

University of Nebraska - Lincoln

DigitalCommons@University of Nebraska - Lincoln

---

Gregory Snow Publications

Research Papers in Physics and Astronomy

---

8-21-2000

## Search for $R$ -parity violation in multilepton final states in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV

B. Abbott

*New York University, New York, New York 10003*

Gregory R. Snow

*University of Nebraska-Lincoln, gsnow1@unl.edu*

D0 Collaboration

Follow this and additional works at: <https://digitalcommons.unl.edu/physicsnow>



Part of the [Physics Commons](#)

---

Abbott, B.; Snow, Gregory R.; and Collaboration, D0, "Search for  $R$ -parity violation in multilepton final states in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.8$  TeV" (2000). *Gregory Snow Publications*. 36.

<https://digitalcommons.unl.edu/physicsnow/36>

This Article is brought to you for free and open access by the Research Papers in Physics and Astronomy at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in Gregory Snow Publications by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.

Search for  $R$ -parity violation in multilepton final states in  $p\bar{p}$  collisions at  $\sqrt{s}=1.8$  TeV

B. Abbott,<sup>48</sup> M. Abolins,<sup>45</sup> V. Abramov,<sup>21</sup> B. S. Acharya,<sup>15</sup> D. L. Adams,<sup>55</sup> M. Adams,<sup>32</sup> V. Akimov,<sup>19</sup> G. A. Alves,<sup>2</sup> N. Amos,<sup>44</sup> E. W. Anderson,<sup>37</sup> M. M. Baarmand,<sup>50</sup> V. V. Babintsev,<sup>21</sup> L. Babukhadia,<sup>50</sup> A. Baden,<sup>41</sup> B. Baldin,<sup>31</sup> S. Banerjee,<sup>15</sup> J. Bantly,<sup>54</sup> E. Barberis,<sup>24</sup> P. Baringer,<sup>38</sup> J. F. Bartlett,<sup>31</sup> U. Bassler,<sup>11</sup> A. Bean,<sup>38</sup> A. Belyaev,<sup>20</sup> S. B. Beri,<sup>13</sup> G. Bernardi,<sup>11</sup> I. Bertram,<sup>22</sup> V. A. Bezzubov,<sup>21</sup> P. C. Bhat,<sup>31</sup> V. Bhatnagar,<sup>13</sup> M. Bhattacharjee,<sup>50</sup> G. Blazey,<sup>33</sup> S. Blessing,<sup>29</sup> A. Boehnlein,<sup>31</sup> N. I. Bojko,<sup>21</sup> F. Borchering,<sup>31</sup> A. Brandt,<sup>55</sup> R. Breedon,<sup>25</sup> G. Briskin,<sup>54</sup> R. Brock,<sup>45</sup> G. Brooijmans,<sup>31</sup> A. Bross,<sup>31</sup> D. Buchholz,<sup>34</sup> M. Buehler,<sup>32</sup> V. Buescher,<sup>49</sup> V. S. Burtovoi,<sup>21</sup> J. M. Butler,<sup>42</sup> F. Canelli,<sup>49</sup> W. Carvalho,<sup>3</sup> D. Casey,<sup>45</sup> Z. Casilum,<sup>50</sup> H. Castilla-Valdez,<sup>17</sup> D. Chakraborty,<sup>50</sup> K. M. Chan,<sup>49</sup> S. V. Chekulaev,<sup>21</sup> D. K. Cho,<sup>49</sup> S. Choi,<sup>28</sup> S. Chopra,<sup>51</sup> B. C. Choudhary,<sup>28</sup> J. H. Christenson,<sup>31</sup> M. Chung,<sup>32</sup> D. Claes,<sup>46</sup> A. R. Clark,<sup>24</sup> J. Cochran,<sup>28</sup> L. Coney,<sup>36</sup> B. Connolly,<sup>29</sup> W. E. Cooper,<sup>31</sup> D. Coppage,<sup>38</sup> D. Cullen-Vidal,<sup>54</sup> M. A. C. Cummings,<sup>33</sup> D. Cutts,<sup>54</sup> O. I. Dahl,<sup>24</sup> K. Davis,<sup>23</sup> K. De,<sup>55</sup> K. Del Signore,<sup>44</sup> M. Demarteau,<sup>31</sup> D. Denisov,<sup>31</sup> S. P. Denisov,<sup>21</sup> H. T. Diehl,<sup>31</sup> M. Diesburg,<sup>31</sup> G. Di Loreto,<sup>45</sup> S. Doulas,<sup>43</sup> P. Draper,<sup>55</sup> Y. Ducros,<sup>12</sup> L. V. Dudko,<sup>20</sup> S. R. Dugad,<sup>15</sup> A. Dyshkant,<sup>21</sup> D. Edmunds,<sup>45</sup> J. Ellison,<sup>28</sup> V. D. Elvira,<sup>31</sup> R. Engelmann,<sup>50</sup> S. Eno,<sup>41</sup> G. Eppley,<sup>57</sup> P. Ermolov,<sup>20</sup> O. V. Eroshin,<sup>21</sup> J. Estrada,<sup>49</sup> H. Evans,<sup>47</sup> V. N. Evdokimov,<sup>21</sup> T. Fahland,<sup>27</sup> S. Feher,<sup>31</sup> D. Fein,<sup>23</sup> T. Ferbel,<sup>49</sup> H. E. Fisk,<sup>31</sup> Y. Fisyak,<sup>51</sup> E. Flattum,<sup>31</sup> F. Fleuret,<sup>24</sup> M. Fortner,<sup>33</sup> K. C. Frame,<sup>45</sup> S. Fuess,<sup>31</sup> E. Gallas,<sup>31</sup> A. N. Galyaev,<sup>21</sup> P. Gartung,<sup>28</sup> V. Gavrilov,<sup>19</sup> R. J. Genik II,<sup>22</sup> K. Genser,<sup>31</sup> C. E. Gerber,<sup>31</sup> Y. Gershtein,<sup>54</sup> B. Gibbard,<sup>51</sup> R. Gilmartin,<sup>29</sup> G. Ginther,<sup>49</sup> B. Gómez,<sup>5</sup> G. Gómez,<sup>41</sup> P. I. Goncharov,<sup>21</sup> J. L. González Solís,<sup>17</sup> H. Gordon,<sup>51</sup> L. T. Goss,<sup>56</sup> K. Gounder,<sup>28</sup> A. Goussiou,<sup>50</sup> N. Graf,<sup>51</sup> P. D. Grannis,<sup>50</sup> J. A. Green,<sup>37</sup> H. Greenlee,<sup>31</sup> S. Grinstein,<sup>1</sup> P. Grudberg,<sup>24</sup> S. Grünendahl,<sup>31</sup> G. Guglielmo,<sup>53</sup> A. Gupta,<sup>15</sup> S. N. Gurzhev,<sup>21</sup> G. Gutierrez,<sup>31</sup> P. Gutierrez,<sup>53</sup> N. J. Hadley,<sup>41</sup> H. Haggerty,<sup>31</sup> S. Hagopian,<sup>29</sup> V. Hagopian,<sup>29</sup> K. S. Hahn,<sup>49</sup> R. E. Hall,<sup>26</sup> P. Hanlet,<sup>43</sup> S. Hansen,<sup>31</sup> J. M. Hauptman,<sup>37</sup> C. Hays,<sup>47</sup> C. Hebert,<sup>38</sup> D. Hedin,<sup>33</sup> A. P. Heinson,<sup>28</sup> U. Heintz,<sup>42</sup> T. Heuring,<sup>29</sup> R. Hirosky,<sup>32</sup> J. D. Hobbs,<sup>50</sup> B. Hoeneisen,<sup>8</sup> J. S. Hoftun,<sup>54</sup> A. S. Ito,<sup>31</sup> S. A. Jerger,<sup>45</sup> R. Jesik,<sup>35</sup> T. Joffe-Minor,<sup>34</sup> K. Johns,<sup>23</sup> M. Johnson,<sup>31</sup> A. Jonckheere,<sup>31</sup> M. Jones,<sup>30</sup> H. Jöstlein,<sup>31</sup> A. Juste,<sup>31</sup> S. Kahn,<sup>51</sup> E. Kajfasz,<sup>10</sup> D. Karmanov,<sup>20</sup> D. Karmgard,<sup>36</sup> R. Kehoe,<sup>36</sup> S. K. Kim,<sup>16</sup> B. Klima,<sup>31</sup> C. Klopfenstein,<sup>25</sup> B. Knuteson,<sup>24</sup> W. Ko,<sup>25</sup> J. M. Kohli,<sup>13</sup> A. V. Kostrikskiy,<sup>21</sup> J. Kotcher,<sup>51</sup> A. V. Kotwal,<sup>47</sup> A. V. Kozelov,<sup>21</sup> E. A. Kozlovsky,<sup>21</sup> J. Krane,<sup>37</sup> M. R. Krishnaswamy,<sup>15</sup> S. Krzywdzinski,<sup>31</sup> M. Kubantsev,<sup>39</sup> S. Kuleshov,<sup>19</sup> Y. Kulik,<sup>50</sup> S. Kunori,<sup>41</sup> G. Landsberg,<sup>54</sup> A. Leflat,<sup>20</sup> F. Lehner,<sup>31</sup> J. Li,<sup>55</sup> Q. Z. Li,<sup>31</sup> J. G. R. Lima,<sup>3</sup> D. Lincoln,<sup>31</sup> S. L. Linn,<sup>29</sup> J. Linnemann,<sup>45</sup> R. Lipton,<sup>31</sup> J. G. Lu,<sup>4</sup> A. Lucotte,<sup>50</sup> L. Lueking,<sup>31</sup> C. Lundstedt,<sup>46</sup> A. K. A. Maciel,<sup>33</sup> R. J. Madaras,<sup>24</sup> V. Manankov,<sup>20</sup> S. Mani,<sup>25</sup> H. S. Mao,<sup>4</sup> T. Marshall,<sup>35</sup> M. I. Martin,<sup>31</sup> R. D. Martin,<sup>32</sup> K. M. Mauritz,<sup>37</sup> B. May,<sup>34</sup> A. A. Mayorov,<sup>35</sup> R. McCarthy,<sup>50</sup> J. McDonald,<sup>29</sup> T. McMahon,<sup>52</sup> H. L. Melanson,<sup>31</sup> X. C. Meng,<sup>4</sup> M. Merkin,<sup>20</sup> K. W. Merritt,<sup>31</sup> C. Miao,<sup>54</sup> H. Miettinen,<sup>57</sup> D. Mihalcea,<sup>53</sup> A. Mincer,<sup>48</sup> C. S. Mishra,<sup>31</sup> N. Mokhov,<sup>31</sup> N. K. Mondal,<sup>15</sup> H. E. Montgomery,<sup>31</sup> M. Mostafa,<sup>1</sup> H. da Motta,<sup>2</sup> E. Nagy,<sup>10</sup> F. Nang,<sup>23</sup> M. Narain,<sup>42</sup> V. S. Narasimham,<sup>15</sup> H. A. Neal,<sup>44</sup> J. P. Negret,<sup>5</sup> S. Negroni,<sup>10</sup> D. Norman,<sup>56</sup> L. Oesch,<sup>44</sup> V. Oguri,<sup>3</sup> B. Olivier,<sup>11</sup> N. Oshima,<sup>31</sup> P. Padley,<sup>57</sup> L. J. Pan,<sup>34</sup> A. Para,<sup>31</sup> N. Parashar,<sup>43</sup> R. Partridge,<sup>54</sup> N. Parua,<sup>9</sup> M. Paterno,<sup>49</sup> A. Patwa,<sup>50</sup> B. Pawlik,<sup>18</sup> J. Perkins,<sup>55</sup> M. Peters,<sup>30</sup> R. Piegaia,<sup>1</sup> H. Piekarczyk,<sup>29</sup> B. G. Pope,<sup>45</sup> E. Popkov,<sup>36</sup> H. B. Prosper,<sup>29</sup> S. Protopopescu,<sup>51</sup> J. Qian,<sup>44</sup> P. Z. Quintas,<sup>31</sup> R. Raja,<sup>31</sup> S. Rajagopalan,<sup>51</sup> N. W. Reay,<sup>39</sup> S. Reucroft,<sup>43</sup> M. Rijssenbeek,<sup>50</sup> T. Rockwell,<sup>45</sup> M. Roco,<sup>31</sup> P. Rubinov,<sup>31</sup> R. Ruchti,<sup>36</sup> J. Rutherford,<sup>23</sup> A. Santoro,<sup>2</sup> L. Sawyer,<sup>40</sup> R. D. Schamberger,<sup>50</sup> H. Schellman,<sup>34</sup> A. Schwartzman,<sup>1</sup> J. Sculli,<sup>48</sup> N. Sen,<sup>57</sup> E. Shabalina,<sup>20</sup> H. C. Shankar,<sup>15</sup> R. K. Shivpuri,<sup>14</sup> D. Shpakov,<sup>50</sup> M. Shupe,<sup>23</sup> R. A. Sidwell,<sup>39</sup> V. Simak,<sup>7</sup> H. Singh,<sup>28</sup> J. B. Singh,<sup>13</sup> V. Sirotenko,<sup>33</sup> P. Slattery,<sup>49</sup> E. Smith,<sup>53</sup> R. P. Smith,<sup>31</sup> R. Snihur,<sup>34</sup> G. R. Snow,<sup>46</sup> J. Snow,<sup>52</sup> S. Snyder,<sup>51</sup> J. Solomon,<sup>32</sup> X. F. Song,<sup>4</sup> V. Sorin,<sup>1</sup> M. Sosebee,<sup>55</sup> N. Sotnikova,<sup>20</sup> K. Soustruznik,<sup>6</sup> M. Souza,<sup>2</sup> N. R. Stanton,<sup>39</sup> G. Steinbrück,<sup>47</sup> R. W. Stephens,<sup>55</sup> M. L. Stevenson,<sup>24</sup> F. Stichelbaut,<sup>51</sup> D. Stoker,<sup>27</sup> V. Stolin,<sup>19</sup> D. A. Stoyanova,<sup>21</sup> M. Strauss,<sup>53</sup> K. Streets,<sup>48</sup> M. Strovink,<sup>24</sup> L. Stutte,<sup>31</sup> A. Sznajder,<sup>3</sup> W. Taylor,<sup>50</sup> S. Tentindo-Repond,<sup>29</sup> T. L. T. Thomas,<sup>34</sup> J. Thompson,<sup>41</sup> D. Toback,<sup>41</sup> T. G. Trippe,<sup>24</sup> A. S. Turcot,<sup>44</sup> P. M. Tuts,<sup>47</sup> P. van Gemmeren,<sup>31</sup> V. Vaniev,<sup>21</sup> R. Van Kooten,<sup>35</sup> N. Varelas,<sup>32</sup> A. A. Volkov,<sup>21</sup> A. P. Vorobiev,<sup>21</sup> H. D. Wahl,<sup>29</sup> H. Wang,<sup>34</sup> J. Warchol,<sup>36</sup> G. Watts,<sup>58</sup> M. Wayne,<sup>36</sup> H. Weerts,<sup>45</sup> A. White,<sup>55</sup> J. T. White,<sup>56</sup> D. Whiteson,<sup>24</sup> J. A. Wightman,<sup>37</sup> S. Willis,<sup>33</sup> S. J. Wimpenny,<sup>28</sup> J. V. D. Wirjawan,<sup>56</sup> J. Womersley,<sup>31</sup> D. R. Wood,<sup>43</sup> R. Yamada,<sup>31</sup> P. Yamin,<sup>51</sup> T. Yasuda,<sup>31</sup> K. Yip,<sup>31</sup> S. Youssef,<sup>29</sup> J. Yu,<sup>31</sup> Z. Yu,<sup>34</sup> M. Zanabria,<sup>5</sup> H. Zheng,<sup>36</sup> Z. Zhou,<sup>37</sup> Z. H. Zhu,<sup>49</sup> M. Zielinski,<sup>49</sup> D. Zieminska,<sup>35</sup> A. Zieminski,<sup>35</sup> V. Zutshi,<sup>49</sup> E. G. Zverev,<sup>20</sup> and A. Zylberstein<sup>12</sup>

(DØ Collaboration)

<sup>1</sup>Universidad de Buenos Aires, Buenos Aires, Argentina<sup>2</sup>LAFEX, Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil<sup>3</sup>Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil<sup>4</sup>Institute of High Energy Physics, Beijing, People's Republic of China<sup>5</sup>Universidad de los Andes, Bogotá, Colombia<sup>6</sup>Charles University, Prague, Czech Republic<sup>7</sup>Institute of Physics, Academy of Sciences, Prague, Czech Republic<sup>8</sup>Universidad San Francisco de Quito, Quito, Ecuador<sup>9</sup>Institut des Sciences Nucléaires, IN2P3-CNRS, Université de Grenoble I, Grenoble, France

- <sup>10</sup>CPPM, IN2P3-CNRS, Université de la Méditerranée, Marseille, France  
<sup>11</sup>LPNHE, Universités Paris VI and VII, IN2P3-CNRS, Paris, France  
<sup>12</sup>DAPNIA/Service de Physique des Particules, CEA, Saclay, France  
<sup>13</sup>Panjab University, Chandigarh, India  
<sup>14</sup>Delhi University, Delhi, India  
<sup>15</sup>Tata Institute of Fundamental Research, Mumbai, India  
<sup>16</sup>Seoul National University, Seoul, Korea  
<sup>17</sup>CINVESTAV, Mexico City, Mexico  
<sup>18</sup>Institute of Nuclear Physics, Kraków, Poland  
<sup>19</sup>Institute for Theoretical and Experimental Physics, Moscow, Russia  
<sup>20</sup>Moscow State University, Moscow, Russia  
<sup>21</sup>Institute for High Energy Physics, Protvino, Russia  
<sup>22</sup>Lancaster University, Lancaster, United Kingdom  
<sup>23</sup>University of Arizona, Tucson, Arizona 85721  
<sup>24</sup>Lawrence Berkeley National Laboratory and University of California, Berkeley, California 94720  
<sup>25</sup>University of California, Davis, California 95616  
<sup>26</sup>California State University, Fresno, California 93740  
<sup>27</sup>University of California, Irvine, California 92697  
<sup>28</sup>University of California, Riverside, California 92521  
<sup>29</sup>Florida State University, Tallahassee, Florida 32306  
<sup>30</sup>University of Hawaii, Honolulu, Hawaii 96822  
<sup>31</sup>Fermi National Accelerator Laboratory, Batavia, Illinois 60510  
<sup>32</sup>University of Illinois at Chicago, Chicago, Illinois 60607  
<sup>33</sup>Northern Illinois University, DeKalb, Illinois 60115  
<sup>34</sup>Northwestern University, Evanston, Illinois 60208  
<sup>35</sup>Indiana University, Bloomington, Indiana 47405  
<sup>36</sup>University of Notre Dame, Notre Dame, Indiana 46556  
<sup>37</sup>Iowa State University, Ames, Iowa 50011  
<sup>38</sup>University of Kansas, Lawrence, Kansas 66045  
<sup>39</sup>Kansas State University, Manhattan, Kansas 66506  
<sup>40</sup>Louisiana Tech University, Ruston, Louisiana 71272  
<sup>41</sup>University of Maryland, College Park, Maryland 20742  
<sup>42</sup>Boston University, Boston, Massachusetts 02215  
<sup>43</sup>Northeastern University, Boston, Massachusetts 02115  
<sup>44</sup>University of Michigan, Ann Arbor, Michigan 48109  
<sup>45</sup>Michigan State University, East Lansing, Michigan 48824  
<sup>46</sup>University of Nebraska, Lincoln, Nebraska 68588  
<sup>47</sup>Columbia University, New York, New York 10027  
<sup>48</sup>New York University, New York, New York 10003  
<sup>49</sup>University of Rochester, Rochester, New York 14627  
<sup>50</sup>State University of New York, Stony Brook, New York 11794  
<sup>51</sup>Brookhaven National Laboratory, Upton, New York 11973  
<sup>52</sup>Langston University, Langston, Oklahoma 73050  
<sup>53</sup>University of Oklahoma, Norman, Oklahoma 73019  
<sup>54</sup>Brown University, Providence, Rhode Island 02912  
<sup>55</sup>University of Texas, Arlington, Texas 76019  
<sup>56</sup>Texas A&M University, College Station, Texas 77843  
<sup>57</sup>Rice University, Houston, Texas 77005  
<sup>58</sup>University of Washington, Seattle, Washington 98195

(Received 24 May 2000; published 24 August 2000)

The result of a search for gaugino pair production with a trilepton signature is reinterpreted in the framework of minimal supergravity (MSUGRA) with  $R$ -parity violation via leptonic  $\lambda$  Yukawa couplings. The search used  $95 \text{ pb}^{-1}$  of  $p\bar{p}$  collisions at  $\sqrt{s} = 1.8 \text{ TeV}$  recorded by the  $D\bar{0}$  detector at the Fermilab Tevatron. A large domain of the MSUGRA parameter space is excluded for  $\lambda_{121}, \lambda_{122} \geq 10^{-4}$ .

PACS number(s): 14.80.Ly, 12.60.Jv, 13.85.Rm

TABLE I. The result of the search for a trilepton signature at  $D\bar{O}$  [3].

Event categories	$eee$	$ee\mu$	$e\mu\mu$	$\mu\mu\mu$
$\mathcal{L}_{\text{int}}$ (pb $^{-1}$ )	$98.7 \pm 5.2$	$98.7 \pm 5.2$	$93.1 \pm 4.9$	$78.3 \pm 4.1$
Observed events	0	0	0	0
Background events	$0.34 \pm 0.07$	$0.61 \pm 0.36$	$0.11 \pm 0.04$	$0.20 \pm 0.04$

Supersymmetry (SUSY) is one of the possible extensions of the standard model (SM). For each SM particle there is a hypothesized supersymmetric partner with spin differing by 1/2-integer. Most searches for supersymmetric particles assume conservation of  $R$ -parity,  $R_p$ , a multiplicative quantum number defined as  $(-1)^{3N_B + N_L + 2S}$ , where  $N_B$  is the baryon number,  $N_L$  is the lepton number, and  $S$  is the spin quantum number [1]. However, SUSY does not require  $R$ -parity conservation. In particular, the lightest supersymmetric particle (LSP) can decay into a purely leptonic state due to the presence of an  $R_p$ - and  $N_L$ -violating term in the supersymmetric potential,  $\lambda_{ijk} L_i L_j E_k^C$ , where  $L_i$  and  $E_k$  are isodoublet and isosinglet supersymmetric lepton fields, respectively (the superscript  $C$  indicates charge conjugation). The indices  $i, j, k$  run over the three lepton generations and the potential is antisymmetric for the indices  $i$  and  $j$ . Current upper limits on  $R$ -parity violating SUSY Yukawa couplings,  $\lambda_{ijk}$ , are of the order of  $\approx 10^{-2}$  [2]. If these couplings are not vanishingly small, an enhancement is expected in the number of produced multilepton events.

In this paper, we reinterpret the result of a previous search by the  $D\bar{O}$  Collaboration for gaugino pair production in multilepton channels [3]. We use the minimal low-energy supergravity (MSUGRA) model [4,5] as a starting point, and add non-vanishing  $\lambda_{ijk}$  couplings. The MSUGRA model has four continuous parameters and one discrete parameter:  $m_0$  — the universal scalar mass,  $m_{1/2}$  — the universal gaugino mass,  $A_0$  — the common trilinear interaction term,  $\tan\beta$  — the ratio of the vacuum expectation values of the two Higgs fields, and the sign of  $\mu$  — the Higgsino mass parameter. The mass spectrum of the SUSY partners at the electroweak scale and their decay branching ratios are obtained from the above parameters by solving a set of renormalization group equations using the program ISAJET [6]. Present limits on the  $\lambda_{ijk}$  Yukawa couplings [2] imply that this mass spectrum is the same as for the case of conserved  $R$ -parity. In this analysis we consider only parameter regions with a neutralino ( $\tilde{\chi}_1^0$ ) as LSP.

The Collider Detector at Fermilab (CDF) and  $D\bar{O}$  Collaborations have previously reported on searches for  $R$ -parity violation in the di-electron+jets channels [7,8]. They assumed an  $R_p$ - and  $N_L$ -violating supersymmetric potential term  $\lambda'_{ijk} Q_i L_j D_k^C$ , where  $Q_i$  and  $D_k$  are isodoublet and isosinglet supersymmetric quark fields, respectively. Some regions of the MSUGRA parameter space are excluded by non-observation of SUSY or Higgs particles at the CERN  $e^+e^-$  collider (LEP2): the present limit on the mass of the lightest neutral SUSY Higgs boson (88.3 GeV [9]) implies that  $\tan\beta \leq 2$  is excluded, independent of the other parameters. At higher  $\tan\beta$ , part of the parameter space is ex-

cluded by the lower limit on the  $\tilde{\chi}_1^0$  mass [10] obtained assuming  $R$ -parity violation through  $\lambda$  couplings.

The event selection and background estimations used in this work are discussed in the above-mentioned  $D\bar{O}$  search [3]. Four different final states were considered:  $eee$ ,  $ee\mu$ ,  $e\mu\mu$ , and  $\mu\mu\mu$ , requiring at the least three electrons, two electrons and a muon, two muons and an electron, or three muons, in the respective channels. No acceptable events were found. The result is summarized in Table I. The corresponding selection criteria (including the triggers) are detailed in Ref. [3]. A minimum value of missing transverse energy and a minimum number of leptons above a threshold in transverse energy were required for each channel. Although no explicit veto was used to minimize jet activity, mild selection criteria were applied on masses of lepton pairs of the same flavor and on the angles between these leptons, as well as between the directions of the leptons and missing transverse energy, in order to reduce Drell-Yan and instrumental background. We consider the selection criteria of Ref. [3] adequate for the present analysis.

Our search is most sensitive to decays with highest electron and muon multiplicity, i.e., those with no  $\tau$  lepton among the decay products of the LSP. The detection efficiency is highest, especially for the case of  $\lambda_{121}$ , when electrons dominate. On the other hand, couplings  $\lambda_{133}$  and  $\lambda_{233}$  correspond to decays with the least sensitivity, because the number of  $\tau$  leptons is highest. We limit ourselves to the three extreme cases:  $\lambda_{121}$ ,  $\lambda_{122}$  and  $\lambda_{233}$ .

We generate Monte Carlo (MC) events with all possible production and decay modes of SUSY particles assuming the MSUGRA model using ISAJET [6] with  $R$ -parity violation [11,12]. We apply the same selection criteria as used in [3] to these generated events, and calculate all signal efficiencies.

Detector response is modeled using a parametrized, fast, particle-level simulation of isolated electrons, photons, and both isolated and non-isolated muons. The model contains jet reconstruction and a simulation of the missing transverse energy in an event. Lepton acceptance criteria include the loss of electrons in the region between the central and end cryostats of the calorimeter ( $1.2 \leq |\eta| \leq 1.4$ ), and a lookup table of the muon efficiency as a function of  $\eta$  and  $\phi$  [13,14], where  $\eta$  and  $\phi$  are the pseudorapidity and the azimuthal angle of the lepton, respectively. The parameters of the program are tuned so that the total acceptance,  $\epsilon^{\text{total}}$ , and the shapes of the missing transverse energy distributions and charged lepton  $\eta$ ,  $\phi$  and transverse energy distributions agree with detailed simulation based on GEANT [15,16]. The total acceptance includes the geometrical acceptance, efficiency factors for the trigger, track reconstruction, and lepton identification. It depends mainly on the type of coupling and

on the value of  $m_{1/2}$ . In the vicinity of the exclusion contour, the typical values are 20%, 10%, and 0.3% for  $\lambda_{121}$ ,  $\lambda_{122}$ , and  $\lambda_{233}$ , respectively.  $\epsilon^{\text{total}}$  decreases with decreasing  $m_{1/2}$ , mainly because the masses of the gauginos decrease and the energies of their decay products fall below the detection threshold. For the case of the  $\lambda_{121}$  coupling, the detection efficiencies are 5, 15 and 19% for the  $\tilde{\chi}_1^\pm$  ( $\tilde{\chi}_1^0$ ) masses of 56(32), 102(56) and 147(79) GeV, respectively. For  $m_{\tilde{\chi}_1^\pm} = 56$  GeV the efficiencies are 5, 2.4 and 0.2% for the  $\lambda_{121}$ ,  $\lambda_{122}$  and  $\lambda_{233}$  couplings, respectively.

Our 95% C.L. exclusion contours are based on a Bayesian approach [17,18]. For each point in the  $(m_0, m_{1/2})$  plane, we calculate a 95% C.L. upper limit on the cross section. The excluded region is determined from the intersection of this surface with the corresponding cross section predicted by ISAJET. In this calculation, we use as input the total integrated luminosities, and the uncertainties in the numbers of background events (cf. Table I) and in  $\epsilon^{\text{total}}$ . The latter includes the statistical error, an overall 10% systematic error in the MC simulation, and the error on efficiency factors for the trigger, track reconstruction, and lepton identification, determined through independent measurements described in Ref. [3]. Their values are between 10% and 20%, and depend on the event category (and therefore on the  $\lambda_{ijk}$  coupling) and to a lesser extent on event kinematics (e.g., on supersymmetric particle masses). Finally, we include a 10% uncertainty on the theoretical cross section, due to, e.g., the choice of parton distribution function.

Figures 1 through 4 show, respectively, the exclusion regions in the  $(m_0, m_{1/2})$  plane for the three chosen couplings, for  $\tan\beta=5$  and 10, and for both signs of  $\mu$ . Since the characteristics of SUSY signatures at hadron colliders are rather insensitive to values of  $A_0$  [19], we have fixed the value of  $A_0$  to zero. The dashed line indicates the limit of our sensitivity in  $m_{1/2}$  for the least favorable case, i.e., for the

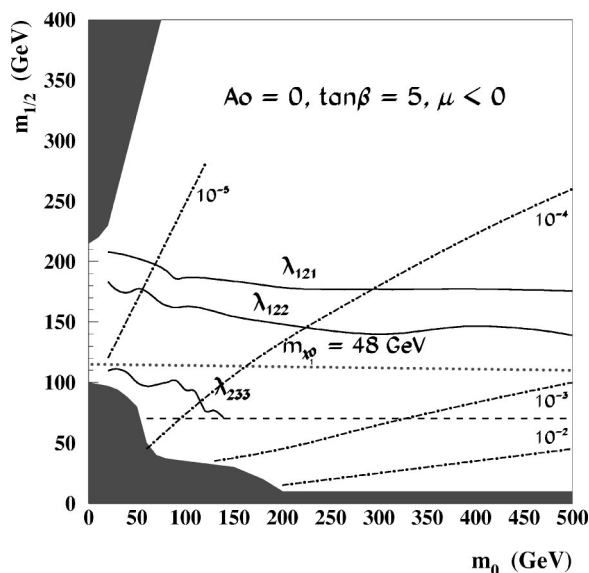


FIG. 1. Exclusion contours at 95% C.L. limits for  $\tan\beta = 5$ ,  $\mu < 0$ , for the case of finite  $\lambda_{121}$ ,  $\lambda_{122}$  and  $\lambda_{233}$  couplings. For the explanation of the different curves, see the text.

coupling of  $\lambda_{233}$ , where  $\epsilon^{\text{total}} < 10^{-4}$ . The exclusion regions correspond to the spaces below the solid lines labeled with the coupling types, and above the higher of the dashed line and the dash-dotted curves specifying the numerical values of  $\lambda$ . In the regions beyond the dash-dotted curves, the average decay length of the LSP calculated for the value of the coupling indicated on the curve is less than 1 cm. Since efficiency studies for high impact parameter tracks have not been done, we conservatively restrict the present study to decay lengths less than 1 cm. Thus, for example, the region between curves labeled with  $\lambda_{121}$  and  $10^{-3}$  is excluded if  $\lambda_{121} > 10^{-3}$ . The shaded areas indicate the regions where there is no electroweak symmetry breaking or where the LSP is not the lightest neutralino. Finally, we also show limits corresponding to the present lower limit on the  $\tilde{\chi}_1^0$  mass (dotted line), which exclude the regions below. The wiggles on the  $\lambda_{233}$  curves are due to statistical fluctuations and to the 10 GeV spacing between neighboring  $m_0$  points used to calculate the curves.

In conclusion, we have reinterpreted the result of a search for trilepton events in terms of possible  $R$ -parity violation in decays of the LSP. We have found that a large domain of MSUGRA parameter space can be excluded, provided that  $R$ -parity breaking is achieved by lepton-number non-conservation with  $\lambda_{121}$  or  $\lambda_{122}$  couplings greater than  $\approx 10^{-4}$ . The region of sensitivity extends beyond that presently excluded by LEP experiments [9,10]. For  $\lambda_{233}$ , where our experiment is least sensitive, only a very limited domain of parameter space can be excluded, and this region is already excluded by LEP. The excluded values of  $m_{1/2}$  depend mainly on the type of coupling, and much less on the values of other parameters. In particular, the excluded region is slightly larger for  $\mu > 0$  than for  $\mu < 0$ , and is almost independent of  $\tan\beta$ .

We thank the staffs at Fermilab and at collaborating institutions for contributions to this work, and acknowledge

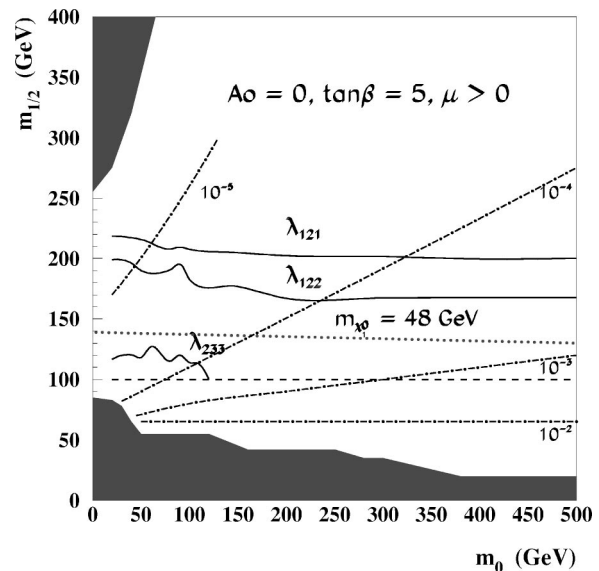


FIG. 2. Exclusion contours at 95% C.L. limits for  $\tan\beta = 5$ ,  $\mu > 0$ , for the case of finite  $\lambda_{121}$ ,  $\lambda_{122}$  and  $\lambda_{233}$  couplings.

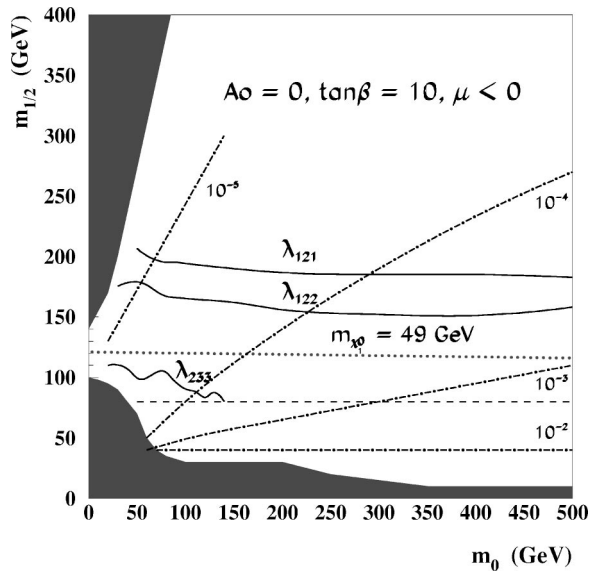


FIG. 3. Exclusion contours at 95% C.L. limits for  $\tan\beta = 10$ ,  $\mu < 0$ , for the case of finite  $\lambda_{121}$ ,  $\lambda_{122}$  and  $\lambda_{233}$  couplings.

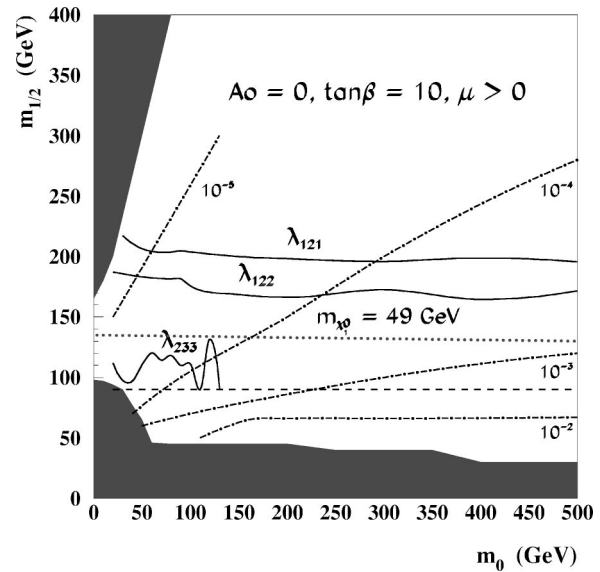


FIG. 4. Exclusion contours at 95% C.L. limits for  $\tan\beta = 10$ ,  $\mu > 0$ , for the case of finite  $\lambda_{121}$ ,  $\lambda_{122}$  and  $\lambda_{233}$  couplings.

support from the Department of Energy and National Science Foundation (USA), Commissariat à l'Énergie Atomique and CNRS/Institut National de Physique Nucléaire et de Physique des Particules (France), Ministry for Science and Technology and Ministry for Atomic Energy (Russia),

CAPES and CNPq (Brazil), Departments of Atomic Energy and Science and Education (India), Colciencias (Colombia), CONACyT (Mexico), Ministry of Education and KOSEF (Korea), CONICET and UBACyT (Argentina), A.P. Sloan Foundation, and the Humboldt Foundation.

- [1] G.R. Farrar and P. Fayet, Phys. Lett. **76B**, 575 (1978).  
 [2] H. Dreiner, in *An Introduction to Explicit R Parity Violation*, edited by G.L. Kane (World Scientific, Singapore, 1998); R. Barbier *et al.*, "Report of the group on the R-parity violation," hep-ph/9810232.  
 [3] DØ Collaboration, B. Abbott *et al.*, Phys. Rev. Lett. **80**, 1591 (1998).  
 [4] For reviews see H.P. Nilles, Phys. Rep. **111**, 1 (1984); H.E. Haber and G.L. Kane, *ibid.* **117**, 75 (1985).  
 [5] L. Alvarez-Gaume, J. Polchinski, and M.B. Wise, Nucl. Phys. **B221**, 495 (1983); L. Ibáñez, Phys. Lett. **118B**, 73 (1982); J. Ellis, D.V. Nanopoulos, and K. Tamvakis, *ibid.* **121B**, 123 (1983); K. Inoue *et al.*, Prog. Theor. Phys. **68**, 927 (1982); A.H. Chamseddine, R. Arnowitt, and P. Nath, Phys. Rev. Lett. **49**, 970 (1982).  
 [6] F. Paige and S. Protopopescu, in *Supercollider Physics*, edited by D. Soper (World Scientific, Singapore, 1986), p. 41; H. Baer, F. Paige, S. Protopopescu and X. Tata, in *Proceedings of the Workshop of Physics at Current Accelerators and Supercolliders*, edited by J. Hewett, A. White and D. Zeppenfeld (Argonne National Laboratory, Argonne, IL, 1993). We used version V7.29.  
 [7] CDF Collaboration, F. Abe *et al.*, Phys. Rev. Lett. **83**, 2133 (1999).  
 [8] DØ Collaboration, B. Abbott *et al.*, Phys. Rev. Lett. **83**, 4476 (1999).  
 [9] ALEPH, Delphi, L3 and OPAL Collaborations, CERN-EP-2000-055 (2000).  
 [10] ALEPH Collaboration, R. Barate *et al.*, Eur. Phys. J. C **4**, 433 (1998); Delphi Collaboration, P. Abreu *et al.*, CERN-EP/99-49 (1999); L3 Collaboration, M. Acciari *et al.*, Phys. Lett. B **459**, 283 (1999); OPAL Collaboration, G. Abbiendi *et al.*, CERN-EP/99-123 (1999).  
 [11] A. Mirea, Ph.D. thesis, Université de la Méditerranée, Marseille, France, 1999.  
 [12] S. Katsanevas and P. Morawitz, Comput. Phys. Commun. **112**, 227 (1998).  
 [13] S. Glenn, Ph.D thesis, University of California at Davis, 1996.  
 [14] DØ Collaboration, B. Abbott *et al.*, Phys. Rev. D **61**, 032004 (2000).  
 [15] R. Brun and F. Carminati, CERN Program Library Long Writup W5013, 1993.  
 [16] DØ Collaboration, S. Abachi *et al.*, Phys. Rev. Lett. **74**, 2632 (1995); DØ Collaboration, B. Abbott *et al.*, Phys. Rev. D **58**, 052001 (1998).  
 [17] H. Jeffreys, *Theory of Probability* (Clarendon Press, Oxford, 1961), p. 115; G. D'Agostini, "Bayesian reasoning in high energy physics: Principles and applications," CERN 99-03.  
 [18] I. Bertram *et al.*, FERMILAB-TM-2104.  
 [19] I. Hinchliffe *et al.*, Phys. Rev. D **55**, 5520 (1997).