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HIGH ENERGY ELASTIC ν_μ SCATTERING OFF ELECTRONS IN GARGAMELLE

N. Armenise, O. Erriquez, M.T. Fogli-Muciaccia, S. Natali,
S. Nuzzo, F. Romano.
Istituto di Fisica dell'Università and INFN, Bari (Italy)

G. Bonneaud, G. Carnesecchi, M. Haguenauer, P. Lundborg, C. Matteuzzi,
P. Musset, B. Pattison, M. Price, J.P. Vialle, M. Willutzky.
CERN, Geneva (Switzerland)

P. Alibran, A. Blondel, J. Bourotte, B. Degrange, J. Gillespie,
F. Jacquet, U. Nguyen-Khac.
LPNHE, Ecole Polytechnique, Palaiseau (France)

E. Bellotti, S. Bonetti, D. Cavalli, E. Fiorini, A. Pullia,
M. Rollier, L. Zanotti.
Istituto di Fisica dell'Università, and INFN Milano (Italy)

C. Arnault, D. Blum, P. Heusse, A.M. Lutz, C. Pascaud, J. Sleeman.
Laboratoire de l'Accélérateur Linéaire, Orsay (France)

ABSTRACT

The reaction $\nu_\mu e \rightarrow \nu_\mu e$ has been investigated in the bubble chamber Gargamelle exposed to the wide-band neutrino beam of the CERN SPS. Nine electron candidates of which 0.5 are expected to be background, were found in a total statistics available of 64000 charged current neutrino events. Results are given in terms of vector and axial vector coupling constants. The present results agree with the standard SU(2) $\otimes$ U(1) model for current values of $\sin^2\theta_W$. A critical comparison is made with the previous result based on statistics which were smaller by a factor 2.6 and which led to a rather higher cross section.

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The ν_μ elastic scattering off electrons $\nu_\mu + e^- \to \nu_\mu + e^-$ (a) is a very important purely leptonic neutral current reaction [1] which, since it can be studied in a model independent way, gives clean information about the weak neutral coupling of the electron and can test different models in a very direct way [2,3].

About one year ago, an unexpectedly large number of isolated electrons in the kinematical region of the reaction (a) was found in the bubble chamber Gargamelle, exposed to the CERN-SPS wide-band neutrino beam [4]. Since then, in order to investigate further this observation, a second exposure of the chamber was made. The total neutrino flux was then increased by a factor 2.6. The analysis presented here also includes the old sample of pictures.

The liquid filling the chamber was a mixture of freon (9.5)% and propane (90.5)% with a radiation length of $X_o = 61$ cm. A fiducial volume of 5.1 m^3 was chosen in such a way that an electron has in average 4 X_o to identify itself inside the chamber. The experimental apparatus is described in Ref. 5.

The sample consisted of 410 000 pictures corresponding to 2.2×10^{18} protons on target. The wide-band neutrino beam of the CERN-SPS was peaking at about 20 GeV and extended up to 200 GeV. The whole volume of the chamber was scanned for electrons and gammas which had no visible interaction as origin. Events inside the fiducial volume were retained if the energy was greater than 2 GeV and the emission angle θ_e was smaller than 3^o. In order to eliminate possible bremsstrahlung γ-rays from through-going muons, candidates had to be at a distance $d > 2$ cm in space from any muon, and to be outside a cone of 20 mrad opening angle centered on any incoming muon.

The events were classified as electrons if there was only a single track at the vertex and no e^+ nor e^- above 30 MeV on the track in the first 7 cm. Furthermore no e^+ above 2.5 MeV had to be present in the first cm. Two other cuts were applied to ensure that a track was indeed single: first, if an electron candidate was in fact an $e^+ - e^-$ pair, the two tracks would be separated by the magnetic field after a maximum distance $L_{(meters)} = 0.05 \sqrt{E_{GeV}}$, where the spatial resolution for the separation is 3 mm. Secondly, ionization was measured using a microscope. In this method the gaps between bubbles were measured [6]. The total gap length per unit length (f) is expected to be different for the overlap region of the e^+ and e^- of a γ-ray (f_γ) and for the two separated branches (f_{e1}, f_{e2}). In order to check this hypothesis the parameters $R_\gamma = f_{e1(e2)}/f_\gamma$ and $R_e = f_{e1}/f_{e2}$ were measured on a sample of 60 high energy γ-rays. The R_e distribution is centered around 1, whereas R_γ takes larger values as is shown in Fig. 1. If a cut is made at $R_\gamma = 1.5$, a good separation is obtained, only 3% of the γ-rays having $R_\gamma < 1.5$ and thus falling in the region of electrons ionization. Using the above criteria, 8 e^-, 1 $e^\pm$ and 26 γ's were found within the cuts (Table 1). All the electrons fulfill, within experimental errors, the condition $E_e\theta^2_e \leq 2\ m_e$ (fig. 2) imposed by the kinematics of reaction (a). Actually this condition was weakened by the energy and angle measurement errors, and the expected distribution (dotted line in fig. 2) extended up to 10 MeV.

The separation of events into electrons and gammas was also checked by a likelihood method [7] using two variables: $E\theta^2/2\ m_e$, which relates to kinematics and $R_{e,\gamma}$ which takes into account the ionization information. The sources of events were assumed to be i) the elastic electron-neutrino reaction, ii) γ-rays with origin outside the chamber, and iii) π^0 production by neutral currents inside. The results obtained with the likelihood method confirmed the validity of the e-γ separation obtained with the criteria described above.

The sample of 9 electron candidates must be corrected for background and for losses due to cuts and selection criteria. A partial re-scan indicates that the scanning efficiency was (87 ± 3)%.

The probability for an isolated electron being identified by electromagnetic processes is 99% whilst the probability of misclassifying an electron as a γ-ray is about 6%. Both these corrections are obtained by Monte-Carlo calculations. This has been checked on the 9 selected electrons by means of the distribution of the distance from the vertex of the first accident which would have caused a wrong classification.

The background is essentially due to i) high energy γ-rays materializing into an asymmetric e^+e^- pair, or appearing as an e^- for the e^+ annihiled close to the vertex, or creating a Compton electron; ii) charged current ν_e interactions in which no hadron is visible; iii) nuclear resonance excitation of the type $\nu_e + {}^{12}C \to {}^{12}N^* + e^-$. All three contributions are calculated on the basis of experimental observation in the same experiment. The probability for a γ-ray to simulate a single electron is < 1.2% at 90% C.L. (Ref. 4). This asymmetry had to be applied to the 18 γ-rays out of the 26, for which $E_\gamma \theta_\gamma^2 < 10$ MeV. The background from source i) is thus < 0.10 events. Reaction $\nu_e n \to e^- p$ simulates reaction (a) if the proton is not visible. This background was estimated from 5 observed e^-p and the observed ratio

$$R_\mu = \frac{\mu^-(E\theta^2 < 10 \text{ MeV})}{\mu^-p}$$

In R_μ, the numerator contains events from reaction $\nu_\mu e \to \mu^- \nu_e$ and from $\nu_\mu + {}^{12}C \to \mu^- + N^*$ as well as from elastic channels in which the proton is not detected. After subtraction of the inverse muon decay contribution[5] the value R was found to be $R_\mu = (8 \pm 2)\%$. Consequently the background from ii) and iii) together turns out to be (0.4 ± 0.2).

Reaction $\bar{\nu}_e p \to e^+ n$ simulates reaction (a) if the electron sign is not identified. From the $\bar{\nu}_e$ flux, about 1.5 events are expected of the type e^+n (where 2 are observed) of which about 0.04 ± 0.04 should appear as $e^\pm$ within the cuts. Any other possible background is negligible. The total background is therefore (0.5 ± 0.2) events. This estimate is conservative but it does not affect the final result since its value is small.

The signal contains both the contribution from $\nu_\mu \epsilon^- \to \nu_\mu e^-$ and $\nu_e e^- \to \nu_e e^-$ which are not separable experimentally. Knowing the ν_μ and ν_e fluxes, the cross-section for the process $\nu_\mu e^- \to \nu_\mu e^-$ can be calculated. The flux calculation was checked measuring a sample of charged current events. The total number of charged current was expected to be 64 000 from the flux, and found to be ∿ 62 600 ± 5000 from the measured events, this proves the reliability of the flux calculation, which is performed within 10%.

If only the V and A currents contribute, and $E \gg m_e$, the differential cross section can be written as:

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

with $g^{\nu_e}_{V,A} = 1 + g^{\nu_\mu}_{V,A}$.

This defines an ellipse in g_V, g_A plane, allowing a complete model-independent analysis of this purely leptonic reaction. Fig. 3 shows the domain allowed. The value of the slope, $s = \sigma/E$ is found to be $2.4^{+1.2}_{-0.9} \times 10^{-42}$ cm^2/GeV.

The cross section value obtained is 3 times smaller than that quoted in Ref. 4. The criteria adopted here to identify isolated electrons are stricter than those previously used. These remove two events from the sample in Ref. 4, tentatively interpreted as being due to bremsstrahlung γ-rays from through-going muons, with the effect of lowering the published cross section by a factor 1.2. The remaining factor of 2.6 is apparently due to a large fluctuation, which has a probability of 3.5×10^{-3}.

The results reported here agree with the results of other experiments on purely leptonic neutrino reactions [8].

The g_V, g_A domain obtained can be compared to the predictions of the SU(2) ⊗ U(1) model in which $g_A = -\frac{1}{2}$ and $g_V = -\frac{1}{2} + 2 \sin^2\theta$. The two values allowed for $\sin^2\theta$ are:

$$\sin^2\theta_w = 0.12^{+0.11}_{-0.07} \quad \text{and} \quad \sin^2\theta_w = 0.6 \pm 0.10.$$

The first value is in good agreement with the $\sin^2\theta_w$ values obtained in other reactions, i.e. semi-leptonic neutrino [9] and electron reactions [10].

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FIGURE CAPTIONS

Fig. 1 $R_{\gamma e}$ distributions for a) γ's and b) electrons. The 9 electrons and the 19 of the 26 gammas retained for the analysis are in the shaded area.

Fig. 2 $E\theta^2$ distribution for the 9 electron candidates. The line is the theoretical distribution smeared by measurement errors.

Fig. 3 Domain in the g_V, g_A plane allowed by the reaction $\nu_\mu e \rightarrow \nu_\mu e$.

TABLE CAPTION

Table 1 Energy and emission angle of the 9 electrons.

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TABLE I

Event		E (GeV)	θ^2(mrad^2)
6022 411	e^-	$35\,^{+30}_{-10}$	4 ± 16
5972 262	e^-	3.3 ± 1.3	324 ± 165
6008 041	e^-	2.2 ± 0.8	225 ± 176
5948 192	$e^\pm$	67 ± 35	25 ± 44
5953 261	e^-	13.3 ± 1.5	4 ± 3
5949 389	e^-	9 ± 2	36 ± 60
5969 272	e^-	3.3 ± 0.3	144 ± 137
6102 081	e^-	47 ± 10	4 ± 16
6427 658	e^-	25.3 ± 11.1	16 ± 38

Energy and emission angle of the
9 electrons

Fig. 1

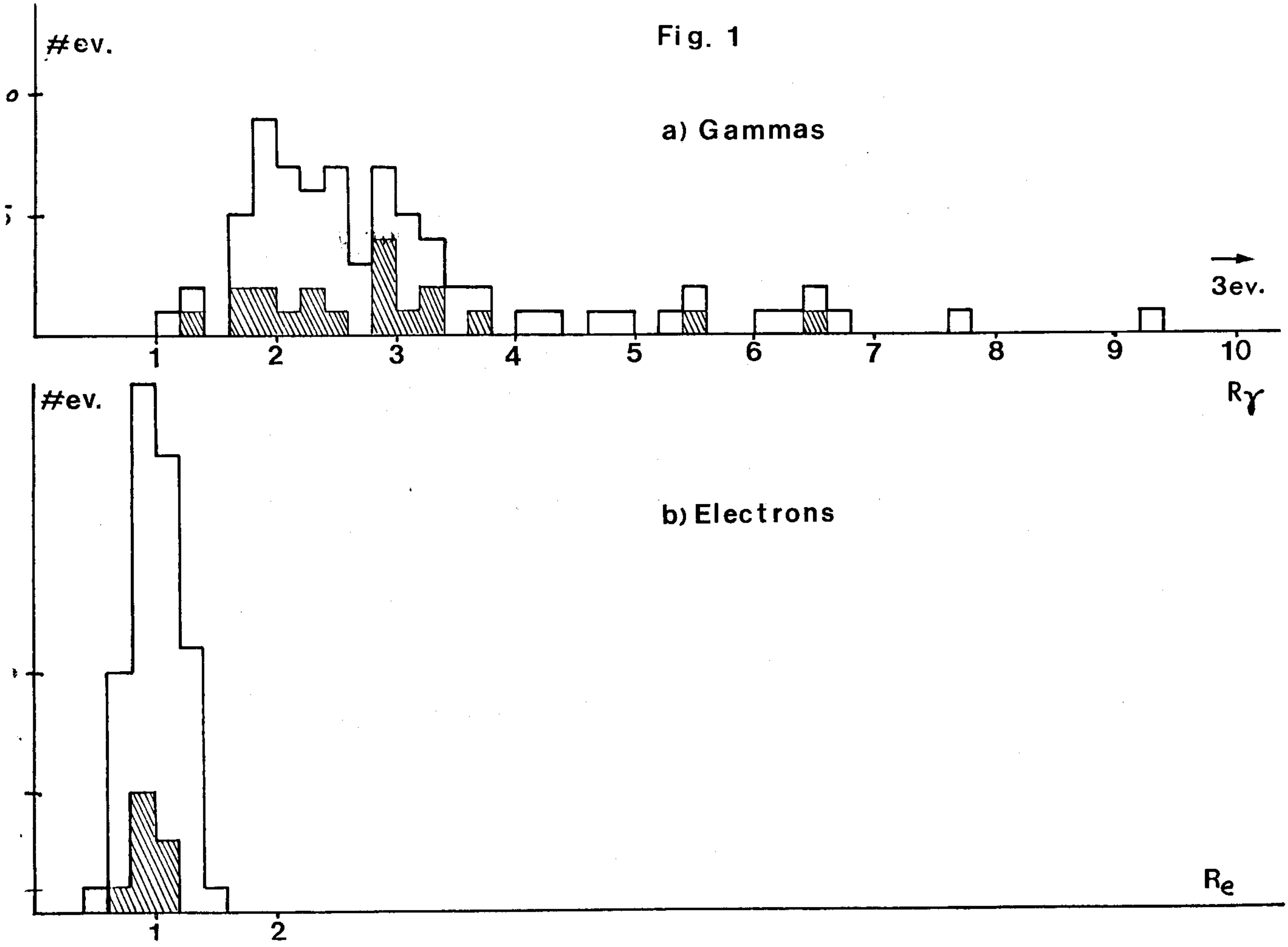

Fig. 2

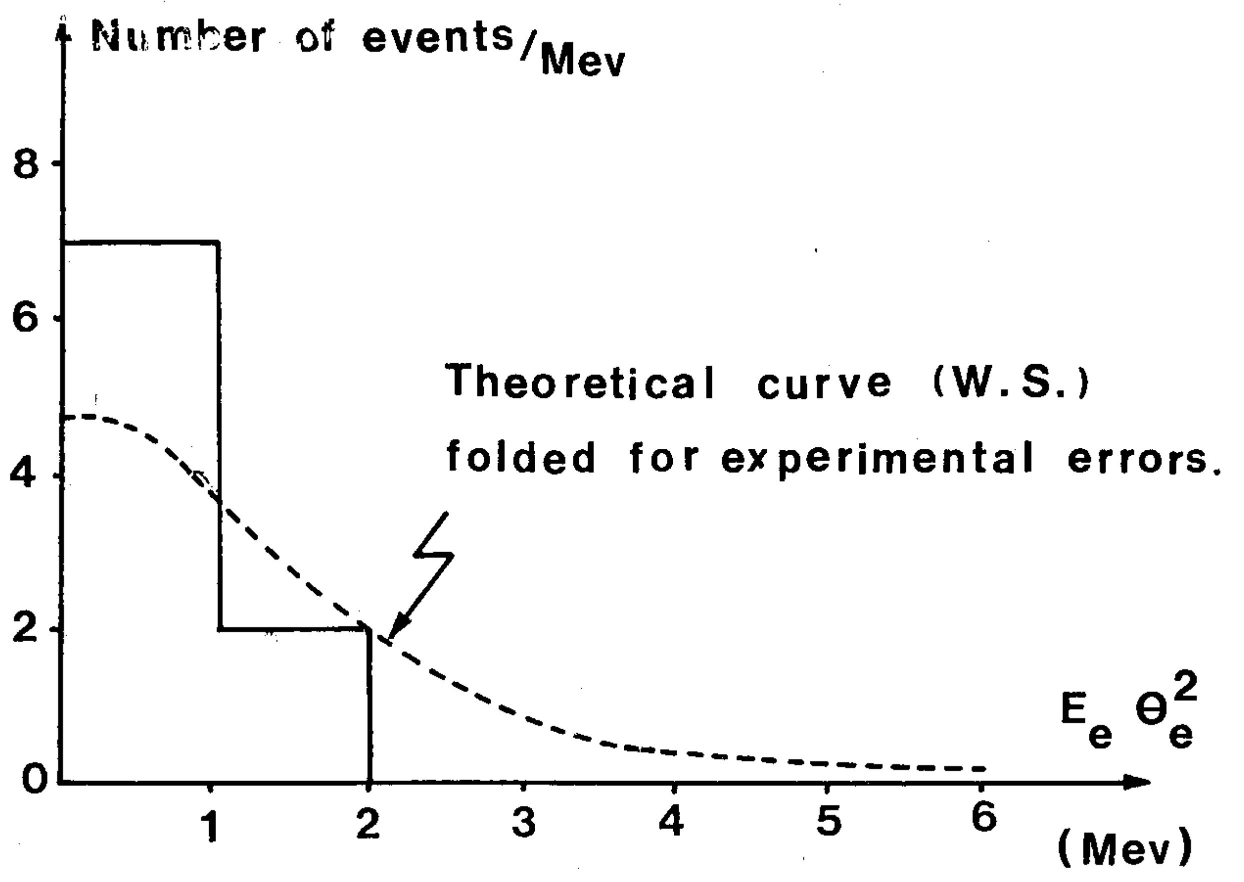
Number of events/Mev
8
6
4
2
0
Theoretical curve (W.S.)
folded for experimental errors.
$E_e \theta_e^2$
1
2
3
4
5
6
(Mev)

Fig. 3