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Recent results on open and hidden charm production in e^+e^- annihilation at 29 GeV*

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ABSTRACT

Inclusive ψ production in e^+e^- annihilation at 29 GeV has been measured with the Mark II detector. The ψ cross section is found to be $1.1 \pm 0.5 \pm 0.4$ pb. An upper limit of 0.02 $\sigma_{\mu\mu}$ is obtained for other sources of ψ production. η production has also been investigated, using the $\gamma\gamma$ 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 evidence has been found for both decay modes at the 3 σ level.

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1. Search for ψ production

We present a search for inclusive ψ production in e^+e^- annihilation at 29 GeV, where the ψ is reconstructed via its leptonic decay modes e^+e^- and $\mu^+\mu^-$. The only known source of ψ production in high energy e^+e^- annihilation is B meson decay. The $B \to \psi$ branching ratio has been measured at the $\Upsilon(4S)$ resonance[1] . Therefore, a measurement of the ψ cross section at high energy can provide some information about other possible sources of ψ production.

The data sample was collected at the PEP storage ring at a center of mass energy of 29 GeV with the Mark II detector. The integrated luminosity is 208 pb^{-1}, corresponding to 100,000 hadronic events. A more detailed description of our analysis has been published.[2]

1.1 THE ψ SEARCH

For this measurement, the relevant parts of the Mark II detector, which is described in detail elsewhere,[3] are the drift chamber tracking system, the central electromagnetic calorimeter and the muon filter. The tracking system consists of an inner, high-resolution vertex drift chamber with seven concentric layers of sense wires,and an outer drift chamber with sixteen layers of sense wires. The system measures charged particle momenta with a resolution of $\sigma_p/p = ((0.025)^2 + (0.011p)^2)^{1/2}$ (p in GeV/c), in a 2.3 kG solenoidal magnetic field. The impact parameter resolution of the vertex chamber is 85 μm . The calorimeter consists of eight lead liquid argon modules of 14 radiation lengths, which covers 65% of the solid angle and detect electromagnetic showers with an energy resolution of $\sigma_E/E = 0.14/\sqrt{E}$, ($E$ in GeV). Electron identification is based on the detailed analysis of the observed shower in the calorimeter. The muon filter covers 45% of the solid angle and consists of 4 layers of steel plates, interlaced with proportional tubes. Muon identification requires the association with the candidate track of one hit in all four layers.

A pair of tracks is considered a candidate if both tracks are identified as electrons or muons.

In addition, the following requirements are imposed:

1. The two leptons must be in the same hemisphere.
2. In the electron channel, good spatial agreement between the shower and the extrapolation of the track is required.
3. The momenta of both tracks must be less than 11 GeV/c to remove possible contamination from beam electrons and two photon processes.

The distribution of invariant mass for unlike-sign lepton candidates is shown in Fig.1(a), where the muon and the electron channels are combined. Four muon events are found in the ψ mass range, with a small background. The electron spectrum shows an accumulation of 5 events in the same mass range. When both channels are added, a clear excess of events can be seen in the 3 GeV region. The solid curve is our fit to the data of the sum of a Gaussian centered at the ψ mass and the predicted background contribution discussed below.

.1.2 BACKGROUND PREDICTIONS

The background prediction consists of the sum of a cascade contribution and a misidentification contribution. The cascade contribution (dashed curve in Fig.1(a)) arises from events in which both the b quark and its c quark decay product undergo semileptonic decays. It is the only sizable contribution to the production of two essentially true prompt leptons in the same jet. Its magnitude and shape are estimated with a Monte Carlo simulation whose luminosity corresponds to 40 times that of the data. The same Monte Carlo program was used in the MarkII analysis of the inclusive lepton production and the b lifetime measurement[4] . The characteristics of this simulation including b and c fragmentation functions, have been carefully checked against experimental data. The yield of e-μ pairs, to which only the backgrounds contribute, is also found to be compatible with expectations.[5]

The misidentification contribution (dotted curve in Fig.1(a)) has been measured using the observed same-sign dilepton mass distribution, shown in Fig.1(b), scaled by a factor of 1.2 to take into account for the phase space suppression of like-sign pairs compared to unlike-sign pairs. The precise shape of this background is determined by looking at the same-sign distribution obtained with slightly looser identification criteria because of the small numbers of events in Fig.1 (b) . Here, we assume that the same-sign pairs in a single jet are all due to misidentification.

Since we have no same-sign candidate with a mass higher than 2.3 GeV, it is clear that the misidentification background is not dominant.

It can be seen from Fig.1(a) that the predicted background is compatible both in shape and in magnitude with the observed event population at low masses and cannot explain the excess of events at high masses. The observation of a ψ signal is the most likely interpretation of this excess.

1.3 ψ CROSS SECTION MEASUREMENT

The number of ψ is determined by fitting a Gaussian of fixed mass and width, obtained from the Monte Carlo estimate of our resolution, plus the fixed background to the experimental data, between 0.5 GeV to 4 GeV. The fit has only 1 free parameter, the ψ yield, N_ψ. The result is $N_\psi = 5.8 \pm 2.7$.

The ψ detection efficiency has been determined by Monte Carlo simulation. It has already been shown[6] that this efficiency does not depend very much on the assumed production model because of the flat acceptance for ψ momenta between 4 and 12 GeV/c . From the total dilepton sample, the ψ production cross section is, after having taken into account radiative corrections :

$$\sigma(e^+e^- \rightarrow \psi + X) = 1.1 \pm 0.5 \pm 0.4 \text{ pb} .$$

This result can also be expressed in terms of the muon pair cross section:

$$\sigma(e^+e^- \rightarrow \psi + X) = (0.011 \pm 0.005 \pm 0.004) \times \sigma_{\mu\mu}.$$

The quoted systematic error includes the uncertainties associated with the production mechanism, the background estimate,the b fragmentation function, the identification efficiencies, the luminosity measurement and the leptonic ψ branching ratio. This number can be compared with the 0.8 $\pm$ 0.08 pb cross section for ψ produced by B decays, assuming an average branching ratio of beauty particles to ψ of 1.08%$\pm$0.11%[1] .

The observed lifetime distribution of the ψ candidates is consistent with the hypothesis that all or most of the ψ are from B decays.

An upper limit can be derived for the production of ψ from sources other than B decays. The expected number of ψ coming from B decays is statistically subtracted from the number of observed ψ . The upper limit at 90 % c.l. for ψ production from any other source than b decays is 0.02 $\sigma_{\mu\mu}$. This limit is not valid for models in which the fraction of ψ produced with a momentum below 4 GeV/c exceeds 20% .

1.4 CONCLUSION

The inclusive cross section for ψ production in e^+e^- annihilation at 29 GeV has been measured and found to be 1.1 $\pm$0.5$\pm$0.4 pb or (0.011$\pm$0.005$\pm$0.004)$\times$ $\sigma_{\mu\mu}$. This production rate should be compared with the 0.8$\pm$0.08 pb cross section expected from B decays. We set an upper limit of 0.02 $\sigma_{\mu\mu}$ on other possible sources.

2. η physics

We present a measurement of inclusive η and η' production based on the same sample as above. We also present evidence for exclusive decays of the $D_s^{\pm}$ involving η and η' . A more detailed description of this analysis can be found elsewhere.[7]

2.1 INCLUSIVE η PRODUCTION

Hadronic events were selected as in the previous chapter. 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 Fig.1a and Fig.1b, for z>.2 and z>.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 efficiency rises slowly with energy from 3% at 4 GeV to 5 % at 10 GeV .

The fragmentation function is plotted in Fig.3 , 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[8] and HRS[9] groups. The agreement with the LUND prediction, as represented by the solid curve, is also good. The η multiplicity per event for different z cuts is summarized in the table below.

Table 1. η multiplicities per event

z cuts	Multiplicty per event
z>.1	0.30±0.07± 0.05
z>.2	0.12±0.03±0.02
z>.3	0.09±0.02±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 prediction of 0.70 .

2.2 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. Only pairs with 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.
2. $\cos\theta^*$ has to be less than 0.7 , where θ^* 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 $\cos\theta^* = 1$, corresponding to asymmetric photon pairs.

A clear η' signal of 45 ± 11 events can be seen in Fig.4. 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. The η' fragmentation function is shown in Fig.3 . The number of η' above z=.2 is $N_{\eta'}(z > .2) = 0.09 \pm 0.03 \pm 0.02$. Assuming the Lund fragmentation function leads to a number of η' per event of $0.26 \pm 0.09 \pm 0.05$.

2.3 SEARCH FOR $D_s^\pm \rightarrow \eta\ \pi^\pm$

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 additionnal cuts which reduce the background to an acceptable level.

1. The η momentum is required to be greater than 4.5 GeV (i.e. z>.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)). We have thus observed evidence for the decay $D_s^\pm \rightarrow \eta\ \pi^\pm$ at the 3 σ level.

A 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:

$\sigma(e^+e^- \to D_s^\pm) \times B(D_s^\pm \to \eta\ \pi^\pm) = 5.2 \pm 2.2$ pb.

Using standard hypothesis for the $D_s^\pm$ production rate this result translates into a branching ratio around 11 % , about 3 times larger than the world average value for the $\phi\pi^\pm$ mode. The MarkIII collaboration has presented preliminary evidence[10] for the same decay mode of the $D_s^\pm$, with a comparable branching ratio.

2.4 SEARCH FOR $D_s^\pm \to \eta'\ \pi^\pm$

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, the η momentum has to be greater than 2.5 GeV.

An excess of events is found in the $D_s^\pm$ mass region,(see Fig.4(b)), indicating the observation of the decay $D_s^\pm \to \eta'\ \pi^\pm$ at a 3 σ level. This leads to after radiative corrections: $\sigma(e^+e^- \to D_s^\pm) \times B(D_s^\pm \to \eta'\ \pi^\pm) = 8.4 \pm 3.7$ pb.
With the same production hypothesis as above, the branching ratio for $D_s^\pm \to \eta'\ \pi^\pm$ 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 Kamal et al.[11]

2.5 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±0.07±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±0.03±0.02 , somewhat lower than the Lund prediction of 0.14.

Indications have been found for the decays $D_s^\pm \to \eta\ \pi^\pm$ and $D_s^\pm \to \eta'\ \pi^\pm$. The $D_s^\pm$ production cross section multipied by the branching ratio $B(D_s^\pm \to \eta\ \pi^\pm)$ is found to be 5.2±2.2 pb , corresponding to a branching ratio about 3 times as large as $D_s^\pm \to \phi\pi^\pm$ and in good agreement with a recent MarkIII preliminary result. $\sigma(e^+e^- \to D_s^\pm) \times B(D_s^\pm \to \eta'\ \pi^\pm)$ is found to be 8.4 ±3.7 pb, corresponding to a branching ratio of about 19% .

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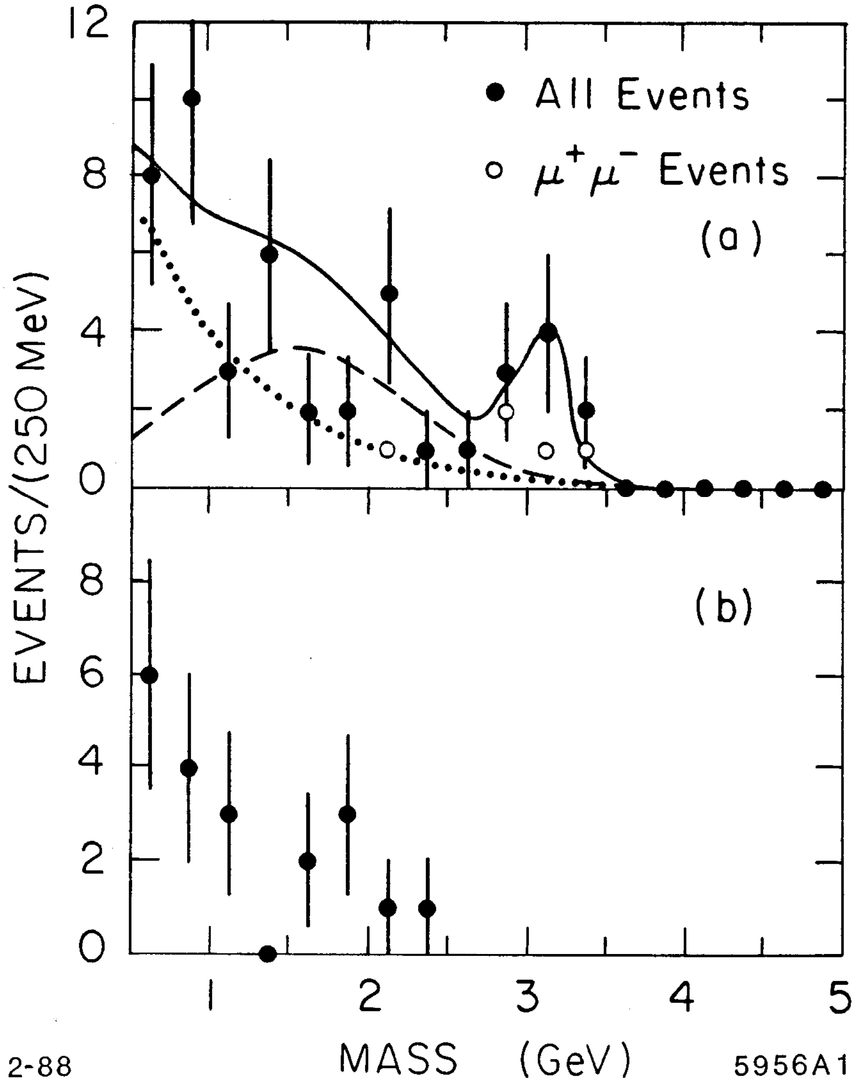
FIGURE CAPTIONS

1. Fig. 1(a) : Unlike-sign dilepton mass distribution for all events (solid circles) and for $\mu^+\mu^-$ events (open circles) . The dotted curve is the prediction of the misidentification background , the dashed curve is the estimated cascade contribution. The solid curve is the sum of these two contributions and of a gaussian centred on the ψ mass.
   Fig. 1(b) : Same-sign dilepton mass distribution.
2. $\gamma\gamma$ 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
3. η (solid points) and η' (open circles) fragmentation functions.The solid curve is the LUND prediction for the η fragmentation function.
4. $\eta\ \pi^+\ \pi^-$ mass spectrum. The solid curve is a fit with a polynomial background and a Gaussian (see text).
5. (a) $\eta\ \pi^{\pm}$ and (b) $\eta'\ \pi^{\pm}$ mass spectra. The solid curves are fits with polynomial backgrounds and Gaussian (see text).



12
8
4
0
8
6
4
2
0
1
2
3
4
5
EVENTS/(250 MeV)
MASS (GeV)
All Events
$\mu^+\mu^-$ Events
(a)
(b)
2-88
5956A1

Fig. 1

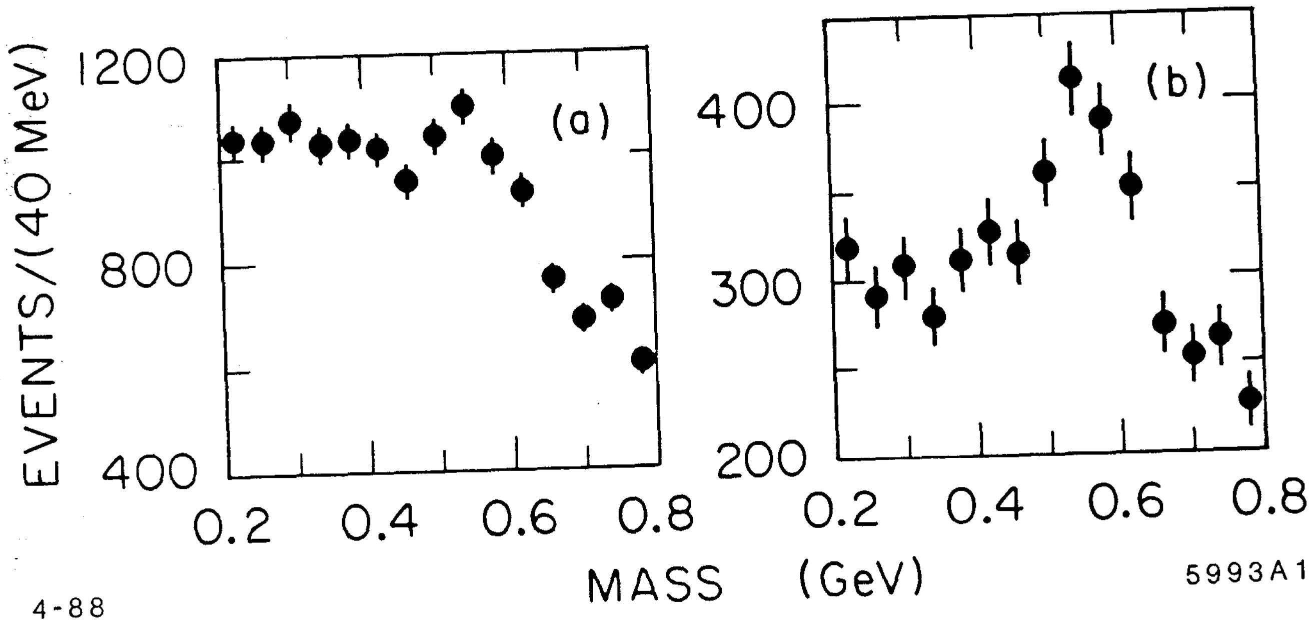

EVENTS/(40 MeV)
1200
800
400
(a)
0.2
0.4
0.6
0.8
400
300
200
(b)
0.2
0.4
0.6
0.8
MASS (GeV)
4-88
5993A1

Fig. 2

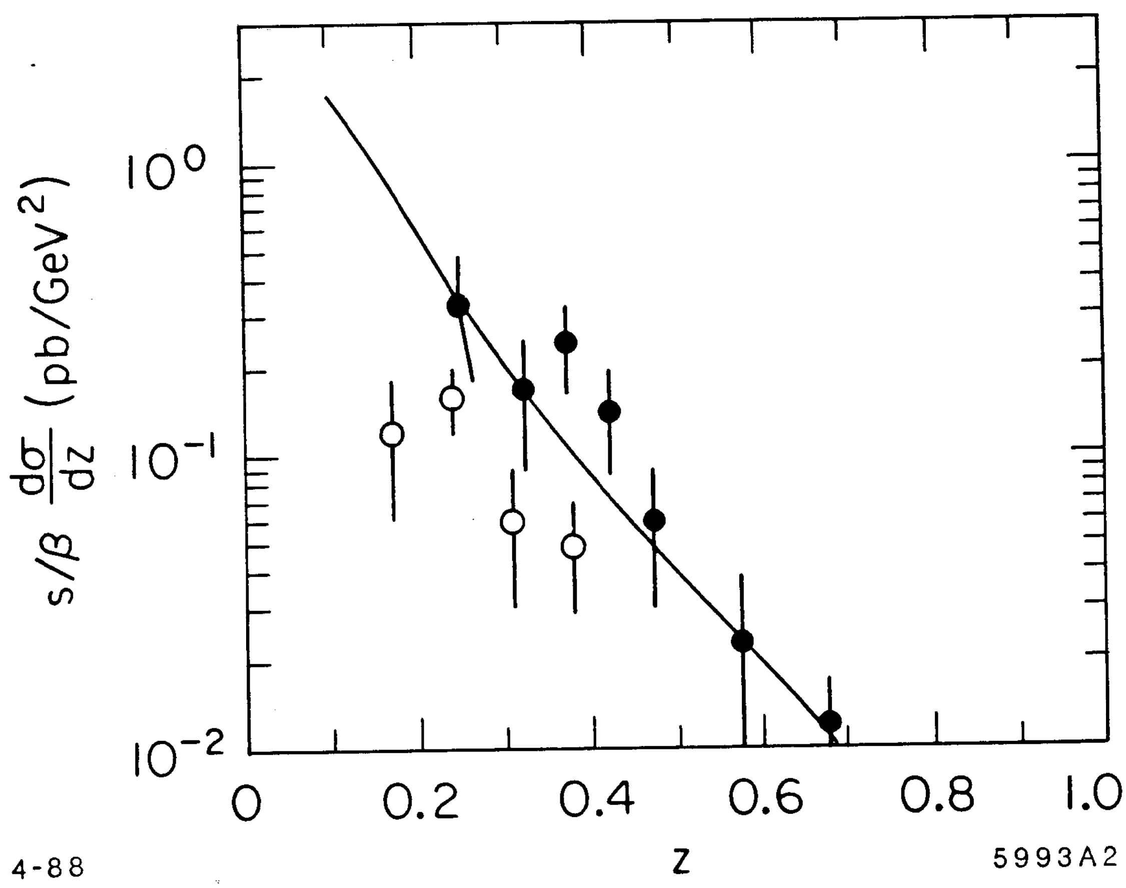

$s/\beta \frac{d\sigma}{dz}$ (pb/GeV^2)
10^0
10^{-1}
10^{-2}
0
0.2
0.4
0.6
0.8
1.0
z
4-88
5993A2

Fig. 3

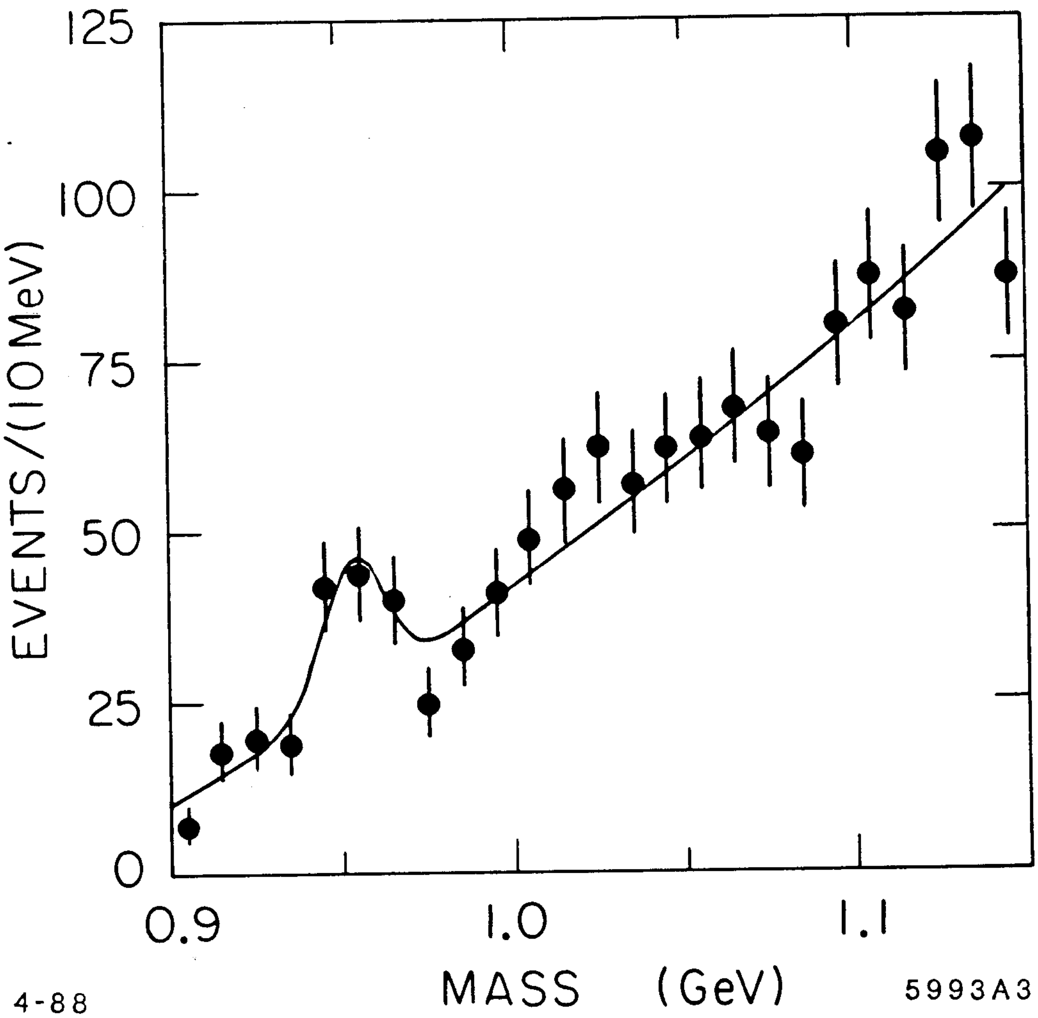


Fig. 4

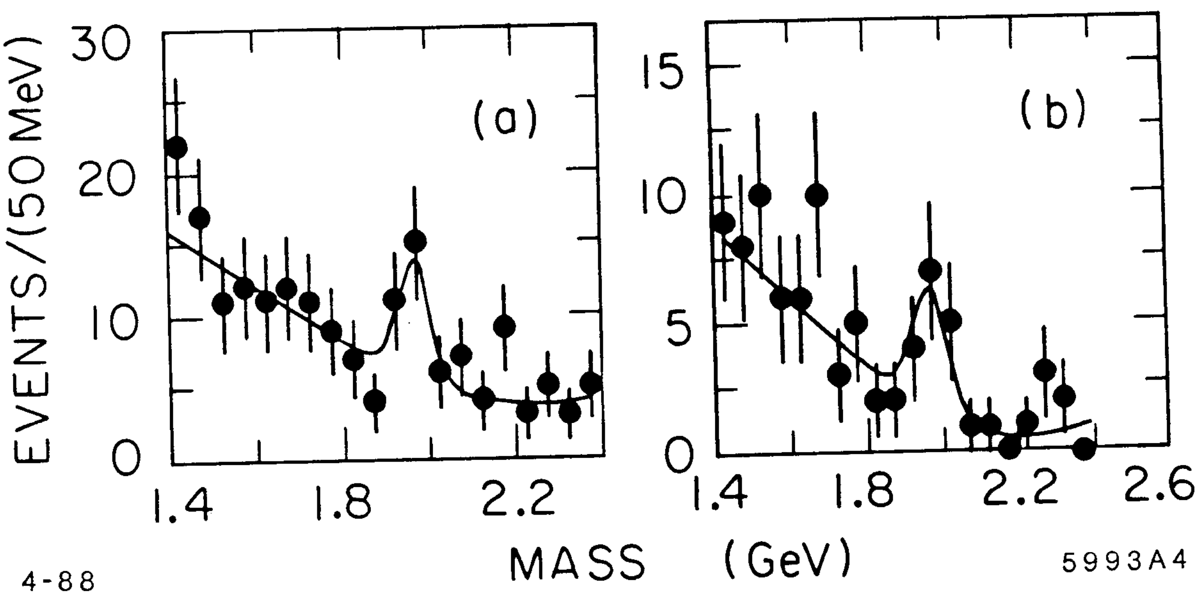

EVENTS/(50 MeV)
30
20
10
0
(a)
15
10
5
0
(b)
1.4
1.8
2.2
1.4
1.8
2.2
2.6
MASS (GeV)
4-88
5993A4

Fig. 5