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Charm D Production in e^+e^- Annihilation at 29 GeV

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HRS COLLABORATION

Abstract

Results are presented on the analysis of charm D Production from 300 pb^{-1} of data taken with the HRS Detector at PEP. The electroweak asymmetry is $-8.4 \pm 3.6\%$ and R $(D + D^*) = 1.57 \pm 0.17$. Fragmentation functions for D^o, D^+, D^{*+} production and the results of a search for the D^{**} are given.

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MASTER

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The characteristics of charm quark production and fragmentation have been studied using D°, D^+ and D^{*+} charm meson production and their charge conjugates. The data come from an integrated luminosity of 300 pb^{-1} collected by the High Resolution Spectrometer (HRS) over a five year running period at PEP at a center of mass energy of 29 GeV. We have previously published[1,2] results on charm meson production from 106 pb^{-1} and the results presented here use the same experimental techniques.

The HRS is a general purpose detector using a 1.62T solenoidal magnetic field with a resolution for high momentum tracks at large angles of $\sigma_p/p \approx 2 \times 10^{-3}p$ (p in GeV/c). In reconstructing D°, D^+ and D^* decays, no particle identification was used and each track in the events passing the above cuts was taken as both a kaon and a pion.

We have observed charged D^* production in the decay mode

$$D^{*+} \rightarrow D^\circ \pi^+ \qquad (1)$$

with the D° decaying into the $K^-\pi^+$, $K^-\pi^+\pi^+\pi^-$ and $K^-\pi^+\pi^\circ$ modes. Our analysis also includes the charge conjugate states. The excellent mass resolution of the HRS and the fact that the Q value of reaction (1) is only 5.8 MeV, so that the $D^{*+} - D^\circ$ mass difference (δ) is well determined, means that clear signals with small backgrounds can be observed. For the decay $D^\circ \rightarrow K^-\pi^+$, all $K^-\pi^+$ combinations were used and the quantity $\delta = (M_{K^-\pi^+\pi^+} - M_{K^-\pi^+})$ was determined for those combinations with $1.81 < M_{K^-\pi^+} < 1.92$ GeV which is the mass region for D° decays. The same technique was used also for the $K^-\pi^+\pi^+\pi^-$ decay of the D°. Fig. 1b shows the mass difference δ distribution for the $K^-\pi^+$ decay mode with $Z_{D^*} \geq 0.4$ and Fig. 1a the δ distribution for $K^-\pi^+$ decay mode with $0.2 \leq Z_{D^*} \leq 0.4$. Prominent peaks are evident at $\delta \sim 0.145$ GeV.

Figs. 2a and b show the corresponding mass distributions for $0.143 \leq \delta \leq 0.149$ GeV; clear D° peaks can be seen. In order to reduce background at low z $(0.2 \rightarrow 0.4)$ events were selected with $|\cos\theta^*_\pi| < 0.8$ where θ^*_π is the decay angle of the D° in its helicity frame[3].

Distributions for the $K^-\pi^+\pi^+\pi^-$ decay of the D° are shown in Fig. 3a,b.

For the $K\pi\pi^\circ$ decay mode of the D°, no attempt was made to reconstruct the π°. The well known kinematic enhancement around 1.6 GeV, the so called S° peak, formed by the $K^-\pi^+$ from the D° was used. This region corresponds to the D° decays where the D° has a velocity close to that of the $K^-\pi^+$ system, so that the resolution in δ is still good. Fig. 4a shows the distribution of $\delta = M_{K^-\pi^+\pi^+} - M_{K^-\pi^+}$ for $1.55 \leq M_{K^-\pi^+} \leq 1.70$ GeV and $z \geq 0.4$. A signal, corresponding to D^{*+} production is observed around $\delta = 0.145$ GeV, although the peak is broadened due to the missing π°.

Electroweak Asymmetry

The D^* production shown in Figs. 1,2,3 and 4 have been used to determine the electroweak asymmetry. In the standard model it is expected that the integrated forward-backward asymmetry

$$A = \frac{3}{2}\frac{1}{q} g^e g^c \quad \frac{G_F}{2\sqrt{2}\ \pi\alpha} \quad \frac{s}{1-s/M_Z^2} \tag{2}$$

where, M_Z is the Z° mass, q is the charge of the c quark, and g^e and g^c are the electron and quark axial vector coupling constants. The predicted asymmetry at $\sqrt{s} = 29$ GeV, using $M_Z = 94$ GeV, $q = 2/3$, and $g^c = -g^e = 1/2$, is $A = -0.095$. Since the charm quark is not observed directly, θ is determined by the line of flight of charmed D^* mesons with high fractional energy $Z = 2\ E_{D^*}/\sqrt{s}$, where E_{D^*} is the energy of the meson.

The production angular distribution for the D^{*+} is shown in Fig. 5 after combining all the decay modes. There are 660 events in the range $|\cos\theta| \leq 0.7$ with an estimated background of < 10%. We have checked these data for systematic biases and other effects which could influence the asymmetry measurements and have found none of any significance. A fit of the data to the form $1 + a(\cos\theta) + \cos^2\theta$ gives $A = -0.06 \pm 0.04$ for the full solid angle.

We have also independently measured the charm quark asymmetry using the inclusive $K^-\pi^+$ decay of the D° and the $K^-\pi^+\pi^+$ decay of the D^+. The combined mass spectra for these two channels for $Z > 0.45$ and $|\cos\theta| < 0.8$ is shown in Fig. 6c. To improve the signal to background certain decay angular regions in the D rest frame are excluded[4]. Figs. 6a and 6b show this mass spectra divided into forward and backward hemispheres for the charmed quark relative to the electron direction. The asymmetry, $A = (F-B)/(F+B)$, is measured by a simultaneous fit with identical background shape and normalization. The measured forward-backward asymmetry correcting to the full solid angle yields $A = -0.18 \pm .08$. Combining this with our value for D^* production gives our best value of -0.084 ± 0.0036 which can be compared to the expected -0.095.

Cross Sections and Branching Ratios

The main uncertainly in determining the total and differential cross sections comes from the errors in the branching ratios for the observed decay modes. Recently Mark III has published[5] new values for D° and D^+ decays, however, the $D^* \rightarrow D^\circ\pi^+$ branching ratio is still poorly determined. In our published papers we have used 0.44 ± 0.1 but for this analysis we use a value determined from our own data using the ratio of inclusive D° to D^{*+} production with the $D^\circ \rightarrow K^-\pi^+$.

For the D^* production and decay we take $D^{*\circ} \rightarrow D^\circ + (\pi^\circ, \gamma)$ with a branching ratio of 1 and $D^{*+} \rightarrow D^\circ \pi^+$ with a branching ratio of ε. In addition we will assume that there is a fraction f of directly produced D mesons, therefore

$$\frac{N_{D^\circ}}{N_{D^*}} = \frac{1 + \varepsilon + f}{2}$$

This ratio is measured experimentally to be 1.477 ± 0.15 and does not depend on the D° acceptance or the branching ratio $D^\circ \rightarrow K^- \pi^+$.

This gives $\varepsilon = 0.51 \pm 0.08$ for $f = 0$ and $\varepsilon = 0.68 \pm 0.1$ for $f = 0.33$. The first number is a lower limit on ε and the second is the expected value of f using simple spin statistics. For the determination of cross sections and R values we use 0.6 ± 0.1, a value which is also consistent with our D°/D^+ ratio. The cross sections and R values from our data using 0.6 ± 0.1 and the Mark III branching ratios of $D^\circ \rightarrow K\pi = 5.6\%$ and $D^+ \rightarrow K\pi\pi = 11.6\%$ are shown in Table 1.

Of interest is the total R value for D°, D^+ and D^{*+} mesons.

$$R_{Total} = R_{D^\circ} + R_{D^+}$$

Our measured value[6] is $R_{Total} = 1.57 \pm 0.17$. The total expected $c\bar{c}$ production value using $\alpha_s = 0.17$ is 2.8 units of R with an additional .7 units from $b \rightarrow c$. Our total R value for D and D^* production, therefore, only accounts for about 50% of charm quark jets. This change from our previously published value or R_{Total} is almost entirely due to the much larger Mark III branching ratios for D decay. In principle we can verify the cross section for D^* production and the D° branching ratios if some other characteristic of D^* decay can be observed. In particular, we have used the same sample of D^* events which were used to determine the electroweak

asymmetry to search for the cascade pion from D^* decays in the opposite jet. This cascade pion is restricted to momenta less than ~ 1 GeV and with $P_T < 40$ MeV to the parent D^* direction. We have determined the thrust axis for each event and used the P, P_T of the cascade pion from the reconstructed D^* to compare with the P-P_T distributions of like and unlike charged particles in the opposite jet. Using the value of $R_{D^*} = 1.32 \pm .25$ and particular cuts on P and P_T we expect 28 ± 6 unlike pions and have observed 52 ± 15. This is a weak indication that the $D^\circ \to K\pi$ branching ratio is lower than the Mark III value and that R_{Total} is larger.

Fragmentation Function

We have used the channel $D^* \to (D^\circ\pi)$, $D^\circ \to K^-\pi^+$ to determine the fragmentation function over the whole z range.

Fig. 7a shows the fragmentation function $D(Z) = 1/N\ dN/dZ$ and Fig. 7b the scaling cross section $s/\beta\ d\sigma/dZ$ for this analysis[7]. Table 1 lists the data for each region of Z, along with the values for D° and D^+ production[8]. The experimental data for the D^{*+} peaks near Z = 0.53 and has a mean value of 0.523 ± 0.017. This hard fragmentation is undoubtedly due to the process $e^+e^- \to c\bar{c}$, with the D^* containing the primary charmed quark since charmed mesons from the process $e^+e^- \to b\bar{b}$ are expected to carry a much smaller fraction of the available energy. We note that although our results extend to low Z where b fragmentation is expected to be important compared to charm fragmentation we have not separated the two components in our analysis. Fig. 1a does show, however, a significant D^* peak presumably due to b fragmentation.

Search for the D^{**}

Recently the ARGUS group has published[9] evidence for a new charmed meson decaying into $D^*\pi$ with a mass of 2420 ± 6 MeV and a width of 70 ± 21 MeV. We have used our D^* data and made a similar analysis by combining the D^* with an extra pion and computing the mass difference between the $D^*\pi$ and D^*. This is done, rather than plot mass directly, both to improve resolution and to be able to use the $D^\circ \to K\pi\ \pi^\circ$ channel. The result for $Z > 0.4$ is shown in Figure 8a where a broad enhancement can be seen. The curve shown is that of the $D^*\pi$ charge two system with an arbitrary normalization. Figures 8b and 8c show this data divided into two Z regions. It is clear that the mass and shape of the enhancement changes depending on the Z region chosen. We have examined the helicity angle for the $D^*\pi$ system and find a backward peak $\cos\theta^*_\pi < -0.7$ due to background pions from the opposite jet. Figure 9 shows the mass difference with this region removed. Once again a clear peak can be seen with similar variations in Z.

It is clear from our data that an enhancement exists in the $(D^*\pi)^\circ$ system that is not present in the $(D^*\pi)^{++}$ system. It appears, however, that this enhancement is more complicated than a single narrow resonance decaying strongly. Whether this is due to the presence of other D^{**} states or to a limited phase space background coming because the jet prefers to be charge zero is not clear. A number of resonances are expected in this mass region and some predictions have been discussed recently by Rosner[10]. We have also looked for possible decays in the $D\pi$ system. No significant peaks are observed although the background is much higher and a large branching ratio into this mode cannot be ruled out.

Summary

Using a 300 pb^{-1} data sample we have determined the properties of inclusive charm D°, D^{+} and D^{*+} production. The electroweak asymmetry is $-8.6 \pm 3.6\%$ in very good agreement with the standard model. The total R value of 1.57 ± 0.17 for inclusive D production accounts for only ~ 50% of charm quark fragmentation. A clear enhancement is seen in the $(D^{*}\pi)^{\circ}$ system which appears to be more complicated than a single D^{**} state.

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References

1) M. Derrick et al., Phys. Rev. Lett. 53 (1984) 1971.

2) M. Derrick et al., Phys. Lett. 146B (1984) 261.

3) The jet structure of the events tends to produce asymmetric "decays" ($|\cos\theta^*_\pi| \to 1$) for random combinations of tracks because the limited p_t of the average background track is smaller relative to the D axis than is the average p_t of the products of an actual D° decay. We have checked the effect of the decay angle cut by using $D^\circ \to K^-\pi^+$ combinations observed within a $D^{*+} \to D^\circ\pi^+$ transition for $Z > 0.6$. For this very clean subsample of $D^\circ \to K^-\pi^+$ events, the distribution in decay angle is observed to be isotropic as expected.

4) For the inclusive $K^-\pi^+$ mass spectrum $|\cos\theta^*_\pi| < 0.7$ and for the $K^-\pi^+\pi^+$ mass spectrum $|\cos\theta^*_p| > 0.3$ where θ^*_p is the angle between the line of flight and the perpendicular to the decay plane in the $K\pi\pi$ center of mass system.

5) R.M. Baltrusaitis, Phys. Rev. Lett. 56 (1986) 2140.

6) R_{Total} can also be determined from the D° and D^* production independent of f and ε. Our value of $1.547 \pm .35$ is consistent with that from $R_{D^+} + R_{D^\circ}$.

7) We have used a point crossection for $\sqrt{s} = 27.3$ GeV which is the $\sqrt{s}$ value after radiative corrections.

8) The fractional energy Z carried by D mesons resulting from D^* decay is about 7% lower than that of the D^*.

9) H. Albrecht, et al., Phys. Rev. Lett. 56 (1986 549.

10) J. Rosner, P-Wave Mesons With One Heavy Quark, EFI85/91.

Table 1

(a) D^* Fragmentation

z	$s/\beta\ d\sigma/dZ$	$1/N\ dN/dz$
.2 → .4	.086 ± .022	1.366 ± .22
.4 → .5	.112 ± .027	1.868 ± .27
.5 → .6	.158 ± .033	2.667 ± .31
.6 → .7	.081 ± .022	1.391 ± .23
.7 → .8	.047 ± .011	.800 ± .13
.8 → 1.0	.016 ± .009	.270 ± .05

(b) D°, D^+ Fragmentation

z	$s/\beta\ d\sigma/dz$	
	D°	D^+
.3 → .5	.203 ± .035	.039 ± .03
.5 → .6	.200 ± .026	.091 ± .02
.6 → .7	.164 ± .02	.072 ± .015
.7 → 1.0	.037 ± .006	.012 ± .004

(c) Crossections / R values

	σ(nb)	R
$D^{*+} + D^{*\circ}$	.154 ± .03	1.32 ± .25
$D^\circ + \bar{D}^{\bar{\circ}}$	.136 ± .015	1.17 ± .13
$D^+ + D^-$	.047 ± .011	.40 ± .10
R_{Total} $(D+D^*)$	.183 ± .02	1.57 ± .17

TABLE AND FIGURE CAPTIONS

Table 1 The invariant cross section and fragmentation function for D^{*+}, D°, D^{+} production

Figure 1 The quantity δ

1 (a) for $D^{\circ} \to K^{-}\pi^{+}$ with $1.81 \leq M_{K\pi} \leq 1.92$ GeV and $0.2 \leq Z \leq 0.4$ and $|\cos\theta^{*}_{\pi}| \leq 0.8$

(b) for $D^{\circ} \to K^{-}\pi^{+}$ with $1.81 \leq M_{K\pi} \leq 1.92$ GeV and $Z \geq 0.4$

Figure 2 (a) Mass of the $K\pi$ system with $0.143 \leq \delta \leq 0.149$ GeV and $0.2 \leq Z \leq 0.4$ and $|\cos\theta^{*}_{\pi}| \leq 0.8$

(b) Mass of the $K\pi$ system with $0.143 \leq \delta \leq 0.149$ GeV and $Z \geq 0.4$

Figure 3 (a) The quantity δ for $D^{\circ} \to K^{-}\pi^{+}\pi^{+}\pi^{-}$ with $1.81 \leq M_{K3\pi} \leq 1.92$ GeV and $Z \geq 0.6$

(b) Mass of the $K\pi\pi\pi$ system with $0.143 \leq \delta \leq 0.149$ GeV and $Z \geq 0.6$

Figure 4 (a) The quantity δ for $D^{\circ} \to K^{-}\pi^{+}\pi^{\circ}$ with $1.55 \leq M_{K\pi} \leq 1.70$ GeV and $Z \geq 0.4$

Figure 5 The production angular distribution of D^{*+} events.

Figure 6 Combined $K\pi$ and $K\pi\pi$ mass distributions for $z_D \geq 0.45$ and $|\cos\theta| \leq 0.8$

(a) for forward hemisphere events

(b) for backward hemisphere events

(c) for all laboratory angles $|\cos\theta| \leq 0.8$

The $K\pi$ mass distribution has $|\cos\theta^{*}_{\pi}| \leq 0.7$

The $K\pi\pi$ mass distribution has $|\cos\theta^{*}_{p}| \geq 0.3$

Figure 7 (a) The fragmentation function $D(Z) = 1/N\ dN/dZ$ versus Z

(b) The scaling cross section as a function of Z

Figure 8 The mass difference $M(D^*\pi)^\circ - M(D^*)$ for the indicated Z regions. The curve is for the $M(D^*\pi) - M(D^*)$ charge two system

Figure 9 The mass difference $M(D^*\pi) - M(D^*)$ for the indicated Z regions and $\cos\theta^*_\pi > -0.7$

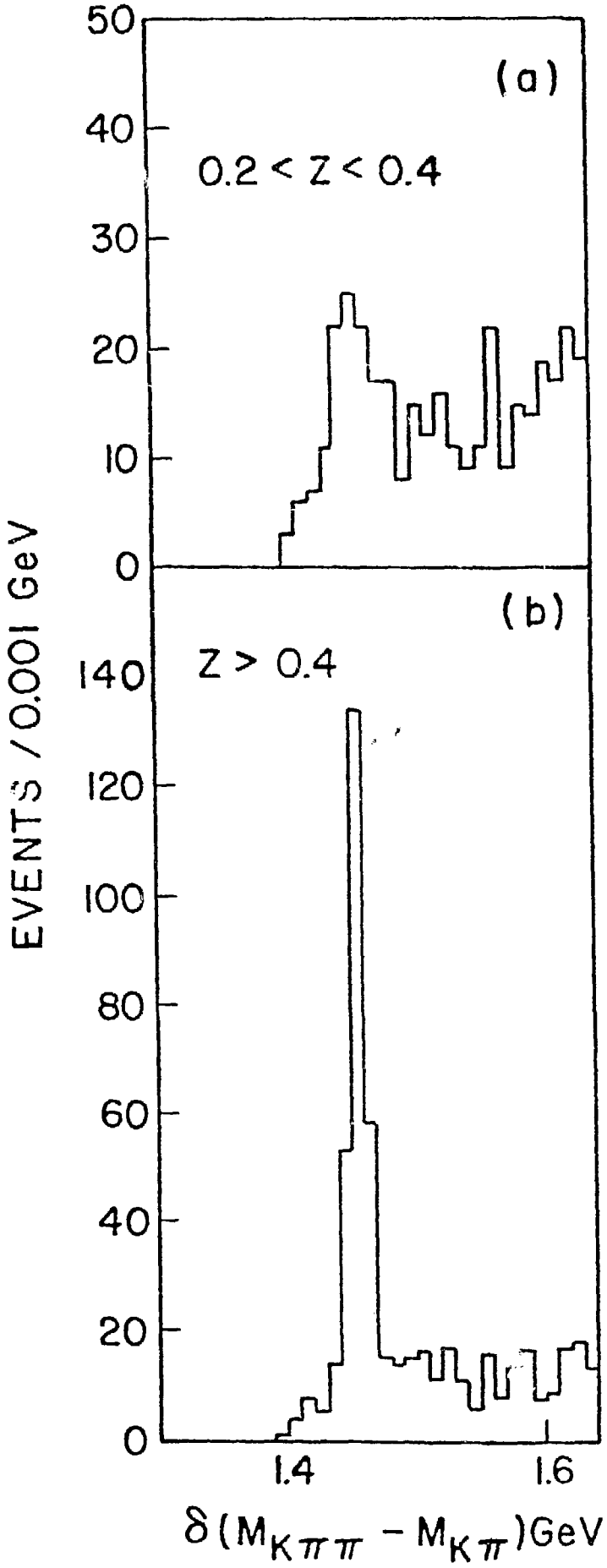

(a)
0.2 < Z < 0.4
(b)
Z > 0.4
EVENTS /0.001 GeV
50
40
30
20
10
0
140
120
100
80
60
40
20
0
1.4
1.6
δ(M_Kππ − M_Kπ)GeV

Figure 1

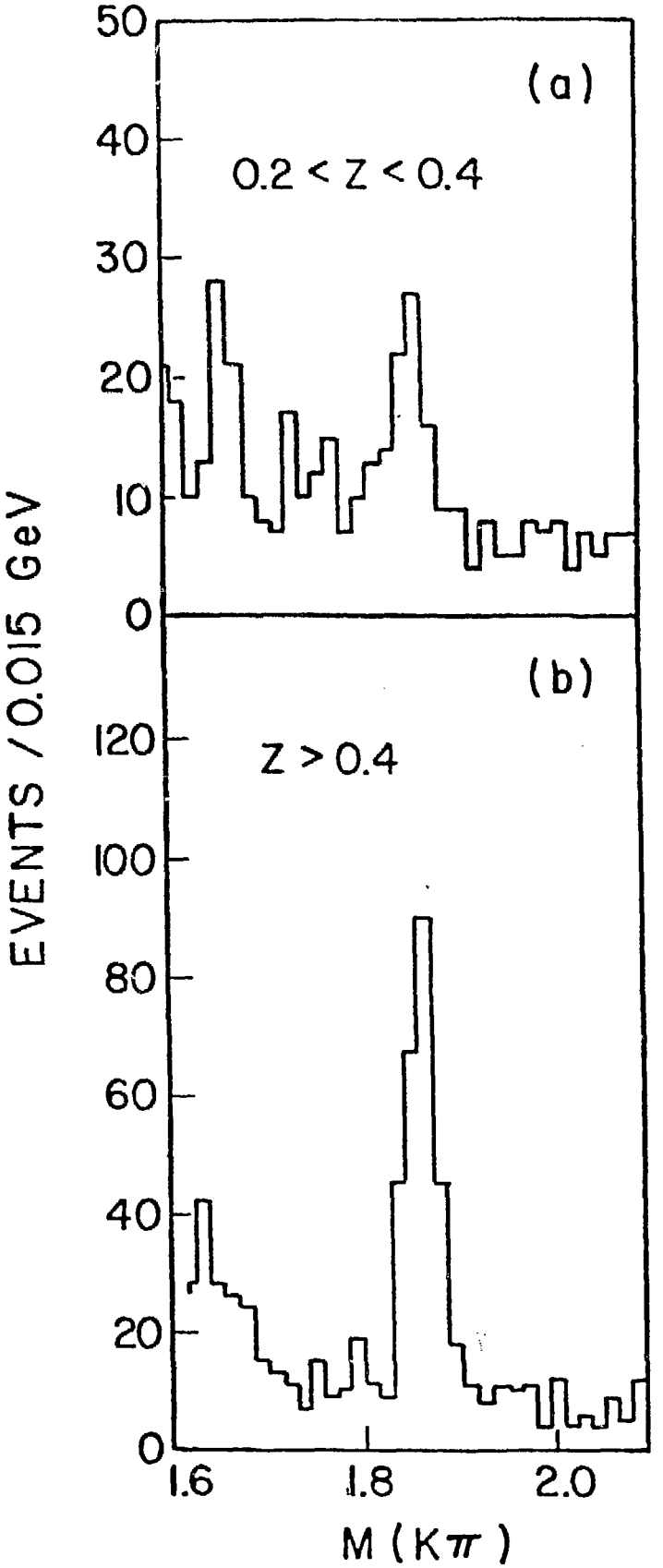

(a)
0.2 < Z < 0.4
(b)
Z > 0.4
EVENTS /0.015 GeV
M (Kπ)
50
40
30
20
10
0
120
100
80
60
40
20
0
1.6
1.8
2.0

Figure 2

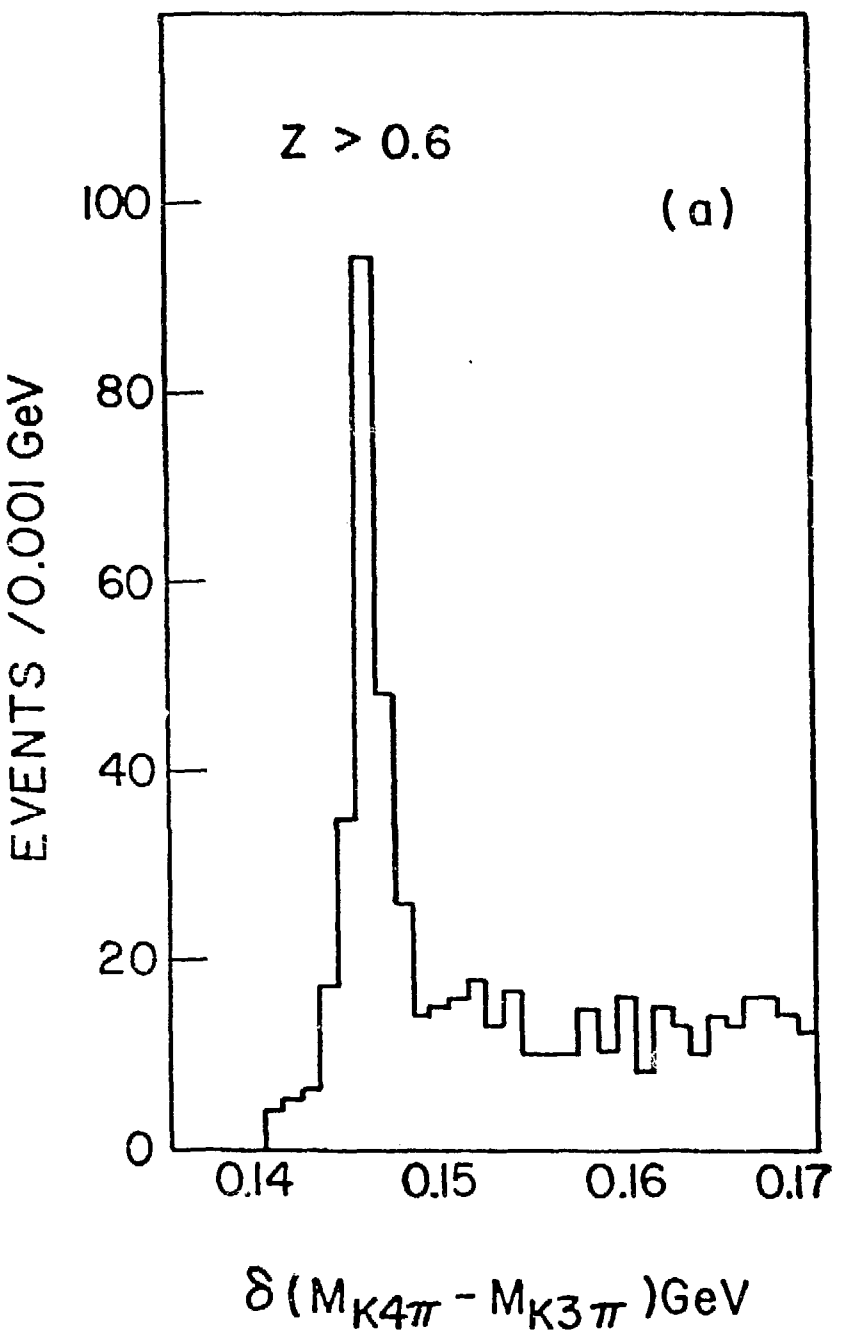

Z > 0.6
(a)
100
80
60
40
20
0
EVENTS /0.001 GeV
0.14
0.15
0.16
0.17
δ (M_K4π - M_K3π)GeV

Figure 3

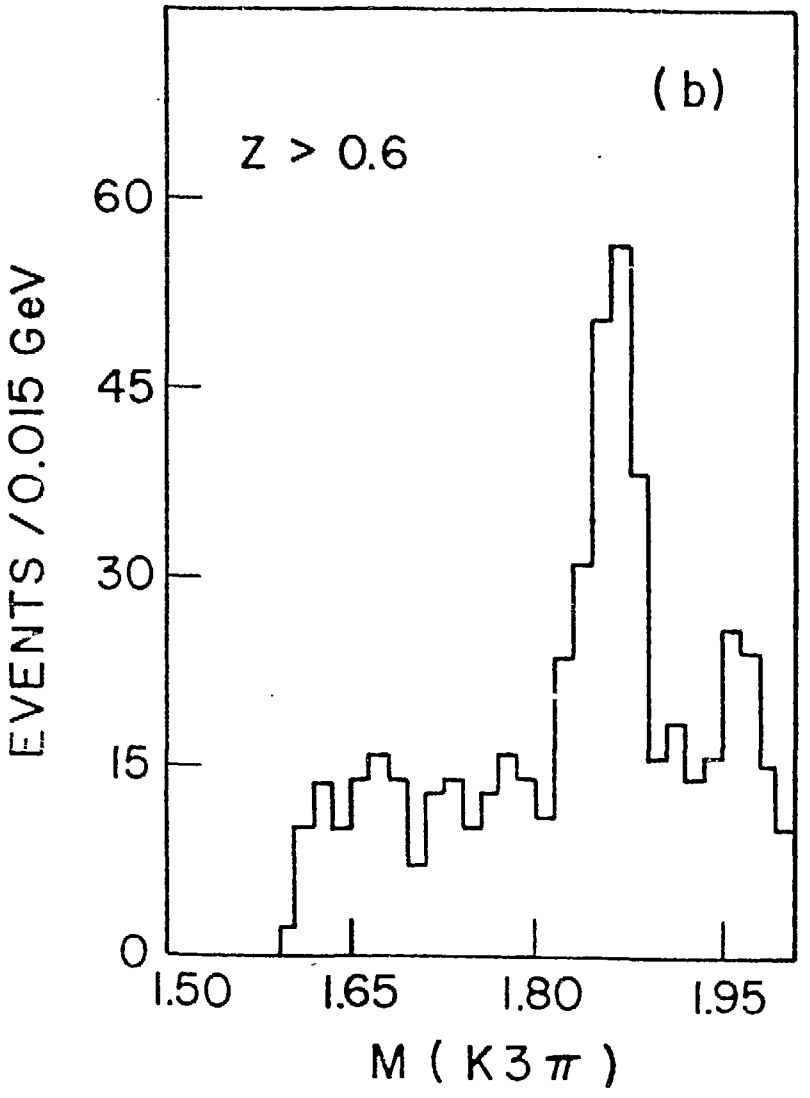


Figure 3

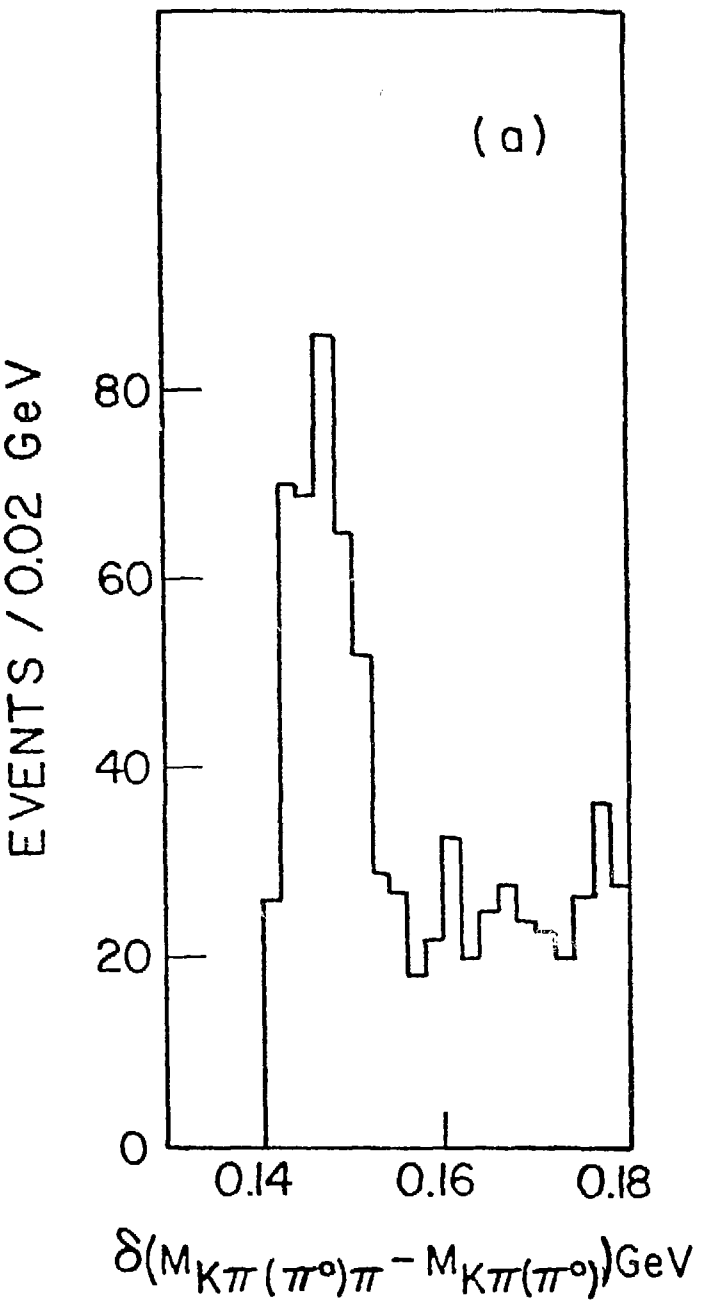


Figure 4

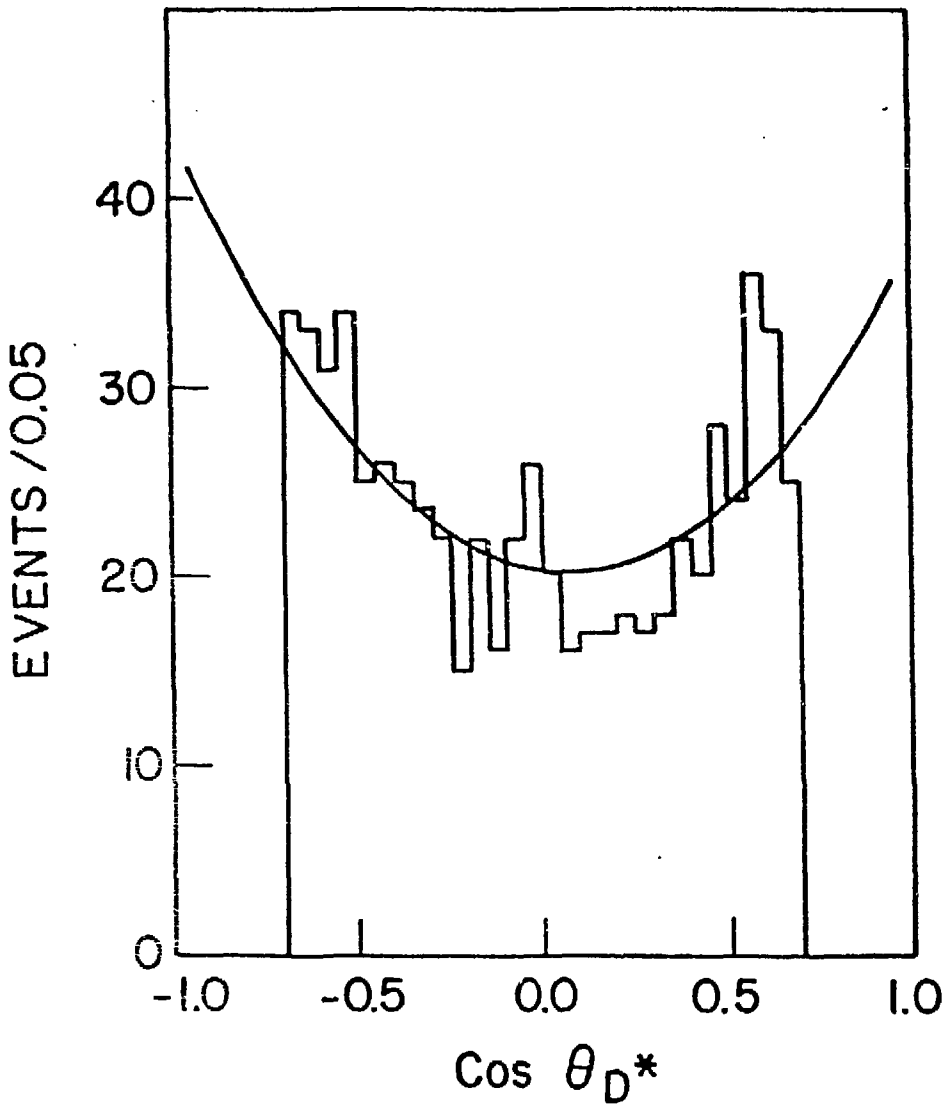


Figure 5

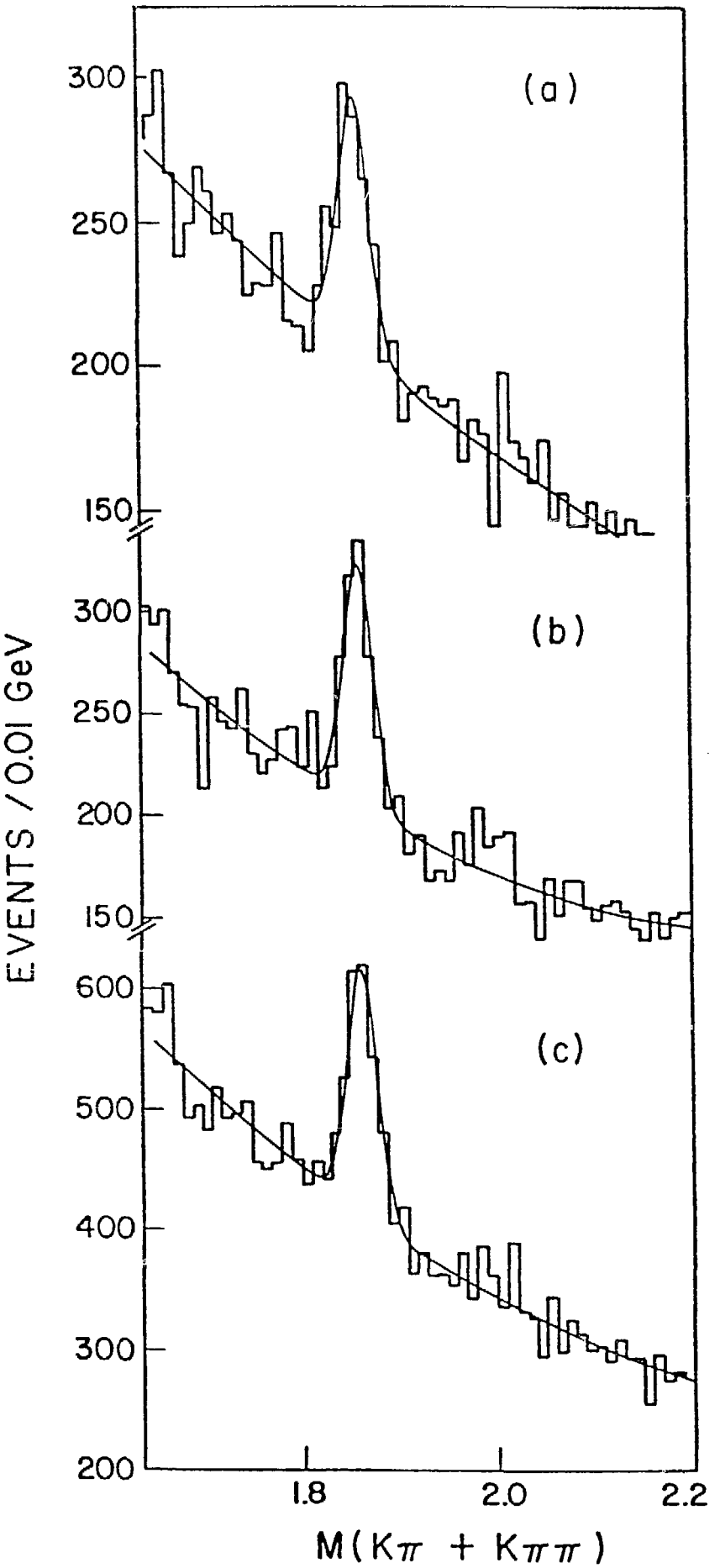

(a)
(b)
(c)
300
250
200
150
300
250
200
150
600
500
400
300
200
EVENTS / 0.01 GeV
1.8
2.0
2.2
M(Kπ + Kππ)

Figure 6

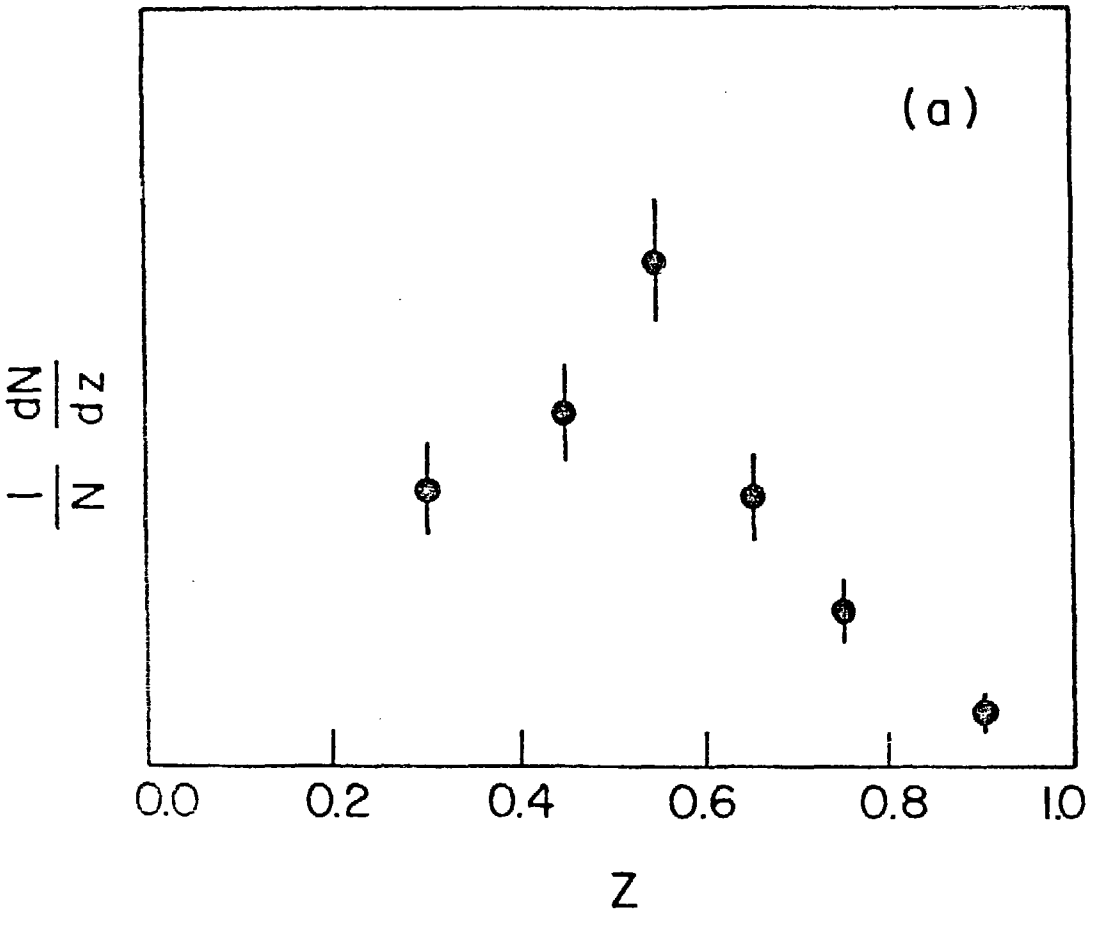


Figure 7

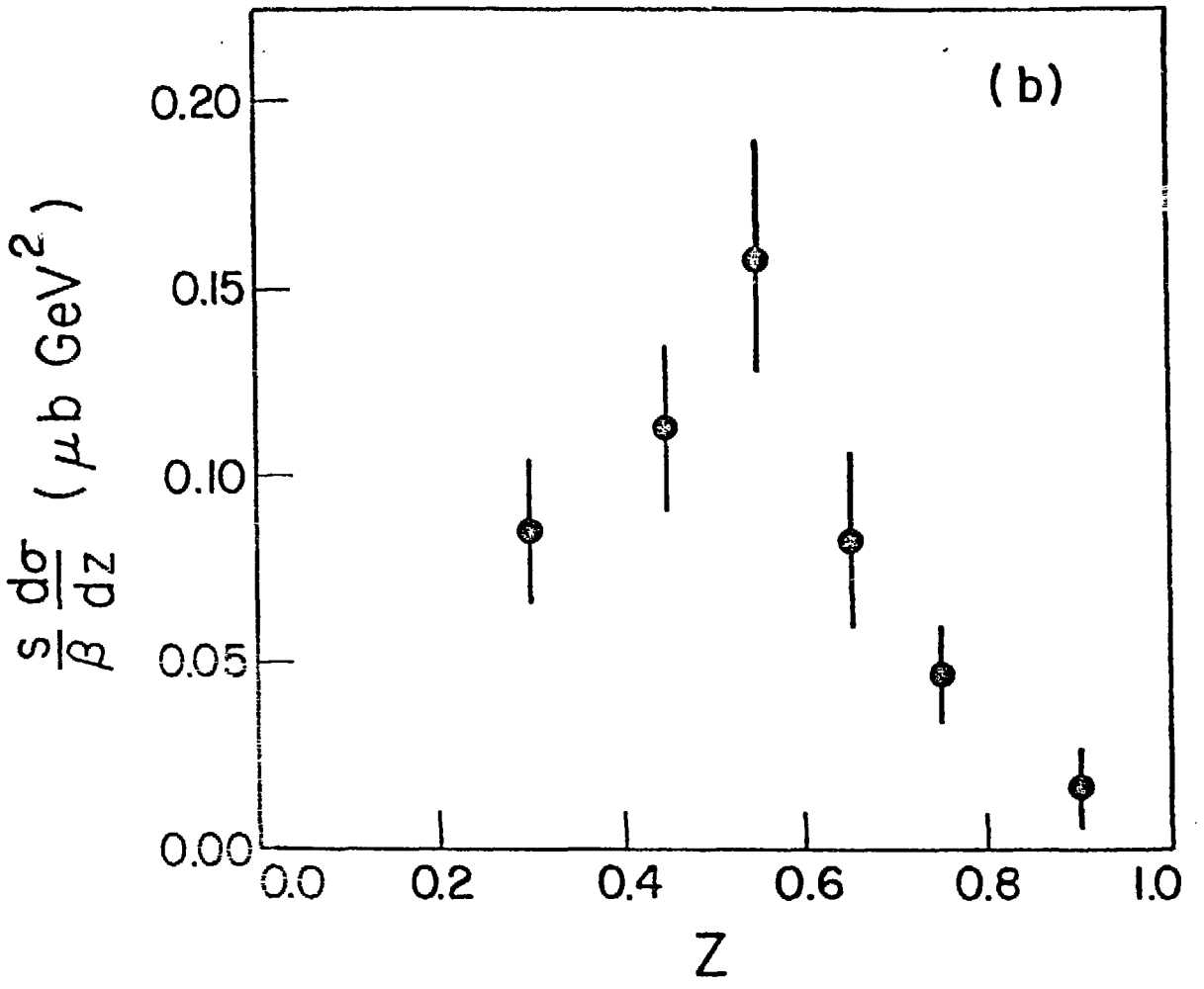
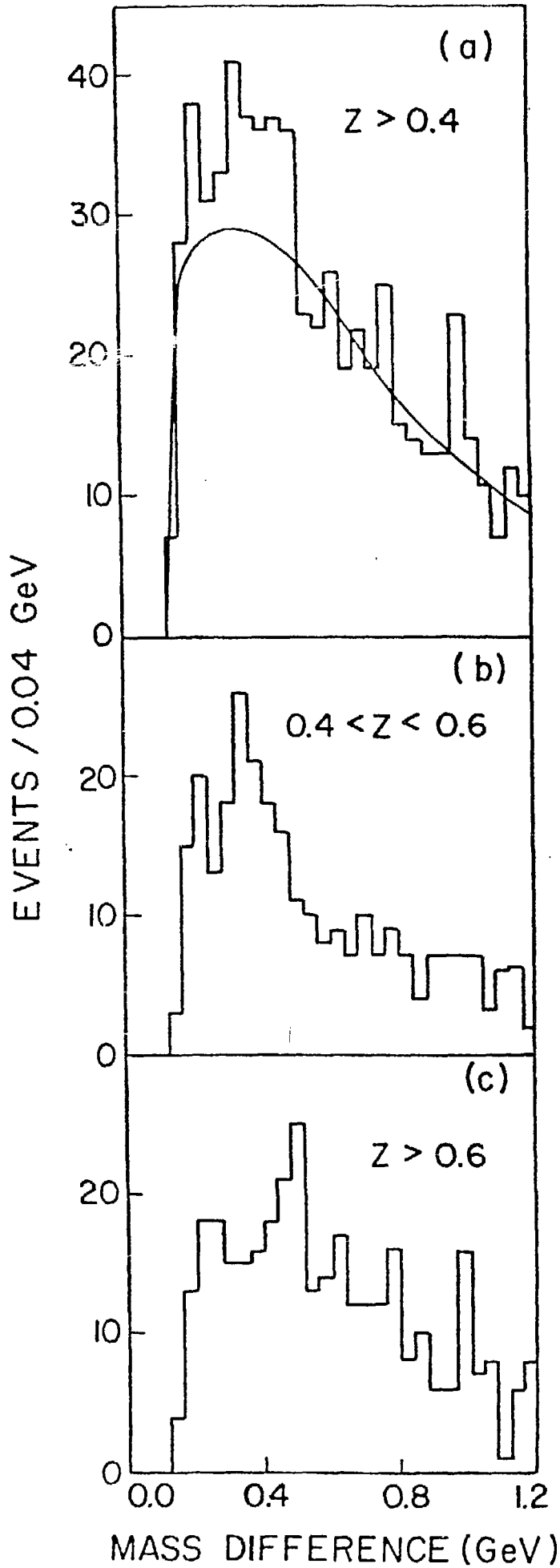

(b)
0.20
0.15
0.10
0.05
0.00
$\frac{s}{\beta}\frac{d\sigma}{dz}$ (μb GeV^2)
0.0
0.2
0.4
0.6
0.8
1.0
Z

Figure 7


(a)
Z > 0.4
(b)
0.4 < Z < 0.6
(c)
Z > 0.6
EVENTS / 0.04 GeV
MASS DIFFERENCE (GeV)
0
10
20
30
40
0.0
0.4
0.8
1.2

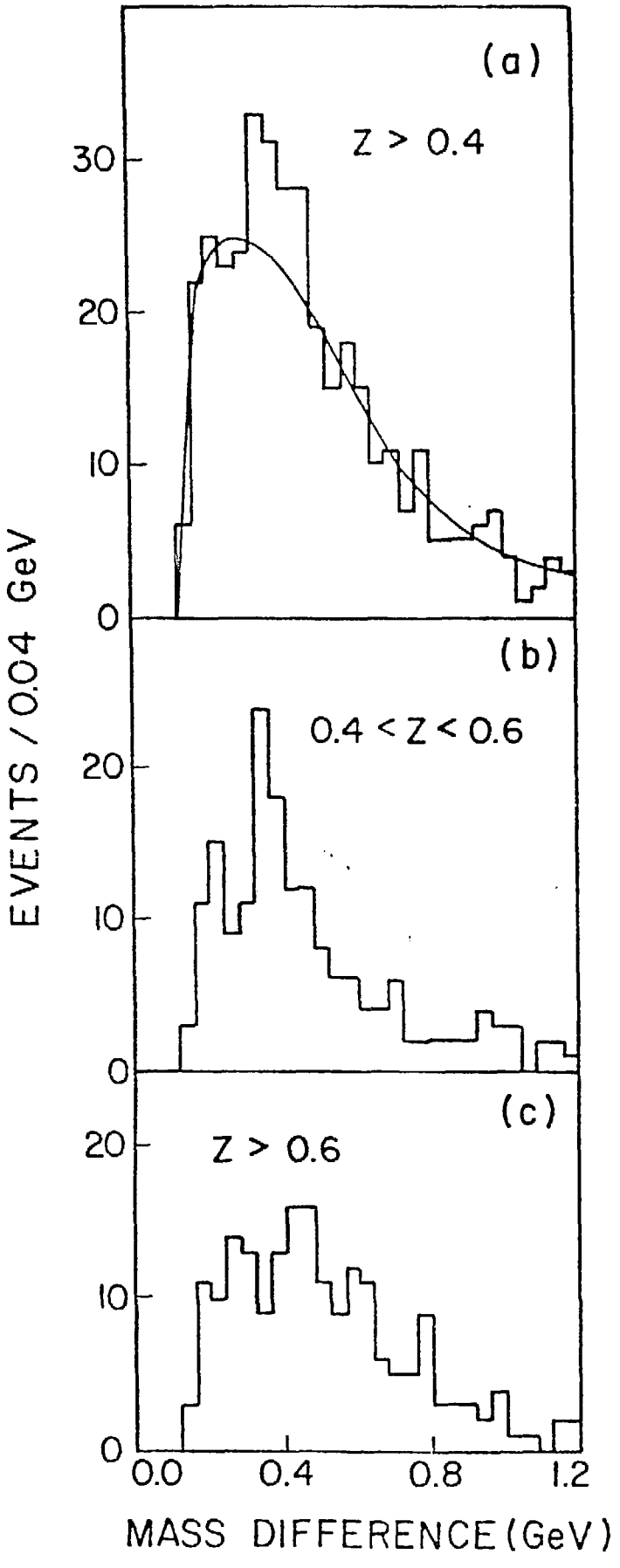

(a)
Z > 0.4
30
20
10
0
(b)
0.4 < Z < 0.6
20
10
0
(c)
Z > 0.6
20
10
0
EVENTS / 0.04 GeV
0.0
0.4
0.8
1.2
MASS DIFFERENCE (GeV)

Figure 9

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