ON THE POSSIBILITIES TO OBTAIN THE NEUTRINO SPECTRUM BY MEASURING THE CORRESPONDING MUON SPECTRUM

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I. Introduction

The neutrinos of the present neutrino experiment at CERN are obtained from pions and kaons which are produced by bombarding a long rod shaped target inside the magnetic horn (1) with the external 25 GeV/c proton beam. The momentum spectrum of the neutrinos is calculated by applying the few \( \pi^-, K^- \) production cross sections measured in pp - interactions (2) on a thick target taking into account the focusing properties of the magnetic horn (3). It is generally agreed to consider the experimental determination of the actual neutrino spectrum as an essential part of the neutrino experiment.

Because the neutrinos are produced in two-body decays

\[
\begin{align*}
\pi &\rightarrow \mu + \nu_e + 33.9 \text{ MeV} \\
K &\rightarrow \mu + \nu_e + 338.3 \text{ MeV}
\end{align*}
\]

there are in principle two possibilities to determine the neutrino spectrum,

a) the more direct one is to measure the momentum and angular distribution of the neutrino producing kaons and pions behind the horn (4);

b) the second way which might be considered is to use the spectrum of the muons produced together with the neutrinos;

As far as the second way is concerned two methods can be thought of: first to use the muon distributions in the shielding material between the decay tunnel and neutrino detectors and secondly to use the muon fluxes close to the decay tunnel as a means to get information on the corresponding neutrino spectrum. Here will be reported only on the first method. The second is still being investigated.

II. Distribution of the muons in the shielding material

1. Principle

In the shielding iron between decay tunnel and neutrino detectors (see fig. 1) the muons from the pion and kaon decay will stop at certain distances according to their momentum. Using the momentum range relation the radial distributions in 3 iron depths.
(calculated by Sternheimer (5) one obtains the muon spectrum and according to the two-body kinematics (Fig. 2) one might hope to be able to calculate the corresponding neutrino spectrum.

2. Drawbacks

Apart from experimental difficulties concerning calibration of the detectors and accuracy of the momentum range relation there are technical difficulties to build appropriate channels for the detectors in the iron shielding. The main problem however is that the muons are produced by pions as well as by kaons. Thus, a muon spectrum measured could be explained by an infinite number of \( \pi^-, K^- \) flux compositions giving an infinite number of neutrino spectra. This problem will be examined in the following:

3. Computational results

It has to be searched whether the difference of pion and kaon decay are large enough to render an unambiguous correlation between muon distribution and \( \pi^-, K^- \) spectrum. The differences are: a) the angles under which the muons leave the kaons (in the laboratory system) are in each momentum region about 20 times larger than the corresponding for the pions (see fig. 2), and b) the decay path per GeV/c of the kaon is about 7 times shorter than that of the pion.

An IBM programme has been written to calculate for a given \( \pi^-, K^- \) spectrum the muon distribution in the shielding. It takes into account the two-body kinematics, the decay probabilities along the decay channel, multiple scattering of the muons in the iron and the range energy relation as calculated by Sternheimer (5). Thus the number of stopping muons per cm\(^3\) iron in different points of the shielding has been determined using the \( \pi^-, K^- \) spectrum (fig. 3) behind the horn which produces the present neutrino spectrum (3).

a) Radial and axial distribution

The difference in decay angle should become apparent in the radial distribution of the stopping muons. But the angular distribution of the pions and kaons behind the horn and the spreading of the muons by multiple scattering smear out the difference in the decay angles. Only at some distances in the iron (after about 2.5 m iron) the difference in \( K^- \), \( \pi^- \) behaviour is slightly observable. Fig. 4 shows
In fig. 5 a) the distribution of stopping muons on the axis is given representing the muon momentum spectrum. Fig. 5 b) shows the same in 1.5 m radial distance from the axis; the difference in decay angles is again only slightly observable.

b) Sensitivity of the \( \mu \) - spectrum to a change of the parents' spectra

These calculations were repeated using a fictitious \( \pi \) - , \( K \) - composition constructed by increasing the \( \pi \) - spectrum by 20 o/o and reducing the upper part of the \( K \) - spectrum (above 6 GeV/c) by 90 o/o. Thus the corresponding neutrino spectrum is practically cut off at 6 GeV/c. The muon distribution is not changed appreciably as can be seen in fig. 6 and 7 where the radial and axial distributions respectively for both spectra are compared. Generally any contribution of the pions to the muon spectrum can be compensated by a corresponding contribution of kaons and vice-versa.

c) Different decay lengths

The difference in decay time of pions and kaons should become apparent if the decay length is substantially changed. So putting the iron some metres behind the horn the contribution of the longer living pions to the muons should be reduced. To check to which extent this would be observable, the number of muons stopping in an iron block beginning 3 m behind the horn has been calculated. Fig. 8 shows the result for muons stopping on the axis of the horn where, contrary to what has been expected, the overall behaviour of the \( \mu \) - spectrum is still the same as for 24 m decay length. Fig. 9, however, shows that for instance in 1.2 m distance from the axis up to about 5 GeV/c \( \mu \) - momentum essentially only \( K \) - muons will be observed. However, for this calculation particles decaying inside the 3 m long horn before they are focused have been neglected. Also the defocused pions will contribute to the muon flux, so that the distinction between pions and kaons will be less clear.
To have only K- muons also in the upper part of the $\mu$- momentum spectrum it is necessary to look for modified decay and shielding geometries e.g. at the side of the decay tunnel. This will be studied more thoroughly.

4. Experimental checks

Fig. 1 shows the general layout of the neutrino experiment. Experimentally it is necessary either to determine the muon flux or the stopping muons at different points in the shielding material. This can be done by emulsion or counter techniques.

a) with nuclear emulsions

Up to now only one experimental check of the muon spectrum has been carried out (6) using nuclear emulsions. These were exposed in the first 4 metres of the iron shielding and scanned for muon tracks. The measurements have not yet been finished. The results would be valuable as a check of the calculated $\mu$-spectrum.

b) with counters

To measure muon fluxes simple plexiglass rods viewed by photo-multipliers could be used. The Čerenkov light produced by the particles in the rods is proportional to the number of crossing relativistic particles.

The stopping muons (life-time at rest 2.2 $\mu$s, $\mu \to e + \nu + \bar{\nu}$) can be detected by their decay electrons (momenta from 0 to 55 MeV) in a special device like that shown in fig. 10. It mainly consists of a block of plexiglass and metal plates (P), a light guide (L) and a photo-multiplier (PM); muons stopping in the metal plates would emit their Čerenkov light to a known fraction into the plexiglass plates; the Čerenkov light produced by the electrons will be partially collected by the reflector (R) and the light-guide and measured by the photo-multiplier. According to the calculations (see below) about $5 \times 10^{-9}$ muons of 2 GeV/c and $10^{-11}$ of 10 GeV/c are expected to stop per cm$^3$ and circulating proton. Hence with an effective absorber of e.g. 100 g/cm$^2$ enough Čerenkov light will be produced as can be shown by a rough estimate. The Čerenkov light of the passing muons would be absorbed in the end-plate B.
Turning this detector around the axis AA one could use it also as a muon flux detector.

The $\mu^+ / \mu^-$ ratio could in principle be determined with the help of the Conversi - Pancini - Piccioni effect \(^{(7)}\). This well studied effect would enable us to obtain a clear distinction between $\mu^+$ and $\mu^-$ comparing for instance the rates of decay electrons in Al and Cu.

III. Conclusions

It has been shown that there is no unambiguous correlation between the $\mu$ - spectrum in the iron shielding and the corresponding neutrino spectrum. The only value of such measurements would be a comparison between the calculated $\mu$ - spectrum obtained for the $\pi^-$, $K^-$ spectra presently assumed and the $\mu$ - spectrum measured.

There might be some hope to get a critical check of the neutrino spectrum at present assumed using the muons at the side of the decay tunnel which are mainly due to $K^-$ decay and making a quantitative comparison with the muon spectrum around the tunnel axis. This will be further investigated.

IV. Acknowledgement

We thank Prof. G. Bernardini and Dr. C.A. Ramm for many stimulating discussions and suggestions.

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Distribution: (open)

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FS/4246
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Decay Angles of the Muons and Momentum Spectra for $\mu$ and $\nu$ in $\pi^+$ and $K^-$ Decay

$\pi^+ \to \mu + \nu + 33.9$ MeV

$K^- \to \mu + \nu + 338.3$ MeV
FIG. 3

T-spectrum after horn

K-spectrum after horn

Logan, Teilung 1-10000, Ethanol 30 mm
Radial distribution of stopping muons in the iron shielding.

FIG. 4
Stopping muons in iron.

Graph showing the number of muons per circulating proton ($N_u [cm^{-3}]$) as a function of radial distance in iron after different depths.

- After 2.56 m of iron
- After 3.85 m of iron
- After 6.3 m of iron

Logarithmic scale with a division of 10,000 and unit 50 mm.

Legend:
- Ti-production 20% increased; K-production above 6 GeV/c
- 90% reduced.

FIG. 6
$N_A [cm^{-3}]$ per circulating proton

+ + + π-production 20% increased
K-production above 6 GeV/c, 90% reduced

Sm off axis
Sm on the axis

$P_{\mu} [GeV/c]$
$\mu [\text{cm}^{-3}]$ per circulating proton

Stopping muons on axis

$5$ cm behind horn

$N(\mu_\pi)$

$N(\mu_K)$

$P_\mu [\text{GeV/c}]$

**FIG. 8**
Stopping muons 1.2 m off axis.
Iron 3m behind horn.

FIG. 9
Proposed device for muon detection

FIG. 10

(explanation see § 46)