CERN Summer School 2017

Summer Student Project

Reanimation of the RICH Test Beam Simulation in GEANT4

Student: Kenenbek Arzymatov
Supervisor: Dmitry Popov

Meyrin, Switzerland

Theoretical intoduction

The radiation of Cerenkov light occurs when a charged particle moves through a dispersive medium faster than the speed of light in that medium. A dispersive medium is one whose index of refraction is an increasing function of photon energy. Two things happen when such a particle slows down:

1. a cone of Cerenkov photons is emitted, with the cone angle (measured with respect to the particle momentum) decreasing as the particle loses energy;
2. the momentum of the photons produced increases, while the number of photons produced decreases.

When the particle velocity drops below the local speed of light, photons are no longer emitted. At that point, the Cerenkov cone collapses to zero.

In order to simulate Cerenkov radiation the number of photons per track length must be calculated.

In order to simulate Cerenkov radiation the number of photons per track length must be calculated. The formulae used for this calculation can be found below and in [1,2]. Let n be the refractive index of the dielectric material acting as a radiator. Here $n=c/c_1$ where c_1 is the group velocity of light in the material, hence $1 \leq n$. In a dispersive material n is an increasing function of the photon energy $\epsilon \left(dn/d\epsilon \geq 0 \right)$. A particle traveling with speed $\beta = v/c$ will emit photons at an angle θ with respect to its direction, where i θ s given by:

$$\cos(\theta) = \frac{1}{\beta \cdot n}$$

From this follows the limitation for the momentum of the emitted photons:

$$n(\epsilon_{min}) = \frac{1}{\beta}$$

Photons emitted with an energy beyond a certain value are immediately re-absorbed by the material; this is the window of transparency of the radiator. As a consequence, all photons are contained in a cone of opening angle $\cos(\theta_{max}) = 1/\beta n(\epsilon_{max})$.

The average number of photons produced is given by the relations :

$$dN = \frac{\alpha z^2}{\hbar c} \sin^2(\theta)\, d\epsilon\, dx = \frac{\alpha z^2}{\hbar c} \left(1 - \frac{1}{n^2 \beta^2}\right) d\epsilon\, dx \approx 370 z^2 \frac{photons}{eV\, cm} \left(1 - \frac{1}{n^2 \beta^2}\right) d\epsilon\, dx$$

and the number of photons generated per track length is:

$$\frac{dN}{dx} \approx 370 z^2 \int_{\epsilon_{min}}^{\epsilon_{max}} \left(1 - \frac{1}{n^2 \beta^2}\right) d\epsilon = 370 z^2 \left[\epsilon_{max} - \epsilon_{min} - \frac{1}{\beta^2} \frac{\int_{\epsilon_{min}}^{\epsilon_{max}} d\epsilon}{n^2(\epsilon)} \right]$$

The number of photons produced is calculated from a Poisson distribution with a mean of $\langle n \rangle = StepLength\, dN\, dx$. The energy distribution of the photon is then sampled from the density function:

$$f(\epsilon) = 1 - \frac{1}{\left[n^2(\epsilon)\beta^2\right]}$$

Goals of project

This test was originally developed by Sajan Easo (LHCb) ten years ago mostly for the purpose of testing the behavior of photomultipliers, but it wasn’t used in regression testing in Gauss/Geant4 famework.

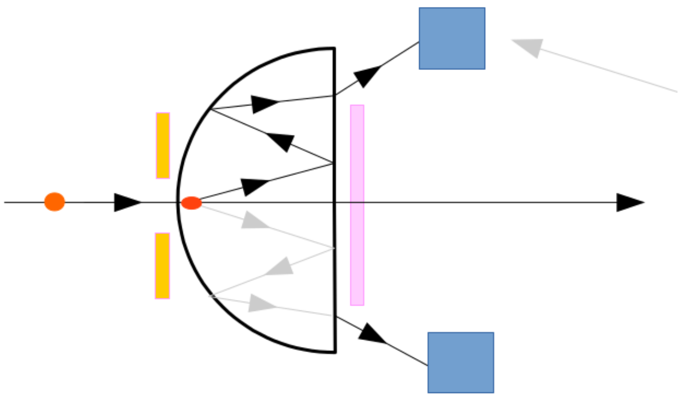
The goal of project is to revive simulation of cherenkov radiaton test by completing following steps:

- add CMake compatibility because this application was built by outdated CMT builder (configuration management tool)
- Make the application compatible with:
  - Current production version of Geant4 (v96.x)
  - Future Geant4r10
- Add the test to LHCbPR2

Including test to LHCbPR2 will allow to build everyday this application, run tests, save and compare results between different versions.

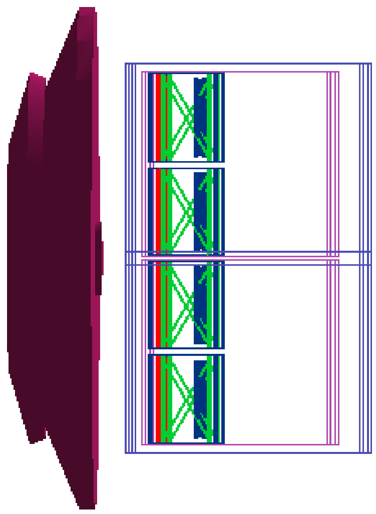
Test overview

The schematic representation is shown on the first picture. This installation is located inside box. The gun produces charged pion which goes thourogh glass material with refractive index greather than 1. And particle starts to emit photons (cherenkov photons) which after several reflections inside this glass get on 16 photomultipliers (blue square).

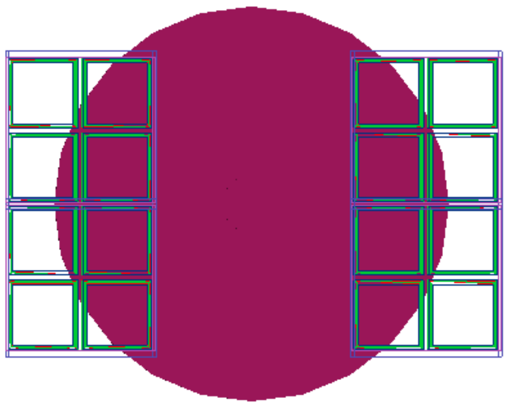


Pic. 1: Schematic representation of test

On the bottom pics you can see geometry of experiment visualized by Geant4.

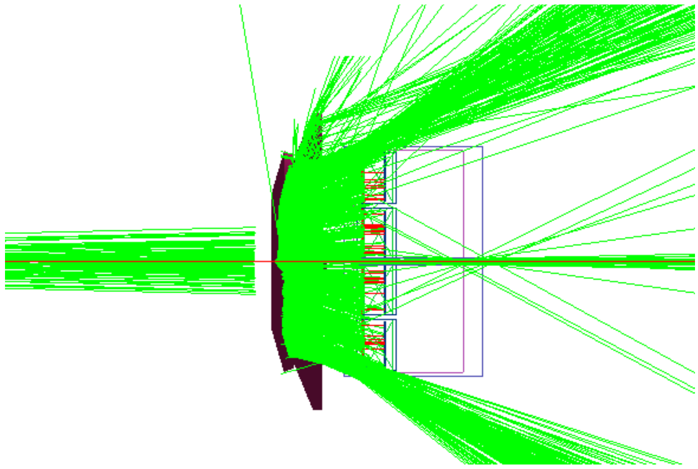


Pic. 2: The lateral view of installation



Pic. 3: The back view of installation

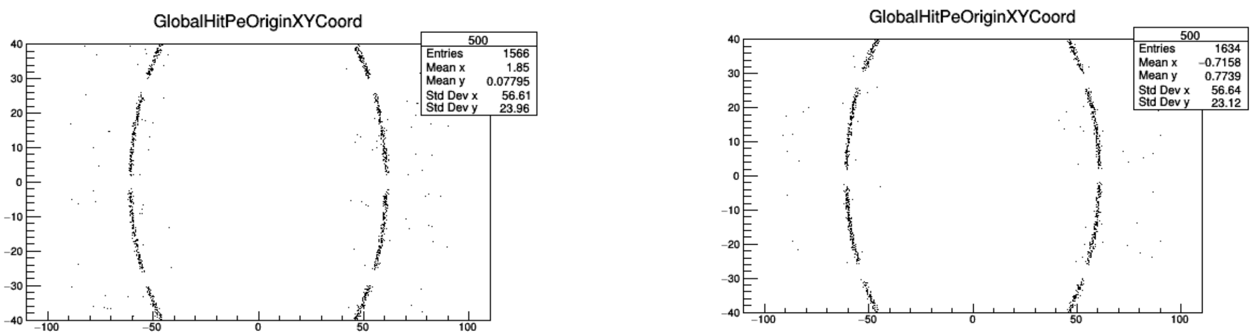
On the pic. 4 you can see the simulation of the process also visualized by means of Geant4. The red center line is the trajectory of the charged pion. Green lines are trajectories of emitted photons. Before the glass construction there is a shield which doesn’t allow secondary particles to go into installation. So inside glass pion emits cherenkov photons which are consumed thereafter by pmt.



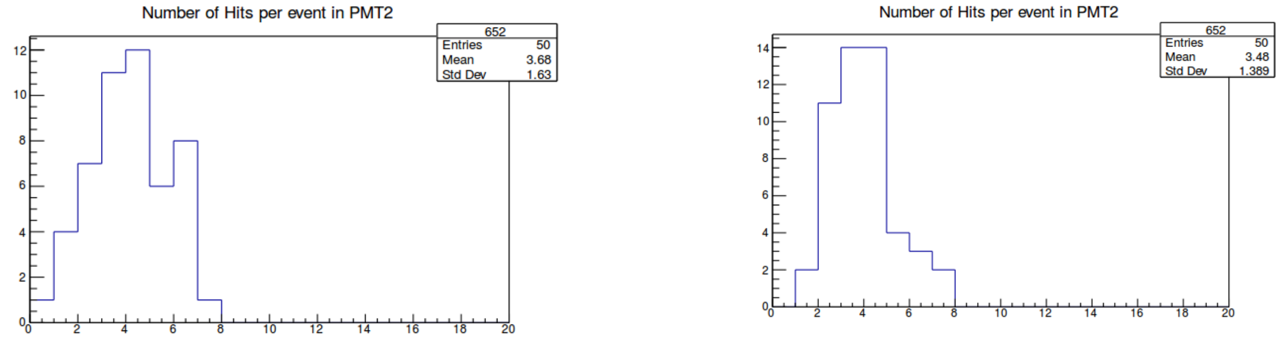
Pic. 4: The simulation of Cherenkov Radiation Test

Comprasion between G4v96.4.x and G4r10.3.x

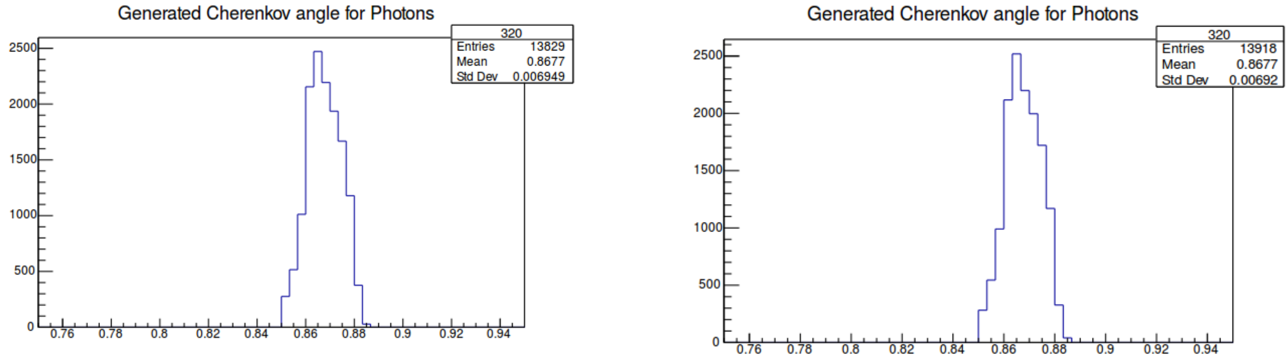
We made changes in code of the application to make it compatible with the tenth version of Geant4. To verify changes we compare the output plots produced by simulation between origanal (old) version of test and version which is compatible with Geant4 version 10.3.



Pic. 5: These plots show us XY coordinates of each cherenkov photons which reached photomultipliers.



Pic. 6: These plots show us shows histogram of number photons hits which reached pmt #2.



Pic. 7: Distribution of angles cherenkov photons were emitted at.

After visual compasion we conclude that updating of the test was correctly done.

Results

The main results of the project are:

- Reanimated project in Gitlab
  - Sim09 branch compatible with G4v96.4.x
  - Sim10 branch upgrade to G4r10.3.x
    - Builds in the nightlies in lhcb-g4r103 slot
  - Separate project available under: https://gitlab.cern.ch/karzymat/G4RichTbSimH
- The test was added to LHCb/Geant4 project
  - Resides under repackaged LHCbG4Tests
  - For more details see merge request
- Handler for the test was created in LHCbPR2