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Evidence for the F Meson

DASP Collaboration

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Abstract: Inclusive η production by e^+e^- annihilation for cm energies between 4 and 5.2 GeV was studied. A strong η signal was observed at 4.4 GeV, produced predominantly in conjunction with a low energy photon suggestive of $F\bar{F}^*$ or $F^*\bar{F}^*$ production. From events containing a $\pi^\pm$, and η, and a low energy photon the F and F^* masses were found to be 2.03 ± 0.06 and 2.14 ± 0.06 GeV, respectively.

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I. Introduction

The charm model [1)] has been quite successful in describing the properties of the new mesons, viz. the ψ's (charm = 0), and the D's (charm = 1). The model also requires the existence of charmed baryons, and there is evidence that these also exist [2)]. Furthermore, the model predicts the existence of mesons having both charm and strangeness, called F's, consisting of a $c\bar{s}$ quark pair [3)]. While the D's have been identified by invariant mass [4)] and semileptonic decays [5)], the F's have so far escaped detection. The lowest mass member of this set should have a weak decay predominantly into an $s\bar{s}$ system leading to final states containing $K\bar{K}$, ϕ, η, or η'. The first excited state, F^*, is predicted to be so close to the F that $F^* \to \gamma F$ is the favored decay channel since both F and F^* are isosinglets. The energy of the photon is expected to be ~ 0.1 GeV.

Experience has shown that in e^+e^- annihilation near the D^* threshold at 4.028 GeV the production of $D\bar{D}^*$ and $D^*\bar{D}^*$ is copious [4)]. Analogously one should expect production of $F\bar{F}^*$ and $F^*\bar{F}^*$ to be enhanced near the F^* threshold. Thus a technique to find the F is to measure η production in conjunction with a low energy photon. Since the simplest decay channel is $\eta \to \gamma\gamma$, we seek events having at least three photons. Because η is a frequent byproduct of η' decay a search for η includes a search for η'.

II. Data

Data were collected at the e^+e^- storage ring DORIS for cm energies between 3.99 and 5.2 GeV using the DASP detector. For the purpose of analysis the data have been grouped into five regions,
3.99 to 4.04 = "4.0" GeV (831 nb^{-1}), 4.04 to 4.32 = "4.15" GeV (894 nb^{-1}),
4.32 to 4.44 = "4.4" GeV (654 nb^{-1}), 4.44 to 4.90 = "4.5" GeV (1200 nb^{-1}),
and 4.90 to 5.20 = "5.1" GeV (2073 nb^{-1}). The numbers in quotes are the average energies and the numbers in parentheses are the integrated luminosities for each data set. The DASP detector has been discussed elsewhere [6)]; for the purpose of this paper we mainly used the "inner detector", consisting of proportional chambers, proportional tubes, and lead-scintillator sandwich counters, which measure the direction of charged particles, as well as the conversion point and the energy of photons. The detection efficiency for photons was 50% at 0.05 GeV rising to 80% at 0.1 GeV and 95% above 0.3 GeV, excluding geometrical acceptance. The measured energy resolution of the shower counters is

$\sigma(E) = 0.14\sqrt{E}$ in GeV for $E > 0.05$ GeV. The angular resolution for photons in both the polar and azimuthal angles is ~ 0.03 radians. The resulting rms invariant mass resolution is varying between 0.05 and 0.1 GeV in the region of the π^0, and is 0.08 GeV in the region of the η.

Events accepted were required to have at least two charged tracks coming from the interaction region and at least two photons with energies exceeding 0.10 GeV. All such photons are candidates used to reconstruct the invariant mass $m_{\gamma\gamma}$. The vector sum of the momenta of these two photons was required to be between 0.3 and 1.2 GeV/c. Events having more than six photons were not used. For the purpose of reducing background we have also required that at least 0.1 GeV be deposited in both the forward and backward hemispheres with respect to the e^+ direction. Events containing a photon of less than 0.14 GeV (γ_{low}) in addition to the two used for forming $m_{\gamma\gamma}$ are called low energy photon events.

III. Results

We shall show that there is evidence for production of η's only in the region of 4.4 GeV by two different methods, and that this η production occurs predominantly in conjunction with a low energy photon. We shall show that four events result from $F^{\pm} \to \eta\pi^{\pm}$, from which an F mass may be deduced.

Figures 1a – e show the $m_{\gamma\gamma}$ distribution for low energy photon events for the five energy intervals. The solid line represents a smoothed *) estimate of the background, obtained by forming the invariant mass of photons from different events having the same number of photons. The background spectrum is normalized to the data by requiring all combinations having $m_{\gamma\gamma} > 0.70$ GeV to be ascribed to background. Using this background estimate one sees a π^0 peak at all energies and an η signal at $E_{cm} = 4.4$ GeV. The width of the η peak is consistent with expected resolution. At $E_{cm} = 4.4$ GeV the η plus low energy photon signal inside $0.45 \leq m_{\gamma\gamma} < 0.65$ GeV is 60 ± 14 events. This corresponds

* The nonlinear, robust smoothing operator is known technically as (353 QH) twice, which has been shown to be quite successful; c.f. reference 7.

to a visible cross section of 0.24 ± 0.06 nb, corrected for the branching ratio $\eta \to \gamma\gamma$, but not for acceptance.

Although the background estimate explicitly ignores any correlations within an event, it does reproduce the data fairly well. As a check on the background reliability we have compared the background spectra at the five energies. In general they are similar.

As a further test with improved $m_{\gamma\gamma}$ resolution we made an additional requirement that detected photons used in forming $m_{\gamma\gamma}$ be well separated spatially from any other particles so that sharing of energy is excluded. The shaded area in Fig. 1 shows the result of this requirement. This cut reduces the η yield but the signal to noise ratio is improved.

Figures 2a – e show the ratio of the number of combinations accompanied by a low energy photon to the number of combinations without a low energy photon as a function of $m_{\gamma\gamma}$. There is a clear peak at the η mass for $E_{cm} = 4.4$ GeV, indicating that η production is correlated with a low energy photon. A second estimate of the η plus low energy photon yield can be obtained if we assume that events not having a low energy photon are a measure of the background. This background is scaled to match the spectrum from events with a low energy photon in the mass region outside the η, $0.25 \leq m_{\gamma\gamma} < 0.45$ and $0.65 \leq m_{\gamma\gamma} < 1.05$ GeV. After a subtraction, 53 ± 15 events remain in the η region $0.45 \leq m_{\gamma\gamma} < 0.65$ GeV. However, the scaled "background" contains some events where a low energy photon went undetected, since the detection efficiency for such a photon is only about 40%. Correcting the subtracted background to account for this mistaken assignment of genuine events to background, we find 71 ± 17 observed events in the 4.4 GeV data containing a low energy photon plus an η. No significant signal is seen at the other energies. From the 71 events we obtain a visible cross section of 0.29 ± 0.07 nb. The agreement of this estimate and the previous one means that the two background estimates are similar and furthermore that there is little η production without low energy photons.

Figure 3 shows the visible η plus low energy photon cross section as a function of E_{cm} for the two methods described. Method 1 uses the pairing of photons from neighboring events to calculate the background estimate. The vanishing of the cross section away from 4.4 GeV indicates that the background calculations are consistent. At 4.4 GeV the visible cross is ∿ 0.25 nb above a base line. The agreement of the two methods at 4.4 GeV indicates that η production occurs predominantly with a low energy photon. A rough estimate of the detection efficiency for η plus low energy photon events indicates that the true cross section is on the order of a few nanobarns. Thus η production accounts for a substantial fraction of the increase of the total e^+e^- cross section at 4.4 GeV [8].

The occurence of η production in association with low energy photons at 4.4 GeV strongly suggests the presence of F meson production via $F\bar{F}^*$ and/or $F^*\bar{F}^*$. We searched for the two body decay of the $F^\pm$ into $\eta\,\pi^\pm$ detecting the pion in one of the spectrometer arms. The events had to fulfill the following selection criteria: There was an identified charged pion with momentum above 0.6 GeV/c coming from the interaction region. (The momentum resolution was $\sigma(p)/p = 0.02 \cdot p$ (GeV/c)). There were at least two photons with energies above 0.1 GeV forming a $\gamma\gamma$ mass combination in the η mass region. One of the photons forming $m_{\gamma\gamma}$ had to be detected in the inner detector while the other one could either be in the inner detector or in one of the spectrometer arms. In the latter case the photon energy determination was less precise, $\sigma(E) = 0.3\sqrt{E(\text{GeV})}$. Consequently, the η mass region was chosen wider in the latter case: $0.45 \leq m_{\gamma\gamma} < 0.65$ GeV if both photons were detected in the inner detector; $0.3 \leq m_{\gamma\gamma} < 0.8$ GeV if one photon was in a spectrometer arm. Finally there had to be at least one more photon with an energy below 0.2 GeV (γ_{low}).

A total of 19 events satisfied these selection criteria; of these, three events had two $m_{\gamma\gamma}$ combinations in the η region and three had two low energy photons. The events were fitted to the reactions

$$e^+e^- \rightarrow F^\pm\, F\, \gamma_{low}, \quad F^\pm \rightarrow \pi^\pm\, \eta, \quad \eta \rightarrow \gamma\gamma \qquad (1)$$

and

$$e^+e^- \rightarrow F^{\pm *} F^*, \quad F^{\pm *} \rightarrow \gamma_{low}\, F^\pm, \quad F^\pm \rightarrow \pi^\pm\, \eta, \quad \eta \rightarrow \gamma\gamma \qquad (2)$$

These are 2C fits because of the mass constraint on $m_{\gamma\gamma}$ and the requirement that for (1) $\pi\eta$ and the missing vector must have the same mass m_F; for (2) the γ_{low} system and the missing vector must have the same mass m_{F^*}.

There were six events which gave a fit to hypothesis (1) with a $\chi^2 < 10$. No events were found with $10 \leq \chi^2 < 20$. Fig. 4 shows a scatter plot of the fitted $\pi\eta$ mass versus the mass of recoil system. There are four events which give the same ($m_{\pi\eta}$, m_{recoil}) mass values within errors: $m_{\pi\eta} = 2.04$ GeV, $m_{recoil} = 2.17$ GeV. The rms errors are typically 0.03 to 0.04 GeV. From the absence of events near this cluster we estimate the background amongst the four events to be negligible. We attribute these events to production of F and F^*.

The six events, and only those also gave an acceptable fit ($\chi^2 < 10$) to the $F^*\bar{F}^*$ hypothesis (2). The resulting F and F^* mass values are slightly lower than those from the $F\bar{F}^*$ fit: $m_F = 2.01$ GeV, $m_{F^*} = 2.11$ GeV.

Allowing for possible systematic uncertainties our best estimates are
$m_F = 2.03 \pm 0.06$ GeV and $m_{F^*} = 2.14 \pm 0.06$ GeV .

The mass difference between F^* and F can be directly determined from the energy of γ_{low} for the four events. The result is $m_{F^*} - m_F = 0.12 \pm 0.04$ GeV.

CONCLUSIONS

In the center of mass energy range 4.0 to 5.2 GeV we find a significant production of η with a low energy photon only near 4.4 GeV. The η production is predominantly accompanied by a low energy photon. The total η production cross section is a substantial fraction of the $\psi(4413)$ cross section, indicating that $F\bar{F}^*$ or $F^*\bar{F}^*$ may be major decay modes.

Analysing events containing η, π and a low energy photon in the final state and fitting these events to either $e^+e^- \to F\bar{F}^*$ or $F^*\bar{F}^*$ we find four events which give the same F and F^* mass values, $m_F = 2.03 \pm 0.06$ GeV and $m_{F^*} = 2.14 \pm 0.06$ GeV. From the energy distribution of the low energy photon alone we find $m_{F^*} - m_F = 0.12 \pm 0.04$ GeV.

We would like to thank the engineers and technicians from DESY and the collaborating institutions who have made this experiment possible by building, operating and maintaining DESY, DORIS, DASP and the computer center. The non-DESY members of the collaboration thank the DESY directorate for their hospitality.

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Figure Captions

Figure 1 Distribution of $m_{\gamma\gamma}$ for events having a low energy photon (< 0.14 GeV). Each acceptable pair is plotted. The solid lines are estimates of uncorrelated photon background. The shaded area shows the result of especially stringent photon selection criteria; see text.

Figure 2 Ratio of the number of combinations for events having a low energy photon to the number of combinations for events not having a low energy photon as a function of $m_{\gamma\gamma}$.

Figure 3 Visible cross section, i.e. not corrected for acceptance, for production of η plus a low energy photon as a function of E_{cm} calculated by two methods (see text).
ϕ = method 1; X = method 2.

Figure 4 Fitted $\eta\pi$ mass vs. recoil mass assuming $e^+e^- \to F\,F^*$, where $F^* \to \gamma F$ and $F \to \eta\pi$.

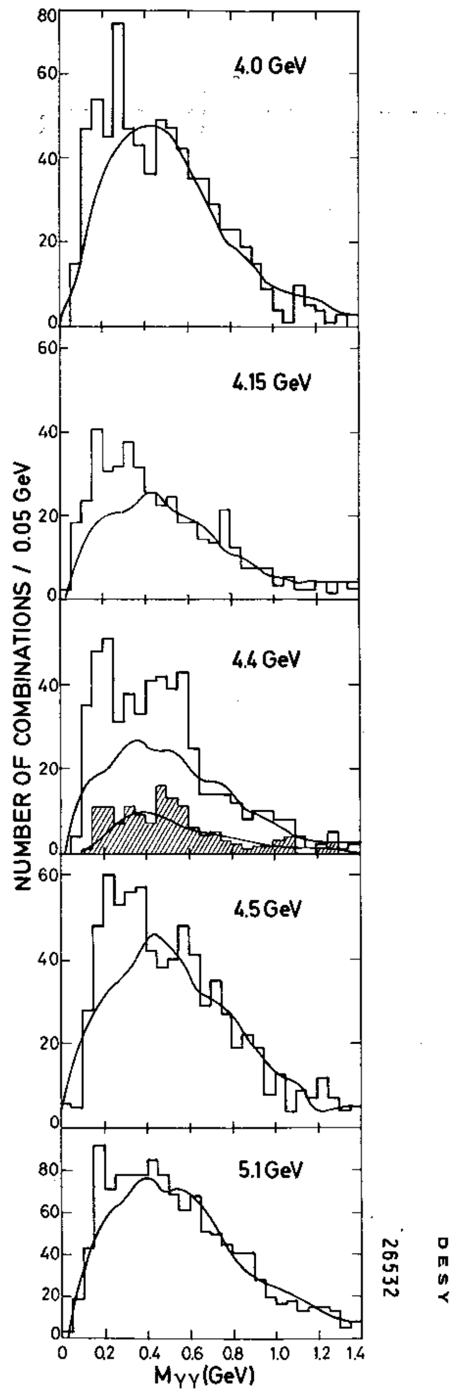
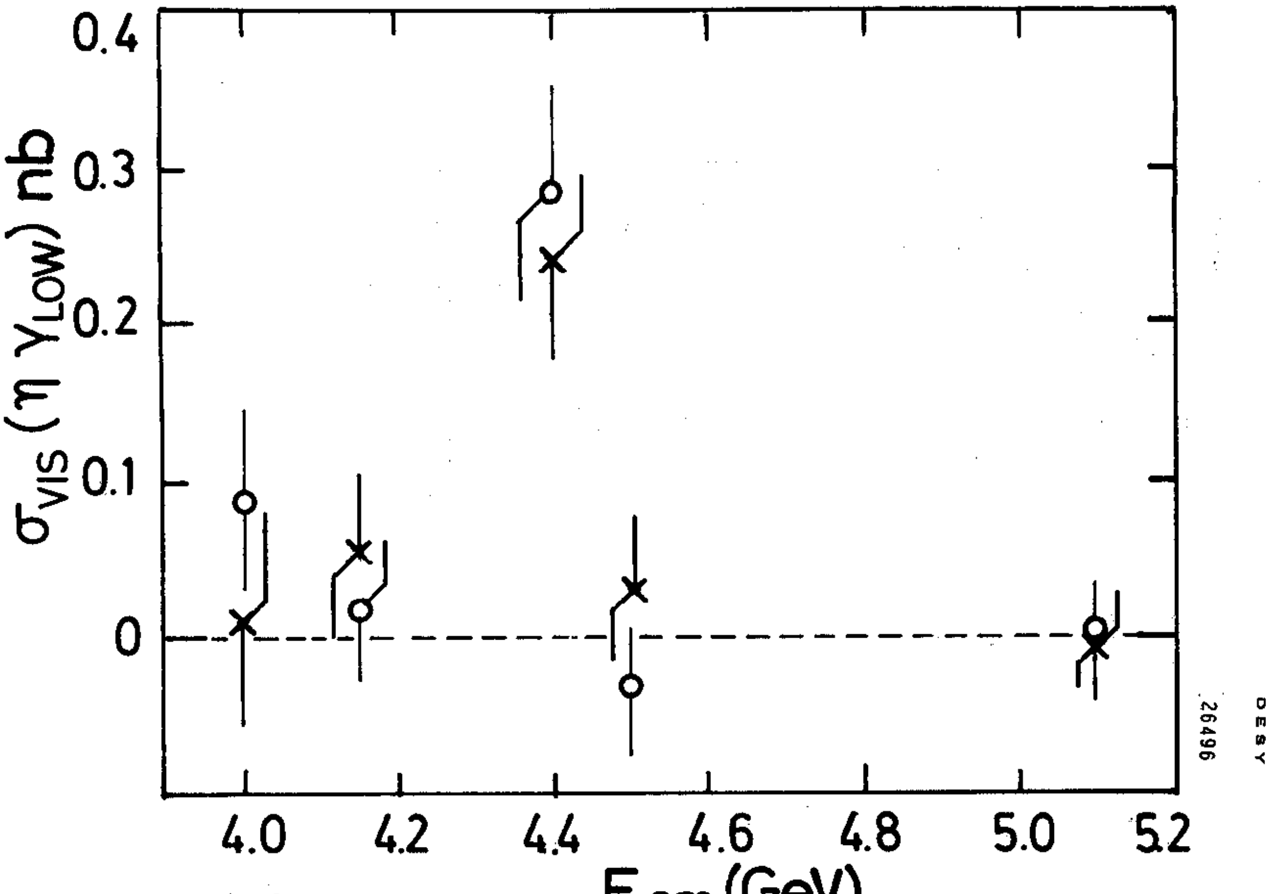
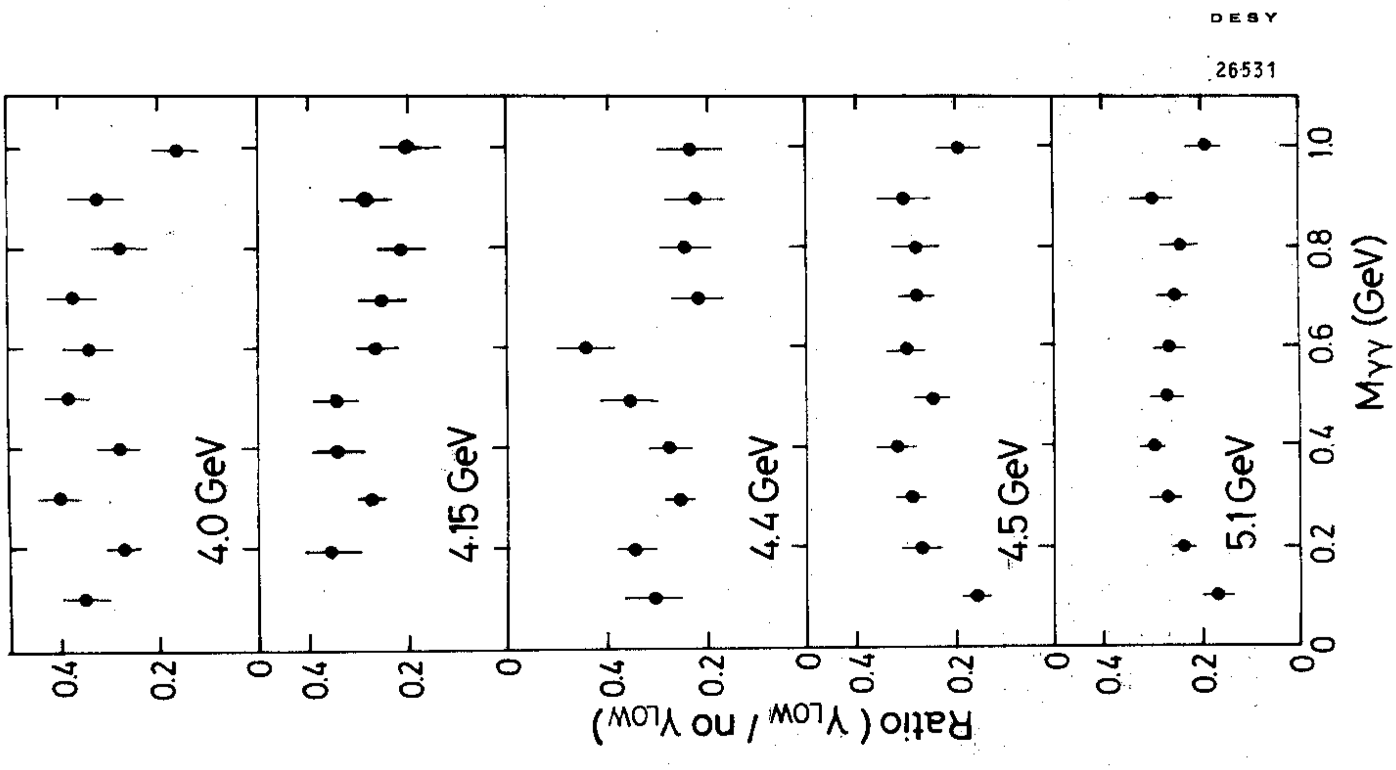


Fig. 1


σVIS (η γLOW) nb
0.4
0.3
0.2
0.1
0
4.0
4.2
4.4
4.6
4.8
5.0
5.2
Ecm (GeV)
26496
DESY
Fig. 3


DESY
26531
4.0 GeV
4.15 GeV
4.4 GeV
4.5 GeV
5.1 GeV
Mγγ (GeV)
Ratio (γLOW / no γLOW)
Fig. 2

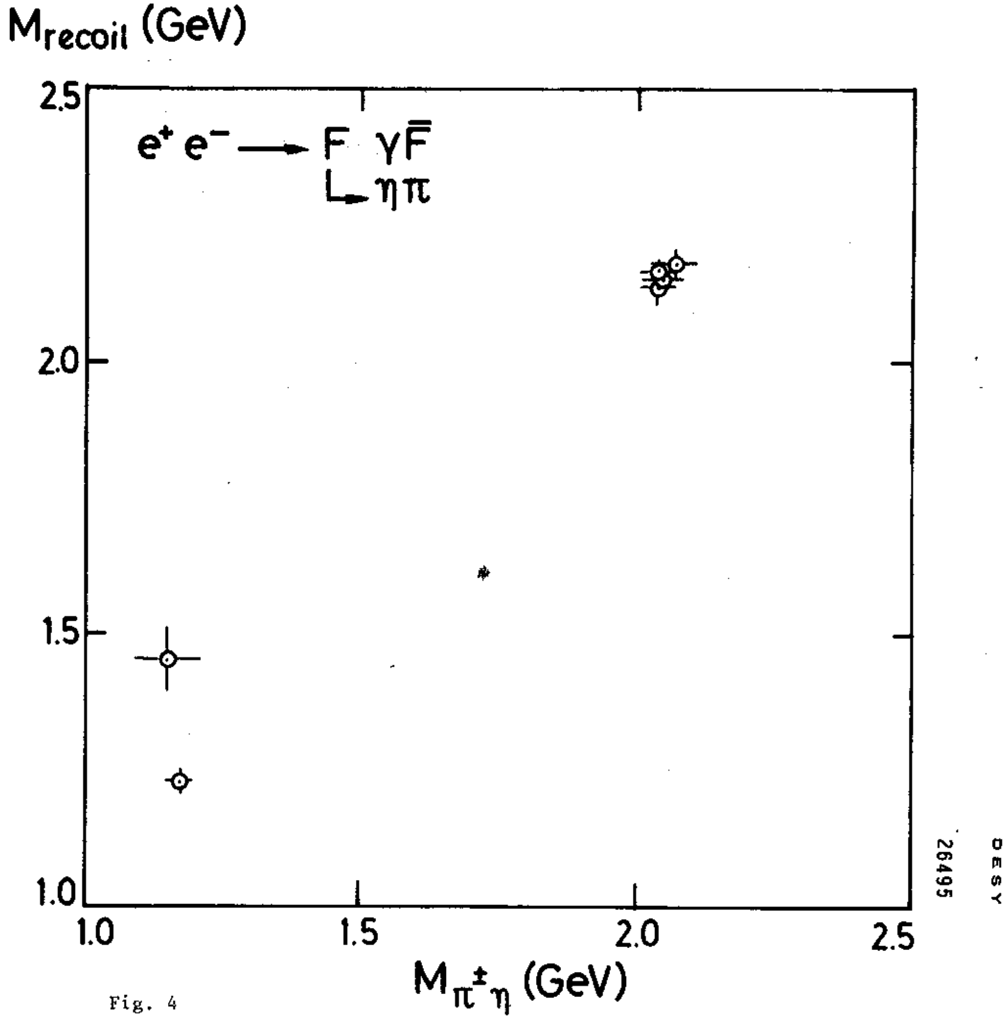


Fig. 4