# 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

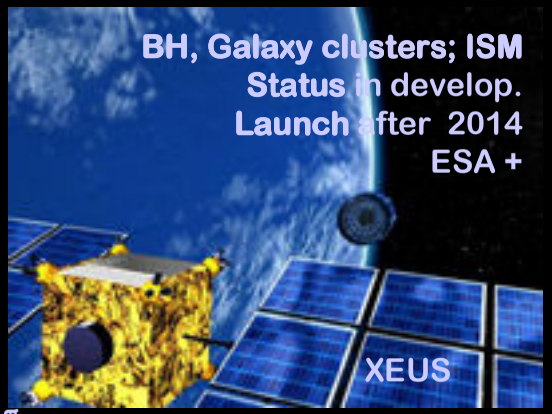
- Energy spectrum peaked at ~1 GeV/n
- < 1 GeV/n affected by 11-year solar cycle
- Flux modulated by solar cycle (inversely proportional to solar activity)

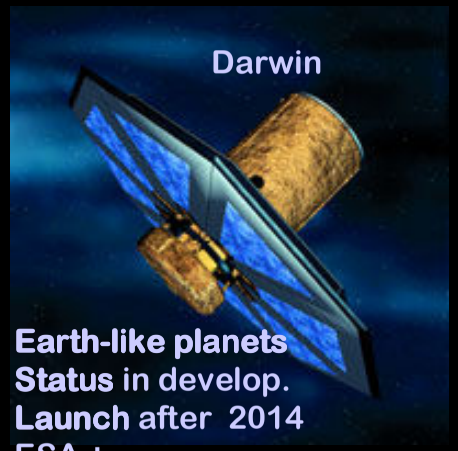
## Solar Energetic Particles (SPE)

- 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





Laser Interferometer Space Antenna




James Webb Space Telescope

# 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:**

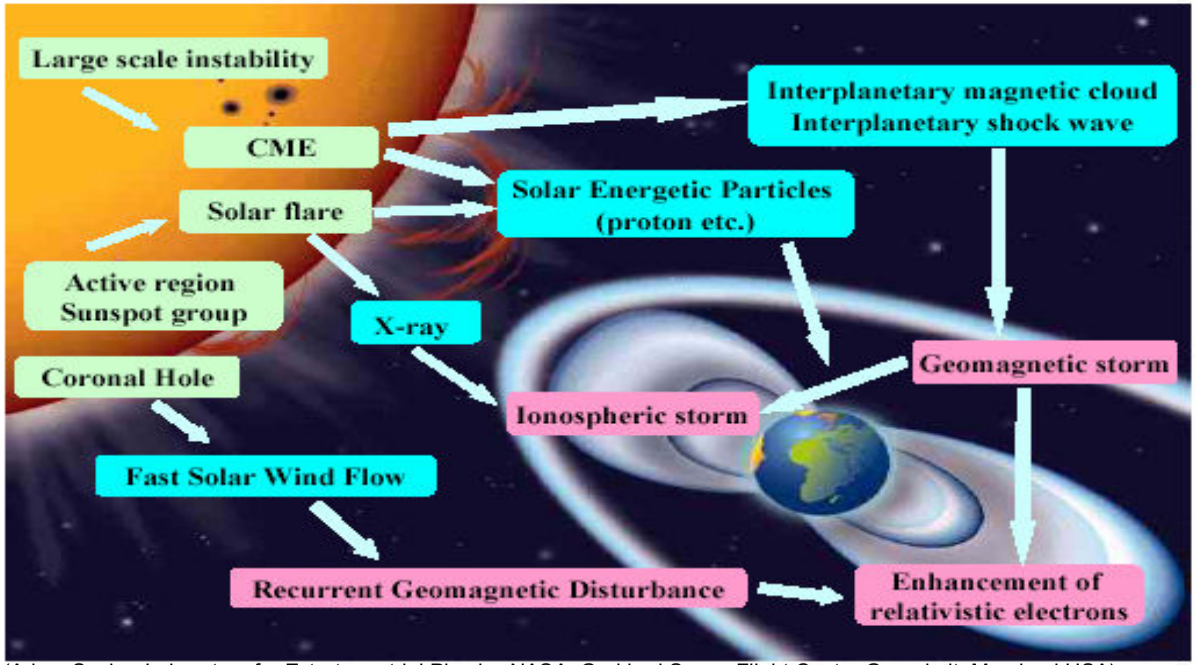
**Measure electrons : ~ 0.5 MeV – 20 MeV ;**
**protons and ions : 0.5 MeV/n – 150 MeV/n ;**

**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

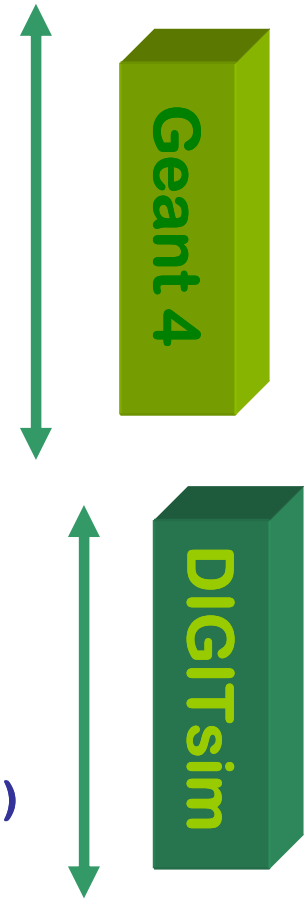



(Adam Szabo, Laboratory for Extraterrestrial Physics,NASA, Goddard Space Flight Center Greenbelt, Maryland,USA)

# 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.

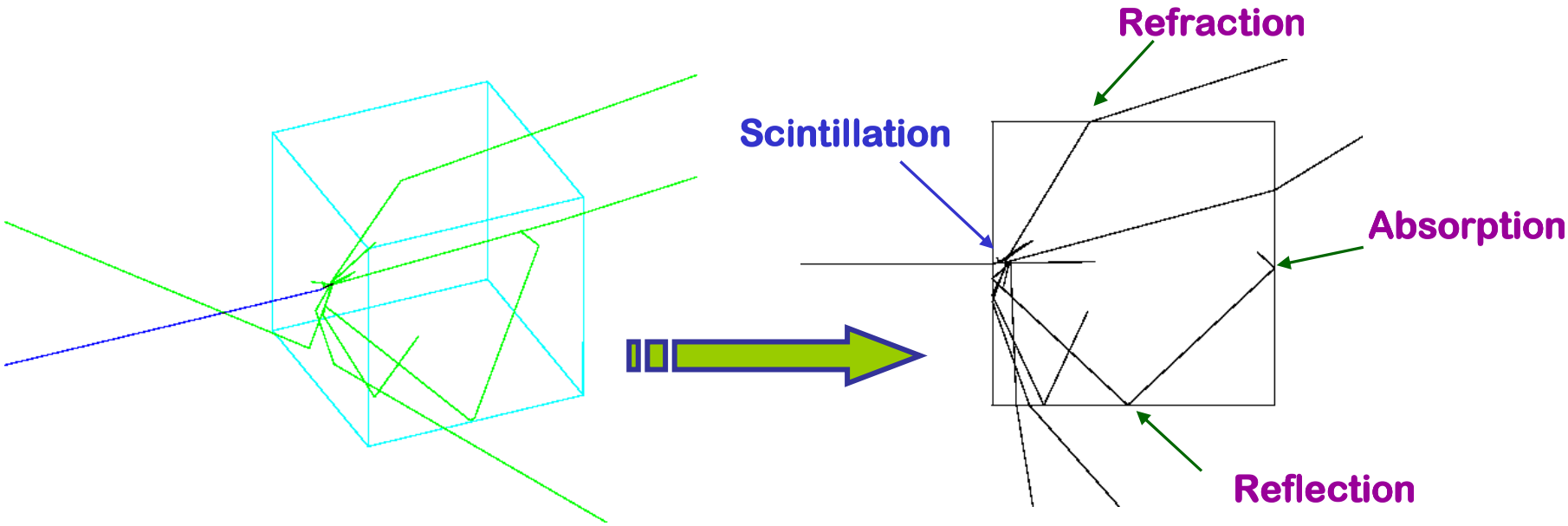


# Geant 4 toolkit

**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:

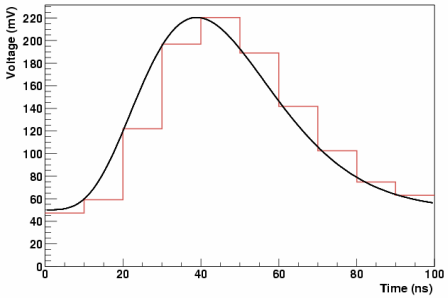



+ Cerenkov & Transition radiation, Rayleigh scattering
+ description of surface roughness (Unified Model)

# DIGITsim - Digitization Module

## Set of abstract interfaces for:

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

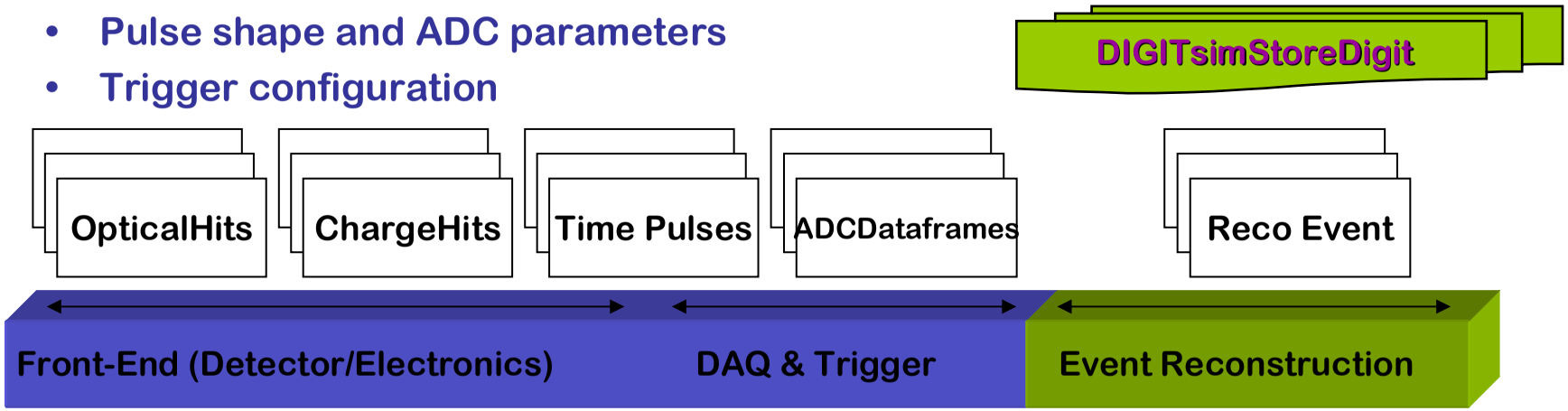



(Re-use of ClearPEM DIGITsim module, based on CMS/ECAL approach)

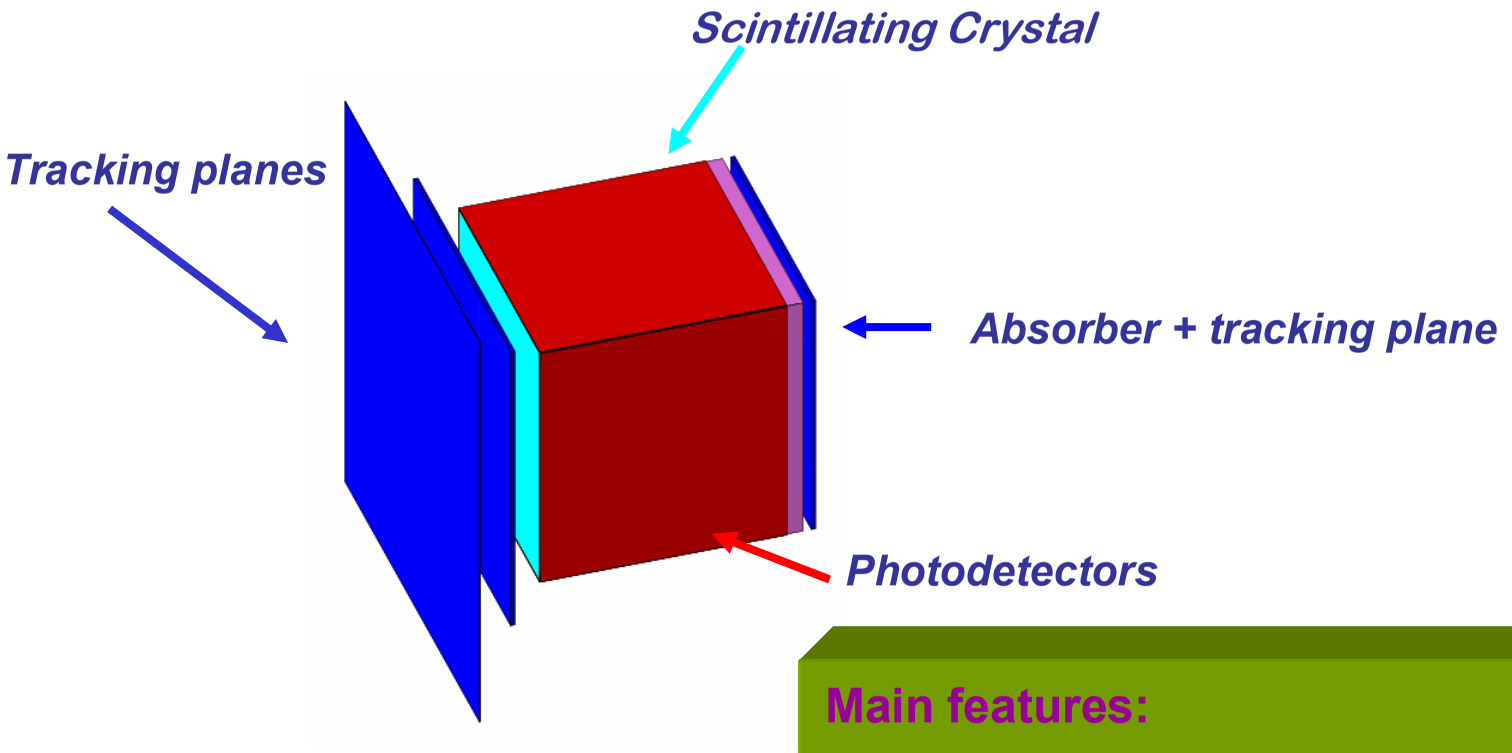
**The electronics configuration is stored in a macro file and can be changed interactively**

## 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



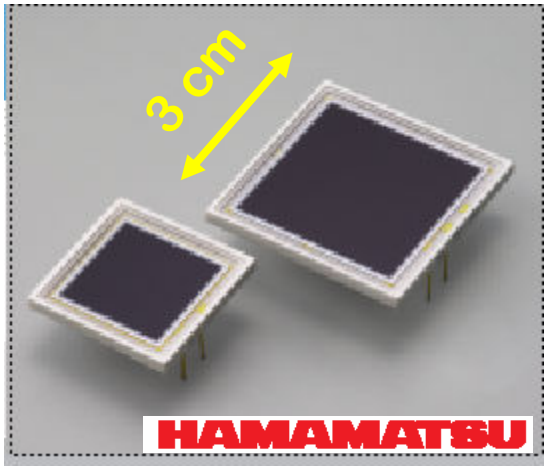

**Main features:**

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

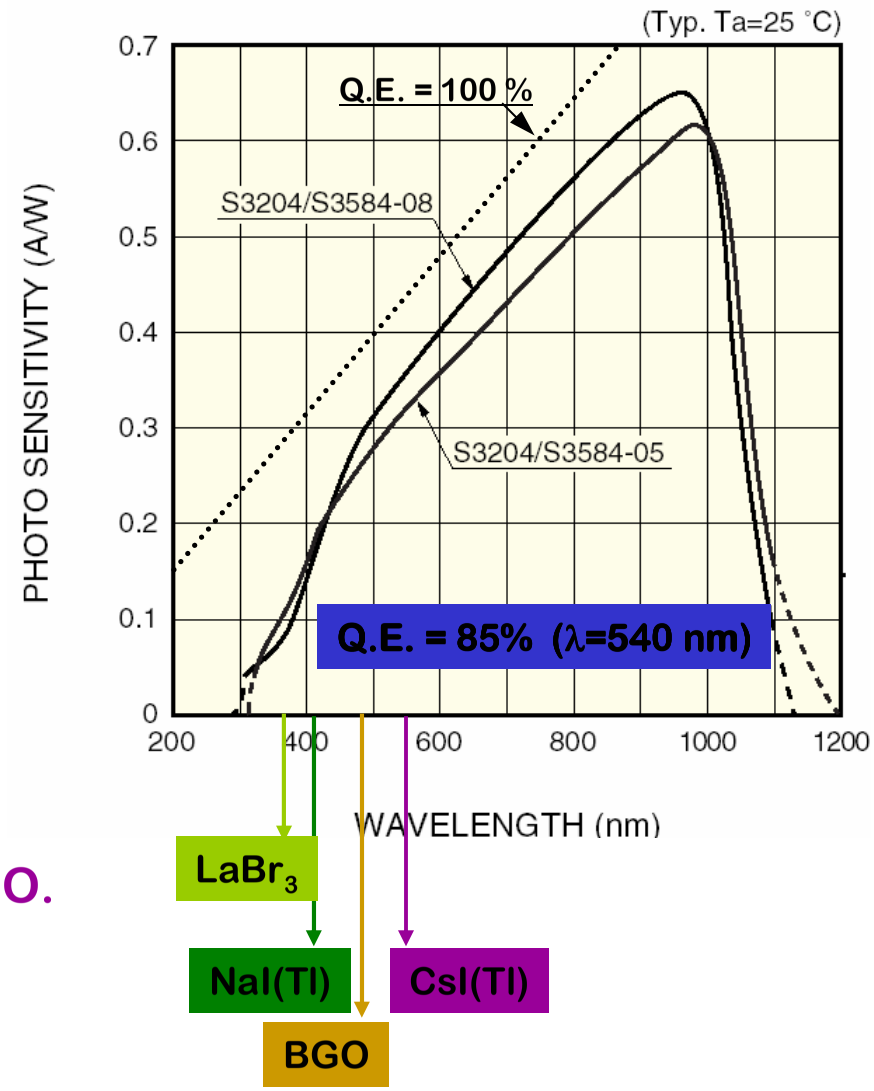
*Similar concepts from, e.g.:*

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

# Si PIN photodiode

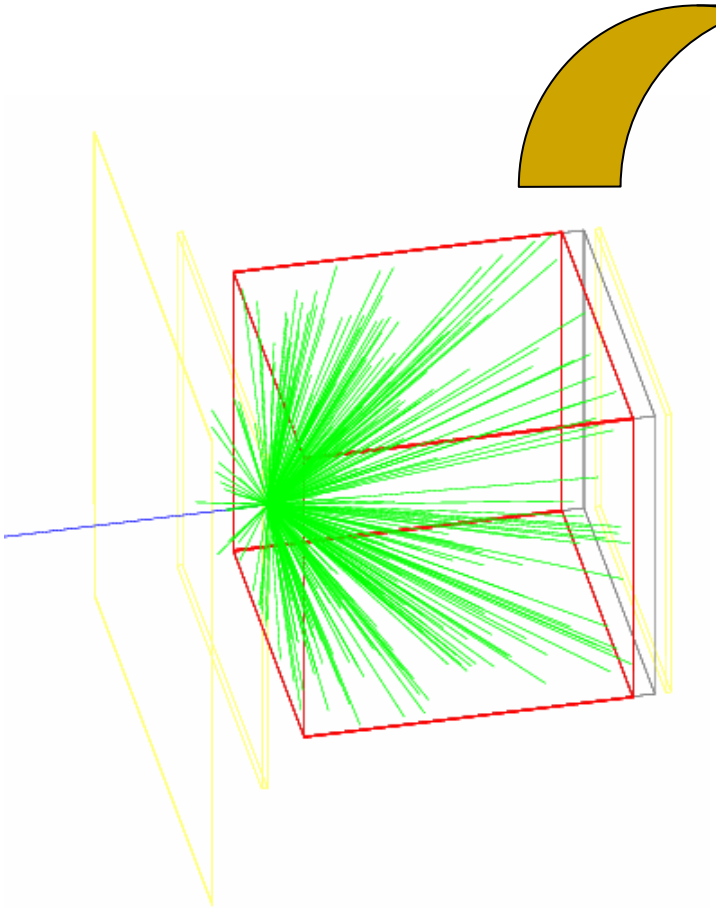



- High quantum efficiency
- Low voltage
- Low power dissipation

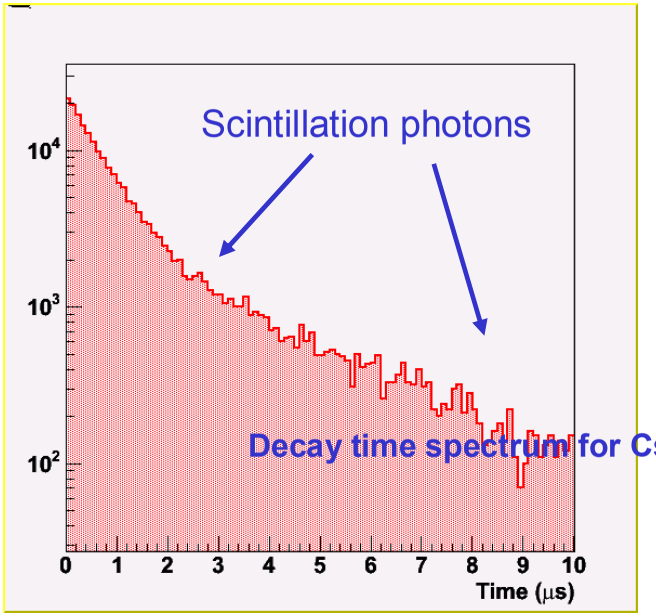



Good sensitivity matching with CsI, BGO.

# A 10 MeV proton

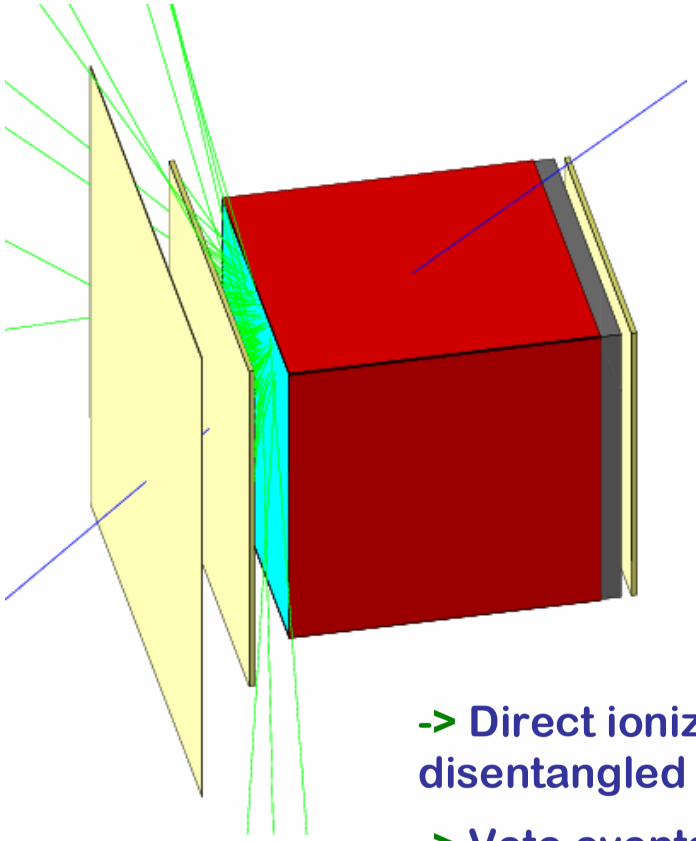


Time spectrum of signals in the photodetectors




Decay time spectrum for CsI (Tl)

# A 100 MeV proton



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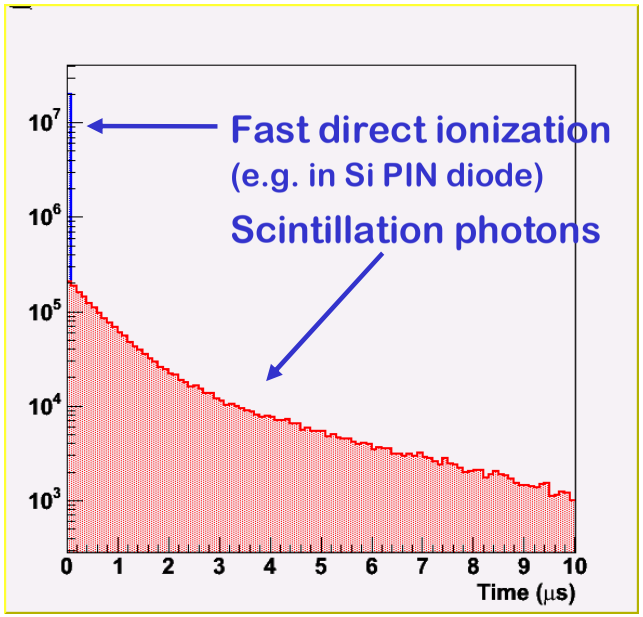
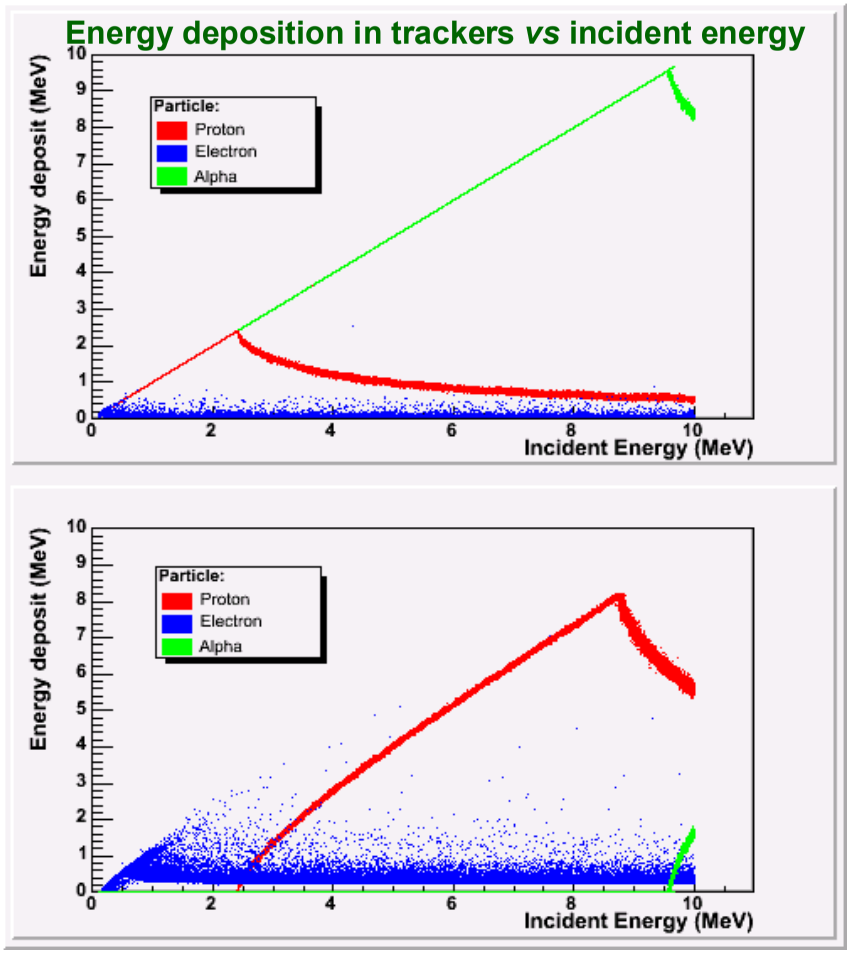
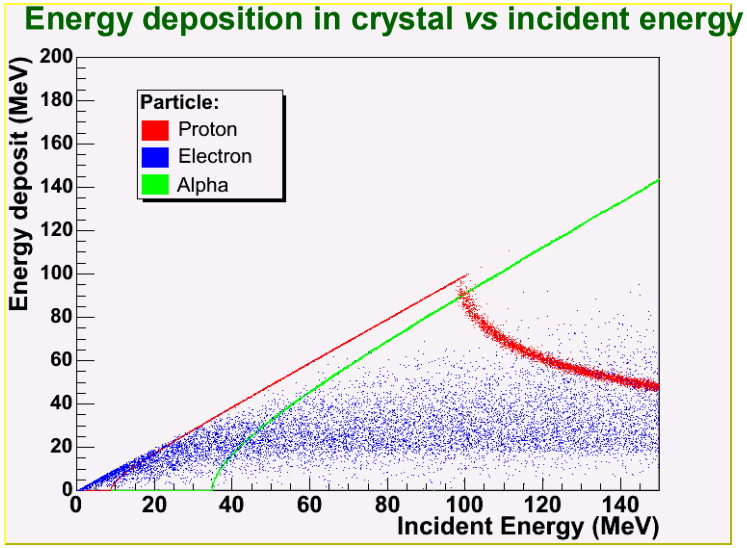



-> Direct ionization and scintillation signals can be disentangled by real time pulse height analysis.

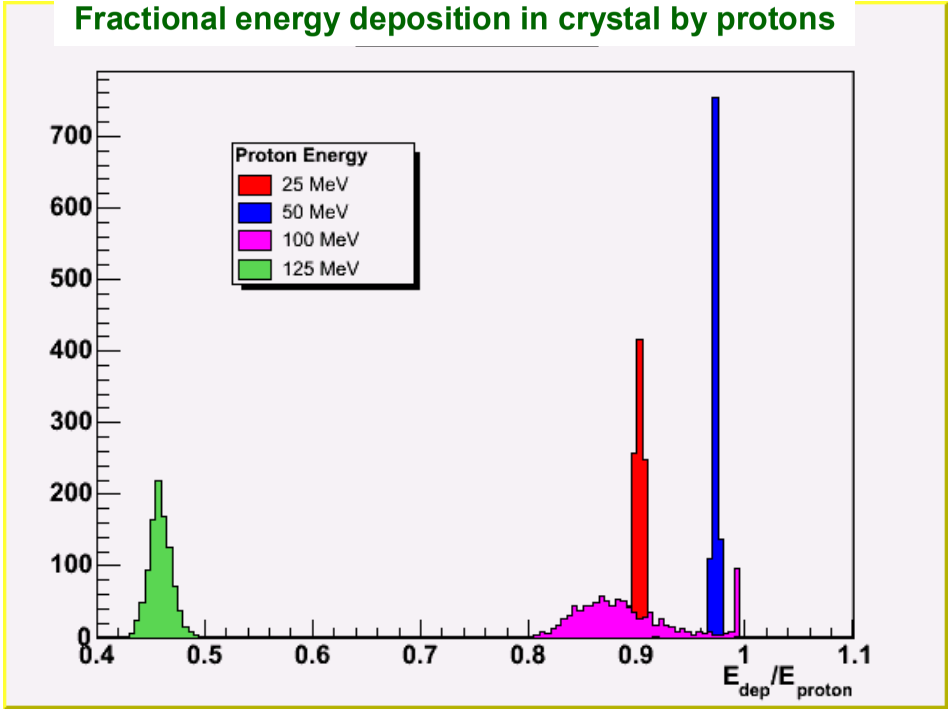
-> Veto events not fully contained; energy resolution improved.

# Some illustrative results from simulation (1)



# 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%)<br>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).