FIRST RESULTS FROM THE $\nu_\mu \rightarrow \nu_e$ OSCILLATIONS SEARCH IN THE NOMAD EXPERIMENT

The NOMAD Collaboration

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Abstract

The NOMAD experiment has been optimized to detect primary electrons with good efficiency. ν_e charged current interactions can be analysed to search for a $\nu_\mu \rightarrow \nu_e$ signal: no evidence for such a signal is observed in the NOMAD data collected during 1995 run. Comparing the ratio ν_e/ν_μ of observed ν_e and ν_μ charged current interactions to expectations shows no evidence for oscillations. A preliminary limit of $\sin^2 2\theta < 1.8 \times 10^{-3}$ can be set for high Δm^2.

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1 Introduction

The NOMAD experiment [1] has been designed to look for $\nu_\mu \rightarrow \nu_\tau$ oscillations, aiming to identify the ν_τ through its charged current interactions and the subsequent detection of the τ^- decay products. In order to exploit the low ν_e contamination ($\approx 1\%$) in the CERN-SPS wide band ν_μ beam, the apparatus has been optimized to efficiently detect electrons and in particular ν_e charged current interactions (ν_eCC). Their analysis is relevant for the $\nu_\mu \rightarrow \nu_e$ search, since an oscillation signal would manifest itself as an excess of events in the total energy spectrum (E_ν) for that sample.

The interest for this kind of study has recently highly increased, following the LSND [2] collaboration claim for evidence of $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillations. NOMAD is sensitive to a large fraction of the parameter region corresponding to the LSND most probable values in the $(\sin^2 2\theta, \Delta m^2)$ plane. In fact, given the energy spectrum of the West Area neutrino beam ($< E_{\nu_\mu} > \approx 24$ GeV) and the mean source-to-detector distance ($< L > \approx$ 650 m), in case of oscillations with $\Delta m^2 > 10$ eV^2 a signal should be seen in NOMAD data.

Since the measurement implies a direct comparison between the observed and the expected spectra, a very good knowledge of the beam characteristics is crucial.

2 The CERN West Area Neutrino Beam

The CERN wide-band neutrino beam [3] is obtained by making 450 GeV/c protons hit a Beryllium target, thus producing many secondary particles (mainly pions and kaons); the positive component of the secondary beam is focused by a system of magnetic lenses (the *horn* and the *reflector*) and then is allowed to decay in a vacuum tunnel. The residual charged particles are finally stopped by a thick shield, placed before the experimental site, where only neutrinos can penetrate.

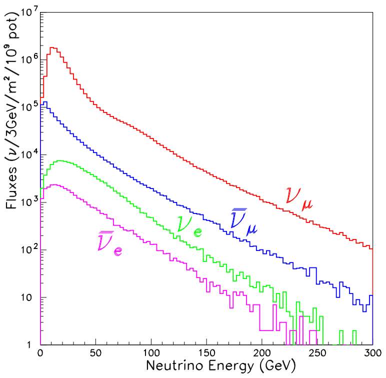

Figure 1: Energy spectra for the different component of the CERN-SPS wide band neutrino beam.

A Monte-Carlo package has been developed to describe the entire beam line: it is based on the GEANT [4] library for the detectors and the material description and makes use of the FLUKA [5] package to simulate hadronic interactions. The predicted energy spectra for the different beam components are showed in Fig. 2. As already mentioned, the ν_e/ν_μ contamination is of the order of 1%; furthermore, the ν_e spectrum is harder than the ν_μ's ($< E_{\nu_e} > \approx$ 37 GeV), increasing the experiment sensitivity in the energy range relevant for the oscillation analysis. Since electron neutrinos mainly come from K decays, the fraction of ν_e's in the beam is determined by the kaon content of the secondary mesons flux. At the present time, the K/π ratio in the interesting kinematic region is known with a systematic uncertainty of 10%; further constraints are expected soon from the NA56 [6] collaboration, which in 1996 has studied p-Be interactions for 450 GeV/c protons and secondary particles with momenta below 40 GeV/c.

Another possible approach tries to use data itself to extract beam information and predict the ν_e spectrum in absence of oscillations. The way this can be done is illustrated in Fig. 2, where all the (anti-)neutrino spectra are given in terms of parent particles: since possible oscillations could not appear in the antineutrino sample, because of the low statistics, one can deduce all the relevant information using only events with a primary μ^-, μ^+ or e^+ (not e^- !). In fact, K^+ can be constrained by the high energy ν_μ spectrum, while the low energy part fixes the π^+ (and hence the μ^+) content of the beam. In a similar way, combined information from $\bar{\nu}_\mu$ and $\bar{\nu}_e$ spectra allow to extract the K_L^0 component. Once the contributions from all parents are known, the expected ν_e energy distribution in absence of oscillations can be computed.

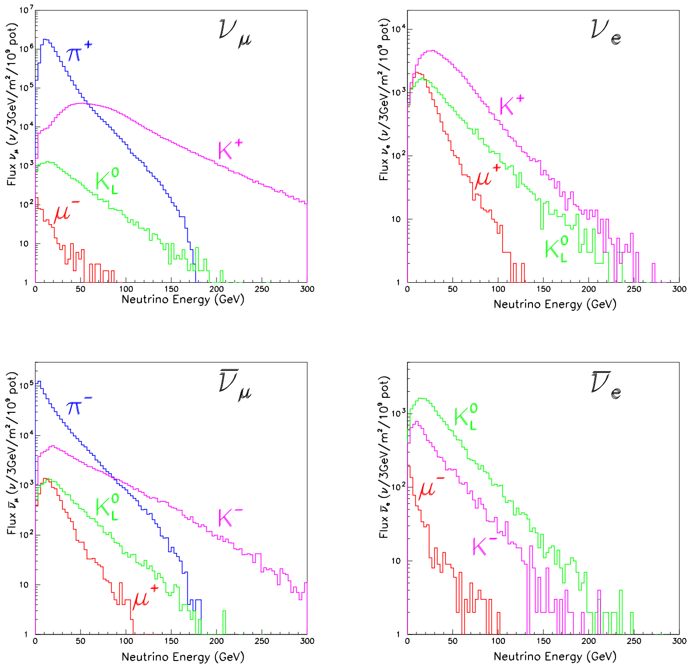

Figure 2: Parent particles contribution to the different beam components.

3 Selection of ν_e Charged Current Interactions

The NOMAD detector has been designed to achieve optimal electron identification; a detailed description of the apparatus is given elsewhere [7]: here the standard way to select a primary electron is summarized. For a ν_eCC interaction occurring inside the active target (Fig. 3), if the produced electron is energetic enough, a primary Drift Chambers (DC) track is matched to a track in the Transition Radiation Detector (TRD), to a Preshower (PRS) cluster in both projections and to a cluster in the Electromagnetic Calorimeter (ECAL). Since the target is made of a dense medium, before reaching the calorimeter the electron can emit bremsstrahlung photons, which can in turn convert inside the target volume: collecting all the different contributions, the electron energy can be reconstructed with a 3% resolution.

Using the signal associated to the track in each TRD plane, a likelihood function can be introduced to separate electrons from hadrons in that subdetector; in PRS, the total signal associated to the track is required to be above the typical threshold for minimum ionizing particles. In ECAL, the measured matched shower has to be compatible with what is expected for an electromagnetic particle with the same kinematic characteristics as the candidate electron; moreover, consistency is asked between the energy released in ECAL and initial momentum of the track. A cut on the invariant mass, built using the candidate track and any opposite sign track in the event, is used to reject conversions.

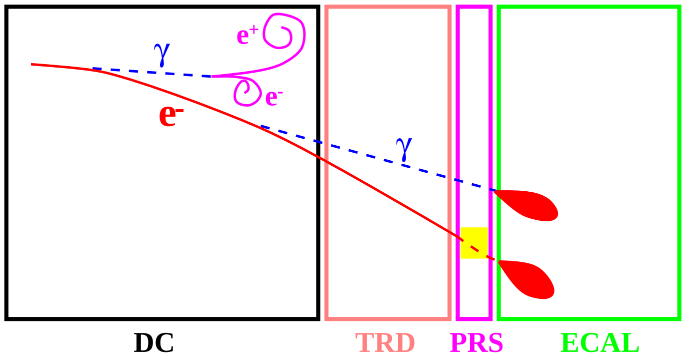

Figure 3: Sketch of a primary electron inside the NOMAD detector

In charged current interactions, the primary charged lepton is spatially well separated from the hadronic jet; on the contrary, in case of conversions, which are the main source of background, the electron is approximately collinear to the jet. This distinctive property is used in the present analysis to reject ν_μ neutral current interactions or charged current interactions with the muon not identified.

The electron identification efficiency achieved applying the described criteria is of the order of 40% for energies above 15 GeV.

4 $\nu_\mu \to \nu_e$ Oscillations Search in 1995 Data

If oscillations occured with parameters in the high Δm^2 range of LSND solutions, a significative effect should be observed in the measured ν_eCC total energy spectrum. For example, in case of oscillations with $\sin^2 2\theta = 0.006$, $\Delta m^2 = 19$ eV^2, the number of ν_e charged current interactions would approximately double for $10 < E_\nu < 40$ GeV.

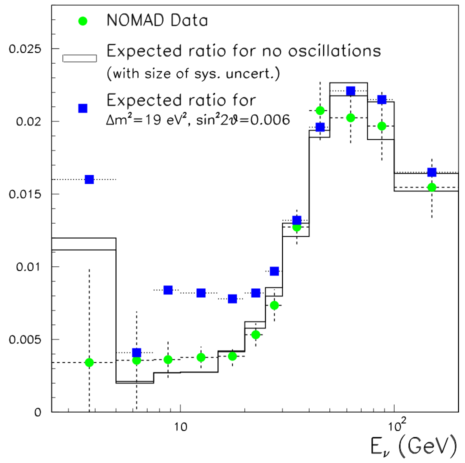

Figure 4: Observed $\mathcal{R}_{e\mu}$, compared to expectations in absence of oscillations and for oscillations with $\sin^2 2\theta = 0.006, \Delta m^2 = 19$ eV^2.

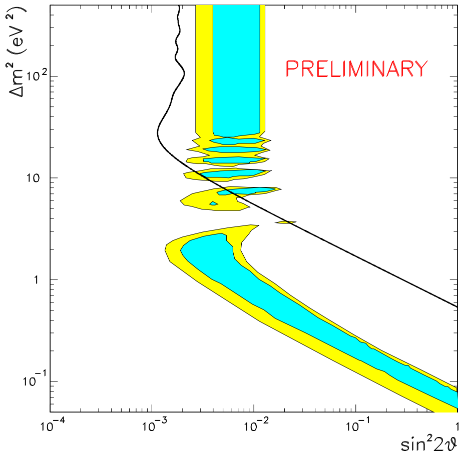

Figure 5: Preliminary exclusion plot on the oscillations parameters plane, obtained using 1995 NOMAD data; the LSND allowed region is also shown..

Results shown in this section refer to the sample collected during 1995 data taking.

In order to reduce systematic uncertainties, it is preferable to study the ratio between the number of ν_e and ν_μ charged current interactions as a function of the total energy:

$$\mathcal{R}_{e\mu}(E_\nu) = \left[\frac{\text{Nr. of } \nu_e\text{CC events}}{\text{Nr. of } \nu_\mu\text{CC events}}\right](E_\nu) \qquad (1)$$

In Fig. 4 the measured ratio (circles) is superimposed to the expected one in absence of oscillations, for which the size of systematic uncertainties is also given (area between solid histograms): error bars on data points include statistical errors only. For comparison, the expected $\mathcal{R}_{e\mu}$ for oscillations with $\sin^2 2\theta = 0.006$, $\Delta m^2 = 19$ eV^2 is also given (squares). The measured ratio fits expectations well, meaning that no evidence for oscillations is observed in NOMAD data.

A statistical comparison of the measured $\mathcal{R}_{e\mu}$ to what is expected for different values of the oscillations parameters allows to compute an exclusion plot on the $(\sin^2 2\theta, \Delta m^2)$ plane. A preliminary curve, which takes into account a 10% systematic error on the K/π ratio, is shown in Fig. 5: it corresponds to $\sin^2 2\theta < 0.0018$ for high values of Δm^2, while the limits in the maximal mixing region are determined by the experiment sensitivity; for comparison, the LSND allowed solutions are drawn.

5 Conclusions

NOMAD is able to select ν_e and ν_μ charged current interactions with good efficiency. The knowledge of the neutrino beam is such as to know ν_e/ν_μ contamination at the level of 10%. The study of this ratio as a function of the neutrino energy excludes any evidence for $\nu_e \rightarrow \nu_\mu$ oscillations from NOMAD data (1995 sample). Preliminary limits on the oscillations parameters plane have been computed, giving $\sin^2 2\theta < 0.0018$ for high values of Δm^2.

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