GEANT4 DETECTOR SIMULATIONS: RADIATION INTERACTION SIMULATIONS FOR THE HIGH-ENERGY ASTROPHYSICS EXPERIMENTS EUSO AND AMS*

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The system architecture of a GEANT4 based simulation framework and its application to EUSO/ULTRA and AMS/RICH performance studies are presented. ULTRA (Ultraviolet Light Transmission and Reflection in the Atmosphere) is an experimental support activity of EUSO (Extreme Universe Space Observatory), an experiment devoted to the study of extreme energy cosmic rays and neutrinos. Relevant aspects of the ULTRA simulation, namely the description of optical processes and the simulation of Fresnel lenses using parameterisation/replication techniques are described. The RICH (Ring Imaging CHerenkov detector) of the AMS (Alpha Magnetic Spectrometer) experiment, will incorporate a dual radiator, made of a low refractive index material, aerogel, and of sodium fluoride (NaF). A more realistic description of Cherenkov photon transmission through the aerogel surface, based on Atomic Force Microscopy images, was implemented in GEANT4.

1. The simulation framework

GEANT4 [1,2] is a toolkit for the simulation of particle transport and interaction with matter, featuring namely: the description of geometries of arbitrary complexity, standard electromagnetic physics processes (photons, electrons, positrons and muons). It describes *Optical physics* processes including the generation of photons by Scintillation, Cherenkov and transition radiation effects, Rayleigh scattering and media-boundary interactions (reflection, refraction). GEANT4 is based on an Object Oriented design, allowing the implementation of flexible simulation applications and of new/upgraded physics processes. The GEANT4 based part of the simulation framework entitled "GEANT4SpaceApplication" consisted of the description of different AMS and EUSO related detector geometries, of the interface with alternative sets of primary event generators and of the radiation transport processes. As for the integration of the readout electronics, signal digitisation and event reconstruction, it was done via the DIGITsim module [3] .The object oriented technology for event data persistency and data analysis was handled through ROOT, LCG PI/AIDA and POOL.

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2. The ULTRA experiment simulation

Within the EUSO experiment [4] there is an on-going program of critical design parameter studies, implying a set of dedicated experiments. The detection of the Cherenkov light associated with the Extensive Air Showers (EAS), measuring UV light diffusion coefficients of different types of media at the surface of the Earth, is the main goal of the ULTRA project (ULTRA - UV Light Transmission and Reflection in the Atmosphere) [5]. The ULTRA detector is a hybrid system consisting of a UV detection system, the UVscope, sensitive to the diffused Cherenkov light from EAS, in coincidence an array of scintillation detectors, the ETscope. A typical configuration of the ULTRA experiment is shown in Fig.1.

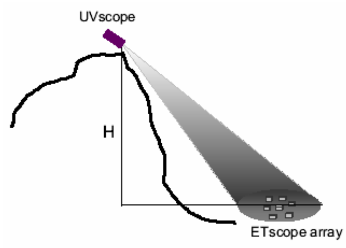

Fig.1.Typical configuration of the ULTRA experiment. The area covered by the ETscope array is seen in the UVscope field of view. The UVscope is located on top of a hill (represented by the thick line) at a height H.

2.1. *Simulation of the ULTRA ground detectors*

Each ULTRA ETscope station consists of a NUCLEAR NE 102A plastic scintillator, with dimensions 80x80cm^2 and 4cm thick, housed in a pyramidal stainless steel box. The inner walls of the box are coated with a white diffusing paint (similar to Oxide Titanium paint). The scintillation light is collected by two photomultipliers at approximately 30cm from the scintillator surface. The optical properties of the interface defined by the air and the white reflector covering the aluminum were specified within the UNIFIED model the “dielectricdielectric” TYPE and the “groundfrontpainted” FINISH were chosen. The scintillator emission spectrum, peaking at 423nm, and its light yield, about 10000 photons/MeV of deposited energy, were included in the material optical properties.

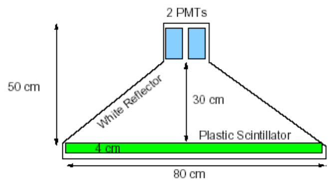

Fig.2. Schematic drawing of an ULTRA ETscope station.

2.2. *Simulation of the ULTRA UV telescope*

The Uvscope consists mainly of a Fresnel lens and one photomultiplier (PMT) located in the focal plane, enclosed in a cylindrical aluminum housing. The lens is 457 mm in diameter and is made of UV transmitting acrylic with 5.6 grooves per mm. A wide band filter (300 to 400 nm) is used to reduce the background. The external housing consists of a 1mm thick aluminum cylinder, with a length of 1030mm and a diameter of 518mm. To describe the geometry of the lens a parameterised replication of G4Cons volumes used. Each lens groove is described as a frustrum of a cone, with cross-section represented by a straight line with slope varying as a function of the radius. For this purpose the GEANT4 classes SpaceGEANT4FresnelLensParameterisation (inheriting from the G4VPVParameterisation class) and SpaceGEANT4FresnelLens were designed. A PMT with a 68mm diameter window was placed at a distance of 441.97mm from the lens, corresponding to the effective focal length at λ=400nm. The UNIFIED model was chosen to describe optical processes at material interfaces. For the “G4OpticalSurface” attributes of the Air/Aluminum interfaces, the "dielectricdielectric" TYPE and "groundfrontpainted" FINISH were used. All aluminum parts (cylinder walls and lens support) are assumed to have 5% reflectivity. Fig. 3 represents the behavior of the UVscope when hit by a beam Ultraviolet photons.

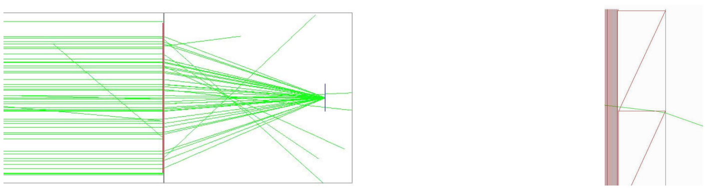

Fig. 3. Left: ultraviolet photons focused by the Fresnel lens into the PMT. Right: the photons out of focus cross the lens surface in more than one point.

3. Simulating the AMS RICH radiator

The AMS (Alpha Magnetic Spectrometer) experiment aims at characterising cosmic rays before reaching Earth’s atmosphere. Its main objectives are the search for anti-matter and dark matter and the study of the propagation and confinement of cosmic rays in the galaxy [6]. AMS had a precursor flight in June 1998 aboard the Discovery Space Shuttle, with around 100 million events recorded. The capabilities of the AMS spectrometer will be improved and extended through the inclusion both of new detectors and of a stronger magnetic field. Lip's collaboration in AMS is centred in the RICH (Ring Imaging CHerenkov) detector.

3.1. *RICH radiator simulation*

The AMS RICH will be built with a dual radiator, made of a low refractive index material, aerogel (n=1.03), and of sodium fluoride (NaF, n=1.33). It will provide an independent measurement of the velocity and charge of the cosmic rays. The RICH is a complex detector and performance assessment depends critically on the correct modeling of the light production, transmission and collection. A simplified design of the AMS RICH radiator setup, consisting of aerogel tiles supported by a plexiglas foil, was implemented in the GEANT4 based simulation framework. A variable number of 11.3 x 11.3 x 11.3cm aerogel tiles, separated by a 0.1cm gap, were placed in a vacuum tank, of corresponding variable dimension, on top of a 0.1cm thick plexiglas foil. The gaps between the aerogel tiles can be alternatively left in vacuum, filled with plexiglas or with a material opaque to the Cherenkov photons. The implemented aerogel (SiO_2+vacuum) and plexiglas ($C_5H_8O_2$) properties, refractive index, absorption length, and clarity, in the case of aerogel, correspond to the AMS RICH radiator specifications. The setup implemented is shown in for a 3x3 aerogel tile array. This setup is being used to study more realistic models describing photon scattering in the aerogel surface, and to compare them with the results of the test beam of the AMS RICH prototype. In Fig. 4, shows the Cherenkov light produced by an 80GeV electron crossing the simulated radiator setup were also the effects of Rayleigh scattering and absorption can be observed.

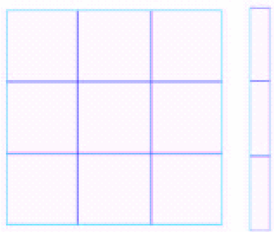

Fig.4. Implemented setup for the aerogel radiator

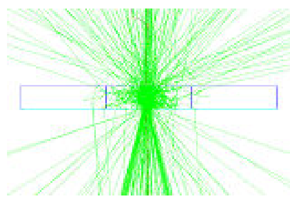

Fig.5. Cherenkov light produced by one 80GeV electron crossing the RICH radiator.

3.2. *AFM: Atomic Force Microscopy*

Previous test beam results revealed a disagreement between aerogel photon scattering in data and its description in the simulation. This effect, which cannot be described by the UNIFIED model in GEANT4, is thought to come from the interference of the photons with the aerogel surface defects. Although the UNIFIED model allows for a rather detailed description of photon reflection, this is not the case for transmitted photons, unfortunately the case of Cherenkov photons. Therefore, a more realistic description of the directional behavior of the transmitted Cherenkov photons was implemented with basis on Atomic Force Microscopy (AFM) scanning of the aerogel surface. In Fig. 6, a 2D view of the surface of an aerogel sample is shown, where surface defects can be observed. Two approaches were followed to obtain a realistic description within GEANT4 of the direction of Cherenkov photons after crossing this type of surface. In one approach, a new virtual class "G4VUserMapBoundaryModel" interfaces the surface maps to GEANT4. The other approach consisted of extending the UNIFIED model parameterisation by providing new methods to the GEANT4 class "G4OpBoundaryProcess".

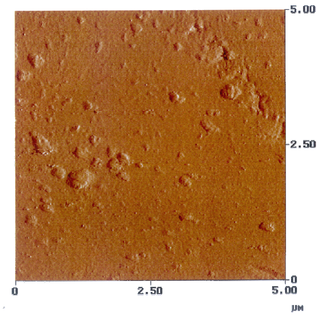

Fig. 4. Atomic Force Microscopy image of the surface of an aerogel sample.

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