Ultra-high energy neutrino simulations

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Citation for published version (APA):
Appendix C

SIRENE software implementation

SIRENE runs on a UNIX platform and consists of a library of C++ classes \(^1\) that enables the implementation of different sources of Cherenkov photons, different scattering models for the transparent medium surrounding the telescope, and various detector geometries. The program assumes that a neutrino telescope is a collection of modules housing one or more photomultiplier tubes (PMTs), which allows any neutrino detector geometry, and any configuration of the photomultiplier tubes inside these modules. Sometimes, for example in the case of ANTARES, these modules are referred to as optical modules (see Chapter 2).

Figure C.1 shows a schematic overview of the detector simulation program SIRENE. The most important C++ classes which compose the program, are shown as well as their hierarchy. These classes are described one by one in the next subsection.

C.0.1 Classes to build the geometry of a telescope

The geometry of a Cherenkov neutrino telescope is determined by the number of modules housing photomultiplier tubes, as well as their positions and their characteristics. The type of photomultiplier tubes, their position and direction within the modules of the telescope and their characteristics have also to be specified. An interface has been developed such that SIRENE may use files produced with GENDET [117] to describe the geometry of the ANTARES telescope. With this convention the reference system is such that the x-axis is directed towards the North, the y-axis towards the West and the z-axis is pointing upward. The origin of the coordinate system is located at the center of gravity of the telescope. To enable the (software) reconstruction of a neutrino telescope, the following classes are implemented.

\(^1\)The C++ programming language allows to define program-specific datatypes through the use of classes. Examples of these data types are known as objects and can contain member variables, constants, member functions, and overloaded operators defined by the programmer [116].
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**Figure C.1:** Schematic overview of the classes of the detector simulation program SIRENE. All currently implemented classes are shown. Dark grey boxes represent classes used for the geometry of the telescope. Light grey boxes represent classes used to represent the tracking of the secondary particles and the produced Cherenkov photons.

**PMT** The class PMT defines a photo-multiplier tube with its main characteristics such as its effective area, time transit (TT), time transit spread (TTS), amplitude spread and the quantum efficiency of its cathode. These parameters can be read from external cards so the program does not need to be recompiled if a different type of PMT has to be used. The default values correspond to the ANTARES PMT purchased from Hamamatsu [91].

**PMT EXTEND** The class PMT EXTEND provides the orientation and position of a photo-multiplier tube inside the module. It is derived from the classes PMT and GEOMETRY.

**ABSTRACT MODULE** The class ABSTRACT MODULE defines a virtual sphere with a given radius. This class is used to track the Cherenkov photons towards the modules of the telescope and constitutes a pure artificial object of the simulation which does not represent a physical object. The radius of the virtual sphere can be chosen such that it envelops one or more modules of the telescope. The surface of the cross section through the center of the virtual sphere is oriented...
perpendicular to the direction of the arriving Cherenkov photons. The orientation depends on the position and direction of each source of Cherenkov photons. Once the photons have been tracked towards the modules of the telescope, their position, direction, and arrival time are recorded on this optimally oriented surface. This gives each ABSTRACT MODULE a list of recorded photons inside the volume and on the surface delimited by the virtual sphere (see the definition of the class MODULE HIT). The class ABSTRACT MODULE derives its data from the classes GEOMETRY and IDENTIFIER.

**MODULE**  The class MODULE defines a module of the telescope. It consists of a container housing a set of one or more photo-multiplier tubes. The class MODULE is derived from the class ABSTRACT MODULE. The characteristics of the glass and the gel are implemented with their thickness but also their absorption length as a function of the wavelength.

**TELESCOPE**  The class TELESCOPE defines a neutrino telescope which consists of positioned virtual spheres called ABSTRACT MODULEs.

**IDENTIFIER**  The class IDENTIFIER gives a unique identifier to every module of the telescope.

**POSITION**  The class POSITION is an utility class used to define a cartesian vector position in three dimensions.

**DIRECTION**  The class DIRECTION is an utility class to define a three dimensional orientation with spherical polar coordinates.

**GEOMETRY**  The class GEOMETRY defines the position and the orientation of each object in the telescope. It is derived from the classes POSITION and DIRECTION.

**ROTATION**  The class ROTATION is an utility class to define a three dimensional rotation with spherical polar coordinates.

**C.0.2 Classes for the tracking of the particles**

An interface has been developed within the ANTARES Monte Carlo generators, producing ASCII format output of SIRENE, such that the program can use input files created with GENHEN or ANIS (and MMC). The program MonteCarloEvent can then be used to translate the output of SIRENE written in the ANTARES ASCII
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event format into the ANTARES ROOT event format for a more efficient storage and processing of the data with the trigger (TriggerEfficiency) and Reconstruction (Aart Strategy, ScanFit) codes. The entire ANTARES library for simulation codes (ANTCC) was changed in order to take the photon weights calculated by SIRENE into account. For the tracking of the secondary particles created at the neutrino interaction vertices and the Cherenkov photons they generate, the following classes are constructed.

PHOTON The class PHOTON defines the light emitted by a Cherenkov radiation source. The class PHOTON is derived from the class GEOMETRY.

SOURCE The class SOURCE represents the type of Cherenkov light source. Currently, muons and electromagnetic showers are implemented as possible sources, but SIRENE is designed such that new sources can be easily added.

EMSHOWER The class EMSHOWER defines a Bremsstrahlung initiated electromagnetic shower. All its energy is deposited over a short distance and it is considered point-like. The class EMSHOWER is derived from the classes GEOMETRY and SOURCE.

TRACK The class TRACK is a particle track with a starting time and energy. The class TRACK is derived from the class GEOMETRY.

MUON The class MUON defines a muon. A muon is characterised by a straight track losing energy and emitting Cherenkov light. Stochastic losses which produce independent electromagnetic showers are implemented. The class MUON is derived from the classes TRACK and SOURCE.

MODULE HIT The class MODULE HIT corresponds to an ABSTRACT MODULE with the list of all the photons that hit the corresponding virtual sphere. The class MODULE HIT is derived from the class GEOMETRY.

C.0.3 Classes to model the scattering of the particles

For the scattering of the Cherenkov photons inside the medium surrounding the instrumented volume of the neutrino telescope, the following classes are implemented.

MEDIUM The class MEDIUM defines the properties of the detection medium to include the effect of the medium on light propagation.
ANTARES WATER  The class ANTARES WATER represents the scattering model and water properties at the ANTARES telescope site. The class ANTARES WATER is derived from the class MEDIUM.