SLAC-PUB-2731
CALT-68-840
May 1981
(T/E)

MEASUREMENT OF INCLUSIVE η PRODUCTION IN e^+e^- INTERACTIONS NEAR CHARM THRESHOLD*

R. Partridge, C. Peck, F. C. Porter
Physics Department, California Institute of Technology
Pasadena, California 91125

Y. F. Gu,[a] W. Kollmann,[b] M. Richardson, K. Strauch, K. Wacker
Lyman Laboratory of Physics, Harvard University
Cambridge, Massachusetts 02138

D. Aschman, J. Bagger, T. Burnett,[c] M. Cavalli-Sforza,
D. Coyne, M. Joy, H. F. W. Sadrozinski[d]
Physics Department, Princeton University
Princeton, New Jersey 08544

R. Hofstadter, R. Horisberger, I. Kirkbride, H. Kolanoski,[e]
K. Königsmann, A. Liberman,[f] J. O'Reilly,[g] A. Osterheld, J. Tompkins
Physics Department and High Energy Physics Laboratory
Stanford University, Stanford, California 94305
and
E. Bloom, F. Bulos, R. Chestnut, J. Gaiser
G. Godfrey, C. Kiesling,[h] W. Lockman, M. Oreglia
Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

Submitted to Physical Review Letters

---

*Work supported in part by the Department of Energy under contracts DE-AC03-76SF00515 (SLAC), EY-76-C02-3064 (Harvard) and DE-AC03-76ER00068 (CIT); by the National Science Foundation, contracts PHY78-00967 (HEPL), PHY79-16461 (Princeton) and PHY75-22980 (CIT); by the NATO Fellowship (HK), the Chaim Weizmann Fellowship (FP) and the Sloan Foundation (TB).

[a]On leave from the Institute of High Energy Physics, Academia Sinica, People's Republic of China.

Present Address: [b]Wentorfer Strasse 149, D-2050 Hamburg, Federal Republic of Germany.

[c]Physics Department, University of Washington, Seattle, Washington 98195.

[d]SCIPP, University of California at Santa Cruz, Santa Cruz, California 95064.

[e]University of Bonn, Bonn, Federal Republic of Germany.

[f]Schlumberger-Doll Research Center, Ridgefield, Connecticut 06877.

[g]Systems Control Technology, Palo Alto, California 94304.

[h]Max Planck Institute for Physics and Astrophysics, D-8000 Munich (40), Federal Republic of Germany.

ABSTRACT

We have measured the inclusive cross section for η production in e^+e^- interactions near charm threshold using the Crystal Ball detector. No pronounced structure in the energy dependence is observed. By comparing cross sections above and below charm threshold we obtain the limits (90% C.L.): $R(e^+e^- \to F\bar{F}X) \cdot BR(F \to \eta x) < 0.15$–$0.32$ (for $E_{c.m.}$ from 4.0 to 4.5 GeV), $BR(D \to \eta x) < 0.13$ [averaged over charged and neutral D components of the $\psi''(3770)$ decays]. Our results are inconsistent with a previous report of a large energy dependence of the η-cross section ascribed to the crossing of the FF^* and F^*F^* production thresholds.

The charmed-strange F-meson is expected to have a significant branching fraction to η mesons.[1] The DASP collaboration has reported a strong increase in η production in e^+e^- interactions at $E_{c.m.} \sim 4.4$ GeV (and possibly at 4.17 GeV) relative to production at 4.03 GeV,[2a] which they have interpreted as evidence for production of the F. In this letter we present a new and more sensitive measurement of inclusive production as a function of $E_{c.m.}$ at similar and additional energies using the Crystal Ball detector at SPEAR.

This new measurement shows that the inclusive η production cross section exhibits only small variations as charm threshold and expected FF^* and F^*F^* thresholds are crossed. This allows us to set tight limits on the decays of F's involving η's; these limits disagree with the sole previous measurement of the same quantity. We stress that this result does not bear directly on other evidence presented for the existence of the F and F^* [2a,2b,2c] where observations of specific final states are reported.

The Crystal Ball detector, event trigger and data reduction have been described elsewhere;[3] we summarize the relevant parameters here. This detector consists primarily of a segmented array of NaI(Tℓ) crystals for high-resolution measurement of the energy and position of electromagnetic showers. The solid angle coverage with the main array is 94% of 4π steradians, and is extended to 98% with crystals in the endcap regions. The beam pipe is surrounded by spark and proportional chambers for charged particle detection and tracking (no magnetic field) which cover approximately the same solid angle as the sodium iodide. The mass resolution for η mesons decaying into two photons is $\sigma \sim$ 20-25 MeV, with a weak energy dependence.

The results reported here are based on the data listed in Table I, which includes samples of annihilation into hadrons taken below and above charm threshold. The data between $E_{c.m.}$ = 3.878 and 4.500 GeV were taken in scans using fine steps in center-of-mass energy (2-12 MeV). We combine these data into larger $E_{c.m.}$ bins as indicated in Table I. The binning is chosen for correlation with the observed structure in $R(e^+e^- \rightarrow \text{hadrons})$, where the hadronic events were selected in a similar fashion.[4]

The observed number of mesons at each energy is extracted from the inclusive gamma-gamma mass ($m_{\gamma\gamma}$) plot (Fig. 1). To be included in a $\gamma\gamma$ mass pair, a photon must satisfy the following conditions:

i) $\left|\cos\theta_{\gamma\cdot\text{beam}}\right| < 0.85$.

ii) It has a lateral shower distribution consistent with that expected for an electromagnetically showering particle.

iii) It is not likely to have resulted from a $\pi^0 \rightarrow \gamma\gamma$ decay.[5]

The resulting $m_{\gamma\gamma}$ spectra (with fits superimposed) are shown in

Fig. 1(a-m). The fits shown are Gaussians for the η with fixed mass and fixed width (corresponding to our resolution), plus empirical backgrounds of the form: $(a + bm_{\gamma\gamma} + cm^2_{\gamma\gamma})/m^{2.7}_{\gamma\gamma}$.

The total number of etas produced at each energy is obtained by correcting the fitted result for the branching fraction for $\eta \to \gamma\gamma$ (38%) and for the η-detection efficiency (ε). The η-detection efficiency has been determined by Monte Carlo calculations and ranges from $\varepsilon = 0.38$ at the J/ψ to $\varepsilon = 0.27$ at 5.2 GeV. In the 3.88-4.50 GeV region, the calculated efficiency range is 0.29-0.33. Monte Carlo calculations for final states resulting from the production of D or F mesons (based on the constant-matrix-element model in Quigg and Rosner, Ref. 1) yield higher-than-average event multiplicities, and, hence, lower-than-average values for ε (e.g., $\varepsilon = 0.27 \pm 0.04$ for $D\bar{D}$ production and $\varepsilon = 0.19 \pm 0.01$ for equal $F\bar{F}^*$ and $F^*\bar{F}^*$ production). This is taken into account in the limits we obtain. We have also made several consistency checks to determine that our results are not sensitive to the photon cuts described above. These checks involved: a) the introduction of additional cuts on the angular separation between a gamma and other particles (charged and/or neutral) in the event, and b) the relaxation of criteria ii) and/or iii).

Dividing the number of etas produced by the number of hadronic events, we obtain f_η, the average number of etas per hadronic event (Table I). This quantity is plotted as a function of $E_{c.m.}$ in Fig. 2. Note that f_η shows little variation over the energy range, including the charmonium resonances, the point below charm threshold at 3.67 GeV, and the points above charm threshold. For reference, we note that the average charged pion multiplicity lies between 3 and 5 at these energies.[6]

The inclusive cross section for η production in the form of $R_\eta = \sigma(e^+e^- \to \eta X)/\sigma(e^+e^- \to \mu^+\mu^-) = f_\eta R(e^+e^- \to \text{hadrons})$ is shown as a function of $E_{c.m.}$ in Fig. 3 (excluding the off-scale values at the J/Ψ and Ψ'). Because R_η at the J/Ψ and Ψ' is large, the contributions from the radiative tails of these resonances to the other points has been subtracted (largest correction is 0.06 at the ψ"). In Fig. 3 we see that values for R_η above and below charm threshold are not dramatically different, although there may be some correlation with the total hadronic cross section.

Assuming that R_η for non-charm physics is constant, and that all excess in R_η is due to F decays, we can set limits on the product of the cross section for $F\bar{F}$ production times the branching fraction for F decay to η by comparing the values for R_η above $E_{c.m.} \sim 4$ GeV with the value below charm threshold ($E_{c.m.} = 3.67$ GeV). Table II presents these limits, with the $F\bar{F}$ production cross section expressed as

$$R\left(e^+e^- \to F\bar{F}X\right) = \frac{\sigma\left(e^+e^- \to F\bar{F}X\right)}{\sigma\left(e^+e^- \to \mu^+\mu^-\right)} \quad .$$

We have written "$F\bar{F}X$" in recognition of the fact that the creation of an $F\bar{F}$ pair may occur via the production of excited F-mesons, e.g., $e^+e^- \to F^*\bar{F}$, with $F^* \to \gamma F$. Our 90% confidence level upper limit of 0.19 for $R(e^+e^- \to F\bar{F}X) \cdot BR(F \to \eta x)$ at 4.365-4.500 GeV may be compared with the DASP result[2a] that $R(e^+e^- \to F\bar{F}X) \cdot BR(F \to \eta x) = 0.46 \pm 0.10$ at 4.36-4.49 GeV. Most of the disagreement between the two experiments is traceable to the absence of an η-signal at 4.03 GeV in the DASP experiment (resulting in the attribution of the entire DASP signal at 4.42 GeV to an onset in F production), while etas are observed in the Crystal Ball experiment with nearly the same strength at 4.03 (and 3.67 and ψ'') as at 4.4 GeV. Note that for center-of-mass energies above ~ 4.1 GeV the DASP cross sections are, on the average, compatible with our measurement.

A similar comparison between the values for R_η at the ψ'' and at 3.67 GeV allows us to obtain a limit on the branching fraction for D decay into η:

$$BR(D \to \eta X) < 0.13 \quad (90\% \text{ C.L.})$$

This limit is an average over the charged and neutral D components of the ψ'' decays. If it turned out that one of the charge states had a smaller branching ratio, then the limit for the other charge state would be correspondingly higher. The DASP experiment [2a] obtained an upper limit of 0.02, based on the absence of an η signal at 4.03 GeV. However, it must be remarked, as already noted above in the discussion of the F-limits, that we observe a substantially higher η cross section in the 4.03 GeV region (and at the ψ'' and at 3.67 GeV) than the DASP limit.

In conclusion, we find no evidence for a dramatic threshold in inclusive η production in e^+e^- collisions at center-of-mass energies just above charm threshold. We set limits on the product of the cross section for $F\bar{F}$ production times the branching ratio for F decay into η as given in Table II. Finally, our measurement of the inclusive η cross section at the ψ'' resonance allows us to set an upper limit of 0.13 on the branching ratio for D decay to η (averaged over the charged and neutral D components of the ψ'' decays).

Acknowledgments

We gratefully acknowledge the efforts of A. Baumgarten and J. Broeder (SLAC) and B. Beron, E. B. Hughes, and R. Parks (High Energy Physics Laboratory, Stanford University), as well as those of the linac and SPEAR staff at SLAC. This work was supported in part by the Department of Energy under contracts DE-AC03-76SF00515 (SLAC) EY-76-C02-3064 (Harvard) and DE-AC03-76ER00068 (CIT); by the National Science Foundation contracts PHY78-00967 (HEPL), PHY79-16461 (Princeton) and PHY75-22980 (CIT); by the NATO Fellowship (HK), the Chaim Weizmann Fellowship (FP) and the Sloan Foundation (TB).

References

[a]On leave from the Institute of High Energy Physics, Academia Sinica, People's Republic of China.

[b]Present address: Wentorfer Strasse 149, D-2050 Hamburg, Federal Republic of Germany.

[c]Present address: Physics Department, University of Washington, Seattle, Washington 98195.

[d]Present address: SCIPP, University of California at Santa Cruz, Santa Cruz, Californaia 95064.

[e]Present address: University of Bonn, Bonn, Federal Republic of Germany.

[f]Present address: Schlumberger-Doll Research Center Ridgefield, Connecticut 06877.

[g]Present address: Systems Control Technology Palo Alto, California 94304.

[h]Present address: Max Planck Institute for Physics and Astrophysics, D-8000 Munich (40), Federal Republic of Germany.

1. See, for example, Martin B. Einhorn and C. Quigg, Phys. Rev. D12, 2015 (1975); John Ellis, M. K. Gaillard and D. V. Nanopoulos, Nucl. Phys. B100, 313 (1975); C. Quigg and Jonathan L. Rosner, Phys. Rev. D17, 239 (1978); Dotcho Fakirov and Berthold Stech, Nucl. Phys. B133, 315 (1978).

2. (a) R. Brandelik *et al.*, Phys. Lett. 70B, 132 (1977); R. Brandelik *et al.*, Phys. Lett. 80B, 412 (1979); R. Brandelik *et al.*, Z. Physik C1, 233 (1979).
   (b) R. Ammar, et al., Phys. Lett. 94B, 118 (1980); N. Ushida *et al.*, Phys. Rev. Lett. 45, 1053 (1980).
   (c) D. Aston *et al.*, Phys. Lett. 100B, 91 (1981).

3. J. C. Tompkins, "Recent Results from the Crystal Ball," SLAC Report 224, 578 (1980); E. D. Bloom, in Proceedings of the 1979 International Symposium on Lepton and Photon Interactions at High Energies, ed., T. Kirk and H. Abarbanel, p. 92 (1979); M. Oreglia, Ph.D. thesis, Stanford University, SLAC-236, 1980 (unpublished).

4. F. C. Porter, in Proceedings of the XXth International Conference on High Energy Physics, Madison, Wisconsin, July 17-23, 1980, AIP Conference Proceedings Number 68, eds., Loyal Durand and Lee G. Pondrom. pp. 380-4.

5. The assignment of gammas to π^0 decays is based on an algorithm which performs a least-squares optimization over the possible sets of gamma-gamma pairings (to come from π^0's) in an event .

6. V. Lüth, in Proceedings of Summer Institute on Particle Physics, SLAC, July 11-22, 1977 (SLAC-204); R. Brandelik et al., Nucl. Phys. B148, 189 (1979).

TABLE I

Data Sample for Inclusive η Measurement

$E_{c.m.}$ (GeV)	$\int Ldt\,(nb^{-1})$	f_η
Fixed Points		
(a) J/ψ (3.095) [a]	120	0.143 ± 0.015
(b) 3.670	530	0.175 ± 0.033
(c) ψ' (3.684) [a]	320	0.135 ± 0.015
(d) ψ" (3.772)	1770	0.141 ± 0.019
(e) 4.028	890	0.103 ± 0.020
(f) 5.200	6870	0.115 ± 0.020
Scan Data		
(g) 3.878 - 4.004	420	0.089 ± 0.032
(h) 4.005 - 4.082 [b]	900	0.086 ± 0.019
(i) 4.083 - 4.142	1810	0.135 ± 0.019
(j) 4.143 - 4.225	2190	0.139 ± 0.019
(k) 4.226 - 4.300	1130	0.124 ± 0.023
(l) 4.301 - 4.364	860	0.146 ± 0.028
(m) 4.365 - 4.500	1600	0.114 ± 0.020

[a] Only a subsample of the available J/ψ, ψ' data is used because the systematic errors dominate.

[b] The 4.028 data is not included in the 4.005 - 4.082 bin.

TABLE II

Limits on $R\left(e^+e^- \to F\bar{F}X\right) \cdot BR(F \to \eta x)$

$E_{c.m.}$ (GeV)	Upper Limit[a]
3.878 – 4.004	0.14
4.028	0.23
4.005 – 4.082	0.15
4.083 – 4.142	0.32
4.143 – 4.225	0.30
4.226 – 4.300	0.18
4.301 – 4.364	0.30
4.365 – 4.500	0.19
5.200	0.21

[a] 90% C.L.

FIGURE CAPTIONS

Fig. 1. The $\gamma\gamma$-mass distributions (for $340 < M_{\gamma\gamma} < 800$ MeV) for each value of $E_{c.m.}$ as listed. The curves are fits to the data as described in the text (dashed is background, solid is background plus η).

Fig. 2. The average number of etas per hadronic event versus $E_{c.m.}$. The error bars include the estimated point-to-point systematic errors, but do not include the systematic uncertainty in absolute normalization, which is estimated to be less than ±20%.

Fig. 3. The inclusive cross section for η production divided by the QED point cross section versus $E_{c.m.}$. The first two points are for $E_{c.m.} = 3.67$ GeV and ψ'', and the ψ' point is off-scale. As in Fig. 2, the error bars include the point-to-point systematic uncertainties, but not the uncertainty in absolute normalization, estimated to be less than ±20%.

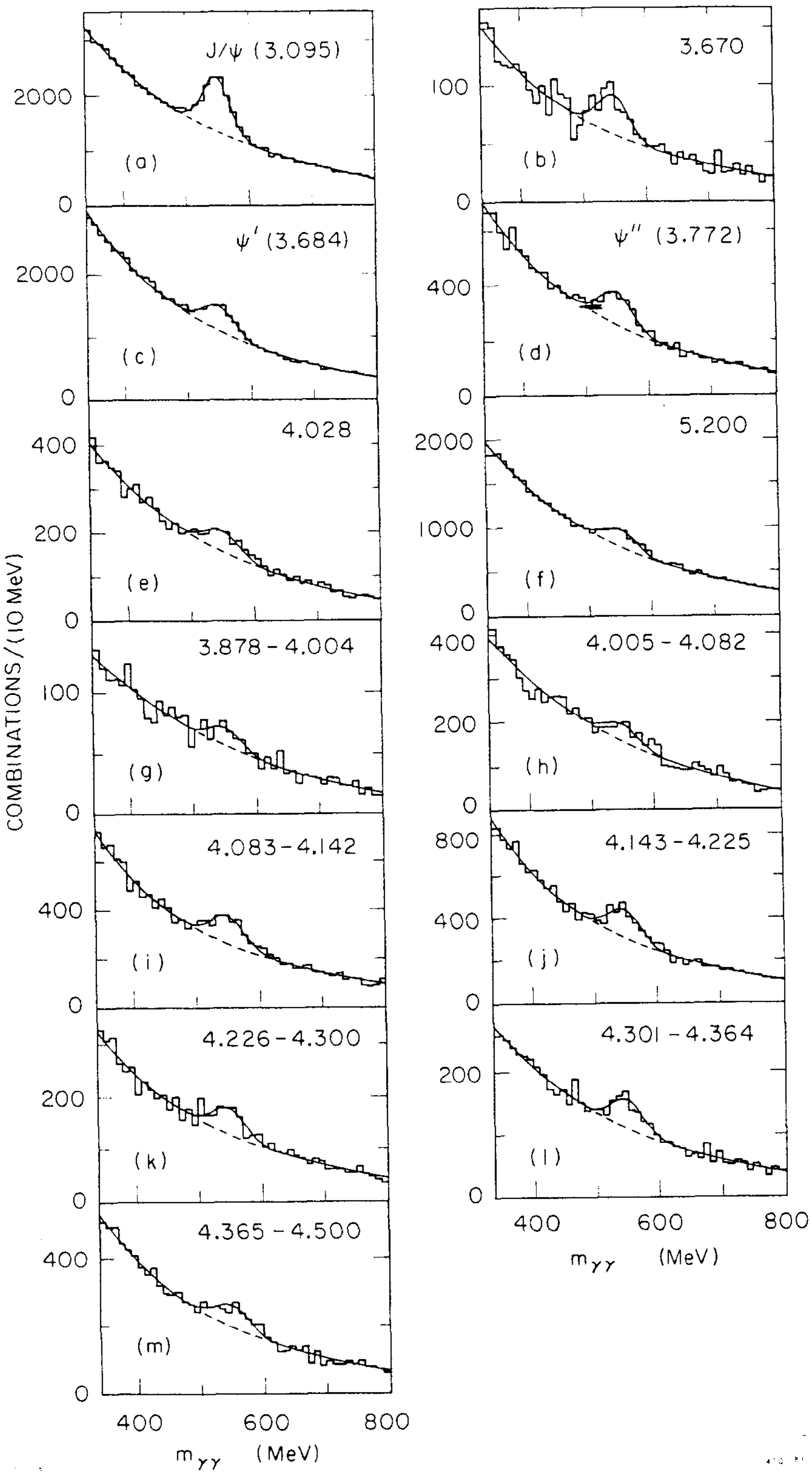
J/ψ (3.095)
3.670
ψ' (3.684)
ψ'' (3.772)
4.028
5.200
3.878 - 4.004
4.005 - 4.082
4.083 - 4.142
4.143 - 4.225
4.226 - 4.300
4.301 - 4.364
4.365 - 4.500
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
(j)
(k)
(l)
(m)
COMBINATIONS/(10 MeV)
m_γγ (MeV)
400
600
800

Fig. 1

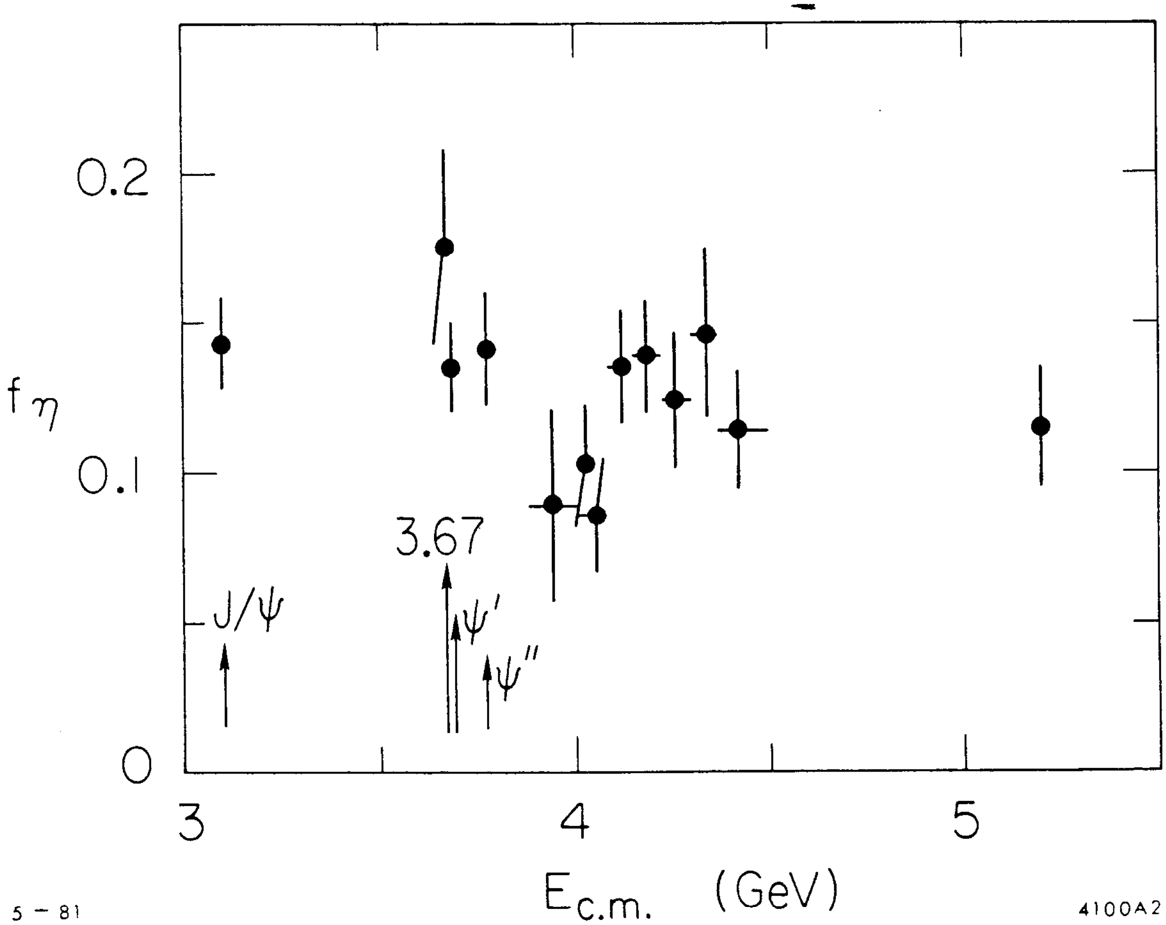

Fig. 2

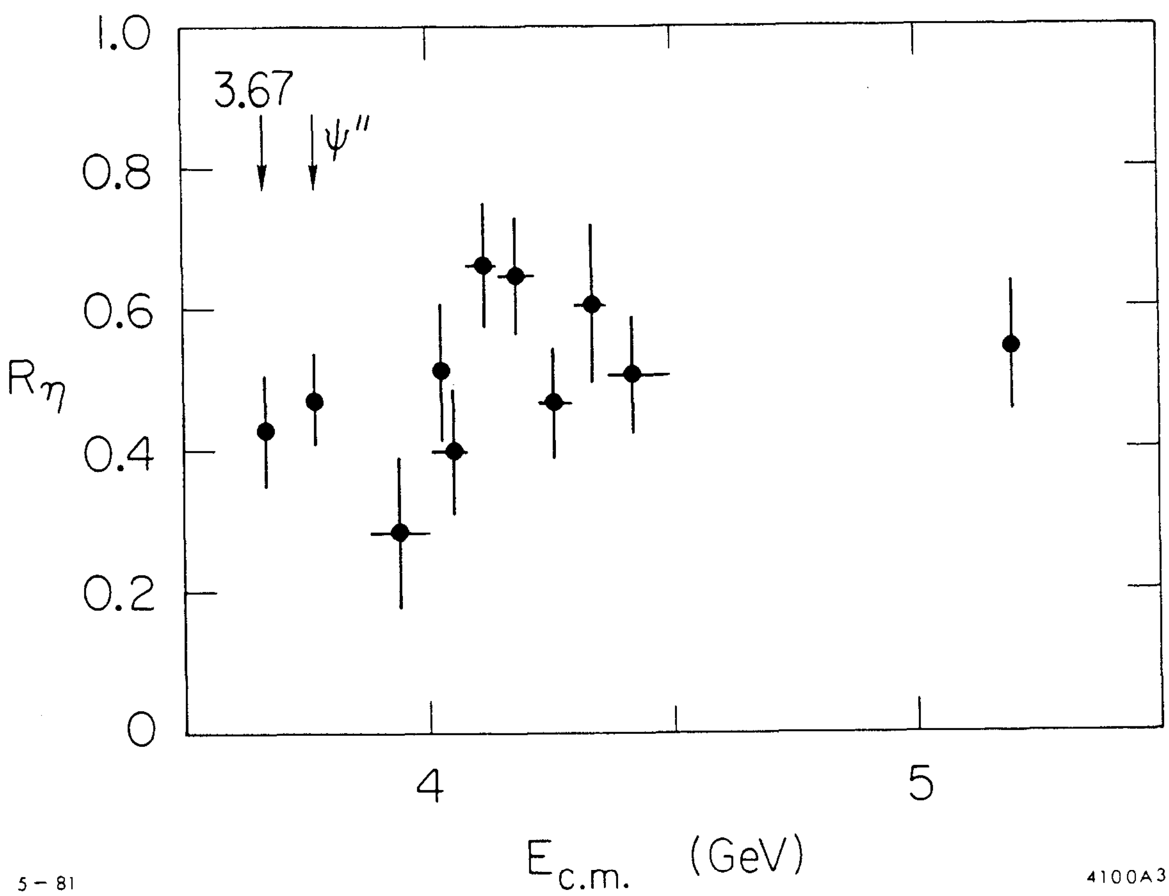

Fig. 3