



JOINT INSTITUTE FOR NUCLEAR RESEARCH  
Dzhelepov Laboratory of Nuclear Problems

## **FINAL REPORT ON THE INTEREST PROGRAMME**

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

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## ***Abstract***

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 analyze the data. In the last two years the portal hosted a first non-LHC experiment open data issued by the OPERA Collaboration. The OPERA experiment has discovered the transmutation of muon-neutrinos into tau-neutrinos along their flight from CERN to the INFN Gran Sasso laboratory (Italy) where they were caught, by observing ten tau-neutrino candidates. While searching for tau-neutrinos, the collaboration has also deeply studied the interactions of muon and electron neutrinos, since the OPERA hybrid apparatus consisted of an emulsion/lead target with a big (~1.2 kt) mass and a micrometric resolution, complemented by electronic detectors, was unique in identifying all three types of neutrinos. The corresponding data samples, published on the Open Data Portal, were extracted from the official OPERA data repository and supplemented with detailed descriptions. All the data samples contain two separate data sets, one for the electronic detectors and the other for the emulsion films. Each data set is compressed into a .zip archive containing text .csv (comma separated values) files with information of registered neutrino events. The events can be interactively visualized on the portal using an embedded browser based event display. Any data files or the whole data sets can also be freely downloaded by users for their study and analysis. Results of the analysis (such as histograms, etc.) could be interactively displayed in the ROOT data analysis framework and/or saved to image files. Also it will be shown how to develop elements of 2D or 3D event display in a web browser using the HTML and the CSS languages as well as the JavaScript graphics libraries in order to visualize typical topologies of neutrino interaction events.

# ***Introduction***

## **About OPERA**

The Oscillation Project with Emulsion-t-Racking Apparatus (OPERA) was an instrument used in a scientific experiment for detecting tau neutrinos from muon neutrino oscillations. The experiment is a collaboration between CERN in Geneva, Switzerland, and the Laboratori Nazionali del Gran Sasso (LNGS) in Gran Sasso, Italy and uses the CERN Neutrinos to Gran Sasso (CNGS) neutrino beam.

The process started with protons from the Super Proton Synchrotron (SPS) at CERN being fired in pulses at a carbon target to produce pions and kaons. These particles decay to produce muons and neutrinos.<sup>[1]</sup>

The beam from CERN was stopped on 3 December 2012,<sup>[2]</sup> ending data taking, but the analysis of the collected data has continued.

## **Tau Neutrinos (Observations)**

In total, five tau neutrinos were detected. On 31 May 2010, OPERA researchers observed the first tau neutrino candidate event in a muon neutrino beam. On 6 June 2012, OPERA announced the observation of a second tau neutrino event. On 26 March 2013, the experiment caught for the third time a muon neutrino oscillating into a tau neutrino during travel from CERN to LNGS. The fourth one was found in 2014, and the fifth was seen in 2015.

## **Goal (Tasks)**

1. Download the OPERA emulsion dataset for the neutrino-induced charmed hadron production studies from the Open Data Portal. Develop a C++ program for analysis of the dataset. Read the positions of the primary and the secondary interaction vertices as well as the parameters of the charm decay daughter particle tracks. Calculate and save to histograms a) the flight lengths of charmed hadrons and b) the impact parameters of the daughter particle tracks with respect to the primary neutrino interaction vertices. Save the histograms to a ROOT or to an image file. Compare the results with the ones published in the corresponding OPERA paper.

2. Download the OPERA emulsion dataset for the charged hadron multiplicity studies from the Open Data Portal. Develop a C++ program for analysis of the dataset. Read the positions of the primary neutrino-lead interaction vertices as well as the parameters of the secondary charged particle tracks. Find and save to histograms a) the multiplicities of all produced charged particles and b) the angles of the muon tracks. Save the histograms to a ROOT or to an image file. Compare the results with the ones published in the corresponding OPERA paper.
3. Download the OPERA emulsion dataset for the tau neutrino appearance studies from the Open Data Portal. Develop a browser-based 3D event display to view tracks and vertices reconstructed in nuclear emulsions of the 10 tau neutrino candidate events using the three.js graphics library.

## ***Work requirements and learnings***

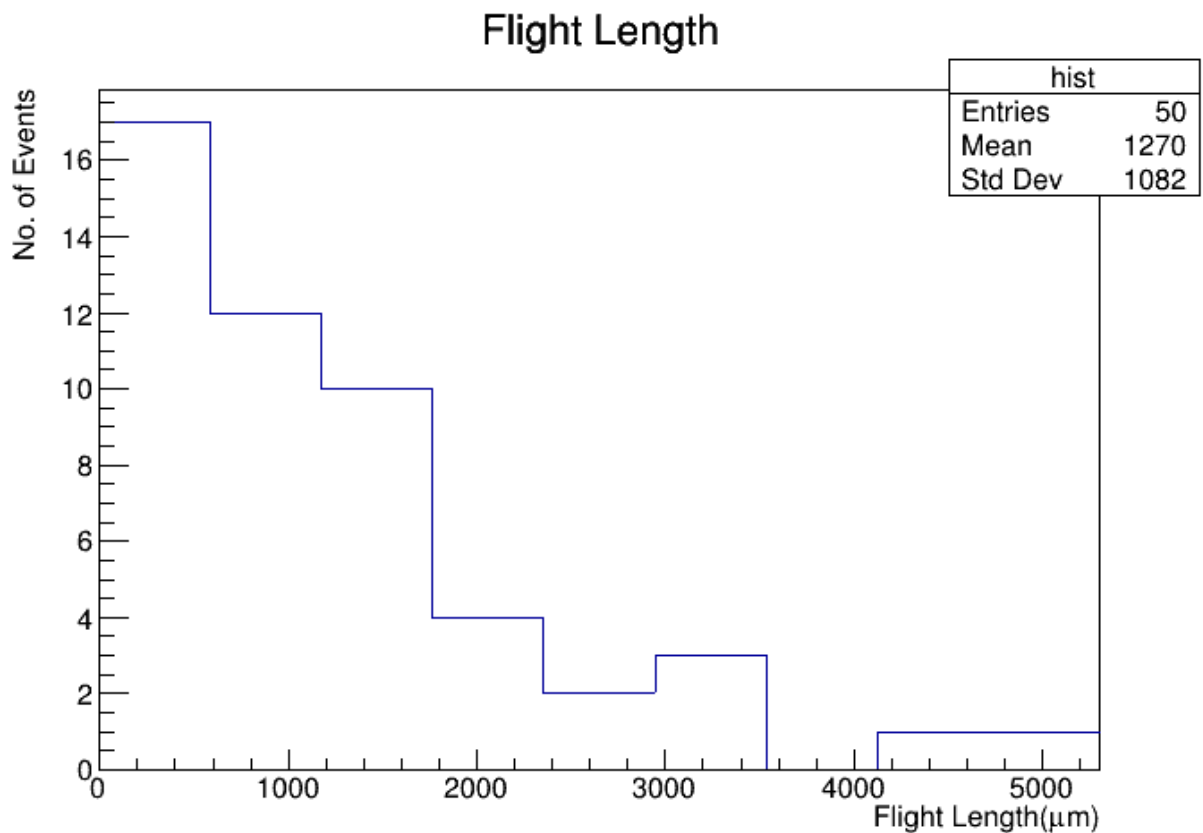
1. CERN Open Data Portal
2. CERN ROOT data analysis framework (C++)
3. Linux System

## Task 1

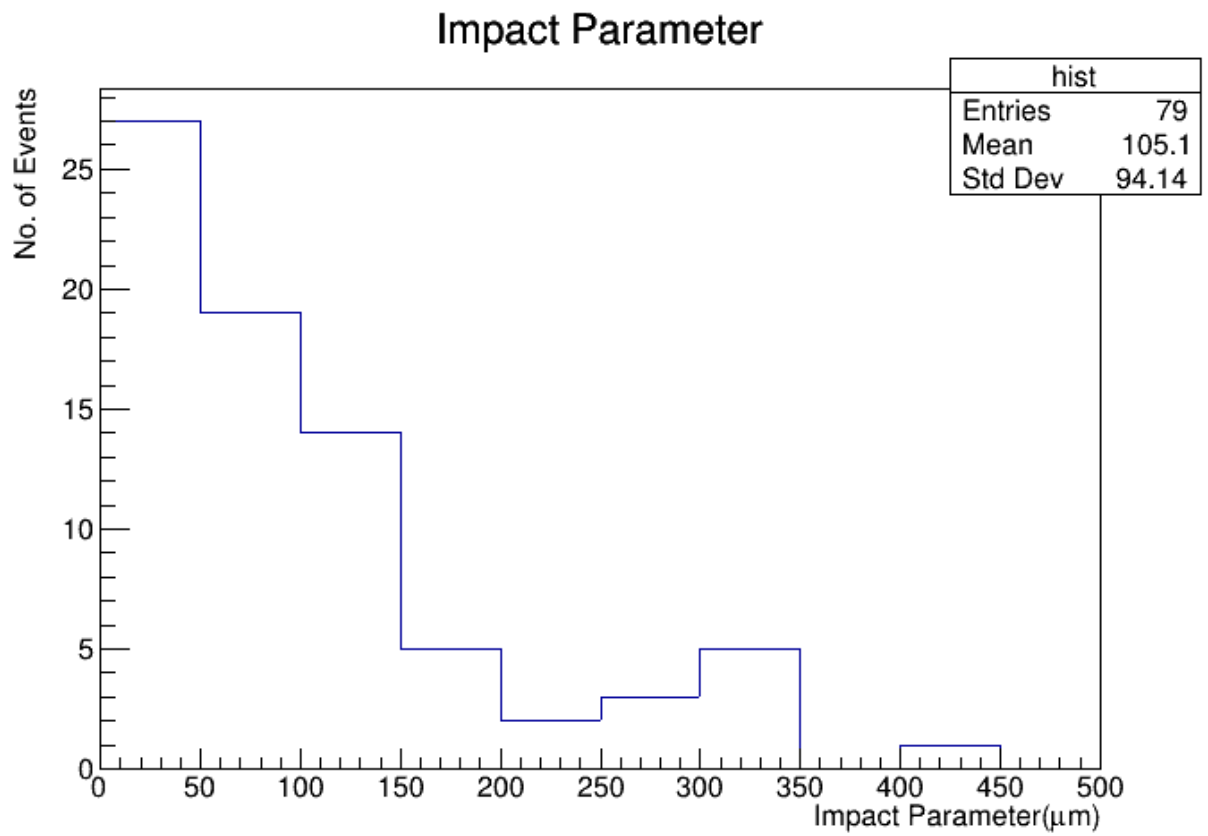
**Statement:-** Download the OPERA emulsion dataset for the neutrino-induced charmed hadron production studies from the Open Data Portal. Develop a C++ program for analysis of the dataset. Read the positions of the primary and the secondary interaction vertices as well as the parameters of the charm decay daughter particle tracks. Calculate and save to histograms a) the flight lengths of charmed hadrons and b) the impact parameters of the daughter particle tracks with respect to the primary neutrino interaction vertices. Save the histograms to a ROOT or to an image file. Compare the results with the ones published in the corresponding OPERA paper.

### Results:-

1. The flight lengths of charmed hadrons.



- The impact parameters of the daughter particle tracks with respect to the primary neutrino interaction vertices.

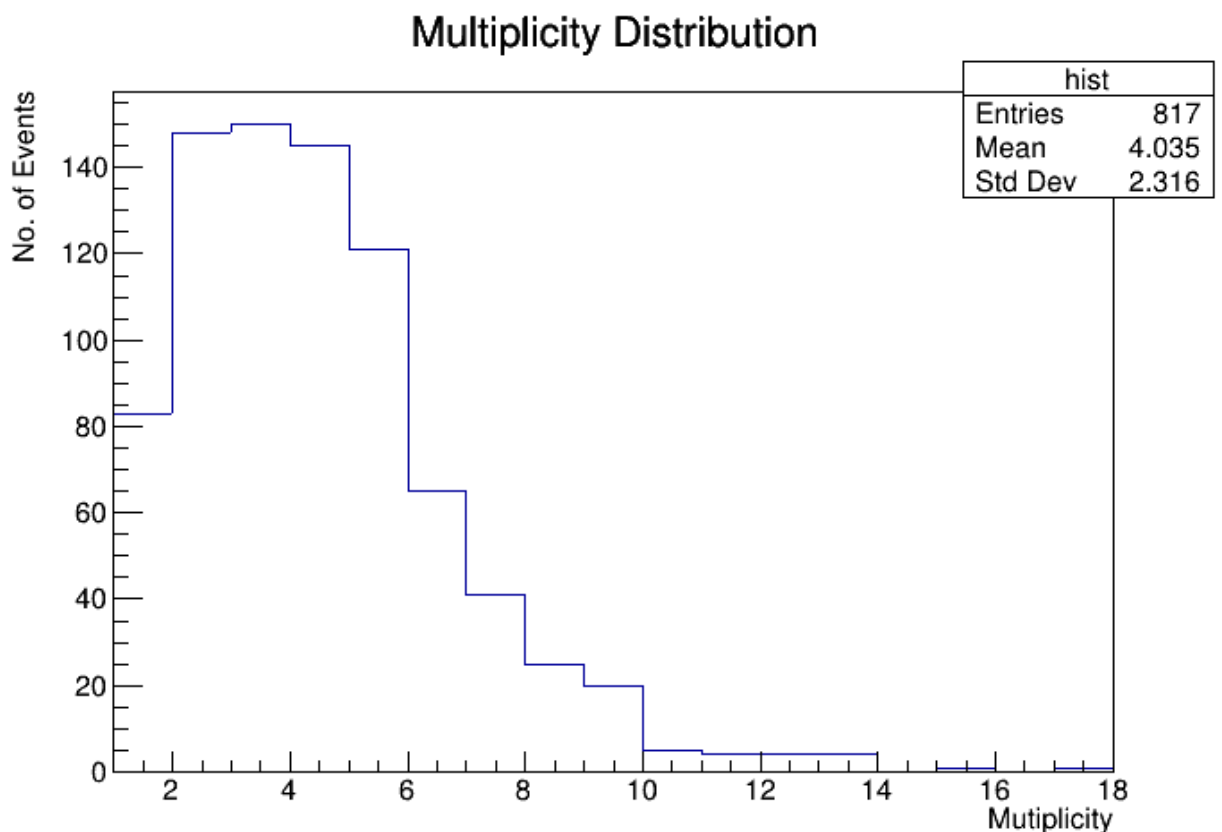


## Task 2

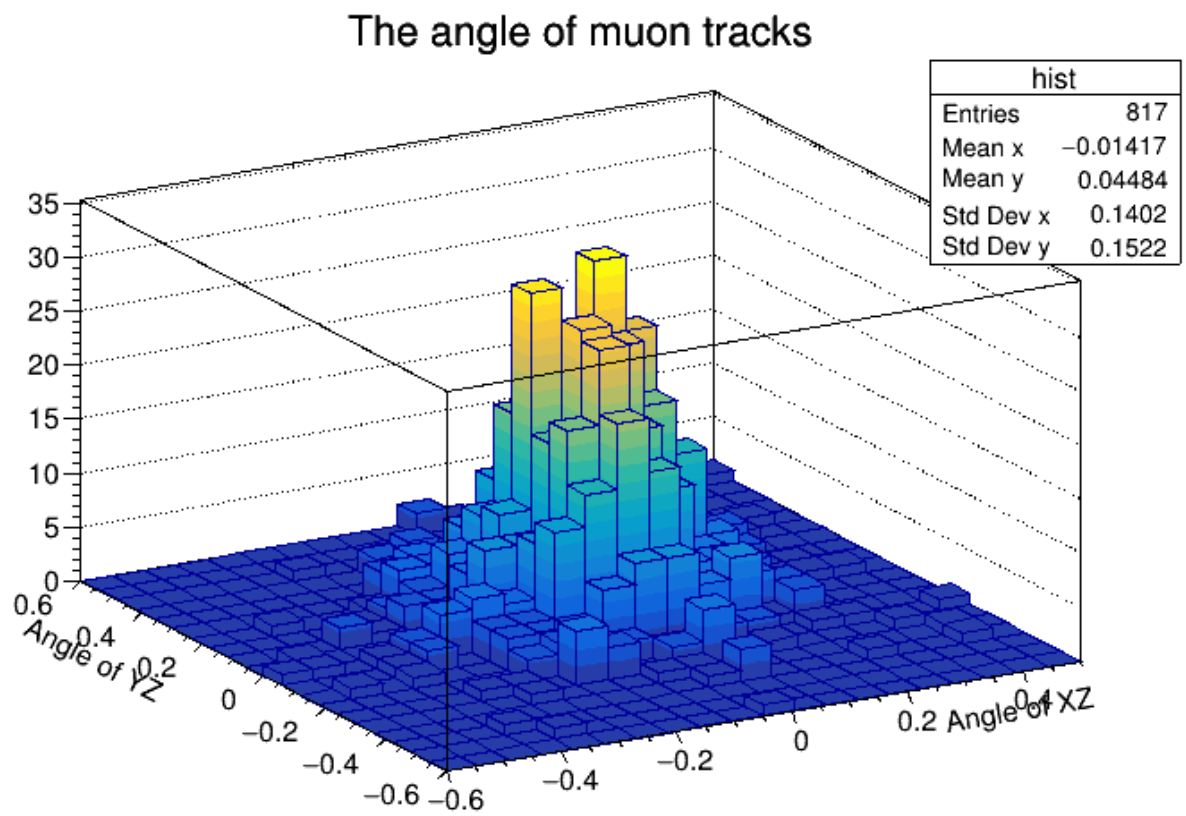
**Statement:-** Download the OPERA emulsion dataset for the charged hadron multiplicity studies from the Open Data Portal. Develop a C++ program for analysis of the dataset. Read the positions of the primary neutrino-lead interaction vertices as well as the parameters of the secondary charged particle tracks. Find and save to histograms a) the multiplicities of all produced charged particles and b) the angles of the muon tracks. Save the histograms to a ROOT or to an image file. Compare the results with the ones published in the corresponding OPERA paper.

### Results:-

1. The multiplicities of all produced charged particles.



2. The angles of the muon tracks.

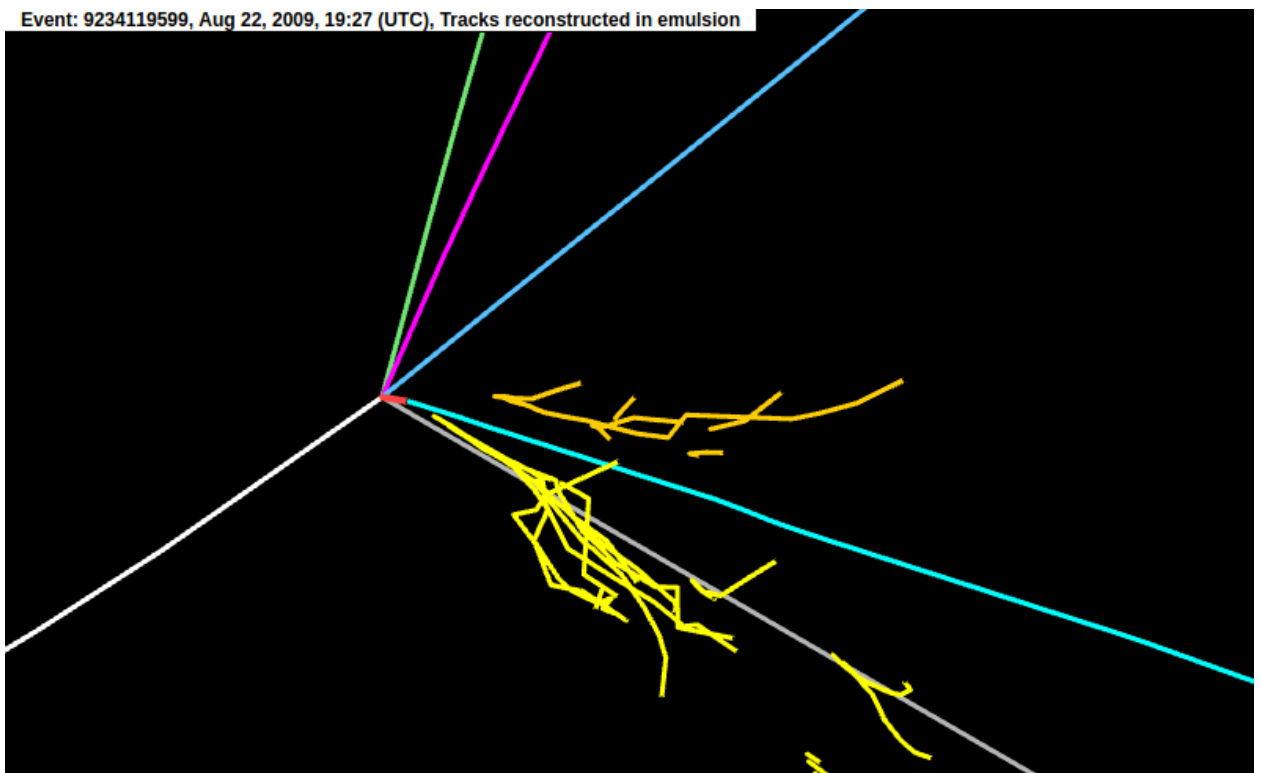




## Task 3

**Statement:-** Download the OPERA emulsion dataset for the tau neutrino appearance studies from the Open Data Portal. Develop a browser-based 3D event display to view tracks and vertices reconstructed in nuclear emulsions of the 10 tau neutrino candidate events using the three.js graphics library.

**Results:-**



## ***Conclusion***

The Analysis of data we did was to be compared with to data analysis done by CERN on the OPERA experiment. Throughout this process we were able to learn programming using C++ on ROOT analysis software developed by CERN.

Various histograms including 2D and 3D were used to analyse the data using ROOT software for reading and analysing the data extracted from CERN Open Data Portal (OPERA).

## References

1. About the CERN Open Data Portal (<http://opendata.cern.ch/docs/about>)
2. About the OPERA neutrino oscillation experiment (<http://operaweb.lngs.infn.it/spip.php?rubrique1>)
3. The OPERA experiment in the CERN to Gran Sasso neutrino beam (<https://iopscience.iop.org/article/10.1088/1748-0221/4/04/P04018/pdf>)
4. C++ language tutorial (<https://www.cplusplus.com/files/tutorial.pdf>)
5. CERN ROOT online manual (<https://root.cern>)
6. HTML tutorial (<https://www.w3schools.com/html/>)
7. CSS tutorial (<https://www.w3schools.com/css/>)
8. JavaScript guide (<https://developer.mozilla.org/en-US/docs/Web/JavaScript/Guide>)
9. D3.js graphics library: (<https://d3js.org/>)
10. three.js graphics library: (<https://threejs.org/>)

## ***Acknowledgement***

I am really thankful to Dr. Sergey Dmitrievsky for giving such an opportunity to work on a project and also guiding us thoroughly throughout it's completion without any complaints.

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Thanks and Regards  
Lalitesh Patil

***Thank You***