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# THE DECAY MODE $\omega \rightarrow e^+e^-$ AND A DIRECT DETERMINATION OF THE $\omega$-$\varphi$ MIXING ANGLE

D. Bollini, A. Buhler-Broglin, P. Dalpiaz, T. Massam, F. Navach,
F.L. Navarria, M.A. Schneegans and A. Zichichi

CERN, Geneva, Switzerland
Istituto di Fisica dell'Università di Bologna, Italy
Istituto Nazionale di Fisica Nucleare, Sezione di Bologna, Italy
Centre de Recherches Nucléaires, Strasbourg, France

## ABSTRACT

The generalized $\omega$-$\varphi$ mixing angle has been measured to be $|\Theta| = (23^{+7}_{-5})°$.

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## 1. INTRODUCTION

We have recently reported$^{1)}$ on the ($e^+e^-$) decay mode of the $\varphi$ meson, observed using a system which consisted essentially of two large electron detectors and two large neutron detectors. Using the same experimental set-up but changing the incident pion momentum to 1.67 GeV/c, and the angle of both the neutron and electron detectors, the production reaction:

$$\pi^- + p \rightarrow n + V^0 \qquad (1)$$
$$\hookrightarrow e^+ + e^-$$

was studied in the invariant mass region of the $V^0$ around the $\omega$ mass value.

The principle of the method was, as before:

i) to determine the mass of the neutral state $V^0$ to ±10 MeV by simultaneous measurements of the velocity and direction of the neutron;

ii) to identify the decay of the neutral state $V^0$ into an electron-positron pair by means of two large electron detectors which allowed, to ±35 MeV, a second determination of the $V^0$ mass through the measurement of the $e^+e^-$ opening angle and of their energies.

This paper contains the results obtained on the decay mode $\omega \rightarrow e^+ + e^-$ and on the direct determination of the $\omega$-$\varphi$ mixing angle.

## 2. EXPERIMENTAL SET-UP

The experimental set-up is sketched in Fig. 1. The details concerning the beam telescope, the electron and neutron detectors, and the electronic logic have already been given in our $\varphi$-paper$^{1)}$.

For the $\omega$-run, the two electron detectors were placed at 32° above and below the beam line. The two neutron detectors were set at an angle of 38° to the right and to the left of the beam line.

Figure 2 shows the acceptance of our apparatus in the plane $\Theta$-$t_1$, where $\Theta$ is the laboratory angle of the neutron from reaction (1), and $t_1$ is a quantity strictly related to its time-of-flight.

## 3. BACKGROUND

There were two sources of background and these have been analysed in a way similar to that used for the φ-run[1].

The first, the background due to the random superposition of a charged pion and a γ ray, was found to be negligible.

The second source of background was the simulation of electrons by γ rays which converted in the walls of the target or in the M counters, and gave rise to $(e^+e^-)$ pairs which were not resolved in the thin-plate chambers K. Figure 3 shows how we can evaluate this background. In this graph, all events which appear to have an electron in one electron detector, and either an electron or a converted γ ray in the other detector have been included. In this detector, the event is characterized by the distance between the two tracks of the $(e^+e^-)$ pair in the K chambers. The distribution of these distances is shown in Fig. 3. The genuine events are then observed as a peak at zero distance superimposed on a ~7% background of unresolved pairs.

## 4. RESULTS AND DISCUSSION

The mass distribution of the events contained in the zero distance peak of Fig. 3 is given in Fig. 4 which shows the ω peak superimposed on the ρ peak. The first conclusion we can draw from Fig. 4 is that the decay of the ω meson into $(e^+e^-)$ pairs is clearly established.

To the lowest order in α (the fine structure constant), the decay $\omega \to e^+ + e^-$ is mediated by a single photon, and therefore our experimental result is a direct proof of the fact that the ω quantum numbers are: $J^{PC} = 1^{--}$. Moreover, the observation of the decay $\omega \to e^+e^-$ is a direct proof that the ω meson cannot be a pure SU(3) singlet if we accept the general belief that the electromagnetic current is a pure SU(3) octet.

In order to derive other consequences from our experimental result we need to know the number of events attributable to ω decay into $e^+e^-$. This number depends on the contribution of interference between ρ and ω. The available experimental data[2] have been fitted with a peripheral model with absorption[3] in order to estimate the amount of ω-ρ interference. Full constructive or destructive interference would change the observed number of

$\omega \to e^+e^-$ by +35% or -35%, respectively[3]. Since existing strong interaction data are consistent with no $\omega$-$\rho$ interference, we will start by quoting our data for the case of no interference, and then quote the effect of complete destructive or constructive interference on the mixing angle.

The relative contributions of $\omega$ and $\rho$ to the mass distribution have been determined by the maximum likelihood method, using the expected shapes of the $\rho$ and $\omega$ mass distributions. The latter were calculated using the known production angular distributions, density matrices and natural widths of the resonances, and folding in the experimental acceptance and resolution. The fitted $\rho$ background is shown as the dashed curve in Fig. 4.

Eleven $\omega$ events were found, corresponding to a cross-section:

$$\sigma(\pi^- + p \to n + \underset{\hookrightarrow e^+e^-}{\omega}) = (67 \pm 25) \times 10^{-33}\ \mathrm{cm}^2 . \tag{2}$$

Radiative corrections for reaction (1) have been estimated[4] and found to be negligible (not more than a few per cent). Using the cross-section for $\omega$ production in $\pi^-p$ interactions at the same primary pion momentum[2]:

$$\sigma(\pi^- + p \to n + \omega) = (1.67 \pm 0.07) \times 10^{-27}\ \mathrm{cm}^2 \tag{3}$$

we get the following value for the branching ratio[*]:

$$\frac{\Gamma(\omega \to e^+ + e^-)}{\Gamma(\omega \to \mathrm{total})} = (4.0 \pm 1.5) \times 10^{-5} . \tag{4}$$

Using the total $\omega$ width[5], $\Gamma(\omega \to \mathrm{total}) = (12.2 \pm 1.3)$ MeV, it is possible by means of Eq. (4) to derive the partial $\omega$ width:

$$\Gamma(\omega \to e^+ + e^-) = (0.49 \pm 0.19)\ \mathrm{keV} . \tag{5}$$

The observation of the decay mode $\omega \to e^+ + e^-$ with the rate (5) is strong evidence against the validity of the A-quantum number conservation[6].

If we combine result (5) with that recently obtained by us[1] for the $\varphi$ decay:

$$\Gamma(\varphi \to e^+ + e^-) = (2.1 \pm 0.9)\ \mathrm{keV} , \tag{6}$$

we obtain a direct determination of the $\omega$-$\varphi$ mixing angle.

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[*] N.B. The value reported in the Rosenfeld et al. tables[5] is derived from the $\rho$ branching ratio plus SU(3), rather than from a direct observation of $\omega \to e^+e^-$.

This mixing[7-9] can be described in terms of two different models:

i) the "mass-mixing" model[10-12] and

ii) the "current mixing" model[11,12].

As emphasized by Kroll, Lee and Zumino[12], in the latter model two angles $\Theta_Y$ and $\Theta_N$ are needed in order to describe the mixing, but a relation exists between these angles:

$$m_\omega^2 \tan \Theta_Y = m_\varphi^2 \tan \Theta_N , \qquad (7)$$

so it is convenient to describe the mixing in terms of $\Theta$, the generalized mixing angle:

$$\tan \Theta = \frac{m_\omega}{m_\varphi} \tan \Theta_Y = \frac{m_\varphi}{m_\omega} \tan \Theta_N = \sqrt{\frac{m_\omega \Gamma(\omega \to e^+e^-)}{m_\varphi \Gamma(\varphi \to e^+e^-)}} . \qquad (8)$$

Recently, Das, Mathur and Okubo[13], and Oakes and Sakurai[14], on the basis of the first Weinberg sum rule[15], derived a relation between the decay widths of all vector mesons,

$$1/3\ m_\rho \Gamma(\rho \to e^+e^-) = m_\omega \Gamma(\omega \to e^+e^-) + m_\varphi \Gamma(\varphi \to e^+e^-) , \qquad (9)$$

as well as relation (7).

Finally, the quark model of Van Royen and Weisskopf[16] predicts the partial widths for $\rho$, $\omega$ and $\varphi$ decay to $e^+e^-$, which satisfy equation (9). On the other hand, the quark model requires $\Theta_Y = \Theta_N$ and is therefore in conflict with the other part of the generalized first Weinberg sum rule, Eq. (7).

A comparison of our results with all theoretical predictions is shown in Fig. 5.

In this graph the consistency region corresponding to the generalized first Weinberg sum rule[10-12] is given by the circle and its error band. The data used were $\Gamma(\rho \to \text{total}) = (105 \pm 21)$MeV[17], $m_\rho = (754 \pm 9)$MeV[17], and $\Gamma(\rho \to e^+e^-)/\Gamma(\rho \to \text{total}) = (5 \pm 2) \times 10^{-5}$*).

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*) This is the value we obtain for the branching ratio, by combining the results of Novosibirsk[17] and Orsay[18] experiments.

The generalized mixing angle Θ is found to be*):

$$|\Theta| = \left(23^{+7}_{-5}\right)^{\circ} \tag{10}$$

It should be emphasized that this result is obtained on the basis of no $\omega$–$\rho$ interference. Using the phenomenological model of $\omega$–$\rho$ interference[3] mentioned above, the result (10) would change into $|\Theta| = 26°$ for constructive interference and $|\Theta| = 20°$ for destructive interference.

In conclusion, the results reported in this paper show that:

i) the general idea of $\omega$–$\varphi$ mixing[7-14,16] is confirmed

ii) the generalized first Weinberg sum rule[13-15] works within the 30% over-all experimental uncertainties;

iii) there is no evidence for a coupling of the electromagnetic field to an SU(3) singlet;

iv) the A-quantum number[6] is not a good quantum number.

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*) The radiative corrections almost cancel when we take the ratio $\Gamma(\omega \to e^+e^-)/\Gamma(\varphi \to e^+e^-)$.

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## Figure captions

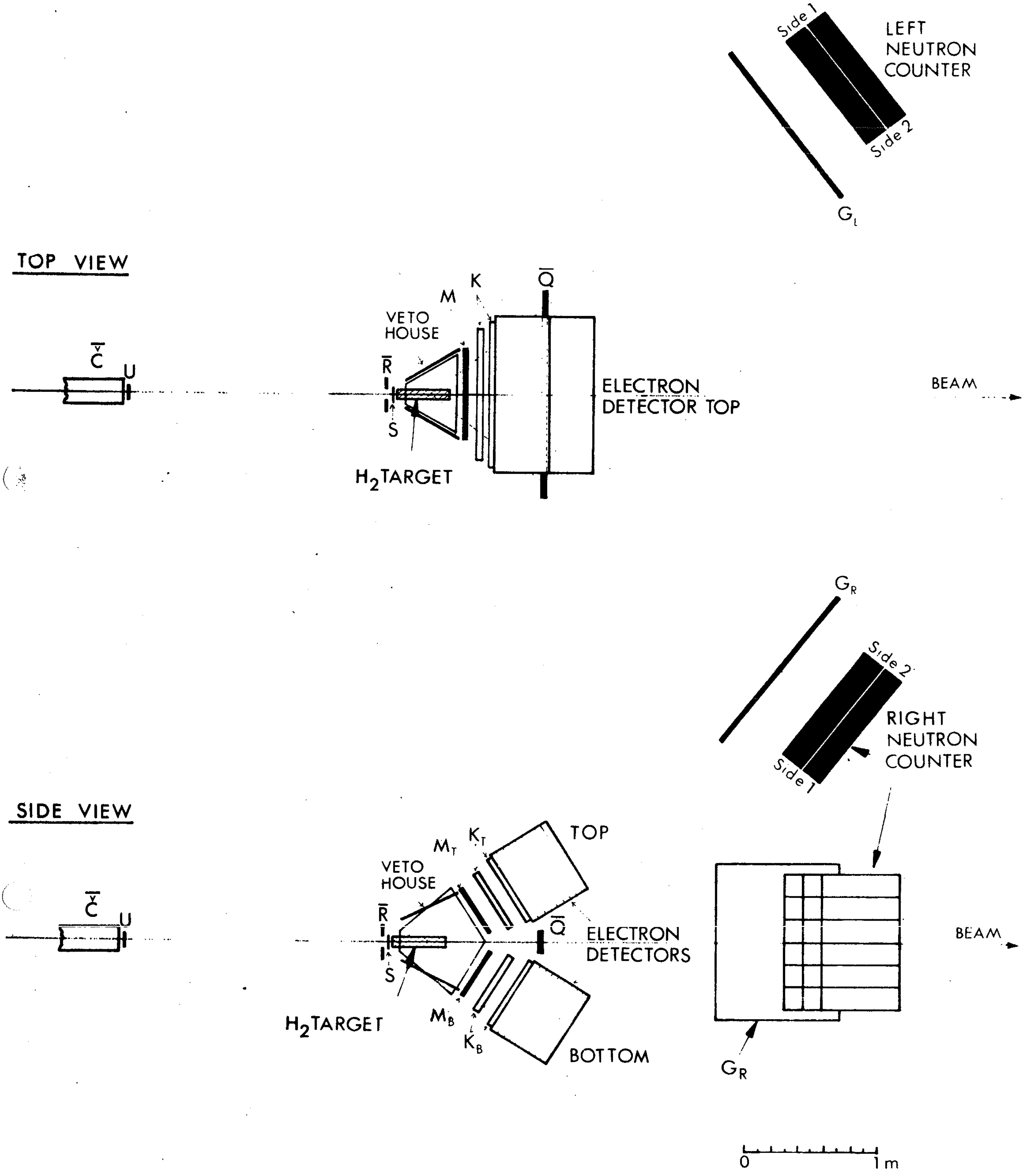
Fig. 1 : Schematic diagram of the experimental set-up.

Fig. 2 : Kinematic curves in the $t_1 - \Theta$ plane. The curves are labelled with the missing mass. $t_1$ is the neutron time-of-flight measured using side 1 of the neutron counters.
$\Theta$ is the lab. angle of the neutron emitted in reaction (1).
The dashed area represents the acceptance of our apparatus.

Fig. 3 : Distribution of the distances in space between the two tracks of a "converted $\gamma$ ray". Electron-positron events may be simulated by unresolved converted $\gamma$ rays. The excess of events with zero distance shows that the $e^+e^-$ events are genuine and are not due to materialized $\gamma$ rays.

Fig. 4 : The mass distribution for the events with zero opening distance in Fig. 3. The shape of the $\rho$ distribution is determined by its natural width, the known production cross-section and density matrix, and the experimental acceptance and resolution. The dashed curves are the result of a maximum likelihood fit to the experimental data.

Fig. 5 : Experimental results compared with theoretical predictions. The heavy circle indicates the relation existing between the $(e^+e^-)$ decay widths of the three vector mesons, $\rho$, $\omega$, $\varphi$, on the basis of the generalized first Weinberg sum rule (Eq. 9). The dotted circles indicate the error limits due to the uncertainty in $\Gamma(\rho \rightarrow e^+e^-)$ and $m_\rho$. The two points indicated with MMM correspond to the two versions of the mass-mixing model of Kroll, Lee and Zumino[12], while the CMM point is the prediction of their current mixing model. The quark model is that of Van Royen and Weisskopf[16]. Notice that the two MMM models and the quark model require $\Theta_Y = \Theta_N$ and are therefore incompatible with that part of the generalized first Weinberg sum rule given by Eq. (7).



SCHEMATIC OF THE EXPERIMENTAL SET-UP

FIG. 1

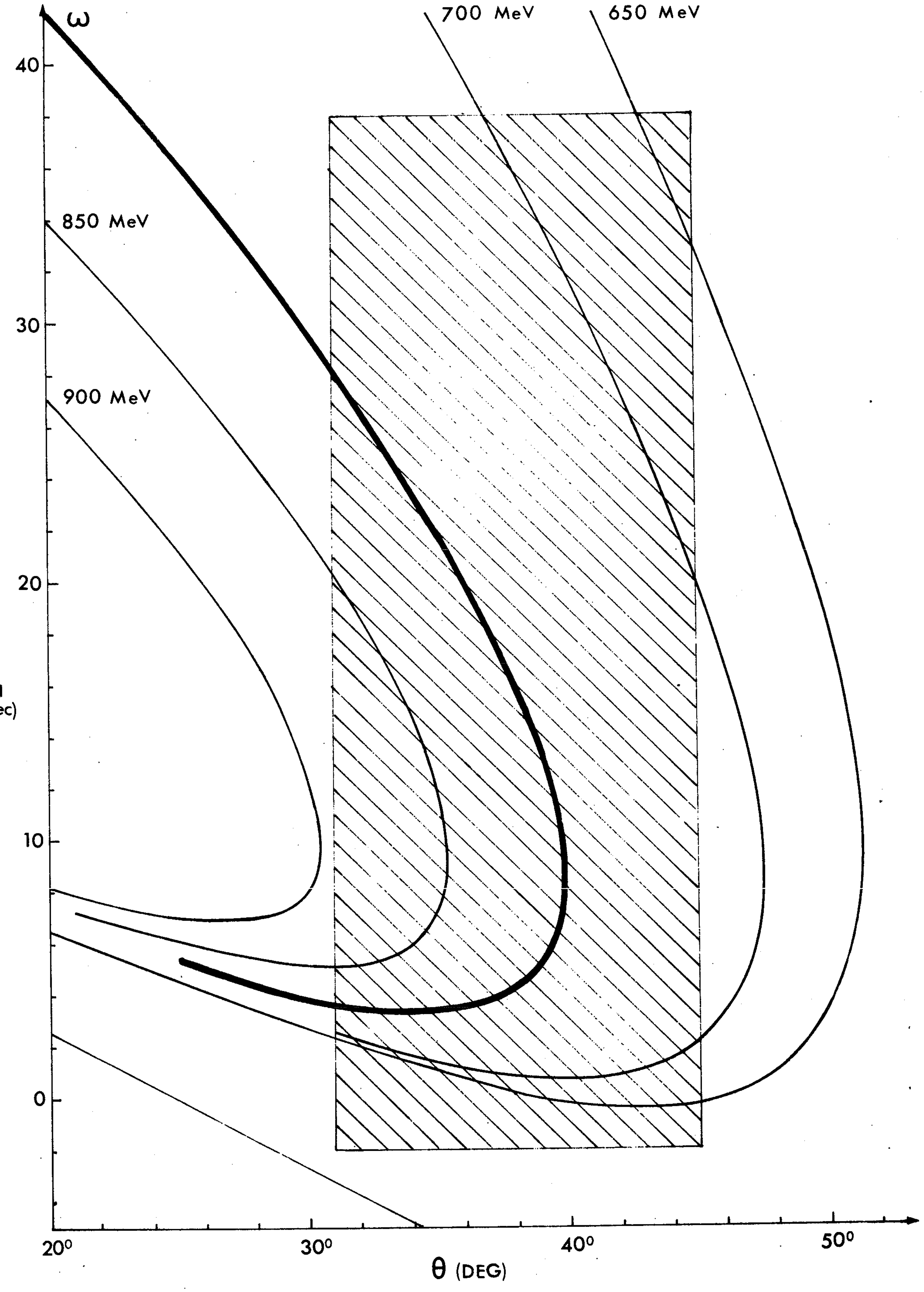

ω
700 MeV
650 MeV
850 MeV
900 MeV
40
30
20
10
0
$t_1$
(n sec)
20°
30°
40°
50°
θ (DEG)

FIG. 2

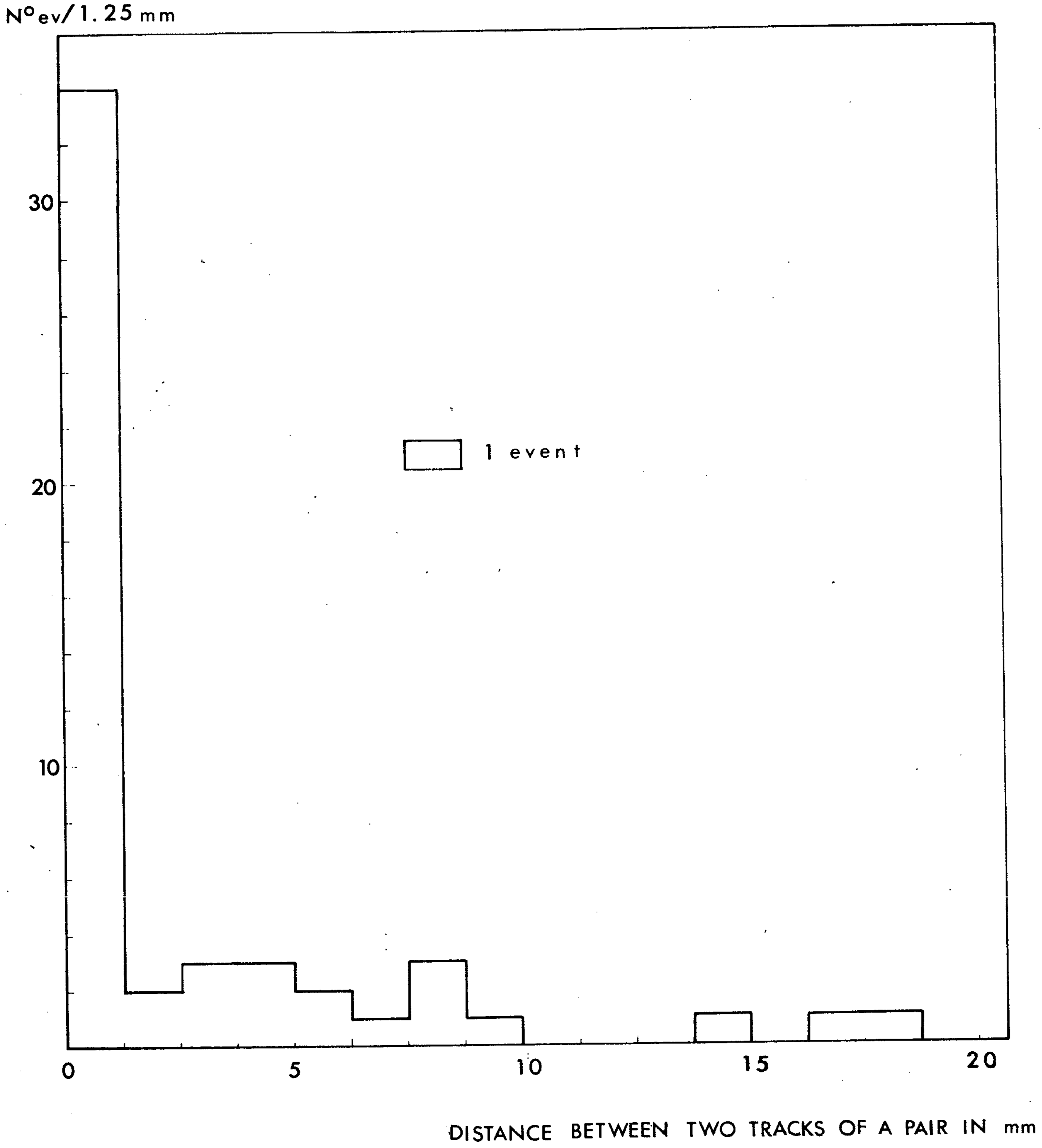

N°ev/1.25 mm
30
20
10
1 event
0
5
10
15
20
DISTANCE BETWEEN TWO TRACKS OF A PAIR IN mm

FIG. 3

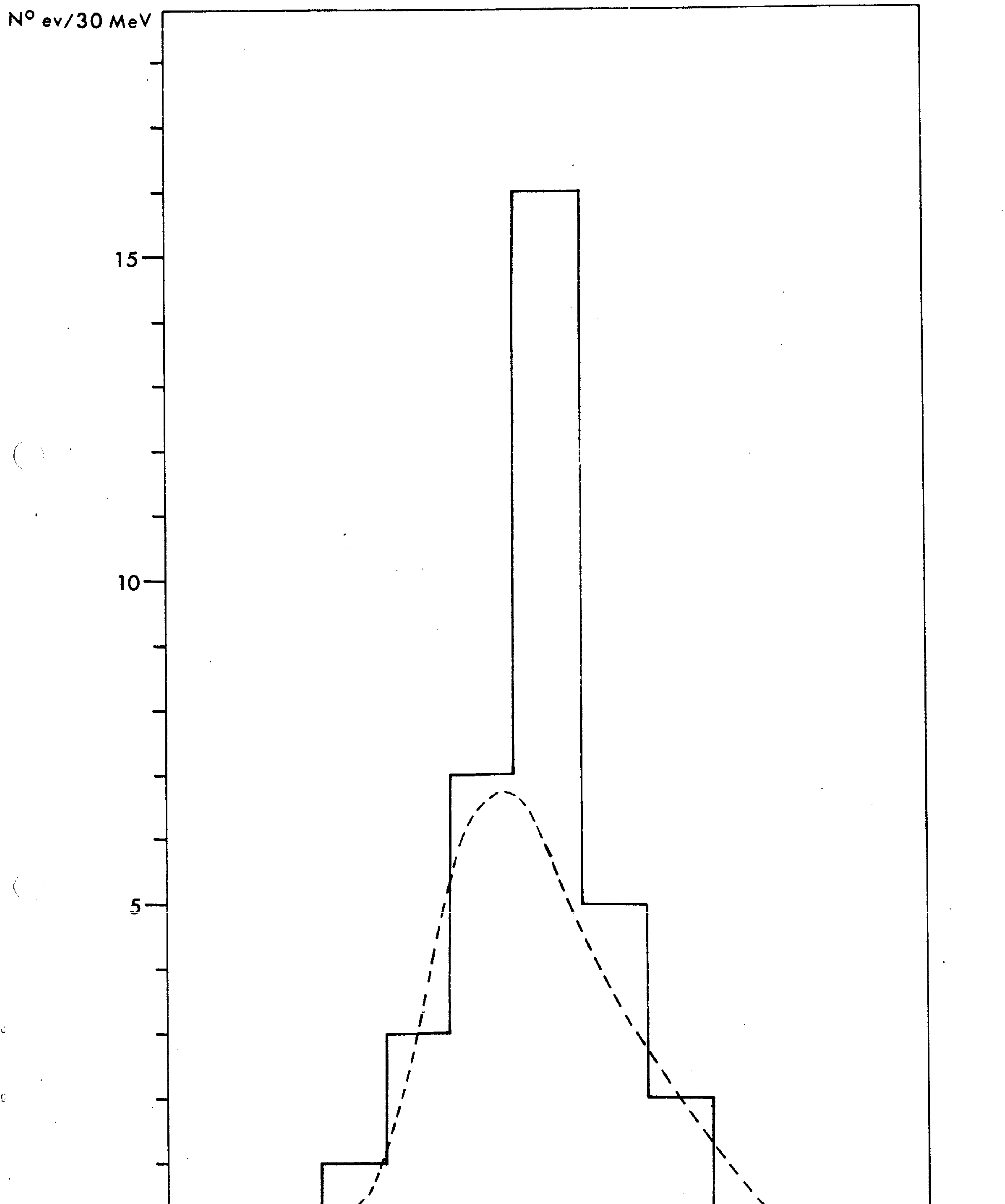
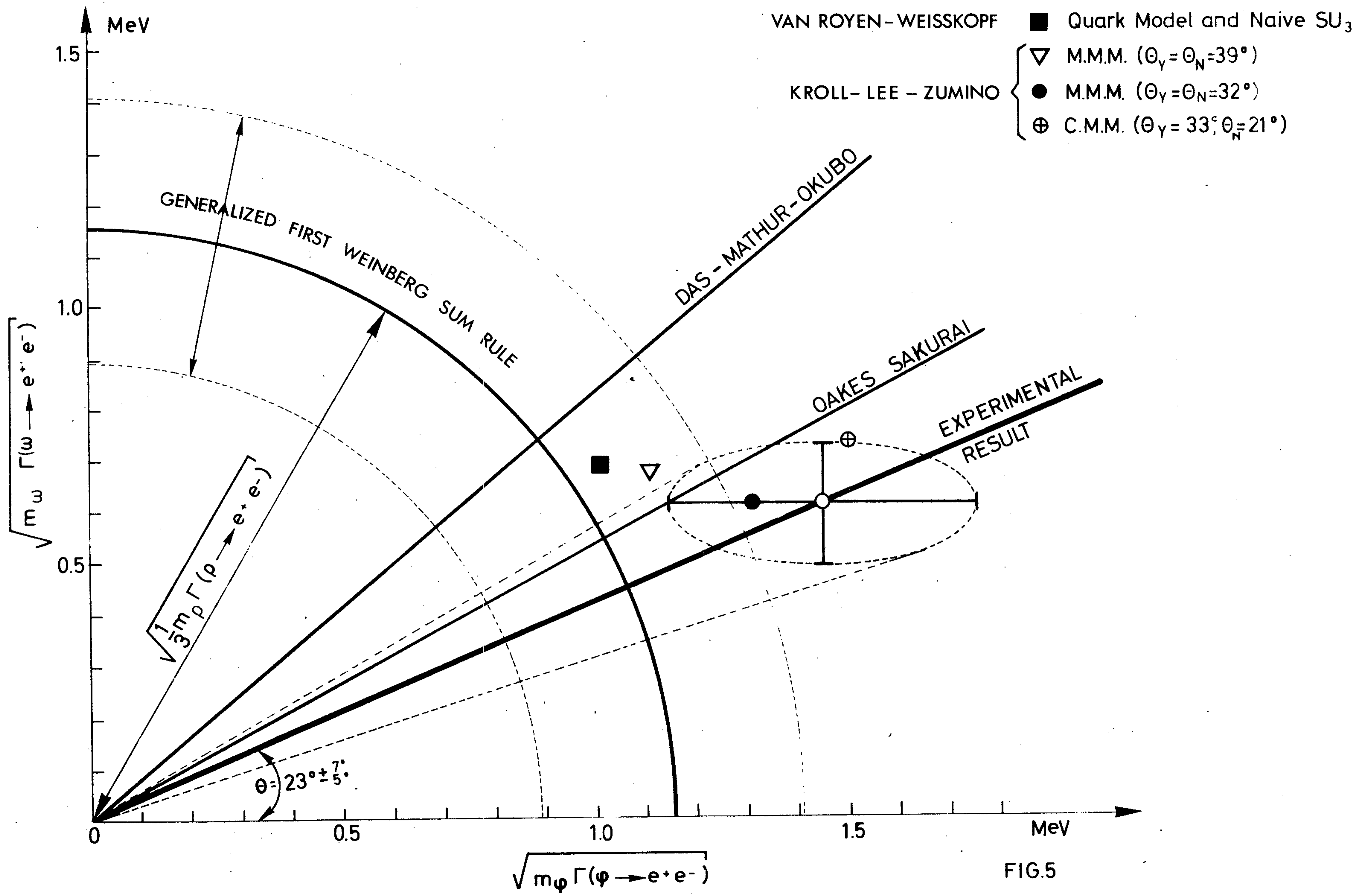


FIG. 4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■ Quark Model and Naive $SU_3$
KROLL-LEE-ZUMINO
▽ M.M.M. ($\Theta_Y = \Theta_N = 39°$)
● M.M.M. ($\Theta_Y = \Theta_N = 32°$)
⊕ C.M.M. ($\Theta_Y = 33°, \Theta_N = 21°$)
MeV
1.5
1.0
0.5
0
$\sqrt{m_\omega \Gamma(\omega \to e^+ e^-)}$
GENERALIZED FIRST WEINBERG SUM RULE
DAS-MATHUR-OKUBO
OAKES SAKURAI
EXPERIMENTAL RESULT
$\sqrt{\frac{1}{3} m_\rho \Gamma(\rho \to e^+ e^-)}$
$\theta = 23° {}^{+7°}_{-5°}$
$\sqrt{m_\varphi \Gamma(\varphi \to e^+ e^-)}$

FIG.5