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NUCLEAR PHYSICS B
PROCEEDINGS
SUPPLEMENTS

The CHORUS experiment

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The Chorus experiment, which aims at a search for $\nu_\mu \to \nu_\tau$ oscillations using the neutrino beam of the CERN-SPS, has successfully taken data in 1994 and 1995. The detection technique will be discussed and the performances of the apparatus as well as a status report will be given.

1. INTRODUCTION

The fundamental questions about neutrinos remain one of the most challenging questions of experimental high energy physics. Answers may come from searches of neutrino oscillations. Results from recent experiments on solar neutrinos are consistent with a Mikheyev-Smirnov-Wolfenstein solution to the solar problem [1]. One of the favoured solutions gives a mass of $\sim$ 3 meV to the ν_μ and through the see-saw mechanism a mass to the ν_τ ($m_{\nu_\tau} \sim 10$ eV) which would make it a candidate for dark matter [2]. Recent results on the anisotropy of the cosmic background radiation favour $m_{\nu_\tau} \sim 7$ eV. None of these considerations is compelling however, it

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suggests that $\nu_\tau - \nu_\tau$ oscillation may be within the region that the CHORUS experiment will explore, namely $\Delta m^2 > 1eV^2$ and $\sin^2 2\theta \sim 3\cdot 10^{-4}$.

2. DETECTION METHOD

The CHORUS experiment is a neutrino oscillation appearance experiment performed at the 450 GeV proton CERN-SPS muon neutrino beam. The method consists in the detection of the reaction

$$\nu_\tau N \rightarrow \tau^- X \tag{1}$$

in a background of ν_μ induced reactions. The CERN-SPS neutrino beam is very favourable for a ν_τ appearance search because, at the SPS energy, the prompt background of ν_τ, mainly produced through the decay of the D_s meson, is negligible ($\Phi(\nu_\tau) < 10^{-7}\Phi(\nu_\mu)$). Furthermore, the mean neutrino energy ($< E_{\nu_\mu} > \approx 30$ GeV) is high enough to reach the τ production threshold ($\sigma^{TOT}_{\nu_\tau\rightarrow\tau} \approx 0.6\,\sigma^{TOT}_{\nu_\mu\rightarrow\mu}$). The peculiarity of the experiment consists in its ability of directly observing the τ decay topology by means of a hybrid apparatus. The reaction $\nu_\tau N \rightarrow \tau^- X$ with one of the subsequent decay modes, $\tau^- \rightarrow \mu^-\bar{\nu}_\mu\nu_\tau$, $\tau^- \rightarrow h^-(n\pi^0)\nu_\tau$, $\tau^- \rightarrow \pi^+\pi^-\pi^-(n\pi^0)\nu_\tau$ is searched for.

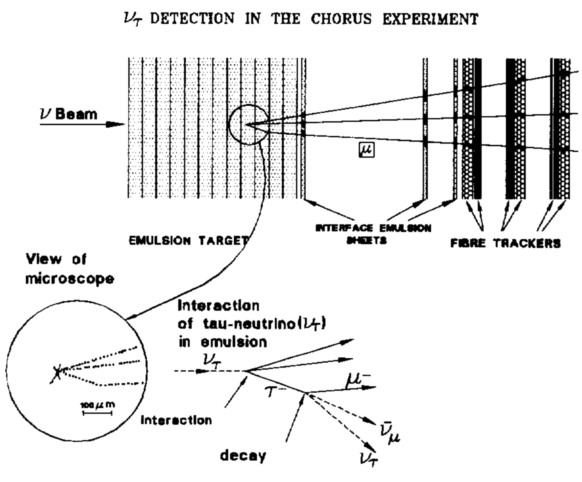

Figure 1. ν_τ detection in CHORUS

Nuclear emulsion recordings of events provide the spatial resolution needed to detect the short lived τ lepton produced in ν_τ CC interactions on an event by event basis. Electronic detectors are designed to pre-select τ candidates and to give a precise prediction of the exiting point of the charged particles in the emulsions. This procedure reduces the sample of events to be scanned in emulsions without a too large loss of efficiency. This "hybrid" approach consists of:

1) Kinematical event selection. Taking as an example the cleanest τ decay channel:

$$\nu_\tau N \rightarrow \tau^-(\hookrightarrow \mu^-\bar{\nu}_\mu\nu_\tau)X \tag{2}$$

the kinematical properties of the final state should be different once compared to those corresponding to the dominant background process:

$$\nu_\mu N \rightarrow \mu^- X \tag{3}$$

The signal (2)-to-background (3) ratio can be increased taking into account: i) in the reaction (2) a high missing transverse momentum is expected because of the two undetected neutrinos; ii) the missing transverse momentum tends to be opposite to the hadronic transverse momentum in the reaction (2) and nearly symmetric in the reaction (3).
For an effective kinematical event selection to strongly reduce the number of events that have to be scanned in emulsion, a high resolution calorimeter (p_T unbalance detection), and spectrometers (charge and momentum determination and muon identification) are needed.

2) Precise tracking. In order to reach a high detection sensitivity a large emulsion target has to be exposed for a long time. Meanwhile, a large number of particles (background beam muons, cosmic rays, products of ambient radioactivity..) will traverse the ever sensitive emulsion sheets, leaving their latent image till the photographic development. For this reason a high precision tracking system is needed as well as a very effective geometrical inter-calibration procedure.

3) τ decay and topological background . The emulsion target allows the direct observation of the decay topologies of short-lived particles such

Table 1
Efficiency of the ν_{τ^-} detection

τ^- Decay mode	Branching ratio (BR)	Efficiency (ϵ)	N^*_τ	Background	Background after vertex cut
$\mu^- \bar{\nu}_\mu \nu_\tau$	0.178	0.098	23	0.27	
$h^-(n\pi^0)\nu_\tau$	0.50	0.046	29	0.72	
$\pi^-\pi^+\pi^-(n\pi^0)\nu_\tau$	0.13	0.065	12	0.71	
ϵ total = BR $\cdot\epsilon$		0.0494	64	1.70	0.4

* The number of events corresponds to $\sin^2 2\theta = 5 \cdot 10^{-3}$ and $\Delta m^2 \geq 40 eV^2$ and a run of 2.4 $\cdot 10^{19}$ protons on target

as the τ and the precise measurement of the decay angles. Thereafter, a good measurement of the momentum and of the charge of the decay particle by electronic counters will allow to rule out most of the competing background topologies. However, some topological backgrounds will survive any cut appropriate for the τ decay (e.g. $p_T^{decay} \geq 0.24$ GeV/c), namely:
i) $\nu_\mu N \to \nu_\mu \pi^- X$, if the π^- scatters with a wide-angle without recoil ("white kink" in emulsion)
ii) $\bar{\nu}_\mu(\bar{\nu}_e)N \to \mu^+(e^+)D^-X$ (anti-charm decay), if the $\mu^+(e^+)$ are not identified.

Using this technique a total efficiency of $\sim 5\%$ for detecting one of the τ-decay modes can be achieved (table 1). Should the $\nu_\mu \to \nu_\tau$ oscillation phenomenon exist at the level of the present 90% C.L., CHORUS would observe 64 events of reaction (1) and a background of $\sim$ 1.7 events. In case some τ candidates will be found the expected background can be reduced to 0.4 events and the acceptance efficiency to 4.5% requiring a particular vertex configuration. Indeed the τ candidate track before the decay kink must balance the p_T of tracks coming from the hadron vertex. This is generally not the case for background events.

3. DESIGN AND PERFORMANCES

Design and performances of the CHORUS detector elements are briefly discussed in this section.

3.1. The Emulsion Target

The emulsion target, 800 kg in total, is segmented in 4 stacks, 8 sectors each. The emulsion sectors, 70x35 cm^2, were built piling up 36 sheets of double-coated emulsion (350 μm + 350 μm on a 90 μm thick acetate base). One stack has been replaced and developed at the end of the 1994 exposure, to start the event search procedure. The other 3 stacks have been kept at low temperature, shielded from cosmic-rays and in a low radioactivity environment, and re-exposed in 1995.
The link between the emulsion target and the fiber tracker is ensured by a "special" sheet in front of each sector, and by pairs of "changeable" sheets, separated by honeycomb spacers (fig.1). These sheets are obtained by double-coating thin emulsion layers ($\simeq$ 100 μm) on a thick acrylic base ($\simeq$ 800 μm). Sets of changeable sheets, 8 in total, were freshly produced, replaced and processed without delay during the 1994 and 1995 data taking. The background collected during the 2-3 weeks exposure of each set was found to be acceptable. The development of all emulsions (bulk target, special and changeable sheets) is being performed at CERN.
In Nagoya a completely new technique was developed, which allows a fully automatic scanning of the tracks in the emulsions with the help of CCD cameras and process computers. Semi-automatic and fully automatic measuring devices are also in use or under development in other CHORUS institutes.

3.2. The scintillating fiber tracker and the hexagonal magnet

The CHORUS tracking system consists of a target section and a hexagonal tracker system.
The former is an array of four tracker planes for each pair of emulsion stacks, i.e. one plane in-between and three downstream. Each plane pro-

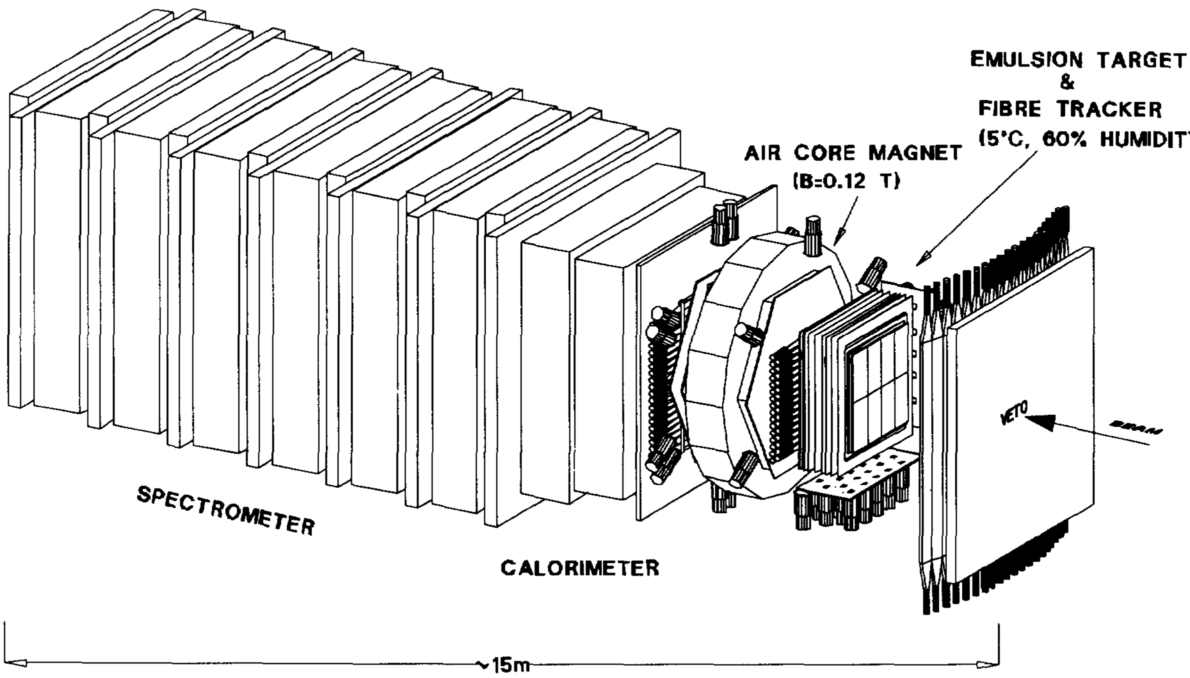

Figure 2. Lay-out of the Chorus detector

vides a measurement in 4 projections to determine an unambiguous space track. Each tracker projection is composed of ribbons of 500 μm diameter scintillating fibers arranged in seven staggered layers. The scintillating target tracker devices provide a precise prediction of the tracks on the changeable emulsion sheets.

The fibers of all the tracker modules are coupled to optoelectronic readout chains to intensify and demagnify the bundle image viewed by high resolution CCDs.

The target tracker planes have been aligned with beam and cosmic muons. The reconstructed tracks of a neutrino event predict the tracks position into the changeable sheets with a measured precision $\sim 180\,\mu$m and with an angular resolution of ~ 2.5 mrad.

The hexagonal tracker is an array of three planes. One is placed directly upstream and two downstream of the hexagonal magnet. Each plane is composed of six diamond-shaped fiber modules, arranged at a relative angle of 60°. The last coordinate plane of the target region and the first hexagonal plane are spaced by 40 cm and provide a high precision angle measurement before the magnet. The deflection of the magnet is measured with the two other hexagonal trackers placed downstream to the magnet.

The hexagonal magnet is an air-core magnet made of six equal-sided triangles with 1.5 m sides, built inside a cylinder of 3.6 m diameter and 0.75 m depth. The triangular faces are covered by aluminium windings. Each face corresponds to $\leq 4\%$ radiation length. A homogeneous field of 0.12 T is produced in each triangle, parallel to the faces and without a radial component.

The hexagonal tracker magnet and the magnet constitute a high-acceptance spectrometer, placed between the target sector and the calorimeter with the purpose of charge assignment and momentum measurement of hadrons and low-energy muons.

3.3. The Calorimeter

The CHORUS calorimeter is the first large scale application of embedding scintillating fibers into a lead matrix to obtain a fine-grained energy sampling. The calorimeter is longitudinally subdivided into three subsequent sectors: one electro-magnetic and two hadronic. The first two upstream sectors (2.6 x 2.6 m^2 and 3.35 x 3.35 m^2 respectively) are made of lead and plastic scintillating fibers in the volume ratio 4/1. The third sector (3.7 x 3.7 m^2) is made of a sandwich of lead plates and scintillator strips and complements the measurement of the hadron energy flow. The total calorimeter thickness is about 5.2 interaction lengths sufficient to contain 99% of the shower induced by a 5 GeV/c pion: about 90% of the hadrons produced in the neutrino interactions have momentum less than 5 GeV/c [3]. The calorimeter was exposed to electron and pion test beams in the momentum range from 2.5 to 20 GeV/c at CERN SPS. The energy resolution turned out to be excellent for pions and reasonably good for electrons [4]:

$$\left[\frac{\sigma(E)}{E}\right]_\pi = \left[\frac{(32.3 \pm 2.4)}{\sqrt{E}} + (1.4 \pm 0.7)\right]\% \qquad (4)$$

$$\left[\frac{\sigma(E)}{E}\right]_e = \left[\frac{(13.8 \pm 0.9)}{\sqrt{E}} + (-0.2 \pm 0.4)\right]\% \qquad (5)$$

3.4. The spectrometer

The muon spectrometer consists of six circularly magnetised iron modules made of iron plates and scintillating strip counters with a magnetic field of $\sim$ 1.6 Tesla. Five tracking sections are interleaved between the modules, and two more sections are put one in front and one behind them. The tracking sections consist of one drift chamber equipped with three planes with different orientations and eight streamer tubes.

The muon spectrometer was calibrated with a 70 GeV/c muon beam and the resolution was found to be 16.6%. In general the resolution depends on the number of modules crossed and reaches the value of $\sim$ 40% for muons crossing just one module with momentum > 10 GeV/c.

4. THE 1994-1995 DATA TAKING, ANALYSIS AND PERSPECTIVES

In 1994 and 1995 CHORUS took data with an efficiency of 83%. The total number of protons sent to the target of the CERN-SPS neutrino facility was $2x10^{19}$.

At the end of the 1994 exposure one of the four stacks was developed. The interface layer scanning started at the end of April 1995 and, at the present moment, $\sim$ 10000 tracks have been searched in the "changeable sheets" and $\sim$ 4600 in the special sheets. For some of these tracks the vertex search in the developed stack has been performed and $\sim$ 1000 vertices have been localised up to now. A few "kink events", as expected from the decay of short-lived particles produced in the ν_μ interactions, have already been found showing that the experiment is ready for an eventual τ detection.

A two year extension of data taking has been approved for the experiment. Therefore the CHORUS detector will be equipped with four new emulsion stacks since the fading phenomenon imposes the development of the old ones at the end of the 1995 data taking. Because of the low expected background, the increase of the statistics due to the 1996-1997 runs will practically double the sensitivity of the CHORUS experiment. The analysis will be completed by the end of 1998.

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