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NEUTRINO-ELECTRON SCATTERING: PROSPECT WITH THE CHARM II DETECTOR

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NEUTRINO-ELECTRON SCATTERING:
PROSPECTS WITH THE CHARM II DETECTOR

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ABSTRACT

The importance of a precise determination of $\sin^2\theta_w$ in purely leptonic $\overset{(-)}{\nu}_\mu e$ elastic scattering is briefly reviewed. The severe experimental problems involved in the measurement are discussed. Progress in the construction and preliminary operation of the new massive, fine-grained, low density CHARM II detector is reported.

INTRODUCTION: present knowledge of the e.w. mixing angle

The standard model of the electroweak interactions[1], in its simplest version with one single doublet of Higgs fields, is a one-parameter theory. This one parameter, the e.w. mixing angle θ_w, determines both the cross sections of scattering processes mediated by the neutral weak boson Z^0 and the masses of the (neutral and charged) weak boson Z^0 and $W^{\pm}$. It is possible, therefore, to check the basic assumption of the theory by means of widely different experimental measurements.

The standard model is a renormalizable quantum field theory (QFT), capable in principle of calculating observable quantities to any order in the perturbation expansion. The most precise experimental determinations[3] of $\sin^2\theta_w$, extracted from the data using the Born approximation of theory, agree remarkably well with each other (table 1a). Less precise determinations from lepton-quark scattering and electron-positron annihilation show[3] good consistency. The model therefore provides an excellent description of the e.w. interactions at the tree level.

Table 1

		neutrino-quark scattering	neutrino-electron scattering	W and Z production
1a)	$\sin^2\theta_W$ (tree level)	.232 ± .010	.215 ± .030	.207 ± .010
1b)	size of 1-loop corrections	∿ 5%	∿ 1%	∿ 7%
	$\sin^2\theta_W$ (1-loop level)	.225 ± 010	.215 ± .030	.223 ± .010
1c)	ultimate accuracy $\Delta\sin^2\theta_W$	± .005 (+theor. uncer.)	± .005	± .002
	experiments	CHARM, CDHS	CHARM II	UA's, CDF, LEP I/II

The same data can also be compared to one loop calculations[4] of cross sections and masses. Different processes are affected by very different corrections. The conclusion (table 1b) that inclusion of one-loop radiative corrections does improve agreement between experiments is certainly reasonable[5]; it is evident, however, that a conclusive statement, which would strongly reinforce our confidence in the model as a renormalizable QFT, needs much more precise values of $\sin^2\theta_W$ from as many as possible of the above-mentioned physical processes. Even small deviations from universal agreement may signal new physics.

Much better measurements of M_W and M_Z will come from hadron colliders within a few years[6], the ultimately precise measurements of M_Z and M_W being left[7] for LEP I and LEP II. More precise results from low energy neutrino scattering will also be coming. The prospects are summarized in table 1c.

More accurate results from $\nu_\mu q$ scattering were already presented to this conference[8] and are rapidly approaching their final values. The quoted experimental accuracy of ±.005 is, however, admittedly[4] accompanied by a comparable (or larger!) theoretical uncertainty in the strongly interacting quark sector. The best low-energy determination of $\sin^2\theta_W$ may well come in the end from the purely leptonic $\nu_\mu e$ and $\bar{\nu}_\mu e$ scattering, in spite of the smallness of its cross sections.

NEUTRINO-ELECTRON SCATTERING

The ratio $R = \sigma(\nu_\mu e)/\sigma(\bar{\nu}_\mu e)$ of ν_μ and $\bar{\nu}_\mu$ cross sections on electrons is a very sensitive estimator of $\sin^2\theta_W$. It is of order unity for $\sin^2\theta_W \approx .25$; in that vicinity $|\Delta R/\Delta\sin^2\theta_W|$ is about 8 (fig. 1), so that only a relatively poor (± 4%) measurement of R is required to give $\Delta\sin^2\theta_W = \pm 0.005$. Only relative normalization is necessary. No theoretical uncertainty enters. Systematic uncertainties and even radiative corrections[4)] largely cancel in the ratio.

The experimental signature for $\overset{(-)}{\nu}_\mu e$ scattering is in principle very clean; it requires the detection of an isolated electron, kinematically constrained to very small forward angles θ_e, within a narrow "natural" cone $\theta_e \le \sqrt{2m_e/E_e} \sim$ 32 mrad/$\sqrt{E_e}$, E_e being the electron energy.

The very low cross sections ($\approx 10^{-42}$ cm^2) involved, however, have limited so far experimental data samples to less than 100 events per channel. Two such (± 25%) measurements of R have been completed by the CHARM[9)] group at CERN ($\sin^2\theta_W = .215 \pm .032$) and the E734[10)] group at BNL ($\sin^2\theta_W = .209 \pm .029$). The merits of the R method are far from being fully exploited.

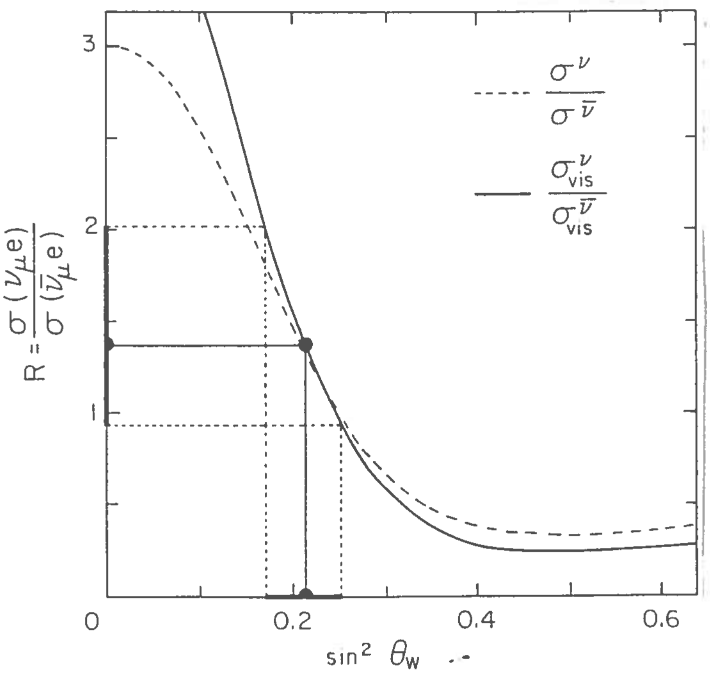

Fig. 1 The ratio R as a function of $\sin^2\theta_W$. The dashed curve represents the expectation in the case of full energy acceptance. The full curve represents the expectation for events in the energy range 7.5 to 30 GeV experimentally accessible to CHARM. The measured value of R and $\sin^2\theta_W$ are shown together with their statistical errors.

A 4% measurement of R is however both necessary and possible. The CHARM II detector being assembled at CERN aims[11)] at the collection of about 3000 events per channel, i.e. a statistical uncertainty in the ratio of collected events of about 2.6%. This will be achieved by means of a target fiducial mass adequately large to provide enough e^- scatterers and adequately instrumented to ensure efficient detection of their recoil. The choice of a massive fine grain calorimeter re-emerges naturally. Its design is deeply rooted in the experience accumulated with CHARM.

Neutrino-electron interactions will have to be isolated from a 10^4 times larger background of (muonless) neutrino-quark interactions. A small most stubborn "electromagnetic" fraction*) of this background will actually have to be estimated and subtracted from the signal. The most powerful rejection tool is good resolution in the measurement of the shower recoil angle. This angular resolution is proportional to Z, the atomic number of the target material, imposing the choice of a low-density calorimeter. The uncertainties associated with rejection and subtraction procedures can be controlled down to a level small with respect to the statistical uncertainty.

The measurement of R needs, of course, a precise measurement of the relative flux of ν_μ's ($R = F \frac{N(\nu_\mu e)}{N(\bar{\nu}_\mu e)}$, where $F = \frac{\phi(\bar{\nu}_\mu)}{\phi(\nu_\mu)}$ is the ratio of fluxes and N are number of events). F can be measured at the 2-3% level, thus providing $\Delta R/R \lesssim \sqrt{2.6^2 + 3.0^2} = 4\%$ and $\Delta \sin^2\theta_W = \pm .005$.

THE CHARM II DESIGN

The major improvements with respect to CHARM, in response[12] to the severe experimental problems being faced, are:

1) low event rate:

   (a) fiducial mass: the 80 tons of CHARM are "brute forcedly" scaled-up by a factor 5.5 (440 tons).

   (b) electron detection efficiency: an improvement of about a factor 1.6 (up to ∿ 95%) is achieved by means of a much finer detector granularity. The lateral granularity is 1 cm rather than 3 cm: electron-hadron separation criteria, based on lateral shower profiles, will more efficiently single out the narrow and regular electron showers. The longitudinal granularity is also reduced from 1.0 to 0.5 rad. lengths:

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*) It contains events due to two main sources:

NC background (hadronic showers with purely e.m. component, like coherent production off nucleons $\nu N \to \nu \pi^0 X$)

CC background (quasi-elastic scattering on nucleons of $\overset{(-)}{\nu}_e$'s contaminating the $\overset{(-)}{\nu}_\mu$ beam, i.e. $\overset{(-)}{\nu}_e N \to \overset{(-)}{e} X$)

where recoil or soft break-up of the X system has escaped detection.

electron-photon separation criteria, based on the requirement of one single hit in the first active detector in the shower, will accept a significantly larger fraction of the electron signal.

(c) kinematical acceptance: hadron rejection is altogether more poweful, particularly for low shower energies. CHARM II will reliably tag electrons down*) to an energy E_e of about 2.5 GeV (7.5 GeV in CHARM), i.e. it will detect a fraction of the $\overset{(-)}{\nu}_\mu e$ cross-sections larger by about a factor 1.5.

(d) upgraded WBB: a larger yield of $\overset{(-)}{\nu}_\mu e$ events per SPS proton will be obtained thanks to a higher momentum (450 GeV/c) primary proton beam and of a newly built high flux magnetic horn whose shape is designed to maximize the yield of recoil electrons with $2.5 \leq E_e \leq 30$ GeV. WBB exposures longer than in the past have been approved. An overall gain of 2.2 in event rate is expected.

The net result of a) b) c) d) is an expected number of events per channel about a factor 30 larger than in CHARM.

2) background subtraction:

$\overset{(-)}{\nu}_e$ elastic scattering is strongly forward peaked ($E_e\theta_e^2 \leq 2\ m_e \approx 1$ MeV). A precise measurement of the electron recoil angle will powerfully suppress the contamination of NC and CC backgrounds, as they have much flatter angular distributions. Glass is used as a target material ($\langle Z \rangle \simeq 11$, similar to the value of $\langle Z \rangle \simeq 13$ of CHARM marble). The much improved granularity, however, provides $\sigma_\theta \sim 16$ mrad/$\sqrt{E}$ in each projection ($\sigma_\theta \sim 48$ mrad/$\sqrt{E}$ in CHARM). A cut $E_e\theta_e^2 \leq 1.6$ MeV or so will be applied to isolate the $\overset{(-)}{\nu}_\mu e$ signal (fig. 2), with a signal to background ratio S/B ~ 2.5 (~ 0.5 in CHARM). The systematic error due to background subtraction of CC and NC background from the forward peak will therefore be small, negligible with respect to the

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*) Contamination from the CC background grows with E_e; $\overset{(-)}{\nu}_e$ come from the decay of energetic kaons and quasi-elastic electrons retain all of the ν's energy. The same $E_e \leq 30$ GeV cut as in CHARM will be applied.

dominant statistical error.*)

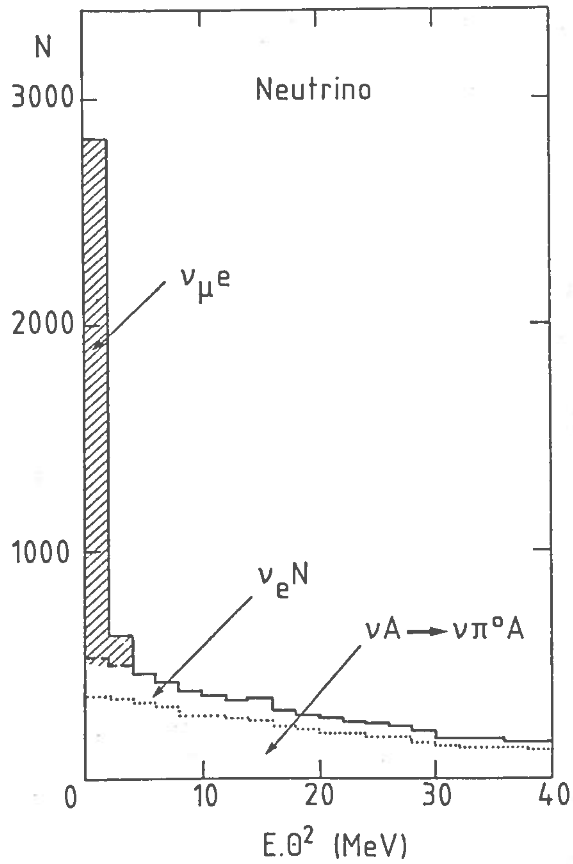

Fig. 2. Expected $E\theta^2$ distribution of $\nu_\mu e$ events and of the CC and NC background in the neutrino beam. The distribution is very similar in the anti-neutrino beam.

3) <u>flux normalization:</u>

A process with ν_μ and $\bar{\nu}_\mu$ cross sections large and equal to each other is best suited to the job. Quasi-elastic scattering ($\nu_\mu n \rightarrow \mu^- p$ and $\bar{\nu}_\mu p \rightarrow \mu^+ n$) off nucleons in an isoscalar target gives $(\sigma_\nu - \sigma_{\bar{\nu}})/\sigma_\nu \sim Q^2/E_\nu$ so that $\nu/\bar{\nu}$ asymmetry will be small at low Q^2 and large E_ν. Experimentally one has to isolate recoil-less CC neutrino interactions at $Q^2 \simeq 0$. A forward spectrometer will be sufficient to measure the

*) The contamination of the forward signal due to background is determined by extrapolating back from the larger $E_e\theta_e{}^2$ region. A measurement of energy deposition in the early stage of the development of e.m. showers will permit to reject photons (NC events) while retaining electrons (CC events) with a known efficiency; it is thus possible to determine separately the number of events at large $E_e\theta_e{}^2$ from the two backgrounds. As their $E\theta^2$ distributions are both known, the two contaminations to the forward signal can be separately subtracted.

momentum of the muon, establish its quasi-elastic origin and map the ν_μ and $\bar{\nu}_\mu$ spectra. Uncertainties in the F factor (in particular from the corrections for the small $\nu/\bar{\nu}$ asymmetry, for the N^* and Δ contamination, for the effect of Fermi motion and of Pauli's principle) will hopefully be controllable down to 2% or slightly more. The ratio of the inclusive ν and $\bar{\nu}$ rates, known[8] to $\sim$ 3%, will also be monitored, providing a welcome check of the relative normalization.

The detector will also be in a good position to provide additional physics results. Among them, the detection of coherent production of unlike-sign dimuons in a Coulomb field (a process equivalent to $\nu_\mu \mu$ scattering). A signal about 10 times larger than the two event candidates found by CHARM[13] is expected and should be adequate to establish the predicted NC/CC negative interference.

THE CHARM II DETECTOR

The detector consists[11] of a modular target calorimeter of 36 m length, instrumented with streamer tubes and scintillators, followed by an 8.6 m long muon spectrometer. The total mass of the target calorimeter is about 700 tons.

The basic module of the calorimeter has an active area of 3.7 x 3.7 m^2 and is built of a glass target plate of $\frac{1}{2}$ X^0 thickness (48 mm) followed by a plane of 352 plastic streamer tubes of the Mont Blanc type with about 1 cm wire spacing. Four hundred and twenty modules constitute the calorimeter, the wire orientation of consecutive modules being alternatively rotated by 90^o (fig. 3). Wire signals are digitally read-out, while pick-up strips of 21 mm spacing in the projection orthogonal to the curves are read-out analogically. A total number of 150 thousand digital and 10 thousand analog channels is attained. The streamer tubes are used to measure width, energy and direction of the shower. They also give the vertex position and the hit multiplicity in the plane following the vertex. Each sixth module is also equipped with a plane of 3 cm thick scintillators of 3 x 3 m^2 active area, used to measure energy deposition. The availability of this information, even only for a fraction of the calorimeter, will strengthen control of the background subtraction procedure.

The forward muon spectrometer consists of six modules of the disassembled CDHS detector[14], kindly made available to us. Each module is a magnetized iron toroid of 50 cm thickness with a field of 1.6 T, followed by a triplet of tracking (drift) chambers. A momentum resolution of $\sim$ 15% is expected.

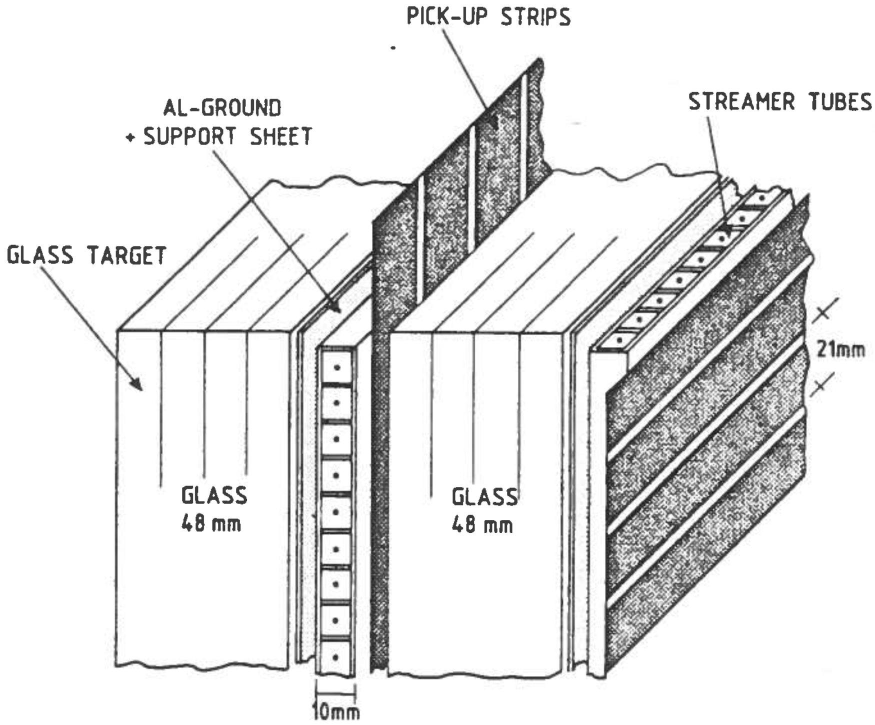

Fig. 3 Basic modules of the target calorimeter

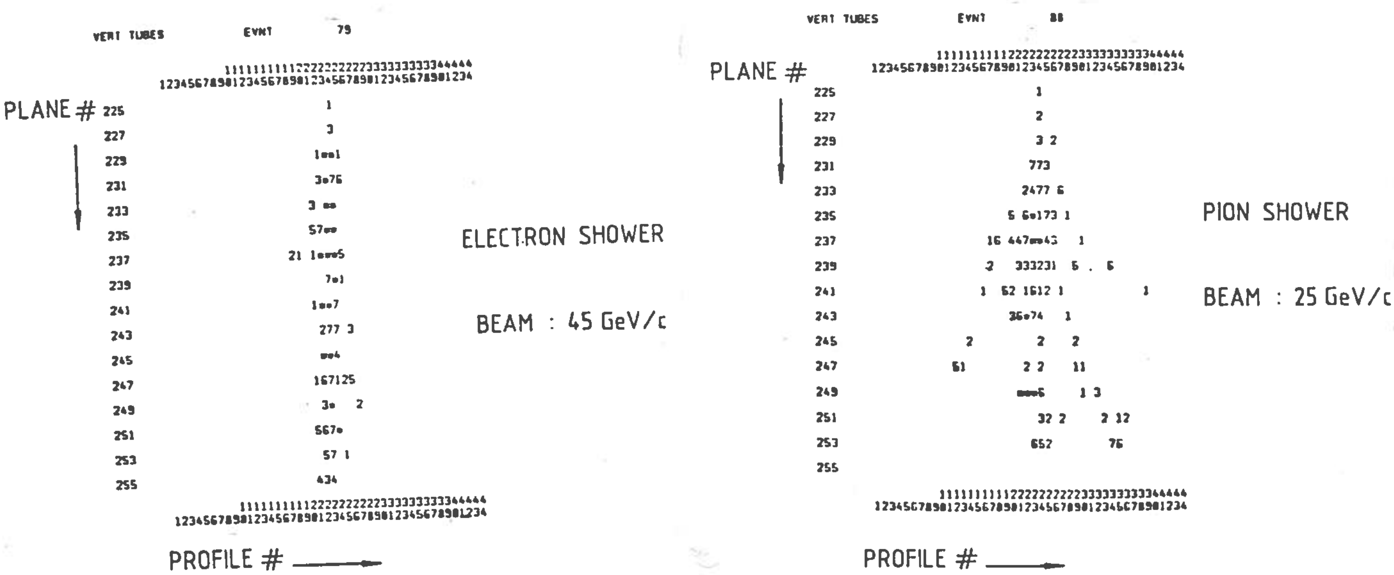

Fig. 4 Test beam events for an electron-induced shower and for a pion-induced shower

A number of calorimeter modules equivalent to about 15% of the total was tested[15)] with cosmic ray and with a test beam of electrons and pions. The best position resolution is given by the analog strips; it has a $\sigma \simeq 2.1$ mm for minimum ionizing particles. Typical electron and pion showers are shown for one projection in fig. 4. A plane of streamer wires is divided into 44 groups of 8 wires, the number of wires hit in each group is displayed. The horizontal axis gives the number of the 8-wires group; the vertical axis gives the plane number in the detector. The distinctive high density and narrow shower profile of the electron-induced shower is clearly visible. The effectiveness of the separation techniques is presently under detailed investigation.

Test beam data were taken only with digital read-out of the wires; the effective sampling step was thus only 1 X^0 in each projection. The angular resolution measured in this condition can be parametrized as 20 mrad/$\sqrt{E}$. A combined analysis of digital and analog information should therefore achieve the goal of a 16 mrad/$\sqrt{E}$ angular resolution.

Data collection will begin with the start of the 1986 operation of the CERN SPS. Half of the statistics should be collected by the end of the year, already providing the most accurate determination of $\sin^2\theta_W$ in purely leptonic interactions. Completion of data taking will follow when SPS operation restarts in the second half of 1987 after the ACOL shutdown.

REFERENCES

1) S.L. Glashow, Nucl. Phys. 22 (1961) 579; S. Weinberg, Phys. Rev. Lett. 19 (1967) 1264, and 27 (1971) 1688; A. Salam, "Elem. particle theory", Almquist and Wiksells, Stockholm (1969) 367.

2) G.W. t'Hooft, Nucl. Phys. B83 (1971) 173.

3) For a recent review, see:
A. Blondel, CERN-EP/86-16, February '86, and references therein.

4) A. Sirlin, W. Marciano, Proc. of the 1983 Symposium on Lepton and Photon Interactions; W. Hollick, Review of radiative corrections presented at this "Rencontre".

5) L. Maiani, Int. Conf. on High Energy Physics, Bari, July 1985, CERN-TH 4326.

6) L. di Lella, Int. Conf. on High Energy Physics, Bari, July 1985, CERN-EP/85-184.

7) LEP Physics Workshop, CERN yellow report 86-02.

8) CDHS Collaboration, result presented by E. Hughes at this "Rencontre", $\sin^2\theta_w = .224 \pm .005$; CHARM Collaboration, result presented by J. Panman at this "Rencontre", $\sin^2\theta_w = .236 \pm .005$.

9) CHARM Collaboration, Phys. Lett. 117B (1982) 272 and 147B (1984) 481.

10) E734 Collaboration, Phys. Rev. Lett. 54 (1985) 18.

11) CHARM II proposal, CERN/SPSC/83-24 and 83-37.

12) K. Winter, CERN-EP/84-137.

13) CHARM Collaboration, Phys. Lett. 122B (1983) 185.

14) CDHS Collaboration, Nucl. Instr. and Methods 148 (1978) 235, and CERN/SPSC/79-34.

15) CHARM II Collaboration, Wire Chamber Conference, Vienna, February 1986, presented by W. Flegel.