PERFORMANCE OF THE NEW NEUTRINO BEAM AT THE CERN PROTON SYNCHROTRON

by

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1. The Neutrino Area

A new facility designed primarily for neutrino experiments has been constructed during 1965 - 1966 at the South East side of the CERN Proton Synchrotron. The experimental area and installations - fast ejection, septum magnet, external proton beam channel, target, secondary beam focusing elements, neutrino filter and heavy liquid bubble chamber - are shown in figs. 1 and 2. The design of this facility is such that the length available in the ejected beam direction can be utilized to the best advantage, e.g. the positioning of the target and secondary beam focusing elements with respect to the filter and bubble chamber.

After ejection from the C.P.S. ring the proton beam enters an 80 m long, 3.5 m diameter tunnel which is shielded in a manner similar to the C.P.S. The boron-carbide target (60 cm long, 6 mm diameter) is situated 60 m upstream of the filter at the beginning of the magnetic horn. The secondary beam is then focused by the magnetic horn[1] (fig. 3) and two pulsed toroidal lenses[2] (fig. 4) such that positive and negative charged secondaries are focused and defocused respectively. Those high energy secondaries produced in the forward direction which would be unaffected by these focusing devices are stopped by a plug of tungsten situated at the downstream end of the target.

At the end of the 60 m decay tunnel the secondary beam enters the neutrino filter which comprises 7000 carefully stacked 900 kg. steel ingots surrounded by 1.6 m of concrete. Those hadrons which have not decayed during their flight along the decay tunnel are absorbed in the first 2 m of the filter. The muon beam is gradually attenuated by the 20 m long filter. In order to provide a test beam for the heavy liquid bubble chamber, a 15 m long pipe filled with mercury is placed along the axis of the filter.

The CERN 1.1 m^3 heavy liquid bubble chamber, filled with propane (C_3H_8) and an array of spark chambers are situated in a blockhouse having concrete walls and a steel roof which provide some shielding against cosmic rays and leaking neutrons.

The neutrino flux per proton hitting the target is about 6 times more intense than achieved in the earlier CERN Neutrino Experiments.[3] This is due to the 3-stage secondary beam focusing system and the increased decay length.

Whilst the proton beam transport elements are similar to those used in the previous neutrino experiments[4] the septum magnet in section 74 of the C.P.S., is a shorter version of the ejector magnet[5] used previously and is stationary, the beam being steered near it by backleg windings on the C.P.S. magnet. The betatron oscillation required to make the circulating proton beam jump the septum is excited by the kicker magnet located in straight section 97 of the C.P.S., i.e. 4 13/16 betatron wavelengths upstream. During the 1967 neutrino experiment, the proton momentum is 20.6 GeV/c at a repetition rate of 2.3 sec. Seventeen bunches are ejected to the neutrino area, the remaining 3 bunches being used by the 2 m hydrogen bubble chamber.

2. Primary and Secondary Beam Monitoring[6]

2.1. The proton beam

Eight ZnS screens viewed by television cameras and 5 induction monitors are placed along the length of the external proton beam. The induction monitors consist of a toroidal transformer in which the proton beam forms the primary winding. The signal is amplified and integrated in an A.C. - coupled lag amplifier whose output is digitized and displayed. The beam transport elements are set up approximately with the aid of the television system, and then optimized for minimum loss using the induction monitor[7] information, and for maximum efficiency by reference to the muon flux measured in the neutrino filter.

The structure and position of the proton beam in front of the target are determined by measuring the radioactivity (Na^{24}, half-life 15 hours) induced in aluminium foils, and are continuously monitored by a pierced T.V. screen and a standard C.P.S. secondary emission monitor[8]. The total number of protons hitting the target during the experiment is obtained by electronic integration of the output of an induction monitor close to the target, and by measuring the Na^{22} (half-life 2.6 years) produced in two aluminium foils. During times when the heavy liquid bubble chamber is inoperative (e.g. film change) these aluminium foils are automatically flipped out of the proton beam.

In addition, solid and gaseous scintillators as well as intensity and position monitors using the Cerenkov effect are being tested.

2.2. The neutrino beam

Since no observable signals are given by neutrinos, the neutrino beam is monitored indirectly. The main source of neutrino production is in the decays $\pi^+ \rightarrow \mu^+ + \nu$ and $K^+ \rightarrow \mu^+ + \nu$ with the corresponding anti-particles for $\bar{\nu}$ production. These muons, together with their decay electrons, are detected in the neutrino filter. To this end, a series of channels have been built into the filter, the axes of these channels being perpendicular to the secondary beam axis. Ionization chambers and scintillators are used in the high and low flux regions respectively. The ionization chambers are calibrated using nuclear emulsions, and their sensitivities matched to local flux conditions by adjusting their gas pressures and signals amplification. Similarly the local conditions determine the size of the scintillators in the lower flux regions (i.e. single particle detection).

Observation of the muon flux distribution in the filter can yield the following information :

a) the stability and conversion efficiency in the target of the proton beam,

b) the stability and alignment of the secondary beam focusing elements,

c) the efficiency of the neutrino filter.

Since the energies of the products in a two-body decay follow a known relation, the neutrino momentum spectrum can, in principle, be derived from the measured muon spectrum[9].

The muon detectors have been successfully used for points (a) - (c) and an attempt is being made to determine the neutrino spectrum. For some purposes it is also of interest to be able to distinguish between positive and negative muons. Thus, Cerenkov detectors using plexiglass as the radiator have been prepared in order to measure the life-time of the stopping muons. Separation would be possible because of the different apparent life-times of positive and negative muons in matter.

3. Performance

Short test runs of the neutrino experiments were made in Spring 1967, and two successful weeks of operation were made during August 1967. To date, approximately 2×10^{17} protons have been ejected onto the target, in 4×10^5 pulses.

3.1. Proton beam profile

In order to determine the most efficient target diameter, a study has been made of the extracted proton beam profile at the target. The histograms shown in figure 5, represent the distribution of the Na^{24} activity induced in stacks of aluminium foils exposed to 1 burst at the upstream end of the target. Corresponding 100 burst exposures show good short time beam stability.

3.2. The secondary beam focusing elements

During the August 1967 neutrino runs, the magnetic horn and two toroidal lenses have been operated at 260, 400 and 300 kA respectively for 90, 95 and 81% of the available time.

3.3. The muon flux in the neutrino filter

From tests made earlier in the year, it has been shown that those ionization chambers situated at a longitudinal depth of 4.7 m in the filter (corresponding to initial muon energies 6 GeV) are sufficient for a continuous monitoring of the muon beam and therefore the neutrino beam. Two of these ionization chambers situated 80 cm above and below the beam axis monitor the up-down asymmetry of the muon beam. This was found to be zero. From the measured transverse muon flux distribution, it has been shown that neither is there any left-right asymmetry of the muon beam. The third ionization chamber is placed as close as possible to the beam axis ($\sim$ 0.2 m) and gives the number of pulses during the run in which any of the three focusing elements failed. Failure of one of these three elements decreases the muon flux passing this chamber by 88, 62, 12% for the horn and first and second toroidal lens respectively. The digitized signals from these three monitor chambers are continuously displayed on a multi-channel analyser oscilloscope.

The remaining ionization chambers and scintillators are used for measuring the muon intensity through the whole filter, and the longitudinal depth-intensity spectrum of muons on axis is shown in fig. 6.

3.4 External radiation levels

The radiation level in the neutrino area has been surveyed using standard Health Physics methods and some results [10] are shown in fig. 7.

4. Acknowledgements

The new neutrino beam and the muon monitoring system would not have been achieved without the continued interest and support of Dr. C.A. Ramm. We are indebted to him, Dr. W. Venus and other colleagues and visitors in the Neutrino Physics Group for numerous fruitful discussions.

We are grateful to M. Giesch who was in charge of the construction of the magnetic horn, and to the many technicians and mechanics who took part in the preparation and operation of the experiment. H. Bakker was charged with the general installations in the area. E. Frick, J.Cl. Gallay and J.J. Hirsbrunner did most of the design work and B. Boileau and G. Zanolin contributed by untiring effort in the preparation and execution of the measurements.

Our thanks are also due to Dr. A. Kjelberg and the Nuclear Chemistry Group for the evaluation of the activation samples and to Dr. A.J. Herz and the Emulsion Group for many valuable discussions. Finally, we thank the MPS Main Control Room Staff for their constant willing and efficient collaboration and the MPS Apparatus Layout Group for their help with survey work and with the construction of the filter and the blockhouse.

References

1) D. Perkins, W. Venus - Unpublished

2) A. Asner, C. Iselin - CERN 65 - 17 and 66 - 24

3) R. Bertolotto, H.van Breugel, L. Caris, E. Consigny, H. Dijkhuizen, J. Goni, J.J. Hirsbrunner, B. Kuiper, B. Langeseth, S. Milner, S. Pichler, G. Plass, G. Pluym, H.W. Wachsmuth and J.P. Zanasco - Proc. Int. conference on High Energy Physics, Sienna (1963), p.523.
M. Giesch, S.van der Meer, G. Pluym and K.M. Vahlbruch, - Proc. Int. conference on High Energy Physics, Sienna (1963), p.536.

4) B. Langeseth - CERN 64 - 35.

5) B. Kuiper, G. Plass - Proc. Int. conference on High Energy Accelerators, Frascati (1965).

6) D. Bloess, J.B.M. Pattison, G. Plass, D. Rusch, K.M. Vahlbruch and H. Wachsmuth, - CERN-NPA/Int. 67-14.

7) R. Bertolotto - CERN-NPA/Int. 67- (in preparation)

8) K. Budal - CERN 67 - 17.

9) R. Burns, K. Goulianos, E. Hyman, L. Lederman, W. Lee, N. Mistry, J. Rettberg, M. Schwartz, J. Steinberger and J. Sunderland, - Proc. Informal conference on Experimental Neutrino Physics, CERN 65-32, p.97.

10) CERN Health Physics Group - private communication.

DISCUSSION (condensed and reworded)

<u>G.T. Danby (BNL)</u>: You showed muon enhancement when measuring in your shield. Is this geared so you can do differential momentum tuning?

<u>Plass</u>: Yes. We have channels for counting along the whole depth of the filter. We can really get the whole plot and either do differential tuning or compute the spectrum of neutrinos from the measured yield spectrum. Measuring along the depth corresponds to getting the muon spectrum.

<u>Danby</u>: What about the gain factors you mentioned? Was this a gross gain? What were the criteria in your curve?

<u>Plass</u>: These are measured at a depth corresponding to a muon energy larger than 6 GeV. This is just an illustration that things work. It does say that the same factors apply to neutrinos.

<u>Danby</u>: But it is a significant enhancement at quite a high momentum?

<u>Plass</u>: Yes.

<u>P.I.P. Kalmus (London)</u>: What is the predicted rate of neutrino events in the bubble chamber?

<u>Plass</u>: In two weeks we have taken 400,000 pictures. We get about one event per thousand pictures, so we have about 400 events.

<u>N.M. King (Rutherford Lab)</u>: I was interested in the distribution you got from the aluminum foils. Did you irradiate the foils and then cut them into strips and measure each strip?

<u>Plass</u>: No. The foils were arranged longitudinally along the beam. If they had been placed perpendicular to the beam, there would not have been enough counting rate from a single beam burst.

<u>A.J. Egginton (Daresbury)</u>: How good is boron carbide in comparison to copper?

<u>Plass</u>: Averaged over the entire flux range, it is about thirty percent better than copper.

<u>V. Dzhelepov (Dubna)</u>: How does the flux of mu mesons and neutrinos for this installation compare with that from your old installation? Also how much does the second lens improve things?

<u>Plass</u>: We have no comparable results for using one and two lenses. In the previous installation we ran with 25 GeV. protons. Now we are running at 20.6 GeV. This happens to be the optimum energy. If all factors are taken into account, an estimate of the improvement for comparable

conditions would be a factor of 5 to 6.

Danby: Is the optimum target somewhat tied up with the optical acceptance of the focusing device?

Plass: Yes. Its dimension is fixed by the proton beam, and one has to reach a compromise to attain a maximum interaction of the protons with a minimum of mesons being reabsorbed.

Danby: Is this essentially independent of your horn?

Plass: Yes.

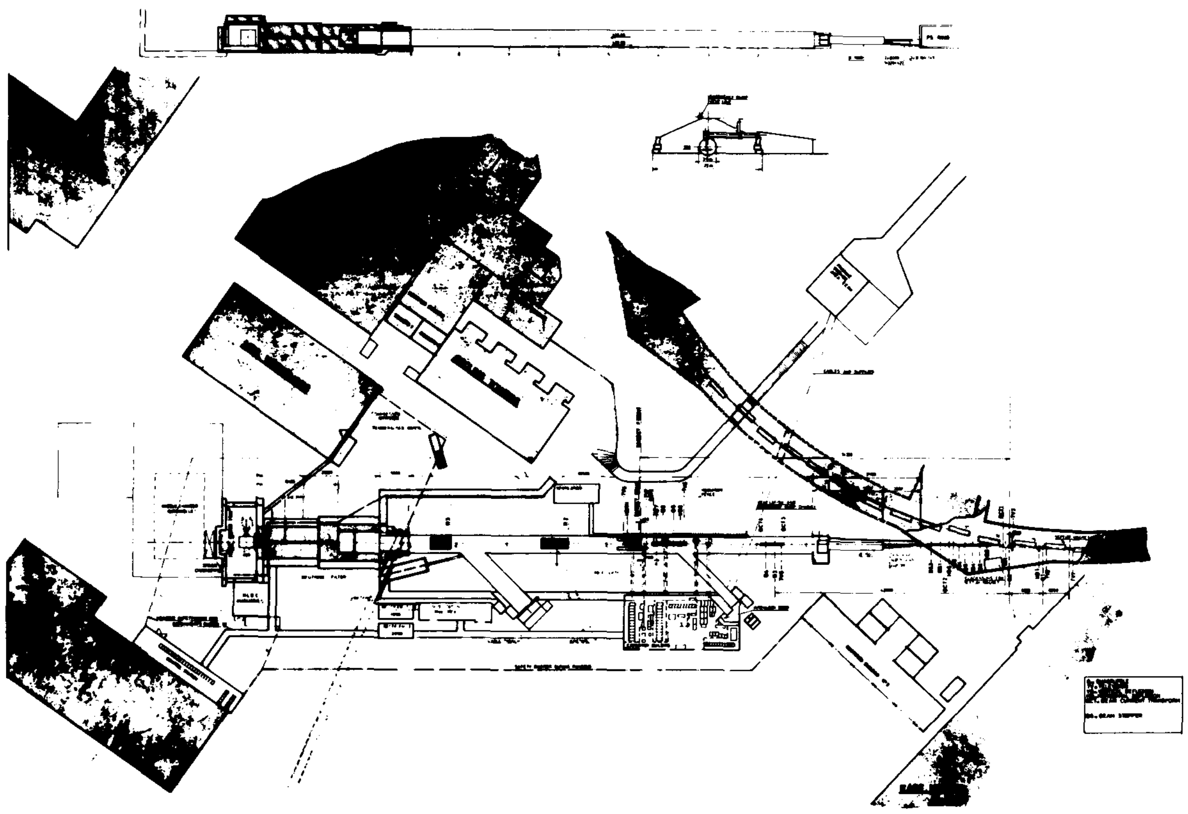

Fig. 1. Schematic layout of the neutrino area.

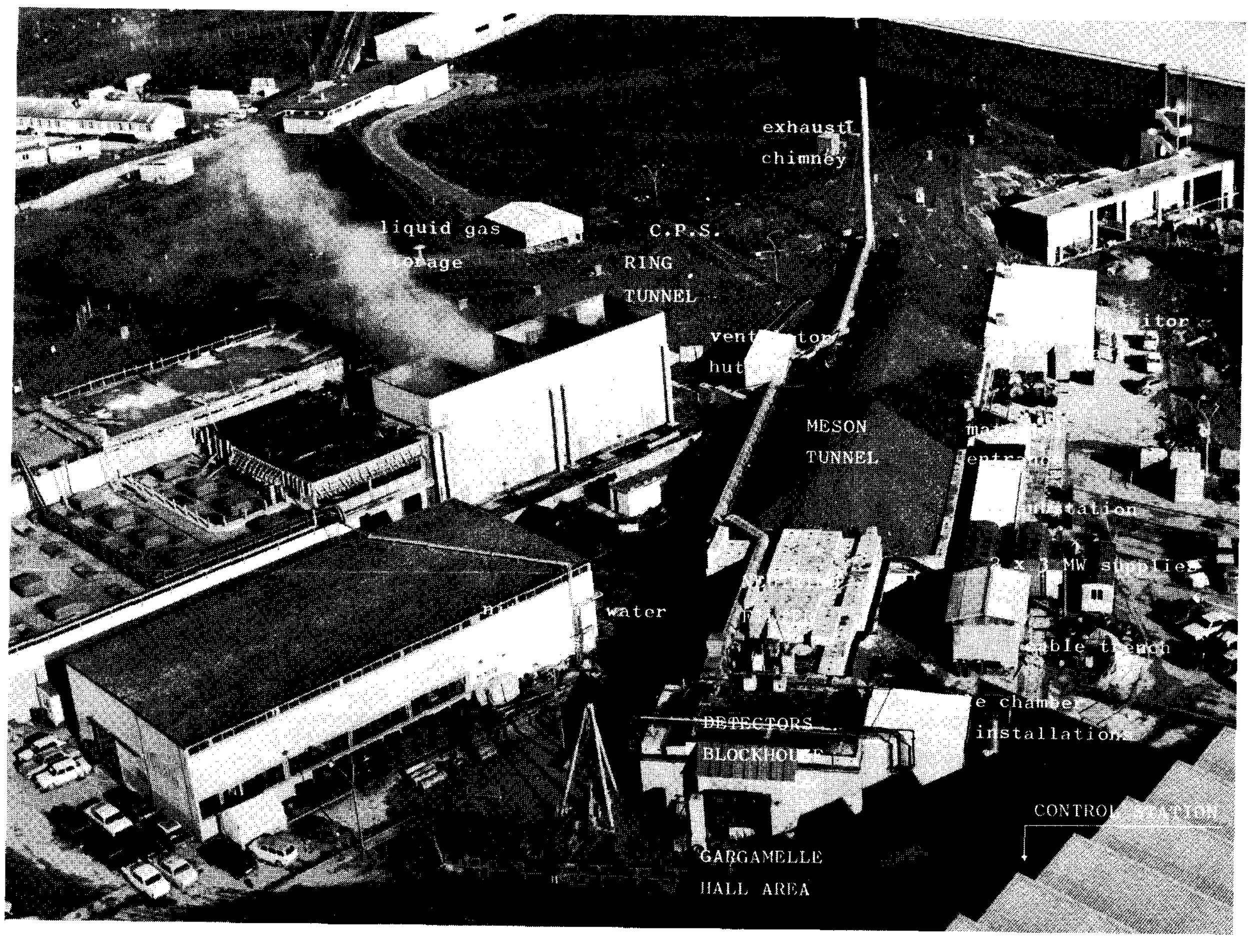

Fig. 2. Aerial view of the neutrino area.

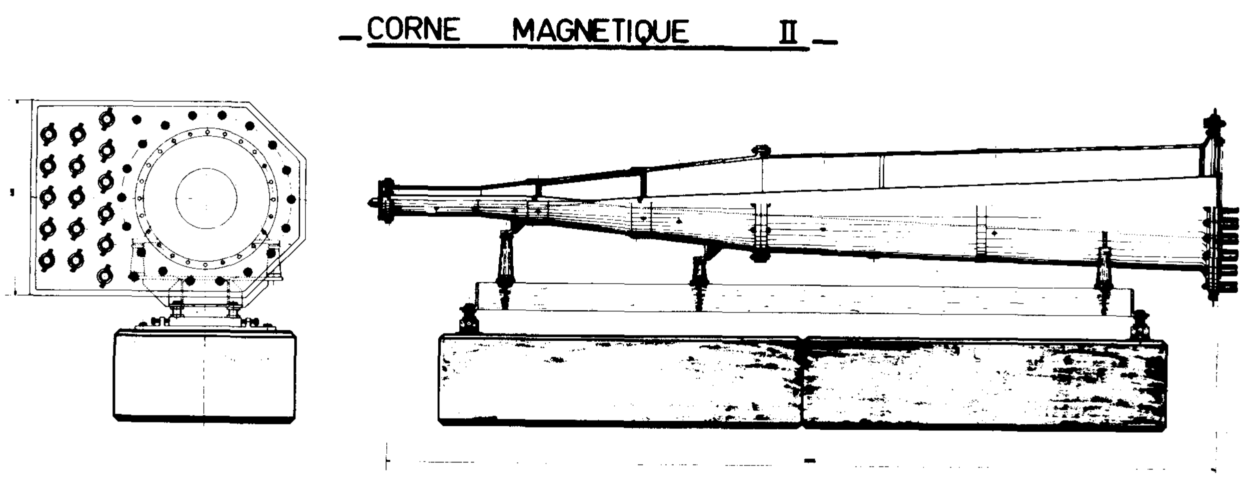

Fig. 3. Improved magnetic horn.

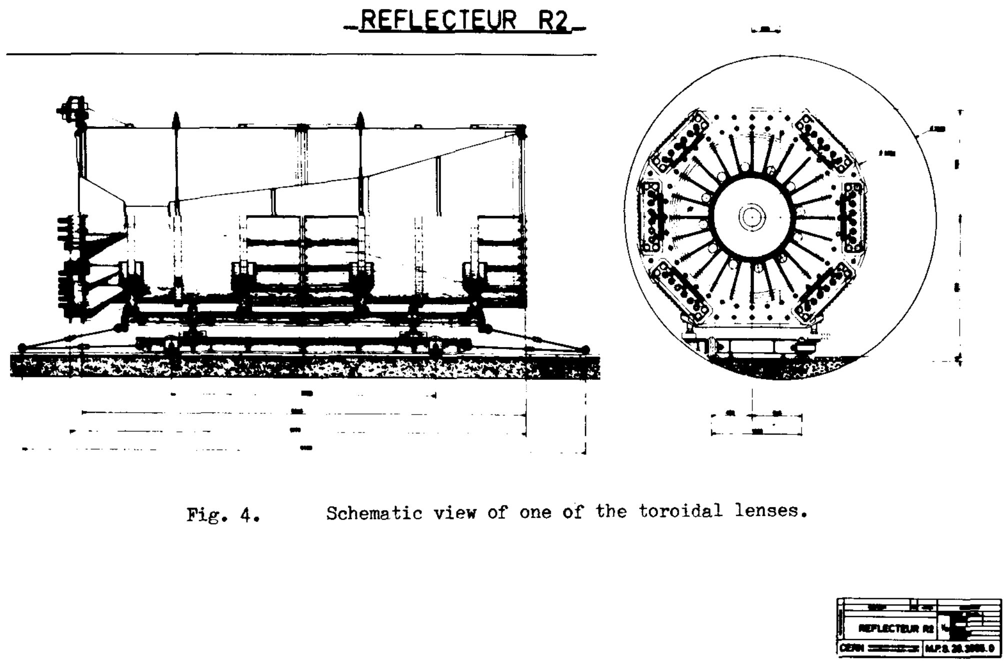

Fig. 4. Schematic view of one of the toroidal lenses.

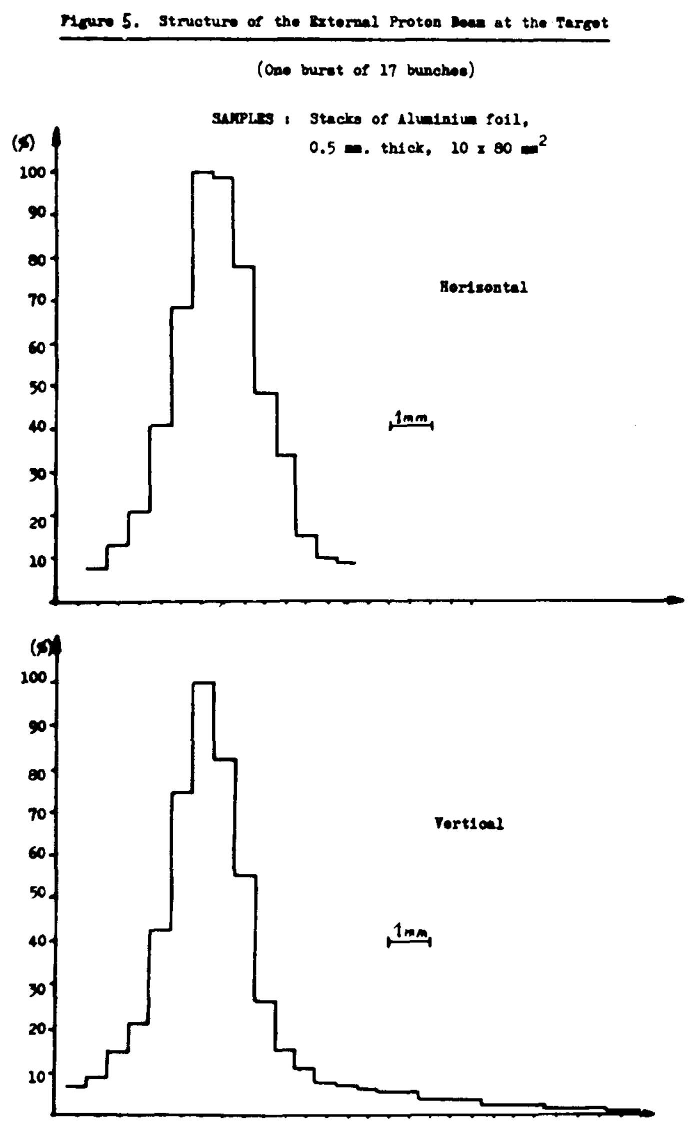

Fig. 5. Beam profiles at the target (1 shot).

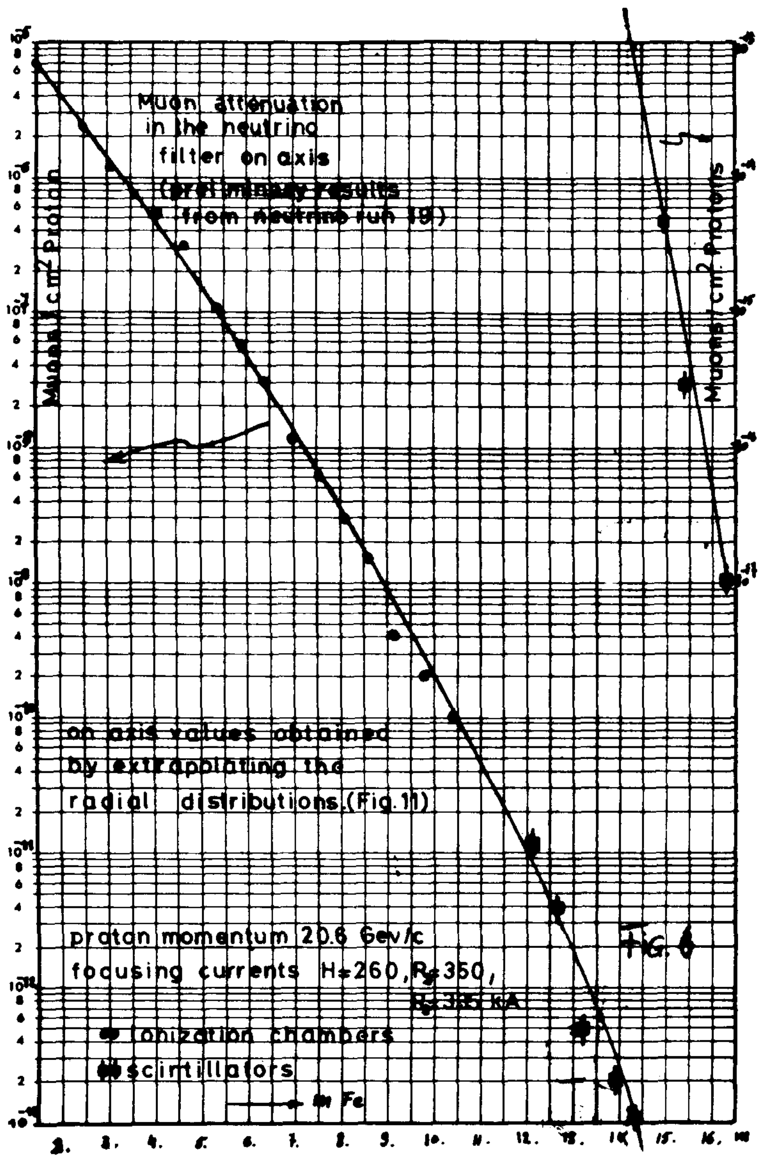

Fig. 6. Muon attenuation on axis in the neutrino filter.

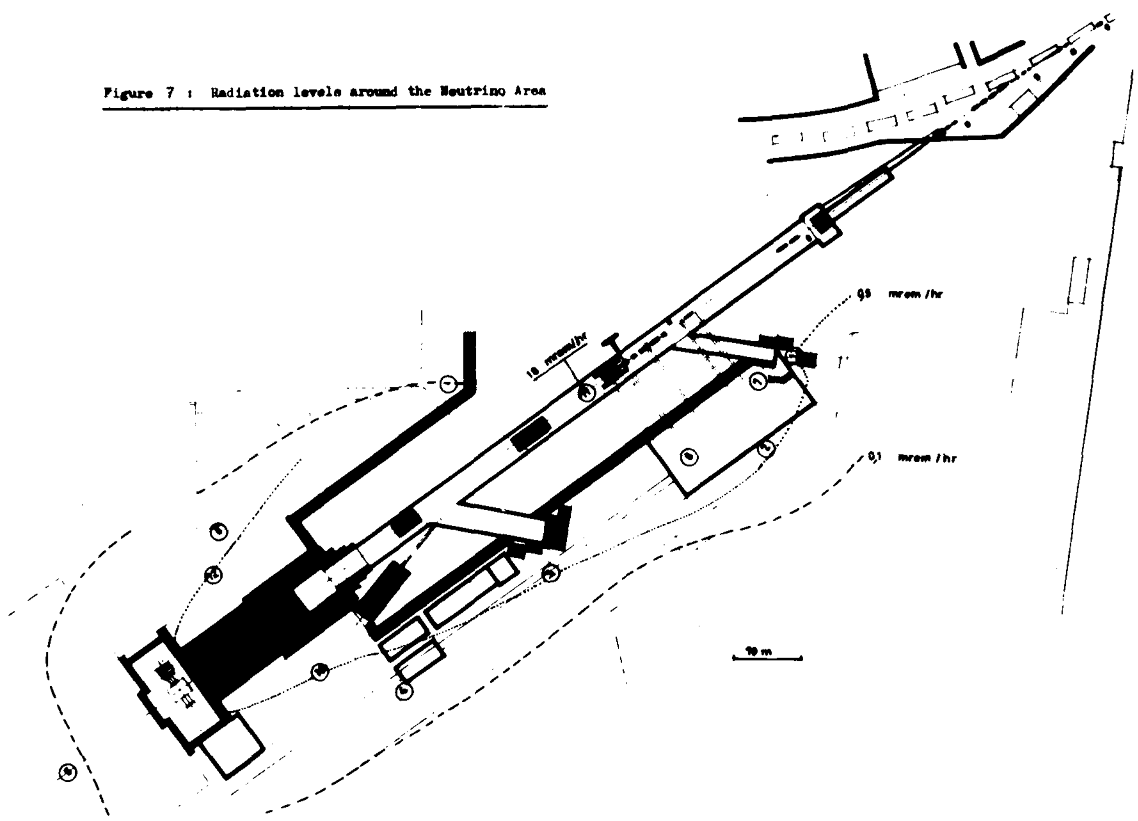

Fig. 7. Radiation field around the neutrino area.