PROPOSAL TO STUDY NEUTRINO-ELECTRON SCATTERING AT THE SPS\(^{+}\)

CERN-Hamburg-Moscow-Naples-Rome Collaboration

(CHARM II)

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1. INTRODUCTION

Muon-neutrino-electron scattering was discovered ten years ago by the Gargamelle Collaboration\textsuperscript{1}). Several measurements of the cross-sections for neutrino and antineutrino scattering on electrons have been performed in the meantime. Taking all experiments together, about 100 events have been observed in each channel. These results have been important for our understanding of the structure and of the strength of the weak neutral current.

Neutrino-electron scattering is a field that can progress further, following the demonstration that experiments at high energy, using fine-grain electronic calorimeters, can detect these rare events and separate them reliably from the dominant semileptonic reactions.

We think that further work can be done at CERN in the way of more precise measurements using a dedicated detector based on the principle of a fine-grain target-calorimeter and on the accumulated experience of the CHARM Collaboration with instrumentation of this type \textsuperscript{2}).

2. PHYSICS AIMS

The most precise determination of the value of $\sin^2 \theta$, the electroweak mixing angle, in the leptonic sector has been obtained at present by the CHARM Collaboration\textsuperscript{1}), making use of the direct relation between the ratio of $\sigma(\nu_\mu e)/\sigma(\bar{\nu}_\mu e)$ and $\sin^2 \theta$,

$$ R = \frac{\sigma(\nu_\mu e)}{\sigma(\bar{\nu}_\mu e)} = \frac{1+\xi+\xi^2}{1-\xi+\xi^2}, \quad \sin^2 \theta = \frac{1-\xi}{4}. $$

In the vicinity of $\sin^2 \theta = 0.22$ this relation gives $\Delta \sin^2 \theta \sim 1/10 \Delta R$ and, hence, a very precise determination of the mixing angle. The detection efficiencies cancel in the ratio and only the ratio of $\nu_\mu$ and $\bar{\nu}_\mu$ fluxes enters.
An accuracy to be achieved can be estimated by comparing the error induced in the Born term of the $Z^0$ mass

\[
M_{Z^0} = \frac{37.4 \text{ GeV}}{\sin \theta \cdot \cos \theta}
\]

to the first order electro-weak correction of the physical $Z^0$ mass, $M_{Z^0}$, e.g. for $\sin^2 \theta = 0.220 \pm 0.015$, as determined by the CHARM Collaboration from semileptonic neutral current interactions\(^1\). Wheater and Llewellyn-Smith\(^2\) predict

\[
M_{Z^0} \text{ (Born)} = 90 \pm 2.3 \text{ GeV}
\]
\[
M_{Z^0} \text{ (physical)} = 94.6 \pm 2.3 \text{ GeV}
\]

and hence a shift of $\sim 5$ GeV. A precise experimental determination of this shift would constitute an important test of the underlying electroweak gauge theory. A significant test can be performed if the present error can be reduced to 0.7 GeV corresponding to an error on $\sin^2 \theta$ of $\pm 0.005$. This accuracy can be achieved by a measurement of the ratio $R$ to $\pm 0.05$.

Some additional information can be gained from the $y$ distribution of the events.

The strength of the neutral and of the charged current couplings can be compared directly by forming the ratio of the cross-sections of elastic neutrino-electron scattering and of inverse muon decay,

\[
R' = \frac{\sigma(\nu_e \rightarrow \nu_e)}{\sigma(\nu_\mu \rightarrow \mu^- \nu_e)}
\]

Deviations from the universal strength, $G_F^{NC} = G_F^{CC}$ are expected due to heavy leptons, which affect the $W^\pm$ and $Z^0$ propagators in different ways. An accuracy at the $10^{-2}$ level gives sensitivity to heavy leptons of mass $\sim 200$ GeV.

Although the detector we describe in Chapter 3 is optimized for the study of neutrino-electron scattering, it will perform other experiments as well. Among these we mention here coherent muon pair production, a process equivalent to $\nu_\mu^\nu_\mu + \nu_\mu^\mu$ scattering. A measurement of the cross-section of that process at the 25% level (25 events) could demonstrate the predicted destructive interference term of neutral and charged currents at the 3$\sigma$ level.
3. THE DETECTOR

3.1 Design principles

To achieve an accuracy of ±0.05 on the ratio of $\sigma(\nu_\mu e)/\sigma(\bar{\nu}_\mu e)$ the following experimental problems have to be solved:

1. EVENT RATE (more than 1000 events in each channel) requiring a large fiducial mass and a high event selection efficiency over a wide range of electron energies;

2. BACKGROUND, dominantly due to quasi-elastic electron-neutrino scattering and to coherent $\pi^0$ production has to be reduced by efficient $e/\pi$ discrimination and by precise measurement of the shower direction;

3. MONITORING of the relative flux of the different neutrino components of the beam ($\nu_\mu$, $\bar{\nu}_\mu$ and $\nu_e + \bar{\nu}_e$) is required at the level of ±2%.

Our design of a new dedicated detector is based on the principle of a fine-grain target-calorimeter and on the accumulated experience of the CHARM Collaboration with instrumentation of this type. We believe that this technique can be sufficiently improved to achieve the required accuracies.

The accuracy of shower direction measurements depends mainly on three conditions:

$$\sigma^2(\theta) = (\Delta \theta_N)^2 + (\Delta \theta_{\text{vertex}})^2 + (\Delta \theta_{\text{smear}})^2$$

- on the sampling frequency and on the method used to count the number of shower particles $N$;
- on the vertex resolution determined by the target plate thickness and by the detector granularity;
- on the width of the detector elements used to sample the lateral shower profile (smearing);

The limiting accuracy, given by the % number of the target material, is

$$\sigma(\theta) = \frac{\%}{\sqrt{N}}.$$
independent of the target density. Low Z material such as marble (Z ~ 13) or glass (Z ~ 11) is therefore favoured. In these light targets with an absorption length of $\lambda_{abs} \approx 4$ radiation lengths, electromagnetic and hadronic showers have very similar longitudinal profiles. The CHARM Collaboration has developed a method to discriminate between electromagnetic and hadronic showers in low Z materials, based on the characteristic difference of their lateral profiles. A discrimination by a factor of about 100 has been achieved with the present CHARM detector.

We will monitor the fluxes of $\nu_\mu$ and $\bar{\nu}_\mu$ and measure their spectra by analyzing the quasielastic reactions:

$$\nu_\mu n \rightarrow \mu^- p$$
$$\bar{\nu}_\mu p \rightarrow \mu^+ n.$$

Neutrinos and antineutrinos are separated by measuring the sign of the muon charge, and the neutrino energy of each event is determined by measuring the angle and the momentum of the muon. We require a momentum resolution of $\sigma(p)/p \sim 10\%$

in the momentum range $2.5 < p_\mu < 300$ GeV/c to be able to unfold the measured spectra in a reliable way. Using toroidal iron magnets ($B=1.7$ T), as in WA1 and WA18, a length of 3m is required to achieve a ratio of multiple scattering and magnetic deflection of less than 10%. The tracking accuracy of muons is contributing another term to the momentum resolution which is proportional to $p_\mu^2$. Because of the small values of $q^2$ at which quasielastic scattering occurs a forward muon spectrometer is sufficient.

3.2 The fine-grain calorimeter

The structure of the proposed, dedicated detector is shown in figure 1. It consists of 552 units of $3.7 \times 3.7 \text{ m}^2$ surface area, each composed of a 3.3 cm thick target plate of glass corresponding to 1/3 of a radiation length and of a plane of streamer tubes of the Mont Blanc experiment type with 1 cm wire spacing, read out by cathode strips of 2 cm spacing in the projection orthogonal to the wires and digitally from the wires.
Using analog electronics the centroid position of a track or a vertex can be reconstructed with ± 2 mm accuracy. The wire orientation is rotated by 90° in successive units and the position is shifted laterally by one-half wire spacing. Electromagnetic showers are characterized by a narrow lateral profile containing 95% of the energy within a range of ± 10 cm from the centre. We therefore add up the charge from 8 strips spaced by 44 cm laterally and feed it to one analog channel. There are 12 144 analog channels and 193 600 digital channels.

The total mass of the target calorimeter is 618 tons. The calorimeter is followed by a muon spectrometer.

We describe the structure in more detail in figure 1. A target plate is formed by 6 sheets of float glass glued together. This is the base plate on which we glue the streamer tube plane and the analog strips (see detail A in fig.1). The lateral wire positions are thus fixed to better than 1 mm accuracy.

The glass sheets of each unit are surrounded by a frame of A4-profile, which supports the electronics and the gas distribution, and positions the unit. The units are mounted vertically, i.e. at an angle of ~ 42 mrad with respect to the normal to the beam which slopes upwards. After every 6th unit, a layer of 20 scintillators of 15 cm width each and of 3 m length is inserted (only in the fiducial volume).

For the purpose of calibration, part of the calorimeter (~ 120 units) can be moved sideways on chariots into a test beam (see Chapter 6).

The streamer tubes are used to measure the vertex position, the shower width, and its direction and energy. These measurements allow selection of events in the fiducial volume of 436 tons, and of small shower width and small angle (or p_T²) as candidates for neutrino-electron scattering. The performance of the detector and the event selection criteria are described in Chapter 4.

The pulse height observed in the scintillator plane following the unit in which the event occurred gives additional information about the fraction of events with a single electron and of that with an initial photon. This information is required to determine the flux of electron-neutrinos in the beam and to measure the shape of the photon induced background at small angles.
The analog electronics of the streamer tube system is shown schematically in figure 2. Eight strips spaced laterally by 44 cm are connected together to one analog bus line running along each unit. The charge on each of the 22 bus lines passes a charge amplifier-stretcher, a hold circuit and a switch. The signal is divided into two, 95% being analyzed by one 8-bit ADC and 5% by another 8-bit ADC, thus providing a range of pulse-height analysis of up to 5000 channels. Pulse height conversion in an 8 bit ADC is completed after 1.2 μs and stored in a fast (55 ns cycle time) buffer memory dimensioned for 128 events from 16 channels. After the burst these memories are read out by dedicated processors on an event-by-event basis. Pedestal subtraction and suppression of channels with zero content is performed during this readout. These compacted data are then read into the on-line computer, checked, monitored and written onto tape. Before the next burst, test pulses generated by a cycling program are injected and read out by the dedicated processors to update their conversion constants and pedestal tables.

The electronics of the digital read-out is shown in figure 3. The front-end electronics is shown in figure 3a. The signals from the streamer tubes are transmitted to the daughter cards via connectors. A simple comparator is used for the front end. The comparator (LM311) is wired as a monostable.

The logical interconnections are based on a hierarchical system, as shown in figure 3b. Thirty-two channels are mounted on a "daughter" card, as in the CHARM I detector, to accept and buffer the signals from the wires of one chamber (32 wires). A "mother" card groups the outputs from 11 daughter cards. A "grandmother" card groups the outputs from the 16 mothercards and finally the CAMAC readout unit treats the outputs from the grandmother cards. The mother, grandmother and readout box multiplex the data to the event buffer. They also perform the fan-out of the control signals needed for the logic system.

The output pulse length is 1 μs, giving a dead time of 2 μs. This is a good compromise to avoid after-pulsing. The outputs from the comparators are latched by a signal derived from the scintillators. The output of the latches are written into a RAM buffer which can store 128 events. At the end of the accelerator burst, the buffers are read in parallel and then their outputs scanned by the readout box, suppressing zeros and loading the event buffer with one event from the tubes. Once an event is buffered a CAMAC transfer can take place.
3.3 The muon spectrometer

The fine-grain calorimeter is followed by a forward muon spectrometer (see Figure 1). We would like to use six of the new toroidal iron magnets of the WA1 detector and complement each by a package of eight drift tube planes of WA18 and one streamer tube plane. The total length of the system is 7m.

Each of these magnets is composed of 20 iron discs of 25 mm thickness and 375 cm diameter. They have a toroidal magnetic field of $\sim 1.7$ T. The disposal of the seven packages of wire chambers is shown in detail B of Figure 1. There are four planes of drift-tubes of each projection in alternating sequence. The track coordinate is measured with 95\% efficiency by the drift time to a precision of 1 mm in each tube. Track segments are formed by four points in each projection providing sufficient redundancy for rejecting points which deviate systematically, e.g. because of $\delta$-rays, and for resolving the left-right ambiguity locally. Each package will be completed by a plane of streamer tubes with 2 planes of 2 cm wide cathode strips oriented at $20^\circ$ with respect to the horizontal and the vertical drift tubes. These strips provide the information required to match the track projections. A global fit of these track segments across the magnets gives the muon momentum.

Bremsstrahlung of muons will be detected by the scintillation counters interspersed between the iron discs. The energy loss will be measured and taken into account in the fit of the muon track. The performance of the spectrometer can be extrapolated from the experience with the WA1 and the CHARM I-detectors, which are equipped with similar systems.

The measurement accuracy ($\sim 1$ mm) of the drift-tubes is sufficient to ensure that the contribution of the measurement error is smaller than the error induced by multiple scattering up to $p_\mu \leq 300$ GeV/c.
4. PHYSICS PERFORMANCE

In the design of the detector and in the evaluation of its performance we have been guided by the experience and the results \(^2\) we obtained using the present detector (CHARM I) and its upgraded version with streamer tubes \(^6\).

4.1 Selection of event candidates

Candidates of neutrino electron scattering events are selected by the topology of an electron shower and by the characteristic small scattering angle.

1. no muon with \(p_\mu > 1 \text{ GeV/c}\), corresponding to a range of 60 units;

2. a narrow shower profile characteristic of showers initiated by a single electron, photon or \(\pi^0\), having only a small fraction of the energy outside \(\pm 4 \text{ cm}\) from the shower centre (see figure 4);

3. "holicity", the mean number of holes in the streamer tube hit distribution in the first 24 planes (BX\(_4\)) of a shower, less than an energy dependent value compatible with an electron shower; the efficiency for electron and pion induced showers is shown in Figure 5;

4. a single electron, appearing as only one hit in both projections following the vertex plane, i.e. as one wire hit and as one strip hit;

These conditions have an estimated efficiency of 95\% for electron showers and discriminate against pion showers by a factor > 100. Among these electromagnetic shower events we select those which are characteristic of neutrino-electron scattering:

5. the electron has an energy between 2.5 and 30 GeV;

6. the electron has a value of \(E\theta^2 < 1.6 \text{ MeV}\).
These intervals are selected to enhance the signal over the background, due to $\nu_e^- \overline{\nu}_e$ (quasi) elastic scattering and to neutral current events with a $\gamma$ or a $\pi^0$ in the final state produced by coherent scattering of neutrinos on nuclei. They contain 61% of the $\nu_e$ events, to be compared with 41% in CHARM I.

The $E^2 \theta^2$ distributions observed in the CHARM I detector for events selected by conditions 1, 2, 4 and 5 ($7.5 < E < 30$ GeV) in the neutrino and in the antineutrino beam are shown in Figure 6a, b. The measured electron energy and angular resolutions imply that 90% of the $\nu_e$ events have $E^2 \theta^2 < 0.12$ GeV$^2$. The full and dotted lines in Figure 6 show the $E^2 \theta^2$ dependence of the background. We shall scale these event rates to estimate the background of the CHARM II experiment.

The main characteristic of the neutrino-electron scattering process is the small scattering angle. To exploit this fact an angular resolution comparable to the typical scattering angle of the signal

$$\theta_{\text{proj}} \sim \frac{16 \text{ mrad}}{\sqrt{E/\text{GeV}}}$$

is needed. The measured angular resolution of the CHARM I detector is shown in Figure 7. In one projection the lateral vertex position was measured after the shower traversed on average 0.5 $X_0$ ($\Delta \theta_1$ close) and in the other projection after traversal of 1.5 $X_0$ on average ($\Delta \theta_2$ far). These measurements were performed using 3 cm wide proportional tubes (pt) and 15 cm wide scintillators. The average of the two projections gives

$$\sigma(\theta) \sim \frac{48 \text{ mrad}}{\sqrt{E/\text{GeV}}} \quad \text{(CHARM I)}.$$ 

The CHARM I detector was upgraded by adding streamer tubes (st) with wires oriented at 90° with respect to the proportional tubes to each unit. The lateral position of the shower is then measured in both projections after traversal of 0.5 $X_0$, and the angular resolution is correspondingly improved ($\Delta \theta_1 \text{(st)}$), giving
\[ \sigma(\theta) = \frac{32 \text{ mrad}}{\sqrt{E/\text{GeV}}} \quad (\text{CHARM I - upgraded}). \]

For the proposed CHARM II detector the angular resolution is

\[ \sigma(\theta) \sim \frac{16 \text{ mrad}}{\sqrt{E/\text{GeV}}} , \quad (\text{CHARM II}) \]

because of its finer granularity. The energy resolution will be \( \sigma(E)/E = 20 \%/\sqrt{E/\text{GeV}} \), adequate for measuring the value of \( E\theta^2 \). Figure 8 shows the expected dependence of the background \( B \) on the angular resolution \( \sigma(\theta) = c/\sqrt{E} \), normalized to a signal of 1, for an accepted angular interval giving 90\% efficiency for \( n^{-} \) events and for \( \sin^2 \theta = 0.22 \). The resolutions of the CHARM I, the upgraded CHARM I and of the CHARM II detectors are indicated. The improvement of \( B \) depends nearly quadratically on \( \sigma(\theta) \) for \( c > 16 \text{ mrad} \); for \( \sigma(\theta) \) approaching the typical \( n^{-} \) scattering angle, \( \theta_{\text{proj}} \sim 16 \text{ mrad}/\sqrt{E/\text{GeV}} \), the background is improving more slowly and becomes nearly constant when the intrinsic angular spread of the neutrino beam is approached (~ 1 mrad). The background reduction due to the improved angular resolution of the CHARM II detector is a factor of ~ 7. We prefer the variable \( E\theta^2 \) for selecting \( n^{-} \) events because of its direct relation to the kinematics of \( n^{-} \) scattering \( (E\theta^2 = 2m_n(1-y)) \) and because of the energy independent efficiency of a cut at \( E\theta^2 < 1.6 \text{ MeV} \).

4.2 Background

The normalization of the two sources of background,

1. elastic and quasielastic charged current events induced by the \( \nu_e \) and \( \bar{\nu}_e \) contamination of the beam, and

2. neutral-current events with a \( \gamma \) or a \( \pi^0 \) in the final state produced by coherent \( \nu \) scattering on nuclei,
will be obtained, as in the CHARM I experiment\(^1\), by measuring the energy deposition (\(E_F\)) in the scintillator plane following the shower vertex in one of three units preceding it. This analysis is based on the observation that electromagnetic showers initiated by one or more photons deposit in this scintillator plane an energy larger than one minimum ionizing particle (10 MeV), whilst a large fraction of the showers induced by a single electron give an energy deposition corresponding to one minimum ionizing particle. The situation will be very similar as for the CHARM I detector seen in Figure 9, showing the energy deposition for 15 GeV electrons, as measured in a test beam (a), and for neutrino-induced events in a kinematical region where the final state is predominantly composed of photons and neutral pions (b). The number of events attributed to background (1) is obtained from events with \(E_F < 8\) MeV, observed in a reference region outside the \(\nu_e\) peak, 0.0016 < \(E\theta^2\) < 0.25 GeV and the remaining to background (2).

The \(E\theta^2\) distribution will be determined by folding the measured \(E\theta^2\) distribution of (quasi)elastic charged-current reactions induced by \(\nu_e\) and \(\bar{\nu}_e\) with the electron energy and angular resolution. The \(E\theta^2\) distribution of background (2) will be directly measured. Because of the limited number of existing scintillator planes (80) each viewing 3 target plates as compared to the total number of target planes in the fiducial volume (490) and their limited width (3 x 3 m\(^2\)) about 40% of the events can be \(E_F\)-analysed.

The results of this analysis is summarized in Table 1 of the next chapter (4.3). Using this experimental data the background contributions to the peak region (\(E\theta^2 < 1.6\) MeV) will be subtracted.

4.3 Event rates

We estimate the event rates of the proposed experiment by scaling the rates observed in the CHARM I experiment. The efficiency for selecting \(\nu_e\) scattering events is given both for the CHARM I and for the CHARM II detector. The results are summarized in Table 1, together with the background, scaled down according to figure 8. The fiducial weight of the proposed detector is 436 tons, defined by excluding 20 radiation lengths (60 units) at the end of the target-calorimeter and two Molière units (~ 20 cm) at each side for containment, and the first two units for veto purposes.
Forming the ratio $R$ of the expected neutrino and antineutrino events and taking into account the error due to the background, we find an error of $\Delta R = \pm 0.035$.

**TABLE 1**
Summary of event rates and background

<table>
<thead>
<tr>
<th>Conditions</th>
<th>$\nu$</th>
<th>$\bar{\nu}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHARM I (70 tons)</td>
<td>$(46 \pm 12) / 1.4 \cdot 10^{18}p$</td>
<td>$(77 \pm 19) / 5.7 \cdot 10^{18}p$</td>
</tr>
<tr>
<td>$7.5 &lt; E &lt; 30$ GeV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\varepsilon(1 \text{ hit}) = 61%$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\varepsilon(\text{kinem}) = 41%$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHARM II (436 tons)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>improved efficiency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\varepsilon(1 \text{ hit}) = 95%$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$2.5 &lt; E &lt; 30$ GeV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\varepsilon(\text{kinem}) = 61%$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$1023 / 5 \cdot 10^{18}p$</td>
<td>$841 / 10^{19}p$</td>
</tr>
<tr>
<td></td>
<td>$2182 / 5 \cdot 10^{18}p$</td>
<td>$1942 / 10^{19}p$</td>
</tr>
<tr>
<td>CHARM II</td>
<td></td>
<td></td>
</tr>
<tr>
<td>($E_\theta^2 &lt; 1.6$ MeV)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>signal $\nu e$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>e backgr. (1)</td>
<td>2182</td>
<td>1942</td>
</tr>
<tr>
<td>$\mu$ backgr. (2)</td>
<td>136</td>
<td>342</td>
</tr>
<tr>
<td></td>
<td>296</td>
<td>285</td>
</tr>
<tr>
<td>SUM</td>
<td>$2616 \pm 51$</td>
<td>$2569 \pm 51$</td>
</tr>
<tr>
<td>Backgr. subtracted</td>
<td>$2182 \pm 51$</td>
<td>$1942 \pm 51$</td>
</tr>
</tbody>
</table>
4.4 Monitoring

In the CHARM I experiment [3] the neutrino flux was measured using the (quasi) elastic reactions

$$\bar{\nu}_\mu p \rightarrow \mu^- n$$
$$\nu_\mu n \rightarrow \mu^+ p,$$

and we will use the same method for CHARM II. At large energy ($E_\nu > 8$ GeV) the total cross section and the $Q^2$ dependence of these processes becomes energy independent and equal for neutrinos and antineutrinos. Using these facts, the ratio of the $\nu_\mu$ and $\bar{\nu}_\mu$ fluxes and their energy spectra can be determined, without detailed knowledge of the form factors, of the influence of the Pauli principle or of the effects due to the Fermi motion of the nucleons inside the nucleus. This method can be extended to lower neutrino energies ($E_\nu \geq 2.5$ GeV) by restricting $Q^2$ to a region of small but finite values to equalize the cross sections for the neutrino and antineutrino induced reactions. Figure 10 shows our measurements [7] for quasielastic reactions at low $Q^2$. A peak appears at small $Q^2$ for $E_\nu > 10.8$ GeV, because of the inverse $\mu$ decay reaction

$$\nu_\mu e^- + \mu^- \nu_e.$$

Figure 11 shows the measured energy spectra of the selected quasielastic events after unfolding of the muon momentum resolution. The contamination of neutrinos with wrong helicity is 7% in the neutrino beam and 9% in the antineutrino beam. Above 30 GeV the spectra are falling exponentially with energy, and around 80 GeV a change of slope is observed due to kaon decays. The energy-weighted ratio of $\nu_\mu$ and $\bar{\nu}_\mu$ fluxes will be determined to ±2% accuracy, including systematic uncertainties, e.g. those due to the selection of events in a small interval of $Q^2$.

The background of electron neutrinos, also shown in figure 11, has been obtained by Monte Carlo calculations; it amounts to approximately 2%. As, however, the cross section of electron neutrino-electron scattering is ten times larger [8] than that of $\nu_e$ scattering, a measurement of the $\nu_e + \bar{\nu}_e$ flux to better than ±10% is needed. This will be achieved by selecting electromagnetic shower events with $E_P < 8$ MeV and $Q^2 > 0.016 \text{ GeV}^2$, due to the quasielastic reactions.
\( \nu_e (\bar{\nu}_e) N \rightarrow eN \).

As shown in Chapter 4.2, this method will select \( \sim 40\% \) of all events, typically a few hundred events in each beam.

We conclude that neutrino flux ratios can be monitored to \( \pm 2\% \) and, hence, that the aim of measuring the ratio of \( (\nu_\mu, e) \) and \( (\bar{\nu}_\mu, e) \) cross sections to \( \pm 0.05 \) can be achieved.

5. THE NEUTRINO BEAM

Aiming for high statistics measurements of neutrino-electron scattering we require a wide band neutrino and antineutrino beam, optimized for the highest event rate in the energy range of recoil electrons between 2.5 and 30 GeV. The horn focussed wide band beam at the CERN West Area Neutrino Facility can match these conditions, provided a number of special provisions are made for the proposed experiment:

1. 400 GeV protons, obtained by ejection during the rise or the fall of the magnetic field during 450 GeV operation;

2. no angular collimation of the parent beam (e.g. collimation at 3 mrad reduces the event rate by a factor of \( \sim 2 \));

3. rate optimized target length and horn-reflector operation;

4. thin titanium window for the decay tunnel;

5. 2 ms spill length.

We require accurate knowledge of the ratio of \( \nu_\mu \) and \( \bar{\nu}_\mu \) fluxes as a function of energy. In the CHARM I experiments this has been achieved using quasielastic \( \mu^- \) and \( \mu^+ \) events. We will extend this technique to lower neutrino energies, restricting the value of \( Q^2 \) to small values to equalize the cross sections for the neutrino and antineutrino induced reactions (see also Chapter 4.4).
An important cross check can be obtained by measuring the flux ratio of muons in different gaps of the iron shield. Solid state detectors calibrated by scintillation telescopes are required for this measurement. Beam monitoring, steering and positioning equipment, in front of the target and in the iron shield, is needed to keep the effective neutrino spectrum constant.

6. LOCATION OF THE DETECTOR AND RUNNING CONDITIONS

The total length of the proposed detector, including the muon spectrometer, is \( \sim 38 \) m and requires most of the space available in Hall 182 which is presently housing the neutrino experiments WA1 and WA18.

Much of the present infrastructure of this hall will be used again, e.g. gas systems, cables, cooling, power and counting rooms.

We foresee the need of calibrating the response and the resolution of the new detector in a test beam. The design allows us to move 120 units (corresponding to 40 radiation lengths and 10 absorption lengths) sideways by \( \sim 4 \) m into a beam of negative particles with momenta from 2 to 300 GeV/c to be derived from the H3 beam of the West Area. This beam has to travel in vacuum up to the detector.

As stressed in Chapter 5, we require SPS operation at 400 GeV to optimize the event rate.
7. COST ESTIMATE

We estimate the costs as follows:

## 1. TARGET CALORIMETER

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Cost (KSF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 552 target plates (618 tons)</td>
<td>860</td>
</tr>
<tr>
<td>1.2 Streamer tubes for 552 units (194K)</td>
<td>1000</td>
</tr>
<tr>
<td>1.3 Support structure</td>
<td>210</td>
</tr>
<tr>
<td>1.4 Accessories for streamer tubes</td>
<td>300</td>
</tr>
<tr>
<td>1.5 Analogue electronics (12 144 ch)</td>
<td>785</td>
</tr>
<tr>
<td>1.6 Digital electronics (194 Kch)</td>
<td>1280</td>
</tr>
<tr>
<td>1.7 Gas supply and mixing system</td>
<td>100</td>
</tr>
<tr>
<td>1.8 80 planes of scintillation counters, phototubes and pulse height analysis</td>
<td>(existing)</td>
</tr>
<tr>
<td>1.9 Rail system for maintenance bridge</td>
<td>15</td>
</tr>
</tbody>
</table>

**Total for Target Calorimeter:** 4550 KSF

## 2. MUON SPECTROMETER

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Cost (KSF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1 6 toroidal iron magnets of WA1</td>
<td>existing</td>
</tr>
<tr>
<td>2.2 Seven packs of 8 planes of drift tubes each, streamer tube electronics 2664 channels</td>
<td>existing 20 K</td>
</tr>
<tr>
<td>2.3 Support system for drift tubes</td>
<td>100</td>
</tr>
<tr>
<td>2.4 Drift time electronics for 7200 wires</td>
<td>155</td>
</tr>
</tbody>
</table>

**Total for Muon Spectrometer:** 275 KSF

## 3. DATA ACQUISITION SYSTEM

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost (KSF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change of existing on-line system</td>
<td>-</td>
</tr>
<tr>
<td>(replacement of 21MX by NORD 500)</td>
<td></td>
</tr>
<tr>
<td>Extension of CAMAC system for readout</td>
<td>200</td>
</tr>
</tbody>
</table>

**Total for Data Acquisition System:** 200 KSF

## 4. GRAND TOTAL

**Total:** 5025 KSF
We are asking our funding agencies for the following contributions in money and materials to finance these costs:

<table>
<thead>
<tr>
<th>Location</th>
<th>Amount (KSF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hamburg</td>
<td>900</td>
</tr>
<tr>
<td>Rome-Naples</td>
<td>1000</td>
</tr>
<tr>
<td>Moscow</td>
<td>500</td>
</tr>
<tr>
<td>CERN</td>
<td>2600</td>
</tr>
</tbody>
</table>

It is not yet decided how the constructions are to be shared by the participants. It will be similar, in some way, as for the construction of the CHARM I detector: Hamburg analog and readout electronics and target plates, Rome and Naples streamer tubes and digital electronics, CERN mechanical construction, streamer tubes and electronics, Moscow printed boards, mounting and testing of electronics.

We would, of course, welcome other groups or individuals who are interested in participating in this experiment.

8. TIME SCHEDULE

It is our intention to have the new detector ready and installed for the SPS fixed target running periods starting in June 1985. Installation in building 182 should start in the summer of 1984, preferentially from the upstream side, to allow running of the CHARM I detector in the WBB during the fixed target periods of 1984.
REFERENCES


Fig. 1  Layout of the fine-grain calorimeter, composed of 552 units, and of the muon spectrometer, composed of 6 toroidal iron magnets. Details A and B show the modular structure of the fine-grain calorimeter and of the muon spectrometer, respectively.
Fig. 5 Efficiency of selecting electron and pion showers by requiring a minimum number of holes in the hit distribution of the streamer tubes in the first 3 $X_0$. 
Fig. 6 Distribution of the candidate events as a function of $E^2 \theta^2$ (a) in the neutrino beam, (b) in the antineutrino beam, as observed in the CHARM I experiment [3]. The lines show the $E^2 \theta^2$ dependence of the background.
Fig. 7 Measured angular resolution for electron showers in the CHARM I and the upgraded CHARM I detector.
Fig. 8 Background in an $E^{0.2}$ interval containing 90% of the $\bar{\nu}_\mu$ events as a function of the angular resolution $\sigma(\theta) = c/\sqrt{E/\text{GeV}}$, $c$ in mrad. The CHARM I, upgraded CHARM I and CHARM II resolutions are indicated. The background is normalized for a signal equal to 1, using the experimental data of figure 6b.
Fig. 9 Energy deposition ($E_F$) observed in the CHARM I detector in the scintillator plane following the vertex (a) for 15 GeV electrons (b) for $\pi^0$'s. The situation in the CHARM II detector will be very similar.
Fig. 10 Observed $Q^2$ dependence of (quasi)elastic $\nu_\mu(\mu^-)$ and $\bar{\nu}_\mu(\mu^+)$ events.
Fig. 11 Neutrino spectra in neutrino and antineutrino WBB as determined by quasielastic events (νμ and νμ). The νe + ν̄e contamination has been calculated by Monte Carlo methods. In the CHARM II experiment this contamination will be measured by the quasielastic events (νe + ν̄e).