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Measurement of the branching fraction $\mathrm{Br}(B_s^0 \to D_s^{(*)} D_s^{(*)})$

V.M. Abazov,[35] B. Abbott,[75] M. Abolins,[65] B.S. Acharya,[28] M. Adams,[51] T. Adams,[49] E. Aguilo,[5] S.H. Ahn,[30] M. Ahsan,[59] G.D. Alexeev,[35] G. Alkhazov,[39] A. Alton,[64,*] G. Alverson,[63] G.A. Alves,[2] M. Anastasoaie,[34] L.S. Ancu,[34] T. Andeen,[53] S. Anderson,[45] B. Andrieu,[16] M.S. Anzelc,[53] Y. Arnoud,[13] M. Arov,[52] A. Askew,[49] B. Åsman,[40] A.C.S. Assis Jesus,[3] O. Atramentov,[49] C. Autermann,[20] C. Avila,[7] C. Ay,[23] F. Badaud,[12] A. Baden,[61] L. Bagby,[52] B. Baldin,[50] D.V. Bandurin,[59] P. Banerjee,[28] S. Banerjee,[28] E. Barberis,[63] A.-F. Barfuss,[14] P. Bargassa,[80] P. Baringer,[58] J. Barreto,[2] J.F. Bartlett,[50] U. Bassler,[16] D. Bauer,[43] S. Beale,[5] A. Bean,[58] M. Begalli,[3] M. Begel,[71] C. Belanger-Champagne,[40] L. Bellantoni,[50] A. Bellavance,[67] J.A. Benitez,[65] S.B. Beri,[26] G. Bernardi,[16] R. Bernhard,[22] L. Berntzon,[14] I. Bertram,[42] M. Besançon,[17] R. Beuselinck,[43] V.A. Bezzubov,[38] P.C. Bhat,[50] V. Bhatnagar,[26] M. Binder,[24] C. Biscarat,[19] G. Blazey,[52] F. Blekman,[43] S. Blessing,[49] D. Bloch,[18] K. Bloom,[67] A. Boehnlein,[50] D. Boline,[62] T.A. Bolton,[59] G. Borissov,[42] K. Bos,[33] T. Bose,[77] A. Brandt,[78] R. Brock,[65] G. Brooijmans,[70] A. Bross,[50] D. Brown,[78] N.J. Buchanan,[49] D. Buchholz,[53] M. Buehler,[81] V. Buescher,[21] S. Burdin,[50] S. Burke,[45] T.H. Burnett,[82] E. Busato,[16] C.P. Buszello,[43] J.M. Butler,[62] P. Calfayan,[24] S. Calvet,[14] J. Cammin,[71] S. Caron,[33] W. Carvalho,[3] B.C.K. Casey,[77] N.M. Cason,[55] H. Castilla-Valdez,[32] S. Chakrabarti,[17] D. Chakraborty,[52] K. Chan,[5] K.M. Chan,[71] A. Chandra,[48] F. Charles,[18] E. Cheu,[45] F. Chevallier,[13] D.K. Cho,[62] S. Choi,[31] B. Choudhary,[27] L. Christofek,[77] T. Christoudias,[43] S. Cihangir,[50] D. Claes,[67] B. Clément,[18] C. Clément,[40] Y. Coadou,[5] M. Cooke,[80] W.E. Cooper,[50] M. Corcoran,[80] F. Couderc,[17] M.-C. Cousinou,[14] S. Crépé-Renaudin,[13] D. Cutts,[77] M. Ćwiok,[29] H. da Motta,[2] A. Das,[62] G. Davies,[43] K. De,[78] P. de Jong,[33] S.J. de Jong,[34] E. De La Cruz-Burelo,[64] C. De Oliveira Martins,[3] J.D. Degenhardt,[64] F. Déliot,[17] M. Demarteau,[50] R. Demina,[71] D. Denisov,[50] S.P. Denisov,[38] S. Desai,[50] H.T. Diehl,[50] M. Diesburg,[50] A. Dominguez,[67] H. Dong,[72] L.V. Dudko,[37] L. Duflot,[15] S.R. Dugad,[28] D. Duggan,[49] A. Duperrin,[14] J. Dyer,[65] A. Dyshkant,[52] M. Eads,[67] D. Edmunds,[65] J. Ellison,[48] V.D. Elvira,[50] Y. Enari,[77] S. Eno,[61] P. Ermolov,[37] H. Evans,[54] A. Evdokimov,[36] V.N. Evdokimov,[38] A.V. Ferapontov,[59] T. Ferbel,[71] F. Fiedler,[24] F. Filthaut,[34] W. Fisher,[50] H.E. Fisk,[50] M. Ford,[44] M. Fortner,[52] H. Fox,[22] S. Fu,[50] S. Fuess,[50] T. Gadfort,[82] C.F. Galea,[34] E. Gallas,[50] E. Galyaev,[55] C. Garcia,[71] A. Garcia-Bellido,[82] V. Gavrilov,[36] P. Gay,[12] W. Geist,[18] D. Gelé,[18] C.E. Gerber,[51] Y. Gershtein,[49] D. Gillberg,[5] G. Ginther,[71] N. Gollub,[40] B. Gómez,[7] A. Goussiou,[55] P.D. Grannis,[72] H. Greenlee,[50] Z.D. Greenwood,[60] E.M. Gregores,[4] G. Grenier,[19] Ph. Gris,[12] J.-F. Grivaz,[15] A. Grohsjean,[24] S. Grünendahl,[50] M.W. Grünewald,[29] F. Guo,[72] J. Guo,[72] G. Gutierrez,[50] P. Gutierrez,[75] A. Haas,[70] N.J. Hadley,[61] P. Haefner,[24] S. Hagopian,[49] J. Haley,[68] I. Hall,[75] R.E. Hall,[47] L. Han,[6] K. Hanagaki,[50] P. Hansson,[40] K. Harder,[44] A. Harel,[71] R. Harrington,[63] J.M. Hauptman,[57] R. Hauser,[65] J. Hays,[43] T. Hebbeker,[20] D. Hedin,[52] J.G. Hegeman,[33] J.M. Heinmiller,[51] A.P. Heinson,[48] U. Heintz,[62] C. Hensel,[58] K. Herner,[72] G. Hesketh,[63] M.D. Hildreth,[55] R. Hirosky,[81] J.D. Hobbs,[72] B. Hoeneisen,[11] H. Hoeth,[25] M. Hohlfeld,[15] S.J. Hong,[30] R. Hooper,[77] P. Houben,[33] Y. Hu,[72] Z. Hubacek,[9] V. Hynek,[8] I. Iashvili,[69] R. Illingworth,[50] A.S. Ito,[50] S. Jabeen,[62] M. Jaffré,[15] S. Jain,[75] K. Jakobs,[22] C. Jarvis,[61] R. Jesik,[43] K. Johns,[45] C. Johnson,[70] M. Johnson,[50] A. Jonckheere,[50] P. Jonsson,[43] A. Juste,[50] D. Käfer,[20] S. Kahn,[73] E. Kajfasz,[14] A.M. Kalinin,[35] J.M. Kalk,[60] J.R. Kalk,[65] S. Kappler,[20] D. Karmanov,[37] J. Kasper,[62] P. Kasper,[50] I. Katsanos,[70] D. Kau,[49] R. Kaur,[26] V. Kaushik,[78] R. Kehoe,[79] S. Kermiche,[14] N. Khalatyan,[38] A. Khanov,[76] A. Kharchilava,[69] Y.M. Kharzheev,[35] D. Khatidze,[70] H. Kim,[31] T.J. Kim,[30] M.H. Kirby,[34] B. Klima,[50] J.M. Kohli,[26] J.-P. Konrath,[22] M. Kopal,[75] V.M. Korablev,[38] J. Kotcher,[73] B. Kothari,[70] A. Koubarovsky,[37] A.V. Kozelov,[38] D. Krop,[54] A. Kryemadhi,[81] T. Kuhl,[23] A. Kumar,[69] S. Kunori,[61] A. Kupco,[10] T. Kurča,[19] J. Kvita,[8] D. Lam,[55] S. Lammers,[70] G. Landsberg,[77] J. Lazoflores,[49] P. Lebrun,[19] W.M. Lee,[50] A. Leflat,[37] F. Lehner,[41] V. Lesne,[12] J. Leveque,[45] P. Lewis,[43] J. Li,[78] L. Li,[48] Q.Z. Li,[50] S.M. Lietti,[4] J.G.R. Lima,[52] D. Lincoln,[50] J. Linnemann,[65] V.V. Lipaev,[38] R. Lipton,[50] Z. Liu,[5] L. Lobo,[43] A. Lobodenko,[39] M. Lokajicek,[10] A. Lounis,[18] P. Love,[42] H.J. Lubatti,[82] M. Lynker,[55] A.L. Lyon,[50] A.K.A. Maciel,[2] R.J. Madaras,[46] P. Mättig,[25] C. Magass,[20] A. Magerkurth,[64] N. Makovec,[15] P.K. Mal,[55] H.B. Malbouisson,[3] S. Malik,[67] V.L. Malyshev,[35] H.S. Mao,[50] Y. Maravin,[59] B. Martin,[13] R. McCarthy,[72] A. Melnitchouk,[66] A. Mendes,[14] L. Mendoza,[7] P.G. Mercadante,[4] M. Merkin,[37] K.W. Merritt,[50] A. Meyer,[20] J. Meyer,[21] M. Michaut,[17] H. Miettinen,[80] T. Millet,[19] J. Mitrevski,[70] J. Molina,[3] R.K. Mommsen,[44] N.K. Mondal,[28] J. Monk,[44] R.W. Moore,[5] T. Moulik,[58] G.S. Muanza,[19] M. Mulders,[50] M. Mulhearn,[70] O. Mundal,[21] L. Mundim,[3] E. Nagy,[14] M. Naimuddin,[50] M. Narain,[77] N.A. Naumann,[34] H.A. Neal,[64] J.P. Negret,[7] P. Neustroev,[39] H. Nilsen,[22]

C. Noeding,[22] A. Nomerotski,[50] S.F. Novaes,[4] T. Nunnemann,[24] V. O'Dell,[50] D.C. O'Neil,[5] G. Obrant,[39] C. Ochando,[15] V. Oguri,[3] N. Oliveira,[3] D. Onoprienko,[59] N. Oshima,[50] J. Osta,[55] R. Otec,[9] G.J. Otero y Garzón,[51] M. Owen,[44] P. Padley,[80] M. Pangilinan,[77] N. Parashar,[56] S.-J. Park,[71] S.K. Park,[30] J. Parsons,[70] R. Partridge,[77] N. Parua,[72] A. Patwa,[73] G. Pawloski,[80] P.M. Perea,[48] K. Peters,[44] Y. Peters,[25] P. Pétroff,[15] M. Petteni,[43] R. Piegaia,[1] J. Piper,[65] M.-A. Pleier,[21] P.L.M. Podesta-Lerma,[32,§] V.M. Podstavkov,[50] Y. Pogorelov,[55] M.-E. Pol,[2] A. Pompoš,[75] B.G. Pope,[65] A.V. Popov,[38] C. Potter,[5] W.L. Prado da Silva,[3] H.B. Prosper,[49] S. Protopopescu,[73] J. Qian,[64] A. Quadt,[21] B. Quinn,[66] M.S. Rangel,[2] K.J. Rani,[28] K. Ranjan,[27] P.N. Ratoff,[42] P. Renkel,[79] S. Reucroft,[63] M. Rijssenbeek,[72] I. Ripp-Baudot,[18] F. Rizatdinova,[76] S. Robinson,[43] R.F. Rodrigues,[3] C. Royon,[17] P. Rubinov,[50] R. Ruchti,[55] G. Sajot,[13] A. Sánchez-Hernández,[32] M.P. Sanders,[16] A. Santoro,[3] G. Savage,[50] L. Sawyer,[60] T. Scanlon,[43] D. Schaile,[24] R.D. Schamberger,[72] Y. Scheglov,[39] H. Schellman,[53] P. Schieferdecker,[24] C. Schmitt,[25] C. Schwanenberger,[44] A. Schwartzman,[68] R. Schwienhorst,[65] J. Sekaric,[49] S. Sengupta,[49] H. Severini,[75] E. Shabalina,[51] M. Shamim,[59] V. Shary,[17] A.A. Shchukin,[38] R.K. Shivpuri,[27] D. Shpakov,[50] V. Siccardi,[18] R.A. Sidwell,[59] V. Simak,[9] V. Sirotenko,[50] P. Skubic,[75] P. Slattery,[71] D. Smirnov,[55] R.P. Smith,[50] G.R. Snow,[67] J. Snow,[74] S. Snyder,[73] S. Söldner-Rembold,[44] L. Sonnenschein,[16] A. Sopczak,[42] M. Sosebee,[78] K. Soustruznik,[8] M. Souza,[2] B. Spurlock,[78] J. Stark,[13] J. Steele,[60] V. Stolin,[36] D.A. Stoyanova,[38] J. Strandberg,[64] S. Strandberg,[40] M.A. Strang,[69] M. Strauss,[75] R. Ströhmer,[24] D. Strom,[53] M. Strovink,[46] L. Stutte,[50] S. Sumowidagdo,[49] P. Svoisky,[55] A. Sznajder,[3] M. Talby,[14] P. Tamburello,[45] A. Tanasijczuk,[1] W. Taylor,[5] P. Telford,[44] J. Temple,[45] B. Tiller,[24] F. Tissandier,[12] M. Titov,[22] V.V. Tokmenin,[35] M. Tomoto,[50] T. Toole,[61] I. Torchiani,[22] T. Trefzger,[23] S. Trincaz-Duvoid,[16] D. Tsybychev,[72] B. Tuchming,[17] C. Tully,[68] P.M. Tuts,[70] R. Unalan,[65] L. Uvarov,[39] S. Uvarov,[39] S. Uzunyan,[52] B. Vachon,[5] P.J. van den Berg,[33] B. van Eijk,[35] R. Van Kooten,[54] W.M. van Leeuwen,[33] N. Varelas,[51] E.W. Varnes,[45] A. Vartapetian,[78] I.A. Vasilyev,[38] M. Vaupel,[25] P. Verdier,[19] L.S. Vertogradov,[35] M. Verzocchi,[50] F. Villeneuve-Seguier,[43] P. Vint,[43] J.-R. Vlimant,[16] E. Von Toerne,[59] M. Voutilainen,[67,‡] M. Vreeswijk,[33] H.D. Wahl,[49] J. Walder,[42] L. Wang,[61] M.H.L.S Wang,[50] J. Warchol,[55] G. Watts,[82] M. Wayne,[55] G. Weber,[23] M. Weber,[50] H. Weerts,[65] A. Wenger,[22,#] N. Wermes,[21] M. Wetstein,[61] A. White,[78] D. Wicke,[25] G.W. Wilson,[58] S.J. Wimpenny,[48] M. Wobisch,[50] D.R. Wood,[63] T.R. Wyatt,[44] Y. Xie,[77] S. Yacoob,[53] R. Yamada,[50] M. Yan,[61] T. Yasuda,[50] Y.A. Yatsunenko,[35] K. Yip,[73] H.D. Yoo,[77] S.W. Youn,[53] C. Yu,[13] J. Yu,[78] A. Yurkewicz,[72] A. Zatserklyaniy,[52] C. Zeitnitz,[25] D. Zhang,[50] T. Zhao,[82] B. Zhou,[64] J. Zhu,[72] M. Zielinski,[71] D. Zieminska,[54] A. Zieminski,[54] V. Zutshi,[52] and E.G. Zverev[37]
(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, Simon Fraser University, Burnaby, British Columbia, Canada, York University, Toronto, Ontario, Canada, and McGill University, Montreal, Quebec, Canada*
[6] *University of Science and Technology of China, Hefei, People's Republic of China*
[7] *Universidad de los Andes, Bogotá, Colombia*
[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, Universite de Grenoble 1, Grenoble, France*
[14] *CPPM, IN2P3-CNRS, Université de la Méditerranée, Marseille, France*
[15] *Laboratoire de l'Accélérateur Linéaire, IN2P3-CNRS et 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, IN2P3-CNRS, Université Louis Pasteur, Strasbourg, France, and Université de Haute Alsace, Mulhouse, 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*
[82]*University of Washington, Seattle, Washington 98195, USA*

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We report a measurement of the branching fraction $\mathrm{Br}(B_s^0 \rightarrow D_s^{(*)} D_s^{(*)})$ using a data sample corresponding to 1.3 fb^{-1} of integrated luminosity collected by the D0 experiment in 2002–2006 during Run II of the Fermilab Tevatron Collider. One $D_s^{(*)}$ meson was partially reconstructed in the decay $D_s \rightarrow \phi\mu\nu$, and the other $D_s^{(*)}$ meson was identified using the decay $D_s \rightarrow \phi\pi$ where no attempt was made to distinguish D_s and D_s^* states. The resulting measurement is

$\mathrm{Br}(B_s^0 \to D_s^{(*)} D_s^{(*)}) = 0.039^{+0.019}_{-0.017}(\mathrm{stat})^{+0.016}_{-0.015}(\mathrm{syst})$. This was subsequently used to estimate the width difference $\Delta\Gamma_s^{CP}$ in the B_s^0–$\bar{B}_s^0$ system: $\Delta\Gamma_s^{CP}/\Gamma_s = 0.079^{+0.038}_{-0.035}(\mathrm{stat})^{+0.031}_{-0.030}(\mathrm{syst})$.

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In the standard model (SM), mixing in the B_s^0 system is expected to produce a large decay width difference $\Delta\Gamma_s = \Gamma_L - \Gamma_H$ between the light and heavy mass eigenstates with a small CP-violating phase ϕ_s [1]. New phenomena could produce a significant CP-violating phase leading to a reduction in the observed value of $\Delta\Gamma_s$ compared with the SM prediction of $\Delta\Gamma_s/\Gamma_s = 0.127 \pm 0.024$ [2]. $\Delta\Gamma_s^{CP} = \Delta\Gamma_s^{\mathrm{CP-even}} - \Delta\Gamma_s^{\mathrm{CP-odd}}$ ($\Delta\Gamma_s = \Delta\Gamma_s^{CP} \mid \cos\phi_s \mid$) can be estimated from the branching fraction $\mathrm{Br}(B_s^0 \to D_s^{(*)} D_s^{(*)})$ [1, 3]. This decay is predominantly CP-even and is related to $\Delta\Gamma_s^{CP}$ [1, 3]: $2\mathrm{Br}(B_s^0 \to D_s^{(*)} D_s^{(*)}) \approx (\Delta\Gamma_s^{CP}/\Gamma_s)\,[1 + \mathcal{O}(\Delta\Gamma_s/\Gamma_s)]$. Only one measurement of $\mathrm{Br}(B_s^0 \to D_s^{(*)} D_s^{(*)})$ has previously been published, by the ALEPH [4] experiment at the CERN LEP collider from the study of correlated production of $\phi\phi$ in Z^0 decays.

In this Letter we present a measurement of $\mathrm{Br}(B_s^0 \to D_s^{(*)} D_s^{(*)})$ using a sample of semileptonic B_s^0 decays collected by the D0 experiment at Fermilab in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV. The data correspond to an integrated luminosity of approximately 1.3 fb^{-1}. We present an analysis of the decay chain $B_s^0 \to D_s^{(*)} D_s^{(*)}$ where one D_s^+ decays to $\phi_1\pi^+$, the other D_s^- decays to $D_s^- \to \phi_2\mu^-\nu$, and where each ϕ meson decays to $\phi \to K^+K^-$. Charge conjugate states are implied throughout. No attempt was made to reconstruct the photon or π^0 from the decay $D_s^* \to D_s\,\gamma/\pi^0$ and thus the state $D_s^{(*)} D_s^{(*)}$ contains contributions from D_sD_s, $D_s^*D_s$ and $D_s^*D_s^*$. To reduce systematic effects, $\mathrm{Br}(B_s^0 \to D_s^{(*)} D_s^{(*)})$ was normalized to the decay $B_s^0 \to D_s^{(*)}\mu\nu$.

The D0 detector is described in detail elsewhere [5]. The detector components relevant to this analysis are the central tracking and muon systems. The D0 central-tracking system consists of a silicon microstrip tracker (SMT) closest to the beampipe surrounded by a central scintillating-fiber tracker (CFT) with an outer radius of 52 cm. Both tracking systems are located within a 2 T superconducting solenoidal magnet and are optimized for tracking and vertexing for pseudorapidities $|\eta| < 3$ (SMT) and $|\eta| < 2.5$ (CFT), where $\eta = -\ln[\tan(\theta/2)]$, and θ is the polar angle with respect to the beam axis. The muon system is located outside of the liquid-argon/uranium calorimetry system and has pseudorapidity coverage $|\eta| < 2$. It consists of a layer of tracking detectors and trigger scintillation counters in front of a 1.8 T iron toroid, followed by two similar layers outside of the toroid. The trigger system identifies events of interest in a high-luminosity environment based on muon identification, charged tracking, and vertexing. No explicit trigger requirement was applied, however most events satisfied inclusive single-muon triggers.

The measurement began with reconstruction of the decay chain $D_s \to \phi_1\pi$, $\phi_1 \to K^+K^-$, with tracks originating from the same $p\bar{p}$ collision point (primary vertex) as a muon. All charged tracks used in the analysis were required to have at least two hits in both the SMT and CFT. Muons were required to have transverse momentum $p_T > 2$ GeV/c, total momentum $p > 3$ GeV/c, and to have measurements in at least two layers of the muon system. Two oppositely charged particles with $p_T > 0.8$ GeV/c were selected from the remaining particles in the event and were assigned the mass of a kaon. An invariant mass of $1.01 < M(K^+K^-) < 1.03$ GeV/c^2 was required, to be consistent with the mass of a ϕ meson. Each pair of kaons satisfying these criteria was combined with a third particle with $p_T > 1.0$ GeV/c, which was assigned the mass of a pion. The three tracks were required to form a D_s vertex using the algorithm described in Ref. [6]. The cosine of the angle between the D_s momentum and the direction from the primary vertex to the D_s vertex was required to be greater than 0.9. The D_s vertex was required to have a displacement from the primary vertex in the plane perpendicular to the beam with at least 4σ significance. The helicity angle χ is defined as the angle between the momenta of the D_s and a K meson in the (K^+K^-) center of mass system. The decay of $D_s \to \phi\pi$ follows a $\cos^2\chi$ distribution, while for background $\cos\chi$ is expected to be flat. Therefore, to enhance the signal, the criterion $|\cos\chi| > 0.35$ was applied. The muon and pion were required to have opposite charge. The events passing these selections, referred to as the preselection sample, were used to produce the samples of $(\mu\phi_2 D_s)$ and the normalizing sample (μD_s) defined below.

To construct a (μD_s) candidate from the preselection sample, the D_s candidate and the muon were required to originate from a common B_s^0 vertex. The mass of the (μD_s) system was required to be less than 5.2 GeV/c^2. The number of tracks near the B_s^0 meson tends to be small, thus to reduce the background from combinatorics, an isolation criterion was applied. The isolation is defined as the sum of the momenta of the tracks used to reconstruct the signal divided by the total momentum of tracks contained within a cone of radius $\Delta\mathcal{R} = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.5$ centered on the direction of the B_s^0 candidate. We required the isolation to exceed 0.6. To suppress background, the visible proper decay length, defined as $M(B_s^0) \cdot (\vec{L}_T \cdot \vec{p}_T)/p_T^2$, was required to exceed 150 μm. Here $\vec{L}_T$ is the displacement from the primary vertex to the B_s^0 decay vertex in the transverse

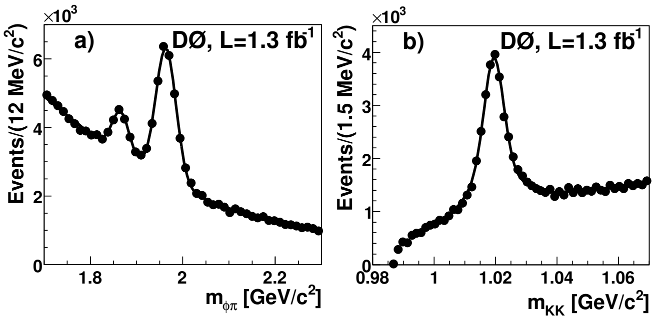

FIG. 1: (a) The $(K^+K^-\pi)$ invariant mass spectrum in the mass window $1.01 < M(K^+K^-) < 1.03$ GeV$/c^2$. (b) Mass spectrum of the (K^+K^-) system in the mass window $1.92 < M(K^+K^-\pi) < 2.00$ GeV$/c^2$.

plane, and $M(B_s^0)$ is the mass of the B_s^0 meson [7]. These data are referred to as the (μD_s) sample; the resulting mass spectrum of the $(K^+K^-\pi)$ system is shown in Fig. 1(a), where the D_s and D^+ mass peaks are described by single Gaussians with a second-order polynomial to parameterize the background. The signals of $D_s \to \phi_1\pi$ and $D^+ \to \phi_1\pi^+$ are clearly seen. Figure 1(b) shows the mass spectrum of the (K^+K^-) system, where a double Gaussian describes the ϕ mass peak, and a second-order polynomial is used to parameterize the background.

To construct a $(\mu\phi_2 D_s)$ candidate from the preselection sample, a second ϕ_2 meson from $D_s \to \phi_2\mu\nu$ was required. The selection criteria to reconstruct the second ϕ_2 meson were identical to those of the first ϕ_1 meson, with the exception that a wider mass range $0.99 < M(K^+K^-) < 1.07$ GeV$/c^2$ was used to estimate the background distribution under the ϕ_2 meson. This ϕ_2 meson and muon were required to form a D_s vertex. To suppress background, the mass of the $(\mu\phi_2)$ system was required to be $1.2 < M(\mu\phi_2) < 1.85$ GeV$/c^2$. The $D_s(\phi_1\pi)$ and $D_s(\phi_2\mu)$ mesons were required to form a B_s^0 vertex. The mass of the $(\mu\phi_2 D_s)$ system, i.e., the combined $D_s \to \phi_2\mu\nu$ and $D_s \to \phi_1\pi$ candidates, was required to be $4.3 < M(\mu\phi_2 D_s) < 5.2$ GeV$/c^2$. An isolation value exceeding 0.6 and visible proper decay length greater than 150 μm were required for the B_s^0 meson.

To reduce the effect of systematic uncertainties, we calculated the ratio $R = \mathrm{Br}(B_s^0 \to D_s^{(*)}D_s^{(*)}) \cdot \mathrm{Br}(D_s \to \phi\mu\nu)/\mathrm{Br}(B_s^0 \to \mu\nu D_s^{(*)})$. We extracted $\mathrm{Br}(B_s^0 \to D_s^{(*)}D_s^{(*)})$ from R using the known values [7] for $\mathrm{Br}(D_s \to \phi\mu\nu)$, $\mathrm{Br}(B_s^0 \to D_s^{(*)}\mu\nu)$, and $\mathrm{Br}(D_s \to \phi\pi)$. R can be expressed in terms of experimental observables:

$$R = \frac{N_{\mu\phi_2 D_s} - N_{\rm bkg}}{N_{\mu D_s}\ f(B_s^0 \to D_s^{(*)}\mu\nu)} \times \frac{1}{2\mathrm{Br}(\phi \to K^+K^-)} \frac{\varepsilon(B_s^0 \to D_s^{(*)}\mu\nu)}{\varepsilon(B_s^0 \to D_s^{(*)}D_s^{(*)})}, \quad (1)$$

where $N_{\mu D_s}$ is the number of (μD_s) events, $N_{\mu\phi_2 D_s}$ is the number of $(\mu\phi_2 D_s)$ events, $N_{\rm bkg}$ is the number of background events in the $(\mu\phi_2 D_s)$ sample that are not produced by $B_s^0 \to D_s^{(*)}D_s^{(*)}$ decays, and $f(B_s^0 \to D_s^{(*)}\mu\nu)$ is the fraction of events in (μD_s) coming from $B_s^0 \to D_s^{(*)}\mu\nu X$. The ratio of efficiencies $\varepsilon(B_s^0 \to D_s^{(*)}D_s^{(*)})/\varepsilon(B_s^0 \to D_s^{(*)}\mu\nu)$ to reconstruct the two processes was determined from simulation. All processes involving b hadrons were simulated with EvtGen [8] interfaced to PYTHIA [9], followed by full modeling of the detector response with GEANT [10] and event reconstruction as in data. The number of (μD_s) events was estimated from a binned fit to the $(K^+K^-\pi)$ mass distribution shown in Fig. 1(a) from the 145,000 candidates passing the selection criteria. The resulting fit is superimposed in Fig. 1(a) as a solid line and gives $N_{\mu D_s} = 17670 \pm 230$ (stat) events.

The number of $(\mu\phi_2 D_s)$ events was extracted using a unbinned log-likelihood fit to the two-dimensional distribution of the invariant masses M_D of the $(\phi_1\pi)$ system and M_{ϕ_2} of the two additional kaons from the $(\phi_2\mu)$ system. All candidates from the $(\mu\phi_2 D_s)$ sample with $1.7 < M_D < 2.3$ GeV$/c^2$ and $0.99 < M_{\phi_2} < 1.07$ GeV$/c^2$ were included in the fit. In the fit, the masses and widths for both D_s and ϕ signals were fixed to the values extracted from a fit to the (μD_s) data sample. Extracted from the fit were the numbers of: $N_{\mu\phi_2 D_s}$ events from correlated (joint) signal production of $(\phi_1\pi)$ and ϕ_2, events with a reconstructed $(\phi_1\pi)$ in the mass peak of $D_s(\phi_1\pi)$ without joint production of ϕ_2 from $(\phi_2\mu)$ (i.e., uncorrelated), events with a reconstructed ϕ_2 from $(\phi_2\mu)$ without joint production of $(\phi_1\pi)$ in the mass peak of the $D_s(\phi_1\pi)$ (i.e., also uncorrelated), and combinatorial background.

The results of the fit are displayed in Fig. 2. Figure 2(a) displays the invariant mass distribution of $(\phi_1\pi)$ candidates from the invariant mass signal window of $D_s(\phi_2\mu)$, and Fig. 2(b) displays the ϕ_2 meson from $D_s(\phi_2\mu)$ in the invariant mass signal decay window of $D_s(\phi_1\pi)$ candidates. The fit gives $N_{\mu\phi_2 D_s} = 13.4^{+6.6}_{-6.0}$ events from the 340 candidates included in the fit.

As a consistency check, a similar sample was produced, but requiring the same charge for the muon and pion. From the fit, the number of $(\mu^+\phi_2 D_s^+)$ signal events is found to be zero with an upper limit of 2.6 events (68% CL).

To extract the number of $B_s^0 \to D_s^{(*)}\mu\nu$ and $B_s^0 \to D_s^{(*)}D_s^{(*)}$ events, the composition of the selected samples must be determined. The decays $B_s^0 \to D_s^{(*)}\mu\nu X$ and $B_s^0 \to D_s^{(*)}\tau(\to \mu\nu)\nu X$ were considered as signal. The branching fractions for $B \to D_s D^{(*)}X$ and $B_s^0 \to D_s^{(*)}D_s^{(*)}$ are taken from the Ref. [7]. There is no experimental information for the $\mathrm{Br}(B_s^0 \to D_s D X)$,

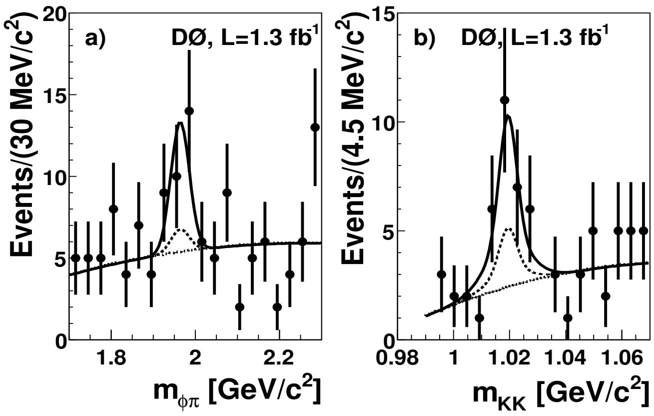

FIG. 2: Invariant mass distributions of (a) $D_s(\phi_1\pi)$ events in the signal window of the invariant mass (K^+K^-) from $D_s(\phi_2\mu)$, and (b) (K^+K^-) events from $D_s(\phi_2\mu)$ in the invariant mass window of the $D_s(\phi_1\pi)$ signal region. The solid curve is the projected result of the unbinned log-likelihood fit, the dotted curve shows the polynomial background contribution, and the dashed line shows the uncorrelated production of (a) $D_s(\phi_1\pi)$ and (b) ϕ_2 mesons.

therefore we used the value 15.4% provided by Ref. [8] with an assigned uncertainty of 100%.

In addition, the (μD_s) sample includes the processes $c\bar{c} \to D_s\mu\nu X$, $b\bar{b} \to D_s\mu\nu X$, and events with a misidentified muon, etc. which we refer to as the "peaking background." The estimated contribution of these processes in the (μD_s) signal is (2 ± 1)%. In total, we estimate that the fraction of events in the (μD_s) signal coming from $B_s^0 \to D_s^{(*)}\mu\nu X$ is $f(B_s^0 \to D_s^{(*)}\mu\nu) = 0.82 \pm 0.05$.

We considered the number of events $N_{\mu\phi_2 D_s}$ from the $(\mu\phi_2 D_s)$ sample to contain contributions from 1) the main signal $B_s^0 \to D_s^{(*)}D_s^{(*)}$, and the following background processes 2) $B \to D_s^{(*)}D_s^{(*)}KX$, 3) $B_s^0 \to D_s^{(*)}D_s^{(*)}X$, 4) $B_s^0 \to D_s^{(*)}\phi\mu\nu$, 5) peaking background, and 6) $B_s^0 \to D_s^{(*)}\mu\nu$ combined with a ϕ meson from fragmentation. There is no experimental information for most of the processes, therefore their contributions were estimated by counting events in different regions of the $(\mu\phi_2 D_s)$ phase space and comparing the obtained numbers with the expected mass distribution for each background process.

The mass of the $(\mu\phi_2 D_s)$ system for the second and third processes is much less than that for the main decay $B_s^0 \to D_s^{(*)}D_s^{(*)}$ because of the additional particles, and the requirement $M(\mu\phi_2 D_s) > 4.3$ GeV$/c^2$ strongly suppresses them. The contribution of $B_s^0 \to D_s^{(*)}D_s^{(*)}X$ is much less than $B \to D_s^{(*)}D_s^{(*)}KX$ because of higher production rates of B^+ and B^0 compared to B_s^0. Compared to the $B \to D_s^{(*)}D_s^{(*)}KX$ process, the final state in the decay $B_s^0 \to D_s^{(*)}D_s^{(*)}X$ includes at least two pions due to isospin considerations. At least two gluons are required to produce this state (similar to $\psi(2S) \to J/\psi\pi\pi$); it is therefore additionally suppressed and its contribution was neglected. Simulation shows that for the $B \to D_s^{(*)}D_s^{(*)}KX$ decay, the fraction of events with $M(\mu\phi_2 D_s) > 4.3$ GeV$/c^2$ is 0.05. Requiring $M(\mu\phi_2 D_s) < 4.3$ GeV$/c^2$ and keeping all other selections, we observe $2.8^{+11.2}_{-2.8}$ events in data. Assuming that all these events are due to $B \to D_s^{(*)}D_s^{(*)}KX$, we estimate their contribution to the signal $(\mu\phi_2 D_s)$ as $0.14^{+0.56}_{-0.14}$ events.

The fourth process produces a high mass for both the $(\mu\phi_2)$ and $(\mu\phi_2 D_s)$ systems and requiring $M(\mu\phi_2) < 1.85$ GeV$/c^2$ strongly suppresses it. Simulation shows that for this process, the fraction of events with $M(\mu\phi_2) < 1.85$ GeV$/c^2$ is 0.14. Requiring $M(\mu\phi_2) > 1.85$ GeV$/c^2$ and keeping all other selections, we observe 13 ± 11 events. Assuming that all these events are due to the fourth background process, we estimate its contribution to the $(\mu\phi_2 D_s)$ signal as 1.88 ± 1.51 events.

The contribution of the peaking background is strongly suppressed by the event selection with an upper limit of 0.4 events. We therefore included it as an additional uncertainty in the number of background events.

The fitting procedure accounts for the possible background contribution of the decay $B_s^0 \to D_s^{(*)}\mu\nu$ together with the uncorrelated production of a ϕ meson from fragmentation. In addition, an attempt was made to reconstruct $(\mu\phi_2 D_s)$ events in the $B_s^0 \to D_s^{(*)}\mu\nu$ simulation containing approximately 9200 reconstructed (μD_s) events, and no such events were found. Therefore the contribution of this process was neglected. In total, we estimate the number of background events as $N_{\rm bkg} = 2.0 \pm 1.6$.

In determination of efficiencies, the final states in the (μD_s) and $(\mu\phi_2 D_s)$ samples differ only by the two kaons from the additional ϕ_2 meson. With the exception of the isolation criterion, all other applied selections are the same, so many detector-related systematic uncertainties cancel. The muon p_T spectrum in $B_s^0 \to D_s^{(*)}\mu\nu$ decay differs between data and simulation due to trigger effects and the uncertainties in B meson production in simulation. To correct for this difference, weighting functions were applied to all Monte Carlo events. They were obtained from the ratio of simulated and data events for p_T distributions of the B_s^0 meson and muon. With this correction, the ratio of efficiencies is $\varepsilon(B_s^0 \to D_s^{(*)}D_s^{(*)})/\varepsilon(B_s^0 \to D_s^{(*)}\mu\nu) = 0.055 \pm 0.001$ (stat). The systematic uncertainty in this value is discussed below. The difference in efficiency is mainly due to the softer momentum spectrum of the muon from the $D_s \to \phi\mu\nu$ decay in the $(\mu\phi_2 D_s^{(*)})$ sample, compared to the muon from the $B_s^0 \to D_s^{(*)}\mu\nu$ decay in the $(\mu D_s^{(*)})$ sample.

Using all these inputs and taking the value $\mathrm{Br}(\phi \to K^+K^-) = 0.492 \pm 0.006$ [7], we obtain $R = 0.015 \pm 0.007$ (stat). The statistical uncertainty shown includes only the uncertainty in $N_{\mu\phi_2 D_s}$. All other uncertainties are included in the systematics.

The experimental extraction of both $\mathrm{Br}(B_s^0 \to D_s^{(*)}\mu\nu)$ and $\mathrm{Br}(D_s \to \phi\mu\nu)$ depend on $\mathrm{Br}(D_s \to \phi\pi)$. Factorizing the dependence on $\mathrm{Br}(D_s \to \phi\pi)$, we obtain $\mathrm{Br}(B_s^0 \to \mu\nu D_s^{(*)})\mathrm{Br}(D_s \to \phi\pi) = (2.84 \pm 0.49) \times 10^{-3}, \mathrm{Br}(D_s \to \phi\mu\nu) = (0.55 \pm 0.04) \cdot \mathrm{Br}(D_s \to \phi\pi)$. Using these numbers, we finally obtain $\mathrm{Br}(B_s^0 \to D_s^{(*)}D_s^{(*)}) = 0.039^{+0.019}_{-0.018}(\mathrm{stat})$.

The systematic uncertainties in the measured value of $\mathrm{Br}(B_s^0 \to D_s^{(*)}D_s^{(*)})$ were estimated as follows. All external branching fractions [7] were varied within one standard deviation. A 100% uncertainty in the number of background events N_{bkg} in the $(\mu\phi_2 D_s)$ sample was assumed. The ratio of efficiencies can be affected by the uncertainties of reconstruction of two additional charged particles from the ϕ meson decay. The efficiency to reconstruct a charged pion from the decay $D^{*+} \to D^0\pi^+$ was measured in Ref. [11], and the obtained value was in a good agreement with the MC estimate. This comparison is valid within the uncertainty of branching fractions of different B meson semileptonic decays, which is about 7%. Therefore we conservatively assigned a 14% systematic uncertainty (7% for each charged particle, 100% correlated) to the ratio of efficiencies and propagated it to the final result. For the ratio of efficiencies, a 15% uncertainty was assigned for the reweighting procedure, which reflects the difference in efficiency between weighted and unweighted estimates. The dependence of the number of $(\mu\phi_2 D_s)$ events on the fitting procedure was estimated by adding a possible signal contribution from D^+ events which decreased the correlated signal by 3%, which we assigned as a systematic uncertainty.

Using these numbers, we obtain $\mathrm{Br}(B_s^0 \to D_s^{(*)}D_s^{(*)}) = \left[0.039^{+0.019}_{-0.017}(\mathrm{stat}) \pm 0.014(\mathrm{syst})\right] \cdot [0.044/\mathrm{Br}(D_s \to \phi\pi)]^2$. Using $\mathrm{Br}(D_s \to \phi\pi) = 0.044 \pm 0.006$ [7], we find

$$\mathrm{Br}(B_s^0 \to D_s^{(*)}D_s^{(*)}) = 0.039^{+0.019}_{-0.017}(\mathrm{stat})^{+0.016}_{-0.015}(\mathrm{syst}). \quad (2)$$

The result is consistent with, and more precise than the ALEPH measurement $\mathrm{Br}(B_s^0 \to D_s^{(*)}D_s^{(*)}) = 0.077 \pm 0.034^{+0.038}_{-0.026}$ [4], where the value has been recalculated using the current value of $\mathrm{Br}(D_s \to \phi\pi)$ [7]. We calculate $\Delta\Gamma_s^{CP}$ [1] assuming that the decay $B_s^0 \to D_s^{(*)}D_s^{(*)}$ is mainly CP-even and gives the primary contribution to the width difference between the CP-even and CP-odd B_s^0 states [3]:

$$\frac{\Delta\Gamma_s^{CP}}{\Gamma_s} = 0.079^{+0.038}_{-0.035}(\mathrm{stat})^{+0.031}_{-0.030}(\mathrm{syst}). \quad (3)$$

Assuming CP-violation in B_s^0 mixing is small [2], this estimate is in good agreement with the SM prediction $\Delta\Gamma_s/\Gamma_s = 0.127 \pm 0.024$ [2] and with the direct measurement of this parameter by the D0 experiment in $B_s^0 \to J/\psi\phi$ decays [12]. The agreement with the CDF measurement of $\Delta\Gamma_s/\Gamma_s$, which was also performed in $B_s^0 \to J/\psi\phi$ [13], is not as good, although still within two standard deviations.

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[*] Visitor from Augustana College, Sioux Falls, SD, USA.
[§] Visitor from ICN-UNAM, Mexico City, Mexico.
[‡] Visitor from Helsinki Institute of Physics, Helsinki, Finland.
[#] Visitor from Universität Zürich, Zürich, Switzerland.

[1] I. Dunietz *et al.*, Phys. Rev. D **63**, 114015 (2001).
[2] A. Lenz and U. Nierste, arXiv:hep-ph/0612167.
[3] R. Aleksan *et al.*, Phys. Lett. B **316**, 567 (1993).
[4] R. Barate *et al.* (ALEPH Collaboration), Phys. Lett. B **486**, 286 (2000).
[5] V.M. Abazov *et al.* (D0 Collaboration), Nucl. Instrum. and Methods A **565**, 463 (2006).
[6] J. Abdallah *et al.*, (DELPHI Collaboration), Eur. Phys. J. C **32**, 185 (2004).
[7] W.-M. Yao *et al.* (Particle Data Group), J. Phys. G **33**, 1 (2006).
[8] D.J. Lange, Nucl. Instrum. Meth. A **462**, 152 (2001).
[9] T. Sjöstrand *et al.*, Comp. Phys. Commun. **135**, 238 (2001).
[10] R. Brun and F. Carminati, CERN Program Library Long Writeup W5013 (1993).
[11] V.M. Abazov *et al.* (D0 Collaboration), Phys. Rev. Lett. **94**, 182001 (2005).
[12] V.M. Abazov *et al.* (D0 Collaboration), arXiv:hep-ex/0701012.
[13] D. Acosta *et al.* (CDF Collaboration), Phys. Rev. Lett. **94**, 101803 (2005).