Dataset of tau neutrino interactions recorded by the OPERA experiment

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Abstract. We describe the dataset of very rare events recorded by the OPERA experiment. The events represent tracks of particles associated with tau neutrino interactions coming from the transformation of muon neutrinos due to a process known as neutrino oscillations. The events have been published on the CERN Open Data Portal. We describe the dataset semantics and the interactive event display visualisation tool accompanying the data release.

1 Introduction

The OPERA experiment (Oscillation Project with Emulsion-tRacking Apparatus) [1] has demonstrated the tau neutrino (ν_τ) appearance in a muon neutrino (ν_μ) beam due to a process know as neutrino oscillations. Its detector, located at the underground Gran Sasso Laboratory, consisted of an emulsion/lead target with an average mass of about 1.25 kt, complemented by electronic detectors. It was exposed, from 2008 to 2012, to the CNGS (CERN Neutrinos to Gran Sasso) beam, an almost pure muon neutrino beam, induced by a total of 17.97×10^{19} protons on target, travelling from CERN to Gran Sasso over a baseline of 730 km. The OPERA Collaboration discovered $\nu_\mu \rightarrow \nu_\tau$ oscillations in appearance mode in 2015 [2]. In 2018 the Collaboration reported its final results with a significance of 6.1 σ and the observation of ten ν_τ candidates [3]. These events with all the corresponding details have been published in the Open Data Portal and will be reported in this paper.

The neutrino interactions were observed in target units called *bricks*, consisting of nuclear emulsion films interleaved with lead plates. Tau neutrinos are characterised by the presence of two vertices, one produced by the neutrino interaction and the other one produced by the tau lepton decay. These events are very rare, and a dedicated procedure was developed to reduce the background [4]. The detection results from combining Electronic Detectors (ED) also referred to as Electronic Trackers providing the "time stamp" to the event and the brick where they originated from. Moreover, they provide the muon identification and its charge and momentum measurement. The neutrino interactions were observed in target units called bricks, consisting of nuclear emulsion films interleaved with lead plates, the Emulsion Cloud
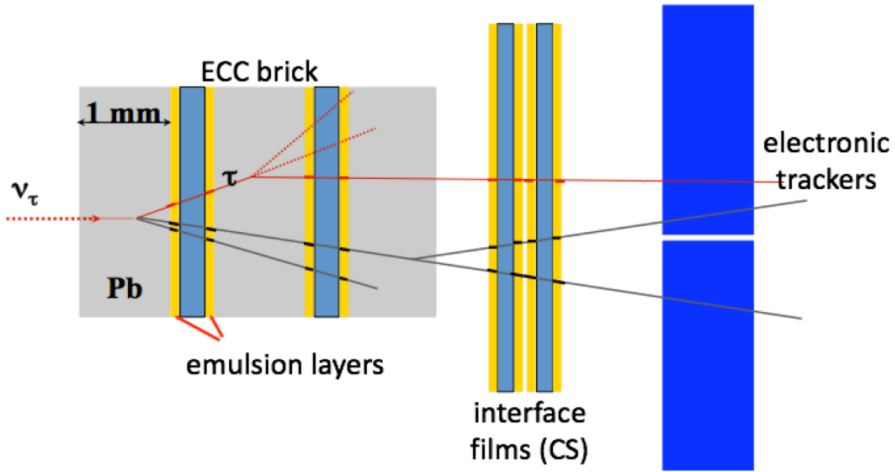
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Figure 1. Schematic view of the OPERA apparatus, consisting of Electronic Detectors (ED), such as electronic trackers, and Emulsion Cloud Chambers (ECC) for the detection of tau neutrinos.
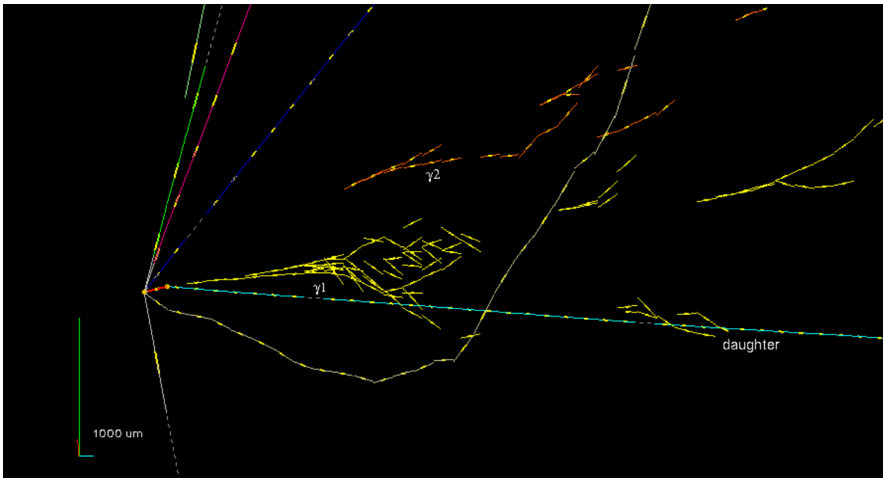

Figure 2. First ν_τ candidate observed in the emulsion brick [5].

Chambers (ECC). The combined action of ECC and ED detectors is illustrated in Figure 1. The first-ever observed ν_τ tau-neutrino event [5] is presented in Figure 2.

2 Dataset

Ten ν_τ events were observed throughout the OPERA data-taking. These events constitute a dataset that was published on the CERN Open Data portal [6]. The datasets from Electronic Detector and Emulsion Cloud Chamber were released separately [7, 8]. The dataset is small in size (Kilobytes) and is published in a custom Comma-Separated-Values (CSV) format. The data comes with detailed documentation about each observed event and the information

Figure 3. An example description of a released event 12123032048 in the CERN Open Data portal.

about how the data was selected and validated. Figures 3 and 4 illustrate one example of a released event. The CSV column semantics is described in detail in Section 3.

3 Dataset semantics

The dataset semantics, describing the meaning of CSV data file columns, can be seen in the following list:

amplL
Photomultiplier (PMT) amplitude measured from the "left" side of a scintillator strip (in photo-electrons).

amplR
PMT amplitude measured from the "right" side of a scintillator strip (in photo-electrons).

amplRec
PMT amplitude reconstructed from the "left" and "right" side amplitudes of a scintillator strip taking into account light attenuation in a WLS fiber (in photo-electrons).

clLength
Cluster length (in cm).

driftDist
Drift distance (in cm).

Figure 4. Files accompanying the example event 12123032048 in the CERN Open Data portal.

enHad

Energy of the hadron jet (in GeV).

enNeu

Energy of the neutrino (in GeV).

enVis

Visible energy (in MeV).

evID

Event ID (10- or 11-digit number).

globPosX

X position of a vertex in the OPERA detector system of reference (in cm).

globPosY

Y position of a vertex in the OPERA detector system of reference (in cm).

globPosZ

Z position of a vertex in the OPERA detector system of reference (in cm).

muMom

If present, momentum of the muon (in GeV/c).

posX

For Electronic Detector events, X position of a drift tube, Resistive Plate Chambers (RPC), Target Tracker hit in the OPERA detector system of reference (in cm). For

Emulsion Detector events, X position of a track/vertex in the OPERA brick system of reference (in micrometers).

posX1

X position of the beginning of a line in the OPERA brick system of reference (in micrometers).

posX2

X position of the end of a line in the OPERA brick system of reference (in micrometers).

posY

For Electronic Detector events, Y position of an RPC hit in the OPERA detector system of reference (in cm). For Emulsion Detector events, Y position of a track/vertex in the OPERA brick system of reference (in micrometers).

posY1

Y position of the beginning of a line in the OPERA brick system of reference (in micrometers).

posY2

Y position of the end of a line in the OPERA brick system of reference (in micrometers).

posZ

For Electronic Detector events, Z position of a drift tube, RPC, Target Tracker hit in the OPERA detector system of reference (in cm). For Emulsion Detector events, Z position of a track/vertex in the OPERA brick system of reference (in micrometers).

posZ1

Z position of the beginning of a line in the OPERA brick system of reference (in micrometers).

posZ2

Z position of the end of a line in the OPERA brick system of reference (in micrometers).

primary

Flag of a vertex: 1 - primary vertex; 0 - not primary vertex.

slopeXZ

Tangent of a track angle in XZ view.

slopeYZ

Tangent of a track angle in YZ view.

timestamp

Event time in milliseconds since 01/01/1970.

trType

Type of a track: 1 - muon; 2 - hadron; 3 - electron/positron; 8 - tau lepton.

4 Visualisation

The published event data can be visualised directly on the CERN Open Data portal. Figure 5 shows the interactive event display interface that we have developed.

The event display interface allows the end user to select desired data sample and event number in order to visualise the given neutrino interaction event in the OPERA detector. The user can zoom into the more specific event region. The Electronic Detector (ED) interactions are shown in two perpendicular planes, the XZ top view and YZ side view. The user can visualise reconstructed tracks by tau leptons and other observed particles. In addition, the ECC emulsion brick that most probably contained the neutrino interaction vertex is shown below the ED display view and provides a detailed three-dimensional view of the vertex brick interactions. The ECC view can be further rotated and animated by the user.
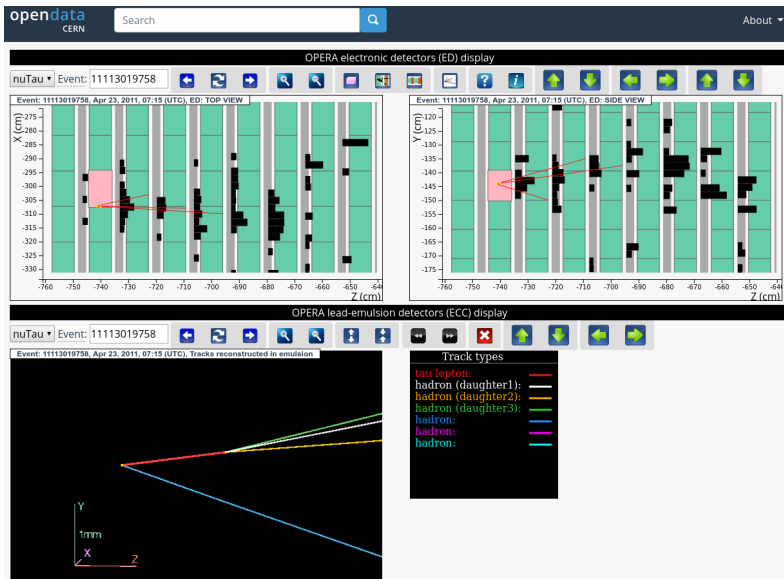

Figure 5. The Electronic Detector and the Emulsion Cloud Chamber tracks can be visualised interactively on the CERN Open Data portal.

5 Conclusions

The OPERA collaboration released ten $\nu_\mu \rightarrow \nu_\tau$ candidate events. They constitute the first-ever observation of ν_τ appearance in a ν_μ beam due to a process known as neutrino oscillations. In total, ten ν_τ events were observed throughout OPERA experiment data-taking period from 2008 to 2012. The dataset was released on the CERN Open Data portal as a first non-LHC experiment release. The data comes in custom CSV format with fully documented semantics. A full web-based event display was developed for users to explore the data *in situ*. The data release will be complemented in the future, e.g. charmed hadron and ν_e events.

Acknowledgements

References

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