JOINT INSTITUTE FOR NUECLEAR RESEARCH

Dzhelepov Laboratory of Nuclear Problems

FINAL REPORT ON THE INTEREST PROGRAMME

Analysis and interactive visualization of neutrino event topologies registered in the OPERA experiment

Supervisor:

Dr. Sergey Dmitrievsky

Student:

Keinih Danil, Russia,

Tomsk Polytechnic University

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Content

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Abstract

In this project, different topologies of neutrino events registered in the OPERA experiment were considered. An overview of the CERN open data portal was presented, which provides access to an increasing range of data obtained as a result of CERN research. Several data sets from the OPERA experiment were analyzed using C++ code and ROOT software. In the first two tasks, 1D and 2D histograms were constructed using the ROOT software. In the third task, an interactive visualization for tau neutrino interactions was created using the HTML, CSS and Javascript.

Introduction

Neutrinos are elementary particles postulated by Pauli in the 30's as a "desperate attempt" to save the principle of energy conservation in radioactive beta decays. They have been observed 20 years later emerging from nuclear reactors and, since then, many of their physical properties have been established. There are three types, or "flavors", of neutrinos: electron neutrinos, muon neutrinos and tau neutrinos. If the rest mass of the neutrinos is different from zero, transitions among different flavors can take place when they propagate through space ("neutrino oscillations") [2].

There are many experiments on the study of neutrinos. In this project, open data of the OPERA experiment are used for visualization and analysis. OPERA was designed to conclusively prove the oscillation of muon neutrinos to tau neutrinos in appearance mode, i.e. through the observation of the appearance of tau neutrinos in a muon neutrino. Tau neutrinos are identified by the presence of the tau lepton in the final state. The experiment is unique in its capability of detecting all three neutrino flavours. Tau neutrinos are identified through their charged-current interactions where the short-lived tau lepton is produced and its decay vertex is detected. This challenging goal is achieved thanks to the Emulsion Cloud Chamber technology based on nuclear emulsion films with the unsurpassed sub-micrometric accuracy, readout by fully-automated and high-speed optical microscopes.

1. Theoretical part

1.1. Neutrino oscillations

As mentioned earlier, neutrino oscillations (fig. 1.1) are the process of transition from one type of neutrino to another, in our case, the transition of a tau neutrino to a muon neutrino with the emission of particles. The neutrino sector has the potential to create a fundamental theory that goes beyond the Standard Model.

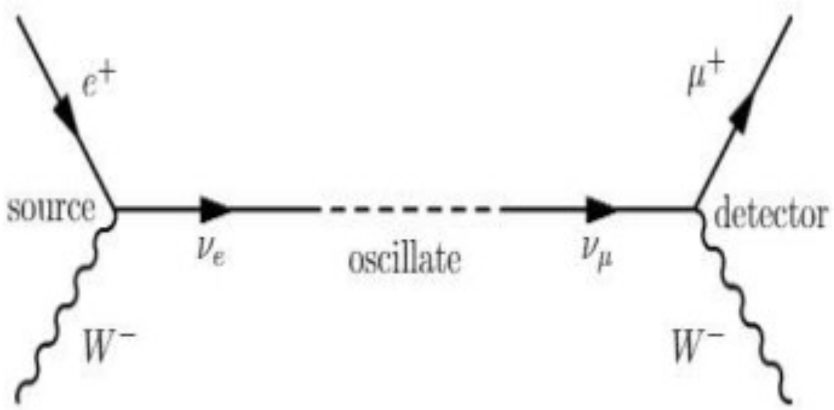


Figure 1.1 – Neutrino oscillations

Within the framework of this project, the events of tau neutrino oscillations into a muon neutrino were considered.

1.2. CERN Open Data Portal

The CERN Open Data portal is the access point to a growing range of data produced through the research performed at CERN. It disseminates the preserved output from various research activities and includes accompanying software and documentation needed to understand and analyse the data.

The portal adheres to established global standards in data preservation and Open Science: the products are shared under open licenses; they are issued with a Digital Object Identifier (DOI) to make them citable objects. The CERN Open Data portal hosts several thousands of records representing datasets, software, configuration files, documentation and related supplementary information released as open data by the LHC and other high energy physics experiments. The total amount of released data represents more than 1400 Terabytes. The data assets themselves are stored on the CERN EOS Open Storage system. The CERN Open Data portal relies heavily on the EOS distributed storage system regarding its backend data storage needs [2].

CERN Open Data Portal provides various search settings by criteria and the ability to download data from the presented experiments, for example, OPERA, CMS and others (fig. 2.1)

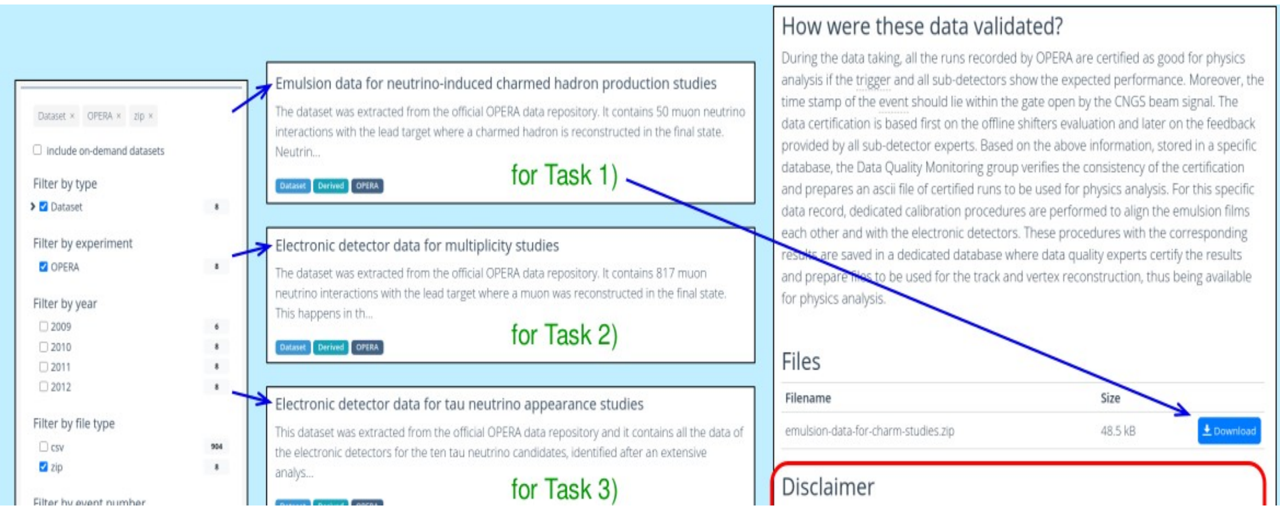


Figure 2.1 - Search menu CERN Open Data Protal

1.3. OPERA Experiment

The OPERA experiment has been designed to perform the most straightforward test of the phenomenon of neutrino oscillations. This experiment exploits the CNGS high-intensity and high-energy beam of muon neutrinos produced at the CERN SPS in Geneva pointing towards the LNGS underground laboratory at Gran Sasso, 730 km away in central Italy (fig. 3.1) [5].

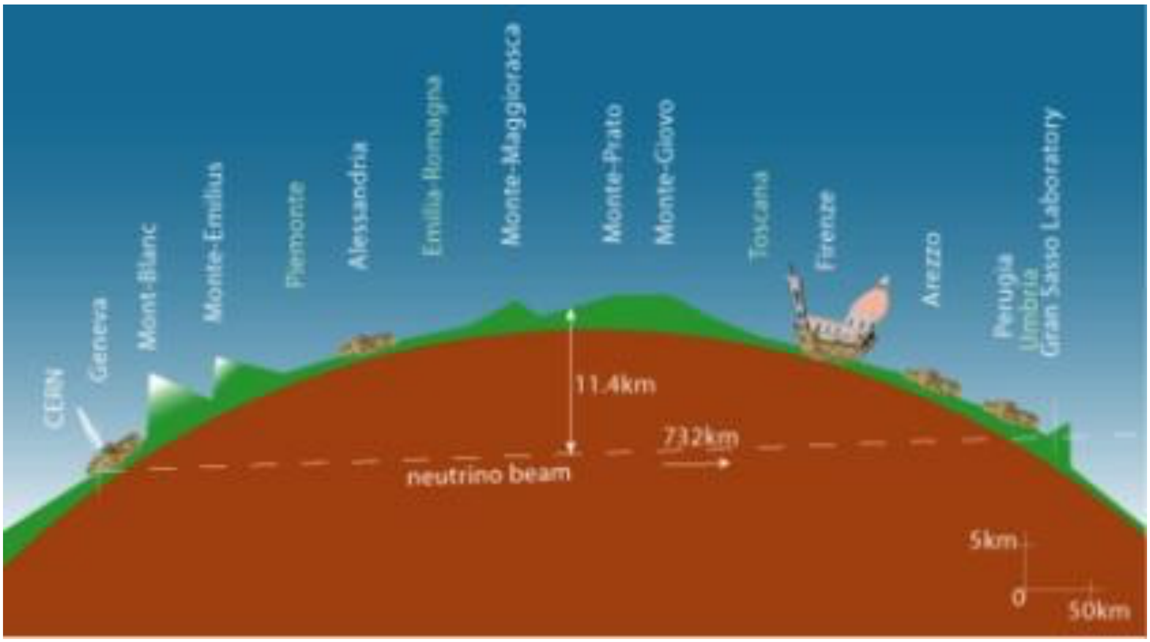


Figure 3.1 – OPERA Experiment

OPERA was located in the LNGS Hall C and aimed to detect for the first time the appearance of tau neutrinos as a result of the transmutation (oscillation) of muon neutrinos during their 3 millisecond journey from Geneva to Gran Sasso. In OPERA, tau-leptons resulting from the interaction of tau-neutrinos were observed in the "bricks" of photoemulsion films alternating with lead plates. The device contained about 150,000 such bricks with a total weight of 1300 tons and was supplemented with electronic detectors (trackers and spectrometers) and auxiliary infrastructure. Its construction has been completed in spring 2008 and the experiment was taking data up to the end of 2012. During this period, about $18*10^{19}$ of protons on target were delivered by the CERN SPS accelerator, and 16879 of neutrino events were registered in the detector's fiducial.

The data analysis is finished, in total 10 tau neutrino candidate events were found. Given the background of 2.0 ± 0.4 events expected from all the sources, the current results confirm with a significance of 6.1 sigma the hypothesis of the muon neutrino oscillations to tau neutrinos as a dominant process responsible for the deficit of atmospheric muon neutrinos and the results of the disappearance accelerator neutrino experiments (K2K, MINOS) [1].

2. Practical part

2.1. Task 1

As part of the first task, it was necessary to study the emulsion data for the neutrino-induced production of enchanted hadrons and analyze them using the calculation of the flight length of the enchanted hadron and calculate the impact parameter of the child tracks relative to the primary vertex.

The formula by which the flight length was calculated:

$$l = \sqrt{((x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2)}$$

where x_1, y_1, z_1, and x_2, y_2, z_2 are the co-ordinates of the primary vertex and secondary vertex respectively.

As a result of the completion of the C++ code, a ROOT file was obtained, which contains 2 histograms with distributions of flight lengths (fig. 4.1) and impact parameters (fig. 4.2).

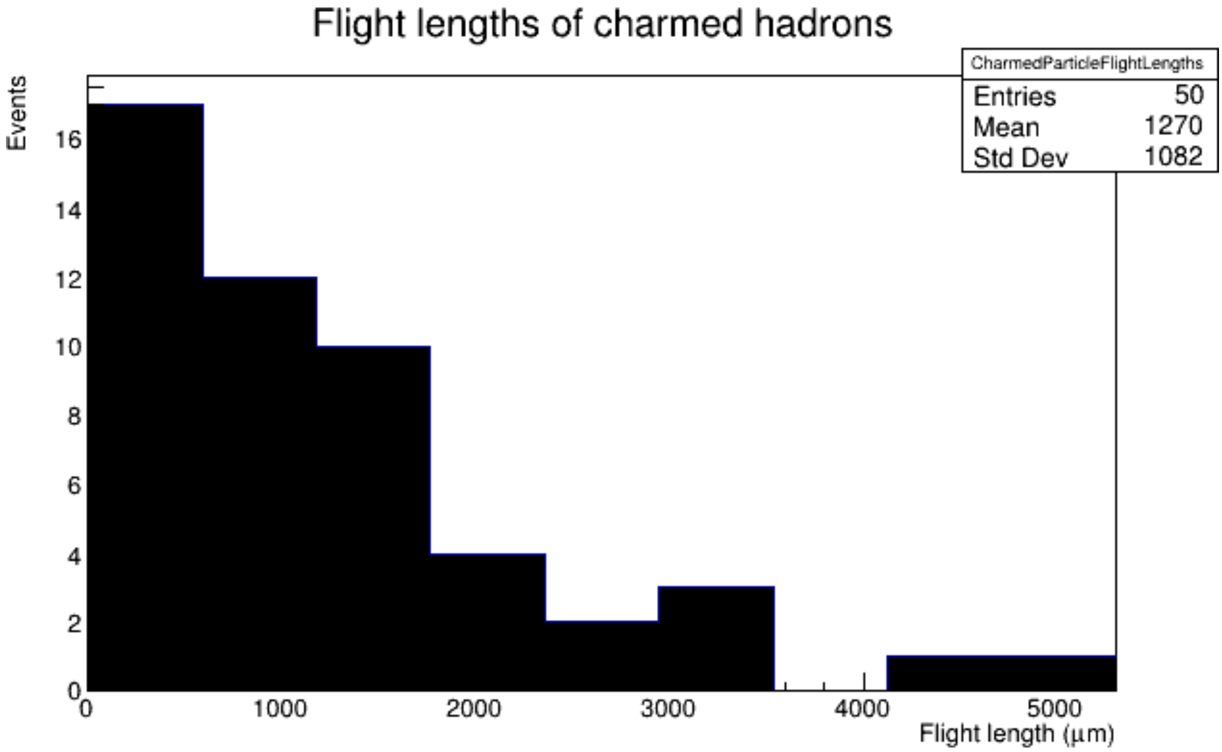


Figure 4.1 – Flight lenght

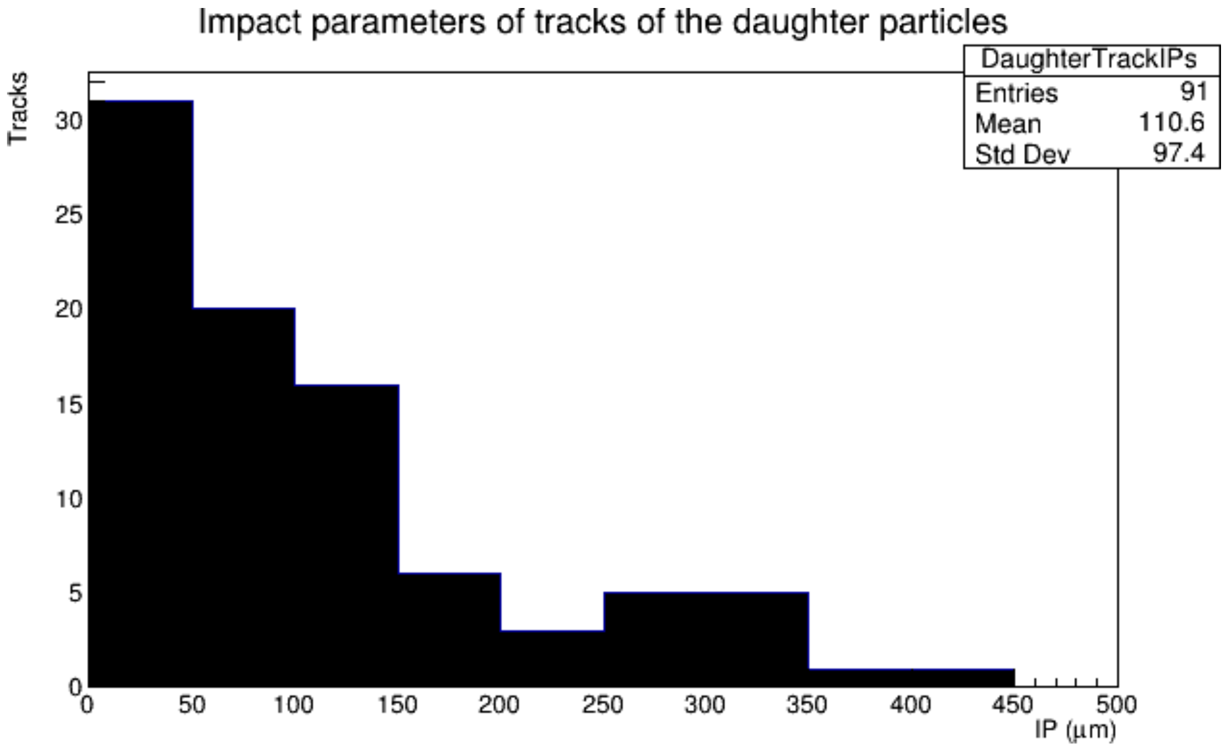


Figure 4.2 – Impact parameter

2.2. Task 2

As a second task, it was necessary: firstly, plotting the histogram for multiplicities of all produced charged particles (fig. 5.1) and, secondly, calculating the angles of the muon tracks (fig. 5.2)

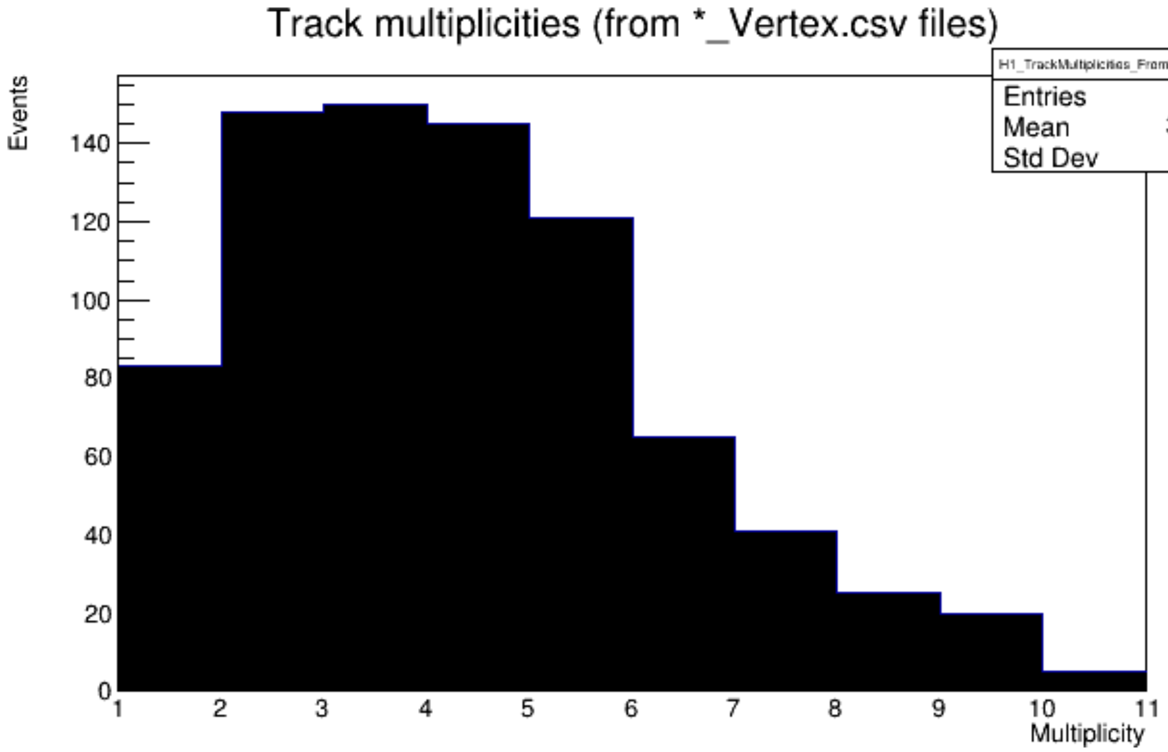


Figure 5.1 – Multiplicity distribution

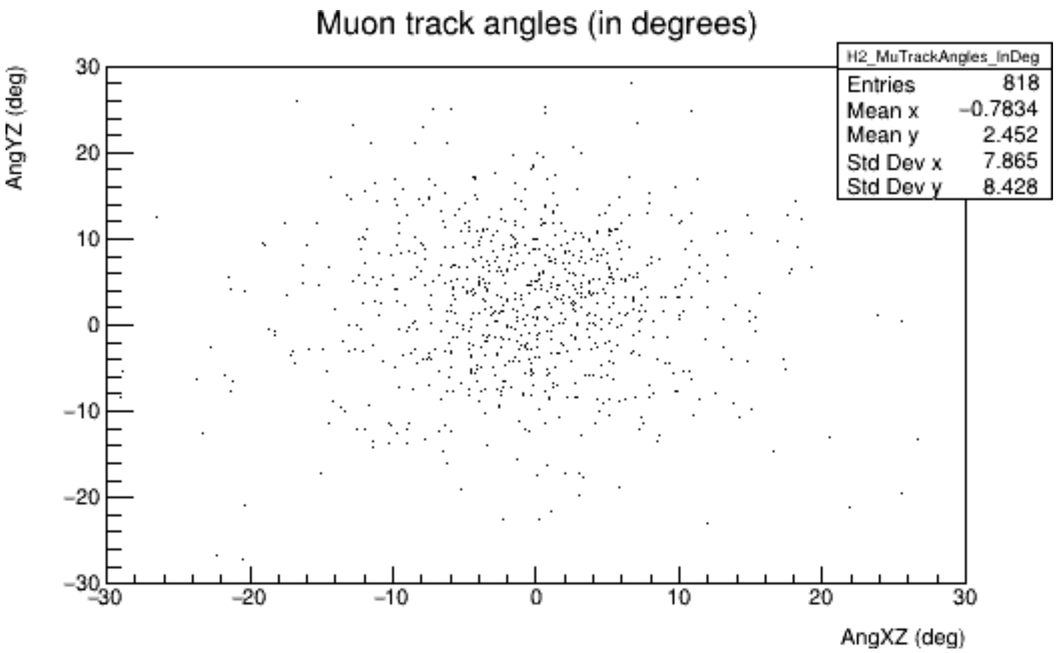
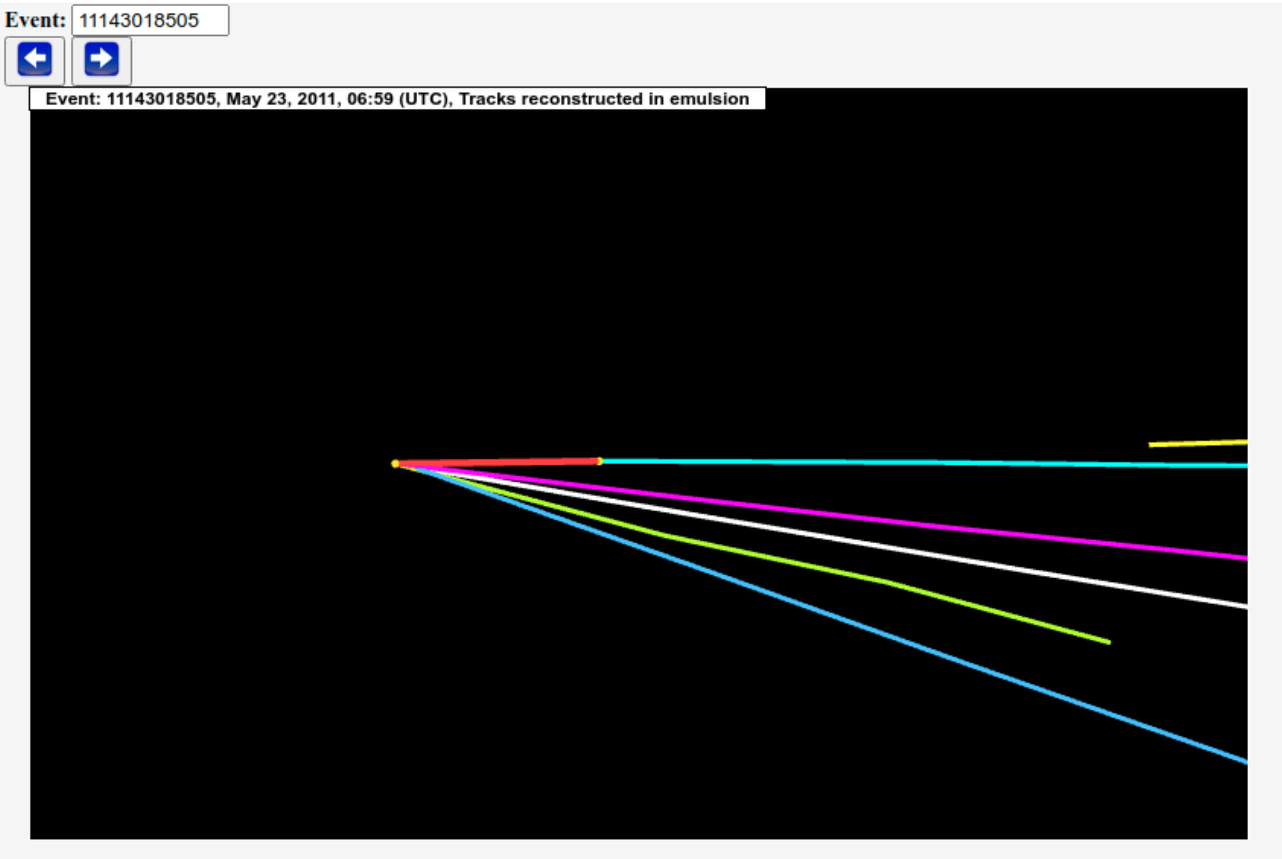


Figure 5.2 – Muon track angles

2.3. Task 3

As part of the third task, it was necessary to restore the missing parts of the program code for visualizing events. In the OPERA experiment, 5603 neutrino interactions were detected in nuclear emulsion detectors. After analyzing the received events, 10 tau candidates were identified.

After restoring the code, a browser opens a window (fig. 6.1) with simplified version of OPERA event display that a user can interact with: zoom in or out. It is also possible to rotate the image in 3D and, of course, to view events of the data set. In this window, the golden dots indicate the vertices of the interaction, and the colored lines indicate any decay products and interactions.



Fiure 6.1 – Event number 11143018505

Conclusions

During the implementation of this project, 3 tasks were completed. All tasks used the knowledge and use of libraries of the high-level C++ programming language, and the CERN ROOT analysis framework was used to build the histogram.

Data for the analysis was taken from the CERN Open Data Portal. The obtained results are in agreement with the ones published by the OPERA Collaboration.

In the course of the project, not only C++ programming skills and the use of ROOT software was obtained, but also skills in using other languages: the markup language - HTML, the programming language - Javascript and the formatting language - CSS, which were applied as part of the third task.

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