The OPERA experiment was proposed in 1998 to prove oscillations of muon neutrinos to tau neutrinos (as explanation of the observed atmospheric neutrinos anomaly) through direct detection of the appearance of tau neutrino in the CNGS muon neutrino beam as a result of the oscillations. The OPERA hybrid detector consisted of the target part made of 150000 lead-nuclear emulsion bricks, where neutrino interaction occurred, and the electronic detectors: Target Tracker (TT), which provided the real time trigger for the events recording and the event vertex location at the brick level, and magnetic spectrometers to identify muons and to measure their momentum.

**CNGS: CERN Neutrinos to Gran Sasso**

**OPERA hybrid detector:** 150000 bricks, 1.25 kT, 3100 m.w.e.; 1 µm/h

**OPERAs' Facebook**

**Vertex brick finding – first step of the analysis**

**V_µ → V_τ oscillation analysis:**

By proving with 5.1 sigmas appearance of tau neutrinos, OPERA successfully accomplished the mission, but several analyses are still in progress and more results are coming soon.

**Cosmic-muon rate and temperature dependence**

- Gran Sasso underground ~ 3800 m.w.e. → Minimum muon energy ~ 1.8 TeV.
- Atmospheric temperature increase → density decrease → increase the pion decay rate → muon rate increase
- High W in high atmosphere → high energy muons

**Sterile neutrino search**

- Appearance probability modified by one possible sterile (sterile) (2+1 scheme)

**V_µ → V_τ**

- Full data sample (2008-2012)
- Use of electronic detector data only and separation between CC and NC events

**V_µ → V_µ**

- Preliminary measurement of \(\Delta m^2\), consistent with the world average and the internal OPERA analysis results

**V_µ disappearance**

- In a fit using NC-like CC-like ratio in which all mixing parameters are fixed to the PDG values had \(P_{\text{data}} = 5\%\)

**Average beam power**

- 99% of the beam power falls into the brick level, where the electronic detectors

**Target and Target Tracker (6.7 m)**

- Target: 7750 bricks, 29 walls
- Target tracker: 31 XY doublets of 256 scintillator strips + WLS fibres + multi-layer PMT for:
  - Brick selection
  - Calorimetry

**Automatic scanning system as a reader**

- Scanning speed system: 75cm/h
- High speed CCD camera (3 kHz), Piezo-controlled objective lens
- FPGA Hard-coded algorithm

**V_µ → V_e oscillation analysis**

**Selection of a brick most probably containing the neutrino**

- Reduce scanning load
- Minimise the target mass loss


**OPERAs' Facebook**

**Background**

- \(\nu_e + \mu \rightarrow \nu_e + \mu\)
- 1.4 \(\nu_e\) per year, low rate
- \(\tau\) → \(\nu_e\) + CC interaction, 2.44 \(\times 10^{-7}\)
- \(\nu_e\) CC interaction, production and detection (4-6\%)
- \(\tau\) → \(\nu_e\) + CC interaction, production and detection (5-7\%
- \(\tau\) neutrino interaction in lead: 1.2% less rate in a similar environment

**Probability to be explained by background fluctuation p = 1.1 \times 10^{-2}\)

**No oscillation hypothesis excluded at 3.1 \sigma**

**Probability of having 5 events or more (9.0.9) events expected: 1.7%**

**Frequency of configurations being less probable than the observed one: 6.4%**