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ON INVESTIGATION OF NEUTRINO INTERACTION IN 14-FOOT BUBBLE CHAMBER AT NAL ACCELERATOR

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ABSTRACT.

The possibilities of investigating the interaction of high energy neutrino (antineutrino) in the 14-foot bubble chamber of NAL have been considered.

In the cases when it is possible, there are presented the estimations of the expected number of the events for various processes caused by neutrino, the bubble chamber being filled with hydrogen, deuterium and neon. The experiments with different operational fillings of the bubble chamber allow to gain the most complete picture of neutrino interactions under the optimum conditions.

I. Introduction.

Experimental studies of the interaction of high energy neutrino at the accelerators are of great interest for the weak interaction theory. These results as any other results in investigating unknown nature phenomena are extremely interesting.

The problems of high energy neutrino experimental physics have been treated many times and in detail, in particular., in papers[1-10] and they are well known. Therefore we would not like to consider them in the present proposal.

We present a brief discussion of the experiment with application of the NAL 14-foot bubble chamber, used as a device that will provide a detailed investigation of kinematic analysis of the events under observation.

As hydrogen and deuterium targets are to be used in e.g. quantitative investigations of elastic scattering or production of nucleon excited states, while more massive targets are required in the search for new particles., therefore a number of experiments with various pure substances such as hydrogen, deuterium and neon is preferable to be carried out.

A group of IHEP physicists could participate in handling the bubble chamber pictures, obtained with different fillings of the chamber and in discussing the obtained results,

II. Neutrino Spectra.

Neutrino energy spectrum is fully detirmined with angular and energy pion and kaon distribution (main neutrino sources); with the experimental area geometry and the focusing system.

For estimation of meson spectra we use an empirical formula, that gives a satisfactory discription for all the present known experimental meson spectra in the proton energy region of $E_o \leq 70$GeV in a wide angle and momentum range. The formula is of the form:

$$\frac{d^2N}{dE\,d\Omega} = AE\left(1-\frac{E}{E_{max}}\right)^N \exp\left(-\frac{E^*}{D\sqrt{S}}\right)\left[1-\exp\left(-\frac{E^{*2}}{T}-\frac{x^2}{H}\right)\right]\Phi(x),$$

$$\Phi(x) = (1-F)\exp(-Bx^2) + F\exp(-Gx^2),$$

$$x = E\cdot\sin\theta, \quad A = A_0/E_0^{1/4}, \quad S = 2M(M+E_0),$$

$$E^* = \gamma_0\,(E - Pv_0\cos\theta),$$

$$\gamma_0 = \sqrt{S}/2M$$

E_{max} kinematic energy limit for mesons.

A_0,N,D,B,C,F - numerical constants.

A. Wide Band Neutrino Spectrum.

The results of calculating neutrino spectra, normalized for one interacting proton with E_0=200 GeV, are presented in Fig.1. The length of the decay path L and the decay channel diameter d were taken to be equal to 45 m and 1.0 m correspondingly. The muon shielding was taken to be equal to T=1000 m.

Not knowing the parameters of the focusing system, we had to calculate muon and electron-neutrino spectra for the perfect case of meson focising (curves 1,3) and muon neutrino spectrum in the absence of any focusing (curve 2).

Taking into account the information on the parameters of now existing focusing systems and on the target efficiency, the perfect focusing is reasonably assumed to provide intensity approximately three times higher than neutrino intensity, obtainable under real conditions.

B. Monochromatized Neutrino Beam.

The application of a monochromatized neutrino beam is advantageous in analyzing neutrino events as compared with the application of a continuous spectrum.

There are two neutrino "lines" from pion and kaon decay. in the monochromatized beam; they differ in energy approximately two times. Therefore even a very rough estimation of the total energy of an interaction in the bubble chamber with a "visibale"

energy release will allow to assign as event to one of the two available possibilities. The estimation results of the expected monochromatized neutrino intensity at NAL accelerator at the proton beam energy 200 GeV shown in fig.1. The shapes of neutrino "lines" (presented in fig.1) obtained in pion and kaon decay are related to the following assumption:

1. The full width of the line from $K \to \mu\nu$ decay equals 12%.
2. Meson beam is parallel.
3. Selection of neutrino events in the detector is limited with a cylinder with 0.5 m radius. Then 2.2 10^{13} neutrinos from $\pi \to \mu\nu$ decay and 3.5 10^{12} neutrinos from $K \to \mu\nu$ decay may be expected per 10^{18} protons interacting with the target. The ways of monochromatizing the meson beam define the level of continuous background. Standard quadrupole lenses may be applied along with the specially constructed lenses.

III. Neutrino Interactions.

The number of neutrino events in the bubble chamber is estimated for the fiducial volume of 20 m^3 and for the neutrino spectra, fig.1.

Taking into account the remarks on the efficiency of the now-existing focusing systems, the neutrino intensity with the perfect focusing was decreased uniformly 3 times in the entire spectra.

A. Total Number of Events (Boson Production not Taken into Account)

The total cross-section of neutrino interaction with nucleon was assumed to be equal to $7.10^{39} E_{cm}^2$ (E-neutrino energy in GeV) Fig.2 presents the energy spectrum of the events in hydrogen.

Attention should be paid to the necessity of a rather good determination of interacting neutrino energy in each individual case both for the determination of the total cross-section energy dependence and for the investigation of the differential structure of inelastic interaction $d^2\sigma/dt\,d\nu$.

Here the filling of the bubble chamber with neon is preferable. It is desirable

to carry out the experiment at two-three energy values of the monochromatized neutrino beam that will give a possibility to receive 4-6 experimental points in the cross-section dependence upon the energy.

The approximate number of interactions in neon can be recieved if one makes use of the estimations of the monochromatized beam intensity: i.e. at E_ν=40 GeV it is about 1000 events and at E_ν=100 - about 400 events (per 10^{18} interacting protons at E_0=200 GeV).

B. W-Boson.

The expected number of W-boson production events for different W-boson masses in the reactions $\nu N \to \mu^- W^+ N$ and $\nu N \to \mu^- W^+ +$ hadrons is shown in fig.3. This number will be at least one order of magnitude higher in neon under other equal conditions.

It seems to us that the identification of W boson in the bubble chamber by observing negative muon and positron from $W^+ \to e^+ \nu_e$ decay is the most reliable was for the hydrogen filling as well as for the neon one.

In the experiment with 200 GeV protons the vector boson can be found if its mass does not exceed 8-10 GeV (see Table 1).

C. Quasielastic Neutrino(Antineutrino) Scattering.

The combined experiment, i.e. neutrino and antineutrino scattering by neutron and proton in hydrogen and deuterium $\nu n \to \mu^- p$, $\tilde{\nu} p \to \mu^+ n$ is of great interest.

In the deuterium bubble chamber antineutrino will be identified with $\sim 30\%$ probability (it is the probability of neutron interaction in the fiducial volume of the chamber).

The total number of quasielastic scattering events in deuterium comprises approximately 240 and 40 (per 10^{18} interacting protons) for reactions $\nu n \to \mu^- p$ and $\tilde{\nu} p \to \mu^+ n$, correspondingly. Thus the duration of the experiment in the antineutrino beam should be approximately one order of magnitude higher than the one in the neutrino beam.

As the first step this investigation may be performed with neon filling when the number of interactions will be an order of magnitude higher.

The q^2 distribution of elastic events is shown in fig.1.

D. One Pion Events.

Table 1 presents the expected number of the events for production of N^*1236 in hydrogen and deuterium.

The cross-section of the reactions $\nu N \to \mu N^*$ at the neutrino energy above 5 GeV are estimated as $\sigma\ (N^*=1236)=4.10^{-39}cm^2$; $\sigma\ (N^*=1680)=2.5.10^{-39}cm^2$; $\sigma(N^*=1525)=2.10^{-39}cm^2$.

For comparison an approximate number of one pion events is indicated in the Table. Though the number of the events in neon will be an order of magnitude higher as compared with hydrogen and deuterium, the latter are more preferable thanks to their higher reliability in interpretation.

E. Hyperon Production.

A considerable number of hyperon production events can be expected in antineutrino beam. The estimations of the number of the events in deuterium per 10^{18} interacting protons are quoted in Table 2.

TABLE 2.

REACTION	$\bar{\nu}p \to \mu^+\Lambda$	$\bar{\nu}p \to \mu^+\Sigma^0$	$\bar{\nu}n \to \mu^+\Sigma^-$	$\bar{\nu}N \to \mu^+Y^*$
1	2	3	4	5
number of events	20	7	14	15

The fulfilling of the rule $\Delta Q = \Delta S$ in neutrino processes at high energy can also be checked in the neutrino beam. The check accuracy will be limited with uncertainty of our knowledge of the antineutrino contamination (1%) in the neutrino beam. The expected number of hyperon production events in neon is also given in the Table.

6 F. Lepton Pairs and $\nu_e e$ - Scattering.

The reaction $\nu_e e \to \nu_e e$; $\nu_\mu N \to \mu^+\mu^-\nu_\mu N$; $\nu_\mu N \to \mu^- e^+ \nu_e N$ will not be practically observed in hydrogen, deuterium and neon (see Table 1).

2. Reaction $\nu_\mu e \to \nu_\mu e$.

The process of muonic neutrino-electron scattering $\nu_\mu e \to \nu_\mu e$ is possible within the usual weak four-fermion interaction scheme due to higher orders of weak interaction hamiltonian. When the weak interaction being not cut off up to the unitary limit the cross-section of this process can have the same order of magnitudeas $\nu_e e \to \nu_e e$ cross-section.

The reaction $\nu_\mu e \to \nu_\mu e$ may exist in the theory of weak neutral currents (12), as well as in the Lipmanov scheme (13), if there is a deviation from (V-A) interaction.

The existance of this process is a natural consequence of the existance of the intermediate scalar B-boson.

The number of the scattering events in the 14-feet bubble chamber is given in Table I under assumption, that the cross-section of this reaction is $\sigma = 1.6\ 10^{-41} E\ cm^2$.

Here it should be noted that the bubble chamber filled with neon may come to be the most perspective detecting device for $\nu_\mu e \to \nu_\mu e$ scattering detection.

3. Search for Heavy Leptons.

At the mass of μ'-lepton being not very large (3÷ 4 GeV) the total number of the produced events in the reaction $\nu_\mu n \to \mu'^- p$, where μ'^- is a heavy lepton with muonic quantum numbers practically equals the total number of the elastic events of $\nu_\mu n \to \mu^- p$ scattering.

The production of heavy leptons with a lepton quantum number different from the muonic one is similar to the production of the muon pair in the Coulomb field. Therefore the relation:

$$\sigma(\nu_\mu Z \to \mu^- \lambda^+ \nu_\lambda Z) \leq \sigma(\nu_\mu Z \to \mu^- \mu^+ \nu_\mu Z)$$

is valid.

The expected number of the events for both reactions is enlisted in Table I.

A detailed analysis of the production process of heavy leptons is given in papers /10, 11/.

I. Comparison of $\nu_\mu N$ and $\nu_e N$ interactions.

The muon neutrino beam always contains a certain percentage of electron neutrinos from K_{e3}-decay. As it is seen from the Table, the total number of the electron neutrino interactions in neon becomes sufficient for quantitative comparison.

J. Unexpected Phenomena.

In the high energy neutrino experiments as in any other area, where the investigations are at the very beginning new phenomena and unexpected processes may develop. Unfortunatelytthere are no ways to make any reliable estimations on their probability, but in any case, if they do appear in the experiments with the bubble chamber, the result will be of the greatest interest.

Barolepton production is one of such possibilities. CERN Neutrino experiment seems to give some hints on its production. Or as an example it may be hypothetical unusually strong neutrino-neutrino interaction /14/.

Conclusion.

We would like to take part in the neutrino experiment at the NAL accelerator mainly by participating in processing some pictures from the NAL bubble chamber on the IHEP scanning-measuring systems.

Bearing in mind the estimations of the expected number of the events (at 10^{13} interacting protons per pulse) we assume, that $5 \cdot 10^5 \div 10^6$ pictures in each exposure of the bubble chamber in the neutrino beam with hydrogen, deuterium and neon filling, and about 10^6 pictures in the antineutrino beam with deuterium filling of the chamber are needed to solve the problems discussed in the proposal. It would be desiarable to have 10^5 pictures with neon in the monochromatized neutrino beam at 2-3 meason energies.

The proton beam with E_0=200 GeV preferable in the first experiment with the bubble chamber.

At the present moment the Institute for High Energy Physics is preparing a system for processing the bubble chamber pictures, in particular, it can analyse big european bubble chamber pictures. As the optics of the NAL chamber is planned to be similar to the BEBC' optics, our system will be able to analyze pictures from the NAL bubble chamber too. In this semiautomatic devices will be apllied, and if it becomes useful the automatic device FSD and the one with CRT will also be used. We could handle some fraction of pictures from any of the above mentioned exposures of the chamber.

About 10 physicists may participate in the experiment.

TABLE I

E_0 = 200 Gev, L = 450 m, T = 1000 m, R_d = 1,25 m 14 - foot Bubble Chamber (H_2, D_2, Ne).

		$\langle\sigma\rangle = \int \sigma \frac{dN}{N dE_\nu} dE_\nu$	Number of ν - events per 10^{18} interacting protons		
			H_2	D_2	Ne
1.	Number of ν - events for $\sigma = 10^{-38}$ cm^2	$2,38.10^{-41}$	330	430	2800
2.	All ν-events without W-boson production	$3,3.10^{-40}$	4600	5800	39000
3	Elastic ν - events *) $\nu n \to \mu^- p$	$1,43.10^{-41}$	--	260	1700
	$q^2 > 1$	$1,9.10^{-42}$	_	34	230
	$q^2 > 2$	$7,17.10^{-43}$	_	13	83
	$q^2 > 4$	$2,13.10^{-43}$	_	4	27
	$q^2 > 6$	$9,7.10^{-44}$	_	1,7	12
4.	Elastic ν - events $\tilde{\nu} p \to \mu^+ n$	$2,38.10^{-42}$	33	43	280
	$q^2 > 1$	$3,23.10^{-43}$	4,5	6	38
	$q^2 > 2$	$1,2.10^{-43}$	1,7	2,2	14
	$q^2 > 4$	$3,6.10^{-44}$	0,5	0,67	4,3
	$q^2 > 6$	$1,57.10^{-44}$	0,22	0,28	1,9
5.	One-pion events	$1,2.10^{-41}$			
	$\nu + n \to \mu^- + p + \pi^0$		—	36	240
	$\nu + n \to \mu^- + n + \pi^+$		—	18	120
	$\nu + p \to \mu^- + p + \pi^+$		120	160	1100
6.	Hyperons production ($\tilde{\nu}$ - beam)	$2,38.10^{-42}$	33	43	280

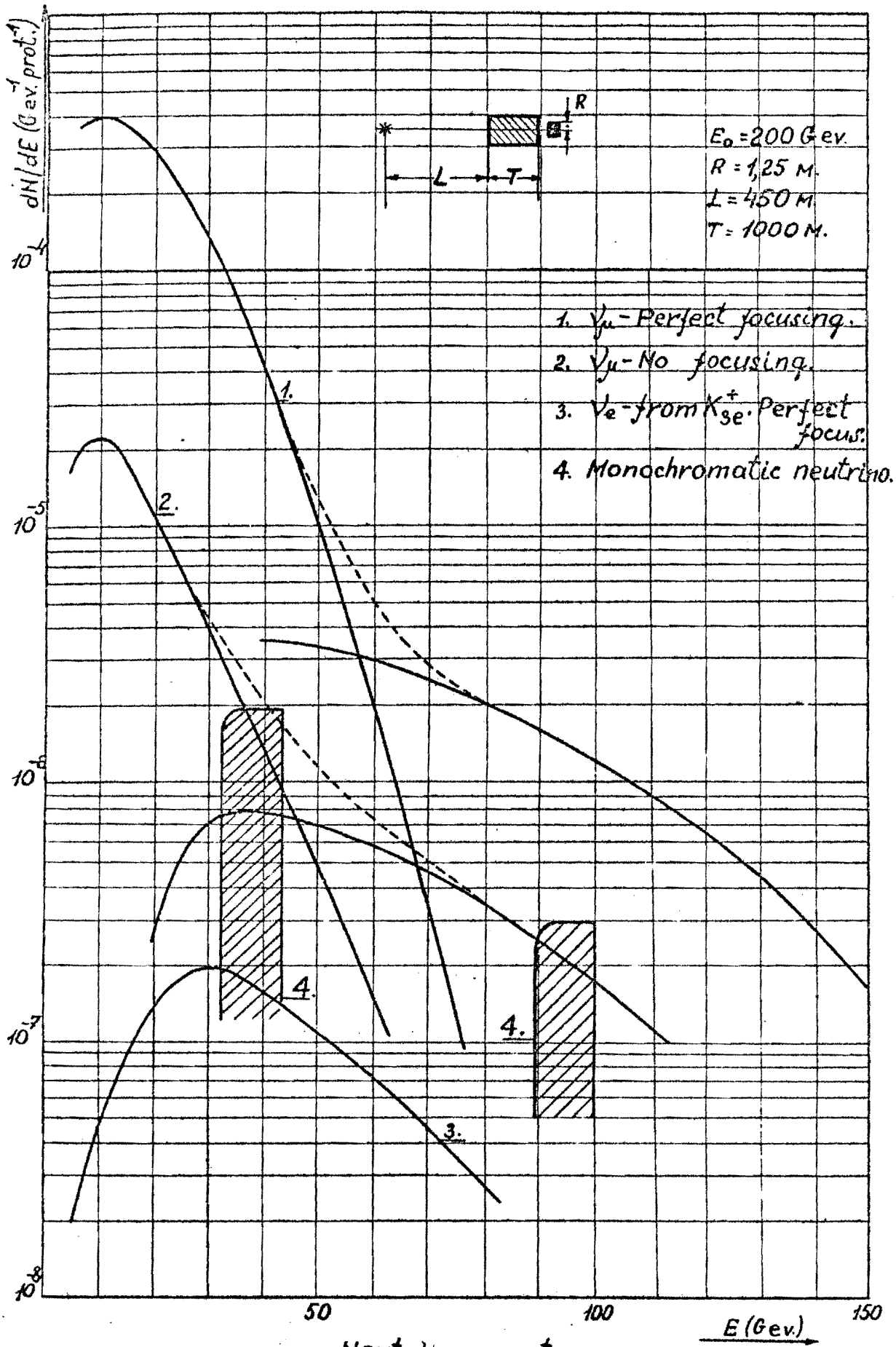
TABLE I

(Continued)

		$\langle\sigma\rangle = \int \sigma_\nu \frac{dN}{dE_\nu} dE_\nu$	Number of ν - events per 10^{18} interacting protons		
			H_2	D_2	Ne
7.	+) $\nu_\mu p \to \nu_\mu \mu^+ \mu^- p$	$4,0.10^{-45}$	0,044	0,060	0,370
8.	**) $\nu_\mu n \to \mu^- p$	$\sigma^{**)} \lesssim \sigma^{*)}$	—	$\lesssim$ 260	$\lesssim$ 1700
9.	++) $\nu_\mu p \to \mu^- \nu_\lambda \lambda^+ p$	$\sigma^{++)} \lesssim \sigma^{+)}$	$\lesssim$ 0,044	$\lesssim$ 0,060	$\lesssim$ 0,370
10.	$\nu_\mu e \to \nu_\mu e$	$8,3.10^{-43}$	8,5	10,6	72
11.	$\nu_e e \to \nu_e e$	$8,3.10^{-45}$	0,085	0,106	0,72
12.	Production of W - bosons $\nu N \to W\mu$ + hadrons M = 2 Gev	$7,0.10^{-40}$	7700	10000	65000
	4 Gev	$6,0.10^{-41}$	660	860	5600
	6 Gev	$1,0.10^{-41}$	110	140	910
	8 Gev	$1,2.10^{-42}$	13	17	110
	Production of W - bosons $\nu N \to W\mu N$ M = 2 Gev	$5,0.10^{-40}$	5500	7100	46000
	4 Gev	$2,17.10^{-41}$	240	310	2000
	6 Gev	$1,1.10^{-42}$	12	16	107
	8 Gev	$1,3.10^{-43}$	1,4	1,8	12

References.

1. B.Pontecorvo. JETP, 37, 175, 1959.
2. M.A.Markov. Proc.Intern.Conf.High Energy Physics, Rochester, 1960.
3. T.D.Lee, C.N.Yang, Phys.Rev.Lett., 4, 307, 1960.
4. G.Bernardini. Proc. Rochester Conference. 1960.
5. The 1963 NPA. Seminars, CERN 63-37
6. Inform.Conf.Exper.Neutrino Physics, CERN 65-32.
7. Proc.Intern.Conf. Weak Interact., ANL - 7130.
8. C.Franzinetti. CERN 66-13.
9. C.Young. CERN 67-12.
10. IHEP Neutrino Experiment, Preprint IHEP 68-56-K.
11. S.Gerstein, V.Folomeshkin, Yadern. Phys., 8, 447, 1969.
12. M. Good, L.Mishel, F. de Rafael, Phys.Rev. 151, 1194, 1966.
13. E.Lipmanov, JETP, 55, 2245, 1968.
14. D.Yu.Bardin, S.M. Bilenky, B.M.Pontecorvo, Phys. Lett., B 32, 121, 1970.



Neutrino spectra

Fig. 1

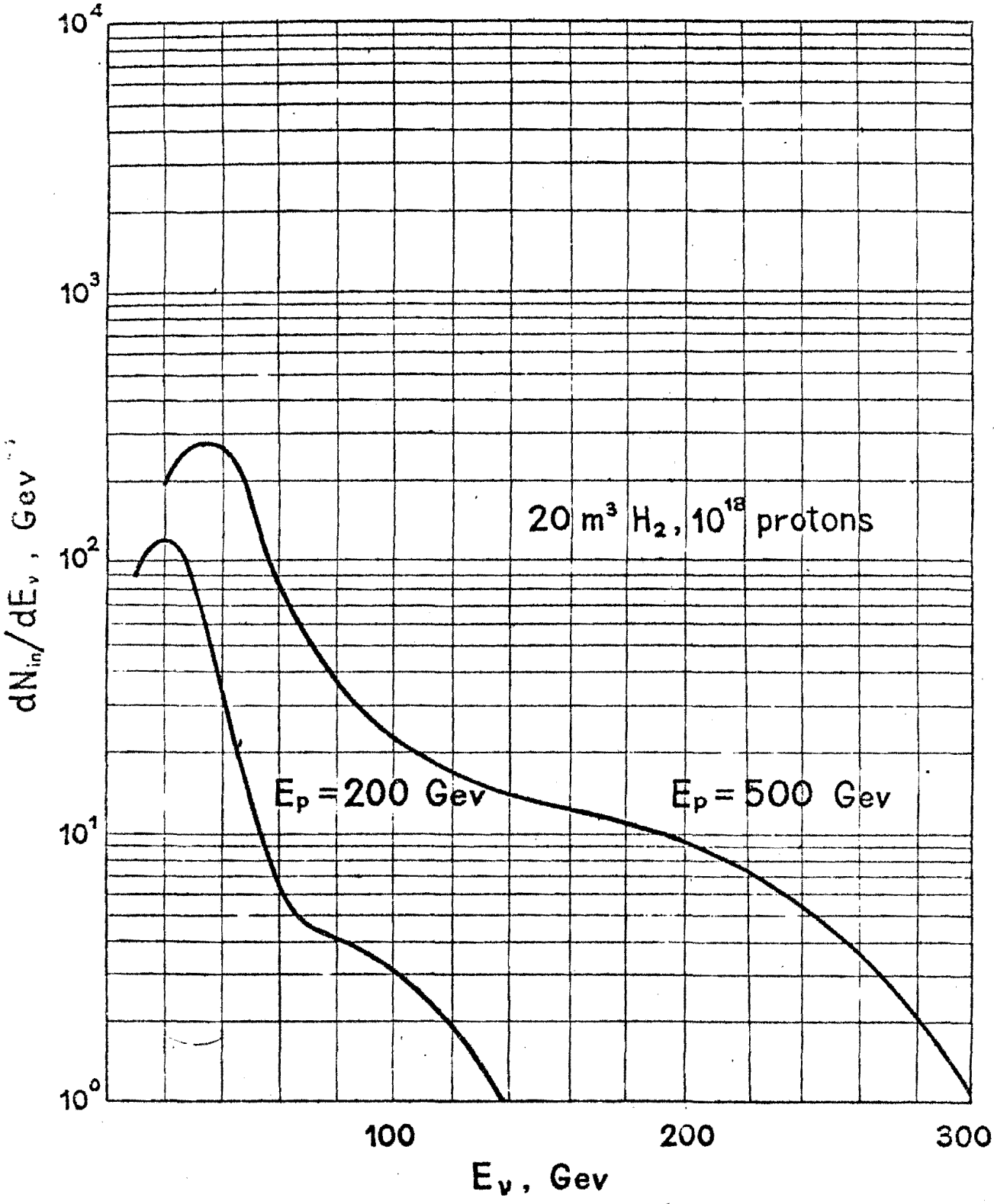


Fig. 2. Expected number of νN - inelastic interactions in hydrogen.

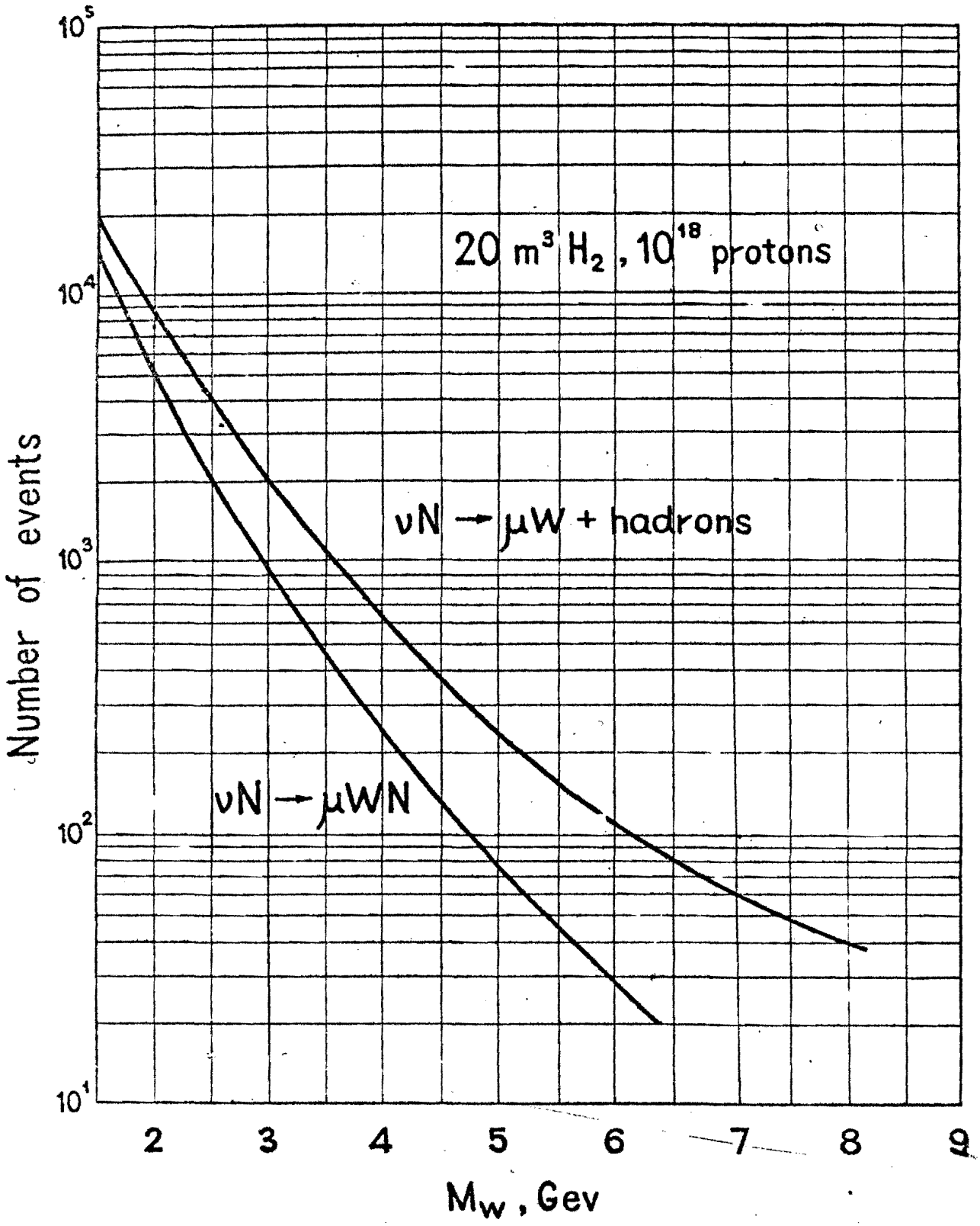


Fig.3. Vector meson production.