Geant4 Simulation Study of Low-Z Material Identification Using Muon Tomography

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Abstract

Traditional X-ray scanning systems for cargo use ionising radiation which can be harmful to operators and the environment and requires shielding. Fully passive muon tomography is a promising alternative or a complementary approach to X-ray scanners. Muon tomography is a non-invasive technique that uses naturally occurring cosmic-ray muons and their scattering in various materials to create images of cargo in trucks or containers without applying ionising radiation. Muons are high-energy particles that are produced when primary cosmic rays collide with the Earth’s atmosphere. These muons can penetrate through thick materials, such as concrete or metal, and are therefore useful for detecting hidden objects, including contraband. Muon tomography is expected to be used for detection of a wide range of materials, including metals, plastics, and organic materials like drugs or cigarettes, as well as weapons and explosives.

In this work we have used the GEANT4 toolkit to simulate the performance of muon tomography in identifying the contraband cigarettes hidden inside the legal low-Z materials in a truck trailer. We have used the Point of Closest Approach (PoCA) reconstruction algorithm to reconstruct the three-dimensional image of a loaded truck.

Introduction

This work is part of the ongoing SilentBorder project. Objectives of this project are to develop and construct a cosmic ray tomography (CRT) scanner for identification of hazardous and illegal goods hidden in trucks and sea containers. The developed sea container scanner system will be lightweight, compact and transportable. Be based on natural cosmic ray tomography technology that is inherently safe for people, generate full 3D images of the scanned volume, support automated customs procedures integrated to system, provides confirmation of container contents according to customs declarations.

Monte Carlo simulations of SilentBorder project includes studying the CRT detector performance, development of detailed models shipping containers and trucks and also creating models of committed shapes of container loadings with custom goods. Then we modify custom loadings adding some amount of illegal goods. Most of previous works on muon tomography were concerning using this method for detection of special nuclear materials to prevent nuclear terrorism.

Muon generators

We have applied CR4 and MUSIBO muon generators to sample cosmic-ray muons at the surface of the Earth. The CR4 software package generates muons on a horizontal plane while MUSIBO, based on a well-known Gaisser’s parameterisation of the muon spectrum and angular distribution, modified to account for muon decay and Earth surface curvature, generates muons on the surfaces of a box (cubical (parallellepiped) which is more appropriate for simulation of inclined muons. MUSIBO is a parametric generator, where the flux and kinematics of muons are based on Gaisser parameterization of the muon spectrum and angular distribution, particles sampled on surfaces of cube (parallellepiped) or flat surface. An advantage of such a sampling of muons on cube is the better coverage of highly inclined muons. As particular interest of SilentBorder project is scanning of sea containers and trucks the advantage of MUSIBO generator is obvious due to better sampling of inclined muons.

Geant4 model of sea container and cargo material composition

Besides modeling muon detectors, creating Geant4 models of shipping container and cargo loaded into shipping containers is an important part of the simulation chain. The shipping (sea) container is a standard-sized rectangular box used to transport goods by ship, train, or truck. As a source of data for cargo contents and average densities of cargo shipments one can use a PIERS (Port Import/Export Reporting Service) United States import data set. It can be used to understand containerized cargo traffic and cargo material composition. According to research [1] the mean cargo density is just under 0.2 g/cm³. In order to evaluate sensitivity of CRT to realistic scenario’s of cargo materials we create 3D models using Blender and FreeCAD tools. For testing Geant4 models of sea container and cargo materials we use simplified detector design - rectangular planes as ideal detectors. PoCA reconstruction algorithm is used to evaluate the quality of created Geant4 models.

On Fig. 1 an examples of CAD models which can be imported into Geant4 are presented. Fig. 2 shows the Geant4 model of sea container with plane detectors. Fig. 3 and 4 shows PoCa reconstructed image of empty container in 3D and 2D projections.

Simulation of truck and semi-trailer

Another real smuggling scenario taken from online resources describing cigarette smuggling hidden within wood pellets, plasterboards, or wooden boards. As an example, we looked at cigarettes (density 0.18 g/cm³) hidden within wooden boards (density 0.8 g/cm³).

Conclusion

In this simulation study using GEANT4 we have used simplified detector design in form of ideal plane detectors and simple PoCa reconstruction algorithm to investigate the potential of muon tomography for detecting hidden materials in cargo. We conclude that muon tomography is capable of producing images of low-Z objects and can become a powerful tool for detecting various types of contraband in a harmless way.

References


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