Radiation Interaction Simulation for High-Energy Astrophysics Experiments EUSO and AMS

L I P

Geant 4

Maria Catarina Espírito-Santo, Patrícia Gonçalves, Mário Pimenta,
Pedro Rodrigues, Bernardo Tomé, Andreia Trindade

SpaceGEANT4 Simulation Framework

EUSO Analysis and Simulations

AMS/RICH Radiator Simulations

Simulation Framework Overview

Simulation requirements

- Description of different AMS and EUSO related detector geometries: GEANT4
- Interface with alternative sets of primary event generators : GEANT4
- Integration of readout electronics, signal digitization and event reconstruction: DIGITsim
- OO-technology for event data persistency and data analysis : ROOT, LCG PI/AIDA , LGC POOL

Radiation transport: GEANT4 toolkit

Signal digitization: DIGITsim module

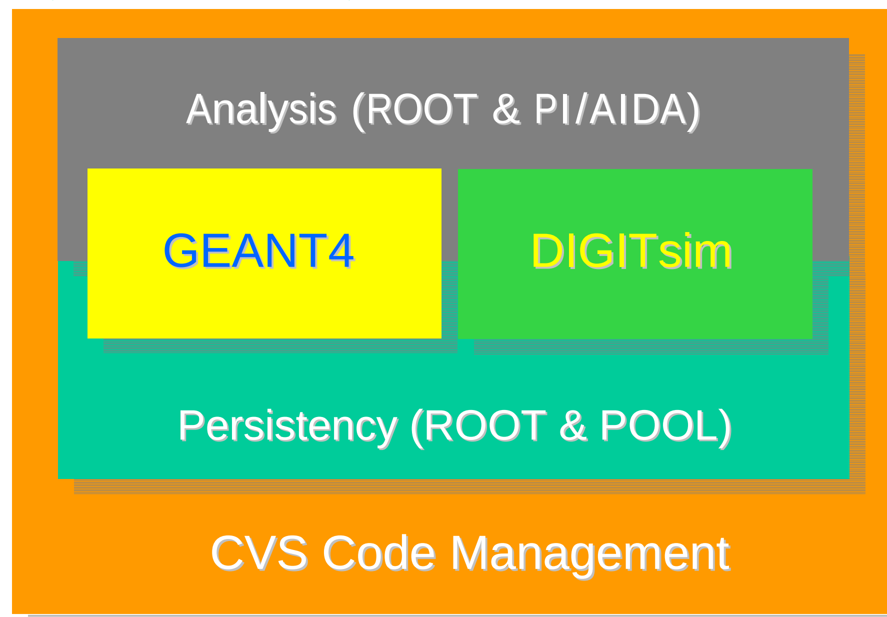
Baseline Configuration

Analysis & Event Storage: ROOT

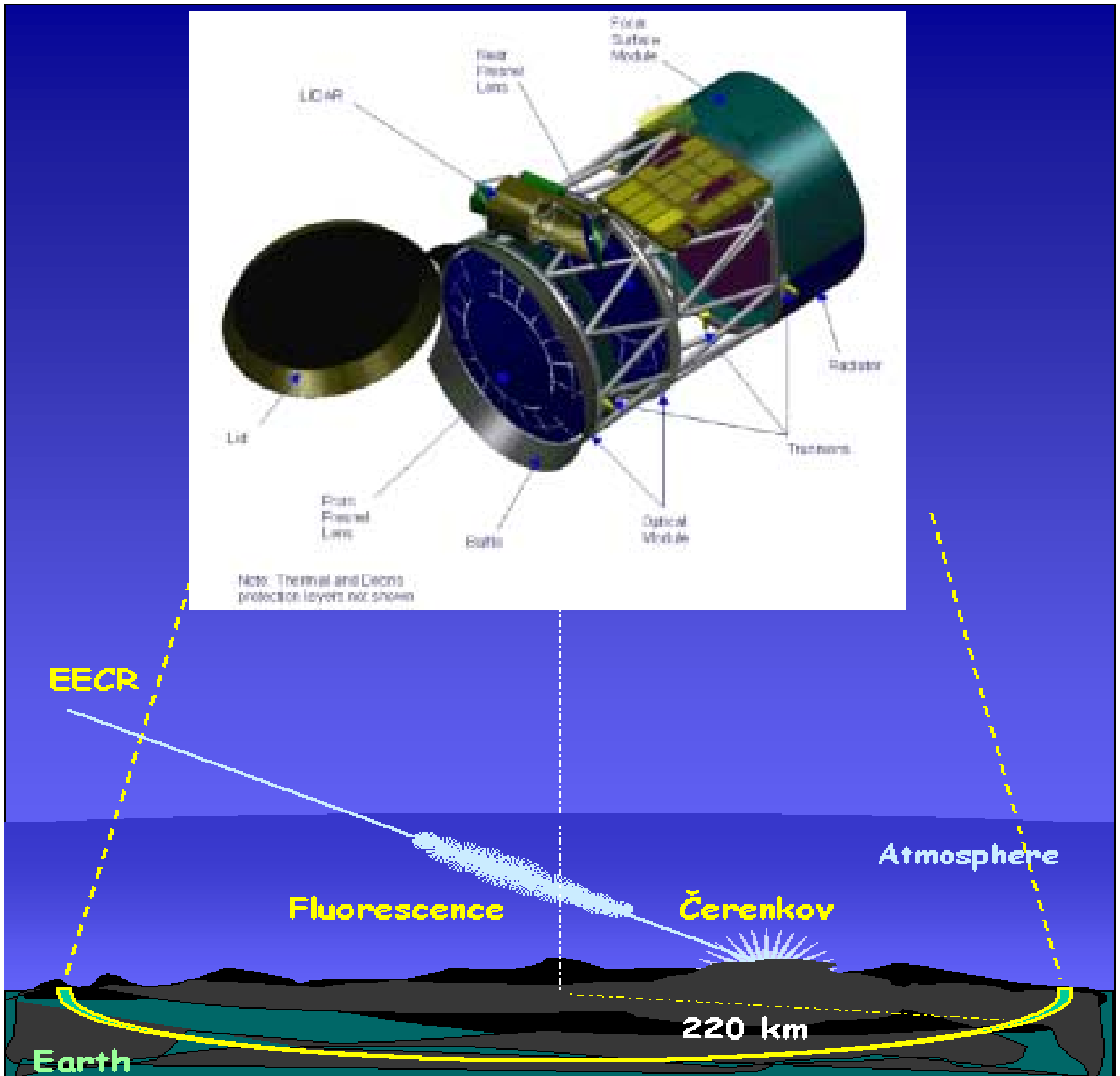
Options

Analysis: LCG PI/AIDA

Event Storage: LCG POOL



EUSO :
Extreme Universe Space Observatory



EUSO will detect
Extensive Air Showers
(EAS) light from above !

Fluorescence photons
isotropically produced at
different depths

Čerenkov photons
collimated with the shower
and diffused in a surface

ULTRA:
a supporting experiment for EUSO

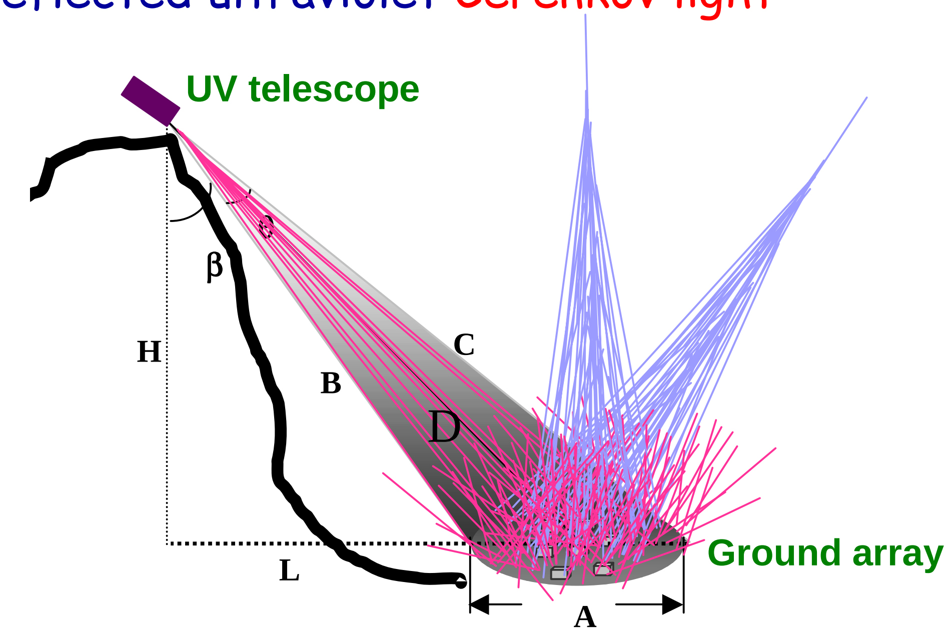
(UV Light Transmission and Reflection in the Atmosphere)

Study the detection of EAS Čerenkov light reflected on different surfaces **(ground, water,…)**

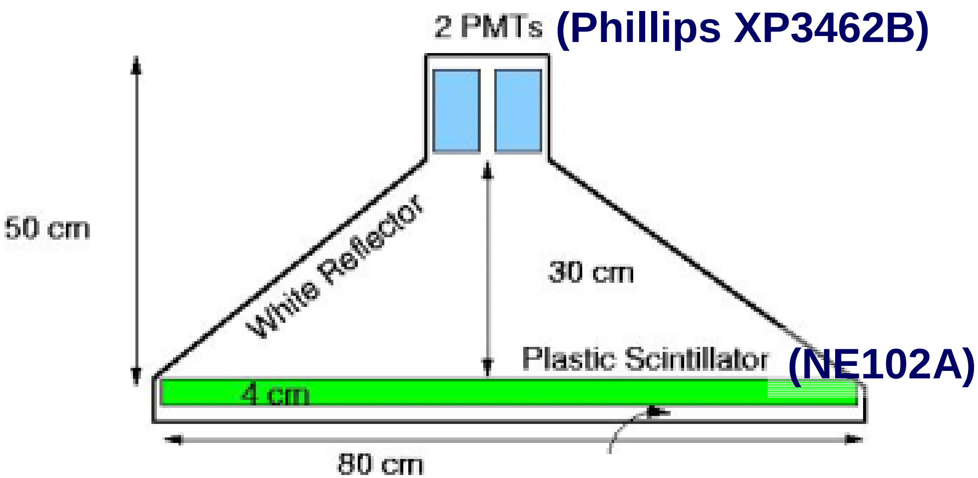
Two main detectors:

Ground array → measures the shower size and axis direction

UV telescope → detects the reflected ultraviolet Čerenkov light



The ULTRA array stations



NE102A scintillator:

Polystirene based

H:C ratio = 10:9
density =1.032 g/cm3

Refractive index = 1.58

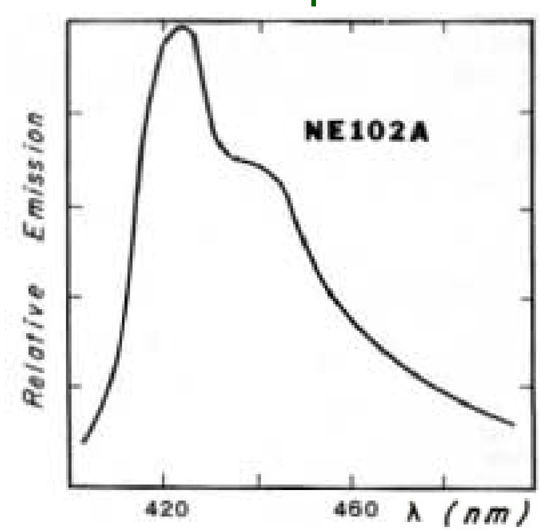
Absorption length =160 cm

Light yield=10000 Photons/MeV

Optical boundaries:

- UNIFIED model
- Scintillator-Air interface:
  - **TYPE :** dielectric-dielectric
  - **FINISH :** ground
- Air-Painted aluminium interface:
  - **TYPE:** dielectric-dielectric
  - **FINISH :** GroundFrontPainted

Emission spectrum



Event data storage

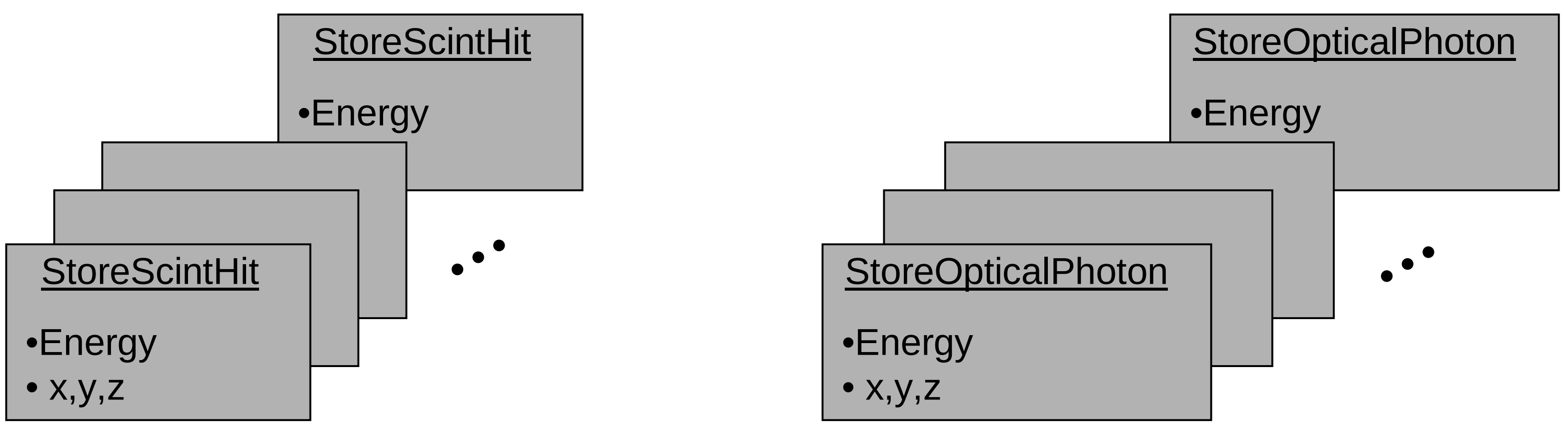
- Events are stored under a ROOT Tree organization
- **EventForTree** is the ROOT persistent class
- For each event, the EventForTree object contains namely:

Primary particle initial position and momentum

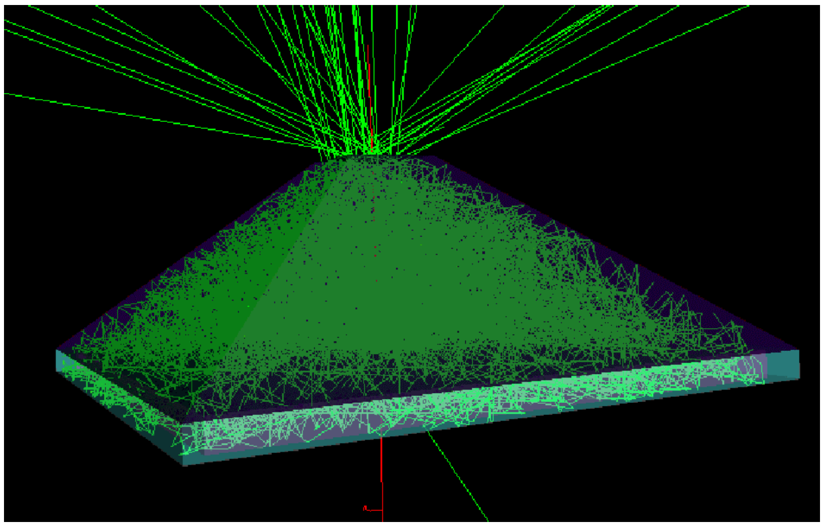
Total energy deposited in the scintillator

Number of detected optical photons

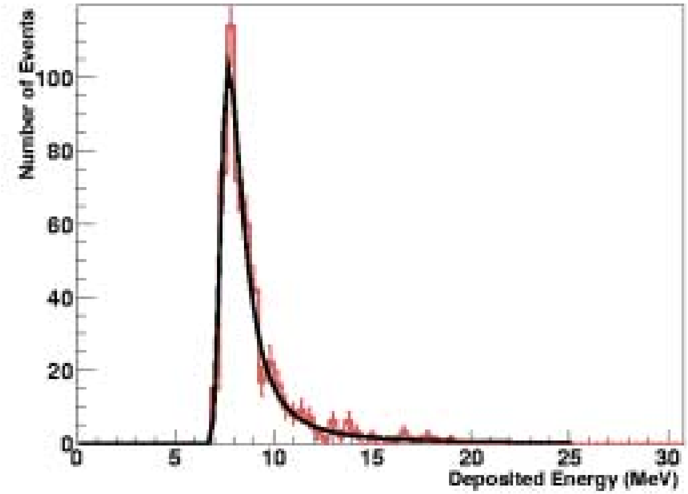
TClonesArray(s) of **StoreScintHit** and **StoreOpticalPhoton** objects



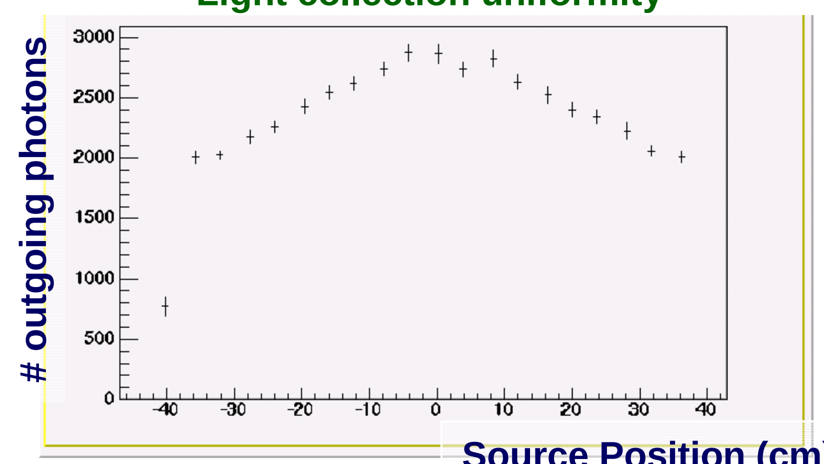
Simulation results



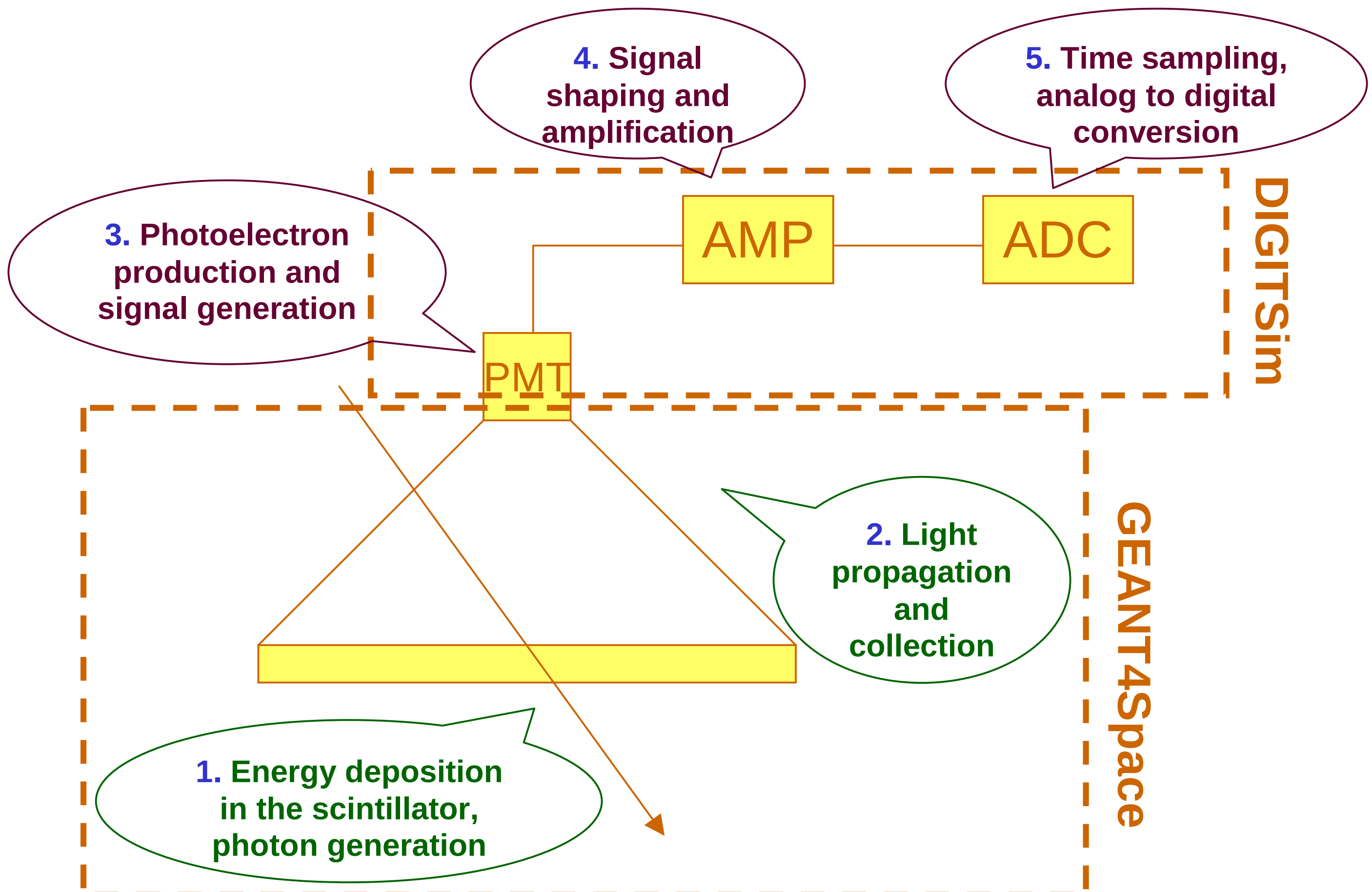
Energy deposited in the scintillator



Light collection uniformity



Digitization in the ULTRA SpaceGEANT4 application



Implementation

DIGITsimULTRAPulse

Inherits from DIGITsimVPulse

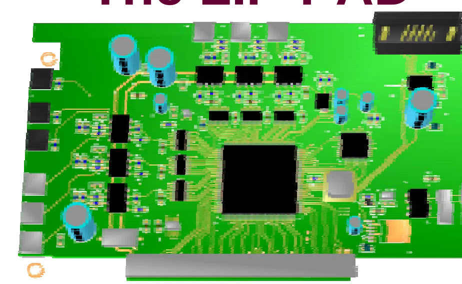
Contains the ULTRA **pulse shape definiton**

$$V(t) = V_{max} \cdot e^{-\frac{1}{2\varpi^2}\log^2\left(\frac{t-t_0}{\Delta}\right)}$$

DIGITsimULTRAAmplifier

Inherits from DIGITsimVAmplifier

The LIP-PAD



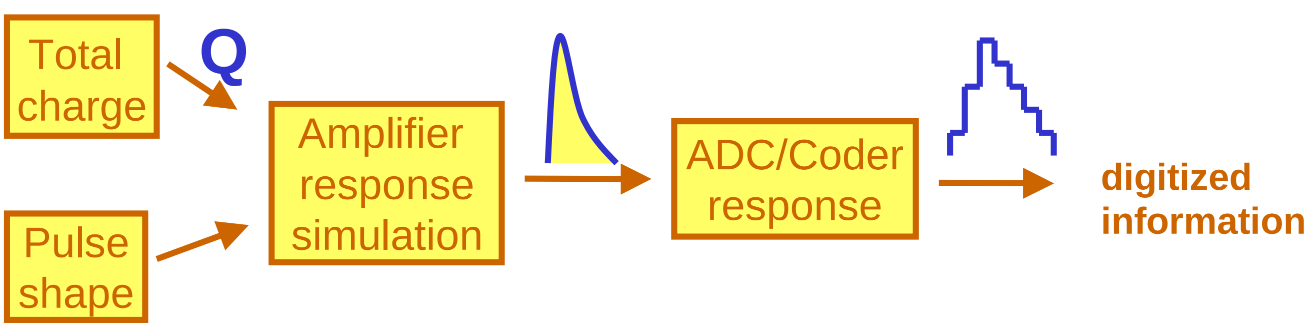
ADC/Coder parameters:

Frequency **100 MHz**, **10 bits**, 8 time samples, voltage range **0-1 V**

Photodetector:

Energy deposited in the scintillator **(E_{dep})** directly used to obtain the total collected charge **(Q)** :

$$Q = E_{dep} \cdot Y \cdot \varepsilon_{coll} \cdot \varepsilon_{QE} \cdot \varepsilon_{acc} \cdot G$$



An example...

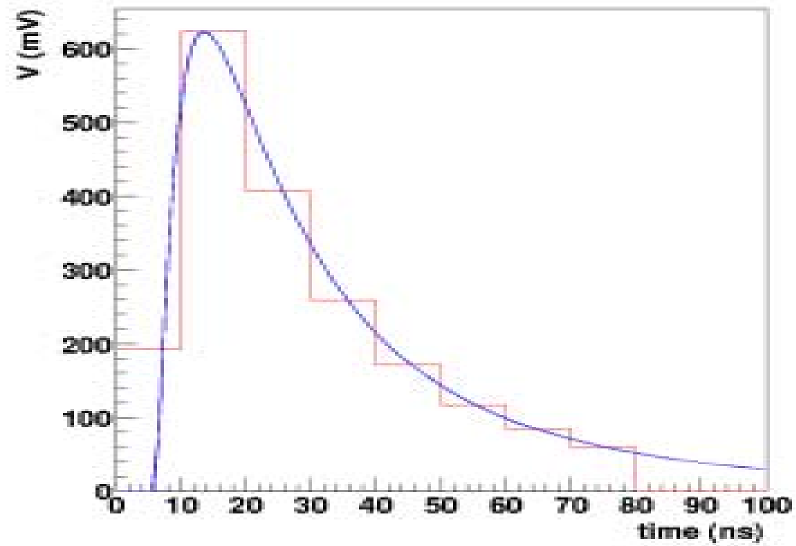
$Y=10^4$ photon/MeV

$\varepsilon_{coll} \cong 0.10$

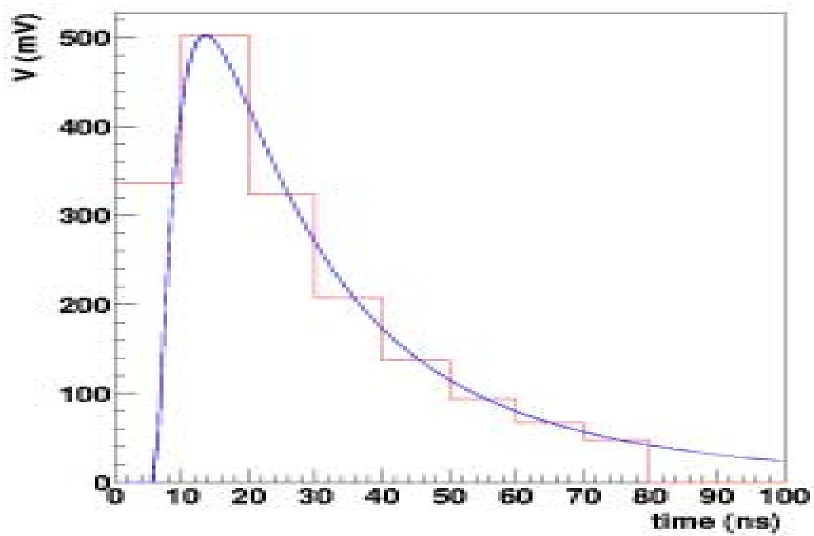
$\varepsilon_{QE} \cong 0.15$

$\varepsilon_{acc} \cong 1.0$

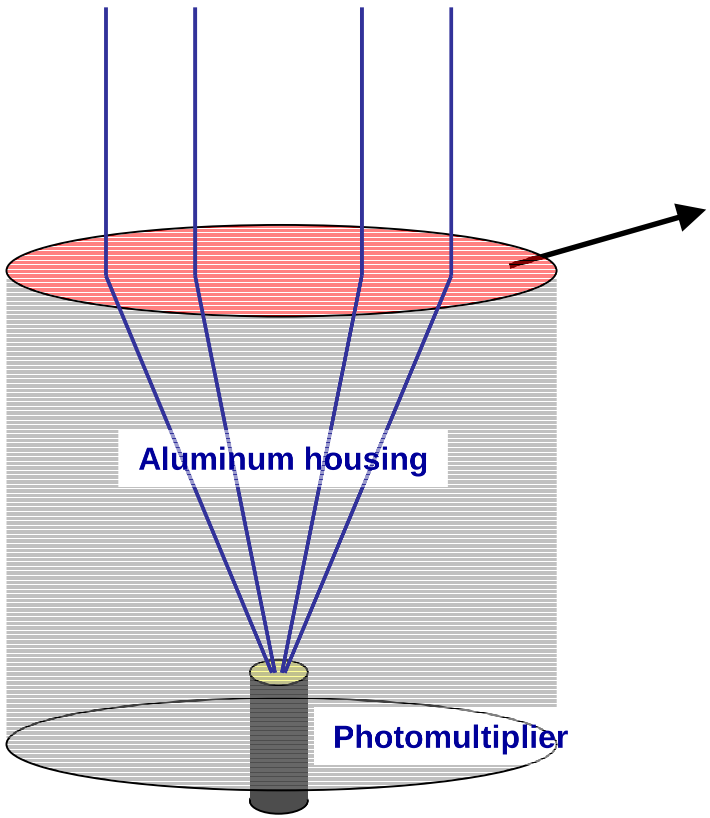
$G \cong 5.10^6$



- Amplifier gain ≅ 50 V/A
- Pulse shape
  - $\Delta \cong 8$ ns
  - $\omega \cong 1$
- Pedestal=0



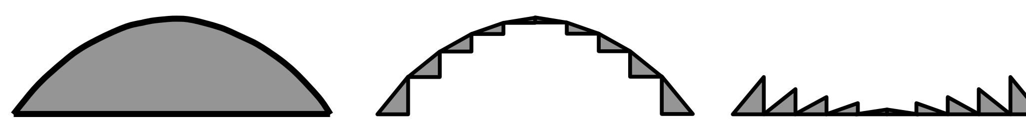
The ULTRA UV telescope



Fresnel lens:

457 mm diameter
457 mm focal length
5.6 grooves/mm
UV transmitting acrylic

Challenge !!



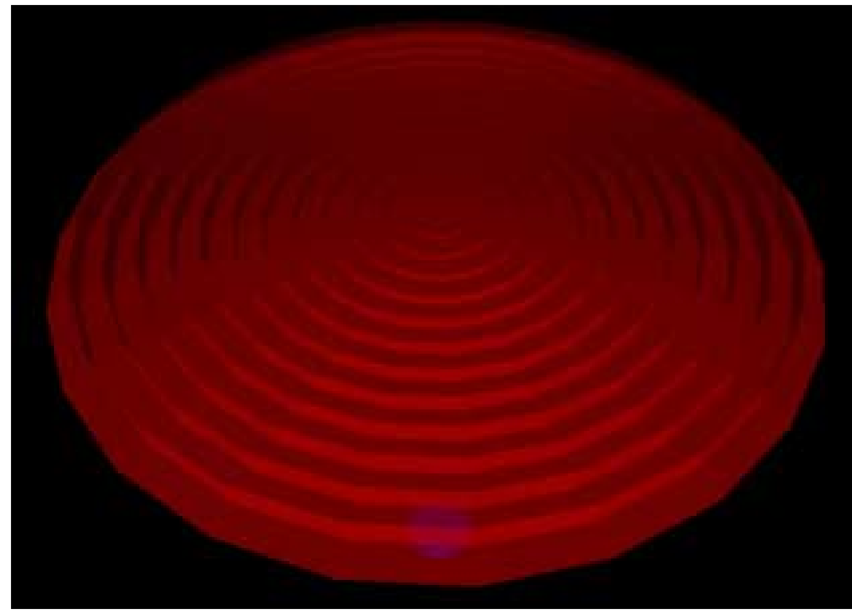
Fresnel lens description in the SpaceGEANT4 framework

SpaceGEANT4FresnelLens Class

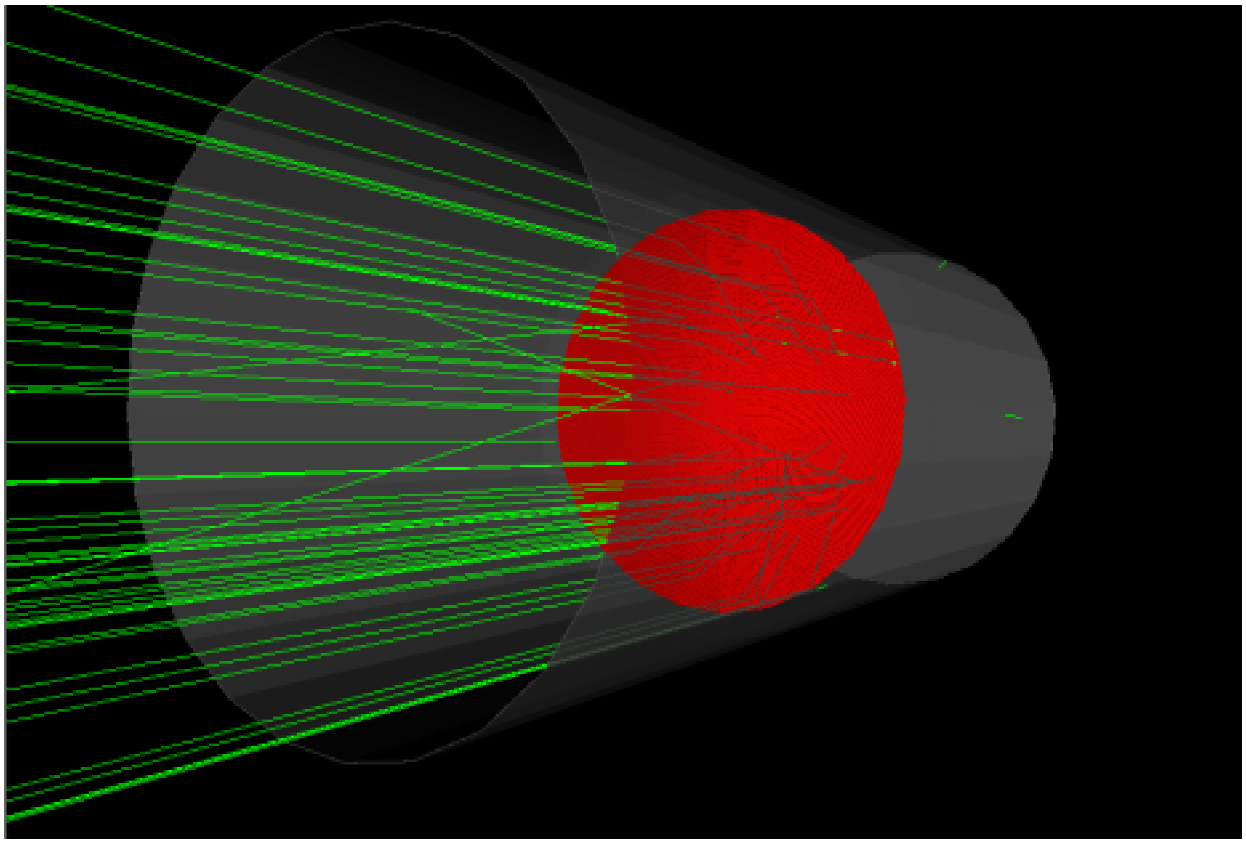
Lens defined through a parameterised replication of G4Cons volumes

Lens grooves are frustra of cones

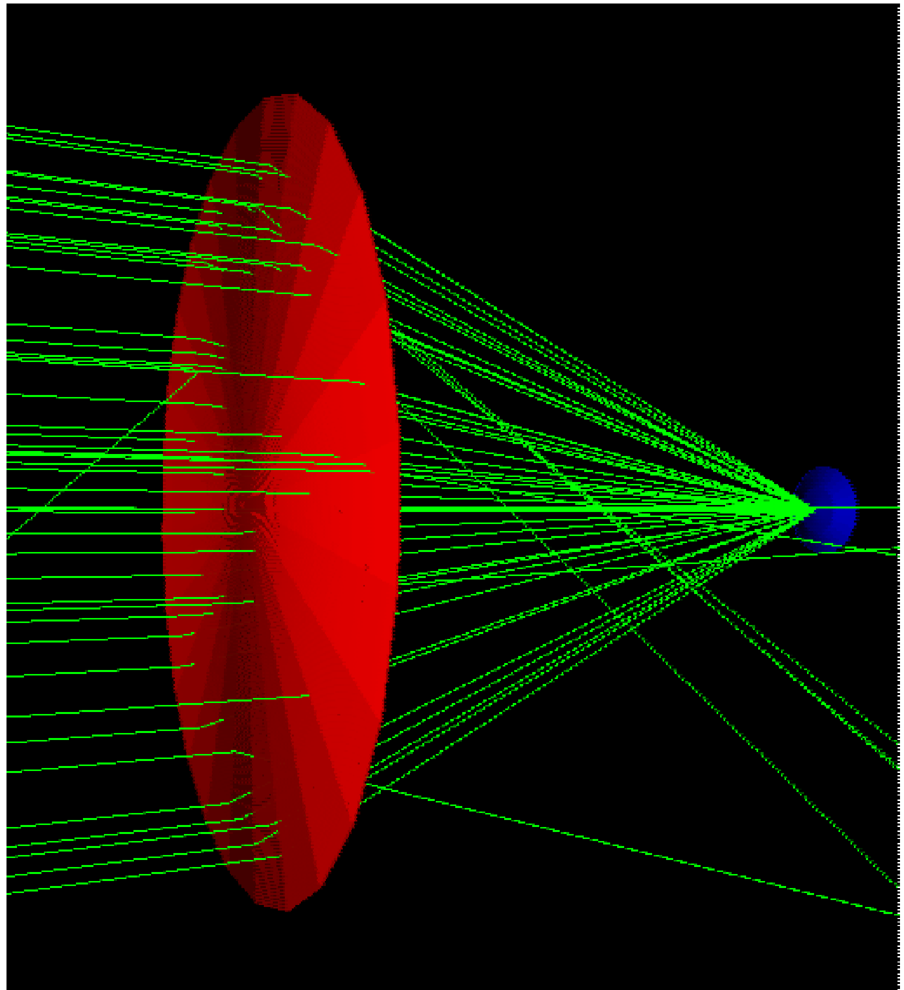
5.6 grooves/mm



Simulation of the UV telescope (I)

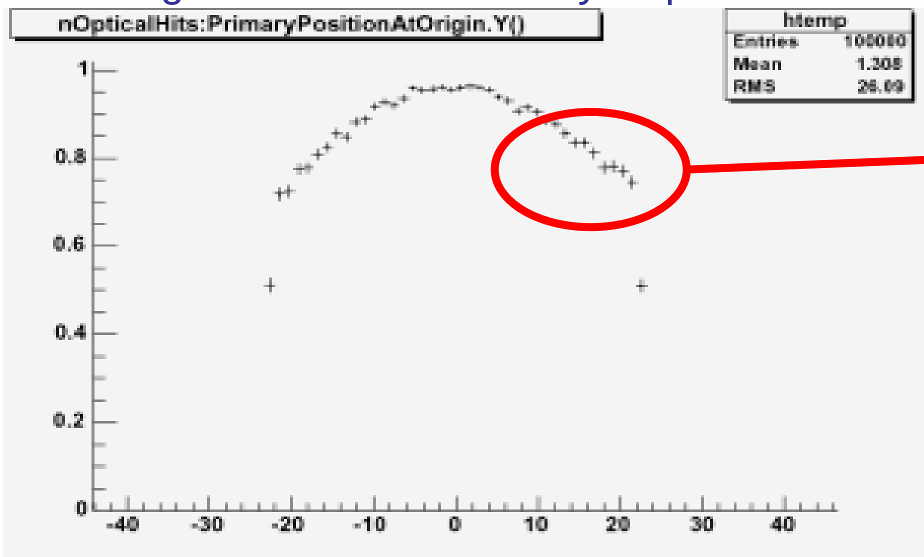


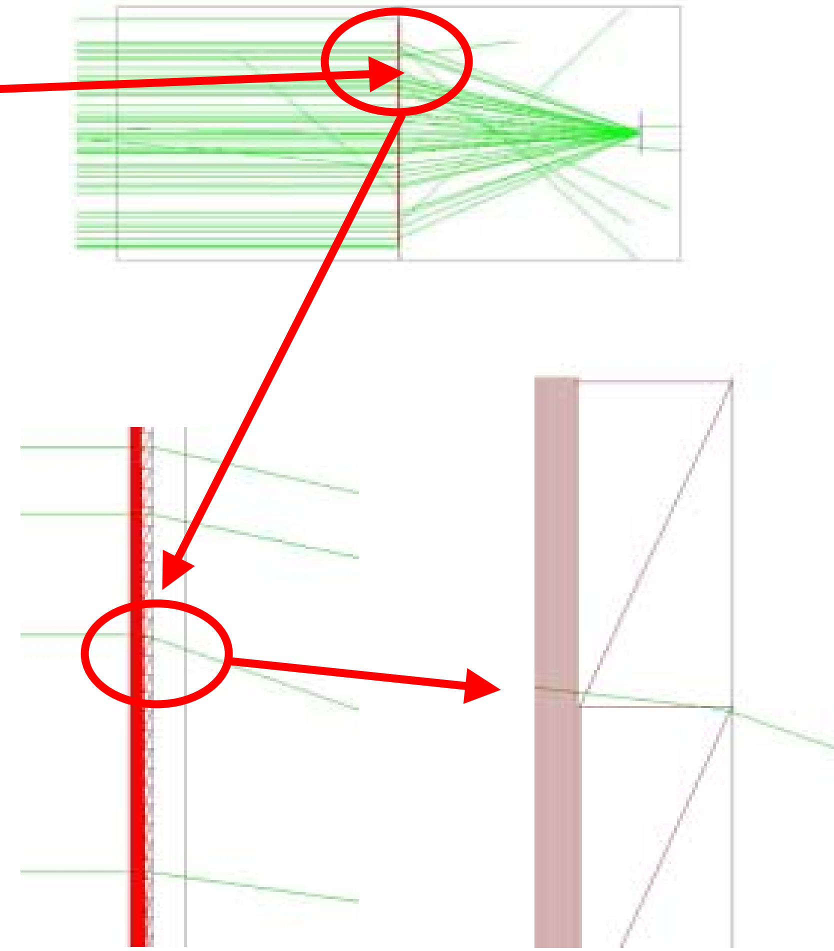
Simulation of the UV telescope (II)



Light collection efficiency

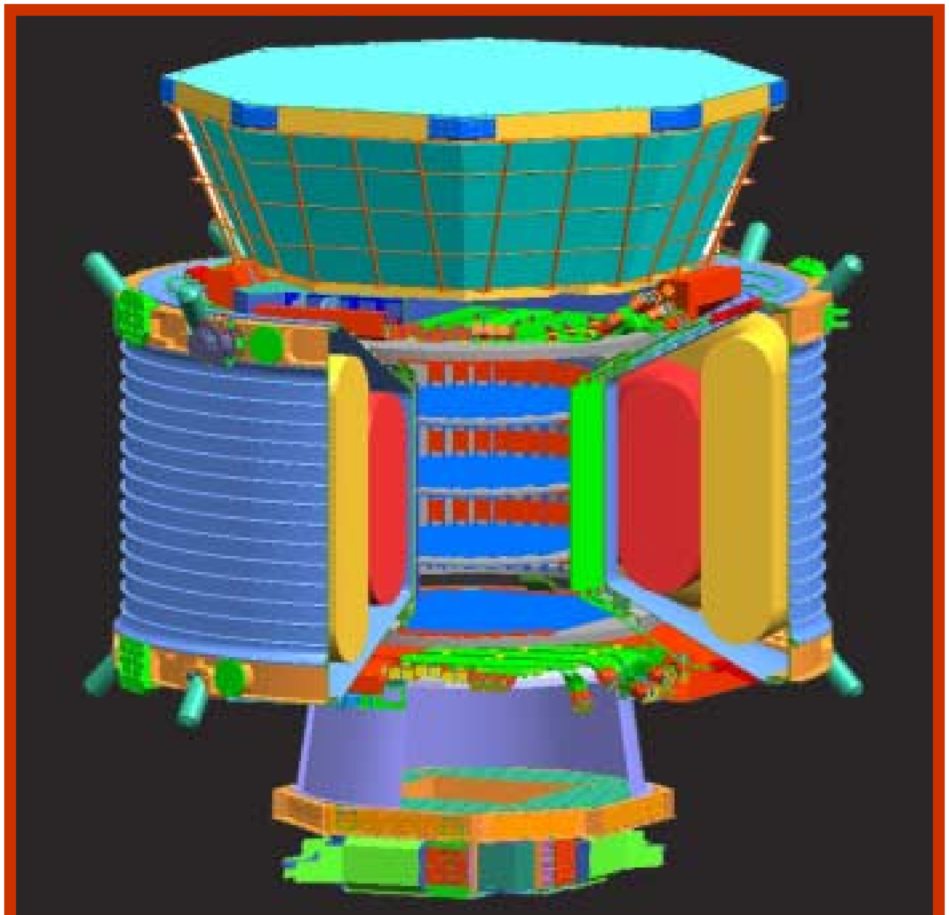
Light collection efficiency vs position





GEANT4 potential explored in detailed studies

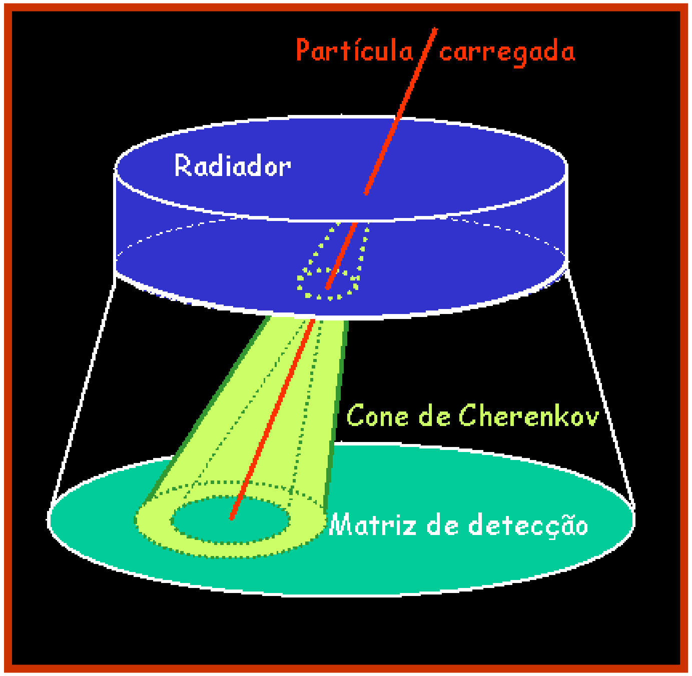
AMS - Alpha Magnetic Spectrometer

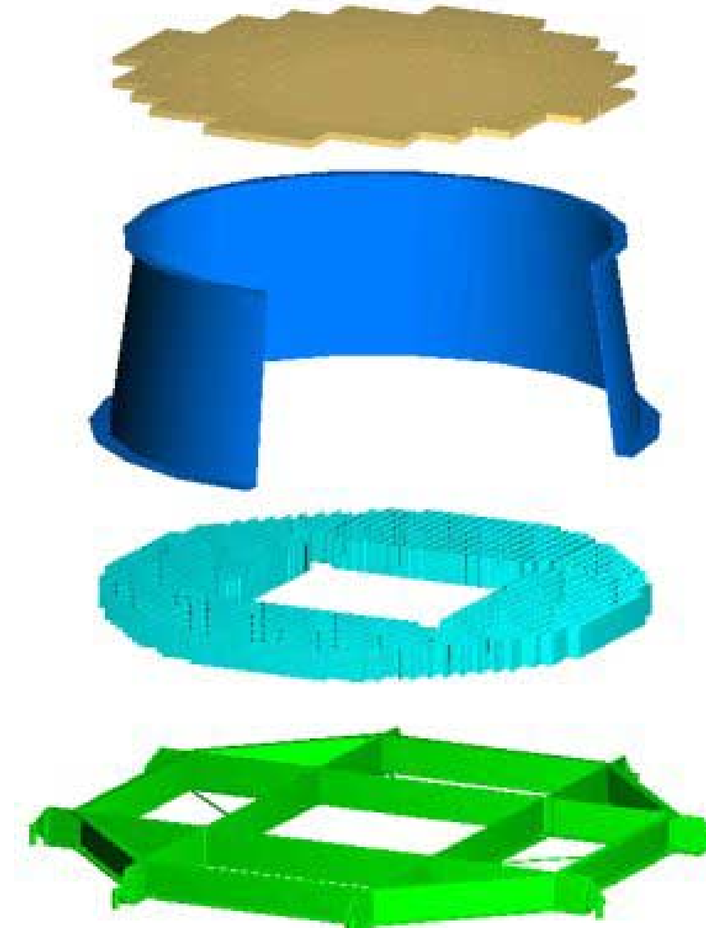


The **AMS spectrometer** is constituted by different subdetectors surrounded by a superconducting magnet, which aims at characterising cosmic rays before reaching the earth atmosphere.

LIP´s collaboration in AMS is centered in the **RICH** – Ring Imaging Cherenkov – detector.

The RICH detector of AMS



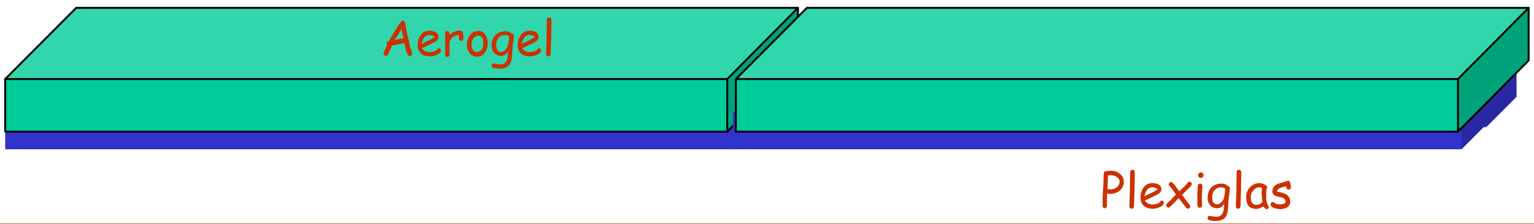


The light emitted by **charged particles** with **velocity greater than the speed of light** in the radiator enables to reconstruct their charge and velocity…

The **number of photons** is proportional to Z^2

The **Cherenkov cone opening angle** is related to the **velocity** β, by: $\cos(\theta_c)=1/(\beta\ n)$.

RICH radiator simulation parameters



Aerogel tiles n=1.03 Clarity=0.007598 Abs_length=100.cm

11.3 cm x 11.3 cm x 3.0 cm , gap 0.1 cm

Variable number NTilesx x NTilesy

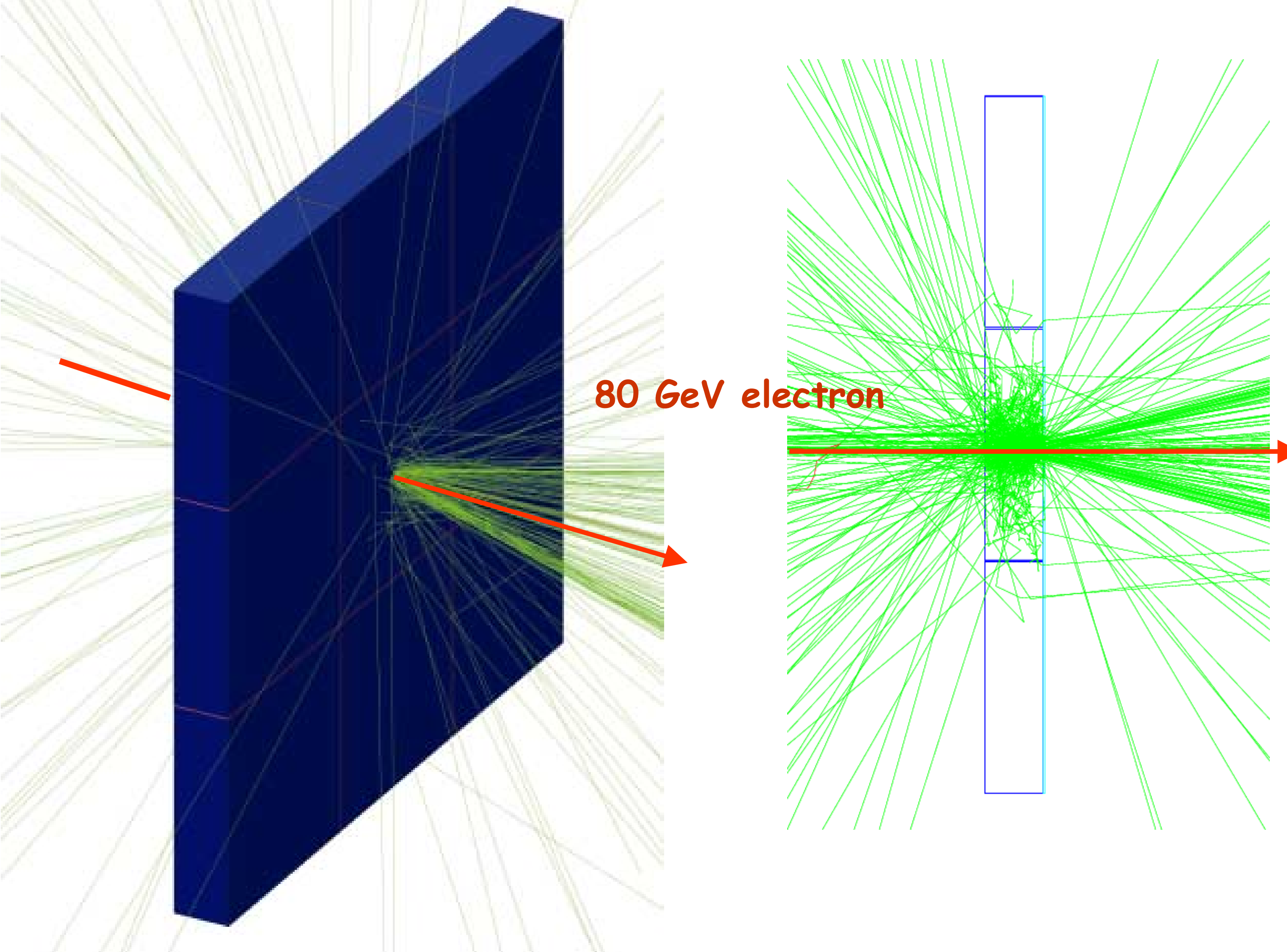
Plexiglas foil n=1.49 Abs_length~100.cm (λ =400 nm)

below the Aerogel tiles (size depends on NTilesx x NTilesy)

Surface description (for aerogel-air and plexi-air interface**)**

Type - dielectric_dielectric Model - Unified Finish - Ground

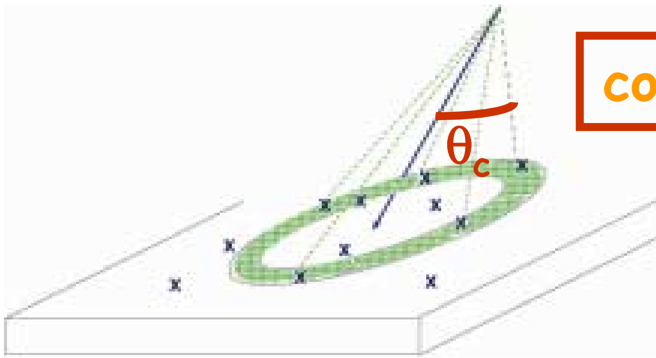
One event in the RICH radiator



Velocity reconstruction

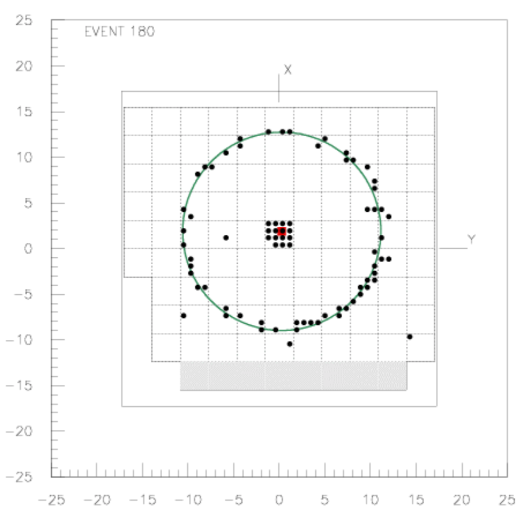
The relevance of the direction of the transmitted photons ....

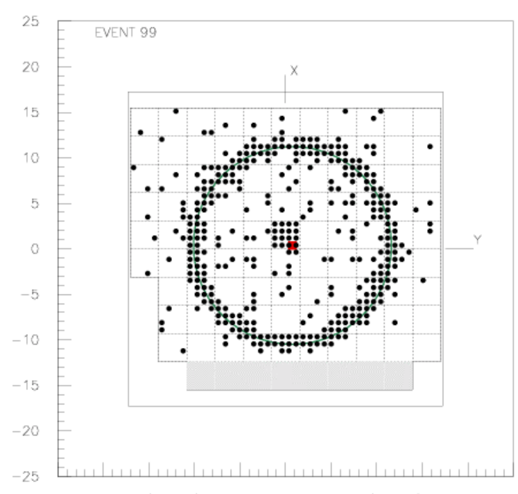
The Cherenkov cone opening angle is related to the velocity β, by:



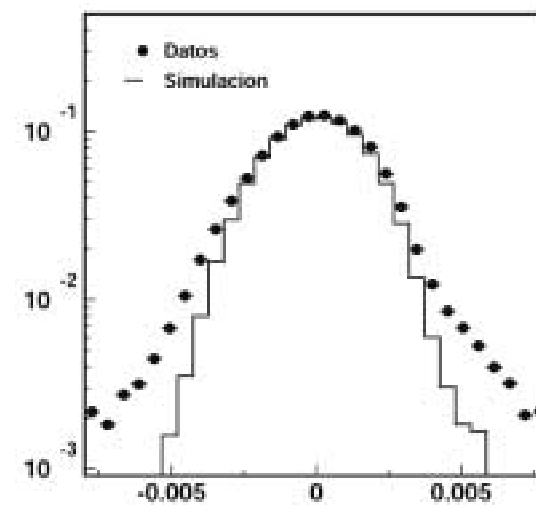
$$\cos(\theta_c)=1/(\beta\ n). \quad \Rightarrow \quad \Delta\beta/\beta(\mathrm{hit})=\tan(\theta_c)\ \Delta\theta_c$$

Test beam data (2002)





$\beta_{rec.} - \beta_{exp.}$

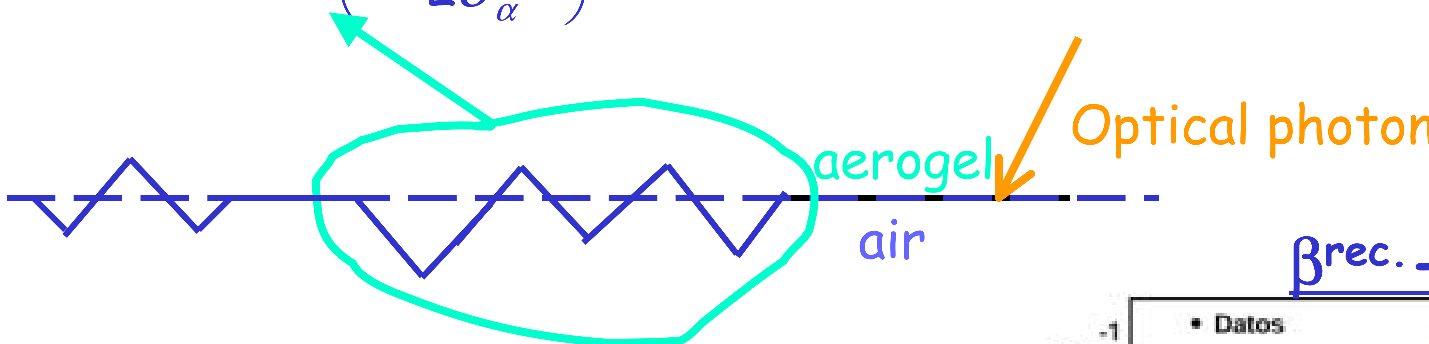


Photon scattering in the aerogel radiator surface

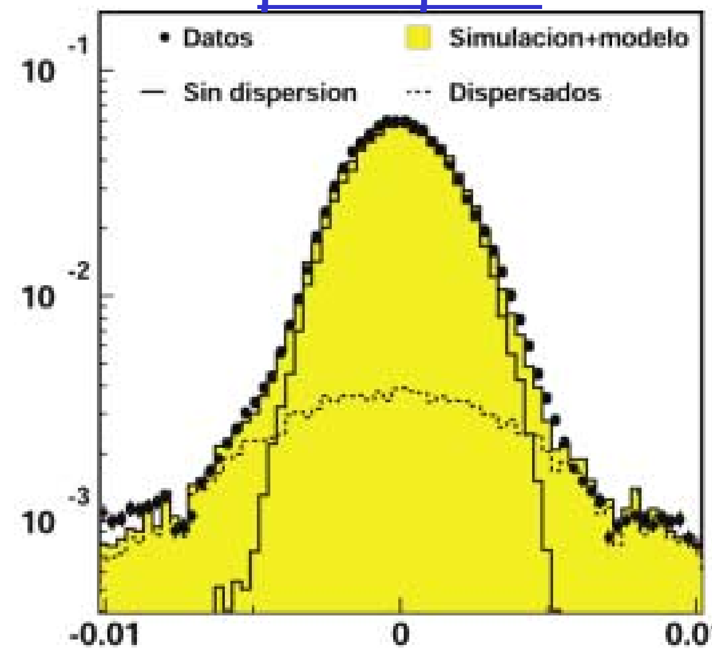
An empirical model with Geant3:

$$p(\alpha)d\alpha \approx \exp\left(-\frac{\sin^2\alpha}{2\sigma_\alpha{}^2}\right)d(\sin^2\alpha)$$

for P< P(scattering.)



βrec. – βexp.



Fit to data:

Aerogel	P(scattering)	σ_α
Mats. 1.05	0.20±0.02	25±3
Mats. 1.03	0.28±0.02	24±2
Mats. 1.03 n	0.33±0.02	20±3
Nov. 1.03	0.15±0.01	24±1
Nov. 1.04	0.21±0.01	25±4

Measurement of the aerogel surface

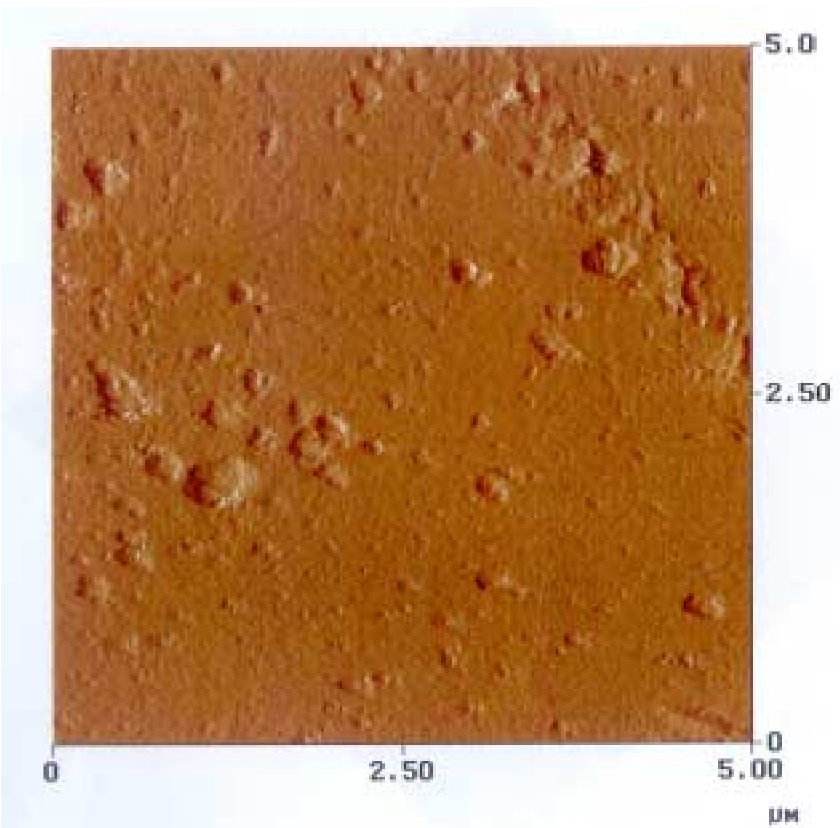
A more precise description of the photon scattering in aerogel

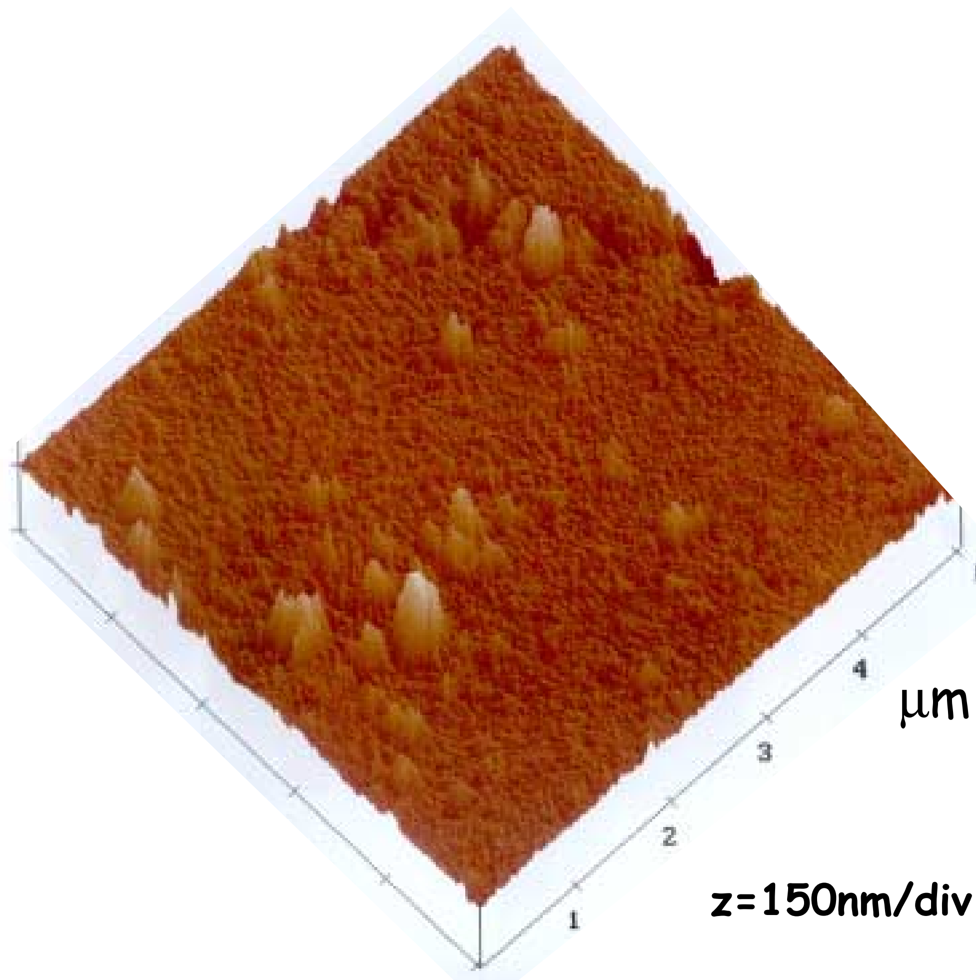
Atomic Force Microscopy (AFM):

- Study of the surface of different aerogel types : from different manufacturers /with different refractive indices.
- Contribute for the choice of the aerogel type to be used in the AMS RICH flight configuration ?
- Obtain aerogel surface mappings and/or estimate effective parameters for the surface.

Atomic Force Microscopy

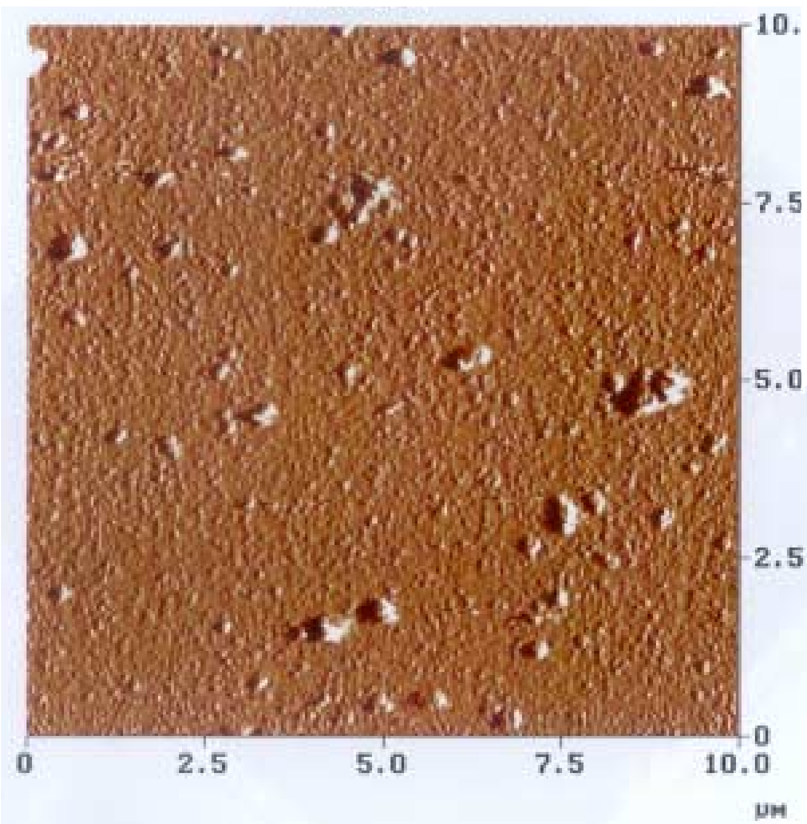
Aerogel: n=1.03 (Matsushita)

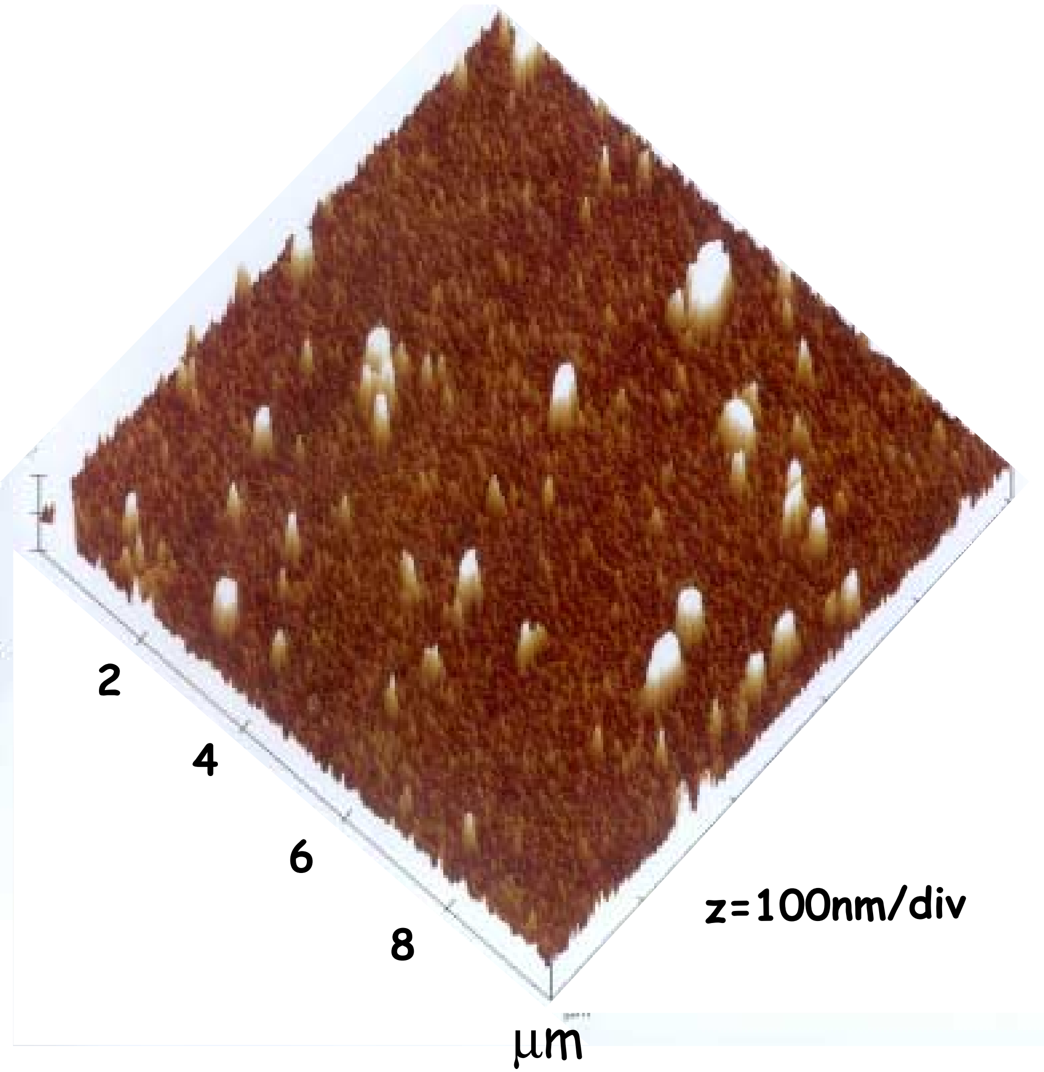




Atomic Force Microscopy

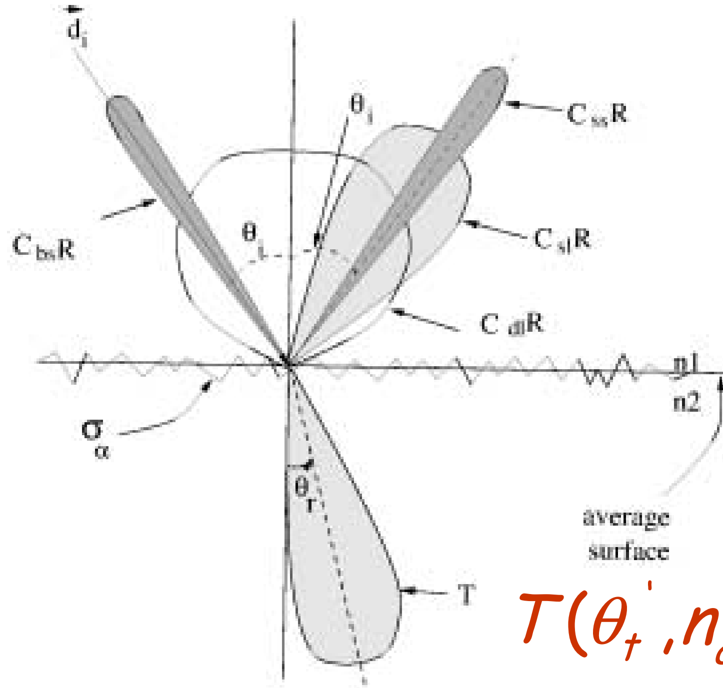
Aerogel: n=1.05 (Matsushita)





Rich radiator studies with Geant4

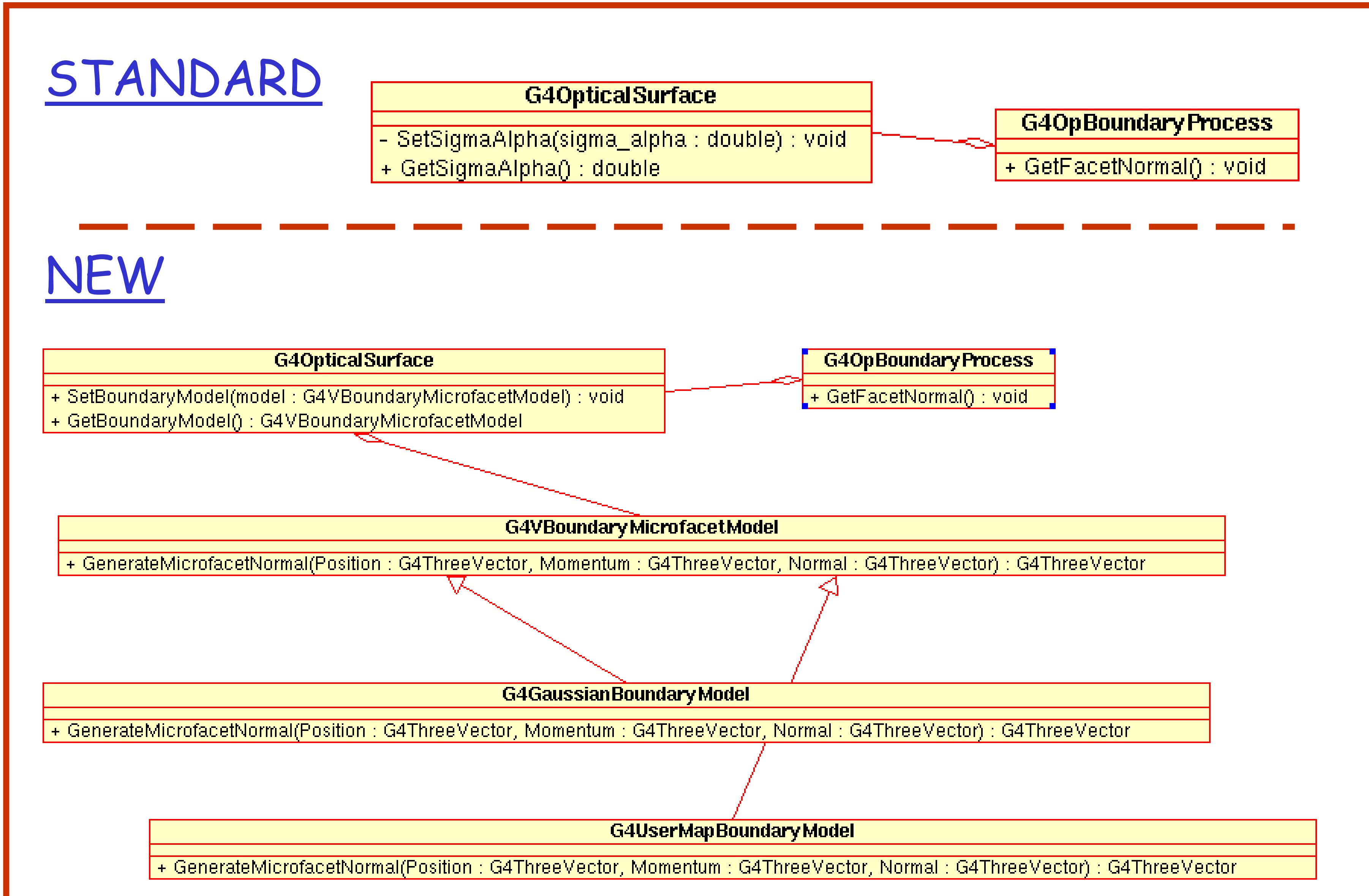
Can the unified model describe photon scattering in aerogel ?



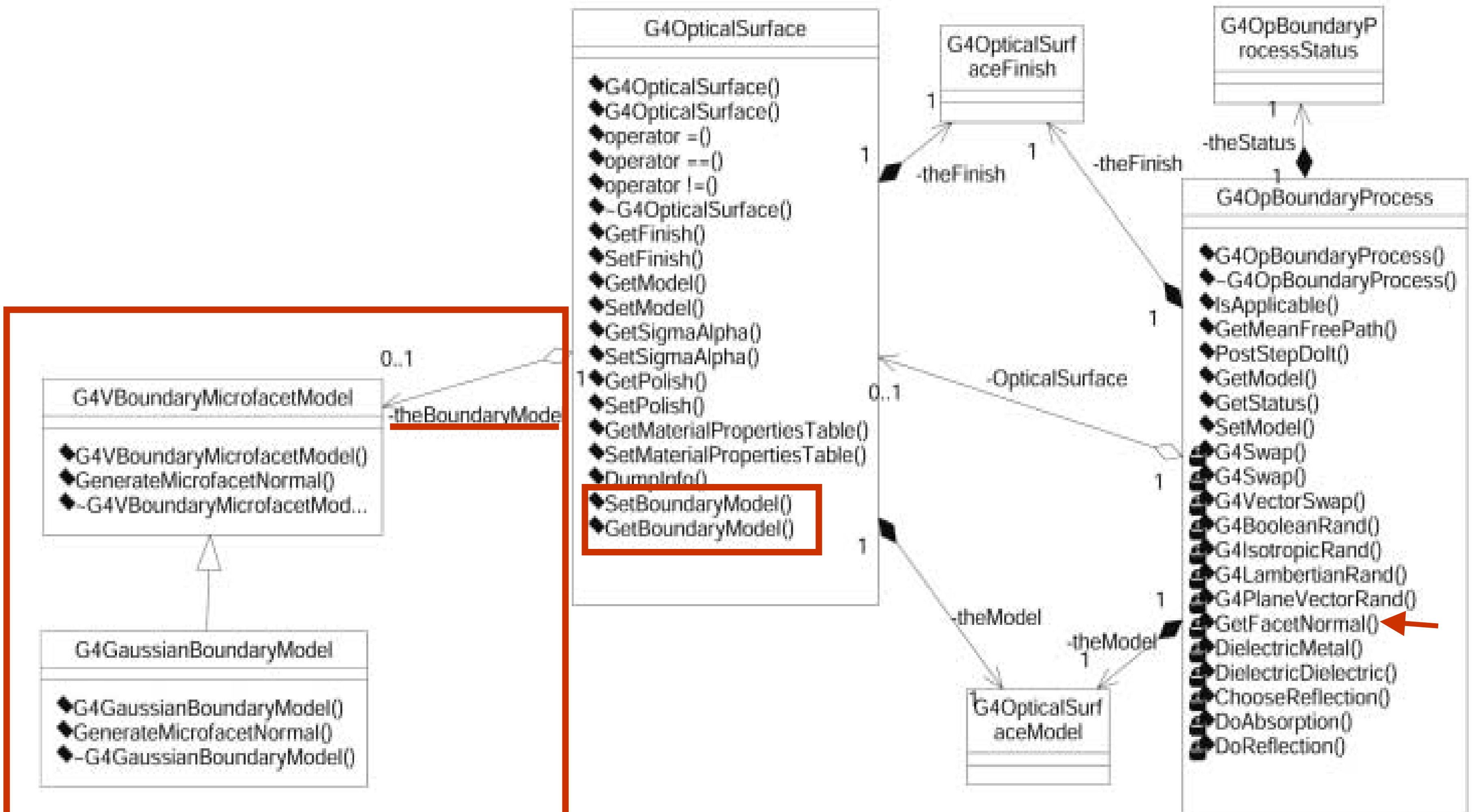
$$T(\theta_t^{'}, n_{agl}, n_{air})[g(\alpha_t, 0, \sigma_\alpha)]$$

In the unified model the direction of the transmitted photons is only parameterised by a Gaussian distribution of resolution σ_α (α is the difference between the average surface normal and the microfacet slope).

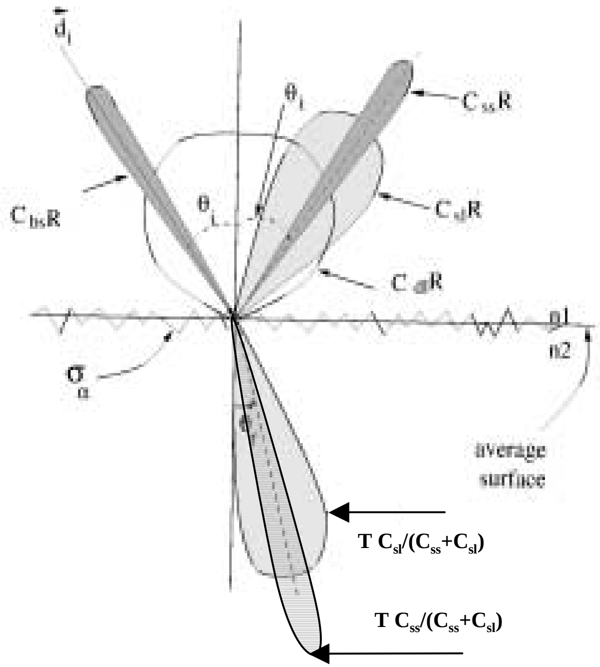
Revisiting the class G4OpBoundaryProcess

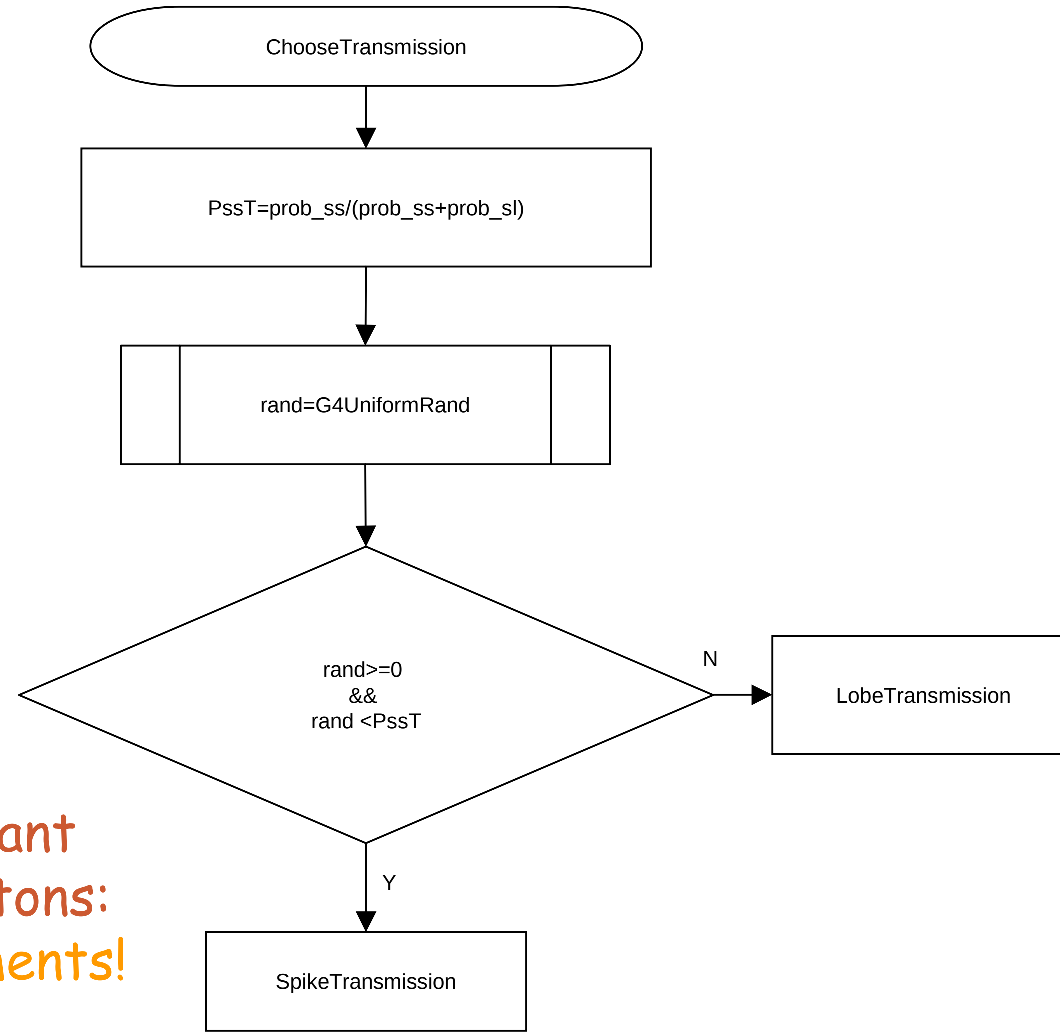


Present implementation with interface class



Extension to the unified model





Parameterisation of the radiant intensity for transmitted photons:
obtained from AFM measurements!

Outlook

- The detailed description of photon scattering in aerogel is fundamental to understand the performance of the AMS RICH detector, both in what concerns the charge and the velocity reconstruction.

- Given the characteristics of the aerogel surfaces the Unified model, in its present implementation, does not describe accurately the direction of the Cerenkov photons after leaving the radiator.

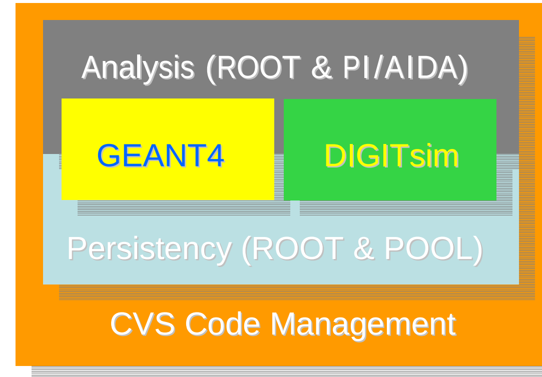
- An interface class G4VBoundaryMicrofacetModel was implemented in Geant4 enabling the choice of different surface description frameworks.

-> AFM preliminary measurements compatible with parameters fitted from data for Geant3.

-> The implementation of surface mappings as a concrete class is underway.

-> Extension to the UNIFIED model with realistic transmission is being studied.

Summary

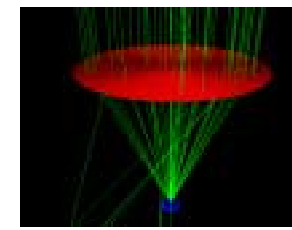


A complete simulation framework was implemented

Simulation tools were developed:

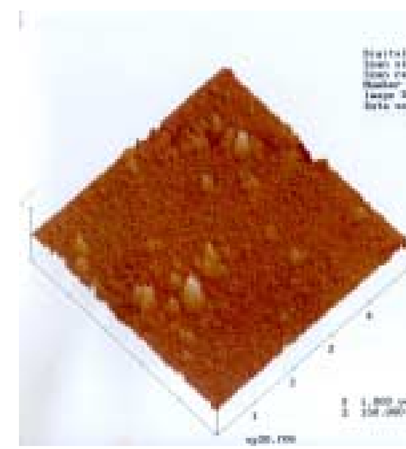
EUSO/ULTRA :

Fresnel lens description



AMS/RICH:

realistic (AFM measurements) optical surface description



“Geant4 Applications for Astroparticle Experiments”
presented at IEEE/NSS 2003 conference accepted for publication

GEANT4SpaceApplication: Class Overview

- SpaceGEANT4DataManager
  - Interface class to data histograms and analysis (ROOT or PI)
- SpaceGEANT4POOLManager
  - Interface class to POOL storage system
- SpaceGEANT4PrimaryGeneratorAction
  - Uses ESA General Particle Source Module
- SpaceGEANT4PhysicsLists
  - Standard EM physics process for photons, electrons, positrons and muons

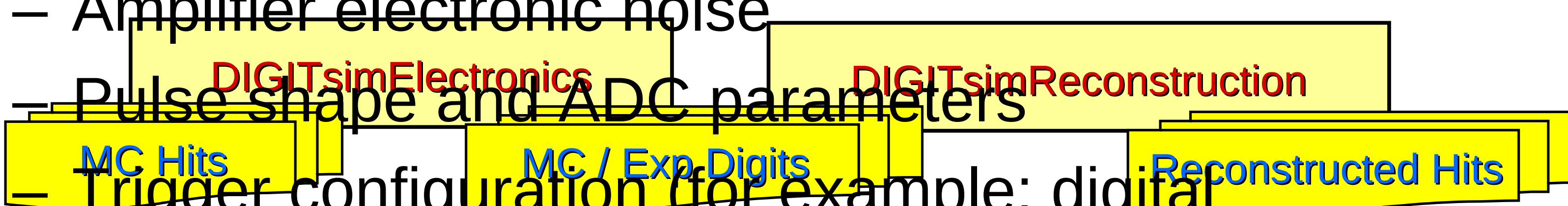
DIGITsim - Digitization Module

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

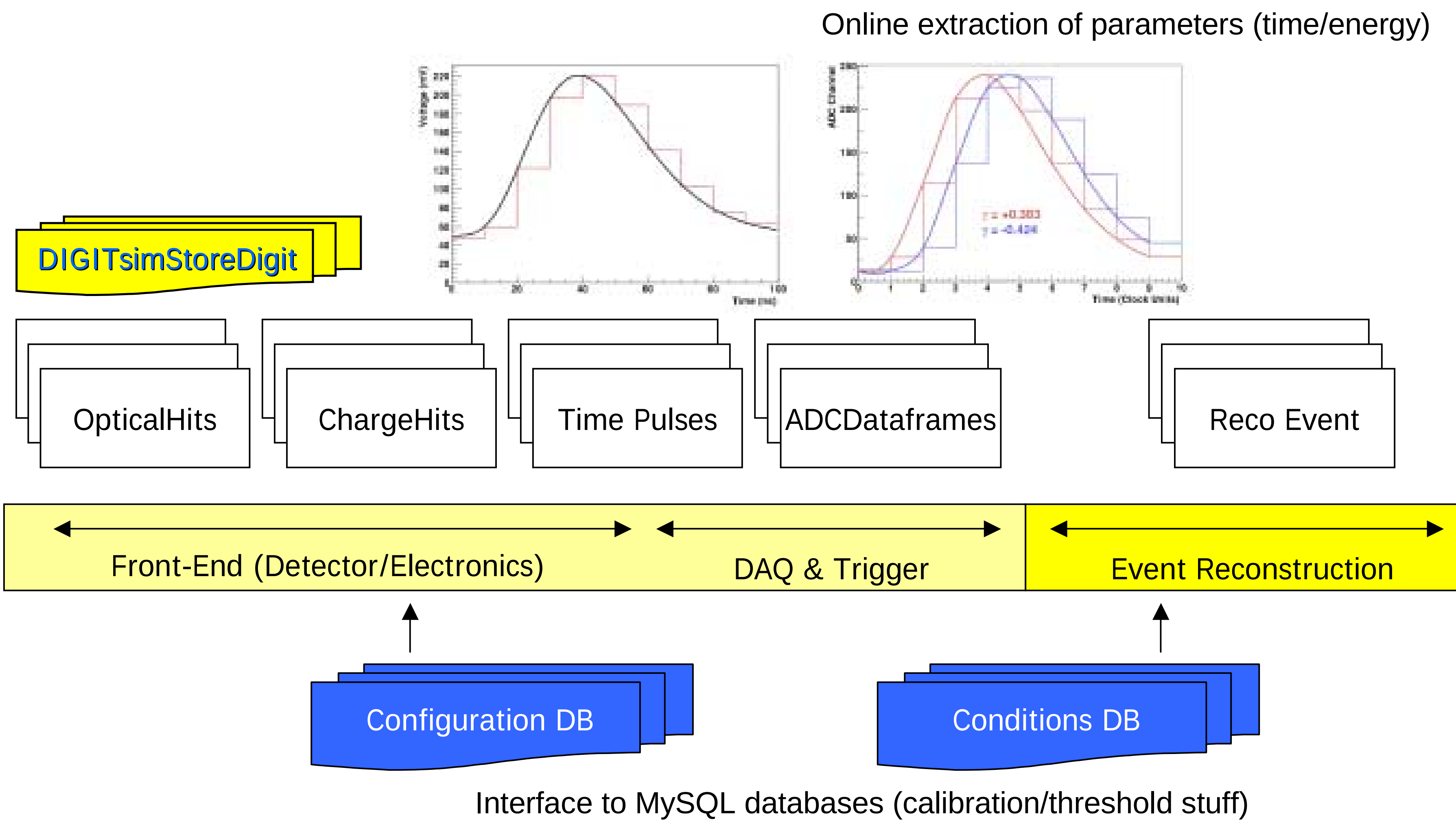
- Set of abstract interfaces for:
  - Detector charge signal simulation
  - A/D conversion
  - Trigger implementation
  - Pulse amplitude and time reconstruction

- 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 (dependence on temperature)
  - Amplifier electronic noise
  - Pulse shape and ADC parameters
  - Trigger configuration (for example: digital



DIGITsim - Digitization Module



Persistency & Analysis

- ROOT for data analysis and persistency (baseline solution)
- A persistent object **EventForTree** (stored in ROOT Tree organization) has been defined
  - Used to hold physical quantities that characterize detector response and primary particle characteristics
- Since Jan'2004 – Introduction of PI/LCG application (Linux 7.3/g++3.2)

  http://lcgapp.cern.ch/project/pi/
  - Provides AIDA native histograms and ROOT histograms using the same code
  - Histogram analysis can now be performed with different tools (ROOT/JAS3/...)

  http://lcgapp.cern.ch/project/persist/