A STUDY OF e^+e^- ANNIHILATION INTO HADRONS IN THE 1600-2200 MeV ENERGY RANGE WITH THE MAGNETIC DETECTOR DM1 AT DCI

J.C. Bizot, J. Buon, A. Cordier, B. Delcourt, I. Derado*, P. Eschstruth, L. Fayard, J. Jeanjean, M. Jeanjean, F. Mané, J.C. Parvan, M. Ribes, F. Rumpf, J.L. Bertrand, D. Bisello**.

Laboratoire de l'Accélérateur Linéaire Université de Paris-Sud - 91405 Orsay.

ABSTRACT

We present here the results obtained with the Magnetic Detector DM1 on the Orsay e^+e^- colliding beams (DCI) for $1570 < \sqrt{S} < 2180$ MeV. The total integrated luminosity is 936 nb^{-1} over the whole energy range. Kinematics of annihilation events is determined by momentum measurements on the charged particles with an accuracy $\Delta p/p \simeq 2.5$ % at 500 MeV/c over a solid angle $\Omega = .6 \times 4\pi$ sr. Cross sections are given for e^+e^- annihilation into $p\bar{p}$, into four and five pions : $\pi^+\pi^-\pi^+\pi^-$ including $\rho^+\pi^+\pi^-$, $\pi^+\pi^-\pi^+\pi^-\pi^0$ including $\omega\pi^+\pi^-$, and into strange mesons K^+K^-, $K^0_SK^0_L$, KK^*, $K\bar{K}\pi\pi$ including $K^*K\pi$, inclusive K^0_S. Limits on rare channels like baryonium states, $\phi^0\pi^0$, $\phi^0\eta^0$ are also obtained.

Data taking with the Magnetic Detector DM1 on the DCI colliding beam rings began in April 1978.

The detector [1] consists of four concentric cylindrical multiwire proportional chambers in a uniform magnetic field of .82T and covers a solid angle of $.6 \times 4\pi$ sr. In each chamber are measured both the azimuthal angle (in a plane normal to the beam line) and the longitudinal coordinate (along the beam line) of charged particle impacts with accuracy $r\Delta\phi = .7$ mm and $\Delta z = 2$ mm respectively. The thickness of each chamber is $.7 \times 10^{-3}$ Radiation Length, the vacuum chamber thickness being 12×10^{-3} R.L. The trigger requires that at least two charged particles reach the third chamber (75 MeV/c for the minimum transverse momentum). The system detects charged particles and measures their momentum with an accuracy $\frac{\Delta p}{p} = \frac{p}{500 \text{ MeV/c}} \times 2.5$ %. Twenty five scintillators surrounding the magnet are used to eliminate cosmic ray background by time of flight.

For every event we measure the time difference between the beam collision and the chamber signal. This allows us to make a very accurate estimate of the contamination of two body channels (e^+e^-, $p\bar{p}$, K^+K^-) by unidentified cosmic rays : the jitter of the chambers is 30 ns and the time between collisions is 300 ns.

We have used only the lower of the two DCI rings. The luminosity has been improved during the past year and now reaches 4.8×10^{29} cm^{-2} s^{-1} at 1.8 GeV total energy. Data were taken in energy steps of the same order as the beam dispersion (1 to 2 MeV total energy). The results are combined in wider intervals to get enough statistics. The energy intervals chosen are indicated by horizontal bars in the figures. The total analysed luminosity is 936 nb^{-1} over the energy regions 1570-1840, 1925-2060 and 2110-2180 MeV.

---

*) Present address : Max Planck Institut für Physik. D8 München 40, Germany.

**) On leave from Istituto di Fisica, ISN Sectione di Padova, Italy.

Selection of channels

Charged two body events (e^+e^-, K^+K^-, $p\bar{p}$) are selected by cuts on the angle ζ between the two tracks, the difference Δp between the two momenta, and the average value p_A of the two momenta. Typical cuts are $|\zeta - 180°| < 5°$ to $10°$, $\Delta P/p_A < 7$ to 15 % and p_A equal to the predicted value within 7 to 10 %.

Charged four body events ($\pi^+\pi^-\pi^+\pi^-$, $K^o_S(\to\pi^+\pi^-)\ K^\pm\pi^\mp$, $K^+K^-\pi^+\pi^-$) are selected in three or four visible tracks. In the case of four visible tracks, cuts are applied on total momentum and reconstructed energy assuming the nature of the particles. For three visible tracks (not yet used for $K^+K^-\pi^+\pi^-$) cuts are applied on reconstructed energy with the momentum of the unseen particle set equal to the missing momentum.

For $\pi^+\pi^-\pi^+\pi^-\pi^o$, special care must be taken to avoid contamination by radiative four charged pion events. So we require a minimum missing momentum (12 % of the energy of one beam) and a minimum angle between the missing momentum and the beam line (10°).

K^o_S are identified by their decay into $\pi^+\pi^-$. In order to suppress background from pion events, a minimum distance of 6 mm from the decay vertex to the beam line is required, cuts are also applied to the angle between the two pions, and to the direction of their total momentum. The background below the K^o_S mass is estimated from side bins and subtracted.

Luminosity measurement

The on-line measurement is done with small angle Bhabha scattering$^{2)}$. The final determination is achieved using large angle Bhabha scattering. The e^+e^- are contaminated by unidentified cosmic rays (3 % very accurately known), $\mu^+\mu^-$ (8 % estimated by QED) and $\pi^+\pi^-$ (giving a 1 % systematic error). The two determinations agree with each other within 10 %. To the statistical error on the luminosity measurement (100 Bhabha events/nb^{-1}) we add a 10 % systematic error for possible uncontrolled variations of detection efficiency.

Efficiency determination

For each channel the efficiency has been determined by a Monte Carlo method taking into account the efficiency of detection of the MWPC and the production dynamics. As the detector does not cover a 4π solid angle, the efficiency may depend on the dynamics. We give the results for what we think the likeliest dynamics and include as systematic errors the differences with other possible dynamics. Radiative corrections of the bremsstrahlung type have been included in the Monte Carlo calculation. This has been done in the peaking approximation, using the formulas of Bonneau and Martin$^{3)}$.

RESULTS

$p\bar{p}$ cross section

Events selection for this channel could not be done for the whole solid angle as the cosmic-ray veto-system is not sufficiently efficient : cosmic ray muons having the same momentum inside the apparatus as $p\bar{p}$ are stopped by the magnet coil or iron. We have used only the azimuthal range $-70° < \phi_p < 160°$ where cosmic-rays are scarce or enter the system through the scintillator in the direction of what we think to be the proton : a real proton

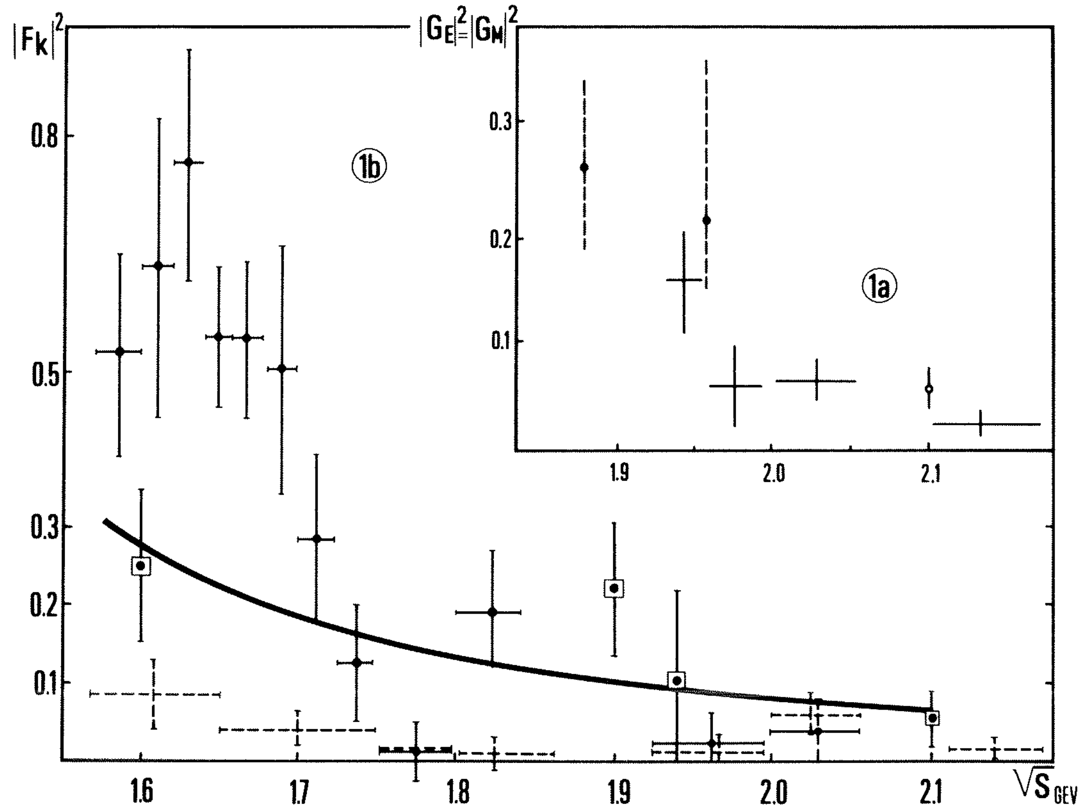

Figure 1 : Two body form factors
a - $p\bar{p}$ assuming $|G_E|^2 = |G_M|^2$
ϕ ref.5) ⧫ ref.4) + this experiment
b - K^+K^- and $K^0_S K^0_L$
K^+K^- = ⊡ ref.8) ✦ this experiment - Full line theory ref.7)
$K^0_S K^0_L$ = -+- this experiment

cannot reach this scintillator at these energies. The signal obtained in the p_A distribution with the above cuts is quite clean. Assuming identical electric and magnetic form factors, the overall detection efficiency is ≃ 17 %. With the same assumption, fig. 1.a shows the squared form factor versus energy. Results of Castellano and al[4]) and Bassompierre and al[5]) are also shown.

The question arises whether one of the previously reported[6]) baryonium states at 1935 and 2020 MeV could be a 1^{--} resonant state decaying into e^+e^-. Our results give the following limits on $\Gamma_{e^+e^-} B_{p\bar{p}}$ for these two states within 95 % confidence level.

$m = 1935$ MeV $\Gamma = 9$ MeV $\Gamma_{e^+e^-} B_{p\bar{p}} < 1 \times 10^{-5}$ MeV

$m = 2020$ MeV $\Gamma = 24$ MeV $\Gamma_{e^+e^-} B_{p\bar{p}} < 2.5 \times 10^{-5}$ MeV

K^+K^- and $K_S^\circ K_L^\circ$ cross section

The K^+K^- signal is clearly seen for $\sqrt{S} < 1700$. The efficiency is well known as there is only one form factor. It is equal to 27 %. For the K_S° channel we require a clearly recognized K_S° and a missing mass consistent with a K_L°. The signal is clear but weak. The efficiency amounts to 14 %. The form factors of K^+K^- and $K_S^\circ K_L^\circ$ are given in fig. 1.b. We see that the $K_S^\circ K_L^\circ$ form factor is 10 times less than the K^+K^- for $\sqrt{S} < 1700$ MeV indicating that $K\bar{K}$ is mainly produced by a pure SU3 photon. Fig. 1.b also gives the prediction obtained by Renard⁷⁾ using only ρ, ω and ϕ contribution, and the results of Bernardini and al⁸⁾.

$\pi^+\pi^-\pi^+\pi^-$ production

This channel has a rather large cross section in this energy range. Its dynamics are dominated by $\rho^\circ\pi^+\pi^-$ production but no clear structure is found either in the $\rho^\circ\pi^\pm$ invariant

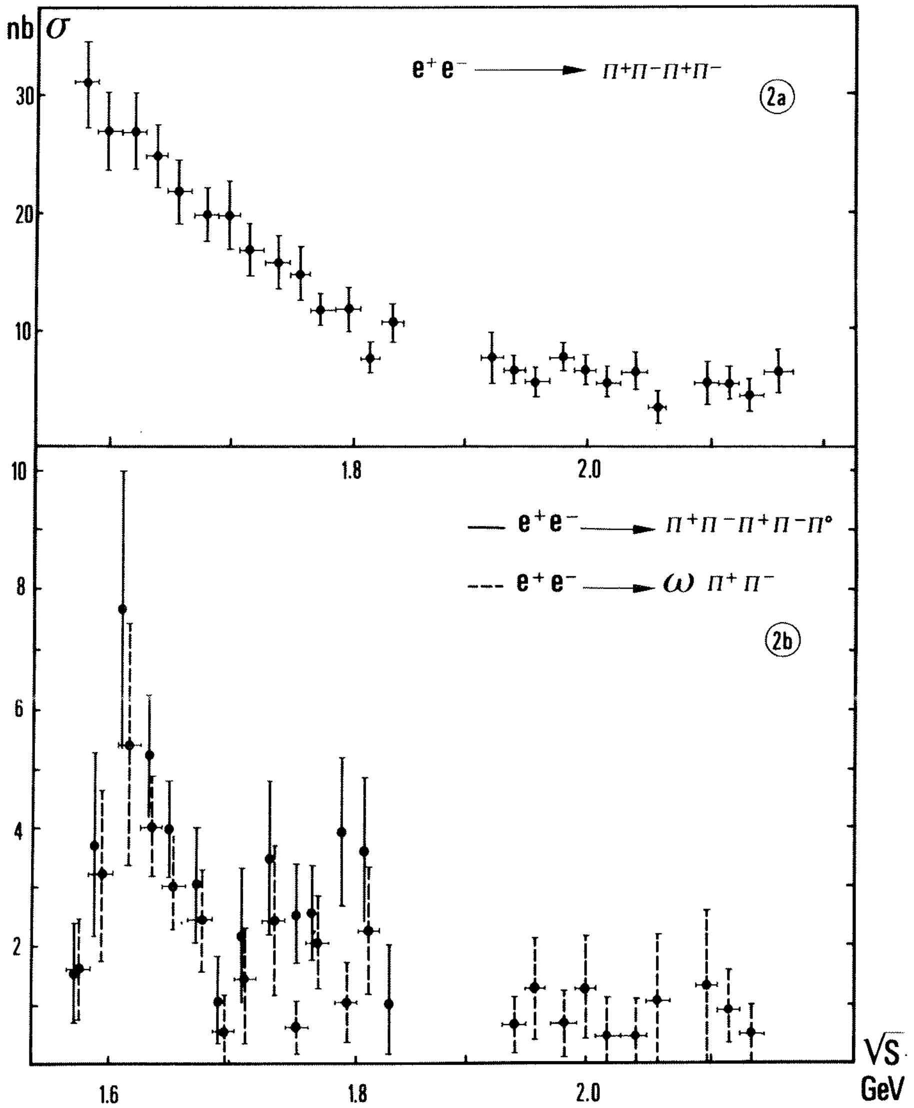

Figure 2 : Multipion cross sections
a - $\pi^+\pi^-\pi^+\pi^-$ b - $\pi^+\pi^-\pi^+\pi^-\pi^\circ$

mass distribution or in the $\pi^+\pi^-$ mass recoiling in front of the ρ. The efficiency depends on the production dynamics but is roughly the same for any simple dynamics as long as there is a ρ production : at 1800 MeV we get 42.2 % for pure phase space production and, for the following ρ production dynamics : 48.5 % for π A_1 ($m = 1100$, $\Gamma = 300$), 49.6 % for ρ plus a $\pi^+\pi^-$ pair in s wave, 51.0 % for $\rho\varepsilon$ ($m = 1200$, $\Gamma = 600$). So we have used at each energy the $\rho\pi\pi$ efficiency for computing the cross section (fig. 2.a). In the quoted error are combined quadratically statistical errors and an error of 10 % for possible variations of detection efficiency. To these errors we must add a 12 % systematic error for the dynamics and the luminosity determination.

The cross section agrees with the high energy part of previously reported ρ' [9].

$\pi^+\pi^-\pi^+\pi^-\pi^\circ$ production

In order to avoid contamination by $\pi^+\pi^-\pi^+\pi^-$, the events are selected from a region of the missing momentum-missing mass scatter-plot where this contamination is sufficiently weak. We have not yet completely analysed the remaining contamination and the cross section we give may be overestimated. However in the 1570-1700 MeV energy range, about 70 % of the selected events are seen to come from $\omega^\circ\pi^+\pi^-$ production. We are then able to determine correctly $\omega^\circ\pi^+\pi^-$ cross section. The efficiency depends only slightly on the production dynamics : 10.7 % for $\omega\pi^+\pi^-$ in phase space and 9.9 % for $\pi^+\pi^-\pi^+\pi^-\pi^\circ$ in phase space at 1650 MeV total energy. The results given fig. 2.b are not corrected for radiative effects and must be considered as preliminary.

$K^+K^-\pi^+\pi^-$ production

The $K^+K^-\pi^+\pi^-$ events are well separated on the scatter-plot : they have a zero total momentum and an apparent energy close to $\lambda\sqrt{S}$, assigning four pions masses ; λ varies with energy : .65 for $\sqrt{S} \simeq 1600$ MeV to .8 for $\simeq 2150$ MeV. Although the particles are not individually identified, we are able to study the production dynamics : we choose from the 4 possibilities the mass assignement giving the best value for the reconstructed energy. The production is dominated by $K^{*\circ}$ $K\pi$. No evident ρ structure appears in the high energy part (> 1925 MeV) of the data.

There is no evident structure either in three body mass spectra including the $K^{*\circ}$ or the $K^\pm$ $\pi^\mp$ recoiling in front of $K^{*\circ}$. In particular $K^{*\circ}\bar{K}^{*\circ}$ production if any is weak. Again the efficiency depends on dynamics (8.9 % for pure phase space and 12.5 % for $K^{*\circ}$ with opposite $K\pi$ in s wave at 2130 MeV) but is roughly the same for all simple dynamics producing $K^{*\circ}$. So we take this value for computing the cross section given in fig. 3.a.

Inclusive K°_S production

The efficiency for detecting a K°_S decaying into $\pi^+\pi^-$ is slightly momentum dependent and is evaluated by a Monte-Carlo technique. The production angular distribution is assumed to be isotropic. In the low energy part ($\sqrt{S} < 1800$ MeV), where the KK^* production is dominant, this assumption introduces at most 10 % systematic error. The detection efficiency is essentially zero below 120 MeV/c. This loss at low momentum is estimated from an extrapolation of the momentum spectrum to zero momentum. The correction amounts to 5 %. The data are

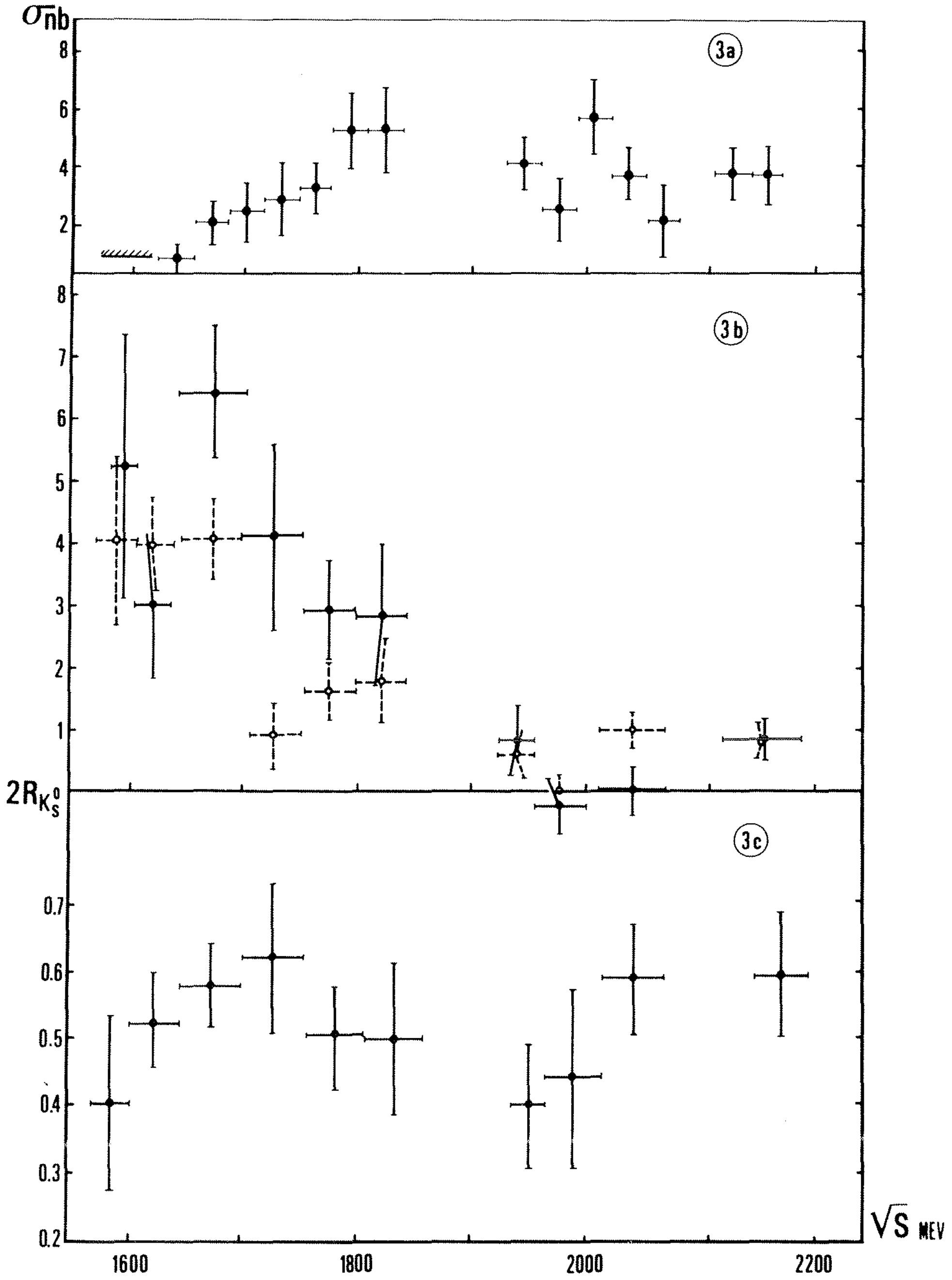

Figure 3 : Strange meson cross sections

a - $K^+K^-\pi^+\pi^-$ b - $K^0_SK^\pm\pi^\mp$: -+- and

$K^0_SK^{*0}$ + c - $R_{K^0} = 2\ \sigma_{K^0_S}/\sigma_{\mu\mu}$

corrected for the unobserved decay mode $K^0_S \to \pi^0\pi^0$.

In fig. 3.c the neutral kaon production is compared to muon pair production. Assuming an equal number of K_S and K_L, the ratio $R_{K^0} = 2\sigma_{K^0_S}/\sigma_{\mu\mu}$ is given between 1570 and 2180 MeV. In this energy region R_{K^0} stays almost constant. Its value, about .5, is somewhat higher than .33 as expected from the direct production of a $s\bar{s}$ pair by a photon.

$K^o_S K^\pm \pi^\mp$ production

This channel is selected from events with 3 or 4 visible tracks, two of them compatible with a decay $K^o_S \rightarrow \pi^+\pi^-$. No cut on the flight distance of the K^o_S is necessary for the four prong events, as the contamination by other channels is small. We also require one of the two possibilities, assigning a K and a π to the two remaining tracks (one missing at most), to be equal to centre of mass energy within 2.5 %.

The kinematics of the observed events is consistent with a dominant K^*K production.

We select also the $K^o_S K^{*o}$ channel by requiring only a clearly recognized K^o_S and a missing mass consistent with a K^{*o}.

Fig. 3.b shows the measured cross sections of $K^o_S K^\pm \pi^\mp$ and $K^o_S K^{*o}$. They are only important in the low energy region ($\sqrt{S} < 1800$ MeV).

From these preliminary data, the $K^o K^{*o}$ production seems to be more important than the $K^\pm K^{*\mp}$ as is expected if KK^* is produced by a pure SU3 photon.

Upper limits on ϕ production

We have examined the K^+K^- pair at the ϕ invariant mass in $K^+K^-\pi^+\pi^-$ events and get the upper limit for $\sqrt{S} > 1775$ MeV :

$$\sigma(\phi\pi^+\pi^-) < .5 \text{ nb} \qquad (90\ \%\ \text{C.L.})$$

We have also looked for $\phi\pi^o$ and $\phi\eta^o$ in all two prong events with two not aligned tracks : we assume that the two particles are K^+ and K^- and take the phase space for which the two kaons form a ϕ and the missing mass is consistent with a π^o or a η^o . We find for $\sqrt{S} > 1700$ MeV :

$$\sigma(\phi\pi^o) < 2 \text{ nb} \qquad (90\ \%\ \text{C.L.})$$

$$\sigma(\phi\eta^o) < 2 \text{ nb} \qquad (90\ \%\ \text{C.L.})$$

* * *

REFERENCES

1) J. Jeanjean and al., Nucl. Instr. and Meth. 117, 349 (1974).
A. Cordier and al., Nucl. Instr. and Meth. 133, 237 (1976).

2) J.E. Augustin, Internal Report DCI 12-74.

3) G. Bonneau and F. Martin, Nucl. Phys. B27, 381 (1971).

4) M. Castellano and al., Nuovo Cimento 14A, 1 (1973).

5) G. Bassompierre and al., Phys. Lett. 68B, 477 (1977).

6) A.S. Caroll and al.,Phys. Rev. Lett. 32, 247 (1974), V. Chaloupka and al., Phys. Lett. 61B, 487 (1976), W. Bruckner and al.,Phys. Lett. 67B, 222(1977), P. Benkheiri and al., Phys. Lett. 68B, 483 (1977).

7) F.M. Renard, Nucl. Phys. B82, 1 (1974).

8) M. Bernardini et al., Phys. Lett. 46B, 261 (1973).

9) See for example G.J. Feldman in Proceedings of Tokyo Conference (1978) p. 777.