

# Searches for Lepton Flavor Violation in the Decays $\tau^\pm \rightarrow e^\pm \gamma$ and $\tau^\pm \rightarrow \mu^\pm \gamma$

B. Aubert,<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> M. Martinelli<sup>ab,3</sup> A. Palano<sup>ab,3</sup> M. Pappagallo<sup>ab,3</sup> G. Eigen,<sup>4</sup> B. Stugu,<sup>4</sup> L. Sun,<sup>4</sup> M. Battaglia,<sup>5</sup> D. N. Brown,<sup>5</sup> B. Hooberman,<sup>5</sup> L. T. Kerth,<sup>5</sup> Yu. G. Kolomensky,<sup>5</sup> G. Lynch,<sup>5</sup> I. L. Osipenkov,<sup>5</sup> K. Tackmann,<sup>5</sup> T. Tanabe,<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. J. Asgeirsson,<sup>8</sup> C. Hearty,<sup>8</sup> T. S. Mattison,<sup>8</sup> J. A. McKenna,<sup>8</sup> M. Barrett,<sup>9</sup> A. Khan,<sup>9</sup> A. Randle-Conde,<sup>9</sup> V. E. Blinov,<sup>10</sup> A. D. Bukin,<sup>10,\*</sup> A. R. Buzykaev,<sup>10</sup> V. P. Druzhinin,<sup>10</sup> V. B. Golubev,<sup>10</sup> A. P. Onuchin,<sup>10</sup> S. I. Serednyakov,<sup>10</sup> Yu. I. Skovpen,<sup>10</sup> E. P. Solodov,<sup>10</sup> K. Yu. Todyshev,<sup>10</sup> M. Bondioli,<sup>11</sup> S. Curry,<sup>11</sup> I. Eschrich,<sup>11</sup> D. Kirkby,<sup>11</sup> A. J. Lankford,<sup>11</sup> P. Lund,<sup>11</sup> M. Mandelkern,<sup>11</sup> E. C. Martin,<sup>11</sup> D. P. Stoker,<sup>11</sup> H. Atmacan,<sup>12</sup> J. W. Gary,<sup>12</sup> F. Liu,<sup>12</sup> O. Long,<sup>12</sup> G. M. Vitug,<sup>12</sup> Z. Yasin,<sup>12</sup> V. Sharma,<sup>13</sup> C. Campagnari,<sup>14</sup> T. M. Hong,<sup>14</sup> D. Kovalskyi,<sup>14</sup> M. A. Mazur,<sup>14</sup> J. D. Richman,<sup>14</sup> T. W. Beck,<sup>15</sup> A. M. Eisner,<sup>15</sup> C. A. Heusch,<sup>15</sup> J. Kroseberg,<sup>15</sup> W. S. Lockman,<sup>15</sup> A. J. Martinez,<sup>15</sup> T. Schalk,<sup>15</sup> B. A. Schumm,<sup>15</sup> A. Seiden,<sup>15</sup> L. Wang,<sup>15</sup> L. O. Winstrom,<sup>15</sup> C. H. Cheng,<sup>16</sup> D. A. Doll,<sup>16</sup> B. Echenard,<sup>16</sup> F. Fang,<sup>16</sup> D. G. Hitlin,<sup>16</sup> I. Narsky,<sup>16</sup> P. Ongmongkolkul,<sup>16</sup> T. Piatenko,<sup>16</sup> F. C. Porter,<sup>16</sup> R. Andreassen,<sup>17</sup> G. Mancinelli,<sup>17</sup> B. T. Meadows,<sup>17</sup> K. Mishra,<sup>17</sup> M. D. Sokoloff,<sup>17</sup> P. C. Bloom,<sup>18</sup> W. T. Ford,<sup>18</sup> A. Gaz,<sup>18</sup> J. F. Hirschauer,<sup>18</sup> M. Nagel,<sup>18</sup> U. Nauenberg,<sup>18</sup> J. G. Smith,<sup>18</sup> S. R. Wagner,<sup>18</sup> R. Ayad,<sup>19,†</sup> W. H. Toki,<sup>19</sup> E. Feltresi,<sup>20</sup> A. Hauke,<sup>20</sup> H. Jasper,<sup>20</sup> T. M. Karbach,<sup>20</sup> J. Merkel,<sup>20</sup> A. Petzold,<sup>20</sup> B. Spaan,<sup>20</sup> K. Wacker,<sup>20</sup> M. J. Kobel,<sup>21</sup> R. Nogowski,<sup>21</sup> K. R. Schubert,<sup>21</sup> R. Schwierz,<sup>21</sup> D. Bernard,<sup>22</sup> E. Latour,<sup>22</sup> M. Verderi,<sup>22</sup> P. J. Clark,<sup>23</sup> S. Playfer,<sup>23</sup> J. E. Watson,<sup>23</sup> M. Andreotti<sup>ab,24</sup> D. Bettoni<sup>a,24</sup> C. Bozzi<sup>a,24</sup> R. Calabrese<sup>ab,24</sup> A. Cecchi<sup>ab,24</sup> G. Cibinetto<sup>ab,24</sup> E. Fioravanti<sup>ab,24</sup> P. Franchini<sup>ab,24</sup> E. Luppi<sup>ab,24</sup> M. Munerato<sup>ab,24</sup> M. Negrini<sup>ab,24</sup> A. Petrella<sup>ab,24</sup> L. Piemontese<sup>a,24</sup> V. Santoro<sup>ab,24</sup> R. Baldini-Feroli,<sup>25</sup> A. Calcaterra,<sup>25</sup> R. de Sangro,<sup>25</sup> G. Finocchiaro,<sup>25</sup> S. Pacetti,<sup>25</sup> P. Patteri,<sup>25</sup> I. M. Peruzzi,<sup>25,‡</sup> M. Piccolo,<sup>25</sup> M. Rama,<sup>25</sup> A. Zallo,<sup>25</sup> R. Contri<sup>ab,26</sup> E. Guido,<sup>26</sup> M. Lo Vetere<sup>ab,26</sup> M. R. Monge<sup>ab,26</sup> S. Passaggio<sup>a,26</sup> C. Patrignani<sup>ab,26</sup> E. Robutti<sup>a,26</sup> S. Tosi<sup>ab,26</sup> M. Morii,<sup>27</sup> A. Adametz,<sup>28</sup> J. Marks,<sup>28</sup> S. Schenk,<sup>28</sup> U. Uwer,<sup>28</sup> F. U. Bernlochner,<sup>29</sup> H. M. Lacker,<sup>29</sup> T. Lueck,<sup>29</sup> A. Volk,<sup>29</sup> P. D. Dauncey,<sup>30</sup> M. Tibbetts,<sup>30</sup> P. K. Behera,<sup>31</sup> M. J. Charles,<sup>31</sup> U. Mallik,<sup>31</sup> J. Cochran,<sup>32</sup> H. B. Crawley,<sup>32</sup> L. Dong,<sup>32</sup> V. Eyges,<sup>32</sup> W. T. Meyer,<sup>32</sup> S. Prell,<sup>32</sup> E. I. Rosenberg,<sup>32</sup> A. E. Rubin,<sup>32</sup> Y. Y. Gao,<sup>33</sup> A. V. Gritsan,<sup>33</sup> Z. J. Guo,<sup>33</sup> N. Arnaud,<sup>34</sup> A. D'Orazio,<sup>34</sup> M. Davier,<sup>34</sup> D. Derkach,<sup>34</sup> J. Firmino da Costa,<sup>34</sup> G. Grosdidier,<sup>34</sup> F. Le Diberder,<sup>34</sup> V. Lepeltier,<sup>34</sup> A. M. Lutz,<sup>34</sup> B. Malaescu,<sup>34</sup> P. Roudeau,<sup>34</sup> M. H. Schune,<sup>34</sup> J. Serrano,<sup>34</sup> V. Sordini,<sup>34,§</sup> A. Stocchi,<sup>34</sup> G. Wormser,<sup>34</sup> D. J. Lange,<sup>35</sup> D. M. Wright,<sup>35</sup> I. Bingham,<sup>36</sup> J. P. Burke,<sup>36</sup> C. A. Chavez,<sup>36</sup> J. R. Fry,<sup>36</sup> E. Gabathuler,<sup>36</sup> R. Gamet,<sup>36</sup> D. E. Hutchcroft,<sup>36</sup> D. J. Payne,<sup>36</sup> C. Touramanis,<sup>36</sup> A. J. Bevan,<sup>37</sup> C. K. Clarke,<sup>37</sup> F. Di Lodovico,<sup>37</sup> R. Sacco,<sup>37</sup> M. Sigamani,<sup>37</sup> G. Cowan,<sup>38</sup> S. Paramesvaran,<sup>38</sup> A. C. Wren,<sup>38</sup> D. N. Brown,<sup>39</sup> C. L. Davis,<sup>39</sup> A. G. Denig,<sup>40</sup> M. Fritsch,<sup>40</sup> W. Gradl,<sup>40</sup> A. Hafner,<sup>40</sup> K. E. Alwyn,<sup>41</sup> D. Bailey,<sup>41</sup> R. J. Barlow,<sup>41</sup> G. Jackson,<sup>41</sup> G. D. Lafferty,<sup>41</sup> T. J. West,<sup>41</sup> J. I. Yi,<sup>41</sup> J. Anderson,<sup>42</sup> C. Chen,<sup>42</sup> A. Jawahery,<sup>42</sup> D. A. Roberts,<sup>42</sup> G. Simi,<sup>42</sup> J. M. Tuggle,<sup>42</sup> C. Dallapiccola,<sup>43</sup> E. Salvati,<sup>43</sup> R. Cowan,<sup>44</sup> D. Dujmic,<sup>44</sup> P. H. Fisher,<sup>44</sup> S. W. Henderson,<sup>44</sup> G. Sciolla,<sup>44</sup> M. Spitznagel,<sup>44</sup> R. K. Yamamoto,<sup>44</sup> M. Zhao,<sup>44</sup> P. M. Patel,<sup>45</sup> S. H. Robertson,<sup>45</sup> M. Schram,<sup>45</sup> P. Biassoni<sup>ab,46</sup> A. Lazzaro<sup>ab,46</sup> V. Lombardo<sup>a,46</sup> F. Palombo<sup>ab,46</sup> S. Stracka<sup>ab,46</sup> L. Cremaldi,<sup>47</sup> R. Godang,<sup>47,¶</sup> R. Kroeger,<sup>47</sup> P. Sonnek,<sup>47</sup> D. J. Summers,<sup>47</sup> H. W. Zhao,<sup>47</sup> X. Nguyen,<sup>48</sup> M. Simard,<sup>48</sup> P. Taras,<sup>48</sup> H. Nicholson,<sup>49</sup> G. De Nardo<sup>ab,50</sup> L. Lista<sup>a,50</sup> D. Monorchio<sup>ab,50</sup> G. Onorato<sup>ab,50</sup> C. Sciacca<sup>ab,50</sup> G. Raven,<sup>51</sup> H. L. Snoek,<sup>51</sup> C. P. Jessop,<sup>52</sup> K. J. Knoepfel,<sup>52</sup> J. M. LoSecco,<sup>52</sup> W. F. Wang,<sup>52</sup> L. A. Corwin,<sup>53</sup> K. Honscheid,<sup>53</sup> H. Kagan,<sup>53</sup> R. Kass,<sup>53</sup> J. P. Morris,<sup>53</sup> A. M. Rahimi,<sup>53</sup> S. J. Sekula,<sup>53</sup> N. L. Blount,<sup>54</sup> J. Brau,<sup>54</sup> R. Frey,<sup>54</sup> O. Igonkina,<sup>54</sup> J. A. Kolb,<sup>54</sup> M. Lu,<sup>54</sup> R. Rahmat,<sup>54</sup> N. B. Sinev,<sup>54</sup> D. Strom,<sup>54</sup> J. Strube,<sup>54</sup> E. Torrence,<sup>54</sup> G. Castelli<sup>ab,55</sup> N. Gagliardi<sup>ab,55</sup> M. Margoni<sup>ab,55</sup> M. Morandin<sup>a,55</sup> M. Posocco<sup>a,55</sup> M. Rotondo<sup>a,55</sup> F. Simonetto<sup>ab,55</sup> R. Stroili<sup>ab,55</sup> C. Voci<sup>ab,55</sup> P. del Amo Sanchez,<sup>56</sup> E. Ben-Haim,<sup>56</sup> G. R. Bonneaud,<sup>56</sup> H. Briand,<sup>56</sup> J. Chauveau,<sup>56</sup> O. Hamon,<sup>56</sup> Ph. Leruste,<sup>56</sup> G. Marchiori,<sup>56</sup> J. Ocariz,<sup>56</sup> A. Perez,<sup>56</sup> J. Prendki,<sup>56</sup> S. Sitt,<sup>56</sup> L. Gladney,<sup>57</sup> M. Biasini<sup>ab,58</sup> E. Manoni<sup>ab,58</sup> C. Angelini<sup>ab,59</sup> G. Batignani<sup>ab,59</sup>

S. Bettarini<sup>ab,59</sup> G. Calderini<sup>ab,59,\*\*</sup> M. Carpinelli<sup>ab,59,††</sup> A. Cervelli<sup>ab,59</sup> F. Forti<sup>ab,59</sup> M. A. Giorgi<sup>ab,59</sup>  
 A. Lusiani<sup>ac,59</sup> M. Morganti<sup>ab,59</sup> N. Neri<sup>ab,59</sup> E. Paoloni<sup>ab,59</sup> G. Rizzo<sup>ab,59</sup> J. J. Walsh<sup>a,59</sup> D. Lopes Pegna,<sup>60</sup>  
 C. Lu,<sup>60</sup> J. Olsen,<sup>60</sup> A. J. S. Smith,<sup>60</sup> A. V. Telnov,<sup>60</sup> F. Anulli<sup>a,61</sup> E. Baracchini<sup>ab,61</sup> G. Cavoto<sup>a,61</sup> R. Faccini<sup>ab,61</sup>  
 F. Ferrarotto<sup>a,61</sup> F. Ferroni<sup>ab,61</sup> M. Gaspero<sup>ab,61</sup> P. D. Jackson<sup>a,61</sup> L. Li Gioi<sup>a,61</sup> M. A. Mazzoni<sup>a,61</sup> S. Morganti<sup>a,61</sup>  
 G. Piredda<sup>a,61</sup> F. Renga<sup>ab,61</sup> C. Voena<sup>a,61</sup> M. Ebert,<sup>62</sup> T. Hartmann,<sup>62</sup> H. Schröder,<sup>62</sup> R. Waldi,<sup>62</sup> T. Adye,<sup>63</sup>  
 B. Franek,<sup>63</sup> E. O. Olaiya,<sup>63</sup> F. F. Wilson,<sup>63</sup> S. Emery,<sup>64</sup> L. Esteve,<sup>64</sup> G. Hamel de Monchenault,<sup>64</sup> W. Kozanecki,<sup>64</sup>  
 G. Vasseur,<sup>64</sup> Ch. Yèche,<sup>64</sup> M. Zito,<sup>64</sup> M. T. Allen,<sup>65</sup> D. Aston,<sup>65</sup> D. J. Bard,<sup>65</sup> R. Bartoldus,<sup>65</sup> J. F. Benitez,<sup>65</sup>  
 R. Cenci,<sup>65</sup> J. P. Coleman,<sup>65</sup> M. R. Convery,<sup>65</sup> J. C. Dingfelder,<sup>65</sup> J. Dorfan,<sup>65</sup> G. P. Dubois-Felsmann,<sup>65</sup>  
 W. Dunwoodie,<sup>65</sup> R. C. Field,<sup>65</sup> M. Franco Sevilla,<sup>65</sup> B. G. Fulsom,<sup>65</sup> A. M. Gabareen,<sup>65</sup> M. T. Graham,<sup>65</sup>  
 P. Grenier,<sup>65</sup> C. Hast,<sup>65</sup> W. R. Innes,<sup>65</sup> J. Kaminski,<sup>65</sup> M. H. Kelsey,<sup>65</sup> H. Kim,<sup>65</sup> P. Kim,<sup>65</sup> M. L. Kocian,<sup>65</sup>  
 D. W. G. S. Leith,<sup>65</sup> S. Li,<sup>65</sup> B. Lindquist,<sup>65</sup> S. Luitz,<sup>65</sup> V. Luth,<sup>65</sup> H. L. Lynch,<sup>65</sup> D. B. MacFarlane,<sup>65</sup>  
 H. Marsiske,<sup>65</sup> R. Messner,<sup>65,\*</sup> D. R. Muller,<sup>65</sup> H. Neal,<sup>65</sup> S. Nelson,<sup>65</sup> C. P. O'Grady,<sup>65</sup> I. Ofte,<sup>65</sup> M. Perl,<sup>65</sup>  
 B. N. Ratcliff,<sup>65</sup> A. Roodman,<sup>65</sup> A. A. Salmikov,<sup>65</sup> R. H. Schindler,<sup>65</sup> J. Schwiening,<sup>65</sup> A. Snyder,<sup>65</sup> D. Su,<sup>65</sup>  
 M. K. Sullivan,<sup>65</sup> K. Suzuki,<sup>65</sup> S. K. Swain,<sup>65</sup> J. M. Thompson,<sup>65</sup> J. Va'vra,<sup>65</sup> A. P. Wagner,<sup>65</sup> M. Weaver,<sup>65</sup>  
 C. A. West,<sup>65</sup> W. J. Wisniewski,<sup>65</sup> M. Wittgen,<sup>65</sup> D. H. Wright,<sup>65</sup> H. W. Wulsin,<sup>65</sup> A. K. Yarritu,<sup>65</sup> C. C. Young,<sup>65</sup>  
 V. Ziegler,<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. Bellis,<sup>67</sup>  
 P. R. Burchat,<sup>67</sup> A. J. Edwards,<sup>67</sup> T. S. Miyashita,<sup>67</sup> S. Ahmed,<sup>68</sup> M. S. Alam,<sup>68</sup> J. A. Ernst,<sup>68</sup> B. Pan,<sup>68</sup>  
 M. A. Saeed,<sup>68</sup> S. B. Zain,<sup>68</sup> A. Soffer,<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. C. Wray,<sup>71</sup> B. W. Drummond,<sup>72</sup> J. M. Izen,<sup>72</sup>  
 X. C. Lou,<sup>72</sup> F. Bianchi<sup>ab,73</sup> D. Gamba<sup>ab,73</sup> M. Pelliccioni<sup>ab,73</sup> M. Bomben<sup>ab,74</sup> L. Bosisio<sup>ab,74</sup> C. Cartaro<sup>ab,74</sup>  
 G. Della Ricca<sup>ab,74</sup> L. Lanceri<sup>ab,74</sup> L. Vitale<sup>ab,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>  
 G. J. King,<sup>76</sup> R. Kowalewski,<sup>76</sup> M. J. Lewczuk,<sup>76</sup> C. D. Lindsay,<sup>76</sup> C. B. Locke,<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> E. M. T. Puccio,<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> 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 d'Annecy-le-Vieux de Physique des Particules (LAPP),

Université de Savoie, CNRS/IN2P3, F-74941 Annecy-Le-Vieux, France

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

<sup>3</sup>INFN Sezione di Bari<sup>a</sup>; Dipartimento di Fisica, Università di Bari<sup>b</sup>, 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 British Columbia, Vancouver, British Columbia, Canada V6T 1Z1

<sup>9</sup>Brunel University, Uxbridge, Middlesex UB8 3PH, United Kingdom

<sup>10</sup>Budker Institute of Nuclear Physics, Novosibirsk 630090, Russia

<sup>11</sup>University of California at Irvine, Irvine, California 92697, USA

<sup>12</sup>University of California at Riverside, Riverside, California 92521, USA

<sup>13</sup>University of California at San Diego, La Jolla, California 92093, USA

<sup>14</sup>University of California at Santa Barbara, Santa Barbara, California 93106, USA

<sup>15</sup>University of California at Santa Cruz, Institute for Particle Physics, Santa Cruz, California 95064, USA

<sup>16</sup>California Institute of Technology, Pasadena, California 91125, USA

<sup>17</sup>University of Cincinnati, Cincinnati, Ohio 45221, USA

<sup>18</sup>University of Colorado, Boulder, Colorado 80309, USA

<sup>19</sup>Colorado State University, Fort Collins, Colorado 80523, USA

<sup>20</sup>Technische Universität Dortmund, Fakultät Physik, D-44221 Dortmund, Germany

<sup>21</sup>Technische Universität Dresden, Institut für Kern- und Teilchenphysik, D-01062 Dresden, Germany

<sup>22</sup>Laboratoire Leprince-Ringuet, CNRS/IN2P3, Ecole Polytechnique, F-91128 Palaiseau, France

<sup>23</sup>University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom

<sup>24</sup>INFN Sezione di Ferrara<sup>a</sup>; Dipartimento di Fisica, Università di Ferrara<sup>b</sup>, I-44100 Ferrara, Italy

<sup>25</sup>INFN Laboratori Nazionali di Frascati, I-00044 Frascati, Italy

<sup>26</sup>INFN Sezione di Genova<sup>a</sup>; Dipartimento di Fisica, Università di Genova<sup>b</sup>, I-16146 Genova, Italy

<sup>27</sup>Harvard University, Cambridge, Massachusetts 02138, USA

<sup>28</sup>Universität Heidelberg, Physikalisches Institut, Philosophenweg 12, D-69120 Heidelberg, Germany

<sup>29</sup>Humboldt-Universität zu Berlin, Institut für Physik, Newtonstr. 15, D-12489 Berlin, Germany

<sup>30</sup>Imperial College London, London, SW7 2AZ, United Kingdom

- <sup>31</sup> University of Iowa, Iowa City, Iowa 52242, USA  
<sup>32</sup> Iowa State University, Ames, Iowa 50011-3160, USA  
<sup>33</sup> Johns Hopkins University, Baltimore, Maryland 21218, USA  
<sup>34</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>35</sup> Lawrence Livermore National Laboratory, Livermore, California 94550, USA  
<sup>36</sup> University of Liverpool, Liverpool L69 7ZE, United Kingdom  
<sup>37</sup> Queen Mary, University of London, London, E1 4NS, United Kingdom  
<sup>38</sup> University of London, Royal Holloway and Bedford New College, Egham, Surrey TW20 0EX, United Kingdom  
<sup>39</sup> University of Louisville, Louisville, Kentucky 40292, USA  
<sup>40</sup> Johannes Gutenberg-Universität Mainz, Institut für Kernphysik, D-55099 Mainz, Germany  
<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, Québec, Canada H3A 2T8  
<sup>46</sup> INFN Sezione di Milano<sup>a</sup>; Dipartimento di Fisica, Università di Milano<sup>b</sup>, I-20133 Milano, Italy  
<sup>47</sup> University of Mississippi, University, Mississippi 38677, USA  
<sup>48</sup> Université de Montréal, Physique des Particules, Montréal, Québec, Canada H3C 3J7  
<sup>49</sup> Mount Holyoke College, South Hadley, Massachusetts 01075, USA  
<sup>50</sup> INFN Sezione di Napoli<sup>a</sup>; Dipartimento di Scienze Fisiche, Università di Napoli Federico II<sup>b</sup>, 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> INFN Sezione di Padova<sup>a</sup>; Dipartimento di Fisica, Università di Padova<sup>b</sup>, I-35131 Padova, Italy  
<sup>56</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>57</sup> University of Pennsylvania, Philadelphia, Pennsylvania 19104, USA  
<sup>58</sup> INFN Sezione di Perugia<sup>a</sup>; Dipartimento di Fisica, Università di Perugia<sup>b</sup>, I-06100 Perugia, Italy  
<sup>59</sup> INFN Sezione di Pisa<sup>a</sup>; Dipartimento di Fisica, Università di Pisa<sup>b</sup>; Scuola Normale Superiore di Pisa<sup>c</sup>, I-56127 Pisa, Italy  
<sup>60</sup> Princeton University, Princeton, New Jersey 08544, USA  
<sup>61</sup> INFN Sezione di Roma<sup>a</sup>; Dipartimento di Fisica, Università di Roma La Sapienza<sup>b</sup>, I-00185 Roma, Italy  
<sup>62</sup> Universität Rostock, D-18051 Rostock, Germany  
<sup>63</sup> Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, OX11 0QX, United Kingdom  
<sup>64</sup> CEA, Irfu, SPP, Centre de Saclay, F-91191 Gif-sur-Yvette, France  
<sup>65</sup> SLAC National Accelerator Laboratory, Stanford, California 94309 USA  
<sup>66</sup> University of South Carolina, Columbia, South Carolina 29208, USA  
<sup>67</sup> Stanford University, Stanford, California 94305-4060, USA  
<sup>68</sup> State University of New York, Albany, New York 12222, USA  
<sup>69</sup> Tel Aviv University, School of Physics and Astronomy, Tel Aviv, 69978, Israel  
<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> INFN Sezione di Torino<sup>a</sup>; Dipartimento di Fisica Sperimentale, Università di Torino<sup>b</sup>, I-10125 Torino, Italy  
<sup>74</sup> INFN Sezione di Trieste<sup>a</sup>; Dipartimento di Fisica, Università di Trieste<sup>b</sup>, 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

(Dated: January 25, 2010)

Searches for lepton-flavor-violating decays of a  $\tau$  lepton to a lighter mass lepton and a photon have been performed with the entire dataset of  $(963 \pm 7) \times 10^6$   $\tau$  decays collected by the BABAR detector near the  $\Upsilon(4S)$ ,  $\Upsilon(3S)$  and  $\Upsilon(2S)$  resonances. The searches yield no evidence of signals and we set upper limits on the branching fractions of  $\mathcal{B}(\tau^\pm \rightarrow e^\pm \gamma) < 3.3 \times 10^{-8}$  and  $\mathcal{B}(\tau^\pm \rightarrow \mu^\pm \gamma) < 4.4 \times 10^{-8}$  at 90% confidence level.

PACS numbers: 13.35.Dx, 14.60.Fg, 11.30.Hv

Amongst all the possible lepton-flavor-violating  $\tau$  processes,  $\tau^\pm \rightarrow \ell^\pm \gamma$  (where  $\ell = e, \mu$ ) is predicted to be the dominant decay mode in a wide variety of new physics scenarios, with rates close to current experimental limits. Despite the existence of neutrino oscillations [1], such decays are predicted to have unobservably low rates [2] in the Standard Model (SM). Thus, an observation of charged lepton flavor violation would be an unambiguous signature of new physics, while improvements on existing limits will constrain many models. As the relationships between  $\mu^\pm \rightarrow e^\pm \gamma$ ,  $\tau^\pm \rightarrow e^\pm \gamma$  and  $\tau^\pm \rightarrow \mu^\pm \gamma$  decays are model-dependent, searches for both  $\tau$  modes provide independent information, even in the light of the small limit of  $\mathcal{B}(\mu^+ \rightarrow e^+ \gamma) < 1.2 \times 10^{-11}$  at 90% confidence level (C.L.) [3].

Presently, the most stringent limits are  $\mathcal{B}(\tau^\pm \rightarrow e^\pm \gamma) < 1.1 \times 10^{-7}$  [4] and  $\mathcal{B}(\tau^\pm \rightarrow \mu^\pm \gamma) < 4.5 \times 10^{-8}$  [5] at 90% C.L., using  $232.2 \text{ fb}^{-1}$  and  $535 \text{ fb}^{-1}$  of  $e^+e^-$  annihilation data collected near the  $\Upsilon(4S)$  resonance by the *BABAR* and Belle experiments, respectively. This paper reports the final result on these processes from BaBar. It utilizes the entire dataset recorded by the *BABAR* detector at the SLAC PEP-II  $e^+e^-$  storage rings, corresponding to a luminosity of  $425.5 \text{ fb}^{-1}$ ,  $28.0 \text{ fb}^{-1}$  and  $13.6 \text{ fb}^{-1}$  recorded at the  $\Upsilon(4S)$ ,  $\Upsilon(3S)$  and  $\Upsilon(2S)$  resonances, and  $44.4 \text{ fb}^{-1}$ ,  $2.6 \text{ fb}^{-1}$  and  $1.4 \text{ fb}^{-1}$  recorded at 40 MeV, 30 MeV and 30 MeV below the resonances, respectively.

For the bulk of the data sample at the  $\Upsilon(4S)$  resonance, the cross-section  $\sigma_{e^+e^- \rightarrow \tau^+\tau^-} = (0.919 \pm 0.003) \text{ nb}$  [6], determined to high precision using the KK Monte Carlo (MC) generator [7], receives negligible contribution from  $\Upsilon(4S)$  due to its large decay width. But, for the remaining data at the  $\Upsilon(3S)$  and  $\Upsilon(2S)$  resonances, the  $\tau$ -pair cross-section receives additional contributions of  $\mathcal{B}(\Upsilon \rightarrow \tau^+\tau^-) \approx 2\%$ , which are known only at the 10% level [8]. Including a systematic uncertainty of 0.6% on the luminosity determination, this gives a total of  $N_\tau = (963 \pm 7) \times 10^6$   $\tau$  decays.

The *BABAR* detector is described elsewhere [9]. Charged particles are reconstructed as tracks with a 5 layer silicon vertex tracker and a 40 layer drift chamber inside a 1.5 T solenoidal magnet. A CsI(Tl) electromagnetic calorimeter is used to identify electrons and photons. A ring-imaging Cherenkov detector is used to identify charged pions and kaons. The flux return of the solenoid, instrumented with resistive plate chambers and limited streamer tubes, is used to identify muons.

The signal is characterized by a  $\ell^\pm \gamma$  pair with an invariant mass and total energy in the center-of-mass (CM) frame ( $E_{\ell\gamma}^{\text{CM}}$ ) close to  $m_\tau = 1.777 \text{ GeV}/c^2$  [8] and  $\sqrt{s}/2$ , respectively. The event must also contain another  $\tau$  decay, reconstructed as decaying to one or three tracks.

The dominant irreducible background comes from  $\tau$ -pair events containing hard photon radiation and one of the  $\tau$  leptons decaying to a charged lepton. The remaining backgrounds for  $\tau^\pm \rightarrow e^\pm \gamma$  and  $\tau^\pm \rightarrow \mu^\pm \gamma$  de-

cays arise from the relevant radiative processes,  $e^+e^- \rightarrow e^+e^-\gamma$  and  $e^+e^- \rightarrow \mu^+\mu^-\gamma$ , and from hadronic  $\tau$  decays where a pion is misidentified as the electron or muon.

Signal events are simulated using KK and TAUOLA [10] with measured  $\tau$  branching fractions [8]. The  $\mu^+\mu^-$  and  $\tau^+\tau^-$  background processes are generated using KK and TAUOLA, while the  $q\bar{q}$  processes are generated using JETSET [11] and EVTGEN [12]. Radiative corrections for all processes are simulated using PHOTOS [13]. The Bhabha background is studied using events with two identified electrons in the data. The two-photon background has been studied and found to be negligible. The detector response to generated particles is simulated using the GEANT4 package [14]. MC events are used to optimize the selection criteria and estimate the systematic uncertainties on the efficiency, while the background rates are estimated directly from data.

Events with two or four well reconstructed tracks and zero total charge are selected, where no track pair is consistent with being a photon conversion in the detector material. Each event is divided into hemispheres (“signal-” and “tag-” sides) in the CM frame by a plane perpendicular to the thrust axis calculated using all reconstructed charged and neutral particles [15].

The signal-side hemisphere must contain one photon with CM energy  $E_\gamma^{\text{CM}}$  greater than 1 GeV, and no other photon with energy greater than 100 MeV in the laboratory frame. The signal side must contain one track within the calorimeter acceptance with momentum in the CM frame less than  $0.77\sqrt{s}/2$ . This track must be identified as an electron or a muon for the  $\tau^\pm \rightarrow e^\pm \gamma$  or  $\tau^\pm \rightarrow \mu^\pm \gamma$  search. The electron selectors have an efficiency of 96% within the fiducial coverage. For reliable muon identification, the track momentum is required to be greater than  $0.7 \text{ GeV}/c$  in the laboratory frame, above which the selection efficiency is 83%.

In the rest-frame of the  $\tau^\pm$ , the  $\ell^\pm$  and the  $\gamma$  are produced back-to-back. When boosted to the CM frame, kinematic considerations of two-body decays require there to be a minimum opening angle between them. The cosine of the opening angle,  $\cos \theta_{\ell\gamma}$ , between signal-track and signal-photon is required to be less than 0.786.

The tag-side hemisphere is expected to contain a SM  $\tau$  decay. A tag-side hemisphere containing a single track is classified as  $e$ -tag,  $\mu$ -tag, or  $\pi$ -tag if the total photon CM energy in the hemisphere is less than 200 MeV and the track is exclusively identified as an electron ( $e$ -tag), as a muon ( $\mu$ -tag), or as neither ( $\pi$ -tag). Events with the tag-side track failing both the lepton selectors are classified as  $\rho$ -tag if they contain at least one  $\pi^0$  candidate reconstructed from a pair of photons with invariant mass between 90 and 165  $\text{MeV}/c^2$ . If the tag-side hemisphere contains three charged tracks, all of which fail the lepton identification, it is classified as a  $3h$ -tag.

The definitions of the tag-side modes are designed to minimize the residual backgrounds from radiative QED

processes. For the  $\tau^\pm \rightarrow e^\pm \gamma$  search, very loose electron selection criteria are applied for the  $e$ -tag sample. Thus, the remaining tags which fail these very loose electron criteria have small Bhabha contamination. The  $e$ -tag events are used as the control sample to model the Bhabha background characteristics, and are removed from the final sample of events in the  $\tau^\pm \rightarrow e^\pm \gamma$  search. Similarly, for the  $\tau^\pm \rightarrow \mu^\pm \gamma$  search, very loose muon criteria are applied for the  $\mu$ -tag, on which stricter kinematic requirements are later imposed with tolerable loss in signal efficiency. The other tags are required to fail these very loose muon criteria, thereby reducing di-muon backgrounds.

To suppress non- $\tau$  backgrounds with missing momentum along the beam direction due to initial and final state photon radiation, we require that the polar angle  $\theta_{\text{miss}}$  of the missing momentum be inside the detector acceptance, i.e.  $-0.76 < \cos \theta_{\text{miss}} < 0.92$ .

The total CM momentum of all tracks and photon candidates on the tag-side is required to be less than  $0.77\sqrt{s}/2$  for  $e$ -,  $\mu$ -,  $\pi$ -tags and less than  $0.9\sqrt{s}/2$  for  $\rho$ - and  $3h$ -tags. The tag-side pseudomass [16] is required to be less than  $0.5 \text{ GeV}/c^2$  for  $e$ -,  $\mu$ -,  $\pi$ -tags and less than  $1.777 \text{ GeV}/c^2$  for  $\rho$ - and  $3h$ -tags.

The mass squared  $m_\nu^2$  of the missing particles on the tag side is calculated using the tag-side tracks and photon candidates and assuming that in the CM frame, the tag-side  $\tau$  momentum is opposite that of the signal  $\tau$  and that its energy is  $\sqrt{s}/2$ . To reduce backgrounds, we require  $m_\nu^2 > -0.25 \text{ GeV}^2/c^4$  for  $e$ - and  $\mu$ -tags,  $|m_\nu^2| < 0.25 \text{ GeV}^2/c^4$  for  $\pi$ - and  $3h$ -tags, and  $|m_\nu^2| < 0.50 \text{ GeV}^2/c^4$  for  $\rho$ -tags.

For radiative Bhabha and di-muon events, the expected photon energy in the CM frame  $(E_\gamma^{\text{CM}})_{\text{exp}}$  is  $\frac{|\sin(\theta_1+\theta_2)|\sqrt{s}}{\sin\theta_1+\sin\theta_2+|\sin(\theta_1+\theta_2)|}$ , where  $\pi-\theta_1$  and  $\pi-\theta_2$  are the angles the photon momentum makes with the signal-track and the total observed tag-side momentum, respectively. Also, for such events, we expect the cosine of the opening angle,  $\theta_{\text{recoil}}$ , between the signal-track and the total observed tag-side momentum in the reference frame obtained by removing the signal photon from the CM frame to peak at -1. To suppress these backgrounds, we remove events having reconstructed photon energy consistent with the expected value, i.e.  $|E_\gamma^{\text{CM}} - (E_\gamma^{\text{CM}})_{\text{exp}}| \equiv |\Delta E_\gamma| < 0.125\sqrt{s}$  and  $\cos \theta_{\text{recoil}} < -0.975$  in  $e$ - and  $\mu$ -tags for the  $\tau^\pm \rightarrow \mu^\pm \gamma$  search. No such criteria are necessary for the  $\tau^\pm \rightarrow e^\pm \gamma$  search according to the optimization procedure.

To further suppress the remaining backgrounds, neural net (NN) based discriminators are employed separately for each tag and for each dataset taken at values of  $\sqrt{s}$  near the  $\Upsilon(4S)$ ,  $\Upsilon(3S)$  and  $\Upsilon(2S)$  resonances. Six observables are used as input to the NN: the total tag-side momentum divided by  $\sqrt{s}/2$ ,  $m_\nu^2$ ,  $\Delta E_\gamma/\sqrt{s}$ ,  $\cos \theta_{\text{recoil}}$ ,  $\cos \theta_{\ell\gamma}$ , and the transverse component of missing momentum relative to the collision axis. The NN based discrim-

inators improve the signal to background ratios for the two searches by factors of 1.4 and 1.3, respectively.

Signal decays are identified by two kinematic variables: the energy difference  $\Delta E = E_{\ell\gamma}^{\text{CM}} - \sqrt{s}/2$  and the beam-energy constrained  $\tau$  mass ( $m_{\text{EC}}$ ), obtained from a kinematic fit after requiring the CM  $\tau$  energy to be  $\sqrt{s}/2$  and after assigning the origin of the  $\gamma$  candidate to the point of closest approach of the signal lepton track to the  $e^+e^-$  collision axis. The distributions of these two variables have a small correlation arising from initial- and final-state radiation. For signal MC events, the  $m_{\text{EC}}$  and  $\Delta E$  distributions are centered at  $m_\tau$  and small negative values, respectively, where the shifts from zero for the latter are due to radiation and photon energy reconstruction effects. The mean and standard deviations of the  $m_{\text{EC}}$  and  $\Delta E$  distributions for the reconstructed signal MC events are presented in Table I. The data events falling within a  $3\sigma$  ellipse in the  $m_{\text{EC}}$  vs.  $\Delta E$  plane, centered around the reconstructed peak positions as obtained using signal MC, are not examined until all optimization and systematic studies have been completed. The selections are optimized to yield the smallest expected upper limits [17] for observing events inside a  $2\sigma$  signal ellipse under background-only hypotheses.

The distributions of events in  $m_{\text{EC}}$  vs.  $\Delta E$  are shown in Fig. 1. To study signal-like events, a Grand Signal Box (GSB) is defined as  $m_{\text{EC}} \in [1.55, 2.05] \text{ GeV}/c^2$  and  $\Delta E \in [-1.0, 0.5] \text{ GeV}$ . Outside the blinded  $3\sigma$  ellipse, 1389 data events survive in the GSB for the  $\tau^\pm \rightarrow e^\pm \gamma$  channel, and 2053 data events survive for the  $\tau^\pm \rightarrow \mu^\pm \gamma$  channel. These agree to within 2.4% and 1.7% with the numbers of background MC events observed. The signal-track arises from a real electron or muon in 96% and 82% of the background MC events for the two searches.

A Fit Box (FB) region is defined as  $m_{\text{EC}} \in [1.6, 2.0] \text{ GeV}/c^2$  and  $\Delta E \in [-0.14, 0.14] \text{ GeV}$ , excluding the blinded  $3\sigma$  ellipse. The  $m_{\text{EC}}$  vs.  $\Delta E$  distributions of events inside the FB are modeled by 2-dimensional probability density functions (PDFs) summed over all background event types. The PDFs have correlations built in using Gaussian weights with an adaptive kernel estimation procedure [18]. The shape of the Bhabha component is obtained using the data samples having  $\cos \theta_{\text{recoil}} < -0.8$  from events selected in the  $e$ -tag sample for the  $\tau^\pm \rightarrow e^\pm \gamma$  search, while the shapes of  $\mu^+\mu^-$ ,  $\tau^+\tau^-$  and  $q\bar{q}$  PDFs are obtained from their respective MC samples.

The fractions of events for each background type are obtained from separate maximum likelihood fits to 41 and 105 events inside the FB, respectively, for the two searches. We find  $(70 \pm 15)\%$  and  $(90 \pm 8)\%$  of the background events are  $\tau$ -pair events. By integrating the total PDF summed over background types only, we expect  $(1.6 \pm 0.3)$  and  $(3.6 \pm 0.4)$  events inside the  $2\sigma$  signal ellipse for the two searches, where the quoted statistical errors are due to the sizes of the fitted dataset.

TABLE I: Means and resolutions of  $m_{\text{EC}}$  and  $\Delta E$  distributions for the signal MC events, the numbers of observed (obs) and expected (exp) events inside the  $2\sigma$  signal ellipse, the signal efficiencies ( $\varepsilon$ ), and the 90% C.L. upper limits (UL).

Decay modes	$\langle m_{\text{EC}} \rangle$	$\sigma(m_{\text{EC}})$	$\langle \Delta E \rangle$	$\sigma(\Delta E)$	2 $\sigma$ signal ellipse		$\varepsilon$	UL ( $\times 10^{-8}$ )	
	MeV/ $c^2$	MeV/ $c^2$	MeV	MeV	obs	exp	(%)	obs	exp
$\tau^\pm \rightarrow e^\pm \gamma$	1777.3	8.6	-21.4	42.1	0	$1.6 \pm 0.4$	$3.9 \pm 0.3$	3.3	9.8
$\tau^\pm \rightarrow \mu^\pm \gamma$	1777.4	8.3	-18.3	42.2	2	$3.6 \pm 0.7$	$6.1 \pm 0.5$	4.4	8.2

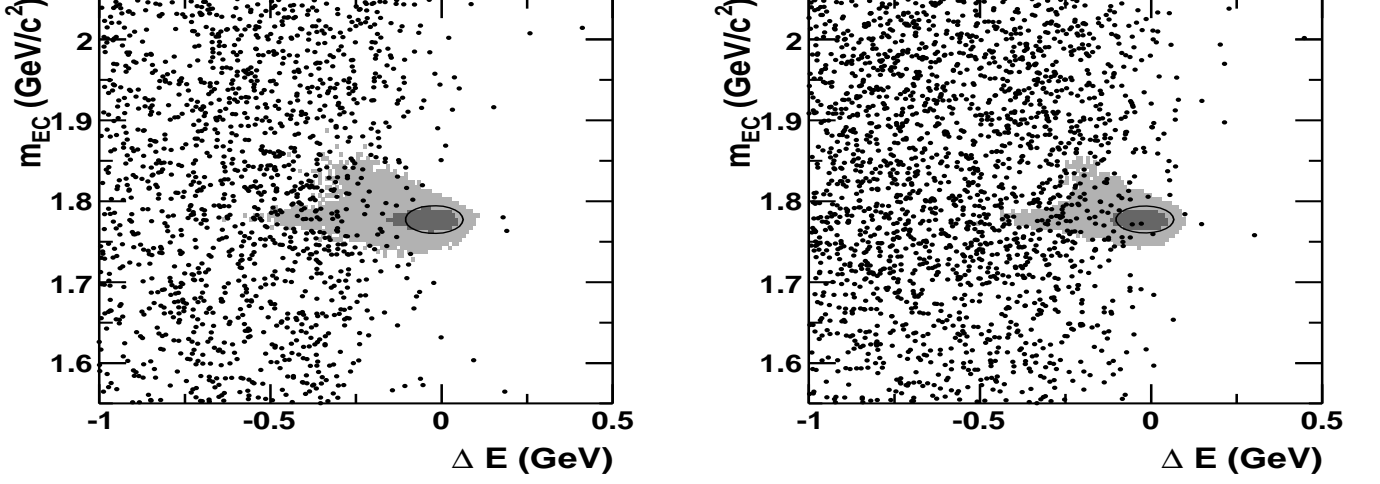


FIG. 1: The GSB and the  $2\sigma$  ellipse for  $\tau^\pm \rightarrow e^\pm \gamma$  (left) and  $\tau^\pm \rightarrow \mu^\pm \gamma$  (right) decays in the  $m_{\text{EC}}$  vs.  $\Delta E$  plane. Data are shown as dots and contours containing 90% (50%) of signal MC events are shown as light- (dark-) shaded regions.

As a cross-check, we integrate the total PDF over four  $2\sigma$  ellipses inside the FB, whose centers are shifted by  $\pm 5\sigma$  or by  $\pm 9\sigma$  along  $m_{\text{EC}}$  only. The numbers of observed events in each of these neighboring regions and their sums are consistent with the expected numbers of events, which are shown along with their statistical errors in Table II.

TABLE II: Numbers of observed (obs) and expected (exp) numbers of background events along with statistical errors inside  $2\sigma$  ellipses whose centers are shifted by  $\pm 5\sigma$  and  $\pm 9\sigma$  in  $m_{\text{EC}}$  only, and their sums.

		-9 $\sigma$	-5 $\sigma$	+5 $\sigma$	+9 $\sigma$	sum
$\tau^\pm \rightarrow e^\pm \gamma$	obs	2	1	2	2	7
	exp	$1.2 \pm 0.2$	$1.4 \pm 0.2$	$1.9 \pm 0.3$	$2.1 \pm 0.3$	$6.6 \pm 0.5$
$\tau^\pm \rightarrow \mu^\pm \gamma$	obs	3	1	4	6	14
	exp	$2.8 \pm 0.3$	$3.1 \pm 0.3$	$4.2 \pm 0.4$	$4.8 \pm 0.5$	$14.9 \pm 0.8$

To obtain the systematic errors on the numbers of expected background events, we fit the  $m_{\text{EC}}$  distributions of 32 and 81 data events inside the  $\pm 2\sigma$  band in  $\Delta E$  over the GSB region but outside the blinded  $3\sigma$  ellipse. Varying degrees of polynomial functions are used to model

the  $m_{\text{EC}}$  distributions, which are then integrated to obtain the number of expected events inside the  $2\sigma$  ellipse. The largest deviations between the predictions from 1-dimensional and 2-dimensional fits are used to set the total uncertainties of 0.4 and 0.7 events on the background estimates.

The systematic uncertainties in the signal selection and reconstruction efficiencies for  $\tau^\pm \rightarrow e^\pm \gamma$  and  $\tau^\pm \rightarrow \mu^\pm \gamma$  decays due to the modeling of the variables entering the NN are 2.7% and 1.8%, respectively. Those due to the photon reconstruction efficiency are 1.8% for both decays, while those due to the signal-lepton track identification are 2.3% and 2.7%, respectively. The contributions due to the uncertainty in the signal-track momentum and signal-photon energy scale and resolution, estimated by varying the peak position and resolution of the  $m_{\text{EC}}$  and  $\Delta E$  distributions, are 6.4% and 6.2%, respectively. Other systematic uncertainties totaling less than 1.5% for both signal decay modes include those arising from trigger and filter efficiencies, tracking efficiencies, and the beam-energy scale and spread. We use approximately  $10^6$  MC events per channel, resulting in a negligible systematic uncertainty due to MC statistics. Although the signal MC has been modeled using a flat

phase space model, the efficiencies are insensitive to this assumption as demonstrated by considering the two extreme cases of  $V - A$  and  $V + A$  forms of interaction for the signal MC. All contributions to the systematic uncertainties are added in quadrature to give total relative systematic uncertainties on the efficiencies of 7.7% and 7.4% for  $\tau^\pm \rightarrow e^\pm \gamma$  and  $\tau^\pm \rightarrow \mu^\pm \gamma$  decays, respectively.

We observe 0 and 2 events for the  $\tau^\pm \rightarrow e^\pm \gamma$  and  $\tau^\pm \rightarrow \mu^\pm \gamma$  searches inside the  $2\sigma$  signal ellipse, respectively. As there is no evidence for a signal, we set a frequentist upper limit calculated using  $\mathcal{B}_{UL}^{90} = N_{UL}^{90}/(N_\tau \varepsilon)$  to be  $\mathcal{B}(\tau^\pm \rightarrow e^\pm \gamma) < 3.3 \times 10^{-8}$  and  $\mathcal{B}(\tau^\pm \rightarrow \mu^\pm \gamma) < 4.4 \times 10^{-8}$  at 90% C.L., where  $\varepsilon$  is the signal efficiency inside the  $2\sigma$  signal ellipse and  $N_{UL}^{90}$  is the 90% C.L. upper limit on the number of signal events, estimated using the POLE program [19]. The upper limits which include all systematic uncertainties, are presented in Table I, along with signal efficiencies and numbers of observed and expected background events. These results supersede previous *BABAR* results [4, 20], reducing the upper limits by factors of 3.3 and 1.5, respectively, and are the most stringent limits on searches for lepton flavor violation in  $\tau^\pm \rightarrow e^\pm \gamma$  and  $\tau^\pm \rightarrow \mu^\pm \gamma$  decays.

We are grateful for the excellent luminosity and machine conditions provided by our PEP-II colleagues, and for the substantial dedicated effort from the computing organizations that support *BABAR*. The collaborating institutions wish to thank SLAC for its support and kind hospitality. This work is supported by DOE and NSF (USA), NSERC (Canada), CEA and CNRS-IN2P3 (France), BMBF and DFG (Germany), INFN (Italy), FOM (The Netherlands), NFR (Norway), MES (Russia), MEC (Spain), and STFC (United Kingdom). Individuals have received support from the Marie Curie EIF (European Union) and the A. P. Sloan Foundation.

---

\* Deceased

† Now at Temple University, Philadelphia, Pennsylvania 19122, USA

‡ Also with Università di Perugia, Dipartimento di Fisica, Perugia, Italy

§ Also with Università di Roma La Sapienza, I-00185 Roma, Italy

¶ Now at University of South Alabama, Mobile, Alabama 36688, USA

\*\* Also with Laboratoire de Physique Nucléaire et de Hautes Energies, IN2P3/CNRS, Université Pierre et Marie Curie-Paris6, Université Denis Diderot-Paris7, F-75252 Paris, France

†† Also with Università di Sassari, Sassari, Italy

- [1] B. T. Cleveland *et al.*, *Astrophys. J.* **496**, 505 (1998); Y. Fukuda *et al.* [Super-Kamiokande Collab.], *Phys. Rev. Lett.* **81**, 1562 (1998); Q. R. Ahmad *et al.* [SNO Collab.], *Phys. Rev. Lett.* **89**, 011301 (2002); M. H. Ahn *et al.* [K2K Collab.], *Phys. Rev. Lett.* **90**, 041801 (2003).
- [2] B. W. Lee and R. E. Shrock, *Phys. Rev. D* **16**, 1444 (1977). A value of  $\Delta m_{32}^2 \approx 3 \times 10^{-3} (\text{eV}/c^2)^2$  [1] and maximal mixing implies  $\mathcal{B}(\tau^\pm \rightarrow \mu^\pm \gamma) \approx \mathcal{O}(10^{-54})$ .
- [3] M. L. Brooks *et al.* [MEGA Collab.], *Phys. Rev. Lett.* **83**, 1521 (1999).
- [4] B. Aubert *et al.* [*BABAR* Collab.], *Phys. Rev. Lett.* **96**, 041801 (2006).
- [5] K. Hayasaka *et al.* [Belle Collab.], *Phys. Lett. B* **666**, 16 (2008).
- [6] S. Banerjee, B. Pietrzyk, J. M. Roney and Z. Wąs, *Phys. Rev. D* **77**, 054012 (2008).
- [7] S. Jadach, B. F. L. Ward and Z. Wąs, *Comput. Phys. Commun.* **130**, 260 (2000).
- [8] C. Amsler *et al.* [Particle Data Group], *Phys. Lett. B* **667**, 1 (2008).
- [9] B. Aubert *et al.* [*BABAR* Collab.], *Nucl. Instrum. Methods Phys. Res., Sect. A* **479**, 1 (2002).
- [10] S. Jadach, Z. Wąs, R. Decker, and J. H. Kühn, *Comput. Phys. Commun.* **76**, 361 (1993).
- [11] T. Sjöstrand, *Comput. Phys. Commun.* **82**, 74 (1994).
- [12] D. J. Lange, *Nucl. Instrum. Methods Phys. Res., Sect. A* **462**, 152 (2001).
- [13] P. Golonka and Z. Wąs, *Eur. Phys. J. C* **45**, 97 (2006).
- [14] S. Agostinelli *et al.* [GEANT4 Collab.], *Nucl. Instrum. Methods Phys. Res., Sect. A* **506**, 250 (2003).
- [15] S. Brandt, C. Peyrou, R. Sosnowski, and A. Wroblewski, *Phys. Lett.* **12**, 57 (1964); E. Farhi, *Phys. Rev. Lett.* **39**, 1587 (1977).
- [16] H. Albrecht *et al.* [ARGUS Collab.], *Phys. Lett. B* **292**, 221 (1992).
- [17] G. J. Feldman and R. D. Cousins, *Phys. Rev. D* **57**, 3873 (1998).
- [18] K. S. Cranmer, *Comput. Phys. Commun.* **136**, 198 (2001).
- [19] J. Conrad, O. Botner, A. Hallgren, and C. Perez de los Heros, *Phys. Rev. D* **67**, 012002 (2003).
- [20] B. Aubert *et al.* [*BABAR* Collab.], *Phys. Rev. Lett.* **95**, 041802 (2005).

