

**Measurement of the production fraction times branching fraction  $f(b \rightarrow \Lambda_b) \cdot \mathcal{B}(\Lambda_b \rightarrow J/\psi \Lambda)$** 

V. M. Abazov,<sup>35</sup> B. Abbott,<sup>73</sup> B. S. Acharya,<sup>29</sup> M. Adams,<sup>49</sup> T. Adams,<sup>47</sup> G. D. Alexeev,<sup>35</sup> G. Alkhazov,<sup>39</sup> A. Alton,<sup>61,\*</sup> G. Alverson,<sup>60</sup> G. A. Alves,<sup>2</sup> L. S. Ancu,<sup>34</sup> M. Aoki,<sup>48</sup> M. Arov,<sup>58</sup> A. Askew,<sup>47</sup> B. Åsman,<sup>41</sup> O. Atramentov,<sup>65</sup> C. Avila,<sup>8</sup> J. BackusMayer,<sup>80</sup> F. Badaud,<sup>13</sup> L. Bagby,<sup>48</sup> B. Baldin,<sup>48</sup> D. V. Bandurin,<sup>47</sup> S. Banerjee,<sup>29</sup> E. Barberis,<sup>60</sup> P. Baringer,<sup>56</sup> J. Barreto,<sup>3</sup> J. F. Bartlett,<sup>48</sup> U. Bassler,<sup>18</sup> V. Bazterra,<sup>49</sup> S. Beale,<sup>6</sup> A. Bean,<sup>56</sup> M. Begalli,<sup>3</sup> M. Begel,<sup>71</sup> C. Belanger-Champagne,<sup>41</sup> L. Bellantoni,<sup>48</sup> S. B. Beri,<sup>27</sup> G. Bernardi,<sup>17</sup> R. Bernhard,<sup>22</sup> I. Bertram,<sup>42</sup> M. Besançon,<sup>18</sup> R. Beuselinck,<sup>43</sup> V. A. Bezzubov,<sup>38</sup> P. C. Bhat,<sup>48</sup> V. Bhatnagar,<sup>27</sup> G. Blazey,<sup>50</sup> S. Blessing,<sup>47</sup> K. Bloom,<sup>64</sup> A. Boehnlein,<sup>48</sup> D. Boline,<sup>70</sup> E. E. Boos,<sup>37</sup> G. Borissov,<sup>42</sup> T. Bose,<sup>59</sup> A. Brandt,<sup>76</sup> O. Brandt,<sup>23</sup> R. Brock,<sup>62</sup> G. Brooijmans,<sup>68</sup> A. Bross,<sup>48</sup> D. Brown,<sup>17</sup> J. Brown,<sup>17</sup> X. B. Bu,<sup>48</sup> M. Buehler,<sup>79</sup> V. Buescher,<sup>24</sup> V. Bunichev,<sup>37</sup> S. Burdin,<sup>42,†</sup> T. H. Burnett,<sup>80</sup> C. P. Buszello,<sup>41</sup> B. Calpas,<sup>15</sup> E. Camacho-Pérez,<sup>32</sup> M. A. Carrasco-Lizarraga,<sup>56</sup> B. C. K. Casey,<sup>48</sup> H. Castilla-Valdez,<sup>32</sup> S. Chakrabarti,<sup>70</sup> D. Chakraborty,<sup>50</sup> K. M. Chan,<sup>54</sup> A. Chandra,<sup>78</sup> G. Chen,<sup>56</sup> S. Chevalier-Théry,<sup>18</sup> D. K. Cho,<sup>75</sup> S. W. Cho,<sup>31</sup> S. Choi,<sup>31</sup> B. Choudhary,<sup>28</sup> S. Cihangir,<sup>48</sup> D. Claes,<sup>64</sup> J. Clutter,<sup>56</sup> M. Cooke,<sup>48</sup> W. E. Cooper,<sup>48</sup> M. Corcoran,<sup>78</sup> F. Couderc,<sup>18</sup> M.-C. Cousinou,<sup>15</sup> A. Croc,<sup>18</sup> D. Cutts,<sup>75</sup> A. Das,<sup>45</sup> G. Davies,<sup>43</sup> K. De,<sup>76</sup> S. J. de Jong,<sup>34</sup> E. De La Cruz-Burelo,<sup>32</sup> F. Déliot,<sup>18</sup> M. Demarteau,<sup>48</sup> R. Demina,<sup>69</sup> D. Denisov,<sup>48</sup> S. P. Denisov,<sup>38</sup> S. Desai,<sup>48</sup> C. Deterre,<sup>18</sup> K. DeVaughan,<sup>64</sup> H. T. Diehl,<sup>48</sup> M. Diesburg,<sup>48</sup> A. Dominguez,<sup>64</sup> T. Dorland,<sup>80</sup> A. Dubey,<sup>28</sup> L. V. Dudko,<sup>37</sup> D. Duggan,<sup>65</sup> A. Duperrin,<sup>15</sup> S. Dutt,<sup>27</sup> A. Dyshkant,<sup>50</sup> M. Eads,<sup>64</sup> D. Edmunds,<sup>62</sup> J. Ellison,<sup>46</sup> V. D. Elvira,<sup>48</sup> Y. Enari,<sup>17</sup> H. Evans,<sup>52</sup> A. Evdokimov,<sup>71</sup> V. N. Evdokimov,<sup>38</sup> G. Facini,<sup>60</sup> T. Ferbel,<sup>69</sup> F. Fiedler,<sup>24</sup> F. Filthaut,<sup>34</sup> W. Fisher,<sup>62</sup> H. E. Fisk,<sup>48</sup> M. Fortner,<sup>50</sup> H. Fox,<sup>42</sup> S. Fuess,<sup>48</sup> A. Garcia-Bellido,<sup>69</sup> V. Gavrilov,<sup>36</sup> P. Gay,<sup>13</sup> W. Geng,<sup>15,62</sup> D. Gerbaudo,<sup>66</sup> C. E. Gerber,<sup>49</sup> Y. Gershtein,<sup>65</sup> G. Ginther,<sup>48,69</sup> G. Golovanov,<sup>35</sup> A. Goussiou,<sup>80</sup> P. D. Grannis,<sup>70</sup> S. Greder,<sup>19</sup> H. Greenlee,<sup>48</sup> Z. D. Greenwood,<sup>58</sup> E. M. Gregores,<sup>4</sup> G. Grenier,<sup>20</sup> Ph. Gris,<sup>13</sup> J.-F. Grivaz,<sup>16</sup> A. Grohsjean,<sup>18</sup> S. Grünendahl,<sup>48</sup> M. W. Grünewald,<sup>30</sup> T. Guillemin,<sup>16</sup> F. Guo,<sup>70</sup> G. Gutierrez,<sup>48</sup> P. Gutierrez,<sup>73</sup> A. Haas,<sup>68,‡</sup> S. Hagopian,<sup>47</sup> J. Haley,<sup>60</sup> L. Han,<sup>7</sup> K. Harder,<sup>44</sup> A. Harel,<sup>69</sup> J. M. Hauptman,<sup>55</sup> J. Hays,<sup>43</sup> T. Head,<sup>44</sup> T. Hebbeker,<sup>21</sup> D. Hedin,<sup>50</sup> H. Hegab,<sup>74</sup> A. P. Heinson,<sup>46</sup> U. Heintz,<sup>75</sup> C. Hensel,<sup>23</sup> I. Heredia-De La Cruz,<sup>32</sup> K. Herner,<sup>61</sup> G. Hesketh,<sup>44,§</sup> M. D. Hildreth,<sup>54</sup> R. Hirosky,<sup>79</sup> T. Hoang,<sup>47</sup> J. D. Hobbs,<sup>70</sup> B. Hoeneisen,<sup>12</sup> M. Hohlfeld,<sup>24</sup> Z. Hubacek,<sup>10,18</sup> N. Huske,<sup>17</sup> V. Hynek,<sup>10</sup> I. Iashvili,<sup>67</sup> R. Illingworth,<sup>48</sup> A. S. Ito,<sup>48</sup> S. Jabeen,<sup>75</sup> M. Jaffré,<sup>16</sup> D. Jamin,<sup>15</sup> A. Jayasinghe,<sup>73</sup> R. Jesik,<sup>43</sup> K. Johns,<sup>45</sup> M. Johnson,<sup>48</sup> D. Johnston,<sup>64</sup> A. Jonckheere,<sup>48</sup> P. Jonsson,<sup>43</sup> J. Joshi,<sup>27</sup> A. W. Jung,<sup>48</sup> A. Juste,<sup>40</sup> K. Kaadze,<sup>57</sup> E. Kajfasz,<sup>15</sup> D. Karmanov,<sup>37</sup> P. A. Kasper,<sup>48</sup> I. Katsanos,<sup>64</sup> R. Kehoe,<sup>77</sup> S. Kermiche,<sup>15</sup> N. Khalatyan,<sup>48</sup> A. Khanov,<sup>74</sup> A. Kharchilava,<sup>67</sup> Y. N. Kharzheev,<sup>35</sup> D. Khatidze,<sup>75</sup> M. H. Kirby,<sup>51</sup> J. M. Kohli,<sup>27</sup> A. V. Kozelov,<sup>38</sup> J. Kraus,<sup>62</sup> S. Kulikov,<sup>38</sup> A. Kumar,<sup>67</sup> A. Kupco,<sup>11</sup> T. Kurča,<sup>20</sup> V. A. Kuzmin,<sup>37</sup> J. Kvita,<sup>9</sup> S. Lammers,<sup>52</sup> G. Landsberg,<sup>75</sup> P. Lebrun,<sup>20</sup> H. S. Lee,<sup>31</sup> S. W. Lee,<sup>55</sup> W. M. Lee,<sup>48</sup> J. Lellouch,<sup>17</sup> L. Li,<sup>46</sup> Q. Z. Li,<sup>48</sup> S. M. Lietti,<sup>5</sup> J. K. Lim,<sup>31</sup> D. Lincoln,<sup>48</sup> J. Linnemann,<sup>62</sup> V. V. Lipaev,<sup>38</sup> R. Lipton,<sup>48</sup> Y. Liu,<sup>7</sup> Z. Liu,<sup>6</sup> A. Lobodenko,<sup>39</sup> M. Lokajicek,<sup>11</sup> R. Lopes de Sa,<sup>70</sup> H. J. Lubatti,<sup>80</sup> R. Luna-Garcia,<sup>32,||</sup> A. L. Lyon,<sup>48</sup> A. K. A. Maciel,<sup>2</sup> D. Mackin,<sup>78</sup> R. Madar,<sup>18</sup> R. Magaña-Villalba,<sup>32</sup> S. Malik,<sup>64</sup> V. L. Malyshev,<sup>35</sup> Y. Maravin,<sup>57</sup> J. Martínez-Ortega,<sup>32</sup> R. McCarthy,<sup>70</sup> C. L. McGivern,<sup>56</sup> M. M. Meijer,<sup>34</sup> A. Melnitchouk,<sup>63</sup> D. Menezes,<sup>50</sup> P. G. Mercadante,<sup>4</sup> M. Merkin,<sup>37</sup> A. Meyer,<sup>21</sup> J. Meyer,<sup>23</sup> F. Miconi,<sup>19</sup> N. K. Mondal,<sup>29</sup> G. S. Muanza,<sup>15</sup> M. Mulhearn,<sup>79</sup> E. Nagy,<sup>15</sup> M. Naimuddin,<sup>28</sup> M. Narain,<sup>75</sup> R. Nayyar,<sup>28</sup> H. A. Neal,<sup>61</sup> J. P. Negret,<sup>8</sup> P. Neustroev,<sup>39</sup> S. F. Novaes,<sup>5</sup> T. Nunnemann,<sup>25</sup> G. Obrant,<sup>39</sup> J. Orduna,<sup>78</sup> N. Osman,<sup>15</sup> J. Osta,<sup>54</sup> G. J. Otero y Garzón,<sup>1</sup> M. Padilla,<sup>46</sup> A. Pal,<sup>76</sup> N. Parashar,<sup>53</sup> V. Parihar,<sup>75</sup> S. K. Park,<sup>31</sup> J. Parsons,<sup>68</sup> R. Partridge,<sup>75,‡</sup> N. Parua,<sup>52</sup> A. Patwa,<sup>71</sup> B. Penning,<sup>48</sup> M. Perfilov,<sup>37</sup> K. Peters,<sup>44</sup> Y. Peters,<sup>44</sup> K. Petridis,<sup>44</sup> G. Petrillo,<sup>69</sup> P. Pétroff,<sup>16</sup> R. Piegaiia,<sup>1</sup> J. Piper,<sup>62</sup> M.-A. Pleier,<sup>71</sup> P. L. M. Podesta-Lerma,<sup>32,||</sup> V. M. Podstavkov,<sup>48</sup> P. Polozov,<sup>36</sup> A. V. Popov,<sup>38</sup> M. Prewitt,<sup>78</sup> D. Price,<sup>52</sup> N. Prokopenko,<sup>38</sup> S. Protopopescu,<sup>71</sup> J. Qian,<sup>61</sup> A. Quadt,<sup>23</sup> B. Quinn,<sup>63</sup> M. S. Rangel,<sup>2</sup> K. Ranjan,<sup>28</sup> P. N. Ratoff,<sup>42</sup> I. Razumov,<sup>38</sup> P. Renkel,<sup>77</sup> M. Rijssenbeek,<sup>70</sup> I. Ripp-Baudot,<sup>19</sup> F. Rizatdinova,<sup>74</sup> M. Rominsky,<sup>48</sup> A. Ross,<sup>42</sup> C. Royon,<sup>18</sup> P. Rubinov,<sup>48</sup> R. Ruchti,<sup>54</sup> G. Safronov,<sup>36</sup> G. Sajot,<sup>14</sup> P. Salcido,<sup>50</sup> A. Sánchez-Hernández,<sup>32</sup> M. P. Sanders,<sup>25</sup> B. Sanghi,<sup>48</sup> A. S. Santos,<sup>5</sup> G. Savage,<sup>48</sup> L. Sawyer,<sup>58</sup> T. Scanlon,<sup>43</sup> R. D. Schamberger,<sup>70</sup> Y. Scheglov,<sup>39</sup> H. Schellman,<sup>51</sup> T. Schliephake,<sup>26</sup> S. Schlobohm,<sup>80</sup> C. Schwanenberger,<sup>44</sup> R. Schwienhorst,<sup>62</sup> J. Sekaric,<sup>56</sup> H. Severini,<sup>73</sup> E. Shabalina,<sup>23</sup> V. Shary,<sup>18</sup> A. A. Shchukin,<sup>38</sup> R. K. Shivpuri,<sup>28</sup> V. Simak,<sup>10</sup> V. Sirotenko,<sup>48</sup> P. Skubic,<sup>73</sup> P. Slattery,<sup>69</sup> D. Smirnov,<sup>54</sup> K. J. Smith,<sup>67</sup> G. R. Snow,<sup>64</sup> J. Snow,<sup>72</sup> S. Snyder,<sup>71</sup> S. Söldner-Rembold,<sup>44</sup> L. Sonnenschein,<sup>21</sup> K. Soustruznik,<sup>9</sup> J. Stark,<sup>14</sup> V. Stolin,<sup>36</sup> D. A. Stoyanova,<sup>38</sup> M. Strauss,<sup>73</sup> D. Strom,<sup>49</sup> L. Stutte,<sup>48</sup> L. Suter,<sup>44</sup> P. Svoisky,<sup>73</sup> M. Takahashi,<sup>44</sup> A. Tanasijczuk,<sup>1</sup> W. Taylor,<sup>6</sup> M. Titov,<sup>18</sup> V. V. Tokmenin,<sup>35</sup> Y.-T. Tsai,<sup>69</sup> D. Tsybychev,<sup>70</sup> B. Tuchming,<sup>18</sup> C. Tully,<sup>66</sup> L. Uvarov,<sup>39</sup> S. Uvarov,<sup>39</sup> S. Uzunyan,<sup>50</sup> R. Van Kooten,<sup>52</sup> W. M. van Leeuwen,<sup>33</sup> N. Varelas,<sup>49</sup> E. W. Varnes,<sup>45</sup> I. A. Vasilyev,<sup>38</sup> P. Verdier,<sup>20</sup> L. S. Vertogradov,<sup>35</sup> M. Verzocchi,<sup>48</sup> M. Vesterinen,<sup>44</sup> D. Vilanova,<sup>18</sup> P. Vokac,<sup>10</sup> H. D. Wahl,<sup>47</sup>

M. H. L. S. Wang,<sup>69</sup> J. Warchol,<sup>54</sup> G. Watts,<sup>80</sup> M. Wayne,<sup>54</sup> M. Weber,<sup>48,\*\*</sup> L. Welty-Rieger,<sup>51</sup> A. White,<sup>76</sup> D. Wicke,<sup>26</sup> M. R. J. Williams,<sup>42</sup> G. W. Wilson,<sup>56</sup> M. Wobisch,<sup>58</sup> D. R. Wood,<sup>60</sup> T. R. Wyatt,<sup>44</sup> Y. Xie,<sup>48</sup> C. Xu,<sup>61</sup> S. Yacoob,<sup>51</sup> R. Yamada,<sup>48</sup> W.-C. Yang,<sup>44</sup> T. Yasuda,<sup>48</sup> Y. A. Yatsunenko,<sup>35</sup> Z. Ye,<sup>48</sup> H. Yin,<sup>48</sup> K. Yip,<sup>71</sup> S. W. Youn,<sup>48</sup> J. Yu,<sup>76</sup> S. Zelitch,<sup>79</sup> T. Zhao,<sup>80</sup> B. Zhou,<sup>61</sup> J. Zhu,<sup>61</sup> M. Zielinski,<sup>69</sup> D. Zieminska,<sup>52</sup> and L. Zivkovic<sup>75</sup>

(D0 Collaboration)

- <sup>1</sup>Universidad de Buenos Aires, Buenos Aires, Argentina  
<sup>2</sup>LAFEX, Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil  
<sup>3</sup>Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil  
<sup>4</sup>Universidade Federal do ABC, Santo André, Brazil  
<sup>5</sup>Instituto de Física Teórica, Universidade Estadual Paulista, São Paulo, Brazil  
<sup>6</sup>Simon Fraser University, Vancouver, British Columbia, and York University, Toronto, Ontario, Canada  
<sup>7</sup>University of Science and Technology of China, Hefei, People's Republic of China  
<sup>8</sup>Universidad de los Andes, Bogotá, Colombia  
<sup>9</sup>Charles University, Faculty of Mathematics and Physics, Center for Particle Physics, Prague, Czech Republic  
<sup>10</sup>Czech Technical University in Prague, Prague, Czech Republic  
<sup>11</sup>Center for Particle Physics, Institute of Physics, Academy of Sciences of the Czech Republic, Prague, Czech Republic  
<sup>12</sup>Universidad San Francisco de Quito, Quito, Ecuador  
<sup>13</sup>LPC, Université Blaise Pascal, CNRS/IN2P3, Clermont, France  
<sup>14</sup>LPSC, Université Joseph Fourier Grenoble 1, CNRS/IN2P3, Institut National Polytechnique de Grenoble, Grenoble, France  
<sup>15</sup>CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille, France  
<sup>16</sup>LAL, Université Paris-Sud, CNRS/IN2P3, Orsay, France  
<sup>17</sup>LPNHE, Universités Paris VI and VII, CNRS/IN2P3, Paris, France  
<sup>18</sup>CEA, Irfu, SPP, Saclay, France  
<sup>19</sup>IPHC, Université de Strasbourg, CNRS/IN2P3, Strasbourg, France  
<sup>20</sup>IPNL, Université Lyon 1, CNRS/IN2P3, Villeurbanne, France and Université de Lyon, Lyon, France  
<sup>21</sup>III. Physikalisches Institut A, RWTH Aachen University, Aachen, Germany  
<sup>22</sup>Physikalisches Institut, Universität Freiburg, Freiburg, Germany  
<sup>23</sup>II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen, Germany  
<sup>24</sup>Institut für Physik, Universität Mainz, Mainz, Germany  
<sup>25</sup>Ludwig-Maximilians-Universität München, München, Germany  
<sup>26</sup>Fachbereich Physik, Bergische Universität Wuppertal, Wuppertal, Germany  
<sup>27</sup>Panjab University, Chandigarh, India  
<sup>28</sup>Delhi University, Delhi, India  
<sup>29</sup>Tata Institute of Fundamental Research, Mumbai, India  
<sup>30</sup>University College Dublin, Dublin, Ireland  
<sup>31</sup>Korea Detector Laboratory, Korea University, Seoul, Korea  
<sup>32</sup>CINVESTAV, Mexico City, Mexico  
<sup>33</sup>FOM-Institute NIKHEF and University of Amsterdam/NIKHEF, Amsterdam, The Netherlands  
<sup>34</sup>Radboud University Nijmegen/NIKHEF, Nijmegen, The Netherlands  
<sup>35</sup>Joint Institute for Nuclear Research, Dubna, Russia  
<sup>36</sup>Institute for Theoretical and Experimental Physics, Moscow, Russia  
<sup>37</sup>Moscow State University, Moscow, Russia  
<sup>38</sup>Institute for High Energy Physics, Protvino, Russia  
<sup>39</sup>Petersburg Nuclear Physics Institute, St. Petersburg, Russia  
<sup>40</sup>Institució Catalana de Recerca i Estudis Avançats and Institut de Física d'Altes Energies, Barcelona, Spain  
<sup>41</sup>Stockholm University, Stockholm and Uppsala University, Uppsala, Sweden  
<sup>42</sup>Lancaster University, Lancaster LA1 4YB, United Kingdom  
<sup>43</sup>Imperial College London, London SW7 2AZ, United Kingdom  
<sup>44</sup>The University of Manchester, Manchester M13 9PL, United Kingdom  
<sup>45</sup>University of Arizona, Tucson, Arizona 85721, USA  
<sup>46</sup>University of California Riverside, Riverside, California 92521, USA  
<sup>47</sup>Florida State University, Tallahassee, Florida 32306, USA  
<sup>48</sup>Fermi National Accelerator Laboratory, Batavia, Illinois 60510, USA  
<sup>49</sup>University of Illinois at Chicago, Chicago, Illinois 60607, USA  
<sup>50</sup>Northern Illinois University, DeKalb, Illinois 60115, USA  
<sup>51</sup>Northwestern University, Evanston, Illinois 60208, USA

- <sup>52</sup>Indiana University, Bloomington, Indiana 47405, USA  
<sup>53</sup>Purdue University Calumet, Hammond, Indiana 46323, USA  
<sup>54</sup>University of Notre Dame, Notre Dame, Indiana 46556, USA  
<sup>55</sup>Iowa State University, Ames, Iowa 50011, USA  
<sup>56</sup>University of Kansas, Lawrence, Kansas 66045, USA  
<sup>57</sup>Kansas State University, Manhattan, Kansas 66506, USA  
<sup>58</sup>Louisiana Tech University, Ruston, Louisiana 71272, USA  
<sup>59</sup>Boston University, Boston, Massachusetts 02215, USA  
<sup>60</sup>Northeastern University, Boston, Massachusetts 02115, USA  
<sup>61</sup>University of Michigan, Ann Arbor, Michigan 48109, USA  
<sup>62</sup>Michigan State University, East Lansing, Michigan 48824, USA  
<sup>63</sup>University of Mississippi, University, Mississippi 38677, USA  
<sup>64</sup>University of Nebraska, Lincoln, Nebraska 68588, USA  
<sup>65</sup>Rutgers University, Piscataway, New Jersey 08855, USA  
<sup>66</sup>Princeton University, Princeton, New Jersey 08544, USA  
<sup>67</sup>State University of New York, Buffalo, New York 14260, USA  
<sup>68</sup>Columbia University, New York, New York 10027, USA  
<sup>69</sup>University of Rochester, Rochester, New York 14627, USA  
<sup>70</sup>State University of New York, Stony Brook, New York 11794, USA  
<sup>71</sup>Brookhaven National Laboratory, Upton, New York 11973, USA  
<sup>72</sup>Langston University, Langston, Oklahoma 73050, USA  
<sup>73</sup>University of Oklahoma, Norman, Oklahoma 73019, USA  
<sup>74</sup>Oklahoma State University, Stillwater, Oklahoma 74078, USA  
<sup>75</sup>Brown University, Providence, Rhode Island 02912, USA  
<sup>76</sup>University of Texas, Arlington, Texas 76019, USA  
<sup>77</sup>Southern Methodist University, Dallas, Texas 75275, USA  
<sup>78</sup>Rice University, Houston, Texas 77005, USA  
<sup>79</sup>University of Virginia, Charlottesville, Virginia 22901, USA  
<sup>80</sup>University of Washington, Seattle, Washington 98195, USA

(Received 5 May 2011; published 4 August 2011)

The  $\Lambda_b(udb)$  baryon is observed in the decay  $\Lambda_b \rightarrow J/\psi \Lambda$  using  $6.1\text{fb}^{-1}$  of  $p\bar{p}$  collisions collected with the D0 detector at  $\sqrt{s} = 1.96$  TeV. The production fraction multiplied by the branching fraction for this decay relative to that for the decay  $B^0 \rightarrow J/\psi K_s^0$  is measured to be  $0.345 \pm 0.034(\text{stat}) \pm 0.033(\text{syst}) \pm 0.003(\text{PDG})$ . Using the world average value of  $f(b \rightarrow B^0) \cdot \mathcal{B}(B^0 \rightarrow J/\psi K_s^0) = (1.74 \pm 0.08) \times 10^{-5}$ , we obtain  $f(b \rightarrow \Lambda_b) \cdot \mathcal{B}(\Lambda_b \rightarrow J/\psi \Lambda) = (6.01 \pm 0.60(\text{stat}) \pm 0.58(\text{syst}) \pm 0.28(\text{PDG})) \times 10^{-5}$ . This measurement represents an improvement in precision by about a factor of 3 with respect to the current world average.

DOI: 10.1103/PhysRevD.84.031102

PACS numbers: 14.20.Mr, 13.30.Eg, 13.85.Ni

The study of  $b$  hadron decays, in particular,  $b \rightarrow s$  decays, offers good opportunities to search for physics beyond the standard model (BSM). For this reason, these decays have been the subject of intensive experimental [1–6] and theoretical [7–9] work. Studies of  $b$  baryons at the Fermilab Tevatron Collider and the CERN Large Hadron Collider are a natural extension of these studies which have been mostly performed on  $B$  mesons [10–13]. The experimental

knowledge of  $b$  baryons is currently limited [14]. For the  $\Lambda_b(udb)$ , the lightest  $b$  baryon, only a few decay channels have been studied, and the uncertainties on its branching fractions are large,  $\sim(30\text{--}60)\%$ . For higher mass  $b$  baryon states, even less information is available. Because of its relative abundance, the  $\Lambda_b$  baryon has been used to investigate production and decay properties of heavier  $b$  baryons, to search for possible polarization effects [15], for violation of discrete symmetries in the decay ( $CP$  [16] and  $T$  [17] violation), and to search for BSM effects [18]. There are several models (perturbative QCD [19], relativistic and nonrelativistic quark models based on factorization approximations [20–25] are examples) to describe  $b$  baryon decays such as  $\Lambda_b \rightarrow J/\psi \Lambda$ . Increasingly precise measurements of  $f(b \rightarrow \Lambda_b) \cdot \mathcal{B}(\Lambda_b \rightarrow J/\psi \Lambda)$  [where  $f(b \rightarrow \Lambda_b)$  is the fraction of  $b$  quarks which hadronize to  $\Lambda_b$  baryons] will allow better tests of these models. Moreover, these

\*Visitor from Augustana College, Sioux Falls, SD, USA.

†Visitor from The University of Liverpool, Liverpool, UK.

‡Visitor from SLAC, Menlo Park, CA, USA.

§Visitor from University College London, London, UK.

||Visitor from Centro de Investigacion en Computacion—IPN, Mexico City, Mexico.

¶Visitor from ECFM, Universidad Autonoma de Sinaloa, Culiacán, Mexico.

\*\*Visitor from Universität Bern, Bern, Switzerland.

measurements could help in the study of  $b \rightarrow s$  decays such as  $\Lambda_b \rightarrow \mu^+ \mu^- \Lambda$  [26,27], which are topologically similar to  $\Lambda_b \rightarrow J/\psi \Lambda$ , where  $J/\psi$  decays to dimuons.

This paper reports an improved measurement with respect to the previous Tevatron result [28] of the production fraction multiplied by the branching fraction of the  $\Lambda_b \rightarrow J/\psi \Lambda$  decay relative to that of the decay  $B^0 \rightarrow J/\psi K_S^0$ . From this measurement we can obtain  $f(b \rightarrow \Lambda_b) \cdot \mathcal{B}(\Lambda_b \rightarrow J/\psi \Lambda)$  with significantly improved precision compared to the current world average [14]. The  $J/\psi$ ,  $\Lambda$ , and  $K_S^0$  are reconstructed in the  $\mu^+ \mu^-$ ,  $p\pi^-$ , and  $\pi^+ \pi^-$  modes, respectively. Throughout this paper, the appearance of a specific charge state also implies its charge conjugate. The study is performed using  $6.1 \text{ fb}^{-1}$  of  $p\bar{p}$  collisions collected with the D0 detector between 2002 and 2009 at  $\sqrt{s} = 1.96 \text{ TeV}$  at the Fermilab Tevatron Collider.

A detailed description of the D0 detector can be found in [29]. 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  $|\eta| < 3.0$  (where  $\eta = -\ln[\tan(\theta/2)]$  and  $\theta$  is the polar angle), while the CFT has coverage for  $|\eta| < 2.0$ . Liquid-argon and uranium calorimeters in a central and two endcap cryostats cover the pseudorapidity region  $|\eta| < 4.2$ . The muon spectrometer is located outside the calorimeter and covers  $|\eta| < 2.0$ . It comprises a layer of drift tubes and scintillator trigger counters in front of 1.8 T iron toroids followed by two similar layers after the toroids.

We closely follow the data selection for  $J/\psi \rightarrow \mu^+ \mu^-$ ,  $\Lambda \rightarrow p\pi^-$ , and  $K_S^0 \rightarrow \pi^+ \pi^-$  used in the measurement [30] of the ratio of the lifetimes,  $\tau(\Lambda_b)/\tau(B^0)$ , that used the same decay products of the  $\Lambda_b$  and  $B^0$ . Events satisfying muon or dimuon triggers are used. At least one  $p\bar{p}$  interaction vertex must be identified in each event, determined by minimizing a  $\chi^2$  function that depends on all reconstructed tracks in the event and a term that represents the average beam position constraint. We begin by searching for  $J/\psi \rightarrow \mu^+ \mu^-$  decays reconstructed from two oppositely charged muons that have a common vertex with a  $\chi^2$  probability greater than 1%. Muons are identified by matching tracks reconstructed in the central tracking system with track segments in the muon spectrometer. The requirements of transverse momentum  $p_T > 2.0 \text{ GeV}/c$  and  $|\eta| < 2.0$  are imposed on these matched tracks, and each of them must be associated to at least two hits in the SMT and two hits in the CFT. In addition, at least one muon track must have segments in the muon system both inside and outside the toroid. The dimuon transverse momentum  $p_T(\mu^+ \mu^-)$  is required to be greater than  $3.0 \text{ GeV}/c$ , and its invariant mass  $M_{\mu^+ \mu^-}$  must be in the range  $2.8\text{--}3.35 \text{ GeV}/c^2$ . In these dimuon events we search for

$\Lambda \rightarrow p\pi^-$  and  $K_S^0 \rightarrow \pi^+ \pi^-$  candidates formed from two oppositely charged tracks with a common vertex with a  $\chi^2$  probability greater than 1% and invariant mass between  $1.102 < M_\Lambda < 1.130 \text{ GeV}/c^2$  and  $0.466 < M_{K_S^0} < 0.530 \text{ GeV}/c^2$ . To reduce the contribution from fake vertices reconstructed from random track crossings, the two tracks are required to have at most two hits associated with them in the tracking detectors located between the reconstructed  $p\bar{p}$  interaction vertex and the common two-track vertex. The impact parameter significance (the impact parameter with respect to the  $p\bar{p}$  vertex divided by its uncertainty) for the tracks forming  $\Lambda$  or  $K_S^0$  candidates must exceed 3 for both tracks and 4 for at least one of them. To reconstruct  $\Lambda$  candidates, the track with the higher  $p_T$  is assumed to be a proton. Monte Carlo (MC) studies show that this is always the correct assignment, given the track  $p_T$  detection threshold. To suppress contamination from cascade decays of more massive baryons such as  $\Sigma^0 \rightarrow \Lambda\gamma$  and  $\Xi^0 \rightarrow \Lambda\pi^0$ , we require the cosine of the angle between the  $p_T$  of the  $\Lambda$  and the vector from the  $J/\psi$  vertex to the  $\Lambda$  decay vertex in the plane perpendicular to the beam direction to be larger than 0.999. For  $\Lambda$  candidates coming from  $\Lambda_b$  decays, the cosine of this angle is typically greater than 0.9999.

The  $\Lambda_b$  ( $B^0$ ) is reconstructed by performing a constrained fit to a common vertex for the  $\Lambda$  ( $K_S^0$ ) candidate and the two muon tracks, with the muons constrained to the nominal  $J/\psi$  mass of  $3.097 \text{ GeV}/c^2$  [14]. The  $p_T$  of the  $\Lambda_b$  or  $B^0$  candidate is required to be greater than  $5 \text{ GeV}/c$ . The invariant mass of the  $J/\psi$  and the two additional tracks is required to be within the range  $5.0\text{--}6.2 \text{ GeV}/c^2$  for  $\Lambda_b$  candidates and within  $4.8\text{--}5.8 \text{ GeV}/c^2$  for  $B^0$  candidates.

To determine the final selection criteria, we maximize  $N_S/\sqrt{N_S + N_B}$ , where  $N_S$  is the number of signal ( $\Lambda_b$  or  $B^0$ ) candidates determined by Monte Carlo simulations and  $N_B$  is the number of background candidates estimated by using data events in the sidebands of the expected signal. For the Monte Carlo simulations, we use PYTHIA [31] and EVTGEN [32] for the production and decay of the simulated particles, respectively, and GEANT3 [33] to simulate detector effects. As a result of this optimization, for the  $\Lambda$  ( $K_S^0$ ) we require the transverse decay length to be greater than  $0.8$  ( $0.4$ ) cm, the  $p_T$  to be greater than  $1.6$  ( $1.0$ )  $\text{GeV}/c$ , and the significance of its transverse proper decay length (transverse decay length corrected by the boost in the transverse plane) to be greater than  $4.0$  ( $9.0$ ). For the  $\Lambda_b$  ( $B^0$ ) candidate, the significance of the proper decay length is required to be greater than  $2.0$  ( $3.0$ ). In addition, the  $\Lambda_b$  and  $B^0$  vertices must be well reconstructed.

A track pair can be simultaneously identified as both  $\Lambda$  and  $K_S^0$  due to different mass assignments to the same tracks. Events containing such track pair ambiguities are removed. Finally, if more than one candidate is found in the event, the candidate with the best vertex  $\chi^2$  probability is selected as the  $\Lambda_b$  ( $B^0$ ).

The invariant mass distributions of the final  $\Lambda_b$  and  $B^0$  candidates passing our selection criteria are shown in Fig. 1. To extract the yields of the observed  $\Lambda_b$  and  $B^0$  hadrons, we perform an unbinned likelihood fit to each mass distribution assuming a double Gaussian function for the signal and a second order polynomial distribution for the background. The fits yield  $N_{\Lambda_b \rightarrow J/\psi \Lambda} = 314 \pm 29$  events and  $N_{B^0 \rightarrow J/\psi K_S^0} = 2335 \pm 73$  events.

The relative production fraction times branching fraction for  $\Lambda_b \rightarrow J/\psi \Lambda$  decays to that of  $B^0 \rightarrow J/\psi K_S^0$  decays is given by

$$\begin{aligned} \sigma_{\text{rel}} &\equiv \frac{f(b \rightarrow \Lambda_b) \cdot \mathcal{B}(\Lambda_b \rightarrow J/\psi \Lambda)}{f(b \rightarrow B^0) \cdot \mathcal{B}(B^0 \rightarrow J/\psi K_S^0)} \\ &= \frac{N_{\Lambda_b \rightarrow J/\psi \Lambda}}{N_{B^0 \rightarrow J/\psi K_S^0}} \cdot \frac{\mathcal{B}(K_S^0 \rightarrow \pi^+ \pi^-)}{\mathcal{B}(\Lambda \rightarrow p \pi^-)} \cdot \epsilon. \end{aligned} \quad (1)$$

Here,  $\epsilon = \epsilon_{B^0 \rightarrow J/\psi K_S^0} / \epsilon_{\Lambda_b \rightarrow J/\psi \Lambda}$  is the relative detection efficiency of  $B^0 \rightarrow J/\psi K_S^0$  to  $\Lambda_b \rightarrow J/\psi \Lambda$  decays. This relative efficiency is determined from MC simulation to be  $\epsilon = 2.37 \pm 0.05$  (MC stat). Using  $\mathcal{B}(K_S^0 \rightarrow \pi^+ \pi^-) = 0.6920 \pm 0.0005$  and  $\mathcal{B}(\Lambda \rightarrow p \pi^-) = 0.639 \pm 0.005$  [14], we obtain  $\mathcal{B}(K_S^0 \rightarrow \pi^+ \pi^-) / \mathcal{B}(\Lambda \rightarrow p \pi^-) = 1.083 \pm 0.009$ . With these inputs and the reconstructed  $\Lambda_b$  and  $B^0$  yields, the relative production fraction is found to be

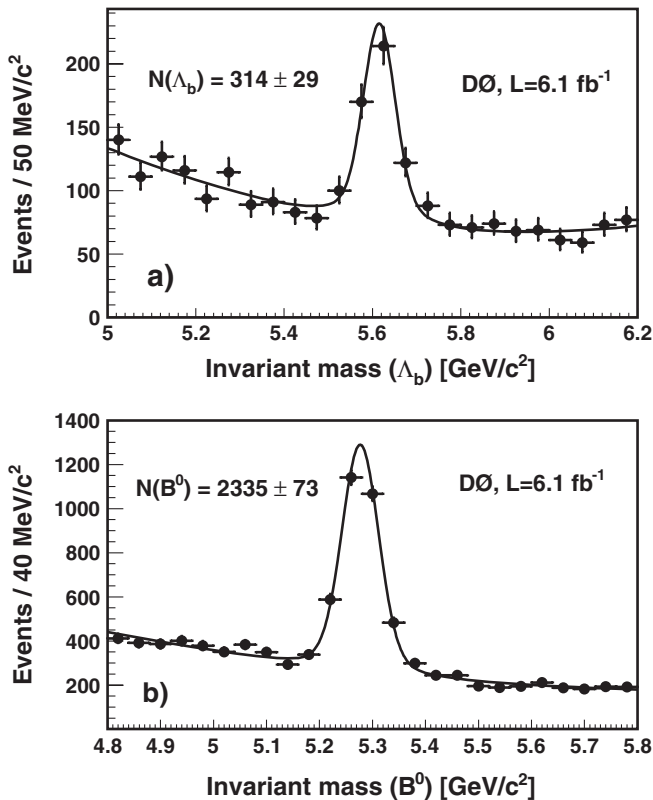


FIG. 1. Invariant mass distribution in data for (a)  $\Lambda_b \rightarrow J/\psi \Lambda$  and (b)  $B^0 \rightarrow J/\psi K_S^0$  decays. Fit results are superimposed.

$\sigma_{\text{rel}} = 0.345 \pm 0.034$  (stat)  $\pm 0.003$  (PDG), where (PDG) denotes the uncertainty due to the inputs from [14].

The sources of systematic uncertainty on  $\sigma_{\text{rel}}$  are as follows: (i) uncertainties in the determination of the  $\Lambda_b$  and  $B^0$  yields, (ii) the determination of the relative efficiency  $\epsilon$ , (iii) contamination from  $\Lambda_b$  in  $B^0$  and conversely, and (iv)  $\Lambda_b$  polarization effects on the relative efficiency  $\epsilon$ . Many other systematic uncertainties common to both  $\Lambda_b \rightarrow J/\psi \Lambda$  and  $B^0 \rightarrow J/\psi K_S^0$  decays, such as  $b$  quark production, integrated luminosity, trigger and selection efficiencies, cancel in the ratio. The models used for describing signal and background in data are varied, and the resulting changes in the  $\Lambda_b$  and  $B^0$  yields introduce a maximum deviation of  $\sigma_{\text{rel}}$  from its central value of 5.5%, which is included as a systematic uncertainty. The simulation used to estimate  $\epsilon$  uses a phase space model in EVTGEN to decay  $\Lambda_b$  and  $B^0$  particles. For  $B^0$  decays we can also use the SVSCP (scalar-vector-scalar with  $CP$  violation) model [32]. When using this alternative model, we observe a deviation of 2.0% in  $\sigma_{\text{rel}}$ . Given the similar topologies of the  $\Lambda_b \rightarrow J/\psi(\mu^+ \mu^-)\Lambda(p \pi^-)$  and  $B^0 \rightarrow J/\psi(\mu^+ \mu^-)K_S^0(\pi^+ \pi^-)$  decays, the  $\Lambda_b$  sample may be contaminated with  $B^0$  events that pass the  $\Lambda_b$  selection, or vice versa. We quantify this effect in simulation and find a deviation of 2.3% in  $\sigma_{\text{rel}}$ , which we include as a systematic uncertainty. Finally, the effect of the unknown polarization and decay parameters of the  $\Lambda_b$  baryon on the relative efficiency is studied following the formalism of [15,34]. The main effect of the polarization is observed through  $\Theta$ , the emission angle of the  $\Lambda$  baryon with respect to the polarization direction in the  $\Lambda_b$  rest frame. This angle follows the distribution  $I(\Theta) \propto 1 + \alpha_{\Lambda_b} P_{\Lambda_b} \cos(\Theta)$ , where  $\alpha_{\Lambda_b}$  and  $P_{\Lambda_b}$  are the asymmetry parameter and polarization of the  $\Lambda_b$  baryon. We study the extreme cases  $\alpha_{\Lambda_b} P_{\Lambda_b} = \pm 1$  in simulations. The maximum deviation found in  $\sigma_{\text{rel}}$  is 7.2%, which is included as a systematic uncertainty due to the unknown  $\Lambda_b$  polarization. All of these systematic uncertainties are combined assuming no correlations, giving a total systematic uncertainty of 9.6%.

We study the stability of the measurement by performing cross-checks on the two main inputs to the computation of  $\sigma_{\text{rel}}$ : the ratio between the numbers of observed  $\Lambda_b$  and  $B^0$  candidates extracted from data and the relative efficiency determined from Monte Carlo simulations. We investigate the possibility that the number of  $\Lambda_b$  and  $B^0$  candidates is affected by time- or kinematics-dependent changes in the detection and selection efficiency. We divide the data into subsamples and determine the value of  $\sigma_{\text{rel}}$  in each individual subsample without observing any significant deviation from the measurement based on the full sample. We split the sample based on different data taking periods, in different  $p_T$ ,  $\eta$  regions,  $\Lambda$  and  $K_S^0$  decay lengths, and also investigated differences between  $\Lambda_b$  and  $\bar{\Lambda}_b$  rates. To test for any mismodeling of the detector efficiency that could

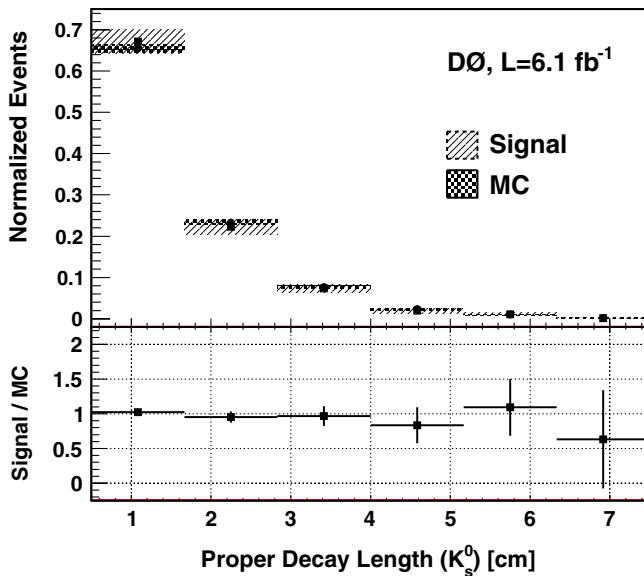


FIG. 2 (color online). Proper decay length distributions for  $K_S^0$  candidates in the decay  $B^0 \rightarrow J/\psi K_S^0$  for a background subtracted signal compared to the full MC simulation. The ratio signal/MC is given in the bottom panel.

affect the determination of  $\sigma_{\text{rel}}$ , decay length distributions are compared between data and Monte Carlo simulations, as well as proper decay length significance,  $\chi^2$  vertex distributions, and other variables used in the selection. In all these comparisons, the data and Monte Carlo distributions are found to be in good agreement. One such example is Fig. 2, which shows the proper decay length [35] distribution of  $K_S^0$  candidates. As a final cross-check, lifetime measurements are performed for the  $\Lambda$  and  $K_S^0$  with results in agreement with the world average values [14].

In summary, using an integrated luminosity of  $6.1 \text{ fb}^{-1}$  collected with the D0 detector, we measure the production fraction multiplied by the branching fraction for the decay  $\Lambda_b \rightarrow J/\psi \Lambda$  relative to that for the decay  $B^0 \rightarrow J/\psi K_S^0$ ,

$$\sigma_{\text{rel}} = 0.345 \pm 0.034(\text{stat}) \pm 0.033(\text{syst}) \pm 0.003(\text{PDG}). \quad (2)$$

Combining the uncertainties in quadrature, we obtain  $\sigma_{\text{rel}} = 0.345 \pm 0.047$ . Our measurement is the most precise to date and exceeds the precision of the current value reported as the world average,  $0.27 \pm 0.13$  [14]. Using the PDG value  $f(b \rightarrow B^0) \cdot \mathcal{B}(B^0 \rightarrow J/\psi K_S^0) = (1.74 \pm 0.08) \times 10^{-4}$  (from [14]), we obtain

$$\begin{aligned} f(b \rightarrow \Lambda_b) \cdot \mathcal{B}(\Lambda_b \rightarrow J/\psi \Lambda) \\ = [6.01 \pm 0.60(\text{stat}) \pm 0.58(\text{syst}) \pm 0.28(\text{PDG})] \times 10^{-5} \\ = (6.01 \pm 0.88) \times 10^{-5}, \end{aligned} \quad (3)$$

which can be compared directly to the world average value of  $(4.7 \pm 2.3) \times 10^{-5}$  [14]. This result represents a reduction by a factor of  $\sim 3$  of the uncertainty with respect to the previous measurement [28].

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); CNPq, FAPERJ, FAPESP and FUNDUNESP (Brazil); DAE and DST (India); Colciencias (Colombia); CONACyT (Mexico); KRF and KOSEF (Korea); CONICET and UBACyT (Argentina); FOM (The Netherlands); STFC and the Royal Society (United Kingdom); MSMT and GACR (Czech Republic); CRC Program and NSERC (Canada); BMBF and DFG (Germany); SFI (Ireland); The Swedish Research Council (Sweden); and CAS and CNSF (China).

- 
- [1] V. M. Abazov *et al.* (D0 Collaboration), *Phys. Rev. D* **82**, 012003 (2010).  
 [2] V. M. Abazov *et al.* (D0 Collaboration), *Phys. Rev. Lett.* **101**, 241801 (2008).  
 [3] T. Aaltonen *et al.* (CDF Collaboration), *Phys. Rev. Lett.* **100**, 121803 (2008).  
 [4] V. M. Abazov *et al.* (D0 Collaboration), *Phys. Rev. D* **74**, 031107 (2006).  
 [5] T. Aaltonen *et al.* (CDF Collaboration), *Phys. Rev. D* **79**, 011104(R) (2009).  
 [6] V. M. Abazov *et al.* (D0 Collaboration), *Phys. Rev. Lett.* **102**, 091801 (2009).  
 [7] R. Mohanta and A. K. Giri, *Phys. Rev. D* **76**, 075015 (2007).  
 [8] A. Lenz and U. Nierste, *J. High Energy Phys.* **06** (2007) 072.  
 [9] I. Dunietz, R. Fleischer, and U. Nierste, *Phys. Rev. D* **63**, 114015 (2001).  
 [10] E. Di Salvo and Z. J. Ajaltouni, *Mod. Phys. Lett. A* **24**, 109 (2009).  
 [11] T. M. Aliev *et al.*, *Phys. Rev. D* **81**, 056006 (2010).  
 [12] C. H. Chen *et al.*, *Phys. Rev. D* **65**, 091502 (2002).  
 [13] M. Jamil Aslam *et al.*, *Phys. Rev. D* **78**, 114032 (2008).  
 [14] K. Nakamura *et al.* (Particle Data Group), *J. Phys. G* **37**, 075021 (2010).  
 [15] J. Hrivnac *et al.*, *J. Phys. G* **21**, 629 (1995).  
 [16] I. Dunietz, *Z. Phys. C* **56**, 129 (1992).  
 [17] E. Di Salvo, and Z. J. Ajaltouni, *Mod. Phys. Lett. A* **24**, 109 (2009).  
 [18] C. Q. Geng *et al.*, *Phys. Rev. D* **65**, 091502 (2002).  
 [19] C. Chou, H. Shih, S. Lee, and H. Li, *Phys. Rev. D* **65**, 074030 (2002).  
 [20] Fayyazuddin and Riazuddin, *Phys. Rev. D* **58**, 014016 (1998).

- [21] Z. Wei, H. Ke, and X. Li, *Phys. Rev. D* **80**, 094016 (2009).
- [22] M. A. Ivanov *et al.*, *Phys. Rev. D* **57**, 5632 (1998).
- [23] R. Mohanta *et al.*, *Prog. Theor. Phys.* **101**, 959 (1999).
- [24] H. Cheng, *Phys. Rev. D* **56**, 2799 (1997).
- [25] H. Y. Cheng and B. Tseng, *Phys. Rev. D* **53**, 1457 (1996); **55**, 1697(E) (1997).
- [26] C.-H. Chen and C. Q. Geng, *Phys. Rev. D* **64**, 074001 (2001).
- [27] T. M. Aliev, A. Ozpineci, and M. Savci, *Phys. Rev. D* **65**, 115002 (2002).
- [28] F. Abe *et al.* (CDF Collaboration), *Phys. Rev. D* **55**, 1142 (1997).
- [29] V. M. Abazov *et al.* (D0 Collaboration), *Nucl. Instrum. Methods Phys. Res., Sect. A* **565**, 463 (2006).
- [30] V. M. Abazov *et al.* (D0 Collaboration), *Phys. Rev. Lett.* **99**, 142001 (2007).
- [31] T. Sjöstrand *et al.*, *Comput. Phys. Commun.* **135**, 238 (2001).
- [32] D. J. Lange, *Nucl. Instrum. Methods Phys. Res., Sect. A* **462**, 152 (2001).
- [33] R. Brun and F. Carminati, CERN Program Library Long Writup Report No. W5013, 1993 (unpublished).
- [34] M. Biglietti *et al.*, *Nucl. Phys. B, Proc. Suppl.* **156**, 151 (2006).
- [35] The event-by-event value of the proper decay length is defined as  $L_{xy}M/p_T$ , where  $p_T$  and  $M$  are the transverse momentum and mass of the  $b$  hadron, respectively, and  $L_{xy}$  is the distance between the  $p\bar{p}$  interaction vertex and the  $b$  hadron decay vertex in the transverse plane.