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Laboratori Nazionali di Frascati

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4 Novembre 1992

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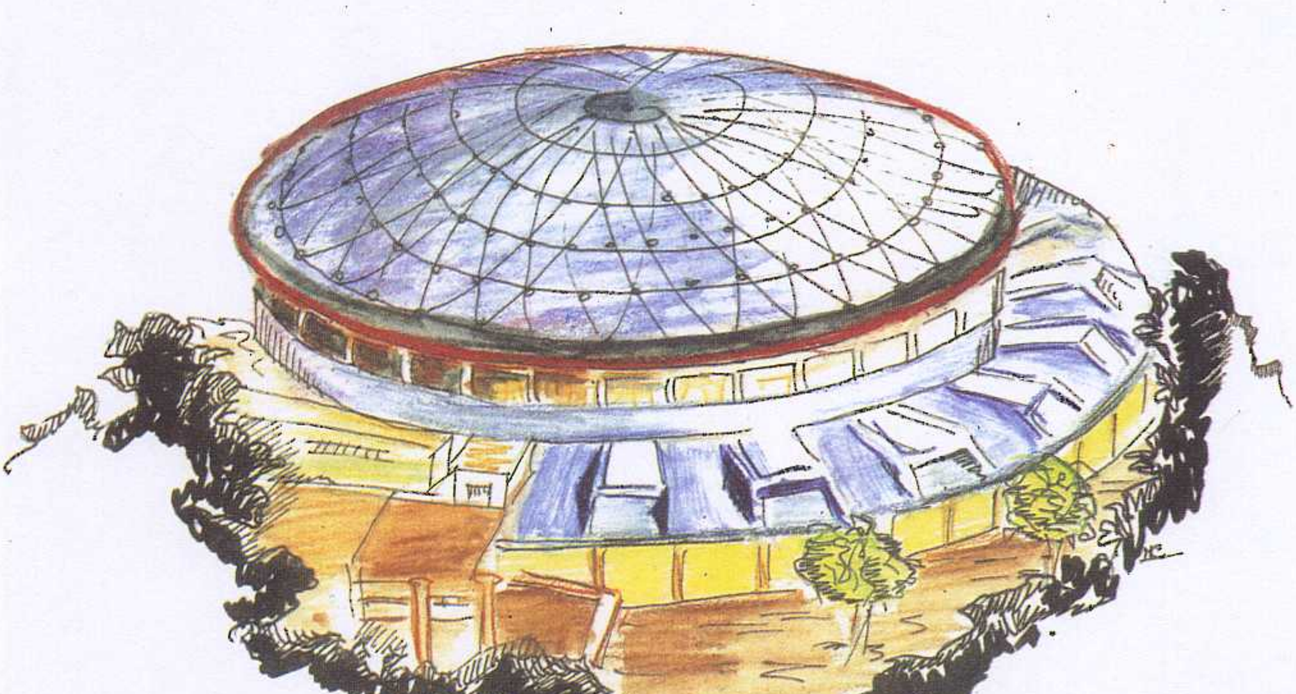
VECTOR MESON SPECTROSCOPY ABOVE THE Φ AT DAΦNE

Contribution to the DAΦNE Physics Handbook



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VECTOR MESON SPECTROSCOPY ABOVE THE ϕ AT DAFNE

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Abstract

The production of 1^{--} states with mass above the ϕ , up to 2 GeV, is shortly reviewed. The importance of having a high luminosity e^+e^- collider covering this mass range is enphasized.

1. Introduction.

Recurrencies of the well-known ρ, ω, ϕ mesons are definitely expected to populate the e^+e^- annihilation process into hadrons in the $1 - 3$ GeV interval. Nevertheless the observation of such recurrencies is still controversial.

Data on vector mesons are available not only from e^+e^- storage rings, but also from diffractive photoproduction, from phase shift analysis of many-pion production in high statistics hadronic interactions and from τ decays into an even number of pions according to the CVC hypothesis. However, the direct observation as a resonant production in final states of e^+e^- annihilation remains the best signature. Actually photoproduction results also depend on large inelastic contributions which may account for the observed discrepancies with corresponding e^+e^- data. Unfortunately at present e^+e^- data, when they do not suffer of low statistical significance, are hard to interpret because of large interference effects.

It may be worthwhile to review the evolution of these data, to understand which are the experimental facts with respect to the theoretical expectations.

2. Isovector Resonances.

Isovector mesons, representing the largest contribution to the total cross section, will be considered first. Ten years ago, before the DM2 experiment at DCI, the salient experimental features were:

- In the most relevant process, $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-$ a very large and smooth bump[1] , peaked at 1.5 GeV with a width of the order of 0.4 GeV (Fig. 1a). The same bump was observed in $\pi^+\pi^-\pi^+\pi^-$ and , with a smaller width , in $\pi^+\pi^-$ photoproduction[2] (Fig. 2a).
- In the other relevant process, $e^+e^- \rightarrow \pi^+\pi^-\pi^0\pi^0$ including $\omega\pi^0$, a sharp rise in the cross section at 1.1 GeV followed by a slow fluctuating decrease[3] (Fig. 1b). That was roughly consistent with $\pi^+\pi^-\pi^0\pi^0$ diffractive photoproduction[4] taking in mind the large background coming from the photoproduction of the axial meson B(1.25) .

The $4\pi^{\pm}$ data were interpreted as evidence of a ρ recurrency, the $\rho'(1.6)$. On the other hand, to explain the $\pi^+\pi^-\pi^0\pi^0$ behaviour, the process $\rho \to \omega\pi^0$ was considered by adding[5] to the $\rho'(1.6)$ a contribution from a ρ tail with coupling constants evaluated from $e^+e^- \to \rho$ and $\omega \to \rho\pi$.

The total hadronic cross section was assumed to be mainly due to the contributions of even ρ recurrencies[6], according to the Veneziano formula. Assuming $\Gamma_{ee}(\rho_n) \propto 1/M(\rho_n)$ and $\Gamma_{tot}(\rho_n) \propto M(\rho_n)$, in agreement with the $\rho'(1.6)$ parameters, the asymptotic value of $\sigma_{tot}/\sigma_{\mu\mu}$ was consistent with the quark model prediction[7]. In this scenario a $\rho'(1.3)$ and orbital ρ excitations were disregarded.

The naive expectation of a single $\rho'(1.6)$ has been ruled out by the DM2[8] measurement of the pion form factor from $e^+e^- \to \pi^+\pi^-$ (Fig. 2b). The interference pattern requires at least two resonances, a $\rho'(1.45)$ and a $\rho'(1.7)$[9]. On the other hand, in $\pi^+\pi^-$ diffractive photoproduction a bump is observed at 1.6 GeV in the $\pi\pi$ invariant mass (Fig. 2a), corresponding to a dip in the pion form factor. To preserve the vector meson dominance model of diffractive photoproduction very large inelastic contributions must be taken into account[9], spoiling in part the strength of this model.

The smooth bump in $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$, peaked at 1.5 GeV, has been confirmed by DM2[10] , (Fig. 3a). Of course this pattern is not in disagreement with the abovementioned two superimposed resonances . It remains to be explained how these two resonances can manage to achieve so smooth cross sections in a many body process. A good candidate to disentangle the two resonances is the two body process $\rho\eta$. Indeed data on $e^+e^- \to \rho\eta$[11] (Fig. 4a), as well as data on phase shift analysis[12] on $\pi^-p \to \rho\eta n$ (Fig. 4b), are in favour of the two resonances hypothesis, but the statistical accuracies are not very compelling .

DM2 data[10] on $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$ are also consistent with the two ρ' hypothesis. Actually the sharp drop of the $e^+e^- \to \omega\pi^0$ cross section at 1.5 GeV, in good agreement with data on $\tau \to \omega\pi^0$ [13], is evidence for an interference between a ρ tail and a $\rho'(1.4)$ (Fig. 5). On the other hand a different bump in $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$, peaked at 1.7 GeV, has been put in evidence, once $e^+e^- \to \omega\pi^0$ has been removed (Fig. 3b). Unfortunately high statistics Novosibirsk[14] data at lower energies do not match with those of DM2 and are inconsistent with data at the same energies extracted from $\tau \to \pi^-\pi^+\pi^-\pi^0$ [15]. By the way a disagreement is also observed at this moment between $\tau \to \pi^-3\pi^0$ and $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ [40] .

In conclusion the DM2 data show evidence for two isovector resonances at $\simeq 1.4$ and $\simeq 1.7$ GeV. Nevertheless such results cannot be taken as conclusive.

Actually a new feature has emerged in the $\pi^+\pi^-$ phase shift analysis in $K^-p \to \pi^+\pi^-\Lambda$ from LASS[16]: namely a renewed evidence for the old $\rho'(1.3)$ with mass $m = 1.30 \pm 0.03$ GeV, width $\Gamma = 0.14 \pm 0.05$ GeV and $\pi^+\pi^-$ branching ratio $(4 \pm 1)\%$ (Fig. 6a,b). The statistical evidence is not overwhelming, however a check of this experiment is that a clear $\rho - \omega$ interference effect is observed (Fig. 6c), with branching ratio and phase in agreement with storage ring measurements.

MARK III[17] measuring the pion form factor from $J/\psi \to \pi^+\pi^-\pi^0$ claims to be consistent with LASS (Fig. 2c). However no real evidence is found for a $\rho'(1.3)$ in the pion form factor or in the 4π channels at a level $\Gamma_{ee}(\rho') < 0.1$ keV in the DM2 and photoproduction data [18] . Relevant channels in which this resonance should be seen are $K\bar{K}$ and $\omega\pi^0$, but for the latter one should get rid of the non resonant background coming from the ρ tail.

Several years ago an experiment at DESY , on photoproduction of e^+e^- pairs on protons[19], gave a clear indication of a ρ' , with mass and width consistent with the LASS result (Fig. 7a). In such a reaction a Bethe-Heitler C-even, real amplitude and a Compton C-odd amplitude, real if resonant, contribute. The events were weighted in a suitable way to extract the interference between these two amplitudes. In fact that is not vanishing only if there is a resonant amplitude, which in turn is amplified by the interference.

The experiment, optimized in the 1 GeV mass region, presented also ρ and ϕ cross sections in good agreement with the expectations from the vector dominance model of diffractive photoproduction on protons (Fig. 7b). Nevertheless at that time this experiment was disregarded because the ρ' photoproduction cross section on protons would have implied a too high e^+e^- cross section, still according to the vector dominance model.

This result could be revived if there is an anomalous $\rho'(1.3)$ coupling to a baryon, like for instance a I=1 $q^2\bar{q}^2$ interpretation of the $\rho'(1.3)$.

Currently a serious candidate for an isoscalar $q^2\bar{q}^2$ or baryonium state has been observed by various high statistics experiments[20], with a mass 1.52 GeV and $J^{PC} = 2^{++}$. It has been pointed out[21] that an isoscalar $J^{PC} = 1^{--}$ is expected exactly at 1.1 GeV if these states lie on a Regge trajectory with the universal slope 0.9 GeV^{-2}. Actually the DESY experiment showed also another unexpected narrow resonance at 1.10 GeV, which could be just this I=0 partner of the $\rho'(1.3)$ (Fig. 7a).

Concerning exotic isovector states, the existence of a vector meson decaying into $\phi\pi$ has been proposed by a hadroproduction experiment[39] at $\simeq 1.48$ GeV. No evidence for such a state has been observed until now, in e^+e^- experiments[29] but the present limits are not stringent because of the low integrated luminosity.

In the near future, $q^2\bar{q}^2$ or baryonium mesons should be identified in the $p\bar{p}$ annihilation at threshold at LEAR. On the other hand new important results from e^+e^- storage rings are unlikely in the next few years.

3. Isoscalar Resonances.

The situation is still more confusing in the isoscalar sector because of the smaller statistics, roughly 1,500 events to be compared to $\simeq 40,000$ with positive G-parity.

In the past, the DM1 experiment showed evidence of a state around 1650 GeV/c^2 in the $e^+e^- \to K\bar{K}$, $K^0_S K^\pm\pi^\mp$ and $\omega\pi^+\pi^-$ channels. The lack of signal in the $\rho\pi$ reaction strongly supported the interpretation[22] of this state as a ϕ recurrency, a $\phi'(1.68)$. Moreover the existence of an ω' degenerate in mass and width with the $\rho'(1.6)$ had been supposed.

However a peak in $\pi^+\pi^-\pi^0$ was subsequently observed in photoproduction[23] at the same mass, mostly suggesting an ω' assignment for the observed state. The same experiment claimed for a ϕ' state observed in its K^+K^- decay at 1.76 GeV[24].

The kaon form factor has been extensively studied at the ϕ mass in the charged and neutral modes. Above this energy data from Novosibirsk[25] and Frascati[26] suggested that

$|F_{K^\pm}|$ could be larger than the contribution of ρ, ω and ϕ tails. The DM1 experiment[27] concluded that the experimental behaviour of $|F_{K^\pm}|^2$ was not compatible (Fig. 8a) with the VDM hypothesis because of an enhancement in the $1.35 \div 1.70$ GeV energy range. This enhancement has been related to the contribution of higher vector mesons like the $\rho'(1.6)$. On the contrary the $e^+e^- \to K^0_S K^0_L$ cross section[28] was generally depressed but showed a resonant behaviour at $\simeq 1.65$ GeV/c^2 (Fig. 8b). This effect and the fast drop of both form factors near 1.7 GeV cannot be explained by the $\rho'(1.6)$ alone and an interference with an isoscalar vector meson is needed, identified[22] later as the $\phi(1.68)$.

DM2[29] has confirmed the DM1 results on the charged kaon form factor. The ρ, ω, ϕ and $\rho'(1.6)$ are not sufficient in order to explain its behaviour and the contribution of a further amplitude, compatible with the $\phi(1.68)$, is the most consistent with the data. In particular its branching ratio into $K\bar{K}$ seems too large for an ω' assignment. On the other hand the contribution of a narrow ϕ' state at 1.76 GeV[24], alone or associated to an $\omega'(1.6)$, is rejected by DM2.

As said before, a resonant signal at $\simeq 1.67$ GeV was first observed by DM1 (Fig. 8c) in the $K^0_s K^\pm \pi^\mp$ channel[30]. The related Dalitz plot showed a clear K^*K dynamics with K^{*0} dominance. This effect indicated an interference between isovector ($\rho - like$) and isoscalar ($\phi - like$) amplitudes. A Dalitz plot analysis showed a resonant behaviour for the isoscalar amplitude whose phase crosses 90^0 on the resonance peak whereas the isovector cross section was largely suppressed. DM2[32] has confirmed these results with a larger statistical significance (Figs. 9,10). Furthermore a measurement of the $e^+e^- \to K^+K^-\pi^0$ cross section is well compatible with the one expected (Fig. 11) by SU(3) relations for the coupling constants which imply a destructive interference between ρ-like and ϕ-like resonances for this channel.

Concerning the final states with an odd number of pions, in the past results were available from DM1[22,32] at Orsay and ND[14] at Novosibirsk. The former experiment measured the $e^+e^- \to \omega\pi^+\pi^-$ channel giving evidence for a large bump centered at $\simeq$ 1.68 GeV/c^2, $\simeq .23$ GeV/c^2 wide (Fig. 8d). The second showed that the $e^+e^- \to \pi^+\pi^-\pi^0$ cross section is larger than a VDM extrapolation from the $\omega - \phi$ peaks, but does not show structures (Fig. 12).

Subsequent DM2 results[33] show that the cross section for $e^+e^- \to \pi^+\pi^-\pi^0$, which is dominated by the $\rho\pi$ dynamics, remains constant up to $\simeq 1.62$ GeV where it goes suddenly to zero (Fig. 13). On the other hand the cross section for $e^+e^- \to \omega\pi^+\pi^-$ is dominated by the same wide bump reported by DM1 (Fig. 14). A recent analysis[34] of the available $\pi^+\pi^-\pi^0$ and $\omega\pi^+\pi^-$ data, including preliminary DM2 results, has proposed the existence of two ω' states with $m_{\omega'_1} \simeq 1.39$ GeV/c^2 and $m_{\omega'_2}$ ranging in the $1.6 - 1.7$ GeV/c^2 interval depending on the parametrization model. The existence of a further ω' state at higher mass has been also suggested[35].

Finally from a coupled channel analysis, the DM2 results are compatible with three contributing states, $\omega'(1.43)$, $\omega'(1.63)$ and $\omega'(1.82)$, as reported in Tab. 2. The $\omega'(1.43)$ and $\omega'(1.82)$ are not coupled to the $\omega\pi\pi$ and $\rho\pi$ final state respectively. The parameters of the $\omega'(1.63)$ are largely compatible with those of the isoscalar resonance observed in the

$K\bar{K}\pi$[30,31] reaction. However the identification of these two signals with a single state is not at all automatic. The large $\omega\pi\pi$ production would suggest an ω' nature for this state, but then SU(3) invariance would imply a $\rho\pi$ cross section even higher than the K^*K one. On the other hand strict application of the OZI rule for a pure $s\bar{s}$ state would suppress both $\omega\pi\pi$ and $\rho\pi$ decays relatively to K^*K. Therefore the mixing between ω' and ϕ' could be different from the ideal value.

The existence of both such states has been recently suggested by an analysis of the DM2 data[36] and also proposed[37] on an independent basis.

3. Conclusion.

The $\rho'(1.4)$ and the $\rho'(1.7)$ are consistent with quark model predictions for a 2 S and a 1 D excitations of the ρ[38]. On the other hand, although three ω' and one ϕ' states seems to be observed, it is not yet clear at which recurrencies they correspond and if space is available for the other exotic states which have been foreseen.

DAFNE can make definitive contributions thanks to its high luminosity. Moreover it would be the first machine able to cover the whole energy interval of interest if its maximum energy can be raised up to at least 1.9 GeV. In this case the contributions of both radial and orbital recurrencies could be precisely measured, including mixing angle values in the isovector sector.

However a maximum energy in the center of mass of 1.5 GeV, as scheduled for the moment, should be very useful to settle at least the $\rho'(1.3)$ and $\rho'(1.1)$ puzzles. It must be stressed that any present interpretation strongly suffers of large systematic errors because no experiment has completely covered this energy interval. A careful study of the hadron form factors and of the presently flat $e^+e^- \to \rho\pi$ cross section should reveal the contributions from unseen isoscalar resonances. The actual production of the exotic state around 1.48 GeV should be also evidenced.

Finally the expected very high rates should allow for more exotic physics. In particular even the real part of the hadronic contribution to $e^+e^- \to \mu^+\mu^-$ should be put in evidence. This measurement is slightly similar to that of Ref.[19]. In fact QED expectations should be modulated by a factor $2(B_{ee}\sigma_{tot}/\sigma_{\mu\mu})^{1/2} \simeq \pm 0.5\%$, assuming $B_{ee} \simeq \sigma_{tot} W^2/12\pi$, with opposite signs in $\mu^+\mu^-$ and e^+e^- at large angles.

We warmly acknowledge our DM2 colleagues.

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Figure Captions

Fig. 1 a) $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-$, as measured by experiments preceding DM2 ;
b) the same for $e^+e^- \rightarrow \pi^+\pi^-\pi^0\pi^0$.

Fig. 2 a) $\pi^+\pi^-$ diffractive photoproduction cross section ;
b) $e^+e^- \rightarrow \pi^+\pi^-$ cross section ;
c) pion form factor squared from $J/\psi \rightarrow \pi^+\pi^-\pi^0$.

Fig. 3 a) DM2 results on $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-$;
b) the same for $e^+e^- \rightarrow \pi^+\pi^-\pi^0\pi^0$.

Fig. 4 a) DM2 results on $e^+e^- \rightarrow \rho\eta$(11) ;
b) 1^{--} from $\rho\eta$ phase shift analysis of $\pi^-p \rightarrow \rho\eta n$.

Fig. 5 $e^+e^- \rightarrow \omega\pi^0$ cross section.

Fig. 6 a) 1^{--} from $\pi^+\pi^-$ phase shift analysis of $K^-p \rightarrow \pi^+\pi^-\Lambda$;
b) difference in phase between 1^{--} and 2^{++};
c) evidence for the $\rho - \omega$ interference .

Fig. 7 a) Interference between C-even and C-odd amplitudes in photoproduction of e^+e^- ;
b) e^+e^- pairs photoproduction cross section on protons.

Fig. 8 Summary of DM1 results:
a)$\omega\pi^+\pi^-$;
b)K^+K^- ;
c) $K^0_S K^0_L$;
d) $K^0_S K^\pm \pi^\pm$;
e) cross sections and relative phase between isoscalar and isovector production in $K^0_S K^\pm \pi^\mp$. . The curves refer to the global fit described in Ref.[22].

Fig. 9 Dalitz plot of $K^0_S K^\pm \pi^\mp$ events.

Fig. 10 a) Isoscalar , b) isovector cross sections, c) relative and d) absolute isoscalar phase in $K^0_S K^\pm \pi^\mp$.

Fig. 11 $K^+K^-\pi^0$ cross section compared with the expectation from the $K^0_S K^\pm \pi^\mp$ analysis.

Fig. 12 ND results (14) on $e^+e^- \rightarrow \rho\pi$ with DM2 data at the lower energies (33).

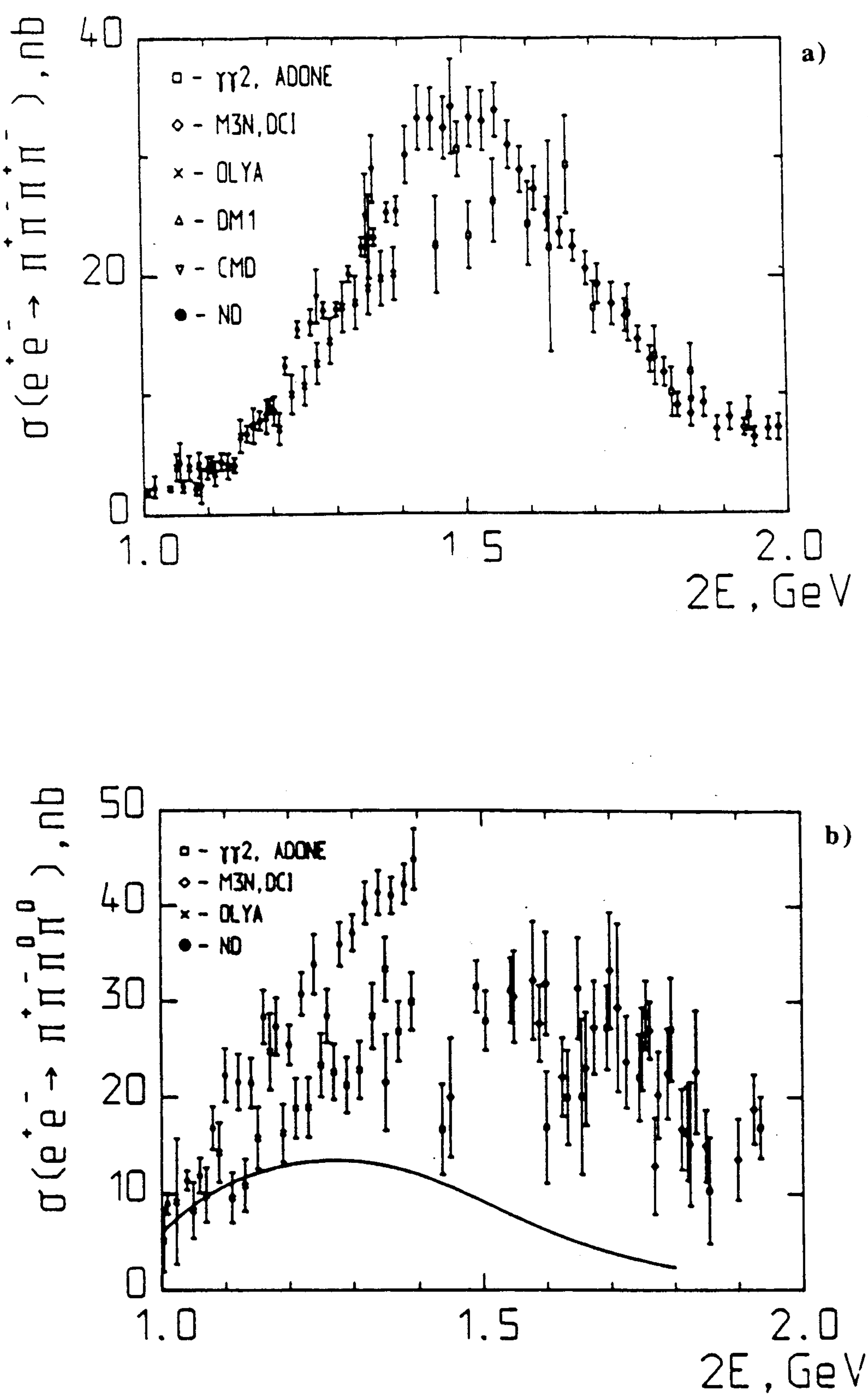
Fig. 13 DM2 results on $e^+e^- \rightarrow \rho\pi$. Lines correspond to the fits with a single or two Breit Wigner functions.

Fig. 14 DM2 results on $e^+e^- \rightarrow \omega\pi\pi$. Lines correspond to the fits with a single or two Breit Wigner functions.

Table Captions

Tab. 1 DM1 and DM2 results on isoscalar resonant productions.

Tab. 2 Parameters of the three ω' states.



a)
b)
σ(e⁺e⁻ → π⁺π⁻π⁺π⁻), nb
σ(e⁺e⁻ → π⁺π⁻π⁰π⁰), nb
□ - γγ2, ADONE
◇ - M3N, DCI
× - OLYA
△ - DM1
▽ - CMD
● - ND
2E, GeV

FIG. 1

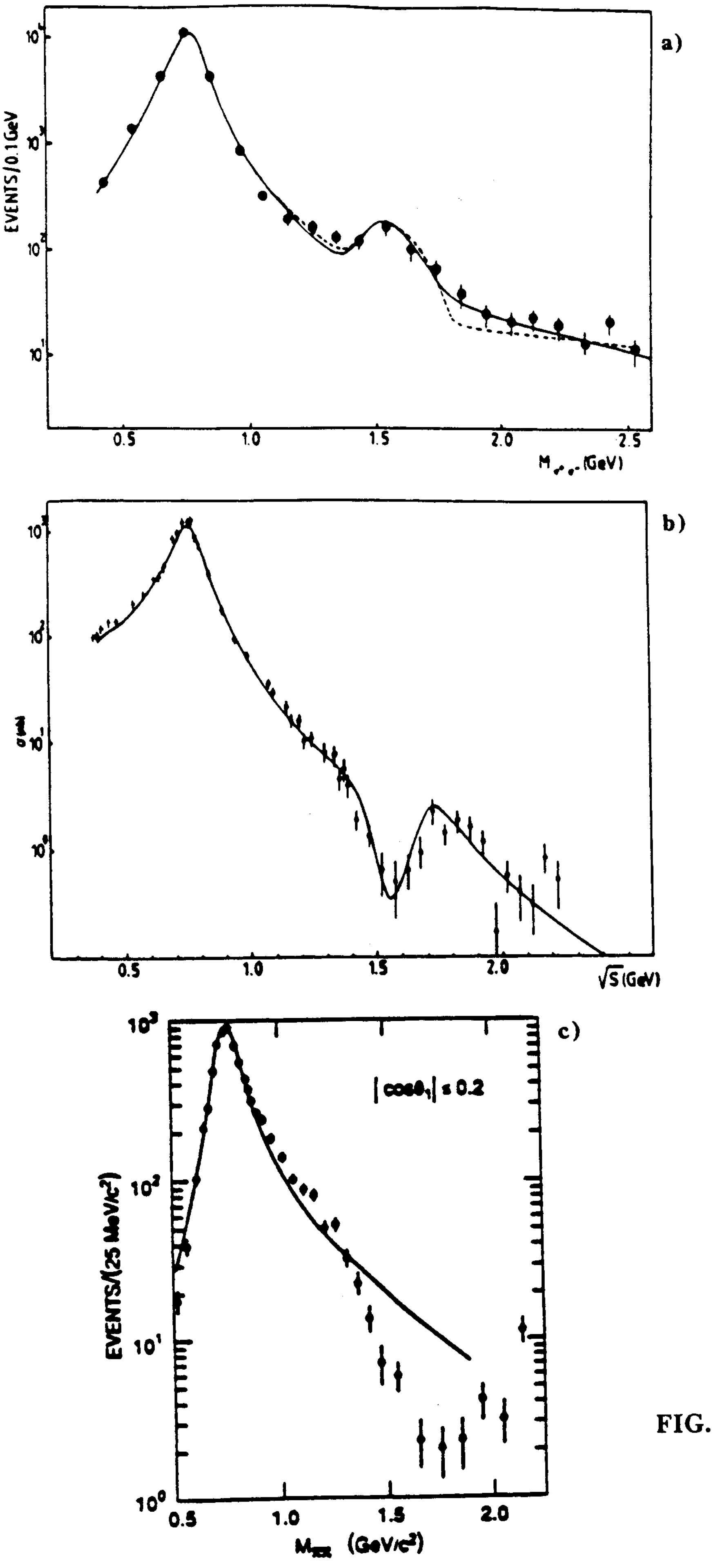

a)
EVENTS / 0.1 GeV
0.5
1.0
1.5
2.0
2.5
b)
0.5
1.0
1.5
2.0
√S (GeV)
c)
EVENTS/(25 MeV/c²)
|cosθ₁| ≤ 0.2
0.5
1.0
1.5
2.0
(GeV/c²)

FIG. 2

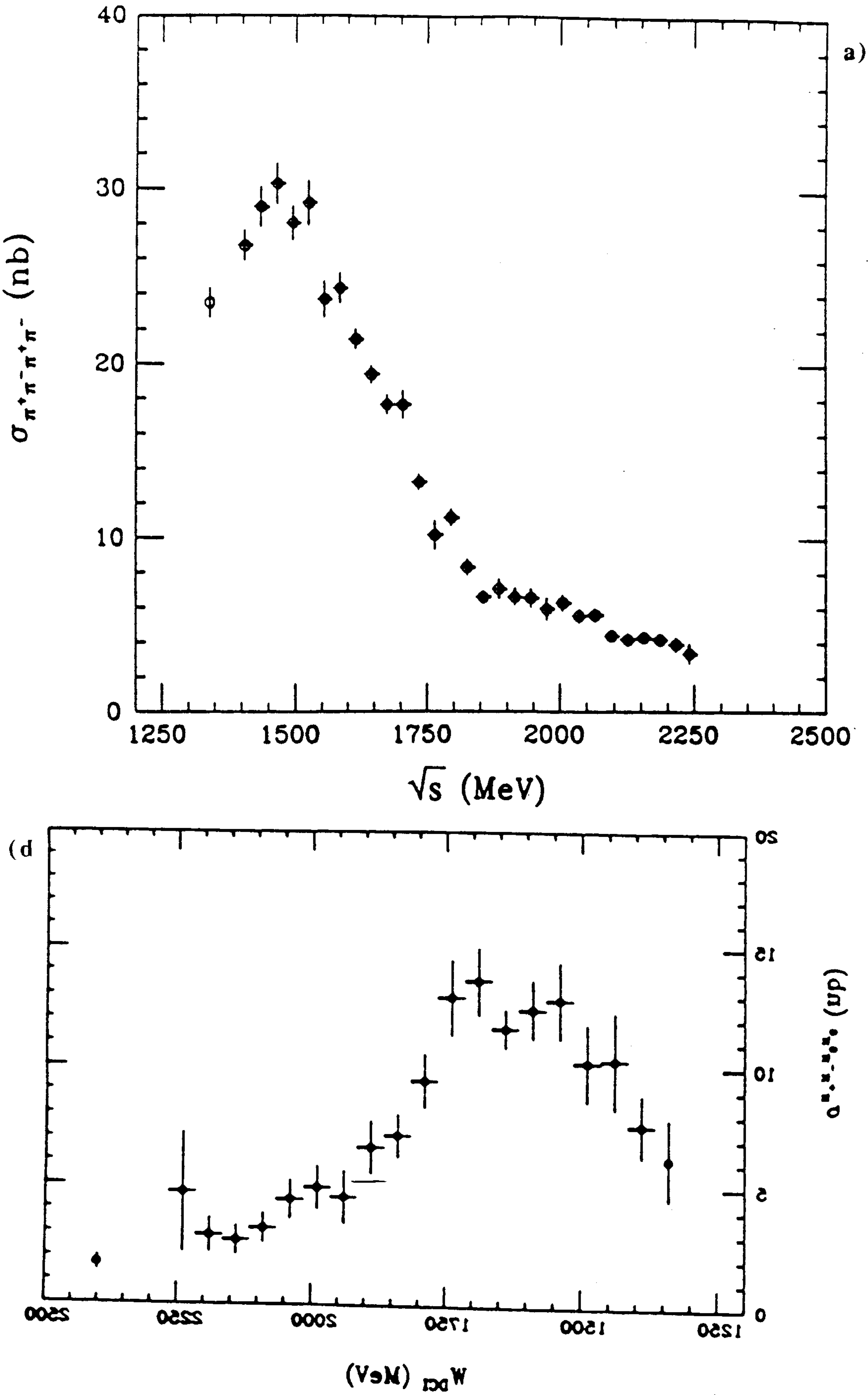

a)
$\sigma_{\pi^+\pi^-\pi^+\pi^-}$ (nb)
0
10
20
30
40
1250
1500
1750
2000
2250
2500
$\sqrt{s}$ (MeV)
b)

FIG. 3

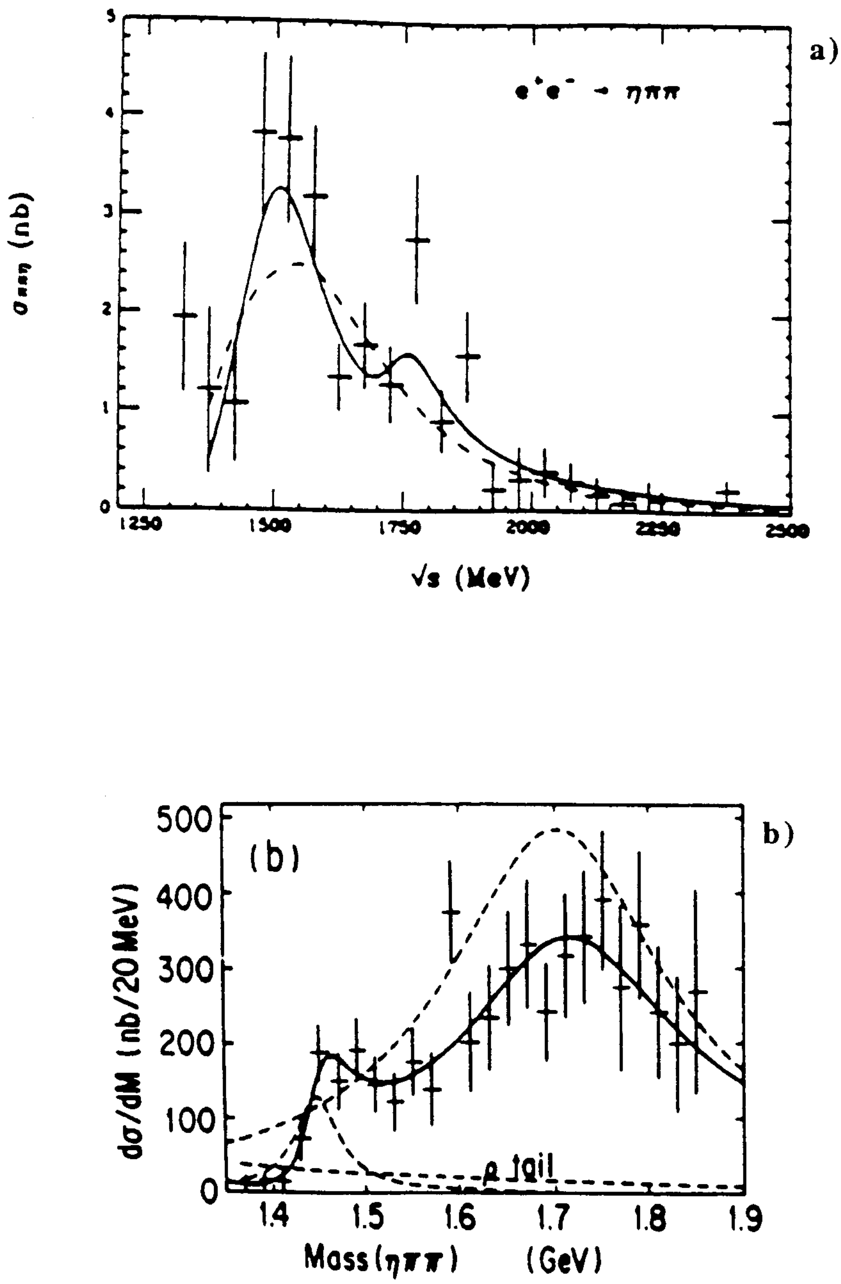


FIG. 4

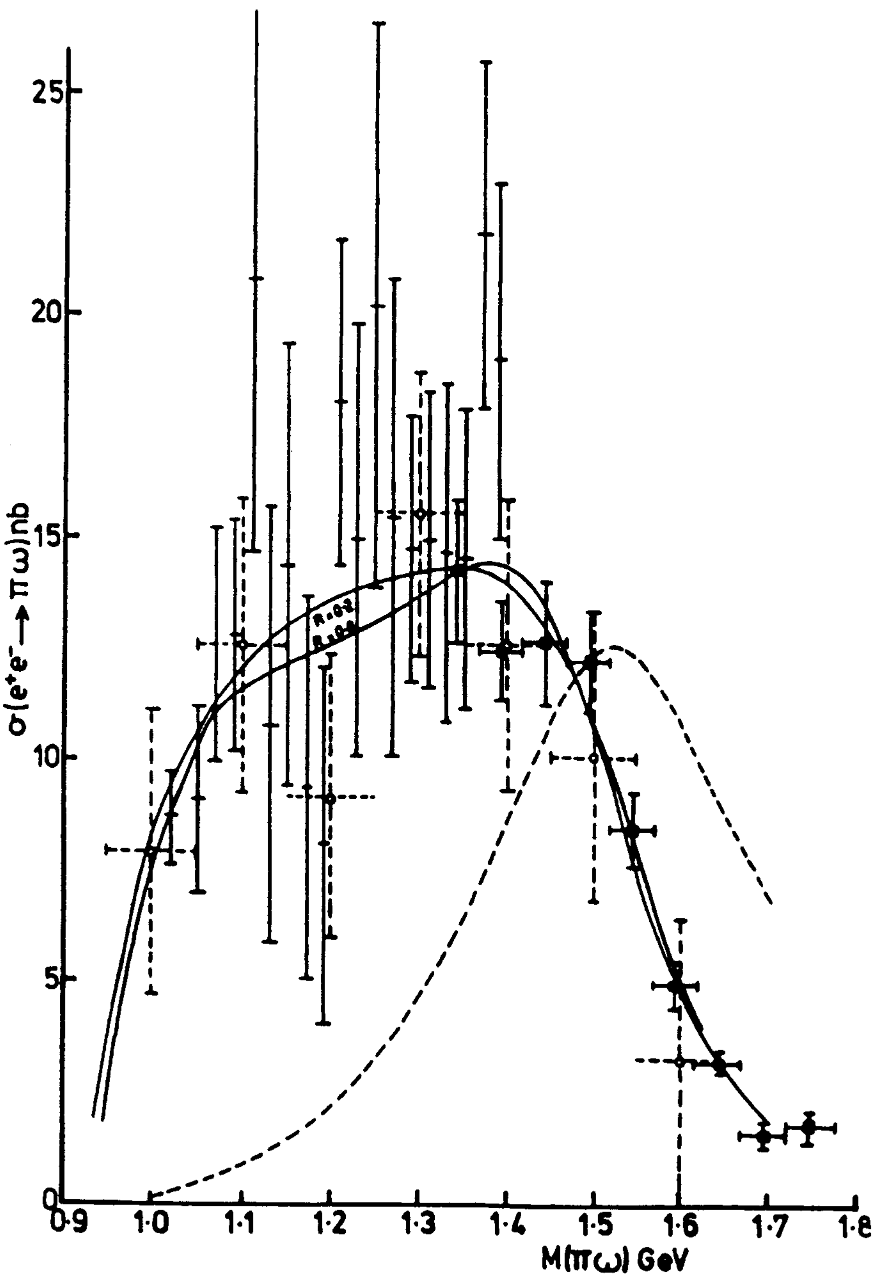


FIG. 5

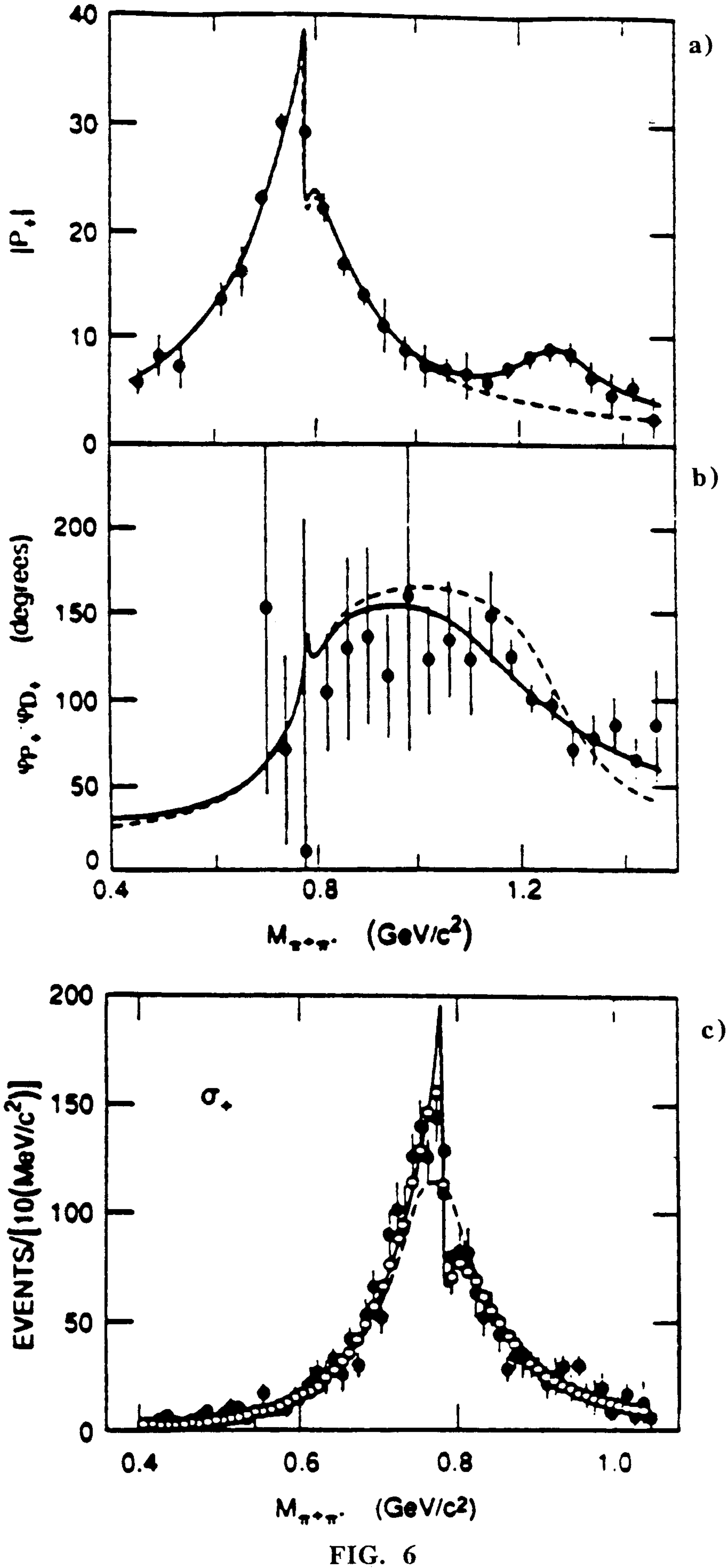

a)
40
30
20
10
0
$|P_+|$
b)
200
150
100
50
0
$\varphi_{P_+}, \varphi_{D_+}$ (degrees)
0.4
0.8
1.2
$M_{\pi^+\pi^-}$ (GeV/c^2)
c)
σ_+
200
150
100
50
0
EVENTS/[10(MeV/c^2)]
0.4
0.6
0.8
1.0
$M_{\pi^+\pi^-}$ (GeV/c^2)

FIG. 6

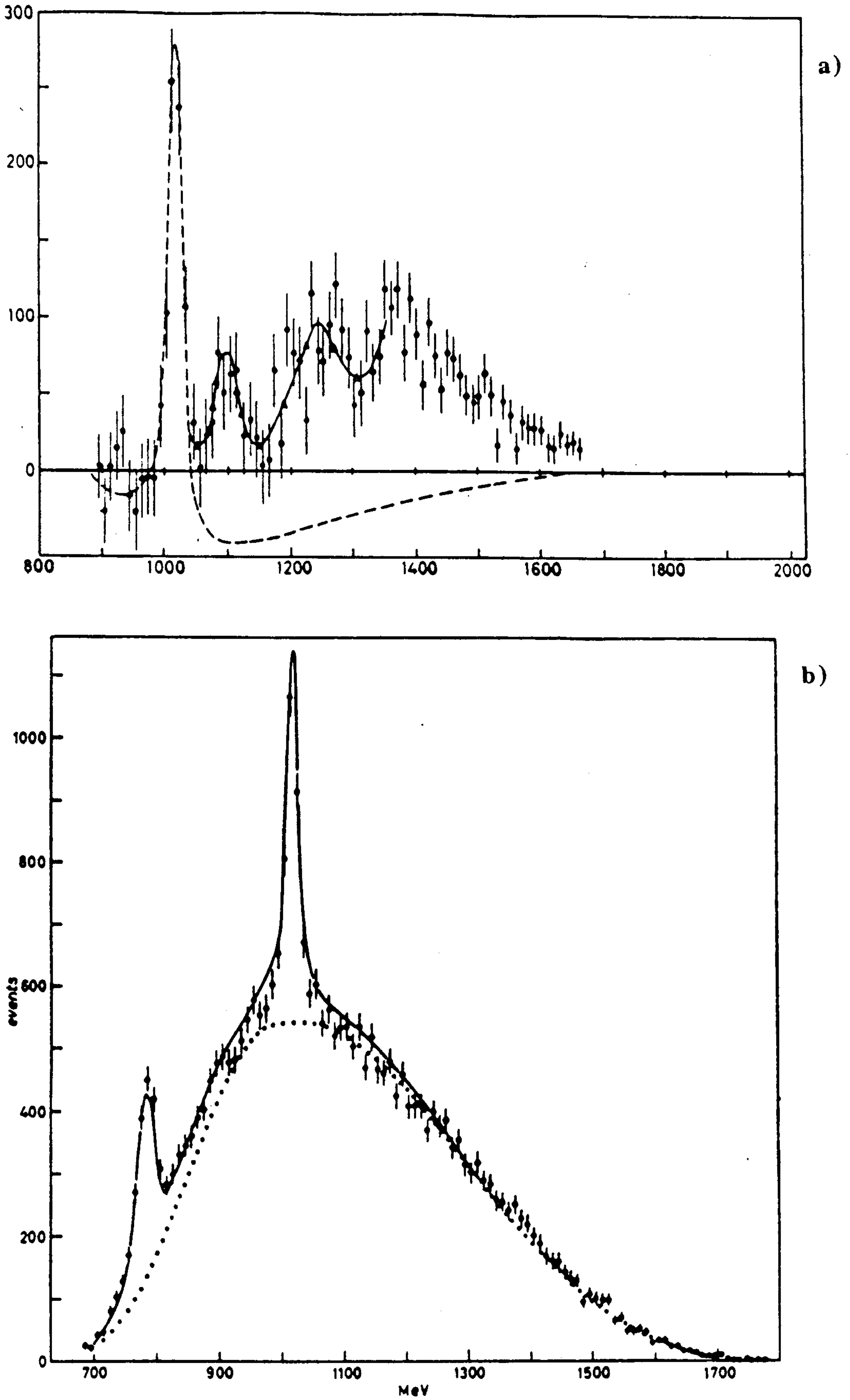

300
200
100
0
800
1000
1200
1400
1600
1800
2000
a)
b)
events
1000
800
600
400
200
0
700
900
1100
1300
1500
1700
MeV

FIG. 7

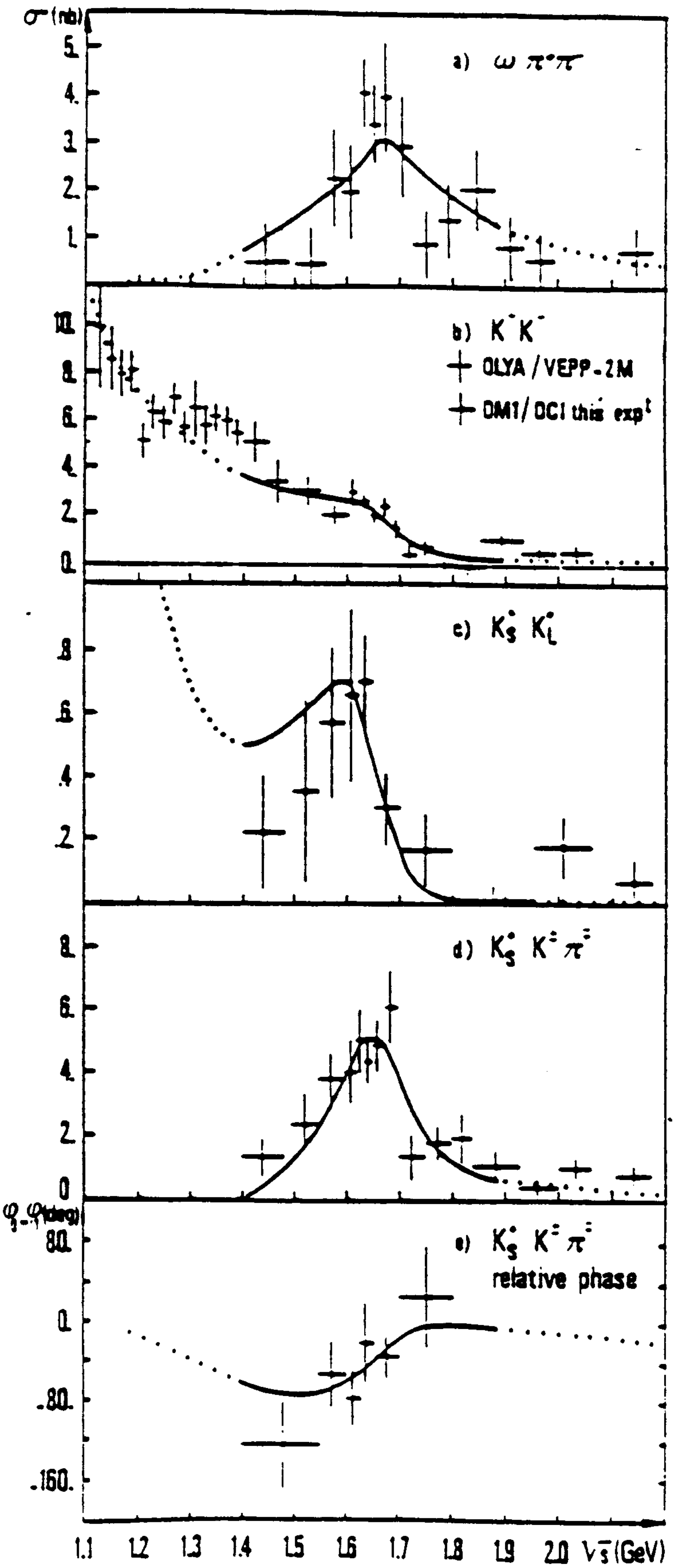

σ (nb)
a) ω π°π
b) K K
OLYA / VEPP-2M
DM1/DCI this exp^t
c) K_S° K_L°
d) K_S° $K^\pm \pi^\mp$
$\varphi_1 - \varphi_1$ (deg)
e) K_S° $K^\pm \pi^\mp$
relative phase
1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 √s (GeV)

FIG. 8

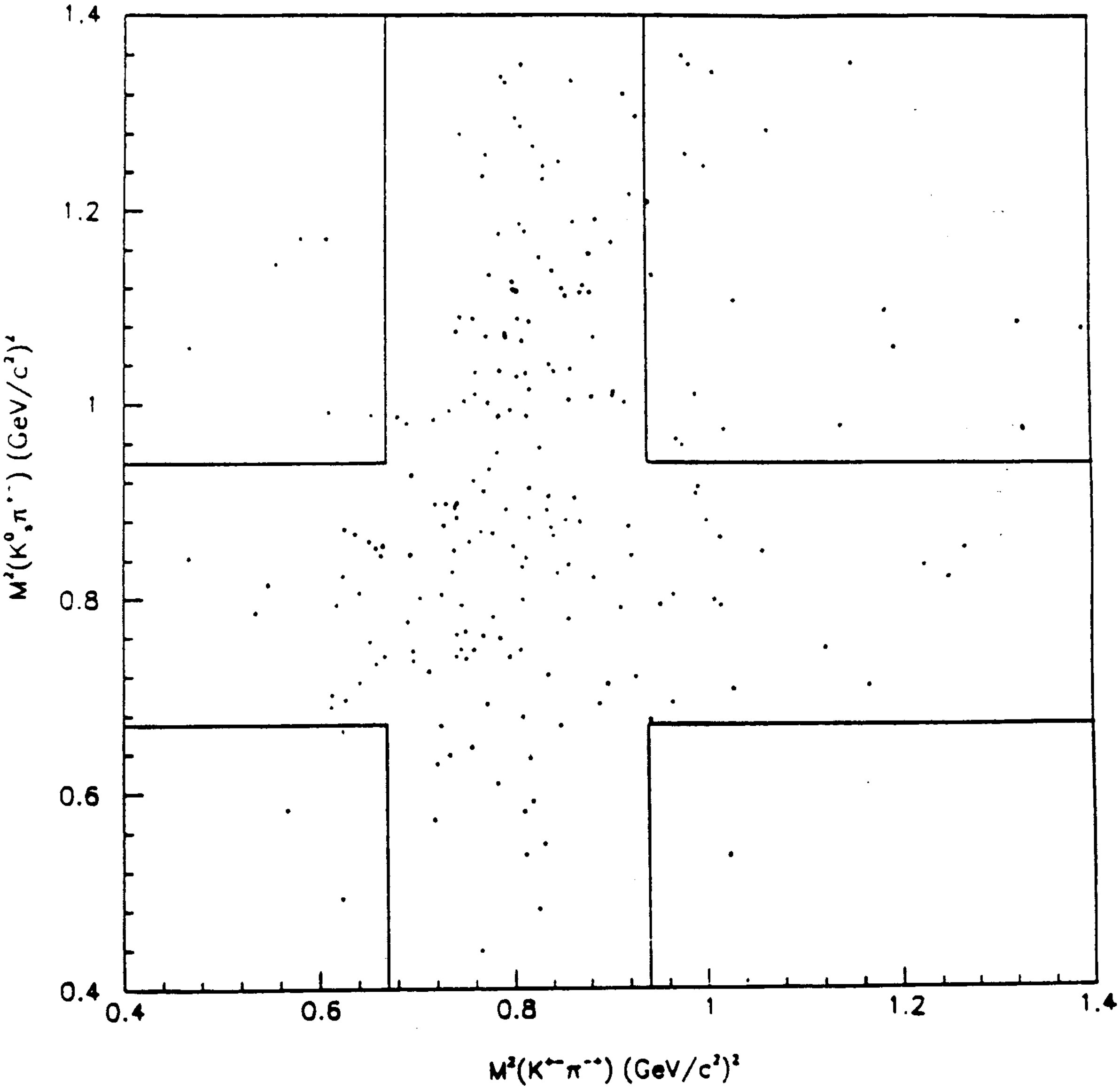


FIG. 9

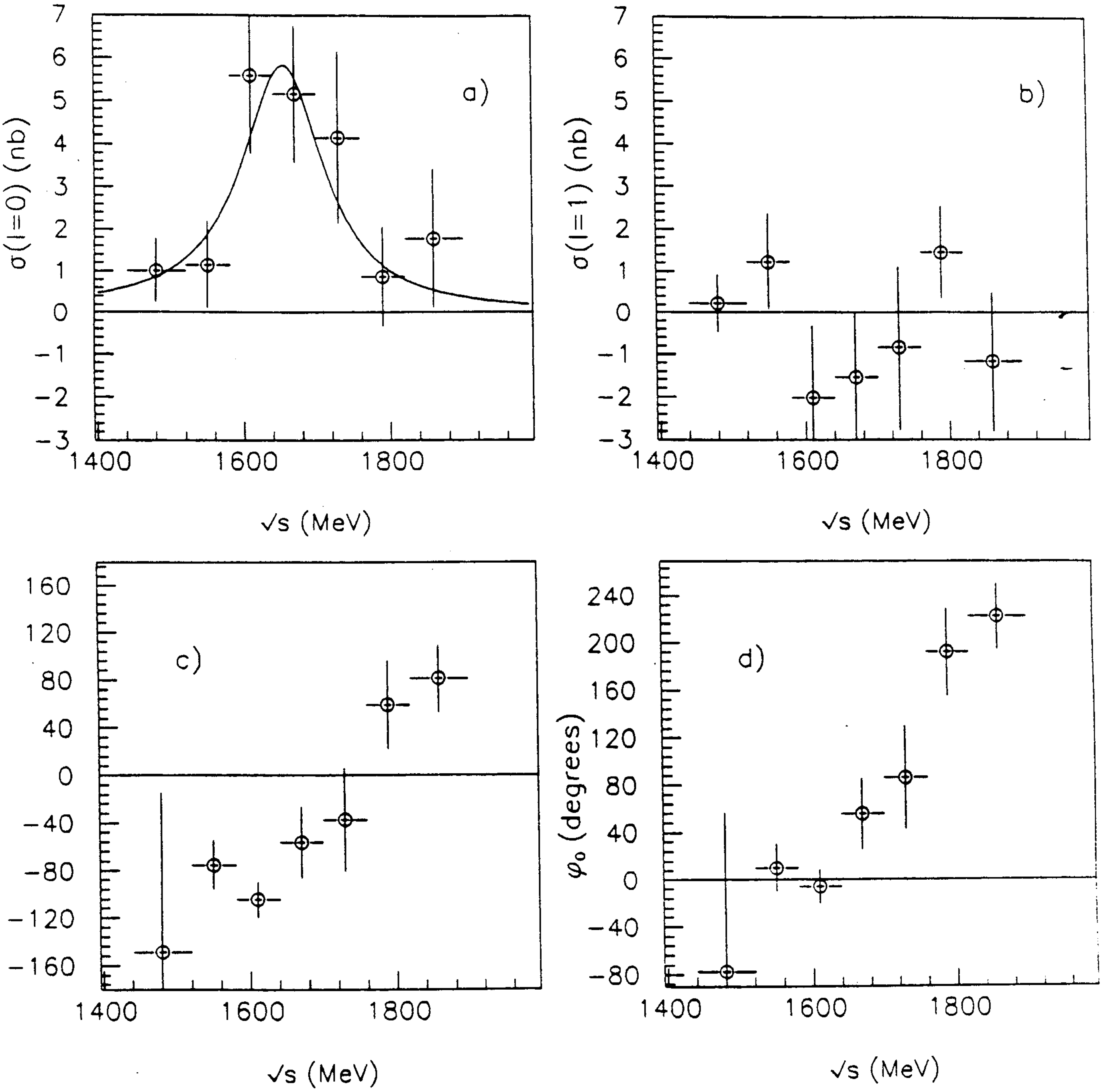


FIG. 10

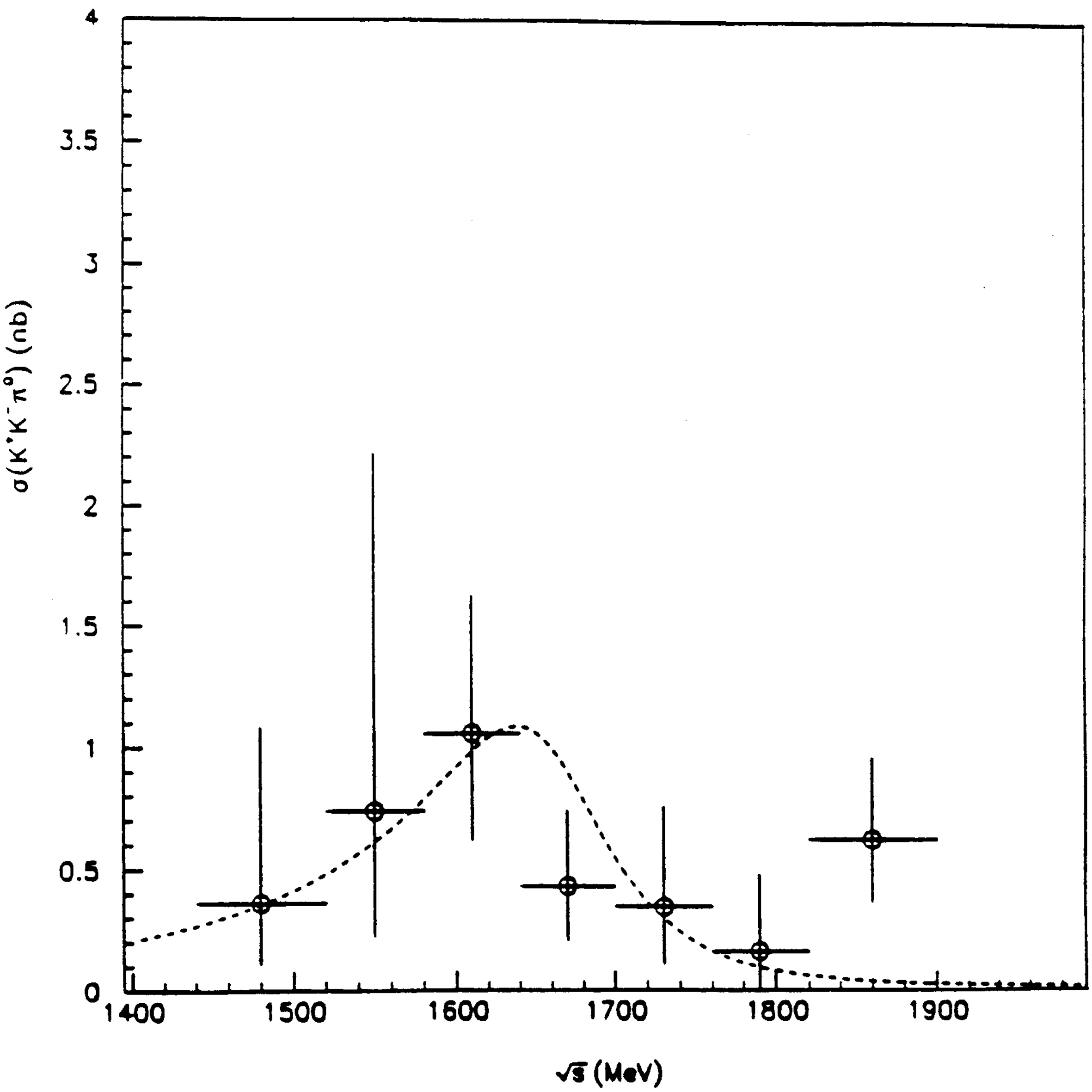


FIG. 11

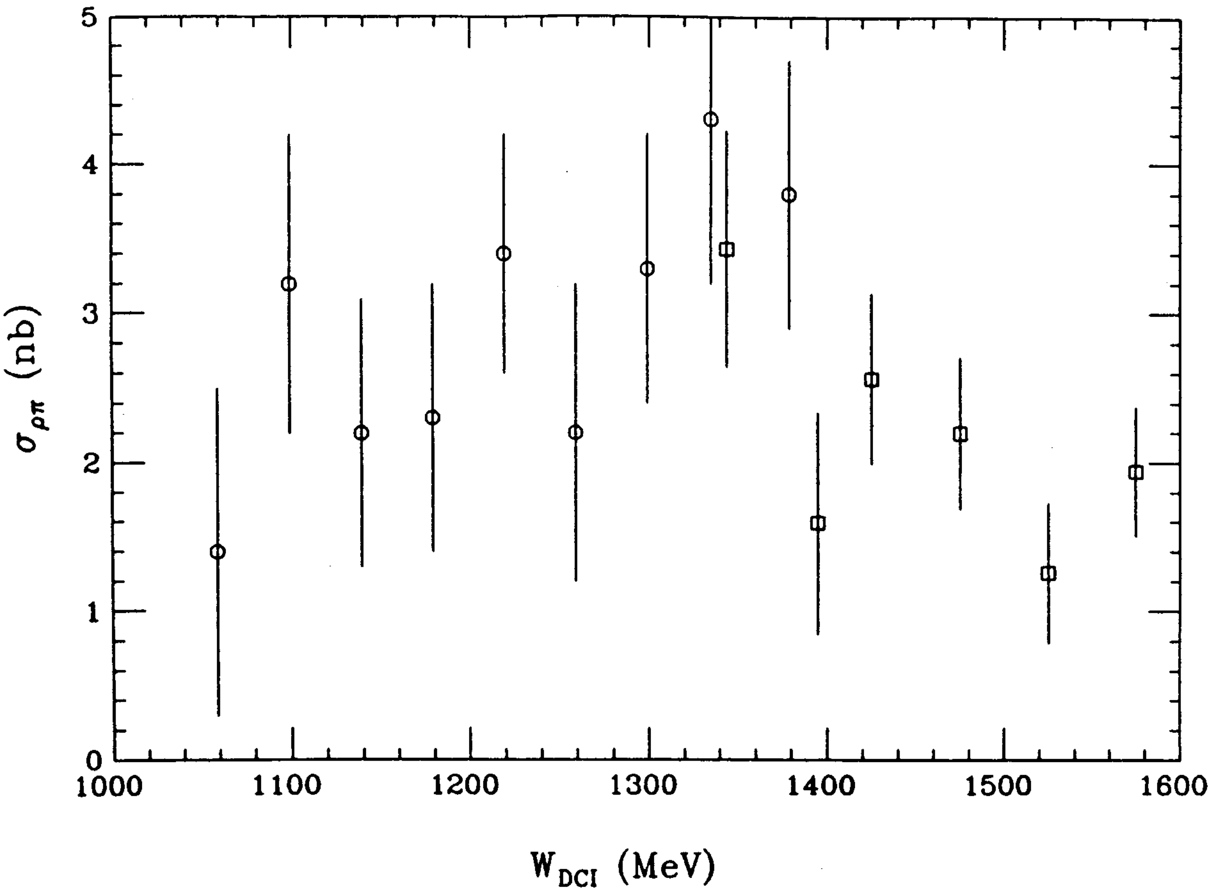


FIG. 12

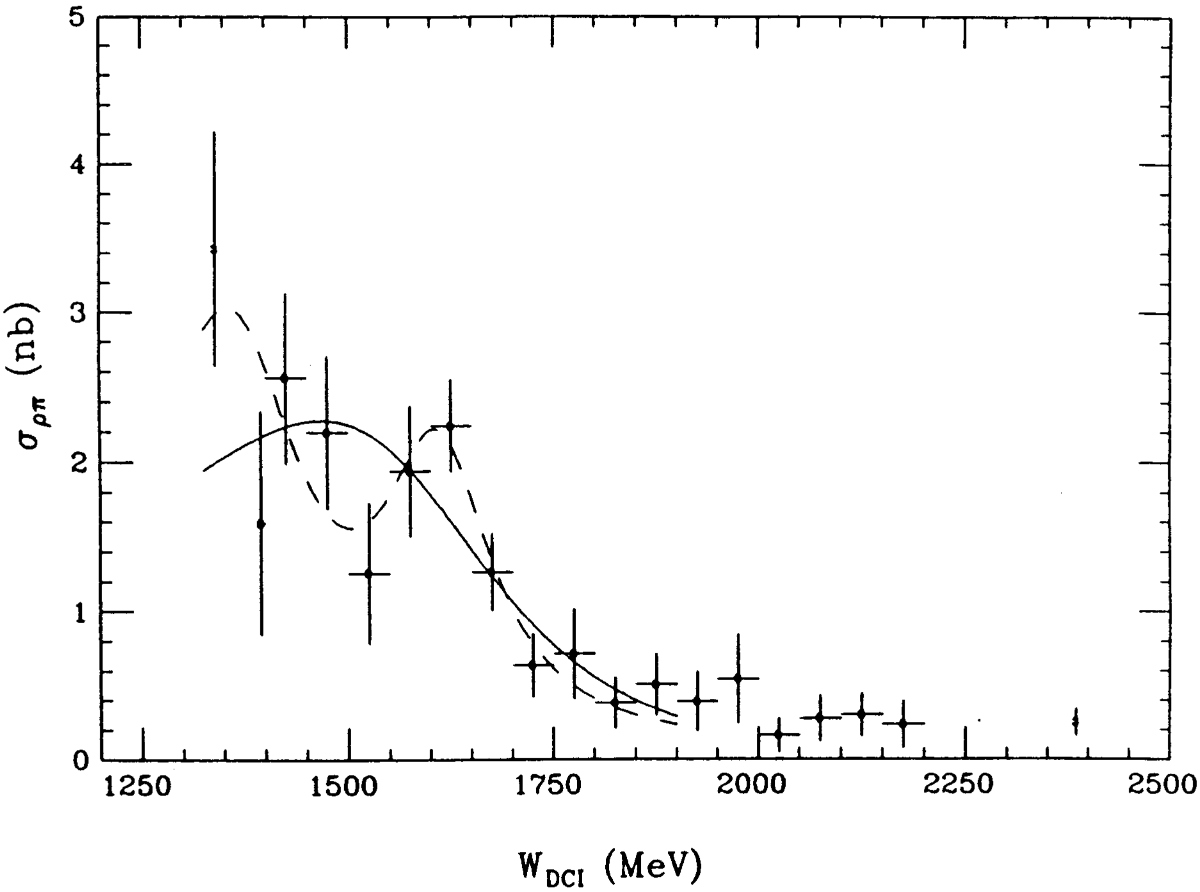


FIG. 13

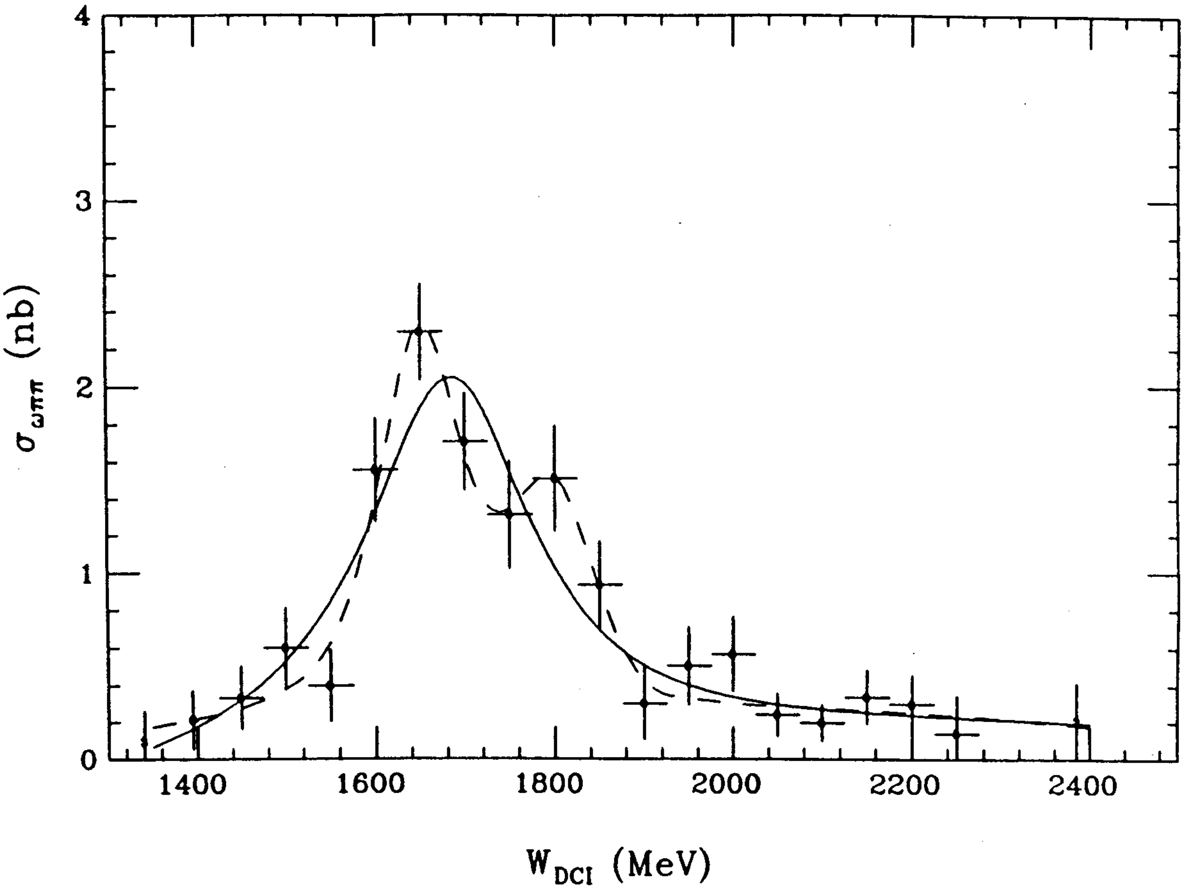

4
3
2
1
0
$\sigma_{\omega\pi\pi}$ (nb)
1400
1600
1800
2000
2200
2400
W_{DCI} (MeV)

FIG. 14

TABLE I

$channel\ [mass/width\ (MeV/c^2)]$	$DM1$	$DM2$
$K\bar{K}$	~ 1670 ~ 100	1655 ± 17 207 ± 45
$K\bar{K}\pi$	1653 ± 18 113 ± 55	1657 ± 27 146 ± 55
$\omega\pi\pi$	1657 ± 13 136 ± 46	$(1BW)$ 1682 ± 12 226 ± 44
$\rho\pi$		$(1BW)$ 1540 ± 35 505 ± 26

TABLE II

	ω'	ω''	ω'''
$m\ (MeV/c^2)$	1439 ± 29	1626 ± 11	1820 ± 19
$\Gamma\ (MeV/c^2)$	180 ± 54	119 ± 20	131 ± 61
$\Gamma_{ee}B_{\rho\pi}\ (eV)$	79 ± 27	71 ± 13	–
$\Gamma_{ee}B_{\omega\pi\pi}\ (eV)$	–	69 ± 12	51 ± 24