0 0 0 0 4 6 0 1 5 6 8

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X SPECTROSCOPY AND NEWER PARTICLES

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LBL-5372

X SPECTROSCOPY AND NEWER PARTICLES*

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ABSTRACT

Two recent results from the SPEAR Magnetic detector are covered.

First a study of $\Psi' \to \gamma + X$, $\gamma\gamma\Psi$, $\gamma +$ hadrons is presented ; four intermediate states are seen, branching fractions and production angular distribution are given, which agree with the predictions of the charm quark model.

In the second part, evidence is presented for 2 narrow new states (charges 0 and 1) decaying to a kaon and pions. Structures are seen in the recoil mass spectra. The production and decay characteristics support the assignment of those states as the low-lying non-strange charmed mesons.

* Shortened version of invited talk to the Tbilisi Intern. Conference on High Energy Physics, July 15-22, 1976.

INTRODUCTION

In this report, I present two sets of results obtained by the LBL/SLAC collaboration in the magnetic detector at the SPEAR storage ring facility, SLAC. Due to the lack of space, most experimental details are skipped.

In the first part, the radiative decays of $\Psi(3684)$ are studied by three techniques. Earlier results have been reviewed previously [1].

In the second part, evidence is presented for two new narrow states at 1.86 GeV produced between 3.9 and 4.6 GeV, center of mass energy (c.m.e.). Recoil mass spectra and results of search in other energy regions are given.

I - RADIATIVE DECAYS OF Ψ's

After the discoveries of the narrow J/Ψ and Ψ' in 1974, observation of radiative decays of the Ψ' to narrow states has been reported in 1975 [2, 3, 4]. Here 350 000 events have been used in the analysis at $\Psi(3684)$ and 150 000 at $\Psi(3095)$.

1°) Energy spectrum of inclusive photons

In this first study, photons are detected by pair spectrometry, using the 5.2 % radiation length in the inner part of the detector. Electrons at energies below 55 MeV are not seen, due to tracking cut-off. Fig. 1c) shows the gross shape expected for γ originating from π°'s, computed from an all pion model Monte-Carlo at the Ψ energy, fig. 1a) and b) the data obtained for Ψ and Ψ' respectively.

A clear peak at $\sim$ 260 MeV is seen in fig. 1b), which is interpreted as the production of $\chi(3410)$ [3], the width being consistent with the resolution ($\sim$ 6 %). The resulting branching ratio is (5.5 ± 1.9) % for an isotropic angular distribution and (6.5 ± 2.2) for a $1 + \cos^2\theta$, θ being the angle between the photon and the beam line.

From the Ψ spectrum (fig. 1a) an upper limit of 4 % is obtained (90 % C.L.) for a photon energy around 300 MeV, which would correspond to a radiative transition to a 2.8 GeV state [5].

2°) The radiative cascade $\Psi' \to \Psi\gamma\gamma$

Here the Ψ is detected through its leptonic decay, 1 photon by conversion, and the other one by kinematics. After various cuts, 21 events are obtained and we show in fig. 2) the scatter plot of the two $\Psi\gamma$ masses ; the expected background is 1 event. The most probable interpretation on fig. 2) requires 3 states at 3.45, 3.50 and 3.55 GeV (the 3.45 peak could in fact be due to a state at 3.34). Corresponding branching ratios are presented in the table.

3°) $\Psi' \to \gamma$ + hadrons

For these final states, we identify the photon by the missing mass, which centers at 0. and not at $M^2_{\pi^0}$. Time of flight information is used to separate $\pi^+\pi^-\pi^+\pi^-\gamma$ and $\pi^+\pi^-K^+K^-\gamma$. Cuts are made on shower counter pulse heights and μ chambers to separate the $\pi^+\pi^-\gamma$ and $K^+K^-\gamma$ final states from lepton pairs.

The hadronic mass spectra, obtained after kinematic fitting, are shown in fig. 3. From the 4-body spectra (figs. 3a) and b)) there is evidence for 3 states at 3.415, 3.500, 3.550 GeV. The 2-body decay modes (3d) show that the 3.415 and 3.550 have natural parity. Corresponding branching ratios are presented in the table.

Fig. 4) shows the production angular distributions of the 3 states, where different decay modes have been merged. These distributions have been fitted to $1 + \alpha \cos^2\theta$ form and the α coefficients are presented in the table. For the $\chi(3\ 415)$, α is consistent with 1. as it would be expected for a spin 0 state. The 2 other states appear to have more isotropic distributions, which is consistent with higher spin assignments.

Conclusions

- 4 states have been identified, $\chi(3\ 415)$, $\chi(3\ 450)$, $\chi(3\ 500)$, $\chi(3\ 550)$
- $\chi(3\ 415)$, $\chi(3\ 500)$, $\chi(3\ 550)$ decays to hadrons are seen
- $\chi(3\ 415)$, $\chi(3\ 550)$ decay to a pair of pseudoscalar mesons
- $\chi(3\ 450)$, $\chi(3\ 500)$, $\chi(3\ 550)$ decay to $\gamma\Psi$

- $\chi(3\ 415)$ is seen in the inclusive γ spectrum and represents $\sim$ 6 % of all Ψ' decays
- $\chi(3\ 415)$ production angular distribution is consistent with the spin 0 prediction, and $\chi(3\ 500)$ and $\chi(3\ 550)$ seem to be more isotropically produced.

This set of observations is consistent with the popular charm quark model, but due to large experimental errors no definite spin-parity assignments can be made at this stage.

II - NEWER PARTICLES

An unsucessful search for the production of new particles has been previously reported at 4.8 GeV c.m.e. [6]. Here positive evidence is presented for new states from 24 000 events ($\geqslant$ 3 prongs) collected before May 76 between 3.9 and 4.6 GeV c.m.e. [7] and from 17 000 events collected in May-June 76 at 4.03 GeV.

A two-body peak appears - through kinematical reflections - in the inclusive effective mass of $\pi^+\pi^-$, $K^\pm\pi^\mp$, K^+K^- at 1.74, 1.87 and 1.99 GeV (fig. 5a), b), c)) ; here no particle identification has been used. Fig. 5 d), e), f) shows the corresponding plots using particle identification by time-of-flight (TOF) ; the $K\pi$ peak stands prominently and the 2 others have almost disappeared. Monte-Carlo runs with narrow states have been generated for each channel and compared to the data : the existence of a $K\pi$ state is necessary and sufficient to explain the data ; in the following we assume that the whole peak population is due to $K\pi$. The total signal consists of 110 $\pm$ 24 events. From now on, all plots are made with TOF.

Fig. 5h) presents evidence for a peak at 1.86 GeV in the $K^\pm\pi^\mp\pi^+\pi^-$ mass, with 124 $\pm$ 21 events, and no significant signal is seen in 4 $\pi^\pm$ and $K^+K^-\pi^+\pi^-$ (fig. 5g) and i)).

Fits with various cuts have been made to the $K\pi$ and $K3\pi$ mass spectra : the existence of a state at 1.865 $\pm$ 0.15 GeV, with a width less than 40 MeV (90 % C.L.), and decaying to $K\pi$ and $K3\pi$ explains the data.

In fig. 6a), b) are shown the recoil mass spectra in the peak region, for $K\pi$ and $K3\pi$ respectively. The lines represent the background, estimated from control regions. Those histograms show that the 1.865 GeV state is produced in association with systems of equal or higher masses.

We have estimated the product of production cross section times branching ratios (σ.BR) to be 0.20 ± 0.05 nb and 0.69 ± 0.15 nb for $K\pi$ and $K3\pi$ respectively, to be compared with a total hadronic cross section of 27 ± 3 nb, that is to say an average multiplicity of ~ 3 % for those 2 decay modes. At 3.1 GeV, where we have about 70 000 events obtained from Ψ decay through second-order electromagnetic, no signals are seen, and the upper limit for the $K\pi$ mode multiplicity is about 0.1 % (90 % C.L.). This corroborates the suggestion, obtained from the recoil mass spectra, of an associated production mechanism having a threshold at or above 3.73 GeV.

With the recent runs added, the full $K\pi$ mass spectrum is shown in fig. 7), exhibiting no other structure than $K^*(890)$ and $K\pi(1865)$. The corresponding missing mass to $K\pi(1865)$ is presented in fig. 8), showing clear evidence for narrow peaks at 2.01 and 2.15 GeV, the widths of which are consistent with the resolution.

Evidence for a charged state has been obtained from the events in the c.m.e. range 4.00 - 4.16 GeV. Figs. 9) and 10) show the $(K\pi\pi)^{\pm}$ mass spectra for the exotic and non-exotic modes, respectively (here exotic is used in the sense of strong interactions). An effect of more than 3 s.d. is present in the exotic mass spectrum at about 1.86 GeV, with no such signal in the non exotic one. Using the events in the peak region, we obtained the recoil mass spectrum of fig. 11), where a peak near 2.01 GeV is present. The background subtracted plot (not shown) is consistent with the assumption of associated production, as observed previously with the neutral state.

Selecting the events with missing masses in the 2.01 GeV region, the exotic $K\pi\pi$ peak at 1.86 GeV becomes highly significant (fig. 12)).

Summary and Conclusions

- Two peaks in $K^{\pm}\pi^{\mp}$ and $K^{\pm}\pi^{\mp}\pi^{+}\pi^{-}$ mass spectra have been seen near 1.86 GeV. The agreement in mass and the consistency of the recoil mass spectra strongly suggests they are two decay modes of the same state at 1.865 $\pm$ 0.015 GeV with a width less than 40 MeV.

- The recoil mass to this state shows no significant contribution below 1.86 GeV, and narrow peaks at 2.01 and 2.15 GeV.

- This associated production behaviour is corroborated by the absence of a signal at 3.1 GeV c.m.e.

- A charged narrow state is observed at about the same mass, decaying to the exotic $K\pi\pi$ mode but not seen in the non exotic mode.

- The recoil mass spectrum for the charged state has the same behaviour are the neutral one, but only one significant peak, at 2.01.

These facts, with the remarks that the seen decays have 1 kaon and that the threshold for pair-producing these states lies just above the narrow $\Psi(3684)$ (and below the rise in R), lead to the conclusion that we have observed for the first time the low-lying non-strange charmed mesons, predicted in 1970 by Glashow, Iliopoulos and Maiani [8, 9].

The other team members involved in this experiment are : G.S. Abrams, W.C. Carithers, W. Chinowsky, S.C. Cooper, R.G. Devoe, C.E. Friedberg, G. Goldhaber, A.D. Johnson, J.A. Kadyk, R.J. Madaras, H.K. Nguyen, B. Sadoulet, G.H. Trilling, J.S. Whitaker, F.C. Winkelmann, and J.E. Wiss of the Lawrence Berkeley Laboratory and S. Alam, A.M. Boyarski, M. Breidenbach, J. Dorfan, G.J. Feldman, G.E. Fischer, D. Fryberger, G. Hanson, J. Jaros, B. Jean-Marie, R.R. Larsen, D. Lüke, V. Lüth, H.L. Lynch, C.C. Morehouse, J.M. Paterson, M.L. Perl, I. Peruzzi, M. Piccolo, T.P. Pun, P. Rapidis, B. Richter, R. Schindler, R.F. Schwitters, J. Siegrist, W. Tanenbaum, and F. Vannucci of the Stanford Linear Accelerator Center.

	BR ($\chi\ \gamma$) × BR (χ decay) × 10^3						Coeff. α in
	$\pi^+\pi^-\pi^+\pi^-$	$\pi^+\pi^-K^+K^-$	$6\pi^\pm$	$\pi^+\pi^-$	K^+K^-	$\gamma\ \Psi$	$1 + \alpha \cos^2\theta$
χ(3 415)	3.2 ± 0.6	2.7 ± 0.7	1.4 ± 0.5	0.7 ± 0.2	0.7 ± 0.2	(1 event)	1.4 ± 0.4
χ(3 450)	?	?	?	?	?	12 ± 6	?
χ(3 500)	1.1 ± 0.4	0.6 ± 0.3	2.5 ± 0.8	< 0.15		37 ± 11	0.26 ± 0.5
χ(3 550)	1.6 ± 0.4	1.4 ± 0.4		0.23 ± 0.13		12 ± 6	0.22 ± 0.4

Table

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[3] G.J. Feldman et al., Phys. Rev. Letters 35 (1975) 821.

[4] W.M. Tannenbaum et al., Phys. Rev. Letters 35 (1975) 1323.

[5] B. Wiik, report to the Lepton-Photon Symposium, Stanford, August 1975.

[6] A.M. Boyarski et al., Phys. Rev. Letters 35 (1975) 196.

[7] G. Goldhaber et al., Submitted to Phys. Rev. Letters, June 1976, LBL - 5309, SLAC - 1762.

[8] S.L. Glashow et al., Phys. Rev. D2 (1970) 1285.

[9] A review of expected charm phenomenology can be found in M.K. Gaillard et al., Rev. Mod. Phys. 47 (1975) 277.

FIGURE CAPTIONS

1 Inclusive photon energy spectra : a) data from 150 000 events at Ψ ; b) data from 350 000 events at Ψ' ; c) all pion phase-space Monte-Carlo model at Ψ energy.

2 Scatter plot of the two ($\Psi\gamma$) masses for the reaction $\Psi' \to \Psi_{\hookrightarrow \ell^+\ell^-}\ \gamma_{\hookrightarrow e^+e^-}\ \gamma$

3 Hadron system mass spectra for various reactions $\Psi' \to \gamma$ + hadrons
a) $\pi^+\pi^-\pi^+\pi^-$ b) $\pi^+\pi^-K^+K^-$ c) $\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-$ d) $\pi^+\pi^-$ and K^+K^- .

4 Distributions of $\cos\theta$, where θ is the angle between γ and e^+e^- line
a) $\chi(3415) \to 4\pi^\pm$, $\pi^+\pi^-K^+K^-$ b) $\chi(3500) \to 4\pi^\pm$, $\pi^+\pi^-K^+K^-$
c) $\chi(3550) \to 4\pi^\pm$, $\pi^+\pi^-K^+K^-$.

5 Invariant mass spectra for neutral combinations of charged particles. a) $\pi^+\pi^-$ assigning π mass to all tracks, b) $K^\mp\pi^\pm$ assigning K and π masses to all tracks, c) K^+K^- assigning KK mass to all tracks, d) $\pi^+\pi^-$ weighted by $\pi\pi$ TOF probability, e) $K^\pm\pi^\mp$ weighted by $K\pi$ TOF probability, f) K^+K^- weighted by KK TOF probability, g) $\pi^+\pi^-\pi^+\pi^-$ weighted by 4π TOF probability, h) $K^\pm\pi^\mp\pi^\pm\pi^\mp$ weighted by K3 TOF probability, i) $K^+K^-\pi^+\pi^-$ weighted by $KK\pi\pi$ TOF probability.

6 Recoil mass spectra for combinations in the $K\pi$ and $K3\pi$ peaks. Smooth curves, obtained from combinations whose invariant masses are on either side of the peak mass region, are estimates of the background.
a) $K^\pm\pi^\mp$, peak mass region of 1.84 to 1.90 GeV/c^2 and background mass regions of 1.70 to 1.82 GeV/c^2 and 1.92 to 2.04 GeV/c^2. b) $K^\pm\pi^\mp\pi^\pm\pi^\mp$, peak mass region of 1.84 to 1.88 GeV/c^2 and background mass regions of 1.74 to 1.82 GeV/c^2 and 1.90 to 1.98 GeV/c^2.

from the early data (24 000 events $\geq$ 3 prongs)

7	$K^{\pm}\pi^{\mp}$ effective mass	from the total sample (41 000 events)
8	Recoil mass to $K\pi(1865)$ background subtracted (in this plot, the $K\pi$ mass is constrained at 1865 GeV and phase space limit correction are applied in the background subtraction procedure)	
9	Effective mass $K^{\mp}\pi^{\pm}\pi^{\pm}$	$4.00 < \sqrt{s} < 4.16$ GeV sample of $\sim$ 26 000 events
10	Effective mass $K^{\mp}\pi^{\mp}\pi^{\pm}$	
11	Recoil mass to $(K^{\pm}\pi^{\mp}\pi^{\mp})$ for $1.82 < M(K\pi\pi) < 1.90$ GeV	
12	Effective mass $(K^{\pm}\pi^{\mp}\pi^{\mp})$ for recoil mass in the range 2.00 - 2.1 GeV	

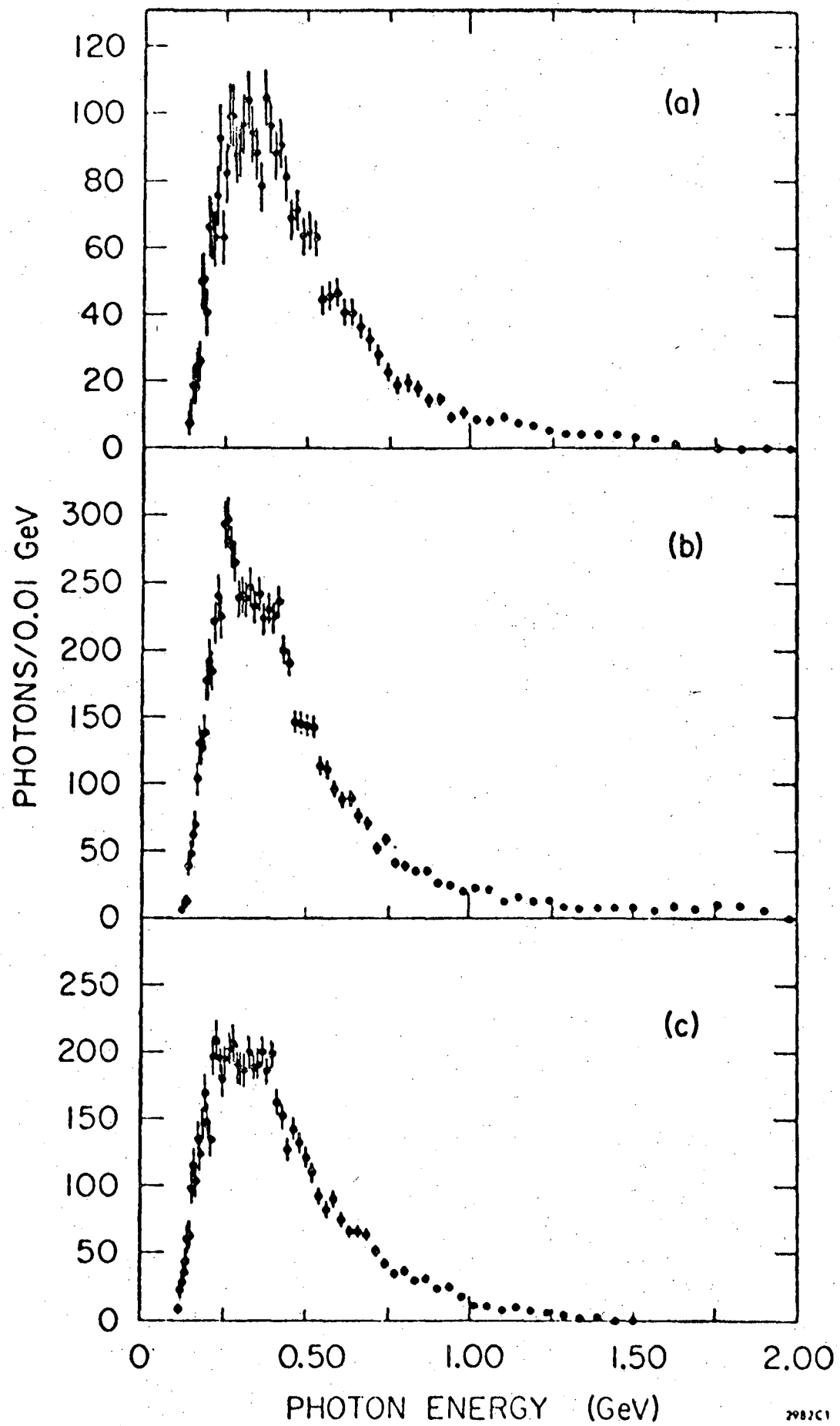
(a)
(b)
(c)
PHOTONS/0.01 GeV
PHOTON ENERGY (GeV)
0
0.50
1.00
1.50
2.00
298JC1

Fig.1

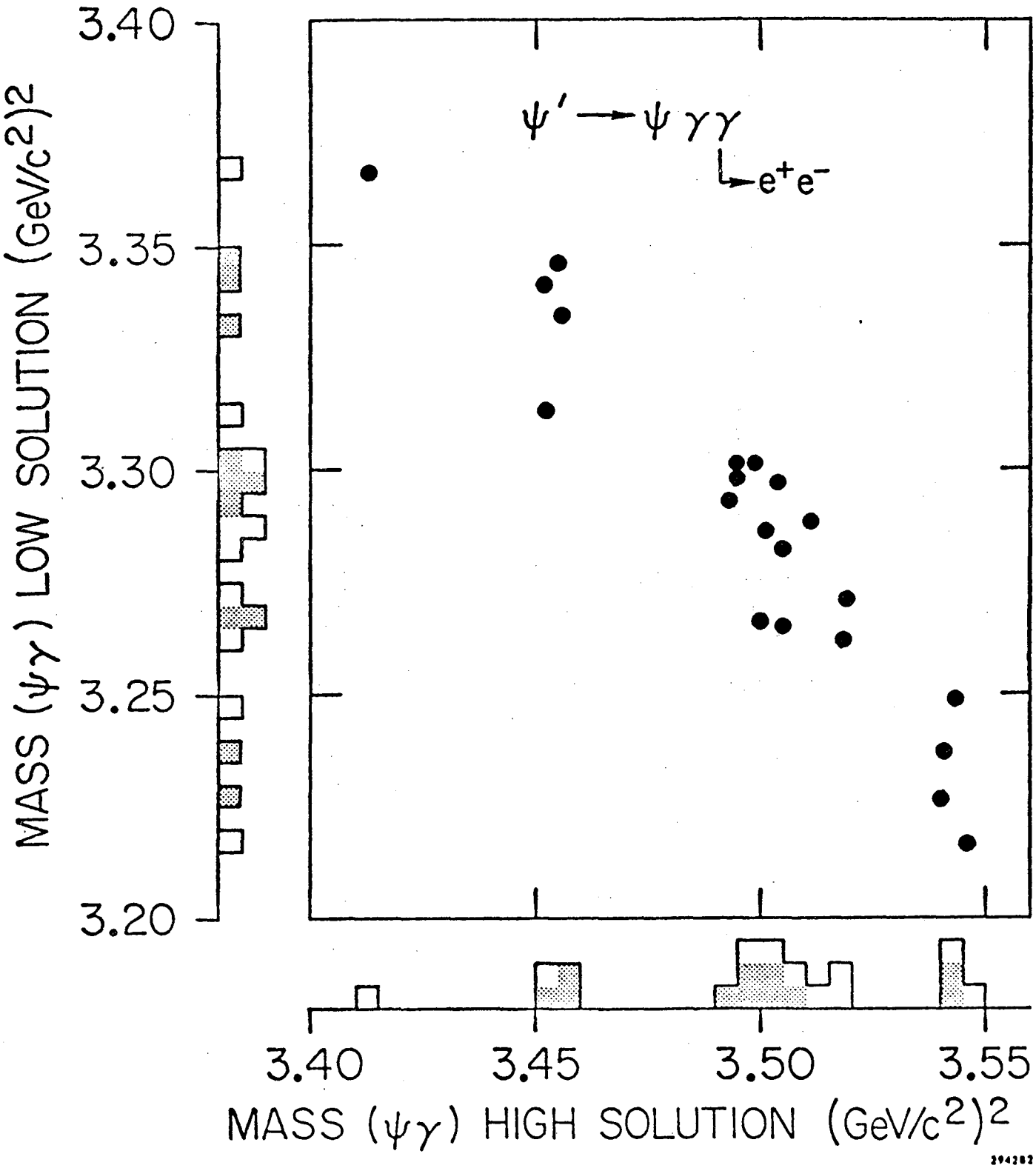
3.40
3.35
3.30
3.25
3.20
MASS (ψγ) LOW SOLUTION (GeV/c²)²
ψ′ → ψ γγ
↳ e⁺e⁻
3.40
3.45
3.50
3.55
MASS (ψγ) HIGH SOLUTION (GeV/c²)²

Fig. 2

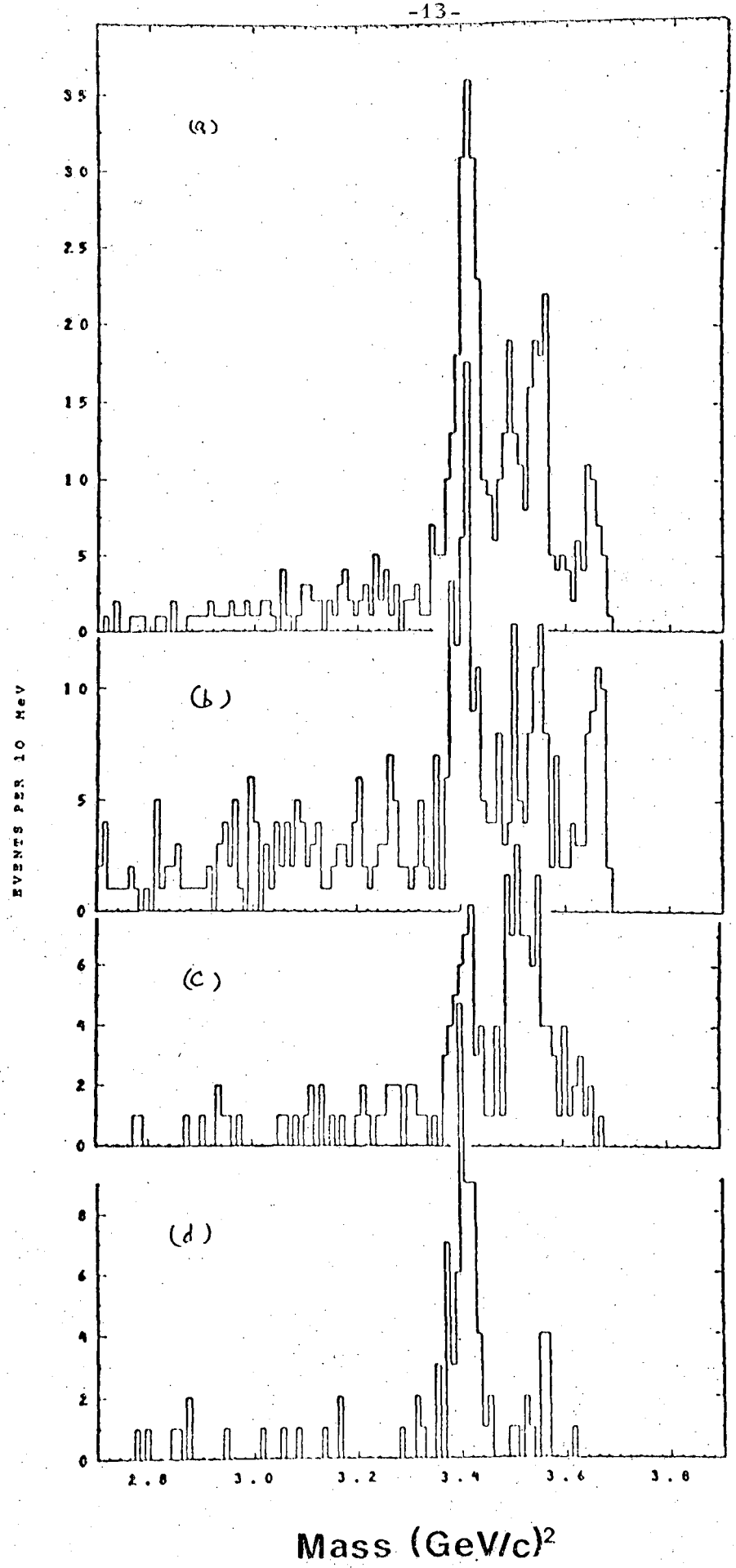

Fig. 3

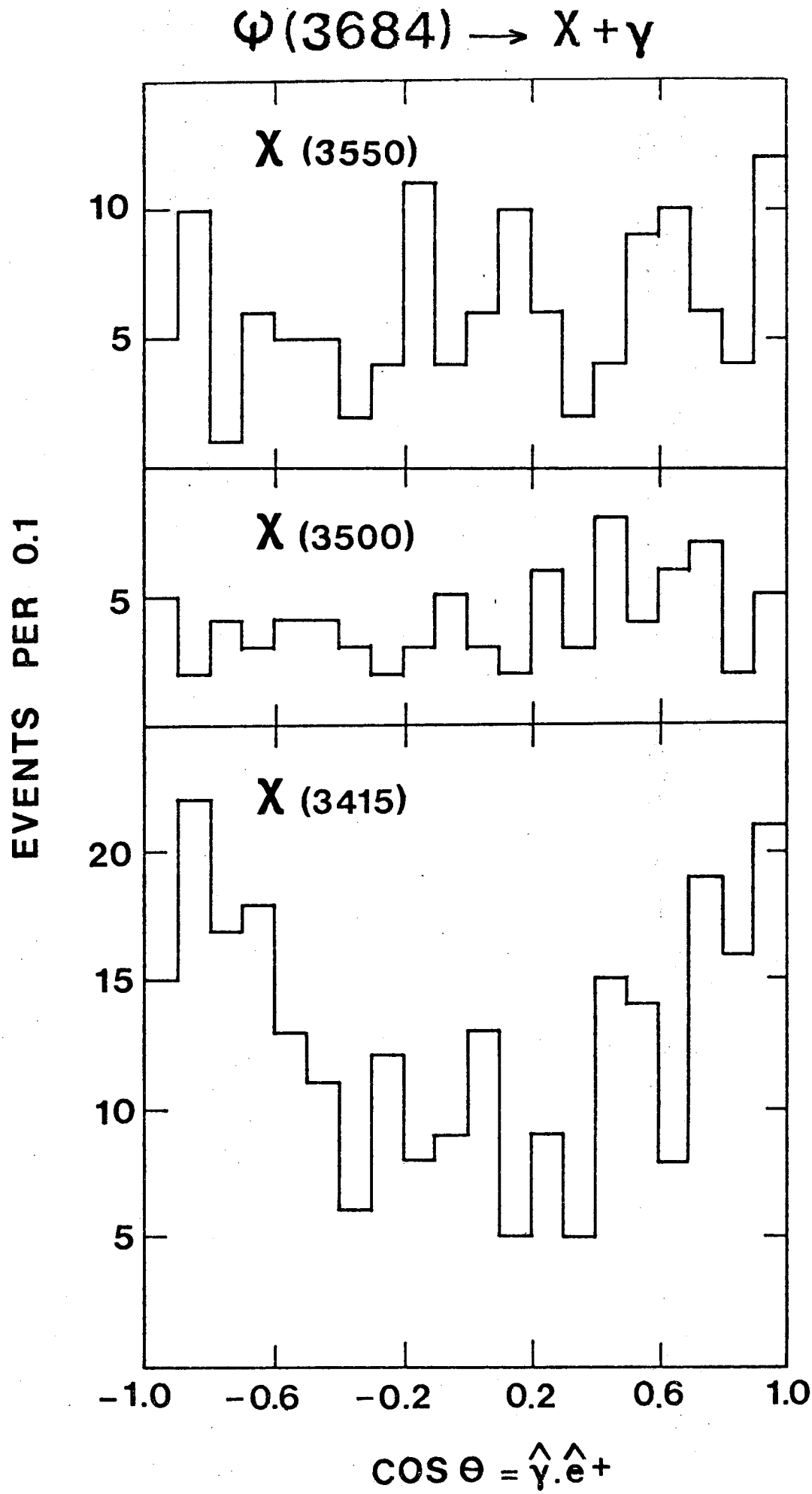
Ψ(3684) → X + γ
X (3550)
X (3500)
X (3415)
EVENTS PER 0.1
10
5
5
20
15
10
5
-1.0
-0.6
-0.2
0.2
0.6
1.0
COS Θ = γ̂.ê+

Fig.4

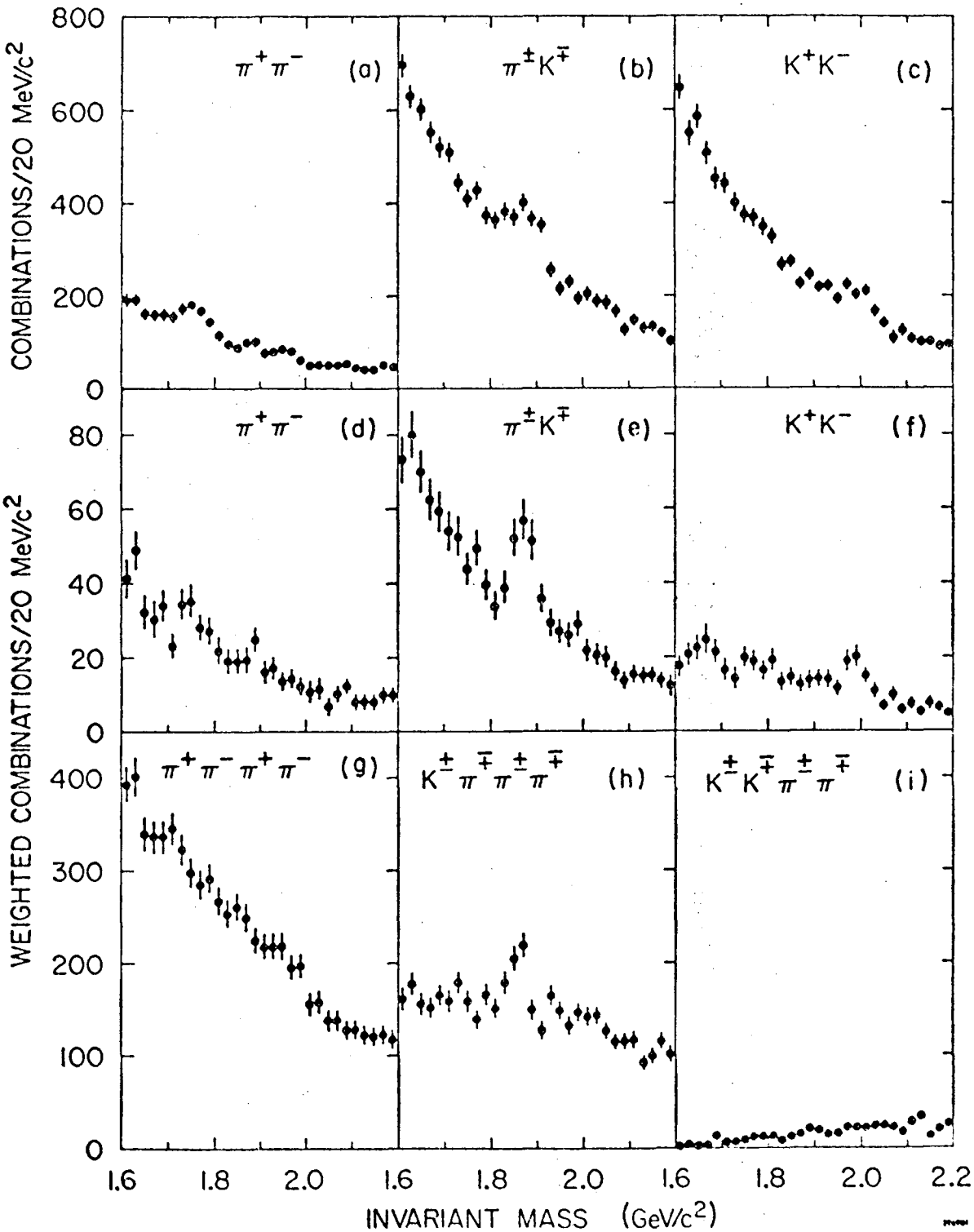
COMBINATIONS/20 MeV/c²
WEIGHTED COMBINATIONS/20 MeV/c²
π⁺π⁻ (a)
π±K∓ (b)
K⁺K⁻ (c)
π⁺π⁻ (d)
π±K∓ (e)
K⁺K⁻ (f)
π⁺π⁻π⁺π⁻ (g)
K±π∓π±π∓ (h)
K±K∓π±π∓ (i)
INVARIANT MASS (GeV/c²)

Fig. 5

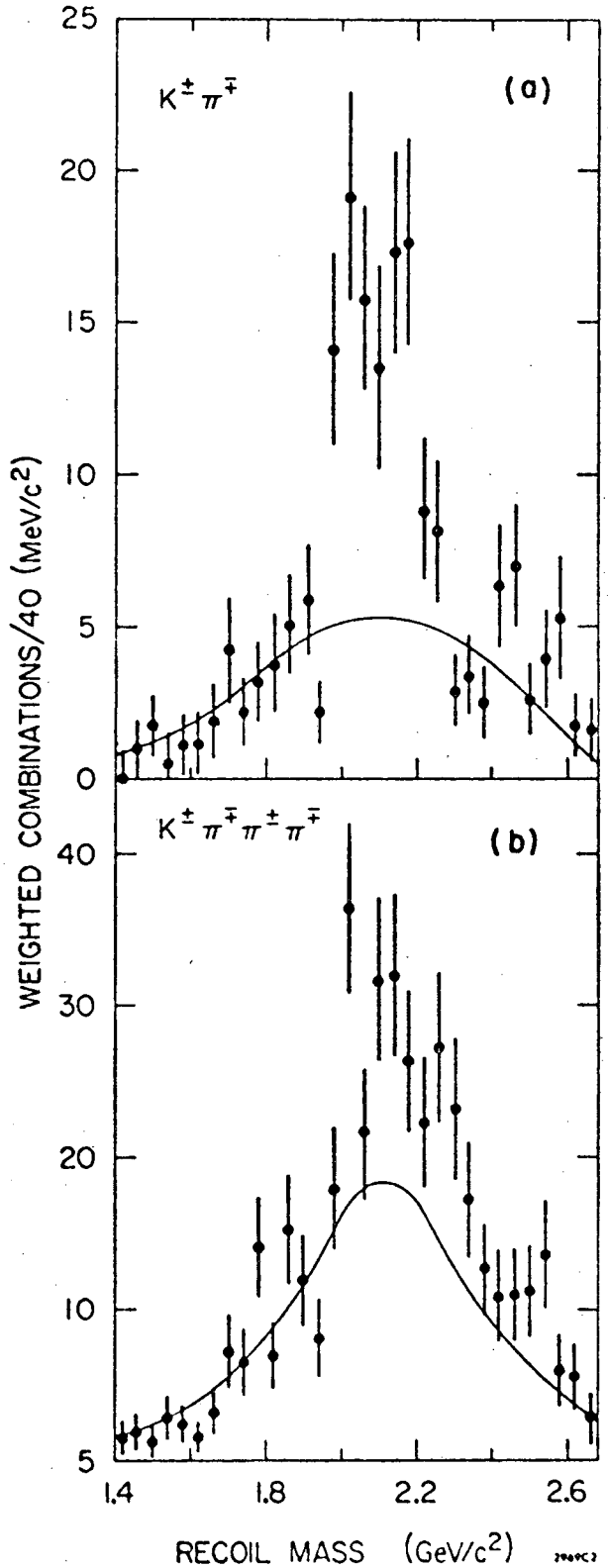
25
20
15
10
5
0
$K^{\pm}\pi^{\mp}$
(a)
40
30
20
10
5
$K^{\pm}\pi^{\mp}\pi^{\pm}\pi^{\mp}$
(b)
WEIGHTED COMBINATIONS/40 (MeV/c²)
1.4
1.8
2.2
2.6
RECOIL MASS (GeV/c²)

Fig. 6

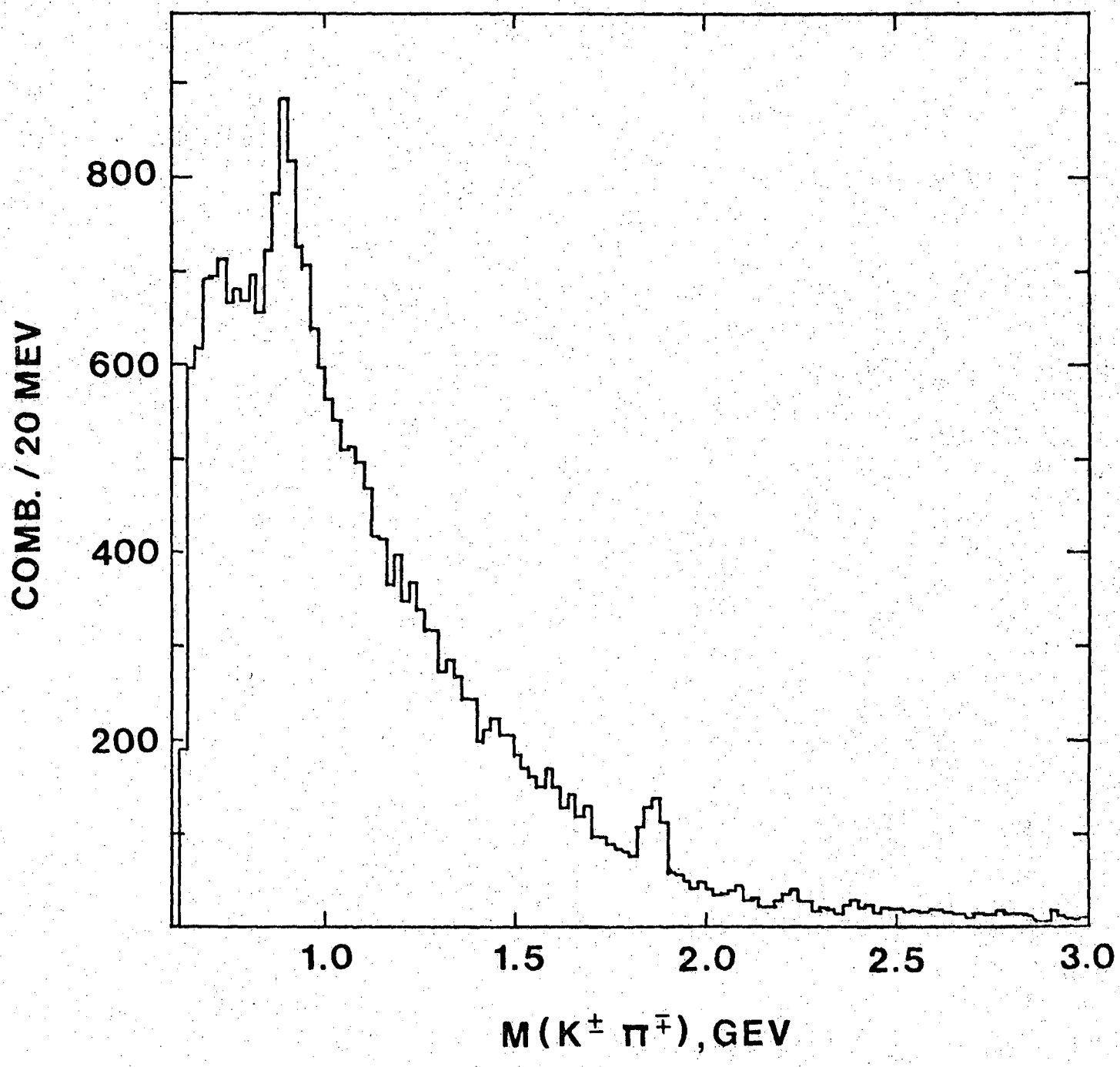

Fig. 7

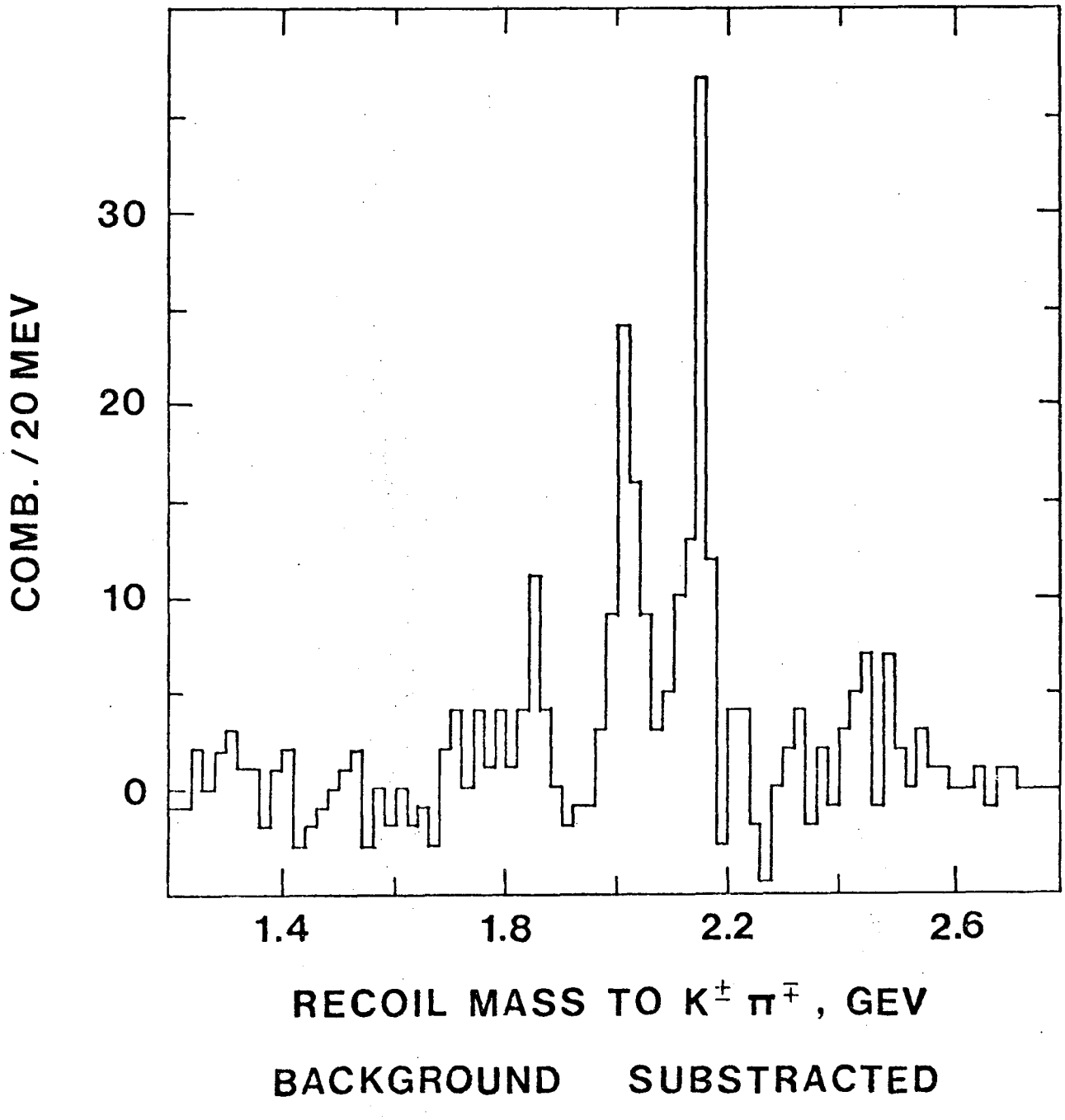
30
20
10
0
COMB. /20 MEV
1.4
1.8
2.2
2.6
RECOIL MASS TO $K^{\pm}\pi^{\mp}$, GEV
BACKGROUND SUBSTRACTED

Fig. 8

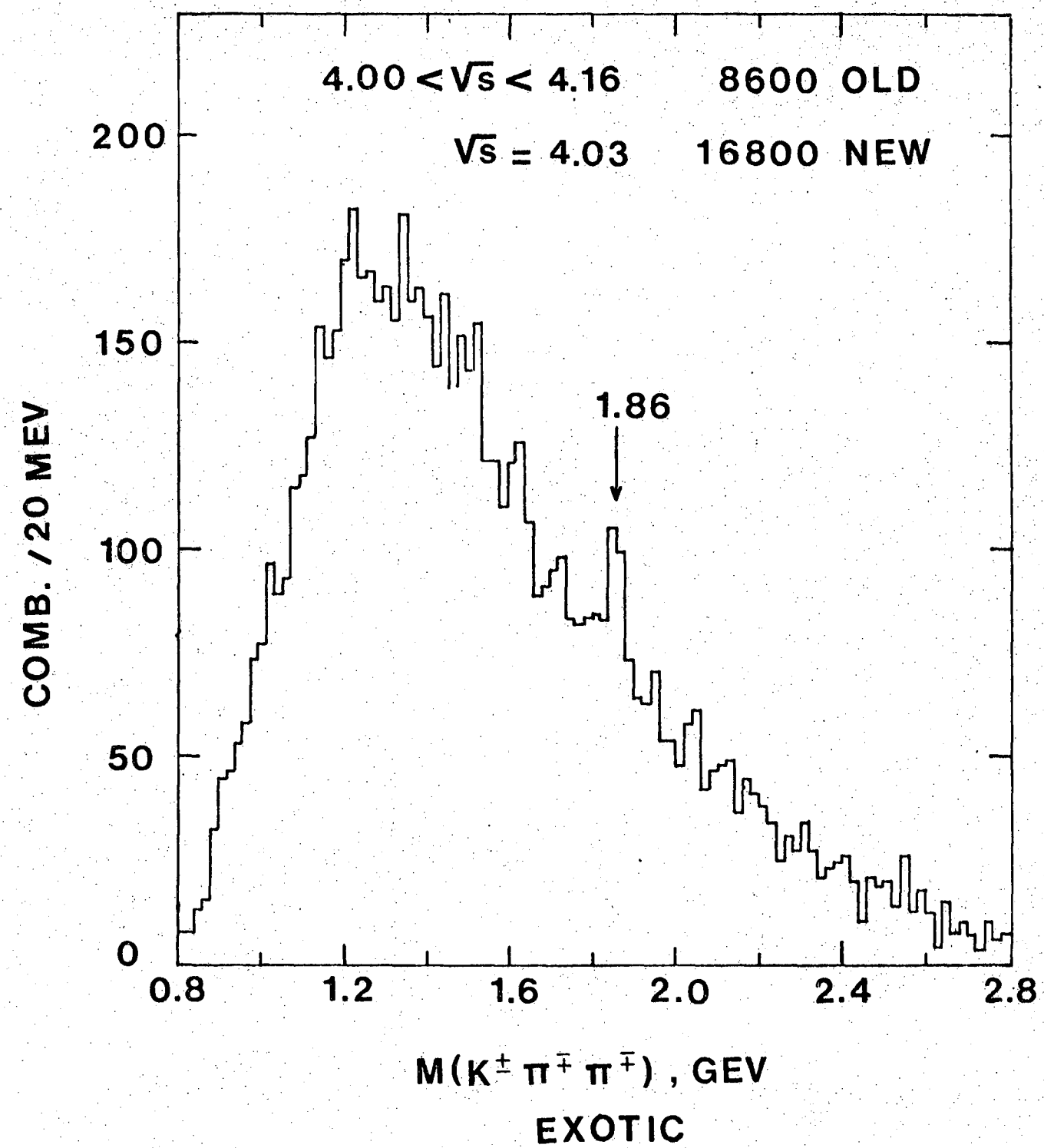
4.00 < √s < 4.16
8600 OLD
√s = 4.03
16800 NEW
1.86
COMB. /20 MEV
200
150
100
50
0
0.8
1.2
1.6
2.0
2.4
2.8
M(K± π∓ π∓) , GEV
EXOTIC

Fig.9

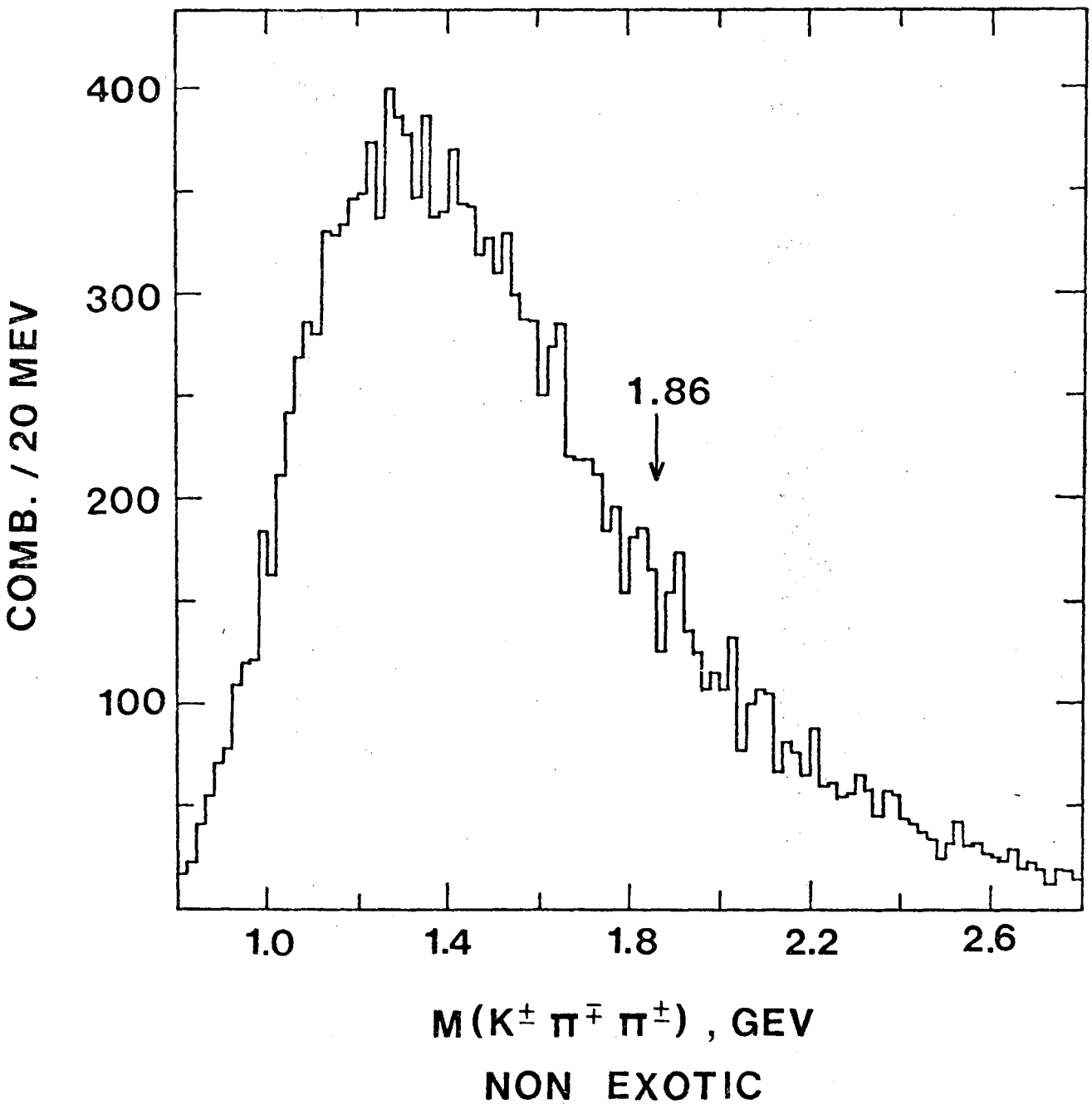
400
300
200
100
COMB. / 20 MEV
1.86
1.0
1.4
1.8
2.2
2.6
M(K± π∓ π±) , GEV
NON EXOTIC

Fig.10

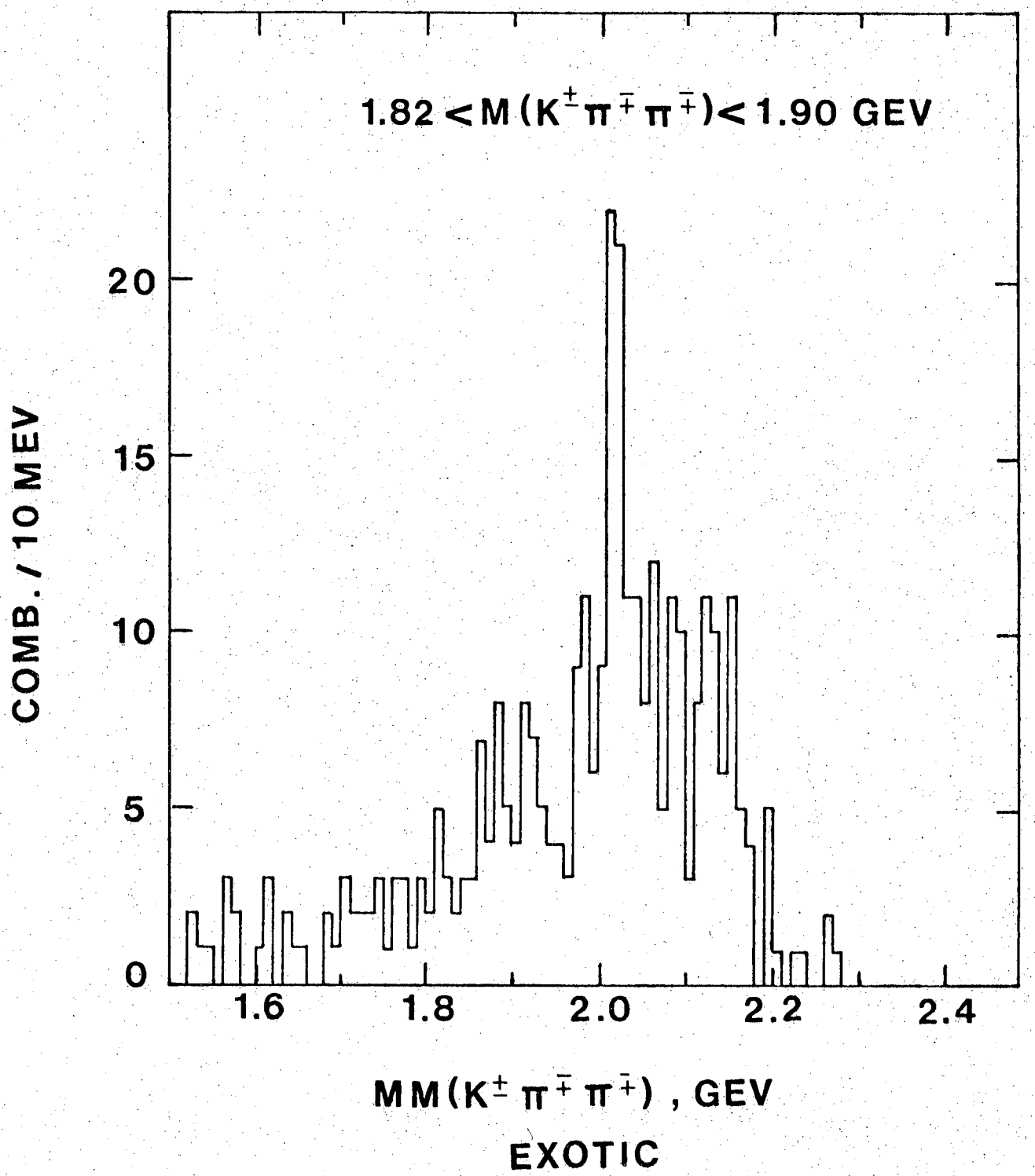
1.82 < M(K±π∓π∓) < 1.90 GEV
COMB. / 10 MEV
0
5
10
15
20
1.6
1.8
2.0
2.2
2.4
MM(K± π∓ π∓) , GEV
EXOTIC

Fig. 11

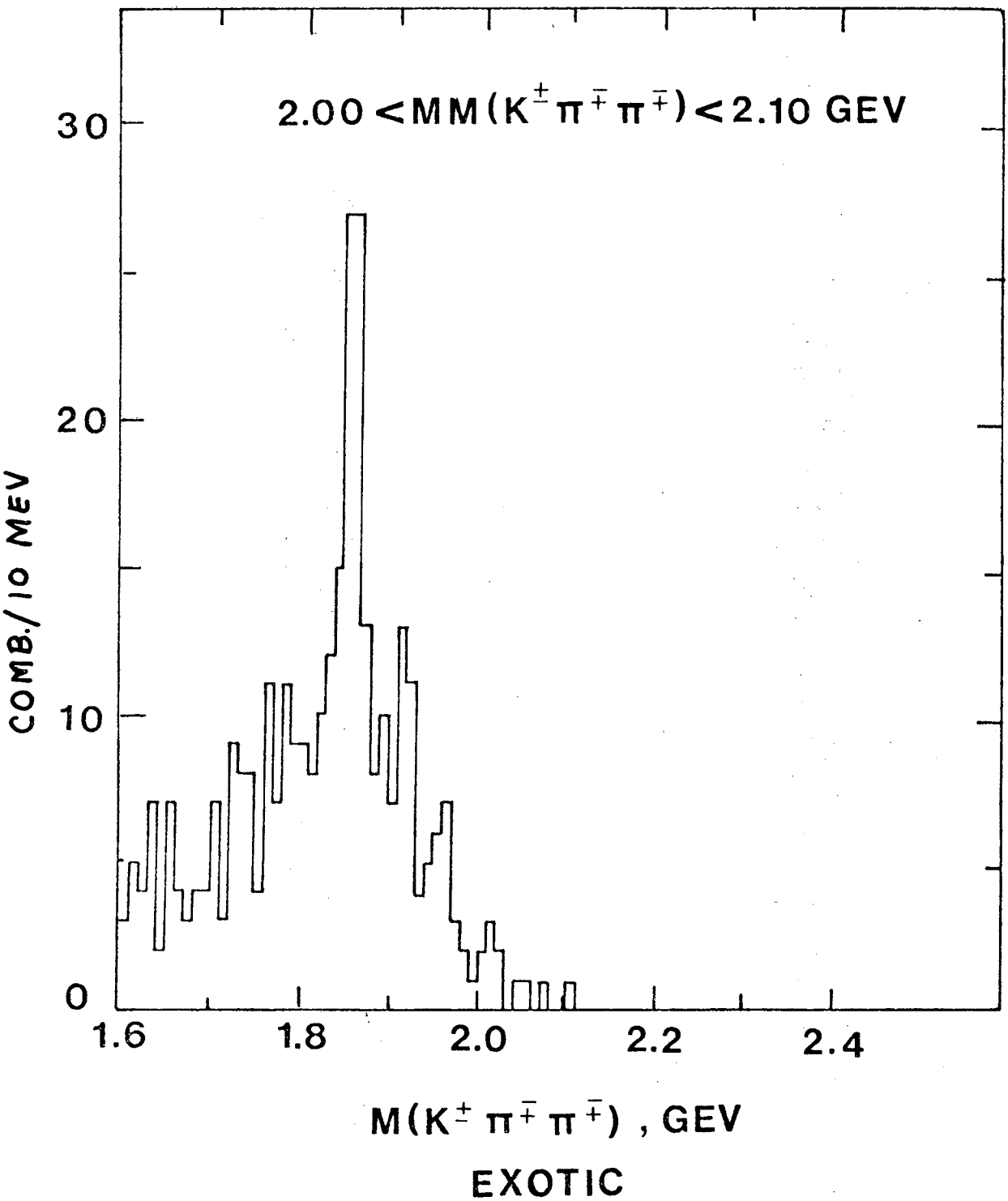
2.00 < MM(K± π∓ π∓) < 2.10 GEV
30
20
10
0
COMB./10 MEV
1.6
1.8
2.0
2.2
2.4
M(K± π∓ π∓) , GEV
EXOTIC

Fig.12

0 0 0 0 4 6 0 1 5 8 0

This report was done with support from the United States Energy Research and Development Administration. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the United States Energy Research and Development Administration.

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