DEUTSCHES ELEKTRONEN – SYNCHROTRON

DESY 90-157
December 1990

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ISSN 0418-9833

NOTKESTRASSE 85 · D-2000 HAMBURG 52

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H. Albrecht, H. Ehrlichmann, G. Harder, A. Krüger, R. Mundt, A. Nau, A. Nippe, T. Oest, M. Reidenbach, M. Schäfer, W. Schmidt-Parzefall, H. Schröder, H. D. Schulz, F. Sefkow, R. Wurth
DESY, Hamburg, Germany

R. D. Appuhn, C. Hast, G. Herrera, H. Kolanoski, A. Lange, A. Lindner, R. Mankel, M. Schieber, G. Schweda, T. Siegmund, B. Spaan, H. Thurn, A. Walther, D. Wegener
Institut für Physik[1], *Universität Dortmund, Germany*

M. Paulini, K. Reim, U. Volland, H. Wegener
Physikalisches Institut[2], *Universität Erlangen-Nürnberg, Germany*

W. Funk, J. Stiewe, S. Werner
Institut für Hochenergiephysik[3], *Universität Heidelberg, Germany*

S. Ball, J. C. Gabriel, C. Geyer, A. Hölscher, W. Hofmann, B. Holzer, S. Khan, K. T. Knöpfle, J. Spengler
Max-Planck-Institut für Kernphysik, Heidelberg, Germany

D. I. Britton[4], C. E. K. Charlesworth[5], K. W. Edwards[6], H. Kapitza[6], P. Krieger[5], R. Kutschke[5], D. B. MacFarlane[4], R. S. Orr[5], P. M. Patel[4], J. D. Prentice[5], S. C. Seidel[5], G. Tsipolitis[4], K. Tzamariudaki[4], R. van de Water[5], T.-S. Yoon[5]
Institute of Particle Physics[7], *Canada*

D. Ressing, S. Schael, K. R. Schubert, K. Strahl, R. Waldi, S. Weseler
Institut für Experimentelle Kernphysik[8], *Universität Karlsruhe, Germany*

B. Boštjančič, G. Kernel, P. Križan[9], E. Križnič, T. Živko
Institut J. Stefan and Oddelek za fiziko[10], *Univerza v Ljubljani, Ljubljana, Yugoslavia*

H. I. Cronström, L. Jönsson
Institute of Physics[11], *University of Lund, Sweden*

A. Babaev, V. Balagura, M. Danilov, A. Droutskoy, B. Fominykh, A. Golutvin, I. Gorelov, F. Ratnikov, V. Lubimov, A. Rostovtsev, A. Semenov, S. Semenov, V. Shevchenko, V. Soloshenko, I. Tichomirov, Yu. Zaitsev
Institute of Theoretical and Experimental Physics, Moscow, USSR

R. Childers, C. W. Darden
University of South Carolina[12], *Columbia, SC, USA*

[1] Supported by the German Bundesministerium für Forschung und Technologie, under contract number 054DO51P.
[2] Supported by the German Bundesministerium für Forschung und Technologie, under contract number 054ER12P.
[3] Supported by the German Bundesministerium für Forschung und Technologie, under contract number 054HD24P.
[4] McGill University, Montreal, Quebec, Canada.
[5] University of Toronto, Toronto, Ontario, Canada.
[6] Carleton University, Ottawa, Ontario, Canada.
[7] Supported by the Natural Sciences and Engineering Research Council, Canada.
[8] Supported by the German Bundesministerium für Forschung und Technologie, under contract number 054KA17P.
[9] Supported by Alexander v. Humboldt Stiftung, Bonn.
[10] Supported by Raziskovalna skupnost Slovenije and the Internationales Büro KfA, Jülich.
[11] Supported by the Swedish Research Council.

Abstract

Measurements of the absolute branching ratios of the decays $\bar{B}^0 \to D^{*+}D_s^{*-}$ and $D_s^- \to \phi\pi^-$ are made using partial reconstructions of the first decay. The measurement of each decay requires no assumption on the branching ratio of the other. We find $BR(\bar{B}^0 \to D^{*+}D_s^{*-}) = (5.5 \pm 1.9 \pm 1.4)\%$ and $BR(D_s^- \to \phi\pi^-) = (1.4 \pm 0.7 \pm 0.4)\%$.

Decays of B Mesons to D_s final states have been measured in inclusive studies [1, 2] and more recently in exclusive final states [3]. However, due to the large uncertainty in the $D_s^- \to \phi\pi^-$ [1] branching ratio, which sets the scale for all measurements of D_s decays, it has not been possible to derive absolute B decay branching ratios until now. A measurement of B decays to D_s final states made without the reconstruction of the D_s decay would be free of this uncertainty, and thus provide a meaningful comparison with theoretical predictions [4, 5]. Measuring the same B decay with and without D_s reconstruction also provides a means of determining the branching ratio of $D_s^- \to \phi\pi^-$, free from any theoretical input. We present such an analysis of the decay $\bar{B}^0 \to D^{*+}D_s^{*-}$.

The data sample consists of 237 pb^{-1} collected at the $\Upsilon(4S)$ resonance, including approximately 200000 B^0 decays, assuming that equal numbers of charged and neutral B mesons are produced. The ARGUS detector, event reconstruction, and particle identification are described in detail elsewhere [6]. Charged particles are identified on the basis of specific ionization in the drift chamber, time of flight measurements, and information from the μ-chambers and electromagnetic calorimeter. Likelihood ratios are calculated for each charged particle hypothesis: e, μ, π, K, and p. Unless otherwise indicated, all hypotheses with a likelihood ratio greater than 1% are accepted. Photons are identified through electromagnetic showers which are not associated with a charged track.

A partial reconstruction of the decay $\bar{B}^0 \to D^{*+}D_s^{*-}$ can be performed similar to the method used to partially reconstruct the decay $\bar{B}^0 \to D^{*+}\pi^-$. An ARGUS measurement of the later decay made with reconstruction of only the two pions in decay chain $\bar{B}^0 \to D^{*+}\pi^-$, $D^{*+} \to D^0\pi^+$ [7] is in good agreement with those based on full reconstruction of the decay [8, 9]. We first present an update of this analysis to demonstrate the utility of the method.

[1] References in this paper to a specific charged state are to be interpreted as implying the charge conjugate state also.

To calculate the mass of the B candidate from the measured pions, the four needed yet unmeasured kinematic quantities, $\vec{p}_{D^0}$ and E_{D^0}, cannot be completely determined from the three constraints: the missing mass M_{D^0}, the mass of the $D^0\pi^+$ system $M_{D^{*+}}$, and the energy of the B meson E_{beam}. One additional constraint can be derived from the fact that the known B mass (5.28 GeV) is nearly the maximum possible mass allowed from the $\Upsilon(4S)$ decay. Nearly the correct mass is obtained when requiring the missing momentum vector $\vec{p}_{D^0}$ to lie in the same plane formed by the two measured momenta $\vec{p}_{\pi^+}$ and $\vec{p}_{\pi^-}$, which also yields the maximum kinematically allowed mass. Figure 1a shows the expected signal and background from $B\bar{B}$ Monte Carlo [10] in which the 2-body B decay rates are given by the predictions of reference [5]. The signal shape is approximately gaussian, though the upper tail is cut short by the kinematic threshold. The fitted mass and width are 5283.6 MeV and 5.9 MeV, respectively, both slightly larger than with full reconstruction (5280 MeV and 4 MeV [8]). The background, shown as the shaded histogram, is smoothly varying and is well described by a first order polynomial.

In the data, to suppress the large continuum background, a cut on the event shape relative to the $\pi^-\pi^+$ system is made. Since continuum events are peaked strongly at $|cos\alpha| = 1$, where α is the angle between the momentum of the $\pi^-\pi^+$ system and the thrust axis of the rest of the event, we require $|cos\alpha| < 0.9$. Figure 1b shows the resulting mass distribution for data from the $\Upsilon(4S)$ (crosses) and from the nearby continuum (histogram), where the later has not been scaled by the ratio of luminosities, a factor of 2.2 for the $\Upsilon(4S)$ data relative to continuum data. The fitted signal contains 221 ± 35 events, which results in the branching ratio $BR(\bar{B}^0 \to D^{*+}\pi^-) = (0.41 \pm 0.09 \pm 0.03)\%$ where the first error contains statistical and systematic errors added in quadrature and the second error is from the uncertainty on the $D^{*+} \to D^0\pi^+$ branching ratio [11]. This is in agreement with previous measurements made with partial [7] and full [8, 9] reconstruction methods, and with theoretical expectations [4, 5]. The recent ARGUS measurement performed with full reconstruction is $BR(\bar{B}^0 \to D^{*+}\pi^-) = (0.33 \pm 0.10 \pm 0.04)\%$ [8], which has been scaled to the $D^{*+} \to D^0\pi^+$ and $D^0 \to K^-\pi^+$ branching ratios of reference [11], which contribute the dominant part of the second error. Since the D^0 is not reconstructed in the method of partial reconstruction, one can use both measurements to obtain the branching ratio of $D^0 \to K^-\pi^+$; we find $BR(D^0 \to K^-\pi^+) = (3.0 \pm 1.1)\%$ in comparison with the Particle Data Group value of $(3.71 \pm 0.25)\%$ [11].

Two methods of partial reconstruction can be used for the decay chain

$$\bar{B}^0 \to D^{*+} D_s^{*-}, \quad D_s^{*-} \to D_s^- \gamma, \quad D^{*+} \to D^0 \pi^+$$

The analyses are very similar to that described above for the decay $\bar{B}^0 \to D^{*+}\pi^-$. The first method requires reconstruction of the $D^{*+} \to D^0\pi^+$ decay and the photon from the $D_s^{*-} \to D_s^-\gamma$ decay. The second method requires reconstruction of the π^+ from the $D^{*+} \to D^0\pi^+$ decay and of the entire $D_s^{*-} \to D_s^-\gamma$ decay. Expected signal shapes from Monte Carlo are very similar to that of the previous analysis, though slightly broader. The respective masses and widths of the fitted gaussians are 5281.5 MeV and 7.6 MeV for the first method and 5281.6 MeV and 6.5 MeV for the second method. An expected contribution to a non-gaussian tail for the first method cannot be reliably extracted from a smooth background and is thus treated as background in both Monte Carlo and data.

For the first method, the D^0 decay is reconstructed only through $D^0 \to K^-\pi^+$, where $K^-\pi^+$ combinations having an invariant mass within 40 MeV of the D^0 mass are accepted. The mass constrained D^0 is then combined with π^+; the $D^0\pi^+$ system is required to have an invariant mass within 2.5 MeV of the D^{*+} mass, providing a very clean D^{*+} sample. A mass constraint is also performed on the D^{*+}. For the reconstruction of the photon from the $D_s^{*-} \to D_s^-\gamma$ decay, the large background of soft photons in B decays is suppressed by accepting only photons of energy greater than 160 MeV. The unknown D_s^{*-} polarization induces only a small uncertainty in the acceptance ($< 10\%$) due to the choice of the cut at nearly the mid-point of the photon spectrum, which extends from 60 to 290 MeV. An isotropic distribution is assumed. Similar to the former analysis, to suppress continuum background, a cut is made on the angle α between thrust axes of the $D^{*+}\gamma$ system and the rest of the event at $|cos\alpha| < 0.9$.

From the D^{*+} and the photon the pseudomass is calculated. To determine the background shape of the pseudomass distribution we have performed the analysis on data in which the photon momentum direction is inverted, for data with photons taken from other events, and for Monte Carlo events with B decays not involving D_s. The first analysis results in the distribution shown in Figure 2a. It is fitted with a first order polynomial, which describes the shape well. The distributions obtained from event mixing and Monte Carlo are very similar, each being well described by a first order polynomial. The correct combinations in data, shown in Figure 2b, reveal an excess of events in the signal region.

The fit shown, which includes the Monte Carlo determined gaussian for the signal and a first order polynomial for the background shape, contains 36 ± 12 signal events.

Many specific background sources were studied in detail. Background from the decay $\bar{B} \to D(2414)D_s^{*-}$ followed by $D(2414) \to D^{*+}\pi$ yields a nearly flat distribution for $M > 5.2$ GeV. Background from the decay $\bar{B}^0 \to D^{*+}D_s^-$ in which a random photon fakes the D_s^{*-} decay has been determined by Monte Carlo studies to contribute less than 3% of that coming from an equal number of $\bar{B}^0 \to D^{*+}D_s^{*-}$ decays to the signal region, $M > 5.27$ GeV. Background from the cabbibo-suppressed decays $\bar{B}^0 \to D^{*+}D^{*-}$ or $B^+ \to D^{*+}\bar{D}^{*0}$ followed by decays of the D^{*-} or $\bar{D}^{*0}$ to neutrals can contaminate the signal. Assuming the branching ratios for these decays are simply $|\frac{V_{cd}}{V_{cs}}|^2 = 0.05$ relative to that of $\bar{B}^0 \to D^{*+}D_s^{*-}$, we estimate a contamination of 2 ± 1 events in the signal of 36 ± 12. No other background sources were found which can simulate the observed signal.

As further evidence that the signal is indeed due to the decay $\bar{B}^0 \to D^{*+}D_s^{*-}$, we have searched in these events for well identified Kaons (K^- or K_s^0). Though a Kaon is expected to be produced often in the other B decay, there is a higher probability of detecting a Kaon in events with a D_s^- decay in addition, since it is likely that two more Kaons are produced. The histograms in Figure 2c and 2d show the events remaining from the two previous distributions after requiring a well-identified Kaon in the hemisphere opposite to the D^{*+}. Most (29 ± 8) of the B signal in the correct combinations remains, whereas the background is substantially reduced. In contrast, events with a Kaon in the same hemisphere as the D^{*+}, which come primarily from separate B decays, yield a signal of only 2 ± 5, in agreement with the expectation of approximately 5. The probability that 29 ± 8 is consistent with 2 ± 5 is less than 0.5%, favoring a strongly correlated source of Kaons as one expects from the double-charm B decay.

From the background-subtracted signal of 34 ± 12 events we derive the branching ratio:

$$BR(\bar{B}^0 \to D^{*+}D_s^{*-}) = (5.5 \pm 1.9 \pm 1.4)\%$$

where the first error is statistical and the second is systematic. Again, the $D^{*+} \to D^0\pi^+$ and $D^0 \to K^-\pi^+$ branching ratios have been taken from reference [11]. Our measured value is fully consistent with the theoretical estimate[2] of Körner, 5.4% [4], but somewhat larger than that of Bauer et al., 2.0% [5]. We emphasize again that this measurement is independent of the assumption of $BR(D_s^- \to \phi\pi^-)$.

[2] We have scaled the theoretical values to the KM matrix element $|V_{bc}| = 0.047$ [12] and the B lifetime $\tau_B = 1.13 * 10^{-12}$ sec [13].

For the second partial reconstruction of the decay $\bar{B}^0 \to D^{*+}D_s^{*-}$, the D_s^- decay is reconstructed through known 2-body decays to final states with only charged particles. These include:

$$D_s^- \to \phi\pi^-$$
$$D_s^- \to K^{*0}K^-$$
$$D_s^- \to K^{*0}K^{*-}$$
$$D_s^- \to K_s^0K^-$$
$$D_s^- \to K_s^0K^{*-}$$

where $\phi \to K^-K^+$, $K^{*0} \to K^+\pi^-$, $K^{*-} \to K_s^0\pi^-$, and $K_s^0 \to \pi^+\pi^-$. For the D_s^- decays to a vector and a pseudoscalar, we expect the subsequent vector decay to two pseudoscalars to have a $cos^2\theta$ distribution, where θ is the angle between one of the two pseudoscalars and the vector particles helicity axis in the vector particles frame. To suppress background, we require $|cos\theta| > 0.4$. Other combinatorial background in the $\phi\pi^-$ mode is reduced with the requirement $cos\theta_\phi < 0.9$, where θ_ϕ is the angle between the ϕ and the D_s^- in the D_s^- frame. Except for the $\phi \to K^-K^+$ decay we require a K^- likelihood ratio greater than 10%. Further background is reduced in the $K^{(*)}K^-$ modes with the requirement $cos\theta_K < 0.8$ where θ_K is the angle between the K^- and the D_s^- in the D_s^- frame. For all modes the D_s^- candidates are required to have a mass within 30 MeV of the D_s^- mass. The branching ratios relative to $D_s^- \to \phi\pi^-$ have been taken from reference [11], except for $D_s^- \to K^{*0}K^{*-}$ which is taken from reference [14]. For the D_s^{*-} reconstruction all photons with energy greater than 80 MeV are accepted, which includes nearly all of the kinematic region. All $D_s^-\gamma$ combinations within 20 MeV of the D_s^{*-} mass are accepted for the pseudomass analysis. A mass constrained fit is performed on all long-lived intermediate states. As before, the cut on the angle between thrust axes of the $D_s^{*-}\pi^+$ system and the rest of the event is made at $|cos\alpha| < 0.9$ to reduce continuum background.

For the pseudomass calculated from $D_s^{*-}\pi^+$ combinations, the background shape was studied using the D_s^{*-} sidebands, data with inverted π^+ direction, and Monte Carlo. The results from the sidebands ($2020MeV < M(D_s^-\gamma) < 2060MeV$ and $2160MeV < M(D_s^-\gamma) < 2220MeV$) are combined together in Figure 3a. Again, the shape is well described by a first order polynomial, as well as the distributions from the other background studies. Background from the decay $\bar{B} \to D(2414)D_s^{*-}$ results in a nearly flat contribution for $M > 5.2$ GeV. Background from the decay $\bar{B}^0 \to D^{*+}D_s^-$ is again expected to be relatively small; this being supported by the absence of a signal in the mass distribution from the D_s^{*-} sideband, where such events should contribute equally. The correct combinations, shown in Figure 3b, reveal evidence for a signal. The fit yields 22 ± 8 events.

An important cross-check for the signal comes from analysing all $D_s^- \gamma$ combinations. For the B pseudomass signal region, $M > 5.27$ GeV, the $D_s^- \gamma$ invariant mass is shown as the open histogram in Figure 4. For these entries, an additional cut has been made at $P(D_s^- \gamma) > 1.5$ GeV to reduce combinatorial background. The shaded distribution in Figure 4 is from the pseudomass region $5.10 GeV < M < 5.25 GeV$, normalized beyond $M(D_s^- \gamma) > 2.16$ GeV to the former one. A fit with a smooth polynomial background and fixed gaussian width for the D_s^{*-} signal yields 27 ± 8 events for the former distribution, in excellent agreement with the expectation of 25 from the B signal. Further confirmation of this signal comes from the full reconstruction of $\bar{B}^0 \to D^{*+} D_s^{*-}$, of which 4 events, virtually background free, have been found in the ARGUS data [15], consistent with the expectation of 3 events.

This second method does not provide a crosscheck on the first measurement of $\bar{B}^0 \to D^{*+} D_s^{*-}$ since the $D_s^- \to \phi\pi^-$ branching ratio is unknown. However, both can be used to provide the first nearly assumption free measurement of $D_s^- \to \phi\pi^-$. The result is:

$$BR(D_s^- \to \phi\pi^-) = (1.4 \pm 0.7 \pm 0.4)\%.$$

The systematic error contains the errors on the $D^0 \to K^-\pi^+$ branching ratio and the D_s^- branching ratios relative to $D_s^- \to \phi\pi^-$, and uncertanties in the acceptance and the background parametrizations. This branching ratio can be converted into an upper limit; we find:

$$BR(D_s^- \to \phi\pi^-) < 2.5\% \quad at\ 90\% CL$$

which results from taking the statistical and systematic errors in quadrature. This constraint on $BR(D_s^- \to \phi\pi^-)$ is presently the most stringent upper limit, a significant improvement on the MARK III upper limit of 4.1% [16], also at 90% CL. Several recent estimates have been made by combining experimental data with theoretical input. The Particle Data Group 1990 value, $(2.7 \pm 0.7)\%$ [11], is derived from assumptions on D_s production in e^+e^- continuum data. From analyses of the decay $D_s^- \to \phi e^- \nu$ and its expected similar width to that of the decay $D \to K^* e^- \nu$ come the estimates: $> 2.9\%$ at 90%CL [17], $(2.6^{+1.0}_{-0.9})\%$ [18], and $(2.4 \pm 1.0)\%$ [19], where the values have been scaled to the D branching ratios of reference [11]. Estimates from the fixed target experiments NA14',

$(4.8 \pm 1.7 \pm 1.9)\%$ [20], and ACCMOR, $(6.0^{+2.1}_{-1.6})\%$ [14], favor a value much larger than what is consistent with our measurement. Theoretical estimates are highly uncertain, ranging from 2% to 6% [5, 21]. Much of this range is excluded by our upper limit.

In conclusion, we have measured the branching ratios of the decays $\bar{B}^0 \to D^{*+} D_s^{*-}$ and $D_s^- \to \phi\pi^-$, each measurement being independent of the branching ratio of the other. We find $BR(\bar{B}^0 \to D^{*+} D_s^{*-}) = (5.5 \pm 1.9 \pm 1.4)\%$ and $BR(D_s^- \to \phi\pi^-) = (1.4 \pm 0.7 \pm 0.4)\%$. The later branching ratio corresponds to an upper limit of $BR(D_s^- \to \phi\pi^-) < 2.5\%$ at 90% confidence level.

It is a pleasure to thank U.Djuanda, E.Konrad, E.Michel, and W.Reinsch for their competent technical help in running the experiment and processing the data. We thank Dr.H.Nesemann, B.Sarau, and the DORIS group for the excellent operation of the storage ring. The visiting groups wish to thank the DESY directorate for the support and kind hospitality extended to them.

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Figure Captions

1. B pseudomass distributions of the decay $\bar{B}^0 \to D^{*+}\pi^-$ from a) $\Upsilon(4S)$ Monte Carlo (background shaded) and b) data from the $\Upsilon(4S)$ resonance (crosses) and from the nearby continuum (histogram).

2. B pseudomass distributions of the decay $\bar{B}^0 \to D^{*+}D_s^{*-}$ using the first method a) where the photon direction is inverted, b) for correct combinations, c) for events shown in a) with a detected K, and d) for correct combinations with a detected K.

3. B pseudomass distribution of the decay $\bar{B}^0 \to D^{*+}D_s^{*-}$ using the second method from a) data from the D_s^{*-} sidebands and b) data from the D_s^{*-} signal.

4. $M(D_s^-\gamma)$ distribution from $M > 5.27\ GeV/c^2$ of the B signal (open histogram) and from $5.10 < M < 5.25\ GeV/c^2$ of the B sideband (shaded histogram).

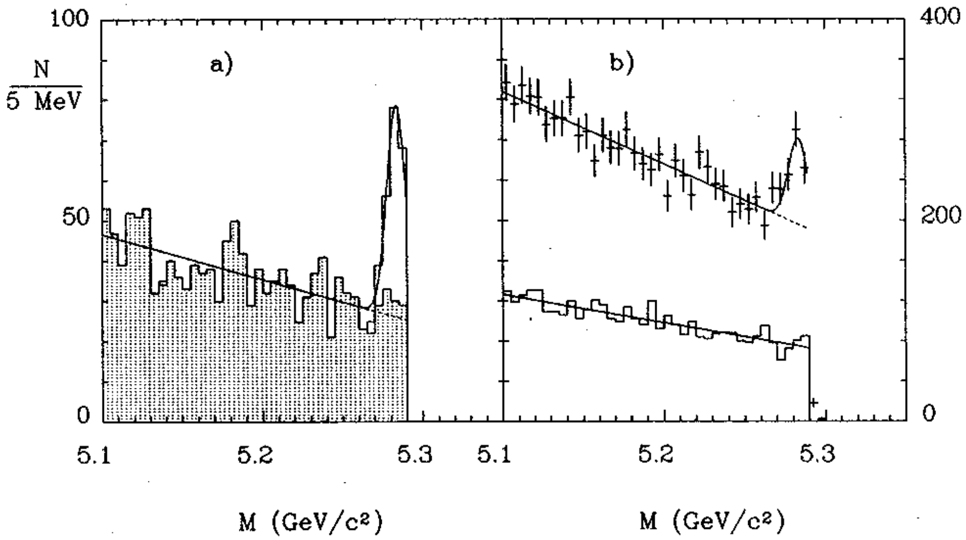

Figure 1

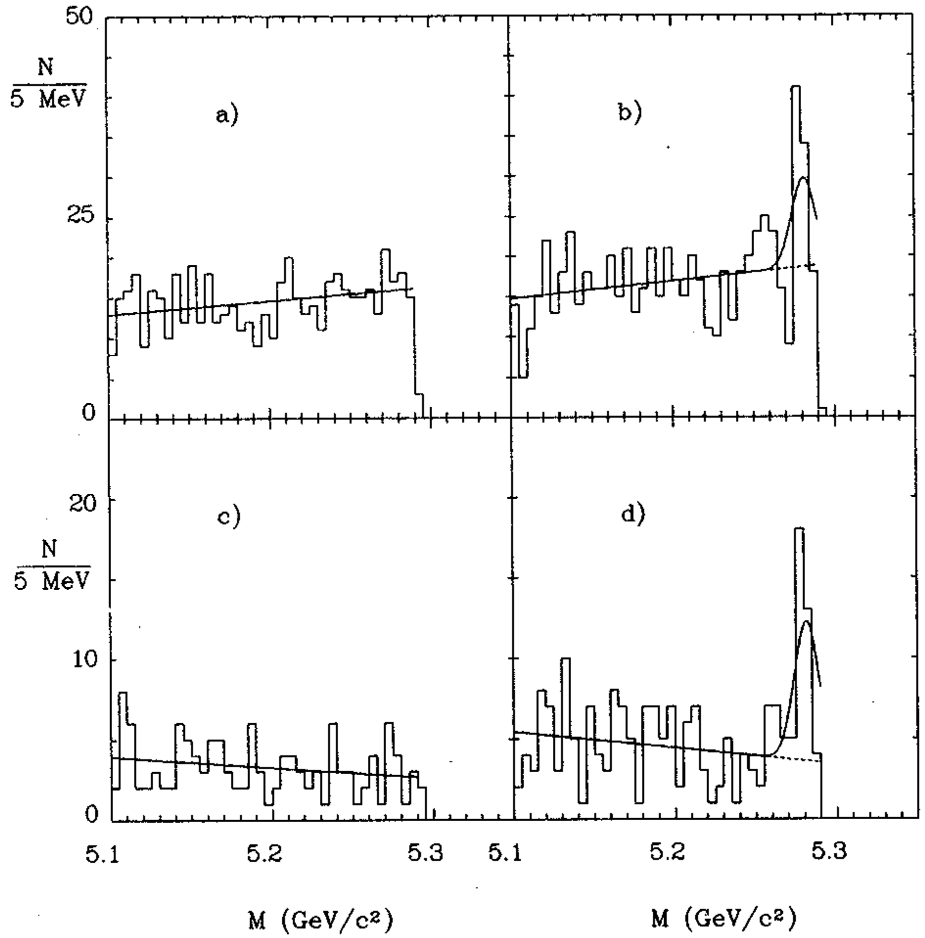

Figure 2

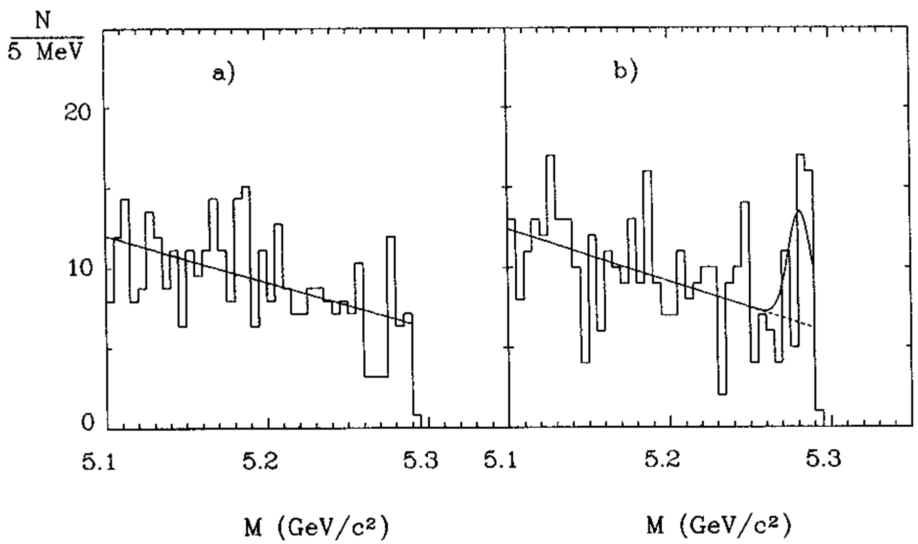

Figure 3

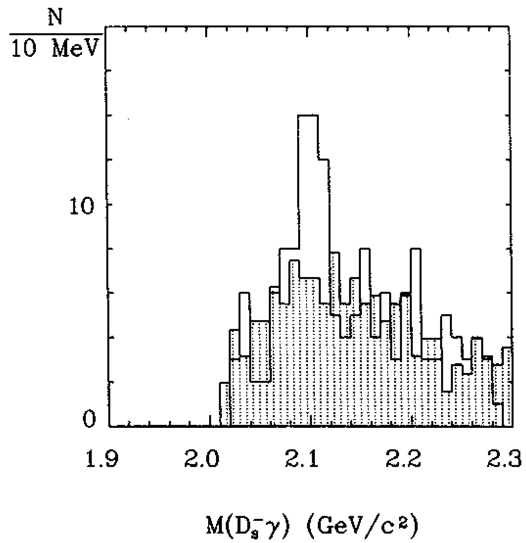

Figure 4