Direct observation of the strange $b$ baryon $\Xi^+_b$
A. Nomertski, S.F. Novaes, T. Numemann, V. O'Dell, D.C. O’Neil, G. Obran, C. Ochando, D. Onoprienko, N. Oshima, J. Osta, R. Otec, G.J. Otero y Garzón, M. Owen, P. Padley, M. Pangilinan, G. Panov, N. Parashar, S.-J. Park, S.K. Park, J. Parsons, R. Partridge, N. Parua, A. Patwa, G. Pawloski, B. Penning, P.M. Perea, K. Peters, Y. Peters, P. Pétroff, M. Petteni, R. Piegäin, J. Pijper, M.-A. Pleier, P.L.M. Posteda-Lerma, V.M. Podstavkov, Y. Pogorelov, M.-E. Pol, P. Polozov, A. Pompo, B.G. Pope, A.V. Popov, C. Potter, W.L. Prado da Silva, H.B. Prosper, S. Protopopescu, G. Watts, N. Varelas, S. Robinson, M. Souza, M. Souza, B. Spurlock, S. Sumowidagdo, V. Siccardi, M. Voutilainen, G. Sajot, H. Severini, S. Sumowidagdo, J. Piper, M. Strovink, A. Santoro, G. Savage, T. Scanlon, D. Schaile, R.D. Schanberger, Y. Scheglov, H. Schellman, P. Schieferdecker, T. Schliephake, C. Schmitt, C. Schwabenberger, A. Schwartz, R. Schwienhorst, J. Sekaric, S. Sengupta, H. Severini, E. Shabalina, M. Shamin, V. Shary, A.A. Shchukin, R.K. Shivpuri, D. Shpakov, V. Siccardi, V. Simak, V. Sirotenko, P. Skubic, P. Slattery, D. Smirnov, R.P. Smith, J. Snow, G.R. Snow, S. Snyder, S. Söldner-Rembold, L. Sonnenschein, A. Sopczak, M. Sosebe, K. Soustruznik, M. Souza, B. Spurlock, J. Stark, J. Steele, V. Stolin, A. Stone, D.A. Stoyanova, J. Strandberg, S. Strandberg, M.A. Straub, E. Strauss, D. Ström, M. Strovink, L. Stutte, S. Sumowidagdo, P. Svoisky, A. Sznajder, M. Talby, P. Tamburello, A. Tansisjczyk, W. Taylor, P. Telford, J. Temple, B. Tiller, F. Tissandier, M. Titov, V.V. Tokmenin, M. Tomoto, T. Toole, I. Torciani, T. Trefzger, D. Tsyplyachev, B. Tuchming, C. Tully, P.M. Tuts, R. Unalau, S. Uvarov, L. Uvarov, S. Uzunyan, B. Vachon, P.J. van den Berg, Y. Vartapetian, M. Varela, I.A. Vasylyev, M. Vaulp, P. Verdiër, L.S. Vertogradova, Y. Vertogradova, M. Verzochi, F. Villeneuve-Seguini, P. Vint, P. Voke, E. Von Toerne, M. Voutilainen, M. Vreesswijak, R. Wagner, H.D. Wahl, L. Wang, M.H.L.S Wang, J. Warchol, G. Watts, M. Wayne, M. Weber, G. Weber, H. Weerts, A. Wenge, W. Wen, N. Wernes, M. Wetstein, A. White, D. Wicke, G.W. Wilson, S.J. Wimpenny, M. Wobisch, D.R. Wood, T.R. Wyatt, Y. Xie, S. Yacooob, R. Yamada, M. Yan, T. Yasuda, Y.A. Yatsunenko, K. Yip, H.D. Yoo, S.W. Youn, J. Yu, C. Yu, A. Yurkewicz, A. Zatserklyaniy, C. Zeitnitz, D. Zhang, T. Zhao, B. Zhon, J. Zhu, M. Zielinski, D. Zieminska, A. Zieminski, L. Zivkovic, R. Zou, T. Tollefson, N. Zou, E.G. Zverev

(The DØ Collaboration)

1 Universidad de Buenos Aires, Buenos Aires, Argentina
2 LAFEX, Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil
3 Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil
4 Instituto de Física Teórica, Universidade Estadual Paulista, São Paulo, Brazil
5 University of Alberta, Edmonton, Alberta, Canada
6 University of Virginia, Charlottesville, Virginia, USA
7 University of Wisconsin, Madison, Wisconsin, USA
8 Center for Particle Physics, Charles University, Prague, Czech Republic
9 Czech Technical University, Prague, Czech Republic
10 Center for Particle Physics, Institute of Physics, Academy of Sciences of the Czech Republic, Prague, Czech Republic
11 Universidad San Francisco de Quito, Quito, Ecuador
12 Laboratoire de Physique Corpusculaire, IN2P3-CNRS, Université Blaise Pascal, Clermont-Ferrand, France
13 Laboratoire de Physique Subatomique et de Cosmologie, IN2P3-CNRS, Université Grenoble 1, Grenoble, France
14 CPPM, IN2P3-CNRS, Université de la Méditerranée, Marseille, France
15 Laboratoire de l’Accélérateur Linéaire, IN2P3-CNRS and Université Paris-Sud, Orsay, France
16 LPNHE, IN2P3-CNRS, Universités Paris VI and VII, Paris, France
17 DAPNIA/Service de Physique des Particules, CEA, Saclay, France
18 IPHC, Université Louis Pasteur and Université de Haute Alsace, CNRS, IN2P3, Strasbourg, France
19 IPNL, Université Lyon 1, CNRS/IN2P3, Villeurbanne, France and Université de Lyon, Lyon, France
20 III. Physikalisches Institut A, RWTH Aachen, Aachen, Germany
21 Physikalisches Institut, Universität Bonn, Bonn, Germany  
22 Physikalisches Institut, Universität Freiburg, Freiburg, Germany  
23 Institut für Physik, Universität Mainz, Mainz, Germany  
24 Ludwig-Maximilians-Universität München, München, Germany  
25 Fachbereich Physik, University of Wuppertal, Wuppertal, Germany  
26 Panjab University, Chandigarh, India  
27 Delhi University, Delhi, India  
28 Tata Institute of Fundamental Research, Mumbai, India  
29 University College Dublin, Dublin, Ireland  
30 Korea Detector Laboratory, Korea University, Seoul, Korea  
31 SungKyunKwan University, Suwon, Korea  
32 CINVESTAV, Mexico City, Mexico  
33 FOM-Institute NIKHEF and University of Amsterdam/NIKHEF, Amsterdam, The Netherlands  
34 Radboud University Nijmegen/NIKHEF, Nijmegen, The Netherlands  
35 Joint Institute for Nuclear Research, Dubna, Russia  
36 Institute for Theoretical and Experimental Physics, Moscow, Russia  
37 Moscow State University, Moscow, Russia  
38 Institute for High Energy Physics, Protvino, Russia  
39 Petersburg Nuclear Physics Institute, St. Petersburg, Russia  
40 Lund University, Lund, Sweden, Royal Institute of Technology and Stockholm University, Stockholm, Sweden, and Uppsala University, Uppsala, Sweden  
41 Physik Institut der Universität Zürich, Zürich, Switzerland  
42 Lancaster University, Lancaster, United Kingdom  
43 Imperial College, London, United Kingdom  
44 University of Manchester, Manchester, United Kingdom  
45 University of Arizona, Tucson, Arizona 85721, USA  
46 Lawrence Berkeley National Laboratory and University of California, Berkeley, California 94720, USA  
47 California State University, Fresno, California 93740, USA  
48 University of California, Riverside, California 92521, USA  
49 Florida State University, Tallahassee, Florida 32306, USA  
50 Fermi National Accelerator Laboratory, Batavia, Illinois 60510, USA  
51 University of Illinois at Chicago, Chicago, Illinois 60607, USA  
52 Northern Illinois University, DeKalb, Illinois 60115, USA  
53 Northwestern University, Evanston, Illinois 60208, USA  
54 Indiana University, Bloomington, Indiana 47405, USA  
55 University of Notre Dame, Notre Dame, Indiana 46556, USA  
56 Purdue University Calumet, Hammond, Indiana 46323, USA  
57 Iowa State University, Ames, Iowa 50011, USA  
58 University of Kansas, Lawrence, Kansas 66045, USA  
59 Kansas State University, Manhattan, Kansas 66506, USA  
60 Louisiana Tech University, Ruston, Louisiana 71272, USA  
61 University of Maryland, College Park, Maryland 20742, USA  
62 Boston University, Boston, Massachusetts 02215, USA  
63 Northeastern University, Boston, Massachusetts 02115, USA  
64 University of Michigan, Ann Arbor, Michigan 48109, USA  
65 Michigan State University, East Lansing, Michigan 48824, USA  
66 University of Mississippi, University, Mississippi 38677, USA  
67 University of Nebraska, Lincoln, Nebraska 68588, USA  
68 Princeton University, Princeton, New Jersey 08544, USA  
69 State University of New York, Buffalo, New York 14260, USA  
70 Columbia University, New York, New York 10027, USA  
71 University of Rochester, Rochester, New York 14627, USA  
72 State University of New York, Stony Brook, New York 11794, USA  
73 Brookhaven National Laboratory, Upton, New York 11973, USA  
74 Langston University, Langston, Oklahoma 73050, USA  
75 University of Oklahoma, Norman, Oklahoma 73019, USA  
76 Oklahoma State University, Stillwater, Oklahoma 74078, USA  
77 Brown University, Providence, Rhode Island 02912, USA  
78 University of Texas, Arlington, Texas 76019, USA  
79 Southern Methodist University, Dallas, Texas 75275, USA  
80 Rice University, Houston, Texas 77005, USA  
81 University of Virginia, Charlottesville, Virginia 22901, USA and  
82 University of Washington, Seattle, Washington 98195, USA  
(Dated: February 1, 2008)
We report the first direct observation of the strange b baryon \( \Xi_b^- \) (\( \Xi_b^0 \)). We reconstruct the decay \( \Xi_b^- \rightarrow J/\psi \Xi^- \), with \( J/\psi \rightarrow \mu^+ \mu^- \), and \( \Xi^- \rightarrow \Lambda \pi^- \rightarrow p\pi^- \pi^- \) in \( p\bar{p} \) collisions at \( \sqrt{s} = 1.96 \text{ TeV} \). Using 1.3 fb\(^{-1}\) of data collected by the D0 detector, we observe 15.2 ± 4.4 (stat.\) ± 1.9 (syst.) \( \Xi_b^- \) candidates at a mass of \( 5.774 \pm 0.011 \text{ (stat.)} \pm 0.015 \text{ (syst.)} \text{ GeV} \). The significance of the observed signal is 5.5\( \sigma \), equivalent to a probability of \( 3.3 \times 10^{-8} \) of it arising from a background fluctuation. Normalizing to the decay \( \Lambda_b \rightarrow J/\psi \Lambda \), we measure the relative rate

\[
\frac{\sigma(\Xi_b^-) \times B(\Xi_b^- \rightarrow J/\psi \Xi^-)}{\sigma(\Lambda_b) \times B(\Lambda_b \rightarrow J/\psi \Lambda)} = 0.28 \pm 0.09 \text{ (stat.)} \pm 0.09 \text{ (syst.)}.
\]

PACS numbers: 14.20.-c, 14.20.Mr, 14.65.Fy

The quark model of hadrons \cite{1} predicts the existence of a number of baryons containing b quarks, with a hierarchical structure similar to that of charmed baryons. Despite significant progress in studying b hadrons over the last decade, only the \( \Lambda_b \) (udb) b baryon has been directly observed. The \( \Xi^- \) (dub) \( \bar{d}b \) baryon has been made of valence quarks from all three known generations of fermions and is expected to decay through the weak interaction. Theoretical calculations of heavy quark effective theory \cite{2} and nonrelativistic QCD \cite{3} predict the \( \Xi^- \) mass in the range 5.7 – 5.8 GeV \cite{4}.

Experiments at the CERN LEP e\(^+\)e\(^-\) collider have reported indirect evidence of the \( \Xi_b^- \) baryon based on an excess of same-sign \( \Xi^- \) events in jets \cite{5}. Interpreting the excess as the semi-inclusive \( \Xi_b^- \rightarrow \Xi^- \ell^- \nu \chi \) decay, the average lifetime of the \( \Xi_b^- \) is 1.42\( ^{+0.28} _{-0.24} \) ps \cite{6}. In this Letter, we report the first direct observation of the \( \Xi_b^- \) baryon, fully reconstructed in an exclusive decay. We observe the decay \( \Xi_b^- \rightarrow J/\psi \Xi^- \), with \( J/\psi \rightarrow \mu^+ \mu^- \), \( \Xi^- \rightarrow \Lambda \pi^- \), and \( \Lambda \rightarrow p\pi^- \). The analysis is based on a data sample of 1.3 fb\(^{-1}\) integrated luminosity collected in \( p\bar{p} \) collisions at \( \sqrt{s} = 1.96 \text{ TeV} \) with the D0 detector at the Fermilab Tevatron collider during 2002 – 2006.

The D0 detector is described in detail elsewhere \cite{7}. The components most relevant to this analysis are the central tracking system and the muon spectrometer. The central tracking system consists of a silicon microstrip tracker (SMT) and a central fiber tracker (CFT) that are surrounded by a 2 T superconducting solenoid. The SMT is optimized for tracking and vertexing for the pseudorapidity region \(|\eta| < 3 \) \( (\eta = -\ln[\tan(\theta/2)] \) and \( \theta \) is the polar angle) while the CFT has coverage for \(|\eta| < 2 \). Liquid-argon and uranium calorimeters in a central and two end-cap cryostats cover the pseudorapidity region \(|\eta| < 4.2 \). The muon spectrometer is located outside the calorimeter and covers the pseudorapidity region \(|\eta| < 2 \). It comprises a layer of drift tubes and scintillator trigger counters in front of 1.8 T iron toroids followed by two similar layers behind the toroids.

The topology of \( \Xi_b^- \rightarrow J/\psi \Xi^- \rightarrow J/\psi \Lambda \pi^- \rightarrow (\mu^+ \mu^-) (p\pi^-) \pi^- \) decay topology. The \( \Lambda \) and \( \Xi^- \) baryons have decay lengths of the order of cm; the \( \Xi_b^- \) has an expected decay length of the order of mm.

\( J/\psi \rightarrow \mu^+ \mu^- \) decays are reconstructed from two oppositely charged muons that have a common vertex. Muons are identified by matching tracks reconstructed in the central tracking system with either track segments in the muon spectrometer or calorimeter energies consistent with the muon trajectory. They are required to have \( p_T > 1.5 \text{ GeV} \) and at least one of them must be reconstructed in each of the three muon drift tube layers. The dimuon invariant mass \( M(\mu^+ \mu^-) \) is required to be in the range 2.5 – 3.6 GeV. In addition, events must have at least one reconstructed primary vertex of the \( p\bar{p} \) interaction. If two or more vertices are reconstructed, the one closest to the reconstructed \( \Xi_b^- \) vertex (see below) is used. Events containing a \( J/\psi \) candidate are reprocessed with a version of the track reconstruction algorithm that improves the efficiency for tracks with low \( p_T \).
and high impact parameters. Consequently, the efficiencies for \( K_S^0, \Lambda, \) and \( \Xi^- \) reconstruction are significantly increased. Figure 2(a) shows the invariant mass distributions of the reconstructed \( \Xi^- \) candidates (see below) before and after the reprocessing. The reprocessing increases the \( \Xi^- \) yield by approximately a factor of 5.5. For further analysis, \( J/\psi \rightarrow \mu^+\mu^- \) candidates are required to have mass \( 2.80 < M(\mu^+\mu^-) < 3.35 \) GeV and \( p_T > 5 \) GeV. The mass windows here and below are chosen to be approximately \( \pm 5 \sigma \) and the \( p_T \) requirement ensures that the selected \( J/\psi \) candidates are above the sharp turn-on of the detector and trigger acceptances.

\( \Lambda \rightarrow p\pi^- \) candidates are formed from two oppositely charged tracks that originate from a common vertex. The track with the higher \( p_T \) is assumed to be the proton. MC studies show that this assignment gives nearly 100% correct combination. The invariant mass of the \( p\pi^- \) pair must have a mass between 1.105 and 1.125 GeV. The two tracks are required to have a total of no more than two hits in the tracking detector before the reconstructed \( p\pi^- \) vertex. Furthermore, the impact parameter significance (the impact parameter with respect to the event vertex divided by its uncertainty) must exceed three for both tracks and exceed four for at least one of them. These selection cuts are the same as those in Ref. [8].

The \( \Lambda \) candidates are then combined with negatively charged tracks (assumed to be pions) to form \( \Xi^- \rightarrow \Lambda\pi^- \) decay candidates. The pion must have an impact parameter significance greater than three. The \( \Lambda \) and the pion are required to have a common vertex. For both \( \Lambda \) and \( \Xi^- \) candidates, the distance between the event vertex and its decay vertex is required to exceed four times its uncertainty. Moreover, the uncertainty of the distance between the production vertex and its decay vertex (decreased length) in the transverse plane (the plane perpendicular to the beam direction) must be less than 0.5 cm. These two requirements reduce combinatoric and track mismeasurement backgrounds.

The two pions from \( \Xi^- \rightarrow \Lambda\pi^- \rightarrow (p\pi^-)\pi^- \) decays (right-sign) have the same charge. Consequently, the combination \( \Lambda\pi^+ \) (wrong-sign) events form an ideal control sample for background studies. Figure 2(b) compares mass distributions of the right-sign \( \Lambda\pi^- \) and the wrong-sign \( \Lambda\pi^+ \) combinations. The \( \Xi^- \) mass peak is evident in the distribution of the right-sign events. A \( \Lambda\pi^- \) pair is considered to be a \( \Xi^- \) candidate if its mass is within the range \( 1.305 < M(\Lambda\pi^-) < 1.340 \) GeV.

\( \Xi^-_{B^-} \rightarrow J/\psi \Xi^- \rightarrow J/\psi \Lambda \pi^- \rightarrow (\mu^+\mu^-)(p\pi^-)\pi^- \) decay are utilized to further suppress backgrounds. The wrong-sign background events from the data and MC signal \( \Xi^-_{B^-} \) events are used for studying additional event selection criteria. Protons and pions from the \( \Xi^- \) decays of the \( \Xi^-_{B^-} \) events are expected to have higher momenta than those from most of the background processes. Therefore, protons are required to have \( p_T > 0.7 \) GeV. Similarly, minimum \( p_T \) requirements of 0.3 and 0.2 GeV are imposed on pions from \( \Lambda \) and \( \Xi^- \) decays, respectively. These requirements remove 91.6% of the wrong-sign background events while keeping 68.7% of the MC \( \Xi^-_{B^-} \) signal events. Backgrounds from combinatorics and other \( b \) hadrons are reduced by using topological decay information. Contamination from decays such as \( B^- \rightarrow J/\psi K^- \rightarrow J/\psi K^0_S \pi^- \) and \( B^0 \rightarrow J/\psi K^+ \pi^- \rightarrow J/\psi (K^0_S \pi^-)\pi^- \) are suppressed by requiring the \( \Xi^- \) candidates to have decay lengths greater than 0.5 cm and \( \cos(\theta_{col}) > 0.99 \), as the \( \Xi^- \) baryons in MC have an average decay length of 4.8 cm. Here \( \theta_{col} \) is the angle between the \( \Xi^- \) direction and the direction from the \( \Xi^- \) production vertex to its decay vertex in the transverse plane. These two requirements on the \( \Xi^- \) reduce the background by an additional 56.4%, while removing only 1.7% of the MC signal events. The contribution from the \( \Omega^-_{b\Xi} \) baryon is estimated to be negligible. Finally, \( \Xi^-_{B^-} \) baryons are expected to have a sizable lifetime. To reduce prompt backgrounds, the transverse proper decay length significance of the \( \Xi^-_{B^-} \) candidates is required to be greater than two. This final criterion retains 83.1% of the MC signal events but only 43.9% of the remaining background events.

In the data, 51 events with the \( \Xi^-_{B^-} \) candidate mass between 5.2 and 7.0 GeV pass all selection criteria. The
mass range is chosen to be wide enough to encompass masses of all known $b$ hadrons as well as the predicted mass of the $\Xi_b^-$ baryon. The candidate mass, $M(\Xi_b^-)$, is calculated as $M(\Xi_b^-) = M(J/\psi \Xi^-) - M(\mu^+\mu^-) - M(\Lambda\pi^-) + M_{PDG}(J/\psi) + M_{PDG}(\Xi^-)$ to improve the resolution. Here $M(J/\psi \Xi^-)$, $M(\mu^+\mu^-)$, and $M(\Lambda\pi^-)$ are the reconstructed masses while $M_{PDG}(J/\psi)$ and $M_{PDG}(\Xi^-)$ are taken from Ref. [1]. The distribution of $M(\Xi_b^-)$ is shown in Fig. [3a]. A mass peak near 5.8 GeV is apparent. A number of cross checks are performed to ensure the observed peak is not due to artifacts of the analysis: (1) The $J/\psi \Lambda\pi^+$ mass distribution of the wrong-sign events, shown in Fig. [3b], is consistent with a flat background. (2) The event selection is applied to the sideband events of the $\Xi^-\pi^+$ contributions. (3) The broadness fluctuating to 19 or more events is $2^{+1}_{-0.6}$ (stat.) and $3^{+1}_{-0.4}$ (syst.). The significance of the observed mass peak is equal to or more significant than what is seen in the data. Including systematic effects from the mass range, signal and background models, and the track momentum scale results in a minimum significance of $5.3\sigma$ and a $\Xi_b^-$ yield of 15.2 $\pm$ 4.4 (stat.)$^{+1.9}_{-0.4}$ (syst.). The significance can also be estimated from the numbers of candidate events and estimated background events. In the mass region of 2.5 times the fitted width centered on the fitted mass, 19 candidate events ($8 J/\psi \Xi^-$ and 11 $J/\psi \Xi^-$) are observed while 14.8 $\pm$ 4.3 (stat.)$^{+1.9}_{-0.4}$ (syst.) signal and 3.6 $\pm$ 0.6 (stat.)$^{+0.4}_{-0.4}$ (syst.) background events are estimated from the fit. The probability of backgrounds fluctuating to 19 or more events is $2.2 \times 10^{-7}$, equivalent to a Gaussian significance of $5.2\sigma$.

The new likelihood $\mathcal{L}_b$ is found. The logarithmic likelihood ratio $\sqrt{2\ln(\mathcal{L}_{s+b}/\mathcal{L}_b)}$ indicates a statistical significance of $5.9\sigma$, corresponding to a probability of $3.3 \times 10^{-8}$ from background fluctuation for observing a signal that is equal to or more significant than what is seen in the data. Including systematic effects from the mass range, signal and background models, and the track momentum scale results in a minimum significance of $5.3\sigma$ and a $\Xi_b^-$ yield of 15.2 $\pm$ 4.4 (stat.)$^{+1.9}_{-0.4}$ (syst.). The significance can also be estimated from the numbers of candidate events and estimated background events. In the mass region of 2.5 times the fitted width centered on the fitted mass, 19 candidate events ($8 J/\psi \Xi^-$ and 11 $J/\psi \Xi^-$) are observed while 14.8 $\pm$ 4.3 (stat.)$^{+1.9}_{-0.4}$ (syst.) signal and 3.6 $\pm$ 0.6 (stat.)$^{+0.4}_{-0.4}$ (syst.) background events are estimated from the fit. The probability of backgrounds fluctuating to 19 or more events is $2.2 \times 10^{-7}$, equivalent to a Gaussian significance of $5.2\sigma$.

Figure 3 shows distributions of the proper decay length for the 19 candidate events, the $\Xi_b^-$ sideband events, and the MC $\Xi_b^-$ signal events plus estimated background events. The distribution of the candidate events agrees well with that expected from the $\Xi_b^-$ signal while the sideband events have a lower mean proper decay length. Due to the use of lifetime information in the event selection, a $\Xi_b^-$ lifetime measurement is not made in this Letter.

Potential systematic biases on the measured $\Xi_b^-$ masses are studied for the event selection, signal and background models, and the track momentum scale. Varying cut values and using a multivariate technique of different variables for event selection leads to a maximum change of 0.020 GeV in the $\Xi_b^-$ mass. Subtracting an estimated statistical contribution to the change,
transverse plane of the 19 candidate events in the ±2.5σ signal mass window along with that of the events in the sidebands, defined to be 3σ away from the fitted mass. Also shown is the expected distribution from 14.8 MC Ξ−b signal events plus 3.6 background events. The distribution of the sideband events is scaled to the number of events in the signal mass window. Kolmogorov-Smirnov tests indicate that the distribution of the signal events is favored over that of the sideband events with respect to the MC expectation by a ratio of five to one.

The distribution of the signal events plus 3.6 background events in the transverse plane of the 19 candidate events in the ±2.5σ signal mass window along with that of the events in the sidebands, defined to be 3σ away from the fitted mass. Also shown is the expected distribution from 14.8 MC Ξ−b signal events plus 3.6 background events. The distribution of the sideband events is scaled to the number of events in the signal mass window. Kolmogorov-Smirnov tests indicate that the distribution of the signal events is favored over that of the sideband events with respect to the MC expectation by a ratio of five to one.

A conservative ±0.015 GeV systematic uncertainty is assigned due to the event selection. Using double Gaussians for the signal model, a first-order polynomial for the background model, or fixing the mass resolution to that obtained from the MC Ξ−b events all lead to negligible changes in the mass. The mass, calculated using the world average values of intermediate particle masses above, is found to have a weak dependence on the track momentum scale. This has been verified using the Λb → J/ψ Λ and B0 → J/ψ Ks events observed in the data. A systematic uncertainty of ±0.002 GeV is assigned, corresponding to the mass difference between our measurement and the world average of Λb and B0 hadrons. Adding in quadrature, a total systematic uncertainty of ±0.015 GeV is obtained to yield the measured Ξ−b mass: 5.774 ± 0.011 (stat.) ± 0.015 (syst.) GeV.

The Ξ−b σ × B relative to that of the Λb baryon is calculated using

\[
\frac{\sigma(\Xi^-_b) \times B(\Xi^-_b \rightarrow J/\psi \Xi^-)}{\sigma(\Lambda_b) \times B(\Lambda_b \rightarrow J/\psi \Lambda)} \sim \frac{\epsilon(\Lambda_b \rightarrow J/\psi \Lambda)}{\epsilon(\Xi^-_b \rightarrow J/\psi \Xi^-)} \frac{N_{\Xi^-_b}}{N_{\Lambda_b}}
\]

where \(N_{\Xi^-_b}\) and \(N_{\Lambda_b}\) are the numbers of Ξ−b and Λb events reconstructed in data. Analyzing the same data and using the similar event selection criteria and fitting procedure as the Ξ−b analysis, a yield of \(240 \pm 30\) (stat.) +12 (syst.) Λb baryons is determined. The efficiencies to reconstruct the decays, \(\epsilon(\Xi^-_b)\) and \(\epsilon(\Lambda_b)\), are determined by MC simulation, and the efficiency ratio, \(\epsilon(\Lambda_b)/\epsilon(\Xi^-_b)\), is found to be 4.4 ± 1.3. The uncertainty on \(\epsilon(\Lambda_b)/\epsilon(\Xi^-_b)\) arises from MC modeling (27%), MC statistics (10%), the reconstruction of the additional pion in the Ξ−b decay (7%), and the Ξ−b mass difference between data and MC (5%). The largest component, MC modeling uncertainty, is due to the difference in the efficiency ratio with and without MC reweighting. The efficiency ratio is found to be insensitive to changes in Λb and Ξ−b production models. Many other systematic uncertainties on the efficiencies themselves tend to cancel in the ratio of the efficiencies. We find a relative production ratio of 0.28 ± 0.09 (stat.) +0.09 −0.08 (syst.).

In summary, in 1.3 fb−1 of data collected by the D0 experiment in \(p\bar{p}\) collisions at √s = 1.96 TeV at the Fermilab Tevatron collider, we have made the first direct observation of the strange b baryon Ξ−b with a statistical significance of 5.5σ. We observe the decay mode \(\Xi^-_b \rightarrow J/\psi \Xi^-\) with \(J/\psi \rightarrow \mu^+ \mu^-\), \(\Xi^- \rightarrow \Lambda \pi^- \rightarrow p \pi^- \pi^−\). We measure the Ξ−b mass to be 5.774 ± 0.011 (stat.) ± 0.015 (syst.) GeV and determine its \(\sigma \times B\) relative to that of the Λb to be 0.28 ± 0.09 (stat.) +0.09 ±0.08 (syst.).

We thank the staffs at Fermilab and collaborating institutions, and acknowledge support from the DOE and NSF (USA); CEA and CNRS/IN2P3 (France); FASI, Rosatom and RFBR (Russia); CAPES, CNPq, FAPERJ, FAPESP and FUNDUNESP (Brazil); DAE and DST (India); Ciencias (Colombia); CONACyT (Mexico); KRF and KOSEF (Korea); CONICET and UBACyT (Argentina); FOM (The Netherlands); Science and Technology Facilities Council (United Kingdom); MSMT and GACR (Czech Republic); CRC Program, CFI, NSERC and WestGrid Project (Canada); BMBF and DFG (Germany); SFI (Ireland); The Swedish Research Council (Sweden); CAS and CNSF (China); Alexander von Humboldt Foundation; and the Marie Curie Program.

[1] Visitor from Augustana College, Sioux Falls, SD, USA.
[2] Visitor from The University of Liverpool, Liverpool, UK.
[3] Visitor from ICN-UNAM, Mexico City, Mexico.
[4] Visitor from Helsinki Institute of Physics, Helsinki, Finland.
[5] Visitor from Universität Zürich, Zürich, Switzerland.

[1] W.-M. Yao et al., Journal of Physics G 33, 1 (2006).
[2] N. Isgur and M.B. Wise, Phys. Rev. Lett. 66, 1130 (1991).
[3] G.T. Bodwin, E. Braaten, G.P. Lepage, Phys. Rev. D 51, 1125 (1995); erratum-ibid, Phys. Rev. D 55 5853 (1997).
[4] E. Jenkins, Phys. Rev. D 55, R10 (1997); ibid, Phys. Rev. D 54, 4515 (1996); N. Mathur, R. Lewis and R.M. Woloshyn, Phys. Rev. D 66, 014502 (2002).
[5] J. Abdallah et al. (DELPHI Collaboration), Eur. Phys. J. C44, 299 (2005); D. Buskulic et al. (ALEPH Collaboration), Phys. Lett. B 384, 449 (1996).
[6] E. Barberio et al. (Heavy Flavor Averaging Group Collaboration), arXiv:0704.3575
[7] V.M. Abazov et al. (D0 Collaboration), Nucl. Instrum. Methods A 565, 463 (2006).
[8] V.M. Abazov et al. (D0 Collaboration), arXiv:0704.3908
[9] T. Sjöstrand et al., Comput. Phys. Commun. 135, 238 (2001).
[10] D.J. Lange, Nucl. Instrum. Methods A 462, 152 (2001).
[11] R. Brun and F. Carminati, CERN Program Library Writeup W5013, 1993 (unpublished).