STATUS OF THE CHORUS EXPERIMENT

The CHORUS collaboration
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Abstract: A large number of experiments are currently trying to observe the phenomenon of neutrino oscillation in various ways. Among these, the CHORUS appearance experiment focuses on $\nu_\mu \rightarrow \nu_\tau$ and $\nu_\tau \rightarrow \nu_\tau$ detection through the observation of $\nu_\tau$ induced interactions in the Wide Band neutrino Beam at SPS (CERN). The $\nu_\tau$ identification is performed in nuclear emulsions by searching for the decay of the $\tau$ lepton in a sample of events "enriched" by kinematical selection. The detection technique will be discussed and the measured performances of the apparatus will be reported.
1. The concept of the experiment

The main characteristic of the CHORUS experiment is the visual observation of $\nu_eN \rightarrow rX$ reactions in an environment which has intrinsically no $\nu_e$ background if neutrino oscillations did not take place. In fact the 450 GeV proton SPS beamline generates a neutrino secondary beam composed mainly of $\nu_e$ (fig. 1), and the $\nu_e$ flux is estimated [1] to be $\Phi(\nu_e) \lesssim 10^{-7} \Phi(\nu_\mu)$. Such a condition is very favourable for an appearance experiment. This is not expected to be true at higher proton energies due to $D_s \rightarrow r
\nu_e$ production and decay in the target. Furthermore, the mean neutrino energy ($E_\nu \approx 30$ GeV) is high enough that $r$ production is not phase space suppressed ($\sigma_{\nu_e \rightarrow r} \approx 0.6\sigma_{\nu_\mu \rightarrow r}$). Since there is a $\nu_e$ component in the beam, upper limits on both $\nu_\mu \rightarrow \nu_e$ and $\nu_e \rightarrow \nu_\tau$ may be given if no $\nu_\tau$ candidates are found. The identification of $\nu_\tau$ induced interactions would establish the new phenomenon of neutrino oscillation. It is also necessary to discriminate against the "natural" background of the events generated by the main beam component, $\nu_\mu$. The identification of the signal is pursued in three steps: - kinematical selection, - topological identification, - events reconstruction.

**Kinematical selection**: the data sample is reduced by kinematical selection of the long lived particles produced in the neutrino interaction and detected in two magnetic spectrometers and a hadronic calorimeter (fig. 2). The muon spectrometer is dedicated to charge and momentum determination of muons up to 100 GeV/c with a measured resolution of 20% at 75 GeV/c. This is achieved by reconstructing the curvature of the trajectories of the particles in a 1.8 T toroidal magnetic field.

The high resolution hadronic calorimeter is detecting neutrals and measures the energy and
the direction of the hadronic shower produced in the neutrino induced interactions. The resolution measured with a pion beam is [2]

\[ \frac{\sigma(E)}{E} = \frac{(30.3 \pm 2.3)\%}{\sqrt{E(\text{GeV})}} + (1.8 \pm 0.7)\% \]

among the best ever obtained in a high energy experiment. This was made possible by the use of a high sampling lead/scintillating fibers matrix (spaghetti technique) optimized for compensation, which is an equal efficiency (i.e. output response) to electromagnetic and hadronic energy deposit.

The magnetic spectrometer is an air core magnet and accomplishes charge determination and momentum measurements for low energy particles. The measurement has been estimated to discriminate positive and negative charge with better than 8 standard deviations for particle momenta below 10 GeV/c, corresponding to about 90% of the tracks in neutrino induced events.

In this phase, we aim at selecting the following \( \tau \) decay channels

\[
\begin{align*}
\tau^- \rightarrow \mu^- \nu_\mu \nu_\tau & \quad (BR : 17.6\%) \\
\tau^- \rightarrow h^- \nu_\tau (\pi^0) & \quad h = \pi, K \quad (BR : 49.8\%) \\
\tau^- \rightarrow h^- h^+ \nu_\tau (\pi^0) & \quad h = \pi, K \quad (BR : 14.3\%) 
\end{align*}
\]

The typical kinematical background is due to \( \nu_\tau \) charged and neutral current interactions.
These selections, based mainly on particles energies and missing transverse momentum, have the goal to reduce by a factor $3 \div 10$ the size of the sample to be further analyzed.

**Topological identification:** the long lived particles are tracked backward, event by event, towards their origin. This is accomplished with a large scale, high resolution scintillating fiber array (target tracker). The 500 $\mu$m diameter fibers have a high two-track resolution and overall spatial resolution of about $300 \times 300 \mu m^2$ on the interface emulsion layers (c.s., fig. 3). These nuclear emulsion sheets are replaced every month during the data taking to record “unique” track candidates for each target tracker prediction; after the development, and after automatic microscope scanning controlled by computers, the track direction resolution is improved to about 0.2 mrad and the spatial position is defined up to $10 \mu m$ (s.s., fig. 3). These refined predictions are then followed into the core of the CHORUS detector, a nuclear emulsion target with a total mass of about 800 kg. It is exposed to cosmic background and to the beam for about 300 days, after which it is developed so to reconstruct, thanks to the accurate track predictions from the interface emulsions, the complete interaction topology for the selected events.

With the characteristic emulsion resolution ($< 1 \mu m$), it is possible to recognize the typical “kink” which is the signature for the $\tau$ decay into a single charged particle. The topological information, obtained with automatic and semi-automatic microscope scanning, is digitized and stored for further processing. At this stage, the main source of background is
constituted by short lived particles (mainly charmed meson decays) and so called "white kinks", i.e. coherent elastic scattering of low energy charged pions on nuclei without visible recoil. With this hybrid technique, it is possible to profit of the high spatial resolution typical of the nuclear emulsion detectors (which, however, record all the interactions and cosmic rays from the emulsion pouring to the development) and of the good time resolution characteristic of the electronic devices.

**Event reconstruction:** the $\nu$, candidate background can be additionally rejected by using the high precision track directions. The direction of the $\tau$ lepton can be measured in the emulsion, and transverse momentum conservation in the $\nu, N \rightarrow \tau X$ reaction is an additional constraint; an overall kinematical fit, together with charge conservation, is a way to increase the signal to background ratio. It has been estimated that, starting from a sample

![Figure 4: Exclusion plot for $\nu_\mu \rightarrow \nu_e$.](image)

containing $5 \cdot 10^5 \nu_\mu$ charged current interactions (which will be collected in two years of data taking), the background can be reduced to $\approx 0.4$ events. If neutrino mixing occurs at the current $\nu_\mu \rightarrow \nu_e$ limit ($\sin^2 2\theta = 5 \cdot 10^{-3}$, (3)) about 64 events are expected from the various $\tau$ decay channels indicated in (1). As the background is negligible, the experiment can
reach a probability limit which is inversely proportional to the total number of neutrino events collected. Fig. 4 shows the expected exclusion plot for the statistics indicated above.

2. Perspectives

The CHORUS detector capabilities are represented in fig. 5, where a charged current $\nu_\mu$ induced event is shown with the full detector operational. In 1994 data taking, about 150 days of successful neutrino data taking have been fulfilled, and one of the four emulsion stacks exposed to the beam has been replaced and developed to start the emulsion scanning. With the partial data set contained in these emulsions, it will be possible to put an upper limit on the neutrino oscillation probability comparable to the existing one[3]. By the end of the 1995 run, all the emulsion targets will be developed, and the search for $\nu_e$ candidates in the unexplored $\Delta m^2 - \sin^2 \theta$ region will begin.

References