SLAC – PUB – 4554
LBL – 25072
March 1988
(T/E)

η AND η' PRODUCTION IN e^+e^- ANNIHILATION AT 29 GEV: INDICATIONS FOR THE $D_s^\pm$ DECAYS INTO $\eta\ \pi^\pm$ AND $\eta'\ \pi^\pm$*

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Submitted to *Physical Review Letters*

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*This work was supported in part by the Department of Energy, contracts DE–AC03–76SF00515 (SLAC), DE–AC03–76SF0098 (LBL), and DE–AC02–76ER03064 (Harvard).

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ABSTRACT

η production has been investigated by the Mark II collaboration at the PEP e^+e^- storage ring. η particles are reconstructed by their $\gamma\gamma$ decay mode. The η fragmentation function has been measured and found to be in good agreement with the Lund model prediction. η' production has been measured for the first time in high energy e^+e^- annihilation. A search for $D_s^{\pm}$ decays into $\eta\ \pi^{\pm}$ and $\eta'\ \pi^{\pm}$ has been performed and indications at the 3 σ level are found for both decay modes.

This letter presents a measurement of inclusive η and η' production in e^+e^- annihilation using the 208 pb^{-1} data sample collected with the Mark II detector at PEP. The measurements of these two fragmentation functions provide interesting insights of the fragmentation mechanism. Since the η and the η' share the same quantum numbers and neither is produced significantly in resonance decays, their relative yield is mainly related to the mass suppression mechanism involved in the fragmentation chain. This mechanism differs from model to model and thus, this measurement could provide interesting tests of the fragmentation models in regions where, because of the lack of experimental data, they have not been tuned yet.

We also present evidence for exclusive decays of the $D_s^\pm$ involving η and η'. These decay modes have been predicted to be rather large by various models but the experimental information available up to now is rather scarce.

The Mark II detector is described in detail elsewhere.[1] Since the η particles are reconstructed via their $\gamma\gamma$ decay mode, the Liquid Argon electromagnetic calorimeter is of primary importance for this analysis. The calorimeter covers 65% of 4 π. Its energy resolution has been measured to be 14% $/\sqrt{E}$ and its angular resolution is 8 mrad. Charged tracks are measured in a cylindrical drift chamber system placed in a 2.3 kGauss solenoid magnet. The momentum resolution is given by $\sigma_p/p=((0.025)^2 + (0.011p)^2)^{1/2}$, (p in GeV/c). Particle identification is provided by a time-of-flight system (TOF) with a 400 ps resolution.

01 INCLUSIVE η PRODUCTION

Hadronic events were selected by requiring a minimum number of five charged tracks with a minimum total energy of 7 GeV. The event is divided into two hemispheres about the sphericity axis. Events with at least two neutral tracks in the same hemisphere were considered, where a neutral track is defined as an energy cluster of at least 200 MeV in the liquid argon calorimeter with a distance to the closest charged track greater than 7 cm.

To reduce the combinatorial background generated by photons coming from π^0 decays, all photons having an invariant mass between 50 MeV and 200 MeV with any other photon were rejected.

The resulting $\gamma\gamma$ invariant mass distribution is shown in Figs. 1(a) and 1(b), for $z > 0.2$ and $z > 0.3$, respectively, where z is the energy of the $\gamma\gamma$ pair divided by the beam energy. Clear evidence for η production is seen in both regions.

The number of η in each z bin is extracted from a fit of the measured spectrum. The fitting function consists of a quadratic polynomial background[♯1] and a Gaussian of fixed mass and free width. This allows the same fitting procedure to be applied on both data and Monte Carlo samples. The efficiency is measured on a sample of Monte Carlo hadronic events by the ratio of observed η obtained in the way described above and the number of produced η. In this way, the systematic effects associated with the fitting procedure are reduced. Because of its high efficiency (around 80%), the π^0 removal procedure does not introduce a significant systematic error. The efficiency rises slowly with energy from 3% at 4 GeV to 5% at 10 GeV.

The fragmentation function is plotted in Fig. 2, where the errors include the statistical error on the data, the uncertainty in the efficiency and a remaining systematic error estimated to be 15%, caused by the uncertainty in the width of the η signal. These data are in good agreement with the previous measurements of the JADE[2] and HRS[3] groups. The agreement with the LUND prediction, as represented by the solid curve, is also good.[♯2] The η multiplicity per event for different z cuts is summarized in Table 1.

♯1 First and third order polynomials were also tried and the observed differences have been included in the estimation of the systematic errors.

♯2 The η fragmentation in the Webber model is very similar to the Lund one.

Table 1. η multiplicities per event

z cuts	Multiplicity per event
$z > 0.1$	$0.30 \pm 0.07 \pm 0.05$
$z > 0.2$	$0.12 \pm 0.03 \pm 0.02$
$z > 0.3$	$0.09 \pm 0.02 \pm 0.02$

The total η multiplicity per event was obtained by extrapolating the measured multiplicity for $z > 0.1$ using the Lund fragmentation function. This is justified by the good agreement observed at low z between JADE data and the LUND model. The result, $N_\eta = 0.62 \pm 0.17 \pm 0.15$, where the systematic error includes the uncertainty in the extrapolation is in good agreement with the JADE and HRS measurements of 0.64 ± 0.15 and 0.58 ± 0.10, respectively, and the LUND and Webber prediction of 0.70.

02 INCLUSIVE η' PRODUCTION

The η' is searched for in the $\eta\ \pi^+\ \pi^-$ mode. The two pions are required to be in the same hemisphere as the η candidate. A pion is any track compatible with the pion hypothesis according to the TOF system. An η candidate is defined as follows: using photon pairs selected as above, a kinematical fit is performed on both photons assuming the angles are perfectly measured. The energy of each photon is thus rescaled using the nominal η mass as a constraint. Only pairs with an unconstrained mass between 450 and 650 MeV and with a χ^2 for the kinematic fit less than 6 are retained. In order to ensure the best possible signal/noise ratio for the η peak, further cuts were applied:

1. Cuts were applied to reject clusters formed by two merged photons coming from an energetic π^0 decay. The electromagnetic shower was required to be compatible with the presence of a single photon in the first layer of the liquid argon calorimeter. The efficiency of this cut has been measured in different ways: using the η spectrum, using a sample of pure single photons

coming from $e^+e^-\ \gamma$ events and using the Monte Carlo. The three methods agree within 10% and yield an efficiency of 65%.

2. $\cos\theta^\star$ has to be less than 0.7, where $\theta^\star$ is the angle between one of the photons and the η line of flight in the η rest frame. The background tends to peak at $\cos\theta^\star = 1$, corresponding to asymmetric photon pairs.

A clear η' signal of 45 ± 11 events can be seen in Fig. 3, where $z_{\gamma\gamma}$ is required to be above 0.2. This is the first measurement of η' production in high energy e^+e^- annihilation.

The fragmentation function has been extracted from these data in a similar manner as above. A polynomial background and a Gaussian of fixed mass and free width were fitted to the data in each z bin for both the data and the Monte Carlo. The reconstruction efficiency varies from 2% at 2 GeV to 7% at 7 GeV (not taking into account the 17% branching ratio for the decay $\eta' \to \gamma\gamma\pi^+\pi^-$). The η' fragmentation function is shown in Fig. 2. The number of η' with $z > 0.2$ is

$$N_{\eta'}(z > 0.2) = 0.09 \pm 0.03 \pm 0.02 \quad .$$

Assuming the Lund fragmentation function leads to a number of η' per event of 0.26 ± 0.09 ± 0.05.

As mentioned above, the η'/η production ratio in e^+e^- jets provides an interesting test of fragmentation models. As an example, the η'/η ratio is predicted to 0.56 in the Lund model, 0.2 in the Webber model and 0.30 in the UCLA model.[4] Our data sample is not large enough to enable us to distinguish between these different models.

03 SEARCH FOR $D_s^\pm \to \eta\ \pi^\pm$

The η candidates are combined with any charged track found in the same hemisphere and compatible with a π according to the TOF system. An η candidate is defined as above, with two additional cuts which reduce the background under the η peak:

1. The η momentum is required to be greater than 4.5 GeV (i.e., $z > 0.3$).

2. One photon has to have a p_t relative to the thrust axis greater than 500 MeV. This cut favors photons from $D_s^{\pm}$ decays compared to those coming from soft π^0 decays.

An excess of events is found in the $D_s^{\pm}$ mass range [Fig. 4(a)]. The probability that this excess is due to a statistical fluctuation of the background deduced from the observed mass spectrum both in the data and in the Monte Carlo is at the 10^{-3} level. We have thus observed evidence for the decay $D_s^{\pm} \rightarrow \eta\ \pi^{\pm}$ at the 3 σ level.

A quadratic polynomial background and a Gaussian of fixed mass and free width were fitted to the data. The fit gave 16 ± 6 $D_s^{\pm}$, with a width of 40 ± 15 MeV consistent with the 50 MeV expected from our resolution. This corresponds to, after radiative corrections:

$$\sigma(e^+e^- \rightarrow D_s^{\pm}) \times B(D_s^{\pm} \rightarrow \eta\ \pi^{\pm}) = 5.2 \pm 2.2 \text{ pb} \quad .$$

Using the standard hypothesis for the $D_s^{\pm}$ production rate (assuming quark counting and a 15% probability for a c quark to produce a $D_s^{\pm}$ meson, thus leading to a $D_s^{\pm}$ cross section around 44 pb or .11 $D_s^{\pm}$ per hadronic event), this result translates into a branching ratio around 12%, about three times larger than the world average value for the $\phi\pi^{\pm}$ mode.

The Mark III collaboration has presented preliminary evidence[5] for the same decay mode of the $D_s^{\pm}$, with a comparable branching ratio.

04 SEARCH FOR $D_s^{\pm} \rightarrow \eta'\ \pi^{\pm}$

η' candidates were combined with any charged track above 1 GeV found in the same hemisphere. An η' candidate was required to have an invariant mass of the $\eta\ \pi^+\ \pi^-$ system between 0.9 and 1 GeV. The invariant mass was constrained to the nominal η' mass. Furthermore, $z_{\gamma\gamma}$ has to be greater than 0.2.

An excess of events is found in the $D_s^\pm$ mass region [see Fig. 4(b)], indicating the observation of the decay $D_s^\pm \rightarrow \eta' \pi^\pm$ at a 3 σ level. This leads to, after radiative corrections,

$$\sigma(e^+e^- \rightarrow D_s^\pm) \times B(D_s^\pm \rightarrow \eta' \pi^\pm) = 8.4 \pm 3.7 \text{ pb} \quad .$$

With the same production hypothesis as above, the branching ratio for $D_s^\pm \rightarrow \eta' \pi^\pm$ is around 19%.

The theoretical implications of large branching ratios for both the $\eta \pi^\pm$ and the $\eta' \pi^\pm$ mode have been discussed by several authors.[6,7] The presence of a scalar resonance in the 2 GeV range could lead to such effects without affecting the standard mixture of spectator and annihilation mechanisms in the $D_s^\pm$ decays.

05 CONCLUSION

The η fragmentation function has been measured and found to be in agreement with previous measurements and with the Lund model. The η multiplicity for $z > 0.1$ is found to be $0.30 \pm 0.07 \pm 0.05$. The η' inclusive production has been measured for the first time in high energy annihilation events. The η' multiplicity for $z > 0.2$ is found to be $0.09 \pm 0.03 \pm 0.02$, somewhat lower than the Lund prediction of 0.14.

Indications have been found for the decays $D_s^\pm \rightarrow \eta \pi^\pm$ and $D_s^\pm \rightarrow \eta' \pi^\pm$. The $D_s^\pm$ production cross section multiplied by the branching ratio $B(D_s^\pm \rightarrow \eta \pi^\pm)$ is found to be 5.2 ± 2.2 pb, corresponding to a branching ratio about three times as large as $D_s^\pm \rightarrow \phi\pi^\pm$ and in good agreement with a recent Mark III preliminary result.

$\sigma(e^+e^- \rightarrow D_s^\pm) \times B(D_s^\pm \rightarrow \eta' \pi^\pm)$ is found to be 8.4 ± 3.7 pb, corresponding to a branching ratio of about 19%.

We would like to acknowledge fruitful discussions with J. C. Brient concerning the search for $D_s^\pm$ decays.

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FIGURE CAPTIONS

1. $\gamma\gamma$ mass spectrum for: (a) $z > 0.2$ and (b) $z > 0.3$, where z is the $\gamma\gamma$ pair energy divided by the beam energy.
2. η (solid points) and η' (open circles) fragmentation functions. The solid curve is the LUND prediction for the η fragmentation function.
3. $\eta\ \pi^+\ \pi^-$ mass spectrum. The solid curve is a fit with a polynomial background and a Gaussian (see text).
4. (a) $\eta\ \pi^\pm$ and (b) $\eta'\ \pi^\pm$ mass spectra. The solid curves are fits with polynomial backgrounds and Gaussian (see text).

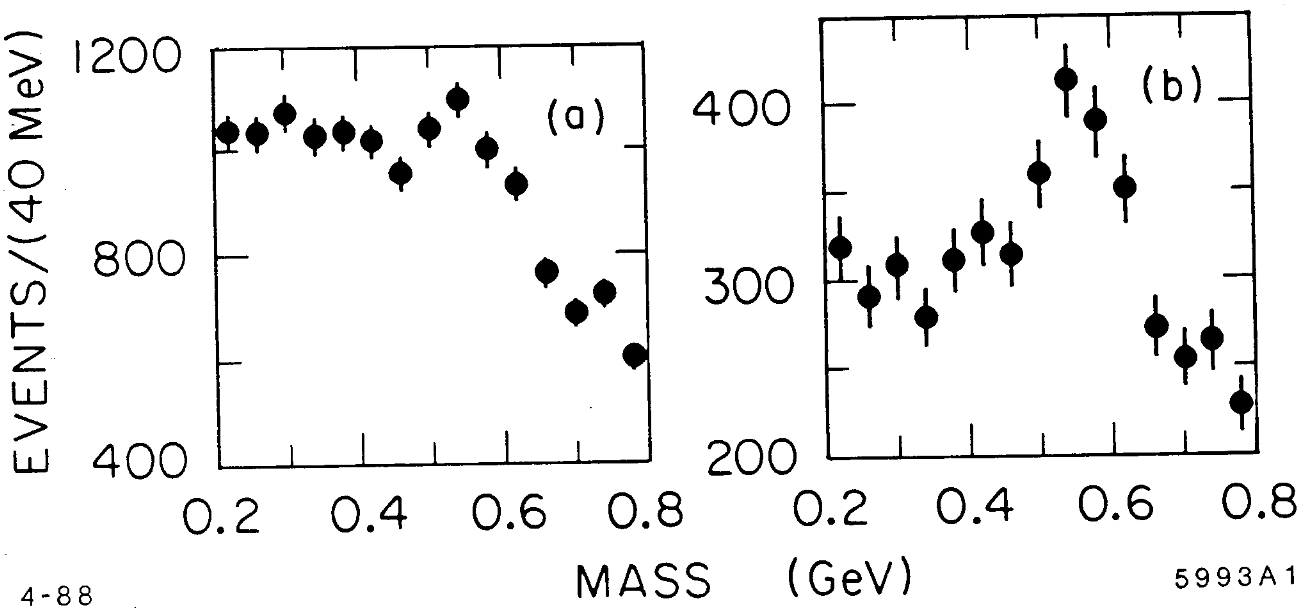

EVENTS/(40 MeV)
1200
800
400
(a)
400
300
200
(b)
0.2
0.4
0.6
0.8
0.2
0.4
0.6
0.8
MASS (GeV)
4-88
5993A1

Fig. 1

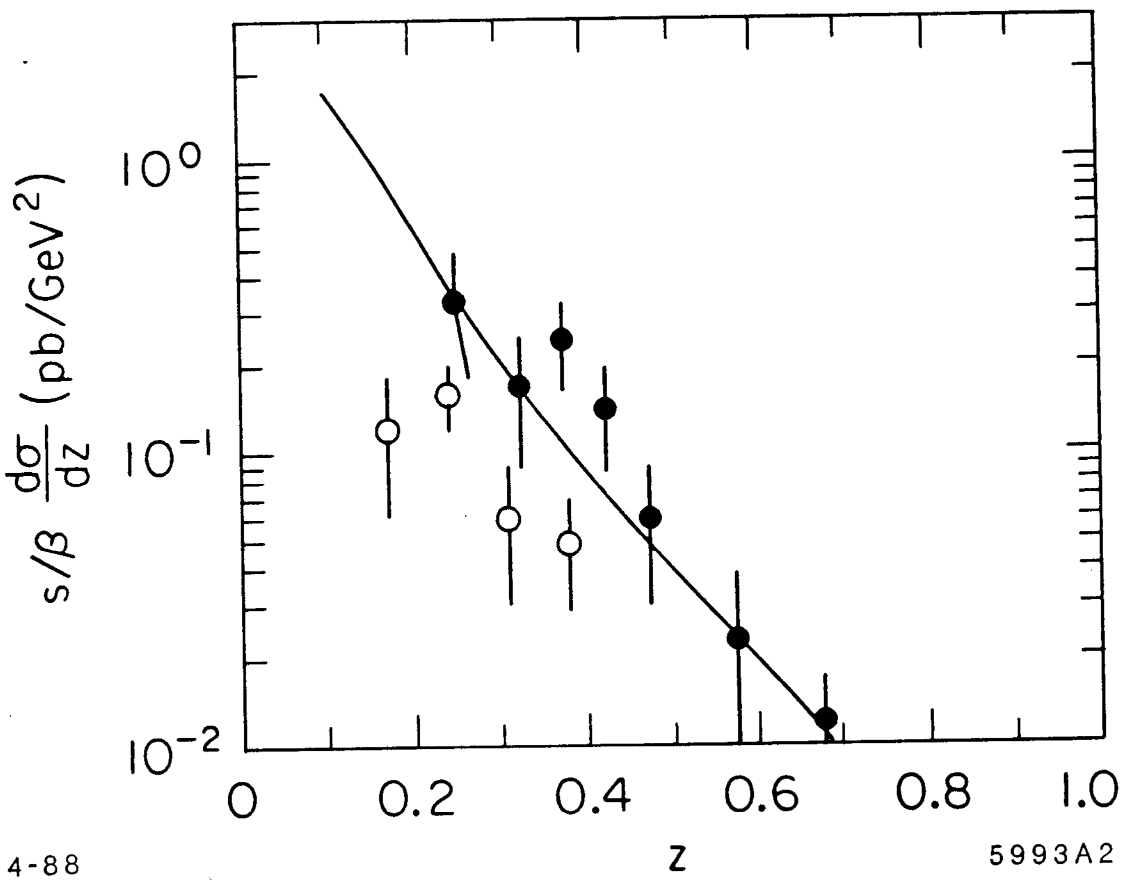

10^0
10^{-1}
10^{-2}
$s/\beta \frac{d\sigma}{dz}$ (pb/GeV^2)
0
0.2
0.4
0.6
0.8
1.0
z
4-88
5993A2

Fig. 2

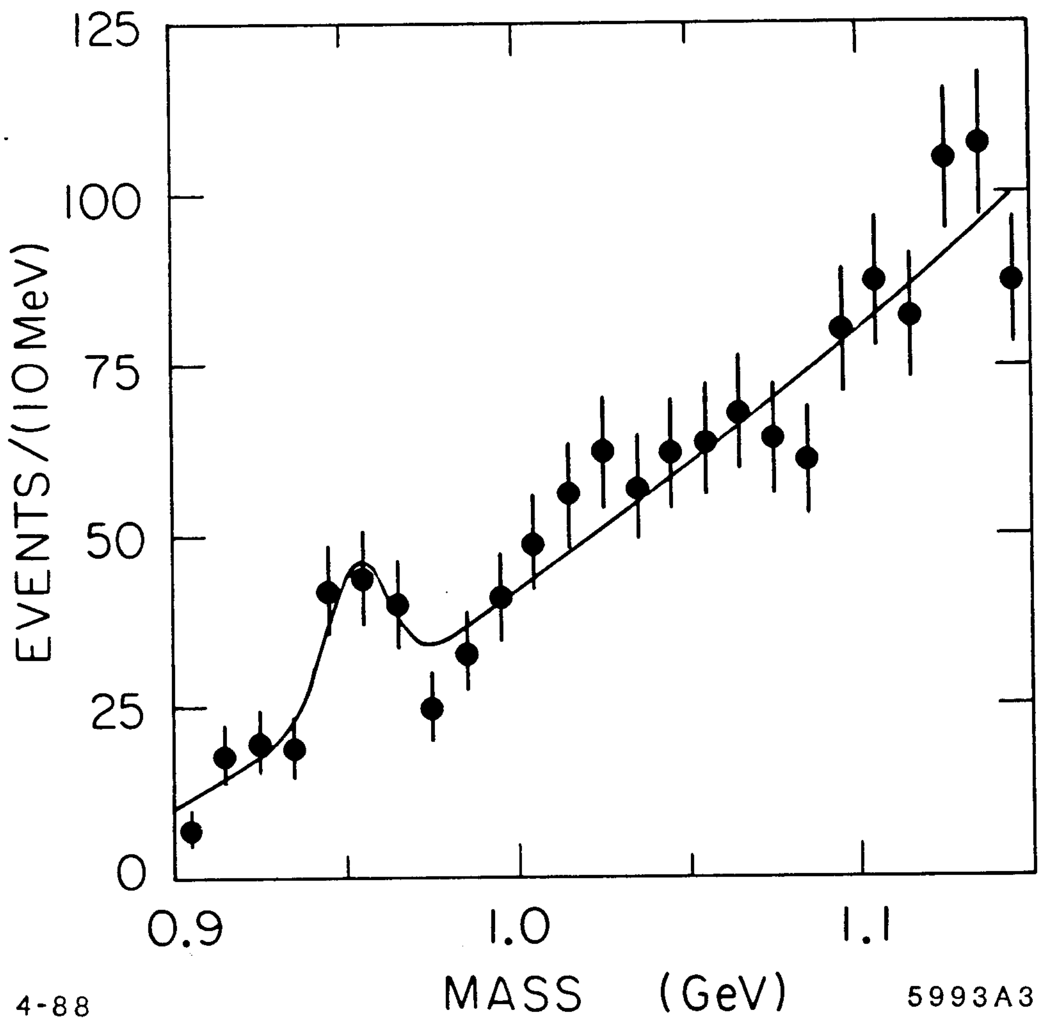
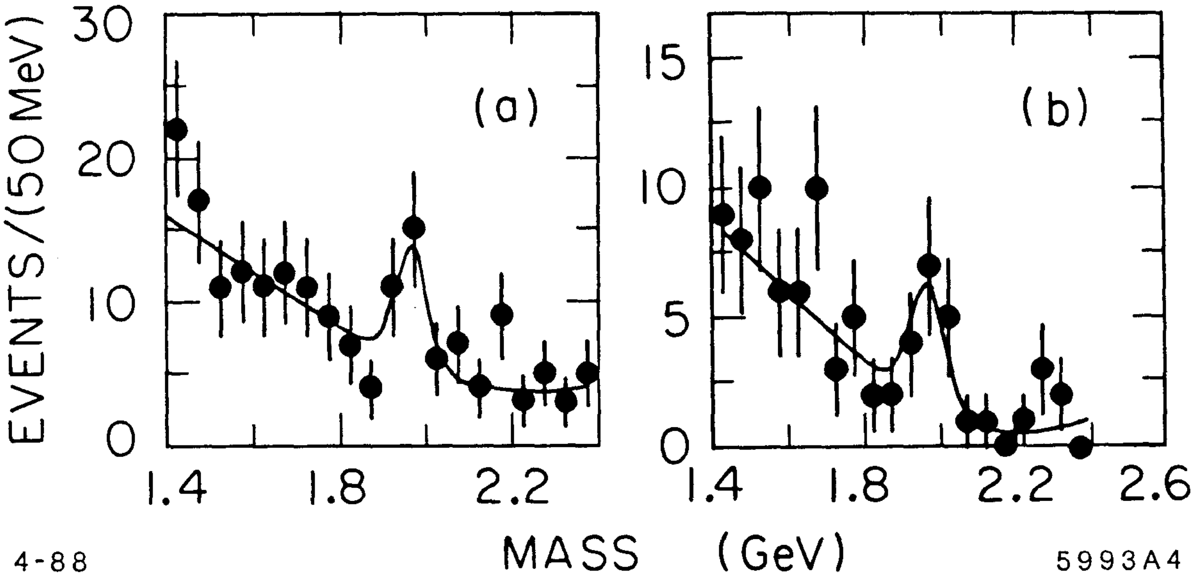


Fig. 3



EVENTS/(50 MeV)
30
20
10
0
(a)
15
10
5
0
(b)
1.4
1.8
2.2
2.6
MASS (GeV)
4-88
5993A4

Fig. 4