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### Authors

Aubert, B  
Bona, M  
Boutigny, D  
[et al.](#)

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Search for neutral  $B$ -meson decays to  $a_0\pi$ ,  $a_0K$ ,  $\eta\rho^0$ , and  $\eta f_0$ 

B. Aubert,<sup>1</sup> M. Bona,<sup>1</sup> D. Boutigny,<sup>1</sup> Y. Karyotakis,<sup>1</sup> J. P. Lees,<sup>1</sup> V. Poireau,<sup>1</sup> X. Prudent,<sup>1</sup> V. Tisserand,<sup>1</sup> A. Zghiche,<sup>1</sup> J. Garra Tico,<sup>2</sup> E. Grauges,<sup>2</sup> L. Lopez,<sup>3</sup> A. Palano,<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> Y. Groyzman,<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> D. Lopes Pegna,<sup>5</sup> G. Lynch,<sup>5</sup> L. M. Mir,<sup>5</sup> T. J. Orimoto,<sup>5</sup> M. T. Ronan,<sup>5,\*</sup> K. Tackmann,<sup>5</sup> W. A. Wenzel,<sup>5</sup> P. del Amo Sanchez,<sup>6</sup> C. M. Hawkes,<sup>6</sup> A. T. Watson,<sup>6</sup> T. Held,<sup>7</sup> H. Koch,<sup>7</sup> B. Lewandowski,<sup>7</sup> M. Pelizaeus,<sup>7</sup> T. Schroeder,<sup>7</sup> M. Steinke,<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> N. S. Knecht,<sup>9</sup> T. S. Mattison,<sup>9</sup> J. A. McKenna,<sup>9</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> 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> S. D. Foulkes,<sup>14</sup> J. W. Gary,<sup>14</sup> F. Liu,<sup>14</sup> O. Long,<sup>14</sup> B. C. Shen,<sup>14</sup> L. Zhang,<sup>14</sup> H. P. Paar,<sup>15</sup> S. Rahatlou,<sup>15</sup> V. Sharma,<sup>15</sup> J. W. Berryhill,<sup>16</sup> C. Campagnari,<sup>16</sup> A. Cunha,<sup>16</sup> B. Dahmes,<sup>16</sup> T. M. Hong,<sup>16</sup> D. Kovalskyi,<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> D. C. Williams,<sup>17</sup> M. G. Wilson,<sup>17</sup> L. O. Winstrom,<sup>17</sup> E. Chen,<sup>18</sup> C. H. Cheng,<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> G. Mancinelli,<sup>19</sup> B. T. Meadows,<sup>19</sup> K. Mishra,<sup>19</sup> M. D. Sokoloff,<sup>19</sup> J. Becker,<sup>20</sup> F. Blanc,<sup>20</sup> P. C. Bloom,<sup>20</sup> S. Chen,<sup>20</sup> W. T. Ford,<sup>20</sup> J. Hachtel,<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> J. Zhang,<sup>20</sup> A. M. Gabareen,<sup>21</sup> A. Soffer,<sup>21</sup> W. H. Toki,<sup>21</sup> R. J. Wilson,<sup>21</sup> F. Winklmeier,<sup>21</sup> Q. Zeng,<sup>21</sup> D. D. Altenburg,<sup>22</sup> E. Feltresi,<sup>22</sup> A. Hauke,<sup>22</sup> H. Jasper,<sup>22</sup> J. Merkel,<sup>22</sup> A. Petzold,<sup>22</sup> B. Spaan,<sup>22</sup> K. Wacker,<sup>22</sup> T. Brandt,<sup>23</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> J. Schubert,<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> V. Lombardo,<sup>24</sup> Ch. Thiebaux,<sup>24</sup> M. Verderi,<sup>24</sup> P. J. Clark,<sup>25</sup> W. Gradl,<sup>25</sup> F. Muheim,<sup>25</sup> S. Playfer,<sup>25</sup> A. I. Robertson,<sup>25</sup> Y. Xie,<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> E. Prencipe,<sup>26</sup> V. Santoro,<sup>26</sup> F. Anulli,<sup>27</sup> R. Baldini-Ferroli,<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> J. Wu,<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> R. L. Flack,<sup>31</sup> J. A. Nash,<sup>31</sup> M. B. Nikolich,<sup>31</sup> W. Panduro Vazquez,<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> N. T. Meyer,<sup>32</sup> V. Ziegler,<sup>32</sup> J. Cochran,<sup>33</sup> H. B. Crawley,<sup>33</sup> L. Dong,<sup>33</sup> V. Eyges,<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> 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> M. Davier,<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> S. Rodier,<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> C. A. Chavez,<sup>38</sup> I. J. Forster,<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> K. C. Schofield,<sup>38</sup> C. Touramanis,<sup>38</sup> A. J. Bevan,<sup>39</sup> F. Di Lodovico,<sup>39</sup> K. A. George,<sup>39</sup> W. Menges,<sup>39</sup> R. Sacco,<sup>39</sup> G. Cowan,<sup>40</sup> H. U. Flaecher,<sup>40</sup> D. A. Hopkins,<sup>40</sup> P. S. Jackson,<sup>40</sup> T. R. McMahon,<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> J. Allison,<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> G. Blaylock,<sup>44</sup> C. Dallapiccola,<sup>44</sup> S. S. Hertzbach,<sup>44</sup> X. Li,<sup>44</sup> T. B. Moore,<sup>44</sup> E. Salvati,<sup>44</sup> S. Saremi,<sup>44</sup> R. Cowan,<sup>45</sup> P. H. Fisher,<sup>45</sup> G. Sciolla,<sup>45</sup> S. J. Sekula,<sup>45</sup> M. Spitznagel,<sup>45</sup> F. Taylor,<sup>45</sup> R. K. Yamamoto,<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> 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> F. Fabozzi,<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> J. M. LoSecco,<sup>53</sup> G. Benelli,<sup>54</sup> L. A. Corwin,<sup>54</sup> K. K. Gan,<sup>54</sup> K. Honscheid,<sup>54</sup> D. Hufnagel,<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> R. Ter-Antonyan,<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> N. Gagliardi,<sup>56</sup> A. Gaz,<sup>56</sup> M. Margoni,<sup>56</sup> M. Morandin,<sup>56</sup> A. Pompili,<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> 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> Ch. de la Vaissière,<sup>57</sup> O. Hamon,<sup>57</sup> Ph. Leruste,<sup>57</sup> J. Malclès,<sup>57</sup> J. Ocariz,<sup>57</sup> A. Perez,<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>

R. Cenci,<sup>60</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. A. Mazur,<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> M. Haire,<sup>61</sup> J. Biesiada,<sup>62</sup> P. Elmer,<sup>62</sup> Y. P. Lau,<sup>62</sup> C. Lu,<sup>62</sup> J. Olsen,<sup>62</sup> A. J. S. Smith,<sup>62</sup> A. V. Telnov,<sup>62</sup> E. Baracchini,<sup>63</sup> F. Bellini,<sup>63</sup> G. Cavoto,<sup>63</sup> A. D’Orazio,<sup>63</sup> D. del Re,<sup>63</sup> E. Di Marco,<sup>63</sup> R. Faccini,<sup>63</sup> F. Ferrarotto,<sup>63</sup> F. Ferroni,<sup>63</sup> M. Gaspero,<sup>63</sup> P. D. Jackson,<sup>63</sup> L. Li Gioi,<sup>63</sup> M. A. Mazzoni,<sup>63</sup> S. Morganti,<sup>63</sup> G. Piredda,<sup>63</sup> F. Polci,<sup>63</sup> F. Renga,<sup>63</sup> C. Voena,<sup>63</sup> M. Ebert,<sup>64</sup> H. Schröder,<sup>64</sup> R. Waldi,<sup>64</sup> T. Adye,<sup>65</sup> G. Castelli,<sup>65</sup> B. Franek,<sup>65</sup> E. O. Olaiya,<sup>65</sup> S. Ricciardi,<sup>65</sup> W. Roethel,<sup>65</sup> F. F. Wilson,<sup>65</sup> R. Aleksan,<sup>66</sup> S. Emery,<sup>66</sup> M. Escalier,<sup>66</sup> A. Gaidot,<sup>66</sup> S. F. Ganzhur,<sup>66</sup> G. Hamel de Monchenault,<sup>66</sup> W. Kozanecki,<sup>66</sup> M. Legendre,<sup>66</sup> G. Vasseur,<sup>66</sup> Ch. Yèche,<sup>66</sup> M. Zito,<sup>66</sup> X. R. Chen,<sup>67</sup> H. Liu,<sup>67</sup> W. Park,<sup>67</sup> M. V. Purohit,<sup>67</sup> J. R. Wilson,<sup>67</sup> M. T. Allen,<sup>68</sup> D. Aston,<sup>68</sup> R. Bartoldus,<sup>68</sup> P. Bechtle,<sup>68</sup> N. Berger,<sup>68</sup> R. Claus,<sup>68</sup> J. P. Coleman,<sup>68</sup> M. R. Convery,<sup>68</sup> J. C. Dingfelder,<sup>68</sup> J. Dorfan,<sup>68</sup> G. P. Dubois-Felsmann,<sup>68</sup> D. Dujmic,<sup>68</sup> W. Dunwoodie,<sup>68</sup> R. C. Field,<sup>68</sup> T. Glanzman,<sup>68</sup> S. J. Gowdy,<sup>68</sup> M. T. Graham,<sup>68</sup> P. Grenier,<sup>68</sup> C. Hast,<sup>68</sup> T. Hryn’ova,<sup>68</sup> W. R. Innes,<sup>68</sup> J. Kaminski,<sup>68</sup> M. H. Kelsey,<sup>68</sup> H. Kim,<sup>68</sup> P. Kim,<sup>68</sup> M. L. Kocian,<sup>68</sup> D. W. G. S. Leith,<sup>68</sup> S. Li,<sup>68</sup> S. Luitz,<sup>68</sup> V. Luth,<sup>68</sup> H. L. Lynch,<sup>68</sup> D. B. MacFarlane,<sup>68</sup> H. Marsiske,<sup>68</sup> R. Messner,<sup>68</sup> D. R. Muller,<sup>68</sup> C. P. O’Grady,<sup>68</sup> I. Ofte,<sup>68</sup> A. Perazzo,<sup>68</sup> M. Perl,<sup>68</sup> T. Pulliam,<sup>68</sup> B. N. Ratcliff,<sup>68</sup> A. Roodman,<sup>68</sup> A. A. Salnikov,<sup>68</sup> R. H. Schindler,<sup>68</sup> J. Schwiening,<sup>68</sup> A. Snyder,<sup>68</sup> J. Stelzer,<sup>68</sup> D. Su,<sup>68</sup> M. K. Sullivan,<sup>68</sup> K. Suzuki,<sup>68</sup> S. K. Swain,<sup>68</sup> J. M. Thompson,<sup>68</sup> J. Va’vra,<sup>68</sup> N. van Bakel,<sup>68</sup> A. P. Wagner,<sup>68</sup> M. Weaver,<sup>68</sup> W. J. Wisniewski,<sup>68</sup> M. Wittgen,<sup>68</sup> D. H. Wright,<sup>68</sup> A. K. Yarritu,<sup>68</sup> K. Yi,<sup>68</sup> C. C. Young,<sup>68</sup> P. R. Burchat,<sup>69</sup> A. J. Edwards,<sup>69</sup> S. A. Majewski,<sup>69</sup> B. A. Petersen,<sup>69</sup> L. Wilden,<sup>69</sup> S. Ahmed,<sup>70</sup> M. S. Alam,<sup>70</sup> R. Bula,<sup>70</sup> J. A. Ernst,<sup>70</sup> V. Jain,<sup>70</sup> B. Pan,<sup>70</sup> M. A. Saeed,<sup>70</sup> F. R. Wappler,<sup>70</sup> S. B. Zain,<sup>70</sup> W. Bugg,<sup>71</sup> M. Krishnamurthy,<sup>71</sup> S. M. Spanier,<sup>71</sup> R. Eckmann,<sup>72</sup> J. L. Ritchie,<sup>72</sup> A. M. Ruland,<sup>72</sup> C. J. Schilling,<sup>72</sup> R. F. Schwitters,<sup>72</sup> J. M. Izen,<sup>73</sup> X. C. Lou,<sup>73</sup> S. Ye,<sup>73</sup> F. Bianchi,<sup>74</sup> F. Gallo,<sup>74</sup> D. Gamba,<sup>74</sup> M. Pelliccioni,<sup>74</sup> M. Bomben,<sup>75</sup> L. Bosisio,<sup>75</sup> C. Cartaro,<sup>75</sup> F. Cossutti,<sup>75</sup> G. Della Ricca,<sup>75</sup> L. Lanceri,<sup>75</sup> L. Vitale,<sup>75</sup> V. Azzolini,<sup>76</sup> N. Lopez-March,<sup>76</sup> F. Martinez-Vidal,<sup>76</sup> D. A. Milanes,<sup>76</sup> A. Oyanguren,<sup>76</sup> J. Albert,<sup>77</sup> Sw. Banerjee,<sup>77</sup> B. Bhuyan,<sup>77</sup> K. Hamano,<sup>77</sup> R. Kowalewski,<sup>77</sup> I. M. Nugent,<sup>77</sup> J. M. Roney,<sup>77</sup> R. J. Sobie,<sup>77</sup> J. J. Back,<sup>78</sup> P. F. Harrison,<sup>78</sup> T. E. Latham,<sup>78</sup> G. B. Mohanty,<sup>78</sup> M. Pappagallo,<sup>78</sup> H. R. Band,<sup>79</sup> X. Chen,<sup>79</sup> S. Dasu,<sup>79</sup> K. T. Flood,<sup>79</sup> J. J. Hollar,<sup>79</sup> P. E. Kutter,<sup>79</sup> Y. Pan,<sup>79</sup> M. Pierini,<sup>79</sup> R. Prepost,<sup>79</sup> S. L. Wu,<sup>79</sup> Z. Yu,<sup>79</sup> and H. Neal<sup>80</sup>

(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>Facultat de Física, Departament ECM, Universitat de Barcelona, E-08028 Barcelona, Spain

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

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

<sup>5</sup>Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA  
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 I, 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>Universität Dortmund, Institut für 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>Dipartimento di Fisica and INFN, Università di Ferrara, I-44100 Ferrara, Italy

<sup>27</sup>Laboratori Nazionali di Frascati dell’INFN, I-00044 Frascati, Italy

<sup>28</sup>Dipartimento di Fisica and INFN, Università di Genova, 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>Dipartimento di Fisica and INFN, Università di Milano, 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>Dipartimento di Scienze Fisiche and INFN, Università di Napoli Federico II, 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>Dipartimento di Fisica and INFN, Università di Padova, I-35131 Padova, Italy
- <sup>57</sup>Laboratoire de Physique Nucléaire et de Hautes Energies, IN2P3/CNRS, Université Pierre et Marie Curie-Paris6, F-75252 Paris, France and Université Denis Diderot-Paris7, F-75252 Paris, France
- <sup>58</sup>University of Pennsylvania, Philadelphia, Pennsylvania 19104, USA
- <sup>59</sup>Dipartimento di Fisica and INFN, Università di Perugia, I-06100 Perugia, Italy
- <sup>60</sup>Dipartimento di Fisica, Scuola Normale Superiore and INFN, Università di Pisa, I-56127 Pisa, Italy
- <sup>61</sup>Prairie View A&M University, Prairie View, Texas 77446, USA
- <sup>62</sup>Princeton University, Princeton, New Jersey 08544, USA
- <sup>63</sup>Dipartimento di Fisica and INFN, Università di Roma La Sapienza, I-00185 Roma, Italy
- <sup>64</sup>Universität Rostock, D-18051 Rostock, Germany
- <sup>65</sup>Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, OX11 0QX, United Kingdom
- <sup>66</sup>DSM/Dapnia, CEA/Saclay, F-91191 Gif-sur-Yvette, France
- <sup>67</sup>University of South Carolina, Columbia, South Carolina 29208, USA
- <sup>68</sup>Stanford Linear Accelerator Center, Stanford, California 94309, USA
- <sup>69</sup>Stanford University, Stanford, California 94305-4060, USA
- <sup>70</sup>State University of New York, Albany, New York 12222, USA
- <sup>71</sup>University of Tennessee, Knoxville, Tennessee 37996, USA
- <sup>72</sup>University of Texas at Austin, Austin, Texas 78712, USA
- <sup>73</sup>University of Texas at Dallas, Richardson, Texas 75083, USA
- <sup>74</sup>Dipartimento di Fisica Sperimentale and INFN, Università di Torino, I-10125 Torino, Italy
- <sup>75</sup>Dipartimento di Fisica and INFN, Università di Trieste, I-34127 Trieste, Italy
- <sup>76</sup>IFIC, Universitat de Valencia-CSIC, E-46071 Valencia, Spain
- <sup>77</sup>University of Victoria, Victoria, British Columbia, Canada V8W 3P6
- <sup>78</sup>Department of Physics, University of Warwick, Coventry CV4 7AL, United Kingdom
- <sup>79</sup>University of Wisconsin, Madison, Wisconsin 53706, USA
- <sup>80</sup>Yale University, New Haven, Connecticut 06511, USA

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\* Deceased.

† Also with Università di Perugia, Dipartimento di Fisica, Perugia, Italy.

‡ Also with Università della Basilicata, Potenza, Italy.

§ Also with IPPP, Physics Department, Durham University, Durham DH1 3LE, United Kingdom.

We present a search for  $B^0$  decays to charmless final states involving an  $\eta$  meson, a charged pion, and a second charged pion or kaon. The data sample corresponds to  $383 \times 10^6$   $B\bar{B}$  pairs collected with the BABAR detector operating at the PEP-II asymmetric-energy  $B$  factory at SLAC. We find no significant signals and determine the following 90% C.L. upper limits:  $\mathcal{B}(B^0 \rightarrow a_0^- \pi^+) \times \mathcal{B}(a_0^- \rightarrow \eta \pi^-) < 3.1 \times 10^{-6}$ ,  $\mathcal{B}(B^0 \rightarrow a_0^- K^+) \times \mathcal{B}(a_0^- \rightarrow \eta \pi^-) < 1.9 \times 10^{-6}$ ,  $\mathcal{B}(B^0 \rightarrow a_0(1450)^- \pi^+) \times \mathcal{B}(a_0(1450)^- \rightarrow \eta \pi^-) < 2.3 \times 10^{-6}$ ,  $\mathcal{B}(B^0 \rightarrow a_0(1450)^- K^+) \times \mathcal{B}(a_0(1450)^- \rightarrow \eta \pi^-) < 3.1 \times 10^{-6}$ ,  $\mathcal{B}(B^0 \rightarrow \eta \rho^0) < 1.5 \times 10^{-6}$ , and  $\mathcal{B}(B^0 \rightarrow \eta f_0(980)) \times \mathcal{B}(f_0(980) \rightarrow \pi^+ \pi^-) < 0.4 \times 10^{-6}$ .

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We investigate the decays of a  $B^0$  meson to final states with an  $\eta$  meson, a charged pion, and either a second charged pion or kaon. The Dalitz plots for the decays without an intermediate charmed meson are expected to have contributions from quasi-two-body decays such as  $B^0 \rightarrow a_0^- \pi^+$ ,  $B^0 \rightarrow a_0^- K^+$ ,  $B^0 \rightarrow \eta \rho^0$ ,  $B^0 \rightarrow \eta f_0$ , and  $B^0 \rightarrow \eta K^{*0}$  [1]. The last of these has been investigated recently [2] so in this paper we concentrate on the others, where  $a_0$  is either  $a_0(980)$  or  $a_0(1450)$  and  $f_0$  is  $f_0(980)$ . Measurements of  $B$  decays involving a scalar meson are interesting since they provide information on such  $B$  decays and the nature of scalar mesons. Several  $B$  decays involving scalar mesons have been observed, either with an  $f_0(980)$  [3,4] or  $K^*(1430)$  [2,3,5] in the final state.

Specific predictions can be made for the decays  $B \rightarrow a_0 \pi$  if factorization is assumed and if the decay involves only tree or penguin (loop) processes. The dominant amplitude is shown in Fig. 1(a). The companion tree amplitude, shown in Fig. 1(b), is expected to be greatly suppressed, since, neglecting light-quark mass splittings, the virtual  $W$  cannot produce an  $a_0$  meson [6]. This is a firm prediction of the standard model because the weak current has a  $G$ -parity even vector part and a  $G$ -parity odd

axial-vector part. The latter can produce an axial-vector or pseudoscalar particle while the former produces a vector particle, but neither can produce a  $G$ -parity odd scalar meson (e.g.  $a_0$ ). Thus the decay  $B \rightarrow a_0 \pi^\pm$  is expected to be “self-tagging”—the pion charge specifies the  $B$  flavor. Penguin processes such as shown in Fig. 1(c) are allowed, but are suppressed relative to the tree processes. The decays with a kaon in the final state should be dominated by the penguin processes [Fig. 1(c)], though there is a cancellation between two terms in the penguin amplitudes for these decays [7].

The theoretical expectations for these decays with an  $a_0(980)$  meson [7–10] are larger than previous experimental limits [11]. The decays with a  $\rho^0$  meson are expected to have branching fractions  $\leq 1 \times 10^{-7}$  [12] since they are dominated by color-suppressed tree amplitudes [Fig. 1(d)]. There are no predictions for the decay  $B^0 \rightarrow \eta f_0$ , but it should have a small branching fraction for the same reason.

The nature of the  $a_0$  meson is not well understood. It is thought to be a  $q\bar{q}$  state with a possible admixture of a  $K\bar{K}$  bound-state component due to the proximity to the  $K\bar{K}$  threshold [13,14]. The  $a_0$  mass is known to be about 985 MeV with a width of  $71 \pm 7$  MeV [15] for the dominant  $a_0 \rightarrow \eta \pi$  decay mode [13]. The  $a_0(1450)$  has a measured width of 265 MeV [13]. Since the branching fraction for  $a_0 \rightarrow \eta \pi$  is not well known, we report the product branching fraction  $\mathcal{B}(B^0 \rightarrow a_0^- X^+) \times \mathcal{B}(a_0^- \rightarrow \eta \pi)$ , where  $X$  indicates  $K$  or  $\pi$ . The properties of the  $f_0(980)$  meson are well measured for the  $\pi^+ \pi^-$  channel that is used in this analysis [16].

Only limits for the following decays have been reported previously:  $B^0 \rightarrow a_0(980)^- \pi^+$  and  $B^0 \rightarrow a_0(980)^- K^+$  [11] and  $B^0 \rightarrow \eta \rho^0$  [17–19]. There have been no previous searches for  $B^0 \rightarrow \eta f_0$  or the decays with an  $a_0(1450)$ . The results presented here are based on data collected with the BABAR detector [20] at the PEP-II asymmetric-energy  $e^+ e^-$  collider located at the Stanford Linear Accelerator Center. An integrated luminosity of approximately  $347 \text{ fb}^{-1}$ , corresponding to  $383 \times 10^6$   $B\bar{B}$  pairs, was recorded at the  $\Upsilon(4S)$  resonance (center-of-mass energy  $\sqrt{s} = 10.58 \text{ GeV}$ ).

The track parameters of charged particles are measured by a combination of a silicon vertex tracker, with five layers of double-sided silicon sensors, and a 40-layer central drift chamber, both operating in the 1.5 T magnetic field of a superconducting solenoid. We identify photons

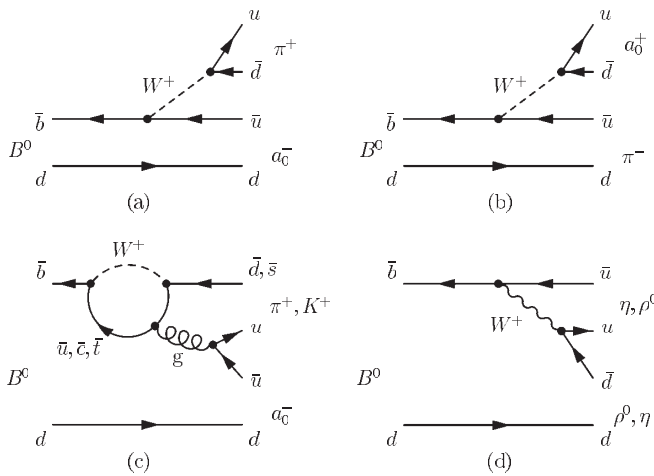


FIG. 1. Feynman diagrams for decays involving charged  $a_0$  mesons: (a) dominant and (b)  $G$ -parity-suppressed tree diagrams for  $B^0 \rightarrow a_0^\pm \pi^\pm$ , (c) penguin diagram for  $B^0 \rightarrow a_0^\pm \pi^\pm$  and  $B^0 \rightarrow a_0^- K^+$  [a tree diagram similar to (a) also contributes to  $B^0 \rightarrow a_0^- K^+$ ], (d) tree diagrams for  $B^0 \rightarrow \eta \rho^0$  ( $B^0 \rightarrow \eta f_0$  is similar with the  $\rho^0$  being replaced by a  $f_0$ ).

and electrons using a CsI(Tl) electromagnetic calorimeter (EMC). Further charged particle identification (PID) is provided by measurements of the average energy loss ( $dE/dx$ ) in the tracking devices and by an internally reflecting, ring-imaging Cherenkov detector (DIRC) covering the central region.

We select  $a_0$  candidates from the decay channel  $a_0 \rightarrow \eta\pi$  with the decays  $\eta \rightarrow \gamma\gamma$  ( $\eta_{\gamma\gamma}$ ) and  $\eta \rightarrow \pi^+\pi^-\pi^0$  ( $\eta_{3\pi}$ ). All charged tracks are required to originate from a common vertex. For the decays  $B^0 \rightarrow \eta\rho^0$  and  $B^0 \rightarrow \eta f_0$ , we use the same  $\eta$  decay modes and  $\rho^0 \rightarrow \pi^+\pi^-$  or  $f_0 \rightarrow \pi^+\pi^-$ . We apply the following requirements on the invariant masses (in MeV) relevant here:  $500 < m_{\gamma\gamma} < 585$  for  $\eta_{\gamma\gamma}$ ,  $535 < m_{\pi\pi\pi} < 560$  for  $\eta_{3\pi}$ ,  $120 < m_{\gamma\gamma} < 150$  for  $\pi^0$ , and  $510 < m_{\pi\pi} < 1060$  for  $\rho^0/f_0$ . For the  $a_0(980)$  analysis we use a mass range  $775 < m_{\eta\pi} < 1175$ , while for  $a_0(1450)$  we require  $775 < m_{\eta\pi} < 1750$ ; the latter upper limit removes background from  $D$  decays. These requirements, except for  $\pi^0$  and  $\eta$ , are chosen to remove  $\lesssim 10\%$  of real signal and retain sufficient sidebands to characterize the background for subsequent fitting.

The average number of candidates found per selected event is in the range 1.04 to 1.17, depending on the final state. We choose the candidate with  $\eta$  mass closest to the nominal PDG value [13].

We make several PID requirements to ensure the identity of the pions and kaons. Secondary tracks from  $\eta$ ,  $\rho^0$ , or  $f_0$  decays must have measured DIRC,  $dE/dx$ , and EMC outputs consistent with pions. For the  $B^0 \rightarrow a_0^-\pi^+$  ( $B^0 \rightarrow a_0^-K^+$ ) decays, we require an associated DIRC Cherenkov angle between  $-2$  and  $+5$  ( $-5$  and  $+2$ ) standard deviations ( $\sigma$ ) from the expected value for a pion (kaon); the requirement is more restrictive on the side where there is kaon (pion) background. The distributions are corrected as a function of momenta and angles so that the distributions are normalized Gaussians. These requirements keep  $>90\%$  of the wanted particle species with a misidentification background of  $<10\%$ .

A  $B$ -meson candidate is characterized kinematically by the energy-substituted mass  $m_{\text{ES}} = (\frac{1}{4}s - \mathbf{p}_B^2)^{1/2}$  and energy difference  $\Delta E = E_B - \frac{1}{2}\sqrt{s}$ , where  $(E_B, \mathbf{p}_B)$  is the  $B$ -meson 4-momentum vector and all values are calculated in the  $Y(4S)$  frame. Signal events peak at zero for  $\Delta E$ , and at the  $B$  nominal mass for  $m_{\text{ES}}$ . The  $\Delta E$  ( $m_{\text{ES}}$ ) resolution is about 30 MeV (3.0 MeV). We require  $|\Delta E| \leq 0.2$  GeV and  $5.25 \leq m_{\text{ES}} \leq 5.29$  GeV.

Backgrounds arise primarily from random combinations in continuum  $e^+e^- \rightarrow q\bar{q}$  ( $q = u, d, s, c$ ) events. We reduce these by using the angle  $\theta_T$  between the thrust axis of the  $B^0$  candidate in the  $Y(4S)$  frame and that of the rest of the charged tracks and neutral clusters in the event. The distribution of  $|\cos\theta_T|$  is sharply peaked near 1.0 for combinations drawn from jetlike  $q\bar{q}$  pairs, and nearly uniform for  $B$ -meson decays. We require  $|\cos\theta_T| <$

0.7(0.8) for the  $\eta_{\gamma\gamma}$  ( $\eta_{3\pi}$ ) channels. We also use, in the fit described below, a Fisher discriminant  $\mathcal{F}$  that combines the angles of the candidate direction with respect to the beam axis of the  $B$  momentum and  $B$  thrust axis [in the  $Y(4S)$  frame], and moments describing the energy flow about the  $B$  thrust axis [21].

We use additional event-selection criteria to further reduce backgrounds from  $B$  decays. For the  $\eta \rightarrow \gamma\gamma$  modes we remove backgrounds with one high-energy photon and a spurious low-energy photon such as  $B \rightarrow K^*\gamma$  by requiring  $|\cos\theta_{\text{dec}}^\eta| \leq 0.86$ , where  $\theta_{\text{dec}}^\eta$  is the angle of the photons in the  $\eta$  rest frame with respect to the direction of the particle recoiling against the  $\eta$ . Many backgrounds with low-energy  $\pi$ ,  $K$ , or  $a_0$  mesons are reduced with the requirement  $|\cos\theta_{\text{dec}}^{a_0}| \leq 0.8$ , where  $\theta_{\text{dec}}^{a_0}$  is defined similarly to  $\theta_{\text{dec}}^\eta$ . For  $B^0 \rightarrow \eta\rho^0$  decays, we define  $\mathcal{H}$  to be the magnitude of the cosine of the angle between the pion from the  $\rho$  and the  $B^0$  momentum in the  $\rho$  rest frame, and require  $\mathcal{H} < 0.75$  to remove background from  $B^0 \rightarrow D^+(\eta\pi^+)\pi^-$  that populates a narrow region near  $\mathcal{H} = 0.8$ . These additional requirements reduce the backgrounds by a factor of 2–4, depending on the decay mode. We use Monte Carlo (MC) simulation [22] for an estimate of the residual  $B\bar{B}$  background and to identify the few (mostly charmless) decays that survive the candidate selection and have characteristics similar to the signal (20–270 events, depending on mode). We include a component in the fit to account for them.

We obtain yields and branching fractions from extended unbinned maximum-likelihood fits, with input observables  $\Delta E$ ,  $m_{\text{ES}}$ ,  $m_{\text{res}}$  for the  $a_0(1450)$  fits, these observables plus  $\mathcal{F}$  for the  $a_0(980)$  fits, and these plus  $\mathcal{H}$  for the  $\eta\rho^0/\eta f_0$  fits. The observable  $m_{\text{res}}$  denotes the  $\eta\pi$  mass for the  $a_0$  analyses and the  $\eta$  and  $\pi^+\pi^-$  masses for the  $\eta\rho^0/\eta f_0$  fits. Early MC studies showed that a fit to the restricted low-mass range yields  $\sim 20\%$  better sensitivity for  $a_0(980)$ , due to simplified PDF description and lower  $B\bar{B}$  backgrounds. Thus we employ separate fits to determine the  $a_0(980)$  and  $a_0(1450)$  yields. The  $a_0(1450)$  fit has a component for  $a_0(980)$  with the yield fixed to the value found in the  $a_0(980)$  fit, corrected for the small efficiency difference. No  $a_0(1450)$  component is used for the  $a_0(980)$  fit since none of the subsamples have evidence of  $a_0(1450)$  signals.

For each event  $i$  and hypothesis  $j$  (signal, continuum background,  $B\bar{B}$  background), we define a product of probability density functions (PDF)

$$\mathcal{P}_j^i = \mathcal{P}_j(m_{\text{ES}}^i)\mathcal{P}_j(\Delta E^i)\mathcal{P}_j(m_{\text{res}}^i)[\mathcal{P}_j(\mathcal{F}^i)][\mathcal{P}_j(\mathcal{H}^i)]. \quad (1)$$

The bracketed variables  $\mathcal{F}$  and  $\mathcal{H}$  are not used in all fits. For all decays except for those involving  $a_0(1450)$ , the absence of significant correlations among observables in the background is confirmed with the background-dominated data samples entering the fits. For the  $a_0(1450)$  decays, we find a substantial correlation in data

between  $\mathcal{F}$  and the  $\eta\pi$  invariant mass, due to the large  $\eta\pi$  mass range. We therefore require  $\mathcal{F} < 0$  for these modes, which keeps 90% of the signal, and exclude  $\mathcal{F}$  from the fit. For the signal component, we correct for effects due to the neglect of small correlations (more details are provided in the systematics discussion below). The  $B\bar{B}$  background yield is free in the  $\eta\rho^0/\eta f_0$  fits and is found to be in agreement with expectations from MC simulations. For the decays involving  $a_0$  mesons, we fix the  $B\bar{B}$  yield to the value predicted by MC and include the uncertainty in the systematic errors (see below).

The likelihood function is

$$\mathcal{L} = \exp\left(-\sum_j Y_j\right) \prod_{i=1}^N \left[ \sum_j Y_j \mathcal{P}_j^i \right], \quad (2)$$

where  $Y_j$  is the yield of events of hypothesis  $j$  that we find by maximizing  $\mathcal{L}$ , and  $N$  is the number of events in the sample.

We determine the PDF parameters from simulation for the signal and  $B\bar{B}$  background components. We parameterize each of the functions  $\mathcal{P}_{\text{sig}}(m_{\text{ES}})$ ,  $\mathcal{P}_{\text{sig}}(\Delta E)$ ,  $\mathcal{P}_j(\mathcal{F})$ , and  $\mathcal{P}_{\text{sig}}(m_{\text{res}})$  with either the sum of two Gaussian functions, a Breit-Wigner shape, or an asymmetric Gaussian function, as required to describe the distribution.  $\mathcal{P}_{\text{sig}}(\mathcal{H})$  for  $B^0 \rightarrow \eta\rho^0$  is described by a second order polynomial. The shape of the real-meson component of  $\mathcal{P}_j(m_{\text{res}})$  in the combinatorial background is described with the same parameters as for signal. The distributions of  $m_{\text{res}}$ ,  $\Delta E$ , and  $\mathcal{H}$  for  $B\bar{B}$  and combinatorial background are represented by second order Chebyshev polynomials and/or the sum of

two Gaussian functions. The  $q\bar{q}$  combinatorial background in  $m_{\text{ES}}$  is described by the function [23]  $f(x) = x\sqrt{1-x^2} \exp[-\xi(1-x^2)]$ , with  $x \equiv 2m_{\text{ES}}/\sqrt{s}$  and free parameter  $\xi$ ; for peaking  $B\bar{B}$  background, generally with the same or similar final state as signal, we add a Gaussian function to the quantity  $f(x)$ .

Large control samples of  $B \rightarrow D\pi$  with a topology similar to the signal are used to verify the simulated resolutions in  $\Delta E$  and  $m_{\text{ES}}$ . Where the control data samples reveal small differences from MC, we shift or scale the resolution used in the likelihood fits. Examples of many of these PDF shapes from a similar analysis are shown in Ref. [21]. Additionally, the signal parameters for the  $a_0(980)$  mass (983.5 MeV) and width (80 MeV) are determined from an inclusive data set that is much larger than the sample used for this analysis; they are consistent with expectations from the natural-width values of Ref. [15]. The values for  $a_0(1450)$  are taken from Ref. [13].

In Table I we show for each decay mode the measured product branching fraction, together with the quantities entering into its determination. In order to account for the uncertainties in the background PDF parameterization, we include as free parameters in the fit, in addition to the signal and background yields, the principal parameters describing the background PDFs. These include slopes for the polynomial shape for the  $\Delta E$  and  $m_{\text{res}}$  distributions, the parameter  $\xi$  used for  $m_{\text{ES}}$ , and three parameters describing the asymmetric Gaussian function for  $\mathcal{F}$ . For calculation of branching fractions, we assume that the decay rates of the  $Y(4S)$  to  $B^+B^-$  and  $B^0\bar{B}^0$  are equal [24]. We combine branching fraction results from the two

TABLE I. Signal yield with statistical error, yield bias correction, detection efficiency  $\epsilon$ , relevant daughter branching fraction product  $\prod \mathcal{B}_i$ , significance (including additive systematic uncertainties), measured branching fraction  $\mathcal{B}$ , and the 90% C.L. upper limit on this branching fraction. For the  $a_0$  and  $f_0$  modes,  $\mathcal{B}$  includes the daughter branching fractions for  $a_0 \rightarrow \eta\pi$  or  $f_0 \rightarrow \pi^+\pi^-$ .

Mode	Fit yield (events)	Bias (events)	$\epsilon$ (%)	$\prod \mathcal{B}_i$ (%)	Signif. ( $\sigma$ )	$\mathcal{B}$ ( $10^{-6}$ )	$\mathcal{B}$ U.L. ( $10^{-6}$ )
<b><math>a_0(980)^-\pi^+</math></b>					<b>2.4</b>	<b><math>2.1 \pm 0.8 \pm 0.3</math></b>	<b>&lt;3.1</b>
$a_0(980)_{\gamma\gamma}^-\pi^+$	$87 \pm 23$	16	15.3	39.4	3.3	$3.1_{-1.0}^{+1.1}$	
$a_0(980)_{3\pi}^-\pi^+$	$4_{-10}^{+12}$	1	11.8	22.6	0.1	$0.1_{-1.1}^{+1.3}$	
<b><math>a_0(980)^-K^+</math></b>					<b>2.0</b>	<b><math>1.0 \pm 0.6 \pm 0.2</math></b>	<b>&lt;1.9</b>
$a_0(980)_{\gamma\gamma}^-K^+$	$28_{-13}^{+15}$	14	14.0	39.4	2.0	$1.1_{-0.6}^{+0.7}$	
$a_0(980)_{3\pi}^-K^+$	$9_{-9}^{+12}$	11	11.0	22.6	0.7	$0.7_{-1.0}^{+1.2}$	
<b><math>a_0(1450)^-\pi^+</math></b>					—	<b><math>-3.5 \pm 2.2 \pm 0.8</math></b>	<b>&lt;2.3</b>
$a_0(1450)_{\gamma\gamma}^-\pi^+$	$-47 \pm 56$	26	13.8	39.4	—	$-3.5_{-2.6}^{+2.7}$	
$a_0(1450)_{3\pi}^-\pi^+$	$-24 \pm 32$	5	9.8	22.6	—	$-3.5_{-3.6}^{+3.8}$	
<b><math>a_0(1450)^-K^+</math></b>					<b>0.6</b>	<b><math>0.8 \pm 1.5 \pm 0.3</math></b>	<b>&lt;3.1</b>
$a_0(1450)_{\gamma\gamma}^-K^+$	$22 \pm 36$	12	13.3	39.4	0.3	$0.5_{-1.7}^{+1.8}$	
$a_0(1450)_{3\pi}^-K^+$	$13 \pm 24$	0	9.7	22.6	0.6	$1.6_{-2.7}^{+2.9}$	
<b><math>\eta\rho^0</math></b>					<b>0.6</b>	<b><math>0.4 \pm 0.7 \pm 0.2</math></b>	<b>&lt;1.5</b>
$\eta_{\gamma\gamma}\rho^0$	$15_{-11}^{+13}$	7	10.7	39.4	0.7	$0.5_{-0.7}^{+0.8}$	
$\eta_{3\pi}\rho^0$	$4_{-10}^{+12}$	5	8.4	22.6	—	$-1.4_{-1.4}^{+1.6}$	
<b><math>\eta f_0</math></b>					—	<b><math>-0.3 \pm 0.3 \pm 0.1</math></b>	<b>&lt;0.4</b>
$\eta_{\gamma\gamma}f_0$	$-11_{-8}^{+10}$	1	18.8	39.4	—	$-0.4 \pm 0.3$	
$\eta_{3\pi}f_0$	$-4 \pm 11$	-4	14.9	22.6	0.1	$0.0 \pm 0.5$	

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$\eta$  decay channels by adding the values of  $-2 \ln \mathcal{L}$ , adjusted for a fit bias (see below), and taking proper account of the correlated and uncorrelated systematic errors. We quote 90% confidence level (C.L.) upper limits, taken to be the branching fraction below which lies 90% of the total of the likelihood integral in the positive branching fraction region.

In Fig. 2 we show projections onto  $m_{ES}$  and  $\eta\pi$  mass of subsamples enriched by a mode-dependent threshold requirement on the ratio of signal to total likelihood (computed without the variable plotted). We show analogous projections of  $m_{ES}$  and the  $\pi^+\pi^-$  invariant mass in Fig. 3.

The significance is taken as the square root of the difference between the value of  $-2 \ln \mathcal{L}$  (with additive

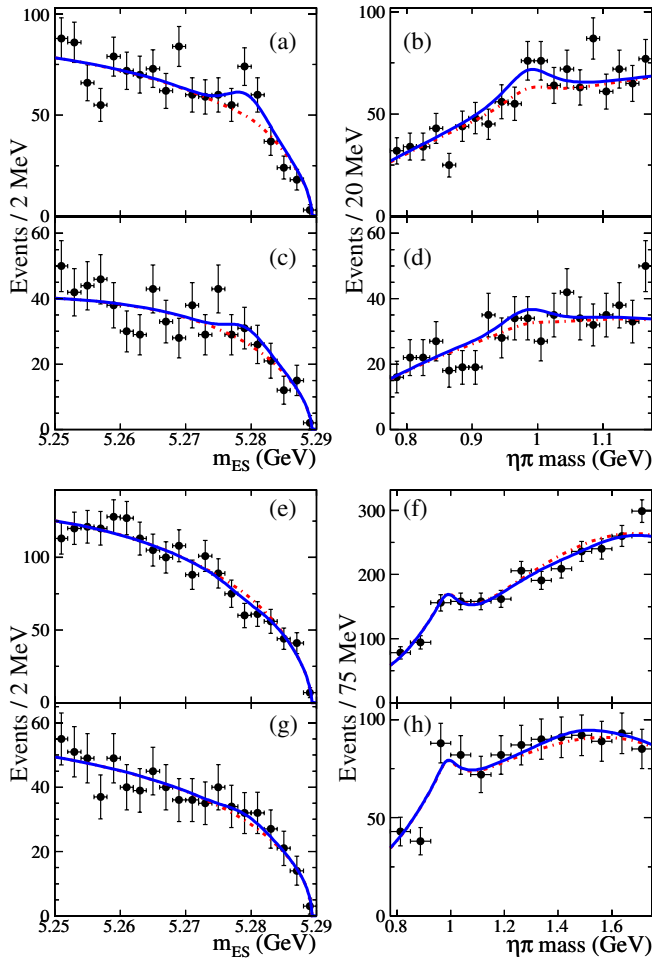


FIG. 2 (color online). Signal-enhanced projections of the  $B^0$ -candidate  $m_{ES}$  and  $\eta\pi$  mass for (a, b)  $a_0^- \pi^+$ , (c, d)  $a_0^- K^+$ , (e, f)  $a_0(1450)^- \pi^+$ , and (g, h)  $a_0(1450)^- K^+$ . Points with errors represent data, solid curves the full fit functions (both signal modes combined), and dotted-dashed curves the background functions (the peaking  $B\bar{B}$  background component is small). For the  $a_0(1450)$  plots, the  $a_0(980)$  signal is included in the background curves. These plots are made with a minimum requirement on the likelihood that has an efficiency for signal of 60%–70%.

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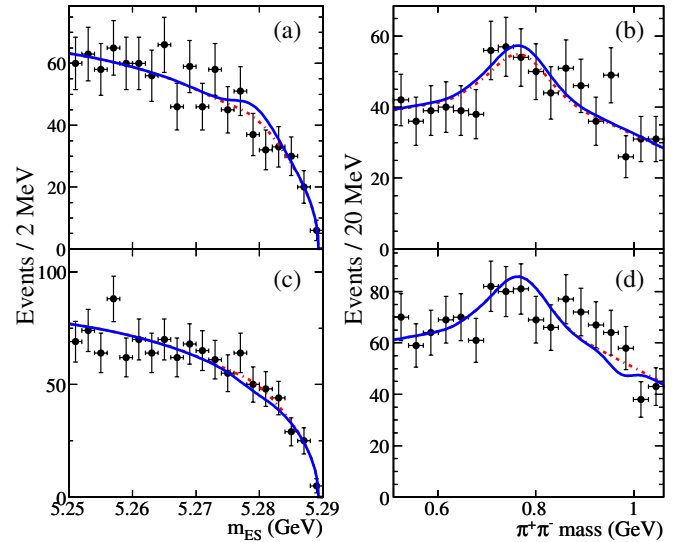


FIG. 3 (color online). Signal-enhanced projections of the  $B^0$ -candidate  $m_{ES}$  and  $\pi^+\pi^-$  mass for (a, b)  $\eta\rho^0$  and (c, d)  $\eta f_0$ . Points with errors represent data, solid curves the full fit functions (both signal modes combined), and dotted-dashed curves the background functions (the peaking  $B\bar{B}$  background component is small). These plots are made with a minimum requirement on the likelihood that has an efficiency for signal of 70%–90%.

systematic uncertainties included) for zero signal and the value at the minimum, with other parameters free in both cases.

Most of the yield uncertainties arising from lack of knowledge of the PDFs have been included in the statistical error since most background parameters are free in the fit. Varying the signal PDF parameters within their estimated uncertainties, we determine the uncertainties in the signal yields to be 0–9 events, depending on the final state. This uncertainty is substantial only for the modes with one of the  $a_0$  resonances, where it is dominated by uncertainties in the parameterization of the  $a_0$  signal shape. The neglect of correlations among observables in the fit can cause a systematic bias; the correction for this bias (between  $-4$  and  $+26$  events) and assignment of the resulting systematic uncertainty (0.1–13 events) is determined from simulated samples with varying background populations. For the  $a_0$  modes where the  $B\bar{B}$  background yield is fixed, we estimate the uncertainty from modeling the  $B\bar{B}$  backgrounds by varying the expected  $B\bar{B}$  yield by 100% (0.1–12 events).

The above uncertainties are additive in nature and affect the significance of the results. The largest multiplicative uncertainties include our knowledge of the efficiency and other quantities entering the branching fraction calculation. Selection efficiency uncertainties are 1%–2% for  $\cos\theta_T$  and 0.5%–0.8% due to the limited size of the MC samples. Uncertainties in the reconstruction efficiency found from auxiliary studies on inclusive control samples



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[21], include  $0.5\% \cdot N_t$  and  $1.5\% \cdot N_\gamma$ , where  $N_t$  and  $N_\gamma$  are the number of signal tracks and photons, respectively. The uncertainty on the total number of  $B\bar{B}$  events is 1.1%. Published data [13] provide the uncertainties in the  $B$ -daughter product branching fractions (1%–2%).

In conclusion, we do not find significant signals for the  $B$ -meson decays presented here. The measured branching fractions and 90% C.L. upper limits are given in Table I. The limits for the  $a_0(980)$  channels are smaller than expectations [7–10]. This has been cited as evidence that the  $a_0(980)$  meson is a four-quark state, not the lowest-lying member of the  $q\bar{q}$  scalar multiplet [9]. The limits for the  $a_0(1450)$  channels and  $B^0 \rightarrow \eta\rho^0$  are consistent with theoretical expectations [9,12]. There are no previous measure-

ments or theoretical predictions for the  $B^0 \rightarrow \eta f_0$  decay.

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