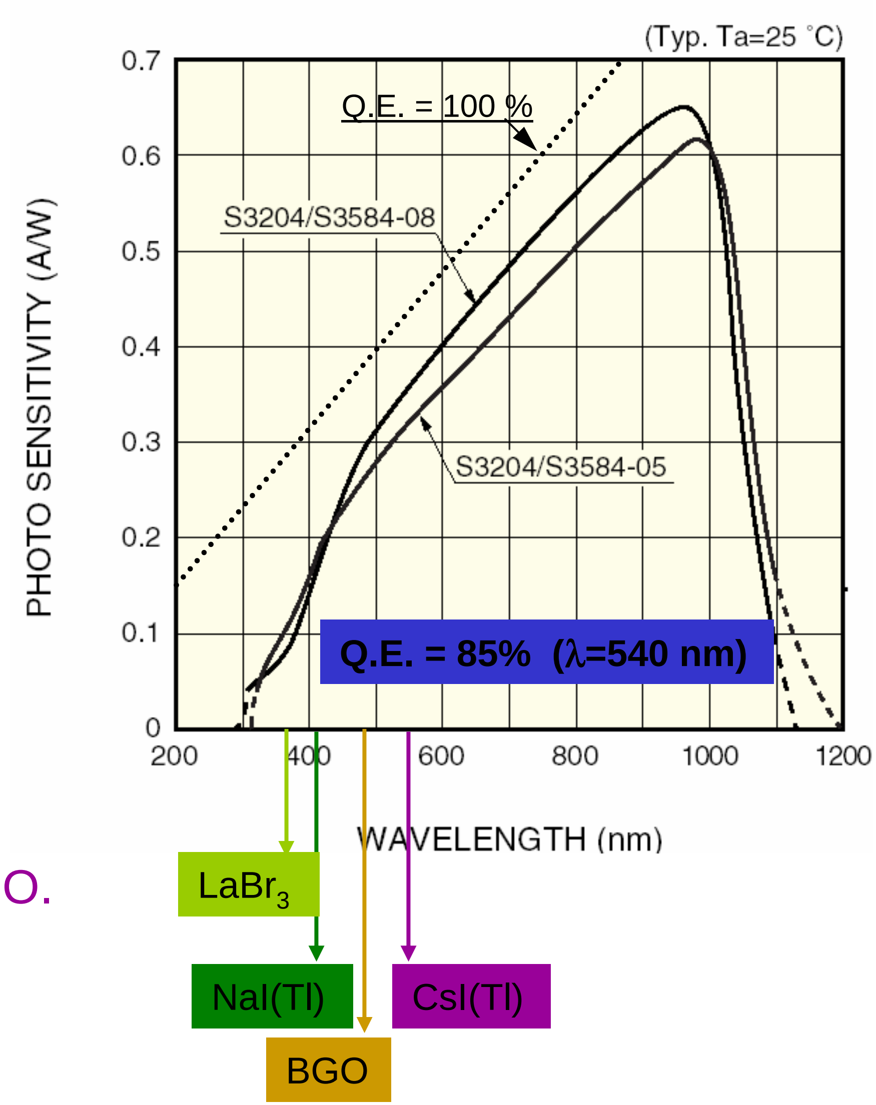
- *G. Pasquali et. al, NIM A301 (1991)101*
- *Sensys MRM´s*
- *???*

Si PIN photodiode

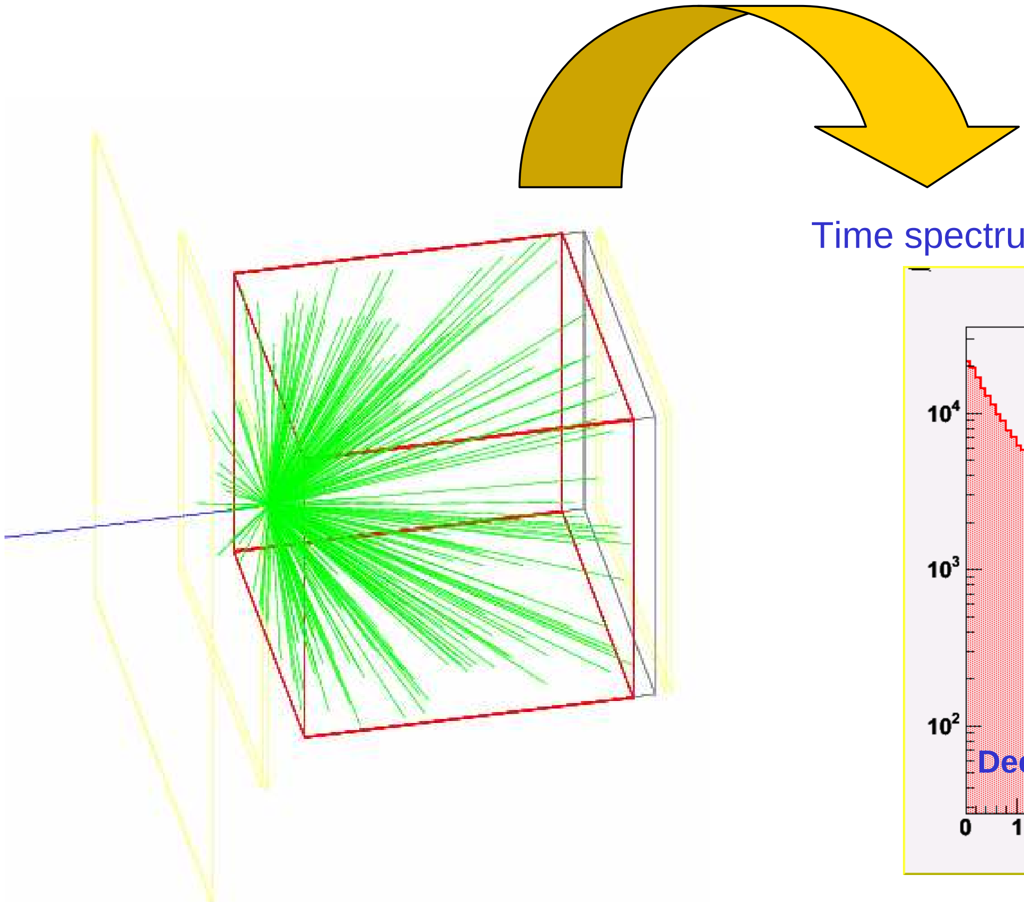


- **High quantum efficiency**
- **Low voltage**
- **Low power dissipation**

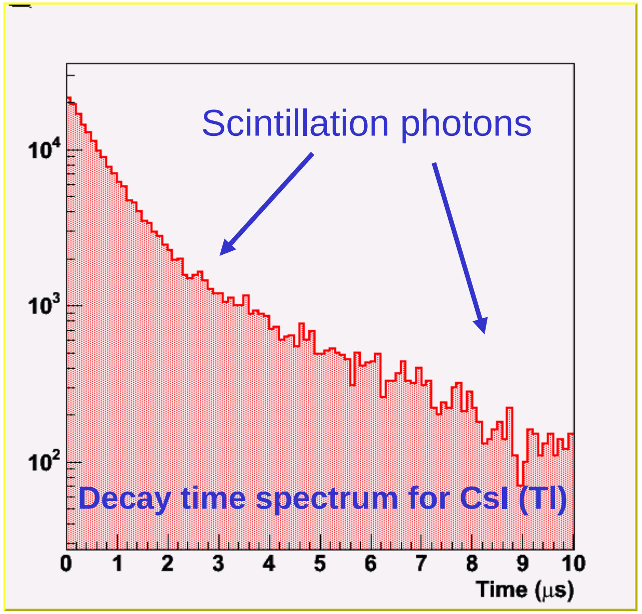
Good sensitivity matching with CsI(Tl), BGO.



A 10 MeV proton



Time spectrum of signals in the photodetectors



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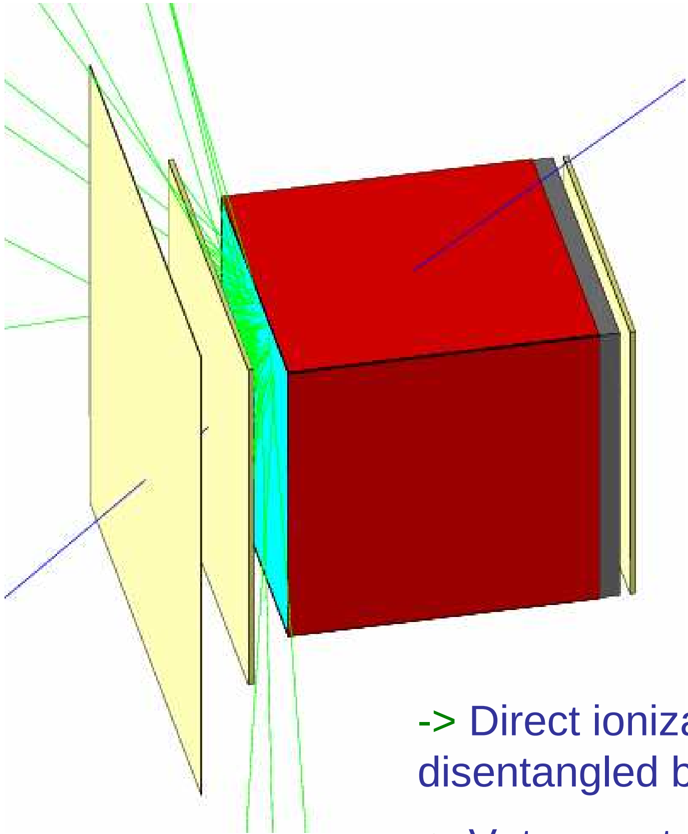

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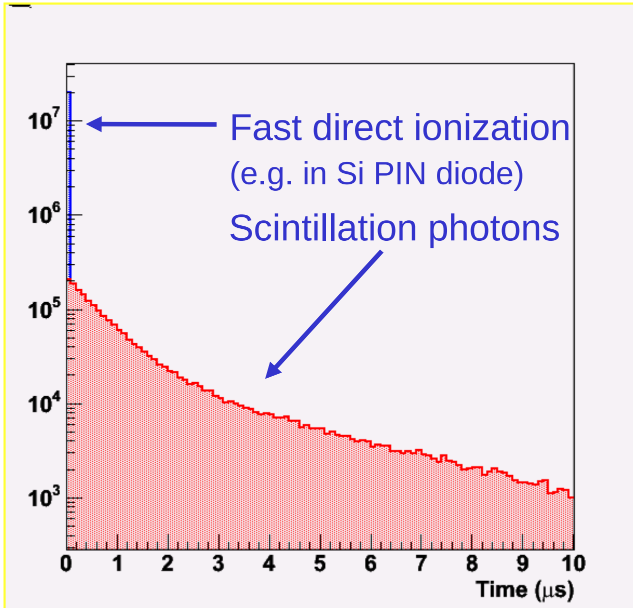


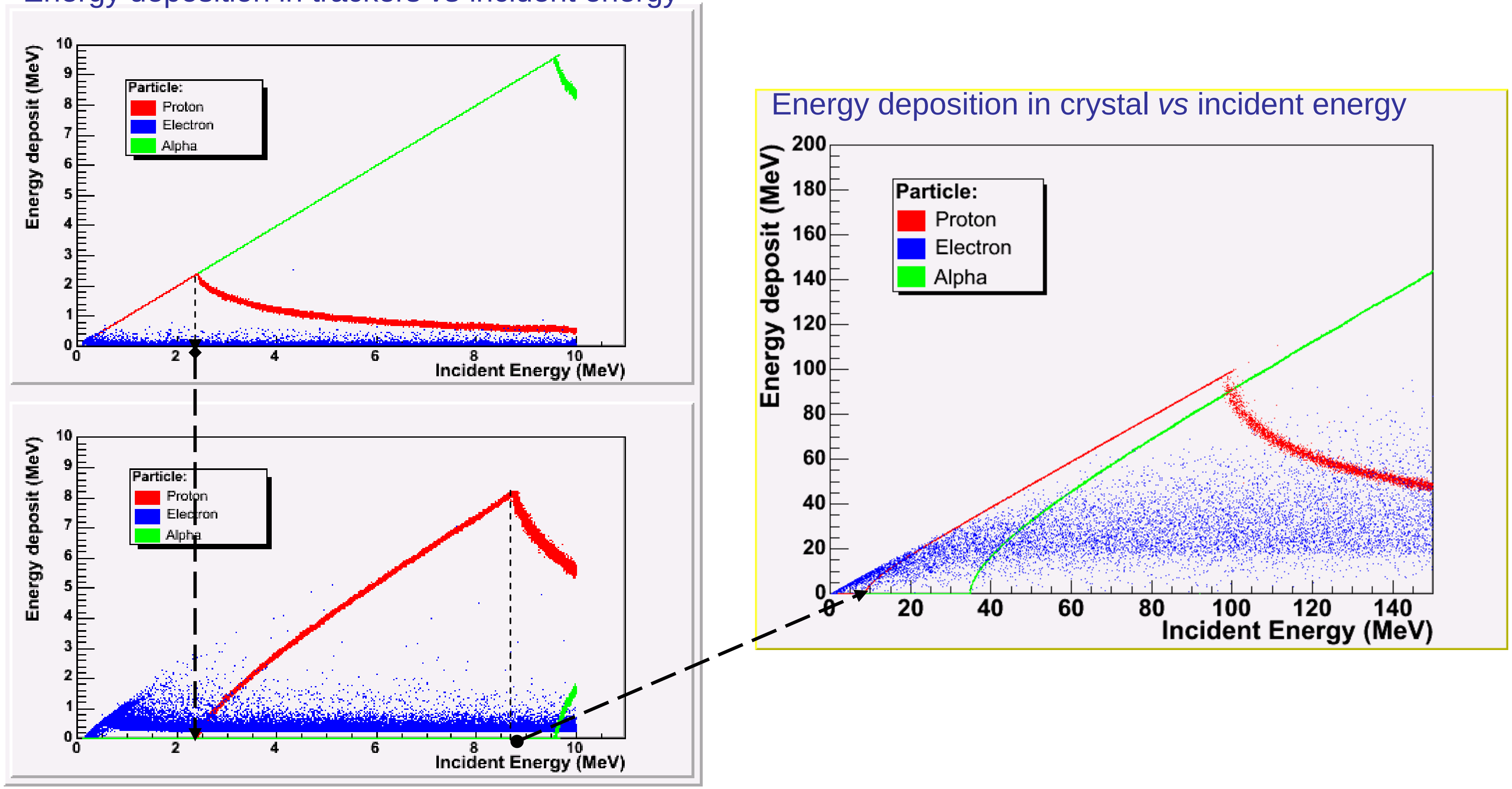
-> Direct ionization and scintillation signals can be disentangled by real time pulse height analysis.

-> Veto events not fully contained -> energy resolution improved.

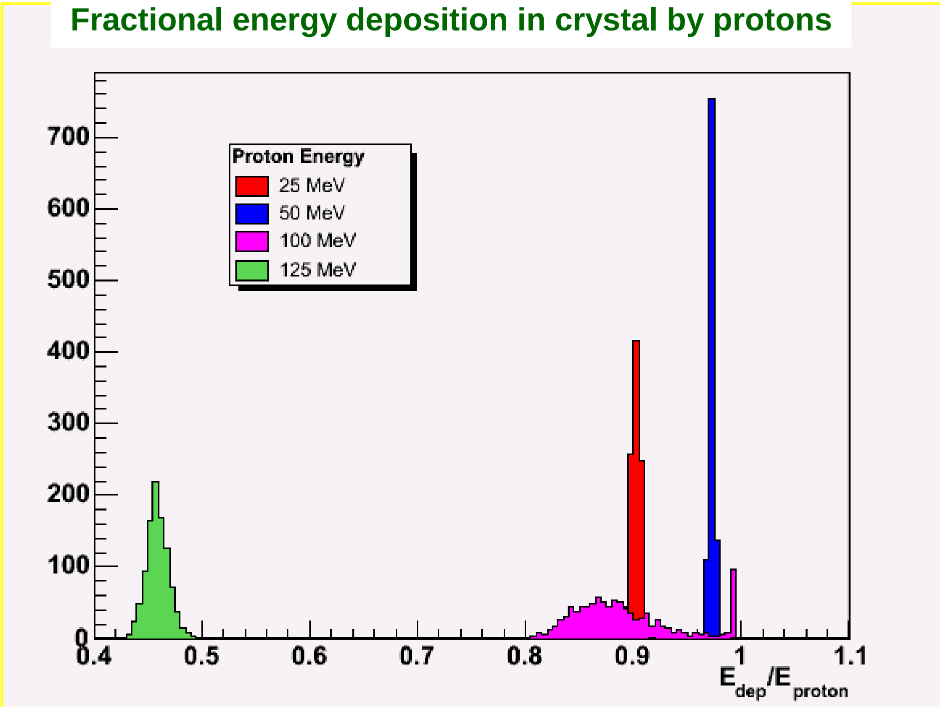
Some illustrative results from simulation (1)

Energy deposition in trackers *vs* incident energy

Energy deposition in crystal *vs* incident energy



Some illustrative results from simulation (2)



Concept optimization & developments

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

Proprieties	**CsI(Tl)**	**NaI(Tl)**	**BGO**	**LSO**	**$LaBr_3$**	**LuYAP**	**LuAP**
Decay time(ns)	680 (64%) 3340 (36%)	230	300	40	26	20	17
Spec.mass	4.51	3.67	7.13	7.40	5.29	7.40	8.40
Light yield(/MeV)	65000	38000	8200	25000	61000	12000	17000
$\lambda_{max.emission}$(nm)	540	415	480	420	350		365

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

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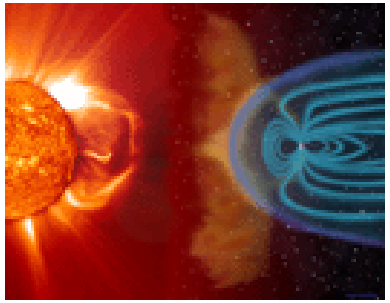

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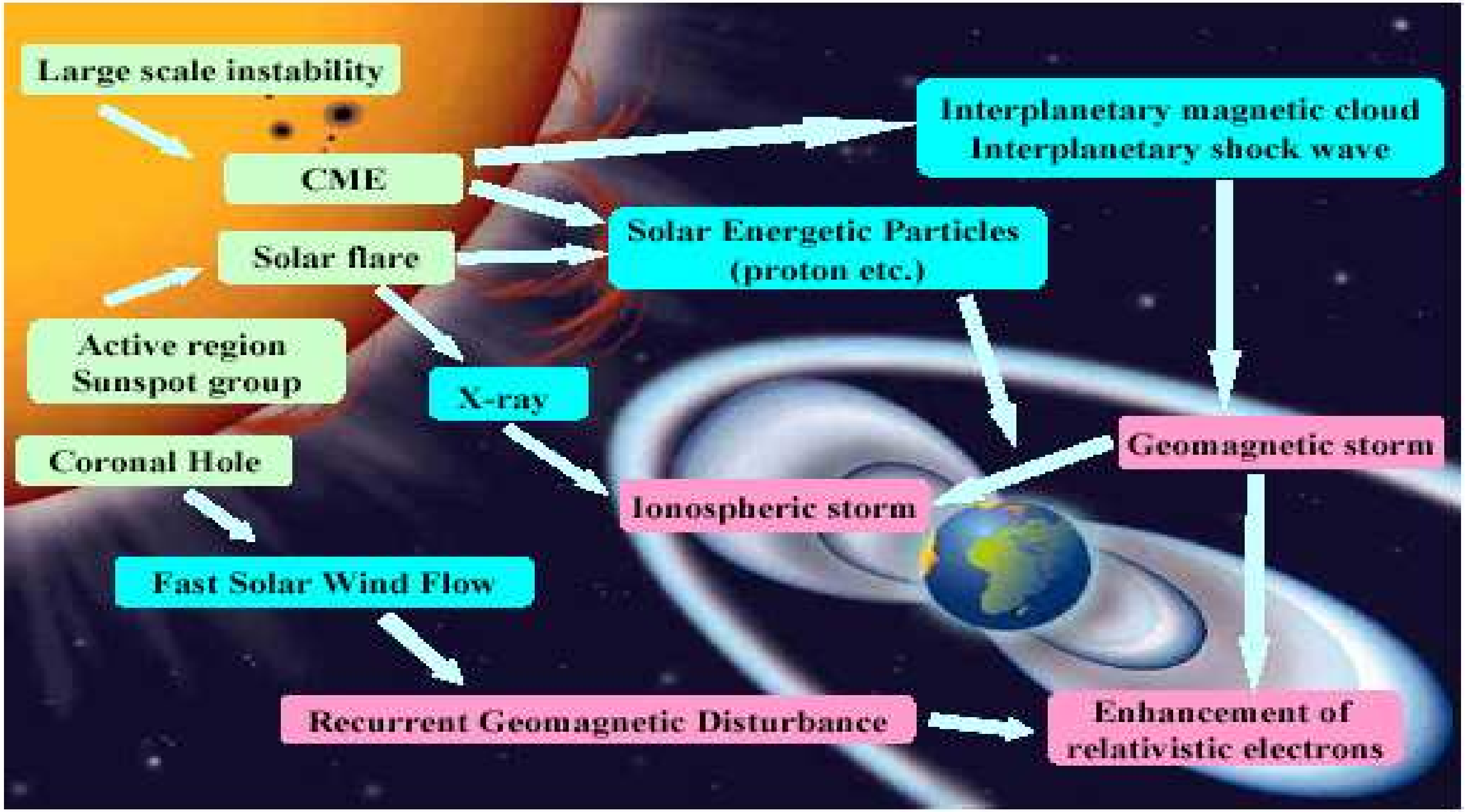
Geant 4

DIGITsim



Large scale instability
CME
Solar flare
Active region
Sunspot group
Coronal Hole
X-ray
Fast Solar Wind Flow
Recurrent Geomagnetic Disturbance
Interplanetary magnetic cloud
Interplanetary shock wave
Solar Energetic Particles
(proton etc.)
Geomagnetic storm
Ionospheric storm
Enhancement of
relativistic electrons