Final results from the ν_τ appearance search in the NOMAD experiment

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An updated analysis of the full NOMAD data corresponding to $\sim 1.35\times10^6$ charged current interactions has been performed to search for neutrino oscillations through ν_τ appearance. This document updates the recently published results on the $\nu_\mu \to \nu_\tau$ and $\nu_\mu \to \nu_e$ oscillations search in NOMAD [1] with a unified analysis of the hadronic channels.

1. The Neutrino Beam and the NOMAD Detector

The NOMAD detector is described in Ref [2]. Inside a 0.4 T magnetic field there is an active target (2.7 tons, with a density of 0.1 Kg/l and a thickness of $1\ X_0$) of drift chambers (DC), followed by a transition radiation detector(TRD), a preshower detector (PS), and an electromagnetic calorimeter (ECAL). A hadron calorimeter (HCAL) and two muon stations are located just after the magnetic coil. The neutrinos are produced at an average distance of 625m from the detector. The estimated beam composition is ν_μ:$\overline{\nu}_\mu$:ν_e:$\overline{\nu}_e$= 1.00:0.061:0.0094:0.0024. with average energies of 23.5, 19.2, 37.1 and 31.3 GeV respectively [3]. The prompt ν_τ component is negligible [4].

2. The analysis principles

The ν_τ is detected via its CC interaction in the active target followed by the τ decay, which can be recognized through its visible decay product(s). The total branching ratio (BR) of the channels considered is 82.5%. These are $\tau^- \to e^-\overline{\nu}_e\nu_\tau$, $\tau^- \to h^-(\mathrm{n}\pi^0)\nu_\tau$, and $\tau^- \to 3h^-(\mathrm{n}\pi^0)\nu_\tau$. NOMAD can separate signal from background using kinematical criteria. The experimental backgrounds are ν_μ and ν_e NC and CC interactions where the lepton is not identified. There are two main kinematical signatures of a ν_τCC interaction. First, the missing P_T is larger in ν_τ CC events than in ν_μ or ν_e CC -due to the escaping ν_τ from the τ decay- and smaller than in NC events, for which the leading lepton is a ν. Secondly, the τ decay product(s) are much more isolated from the hadronic jet than the misidentified τ decay product(s) in a NC but less than in a ν_e or ν_μ CC, where the resulting lepton is misidentified as a τ decay product. On top of these features there is the internal structure of the τ decay.

2.1. Likelihood techniques

There is no single variable that discriminates ν_τCC interactions from the background with the desired signal to background ratio. Several kinematical variables and the correlations among them -which can contain as much information as the variables themselves- are combined in likelihoods to distinguish signal from background. We define multidimensional (up to 4D) probability density functions, pdf's $\mathcal{L}$, describing the probability for an event with the given set of N variables X_i, to be signal ($\mathcal{L}_S$) or background ($\mathcal{L}_B$). The logarithm of the likelihood ratio, $\ln\lambda=\ln\frac{\mathcal{L}_S}{\mathcal{L}_B}$, is used to separate signal from backgrounds, with large values of this ratio yielding the best signal to background discrimination. In NOMAD the likelihood ratio distributions are subdivided into bins (corresponding to different sensitivities[1] [5]) in order to take advantage not only of the integral above one cut value but also of the shape of the likelihood function. As the signal lies in between the two different types of backgrounds (NC & CC) for all the kinematical features, one likeli-

[1]sensitivity is defined as the average upper limit that would be observed by an ensemble of experiments with the expected background and no true signal.

hood per kinematical feature is used. Fig. 1 shows the distribution in the plane ln$\lambda^{\tau/CC}$-ln$\lambda^{\tau/NC}$ of the two types of backgrounds and the signal for the $\tau \to 3\pi$ analysis. ln$\lambda^{\tau/CC}$ is mainly based on P_T^{miss} and ln$\lambda^{\tau/NC}$ on isolation. Independent measurements from different decay modes & signal bins are combined within a *unified aproach* [5].

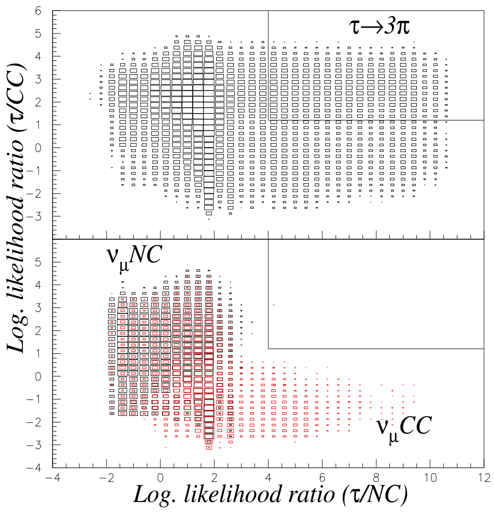

Figure 1. Distribution of the signal and ν_μ NC and CC backgrounds in the ln$\lambda^{\tau/CC}$-ln$\lambda^{\tau/NC}$ plane.

2.2. Data Simulator

All the pdf's are based exclusively on MC simulations, however MC does not reproduce well enough the properties of the hadrons [7]. In order to reliably compute background rejections and reduce systematic uncertainties all MC results are corrected using real data [6]. This is performed using a sample of ν_μCC in data (DS) and montecarlo (MCS) and by replacing the μ with a MC-generated lepton l (ν,e^-or τ^-) of appropriate momentum vector. Signal and background efficiencies are then obtained from: $\epsilon = \epsilon(MC) \times \frac{\epsilon(DS)}{\epsilon(MCS)}$.

2.3. Blind Analysis

In order to avoid biases, a blind analysis strategy has been adopted. This consists in defining a signal kinematical region by optimizing the overall sensitivity to oscillations. Real data in this region cannot be studied until the analysis robustness is demonstrated with control samples. These are the τ^- search outside the box, and τ^+ search, where no signal is expected given the small $\overline{\nu}$ content of the beam.

3. Results

Fig. 2 illustrates the distribution of the most discriminating likelihood for some important channels. The distributions for real data and background expected in the absence of signal, as well as Nτ are shown, where Nτ is the number of expected τ events if the oscillation probability was unity. Data are consistent with expectations in absence of signal. No evidence for oscillation is found: 51.1±5.4 events are expected and 52 found with N_τ=14415.The final result is expressed as a confidence interval [5] which uses the information of 31 bins. Notice, however that 75 % of the overall sensitivity comes from the regions with lowest background. The low background bins are listed in table 1. They contain N_τ=8215 for 1.62 background events expected with 1 event seen in this region. The overall systematic uncertainty on the background prediction is estimated to be 20% and 10% on N_τ. The resulting 90% CL upper limit in the $\nu_\mu \to \nu_\tau$ oscillation probability is: $P_{osc}(\nu_\mu \to \nu_\tau) < 1.7 \times 10^{-4}$ which corresponds to the exclusion region in the $\triangle m^2$-sin$^2 2\theta$ plane shown in the upper plot in figure Fig 3. The sensitivity [5] of the experiment is 2.5×10^{-4}. In the absence of signal events, the probability to obtain this limit or lower is 39%. NOMAD has searched for $\nu_e \to \nu_\tau$ oscillations, reweighting the simulated signal events for the ν_e to ν_μ flux ratio, obtaining an upper limit, at 90% CL, of $P_{osc}(\nu_e \to \nu_\tau) < 0.8 \times 10^{-2}$. The corresponding exclusion region in the $\triangle m^2$-sin$^2 2\theta$ plane is shown in the lower plot in figure Fig 3. The sensitivity is 1.2×10^{-2}, and the probability of obtaining this result or lower is of 43 %.

4. Conclusions

NOMAD has demonstrated that a sensitive search for ν_τ appearance can be achieved with a kinematical analysis. No evidence for oscillations has been found. These results strongly constrain

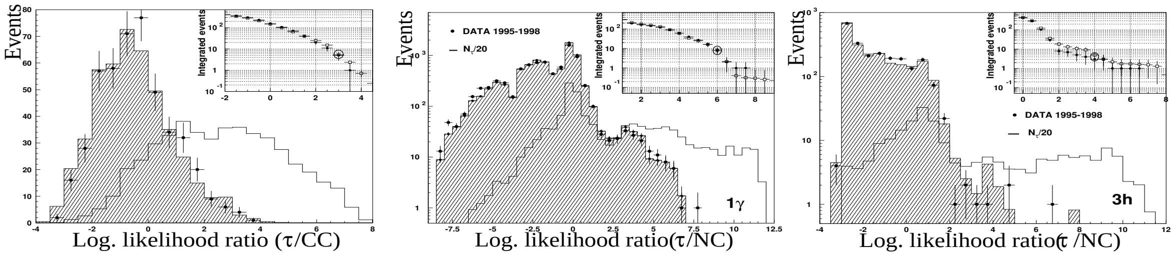

Figure 2. Projection on the most relevant likelihood ratio function of the expected background (filled histograms), data 95-98 (dots with error bars) and Nτ/20 (continuous line) for the $\tau^- \to e^- \overline{\nu}_e \nu_\tau$, one of the $\tau^- \to h^-(\mathrm{n}\pi^0)\nu_\tau$ and $\tau^- \to 3h^-(\mathrm{n}\pi^0)\nu_\tau$ deep inelastic channels.

Table 1
The low background bins

Analysis	Bin	Tot. bkg.	$N^\tau_{P=1}$	Data
$\nu_\tau \bar{\nu}_e e$	III	$0.28^{+0.31}_{-0.09}$	903	0
$\nu_\tau \bar{\nu}_e e$	VI	0.25 ± 0.09	1694	0
$\nu_\tau h(0\gamma)$	III	$0.05^{+0.60}_{-0.03}$	274	0
$\nu_\tau h(0\gamma)$	IV	$0.12^{+0.60}_{-0.05}$	1246	0
$\nu_\tau h(1\gamma)$	VII	$0.07^{+0.70}_{-0.04}$	211	0
$\nu_\tau h(1\gamma)$	VIII	$0.07^{+0.70}_{-0.04}$	1037	0
$\nu_\tau h(2\gamma)$	XII	$0.11^{+0.60}_{-0.06}$	197	0
$\nu_\tau h(1/2\gamma)$	XV	$0.20^{+0.70}_{-0.06}$	660	1
$\nu_\tau h(0/1\gamma)$	XVI	$0.14^{+0.70}_{-0.06}$	1348	0
$\nu_\tau 3h(n\pi^0)$	IV	$0.33^{+0.65}_{-0.33}$	645	0

the large $\triangle m^2$ region of the parameter space as shown in Fig. 3.

REFERENCES

1. NOMAD Collaboration, P. Astier *et al.*,Phys. Lett. B 453 (2000) 169.
2. NOMAD Collaboration, J. Altegoer *et al.*,Nucl. Inst. and Meth. A404(1998), 96.
3. G.Collazuol *et al.*, Nucl. Inst. and Meth. A 449 (2000) 609.
4. M.C. Gonzalez-Garcia, J.J. Gomez-Cadenas,Phys. Rev. D 55 (1997) 1297.
5. R.D. Cousins, G.F. Feldman, Phys. Rev. D57 (1998) 3873.
6. NOMAD Collaboration, P. Astier *et al.*,Phys. Lett. B 453 (1998) 169.
7. NOMAD Collaboration, J.Altegoer *et al.*,Phys. Lett. B 431 (1998) 219.

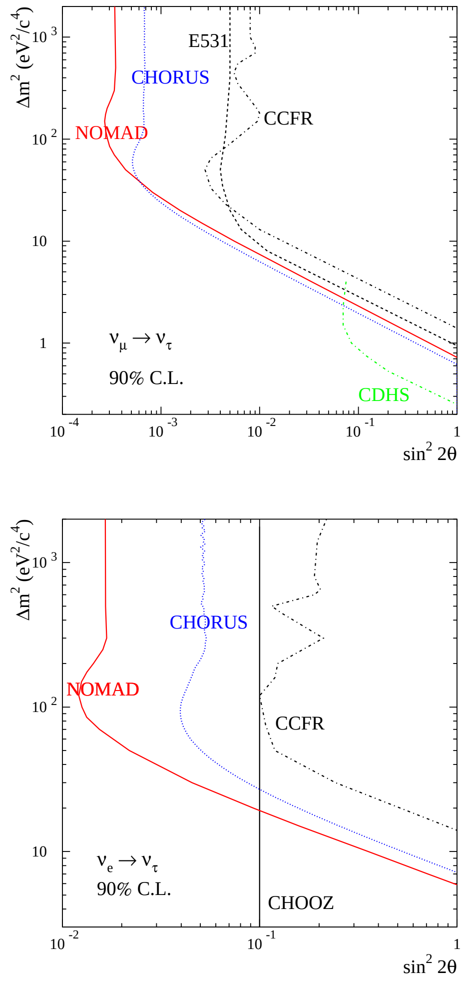

Figure 3. Exclusion plots at 90% CL.