СООБЩЕНИЯ
ОБЪЕДИНЕННОГО
ИНСТИТУТА
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ

Дубна

E2 - 5092

Z. Kunszt, G. Vesztergombi

ЛАБОРАТОРИЯ ТЕОРЕТИЧЕСКОЙ ФИЗИКИ

ATMOSPHERIC NEUTRINOS AND THE PROPERTIES OF THE NEUTRINO INTERACTIONS AT HIGH ENERGIES

1970

E2 - 5092

Z. Kunszt, G. Vesztergombi*

ATMOSPHERIC NEUTRINOS AND THE PROPERTIES OF THE NEUTRINO INTERACTIONS AT HIGH ENERGIES

* Central Research Institute for Physics, Budapest.

Currently several experiments are in progress to detect muons deep underground in order to obtain the main features of neutrino interactions at very high energies. The latest result, reported in[1], on the intensity of neutrino induced events is

$$I = (3.5 \pm 0.5) \cdot 10^{-13} \frac{\text{muon}}{\text{cm}^2 \text{ sterad sec}} . \tag{1}$$

The following process contribute to this flux

i) $\nu_\mu + N \to \mu + N'$ Hadrons (elastic and inelastic scattering)

ii) $\nu_\mu + Z \to \mu + Z' + W$

(both the coherent and incoherent productions are involved).

iii) $\nu_e + e \to W \to \mu + \nu_\mu$.

Assuming various cross sections for these processes, the intensity of the ν_μ-induced muon can be estimated[2],[3]. At high energies (E_ν greater than 10 GeV) the main contributions come from the νN inelastic scatterings. Due to the great theoretical and experimental uncertainties, the comparison between the estimated and measured value is not conclusive. Recently, however, induced by the SLAC electroproduction experiments some new theoretical ideas have emerged in connection with the deep inelastic region[4-11]. As to the cosmic ray experiments, in case of local lepton current, the main conclusion of these theoretical investigations is the linear rise (at high energies) of the total cross section in the neutrino energy[4].

Particularly, the scale invariant property of the νW_2 structure function in itself ensures this linearly rising cross section[8]. The scale invariance of the νW_2, MW_1 structure functions restricts the mean fractional energy transferred to prompt muon produced in the inelastic reactions to the interval

$$0.56 \leq k_\mu < 1 \tag{2}$$

contrary to the guess that at high energy k_μ is small[2]. In more specific models the absolute value of the total cross section can be estimated as well. In the parton model, applying the CVC hypothesis and assuming that in the infinite momentum frame $g_A/g_V = 1$ for the partons, Bjorken and Paschos[8] predict

$$\sigma_{tot} = 0.59 \cdot E_\nu \cdot 10^{-38} \frac{cm^2}{nucleon} \tag{3}$$

(E_ν in GeV). Estimating the expectation value between baryons of the equal-time commutator $[J_i^a, J_j^b]$ of the $U(3) \times U(3)$ currents in the gluon model, Brandt and Preparata predict a little bit smaller value[12]. In comparison, the cross section obtained in machine experiments up to 12 GeV[13] is

$$\sigma_{tot}^{\nu N} = (0.8 \pm 0.20) \cdot 10^{-38} E_\nu \frac{cm^2}{nucleon} . \tag{4}$$

Applying the three assumptions

i) the structure functions of the νN interaction have scale invariant behaviour in the deep inelastic region,

ii) intermediate vector boson (IVB) exists,

iii) the weak interactions can be calculated as first order perturbations up to the energies $E_\nu \approx 10^5$–10^6 GeV, we once more estimated the muon flux and it turned out that it is in contradiction with experimental value at 99% confidence level if the slope in the total cross section is greater than 0.8 (see Figure 1). The slope value of 0.6 is in agreement only if the mass of the IVB lies in the region

$$3.5 \text{ GeV} < m_W < 12 \text{ GeV} \tag{5}$$

As to the validity of the applied hypotheses these results are not conclusive as well since in the linear rise even the value of 0.2 is not out of question. Reduction in the experimental errors by a factor of ≈ 3 may give conclusive results.

The intensity of ν_μ - induced muons from a zenith angle θ /14/ is

$$I_\mu(\theta) = \frac{N_A}{A} \int_{E_{min}}^{\infty} N(\nu + \tilde{\tilde{\nu}}, E_\nu, \theta)\, dE_\nu \int_{\epsilon}^{E_\nu} (E_\mu - \epsilon) \frac{d\sigma}{dE_\mu} \left(\frac{dE_\mu}{dx}\right)^{-1} dE_\mu , \tag{6}$$

where N denotes the Avogadro-number, A the atomic weight, $N(E_\nu, \theta)$ the intensity of ν_μ-s and $\tilde{\tilde{\nu}}_\mu$-s of energy E_ν $\frac{d\sigma}{dE_\mu}$ the differential cross section per nucleus for the interaction in question, $\frac{dE_\mu}{dx}$ the average rate of energy loss, ϵ a certain threshold of energy. We adopted the $N(E_\nu, \theta)$ function given in (15) and the $\frac{dE_\mu}{dx}$ function given in/16/. The contributions of the process i) for high energy neutrinos ($\bar{E}_\nu$> 10 GeV) are calculated by the help of the formula (6) and the differential cross section predicted by scale invariant models/5-11/ which is (assuming that IVB exists):

$$\frac{d\sigma}{dx} = \frac{G^2 MK}{2\pi} \times \frac{1 + \left(\frac{E_\mu}{E_\nu}\right)^2}{1 + 2\frac{(E_\nu - E_\mu) M}{m_W^2}} \tag{7}$$

m_W denotes the mass of the IVB, E_μ , E_ν the corresponding energy in laboratory frame and M is the nucleon mass. The definition of K is the same as in Ref./13/ with the assumption that $K_1 = K_2$.

The contributions coming from low energy neutrinos (E_ν < 10 GeV) are taken into account by the integral

$$I_\mu(\theta) \approx \frac{N_A}{A} \int_{E_{min}}^{10} \sigma_T(E_\nu) R[k_\mu(E_\mu - \epsilon)] N(\nu + \tilde{\tilde{\nu}}, E_\nu, (\theta)\, dE_\nu , \tag{8}$$

where $R(E_\mu)$ is the effective range of the muons, $\sigma_T(E_\nu)$ the total cross section per nucleus. We have chosen the value of 0.67 for k_μ. For the total cross section the measured values (4) are taken.

As the function of the IVB's mass the contributions of the process ii) are calculated by Coswik[17]. It is possible however that the numerical results obtained in that work are overestimated by a factor of 4 or 5 because the value of 0.65 is chosen for k_μ, but the energy shared by the muon in these reactions corresponds more probably to the "near threshold" case given by Menon et al.[18] which prefers the value of ≈ 0.15 (It depends on the branching ratio of the muon decay mode of the IVB).

The contributions, which derive from the process iii) are neglected[19].

With a confidence level better than 99% we can say that (see (I))

$$I_\mu < 5.0 \cdot 10^{-13} \frac{\text{muon}}{\text{cm}^2 \text{ sterad sec}} \tag{9}$$

if $\epsilon \approx 0.2$ GeV.

The intensity of ν_μ -induced muons is calculated applying the assumptions mentioned above. The curves of Fugure I represent the intensity as the function of m_W. Adopting at every point the published averages we get the curve A. If the slope of the total cross section is fixed at 0.8 (k = 0.9), but at other places all the possible errors are taken into account to estimate a lower limit we get the curve B. Repeating this latter calculation with the slopes 0.6 and 0.4 the curves C and D are obtained. The firm conclusion turns out that if the applied hypotheses are true the slope of the total cross section is less than 0.8. In case of the linear rise with 0.6 the mass of the IVB must lie in the interval

$$3{,}5 \text{ GeV} < m_W < 12 \text{ GeV} \tag{10}$$

Omitting the contributions of the process ii) we get the curves A′, C′, D′ of Figure 2 corresponding to the curves A, C, D of Figure 1. The $E_c = \frac{m_W^2}{M}$ represents the critical value of energy where the νN cross sections saturate due to some non-local mechanism. The contradiction to the slope of 0.8 survives.

Acknowledgements. One of the authors (Z.K.) would like to thank Dr. J.L. Osborne for valuable information on the ν-flux and Prof. G. Marx, A.N. Tavkhelidze and R.M. Muradyan for valuable discussions.

References

1. Proceedings of the 11th Conference on Cosmic Rays, Budapest, 1969.
2. R. Craig, J.L. Osborne, A.W. Wolfendale, E.C.M. Yong. Canad. J. of Phys., 46, 5344 (1968) (References to the previous works can be found there).
3. F. Reines. et al. Canad. J. of Phys., 46, 350 (1968).
4. J.D. Bjorken. Phys.Rev., 179, 1547 (1969).
5. J.D. Bjorken and E.A. Paschos. Phys.Rev., 185, 1975 (1969).
6. H. Harari. Phys.Rev.Letters, 22, 1078 (1969).
7. H.A.I. Abarbanel, M.L. Goldberger, S.B. Treiman. Phys.Rev.Letters, 22, 500 (1964).
8. J.D. Bjorken and E.A. Paschos. Preprint SLAC - PUB 678 (1969 December).
9. V.A. Matveev, R.M. Muradyan, A.N. Tavkhelidze. In the Proc. of the Int. Seminar on Vector Mesons and Electromagnetic Interactions, Dubna (1969);
   Scale Invariance, Current Commutators in Deep Inelastic Lepton-Hadron Interactions, JINR preprint E2-4968 (1970).
10. S.D. Drell, D.J. Levy and T.M. Yan. SLAC-PUB-606 (1969); Phys.Rev.Letters, 22, 744 (1969).
11. D.J. Gross and C.H. Llewellyn Smith. Preprint, TH 1043-CERN (1969).
12. R.A. Brandt and A. Preparata. Lepton-Hadron Deep Inelastic Scattering, Gluon Model and Reggeized Symmetry Breaking, Rockefeller University preprint (1970).
13. I. Budagov et al. Physics Letters, 30,B, 364 (1969).
14. R. Cool, T.XD. Lee, H. Robinson and M. Schwartz. Phys.Rev., 132, 12 97 (1963).

15. J.L. Osborne, S.S. Said and A.W. Wolfendale. Proceedings of Physical Society, 86, 93 (1965).

16. P. Hayman, N. Palmer, A.W. Wolfendale. Proceedings of Royal Society, A275, 137 (1964).

17. T.R. Coswik. Lower Limit on the Mass of the IVB, paper contributed to the 11th Conference on Cosmic Rays, Budapest (1969).

18. C.V. Achar et al. Proc. Int. Conf. on Cosmic Rays, London, p.1012 (1965).

19. Железных И.М., Загребин В.А., Изв. АН СССР Сер. физ. 29, 9, стр. 1746 (1965).

Received by Publishing Department
on April 29, 1970.

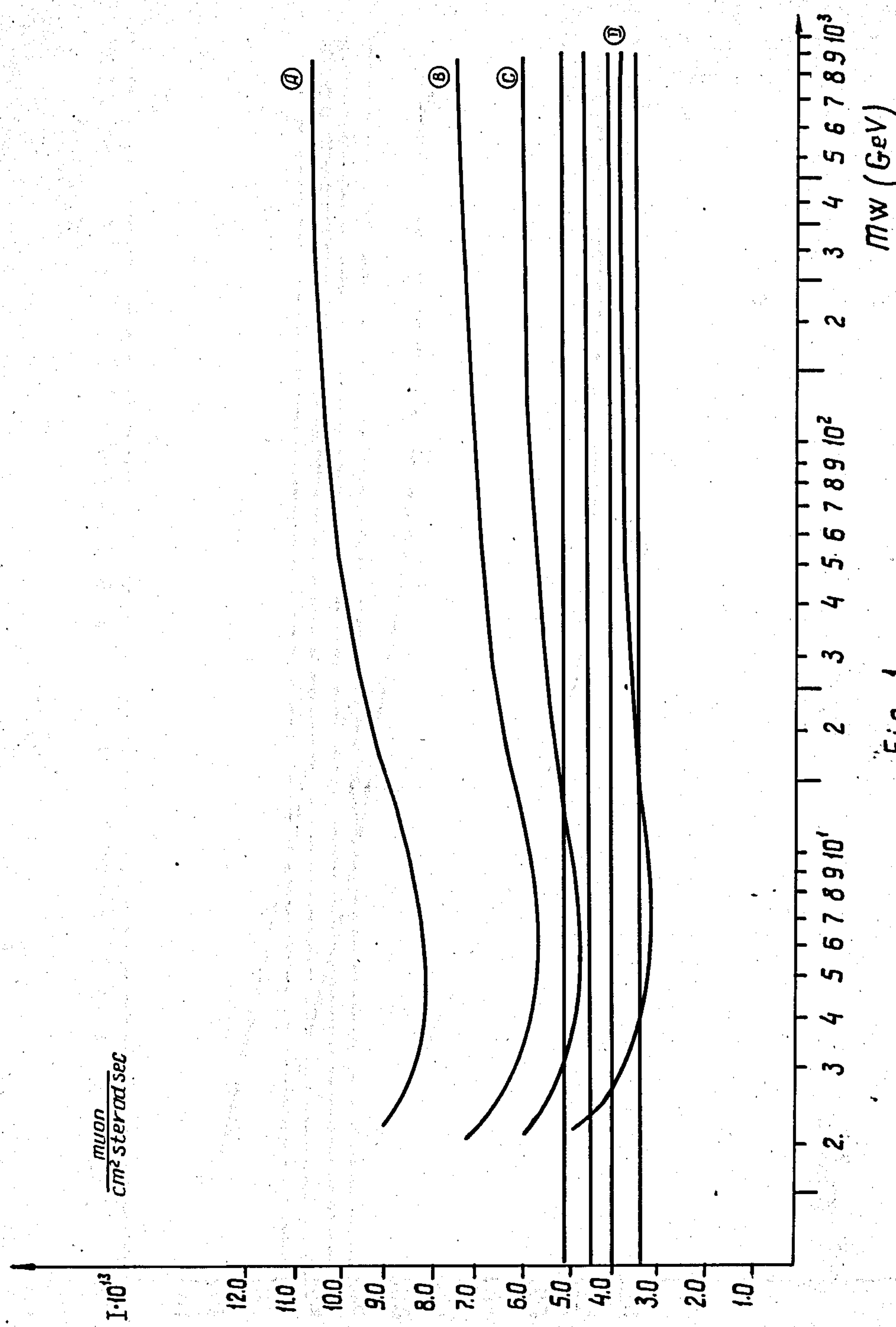
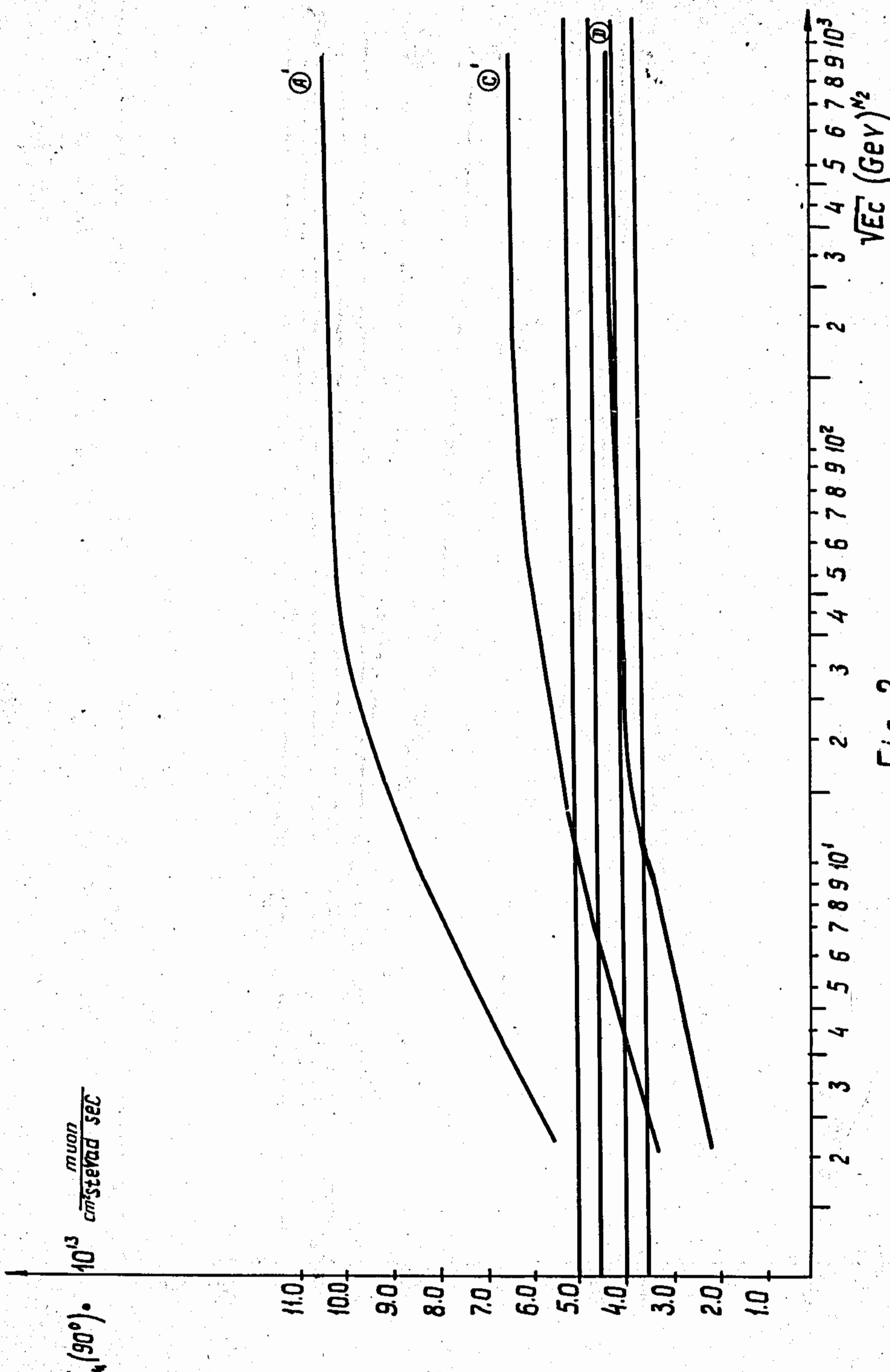

I·10^13
muon / cm² sterad sec
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
A
B
C
D
2
3
4
5
6
7
8
9
10¹
10²
10³
mw (GeV)

Fig. 1



$I_\lambda(90°) \cdot 10^{13}$ $\frac{muon}{cm^2 sterad\ sec}$
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
A'
C'
D
2 3 4 5 6 7 8 9 10^1 2 3 4 5 6 7 8 9 10^2 2 3 4 5 6 7 8 9 10^3
$\sqrt{Ec}\ (GeV)^{1/2}$

Fig. 2