PROGRESS REPORT ON THE KOLAR GOLD FIELD NEUTRINO EXPERIMENT

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Abstract

The latest results on the interactions of cosmic ray muon neutrinos underground in the experiments in the Kolar Gold Fields are presented.

Unambiguous examples of upward moving muon secondaries are reported and measurements made on the momenta of some of the secondaries are described.

The observation of a comparatively high frequency of multiple particle events points to the importance of inelastic neutrino interactions.

§1 Introduction

As with many cosmic ray experiments, studies of neutrino interactions have two aspects: Nuclear Physical and Astrophysical. The interest to Nuclear Physics arises from the fact that cosmic ray neutrinos have an energy spectrum which extends to far higher energies than those available from accelerators and there is thus the possibility of studying weak interaction processes at these higher energies, notably with regard to the behaviour of the inelastic cross-section and the possible production of the intermediate boson. The Astrophysical aspect concerns the origin of the neutrinos; although *a priori* the detected neutrinos should be of atmospheric origin there is always the possibility of some of the particles being of extra-terrestrial origin and the directions of the detected particles (muons) are thus another subject of study.

The very small cross-section for neutrino interactions makes it necessary to perform the experiments underground where background effects are low. Although the fluxes of electron and muon neutrinos produced in the atmosphere are not too dissimilar the longer range of an energetic muon secondary means that the target thickness (of underground rock) for ν_μ (and $\bar{\nu}_\mu$) is much greater than that of their electron counterparts and the cosmic ray experiments study essentially muon neutrino interactions. The problem is to distinguish between muons which have penetrated to the underground laboratory from ground level, the so-called 'atmospheric' muons, and those muons which are secondary to neutrino interactions. In the Kolar Gold Field (K.G.F.) experiment the depth, 7500 metres water equivalent, is such that muons at angles to the vertical of less than 50° are mainly of atmospheric origin whereas the bulk of those above 50° are neutrino secondaries.

A number of reports of the results of the experiment have been given already1) - 5) and the reader is referred to them for experimental details.

§2 The Experimental Arrangement

The detectors in the underground laboratory at present comprise five 'telescopes' and two magnet spectrographs. All the detectors use plastic scintillators as particle selectors and neon flash-tubes to give information about particle directions, interactions, etc.

Two of the telescopes (Telescopes 1 and 2) contain flash-tubes in one plane only, the other three (Telescopes 3, 4 and 5 - see Figure 2) have crossed-tubes in order to give a 3-dimensional reconstruction of the events. The spectrographs (see Figure 3) are arranged with their axes horizontally to give maximum acceptance at large zenith angles, but scintillators mounted above the magnets are used to give an additional flux of predominantly downward moving atmospheric muons. The disposition of the apparatus in the tunnel is shown in Figure 1.

§3 Basic Data

The experiment commenced at the beginning of 1965 and the basic data up to the end of 1968 are summarised in Table 1. An explanation of the contents is as follows. 'Penetrating atmospheric muons' are defined as events in which a track at a zenith angle of less than 50° is seen to penetrate at least one of the absorbers; similarly, 'neutrino-induced events' refer to angles above 50° (45° in the spectrographs, where momentum resolution gives additional information).

TABLE 1 Division of events and exposure times

	Tels. 1&2	Tels. 3,4&5	O.S.T.	Specs. 1&2
No. of atmospheric muons	45	2	43	29
No. of neutrino-induced events ($\phi > 50^\circ$)	6	2	3	3
Exposure time (hrs)	43,722	17,560	18,452	18,946
Aperture x time for ν - induced events, isotropic distribution (cm^2 sec sterad)	2.49×10^{13}	0.47×10^{13}	1.19×10^{13}	1.36×10^{13}

'O.S.T.' refers to a modified triggering arrangement which has been used for the latest series of observations with Telescopes 3, 4 and 5. Here the triggering requirement is that only a scintillator on one side of a telescope need be penetrated (one-side-triggering) and the apparatus is therefore also sensitive to low energy secondaries and to neutrino interactions occurring within it. This arrangement is achieved by demanding only a two-fold coincidence between photo-multipliers viewing the same scintillator and in order to keep the counting rate (and thus the rate of photography) to a manageable value - 'noise'being responsible for most of the counts - the photomultiplier voltage has been reduced. This results in some loss of efficiency for single muons at large angles but multiple events are recorded normally.

§4 Discussion of the results

4.1 Description of individual events

The events accepted as being due to neutrino interactions are shown in Table 2.

Two of the events are indicated diagrammatically in Figures2 and 3.

Although the total number of events is small (14) a number of interesting conclusions can be drawn.

(i) A number of upward moving events have been seen - a sure indication of neutrino origin. The division of events by sense of direction is: upward 5, downward 5 and 4 of uncertain direction.

(ii) Two events have been seen in which neutrinos incident at very large zenith angles - both moving upwards - have interacted inside the apparatus.

(iii) The penetration of considerable thickness of absorber by some of the particles indicates that they are almost certainly muons.

(iv) The frequency of multiple events is comparatively high; 4 out of a total of 11, discounting the biassed O.S.T. data.

Table 2 Description of individual neutrino-induced events

	Projected Z.A.	Penetration
Tels. 1 - 5 Single Muons	75°	>6 cm Pb
	60° (spatial 72°)	>45cm Fe
	73° (spatial 74°)	>32cm Fe
	51.5°	>7 cm Pb
Multiple events		
2 diverging particles	96°, 99°	>6 cm Pb, > 3 cm Pb
3 diverging particles	96°, 335°, 48°	>6 cm Pb, ?, interaction
Pen. particle + associated wide cascade	85°	>5 cm Pb.
2 pen. particles + 2 associated particles	51°, 57°, 60°, 10°	>8 cm Pb, > 8 cm Pb, <3 cm Pb, ?
O.S.T. Single muons (producing small shower - Figure 2)	94°	>35 cm Fe
Multiple events		
Dense shower	ν at 98±10° inside detector	$\gtrsim$10 cm Fe, Cascade energy $\gtrsim$ 2.5 GeV.
3 diverging particles	ν at 125±30° inside detector	One particle penetrates at least 50 cm Fe.

Spectrographs	Projected Z.A.	Momentum	Sign
Downward muon(losing energy)	48°	~2 GeV/c	+
Upward muon (K. o. electron - Fig. 3)	121°	$\gtrsim$4 GeV/c	probably +
Downward muon (losing energy)	83°	1 - 2 GeV/c	+

(v) The earlier studies of the interaction properties of the muons4) taken together with the spectrograph measurements indicate that the mean energy of the neutrino-induced muons is low, certainly much lower than the mean for atmospheric muons ($\gtrsim$ 300 GeV)

(vi) It should also be mentioned that there are phenomena occurring at this depth which are not completely understood. For example, the angular distribution of the muons shows an unusual excess in the region of 40° - 50° 4),5) and one event has been observed (not shown in Table 2) which appears to represent an electromagnetic cascade of several hundred GeV incident on a telescope in the near horizontal direction.

4.2. The intensity of neutrino-induced events

The data given in Tables 1 and 2 have been used to calculate the intensities shown in Figure 4. Insofar as the O.S.T. data are biassed, the intensity shown is a lower limit. Taking all the data together the best estimate of the intensity of neutrino-induced muons is $(3^{+1.2}_{-0.8}) \times 10^{-13}$ $cm^{-2} sec^{-1} ster^{-1}$.

§5 Theoretical interpretation of the results

Contributions to the intensity of detected muons come from elastic and inelastic interactions. The results of previous calculations4) are shown in Figure 5, denoted 'Case (i)'. In these calculations it was assumed that the form of the inelastic cross-section as a function of neutrino energy was $\sigma_{in} = 0.3\ E_\nu \times 10^{-38}$ cm^2/nucleon, with E_ν in GeV, over the range of energy 1 - 10 GeV, where accelerator data exist, together with alternative behaviours above 10 GeV. Furthermore, it was assumed that on average the muon takes a fraction $f = 0.67$ of the energy of the neutrino in the rising cross section region and $f = 1$ where the cross section is constant. Figure 5 shows a comparison of the intensities of neutrino-induced muons with observation and it is seen that there is some evidence for an increase in the inelastic cross section beyond 10 GeV, assuming, that is, that the neutrino energy spectra used to calculate the intensities are accurate.

However, the conclusion leans heavily on the assumption about the form of the inelastic cross section below 10 GeV and the value of f at all energies and recent studies suggest that σ_{in} rises more rapidly with E_{ν} than had been assumed. Perkins6) suggests a relation $\sigma_{in} = 0.6\ E_{\nu} 10^{-38} cm^2$/nucleon and it is likely that f is nearer 0.5 in the energy range 1 - 10 GeV. The predicted intensities for these conditions are also shown in Figure 5, designated 'Case (ii)', and it is now seen that there is not much evidence for an increase in σ_{in} above 10 GeV.

Even this observation must be qualified, however, because there is still doubt about the value of f at high energies. In particular, if f were to fall with increasing energy then the data would be consistent with an increasing cross-section; the observation of so many inelastic interactions close to the underground detectors gives a slight suggestion in this direction but confirmation will need the accumulation of more data.

References

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6) D.H. Perkins (these Proceedings)

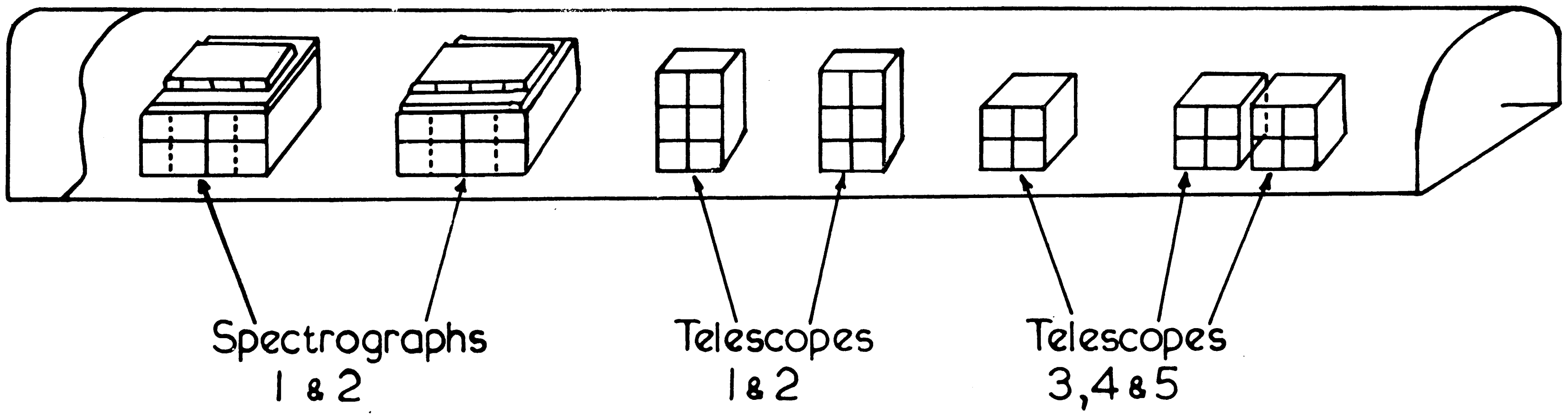

Figure 1. Disposition of the apparatus in the tunnel at 7500 m.w.e. underground.

Event No.: OST 16
Direction: Upwards
Run No.: 802
Spatial zenith angle: 94·4°
Date: 14·2·1968
Time (M.S.T.) 10·31

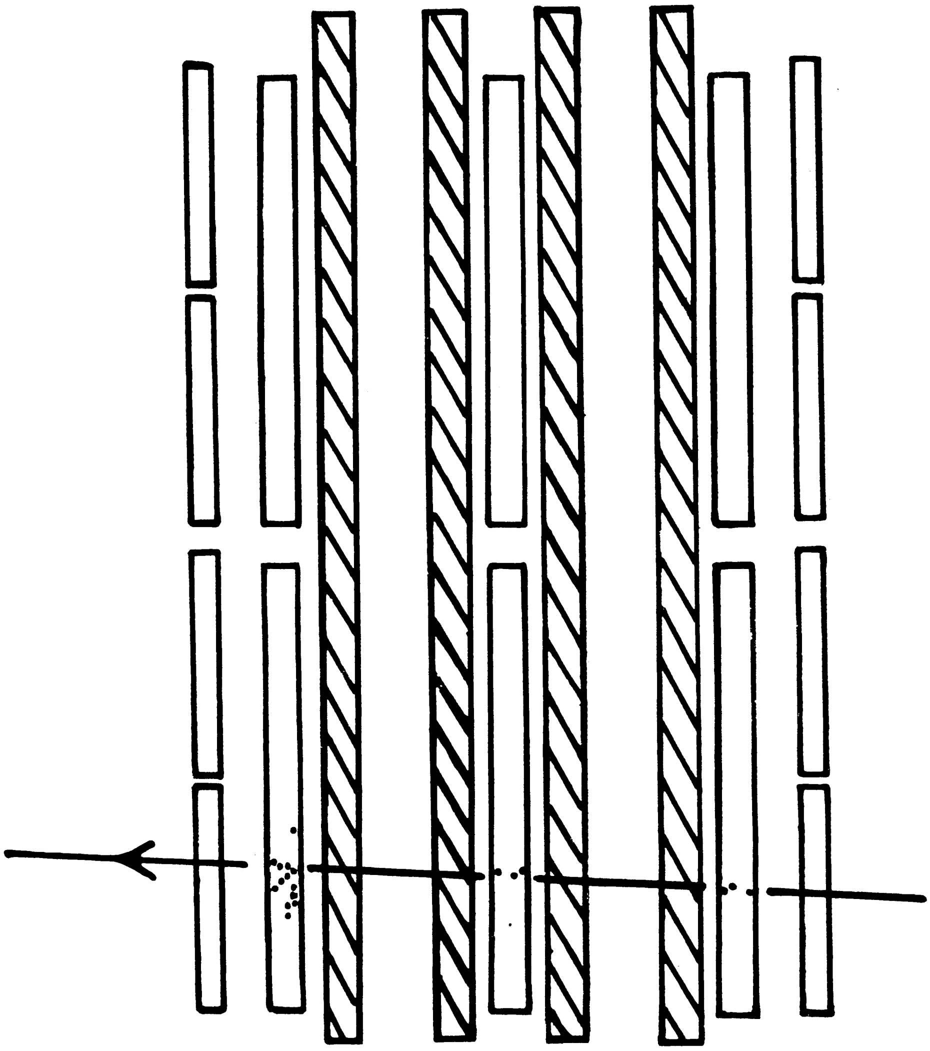

Fig.2. Upward moving ν-induced muon (O.S.T.)

Event No.: S40
Run No.: 796
Date: 7·2·1968
Time (M.S.T.) 12·26

Direction: Upwards
Projected zenith angle: 58·9°
Momentum: $\gtrsim 4$ GeV/c

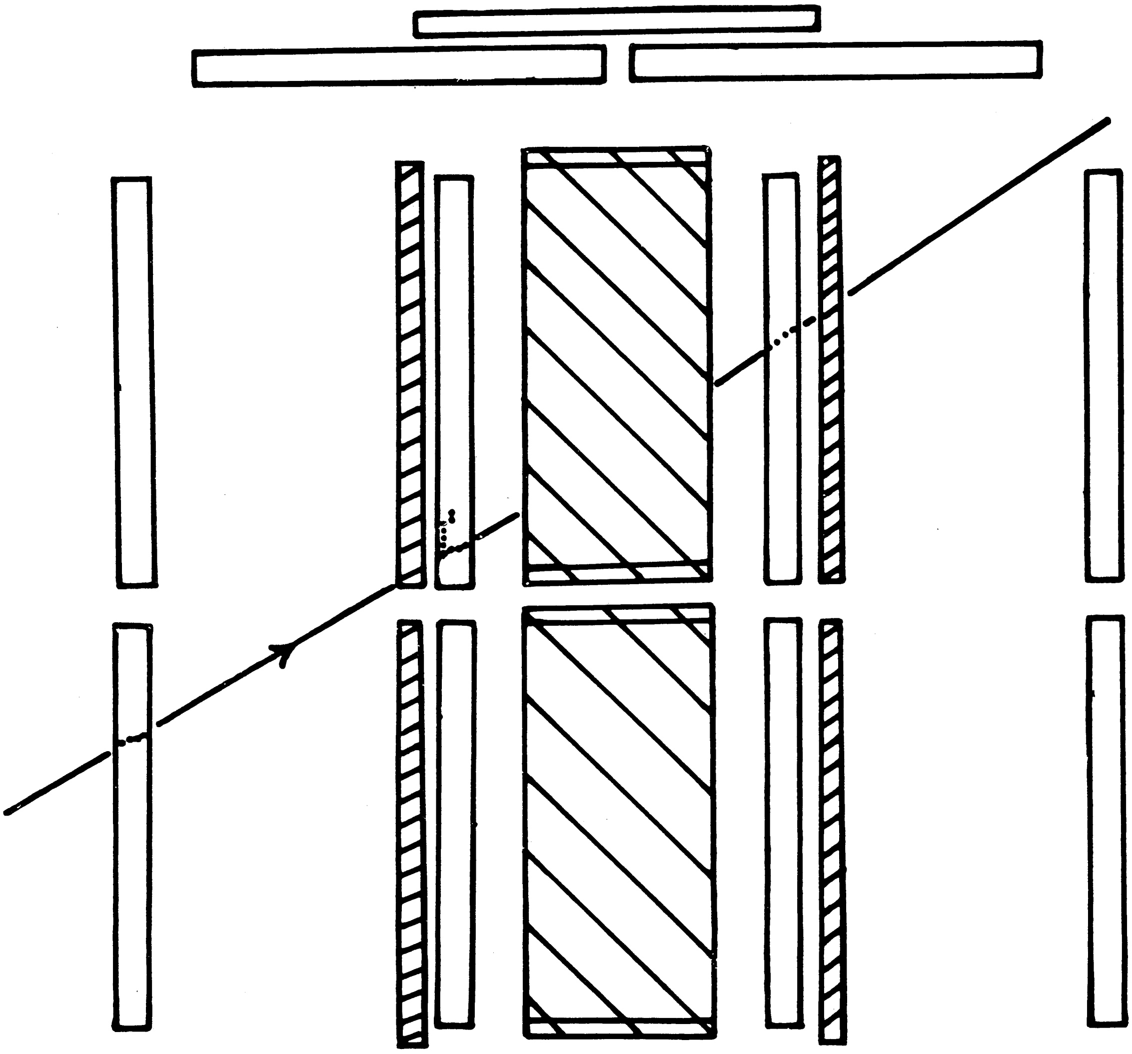

Fig 3. Upward moving ν-induced muon in a Spectrograph.

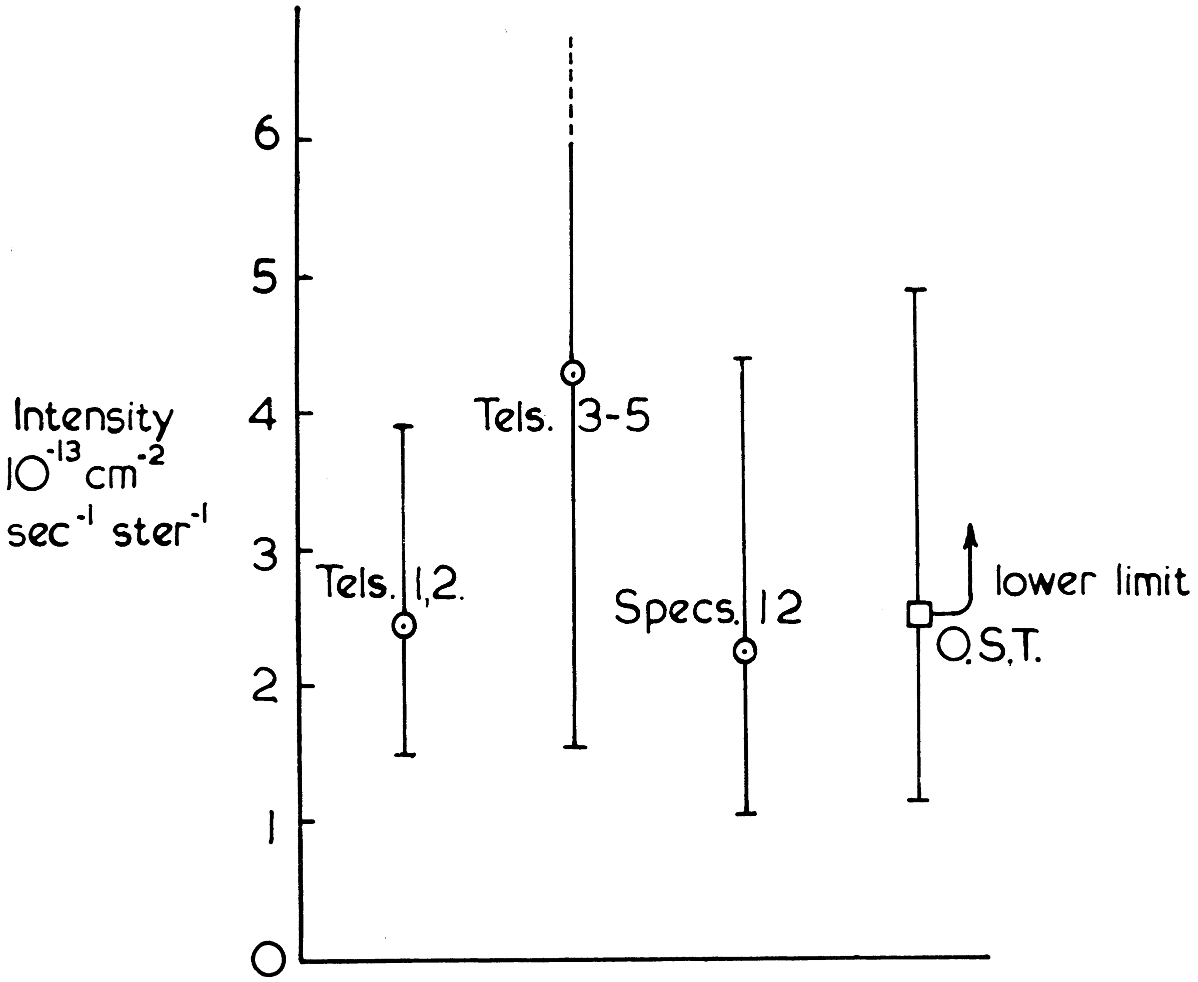

Fig.4 Neutrino-induced muon intensities derived from the various arrangements.

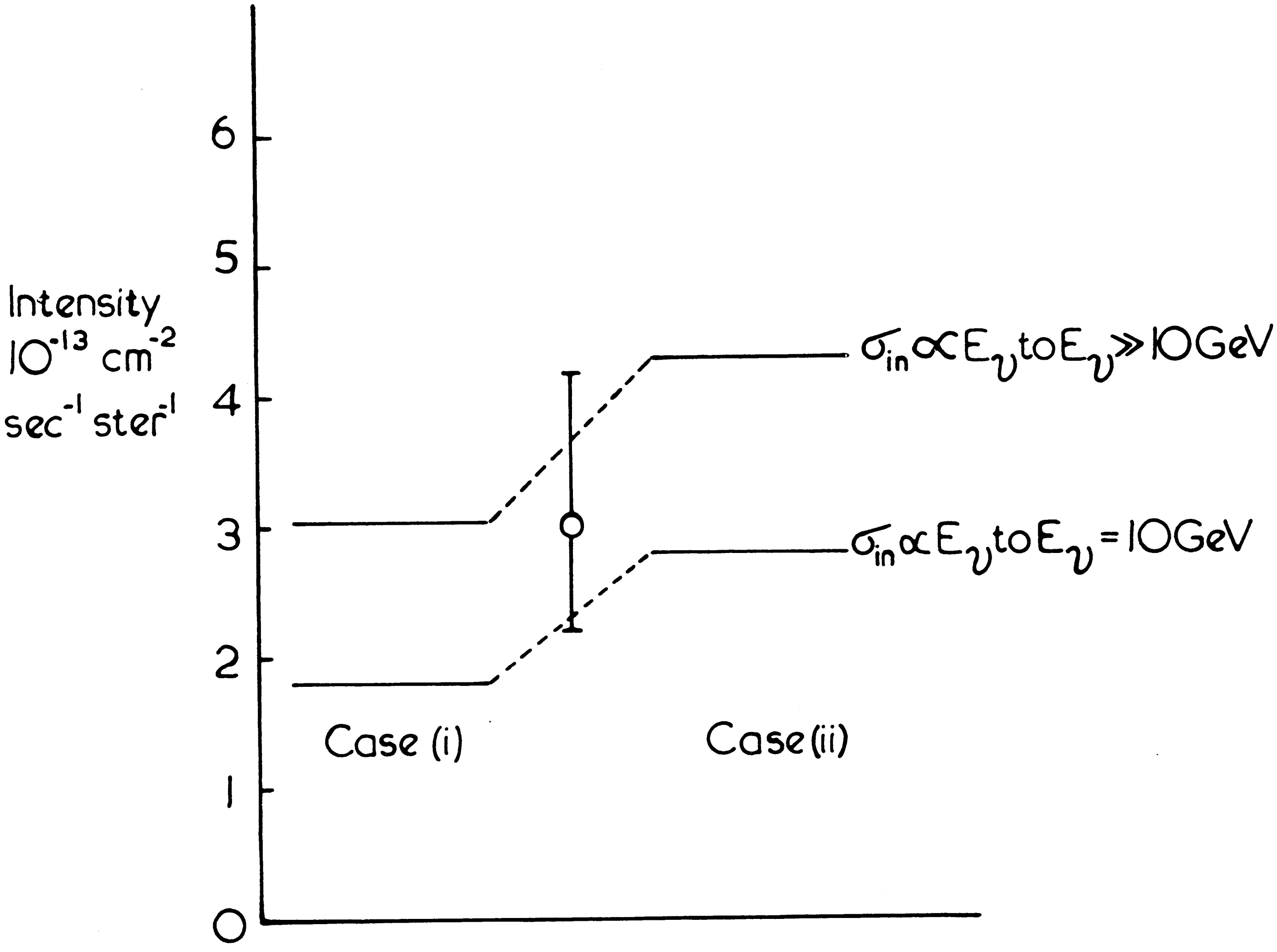

Fig.5. Comparison of the ν-induced muon intensity with expectation.