Litrani: a general purpose Monte-Carlo program simulating light propagation in isotropic or anisotropic media

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Abstract

Litrani is a general purpose Monte-Carlo program simulating light propagation in any type of setup describable by the shapes provided by ROOT. Each shape may be made of a different material. Dielectric constant, absorption length and diffusion length of materials may depend upon wavelength. Dielectric constant and absorption length may be anisotropic. Each face of a volume is either partially or totally in contact with a face of another volume, or covered with some wrapping having defined characteristics of absorption, reflection and diffusion. When in contact with another face of another volume, the possibility exists to have a thin slice of width *d* and index *n* between the 2 faces. The program has various sources of light: spontaneous photons, photons coming from an optical fibre, photons generated by the crossing of particles or photons generated by an electromagnetic shower. The time and wavelength spectra of emitted photons may reproduce any scintillation spectrum. As detectors, phototubes, APD, or any general type of surface or volume detectors may be specified. The aim is to follow each photon until it is absorbed or detected. Quantities to be delivered by the program are the proportion of photons detected, and the time distribution for the arrival of these, or the various ways photons may be lost.

Keywords: simulation; optics; photons; light collection; calorimeter

1. Introduction: motivations

Litrani [1] is a Monte-Carlo following optical photons. The motivation of the program was to simulate emission, collection and detection of light in the type of set-up used in high-energy experiments and in particular in CMS [2]. One of the most advanced characteristics of Litrani, its ability to handle anisotropic materials, is due to the fact that the CMS crystal is made of highly anisotropic $PbWO_4$. But the program is a quite general application, not at all tied to a single experiment. A particular effort has been made to implement into Litrani special features, like anisotropy in the index of refraction, anisotropy in the light absorption, thin slices, diffusion lengths, detailed handling of wrapping characteristics, roughness of faces, precise description of the fluorescent characteristics of the materials. Classical optics without interference is used in Litrani, except for the handling of thin slices, where interference matters.

2. Description of the program

2.1. Parameter dependency

Many physical quantities used in Litrani depend upon a variable parameter. Litrani offers the possibility to describe these variations by mean of fits or interpolation between experimentally measured values:

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2.1.1. Dependence upon wavelength:

?? Index of refraction.
?? Dielectric constant.
?? Dielectric tensor.
?? Absorption length.
?? Diffusion length.
?? Re/Im part of index of wrapping.
?? Proportion of diffusion for wrappings.
?? Quantum efficiency of photocathode.

2.1.2. Dependence upon depth:

?? Gain profile of APD.

2.1.3. Dependence upon energy:

?? Deposited energy by crossing of a particle.

2.2. Shapes

Litrani is intended to generate and follow photons inside any set-up made of different volumes or shapes of the types provided by ROOT [3], with some exceptions. The types available are:

?? *Any* shape with 8 vertices and 6 plane faces.
?? Cylinders with or without hole
?? Cones, truncated or not.

It is not possible in Litrani to simulate a set-up with lenses.

2.3. Materials

Each shape of the set-up is made of a material. A material has the following properties:

?? Index of refraction or dielectric constant or dielectric tensor.
?? Isotropic or anisotropic absorption length.
?? Isotropic diffusion length.
?? Magnetic permeability (usually 1).
?? Sensibility: the material is or is not a detector.
?? Fluorescent characteristics if the material emits light when crossed by particles. Any type of fluorescent spectrum can be reproduced.
?? d*E*/d*x* characteristics when crossed by particle.
?? Radiation length, Moliere radius, critical energy when crossed by electromagnetic shower.

A material can be optically isotropic or anisotropic, meaning that the dielectric constant may be a scalar or a symmetric tensor. You can define the index of refraction (or the diagonal components $?_a$, $?_b$, $?_c$ of the dielectric tensor *?* in the system in which it is diagonal) in 3 ways:

?? Either these elements are constant.
?? Or they depend upon wavelength where the dependency is provided by defining a fit or interpolation on experimentally measured values.
?? Or the program is instructed to obtain these elements using the Sellmeier law.

Not only the dielectric tensor may show anisotropic properties, but also the absorption length. A material can also have a diffusion length, dependent or not upon wavelength. It is observed that sometimes a material diffuses a photon in some other direction. This phenomenon is due to bubbles of impurities or to defaults in the crystal structure. The way Litrani simulates diffusion is by absorbing the photon and re-emitting it at the same place, with the same wavelength but with a new ***k*** vector, which is randomly generated on 4?. In order to take into account possible radiation damages inside a given shape, it is possible to have the absorption length multiplied by a position dependent damage factor.

2.4. Faces and contacts

Each face of a shape may be either partially or totally in contact with another face of another shape, or covered with some wrapping having defined characteristics of absorption, reflection and diffusion. Each face may have a different type of wrapping. Each face may be subdivided into sub-faces.

If a contact is declared between 2 shapes, it means that a photon may go from one to the other shape. A face may be polished or depolished. When depolished, the normal to the surface at the point hit by the photon is randomly tilted, with respect to the true normal of the surface, by the angles *?*, ??, generated randomly according to the distribution sin?d?d?, with $0 < ? < ?_M$. So $?_M$ ($0° ? ?_M < 90°$) can adjust the roughness of the grinding.

In addition, Litrani provides a simple way of simulating bevelled edges (chamfers).

When in contact with another face of another shape, the possibility exists to have a thin slice of width *d* and index *n* between the 2 faces. We mean by that a true thin slice, whose width is of the order of the wavelength, so that standard Fresnel formulae do not apply. This is necessary to simulate for instance the entrance window of an APD.

2.5. Wrappings

When a face is covered by some wrapping, there may be, between the face and the wrapping, a slice of some material, for instance air, allowing total reflection. The wrapping has a complex index of refraction. The absorption by the wrapping results then from the fact that the real part is non-zero. To this usual, Fresnel, absorption may be added at will a supplementary absorption, useful for instance in case one wants to simulate dirtiness or degradation of the wrapping.

When the photon is not absorbed, it is either reflected or diffused, according to probabilities given in the definition of the wrapping. Diffusion is calculated exactly as reflection, except that it occurs on a plane of any orientation. More exactly, the direction of reemission of the diffused photon is chosen according to the distribution cos??sin??d?d?. Notice the extra factor cos?? slightly favoring the direction normal to the surface, as generally observed. Diffusion is treated as reflection on a granular metallic surface.

2.6. Sources of light

The program has the following sources of light:

?? **Spontaneous photons** can be generated from any point, surface or volume inside any shape of the set-up. Their characteristics of wavelengths and emission times will be those specific to the material of the shape in which they are generated or be fixed at a given value by the user. Various kind of angular distributions for the emitted photons are available, including experimentally measured ones.

?? **Optical fibre**: photons coming through a fibre located on the face of a shape. Various kind of angular distributions are available, including, experimentally measured ones.

?? **Beam of particles**: it is also possible to define a beam of particles, to propagate them inside the set-up and let them generate light along their path. By default, a particle also generates Cerenkov light.

?? **Electromagnetic showers**: they are simulated using the very simplified formulae (23.28) and (23.32) proposed in the "Review of Particle physics" [4].

2.7. Detectors

Different types of detectors are available in Litrani:

?? General type of surface detectors.

?? Phototubes: variation of the quantum efficiency of the photo-cathode as a function of wavelength is taken into account.

?? General type of volume detectors.

?? Avalanche Photo-Diodes: the handling of APD goes until the generation of electrons and simulation of the electronic pulse, taking into account the gain profile as a function of depth.

?? PIN diodes are handled as APD with a gain profile always smaller or equal to 1.

3. Histograms and files

Typically, Litrani is used by doing a certain number of runs. Between each run, some parameter is varied. At the end of the job, different counters and histograms, giving for each run or for the sum of all runs the number of photons seen, the time of arrival of these, the different way photons have been lost, are available. A number of histograms giving for instance the efficiency as a function of the parameter varying from run to run, or the different ways of loosing photons as a function of this same parameter, are also available. All these counters and histograms are saved into a unique ROOT file. This ROOT file stores everything: global histograms for all runs, histograms showing the dependency as a function of the varying parameter and separate histograms for each run.

4. Coding and availability

Litrani, with its sources, is freely available from the web [1]. The web site provides a very complete description of Litrani and allows setting it up without outside help. Even the physics behind

Litrani is described in detail on the web. Litrani is an object-oriented application written in C++ and is built upon ROOT [3], which means that Litrani uses the classes of ROOT and that most classes of Litrani inherit from the classes of ROOT. ROOT is a very powerful framework for data analysis, so that the user of Litrani can analyze his results within Litrani. Binary versions are available for Windows 9x, NT or 2000 and for Linux. It should be quite easy to produce versions for all other flavors of Unix for which ROOT is available.

5. Applications using Litrani

I personally have used Litrani for many problems concerning the CMS [2] crystals. I have also used it for the GLAST [5] experiment. Inside CMS, Litrani has also been used by Rémi Chipaux [6] and by J.P.Peigneux [7]. Having put the program on the web, other users all around the world have used it as well. Among those, ten have exchanged mails with me, helping in finding bugs and improving the program.

6. Conclusions and caveat

Monte-Carlo simulating propagation of photons have not the same status as other Monte-Carlo, like GEANT, simulating propagation of particles inside detectors. This is because of casual disappointments, having mainly two origins:

Difficulty in preparing the set-up. Results of the program may be different from the measured ones because of real bad conditions:

?? Fingerprints on some surface,
?? Wrapping so tight that the slice of air disappears at some places, and so on.

The effect of such defaults may be tremendous and contradict the predictions of the program. But even in those circumstances, Litrani may be helpful. Consider for instance the case where you have to decide between many types of wrappings. The measured differences you get experimentally between two wrappings may be due to the defaults described above in preparing the set-up. Instead of simply comparing the light output of your set-up with different wrappings, it would probably be safer to *measure* precisely the reflection or diffusion characteristics of each wrapping, and to use these measured values inside Litrani to decide of the best wrapping. Or at least, to redo carefully a measurement when Litrani disagrees!

Physical phenomenon overlooked by the program. For instance in the case of the CMS crystals, it appeared that Litrani was unable to reproduce the slope of the dependency of the light output as a function of the position of the light emission along the crystal axis. When it was realized that the phenomenon of diffusion should be taken into account into Litrani, everything was fine.

A simulation program like Litrani will also be useful when results of measurements are not understood. Clarifying the situation by doing more and more measurements can take a very long time. Using Litrani, overlooked points can be found more rapidly.

Litrani has been built taking these points into account. We have not tried to sacrifice precision for speed. We have put into Litrani as many possibilities to describe fancy phenomenon as possible.

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