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PROPOSAL FOR A NEUTRINO EXPERIMENT IN GARGAMELLE

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1. INTRODUCTION

Among the many problems posed in weak interactions, it appears that neutrino experiments in Gargamelle would be especially suitable to investigate the following : *)

i) Total cross-sections in the high energy region, for ν and $\bar{\nu}$;

ii) Inelastic continuum excitation of the hadronic amplitude-structure factors and "partons";

iii) Existence of the intermediate W-boson;

iv) Coupling constants for diagonal and non-diagonal weak interactions;

v) Neutral currents.

In addition, there are of course, many other topics of interest; for example, form factors for the elastic and quasi-elastic $\Delta S = 0$ and $\Delta S = 1$ transitions ($n \rightarrow p$, $p \rightarrow \Lambda$, $n \rightarrow N^*$, $n \rightarrow Y^*$ e tests of CVC and PCAC. However, these problems can also be investigated with large H^2, D^2 and H^2/Ne chambers.

Gargamelle is, we claim, a <u>unique</u> instrument for investigating problems (i) - (v), which are now discussed in more detail.

*) these conclusions follow from very detailed studies to be found in reports TCC/68-18 and TCC/68-40.

2. STRUCTURE OF THE WEAK HADRONIC CURRENTS

Assuming the leptonic weak current is point-like, the differential inelastic cross-section can be written in the form

$$\frac{d^2\sigma}{dq^2 d\nu} = \frac{E_\mu}{EM}\frac{G^2}{2\pi}\left[W_2 \cos^2\frac{\theta}{2} + 2\, W_1 \sin^2\frac{\theta}{2} + \frac{E + E_\mu}{M} W_3 \sin^2\frac{\theta}{2} \right] \quad ($$

where W_2, W_1 and W_3 are dimensionless structure functions depending only on q^2 and ν.

"Scale invariance" is the name given to describe a remarkable property of the inelastic continuum structure factors W_i, in the region where $q^2 > M^2$, $\nu > M$ †). It was found in SLAC electro-production experiments that W_1 and νW_2 are functions <u>only</u> of the dimensionless variable

$$\rho = M\nu/q^2$$

This result holds at least for spacelike q^2 up to 5 $(\mathrm{GeV}/c)^2$.

Such a general property was proposed theoretically by Bjorken but <u>only</u> in the asymptotic region $q^2 \longrightarrow \infty$, $\nu \longrightarrow \infty$. A possible interpretation was given by Feynman in terms of point-like constituents, or "partons". A nucleon is then pictured as a "gas" of quasi-free partons, so that $\rho = M/2\,m$ where m is the effective parton mass.

<u>i) Measurement of the total ν and $\bar{\nu}$ Cross-section</u>

Scale invariance of one of the 3 inelastic form-factors W_1, W_2 and W_3 is sufficient to ensure a linear dependence of σ_{total} (ν + p, n $\longrightarrow$ anything) with neutrino energy, provided the leptonic current is point-like. The numerical coefficient K in the expression σ = KE is of fundamental importance for any model of the hadronic weak current. Some theoretical predictions are available. For spin 1/2 partons it is customary to assume pure V-A coupling of lepton and parton currents, whence K can be related to the virtual photo-production

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†) q^2 is the square of the four-momentum transfer, ν the energy transfer to the baryon vertex, and M the nucleon mass.

amplitudes via CVC. The observed ratio [2] $(\nu W_2^{weak} / \nu W_2^{e.m.}) \approx 3 \pm 1$, for $(M\nu / q^2) > 2$, is consistent with estimates [1] assuming $G_V = G_A$.

The previous CERN experiments [2], which found the relation $\sigma_{total} = (0.8 \pm .2)\, E_\nu \times 10^{-38}\ cm^2$/nucleon, had errors on σ_{total} of order $\pm$ 25 % at (10 $\pm$ 2 GeV).

In Gargamelle, a 10^6 picture run at $E_p = 24.5$ GeV would give a $\pm$ 6 % statistical error in σ_{total} at 10 ($\pm \frac{1}{2}$) GeV rising to $\pm$ 20 % at 15 ($\pm \frac{1}{2}$) GeV. (Fig. 1). For $E_p = 28$ GeV, these errors would be reduced by a factor $\sim$1.25. We expect that the ν flux will be determined to $\pm$ 5 %. More detailed event rates and operating conditions are given in table 1.

An important point is that the ratio $\sigma_{\bar{\nu}} / \sigma_\nu$, in the high energy region could be quite different according to the different models, (as shown in Table 2). Systematic errors are very important. The main experimental requirements are good calibration of ν and $\bar{\nu}$ fluxes and proper understanding of background, which is quite different for ν and $\bar{\nu}$ beams. Unambiguous identification of the charged lepton, while unimportant in the estimate of neutrino energy, is vital to discriminate between $\bar{\nu}$ events and ν background.

In the CERN HLBC experiments large average correction factors (15 % in CF_3Br, 35 % in C_3H_8) were required to account for missing energy. These correction factors will be reduced by a factor of 3 in a freon run in Gargamelle. This is a very significant gain, as any systematic error in corrections to the visible energy is reflected in a much larger error in σ and K, because of the rapid variation in ν flux with energy.

ii) Inelastic continuum excitation

Because of the small number of events available in the previous experiments, the analysis of the inelastic form-factors had to be carried out assuming scale invariance. Then, employing the dimensionless variables

$$\rho = M\nu / q^2$$

$$x = \nu / E$$

it was possible to utilise the data over a range of neutrino energies. In Gargamelle, the approximately 100-fold increase in statistics will allow one to investigate the validity of scale invariance in neutrino interactions. Fig. 2 shows the apportionment in q^2 and ν of the existing CERN neutrino events. We estimate that 16 % of the events will have $q^2 > 1\ (\text{GeV}/c)^2$ and $\nu > 1$ GeV.

It should be emphasized that neutrino experiments in Gargamelle will give information not attainable with electron machines.

Firstly, the factor W_3 (representing the V-A interference term), is absent in electron scattering. W_3 measures the mean baryon number of the partons. It is also important because it should vanish at large ρ, and is therefore a good test of the Pomeron exchange hypothesis.

Secondly, detailed information about the hadronic vertex is absent in the electroproduction experiments, and a visual detector is obviously essential.

It is also relevant to point out that ν experiments do not suffer from the disadvantage of large radiative corrections as in the electron experiments. Furthermore the lower ν event rate is partially compensated for by having no $\frac{1}{q^4}$ fall off in cross-section. There are several theoretical predictions concerning the relevant magnitudes of the different form-factors. Table 2 shows predictions from two extreme parton models. In the Drell model [3], the nucleon consists of a "bare" point-like nucleon plus a pion cloud, and the lepton current couples preferentially to the bare nucleon. In the quark model of Bjorken and Paschos [4] the nucleon consists of a large number of quark-antiquark pairs in closed shells, plus the usual 3 "valency" quarks of SU6.

The first five rows of Table 2 depend on the parton quantum numbers which determine the behaviour of W_1/W_2 and W_3/W_2 in the region $\rho \gg 1$. A comparison of ν and $\bar{\nu}$ cross-sections and measurement of the x-dependence will discriminate between the Drell and other models.

What is also interesting is the actual dynamics of the hadronic amplitude, especially in the non-asymptotic region (i.e. $\rho \sim 1$). This is illustrated by the last 2 rows in the table, which give the general forms of multiplicity and transverse momentum distributions.

3. LEPTONIC CURRENTS

iii) W-Boson

Experiments with Gargamelle will substantially improve on the cross-section limit for electromagnetic production of real W-bosons. This is made possible by the factor $\sim$ 100 increase of the product (beam intensity X detection volume) as compared with the CERN freon chamber used in 1963/64. The study of both the leptonic decay $W \longrightarrow e^+ + \nu$ and the hadronic decay $W \longrightarrow \pi$'s, K's in Gargamelle, appears to be more favourable than by any other technique. Comparison with the old CERN HLBC results suggest that background will not be a big problem, and hence a factor 100 in rate implies an increase in the mass limit from $M_W \gtrsim 1.7$ GeV for the hadronic mode to $M_W \gtrsim 3$ GeV, for both leptonic and hadronic modes.

Another effect of a finite W-boson mass is to introduce a propagator term in σ_{total}. Fig. 1 shows the modification introduced by a finite value of M_W. The calculations were done using the Drell parton model, for incident neutrinos. For other models (e.g. quark parton model) the curves are closely similar. Normalization has been made arbitrarily at $E_\nu = 5$ GeV.

iv) Coupling Constants for diagonal and non-diagonal weak Interactions

A reactor experiment by Reines and Gurr [5] claims to have detected $\bar{\nu}_e + e^- \longrightarrow e^- + \bar{\nu}_e$, with a cross-section corresponding to a diagonal weak coupling $G_D \approx 10\ G_F$. The CERN HLBC experiment [6] gives, for $\nu_e + e^- \longrightarrow e^- + \nu_e$, $G_D < 18\ G_F$ at 90 % c.l.

For a 10^6 picture freon run in Gargamelle we expect 0.3 events of $\nu_e + e^- \rightarrow e^- + \nu_e$ for $G_D = G_F$. We estimate that we should be able to set a limit $G_D < 4\ G_F$ at 90 % c.l. If the lower Reines number is correct, 30 events will be obtained. In this case also a $\bar{\nu}$ experiment ($\bar{\nu}_e + e^- \rightarrow e^- + \bar{\nu}_e$) would be important, since it would discriminate between a specifically magnetic moment interaction (yielding $\sigma_\nu = \sigma_{\bar{\nu}}$) which cannot be excluded from present limits on neutral currents, and a V-A type theory with massless neutrino but anomalous coupling ($\sigma_{\bar{\nu}} = \sigma_\nu / 3$).

v) Neutral Currents

The present upper limit 6) of $\dfrac{\sigma_{\nu p \rightarrow \nu p}}{\sigma_{\nu n \rightarrow \mu^- p}} \leqslant 0.12$ is set by the level of neutron interactions. If we use a small ($\sim 0.5\ m^3$) central fiducial region in Gargamelle and require no interaction in the rest of the chamber we can reduce this limit to .05. Furthermore by studying the neutron attenuation in the rest of the chamber and making a background subtraction an upper limit of .03 can be reached. Equally the present upper limits for other neutral current processes can be reduced by about a factor of 4.

A similar analysis can be applied to the search for small recoil electrons which could be due to a neutrino magnetic moment. If one scans for recoil electrons > 5 MeV (i.e. 3 cm range), it will be possible to reach $< 10^{-8}$ Bohr electron magnetons for ν_μ magnetic moment.

4. OTHER ν AND $\bar{\nu}$ PROCESSES

i) Elastic Hyperon Production

During an $\bar{\nu}$ run in Gargamelle one would hope to observe for the first time the $\Delta S = 1$ elastic hyperon production. According to SU_3 calculations ~ 100 hyperons would be produced in $\sim 10^6$ $\bar{\nu}$ pictures. At least one half of these would get out of nucleus and hence one might hope to measure the total elastic hyperon cross-section to ~ 30 %.

ii) T Violation

With 10^6 $\bar{\nu}$ pictures in freon, T invariance could be investigated by measuring the transverse polarization of the stopping μ^+ with respect to the neutrino-muon plane. We estimate that the transverse polarization could be determined to $\sim$ 10 %.

iii) Elastic $\bar{\nu}$ Interactions

The elastic reaction $\bar{\nu} + p \longrightarrow \mu^+ + n$, has not yet been studied in detail. With respect to future antineutrino experiments in hydrogen or deuterium, we feel that Gargamelle could be competitive for two reasons :

a) with a freon filling the event rate can be as much as 30 times larger, for the same antineutrino flux;

b) the events can be determined kinematically only if the outgoing neutron interacts in the chamber, thus signalling its direction. The background from reaction $\bar{\nu} + p \longrightarrow \mu^+ + n + \pi^o$ should be negligible in Gargamelle, due to high π^o detection efficiency. One would hope to reach an accuracy similar to that of present elastic neutrino reactions in heavy liquid.

iv) Adler Tests of CVC and PCAC

Previous studies of the Adler PCAC tests can be continued and in addition, due to higher statistics, a study of the Adler CVC test concerning the scalar product of the perpendicular to the dipion plane and ν direction can be attempted.

5. EXPERIMENTAL DETAILS

The request is for an exposure of at least 10^6 photographs with an average of 1.5×10^{12} accelerated protons at the highest available proton energy (28 GeV), using a freon filling.

i) Proton Energy

Most of the problems discussed above require a beam of the highest possible energy. The actual value used will depend on experience with the available repetition rate of Gargamelle, and the use of the PS for other experiments, (see table 1).

ii) Determination of the ν flux

The ν spectrum will be determined to $\sim$ 5 GeV with an accuracy of 5 % from muon measurements in the shielding. However, for higher neutrino energies it is vital that the K/π ratio be measured in a separate experiment already proposed [7] in order to reduce the errors in this part of the spectrum to the 5 % level. The expected ν and $\bar{\nu}$ spectra for 25 and 27.5 GeV/c proton momenta are shown in figure 3.

iii) ν and $\bar{\nu}$ Running

It is proposed to divide the running into 2 phases. The first phase consists of a total of 0.25 million pictures, with running time divided equally and alternatively between ν and $\bar{\nu}$. The rest of the pictures will be divided according to the results of the preliminary analysis of the first phase.

6. ANALYSIS FACILITIES

Laboratory	Scan Measurement Tables
Aachen	4
Bruxelles	4
CERN	4
Ecole Polytechnique	6
Milan	3
Orsay	6
UCL	3
Total	30

References

1) D. Gross and C. Llewellyn-Smith - Nucl. Phys. B 14, 337 (1969).

2) J. Budagov et al. - Physics Letters 30 B, 364 (1969).

3) S. Drell, D. Levy and T. Yan - Phys. Rev. Letters, 22, 744 (1969)

4) J.D. Bjorken and E. Paschos - SLAC-PUB-572 (1969).

5) F. Reines and H. Gurr - PRL (in press).

6) D.C. Cundy et al. - (to be published in Physics Letters), see also D.H. Perkins - CERN Weak Int. Conf. Jan. 1969.

7) Proposal PHI/COM/70-60.

Table 1

Expected Event Rates in Gargamelle assuming $\sigma_\nu = .8\ E_\nu \times 10^{-38}\ cm^2/nucleon$ ($E_\nu \geqslant$ 2 GeV) for 5×10^5 pictures

E_ν	Neutrino Number of Events/GeV	Anti-Neutrino ($\sigma_{\bar{\nu}} = \sigma_\nu$) Number of Events/GeV
1	6000*	~1000*
2	5600	3300
3	3000	1300
4	1300	390
5	620	160
6	350	110
7	280	80
8	270	72
9	250	57
10	210	40
11	160	22
12	120	11
13	72	5
14	45	2
15	26	1
	Total 18300	Total 6550

* Extrapolated from previous experiments

Assumptions used in event rate calculation :

a) Chamber fiducial volume 6 m^3

b) Density of freon 1.2 gm/cm^3

c) 1.5×10^{12} accelerated protons/burst at 27.5 GeV/c

d) 17 ejected bunches

e) Decay length 70 m

f) Shielding length 22 m iron

g) Expected ejection efficiency, beam transport efficiency etc. ~ 80 %

Table 2

PREDICTIONS OF SPIN 1/2 PARTON MODELS

	Quark Parton Model [4]	Drell Model [3]
$\sigma_\nu / \sigma_{\bar{\nu}}$ (total)	1	3
$d\sigma(\nu)/dx$	$1 - x + x^2/2$	1
$d\sigma(\bar{\nu})/dx$	$1 - x + x^2/2$	$(1 - x)^2$
* W_1/W_2	1	1
$W_3/W_2 = \langle B \rangle_{\text{parton}}$	~ 0	1
$\langle P_T \rangle_\pi$	~ 0.3 GeV/c	~ 0.3 GeV/c
$\langle \acute{P} \rangle_{\text{nucleon}}$	$\sim q_{\text{lepton}} / n_\pi$	$\sim q_{\text{lepton}}$

where : $\langle \; \rangle$ = average;

$x = (E_\nu - E_\mu) / E_\nu$

n_π is the pion multiplicity

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* For the region $\rho \gg 1$. For J = 0 parton, $W_1 \longrightarrow 0$.

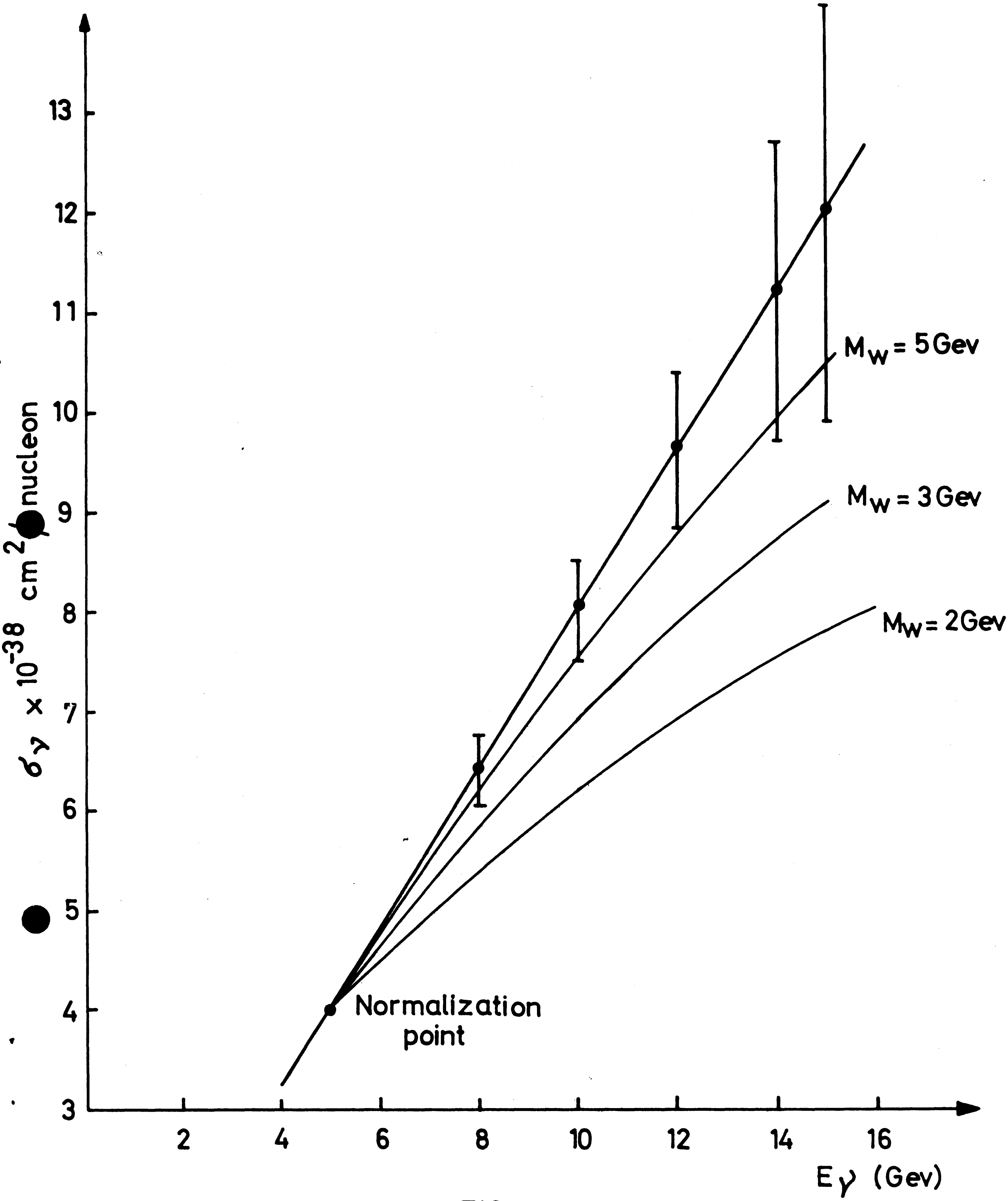

FIG. 1

Expected accuracy on total ν cross-section for 5×10^5 pictures and effect of finite Boson mass

225.356

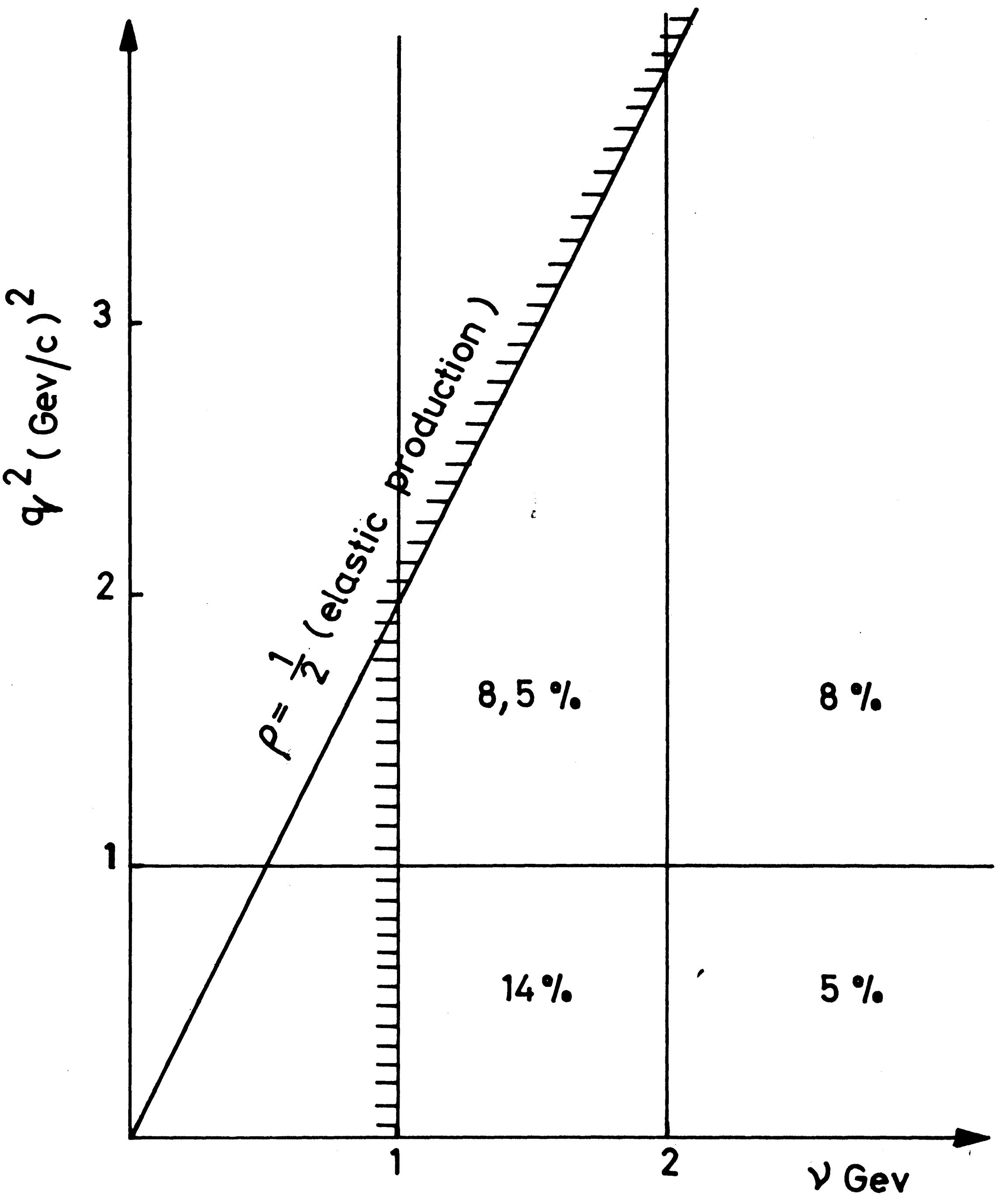

Fig_2

Apportionment of H.L.B.C. neutrino events in q^2 and ν

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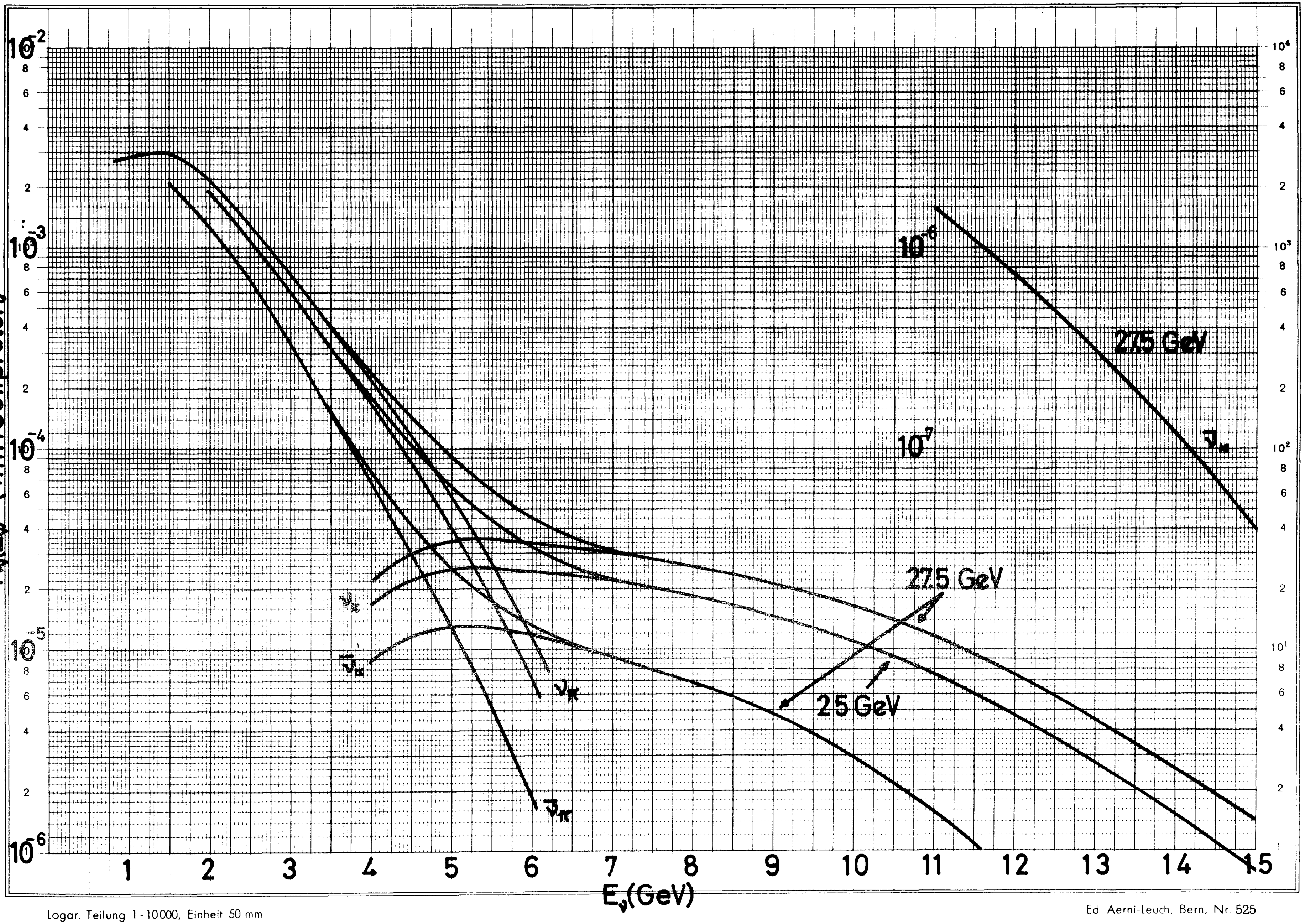

10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
$N_\nu(E_\nu)$ (ν/m^2/GeV/proton)
E_ν(GeV)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
10^{-6}
10^{-7}
27.5 GeV
25 GeV
ν_π
$\bar\nu_\pi$
ν_K
$\bar\nu_K$
Logar. Teilung 1-10000, Einheit 50 mm
Ed Aerni-Leuch, Bern, Nr. 525

fig. 3