NEUTRINO SPECTRUM DETERMINATION FROM MUON FLUX MEASUREMENTS

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ABSTRACT

The muon flux measured in the neutrino shielding during a neutrino experiment can be used to determine the neutrino spectrum. This method has been applied for the CERN 1967 neutrino experiments.[1] In this note a crude extension to 200-GeV proton energy is given and improvements to be done are pointed out.

1. RELATION BETWEEN MUON FLUX AND NEUTRINO SPECTRUM

From a given production spectrum of pions and kaons (using the CKP formula in the same way as for the neutrino beam design by Kang and Nezrick[2]) the neutrino spectrum and simultaneously the muon flux distribution in the neutrino shielding has been calculated for the beam parameters of Ref. 2.

The neutrino spectrum (Fig. 1) comes out to be the same as calculated by Kang and Nezrick.[2] The axial and radial muon flux distribution is shown in Figs. 2 and 3.

In calculating the muon flux distribution the following assumptions have been made:

1. Muons come only from $\pi_{\mu 2}$ and $K_{\mu 2}$ decay.

2. Muons are bent only in focusing device 2 and 3. Decays in the horn have been placed at the horn end.

3. Infinitely thin proton beam (no skew secondary particles) and no tertiary particle production, as in the neutrino flux calculations.

4. Gaussian distribution of multiple-scattering displacements. The rms displacements have been obtained from a logarithmic extrapolation of calculations[3] done for up to 30-GeV muons.

5. Momentum range relation from Ref. 4 and only a 1% straggling.

The results show that the muon flux within 50 or 60 cm radial distance and in shielding depths up to 40 or 50 m Fe comes to more than 90% from pions and is sufficient to determine the pion part of the neutrino spectrum. This is due to the fact that the pions and kaons are collimated in the decay channel and that the Q value of the K decay is 10 times bigger than that of the π decay.

In larger depths the focusing effect decreases and the composition of pion and kaon muons corresponds more and more to the K/π production ratio. At larger radial distances (> 1.5 m) the kaon contribution to the muon flux can reach as much as 50% for this actual neutrino beam. For special beam designs (narrow tube decay channel) and certainly for the so-called ideal parent pencil beams, the kaon-muon flux dominates the muon flux at large radial distances. In unfocused neutrino beams, the angular distribution of pions and kaons at production overrides the decay angle difference of pions and kaons and nowhere in the neutrino shield will be a separation between pion and kaon muons.

II. DETECTORS AND DATA ACQUISITION

Simple ionization chambers can be used to measure the muon fluxes. Glass cylinders of ~ 2 to 5 cm height and ~ 2 to 5 cm diameter sealed with kovar plates and filled with 100 to 700 mm Hg argon (+ 5% propane) yield a sensitivity range of 1 to ~ 200. Suitably matched charge sensitive preamplifiers yield a sensitivity range of 1 to 10^2 to 10^3 and proper attenuation in the main amplifiers a range of 1 to 1,000 so that, say, 10 different ionization chambers can cover the relevant muon flux region of 10^8 muons/cm^2 (in 5 m iron depth) down to several muons/cm^2 (in ~ 60 m depth). Main amplifiers, gated analogue-to-digital converters and some digital data storage system (a series of scalers, the memory of a multichannel analyser or a computer) complete the measuring equipment.

III. MEASUREMENTS TO OBTAIN THE NEUTRINO SPECTRUM

A. Relative Measurements

The sensitivity ratio of two flux detectors is easily obtained by putting one behind the other thus recording the same flux by both detectors. Knowing the sensitivity scale for a set of detectors the following measurements can be done:

1. Energy spectrum of the muon flux.

2. Monitoring the axial beam symmetry to ensure that the wanted part of the neutrino flux traverses the detector.

3. Monitoring the focusing status of the neutrino beam (slope of the radial muon flux distribution).

4. The neutrino spectrum, if it is absolutely known from other methods: calculation from the known pion and kaon production cross sections and all secondary and tertiary processes or from the zero-q^2 elastic neutrino interactions in the neutrino detector.

5. The ratio of $\bar{\nu}$ to ν fluxes by changing the polarity of the focusing channel; this is important for most of the neutrino physics issues which depend on a comparison of antineutrino with neutrino cross sections.

B. Quantitative Measurements

Even if pion and kaon production data exist at the time of 200-GeV neutrino experiments, it would be advisable not to rely completely on absolute neutrino spectrum calculations. Absorption and cascade processes in the target, focusing devices and tunnel air, errors in the focusing current measurements (400,000 A), errors in the proton beam intensity and radial distribution measurements could easily add up to 20 or 30% spectrum uncertainties. The muon flux detectors could be calibrated at least to 5% by several methods:

1. In shielding regions where they are traversed by 1 to ~ 20 muons by making a pulse-height analysis and using highly linear amplifiers and attenuators for the higher fluxes.

2. By exposing nuclear emulsions mounted onto the ionization chambers and counting the number of muon tracks.

This means that a muon flux scan (~ 100 points) in the region of 5-50 m iron depth and up to ~ 0.6 m radial distance over the whole neutrino experiment would yield the pion neutrino spectrum and by computation the kaon neutrino spectrum with an accuracy of better than 5%, if pion and kaon production data are sufficiently known. If only the K/π ratio is sufficiently known, the pion part of the neutrino spectrum could be determined by fitting the calculated muon flux distribution to the measured muon fluxes varying the parameters in a suitable pion production formula. Then the errors in shielding density, detector position, and fitting procedure must be combined with the calibration error and the spectrum accuracy below 40 BeV and will be between 5 and 10% depending on the effort; the accuracy for $E > 40$ BeV then depends on the K/π ratio error, and for $E < 5$ BeV on the success to unfold the hadron contribution in the measurements.

If also the K/π production ratio is unknown, then careful studies of the muon flux at larger radial distances, where the kaon muons contribute 50% and more, will be necessary and the calculation of the radial flux distribution must account in detail for all muon scattering processes.

C. Combination With Other Methods

At the end of any neutrino experiment a cross calibration of the neutrino flux could be done using the zero-q^2 elastic event method.[4] This method should be free of uncertainties (except for scanning efficiency) for antineutrino events and is in principle valid over the entire range of neutrino energies.

REFERENCES

[1]H. Wachsmuth, CERN Neutrino Conference, 1969, and D. Bloess et al., to be published.

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[3]H. Øverås, CERN 60-18, 1960, and private communication.

[4]M. Block, CERN, NPA Internal Report, 1963.

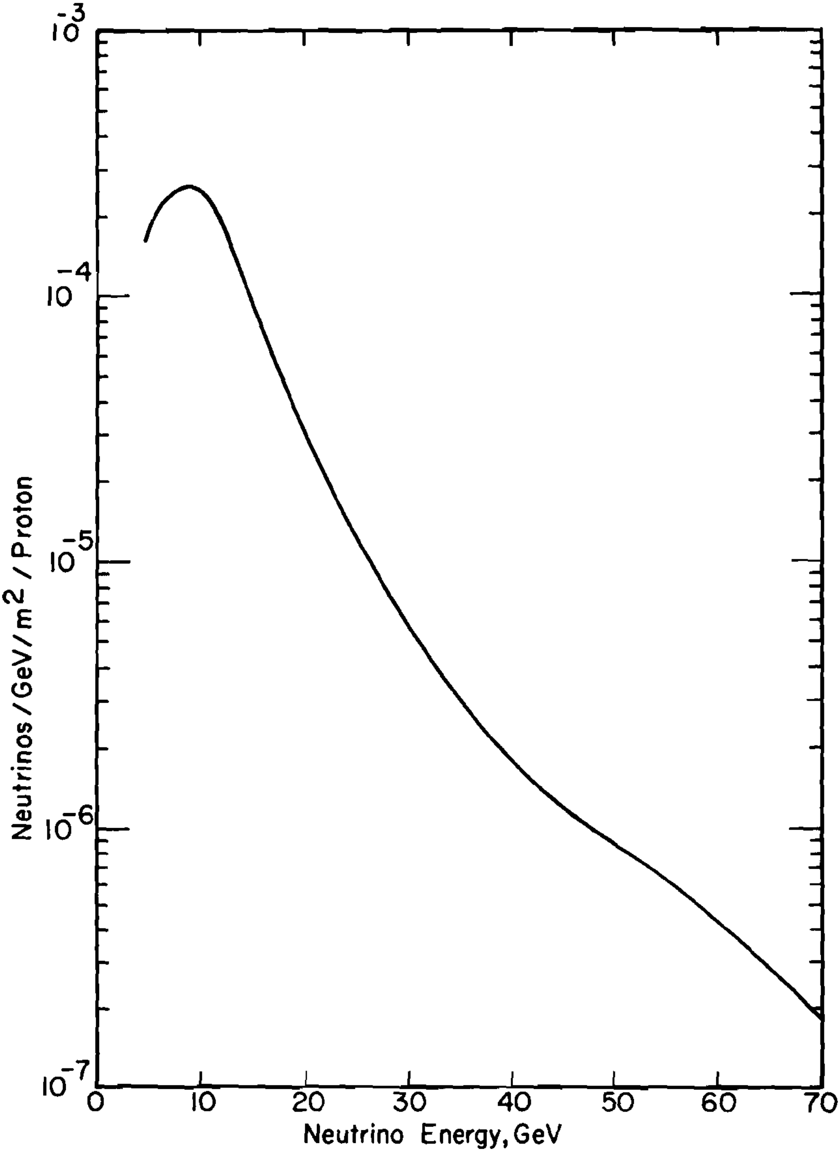

Fig. 1. Neutrino energy spectrum from Nezrick beam (SS-146).

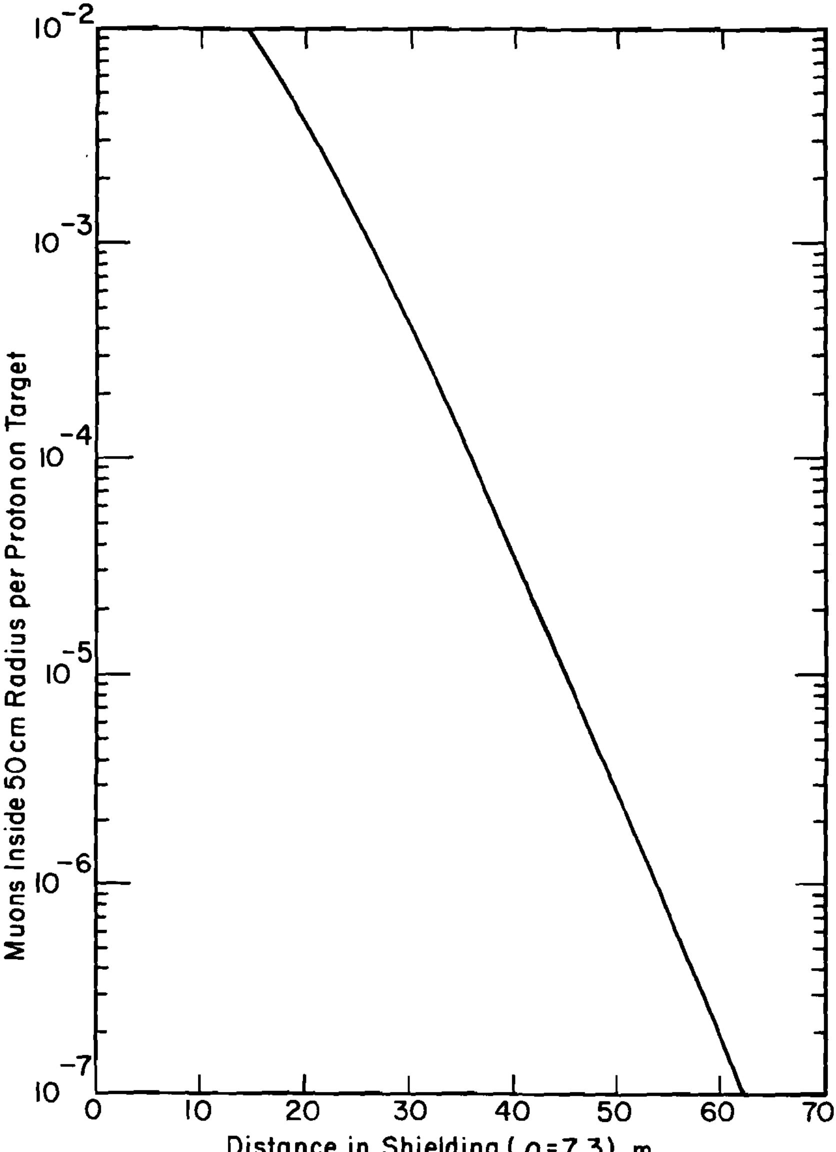

Fig. 2. Estimated muon flux attenuation in shield, with 200-GeV protons.

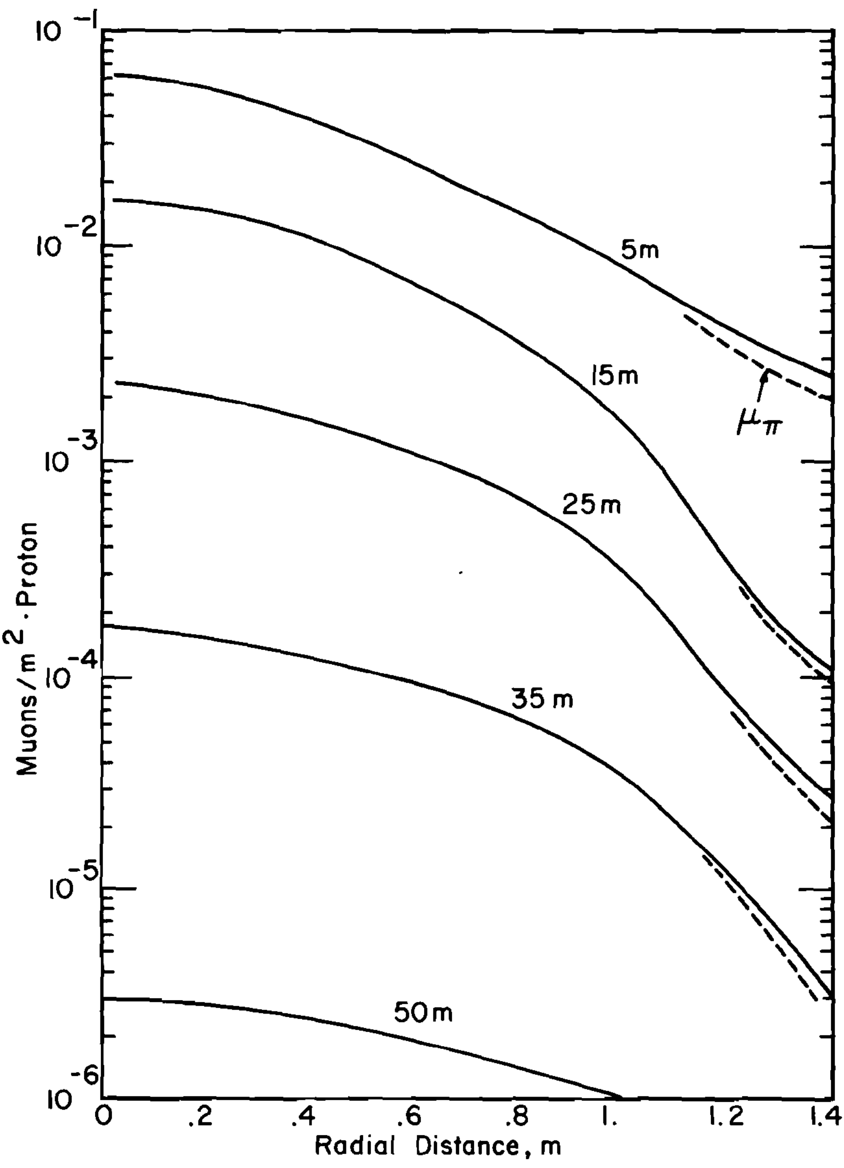

Fig. 3. Radial distribution of muon flux in iron shield.