Fermi National Accelerator Laboratory

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Observation of the Decay $B_s^0 \to J/\psi\phi$ in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV

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Chikamatsu,[30] S. Cihangir,[7] A. G. Clark,[23] M. Cobal,[23] M. Contreras,[5] J. Conway,[27] J. Cooper,[7] M. Cordelli,[8] D. P. Coupal,[28] D. Crane,[7] J. D. Cunningham,[2] T. Daniels,[15] F. DeJongh,[7] S. Dell'Agnello,[23] M. Dell'Orso,[23] L. Demortier,[26] B. Denby,[7] M. Deninno,[3] P. F. Derwent,[16] T. Devlin,[27] M. Dickson,[25] J. P. Done,[29] R. B. Drucker,[14] A. Dunn,[16] K. Einsweiler,[14] J. E. Elias,[7] R. Ely,[14] E. Engels, Jr.,[22] S. Eno,[5] D. Errede,[10] S. Errede,[10] A. Etchegoyen,[7a] Q. Fan,[25] B. Farhat,[15] I. Fiori,[3] B. Flaugher,[7] G. W. Foster,[7] M. Franklin,[9] M. Frautschi,[18] J. Freeman,[7] J. Friedman,[15] H. Frisch,[5] A. Fry,[28] T. A. Fuess,[28] Y. Fukui,[13] S. Funaki,[30] A. F. Garfinkel,[24] S. Geer,[7] D. W. Gerdes,[16] P. Giannetti,[23] N. Giokaris,[26] P. Giromini,[8] L. Gladney,[21] D. Glenzinski,[12] M. Gold,[18] J. Gonzalez,[21] A. Gordon,[9] A. T. Goshaw,[6] K. Goulianos,[26] H. Grassmann,[28] A. Grewal,[21] G. Grieco,[23] L. Groer,[27] C. Grosso-Pilcher,[5] C. Haber,[14] S. R. Hahn,[7] R. Hamilton,[9] R. Handler,[32] R. M. Hans,[33] K. Hara,[30] B. Harral,[21] R. M. Harris,[7] S. A. Hauger,[6] J. Hauser,[4] C. Hawk,[27] J. Heinrich,[21] D. Hennessy,[6] R. Hipple,[17] R. Hollebeek,[21] L. Holloway,[10] A. Hölscher,[11] S. Hong,[16] G. Houk,[21] P. Hu,[22] B. T. Huffman,[22] R. Hughes,[25] P. Hurst,[9] J. Huston,[17] J. Huth,[7] J. Hylen,[7] M. Incagli,[23] J. Incandela,[7] H. Iso,[30] H. Jensen,[7] C. P. Jessop,[9] U. Joshi,[7] R. W. Kadel,[14] T. Kamon,[29] T. Kaneko,[30] D. A. Kardelis,[10] H. Kasha,[33] Y. Kato,[19] L. Keeble,[29] R. Kennedy,[27] R. Kephart,[7] P. Kesten,[14] D. Kestenbaum,[9] R. M. Keup,[10] H. Keutelian,[7] F. Keyvan,[4] D. H. Kim,[7] H. S. Kim,[11] S. B. Kim,[16] S. H. Kim,[30] Y. K. Kim,[14] L. Kirsch,[2] P. Koehn,[25] K. Kondo,[30] J. Konigsberg,[9] S. Kopp,[5] K. Kordas,[11] W. Koska,[7] E. Kovacs,[7a] M. Krasberg,[16] S. E. Kuhlmann,[1] E. Kuns,[27] A. T. Laasanen,[24] S. Lammel,[4] J. I. Lamoureux,[32] T. LeCompte,[10] S. Leone,[23] J. D. Lewis,[7] P. Limon,[7] M. Lindgren,[4] T. M. Liss,[10] N. Lockyer,[21] O. Long,[21] M. Loreti,[20] E. H. Low,[21] J. Lu,[29] D. Lucchesi,[23] C. B. Luchini,[10] P. Lukens,[7] P. Maas,[32] K. Maeshima,[7] A. Maghakian,[26] P. Maksimovic,[15] M. Mangano,[23] J. Mansour,[17] M. Mariotti,[23] J. P. Marriner,[7] A. Martin,[10] J. A. J. Matthews,[18] R. Mattingly,[2] P. McIntyre,[29] P. Melese,[26] A. Menzione,[23] E. Meschi,[23] S. Mikamo,[13] M. Miller,[5] R. Miller,[17] T. Mimashi,[30] S. Miscetti,[8] M. Mishina,[13] H. Mitsushio,[30] S. Miyashita,[30] Y. Morita,[13] S. Moulding,[26] J. Mueller,[27] A. Mukherjee,[7] T. Muller,[4] L. F. Nakae,[28] I. Nakano,[30] C. Nelson,[7] D. Neuberger,[4] C. Newman-Holmes,[7] L. Nodulman,[1] S. Ogawa,[30] K. E. Ohl,[33] R. Oishi,[30] T. Okusawa,[19] R. Paoletti,[23] V. Papadimitriou,[7] S. Park,[7] J. Patrick,[7] G. Pauletta,[23] L. Pescara,[20] M. D. Peters,[14] T. J. Phillips,[6] G. Piacentino,[3] M. Pillai,[25] R. Plunkett,[7] L. Pondrom,[32] N. Produit,[14] J. Proudfoot,[1] F. Ptohos,[9] G. Punzi,[23] K. Ragan,[11] F. Rimondi,[3] L. Ristori,[23] M. Roach-Bellino,[31] W. J. Robertson,[6] T. Rodrigo,[7] J. Romano,[5] L. Rosenson,[15] W. K. Sakumoto,[25] D. Saltzberg,[5] A. Sansoni,[8] V. Scarpine,[29] A. Schindler,[14] P. Schlabach,[9] E. E. Schmidt,[7] M. P. Schmidt,[33] O. Schneider,[14] G. Sciacca,[23] A. Scribano,[23] S. Segler,[7] S. Seidel,[18] Y. Seiya,[30] G. Sganos,[11] M. Shapiro,[14] N. M. Shaw,[24] Q. Shen,[24] P. F. Shepard,[22] M. Shimojima,[30] M. Shochet,[5] J. Siegrist,[28] A. Sill,[7a] P. Sinervo,[11] P. Singh,[22] J. Skarha,[12] K. Sliwa,[31] D. A. Smith,[23] F. D. Snider,[12] L. Song,[7] T. Song,[16] J. Spalding,[7] P. Sphicas,[15] A. Spies,[12] L. Stanco,[20] J. Steele,[32] A. Stefanini,[23] K. Strahl,[11] G. Sullivan,[5] K. Sumorok,[15] R. L. Swartz, Jr.,[10] T. Takahashi,[19] K. Takikawa,[30] B. Tannenbaum,[17] F. Tartarelli,[23] Y. Teramoto,[19] S. Tether,[15] D. Theriot,[7] J. Thomas,[28] R. Thun,[16] M. Timko,[31] P. Tipton,[25] A. Titov,[26] S. Tkaczyk,[7] A. Tollestrup,[7] J. Tonnison,[24] J. Tseng,[12] M. Turcotte,[28] N. Turini,[3] N. Uemura,[30] F. Ukegawa,[21] G. Unal,[21] S. Vejcik, III,[16] M. Vondracek,[10] R. G. Wagner,[1] R. L. Wagner,[7] N. Wainer,[7] R. C. Walker,[25] J. Wang,[5] Q. F. Wang,[26] A. Warburton,[11] G. Watts,[25] T. Watts,[27] R. Webb,[29] C. Wendt,[32] H. Wenzel,[7a] W. C. Wester, III,[14] T. Westhusing,[10] A. B. Wicklund,[1] E. Wicklund,[7] R. Wilkinson,[21] H. H. Williams,[21] B. L. Winer,[25] J. Wolinski,[29] D. Y. Wu,[16] X. Wu,[23] J. Wyss,[20] A. Yagil,[7] W. Yao,[14] K. Yasuoka,[30] Y. Ye,[11] G. P. Yeh,[7] M. Yin,[6] J. Yoh,[7] T. Yoshida,[19] D. Yovanovitch,[7] I. Yu,[33] J. C. Yun,[7] A. Zanetti,[23] F. Zetti,[23] L. Zhang,[32] S. Zhang,[15] W. Zhang,[21] and S. Zucchelli[3]

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This letter reports the observation and mass measurement of fully reconstructed B_s^0 mesons through the decay chain $B_s^0 \to J/\psi\phi$, $J/\psi \to \mu^+\mu^-$, $\phi \to K^+K^-$ using data obtained at the Collider Detector at Fermilab in $\bar{p}p$ collisions at $\sqrt{s} = 1.8$ TeV. A signal of 14.0 ± 4.7 events is observed. Comparison of the B_s^0 signal with the kinematically similar decays $B^+ \to J/\psi K^+$ and $B^0 \to J/\psi K^*(892)^0$ is presented. The mass of the B_s^0 meson is determined to be 5383.3 ± 4.5 (stat) $\pm$ 5.0 (syst) MeV/c^2.

The quark model predicts the existence of the B_s^0 [1] meson, a bound state of a bottom and strange quark-antiquark pair. A recent theoretical prediction gives a range for the B_s^0 mass of 5345–5388 MeV/c^2 using nonrelativistic quark models [2]. Indirect experimental evidence for the existence of the B_s^0 meson has been obtained by several groups [3, 4]. However, these observations do not lead to an unambiguous determination of the B_s^0 mass. More recently, there are reports that candidate B_s^0 events in several decay modes have been fully reconstructed by experiments at LEP [5]. This letter reports the full reconstruction and mass measurement of B_s^0 mesons using the $J/\psi\phi$ decay channel.

We exploit the large cross section for b-quark production at the Tevatron center-of-mass energy of 1.8 TeV [6, 7] using a data set with an integrated luminosity of $\sim$ 12.5 pb^{-1} accumulated during part of the 1992-1993 run by the Collider Detector at Fermilab (CDF). Events that contain $J/\psi \to \mu^+\mu^-$ are obtained with a dimuon trigger which is implemented at low transverse momentum (P_T). These events are enriched with reconstructible B mesons. We focus our search for B_s^0 mesons on the decay chain $B_s^0 \to J/\psi\phi$, $J/\psi \to \mu^+\mu^-$, $\phi \to K^+K^-$.

The CDF detector has been described in detail elsewhere [8]. We describe subsystems used in this analysis including those recently commissioned. A silicon vertex detector (SVX) [9] consisting of four layers of silicon strip detectors located between radii of 2.9 and 7.9 cm and extending $\pm$ 25 cm in z from the center of the detector provides spatial measurements for charged tracks with a resolution of 13 μm in the r-ϕ plane [10]. The geometric acceptance for the SVX is $\sim$ 60% as the interactions are distributed along the beam axis with standard deviation σ of $\sim$ 30 cm. Surrounding the SVX is a time projection chamber (VTX) which provides tracking measurements in the r-z plane. Momenta of charged particles are measured in three dimensions by the central tracking chamber (CTC), an 84-layer drift chamber which covers the

pseudorapidity interval $|\eta| < 1.1$, where $\eta = -\ln[\tan(\theta/2)]$. The SVX, VTX, and CTC are immersed in a 1.4116 T axial magnetic field. Electromagnetic and hadronic calorimeters are located outside the magnet. Muons are identified using three different subsystems each consisting of four layers of drift chambers. The central muon chambers, located behind ~ 5 absorption lengths of calorimeter, cover 85% of ϕ in the range of $|\eta| < 0.6$. Gaps in the ϕ coverage are filled in part by the central upgrade muon chambers with total coverage in ϕ of 80% and $|\eta| \lesssim 0.6$. These chambers are located behind ~ 8 absorption lengths. Finally, central extension muon chambers provide 67% coverage in ϕ for the region $0.6 < |\eta| < 1.0$ behind ~ 6 absorption lengths.

Dimuon events are collected using a three-level trigger. The first-level trigger requires two charged track segments in the muon chambers with $P_T > 3$ GeV/c. The second level requires a CTC track with $P_T > 3$ GeV/c, identified by a fast hardware track processor, to match a muon chamber track segment. The third level, implemented with online track reconstruction software, requires two oppositely-charged CTC tracks to match muon track segments and a dimuon invariant mass between 2.8 and 3.4 GeV/c^2.

The search procedure for $B_s^0 \to J/\psi\phi$ is based on studies of the decays of B^+ and B^0 with Monte Carlo simulation [11] and in the data. We first describe the reconstruction of $B^+ \to J/\psi K^+$ and $B^0 \to J/\psi K^*(892)^0$. Results on these decay modes derived from our earlier data have been published [7]. For each muon candidate we require that the position of the muon track segment and the extrapolated CTC track match to within 3σ, where σ is the uncertainty in the extrapolation due to multiple scattering. Tracks measured in three dimensions by the CTC are used and SVX information is added when available. We calculate the invariant mass of two oppositely-charged muon candidates after constraining them to originate from a

common vertex. The J/ψ candidates are selected by requiring the difference between the dimuon mass and the world average J/ψ mass of 3096.9 MeV/c^2 [12] to be $< 3\sigma$, where σ is the mass uncertainty calculated for each dimuon candidate. The sample contains 41200 $\pm$ 300 J/ψ candidates at a mean mass of 3095.8 $\pm$ 0.2 (stat) MeV/c^2 after corrections for dE/dX losses. The J/ψ signal has a width of $\sim$ 20 MeV/c^2 and a signal-to-noise ratio of 13:1 at the J/ψ mass.

In this analysis, any charged track is considered a kaon candidate for the decay $B^+ \to J/\psi K^+$. The K^* candidates are formed from combinations of two oppositely-charged tracks with both $K^\pm\pi^\mp$ mass assignments. The invariant mass of the track pair is required to be within 80 MeV/c^2 of the mass of the K^* which has a natural width of 51 MeV/c^2 [12]. To improve the mass resolution, we constrain the 3-track ($\mu^+\mu^-K^+$) or 4-track ($\mu^+\mu^-K^+\pi^-$) system to a common secondary vertex and simultaneously constrain the dimuon mass to the world average J/ψ mass. We form a confidence level for this combined constraint, CL(χ^2), where the number of degrees of freedom is 4 (6) for the 3-(4-)track systems. The signed two-dimensional decay length L_{xy} is the distance between the primary and secondary vertex projected onto the B meson candidate momentum vector in the r-ϕ plane. The position of the primary vertex in r-ϕ is calculated using tracks measured by the SVX averaged over many events with an uncertainty dominated by the $\sim$ 40 μm beam spot size.

The reconstruction procedure results in mass distributions with combinatoric backgrounds that are reduced by applying requirements on the P_T of the decay products, the P_T of the B meson candidate $P_T(B)$, L_{xy}, and CL(χ^2). For $B^+ \to J/\psi K^+$, we require $P_T(K^+) > 2$ GeV/c, $P_T(B^+) > 8$ GeV/c, $L_{xy} > 100$ μm, and CL(χ^2) $>$ 1%. Figure 1a shows the $J/\psi K^+$ mass spectrum. A binned maximum likelihood fit of a linear background and a Gaussian signal distribution gives 79.5 $\pm$ 11.4 candidates reconstructed in the $B^+ \to J/\psi K^+$ channel at a mass of 5278.2 $\pm$ 2.6 MeV/c^2 (world

average: 5278.6 $\pm$ 2.0 MeV/c^2 [12]). The σ of the Gaussian is fixed at 15 MeV/c^2 using expectations from Monte Carlo studies and knowledge of the tracking resolution. The fit excludes the mass region below 5140 MeV/c^2 where B decays with an unobserved pion may contribute.

For the $J/\psi K^*$ channel, the combinatoric background is large because we select K^* candidates within the $\pm$ 80 MeV/c^2 mass region and allow for both $K^\pm\pi^\mp$ combinations. We reduce this background by requiring $P_T(K^*) > 3$ GeV/c, $P_T(B^0) > 8$ GeV/c, $L_{xy} > 100$ μm, and CL(χ^2) > 1%. Figure 1b shows the $J/\psi K^*$ mass spectrum. Using the above fit procedure, we obtain 43.7 $\pm$ 8.7 candidates reconstructed at a mass of 5279.6 $\pm$ 2.9 MeV/c^2 (world average: 5278.7 $\pm$ 2.1 MeV/c^2 [12]). The σ of the Gaussian is fixed at the expected 12 MeV/c^2.

The reconstruction of $B_s^0 \to J/\psi\phi$ uses the aforementioned J/ψ selection criteria. To form a ϕ candidate, we require the invariant mass of two oppositely-charged tracks assigned kaon masses to be within 10 MeV/c^2 of the 1019.4 MeV/c^2 ϕ mass [12]. The $\mu^+\mu^-K^+K^-$ system is constrained with the procedure used for the $J/\psi K^+$ and $J/\psi K^*$ systems. Due to the ϕ natural width of 4.4 MeV/c^2 [12], the combinatoric background is small relative to the $J/\psi K^*$ channel. Hence, we require $P_T(\phi) > 2$ GeV/c, CL(χ^2) > 1%, and positive L_{xy}. The histogram in Fig. 2a shows the resulting $J/\psi K^+K^-$ mass distribution. The signal is clearly visible and remains significant under variation of the selection criteria. Figure 2b shows the K^+K^- mass distribution for $J/\psi K^+K^-$ combinations within 20 MeV/c^2 of 5380 MeV/c^2 without the $\pm$ 10 MeV/c^2 ϕ window on the K^+K^- mass. An excess near the ϕ mass is observed.

The mass of the B_s^0 meson is determined by performing a binned maximum likelihood fit to the $J/\psi K^+K^-$ mass distribution using a linear background and a Gaussian signal distribution with the width fixed at 12 MeV/c^2. The fit result is 14.0 $\pm$ 4.7

fully reconstructed B_s^0 candidates at a mass of 5383.3 $\pm$ 4.5 (stat) MeV/c^2.

Additional checks on the signal are performed. The dotted histogram in Fig. 2a shows no enhancement when $J/\psi K^+K^-$ combinations are formed using K^+K^- with invariant mass in the region 1050–1090 MeV/c^2. We see no signal when forming same-sign $J/\psi K^\pm K^\pm$ combinations. We also study the possibility that combinations from $B^0 \to J/\psi K^*$ decay contribute to the signal region if the pion from the K^* decay is assigned a kaon mass. Monte Carlo studies of this process predict 0.9 $\pm$ 0.9 events in the $J/\psi\phi$ signal region. There are no common events in the $J/\psi K^*$ and $J/\psi\phi$ signals.

We investigate several sources of systematic uncertainty on the mass determination. A 0.05% uncertainty in the magnetic field [13] contributes to a mass scale uncertainty of about 1 MeV/c^2. The systematic error due to the mass fitting procedure is estimated to be 2 MeV/c^2 by varying the histogram bin size and the Gaussian width. The selection criteria are varied for the three B decay modes, and we estimate this systematic uncertainty to be 2 MeV/c^2. A systematic error of 3 MeV/c^2 is assigned due to the current uncertainty in the tracking calibration. Alternative methods for constraining the 4-track system lead us to assign a systematic uncertainty of 2 MeV/c^2. We combine these errors in quadrature and round the overall systematic uncertainty to 5.0 MeV/c^2 on the B_s^0 mass determination. The CDF measurements of the B^+ and B^0 masses are consistent with the world averages within the stated systematic uncertainty.

In conclusion, we observe the decay $B_s^0 \to J/\psi\phi$ with 14.0 $\pm$ 4.7 events. We determine the mass of the B_s^0 meson to be 5383.3 $\pm$ 4.5 (stat) $\pm$ 5.0 (syst) MeV/c^2.

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REFERENCES

[a] Visitor.

[1] References to specific charge states imply the charge-conjugate state as well.

[2] W. Kwong and J. Rosner, Phys. Rev. D **44**, 212 (1991).

[3] CUSB Collaboration, J. Lee-Franzini *et al.*, Phys. Rev. Lett. **65**, 2947 (1990).

[4] ALEPH Collaboration, D. Buskulic *et al.*, Phys. Lett. B **294**, 145 (1992); DELPHI Collaboration, P. Abreu *et al.*, Phys. Lett B **289**, 199 (1992); OPAL Collaboration, P. T. Acton *et al.*, Phys. Lett B **295**, 357 (1992).

[5] A. Bonissent, talk given at *High Energy Hadronic Interactions,* XXVIIIth Rencontres de Moriond, Les Arcs, France, 1993.

[6] CDF Collaboration, Phys. Rev. Lett. **69**, 3704 (1992); Fermilab Report No. FERMILAB-PUB-93/091-E (submitted to Phys. Rev. Lett.).

[7] CDF Collaboration, F. Abe *et al.*, Phys. Rev. Lett. **68**, 3403 (1992); Fermilab Report No. FERMILAB-PUB-93/131-E (to be submitted to Phys. Rev. D).

[8] CDF Collaboration, F. Abe *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **271**, 387 (1988); F. Bedeschi *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **268**, 50 (1988); G. Ascoli *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **268**, 33 (1988).

[9] F. Bedeschi *et al.*, Fermilab Report No. FERMILAB-CONF-92/263-E.

[10] In CDF, ϕ is the azimuthal angle, θ is the polar angle, and r is the radius from

the proton beam axis (z-axis).

[11] P. Nason, S. Dawson, and R. K. Ellis, Nucl. Phys. **B303**, 607 (1988); **B327**, 49 (1989); C. Peterson *et al.*, Phys. Rev. D **27**, 105 (1983).

[12] Particle Data Group, K. Hikasa *et al.*, Phys. Rev. D **45**, (1992).

[13] C. Newman-Holmes, E. E. Schmidt, and R. Yamada, Nucl. Instrum. Methods Phys. Res., Sect. A **274**, 443 (1989).

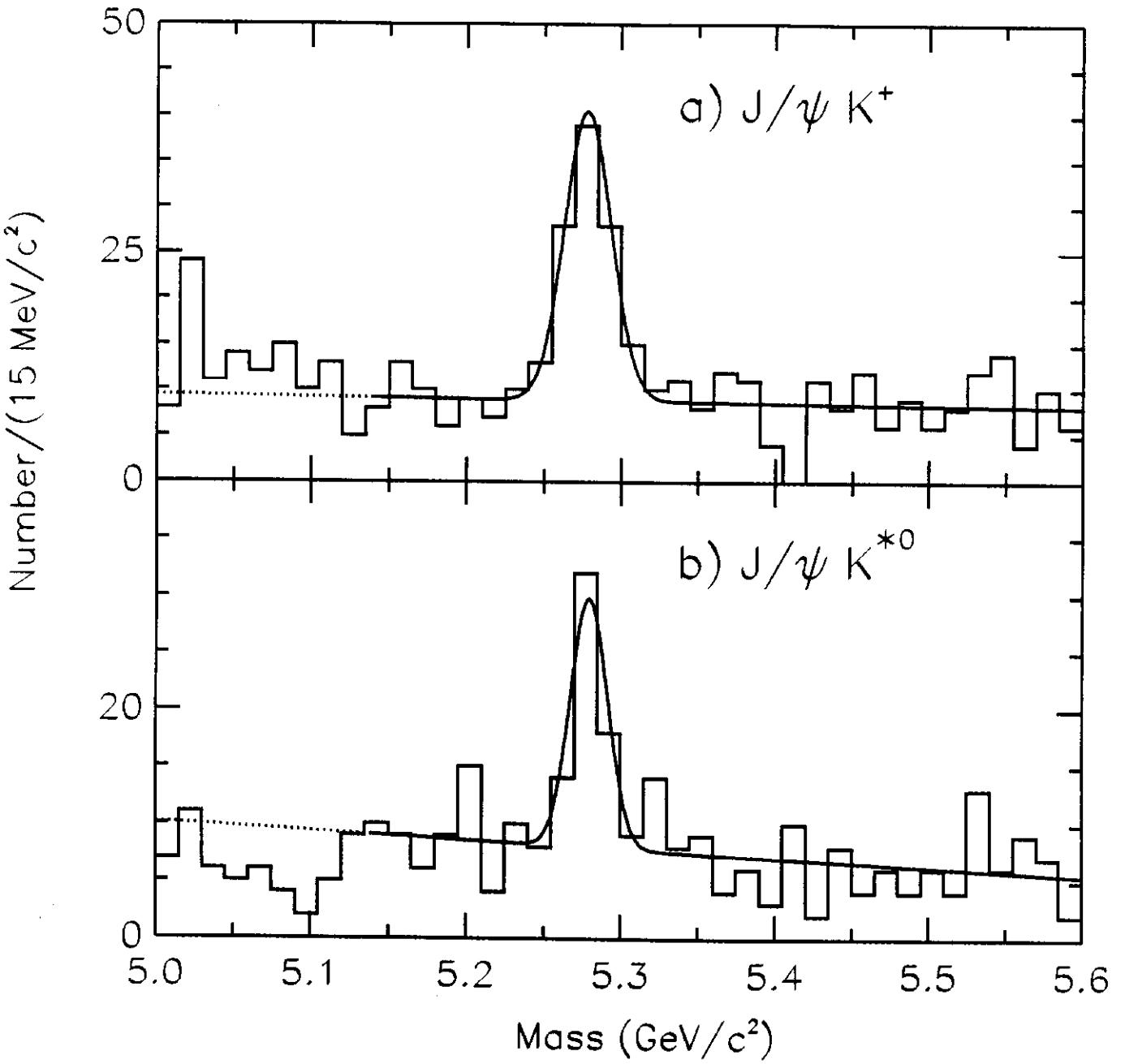

FIG. 1. The mass distribution for (a) $J/\psi\ K^+$ and (b) $J/\psi\ K^*$. The solid line indicates the fit region.

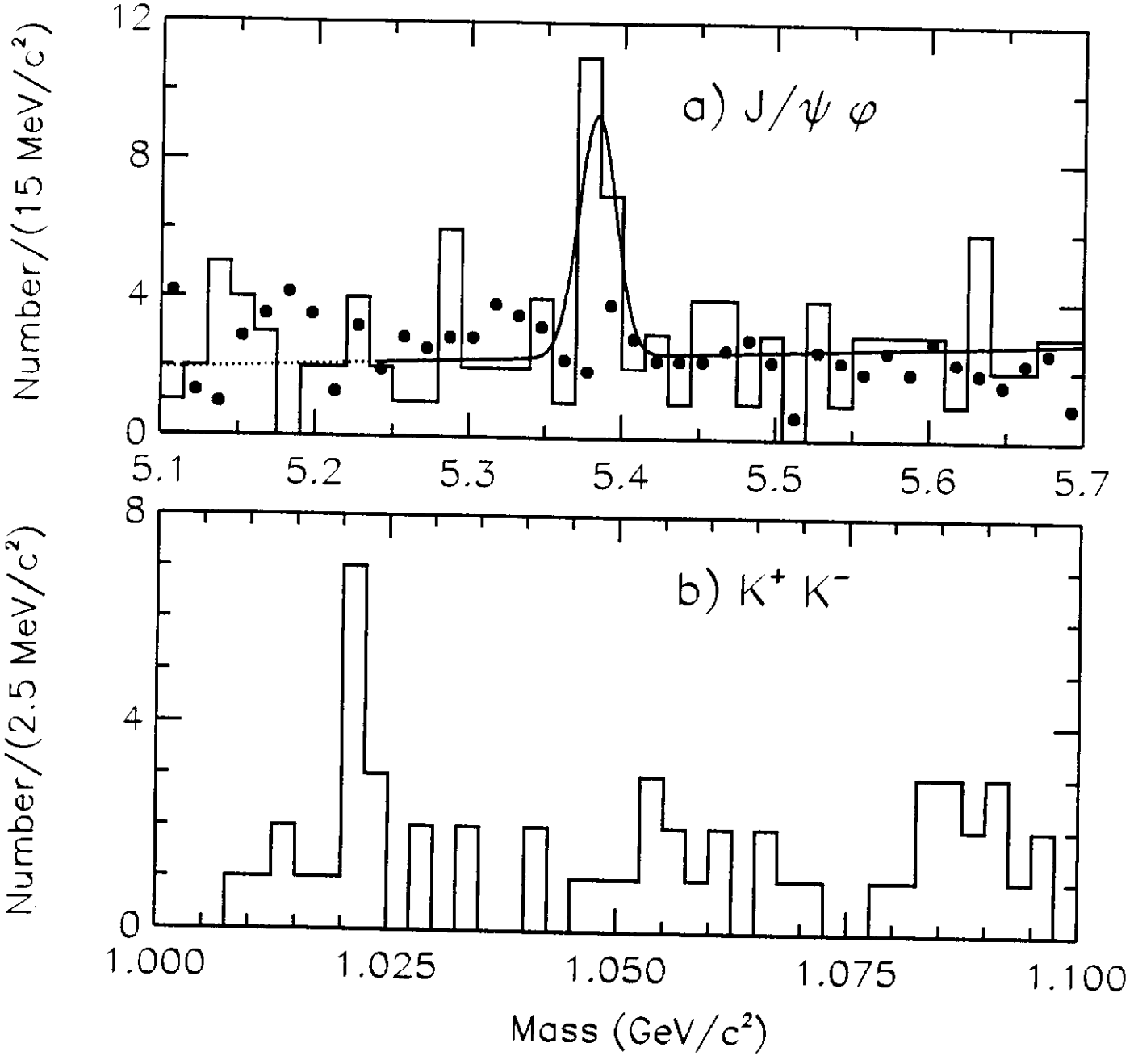

FIG. 2. (a) The $J/\psi\ K^+K^-$ mass distribution for K^+K^- within 10 MeV/c^2 of the ϕ mass (solid), and for the normalized ϕ sideband region (dots). (b) The K^+K^- mass distribution for $J/\psi\ K^+K^-$ combinations within 20 MeV/c^2 of 5380 MeV/c^2.