Physics

Physics Research Publications

Purdue University *Year* 2007

Search for new physics in high-mass electron-positron events in p(p)over-bar collisions at root s p=1.96 TeV

T. Aaltonen, A. Abulencia, J. Adelman, T. Affolder, T. Akimoto, M. G. Albrow, S. Amerio, D. Amidei, A. Anastassov, K. Anikeev, A. Annovi, J. Antos, M. Aoki, G. Apollinari, T. Arisawa, A. Artikov, W. Ashmanskas, A. Attal, A. Aurisano, F. Azfar, P. Azzi-Bacchetta, P. Azzurri, N. Bacchetta, W. Badgett, A. Barbaro-Galtieri, V. E. Barnes, B. A. Barnett, S. Baroiant, V. Bartsch, G. Bauer, P. H. Beauchemin, F. Bedeschi, S. Behari, G. Bellettini, J. Bellinger, A. Belloni, D. Benjamin, A. Beretvas, J. Beringer, T. Berry, A. Bhatti, M. Binkley, D. Bisello, I. Bizjak, R. E. Blair, C. Blocker, B. Blumenfeld, A. Bocci, A. Bodek, V. Boisvert, G. Bolla, A. Bolshov, D. Bortoletto, J. Boudreau, A. Boveia, B. Brau, L. Brigliadori, C. Bromberg, E. Brubaker, J. Budagov, H. S. Budd, S. Budd, K. Burkett, G. Busetto, P. Bussey, A. Buzatu, K. L. Byrum, S. Cabrera, M. Campanelli, M. Campbell, F. Canelli, A. Canepa, S. Carrillo, D. Carlsmith, R. Carosi, S. Carron, B. Casal, M. Casarsa, A. Castro, P. Catastini, D. Cauz, M. Cavalli-Sforza, A. Cerri, L. Cerrito, S. H. Chang, Y. C. Chen, M. Chertok, G. Chiarelli, G. Chlachidze, F. Chlebana, I. Cho, K. Cho, D. Chokheli, J. P. Chou, G. Choudalakis, S. H. Chuang, K. Chung, W. H. Chung, Y. S. Chung, M. Cilijak, C. I. Ciobanu, M. A. Ciocci, A. Clark, D. Clark, M. Coca, G. Compostella, M. E. Convery, J. Conway, B. Cooper, K. Copic, M. Cordelli, G. Cortiana, F. Crescioli, C. C. Almenar, J. Cuevas, R. Culbertson, J. C. Cully, S. DaRonco, M. Datta, S. D'Auria, T. Davies, D. Dagenhart, P. De Barbaro, S. De Cecco, A. Deisher, G. De Lentdecker, G. De Lorenzo, M. Dell'Orso, F. D. Paoli, L. Demortier, J. Deng, M. Deninno, D. De Pedis, P. F. Derwent, G. P. Di Giovanni, C. Dionisi, B. Di Ruzza, J. R. Dittmann, M. D'Onofrio, C. D. Rr, S. Donati, P. Dong, J. Donini, T. Dorigo, S. Dube, J. Efron, R. Erbacher, D. Errede, S. Errede, R. Eusebi, H. C. Fang, S. Farrington, I. Fedorko, W. T. Fedorko, R. G. Feild, M. Feindt, J. P. Fernandez, R. Field, G. Flanagan, R. Forrest, S. Forrester, M. Franklin, J. C. Freeman, I. Furic, M. Gallinaro, J. Galyardt, J. E. Garcia, F. Garberson, A. F. Garfinkel, C. Gay, H. Gerberich, D. Gerdes, S. Giagu, P. Giannetti, K. Gibson, J. L. Gimmell, C. Ginsburg, N.

Giokaris, M. Giordani, P. Giromini, M. Giunta, G. Giurgiu, V. Glagolev, D. Glenzinski, M. Gold, N. Goldschmidt, J. Goldstein, A. Golossanov, G. Gomez, G. Gomez-Ceballos, M. Goncharov, O. Gonzalez, I. Gorelov, A. T. Goshaw, K. Goulianos, A. Gresele, S. Grinstein, C. Grosso-Pilcher, R. C. Group, U. Grundler, J. G. Da Costa, Z. Gunay-Unalan, C. Haber, K. Hahn, S. R. Hahn, E. Halkiadakis, A. Hamilton, B. Y. Han, J. Y. Han, R. Handler, F. Happacher, K. Hara, D. Hare, M. Hare, S. Harper, R. F. Harr, R. M. Harris, M. Hartz, K. Hatakeyama, J. Hauser, C. Hays, M. Heck, A. Heijboer, B. Heinemann, J. Heinrich, C. Henderson, M. Herndon, J. Heuser, D. Hidas, C. S. Hill, D. Hirschbuehl, A. Hocker, A. Holloway, S. Hou, M. Houlden, S. C. Hsu, B. T. Huffman, R. E. Hughes, U. Husemann, J. Huston, J. Incandela, G. Introzzi, M. Iori, A. Ivanov, B. Iyutin, E. James, D. Jang, B. Jayatilaka, D. Jeans, E. J. Jeon, S. Jindariani, W. Johnson, M. Jones, K. K. Joo, S. Y. Jun, J. E. Jung, T. R. Junk, T. Kamon, P. E. Karchin, Y. Kato, Y. Kemp, R. Kephart, U. Kerzel, V. Khotilovich, B. Kilminster, D. H. Kim, H. S. Kim, J. E. Kim, M. J. Kim, S. B. Kim, S. H. Kim, Y. K. Kim, N. Kimura, L. Kirsch, S. Klimenko, M. Klute, B. Knuteson, B. R. Ko, K. Kondo, D. J. Kong, J. Konigsberg, A. Korytov, A. V. Kotwal, A. C. Kraan, J. Kraus, M. Kreps, J. Kroll, N. Krumnack, M. Kruse, V. Krutelyov, T. Kubo, S. E. Kuhlmann, T. Kuhr, N. P. Kulkarni, Y. Kusakabe, S. Kwang, A. T. Laasanen, S. Lai, S. Lami, S. Lammel, M. Lancaster, R. L. Lander, K. Lannon, A. Lath, G. Latino, I. Lazzizzera, T. LeCompte, J. Lee, J. Lee, Y. J. Lee, S. W. Lee, R. Lefevre, N. Leonardo, S. Leone, S. Levy, J. D. Lewis, C. Lin, S. Lin, M. Lindgren, E. Lipeles, A. Lister, D. O. Litvintsev, T. Liu, N. S. Lockyer, A. Loginov, M. Loreti, R. S. Lu, D. Lucchesi, P. Lujan, P. Lukens, G. Lungu, L. Lyons, J. Lys, R. Lysak, E. Lytken, P. Mack, D. MacQueen, R. Madrak, K. Maeshima, K. Makhoul, T. Maki, P. Maksimovic, S. Malde, S. Malik, G. Manca, A. Manousakis, F. Margaroli, R. Marginean, C. Marino, C. P. Marino, A. Martin, M. Martin, V. Martin, M. Martinez, R. Martinez-Ballarin, T. Maruyama, P. Mastrandrea, T. Masubuchi, H. Matsunaga, M. E. Mattson, R. Mazini, P. Mazzanti, K. S. McFarland, P. McIntyre, R. McNulty, A. Mehta, P. Mehtala, S. Menzemer, A. Menzione, P. Merkel, C. Mesropian, A. Messina, T. Miao, N. Miladinovic, J. Miles, R. Miller, C. Mills, M. Milnik, A. Mitra, G. Mitselmakher, A. Miyamoto, S. Moed, N. Moggi, B. Mohr, C. S. Moon, R. Moore, M. Morello, P. M. Fernandez, J. Mulmenstadt, A. Mukherjee, T. Muller, R. Mumford, P. Murat, M. Mussini, J. Nachtman, A. Nagano, J. Naganoma, K. Nakamura, I. Nakano, A. Napier, V. Necula, C. Neu, M. S. Neubauer, J. Nielsen, L. Nodulman, O. Norniella, E. Nurse, S. H. Oh, Y. D. Oh, I. Oksuzian, T. Okusawa, R. Oldeman, R. Orava, K. Osterberg, C. Pagliarone, E. Palencia, V. Papadimitriou, A. Papaikonomou, A. A. Paramonov, B. Parks, S. Pashapour, J. Patrick, G. Pauletta, M. Paulini, C. Paus, D. E. Pellett, A. Penzo, T. J. Phillips, G. Piacentino, J. Piedra, L. Pinera, K. Pitts, C. Plager, L. Pondrom, X. Portell, O. Poukhov, N. Pounder, F. Prakoshyn, A. Pronko, J. Proudfoot, F. Ptohos, G. Punzi, J. Pursley, J. Rademacker, A. Rahaman, V. Ramakrishnan, N. Ranjan, I. Redondo, B. Reisert, V. Rekovic, P. Renton, M. Rescigno, S. Richter, F. Rimondi, L. Ristori, A. Robson, T. Rodrigo, E. Rogers, S. Rolli, R. Roser, M. Rossi, R. Rossin, P. Roy, A. Ruiz, J. Russ, V. Rusu, H. Saarikko,

A. Safonov, W. K. Sakumoto, G. Salamanna, O. Salto, L. Santi, S. Sarkar, L. Sartori, K. Sato, P. Savard, A. Savoy-Navarro, T. Scheidle, P. Schlabach, E. E. Schmidt, M. P. Schmidt, M. Schmitt, T. Schwarz, L. Scodellaro, A. L. Scott, A. Scribano, F. Scuri, A. Sedov, S. Seidel, Y. Seiya, A. Semenov, L. Sexton-Kennedy, A. Sfyrla, S. Z. Shalhout, M. D. Shapiro, T. Shears, P. F. Shepard, D. Sherman, M. Shimojima, M. Shochet, Y. Shon, I. Shreyber, A. Sidoti, P. Sinervo, A. Sisakyan, A. J. Slaughter, J. Slaunwhite, K. Sliwa, J. R. Smith, F. D. Snider, R. Snihur, M. Soderberg, A. Soha, S. Somalwar, V. Sorin, J. Spalding, F. Spinella, T. Spreitzer, P. Squillacioti, M. Stanitzki, A. Staveris-Polykalas, R. S. Denis, B. Stelzer, O. Stelzer-Chilton, D. Stentz, J. Strologas, D. Stuart, J. S. Suh, A. Sukhanov, H. Sun, I. Suslov, T. Suzuki, A. Taffard, R. Takashima, Y. Takeuchi, R. Tanaka, M. Tecchio, P. K. Teng, K. Terashi, J. Thom, A. S. Thompson, E. Thomson, P. Tipton, V. Tiwari, S. Tkaczyk, D. Toback, S. Tokar, K. Tollefson, T. Tomura, D. Tonelli, S. Torre, D. Torretta, S. Tourneur, W. Trischuk, S. Tsuno, Y. Tu, N. Turini, F. Ukegawa, S. Uozumi, S. Vallecorsa, N. van Remortel, A. Varganov, E. Vataga, F. Vazquez, G. Velev, C. Vellidis, G. Veramendi, V. Veszpremi, M. Vidal, R. Vidal, I. Vila, R. Vilar, T. Vine, M. Vogel, I. Vollrath, I. Volobouev, G. Volpi, F. Wurthwein, P. Wagner, R. G. Wagner, R. L. Wagner, J. Wagner, W. Wagner, R. Wallny, S. M. Wang, A. Warburton, D. Waters, M. Weinberger, W. C. Wester, B. Whitehouse, D. Whiteson, A. B. Wicklund, E. Wicklund, G. Williams, H. H. Williams, P. Wilson, B. L. Winer, P. Wittich, S. Wolbers, C. Wolfe, T. Wright, X. Wu, S. M. Wynne, A. Yagil, K. Yamamoto, J. Yamaoka, T. Yamashita, C. Yang, U. K. Yang, Y. C. Yang, W. M. Yao, G. P. Yeh, J. Yoh, K. Yorita, T. Yoshida, G. B. Yu, I. Yu, S. S. Yu, J. C. Yun, L. Zanello, A. Zanetti, I. Zaw, X. Zhang, J. Zhou, and S. Zucchelli

Search for New Physics in High-Mass Electron-Positron Events in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV

T. Aaltonen,[23] A. Abulencia,[24] J. Adelman,[13] T. Affolder,[10] T. Akimoto,[55] M. G. Albrow,[17] S. Amerio,[43] D. Amidei,[35] A. Anastassov,[52] K. Anikeev,[17] A. Annovi,[19] J. Antos,[14] M. Aoki,[55] G. Apollinari,[17] T. Arisawa,[57] A. Artikov,[15] W. Ashmanskas,[17] A. Attal,[3] A. Aurisano,[53] F. Azfar,[42] P. Azzi-Bacchetta,[43] P. Azzurri,[46] N. Bacchetta,[43] W. Badgett,[17] A. Barbaro-Galtieri,[29] V. E. Barnes,[48] B. A. Barnett,[25] S. Baroiant,[7] V. Bartsch,[31] G. Bauer,[33] P.-H. Beauchemin,[34] F. Bedeschi,[46] S. Behari,[25] G. Bellettini,[46] J. Bellinger,[59] A. Belloni,[33] D. Benjamin,[16] A. Beretvas,[17] J. Beringer,[29] T. Berry,[30] A. Bhatti,[50] M. Binkley,[17] D. Bisello,[43] I. Bizjak,[31] R. E. Blair,[2] C. Blocker,[6] B. Blumenfeld,[25] A. Bocci,[16] A. Bodek,[49] V. Boisvert,[49] G. Bolla,[48] A. Bolshov,[33] D. Bortoletto,[48] J. Boudreau,[47] A. Boveia,[10] B. Brau,[10] L. Brigliadori,[5] C. Bromberg,[36] E. Brubaker,[13] J. Budagov,[15] H. S. Budd,[49] S. Budd,[24] K. Burkett,[17] G. Busetto,[43] P. Bussey,[21] A. Buzatu,[34] K. L. Byrum,[2] S. Cabrera,[16,q] M. Campanelli,[20] M. Campbell,[35] F. Canelli,[17] A. Canepa,[45] S. Carrillo,[18,i] D. Carlsmith,[59] R. Carosi,[46] S. Carron,[34] B. Casal,[11] M. Casarsa,[54] A. Castro,[5] P. Catastini,[46] D. Cauz,[54] M. Cavalli-Sforza,[3] A. Cerri,[29] L. Cerrito,[31,m] S. H. Chang,[28] Y. C. Chen,[1] M. Chertok,[7] G. Chiarelli,[46] G. Chlachidze,[17] F. Chlebana,[17] I. Cho,[28] K. Cho,[28] D. Chokheli,[15] J. P. Chou,[22] G. Choudalakis,[33] S. H. Chuang,[52] K. Chung,[12] W. H. Chung,[59] Y. S. Chung,[49] M. Cilijak,[46] C. I. Ciobanu,[24] M. A. Ciocci,[46] A. Clark,[20] D. Clark,[6] M. Coca,[16] G. Compostella,[43] M. E. Convery,[50] J. Conway,[7] B. Cooper,[31] K. Copic,[35] M. Cordelli,[19] G. Cortiana,[43] F. Crescioli,[46] C. Cuenca Almenar,[7,q] J. Cuevas,[11,l] R. Culbertson,[17] J. C. Cully,[35] S. DaRonco,[43] M. Datta,[17] S. D'Auria,[21] T. Davies,[21] D. Dagenhart,[17] P. de Barbaro,[49] S. De Cecco,[51] A. Deisher,[29] G. De Lentdecker,[49,c] G. De Lorenzo,[3] M. Dell'Orso,[46] F. Delli Paoli,[43] L. Demortier,[50] J. Deng,[16] M. Deninno,[5] D. De Pedis,[51] P. F. Derwent,[17] G. P. Di Giovanni,[44] C. Dionisi,[51] B. Di Ruzza,[54] J. R. Dittmann,[4] M. D'Onofrio,[3] C. Dörr,[26] S. Donati,[46] P. Dong,[8] J. Donini,[43] T. Dorigo,[43] S. Dube,[52] J. Efron,[39] R. Erbacher,[7] D. Errede,[24] S. Errede,[24] R. Eusebi,[17] H. C. Fang,[29] S. Farrington,[30] I. Fedorko,[46] W. T. Fedorko,[13] R. G. Feild,[60] M. Feindt,[26] J. P. Fernandez,[32] R. Field,[18] G. Flanagan,[48] R. Forrest,[7] S. Forrester,[7] M. Franklin,[22] J. C. Freeman,[29] I. Furic,[13] M. Gallinaro,[50] J. Galyardt,[12] J. E. Garcia,[46] F. Garberson,[10] A. F. Garfinkel,[48] C. Gay,[60] H. Gerberich,[24] D. Gerdes,[35] S. Giagu,[51] P. Giannetti,[46] K. Gibson,[47] J. L. Gimmell,[49] C. Ginsburg,[17] N. Giokaris,[15,a] M. Giordani,[54] P. Giromini,[19] M. Giunta,[46] G. Giurgiu,[25] V. Glagolev,[15] D. Glenzinski,[17] M. Gold,[37] N. Goldschmidt,[18] J. Goldstein,[42,b] A. Golossanov,[17] G. Gomez,[11] G. Gomez-Ceballos,[33] M. Goncharov,[53] O. González,[32] I. Gorelov,[37] A. T. Goshaw,[16] K. Goulianos,[50] A. Gresele,[43] S. Grinstein,[22] C. Grosso-Pilcher,[13] R. C. Group,[17] U. Grundler,[24] J. Guimaraes da Costa,[22] Z. Gunay-Unalan,[36] C. Haber,[29] K. Hahn,[33] S. R. Hahn,[17] E. Halkiadakis,[52] A. Hamilton,[20] B.-Y. Han,[49] J. Y. Han,[49] R. Handler,[59] F. Happacher,[19] K. Hara,[55] D. Hare,[52] M. Hare,[56] S. Harper,[42] R. F. Harr,[58] R. M. Harris,[17] M. Hartz,[47] K. Hatakeyama,[50] J. Hauser,[8] C. Hays,[42] M. Heck,[26] A. Heijboer,[45] B. Heinemann,[29] J. Heinrich,[45] C. Henderson,[33] M. Herndon,[59] J. Heuser,[26] D. Hidas,[16] C. S. Hill,[10,b] D. Hirschbuehl,[26] A. Hocker,[17] A. Holloway,[22] S. Hou,[1] M. Houlden,[30] S.-C. Hsu,[9] B. T. Huffman,[42] R. E. Hughes,[39] U. Husemann,[60] J. Huston,[36] J. Incandela,[10] G. Introzzi,[46] M. Iori,[51] A. Ivanov,[7] B. Iyutin,[33] E. James,[17] D. Jang,[52] B. Jayatilaka,[16] D. Jeans,[51] E. J. Jeon,[28] S. Jindariani,[18] W. Johnson,[7] M. Jones,[48] K. K. Joo,[28] S. Y. Jun,[12] J. E. Jung,[28] T. R. Junk,[24] T. Kamon,[53] P. E. Karchin,[58] Y. Kato,[41] Y. Kemp,[26] R. Kephart,[17] U. Kerzel,[26] V. Khotilovich,[53] B. Kilminster,[39] D. H. Kim,[28] H. S. Kim,[28] J. E. Kim,[28] M. J. Kim,[17] S. B. Kim,[28] S. H. Kim,[55] Y. K. Kim,[13] N. Kimura,[55] L. Kirsch,[6] S. Klimenko,[18] M. Klute,[33] B. Knuteson,[33] B. R. Ko,[16] K. Kondo,[57] D. J. Kong,[28] J. Konigsberg,[18] A. Korytov,[18] A. V. Kotwal,[16] A. C. Kraan,[45] J. Kraus,[24] M. Kreps,[26] J. Kroll,[45] N. Krumnack,[4] M. Kruse,[16] V. Krutelyov,[10] T. Kubo,[55] S. E. Kuhlmann,[2] T. Kuhr,[26] N. P. Kulkarni,[58] Y. Kusakabe,[57] S. Kwang,[13] A. T. Laasanen,[48] S. Lai,[34] S. Lami,[46] S. Lammel,[17] M. Lancaster,[31] R. L. Lander,[7] K. Lannon,[39] A. Lath,[52] G. Latino,[46] I. Lazzizzera,[43] T. LeCompte,[2] J. Lee,[49] J. Lee,[28] Y. J. Lee,[28] S. W. Lee,[53,o] R. Lefèvre,[20] N. Leonardo,[33] S. Leone,[46] S. Levy,[13] J. D. Lewis,[17] C. Lin,[60] C. S. Lin,[17] M. Lindgren,[17] E. Lipeles,[9] A. Lister,[7] D. O. Litvintsev,[17] T. Liu,[17] N. S. Lockyer,[45] A. Loginov,[60] M. Loreti,[43] R.-S. Lu,[1] D. Lucchesi,[43] P. Lujan,[29] P. Lukens,[17] G. Lungu,[18] L. Lyons,[42] J. Lys,[29] R. Lysak,[14] E. Lytken,[48] P. Mack,[26] D. MacQueen,[34] R. Madrak,[17] K. Maeshima,[17] K. Makhoul,[33] T. Maki,[23] P. Maksimovic,[25] S. Malde,[42] S. Malik,[31] G. Manca,[30] A. Manousakis,[15,a] F. Margaroli,[5] R. Marginean,[17] C. Marino,[26] C. P. Marino,[24] A. Martin,[60] M. Martin,[25] V. Martin,[21,g] M. Martínez,[3] R. Martínez-Ballarín,[32] T. Maruyama,[55] P. Mastrandrea,[51] T. Masubuchi,[55] H. Matsunaga,[55] M. E. Mattson,[58] R. Mazini,[34] P. Mazzanti,[5] K. S. McFarland,[49] P. McIntyre,[53] R. McNulty,[30,f] A. 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We report the results of a search for a narrow resonance in electron-positron events in the invariant mass range of 150–950 GeV/c^2 using 1.3 fb^{-1} of $p\bar{p}$ collision data at $\sqrt{s} = 1.96$ TeV collected by the CDF II detector at Fermilab. No significant evidence of such a resonance is observed and we interpret the results to exclude the standard-model-like Z' with a mass below 923 GeV/c^2 and the Randall-Sundrum graviton with a mass below 807 GeV/c^2 for $k/\overline{M}_{\mathrm{pl}} = 0.1$, both at the 95% confidence level. Combining with diphoton data excludes the Randall-Sundrum graviton for masses below 889 GeV/c^2 for $k/\overline{M}_{\mathrm{pl}} = 0.1$.

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At hadron colliders, electron-positron pairs (ee) are a distinct experimental signature with a low background rate. Since many models introducing new physics beyond the standard model of particle physics (SM) predict an excess in ee production at a hadron collider, this channel has a strong discovery potential. This Letter describes a search for a new high-mass state in ee events from $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV. The data used in this analysis were collected by the CDF II detector at the Fermilab Tevatron and correspond to an integrated luminosity of 1.3 fb^{-1}. The analysis also uses results from the $\gamma\gamma$ channel described in [1] to increase the analysis' sensitivity to the Randall-Sundrum (RS) graviton [2].

The search is optimized for new physics processes which produce narrow ee resonances [3], but is otherwise model independent. In addition to the above search, cross section times branching ratio ($\sigma\mathcal{B}$) upper limits [4] are set for generic neutral spin-1 and spin-2 bosons. These $\sigma\mathcal{B}$ limits are then used to set lower bounds on the masses of specific particles predicted by new physics models. These particles are the E_6 Z's [5] and the RS graviton. The E_6 model unifies the forces of the SM into the E_6 gauge group and in doing so predicts the presence of two additional neutral massive spin-1 bosons, referred to as Z's, which can mix with some arbitrary mixing angle. The Z'_η, Z'_χ, Z'_ψ, and Z'_I Z's correspond to specific values of the mixing angle and are used to benchmark the model. The RS graviton is predicted by the RS model of warped extra dimensions which solves the hierarchy between the weak and Planck scales by introducing an extra spatial dimension with negative curvature k. The model predicts a series of narrow neutral spin-2 resonances which couple to all SM particles, with the lowest mass resonance referred to here as the RS graviton. The properties of this model are determined by the mass of the RS graviton and the ratio $k/\overline{M}_{\rm pl}$, where $\overline{M}_{\rm pl}$ is the reduced effective Planck scale. This ratio governs the couplings of the graviton to SM particles and it has a favored range of 0.01 to 0.1 [6].

The most recent similar search by the D0 collaboration used an integrated luminosity of 260 pb^{-1} and treated the ee and the diphoton ($\gamma\gamma$) channels as a single channel to perform the first dedicated RS graviton search [7]. The most recent search for new physics in the ee channel by the CDF collaboration was a dedicated Z' search and used an integrated luminosity of 448 pb^{-1} [8].

This analysis is based on an integrated luminosity of 1.3 fb^{-1} collected with the CDF II detector. The CDF II detector is a general purpose detector which is azimuthally and forward-backward symmetric and is described in detail elsewhere [9]. The relevant components for this analysis are the central tracking chamber (COT) and the central and plug calorimeters. The COT is a 96-layer drift chamber placed within a 1.4 T magnetic field and is used to measure the momenta of charged particles within the pseudorapidity range $|\eta| \leq 1.1$ [10]. The COT is complemented by a silicon microstrip detector which directly surrounds the beampipe and has a tracking coverage of $|\eta| \leq 2.0$ [11]. The central and plug calorimeters are sampling calorimeters that surround the COT; they consist of electromagnetic (EM) and hadronic sections that measure the energy of particles in the range $|\eta| \leq 1.1$ and $1.2 \leq |\eta| \leq 3.6$ respectively.

The trigger used in this analysis requires two separate deposits of EM energy in the calorimeter and is effectively 100% efficient for selecting ee events within the acceptance of the analysis. Events are selected by requiring two electron candidates with $E_T \geq 25$ GeV. Events are separated into two channels: central-central (CC) where both electrons are in the central EM calorimeter (CEM) ($|\eta| \leq 1.1$) and central-plug (CP) where one electron is in the plug EM calorimeter (PEM) ($1.2 \leq |\eta| \leq 3.0$). The region of the PEM with $|\eta| > 3.0$ has significant activity from the underlying event, and so is not used. Electrons in the CEM are required to have a well-measured track, whereas there is no tracking requirement for electron candidates in the PEM. Because of the lack of tracking in the plug region there is no opposite sign requirement for any of the ee pairs. In the CC channel, 5% of the electron pairs in the signal region ($M_{ee} \geq 150$ GeV$/c^2$) are same sign, which is compatible with the fraction of misidentified opposite sign pairs predicted by simulation. Electrons are identified in an identical way to the previously published analysis [8], with the exception that a photon conversion veto is applied to central electrons in CP events. This selection cut improves the sensitivity of the analysis by reducing the $\gamma\gamma$ background in this channel. The event selection and the search method defined later were chosen without regard to events observed in the signal region to ensure a statistical robust result.

The geometric and kinematic acceptance as a function of resonance mass is estimated using event samples generated by Monte Carlo (MC) simulation. The PYTHIA event generator [12], with the CTEQ5L parton distribution functions (PDF) [13] and the CDF II detector simulation based on GEANT 3 [14] are used to generate all simulation samples unless otherwise stated. A Z' with the couplings of the SM Z (SM-like Z') is used for the simulated spin-1 signal sample and a RS graviton with $k/\overline{M}_{\rm pl} = 0.1$ is used for the spin-2 sample. Both the Z' and RS graviton bosons are constrained to be within $\pm 10\%$ of their on-shell mass at generator level. The uncertainty on the acceptance resulting from the PDF parameterization is estimated to be 2%–4% using the procedure recommended by the CTEQ Collaboration [15]. The uncertainty on the acceptance due to initial state radiation (ISR) is estimated to be 4% by varying the parameters governing ISR in PYTHIA. The electron identification efficiency ranges from 90% to 95% per electron and is estimated using the simulated signal samples. These estimates are corrected for imperfections in the simulation by comparing the simulation with the data at the Z pole, resulting in a 2% systematic uncertainty. The total selection efficiency $\times$ acceptance over the entire signal region is in the range of 40% to 45% for spin-1 and spin-2 bosons.

The most significant source of background to new physics in the ee channel is the SM Drell-Yan process via Z/γ^* which is an irreducible background. Jet events, such as dijet or W + jet events where the jets are misidentified as electrons, represent the most significant reducible background. Other less significant backgrounds result from $t\bar{t}$, $\tau^+\tau^-$, WW, WZ, $W\gamma$, and $\gamma\gamma$ events. Figure 1 shows the invariant mass distribution for all the background components properly normalized, together with the observed data for the CC and CP channels combined.

The SM Drell-Yan contribution is estimated using MC simulated events normalized to the data at the Z pole. By

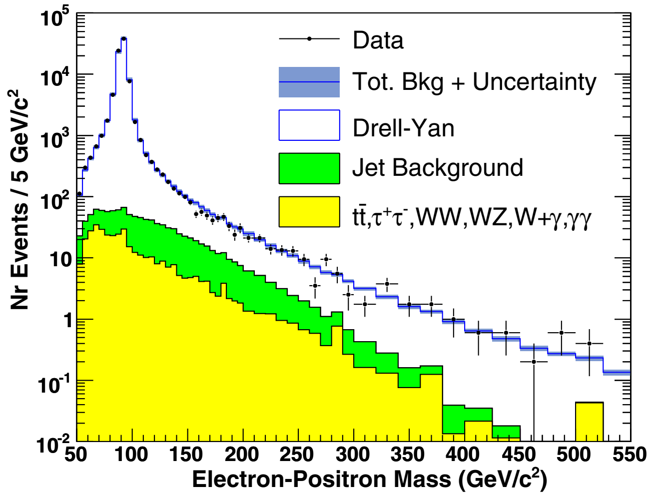

FIG. 1 (color online). The measured ee mass spectrum with the expected background for the CC and CP channels combined. The backgrounds are displayed cumulatively. There are no observed events above 550 GeV$/c^2$.

investigating the stability of the normalization factor a 4% systematic uncertainty is obtained on the SM Drell-Yan normalization. An uncertainty on the SM Drell-Yan shape due to PDF uncertainties is determined using the same method as used for the acceptance. The di-jet and $W+$jet backgrounds are treated as a single background, referred to as the jet background. The size of this background is estimated from a sample of jet events constructed from the data identically to the signal sample except that at least one electron candidate is not isolated [16] and therefore likely to be a jet. From the distribution of the isolation of these "electron" candidates, the number of jet events in the signal sample and its uncertainty is extracted. The shape of the jet background is estimated from a jet $+ Y$ sample, where Y is either an electron or a jet misidentified as an electron. In the region where the jet background is significant, the normalization uncertainty is the dominant uncertainty on the jet background. Using these methods, the jet background is estimated to account for $0.8 \pm 0.7\%$ and $25 \pm 8\%$ of the total background above 150 GeV$/c^2$ in the CC and CP channels, respectively. The remaining backgrounds are all estimated using MC simulation normalized to the theoretical next-to-leading-order (NLO) or higher order cross section. The uncertainties in these background estimates are dominated by the 6% uncertainty on the luminosity [17].

A model-independent search for an excess over SM predictions is performed in an invariant mass range of 150–950 GeV$/c^2$. The search is optimized for a narrow resonance, but still retains sensitivity to other signals which would produce an excess over SM predictions. Using 1 GeV$/c^2$ steps from $M_{ee} = 150$ to 950 GeV$/c^2$, the probability, referred to as the p value, of observing at least as many events as recorded in the real experiment given the expected background rate is calculated using Poisson statistics in a mass window of $4.8 + 0.044 \times M_{ee}$ GeV$/c^2$. This mass window is approximately the width a narrow resonance would have if observed in the CDF detector, and this choice of mass window maximizes the sensitivity to discovering such a resonance for this particular analysis, as verified from studies of simulated events. The uncertainty on the background estimate is treated as a nuisance parameter with a Gaussian distribution. The p values for the CC and CP channels are combined multiplicatively and the results are shown in Fig. 2. The minimum p value expected in the absence of new physics depends on the size of the search range, with the expected minimum p value decreasing as the search range increases. The range in which minimum p value is expected to occur is shown in Fig. 2 and is defined to include 68.3% of the minimum p values centered on the median value, using 1×10^6 simulated mass spectra. Similarly, the 3σ evidence line is the p value above which the minimum p value in 99.85% of the simulated mass spectra fall; any p value lower than this would be taken as evidence for the presence of new physics. The lowest p value observed is at 367 GeV$/c^2$ and is within the expected range. It is therefore concluded that the results of this analysis are consistent with the SM.

To complement the above search, a Bayesian binned likelihood method is used to extract limits on $\sigma\mathcal{B}(X \to ee)$, where the mass of X is within $\pm 10\%$ of its on-shell mass. As the acceptance of the final-state ee system is required to extract a cross section, it is necessary to specify

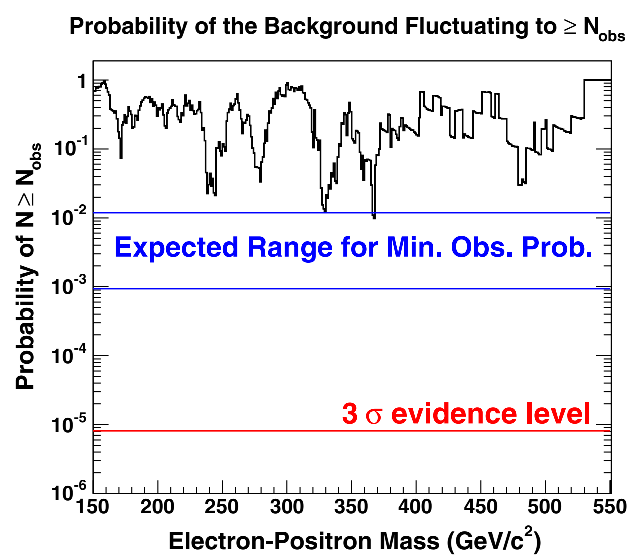

FIG. 2 (color online). The probability that the background alone could give rise to the observed number of events in a mass window equal to the width of a narrow resonance in the CDF detector. The expected range and the 3σ evidence line are defined in the text. The region 550–950 GeV$/c^2$ is not shown as no events are observed in data and therefore the p value is always 1 in this region.

the spin of the particle. Both spin-1 and spin-2 particles are considered here. The likelihood is one-dimensional with the signal cross section as the free parameter and the bin contents treated using Poisson statistics. The likelihood is then convoluted with a Gaussian to allow for the uncertainty on the cross section from the acceptance, background, and luminosity estimates. The probability density function is formed by taking a flat prior for the signal cross section and is numerically integrated to obtain the limit on $\sigma\mathcal{B}(X \to ee)$. The observed limits are shown in Fig. 3 for the spin-1 case. The Z' model lines are obtained using the leading-order PYTHIA event generator using the couplings in [18], with a factor of 1.3 applied multiplicatively to account for NLO corrections [19].

For the specific case of the RS graviton, which has a branching ratio to $\gamma\gamma$ twice that of ee, the analysis sensitivity can be improved by combining with the $\gamma\gamma$ channel described in [1]. The $\gamma\gamma$ events are required to have two photons with $E_T \geq 15$ GeV, with one in the CEM ($|\eta| \leq 1.04$) and the other either in the CEM or the portion of the PEM with sufficient silicon microstrip coverage ($1.2 \leq |\eta| \leq 2.8$). The CC and CP channels use integrated luminosities of 1.2 fb^{-1} and 1.1 fb^{-1} respectively, with the difference arising from the requirement that the silicon system be operational for track veto purposes for photons in the PEM. Selected photons have similar isolation and shower shape requirements to electrons; however photons are required not to have an associated track, which ensures there is no overlap between the $\gamma\gamma$ and ee sample.

The $\gamma\gamma$ channel is combined with the ee channel by multiplying their individual likelihoods together. The uncertainties on the background estimates are considered to be uncorrelated. The uncertainties on the acceptance and luminosity are taken to be 100% correlated. The combined limits, together with the $k/\overline{M}_{\rm pl}$ vs graviton mass exclusion region, are shown in Fig. 4. The RS graviton model lines are obtained using the HERWIG event generator [20] with a factor of 1.3 applied multiplicatively to account for NLO corrections.

In summary a search has been made for new physics in the ee channel, and no significant excess over the standard model prediction is observed. Limits are placed on new spin-1 and spin-2 bosons. The SM-like Z' is found to be excluded for masses below 923 GeV$/c^2$ and the E_6 Z' bosons; the Z'_I, the Z'_ψ, the Z'_χ, and the Z'_η bosons are excluded with masses below 729, 822, 822, and 891 GeV$/c^2$ respectively. The direct limits presented here on all the E_6 Z' bosons surpass the corresponding indirect limits from LEP [21]. The RS graviton with $k/\overline{M}_{\rm pl} = 0.1$ is excluded for masses below 807 GeV$/c^2$. When combined with the $\gamma\gamma$ channel, masses less than 889 GeV$/c^2$ are excluded for $k/\overline{M}_{\rm pl} = 0.1$. The above

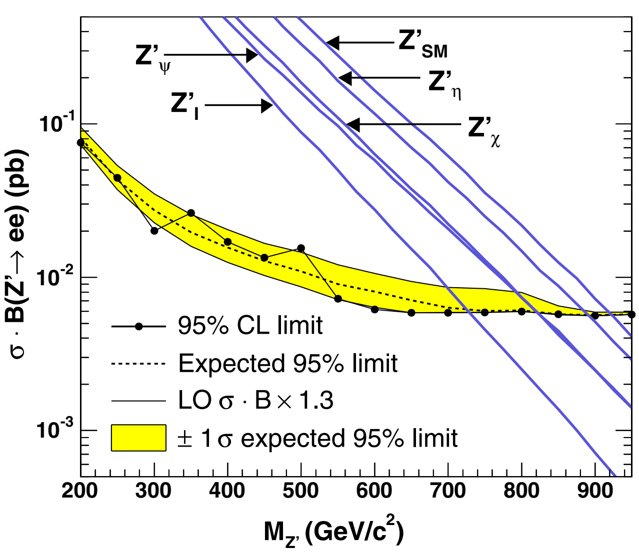

FIG. 3 (color online). The observed and expected limits on the $\sigma\mathcal{B}(X \to ee)$ of a spin-1 particle.

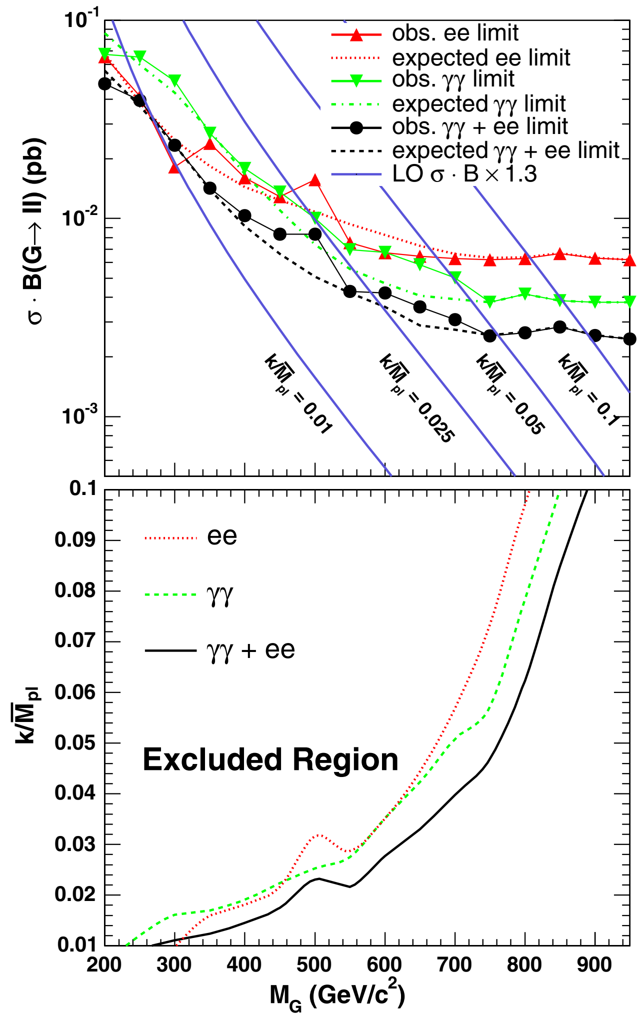

FIG. 4 (color online). The limits on $\sigma\mathcal{B}(G \to ee)$ (top) and $k/\bar{M}_{pl}$ (bottom) for a RS graviton in the ee, $\gamma\gamma$ channels separately and combined.

limits on Z's and the RS graviton represent the best single-experiment direct limits to date.

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