The JURA neutrino experiment:
The first H.E. long-baseline oscillation search

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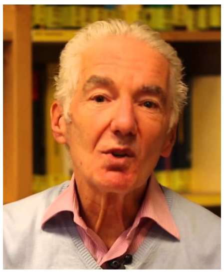

Following the Memorandum SPSC/80-58, a Letter of Intent SPSC/80-74 was submitted to the CERN SPS committee in August 1980, then a proposal P158 followed in Feb. 1981. It discussed a search for oscillations in the SPS high energy neutrino beam.

1 Neutrino oscillations

The idea of neutrino oscillations was proposed long before 1980[1]. They became topical with the publication of results suggesting that neutrinos may have a non-zero mass:

- A mass around 30 eV for the ν_e was claimed in a study of the endpoint in the β decay spectrum of tritium[2];
- A ratio of neutral current (NC) to charged current (CC) cross-sections induced by anti-ν_e at a reactor was interpreted as evidence for neutrino instability[3].

Moreover Grand Unified Theories predicted very small neutrino masses[4] and the phenomenon of oscillations appeared to be the only way to investigate the problem.

2 Hot Dark Matter

At the same time, the existence of Dark Matter in the Universe took strength with the measurement of rotation curves in galaxies. The visible mass, namely the radiative one, came up to be a small part of the total mass of galaxies. Among the known elementary constituents, only neutrinos had the right properties.

Knowing that Big Bang cosmological neutrinos amount to 110 in each cm^3 for each flavor, one calculates that a neutrino mass around 1 eV/c^2 was enough to account for the missing mass. Being produced relativistically, this hypothesis gave the so-called HDM (hot dark matter) scenario. It was fast recognized that relativistic particles tend to wash out structures, not in

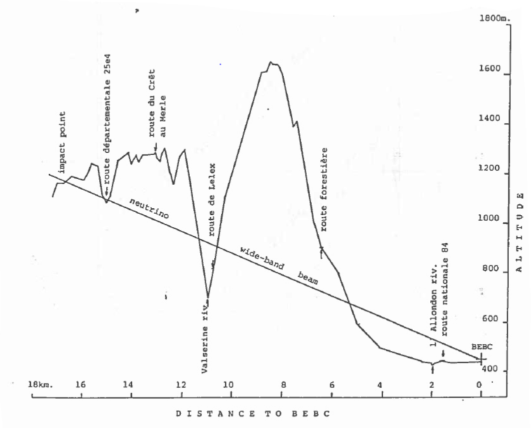

Fig. 1

Figure 1 – Neutrino beam direction accross the Jura mountain. The BEBC bubble chamber on the right-bottom shows the start of the beam.

agreement with astrophysics observations. So the MDM model was invented with a mixture of hot and cold components, the neutrinos explaining a part of the total.

Neutrino masses were not known. Upper limits were loose: 20 eV, 170 keV and 30 MeV respectively for the 3 flavors. It was essential to improve these limits and only oscillation searches were able to do so. Previous results from Gargamelle [5], LAMPF [6] and FNAL [7] had reached a level of 1 eV/c^2 for Δm^2 at maximum mixing; CDHS and CHARM were preparing low energy searches at the CERN PS.

3 The CERN high energy wide-band beam

A high energy beam had been built in the years 1970 providing neutrinos to CDHS, BEBC and CHARM detectors. It happened that the proton target was at the level of the accelerator, namely underground, while the detectors were built at ground level, consequently the beam was going up as seen on Figure 1. It crossed the Jura mountain and exited at an altitude of 1200 m in the "forêt communale de Cernétrou", 17 km from the production source. The place was easy to reach and the beam position was known to better than 1 m.

The protons were accelerated at 450 GeV giving neutrinos and antineutrinos of the predominantly muon flavor with an energy spectrum peaking at 20 GeV. There were several advantages to use high energy neutrinos: rates were more favorable, background from cosmics easy to reject, initial ν_e contamination smaller, identification of flavors more efficient. Furthermore ν_τ was no more sterile.

3.1 Achievable limits

The detection strategy was to search for a change in composition between a near-detector housed on the CERN site ~ 1 km from the target and a far detector on top of the Jura.

Both detectors were identical and composed of a fine-sampling calorimeter followed by a magnetized iron spectrometer. The electron calorimeter adopted 3 mm thick iron plates as radiator and was instrumented with flash-tube chambers for a total of 100 tons of fiducial active target. Scintillator planes were used to trigger. Muons were identified above a threshold of 1.5 GeV corresponding to 95% of CC events. Thus ν_e and ν_μ CC interactions were well recognized and measured.

Oscillations manifest themselves by the disappearance of ν_μ and the appearance of ν_e/ν_τ signed by an identified electron. NC events appear unchanged. The phenomenon depends on two

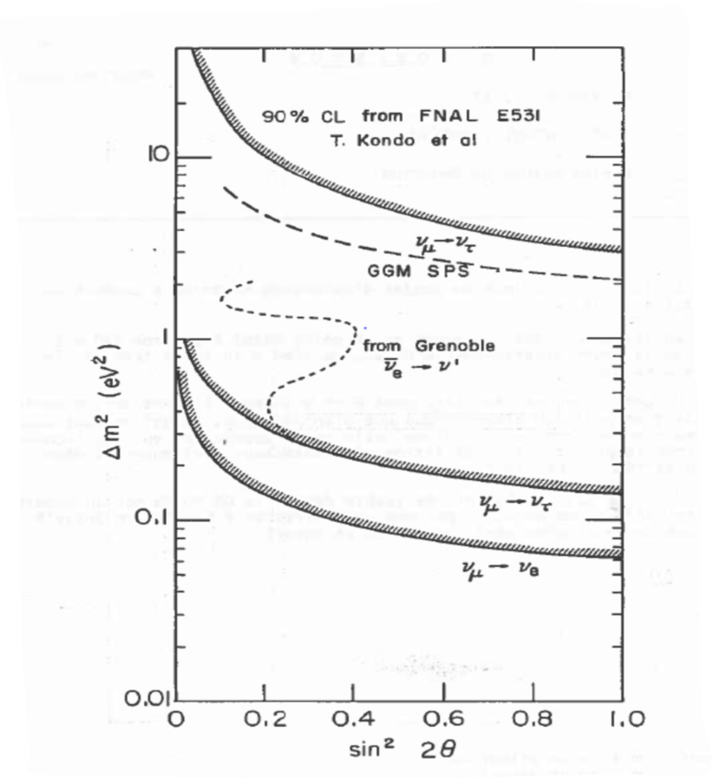

Figure 2 – Sensitivity in the Δm^2 vs $sin^2 2\theta$ plane.

parameters, a mixing factor $\sin^2 2\theta$ between oscillating flavors and $\Delta\mathrm{m}^2$, the difference between the squared masses of two mass eigenstates.

The expected rate was 1250 events per day. With the distance R of propagation, the limit on Δm^2 goes as $1/\sqrt{R}$ in first approximation. With a total statistics of 100 000 events, the reachable limits at maximum mixing were:

- For the disappearance channel: $sin2\theta\ \Delta m^2 < 0.15\ eV^2$.
- For the appearance into ν_e : $sin2\theta\ \Delta m^2 < 0.06\ eV^2$
- For the appearance into ν_τ : $sin2\theta\ \Delta m^2 < 0.13\ eV^2$

The improvement over other results was at least one order of magnitude as shown on the exclusion plot $sin^2(2\theta)/\Delta m^2$. Figure 2 shows the achievable limits of the proposal, with two curves in case of $\nu_\mu \leftrightarrow \nu_\tau$ and $\nu_\mu \leftrightarrow \nu_e$ respectively.

The cost was minimal since the electron calorimeter was a small part of a huge set-up in construction to search for proton lifetime, and the muon spectrometer was recycled from a previous experiment. The logistics of having a detector in the mountain were considered soluble.

3.2 A disappointing conclusion

The aim of the experiment dealt with ambitious problems: proving the existence of neutrino masses and of lepton number violation, thus indicating the first hints of physics beyond the Standard Model, and at the same time shedding light on the Dark Matter problem.

The committee, after having received the proposal P158 in February 1981, was convinced and ready to approve the proposal. Unfortunately, CERN was in the process of building the LEP complex and the whole experimental activity was subject to criticism from some local people. The Direction was nervous to let know that the accelerator was producing a beam getting out of the CERN territory. After months of sterile discussions, the decision was postponed sine die.

Note that the obtained limit would have avoided the dilemma of the still pending LSND and MiniBoone results.

References

1. B.Pontecorvo, “Neutrino experiments and the question of leptonic-charge conservation”, ZETF 53 (1967) 1717 (Soviet Physics JETP 26 (1968) 984; S.M. Bilenky and B.Pontecorvo, “Lepton mixing and neutrino oscillations”, Phys. Rep. 41 (1978) 225
2. V.A.Lubimov *et al.*, “An estimate of the electron-neutrino mass from the beta-spectrum of tritium in the valine molecule”, Phys. Lett. 94B (1980) 266
3. F.Reines, H.W. Sobel, E. Pasierb, “Evidence for neutrino instability”, Phys. Rev. Lett. 45 (1980) 1307
4. L. Maiani, “Neutrino oscillations”, preprint CERN-TH-2846 (1980)
5. J.Blietschau *et al.*, “Total cross sections for electron neutrinos and antineutrinos interactions and search for neutrino oscillations and decay”, Nucl. Phys. B133 (1978) 205
6. S.E.Willis et al., “Neutrino experiment to test the nature of the muon-number conservation”, Phys. Rev. Lett. 44 (1980) 522; Phys. Rev. Lett. 45 (1980) 1370
7. A.M.Cnops et al., “Experimental Limits on Heavy Lepton Production by Neutrinos”, Phys. Rev. Lett. 40 (1978) 144