

# Rayleigh scattering studies with the Geant4 simulation toolkit

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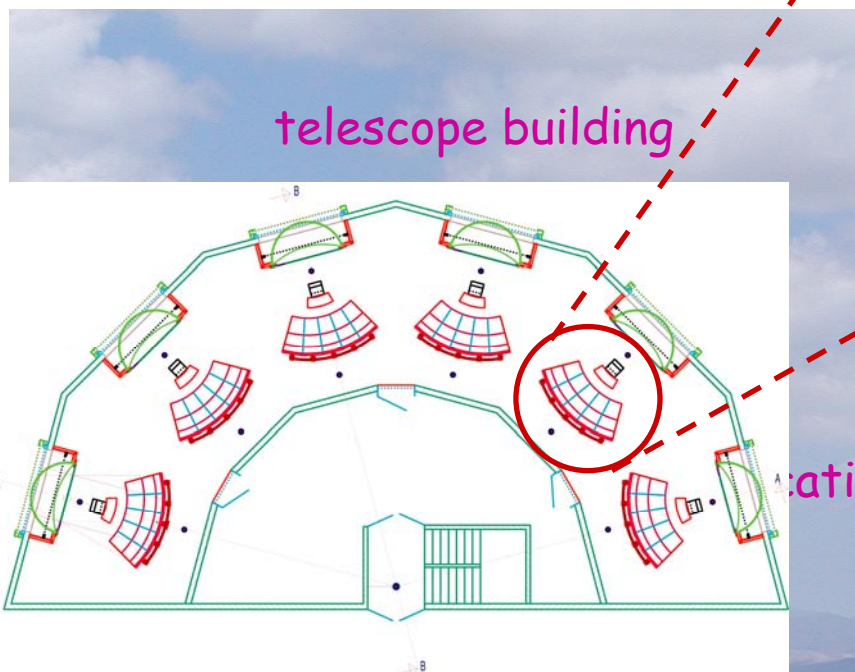
LIP - Laboratório de Instrumentação e Física Experimental de  
Partículas  
Lisboa, Portugal



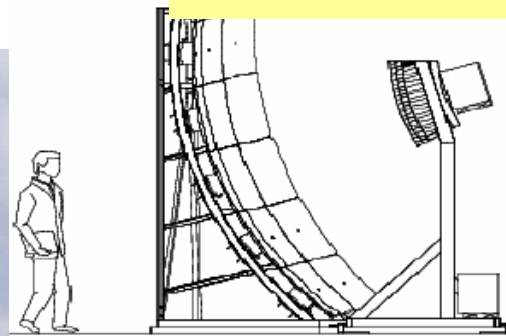
# The Southern Pierre Auger Observatory

A giant hybrid detector in Argentina

FOV = 30° x 30°



telescope building



station tower

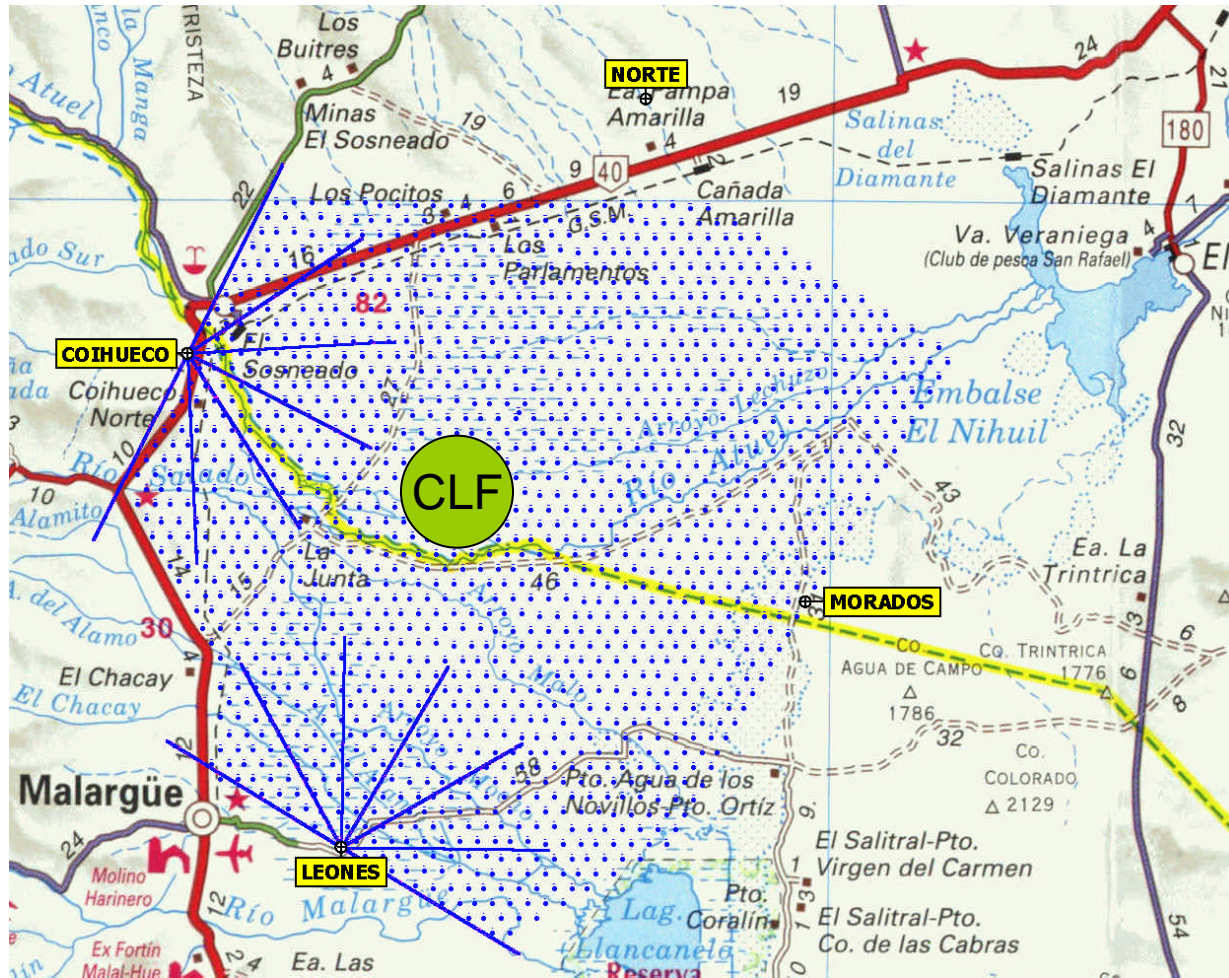
Cherenkov water tank



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# The Southern Pierre Auger Observatory

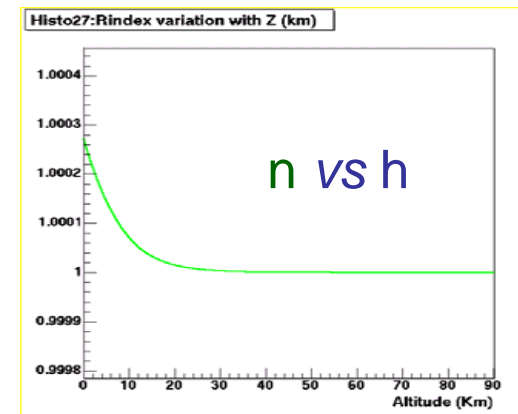
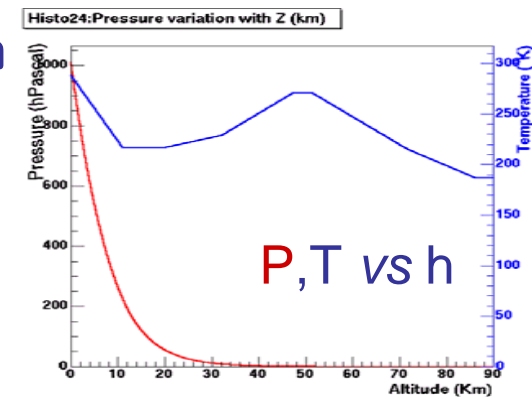




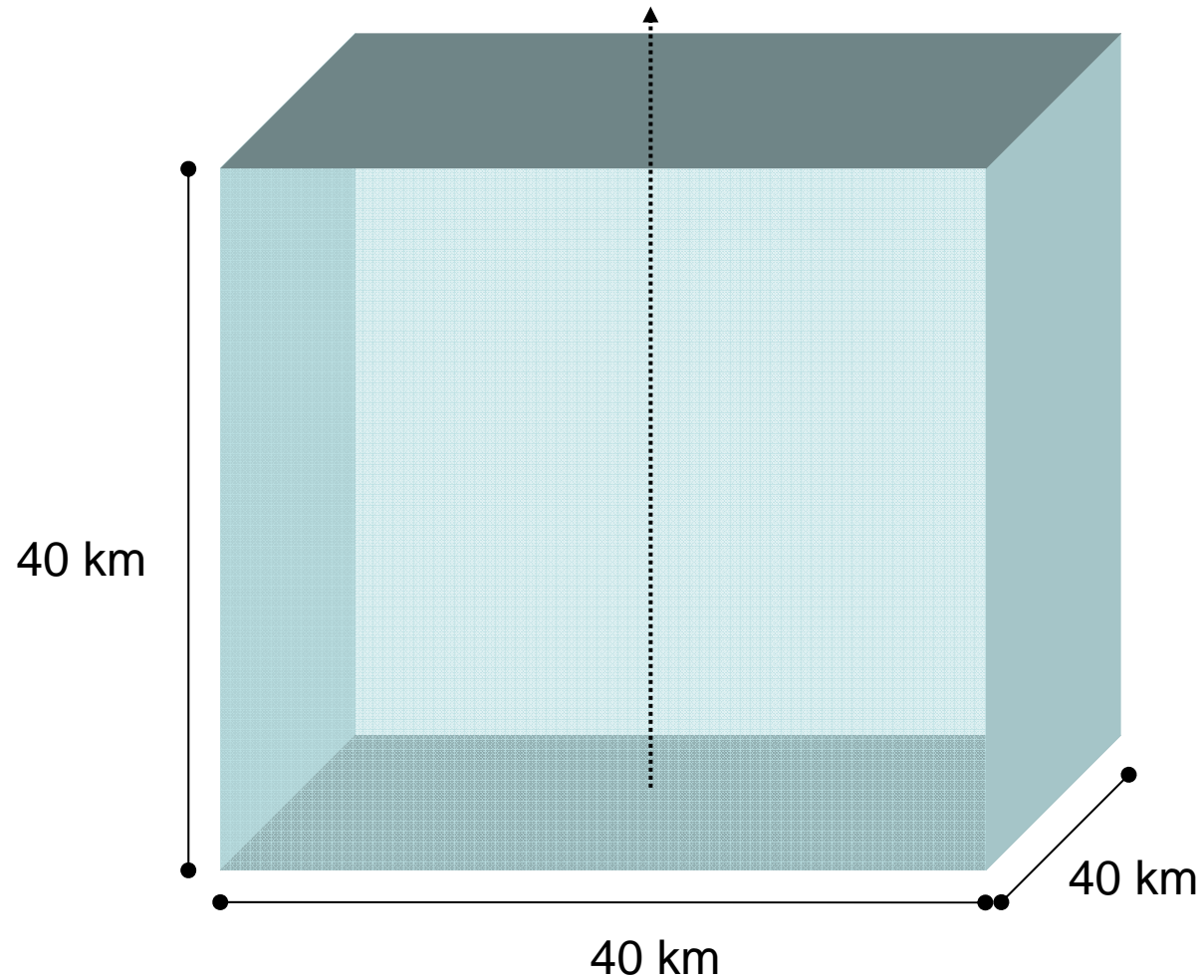
# The Atmosphere

## Atmosphere description implemented in Geant4:

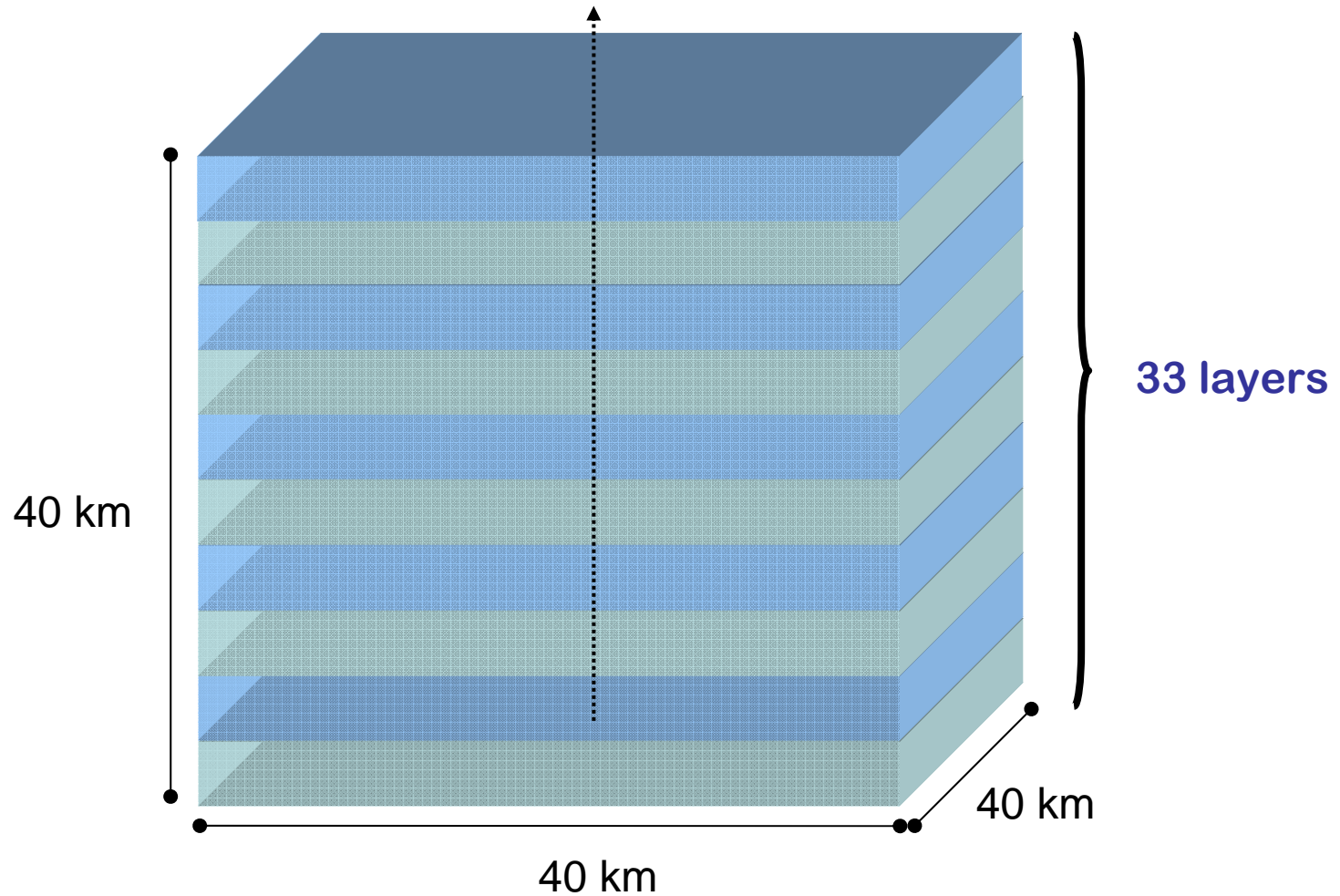
- U.S. Standard Atmosphere parameterization
- Layers with  $dh = 1200$  m
- No Earth curvature included (for now)
- $T, P, \rho, n$  are constant in each layer
- Rayleigh scattering included
- **Mie scattering not included yet**



# The Atmosphere

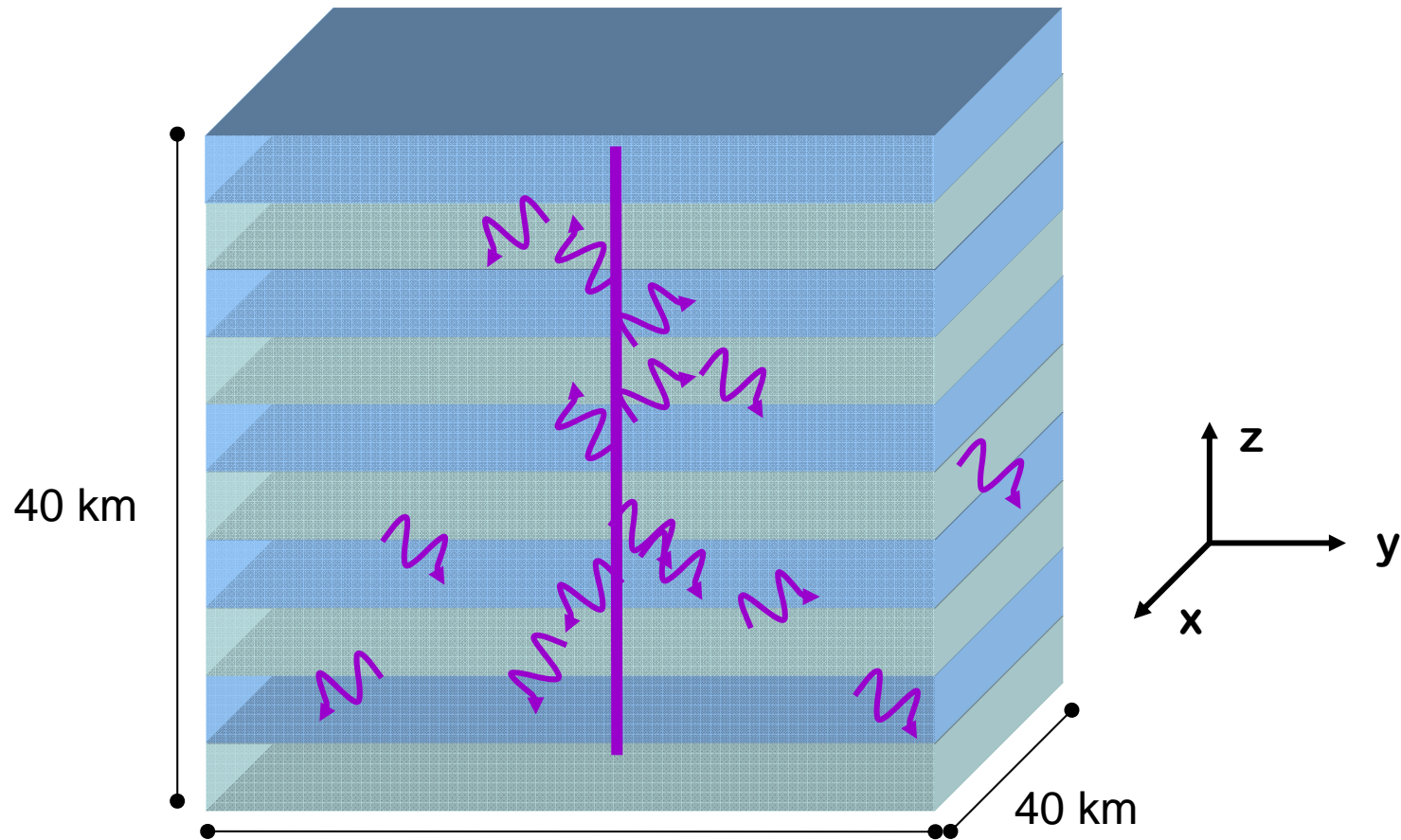


# The Atmosphere



# CLF (Central Laser Facility) simulation

The CLF ( $\lambda=355$  nm) was simulated to illustrate the Geant4 capabilities



# Simulation

## Simulation:

$10^{+6}$  generated photons  
 $\lambda=355$  nm  
Position (0,0,0)  
Direction (0,0,1)

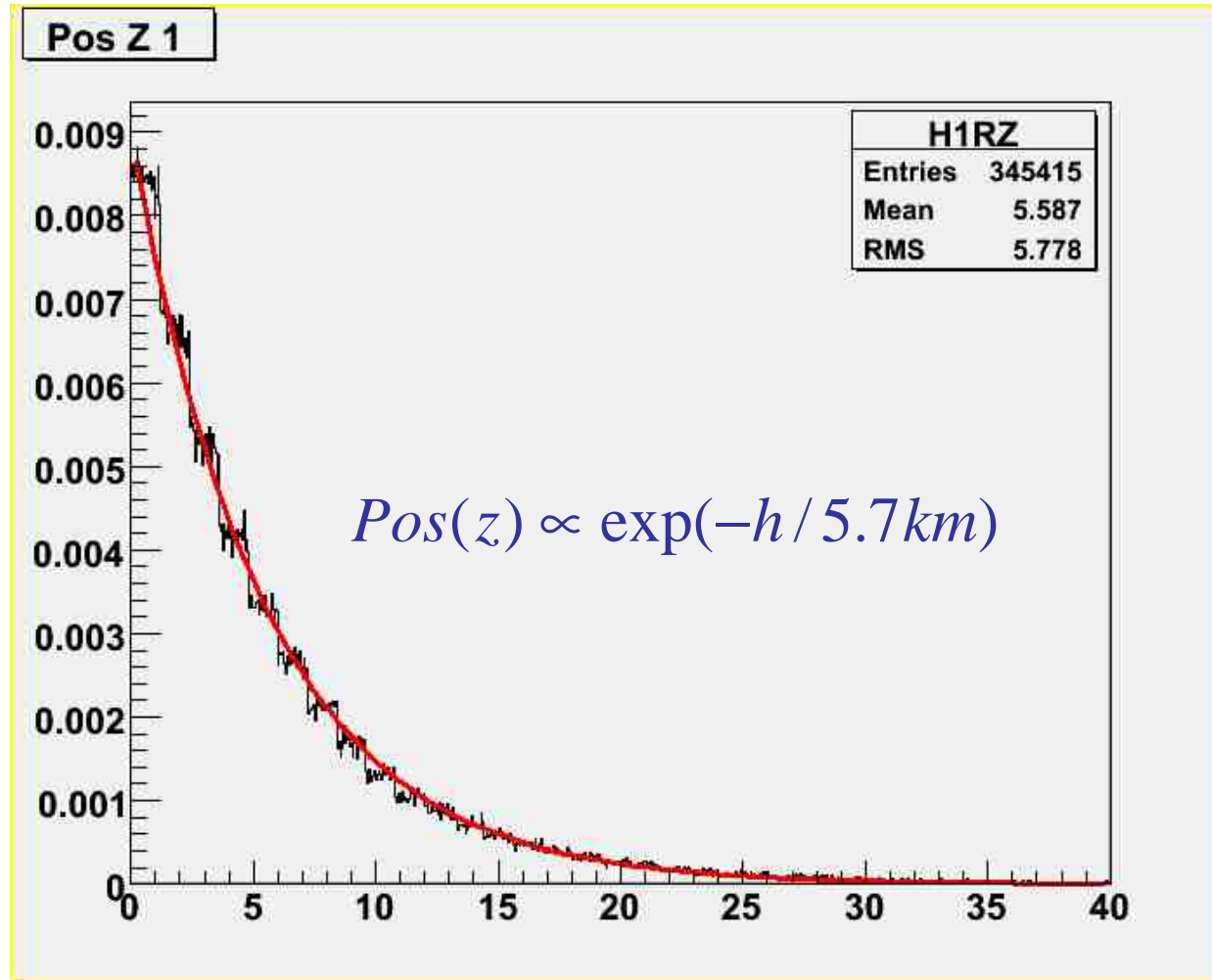
Photons are traced through the atmosphere, which is defined as a sensitive volume.

The number of scatterings are kept as well as the time, position, and outgoing direction of the photon for each interaction.

For each interaction:  
 $\text{time}(\gamma_{sc}), \text{Pos}(\gamma_{sc}), \text{dir}(\gamma_{sc})$

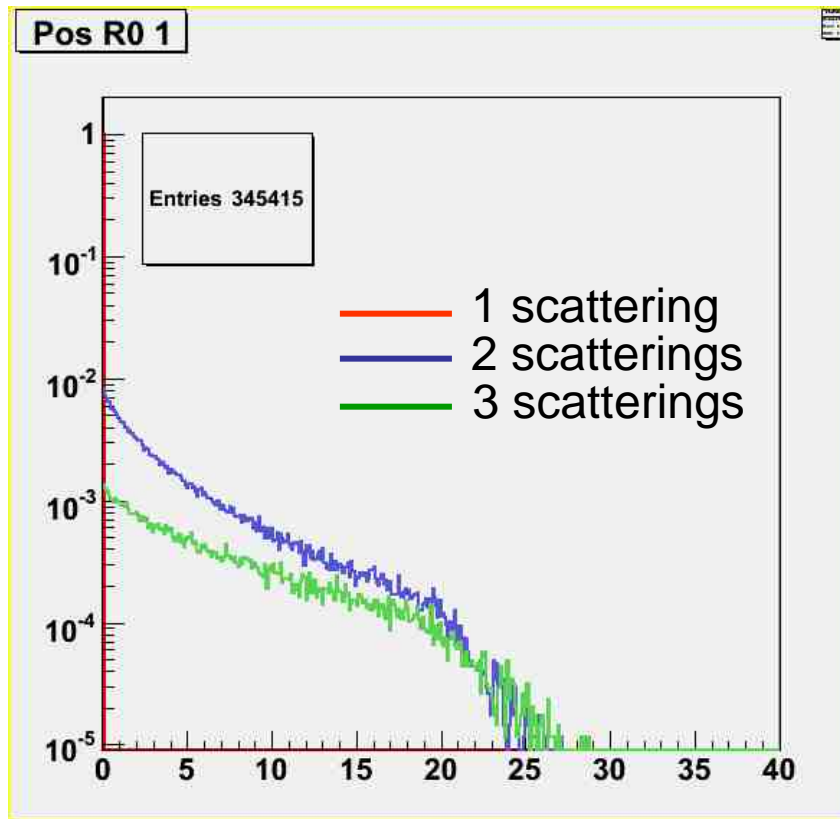


# Altitude for the 1st interaction

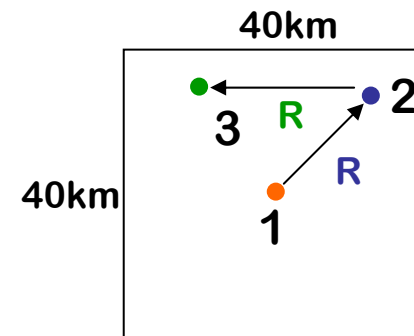


# Radial interaction point

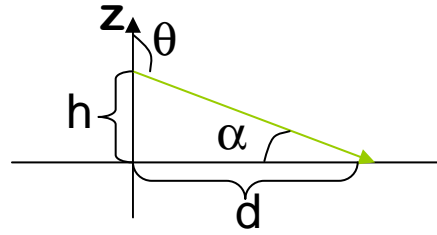
N/N1



R (km)



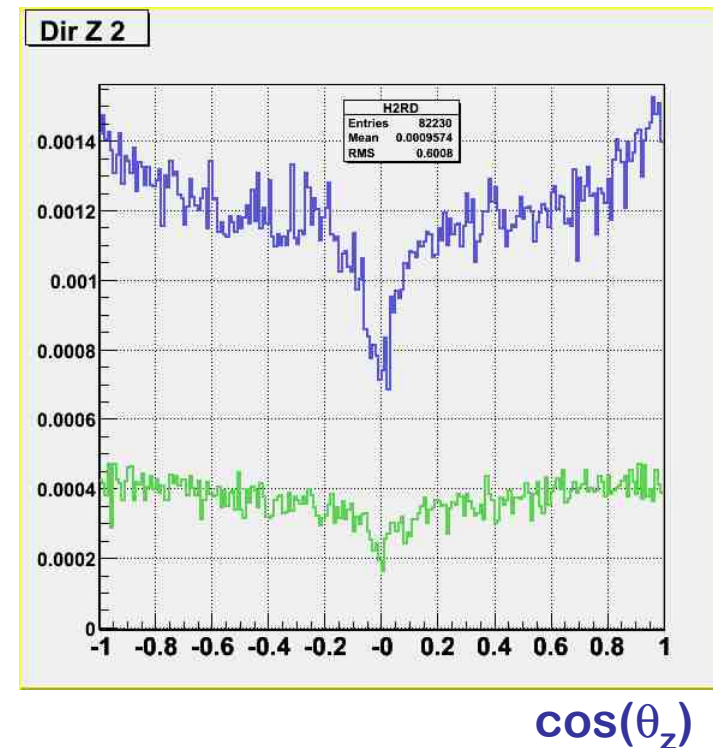
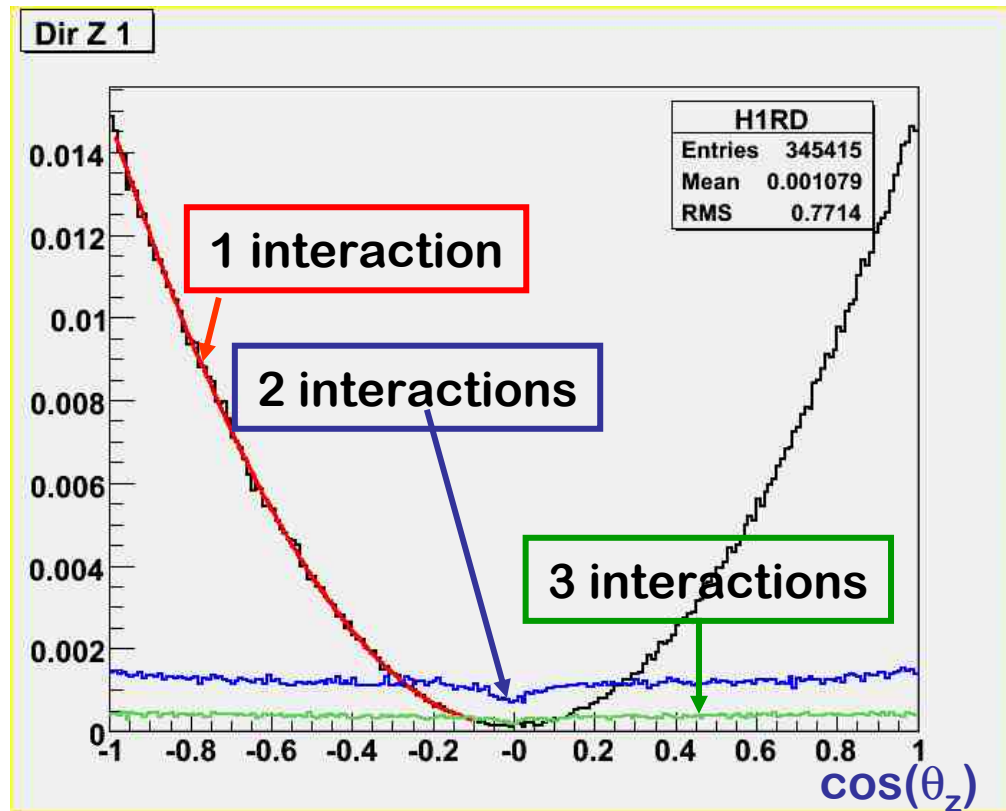
# Photons Z direction



elevation:  $\alpha = \theta - 90^\circ$

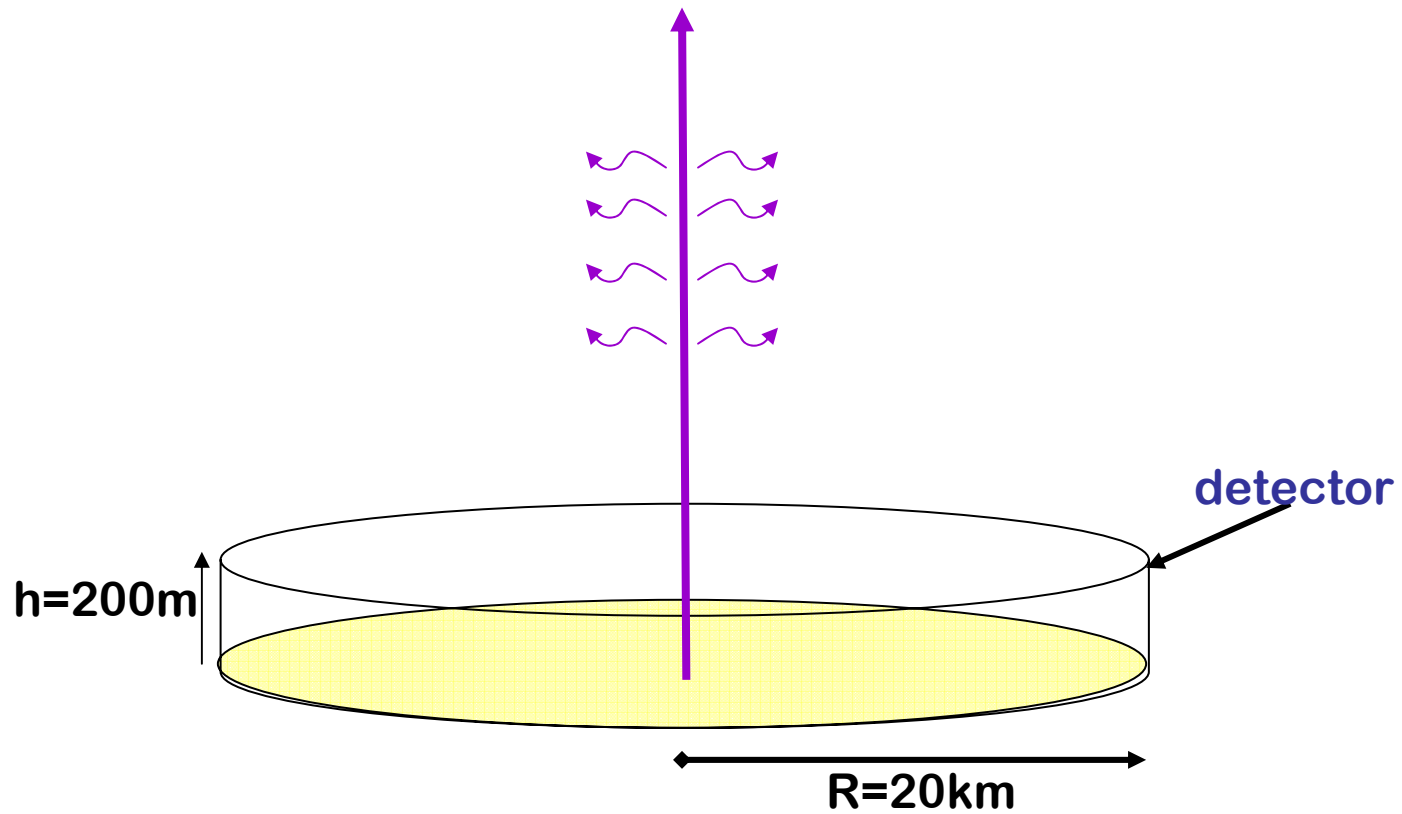
$$\cos(\theta_z) = -\frac{d}{\sqrt{h^2 + d^2}}$$

photons must have  $\cos(\theta_z) < 0$  in order to be detected



# Detecting photons

## Simulated setup



# Detecting photons

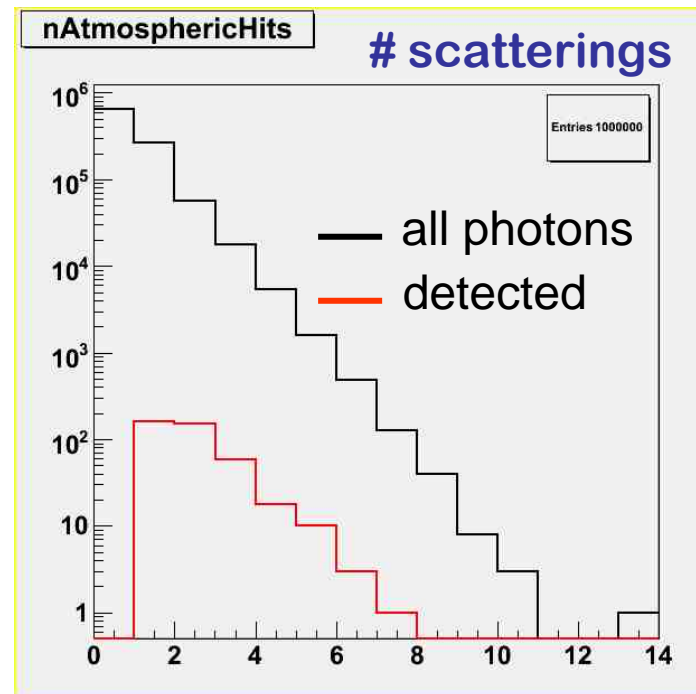
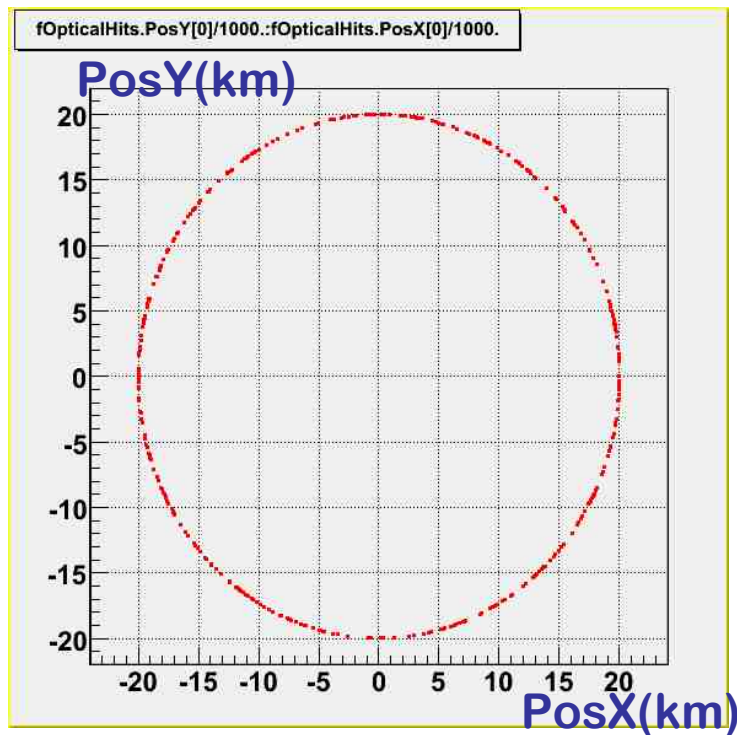
Test with:  $10^6$  generated photons  
(30 min laptop)

## 400 detected photons

photon from 1<sup>st</sup> scattering detected - 160 photons : 40%

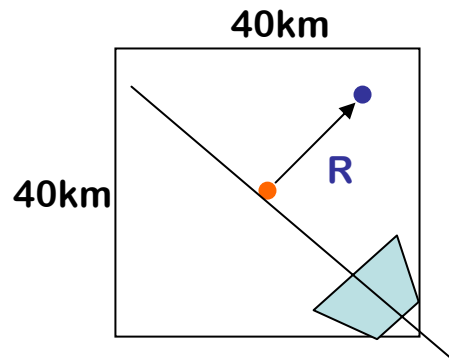
photon from N<sup>th</sup> scattering detected - 240 photons: 60%

1st scattering pointing to detector - 343 photons (183 “lost”)

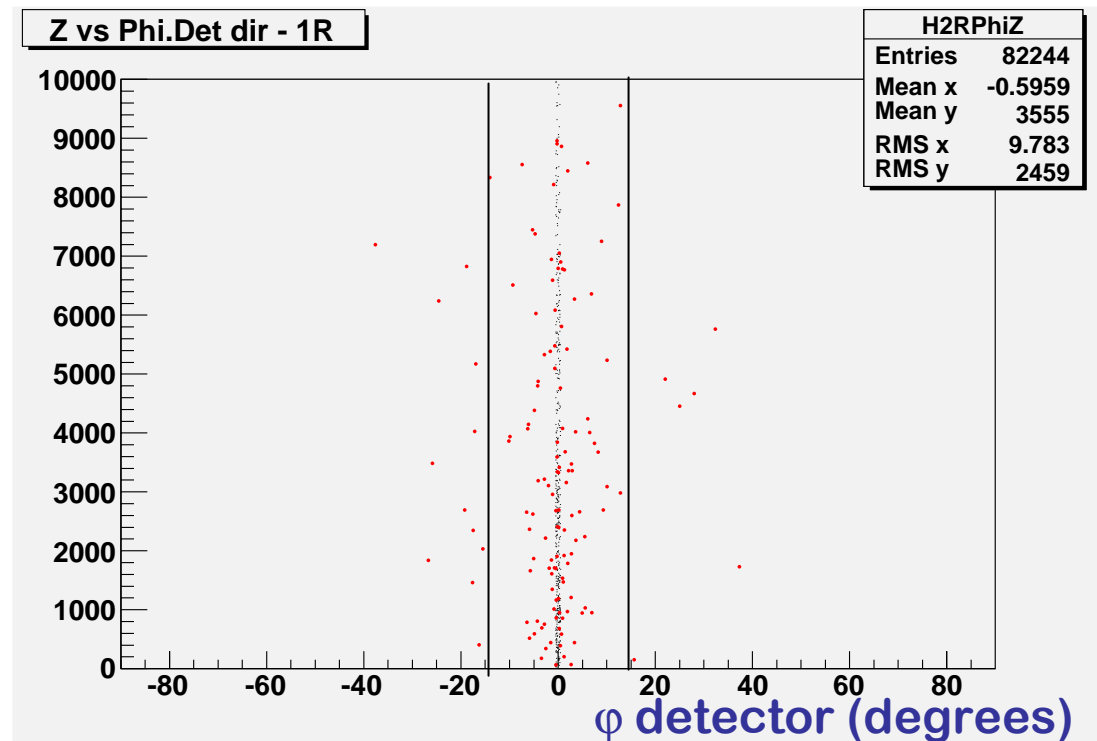


Towards a real detector:  
 2m diameter diafragm,  
 30 deg, fov

— Azimuthal fov:



— 1 scattering  
 — > 1 scattering  
 $\phi$  in detector frame , any Z



— Time information to be taken into account:

multiscattered photons are *slower* to reach the detector



# Summary

Geant 4 a can be used to perform multiscattering studies for the Auger fluorescence detectors:

Atmosphere description implemented.

Rayleigh scattering is available and Mie scattering will be implemented.

Simulation has to be optimised for photons reaching the detectors:

Event biasing based on geometry ?

Implementation of Mie Scattering as na Optical process:

(highly dependent on atmospheric conditions):

Effective model for different aerosol concentrations and wind speed?