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Study of the  $X(3872)$  and  $Y(4260)$  in  $B^0 \rightarrow J/\psi\pi^+\pi^-K^0$   
and  $B^- \rightarrow J/\psi\pi^+\pi^-K^-$  decays

B. Aubert,<sup>1</sup> R. Barate,<sup>1</sup> D. Boutigny,<sup>1</sup> F. Couderc,<sup>1</sup> Y. Karyotakis,<sup>1</sup> J. P. Lees,<sup>1</sup> V. Poireau,<sup>1</sup> V. Tisserand,<sup>1</sup>  
A. Zghiche,<sup>1</sup> E. Grauges,<sup>2</sup> A. Palano,<sup>3</sup> M. Pappagallo,<sup>3</sup> A. Pompili,<sup>3</sup> J. C. Chen,<sup>4</sup> N. D. Qi,<sup>4</sup> G. Rong,<sup>4</sup> P. Wang,<sup>4</sup>  
Y. S. Zhu,<sup>4</sup> G. Eigen,<sup>5</sup> I. Ofte,<sup>5</sup> B. Stugu,<sup>5</sup> G. S. Abrams,<sup>6</sup> M. Battaglia,<sup>6</sup> A. B. Breon,<sup>6</sup> D. N. Brown,<sup>6</sup>  
J. Button-Shafer,<sup>6</sup> R. N. Cahn,<sup>6</sup> E. Charles,<sup>6</sup> C. T. Day,<sup>6</sup> M. S. Gill,<sup>6</sup> A. V. Gritsan,<sup>6</sup> Y. Groysman,<sup>6</sup>  
R. G. Jacobsen,<sup>6</sup> R. W. Kadel,<sup>6</sup> J. Kadyk,<sup>6</sup> L. T. Kerth,<sup>6</sup> Yu. G. Kolomensky,<sup>6</sup> G. Kukartsev,<sup>6</sup> G. Lynch,<sup>6</sup>  
L. M. Mir,<sup>6</sup> P. J. Oddone,<sup>6</sup> T. J. Orimoto,<sup>6</sup> M. Pripstein,<sup>6</sup> N. A. Roe,<sup>6</sup> M. T. Ronan,<sup>6</sup> W. A. Wenzel,<sup>6</sup> M. Barrett,<sup>7</sup>  
K. E. Ford,<sup>7</sup> T. J. Harrison,<sup>7</sup> A. J. Hart,<sup>7</sup> C. M. Hawkes,<sup>7</sup> S. E. Morgan,<sup>7</sup> A. T. Watson,<sup>7</sup> M. Fritsch,<sup>8</sup> K. Goetzen,<sup>8</sup>  
T. Held,<sup>8</sup> H. Koch,<sup>8</sup> B. Lewandowski,<sup>8</sup> M. Pelizaeus,<sup>8</sup> K. Peters,<sup>8</sup> T. Schroeder,<sup>8</sup> M. Steinke,<sup>8</sup> J. T. Boyd,<sup>9</sup>  
J. P. Burke,<sup>9</sup> N. Chevalier,<sup>9</sup> W. N. Cottingham,<sup>9</sup> T. Cuhadar-Donszelmann,<sup>10</sup> B. G. Fulsom,<sup>10</sup> C. Hearty,<sup>10</sup>  
N. S. Knecht,<sup>10</sup> T. S. Mattison,<sup>10</sup> J. A. McKenna,<sup>10</sup> A. Khan,<sup>11</sup> P. Kyberd,<sup>11</sup> M. Saleem,<sup>11</sup> L. Teodorescu,<sup>11</sup>  
A. E. Blinov,<sup>12</sup> V. E. Blinov,<sup>12</sup> A. D. Bukin,<sup>12</sup> V. P. Druzhinin,<sup>12</sup> V. B. Golubev,<sup>12</sup> E. A. Kravchenko,<sup>12</sup>  
A. P. Onuchin,<sup>12</sup> S. I. Serednyakov,<sup>12</sup> Yu. I. Skovpen,<sup>12</sup> E. P. Solodov,<sup>12</sup> A. N. Yushkov,<sup>12</sup> D. Best,<sup>13</sup> M. Bondioli,<sup>13</sup>  
M. Bruinsma,<sup>13</sup> M. Chao,<sup>13</sup> S. Curry,<sup>13</sup> I. Eschrich,<sup>13</sup> D. Kirkby,<sup>13</sup> A. J. Lankford,<sup>13</sup> P. Lund,<sup>13</sup> M. Mandelkern,<sup>13</sup>  
R. K. Mommsen,<sup>13</sup> W. Roethel,<sup>13</sup> D. P. Stoker,<sup>13</sup> C. Buchanan,<sup>14</sup> B. L. Hartfel,<sup>14</sup> A. J. R. Weinstein,<sup>14</sup>  
S. D. Foulkes,<sup>15</sup> J. W. Gary,<sup>15</sup> O. Long,<sup>15</sup> B. C. Shen,<sup>15</sup> K. Wang,<sup>15</sup> L. Zhang,<sup>15</sup> D. del Re,<sup>16</sup> H. K. Hadavand,<sup>16</sup>  
E. J. Hill,<sup>16</sup> D. B. MacFarlane,<sup>16</sup> H. P. Paar,<sup>16</sup> S. Rahatlou,<sup>16</sup> V. Sharma,<sup>16</sup> J. W. Berryhill,<sup>17</sup> C. Campagnari,<sup>17</sup>  
A. Cunha,<sup>17</sup> B. Dahmes,<sup>17</sup> T. M. Hong,<sup>17</sup> M. A. Mazur,<sup>17</sup> J. D. Richman,<sup>17</sup> W. Verkerke,<sup>17</sup> T. W. Beck,<sup>18</sup>  
A. M. Eisner,<sup>18</sup> C. J. Flacco,<sup>18</sup> C. A. Heusch,<sup>18</sup> J. Kroseberg,<sup>18</sup> W. S. Lockman,<sup>18</sup> G. Nesom,<sup>18</sup> T. Schalk,<sup>18</sup>  
B. A. Schumm,<sup>18</sup> A. Seiden,<sup>18</sup> P. Spradlin,<sup>18</sup> D. C. Williams,<sup>18</sup> M. G. Wilson,<sup>18</sup> J. Albert,<sup>19</sup> E. Chen,<sup>19</sup>  
G. P. Dubois-Felsmann,<sup>19</sup> A. Dvoretzki,<sup>19</sup> D. G. Hitlin,<sup>19</sup> I. Narsky,<sup>19</sup> T. Piatenko,<sup>19</sup> F. C. Porter,<sup>19</sup> A. Ryd,<sup>19</sup>  
A. Samuel,<sup>19</sup> R. Andreassen,<sup>20</sup> S. Jayatilake,<sup>20</sup> G. Mancinelli,<sup>20</sup> B. T. Meadows,<sup>20</sup> M. D. Sokoloff,<sup>20</sup> F. Blanc,<sup>21</sup>  
P. Bloom,<sup>21</sup> S. Chen,<sup>21</sup> W. T. Ford,<sup>21</sup> J. F. Hirschauer,<sup>21</sup> A. Kreisel,<sup>21</sup> U. Nauenberg,<sup>21</sup> A. Olivas,<sup>21</sup> P. Rankin,<sup>21</sup>  
W. O. Ruddick,<sup>21</sup> J. G. Smith,<sup>21</sup> K. A. Ulmer,<sup>21</sup> S. R. Wagner,<sup>21</sup> J. Zhang,<sup>21</sup> A. Chen,<sup>22</sup> E. A. Eckhart,<sup>22</sup>  
A. Soffer,<sup>22</sup> W. H. Toki,<sup>22</sup> R. J. Wilson,<sup>22</sup> F. Winklmeier,<sup>22</sup> Q. Zeng,<sup>22</sup> D. Altenburg,<sup>23</sup> E. Feltresi,<sup>23</sup> A. Hauke,<sup>23</sup>  
B. Spaan,<sup>23</sup> T. Brandt,<sup>24</sup> J. Brose,<sup>24</sup> M. Dickopp,<sup>24</sup> V. Klose,<sup>24</sup> H. M. Lacker,<sup>24</sup> R. Nogowski,<sup>24</sup> S. Otto,<sup>24</sup>  
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G. R. Bonneaud,<sup>25</sup> P. Grenier,<sup>25</sup> S. Schrenk,<sup>25</sup> Ch. Thiebaux,<sup>25</sup> G. Vasileiadis,<sup>25</sup> M. Verderi,<sup>25</sup> D. J. Bard,<sup>26</sup>  
P. J. Clark,<sup>26</sup> W. Gradl,<sup>26</sup> F. Muheim,<sup>26</sup> S. Playfer,<sup>26</sup> Y. Xie,<sup>26</sup> M. Andreotti,<sup>27</sup> V. Azzolini,<sup>27</sup> D. Bettini,<sup>27</sup>  
C. Bozzi,<sup>27</sup> R. Calabrese,<sup>27</sup> G. Cibinetto,<sup>27</sup> E. Luppi,<sup>27</sup> M. Negrini,<sup>27</sup> L. Piemontese,<sup>27</sup> F. Anulli,<sup>28</sup>  
R. Baldini-Feroli,<sup>28</sup> A. Calcaterra,<sup>28</sup> R. de Sangro,<sup>28</sup> G. Finocchiaro,<sup>28</sup> P. Patteri,<sup>28</sup> I. M. Peruzzi,<sup>28</sup> \* M. Piccolo,<sup>28</sup>  
A. Zallo,<sup>28</sup> A. Buzzo,<sup>29</sup> R. Capra,<sup>29</sup> R. Contri,<sup>29</sup> M. Lo Vetere,<sup>29</sup> M. Macri,<sup>29</sup> M. R. Monge,<sup>29</sup> S. Passaggio,<sup>29</sup>  
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N. Arnaud,<sup>35</sup> M. Davier,<sup>35</sup> X. Giroux,<sup>35</sup> G. Grosdidier,<sup>35</sup> A. Höcker,<sup>35</sup> F. Le Diberder,<sup>35</sup> V. Lepeltier,<sup>35</sup>  
A. M. Lutz,<sup>35</sup> A. Oyanguren,<sup>35</sup> T. C. Petersen,<sup>35</sup> M. Pierini,<sup>35</sup> S. Plaszczynski,<sup>35</sup> S. Rodier,<sup>35</sup> P. Roudeau,<sup>35</sup>  
M. H. Schune,<sup>35</sup> A. Stocchi,<sup>35</sup> G. Wormser,<sup>35</sup> C. H. Cheng,<sup>36</sup> D. J. Lange,<sup>36</sup> M. C. Simani,<sup>36</sup> D. M. Wright,<sup>36</sup>  
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D. E. Hutchcroft,<sup>37</sup> R. J. Parry,<sup>37</sup> D. J. Payne,<sup>37</sup> K. C. Schofield,<sup>37</sup> C. Touramanis,<sup>37</sup> C. M. Cormack,<sup>38</sup>  
F. Di Lodovico,<sup>38</sup> W. Menges,<sup>38</sup> R. Sacco,<sup>38</sup> C. L. Brown,<sup>39</sup> G. Cowan,<sup>39</sup> H. U. Flaecher,<sup>39</sup> M. G. Green,<sup>39</sup>  
D. A. Hopkins,<sup>39</sup> P. S. Jackson,<sup>39</sup> T. R. McMahon,<sup>39</sup> S. Ricciardi,<sup>39</sup> F. Salvatore,<sup>39</sup> D. Brown,<sup>40</sup> C. L. Davis,<sup>40</sup>  
J. Allison,<sup>41</sup> N. R. Barlow,<sup>41</sup> R. J. Barlow,<sup>41</sup> C. L. Edgar,<sup>41</sup> M. C. Hodgkinson,<sup>41</sup> M. P. Kelly,<sup>41</sup> G. D. Lafferty,<sup>41</sup>  
M. T. Naisbit,<sup>41</sup> J. C. Williams,<sup>41</sup> C. Chen,<sup>42</sup> W. D. Hulsbergen,<sup>42</sup> A. Jawahery,<sup>42</sup> D. Kovalskyi,<sup>42</sup> C. K. Lae,<sup>42</sup>

D. A. Roberts,<sup>42</sup> G. Simi,<sup>42</sup> G. Blaylock,<sup>43</sup> C. Dallapiccola,<sup>43</sup> S. S. Hertzbach,<sup>43</sup> R. Kofler,<sup>43</sup> V. B. Koptchev,<sup>43</sup> X. Li,<sup>43</sup> T. B. Moore,<sup>43</sup> S. Saremi,<sup>43</sup> H. Staengle,<sup>43</sup> S. Willocq,<sup>43</sup> R. Cowan,<sup>44</sup> K. Koenke,<sup>44</sup> G. Sciolla,<sup>44</sup> S. J. Sekula,<sup>44</sup> M. Spitznagel,<sup>44</sup> F. Taylor,<sup>44</sup> R. K. Yamamoto,<sup>44</sup> H. Kim,<sup>45</sup> P. M. Patel,<sup>45</sup> S. H. Robertson,<sup>45</sup> A. Lazzaro,<sup>46</sup> V. Lombardo,<sup>46</sup> F. Palombo,<sup>46</sup> J. M. Bauer,<sup>47</sup> L. Cremaldi,<sup>47</sup> V. Eschenburg,<sup>47</sup> R. Godang,<sup>47</sup> R. Kroeger,<sup>47</sup> J. Reidy,<sup>47</sup> D. A. Sanders,<sup>47</sup> D. J. Summers,<sup>47</sup> H. W. Zhao,<sup>47</sup> S. Brunet,<sup>48</sup> D. Côté,<sup>48</sup> P. Taras,<sup>48</sup> B. Viaud,<sup>48</sup> H. Nicholson,<sup>49</sup> N. Cavallo,<sup>50</sup>,<sup>†</sup> G. De Nardo,<sup>50</sup> F. Fabozzi,<sup>50</sup>,<sup>†</sup> C. Gatto,<sup>50</sup> L. Lista,<sup>50</sup> D. Monorchio,<sup>50</sup> P. Paolucci,<sup>50</sup> D. Piccolo,<sup>50</sup> C. Sciacca,<sup>50</sup> M. Baak,<sup>51</sup> H. Bulten,<sup>51</sup> G. Raven,<sup>51</sup> H. L. Snoek,<sup>51</sup> L. Wilden,<sup>51</sup> C. P. Jessop,<sup>52</sup> J. M. LoSecco,<sup>52</sup> T. Allmendinger,<sup>53</sup> G. Benelli,<sup>53</sup> K. K. Gan,<sup>53</sup> K. Honscheid,<sup>53</sup> D. Hufnagel,<sup>53</sup> P. D. Jackson,<sup>53</sup> H. Kagan,<sup>53</sup> R. Kass,<sup>53</sup> T. Pulliam,<sup>53</sup> A. M. Rahimi,<sup>53</sup> R. Ter-Antonyan,<sup>53</sup> Q. K. Wong,<sup>53</sup> J. Brau,<sup>54</sup> R. Frey,<sup>54</sup> O. Igonkina,<sup>54</sup> M. Lu,<sup>54</sup> C. T. Potter,<sup>54</sup> N. B. Sinev,<sup>54</sup> D. Strom,<sup>54</sup> J. Strube,<sup>54</sup> E. Torrence,<sup>54</sup> F. Galeazzi,<sup>55</sup> M. Margoni,<sup>55</sup> M. Morandin,<sup>55</sup> M. Posocco,<sup>55</sup> M. Rotondo,<sup>55</sup> F. Simonetto,<sup>55</sup> R. Stroili,<sup>55</sup> C. Voci,<sup>55</sup> M. Benayoun,<sup>56</sup> H. Briand,<sup>56</sup> J. Chauveau,<sup>56</sup> P. David,<sup>56</sup> L. Del Buono,<sup>56</sup> Ch. de la Vaissière,<sup>56</sup> O. Hamon,<sup>56</sup> M. J. J. John,<sup>56</sup> Ph. Leruste,<sup>56</sup> J. Malclès,<sup>56</sup> J. Ocariz,<sup>56</sup> L. Roos,<sup>56</sup> G. Therin,<sup>56</sup> P. K. Behera,<sup>57</sup> L. Gladney,<sup>57</sup> Q. H. Guo,<sup>57</sup> J. Panetta,<sup>57</sup> M. Biasini,<sup>58</sup> R. Covarelli,<sup>58</sup> S. Pacetti,<sup>58</sup> M. Pioppi,<sup>58</sup> C. Angelini,<sup>59</sup> G. Batignani,<sup>59</sup> S. Bettarini,<sup>59</sup> F. Bucci,<sup>59</sup> G. Calderini,<sup>59</sup> M. Carpinelli,<sup>59</sup> R. Cenci,<sup>59</sup> F. Forti,<sup>59</sup> M. A. Giorgi,<sup>59</sup> A. Lusiani,<sup>59</sup> G. Marchiori,<sup>59</sup> M. Morganti,<sup>59</sup> N. Neri,<sup>59</sup> E. Paoloni,<sup>59</sup> M. Rama,<sup>59</sup> G. Rizzo,<sup>59</sup> J. Walsh,<sup>59</sup> M. Haire,<sup>60</sup> D. Judd,<sup>60</sup> D. E. Wagoner,<sup>60</sup> J. Biesiada,<sup>61</sup> N. Danielson,<sup>61</sup> P. Elmer,<sup>61</sup> Y. P. Lau,<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> F. Bellini,<sup>62</sup> G. Cavoto,<sup>62</sup> A. D’Orazio,<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> 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. Safai Tehrani,<sup>62</sup> C. Voena,<sup>62</sup> H. Schröder,<sup>63</sup> G. Wagner,<sup>63</sup> R. Waldi,<sup>63</sup> T. Adye,<sup>64</sup> N. De Groot,<sup>64</sup> B. Franek,<sup>64</sup> G. P. Gopal,<sup>64</sup> E. O. Olaiya,<sup>64</sup> F. F. Wilson,<sup>64</sup> R. Aleksan,<sup>65</sup> S. Emery,<sup>65</sup> A. Gaidot,<sup>65</sup> S. F. Ganzhur,<sup>65</sup> P.-F. Giraud,<sup>65</sup> G. Graziani,<sup>65</sup> G. Hamel de Monchenault,<sup>65</sup> W. Kozanecki,<sup>65</sup> M. Legendre,<sup>65</sup> G. W. London,<sup>65</sup> B. Mayer,<sup>65</sup> G. Vasseur,<sup>65</sup> Ch. Yèche,<sup>65</sup> M. Zito,<sup>65</sup> M. V. Purohit,<sup>66</sup> A. W. Weidemann,<sup>66</sup> J. R. Wilson,<sup>66</sup> F. X. Yumiceva,<sup>66</sup> T. Abe,<sup>67</sup> M. T. Allen,<sup>67</sup> D. Aston,<sup>67</sup> N. van Bakel,<sup>67</sup> R. Bartoldus,<sup>67</sup> N. Berger,<sup>67</sup> A. M. Boyarski,<sup>67</sup> O. L. Buchmueller,<sup>67</sup> R. Claus,<sup>67</sup> J. P. Coleman,<sup>67</sup> M. R. Convery,<sup>67</sup> M. Cristinziani,<sup>67</sup> J. C. Dingfelder,<sup>67</sup> D. Dong,<sup>67</sup> J. Dorfan,<sup>67</sup> D. Dujmic,<sup>67</sup> W. Dunwoodie,<sup>67</sup> S. Fan,<sup>67</sup> R. C. Field,<sup>67</sup> T. Glanzman,<sup>67</sup> S. J. Gowdy,<sup>67</sup> T. Hadig,<sup>67</sup> V. Halyo,<sup>67</sup> C. Hast,<sup>67</sup> T. Hryn’ova,<sup>67</sup> W. R. Innes,<sup>67</sup> M. H. Kelsey,<sup>67</sup> P. Kim,<sup>67</sup> M. L. Kocian,<sup>67</sup> D. W. G. S. Leith,<sup>67</sup> J. Libby,<sup>67</sup> S. Luitz,<sup>67</sup> V. Luth,<sup>67</sup> H. L. Lynch,<sup>67</sup> H. Marsiske,<sup>67</sup> R. Messner,<sup>67</sup> D. R. Muller,<sup>67</sup> C. P. O’Grady,<sup>67</sup> V. E. Ozcan,<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> J. Stelzer,<sup>67</sup> D. Su,<sup>67</sup> M. K. Sullivan,<sup>67</sup> K. Suzuki,<sup>67</sup> S. Swain,<sup>67</sup> J. M. Thompson,<sup>67</sup> J. Va’vra,<sup>67</sup> M. Weaver,<sup>67</sup> W. J. Wisniewski,<sup>67</sup> M. Wittgen,<sup>67</sup> D. H. Wright,<sup>67</sup> A. K. Yarritu,<sup>67</sup> K. Yi,<sup>67</sup> C. C. Young,<sup>67</sup> P. R. Burchat,<sup>68</sup> A. J. Edwards,<sup>68</sup> S. A. Majewski,<sup>68</sup> B. A. Petersen,<sup>68</sup> C. Roat,<sup>68</sup> M. Ahmed,<sup>69</sup> S. Ahmed,<sup>69</sup> M. S. Alam,<sup>69</sup> J. A. Ernst,<sup>69</sup> M. A. Saeed,<sup>69</sup> F. R. Wappler,<sup>69</sup> S. B. Zain,<sup>69</sup> W. Bugg,<sup>70</sup> M. Krishnamurthy,<sup>70</sup> S. M. Spanier,<sup>70</sup> R. Eckmann,<sup>71</sup> J. L. Ritchie,<sup>71</sup> A. Satpathy,<sup>71</sup> R. F. Schwitters,<sup>71</sup> J. M. Izen,<sup>72</sup> I. Kitayama,<sup>72</sup> X. C. Lou,<sup>72</sup> G. Williams,<sup>72</sup> S. Ye,<sup>72</sup> F. Bianchi,<sup>73</sup> M. Bona,<sup>73</sup> F. Gallo,<sup>73</sup> D. Gamba,<sup>73</sup> M. Bomben,<sup>74</sup> L. Bosisio,<sup>74</sup> C. Cartaro,<sup>74</sup> F. Cossutti,<sup>74</sup> G. Della Ricca,<sup>74</sup> S. Dittongo,<sup>74</sup> S. Grancagnolo,<sup>74</sup> L. Lanceri,<sup>74</sup> L. Vitale,<sup>74</sup> F. Martinez-Vidal,<sup>75</sup> R. S. Panvini,<sup>76</sup>,<sup>‡</sup> Sw. Banerjee,<sup>77</sup> B. Bhuyan,<sup>77</sup> C. M. Brown,<sup>77</sup> D. Fortin,<sup>77</sup> K. Hamano,<sup>77</sup> R. Kowalewski,<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> H. R. Band,<sup>79</sup> X. Chen,<sup>79</sup> B. Cheng,<sup>79</sup> S. Dasu,<sup>79</sup> M. Datta,<sup>79</sup> A. M. Eichenbaum,<sup>79</sup> K. T. Flood,<sup>79</sup> M. Graham,<sup>79</sup> J. J. Hollar,<sup>79</sup> J. R. Johnson,<sup>79</sup> P. E. Kutter,<sup>79</sup> H. Li,<sup>79</sup> R. Liu,<sup>79</sup> B. Mellado,<sup>79</sup> A. Mihalyi,<sup>79</sup> Y. Pan,<sup>79</sup> R. Prepost,<sup>79</sup> P. Tan,<sup>79</sup> J. H. von Wimmersperg-Toeller,<sup>79</sup> S. L. Wu,<sup>79</sup> Z. Yu,<sup>79</sup> and H. Neal<sup>80</sup>

(The BABAR Collaboration)

<sup>1</sup>Laboratoire de Physique des Particules, F-74941 Annecy-le-Vieux, France

<sup>2</sup>IFAE, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Barcelona, Spain

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

<sup>4</sup>Institute of High Energy Physics, Beijing 100039, China

<sup>5</sup>University of Bergen, Inst. of Physics, N-5007 Bergen, Norway

<sup>6</sup>Lawrence Berkeley National Laboratory and University of California, Berkeley, California 94720, USA

<sup>7</sup>University of Birmingham, Birmingham, B15 2TT, United Kingdom

<sup>8</sup>Ruhr Universität Bochum, Institut für Experimentalphysik 1, D-44780 Bochum, Germany

<sup>9</sup>University of Bristol, Bristol BS8 1TL, United Kingdom

<sup>10</sup>University of British Columbia, Vancouver, British Columbia, Canada V6T 1Z1

- <sup>11</sup> Brunel University, Uxbridge, Middlesex UB8 3PH, United Kingdom
- <sup>12</sup> Budker Institute of Nuclear Physics, Novosibirsk 630090, Russia
- <sup>13</sup> University of California at Irvine, Irvine, California 92697, USA
- <sup>14</sup> University of California at Los Angeles, Los Angeles, California 90024, USA
- <sup>15</sup> University of California at Riverside, Riverside, California 92521, USA
- <sup>16</sup> University of California at San Diego, La Jolla, California 92093, USA
- <sup>17</sup> University of California at Santa Barbara, Santa Barbara, California 93106, USA
- <sup>18</sup> University of California at Santa Cruz, Institute for Particle Physics, Santa Cruz, California 95064, USA
- <sup>19</sup> California Institute of Technology, Pasadena, California 91125, USA
- <sup>20</sup> University of Cincinnati, Cincinnati, Ohio 45221, USA
- <sup>21</sup> University of Colorado, Boulder, Colorado 80309, USA
- <sup>22</sup> Colorado State University, Fort Collins, Colorado 80523, USA
- <sup>23</sup> Universität Dortmund, Institut für Physik, D-44221 Dortmund, Germany
- <sup>24</sup> Technische Universität Dresden, Institut für Kern- und Teilchenphysik, D-01062 Dresden, Germany
- <sup>25</sup> Ecole Polytechnique, LLR, F-91128 Palaiseau, France
- <sup>26</sup> University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom
- <sup>27</sup> Università di Ferrara, Dipartimento di Fisica and INFN, I-44100 Ferrara, Italy
- <sup>28</sup> Laboratori Nazionali di Frascati dell'INFN, I-00044 Frascati, Italy
- <sup>29</sup> Università di Genova, Dipartimento di Fisica and INFN, I-16146 Genova, Italy
- <sup>30</sup> Harvard University, Cambridge, Massachusetts 02138, USA
- <sup>31</sup> Universität Heidelberg, Physikalisches Institut, Philosophenweg 12, D-69120 Heidelberg, Germany
- <sup>32</sup> Imperial College London, London, SW7 2AZ, United Kingdom
- <sup>33</sup> University of Iowa, Iowa City, Iowa 52242, USA
- <sup>34</sup> Iowa State University, Ames, Iowa 50011-3160, USA
- <sup>35</sup> Laboratoire de l'Accélérateur Linéaire, F-91898 Orsay, France
- <sup>36</sup> Lawrence Livermore National Laboratory, Livermore, California 94550, USA
- <sup>37</sup> University of Liverpool, Liverpool L69 7ZE, United Kingdom
- <sup>38</sup> Queen Mary, University of London, E1 4NS, United Kingdom
- <sup>39</sup> University of London, Royal Holloway and Bedford New College, Egham, Surrey TW20 0EX, United Kingdom
- <sup>40</sup> University of Louisville, Louisville, Kentucky 40292, USA
- <sup>41</sup> University of Manchester, Manchester M13 9PL, United Kingdom
- <sup>42</sup> University of Maryland, College Park, Maryland 20742, USA
- <sup>43</sup> University of Massachusetts, Amherst, Massachusetts 01003, USA
- <sup>44</sup> Massachusetts Institute of Technology, Laboratory for Nuclear Science, Cambridge, Massachusetts 02139, USA
- <sup>45</sup> McGill University, Montréal, Quebec, Canada H3A 2T8
- <sup>46</sup> Università di Milano, Dipartimento di Fisica and INFN, I-20133 Milano, Italy
- <sup>47</sup> University of Mississippi, University, Mississippi 38677, USA
- <sup>48</sup> Université de Montréal, Laboratoire René J. A. Lévêque, Montréal, Quebec, Canada H3C 3J7
- <sup>49</sup> Mount Holyoke College, South Hadley, Massachusetts 01075, USA
- <sup>50</sup> Università di Napoli Federico II, Dipartimento di Scienze Fisiche and INFN, I-80126, Napoli, Italy
- <sup>51</sup> NIKHEF, National Institute for Nuclear Physics and High Energy Physics, NL-1009 DB Amsterdam, The Netherlands
- <sup>52</sup> University of Notre Dame, Notre Dame, Indiana 46556, USA
- <sup>53</sup> Ohio State University, Columbus, Ohio 43210, USA
- <sup>54</sup> University of Oregon, Eugene, Oregon 97403, USA
- <sup>55</sup> Università di Padova, Dipartimento di Fisica and INFN, I-35131 Padova, Italy
- <sup>56</sup> Universités Paris VI et VII, Laboratoire de Physique Nucléaire et de Hautes Energies, F-75252 Paris, France
- <sup>57</sup> University of Pennsylvania, Philadelphia, Pennsylvania 19104, USA
- <sup>58</sup> Università di Perugia, Dipartimento di Fisica and INFN, I-06100 Perugia, Italy
- <sup>59</sup> Università di Pisa, Dipartimento di Fisica, Scuola Normale Superiore and INFN, I-56127 Pisa, Italy
- <sup>60</sup> Prairie View A&M University, Prairie View, Texas 77446, USA
- <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>*Vanderbilt University, Nashville, Tennessee 37235, USA*

<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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We present results of a search for the  $X(3872)$  in  $B^0 \rightarrow X(3872)K_S^0$ ,  $X(3872) \rightarrow J/\psi\pi^+\pi^-$ , improved measurements of  $B^- \rightarrow X(3872)K^-$ , and a study of the  $J/\psi\pi^+\pi^-$  mass region above the  $X(3872)$ . We use 232 million  $B\bar{B}$  pairs collected at the  $\Upsilon(4S)$  resonance with the *BABAR* detector at the PEP-II  $e^+e^-$  asymmetric-energy storage rings. The results include the 90% confidence interval  $1.34 \times 10^{-6} < \mathcal{B}(B^0 \rightarrow X(3872)K^0, X \rightarrow J/\psi\pi^+\pi^-) < 10.3 \times 10^{-6}$  and the branching fraction  $\mathcal{B}(B^- \rightarrow X(3872)K^-, X \rightarrow J/\psi\pi^+\pi^-) = (10.1 \pm 2.5 \pm 1.0) \times 10^{-6}$ . We observe a  $(2.7 \pm 1.3 \pm 0.2)$  MeV/ $c^2$  mass difference of the  $X(3872)$  produced in the two decay modes. Furthermore, we search for the  $Y(4260)$  in  $B$  decays and set the 95% C.L. upper limit  $\mathcal{B}(B^- \rightarrow Y(4260)K^-, Y(4260) \rightarrow J/\psi\pi^+\pi^-) < 2.9 \times 10^{-5}$ .

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The  $X(3872)$  was first observed in the charged  $B$ -meson decay [1]  $B^- \rightarrow X(3872)K^-$ ,  $X(3872) \rightarrow J/\psi\pi^+\pi^-$  by the Belle Collaboration [2]. It has been confirmed by the *BABAR* Collaboration [3] and observed inclusively in the same final state by the CDF and D0 collaborations [4]. This narrow-width particle has a mass very near the  $D^0\bar{D}^{*0}$  threshold and decays into final states containing charmonium ( $J/\psi$ ). The most plausible interpretation [5] was a  $1^3D_2$  or  $1^1D_2$   $c\bar{c}$  state which would be narrow since it would be forbidden to decay into open charm  $D\bar{D}$  states. However, these candidates should have large radiative transitions into  $\chi_c$  states that have not been observed [2]. Recent studies from Belle that combine angular and kinematic properties of the  $\pi^+\pi^-$  mass, strongly favor a  $J^{PC} = 1^{++}$  state [7]. Other explanations include  $2^1P_1$   $c\bar{c}$  ( $1^{+-}$ ) or  $2^3P_1$   $1^{++}$  states that should be narrow, but are predicted to be about 100 MeV/ $c^2$  higher than the  $X(3872)$  mass and are not expected to have a large decay rate into  $J/\psi\pi\pi$  final states [6]. Hence, the  $X(3872)$  appears not to be a simple quark model  $q\bar{q}$  meson state.

Many explanations have been proposed for the nature of the  $X(3872)$ . Recent interpretations include the diquark-antidiquark model [8] and the S-wave  $D^0\bar{D}^{*0}$  molecule model [9]. The diquark-antidiquark model predicts a spectrum of  $J = 0, 1, 2$  particles and identifies the  $X(3872)$  as its  $1^{++}$  member state with the two quark combinations  $X_u = [cu][\bar{c}\bar{u}]$  and  $X_d = [cd][\bar{c}\bar{d}]$  with a mass difference  $m(X_d) - m(X_u) \approx (7 \pm 2)$  MeV/ $c^2$ . In addition, these two states could form mixed states that are produced in both charged and neutral  $B$ -meson decays with different masses and rates depending on the mixing angle. A search for the predicted charged partner of the  $X(3872)$  has been addressed in a previous analysis with an upper limit that is still consistent with the model [10]. The  $D^0\bar{D}^{*0}$  molecule model interprets the  $X(3872)$  as a loosely bound  $D^0\bar{D}^{*0}$  S-wave state that is produced in weak decays of the  $B$ -meson into  $D^0\bar{D}^{*0}K$ .

In this picture, the S-wave molecule must form a  $J^P = 1^+$  state. From factorization, heavy-quark symmetry, and isospin symmetry, the decay  $B^0 \rightarrow X(3872)K^0$  is predicted to be suppressed by an order of magnitude relative to  $B^- \rightarrow X(3872)K^-$  [9]. To investigate these predictions, we present in this letter a study of the neutral mode  $B^0 \rightarrow X(3872)K^0$ ,  $X(3872) \rightarrow J/\psi\pi^+\pi^-$  and we analyze  $B^- \rightarrow J/\psi\pi^+\pi^-K^-$  decays with increased statistics to obtain improved measurements of  $X(3872) \rightarrow J/\psi\pi^+\pi^-$ . In addition, we examine the higher  $J/\psi\pi^+\pi^-$  invariant mass region to search for a structure recently observed in initial state radiation (ISR) events [11].

The data were collected with the *BABAR* detector at the PEP-II asymmetric-energy  $e^+e^-$  storage rings on the  $\Upsilon(4S)$  resonance. The integrated luminosity of the data used in this analysis is  $211 \text{ fb}^{-1}$ ; this corresponds to the production of  $(232 \pm 3) \times 10^6$   $B\bar{B}$  pairs.

The *BABAR* detector is described in detail elsewhere [12]. Charged-particle trajectories are measured by a combination of a five-layer silicon vertex tracker (SVT) and a 40-layer drift chamber (DCH) in a 1.5-T solenoidal magnetic field. For charged-particle identification, we combine information from a ring-imaging Cherenkov detector (DIRC) and energy-loss measurements provided by the SVT and the DCH. Photons and electrons are detected in a CsI(Tl) electromagnetic calorimeter (EMC). Penetrating muons are identified by resistive-plate chambers in the instrumented magnetic flux return (IFR).

Charged pion candidates are required to be detected in at least 12 DCH layers and have a transverse momentum greater than 100 MeV/ $c$ . Kaons, electrons, and muons are separated from pions based on information from the IFR and DIRC, energy loss in the SVT and DCH ( $dE/dx$ ), or the ratio of the candidate EMC energy deposition to its momentum ( $E/p$ ). Photon candidates are identified with clusters in the EMC with total energy  $> 30$  MeV and a shower shape consistent with that expected from



a photon.

The  $B^0 \rightarrow J/\psi \pi^+ \pi^- K_s^0$  and  $B^- \rightarrow J/\psi \pi^+ \pi^- K^-$  decays are reconstructed in the following way. Electron candidates and bremsstrahlung photons satisfying  $2.95 < m(e^+ e^- (\gamma)) < 3.14 \text{ GeV}/c^2$  are used to form  $J/\psi \rightarrow e^+ e^-$  candidates. A pair of muon candidates within the mass interval  $3.06 < m(\mu^+ \mu^-) < 3.14 \text{ GeV}/c^2$  is required for a  $J/\psi \rightarrow \mu^+ \mu^-$  candidate. A mass constraint to the nominal  $J/\psi$  mass [13] is imposed in the fit of the lepton pairs. We reconstruct  $K_s^0 \rightarrow \pi^+ \pi^-$  candidates from pairs of oppositely charged tracks forming a vertex with a  $\chi^2$  probability larger than 0.1%, a flight-length significance  $l/\sigma(l) > 3$  and an invariant mass within  $15 \text{ MeV}/c^2$  of the nominal  $K_s^0$  mass [13].  $X(3872)$  candidates are formed by combining  $J/\psi$  candidates with two oppositely charged pion candidates fitted to a common vertex. Finally, we form  $B^0(B^-)$  candidates by combining  $X(3872)$  candidates with  $K_s^0(K^-)$  candidates. To suppress continuum background, we select only events with a ratio of the second to the zeroth Fox-Wolfram moment [14] less than 0.5.

We use two kinematic variables to identify signal events from  $B$  decays: the difference between the energy of the  $B$  candidate and the beam energy,  $\Delta E \equiv E_B^* - \sqrt{s}/2$ , and the energy-substituted mass  $m_{\text{ES}} \equiv \sqrt{(s/2 + \mathbf{p}_i \cdot \mathbf{p}_B)^2/E_i^2 - \mathbf{p}_B^2}$ . Here  $(E_i, \mathbf{p}_i)$  is the four-vector (in the laboratory frame) and  $\sqrt{s}$  is the center-of-mass (CM) energy of the  $e^+ e^-$  system.  $E_B^*$  is the energy of the  $B$  candidate in the CM system and  $\mathbf{p}_B$  the momentum in the laboratory frame. The signature of signal events is  $\Delta E \approx 0$ , and  $m_{\text{ES}} \approx m_B$  where  $m_B$  is the mass of the  $B$ -meson [13].

We optimize the signal selection criteria by maximizing the ratio  $n_s^{mc}/(3/2 + \sqrt{n_b^{mc}})$  [15] where  $n_s^{mc}$  ( $n_b^{mc}$ ) are the number of reconstructed Monte Carlo (MC) signal (background) events. The optimization was performed by varying the selection criteria on  $\Delta E$ ,  $m_{\text{ES}}$ , the candidate masses of the  $X(3872)$  and  $K_s^0$ , and the particle identification (PID) requirements of leptons, pions, and charged kaons. The criteria  $|\Delta E| < 15 \text{ MeV}$ ,  $|m_{\text{ES}} - m_B| < 6 \text{ MeV}/c^2$  and  $|m(J/\psi \pi^+ \pi^-) - 3872 \text{ MeV}/c^2| < 6 \text{ MeV}/c^2$  (signal region) were found to be optimal for selecting signal events. In case of multiple candidates in an event, we select the candidate with the smallest value of  $|\Delta E|$ . Applying our optimized selection criteria, we compute the  $J/\psi \pi^+ \pi^-$  invariant mass in the range  $3.8 - 3.95 \text{ GeV}/c^2$  shown in Figs. 1(a) and 1(b) for the  $B^-$  and  $B^0$  mode, respectively. The shaded area shows events in the sideband region  $|m_{\text{ES}} - 5260| < 6 \text{ MeV}/c^2$ .

We extract the number of signal events with an extended unbinned maximum-likelihood fit to the two-dimensional distribution  $y(m_{\text{ES}}, m_X)$  where  $m_X$  is the  $J/\psi \pi^+ \pi^-$  invariant mass. The probability density function (PDF) (normalized to the total number of events) is  $\mathcal{P}(y) = \sum_t n_t \mathcal{P}_t(y)$  where  $n_t$  is the number of events of category  $t$ . We consider three different event cate-

gories: signal,  $B$  decays with the same final-state particles as the signal that accumulate near  $m_{\text{ES}} \approx m_B$  (peaking background), and combinatorial background. The individual PDFs  $\mathcal{P}_t$  are assumed to be uncorrelated in  $m_{\text{ES}}$  and  $m_X$  and can therefore be factorized as  $\mathcal{P}_t(y) = g_t(m_{\text{ES}})h_t(m_X)$ , where  $g_t$  and  $h_t$  represent the  $m_{\text{ES}}$  and  $m_X$  probability distributions, respectively. The  $B \rightarrow X(3872)K$  signal events are modeled by a Gaussian distribution in  $m_{\text{ES}}$ . The resolution function in  $m_X$  for those events is best described by a Cauchy function [16] due to the mass constraint of the  $J/\psi$  candidate. The PDF for peaking background events is parameterized by a Gaussian distribution in  $m_{\text{ES}}$  and a linear function in  $m_X$ . We model combinatorial background events by an ARGUS function [17] in  $m_{\text{ES}}$  and a linear function in  $m_X$ . The fit performance was validated with MC experiments. The mean and width of the  $m_{\text{ES}}$  Gaussian distribution for signal and peaking background and the width of the  $m_X$  Cauchy distribution for the  $B^0$  mode were fixed to values obtained from MC samples. Other parameters are allowed to vary in the fit.

The fit is performed in the region  $5.2 < m_{\text{ES}} < 5.3 \text{ GeV}/c^2$  and  $3.80 < m_X < 3.95 \text{ GeV}/c^2$  without applying the optimized selection criteria on those two variables. The signal region projections of the two-dimensional fit are shown in Fig. 1 for the  $B^-$  (a,c) and  $B^0$  (b,d) modes. We obtain  $61.2 \pm 15.3$  signal events for the  $B^-$  mode ( $n_s^-$ ) and  $8.3 \pm 4.5$  signal events for the  $B^0$  mode ( $n_s^0$ ), respectively. In the following we interpret the observed events in the  $B^0$  mode as the  $X(3872)$ .

The efficiency is determined from MC samples with an  $X(3872)$  signal of zero width at  $3.872 \text{ GeV}/c^2$ . The decay model consists of the sequential isotropic decays  $B \rightarrow X(3872)K$ ,  $X(3872) \rightarrow J/\psi \rho^0$ , and  $\rho^0 \rightarrow \pi^+ \pi^-$ . Compared to a three-body decay, this gives a more accurate description of the observed  $\pi^+ \pi^-$  invariant mass distribution [3]. Efficiencies are corrected for the small differences in PID and tracking efficiencies that are found by comparing data and MC control samples. The final efficiencies are  $(17.4 \pm 0.2)\%$  for the  $B^0/K_s^0$  mode and  $(22.2 \pm 0.2)\%$  for the  $B^-/K^-$  mode.

The branching fraction systematic errors ( $B^-$ ,  $B^0$  mode in %) include uncertainties in the number of  $B\bar{B}$  events (1.1, 1.1), secondary branching fractions (5.0, 5.0) [13], efficiency calculation due to limited MC statistics (0.7, 1.9), MC decay model of the  $X(3872)$  (1.0, 1.6), differences between data and MC (1.8, 8.9), PID (5.0, 5.0), charged particle tracking (6.0, 4.8), and  $K_s^0$  reconstruction (-, 1.6). The production ratio of  $B^0$  and  $B^-$  mesons in  $\Upsilon(4S)$  decays is  $1.006 \pm 0.048$  [18]. The total fractional error obtained by adding the uncertainties in quadrature is 9.6% and 12.8% for the  $B^-$  and  $B^0$  mode, respectively.

Assuming Gaussian systematic errors with a PDF  $P_{sys}(n) \sim \exp[-(n - n_s)^2/2\sigma_{sys}^2]$ , the negative log-likelihood (NLL) function including systematic errors

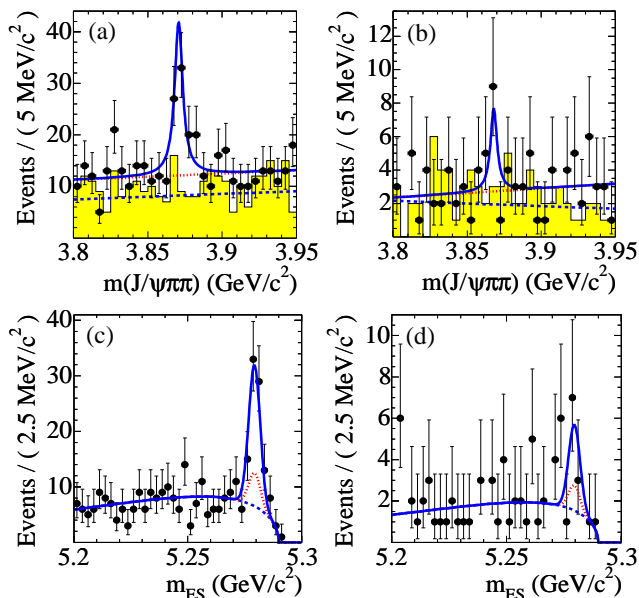


FIG. 1: Signal region projections of  $m(J/\psi\pi^+\pi^-)$  and  $m_{ES}$  for  $B^- \rightarrow X(3872)K^-$  (a,c) and  $B^0 \rightarrow X(3872)K_s^0$  (b,d). The dashed line represents the combinatorial background PDF, the dotted line represents the sum of the combinatorial and peaking background PDF, and the solid line the sum of all background plus the signal PDF. The shaded area shows events in the  $m_{ES}$  sideband region  $|m_{ES} - 5260 \text{ MeV}/c^2| < 6 \text{ MeV}/c^2$ .

is  $L_{sys} = ([1/L(n)] - [1/\ln P_{sys}(n)])^{-1}$  where  $L(n) = -\ln(\mathcal{L}(n)/\mathcal{L}_{max})$  is the NLL projection of the parameter estimate  $n$  of the number of signal events and  $\sigma_{sys}$  is the systematic error on the number of signal events. The significance including systematic errors obtained from  $\sqrt{2L_{sys}(n=0)}$  is  $2.5\sigma$  for the  $B^0$  mode and  $6.1\sigma$  for the  $B^-$  mode. The statistical significance ( $\sigma_{sys} = 0$ ) of the signal is  $2.6\sigma$  and  $7.5\sigma$ , respectively.

Using  $n_S^0$  and  $n_S^-$ , the efficiencies, the secondary branching fractions and the number of  $B\bar{B}$  events, we obtain the branching fractions  $\mathcal{B}^0 \equiv \mathcal{B}(B^0 \rightarrow X(3872)K^0, X \rightarrow J/\psi\pi^+\pi^-) = (5.1 \pm 2.8 \pm 0.7) \times 10^{-6}$  and  $\mathcal{B}^- \equiv \mathcal{B}(B^- \rightarrow X(3872)K^-, X \rightarrow J/\psi\pi^+\pi^-) = (10.1 \pm 2.5 \pm 1.0) \times 10^{-6}$ . For the ratio of branching fractions,  $R \equiv \mathcal{B}^0/\mathcal{B}^-$ , where most of the systematic errors cancel, we obtain  $R = 0.50 \pm 0.30 \pm 0.05$ . We calculate a 90% confidence level (C.L.) likelihood interval [19]  $[n_l, n_h]$  for the number of signal events in the  $B^0$  mode by solving the equation  $2L_{sys}(n_{l,h}) = [\text{erf}^{-1}(0.95)]^2$ . With  $n_l = 2.2$  and  $n_h = 16.9$  the 90% C.L. interval on  $\mathcal{B}^0$  is  $1.34 \times 10^{-6} < \mathcal{B}^0 < 10.3 \times 10^{-6}$ . Using the same strategy, the confidence interval on the ratio of branching fractions becomes  $0.13 < R < 1.10$  at 90% C.L.

We measure the mass of the  $X(3872)$  in both modes in reference to the precisely measured  $\psi(2S)$  mass [13]. We fit the  $J/\psi\pi^+\pi^-$  invariant mass in the  $\psi(2S)$  and

$X(3872)$  region and calculate  $m_X = m_{X,\text{fit}} - m_{\psi(2S),\text{fit}} + m_{\psi(2S)}$ . The result for the  $B^0$  mode is  $(3868.6 \pm 1.2 \pm 0.2) \text{ MeV}/c^2$  and  $(3871.3 \pm 0.6 \pm 0.1) \text{ MeV}/c^2$  for the  $B^-$  mode, where the first error is the statistical uncertainty on  $m_{X,\text{fit}}$  and the second is the uncertainty on  $m_{\psi(2S),\text{fit}}$  and  $m_{\psi(2S)}$  [13]. The mass difference of the  $X(3872)$  produced in  $B^0$  and  $B^-$  decays is  $\Delta m = (2.7 \pm 1.3 \pm 0.2) \text{ MeV}/c^2$ . The full width at half maximum of the  $X$ -mass distribution from the fit on data is  $(6.7 \pm 2.7) \text{ MeV}/c^2$ , which is consistent with the MC-determined value of  $(5.4 \pm 0.1) \text{ MeV}/c^2$ . From this we calculate the 90% C.L. upper limit on the natural width as  $\Gamma < 4.1 \text{ MeV}/c^2$ .

Recent observations by BABAR [11] in ISR events provide evidence for at least one broad resonance in the invariant mass spectrum of  $J/\psi\pi^+\pi^-$  at  $4.259 \text{ GeV}/c^2$  that can be characterized by a single resonance with a full width of  $88 \text{ MeV}/c^2$ . This structure is referred to as  $Y(4260)$ . We search in  $B^-$  decays for states decaying into  $J/\psi\pi^+\pi^-$  above  $4 \text{ GeV}/c^2$  and impose the additional selection criterion  $|m(K^-\pi^+\pi^-) - 1273 \text{ MeV}/c^2| > 250 \text{ MeV}/c^2$ , which removes backgrounds from  $K_1(1270)$  decays. In the resulting mass distribution, Fig. 2, we observe large combinatoric backgrounds and cannot reliably determine the parameters of one or more resonances. We use a two-dimensional PDF identical to the previous model, but fix the central value and width of the signal component to the ISR results [11]. The natural width of  $88 \text{ MeV}/c^2$  has been enlarged by the detector resolution, which is found to be the same as for the mass region around  $3.87 \text{ GeV}/c^2$ . The  $m_X$  projection of the two-dimensional fit is overlaid in Fig. 2 and yields  $128 \pm 42$  signal events. The statistical significance calculated from  $\sqrt{-2 \ln \mathcal{L}_0/\mathcal{L}}$  is  $3.1\sigma$  where  $\mathcal{L}$  and  $\mathcal{L}_0$  are the maximum likelihood of the fit and the null hypothesis fit, respectively. Using a phase-space MC simulation of a state at  $4.26 \text{ GeV}/c^2$  decaying into  $J/\psi\pi^+\pi^-$  and assuming the same systematic uncertainties and efficiency corrections as for the  $X(3872)$ , we obtain the 95% C.L. upper limit on the branching fraction  $\mathcal{B}_Y = \mathcal{B}(B^- \rightarrow Y(4260)K^-, Y(4260) \rightarrow J/\psi\pi^+\pi^-) < 2.9 \times 10^{-5}$ . The 90% C.L. likelihood interval on the branching fraction  $\mathcal{B}_Y = (2.0 \pm 0.7 \pm 0.2) \times 10^{-5}$  is  $1.2 \times 10^{-5} < \mathcal{B}_Y < 2.9 \times 10^{-5}$ .

In conclusion, our studies of the  $J/\psi\pi^+\pi^-$  invariant mass below  $4 \text{ GeV}/c^2$  yield a signal of  $2.5\sigma$  and  $6.1\sigma$  significance in the  $B^0$  and  $B^-$  mode, respectively, with a ratio of branching fractions  $R = 0.50 \pm 0.30 \pm 0.05$ . We observe an excess of events above background in the  $J/\psi\pi^+\pi^-$  invariant mass between  $4.2$  and  $4.4 \text{ GeV}/c^2$ . These events are consistent with the broad structure observed in ISR events [11].

If one narrow state is observed in the mode  $B^- \rightarrow X(3872)K^-$ ,  $X \rightarrow J/\psi\pi^+\pi^-$ , the diquark-antidiquark model [8] predicts one amplitude (from  $X_d$  or  $X_u$ ) to be dominant in the charged mode and the other amplitude

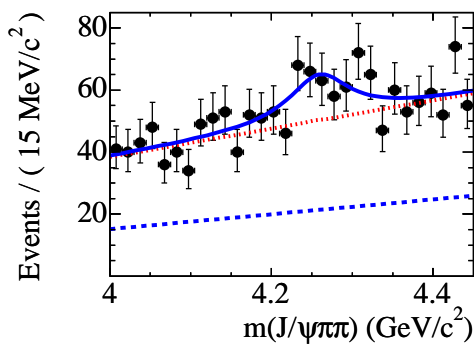


FIG. 2: Projection of the two-dimensional fit for the mass region above  $4 \text{ GeV}/c^2$  for events within the  $m_{ES}$  signal region in  $B^- \rightarrow J/\psi \pi^+ \pi^- K^-$ . The lines represent the same event types as in Fig. 1.

to be dominant in the neutral mode. In this case, the model predicts the relative rates to be equal ( $R = 1$ ) and the mass difference to be  $(7 \pm 2) \text{ MeV}/c^2$ . The ratio of branching fractions is consistent with our measurement,  $0.13 < R < 1.10$  at 90% C.L., and the observed mass difference of  $(2.7 \pm 1.3 \pm 0.2) \text{ MeV}/c^2$  is both consistent with zero and the model prediction within two standard deviations. In the S-wave molecule model [9], the neutral mode branching fraction is predicted to be at least 10 times smaller ( $R < 0.1$ ) than the charged mode. However, we obtain a ratio of neutral to charged branching fractions which is slightly more consistent with isospin-conserving decays.

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\* Also with Università di Perugia, Dipartimento di Fisica, Perugia, Italy

† Also with Università della Basilicata, Potenza, Italy

‡ Deceased

- [1] Charge conjugate reactions are included implicitly throughout.
- [2] Belle Collaboration, S. K. Choi *et al.*, Phys. Rev. Lett. **91**, 262001 (2003).
- [3] *BABAR* Collaboration, B. Aubert *et al.*, Phys. Rev. **D71**, 071103 (2005).
- [4] CDF Collaboration, D. Acosta *et al.*, Phys. Rev. Lett. **93**, 072001 (2004). D0 Collaboration, V. M. Abazov *et al.*, Phys. Rev. Lett. **93**, 162002 (2004).
- [5] E. J. Eichten, K. Lane, and C. Quigg, Phys. Rev. **D69**, 094019 (2004);
- [6] T. Barnes and S. Godfrey, Phys. Rev. **D69**, 054008, (2004); T. Barnes, S. Godfrey, and E.S. Swanson, hep-ph/0505002 (2005).
- [7] Belle Collaboration, K. Abe *et al.*, hep-ex/0505038 (2005).
- [8] L. Maiani, F. Piccinini, A. D. Polosa, and V. Riquer, Phys. Rev. **D71**, 014028 (2005).
- [9] E. Braaten and M. Kusunoki, Phys. Rev. **D71**, 074005 (2005).
- [10] *BABAR* Collaboration, B. Aubert *et al.*, Phys. Rev. **D71**, 031501 (2005).
- [11] *BABAR* Collaboration, B. Aubert *et al.*, Phys. Rev. Lett. **95**, 142001 (2005).
- [12] *BABAR* Collaboration, B. Aubert *et al.*, Nucl. Instrum. Meth. **A479**, 1 (2002).
- [13] Particle Data Group, K. Eidelman *et al.*, Phys. Lett. **B592**, 1 (2004).
- [14] S. Wolfram and G.C. Fox, Nucl. Phys. **B149**, 413 (1979).
- [15] G. Punzi, physics/0308063 (2003). The value of 3/2 corresponds to an optimization for a signal of  $3\sigma$  significance.
- [16] A non-relativistic Breit-Wigner shape.
- [17] ARGUS Collaboration, H. Albrecht *et al.*, Phys. Lett. B **185**, 218(1987); Phys. Lett. B **241**, 278 (1990).
- [18] *BABAR* Collaboration, B. Aubert *et al.*, Phys. Rev. **D69**, 071101 (2004).
- [19] G. Cowan, *Statistical Data Analysis* (Oxford Science Publications, 1998).