Neutrino oscillation results of the OPERA experiment in the CNGS beam

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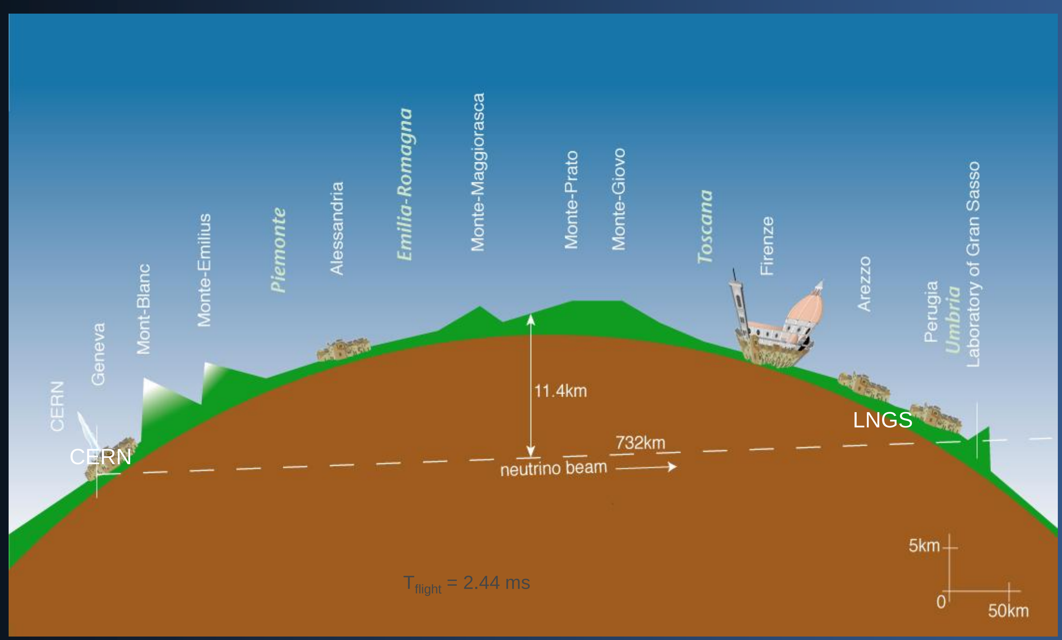
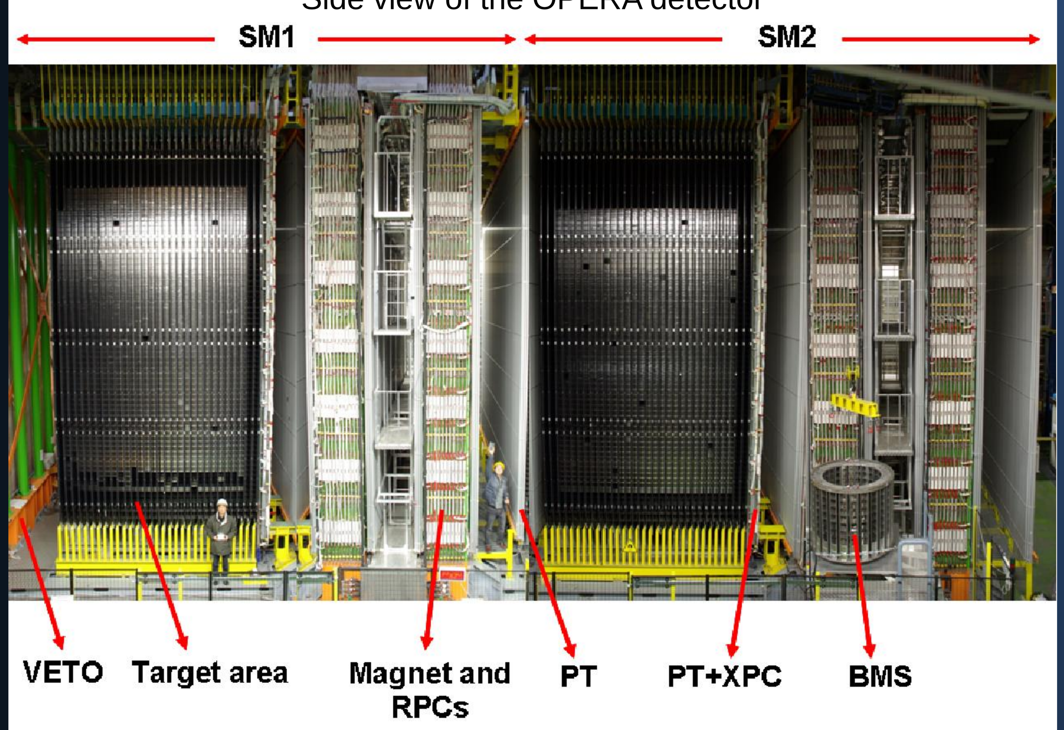
The OPERA experiment

The OPERA experiment [1] was designed to detect tau neutrino appearance in the predominantly muon neutrino CNGS beam [2].



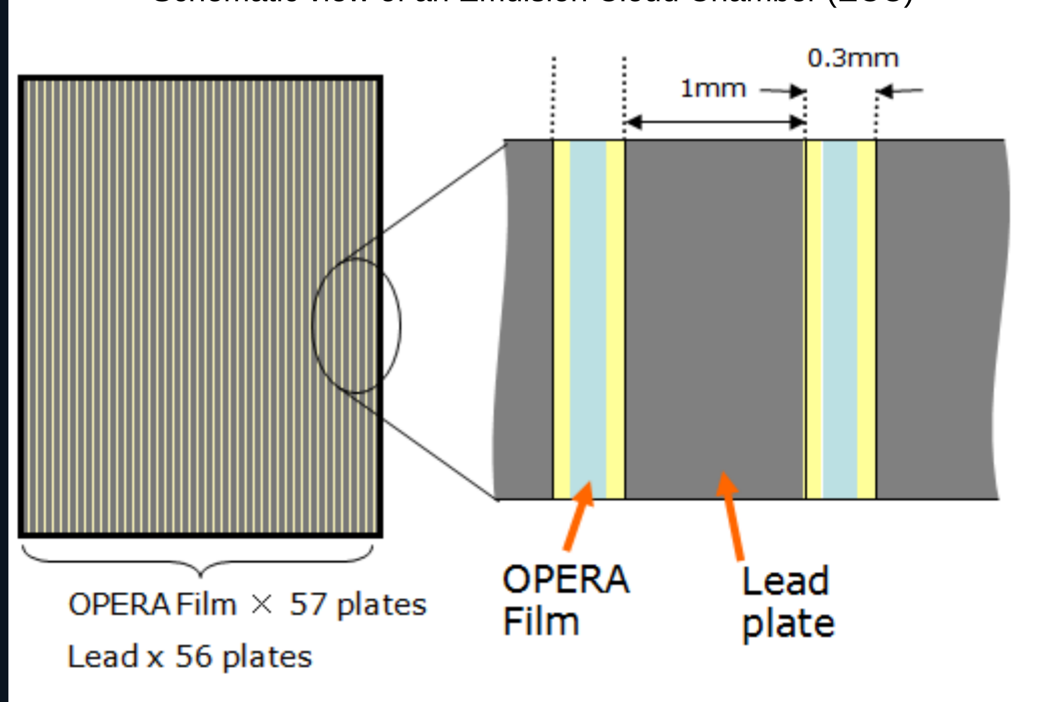
The OPERA detector target consisted of about 150 thousand stacks of lead plates and emulsion films, called Emulsion Cloud Chamber (ECC) elements, embedded between scintillator planes. The detector also featured two muon spectrometers, used for momentum reconstruction of charged particles.

Side view of the OPERA detector



Scintillator planes were used to predict the ECC element in which neutrino interaction occured. Selected ECCs were then extracted, and contained emulsions were scanned by automatic scanning microscopes.

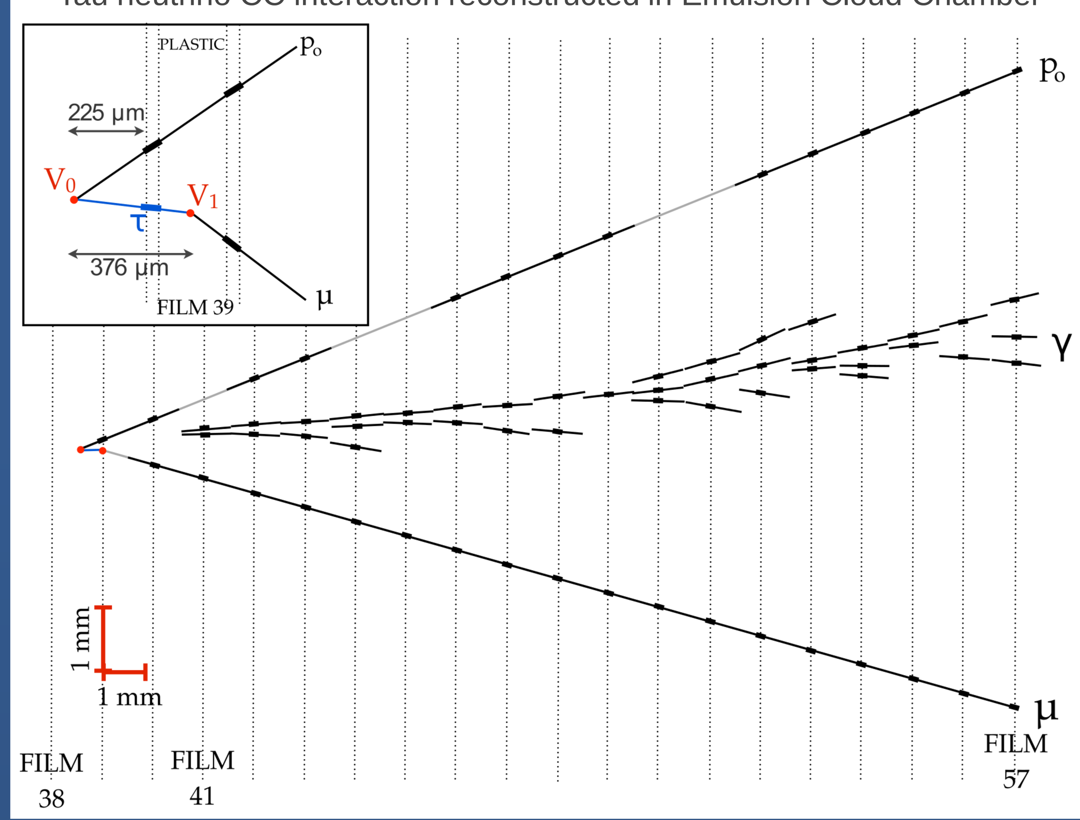
Schematic view of an Emulsion Cloud Chamber (ECC)



Data taking run lasted from 2008 to 2012 with an exposure of 17.97 x 10^{19} p.o.t, in which 19505 events were recorded in the target, of which 5603 were fully reconstructed in emulsion.

The OPERA experiment (cont.)

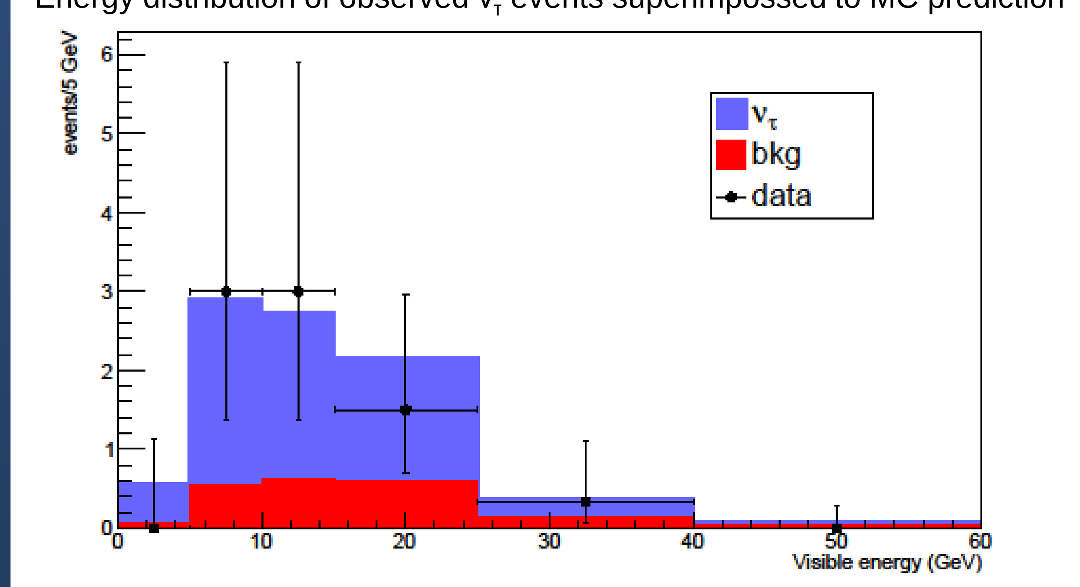
Tau neutrino CC interaction reconstructed in Emulsion Cloud Chamber



$\nu_\mu \rightarrow \nu_\tau$ appearance channel (std. osc)

Final results on the ν_τ appearance channel were published in 2018 [3]. Ten ν_τ candidates were observed with expected background of 2 ± 0.4 events, corresponding to significance 6.1 σ.

Energy distribution of observed ν_τ events superimpossed to MC prediction



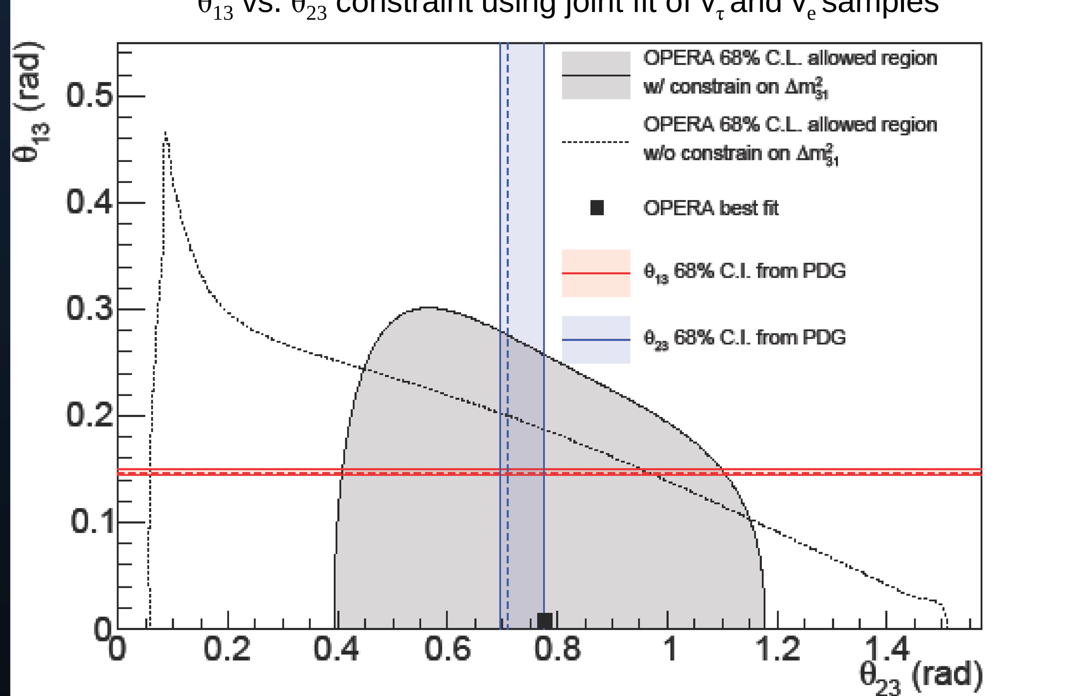
Assuming maximal mixing, OPERA measured the atmospheric mass splitting in ν_τ appearance mode:

$$|\Delta m^2_{32}| = (2.7^{+0.7}_{-0.6}) \times 10^{-3}\ \mathrm{eV}^2$$

Combined ν_τ and ν_e appearance (std. osc.)

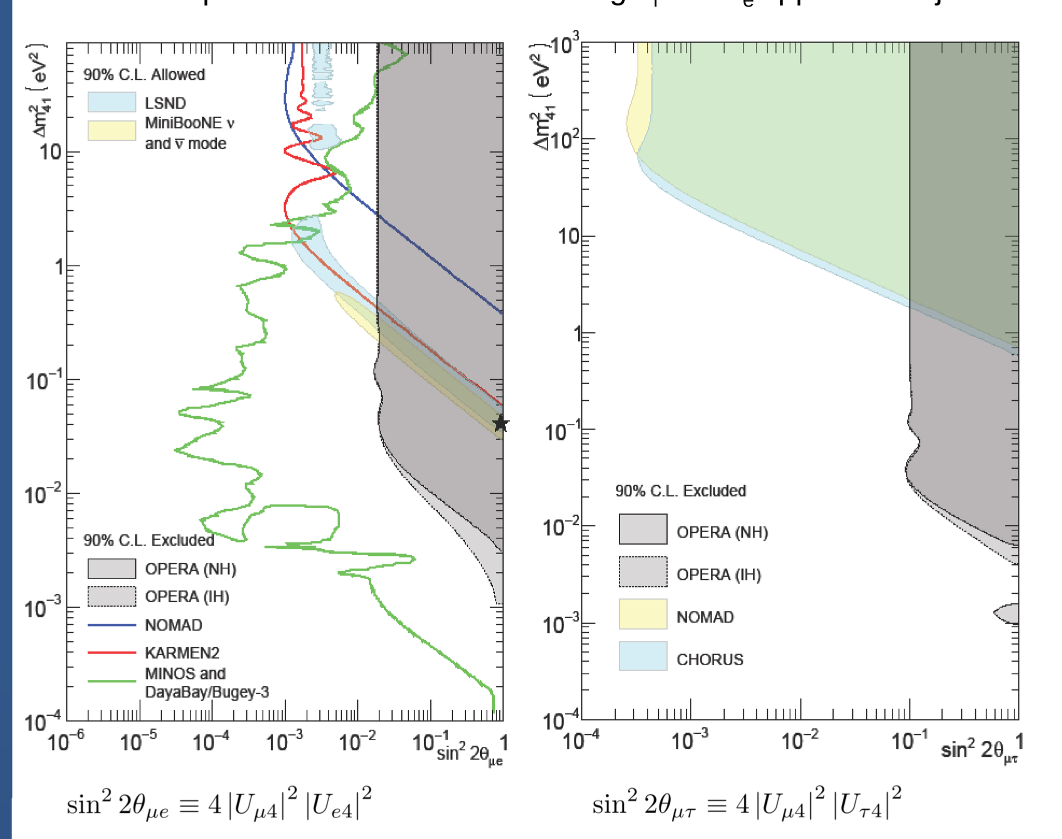
OPERA detecor is also sensitive to ν_e CC interactions. Expected number of ν_e candidate events is 31.9 ± 3.2 in case of no oscillations, and 34.3 ± 3.4 for standard oscillations. 35 events were observed, consistent with both cases [4]. A joint fit using ν_τ and ν_e appearance in θ_{13}-θ_{23} plane has been performed.

θ_{13} vs. θ_{23} constraint using joint fit of ν_τ and ν_e samples



Combined ν_τ and ν_e appearance (sterile)

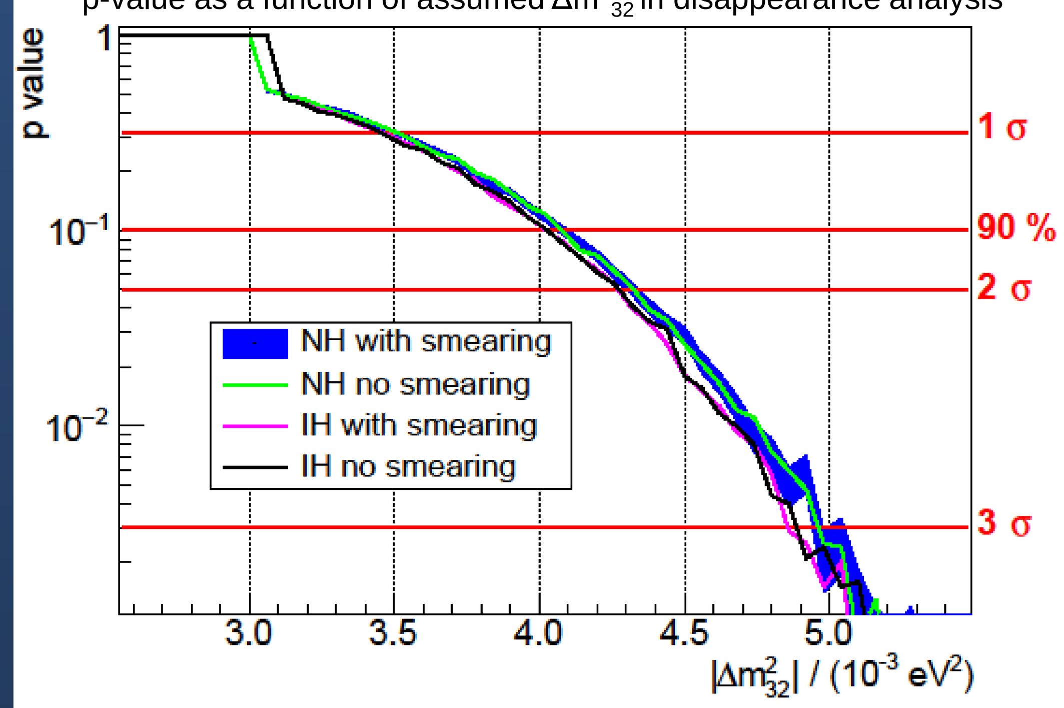
Exclusion plots in the sterile sector using ν_τ and ν_e appearance joint fit



In the sterile sector, OPERA excludes recent MiniBoone result [5] with significance of 3.3 σ, using joint fit of ν_τ and ν_e samples.

ν_μ disappearance channel

p-value as a function of assumed Δm^2_{32} in disappearance analysis



Due to the lack of a near detector, NC/CC event rate ratio was used to search for ν_μ disappearance signal. Assuming all other oscillation parameters fixed, an upper limit on atmospheric mass splitting was obtained:

$$|\Delta m^2_{32}| < 4.1 \times 10^{-3}\ \mathrm{eV}^2\ @\ 90\%\ \mathrm{C.L.}$$

Conclusions

OPERA is the only experiment able to study all three channels of ν_μ oscillatios: $\nu_\mu \rightarrow \nu_\tau$, $\nu_\mu \rightarrow \nu_e$, $\nu_\mu \rightarrow \nu_\mu$. Apart from the primary ν_τ analysis, a joint fit of ν_τ and ν_e has been performed in both standard and sterile hypothesis. Additionally, a search to ν_μ disappeaance has been performed.

References

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2. K. Elsener, Reports No. CERN 98-02 and No. INFN/AE-98/05, 1998; R. Bailey et al., Reports No. CERN-SL-99-034-DI and No. INFN-AE-99-05, 1999, addendum to Reports No. CERN 98-02 and No. INFN-AE-98-05, 1998; CNGS Web site, http://proj-cngs.web.cern.ch/proj-cngs
3. N. Agafonova et al. (OPERA), Phys. Rev. Lett. 120.21 (2018), p. 211801
4. N. Agafonova et al. (OPERA), JHEP 06 (2018), p. 151
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