RESULTS FROM GARGAMELLE NEUTRINO EXPERIMENT AT CERN SPS

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ABSTRACT

Three results are presented: a) from the study of 117 neutrino induced dimuons events a production rate of $\sigma(\mu^+\mu^-)/\sigma(\mu^-)=(0.72 \pm 0.14)\cdot 10^{-2}$ has been measured. The $\mu^+\mu^-$ channel is found to be dominated by D-meson production and decay. b) the inverse muon decay reaction is observed for the first time with a clear signal of 26 ± 6 events in good agreement with predictions from standard V-A theory. c) results with the complete statistics are presented for the pure leptonic neutral current reaction ($\nu_\mu e^- \to \nu_\mu e^-$). The measured cross section is now in agreement with other experiments and with the predictions from the standard SU(2)×U(1) model.

1. INTRODUCTION

Results will be presented on these three topics:

i) study of dimuons production from neutrinos ($\nu_\mu N \to \mu^+\mu^- X$)

ii) observation of the inverse muon decay ($\nu_\mu e^- \to \mu^-\nu_e$)

iii) measurement of the production cross section for the purely leptonic reaction: ($\nu_\mu e^- \to \nu_\mu e^-$)

2. EXPERIMENTAL APPARATUS

The heavy liquid bubble chamber Gargamelle (∿4 m³ fiducial volume), filled with a propane freon mixture (90% C_3H_8 and 10% CF_3Br in moles, 61 cm radiation length and 0.51 g/cm³ density) has been exposed to the CERN-SPS wide band neutrino beam using a total of $2.3\cdot 10^{18}$ protons on the target. The chamber was operated with a set of counters[1]) all around the chamber (Fig.1) which allows the muon identification and also the scanning of selected topologies. Upstream the first plane of MWPC (veto counter) eliminate the incoming particles, downstream the "picket fence" selects the exact time of each interaction in the chamber. The EMI (two MWPC planes separated by 160 cm of iron) identifies the outgoing muons.

Our experiment using this hybrid technique offers the advantages of an efficient selection of rare events, and at the same time, the possibility to study all the details of the interactions.

3. DIMUONS

From the counter data candidates for the reaction:

$$\nu_\mu + N \to \mu\mu X \tag{1}$$

have been selected requiring:

- no particle in the veto
- at least one particle in the "picket fence"
- two possible muons coming from GGM and crossing the two EMI planes in the same time slot defined in the picket fence.

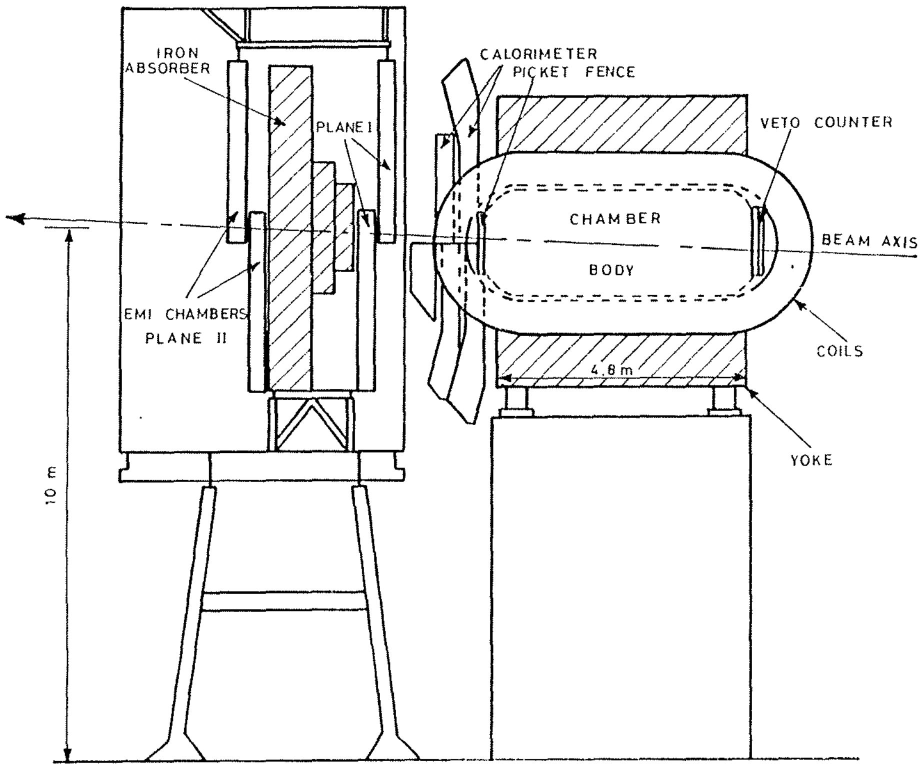


Fig.1 Experimental apparatus with counters around GGM.

All events selected by these criteria have been carefully analyzed and the possible candidates measured. All muon tracks are described in terms of a χ^2 of association with the nearest hit in each EMI plane.

Events were retained as dimuons candidates when at least two tracks had a χ^2 less than 40. Results are presented in Table I for 420.000 pictures corresponding to 39.000 CC events obtained with $2.3 \cdot 10^{18}$ protons on the target.

	$\mu^-\mu^+$	$\mu^-\mu^-$
events $\chi^2 < 40$	117	41
after cut at $\chi^2 < 10$	94	25
Background		
π decay in flight	24.2 ± 2	14.5 ± 1
K decay in flight	3.9 ± 1	2.5 ± 1
Punch through + random association	4 ± 2	3 ± 2
Total background	32.1 ± 3	20 ± 2.5
SIGNAL	62 ± 10	5 ± 6

TABLE 1: Summary of background calculations

The background comes from the following sources:

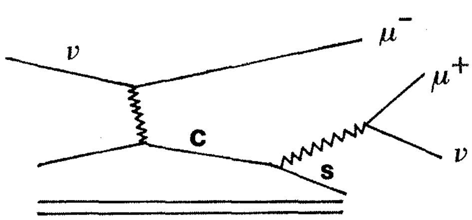
- B1 - decay in flight of π's and K's.
- B2 - punch through of an hadron which can reach with its shower the second EMI plane.
- B3 - association of random hits in the EMI.

A cut at χ^2=10 eliminate most of the background B2 and B3 and background B1 can be computed by Montecarlo.

We conclude from Table I that no significant signal of $\mu^-\mu^-$ is observed, but a signal of $\mu^+\mu^-$ is clearly present.

Dimuons events ($\mu^+\mu^-$) are currently interpreted as being due to the production of charmed particles and their semileptonic decay.

If this hypothesis is correct we expect: high V^0 production and missing energy due to the undetected neutrino.



In the 94 $\mu^+\mu^-$ events there are 9 K^0s and 3Λ^0. If we take into account our detection efficiencies (0.25 ± 0.02 for K^0s and 0.48 ± 0.03 for Λ^0) and we correct for background the rates are:

$$0.53^{+0.25}_{-0.20}\ K^0 \text{ per dimuon event} \qquad 0.03^{+0.06}_{-0.04}\ \Lambda^0 \text{ per dimuon event}$$

showing no evidence for Λ^0 production.

As all $K^0\mu^+$ masses are compatible with the decay of the highest known charmed meson D, we conclude that our sample is probably dominated by D production. At our energies the production of charmed barions is desfavoured by our acceptance which requires high energy μ^+.

The missing energy due to undetected neutrals can be estimated [2] from the transverse momentum balance, and the best and almost unbiased measure of the fraction of the total hadronic energy actually measured is given by:

$$f = \frac{P_\perp(h)}{P_\perp(\mu^-)}$$

where $P_\perp(h)$ is the transverse momentum of hadrons projected on the $\nu\mu$ plane and $P_\perp(\mu^-)$ the transverse momentum of the negative muon.

In Fig.2 this function f is shown for our $\mu^+\mu^-$ sample (signal) and for the $\mu^-\mu^-$ sample (background). Clearly the signal has a lower mean value of f. If we interpret this to be due to the missing energy of the undetected neutrino, we can estimate the mean fraction $\langle Z_\nu \rangle$ of hadronic energy carried by the neutrino:

$$\langle Z_\nu \rangle = 0.25 \pm 0.09$$

Assuming the $\mu^+\mu^-$ sample to be due to D production and subsequent leptonic decay, we can compare the experimental inclusive properties of our events with the predictions of a standard quark parton model [3]. Assuming from e^+e^- data [4] the branching ratios for the

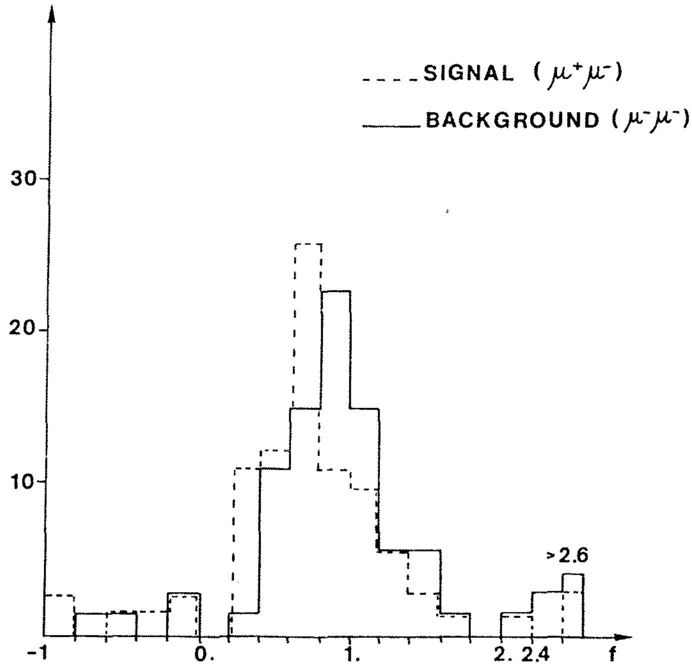


Fig.2 Fraction of hadronic energy actually measured for signal events ($\mu^+\mu^-$) and background events ($\mu^-\mu^-$)

decay modes $D \to K\mu\nu$ and $D \to K\pi\mu\nu$ to be 0.4 and 0.6 respectively, we see that the most sensitive parameter in the model is the "parton fermentation function" $D(Z_D)$ where Z_D is the fraction of the hadronic energy carried by the D meson.

With a Z_D dependence of the type e^{+bZ_D} we can fit the b parameter from same experimental distributions (Z_μ, y, E_{vis}). In Fig. 3 the expected distributions for Z_{μ^+} for different values of the b parameter is compared with experimental data. The best estimate for b is $b=1.25^{+1.1}_{-0.75}$ and as shown in Fig.4 negative b values, as found for usual hadrons, seems to be excluded by our data.

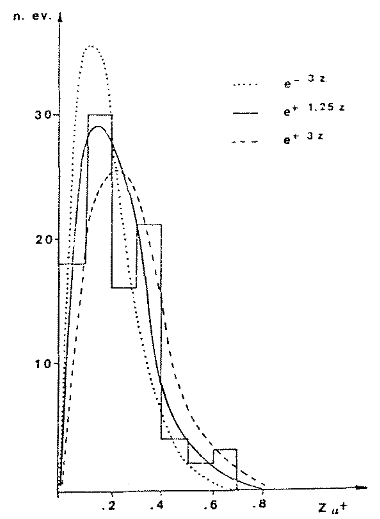


Fig.3 Distribution of $Z_{\mu^+} = P_{\mu^+}/E_H$.

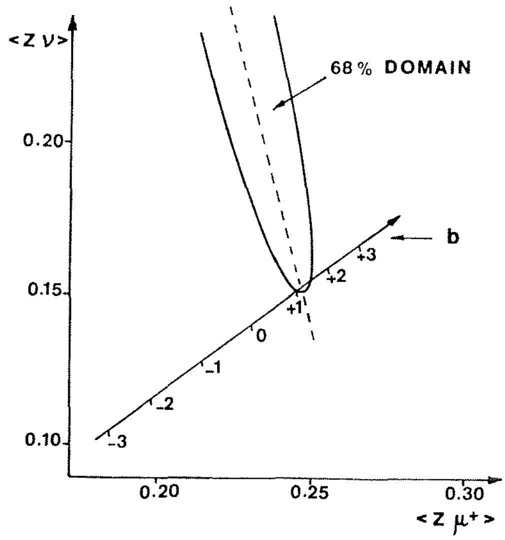


Fig.4 Comparison of this experiment with predictions of the D production model for different b values.

In order to compute the $\mu^+\mu^-$ production rate as a function of neutrino energy, the data were corrected for the geometrical and kinematical acceptance of the EMI.

The efficiency ranges from 14% at low neutrino energies to 55% for high energy with a mean value of 28 ± 4%.

In Fig.5 the rate $\sigma(\mu^+\mu^-)/\sigma(\mu^-)$ is shown for different energies and compared with the results of other experiments for dilepton production. The GGM mean value $(7.2 \pm 1.4)\cdot 10^{-3}$ is in good agreement.

In our sample no clear vertex for the D decay has been seen. It is only possible to give a limit on the D mean life defining for all events the maximum lengths after which clearly none of the considered D decay have occured.

With assumptions on the branching ratio of the D to take into account when the decay is clearly visible in the bubble chamber, and assumptions on the mean D momentum, it is possible, by a likelihood method, to give an upper limit at 90% confidence level for the D mean life:

$$\tau_D < 0.8\cdot 10^{-12} \text{ sec}$$

in agreement with the experimental results presented at this Conference [5].

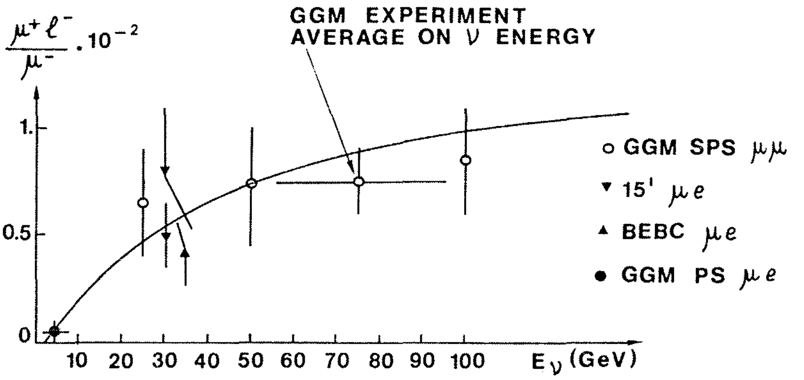


Fig.5. Rate of dilepton production as a function of the neutrino energy.

4. INVERSE MUON DECAY

The inverse muon decay reaction predicted by the V-A theory [6]:

$$\nu_\mu e^- \rightarrow \mu^- \nu_e \qquad (2)$$

has never been observed due to the high threshold (∿10.9 GeV) and to the low cross section [7]:

$$\sigma_{V-A} = 1.55 \frac{(E_\nu - 10.9)^2}{E_\nu} \cdot 10^{-41} \text{ cm}^2$$

From the kinematics we expect high energy muons ($E_\mu > 10.9$) emitted in a very small angle with the neutrino beam ($\vartheta_{\mu\nu} < 5$ mrad). The $q^2 = \tilde{p}_\mu - \tilde{p}_\nu$ region allowed by the reaction ranges up to about ~ 0.1 GeV^2 (for E_ν=100 GeV) in a wide region far from the point $q^2= -m_\mu^2$ of the muon decay.

Events candidates for reaction (2) were selected using the data from the counters around the bubble chamber requiring only one muon track of high energy with a small $\vartheta_{\mu\nu}$ angle.

This procedure reduces by a big factor the number of pictures to be scanned and increase the detection efficiency for finding "isolated muons" which was found to be 94 ± 3%.

84 isolated μ^- with E_μ > 10 GeV and $\vartheta_{\mu\nu}$ < 100 mrad were selected.

The background mainly comes from two sources:

i) the quasi elastic reaction on nucleons $\nu\mu + N \rightarrow \mu^-$ + unseen proton.

ii) the reaction on nuclei, by excitation of the giant dipole resonance $\nu_\mu + {}^{12}C \rightarrow \mu^- + {}^{12}N$

Both background processes have different kinematical properties than the signal. First in the background reaction the muon carries almost all the neutrino energy, whereas for reaction (2) the muon takes about half neutrino energy. In Fig.6 the muon energy is plotted and compared with what expected for signal and background.

Secondly in the reaction (2) the angle $\vartheta_{\mu\nu}$ is severely limited and satisfy the constraint $\rho = E_\mu \vartheta_{\mu\nu}/2m_e < 1$. On the contrary for the background reactions, very low values of q^2, and consequently of $\vartheta_{\mu\nu}$, are suppressed and we expect a broader distribution of the ρ variable. The experimental distribution (Fig.7) show a very clear peak at low values as expected from the inverse muon decay reaction.

By a likelihood method based on both variable E_μ and $\vartheta_{\mu\nu}$ the signal was estimated to be, after scanning efficiency correction, 26 ± 6 events. We conclude that for the first time a clear signal of reaction (2) is observed.

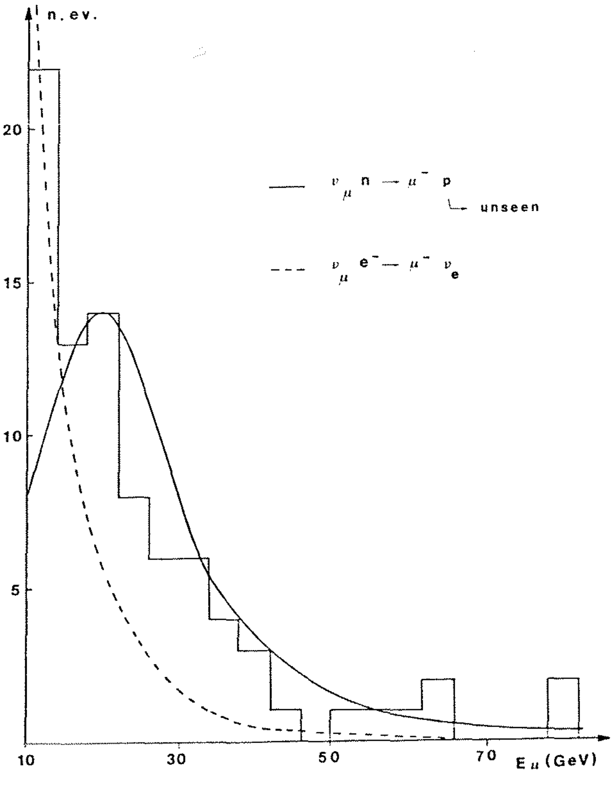


Fig.6 Muon energy distribution.

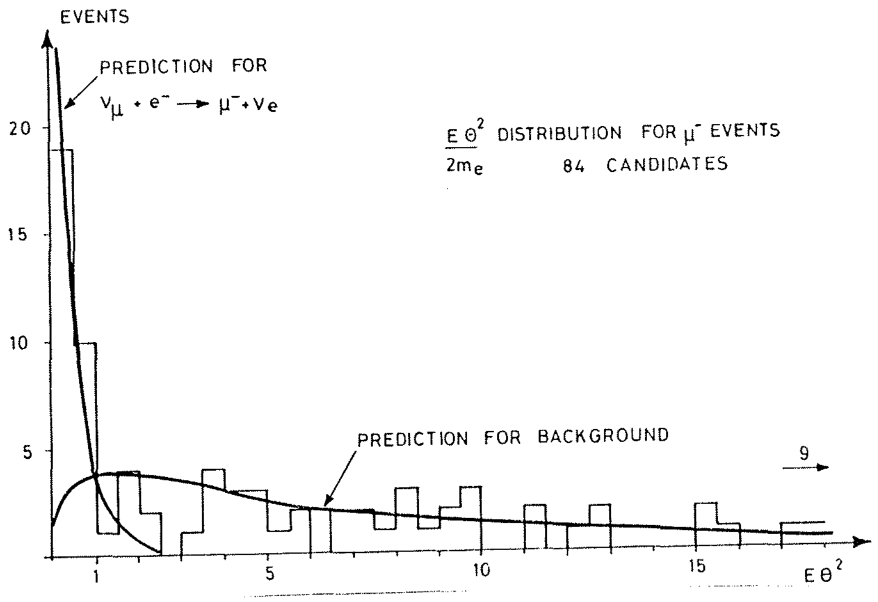


Fig.7 $\rho = E_\mu \vartheta_\mu / 2m_e$ distribution.

With the ν flux information if we compared the expected cross section from V-A theory (29 events predicted) with the experiment. We find a good agreement:

$$\frac{\sigma^{exp}}{\sigma^{V-A}} = 0.9 \pm 0.2$$

In a more general way, assuming only V and A contributions, we can write the expected number of events only as a function of two parameters $\lambda = 2g_A g_V / (|g_A|^2 + |g_V|^2)$ (axial and vector contributions) and $p = N_R - N_L / (N_R + N_L)$ (contribution from right and left handed neutrino):

$$N = \frac{29}{32} \{(1+p)(1-\lambda)\cdot 3 + 8(1-p)(1+\lambda)\}$$

The result of this experiment, illustrated in Fig.8, is in agreement with V-A theory (λ=1) with only left handed neutrinos (p= -1) and rules out exotic possibilities like V+A coupling or right handed neutrinos.

5. NEUTRAL CURRENT REACTION $\nu_\mu e^- \to \nu_\mu e^-$

One year ago [8] our collaboration published a preliminary result (based on 1/3 of the statistics) on the total cross-section for the purely leptonic reaction: $\nu_\mu e^- \to \nu_\mu e^-$ which was unexpectedly high.

We present here the final result based on the total statistics of the experiment. The total neutrino flux was increased by a factor 2.6 and the results come from the analysis of 410.000 pictures corresponding to $2.2\cdot 10^{18}$ protons on the target and 64.000 CC events.

I will not go into the details of the analysis which is similar to the previous one.

Only one new selection criterion was added in order to eliminated the possible background coming from the bremsstrahlung of muons tracks crossing the chamber.

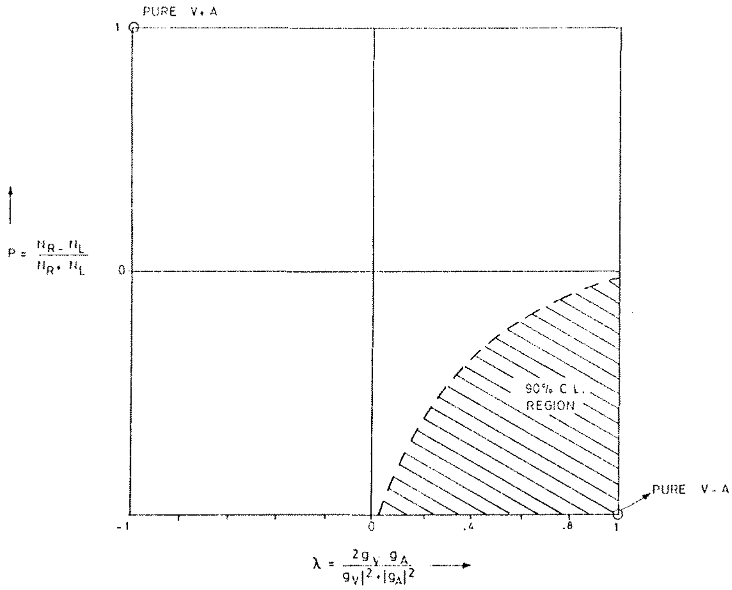


Fig.8 Allowed domain at 90% CL from GGM experiment in the p,λ plane.

For that we required the isolated electrons or gammas to be at a distance from all muon tracks larger than 2 cm and with an angle with the muon track of more than 20 mrad. With this new criterion two of the previously selected electrons were rejected and the final sample is now 9 events in the cuts $E_e > 2$ GeV and $\vartheta_e < 3^0$

From background calculation we expect only 0.5 ± 0.2 events mainly coming from the quasi-elastic reaction $\nu_e n \to e^-(p)$ and from asymmetric isolated γ rays.

After corrections for losses and for background the experimental total cross section is now:

$$\sigma = 2.4^{+1.2}_{-0.9} \cdot 10^{-42} \cdot E_\nu \quad cm^2/electron$$

which is in agreement with other experiments [9] as shown in Table II.

TABLE II

Experiment	n. events	background	cross sections ($\times E_\nu \cdot 10^{-42}$)
GGM PS	≤ 1	0.3 ± 0.1	≤ 3
AACHEN-PADOVA	32	21	1.1 ± 0.6
COLUMBIA-BNL	11	0.7 ± 0.7	1.8 ± 0.8
GGM SPS	9	0.5 ± 0.2	$2.4^{+1.2}_{-0.9}$

If we consider the predicted cross section:

$$\frac{d\sigma}{dE_e} = \frac{G^2 m_e}{2\pi} \{(g_V+g_A)^2+(g_V-g_A)^2(1-\frac{E_e}{E_\nu})^2\}$$

our result defines an allowed domain at 90% confidence level in the g_A, g_V plane (Fig.9).

In Fig.9 also the prediction from SU(2)×U(1) model in which g_A=- 1/2 and g_V= 1/2+2sinϑ_W is shown. The two allowed values for $\sin^2\vartheta_W$ are:

$$\sin^2\vartheta_W=0.12^{+0.11}_{-0.07} \qquad \sin^2\vartheta_W=0.6 \pm 0.10$$

The first value is in good agreement with the $\sin^2\vartheta_W$ values obtained in other reactions [10].

If we compare the present result with the one published in 1978 we find:

$$\sigma^{1979} = \sigma^{1978}/3.1$$

Let us remark that only a factor 1.2 is due to the new selection criteria, but the big factor 2.6 is apparently only due to a very large statistical fluctuation which has a probability of $3.1\cdot10^{-3}$

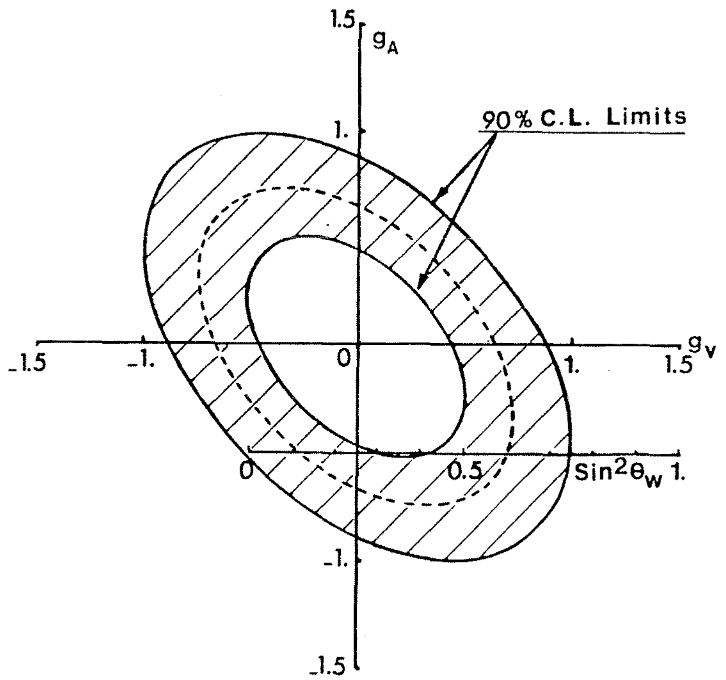


Fig.9 Allowed domain at 90% level from the GGM experiment in the g_V, g_A plane.

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