

## Study of $B$ -meson decays to $\eta_c K^{(*)}$ , $\eta_c(2S)K^{(*)}$ and $\eta_c \gamma K^{(*)}$

B. Aubert,<sup>1</sup> M. Bona,<sup>1</sup> Y. Karyotakis,<sup>1</sup> J. P. Lees,<sup>1</sup> V. Poireau,<sup>1</sup> E. Prencipe,<sup>1</sup> X. Prudent,<sup>1</sup> V. Tisserand,<sup>1</sup> J. Garra Tico,<sup>2</sup> E. Grauges,<sup>2</sup> L. Lopez,<sup>3</sup> A. Palano,<sup>3</sup> M. Pappagallo,<sup>3</sup> G. Eigen,<sup>4</sup> B. Stugu,<sup>4</sup> L. Sun,<sup>4</sup> G. S. Abrams,<sup>5</sup> M. Battaglia,<sup>5</sup> D. N. Brown,<sup>5</sup> J. Button-Shafer,<sup>5</sup> R. N. Cahn,<sup>5</sup> R. G. Jacobsen,<sup>5</sup> J. A. Kadyk,<sup>5</sup> L. T. Kerth,<sup>5</sup> Yu. G. Kolomensky,<sup>5</sup> G. Kukartsev,<sup>5</sup> G. Lynch,<sup>5</sup> I. L. Osipenkov,<sup>5</sup> M. T. Ronan,<sup>5,\*</sup> K. Tackmann,<sup>5</sup> T. Tanabe,<sup>5</sup> W. A. Wenzel,<sup>5</sup> C. M. Hawkes,<sup>6</sup> N. Soni,<sup>6</sup> A. T. Watson,<sup>6</sup> H. Koch,<sup>7</sup> T. Schroeder,<sup>7</sup> D. Walker,<sup>8</sup> D. J. Asgeirsson,<sup>9</sup> T. Cuhadar-Donszelmann,<sup>9</sup> B. G. Fulsom,<sup>9</sup> C. Hearty,<sup>9</sup> T. S. Mattison,<sup>9</sup> J. A. McKenna,<sup>9</sup> M. Barrett,<sup>10</sup> A. Khan,<sup>10</sup> M. Saleem,<sup>10</sup> L. Teodorescu,<sup>10</sup> V. E. Blinov,<sup>11</sup> A. D. Bukin,<sup>11</sup> A. R. Buzykaev,<sup>11</sup> V. P. Druzhinin,<sup>11</sup> V. B. Golubev,<sup>11</sup> A. P. Onuchin,<sup>11</sup> S. I. Serednyakov,<sup>11</sup> Yu. I. Skovpen,<sup>11</sup> E. P. Solodov,<sup>11</sup> K. Yu. Todyshev,<sup>11</sup> M. Bondioli,<sup>12</sup> S. Curry,<sup>12</sup> I. Eschrich,<sup>12</sup> D. Kirkby,<sup>12</sup> A. J. Lankford,<sup>12</sup> P. Lund,<sup>12</sup> M. Mandelkern,<sup>12</sup> E. C. Martin,<sup>12</sup> D. P. Stoker,<sup>12</sup> S. Abachi,<sup>13</sup> C. Buchanan,<sup>13</sup> J. W. Gary,<sup>14</sup> F. Liu,<sup>14</sup> O. Long,<sup>14</sup> B. C. Shen,<sup>14,\*</sup> G. M. Vitug,<sup>14</sup> Z. Yasin,<sup>14</sup> L. Zhang,<sup>14</sup> V. Sharma,<sup>15</sup> C. Campagnari,<sup>16</sup> T. M. Hong,<sup>16</sup> D. Kovalskyi,<sup>16</sup> M. A. Mazur,<sup>16</sup> J. D. Richman,<sup>16</sup> T. W. Beck,<sup>17</sup> A. M. Eisner,<sup>17</sup> C. J. Flacco,<sup>17</sup> C. A. Heusch,<sup>17</sup> J. Kroseberg,<sup>17</sup> W. S. Lockman,<sup>17</sup> T. Schalk,<sup>17</sup> B. A. Schumm,<sup>17</sup> A. Seiden,<sup>17</sup> L. Wang,<sup>17</sup> M. G. Wilson,<sup>17</sup> L. O. Winstrom,<sup>17</sup> C. H. Cheng,<sup>18</sup> D. A. Doll,<sup>18</sup> B. Echenard,<sup>18</sup> F. Fang,<sup>18</sup> D. G. Hitlin,<sup>18</sup> I. Narsky,<sup>18</sup> T. Piatenko,<sup>18</sup> F. C. Porter,<sup>18</sup> R. Andreassen,<sup>19</sup> G. Mancinelli,<sup>19</sup> B. T. Meadows,<sup>19</sup> K. Mishra,<sup>19</sup> M. D. Sokoloff,<sup>19</sup> F. Blanc,<sup>20</sup> P. C. Bloom,<sup>20</sup> W. T. Ford,<sup>20</sup> A. Gaz,<sup>20</sup> J. F. Hirschauer,<sup>20</sup> A. Kreisel,<sup>20</sup> M. Nagel,<sup>20</sup> U. Nauenberg,<sup>20</sup> A. Olivas,<sup>20</sup> J. G. Smith,<sup>20</sup> K. A. Ulmer,<sup>20</sup> S. R. Wagner,<sup>20</sup> R. Ayad,<sup>21,†</sup> A. M. Gabareen,<sup>21</sup> A. Soffer,<sup>21,‡</sup> W. H. Toki,<sup>21</sup> R. J. Wilson,<sup>21</sup> D. D. Altenburg,<sup>22</sup> E. Feltresi,<sup>22</sup> A. Hauke,<sup>22</sup> H. Jasper,<sup>22</sup> M. Karbach,<sup>22</sup> J. Merkel,<sup>22</sup> A. Petzold,<sup>22</sup> B. Spaan,<sup>22</sup> K. Wacker,<sup>22</sup> V. Klose,<sup>23</sup> M. J. Kobel,<sup>23</sup> H. M. Lacker,<sup>23</sup> W. F. Mader,<sup>23</sup> R. Nogowski,<sup>23</sup> K. R. Schubert,<sup>23</sup> R. Schwierz,<sup>23</sup> J. E. Sundermann,<sup>23</sup> A. Volk,<sup>23</sup> D. Bernard,<sup>24</sup> G. R. Bonneaud,<sup>24</sup> E. Latour,<sup>24</sup> Ch. Thiebaux,<sup>24</sup> M. Verderi,<sup>24</sup> P. J. Clark,<sup>25</sup> W. Gradl,<sup>25</sup> S. Playfer,<sup>25</sup> J. E. Watson,<sup>25</sup> M. Andreotti,<sup>26</sup> D. Bettoni,<sup>26</sup> C. Bozzi,<sup>26</sup> R. Calabrese,<sup>26</sup> A. Cecchi,<sup>26</sup> G. Cibinetto,<sup>26</sup> P. Franchini,<sup>26</sup> E. Luppi,<sup>26</sup> M. Negrini,<sup>26</sup> A. Petrella,<sup>26</sup> L. Piemontese,<sup>26</sup> V. Santoro,<sup>26</sup> F. Anulli,<sup>27</sup> R. Baldini-Ferrolì,<sup>27</sup> A. Calcaterra,<sup>27</sup> R. de Sangro,<sup>27</sup> G. Finocchiaro,<sup>27</sup> S. Pacetti,<sup>27</sup> P. Patteri,<sup>27</sup> I. M. Peruzzi,<sup>27,§</sup> M. Piccolo,<sup>27</sup> M. Rama,<sup>27</sup> A. Zallo,<sup>27</sup> A. Buzzo,<sup>28</sup> R. Contri,<sup>28</sup> M. Lo Vetere,<sup>28</sup> M. M. Macri,<sup>28</sup> M. R. Monge,<sup>28</sup> S. Passaggio,<sup>28</sup> C. Patrignani,<sup>28</sup> E. Robutti,<sup>28</sup> A. Santroni,<sup>28</sup> S. Tosi,<sup>28</sup> K. S. Chaisanguanthum,<sup>29</sup> M. Morii,<sup>29</sup> R. S. Dubitzky,<sup>30</sup> J. Marks,<sup>30</sup> S. Schenk,<sup>30</sup> U. Uwer,<sup>30</sup> D. J. Bard,<sup>31</sup> P. D. Dauncey,<sup>31</sup> J. A. Nash,<sup>31</sup> W. Panduro Vazquez,<sup>31</sup> M. Tibbetts,<sup>31</sup> P. K. Behera,<sup>32</sup> X. Chai,<sup>32</sup> M. J. Charles,<sup>32</sup> U. Mallik,<sup>32</sup> J. Cochran,<sup>33</sup> H. B. Crawley,<sup>33</sup> L. Dong,<sup>33</sup> W. T. Meyer,<sup>33</sup> S. Prell,<sup>33</sup> E. I. Rosenberg,<sup>33</sup> A. E. Rubin,<sup>33</sup> Y. Y. Gao,<sup>34</sup> A. V. Gritsan,<sup>34</sup> Z. J. Guo,<sup>34</sup> C. K. Lae,<sup>34</sup> A. G. Denig,<sup>35</sup> M. Fritsch,<sup>35</sup> G. Schott,<sup>35</sup> N. Arnaud,<sup>36</sup> J. Béquilleux,<sup>36</sup> A. D’Orazio,<sup>36</sup> M. Davier,<sup>36</sup> J. Firmino da Costa,<sup>36</sup> G. Grosdidier,<sup>36</sup> A. Höcker,<sup>36</sup> V. Lepeltier,<sup>36</sup> F. Le Diberder,<sup>36</sup> A. M. Lutz,<sup>36</sup> S. Pruvot,<sup>36</sup> P. Roudeau,<sup>36</sup> M. H. Schune,<sup>36</sup> J. Serrano,<sup>36</sup> V. Sordini,<sup>36</sup> A. Stocchi,<sup>36</sup> W. F. Wang,<sup>36</sup> G. Wormser,<sup>36</sup> D. J. Lange,<sup>37</sup> D. M. Wright,<sup>37</sup> I. Bingham,<sup>38</sup> J. P. Burke,<sup>38</sup> C. A. Chavez,<sup>38</sup> J. R. Fry,<sup>38</sup> E. Gabathuler,<sup>38</sup> R. Gamet,<sup>38</sup> D. E. Hutchcroft,<sup>38</sup> D. J. Payne,<sup>38</sup> C. Touramanis,<sup>38</sup> A. J. Bevan,<sup>39</sup> K. A. George,<sup>39</sup> F. Di Lodovico,<sup>39</sup> R. Sacco,<sup>39</sup> M. Sigamani,<sup>39</sup> G. Cowan,<sup>40</sup> H. U. Flaecher,<sup>40</sup> D. A. Hopkins,<sup>40</sup> S. Paramesvaran,<sup>40</sup> F. Salvatore,<sup>40</sup> A. C. Wren,<sup>40</sup> D. N. Brown,<sup>41</sup> C. L. Davis,<sup>41</sup> K. E. Alwyn,<sup>42</sup> N. R. Barlow,<sup>42</sup> R. J. Barlow,<sup>42</sup> Y. M. Chia,<sup>42</sup> C. L. Edgar,<sup>42</sup> G. D. Lafferty,<sup>42</sup> T. J. West,<sup>42</sup> J. I. Yi,<sup>42</sup> J. Anderson,<sup>43</sup> C. Chen,<sup>43</sup> A. Jawahery,<sup>43</sup> D. A. Roberts,<sup>43</sup> G. Simi,<sup>43</sup> J. M. Tuggle,<sup>43</sup> C. Dallapiccola,<sup>44</sup> S. S. Hertzbach,<sup>44</sup> X. Li,<sup>44</sup> E. Salvati,<sup>44</sup> S. Saremi,<sup>44</sup> R. Cowan,<sup>45</sup> D. Dujmic,<sup>45</sup> P. H. Fisher,<sup>45</sup> K. Koeneke,<sup>45</sup> G. Sciolla,<sup>45</sup> M. Spitznagel,<sup>45</sup> F. Taylor,<sup>45</sup> R. K. Yamamoto,<sup>45</sup> M. Zhao,<sup>45</sup> S. E. Mclachlin,<sup>46,\*</sup> P. M. Patel,<sup>46</sup> S. H. Robertson,<sup>46</sup> A. Lazzaro,<sup>47</sup> V. Lombardo,<sup>47</sup> F. Palombo,<sup>47</sup> J. M. Bauer,<sup>48</sup> L. Cremaldi,<sup>48</sup> V. Eschenburg,<sup>48</sup> R. Godang,<sup>48</sup> R. Kroeger,<sup>48</sup> D. A. Sanders,<sup>48</sup> D. J. Summers,<sup>48</sup> H. W. Zhao,<sup>48</sup> S. Brunet,<sup>49</sup> D. Côté,<sup>49</sup> M. Simard,<sup>49</sup> P. Taras,<sup>49</sup> F. B. Viaud,<sup>49</sup> H. Nicholson,<sup>50</sup> G. De Nardo,<sup>51</sup> L. Lista,<sup>51</sup> D. Monorchio,<sup>51</sup> C. Sciacca,<sup>51</sup> M. A. Baak,<sup>52</sup> G. Raven,<sup>52</sup> H. L. Snoek,<sup>52</sup> C. P. Jessop,<sup>53</sup> K. J. Knoepfel,<sup>53</sup> J. M. LoSecco,<sup>53</sup> G. Benelli,<sup>54</sup> L. A. Corwin,<sup>54</sup> K. Honscheid,<sup>54</sup> H. Kagan,<sup>54</sup> R. Kass,<sup>54</sup> J. P. Morris,<sup>54</sup> A. M. Rahimi,<sup>54</sup> J. J. Regensburger,<sup>54</sup> S. J. Sekula,<sup>54</sup> Q. K. Wong,<sup>54</sup> N. L. Blount,<sup>55</sup> J. Brau,<sup>55</sup> R. Frey,<sup>55</sup> O. Igonkina,<sup>55</sup> J. A. Kolb,<sup>55</sup> M. Lu,<sup>55</sup> R. Rahmat,<sup>55</sup>

N. B. Sinev,<sup>55</sup> D. Strom,<sup>55</sup> J. Strube,<sup>55</sup> E. Torrence,<sup>55</sup> G. Castelli,<sup>56</sup> N. Gagliardi,<sup>56</sup> M. Margoni,<sup>56</sup> M. Morandin,<sup>56</sup> M. Posocco,<sup>56</sup> M. Rotondo,<sup>56</sup> F. Simonetto,<sup>56</sup> R. Stroili,<sup>56</sup> C. Voci,<sup>56</sup> P. del Amo Sanchez,<sup>57</sup> E. Ben-Haim,<sup>57</sup> H. Briand,<sup>57</sup> G. Calderini,<sup>57</sup> J. Chauveau,<sup>57</sup> P. David,<sup>57</sup> L. Del Buono,<sup>57</sup> O. Hamon,<sup>57</sup> Ph. Leruste,<sup>57</sup> J. Ocariz,<sup>57</sup> A. Perez,<sup>57</sup> J. Prendki,<sup>57</sup> L. Gladney,<sup>58</sup> M. Biasini,<sup>59</sup> R. Covarelli,<sup>59</sup> E. Manoni,<sup>59</sup> C. Angelini,<sup>60</sup> G. Batignani,<sup>60</sup> S. Bettarini,<sup>60</sup> M. Carpinelli,<sup>60</sup>,<sup>¶</sup> A. Cervelli,<sup>60</sup> F. Forti,<sup>60</sup> M. A. Giorgi,<sup>60</sup> A. Lusiani,<sup>60</sup> G. Marchiori,<sup>60</sup> M. Morganti,<sup>60</sup> N. Neri,<sup>60</sup> E. Paoloni,<sup>60</sup> G. Rizzo,<sup>60</sup> J. J. Walsh,<sup>60</sup> J. Biesiada,<sup>61</sup> D. Lopes Pegna,<sup>61</sup> C. Lu,<sup>61</sup> J. Olsen,<sup>61</sup> A. J. S. Smith,<sup>61</sup> A. V. Telnov,<sup>61</sup> E. Baracchini,<sup>62</sup> G. Cavoto,<sup>62</sup> D. del Re,<sup>62</sup> E. Di Marco,<sup>62</sup> R. Faccini,<sup>62</sup> F. Ferrarotto,<sup>62</sup> F. Ferroni,<sup>62</sup> M. Gaspero,<sup>62</sup> P. D. Jackson,<sup>62</sup> L. Li Gioi,<sup>62</sup> M. A. Mazzoni,<sup>62</sup> S. Morganti,<sup>62</sup> G. Piredda,<sup>62</sup> F. Polci,<sup>62</sup> F. Renga,<sup>62</sup> C. Voena,<sup>62</sup> M. Ebert,<sup>63</sup> T. Hartmann,<sup>63</sup> H. Schröder,<sup>63</sup> R. Waldi,<sup>63</sup> T. Adye,<sup>64</sup> B. Franek,<sup>64</sup> E. O. Olaiya,<sup>64</sup> W. Roethel,<sup>64</sup> F. F. Wilson,<sup>64</sup> S. Emery,<sup>65</sup> M. Escalier,<sup>65</sup> L. Esteve,<sup>65</sup> A. Gaidot,<sup>65</sup> S. F. Ganzhur,<sup>65</sup> G. Hamel de Monchenault,<sup>65</sup> W. Kozanecki,<sup>65</sup> G. Vasseur,<sup>65</sup> Ch. Yèche,<sup>65</sup> M. Zito,<sup>65</sup> X. R. Chen,<sup>66</sup> H. Liu,<sup>66</sup> W. Park,<sup>66</sup> M. V. Purohit,<sup>66</sup> R. M. White,<sup>66</sup> J. R. Wilson,<sup>66</sup> M. T. Allen,<sup>67</sup> D. Aston,<sup>67</sup> R. Bartoldus,<sup>67</sup> P. Bechtle,<sup>67</sup> J. F. Benitez,<sup>67</sup> R. Cenci,<sup>67</sup> J. P. Coleman,<sup>67</sup> M. R. Convery,<sup>67</sup> J. C. Dingfelder,<sup>67</sup> J. Dorfan,<sup>67</sup> G. P. Dubois-Felsmann,<sup>67</sup> W. Dunwoodie,<sup>67</sup> R. C. Field,<sup>67</sup> S. J. Gowdy,<sup>67</sup> M. T. Graham,<sup>67</sup> P. Grenier,<sup>67</sup> C. Hast,<sup>67</sup> W. R. Innes,<sup>67</sup> J. Kaminski,<sup>67</sup> M. H. Kelsey,<sup>67</sup> H. Kim,<sup>67</sup> P. Kim,<sup>67</sup> M. L. Kocian,<sup>67</sup> D. W. G. S. Leith,<sup>67</sup> S. Li,<sup>67</sup> B. Lindquist,<sup>67</sup> S. Luitz,<sup>67</sup> V. Luth,<sup>67</sup> H. L. Lynch,<sup>67</sup> D. B. MacFarlane,<sup>67</sup> H. Marsiske,<sup>67</sup> R. Messner,<sup>67</sup> D. R. Muller,<sup>67</sup> H. Neal,<sup>67</sup> S. Nelson,<sup>67</sup> C. P. O'Grady,<sup>67</sup> I. Ofte,<sup>67</sup> A. Perazzo,<sup>67</sup> M. Perl,<sup>67</sup> B. N. Ratcliff,<sup>67</sup> A. Roodman,<sup>67</sup> A. A. Salnikov,<sup>67</sup> R. H. Schindler,<sup>67</sup> J. Schwiening,<sup>67</sup> A. Snyder,<sup>67</sup> D. Su,<sup>67</sup> M. K. Sullivan,<sup>67</sup> K. Suzuki,<sup>67</sup> S. K. Swain,<sup>67</sup> J. M. Thompson,<sup>67</sup> J. Va'vra,<sup>67</sup> A. P. Wagner,<sup>67</sup> M. Weaver,<sup>67</sup> C. A. West,<sup>67</sup> W. J. Wisniewski,<sup>67</sup> M. Wittgen,<sup>67</sup> D. H. Wright,<sup>67</sup> H. W. Wulsin,<sup>67</sup> A. K. Yarritu,<sup>67</sup> K. Yi,<sup>67</sup> C. C. Young,<sup>67</sup> V. Ziegler,<sup>67</sup> P. R. Burchat,<sup>68</sup> A. J. Edwards,<sup>68</sup> S. A. Majewski,<sup>68</sup> T. S. Miyashita,<sup>68</sup> B. A. Petersen,<sup>68</sup> L. Wilden,<sup>68</sup> S. Ahmed,<sup>69</sup> M. S. Alam,<sup>69</sup> R. Bula,<sup>69</sup> J. A. Ernst,<sup>69</sup> B. Pan,<sup>69</sup> M. A. Saeed,<sup>69</sup> S. B. Zain,<sup>69</sup> S. M. Spanier,<sup>70</sup> B. J. Wogslund,<sup>70</sup> R. Eckmann,<sup>71</sup> J. L. Ritchie,<sup>71</sup> A. M. Ruland,<sup>71</sup> C. J. Schilling,<sup>71</sup> R. F. Schwitters,<sup>71</sup> B. W. Drummond,<sup>72</sup> J. M. Izen,<sup>72</sup> X. C. Lou,<sup>72</sup> S. Ye,<sup>72</sup> F. Bianchi,<sup>73</sup> D. Gamba,<sup>73</sup> M. Pelliccioni,<sup>73</sup> M. Bomben,<sup>74</sup> L. Bosisio,<sup>74</sup> C. Cartaro,<sup>74</sup> G. Della Ricca,<sup>74</sup> L. Lanceri,<sup>74</sup> L. Vitale,<sup>74</sup> V. Azzolini,<sup>75</sup> N. Lopez-March,<sup>75</sup> F. Martinez-Vidal,<sup>75</sup> D. A. Milanes,<sup>75</sup> A. Oyanguren,<sup>75</sup> J. Albert,<sup>76</sup> Sw. Banerjee,<sup>76</sup> B. Bhuyan,<sup>76</sup> H. H. F. Choi,<sup>76</sup> K. Hamano,<sup>76</sup> R. Kowalewski,<sup>76</sup> M. J. Lewczuk,<sup>76</sup> I. M. Nugent,<sup>76</sup> J. M. Roney,<sup>76</sup> R. J. Sobie,<sup>76</sup> T. J. Gershon,<sup>77</sup> P. F. Harrison,<sup>77</sup> J. Ilic,<sup>77</sup> T. E. Latham,<sup>77</sup> G. B. Mohanty,<sup>77</sup> H. R. Band,<sup>78</sup> X. Chen,<sup>78</sup> S. Dasu,<sup>78</sup> K. T. Flood,<sup>78</sup> Y. Pan,<sup>78</sup> M. Pierini,<sup>78</sup> R. Prepost,<sup>78</sup> C. O. Vuosalo,<sup>78</sup> and S. L. Wu<sup>78</sup>

(The BABAR Collaboration)

<sup>1</sup>Laboratoire de Physique des Particules, IN2P3/CNRS et Université de Savoie, F-74941 Annecy-Le-Vieux, France

<sup>2</sup>Universitat de Barcelona, Facultat de Física, Departament ECM, E-08028 Barcelona, Spain

<sup>3</sup>Università di Bari, Dipartimento di Fisica and INFN, I-70126 Bari, Italy

<sup>4</sup>University of Bergen, Institute of Physics, N-5007 Bergen, Norway

<sup>5</sup>Lawrence Berkeley National Laboratory and University of California, Berkeley, California 94720, USA

<sup>6</sup>University of Birmingham, Birmingham, B15 2TT, United Kingdom

<sup>7</sup>Ruhr Universität Bochum, Institut für Experimentalphysik 1, D-44780 Bochum, Germany

<sup>8</sup>University of Bristol, Bristol BS8 1TL, United Kingdom

<sup>9</sup>University of British Columbia, Vancouver, British Columbia, Canada V6T 1Z1

<sup>10</sup>Brunel University, Uxbridge, Middlesex UB8 3PH, United Kingdom

<sup>11</sup>Budker Institute of Nuclear Physics, Novosibirsk 630090, Russia

<sup>12</sup>University of California at Irvine, Irvine, California 92697, USA

<sup>13</sup>University of California at Los Angeles, Los Angeles, California 90024, USA

<sup>14</sup>University of California at Riverside, Riverside, California 92521, USA

<sup>15</sup>University of California at San Diego, La Jolla, California 92093, USA

<sup>16</sup>University of California at Santa Barbara, Santa Barbara, California 93106, USA

<sup>17</sup>University of California at Santa Cruz, Institute for Particle Physics, Santa Cruz, California 95064, USA

<sup>18</sup>California Institute of Technology, Pasadena, California 91125, USA

<sup>19</sup>University of Cincinnati, Cincinnati, Ohio 45221, USA

<sup>20</sup>University of Colorado, Boulder, Colorado 80309, USA

<sup>21</sup>Colorado State University, Fort Collins, Colorado 80523, USA

<sup>22</sup>Technische Universität Dortmund, Fakultät Physik, D-44221 Dortmund, Germany

<sup>23</sup>Technische Universität Dresden, Institut für Kern- und Teilchenphysik, D-01062 Dresden, Germany

<sup>24</sup>Laboratoire Leprince-Ringuet, CNRS/IN2P3, Ecole Polytechnique, F-91128 Palaiseau, France

<sup>25</sup>University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom

<sup>26</sup>Università di Ferrara, Dipartimento di Fisica and INFN, I-44100 Ferrara, Italy

- <sup>27</sup>Laboratori Nazionali di Frascati dell'INFN, I-00044 Frascati, Italy
- <sup>28</sup>Università di Genova, Dipartimento di Fisica and INFN, I-16146 Genova, Italy
- <sup>29</sup>Harvard University, Cambridge, Massachusetts 02138, USA
- <sup>30</sup>Universität Heidelberg, Physikalisches Institut, Philosophenweg 12, D-69120 Heidelberg, Germany
- <sup>31</sup>Imperial College London, London, SW7 2AZ, United Kingdom
- <sup>32</sup>University of Iowa, Iowa City, Iowa 52242, USA
- <sup>33</sup>Iowa State University, Ames, Iowa 50011-3160, USA
- <sup>34</sup>Johns Hopkins University, Baltimore, Maryland 21218, USA
- <sup>35</sup>Universität Karlsruhe, Institut für Experimentelle Kernphysik, D-76021 Karlsruhe, Germany
- <sup>36</sup>Laboratoire de l'Accélérateur Linéaire, IN2P3/CNRS et Université Paris-Sud 11, Centre Scientifique d'Orsay, B. P. 34, F-91898 ORSAY Cedex, France
- <sup>37</sup>Lawrence Livermore National Laboratory, Livermore, California 94550, USA
- <sup>38</sup>University of Liverpool, Liverpool L69 7ZE, United Kingdom
- <sup>39</sup>Queen Mary, University of London, E1 4NS, United Kingdom
- <sup>40</sup>University of London, Royal Holloway and Bedford New College, Egham, Surrey TW20 0EX, United Kingdom
- <sup>41</sup>University of Louisville, Louisville, Kentucky 40292, USA
- <sup>42</sup>University of Manchester, Manchester M13 9PL, United Kingdom
- <sup>43</sup>University of Maryland, College Park, Maryland 20742, USA
- <sup>44</sup>University of Massachusetts, Amherst, Massachusetts 01003, USA
- <sup>45</sup>Massachusetts Institute of Technology, Laboratory for Nuclear Science, Cambridge, Massachusetts 02139, USA
- <sup>46</sup>McGill University, Montréal, Québec, Canada H3A 2T8
- <sup>47</sup>Università di Milano, Dipartimento di Fisica and INFN, I-20133 Milano, Italy
- <sup>48</sup>University of Mississippi, University, Mississippi 38677, USA
- <sup>49</sup>Université de Montréal, Physique des Particules, Montréal, Québec, Canada H3C 3J7
- <sup>50</sup>Mount Holyoke College, South Hadley, Massachusetts 01075, USA
- <sup>51</sup>Università di Napoli Federico II, Dipartimento di Scienze Fisiche and INFN, I-80126, Napoli, Italy
- <sup>52</sup>NIKHEF, National Institute for Nuclear Physics and High Energy Physics, NL-1009 DB Amsterdam, The Netherlands
- <sup>53</sup>University of Notre Dame, Notre Dame, Indiana 46556, USA
- <sup>54</sup>Ohio State University, Columbus, Ohio 43210, USA
- <sup>55</sup>University of Oregon, Eugene, Oregon 97403, USA
- <sup>56</sup>Università di Padova, Dipartimento di Fisica and INFN, I-35131 Padova, Italy
- <sup>57</sup>Laboratoire de Physique Nucléaire et de Hautes Energies, IN2P3/CNRS, Université Pierre et Marie Curie-Paris6, Université Denis Diderot-Paris7, F-75252 Paris, France
- <sup>58</sup>University of Pennsylvania, Philadelphia, Pennsylvania 19104, USA
- <sup>59</sup>Università di Perugia, Dipartimento di Fisica and INFN, I-06100 Perugia, Italy
- <sup>60</sup>Università di Pisa, Dipartimento di Fisica, Scuola Normale Superiore and INFN, I-56127 Pisa, Italy
- <sup>61</sup>Princeton University, Princeton, New Jersey 08544, USA
- <sup>62</sup>Università di Roma La Sapienza, Dipartimento di Fisica and INFN, I-00185 Roma, Italy
- <sup>63</sup>Universität Rostock, D-18051 Rostock, Germany
- <sup>64</sup>Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, OX11 0QX, United Kingdom
- <sup>65</sup>DSM/Dapnia, CEA/Saclay, F-91191 Gif-sur-Yvette, France
- <sup>66</sup>University of South Carolina, Columbia, South Carolina 29208, USA
- <sup>67</sup>Stanford Linear Accelerator Center, Stanford, California 94309, USA
- <sup>68</sup>Stanford University, Stanford, California 94305-4060, USA
- <sup>69</sup>State University of New York, Albany, New York 12222, USA
- <sup>70</sup>University of Tennessee, Knoxville, Tennessee 37996, USA
- <sup>71</sup>University of Texas at Austin, Austin, Texas 78712, USA
- <sup>72</sup>University of Texas at Dallas, Richardson, Texas 75083, USA
- <sup>73</sup>Università di Torino, Dipartimento di Fisica Sperimentale and INFN, I-10125 Torino, Italy
- <sup>74</sup>Università di Trieste, Dipartimento di Fisica and INFN, I-34127 Trieste, Italy
- <sup>75</sup>IFIC, Universitat de Valencia-CSIC, E-46071 Valencia, Spain
- <sup>76</sup>University of Victoria, Victoria, British Columbia, Canada V8W 3P6
- <sup>77</sup>Department of Physics, University of Warwick, Coventry CV4 7AL, United Kingdom
- <sup>78</sup>University of Wisconsin, Madison, Wisconsin 53706, USA

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We study two-body  $B$ -meson decays to a charmonium state ( $\eta_c$ ,  $\eta_c(2S)$  or  $h_c$ ) and a  $K^+$  or  $K^{*0}(892)$  meson using a sample of  $349 \text{ fb}^{-1}$  of data collected with the BABAR detector at the PEP-II asymmetric-energy  $B$  Factory at SLAC. We measure  $\mathcal{B}(B^0 \rightarrow \eta_c K^{*0}) = (5.7 \pm 0.6(\text{stat}) \pm 0.9(\text{syst})) \times 10^{-4}$ ,  $\mathcal{B}(B^0 \rightarrow \eta_c(2S)K^{*0}) < 3.9 \times 10^{-4}$ ,  $\mathcal{B}(B^+ \rightarrow h_c K^+) \times \mathcal{B}(h_c \rightarrow \eta_c \gamma) < 4.8 \times 10^{-5}$  and  $\mathcal{B}(B^0 \rightarrow h_c K^{*0}) \times \mathcal{B}(h_c \rightarrow \eta_c \gamma) < 2.2 \times 10^{-4}$  at the 90% C.L., and  $\mathcal{B}(\eta_c(2S) \rightarrow K \bar{K} \pi) = (1.9 \pm 0.4(\text{stat}) \pm 1.1(\text{syst}))\%$ . We also measure the mass and width of the  $\eta_c$  meson to be  $m(\eta_c) = (2985.8 \pm 1.5(\text{stat}) \pm 3.1(\text{syst})) \text{ MeV}/c^2$  and  $\Gamma(\eta_c) = (36.3_{-3.6}^{+3.7}(\text{stat}) \pm 4.4(\text{syst})) \text{ MeV}$ .

In the simplest approximation,  $B$  decays to a charmonium state and a  $K$  or  $K^*$  meson arise from the quark-level process  $b \rightarrow c\bar{c}s$  and have been observed to occur with large rates [1]. However several decay modes are still poorly known, particularly in the case of singlet states such as  $\eta_c$  and  $h_c$ . A better knowledge of the relative abundances of the decay to the various charmonium states allows a deeper understanding of the underlying strong processes and tests of the predictions of models such as non-relativistic QCD [2]. In this document, we study  $B$ -meson decays to  $(K\bar{K}\pi)K^+$ ,  $(K\bar{K}\pi)K^{*0}$ ,  $\eta_c\gamma K^+$  and  $\eta_c\gamma K^{*0}$ , from which we measure the branching fractions for the following decay modes:  $B^0 \rightarrow \eta_c K^{*0}$ ,  $B^0 \rightarrow \eta_c(2S)K^{*0}$ ,  $B^0 \rightarrow h_c K^{*0}$ ,  $B^+ \rightarrow h_c K^+$  [3], and  $\eta_c(2S) \rightarrow K\bar{K}\pi$ . We also measure the mass and width of the  $\eta_c$  meson. The  $h_c$  meson has recently been discovered by the CLEO Collaboration as a narrow peak at  $3524.4 \pm 0.7$  MeV/ $c^2$  in the  $\eta_c\gamma$  invariant mass distribution in  $\psi(2S) \rightarrow \eta_c\gamma\pi^0$  decays [4], and this observation was confirmed by the E835 Collaboration [5]. The  $\eta_c(2S)$  state was discovered by the Belle Collaboration in  $B$  decays to  $(K_s^0 K^\pm \pi^\mp)K$  [6], and subsequently observed in the processes  $\gamma\gamma \rightarrow \eta_c(2S) \rightarrow K_s^0 K^\pm \pi^\mp$  and  $e^+e^- \rightarrow J/\psi\eta_c(2S)$ ; its mass is  $(3637 \pm 4)$  MeV/ $c^2$  and its width is  $(14 \pm 7)$  MeV [1]. No branching fraction for any  $\eta_c(2S)$  decay mode is yet listed by the Particle Data Group [1]. The branching fraction of  $B^0 \rightarrow \eta_c K^{*0}$  is currently known with a 40% uncertainty,  $(1.2 \pm 0.5) \times 10^{-3}$  [7], while  $B$  decays to  $\eta_c(2S)K^*$  and  $h_c K^{(*)}$  have never been observed. The Belle Collaboration studied the decay  $B^+ \rightarrow h_c K^+$  with  $h_c \rightarrow \eta_c\gamma$  and reported  $\mathcal{B}(B^+ \rightarrow \eta_c\gamma K^+) < 3.8 \times 10^{-5}$  at the 90% C.L. for an invariant mass of the  $\eta_c\gamma$  pair in the range [3.47,3.57] GeV/ $c^2$  [8]. No other  $B^+$  or  $B^0$  decay modes with  $h_c$  have yet been studied. The mass and width of the  $\eta_c$  are important parameters in models of the charmonium spectrum: the measurements reported in the literature [1] are often in poor agreement with one another. The listed world average for the mass is  $(2979.8 \pm 1.2)$  MeV/ $c^2$ , with measurements ranging from 2969 to 2984 MeV/ $c^2$ , and for the width it is  $(26.5 \pm 3.5)$  MeV with values ranging from 7 to 48 MeV.

In this analysis we reconstruct the  $\eta_c$  and  $\eta_c(2S)$  in the  $K_s^0 K^\pm \pi^\mp$  and  $K^+ K^- \pi^0$  decay modes, the  $h_c$  in its decay to  $\eta_c\gamma$ , the  $K_s^0$  in the mode  $K_s^0 \rightarrow \pi^+ \pi^-$  and the  $K^{*0}$  in  $K^{*0} \rightarrow K^+ \pi^-$ . The  $K_s^0 K^\pm \pi^\mp$  and  $K^+ K^- \pi^0$  final states are chosen because they are among the easier  $\eta_c$  decay modes to reconstruct and have a rather large branching fraction,  $\mathcal{B}(\eta_c \rightarrow K\bar{K}\pi) = (7.0 \pm 1.2)\%$  [1]. For the  $\eta_c(2S)$ , the  $K_s^0 K^\pm \pi^\mp$  mode is the only decay observed so far. The  $\eta_c\gamma$  decay of the  $h_c$  is chosen because it is expected to comprise about half of the total  $h_c$  decay width [2]. For decays with  $\eta_c$  and  $h_c$ , we measure ratios

of branching fractions with respect to  $\mathcal{B}(B^+ \rightarrow \eta_c K^+) = (9.1 \pm 1.3) \times 10^{-4}$  [1], to cancel the 17% uncertainty on  $\mathcal{B}(\eta_c \rightarrow K\bar{K}\pi)$ . Similarly, we measure the ratio  $\mathcal{B}(B^0 \rightarrow \eta_c(2S)K^{*0})/\mathcal{B}(B^+ \rightarrow \eta_c(2S)K^+)$ , to cancel the unknown branching fraction of  $\eta_c(2S) \rightarrow K\bar{K}\pi$ .

The data used in this analysis were collected with the BABAR detector at the PEP-II  $e^+e^-$  storage rings, and correspond to  $349 \text{ fb}^{-1}$  of integrated luminosity collected at the  $\Upsilon(4S)$  resonance, comprising 384 million  $B\bar{B}$  pairs. The BABAR detector is described elsewhere [9]. We make use of Monte Carlo (MC) simulations based on GEANT4 [10].

The event selection is optimized by maximizing the quantity  $N_S/\sqrt{N_S + N_B}$ , where  $N_S$  ( $N_B$ ) represents the number of signal (background) candidates surviving the selection.  $N_S$  is estimated from samples of simulated events of  $B \rightarrow \eta_c K^{(*)}$ ,  $\eta_c \rightarrow K\bar{K}\pi$  decays for  $B \rightarrow (K\bar{K}\pi)K^{(*)}$ , and  $B \rightarrow h_c K^{(*)}$ ,  $h_c \rightarrow \eta_c\gamma$ ,  $\eta_c \rightarrow K\bar{K}\pi$  for  $B \rightarrow \eta_c\gamma K^{(*)}$ .  $N_B$  is estimated from regions far from the signal on data. Simulated signal events and data are normalized to each other using the available measurements for  $B$  decays to  $\eta_c$  and assuming  $\mathcal{B}(B \rightarrow h_c K^{(*)}) = 1 \times 10^{-5}$ .

We select events with  $B\bar{B}$  pairs by requiring at least four charged tracks, the ratio of the second to the zeroth order Fox-Wolfram moment [11] to be less than 0.2, and the total energy of all the charged and neutral particles to be greater than 4.5 GeV.

Charged pion and kaon candidates are reconstructed tracks having at least 12 hits in the drift chamber, a transverse momentum with respect to the beam direction larger than 100 MeV/ $c$ , and a distance of closest approach to the beam spot smaller than 1.5 cm in the plane transverse to the beam axis and 10 cm along the beam axis. We use particle identification provided by measurements of the energy loss in the tracking devices and the Cherenkov detector. A  $K^{*0}$  candidate is formed from a pair of oppositely charged kaon and pion candidates originating from a common vertex and having an invariant mass within 60 MeV/ $c^2$  of the nominal  $K^{*0}$  mass [1].

Photon candidates are energy deposits in the electromagnetic calorimeter that are not associated with charged tracks, having energy greater than 100 MeV and a shower shape consistent with that of a photon. A  $\pi^0 \rightarrow \gamma\gamma$  candidate is formed from a pair of photon candidates with invariant mass in the range [115,150] MeV/ $c^2$  and energy greater than 400 MeV. These candidates are assigned a nominal  $\pi^0$  mass [1] when subsequently computing kinematic quantities.

A  $K_s^0 \rightarrow \pi^+ \pi^-$  candidate is formed from a pair of oppositely charged tracks originating from a common vertex and having an invariant mass within 20 MeV/ $c^2$  of the  $K^0$  mass. Its measured decay-length significance is required

to exceed three standard deviations. The candidate is constrained to the nominal  $K^0$  mass [1].

The  $B^{+,0} \rightarrow (K\bar{K}\pi)K^{+,*0}$  candidates are formed by pairing a  $K^{*0}$  or  $K^+$  candidate, referred to as the primary kaon, and a  $K_s^0 K^\pm \pi^\mp$  or  $K^+ K^- \pi^0$  combination with invariant mass above 2.75 GeV/ $c^2$  to include the whole charmonium region. The  $B^{+,0} \rightarrow \eta_c \gamma K^{+,*0}$  candidates are formed by combining a  $K^{*0}$  or  $K^+$  candidate, a photon with energy exceeding 250 MeV, and a  $K_s^0 K^\pm \pi^\mp$  or  $K^+ K^- \pi^0$  combination with invariant mass consistent with the  $\eta_c$  mass. We perform a vertex fit to the  $B$  candidates and require the  $\chi^2$  probability to exceed 0.002. We define two kinematic variables: the beam-energy substituted mass,  $m_{\text{ES}} = \sqrt{E_{\text{beam}}^2 - p_B^2}$  and  $\Delta E = E_B - E_{\text{beam}}$ , where  $p_B$  ( $E_B$ ) is the reconstructed  $B$  momentum (energy) and  $E_{\text{beam}}$  is the beam energy, in the  $e^+e^-$  center-of-mass (c.m.) frame.  $B$  candidates are retained if they have  $m_{\text{ES}}$  greater than 5.2 GeV/ $c^2$  and  $\Delta E$  within  $[-24,30]$ ,  $[-40,30]$ ,  $[-34,30]$ , and  $[-40,30]$  MeV for the  $K_s^0 K^\pm \pi^\mp K^{*0,+}$ ,  $K^+ K^- \pi^0 K^{*0,+}$ ,  $K_s^0 K^\pm \pi^\mp \gamma K^{*0,+}$ , and  $K^+ K^- \pi^0 \gamma K^{*0,+}$  combinations, respectively.  $B$  mesons produced in the process  $\Upsilon(4S) \rightarrow B\bar{B}$  follow a  $\sin^2 \theta_B$  distribution, where  $\theta_B$  is the polar angle of the  $B$  candidate momentum vector in the  $e^+e^-$  c.m. frame: we require  $|\cos \theta_B| < 0.9$ .

To suppress background,  $K^+\pi^-$ ,  $K^+K^-$ ,  $K^+K_s^0$ ,  $K_s^0\pi^-$  and  $K^+\pi^-\pi^+$  combinations with invariant masses within 30 MeV/ $c^2$  of the  $D^0$ ,  $D_s$  and  $D^+$  meson masses [1] are excluded when forming  $B$  candidates. We also remove  $K^+K^-$  pairs containing a primary kaon where the invariant mass of the pair is within 30 MeV/ $c^2$  of the  $\phi$  meson mass [1].

In events where more than one  $B$  candidate survives the selection, the one with the smallest  $|\Delta E|$  is retained. In cases of multiple  $B$  candidates composed from the same final state particles, and thus having the same value of  $|\Delta E|$ , we retain the one for which the primary kaon has the largest momentum in the  $e^+e^-$  c.m. frame.

The samples surviving the selection include a signal component, a combinatorial background component given by random combinations of tracks and neutral clusters both from  $B\bar{B}$  and continuum events  $e^+e^- \rightarrow q\bar{q}$  ( $q = u, d, s, c$ ), and a component due to  $B$  decays with a similar final state to the signal. Such ‘‘peaking backgrounds’’ exhibit the same distribution as signal events in  $m_{\text{ES}}$  and  $\Delta E$ , but their  $K\bar{K}\pi(\gamma)$  invariant-mass distribution ( $m_X$ ) is different. The signal content in data is therefore obtained by means of a maximum likelihood fit to  $m_X$  for all candidates having  $m_{\text{ES}}$  in the signal region  $[5.274, 5.284]$  GeV/ $c^2$ , after subtracting the combinatorial background. The  $m_X$  distribution for the combinatorial background events is obtained by extrapolating into the  $m_{\text{ES}}$  signal region the  $m_X$  distribution measured in the  $m_{\text{ES}}$  sideband, defined by  $5.20 < m_{\text{ES}} < 5.26$  GeV/ $c^2$ . The correlation between  $m_X$  and  $m_{\text{ES}}$  is found to be negligible in the relevant regions. A binned fit is then

performed on the  $m_{\text{ES}}$ -sideband-subtracted  $m_X$  distribution.

To estimate the background we perform an unbinned maximum likelihood fit to the  $m_{\text{ES}}$  distribution as follows. The  $B$  component, accounting for the sum of signal and peaking background, is modelled by a Gaussian function whose width is taken from the simulation and whose mean is fixed to the  $B$ -meson mass [1]. The  $m_{\text{ES}}$  distribution of the combinatorial background is represented by an ARGUS function [12]. The total number of events and the exponent of the ARGUS function are left free in the fit. The spectrum for candidates in the  $m_{\text{ES}}$  sideband is normalized to the  $m_{\text{ES}}$  signal window by using the integrals of the ARGUS component in the two regions (Fig. 1).

The  $m_X$  distribution for  $B^+ \rightarrow (K\bar{K}\pi)K^+$  and  $B^0 \rightarrow (K\bar{K}\pi)K^{*0}$  is shown in Fig. 2, after subtraction of the  $m_{\text{ES}}$  sideband background. The two samples are simultaneously fitted to the sum of an  $\eta_c$ , an  $\eta_c(2S)$ , a  $J/\psi$ , a  $\chi_{c1}$  and a  $\psi(2S)$ , and a background component accounted for by first-order polynomials. The  $\eta_c$  and  $\eta_c(2S)$  peaks are modelled by a non-relativistic Breit-Wigner convolved with a Gaussian function, the others by Gaussians. The masses of  $\chi_{c1}$ ,  $\eta_c(2S)$  and  $\psi(2S)$  and the width of the  $\eta_c(2S)$  are fixed to the world average values [1]. To reduce systematic uncertainties on the  $\eta_c$  mass measurement from potential distortion effects in data shifting the peak positions, in the fit we float the mass of the  $J/\psi$  and fit for the mass difference between  $J/\psi$  and  $\eta_c$ . We also float the width of the  $\eta_c$ ; the mass resolutions, modelled by the widths of the Gaussian functions, separately for the  $K_s^0 K^\pm \pi^\mp$  and  $K^+ K^- \pi^0$  modes; the coefficients of the background polynomial functions and the number of signal and background events. The fit extends over the  $m_X$  range  $[2.75, 3.95]$  GeV/ $c^2$ . No component is included for other charmonium states such as  $\chi_{c0}$ ,  $h_c$  and  $\chi_{c2}$ , since they have not been observed to decay to  $K\bar{K}\pi$  and/or in  $B$  decays. Table I summarizes the numbers of events found by the fit, separately for the  $B^+ \rightarrow (K\bar{K}\pi)K^+$  and  $B^0 \rightarrow (K\bar{K}\pi)K^{*0}$  samples. The  $\chi^2$  of the fit divided by the number of degrees of freedom ( $N_{\text{Dof}}$ ) is 1.2. The mass resolution is determined by the fit to be  $9 \pm 1$  MeV/ $c^2$  and  $20 \pm 9$  MeV/ $c^2$  for  $K_s^0 K^\pm \pi^\mp$  and  $K^+ K^- \pi^0$ , respectively. The mass of the  $J/\psi$  is found to be  $3096.4 \pm 1.0$  MeV/ $c^2$ , the mass difference between  $J/\psi$  and  $\eta_c$   $111.1 \pm 1.5$  MeV/ $c^2$ , and the  $\eta_c$  width  $36.3^{+3.7}_{-3.6}$  MeV. Using  $m(J/\psi) = 3096.916 \pm 0.011$  MeV/ $c^2$  from [1], we derive  $m(\eta_c) = 2985.8 \pm 1.5$  MeV/ $c^2$ .

In the case of  $B^+ \rightarrow \eta_c \gamma K^+$  and  $B^0 \rightarrow \eta_c \gamma K^{*0}$  (Fig. 3), the  $m_{\text{ES}}$ -sideband-subtracted  $m_X$  distribution is fitted to the sum of an  $h_c$  signal modelled by a Gaussian, and a background represented by a first-order polynomial. The mass of the  $h_c$  is fixed to the CLEO measurement, 3524 MeV/ $c^2$  [4]. The Gaussian resolution is fixed to the value determined from MC events, 16 MeV/ $c^2$  [13]. In the fit, the numbers of signal and background events

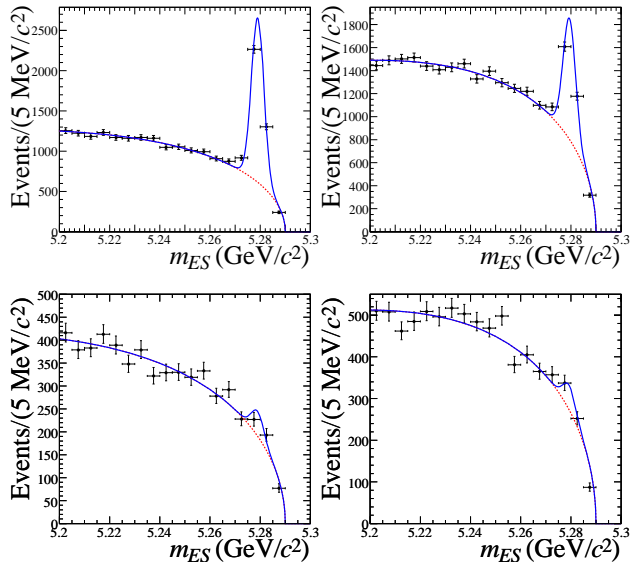


FIG. 1: The  $m_{ES}$  distributions for  $B^+ \rightarrow (K\bar{K}\pi)K^+$  (top left),  $B^0 \rightarrow (K\bar{K}\pi)K^{*0}$  (top right),  $B^+ \rightarrow \eta_c\gamma K^+$  (bottom left) and  $B^0 \rightarrow \eta_c\gamma K^{*0}$  (bottom right) candidates; points with error bars are data, the solid line represents the result of the fit described in the text, and the dotted line represents the ARGUS background parameterization. No appreciable  $B$  component, either signal or peaking background, is observed for the  $B^+ \rightarrow \eta_c\gamma K^+$  and  $B^0 \rightarrow \eta_c\gamma K^{*0}$  cases.

TABLE I: Numbers of  $\eta_c$ ,  $J/\psi$ ,  $\chi_{c1}$ ,  $\eta_c(2S)$  and  $\psi(2S)$  events obtained from the fit described in the text with statistical errors only.

	$B^+ \rightarrow (K\bar{K}\pi)K^+$	$B^0 \rightarrow (K\bar{K}\pi)K^{*0}$
$N_{\eta_c}$	$732 \pm 27$	$189 \pm 18$
$N_{J/\psi}$	$154 \pm 15$	$56 \pm 9$
$N_{\chi_{c1}}$	$59 \pm 10$	$13 \pm 7$
$N_{\eta_c(2S)}$	$59 \pm 12$	$13 \pm 9$
$N_{\psi(2S)}$	$15 \pm 8$	$0 \pm 4$

are left free. The fit is performed over the  $m_X$  range [3.3,3.7]  $\text{GeV}/c^2$ . It yields  $11 \pm 6$  and  $21 \pm 8$   $h_c$  candidates with a  $\chi^2/N_{Dof}$  of 41/39 and 42/39 for the  $B^+$  and  $B^0$  yields, respectively.

The stability of the fit results is verified for various configurations of the fitting conditions. For  $B \rightarrow (K\bar{K}\pi)K^{(*)}$ , we perform the fits with and without components for  $\chi_{c0}$ ,  $\chi_{c2}$ ,  $h_c$  and  $\psi(2S)$  in various combinations. The values for the signal yields and the floated parameters returned by these fits are consistent with the nominal configuration. We validate the fit procedure using a MC technique: we simulate a number of experiments by randomly generating samples of events distributed in  $m_X$  according to the models used in the fit. The number of events generated is equal to the number of events in the corresponding real data sample. The

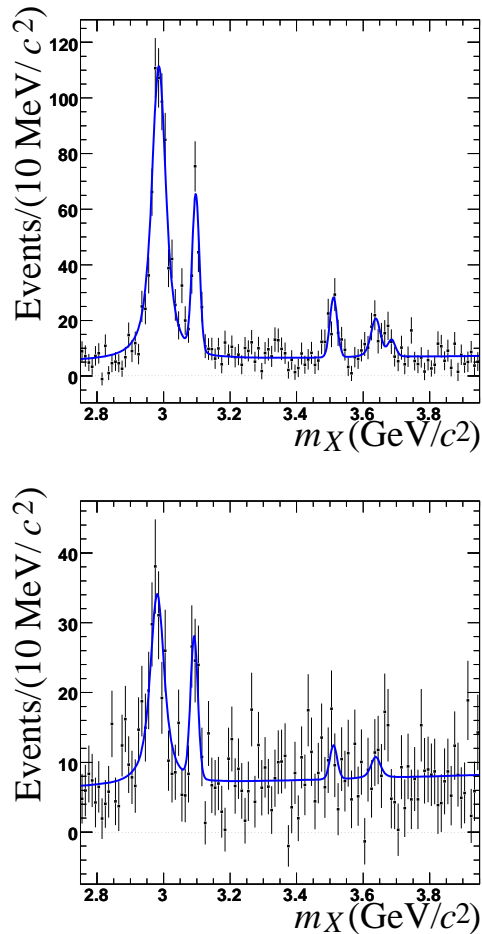


FIG. 2: Fit result (solid line) superimposed on the  $m_{ES}$ -sideband-subtracted  $m_X$  distribution (points with error bars) for  $B^+ \rightarrow (K\bar{K}\pi)K^+$  (top) and  $B^0 \rightarrow (K\bar{K}\pi)K^{*0}$  (bottom).

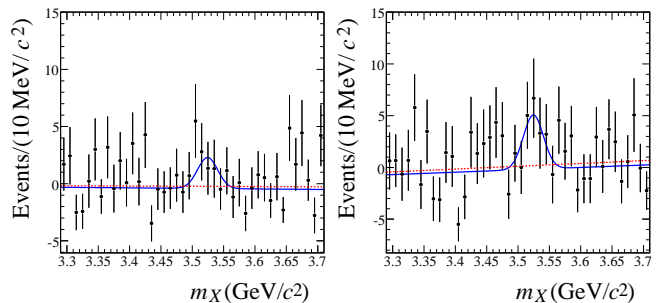


FIG. 3: Fit result (solid line) superimposed on the  $m_{ES}$ -sideband-subtracted  $m_X$  distribution (points with error bars) for  $B^+ \rightarrow \eta_c\gamma K^+$  (left) and  $B^0 \rightarrow \eta_c\gamma K^{*0}$  (right). No significant  $h_c$  signal is evident. The dashed line is the result of the fit with no signal component.

parameters of the distributions are set to their fixed or fitted values. The fit is repeated under the same conditions as used on real data. The numbers of signal and

background events are distributed as expected. The robustness of the fit is tested on simulated events by varying the numbers of signal and background events input, including the null result. The numbers of events returned by the fit are consistent with the inputs for all cases. As additional cross-checks, we verify that the observed numbers of  $J/\psi$ ,  $\chi_{c1}$  and  $\psi(2S)$  candidates in the data agree with the expectations.

We evaluate systematic uncertainties on the numbers of signal candidates and the mass and width determination by individually varying the parameters that are fixed in the fits by  $\pm 1$  standard deviation from their nominal values. We also estimate the systematic uncertainties that arise from a different choice of binning, fit range, and background parameterization. For  $B^+ \rightarrow (K\bar{K}\pi)K^+$  and  $B^0 \rightarrow (K\bar{K}\pi)K^{*0}$ , where the mass resolutions are floated, we estimate an additional systematic uncertainty by taking the variations with respect to a fit performed by fixing the mass resolutions to the values determined from the simulation, 8 MeV/ $c^2$  and 19 MeV/ $c^2$  for  $K_S^0 K^\pm \pi^\mp$  and  $K^+ K^- \pi^0$ , respectively. The large natural widths of the  $\eta_c$  and  $\eta_c(2S)$  introduce the possibility of interference effects with non-resonant  $B$  decays to the same final state particles. This can modify the  $m_X$  distribution with respect to the one used in the fit. The fit is repeated including an interference term between the  $\eta_c$  and the background in the fitting functions. The amplitude and phase of the interference term are left free in the fit. The variation of the  $\eta_c$  yield with respect to the nominal fit is taken as an estimate of the systematic error due to neglecting interference effects. A similar approach is undertaken for  $\eta_c(2S)$ . Summing in quadrature all the contributions, the total systematic uncertainty on the signal yield determination is 6%, 3%, 25%, 18%, 25% and 23% for  $B^+ \rightarrow \eta_c K^+$ ,  $B^0 \rightarrow \eta_c K^{*0}$ ,  $B^+ \rightarrow h_c K^+$ ,  $B^0 \rightarrow h_c K^{*0}$ ,  $B^+ \rightarrow \eta_c(2S)K^+$  and  $B^0 \rightarrow \eta_c(2S)K^{*0}$ , respectively, and the total systematic uncertainties on the  $\eta_c$  mass and width are 3.1 MeV/ $c^2$  and 4.4 MeV, respectively.

The selection efficiency for  $B^+ \rightarrow \eta_c K^+$  is 6%. The ratios of the selection efficiencies with respect to  $B^+ \rightarrow \eta_c K^+$ , estimated by using simulated events, are, including systematic uncertainties,  $0.64 \pm 0.01$ ,  $0.51 \pm 0.01$ ,  $0.29 \pm 0.02$ ,  $0.84 \pm 0.01$  and  $0.54 \pm 0.01$  for  $B^0 \rightarrow \eta_c K^{*0}$ ,  $B^+ \rightarrow h_c K^+$ ,  $B^0 \rightarrow h_c K^{*0}$ ,  $B^+ \rightarrow \eta_c(2S)K^+$  and  $B^0 \rightarrow \eta_c(2S)K^{*0}$ , respectively. Most uncertainties on the efficiencies cancel out in the ratios because of the similar final states. The remaining uncertainties are mainly due to differences between real data and simulation in the photon reconstruction as estimated from photon control samples from data (1.8%), and the unknown polarization for  $B^0 \rightarrow h_c K^{*0}$  estimated as in [14] (6%).

As a check, using the signal efficiency computed from MC events, the signal yield observed in data, and the number of  $B\bar{B}$  pairs in the data sample, we derive  $\mathcal{B}(B^+ \rightarrow \eta_c K^+) \times \mathcal{B}(\eta_c \rightarrow K\bar{K}\pi) = (8.0 \pm 0.4(\text{stat})) \times$

$10^{-5}$ . This is in agreement with the world average value of  $(6.4 \pm 1.4) \times 10^{-5}$  [1].

We calculate the ratios of the branching fractions with respect to  $\mathcal{B}(B^+ \rightarrow \eta_c K^+)$  using the ratios of signal yields and efficiencies with respect to  $B^+ \rightarrow \eta_c K^+$ ,  $R_{\Upsilon} = \Gamma(\Upsilon(4S) \rightarrow B^+ B^-) / \Gamma(\Upsilon(4S) \rightarrow B^0 \bar{B}^0) = 1.026 \pm 0.032$  [1], and  $\mathcal{B}(K^{*0} \rightarrow K^+ \pi^-) = 2/3$ , and summing the uncertainties in quadrature. We define  $R_{\eta_c K^*} = \mathcal{B}(B^0 \rightarrow \eta_c K^{*0}) / \mathcal{B}(B^+ \rightarrow \eta_c K^+)$ ,  $R_{h_c K} = \mathcal{B}(B^+ \rightarrow h_c K^+) \times \mathcal{B}(h_c \rightarrow \eta_c \gamma) / \mathcal{B}(B^+ \rightarrow \eta_c K^+)$ ,  $R_{h_c K^*} = \mathcal{B}(B^0 \rightarrow h_c K^{*0}) \times \mathcal{B}(h_c \rightarrow \eta_c \gamma) / \mathcal{B}(B^+ \rightarrow \eta_c K^+)$ ,  $R_{\eta_c(2S)K} = \mathcal{B}(B^+ \rightarrow \eta_c(2S)K^+) \times \mathcal{B}(\eta_c(2S) \rightarrow K\bar{K}\pi) / (\mathcal{B}(B^+ \rightarrow \eta_c K^+) \times \mathcal{B}(\eta_c \rightarrow K\bar{K}\pi))$  and  $R_{\eta_c(2S)K^*} = \mathcal{B}(B^0 \rightarrow \eta_c(2S)K^{*0}) / \mathcal{B}(B^+ \rightarrow \eta_c(2S)K^+)$ . Table II summarizes the systematic uncertainties on the measurements.

We obtain  $R_{\eta_c K^*} = 0.62 \pm 0.06(\text{stat}) \pm 0.05(\text{syst})$ ,  $R_{\eta_c(2S)K} = 0.096_{-0.019}^{+0.020}(\text{stat}) \pm 0.025(\text{syst})$  and the 90% C.L. upper limits  $R_{h_c K} < 0.052$ ,  $R_{h_c K^*} < 0.236$ , and  $R_{\eta_c(2S)K^*} < 1.0$ . These are determined by assuming that each measurement follows a Gaussian distribution around the central value, with standard deviation given by the statistical and systematic uncertainties added in quadrature.

TABLE II: Summary of the relative contributions to the systematic errors on  $R_{\eta_c K^*}$ ,  $R_{h_c K}$ ,  $R_{h_c K^*}$ ,  $R_{\eta_c(2S)K}$  and  $R_{\eta_c(2S)K^*}$ .

	$\sigma(R)/R$ (%)				
	$R_{\eta_c K^*}$	$R_{h_c K}$	$R_{h_c K^*}$	$R_{\eta_c(2S)K}$	$R_{\eta_c(2S)K^*}$
Signal yield	6.6	26	19	26	34
Signal efficiency	1.4	2.2	6.7	1.3	2.2
$R_{\Upsilon}$	3.1	—	3.1	—	3.1
Total	7.2	26	20	26	34

Using  $\mathcal{B}(B^+ \rightarrow \eta_c K^+) = (9.1 \pm 1.3) \times 10^{-4}$ , we derive  $\mathcal{B}(B^0 \rightarrow \eta_c K^{*0}) = (5.7 \pm 0.6(\text{stat}) \pm 0.4(\text{syst}) \pm 0.8(\text{br})) \times 10^{-4}$ ,

where the last error is from the uncertainty on  $\mathcal{B}(B^+ \rightarrow \eta_c K^+)$ , and the 90% C.L. upper limits

$$\begin{aligned} \mathcal{B}(B^+ \rightarrow h_c K^+) \times \mathcal{B}(h_c \rightarrow \eta_c \gamma) &< 4.8 \times 10^{-5}, \\ \mathcal{B}(B^0 \rightarrow h_c K^{*0}) \times \mathcal{B}(h_c \rightarrow \eta_c \gamma) &< 2.2 \times 10^{-4}. \end{aligned}$$

Using the world average value  $\mathcal{B}(B^+ \rightarrow \eta_c(2S)K^+) = (3.4 \pm 1.8) \times 10^{-4}$  [1], we derive

$$\mathcal{B}(B^0 \rightarrow \eta_c(2S)K^{*0}(890)) < 3.9 \times 10^{-4},$$

at the 90% C.L. Finally, using  $\mathcal{B}(B^+ \rightarrow \eta_c K^+) \times \mathcal{B}(\eta_c \rightarrow K\bar{K}\pi) = (6.88 \pm 0.77_{-0.66}^{+0.55}) \times 10^{-5}$  [15], we derive

$$\mathcal{B}(\eta_c(2S) \rightarrow K\bar{K}\pi) = (1.9 \pm 0.4(\text{stat}) \pm 0.5(\text{syst}) \pm 1.0(\text{br}))\%,$$

where the last error accounts for the uncertainties on the branching fractions used in the calculation.

In summary, we obtain a measurement of  $\mathcal{B}(B^0 \rightarrow \eta_c K^{*0})$  in agreement with, and greatly improving upon, the previous world average value [1]. We obtain an upper limit for  $\mathcal{B}(B^+ \rightarrow h_c K^+) \times \mathcal{B}(h_c \rightarrow \eta_c \gamma)$  in agreement with the previous Belle result [8], first upper limits on  $\mathcal{B}(B^0 \rightarrow \eta_c(2S)K^{*0})$  and  $\mathcal{B}(B^0 \rightarrow h_c K^{*0}) \times \mathcal{B}(h_c \rightarrow \eta_c \gamma)$ , and a first measurement of  $\mathcal{B}(\eta_c(2S) \rightarrow K \bar{K} \pi)$ . We measure  $m(\eta_c) = 2985.8 \pm 1.5 \pm 3.1$  MeV/ $c^2$  and  $\Gamma(\eta_c) = 36.3_{-3.6}^{+3.7} \pm 4.4$  MeV. These are in agreement with previous *BABAR* measurements from  $\gamma\gamma$  collisions [16] and slightly higher than the world average values [1].

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<sup>†</sup> Now at Temple University, Philadelphia, Pennsylvania 19122, USA

<sup>‡</sup> Now at Tel Aviv University, Tel Aviv, 69978, Israel

<sup>§</sup> Also with Università di Perugia, Dipartimento di Fisica, Perugia, Italy

<sup>¶</sup> Also with Università di Sassari, Sassari, Italy

- [1] W.-M. Yao *et al.* (Particle Data Group), *J. Phys. G* **33**, 1 (2006) and 2007 partial update for the 2008 edition.
- [2] G. T. Bodwin, E. Braaten and G. P. Lepage, *Phys. Rev. D* **51**, 1125 (1995).
- [3] Charge conjugated modes are implied throughout.
- [4] CLEO Collaboration, P. Rubin *et al.*, *Phys. Rev. D* **72**, 092004 (2005).
- [5] E835 Collaboration, M. Andreotti *et al.*, *Phys. Rev. D* **72**, 032001 (2005).
- [6] Belle Collaboration, S.-K. Choi *et al.*, *Phys. Rev. Lett.* **89**, 102001 (2002).
- [7] From the value reported in [1] rescaled using the new world average for  $\mathcal{B}(\eta_c \rightarrow K \bar{K} \pi)$ , again from [1].
- [8] Belle Collaboration, F. Fang *et al.*, *Phys. Rev. D* **74**, 012007 (2006).
- [9] *BABAR* Collaboration, B. Aubert *et al.*, *Nucl. Instrum. Methods Phys. Res., Sect. A* **479**, 1 (2002).
- [10] S. Agostinelli *et al.*, *Nucl. Instrum. Methods Phys. Res., Sect. A* **506**, 250 (2003).
- [11] G. C. Fox and S. Wolfram, *Phys. Rev. Lett.* **41**, 1581 (1978).
- [12] The ARGUS function is zero above  $m_0 = E_{\text{beam}}$ , and it is  $m_{\text{ES}} e^{\phi t} \sqrt{t}$  below, where  $t = 1 - (m_{\text{ES}}/m_0)^2$ . ARGUS Collaboration, H. Albrecht *et al.*, *Z. Phys. C* **48**, 543 (1990).
- [13] In MC events, the total width of the  $h_c$  meson is 1 MeV.
- [14] *BABAR* Collaboration, B. Aubert *et al.*, *Phys. Rev. Lett.* **94**, 171801 (2005).
- [15] Belle Collaboration, F. Fang *et al.*, *Phys. Rev. Lett.* **90**, 071801 (2003). To avoid correlations, the world averages of  $\mathcal{B}(B^+ \rightarrow \eta_c K^+)$  and  $\mathcal{B}(\eta_c \rightarrow K \bar{K} \pi)$  reported in [1] are not used since they are mostly based on *BABAR* results obtained from a subset of the data used here.
- [16] *BABAR* Collaboration, B. Aubert *et al.*, *Phys. Rev. Lett.* **92**, 142002 (2004).

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